

O'REILLY®

2nd Edition



Early Release

RAW & UNEDITED

HBase

The Definitive Guide

RANDOM ACCESS TO YOUR PLANET-SIZE DATA

Lars George

SECOND EDITION

HBase - The Definitive Guide - 2nd Edition

Lars George

HBase - The Definitive Guide - 2nd Edition, Second Edition

by Lars George

Copyright © 2010 Lars George. All rights reserved.

Printed in the United States of America.

Published by O'Reilly Media, Inc., 1005 Gravenstein Highway North, Sebastopol, CA 95472.

O'Reilly books may be purchased for educational, business, or sales promotional use. Online editions are also available for most titles (<http://safaribooksonline.com>). For more information, contact our corporate/institutional sales department: 800-998-9938 or <corporate@oreilly.com>.

Editor: Ann Spencer

Proofreader: FIX ME!

Production Editor: FIX ME!

Indexer: FIX ME!

Copyeditor: FIX ME!

Cover Designer: Karen Montgomery

Interior Designer: David Futato

Illustrator: Rebecca Demarest

January -4712: Second Edition

Revision History for the Second Edition:

2015-04-10 Early release revision 1

2015-07-07 Early release revision

See <http://oreilly.com/catalog/errata.csp?isbn=0636920033943> for release details.

Nutshell Handbook, the Nutshell Handbook logo, and the O'Reilly logo are registered trademarks of O'Reilly Media, Inc. !!FILL THIS IN!! and related trade dress are trademarks of O'Reilly Media, Inc.

Many of the designations used by manufacturers and sellers to distinguish their products are claimed as trademarks. Where those designations appear in this book, and O'Reilly Media, Inc. was aware of a trademark claim, the designations have been printed in caps or initial caps.

While every precaution has been taken in the preparation of this book, the publisher and authors assume no responsibility for errors or omissions, or for damages resulting from the use of the information contained herein.

ISBN: 063-6-920-03394-3

[?]

Table of Contents

Foreword: Michael Stack	ix
Foreword: Carter Page	xiii
Preface	xvii
1. Introduction	1
The Dawn of Big Data	1
The Problem with Relational Database Systems	7
Nonrelational Database Systems, Not-Only SQL or NoSQL?	10
Dimensions	13
Scalability	15
Database (De-)Normalization	16
Building Blocks	19
Backdrop	19
Namespaces, Tables, Rows, Columns, and Cells	21
Auto-Sharding	26
Storage API	28
Implementation	29
Summary	33
HBase: The Hadoop Database	34
History	34
Nomenclature	37
Summary	37
2. Installation	39
Quick-Start Guide	39
Requirements	43
Hardware	43
Software	51
Filesystems for HBase	67
Local	69
HDFS	70

S3	70
Other Filesystems	72
Installation Choices	73
Apache Binary Release	73
Building from Source	76
Run Modes	79
Standalone Mode	79
Distributed Mode	79
Configuration	85
<code>hbase-site.xml</code> and <code>hbase-default.xml</code>	87
<code>hbase-env.sh</code> and <code>hbase-env.cmd</code>	88
<code>regionserver</code>	88
<code>log4j.properties</code>	89
Example Configuration	89
Client Configuration	91
Deployment	92
Script-Based	92
Apache Whirr	94
Puppet and Chef	94
Operating a Cluster	95
Running and Confirming Your Installation	95
Web-based UI Introduction	96
Shell Introduction	98
Stopping the Cluster	99
3. Client API: The Basics	101
General Notes	101
Data Types and Hierarchy	103
Generic Attributes	104
Operations: Fingerprint and ID	104
Query versus Mutation	106
Durability, Consistency, and Isolation	108
The Cell	112
API Building Blocks	117
CRUD Operations	122
Put Method	122
Get Method	146
Delete Method	168
Append Method	181
Mutate Method	184
Batch Operations	187
Scans	193
Introduction	193
The ResultScanner Class	199

Scanner Caching	203
Scanner Batching	206
Slicing Rows	210
Load Column Families on Demand	213
Scanner Metrics	214
Miscellaneous Features	215
The Table Utility Methods	215
The Bytes Class	216
4. Client API: Advanced Features.	219
Filters	219
Introduction to Filters	219
Comparison Filters	223
Dedicated Filters	232
Decorating Filters	252
FilterList	256
Custom Filters	259
Filter Parser Utility	269
Filters Summary	272
Counters	273
Introduction to Counters	274
Single Counters	277
Multiple Counters	278
Coprocessors	282
Introduction to Coprocessors	282
The Coprocessor Class Trinity	285
Coprocessor Loading	289
Endpoints	298
Observers	311
The ObserverContext Class	312
The RegionObserver Class	314
The MasterObserver Class	334
The RegionServerObserver Class	340
The WALObserver Class	342
The BulkLoadObserver Class	344
The EndPointObserver Class	344
5. Client API: Administrative Features.	347
Schema Definition	347
Namespaces	347
Tables	350
Table Properties	358
Column Families	362
HBaseAdmin	375
Basic Operations	375

Namespace Operations	376
Table Operations	378
Schema Operations	391
Cluster Operations	393
Cluster Status Information	411
ReplicationAdmin	422
6. Available Clients	427
Introduction	427
Gateways	427
Frameworks	431
Gateway Clients	432
Native Java	432
REST	433
Thrift	444
Thrift2	458
SQL over NoSQL	459
Framework Clients	460
MapReduce	460
Hive	460
Mapping Existing Tables	469
Mapping Existing Table Snapshots	473
Pig	474
Cascading	479
Other Clients	480
Shell	481
Basics	481
Commands	484
Scripting	497
Web-based UI	503
Master UI Status Page	504
Master UI Related Pages	521
Region Server UI Status Page	532
Shared Pages	551
7. Hadoop Integration	559
Framework	559
MapReduce Introduction	560
Processing Classes	562
Supporting Classes	575
MapReduce Locality	581
Table Splits	583
MapReduce over Tables	586
Preparation	586
Table as a Data Sink	603

Table as a Data Source	610
Table as both Data Source and Sink	614
Custom Processing	617
MapReduce over Snapshots	620
Bulk Loading Data	627
A. Upgrade from Previous Releases.	633

Foreword: Michael Stack

The HBase story begins in 2006, when the San Francisco-based start-up Powerset was trying to build a natural language search engine for the Web. Their indexing pipeline was an involved multistep process that produced an index about two orders of magnitude larger, on average, than your standard term-based index. The datastore that they'd built on top of the then nascent Amazon Web Services to hold the index intermediaries and the webcrawl was buckling under the load (Ring. Ring. "Hello! This is AWS. Whatever you are running, please turn it off!"). They were looking for an alternative. The Google Bigtable paper¹ had just been published.

Chad Walters, Powerset's head of engineering at the time, reflects back on the experience as follows:

Building an open source system to run on top of Hadoop's Distributed Filesystem (HDFS) in much the same way that Bigtable ran on top of the Google File System seemed like a good approach because: 1) it was a proven scalable architecture; 2) we could leverage existing work on Hadoop's HDFS; and 3) we could both contribute to and get additional leverage from the growing Hadoop ecosystem.

After the publication of the Google Bigtable paper, there were on-again, off-again discussions around what a Bigtable-like system on top of Hadoop might look. Then, in early 2007, out of the blue, Mike Cafarella dropped a tarball of thirty odd Java files into the Hadoop issue tracker: "I've written some code for HBase, a Bigtable-like file store. It's not perfect, but it's ready for other people to play with and exam-

1. ["Bigtable: A Distributed Storage System for Structured Data"](#) by Fay Chang et al.

ine.” Mike had been working with Doug Cutting on Nutch, an open source search engine. He’d done similar drive-by code dumps there to add features such as a Google File System clone so the Nutch indexing process was not bounded by the amount of disk you attach to a single machine. (This Nutch distributed filesystem would later grow up to be HDFS.)

Jim Kellerman of Powerset took Mike’s dump and started filling in the gaps, adding tests and getting it into shape so that it could be committed as part of Hadoop. The first commit of the HBase code was made by Doug Cutting on April 3, 2007, under the *contrib* subdirectory. The first HBase “working” release was bundled as part of Hadoop 0.15.0 in October 2007.

Not long after, Lars, the author of the book you are now reading, showed up on the #hbase IRC channel. He had a big-data problem of his own, and was game to try HBase. After some back and forth, Lars became one of the first users to run HBase in production outside of the Powerset home base. Through many ups and downs, Lars stuck around. I distinctly remember a directory listing Lars made for me a while back on his production cluster at WorldLingo, where he was employed as CTO, sysadmin, and grunt. The listing showed ten or so HBase releases from Hadoop 0.15.1 (November 2007) on up through HBase 0.20, each of which he’d run on his 40-node cluster at one time or another during production.

Of all those who have contributed to HBase over the years, it is poetic justice that Lars is the one to write this book. Lars was always dogging HBase contributors that the documentation needed to be better if we hoped to gain broader adoption. Everyone agreed, nodded their heads in ascent, amen’d, and went back to coding. So Lars started writing critical how-to’s and architectural descriptions in-between jobs and his intra-European travels as unofficial HBase European ambassador. His [Lineland blogs on HBase](#) gave the best description, outside of the source, of how HBase worked, and at a few critical junctures, carried the community across awkward transitions (e.g., an important blog explained the labyrinthian HBase build during the brief period we thought an Ivy-based build to be a “good idea”). His luscious diagrams were poached by one and all wherever an HBase presentation was given.

HBase has seen some interesting times, including a period of sponsorship by Microsoft, of all things. Powerset was acquired in July 2008, and after a couple of months during which Powerset employees were disallowed from contributing while Microsoft’s legal department vetted the HBase codebase to see if it impinged on SQLServer patents,

we were allowed to resume contributing (I was a Microsoft employee working near full time on an Apache open source project). The times ahead look promising, too, whether it's the variety of contortions HBase is being put through at Facebook—as the underpinnings for their massive Facebook mail app or fielding millions of hits a second on their analytics clusters—or more deploys along the lines of Yahoo!'s 1k node HBase cluster used to host their snapshot of Microsoft's Bing crawl. Other developments include HBase running on file-systems other than Apache HDFS, such as MapR.

But plain to me though is that none of these developments would have been possible were it not for the hard work put in by our awesome HBase community driven by a core of HBase committers. Some members of the core have only been around a year or so—Todd Lipcon, Gary Helmling, and Nicolas Spiegelberg—and we would be lost without them, but a good portion have been there from close to project inception and have shaped HBase into the (scalable) general datastore that it is today. These include Jonathan Gray, who gambled his startup streamy.com on HBase; Andrew Purtell, who built an HBase team at Trend Micro long before such a thing was fashionable; Ryan Rawson, who got StumbleUpon—which became the main sponsor after HBase moved on from Powerset/Microsoft—on board, and who had the sense to hire John-Daniel Cryans, now a power contributor but just a bushy-tailed student at the time. And then there is Lars, who during the bug fixes, was always about documenting how it all worked. Of those of us who know HBase, there is no better man qualified to write this first, critical HBase book.

—Michael Stack
HBase Project Janitor

Foreword: Carter Page

In late 2003, Google had a problem: We were continually building our web index from scratch, and each iteration was taking an entire month, even with all the parallelization we had at our disposal. What's more the web was growing geometrically, and we were expanding into many new product areas, some of which were personalized. We had a filesystem, called GFS, which could scale to these sizes, but it lacked the ability to update records in place, or to insert or delete new records in sequence.

It was clear that Google needed to build a new database.

There were only a few people in the world who knew how to solve a database design problem at this scale, and fortunately, several of them worked at Google. On November 4, 2003, Jeff Dean and Sanjay Ghemawat committed the first 5 source code files of what was to become Bigtable. Joined by seven other engineers in Mountain View and New York City, they built the first version, which went live in 2004.

To this day, the biggest applications at Google rely on Bigtable: GMail, search, Google Analytics, and hundreds of other applications. A Bigtable cluster can hold many hundreds of petabytes and serve over a terabyte of data each second. Even so, we're still working each year to push the limits of its scalability.

The book you have in your hands, or on your screen, will tell you all about how to use and operate HBase, the open-source re-creation of Bigtable. I'm in the unusual position to know the deep internals of both systems; and the engineers who, in 2006, set out to build an open source version of Bigtable created something very close in design and behavior.

My first experience with HBase came after I had been with the Bigtable engineering team in New York City. Out of curiosity, I attended a HBase meetup in Facebook's offices near Grand Central Terminal. There I listened to three engineers describe work they had done in what turned out to be a mirror world of the one I was familiar with. It was an uncanny moment for me. Before long we broke out into sessions, and I found myself giving tips to strangers on schema design in this product that I had never used in my life. I didn't tell anyone I was from Google, and no one asked (until later at a bar), but I think some of them found it odd when I slipped and mentioned "tablets" and "merge compactions"--alien nomenclature for what HBase refers to as "regions" and "minor compactions".

One of the surprises at that meetup came when a Facebook engineer presented a new feature that enables a client to read snapshot data directly from the filesystem, bypassing the region server. We had coincidentally developed the exact same functionality internally on Bigtable, calling it Offline Access. I looked into HBase's history a little more and realized that many of its features were developed in parallel with similar features in Bigtable: replication, coprocessors, multi-tenancy, and most recently, some dabbling in multiple write-ahead logs. That these two development paths have been so symmetric is a testament to both the logical cogency of the original architecture and the ingenuity of the HBase contributors in solving the same problems we encountered at Google.

Since I started following HBase and its community for the past year and a half, I have consistently observed certain characteristics about its culture. The individual developers love the academic challenge of building distributed systems. They come from different companies, with often competing interests, but they always put the technology first. They show a respect for each other, and a sense of responsibility to build a quality product for others to rely upon. In my shop, we call that "being Googley." Culture is critical to success at Google, and it comes as little surprise that a similar culture binds the otherwise disparate group of engineers that built HBase.

I'll share one last realization I had about HBase about a year after that first meetup, at a Big Data conference. In the Jacob Javitz Convention Center on the west side of Manhattan, I saw presentation after presentation by organizations that had built data processing infrastructures that scaled to insane levels. One had built its infrastructure on Hadoop, another on Storm and Kafka, and another using the darling of that conference, Spark. But there was one consistent factor, no matter which data processing framework had been used or what problem was being solved. Every brain-explodingly large system that need-

ed a real database was built on HBase. The biggest timeseries architectures? HBase. Massive geo data analytics? HBase. The UIDAI in India, which stores biometrics for more than 600 million people? What else but HBase. Presenters were saying, “I built a system that scaled to petabytes and millions of operations per second!” and I was struck by just how much HBase and its amazing ecosystem and contributors had enabled these applications.

Dozens of the biggest technology companies have adopted HBase as the database of choice for truly big data. Facebook moved its messaging system to HBase to handle billions of messages per day. Bloomberg uses HBase to serve mission-critical market data to hundreds of thousands of traders around the world. And Apple uses HBase to store the hundreds of terabytes of voice recognition data that power Siri.

And you may wonder, what are the eventual limits? From my time on the Bigtable team, I’ve seen that while the data keeps getting bigger, we’re a long way from running out of room to scale. We’ve had to reduce contention on our master server and our distributed lock server, but theoretically, we don’t see why a single cluster couldn’t hold many exabytes of data. To put it simply, there’s a lot of room to grow. We’ll keep finding new applications for this technology for years to come, just as the HBase community will continue to find extraordinary new ways to put this architecture to work.

—Carter Page
Engineering Manager, Bigtable Team, Google

Preface

You may be reading this book for many reasons. It could be because you heard all about *Hadoop* and what it can do to crunch petabytes of data in a reasonable amount of time. While reading into Hadoop you found that, for random access to the accumulated data, there is something called *HBase*. Or it was the hype that is prevalent these days addressing a new kind of data storage architecture. It strives to solve large-scale data problems where traditional solutions may be either too involved or cost-prohibitive. A common term used in this area is *NoSQL*.

No matter how you have arrived here, I presume you want to know and learn—like I did not too long ago—how you can use HBase in your company or organization to store a virtually endless amount of data. You may have a background in relational database theory or you want to start fresh and this “column-oriented thing” is something that seems to fit your bill. You also heard that HBase can scale without much effort, and that alone is reason enough to look at it since you are building the next web-scale system. And did I mention it is free like Hadoop?

I was at that point in late 2007 when I was facing the task of storing millions of documents in a system that needed to be fault-tolerant and scalable while still being maintainable by just me. I had decent skills in managing a MySQL database system, and was using the database to store data that would ultimately be served to our website users. This database was running on a single server, with another as a backup. The issue was that it would not be able to hold the amount of data I needed to store for this new project. I would have to either invest in serious RDBMS scalability skills, or find something else instead.

Obviously, I took the latter route, and since my mantra always was (and still is) “How does someone like Google do it?” I came across Hadoop. After a few attempts to use Hadoop, and more specifically HDFS, directly, I was faced with implementing a random access layer on top of it—but that problem had been solved already: in 2006, Google had published a paper titled “Bigtable”¹ and the Hadoop developers had an open source implementation of it called HBase (the *Hadoop Database*). That was the answer to all my problems. Or so it seemed...

These days, I try not to think about how difficult my first experience with Hadoop and HBase was. Looking back, I realize that I would have wished for this particular project to start today. HBase is now mature, completed a 1.0 release, and is used by many high-profile companies, such as Facebook, Apple, eBay, Adobe, Yahoo!, Xiaomi, Trend Micro, Bloomberg, Nielsen, and Salesforce.com (see <http://wiki.apache.org/hadoop/Hbase/PoweredBy> for a longer, though not complete list). Mine was one of the very first clusters in production and my use case triggered a few very interesting issues (let me refrain from saying more).

But that was to be expected, betting on a 0.1x version of a community project. And I had the opportunity over the years to contribute back and stay close to the development team so that eventually I was humbled by being asked to become a full-time committer as well.

I learned a lot over the past few years from my fellow HBase developers and am still learning more every day. My belief is that we are nowhere near the peak of this technology and it will evolve further over the years to come. Let me pay my respect to the entire HBase community with this book, which strives to cover not just the internal workings of HBase or how to get it going, but more specifically, how to apply it to your use case.

In fact, I strongly assume that this is why you are here right now. You want to learn how HBase can solve *your* problem. Let me help you try to figure this out.

General Information

Before we get started a few general notes. More information about the code examples and *Hush*, a complete HBase application used throughout the book, can be found in (to come).

1. See the [Bigtable](#) paper for reference.

HBase Version

This book covers the 1.0.0 release of HBase. This in itself is a very major milestone for the project, seeing HBase maturing over the years where it is now ready to fall into a proper release cycle. In the past the developers were free to decide the versioning and indeed changed the very same a few times. More can be read about this throughout the book, but suffice it to say that this should not happen again. (to come) sheds more light on the future of HBase, while “[History](#)” (page 34) shows the past.

Moreover, there is now a system in place that annotates all external facing APIs with a audience and stability level. In this book we only deal with these classes and specifically with those that are marked *public*. You can read about the entire set of annotations in (to come).

The code for HBase can be found in a few official places, for example the Apache archive (<http://s.apache.org/hbase-1.0.0-archive>), which has the release files as binary and source tarballs (aka compressed file archives). There is also the source repository (<http://s.apache.org/hbase-1.0.0-apache>) and a mirror on the popular GitHub site (<https://github.com/apache/hbase/tree/1.0.0>). Chapter 2 has more on how to select the right source and start from there.

Since this book was printed there may have been important updates, so please check the book’s website at <http://www.hbasebook.com> in case something does not seem right and you want to verify what is going on. I will update the website as I get feedback from the readers and time is moving on.

What is in this Book?

The book is organized in larger chapters, where Chapter 1 starts off with an overview of the origins of HBase. Chapter 2 explains the intricacies of spinning up a HBase cluster. Chapter 3, Chapter 4, and Chapter 5 explain all the user facing interfaces exposed by HBase, continued by Chapter 6 and Chapter 7, both showing additional ways to access data stored in a cluster and—though limited here—how to administrate it.

The second half of the book takes you deeper into the topics, with (to come) explaining how everything works under the hood (with some particular deep details moved into appendixes). [Link to Come] explains the essential need of designing data schemas correctly to gain most out of HBase and introduces you to key design.

For the operator of a cluster (to come) and (to come), as well as (to come) do hold vital information to make their life easier. While operating HBase is not rocket science, a good command of specific operational skills goes a long way. (to come) discusses all aspects required to operate a cluster as part of a larger (very likely well established) IT landscape, which pretty much always includes integration into a company wide authentication system.

Finally, (to come) discusses application patterns observed at HBase users, those I know personally or have met at conferences over the years. There are some use-cases where HBase works as-is out-of-the-box. For others some care has to be taken ensuring success early on, and you will learn about the distinction in due course.

Target Audience

I was asked once what the intended audience is for this book, as it seemed to cover a lot but maybe not enough or too much? I am squarely aiming at the HBase developer and operator (or the newfangled *devops*, especially found in startups). These are the engineers that work at any size company, from large ones like eBay and Apple, all the way to small startups that aim high, i.e. wanting to serve the world. From someone who has never used HBase before, to the power users that develop with and against its many APIs, I am humbled by your work and hope to help you with this book.

On the other hand, it seemingly is not for the open-source contributor or even committer necessarily, as there are many more intrinsic things to know when working on the bowels of the beast-yet I believe we all started as an API user first and hence I believe it is a great source even for those rare folks.

What is New in the Second Edition?

The second edition has new chapters and appendices: (to come) was added to tackle the entire topic of enterprise security setup and integration. (to come) was added to give more real world use-case details, along with selected case studies.

The code examples were updated to reflect the new HBase 1.0.0 API. The repository (see (to come) for more) was tagged with “rev1” before I started updating it, and I made sure that revision worked as well against the more recent versions. It will not all compile and work against 1.0.0 though since for example RowLocks were removed in 0.96. Please see [Appendix A](#) for more details on the changes and how to migrate existing clients to the new API.

Conventions Used in This Book

The following typographical conventions are used in this book:

Italic

Indicates new terms, URLs, email addresses, filenames, file extensions, and Unix commands

Constant width

Used for program listings, as well as within paragraphs to refer to program elements such as variable or function names, databases, data types, environment variables, statements, and keywords

Constant width bold

Shows commands or other text that should be typed literally by the user

Constant width italic

Shows text that should be replaced with user-supplied values or by values determined by context

This icon signifies a tip, suggestion, or general note.

This icon indicates a warning or caution.

Using Code Examples

This book is here to help you get your job done. In general, you may use the code in this book in your programs and documentation. You do not need to contact us for permission unless you're reproducing a significant portion of the code. For example, writing a program that uses several chunks of code from this book does not require permission. Selling or distributing a CD-ROM of examples from O'Reilly books does require permission. Answering a question by citing this book and quoting example code does not require permission. Incorporating a significant amount of example code from this book into your product's documentation does require permission.

We appreciate, but do not require, attribution. An attribution usually includes the title, author, publisher, and ISBN. For example: "*HBase: The Definitive Guide*, Second Edition, by Lars George (O'Reilly). Copyright 2015 Lars George, 978-1-491-90585-2."

If you feel your use of code examples falls outside fair use or the permission given here, feel free to contact us at <permissions@oreilly.com>.

Safari® Books Online

Safari Books Online is an on-demand digital library that lets you easily search over 7,500 technology and creative reference books and videos to find the answers you need quickly.

With a subscription, you can read any page and watch any video from our library online. Read books on your cell phone and mobile devices. Access new titles before they are available for print, and get exclusive access to manuscripts in development and post feedback for the authors. Copy and paste code samples, organize your favorites, download chapters, bookmark key sections, create notes, print out pages, and benefit from tons of other time-saving features.

O'Reilly Media has uploaded this book to the Safari Books Online service. To have full digital access to this book and others on similar topics from O'Reilly and other publishers, sign up for free at <http://my.safaribooksonline.com>.

How to Contact Us

Please address comments and questions concerning this book to the publisher:

O'Reilly Media, Inc.
1005 Gravenstein Highway North
Sebastopol, CA 95472
800-998-9938 (in the United States or Canada)
707-829-0515 (international or local)
707-829-0104 (fax)

We have a web page for this book, where we list errata, examples, and any additional information. You can access this page at:

<http://shop.oreilly.com/product/0636920033943.do>

The author also has a site for this book at:

<http://www.hbasebook.com/>

To comment or ask technical questions about this book, send email to:
[<bookquestions@oreilly.com>](mailto:bookquestions@oreilly.com)

For more information about our books, courses, conferences, and news, see our website at <http://www.oreilly.com>.

Find us on Facebook: <http://facebook.com/oreilly>

Follow us on Twitter: <http://twitter.com/oreillymedia>

Watch us on YouTube: <http://www.youtube.com/oreillymedia>

Acknowledgments

I first want to thank my late dad, Reiner, and my mother, Ingrid, who supported me and my aspirations all my life. You were the ones to make me a better person.

Writing this book was only possible with the support of the entire HBase community. Without that support, there would be no HBase, nor would it be as successful as it is today in production at companies all around the world. The relentless and seemingly tireless support given by the core committers as well as contributors and the community at large on IRC, the Mailing List, and in blog posts is the essence of what open source stands for. I stand tall on your shoulders!

Thank you to Jeff Hammerbacher to talk me into writing the book in the first place, and also making the initial connections with the awesome staff at O'Reilly.

Thank you to the committers, who included, as of this writing, Amitanand S. Aiyer, Andrew Purtell, Anoop Sam John, Chunhui Shen, Devaraj Das, Doug Meil, Elliott Clark, Enis Soztutar, Gary Helmling, Gregory Chanan, Honghua Feng, Jean-Daniel Cryans, Jeffrey Zhong, Jesse Yates, Jimmy Xiang, Jonathan Gray, Jonathan Hsieh, Kannan Muthukaruppan, Karthik Ranganathan, Lars George, Lars Hofhansl, Liang Xie, Liyin Tang, Matteo Bertozzi, Michael Stack, Mikhail Bautin, Nick Dimiduk, Nicolas Liochon, Nicolas Spiegelberg, Rajeshbabu Chintaguntla, Ramkrishna S Vasudevan, Ryan Rawson, Sergey Shelukhin, Ted Yu, and Todd Lipcon; and to the emeriti, Mike Cafarella, Bryan Duxbury, and Jim Kellerman.

I would like to extend a heartfelt thank you to all the contributors to HBase; you know who you are. Every single patch you have contributed brought us here. Please keep contributing!

Further, a huge thank you to the book's reviewers. For the first edition these were: Patrick Angeles, Doug Balog, Jeff Bean, Po Cheung,

Jean-Daniel Cryans, Lars Francke, Gary Helmling, Michael Katzenellenbogen, Mingjie Lai, Todd Lipcon, Ming Ma, Doris Maassen, Cameron Martin, Matt Massie, Doug Meil, Manuel Meßner, Claudia Nielsen, Joseph Pallas, Josh Patterson, Andrew Purtell, Tim Robertson, Paul Rogalinski, Joep Rottinghuis, Stefan Rudnitzki, Eric Sammer, Michael Stack, and Suraj Varma.

The second edition was reviewed by: Lars Francke, Ian Buss, Michael Stack, ...

A special thank you to my friend Lars Francke for helping me deep dive on particular issues before going insane. Sometimes a set of extra eyes - and ears - is all that is needed to get over a hump or through a hoop.

Further, thank you to anyone I worked or communicated with at O'Reilly, you are the nicest people an author can ask for and in particular, my editors Mike Loukides, Julie Steele, and Marie Beaugureau.

Finally, I would like to thank Cloudera, my employer, which generously granted me time away from customers so that I could write this book. And to all my colleagues within Cloudera, you are the most awesomest group of people I have ever worked with. Rock on!

Chapter 1

Introduction

Before we start looking into all the moving parts of HBase, let us pause to think about why there was a need to come up with yet another storage architecture. *Relational database management systems* (RDBMSes) have been around since the early 1970s, and have helped countless companies and organizations to implement their solution to given problems. And they are equally helpful today. There are many use cases for which the relational model makes perfect sense. Yet there also seem to be specific problems that do not fit this model very well.¹

The Dawn of Big Data

We live in an era in which we are all connected over the Internet and expect to find results instantaneously, whether the question concerns the best turkey recipe or what to buy mom for her birthday. We also expect the results to be useful and tailored to our needs.

Because of this, companies have become focused on delivering more targeted information, such as recommendations or online ads, and their ability to do so directly influences their success as a business. Systems like *Hadoop*² now enable them to gather and process petabytes of data, and the need to collect even more data continues to in-

1. See, for example, “One Size Fits All’: An Idea Whose Time Has Come and Gone”) by Michael Stonebraker and Uğur Çetintemel.
2. Information can be found on the project’s [website](#). Please also see the excellent *Hadoop: The Definitive Guide* (Fourth Edition) by Tom White (O’Reilly) for everything you want to know about Hadoop.

crease with, for example, the development of new machine learning algorithms.

Where previously companies had the liberty to ignore certain data sources because there was no cost-effective way to store all that information, they now are likely to lose out to the competition. There is an increasing need to store and analyze every data point they generate. The results then feed directly back into their e-commerce platforms and may generate even more data.

In the past, the only option to retain all the collected data was to prune it to, for example, retain the last N days. While this is a viable approach in the short term, it lacks the opportunities that having all the data, which may have been collected for months and years, offers: you can build mathematical models that span the entire time range, or amend an algorithm to perform better and rerun it with all the previous data.

Dr. Ralph Kimball, for example, states³ that

Data assets are [a] major component of the balance sheet, replacing traditional physical assets of the 20th century

and that there is a

Widespread recognition of the value of data even beyond traditional enterprise boundaries

Google and Amazon are prominent examples of companies that realized the value of data early on and started developing solutions to fit their needs. For instance, in a series of technical publications, Google described a scalable storage and processing system based on commodity hardware. These ideas were then implemented outside of Google as part of the open source Hadoop project: *HDFS* and *MapReduce*.

Hadoop excels at storing data of arbitrary, semi-, or even unstructured formats, since it lets you decide how to interpret the data at analysis time, allowing you to change the way you classify the data at any time: once you have updated the algorithms, you simply run the analysis again.

Hadoop also complements existing database systems of almost any kind. It offers a limitless pool into which one can sink data and still pull out what is needed when the time is right. It is optimized for large

3. The quotes are from a presentation titled “Rethinking EDW in the Era of Expansive Information Management” by Dr. Ralph Kimball, of the Kimball Group, available [online](#). It discusses the changing needs of an evolving *enterprise data warehouse* market.

file storage and batch-oriented, streaming access. This makes analysis easy and fast, but users also need access to the final data, not in batch mode but using random access—this is akin to a full table scan versus using indexes in a database system.

We are used to querying databases when it comes to random access for structured data. RDBMSes are the most prominent systems, but there are also quite a few specialized variations and implementations, like object-oriented databases. Most RDBMSes strive to implement *Codd's 12 rules*,⁴ which forces them to comply to very rigid requirements. The architecture used underneath is well researched and has not changed significantly in quite some time. The recent advent of different approaches, like *column-oriented* or *massively parallel processing* (MPP) databases, has shown that we can rethink the technology to fit specific workloads, but most solutions still implement all or the majority of Codd's 12 rules in an attempt to not break with tradition.

Column-Oriented Databases

Column-oriented databases save their data grouped by columns. Subsequent column values are stored contiguously on disk. This differs from the usual row-oriented approach of traditional databases, which store entire rows contiguously—see [Figure 1-1](#) for a visualization of the different physical layouts.

The reason to store values on a per-column basis instead is based on the assumption that, for specific queries, not all of the values are needed. This is often the case in analytical databases in particular, and therefore they are good candidates for this different storage schema.

Reduced I/O is one of the primary reasons for this new layout, but it offers additional advantages playing into the same category: since the values of one column are often very similar in nature or even vary only slightly between logical rows, they are often much better suited for compression than the heterogeneous values of a row-oriented record structure; most compression algorithms only look at a finite window of data.

4. Edgar F. Codd defined 13 rules (numbered from 0 to 12), which define what is required from a *database management system* (DBMS) to be considered *relational*. While HBase does fulfill the more generic rules, it fails on others, most importantly, on rule 5: *the comprehensive data sublanguage rule*, defining the support for at least one *relational* language. See [Codd's 12 rules](#) on Wikipedia.

Specialized algorithms—for example, delta and/or prefix compression—selected based on the type of the column (i.e., on the data stored) can yield huge improvements in compression ratios. Better ratios result in more efficient bandwidth usage.

Note, though, that HBase is *not* a column-oriented database in the typical RDBMS sense, but utilizes an on-disk column storage format. This is also where the majority of similarities end, because although HBase stores data on disk in a column-oriented format, it is distinctly different from traditional columnar databases: whereas columnar databases excel at providing real-time analytical access to data, HBase excels at providing key-based access to a specific cell of data, or a sequential range of cells.

In fact, I would go as far as classifying HBase as *column-family-oriented* storage, since it does group columns into families and within each of those data is stored row-oriented. (to come) has much more on the storage layout.

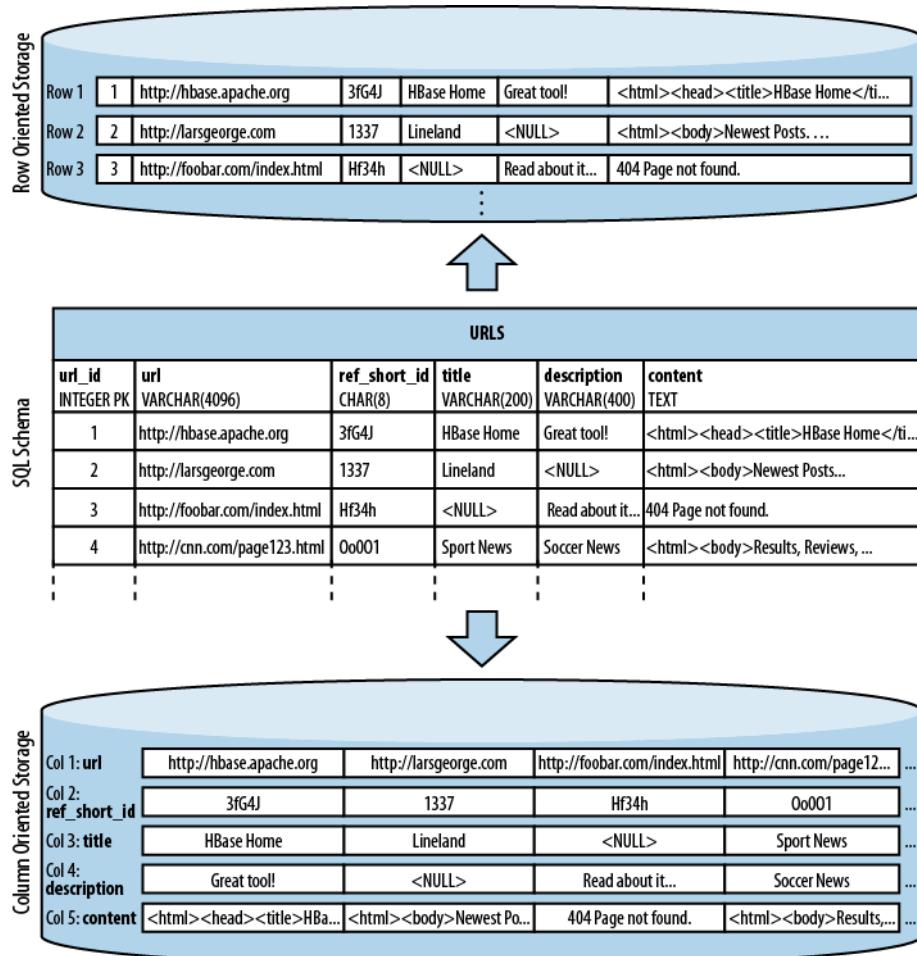


Figure 1-1. Column-oriented and row-oriented storage layouts

The speed at which data is created today is already greatly increased, compared to only just a few years back. We can take for granted that this is only going to increase further, and with the rapid pace of globalization the problem is only exacerbated. Websites like Google, Amazon, eBay, and Facebook now reach the majority of people on this planet. The term *planet-size web application* comes to mind, and in this case it is fitting.

Facebook, for example, is adding more than 15 TB of data into its Hadoop cluster every day⁵ and is subsequently processing it all. One source of this data is click-stream logging, saving every step a user performs on its website, or on sites that use the social plug-ins offered by Facebook. This is an ideal case in which batch processing to build machine learning models for predictions and recommendations is appropriate.

Facebook also has a real-time component, which is its messaging system, including chat, wall posts, and email. This amounts to 135+ billion messages per month,⁶ and storing this data over a certain number of months creates a huge tail that needs to be handled efficiently. Even though larger parts of emails—for example, attachments—are stored in a secondary system,⁷ the amount of data generated by all these messages is mind-boggling. If we were to take 140 bytes per message, as used by Twitter, it would total more than 17 TB every month. Even before the transition to HBase, the existing system had to handle more than 25 TB a month.⁸

In addition, less web-oriented companies from across all major industries are collecting an ever-increasing amount of data. For example:

Financial

Such as data generated by stock tickers

Bioinformatics

Such as the *Global Biodiversity Information Facility* (<http://www.gbif.org/>)

Smart grid

Such as the *OpenPDC* (<http://openpdc.codeplex.com/>) project

Sales

Such as the data generated by *point-of-sale* (POS) or stock/inventory systems

5. See this [note](#) published by Facebook.
6. See this [blog post](#), as well as [this one](#), by the Facebook engineering team. Wall messages count for 15 billion and chat for 120 billion, totaling 135 billion messages a month. Then they also add SMS and others to create an even larger number.
7. Facebook uses [Haystack](#), which provides an optimized storage infrastructure for large binary objects, such as photos.
8. See this [presentation](#), given by Facebook employee and HBase committer, Nicolas Spiegelberg.

Genomics

Such as the *Crossbow* (<http://bowtie-bio.sourceforge.net/crossbow/index.shtml>) project

Cellular services, military, environmental

Which all collect a tremendous amount of data as well

Storing petabytes of data efficiently so that updates and retrieval are still performed well is no easy feat. We will now look deeper into some of the challenges.

The Problem with Relational Database Systems

RDBMSes have typically played (and, for the foreseeable future at least, will play) an integral role when designing and implementing business applications. As soon as you have to retain information about your users, products, sessions, orders, and so on, you are typically going to use some storage backend providing a persistence layer for the frontend application server. This works well for a limited number of records, but with the dramatic increase of data being retained, some of the architectural implementation details of common database systems show signs of weakness.

Let us use *Hush*, the HBase URL Shortener discussed in detail in (to come), as an example. Assume that you are building this system so that it initially handles a few thousand users, and that your task is to do so with a reasonable budget—in other words, use free software. The typical scenario here is to use the open source LAMP⁹ stack to quickly build out a prototype for the business idea.

The relational database model normalizes the data into a `user` table, which is accompanied by a `url`, `shorturl`, and `click` table that link to the former by means of a foreign key. The tables also have indexes so that you can look up URLs by their `short_ID`, or the users by their `username`. If you need to find all the shortened URLs for a particular list of customers, you could run an SQL `JOIN` over both tables to get a comprehensive list of URLs for each customer that contains not just the shortened URL but also the customer details you need.

In addition, you are making use of built-in features of the database: for example, *stored procedures*, which allow you to consistently up-

9. Short for Linux, Apache, MySQL, and PHP (or Perl and Python).

date data from multiple clients while the database system guarantees that there is always coherent data stored in the various tables.

Transactions make it possible to update multiple tables in an atomic fashion so that either all modifications are visible or none are visible. The RDBMS gives you the so-called *ACID*¹⁰ properties, which means your data is *strongly consistent* (we will address this in greater detail in “[Consistency Models](#)” (page 11)). *Referential integrity* takes care of enforcing relationships between various table schemas, and you get a domain-specific language, namely SQL, that lets you form complex queries over everything. Finally, you do not have to deal with how data is actually stored, but only with higher-level concepts such as table schemas, which define a fixed layout your application code can reference.

This usually works very well and will serve its purpose for quite some time. If you are lucky, you may be the next hot topic on the Internet, with more and more users joining your site every day. As your user numbers grow, you start to experience an increasing amount of pressure on your shared database server. Adding more application servers is relatively easy, as they share their state only with the central database. Your CPU and I/O load goes up and you start to wonder how long you can sustain this growth rate.

The first step to ease the pressure is to add slave database servers that are used to being read from in parallel. You still have a single master, but that is now only taking writes, and those are much fewer compared to the many reads your website users generate. But what if that starts to fail as well, or slows down as your user count steadily increases?

A common next step is to add a cache—for example, Memcached.¹¹ Now you can offload the reads to a very fast, in-memory system—however, you are losing consistency guarantees, as you will have to invalidate the cache on modifications of the original value in the database, and you have to do this fast enough to keep the time where the cache and the database views are inconsistent to a minimum.

While this may help you with the amount of reads, you have not yet addressed the writes. Once the master database server is hit too hard with writes, you may replace it with a beefed-up server—scaling up

10. Short for Atomicity, Consistency, Isolation, and Durability. See “[ACID](#)” on Wikipedia.

11. Memcached is an in-memory, nonpersistent, nondistributed key/value store. See the [Memcached project](#) home page.

vertically—which simply has more cores, more memory, and faster disks... and costs a lot more money than the initial one. Also note that if you already opted for the master/slave setup mentioned earlier, you need to make the slaves as powerful as the master or the imbalance may mean the slaves fail to keep up with the master's update rate. This is going to double or triple the cost, if not more.

With more site popularity, you are asked to add more features to your application, which translates into more queries to your database. The SQL JOINs you were happy to run in the past are suddenly slowing down and are simply not performing well enough at scale. You will have to denormalize your schemas. If things get even worse, you will also have to cease your use of stored procedures, as they are also simply becoming too slow to complete. Essentially, you reduce the database to just storing your data in a way that is optimized for your access patterns.

Your load continues to increase as more and more users join your site, so another logical step is to prematerialize the most costly queries from time to time so that you can serve the data to your customers faster. Finally, you start dropping secondary indexes as their maintenance becomes too much of a burden and slows down the database too much. You end up with queries that can only use the primary key and nothing else.

Where do you go from here? What if your load is expected to increase by another order of magnitude or more over the next few months? You could start *sharding* (see the sidebar titled “[Sharding](#)” (page 9)) your data across many databases, but this turns into an operational nightmare, is very costly, and still does not give you a truly fitting solution. You essentially make do with the RDBMS for lack of an alternative.

Sharding

The term *sharding* describes the logical separation of records into horizontal partitions. The idea is to spread data across multiple storage files—or servers—as opposed to having each stored contiguously.

The separation of values into those partitions is performed on fixed boundaries: you have to set fixed rules ahead of time to route values to their appropriate store. With it comes the inherent difficulty of having to *reshard* the data when one of the horizontal partitions exceeds its capacity.

Resharding is a very costly operation, since the storage layout has to be rewritten. This entails defining new boundaries and then

horizontally splitting the rows across them. Massive copy operations can take a huge toll on I/O performance as well as temporarily elevated storage requirements. And you may still take on updates from the client applications and need to negotiate updates during the resharding process.

This can be mitigated by using *virtual shards*, which define a much larger key partitioning range, with each server assigned an equal number of these shards. When you add more servers, you can reassign shards to the new server. This still requires that the data be moved over to the added server.

Sharding is often a simple afterthought or is completely left to the operator. Without proper support from the database system, this can wreak havoc on production systems.

Let us stop here, though, and, to be fair, mention that a lot of companies are using RDBMSes successfully as part of their technology stack. For example, Facebook—and also Google—has a very large MySQL setup, and for their purposes it works sufficiently. These database farms suits the given business goals and may not be replaced anytime soon. The question here is if you were to start working on implementing a new product and knew that it needed to scale very fast, wouldn't you want to have all the options available instead of using something you know has certain constraints?

Nonrelational Database Systems, Not-Only SQL or NoSQL?

Over the past four or five years, the pace of innovation to fill that exact problem space has gone from slow to insanely fast. It seems that every week another framework or project is announced to fit a related need. We saw the advent of the so-called *NoSQL* solutions, a term coined by Eric Evans in response to a question from Johan Oskarsson, who was trying to find a name for an event in that very emerging, new data storage system space.¹²

The term quickly rose to fame as there was simply no other name for this new class of products. It was (and is) discussed heavily, as it was also deemed the nemesis of "SQL" or was meant to bring the plague to anyone still considering using traditional RDBMSes... just kidding!

12. See "[NoSQL](#)" on Wikipedia.

The actual idea of different data store architectures for specific problem sets is not new at all. Systems like Berkeley DB, Coherence, GT.M, and object-oriented database systems have been around for years, with some dating back to the early 1980s, and they fall into the NoSQL group by definition as well.

The tagword is actually a good fit: it is true that most new storage systems do not provide SQL as a means to query data, but rather a different, often simpler, API-like interface to the data.

On the other hand, tools are available that provide SQL dialects to NoSQL data stores, and they can be used to form the same complex queries you know from relational databases. So, limitations in querying no longer differentiate RDBMSes from their nonrelational kin.

The difference is actually on a lower level, especially when it comes to schemas or ACID-like transactional features, but also regarding the actual storage architecture. A lot of these new kinds of systems do one thing first: throw out the limiting factors in truly scalable systems (a topic that is discussed in “[Dimensions](#) (page 13)”). For example, they often have no support for transactions or secondary indexes. More importantly, they often have no fixed schemas so that the storage can evolve with the application using it.

Consistency Models

It seems fitting to talk about consistency a bit more since it is mentioned often throughout this book. On the outset, consistency is about guaranteeing that a database always appears *truthful* to its clients. Every operation on the database must carry its state from one consistent state to the next. How this is achieved or implemented is not specified explicitly so that a system has multiple choices. In the end, it has to get to the next consistent state, or return to the previous consistent state, to fulfill its obligation.

Consistency can be classified in, for example, decreasing order of its properties, or guarantees offered to clients. Here is an informal list:

Strict

The changes to the data are atomic and appear to take effect instantaneously. This is the highest form of consistency.

Sequential

Every client sees all changes in the same order they were applied.

Causal

All changes that are causally related are observed in the same order by all clients.

Eventual

When no updates occur for a period of time, eventually all updates will propagate through the system and all replicas will be consistent.

Weak

No guarantee is made that all updates will propagate and changes may appear out of order to various clients.

The class of system adhering to eventual consistency can be even further divided into subtler sets, where those sets can also coexist. Werner Vogels, CTO of Amazon, lists them in his post titled "[Eventually Consistent](#)". The article also picks up on the topic of the *CAP theorem*,¹³ which states that a distributed system can only achieve two out of the following three properties: consistency, availability, and partition tolerance. The CAP theorem is a highly discussed topic, and is certainly not the only way to classify, but it does point out that distributed systems are not easy to develop given certain requirements. Vogels, for example, mentions:

An important observation is that in larger distributed scale systems, network partitions are a given and as such consistency and availability cannot be achieved at the same time. This means that one has two choices on what to drop; relaxing consistency will allow the system to remain highly available [...] and prioritizing consistency means that under certain conditions the system will not be available.

Relaxing consistency, while at the same time gaining availability, is a powerful proposition. However, it can force handling inconsistencies into the application layer and may increase complexity.

There are many overlapping features within the group of nonrelational databases, but some of these features also overlap with traditional storage solutions. So the new systems are not really revolutionary, but rather, from an engineering perspective, are more evolutionary.

13. See Eric Brewer's original [paper](#) on this topic and the follow-up [post](#) by Coda Hale, as well as this [PDF](#) by Gilbert and Lynch.

Even projects like *Memcached* are lumped into the NoSQL category, as if anything that is not an RDBMS is automatically NoSQL. This creates a kind of false dichotomy that obscures the exciting technical possibilities these systems have to offer. And there are many; within the NoSQL category, there are numerous dimensions you could use to classify where the strong points of a particular system lie.

Dimensions

Let us take a look at a handful of those dimensions here. Note that this is not a comprehensive list, or the only way to classify them.

Data model

There are many variations in how the data is stored, which include key/value stores (compare to a *HashMap*), semistructured, column-oriented, and document-oriented stores. How is your application accessing the data? Can the schema evolve over time?

Storage model

In-memory or persistent? This is fairly easy to decide since we are comparing with RDBMSes, which usually persist their data to permanent storage, such as physical disks. But you may explicitly need a purely in-memory solution, and there are choices for that too. As far as persistent storage is concerned, does this affect your access pattern in any way?

Consistency model

Strictly or eventually consistent? The question is, how does the storage system achieve its goals: does it have to weaken the consistency guarantees? While this seems like a cursory question, it can make all the difference in certain use cases. It may especially affect latency, that is, how fast the system can respond to read and write requests. This is often measured in *harvest* and *yield*.¹⁴

Atomic read-modify-write

While RDBMSes offer you a lot of these operations directly (because you are talking to a central, single server), they can be more difficult to achieve in distributed systems. They allow you to prevent race conditions in multithreaded or shared-nothing application server design. Having these *compare and swap* (CAS) or *check and set* operations available can reduce client-side complexity.

14. See Brewer: “Lessons from giant-scale services.”, *Internet Computing*, IEEE (2001) vol. 5 (4) pp. 46–55.

Locking, waits, and deadlocks

It is a known fact that complex transactional processing, like two-phase commits, can increase the possibility of multiple clients waiting for a resource to become available. In a worst-case scenario, this can lead to deadlocks, which are hard to resolve. What kind of locking model does the system you are looking at support? Can it be free of waits, and therefore deadlocks?

Physical model

Distributed or single machine? What does the architecture look like—is it built from distributed machines or does it only run on single machines with the distribution handled client-side, that is, in your own code? Maybe the distribution is only an afterthought and could cause problems once you need to scale the system. And if it does offer scalability, does it imply specific steps to do so? The easiest solution would be to add one machine at a time, while sharded setups (especially those not supporting virtual shards) sometimes require for each shard to be increased simultaneously because each partition needs to be equally powerful.

Read/write performance

You have to understand what your application's access patterns look like. Are you designing something that is written to a few times, but is read much more often? Or are you expecting an equal load between reads and writes? Or are you taking in a lot of writes and just a few reads? Does it support range scans or is it better suited doing random reads? Some of the available systems are advantageous for only one of these operations, while others may do well (but maybe not perfect) in all of them.

Secondary indexes

Secondary indexes allow you to sort and access tables based on different fields and sorting orders. The options here range from systems that have absolutely no secondary indexes and no guaranteed sorting order (like a `HashMap`, i.e., you need to know the keys) to some that weakly support them, all the way to those that offer them out of the box. Can your application cope, or emulate, if this feature is missing?

Failure handling

It is a fact that machines crash, and you need to have a mitigation plan in place that addresses machine failures (also refer to the discussion of the CAP theorem in “[Consistency Models](#)” (page 11)). How does each data store handle server failures? Is it able to continue operating? This is related to the “Consistency model” dimension discussed earlier, as losing a machine may cause *holes* in your

data store, or even worse, make it completely unavailable. And if you are replacing the server, how easy will it be to get back to being 100% operational? Another scenario is decommissioning a server in a clustered setup, which would most likely be handled the same way.

Compression

When you have to store terabytes of data, especially of the kind that consists of prose or human-readable text, it is advantageous to be able to compress the data to gain substantial savings in required raw storage. Some compression algorithms can achieve a 10:1 reduction in storage space needed. Is the compression method pluggable? What types are available?

Load balancing

Given that you have a high read or write rate, you may want to invest in a storage system that transparently balances itself while the load shifts over time. It may not be the full answer to your problems, but it may help you to ease into a high-throughput application design.

We will look back at these dimensions later on to see where HBase fits and where its strengths lie. For now, let us say that you need to carefully select the dimensions that are best suited to the issues at hand. Be pragmatic about the solution, and be aware that there is no hard and fast rule, in cases where an RDBMS is not working ideally, that a NoSQL system is the perfect match. Evaluate your options, choose wisely, and mix and match if needed.

An interesting term to describe this issue is *impedance match*, which describes the need to find the ideal solution for a given problem. Instead of using a “one-size-fits-all” approach, you should know what else is available. Try to use the system that solves your problem best.

Scalability

While the performance of RDBMSes is well suited for transactional processing, it is less so for very large-scale analytical processing. This refers to very large queries that scan wide ranges of records or entire tables. Analytical databases may contain hundreds or thousands of terabytes, causing queries to exceed what can be done on a single server in a reasonable amount of time. Scaling that server vertically—that is, adding more cores or disks—is simply not good enough.

What is even worse is that with RDBMSes, waits and deadlocks are increasing nonlinearly with the size of the transactions and concurrency—that is, the square of concurrency and the third or even fifth power of the transaction size.¹⁵ Sharding is often an impractical solution, as it has to be done within the application layer, and may involve complex and costly (re)partitioning procedures.

Commercial RDBMSes are available that solve many of these issues, but they are often specialized and only cover certain aspects. Above all, they are very, very expensive. Looking at open source alternatives in the RDBMS space, you will likely have to give up many or all relational features, such as secondary indexes, to gain some level of performance.

The question is, wouldn't it be good to trade relational features permanently for performance? You could denormalize (see the next section) the data model and avoid waits and deadlocks by minimizing necessary locking. How about built-in horizontal scalability without the need to repartition as your data grows? Finally, throw in fault tolerance and data availability, using the same mechanisms that allow scalability, and what you get is a NoSQL solution—more specifically, one that matches what HBase has to offer.

Database (De-)Normalization

At scale, it is often a requirement that we design schemas differently, and a good term to describe this principle is *Denormalization, Duplication, and Intelligent Keys (DDI)*.¹⁶ It is about rethinking how data is stored in Bigtable-like storage systems, and how to make use of it in an appropriate way.

Part of the principle is to denormalize schemas by, for example, duplicating data in more than one table so that, at read time, no further aggregation is required. Or the related prematerialization of required views, once again optimizing for fast reads without any further processing.

There is much more on this topic in [Link to Come], where you will find many ideas on how to design solutions that make the best use of the features HBase provides. Let us look at an example to understand the basic principles of converting a classic *relational* database model to one that fits the columnar nature of HBase much better.

15. See “[FT 101](#)” by Jim Gray et al.

16. The term *DDI* was coined in the paper “Cloud Data Structure Diagramming Techniques and Design Patterns” by D. Salmen et al. (2009).

Consider the HBase URL Shortener, Hush, which allows us to map long URLs to *short URLs*. The *entity relationship diagram* (ERD) can be seen in Figure 1-2. The full SQL schema can be found in (to come).¹⁷

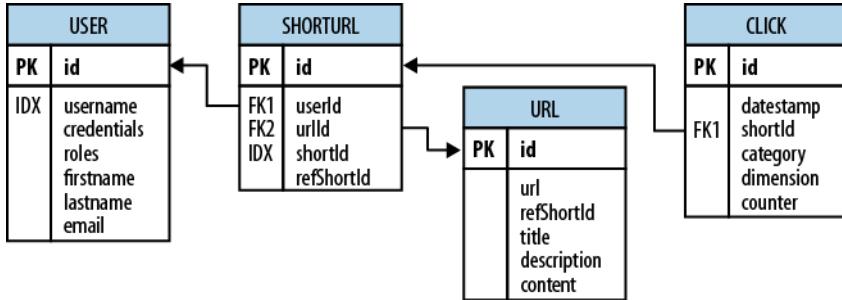


Figure 1-2. The Hush schema expressed as an ERD

The shortened URL, stored in the `shorturl` table, can then be given to others that subsequently click on it to open the linked full URL. Each click is tracked, recording the number of times it was used, and, for example, the country the click came from. This is stored in the `click` table, which aggregates the usage on a daily basis, similar to a counter.

Users, stored in the `user` table, can sign up with Hush to create their own list of shortened URLs, which can be edited to add a description. This links the `user` and `shorturl` tables with a foreign key relationship.

The system also downloads the linked page in the background, and extracts, for instance, the `TITLE` tag from the HTML, if present. The entire page is saved for later processing with asynchronous batch jobs, for analysis purposes. This is represented by the `url` table.

Every linked page is only stored once, but since many users may link to the same long URL, yet want to maintain their own details, such as the usage statistics, a separate entry in the `shorturl` is created. This links the `url`, `shorturl`, and `click` tables.

It also allows you to aggregate statistics about the original short ID, `refShortId`, so that you can see the overall usage of any short URL to

17. Note, though, that this is provided purely for demonstration purposes, so the schema is deliberately kept simple.

map to the same long URL. The `shortId` and `refShortId` are the hashed IDs assigned uniquely to each shortened URL. For example, in

<http://hush.li/a23eg>

the ID is `a23eg`.

Figure 1-3 shows how the same schema could be represented in HBase. Every shortened URL is stored in a table, `shorturl`, which also contains the usage statistics, storing various time ranges in separate column families, with distinct *time-to-live* settings. The columns form the actual counters, and their name is a combination of the date, plus an optional dimensional postfix—for example, the country code.

Table: shorturl		
Row Key:	shortId	
Family:	data:	Columns: url, refShortId, userId, clicks
	stats-daily: [ttl: 7days]	Columns: YYYYMMDD, YYYYMMDD\x00<country-code>
	stats-weekly: [ttl: 4weeks]	Columns: YYYYWW, YYYYWW\x00<country-code>
	stats-monthly: [ttl: 12months]	Columns: YYYYMM, YYYYMM\x00<country-code>

Table: url		
Row Key:	MD5(url)	
Family:	data: [compressed]	Columns: refShortId, title, description
	content: [compressed]	Columns: raw

Table: user-shorturl		
Row Key:	username\x00shortId	
Family:	data:	Columns: timestamp

Table: user		
Row Key:	username	
Family:	data:	Columns: credentials, roles, firstname, lastname, email

Figure 1-3. The Hush schema in HBase

The downloaded page, and the extracted details, are stored in the `url` table. This table uses compression to minimize the storage requirements, because the pages are mostly HTML, which is inherently verbose and contains a lot of text.

The `user-shorturl` table acts as a lookup so that you can quickly find all short IDs for a given user. This is used on the user's home page, once she has logged in. The `user` table stores the actual user details.

We still have the same number of tables, but their meaning has changed: the `clicks` table has been absorbed by the `shorturl` table, while the statistics columns use the date as their key, formatted as `YYYYMMDD`--for instance, `20150302`--so that they can be accessed sequentially. The additional `user-shorturl` table is replacing the foreign key relationship, making user-related lookups faster.

There are various approaches to converting *one-to-one*, *one-to-many*, and *many-to-many* relationships to fit the underlying architecture of HBase. You could implement even this simple example in different ways. You need to understand the full potential of HBase storage design to make an educated decision regarding which approach to take.

The support for sparse, wide tables and column-oriented design often eliminates the need to normalize data and, in the process, the costly `JOIN` operations needed to aggregate the data at query time. Use of intelligent keys gives you fine-grained control over how—and where—data is stored. Partial key lookups are possible, and when combined with compound keys, they have the same properties as leading, left-edge indexes. Designing the schemas properly enables you to grow the data from 10 entries to 10 billion entries, while still retaining the same write and read performance.

Building Blocks

This section provides you with an overview of the architecture behind HBase. After giving you some background information on its lineage, the section will introduce the general concepts of the data model and the available storage API, and presents a high-level overview on implementation.

Backdrop

In 2003, Google published a paper titled "*The Google File System*". This scalable distributed file system, abbreviated as GFS, uses a cluster of commodity hardware to store huge amounts of data. The filesystem handled data replication between nodes so that losing a storage

server would have no effect on data availability. It was also optimized for streaming reads so that data could be read for processing later on.

Shortly afterward, another paper by Google was published, titled “[MapReduce: Simplified Data Processing on Large Clusters](#)”. MapReduce was the missing piece to the GFS architecture, as it made use of the vast number of CPUs each commodity server in the GFS cluster provides. MapReduce plus GFS forms the backbone for processing massive amounts of data, including the entire search index Google owns.

What is missing, though, is the ability to access data randomly and in close to real-time (meaning good enough to drive a web service, for example). Another drawback of the GFS design is that it is good with a few very, very large files, but not as good with millions of tiny files, because the data retained in memory by the master node is ultimately bound to the number of files. The more files, the higher the pressure on the memory of the master.

So, Google was trying to find a solution that could drive interactive applications, such as Mail or Analytics, while making use of the same infrastructure and relying on GFS for replication and data availability. The data stored should be composed of much smaller entities, and the system would transparently take care of aggregating the small records into very large storage files and offer some sort of indexing that allows the user to retrieve data with a minimal number of disk seeks. Finally, it should be able to store the entire web crawl and work with MapReduce to build the entire search index in a timely manner.

Being aware of the shortcomings of RDBMSes at scale (see (to come) for a discussion of one fundamental issue), the engineers approached this problem differently: forfeit relational features and use a simple API that has basic *create*, *read*, *update*, and *delete* (or CRUD) operations, plus a *scan* function to iterate over larger key ranges or entire tables. The culmination of these efforts was published in 2006 in a paper titled “[Bigtable: A Distributed Storage System for Structured Data](#)”, two excerpts from which follow:

Bigtable is a distributed storage system for managing structured data that is designed to scale to a very large size: petabytes of data across thousands of commodity servers.

...a sparse, distributed, persistent multi-dimensional sorted map.

It is highly recommended that everyone interested in HBase read that paper. It describes a lot of reasoning behind the design of Bigtable and, ultimately, HBase. We will, however, go through the basic concepts, since they apply directly to the rest of this book.

HBase is implementing the Bigtable storage architecture very faithfully so that we can explain everything using HBase. (to come) provides an overview of where the two systems differ.

Namespaces, Tables, Rows, Columns, and Cells

First, a quick summary: the most basic unit is a *column*. One or more columns form a *row* that is addressed uniquely by a *row key*. A number of rows, in turn, form a *table*, and there can be many of them. Each column may have multiple versions, with each distinct value contained in a separate *cell*. On a higher level, tables are grouped into *namespaces*, which help, for example, with grouping tables by users or application, or with access control.

This sounds like a reasonable description for a typical database, but with the extra *dimension* of allowing multiple versions of each cells. But obviously there is a bit more to it: All *rows* are always sorted lexicographically by their row key. [Example 1-1](#) shows how this will look when adding a few rows with different keys.

Example 1-1. The sorting of rows done lexicographically by their key

```
hbase(main):001:0> scan 'table1'
ROW                                COLUMN+CELL
row-1                               column=cf1:, timestamp=1297073325971 ...
row-10                             column=cf1:, timestamp=1297073337383 ...
row-11                             column=cf1:, timestamp=1297073340493 ...
row-2                               column=cf1:, timestamp=1297073329851 ...
row-22                             column=cf1:, timestamp=1297073344482 ...
row-3                               column=cf1:, timestamp=1297073333504 ...
row-abc                            column=cf1:, timestamp=1297073349875 ...
7 row(s) in 0.1100 seconds
```

Note how the numbering is not in sequence as you may have expected it. You may have to pad keys to get a proper sorting order. In lexicographical sorting, each key is compared on a binary level, byte by byte, from left to right. Since `row-1...` is less than `row-2...`, no matter what follows, it is sorted first.

Having the row keys always sorted can give you something like a primary key index known from RDBMSes. It is also always unique, that is, you can have each row key only once, or you are updating the same row. While the original Bigtable paper only considers a single index, HBase adds support for secondary indexes (see (to come)). The row keys can be any *arbitrary array of bytes* and are not necessarily human-readable.

Rows are composed of *columns*, and those, in turn, are grouped into *column families*. This helps in building semantical or topical boundaries between the data, and also in applying certain features to them, for example, *compression*, or denoting them to stay in-memory. All columns in a column family are stored together in the same low-level storage files, called *HFile*.

Column families need to be defined when the table is created and should not be changed too often, nor should there be too many of them. There are a few known shortcomings in the current implementation that force the count to be limited to the low tens, though in practice only a low number is usually needed anyways (see [Link to Come] for details). The name of the column family must be composed of printable characters, a notable difference from all other names or values.

Columns are often referenced as *family:qualifier* pair with the qualifier being any arbitrary array of bytes.¹⁸ As opposed to the limit on column families, there is no such thing for the number of columns: you could have millions of columns in a particular column family. There is also no type nor length boundary on the column values.

[Figure 1-4](#) helps to visualize how different rows are in a normal database as opposed to the column-oriented design of HBase. You should think about rows and columns not being arranged like the classic spreadsheet model, but rather use a tag metaphor, that is, information is available under a specific tag.

18. You will see in “[Column Families](#)” (page 362) that the qualifier also may be left unset.

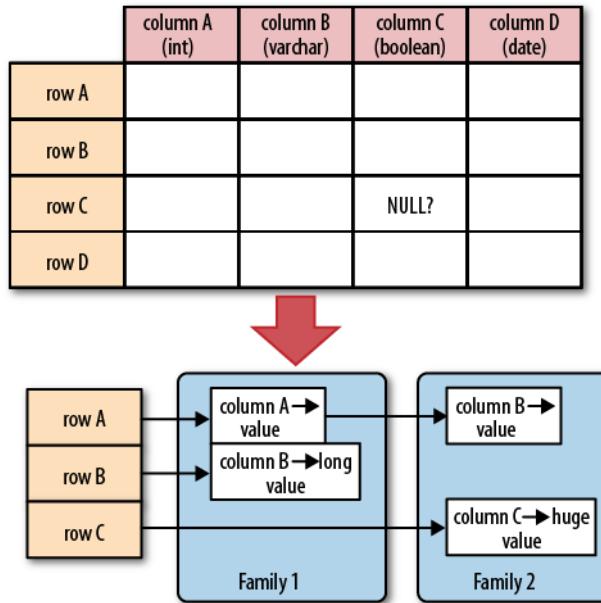


Figure 1-4. Rows and columns in HBase

The "NULL?" in Figure 1-4 indicates that, for a database with a fixed schema, you have to store NULLs where there is no value, but for HBase's storage architectures, you simply omit the whole column; in other words, NULLs are free of any cost: they do not occupy any storage space.

All rows and columns are defined in the context of a *table*, adding a few more concepts across all included column families, which we will discuss shortly.

Every column value, or *cell*, either is timestamped implicitly by the system or can be set explicitly by the user. This can be used, for example, to save multiple *versions* of a value as it changes over time. Different versions of a cell are stored in decreasing timestamp order, allowing you to read the newest value first. This is an optimization aimed at read patterns that favor more current values over historical ones.

The user can specify how many versions of a value should be kept. In addition, there is support for *predicate deletions* (see (to come) for the concepts behind them) allowing you to keep, for example, only values

written in the past week. The values (or cells) are also just uninterpreted arrays of bytes, that the client needs to know how to handle.

If you recall from the quote earlier, the Bigtable model, as implemented by HBase, is a sparse, distributed, persistent, multidimensional map, which is indexed by row key, column key, and a timestamp. Putting this together, we can express the access to data like so:

```
(Table, RowKey, Family, Column, Timestamp) → Value
```

This representation is not entirely correct as physically it is the column family that separates columns and creates *rows per family*. We will pick this up in (to come) later on.

In a more programming language style, this may be expressed as:

```
SortedMap<
    RowKey, List<
        SortedMap<
            Column, List<
                Value, Timestamp
            >
        >
    >
```

Or all in one line:

```
SortedMap<RowKey, List<SortedMap<Column, List<Value, Timestamp>>>>
```

The first `SortedMap` is the table, containing a `List` of column families. The families contain another `SortedMap`, which represents the columns, and their associated values. These values are in the final `List` that holds the value and the timestamp it was set, and is sorted really descending by the timestamp component.

An interesting feature of the model is that cells may exist in multiple versions, and different columns have been written at different times. The API, by default, provides you with a coherent view of all columns wherein it automatically picks the most current value of each cell. [Figure 1-5](#) shows a piece of one specific row in an example table.

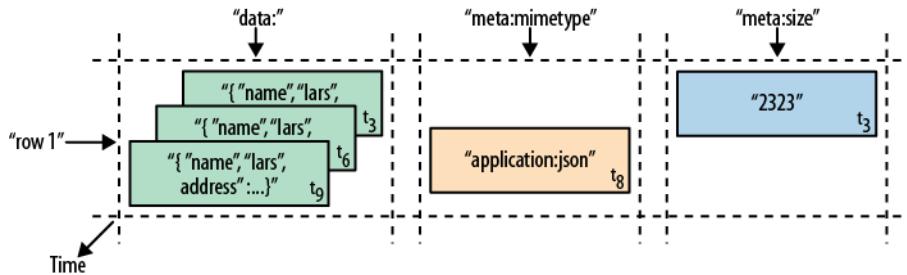


Figure 1-5. A time-oriented view into parts of a row

The diagram visualizes the time component using t_n as the timestamp when the cell was written. The ascending index shows that the values have been added at different times. Figure 1-6 is another way to look at the data, this time in a more spreadsheet-like layout wherein the timestamp was added to its own column.

Row Key	Time Stamp	Column "data:"	Column "meta:" "mimetype"	Column "meta:" "size"	Column "counters:" "updates"
"row1"	t ₃	"{ "name": "lars", "address": ...}"		"2323"	"1"
	t ₆	"{ "name": "lars", "address": ...}"			"2"
	t ₈		"application/json"		
	t ₉	"{ "name": "lars", "address": ...}"			"3"

Figure 1-6. The same parts of the row rendered as a spreadsheet

Although they have been added at different times and exist in multiple versions, you would still see the row as the combination of all columns and their most current versions—in other words, the highest t_n from each column. There is a way to ask for values at (or before) a specific timestamp, or more than one version at a time, which we will see a little bit later in Chapter 3.

The Webtable

The *canonical* use case of Bigtable and HBase is the *webtable*, that is, the web pages stored while crawling the Internet.

The row key is the reversed URL of the page—for example, `org.hbase.www`. There is a column family storing the actual HTML code, the `contents` family, as well as others like `anchor`, which is

used to store outgoing links, another one to store inbound links, and yet another for metadata like the language of the page.

Using multiple versions for the *contents* family allows you to store a few older copies of the HTML, and is helpful when you want to analyze how often a page changes, for example. The timestamps used are the actual times when they were fetched from the crawled website.

Access to row data is *atomic* and includes any number of columns being read or written to. The only additional guarantee is that you can span a mutation across colocated rows atomically using *region-local* transactions (see (to come) for details¹⁹). There is no further guarantee or transactional feature that spans multiple rows across regions, or across tables. The atomic access is also a contributing factor to this architecture being *strictly consistent*, as each concurrent reader and writer can make safe assumptions about the state of a row. Using multiversioning and timestamping can help with application layer consistency issues as well.

Finally, cells, since HBase 0.98, can carry an arbitrary set of *tags*. They are used to flag any cell with metadata that is used to make decisions about the cell during data operations. A prominent use-case is security (see (to come)) where tags are set for cells containing access details. Once a user is authenticated and has a valid security token, the system can use the token to filter specific cells for the given user. Tags can be used for other things as well, and (to come) will explain their application in greater detail.

Auto-Sharding

The basic unit of scalability and load balancing in HBase is called a *region*. Regions are essentially contiguous ranges of rows stored together. They are dynamically split by the system when they become too large. Alternatively, they may also be merged to reduce their number and required storage files (see (to come)).

19. This was introduced in HBase 0.94.0. More on ACID guarantees and MVCC in (to come).

The HBase regions are equivalent to *range partitions* as used in database sharding. They can be spread across many physical servers, thus distributing the load, and therefore providing scalability.

Initially there is only one region for a table, and as you start adding data to it, the system is monitoring it to ensure that you do not exceed a configured maximum size. If you exceed the limit, the region is split into two at the *middle key*—the row key in the middle of the region—creating two roughly equal halves (more details in (to come)).

Each region is served by exactly one *region server*, and each of these servers can serve many regions at any time. [Figure 1-7](#) shows how the logical view of a table is actually a set of regions hosted by many region servers.

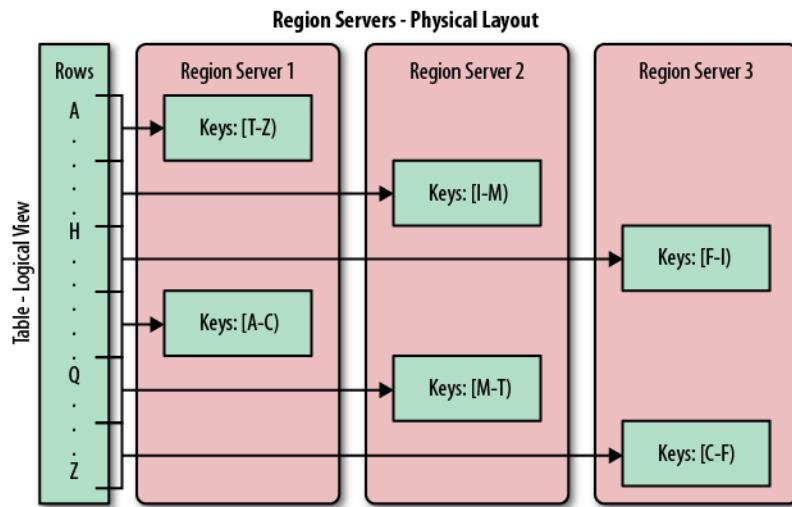


Figure 1-7. Rows grouped in regions and served by different servers

The Bigtable paper notes that the aim is to keep the region count between 10 and 1,000 per server and each at roughly 100 MB to 200 MB in size. This refers to the hardware in use in 2006 (and earlier). For HBase and modern hardware, the number would be more like 10 to 1,000 regions per server, but each between 1 GB and 10 GB in size.

But, while the numbers have increased, the basic principle is the same: the number of regions per server, and their respective sizes, depend on what can be handled sufficiently by a single server.

Splitting and serving regions can be thought of as *autosharding*, as offered by other systems. The regions allow for fast recovery when a server fails, and fine-grained load balancing since they can be moved between servers when the load of the server currently serving the region is under pressure, or if that server becomes unavailable because of a failure or because it is being decommissioned.

Splitting is also very fast—close to instantaneous—because the split regions simply read from the original storage files until a compaction rewrites them into separate ones asynchronously. This is explained in detail in (to come).

Storage API

Bigtable does not support a full relational data model; instead, it provides clients with a simple data model that supports dynamic control over data layout and format [...]

The API offers operations to create and delete tables and column families. In addition, it has functions to change the table and column family metadata, such as compression or block sizes. Furthermore, there are the usual operations for clients to create or delete values as well as retrieving them with a given row key.

A *scan* API allows you to efficiently iterate over ranges of rows and be able to limit which columns are returned or the number of versions of each cell. You can match columns using filters and select versions using time ranges, specifying start and end times.

On top of this basic functionality are more advanced features. The system has support for single-row and region-local²⁰ transactions, and with this support it implements atomic *read-modify-write* sequences on data stored under a single row key, or multiple, colocated ones.

Cell values can be interpreted as counters and updated atomically. These counters can be read and modified in one operation so that, despite the distributed nature of the architecture, clients can use this mechanism to implement global, strictly consistent, sequential counters.

There is also the option to run client-supplied code in the address space of the server. The server-side framework to support this is called *coprocessors*.²¹ The code has access to the server local data and can be used to implement lightweight batch jobs, or use expressions to analyze or summarize data based on a variety of operators.

Finally, the system is integrated with the MapReduce framework by supplying wrappers that convert tables into input source and output targets for MapReduce jobs.

Unlike in the RDBMS landscape, there is no domain-specific language, such as SQL, to query data. Access is not done declaratively, but purely imperatively through the client-side API. For HBase, this is mostly Java code, but there are many other choices to access the data from other programming languages.

Implementation

Bigtable [...] allows clients to reason about the locality properties of the data represented in the underlying storage.

The data is stored in *store files*, called *HFiles*, which are persistent and ordered immutable maps from keys to values. Internally, the files are sequences of blocks with a block index stored at the end. The index is loaded when the HFile is opened and kept in memory. The default block size is 64 KB but can be configured differently if required. The store files provide an API to access specific values as well as to scan ranges of values given a start and end key.

20. Region-local transactions, along with a row-key prefix aware split policy, were added in HBase 0.94. See [HBASE-5229](#).

21. Coprocessors were added to HBase in version 0.92.0.

Implementation is discussed in great detail in (to come). The text here is an introduction only, while the full details are discussed in the referenced chapter(s).

Since every HFile has a block index, lookups can be performed with a single disk seek.²² First, the block possibly containing the given key is determined by doing a binary search in the in-memory block index, followed by a block read from disk to find the actual key.

The store files are typically saved in the Hadoop Distributed File System (HDFS), which provides a scalable, persistent, replicated storage layer for HBase. It guarantees that data is never lost by writing the changes across a configurable number of physical servers.

When data is updated it is first written to a *commit log*, called a *write-ahead log* (WAL) in HBase, and then stored in the in-memory *memstore*. Once the data in memory has exceeded a given maximum value, it is flushed as a HFile to disk. After the flush, the commit logs can be discarded up to the last unflushed modification. While the system is flushing the memstore to disk, it can continue to serve readers and writers without having to block them. This is achieved by rolling the memstore in memory where the new/empty one is taking the updates, while the old/full one is converted into a file. Note that the data in the memstores is already sorted by keys matching exactly what HFiles represent on disk, so no sorting or other special processing has to be performed.

22. This is a simplification as newer HFile versions use a multilevel index, loading partial index blocks as needed. This adds to the latency, but once the index is cached the behavior is back to what is described here.

We can now start to make sense of what the *locality properties* are, mentioned in the Bigtable quote at the beginning of this section. Since all files contain sorted key/value pairs, ordered by the key, and are optimized for block operations such as reading these pairs sequentially, you should specify keys to keep related data together. Referring back to the webtable example earlier, you may have noted that the key used is the reversed FQDN (the domain name part of the URL), such as `org.hbase.www`. The reason is to store all pages from `hbase.org` close to one another, and reversing the URL puts the most important part of the URL first, that is, the top-level domain (TLD). Pages under `blog.hbase.org` would then be sorted with those from `www.hbase.org`--or in the actual key format, `org.hbase.blog` sorts next to `org.hbase.www`.

Because store files are immutable, you cannot simply delete values by removing the key/value pair from them. Instead, a *delete marker* (also known as a tombstone marker) is written to indicate the fact that the given key has been deleted. During the retrieval process, these delete markers mask out the actual values and hide them from reading clients.

Reading data back involves a merge of what is stored in the memstores, that is, the data that has not been written to disk, and the on-disk store files. Note that the WAL is never used during data retrieval, but solely for recovery purposes when a server has crashed before writing the in-memory data to disk.

Since flushing memstores to disk causes more and more HFiles to be created, HBase has a housekeeping mechanism that merges the files into larger ones using *compaction*. There are two types of compaction: *minor compactations* and *major compactations*. The former reduce the number of storage files by rewriting smaller files into fewer but larger ones, performing an n -way merge. Since all the data is already sorted in each HFile, that merge is fast and bound only by disk I/O performance.

The *major compactations* rewrite all files within a column family for a region into a single new one. They also have another distinct feature compared to the minor compactations: based on the fact that they scan all key/value pairs, they can drop deleted entries including their deletion marker. Predicate deletes are handled here as well—for example, removing values that have expired according to the configured *time-to-live* (TTL) or when there are too many versions.

This architecture is taken from LSM-trees (see (to come)). The only difference is that LSM-trees are storing data in multipage blocks that are arranged in a B-tree-like structure on disk. They are updated, or merged, in a rotating fashion, while in Bigtable the update is more coarse-grained and the whole memstore is saved as a new store file and not merged right away. You could call HBase's architecture "Log-Structured Sort-and-Merge-Maps." The background compactions correspond to the merges in LSM-trees, but are occurring on a store file level instead of the partial tree updates, giving the LSM-trees their name.

There are three major components to HBase: the client library, at least one master server, and many region servers. The region servers can be added or removed while the system is up and running to accommodate changing workloads. The master is responsible for assigning regions to region servers and uses *Apache ZooKeeper*, a reliable, highly available, persistent and distributed coordination service, to facilitate that task.

Apache ZooKeeper

ZooKeeper²³ is a separate open source project, and is also part of the Apache Software Foundation. ZooKeeper is the comparable system to Google's use of Chubby for Bigtable. It offers filesystem-like access with directories and files (called *znodes*) that distributed systems can use to negotiate ownership, register services, or watch for updates.

Every region server creates its own ephemeral node in ZooKeeper, which the master, in turn, uses to discover available servers. They are also used to track server failures or network partitions.

Ephemeral nodes are bound to the session between ZooKeeper and the client which created it. The session has a heartbeat keepalive mechanism that, once it fails to report, is declared lost by ZooKeeper and the associated ephemeral nodes are deleted.

HBase uses ZooKeeper also to ensure that there is only one master running, to store the bootstrap location for region discovery,

23. For more information on Apache ZooKeeper, please refer to the official [project website](#).

as a registry for region servers, as well as for other purposes. ZooKeeper is a critical component, and without it HBase is not operational. This is facilitated by ZooKeeper's distributed design using an *ensemble* of servers and the *Zab* protocol to keep its state consistent.

Figure 1-8 shows how the various components of HBase are orchestrated to make use of existing system, like HDFS and ZooKeeper, but also adding its own layers to form a complete platform.

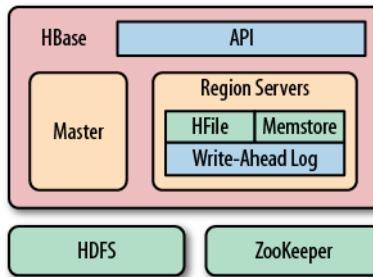


Figure 1-8. HBase using its own components while leveraging existing systems

The master server is also responsible for handling load balancing of regions across region servers, to unload busy servers and move regions to less occupied ones. The master is not part of the actual data storage or retrieval path. It negotiates load balancing and maintains the state of the cluster, but never provides any data services to either the region servers or the clients, and is therefore lightly loaded in practice. In addition, it takes care of schema changes and other metadata operations, such as creation of tables and column families.

Region servers are responsible for all read and write requests for all regions they serve, and also split regions that have exceeded the configured region size thresholds. Clients communicate directly with them to handle all data-related operations.

(to come) has more details on how clients perform the region lookup.

Summary

Billions of rows * millions of columns * thousands of versions = terabytes or petabytes of storage

— The HBase Project

We have seen how the Bigtable storage architecture is using many servers to distribute ranges of rows sorted by their key for load-balancing purposes, and can scale to petabytes of data on thousands of machines. The storage format used is ideal for reading adjacent key/value pairs and is optimized for block I/O operations that can saturate disk transfer channels.

Table scans run in linear time and row key lookups or mutations are performed in logarithmic order—or, in extreme cases, even constant order (using Bloom filters). Designing the schema in a way to completely avoid explicit locking, combined with row-level atomicity, gives you the ability to scale your system without any notable effect on read or write performance.

The column-oriented architecture allows for huge, wide, sparse tables as storing NULLs is free. Because each row is served by exactly one server, HBase is strongly consistent, and using its multiversioning can help you to avoid edit conflicts caused by concurrent decoupled processes, or retain a history of changes.

The actual Bigtable has been in production at Google since at least 2005, and it has been in use for a variety of different use cases, from batch-oriented processing to real-time data-serving. The stored data varies from very small (like URLs) to quite large (e.g., web pages and satellite imagery) and yet successfully provides a flexible, high-performance solution for many well-known Google products, such as Google Earth, Google Reader, Google Finance, and Google Analytics.

HBase: The Hadoop Database

Having looked at the Bigtable architecture, we could simply state that HBase is a faithful, open source implementation of Google’s Bigtable. But that would be a bit too simplistic, and there are a few (mostly subtle) differences worth addressing.

History

HBase was created in 2007 at Powerset²⁴ and was initially part of the contributions in Hadoop. Since then, it has become its own top-level project under the Apache Software Foundation umbrella. It is available under the Apache Software License, version 2.0.

24. Powerset is a company based in San Francisco that was developing a natural language search engine for the Internet. On July 1, 2008, Microsoft acquired Powerset, and subsequent support for HBase development was abandoned.

The project home page is <http://hbase.apache.org/>, where you can find links to the documentation, wiki, and source repository, as well as download sites for the binary and source releases.

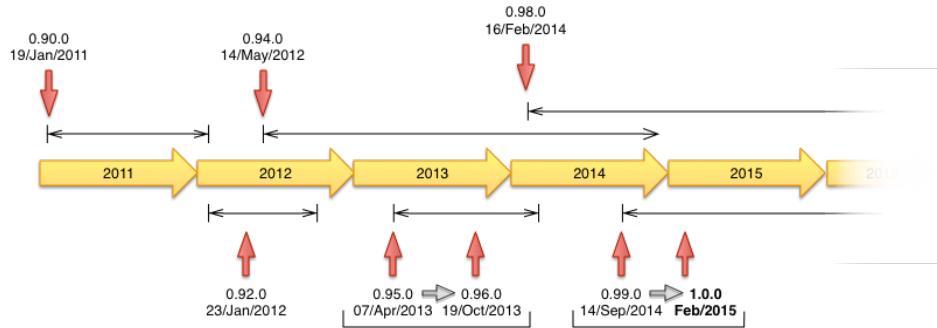


Figure 1-9. The release timeline of HBase.

Here is a short overview of how HBase has evolved over time, which Figure 1-9 shows in a timeline form:

November 2006

Google releases paper on Bigtable

February 2007

Initial HBase prototype created as Hadoop contrib²⁵

October 2007

First "usable" HBase (Hadoop 0.15.0)

January 2008

Hadoop becomes an Apache top-level project, HBase becomes sub-project

October 2008

HBase 0.18.1 released

January 2009

HBase 0.19.0 released

September 2009

HBase 0.20.0 released, the *performance* release

25. For an interesting flash back in time, see [HBASE-287](#) on the Apache JIRA, the issue tracking system. You can see how Mike Cafarella did a code drop that was then quickly picked up by Jim Kellerman, who was with Powerset back then.

May 2010

HBase becomes an Apache top-level project

June 2010

HBase 0.89.20100621, first developer release

January 2011

HBase 0.90.0 released, the *durability and stability* release

January 2012

HBase 0.92.0 released, tagged as *coprocessor and security* release

May 2012

HBase 0.94.0 released, tagged as *performance* release

October 2013

HBase 0.96.0 released, tagged as *the singularity*

February 2014

HBase 0.98.0 released

February 2015

HBase 1.0.0 released

Figure 1-9 shows as well how many months or years a release has been—or still is—active. This mainly depends on the release managers and their need for a specific major version to *keep going*.

Around May 2010, the developers decided to break with the version numbering that used to be in *lockstep* with the Hadoop releases. The rationale was that HBase had a much faster release cycle and was also approaching a version 1.0 level sooner than what was expected from Hadoop.²⁶

To that effect, the jump was made quite obvious, going from 0.20.x to 0.89.x. In addition, a decision was made to title 0.89.x the *early access* version for developers and bleeding-edge integrators. Version 0.89 was eventually released as 0.90 for everyone as the next stable release.

26. Oh, the irony! Hadoop 1.0.0 was released on December 27th, 2011, which means three years ahead of HBase.

Nomenclature

One of the biggest differences between HBase and Bigtable concerns naming, as you can see in [Table 1-1](#), which lists the various terms and what they correspond to in each system.

Table 1-1. Differences in naming

HBase	Bigtable
Region	Tablet
RegionServer	Tablet server
Flush	Minor compaction
Minor compaction	Merging compaction
Major compaction	Major compaction
Write-ahead log	Commit log
HDFS	GFS
Hadoop MapReduce	MapReduce
MemStore	memtable
HFile	SSTable
ZooKeeper	Chubby

More differences are described in (to come).

Summary

Let us now circle back to “Dimensions” ([page 13](#)), and how these dimensions can be used to classify HBase. HBase is a distributed, persistent, strictly consistent storage system with near-optimal write—in terms of I/O channel saturation—and excellent read performance, and it makes efficient use of disk space by supporting pluggable compression algorithms that can be selected based on the nature of the data in specific column families.

HBase extends the Bigtable model, which only considers a single index, similar to a primary key in the RDBMS world, offering the server-side hooks to implement flexible secondary index solutions. In addition, it provides push-down predicates, that is, filters, reducing data transferred over the network.

There is no declarative query language as part of the core implementation, and it has limited support for transactions. Row atomicity and read-modify-write operations make up for this in practice, as they cover many use cases and remove the wait or deadlock-related pauses experienced with other systems.

HBase handles shifting load and failures gracefully and transparently to the clients. Scalability is built in, and clusters can be grown or shrunk while the system is in production. Changing the cluster does not involve any complicated rebalancing or resharding procedure, and is *usually* completely automated.²⁷

27. Again I am simplifying here for the sake of being introductory. Later we will see areas where tuning is vital and might seemingly go against what I am summarizing here. See [Link to Come] for details.

Chapter 2

Installation

In this chapter, we will look at how HBase is installed and initially configured. The first part is a *quickstart* section that gets you going fast, but then shifts gears into proper planning and setting up of a HBase cluster. Towards the end we will see how HBase can be used from the command line for basic operations, such as adding, retrieving, and deleting data.

All of the following assumes you have the Java Runtime Environment (JRE) installed. Hadoop and also HBase require at least version 1.7 (also called Java 7)¹, and the recommended choice is the one provided by Oracle (formerly by Sun), which can be found at <http://www.java.com/download/>. If you do not have Java already or are running into issues using it, please see “Java” (page 58).

Quick-Start Guide

Let us get started with the “tl;dr” section of this book: you want to know how to run HBase and you want to know it now! Nothing is easier than that because all you have to do is download the most recent binary release of HBase from the Apache HBase [release page](#).

1. See “Java” (page 58) for information of supported Java versions for older releases of HBase.

HBase is shipped as a binary and source tarball.² Look for bin or src in their names respectively. For the quickstart you need the binary tarball, for example named hbase-1.0.0-bin.tar.gz.

You can download and unpack the contents into a suitable directory, such as /usr/local or /opt, like so:

```
$ cd /usr/local  
$ wget http://archive.apache.org/dist/hbase/hbase-1.0.0/  
hbase-1.0.0-bin.tar.gz  
$ tar -zxf hbase-1.0.0-bin.tar.gz
```

Setting the Data Directory

At this point, you are ready to start HBase. But before you do so, it is advisable to set the data directory to a proper location. You need to edit the configuration file conf/hbase-site.xml and set the directory you want HBase—and ZooKeeper—to write to by assigning a value to the property key named hbase.rootdir and hbase.zookeeper.property.dataDir:

```
<?xml version="1.0"?>  
<?xml-stylesheet type="text/xsl" href="configuration.xsl"?>  
<configuration>  
  <property>  
    <name>hbase.rootdir</name>  
    <value>file:///<PATH>/hbase</value>  
  </property>  
  <property>  
    <name>hbase.zookeeper.property.dataDir</name>  
    <value>file:///<PATH>/zookeeper</value>  
  </property>  
</configuration>
```

Replace <PATH> in the preceding example configuration file with a path to a directory where you want HBase to store its data. By default, hbase.rootdir is set to /tmp/hbase-\${user.name}, which could mean you lose all your data whenever your server or test machine reboots because a lot of operating systems (OSes) clear out /tmp during a restart.

2. Previous versions were shipped just as source archive and had no special postfix in their name. The quickstart steps will still work though.

With that in place, we can start HBase and try our first interaction with it. We will use the interactive shell to enter the `status` command at the prompt (complete the command by pressing the Return key):

```
$ cd /usr/local/hbase-1.0.0
$ bin/start-hbase.sh
starting master, logging to \
/usr/local/hbase-1.0.0/bin/../logs/hbase-<username>-master-
localhost.out
$ bin/hbase shell
HBase Shell; enter 'help<RETURN>' for list of supported commands.
Type "exit<RETURN>" to leave the HBase Shell
Version 1.0.0, r6c98bff7b719efdb16f71606f3b7d8229445eb81, Sat Feb
14 19:49:22 PST 2015
hbase(main):001:0> status
1 servers, 0 dead, 2.0000 average load
```

This confirms that HBase is up and running, so we will now issue a few commands to show that we can put data into it and retrieve the same data subsequently.

It may not be clear, but what we are doing right now is similar to sitting in a car with its brakes engaged and in neutral while turning the ignition key. There is much more that you need to configure and understand before you can use HBase in a production-like environment. But it lets you get started with some basic HBase commands and become familiar with top-level concepts.

We are currently running in the so-called *Standalone Mode*. We will look into the available modes later on (see “[Run Modes](#)” (page 79)), but for now it’s important to know that in this mode everything is run in a single Java process and all files are stored in `/tmp` by default—unless you did heed the important advice given earlier to change it to something different. Many people have lost their test data during a reboot, only to learn that they kept the default paths. Once it is deleted by the OS, there is no going back!

Let us now create a simple table and add a few rows with some data:

```
hbase(main):002:0> create 'testtable', 'colfam1'
0 row(s) in 0.2930 seconds

=> Hbase::Table - testtable
hbase(main):003:0> list
TABLE
testtable
```

```

1 row(s) in 0.1920 seconds

=> ["testtable"]
hbase(main):004:0> put 'testtable', 'myrow-1', 'colfam1:q1',
'value-1'
0 row(s) in 0.1020 seconds

hbase(main):005:0> put 'testtable', 'myrow-2', 'colfam1:q2',
'value-2'
0 row(s) in 0.0410 seconds

hbase(main):006:0> put 'testtable', 'myrow-2', 'colfam1:q3',
'value-3'
0 row(s) in 0.0380 seconds

```

After we create the table with one column family, we verify that it actually exists by issuing a `list` command. You can see how it outputs the `testtable` name as the only table currently known. Subsequently, we are putting data into a number of rows. If you read the example carefully, you can see that we are adding data to two different rows with the keys `myrow-1` and `myrow-2`. As we discussed in [Chapter 1](#), we have one column family named `colfam1`, and can add an arbitrary qualifier to form actual columns, here `colfam1:q1`, `colfam1:q2`, and `colfam1:q3`.

Next we want to check if the data we added can be retrieved. We are using a `scan` operation to do so:

```

hbase(main):007:0> scan 'testtable'
ROW           COLUMN+CELL
  myrow-1      column=colfam1:q1, timestamp=1425041048735,
  value=value-1
  myrow-2      column=colfam1:q2, timestamp=1425041060781,
  value=value-2
  myrow-2      column=colfam1:q3, timestamp=1425041069442,
  value=value-3
2 row(s) in 0.2730 seconds

```

You can observe how HBase is printing the data in a cell-oriented way by outputting each column separately. It prints out `myrow-2` twice, as expected, and shows the actual value for each column next to it.

If we want to get exactly one row back, we can also use the `get` command. It has many more options, which we will look at later, but for now simply try the following:

```

hbase(main):008:0> get 'testtable', 'myrow-1'
COLUMN       CELL
  colfam1:q1   timestamp=1425041048735, value=value-1
1 row(s) in 0.2220 seconds

```

What is missing in our basic set of operations is to delete a value. Again, the aptly named `delete` command offers many options, but for now we just delete one specific cell and check that it is gone:

```
hbase(main):009:0> delete 'testtable', 'myrow-2', 'colfam1:q2'
0 row(s) in 0.0390 seconds

hbase(main):010:0> scan 'testtable'
ROW                  COLUMN+CELL
  myrow-1            column=colfam1:q1, timestamp=1425041048735,
  value=value-1
  myrow-2            column=colfam1:q3, timestamp=1425041069442,
  value=value-3
2 row(s) in 0.0620 seconds
```

Before we conclude this simple exercise, we have to clean up by first disabling and then dropping the test table:

```
hbase(main):011:0> disable 'testtable'
0 row(s) in 1.4880 seconds

hbase(main):012:0> drop 'testtable'
0 row(s) in 0.5780 seconds
```

Finally, we close the shell by means of the `exit` command and return to our command-line prompt:

```
hbase(main):013:0> exit
$ _
```

The last thing to do is stop HBase on our local system. We do this by running the `stop-hbase.sh` script:

```
$ bin/stop-hbase.sh
stopping hbase.....
```

That is all there is to it. We have successfully created a table, added, retrieved, and deleted data, and eventually dropped the table using the HBase Shell.

Requirements

Not all of the following requirements are needed for specific run modes HBase supports. For purely local testing, you only need Java, as mentioned in “[Quick-Start Guide](#)” (page 39).

Hardware

It is difficult to specify a particular server type that is recommended for HBase. In fact, the opposite is more appropriate, as HBase runs on

many, very different hardware configurations. The usual description is *commodity* hardware. But what does that mean?

For starters, we are not talking about desktop PCs, but server-grade machines. Given that HBase is written in Java, you at least need support for a current Java Runtime, and since the majority of the memory needed per region server is for internal structures—for example, the memstores and the block cache—you will have to install a 64-bit operating system to be able to address enough memory, that is, more than 4 GB.

In practice, a lot of HBase setups are colocated with Hadoop, to make use of locality using HDFS as well as MapReduce. This can significantly reduce the required network I/O and boost processing speeds. Running Hadoop and HBase on the same server results in at least three Java processes running (data node, task tracker or node manager³, and region server) and may spike to much higher numbers when executing MapReduce or other processing jobs. All of these processes need a minimum amount of memory, disk, and CPU resources to run sufficiently.

It is assumed that you have a reasonably good understanding of Hadoop, since it is used as the backing store for HBase in all known production systems (as of this writing). If you are completely new to HBase *and* Hadoop, it is recommended that you get familiar with Hadoop first, even on a very basic level. For example, read the recommended *Hadoop: The Definitive Guide* (Fourth Edition) by Tom White (O'Reilly), and set up a working HDFS and MapReduce or YARN cluster.

Giving all the available memory to the Java processes is also not a good idea, as most operating systems need some spare resources to work more effectively—for example, disk I/O buffers maintained by Linux kernels. HBase indirectly takes advantage of this because the already local disk I/O, given that you colocate the systems on the same server, will perform even better when the OS can keep its own block cache.

3. The naming of the processing daemon per node has changed between the former MapReduce v1 and the newer YARN based framework.

We can separate the requirements into two categories: servers and networking. We will look at the server hardware first and then into the requirements for the networking setup subsequently.

Servers

In HBase and Hadoop there are two types of machines: masters (the HDFS NameNode, the MapReduce JobTracker or YARN Resource-Manager, and the HBase Master) and slaves (the HDFS DataNodes, the MapReduce TaskTrackers or YARN NodeManagers, and the HBase RegionServers). They do benefit from slightly different hardware specifications when possible. It is also quite common to use exactly the same hardware for both (out of convenience), but the master does not need that much storage, so it makes sense to not add too many disks. And since the masters are also more important than the slaves, you could beef them up with redundant hardware components. We will address the differences between the two where necessary.

Since Java runs in *user land*, you can run it on top of every operating system that supports a Java Runtime—though there are recommended ones, and those where it does *not* run without user intervention (more on this in “[Operating system](#)” (page 51)). It allows you to select from a wide variety of vendors, or even build your own hardware. It comes down to more generic requirements like the following:

CPU

It makes little sense to run three or more Java processes, plus the services provided by the operating system itself, on single-core CPU machines. For production use, it is typical that you use *multi-core* processors.⁴ 4 to 8 cores are state of the art and affordable, while processors with 10 or more cores are also becoming more popular. Most server hardware supports more than one CPU so that you can use two quad-core CPUs for a total of eight cores. This allows for each basic Java process to run on its own core while the background tasks like Java garbage collection can be executed in parallel. In addition, there is *hyperthreading*, which adds to their overall performance.

As far as CPU is concerned, you should spec the master and slave machines roughly the same.

Node type	Recommendation
Master	Dual 4 to 8+ core CPUs, 2.0-2.6 GHz
Slave	Dual 4 to 10+ core CPUs, 2.0-2.6 GHz

4. See “[Multi-core processor](#)” on Wikipedia.

HBase use-cases are mostly I/O bound, so having more cores will help keep the data drives busy. On the other hand, higher clock rates are not required (but do not hurt either).

Memory

The question really is: is there too much memory? In theory, no, but in practice, it has been empirically determined that when using Java you should not set the amount of memory given to a single process too high. Memory (called *heap* in Java terms) can start to get fragmented, and in a worst-case scenario, the entire heap would need rewriting—this is similar to the well-known disk fragmentation, but it cannot run in the background. The Java Runtime pauses all processing to clean up the mess, which can lead to quite a few problems (more on this later). The larger you have set the heap, the longer this process will take. Processes that do not need a lot of memory should only be given their required amount to avoid this scenario, but with the region servers and their block cache there is, in theory, no upper limit. You need to find a sweet spot depending on your access pattern.

At the time of this writing, setting the heap of the region servers to larger than 16 GB is considered dangerous. Once a stop-the-world garbage collection is required, it simply takes too long to rewrite the fragmented heap. Your server could be considered dead by the master and be removed from the working set.

This may change sometime as this is ultimately bound to the Java Runtime Environment used, and there is development going on to implement JREs that do not stop the running Java processes when performing garbage collections.

Another recent addition to Java is the G1 garbage collector ("garbage first"), which is fully supported by Java 7 update 4 and later. It holds promises to run with much larger heap sizes, as reported by an Intel engineering team in a [blog post](#). The majority of users at the time of writing are not using large heaps though, i.e. with more than 16GB. Test carefully!

[Table 2-1](#) shows a very basic distribution of memory to specific processes. Please note that this is an example only and highly de-

pends on the size of your cluster and how much data you put in, but also on your access pattern, such as interactive access only or a combination of interactive and batch use (using MapReduce). (to come) will help showing various case-studies and how the memory allocation was tuned.

Table 2-1. Exemplary memory allocation per Java process for a cluster with 800 TB of raw disk storage space

Process	Heap	Description
Active NameNode	8 GB	About 1 GB of heap for every 100 TB of raw data stored, or per every million files/inodes
Standby NameNode	8 GB	Tracks the <i>Active NameNode</i> and therefore needs the same amount
ResourceManager	2 GB	Moderate requirements
HBase Master	4 GB	Usually lightly loaded, moderate requirements only
DataNode	1 GB	Moderate requirements
NodeManager	1 GB	Moderate requirements
HBase RegionServer	12 GB	Majority of available memory, while leaving enough room for the operating system (for the buffer cache), and for the <i>Task Attempt</i> processes
Task Attempts	1 GB (ea.)	Multiply by the maximum number you allow for each
ZooKeeper	1 GB	Moderate requirements

An exemplary setup could be as such: for the master machine, running the Active and Standby NameNode, ResourceManager, ZooKeeper, and HBase Master, 24 GB of memory; and for the slaves, running the DataNodes, NodeManagers, and HBase RegionServers, 24 GB or more.⁵

Node type	Minimal Recommendation
Master	24 GB
Slave	24 GB (and up)

5. Setting up a production cluster is a complex thing, the examples here are given just as a starting point. See the O'Reilly [Hadoop Operations](#) book by Eric Sammer for much more details.

It is recommended that you optimize your RAM for the memory channel width of your server. For example, when using dual-channel memory, each machine should be configured with pairs of DIMMs. With triple-channel memory, each server should have triplets of DIMMs. This could mean that a server has 18 GB ($9 \times 2\text{GB}$) of RAM instead of 16 GB ($4 \times 4\text{GB}$).

Also make sure that not just the server's motherboard supports this feature, but also your CPU: some CPUs only support dual-channel memory, and therefore, even if you put in triple-channel DIMMs, they will only be used in dual-channel mode.

Disks

The data is stored on the slave machines, and therefore it is those servers that need plenty of capacity. Depending on whether you are more read/write- or processing-oriented, you need to balance the number of disks with the number of CPU cores available. Typically, you should have at least one core per disk, so in an eight-core server, adding six disks is good, but adding more might not be giving you optimal performance.

RAID or JBOD?

A common question concerns how to attach the disks to the server. Here is where we can draw a line between the master server and the slaves. For the slaves, you should *not* use RAID,⁶ but rather what is called JBOD.⁷ RAID is slower than separate disks because of the administrative overhead and pipelined writes, and depending on the RAID level (usually RAID 0 to be able to use the entire raw capacity), entire data nodes can become unavailable when a single disk fails.

For the master nodes, on the other hand, it *does* make sense to use a RAID disk setup to protect the crucial filesystem data. A common configuration is RAID 1+0 (or RAID 10 for short).

For both servers, though, make sure to use disks with *RAID firmware*. The difference between these and consumer-grade

6. See “[RAID](#)” on Wikipedia.

7. See “[JBOD](#)” on Wikipedia.

disks is that the RAID firmware will fail fast if there is a hardware error, and therefore will not freeze the DataNode in disk wait for a long time.

Some consideration should be given regarding the type of drives—for example, 2.5" versus 3.5" drives or SATA versus SAS. In general, SATA drives are recommended over SAS since they are more cost-effective, and since the nodes are all redundantly storing replicas of the data across multiple servers, you can safely use the more affordable disks. On the other hand, 3.5" disks are more reliable compared to 2.5" disks, but depending on the server chassis you may need to go with the latter.

The disk capacity is usually 1 to 2 TB per disk, but you can also use larger drives if necessary. Using from six to 12 high-density servers with 1 TB to 2 TB drives is good, as you get a lot of storage capacity and the JBOD setup with enough cores can saturate the disk bandwidth nicely.

Node type Minimal Recommendation

Master	4 × 1 TB SATA, RAID 1+0 (2 TB usable)
Slave	6 × 1 TB SATA, JBOD

IOPS

The size of the disks is also an important vector to determine the overall *I/O operations per second* (IOPS) you can achieve with your server setup. For example, 4 × 1 TB drives is good for a general recommendation, which means the node can sustain about 400 IOPS and 400 MB/second transfer throughput for cold data accesses.⁸

What if you need more? You could use 8 × 500 GB drives, for 800 IOPS/second and near GigE network line rate for the disk throughput per node. Depending on your requirements, you need to make sure to combine the right number of disks to achieve your goals.

Chassis

The actual server chassis is not that crucial, as most servers in a specific price bracket provide very similar features. It is often bet-

8. This assumes 100 IOPS per drive, and 100 MB/second per drive.

ter to shy away from special hardware that offers proprietary functionality and opt for generic servers so that they can be easily combined over time as you extend the capacity of the cluster.

As far as networking is concerned, it is recommended that you use a two- or four-port Gigabit Ethernet card—or two channel-bonded cards. If you already have support for 10 Gigabit Ethernet or InfiniBand, you should use it.

For the slave servers, a single power supply unit (PSU) is sufficient, but for the master node you should use redundant PSUs, such as the optional dual PSUs available for many servers.

In terms of density, it is advisable to select server hardware that fits into a low number of rack units (abbreviated as “U”). Typically, 1U or 2U servers are used in 19” racks or cabinets. A consideration while choosing the size is how many disks they can hold and their power consumption. Usually a 1U server is limited to a lower number of disks or forces you to use 2.5” disks to get the capacity you want.

Node type	Minimal Recommendation
Master	Gigabit Ethernet, dual PSU, 1U or 2U
Slave	Gigabit Ethernet, single PSU, 1U or 2U

Networking

In a data center, servers are typically mounted into 19” racks or cabinets with 40U or more in height. You could fit up to 40 machines (although with half-depth servers, some companies have up to 80 machines in a single rack, 40 machines on either side) and link them together with a *top-of-rack* (ToR) switch. Given the Gigabit speed per server, you need to ensure that the ToR switch is fast enough to handle the throughput these servers can create. Often the backplane of a switch cannot handle all ports at line rate or is oversubscribed—in other words, promising you something in theory it cannot do in reality.

Switches often have 24 or 48 ports, and with the aforementioned channel-bonding or two-port cards, you need to size the networking large enough to provide enough bandwidth. Installing 40 1U servers would need 80 network ports; so, in practice, you may need a staggered setup where you use multiple rack switches and then aggregate to a much larger *core aggregation switch* (CaS). This results in a *two-tier* architecture, where the distribution is handled by the ToR switch and the aggregation by the CaS.

While we cannot address all the considerations for large-scale setups, we can still notice that this is a common design pattern.⁹ Given that the operations team is part of the planning, and it is known how much data is going to be stored and how many clients are expected to read and write concurrently, this involves basic math to compute the number of servers needed—which also drives the networking considerations.

When users have reported issues with HBase on the public mailing list or on other channels, especially regarding slower-than-expected I/O performance bulk inserting huge amounts of data, it became clear that networking was either the main or a contributing issue. This ranges from misconfigured or faulty network interface cards (NICs) to completely oversubscribed switches in the I/O path. Please make sure that you verify every component in the cluster to avoid sudden operational problems—the kind that could have been avoided by sizing the hardware appropriately.

Finally, albeit recent improvements of the built-in security in Hadoop and HBase, it is common for the entire cluster to be located in its own network, possibly protected by a firewall to control access to the few required, client-facing ports.

Software

After considering the hardware and purchasing the server machines, it's time to consider software. This can range from the operating system itself to filesystem choices and configuration of various auxiliary services.

Most of the requirements listed are independent of HBase and have to be applied on a very low, operational level. You may have to advise with your administrator to get everything applied and verified.

Operating system

Recommending an operating system (OS) is a tough call, especially in the open source realm. In terms of the past seven or more years, it seems there is a preference for using Linux with HBase. In fact, Ha-

9. There is more on this in Eric Sammer's [Hadoop Operations](#) book, and in online post, such as Facebook's [Fabric](#).

doop and HBase are inherently designed to work with Linux, or any other Unix-like system, or with Unix. While you are free to run either one on a different OS as long as it supports Java, they have only been thoroughly tested with Unix-like systems. The supplied start and stop scripts, more specifically, expect a command-line shell as provided by Linux, Unix, or Windows.

Running on Windows

HBase running on Windows has not been tested before 0.96 to a great extent, therefore running a production install of HBase on top of Windows is often not recommended. There has been work done recently to add the necessary scripts and other scaffolding to support Windows in HBase 0.96 and later.¹⁰

Within the Unix and Unix-like group you can also differentiate between those that are free (as in they cost no money) and those you have to pay for. Again, both will work and your choice is often limited by company-wide regulations. Here is a short list of operating systems that are commonly found as a basis for HBase clusters:

CentOS

CentOS is a community-supported, free software operating system, based on Red Hat Enterprise Linux (known as RHEL). It mirrors RHEL in terms of functionality, features, and package release levels as it is using the source code packages Red Hat provides for its own enterprise product to create CentOS-branded counterparts. Like RHEL, it provides the packages in *RPM* format.

It is also focused on enterprise usage, and therefore does not adopt new features or newer versions of existing packages too quickly. The goal is to provide an OS that can be rolled out across a large-scale infrastructure while not having to deal with short-term gains of small, incremental package updates.

Fedora

Fedora is also a community-supported, free and open source operating system, and is sponsored by Red Hat. But compared to RHEL and CentOS, it is more a playground for new technologies and strives to advance new ideas and features. Because of that, it has a much shorter life cycle compared to enterprise-oriented products.

10. See [HBASE-6814](#).

An average maintenance period for a Fedora release is around 13 months.

The fact that it is aimed at workstations and has been enhanced with many new features has made Fedora a quite popular choice, only beaten by more desktop-oriented operating systems.¹¹ For production use, you may want to take into account the reduced life cycle that counteracts the freshness of this distribution. You may also want to consider not using the latest Fedora release, but trailing by one version to be able to rely on some feedback from the community as far as stability and other issues are concerned.

Debian

Debian is another Linux-kernel-based OS that has software packages released as free and open source software. It can be used for desktop and server systems and has a conservative approach when it comes to package updates. Releases are only published after all included packages have been sufficiently tested and deemed stable.

As opposed to other distributions, Debian is not backed by a commercial entity, but rather is solely governed by its own project rules. It also uses its own packaging system that supports *DEB* packages only. Debian is known to run on many hardware platforms as well as having a very large repository of packages.

Ubuntu

Ubuntu is a Linux distribution based on Debian. It is distributed as free and open source software, and backed by Canonical Ltd., which is not charging for the OS but is selling technical support for Ubuntu.

The life cycle is split into a longer- and a shorter-term release. The *long-term support* (LTS) releases are supported for three years on the desktop and five years on the server. The packages are also DEB format and are based on the *unstable* branch of Debian: Ubuntu, in a sense, is for Debian what Fedora is for RHEL. Using Ubuntu as a server operating system is made more difficult as the update cycle for critical components is very frequent.

Solaris

Solaris is offered by Oracle, and is available for a limited number of architecture platforms. It is a descendant of Unix System V Release 4, and therefore, the most different OS in this list. Some of

¹¹. [DistroWatch](#) has a list of popular Linux and Unix-like operating systems and maintains a ranking by popularity.

the source code is available as open source while the rest is closed source. Solaris is a commercial product and needs to be purchased. The commercial support for each release is maintained for 10 to 12 years.

Red Hat Enterprise Linux

Abbreviated as RHEL, Red Hat's Linux distribution is aimed at commercial and enterprise-level customers. The OS is available as a server and a desktop version. The license comes with offerings for official support, training, and a certification program.

The package format for RHEL is called *RPM* (the Red Hat Package Manager), and it consists of the software packaged in the `.rpm` file format, and the package manager itself.

Being commercially supported and maintained, RHEL has a very long life cycle of 7 to 10 years.

You have a choice when it comes to the operating system you are going to use on your servers. A sensible approach is to choose one you feel comfortable with and that fits into your existing infrastructure.

As for a recommendation, many production systems running HBase are on top of CentOS, or RHEL.

Filesystem

With the operating system selected, you will have a few choices of filesystems to use with your disks. There is not a lot of publicly available empirical data in regard to comparing different filesystems and their effect on HBase, though. The common systems in use are ext3, ext4, and XFS, but you may be able to use others as well. For some there are HBase users reporting on their findings, while for more exotic ones you would need to run enough tests before using it on your production cluster.

Note that the selection of filesystems is for the HDFS data nodes. HBase is directly impacted when using HDFS as its backing store.

Here are some notes on the more commonly used filesystems:

ext3

One of the most ubiquitous filesystems on the Linux operating system is *ext3*¹². It has been proven stable and reliable, meaning it is a safe bet in terms of setting up your cluster with it. Being part of Linux since 2001, it has been steadily improved over time and has been the default filesystem for years.

There are a few optimizations you should keep in mind when using ext3. First, you should set the `noatime` option when mounting the filesystem of the data drives to reduce the administrative overhead required for the kernel to keep the *access time* for each file. It is not needed or even used by HBase, and disabling it speeds up the disk's read performance.

Disabling the last access time gives you a performance boost and is a recommended optimization. Mount options are typically specified in a configuration file called `/etc/fstab`. Here is a Linux example line where the `noatime` option is specified:

```
/dev/sdd1 /data ext3 defaults,noatime 0 0
```

Note that this also implies the `nodiratime` option, so no need to specify it explicitly.

Another optimization is to make better use of the disk space provided by ext3. By default, it reserves a specific number of bytes in blocks for situations where a disk fills up but crucial system processes need this space to continue to function. This is really useful for critical disks—for example, the one hosting the operating system—but it is less useful for the storage drives, and in a large enough cluster it can have a significant impact on available storage capacities.

12. See <http://en.wikipedia.org/wiki/Ext3> on Wikipedia for details.

You can reduce the number of reserved blocks and gain more usable disk space by using the `tune2fs` command-line tool that comes with ext3 and Linux. By default, it is set to 5% but can safely be reduced to 1% (or even 0%) for the data drives. This is done with the following command:

```
tune2fs -m 1 <device-name>
```

Replace `<device-name>` with the disk you want to adjust—for example, `/dev/sdd1`. Do this for all disks on which you want to store data. The `-m 1` defines the percentage, so use `-m 0`, for example, to set the reserved block count to zero.

A final word of caution: only do this for your data disk, *NOT* for the disk hosting the OS nor for any drive on the master node!

Yahoo! -at one point- did publicly state that it is using ext3 as its filesystem of choice on its large Hadoop cluster farm. This shows that, although it is by far not the most current or modern filesystem, it does very well in large clusters. In fact, you are more likely to saturate your I/O on other levels of the stack before reaching the limits of ext3.

The biggest drawback of ext3 is that during the bootstrap process of the servers it requires the largest amount of time. Formatting a disk with ext3 can take minutes to complete and may become a nuisance when spinning up machines dynamically on a regular basis—although that is not a very common practice.

ext4

The successor to ext3 is called ext4 (see <http://en.wikipedia.org/wiki/Ext4> for details) and initially was based on the same code but was subsequently moved into its own project. It has been officially part of the Linux kernel since the end of 2008. To that extent, it has had only a few years to prove its stability and reliability. Nevertheless, Google has announced plans¹³ to upgrade its storage infrastructure from ext2 to ext4. This can be considered a strong endorsement, but also shows the advantage of the *extended filesystem* (the *ext* in ext3, ext4, etc.) lineage to be upgradable in place.

13. See [this post](#) on the Ars Technica website. Google hired the main developer of ext4, Theodore Ts'o, who announced plans to keep working on ext4 as well as other Linux kernel features.

Choosing an entirely different filesystem like XFS would have made this impossible.

Performance-wise, ext4 does beat ext3 and allegedly comes close to the high-performance XFS. It also has many advanced features that allow it to store files up to 16 TB in size and support volumes up to 1 exabyte (i.e., 10^{18} bytes).

A more critical feature is the so-called *delayed allocation*, and it is recommended that you turn it off for Hadoop and HBase use. Delayed allocation keeps the data in memory and reserves the required number of blocks until the data is finally flushed to disk. It helps in keeping blocks for files together and can at times write the entire file into a contiguous set of blocks. This reduces fragmentation and improves performance when reading the file subsequently. On the other hand, it increases the possibility of data loss in case of a server crash.

XFS

XFS¹⁴ became available on Linux at about the same time as ext3. It was originally developed by Silicon Graphics in 1993. Most Linux distributions today have XFS support included.

Its features are similar to those of ext4; for example, both have *extents* (grouping contiguous blocks together, reducing the number of blocks required to maintain per file) and the aforementioned delayed allocation.

A great advantage of XFS during bootstrapping a server is the fact that it formats the entire drive in virtually no time. This can significantly reduce the time required to provision new servers with many storage disks.

On the other hand, there are some drawbacks to using XFS. There is a known shortcoming in the design that impacts metadata operations, such as deleting a large number of files. The developers have picked up on the issue and applied various fixes to improve the situation. You will have to check how you use HBase to determine if this might affect you. For normal use, you should not have a problem with this limitation of XFS, as HBase operates on fewer but larger files.

14. See <http://en.wikipedia.org/wiki/Xfs> on Wikipedia for details.

ZFS

Introduced in 2005, *ZFS*¹⁵ was developed by Sun Microsystems. The name is an abbreviation for *zettabyte filesystem*, as it has the ability to store 256 zettabytes (which, in turn, is 2^{78} , or 256×10^{21} , bytes) of data.

ZFS is primarily supported on Solaris and has advanced features that may be useful in combination with HBase. It has built-in compression support that could be used as a replacement for the pluggable compression codecs in HBase.

It seems that choosing a filesystem is analogous to choosing an operating system: pick one that you feel comfortable with and that fits into your existing infrastructure. Simply picking one over the other based on plain numbers is difficult without proper testing and comparison. If you have a choice, it seems to make sense to opt for a more modern system like ext4 or XFS, as sooner or later they will replace ext3 and are already much more scalable and perform better than their older sibling.

Installing different filesystems on a single server is not recommended. This can have adverse effects on performance as the kernel may have to split buffer caches to support the different filesystems. It has been reported that, for certain operating systems, this can have a devastating performance impact. Make sure you test this issue carefully if you have to mix filesystems.

Java

It was mentioned in the note *Note* that you do need Java for HBase. Not just any version of Java, but version 7, a.k.a. 1.7, or later-unless you have an older version of HBase that still runs on Java 6, or 1.6. The recommended choice is the one provided by Oracle (formerly by Sun), which can be found at <http://www.java.com/download/>. Table 2-2 shows a matrix of what is needed for various HBase versions.

Table 2-2. Supported Java Versions

HBase Version	JDK 6	JDK 7	JDK 8
1.0	no	yes	yes ^a
0.98	yes	yes	yes ^{ab}

15. See <http://en.wikipedia.org/wiki/ZFS> on Wikipedia for details

HBase Version	JDK 6	JDK 7	JDK 8
0.96	yes	yes	n/a
0.94	yes	yes	n/a

^a Running with JDK 8 will work but is not well tested.

^b Building with JDK 8 would require removal of the deprecated remove() method of the PoolMap class and is under consideration. See [HBASE-7608](#) for more information about JDK 8 support.

In HBase 0.98.5 and newer, you must set `JAVA_HOME` on each node of your cluster. The `hbase-env.sh` script provides a mechanism to do this.

You also should make sure the `java` binary is executable and can be found on your path. Try entering `java -version` on the command line and verify that it works and that it prints out the version number indicating it is version 1.7 or later—for example, `java version "1.7.0_45"`. You usually want the latest update level, but sometimes you may find unexpected problems (version 1.6.0_18, for example, is known to cause random JVM crashes) and it may be worth trying an older release to verify.

If you do not have Java on the command-line path or if HBase fails to start with a warning that it was not able to find it (see [Example 2-1](#)), edit the `conf/hbase-env.sh` file by commenting out the `JAVA_HOME` line and changing its value to where your Java is installed.

Example 2-1. Error message printed by HBase when no Java executable was found

```
+=====
+           Error: JAVA_HOME is not set and Java could not be
found          |
+-----+
+           Please download the latest Sun JDK from the Sun Java web
site          |
|                  > http://java.sun.com/javase/downloads/
<          |
|
|           HBase      requires      Java      1.7      or      lat-
er.
| NOTE: This script will find Sun Java whether you install using
the      |
|                  binary      or      the      RPM      based      instal-
```

ler.

|

+-----
+

Hadoop

In the past HBase was bound very tightly to the Hadoop version it ran with. This has changed due to the introduction of *Protocol Buffer* based Remote Procedure Calls (RPCs). [Table 2-3](#) summarizes the versions of Hadoop supported with each version of HBase. Based on the version of HBase, you should select the most appropriate version of Hadoop. You can use Apache Hadoop, or a vendor's distribution of Hadoop—no distinction is made here. See (to come) for information about vendors of Hadoop.

Hadoop 2.x is faster and includes features, such as short-circuit reads, which will help improve your HBase random read performance. Hadoop 2.x also includes important bug fixes that will improve your overall HBase experience. HBase 0.98 drops support for Hadoop 1.0 and deprecates use of Hadoop 1.1 or later (all 1.x based versions). Finally, HBase 1.0 does not support Hadoop 1.x at all anymore.

When reading [Table 2-3](#), please note that the ✓ symbol means the combination is supported, while ✗ indicates it is *not* supported. A ? indicates that the combination is not tested.

Table 2-3. Hadoop version support matrix

	HBase-0.92.x	HBase-0.94.x	HBase-0.96.x	HBase-0.98.x ^a	HBase-1.0.x ^b
Hadoop-0.20.205	✓	✗	✗	✗	✗
Hadoop-0.22.x	✓	✗	✗	✗	✗
Hadoop-1.0.x	✗	✗	✗	✗	✗
Hadoop-1.1.x	?	✓	✓	?	✗
Hadoop-0.23.x	✗	✓	?	✗	✗
Hadoop-2.0.x-alpha	✗	?	✗	✗	✗
Hadoop-2.1.0-beta	✗	?	✓	✗	✗
Hadoop-2.2.0	✗	?	✓	✓	?
Hadoop-2.3.x	✗	?	✓	✓	?
Hadoop-2.4.x	✗	?	✓	✓	✓
Hadoop-2.5.x	✗	?	✓	✓	✓

^aSupport for Hadoop 1.x is deprecated.

^bHadoop 1.x is *not* supported.

Because HBase depends on Hadoop, it bundles an instance of the Hadoop JAR under its `lib` directory. The bundled Hadoop is usually the latest available at the time of HBase's release, and for HBase 1.0.0 this means Hadoop 2.5.1. It is *important* that the version of Hadoop that is in use on your cluster matches what is used by HBase. Replace the Hadoop JARs found in the HBase `lib` directory with the once you are running on your cluster to avoid version mismatch issues. Make sure you replace the JAR on all servers in your cluster that run HBase. Version mismatch issues have various manifestations, but often the result is the same: HBase does not throw an error, but simply blocks indefinitely.

The bundled JAR that ships with HBase is considered *only* for use in standalone mode. Also note that Hadoop, like HBase, is a modularized project, which means it has many JAR files that have to go with each other. Look for all JARs starting with the prefix `hadoop` to find the ones needed.

Hadoop, like HBase, is using Protocol Buffer based RPCs, so mixing clients and servers from within the same major version should be fine, though the advice is still to replace the HBase included version with the appropriate one from the used HDFS version-just to be safe. The Hadoop project site has more information about the [compatibility](#) of Hadoop versions.

For earlier versions of HBase, please refer to the [online reference guide](#).

ZooKeeper

ZooKeeper version 3.4.x is required as of HBase 1.0.0. HBase makes use of the `multi` functionality that is only available since version 3.4.0. Additionally, the `useMulti` configuration option defaults to `true` in HBase 1.0.0.¹⁶

16. See [HBASE-12241](#) and [HBASE-6775](#) for background.

SSH

Note that ssh must be installed and sshd must be running if you want to use the supplied scripts to manage remote Hadoop and HBase daemons. A commonly used software package providing these commands is OpenSSH, available from <http://www.openssh.com/>. Check with your operating system manuals first, as many OSes have mechanisms to install an already compiled binary release package as opposed to having to build it yourself. On a Ubuntu workstation, for example, you can use:

```
$ sudo apt-get install openssh-client
```

On the servers, you would install the matching server package:

```
$ sudo apt-get install openssh-server
```

You must be able to ssh to all nodes, including your local node, using *passwordless* login. You will need to have a public key pair—you can either use the one you already have (see the .ssh directory located in your home directory) or you will have to generate one—and add your public key on each server so that the scripts can access the remote servers without further intervention.

The supplied shell scripts make use of SSH to send commands to each server in the cluster. It is strongly advised that you *not* use simple *password* authentication. Instead, you should use public key authentication-only!

When you create your key pair, also add a *passphrase* to protect your private key. To avoid the hassle of being asked for the passphrase for every single command sent to a remote server, it is recommended that you use *ssh-agent*, a helper that comes with SSH. It lets you enter the passphrase only once and then takes care of all subsequent requests to provide it.

Ideally, you would also use the *agent forwarding* that is built in to log in to other remote servers from your cluster nodes.

Domain Name Service

HBase uses the local *hostname* to self-report its IP address. Both forward and reverse DNS resolving should work. You can verify if the setup is correct for forward DNS lookups by running the following command:

```
$ ping -c 1 $(hostname)
```

You need to make sure that it reports the public¹⁷ IP address of the server and *not* the *loopback* address 127.0.0.1. A typical reason for this not to work concerns an incorrect /etc/hosts file, containing a mapping of the machine name to the loopback address.

If your machine has multiple interfaces, HBase will use the interface that the primary hostname resolves to. If this is insufficient, you can set hbase.regionserver.dns.interface (see “[Configuration](#) (page 85) for information on how to do this) to indicate the primary interface. This only works if your cluster configuration is consistent and every host has the same network interface configuration.

Another alternative is to set hbase.regionserver.dns.nameserver to choose a different name server than the system-wide default.

Synchronized time

The clocks on cluster nodes should be in basic alignment. Some skew is tolerable, but wild skew can generate odd behaviors. Even differences of only one minute can cause unexplainable behavior. Run [NTP](#) on your cluster, or an equivalent application, to synchronize the time on all servers.

If you are having problems querying data, or you are seeing *weird* behavior running cluster operations, check the system time!

File handles and process limits

HBase is a database, so it uses a lot of files at the same time. The default ulimit -n of 1024 on most Unix or other Unix-like systems is insufficient. Any significant amount of loading will lead to I/O errors stating the obvious: java.io.IOException: Too many open files. You may also notice errors such as the following:

```
2010-04-06 03:04:37,542 INFO org.apache.hadoop.hdfs.DFSClient: Exception  
    in createBlockOutputStream java.io.EOFException  
2010-04-06 03:04:37,542 INFO org.apache.hadoop.hdfs.DFSClient:  
Abandoning  
    block blk_-6935524980745310745_1391901
```

17. *Public* here means *external* IP, i.e. the one used in the LAN to route traffic to this server.

These errors are usually found in the logfiles. See (to come) for details on their location, and how to analyze their content.

You need to change the upper bound on the number of file descriptors. Set it to a number larger than 10,000. To be clear, upping the file descriptors for the user who is running the HBase process is an operating system configuration, not a HBase configuration. Also, a common mistake is that administrators will increase the file descriptors for a particular user but HBase is running with a different user account.

You can estimate the number of required file handles roughly as follows: Per column family, there is at least one storage file, and possibly up to five or six if a region is under load; on average, though, there are three storage files per column family. To determine the number of required file handles, you multiply the number of column families by the number of regions per region server. For example, say you have a schema of 3 column families per region and you have 100 regions per region server. The JVM will open $3 \times 3 \times 100$ storage files = 900 file descriptors, not counting open JAR files, configuration files, CRC32 files, and so on. Run `lsof -p REGIONSERVER_PID` to see the accurate number.

As the first line in its logs, HBase prints the ulimit it is seeing, as shown in [Example 2-2](#). Ensure that it's correctly reporting the increased limit.¹⁸ See (to come) for details on how to find this information in the logs, as well as other details that can help you find—and solve—problems with a HBase setup.

Example 2-2. Example log output when starting HBase

```
Fri Feb 27 13:30:38 CET 2015 Starting master on de1-app-mba-1
core file size          (blocks, -c) 0
data seg size           (kbytes, -d) unlimited
file size               (blocks, -f) unlimited
max locked memory       (kbytes, -l) unlimited
```

18. A useful document on setting configuration values on your Hadoop cluster is Aaron Kimball's "[Configuration Parameters: What can you just ignore?](#)".

```
max memory size          (kbytes, -m) unlimited
open files                (-n) 2560
pipe size                 (512 bytes, -p) 1
stack size                (kbytes, -s) 8192
cpu time                  (seconds, -t) unlimited
max user processes         (-u) 709
virtual memory             (kbytes, -v) unlimited
2015-02-27 13:30:39,352 INFO  [main] util.VersionInfo: HBase 1.0.0
...

```

You may also need to edit `/etc/sysctl.conf` and adjust the `fs.file-max` value. See this [post on Server Fault](#) for details.

Example: Setting File Handles on Ubuntu

If you are on Ubuntu, you will need to make the following changes.

In the file `/etc/security/limits.conf` add this line:

```
hadoop -      nofile 32768
```

Replace `hadoop` with whatever user is running Hadoop and HBase. If you have separate users, you will need two entries, one for each user.

In the file `/etc/pam.d/common-session` add the following as the last line in the file:

```
session required pam_limits.so
```

Otherwise, the changes in `/etc/security/limits.conf` won't be applied.

Don't forget to log out and back in again for the changes to take effect!

You should also consider increasing the number of processes allowed by adjusting the `nproc` value in the same `/etc/security/limits.conf` file referenced earlier. With a low limit and a server under duress, you could see `OutOfMemoryError` exceptions, which will eventually cause the entire Java process to end. As with the file handles, you need to make sure this value is set for the appropriate user account running the process.

Datanode handlers

A Hadoop HDFS data node has an upper bound on the number of files that it will serve at any one time. The upper bound property is called

`dfs.datanode.max.transfer.threads`.¹⁹ Again, before doing any loading, make sure you have configured Hadoop’s `conf/hdfs-site.xml` file, setting the property value to at least the following:

```
<property>
  <name>dfs.datanode.max.transfer.threads</name>
  <value>10240</value>
</property>
```

Be sure to restart your HDFS after making the preceding configuration changes.

Not having this configuration in place makes for strange-looking failures. Eventually, you will see a complaint in the datanode logs about the `xcievers` limit being exceeded, but on the run up to this one manifestation is a complaint about missing blocks. For example:

```
10/12/08 20:10:31 INFO hdfs.DFSClient: Could not obtain block
  blk_XXXXXXXXXXXXXXXXXXXX_YYYYYYYY from any node:
java.io.IOException:
  No live nodes contain current block. Will get new block locations from
  namenode and retry...
```

Swappiness

You need to prevent your servers from running out of memory over time. We already discussed one way to do this: setting the heap sizes small enough that they give the operating system enough room for its own processes. Once you get close to the physically available memory, the OS starts to use the configured *swap* space. This is typically located on disk in its own partition and is used to page out processes and their allocated memory until it is needed again.

Swapping—while being a good thing on workstations—is something to be avoided at all costs on servers. Once the server starts swapping, performance is reduced significantly, up to a point where you may not even be able to log in to such a system because the remote access process (e.g., SSHD) is coming to a grinding halt.

HBase needs guaranteed CPU cycles and must obey certain freshness guarantees—for example, to renew the ZooKeeper sessions. It has been observed over and over again that swapping servers start to

19. In previous versions of Hadoop this parameter was called `dfs.datanode.max.xcievers`, with `xciever` being misspelled.

miss renewing their leases and are considered lost subsequently by the ZooKeeper ensemble. The regions on these servers are redeployed on other servers, which now take extra pressure and may fall into the same trap.

Even worse are scenarios where the swapping server wakes up and now needs to realize it is considered dead by the master node. It will report for duty as if nothing has happened and receive a `YouAreDeadException` in the process, telling it that it has missed its chance to continue, and therefore terminates itself. There are quite a few implicit issues with this scenario—for example, pending updates, which we will address later. Suffice it to say that this is *not good*.

You can tune down the swappiness of the server by adding this line to the `/etc/sysctl.conf` configuration file on Linux and Unix-like systems:

```
vm.swappiness=5
```

You can try values like 0 or 5 to reduce the system's likelihood to use swap space.

Since Linux kernel version 2.6.32 the behavior of the swappiness value [has changed](#). It is advised to use 1 or greater for this setting, not 0, as the latter disables swapping and might lead to *random* process termination when the server is under memory pressure.

Some more radical operators have turned off swapping completely (see `swappoff` on Linux), and would rather have their systems run “against the wall” than deal with swapping issues. Choose something you feel comfortable with, but make sure you keep an eye on this problem.

Finally, you may have to reboot the server for the changes to take effect, as a simple

```
sysctl -p
```

might not suffice. This obviously is for Unix-like systems and you will have to adjust this for your operating system.

Filesystems for HBase

The most common filesystem used with HBase is HDFS. But you are not locked into HDFS because the `FileSystem` used by HBase has a

pluggable architecture and can be used to replace HDFS with any other supported system. In fact, you could go as far as implementing your own filesystem—maybe even on top of another database. The possibilities are endless and waiting for the brave at heart.

In this section, we are *not* talking about the low-level filesystems used by the operating system (see “[Filesystem](#)” ([page 54](#)) for that), but the storage layer filesystems. These are abstractions that define higher-level features and APIs, which are then used by Hadoop to store the data. The data is eventually stored on a disk, at which point the OS filesystem is used.

HDFS is the most used and tested filesystem in production. Almost all production clusters use it as the underlying storage layer. It is proven stable and reliable, so deviating from it may impose its own risks and subsequent problems.

The primary reason HDFS is so popular is its built-in replication, fault tolerance, and scalability. Choosing a different filesystem should provide the same guarantees, as HBase implicitly assumes that data is stored in a reliable manner by the filesystem. It has no added means to replicate data or even maintain copies of its own storage files. This functionality *must* be provided by the lower-level system.

You can select a different filesystem implementation by using a URI²⁰ pattern, where the *scheme* (the part before the first “：“, i.e., the colon) part of the URI identifies the driver to be used. [Figure 2-1](#) shows how the Hadoop filesystem is different from the low-level OS filesystems for the actual disks.

20. See “[Uniform Resource Identifier](#)” on Wikipedia.

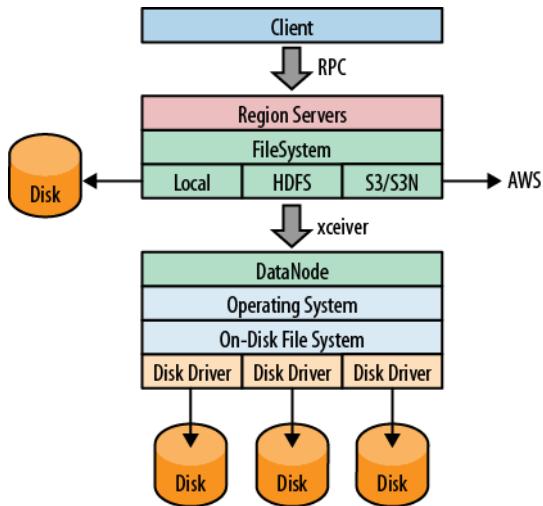


Figure 2-1. The filesystem negotiating transparently where data is stored

You can use a filesystem that is already supplied by Hadoop: it ships with a list of filesystems,²¹ which you may want to try out first. As a last resort—or if you’re an experienced developer—you can also write your own filesystem implementation.

Local

The *local* filesystem actually bypasses Hadoop entirely, that is, you do not need to have a HDFS or any other cluster at all. It is handled all in the `FileSystem` class used by HBase to connect to the filesystem implementation. The supplied `ChecksumFileSystem` class is loaded by the client and uses local disk paths to store all the data.

The beauty of this approach is that HBase is unaware that it is not talking to a distributed filesystem on a remote or colocated cluster, but actually is using the local filesystem directly. The *standalone mode* of HBase uses this feature to run HBase only. You can select it by using the following scheme:

```
file:///<path>
```

Similar to the URIs used in a web browser, the `file:` scheme addresses local files.

21. A full list was compiled by Tom White in his post “[Get to Know Hadoop Filesystems](#)”.

Note that before HBase version 1.0.0 (and 0.98.3) there was a rare problem with data loss, during very specific situations, using the local filesystem. While this setup is just for testing anyways, because HDFS or another reliable filesystem is used in production, you should still be careful.²²

HDFS

The *Hadoop Distributed File System* (HDFS) is the default filesystem when deploying a fully distributed cluster. For HBase, HDFS is the filesystem of choice, as it has all the required features. As we discussed earlier, HDFS is built to work with MapReduce, taking full advantage of its parallel, streaming access support. The scalability, fail safety, and automatic replication functionality is ideal for storing files reliably. HBase adds the random access layer missing from HDFS and ideally complements Hadoop. Using MapReduce, you can do bulk imports, creating the storage files at disk-transfer speeds.

The URI to access HDFS uses the following scheme:

```
hdfs://<namenode>:<port>/<path>
```

S3

Amazon's *Simple Storage Service* (S3)²³ is a storage system that is primarily used in combination with dynamic servers running on Amazon's complementary service named *Elastic Compute Cloud* (EC2).²⁴

S3 can be used directly and without EC2, but the bandwidth used to transfer data in and out of S3 is going to be cost-prohibitive in practice. Transferring between EC2 and S3 is free, and therefore a viable option. One way to start an EC2-based cluster is shown in "[Apache Whirr](#)" (page 94).

The S3 FileSystem implementation provided by Hadoop supports three different modes: the *raw* (or *native*) mode, the *block-based* mode, and the newer AWS *SDK* based mode. The raw mode uses the `s3n:` URI scheme and writes the data directly into S3, similar to the local filesystem. You can see all the files in your bucket the same way as you would on your local disk.

22. [HBASE-11218](#) has the details.

23. See "[Amazon S3](#)" for more background information.

24. See "[EC2](#)" on Wikipedia.

The `s3:` scheme is the block-based mode and was used to overcome S3's former maximum file size limit of 5 GB. This has since been changed, and therefore the selection is now more difficult—or easy: opt for `s3n:` if you are not going to exceed 5 GB per file.

The block mode emulates the HDFS filesystem on top of S3. It makes browsing the bucket content more difficult as only the internal block files are visible, and the HBase storage files are stored arbitrarily inside these blocks and strewn across them.

Both these filesystems share the fact that they use the external *JetS3t* open source Java toolkit to do the actual heavy lifting. A more recent addition is the `s3a:` scheme that replaces the JetS3t block mode with an AWS SDK based one.²⁵ It is closer to the native S3 API and can optimize certain operations, resulting in speed ups, as well as integrate better overall compared to the existing implementation.

You can select the filesystem using these URIs:

```
s3://<bucket-name>
s3n://<bucket-name>
s3a://<bucket-name>
```

What about EBS and ephemeral disk using EC2?

While we are talking about Amazon Web Services, you might wonder what can be said about *EBS* volumes vs. *ephemeral* disk drives (aka *instance storage*). The former has proper persistency across server restarts, something that instance storage does *not* provide. On the other hand, EBS is connected to the EC2 instance using a storage network, making it much more susceptible to latency fluctuations. Some [posts](#) recommend to only allocate the maximum size of a volume and combine four of them in a RAID-0 group.

Instance storage also exposes more latency issues compared to completely local disks, but is slightly more predictable.²⁶ There is still an impact and that has to be factored into the cluster design. Not being persistent is one of the major deterrents to use ephemeral disks, because losing a server will cause data to rebalance—something that might be avoided by starting another EC2 instance and reconnect an existing EBS volume.

25. See [HADOOP-10400](#) and [AWS SDK](#) for details.

26. See this [post](#) for a more in-depth discussion on I/O performance on EC2.

Amazon recently added the option to use SSD (solid-state drive) backed EBS volumes, for low-latency use-cases. This should be interesting for HBase setups running in EC2, as it supposedly smoothes out the latency spikes incurred by the built-in write caching of the EBS storage network. Your mileage may vary!

Other Filesystems

There are other filesystems, and one to mention is QFS, the *Quantcast File System*.²⁷ It is an open source, distributed, high-performance file-system written in C++, with similar features to HDFS. Find more information about it at the [Quantcast website](#).²⁸

There are other file systems, for example the *Azure filesystem*, or the *Swift filesystem*. Both use the native APIs of Microsoft [Azure Blob Storage](#) and [OpenStack Swift](#) respectively allowing Hadoop to store data in these systems. We will not further look into these choices, so please carefully evaluate what you need given a specific use-case. Note though that the majority of clusters in production today are based on HDFS.

Wrapping up the Hadoop supported filesystems, [Table 2-4](#) shows a list of all the important choices. There are more supported by Hadoop, but they are used in different ways and are therefore excluded here.

Table 2-4. A list of HDFS filesystem implementations

File System	URI Scheme	Description
HDFS	hdfs:	The original Hadoop Distributed Filesystem
S3 Native	s3n:	Stores in S3 in a readable format for other S3 users
S3 Block	s3:	Data is stored in proprietary binary blocks in S3, using JetS3t
S3 Block (New)	s3a:	Improved proprietary binary block storage, using the AWS API
Quantcast FS	qfs:	External project providing a HDFS replacement

27. QFS used to be called *CloudStore*, which in turn was formerly known as the *Kosmos* filesystem, abbreviated as KFS and the namesake of the original URI scheme.
28. Also check out the JIRA issue [HADOOP-8885](#) for the details on QFS. Info about the removal of KFS is found under [HADOOP-8886](#).

File System	URI Scheme	Description
Azure Blob Storage	wasb: ^a	Uses the Azure blob storage API to store binary blocks
OpenStack Swift	swift:	Provides storage access for OpenStack's Swift blob storage

^aThere is also a `wasbs:` scheme for secure access to the blob storage.

Installation Choices

Once you have decided on the basic OS-related options, you must somehow get HBase onto your servers. You have a couple of choices, which we will look into next. Also see (to come) for even more options.

Apache Binary Release

The canonical installation process of most Apache projects is to download a release, usually provided as an archive containing all the required files. Some projects, including HBase since version 0.95, have separate archives for a *binary* and *source* release—the former intended to have everything needed to run the release and the latter containing all files needed to build the project yourself.

Over the years the HBase packing has changed a bit, being modularized along the way. Due to the inherent external dependencies to Hadoop, it also had to support various features and versions of Hadoop. Table 2-5 shows a matrix with the available packages for each major HBase version. *Single* means a combined package for source and binary release components, *Security* indicates a separate—but also source and binary combined—package for kerberized setups, *Source* is just for source packages, same for *Binary* but here just for binary packages for Hadoop 2.x and later. Finally, *Hadoop 1 Binary* and *Hadoop 2 Binary* are both binary packages that are specific to the Hadoop version targeted.

Table 2-5. HBase packaging evolution

Version	Single	Security	Source	Binary	Hadoop 1 Binary	Hadoop 2 Binary
0.90.0	✓	✗	✗	✗	✗	✗
0.92.0	✓	✓	✗	✗	✗	✗
0.94.0	✓	✓	✗	✗	✗	✗
0.96.0	✗	✗	✓	✗	✓	✓
0.98.0	✗	✗	✓	✗	✓	✓
1.0.0	✗	✗	✓	✓	✗	✗

The table also shows that as of version 1.0.0 HBase will only support Hadoop 2 as mentioned earlier. For more information on HBase releases, you may also want to check out the [Release Notes](#) page. Another interesting page is titled [Change Log](#), and it lists everything that was added, fixed, or changed in any form or shape for each released version.

You can download the most recent release of HBase from the Apache HBase [release page](#) and unpack the contents into a suitable directory, such as /usr/local or /opt, like so-shown here for version 1.0.0:

```
$ cd /usr/local  
$ wget http://archive.apache.org/dist/hbase/hbase-1.0.0/  
hbase-1.0.0-bin.tar.gz  
$ tar -zvxf hbase-1.0.0-bin.tar.gz
```

Once you have extracted all the files, you can make yourself familiar with what is in the project's directory. The content may look like this:

```
$ cd hbase-1.0.0  
$ ls -l  
-rw-r--r-- 1 larsgeorge staff 130672 Feb 15 04:40 CHANGES.txt  
-rw-r--r-- 1 larsgeorge staff 11358 Jan 25 10:47 LICENSE.txt  
-rw-r--r-- 1 larsgeorge staff 897 Feb 15 04:18 NOTICE.txt  
-rw-r--r-- 1 larsgeorge staff 1477 Feb 13 01:21 README.txt  
drwxr-xr-x 31 larsgeorge staff 1054 Feb 15 04:21 bin  
drwxr-xr-x 9 larsgeorge staff 306 Feb 27 13:37 conf  
drwxr-xr-x 48 larsgeorge staff 1632 Feb 15 04:49 docs  
drwxr-xr-x 7 larsgeorge staff 238 Feb 15 04:43 hbase-  
webapps  
drwxr-xr-x 115 larsgeorge staff 3910 Feb 27 13:29 lib  
drwxr-xr-x 8 larsgeorge staff 272 Mar 3 22:18 logs
```

The root of it only contains a few text files, stating the license terms (LICENSE.txt and NOTICE.txt) and some general information on how to find your way around (README.txt). The CHANGES.txt file is a static snapshot of the change log page mentioned earlier. It contains all the changes that went into the current release you downloaded.

The remainder of the content in the root directory consists of other directories, which are explained in the following list:

bin

The bin--or *binaries*--directory contains the scripts supplied by HBase to start and stop HBase, run separate daemons,²⁹ or start additional master nodes. See [“Running and Confirming Your Installation” \(page 95\)](#) for information on how to use them.

29. Processes that are started and then run in the background to perform their task are often referred to as *daemons*.

`conf`

The configuration directory contains the files that define how HBase is set up. “[Configuration](#)” (page 85) explains the contained files in great detail.

`docs`

This directory contains a copy of the HBase project website, including the documentation for all the tools, the API, and the project itself. Open your web browser of choice and open the `docs/index.html` file by either dragging it into the browser, double-clicking that file, or using the *File→Open* (or similarly named) menu.

`hbase-webapps`

HBase has web-based user interfaces which are implemented as Java web applications, using the files located in this directory. Most likely you will never have to touch this directory when working with or deploying HBase into production.

`lib`

Java-based applications are usually an assembly of many auxiliary libraries, plus the JAR file containing the actual program. All of these libraries are located in the `lib` directory. For newer versions of HBase with a binary package structure and modularized architecture, all HBase JAR files are also in this directory. Older versions have one or few more JARs directly in the project root path.

`logs`

Since the HBase processes are started as daemons (i.e., they are running in the background of the operating system performing their duty), they use logfiles to report their state, progress, and optionally, errors that occur during their life cycle. (to come) explains how to make sense of their rather cryptic content.

Initially, there may be no `logs` directory, as it is created when you start HBase for the first time. The logging framework used by HBase is creating the directory and logfiles dynamically.

Since you have unpacked a binary release archive, you can now move on to “[Run Modes](#)” (page 79) to decide how you want to run HBase.

Building from Source

This section is important only if you want to build HBase from its sources. This might be necessary if you want to apply patches, which can add new functionality you may be requiring.

HBase uses *Maven* to build the binary packages. You therefore need a working Maven installation, plus a full *Java Development Kit* (JDK)--not just a Java Runtime as used in “[Quick-Start Guide](#)” (page 39).

You can download the most recent source release of HBase from the Apache HBase [release page](#) and unpack the contents into a suitable directory, such as /home/<username> or /tmp, like so-shown here for version 1.0.0 again:

```
$ cd /usr/username
$ wget http://archive.apache.org/dist/hbase/hbase-1.0.0/
hbase-1.0.0-src.tar.gz
$ tar -zxvf hbase-1.0.0-src.tar.gz
```

Once you have extracted all the files, you can make yourself familiar with what is in the project’s directory, which is now different from above, because you have a source package. The content may look like this:

```
$ cd hbase-1.0.0
$ ls -l
-rw-r--r--  1 larsgeorge  admin  130672 Feb 15 04:40 CHANGES.txt
-rw-r--r--  1 larsgeorge  admin   11358 Jan 25 10:47 LICENSE.txt
-rw-r--r--  1 larsgeorge  admin     897 Feb 15 04:18 NOTICE.txt
-rw-r--r--  1 larsgeorge  admin   1477 Feb 13 01:21 README.txt
drwxr-xr-x  31 larsgeorge  admin   1054 Feb 15 04:21 bin
drwxr-xr-x   9 larsgeorge  admin    306 Feb 13 01:21 conf
drwxr-xr-x  25 larsgeorge  admin   850 Feb 15 04:18 dev-support
drwxr-xr-x   4 larsgeorge  admin    136 Feb 15 04:42 hbase-
annotations
drwxr-xr-x   4 larsgeorge  admin    136 Feb 15 04:43 hbase-
assembly
drwxr-xr-x   4 larsgeorge  admin    136 Feb 15 04:42 hbase-
checkstyle
drwxr-xr-x   4 larsgeorge  admin    136 Feb 15 04:42 hbase-client
drwxr-xr-x   4 larsgeorge  admin    136 Feb 15 04:42 hbase-common
drwxr-xr-x   5 larsgeorge  admin   170 Feb 15 04:43 hbase-
examples
drwxr-xr-x   4 larsgeorge  admin    136 Feb 15 04:42 hbase-hadoop-
compat
drwxr-xr-x   4 larsgeorge  admin    136 Feb 15 04:42 hbase-
```

```
hadoop2-compat
drwxr-xr-x  4 larsgeorge  admin      136 Feb 15 04:43 hbase-it
drwxr-xr-x  4 larsgeorge  admin      136 Feb 15 04:42 hbase-prefix-
tree
drwxr-xr-x  5 larsgeorge  admin     170 Feb 15 04:42 hbase-
protocol
drwxr-xr-x  4 larsgeorge  admin      136 Feb 15 04:43 hbase-rest
drwxr-xr-x  4 larsgeorge  admin      136 Feb 15 04:42 hbase-server
drwxr-xr-x  4 larsgeorge  admin      136 Feb 15 04:43 hbase-shell
drwxr-xr-x  4 larsgeorge  admin      136 Feb 15 04:43 hbase-
testing-util
drwxr-xr-x  4 larsgeorge  admin      136 Feb 15 04:43 hbase-thrift
-rw-r--r--  1 larsgeorge  admin  86635 Feb 15 04:21 pom.xml
drwxr-xr-x  3 larsgeorge  admin     102 May 22 2014 src
```

Like before, the root of it only contains a few text files, stating the license terms (`LICENSE.txt` and `NOTICE.txt`) and some general information on how to find your way around (`README.txt`). The `CHANGES.txt` file is a static snapshot of the change log page mentioned earlier. It contains all the changes that went into the current release you downloaded. The final, yet new file, is the Maven POM file `pom.xml`, and it is needed for Maven to build the project.

The remainder of the content in the root directory consists of other directories, which are explained in the following list:

`bin`

The `bin`-or *binaries*--directory contains the scripts supplied by HBase to start and stop HBase, run separate daemons, or start additional master nodes. See “[Running and Confirming Your Installation](#)” (page 95) for information on how to use them.

`conf`

The configuration directory contains the files that define how HBase is set up. “[Configuration](#)” (page 85) explains the contained files in great detail.

`hbase-webapps`

HBase has web-based user interfaces which are implemented as Java web applications, using the files located in this directory. Most likely you will never have to touch this directory when working with or deploying HBase into production.

`logs`

Since the HBase processes are started as daemons (i.e., they are running in the background of the operating system performing their duty), they use logfiles to report their state, progress, and optionally, errors that occur during their life cycle. (to come) explains how to make sense of their rather cryptic content.

Initially, there may be no logs directory, as it is created when you start HBase for the first time. The logging framework used by HBase is creating the directory and logfiles dynamically.

hbase-XXXXXX

These are the source modules for HBase, containing all the required sources and other resources. They are structured as Maven modules, which means allowing you to build them separately if needed.

src

Contains all the source for the project site and documentation.

dev-support

Here are some scripts and related configuration files for specific development tasks.

The lib and docs directories as seen in the binary package above are absent as you may have noted. Both are created dynamically-but in other locations-when you compile the code. There are various build targets you can choose to build them separately, or together, as shown below. In addition, there is also a target directory once you have built HBase for the first time. It holds the compiled JAR, site, and documentation files respectively, though again dependent on the Maven command you have executed.

Once you have the sources and confirmed that both Maven and JDK are set up properly, you can build the JAR files using the following command:

```
$ mvn package
```

Note that the tests for HBase need more than one hour to complete. If you trust the code to be operational, or you are not willing to wait, you can also skip the test phase, adding a command-line switch like so:

```
$ mvn -DskipTests package
```

This process will take a few minutes to complete while creating the target directory in the HBase project home directory. Once the build completes with a Build Successful message, you can find the compiled JAR files in the target directory. If you rather want to additionally build the binary package, you need to run this command:

```
$ mvn -DskipTests package assembly:single
```

With that archive you can go back to “[Apache Binary Release](#)” (page 73) and follow the steps outlined there to install your own, private release on your servers. Finally, here the Maven command to build just the *site* details, which is the website and documentation mirror:

```
$ mvn site
```

More information about [building](#) and [contribute](#) to HBase can be found online.

Run Modes

HBase has two run modes: *standalone* and *distributed*. Out of the box, HBase runs in standalone mode, as seen in “[Quick-Start Guide](#)” (page 39). To set up HBase in distributed mode, you will need to edit files in the HBase conf directory.

Whatever your mode, you may need to edit `conf/hbase-env.sh` to tell HBase which java to use. In this file, you set HBase environment variables such as the heap size and other options for the JVM, the preferred location for logfiles, and so on. Set `JAVA_HOME` to point at the root of your java installation. You can also set this variable in your shell environment, but you would need to do this for every session you open, and across all machines you are using. Setting `JAVA_HOME` in the `conf/hbase-env.sh` is simply the easiest and most reliable way to do that.

Standalone Mode

This is the default mode, as described and used in “[Quick-Start Guide](#)” (page 39). In standalone mode, HBase does not use HDFS—it uses the local filesystem instead—and it runs all HBase daemons and a local ZooKeeper in the same JVM process. ZooKeeper binds to a well-known port so that clients may talk to HBase.

Distributed Mode

The *distributed mode* can be further subdivided into *pseudo-distributed*--all daemons run on a single node--and *fully distributed*--where the daemons are spread across multiple, physical servers in the cluster.³⁰

Distributed modes require an instance of the *Hadoop Distributed File System* (HDFS). See the [Hadoop requirements and instructions](#) for

³⁰. The pseudo-distributed versus fully distributed nomenclature comes from Hadoop.

how to set up HDFS. Before proceeding, ensure that you have an appropriate, working HDFS installation.

The following subsections describe the different distributed setups. Starting, verifying, and exploring of your install, whether a *pseudo-distributed* or *fully distributed* configuration, is described in “[Running and Confirming Your Installation](#)” (page 95). The same verification steps apply to both deploy types.

Pseudo-distributed mode

A pseudo-distributed mode is simply a distributed mode that is run on a single host. Use this configuration for testing and prototyping on HBase. Do *not* use this configuration for production or for evaluating HBase performance.

Once you have confirmed your HDFS setup, edit `conf/hbase-site.xml`. This is the file into which you add local customizations and overrides for the default HBase configuration values (see (to come) for the full list, and “[HDFS-Related Configuration](#)” (page 87)). Point HBase at the running Hadoop HDFS instance by setting the `hbase.rootdir` property. For example, adding the following properties to your `hbase-site.xml` file says that HBase should use the `/hbase` directory in the HDFS whose name node is at port 9000 on your local machine, and that it should run with one replica only (recommended for pseudo-distributed mode):

```
<configuration>
  ...
  <property>
    <name>hbase.rootdir</name>
    <value>hdfs://localhost:9000/hbase</value>
  </property>
  <property>
    <name>dfs.replication</name>
    <value>1</value>
  </property>
  ...
</configuration>
```

In the example configuration, the server binds to local host. This means that a remote client cannot connect. Amend accordingly, if you want to connect from a remote location.

The `dfs.replication` setting of 1 in the configuration assumes you are also running HDFS in that mode. On a single machine it means

you only have one DataNode process/thread running, and therefore leaving the default of 3 for the replication would constantly yield warnings that blocks are under-replicated. The same setting is also applied to HDFS in its `hdfs-site.xml` file. If you have a fully distributed HDFS instead, you can remove the `dfs.replication` setting altogether.

If all you want to try for now is the pseudo-distributed mode, you can skip to “[Running and Confirming Your Installation](#)” (page 95) for details on how to start and verify your setup. See (to come) for information on how to start extra master and region servers when running in pseudo-distributed mode.

Fully distributed mode

For running a fully distributed operation on more than one host, you need to use the following configurations. In `hbase-site.xml`, add the `hbase.cluster.distributed` property and set it to `true`, and point the HBase `hbase.rootdir` at the appropriate HDFS name node and location in HDFS where you would like HBase to write data. For example, if your name node is running at a server with the hostname `name.node.foo.com` on port 9000 and you want to home your HBase in HDFS at `/hbase`, use the following configuration:

```
<configuration>
  ...
  <property>
    <name>hbase.rootdir</name>
    <value>hdfs://namenode.foo.com:9000/hbase</value>
  </property>
  <property>
    <name>hbase.cluster.distributed</name>
    <value>true</value>
  </property>
  ...
</configuration>
```

In addition, a fully distributed mode requires that you modify the `conf/regionservers` file. It lists all the hosts on which you want to run HRegionServer daemons. Specify one host per line (this file in HBase is like the Hadoop `slaves` file). All servers listed in this file will be started and stopped when the HBase cluster start or stop scripts are run. By default the file only contains the `localhost` entry, referring back to itself for standalone and pseudo-distributed mode:

```
$ cat conf/regionservers
localhost
```

A distributed HBase setup also depends on a running ZooKeeper cluster. All participating nodes and clients need to be able to access the

running ZooKeeper ensemble. HBase, by default, manages a ZooKeeper cluster (which can be as low as a single node) for you. It will start and stop the ZooKeeper ensemble as part of the HBase start and stop process. You can also manage the ZooKeeper ensemble independent of HBase and just point HBase at the cluster it should use. To toggle HBase management of ZooKeeper, use the `HBASE_MANAGES_ZK` variable in `conf/hbase-env.sh`. This variable, which defaults to `true`, tells HBase whether to start and stop the ZooKeeper ensemble servers as part of the start and stop commands supplied by HBase.

When HBase manages the ZooKeeper ensemble, you can specify the ZooKeeper configuration options directly in `conf/hbase-site.xml`.³¹ You can set a ZooKeeper configuration option as a property in the HBase `hbase-site.xml` XML configuration file by prefixing the ZooKeeper option name with `hbase.zookeeper.property`. For example, you can change the `clientPort` setting in ZooKeeper by setting the `hbase.zookeeper.property.clientPort` property. For all default values used by HBase, including ZooKeeper configuration, see (to come). Look for the `hbase.zookeeper.property` prefix.³²

zoo.cfg Versus hbase-site.xml

Please note that the following information is applicable to versions of HBase before 0.95, or when you enable the old behavior by setting `hbase.config.read.zookeeper.config` to `true`.

There is some confusion concerning the usage of `zoo.cfg` and `hbase-site.xml` in combination with ZooKeeper settings. For starters, if there is a `zoo.cfg` on the classpath (meaning it can be found by the Java process), it takes precedence over all settings in `hbase-site.xml`--but only those starting with the `hbase.zookeeper.property` prefix, plus a few others.

There are some ZooKeeper client settings that are not read from `zoo.cfg` but *must* be set in `hbase-site.xml`. This includes, for example, the important client session timeout value set with `zookeeper.session.timeout`. The following table describes the dependencies in more detail.

31. In versions before HBase 0.95 it was also possible to read an external `zoo.cfg` file. This has been deprecated in [HBASE-4072](#). The issue mentions `hbase.config.read.zookeeper.config` to enable the old behavior for existing, older setups, which is still available in HBase 1.0.0 though should not be used if possible.
32. For the full list of ZooKeeper configurations, see ZooKeeper's `zoo.cfg`. HBase does not ship with that file, so you will need to browse the `conf` directory in an appropriate ZooKeeper download.

Property	zoo.cfg + hbase-site.xml	hbase-site.xml only
hbase.zookeeper.quorum	Constructed from server. <u>_n_</u> lines as specified in zoo.cfg. Overrides any setting in hbase-site.xml.	Used as specified.
hbase.zookeeper.property.*	All values from zoo.cfg override any value specified in hbase-site.xml.	Used as specified.
zookeeper.*	Only taken from hbase-site.xml.	Only taken from hbase-site.xml.

To avoid any confusion during deployment, it is highly recommended that you *not* use a `zoo.cfg` file with HBase, and instead use only the `hbase-site.xml` file. Especially in a fully distributed setup where you have your own ZooKeeper servers, it is not practical to copy the configuration from the ZooKeeper nodes to the HBase servers.

You must at least set the ensemble servers with the `hbase.zookeeper.quorum` property. It otherwise defaults to a single ensemble member at `localhost`, which is not suitable for a fully distributed HBase (it binds to the local machine only and remote clients will not be able to connect).

There are three prefixes to specify ZooKeeper related properties:

`zookeeper`.

Specifies client settings for the ZooKeeper client used by the HBase client library.

`hbase.zookeeper`

Used for values pertaining to the HBase client communicating to the ZooKeeper servers.

`hbase.zookeeper.properties`.

These are only used when HBase is also managing the ZooKeeper ensemble, specifying ZooKeeper server parameters.

How Many ZooKeepers Should I Run?

You can run a ZooKeeper ensemble that comprises one node only, but in production it is recommended that you run a ZooKeeper ensemble of three, five, or seven machines; the more members an ensemble has, the more tolerant the ensemble is of host failures.

Also, run an odd number of machines, since running an even count does not make for an extra server building consensus—you need a majority vote, and if you have three or four servers, for example, both would have a majority with three nodes. Using an odd number, larger than 3, allows you to have two servers fail, as opposed to only one with even numbers.

Give each ZooKeeper server around 1 GB of RAM, and if possible, its own dedicated disk (a dedicated disk is the best thing you can do to ensure the ZooKeeper ensemble performs well). For very heavily loaded clusters, run ZooKeeper servers on separate machines from RegionServers, DataNodes, TaskTrackers, or Node-Managers.

For example, in order to have HBase manage a ZooKeeper quorum on nodes `rs{1,2,3,4,5}.foo.com`, bound to port 2222 (the default is 2181), you must ensure that `HBASE_MANAGES_ZK` is commented out or set to `true` in `conf/hbase-env.sh` and then edit `conf/hbase-site.xml` and set `hbase.zookeeper.property.clientPort` and `hbase.zookeeper.quorum`. You should also set `hbase.zookeeper.property.dataDir` to something other than the default, as the default has ZooKeeper persist data under `/tmp`, which is often cleared on system restart. In the following example, we have ZooKeeper persist to `/var/zookeeper`:

Keep in mind that setting `HBASE_MANAGES_ZK` either way implies that you are using the supplied HBase start scripts. This might not be the case for a packaged distribution of HBase (see (to come)). There are many ways to manage processes and therefore there is no guarantee that any setting made in `hbase-env.sh`, and `hbase-site.xml`, are really taking affect. Please consult with your distribution's documentation ensuring you use the proper approach.

```
<configuration>
  ...
  <property>
    <name>hbase.zookeeper.property.clientPort</name>
    <value>2222</value>
  </property>
  <property>
    <name>hbase.zookeeper.quorum</name>
    <value>rs1,rs2,rs3</value>
  </property>
  <property>
    <name>hbase.zookeeper.property.dataDir</name>
    <value>/var/zookeeper</value>
  </property>
</configuration>
```

```
ue>rs1.foo.com,rs2.foo.com,rs3.foo.com,rs4.foo.com,rs5.foo.com</
value>
</property>
<property>
  <name>hbase.zookeeper.property.dataDir</name>
  <value>/var/zookeeper</value>
</property>
...
</configuration>
```

To point HBase at an existing ZooKeeper cluster, one that is not managed by HBase, set `HBASE_MANAGES_ZK` in `conf/hbase-env.sh` to `false`:

```
...
# Tell HBase whether it should manage it's own instance of Zookeeper
# or not.
export HBASE_MANAGES_ZK=false
```

Next, set the ensemble locations and client port, if nonstandard, in `hbase-site.xml`. When HBase manages ZooKeeper, it will start/stop the ZooKeeper servers as a part of the regular start/stop scripts. If you would like to run ZooKeeper yourself, independent of HBase start/stop, do the following:

```
 ${HBASE_HOME}/bin/hbase-daemons.sh {start,stop} zookeeper
```

Note that you can use HBase in this manner to spin up a ZooKeeper cluster, unrelated to HBase. Just make sure to set `HBASE_MANAGES_ZK` to `false` if you want it to stay up across HBase restarts so that when HBase shuts down, it doesn't take ZooKeeper down with it.

For more information about running a distinct ZooKeeper cluster, see the ZooKeeper [Getting Started Guide](#). Additionally, see the [ZooKeeper wiki](#), or the [ZooKeeper documentation](#) for more information on ZooKeeper sizing.

Configuration

Now that the basics are out of the way (we've looked at all the choices when it comes to selecting the filesystem, discussed the run modes, and fine-tuned the operating system parameters), we can look at how to configure HBase itself. Similar to Hadoop, all configuration parameters are stored in files located in the `conf` directory. These are simple text files either in XML format arranged as a set of properties, or in simple flat files listing one option per line.

For more details on how to modify your configuration files for specific workloads refer to (to come).

Here a list of current configuration files, as available in HBase 1.0.0, with the detailed description of each following in due course:

hbase-env.cmd and hbase-env.sh

Set up the working environment for HBase, specifying variables such as JAVA_HOME. For Windows and Linux respectively.

hbase-site.xml

The main HBase configuration file. This file specifies configuration options which override HBase's default configuration.

backup-masters

This file is actually not present on a fresh install. It is a text file that lists all the hosts which should have backup masters started on.

regionservers

Lists all the nodes that are designated to run a region server instance.

hadoop-metrics2-hbase.properties

Specifies settings for the metrics framework integrated into each HBase process.

hbase-policy.xml

In secure mode, this file is read and defines the authorization rules for clients accessing the servers.

log4j.properties

Configures how each process logs its information using the Log4J libraries.

Configuring a HBase setup entails editing the `conf/hbase-env.{sh|cmd}` file containing environment variables, which is used mostly by the shell scripts (see “[Operating a Cluster](#)” (page 95)) to start or stop a cluster. You also need to add configuration properties to the XML file³³ `conf/hbase-site.xml` to, for example, override HBase defaults, tell HBase what filesystem to use, and tell HBase the location of the ZooKeeper ensemble.

33. Be careful when editing XML files. Make sure you close all elements. Check your file using a tool like `xmllint`, or something similar, to ensure well-formedness of your document after an edit session.

When running in distributed mode, after you make an edit to a HBase configuration file, make sure you copy the content of the `conf` directory to all nodes of the cluster. HBase will *not* do this for you.

There are many ways to synchronize your configuration files across your cluster. The easiest is to use a tool like `rsync`. There are many more elaborate ways, and you will see a selection in “[Deployment](#)” (page 92).

We will now look more closely at each configuration file.

hbase-site.xml and hbase-default.xml

Just as in Hadoop where you add site-specific HDFS configurations to the `hdfs-site.xml` file, for HBase, site-specific customizations go into the file `conf/hbase-site.xml`. For the list of configurable properties, see (to come), or view the raw `hbase-default.xml` source file in the HBase source code at `hbase-common/src/main/resources`. The `doc` directory also has a static HTML page that lists the configuration options.

Not all configuration options are listed in `hbase-default.xml`. Configurations that users would rarely change do exist only in code; the only way to turn find such configuration options is to read the source code itself.

The servers always read the `hbase-default.xml` file first and subsequently merge it with the `hbase-site.xml` file content—if present. The properties set in `hbase-site.xml` always take precedence over the default values loaded from `hbase-default.xml`.

Most changes here will require a cluster restart for HBase to notice the change. However, there is a way to reload some specific settings while the processes are running. See (to come) for details.

HDFS-Related Configuration

If you have made *HDFS*-related configuration changes on your Hadoop cluster—in other words, properties you want the HDFS cli-

ents to use as opposed to the server-side configuration—HBase will not see these properties unless you do one of the following:

- Add a pointer to your \$HADOOP_CONF_DIR to the HBASE_CLASSPATH environment variable in hbase-env.sh.
- Add a copy of core-site.xml, hdfs-site.xml, etc. (or hadoop-site.xml) or, better, symbolic links, under \${HBASE_HOME}/conf.
- Add them to hbase-site.xml directly.

An example of such a HDFS client property is dfs.replication. If, for example, you want to run with a replication factor of 5, HBase will create files with the default of 3 unless you do one of the above to make the configuration available to HBase.

When you add Hadoop configuration files to HBase, they will always take the lowest priority. In other words, the properties contained in any of the HBase-related configuration files, that is, the default and site files, take precedence over any Hadoop configuration file containing a property with the same name. This allows you to override Hadoop properties in your HBase configuration file.

hbase-env.sh and hbase-env.cmd

You set HBase environment variables in these files. Examples include options to pass to the JVM when a HBase daemon starts, such as Java heap size and garbage collector configurations. You also set options for HBase configuration, log directories, niceness, SSH options, where to locate process pid files, and so on. Open the file at conf/hbase-env.{cmd,sh} and peruse its content. Each option is fairly well documented. Add your own environment variables here if you want them read when a HBase daemon is started.

regionserver

This file lists all the known region server names. It is a flat text file that has one hostname per line. The list is used by the HBase maintenance script to be able to iterate over all the servers to start the region server process. An example can be seen in “[Example Configuration](#)” (page 89).

If you used previous versions of HBase, you may miss the `masters` file, available in the `0.20.x` line. It has been removed as it is no longer needed. The list of masters is now dynamically maintained in ZooKeeper and each master registers itself when started.

log4j.properties

Edit this file to change the rate at which HBase files are rolled and to change the level at which HBase logs messages. Changes here will require a cluster restart for HBase to notice the change, though log levels can be changed for particular daemons via the HBase UI. See (to come) for information on this topic, and (to come) for details on how to use the logfiles to find and solve problems.

Example Configuration

Here is an example configuration for a distributed 10-node cluster. The nodes are named `master.foo.com`, `host1.foo.com`, and so on, through node `host9.foo.com`. The HBase Master and the HDFS name node are running on the node `master.foo.com`. Region servers run on nodes `host1.foo.com` to `host9.foo.com`. A three-node ZooKeeper ensemble runs on `zk1.foo.com`, `zk2.foo.com`, and `zk3.foo.com` on the default ports. ZooKeeper data is persisted to the directory `/var/zookeeper`. The following subsections show what the main configuration files--`hbase-site.xml`, `regionservers`, and `hbase-env.sh`--found in the HBase conf directory might look like.

hbase-site.xml

The `hbase-site.xml` file contains the essential configuration properties, defining the HBase cluster setup.

```
<?xml version="1.0"?>
<?xml-stylesheet type="text/xsl" href="configuration.xsl"?>
<configuration>
  <property>
    <name>hbase.zookeeper.quorum</name>
    <value>zk1.foo.com,zk2.foo.com,zk3.foo.com</value>
  </property>
  <property>
    <name>hbase.zookeeper.property.dataDir</name>
    <value>/var/zookeeper</value>
  </property>
  <property>
    <name>hbase.rootdir</name>
    <value>hdfs://master.foo.com:9000/hbase</value>
```

```
</property>
<property>
  <name>hbase.cluster.distributed</name>
  <value>true</value>
</property>
</configuration>
```

regionservers

In this file, you list the nodes that will run region servers. In our example, we run region servers on all but the head node `master.foo.com`, which is carrying the HBase Master and the HDFS NameNode.

```
host1.foo.com
host2.foo.com
host3.foo.com
host4.foo.com
host5.foo.com
host6.foo.com
host7.foo.com
host8.foo.com
host9.foo.com
```

hbase-env.sh

Here are the lines that were changed from the default in the supplied `hbase-env.sh` file. We are setting the HBase heap to be 4 GB:

```
...
# export HBASE_HEAPSIZE=1000
export HBASE_HEAPSIZE=4096
...
```

Before HBase version 1.0 the default heap size was 1GB. This has been changed³⁴ in 1.0 and later to the default value of the JVM. This usually amounts to one-fourth of the available memory, for example on a Mac with Java version 1.7.0_45:

```
$ hostinfo | grep memory
Primary memory available: 48.00 gigabytes
$ java -XX:+PrintFlagsFinal -version | grep MaxHeapSize
  uintx MaxHeapSize          := 12884901888      {product}
```

You can see that the JVM reports a maximum heap of 12GB, which is the mentioned one-fourth of the full 48GB.

Once you have edited the configuration files, you need to distribute them across all servers in the cluster. One option to copy the content of the `conf` directory to all servers in the cluster is to use the `rsync`

34. See [HBASE-11804](#) for details.

command on Unix and Unix-like platforms. This approach and others are explained in “Deployment” (page 92).

(to come) discusses the settings you are most likely to change first when you start scaling your cluster.

Client Configuration

Since the HBase Master may move around between physical machines (see (to come) for details), clients start by requesting the vital information from ZooKeeper—something visualized in (to come). For that reason, clients require the ZooKeeper quorum information in a `hbase-site.xml` file that is on their Java \$CLASSPATH.

You can also set the `hbase.zookeeper.quorum` configuration key in your code. Doing so would lead to clients that need no external configuration files. This is explained in “Put Method” (page 122).

If you are configuring an IDE to run a HBase client, you could include the `conf/` directory in your class path. That would make the configuration files discoverable by the client code.

Minimally, a Java client needs the following JAR files specified in its \$CLASSPATH, when connecting to HBase, as retrieved with the HBase shell `mapredcp` command (and some shell string mangling):

```
$ bin/hbase mapredcp | tr ":" "\n" | sed "s/\/usr\/local\/hbase-1.0.0\/lib///"  
zookeeper-3.4.6.jar  
hbase-common-1.0.0.jar  
hbase-protocol-1.0.0.jar  
htrace-core-3.1.0-incubating.jar  
protobuf-java-2.5.0.jar  
hbase-client-1.0.0.jar  
hbase-hadoop-compat-1.0.0.jar  
netty-all-4.0.23.Final.jar  
hbase-server-1.0.0.jar  
guava-12.0.1.jar
```

Run the same `bin/hbase mapredcp` command without any string mangling to get a properly configured class path output, which can be fed directly to an application setup. All of these JAR files come with HBase and are usually postfix with the a version number of the required

release. Ideally, you use the supplied JARs and do not acquire them somewhere else because even minor release changes could cause problems when running the client against a remote HBase cluster.

A basic example `hbase-site.xml` file for client applications might contain the following properties:

```
<?xml version="1.0"?>
<?xml-stylesheet type="text/xsl" href="configuration.xsl"?>
<configuration>
  <property>
    <name>hbase.zookeeper.quorum</name>
    <value>zk1.foo.com,zk2.foo.com,zk3.foo.com</value>
  </property>
</configuration>
```

Deployment

After you have configured HBase, the next thing you need to do is to think about deploying it on your cluster. There are many ways to do that, and since Hadoop and HBase are written in Java, there are only a few necessary requirements to look out for. You can simply copy all the files from server to server, since they usually share the same configuration. Here are some ideas on how to do that. Please note that you would need to make sure that all the suggested selections and adjustments discussed in “[Requirements](#)” ([page 43](#)) have been applied—or are applied at the same time when provisioning new servers.

Besides what is mentioned below, the much more common way these days to deploy Hadoop and HBase is using a prepackaged distribution, which are listed in (to come).

Script-Based

Using a script-based approach seems archaic compared to the more advanced approaches listed shortly. But they serve their purpose and do a good job for small to even medium-size clusters. It is not so much the size of the cluster but the number of people maintaining it. In a larger operations group, you want to have repeatable deployment procedures, and not deal with someone having to run scripts to update the cluster.

The scripts make use of the fact that the `regionservers` configuration file has a list of all servers in the cluster. [Example 2-3](#) shows a very simple script that could be used to copy a new release of HBase from the master node to all slave nodes.

Example 2-3. Example Script to copy the HBase files across a cluster

```
#!/bin/bash
# Rsync's HBase files across all slaves. Must run on master. Assumes
# all files are located in /usr/local

if [ "$#" != "2" ]; then
    echo "usage: $(basename $0) <dir-name> <ln-name>"
    echo "  example: $(basename $0) hbase-0.1 hbase"
    exit 1
fi

SRC_PATH="/usr/local/$1/conf/regionservers"
for srv in $(cat $SRC_PATH); do
    echo "Sending command to $srv...";
    rsync -vaz --exclude='logs/*' /usr/local/$1 $srv:/usr/local/
    ssh $srv "rm -fR /usr/local/$2 ; ln -s /usr/local/$1 /usr/local/$2"
done

echo "done."
```

Another simple script is shown in [Example 2-4](#); it can be used to copy the configuration files of HBase from the master node to all slave nodes. It assumes you are editing the configuration files on the master in such a way that the master can be copied across to all region servers.

Example 2-4. Example Script to copy configurations across a cluster

```
#!/bin/bash
# Rsync's HBase config files across all region servers. Must run on
# master.

for srv in $(cat /usr/local/hbase/conf/regionservers); do
    echo "Sending command to $srv...";
    rsync -vaz --delete --exclude='logs/*' /usr/local/hadoop/ $srv:/usr/
    local/hadoop/
    rsync -vaz --delete --exclude='logs/*' /usr/local/hbase/ $srv:/usr/
    local/hbase/
done

echo "done."
```

The second script uses `rsync` just like the first script, but adds the `--delete` option to make sure the region servers do not have any older files remaining but have an exact copy of what is on the originating server.

There are obviously many ways to do this, and the preceding examples are simply for your perusal and to get you started. Ask your adminis-

trator to help you set up mechanisms to synchronize the configuration files appropriately. Many beginners in HBase have run into a problem that was ultimately caused by inconsistent configurations among the cluster nodes. Also, do not forget to restart the servers when making changes. If you want to update settings while the cluster is in production, please refer to (to come).

Apache Whirr

Recently, we have seen an increase in the number of users who want to run their cluster in dynamic environments, such as the public cloud offerings by Amazon's EC2, or [Rackspace Cloud Servers](#), as well as in private server farms, using open source tools like [Eucalyptus](#) or [Open-Stack](#).

The advantage is to be able to quickly provision servers and run analytical workloads and, once the result has been retrieved, to simply shut down the entire cluster, or reuse the servers for other dynamic workloads. Since it is not trivial to program against each of the APIs providing dynamic cluster infrastructures, it would be useful to abstract the provisioning part and, once the cluster is operational, simply launch the MapReduce jobs the same way you would on a local, static cluster. This is where [Apache Whirr](#) comes in.

Whirr has support for a variety of public and private cloud APIs and allows you to provision clusters running a range of services. One of those is HBase, giving you the ability to quickly deploy a fully operational HBase cluster on dynamic setups.

You can download the latest Whirr release from the project's website and find preconfigured configuration files in the `recipes` directory. Use it as a starting point to deploy your own dynamic clusters.

The basic concept of Whirr is to use very simple machine images that already provide the operating system (see "[Operating system](#)" (page 51)) and SSH access. The rest is handled by Whirr using *services* that represent, for example, Hadoop or HBase. Each service executes every required step on each remote server to set up the user accounts, download and install the required software packages, write out configuration files for them, and so on. This is all highly customizable and you can add extra steps as needed.

Puppet and Chef

Similar to Whirr, there are other deployment frameworks for dedicated machines. *Puppet* by [Puppet Labs](#) and *Chef* by [Opscode](#) are two such offerings.

Both work similar to Whirr in that they have a central provisioning server that stores all the configurations, combined with client software, executed on each server, which communicates with the central server to receive updates and apply them locally.

Also similar to Whirr, both have the notion of *recipes*, which essentially translate to scripts or commands executed on each node. In fact, it is quite possible to replace the scripting employed by Whirr with a Puppet- or Chef-based process. Some of the available recipe packages are an adaption of early EC2 scripts, used to deploy HBase to dynamic, cloud-based server. For Chef, you can find HBase-related examples at <http://cookbooks.opscode.com/cookbooks/hbase>. For Puppet, please refer to <http://hstack.org/hstack-automated-deployment-using-puppet/> and the repository with the recipes at <http://github.com/hstack/puppet> as a starting point. There are other such modules available on the Internet.

While Whirr solely handles the bootstrapping, Puppet and Chef have further support for changing running clusters. Their master process monitors the configuration repository and, upon updates, triggers the appropriate remote action. This can be used to reconfigure clusters on-the-fly or push out new releases, do rolling restarts, and so on. It can be summarized as configuration management, rather than just provisioning.

You heard it before: select an approach you like and maybe even are familiar with already. In the end, they achieve the same goal: installing everything you need on your cluster nodes. If you need a full configuration management solution with live updates, a Puppet- or Chef-based approach—maybe in combination with Whirr for the server provisioning—is the right choice.

Operating a Cluster

Now that you have set up the servers, configured the operating system and filesystem, and edited the configuration files, you are ready to start your HBase cluster for the first time.

Running and Confirming Your Installation

Make sure HDFS is running first. Start and stop the Hadoop HDFS daemons by running `bin/start-dfs.sh` over in the `$HADOOP_HOME` directory. You can ensure that it started properly by testing the `put` and

get of files into the Hadoop filesystem. HBase does not normally use the YARN daemons. You only need to start them for actual MapReduce jobs, something we will look into in detail in [Chapter 7](#).

If you are managing your own ZooKeeper, start it and confirm that it is running, since otherwise HBase will fail to start.

Just as you started the standalone mode in [“Quick-Start Guide” \(page 39\)](#), you start a fully distributed HBase with the following command:

```
$ bin/start-hbase.sh
```

Run the preceding command from the `$HBASE_HOME` directory. You should now have a running HBase instance. The HBase log files can be found in the `logs` subdirectory. If you find that HBase is not working as expected, please refer to (to come) for help finding the problem.

Once HBase has started, see [“Quick-Start Guide” \(page 39\)](#) for information on how to create tables, add data, scan your insertions, and finally, disable and drop your tables.

Web-based UI Introduction

HBase also starts a web-based user interface (UI) listing vital attributes. By default, it is deployed on the master host at port 16010 (HBase region servers use 16030 by default).³⁵ If the master is running on a host named `master.foo.com` on the default port, to see the master’s home page you can point your browser at `http://master.foo.com:16010`. [Figure 2-2](#) is an example of how the resultant page should look. You can find a more detailed explanation in [“Web-based UI” \(page 503\)](#).

35. Previous versions of HBase used port 60010 for the master and 60030 for the region server respectively.

Master master-1.internal.larsgeorge.com

Region Servers

Base Stats	Memory		Requests		Storefiles
ServerName		Start time		Requests Per Second	Num. Regions
slave-1.internal.larsgeorge.com,16020,1432833667280		Thu May 28 10:21:07 PDT 2015	0		2
slave-2.internal.larsgeorge.com,16020,1432835159618		Thu May 28 10:45:59 PDT 2015	0		0
slave-3.internal.larsgeorge.com,16020,1432833668231		Thu May 28 10:21:08 PDT 2015	0		0
Total:3			0		2

Backup Masters

ServerName	Port	Start Time
master-2.internal.larsgeorge.com	16000	Thu May 28 10:20:42 PDT 2015
master-3.internal.larsgeorge.com	16000	Thu May 28 10:21:05 PDT 2015
Total:2		

Tables

User Tables	System Tables	Snapshots
-------------	---------------	-----------

Tasks

Show All Monitored Tasks Show non-RPC Tasks Show All RPC Handler Tasks Show Active RPC Calls Show Client Operations View as JSON

No tasks currently running on this node.

Software Attributes

Attribute Name	Value	Description
HBase Version	1.1.0, revision=e860c66d41ddc8231004b646098a58abca7fb523	HBase version and revision
HBase Compiled	Tue May 12 13:07:08 PDT 2015, ndimiduk	When HBase version was compiled and by whom
HBase Source Checksum	6424fcab95bfff8337780a181ad7c78	HBase source MD5 checksum
Hadoop Version	2.5.1, revision=2e18d179e4a8065b6a9f29cf2de9451891265cce	Hadoop version and revision
Hadoop Compiled	2015-03-26T16:58Z, ndimiduk	When Hadoop version was compiled and by whom
Zookeeper Quorum	master-1.internal.larsgeorge.com:2181 master-2.internal.larsgeorge.com:2181 master-3.internal.larsgeorge.com:2181	Addresses of all registered ZK servers. For more, see zk dump .
Zookeeper Base Path	/hbase	Root node of this cluster in ZK.
HBase Root Directory	hdfs://master-1.internal.larsgeorge.com:9000/hbase	Location of HBase home directory
HMMaster Start Time	Thu May 28 10:21:02 PDT 2015	Date stamp of when this HMMaster was started
HMMaster Active Time	Thu May 28 10:21:07 PDT 2015	Date stamp of when this HMMaster became active
HBase Cluster ID	d11df898-b760-412d-92a7-71b42444822c	Unique identifier generated for each HBase cluster
Load average	0.67	Average number of regions per regionserver. Naive computation.
Coprocessors	[]	Coprocessors currently loaded by the master
LoadBalancer	org.apache.hadoop.hbase.master.balancer.StochasticLoadBalancer	LoadBalancer to be used in the Master

Figure 2-2. The HBase Master User Interface

From this page you can access a variety of status information about your HBase cluster. The page is separated into multiple sections. The top part has the information about the available region servers, as well as any optional backup masters. This is followed by the known tables, system tables, and snapshots—these are tabs that you can select to see the details you want.

The lower part shows the currently running tasks—if there are any--, and again using tabs, you can switch to other details here, for example, the RPC handler status, active calls, and so on. Finally the bottom of the page has the attributes pertaining to the cluster setup.

After you have started the cluster, you should verify that all the region servers have registered themselves with the master and appear in the appropriate table with the expected hostnames (that a client can connect to). Also verify that you are indeed running the correct version of HBase and Hadoop.

Shell Introduction

You already used the command-line shell that comes with HBase when you went through “[Quick-Start Guide](#)” ([page 39](#)). You saw how to create a table, add and retrieve data, and eventually drop the table.

The HBase Shell is ([J](#))Ruby’s IRB with some HBase-related commands added. Anything you can do in IRB, you should be able to do in the HBase Shell. You can start the shell with the following command:

```
$ bin/hbase shell
HBase Shell; enter 'help<RETURN>' for list of supported commands.
Type "exit<RETURN>" to leave the HBase Shell
Version 1.0.0, r6c98bfff7b719efdb16f71606f3b7d8229445eb81, Sat Feb
14 19:49:22 PST 2015

hbase(main):001:0>
```

Type `help` and then press Return to see a listing of shell commands and options. Browse at least the paragraphs at the end of the help text for the gist of how variables and command arguments are entered into the HBase Shell; in particular, note how table names, rows, and columns, must be quoted. Find the full description of the shell in “[Shell](#)” ([page 481](#)).

Since the shell is JRuby-based, you can mix Ruby with HBase commands, which enables you to do things like this:

```
hbase(main):001:0> create 'testtable', 'colfam1'
hbase(main):002:0> for i in 'a'..'z' do for j in 'a'..'z' do \
  put 'testtable', "row-#{i}#{j}", "colfam1:#{j}", "#{j}" end end
```

The first command is creating a new table named `testtable`, with one column family called `colfam1`, using default values (see “[Column Families](#)” (page 362) for what that means). The second command uses a Ruby loop to create rows with columns in the newly created tables. It creates row keys starting with `row-aa`, `row-ab`, all the way to `row-zz`.

Stopping the Cluster

To stop HBase, enter the following command. Once you have started the script, you will see a message stating that the cluster is being stopped, followed by “.” (period) characters printed in regular intervals (just to indicate that the process is still running, not to give you any percentage feedback, or some other hidden meaning):

```
$ bin/stop-hbase.sh  
stopping hbase.....
```

Shutdown can take several minutes to complete. It can take longer if your cluster is composed of many machines. If you are running a distributed operation, be sure to wait until HBase has shut down completely before stopping the Hadoop daemons.

(to come) has more on advanced administration tasks—for example, how to do a rolling restart, add extra master nodes, and more. It also has information on how to analyze and fix problems when the cluster does not start, or shut down.

Chapter 3

Client API: The Basics

This chapter will discuss the client APIs provided by HBase. As noted earlier, HBase is written in Java and so is its native API. This does not mean, though, that you *must* use Java to access HBase. In fact, [Chapter 6](#) will show how you can use other programming languages.

General Notes

As noted in “[HBase Version](#)” ([page xix](#)), we are mostly looking at APIs that are flagged as *public* regarding their audience. See (to come) for details on the annotations in use.

The primary client entry point to HBase is the `Table` interface in the `org.apache.hadoop.hbase.client` package. It provides the user with all the functionality needed to store and retrieve data from HBase, as well as delete obsolete values and so on. It is retrieved by means of the `Connection` instance that is the umbilical cord to the HBase servers. Though, before looking at the various methods these classes provide, let us address some general aspects of their usage.

All operations that mutate data are guaranteed to be *atomic* on a per-row basis. This affects all other concurrent readers and writers of that same row. In other words, it does not matter if another client or thread is reading from or writing to the same row: they either read a

consistent last mutation, or may have to wait before being able to apply their change.¹ More on this in (to come).

Suffice it to say for now that during normal operations and load, a reading client will not be affected by another updating a particular row since their contention is nearly negligible. There is, however, an issue with many clients trying to update the same row at the same time. Try to batch updates together to reduce the number of separate operations on the same row as much as possible.

It also does not matter how many columns are written for the particular row; all of them are covered by this guarantee of atomicity.

Finally, creating an initial connection to HBase is not without cost. Each instantiation involves scanning the `hbase:meta` table to check if the table actually exists and if it is enabled, as well as a few other operations that make this call quite heavy. Therefore, it is recommended that you create a `Connection` instances only once and reuse that instance for the rest of the lifetime of your client application.

Once you have a connection instance you can retrieve references to the actual tables. Ideally you do this per thread since the underlying implementation of `Table` is not guaranteed to be thread-safe. Ensure that you close all of the resources you acquire though to trigger important house-keeping activities. All of this will be explained in detail in the rest of this chapter.

The examples you will see in partial source code can be found in full detail in the publicly available GitHub repository at <https://github.com/larsgeorge/hbase-book>. For details on how to compile them, see (to come).

Initially you will see the `import` statements, but they will be subsequently omitted for the sake of brevity. Also, specific parts of the code are not listed if they do not immediately help with the topic explained. Refer to the full source if in doubt.

1. The region servers use a *multiversion concurrency control* mechanism, implemented internally by the `MultiVersionConsistencyControl` (MVCC) class, to guarantee that readers can read without having to wait for writers. Equally, writers do need to wait for other writers to complete before they can continue.

Data Types and Hierarchy

Before we delve into the actual operations and their API classes, let us first see how the classes that we will use throughout the chapter are related. There is some very basic functionality introduced in lower-level classes, which surface in the majority of the data-centric classes, such as Put, Get, or Scan. [Table 3-1](#) list all of the *basic* data-centric types that are introduced in this chapter.

Table 3-1. List of basic data-centric types

Type	Kind	Description
Get	Query	Retrieve previously stored data from a single row.
Scan	Query	Iterate over all or specific rows and return their data.
Put	Mutation	Create or update one or more columns in a single row.
Delete	Mutation	Remove a specific cell, column, row, etc.
Increment	Mutation	Treat a column as a counter and increment its value.
Append	Mutation	Attach the given data to one or more columns in a single row.

Throughout the book we will collectively refer to these classes as *operations*. [Figure 3-1](#) shows you the hierarchy of the data-centric types and their relationship to the more generic superclasses and interfaces. Understanding them first will help use them throughout the entire API, and we save the repetitive mention as well. The remainder of this section will discuss what these base classes and interfaces add to each derived data-centric type.

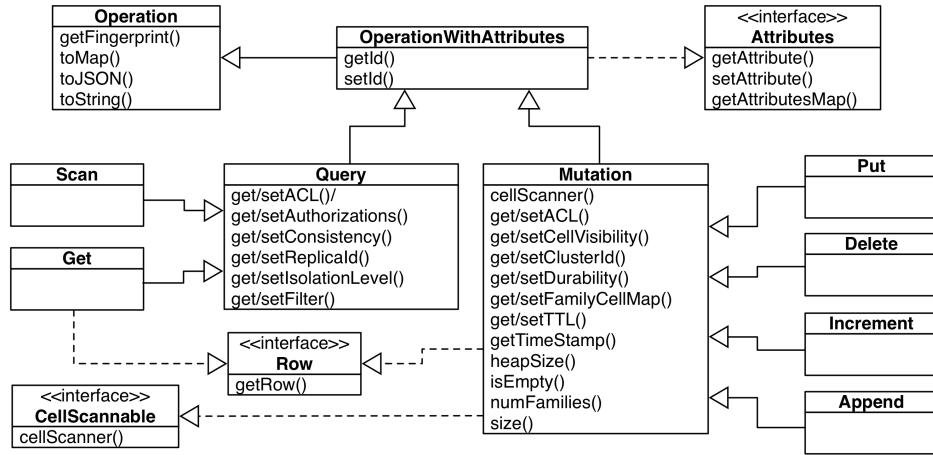


Figure 3-1. The class hierarchy of the basic client API data classes

Generic Attributes

One fundamental interface is `Attributes`, which introduces the following methods:

```

Attributes setAttribute(String name, byte[] value)
byte[] getAttribute(String name)
Map<String, byte[]> getAttributesMap()
  
```

They provide a general mechanism to add any kind of information in form of *attributes* to all of the data-centric classes. By default there are no attributes set (apart from possibly internal ones) and a developer can make use of `setAttribute()` to add custom ones as needed. Since most of the time the construction of a data type, such as `Put`, is immediately followed by an API call to send it off to the servers, a valid question is: where can I make use of attributes?

One thing to note is that attributes are serialized and sent to the server, which means you can use them to inspect their value, for example, in a coprocessor (see “[Coprocessors](#)” (page 282)). Another use-case is the `Append` class, which uses the attributes to return information back to the user after a call to the servers (see “[Append Method](#)” (page 181)).

Operations: Fingerprint and ID

Another fundamental type is the abstract class `Operation`, which adds the following methods to all data types:

```

abstract Map<String, Object> getFingerprint()
abstract Map<String, Object> toMap(int maxCols)
Map<String, Object> toMap()
String toJSON(int maxCols) throws IOException
String toJSON() throws IOException
String toString(int maxCols)
String toString()

```

These were introduced when HBase 0.92 had the *slow query logging* added (see (to come)), and help in generating *useful* information collections for logging and general debugging purposes. All of the latter methods really rely on the specific implementation of `toMap(int maxCols)`, which is abstract in `Operation`. The `Mutation` class implements it for all derived data classes in such a way as described in [Table 3-2](#). The default number of columns included in the output is 5 (hardcoded in HBase 1.0.0) when not specified explicitly.

In addition, the intermediate `OperationWithAttributes` class is extending the above `Operation` class, implements the `Attributes` interface, and is adding the following methods, which are used in conjunction:

```

OperationWithAttributes setId(String id)
String getId()

```

The *ID* is a client-provided value, which identifies the *operation* when logged or emitted otherwise. For example, the client could set it to the method name that is invoking the API, so that when the operation—say the `Put` instance—is logged it can be determined which client call is the root cause. Add the hostname, process ID, and other useful information and it will be much easier to spot the culprit.

Table 3-2. The various methods to retrieve instance information

Method	Description
<code>getId()</code>	Returns what was set by the <code>setId()</code> method.
<code>getFingerprint()</code>	Returns the list of column families included in the instance.
<code>toMap(int maxCols)</code>	Compiles a list including fingerprint, column families with all columns and their data, total column count, row key, and—if set—the ID and cell-level TTL.
<code>toMap()</code>	Same as above, but only for 5 columns. ^a
<code>toJSON(int maxCols)</code>	Same as <code>toMap(maxCols)</code> but converted to JSON. Might fail due to encoding issues.
<code>toJSON()</code>	Same as above, but only for 5 columns. ^a
<code>toString(int maxCols)</code>	Attempts to call <code>toJSON(maxCols)</code> , but when it fails, falls back to <code>toMap(maxCols)</code> .
<code>toString()</code>	Same as above, but only for 5 columns. ^a

Method	Description
^a Hardcoded in HBase 1.0.0. Might change in the future.	

The repository accompanying the book has an example named `Finger printExample.java` which you can experiment with to see the finger-print, ID, and `toMap()` in action.

Query versus Mutation

Before we end with the final data types, there are a few more super-classes of importance. First the `Row` interface, which adds:

```
byte[] getRow()
```

The method simply returns the given row key of the instance. This is implemented by the `Get` class, as it handles exactly one row. It is also implemented by the `Mutation` superclass, which is the basis for all the types that are needed when changing data. Additionally, `Mutation` implements the `CellScannable` interface to provide the following method:

```
CellScanner cellScanner()
```

With it, a client can iterate over the returned cells, which we will learn about in “[The Cell](#)” (page 112) very soon. The `Mutation` class also has many other functions that are shared by all derived classes. Here is a list of the most interesting ones:

Table 3-3. Methods provided by the Mutation superclass

Method	Description
<code>getACL()/setACL()</code>	The Access Control List (ACL) for this operation. See (to come) for details.
<code>getCellVisibility()/setCellVisibility()</code>	The cell level visibility for all included cells. See (to come) for details.
<code>getClusterIds()/setClusterIds()</code>	The cluster ID as needed for replication purposes. See (to come) for details.
<code>getDurability()/setDurability()</code>	The durability settings for the mutation. See “ Durability, Consistency, and Isolation ” (page 108) for details.
<code>getFamilyCellMap()/setFamilyCellMap()</code>	The list of all cells per column family available in this instance.
<code>getTimeStamp()</code>	Retrieves the associated timestamp of the Put instance. Can be optionally set using the constructor’s <code>ts</code> parameter. If not set, may return <code>Long.MAX_VALUE</code> (also defined as <code>HConstants.LATEST_TIMESTAMP</code>).
<code>getTTL()/setTTL()</code>	Sets the cell level TTL value, which is being applied to all included <code>Cell</code> instances before being persisted.

Method	Description
heapSize()	Computes the heap space required for the current Put instance. This includes all contained data and space needed for internal structures.
isEmpty()	Checks if the family map contains any Cell instances.
numFamilies()	Convenience method to retrieve the size of the family map, containing all Cell instances.
size()	Returns the number of Cell instances that will be added with this Put.

While there are many that you learn about at an opportune moment later in the book (see the links provided above), there are also a few that we can explain now and will not have to repeat them later, since they are shared by most data-related types. First is the `getFamilyCellMap()` and `setFamilyCellMap()` pair. Mutations hold a list of columns they act on, and columns are represented as Cell instances ([“The Cell” \(page 112\)](#) will introduce them properly). So these two methods let you retrieve the current list of cells held by the mutation, or set—or replace—the entire list in one go.

The `getTimeStamp()` method returns the instance-wide timestamp set during instantiation, or via a call to `setTimestamp()`² if present. Usually the constructor is the common way to optionally hand in a timestamp. What that timestamp means is different for each derived class. For example, for Delete it sets a global filter to delete cells that are of that version or before. For Put it is stored and applied to all subsequent `addColumn()` calls when no explicit timestamp is specified with it.

Another pair are the `getTTL()` and `setTTL()` methods, allowing the definition of a cell-level *time-to-live* (TTL). They are useful for all mutations that add new columns (or cells, in case of updating an existing column), and in fact for Delete the call to `setTTL()` will throw an exception that the operation is unsupported. The `getTTL()` is to recall what was set before, and by default the TTL is unset. Once assigned, you cannot unset the value, so to disable it again, you have to set it to `Long.MAX_VALUE`.

The `size()`, `isEmpty()`, and `numFamilies()` all return information about what was added to the mutation so far, either using the `addColumn()`, `addFamily()` (and class specific variants), or `setFamilyCellMap()`. `size` just returns the size of the list of cells. So if you, for example, added three specific columns, two to column family 1, and one

2. As of this writing, there is unfortunately a disparity in spelling in these methods.

to column family 2, you would be returned 3. `isEmpty()` compares `size()` to be 0 and would return true in that case, false otherwise. `numFamilies()` is keeping track of how many column families have been addressed during the `addColumn()` and `addFamily()` calls. In our example we would be returned 2 as we have used as many families.

The other larger superclass on the retrieval side is `Query`, which provides a common substrate for all data types concerned with reading data from the HBase tables. The following table shows the methods introduced:

Table 3-4. Methods provided by the Query superclass

Method	Description
<code>getAuthorizations()/setAuthorizations()</code>	Visibility labels for the operation. See (to come) for details.
<code>getACL()/setACL()</code>	The Access Control List (ACL) for this operation. See (to come) for details.
<code>getFilter()/setFilter()</code>	The filters that apply to the retrieval operation. See “ Filters ” (page 219) for details.
<code>getConsistency()/setConsistency()</code>	The consistency level that applies to the current query instance.
<code>getIsolationLevel()/setIsolationLevel()</code>	Specifies the read isolation level for the operation.
<code>getReplicaId()/setReplicaId()</code>	Gives access to the replica ID that served the data.

We will address the latter ones in “[CRUD Operations](#)” (page 122) and “[Durability, Consistency, and Isolation](#)” (page 108), as well as in other parts of the book as we go along. For now please note their existence and once we make use of them you can transfer their application to any other data type as needed. In summary, and to set nomenclature going forward, we can say that all *operations* are either part of writing data and represented by *mutations*, or they are part of reading data and are referred to as *queries*.

Before we can move on, we first have to introduce another set of basic types required to communicate with the HBase API to read or write data.

Durability, Consistency, and Isolation

While we are still talking about the basic data-related types of the HBase API, we have to go on a little tangent now, covering classes (or enums) that are used in conjunction with the just mentioned methods

of Mutation and Query, or, in other words, that widely shared boilerplate functionality found in all derived data types, such as Get, Put, or Delete.

The first group revolves around *durability*, as seen, for example, above in the `setDurability()` method of Mutation. Since it is part of the write path, the durability concerns how the servers handle updates sent by clients. The list of options provided by the implementing Durability enumeration are:

Table 3-5. Durability levels

Level	Description
USE_DEFAULT	For tables use the global default setting, which is SYNC_WAL. For a mutation use the table's default value.
SKIP_WAL	Do not write the mutation to the WAL. ^a
ASYNC_WAL	Write the mutation asynchronously to the WAL.
SYNC_WAL	Write the mutation synchronously to the WAL.
FSYNC_WAL	Write the Mutation to the WAL synchronously and force the entries to disk. ^b

^a This replaces the `setWriteToWAL(false)` call from earlier versions of HBase.

^b This is currently not supported and will behave identical to SYNC_WAL. See [HADOOP-6313](#).

WAL stands for *write-ahead log*, and is the central mechanism to keep data safe. The topic is explained in detail in (to come).

There are some subtleties here that need explaining. For `USE_DEFAULT` there are two places named, the table and the single mutation. We will see in “Tables” (page 350) how tables are defined in code using the `HTableDescriptor` class. For now, please note that this class also offers a `setDurability()` and `getDurability()` pair of methods. It defines the table-wide durability in case it is not overridden by a client operation. This is where the Mutation comes in with its same pair of methods: here you can specify a durability level different from the table wide.

But what does durability really mean? It lets you decide how important your data is to you. Note that HBase is a complex distributed system, with many moving parts. Just because the client library you are using accepts the operation does not imply that it has been applied, or persisted even. This is where the durability parameter comes in. By

default HBase is using the `SYNC_WAL` setting, meaning data is written to the underlying filesystem. This does *not* imply it has reached disks, or another storage media, and in catastrophic circumstances—say the entire rack or even data center loses power—you could lose data. This is still the default as it strikes a performance balance and with the proper cluster architecture it should be pretty much impossible to happen.

If you do not trust your cluster design, or it out of your control, or you have seen Murphy’s Law in action, you can opt for the highest durability guarantee, named `FSYNC_WAL`. It implies that the file system has been advised to push the data to the storage media, before returning success to the client caller. More on this is discussed later in (to come).

As of this writing, the proper `fsync` support needed for `FSYNC_WAL` is *not* implemented by Hadoop! Effectively this means that `FSYNC_WAL` does the same currently as `SYNC_WAL`.

The `ASYNC_WAL` defers the writing to an opportune moment, controlled by the HBase region server and its WAL implementation. It has group write and sync features, but strives to persist the data as quick as possible. This is the second weakest durability guarantee. This leaves the `SKIP_WAL` option, which simply means not to write to the write-ahead log at all—fire and forget style! If you do not care losing data during a server loss, then this is your option. Be careful, here be dragons!

This leads us to the read side of the equation, which is controlled by two settings, first the *consistency* level, as used by the `setConsistency()` and `getConsistency()` methods of the `Query` base class.³ It is provided by the `Consistency` enumeration and has the following options:

Table 3-6. Consistency Levels

Level	Description
<code>STRONG</code>	Strong consistency as per the default of HBase. Data is always current.
<code>TIMELINE</code>	Replicas may not be consistent with each other, but updates are guaranteed to be applied in the same order at all replicas. Data might be stale!

3. Available since HBase 1.0 as part of [HBASE-10070](#).

The consistency levels are needed when *region replicas* are in use (see (to come) on how to enable them). You have two choices here, either use the default STRONG consistency, which is native to HBase and means all client operations for a specific set of rows are handled by one specific server. Or you can opt for the TIMELINE level, which means you instruct the client library to read from any server hosting the same set of rows.

HBase always writes and commits all changes strictly serially, which means that completed transactions are always presented in the exact same order. You can slightly loosen this on the read side by trying to read from multiple copies of the data. Some copies might lag behind the authoritative copy, and therefore return some slightly outdated data. But the great advantage here is that you can retrieve data faster as you now have multiple replicas to read from.

Using the API you can think of this example (ignore for now the classes you have not been introduced yet):

```
Get get = new Get(row);
get.setConsistency(Consistency.TIMELINE);
...
Result result = table.get(get);
...
if (result.isStale()) {
    ...
}
```

The `isStale()` method is used to check if we have retrieved data from a replica, not the authoritative master. In this case it is left to the client to decide what to do with the result, in other words HBase will not attempt to reconcile data for you. On the other hand, receiving *stale* data, as indicated by `isStale()` does *not* imply that the result is outdated. The general contract here is that HBase delivered something from a replica region, and it might be current—or it might be behind (in other words stale). We will discuss the implications and details in later parts of the book, so please stay tuned.

The final lever at your disposal on the read side, is the *isolation* level⁴, as used by the `setIsolationLevel()` and `getIsolationLevel()` methods of the Query superclass.

4. This was introduced in HBase 0.94 as [HBASE-4938](#).

Table 3-7. Isolation Levels

Level	Description
READ_COMMITTED	Read only data that has been committed by the authoritative server.
READ_UNCOMMITTED	Allow reads of data that is in flight, i.e. not committed yet.

Usually the client reading data is expected to see only committed data (see (to come) for details), but there is an option to forgo this service and read anything a server has stored, be it in flight or committed. Once again, be careful when applying the READ_UNCOMMITTED setting, as results will vary greatly dependent on your write patterns.

We looked at the data types, their hierarchy, and the shared functionality. There are more types we need to introduce you to before we can use the API, so let us move to the next now.

The Cell

From your code you may have to work with `Cell` instances directly. As you may recall from our discussion earlier in this book, these instances contain the data as well as the *coordinates* of one specific cell. The coordinates are the row key, name of the column family, column qualifier, and timestamp. The interface provides access to the low-level details:

```
getRowArray(), getRowOffset(), getRowLength()
getFamilyArray(), getFamilyOffset(), getFamilyLength()
getQualifierArray(), getQualifierOffset(), getQualifierLength()
getValueArray(), getValueOffset(), getValueLength()
getTagsArray(), getTagsOffset(), getTagsLength()
getTimestamp()
getTypeByte()
getSequenceId()
```

There are a few additional methods that we have not explained yet. We will see those in (to come) and for the sake of brevity ignore their use for the time being. Since `Cell` is just an interface, you cannot simple create one. The implementing class, named `KeyValue` as of and up to HBase 1.0, is private and cannot be instantiated either. The `CellUtil` class, among many other convenience functions, provides the necessary methods to create an instance for us:

```
static Cell createCell(final byte[] row, final byte[] family,
    final byte[] qualifier, final long timestamp, final byte type,
    final byte[] value)
static Cell createCell(final byte[] rowArray, final int rowOffset,
    final int rowLength, final byte[] familyArray, final int family-
    Offset,
```

```

    final int familyLength, final byte[] qualifierArray,
    final int qualifierOffset, final int qualifierLength)
static Cell createCell(final byte[] row, final byte[] family,
    final byte[] qualifier, final long timestamp, final byte type,
    final byte[] value, final long memstoreTS)
static Cell createCell(final byte[] row, final byte[] family,
    final byte[] qualifier, final long timestamp, final byte type,
    final byte[] value, byte[] tags, final long memstoreTS)
static Cell createCell(final byte[] row, final byte[] family,
    final byte[] qualifier, final long timestamp, Type type,
    final byte[] value, byte[] tags)
static Cell createCell(final byte[] row)
static Cell createCell(final byte[] row, final byte[] value)
static Cell createCell(final byte[] row, final byte[] family,
    final byte[] qualifier)

```

There are probably many you will never need, yet, there they are. They also show what can be assigned to a `Cell` instance, and what can be retrieved subsequently. Note that `memstoreTS` above as a parameter is synonymous with `sequenceId`, as exposed by the getter `Cell.getSequenceId()`. Usually though, you will not have to explicitly create the cells at all, they are created for you as you add columns to, for example, `Put` or `Delete` instances. You can then retrieve them, again for example, using the following methods of `Query` and `Mutation` respectively, as explained earlier:

```

CellScanner cellScanner()
NavigableMap<byte[], List<Cell>> getFamilyCellMap()

```

The data as well as the coordinates are stored as a Java `byte[]`, that is, as a byte array. The design behind this type of low-level storage is to allow for arbitrary data, but also to be able to efficiently store only the required bytes, keeping the overhead of internal data structures to a minimum. This is also the reason that there is an `Offset` and `Length` parameter for each byte array parameter. They allow you to pass in existing byte arrays while doing very fast byte-level operations. And for every member of the coordinates, there is a getter in the `Cell` interface that can retrieve the byte arrays and their given offset and length.

The `CellUtil` class has many more useful methods, which will help the avid HBase client developer handle Cells with ease. For example, you can clone every part of the cell, such as the row or value. Or you can fill a `ByteRange` with each component. There are helpers to create `CellScanners` over a given list of cell instance, do comparisons, or determine the type of mutation. Please consult the `CellUtil` class directly for more information.

There is one more field per Cell instance that is representing an additional dimension for its unique coordinates: the *type*. Table 3-8 lists the possible values. We will discuss their meaning a little later, but for now you should note the different possibilities.

Table 3-8. The possible type values for a given Cell instance

Type	Description
Put	The Cell instance represents a normal Put operation.
Delete	This instance of Cell represents a Delete operation, also known as a <i>tombstone</i> marker.
DeleteFamilyVersion	This is the same as Delete, but more broadly deletes all columns of a column family matching a specific timestamp.
DeleteColumn	This is the same as Delete, but more broadly deletes an entire column.
DeleteFamily	This is the same as Delete, but more broadly deletes an entire column family, including all contained columns.

You can see the type of an existing Cell instance by, for example, using the `getTypeByte()` method shown earlier, or using the `CellUtil.isDeleteFamily(cell)` and other similarly named methods. We can combine the `cellScanner()` with the `Cell.toString()` to see the cell type in human readable form as well. The following comes from the `CellScannerExample.java` provided in the books online code repository:

Example 3-1. Shows how to use the cell scanner

```
Put put = new Put(Bytes.toBytes("testrow"));
put.addColumn(Bytes.toBytes("fam-1"), Bytes.toBytes("qual-1"),
    Bytes.toBytes("val-1"));
put.addColumn(Bytes.toBytes("fam-1"), Bytes.toBytes("qual-2"),
    Bytes.toBytes("val-2"));
put.addColumn(Bytes.toBytes("fam-2"), Bytes.toBytes("qual-3"),
    Bytes.toBytes("val-3"));

CellScanner scanner = put.cellScanner();
while (scanner.advance()) {
    Cell cell = scanner.current();
    System.out.println("Cell: " + cell);
}
```

The output looks like this:

```
Cell: testrow/fam-1:qual-1/LATEST_TIMESTAMP/Put/vlen=5/seqid=0
Cell: testrow/fam-1:qual-2/LATEST_TIMESTAMP/Put/vlen=5/seqid=0
Cell: testrow/fam-2:qual-3/LATEST_TIMESTAMP/Put/vlen=5/seqid=0
```

It prints out the meta information of the current Cell instances, and has the following format:

```
<row-key>/<family>:<qualifier>/<version>/<type>/<value-length>/  
<sequence-id>
```

Versioning of Data

A special feature of HBase is the possibility to store multiple *versions* of each cell (the value of a particular column). This is achieved by using timestamps for each of the versions and storing them in descending order. Each timestamp is a long integer value measured in milliseconds. It records the time that has passed since midnight, January 1, 1970 UTC—also known as *Unix time*, or *Unix epoch*.⁵ Most operating systems provide a timer that can be read from programming languages. In Java, for example, you could use the `System.currentTimeMillis()` function.

When you put a value into HBase, you have the choice of either explicitly providing a timestamp (see the `ts` parameter above), or omitting that value, which in turn is then filled in by the Region-Server when the `put` operation is performed.

As noted in “[Requirements](#)” (page 43), you *must* make sure your servers have the proper time and are synchronized with one another. Clients might be outside your control, and therefore have a different time, possibly different by hours or sometimes even years.

As long as you do not specify the time in the client API calls, the server time will prevail. But once you allow or have to deal with explicit timestamps, you need to make sure you are not in for unpleasant surprises. Clients could insert values at unexpected timestamps and cause seemingly unordered version histories.

While most applications never worry about versioning and rely on the built-in handling of the timestamps by HBase, you should be aware of a few peculiarities when using them explicitly.

Here is a larger example of inserting multiple versions of a cell and how to retrieve them:

```
hbase(main):001:0> create 'test', { NAME => 'cf1', VERSIONS =>  
3 }  
0 row(s) in 0.1540 seconds
```

5. See “[Unix time](#)” on Wikipedia.

```

=> Hbase::Table - test
hbase(main):002:0> put 'test', 'row1', 'cf1', 'val1'
0 row(s) in 0.0230 seconds

hbase(main):003:0> put 'test', 'row1', 'cf1', 'val2'
0 row(s) in 0.0170 seconds

hbase(main):004:0> scan 'test'
ROW          COLUMN+CELL
  row1        column=cf1:, timestamp=1426248821749, val-
ue=val2
1 row(s) in 0.0200 seconds

hbase(main):005:0> scan 'test', { VERSIONS => 3 }
ROW          COLUMN+CELL
  row1        column=cf1:, timestamp=1426248821749, val-
ue=val2
  row1        column=cf1:, timestamp=1426248816949, val-
ue=val1
1 row(s) in 0.0230 seconds

```

The example creates a table named `test` with one column family named `cf1`, and instructs HBase to keep three versions of each cell (the default is 1). Then two `put` commands are issued with the same row and column key, but two different values: `val1` and `val2`, respectively. Then a `scan` operation is used to see the full content of the table. You may not be surprised to see only `val2`, as you could assume you have simply replaced `val1` with the second `put` call.

But that is not the case in HBase. Because we set the versions to 3, you can slightly modify the `scan` operation to get all available values (i.e., versions) instead. The last call in the example lists both versions you have saved. Note how the row key stays the same in the output; you get all cells as separate lines in the shell's output.

For both operations, `scan` and `get`, you only get the *latest* (also referred to as the *newest*) version, because HBase saves versions in time descending order and is set to return only one version by default. Adding the *maximum versions* parameter to the calls allows you to retrieve more than one. Set it to the aforementioned `Long.MAX_VALUE` (or a very high number in the shell) and you get all available versions.

The term *maximum versions* stems from the fact that you may have fewer versions in a particular cell. The example sets `VERSIONS` (a shortcut for `MAX_VERSIONS`) to "3", but since only two are stored, that is all that is shown.

Another option to retrieve more versions is to use the *time range* parameter these calls expose. They let you specify a start and end time and will retrieve all versions matching the time range. More on this in “[Get Method](#)” (page 146) and “[Scans](#)” (page 193).

There are many more subtle (and not so subtle) issues with versioning and we will discuss them in (to come), as well as revisit the advanced concepts and nonstandard behavior in (to come).

Finally, there is the `CellComparator` class, forming the basis of classes which compare given cell instances using the Java Comparator pattern. One class is publicly available as an inner class of `CellComparator`, namely the `RowComparator`. You can use this class to compare cells by just their row component, in other words, the given row key. An example can be seen in `CellComparatorExample.java` in the code repository.

API Building Blocks

With this introduction of the underlying classes and their functionality out of the way, we can resume to look at the basic client API. It is (mostly) required for any of the following examples to connect to a HBase instance, be it local, pseudo-distributed, or fully deployed on a remote cluster. For that there are classes provided to establish this connection and start executing the API calls for data manipulation. The basic flow of a client connecting and calling the API looks like this:

```
Configuration conf = HBaseConfiguration.create();
Connection connection = ConnectionFactory.createConnection(conf);
TableName tableName = TableName.valueOf("testtable");
Table table = connection.getTable(tableName);
...
Result result = table.get(get);
...
table.close();
connection.close();
```

There are a few classes introduced here in one swoop:

Configuration

This is a Hadoop class, shared by HBase, to load and provide the configuration to the client application. It loads the details from the configuration files explained in “[hbase-site.xml](#) and [hbase-default.xml](#)” (page 87).

`ConnectionFactory`

Provides a factory method to retrieve a `Connection` instance, configured as per the given configuration.

`Connection`

The actual connection. Create this instance only once per application and share it during its runtime. Needs to be closed when not needed anymore to free resources.

`TableName`

Represents a table name with its namespace. The latter can be unset and then points to the default namespace. The table name, before namespaces were introduced into HBase, used to be just a `String`.

`Table`

The lightweight, not thread-safe representation of a data table within the client API. Create one per thread, and close it if not needed anymore to free resources.

In practice you should take care of allocating the HBase client resources in a reliable manner. You can see this from the code examples in the book repository. Especially `GetTryWithResourcesExample.java` is a good one showing how to make use of a newer Java 7 (and later) construct called *try-with-resources* (refer to the online [tutorial](#) for more info).

The remaining classes from the example will be explained as we go through the remainder of the chapter, as part of the client API usage.

Accessing Configuration Files from Client Code

“Client Configuration” (page 91) introduced the configuration files used by HBase client applications. They need access to the `hbase-site.xml` file to learn where the cluster resides—or you need to specify this location in your code.

Either way, you need to use an `HBaseConfiguration` class within your code to handle the configuration properties. This is done using one of the following static methods, provided by that class:

```
static Configuration create()  
static Configuration create(Configuration that)
```

As you will see soon, the [Example 3-2](#) is using `create()` to retrieve a `Configuration` instance. The second method allows you to hand in an existing configuration to merge with the HBase-specific one.

When you call any of the static `create()` methods, the code behind it will attempt to load two configuration files, `hbase-default.xml` and `hbase-site.xml`, using the current Java class path.

If you specify an existing configuration, using `create(Configuration that)`, it will take the highest precedence over the configuration files loaded from the classpath.

The `HBaseConfiguration` class actually extends the Hadoop Configuration class, but is still compatible with it: you could hand in a Hadoop configuration instance and it would be merged just fine.

After you have retrieved an `HBaseConfiguration` instance, you will have a merged configuration composed of the default values and anything that was overridden in the `hbase-site.xml` configuration file—and optionally the existing configuration you have handed in. You are then free to modify this configuration in any way you like, before you use it with your `Connection` instances. For example, you could override the ZooKeeper *quorum* address, to point to a different cluster:

```
Configuration config = HBaseConfiguration.create();
config.set("hbase.zookeeper.quorum",
"zk1.foo.com,zk2.foo.com");
```

In other words, you could simply omit any external, client-side configuration file by setting the `quorum` property in code. That way, you create a client that needs no extra configuration.

Resource Sharing

Every instance of `Table` requires a connection to the remote servers. This is handled by the `Connection` implementation instance, acquired using the `ConnectionFactory` as demonstrated in “[API Building Blocks](#)” (page 117). But why not create a connection for every table that you need in your application? Why is a good idea to create the connection only *once* and then share it within your application? There are good reasons for this to happen, because every connection does a lot of internal resource handling, such as:

Share ZooKeeper Connections

As each client eventually needs a connection to the ZooKeeper ensemble to perform the initial lookup of where user table regions are located, it makes sense to share this connection once it is established, with all subsequent client instances.

Cache Common Resources

Every lookup performed through ZooKeeper, or the catalog tables, of where user table regions are located requires network round-trips. The location is then cached on the client side to reduce the amount of network traffic, and to speed up the lookup process. Since this list is the same for every local client connecting to a remote cluster, it is equally useful to share it among multiple clients running in the same process. This is accomplished by the shared `Connection` instance.

In addition, when a lookup fails—for instance, when a region was split—the connection has the built-in retry mechanism to refresh the stale cache information. This is then immediately available to all other application threads sharing the same connection reference, thus further reducing the number of network round-trips initiated by a client.

There are no known performance implications for sharing a connection, even for heavily multithreaded applications.

The drawback of sharing a connection is the cleanup: when you do not explicitly close a connection, it is kept open until the client process exits. This can result in many connections that remain open to ZooKeeper, especially for heavily distributed applications, such as MapReduce jobs talking to HBase. In a worst-case scenario, you can run out of available connections, and receive an `IOException` instead.

You can avoid this problem by explicitly closing the shared connection, when you are done using it. This is accomplished with the `close()` method provided by `Connection`. The call decreases an internal reference count and eventually closes all shared resources, such as the connection to the ZooKeeper ensemble, and removes the connection reference from the internal list.

Previous versions of HBase (before 1.0) used to handle connections differently, and in fact tried to manage them for you. An attempt to make usage of shared resources easier was the `HTablePool`, that wrapped a shared connection to hand out shared table instances. All of that was too cumbersome and error-prone (there are quite a few JIRAs over the years documenting the attempts to fix connection management), and in the end the decision was made to put the onus on the client to manage them. That way the contract is clearer and if misuse occurs, it is fixable in the application code.

Especially the `HTablePool` was a stop-gap solution to reuse the older `HTable` instances. This was superseded by the `Connection.getTable()` call, returning a light-weight table implementation.⁶ Light-weight here means that acquiring them is fast. In the past this was not the case, so caching instances was the primary purpose of `HTablePool`. Suffice it to say, the API is much cleaner in HBase 1.0 and later, so that following the easy steps described in this section should lead to production grade applications with no late surprises.

One last note is the advanced option to hand in your own `ExecutorService` instance when creating the initial, shared connection:

```
static Connection createConnection(Configuration conf, ExecutorService pool)
throws IOException
```

The thread pool is needed to parallelize work across region servers for example. One of the methods using this implicitly is the `Table.batch()` call (see “[Batch Operations](#)” (page 187)), where operations are grouped by server and executed in parallel. You are allowed to hand in your own pool, but be diligent setting the pool to appropriate levels. If you do not use your own pool, but rely on the one created for you, there are still configuration properties you can set to control its parameters:

Table 3-9. Connection thread pool configuration parameters

Key	Default	Description
<code>hbase.hconnection.threads.max</code>	256	Sets the maximum number of threads allowed.
<code>hbase.hconnection.threads.core</code>	256	Minimum number of threads to keep in the pool.
<code>hbase.hconnection.threads.keepalivetime</code>	60s	Sets the amount in seconds to keep excess idle threads alive.

If you use your own, or the supplied one is up to you. There are many knobs (often only accessible by reading the code—hey, it is open-source after all!) you could potentially turn, so as always, test carefully and evaluate thoroughly.

6. See [HBASE-6580](#), which introduced the `getTable()` in 0.98 and 0.96 (also backported to 0.94.11).

CRUD Operations

The initial set of basic operations are often referred to as *CRUD*, which stands for *create*, *read*, *update*, and *delete*. HBase has a set of those and we will look into each of them subsequently. They are provided by the Table interface, and the remainder of this chapter will refer directly to the methods without specifically mentioning the containing interface again.

Most of the following operations are often seemingly self-explanatory, but the subtle details warrant a close look. However, this means you will start to see a pattern of repeating functionality so that we do not have to explain them again and again.

Put Method

Most methods come as a whole set of variants, and we will look at each in detail. The group of *put* operations can be split into separate types: those that work on single rows, those that work on lists of rows, and one that provides a server-side, atomic check-and-put. We will look at each group separately, and along the way, you will also be introduced to accompanying client API features.

Region-local transactions are explained in (to come). They still revolve around the Put set of methods and classes, so the same applies.

Single Puts

The very first method you may want to know about is one that lets you store data in HBase. Here is the call that lets you do that:

```
void put(Put put) throws IOException
```

It expects exactly one Put object that, in turn, is created with one of these constructors:

```
Put(byte[] row)
Put(byte[] row, long ts)
Put(byte[] rowArray, int rowOffset, int rowLength)
Put(ByteBuffer row, long ts)
Put(ByteBuffer row)
Put(byte[] rowArray, int rowOffset, int rowLength, long ts)
Put(Put putToCopy)
```

You need to supply a *row* to create a Put instance. A row in HBase is identified by a unique *row key* and—as is the case with most values in

HBase—this is a Java `byte[]` array. You are free to choose any row key you like, but please also note that [Link to Come] provides a whole section on row key design (see (to come)). For now, we assume this can be anything, and often it represents a fact from the physical world—for example, a *username* or an *order ID*. These can be simple numbers but also *UUIDs*⁷ and so on.

HBase is kind enough to provide us with a helper class that has many static methods to convert Java types into `byte[]` arrays. Here a short list of what it offers:

```
static byte[] toBytes(ByteBuffer bb)
static byte[] toBytes(String s)
static byte[] toBytes(boolean b)
static byte[] toBytes(long val)
static byte[] toBytes(float f)
static byte[] toBytes(int val)
...
...
```

For example, here is how to convert a *username* from string to `byte[]`:

```
byte[] rowkey = Bytes.toBytes("johndoe");
```

Besides this direct approach, there are also constructor variants that take an existing byte array and, respecting a given offset and length parameter, copy the needed row key bits from the given array instead. For example:

```
byte[] data = new byte[100];
...
String username = "johndoe";
byte[] username_bytes = username.getBytes(Charset.forName("UTF8"));
...
System.arraycopy(username_bytes,      0,      data,      45,      user-
name_bytes.length);
...
Put put = new Put(data, 45, username_bytes.length);
```

Similarly, you can also hand in an existing `ByteBuffer`, or even an existing `Put` instance. They all take the details from the given object. The difference is that the latter case, in other words handing in an existing `Put`, will copy everything else the class holds. What that might be can be seen if you read on, but keep in mind that this is often used to *clone* the entire object.

7. Universally Unique Identifier; see [http://en.wikipedia.org/wiki/Universal unique identifier](http://en.wikipedia.org/wiki/Universal_unique_identifier) for details.

Once you have created the Put instance you can add data to it. This is done using these methods:

```
PutaddColumn(byte[] family, byte[] qualifier, byte[] value)
PutaddColumn(byte[] family, byte[] qualifier, long ts, byte[] value)
PutaddColumn(byte[] family, ByteBuffer qualifier, long ts, ByteBuffer value)

Put addImmutable(byte[] family, byte[] qualifier, byte[] value)
Put addImmutable(byte[] family, byte[] qualifier, long ts, byte[] value)
Put addImmutable(byte[] family, ByteBuffer qualifier, long ts,
    ByteBuffer value)

Put addImmutable(byte[] family, byte[] qualifier, byte[] value,
    Tag[] tag)
Put addImmutable(byte[] family, byte[] qualifier, long ts, byte[] value,
    Tag[] tag)
Put addImmutable(byte[] family, ByteBuffer qualifier, long ts,
    ByteBuffer value, Tag[] tag)

Put add(Cell kv) throws IOException
```

Each call to `addColumn()`⁸ specifies exactly one column, or, in combination with an optional timestamp, one single cell. Note that if you do *not* specify the timestamp with the `addColumn()` call, the Put instance will use the optional timestamp parameter from the constructor (also called `ts`), or, if also not set, it is the region server that assigns the timestamp based on its local clock. If the timestamp is not set on the client side, the `getTimeStamp()` of the Put instance will return `Long.MAX_VALUE` (also defined in `HConstants` as `LATEST_TIMESTAMP`).

Note that calling any of the `addXYZ()` methods will internally create a `Cell` instance. This is evident by looking at the other functions listed in [Table 3-10](#), for example `getFamilyCellMap()` returning a list of all `Cell` instances for a given family. Similarly, the `size()` method simply returns the number of cells contain in the Put instance.

There are copies of each `addColumn()`, named `addImmutable()`, which do the same as their counterpart, apart from not copying the given byte arrays. It assumes you do *not* modify the specified parameter arrays. They are more efficient memory and performance wise, but rely on proper use by the client (you!). There are also variants that take an

8. In HBase versions before 1.0 these methods were named `add()`. They have been deprecated in favor of a coherent naming convention with Get and other API classes. [“Migrate API to HBase 1.0.x”](#) ([page 635](#)) has more info.

additional Tag parameter. You will learn about tags in (to come) and (to come), but for now—we are in the basic part of the book after all—we will ignore those.

The variant that takes an existing Cell⁹ instance is for advanced users that have learned how to retrieve, or create, this low-level class. To check for the existence of specific cells, you can use the following set of methods:

```
boolean has(byte[] family, byte[] qualifier)
boolean has(byte[] family, byte[] qualifier, long ts)
boolean has(byte[] family, byte[] qualifier, byte[] value)
boolean has(byte[] family, byte[] qualifier, long ts, byte[] value)
```

They increasingly ask for more specific details and return `true` if a match can be found. The first method simply checks for the presence of a column. The others add the option to check for a timestamp, a given value, or both.

There are more methods provided by the Put class, summarized in [Table 3-10](#). Most of them are inherited from the base types discussed in “[Data Types and Hierarchy](#)” ([page 103](#)), so no further explanation is needed here. All of the security related ones are discussed in (to come).

Note that the getters listed in [Table 3-10](#) for the Put class only retrieve what you have set beforehand. They are rarely used, and make sense only when you, for example, prepare a Put instance in a private method in your code, and inspect the values in another place or for unit testing.

Table 3-10. Quick overview of additional methods provided by the Put class

Method	Description
<code>cellScanner()</code>	Provides a scanner over all cells available in this instance.
<code>getACL()/setACL()</code>	The ACLs for this operation (might be <code>null</code>).
<code>getAttribute()/setAttribute()</code>	Set and get arbitrary attributes associated with this instance of Put.
<code>getAttributesMap()</code>	Returns the entire map of attributes, if any are set.

9. This was changed in 1.0.0 from `KeyValue`. `Cell` is now the proper public API class, while `KeyValue` is only used internally.

Method	Description
getCellVisibility()/setCellVisibility()	The cell level visibility for all included cells.
getClusterIds()/setClusterIds()	The cluster IDs as needed for replication purposes.
getDurability()/setDurability()	The durability settings for the mutation.
getFamilyCellMap()/setFamilyCellMap()	The list of all cells of this instance.
getFingerprint()	Compiles details about the instance into a map for debugging, or logging.
getId()/setId()	An ID for the operation, useful for identifying the origin of a request later.
getRow()	Returns the row key as specified when creating the Put instance.
getTimeStamp()	Retrieves the associated timestamp of the Put instance.
getTTL()/setTTL()	Sets the cell level TTL value, which is being applied to all included Cell instances before being persisted.
heapSize()	Computes the heap space required for the current Put instance. This includes all contained data and space needed for internal structures.
isEmpty()	Checks if the family map contains any Cell instances.
numFamilies()	Convenience method to retrieve the size of the family map, containing all Cell instances.
size()	Returns the number of Cell instances that will be applied with this Put.
toJSON()/toJSON(int)	Converts the first 5 or N columns into a JSON format.
toMap()/toMap(int)	Converts the first 5 or N columns into a map. This is more detailed than what getFingerprint() returns.
toString()/toString(int)	Converts the first 5 or N columns into a JSON, or map (if JSON fails due to encoding problems).

[Example 3-2](#) shows how all this is put together (no pun intended) into a basic application.

The examples in this chapter use a very limited, but exact, set of data. When you look at the full source code you will notice that it uses an internal class named `HBaseHelper`. It is used to create a test table with a very specific number of rows and columns. This makes it much easier to compare the before and after.

Feel free to run the code as-is against a standalone HBase instance on your local machine for testing—or against a fully deployed cluster. (to come) explains how to compile the examples. Also, be adventurous and modify them to get a good feel for the functionality they demonstrate.

The example code usually first removes all data from a previous execution by dropping the table it has created. If you run the examples against a production cluster, please make sure that you have no name collisions. Usually the table is called `testtable` to indicate its purpose.

Example 3-2. Example application inserting data into HBase

```
import org.apache.hadoop.conf.Configuration;
import org.apache.hadoop.hbase.HBaseConfiguration;
import org.apache.hadoop.hbase.TableName;
import org.apache.hadoop.hbase.client.Connection;
import org.apache.hadoop.hbase.client.ConnectionFactory;
import org.apache.hadoop.hbase.client.Put;
import org.apache.hadoop.hbase.client.Table;
import org.apache.hadoop.hbase.util.Bytes;

import java.io.IOException;

public class PutExample {

    public static void main(String[] args) throws IOException {
        Configuration conf = HBaseConfiguration.create(); ❶

        Connection connection = ConnectionFactory.createConnection(conf);
        Table table = connection.getTable(TableName.valueOf("testtable")); ❷

        Put put = new Put(Bytes.toBytes("row1")); ❸

        put.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
                     Bytes.toBytes("val1")); ❹
        put.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual2"),
                     Bytes.toBytes("val2")); ❺

        table.put(put); ❻
    }
}
```

```

        table.close(); ⑦
        connection.close();
    }
}

① Create the required configuration.
② Instantiate a new client.
③ Create put with specific row.
④ Add a column, whose name is “colfam1:qual1”, to the put.
⑤ Add another column, whose name is “colfam1:qual2”, to the put.
⑥ Store row with column into the HBase table.
⑦ Close table and connection instances to free resources.

```

This is a (nearly) full representation of the code used and every line is explained. The following examples will omit more and more of the boilerplate code so that you can focus on the important parts.

You can, once again, make use of the command-line shell (see “[Quick-Start Guide](#)” ([page 39](#))) to verify that our insert has succeeded:

```

hbase(main):001:0> list
TABLE
testtable
1 row(s) in 0.0400 seconds

hbase(main):002:0> scan 'testtable'
ROW           COLUMN+CELL
  row1          column=colfam1:qual1, timestamp=1426248302203,
  value=val1
  row1          column=colfam1:qual2, timestamp=1426248302203,
  value=val2
1 row(s) in 0.2740 seconds

```

As mentioned earlier, either the optional parameter while creating a Put instance called `ts`, short for *timestamp*, or the `ts` parameter for the `addColumn()` etc. calls, allow you to store a value at a particular *version* in the HBase table.

Client-side Write Buffer

Each put operation is effectively an [RPC](#) (“remote procedure call”) that is transferring data from the client to the server and back. This is OK for a low number of operations, but not for applications that need to store thousands of values per second into a table.

The importance of reducing the number of separate RPC calls is tied to the *round-trip time*, which is the time it takes for a client to send a request and the server to send a response over the network. This does not include the time required for the data transfer. It simply is the overhead of sending packages over the wire. On average, these take about 1ms on a LAN, which means you can handle 1,000 round-trips per second only.

The other important factor is the message size: if you send large requests over the network, you already need a much lower number of round-trips, as most of the time is spent transferring data. But when doing, for example, counter increments, which are small in size, you will see better performance when batching updates into fewer requests.

The HBase API comes with a built-in client-side *write buffer* that collects put and delete operations so that they are sent in one RPC call to the server(s). The entry point to this functionality is the `BufferedMutator` class.¹⁰ It is obtained from the `Connection` class using one of these methods:

```
BufferedMutator getBufferedMutator(TableName tableName) throws  
IOException  
BufferedMutator getBufferedMutator(BufferedMutatorParams params)  
throws IOException
```

The returned `BufferedMutator` instance is *thread-safe* (note that `Table` instances are *not*) and can be used to ship batched put and delete operations, collectively referred to as mutations, or operations, again (as per the class hierarchy superclass, see “[Data Types and Hierarchy](#)” (page 103)). There are a few things to remember when using this class:

1. You have to call `close()` at the very end of its lifecycle. This flushes out any pending operations synchronously and frees resources.
2. It might be necessary to call `flush()` when you have submitted specific mutations that need to go to the server immediately.
3. If you do *not* call `flush()` then you rely on the internal, asynchronous updating when specific thresholds have been hit—or `close()` has been called.

¹⁰. This class replaces the functionality that used to be available via `HTableInterface#setAutoFlush(false)` in HBase before 1.0.0.

4. Any local mutation that is still cached could be lost if the application fails at that very moment.
-

The local buffer is not backed by a persistent storage, but rather relies solely on the applications memory to hold the details. If you cannot deal with operations not making it to the servers, then you would need to call `flush()` before signalling success to the user of your application—or forfeit the use of the local buffer altogether and use a `Table` instance.

We will look into each of these requirements in more detail in this section, but first we need to further explain how to customize a `BufferedMutator` instance.

While one of the constructors is requiring the obvious table name to send the operation batches to, the latter is a bit more elaborate. It needs an instance of the `BufferedMutatorParams` class, holding not only the necessary table name, but also other, more advanced parameters:

```
BufferedMutatorParams(TableName tableName)
TableName getTableName()
long getWriteBufferSize()
BufferedMutatorParams writeBufferSize(long writeBufferSize)
int getMaxKeyValueSize()
BufferedMutatorParams maxKeyValueSize(int maxValueSize)
ExecutorService getPool()
BufferedMutatorParams pool(ExecutorService pool)
BufferedMutator.ExceptionListener getListener()
BufferedMutatorParams listener(BufferedMutator.ExceptionListener
listener)
```

The first in the list is the constructor of the parameter class, asking for the minimum amount of detail, which is the table name. Then you can further get or set the following parameters:

WriteBufferSize

If you recall the `heapSize()` method of `Put`, inherited from the common `Mutation` class, it is called internally to add the size of the mutations you add to a counter. If this counter exceeds the value assigned to `WriteBufferSize`, then all cached mutations are sent to the servers asynchronously.

If the client does not set this value, it defaults to what is configured on the table level. This, in turn, defaults to what is set in the

configuration under the property `hbase.client.write.buffer`. It defaults to 2097152 bytes in `hbase-default.xml` (and in the code if the latter XML is missing altogether), or, in other words, to 2MB.

A bigger buffer takes more memory—on both the client and server-side since the server deserializes the passed write buffer to process it. On the other hand, a larger buffer size reduces the number of RPCs made. For an estimate of server-side memory-used, evaluate the following formula: `hbase.client.write.buffer * hbase.region.server.handler.count * number of region servers`.

Referring to the *round-trip time* again, if you only store larger cells (say 1KB and larger), the local buffer is less useful, since the transfer is then dominated by the transfer time. In this case, you are better advised to not increase the client buffer size.

The default of 2MB represents a good balance between RPC package size and amount of data kept in the client process.

MaxKeyValueSize

Before an operation is allowed by the client API to be sent to the server, the size of the included cells is checked against the `MaxKeyValueSize` setting. If the cell exceeds the set limit, it is denied and the client is facing an `IllegalArgumentException("KeyValue size too large")` exception. This is to ensure you use HBase within reasonable boundaries. More on this in [Link to Come].

Like above, when unset on the instance, this value is taken from the table level configuration, and that equals to the value of the `hbase.client.keyvalue.maxsize` configuration property. It is set to 10485760 bytes (or 10MB) in the `hbase-default.xml` file, but not in code.

Pool

Since all asynchronous operations are performed by the client library in the background, it is required to hand in a standard Java `ExecutorService` instance. If you do not set the pool, then a default pool is created instead, controlled by `hbasehtable.threads.max`, set to `Integer.MAX_VALUE` (meaning unlimited), and `hbasehtable.threads.keepalivetime`, set to 60 seconds.

Listener

Lastly, you can use a listener hook to be notified when an error occurs during the application of a mutation on the servers. For that you need to implement a `BufferedMutator.ExceptionListener` which provides the `onException()` callback. The default just throws an exception when it is received. If you want to enforce a more elaborate error handling, then the listener is what you need to provide.

[Example 3-3](#) shows the usage of the listener in action.

Example 3-3. Shows the use of the client side write buffer

```
private static final int POOL_SIZE = 10;
private static final int TASK_COUNT = 100;
private static final TableName TABLE = TableName.valueOf("testtable");
private static final byte[] FAMILY = Bytes.toBytes("colfam1");

public static void main(String[] args) throws Exception {
    Configuration configuration = HBaseConfiguration.create();
    BufferedMutator.ExceptionListener listener =
        new BufferedMutator.ExceptionListener() {❶
            @Override
            public void onException(RetriesExhaustedWithDetailsException e,
                BufferedMutator mutator) {
                for (int i = 0; i < e.getNumExceptions(); i++) {❷
                    LOG.info("Failed to sent put: " + e.getRow(i));❸
                }
            }
        };
    BufferedMutatorParams params =
        new BufferedMutatorParams(TABLE).listener(listener);❹

    try {
        Connection conn =ConnectionFactory.createConnection(configuration);❺
        BufferedMutator mutator = conn.getBufferedMutator(params)
    } {
        ExecutorService workerPool = Executors.newFixedThreadPool(POOL_SIZE);❻
        List<Future<Void>> futures = new ArrayList<>(TASK_COUNT);

        for (int i = 0; i < TASK_COUNT; i++) {❽
            futures.add(workerPool.submit(new Callable<Void>() {
                @Override
                public Void call() throws Exception {
                    Put p = new Put(Bytes.toBytes("row1"));
                    p.addColumn(FAMILY, Bytes.toBytes("qual1"), Bytes.to-
Bytes("val1"));
                    mutator.mutate(p);❾
                    // [...]
                }
            }));
        }
    }
}
```

```

        // Do work... Maybe call mutator.flush() after many edits
to ensure      // any of this worker's edits are sent before exiting the
Callable       return null;
    }
    })));
}
}

for (Future<Void> f : futures) {
    f.get(5, TimeUnit.MINUTES); ⑨
}
workerPool.shutdown();
} catch (IOException e) { ⑩
    LOG.info("Exception while creating or freeing resources", e);
}
}
}

```

- ① Create a custom listener instance.
- ② Handle callback in case of an exception.
- ③ Generically retrieve the mutation that failed, using the common superclass.
- ④ Create a parameter instance, set the table name and custom listener reference.
- ⑤ Allocate the shared resources using the Java 7 try-with-resource pattern.
- ⑥ Create a worker pool to update the shared mutator in parallel.
- ⑦ Start all the workers up.
- ⑧ Each worker uses the shared mutator instance, sharing the same backing buffer, callback listener, and RPC execuor pool.
- ⑨ Wait for workers and shut down the pool.
- ⑩ The try-with-resource construct ensures that first the mutator, and then the connection are closed. This could trigger exceptions and call the custom listener.

Setting these values for every `BufferedMutator` instance you create may seem cumbersome and can be avoided by adding a higher value to your local `hbase-site.xml` configuration file—for example, adding:

```
<property>
  <name>hbase.client.write.buffer</name>
  <value>20971520</value>
</property>
```

This will increase the limit to 20 MB.

As mentioned above, the primary use case for the client write buffer is an application with many small mutations, which are put and delete requests. Especially the latter are very small, as they do not carry *any* value: deletes are just the key information of the cell with the type set to one of the possible delete markers (see “[The Cell](#)” ([page 112](#)) again if needed).

Another good use case are MapReduce jobs against HBase (see [Chapter 7](#)), since they are all about emitting mutations as fast as possible. Each of these mutations is most likely independent from any other mutation, and therefore there is no good flush point. Here the default `BufferedMutator` logic works quite well as it accumulates enough operations based on size and, eventually, ships them asynchronously to the servers, while the job task continues to do its work.

The implicit flush or explicit call to the `flush()` method ships all the modifications to the remote server(s). The buffered Put and Delete instances can span many different rows. The client is smart enough to batch these updates accordingly and send them to the appropriate region server(s). Just as with the single `put()` or `delete()` call, you do not have to worry about where data resides, as this is handled transparently for you by the HBase client. [Figure 3-2](#) shows how the operations are sorted and grouped before they are shipped over the network, with one single RPC per region server.

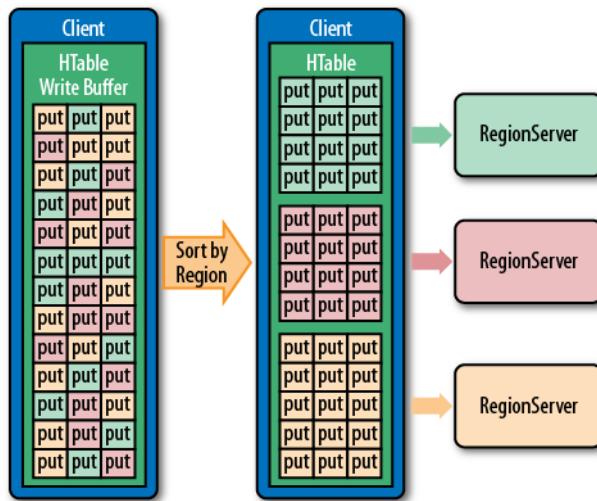


Figure 3-2. The client-side puts sorted and grouped by region server

One note in regards to the executor pool mentioned above. It says that it is controlled by `hbasehtable.threads.max` and is by default set to `Integer.MAX_VALUE`, meaning unbounded. This does not mean that each client sending buffered writes to the servers will create an endless amount of worker threads. It really is creating only *one* thread per region server. This scales with the number of servers you have, but once you grow into the thousands, you could consider setting this configuration property to some maximum, bounding it explicitly where you need it.

[Example 3-4](#) shows another example of how the write buffer is used from the client API.

Example 3-4. Example using the client-side write buffer

```
TableName name = TableName.valueOf("testtable");
Connection connection =ConnectionFactory.createConnection(conf);
Table table = connection.getTable(name);
BufferedMutator mutator = connection.getBufferedMutator(name); ❶

Put put1 = new Put(Bytes.toBytes("row1"));
put1.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    Bytes.toBytes("val1"));
mutator.mutate(put1); ❷

Put put2 = new Put(Bytes.toBytes("row2"));
put2.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
```

```

        Bytes.toBytes("val2"));
mutator.mutate(put2);

Put put3 = new Put(Bytes.toBytes("row3"));
put3.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    Bytes.toBytes("val3"));
mutator.mutate(put3);

Get get = new Get(Bytes.toBytes("row1"));
Result res1 = table.get(get);
System.out.println("Result: " + res1); ③

mutator.flush(); ④

Result res2 = table.get(get);
System.out.println("Result: " + res2); ⑤

mutator.close();
table.close();
connection.close();

```

- ① Get a mutator instance for the table.
- ② Store some rows with columns into HBase.
- ③ Try to load previously stored row, this will print “Result: keyvalues=NONE”.
- ④ Force a flush, this causes an RPC to occur.
- ⑤ Now the row is persisted and can be loaded.

This example also shows a specific behavior of the buffer that you may not anticipate. Let’s see what it prints out when executed:

```

Result: keyvalues=NONE
Result:      keyvalues={row1/colfam1:qual1/1426438877968/Put/vlen=4/
seqid=0}

```

While you have not seen the `get()` operation yet, you should still be able to correctly infer what it does, that is, reading data back from the servers. But for the first `get()` in the example, asking for a column value that has had a previous matching `put` call, the API returns a `NONE` value—what does that mean? It is caused by two facts, with the first explained already above:

1. The client write buffer is an in-memory structure that is literally holding back any unflushed records, in other words, nothing was sent to the servers yet.
2. The `get()` call is synchronous and goes directly to the servers, missing the client-side cached mutations.

You have to be aware of this *pecularity* when designing applications making use of the client buffering.

List of Puts

The client API has the ability to insert single Put instances as shown earlier, but it also has the advanced feature of batching operations together. This comes in the form of the following call:

```
void put(List<Put> puts) throws IOException
```

You will have to create a list of Put instances and hand it to this call. [Example 3-5](#) updates the previous example by creating a list to hold the mutations and eventually calling the list-based put() method.

Example 3-5. Example inserting data into HBase using a list

```
List<Put> puts = new ArrayList<Put>(); ①

Put put1 = new Put(Bytes.toBytes("row1"));
put1.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    Bytes.toBytes("val1"));
puts.add(put1); ②

Put put2 = new Put(Bytes.toBytes("row2"));
put2.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    Bytes.toBytes("val2"));
puts.add(put2); ③

Put put3 = new Put(Bytes.toBytes("row2"));
put3.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual2"),
    Bytes.toBytes("val3"));
puts.add(put3); ④

table.put(puts); ⑤
```

- ① Create a list that holds the Put instances.
- ② Add put to list.
- ③ Add another put to list.
- ④ Add third put to list.
- ⑤ Store multiple rows with columns into HBase.

A quick check with the HBase Shell reveals that the rows were stored as expected. Note that the example actually modified three columns, but in two rows only. It added two columns into the row with the key row2, using two separate qualifiers, qual1 and qual2, creating two uniquely named columns in the same row.

```
hbase(main):001:0> scan 'testtable'
ROW                         COLUMN+CELL
```

```

row1          column=colfam1:qual1, timestamp=1426445826107,
value=val1
row2          column=colfam1:qual1, timestamp=1426445826107,
value=val2
row2          column=colfam1:qual2, timestamp=1426445826107,
value=val3
2 row(s) in 0.3300 seconds

```

Since you are issuing a list of row mutations to possibly many different rows, there is a chance that not all of them will succeed. This could be due to a few reasons—for example, when there is an issue with one of the region servers and the client-side retry mechanism needs to give up because the number of retries has exceeded the configured maximum. If there is a problem with any of the put calls on the remote servers, the error is reported back to you subsequently in the form of an `IOException`.

[Example 3-6](#) uses a *bogus* column family name to insert a column. Since the client is not aware of the structure of the remote table—it could have been altered since it was created—this check is done on the server-side.

Example 3-6. Example inserting a faulty column family into HBase

```

Put put1 = new Put(Bytes.toBytes("row1"));
put1.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    Bytes.toBytes("val1"));
puts.add(put1);
Put put2 = new Put(Bytes.toBytes("row2"));
put2.addColumn(Bytes.toBytes("BOGUS"), Bytes.toBytes("qual1"),
    Bytes.toBytes("val2")); ①
puts.add(put2);
Put put3 = new Put(Bytes.toBytes("row2"));
put3.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual2"),
    Bytes.toBytes("val3"));
puts.add(put3);

table.put(puts); ②

```

- ① Add put with non existent family to list.
- ② Store multiple rows with columns into HBase.

The call to `put()` fails with the following (or similar) error message:

```

WARNING: #3, table=testtable, attempt=1/35 failed=1ops, last exception: null \
on server-1.internal.foobar.com,65191,1426248239595, tracking \
started Sun Mar 15 20:35:52 CET 2015; not retrying 1 - final
failure ①
Exception in thread "main" \
org.apache.hadoop.hbase.client.RetryExhaustedWithDetailsExcep-

```

```

tion: \ ②
Failed 1 action: \ ③
    org.apache.hadoop.hbase.regionserver.NoSuchColumnFamilyException:
        Column family BOGUS does not exist in region \
            testtable,,1426448152586.deecb9559bde733aa2a9fb1e6b42aa93. in
table \
    'testtable', {NAME => 'colfam1', DATA_BLOCK_ENCODING => 'NONE', \
    BLOOMFILTER => 'ROW', REPLICATION_SCOPE => '0', COMPRESSION =>
'NONE', \
    VERSIONS => '1', TTL => 'FOREVER', MIN_VERSIONS => '0', \
    KEEP_DELETED_CELLS => 'FALSE', BLOCKSIZE => '65536', \
    IN_MEMORY => 'false', BLOCKCACHE => 'true'}
: 1 time,

```

- ❶ The first three line state the request ID (#3), the table name (test table), the attempt count (1/35) with number of failed operations (1ops), and the last error (null), as well as the server name, and when the asynchronous processing did start.
- ❷ This is followed by the exception name, which usually is `RetriesExhaustedWithDetailsException`.
- ❸ Lastly, the details of the failed operations are listed, here only one failed (Failed 1 action) and it did so with a `NoSuchColumnFamilyException`. The last line (: 1 time) lists how often it failed.

You may wonder what happened to the other, non-faulty puts in the list. Using the shell again you should see that the two correct puts have been applied:

```

hbase(main):001:0> scan 'testtable'
ROW          COLUMN+CELL
  row1        column=colfam1:qual1, timestamp=1426448152808,
  value=val1
  row2        column=colfam1:qual2, timestamp=1426448152808,
  value=val3
2 row(s) in 0.3360 seconds

```

The servers iterate over all operations and try to apply them. The failed ones are returned and the client reports the remote error using the `RetriesExhaustedWithDetailsException`, giving you insight into how many operations have failed, with what error, and how many times it has retried to apply the erroneous modification. It is interesting to note that, for the bogus column family, the retry is automatically set to 1 (see the `NoSuchColumnFamilyException: 1 time`), as this is an error from which HBase cannot recover.

In addition, you can make use of the exception instance to gain access to more details about the failed operation, and even the faulty muta-

tion itself. [Example 3-7](#) extends the original erroneous example by introducing a special catch block to gain access to the error details.

Example 3-7. Special error handling with lists of puts

```
try {
    table.put(puts); ①
} catch (RetriesExhaustedWithDetailsException e) {
    int numErrors = e.getNumExceptions(); ②
    System.out.println("Number of exceptions: " + numErrors);
    for (int n = 0; n < numErrors; n++) {
        System.out.println("Cause[" + n + "]: " + e.getCause(n));
        System.out.println("Hostname[" + n + "]: " + e.getHostname-
Port(n));
        System.out.println("Row[" + n + "]: " + e.getRow(n)); ③
    }
    System.out.println("Cluster issues: " + e.mayHaveClusterIs-
sues());
    System.out.println("Description: " + e.getExhaustiveDescrip-
tion());
}
```

- ① Store multiple rows with columns into HBase.
- ② Handle failed operations.
- ③ Gain access to the failed operation.

The output of the example looks like this (some lines are omitted for the sake of brevity):

```
Mar 16, 2015 9:54:41 AM org.apache....client.AsyncProcess logNoRe-
submit
WARNING: #3, table=testtable, attempt=1/35 failed=1ops, last excep-
tion: \
null on srv1.foobar.com,65191,1426248239595, \
tracking started Mon Mar 16 09:54:41 CET 2015; not retrying 1 - fi-
nal failure

Number of exceptions: 1

Cause[0]:  org.apache.hadoop.hbase.regionserver.NoSuchColumnFami-
lyException: \
org.apache.hadoop.hbase.regionserver.NoSuchColumnFamilyException:
Column \
family BOGUS does not exist in region \
testtable,,1426496081011.8be8f8bc862075e8bea355aecc6a5b16.    in
table \
'testtable', {NAME => 'colfam1', DATA_BLOCK_ENCODING => 'NONE', \
BLOOMFILTER => 'ROW', REPLICATION_SCOPE => '0', COMPRESSION =>
'NONE', \
VERSIONS => '1', TTL => 'FOREVER', MIN VERSIONS => '0', \
KEEP_DELETED_CELLS => 'FALSE', BLOCKSIZE => '65536', IN_MEMORY =>
```

```

'false', \
BLOCKCACHE => 'true'}
    at org.apache.hadoop.hbase.regionserver.RSRpcServices.doBatch-
Op(....)
    ...
Hostname[0]: srv1.foobar.com,65191,1426248239595

Row[0]: {"totalColumns":1,"families":{"BOGUS": [{" \
"timestamp":9223372036854775807,"tag":[],"qualifier":"qual1", \
"vlen":4}]}}, "row": "row2"}

Cluster issues: false

Description: exception from srv1.foobar.com,65191,1426248239595
for row2
org.apache.hadoop.hbase.regionserver.NoSuchColumnFamilyException:
\
org.apache.hadoop.hbase.regionserver.NoSuchColumnFamilyException: \
Column family BOGUS does not exist in region \
testtable,,1426496081011.8be8f8bc862075e8bea355aec6a5b16.    in
table \
testtable', {NAME => 'colfam1', ... }
    at org.apache.hadoop.hbase.regionserver.RSRpcServices.doBatch-
Op(....)
    ...
    at java.lang.Thread.run(....)

```

As you can see, you can ask for the number of errors incurred, the causes, the servers reporting them, and the actual mutation(s). Here we only have one that we triggered with the bogus column family used. Interesting is that the exception also gives you access to the overall cluster status to determine if there are larger problems at play.

Table 3-11. Methods of the RetriesExhaustedWithDetailsException class

Method	Description
getCauses()	Returns a summary of all causes for all failed operations.
getExhaustiveDescription()	More detailed list of all the failures that were detected.
getNumExceptions()	Returns the number of failed operations.
getCause(int i)	Returns the exact cause for a given failed operation. ^a
getHostnamePort(int i)	Returns the exact host that reported the specific error. ^a

Method	Description
<code>getRow(int i)</code>	Returns the specific mutation instance that failed. ^a
<code>mayHaveClusterIssues()</code>	Allows to determine if there are wider problems with the cluster. ^b

^a Where `i` greater or equal to 0 and less than `getNumExceptions()`.

^b This is determined by all operations failing as *do not retry*, indicating that all servers involved are giving up.

We already mentioned the `MaxKeyValueSize` parameter for the `BufferedMutator` before, and how the API ensures that you can only submit operations that comply to that limit (if set). The same check is done when you submit a single put, or a list of puts. In fact, there is actually one more test done, which is that the mutation submitted is not entirely empty. These checks are done on the *client side*, though, and in the event of a violation the client is throwing an exception that leaves the operations preceding the faulty one in the client buffer.

The list-based `put()` call uses the client-side write buffer—in form of an internal instance of `BatchMutator`—to insert all puts into the local buffer and then to call `flush()` implicitly. While inserting each instance of `Put`, the client API performs the mentioned check. If it fails, for example, at the third put out of five, the first two are added to the buffer while the last two are not. It also then does not trigger the flush command at all. You need to keep inserting `put` instances or call `close()` to trigger a flush of all cached instances.

Because of this behavior of plain `Table` instances and their `put(List)` method, it is recommended to use the `BufferedMutator` directly as it has the most flexibility. If you read the HBase source code, for example the `TableOutputFormat`, you will see the same approach, that is using the `BufferedMutator` for all cases a client-side write buffer is wanted.

You need to watch out for another peculiarity using the list-based `put` call: you cannot control the *order* in which the puts are applied on the server-side, which implies that the order in which the servers are called is also not under your control. Use this call with caution if you have to guarantee a specific order—in the worst case, you need to create smaller batches and explicitly flush the client-side write cache to

enforce that they are sent to the remote servers. This also is only possible when using the `BufferedMutator` class directly.

An example for updates that need to be controlled tightly are *foreign key* relations, where changes to an entity are reflected in multiple rows, or even tables. If you need to ensure a specific order these mutations are applied, you may have to batch them separately, to ensure one batch is applied before another.

Finally, [Example 3-8](#) shows the same example as in “[Client-side Write Buffer](#)” (page 128) using the client-side write buffer, but using a list of mutations, instead of separate calls to `mutate()`. This is akin to what you just saw in this section for the list of puts. If you recall the advanced usage of a Listener, you have all the tools to do the same list based submission of mutations, but using the more flexible approach.

Example 3-8. Example using the client-side write buffer

```
List<Mutation> mutations = new ArrayList<Mutation>(); ❶

Put put1 = new Put(Bytes.toBytes("row1"));
put1.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    Bytes.toBytes("val1"));
mutations.add(put1); ❷

Put put2 = new Put(Bytes.toBytes("row2"));
put2.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    Bytes.toBytes("val2"));
mutations.add(put2);

Put put3 = new Put(Bytes.toBytes("row3"));
put3.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    Bytes.toBytes("val3"));
mutations.add(put3);

mutator.mutate(mutations); ❸

Get get = new Get(Bytes.toBytes("row1"));
Result res1 = table.get(get);
System.out.println("Result: " + res1); ❹

mutator.flush(); ❺

Result res2 = table.get(get);
System.out.println("Result: " + res2); ❻
```

- ❶ Create a list to hold all mutations.
- ❷ Add Put instance to list of mutations.
- ❸ Store some rows with columns into HBase.

- ④ Try to load previously stored row, this will print “Result: keyvalues=NONE”.
- ⑤ Force a flush, this causes an RPC to occur.
- ⑥ Now the row is persisted and can be loaded.

Atomic Check-and-Put

There is a special variation of the put calls that warrants its own section: *check and put*. The method signatures are:

```
boolean checkAndPut(byte[] row, byte[] family, byte[] qualifier,
byte[] value,
    Put put) throws IOException
boolean checkAndPut(byte[] row, byte[] family, byte[] qualifier,
    CompareFilter.CompareOp compareOp, byte[] value, Put put)
throws IOException
```

These calls allow you to issue atomic, server-side mutations that are guarded by an accompanying check. If the check passes successfully, the put operation is executed; otherwise, it aborts the operation completely. It can be used to update data based on current, possibly related, values.

Such guarded operations are often used in systems that handle, for example, account balances, state transitions, or data processing. The basic principle is that you read data at one point in time and process it. Once you are ready to write back the result, you want to make sure that no other client has done the same already. You use the atomic check to compare that the value is not modified and therefore apply your value.

The first call implies that the given value has to be *equal* to the stored one. The second call lets you specify the actual comparison operator (explained in [“Comparison Operators” \(page 221\)](#)), which enables more elaborate testing, for example, if the given value is *equal or less* than the stored one. This is useful to track some kind of modification ID, and you want to ensure you have reached a specific point in the cells lifecycle, for example, when it is updated by many concurrent clients.

A special type of check can be performed using the `checkAndPut()` call: only update if another value is not already present. This is achieved by setting the `value` parameter to `null`. In that case, the operation would succeed when the specified column is nonexistent.

The call returns a boolean result value, indicating whether the Put has been applied or not, returning true or false, respectively. [Example 3-9](#) shows the interactions between the client and the server, returning the expected results.

Example 3-9. Example application using the atomic compare-and-set operations

```
Put put1 = new Put(Bytes.toBytes("row1"));
put1.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    Bytes.toBytes("val1")); ①

boolean res1 = table.checkAndPut(Bytes.toBytes("row1"),
    Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"), null, put1);
② System.out.println("Put 1a applied: " + res1); ③

boolean res2 = table.checkAndPut(Bytes.toBytes("row1"),
    Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"), null, put1);
④ System.out.println("Put 1b applied: " + res2); ⑤

Put put2 = new Put(Bytes.toBytes("row1"));
put2.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual2"),
    Bytes.toBytes("val2")); ⑥

boolean res3 = table.checkAndPut(Bytes.toBytes("row1"),
    Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"), ⑦
    Bytes.toBytes("val1"), put2);
System.out.println("Put 2 applied: " + res3); ⑧

Put put3 = new Put(Bytes.toBytes("row2"));
put3.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    Bytes.toBytes("val3")); ⑨

boolean res4 = table.checkAndPut(Bytes.toBytes("row1"),
    Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"), ⑩
    Bytes.toBytes("val1"), put3);
System.out.println("Put 3 applied: " + res4); ⑪

① Create a new Put instance.
② Check if column does not exist and perform optional put
   operation.
③ Print out the result, should be “Put 1a applied: true”.
④ Attempt to store same cell again.
⑤ Print out the result, should be “Put 1b applied: false” as the
   column now already exists.
```

- ❶ Create another Put instance, but using a different column qualifier.
- ❷ Store new data only if the previous data has been saved.
- ❸ Print out the result, should be “Put 2 applied: true” as the checked column exists.
- ❹ Create yet another Put instance, but using a different row.
- ❺ Store new data while checking a different row.
- ❻ We will not get here as an exception is thrown beforehand!

The output is:

```
Put 1a applied: true
Put 1b applied: false
Put 2 applied: true
Exception in thread "main" org.apache.hadoop.hbase.DoNotRetryIOException:
    org.apache.hadoop.hbase.DoNotRetryIOException:
        Action's getRow must match the passed row
...
...
```

The last call in the example did throw a `DoNotRetryIOException` error because `checkAndPut()` enforces that the checked row has to match the row of the Put instance. You are allowed to check one column and update another, but you cannot stretch that check across row boundaries.

The compare-and-set operations provided by HBase rely on checking and modifying the *same* row! As with most other operations only providing atomicity guarantees on single rows, this also applies to this call. Trying to check and modify two different rows will return an exception.

Compare-and-set (CAS) operations are very powerful, especially in distributed systems, with even more decoupled client processes. In providing these calls, HBase sets itself apart from other architectures that give no means to reason about concurrent updates performed by multiple, independent clients.

Get Method

The next step in a client API is to retrieve what was just saved. For that the Table is providing you with the `get()` call and matching classes. The operations are split into those that operate on a single

row and those that retrieve multiple rows in one call. Before we start though, please note that we are using the `Result` class in passing in the various examples provided. This class will be explained in “[The Result class](#)” (page 159) a little later, so bear with us for the time being. The code—and output especially—should be self-explanatory.

Single Gets

First, the method that is used to retrieve specific values from a HBase table:

```
Result get(Get get) throws IOException
```

Similar to the `Put` class for the `put()` call, there is a matching `Get` class used by the aforementioned `get()` function. A `get()` operation is bound to one specific row, but can retrieve any number of columns and/or cells contained therein. Therefore, as another similarity, you will have to provide a row key when creating an instance of `Get`, using one of these constructors:

```
Get(byte[] row)
Get(Get get)
```

The primary constructor of `Get` takes the `row` parameter specifying the row you want to access, while the second constructor takes an existing instance of `Get` and copies the entire details from it, effectively *cloning* the instance. And, similar to the `put` operations, you have methods to specify rather broad criteria to find what you are looking for—or to specify everything down to exact coordinates for a single cell:

```
Get addFamily(byte[] family)
Get addColumn(byte[] family, byte[] qualifier)
Get setTimeRange(long minStamp, long maxStamp) throws IOException
Get setTimeStamp(long timestamp)
Get setMaxVersions()
Get setMaxVersions(int maxVersions) throws IOException
```

The `addFamily()` call narrows the request down to the given column family. It can be called multiple times to add more than one family. The same is true for the `addColumn()` call. Here you can add an even narrower address space: the specific column. Then there are methods that let you set the exact timestamp you are looking for—or a time range to match those cells that fall inside it.

Lastly, there are methods that allow you to specify how many versions you want to retrieve, given that you have not set an exact timestamp. By default, this is set to 1, meaning that the `get()` call returns the most current match only. If you are in doubt, use `getMaxVersions()` to check what it is set to. The `setMaxVersions()` without a parameter

sets the number of versions to return to `Integer.MAX_VALUE`--which is also the maximum number of versions you can configure in the column family descriptor, and therefore tells the API to return every available version of all matching cells (in other words, up to what is set at the column family level).

As mentioned earlier, HBase provides us with a helper class named `Bytes` that has many static methods to convert Java types into `byte[]` arrays. It also can do the same in reverse: as you are retrieving data from HBase—for example, one of the rows stored previously—you can make use of these helper functions to convert the `byte[]` data back into Java types. Here is a short list of what it offers, continued from the earlier discussion:

```
static String toString(byte[] b)
static boolean toBoolean(byte[] b)
static long toLong(byte[] bytes)
static float toFloat(byte[] bytes)
static int toInt(byte[] bytes)
...
```

[Example 3-10](#) shows how this is all put together.

Example 3-10. Example application retrieving data from HBase

```
Configuration conf = HBaseConfiguration.create(); ❶

Connection connection = ConnectionFactory.createConnection(conf);
Table table = connection.getTable(TableName.valueOf("testtable")); ❷

Get get = new Get(Bytes.toBytes("row1")); ❸
get.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"));
❹

Result result = table.get(get); ❺

byte[] val = result.getValue(Bytes.toBytes("colfam1"),
    Bytes.toBytes("qual1")); ❻

System.out.println("Value: " + Bytes.toString(val)); ❼

table.close(); ❽
connection.close();
```

- ❶ Create the configuration.
- ❷ Instantiate a new table reference.
- ❸ Create get with specific row.
- ❹ Add a column to the get.

- ⑤ Retrieve row with selected columns from HBase.
- ⑥ Get a specific value for the given column.
- ⑦ Print out the value while converting it back.
- ⑧ Close the table and connection instances to free resources.

If you are running this example after, say [Example 3-2](#), you should get this as the output:

```
Value: val1
```

The output is not very spectacular, but it shows that the basic operation works. The example also only adds the specific column to retrieve, relying on the default for maximum versions being returned set to 1. The call to `get()` returns an instance of the `Result` class, which you will learn about very soon in [“The Result class” \(page 159\)](#).

Using the Builder pattern

All of the data-related types and the majority of their add and set methods support the [fluent interface](#) pattern, that is, all of these methods return the instance reference and allow chaining of calls. [Example 3-11](#) show this in action.

Example 3-11. Creates a get request using its fluent interface

```
Get get = new Get(Bytes.toBytes("row1")) ❶
    .setId("GetFluentExample")
    .setMaxVersions()
    .setTimeStamp(1)
    .addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"))
    .addFamily(Bytes.toBytes("colfam2"));

Result result = table.get(get);
System.out.println("Result: " + result);
```

- ❶ Create a new get using the fluent interface.

[Example 3-11](#) showing the fluent interface should emit the following on the console:

```
Before get call...
Cell: row1/colfam1:qual1/2/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual2/4/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam1:qual2/3/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam2:qual1/2/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam2:qual1/1/Put/vlen=4/seqid=0, Value: val1
```

```

Cell: row1/colfam2:qual2/4/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam2:qual2/3/Put/vlen=4/seqid=0, Value: val2

Result: keyvalues={row1/colfam1:qual1/1/Put/vlen=4/seqid=0,  row1/
colfam2:qual1/1/Put/vlen=4/seqid=0}

```

An interesting part of this is the result that is printed last. While the example is adding the entire column family `colfam2`, it only prints a single cell. This is caused by the `setTimeStamp(1)` call, which affects all other selections. We essentially are telling the API to fetch “all cells from column family #2 that have a timestamp equal or less than 1”.

The `Get` class provides additional calls, which are listed in [Table 3-12](#) for your perusal. By now you should recognize many of them as inherited methods from the `Query` and `Row` superclasses.

Table 3-12. Quick overview of additional methods provided by the Get class

Method	Description
<code>familySet()/getFamilyMap()</code>	These methods give you access to the column families and specific columns, as added by the <code>addFamily()</code> and/or <code>addColumn()</code> calls. The family map is a map where the key is the family name and the value a list of added column qualifiers for this particular family. The <code>familySet()</code> returns the set of all stored families, i.e., a set containing only the family names.
<code>getACL()/setACL()</code>	The Access Control List (ACL) for this operation. See (to come) for details.
<code>getAttribute()/setAttribute()</code>	Set and get arbitrary attributes associated with this instance of <code>Get</code> .
<code>getAttributesMap()</code>	Returns the entire map of attributes, if any are set.
<code>getAuthorizations()/setAuthorizations()</code>	Visibility labels for the operation. See (to come) for details.
<code>getCacheBlocks()/setCacheBlocks()</code>	Specify if the server-side cache should retain blocks that were loaded for this operation.
<code>setCheckExistenceOnly()/isCheckExistenceOnly()</code>	Only check for existence of data, but do not return any of it.
<code>setClosestRowBefore()/isClosestRowBefore()</code>	Return all the data for the row that matches the given row key exactly, or the one that immediately precedes it.
<code>getConsistency()/setConsistency()</code>	The consistency level that applies to the current query instance.
<code>getFilter()/setFilter()</code>	The filters that apply to the retrieval operation. See “ Filters (page 219)” for details.

Method	Description
getFingerprint()	Compiles details about the instance into a map for debugging, or logging.
getId()/setId()	An ID for the operation, useful for identifying the origin of a request later.
getIsolationLevel()/setIsolationLevel()	Specifies the read isolation level for the operation.
getMaxResultsPerColumnFamily()/setMaxResultsPerColumnFamily()	Limit the number of cells returned per family.
getMaxVersions()/setMaxVersions()	Override the column family setting specifying how many versions of a column to retrieve.
getReplicaId()/setReplicaId()	Gives access to the replica ID that should serve the data.
getRow()	Returns the row key as specified when creating the Get instance.
getRowOffsetPerColumnFamily()/setRowOffsetPerColumnFamily()	Number of cells to skip when reading a row.
getTimeRange()/setTimeRange()	Retrieve or set the associated timestamp or time range of the Get instance.
setTimeStamp()	Sets a specific timestamp for the query. Retrieve with getTimeRange(). ^a
numFamilies()	Retrieves the size of the family map, containing the families added using the addFamily() or addColumn() calls.
hasFamilies()	Another helper to check if a family—or column—has been added to the current instance of the Get class.
toJSON()/toJSON(int)	Converts the first 5 or N columns into a JSON format.
toMap()/toMap(int)	Converts the first 5 or N columns into a map. This is more detailed than what getFingerprint() returns.
toString()/toString(int)	Converts the first 5 or N columns into a JSON, or map (if JSON fails due to encoding problems).

^aThe API converts a value assigned with setTimeStamp() into a TimeRange instance internally, setting it to the given timestamp and timestamp + 1, respectively.

The getters listed in [Table 3-12](#) for the Get class only retrieve what you have set beforehand. They are rarely used, and make sense only when you, for example, prepare a Get instance in a private method in your code, and inspect the values in another place or for unit testing.

The list of methods is long indeed, and while you have seen the inherited ones before, there are quite a few specific ones for Get that warrant a longer explanation. In order, we start with `setCacheBlocks()` and `getCacheBlocks()`, which controls how the read operation is handled on the server-side. Each HBase region server has a block cache that efficiently retains recently accessed data for subsequent reads of contiguous information. In some events it is better to not engage the cache to avoid too much churn when doing completely random gets. Instead of polluting the block cache with blocks of unrelated data, it is better to skip caching these blocks and leave the cache undisturbed for other clients that perform reading of related, co-located data.

The `setCheckExistenceOnly()` and `isCheckExistenceOnly()` combination allows the client to check if a specific set of columns, or column families are already existent. The [Example 3-12](#) shows this in action.

Example 3-12. Checks for the existence of specific data

```
List<Put> puts = new ArrayList<Put>();
Put put1 = new Put(Bytes.toBytes("row1"));
put1.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    Bytes.toBytes("val1"));
puts.add(put1);
Put put2 = new Put(Bytes.toBytes("row2"));
put2.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    Bytes.toBytes("val2"));
puts.add(put2);
Put put3 = new Put(Bytes.toBytes("row2"));
put3.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual2"),
    Bytes.toBytes("val3"));
puts.add(put3);
table.put(puts); ①

Get get1 = new Get(Bytes.toBytes("row2"));
get1.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"));
get1.setCheckExistenceOnly(true);
Result result1 = table.get(get1); ②

byte[] val = result1.getValue(Bytes.toBytes("colfam1"),
    Bytes.toBytes("qual1"));

System.out.println("Get 1 Exists: " + result1.getExists());
```

```

System.out.println("Get 1 Size: " + result1.size()); ③
System.out.println("Get 1 Value: " + Bytes.toString(val));

Get get2 = new Get(Bytes.toBytes("row2"));
get2.addFamily(Bytes.toBytes("colfam1")); ④
get2.setCheckExistenceOnly(true);
Result result2 = table.get(get2);

System.out.println("Get 2 Exists: " + result2.getExists());
System.out.println("Get 2 Size: " + result2.size());

Get get3 = new Get(Bytes.toBytes("row2"));
get3.addColumn(Bytes.toBytes("colfam1"), Bytes.to-
Bytes("qual9999")); ⑤
get3.setCheckExistenceOnly(true);
Result result3 = table.get(get3);

System.out.println("Get 3 Exists: " + result3.getExists());
System.out.println("Get 3 Size: " + result3.size());

Get get4 = new Get(Bytes.toBytes("row2"));
get4.addColumn(Bytes.toBytes("colfam1"), Bytes.to-
Bytes("qual9999")); ⑥
get4.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"));
get4.setCheckExistenceOnly(true);
Result result4 = table.get(get4);

System.out.println("Get 4 Exists: " + result4.getExists()); ⑦
System.out.println("Get 4 Size: " + result4.size());

```

- ① Insert two rows into the table.
- ② Check first with existing data.
- ③ Exists is “true”, while no cel was actually returned.
- ④ Check for an entire family to exist.
- ⑤ Check for a non-existent column.
- ⑥ Check for an existent, and non-existent column.
- ⑦ Exists is “true” because some data exists.

When executing this example, the output should read like the following:

```

Get 1 Exists: true
Get 1 Size: 0
Get 1 Value: null
Get 2 Exists: true
Get 2 Size: 0
Get 3 Exists: false
Get 3 Size: 0

```

```
Get 4 Exists: true  
Get 4 Size: 0
```

The one peculiar result is the last, you will be returned `true` for any of the checks you added returning `true`. In the example we tested a column that exists, and one that does not. Since one does, the entire check returns positive. In other words, make sure you test very specifically for what you are looking for. You may have to issue multiple get request (batched preferably) to test the exact coordinates you want to verify.

Alternative checks for existence

The `Table` class has another way of checking for the existence of data in a table, provided by these methods:

```
boolean exists(Get get) throws IOException  
boolean[] existsAll(List<Get> gets) throws IOException;
```

You can set up a `Get` instance, just like you do when using the `get()` calls of `Table`. Instead of having to retrieve the cells from the remote servers, just to verify that something exists, you can employ these calls because they only return a `boolean` flag. In fact, these calls are just shorthand for using `Get.setCheckExistenceOnly(true)` on the included `Get` instance(s).

Using `Table.exists()`, `Table.existsAll()`, or `Get.setCheckExistenceOnly()` involves the same lookup semantics on the region servers, including loading file blocks to check if a row or column actually exists. You only avoid shipping the data over the network—but that is very useful if you are checking very large columns, or do so very frequently. Consider using *Bloom filters* to speed up this process (see (to come)).

We move on to `setClosestRowBefore()` and `isClosestRowBefore()`, offering some sort of fuzzy matching for rows. Presume you have a complex row key design, employing compound data comprised of many separate fields (see (to come)). You can only match data from left to right in the row key, so again presume you have some leading fields, but not more specific ones. You can ask for a specific row using `get()`, but what if the requested row key is too specific and does not exist? Without jumping the gun, you could start using a scan operation, explained in “[Scans](#)” (page 193). For one of `get` calls you can in-

stead use the `setClosestRowBefore()` method, setting this functionality to true. [Example 3-13](#) shows the result:

Example 3-13. Retrieves a row close to the requested, if necessary

```
Get get1 = new Get(Bytes.toBytes("row3")); ①
get1.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"));
Result result1 = table.get(get1);

System.out.println("Get 1 isEmpty: " + result1.isEmpty());
CellScanner scanner1 = result1.cellScanner();
while (scanner1.advance()) {
    System.out.println("Get 1 Cell: " + scanner1.current());
}

Get get2 = new Get(Bytes.toBytes("row3"));
get2.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"));
get2.setClosestRowBefore(true); ②
Result result2 = table.get(get2);

System.out.println("Get 2 isEmpty: " + result2.isEmpty());
CellScanner scanner2 = result2.cellScanner();
while (scanner2.advance()) {
    System.out.println("Get 2 Cell: " + scanner2.current());
}

Get get3 = new Get(Bytes.toBytes("row2")); ③
get3.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"));
get3.setClosestRowBefore(true);
Result result3 = table.get(get3);

System.out.println("Get 3 isEmpty: " + result3.isEmpty());
CellScanner scanner3 = result3.cellScanner();
while (scanner3.advance()) {
    System.out.println("Get 3 Cell: " + scanner3.current());
}

Get get4 = new Get(Bytes.toBytes("row2")); ④
get4.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"));
Result result4 = table.get(get4);

System.out.println("Get 4 isEmpty: " + result4.isEmpty());
CellScanner scanner4 = result4.cellScanner();
while (scanner4.advance()) {
    System.out.println("Get 4 Cell: " + scanner4.current());
}
```

- ① Attempt to read a row that does not exist.
- ② Instruct the `get()` call to fall back to the previous row, if necessary.

- ③ Attempt to read a row that exists.
- ④ Read exactly a row that exists.

The output is interesting again:

```
Get 1 isEmpty: true
Get 2 isEmpty: false
Get 2 Cell: row2/colfam1:qual1/1426587567787/Put/vlen=4/seqid=0
Get 2 Cell: row2/colfam1:qual2/1426587567787/Put/vlen=4/seqid=0
Get 3 isEmpty: false
Get 3 Cell: row2/colfam1:qual1/1426587567787/Put/vlen=4/seqid=0
Get 3 Cell: row2/colfam1:qual2/1426587567787/Put/vlen=4/seqid=0
Get 4 isEmpty: false
Get 4 Cell: row2/colfam1:qual1/1426587567787/Put/vlen=4/seqid=0
```

The first call using the default Get instance fails to retrieve anything, as it asks for a row that does not exist (row3, we assume the same two rows exist from the previous example). The second adds a setCloses tRowBefore(true) instruction to match the row exactly, or the closest one sorted before the given row key. This, in our example, is row2, shown to work as expected. What is surprising though is that the entire row is returned, not the specific column we asked for.

This is extended in get #3, which now reads the existing row2, but still leaves the fuzzy matching on. We again get the entire row back, not just the columns we asked for. In get #4 we remove the setCloses tRowBefore(true) and get exactly what we expect, that is only the column we have selected.

Finally, we will look at four methods in a row: getMaxResultsPerColumnFamily(), setMaxResultsPerColumnFamily(), getRowOffsetPerColumnFamily(), and setRowOffsetPerColumnFamily(), as they all work in tandem to allow the client to page through a wide row. The former pair handles the maximum amount of cells returned by a get request. The latter pair then sets an optional offset into the row. [Example 3-14](#) shows this as simple as possible.

Example 3-14. Retrieves parts of a row with offset and limit

```
Put put = new Put(Bytes.toBytes("row1"));
for (int n = 1; n <= 1000; n++) {
    String num = String.format("%04d", n);
    put.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual" +
num),
                 Bytes.toBytes("val" + num));
}
table.put(put);

Get get1 = new Get(Bytes.toBytes("row1"));
get1.setMaxResultsPerColumnFamily(10); ❶
```

```

Result result1 = table.get(get1);
CellScanner scanner1 = result1.cellScanner();
while (scanner1.advance()) {
    System.out.println("Get 1 Cell: " + scanner1.current());
}

Get get2 = new Get(Bytes.toBytes("row1"));
get2.setMaxResultsPerColumnFamily(10);
get2.setRowOffsetPerColumnFamily(100); ②
Result result2 = table.get(get2);
CellScanner scanner2 = result2.cellScanner();
while (scanner2.advance()) {
    System.out.println("Get 2 Cell: " + scanner2.current());
}

```

- ① Ask for ten cells to be returned at most.
- ② In addition, also skip the first 100 cells.

The output in abbreviated form:

```

Get 1 Cell: row1/colfam1:qual0001/1426592168066/Put/vlen=7/seqid=0
Get 1 Cell: row1/colfam1:qual0002/1426592168066/Put/vlen=7/seqid=0
...
Get 1 Cell: row1/colfam1:qual0009/1426592168066/Put/vlen=7/seqid=0
Get 1 Cell: row1/colfam1:qual0010/1426592168066/Put/vlen=7/seqid=0

Get 2 Cell: row1/colfam1:qual0101/1426592168066/Put/vlen=7/seqid=0
Get 2 Cell: row1/colfam1:qual0102/1426592168066/Put/vlen=7/seqid=0
...
Get 2 Cell: row1/colfam1:qual0109/1426592168066/Put/vlen=7/seqid=0
Get 2 Cell: row1/colfam1:qual0110/1426592168066/Put/vlen=7/seqid=0

```

This, on first sight, seems to make sense, we get ten columns (cells) returned from column 1 to 10. For get #2 we get the same but *skip* the first 100 columns, starting at 101 to 110. But that is not exactly how these get options work, they really work on cells, not columns. [Example 3-15](#) extends the previous example to write each column three times, creating three cells—or versions—for each.

Example 3-15. Retrieves parts of a row with offset and limit #2

```

for (int version = 1; version <= 3; version++) { ①
    Put put = new Put(Bytes.toBytes("row1"));
    for (int n = 1; n <= 1000; n++) {
        String num = String.format("%04d", n);
        put.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual"
+ num),
                     Bytes.toBytes("val" + num));
    }
    System.out.println("Writing version: " + version);
    table.put(put);
}

```

```

        Thread.currentThread().sleep(1000);
    }

    Get get0 = new Get(Bytes.toBytes("row1"));
    get0.addColumn(Bytes.toBytes("colfam1"),      Bytes.to-
Bytes("qual0001"));
    get0.setMaxVersions(); ❷
    Result result0 = table.get(get0);
    CellScanner scanner0 = result0.cellScanner();
    while (scanner0.advance()) {
        System.out.println("Get 0 Cell: " + scanner0.current());
    }

    Get get1 = new Get(Bytes.toBytes("row1"));
    get1.setMaxResultsPerColumnFamily(10); ❸
    Result result1 = table.get(get1);
    CellScanner scanner1 = result1.cellScanner();
    while (scanner1.advance()) {
        System.out.println("Get 1 Cell: " + scanner1.current());
    }

    Get get2 = new Get(Bytes.toBytes("row1"));
    get2.setMaxResultsPerColumnFamily(10);
    get2.setMaxVersions(3); ❹
    Result result2 = table.get(get2);
    CellScanner scanner2 = result2.cellScanner();
    while (scanner2.advance()) {
        System.out.println("Get 2 Cell: " + scanner2.current());
    }
}

```

- ❶ Insert three versions of each column.
- ❷ Get a column with all versions as a test.
- ❸ Get ten cells, single version per column.
- ❹ Do the same but now retrieve all versions of a column.

The output, in abbreviated form again:

```

Writing version: 1
Writing version: 2
Writing version: 3
Get 0 Cell: row1/colfam1:qual0001/1426592660030/Put/vlen=7/seqid=0
Get 0 Cell: row1/colfam1:qual0001/1426592658911/Put/vlen=7/seqid=0
Get 0 Cell: row1/colfam1:qual0001/1426592657785/Put/vlen=7/seqid=0

Get 1 Cell: row1/colfam1:qual0001/1426592660030/Put/vlen=7/seqid=0
Get 1 Cell: row1/colfam1:qual0002/1426592660030/Put/vlen=7/seqid=0
...
Get 1 Cell: row1/colfam1:qual0009/1426592660030/Put/vlen=7/seqid=0
Get 1 Cell: row1/colfam1:qual0010/1426592660030/Put/vlen=7/seqid=0

```

```
Get 2 Cell: row1/colfam1:qual0001/1426592660030/Put/vlen=7/seqid=0
Get 2 Cell: row1/colfam1:qual0001/1426592658911/Put/vlen=7/seqid=0
Get 2 Cell: row1/colfam1:qual0001/1426592657785/Put/vlen=7/seqid=0
Get 2 Cell: row1/colfam1:qual0002/1426592660030/Put/vlen=7/seqid=0
Get 2 Cell: row1/colfam1:qual0002/1426592658911/Put/vlen=7/seqid=0
Get 2 Cell: row1/colfam1:qual0002/1426592657785/Put/vlen=7/seqid=0
Get 2 Cell: row1/colfam1:qual0003/1426592660030/Put/vlen=7/seqid=0
Get 2 Cell: row1/colfam1:qual0003/1426592658911/Put/vlen=7/seqid=0
Get 2 Cell: row1/colfam1:qual0003/1426592657785/Put/vlen=7/seqid=0
Get 2 Cell: row1/colfam1:qual0004/1426592660030/Put/vlen=7/seqid=0
```

If we iterate over the same data, we get the same result (get #1 does that). But as soon as we instruct the servers to return all versions, the results change. We added a `Get.setMaxVersions(3)` (we could have used `setMaxVersions()` without a parameter as well) and therefore now iterate over all cells, reflected in what get #2 shows. We still get ten cells back, but this time from column 1 to 4 only, with all versions of the columns in between.

Be wary when using these get parameters, you might not get what you expected initially. But they behave as designed, and it is up to the client application and the accompanying table schema to end up with the proper results.

The Result class

The above examples implicitly show you that when you retrieve data using the `get()` calls, you receive an instance of the `Result` class that contains all the matching cells. It provides you with the means to access everything that was returned from the server for the given row and matching the specified query, such as column family, column qualifier, timestamp, and so on.

There are utility methods you can use to ask for specific results—just as [Example 3-10](#) used earlier—using more concrete dimensions. If you have, for example, asked the server to return all columns of one specific column family, you can now ask for specific columns within that family. In other words, you need to call `get()` with just enough concrete information to be able to process the matching data on the client side. The first set of functions provided are:

```
byte[] getRow()
byte[] getValue(byte[] family, byte[] qualifier)
byte[] value()
ByteBuffer getValueAsByteBuffer(byte[] family, byte[] qualifier)
ByteBuffer getValueAsByteBuffer(byte[] family, int foffset, int flength,
                               byte[] qualifier, int qoffset, int qlength)
boolean loadValue(byte[] family, byte[] qualifier, ByteBuffer dst)
throws BufferOverflowException
```

```
boolean loadValue(byte[] family, int foffset, int flength, byte[]
qualifier,
    int qoffset, int qlength, ByteBuffer dst) throws BufferOverflow-
wException
CellScanner cellScanner()
Cell[] rawCells()
List<Cell> listCells()
boolean isEmpty()
int size()
```

You saw `getRow()` before: it returns the row key, as specified, for example, when creating the instance of the `Get` class used in the `get()` call providing the current instance of `Result`. `size()` is returning the number of `Cell` instances the server has returned. You may use this call—or `isEmpty()`, which checks if `size()` returns a number greater than zero—to check in your own client code if the retrieval call returned any matches.

The `getValue()` call allows you to get the data for a specific cell that was returned to you. As you cannot specify what timestamp—in other words, version—you want, you get the newest one. The `value()` call makes this even easier by returning the data for the newest cell in the first column found. Since columns are also sorted lexicographically on the server, this would return the value of the column with the column name (including family and qualifier) sorted first.

Some of the methods to return data clone the underlying byte array so that no modification is possible. Yet others do not and you have to take care not to modify the returned arrays—for your own sake.

The following methods do clone (which means they create a copy of the byte array) the data before returning it to the caller: `getRow()`, `getValue()`, `value()`, `getMap()`, `getNoVersionMap()`, and `getFamilyMap()`.¹¹

There is another set of accessors for the value of available cells, namely `getValueAsByteBuffer()` and `loadValue()`. They either create a new Java `ByteBuffer`, wrapping the byte array with the value, or copy the data into a provided one respectively. You may wonder why you have to provide the column family and qualifier name as a byte array *plus* specifying an *offset* and *length* into each of the arrays. The assumption is that you may have a more complex array that holds all

11. Be wary as this might change in future versions.

of the data needed. In this case you can set the `family` and `qualifier` parameter to the very same array, just pointing the respective offset and length to where in the larger array the family and qualifier are stored.

Access to the raw, low-level `Cell` instances is provided by the `rawCells()` method, returning the array of `Cell` instances backing the current `Result` instance. The `listCells()` call simply converts the array returned by `raw()` into a `List` instance, giving you convenience by providing iterator access, for example. The created list is backed by the original array of `KeyValue` instances. The `Result` class also implements the already discussed `CellScannable` interface, so you can iterate over the contained cells directly. The examples in the “[Get Method](#)” (page 146) show this in action, for instance, [Example 3-13](#).

The array of cells returned by, for example, `rawCells()` is already lexicographically sorted, taking the full coordinates of the `Cell` instances into account. So it is sorted first by column family, then within each family by qualifier, then by timestamp, and finally by type.

Another set of accessors is provided which are more column-oriented:

```
List<Cell> getColumnCells(byte[] family, byte[] qualifier)
Cell getColumnLatestCell(byte[] family, byte[] qualifier)
Cell getColumnLatestCell(byte[] family, int foffset, int flength,
    byte[] qualifier, int qoffset, int qlength)
boolean containsColumn(byte[] family, byte[] qualifier)
boolean containsColumn(byte[] family, int foffset, int flength,
    byte[] qualifier, int qoffset, int qlength)
boolean containsEmptyColumn(byte[] family, byte[] qualifier)
boolean containsEmptyColumn(byte[] family, int foffset, int flength,
    byte[] qualifier, int qoffset, int qlength)
boolean containsNonEmptyColumn(byte[] family, byte[] qualifier)
boolean containsNonEmptyColumn(byte[] family, int foffset, int flength,
    byte[] qualifier, int qoffset, int qlength)
```

By means of the `getColumnCells()` method you ask for multiple values of a specific column, which solves the issue pointed out earlier, that is, how to get multiple versions of a given column. The number returned obviously is bound to the maximum number of versions you have specified when configuring the `Get` instance, before the call to `get()`, with the default being set to 1. In other words, the returned list contains zero (in case the column has no value for the given row) or

one entry, which is the newest version of the value. If you have specified a value greater than the default of 1 version to be returned, it could be any number, up to the specified maximum (see [Example 3-15](#) for an example).

The `getColumnLatestCell()` methods are returning the newest cell of the specified column, but in contrast to `getValue()`, they do not return the raw byte array of the value but the full `Cell` instance instead. This may be useful when you need more than just the value data. The two variants only differ in one being more convenient when you have two separate arrays *only* containing the family and qualifier names. Otherwise you can use the second version that gives you access to the already explained offset and length parameters.

The `containsColumn()` is a convenience method to check if there was any cell returned in the specified column. Again, this comes in two variants for convenience. There are two more pairs of functions for this check, `containsEmptyColumn()` and `containsNonEmptyColumns()`. They do not only check that there is a cell for a specific column, but also if that cell has no value data (it is *empty*) or has value data (it is *not empty*). All of these `contains` checks internally use the `getColumnLatestCell()` call to get the newest version of a column cell, and then perform the check.

These methods all support the fact that the qualifier can be left unspecified—setting it to `null`—and therefore matching the special column with no name.

Using no qualifier means that there is no label to the column. When looking at the table from, for example, the HBase Shell, you need to know what it contains. A rare case where you might want to consider using the empty qualifier is in column families that only ever contain a single column. Then the family name might indicate its purpose.

There is a third set of methods that provide access to the returned data from the `get` request. These are map-oriented and look like this:

```
NavigableMap<byte[], NavigableMap<byte[],  
          NavigableMap<Long, byte[]>>> getMap()  
NavigableMap<byte[], NavigableMap<byte[], byte[]>> getNoVersion-  
Map()  
NavigableMap<byte[], byte[]> getFamilyMap(byte[] family)
```

The most generic call, named `getMap()`, returns the entire result set in a Java Map class instance that you can iterate over to access all the values. This is different from accessing the raw cells, since here you get only the data in a map, not any accessors or other internal information of the cells. The map is organized as such: family → qualifier → values. The `getNoVersionMap()` does the same while only including the latest cell for each column. Finally, the `getFamilyMap()` lets you select the data for a specific column family only—but including all versions, if specified during the get call.

Use whichever access method of Result matches your access pattern; the data has already been moved across the network from the server to your client process, so it is not incurring any other performance or resource penalties.

Finally, there are a few more methods provided, that do not fit into the above groups

Table 3-13. Additional methods provided by Result

Method	Description
<code>create()</code>	There is a set of these static methods to help create Result instances if necessary.
<code>copyFrom()</code>	Helper method to copy a reference of the list of cells from one instance to another.
<code>compareResults()</code>	Static method, does a deep compare of two instance, down to the byte arrays.
<code>getExists()/setExists()</code>	Optionally used to check for existence of cells only. See Example 3-12 for an example.
<code>getTotalSizeOfCells()</code>	Static method, summarizes the estimated heap size of all contained cells. Uses <code>Cell.heapSize()</code> for each contained cell.
<code>isStale()</code>	Indicates if the result was served by a region replica, not the main one.
<code>addResults()/getStats()</code>	This is used to return region statistics, if enabled (default is false).
<code>toString()</code>	Dump the content of an instance for logging or debugging. See "Dump the Contents" (page 163) .

Dump the Contents

All Java objects have a `toString()` method, which, when overridden by a class, can be used to convert the data of an instance into a text representation. This is not for serialization purposes, but is most often used for debugging.

The `Result` class has such an implementation of `toString()`, dumping the result of a read call as a string. [Example 3-16](#) shows a brief snippet on how it is used.

Example 3-16. Retrieve results from server and dump content

```
Get get = new Get(Bytes.toBytes("row1"));
Result result1 = table.get(get);
System.out.println(result1);

Result result2 = Result.EMPTY_RESULT;
System.out.println(result2);

result2.copyFrom(result1);
System.out.println(result2);
```

The output looks like this:

```
keyvalues={row1/colfam1:qual1/1426669424163/Put/vlen=4/seqid=0,
           row1/colfam1:qual2/1426669424163/Put/vlen=4/seqid=0}
```

It simply prints all contained `Cell` instances, that is, calling `Cell.toString()` respectively. If the `Result` instance is empty, the output will be:

```
keyvalues=NONE
```

This indicates that there were *no* `Cell` instances returned. The code examples in this book make use of the `toString()` method to quickly print the results of previous read operations.

There is also a `Result.EMPTY_RESULT` field available, that returns a shared and final instance of `Result` that is empty. This might be useful when you need to return an empty result from for client code to, for example, a higher level caller.

As of this writing, the shared `EMPTY_RESULT` is not read-only, which means if you modify it, then the shared instance is modified for any other user of this instance. For example:

```
Result result2 = Result.EMPTY_RESULT;
System.out.println(result2);

result2.copyFrom(result1);
System.out.println(result2);
```

Assuming we have the same `result1` as shown in [Example 3-16](#) earlier, you get this:

```
keyvalues=NONE
keyvalues={row1/colfam1:qual1/1426672899223/Put/vlen=4/
seqid=0,
           row1/colfam1:qual2/1426672899223/Put/vlen=4/
seqid=0}
```

Be careful!

List of Gets

Another similarity to the `put()` calls is that you can ask for more than one row using a single request. This allows you to quickly and efficiently retrieve related—but also completely random, if required—data from the remote servers.

As shown in [Figure 3-2](#), the request may actually go to more than one server, but for all intents and purposes, it looks like a single call from the client code.

The method provided by the API has the following signature:

```
Result[] get(List<Get> gets) throws IOException
```

Using this call is straightforward, with the same approach as seen earlier: you need to create a list that holds all instances of the `Get` class you have prepared. This list is handed into the call and you will be returned an array of equal size holding the matching `Result` instances. [Example 3-17](#) brings this together, showing two different approaches to accessing the data.

Example 3-17. Example of retrieving data from HBase using lists of Get instances

```
byte[] cf1 = Bytes.toBytes("colfam1");
byte[] qf1 = Bytes.toBytes("qual1");
byte[] qf2 = Bytes.toBytes("qual2"); ①
byte[] row1 = Bytes.toBytes("row1");
byte[] row2 = Bytes.toBytes("row2");

List<Get> gets = new ArrayList<Get>(); ②

Get get1 = new Get(row1);
get1.addColumn(cf1, qf1);
gets.add(get1);

Get get2 = new Get(row2);
get2.addColumn(cf1, qf1); ③
gets.add(get2);

Get get3 = new Get(row2);
get3.addColumn(cf1, qf2);
gets.add(get3);

Result[] results = table.get(gets); ④

System.out.println("First iteration...");
for (Result result : results) {
    String row = Bytes.toString(result.getRow());
    System.out.print("Row: " + row + " ");
    byte[] val = null;
    if (result.containsColumn(cf1, qf1)) { ⑤
        val = result.getValue(cf1, qf1);
        System.out.println("Value: " + Bytes.toString(val));
    }
    if (result.containsColumn(cf1, qf2)) {
        val = result.getValue(cf1, qf2);
        System.out.println("Value: " + Bytes.toString(val));
    }
}

System.out.println("Second iteration...");
for (Result result : results) {
    for (Cell cell : result.listCells()) { ⑥
        System.out.println(
            "Row: " + Bytes.toString(
                cell.getRowArray(), cell.getRowOffset(), cell.getRowLength()) + ⑦
            " Value: " + Bytes.toString(CellUtil.cloneValue(cell)));
    }
}

System.out.println("Third iteration...");
```

```
for (Result result : results) {  
    System.out.println(result);  
}
```

- ➊ Prepare commonly used byte arrays.
- ➋ Create a list that holds the Get instances.
- ➌ Add the Get instances to the list.
- ➍ Retrieve rows with selected columns from HBase.
- ➎ Iterate over results and check what values are available.
- ➏ Iterate over results again, printing out all values.
- ➐ Two different ways to access the cell data.

Assuming that you execute [Example 3-5](#) just before you run [Example 3-17](#), you should see something like this on the command line:

```
First iteration...  
Row: row1 Value: val1  
Row: row2 Value: val2  
Row: row2 Value: val3  
Second iteration...  
Row: row1 Value: val1  
Row: row2 Value: val2  
Row: row2 Value: val3  
Third iteration...  
keyvalues={row1/colfam1:qual1/1426678215864/Put/vlen=4/seqid=0}  
keyvalues={row2/colfam1:qual1/1426678215864/Put/vlen=4/seqid=0}  
keyvalues={row2/colfam1:qual2/1426678215864/Put/vlen=4/seqid=0}
```

All iterations return the same values, showing that you have a number of choices on how to access them, once you have received the results. What you have not yet seen is how errors are reported back to you. This differs from what you learned in [“List of Puts” \(page 137\)](#). The `get()` call either returns the said array, matching the same size as the given list by the `gets` parameter, or throws an exception. [Example 3-18](#) showcases this behavior.

Example 3-18. Example trying to read an erroneous column family

```
List<Get> gets = new ArrayList<Get>();  
  
Get get1 = new Get(row1);  
get1.addColumn(cf1, qf1);  
gets.add(get1);  
  
Get get2 = new Get(row2);  
get2.addColumn(cf1, qf1); ➊  
gets.add(get2);
```

```

Get get3 = new Get(row2);
get3.addColumn(cf1, qf2);
gets.add(get3);

Get get4 = new Get(row2);
get4.addColumn(Bytes.toBytes("BOGUS"), qf2);
gets.add(get4); ②

Result[] results = table.get(gets); ③

System.out.println("Result count: " + results.length); ④

```

① Add the Get instances to the list.
② Add the bogus column family get.
③ An exception is thrown and the process is aborted.
④ This line will never reached!

Executing this example will abort the entire `get()` operation, throwing the following (or similar) error, and not returning a result at all:

```

org.apache.hadoop.hbase.client.RetryExhaustedWithDetailsException:
  Failed 1 action: NoSuchColumnFamilyException: 1 time,
  servers with issues: 10.0.0.57:51640,

Exception in thread "main" \
  org.apache.hadoop.hbase.client.RetryExhaustedWithDetailsException: \
    Failed 1 action: \
      org.apache.hadoop.hbase.regionserver.NoSuchColumnFamilyException: \
        Column family BOGUS does not exist in region \
          testtable,,1426678215640.de657eebc8e3422376e918ed77fc33ba. \
            in table 'testtable', {NAME => 'colfam1', ...}
              at org.apache.hadoop.hbase.regionserver.HRegion.checkFamily(...)
              at org.apache.hadoop.hbase.regionserver.HRegion.get(...)
              ...

```

One way to have more control over how the API handles partial faults is to use the `batch()` operations discussed in “[Batch Operations](#)” ([page 187](#)).

Delete Method

You are now able to create, read, and update data in HBase tables. What is left is the ability to delete from it. And surely you may have guessed by now that the `Table` provides you with a method of exactly

that name, along with a matching class aptly named `Delete`. Again you have a few variants, one that takes a single delete, one that accepts a list of deletes, and another that provides an atomic, server-side check-and-delete. The following discusses them in that order.

Single Deletes

The variant of the `delete()` call that takes a single `Delete` instance is:

```
void delete(Delete delete) throws IOException
```

Just as with the `get()` and `put()` calls you saw already, you will have to create a `Delete` instance and then add details about the data you want to remove. The constructors are:

```
Delete(byte[] row)
Delete(byte[] row, long timestamp)
Delete(final byte[] rowArray, final int rowOffset, final int rowLength)
Delete(final byte[] rowArray, final int rowOffset, final int rowLength,
      long ts)
Delete(final Delete d)
```

You need to provide the `row` you want to modify, and—optionally—a specific version/timestamp to operate on. There are other variants to create a `Delete` instance, where the next two do the same as the already described first pair, with the difference that they allow you to pass in a larger array, with accompanying offset and length parameter. The final variant allows you to hand in an existing `delete` instance and copy all parameters from it.

Otherwise, you would be wise to narrow down what you want to remove from the given row, using one of the following methods:

```
Delete addFamily(final byte[] family)
Delete addFamily(final byte[] family, final long timestamp)
Delete addFamilyVersion(final byte[] family, final long timestamp)
Delete addColumns(final byte[] family, final byte[] qualifier)
Delete addColumns(final byte[] family, final byte[] qualifier,
                 final long timestamp)
Delete addColumn(final byte[] family, final byte[] qualifier)
Delete addColumn(byte[] family, byte[] qualifier, long timestamp)

void setTimestamp(long timestamp)
```

You do have a choice to narrow in on what to remove using four types of calls. First, you can use the `addFamily()` methods to remove an entire column family, including all contained columns. The next type is `addColumns()`, which operates on exactly one column. The third type is similar, using `addColumn()`. It also operates on a specific, given col-

umn only, but deletes either the most current or the specified version, that is, the one with the matching timestamp.

Finally, there is `setTimestamp()`, and it allows you to set a timestamp that is used for every subsequent `addXYZ()` call. In fact, using a Delete constructor that takes an explicit timestamp parameter is just shorthand to calling `setTimestamp()` just after creating the instance. Once an instance wide timestamp is set, all further operations will make use of it. There is no need to use the explicit timestamp parameter, though you can, as it has the same effect.

This changes quite a bit when attempting to delete the entire row, in other words when you do *not* specify any family or column at all. The difference is between deleting the entire row or just all contained columns, in all column families, that match or have an older timestamp compared to the given one. [Table 3-14](#) shows the functionality in a matrix to make the semantics more readable.

The handling of the explicit versus implicit timestamps is the same for all `addXYZ()` methods, and apply in the following order:

1. If you do *not* specify a timestamp for the `addXYZ()` calls, then the optional one from either the constructor, or a previous call to `setTimestamp()` is used.
2. If that was not set, then `HConstants.LATEST_TIMESTAMP` is used, meaning all versions will be affected by the delete.

`LATEST_TIMESTAMP` is simply the highest value the version field can assume, which is `Long.MAX_VALUE`. Because the delete affects all versions *equal or less than* the given timestamp, this means `LATEST_TIMESTAMP` covers *all* versions.

Table 3-14. Functionality matrix of the `delete()` calls

Method	Deletes without timestamp	Deletes with timestamp
none	Entire row, that is, all columns, all versions.	All versions of all columns in all column families, whose timestamp is equal to or older than the given timestamp.
<code>addColumn()</code>	Only the latest version of the given column; older versions are kept.	Only exactly the specified version of the given column, with the matching

Method	Deletes without timestamp	Deletes with timestamp
		timestamp. If nonexistent, nothing is deleted.
addColumns()	All versions of the given column.	Versions equal to or older than the given timestamp of the given column.
addFamily()	All columns (including all versions) of the given family.	Versions equal to or older than the given timestamp of all columns of the given family.

For advanced user there is an additional method available:

```
Delete addDeleteMarker(Cell kv) throws IOException
```

This call checks that the provided Cell instance is of type delete (see `Cell.getTypeByte()` in “[The Cell](#)” ([page 112](#))), and that the row key matches the one of the current delete instance. If that holds true, the cell is added as-is to the family it came from. One place where this is used are such tools as `Import`. These tools read and deserialize entire cells from an input stream (say a backup file or write-ahead log) and want to add them verbatim, that is, no need to create another internal cell instance and copy the data.

[Example 3-19](#) shows how to use the single `delete()` call from client code.

Example 3-19. Example application deleting data from HBase

```
Delete delete = new Delete(Bytes.toBytes("row1")); ①
delete.setTimestamp(1); ②
    delete.addColumn(Bytes.toBytes("colfam1"),
        Bytes.toBytes("qual1")); ③
    delete.addColumn(Bytes.toBytes("colfam1"),
        Bytes.toBytes("qual3"), 3); ④
    delete.addColumns(Bytes.toBytes("colfam1"),
        Bytes.toBytes("qual1")); ⑤
    delete.addColumns(Bytes.toBytes("colfam1"),
        Bytes.toBytes("qual3"), 2); ⑥
    delete.addFamily(Bytes.toBytes("colfam1")); ⑦
    delete.addFamily(Bytes.toBytes("colfam1"), 3); ⑧
table.delete(delete); ⑨
```

- ① Create delete with specific row.
- ② Set timestamp for row deletes.

- ③ Delete the latest version only in one column.
- ④ Delete specific version in one column.
- ⑤ Delete all versions in one column.
- ⑥ Delete the given and all older versions in one column.
- ⑦ Delete entire family, all columns and versions.
- ⑧ Delete the given and all older versions in the entire column family, i.e., from all columns therein.
- ⑨ Delete the data from the HBase table.

The example lists all the different calls you can use to parameterize the `delete()` operation. It does not make too much sense to call them all one after another like this. Feel free to comment out the various delete calls to see what is printed on the console.

Setting the timestamp for the deletes has the effect of *only* matching the exact cell, that is, the matching column and value with the exact timestamp. On the other hand, not setting the timestamp forces the server to retrieve the latest timestamp on the server side on your behalf. This is slower than performing a delete with an explicit timestamp.

If you attempt to delete a cell with a timestamp that does *not* exist, nothing happens. For example, given that you have two versions of a column, one at version 10 and one at version 20, deleting from this column with version 15 will not affect either existing version.

Another note to be made about the example is that it showcases custom versioning. Instead of relying on timestamps, implicit or explicit ones, it uses sequential numbers, starting with 1. This is perfectly valid, although you are forced to always set the version yourself, since the servers do not know about your schema and would use epoch-based timestamps instead. Another example of using custom versioning can be found in (to come).

The `Delete` class provides additional calls, which are listed in [Table 3-15](#) for your reference. Once again, many are inherited from the superclasses, such as `Mutation`.

Table 3-15. Quick overview of additional methods provided by the Delete class

Method	Description
<code>cellScanner()</code>	Provides a scanner over all cells available in this instance.
<code>getACL()/setACL()</code>	The ACLs for this operation (might be <code>null</code>).

Method	Description
getAttribute()/setAttribute()	Set and get arbitrary attributes associated with this instance of Delete.
getAttributesMap()	Returns the entire map of attributes, if any are set.
getCellVisibility()/setCellVisibility()	The cell level visibility for all included cells.
getClusterIds()/setClusterIds()	The cluster IDs as needed for replication purposes.
getDurability()/setDurability()	The durability settings for the mutation.
getFamilyCellMap()/setFamilyCellMap()	The list of all cells of this instance.
getFingerprint()	Compiles details about the instance into a map for debugging, or logging.
getId()/setId()	An ID for the operation, useful for identifying the origin of a request later.
getRow()	Returns the row key as specified when creating the Delete instance.
getTimeStamp()	Retrieves the associated timestamp of the Delete instance.
getTTL()/setTTL()	Not supported by Delete, will throw an exception when setTTL() is called.
heapSize()	Computes the heap space required for the current Delete instance. This includes all contained data and space needed for internal structures.
isEmpty()	Checks if the family map contains any Cell instances.
numFamilies()	Convenience method to retrieve the size of the family map, containing all Cell instances.
size()	Returns the number of Cell instances that will be applied with this Delete.
toJSON()/toJSON(int)	Converts the first 5 or N columns into a JSON format.
toMap()/toMap(int)	Converts the first 5 or N columns into a map. This is more detailed than what getFingerprint() returns.
toString()/toString(int)	Converts the first 5 or N columns into a JSON, or map (if JSON fails due to encoding problems).

List of Deletes

The list-based `delete()` call works very similarly to the list-based `put()`. You need to create a list of `Delete` instances, configure them, and call the following method:

```
void delete(List<Delete> deletes) throws IOException
```

[Example 3-20](#) shows where three different rows are affected during the operation, deleting various details they contain. When you run this example, you will see a printout of the *before* and *after* states of the delete. The output is printing the raw KeyValue instances, using `KeyValue.toString()`.

Just as with the other list-based operation, you cannot make any assumption regarding the order in which the deletes are applied on the remote servers. The API is free to reorder them to make efficient use of the single RPC per affected region server. If you need to enforce specific orders of how operations are applied, you would need to batch those calls into smaller groups and ensure that they contain the operations in the desired order across the batches. In a worst-case scenario, you would need to send separate delete calls altogether.

Example 3-20. Example application deleting lists of data from HBase

```
List<Delete> deletes = new ArrayList<Delete>(); ①

Delete delete1 = new Delete(Bytes.toBytes("row1"));
delete1.setTimestamp(4); ②
deletes.add(delete1);

Delete delete2 = new Delete(Bytes.toBytes("row2"));
    delete2.addColumn(Bytes.toBytes("colfam1"), Bytes.to-
Bytes("qual1")); ③
    delete2.addColumns(Bytes.toBytes("colfam2"), Bytes.to-
Bytes("qual3"), 5); ④
deletes.add(delete2);

Delete delete3 = new Delete(Bytes.toBytes("row3"));
    delete3.addFamily(Bytes.toBytes("colfam1")); ⑤
    delete3.addFamily(Bytes.toBytes("colfam2"), 3); ⑥
deletes.add(delete3);

table.delete(deletes); ⑦
```

- ① Create a list that holds the Delete instances.
- ② Set timestamp for row deletes.
- ③ Delete the latest version only in one column.
- ④ Delete the given and all older versions in another column.
- ⑤ Delete entire family, all columns and versions.

- ⑥ Delete the given and all older versions in the entire column family, i.e., from all columns therein.
- ⑦ Delete the data from multiple rows the HBase table.

The output you should see is:¹²

```
Before delete call...
Cell: row1/colfam1:qual1/2/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual2/4/Put/vlen=4/seqid=0, Value: val4
Cell: row1/colfam1:qual2/3/Put/vlen=4/seqid=0, Value: val3
Cell: row1/colfam1:qual3/6/Put/vlen=4/seqid=0, Value: val6
Cell: row1/colfam1:qual3/5/Put/vlen=4/seqid=0, Value: val5

Cell: row1/colfam2:qual1/2/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam2:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam2:qual2/4/Put/vlen=4/seqid=0, Value: val4
Cell: row1/colfam2:qual2/3/Put/vlen=4/seqid=0, Value: val3
Cell: row1/colfam2:qual3/6/Put/vlen=4/seqid=0, Value: val6
Cell: row1/colfam2:qual3/5/Put/vlen=4/seqid=0, Value: val5

Cell: row2/colfam1:qual1/2/Put/vlen=4/seqid=0, Value: val2
Cell: row2/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row2/colfam1:qual2/4/Put/vlen=4/seqid=0, Value: val4
Cell: row2/colfam1:qual2/3/Put/vlen=4/seqid=0, Value: val3
Cell: row2/colfam1:qual3/6/Put/vlen=4/seqid=0, Value: val6
Cell: row2/colfam1:qual3/5/Put/vlen=4/seqid=0, Value: val5

Cell: row2/colfam2:qual1/2/Put/vlen=4/seqid=0, Value: val2
Cell: row2/colfam2:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row2/colfam2:qual2/4/Put/vlen=4/seqid=0, Value: val4
Cell: row2/colfam2:qual2/3/Put/vlen=4/seqid=0, Value: val3
Cell: row2/colfam2:qual3/6/Put/vlen=4/seqid=0, Value: val6
Cell: row2/colfam2:qual3/5/Put/vlen=4/seqid=0, Value: val5

Cell: row3/colfam1:qual1/2/Put/vlen=4/seqid=0, Value: val2
Cell: row3/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row3/colfam1:qual2/4/Put/vlen=4/seqid=0, Value: val4
Cell: row3/colfam1:qual2/3/Put/vlen=4/seqid=0, Value: val3
Cell: row3/colfam1:qual3/6/Put/vlen=4/seqid=0, Value: val6
Cell: row3/colfam1:qual3/5/Put/vlen=4/seqid=0, Value: val5

Cell: row3/colfam2:qual1/2/Put/vlen=4/seqid=0, Value: val2
Cell: row3/colfam2:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row3/colfam2:qual2/4/Put/vlen=4/seqid=0, Value: val4
Cell: row3/colfam2:qual2/3/Put/vlen=4/seqid=0, Value: val3
Cell: row3/colfam2:qual3/6/Put/vlen=4/seqid=0, Value: val6
```

12. For easier readability, the related details were broken up into groups using blank lines.

```

Cell: row3/colfam2:qual3/5/Put/vlen=4/seqid=0, Value: val5

After delete call...
Cell: row1/colfam1:qual3/6/Put/vlen=4/seqid=0, Value: val6
Cell: row1/colfam1:qual3/5/Put/vlen=4/seqid=0, Value: val5

Cell: row1/colfam2:qual3/6/Put/vlen=4/seqid=0, Value: val6
Cell: row1/colfam2:qual3/5/Put/vlen=4/seqid=0, Value: val5

Cell: row2/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row2/colfam1:qual2/4/Put/vlen=4/seqid=0, Value: val4
Cell: row2/colfam1:qual2/3/Put/vlen=4/seqid=0, Value: val3
Cell: row2/colfam1:qual3/6/Put/vlen=4/seqid=0, Value: val6
Cell: row2/colfam1:qual3/5/Put/vlen=4/seqid=0, Value: val5

Cell: row2/colfam2:qual1/2/Put/vlen=4/seqid=0, Value: val2
Cell: row2/colfam2:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row2/colfam2:qual2/4/Put/vlen=4/seqid=0, Value: val4
Cell: row2/colfam2:qual2/3/Put/vlen=4/seqid=0, Value: val3
Cell: row2/colfam2:qual3/6/Put/vlen=4/seqid=0, Value: val6

Cell: row3/colfam2:qual2/4/Put/vlen=4/seqid=0, Value: val4
Cell: row3/colfam2:qual3/6/Put/vlen=4/seqid=0, Value: val6
Cell: row3/colfam2:qual3/5/Put/vlen=4/seqid=0, Value: val5

```

The deleted original data is highlighted in the *Before delete call...* block. All three rows contain the same data, composed of two column families, three columns in each family, and two versions for each column.

The example code first deletes, from the entire row, everything up to version 4. This leaves the columns with versions 5 and 6 as the remainder of the row content.

It then goes about and uses the two different column-related add calls on `row2` to remove the newest cell in the column named `col fam1:qual1`, and subsequently every cell with a version of 5 and older—in other words, those with a lower version number—from `col fam1:qual3`. Here you have only one matching cell, which is removed as expected in due course.

Lastly, operating on `row-3`, the code removes the entire column family `colfam1`, and then everything with a version of 3 or less from `colfam2`. During the execution of the example code, you will see the printed Cell details, using something like this:

```

System.out.println("Cell: " + cell + ", Value: " +
    Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
    cell.getValueLength()));

```

By now you are familiar with the usage of the Bytes class, which is used to print out the value of the Cell instance, as returned by the `getValueArray()` method. This is necessary because the `Cell.toString()` output (as explained in “[The Cell](#)” ([page 112](#))) is not printing out the actual value, but rather the key part only. The `toString()` does not print the value since it could be very large. Here, the example code inserts the column values, and therefore knows that these are short and human-readable; hence it is safe to print them out on the console as shown. You could use the same mechanism in your own code for debugging purposes.

Please refer to the entire example code in the accompanying source code repository for this book. You will see how the data is inserted and retrieved to generate the discussed output.

What is left to talk about is the error handling of the list-based `delete()` call. The handed-in `deletes` parameter, that is, the list of `Delete` instances, is modified to only contain the failed delete instances when the call returns. In other words, when everything has succeeded, the list will be empty. The call also throws the exception—if there was one—reported from the remote servers. You will have to guard the call using a `try/catch`, for example, and react accordingly. [Example 3-21](#) may serve as a starting point.

Example 3-21. Example deleting faulty data from HBase

```
Delete delete4 = new Delete(Bytes.toBytes("row2"));
    delete4.addColumn(Bytes.toBytes("BOGUS"), Bytes.to-
Bytes("qual1")); ❶
deletes.add(delete4);

try {
    table.delete(deletes); ❷
} catch (Exception e) {
    System.err.println("Error: " + e); ❸
}
table.close();

System.out.println("Deletes length: " + deletes.size()); ❹
for (Delete delete : deletes) {
    System.out.println(delete); ❺
}
```

- ❶ Add bogus column family to trigger an error.
- ❷ Delete the data from multiple rows the HBase table.
- ❸ Guard against remote exceptions.
- ❹ Check the length of the list after the call.
- ❺ Print out failed delete for debugging purposes.

[Example 3-21](#) modifies [Example 3-20](#) but adds an erroneous delete detail: it inserts a BOGUS column family name. The output is the same as that for [Example 3-20](#), but has some additional details printed out in the middle part:

```
Before delete call...
Cell: row1/colfam1:qual1/2/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
...
Cell: row3/colfam2:qual3/6/Put/vlen=4/seqid=0, Value: val6
Cell: row3/colfam2:qual3/5/Put/vlen=4/seqid=0, Value: val5

Deletes length: 1
Error: org.apache.hadoop.hbase.client.RetryException:
Failed 1 action: \
    org.apache.hadoop.hbase.regionserver.NoSuchColumnFamilyException: \
        Column family BOGUS does not exist ...
...
: 1 time,

{"ts":9223372036854775807,"totalColumns":1,"families":{"BOGUS":[{" \
    "timestamp":9223372036854775807,"tag":[],"qualifier": \
    "qual1","vlen":0}], \
    "row":"row2"}}

After delete call...
Cell: row1/colfam1:qual3/6/Put/vlen=4/seqid=0, Value: val6
Cell: row1/colfam1:qual3/5/Put/vlen=4/seqid=0, Value: val5
...
Cell: row3/colfam2:qual3/6/Put/vlen=4/seqid=0, Value: val6
Cell: row3/colfam2:qual3/5/Put/vlen=4/seqid=0, Value: val5
```

As expected, the list contains one remaining Delete instance: the one with the bogus column family. Printing out the instance—Java uses the implicit `toString()` method when *printing* an object—reveals the internal details of the failed delete. The important part is the family name being the obvious reason for the failure. You can use this technique in your own code to check why an operation has failed. Often the reasons are rather obvious indeed.

Finally, note the exception that was caught and printed out in the catch statement of the example. It is the same `RetryException` you saw twice already. It reports the number of failed actions plus how often it did retry to apply them, and on which server. An advanced task that you will learn about in later chapters (for example (to come)) is how to verify and monitor servers so that the given server address could be useful to find the root cause of the failure. [Table 3-11](#) had a list of available methods.

Atomic Check-and-Delete

You saw in “[Atomic Check-and-Put](#)” (page 144) how to use an atomic, conditional operation to insert data into a table. There are equivalent calls for deletes that give you access to server-side, *read-modify-write* functionality:

```
boolean checkAndDelete(byte[] row, byte[] family, byte[] qualifier,  
    byte[] value, Delete delete) throws IOException  
boolean checkAndDelete(byte[] row, byte[] family, byte[] qualifier,  
    CompareFilter.CompareOp compareOp, byte[] value, Delete delete)  
    throws IOException
```

You need to specify the row key, column family, qualifier, and value to check before the actual delete operation is performed. The first call implies that the given value has to *equal* to the stored one. The second call lets you specify the actual comparison operator (explained in “[Comparison Operators](#)” (page 221)), which enables more elaborate testing, for example, if the given value is *equal or less* than the stored one. This is useful to track some kind of modification ID, and you want to ensure you have reached a specific point in the cells lifecycle, for example, when it is updated by many concurrent clients.

Should the test fail, nothing is deleted and the call returns a `false`. If the check is successful, the delete is applied and `true` is returned. [Example 3-22](#) shows this in context.

Example 3-22. Example application using the atomic compare-and-set operations

```
Delete delete1 = new Delete(Bytes.toBytes("row1"));  
    delete1.addColumn(Bytes.toBytes("colfam1"), Bytes.to-  
Bytes("qual3")); ❶  
  
boolean res1 = table.checkAndDelete(Bytes.toBytes("row1"),  
    Bytes.toBytes("colfam2"), Bytes.toBytes("qual3"), null, de-  
lete1); ❷  
System.out.println("Delete 1 successful: " + res1); ❸  
  
Delete delete2 = new Delete(Bytes.toBytes("row1"));  
    delete2.addColumn(Bytes.toBytes("colfam2"), Bytes.to-  
Bytes("qual3")); ❹  
table.delete(delete2);  
  
boolean res2 = table.checkAndDelete(Bytes.toBytes("row1"),  
    Bytes.toBytes("colfam2"), Bytes.toBytes("qual3"), null, de-  
lete1); ❺  
System.out.println("Delete 2 successful: " + res2); ❻  
  
Delete delete3 = new Delete(Bytes.toBytes("row2"));  
delete3.addFamily(Bytes.toBytes("colfam1")); ❻
```

```

try{
    boolean res4 = table.checkAndDelete(Bytes.toBytes("row1"),
        Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"), ⑧
        Bytes.toBytes("val1"), delete3);
    System.out.println("Delete 3 successful: " + res4); ⑨
} catch (Exception e) {
    System.err.println("Error: " + e.getMessage());
}

```

- ➊ Create a new Delete instance.
- ➋ Check if column does not exist and perform optional delete operation.
- ➌ Print out the result, should be “Delete successful: false”.
- ➍ Delete checked column manually.
- ➎ Attempt to delete same cell again.
- ➏ Print out the result, should be “Delete successful: true” since the checked column now is gone.
- ➐ Create yet another Delete instance, but using a different row.
- ➑ Try to delete while checking a different row.
- ➒ We will not get here as an exception is thrown beforehand!

Here is the output you should see:

```

Before delete call...
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual2/2/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam1:qual3/3/Put/vlen=4/seqid=0, Value: val3
Cell: row1/colfam2:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam2:qual2/2/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam2:qual3/3/Put/vlen=4/seqid=0, Value: val3
Delete 1 successful: false
Delete 2 successful: true

Error: org.apache.hadoop.hbase.DoNotRetryIOException: \
Action's getRow must match the passed row
...
After delete call...
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual2/2/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam2:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam2:qual2/2/Put/vlen=4/seqid=0, Value: val2

```

Using `null` as the `value` parameter triggers the *nonexistence* test, that is, the check is successful if the column specified does *not* exist. Since the example code inserts the checked column before the check

is performed, the test will initially fail, returning `false` and aborting the delete operation. The column is then deleted by hand and the check-and-modify call is run again. This time the check succeeds and the delete is applied, returning `true` as the overall result.

Just as with the put-related CAS call, you can only perform the check-and-modify on the same row. The example attempts to check on one row key while the supplied instance of `Delete` points to another. An exception is thrown accordingly, once the check is performed. It is allowed, though, to check across column families—for example, to have one set of columns control how the filtering is done for another set of columns.

This example cannot justify the importance of the check-and-delete operation. In distributed systems, it is inherently difficult to perform such operations reliably, and without incurring performance penalties caused by external locking approaches, that is, where the atomicity is guaranteed by the client taking out exclusive locks on the entire row. When the client goes away during the locked phase the server has to rely on lease recovery mechanisms ensuring that these rows are eventually unlocked again. They also cause additional RPCs to occur, which will be slower than a single, server-side operation.

Append Method

Similar to the generic CRUD functions so far, there is another kind of mutation function, like `put()`, but with a spin on it. Instead of creating or updating a column value, the `append()` method does an atomic *read-modify-write* operation, adding data to a column. The API method provided is:

```
Result append(final Append append) throws IOException
```

And similar once more to all other API data manipulation functions so far, this call has an accompanying class named `Append`. You create an instance with one of these constructors:

```
Append(byte[] row)
Append(final byte[] rowArray, final int rowOffset, final int rowLength)
Append(Append a)
```

So you either provide the obvious `row` key, or an existing, larger array holding that `byte[]` array as a subset, plus the necessary offset and length into it. The third choice, analog to all the other data-related types, is to hand in an existing `Append` instance and copy all its parameters. Once the instance is created, you move along and add details of the column you want to append to, using one of these calls:

```
Append add(byte[] family, byte[] qualifier, byte[] value)
Append add(final Cell cell)
```

Like with `Put`, you *must* call one of those functions, or else a subsequent call to `append()` will throw an exception. This does make sense as you cannot insert or append to the entire row. Note that this is different from `Delete`, which of course can delete an entire row. The first provided method takes the column family and qualifier (the column) name, plus the value to add to the existing. The second copies all of these parameters from an existing cell instance. [Example 3-23](#) shows the use of `append` on an existing and empty column.

Example 3-23. Example application appending data to a column in HBase

```
Append append = new Append(Bytes.toBytes("row1"));
append.add(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    Bytes.toBytes("newvalue"));
append.add(Bytes.toBytes("colfam1"), Bytes.toBytes("qual2"),
    Bytes.toBytes("anothervalue"));

table.append	append);
```

The output should be:

```
Before append call...
Cell: row1/colfam1:qual1/1/Put/vlen=8/seqid=0, Value: oldvalue
After append call...
Cell: row1/colfam1:qual1/1/1426778944272/Put/vlen=16/seqid=0,
    Value: oldvaluenewvalue
Cell: row1/colfam1:qual1/1/Put/vlen=8/seqid=0, Value: oldvalue
Cell: row1/colfam1:qual2/1426778944272/Put/vlen=12/seqid=0,
    Value: anothervalue
```

You will note in the output how we appended `newvalue` to the existing `oldvalue` for `qual1`. We also added a brand new column with `qual2`, that just holds the new value `anothervalue`. The `append` operation is binary, as is all the value related functionality in HBase. In other words, we appended two *strings* but in reality we appended two `byte[]` arrays. If you use the `append` feature, you may have to insert some delimiter to later parse the appended bytes into separate parts again.

One special option of `append()` is to *not* return any data from the servers. This is accomplished with this pair of methods:

```
Append setReturnResults(boolean returnResults)
boolean isReturnResults()
```

Usually, the newly updated cells are returned to the caller. But if you want to send the `append` to the server, and you do not care about the

result(s) at this point, you can call `setReturnResults(false)` to omit the shipping. It will then return `null` to you instead. The Append class provides additional calls, which are listed in [Table 3-16](#) for your reference. Once again, many are inherited from the superclasses, such as `Mutation`.

Table 3-16. Quick overview of additional methods provided by the Append class

Method	Description
<code>cellScanner()</code>	Provides a scanner over all cells available in this instance.
<code>getACL()/setACL()</code>	The ACLs for this operation (might be <code>null</code>).
<code>getAttribute()/setAttribute()</code>	Set and get arbitrary attributes associated with this instance of Append.
<code>getAttributesMap()</code>	Returns the entire map of attributes, if any are set.
<code>getCellVisibility()/setCellVisibility()</code>	The cell level visibility for all included cells.
<code>getClusterIds()/setClusterIds()</code>	The cluster IDs as needed for replication purposes.
<code>getDurability()/setDurability()</code>	The durability settings for the mutation.
<code>getFamilyCellMap()/setFamilyCellMap()</code>	The list of all cells of this instance.
<code>getFingerprint()</code>	Compiles details about the instance into a map for debugging, or logging.
<code>getId()/setId()</code>	An ID for the operation, useful for identifying the origin of a request later.
<code>getRow()</code>	Returns the row key as specified when creating the Append instance.
<code>getTimeStamp()</code>	Retrieves the associated timestamp of the Append instance.
<code>getTTL()/setTTL()</code>	Sets the cell level TTL value, which is being applied to all included Cell instances before being persisted.
<code>heapSize()</code>	Computes the heap space required for the current Append instance. This includes all contained data and space needed for internal structures.
<code>isEmpty()</code>	Checks if the family map contains any Cell instances.
<code>numFamilies()</code>	Convenience method to retrieve the size of the family map, containing all Cell instances.
<code>size()</code>	Returns the number of Cell instances that will be applied with this Append.
<code>toJSON()/toJSON(int)</code>	Converts the first 5 or N columns into a JSON format.

Method	Description
toMap()/toMap(int)	Converts the first 5 or N columns into a map. This is more detailed than what getFingerprint() returns.
toString()/toString(int)	Converts the first 5 or N columns into a JSON, or map (if JSON fails due to encoding problems).

Mutate Method

Analog to all the other groups of operations, we can separate the *mutate* calls into separate ones. One difference is though that we do not have a list based version, but single mutations and the atomic compare-and-mutate. We will discuss them now in order.

Single Mutations

So far all operations had their specific method in Table and a specific data-related type provided. But what if you want to update a row across these operations, and doing so atomically. That is where the `mutateRow()` call comes in. It has the following signature:

```
void mutateRow(final RowMutations rm) throws IOException
```

The `RowMutations` based parameter is a container that accepts either `Put` or `Delete` instance, and then applies both in one call to the server-side data. The list of available constructors and methods for the `RowMutations` class is:

```
RowMutations(byte[] row)

add(Delete)
add(Put)
getMutations()
getRow()
```

You create an instance with a specific row key, and then add any delete or put instance you have. The row key you used to create the `RowMutations` instance *must* match the row key of any mutation you add, or else you will receive an exception when trying to add them. [Example 3-24](#) shows a working example.

Example 3-24. Modifies a row with multiple operations

```
Put put = new Put(Bytes.toBytes("row1"));
put.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    4, Bytes.toBytes("val99"));
put.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual4"),
    4, Bytes.toBytes("val100"));

Delete delete = new Delete(Bytes.toBytes("row1"));
delete.addColumn(Bytes.toBytes("colfam1"), Bytes.to-
```

```

Bytes("qual2"));

RowMutations mutations = new RowMutations(Bytes.toBytes("row1"));
mutations.add(put);
mutations.add(delete);

table.mutateRow(mutations);

```

The output should read like this:

```

Before delete call...
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual2/2/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam1:qual3/3/Put/vlen=4/seqid=0, Value: val3
After mutate call...
Cell: row1/colfam1:qual1/4/Put/vlen=5/seqid=0, Value: val99
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual3/3/Put/vlen=4/seqid=0, Value: val3
Cell: row1/colfam1:qual4/4/Put/vlen=6/seqid=0, Value: val100

```

With one call did we update `row1`, with column name `qual1`, setting it to a new value of `val99`. We also added a whole new column, named `qual4`, with a value of `val100`. Finally, at the same time we removed one column from the same row, namely column `qual2`.

Atomic Check-and-Mutate

You saw earlier, for example in “[Atomic Check-and-Delete](#)” (page 179), how to use an atomic, conditional operation to modify data in a table. There are equivalent calls for mutations that give you access to server-side, *read-modify-write* functionality:

```

public boolean checkAndMutate(final byte[] row, final byte[] family,
    final byte[] qualifier, final CompareOp compareOp, final byte[] value,
    final RowMutations rm) throws IOException

```

You need to specify the row key, column family, qualifier, and value to check before the actual list of mutations is applied. The call lets you specify the actual comparison operator (explained in “[Comparison Operators](#)” (page 221)), which enables more elaborate testing, for example, if the given value is *equal or less* than the stored one. This is useful to track some kind of modification ID, and you want to ensure you have reached a specific point in the cells lifecycle, for example, when it is updated by many concurrent clients.

Should the test fail, nothing is applied and the call returns a `false`. If the check is successful, the mutations are applied and `true` is returned. [Example 3-25](#) shows this in context.

Example 3-25. Example using the atomic check-and-mutate operations

```
Put put = new Put(Bytes.toBytes("row1"));
put.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1"),
    4, Bytes.toBytes("val99"));
put.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual4"),
    4, Bytes.toBytes("val100"));

Delete delete = new Delete(Bytes.toBytes("row1"));
    delete.addColumn(Bytes.toBytes("colfam1"), Bytes.to-
Bytes("qual2"));

RowMutations mutations = new RowMutations(Bytes.toBytes("row1"));
mutations.add(put);
mutations.add(delete);

boolean res1 = table.checkAndMutate(Bytes.toBytes("row1"),
    Bytes.toBytes("colfam2"), Bytes.toBytes("qual1"),
    CompareFilter.CompareOp.LESS, Bytes.toBytes("val1"), muta-
tions); ❶
System.out.println("Mutate 1 successful: " + res1);

Put put2 = new Put(Bytes.toBytes("row1"));
put2.addColumn(Bytes.toBytes("colfam2"), Bytes.toBytes("qual1"),
    ❷
    4, Bytes.toBytes("val2"));
table.put(put2);

boolean res2 = table.checkAndMutate(Bytes.toBytes("row1"),
    Bytes.toBytes("colfam2"), Bytes.toBytes("qual1"),
    CompareFilter.CompareOp.LESS, Bytes.toBytes("val1"), muta-
tions); ❸
System.out.println("Mutate 2 successful: " + res2);
```

- ❶ Check if the column contains a value that is less than “val1”. Here we receive “false” as the value is equal, but not lesser.
- ❷ Now “val1” is less than “val2” (binary comparison) and we expect “true” to be printed on the console.
- ❸ Update the checked column to have a value greater than what we check for.

Here is the output you should see:

```
Before check and mutate calls...
Cell: row1:colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1:colfam1:qual2/2/Put/vlen=4/seqid=0, Value: val2
Cell: row1:colfam1:qual3/3/Put/vlen=4/seqid=0, Value: val3
Cell: row1:colfam2:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1:colfam2:qual2/2/Put/vlen=4/seqid=0, Value: val2
```

```
Cell: row1/colfam2:qual3/3/Put/vlen=4/seqid=0, Value: val3
Mutate 1 successful: false
Mutate 2 successful: true
After check and mutate calls...
Cell: row1/colfam1:qual1/4/Put/vlen=5/seqid=0, Value: val99
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual3/3/Put/vlen=4/seqid=0, Value: val3
Cell: row1/colfam1:qual4/4/Put/vlen=6/seqid=0, Value: val100
Cell: row1/colfam2:qual1/4/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam2:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam2:qual2/2/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam2:qual3/3/Put/vlen=4/seqid=0, Value: val3
```

Just as before, using `null` as the `value` parameter triggers the *non-existence* test, that is, the check is successful if the column specified does *not* exist. Since the example code inserts the checked column before the check is performed, the test will initially fail, returning `false` and aborting the operation. The column is then updated by hand and the check-and-modify call is run again. This time the check succeeds and the mutations are applied, returning `true` as the overall result.

Different to the earlier examples is that the [Example 3-25](#) is using a LESS comparison for the check: it specifies a column and asks the server to verify that the given value (`val1`) is *less than* the currently stored value. They are exactly equal and therefore the test will fail. Once the value is increased, the second test succeeds with the check and proceeds as expected.

As with the put- or delete-related CAS call, you can only perform the check-and-modify operation on the same row. The earlier [Example 3-22](#) did showcase this with a cross-row check. We omit this here for the sake of brevity.

Batch Operations

You have seen how you can add, retrieve, and remove data from a table using single or list-based operations, applied to a single row. In this section, we will look at API calls to batch different operations across multiple rows.

In fact, a lot of the internal functionality of the list-based calls, such as `delete(List<Delete> deletes)` or `get(List<Get> gets)`, is based on the `batch()` call introduced here. They are more or less legacy calls and kept for convenience. If you start fresh, it is recommended that you use the `batch()` calls for all your operations.

The following methods of the client API represent the available batch operations. You may note the usage of Row, which is the ancestor, or parent class, for Get and all Mutation based types, such as Put, as explained in “Data Types and Hierarchy” (page 103).

```
void batch(final List<? extends Row> actions, final Object[] results)
    throws IOException, InterruptedException
void batchCallback(final List<? extends Row> actions, final Object[] results,
    final Batch.Callback<R> callback) throws IOException, InterruptedException
```

Using the same parent class allows for polymorphic list items, representing any of the derived operations. It is equally easy to use these calls, just like the list-based methods you saw earlier. [Example 3-26](#) shows how you can mix the operations and then send them off as one server call.

Be careful if you mix a Delete and Put operation for the same row in one batch call. There is no guarantee that they are applied in order and might cause indeterminate results.

Example 3-26. Example application using batch operations

```
List<Row> batch = new ArrayList<Row>(); ①
Put put = new Put(ROW2);
put.addColumn(COLFAM2, QUAL1, 4, Bytes.toBytes("val5")); ②
batch.add(put);

Get get1 = new Get(ROW1);
get1.addColumn(COLFAM1, QUAL1); ③
batch.add(get1);

Delete delete = new Delete(ROW1);
delete.addColumns(COLFAM1, QUAL2); ④
batch.add(delete);

Get get2 = new Get(ROW2);
get2.addFamily(Bytes.toBytes("BOGUS")); ⑤
batch.add(get2);

Object[] results = new Object[batch.size()]; ⑥
try {
    table.batch(batch, results);
} catch (Exception e) {
```

```

        System.err.println("Error: " + e); ⑦
    }

    for (int i = 0; i < results.length; i++) {
        System.out.println("Result[" + i + "]: type = " + ⑧
            results[i].getClass().getSimpleName() + "; " + results[i]);
    }

```

① Create a list to hold all values.
② Add a Put instance.
③ Add a Get instance for a different row.
④ Add a Delete instance.
⑤ Add a Get instance that will fail.
⑥ Create result array.
⑦ Print error that was caught.
⑧ Print all results and class types.

You should see the following output on the console:

```

Before batch call...
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual2/2/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam1:qual3/3/Put/vlen=4/seqid=0, Value: val3

Error:  org.apache.hadoop.hbase.client.RetryException: 
sException: \
  Failed 1 action: \
    org.apache.hadoop.hbase.regionserver.NoSuchColumnFamilyException: \
      Column family BOGUS does not exist in ...
    ...
: 1 time,

Result[0]: type = Result; keyvalues=NONE
Result[1]: type = Result; keyvalues={row1/colfam1:qual1/1/Put/
vlen=4/seqid=0}
Result[2]: type = Result; keyvalues=NONE
Result[3]: type = NoSuchColumnFamilyException; \
  org.apache.hadoop.hbase.regionserver.NoSuchColumnFamilyException: \
    org.apache.hadoop.hbase.regionserver.NoSuchColumnFamilyException: \
      Column family BOGUS does not exist in ...
    ...
After batch call...
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual3/3/Put/vlen=4/seqid=0, Value: val3
Cell: row2/colfam2:qual1/4/Put/vlen=4/seqid=0, Value: val5

```

As with the previous examples, there is some wiring behind the printed lines of code that inserts a test row before executing the batch calls. The content is printed first, then you will see the output from the example code, and finally the dump of the rows *after* everything else. The deleted column was indeed removed, and the new column was added to the row as expected.

Finding the result of the Get operation requires you to investigate the middle part of the output, that is, the lines printed by the example code. The lines starting with `Result[n]`--with `n` ranging from zero to 3—is where you see the outcome of the corresponding operation in the batch parameter. The first operation in the example is a Put, and the result is an empty `Result` instance, containing no `Cell` instances. This is the general contract of the batch calls; they return a best match result per input action, and the possible types are listed in [Table 3-17](#).

Table 3-17. Possible result values returned by the batch() calls

Result	Description
<code>null</code>	The operation has failed to communicate with the remote server.
<code>Empty Result</code>	Returned for successful Put and Delete operations.
<code>Result</code>	Returned for successful Get operations, but may also be empty when there was no matching row or column.
<code>Throwable</code>	In case the servers return an exception for the operation it is returned to the client as-is. You can use it to check what went wrong and maybe handle the problem automatically in your code.

Looking through the returned result array in the console output you can see the empty `Result` instances returned by the Put operation, and printing `keyvalues=NONE` (`Result[0]`). The Get call also succeeded and found a match, returning the `Cell` instances accordingly (`Result[1]`). The Delete succeeded as well, and returned an empty `Result` instance (`Result[2]`). Finally, the operation with the BOGUS column family has the exception for your perusal (`Result[3]`).

When you use the `batch()` functionality, the included Put instances will not be buffered using the client-side write buffer. The `batch()` calls are synchronous and send the operations directly to the servers; no delay or other intermediate processing is used. This is obviously different compared to the `put()` calls, so choose which one you want to use carefully.

All the operations are grouped by the destination region servers first and then sent to the servers, just as explained and shown in [Figure 3-2](#). Here we send many different operations though, not just Put instances. The rest stays the same though, including the note there around the executor pool used and its upper boundary on number of region servers (also see the `hbasehtablethreadsmax` configuration property). Suffice it to say that all operations are sent to all affected servers in parallel, making this very efficient.

In addition, all batch operations are executed before the results are checked: even if you receive an error for one of the actions, all the other ones have been applied. In a worst-case scenario, all actions might return faults, though. On the other hand, the batch code is aware of transient errors, such as the `NotServingRegionException` (indicating, for instance, that a region has been moved), and is trying to apply the action(s) multiple times. The `hbaseclientretriesnumber` configuration property (by default set to 35) can be adjusted to increase, or reduce, the number of retries.

There are two different batch calls that look very similar. The code in [Example 3-26](#) makes use of the first variant. The second one allows you to supply a callback instance (shared from the coprocessor package, more in [“Coprocessors” \(page 282\)](#)), which is invoked by the client library as it receives the responses from the asynchronous and parallel calls to the server(s). You need to implement the `Batch.Callback` interface, which provides the `update()` method called by the library. [Example 3-27](#) is a spin on the original example, just adding the callback instance—here implemented as an anonymous inner class.

Example 3-27. Example application using batch operations with callbacks

```
List<Row> batch = new ArrayList<Row>(); ①  
Put put = new Put(ROW2);  
put.addColumn(COLFAM2, QUAL1, 4, Bytes.toBytes("val5")); ②  
batch.add(put);  
  
Get get1 = new Get(ROW1);  
get1.addColumn(COLFAM1, QUAL1); ③  
batch.add(get1);  
  
Delete delete = new Delete(ROW1);  
delete.addColumns(COLFAM1, QUAL2); ④  
batch.add(delete);  
  
Get get2 = new Get(ROW2);  
get2.addFamily(Bytes.toBytes("BOGUS")); ⑤  
batch.add(get2);
```

```

Object[] results = new Object[batch.size()]; ❶
try {
    table.batchCallback(batch, results, new Batch.Callback<Re-
sult>() {
        @Override
        public void update(byte[] region, byte[] row, Result result) {
            System.out.println("Received callback for row[" +
                Bytes.toString(row) + "] -> " + result);
        }
    });
} catch (Exception e) {
    System.err.println("Error: " + e); ❷
}

for (int i = 0; i < results.length; i++) {
    System.out.println("Result[" + i + "]: type = " + ❸
        results[i].getClass().getSimpleName() + "; " + results[i]);
}

```

- ❶ Create a list to hold all values.
- ❷ Add a Put instance.
- ❸ Add a Get instance for a different row.
- ❹ Add a Delete instance.
- ❺ Add a Get instance that will fail.
- ❻ Create result array.
- ❼ Print error that was caught.
- ❽ Print all results and class types.

You should see the same output as in the example before, but with the additional information emitted from the callback implementation, looking similar to this (further shortened for the sake of brevity):

```

Before delete call...
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual2/2/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam1:qual3/3/Put/vlen=4/seqid=0, Value: val3
Received callback for row[row2] ->
  keyvalues=NONE
Received callback for row[row1] ->
  keyvalues={row1/colfam1:qual1/1/Put/vlen=4/seqid=0}
Received callback for row[row1] ->
  keyvalues=NONE
Error: org.apache.hadoop.hbase.client.RetryExhaustedWithDetail-
sException:
  Failed 1 action:
  ...
  : 1 time,

```

```

Result[0]: type = Result; keyvalues=NULL
Result[1]: type = Result; keyvalues={row1/colfam1:qual1/1/Put/
vlen=4/seqid=0}
Result[2]: type = Result; keyvalues=NULL
Result[3]: type = NoSuchColumnFamilyException;
    org.apache.hadoop.hbase.regionserver.NoSuchColumnFamilyException:
    ...
After batch call...
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual3/3/Put/vlen=4/seqid=0, Value: val3
Cell: row2/colfam2:qual1/4/Put/vlen=4/seqid=0, Value: val5

```

The `update()` method in our example just prints out the information it has been given, here the row key and the result of the operation. Obviously, in a more serious application the callback can be used to immediately react to results coming back from servers, instead of waiting for all of them to complete. Keep in mind that the overall runtime of the `batch()` call is dependent on the slowest server to respond, maybe even to timeout after many retries. Using the callback can improve client responsiveness as perceived by its users.

Scans

Now that we have discussed the basic CRUD-type operations, it is time to take a look at *scans*, a technique akin to *cursors*¹³ in database systems, which make use of the underlying sequential, sorted storage layout HBase is providing.

Introduction

Use of the scan operations is very similar to the `get()` methods. And again, similar to all the other functions, there is also a supporting class, named `Scan`. But since scans are similar to iterators, you do not have a `scan()` call, but rather a `getScanner()`, which returns the actual scanner instance you need to iterate over. The available methods are:

```

ResultScanner getScanner(Scan scan) throws IOException
ResultScanner getScanner(byte[] family) throws IOException
ResultScanner getScanner(byte[] family, byte[] qualifier)
    throws IOException

```

13. Scans are similar to *nonscrollable* cursors. You need to *declare*, *open*, *fetch*, and eventually *close* a database cursor. While scans do not need the declaration step, they are otherwise used in the same way. See “[Cursors](#)” on Wikipedia.

The latter two are for your convenience, implicitly creating an instance of Scan on your behalf, and subsequently calling the `getScanner(Scan scan)` method.

The Scan class has the following constructors:

```
Scan()
Scan(byte[] startRow, Filter filter)
Scan(byte[] startRow)
Scan(byte[] startRow, byte[] stopRow)
Scan(Scan scan) throws IOException
Scan(Get get)
```

The difference between this and the Get class is immediately obvious: instead of specifying a single row key, you now can optionally provide a `startRow` parameter—defining the row key where the scan begins to read from the HBase table. The optional `stopRow` parameter can be used to limit the scan to a specific row key where it should conclude the reading.

The start row is always inclusive, while the end row is exclusive. This is often expressed as `[startRow, stopRow)` in the interval notation.

A special feature that scans offer is that you do *not* need to have an exact match for either of these rows. Instead, the scan will match the first row key that is *equal to* or *larger than* the given start row. If no start row was specified, it will start at the beginning of the table. It will also end its work when the current row key is *equal to* or *greater* than the optional stop row. If no stop row was specified, the scan will run to the end of the table.

There is another optional parameter, named `filter`, referring to a `Filter` instance. Often, though, the `Scan` instance is simply created using the empty constructor, as all of the optional parameters also have matching getter and setter methods that can be used instead.

Like with the other data-related types, there is a convenience constructor to copy all parameter from an existing `Scan` instance. There is also one that does the same from an existing `Get` instance. You might be wondering why: the `get` and `scan` functionality is actually the same on the server side. The *only* difference is that for a `Get` the scan has to *include* the stop row into the scan, since both, the start and stop row are set to the same value. You will soon see that the `Scan` type has more functionality over `Get`, but just because of its iterative nature. In

addition, when using this constructor based on a Get instance, the following method of Scan will return true as well:

```
boolean isGetScan()
```

Once you have created the Scan instance, you may want to add more limiting details to it—but you are also allowed to use the empty scan, which would read the entire table, including all column families and their columns. You can narrow down the read data using various methods:

```
Scan addFamily(byte [] family)
Scan addColumn(byte[] family, byte[] qualifier)
```

There is a lot of similar functionality compared to the Get class: you may limit the data returned by the scan by setting the column families to specific ones using `addFamily()`, or, even more constraining, to only include certain columns with the `addColumn()` call.

If you only need subsets of the data, narrowing the scan's scope is playing into the strengths of HBase, since data is stored in column families and omitting entire families from the scan results in those storage files not being read at all. This is the power of column family-oriented architecture at its best.

Scan has other methods that are selective in nature, here the first set that center around the cell versions returned:

```
Scan setTimeStamp(long timestamp) throws IOException
Scan setTimeRange(long minStamp, long maxStamp) throws IOException
TimeRange getTimeRange()
Scan setMaxVersions()
Scan setMaxVersions(int maxVersions)
int getMaxVersions()
```

The `setTimeStamp()` method is shorthand for setting a time range with `setTimeRange(time, time + 1)`, both resulting in a selection of cells that match the set range. Obviously the former is very specific, selecting exactly one timestamp. `getTimeRange()` returns what was set by either method. How many cells per column—in other words, how many versions—are returned by the scan is controlled by `setMaxVersions()`, where one sets it to the given number, and the other to *all* versions. The accompanying getter `getMaxVersions()` returns what was set.

The next set of methods relate to the rows that are included in the scan:

```
Scan setStartRow(byte[] startRow)
byte[] getStartRow()
Scan setStopRow(byte[] stopRow)
byte[] getStopRow()
Scan setRowPrefixFilter(byte[] rowPrefix)
```

Using `setStartRow()` and `setStopRow()` you can define the same parameters the constructors exposed, all of them limiting the returned data even further, as explained earlier. The matching getters return what is currently set (might be `null` since both are optional). The `setRowPrefixFilter()` method is shorthand to set the start row to the value of the `rowPrefix` parameter and the stop row to the next key that is *greater than the current key*: There is logic in place to increment the binary key in such a way that it properly computes the next larger value. For example, assume the row key is { 0x12, 0x23, 0xFF, 0xFF }, then incrementing it results in { 0x12, 0x24 }, since the last two bytes were already at their maximum value.

Next, there are methods around filters:

```
Filter getFilter()
Scan setFilter(Filter filter)
boolean hasFilter()
```

Filters are a special combination of time range *and* row based selectors. They go even further by also adding column family and column name selection support. “[Filters](#)” (page 219) explains them in full detail, so for now please note that `setFilter()` assigns one or more filters to the scan. The `getFilter()` call returns the current one—if set before--, and `hasFilter()` lets you check if there is one set or not.

Then there are a few more specific methods provided by `Scan`, that handle particular use-cases. You might consider them for advanced users only, but they really are straight forward, so let us discuss them now, starting of with:

```
Scan setReversed(boolean reversed)
boolean isReversed()
Scan setRaw(boolean raw)
boolean isRaw()
Scan setSmall(boolean small)
boolean isSmall()
```

The first pair enables the application to not iterate *forward-only* (as per the aforementioned cursor reference) over rows, but do the same in reverse. Traditionally, HBase only provided the forward scans, but

recent versions¹⁴ of HBase introduced the reverse option. Since data is sorted ascending (see (to come) for details), doing a reverse scan involves some more involved processing. In other words, reverse scans are slightly slower than forward scans, but alleviate the previous necessity of building application-level lookup indexes for both directions. Now you can do the same with a single one (we discuss this in (to come)).

One more subtlety to point out about reverse scans is that the reverse direction is per-row, but not within a row. You still receive each row in a scan as if you were doing a forward scan, that is, from the lowest lexicographically sorted column/cell ascending to the highest. Just each call to `next()` on the scanner will return the previous row (or n rows) to you. More on iterating over rows is discussed in “[The ResultScanner Class](#)” (page 199). Finally, when using reverse scans you also need to flip around any start and stop row value, or you will not find anything at all (see [Example 3-28](#)). In other words, if you want to scan, for example, row 20 to 10, you need to set the start row to 20, and the stop row to 09 (assuming padding, and taking into consideration that the stop row specified is excluded from the scan).

The second pair of methods, lead by `setRaw()`, switches the scanner into a special mode, returning every cell it finds. This includes deleted cells that have not yet been removed physically, and also the delete markers, as discussed in “[Single Deletes](#)” (page 169), and “[The Cell](#)” (page 112). This is useful, for example, during backups, where you want to move *everything* from one cluster to another, including deleted data. Making this more useful is the `HColumnDescriptor.setKeepDeletedCells()` method you will learn about in “[Column Families](#)” (page 362).

The last pair of methods deal with *small* scans. These are scans that only ever need to read a very small set of data, which can be returned in a single RPC. Calling `setSmall(true)` on a scan instance instructs the client API to *not* do the usual *open scanner, fetch data, and close scanner* combination of remote procedure calls, but do them in one single call. There are also some server-side read optimizations in this mode, so the scan is as fast as possible.

14. This was added in HBase 0.98, with [HBASE-4811](#).

What is the threshold to consider *small* scans? The rule of thumb is, that the data scanned should ideally fit into one data block. By default the size of a block is 64KB, but might be different if customized cluster- or column family-wide. But this is no hard limit, the scan might exceed a single block.

The `isReversed()`, `isRaw()`, and `isSmall()` return `true` if the respective setter has been invoked beforehand.

The `Scan` class provides additional calls, which are listed in [Table 3-18](#) for your perusal. As before, you should recognize many of them as inherited methods from the `Query` superclass. There are more methods described separately in the subsequent sections, since they warrant a longer explanation.

Table 3-18. Quick overview of additional methods provided by the Scan class

Method	Description
<code>getACL()/setACL()</code>	The Access Control List (ACL) for this operation. See (to come) for details.
<code>getAttribute()/setAttribute()</code>	Set and get arbitrary attributes associated with this instance of <code>Scan</code> .
<code>getAttributesMap()</code>	Returns the entire map of attributes, if any are set.
<code>getAuthorizations()/setAuthorizations()</code>	Visibility labels for the operation. See (to come) for details.
<code>getCacheBlocks()/setCacheBlocks()</code>	Specify if the server-side cache should retain blocks that were loaded for this operation.
<code>getConsistency()/setConsistency()</code>	The consistency level that applies to the current query instance.
<code>getFamilies()</code>	Returns an array of all stored families, i.e., containing only the family names (as <code>byte[]</code> arrays).
<code>getFamilyMap()/setFamilyMap()</code>	These methods give you access to the column families and specific columns, as added by the <code>addFamily()</code> and/or <code>addColumn()</code> calls. The family map is a map where the key is the family name and the value is a list of added column qualifiers for this particular family.
<code>getFilter()/setFilter()</code>	The filters that apply to the retrieval operation. See " Filters " (page 219) for details.
<code>getFingerprint()</code>	Compiles details about the instance into a map for debugging, or logging.

Method	Description
getId()/setId()	An ID for the operation, useful for identifying the origin of a request later.
getIsolationLevel()/setIsolationLevel()	Specifies the read isolation level for the operation.
getReplicaId()/setReplicaId()	Gives access to the replica ID that should serve the data.
numFamilies()	Retrieves the size of the family map, containing the families added using the addFamily() or addColumn() calls.
hasFamilies()	Another helper to check if a family—or column—has been added to the current instance of the Scan class.
toJSON()/toJSON(int)	Converts the first 5 or N columns into a JSON format.
toMap()/toMap(int)	Converts the first 5 or N columns into a map. This is more detailed than what getFingerprint() returns.
toString()/toString(int)	Converts the first 5 or N columns into a JSON, or map (if JSON fails due to encoding problems).

Refer to the end of “[Single Gets](#)” ([page 147](#)) for an explanation of the above methods, for example setCacheBlocks(). Others are explained in “[Data Types and Hierarchy](#)” ([page 103](#)).

Once you have configured the Scan instance, you can call the Table method, named getScanner(), to retrieve the ResultScanner instance. We will discuss this class in more detail in the next section.

The ResultScanner Class

Scans usually do not ship all the matching rows in one RPC to the client, but instead do this on a per-row basis. This obviously makes sense as rows could be very large and sending thousands, and most likely more, of them in one call would use up too many resources, and take a long time.

The ResultScanner converts the scan into a get-like operation, wrapping the Result instance for each row into an iterator functionality. It has a few methods of its own:

```
Result next() throws IOException
Result[] next(int nbRows) throws IOException
void close()
```

You have two types of `next()` calls at your disposal. The `close()` call is required to release all the resources a scan may hold explicitly.

Scanner Leases

Make sure you release a scanner instance as quickly as possible. An open scanner holds quite a few resources on the server side, which could accumulate to a large amount of heap space being occupied. When you are done with the current scan call `close()`, and consider adding this into a `try/finally`, or the previously explained `try-with-resources` construct to ensure it is called, even if there are exceptions or errors during the iterations.

The example code does not follow this advice for the sake of brevity only.

Like row locks, scanners are protected against stray clients blocking resources for too long, using the same lease-based mechanisms. You need to set the same configuration property to modify the timeout threshold (in milliseconds):¹⁵

```
<property>
  <name>hbase.client.scanner.timeout.period</name>
  <value>120000</value>
</property>
```

You need to make sure that the property is set to a value that makes sense for locks as well as the scanner leases.

The `next()` calls return a single instance of `Result` representing the next available row. Alternatively, you can fetch a larger number of rows using the `next(int nbRows)` call, which returns an array of up to `nbRows` items, each an instance of `Result` and representing a unique row. The resultant array may be shorter if there were not enough rows left—or could even be empty. This obviously can happen just before you reach—or are at—the end of the table, or the stop row. Otherwise, refer to “[The Result class](#)” (page 159) for details on how to make use of the `Result` instances. This works exactly like you saw in “[Get Method](#)” (page 146).

Note that `next()` might return `null` if you exhaust the table. But `next(int nbRows)` will always return a valid array to you. It might be empty for the same reasons, but it is a valid array nevertheless.

15. This property was called `hbase.regionserver.lease.period` in earlier versions of HBase.

Example 3-28 brings together the explained functionality to scan a table, while accessing the column data stored in a row.

Example 3-28. Example using a scanner to access data in a table

```
Scan scan1 = new Scan(); ❶
ResultScanner scanner1 = table.getScanner(scan1); ❷
for (Result res : scanner1) {
    System.out.println(res); ❸
}
scanner1.close(); ❹

Scan scan2 = new Scan();
scan2.addFamily(Bytes.toBytes("colfam1")); ❺
ResultScanner scanner2 = table.getScanner(scan2);
for (Result res : scanner2) {
    System.out.println(res);
}
scanner2.close();

Scan scan3 = new Scan();
scan3.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("col-5"));
    addColumn(Bytes.toBytes("colfam2"), Bytes.toBytes("col-33")); ❻
    setStartRow(Bytes.toBytes("row-10"));
    setStopRow(Bytes.toBytes("row-20"));
ResultScanner scanner3 = table.getScanner(scan3);
for (Result res : scanner3) {
    System.out.println(res);
}
scanner3.close();

Scan scan4 = new Scan();
    scan4.addColumn(Bytes.toBytes("colfam1"),
Bytes.toBytes("col-5")); ❼
    setStartRow(Bytes.toBytes("row-10"));
    setStopRow(Bytes.toBytes("row-20"));
ResultScanner scanner4 = table.getScanner(scan4);
for (Result res : scanner4) {
    System.out.println(res);
}
scanner4.close();

Scan scan5 = new Scan();
scan5.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("col-5"));
    setStartRow(Bytes.toBytes("row-20"));
    setStopRow(Bytes.toBytes("row-10"));
    setReversed(true); ❽
ResultScanner scanner5 = table.getScanner(scan5);
for (Result res : scanner5) {
    System.out.println(res);
}
scanner5.close();
```

- ➊ Create empty Scan instance.
- ➋ Get a scanner to iterate over the rows.
- ➌ Print row content.
- ➍ Close scanner to free remote resources.
- ➎ Add one column family only, this will suppress the retrieval of “colfam2”.
- ➏ Use fluent pattern to add specific details to the Scan.
- ➐ Only select one column.
- ➑ One column scan that runs in reverse.

The code inserts 100 rows with two column families, each containing 100 columns. The scans performed vary from the full table scan, to one that only scans one column family, then to another very restrictive scan, limiting the row range, and only asking for two very specific columns. The final two limit the previous one to just a single column, and the last of those two scans also reverses the scan order. The end of the abbreviated output should look like this:

```
...
Scanning table #4...
keyvalues={row-10/colfam1:col-5/1427010030763/Put/vlen=8/seqid=0}
keyvalues={row-100/colfam1:col-5/1427010039565/Put/vlen=9/seqid=0}
...
keyvalues={row-19/colfam1:col-5/1427010031928/Put/vlen=8/seqid=0}
keyvalues={row-2/colfam1:col-5/1427010029560/Put/vlen=7/seqid=0}

Scanning table #5...
keyvalues={row-20/colfam1:col-5/1427010032053/Put/vlen=8/seqid=0}
keyvalues={row-2/colfam1:col-5/1427010029560/Put/vlen=7/seqid=0}
...
keyvalues={row-11/colfam1:col-5/1427010030906/Put/vlen=8/seqid=0}
keyvalues={row-100/colfam1:col-5/1427010039565/Put/vlen=9/seqid=0}
```

Once again, note the actual rows that have been matched. The lexicographical sorting of the keys makes for interesting results. You could simply pad the numbers with zeros, which would result in a more human-readable sort order. This is completely under your control, so choose carefully what you need. Also note how the stop row is exclusive in the scan results, meaning if you really wanted all rows between 20 and 10 (for the reverse scan example), then specify `row-20` as the start and `row-0` as the stop row. Try it yourself!

Scanner Caching

If not configured properly, then each call to `next()` would be a separate RPC for every row—even when you use the `next(int nbRows)` method, because it is nothing else but a client-side loop over `next()` calls. Obviously, this is not very good for performance when dealing with small cells (see “[Client-side Write Buffer](#)” (page 128) for a discussion). Thus it would make sense to fetch more than one row per RPC if possible. This is called *scanner caching* and is enabled by default.

There is a cluster wide configuration property, named `hbase.client.scanner.caching`, which controls the default caching for all scans. It is set to 100¹⁶ and will therefore instruct all scanners to fetch 100 rows at a time, per RPC invocation. You can override this at the Scan instance level with the following methods:

```
void setCaching(int caching)  
int getCaching()
```

Specifying `scan.setCaching(200)` will increase the payload size to 200 rows per remote call. Both types of `next()` take these settings into account. The `getCaching()` returns what is currently assigned.

You can also change the default value of 100 for the entire HBase setup. You do this by adding the following configuration key to the `hbase-site.xml` configuration file:

```
<property>  
  <name>hbase.client.scanner.caching</name>  
  <value>200</value>  
</property>
```

This would set the scanner caching to 200 for all instances of Scan. You can still override the value at the scan level, but you would need to do so explicitly.

You may need to find a sweet spot between a low number of RPCs and the memory used on the client and server. Setting the scanner caching higher will improve scanning performance most of the time, but setting it too high can have adverse effects as well: each call to `next()` will take longer as more data is fetched and needs to be transported to the client, and once you exceed the maximum heap the client process has available it may terminate with an `OutOfMemoryException`.

16. This was changed from 1 in releases before 0.96. See [HBASE-7008](#) for details.

When the time taken to transfer the rows to the client, or to process the data on the client, exceeds the configured scanner lease threshold, you will end up receiving a *lease expired* error, in the form of a `ScannerTimeoutException` being thrown.

[Example 3-29](#) showcases the issue with the scanner leases.

Example 3-29. Example timeout while using a scanner

```
Scan scan = new Scan();
ResultScanner scanner = table.getScanner(scan);

int scannerTimeout = (int) conf.getLong(
    HConstants.HBASE_CLIENT_SCANNER_TIMEOUT_PERIOD, -1); ❶
try {
    Thread.sleep(scannerTimeout + 5000); ❷
} catch (InterruptedException e) {
    // ignore
}
while (true){
    try {
        Result result = scanner.next();
        if (result == null) break;
        System.out.println(result); ❸
    } catch (Exception e) {
        e.printStackTrace();
        break;
    }
}
scanner.close();
```

- ❶ Get currently configured lease timeout.
- ❷ Sleep a little longer than the lease allows.
- ❸ Print row content.

The code gets the currently configured lease period value and sleeps a little longer to trigger the lease recovery on the server side. The console output (abbreviated for the sake of readability) should look similar to this:

```
Adding rows to table...
Current (local) lease period: 60000ms
Sleeping now for 65000ms...
Attempting to iterate over scanner...
org.apache.hadoop.hbase.client.ScannerTimeoutException: \
  65017ms passed since the last invocation, timeout is currently
  set to 60000
```

```

        at org.apache.hadoop.hbase.client.ClientScanner.next(ClientScanner.java)
        at client.ScanTimeoutExample.main(ScanTimeoutExample.java:53)
        ...
Caused by: org.apache.hadoop.hbase.UnknownScannerException: \
    org.apache.hadoop.hbase.UnknownScannerException: Name: 3915, al-
    ready closed?
    at org.apache.hadoop.hbase.regionserver.RSRpcServices.scan(...)
    ...
Caused by: org.apache.hadoop.hbase.ipc.RemoteWithExtrasException( \
    org.apache.hadoop.hbase.UnknownScannerException): \
    org.apache.hadoop.hbase.UnknownScannerException: Name: 3915, al-
    ready closed?
    at org.apache.hadoop.hbase.regionserver.RSRpcServices.scan(...)
    ...
Mar 22, 2015 9:55:22 AM org.apache.hadoop.hbase.client.ScannerCal-
lable close
WARNING: Ignore, probably already closed
org.apache.hadoop.hbase.UnknownScannerException: \
    org.apache.hadoop.hbase.UnknownScannerException: Name: 3915, al-
    ready closed?
    at org.apache.hadoop.hbase.regionserver.RSRpcServices.scan(...)
    ...

```

The example code prints its progress and, after sleeping for the specified time, attempts to iterate over the rows the scanner should provide. This triggers the said timeout exception, while reporting the configured values. You might be tempted to add the following into your code

```

Configuration conf = HBaseConfiguration.create()
conf.setLong(HConstants.HBASE_CLIENT_SCANNER_TIMEOUT_PERIOD,
120000)

```

assuming this increases the lease threshold (in this example, to two minutes). But that is not going to work as the value is configured on the remote region servers, not your client application. Your value is not being sent to the servers, and therefore will have no effect. If you want to change the lease period setting you need to add the appropriate configuration key to the `hbase-site.xml` file on the region servers—while not forgetting to restart (or reload) them for the changes to take effect!

The stack trace in the console output also shows how the `ScannerTimeoutException` is a wrapper around an `UnknownScannerException`. It means that the `next()` call is using a scanner ID that has since expired and been removed in due course. In other words, the ID your client has memorized is now *unknown* to the region servers—which is the namesake of the exception.

Scanner Batching

So far you have learned to use client-side scanner caching to make better use of bulk transfers between your client application and the remote region's servers. There is an issue, though, that was mentioned in passing earlier: *very large rows*. Those—potentially—do not fit into the memory of the client process, but rest assured that HBase and its client API have an answer for that: *batching*. You can control batching using these calls:

```
void setBatch(int batch)
int getBatch()
```

As opposed to caching, which operates on a row level, batching works on the cell level instead. It controls how many cells are retrieved for every call to any of the `next()` functions provided by the `ResultScanner` instance. For example, setting the scan to use `setBatch(5)` would return five cells per `Result` instance.

When a row contains more cells than the value you used for the batch, you will get the entire row piece by piece, with each `next` `Result` returned by the scanner.

The last `Result` may include fewer columns, when the total number of columns in that row is not divisible by whatever batch it is set to. For example, if your row has 17 columns and you set the batch to 5, you get four `Result` instances, containing 5, 5, 5, and the remaining two columns respectively.

The combination of scanner caching and batch size can be used to control the number of RPCs required to scan the row key range selected. [Example 3-30](#) uses the two parameters to fine-tune the size of each `Result` instance in relation to the number of requests needed.

Example 3-30. Example using caching and batch parameters for scans

```
private static void scan(int caching, int batch, boolean small)
throws IOException {
    int count = 0;
    Scan scan = new Scan()
        .setCaching(caching) ①
        .setBatch(batch)
        .setSmall(small)
        .setScanMetricsEnabled(true);
    ResultScanner scanner = table.getScanner(scan);
```

```

        for (Result result : scanner) {
            count++; ②
        }
        scanner.close();
        ScanMetrics metrics = scan.getScanMetrics();
        System.out.println("Caching: " + caching + ", Batch: " + batch +
            ", Small: " + small + ", Results: " + count +
            ", RPCs: " + metrics.countOfRPCcalls());
    }

    public static void main(String[] args) throws IOException {
        ...
        scan(1, 1, false);
        scan(1, 0, false);
        scan(1, 0, true);
        scan(200, 1, false);
        scan(200, 0, false);
        scan(200, 0, true);
        scan(2000, 100, false); ③
        scan(2, 100, false);
        scan(2, 10, false);
        scan(5, 100, false);
        scan(5, 20, false);
        scan(10, 10, false);
        ...
    }
}

```

- ① Set caching and batch parameters.
- ② Count the number of Results available.
- ③ Test various combinations.

The code prints out the values used for caching and batching, the number of results returned by the servers, and how many RPCs were needed to get them. For example:

```

Caching: 1, Batch: 1, Small: false, Results: 200, RPCs: 203
Caching: 1, Batch: 0, Small: false, Results: 10, RPCs: 13
Caching: 1, Batch: 0, Small: true, Results: 10, RPCs: 0
Caching: 200, Batch: 1, Small: false, Results: 200, RPCs: 4
Caching: 200, Batch: 0, Small: false, Results: 10, RPCs: 3
Caching: 200, Batch: 0, Small: true, Results: 10, RPCs: 0
Caching: 2000, Batch: 100, Small: false, Results: 10, RPCs: 3
Caching: 2, Batch: 100, Small: false, Results: 10, RPCs: 8
Caching: 2, Batch: 10, Small: false, Results: 20, RPCs: 13
Caching: 5, Batch: 100, Small: false, Results: 10, RPCs: 5
Caching: 5, Batch: 20, Small: false, Results: 10, RPCs: 5
Caching: 10, Batch: 10, Small: false, Results: 20, RPCs: 5

```

You can tweak the two numbers to see how they affect the outcome. [Table 3-19](#) lists a few selected combinations. The numbers relate to [Example 3-30](#), which creates a table with two column families, adds

10 rows, with 10 columns per family in each row. This means there are a total of 200 columns—or cells, as there is only one version for each column—with 20 columns per row. The value in the *RPCs* column also includes the calls to open and close a scanner for normal scans, increasing the count by two for every such scan. Small scans currently do not report their counts and appear as zero.

Table 3-19. Example settings and their effects

Caching	Batch	Results	RPCs	Notes
1	1	200	203	Each column is returned as a separate Result instance. One more RPC is needed to realize the scan is complete.
200	1	200	4	Each column is a separate Result, but they are all transferred in one RPC (plus the extra check).
2	10	20	13	The batch is half the row width, so 200 divided by 10 is 20 Results needed. 10 RPCs (plus the check) to transfer them.
5	100	10	5	The batch is too large for each row, so all 20 columns are batched. This requires 10 Result instances. Caching brings the number of RPCs down to two (plus the check).
5	20	10	5	This is the same as above, but this time the batch matches the columns available. The outcome is the same.
10	10	20	5	This divides the table into smaller Result instances, but larger caching also means only two RPCs are needed.

To compute the number of RPCs required for a scan, you need to first multiply the number of rows with the number of columns per row (at least some approximation). Then you divide that number by the smaller value of either the batch size or the columns per row. Finally, divide that number by the scanner caching value. In mathematical terms this could be expressed like so:

$$\text{RPCs} = (\text{Rows} * \text{Cols per Row}) / \text{Min}(\text{Cols per Row}, \text{Batch Size}) / \text{Scanner Caching}$$

Figure 3-3 shows how the caching and batching works in tandem. It has a table with nine rows, each containing a number of columns. Using a scanner caching of six, and a batch set to three, you can see that three RPCs are necessary to ship the data across the network (the dashed, rounded-corner boxes).

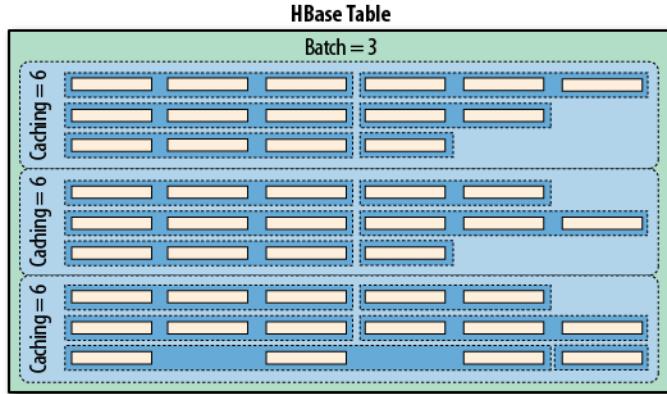


Figure 3-3. The scanner caching and batching controlling the number of RPCs

The small batch value causes the servers to group three columns into one Result, while the scanner caching of six causes one RPC to transfer six rows—or, more precisely, *results*—sent in the batch. When the batch size is not specified but scanner caching is specified, the result of the call will contain complete rows, because each row will be contained in one Result instance. Only when you start to use the batch mode are you getting access to the *intra-row* scanning functionality.

You may not have to worry about the consequences of using scanner caching and batch mode initially, but once you try to squeeze the optimal performance out of your setup, you should keep all of this in mind and find the sweet spot for both values.

Finally, batching cannot be combined with filters that return true from their `hasFilterRow()` method. Such filters cannot deal with partial results, in other words, the row being chunked into batches. It needs to see the entire row to make a filtering decision. It might be that the important column needed for that decision is not yet present. Or, it could be that there have been batches of results sent to the client already, just to realize later that the entire row should have been skipped.

Another combination disallowed is batching with small scans. The latter are an optimization returning the entire result in one call, not in further, smaller chunks. If you try to set the scan batching and small scan flag together, you will receive an `IllegalArgumentException` exception in due course.

Slicing Rows

But wait, this is not all you can do with scans! There is more, and first we will discuss the related *slicing* of table data using the following methods:

```
int getMaxResultsPerColumnFamily()
Scan setMaxResultsPerColumnFamily(int limit)
int getRowOffsetPerColumnFamily()
Scan setRowOffsetPerColumnFamily(int offset)

long getMaxResultSize()
Scan setMaxResultSize(long maxResultSize)
```

The first four work together by allowing the application to cut out a piece of each row selected, using an *offset* to start from a specific column, and a *max results per column family* limit to stop returning data once reached. The latter pair of functions allow to add (and retrieve) an upper *size* limit of the data returned by the scan. It keeps a running tally of the cells selected by the scan and stops returning them once the size limit is exceeded. [Example 3-31](#) shows this in action:

Example 3-31. Example using offset and limit parameters for scans

```
private static void scan(int num, int caching, int batch, int offset,
    int maxResults, int maxResultSize, boolean dump) throws IOException {
    int count = 0;
    Scan scan = new Scan()
        .setCaching(caching)
        .setBatch(batch)
        .setRowOffsetPerColumnFamily(offset)
        .setMaxResultsPerColumnFamily(maxResults)
        .setMaxResultSize(maxResultSize)
        .setScanMetricsEnabled(true);
    ResultScanner scanner = table.getScanner(scan);
    System.out.println("Scan #" + num + " running...");
    for (Result result : scanner) {
        count++;
        if (dump) System.out.println("Result [" + count + "]: " + result);
    }
    scanner.close();
    ScanMetrics metrics = scan.getScanMetrics();
    System.out.println("Caching: " + caching + ", Batch: " + batch +
        ", Offset: " + offset + ", maxResults: " + maxResults +
        ", maxSize: " + maxResultSize + ", Results: " + count +
        ", RPCs: " + metrics.countOfRPCcalls);
}

public static void main(String[] args) throws IOException {
```

```

    ...
    scan(1, 11, 0, 0, 2, -1, true);
    scan(2, 11, 0, 4, 2, -1, true);
    scan(3, 5, 0, 0, 2, -1, false);
    scan(4, 11, 2, 0, 5, -1, true);
    scan(5, 11, -1, -1, -1, 1, false);
    scan(6, 11, -1, -1, -1, 10000, false);
    ...
}

```

The example's hidden scaffolding creates a table with two column families, with ten rows and ten columns in each family. The output, abbreviated, looks something like this:

```

Scan #1 running...
Result [1]:keyvalues={row-01/colfam1:col-01/1/Put/vlen=9/seqid=0,
    row-01/colfam1:col-02/2/Put/vlen=9/seqid=0,
    row-01/colfam2:col-01/1/Put/vlen=9/seqid=0,
    row-01/colfam2:col-02/2/Put/vlen=9/seqid=0}
...
Result [10]:keyvalues={row-10/colfam1:col-01/1/Put/vlen=9/seqid=0,
    row-10/colfam1:col-02/2/Put/vlen=9/seqid=0,
    row-10/colfam2:col-01/1/Put/vlen=9/seqid=0,
    row-10/colfam2:col-02/2/Put/vlen=9/seqid=0}
Caching: 11, Batch: 0, Offset: 0, maxResults: 2, maxSize: -1,
    Results: 10, RPCs: 3

Scan #2 running...
Result [1]:keyvalues={row-01/colfam1:col-05/5/Put/vlen=9/seqid=0,
    row-01/colfam1:col-06/6/Put/vlen=9/seqid=0,
    row-01/colfam2:col-05/5/Put/vlen=9/seqid=0,
    row-01/colfam2:col-06/6/Put/vlen=9/seqid=0}
...
Result [10]:keyvalues={row-10/colfam1:col-05/5/Put/vlen=9/seqid=0,
    row-10/colfam1:col-06/6/Put/vlen=9/seqid=0,
    row-10/colfam2:col-05/5/Put/vlen=9/seqid=0,
    row-10/colfam2:col-06/6/Put/vlen=9/seqid=0}
Caching: 11, Batch: 0, Offset: 4, maxResults: 2, maxSize: -1,
    Results: 10, RPCs: 3

Scan #3 running...
Caching: 5, Batch: 0, Offset: 0, maxResults: 2, maxSize: -1,
    Results: 10, RPCs: 5

Scan #4 running...
Result [1]:keyvalues={row-01/colfam1:col-01/1/Put/vlen=9/seqid=0,
    row-01/colfam1:col-02/2/Put/vlen=9/seqid=0}
Result [2]:keyvalues={row-01/colfam1:col-03/3/Put/vlen=9/seqid=0,
    row-01/colfam1:col-04/4/Put/vlen=9/seqid=0}
...
Result [31]:keyvalues={row-10/colfam1:col-03/3/Put/vlen=9/seqid=0,
    row-10/colfam1:col-04/4/Put/vlen=9/seqid=0}

```

```

Result [32]:keyvalues={row-10/colfam1:col-05/5/Put/vlen=9/seqid=0}
Caching: 11, Batch: 2, Offset: 0, maxResults: 5, maxSize: -1,
    Results: 32, RPCs: 5

Scan #5 running...
Caching: 11, Batch: -1, Offset: -1, maxResults: -1, maxSize: 1,
    Results: 10, RPCs: 13

Scan #6 running...
Caching: 11, Batch: -1, Offset: -1, maxResults: -1, maxSize: 10000,
    Results: 10, RPCs: 5

```

The first scan starts at offset 0 and asks for a maximum of 2 cells, returning columns *one* and *two*. The second scan does the same but sets the offset to 4, therefore retrieving the columns *five* to *six*. Note how the offset really defines the number of cells to skip initially, and our value of 4 causes the first four columns to be skipped.

The next scan, #3, does not emit anything, since we are only interested in the metrics. It is the same as scan #1, but using a caching value of 5. You will notice how the minimal amount of RPCs is 3 (open, fetch, and close call for a non-small scanner). Here we see 5 RPCs that have taken place, which makes sense, since now we cannot fetch our 10 results in one call, but need two calls with five results each, plus an additional one to figure that there are no more rows left.

Scan #4 is combining the previous scans with a batching value of 2, so up to two cells are returned per call to `next()`, but at the same time we limit the amount of cells returned per column family to 5. Additionally combined with the caching value of 11 we see five RPCs made to the server.

Finally, scan #5 and #6 are using `setMaxResultSize()` to limit the amount of data returned to the caller. Just to recall, the scanner caching is set as *number of rows*, while the *max result size* is specified in bytes. What do we learn from the metrics (the rows are omitted as both print the entire table) as printed in the output?

- We need to set the caching to 11 to fetch all ten rows in our example in one RPC. When you set it to 10 an extra RPC is incurred, just to realize that there are no more rows.
- The caching setting is bound by the max result size, so in scan #5 we force the servers to return every row as a separate result, because setting the max result size to 1 byte means we cannot ship more than one row in a call. The caching is rendered useless.

- Even if we set the max result size to 1 byte, we still get *at least* one row per request. Which means, for very large rows we might still get under memory pressure.¹⁷
- The max result size should be set as an upper boundary that could be computed as $\text{max result size} = \text{caching} * \text{average row size}$. The idea is to fit in enough rows into the max result size but still ensure that caching is working.

This is a rather involved section, showing you how to tweak many scan parameters to optimize the communication with the region servers. Like I mentioned a few times so far, your mileage may vary, so please test this carefully and evaluate your options.

Load Column Families on Demand

Scans have another advanced feature, one that deserves a longer explanation: loading column families on demand. This is controlled by the following methods:

```
Scan setLoadColumnFamiliesOnDemand(boolean value)
Boolean getLoadColumnFamiliesOnDemandValue()
boolean doLoadColumnFamiliesOnDemand()
```

This functionality is a read optimization, useful only for tables with more than one column family, and especially then for those use-cases with a dependency between data in those families. For example, assume you have one family with meta data, and another with a heavier payload. You want to scan the meta data columns, and if a particular flag is present in one column, you need to access the payload data in the other family. It would be costly to include both families into the scan *if* you expect the cardinality of the flag to be low (in comparison to the table size). This is because such a scan would load the payload for every row, just to then ignore it.

Enabling this feature with `setLoadColumnFamiliesOnDemand(true)` is only half the of the preparation work: you also need a filter that implements the following method, returning a boolean flag:

```
boolean isFamilyEssential(byte[] name) throws IOException
```

The idea is that the filter is the decision maker if a column family is *essential* or not. When the servers scan the data, they first set up internal scanners for each column family. If *load column families on demand* is enabled and a filter set, it calls out to the filter and asks it to

¹⁷. This has been addressed with implicit row *chunking* in HBase 1.1.0 and later. See [HBASE-11544](#) for details.

decide if an included column family is to be scanned or not. The filter's `isFamilyEssential()` is invoked with the name of the family under consideration, before the column family is added, and must return `true` to approve. If it returns `false`, then the column family is ignored for now and loaded on demand later if needed.

On the other hand, you *must* add *all* column families to the scan, no matter if they are essential or not. The framework will only consult the filter about the inclusion of a family, if they have been added in the first place. If you do not explicitly specify any family, then you are OK. But as soon as you start using the `addColumn()` or `addFamily()` methods of `Scan`, then you have to ensure you add the non-essential columns or families too.

Scanner Metrics

The [Example 3-30](#) uses another feature of the `scan` class, allowing the client to reason about the effectiveness of the operation. This is accomplished with the following methods:

```
Scan setScanMetricsEnabled(final boolean enabled)
boolean isScanMetricsEnabled()
ScanMetrics getScanMetrics()
```

As shown in the example, you can enable the collection of scan metrics by invoking `setScanMetricsEnabled(true)`. Once the scan is complete you can retrieve the `ScanMetrics` using the `getScanMetrics()` method. The `isScanMetricsEnabled()` is a check if the collection of metrics has been enabled previously. The returned `ScanMetrics` instance has a set of fields you can read to determine what *cost* the operation accrued:

Table 3-20. Metrics provided by the ScanMetrics class

Metric Field	Description
<code>countOfRPCcalls</code>	The total amount of RPC calls incurred by the scan.
<code>countOfRemoteRPCcalls</code>	The amount of RPC calls to a remote host.
<code>sumOfMillisSecBetweenNexts</code>	The sum of milliseconds between sequential <code>next()</code> calls.
<code>countOfNSRE</code>	Number of <code>NotServingRegionException</code> caught.
<code>countOfBytesInResults</code>	Number of bytes in <code>Result</code> instances returned by the servers.
<code>countOfBytesInRemoteResults</code>	Same as above, but for bytes transferred from remote servers.
<code>countOfRegions</code>	Number of regions that were involved in the scan.
<code>countOfRPCRetries</code>	Number of RPC retries incurred during the scan.

Metric Field	Description
countOfRemoteRPCRetries	Same again, but RPC retries for non-local servers.

In the example we are printing the `countOfRPCcalls` field, since we want to figure out how many calls have taken place. When running the example code locally the `countOfRemoteRPCcalls` would be zero, as all RPC calls are made to the very same machine. Since scans are executed by region servers, and iterate over all regions included in the selected row range, the metrics are internally collected region by region and accumulated in the `ScanMetrics` instance of the `Scan` object. While it is possible to call upon the metrics as the scan is taking place, only at the very end of the scan you will see the final count.

Miscellaneous Features

Before looking into more involved features that clients can use, let us first wrap up a handful of miscellaneous features and functionality provided by HBase and its client API.

The Table Utility Methods

The client API is represented by an instance of the `Table` class and gives you access to an existing HBase table. Apart from the major features we already discussed, there are a few more notable methods of this class that you should be aware of:

`void close()`

This method was mentioned before, but for the sake of completeness, and its importance, it warrants repeating. Call `close()` once you have completed your work with a table. There is some internal housekeeping work that needs to run, and invoking this method triggers this process. Wrap the opening and closing of a table into a `try/catch`, or even better (on Java 7 or later), a `try-with-resources` block.

`TableName getName()`

This is a convenience method to retrieve the table name. It is provided as an instance of the `TableName` class, providing access to the namespace and actual table name.

`Configuration getConfiguration()`

This allows you to access the configuration in use by the `Table` instance. Since this is handed out *by reference*, you can make changes that are effective immediately.

`HTableDescriptor getTableDescriptor()`

Each table is defined using an instance of the `HTableDescriptor` class. You gain access to the underlying definition using `getTableDescriptor()`.

For more information about the management of tables using the administrative API, please consult “[Tables](#)” (page 350).

The Bytes Class

You saw how this class was used to convert native Java types, such as `String`, or `long`, into the raw, byte array format HBase supports natively. There are a few more notes that are worth mentioning about the class and its functionality. Most methods come in three variations, for example:

```
static long toLong(byte[] bytes)
static long toLong(byte[] bytes, int offset)
static long toLong(byte[] bytes, int offset, int length)
```

You hand in just a byte array, or an array and an offset, or an array, an offset, and a length value. The usage depends on the originating byte array you have. If it was created by `toBytes()` beforehand, you can safely use the first variant, and simply hand in the array and nothing else. All the array contains is the converted value.

The API, and HBase internally, store data in larger arrays using, for example, the following call:

```
static int putLong(byte[] bytes, int offset, long val)
```

This call allows you to write the `long` value into a given byte array, at a specific offset. If you want to access the data in that larger byte array you can make use of the latter two `toLong()` calls instead. The `length` parameter is a bit of an odd one as it has to match the length of the native type, in other words, if you try to convert a `long` from a `byte[]` array but specify 2 as the length, the conversion will fail with an `IllegalArgumentException` error. In practice, you should really only have to deal with the first two variants of the method.

The Bytes class has support to convert from and to the following native Java types: `String`, `boolean`, `short`, `int`, `long`, `double`, `float`, `ByteBuffer`, and `BigDecimal`. Apart from that, there are some noteworthy methods, which are listed in [Table 3-21](#).

Table 3-21. Overview of additional methods provided by the Bytes class

Method	Description
toStringBinary()	While working very similar to <code>toString()</code> , this variant has an extra safeguard to convert non-printable data into human-readable hexadecimal numbers. Whenever you are not sure what a byte array contains you should use this method to print its content, for example, to the console, or into a logfile.
compareTo() / equals()	These methods allow you to compare two <code>byte[]</code> , that is, byte arrays. The former gives you a comparison result and the latter a boolean value, indicating whether the given arrays are equal to each other.
add() / head() / tail()	You can use these to combine two byte arrays, resulting in a new, concatenated array, or to get the first, or last, few bytes of the given byte array.
binarySearch()	This performs a binary search in the given array of values. It operates on byte arrays for the values and the key you are searching for.
incrementBytes()	This increments a <code>long</code> value in its byte array representation, as if you had used <code>toBytes(long)</code> to create it. You can decrement using a negative amount parameter.

There is some overlap of the Bytes class with the Java-provided `Byte Buffer`. The difference is that the former does all operations without creating new class instances. In a way it is an optimization, because the provided methods are called many times within HBase, while avoiding possibly costly garbage collection issues.

For the full documentation, please consult the JavaDoc-based API documentation.¹⁸

18. See the [Bytes](#) documentation online.

Chapter 4

Client API: Advanced Features

Now that you understand the basic client API, we will discuss the advanced features that HBase offers to clients.

Filters

HBase filters are a powerful feature that can greatly enhance your effectiveness when working with data stored in tables. You will find pre-defined filters, already provided by HBase for your use, as well as a framework you can use to implement your own. You will now be introduced to both.

Introduction to Filters

The two prominent read functions for HBase are `Table.get()` and `Table.scan()`, both supporting either direct access to data or the use of a start and end key, respectively. You can limit the data retrieved by progressively adding more limiting selectors to the query. These include column families, column qualifiers, timestamps or ranges, as well as version numbers.

While this gives you control over what is included, it is missing more fine-grained features, such as selection of keys, or values, based on regular expressions. Both classes support *filters* for exactly these reasons: what cannot be solved with the provided API functionality selecting the required row or column keys, or values, can be achieved with filters. The base interface is aptly named `Filter`, and there is a list of

concrete classes supplied by HBase that you can use without doing any programming.

You can, on the other hand, extend the `Filter` classes to implement your own requirements. All the filters are actually applied on the server side, also referred to as *predicate pushdown*. This ensures the most efficient selection of the data that needs to be transported back to the client. You could implement most of the filter functionality in your client code as well, but you would have to transfer much more data—something you need to avoid at scale.

Figure 4-1 shows how the filters are configured on the client, then serialized over the network, and then applied on the server.

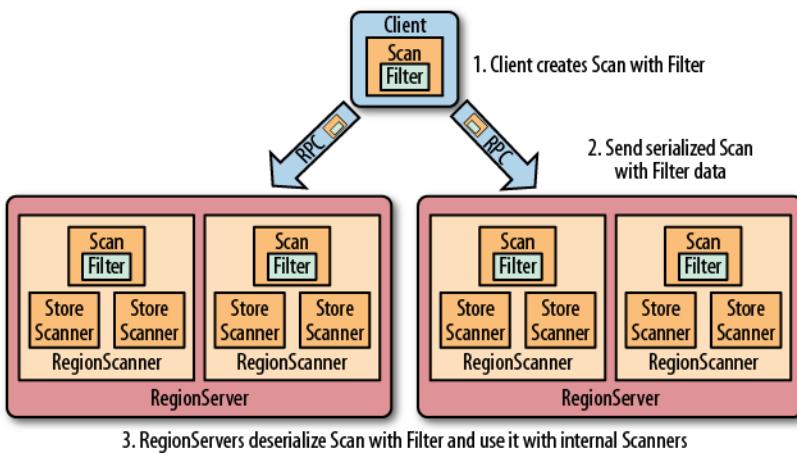


Figure 4-1. The filters created on the client side, sent through the RPC, and executed on the server side

The Filter Hierarchy

The lowest level in the filter hierarchy is the `Filter` interface, and the abstract `FilterBase` class that implements an empty shell, or skeleton, that is used by the actual filter classes to avoid having the same boilerplate code in each of them. Most concrete filter classes are direct descendants of `FilterBase`, but a few use another, intermediate ancestor class. They all work the same way: you define a new instance of the filter you want to apply and hand it to the `Get` or `Scan` instances, using:

```
setFilter(filter)
```

While you initialize the filter instance itself, you often have to supply parameters for whatever the filter is designed for. There is a special subset of filters, based on `CompareFilter`, that ask you for at least two specific parameters, since they are used by the base class to perform its task. You will learn about the two parameter types next so that you can use them in context.

Filters have access to the entire row they are applied to. This means that they can decide the fate of a row based on any available information. This includes the row key, column qualifiers, actual value of a column, timestamps, and so on. When referring to *values*, or *comparisons*, as we will discuss shortly, this can be applied to any of these details. Specific filter implementations are available that consider only one of those criteria each.

While filters can apply their logic to a specific row, they have no state and cannot span across multiple rows. There are also some scan related features—such as batching (see “[Scanner Batching](#)” (page 206))—that counteract the ability of a filter to do its work. We will discuss these limitations in due course below.

Comparison Operators

As `CompareFilter`-based filters add one more feature to the base `FilterBase` class, namely the `compare()` operation, it has to have a user-supplied operator type that defines how the result of the comparison is interpreted. The values are listed in [Table 4-1](#).

Table 4-1. The possible comparison operators for `CompareFilter`-based filters

Operator	Description
LESS	Match values less than the provided one.
LESS_OR_EQUAL	Match values less than or equal to the provided one.
EQUAL	Do an exact match on the value and the provided one.
NOT_EQUAL	Include everything that does not match the provided value.
GREATER_OR_EQUAL	Match values that are equal to or greater than the provided one.
GREATER	Only include values greater than the provided one.
NO_OP	Exclude everything.

The comparison operators define what is included, or excluded, when the filter is applied. This allows you to select the data that you want as either a range, subset, or exact and single match.

Comparators

The second type that you need to provide to `CompareFilter`-related classes is a *comparator*, which is needed to compare various values and keys in different ways. They are derived from `ByteArrayComparable`, which implements the Java `Comparable` interface. You do not have to go into the details if you just want to use an implementation provided by HBase and listed in [Table 4-2](#). The constructors usually take the control value, that is, the one to compare each table value against.

Table 4-2. The HBase-supplied comparators, used with CompareFilter-based filters

Comparator	Description
<code>LongComparator</code>	Assumes the given value array is a Java <code>Long</code> number and uses <code>Bytes.toLong()</code> to convert it.
<code>BinaryComparator</code>	Uses <code>Bytes.compareTo()</code> to compare the current with the provided value.
<code>BinaryPrefixComparator</code>	Similar to the above, but does a left hand, prefix-based match using <code>Bytes.compareTo()</code> .
<code>NullComparator</code>	Does not compare against an actual value, but checks whether a given one is <code>null</code> , or not <code>null</code> .
<code>BitComparator</code>	Performs a bitwise comparison, providing a <code>BitwiseOp</code> enumeration with <code>AND</code> , <code>OR</code> , and <code>XOR</code> operators.
<code>RegexStringComparator</code>	Given a regular expression at instantiation, this comparator does a pattern match on the data.
<code>SubstringComparator</code>	Treats the value and table data as <code>String</code> instances and performs a <code>contains()</code> check.

The last four comparators listed in [Table 4-2](#)—the `NullComparator`, `BitComparator`, `RegexStringComparator`, and `SubstringComparator`—only work with the `EQUAL` and `NOT_EQUAL` operators, as the `compareTo()` of these comparators returns `0` for a match or `1` when there is no match. Using them in a `LESS` or `GREATER` comparison will yield erroneous results.

Each of the comparators usually has a constructor that takes the comparison value. In other words, you need to define a value you compare each cell against. Some of these constructors take a `byte[]`, a byte array, to do the binary comparison, for example, while others take a `String` parameter—since the data point compared against is assumed

to be some sort of readable text. [Example 4-1](#) shows some of these in action.

The string-based comparators, `RegexStringComparator` and `SubstringComparator`, are more expensive in comparison to the purely byte-based versions, as they need to convert a given value into a `String` first. The subsequent string or regular expression operation also adds to the overall cost.

Comparison Filters

The first type of supplied filter implementations are the *comparison* filters. They take the comparison operator and comparator instance as described above. The constructor of each of them has the same signature, inherited from `CompareFilter`:

```
CompareFilter(final CompareOp compareOp, final ByteArrayComparable  
comparator)
```

You need to supply the comparison operator and comparison class for the filters to do their work. Next you will see the actual filters implementing a specific comparison.

Please keep in mind that the general contract of the HBase filter API means you are filtering *out* information—filtered data is *omitted* from the results returned to the client. The filter is not specifying what you want to have, but rather what you do *not* want to have returned when reading data.

In contrast, all filters based on `CompareFilter` are doing the *opposite*, in that they include the matching values. In other words, be careful when choosing the comparison operator, as it makes the difference in regard to what the server returns. For example, instead of using `LESS` to skip some information, you may need to use `GREATER_OR_EQUAL` to include the desired data points.

RowFilter

This filter gives you the ability to filter data based on row keys.

[Example 4-1](#) shows how the filter can use different comparator instances to get the desired results. It also uses various operators to include the row keys, while omitting others. Feel free to modify the code, changing the operators to see the possible results.

Example 4-1. Example using a filter to select specific rows

```
Scan scan = new Scan();
scan.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("col-1"));

    Filter filter1 = new RowFilter(CompareFilter.CompareOp.LESS_OR_EQUAL, ①
        new BinaryComparator(Bytes.toBytes("row-22")));
    scan.setFilter(filter1);
ResultScanner scanner1 = table.getScanner(scan);
for (Result res : scanner1) {
    System.out.println(res);
}
scanner1.close();

Filter filter2 = new RowFilter(CompareFilter.CompareOp.EQUAL, ②
    new RegexStringComparator(".*-5"));
scan.setFilter(filter2);
ResultScanner scanner2 = table.getScanner(scan);
for (Result res : scanner2) {
    System.out.println(res);
}
scanner2.close();

Filter filter3 = new RowFilter(CompareFilter.CompareOp.EQUAL, ③
    new SubstringComparator("-5"));
scan.setFilter(filter3);
ResultScanner scanner3 = table.getScanner(scan);
for (Result res : scanner3) {
    System.out.println(res);
}
scanner3.close();
```

- ① Create filter, while specifying the comparison operator and comparator. Here an exact match is needed.
- ② Another filter, this time using a regular expression to match the row keys.
- ③ The third filter uses a substring match approach.

Here is the full printout of the example on the console:

```
Adding rows to table...
Scanning table #1...
keyvalues={row-1/colfam1:col-1/1427273897619/Put/vlen=7/seqid=0}
keyvalues={row-10/colfam1:col-1/1427273899185/Put/vlen=8/seqid=0}
keyvalues={row-100/colfam1:col-1/1427273908651/Put/vlen=9/seqid=0}
keyvalues={row-11/colfam1:col-1/1427273899343/Put/vlen=8/seqid=0}
keyvalues={row-12/colfam1:col-1/1427273899496/Put/vlen=8/seqid=0}
keyvalues={row-13/colfam1:col-1/1427273899643/Put/vlen=8/seqid=0}
keyvalues={row-14/colfam1:col-1/1427273899785/Put/vlen=8/seqid=0}
keyvalues={row-15/colfam1:col-1/1427273899925/Put/vlen=8/seqid=0}
```

```

keyvalues={row-16/colfam1:col-1/1427273900064/Put/vlen=8/seqid=0}
keyvalues={row-17/colfam1:col-1/1427273900202/Put/vlen=8/seqid=0}
keyvalues={row-18/colfam1:col-1/1427273900343/Put/vlen=8/seqid=0}
keyvalues={row-19/colfam1:col-1/1427273900484/Put/vlen=8/seqid=0}
keyvalues={row-2/colfam1:col-1/1427273897860/Put/vlen=7/seqid=0}
keyvalues={row-20/colfam1:col-1/1427273900623/Put/vlen=8/seqid=0}
keyvalues={row-21/colfam1:col-1/1427273900757/Put/vlen=8/seqid=0}
keyvalues={row-22/colfam1:col-1/1427273900881/Put/vlen=8/seqid=0}
Scanning table #2...
keyvalues={row-15/colfam1:col-1/1427273899925/Put/vlen=8/seqid=0}
keyvalues={row-25/colfam1:col-1/1427273901253/Put/vlen=8/seqid=0}
keyvalues={row-35/colfam1:col-1/1427273902480/Put/vlen=8/seqid=0}
keyvalues={row-45/colfam1:col-1/1427273903582/Put/vlen=8/seqid=0}
keyvalues={row-55/colfam1:col-1/1427273904633/Put/vlen=8/seqid=0}
keyvalues={row-65/colfam1:col-1/1427273905577/Put/vlen=8/seqid=0}
keyvalues={row-75/colfam1:col-1/1427273906453/Put/vlen=8/seqid=0}
keyvalues={row-85/colfam1:col-1/1427273907327/Put/vlen=8/seqid=0}
keyvalues={row-95/colfam1:col-1/1427273908211/Put/vlen=8/seqid=0}
Scanning table #3...
keyvalues={row-5/colfam1:col-1/1427273898394/Put/vlen=7/seqid=0}
keyvalues={row-50/colfam1:col-1/1427273904116/Put/vlen=8/seqid=0}
keyvalues={row-51/colfam1:col-1/1427273904219/Put/vlen=8/seqid=0}
keyvalues={row-52/colfam1:col-1/1427273904324/Put/vlen=8/seqid=0}
keyvalues={row-53/colfam1:col-1/1427273904428/Put/vlen=8/seqid=0}
keyvalues={row-54/colfam1:col-1/1427273904536/Put/vlen=8/seqid=0}
keyvalues={row-55/colfam1:col-1/1427273904633/Put/vlen=8/seqid=0}
keyvalues={row-56/colfam1:col-1/1427273904729/Put/vlen=8/seqid=0}
keyvalues={row-57/colfam1:col-1/1427273904823/Put/vlen=8/seqid=0}
keyvalues={row-58/colfam1:col-1/1427273904919/Put/vlen=8/seqid=0}
keyvalues={row-59/colfam1:col-1/1427273905015/Put/vlen=8/seqid=0}

```

You can see how the first filter did an exact match on the row key, including all of those rows that have a key, equal to or less than the given one. Note once again the lexicographical sorting and comparison, and how it filters the row keys.

The second filter does a regular expression match, while the third uses a substring match approach. The results show that the filters work as advertised.

FamilyFilter

This filter works very similar to the RowFilter, but applies the comparison to the column families available in a row—as opposed to the row key. Using the available combinations of operators and comparators you can filter what is included in the retrieved data on a column family level. [Example 4-2](#) shows how to use this.

Example 4-2. Example using a filter to include only specific column families

```
Filter filter1 = new FamilyFilter(CompareFilter.CompareOp.LESS, ①
    new BinaryComparator(Bytes.toBytes("colfam3")));

Scan scan = new Scan();
scan.setFilter(filter1);
ResultScanner scanner = table.getScanner(scan); ②
for (Result result : scanner) {
    System.out.println(result);
}
scanner.close();

Get get1 = new Get(Bytes.toBytes("row-5"));
get1.setFilter(filter1);
Result result1 = table.get(get1); ③
System.out.println("Result of get(): " + result1);

Filter filter2 = new FamilyFilter(CompareFilter.CompareOp.EQUAL,
    new BinaryComparator(Bytes.toBytes("colfam3")));
Get get2 = new Get(Bytes.toBytes("row-5")); ④
get2.addFamily(Bytes.toBytes("colfam1"));
get2.setFilter(filter2);
Result result2 = table.get(get2); ⑤
System.out.println("Result of get(): " + result2);
```

- ① Create filter, while specifying the comparison operator and comparator.
- ② Scan over table while applying the filter.
- ③ Get a row while applying the same filter.
- ④ Create a filter on one column family while trying to retrieve another.
- ⑤ Get the same row while applying the new filter, this will return “NONE”.

The output—reformatted and abbreviated for the sake of readability—shows the filter in action. The input data has four column families, with two columns each, and 10 rows in total.

```
Adding rows to table...
Scanning table...
keyvalues={row-1/colfam1:col-1/1427274088598/Put/vlen=7/seqid=0,
           row-1/colfam1:col-2/1427274088615/Put/vlen=7/seqid=0,
           row-1/colfam2:col-1/1427274088598/Put/vlen=7/seqid=0,
           row-1/colfam2:col-2/1427274088615/Put/vlen=7/seqid=0}
keyvalues={row-10/colfam1:col-1/1427274088673/Put/vlen=8/seqid=0,
           row-10/colfam1:col-2/1427274088675/Put/vlen=8/seqid=0,
           row-10/colfam2:col-1/1427274088673/Put/vlen=8/seqid=0,
```

```

row-10/colfam2:col-2/1427274088675/Put/vlen=8/seqid=0}
...
keyvalues={row-9/colfam1:col-1/1427274088669/Put/vlen=7/seqid=0,
           row-9/colfam1:col-2/1427274088671/Put/vlen=7/seqid=0,
           row-9/colfam2:col-1/1427274088669/Put/vlen=7/seqid=0,
           row-9/colfam2:col-2/1427274088671/Put/vlen=7/seqid=0}

Result of get(): keyvalues={}
           row-5/colfam1:col-1/1427274088652/Put/vlen=7/seqid=0,
           row-5/colfam1:col-2/1427274088654/Put/vlen=7/seqid=0,
           row-5/colfam2:col-1/1427274088652/Put/vlen=7/seqid=0,
           row-5/colfam2:col-2/1427274088654/Put/vlen=7/seqid=0}

Result of get(): keyvalues=NONE

```

The last get() shows that you can (inadvertently) create an empty set by applying a filter for exactly one column family, while specifying a different column family selector using addFamily().

QualifierFilter

Example 4-3 shows how the same logic is applied on the column qualifier level. This allows you to filter specific columns from the table.

Example 4-3. Example using a filter to include only specific column qualifiers

```

Filter filter = new QualifierFilter(CompareFilter.CompareOp.LESS_OR_EQUAL,
                                     new BinaryComparator(Bytes.toBytes("col-2")));

Scan scan = new Scan();
scan.setFilter(filter);
ResultScanner scanner = table.getScanner(scan);
for (Result result : scanner) {
    System.out.println(result);
}
scanner.close();

Get get = new Get(Bytes.toBytes("row-5"));
get.setFilter(filter);
Result result = table.get(get);
System.out.println("Result of get(): " + result);

```

The output is the following (abbreviated again):

```

Adding rows to table...
Scanning table...
keyvalues={row-1/colfam1:col-1/1427274739258/Put/vlen=7/seqid=0,
           row-1/colfam1:col-10/1427274739309/Put/vlen=8/seqid=0,
           row-1/colfam1:col-2/1427274739272/Put/vlen=7/seqid=0,
           row-1/colfam2:col-1/1427274739258/Put/vlen=7/seqid=0,
           row-1/colfam2:col-10/1427274739309/Put/vlen=8/seqid=0,

```

```

row-1/colfam2:col-2/1427274739272/Put/vlen=7/seqid=0}
...
keyvalues={row-9/colfam1:col-1/1427274739441/Put/vlen=7/seqid=0,
           row-9/colfam1:col-10/1427274739458/Put/vlen=8/seqid=0,
           row-9/colfam1:col-2/1427274739443/Put/vlen=7/seqid=0,
           row-9/colfam2:col-1/1427274739441/Put/vlen=7/seqid=0,
           row-9/colfam2:col-10/1427274739458/Put/vlen=8/seqid=0,
           row-9/colfam2:col-2/1427274739443/Put/vlen=7/seqid=0}

Result of get(): keyvalues={
    row-5/colfam1:col-1/1427274739366/Put/vlen=7/seqid=0,
    row-5/colfam1:col-10/1427274739384/Put/vlen=8/seqid=0,
    row-5/colfam1:col-2/1427274739368/Put/vlen=7/seqid=0,
    row-5/colfam2:col-1/1427274739366/Put/vlen=7/seqid=0,
    row-5/colfam2:col-10/1427274739384/Put/vlen=8/seqid=0,
    row-5/colfam2:col-2/1427274739368/Put/vlen=7/seqid=0}

```

Since the filter asks for columns, or in other words column qualifiers, with a value of `col-2` or less, you can see how `col-1` and `col-10` are also included, since the comparison—once again—is done lexicographically (means binary).

ValueFilter

This filter makes it possible to include only columns that have a specific value. Combined with the `RegexStringComparator`, for example, this can filter using powerful expression syntax. [Example 4-4](#) showcases this feature. Note, though, that with certain comparators—as explained earlier—you can only employ a subset of the operators. Here a substring match is performed and this *must* be combined with an `EQUAL`, or `NOT_EQUAL`, operator.

Example 4-4. Example using the value based filter

```

Filter filter = new ValueFilter(CompareFilter.CompareOp.EQUAL, ❶
    new SubstringComparator(".4"));

Scan scan = new Scan();
scan.setFilter(filter); ❷
ResultScanner scanner = table.getScanner(scan);
for (Result result : scanner) {
    for (Cell cell : result.rawCells()) {
        System.out.println("Cell: " + cell + ", Value: " + ❸
            Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
            cell.getValueLength()));
    }
}
scanner.close();

Get get = new Get(Bytes.toBytes("row-5"));
get.setFilter(filter); ❹
Result result = table.get(get);

```

```

for (Cell cell : result.rawCells()) {
    System.out.println("Cell: " + cell + ", Value: " +
        Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
            cell.getValueLength()));
}

```

- ❶ Create filter, while specifying the comparison operator and comparator.
- ❷ Set filter for the scan.
- ❸ Print out value to check that filter works.
- ❹ Assign same filter to Get instance.

The output, confirming the proper functionality:

```

Adding rows to table...
Results of scan:
Cell: row-1/colfam1:col-4/1427275408429/Put/vlen=7/seqid=0, Value:
val-1.4
Cell: row-1/colfam2:col-4/1427275408429/Put/vlen=7/seqid=0, Value:
val-1.4
...
Cell: row-9/colfam1:col-4/1427275408605/Put/vlen=7/seqid=0, Value:
val-9.4
Cell: row-9/colfam2:col-4/1427275408605/Put/vlen=7/seqid=0, Value:
val-9.4

Result of get:
Cell: row-5/colfam1:col-4/1427275408527/Put/vlen=7/seqid=0, Value:
val-5.4
Cell: row-5/colfam2:col-4/1427275408527/Put/vlen=7/seqid=0, Value:
val-5.4

```

The example's wiring code (hidden, see the online repository again) set the value to *row key + “.” + column number*. The rows and columns start at 1. The filter is instructed to retrieve all cells that have a value containing .4--aiming at the fourth column. And indeed, we see that only column col-4 is returned.

DependentColumnFilter

Here you have a more complex filter that does not simply filter out data based on directly available information. Rather, it lets you specify a *dependent column*—or *reference column*—that controls how other columns are filtered. It uses the timestamp of the reference column and includes all other columns that have the same timestamp. Here are the constructors provided:

```

DependentColumnFilter(final byte[] family, final byte[] qualifier)
DependentColumnFilter(final byte[] family, final byte[] qualifier,
    final boolean dropDependentColumn)

```

```
DependentColumnFilter(final byte[] family, final byte[] qualifier,
    final boolean dropDependentColumn, final CompareOp valueCompar-
    eOp,
    final ByteArrayComparable valueComparator)
```

Since this class is based on `CompareFilter`, it also offers you to further select columns, but for this filter it does so based on their values. Think of it as a combination of a `ValueFilter` and a filter selecting on a reference timestamp. You can optionally hand in your own operator and comparator pair to enable this feature. The class provides constructors, though, that let you omit the operator and comparator and disable the value filtering, including all columns by default, that is, performing the timestamp filter based on the reference column only.

[Example 4-5](#) shows the filter in use. You can see how the optional values can be handed in as well. The `dropDependentColumn` parameter is giving you additional control over how the reference column is handled: it is either included or dropped by the filter, setting this parameter to `false` or `true`, respectively.

Example 4-5. Example using a filter to include only specific column families

```
private static void filter(boolean drop,
    CompareFilter.CompareOp operator,
    ByteArrayComparable comparator)
throws IOException {
    Filter filter;
    if (comparator != null) {
        filter = new DependentColumnFilter(Bytes.toBytes("colfam1"), ❶
            Bytes.toBytes("col-5"), drop, operator, comparator);
    } else {
        filter = new DependentColumnFilter(Bytes.toBytes("colfam1"),
            Bytes.toBytes("col-5"), drop);
    }

    Scan scan = new Scan();
    scan.setFilter(filter);
    // scan.setBatch(4); // cause an error
    ResultScanner scanner = table.getScanner(scan);
    for (Result result : scanner) {
        for (Cell cell : result.rawCells()) {
            System.out.println("Cell: " + cell + ", Value: " +
                Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
                    cell.getValueLength()));
        }
    }
    scanner.close();

    Get get = new Get(Bytes.toBytes("row-5"));
    get.setFilter(filter);
```

```

Result result = table.get(get);
for (Cell cell : result.rawCells()) {
    System.out.println("Cell: " + cell + ", Value: " +
        Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
            cell.getValueLength()));
}
}

public static void main(String[] args) throws IOException {
    filter(true, CompareFilter.CompareOp.NO_OP, null);
    filter(false, CompareFilter.CompareOp.NO_OP, null); ②
    filter(true, CompareFilter.CompareOp.EQUAL,
        new BinaryPrefixComparator(Bytes.toBytes("val-5")));
    filter(false, CompareFilter.CompareOp.EQUAL,
        new BinaryPrefixComparator(Bytes.toBytes("val-5")));
    filter(true, CompareFilter.CompareOp.EQUAL,
        new RegexStringComparator(".*\\".5"));
    filter(false, CompareFilter.CompareOp.EQUAL,
        new RegexStringComparator(".*\\".5"));
}

```

- ① Create the filter with various options.
- ② Call filter method with various options.

This filter is *not* compatible with the batch feature of the scan operations, that is, setting `Scan.setBatch()` to a number larger than zero. The filter needs to see the entire row to do its work, and using batching will not carry the reference column timestamp over and would result in erroneous results.

If you try to enable the batch mode nevertheless, you will get an error:

```

Exception in thread "main" \
  org.apache.hadoop.hbase.filter.IncompatibleFilterEx-
  ception: \
    Cannot set batch on a scan using a filter that re-
    turns true for \
      filter.hasFilterRow
          at org.apache.hadoop.hbase.client.Scan.set-
  Batch(Scan.java:464)
  ...

```

The example also proceeds slightly differently compared to the earlier filters, as it sets the version to the column number for a more reproducible result. The implicit timestamps that the servers use as the ver-

sion could result in fluctuating results as you cannot guarantee them using the exact time, down to the millisecond.

The `filter()` method used is called with different parameter combinations, showing how using the built-in value filter and the drop flag is affecting the returned data set. Here the output of the first two `filter()` call:

```
Adding rows to table...
Results of scan:
Cell: row-1/colfam2:col-5/5/Put/vlen=7/seqid=0, Value: val-1.5
Cell: row-10/colfam2:col-5/5/Put/vlen=8/seqid=0, Value: val-10.5
...
Cell: row-8/colfam2:col-5/5/Put/vlen=7/seqid=0, Value: val-8.5
Cell: row-9/colfam2:col-5/5/Put/vlen=7/seqid=0, Value: val-9.5
Result of get:
Cell: row-5/colfam2:col-5/5/Put/vlen=7/seqid=0, Value: val-5.5

Results of scan:
Cell: row-1/colfam1:col-5/5/Put/vlen=7/seqid=0, Value: val-1.5
Cell: row-1/colfam2:col-5/5/Put/vlen=7/seqid=0, Value: val-1.5
Cell: row-9/colfam1:col-5/5/Put/vlen=7/seqid=0, Value: val-9.5
Cell: row-9/colfam2:col-5/5/Put/vlen=7/seqid=0, Value: val-9.5
Result of get:
Cell: row-5/colfam1:col-5/5/Put/vlen=7/seqid=0, Value: val-5.5
Cell: row-5/colfam2:col-5/5/Put/vlen=7/seqid=0, Value: val-5.5
```

The only difference between the two calls is setting `dropDependentColumn` to `true` and `false` respectively. In the first scan and get output you see the checked column in `colfam1` being omitted, in other words *dropped* as expected, while in the second half of the output you see it included.

What is this filter good for you might wonder? It is used where applications require client-side timestamps (these could be epoch based, or based on some internal global counter) to track dependent updates. Say you insert some kind of transactional data, where across the row all fields that are updated, should form some dependent update. In this case the client could set all columns that are updated in one mutation to the same timestamp, and when later wanting to show the entity at a certain point in time, get (or scan) the row at that time. All modifications from earlier (or later, or exact) changes are then masked out (or included). See (to come) for libraries on top of HBase that make use of such as schema.

Dedicated Filters

The second type of supplied filters are based directly on `FilterBase` and implement more specific use cases. Many of these filters are only

really applicable when performing scan operations, since they filter out entire rows. For `get()` calls, this is often too restrictive and would result in a very harsh filter approach: include the whole row or nothing at all.

PrefixFilter

Given a row *prefix*, specified when you instantiate the filter instance, all rows with a row key *matching* this prefix are returned to the client. The constructor is:

```
PrefixFilter(final byte[] prefix)
```

[Example 4-6](#) has this applied to the usual test data set.

Example 4-6. Example using the prefix based filter

```
Filter filter = new PrefixFilter(Bytes.toBytes("row-1"));

Scan scan = new Scan();
scan.setFilter(filter);
ResultScanner scanner = table.getScanner(scan);
for (Result result : scanner) {
    for (Cell cell : result.rawCells()) {
        System.out.println("Cell: " + cell + ", Value: " +
            Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
                cell.getValueLength()));
    }
}
scanner.close();

Get get = new Get(Bytes.toBytes("row-5"));
get.setFilter(filter);
Result result = table.get(get);
for (Cell cell : result.rawCells()) {
    System.out.println("Cell: " + cell + ", Value: " +
        Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
            cell.getValueLength()));
}
```

The output:

```
Results of scan:
Cell: row-1/colfam1:col-1/1427280142327/Put/vlen=7/seqid=0, Value:
val-1.1
Cell: row-1/colfam1:col-10/1427280142379/Put/vlen=8/seqid=0, Value:
val-1.10
...
Cell: row-1/colfam2:col-8/1427280142375/Put/vlen=7/seqid=0, Value:
val-1.8
Cell: row-1/colfam2:col-9/1427280142377/Put/vlen=7/seqid=0, Value:
val-1.9
Cell: row-10/colfam1:col-1/1427280142530/Put/vlen=8/seqid=0, Val-
```

```
ue: val-10.1
Cell: row-10/colfam1:col-10/1427280142546/Put/vlen=9/seqid=0, Val-
ue: val-10.10
...
Cell: row-10/colfam2:col-8/1427280142542/Put/vlen=8/seqid=0, Val-
ue: val-10.8
Cell: row-10/colfam2:col-9/1427280142544/Put/vlen=8/seqid=0, Val-
ue: val-10.9

Result of get:
```

It is interesting to see how the `get()` call fails to return anything, because it is asking for a row that does *not* match the filter prefix. This filter does not make much sense when doing `get()` calls but is highly useful for scan operations.

The scan also is actively ended when the filter encounters a row key that is larger than the prefix. In this way, and combining this with a start row, for example, the filter is improving the overall performance of the scan as it has knowledge of when to skip the rest of the rows altogether.

PageFilter

You paginate through rows by employing this filter. When you create the instance, you specify a `pageSize` parameter, which controls how many rows per page should be returned.

```
PageFilter(final long pageSize)
```

There is a fundamental issue with filtering on physically separate servers. Filters run on different region servers in parallel and cannot retain or communicate their current state across those boundaries. Thus, each filter is required to scan at least up to `pageCount` rows before ending the scan. This means a slight inefficiency is given for the Page Filter as more rows are reported to the client than necessary. The final consolidation on the client obviously has visibility into all results and can reduce what is accessible through the API accordingly.

The client code would need to remember the last row that was returned, and then, when another iteration is about to start, set the *start row* of the scan accordingly, while retaining the same filter properties.

Because pagination is setting a strict limit on the number of rows to be returned, it is possible for the filter to *early out* the entire scan,

once the limit is reached or exceeded. Filters have a facility to indicate that fact and the region servers make use of this hint to stop any further processing.

[Example 4-7](#) puts this together, showing how a client can reset the scan to a new start row on the subsequent iterations.

Example 4-7. Example using a filter to paginate through rows

```
private static final byte[] POSTFIX = new byte[] { 0x00 };
    Filter filter = new PageFilter(15);

    int totalRows = 0;
    byte[] lastRow = null;
    while (true) {
        Scan scan = new Scan();
        scan.setFilter(filter);
        if (lastRow != null) {
            byte[] startRow = Bytes.add(lastRow, POSTFIX);
            System.out.println("start row: " +
                Bytes.toStringBinary(startRow));
            scan.setStartRow(startRow);
        }
        ResultScanner scanner = table.getScanner(scan);
        int localRows = 0;
        Result result;
        while ((result = scanner.next()) != null) {
            System.out.println(localRows++ + ": " + result);
            totalRows++;
            lastRow = result.getRow();
        }
        scanner.close();
        if (localRows == 0) break;
    }
    System.out.println("total rows: " + totalRows);
```

The abbreviated output:

```
Adding rows to table...
0:      keyvalues={row-1/colfam1:col-1/1427280402935/Put/vlen=7/
seqid=0, ...}
1:      keyvalues={row-10/colfam1:col-1/1427280403125/Put/vlen=8/
seqid=0, ...}
...
14:      keyvalues={row-110/colfam1:col-1/1427280404601/Put/vlen=9/
seqid=0, ...}
start row: row-110\x00
0:      keyvalues={row-111/colfam1:col-1/1427280404615/Put/vlen=9/
seqid=0, ...}
1:      keyvalues={row-112/colfam1:col-1/1427280404628/Put/vlen=9/
seqid=0, ...}
...
14:      keyvalues={row-124/colfam1:col-1/1427280404786/Put/vlen=9/
```

```

seqid=0, ...
start row: row-124\x00
0:      keyvalues={row-125/colfam1:col-1/1427280404799/Put/vlen=9/
seqid=0, ...
...
start row: row-999\x00
total rows: 1000

```

Because of the lexicographical sorting of the row keys by HBase and the comparison taking care of finding the row keys in order, and the fact that the start key on a scan is always inclusive, you need to add an extra zero byte to the previous key. This will ensure that the last seen row key is skipped and the next, in sorting order, is found. The zero byte is the smallest increment, and therefore is safe to use when resetting the scan boundaries. Even if there were a row that would match the previous plus the extra zero byte, the scan would be correctly doing the next iteration—because the start key *is* inclusive.

KeyOnlyFilter

Some applications need to access just the keys of each Cell, while omitting the actual data. The `KeyOnlyFilter` provides this functionality by applying the filter's ability to modify the processed columns and cells, as they pass through. It does so by applying some logic that converts the current cell, stripping out the data part. The constructors of the filter are:

```

KeyOnlyFilter()
KeyOnlyFilter(boolean lenAsVal)

```

There is an optional boolean parameter, named `lenAsVal`. It is handed to the internal conversion call `as-is`, controlling what happens to the value part of each `Cell` instance processed. The default value of `false` simply sets the value to zero length, while the opposite `true` sets the value to the number representing the length of the original value. The latter may be useful to your application when quickly iterating over columns, where the keys already convey meaning and the length can be used to perform a secondary sort. (to come) has an example.

[Example 4-8](#) tests this filter with both constructors, creating random rows, columns, and values.

Example 4-8. Only returns the first found cell from each row

```

int rowCount = 0;
for (Result result : scanner) {
    for (Cell cell : result.rawCells()) {
        System.out.println("Cell: " + cell + ", Value: " +
                           cell.getValueLength() > 0 ?
                           Bytes.toInt(cell.getValueArray(), cell.getValueOffset()),
                           ...

```

```

        cell.getValueLength() : "n/a" ));
    }
    rowCount++;
}
System.out.println("Total num of rows: " + rowCount);
scanner.close();
}

public static void main(String[] args) throws IOException {
    Configuration conf = HBaseConfiguration.create();

    HBaseHelper helper = HBaseHelper.getHelper(conf);
    helper.dropTable("testtable");
    helper.createTable("testtable", "colfam1");
    System.out.println("Adding rows to table...");
    helper.fillTableRandom("testtable", /* row */ 1, 5, 0,
        /* col */ 1, 30, 0, /* val */ 0, 10000, 0, true, "colfam1");

    Connection connection = ConnectionFactory.createConnection(conf);
    table = connection.getTable(TableName.valueOf("testtable"));
    System.out.println("Scan #1");
    Filter filter1 = new KeyOnlyFilter();
    scan(filter1);
    Filter filter2 = new KeyOnlyFilter(true);
    scan(filter2);
}

```

The abbreviated output will be similar to the following:

```

Adding rows to table...
Results of scan:
Cell: row-0/colfam1:col-17/6/Put/vlen=0/seqid=0, Value: n/a
Cell: row-0/colfam1:col-27/3/Put/vlen=0/seqid=0, Value: n/a
...
Cell: row-4/colfam1:col-3/2/Put/vlen=0/seqid=0, Value: n/a
Cell: row-4/colfam1:col-5/16/Put/vlen=0/seqid=0, Value: n/a
Total num of rows: 5

Scan #2
Results of scan:
Cell: row-0/colfam1:col-17/6/Put/vlen=4/seqid=0, Value: 8
Cell: row-0/colfam1:col-27/3/Put/vlen=4/seqid=0, Value: 6
...
Cell: row-4/colfam1:col-3/2/Put/vlen=4/seqid=0, Value: 7
Cell: row-4/colfam1:col-5/16/Put/vlen=4/seqid=0, Value: 8
Total num of rows: 5

```

The highlighted parts show how first the value is simply dropped and the value length is set to zero. The second, setting `lenAsVal` explicitly to `true` see a different result. The value length of 4 is attributed to the length of the payload, an integer of four bytes. The value is the random length of old value, here values between 5 and 9 (the fixed prefix `val-` plus a number between 0 and 10,000).

FirstKeyOnlyFilter

Even if the name implies `KeyValue`, or *key only*, this is both a misnomer. The filter returns the first *cell* it finds in a row, and does so with all its details, including the value. It should be named `FirstCellFilter`, for example.

If you need to access the first column—as sorted implicitly by HBase—in each row, this filter will provide this feature. Typically this is used by *row counter* type applications that only need to check if a row exists. Recall that in column-oriented databases a row really is composed of columns, and if there are none, the row ceases to exist.

Another possible use case is relying on the column sorting in lexicographical order, and setting the column qualifier to an epoch value. This would sort the column with the oldest timestamp name as the first to be retrieved. Combined with this filter, it is possible to retrieve the oldest column from every row using a single scan. More interestingly, though, is when you reverse the timestamp set as the column qualifier, and therefore retrieve the *newest* entry in a row in a single scan.

This class makes use of another optimization feature provided by the filter framework: it indicates to the region server applying the filter that the current row is done and that it should skip to the next one. This improves the overall performance of the scan, compared to a full table scan. The gain is more prominent in schemas with very wide rows, in other words, where you can skip many columns to reach the next row. If you only have one column per row, there will be no gain at all, obviously.

[Example 4-9](#) has a simple example, using random rows, columns, and values, so your output will vary.

Example 4-9. Only returns the first found cell from each row

```
Filter filter = new FirstKeyOnlyFilter();

Scan scan = new Scan();
scan.setFilter(filter);
ResultScanner scanner = table.getScanner(scan);
int rowCount = 0;
for (Result result : scanner) {
    for (Cell cell : result.rawCells()) {
        System.out.println("Cell: " + cell + ", Value: " +
            Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
            cell.getValueLength()));
```

```

        }
        rowCount++;
    }
    System.out.println("Total num of rows: " + rowCount);
    scanner.close();
}

```

The abbreviated output, showing that only one cell is returned per row, confirming the filter's purpose:

```

Adding rows to table...
Results of scan:
Cell: row-0/colfam1:col-10/19/Put/vlen=6/seqid=0, Value: val-76
Cell: row-1/colfam1:col-0/0/Put/vlen=6/seqid=0, Value: val-19
...
Cell: row-8/colfam1:col-10/4/Put/vlen=6/seqid=0, Value: val-35
Cell: row-9/colfam1:col-1/5/Put/vlen=5/seqid=0, Value: val-0
Total num of rows: 30

```

FirstKeyValueMatchingQualifiersFilter

This filter is an extension to the `FirstKeyOnlyFilter`, but instead of returning the first found cell, it instead returns all the columns of a row, up to a given column qualifier. If the row has no such qualifier, all columns are returned. The filter is mainly used in the `rowcounter` shell command, to count all rows in HBase using a distributed process.

The constructor of the filter class looks like this:

```
FirstKeyValueMatchingQualifiersFilter(Set<byte[]> qualifiers)
```

[Example 4-10](#) sets up a filter with two columns to match. It also loads the test table with random data, so you output will most certainly vary.

Example 4-10. Returns all columns, or up to the first found reference qualifier, for each row

```

Set<byte[]> qals = new HashSet<byte[]>();
qals.add(Bytes.toBytes("col-2"));
qals.add(Bytes.toBytes("col-4"));
qals.add(Bytes.toBytes("col-6"));
qals.add(Bytes.toBytes("col-8"));
Filter filter = new FirstKeyValueMatchingQualifiersFilter(qals);

Scan scan = new Scan();
scan.setFilter(filter);
ResultScanner scanner = table.getScanner(scan);
int rowCount = 0;
for (Result result : scanner) {
    for (Cell cell : result.rawCells()) {
        System.out.println("Cell: " + cell + ", Value: " +
                           Bytes.toString(cell.getValueArray(), cell.getValueOffset()),
                           cell.getValueLength());
    }
}

```

```

        cell.getValueLength()));
    }
    rowCount++;
}
System.out.println("Total num of rows: " + rowCount);
scanner.close();

```

Here is the output on the console in an abbreviated form for one execution:

```

Adding rows to table...
Results of scan:
Cell: row-0/colfam1:col-0/1/Put/vlen=6/seqid=0, Value: val-48
Cell: row-0/colfam1:col-1/4/Put/vlen=6/seqid=0, Value: val-78
Cell: row-0/colfam1:col-5/1/Put/vlen=6/seqid=0, Value: val-62
Cell: row-0/colfam1:col-6/6/Put/vlen=5/seqid=0, Value: val-6
Cell: row-10/colfam1:col-1/3/Put/vlen=6/seqid=0, Value: val-73
Cell: row-10/colfam1:col-6/5/Put/vlen=6/seqid=0, Value: val-11
...
Cell: row-6/colfam1:col-1/0/Put/vlen=6/seqid=0, Value: val-39
Cell: row-7/colfam1:col-9/6/Put/vlen=6/seqid=0, Value: val-57
Cell: row-8/colfam1:col-0/2/Put/vlen=6/seqid=0, Value: val-90
Cell: row-8/colfam1:col-1/4/Put/vlen=6/seqid=0, Value: val-92
Cell: row-8/colfam1:col-6/4/Put/vlen=6/seqid=0, Value: val-12
Cell: row-9/colfam1:col-1/5/Put/vlen=6/seqid=0, Value: val-35
Cell: row-9/colfam1:col-2/2/Put/vlen=6/seqid=0, Value: val-22
Total num of rows: 47

```

Depending on the random data generated we see more or less cells emitted per row. The filter is instructed to stop emitting cells when encountering one of the columns col-2, col-4, col-6, or col-8. For row-0 this is visible, as it had one more column, named col-7, which is omitted. row-7 has only one cell, and no matching qualifier, hence it is included completely.

InclusiveStopFilter

The row boundaries of a scan are inclusive for the start row, yet exclusive for the stop row. You can overcome the stop row semantics using this filter, which *includes* the specified stop row. [Example 4-11](#) uses the filter to start at row-3, and stop at row-5 *inclusively*.

Example 4-11. Example using a filter to include a stop row

```

Filter filter = new InclusiveStopFilter(Bytes.toBytes("row-5"));

Scan scan = new Scan();
scan.setStartRow(Bytes.toBytes("row-3"));
scan.setFilter(filter);
ResultScanner scanner = table.getScanner(scan);
for (Result result : scanner) {
    System.out.println(result);

```

```
    }
    scanner.close();
```

The output on the console, when running the example code, confirms that the filter works as advertised:

```
Adding rows to table...
Results of scan:
keyvalues={row-3/colfam1:col-1/1427282689001/Put/vlen=7/seqid=0}
keyvalues={row-30/colfam1:col-1/1427282689069/Put/vlen=8/seqid=0}
...
keyvalues={row-48/colfam1:col-1/1427282689100/Put/vlen=8/seqid=0}
keyvalues={row-49/colfam1:col-1/1427282689102/Put/vlen=8/seqid=0}
keyvalues={row-5/colfam1:col-1/1427282689004/Put/vlen=7/seqid=0}
```

FuzzyRowFilter

This filter acts on row keys, but in a *fuzzy* manner. It needs a list of row keys that should be returned, plus an accompanying byte[] array that signifies the importance of each byte in the row key. The constructor is as such:

```
FuzzyRowFilter(List<Pair<byte[], byte[]>> fuzzyKeysData)
```

The `fuzzyKeysData` specifies the mentioned significance of a row key byte, by taking one of two values:

0

Indicates that the byte at the same position in the row key *must* match as-is.

1

Means that the corresponding row key byte does not matter and is always accepted.

Example: Partial Row Key Matching

A possible example is matching partial keys, but not from left to right, rather somewhere inside a compound key. Assuming a row key format of `<userId>_<actionId>_<year>_<month>`, with fixed length parts, where `<userId>` is 4, `<actionId>` is 2, `<year>` is 4, and `<month>` is 2 bytes long. The application now requests all users that performed certain action (encoded as 99) in January of any year. Then the pair for row key and fuzzy data would be the following:

row key

"????_99_????_01", where the "?" is an arbitrary character, since it is ignored.

```

fuzzy data
=
"\x01\x01\x01\x01\x01\x00\x00\x00\x00\x01\x01\x01\x01\x00\x00"

```

In other words, the fuzzy data array instructs the filter to find all row keys matching "????_99_????_01", where the "?" will accept any character.

An advantage of this filter is that it can likely compute the next matching row key when it comes to an end of a matching one. It implements the `getNextCellHint()` method to help the servers in fast-forwarding to the next range of rows that might match. This speeds up scanning, especially when the skipped ranges are quite large. [Example 4-12](#) uses the filter to grab specific rows from a test data set.

Example 4-12. Example filtering by column prefix

```

List<Pair<byte[], byte[]>> keys = new ArrayList<Pair<byte[], byte[]>>();
keys.add(new Pair<byte[], byte[]>(
    Bytes.toBytes("row-?5"), new byte[] { 0, 0, 0, 0, 1, 0 }));
Filter filter = new FuzzyRowFilter(keys);

Scan scan = new Scan()
    .addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("col-5"))
    .setFilter(filter);
ResultScanner scanner = table.getScanner(scan);
for (Result result : scanner) {
    System.out.println(result);
}
scanner.close();

```

The example code also adds a filtering column to the scan, just to keep the output short:

```

Adding rows to table...
Results of scan:
keyvalues={row-05/colfam1:col-01/1/Put/vlen=9/seqid=0,
           row-05/colfam1:col-02/2/Put/vlen=9/seqid=0,
           ...
           row-05/colfam1:col-09/9/Put/vlen=9/seqid=0,
           row-05/colfam1:col-10/10/Put/vlen=9/seqid=0}
keyvalues={row-15/colfam1:col-01/1/Put/vlen=9/seqid=0,
           row-15/colfam1:col-02/2/Put/vlen=9/seqid=0,
           ...
           row-15/colfam1:col-09/9/Put/vlen=9/seqid=0,
           row-15/colfam1:col-10/10/Put/vlen=9/seqid=0}

```

The test code wiring adds 20 rows to the table, named `row-01` to `row-20`. We want to retrieve all the rows that match the pattern `row-?`

5, in other words all rows that end in the number 5. The output above confirms the correct result.

ColumnCountGetFilter

You can use this filter to only retrieve a specific maximum number of columns per row. You can set the number using the constructor of the filter:

```
ColumnCountGetFilter(final int n)
```

Since this filter stops the entire scan once a row has been found that matches the maximum number of columns configured, it is not useful for scan operations, and in fact, it was written to test filters in get() calls.

ColumnPaginationFilter

This filter's functionality is superseded by the *slicing* functionality explained in “[Slicing Rows](#)” (page 210), and provided by the `setMaxResultsPerColumnFamily()` and `setRowOffsetPerColumnFamily()` methods of Scan, and Get.

Similar to the `PageFilter`, this one can be used to page through columns in a row. Its constructor has two parameters:

```
ColumnPaginationFilter(final int limit, final int offset)
```

It skips all columns up to the number given as `offset`, and then includes `limit` columns afterward. [Example 4-13](#) has this applied to a normal scan.

Example 4-13. Example paginating through columns in a row

```
Filter filter = new ColumnPaginationFilter(5, 15);

Scan scan = new Scan();
scan.setFilter(filter);
ResultScanner scanner = table.getScanner(scan);
for (Result result : scanner) {
    System.out.println(result);
}
scanner.close();
```

Running this example should render the following output:

```
Adding rows to table...
Results of scan:
keyvalues={row-01/colfam1:col-16/16/Put/vlen=9/seqid=0,
           row-01/colfam1:col-17/17/Put/vlen=9/seqid=0,
```

```

row-01/colfam1:col-18/18/Put/vlen=9/seqid=0,
row-01/colfam1:col-19/19/Put/vlen=9/seqid=0,
row-01/colfam1:col-20/20/Put/vlen=9/seqid=0}
keyvalues={row-02/colfam1:col-16/16/Put/vlen=9/seqid=0,
row-02/colfam1:col-17/17/Put/vlen=9/seqid=0,
row-02/colfam1:col-18/18/Put/vlen=9/seqid=0,
row-02/colfam1:col-19/19/Put/vlen=9/seqid=0,
row-02/colfam1:col-20/20/Put/vlen=9/seqid=0}
...

```

This example slightly changes the way the rows and columns are numbered by adding a padding to the numeric counters. For example, the first row is padded to be `row-01`. This also shows how padding can be used to get a more *human-readable* style of sorting, for example—as known from dictionaries or telephone books.

The result includes all 10 rows, starting each row at column 16 (offset = 15) and printing five columns (limit = 5). As a side note, this filter does not suffer from the issues explained in “[PageFilter](#)” ([page 234](#)), in other words, although it is distributed and not synchronized across filter instances, there are no inefficiencies incurred by reading too many columns or rows. This is because a row is contained in a single region, and no overlap to another region is required to complete the filtering task.

ColumnPrefixFilter

Analog to the `PrefixFilter`, which worked by filtering on row key prefixes, this filter does the same for columns. You specify a prefix when creating the filter:

```
ColumnPrefixFilter(final byte[] prefix)
```

All columns that have the given prefix are then included in the result. [Example 4-14](#) selects all columns starting with `col-1`. Here we drop the padding again, to get binary sorted column names.

Example 4-14. Example filtering by column prefix

```

Filter filter = new ColumnPrefixFilter(Bytes.toBytes("col-1"));

Scan scan = new Scan();
scan.setFilter(filter);
ResultScanner scanner = table.getScanner(scan);
for (Result result : scanner) {
    System.out.println(result);

```

```
}
```

```
scanner.close();
```

The result of running this example should show the filter doing its job as advertised:

```
Adding rows to table...
Results of scan:
keyvalues={row-1/colfam1:col-1/1/Put/vlen=7/seqid=0,
           row-1/colfam1:col-10/10/Put/vlen=8/seqid=0,
           ...
           row-1/colfam1:col-19/19/Put/vlen=8/seqid=0}
...
```

MultipleColumnPrefixFilter

This filter is a straight extension to the `ColumnPrefixFilter`, allowing the application to ask for a list of column qualifier prefixes, not just a single one. The constructor and use is also straight forward:

```
MultipleColumnPrefixFilter(final byte[][][] prefixes)
```

The code in [Example 4-15](#) adds two column prefixes, and also a row prefix to limit the output.

Example 4-15. Example filtering by column prefix

```
Filter filter = new MultipleColumnPrefixFilter(new byte[][][] {
    Bytes.toBytes("col-1"), Bytes.toBytes("col-2")
});

Scan scan = new Scan()
    .setRowPrefixFilter(Bytes.toBytes("row-1")) ❶
    .setFilter(filter);
ResultScanner scanner = table.getScanner(scan);
for (Result result : scanner) {
    System.out.print(Bytes.toString(result.getRow()) + ": ");
    for (Cell cell : result.rawCells()) {
        System.out.print(Bytes.toString(cell.getQualifierArray(),
            cell.getQualifierOffset(), cell.getQualifierLength()) + ", "
    );
    }
    System.out.println();
}
scanner.close();
```

- ❶ Limit to rows starting with a specific prefix.

The following shows what is emitted on the console (abbreviated), note how the code also prints out only the row key and column qualifiers, just to show another way of accessing the data:

```

Adding rows to table...
Results of scan:
row-1: col-1, col-10, col-11, col-12, col-13, col-14, col-15,
col-16,
    col-17, col-18, col-19, col-2, col-20, col-21, col-22, col-23,
col-24,
    col-25, col-26, col-27, col-28, col-29,
row-10: col-1, col-10, col-11, col-12, col-13, col-14, col-15,
col-16,
    col-17, col-18, col-19, col-2, col-20, col-21, col-22, col-23,
col-24,
    col-25, col-26, col-27, col-28, col-29,
row-18: col-1, col-10, col-11, col-12, col-13, col-14, col-15,
col-16,
    col-17, col-18, col-19, col-2, col-20, col-21, col-22, col-23,
col-24,
    col-25, col-26, col-27, col-28, col-29,
row-19: col-1, col-10, col-11, col-12, col-13, col-14, col-15,
col-16,
    col-17, col-18, col-19, col-2, col-20, col-21, col-22, col-23,
col-24,
    col-25, col-26, col-27, col-28, col-29,

```

ColumnRangeFilter

This filter acts like two QualifierFilter instances working together, with one checking the lower boundary, and the other doing the same for the upper. Both would have to use the provided BinaryPrefixComparator with a compare operator of LESS_OR_EQUAL, and GREATER_OR_EQUAL respectively. Since all of this is error-prone and extra work, you can just use the ColumnRangeFilter and be done. Here the constructor of the filter:

```
ColumnRangeFilter(final byte[] minColumn, boolean minColumnInclusive,
                  final byte[] maxColumn, boolean maxColumnInclusive)
```

You have to provide an optional *minimum* and *maximum* column qualifier, and accompanying boolean flags if these are exclusive or inclusive. If you do not specify minimum column, then the start of table is used. Same for the maximum column, if not provided the end of the table is assumed. [Example 4-16](#) shows an example using these parameters.

Example 4-16. Example filtering by columns within a given range

```
Filter filter = new ColumnRangeFilter(Bytes.toBytes("col-05"),
true,
    Bytes.toBytes("col-11"), false);

Scan scan = new Scan()
.setStartRow(Bytes.toBytes("row-03"))
```

```

.setStopRow(Bytes.toBytes("row-05"))
.setFilter(filter);
ResultScanner scanner = table.getScanner(scan);
for (Result result : scanner) {
    System.out.println(result);
}
scanner.close();

```

The output is as follows:

```

Adding rows to table...
Results of scan:
keyvalues={row-03/colfam1:col-05/5/Put/vlen=9/seqid=0,
           row-03/colfam1:col-06/6/Put/vlen=9/seqid=0,
           row-03/colfam1:col-07/7/Put/vlen=9/seqid=0,
           row-03/colfam1:col-08/8/Put/vlen=9/seqid=0,
           row-03/colfam1:col-09/9/Put/vlen=9/seqid=0,
           row-03/colfam1:col-10/10/Put/vlen=9/seqid=0}
keyvalues={row-04/colfam1:col-05/5/Put/vlen=9/seqid=0,
           row-04/colfam1:col-06/6/Put/vlen=9/seqid=0,
           row-04/colfam1:col-07/7/Put/vlen=9/seqid=0,
           row-04/colfam1:col-08/8/Put/vlen=9/seqid=0,
           row-04/colfam1:col-09/9/Put/vlen=9/seqid=0,
           row-04/colfam1:col-10/10/Put/vlen=9/seqid=0}

```

In this example you can see the use of the *fluent interface* again to set up the scan instance. It also limits the number of rows scanned (just because).

SingleColumnValueFilter

You can use this filter when you have exactly one column that decides if an entire row should be returned or not. You need to first specify the column you want to track, and then some value to check against. The constructors offered are:

```

SingleColumnValueFilter(final byte[] family, final byte[] qualifi-
er,
    final CompareOp compareOp, final byte[] value)
SingleColumnValueFilter(final byte[] family, final byte[] qualifi-
er,
    final CompareOp compareOp, final ByteArrayComparable compara-
tor)
protected SingleColumnValueFilter(final byte[] family, final
byte[] qualifier,
    final CompareOp compareOp, ByteArrayComparable comparator,
    final boolean filterIfMissing, final boolean latestVersionOnly)

```

The first one is a convenience function as it simply creates a `BinaryComparator` instance internally on your behalf. The second takes the same parameters we used for the `CompareFilter`-based classes. Although the `SingleColumnValueFilter` does not inherit from the `Com`

`pareFilter` directly, it still uses the same parameter types. The third, and final constructor, adds two additional boolean flags, which, alternatively, can be set with getter and setter methods after the filter has been constructed:

```
boolean getFilterIfMissing()
void setFilterIfMissing(boolean filterIfMissing)
boolean getLatestVersionOnly()
void setLatestVersionOnly(boolean latestVersionOnly)
```

The former controls what happens to rows that do not have the column at all. By default, they are included in the result, but you can use `setFilterIfMissing(true)` to reverse that behavior, that is, all rows that do not have the reference column are dropped from the result.

You must include the column you want to filter by, in other words, the reference column, into the families you query for—using `addColumn()`, for example. If you fail to do so, the column is considered missing and the result is either empty, or contains all rows, based on the `getFilterIfMissing()` result.

By using `setLatestVersionOnly(false)`--the default is `true`--you can change the default behavior of the filter, which is only to check the newest version of the reference column, to instead include previous versions in the check as well. [Example 4-17](#) combines these features to select a specific set of rows only.

Example 4-17. Example using a filter to return only rows with a given value in a given column

```
SingleColumnValueFilter filter = new SingleColumnValueFilter(
    Bytes.toBytes("colfam1"),
    Bytes.toBytes("col-5"),
    CompareFilter.CompareOp.NOT_EQUAL,
    new SubstringComparator("val-5"));
filter.setFilterIfMissing(true);

Scan scan = new Scan();
scan.setFilter(filter);
ResultScanner scanner = table.getScanner(scan);
for (Result result : scanner) {
    for (Cell cell : result.rawCells()) {
        System.out.println("Cell: " + cell + ", Value: " +
            Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
                cell.getValueLength()));
    }
}
```

```

scanner.close();

Get get = new Get(Bytes.toBytes("row-6"));
get.setFilter(filter);
Result result = table.get(get);
System.out.println("Result of get: ");
for (Cell cell : result.rawCells()) {
    System.out.println("Cell: " + cell + ", Value: " +
        Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
        cell.getValueLength()));
}

```

The output shows how the scan is filtering out all columns from row-5, since their value starts with val-5. We are asking the filter to do a substring match on val-5 and use the `NOT_EQUAL` comparator to include all other matching rows:

```

Adding rows to table...
Results of scan:
Cell: row-1/colfam1:col-1/1427279447557/Put/vlen=7/seqid=0, Value:
val-1.1
Cell: row-1/colfam1:col-10/1427279447613/Put/vlen=8/seqid=0, Value:
val-1.10
...
Cell: row-4/colfam2:col-8/1427279447667/Put/vlen=7/seqid=0, Value:
val-4.8
Cell: row-4/colfam2:col-9/1427279447669/Put/vlen=7/seqid=0, Value:
val-4.9
Cell: row-6/colfam1:col-1/1427279447692/Put/vlen=7/seqid=0, Value:
val-6.1
Cell: row-6/colfam1:col-10/1427279447709/Put/vlen=8/seqid=0, Value:
val-6.10
...
Cell: row-9/colfam2:col-8/1427279447759/Put/vlen=7/seqid=0, Value:
val-9.8
Cell: row-9/colfam2:col-9/1427279447761/Put/vlen=7/seqid=0, Value:
val-9.9
Result of get:
Cell: row-6/colfam1:col-1/1427279447692/Put/vlen=7/seqid=0, Value:
val-6.1
Cell: row-6/colfam1:col-10/1427279447709/Put/vlen=8/seqid=0, Value:
val-6.10
...
Cell: row-6/colfam2:col-8/1427279447705/Put/vlen=7/seqid=0, Value:
val-6.8
Cell: row-6/colfam2:col-9/1427279447707/Put/vlen=7/seqid=0, Value:
val-6.9

```

SingleColumnValueExcludeFilter

The `SingleColumnValueFilter` we just discussed is extended in this class to provide slightly different semantics: the reference column, as

handed into the constructor, is omitted from the result. In other words, you have the same features, constructors, and methods to control how this filter works. The only difference is that you will never get the column you are checking against as part of the `Result` instance(s) on the client side.

TimestampsFilter

When you need fine-grained control over what versions are included in the scan result, this filter provides the means. You have to hand in a `List` of timestamps:

```
TimestampsFilter(List<Long> timestamps)
```

As you have seen throughout the book so far, a *version* is a specific value of a column at a unique point in time, denoted with a *timestamp*. When the filter is asking for a list of timestamps, it will attempt to retrieve the column versions with the matching timestamps.

[Example 4-18](#) sets up a filter with three timestamps and adds a time range to the second scan.

Example 4-18. Example filtering data by timestamps

```
List<Long> ts = new ArrayList<Long>();
ts.add(new Long(5));
ts.add(new Long(10)); ①
ts.add(new Long(15));
Filter filter = new TimestampsFilter(ts);

Scan scan1 = new Scan();
scan1.setFilter(filter); ②
ResultScanner scanner1 = table.getScanner(scan1);
for (Result result : scanner1) {
    System.out.println(result);
}
scanner1.close();

Scan scan2 = new Scan();
scan2.setFilter(filter);
scan2.setTimeRange(8, 12); ③
ResultScanner scanner2 = table.getScanner(scan2);
for (Result result : scanner2) {
    System.out.println(result);
}
scanner2.close();
```

- ① Add timestamps to the list.

- ② Add the filter to an otherwise default Scan instance.
- ③ Also add a time range to verify how it affects the filter

Here is the output on the console in an abbreviated form:

```

Adding rows to table...
Results of scan #1:
keyvalues={row-1/colfam1:col-10/10/Put/vlen=8/seqid=0,
           row-1/colfam1:col-15/15/Put/vlen=8/seqid=0,
           row-1/colfam1:col-5/5/Put/vlen=7/seqid=0}
keyvalues={row-100/colfam1:col-10/10/Put/vlen=10/seqid=0,
           row-100/colfam1:col-15/15/Put/vlen=10/seqid=0,
           row-100/colfam1:col-5/5/Put/vlen=9/seqid=0}
...
keyvalues={row-99/colfam1:col-10/10/Put/vlen=9/seqid=0,
           row-99/colfam1:col-15/15/Put/vlen=9/seqid=0,
           row-99/colfam1:col-5/5/Put/vlen=8/seqid=0}

Results of scan #2:
keyvalues={row-1/colfam1:col-10/10/Put/vlen=8/seqid=0}
keyvalues={row-10/colfam1:col-10/10/Put/vlen=9/seqid=0}
...
keyvalues={row-98/colfam1:col-10/10/Put/vlen=9/seqid=0}
keyvalues={row-99/colfam1:col-10/10/Put/vlen=9/seqid=0}
```

The first scan, only using the filter, is outputting the column values for all three specified timestamps as expected. The second scan only returns the timestamp that fell into the time range specified when the scan was set up. Both time-based restrictions, the filter and the scanner time range, are doing their job and the result is a combination of both.

RandomRowFilter

Finally, there is a filter that shows what is also possible using the API: including random rows into the result. The constructor is given a parameter named `chance`, which represents a value between `0.0` and `1.0`:

```
RandomRowFilter(float chance)
```

Internally, this class is using a Java `Random.nextFloat()` call to randomize the row inclusion, and then compares the value with the chance given. Giving it a negative chance value will make the filter exclude all rows, while a value larger than `1.0` will make it include all rows. [Example 4-19](#) uses a `chance` of 50%, iterating three times over the scan:

Example 4-19. Example filtering rows randomly

```
Filter filter = new RandomRowFilter(0.5f);

for (int loop = 1; loop <= 3; loop++) {
    Scan scan = new Scan();
    scan.setFilter(filter);
    ResultScanner scanner = table.getScanner(scan);
    for (Result result : scanner) {
        System.out.println(Bytes.toString(result.getRow()));
    }
    scanner.close();
}
```

The random results for one execution looked like:

```
Adding rows to table...
Results of scan for loop: 1
row-1
row-10
row-3
row-9
Results of scan for loop: 2
row-10
row-2
row-3
row-5
row-6
row-8
Results of scan for loop: 3
row-1
row-3
row-4
row-8
row-9
```

Your results will most certainly vary.

Decorating Filters

While the provided filters are already very powerful, sometimes it can be useful to modify, or extend, the behavior of a filter to gain additional control over the returned data. Some of this additional control is not dependent on the filter itself, but can be applied to any of them. This is what the *decorating filter* group of classes is about.

Decorating filters implement the same `Filter` interface, just like any other single-purpose filter. In doing so, they can be used as a drop-in replacement for those filters, while combining their behavior with the wrapped filter instance.

SkipFilter

This filter wraps a given filter and extends it to exclude an entire row, when the wrapped filter hints for a `Cell` to be skipped. In other words, as soon as a filter indicates that a column in a row is omitted, the entire row is omitted.

The wrapped filter *must* implement the `filterKeyValue()` method, or the `SkipFilter` will not work as expected.¹ This is because the `SkipFilter` is only checking the results of that method to decide how to handle the current row. See [Table 4-9](#) on page [Table 4-9](#) for an overview of compatible filters.

[Example 4-20](#) combines the `SkipFilter` with a `ValueFilter` to first select all columns that have no zero-valued column, and subsequently drops all other partial rows that do not have a matching value.

Example 4-20. Example of using a filter to skip entire rows based on another filter's results

```
Filter filter1 = new ValueFilter(CompareFilter.CompareOp.NOT_EQUAL,
    new BinaryComparator(Bytes.toBytes("val-0"));

Scan scan = new Scan();
scan.setFilter(filter1); ①
ResultScanner scanner1 = table.getScanner(scan);
for (Result result : scanner1) {
    for (Cell cell : result.rawCells()) {
        System.out.println("Cell: " + cell + ", Value: " +
            Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
                cell.getValueLength()));
    }
}
scanner1.close();
```

1. The various filter methods are discussed in “[Custom Filters](#)” (page 259).

```

Filter filter2 = new SkipFilter(filter1);

scan.setFilter(filter2); ②
ResultScanner scanner2 = table.getScanner(scan);
for (Result result : scanner2) {
    for (Cell cell : result.rawCells()) {
        System.out.println("Cell: " + cell + ", Value: " +
            Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
            cell.getValueLength()));
    }
}
scanner2.close();

```

- ① Only add the ValueFilter to the first scan.
- ② Add the decorating skip filter for the second scan.

The example code should print roughly the following results when you execute it—note, though, that the values are randomized, so you should get a slightly different result for every invocation:

```

Adding rows to table...
Results of scan #1:
Cell: row-01/colfam1:col-01/1/Put/vlen=5/seqid=0, Value: val-4
Cell: row-01/colfam1:col-02/2/Put/vlen=5/seqid=0, Value: val-4
Cell: row-01/colfam1:col-03/3/Put/vlen=5/seqid=0, Value: val-1
Cell: row-01/colfam1:col-04/4/Put/vlen=5/seqid=0, Value: val-3
Cell: row-01/colfam1:col-05/5/Put/vlen=5/seqid=0, Value: val-1
Cell: row-02/colfam1:col-01/1/Put/vlen=5/seqid=0, Value: val-1
Cell: row-02/colfam1:col-03/3/Put/vlen=5/seqid=0, Value: val-2
Cell: row-02/colfam1:col-04/4/Put/vlen=5/seqid=0, Value: val-4
Cell: row-02/colfam1:col-05/5/Put/vlen=5/seqid=0, Value: val-2
...
Cell: row-30/colfam1:col-01/1/Put/vlen=5/seqid=0, Value: val-2
Cell: row-30/colfam1:col-02/2/Put/vlen=5/seqid=0, Value: val-4
Cell: row-30/colfam1:col-03/3/Put/vlen=5/seqid=0, Value: val-4
Cell: row-30/colfam1:col-05/5/Put/vlen=5/seqid=0, Value: val-4
Total cell count for scan #1: 124
Results of scan #2:
Cell: row-01/colfam1:col-01/1/Put/vlen=5/seqid=0, Value: val-4
Cell: row-01/colfam1:col-02/2/Put/vlen=5/seqid=0, Value: val-4
Cell: row-01/colfam1:col-03/3/Put/vlen=5/seqid=0, Value: val-1
Cell: row-01/colfam1:col-04/4/Put/vlen=5/seqid=0, Value: val-3
Cell: row-01/colfam1:col-05/5/Put/vlen=5/seqid=0, Value: val-1
Cell: row-06/colfam1:col-01/1/Put/vlen=5/seqid=0, Value: val-4
Cell: row-06/colfam1:col-02/2/Put/vlen=5/seqid=0, Value: val-4
Cell: row-06/colfam1:col-03/3/Put/vlen=5/seqid=0, Value: val-4
Cell: row-06/colfam1:col-04/4/Put/vlen=5/seqid=0, Value: val-3
Cell: row-06/colfam1:col-05/5/Put/vlen=5/seqid=0, Value: val-2
...
Cell: row-28/colfam1:col-01/1/Put/vlen=5/seqid=0, Value: val-2

```

```

Cell: row-28/colfam1:col-02/2/Put/vlen=5/seqid=0, Value: val-1
Cell: row-28/colfam1:col-03/3/Put/vlen=5/seqid=0, Value: val-2
Cell: row-28/colfam1:col-04/4/Put/vlen=5/seqid=0, Value: val-4
Cell: row-28/colfam1:col-05/5/Put/vlen=5/seqid=0, Value: val-2
Total cell count for scan #2: 55

```

The first scan returns *all* columns that are *not* zero valued. Since the value is assigned at random, there is a high probability that you will get at least one or more columns of each possible row. Some rows will miss a column—these are the omitted zero-valued ones.

The second scan, on the other hand, wraps the first filter and forces all partial rows to be dropped. You can see from the console output how only complete rows are emitted, that is, those with all five columns the example code creates initially. The total Cell count for each scan confirms the more restrictive behavior of the `SkipFilter` variant.

WhileMatchFilter

This second decorating filter type works somewhat similarly to the previous one, but aborts the entire scan once a piece of information is filtered. This works by checking the wrapped filter and seeing if it skips a row by its key, or a column of a row because of a `Cell` check.²

[Example 4-21](#) is a slight variation of the previous example, using different filters to show how the decorating class works.

Example 4-21. Example of using a filter to skip entire rows based on another filter's results

```

Filter filter1 = new RowFilter(CompareFilter.CompareOp.NOT_EQUAL,
    new BinaryComparator(Bytes.toBytes("row-05")));

Scan scan = new Scan();
scan.setFilter(filter1);
ResultScanner scanner1 = table.getScanner(scan);
for (Result result : scanner1) {
    for (Cell cell : result.rawCells()) {
        System.out.println("Cell: " + cell + ", Value: " +
            Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
                cell.getValueLength()));
    }
}
scanner1.close();

Filter filter2 = new WhileMatchFilter(filter1);

```

2. See [Table 4-9](#) for an overview of compatible filters.

```

scan.setFilter(filter2);
ResultScanner scanner2 = table.getScanner(scan);
for (Result result : scanner2) {
    for (Cell cell : result.rawCells()) {
        System.out.println("Cell: " + cell + ", Value: " +
            Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
            cell.getValueLength()));
    }
}
scanner2.close();

```

Once you run the example code, you should get this output on the console:

```

Adding rows to table...
Results of scan #1:
Cell: row-01/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-01.01
Cell: row-02/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-02.01
Cell: row-03/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-03.01
Cell: row-04/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-04.01
Cell: row-06/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-06.01
Cell: row-07/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-07.01
Cell: row-08/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-08.01
Cell: row-09/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-09.01
Cell: row-10/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-10.01
Total cell count for scan #1: 9

Results of scan #2:
Cell: row-01/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-01.01
Cell: row-02/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-02.01
Cell: row-03/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-03.01
Cell: row-04/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-04.01
Total cell count for scan #2: 4

```

The first scan used just the `RowFilter` to skip one out of 10 rows; the rest is returned to the client. Adding the `WhileMatchFilter` for the second scan shows its behavior to stop the entire scan operation, once the wrapped filter omits a row or column. In the example this is `row-05`, triggering the end of the scan.

FilterList

So far you have seen how filters—on their own, or decorated—are doing the work of filtering out various dimensions of a table, ranging from rows, to columns, and all the way to versions of values within a column. In practice, though, you may want to have more than one filter being applied to reduce the data returned to your client application. This is what the `FilterList` is for.

The `FilterList` class implements the same `Filter` interface, just like any other single-purpose filter. In doing so, it can be used as a drop-in replacement for those filters, while combining the effects of each included instance.

You can create an instance of `FilterList` while providing various parameters at instantiation time, using one of these constructors:

```
FilterList(final List<Filter> rowFilters)
FilterList(final Filter... rowFilters)
FilterList(final Operator operator)
FilterList(final Operator operator, final List<Filter> rowFilters)
FilterList(final Operator operator, final Filter... rowFilters)
```

The `rowFilters` parameter specifies the list of filters that are assessed together, using an operator to combine their results. [Table 4-3](#) lists the possible choices of operators. The default is `MUST_PASS_ALL`, and can therefore be omitted from the constructor when you do not need a different one. Otherwise, there are two variants that take a `List` or filters, and another that does the same but uses the newer Java `vararg` construct (shorthand for manually creating an array).

Table 4-3. Possible values for the `FilterList.Operator` enumeration

Operator	Description
<code>MUST_PASS_ALL</code>	A value is only included in the result when <i>all</i> filters agree to do so, i.e., no filter is omitting the value.
<code>MUST_PASS_ONE</code>	As soon as a value was allowed to pass one of the filters, it is included in the overall result.

Adding filters, *after* the `FilterList` instance has been created, can be done with:

```
void addFilter(Filter filter)
```

You can only specify *one* operator per `FilterList`, but you are free to add other `FilterList` instances to an existing `FilterList`, thus creating a hierarchy of filters, combined with the operators you need.

You can further control the execution order of the included filters by carefully choosing the `List` implementation you require. For example, using `ArrayList` would guarantee that the filters are applied in the order they were added to the list. This is shown in [Example 4-22](#).

Example 4-22. Example of using a filter list to combine single purpose filters

```
List<Filter> filters = new ArrayList<Filter>();

    Filter filter1 = new RowFilter(CompareFilter.CompareOp.GREAT-
ER_OR_EQUAL,
        new BinaryComparator(Bytes.toBytes("row-03")));
    filters.add(filter1);

    Filter filter2 = new RowFilter(CompareFilter.Compar-
eOp.LESS_OR_EQUAL,
        new BinaryComparator(Bytes.toBytes("row-06")));
    filters.add(filter2);

    Filter filter3 = new QualifierFilter(CompareFilter.Compar-
eOp.EQUAL,
        new RegexStringComparator("col-0[03]"));
    filters.add(filter3);

FilterList filterList1 = new FilterList(filters);

Scan scan = new Scan();
scan.setFilter(filterList1);
ResultScanner scanner1 = table.getScanner(scan);
for (Result result : scanner1) {
    for (Cell cell : result.rawCells()) {
        System.out.println("Cell: " + cell + ", Value: " +
            Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
                cell.getValueLength()));
    }
}
scanner1.close();

FilterList filterList2 = new FilterList(
    FilterList.Operator.MUST_PASS_ONE, filters);

scan.setFilter(filterList2);
ResultScanner scanner2 = table.getScanner(scan);
for (Result result : scanner2) {
    for (Cell cell : result.rawCells()) {
        System.out.println("Cell: " + cell + ", Value: " +
            Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
                cell.getValueLength()));
    }
}
scanner2.close();
```

And the output again:

```
Adding rows to table...
Results of scan #1 - MUST_PASS_ALL:
Cell: row-03/colfam1:col-03/3/Put/vlen=9/seqid=0, Value: val-03.03
```

```

Cell: row-04/colfam1:col-03/3/Put/vlen=9/seqid=0, Value: val-04.03
Cell: row-05/colfam1:col-03/3/Put/vlen=9/seqid=0, Value: val-05.03
Cell: row-06/colfam1:col-03/3/Put/vlen=9/seqid=0, Value: val-06.03
Total cell count for scan #1: 4

Results of scan #2 - MUST_PASS_ONE:
Cell: row-01/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-01.01
Cell: row-01/colfam1:col-02/2/Put/vlen=9/seqid=0, Value: val-01.02
...
Cell: row-10/colfam1:col-04/4/Put/vlen=9/seqid=0, Value: val-10.04
Cell: row-10/colfam1:col-05/5/Put/vlen=9/seqid=0, Value: val-10.05
Total cell count for scan #2: 50

```

The first scan filters out a lot of details, as at least one of the filters in the list excludes some information. Only where they all let the information pass is it returned to the client.

In contrast, the second scan includes *all* rows and columns in the result. This is caused by setting the `FilterList` operator to `MUST_PASS_ONE`, which includes all the information as soon as a single filter lets it pass. And in this scenario, all values are passed by at least one of them, including everything.

Custom Filters

Eventually, you may exhaust the list of supplied filter types and need to implement your own. This can be done by either implementing the abstract `Filter` class, or extending the provided `FilterBase` class. The latter provides default implementations for all methods that are members of the interface. The `Filter` class has the following structure:

```

public abstract class Filter {
    public enum ReturnCode {
        INCLUDE, INCLUDE_AND_NEXT_COL, SKIP, NEXT_COL, NEXT_ROW,
        SEEK_NEXT_USING_HINT
    }
    public void reset() throws IOException
        public boolean filterRowKey(byte[] buffer, int offset, int
length)
            throws IOException
        public boolean filterAllRemaining() throws IOException
        public ReturnCode filterKeyValue(final Cell v) throws IOException
        public Cell transformCell(final Cell v) throws IOException
        public void filterRowCells(List<Cell> kvs) throws IOException
        public boolean hasFilterRow()
        public boolean filterRow() throws IOException
        public Cell getNextCellHint(final Cell currentKV) throws IOException
        public boolean isFamilyEssential(byte[] name) throws IOException
        public void setReversed(boolean reversed)
    }
}

```

```

public boolean isReversed()
public byte[] toByteArray() throws IOException
public static Filter parseFrom(final byte[] pbBytes)
    throws DeserializationException
}

```

The interface provides a public enumeration type, named `ReturnCode`, that is used by the `filterKeyValue()` method to indicate what the execution framework should do next. Instead of blindly iterating over all values, the filter has the ability to skip a value, the remainder of a column, or the rest of the entire row. This helps tremendously in terms of improving performance while retrieving data.

The servers may still need to scan the entire row to find matching data, but the optimizations provided by the `filterKeyValue()` return code can reduce the work required to do so.

Table 4-4 lists the possible values and their meaning.

Table 4-4. Possible values for the `Filter.ReturnCode` enumeration

Return code	Description
INCLUDE	Include the given cell instance in the result.
INCLUDE_AND_NEXT_COL	Include current cell and move to next column, i.e. skip all further versions of the current.
SKIP	Skip the current cell and proceed to the next.
NEXT_COL	Skip the remainder of the current column, proceeding to the next. This is used by the <code>TimestampsFilter</code> , for example.
NEXT_ROW	Similar to the previous, but skips the remainder of the current row, moving to the next. The <code>RowFilter</code> makes use of this return code, for example.
SEEK_NEXT_USING_HINT	Some filters want to skip a variable number of cells and use this return code to indicate that the framework should use the <code>getNextCellHint()</code> method to determine where to skip to. The <code>ColumnPrefixFilter</code> , for example, uses this feature.

Most of the provided methods are called at various stages in the process of retrieving a row for a client—for example, during a scan operation. Putting them in call order, you can expect them to be executed in the following sequence:

`hasFilterRow()`

This is checked first as part of the read path to do two things: first, to decide if the filter is clashing with other read settings, such as

scanner batching, and second, to call the `filterRow()` and `filterRowCells()` methods subsequently. It also enforces to load the entire row before calling these methods.

`filterRowKey(byte[] buffer, int offset, int length)`

The next check is against the *row key*, using this method of the `Filter` implementation. You can use it to skip an entire row from being further processed. The `RowFilter` uses it to suppress entire rows being returned to the client.

`filterKeyValue(final Cell v)`

When a row is not filtered (yet), the framework proceeds to invoke this method for every `Cell` that is part of the current row being materialized for the read. The `ReturnCode` indicates what should happen with the current cell.

`transfromCell()`

Once the cell has passed the check and is available, the *transform* call allows the filter to modify the cell, before it is added to the resulting row.

`filterRowCells(List<Cell> kvs)`

Once all row and cell checks have been performed, this method of the filter is called, giving you access to the list of `Cell` instances that have not been excluded by the previous filter methods. The `DependentColumnFilter` uses it to drop those columns that do not match the reference column.

`filterRow()`

After everything else was checked and invoked, the final inspection is performed using `filterRow()`. A filter that uses this functionality is the `PageFilter`, checking if the number of rows to be returned for one iteration in the pagination process is reached, returning `true` afterward. The default `false` would include the current row in the result.

`reset()`

This resets the filter for every new row the scan is iterating over. It is called by the server, *after* a row is read, implicitly. This applies to `get` and `scan` operations, although obviously it has no effect for the former, as `'get()'`s only read a single row.

`filterAllRemaining()`

This method can be used to stop the scan, by returning `true`. It is used by filters to provide the *early out* optimization mentioned. If a filter returns `false`, the scan is continued, and the aforementioned methods are called. Obviously, this also implies that for `get()` operations this call is not useful.

filterRow() and Batch Mode

A filter using `filterRow()` to filter out an entire row, or `filterRowCells()` to modify the final list of included cells, *must* also override the `hasRowFilter()` function to return `true`.

The framework is using this flag to ensure that a given filter is compatible with the selected scan parameters. In particular, these filter methods collide with the scanner's batch mode: when the scanner is using batches to ship partial rows to the client, the previous methods are *not* called for every batch, but only at the actual end of the current row.

Figure 4-2 shows the logical flow of the filter methods for a single row. There is a more fine-grained process to apply the filters on a column level, which is not relevant in this context.

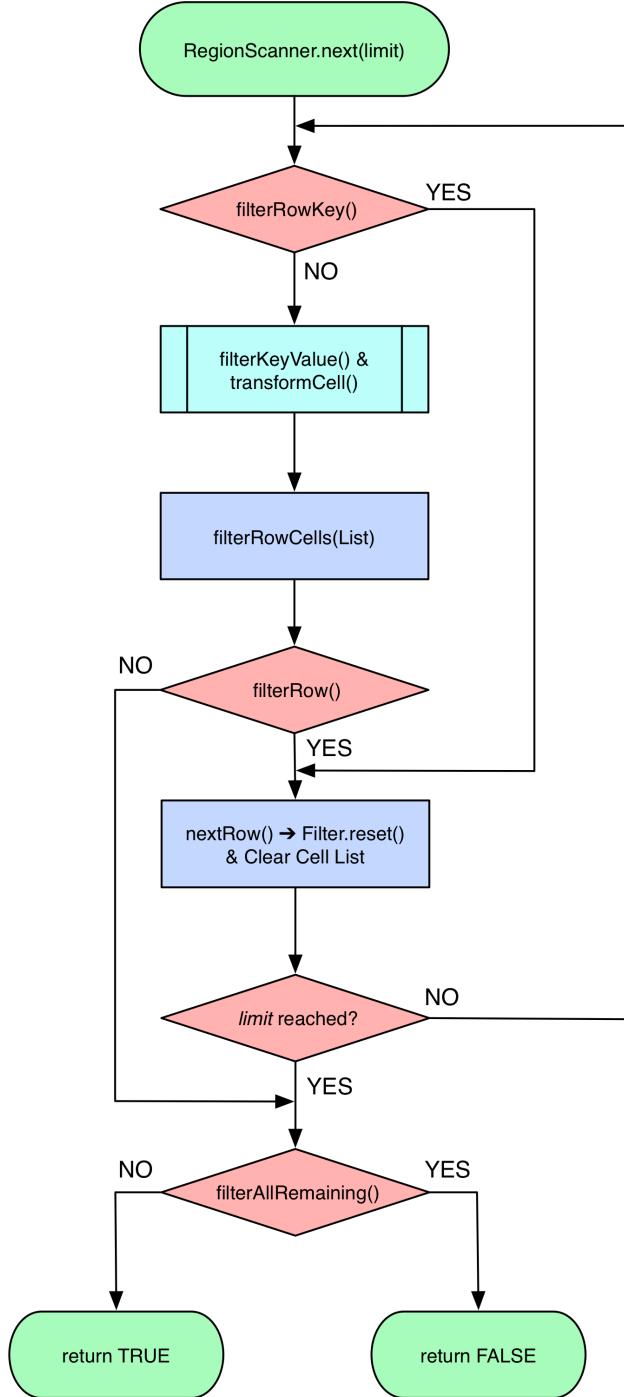


Figure 4-2. The logical flow through the filter methods for a single row. 263

The `Filter` interface has a few more methods at its disposal. [Table 4-5](#) lists them for your perusal.

Table 4-5. Additional methods provided by the Filter class

Method	Description
<code>getNextCellHint()</code>	This method is invoked when the filter's <code>filterKeyValue()</code> method returns <code>ReturnCode.SEEK_NEXT_USING_HINT</code> . Use it to skip large ranges of rows—if possible.
<code>isFamilyEssential()</code>	Discussed in “Load Column Families on Demand” (page 213) , used to avoid unnecessary loading of cells from column families in low-cardinality scans.
<code>setReversed()/isReversed()</code>	Flags the direction the filter instance is observing. A reverse scan <i>must</i> use reverse filters too.
<code>toByteArray()/parseFrom()</code>	Used to de-/serialize the filter's internal state to ship to the servers for application.

The `reverse` flag, assigned with `setReversed(true)`, helps the filter to come to the right decision. Here is a snippet from the `PrefixFilter.filterRowKey()` method, showing how the result of the binary prefix comparison is reversed based on this flag:

```
...
int cmp = Bytes.compareTo(buffer, offset, this.prefix.length,
    this.prefix, 0, this.prefix.length);
if ((!isReversed() && cmp > 0) || (isReversed() && cmp < 0)) {
    passedPrefix = true;
}
...

```

[Example 4-23](#) implements a custom filter, using the methods provided by `FilterBase`, overriding only those methods that need to be changed (or, more specifically, at least implement those that are marked abstract). The filter first assumes all rows should be filtered, that is, removed from the result. Only when there is a value in any column that matches the given reference does it include the row, so that it is sent back to the client. See [“Custom Filter Loading” \(page 268\)](#) for how to load the custom filters into the Java server process.

Example 4-23. Implements a filter that lets certain rows pass

```
public class CustomFilter extends FilterBase {

    private byte[] value = null;
    private boolean filterRow = true;

    public CustomFilter() {
```

```

        super();
    }

    public CustomFilter(byte[] value) {
        this.value = value; ①
    }

    @Override
    public void reset() {
        this.filterRow = true; ②
    }

    @Override
    public ReturnCode filterKeyValue(Cell cell) {
        if (CellUtil.matchingValue(cell, value)) {
            filterRow = false; ③
        }
        return ReturnCode.INCLUDE; ④
    }

    @Override
    public boolean filterRow() {
        return filterRow; ⑤
    }

    @Override
    public byte [] toByteArray() {
        FilterProtos.CustomFilter.Builder builder =
            FilterProtos.CustomFilter.newBuilder();
        if (value != null) builder.setValue(ByteStringer.wrap(value)); ⑥
        return builder.build().toByteArray();
    }

    //@@Override
    public static Filter parseFrom(final byte[] pbBytes)
        throws DeserializationException {
        FilterProtos.CustomFilter proto;
        try {
            proto = FilterProtos.CustomFilter.parseFrom(pbBytes); ⑦
        } catch (InvalidProtocolBufferException e) {
            throw new DeserializationException(e);
        }
        return new CustomFilter(proto.getValue().toByteArray());
    }
}

```

- ① Set the value to compare against.
- ② Reset filter flag for each new row being tested.
- ③ When there is a matching value, then let the row pass.
- ④ Always include, since the final decision is made later.

- ⑤ Here the actual decision is taking place, based on the flag status.
- ⑥ Writes the given value out so it can be send to the servers.
- ⑦ Used by the servers to establish the filter instance with the correct values.

The most interesting part about the custom filter is the serialization using Protocol Buffers (Protobuf, for short).³ The first thing to do is define a message in Protobuf, which is done in a simple text file, here named `CustomFilters.proto`:

```
option java_package = "filters.generated";
option java_outer_classname = "FilterProtos";
option java_generic_services = true;
option java_generate_equals_and_hash = true;
option optimize_for = SPEED;

message CustomFilter {
    required bytes value = 1;
}
```

The file defines the output class name, the package to use during code generation and so on. The next step is to compile the definition file into code. This is done using the Protobuf `protoc` tool.

The Protocol Buffer library usually comes as a source package that needs to be compiled and locally installed. There are also pre-built binary packages for many operating systems. On OS X, for example, you can run the following, assuming Homebrew was installed:

```
$ brew install protobuf
```

You can verify the installation by running `$ protoc --version` and check it prints a version number:

```
$ protoc --version
libprotobuf 2.6.1
```

The online code repository of the book has a script `bin/doprotoc.sh` that runs the code generation. It essentially runs the following command from the repository root directory:

3. For users of older, pre-Protocol Buffer based HBase, please see “[Migrate Custom Filters to post HBase 0.96](#)” (page 640) for a migration guide.

```
$ protoc -Ich04/src/main/protobuf --java_out=ch04/src/main/java \
ch04/src/main/protobuf/CustomFilters.proto
```

This will place the generated class file in the source directory, as specified. After that you will be able to use the generated types in your custom filter as shown in the example. [Example 4-24](#) uses the new custom filter to find rows with specific values in it, also using a `FilterList`.

Example 4-24. Example using a custom filter

```
List<Filter> filters = new ArrayList<Filter>();

Filter filter1 = new CustomFilter(Bytes.toBytes("val-05.05"));
filters.add(filter1);

Filter filter2 = new CustomFilter(Bytes.toBytes("val-02.07"));
filters.add(filter2);

Filter filter3 = new CustomFilter(Bytes.toBytes("val-09.01"));
filters.add(filter3);

FilterList filterList = new FilterList(
    FilterList.Operator.MUST_PASS_ONE, filters);

Scan scan = new Scan();
scan.setFilter(filterList);
ResultScanner scanner = table.getScanner(scan);
for (Result result : scanner) {
    for (Cell cell : result.rawCells()) {
        System.out.println("Cell: " + cell + ", Value: " +
            Bytes.toString(cell.getValueArray(), cell.getValueOffset(),
            cell.getValueLength()));
    }
}
scanner.close();
```

Just as with the earlier examples, here is what should appear as output on the console when executing this example:

```
Adding rows to table...
Results of scan:
Cell: row-02/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-02.01
Cell: row-02/colfam1:col-02/2/Put/vlen=9/seqid=0, Value: val-02.02
...
Cell: row-02/colfam1:col-06/6/Put/vlen=9/seqid=0, Value: val-02.06
Cell: row-02/colfam1:col-07/7/Put/vlen=9/seqid=0, Value: val-02.07
Cell: row-02/colfam1:col-08/8/Put/vlen=9/seqid=0, Value: val-02.08
...
Cell: row-05/colfam1:col-04/4/Put/vlen=9/seqid=0, Value: val-05.04
Cell: row-05/colfam1:col-05/5/Put/vlen=9/seqid=0, Value: val-05.05
Cell: row-05/colfam1:col-06/6/Put/vlen=9/seqid=0, Value: val-05.06
...
```

```
Cell: row-05/colfam1:col-10/10/Put/vlen=9/seqid=0, Value: val-05.10
Cell: row-09/colfam1:col-01/1/Put/vlen=9/seqid=0, Value: val-09.01
Cell: row-09/colfam1:col-02/2/Put/vlen=9/seqid=0, Value: val-09.02
...
Cell: row-09/colfam1:col-09/9/Put/vlen=9/seqid=0, Value: val-09.09
Cell: row-09/colfam1:col-10/10/Put/vlen=9/seqid=0, Value: val-09.10
```

As expected, the entire row that has a column with the value matching one of the references is included in the result.

Custom Filter Loading

Once you have written your filter, you need to deploy it to your HBase setup. You need to compile the class, pack it into a Java Archive (JAR) file, and make it available to the region servers. You can use the build system of your choice to prepare the JAR file for deployment, and a configuration management system to actually provision the file to all servers. Once you have uploaded the JAR file, you have two choices how to load them:

Static Configuration

In this case, you need to add the JAR file to the `hbase-env.sh` configuration file, for example:

```
# Extra Java CLASSPATH elements.  Optional.
# export HBASE_CLASSPATH=
export      HBASE_CLASSPATH="/hbase-book/ch04/target/hbase-book-
ch04-2.0.jar"
```

This is using the JAR file created by the Maven build as supplied by the source code repository accompanying this book. It uses an absolute, local path since testing is done on a standalone setup, in other words, with the development environment and HBase running on the same physical machine.

Note that you *must* restart the HBase daemons so that the changes in the configuration file are taking effect. Once this is done you can proceed to test the new filter.

Dynamic Loading

You still build the JAR file the same way, but instead of hardcoding its path into the configuration files, you can use the cluster wide, shared JAR file directory in HDFS that is used to load JAR files from. See the following configuration property from the `hbase-default.xml` file:

```
<property>
  <name>hbase.dynamic.jars.dir</name>
  <value>${hbase.rootdir}/lib</value>
</property>
```

The default points to \${hbase.rootdir}/lib, which usually resolves to /hbase/lib/ within HDFS. The full path would be similar to this example path: hdfs://master.foobar.com:9000/hbase/lib. If this directory exists and contains files ending in .jar, then the servers will load those files and make the contained classes available. To do so, the files are copied to a local directory named jars, located in a parent directory set again in the HBase default properties:

```
<property>
  <name>hbase.local.dir</name>
  <value>${hbase.tmp.dir}/local/</value>
</property>
```

An example path for a cluster with a configured temporary directory pointing to /data/tmp/ you will see the JAR files being copied to /data/tmp/local/jars. You will see this directory again later on when we talk about dynamic coprocessor loading in “[Coprocessor Loading](#)” (page 289). The local JAR files are flagged to be deleted when the server process ends normally.

The dynamic loading directory is monitored for changes, and will refresh the JAR files locally if they have been updated in the shared location.

Note that no matter how you load the classes and their containing JARs, HBase is currently not able to *unload* a previously loaded class. This means that once loaded, you cannot replace a class with the same name. The only way short of restarting the server processes is to add a version number to the class and JAR name to load the new one by new name. This leaves the previous classes loaded in memory and might cause memory issues after some time.

Filter Parser Utility

The client-side filter package comes with another helper class, named ParseFilter. It is used in all the places where filters need to be described with text and then, eventually, converted to a Java class. This happens in the gateway servers, such as for REST or Thrift. The HBase Shell also makes use of the class allowing a shell user to specify a filter on the command line, and then executing the filter as part of a subsequent scan, or get, operation. The following executes a scan on one of the earlier test tables (so your results may vary), adding a row prefix and qualifier filter, using the shell:

```
hbase(main):001:0> scan 'testtable', \
  { FILTER => "PrefixFilter('row-2') AND QualifierFilter(<=, 'binary:col-2')"
```

```

ROW          COLUMN+CELL
row-20      column=colfam1:col-0, timestamp=7, value=val-46
row-21      column=colfam1:col-0, timestamp=7, value=val-87
row-21      column=colfam1:col-2, timestamp=5, value=val-26
...
row-28      column=colfam1:col-2, timestamp=3, value=val-74
row-29      column=colfam1:col-1, timestamp=0, value=val-86
row-29      column=colfam1:col-2, timestamp=3, value=val-21
10 row(s) in 0.0170 seconds

```

What seems odd at first is the "binary:col-2" parameter. The second part after the colon is the value handed into the filter. The first part is the way the filter parser class is allowing you to specify a comparator for filters based on [CompareFilter](#) (see "[Comparators](#)" (page 222)). Here is a list of supported comparator prefixes:

Table 4-6. String representation of Comparator types

String	Type
binary	BinaryComparator
binaryprefix	BinaryPrefixComparator
regexstring	RegexStringComparator
substring	SubstringComparator

Since a comparison filter also is requiring a comparison operation, there is a way of expressing this in string format. The example above uses "<=" to specify *less than or equal*. Since there is an enumeration provided by the [CompareFilter](#) class, there is a matching pattern between the string representation and the enumeration value, as shown in the next table (also see "[Comparison Operators](#)" (page 221)):

Table 4-7. String representation of compare operation

String	Type
<	CompareOp.LESS
<=	CompareOp.LESS_OR_EQUAL
>	CompareOp.GREATER
>=	CompareOp.GREATER_OR_EQUAL
=	CompareOp.EQUAL
!=	CompareOp.NOT_EQUAL

The filter parser supports a few more text based tokens that translate into filter classes. You can combine filters with the AND and OR keywords, which are subsequently translated into [FilterList](#) instances that are either set to `MUST_PASS_ALL`, or `MUST_PASS_ONE` respectively

(“[FilterList](#)” (page 256) describes this in more detail). An example might be:

```
hbase(main):001:0> scan 'testtable', \
  { FILTER => "(PrefixFilter('row-2') AND ( \
    QualifierFilter(>=, 'binary:col-2'))) AND (TimestampsFilter(1, \
  5))" }
ROW          COLUMN+CELL
row-2        column=colfam1:col-9, timestamp=5, value=val-31
row-21       column=colfam1:col-2, timestamp=5, value=val-26
row-23       column=colfam1:col-5, timestamp=5, value=val-55
row-28       column=colfam1:col-5, timestamp=1, value=val-54
4 row(s) in 0.3190 seconds
```

Finally, there are the keywords SKIP and WHILE, representing the use of a SkipFilter (see “[SkipFilter](#)” (page 253)) and WhileMatchFilter (see “[WhileMatchFilter](#)” (page 255)). Refer to the mentioned sections for details on their features.

```
hbase(main):001:0> scan 'testtable', \
  { FILTER => "SKIP ValueFilter(>=, 'binary:val-5') " }
ROW          COLUMN+CELL
row-11       column=colfam1:col-0, timestamp=8, value=val-82
row-48       column=colfam1:col-3, timestamp=6, value=val-55
row-48       column=colfam1:col-7, timestamp=3, value=val-80
row-48       column=colfam1:col-8, timestamp=2, value=val-65
row-7        column=colfam1:col-9, timestamp=6, value=val-57
3 row(s) in 0.0150 seconds
```

The precedence of the keywords the parser understands is the following, listed from highest to lowest:

Table 4-8. Precedence of string keywords

Keyword	Description
SKIP/WHILE	Wrap filter into SkipFilter, or WhileMatchFilter instance.
AND	Add both filters left and right of keyword to FilterList instance using MUST_PASS_ALL.
OR	Add both filters left and right of keyword to FilterList instance using MUST_PASS_ONE.

From code you can invoke one of the following methods to parse a filter string into class instances:

```
Filter parseFilterString(String filterString)
  throws CharacterCodingException
Filter parseFilterString (byte[] filterStringAsByteArray)
  throws CharacterCodingException
Filter parseSimpleFilterExpression(byte[] filterStringAsByteArray)
  throws CharacterCodingException
```

The `parseSimpleFilterExpression()` parses one specific filter instance, and is used mainly from within the `parseFilterString()` methods. The latter handles the combination of multiple filters with AND and OR, plus the decorating filter wrapping with SKIP and WHILE. The two `parseFilterString()` methods are the same, one is taking a string and the other a `byte[]` array.

The `ParseFilter` class—by default—is only supporting the filters that are shipped with HBase. The unsupported filters on top of that are `FirstKeyValueMatchingQualifiersFilter`, `FuzzyRowFilter`, and `RandomRowFilter` (as of this writing). In your own code you can register your own, and retrieve the list of supported filters using the following methods of this class:

```
static Map<String, String> getAllFilters()
Set<String> getSupportedFilters()
static void registerFilter(String name, String filterClass)
```

Filters Summary

[Table 4-9](#) summarizes some of the features and compatibilities related to the provided filter implementations. The ✓ symbol means the feature is available, while ✗ indicates it is missing.

Table 4-9. Summary of filter features and compatibilities between them

Filter	Batch ^a	Skip ^b	While-Match ^c	List ^d	Early Out ^e	Gets ^f	Scans ^g
RowFilter	✓	✓	✓	✓	✓	✗	✓
FamilyFilter	✓	✓	✓	✓	✗	✓	✓
QualifierFilter	✓	✓	✓	✓	✗	✓	✓
ValueFilter	✓	✓	✓	✓	✗	✓	✓
DependentColumnFilter	✗	✓	✓	✓	✗	✓	✓
SingleColumnValueFilter	✓	✓	✓	✓	✗	✗	✓
SingleColumnValueExcludeFilter	✓	✓	✓	✓	✗	✗	✓
PrefixFilter	✓	✗	✓	✓	✓	✗	✓
PageFilter	✓	✗	✓	✓	✓	✗	✓
KeyOnlyFilter	✓	✓	✓	✓	✗	✓	✓
FirstKeyOnlyFilter	✓	✓	✓	✓	✗	✓	✓

Filter	Batch ^a	Skip ^b	While-Match ^c	List ^d	Early Out ^e	Gets ^f	Scans ^g
FirstKeyValueMatchingQualifiersFilter	✓	✓	✓	✓	✗	✓	✓
InclusiveStopFilter	✓	✗	✓	✓	✓	✗	✓
FuzzyRowFilter	✓	✓	✓	✓	✓	✗	✓
ColumnCountGetFilter	✓	✓	✓	✓	✗	✓	✗
ColumnPaginationFilter	✓	✓	✓	✓	✗	✓	✓
ColumnPrefixFilter	✓	✓	✓	✓	✗	✓	✓
MultipleColumnPrefixFilter	✓	✓	✓	✓	✗	✓	✓
ColumnRange	✓	✓	✓	✓	✗	✓	✓
TimestampsFilter	✓	✓	✓	✓	✗	✓	✓
RandomRowFilter	✓	✓	✓	✓	✗	✗	✓
SkipFilter	✓	✓/✗ ^a	✓/✗ ^b	✓	✗	✗	✓
WhileMatchFilter	✓	✓/✗ ^b	✓/✗ ^b	✓	✓	✗	✓
FilterList	✓/✗ ^b	✓/✗ ^b	✓/✗ ^b	✓	✓/✗ ^b	✓	✓

^a Filter supports Scan.setBatch(), i.e., the scanner batch mode.

^b Filter can be used with the decorating SkipFilter class.

^c Filter can be used with the decorating WhileMatchFilter class.

^d Filter can be used with the combining FilterList class.

^e Filter has optimizations to stop a scan early, once there are no more matching rows ahead.

^f Filter can be usefully applied to Get instances.

^g Filter can be usefully applied to Scan instances.

^h Depends on the included filters.

Counters

In addition to the functionality we already discussed, HBase offers another advanced feature: *counters*. Many applications that collect statistics—such as clicks or views in online advertising—were used to collect the data in logfiles that would subsequently be analyzed. Using counters offers the potential of switching to live accounting, foregoing the delayed batch processing step completely.

Introduction to Counters

In addition to the check-and-modify operations you saw earlier, HBase also has a mechanism to treat columns as counters. Otherwise, you would have to lock a row, read the value, increment it, write it back, and eventually unlock the row for other writers to be able to access it subsequently. This can cause a lot of contention, and in the event of a client process, crashing it could leave the row locked until the lease recovery kicks in—which could be disastrous in a heavily loaded system.

The client API provides specialized methods to do the *read-modify-write* operation atomically in a single client-side call. Earlier versions of HBase only had calls that would involve an RPC for every counter update, while newer versions started to add the same mechanisms used by the *CRUD* operations—as explained in “[CRUD Operations](#)” (page 122)—which can bundle multiple counter updates in a single RPC.

Before we discuss each type separately, you need to have a few more details regarding how counters work on the column level. Here is an example using the shell that creates a table, increments a counter twice, and then queries the current value:

```
hbase(main):001:0> create 'counters', 'daily', 'weekly', 'monthly'
0 row(s) in 1.1930 seconds

hbase(main):002:0> incr 'counters', '20150101', 'daily:hits', 1
COUNTER VALUE = 1
0 row(s) in 0.0490 seconds

hbase(main):003:0> incr 'counters', '20150101', 'daily:hits', 1
COUNTER VALUE = 2
0 row(s) in 0.0170 seconds

hbase(main):04:0> get_counter 'counters', '20150101', 'daily:hits'
COUNTER VALUE = 2
```

Every call to `incr` increases the counter by the given value (here 1). The final check using `get_counter` shows the current value as expected. The format of the shell’s `incr` command is as follows:

```
incr '<table>', '<row>', '<column>', [<increment-value>]
```

Initializing Counters

You should *not* initialize counters, as they are automatically assumed to be zero when you first use a new counter, that is, a column qualifier that does not yet exist. The first increment call to a

new counter will set it to 1--or the increment value, if you have specified one.

You can read and write to a counter directly, but you must use

```
Bytes.toLong()
```

to decode the value and

```
Bytes.toBytes(long)
```

for the encoding of the stored value. The latter, in particular, can be tricky, as you need to make sure you are using a `long` number when using the `toBytes()` method. You might want to consider typecasting the variable or number you are using to a `long` explicitly, like so:

```
byte[] b1 = Bytes.toBytes(1L)
byte[] b2 = Bytes.toBytes((long) var)
```

If you were to try to *erroneously* initialize a counter using the `put` method in the HBase Shell, you might be tempted to do this:

```
hbase(main):001:0> put 'counters', '20150101', 'daily:clicks',
'1'
0 row(s) in 0.0540 seconds
```

But when you are going to use the increment method, you would get this result instead:

```
hbase(main):013:0> incr  'counters',  '20110101',  'dai
ly:clicks', 1
ERROR: org.apache.hadoop.hbase.DoNotRetryIOException: Attempted to increment field that isn't 64 bits wide
      at org.apache.hadoop.hbase.regionserver.HRegion.incre
ment(HRegion.java:5856)
      at org.apache.hadoop.hbase.regionserver.RSRpcServices.in
crement(RSRpcServices.java:490)
      ...

```

That is not the expected value of 2! This is caused by the `put` call storing the counter in the wrong format: the value is the character 1, a single byte, not the byte array representation of a Java `long` value—which is composed of eight bytes.

You can also access the counter with a `get` call, giving you this result:

```
hbase(main):005:0> get 'counters', '20150101'
COLUMN          CELL
    daily:hits           timestamp=1427485256567,      value=
\x00\x00\x00\x00\x00\x00\x00\x02
1 row(s) in 0.0280 seconds
```

This is obviously not very readable, but it shows that a counter is simply a column, like any other. You can also specify a larger increment value:

```
hbase(main):006:0> incr 'counters', '20150101', 'daily:hits', 20
COUNTER VALUE = 22
0 row(s) in 0.0180 seconds

hbase(main):007:0> get_counter 'counters', '20150101', 'daily:hits'
COUNTER VALUE = 22

hbase(main):008:0> get 'counters', '20150101'
COLUMN          CELL
    daily:hits           timestamp=1427489182419,      value=
    \x00\x00\x00\x00\x00\x00\x00\x16
1 row(s) in 0.0200 seconds
```

Accessing the counter directly gives you the byte[] array representation, with the shell printing the separate bytes as hexadecimal values. Using the `get_counter` once again shows the current value in a more human-readable format, and confirms that variable increments are possible and work as expected.

Finally, you can use the increment value of the `incr` call to not only increase the counter, but also retrieve the current value, and decrease it as well. In fact, you can omit it completely and the default of 1 is assumed:

```
hbase(main):009:0> incr 'counters', '20150101', 'daily:hits'
COUNTER VALUE = 23
0 row(s) in 0.1700 seconds

hbase(main):010:0> incr 'counters', '20150101', 'daily:hits'
COUNTER VALUE = 24
0 row(s) in 0.0230 seconds

hbase(main):011:0> incr 'counters', '20150101', 'daily:hits', 0
COUNTER VALUE = 24
0 row(s) in 0.0170 seconds

hbase(main):012:0> incr 'counters', '20150101', 'daily:hits', -1
COUNTER VALUE = 23
0 row(s) in 0.0210 seconds

hbase(main):013:0> incr 'counters', '20150101', 'daily:hits', -1
COUNTER VALUE = 22
0 row(s) in 0.0200 seconds
```

Using the increment value—the last parameter of the `incr` command—you can achieve the behavior shown in [Table 4-10](#).

Table 4-10. The increment value and its effect on counter increments

Value	Effect
greater than zero	<i>Increase</i> the counter by the given value.
zero	Retrieve the <i>current value</i> of the counter. Same as using the <code>get_counter</code> shell command.
less than zero	<i>Decrease</i> the counter by the given value.

Obviously, using the shell's `incr` command only allows you to increase a single counter. You can do the same using the client API, described next.

Single Counters

The first type of increment call is for single counters only: you need to specify the exact column you want to use. The methods, provided by Table, are as such:

```
long incrementColumnValue(byte[] row, byte[] family, byte[] qualifier,
    long amount) throws IOException;
long incrementColumnValue(byte[] row, byte[] family, byte[] qualifier,
    long amount, Durability durability) throws IOException;
```

Given the *coordinates* of a column, and the increment amount, these methods only differ by the optional durability parameter—which works the same way as the `Put.setDurability()` method (see “[Durability, Consistency, and Isolation](#)” (page 108) for the general discussion of this feature). Omitting durability uses the default value of `Durability.SYNC_WAL`, meaning the write-ahead log is active. Apart from that, you can use them straight forward, as shown in [Example 4-25](#).

Example 4-25. Example using the single counter increment methods

```
long cnt1 = table.incrementColumnValue(Bytes.toBytes("20110101"),
①      Bytes.toBytes("daily"), Bytes.toBytes("hits"), 1);
long cnt2 = table.incrementColumnValue(Bytes.toBytes("20110101"),
②      Bytes.toBytes("daily"), Bytes.toBytes("hits"), 1);

long current = table.incrementColumnValue(Bytes.to-
Bytes("20110101"), ③
      Bytes.toBytes("daily"), Bytes.toBytes("hits"), 0);
```

```

long cnt3 = table.incrementColumnValue(Bytes.toBytes("20110101"),
④      Bytes.toBytes("daily"), Bytes.toBytes("hits"), -1);
①  Increase counter by one.
②  Increase counter by one a second time.
③  Get current value of the counter without increasing it.
④  Decrease counter by one.

```

The output on the console is:

```
cnt1: 1, cnt2: 2, current: 2, cnt3: 1
```

Just as with the shell commands used earlier, the API calls have the same effect: they increment the counter when using a positive increment value, retrieve the current value when using zero for the increment, and decrease the counter by using a negative increment value.

Multiple Counters

Another way to increment counters is provided by the `increment()` call of `Table`. It works similarly to the CRUD-type operations discussed earlier, using the following method to do the increment:

```
Result increment(final Increment increment) throws IOException
```

You must create an instance of the `Increment` class and fill it with the appropriate details—for example, the counter coordinates. The constructors provided by this class are:

```

Increment(byte[] row)
Increment(final byte[] row, final int offset, final int length)
Increment(Increment i)

```

You must provide a row key when instantiating an `Increment`, which sets the row containing all the counters that the subsequent call to `increment()` should modify. There is also the variant already known to you that takes a larger array with an offset and length parameter to extract the row key from. Finally, there is also the one you have seen before, which takes an existing instance and copies all state from it.

Once you have decided which row to update and created the `Increment` instance, you need to add the actual counters—meaning columns—you want to increment, using these methods:

```

IncrementaddColumn(byte[] family, byte[] qualifier, long amount)
Increment add(Cell cell) throws IOException

```

The first variant takes the column coordinates, while the second is reusing an existing cell. This is useful, if you have just retrieved a

counter and now want to increment it. The `add()` call checks that the given cell matches the row key of the `Increment` instance.

The difference here, as compared to the `Put` methods, is that there is no option to specify a version—or timestamp—when dealing with increments: versions are handled implicitly. Furthermore, there is no `addFamily()` equivalent, because counters are specific columns, and they need to be specified as such. It therefore makes no sense to add a column family alone.

A special feature of the `Increment` class is the ability to take an optional time range:

```
Increment setTimeRange(long minStamp, long maxStamp) throws IOException  
TimeRange getTimeRange()
```

Setting a time range for a set of counter increments seems odd in light of the fact that versions are handled implicitly. The time range is actually passed on to the servers to restrict the internal get operation from retrieving the current counter values. You can use it to *expire* counters, for example, to partition them by time: when you set the time range to be restrictive enough, you can mask out older counters from the internal get, making them look like they are nonexistent. An increment would assume they are unset and start at 1 again. The `get TimeRange()` returns the currently assigned time range (and might be `null` if not set at all).

Similar to the shell example shown earlier, [Example 4-26](#) uses various increment values to increment, retrieve, and decrement the given counters.

Example 4-26. Example incrementing multiple counters in one row

```
Increment increment1 = new Increment(Bytes.toBytes("20150101"));  
  
increment1.addColumn(Bytes.toBytes("daily"), Bytes.to-  
Bytes("clicks"), 1);  
increment1.addColumn(Bytes.toBytes("daily"), Bytes.to-  
Bytes("hits"), 1); ①  
increment1.addColumn(Bytes.toBytes("weekly"), Bytes.to-  
Bytes("clicks"), 10);  
increment1.addColumn(Bytes.toBytes("weekly"), Bytes.to-  
Bytes("hits"), 10);  
  
Result result1 = table.increment(increment1); ②  
  
for (Cell cell : result1.rawCells()) {  
    System.out.println("Cell: " + cell +  
        " Value: " + Bytes.toLong(cell.getValueArray(), cell.getValueOffset()),
```

```

        cell.getValueLength())); ③
    }

    Increment increment2 = new Increment(Bytes.toBytes("20150101"));

        increment2.addColumn(Bytes.toBytes("daily"), Bytes.to-
Bytes("clicks"), 5);
        increment2.addColumn(Bytes.toBytes("daily"), Bytes.to-
Bytes("hits"), 1); ④
        increment2.addColumn(Bytes.toBytes("weekly"), Bytes.to-
Bytes("clicks"), 0);
        increment2.addColumn(Bytes.toBytes("weekly"), Bytes.to-
Bytes("hits"), -5);

    Result result2 = table.increment(increment2);

    for (Cell cell : result2.rawCells()) {
        System.out.println("Cell: " + cell +
            " Value: " + Bytes.toLong(cell.getValueArray(),
                cell.getValueOffset(), cell.getValueLength()));
    }
}

```

- ① Increment the counters with various values.
- ② Call the actual increment method with the above counter updates and receive the results.
- ③ Print the cell and returned counter value.
- ④ Use positive, negative, and zero increment values to achieve the wanted counter changes.

When you run the example, the following is output on the console:

```

Cell: 20150101/daily:clicks/1427651982538/Put/vlen=8/seqid=0 Value: 1
Cell: 20150101/daily:hits/1427651982538/Put/vlen=8/seqid=0 Value: 1
Cell: 20150101/weekly:clicks/1427651982538/Put/vlen=8/seqid=0 Value: 10
Cell: 20150101/weekly:hits/1427651982538/Put/vlen=8/seqid=0 Value: 10

Cell: 20150101/daily:clicks/1427651982543/Put/vlen=8/seqid=0 Value: 6
Cell: 20150101/daily:hits/1427651982543/Put/vlen=8/seqid=0 Value: 2
Cell: 20150101/weekly:clicks/1427651982543/Put/vlen=8/seqid=0 Value: 10
Cell: 20150101/weekly:hits/1427651982543/Put/vlen=8/seqid=0 Value: 5

```

When you compare the two sets of increment results, you will notice that this works as expected.

The `Increment` class provides additional methods, which are listed in [Table 4-11](#) for your reference. Once again, many are inherited from the superclasses, such as `Mutation` (see “[Query versus Mutation](#)” ([page 106](#)) again).

Table 4-11. Quick overview of additional methods provided by the `Increment` class

Method	Description
<code>cellScanner()</code>	Provides a scanner over all cells available in this instance.
<code>getACL()/setACL()</code>	The ACLs for this operation (might be <code>null</code>).
<code>getAttribute()/setAttribute()</code>	Set and get arbitrary attributes associated with this instance of <code>Increment</code> .
<code>getAttributesMap()</code>	Returns the entire map of attributes, if any are set.
<code>getCellVisibility()/setCellVisibility()</code>	The cell level visibility for all included cells.
<code>getClusterIds()/setClusterIds()</code>	The cluster IDs as needed for replication purposes.
<code>getDurability()/setDurability()</code>	The durability settings for the mutation.
<code>getFamilyCellMap()/setFamilyCellMap()</code>	The list of all cells of this instance.
<code>getFamilyMapOfLongs()</code>	Returns a list of <code>Long</code> instance, instead of cells (which <code>getFamilyCellMap()</code> does), for what was added to this instance so far. The list is indexed by families, and then by column qualifier.
<code>getFingerprint()</code>	Compiles details about the instance into a map for debugging, or logging.
<code>getId()/setId()</code>	An ID for the operation, useful for identifying the origin of a request later.
<code>getRow()</code>	Returns the row key as specified when creating the <code>Increment</code> instance.
<code>getTimeStamp()</code>	Not useful with <code>Increment</code> . Defaults to <code>HConstants.LATEST_TIMESTAMP</code> .
<code>getTTL()/setTTL()</code>	Sets the cell level TTL value, which is being applied to all included <code>Cell</code> instances before being persisted.
<code>hasFamilies()</code>	Another helper to check if a family—or column—has been added to the current instance of the <code>Increment</code> class.
<code>heapSize()</code>	Computes the heap space required for the current <code>Increment</code> instance. This includes all contained data and space needed for internal structures.
<code>isEmpty()</code>	Checks if the family map contains any <code>Cell</code> instances.

Method	Description
numFamilies()	Convenience method to retrieve the size of the family map, containing all Cell instances.
size()	Returns the number of Cell instances that will be applied with this Increment.
toJSON()/toJSON(int)	Converts the first 5 or N columns into a JSON format.
toMap()/toMap(int)	Converts the first 5 or N columns into a map. This is more detailed than what getFingerprint() returns.
toString()/toString(int)	Converts the first 5 or N columns into a JSON, or map (if JSON fails due to encoding problems).

A non-Mutation method provided by `Increment` is:

```
Map<byte[], NavigableMap<byte[], Long>> getFamilyMapOfLongs()
```

The above [Example 4-26](#) in the online repository shows how this can give you access to the list of increment values of a configured `Increment` instance. It is omitted above for the sake of brevity, but the online code has this available (around line number 40).

Coprocessors

Earlier we discussed how you can use filters to reduce the amount of data being sent over the network from the servers to the client. With the coprocessor feature in HBase, you can even move part of the computation to where the data lives.

We slightly go on a tangent here as far as *interface audience* is concerned. If you refer back to [“HBase Version” \(page xix\)](#) you will see how we, up until now, solely covered Public APIs, that is, those that are annotated as being *public*. For coprocessors we are now looking at an API annotated as `@InterfaceAudience.LimitedPrivate(HBaseInterfaceAudience.COPROC)`, since it is meant for HBase system developers. A normal API user will make use of coprocessors, but most likely not develop them. Coprocessors are very low-level, and are usually for very experienced developers only.

Introduction to Coprocessors

Using the client API, combined with specific selector mechanisms, such as filters, or column family scoping, it is possible to limit what

data is transferred to the client. It would be good, though, to take this further and, for example, perform certain operations directly on the server side while only returning a small result set. Think of this as a small *MapReduce* framework that distributes work across the entire cluster.

A coprocessor enables you to run arbitrary code directly on each region server. More precisely, it executes the code on a per-region basis, giving you *trigger*- like functionality—similar to stored procedures in the RDBMS world. From the client side, you do not have to take specific actions, as the framework handles the distributed nature transparently.

There is a set of implicit events that you can use to hook into, performing auxiliary tasks. If this is not enough, you can also extend the RPC protocol to introduce your own set of calls, which are invoked from your client and executed on the server on your behalf.

Just as with the custom filters (see “[Custom Filters](#)” (page 259)), you need to create special Java classes that implement specific interfaces. Once they are compiled, you make these classes available to the servers in the form of a JAR file. The region server process can instantiate these classes and execute them in the correct environment. In contrast to the filters, though, coprocessors can be loaded dynamically as well. This allows you to extend the functionality of a running HBase cluster.

Use cases for coprocessors are, for instance, using hooks into row mutation operations to maintain secondary indexes, or implementing some kind of referential integrity. Filters could be enhanced to become stateful, and therefore make decisions across row boundaries. Aggregate functions, such as *sum()*, or *avg()*, known from RDBMSes and SQL, could be moved to the servers to scan the data locally and only returning the single number result across the network (which is showcased by the supplied `AggregateImplementation` class).

Another good use case for coprocessors is access control. The *authentication*, *authorization*, and *auditing* features added in HBase version 0.92 are based on coprocessors. They are loaded at system startup and use the provided trigger-like hooks to check if a user is authenticated, and authorized to access specific values stored in tables.

The framework already provides classes, based on the coprocessor framework, which you can use to extend from when implementing

your own functionality. They fall into two main groups: *endpoint* and *observer*. Here is a brief overview of their purpose:

Endpoint

Next to event handling there may be also a need to add custom operations to a cluster. User code can be deployed to the servers hosting the data to, for example, perform server-local computations.

Endpoints are dynamic extensions to the RPC protocol, adding callable remote procedures. Think of them as stored procedures, as known from RDBMSes. They may be combined with observer implementations to directly interact with the server-side state.

Observer

This type of coprocessor is comparable to *triggers*: callback functions (also referred to here as *hooks*) are executed when certain events occur. This includes user-generated, but also server-internal, automated events.

The interfaces provided by the coprocessor framework are:

MasterObserver

This can be used to react to administrative or DDL-type operations. These are cluster-wide events.

RegionServerObserver

Hooks into commands sent to a region server, and covers region server-wide events.

RegionObserver

Used to handle data manipulation events. They are closely bound to the regions of a table.

WALObserver

This provides hooks into the write-ahead log processing, which is region server-wide.

BulkLoadObserver

Handles events around the *bulk loading* API. Triggered before and after the loading takes place.

EndpointObserver

Whenever an endpoint is invoked by a client, this observer is providing a callback method.

Observers provide you with well-defined event callbacks, for every operation a cluster server may handle.

All of these interfaces are based on the Coprocessor interface to gain common features, but then implement their own specific functionality.

Finally, coprocessors can be chained, very similar to what the Java Servlet API does with request filters. The following section discusses the various types available in the coprocessor framework. Figure 4-3 shows an overview of all the classes we will be looking into.

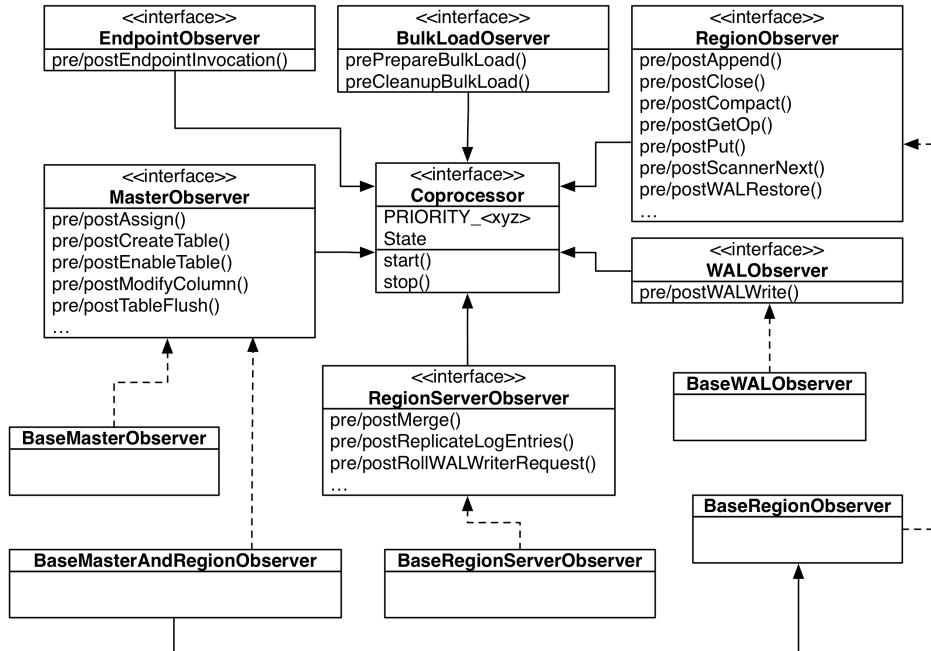


Figure 4-3. The class hierarchy of the coprocessor related classes

The Coprocessor Class Trinity

All user coprocessor classes *must* be based on the Coprocessor interface. It defines the basic contract of a coprocessor and facilitates the management by the framework itself. The interface provides two sets of types, which are used throughout the framework: the PRIORITY constants⁴, and State enumeration. Table 4-12 explains the priority values.

4. This was changed in the final 0.92 release (after the book went into print) from enums to constants in [HBASE-4048](#).

Table 4-12. Priorities as defined by the Coprocessor.PRIORITY_<XYZ> constants

Name	Value	Description
PRIORITY_HIGHEST	0	Highest priority, serves as an upper boundary.
PRIORITY_SYSTEM	536870911	High priority, used for system coprocessors (<code>Integer.MAX_VALUE / 4</code>).
PRIORITY_USER	1073741823	For all user coprocessors, which are executed subsequently (<code>Integer.MAX_VALUE / 2</code>).
PRIORITY_LOWEST	2147483647	Lowest possible priority, serves as a lower boundary (<code>Integer.MAX_VALUE</code>).

The priority of a coprocessor defines in what order the coprocessors are executed: *system-level* instances are called *before* the *user-level* coprocessors are executed.

Within each priority level, there is also the notion of a *sequence number*, which keeps track of the order in which the coprocessors were loaded. The number starts with zero, and is increased by one thereafter.

The number itself is not very helpful, but you can rely on the framework to order the coprocessors—in each priority group—ascending by sequence number. This defines their execution order.

Coprocessors are managed by the framework in their own life cycle. To that effect, the Coprocessor interface offers two calls:

```
void start(CoprocessorEnvironment env) throws IOException
void stop(CoprocessorEnvironment env) throws IOException
```

These two methods are called when the coprocessor class is started, and eventually when it is decommissioned. The provided Coprocessor Environment instance is used to retain the state across the lifespan of the coprocessor instance. A coprocessor instance is always contained in a provided environment, which provides the following methods:

```
String getHBaseVersion()
    Returns the HBase version identification string, for example
    "1.0.0".
int getVersion()
    Returns the version of the Coprocessor interface.
```

`Coprocessor getInstance()`

Returns the loaded coprocessor instance.

`int getPriority()`

Provides the priority level of the coprocessor.

`int getLoadSequence()`

The sequence number of the coprocessor. This is set when the instance is loaded and reflects the execution order.

`Configuration getConfiguration()`

Provides access to the current, server-wide configuration.

`HTableInterface.getTable(TableName tableName)`

`HTableInterface.getTable(TableName tableName, ExecutorService service)`

Returns a `Table` implementation for the given table name. This allows the coprocessor to access the actual table data.⁵ The second variant does the same, but allows the specification of a custom `ExecutorService` instance.

Coprocessors should only deal with what they have been given by their environment. There is a good reason for that, mainly to guarantee that there is no back door for malicious code to harm your data.

Coprocessor implementations should be using the `getTable()` method to access tables. Note that this class adds certain safety measures to the returned `Table` implementation. While there is currently nothing that can stop you from retrieving your own `Table` instances inside your coprocessor code, this is likely to be checked against in the future and possibly denied.

The `start()` and `stop()` methods of the `Coprocessor` interface are invoked implicitly by the framework as the instance is going through its life cycle. Each step in the process has a well-known state. [Table 4-13](#) lists the life-cycle state values as provided by the coprocessor interface.

5. The use of `HTableInterface` is an API remnant from before HBase 1.0. For HBase 2.0 and later this is changed to the proper `Table` in [HBASE-12586](#).

Table 4-13. The states as defined by the Coprocessor.State enumeration

Value	Description
UNINSTALLED	The coprocessor is in its initial state. It has no environment yet, nor is it initialized.
INSTALLED	The instance is installed into its environment.
STARTING	This state indicates that the coprocessor is about to be started, that is, its <code>start()</code> method is about to be invoked.
ACTIVE	Once the <code>start()</code> call returns, the state is set to active.
STOPPING	The state set just before the <code>stop()</code> method is called.
STOPPED	Once <code>stop()</code> returns control to the framework, the state of the coprocessor is set to stopped.

The final piece of the puzzle is the `CoprocessorHost` class that maintains all the coprocessor instances and their dedicated environments. There are specific subclasses, depending on where the host is used, in other words, on the master, region server, and so on.

The trinity of `Coprocessor`, `CoprocessorEnvironment`, and `CoprocessorHost` forms the basis for the classes that implement the advanced functionality of HBase, depending on where they are used. They provide the life-cycle support for the coprocessors, manage their state, and offer the environment for them to execute as expected. In addition, these classes provide an abstraction layer that developers can use to easily build their own custom implementation.

[Figure 4-4](#) shows how the calls from a client are flowing through the list of coprocessors. Note how the order is the same on the incoming and outgoing sides: first are the system-level ones, and then the user ones in the order they were loaded.

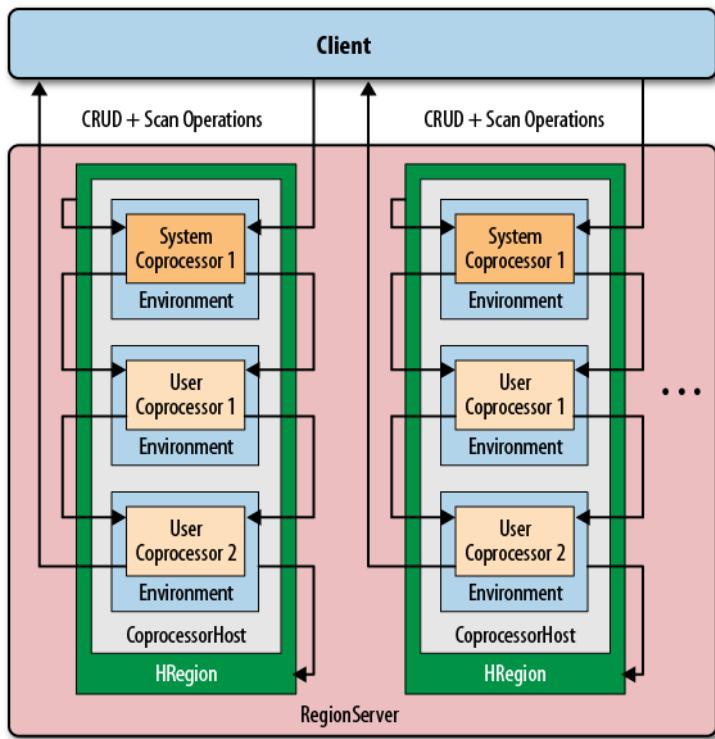


Figure 4-4. Coprocessors executed sequentially, in their environment, and per region

Coprocessor Loading

Coprocessors are loaded in a variety of ways. Before we discuss the actual coprocessor types and how to implement your own, we will talk about how to deploy them so that you can try the provided examples. You can either configure coprocessors to be loaded in a static way, or load them dynamically while the cluster is running. The static method uses the configuration files and table schemas, while the dynamic loading of coprocessors is *only* using the table schemas.

There is also a cluster-wide switch that allows you to disable all coprocessor loading, controlled by the following two configuration properties:

`hbase.coprocessor.enabled`

The default is `true` and means coprocessor classes for system and user tables are loaded. Setting this property to `false` stops the

servers from loading any of them. You could use this during testing, or during cluster emergencies.

`hbase.coprocessor.user.enabled`

Again, the default is `true`, that is, all user table coprocessors are loaded when the server starts, or a region opens, etc. Setting this property to `false` suppresses the loading of user table coprocessors only.

Disabling coprocessors, using the cluster-wide configuration properties, means that whatever additional processing they add, your cluster will not have this functionality available. This includes, for example, security checks, or maintenance of referential integrity. Be very careful!

Loading from Configuration

You can configure globally which coprocessors are loaded when HBase starts. This is done by adding one, or more, of the following to the `hbase-site.xml` configuration file (but please, replace the example class names with your own ones!):

```
<property>
  <name>hbase.coprocessor.master.classes</name>
  <value>coprocessor.Master0bserverExample</value>
</property>
<property>
  <name>hbase.coprocessor.regionserver.classes</name>
  <value>coprocessor.RegionServer0bserverExample</value>
</property>
<property>
  <name>hbase.coprocessor.region.classes</name>
  <value>coprocessor.system.Region0bserverExample,
        coprocessor.AnotherCoprocessor</value>
</property>
<property>
  <name>hbase.coprocessor.user.region.classes</name>
  <value>coprocessor.user.Region0bserverExample</value>
</property>
<property>
  <name>hbase.coprocessor.wal.classes</name>
  <value>coprocessor.WAL0bserverExample, bar.foo.MyWAL0bserver</
value>
</property>
```

The order of the classes in each configuration property is important, as it defines the execution order. All of these coprocessors are loaded with the *system* priority. You should configure all globally active

classes here so that they are executed first and have a chance to take authoritative actions. Security coprocessors are loaded this way, for example.

The configuration file is the first to be examined as HBase starts. Although you can define additional system-level coprocessors in other places, the ones here are executed first. They are also sometimes referred to as *default* coprocessors.

Only one of the five possible configuration keys is read by the matching `CoprocessorHost` implementation. For example, the coprocessors defined in `hbase.coprocessor.master.classes` are loaded by the `MasterCoprocessorHost` class.

Table 4-14 shows where each configuration property is used.

Table 4-14. Possible configuration properties and where they are used

Property	Coprocessor Host	Server Type
<code>hbase.coprocessor.master.classes</code>	<code>MasterCoprocessorHost</code>	Master Server
<code>hbase.coprocessor.regionserver.classes</code>	<code>RegionServerCoprocessorHost</code>	Region Server
<code>hbase.coprocessor.region.classes</code>	<code>RegionCoprocessorHost</code>	Region Server
<code>hbase.coprocessor.user.region.classes</code>	<code>RegionCoprocessorHost</code>	Region Server
<code>hbase.coprocessor.wal.classes</code>	<code>WALCoprocessorHost</code>	Region Server

There are two separate properties provided for classes loaded into regions, and the reason is this:

`hbase.coprocessor.region.classes`

All listed coprocessors are loaded at *system* priority for every table in HBase, including the special catalog tables.

`hbase.coprocessor.user.region.classes`

The coprocessor classes listed here are also loaded at *system* priority, but *only* for user tables, *not* the special catalog tables.

Apart from that, the coprocessors defined with either property are loaded when a region is opened for a table. Note that you *cannot* specify for which user and/or system table, or region, they are loaded, or

in other words, they are loaded for *every* table and region. You need to keep this in mind when designing your own coprocessors.

Be careful what you do as lifecycle events are triggered and your coprocessor code is setting up resources. As instantiating your coprocessor is part of opening regions, any longer delay might be noticeable. In other words, you should be very diligent to only do as light work as possible during open and close events.

What is also important to consider is that when a coprocessor, loaded from the configuration, fails to start, in other words it is throwing an exception, it will cause the entire server process to be aborted. When this happens, the process will log the error and a list of loaded (or configured rather) coprocessors, which might help identifying the culprit.

Loading from Table Descriptor

The other option to define which coprocessors to load is the table descriptor. As this is per table, the coprocessors defined here are *only* loaded for regions of that table—and only by the region servers hosting these regions. In other words, you can only use this approach for region-related coprocessors, not for master, or WAL-related ones. On the other hand, since they are loaded in the context of a table, they are more targeted compared to the configuration loaded ones, which apply to all tables. You need to add their definition to the table descriptor using one of two methods:

1. Using the generic `HTableDescriptor.setValue()` with a specific key, or
2. use the newer `HTableDescriptor.addCoprocessor()` method.

If you use the first method, you need to create a key that *must* start with `COPROCESSOR`, and the value has to conform to the following format:

```
[<path-to-jar>]<classname>[<priority>][|key1=value1,key2=value2,...]
```

Here is an example that defines a few coprocessors, the first with system-level priority, the others with user-level priorities:

```
'COPROCESSOR$1' => \
    'hdfs://localhost:8020/users/leon/test.jar|coprocessor.Test|2147483647'
'COPROCESSOR$2' => \
    '/Users/laura/test2.jar|coprocessor.AnotherTest|1073741822'
'COPROCESSOR$3' => \
    '/home/kg/advacl.jar|coprocessor.AdvancedAcl|1073741823|
```

```
keytab=/etc/keytab'  
'COPROCESSOR$99' => '|com.foo.BarCoprocessor|'
```

The *key* is a combination of the prefix COPROCESSOR, a dollar sign as a divider, and an ordering number, for example: COPROCESSOR\$1. Using the \$<number> postfix for the key enforces the order in which the definitions, and therefore the coprocessors, are loaded. This is especially interesting and important when loading multiple coprocessors with the same priority value. When you use the `addCoprocessor()` method to add a coprocessor to a table descriptor, the method will look for the highest assigned number and use the next free one after that. It starts out at 1, and increments by one from there.

The *value* is composed of three to four parts, serving the following purpose:

path-to-jar

Optional — The path can either be a fully qualified HDFS location, or any other path supported by the Hadoop `FileSystem` class. The second (and third) coprocessor definition, for example, uses a local path instead. If left empty, the coprocessor class must be accessible through the already configured class path.

If you specify a path in HDFS (or any other non-local file system URI), the coprocessor class loader support will first copy the JAR file to a local location, similar to what was explained in “[Custom Filters](#)” (page 259). The difference is that the file is located in a further subdirectory named `tmp`, for example `/data/tmp/hbase-hadoop/local/jars/tmp/`. The name of the JAR is also changed to a unique internal name, using the following pattern:

```
.<path-prefix>.<jar-filename>.<current-timestamp>.jar
```

The *path prefix* is usually a random UUID. Here a complete example:

```
$ $ ls -A /data/tmp/hbase-hadoop/local/jars/tmp/  
.c20a1e31-7715-4016-8fa7-b69f636cb07c.hbase-book-ch04.jar.  
1434434412813.jar
```

The local file is deleted upon normal server process termination.

classname

Required — This defines the actual implementation class. While the JAR may contain many coprocessor classes, only one can be specified per table attribute. Use the standard Java package name conventions to specify the class.

priority

Optional — The priority must be a number between the boundaries explained in [Table 4-12](#). If not specified, it defaults to Coproces

`sor.PRIORITY_USER`, in other words 1073741823. You can set any priority to indicate the proper execution order of the coprocessors. In the above example you can see that coprocessor #2 has a one-lower priority compared to #3. This would cause #3 to be called before #2 in the chain of events.

`key=value`

Optional — These are key/value parameters that are added to the configuration handed into the coprocessor, and retrievable by calling `CoprocessorEnvironment.getConfiguration()` from, for example, the `start()` method. For example:

```
private String keytab;

@Override
public void start(CoprocessorEnvironment env) throws IOException {
    this.keytab = env.getConfiguration().get("keytab");
}
```

The above `getConfiguration()` call is returning the *current* server configuration file, merged with any optional parameter specified in the coprocessor declaration. The former is the `hbase-site.xml`, merged with the provided `hbase-default.xml`, and all changes made through any previous dynamic configuration update. Since this is then merged with the per-coprocessor parameters (if there are any), it is advisable to use a specific, unique prefix for the keys to not accidentally override any of the HBase settings. For example, a key with a prefix made from the coprocessor class, plus its assigned value, could look like this: `com.foobar.copro.ReferentialIntegrity.table.main=production:users`.

It is advised to avoid using extra whitespace characters in the coprocessor definition. The parsing should take care of all leading or trailing spaces, but if in doubt try removing them to eliminate any possible parsing quirks.

The last coprocessor definition in the example is the shortest possible, omitting all optional parts. All that is needed is the class name, as shown, while retaining the dividing pipe symbols. [Example 4-27](#) shows how this can be done using the administrative API for HBase.

Example 4-27. Load a coprocessor using the table descriptor
public class LoadWithTableDescriptorExample {

```

public static void main(String[] args) throws IOException {
    Configuration conf = HBaseConfiguration.create();
    Connection connection = ConnectionFactory.createConnection(conf);
    TableName tableName = TableName.valueOf("testtable");

    HTableDescriptor htd = new HTableDescriptor(tableName); ①
    htd.addFamily(new HColumnDescriptor("colfam1"));
    htd.setValue("COPROCESSOR$1", " | " + ②
        RegionObserverExample.class.getCanonicalName() +
        " | " + Coprocessor.PRIORITY_USER);

    Admin admin = connection.getAdmin(); ③
    admin.createTable(htd);

    System.out.println(admin.getTableDescriptor(tableName)); ④
    admin.close();
    connection.close();
}
}

```

- ① Define a table descriptor.
- ② Add the coprocessor definition to the descriptor, while omitting the path to the JAR file.
- ③ Acquire an administrative API to the cluster and add the table.
- ④ Verify if the definition has been applied as expected.

Using the second approach, using the `addCoprocessor()` method provided by the descriptor class, simplifies all of this, as shown in [Example 4-28](#). It will compute the next *free* coprocessor key using the above rules, and assign the value in the proper format.

Example 4-28. Load a coprocessor using the table descriptor using provided method

```

HTableDescriptor htd = new HTableDescriptor(tableName) ①
    .addFamily(new HColumnDescriptor("colfam1"))
    .addCoprocessor(RegionObserverExample.class.getCanonicalName(),
        null, Coprocessor.PRIORITY_USER, null); ②

Admin admin = connection.getAdmin();
admin.createTable(htd);

```

- ① Use fluent interface to create and configure the instance.
- ② Use the provided method to add the coprocessor.

The examples omit setting the JAR file name since we assume the same test setup as before, and earlier we have added the JAR file to the `hbase-env.sh` file. With that, the coprocessor class is part of the

server class path and we can skip setting it again. Running the examples against the assumed local, standalone HBase setup should emit the following:

```
'testtable', {TABLE_ATTRIBUTES => {METADATA => { \
    'COPROCESSOR$1' => '|coprocessor.RegionObserverExample| \
1073741823'}}, \
  {NAME => 'colfam1', DATA_BLOCK_ENCODING => 'NONE', BLOOMFILTER => \
  'ROW', \
    REPLICATION_SCOPE => '0', VERSIONS => '1', COMPRESSION => \
  'NONE', \
    MIN_VERSIONS => '0', TTL => 'FOREVER', KEEP_DELETED_CELLS => \
  'FALSE', \
    BLOCKSIZE => '65536', IN_MEMORY => 'false', BLOCKCACHE => \
  'true'}
```

The coprocessor definition has been successfully applied to the table schema. Once the table is enabled and the regions are opened, the framework will first load the configuration coprocessors and then the ones defined in the table descriptor. The same considerations as mentioned before apply here as well: be careful to not slow down the region deployment process by long running, or resource intensive, operations in your lifecycle callbacks, and avoid any exceptions being thrown or the server process *might* be ended.

The difference here is that for table coprocessors there is a configuration property named `hbase.coprocessor.abortonerror`, which you can set to `true` or `false`, indicating what you want to happen if an error occurs during the initialization of a coprocessor class. The default is `true`, matching the behavior of the configuration-loaded coprocessors. Setting it to `false` will simply log the error that was encountered, but move on with business as usual. Of course, the erroneous coprocessor will neither be loaded nor be active.

Loading from HBase Shell

If you want to load coprocessors while HBase is running, there is an option to dynamically load the necessary classes and containing JAR files. This is accomplished using the table descriptor and the `alter` call, provided by the administrative API (see [“Table Operations” \(page 378\)](#)) and exposed through the HBase Shell. The process is to updated the table schema and then reload the table regions. The shell does this in one call, as shown in the following example:

```
hbase(main):001:0> alter 'testqauat:usertable', \
  'coprocessor' => 'file:///opt/hbase-book/hbase-book- \
ch05-2.0.jar| \
  coprocessor.SequentialIdGeneratorObserver|' \
Updating all regions with the new schema...
1/11 regions updated.
```

```

6/11 regions updated.
11/11 regions updated.
Done.
0 row(s) in 5.0540 seconds

hbase(main):002:0> describe 'testqauat:usertable'
Table testqauat:usertable is ENABLED
testqauat:usertable, {TABLE_ATTRIBUTES => {coprocessor$1 => \
  'file:///opt/hbase-book/hbase-book-ch05-2.0.jar|coprocessor \
  .SequentialIdGeneratorObserver|'}
COLUMN FAMILIES DESCRIPTION
{NAME => 'cf1', DATA_BLOCK_ENCODING => 'NONE', BLOOMFILTER =>
'ROW', \
  REPLICATION_SCOPE => '0', COMPRESSION => 'NONE', VERSIONS =>
'1', \
  TTL => 'FOREVER', MIN_VERSIONS => '0', KEEP_DELETED_CELLS =>
'FALSE', \
  BLOCKSIZE => '65536', IN_MEMORY => 'false', BLOCKCACHE => 'true'}
1 row(s) in 0.0220 seconds

```

The second command uses `describe` to verify the coprocessor was set, and what the assigned key for it is, here `coprocessor$1`. As for the path used for the JAR file, keep in mind that it is considered the source for the JAR file, and that it is copied into the local temporary location before being loaded into the Java process as explained above. You can use the region server UI to verify that the class has been loaded successfully, by checking the *Software Attributes* section at the end of the status page. In this table the is a line listing the loaded coprocessor classes, as shown in [Figure 4-5](#).

Coprocessors	[SequentialIdGeneratorObserver]	Coprocessors currently loaded by this regionserver
RS Start Time	Tue Jun 16 13:20:31 PDT 2015	Date stamp of when this region server was started

Figure 4-5. The Region Server status page lists the loaded coprocessors

While you will learn more about the HBase Shell in [“Namespace and Data Definition Commands” \(page 488\)](#), a quick tip about using the `alter` command to add a table *attribute*: You can omit the `METHOD => 'table_att'` parameter as shown above, because adding/setting a parameter is the assumed default operation. Only for removing an attribute you have to explicitly specify the method, as shown next when removing the previously set coprocessor.

Once a coprocessor is loaded, you can also remove them in the same dynamic fashion, that is, using the HBase Shell to update the schema and reload the affected table regions on all region servers in one single command:

```
hbase(main):003:0> alter 'testqauat:usertable', METHOD =>
'table_att_unset', \
    NAME => 'coprocessor$1'
Updating all regions with the new schema...
2/11 regions updated.
8/11 regions updated.
11/11 regions updated.
Done.
0 row(s) in 4.2160 seconds

hbase(main):004:0> describe 'testqauat:usertable'
Table testqauat:usertable is ENABLED
testqauat:usertable
COLUMN FAMILIES DESCRIPTION
{NAME => 'cf1', DATA_BLOCK_ENCODING => 'NONE', BLOOMFILTER =>
'ROW', \
    REPLICATION_SCOPE => '0', COMPRESSION => 'NONE', VERSIONS =>
'1', \
    TTL => 'FOREVER', MIN_VERSIONS => '0', KEEP_DELETED_CELLS =>
'FALSE',
    BLOCKSIZE => '65536', IN_MEMORY => 'false', BLOCKCACHE => 'true'}
1 row(s) in 0.0180 seconds
```

Removing a coprocessor requires to know its key in the table schema. We have already retrieved that one earlier with the `describe` command shown in the example. The `unset` (which removes the table schema attribute) operation removes the key named `coprocessor$1`, which was the said key we determined earlier. After all regions are re-loaded, we can use the `describe` command again to check if coprocessor reference has indeed been removed, which is the case here.

Loading coprocessors using the dynamic table schema approach bears the same burden as mentioned before: you cannot unload classes or JAR files, therefore you may have to restart the region server process for an update of the classes. You could work around for a limited amount of time by versioning the class and JAR file names, but the loaded classes may cause memory pressure eventually and force you to cycle the processes.

Endpoints

The first of two major features provided by the coprocessor framework we are going to look at are *endpoints*. They solve a problem with moving data for analytical queries, that would benefit from pre-calculating

intermediate results where the data resides, and just ship the results back to the client. Sounds familiar? Yes, this is what MapReduce does in Hadoop, that is, ship the code to the data, do the computation, and persist the results.

An inherent feature of MapReduce is that it has intrinsic knowledge of what data node is holding which block of information. When you execute a job, the NameNode will instruct the scheduler to ship the code to all nodes that contain data that is part of job parameters. With HBase, we could run a client-side scan that ships all the data to the client to do the computation. But at scale, this will *not* be efficient, because the inertia of data exceeds the amount of processing performed. In other words, all the time is spent in moving the data, the I/O.

What we need instead is the ability, just as with MapReduce, to ship the processing to the servers, do the aggregation or any other computation on the server-side, and only return the much smaller results back to the client. And that, in a nutshell, is what Endpoints are all about. You instruct the servers to load code with every region of a given table, and when you need to scan the table, partially or completely, it will call the server-side code, which then can scan the necessary data where it resides: on the data servers.

Once the computation is completed, the results are shipped back to the client, one result per region, and aggregated there for the final result. For example, if you were to have 1,000 regions and 1 million columns, and you want to summarize the stored data, you would receive 1,000 decimal numbers on the client side—one for each region. This is fast to aggregate for the final result. If you were to scan the entire table using a purely client API approach, in a worst-case scenario you would transfer all 1 million numbers to build the sum.

The Service Interface

Endpoints are implemented as an extension to the RPC protocol between the client and server. In the past (before HBase 0.96) this was done by literally extending the protocol classes. After the move to the Protocol Buffer (Protobuf for short) based RPC, adding custom services on the server side was greatly simplified. The payload is serialized as a Protobuf message and sent from client to server (and back again) using the provided coprocessor services API.

In order to provide an endpoint to clients, a coprocessor generates a Protobuf implementation that extends the Service class. This service can define any methods that the coprocessor wishes to expose. Using the generated classes, you can communicate with the coprocessor instances via the following calls, provided by Table:

```

CoprocessorRpcChannel coprocessorService(byte[] row)

<T extends Service, R> Map<byte[],R> coprocessorService(final
Class<T> service,
    byte[] startKey, byte[] endKey, final Batch.Call<T,R> callable)
    throws ServiceException, Throwable
<T extends Service, R> void coprocessorService(final Class<T> ser-
vice,
    byte[] startKey, byte[] endKey, final Batch.Call<T,R> callable,
    final Batch.Callback<R> callback) throws ServiceException, Throw-
able

<R extends Message> Map<byte[], R> batchCoprocessorService(
    Descriptors.MethodDescriptor methodDescriptor, Message request,
    byte[] startKey, byte[] endKey, R responsePrototype)
    throws ServiceException, Throwable
<R extends Message> void batchCoprocessorService(
    Descriptors.MethodDescriptor methodDescriptor,
    Message request, byte[] startKey, byte[] endKey, R responseProto-
type,
    Batch.Callback<R> callback) throws ServiceException, Throwable

```

Since Service instances are associated with individual regions within a table, the client RPC calls must ultimately identify which regions should be used in the service's method invocations. Though regions are seldom handled directly in client code and the region names may change over time, the coprocessor RPC calls use row keys to identify which regions should be used for the method invocations. Clients can call Service methods against one of the following:

Single Region

This is done by calling `coprocessorService()` with a single row key. This returns an instance of the `CoprocessorRpcChannel` class, which directly extends Protobuf classes. It can be used to invoke any endpoint call linked to the region containing the specified row. Note that the row does *not* need to exist: the region selected is the one that does or would contain the key.

Ranges of Regions

You can call `coprocessorService()` with a start row key and an end row key. All regions in the table from the one containing the start row key to the one containing the end row key (inclusive) will be used as the endpoint targets. This is done in parallel up to the amount of threads configured in the executor pool instance in use.

Batched Regions

If you call `batchCoprocessorService()` instead, you still parallelize the execution across all regions, but calls to the same region server are sent together in a single invocation. This will cut down

the number of network roundtrips, and is especially useful when the expected results of each endpoint invocation is very small.

The row keys passed as parameters to the Table methods are not passed to the Service implementations. They are only used to identify the regions for endpoints of the remote calls. As mentioned, they do not have to actually exist, they merely identify the matching regions by start and end key boundaries.

Some of the table methods to invoke endpoints are using the Batch class, which you have seen in action in “[Batch Operations](#)” (page 187) before. The abstract class defines two interfaces used for Service invocations against multiple regions: clients implement Batch.Call to call methods of the actual Service implementation instance. The interface’s call() method will be called once per selected region, passing the Service implementation instance for the region as a parameter.

Clients can optionally implement Batch.Callback to be notified of the results from each region invocation as they complete. The instance’s

```
void update(byte[] region, byte[] row, R result)
```

method will be called with the value returned by

```
R call(T instance)
```

from each region. You can see how the actual service type "T", and return type "R" are specified as Java generics: they depend on the concrete implementation of an endpoint, that is, the generated Java classes based on the Protobuf message declaring the service, methods, and their types.

Implementing Endpoints

Implementing an endpoint involves the following two steps:

1. Define the Protobuf service and generate classes

This specifies the communication details for the endpoint: it defines the RPC service, its methods, and messages used between the client and the servers. With the help of the Protobuf compiler the service definition is compiled into custom Java classes.

2. Extend the generated, custom Service subclass

You need to provide the actual implementation of the endpoint by extending the generated, abstract class derived from the Service superclass.

The following defines a Protobuf service, named RowCountService, with methods that a client can invoke to retrieve the number of rows and Cells in each region where it is running. Following Maven project layout rules, they go into \${PROJECT_HOME}/src/main/protobuf, here with the name RowCountService.proto:

```
option java_package = "coprocessor.generated";
option java_outer_classname = "RowCounterProtos";
option java_generic_services = true;
option java_generate_equals_and_hash = true;
option optimize_for = SPEED;

message CountRequest {
}

message CountResponse {
    required int64 count = 1 [default = 0];
}

service RowCountService {
    rpc getRowCount(CountRequest)
        returns (CountResponse);
    rpc getCellCount(CountRequest)
        returns (CountResponse);
}
```

The file defines the output class name, the package to use during code generation and so on. The last thing in step #1 is to compile the definition file into code, which is accomplished by using the Protobuf protoc tool.

The Protocol Buffer library usually comes as a source package that needs to be compiled and locally installed. There are also pre-built binary packages for many operating systems. On OS X, for example, you can run the following, assuming Homebrew was installed:

```
$ brew install protobuf
```

You can verify the installation by running \$ protoc --version and check it prints a version number:

```
$ protoc --version
libprotoc 2.6.1
```

The online code repository of the book has a script bin/doprotoc.sh that runs the code generation. It essentially runs the following command from the repository root directory:

```
$ protoc -Ich04/src/main/protobuf --java_out=ch04/src/main/java \
ch04/src/main/protobuf/RowCountService.proto
```

This will place the generated class file in the source directory, as specified. After that you will be able to use the generated types. Step #2 is to flesh out the generated code, since it creates an abstract class for you. All the declared RPC methods need to be implemented with the user code. This is done by extending the generated class, plus merging in the Coprocessor and CoprocessorService interface functionality. The latter two are defining the lifecycle callbacks, plus flagging the class as a service. [Example 4-29](#) shows this for the above row-counter service, using the coprocessor environment provided to access the region, and eventually the data with an InternalScanner instance.

Example 4-29. Example endpoint implementation, adding a row and cell count method.

```
public class RowCountEndpoint extends RowCounterProtos.RowCountService
    implements Coprocessor, CoprocessorService {

    private RegionCoprocessorEnvironment env;

    @Override
    public void start(CoprocessorEnvironment env) throws IOException {
        if (env instanceof RegionCoprocessorEnvironment) {
            this.env = (RegionCoprocessorEnvironment) env;
        } else {
            throw new CoprocessorException("Must be loaded on a table re-
gion!");
        }
    }

    @Override
    public void stop(CoprocessorEnvironment env) throws IOException {
        // nothing to do when coprocessor is shutting down
    }

    @Override
    public Service getService() {
        return this;
    }

    @Override
    public void getRowCount(RpcController controller,
        RowCounterProtos.CountRequest request,
        RpcCallback<RowCounterProtos.CountResponse> done) {
```

```

RowCounterProtos.CountResponse response = null;
try {
    long count = getCount(new FirstKeyOnlyFilter(), false);
    response = RowCounterProtos.CountResponse.newBuilder()
        .setCount(count).build();
} catch (IOException ioe) {
    ResponseConverter.setControllerException(controller, ioe);
}
done.run(response);
}

@Override
public void getCellCount(RpcController controller,
    RowCounterProtos.CountRequest request,
    RpcCallback<RowCounterProtos.CountResponse> done) {
    RowCounterProtos.CountResponse response = null;
    try {
        long count = getCount(null, true);
        response = RowCounterProtos.CountResponse.newBuilder()
            .setCount(count).build();
    } catch (IOException ioe) {
        ResponseConverter.setControllerException(controller, ioe);
    }
    done.run(response);
}

/**
 * Helper method to count rows or cells.
 */
* @param filter The optional filter instance.
* @param countCells Hand in <code>true</code> for cell counting.
* @return The count as per the flags.
* @throws IOException When something fails with the scan.
*/
private long getCount(Filter filter, boolean countCells)
throws IOException {
    long count = 0;
    Scan scan = new Scan();
    scan.setMaxVersions(1);
    if (filter != null) {
        scan.setFilter(filter);
    }
    try {
        InternalScanner scanner = env.getRegion().getScanner(scan);
    } {
        List<Cell> results = new ArrayList<Cell>();
        boolean hasMore = false;
        byte[] lastRow = null;
        do {
            hasMore = scanner.next(results);
            for (Cell cell : results) {
                if (!countCells) {

```

```

        if (lastRow == null || !CellUtil.matchingRow(cell, lastRow)) {
            lastRow = CellUtil.cloneRow(cell);
            count++;
        }
    } else count++;
}
results.clear();
} while (hasMore);
}
return count;
}
}

```

Note how the `FirstKeyOnlyFilter` is used to reduce the number of columns being scanned, in case of performing a row count operation. For small rows, this will not yield much of an improvement, but for tables with very wide rows, skipping all remaining columns (and more so cells if you enabled multi-versioning) of a row can speed up the row count tremendously.

You need to add (or amend from the previous examples) the following to the `hbase-site.xml` file for the endpoint coprocessor to be loaded by the region server process:

```

<property>
  <name>hbase.coprocessor.user.region.classes</name>
  <value>coprocessor.RowCountEndpoint</value>
</property>

```

Just as before, restart HBase after making these adjustments.

Example 4-30 showcases how a client can use the provided calls of `Table` to execute the deployed coprocessor endpoint functions. Since the calls are sent to each region separately, there is a need to summarize the total number at the end.

Example 4-30. Example using the custom row-count endpoint

```

public class EndpointExample {

    public static void main(String[] args) throws IOException {
        Configuration conf = HBaseConfiguration.create();
        TableName tableName = TableName.valueOf("testtable");
        Connection connection =ConnectionFactory.createConnection(conf);
        Table table = connection.getTable(tableName);
        try {
            final RowCounterProtos.CountRequest request =

```

```
RowCounterProtos.CountRequest getDefaultInstance();
Map<byte[], Long> results = table.coprocessorService(
    RowCounterProtos.RowCountService.class, ①
    null, null, ②
    new Batch.Call<RowCounterProtos.RowCountService, Long>() { ③
        public Long call(RowCounterProtos.RowCountService counter)
            throws IOException {
            BlockingRpcCallback<RowCounterProtos.CountResponse>
rpcCallback =
    new BlockingRpcCallback<RowCounterProtos.CountRes-
ponse>(); ④
        counter.getRowCount(null, request, rpcCallback);
        RowCounterProtos.CountResponse response = rpcCall-
back.get();
        return response.hasCount() ? response.getCount() : 0;
    }
}
);
long total = 0;
for (Map.Entry<byte[], Long> entry : results.entrySet()) { ⑤
    total += entry.getValue().longValue();
    System.out.println("Region: " + Bytes.toString(entry.get-
Key()) +
        ", Count: " + entry.getValue());
}
System.out.println("Total Count: " + total);
} catch (Throwable throwable) {
    throwable.printStackTrace();
}
}
```

- ① Define the protocol interface being invoked.
 - ② Set start and end row key to “null” to count all rows.
 - ③ Create an anonymous class to be sent to all region servers.
 - ④ The call() method is executing the endpoint functions.
 - ⑤ Iterate over the returned map, containing the result for each region separately.

The code emits the region names, the count for each of them, and eventually the grand total:

```
Before endpoint call...
Cell: row1/colfam1:qual1/2/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam2:qual1/2/Put/vlen=4/seqid=0, Value: val2
...
Cell: row5/colfam1:qual1/2/Put/vlen=4/seqid=0, Value: val2
Cell: row5/colfam2:qual1/2/Put/vlen=4/seqid=0, Value: val2
Region: testtable,,1427209872848.6eab8b854b5868ec...a66e83ea822c..
```

```
Count: 2
Region: testtable, row3, 1427209872848.3af10e33044...8e071ce165ce.,
Count: 3
Total Count: 5
```

[Example 4-31](#) slightly modifies the example to use the batch calls, that is, where all calls to a region server are grouped and sent together, for all hosted regions of that server.

Example 4-31. Example using the custom row-count endpoint in batch mode

```
final CountRequest request = CountRequest.getDefaultInstance();
Map<byte[], CountResponse> results = table.batchCoprocessorService(
    RowCountService.getDescriptor().findMethodByName("getRowCount"),
    request, HConstants.EMPTY_START_ROW, HConstants.EMPTY_END_ROW,
    CountResponse.getDefaultInstance());

long total = 0;
for (Map.Entry<byte[], CountResponse> entry : results.entrySet()) {
    CountResponse response = entry.getValue();
    total += response.hasCount() ? response.getCount() : 0;
    System.out.println("Region: " + Bytes.toString(entry.getKey()) +
        ", Count: " + entry.getValue());
}
System.out.println("Total Count: " + total);
```

The output is the same (the region name will vary for every execution of the example, as it contains the time a region was created), so we can refrain here from showing it again. Also, for such a small example, and especially running on a local test rig, the difference of either call is none. It will really show when you have many regions per server, and the returned data is very small: only then the cost of the RPC roundtrips are noticeable.

[Example 4-31](#) does not use null for the start and end keys, but rather `HConstants.EMPTY_START_ROW` and `HConstants.EMPTY_END_ROW`, as provided by the API classes. This is synonym to not specifying the keys at all.⁶

6. As of this writing, there is an error thrown when using null keys. See [HBASE-13417](#) for details.

If you want to perform additional processing on the results, you can further extend the `Batch.Call` code. This can be seen in [Example 4-32](#), which combines the row and cell count for each region.

Example 4-32. Example extending the batch call to execute multiple endpoint calls

```
final RowCounterProtos.CountRequest request =
    RowCounterProtos.CountRequest.getDefaultInstance();
Map<byte[], Pair<Long, Long>> results = table.coprocessorService(
    RowCounterProtos.RowCountService.class,
    null, null,
    new Batch.Call<RowCounterProtos.RowCountService, Pair<Long,
    Long>>() {
        public Pair<Long, Long> call(RowCounterProtos.RowCountService
        counter)
            throws IOException {
            BlockingRpcCallback<RowCounterProtos.CountResponse> row-
Callback =
                new BlockingRpcCallback<RowCounterProtos.CountRes-
ponse>();
            counter.getRowCount(null, request, rowCallback);

            BlockingRpcCallback<RowCounterProtos.CountResponse> cell-
Callback =
                new BlockingRpcCallback<RowCounterProtos.CountRes-
ponse>();
            counter.getCellCount(null, request, cellCallback);

            RowCounterProtos.CountResponse rowResponse = rowCall-
back.get();
            Long rowCount = rowResponse.hasCount() ?
                rowResponse.getCount() : 0;

            RowCounterProtos.CountResponse cellResponse = cellCall-
back.get();
            Long cellCount = cellResponse.hasCount() ?
                cellResponse.getCount() : 0;

            return new Pair<Long, Long>(rowCount, cellCount);
        }
    });
long totalRows = 0;
long totalKeyValues = 0;
for (Map.Entry<byte[], Pair<Long, Long>> entry : results.entry-
Set()) {
    totalRows += entry.getValue().getFirst().longValue();
    totalKeyValues += entry.getValue().getSecond().longValue();
    System.out.println("Region: " + Bytes.toString(entry.get-
```

```

Key() + 
    ", Count: " + entry.getValue());
}
System.out.println("Total Row Count: " + totalRows);
System.out.println("Total Cell Count: " + totalKeyValues);

```

Running the code will yield the following output:

```

Region:                                     testtable.,
1428306403441.94e36bc7ab66c0e535dc3c21d9755ad6., Count: {2,4}
Region:                                     testta-
ble, row3, 1428306403441.720b383e551e96cd290bd4b74b472e11., Count:
{3,6}
Total Row Count: 5
Total KeyValue Count: 10

```

The examples so far all used the `coprocessorService()` calls to batch the requests across all regions, matching the given start and end row keys. [Example 4-33](#) uses the *single-row* `coprocessorService()` call to get a local, client-side proxy of the endpoint. Since a row key is specified, the client API will route the proxy calls to the region—and to the server currently hosting it—that contains the given key (again, regardless of whether it actually exists or not: regions are specified with a start and end key only, so the match is done by range only).

Example 4-33. Example using the proxy call of HTable to invoke an endpoint on a single region

```

HRegionInfo hri = admin.getTableRegions(tableName).get(0);
Scan scan = new Scan(hri.getStartKey(), hri.getEndKey())
    .setMaxVersions();
ResultScanner scanner = table.getScanner(scan);
for (Result result : scanner) {
    System.out.println("Result: " + result);
}

CoprocessorRpcChannel channel = table.coprocessorService(
    Bytes.toBytes("row1"));
RowCountService.BlockingInterface service =
    RowCountService.newBlockingStub(channel);
CountRequest request = CountRequest.newBuilder().build();
CountResponse response = service.getCellCount(null, request);
    long cellsInRegion = response.hasCount() ? response.get-
Count() : -1;
System.out.println("Region Cell Count: " + cellsInRegion);

request = CountRequest.newBuilder().build();
response = service.getRowCount(null, request);
    long rowsInRegion = response.hasCount() ? response.getCount() :
-1;
System.out.println("Region Row Count: " + rowsInRegion);

```

The output will be:

```
Result: keyvalues={row1/colfam1:qual1/2/Put/vlen=4/seqid=0,
                  row1/colfam1:qual1/1/Put/vlen=4/seqid=0,
                  row1/colfam2:qual1/2/Put/vlen=4/seqid=0,
                  row1/colfam2:qual1/1/Put/vlen=4/seqid=0}
Result: keyvalues={row2/colfam1:qual1/2/Put/vlen=4/seqid=0,
                  row2/colfam1:qual1/1/Put/vlen=4/seqid=0,
                  row2/colfam2:qual1/2/Put/vlen=4/seqid=0,
                  row2/colfam2:qual1/1/Put/vlen=4/seqid=0}
Region Cell Count: 4
Region Row Count: 2
```

The local scan differs from the numbers returned by the endpoint, which is caused by the coprocessor code setting `setMaxVersions(1)`, while the local scan omits the limit and returns *all* versions of any cell in that same region. It shows once more how careful you should be to set these parameters to what is expected by the clients. If in doubt, you could make the *maximum version* a parameter that is passed to the endpoint through the Request implementation.

With the proxy reference, you can invoke any remote function defined in your derived Service implementation from within client code, and it returns the result for the region that served the request. [Figure 4-6](#) shows the difference between the two approaches offered by `coprocessorService():single` and `multi` region coverage.

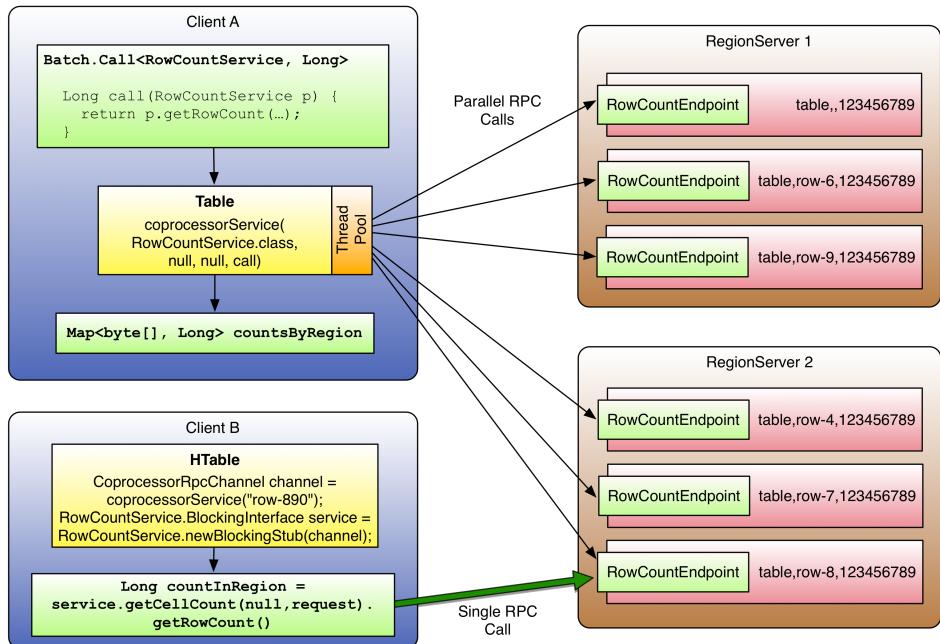


Figure 4-6. Coprocessor calls batched and executed in parallel, and addressing a single region only

Observers

While endpoints somewhat reflect the functionality of database *stored procedures*, the observers are akin to *triggers*. The difference to endpoints is that observers are not *only* running in the context of a region. They can run in many different parts of the system and react to events that are triggered by clients, but also implicitly by servers themselves. For example, when one of the servers is recovering a region after another server has failed. Or when the master is taking actions on the cluster state, etc.

Another difference is that observers are using pre-defined hooks into the server processes, that is, you cannot add your own custom ones. They also act on the server side only, with no connection to the client. What you can do though is combine an endpoint with an observer for region-related functionality, exposing observer state through a custom RPC API (see [Example 4-34](#)).

Since you can load many observers into the same set of contexts, that is, *region*, *region server*, *master server*, *WAL*, *bulk loading*, and *end-*

points, it is crucial to set the order of their invocation chain appropriately. We discussed that in “[Coprocessor Loading](#)” (page 289), looking into the priority and ordering dependent on how they are declared. Once loaded, the observers are chained together and executed in that order.

The `ObserverContext` Class

So far we have talked about the general architecture of coprocessors, their super class, how they are loaded into the server process, and how to implement endpoints. Before we can move on into the actual observers, we need to introduce one more basic class. For the callbacks provided by the `Observer` classes, there is a special context handed in as the first parameter to all calls: an instance of the `ObserverContext` class. It provides access to the current environment, but also adds the interesting ability to indicate to the coprocessor framework what it should do after a callback is completed.

The observer context instance is the same for all coprocessors in the execution chain, but with the environment swapped out for each coprocessor.

Here are the methods as provided by the context class:

`E getEnvironment()`

Returns the reference to the current coprocessor environment. It is parameterized to return the matching environment for a specific coprocessor implementation. A `RegionObserver` for example would be presented with an implementation instance of the `RegionCoprocessorEnvironment` interface.

`void prepare(E env)`

Prepares the context with the specified environment. This is used internally only by the static `createAndPrepare()` method.

`void bypass()`

When your code invokes this method, the framework is going to use your provided value, as opposed to what usually is returned by the calling method.

`void complete()`

Indicates to the framework that any further processing can be skipped, skipping the remaining coprocessors in the execution chain. It implies that this coprocessor’s response is definitive.

```
boolean shouldBypass()
```

Used internally by the framework to check on the *bypass* flag.

```
boolean shouldComplete()
```

Used internally by the framework to check on the *complete* flag.

```
static <T extends CoprocessorEnvironment> ObserverContext<T> createAndPrepare(T env, ObserverContext<T> context)
```

Static function to initialize a context. When the provided context is null, it will create a new instance.

The important context functions are *bypass()* and *complete()*. These functions give your coprocessor implementation the option to control the subsequent behavior of the framework. The *complete()* call influences the execution chain of the coprocessors, while the *bypass()* call stops any further default processing on the server within the current observer. For example, you could avoid automated region splits like so:

```
@Override
public void preSplit(ObserverContext<RegionCoprocessorEnvironment>
e) {
    e.bypass();
    e.complete();
}
```

There is a subtle difference between *bypass* and *complete* that needs to be clarified: they are serving different purposes, with different effects dependent on their usage. The following table lists the usual effects of either flag on the current and subsequent coprocessors, and when used in the *pre* or *post* hooks.

Table 4-15. Overview of bypass and complete, and their effects on coprocessors

Bypass	Complete	Current - Pre	Subsequent - Pre	Current - Post	Subsequent - Post
✗	✗	no effect	no effect	no effect	no effect
✓	✗	skip further processing	no effect	no effect	no effect
✗	✓	no effect	skip	no effect	skip
✓	✓	skip further processing	skip	no effect	skip

Note that there are exceptions to the rule, that is, some *pre* hooks cannot honor the *bypass* flag, etc. Setting *bypass* for *post* hooks usually make no sense, since there is little to nothing left to bypass. Consult

the JavaDoc for each callback to learn if (and how) it honors the bypass flag.

The RegionObserver Class

The first observer subclass of Coprocessor we will look into is the one used at the region level: the `RegionObserver` class. For the sake of brevity, all parameters and exceptions are omitted when referring to the observer calls. Please read the online documentation for the full specification.⁷ Note that all calls of this observer class have the same first parameter (denoted as part of the “...” in the calls below), `ObserverContext<RegionCoprocessorEnvironment> ctx`⁸, providing access to the context instance. The context is explained in “[The ObserverContext Class](#)” (page 312), while the special environment class is explained in “[The RegionCoprocessorEnvironment Class](#)” (page 328).

The operations can be divided into two groups: region *life-cycle* changes and *client API* calls. We will look into both in that order, but before we do, there is a generic callback for many operations of both kinds:

```
enum Operation {  
    ANY, GET, PUT, DELETE, SCAN, APPEND, INCREMENT, SPLIT_REGION,  
    MERGE_REGION, BATCH_MUTATE, REPLAY_BATCH_MUTATE, COMPACT_REGION  
}  
  
postStartRegionOperation(..., Operation operation)  
postCloseRegionOperation(..., Operation operation)
```

These methods in a `RegionObserver` are invoked when any of the possible Operations listed is called. It gives the coprocessor the ability to take invasive, or more likely, evasive actions, such as throwing an exception to stop the operation from taking place altogether.

Handling Region Life-Cycle Events

While (to come) explains the region life-cycle, [Figure 4-7](#) shows a simplified form.

7. See the [RegionServer](#) documentation.

8. Sometimes inconsistently named “c” instead.

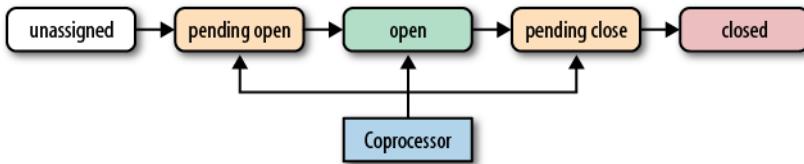


Figure 4-7. The coprocessor reacting to life-cycle state changes of a region

The observers have the opportunity to hook into the *pending open*, *open*, and *pending close* state changes. For each of them there is a set of hooks that are called implicitly by the framework.

State: pending open

A region is in this state when it is about to be opened. Observing coprocessors can either *piggyback* or *fail* this process. To do so, the following callbacks in order of their invocation are available:

```

postLogReplay(...)

preOpen(...)
preStoreFileReaderOpen(...)
postStoreFileReaderOpen(...)
preWALRestore(...) / postWALRestore(...)
postOpen(...)

```

These methods are called just before the region is opened, before and after the store files are opened in due course, the WAL being replayed, and just after the region was opened. Your coprocessor implementation can use them, for instance, to indicate to the framework—in the `preOpen()` call—that it should abort the opening process. Or hook into the `postOpen()` call to trigger a cache warm up, and so on.

The first event, `postLogReplay()`, is triggered dependent on what WAL recovery mode is configured: distributed log splitting or log replay (see (to come) and the `hbase.master.distributed.log.replay` configuration property). The former runs *before* a region is opened, and would therefore be triggering the callback first. The latter opens the region, and then replays the edits, triggering the callback *after* the region open event.

In both recovery modes, but again dependent on which is active, the region server may have to apply records from the write-ahead log (WAL). This, in turn, invokes the `pre/postWALRestore()` methods of the observer. In case of using the distributed log splitting, this will take place after the *pending open*, but just before the

open state. Otherwise, this is called after the open event, as edits are replayed. Hooking into these WAL calls gives you fine-grained control over what mutation is applied during the log replay process. You get access to the edit record, which you can use to inspect what is being applied.

State: open

A region is considered open when it is deployed to a region server and fully operational. At this point, all the operations discussed throughout the book can take place; for example, the region's in-memory store could be flushed to disk, or the region could be split when it has grown too large. The possible hooks are:

```
preFlushScannerOpen(...)  
preFlush(...) / postFlush(...)  
  
preCompactSelection(...) / postCompactSelection(...)  
preCompactScannerOpen(...)  
preCompact(...) / postCompact(...)  
  
preSplit(...)  
preSplitBeforePONR(...)  
preSplitAfterPONR(...)  
postSplit(...)  
postCompleteSplit(...) / preRollBackSplit(...) / postRollBackSplit(...)
```

This should be quite intuitive by now: the *pre* calls are executed *before*, while the *post* calls are executed *after* the respective operation. For example, using the `preSplit()` hook, you could effectively disable the built-in region splitting process and perform these operations manually. Some calls are only available as pre-hooks, some only as post-hooks.

The hooks for *flush*, *compact*, and *split* are directly linked to the matching region housekeeping functions. There are also some more specialized hooks, that happen as part of those three functions. For example, the `preFlushScannerOpen()` is called when the scanner for the memstore (bear with me here, (to come) will explain all the workings later) is set up. This is just before the actual flush takes place.

Similarly, for compactions, first the server selects the files included, which is wrapped in coprocessor callbacks (postfixed Compact Selection). After that the store scanners are opened and, finally, the actual compaction happens.

For splits, there are callbacks reflecting current stage, with a particular *point-of-no-return* (PONR) in between. This occurs, after

the split process started, but before any definitive actions have taken place. Splits are handled like a transaction internally, and when this transaction is about to be committed, the `preSplitBeforePONR()` is invoked, and the `preSplitAfterPONR()` right after. There is also a final *completed* or *rollback* call, informing you of the outcome of the split transaction.

State: pending close

The last group of hooks for the observers is for regions that go into the pending close state. This occurs when the region transitions from *open* to *closed*. Just before, and after, the region is closed the following hooks are executed:

```
preClose(..., boolean abortRequested)
postClose(..., boolean abortRequested)
```

The `abortRequested` parameter indicates why a region was closed. Usually regions are closed during normal operation, when, for example, the region is moved to a different region server for load-balancing reasons. But there also is the possibility for a region server to have gone rogue and be *aborted* to avoid any side effects. When this happens, all hosted regions are also aborted, and you can see from the given parameter if that was the case.

On top of that, this class also inherits the `start()` and `stop()` methods, allowing the allocation, and release, of lifetime resources.

Handling Client API Events

As opposed to the life-cycle events, all client API calls are explicitly sent from a client application to the region server. You have the opportunity to hook into these calls just before they are applied, and just thereafter. Here is the list of the available calls:

Table 4-16. Callbacks for client API functions

API Call	Pre-Hook	Post-Hook
<code>Table.put()</code>	<code>prePut(...)</code>	<code>void postPut(...)</code>
<code>Table.checkAndPut()</code>	<code>preCheckAndPut(...), preCheckAndPutAfterRowLock(...), prePut(...)</code>	<code>postPut(...), postCheckAndPut(...)</code>
<code>Table.get()</code>	<code>preGetOp(...)</code>	<code>void postGetOp(...)</code>
<code>Table.delete(), Table.batch()</code>	<code>preDelete(...), prePrepareTimestampForDeleteVersion(...)</code>	<code>void postDelete(...)</code>
<code>Table.checkAndDelete()</code>	<code>preCheckAndDelete(...), preCheckAndDeleteAfterRowLock(...), preDelete(...)</code>	<code>postDelete(...), postCheckAndDelete(...)</code>

API Call	Pre-Hook	Post-Hook
Table.mutateRow()	preBatchMutate(...), prePut(...)/preGetOp(...)	postBatchMutate(...), postPut(...)/postGetOp(...), postBatchMutateIndispensably()
Table.append(),	preAppend(...), preAppendAfterRowLock()	postMutationBeforeWAL(...), postAppend(...)
Table.batch()	preBatchMutate(...), prePut(...)/preGetOp(...)/preDelete(...), prePrepareTimeStampForDeleteVersion(...)/	postPut(...)/postGetOp(...), postBatchMutate(...)
Table.checkAndMutate()	preBatchMutate(...)	postBatchMutate(...)
Table.getScanner()	preScannerOpen(...), preStoreScannerOpen(...)	postInstantiateDeleteTracker(...), postScannerOpen(...)
ResultScanner.next()	preScannerNext(...)	postScannerFilterRow(...), postScannerNext(...)
ResultScanner.close()	preScannerClose(...)	postScannerClose(...)
Table.increment(), Table.batch()	preIncrement(...), preIncrementAfterRowLock(...)	postMutationBeforeWAL(...), postIncrement(...)
Table.incrementColumnValue()	preIncrementColumnValue(...)	postIncrementColumnValue(...)
Table.getClosestRowBefore() ^a	preGetClosestRowBefore(...)	postGetClosestRowBefore(...)
Table.exists()	preExists(...)	postExists(...)
completebulkload (tool)	preBulkLoadHFile(...)	postBulkLoadHFile(...)

^aThis API call has been removed in HBase 1.0. It will be removed in the coprocessor API soon as well.

The table lists the events in calling order, separated by comma. When you see a slash (“/”) instead, then the callback depends on the contained operations. For example, when you batch a put and delete in one batch() call, then you would receive the pre/postPut() and pre/postDelete() callbacks, for each contained instance. There are many low-level methods, that allow you to hook into very essential processes of HBase’s inner workings. Usually the method name should explain the nature of the invocation, and with the parameters provided in the online API documentation you can determine what your options are. If all fails, you are an expert at this point anyways asking for such details, presuming you can refer to the source code, if need be.

[Example 4-34](#) shows another (albeit somewhat advanced) way of figuring out the call order of coprocessor methods. The example code combines a `RegionObserver` with a custom `Endpoint`, and uses an internal list to track all invocations of any callback.

Example 4-34. Observer collecting invocation statistics.

```
@SuppressWarnings("deprecation") // because of API usage
public class ObserverStatisticsEndpoint
    extends ObserverStatisticsProtos.ObserverStatisticsService
    implements Coprocessor, CoprocessorService, RegionObserver {

    private RegionCoprocessorEnvironment env;
    private Map<String, Integer> stats = new LinkedHashMap<>();

    // Lifecycle methods

    @Override
    public void start(CoprocessorEnvironment env) throws IOException {
        if (env instanceof RegionCoprocessorEnvironment) {
            this.env = (RegionCoprocessorEnvironment) env;
        } else {
            throw new CoprocessorException("Must be loaded on a table region!");
        }
    }

    ...
    // Endpoint methods

    @Override
    public void getStatistics(RpcController controller,
        ObserverStatisticsProtos.StatisticsRequest request,
        RpcCallback<ObserverStatisticsProtos.StatisticsResponse> done) {
        ObserverStatisticsProtos.StatisticsResponse response = null;
        try {
            ObserverStatisticsProtos.StatisticsResponse.Builder builder =
                ObserverStatisticsProtos.StatisticsResponse.newBuilder();
            ObserverStatisticsProtos.NameInt32Pair.Builder pair =
                ObserverStatisticsProtos.NameInt32Pair.newBuilder();
            for (Map.Entry<String, Integer> entry : stats.entrySet()) {
                pair.setName(entry.getKey());
                pair.setValue(entry.getValue().intValue());
                builder.addAttribute(pair.build());
            }
            response = builder.build();
            // optionally clear out stats
            if (request.hasClear() && request.getClear()) {
                synchronized (stats) {
                    stats.clear();
                }
            }
        }
```

```

        } catch (Exception e) {
            ResponseConverter.setControllerException(controller,
                new IOException(e));
        }
        done.run(response);
    }

    /**
     * Internal helper to keep track of call counts.
     *
     * @param call The name of the call.
     */
    private void addCallCount(String call) {
        synchronized (stats) {
            Integer count = stats.get(call);
            if (count == null) count = new Integer(1);
            else count = new Integer(count + 1);
            stats.put(call, count);
        }
    }

    // All Observer callbacks follow here

    @Override
    public void preOpen(
        ObserverContext<RegionCoprocessorEnvironment> observerContext)
        throws IOException {
        addCallCount("preOpen");
    }

    @Override
    public void postOpen(
        ObserverContext<RegionCoprocessorEnvironment> observerContext) {
        addCallCount("postOpen");
    }

    ...
}

```

This is combined with the code in [Example 4-35](#), which then executes every API call, followed by calling on the custom endpoint `getStatistics()`, which returns (and optionally clears) the collected invocation list.

Example 4-35. Use an endpoint to query observer statistics

```

private static Table table = null;

private static void printStatistics(boolean print, boolean clear)
    throws Throwable {
    final StatisticsRequest request = StatisticsRequest
        .newBuilder().setClear(clear).build();

```

```

        Map<byte[], Map<String, Integer>> results = table.coprocessorService(
            ObserverStatisticsService.class,
            null, null,
            new Batch.Call<ObserverStatisticsProtos.ObserverStatisticsService,
            Map<String, Integer>>() {
                public Map<String, Integer> call(
                    ObserverStatisticsService statistics)
                throws IOException {
                    BlockingRpcCallback<StatisticsResponse> rpcCallback =
                        new BlockingRpcCallback<StatisticsResponse>();
                    statistics.getStatistics(null, request, rpcCallback);
                    StatisticsResponse response = rpcCallback.get();
                    Map<String, Integer> stats = new LinkedHashMap<String, Integer>();
                    for (NameInt32Pair pair : response.getAttributeList()) {
                        stats.put(pair.getName(), pair.getValue());
                    }
                    return stats;
                }
            }
        );
        if (print) {
            for (Map.Entry<byte[], Map<String, Integer>> entry : results.entrySet()) {
                System.out.println("Region: " + Bytes.toString(entry.getKey()));
                for (Map.Entry<String, Integer> call : entry.getValue().entrySet()) {
                    System.out.println(" " + call.getKey() + ": " + call.getValue());
                }
            }
            System.out.println();
        }
    }

    public static void main(String[] args) throws IOException {
        Configuration conf = HBaseConfiguration.create();
        Connection connection =ConnectionFactory.createConnection(conf);
        HBaseHelper helper = HBaseHelper.getHelper(conf);
        helper.dropTable("testtable");
        helper.createTable("testtable", 3, "colfam1", "colfam2");
        helper.put("testtable",
            new String[]{"row1", "row2", "row3", "row4", "row5"},
            new String[]{"colfam1", "colfam2"}, new String[]{"qual1",
            "qual1"}, new long[]{1, 2}, new String[]{"val1", "val2"});
        System.out.println("Before endpoint call...");
        helper.dump("testtable",
            new String[]{"row1", "row2", "row3", "row4", "row5"},


```

```

    null, null);
try {
    TableName tableName = TableName.valueOf("testtable");
    table = connection.getTable(tableName);

    System.out.println("Apply single put...");
    Put put = new Put(Bytes.toBytes("row10"));
    put.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual10"),
        Bytes.toBytes("val10"));
    table.put(put);
    printStatistics(true, true);

    System.out.println("Do single get...");
    Get get = new Get(Bytes.toBytes("row10"));
    get.addColumn(Bytes.toBytes("colfam1"), Bytes.to-
Bytes("qual10"));
    table.get(get);
    printStatistics(true, true);
    ...
} catch (Throwable throwable) {
    throwable.printStackTrace();
}
}

```

The output then reveals how each API call is triggering a multitude of callbacks, and different points in time:

```

Apply single put...
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
postStartRegionOperation: 1
- postStartRegionOperation-BATCH_MUTATE: 1
prePut: 1
preBatchMutate: 1
postBatchMutate: 1
postPut: 1
postBatchMutateIndispensably: 1
postCloseRegionOperation: 1
- postCloseRegionOperation-BATCH_MUTATE: 1

Do single get...
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
preGetOp: 1
postStartRegionOperation: 2
- postStartRegionOperation-SCAN: 2
preStoreScannerOpen: 1
postInstantiateDeleteTracker: 1
postCloseRegionOperation: 2
- postCloseRegionOperation-SCAN: 2
postGetOp: 1

Send batch with put and get...
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.

```

```

preGetOp: 1
postStartRegionOperation: 3
- postStartRegionOperation-SCAN: 2
preStoreScannerOpen: 1
postInstantiateDeleteTracker: 1
postCloseRegionOperation: 3
- postCloseRegionOperation-SCAN: 2
postGetOp: 1
- postStartRegionOperation-BATCH_MUTATE: 1
prePut: 1
preBatchMutate: 1
postBatchMutate: 1
postPut: 1
postBatchMutateIndispensably: 1
- postCloseRegionOperation-BATCH_MUTATE: 1

Scan single row...
-> after getScanner()...
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
preScannerOpen: 1
postStartRegionOperation: 1
- postStartRegionOperation-SCAN: 1
preStoreScannerOpen: 2
postInstantiateDeleteTracker: 2
postCloseRegionOperation: 1
- postCloseRegionOperation-SCAN: 1
postScannerOpen: 1

-> after next()...
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
preScannerNext: 1
postStartRegionOperation: 1
- postStartRegionOperation-SCAN: 1
postCloseRegionOperation: 1
- postCloseRegionOperation-ANY: 1
postScannerNext: 1
preScannerClose: 1
postScannerClose: 1

-> after close()...
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.

Scan multiple rows...
-> after getScanner()...
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
preScannerOpen: 1
postStartRegionOperation: 1
- postStartRegionOperation-SCAN: 1
preStoreScannerOpen: 2
postInstantiateDeleteTracker: 2
postCloseRegionOperation: 1
- postCloseRegionOperation-SCAN: 1

```

```

postScannerOpen: 1

-> after next()...
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
  preScannerNext: 1
  postStartRegionOperation: 1
  - postStartRegionOperation-SCAN: 1
  postCloseRegionOperation: 1
  - postCloseRegionOperation-ANY: 1
  postScannerNext: 1
  preScannerClose: 1
  postScannerClose: 1

-> after close()...
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.

Apply single put with mutateRow()...
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
  postStartRegionOperation: 2
  - postStartRegionOperation-ANY: 2
  prePut: 1
  postCloseRegionOperation: 2
  - postCloseRegionOperation-ANY: 2
  preBatchMutate: 1
  postBatchMutate: 1
  postPut: 1
  postBatchMutateIndispensably: 1

Apply single column increment...
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
  preIncrement: 1
  postStartRegionOperation: 4
  - postStartRegionOperation-INCREMENT: 1
  - postStartRegionOperation-ANY: 1
  postCloseRegionOperation: 4
  - postCloseRegionOperation-ANY: 1
  preIncrementAfterRowLock: 1
  - postStartRegionOperation-SCAN: 2
  preStoreScannerOpen: 1
  postInstantiateDeleteTracker: 1
  - postCloseRegionOperation-SCAN: 2
  postScannerFilterRow: 1
  postMutationBeforeWAL: 1
  - postMutationBeforeWAL-INCREMENT: 1
  - postCloseRegionOperation-INCREMENT: 1
  postIncrement: 1

Apply multi column increment...
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
  preIncrement: 1
  postStartRegionOperation: 4
  - postStartRegionOperation-INCREMENT: 1

```

```
- postStartRegion0peration-ANY: 1
postCloseRegion0peration: 4
- postCloseRegion0peration-ANY: 1
preIncrementAfterRowLock: 1
- postStartRegion0peration-SCAN: 2
preStoreScanner0pen: 1
postInstantiateDeleteTracker: 1
- postCloseRegion0peration-SCAN: 2
postScannerFilterRow: 1
postMutationBeforeWAL: 2
- postMutationBeforeWAL-INCREMENT: 2
- postCloseRegion0peration-INCREMENT: 1
postIncrement: 1
```

Apply single incrementColumnValue...

```
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
preIncrement: 1
postStartRegion0peration: 4
- postStartRegion0peration-INCREMENT: 1
- postStartRegion0peration-ANY: 1
postCloseRegion0peration: 4
- postCloseRegion0peration-ANY: 1
preIncrementAfterRowLock: 1
- postStartRegion0peration-SCAN: 2
preStoreScanner0pen: 1
postInstantiateDeleteTracker: 1
- postCloseRegion0peration-SCAN: 2
postMutationBeforeWAL: 1
- postMutationBeforeWAL-INCREMENT: 1
- postCloseRegion0peration-INCREMENT: 1
postIncrement: 1
```

Call single exists()...

```
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
preExists: 1
preGet0p: 1
postStartRegion0peration: 2
- postStartRegion0peration-SCAN: 2
preStoreScanner0pen: 1
postInstantiateDeleteTracker: 1
postCloseRegion0peration: 2
- postCloseRegion0peration-SCAN: 2
postGet0p: 1
postExists: 1
```

Apply single delete...

```
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
postStartRegion0peration: 4
- postStartRegion0peration-DELETE: 1
- postStartRegion0peration-BATCH_MUTATE: 1
preDelete: 1
prePrepareTimeStampForDeleteVersion: 1
```

```
- postStartRegionOperation-SCAN: 2
preStoreScannerOpen: 1
postInstantiateDeleteTracker: 1
postCloseRegionOperation: 4
- postCloseRegionOperation-SCAN: 2
preBatchMutate: 1
postBatchMutate: 1
postDelete: 1
postBatchMutateIndispensably: 1
- postCloseRegionOperation-BATCH_MUTATE: 1
- postCloseRegionOperation-DELETE: 1
```

Apply single append...

```
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
  preAppend: 1
  postStartRegionOperation: 4
  - postStartRegionOperation-APPEND: 1
  - postStartRegionOperation-ANY: 1
  postCloseRegionOperation: 4
  - postCloseRegionOperation-ANY: 1
  preAppendAfterRowLock: 1
  - postStartRegionOperation-SCAN: 2
  preStoreScannerOpen: 1
  postInstantiateDeleteTracker: 1
  - postCloseRegionOperation-SCAN: 2
  postScannerFilterRow: 1
  postMutationBeforeWAL: 1
  - postMutationBeforeWAL-APPEND: 1
  - postCloseRegionOperation-APPEND: 1
  postAppend: 1
```

Apply checkAndPut (failing)...

```
-> success: false
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
  preCheckAndPut: 1
  postStartRegionOperation: 4
  - postStartRegionOperation-ANY: 2
  postCloseRegionOperation: 4
  - postCloseRegionOperation-ANY: 2
  preCheckAndPutAfterRowLock: 1
  - postStartRegionOperation-SCAN: 2
  preStoreScannerOpen: 1
  postInstantiateDeleteTracker: 1
  - postCloseRegionOperation-SCAN: 2
  postCheckAndPut: 1
```

Apply checkAndPut (succeeding)...

```
-> success: true
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
  preCheckAndPut: 1
  postStartRegionOperation: 5
  - postStartRegionOperation-ANY: 2
```

```

postCloseRegionOperation: 5
- postCloseRegionOperation-ANY: 2
preCheckAndPutAfterRowLock: 1
- postStartRegionOperation-SCAN: 2
preStoreScannerOpen: 1
postInstantiateDeleteTracker: 1
- postCloseRegionOperation-SCAN: 2
postScannerFilterRow: 1
- postStartRegionOperation-BATCH_MUTATE: 1
prePut: 1
preBatchMutate: 1
postBatchMutate: 1
postPut: 1
postBatchMutateIndispensably: 1
- postCloseRegionOperation-BATCH_MUTATE: 1
postCheckAndPut: 1

Apply checkAndDelete (failing)...
-> success: false
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
preCheckAndDelete: 1
postStartRegionOperation: 4
- postStartRegionOperation-ANY: 2
postCloseRegionOperation: 4
- postCloseRegionOperation-ANY: 2
preCheckAndDeleteAfterRowLock: 1
- postStartRegionOperation-SCAN: 2
preStoreScannerOpen: 1
postInstantiateDeleteTracker: 1
- postCloseRegionOperation-SCAN: 2
postCheckAndDelete: 1

Apply checkAndDelete (succeeding)...
-> success: true
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
preCheckAndDelete: 1
postStartRegionOperation: 7
- postStartRegionOperation-ANY: 2
postCloseRegionOperation: 7
- postCloseRegionOperation-ANY: 2
preCheckAndDeleteAfterRowLock: 1
- postStartRegionOperation-SCAN: 4
preStoreScannerOpen: 2
postInstantiateDeleteTracker: 2
- postCloseRegionOperation-SCAN: 4
postScannerFilterRow: 1
- postStartRegionOperation-BATCH_MUTATE: 1
preDelete: 1
prePrepareTimeStampForDeleteVersion: 1
preBatchMutate: 1
postBatchMutate: 1
postDelete: 1

```

```

postBatchMutateIndispensably: 1
- postCloseRegionOperation-BATCH_MUTATE: 1
postCheckAndDelete: 1

Apply checkAndMutate (failing)...
-> success: false
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
postStartRegionOperation: 4
- postStartRegionOperation-ANY: 2
postCloseRegionOperation: 4
- postCloseRegionOperation-ANY: 2
- postStartRegionOperation-SCAN: 2
preStoreScannerOpen: 1
postInstantiateDeleteTracker: 1
- postCloseRegionOperation-SCAN: 2

Apply checkAndMutate (succeeding)...
-> success: true
Region: testtable,,1428081747767.4fe07b3f06d5a2ed0ceb686aa0920b0b.
postStartRegionOperation: 8
- postStartRegionOperation-ANY: 4
postCloseRegionOperation: 8
- postCloseRegionOperation-ANY: 4
- postStartRegionOperation-SCAN: 4
preStoreScannerOpen: 2
postInstantiateDeleteTracker: 2
- postCloseRegionOperation-SCAN: 4
prePut: 1
preDelete: 1
prePrepareTimeStampForDeleteVersion: 1
postScannerFilterRow: 1
preBatchMutate: 1
postBatchMutate: 1
postPut: 1
postDelete: 1
postBatchMutateIndispensably: 1

```

Refer to the code for details, but the console output above is complete and should give you guidance to identify the various callbacks, and when they are invoked.

The RegionCoprocessorEnvironment Class

The environment instances provided to a coprocessor that is implementing the `RegionObserver` interface are based on the `RegionCoprocessorEnvironment` class—which in turn is implementing the `CoprocessorEnvironment` interface. The latter was discussed in “[The Coprocessor Class Trinity](#)” (page 285).

On top of the provided methods, the more specific, region-oriented subclass is adding the methods described in [Table 4-17](#).

Table 4-17. Specific methods provided by the RegionCoprocessor Environment class

Method	Description
getRegion()	Returns a reference to the region the current observer is associated with.
getRegionInfo()	Get information about the region associated with the current coprocessor instance.
getRegionServerServices()	Provides access to the shared RegionServerServices instance.
getSharedData()	All the shared data between the instances of this coprocessor.

The `getRegion()` call can be used to get a reference to the hosting `HRegion` instance, and to invoke calls this class provides. If you are in need of general information about the region, call `getRegionInfo()` to retrieve a `HRegionInfo` instance. This class has useful functions that allow to get the range of contained keys, the name of the region, and flags about its state. Some of the methods are:

```
byte[] getStartKey()
byte[] getEndKey()
byte[] getRegionName()
boolean isSystemTable()
int getReplicaId()
...
...
```

Consult the online documentation to study the available list of calls. In addition, your code can access the shared region server services instance, using the `getRegionServerServices()` method and returning an instance of `RegionServerServices`. It provides many, very advanced methods, and [Table 4-18](#) list them for your perusal. We will not be discussing all the details of the provided functionality, and instead refer you again to the Java API documentation.⁹

Table 4-18. Methods provided by the RegionServerServices class

<code>abort()</code>	Allows aborting the entire server process, shutting down the instance with the given reason.
<code>addToOnlineRegions()</code>	Adds a given region to the list of online regions. This is used for internal bookkeeping.
<code>getCompactionRequester()</code>	Provides access to the shared <code>CompactionRequestor</code> instance. This can be used to initiate compactions from within the coprocessor.

9. The Java HBase classes are documented [online](#).

abort()	Allows aborting the entire server process, shutting down the instance with the given reason.
getConfiguration()	Returns the current server configuration.
getConnection()	Provides access to the shared connection instance.
getCoordinatedStateManager()	Access to the shared state manager, gives access to the TableStateManager, which in turn can be used to check on the state of a table.
getExecutorService()	Used by the master to schedule system-wide events.
getFileSystem()	Returns the Hadoop FileSystem instance, allowing access to the underlying file system.
getFlushRequester()	Provides access to the shared FlushRequester instance. This can be used to initiate memstore flushes.
getFromOnlineRegions()	Returns a HRegion instance for a given region, must be hosted by same server.
getHeapMemoryManager()	Provides access to a manager instance, gives access to heap related information, such as occupancy.
getLeases()	Returns the list of leases, as acquired for example by client side scanners.
getMetaTableLocator()	The method returns a class providing system table related functionality.
getNonceManager()	Gives access to the <i>nonce</i> manager, which is used to generate unique IDs.
getOnlineRegions()	Lists all online regions on the current server for a given table.
getRecoveringRegions()	Lists all regions that are currently in the process of replaying WAL entries.
getRegionServerAccounting()	Provides access to the shared RegionServerAccounting instance. It allows you to check on what the server currently has allocated—for example, the global memstore size.
getRegionsInTransition()	List of regions that are currently in-transition.
getRpcServer()	Returns a reference to the low-level RPC implementation instance.
getServerName()	The server name, which is unique for every region server process.
getTableLockManager()	Gives access to the lock manager. Can be used to acquire read and write locks for the entire table.
getWAL()	Provides access to the write-ahead log instance.
getZooKeeper()	Returns a reference to the ZooKeeper watcher instance.
isAborted()	Flag is true when abort() was called previously.

abort()	Allows aborting the entire server process, shutting down the instance with the given reason.
isStopped()	Returns true when stop() (inherited from Stoppable) was called beforehand.
isStopping()	Returns true when the region server is stopping.
postOpenDeployTasks()	Called by the region server after opening a region, does internal housekeeping work.
registerService()	Registers a new custom service. Called when server starts and coprocessors are loaded.
removeFromOnlineRegions()	Removes a given region from the internal list of online regions.
reportRegionStateTransition()	Triggers a report chain when a state change is needed for a region. Sent to the Master.
stop()	Stops the server gracefully.

There is no need of having to implement your own RegionObserver class, based on the interface, you can use the BaseRegionObserver class to only implement what is needed.

The BaseRegionObserver Class

This class can be used as the basis for all your observer-type coprocessors. It has placeholders for all methods required by the RegionObserver interface. They are all left blank, so by default nothing is done when extending this class. You must override all the callbacks that you are interested in to add the required functionality.

[Example 4-36](#) is an observer that handles specific row key requests.

Example 4-36. Example region observer checking for special get requests

```
public class RegionObserverExample extends BaseRegionObserver {
    public static final byte[] FIXED_ROW = Bytes.toBytes("@@@GET-
TIME@@@");

    @Override
    public void preGetOp(ObserverContext<RegionCoprocessorEnvironment>
e,
        Get get, List<Cell> results) throws IOException {
        if (Bytes.equals(get.getRow(), FIXED_ROW)) { ❶
            Put put = new Put(get.getRow());
            put.addColumn(FIXED_ROW, FIXED_ROW, ❷
                Bytes.toBytes(System.currentTimeMillis()));
            CellScanner scanner = put.cellScanner();
            scanner.advance();
            Cell cell = scanner.current(); ❸
            results.add(cell); ❹
        }
    }
}
```

```
    }
}
```

- ➊ Check if the request row key matches a well known one.
- ➋ Create cell indirectly using a Put instance.
- ➌ Get first cell from Put using the CellScanner instance.
- ➍ Create a special KeyValue instance containing just the current time on the server.

The following was added to the `hbase-site.xml` file to enable the coprocessor:

```
<property>
  <name>hbase.coprocessor.user.region.classes</name>
  <value>coprocessor.RegionObserverExample</value>
</property>
```

The class is available to the region server's Java Runtime Environment because we have already added the JAR of the compiled repository to the `HBASE_CLASSPATH` variable in `hbase-env.sh`—see “[Coprocessor Loading](#)” (page 289) for reference.

Do not forget to *restart* HBase, though, to make the changes to the static configuration files active.

The row key `@@@GETTIME@@@` is handled by the observer's `preGetOp()` hook, inserting the current time of the server. Using the HBase Shell —after deploying the code to servers—you can see this in action:

```
hbase(main):001:0> get 'testtable', '@@@GETTIME@@@'
COLUMN                           CELL
@@@GETTIME@@@:@@GETTIME@@@      timestamp=9223372036854775807, \
                                value=\x00\x00\x01L\x857\x9D\x0C
1 row(s) in 0.2810 seconds

hbase(main):002:0> Time.at(Bytes.toLong( \
  "\x00\x00\x01L\x857\x9D\x0C".to_java_bytes) / 1000)
=> Sat Apr 04 18:15:56 +0200 2015
```

This requires an existing table, because trying to issue a get call to a nonexistent table will raise an error, before the actual get operation is executed. Also, the example does not set the *bypass* flag, in which case something like the following could happen:

```
hbase(main):003:0> create 'testtable2', 'colfam1'
0 row(s) in 0.6630 seconds
```

```

=> Hbase::Table - testtable2
hbase(main):004:0> put 'testtable2', '@@GETTIME@@@', \
  'colfam1:qual1', 'Hello there!'
0 row(s) in 0.0930 seconds

hbase(main):005:0> get 'testtable2', '@@GETTIME@@@'
COLUMN                                     CELL
@@@GETTIME@@@:@@GETTIME@@@    timestamp=9223372036854775807, \
                                value=\x00\x00\x01L\x85M\xEC{
  colfam1:qual1                  timestamp=1428165601622, value=Hel-
  lo there!
2 row(s) in 0.0220 seconds

```

A new table is created and a row with the special row key is inserted. Subsequently, the row is retrieved. You can see how the artificial column is mixed with the actual one stored earlier. To avoid this issue, [Example 4-37](#) adds the necessary `e.bypass()` call.

Example 4-37. Example region observer checking for special get requests and bypassing further processing

```

if (Bytes.equals(get.getRow(), FIXED_ROW)) {
    long time = System.currentTimeMillis();
    Cell cell = CellUtil.createCell(get.getRow(), FIXED_ROW,
FIXED_ROW, ①
        time, KeyValue.Type.Put.getCode(), Bytes.toBytes(time));
    results.add(cell);
    e.bypass(); ②
}

```

- ① Create cell directly using the supplied utility.
- ② Once the special cell is inserted all subsequent coprocessors are skipped.

You need to adjust the `hbase-site.xml` file to point to the new example:

```

<property>
  <name>hbase.coprocessor.user.region.classes</name>
  <value>coprocessor.RegionObserverWithBypassExample</
value>
</property>

```

Just as before, please restart HBase after making these adjustments.

As expected, and using the shell once more, the result is now different:

```

hbase(main):006:0> get 'testtable2', '@@GETTIME@@'
COLUMN                           CELL
    @@GETTIME@@:@@GETTIME@@   timestamp=9223372036854775807,
                                value=\x00\x00\x01L\x85T\xE5\xD9
1 row(s) in 0.2840 seconds

```

Only the artificial column is returned, and since the default get operation is bypassed, it is the only column retrieved. Also note how the timestamp of this column is 9223372036854775807--which is Long.MAX_VALUE-- for the first example, and 1428166075865 for the second. The former does not set the timestamp explicitly when it creates the Cell instance, causing it to be set to HConstants.LATEST_TIMESTAMP (by default), and that is, in turn, set to Long.MAX_VALUE. The second example uses the CellUtil class to create a cell instance, which requires a timestamp to be specified (for the particular method used, there are others that allow omitting it), and we set it to the same server time as the value is set to.

Using `e.complete()` instead of the shown `e.bypass()` makes little difference here, since no other coprocessor is in the chain. The online code repository has an example that you can use to experiment with either flag, and both together.

The MasterObserver Class

The second observer subclass of `Coprocessor` discussed handles all possible callbacks the master server may initiate. The operations and API calls are explained in [Chapter 5](#), though they can be classified as data-manipulation operations, similar to DDL used in relational database systems. For that reason, the `MasterObserver` class provides the following hooks:

Table 4-19. Callbacks for master API functions

API Call	Shell Call	Pre-Hook	Post-Hook
<code>createTable()</code>	<code>create</code>	<code>preCreateTable(...), preCreateTableHandler(...)</code>	<code>postCreateTable(...)</code>
<code>deleteTable(), deleteTables()</code>	<code>drop</code>	<code>preDeleteTable(...), preDeleteTableHandler(...)</code>	<code>postDeleteTableHandler(...), postDeleteTable(...)</code>
<code>modifyTable()</code>	<code>alter</code>	<code>preModifyTable(...), preModifyTableHandler(...)</code>	<code>postModifyTableHandler(...), postModifyTable(...)</code>
<code>modifyTable()</code>	<code>alter</code>	<code>preAddColumn(...), preAddColumnHandler(...)</code>	<code>postAddColumnHandler(...), postAddColumn(...)</code>

API Call	Shell Call	Pre-Hook	Post-Hook
modifyTable()	alter	preDeleteColumn(...), preDeleteColumnHan dler(...)	postDeleteColumnHan dler(...), postDeleteColumn(...)
modifyTable()	alter	preModifyColumn(...), preModifyColumnHan dler(...)	postModifyColumnHan dler(...), postModifyColumn(...)
enableTable(), enableTables()	enable	preEnableTable(...), preEnableTableHan dler(...)	postEnableTableHan dler(...), postEnableTable(...)
disableTable(), disableTables()	disable	preDisableTable(...), preDisableTableHan dler(...)	postDisableTableHan dler(...), postDisableTable(...)
flush()	flush	preTableFlush(...)	postTableFlush(...)
truncateTable()	truncate	preTruncateTa ble(...), preTruncat eTableHandler(...)	postTruncateTableHan dler(...), postTruncat eTable(...)
move()	move	preMove(...)	postMove(...)
assign()	assign	preAssign(...)	postAssign(...)
unassign()	unassign	preUnassign(...)	postUnassign(...)
offline()	n/a	preRegionOff line(...)	postRegionOff line(...)
balancer()	balancer	preBalance(...)	postBalance(...)
setBalancerRun ning()	balance_switch	preBalanceS witch(...)	postBalanceS witch(...)
listTable Names()	list	preGetTable Names(...)	postGetTable Names(...)
getTableDescrip tors(), listTa bles()	list	preGetTableDescrip tors(...)	postGetTableDescrip tors(...)
createName space()	create_namespace	preCreateName space(...)	postCreateName space(...)
deleteName space()	drop_namespace	preDeleteName space(...)	postDeleteName space(...)
getNamespaceDe scriptor()	describe_name space	preGetNamespaceDe scriptor(...)	postGetNamespaceDe scriptor(...)
listNamespaceDe scriptors()	list_namespace scriptors()	preListNamespaceDe scriptors(...)	postListNamespaceDe scriptors(...)
modifyName space()	alter_namespace	preModifyName space(...)	postModifyName space(...)
cloneSnapshot()	clone_snapshot	preCloneSnap shot(...)	postCloneSnap shot(...)

API Call	Shell Call	Pre-Hook	Post-Hook
deleteSnap shot(), deleteS napshots()	delete_snapshot, delete_all_snap shot	preDeleteSnap shot(...)	postDeleteSnap shot(...)
restoreSnap shot()	restore_snapshot	preRestoreSnap shot(...)	postRestoreSnap shot(...)
snapshot()	snapshot	preSnapshot(...)	postSnapshot(...)
shutdown()	n/a	void preShut down(...)	n/a ^a
stopMaster()	n/a	preStopMaster(...)	n/a ^b
n/a	n/a	preMasterInitializa tion(...)	postStartMaster(...)

^a There is no *post* hook, because after the shutdown, there is no longer a cluster to invoke the callback.

^b There is no *post* hook, because after the master has stopped, there is no longer a process to invoke the callback.

Most of these methods are self-explanatory, since their name matches the admin API function. They are grouped roughly into *table* and *region*, *namespace*, *snapshot*, and *server* related calls. You will note that some API calls trigger more than one callback. There are special *pre/postXYZHandler* hooks, that indicate the asynchronous nature of the call. The Handler instance is needed to hand off the work to an executor thread pool. And as before, some *pre* hooks cannot honor the *bypass* flag, so please, as before, read the online API reference carefully!

The MasterCoprocessorEnvironment Class

Similar to how the RegionCoprocessorEnvironment is enclosing a single RegionObserver coprocessor, the MasterCoprocessorEnvironment is wrapping MasterObserver instances. It also implements the CoprocessorEnvironment interface, thus giving you, for instance, access to the *getTable()* call to access data from within your own implementation.

On top of the provided methods, the more specific, master-oriented subclass adds the one method described in [Table 4-20](#).

Table 4-20. Specific method provided by the MasterCoprocessorEnvironment class

Method	Description
getMasterServices()	Provides access to the shared MasterServices instance.

Your code can access the shared master services instance, which exposes many functions of the Master admin API, as described in [Chap-](#)

ter 5. For the sake of not duplicating the description of each, I have grouped them here by purpose, but refrain from explaining them. First are the table related calls:

```
createTable(HTableDescriptor, byte[][][])
deleteTable(TableName)
modifyTable(TableName, HTableDescriptor)
enableTable(TableName)
disableTable(TableName)
getTableDescriptors()
truncateTable(TableName, boolean)

addColumn(TableName, HColumnDescriptor)
deleteColumn(TableName, byte[])
modifyColumn(TableName, HColumnDescriptor)
```

This is continued by namespace related methods:

```
createNamespace(NamespaceDescriptor)
deleteNamespace(String)
modifyNamespace(NamespaceDescriptor)
getNamespaceDescriptor(String)
listNamespaceDescriptors()
listTableDescriptorsByNamespace(String)
listTableNamesByNamespace(String)
```

Finally, [Table 4-21](#) lists the more specific calls with a short description.

Table 4-21. Methods provided by the MasterServices class

Method	Description
abort()	Allows aborting the entire server process, shutting down the instance with the given reason.
checkTableModifiable()	Convenient to check if a table exists and is offline so that it can be altered.
dispatchMergingRegions()	Flags two regions to be merged, which is performed on the region servers.
getAssignmentManager()	Gives you access to the assignment manager instance. It is responsible for all region assignment operations, such as assign, unassign, balance, and so on.
getConfiguration()	Returns the current server configuration.
getConnection()	Provides access to the shared connection instance.
getCoordinatedStateManager()	Access to the shared state manager, gives access to the TableStateManager, which in turn can be used to check on the state of a table.
getExecutorService()	Used by the master to schedule system-wide events.
getMasterCoprocessorHost()	Returns the enclosing host instance.

Method	Description
getMasterFileSystem()	Provides you with an abstraction layer for all filesystem-related operations the master is involved in—for example, creating directories for table files and logfiles.
getMetaTableLocator()	The method returns a class providing system table related functionality.
getServerManager()	Returns the server manager instance. With it you have access to the list of servers, live or considered dead, and more.
getServerName()	The server name, which is unique for every region server process.
getTableLockManager()	Gives access to the lock manager. Can be used to acquire read and write locks for the entire table.
getZooKeeper()	Returns a reference to the ZooKeeper watcher instance.
isAborted()	Flag is true when <code>abort()</code> was called previously.
isInitialized()	After the server process is operational, this call will return true.
isServerShutdownHandlerEnabled()	When an optional shutdown handler was set, this check returns true.
isStopped()	Returns true when <code>stop()</code> (inherited from <code>Stoppable</code>) was called beforehand.
registerService()	Registers a new custom service. Called when server starts and coprocessors are loaded.
stop()	Stops the server gracefully.

Even though I am listing all the master services methods, I will not be discussing all the details on the provided functionality, and instead refer you to the Java API documentation once more.¹⁰

The BaseMasterObserver Class

Either you can base your efforts to implement a `MasterObserver` on the interface directly, or you can extend the `BaseMasterObserver` class instead. It implements the interface while leaving all callback functions empty. If you were to use this class unchanged, it would not yield any kind of reaction.

Adding functionality is achieved by overriding the appropriate event methods. You have the choice of hooking your code into the *pre* and/or *post* calls. [Example 4-38](#) uses the post hook after a table was created to perform additional tasks.

10. The Java HBase classes are documented [online](#).

Example 4-38. Example master observer that creates a separate directory on the file system when a table is created.

```
public class MasterObserverExample extends BaseMasterObserver {

    @Override
    public void postCreateTable(
        ObserverContext<MasterCoprocessorEnvironment> ctx,
        HTableDescriptor desc, HRegionInfo[] regions)
        throws IOException {
        TableName tableName = desc.getTableName(); ①

        MasterServices services = ctx.getEnvironment().getMasterServices();
        MasterFileSystem masterFileSystem = services.getMasterFileSystem(); ②
        FileSystem fileSystem = masterFileSystem.getFileSystem();

        Path blobPath = new Path(tableName.getQualifierAsString() + "-blobs"); ③
        fileSystem.mkdirs(blobPath);

    }
}
```

- ① Get the new table's name from the table descriptor.
- ② Get the available services and retrieve a reference to the actual file system.
- ③ Create a new directory that will store binary data from the client application.

You need to add the following to the *hbase-site.xml* file for the coprocessor to be loaded by the master process:

```
<property>
    <name>hbase.coprocessor.master.classes</name>
    <value>coprocessor.MasterObserverExample</value>
</property>
```

Just as before, restart HBase after making these adjustments.

Once you have activated the coprocessor, it is listening to the said events and will trigger your code automatically. The example is using the supplied services to create a directory on the filesystem. A fictitious application, for instance, could use it to store very large binary objects (known as *blobs*) outside of HBase.

To trigger the event, you can use the shell like so:

```
hbase(main):001:0> create 'testtable3', 'colfam1'  
0 row(s) in 0.6740 seconds
```

This creates the table and afterward calls the coprocessor's `postCreateTable()` method. The Hadoop command-line tool can be used to verify the results:

```
$ bin/hadoop dfs -ls  
Found 1 items  
drwxr-xr-x - larsgeorge supergroup 0 ... testtable3-  
blobs
```

There are many things you can implement with the `MasterObserver` coprocessor. Since you have access to most of the shared master resources through the `MasterServices` instance, you should be careful what you do, as it can potentially wreak havoc.

Finally, because the environment is wrapped in an `ObserverContext`, you have the same extra flow controls, exposed by the `bypass()` and `complete()` methods. You can use them to explicitly disable certain operations or skip subsequent coprocessor execution, respectively.

The BaseMasterAndRegionObserver Class

There is another, related `base` class provided by HBase, the `BaseMasterAndRegionObserver`. It is a combination of two things: the `BaseRegionObserver`, as described in "[The BaseRegionObserver Class](#)" (page 331), and the `MasterObserver` interface:

```
public abstract class BaseMasterAndRegionObserver  
    extends BaseRegionObserver implements MasterObserver {  
    ...  
}
```

In effect, this is like combining the previous `BaseMasterObserver` and `BaseRegionObserver` classes into one. This class is only useful to run on the HBase Master since it provides both, a region server and master implementation. This is used to host the system tables directly on the master.¹¹ Otherwise the functionality of both have been described above, therefore we can move on to the next coprocessor subclass.

The RegionServerObserver Class

You have seen how to run code next to regions, and within the master processes. The same is possible within the region servers using the `Re`

¹¹. As of this writing, there are discussions to remove—or at least disable—this functionality in future releases. See [HBASE-11165](#) for details.

`gionServer0bserver` class. It exposes well-defined hooks that pertain to the server functionality, that is, spanning many regions and tables. For that reason, the following hooks are provided:

`postCreateReplicationEndPoint(...)`

Invoked after the server has created a replication endpoint (not to be confused with coprocessor endpoints).

`preMerge(...), postMerge(...)`

Called when two regions are merged.

`preMergeCommit(...), postMergeCommit(...)`

Same as above, but with narrower scope. Called after `preMerge()` and before `postMerge()`.

`preRollBackMerge(...), postRollBackMerge(...)`

These are invoked when a region merge fails, and the merge transaction has to be rolled back.

`preReplicateLogEntries(...), postReplicateLogEntries(...)`

Tied into the WAL entry replay process, allows special treatment of each log entry.

`preRollWALWriterRequest(...), postRollWALWriterRe
quest(...)`

Wrap the rolling of WAL files, which will happen based on size, time, or manual request.

`preStopRegionServer(...)`

This *pre*-only hook is called when the from `Stoppable` inherited method `stop()` is called. The environment allows access to that method on a region server.

The `RegionServerCoprocessorEnvironment` Class

Similar to how the `MasterCoprocessorEnvironment` is enclosing a single `Master0bserver` coprocessor, the `RegionServerCoprocessorEn
vironment` is wrapping `RegionServer0bserver` instances. It also im
plements the `CoprocessorEnvironment` interface, thus giving you, for instance, access to the `getTable()` call to access data from within your own implementation.

On top of the provided methods, the specific, region server-oriented subclass adds the one method described in [Table 4-20](#).

Table 4-22. Specific method provided by the RegionServerCoprocessorEnvironment class

Method	Description
getRegionServerServices()	Provides access to the shared RegionServerServices instance.

We have discussed this class in “[The RegionCoprocessorEnvironment Class](#)” (page 328) before, and refer you to Table 4-18, which lists the available methods.

The BaseRegionServerObserver Class

Just with the other *base* observer classes you have seen, the `BaseRegionServerObserver` is an empty implementation of the `RegionServerObserver` interface, saving you time and effort to otherwise implement the many callback methods. Here you can focus on what you really need, and overwrite the necessary methods only. The available callbacks are very advanced, and we refrain from constructing a simple example at this point. Please refer to the source code if you need to implement at this low level.

The WALObserver Class

The next observer class we are going to address is related to the *write-ahead log*, or WAL for short. It offers a manageable list of callbacks, namely the following two:

`preWALWrite(...), postWALWrite(...)`

Wrap the writing of log entries to the WAL, allowing access to the full edit record.

Since you receive the entire record in these methods, you can influence what is written to the log. For example, an advanced use-case might be to add extra cells to the edit, so that during a potential log replay the cells could help fine tune the reconstruction process. You could add information that trigger external message queueing, so that other systems could react appropriately to the replay. Or you could use this information to create auxiliary data upon seeing the special cells later on.

The WALCoprocessorEnvironment Class

Once again, there is a specialized environment that is provided as part of the callbacks. Here it is an instance of the `WALCoprocessorEnvironment` class. It also extends the `CoprocessorEnvironment` interface, thus giving you, for instance, access to the `getTable()` call to access data from within your own implementation.

On top of the provided methods, the specific, WAL-oriented subclass adds the one method described in [Table 4-23](#).

Table 4-23. Specific method provided by the `WALCoprocessorEnvironment` class

Method	Description
<code>getWAL()</code>	Provides access to the shared WAL instance.

With the reference to the WAL you can roll the current writer, in other words, close the current log file and create a new one. You could also call the `sync()` method to force the edit records into the persistence layer. Here are the methods available from the WAL interface:

```
void registerWALActionsListener(final WALActionsListener listener)
boolean unregisterWALActionsListener(final WALActionsListener listener)
byte[][][] rollWriter() throws FailedLogCloseException, IOException
byte[][][] rollWriter(boolean force) throws FailedLogCloseException,
IOException
void shutdown() throws IOException
void close() throws IOException
long append(HTableDescriptor htd, HRegionInfo info, WALKey key, WALEdit edits,
           AtomicLong sequenceId, boolean inMemstore, List<Cell> memstoreKVs)
           throws IOException
void sync() throws IOException
void sync(long txid) throws IOException
boolean startCacheFlush(final byte[] encodedRegionName)
void completeCacheFlush(final byte[] encodedRegionName)
void abortCacheFlush(byte[] encodedRegionName)
WALCoprocessorHost getCoprocessorHost()
long getEarliestMemstoreSeqNum(byte[] encodedRegionName)
```

Once again, this is very low-level functionality, and at that point you most likely have read large parts of the code already. We will defer the explanation of each method to the online Java documentation.

The `BaseWALObserver` Class

The `BaseWALObserver` class implements the `WALObserver` interface. This is mainly done to help along with a pending (as of this writing, for HBase 1.0) deprecation process of other variants of the same callback methods. You can use this class to implement your own, or implement the interface directly.

The BulkLoadObserver Class

This observer class is used during *bulk loading* operations, as triggered by the HBase supplied `completebulkload` tool, contained in the server JAR file. Using the Hadoop JAR support, you can see the list of tools like so:

```
$ bin/hadoop jar /usr/local/hbase-1.0.0-bin/lib/hbase-server-1.0.0.jar
An example program must be given as the first argument.
Valid program names are:
  CellCounter: Count cells in HBase table
  completebulkload: Complete a bulk data load.
  copytable: Export a table from local cluster to peer cluster
  export: Write table data to HDFS.
  import: Import data written by Export.
  importtsv: Import data in TSV format.
  rowcounter: Count rows in HBase table
  verifyrep: Compare the data from tables in two different clusters.
  WARNING: It doesn't work for incrementColumnValues'd cells
  since the
  timestamp is changed after being appended to the log.
```

Once the `completebulkload` tool is run, it will attempt to move all staged bulk load files into place (more on this in (to come), so for now please bear with me). During that operation the available callbacks are triggered:

`prePrepareBulkLoad(...)`

Invoked before the bulk load operation takes place.

`preCleanupBulkLoad(...)`

Called when the bulk load is complete and clean up tasks are performed.

Both callbacks cannot skip the default processing using the *bypass* flag. They are merely invoked but their actions take no effect on the further bulk loading process. The observer does not have its own environment, instead it uses the `RegionCoprocessorEnvironment` explained in “[The RegionCoprocessorEnvironment Class](#)” (page 328).

The EndPointObserver Class

The final observer is equally manageable, since it does not employ its own environment, but also shares the `RegionCoprocessorEnvironment` (see “[The RegionCoprocessorEnvironment Class](#)” (page 328)). This makes sense, because endpoints run in the context of a region. The available callback methods are:

`preEndpointInvocation(...), postEndpointInvocation(...)`

Whenever an endpoint method is called upon from a client, these callbacks wrap the server side execution.

The client can replace (for the *pre* hook) or modify (for the *post* hook, using the provided `Message.Builder` instance) the given `Message` instance to modify the outcome of the endpoint method. If an exception is thrown during the *pre* hook, then the server-side call is aborted completely.

Chapter 5

Client API: Administrative Features

Apart from the client API used to deal with data manipulation features, HBase also exposes a *data definition*-like API. This is similar to the separation into DDL and DML found in RDBMSes. First we will look at the classes required to define the data schemas and subsequently see the API that makes use of it to, for example, create a new HBase table.

Schema Definition

Creating a table in HBase implicitly involves the definition of a table schema, as well as the schemas for all contained column families. They define the pertinent characteristics of how—and when—the data inside the table and columns is ultimately stored. On a higher level, every table is part of a *namespace*, and we will start with their defining data structures first.

Namespaces

Namespaces were introduced into HBase to solve the problem of organizing many tables.¹ Before this feature, you had a flat list of all tables, including the system catalog tables. This—at scale—was causing difficulties when you had hundreds and hundreds of tables. With namespaces you can organize your tables into groups, where related tables would be handled together. On top of that, namespaces allow to

1. Namespaces were added in 0.96. See [HBASE-8408](#).

further abstract generic concepts, such as security. You can define access control on the namespace level to quickly apply the rules to all comprised tables.

HBase creates two namespaces when it starts: default and hbase. The latter is for the system catalog tables, and you should not create your own tables in that space. Using the shell, you can list the namespaces and their content like so:

```
hbase(main):001:0> list_namespace
NAMESPACE
default
hbase
2 row(s) in 0.0090 seconds

hbase(main):002:0> list_namespace_tables 'hbase'
TABLE
foobar
meta
namespace
3 row(s) in 0.0120 seconds
```

The other namespace, called default, is the one namespace that all unspecified tables go into. You do not have to specify a namespace when you generate a table. It will then automatically be added to the default namespace on your behalf. Again, using the shell, here is what happens:

```
hbase(main):001:0> list_namespace_tables 'default'
TABLE
0 row(s) in 0.0170 seconds

hbase(main):002:0> create 'testtable', 'colfam1'
0 row(s) in 0.1650 seconds

=> Hbase::Table - testtable
hbase(main):003:0> list_namespace_tables 'default'
TABLE
testtable
1 row(s) in 0.0130 seconds
```

The new table (testtable) was created and added to the default namespace, since you did not specify one.

If you have run the previous examples, it may by that you already have a table with that name. You will then receive an error like this one using the shell:

```
ERROR: Table already exists: testtable!
```

You can either use another name to test with, or use the disable 'testtable' and drop 'testtable' commands to remove the table before moving on.

Since namespaces group tables, and their name being a fixed part of a table definition, you are free to create tables with the same name in different namespaces:

```
hbase(main):001:0> create_namespace 'booktest'
0 row(s) in 0.0970 seconds

hbase(main):002:0> create 'booktest:testtable', 'colfam1'
0 row(s) in 0.1560 seconds

=> Hbase::Table - booktest:testtable
hbase(main):003:0> create_namespace 'devtest'
0 row(s) in 0.0140 seconds

hbase(main):004:0> create 'devtest:testtable', 'colfam1'
0 row(s) in 0.1490 seconds

=> Hbase::Table - devtest:testtable
```

This example creates two namespaces, booktest and devtest, and adds the table testtable to both. Applying the above list commands is left for you to try, but you will see how the tables are now part of the respective namespaces as expected. Dealing with namespace within your code revolves around the `NamespaceDescriptor` class, which are constructed using the *Builder* pattern:

```
static Builder create(String name)
static Builder create	NamespaceDescriptor ns)
```

You either hand in a name for the new instance as a string, or an existing `NamespaceDescriptor` instance, which also copies its configuration details. The returned `Builder` instance can then be used to add further configuration details to the new namespace, and eventually build the instance. [Example 5-1](#) shows this in action:

Example 5-1. Example how to create a NamespaceDescriptor in code

```
NamespaceDescriptor.Builder builder =
NamespaceDescriptor.create("testspace");
```

```
builder.addConfiguration("key1", "value1");
NamespaceDescriptor desc = builder.build();
System.out.println("Namespace: " + desc);
```

The result on the console:

```
Namespace: {NAME => 'testspace', key1 => 'value1'}
```

The class has a few more methods:

```
String getName()
String getConfigurationValue(String key)
Map<String, String> getConfiguration()
void setConfiguration(String key, String value)
void removeConfiguration(final String key)
String toString()
```

These methods are self-explanatory, they return the assigned namespace name, allow access to the configuration values, the entire list of key/values, and retrieve the entire state as a string. The primary use for this class is as part of admin API, explained in due course (see [Example 5-7](#)).

Tables

Everything stored in HBase is ultimately grouped into one or more *tables*. The primary reason to have tables is to be able to control certain features that all columns in this table share. The typical things you will want to define for a table are *column families*. The constructor of the *table descriptor* in Java looks like the following:

```
HTableDescriptor(final TableName name)
HTableDescriptor(HTableDescriptor desc)
```

You either create a table with a name or an existing descriptor. You have to specify the name of the table using the `TableName` class (as mentioned in [“API Building Blocks” \(page 117\)](#)). This allows you to specify the name of the table, and an optional namespace with one parameter. When you use the latter constructor, that is, handing in an existing table descriptor, it will copy all settings and state from that instance across to the new one.

A table cannot be renamed. The common approach to rename a table is to create a new table with the desired name and copy the data over, using the API, or a MapReduce job (for example, using the supplied `copytable` tool)

There are certain restrictions on the characters you can use to create a table name. The name is used as part of the path to the actual storage files, and therefore has to comply with filename rules. You can later browse the low-level storage system—for example, HDFS—to see the tables as separate directories—in case you ever need to. The `TableName` class enforces these rules, as shown in [Example 5-2](#).

Example 5-2. Example how to create a TableName in code

```
private static void print(String tablename) {  
    print(null, tablename);  
}  
  
private static void print(String namespace, String tablename) {  
    System.out.print("Given Namespace: " + namespace +  
        ", Tablename: " + tablename + " -> ");  
    try {  
        System.out.println(namespace != null ?  
            TableName.valueOf(namespace, tablename) :  
            TableName.valueOf(tablename));  
    } catch (Exception e) {  
        System.out.println(e.getClass().getSimpleName() +  
            ": " + e.getMessage());  
    }  
}  
  
public static void main(String[] args) throws IOException, InterruptedException {  
    print("testtable");  
    print("testspace:testtable");  
    print("testspace", "testtable");  
    print("testspace", "te_st-ta.ble");  
    print("", "TestTable-100");  
    print("tEsTsPaCe", "te_st-table");  
  
    print("");  
  
    // VALID_NAMESPACE_REGEX = "(?:[a-zA-Z_0-9]+)";  
    // VALID_TABLE_QUALIFIER_REGEX = "(?:[a-zA-Z_0-9][a-zA-Z_0-9-.]*)";  
    print(".testtable");  
    print("te_st-space", "te_st-table");  
    print("tEsTsPaCe", "te_st-table@dev");  
}
```

The result on the console:

```
Given Namespace: null, Tablename: testtable -> testtable  
Given Namespace: null, Tablename: testspace:testtable -> testspace:testtable  
Given Namespace: testspace, Tablename: testtable -> testspace:testtable
```

```

Given Namespace: testspace, Tablename: te_st-table ->
testspace:te_st-table
Given Namespace: , Tablename: TestTable-100 -> TestTable-100
Given Namespace: tEsTsPaCe, Tablename: te_st-table ->
tEsTsPaCe:te_st-table
Given Namespace: null, Tablename: -> IllegalArgumentException:
    Table qualifier must not be empty
Given Namespace: null, Tablename: .testtable ->
    IllegalArgumentException: Illegal first character ❶ at 0.
        User-space table qualifiers can only start with 'alphanumeric
        characters':
            i.e. [a-zA-Z_0-9]: .testtable
Given Namespace: te_st-space, Tablename: te_st-table ->
    IllegalArgumentException: Illegal character ❷ at 5. Namespaces
can
    only contain 'alphanumeric characters': i.e. [a-zA-Z_0-9]: te_st-
space
Given Namespace: tEsTsPaCe, Tablename: te_st-table@dev ->
    IllegalArgumentException: Illegal character code:64, <@> at 11.
User-space
    table qualifiers can only contain 'alphanumeric characters':
        i.e. [a-zA-Z_0-9-.]: te_st-table@dev

```

The class has many static helper methods, for example `isLegalTableQualifierName()`, allowing you to check generated or user provided names before passing them on to HBase. It also has *getters* to access the names handed into the `valueOf()` method as used in the example. Note that the table name is returned using the `getQualifier()` method. The namespace has a matching `getNamespace()` method.

The column-oriented storage format of HBase allows you to store many details into the same table, which, under relational database modeling, would be divided into many separate tables. The usual *database normalization*² rules do not apply directly to HBase, and therefore the number of tables is usually lower, in comparison. More on this is discussed in “[Database \(De-\)Normalization](#)” (page 16).

Although conceptually a table is a collection of rows with columns in HBase, physically they are stored in separate partitions called *regions*. [Figure 5-1](#) shows the difference between the logical and physical layout of the stored data. Every region is served by exactly one region server, which in turn serve the stored values directly to clients.³

2. See “[Database normalization](#)” on Wikipedia.

3. We are brushing over *region replicas* here for the sake of a more generic view at this point.

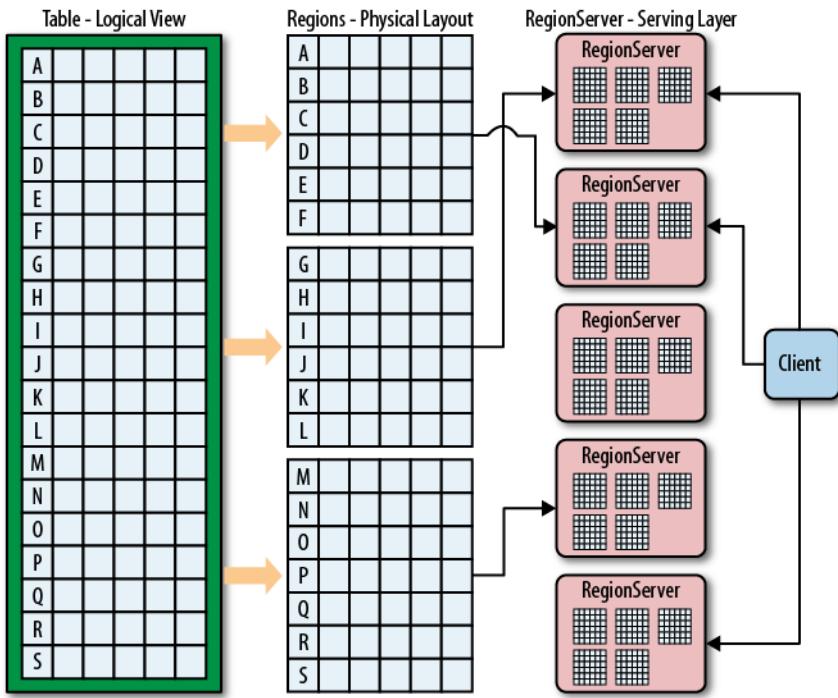


Figure 5-1. Logical and physical layout of rows within regions

Serialization

Before we move on to the table and its properties, there is something to be said about the following specific methods of many client API classes:

```
byte[] toByteArray()
static HTableDescriptor parseFrom(final byte[] bytes)
TableSchema convert()
static HTableDescriptor convert(final TableSchema ts)
```

Every communication between remote disjoint systems—for example, the client talking to the servers, but also the servers talking with one another—is done using the *RPC* framework. It employs the Google Protocol Buffer (or Protobuf for short) library to serialize and deserialize objects (I am treating *class instance* and *object* as synonyms), before they are passed between remote systems.

The above methods are invoked by the framework to *write* the object's data into the output stream, and subsequently *read* it back on the receiving system. For that the framework calls `toByteArray()` on the sending side, serializing the object's fields, while the framework is

taking care of noting the class name and other details on their behalf. Alternatively the `convert()` method in case of the `HTableDescriptor` class can be used to convert the entire instance into a Protobuf class.

On the receiving server the framework reads the metadata, and will create an instance using the static `parseFrom()` of the matching class. This will read back the field data and leave you with a fully working and initialized copy of the sending object. The same is achieved using the matching `convert()` call, which will take a Protobuf object instead of a low-level byte array.

All of this is based on protocol description files, which you can find in the HBase source code. They are like the ones we used in [Chapter 4](#) for custom filters and coprocessor endpoints—but much more elaborate. These protocol text files are compiled the same way when HBase is build and the generated classes are saved into the appropriate places in the source tree. The great advantage of using Protobuf over, for example, Java Serialization, is that it is versioned and can evolve over time. You can even upgrade a cluster *while* it is operational, because an older (or newer) client can communicate with a newer (or older) server.

Since the receiver needs to create the class using these generated classes, it is implied that it must have access to the matching, compiled class. Usually that is the case, as both the servers and clients are using the same HBase Java archive file, or JAR. But if you develop your own extensions to HBase—for example, the mentioned filters and coprocessors—you must ensure that your custom class follows these rules:

- It is available on both sides of the RPC communication channel, that is, the sending and receiving processes.
- It implements the required Protobuf methods `toByteArray()` and `parseFrom()`.

As a client API developer, you should just acknowledge the underlying dependency on RPC, and how it manifests itself. As an advanced developer extending HBase, you need to implement and deploy your custom code appropriately. [“Custom Filters” \(page 259\)](#) has an example and further notes.

The RegionLocator Class

We could have discussed this class in [“API Building Blocks” \(page 117\)](#) but for the sake of complexity and the nature of the `RegionLocator`, it is better to introduce you now to this class. As you recall from [“Auto-Sharding” \(page 26\)](#) and other places earlier, a table is divided

into one to many regions, which are consecutive, sorted sets of rows. They form the basis for HBase's scalability, and the implicit sharding (referred to as *splitting*) performed by the servers on your behalf is one of the fundamental techniques offered by HBase.

Since you could choose the simple path and let the system deal with all the region operations, there is seemingly no need to know more about the regions behind a table. In practice though, this is not always possible. There are times where you need to dig deeper and investigate the structure of a table, for example, what regions a table has, what their boundaries are, and which specific region is serving a given row key. For that, there are a few methods provided by the Region Locator class, which always runs in a context of a specific table:

```
public HRegionLocation getRegionLocation(final byte[] row)
    throws IOException
public HRegionLocation getRegionLocation(final byte[] row,
    boolean reload) throws IOException
public List<HRegionLocation> getAllRegionLocations()
    throws IOException

public byte[][][] getStartKeys() throws IOException
public byte[][][] getEndKeys() throws IOException
public Pair<byte[][][], byte[][][]> getStartEndKeys() throws IOException

TableName getName()
```

The basic building blocks are the same as you know from the Table usage, that is, you retrieve an instance from the shared connection by specifying what table it should represent, and once you are done you free its resources by invoking `close()`:

```
Configuration conf = HBaseConfiguration.create();
Connection connection = ConnectionFactory.createConnection(conf);
TableName tn = TableName.valueOf(tableName);
RegionLocator locator = connection.getRegionLocator(tn);
Pair<byte[][][], byte[][][]> pair = locator.getStartEndKeys();
...
locator.close();
```

The various methods provided are used to retrieve either `HRegionLocation` instances, or the binary start and/or end keys, of the table regions. Regions are specified with the start key inclusive, but the end key exclusive. The primary reason is to be able to connect regions contiguously, that is, without any gaps in the key space. The `HRegionLocation` is giving you access to region details, such as the server currently hosting it, or the associated `HRegionInfo` object (explained in “[The RegionCoprocessorEnvironment Class](#)” (page 328)):

```

HRegionInfo getRegionInfo()
String getHostname()
int getPort()
String getHostnamePort()
ServerName getServerName()
long getSeqNum()
String toString()

```

[Example 5-8](#) uses many of these methods in the context of creating a table in code.

Server and Region Names

There are two essential pieces of information that warrant a proper introduction: the *server name* and *region name*. They appear in many places, such as the HBase Shell, the web-based UI, and both APIs, the administrative and client API. Sometimes they are just emitted in human readable form, which includes encoding unprintable characters as codepoints. Other times, they are returned by functions such as `getServerName()`, or `getRegionNameAsString()` (provided by `HRegionInfo`), or are required as an input parameter to administrative API calls.

[Example 5-3](#) creates a table and then locates the region that contains the row `Foo`. Once the region is retrieved, the server name and region name are printed.

Example 5-3. Shows the use of server and region names

```

TableName tableName = TableName.valueOf("testtable");
HColumnDescriptor coldef1 = new HColumnDescriptor("colfam1");
HTableDescriptor desc = new HTableDescriptor(tableName)
    .addFamily(coldef1)
    .setValue("Description", "Chapter 5 - ServerAndRegionNameExam-
ple");
byte[][][] regions = new byte[][][] { Bytes.toBytes("ABC"),
    Bytes.toBytes("DEF"), Bytes.toBytes("GHI"), Bytes.to-
Bytes("KLM"),
    Bytes.toBytes("OPQ"), Bytes.toBytes("TUV")
};
admin.createTable(desc, regions);

RegionLocator locator = connection.getRegionLocator(tableName);
HRegionLocation location = locator.getRegionLocation(Bytes.to-
Bytes("Foo"));
HRegionInfo info = location.getRegionInfo();
System.out.println("Region Name: " + info.getRegionNameAs-
String());
System.out.println("Server Name: " + location.getServerName());

```

The output for one execution of the code looked like:

```
Region           Name:          testtable,DEF,  
1428681822728.acdd15c7050ec597b484b30b7c744a93.  
Server Name: srv1.foobar.com,63360,1428669931467
```

The *region name* is a combination of table and region details (the start key, and region creation time), plus an optional MD5 hash of the leading prefix of the name, surrounded by dots (".".):

```
<table    name>,<region    start    key>,<region    creation  
time>[.<md5hash(prefix)>.]
```

In the example, "acdd15c7050ec597b484b30b7c744a93" is the MD5 hash of "testtable,DEF,1428681822728". The `getEncodedName()` method of `HRegionInfo` returns *just* the hash, not the leading, readable prefix. The hash itself is used when the system is creating the lower level file structure within the storage layer. For example, the above region hash is visible when listing the content of the storage directory for HBase (this is explained in detail in (to come), for now just notice the hash in the path):

```
$ bin/hdfs dfs -ls -R /hbase  
drwxr-xr-x  - larsgeorge supergroup      0 2015-04-10 18:03 \  
  /hbase/data/default/testtable/acdd15c7050ec597b484b30b7c744a93/  
  colfam1
```

The *region creation timestamp* is issued when a region is created, for example when a table is created, or an existing region split. The *dots* around the hash are mainly to identify the hash, and be able to parse the text representation. There are times where the hash is not part of the region name, and the missing ending dot makes this distinguishable.

As for the *server name*, it is also a combination of various parts, including the host name of the machine:

```
<host name>,<RPC port>,<server start time>
```

The *server start time* is used to handle multiple processes on the same physical machine, created over time. When a region server is stopped and started again, the timestamp makes it possible for the HBase Master to identify the new process on the same physical machine. It will then move the old name, that is, the one with the lower timestamp, into the list of dead servers. On the flip side, when you see a server process reported as dead, make sure to compare the listed timestamp with the current one of the process on that same server using the same port. If the timestamp of the current process is newer then all should be working as expected.

There is a class called `ServerName` that wraps the details into a convenient structure. Some API calls expect to receive an instance of this

class, which can be created from scratch, though the practical approach is to use the API to retrieve an existing instance, for example, using the `getServerName()` method mentioned before.

Keep the two names in mind as you read through the rest of this chapter, since they appear quite a few times and it will make much more sense now that you know about their structure and purpose.

Table Properties

The table descriptor offers *getters* and *setters*⁴ to set many options of the table. In practice, a lot are not used very often, but it is important to know them all, as they can be used to fine-tune the table's performance. We will group the methods by the set of properties they influence.

Name

The constructor already had the parameter to specify the table name. The Java API has additional methods to access the name or change it.

```
TableName getTableName()  
String getNameAsString()
```

This method returns the table name, as set during the construction of this instance. Refer to “[Column Families](#)” (page 362) for more details, and [Figure 5-2](#) for an example of how the table name is used to form a filesystem path.

Column Families

This is the most important part of defining a table. You need to specify the *column families* you want to use with the table you are creating.

```
HTableDescriptor addFamily(final HColumnDescriptor family)  
HTableDescriptor modifyFamily(final HColumnDescriptor family)  
HColumnDescriptor removeFamily(final byte[] column)  
HColumnDescriptor getFamily(final byte[] column)  
boolean hasFamily(final byte[] familyName)  
Set<byte[]> getFamiliesKeys()  
HColumnDescriptor[] getColumnFamilies()  
Collection<HColumnDescriptor> getFamilies()
```

You have the option of adding a family, modifying it, checking if it exists based on its name, getting a list of all known families (in

4. Getters and setters in Java are methods of a class that expose internal fields in a controlled manner. They are usually named like the field, prefixed with `get` and `set`, respectively—for example, `getName()` and `setName()`.

various forms), and getting or removing a specific one. More on how to define the required `HColumnDescriptor` is explained in “[Column Families](#)” (page 362).

Maximum File Size

This parameter is specifying the maximum size a region within the table should grow to. The size is specified in bytes and is read and set using the following methods:

```
long getMaxFileSize()  
HTableDescriptor setMaxFileSize(long maxFileSize)
```

Maximum file size is actually a misnomer, as it really is about the maximum size of each store, that is, all the files belonging to each column family. If one single column family exceeds this maximum size, the region is split. Since in practice, this involves multiple files, the better name would be *maxStoreSize*.

The maximum size is helping the system to split regions when they reach this configured limit. As discussed in “[Building Blocks](#)” (page 19), the unit of scalability and load balancing in HBase is the region. You need to determine what a good number for the size is, though. By default, it is set to 10 GB (the actual value is 10737418240 since it is specified in bytes, and set in the default configuration as `hbase.hregion.max.filesize`), which is good for many use cases. We will look into use-cases in (to come) and show how this can make a difference.

Please note that this is more or less a *desired* maximum size and that, given certain conditions, this size can be exceeded and actually be completely rendered without effect. As an example, you could set the maximum file size to 1 GB and insert a 2 GB cell in one row. Since a row cannot be split across regions, you end up with a region of at least 2 GB in size, and the system cannot do anything about it.

Memstore Flush Size

We discussed the storage model earlier and identified how HBase uses an in-memory store to buffer values before writing them to disk as a new storage file in an operation called *flush*. This parameter of the table controls when this is going to happen and is specified in bytes. It is controlled by the following calls:

```
long getMemStoreFlushSize()  
HTableDescriptor setMemStoreFlushSize(long memstoreFlushSize)
```

As you do with the aforementioned maximum file size, you need to check your requirements before setting this value to something other than the default *128 MB* (set as `hbase.hregion.mem.store.flush.size` to 134217728 bytes). A larger size means you are generating larger store files, which is good. On the other hand, you might run into the problem of longer blocking periods, if the region server cannot keep up with flushing the added data. Also, it increases the time needed to replay the write-ahead log (the WAL) if the server crashes and all in-memory updates are lost.

Compactions

Per table you can define if the underlying storage files should be compacted as part of the automatic housekeeping. Setting (and reading) the flag is accomplished using these calls:

```
boolean isCompactionEnabled()
HTableDescriptor setCompactionEnabled(final boolean isEnabled)
```

Split Policy

Along with specifying the *maximum file size*, you can further influence the splitting of regions. When you specify a different *split policy* class with the following methods, you override the system wide setting configured with `hbase.regionserver.region.split.policy`:

```
HTableDescriptor setRegionSplitPolicyClassName(String clazz)
String getRegionSplitPolicyClassName()
```

Region Replicas

Specify a value for the number of region replicas you want to have for the current table. The default is 1, which means just the main region. Setting it to 2, for example, adds a single additional replica for every region of this table. This is controlled for the table descriptor via:

```
int getRegionReplication()
HTableDescriptor setRegionReplication(int regionReplication)
```

Durability

Controls on the table level how data is persisted in term of durability guarantees. We discussed this option in “[Durability, Consistency, and Isolation](#)” (page 108), and you can set and retrieve the parameter with these methods:

```
HTableDescriptor setDurability(Durability durability)
Durability getDurability()
```

Previous versions of HBase (before 0.94.7) used a boolean *deferred log flush* flag to switch between an immediate sync of the WAL when data was written, or to a delayed one. This has been re-

placed with the finer grained Durability class, that allows to indicate what a client wishes to happen during write operations. The old `setDeferredLogFlush(true)` is replaced by the `Durability.ASYNC_WAL` option.

Read-only

By default, all tables are *writable*, but it may make sense to specify the *read-only* option for specific tables. If the flag is set to true, you can only read from the table and not modify it at all. The flag is set and read by these methods:

```
boolean isReadOnly()
HTableDescriptor setReadOnly(final boolean readOnly)
```

Coprocessors

The listed calls allow you to configure any number of coprocessor classes for a table. There are methods to add, check, list, and remove coprocessors from the current table descriptor instance:

```
HTableDescriptor addCoprocessor(String className) throws IOException
HTableDescriptor addCoprocessor(String className, Path jarFilePath,
    int priority, final Map<String, String> kvs) throws IOException
boolean hasCoprocessor(String className)
List<String> getCoprocessors()
void removeCoprocessor(String className)
```

Descriptor Parameters

In addition to those already mentioned, there are methods that let you set arbitrary key/value pairs:

```
byte[] getValue(byte[] key)
String getValue(String key)
Map<ImmutableBytesWritable, ImmutableBytesWritable> getValues()
HTableDescriptor setValue(byte[] key, byte[] value)
HTableDescriptor setValue(final ImmutableBytesWritable key,
    final ImmutableBytesWritable value)
HTableDescriptor setValue(String key, String value)
void remove(final String key)
void remove(ImmutableBytesWritable key)
void remove(final byte[] key)
```

They are stored with the table definition and can be retrieved if necessary. You can use them to access all configured values, as all of the above methods are effectively using this list to set their parameters. Another use-case might be to store application related metadata in this list, since it is persisted on the server and can be read by any client subsequently. The schema manager in Hush

uses this to store a table description, which is handy in the HBase web-based UI to learn about the purpose of an existing table.

Configuration

Allows you to override any HBase configuration property on a per table basis. This is merged at runtime with the default values, and the cluster wide configuration file. Note though that only properties related to the region or table will be useful to set. Other, unrelated keys will not be used even if you override them.

```
String getConfigurationValue(String key)
Map<String, String> getConfiguration()
HTableDescriptor setConfiguration(String key, String value)
void removeConfiguration(final String key)
```

Miscellaneous Calls

There are some calls that do not fit into the above categories, so they are listed here for completeness. They allow you to check the nature of the region or table they are related to, and if it is a system region (or table). They further allow you to convert the entire, or partial state of the instance into a string for further use, for example, to print the result into a log file.

```
boolean isRootRegion()
boolean isMetaRegion()
boolean isMetaTable()

String toString()
String toStringCustomizedValues()
String toStringTableAttributes()
```

Column Families

We just saw how the `HTableDescriptor` exposes methods to add column families to a table. Related to this is a class called `HColumnDescriptor` that wraps each column family's settings into a dedicated Java class. When using the HBase API in other programming languages, you may find the same concept or some other means of specifying the column family properties.

The class in Java is somewhat of a misnomer. A more appropriate name would be `HColumnFamilyDescriptor`, which would indicate its purpose to define column family parameters as opposed to actual columns.

Column families define shared features that apply to all columns that are created within them. The client can create an arbitrary number of columns by simply using new *column qualifiers* on the fly. Columns are addressed as a combination of the column family name and the column qualifier (or sometimes also called the *column key*), divided by a colon:

```
`family:qualifier`
```

The column family *must* be composed of printable characters, and cannot start with a colon (":"), or be completely empty.⁵ The qualifier, on the other hand, can be composed of any arbitrary binary characters. Recall the `Bytes` class mentioned earlier, which you can use to convert your chosen names to byte arrays. The reason why the family name must be printable is that the name is used as part of the directory name by the lower-level storage layer. [Figure 5-2](#) visualizes how the families are mapped to storage files. The family name is added to the path and must comply with filename standards. The advantage is that you can easily access families on the filesystem level as you have the name in a human-readable format.

You should also be aware of the *empty* column qualifier. You can simply omit the *qualifier* and specify just the column family name. HBase then creates a column with the special empty qualifier. You can write and read that column like any other, but obviously there is only one of those, and you will have to name the other columns to distinguish them. For simple applications, using no qualifier is an option, but it also carries no meaning when looking at the data—for example, using the HBase Shell. You should get used to naming your columns and do this from the start, because you cannot simply rename them later.

5. There are also some reserved names, that is, those used by the system to generate necessary paths.

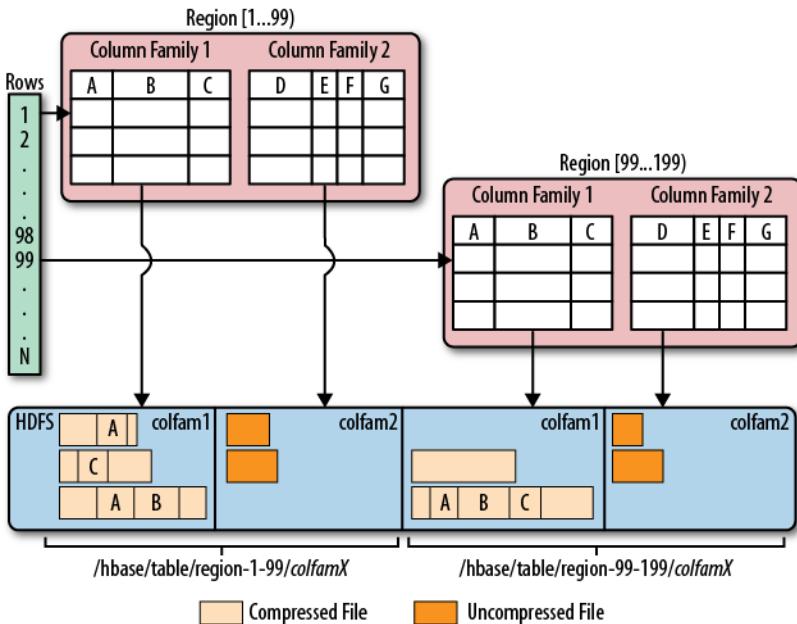


Figure 5-2. Column families mapping to separate storage files

Using the shell once again, we can try to create a column with no name, and see what happens if we create a table with a column family name that does not comply to the checks:

```

hbase(main):001:0> create 'testtable', 'colfam1'
0 row(s) in 0.1400 seconds

=> Hbase::Table - testtable
hbase(main):002:0> put 'testtable', 'row1', 'colfam1:', 'val1'
0 row(s) in 0.1130 seconds

hbase(main):003:0> scan 'testtable'
ROW          COLUMN+CELL
  row1        column=colfam1:, timestamp=1428488894611, val-
  ue=val1
1 row(s) in 0.0590 seconds

hbase(main):004:0> create 'testtable', 'col/fam1'
ERROR: Illegal character <47>. Family names cannot contain control
characters or colons: col/fam1

```

Here is some help for this command:
...

You can use the static helper method to verify the name:

```
static byte[] isLegalFamilyName(final byte[] b)
```

Use it in your program to verify user-provided input conforming to the specifications that are required for the name. It does not return a boolean flag, but throws an `IllegalArgumentException` when the name is malformed. Otherwise, it returns the given parameter value unchanged. The constructors taking in a `familyName` parameter, shown below, uses this method internally to verify the given name; in this case, you do not need to call the method beforehand.

A column family cannot be renamed. The common approach to rename a family is to create a new family with the desired name and copy the data over, using the API.

When you create a column family, you can specify a variety of parameters that control all of its features. The Java class has many constructors that allow you to specify most parameters while creating an instance. Here are the choices:

```
HColumnDescriptor(final String familyName)
HColumnDescriptor(final byte[] familyName)
HColumnDescriptor(HColumnDescriptor desc)
```

The first two simply take the family name as a `String` or `byte[]` array. There is another one that takes an existing `HColumnDescriptor`, which copies all state and settings over from the given instance. Instead of using the constructor, you can also use the getters and setters to specify the various details. We will now discuss each of them, grouped by their purpose.

Name

Each column family has a name, and you can use the following methods to retrieve it from an existing `HColumnDescriptor` instance:

```
byte[] getName();
String getNameAsString();
```

You cannot set the name, but you have to use these constructors to hand it in. Keep in mind the requirement for the name to be *printable* characters etc.

The name of a column family must not start with a “.” (period) and not contain “:” (colon), “/” (slash), or ISO control characters, in other words, if its code is in the range \u0000 through \u001F or in the range \u007F through \u009F.

Maximum Versions

Per family, you can specify how many versions of each value you want to keep. Recall the *predicate deletion* mentioned earlier where the housekeeping of HBase removes values that exceed the set maximum. Getting and setting the value is done using the following API calls:

```
int getMaxVersions()
HColumnDescriptor setMaxVersions(int maxVersions)
```

The default value is 1, set by the hbase.column.max.version configuration property. The default is good for many use-cases, forcing the application developer to override the single version setting to something higher if need be. For example, for a column storing passwords, you could set this value to 10 to keep a history of previously used passwords.

Minimum Versions

Specifies how many versions should always be kept for a column. This works in tandem with the *time-to-live*, avoiding the removal of the last value stored in a column. The default is set to 0, which disables this feature.

```
int getMinVersions()
HColumnDescriptor setMinVersions(int minVersions)
```

Keep Deleted Cells

Controls whether the background housekeeping processes should remove deleted cells, or not.

```
KeepDeletedCells getKeepDeletedCells()
HColumnDescriptor setKeepDeletedCells(boolean keepDeletedCells)
HColumnDescriptor setKeepDeletedCells(KeepDeletedCells keepDeletedCells)
```

The used `KeepDeletedCells` type is an enumeration, having the following options:

Table 5-1. The KeepDeletedCells enumeration

Value	Description
FALSE	Deleted cells are not retained.

Value	Description
TRUE	Deleted cells are retained until they are removed by other means such as time-to-live (TTL) or the max number of versions. If no TTL is specified or no new versions of delete cells are written, they are retained forever.
TTL	Deleted cells are retained until the delete marker expires due to TTL. This is useful when TTL is combined with the number of minimum versions, and you want to keep a minimum number of versions around, but at the same time remove deleted cells after the TTL.

The default is FALSE, meaning no deleted cells are kept during the housekeeping operation.

Compression

HBase has pluggable compression algorithm support (you can find more on this topic in (to come)) that allows you to choose the best compression—or none—for the data stored in a particular column family. The possible algorithms are listed in [Table 5-2](#).

Table 5-2. Supported compression algorithms

Value	Description
NONE	Disables compression (default).
GZ	Uses the Java-supplied or native GZip compression (which needs to be installed separately).
LZO	Enables LZO compression; must be installed separately.
LZ4	Enables LZ4 compression; must be installed separately.
SNAPPY	Enables Snappy compression; binaries must be installed separately.

The default value is NONE--in other words, no compression is enabled when you create a column family. When you use the Java API and a column descriptor, you can use these methods to change the value:

```
Compression.Algorithm getCompression()
Compression.Algorithm getCompressionType()
HColumnDescriptor setCompressionType(Compression.Algorithm
type)
Compression.Algorithm getCompactionCompression()
Compression.Algorithm getCompactionCompressionType()
HColumnDescriptor setCompactionCompressionType(Compression.Al-
gorithm type)
```

Note how the value is not a String, but rather a `Compression.Algorithm` enumeration that exposes the same values as listed in [Table 5-2](#). Another observation is that there are two sets of methods, one for the general compression setting and another for the `compaction` compression setting. Also, each group has a `getCom`

`pression()` and `getCompressionType()` (or `getCompactionCom
pression()` and `getCompactionCompressionType()`, respectively) returning the same type of value. They are indeed redundant, and you can use either to retrieve the current compression algorithm type.⁶ As for *compression* versus *compaction compression*, the latter defaults to what the former is set to, unless set differently.

We will look into this topic in much greater detail in (to come).

Encoding

Sets the encoding used for data blocks. If enabled, you can further influence whether the same is applied to the cell tags. The API methods involved are:

```
DataBlockEncoding getDataBlockEncoding()  
HColumnDescriptor setDataBlockEncoding(DataBlockEncoding type)
```

These two methods control the encoding used, and employ the `DataBlockEncoding` enumeration, containing the following options:

Table 5-3. Options of the DataBlockEncoding enumeration

Option	Description
NONE	No prefix encoding takes place (default).
PREFIX	Represents the <i>prefix</i> compression algorithm, which removes repeating common prefixes from subsequent cell keys.
DIFF	The <i>diff</i> algorithm, which further compresses the key of subsequent cells by storing only differences to previous keys.
FAST_DIFF	An optimized version of the <i>diff</i> encoding, which also omits repetitive cell value data.
PREFIX_TREE	Trades increased write time latencies for faster read performance. Uses a tree structure to compress the cell key.

In addition to setting the encoding for each cell key (and value data in case of *fast diff*), cells also may carry an arbitrary list of *tags*, used for different purposes, such as security and cell-level TTLs. The following methods of the column descriptor allow you to fine-tune if the encoding should also be applied to the tags:

```
HColumnDescriptor setCompressTags(boolean compressTags)  
boolean isCompressTags()
```

The default is `true`, so all optional cell tags are encoded as part of the entire cell encoding.

6. After all, this is open source and a redundancy like this is often caused by legacy code being carried forward. Please feel free to help clean this up and to contribute back to the HBase project.

Block Size

All stored files in HBase are divided into smaller blocks that are loaded during a `get()` or `scan()` operation, analogous to pages in RDBMSes. The size of these blocks is set to *64 KB* by default and can be adjusted with these methods:

```
synchronized int getBlocksize()  
HColumnDescriptor setBlocksize(int s)
```

The value is specified in bytes and can be used to control how much data HBase is required to read from the storage files during retrieval as well as what is cached in memory for subsequent access. How this can be used to optimize your setup can be found in (to come).

There is an important distinction between the column family block size, or `HFile` block size, and the block size specified on the HDFS level. Hadoop, and HDFS specifically, is using a block size of—by default—128 MB to split up large files for distributed, parallel processing using the YARN framework. For HBase the `HFile` block size is—again by default—64 KB, or one 2048th of the HDFS block size. The storage files used by HBase are using this much more fine-grained size to efficiently load and cache data in block operations. It is independent from the HDFS block size and only used internally. See (to come) for more details, especially (to come), which shows the two different block types.

Block Cache

As HBase reads entire blocks of data for efficient I/O usage, it retains these blocks in an in-memory cache so that subsequent reads do not need any disk operation. The default of `true` enables the block cache for every read operation. But if your use case only ever has sequential reads on a particular column family, it is advisable that you disable it to stop it from polluting the block cache by setting the block cache-enabled flag to `false`. Here is how the API can be used to change this flag:

```
boolean isBlockCacheEnabled()  
HColumnDescriptor setBlockCacheEnabled(boolean blockCacheEnabled)
```

There are other options you can use to influence how the block cache is used, for example, during a `scan()` operation by calling `setCacheBlocks(false)`. This is useful during full table scans so

that you do not cause a major churn on the cache. See (to come) for more information about this feature.

Besides the cache itself, you can configure the behavior of the system when data is being written, and store files being closed or opened. The following set of methods define (and query) this:

```
boolean isCacheDataOnWrite()
HColumnDescriptor setCacheDataOnWrite(boolean value)

boolean isCacheDataInL1()
HColumnDescriptor setCacheDataInL1(boolean value)

boolean isCacheIndexesOnWrite()
HColumnDescriptor setCacheIndexesOnWrite(boolean value)

boolean isCacheBloomsOnWrite()
HColumnDescriptor setCacheBloomsOnWrite(boolean value)

boolean isEvictBlocksOnClose()
HColumnDescriptor setEvictBlocksOnClose(boolean value)

boolean isPrefetchBlocksOnOpen()
HColumnDescriptor setPrefetchBlocksOnOpen(boolean value)
```

Please consult (to come) and (to come) for details on how the block cache works, what $L1$ and $L2$ is, and what you can do to speed up your HBase setup. Note, for now, that all of these latter settings default to `false`, meaning none of them is active, unless you explicitly enable them for a column family.

Time-to-Live

HBase supports predicate deletions on the number of versions kept for each value, but also on specific times. The time-to-live (or TTL) sets a threshold based on the timestamp of a value and the internal housekeeping is checking automatically if a value exceeds its TTL. If that is the case, it is dropped during major compactions. The API provides the following getters and setters to read and write the TTL:

```
int getTimeToLive()
HColumnDescriptor setTimeToLive(int timeToLive)
```

The value is specified in seconds and is, by default, set to `HConst.FOREVER`, which in turn is set to `Integer.MAX_VALUE`, or 2,147,483,647 seconds. The default value is treated as the special case of keeping the values *forever*, that is, any positive value less than the default enables this feature.

In-Memory

We mentioned the block cache and how HBase is using it to keep entire blocks of data in memory for efficient sequential access to data. The *in-memory* flag defaults to false but can be read and modified with these methods:

```
boolean isInMemory()  
HColumnDescriptor setInMemory(boolean inMemory)
```

Setting it to true is not a guarantee that all blocks of a family are loaded into memory nor that they stay there. Think of it as a promise, or elevated priority, to keep them in memory as soon as they are loaded during a normal retrieval operation, and until the pressure on the heap (the memory available to the Java-based server processes) is too high, at which time they need to be discarded.

In general, this setting is good for small column families with few values, such as the passwords of a user table, so that logins can be processed very fast.

Bloom Filter

An advanced feature available in HBase is Bloom filters,⁷ allowing you to improve lookup times given you have a specific access pattern (see (to come) for details). They add overhead in terms of storage and memory, but improve lookup performance and read latencies. [Table 5-4](#) shows the possible options.

Table 5-4. Supported Bloom Filter Types

Type	Description
NONE	Disables the filter.
ROW	Use the row key for the filter (default).
ROWCOL	Use the row key and column key (family+qualifier) for the filter.

As of HBase 0.96 the default is set to ROW for all column families of all user tables (they are *not* enabled for the system catalog tables). Because there are usually many more columns than rows (unless you only have a single column in each row), the last option, ROW COL, requires the largest amount of space. It is more fine-grained, though, since it knows about each row/column combination, as opposed to just rows keys.

7. See “[Bloom filter](#)” on Wikipedia.

The Bloom filter can be changed and retrieved with these calls, taking or returning a `BloomType` enumeration, reflecting the above options.

```
BloomType getBloomFilterType()
HColumnDescriptor setBloomFilterType(final BloomType bt)
```

Replication Scope

Another more advanced feature coming with HBase is *replication*. It enables you to have multiple clusters that ship local updates across the network so that they are applied to each other. By default, replication is disabled and the *replication scope* is set to 0, meaning it is disabled. You can change the scope with these functions:

```
int getScope()
HColumnDescriptor setScope(int scope)
```

The only other supported value (as of this writing) is 1, which enables replication to a remote cluster. There may be more scope values in the future. See [Table 5-5](#) for a list of supported values.

Table 5-5. Supported Replication Scopes

Scope Constant	Description
0 REPLICATION_SCOPE_LOCAL	Local scope, i.e., no replication for this family (default).
1 REPLICATION_SCOPE_GLOBAL	Global scope, i.e., replicate family to a remote cluster.

The full details can be found in (to come). Note how the scope is also provided as a public constant in the API class `HConstants`. When you need to set the replication scope in code it is advisable to use the constants, as they are easier to read.

Encryption

Sets encryption related details. See (to come) for details. The following API calls are at your disposal to set and read the encryption type and key:

```
String getEncryptionType()
HColumnDescriptor setEncryptionType(String algorithm)
byte[] getEncryptionKey()
HColumnDescriptor setEncryptionKey(byte[] keyBytes)
```

Descriptor Parameters

In addition to those already mentioned, there are methods that let you set arbitrary key/value pairs:

```
byte[] getValue(byte[] key)
String getValue(String key)
```

```

Map<ImmutableBytesWritable, ImmutableBytesWritable> getValues()
HColumnDescriptor setValue(byte[] key, byte[] value)
HColumnDescriptor setValue(String key, String value)
void remove(final byte[] key)

```

They are stored with the column definition and can be retrieved if necessary. You can use them to access all configured values, as all of the above methods are effectively using this list to set their parameters. Another use-case might be to store application related metadata in this list, since it is persisted on the server and can be read by any client subsequently.

Configuration

Allows you to override any HBase configuration property on a per column family basis. This is merged at runtime with the default values, the cluster wide configuration file, and the table level settings. Note though that only properties related to the region or table will be useful to set. Other, unrelated keys will not read even if you override them.

```

String getConfigurationValue(String key)
Map<String, String> getConfiguration()
HColumnDescriptor setConfiguration(String key, String value)
void removeConfiguration(final String key)

```

Miscellaneous Calls

There are some calls that do not fit into the above categories, so they are listed here for completeness. They allow you to retrieve the *unit* for a configuration parameter, and get hold of the list of all default values. They further allow you to convert the entire, or partial state of the instance into a string for further use, for example, to print the result into a log file.

```

static Unit getUnit(String key)
static Map<String, String> getDefaultValues()

String toString()
String toStringCustomizedValues()

```

The only supported unit as of this writing is for TTL.

[Example 5-4](#) uses the API to create a descriptor, set a custom and supplied value, and then print out the settings in various ways.

Example 5-4. Example how to create a HColumnDescriptor in code

```

HColumnDescriptor desc = new HColumnDescriptor("colfam1")
.setValue("test-key", "test-value")
.setBloomFilterType(BloomType.ROWCOL);

System.out.println("Column Descriptor: " + desc);

```

```

System.out.print("Values: ");
for (Map.Entry<ImmutableBytesWritable, ImmutableBytesWritable>
    entry : desc.getValues().entrySet()) {
    System.out.print(Bytes.toString(entry.getKey().get()) +
        " -> " + Bytes.toString(entry.getValue().get()) + ", ");
}
System.out.println();

System.out.println("Defaults: " +
    HColumnDescriptor.getDefaultValues());

System.out.println("Custom: " +
    desc.toStringCustomizedValues());

System.out.println("Units:");
System.out.println(HColumnDescriptor.TTL + " -> " +
    desc.getUnit(HColumnDescriptor.TTL));
System.out.println(HColumnDescriptor.BLOCKSIZE + " -> " +
    desc.getUnit(HColumnDescriptor.BLOCKSIZE));

```

The output of [Example 5-4](#) shows a few interesting details:

```

Column Descriptor: {NAME => 'colfam1', DATA_BLOCK_ENCODING =>
'NONE',
BLOOMFILTER => 'ROWCOL', REPLICATION_SCOPE => '0',
COMPRESSION => 'NONE', VERSIONS => '1', TTL => 'FOREVER',
MIN VERSIONS => '0', KEEP_DELETED_CELLS => 'FALSE',
BLOCKSIZE => '65536', IN_MEMORY => 'false', BLOCKCACHE => 'true',
METADATA => {'test-key' => 'test-value'}}

Values: DATA_BLOCK_ENCODING -> NONE, BLOOMFILTER -> ROWCOL,
REPLICATION_SCOPE -> 0, COMPRESSION -> NONE, VERSIONS -> 1,
TTL -> 2147483647, MIN_VERSIONS -> 0, KEEP_DELETED_CELLS ->
FALSE,
BLOCKSIZE -> 65536, IN_MEMORY -> false, test-key -> test-value,
BLOCKCACHE -> true

Defaults: {CACHE_BLOOMS_ON_WRITE=false, CACHE_DATA_IN_L1=false,
PREFETCH_BLOCKS_ON_OPEN=false, BLOCKCACHE=true,
CACHE_INDEX_ON_WRITE=false, TTL=2147483647, DATA_BLOCK_ENCODING=NONE,
BLOCKSIZE=65536, BLOOMFILTER=ROW, EVICT_BLOCKS_ON_CLOSE=false,
MIN VERSIONS=0, CACHE_DATA_ON_WRITE=false, KEEP_DELETED_CELLS=FALSE,
COMPRESSION=none, REPLICATION_SCOPE=0, VERSIONS=1, IN_MEMORY=false}

Custom: {NAME => 'colfam1', BLOOMFILTER => 'ROWCOL',
METADATA => {'test-key' => 'test-value'}}

Units:
TTL -> TIME_INTERVAL
BLOCKSIZE -> NONE

```

The custom `test-key` property, with value `test-value`, is listed as `METADATA`, while the one setting that was changed from the default, the Bloom filter set to `ROWCOL`, is listed separately. The `toStringCustomizedValues()` only lists the changed or custom data, while the others print all. The static `getDefaultValue()` lists the default values unchanged, since it is created once when this class is loaded and never modified thereafter.

Before we move on, and as explained earlier in the context of the table descriptor, the serialization functions required to send the configured instances over RPC are also present for the column descriptor:

```
byte[] toByteArray()
static HColumnDescriptor parseFrom(final byte[] bytes) throws De-
    serializationException
static HColumnDescriptor convert(final ColumnFamilySchema cfs)
ColumnFamilySchema convert()
```

HBaseAdmin

Just as with the client API, you also have an API for administrative tasks at your disposal. Compare this to the *Data Definition Language* (DDL) found in RDBMSes—while the client API is more an analog to the *Data Manipulation Language* (DML).

It provides operations to create tables with specific column families, check for table existence, alter table and column family definitions, drop tables, and much more. The provided functions can be grouped into related operations; they're discussed separately on the following pages.

Basic Operations

Before you can use the administrative API, you will have to create an instance of the `Admin` interface implementation. You cannot create an instance directly, but you need to use the same approach as with tables (see “[API Building Blocks](#)” (page 117)) to retrieve an instance using the `Connection` class:

```
Configuration conf = HBaseConfiguration.create();
Connection connection = ConnectionFactory.createConnection(conf);
Admin admin = connection.getAdmin();
...
TableName[] tables = admin.listTableNames();
...
admin.close();
connection.close();
```

For the sake of brevity, this section omits the fact that pretty much all methods may throw an `IOException` (or an exception that inherits from it). The reason is usually a result of a communication error between your client application and the remote servers, or an error that occurred on the server-side and which was marshalled (as in *wrapped*) into a client-side I/O error.

Handing in an existing configuration instance gives enough details to the API to find the cluster using the ZooKeeper quorum, just like the client API does. Use the administrative API instance for the operation required and discard it afterward. In other words, you should not hold on to the instance for too long. Call `close()` when you are done to free any resources still held on either side of the communication.

The class implements the `Abortable` interface, adding the following call to it:

```
void abort(String why, Throwable e)
boolean isAborted()
```

This method is called by the framework implicitly—for example, when there is a fatal connectivity issue and the API should be stopped. You should not call it directly, but rely on the system taking care of invoking it, in case of dire emergencies, that require a complete shutdown—and possible restart—of the API instance.

The `Admin` class also exports these basic calls:

```
Connection getConnection()
void close()
```

The `getConnection()` returns the connection instance, and `close()` frees all resources kept by the current `Admin` instance, as shown above. This includes the connection to the remote servers.

Namespace Operations

You can use the API to create namespaces that subsequently hold the tables assigned to them. And as expected, you can in addition modify or delete existing namespaces, and retrieve a descriptor (see “Namespaces” (page 347)). The list of API calls for these tasks are:

```
void createNamespace(final NamespaceDescriptor descriptor)
void modifyNamespace(final NamespaceDescriptor descriptor)
void deleteNamespace(final String name)
NamespaceDescriptor getNamespaceDescriptor(final String name)
NamespaceDescriptor[] listNamespaceDescriptors()
```

[Example 5-5](#) shows these calls in action. The code creates a new namespace, then lists the namespaces available. It then modifies the new namespace by adding a custom property. After printing the descriptor it deletes the namespace, and eventually confirms the removal by listing the available spaces again.

Example 5-5. Example using the administrative API to create etc. a namespace

```
Configuration conf = HBaseConfiguration.create();
Connection connection = ConnectionFactory.createConnection(conf);
Admin admin = connection.getAdmin();
NamespaceDescriptor namespace =
    NamespaceDescriptor.create("testspace").build();
admin.createNamespace(namespace);

NamespaceDescriptor namespace2 =
    admin.getNamespaceDescriptor("testspace");
System.out.println("Simple Namespace: " + namespace2);

NamespaceDescriptor[] list = admin.listNamespaceDescriptors();
for (NamespaceDescriptor nd : list) {
    System.out.println("List Namespace: " + nd);
}

NamespaceDescriptor namespace3 =
    NamespaceDescriptor.create("testspace")
        .addConfiguration("Description", "Test Namespace")
        .build();
admin.modifyNamespace(namespace3);

NamespaceDescriptor namespace4 =
    admin.getNamespaceDescriptor("testspace");
System.out.println("Custom Namespace: " + namespace4);

admin.deleteNamespace("testspace");

NamespaceDescriptor[] list2 = admin.listNamespaceDescriptors();
for (NamespaceDescriptor nd : list2) {
    System.out.println("List Namespace: " + nd);
}
```

The console output confirms what we expected to see:

```
Simple Namespace: {NAME => 'testspace'}
List Namespace: {NAME => 'default'}
List Namespace: {NAME => 'hbase'}
List Namespace: {NAME => 'testspace'}
Custom Namespace: {NAME => 'testspace', Description => 'Test Namespace'}
List Namespace: {NAME => 'default'}
List Namespace: {NAME => 'hbase'}
```

Table Operations

After the first set of basic and namespace operations, there is a group of calls related to HBase tables. These calls help when working with the tables themselves, not the actual schemas inside. The commands addressing this are in “[Schema Operations](#)” (page 391).

Before you can do anything with HBase, you need to create tables. Here is the set of functions to do so:

```
void createTable(HTableDescriptor desc)
void createTable(HTableDescriptor desc, byte[] startKey,
    byte[] endKey, int numRegions)
void createTable(final HTableDescriptor desc, byte[][][] splitKeys)

void createTableAsync(final HTableDescriptor desc, final byte[][][]
    splitKeys)
```

All of these calls must be given an instance of `HTableDescriptor`, as described in detail in “[Tables](#)” (page 350). It holds the details of the table to be created, including the column families. [Example 5-6](#) uses the simple variant of `createTable()` that just takes a table name.

Example 5-6. Example using the administrative API to create a table

```
Configuration conf = HBaseConfiguration.create();
Connection connection = ConnectionFactory.createConnection(conf);
Admin admin = connection.getAdmin(); ❶

TableName tableName = TableName.valueOf("testtable");
HTableDescriptor desc = new HTableDescriptor(tableName); ❷

HColumnDescriptor coldef = new HColumnDescriptor(❸
    Bytes.toBytes("colfam1"));
desc.addFamily(coldef);

admin.createTable(desc); ❹

boolean avail = admin.isTableAvailable(tableName); ❺
System.out.println("Table available: " + avail);
```

- ❶ Create a administrative API instance.
- ❷ Create the table descriptor instance.
- ❸ Create a column family descriptor and add it to the table descriptor.
- ❹ Call the `createTable()` method to do the actual work.
- ❺ Check if the table is available.

[Example 5-7](#) shows the same, but adds a namespace into the mix.

Example 5-7. Example using the administrative API to create a table with a custom namespace

```
NamespaceDescriptor namespace =
    NamespaceDescriptor.create("testspace").build();
admin.createNamespace(namespace);

TableName tableName = TableName.valueOf("testspace", "testtable");
HTableDescriptor desc = new HTableDescriptor(tableName);

HColumnDescriptor coldef = new HColumnDescriptor(
    Bytes.toBytes("colfam1"));
desc.addFamily(coldef);

admin.createTable(desc);
```

The other `createTable()` versions have an additional—yet more advanced—feature set: they allow you to create tables that are already populated with specific regions. The code in [Example 5-8](#) uses both possible ways to specify your own set of region boundaries.

Example 5-8. Example using the administrative API to create a table with predefined regions

```
private static Configuration conf = null;
private static Connection connection = null;

private static void printTableRegions(String tableName) throws IOException {
    ❶ System.out.println("Printing regions of table: " + tableName);
    TableName tn = TableName.valueOf(tableName);
    RegionLocator locator = connection.getRegionLocator(tn);
    Pair<byte[][][], byte[][]> pair = locator.getStartEndKeys(); ❷
    for (int n = 0; n < pair.getFirst().length; n++) {
        byte[] sk = pair.getFirst()[n];
        byte[] ek = pair.getSecond()[n];
        System.out.println("[ " + (n + 1) + " ]" +
            " start key: " +
            (sk.length == 8 ? Bytes.toLong(sk) : Bytes.toStringBinary(sk)) + ❸
            ", end key: " +
            (ek.length == 8 ? Bytes.toLong(ek) : Bytes.toStringBinary(ek)));
    }
    locator.close();
}
public static void main(String[] args) throws IOException, InterruptedException {
    conf = HBaseConfiguration.create();
    connection = ConnectionFactory.createConnection(conf);
```

```

Admin admin = connection.getAdmin();

HTableDescriptor desc = new HTableDescriptor(
    TableName.valueOf("testtable1"));
HColumnDescriptor coldef = new HColumnDescriptor(
    Bytes.toBytes("colfam1"));
desc.addFamily(coldef);

admin.createTable(desc, Bytes.toBytes(1L), Bytes.toBytes(100L),
10); ④
printTableRegions("testtable1");

byte[][] regions = new byte[][][] { ⑤
    Bytes.toBytes("A"),
    Bytes.toBytes("D"),
    Bytes.toBytes("G"),
    Bytes.toBytes("K"),
    Bytes.toBytes("O"),
    Bytes.toBytes("T")
};
HTableDescriptor desc2 = new HTableDescriptor(
    TableName.valueOf("testtable2"));
desc2.addFamily(coldef);
admin.createTable(desc2, regions); ⑥
printTableRegions("testtable2");
}

```

- ① Helper method to print the regions of a table.
- ② Retrieve the start and end keys from the newly created table.
- ③ Print the key, but guarding against the empty start (and end) key.
- ④ Call the createTable() method while also specifying the region boundaries.
- ⑤ Manually create region split keys.
- ⑥ Call the crateTable() method again, with a new table name and the list of region split keys.

Running the example should yield the following output on the console:

```

Printing regions of table: testtable1
[1] start key: , end key: 1
[2] start key: 1, end key: 13
[3] start key: 13, end key: 25
[4] start key: 25, end key: 37
[5] start key: 37, end key: 49
[6] start key: 49, end key: 61
[7] start key: 61, end key: 73
[8] start key: 73, end key: 85
[9] start key: 85, end key: 100

```

```
[10] start key: 100, end key:  
Printing regions of table: testtable2  
[1] start key: , end key: A  
[2] start key: A, end key: D  
[3] start key: D, end key: G  
[4] start key: G, end key: K  
[5] start key: K, end key: O  
[6] start key: O, end key: T  
[7] start key: T, end key:
```

The example uses a method of the `RegionLocator` implementation that you saw earlier (see “[The RegionLocator Class](#)” (page 354)), `getStartEndKeys()`, to retrieve the region boundaries. The first *start* and the last *end* keys are empty, as is customary with HBase regions. In between the keys are either the computed, or the provided split keys. Note how the end key of a region is also the start key of the subsequent one—just that it is exclusive for the former, and inclusive for the latter, respectively.

The `createTable(HTableDescriptor desc, byte[] startKey, byte[] endKey, int numRegions)` call takes a start and end key, which is interpreted as numbers. You *must* provide a start value that is less than the end value, and a `numRegions` that is at least 3: otherwise, the call will return with an exception. This is to ensure that you end up with at least a minimum set of regions.

The start and end key values are subtracted and divided by the given number of regions to compute the region boundaries. In the example, you can see how we end up with the correct number of regions, while the computed keys are filling in the range.

The `createTable(HTableDescriptor desc, byte[][][] splitKeys)` method used in the second part of the example, on the other hand, is expecting an already set array of split keys: they form the start and end keys of the regions created. The output of the example demonstrates this as expected. But take note how the first start key, and the last end key are the default *empty* one (set to `null`), which means you end up with seven regions, albeit having provided only six split keys.

The `createTable()` calls are, in fact, related. The `createTable(HTableDescriptor desc, byte[] startKey, byte[] endKey, int numRegions)` method is calculating the region keys implicitly for you, using the `Bytes.split()` method to use your given parameters to compute the boundaries. It then proceeds to call the `createTable(HTableDescriptor desc, byte[][] splitKeys)`, doing the actual table creation.

Finally, there is the `createTableAsync(HTableDescriptor desc, byte[][] splitKeys)` method that is taking the table descriptor, and region keys, to asynchronously perform the same task as the `createTable()` call.

Most of the table-related administrative API functions are asynchronous in nature, which is useful, as you can send off a command and not have to deal with waiting for a result. For a client application, though, it is often necessary to know if a command has succeeded before moving on with other operations. For that, the calls are provided in asynchronous—using the `Async` postfix—and synchronous versions.

In fact, the synchronous commands are simply a wrapper around the asynchronous ones, adding a loop at the end of the call to repeatedly check for the command to have done its task. The `createTable()` method, for example, wraps the `createTableAsync()` method, while adding a loop that waits for the table to be created on the remote servers before yielding control back to the caller.

Once you have created a table, you can use the following helper functions to retrieve the list of tables, retrieve the descriptor for an existing table, or check if a table exists:

```
HTableDescriptor[] listTables()
HTableDescriptor[] listTables(Pattern pattern)
HTableDescriptor[] listTables(String regex)
HTableDescriptor[] listTables(Pattern pattern, boolean includeSysTables)
HTableDescriptor[] listTables(String regex, boolean includeSysTables)
HTableDescriptor[] listTableDescriptorsByNamespace(final String name)
```

```

HTableDescriptor getTableDescriptor(final TableName tableName)
HTableDescriptor[] getTableDescriptorsByTableName(List<TableName>
tableNames)
HTableDescriptor[] getTableDescriptors(List<String> names)
boolean tableExists(final TableName tableName)

```

[Example 5-6](#) uses the `tableExists()` method to check if the previous command to create the table has succeeded. The `listTables()` returns a list of `HTableDescriptor` instances for every table that HBase knows about, while the `getTableDescriptor()` method is returning it for a specific one. [Example 5-9](#) uses both to show what is returned by the administrative API.

Example 5-9. Example listing the existing tables and their descriptors

```

Connection connection = ConnectionFactory.createConnection(conf);
Admin admin = connection.getAdmin();

HTableDescriptor[] htds = admin.listTables();
for (HTableDescriptor htd : htds) {
    System.out.println(htd);
}

HTableDescriptor htd1 = admin.getTableDescriptor(
    TableName.valueOf("testtable1"));
System.out.println(htd1);

HTableDescriptor htd2 = admin.getTableDescriptor(
    TableName.valueOf("testtable10"));
System.out.println(htd2);

```

The console output is quite long, since every table descriptor is printed, including every possible property. Here is an abbreviated version:

```

Printing all tables...
'testtable1', {NAME => 'colfam1', DATA_BLOCK_ENCODING => 'NONE',
BLOOMFILTER => 'ROW', REPLICATION_SCOPE => '0', VERSIONS => '1', COMPRESSION => 'NONE',
MIN_VERSIONS => '0', TTL => 'FOREVER', KEEP_DELETED_CELLS => 'FALSE',
BLOCKSIZE => '65536', IN_MEMORY => 'false', BLOCKCACHE => 'true'},
{NAME => 'colfam2', DATA_BLOCK_ENCODING => 'NONE', BLOOMFILTER => 'ROW',
REPLICATION_SCOPE => '0', VERSIONS => '1', COMPRESSION => 'NONE',
MIN_VERSIONS => '0', TTL => 'FOREVER', KEEP_DELETED_CELLS => 'FALSE',
BLOCKSIZE => '65536', IN_MEMORY => 'false', BLOCKCACHE => 'true'},
{NAME => 'colfam3', DATA_BLOCK_ENCODING => 'NONE', BLOOMFILTER => 'ROW',
REPLICATION_SCOPE => '0', VERSIONS => '1', COMPRESSION => 'NONE',

```

```

    MIN VERSIONS => '0', TTL => 'FOREVER', KEEP_DELETED_CELLS =>
    'FALSE',
    BLOCKSIZE => '65536', IN_MEMORY => 'false', BLOCKCACHE => 'true'}
...
Exception in thread "main"
  org.apache.hadoop.hbase.TableNotFoundException: testtable10
    at org.apache.hadoop.hbase.client.HBaseAdmin.getTableDescriptor(...)
    at admin.ListTablesExample.main(ListTablesExample.java:49)
...

```

The interesting part is the exception you should see being printed as well. The example uses a nonexistent table name to showcase the fact that you *must* be using existing table names—or wrap the call into a try/catch guard, handling the exception more gracefully. You could also use the `tableExists()` call, avoiding such exceptions being thrown by first checking if a table exists. But keep in mind, HBase is a distributed system, so just because you checked a table exists does not mean it was already removed before you had a chance to apply the next operation on it. In other words, using try/catch is advisable in any event.

There are additional `listTables()` calls, which take a varying amount of parameters. You can specify a regular expression filter either as a string, or an already compiled `Pattern` instance. Furthermore, you can instruct the call to include system tables by setting `includeSystemTables` to `true`, since by default they are excluded. [Example 5-10](#) shows these calls in use.

Example 5-10. Example listing the existing tables with patterns

```

HTableDescriptor[] htds = admin.listTables(".*");
htds = admin.listTables(".*", true);
htds = admin.listTables("hbase:.*", true);
htds = admin.listTables("def.*:.*", true);
htds = admin.listTables("test.*");
Pattern pattern = Pattern.compile(".*2");
htds = admin.listTables(pattern);
htds = admin.listTableDescriptorsByNamespace("testspace1");

```

The output is as such:

```

List: .*
testspace1:testtable1
testspace2:testtable2
testtable3

List: .*, including system tables
hbase:meta
hbase:namespace
testspace1:testtable1

```

```

testspace2:testtable2
testtable3

List: hbase:.*, including system tables
hbase:meta
hbase:namespace

List: def.*:.*, including system tables
testtable3

List: test.*
testspace1:testtable1
testspace2:testtable2
testtable3

List: .*2, using Pattern
testspace2:testtable2

List by Namespace: testspace1
testspace1:testtable1

```

The next set of list methods revolve around the names, not the entire table descriptor we retrieved so far. The same can be done on the table names alone, using the following calls:

```

TableName[] listTableNames()
TableName[] listTableNames(Pattern pattern)
TableName[] listTableNames(String regex)
TableName[] listTableNames(final Pattern pattern,
    final boolean includeSysTables)
TableName[] listTableNames(final String regex,
    final boolean includeSysTables)
TableName[] listTableNamesByNamespace(final String name)

```

[Example 5-11](#) changes the previous example to use tables names, but otherwise applies the same patterns.

Example 5-11. Example listing the existing tables with patterns

```

TableName[] names = admin.listTableNames(".*");
names = admin.listTableNames(".*", true);
names = admin.listTableNames("hbase:.*", true);
names = admin.listTableNames("def.*:.*", true);
names = admin.listTableNames("test.*");
Pattern pattern = Pattern.compile(".*2");
names = admin.listTableNames(pattern);
names = admin.listTableNamesByNamespace("testspace1");

```

The output is exactly the same and omitted here for the sake of brevity. There is one more table information-related method available:

```

List<HRegionInfo> getTableRegions(final byte[] tableName)
List<HRegionInfo> getTableRegions(final TableName tableName)

```

This is similar to using the aforementioned `RegionLocator` (see “[The `RegionLocator` Class](#)” (page 354)), but instead of returning the more elaborate `HRegionLocation` details for each region of the table, this call returns the slightly less detailed `HRegionInfo` records. The difference is that the latter is just about the regions, while the former also includes their current region server assignments.

After creating a table, you might also be interested to delete it. The Admin calls to do so are:

```
void deleteTable(final TableName tableName)
HTableDescriptor[] deleteTables(String regex)
HTableDescriptor[] deleteTables(Pattern pattern)
```

Hand in a table name and the rest is taken care of: the table is removed from the servers, and all data deleted. The pattern based versions of the call work the same way as shown for `listTables()` above. Just be very careful not to delete the wrong table because of a wrong regular expression pattern! The returned array for the pattern based calls is a list of all tables where the operation *failed*. In other words, if the operation succeeds, the returned list will be empty (but not null).

The is another related call, which does *not* delete the table itself, but removes all data from it:

```
public void truncateTable(final TableName tableName,
    final boolean preserveSplits)
```

Since a table might have grown and has been split across many regions, the `preserveSplits` flag is indicating what you want to have happen with the list of these regions. The `truncate` call is really similar to a `disable` and `drop` call, followed by a `create` operation, which recreates the table. At that point the `preserveSplits` flag decides if the servers recreate the table with a single region, like any other new table (which has no pre-split region list), or with all of its former regions.

But before you can delete a table, you need to ensure that it is first *disabled*, using the following methods:

```
void disableTable(final TableName tableName)
HTableDescriptor[] disableTables(String regex)
HTableDescriptor[] disableTables(Pattern pattern)
void disableTableAsync(final TableName tableName)
```

Disabling the table first tells every region server to flush any uncommitted changes to disk, close all the regions, and update the system tables to reflect that no region of this table is deployed to any servers. The choices are again between doing this asynchronously, or synchronously, and supplying the table name in various formats for convenience.

nience. The returned list of descriptors for the pattern based calls is listing all *failed* tables, that is, which were part of the pattern but failed to disable. If all of them succeed to disable, the returned list will be empty (but not null).

Disabling a table can potentially take a very long time, up to several minutes. This depends on how much data is residual in the server's memory and not yet persisted to disk. Undeploying a region requires all the data to be written to disk first, and if you have a large heap value set for the servers this may result in megabytes, if not even gigabytes, of data being saved. In a heavily loaded system this could contend with other processes writing to disk, and therefore require time to complete.

Once a table has been disabled, but not deleted, you can enable it again:

```
void enableTable(final TableName tableName)
HTableDescriptor[] enableTables(String regex)
HTableDescriptor[] enableTables(Pattern pattern)
void enableTableAsync(final TableName tableName)
```

This call—again available in the usual flavors—reverses the disable operation by deploying the regions of the given table to the active region servers. Just as with the other pattern based methods, the returned array of descriptors is either empty, or contains the tables where the operation failed.

Finally, there is a set of calls to check on the status of a table:

```
boolean isTableEnabled(TableName tableName)
boolean isTableDisabled(TableName tableName)
boolean isTableAvailable(TableName tableName)
boolean isTableAvailable(TableName tableName, byte[][][] splitKeys)
```

[Example 5-12](#) uses various combinations of the preceding calls to create, delete, disable, and check the state of a table.

Example 5-12. Example using the various calls to disable, enable, and check that status of a table

```
Connection connection = ConnectionFactory.createConnection(conf);
Admin admin = connection.getAdmin();

TableName tableName = TableName.valueOf("testtable");
HTableDescriptor desc = new HTableDescriptor(tableName);
HColumnDescriptor coldef = new HColumnDescriptor()
```

```

        Bytes.toBytes("colfam1"));
desc.addFamily(coldef);
admin.createTable(desc);

try {
    admin.deleteTable(tableName);
} catch (IOException e) {
    System.err.println("Error deleting table: " + e.getMessage());
}

admin.disableTable(tableName);
boolean isEnabled = admin.isTableDisabled(tableName);
System.out.println("Table is disabled: " + isEnabled);

boolean avail1 = admin.isTableAvailable(tableName);
System.out.println("Table available: " + avail1);

admin.deleteTable(tableName);

boolean avail2 = admin.isTableAvailable(tableName);
System.out.println("Table available: " + avail2);

admin.createTable(desc);
boolean isEnabled = admin.isTableEnabled(tableName);
System.out.println("Table is enabled: " + isEnabled);

```

The output on the console should look like this (the exception printout was abbreviated, for the sake of brevity):

```

Creating table...
Deleting enabled table...
Error deleting table:
    org.apache.hadoop.hbase.TableNotDisabledException: testtable
        at org.apache.hadoop.hbase.master.HMaster.checkTableModifiable(...)
        ...
Disabling table...
Table is disabled: true
Table available: true
Deleting disabled table...
Table available: false
Creating table again...
Table is enabled: true

```

The error thrown when trying to delete an enabled table shows that you either disable it first, or handle the exception gracefully in case that is what your client application requires. You could prompt the user to disable the table explicitly and retry the operation.

Also note how the `isTableAvailable()` is returning `true`, even when the table is disabled. In other words, this method checks if the table is physically present, no matter what its state is. Use the other two func-

tions, `isTableEnabled()` and `isTableDisabled()`, to check for the state of the table.

After creating your tables with the specified schema, you must either delete the newly created table and recreate it to change its details, or use the following method to *alter* its structure:

```
void modifyTable(final TableName tableName, final HTableDescriptor htd)
Pair<Integer, Integer> getAlterStatus(final TableName tableName)
Pair<Integer, Integer> getAlterStatus(final byte[] tableName)
```

The `modifyTable()` call is *only* asynchronous, and there is no synchronous variant. If you want to make sure that changes have been propagated to all the servers and applied accordingly, you should use the `getAlterStatus()` calls and loop in your client code until the schema has been applied to all servers and regions. The call returns a pair of numbers, where their meaning is summarized in the following table:

Table 5-6. Meaning of numbers returned by `getAlterStatus()` call

Pair Member	Description
<code>first</code>	Specifies the number of regions that still need to be updated.
<code>second</code>	Total number of regions affected by the change.

As with the aforementioned `deleteTable()` commands, you must first disable the table to be able to modify it. [Example 5-13](#) does create a table, and subsequently modifies it. It also uses the `getAlterStatus()` call to wait for all regions to be updated.

Example 5-13. Example modifying the structure of an existing table

```
Admin admin = connection.getAdmin();
TableName tableName = TableName.valueOf("testtable");
HColumnDescriptor coldef1 = new HColumnDescriptor("colfam1");
HTableDescriptor desc = new HTableDescriptor(tableName)
    .addFamily(coldef1)
    .setValue("Description", "Chapter 5 - ModifyTableExample: Original Table");

admin.createTable(desc, Bytes.toBytes(1L), Bytes.toBytes(10000L),
50); ❶

HTableDescriptor htd1 = admin.getTableDescriptor(tableName); ❷
HColumnDescriptor coldef2 = new HColumnDescriptor("colfam2");
htd1
    .addFamily(coldef2)
    .setMaxFileSize(1024 * 1024 * 1024L)
    .setValue("Description",
        "Chapter 5 - ModifyTableExample: Modified Table");
```

```

admin.disableTable(tableName);
admin.modifyTable(tableName, htd1); ③

Pair<Integer, Integer> status = new Pair<Integer, Integer>() {{ ④
    setFirst(50);
    setSecond(50);
}};
for (int i = 0; status.getFirst() != 0 && i < 500; i++) {
    status = admin.getAlterStatus(desc.getTableName()); ⑤
    if (status.getSecond() != 0) {
        int pending = status.getSecond() - status.getFirst();
        System.out.println(pending + " of " + status.getSecond()
            + " regions updated.");
        Thread.sleep(1 * 1000l);
    } else {
        System.out.println("All regions updated.");
        break;
    }
}
if (status.getFirst() != 0) {
    throw new IOException("Failed to update regions after 500 seconds.");
}

admin.enableTable(tableName);

HTableDescriptor htd2 = admin.getTableDescriptor(tableName);
System.out.println("Equals: " + htd1.equals(htd2)); ⑥
System.out.println("New schema: " + htd2);

```

- ① Create the table with the original structure and 50 regions.
- ② Get schema, update by adding a new family and changing the maximum file size property.
- ③ Disable and modify the table.
- ④ Create a status number pair to start the loop.
- ⑤ Loop over status until all regions are updated, or 500 seconds have been exceeded.
- ⑥ Check if the table schema matches the new one created locally.

The output shows that both the schema modified in the client code and the final schema retrieved from the server *after* the modification are consistent:

```

50 of 50 regions updated.
Equals: true
New schema: 'testtable', {TABLE_ATTRIBUTES => {MAX_FILESIZE =>
'1073741824',
METADATA => {'Description' => 'Chapter 5 - ModifyTableExample:'}

```

```

    Modified Table'}}}, {NAME => 'colfam1', DATA_BLOCK_ENCODING =>
'NONE',
    BLOOMFILTER => 'ROW', REPLICATION_SCOPE => '0', VERSIONS => '1',
    COMPRESSION => 'NONE', MIN VERSIONS => '0', TTL => 'FOREVER',
    KEEP_DELETED_CELLS => 'FALSE', BLOCKSIZE => '65536', IN_MEMORY =>
'false',
    BLOCKCACHE => 'true'}, {NAME => 'colfam2', DA-
TA_BLOCK_ENCODING
    => 'NONE', BLOOMFILTER => 'ROW', REPLICATION_SCOPE => '0', COM-
PRESSION
    => 'NONE', VERSIONS => '1', TTL => 'FOREVER', MIN_VERSIONS =>
'0',
    KEEP_DELETED_CELLS => 'FALSE', BLOCKSIZE => '65536', IN_MEMORY
=> 'false',
    BLOCKCACHE => 'true'}

```

Calling the `equals()` method on the `HTableDescriptor` class compares the current with the specified instance and returns `true` if they match in all properties, also including the contained column families and their respective settings. It does *not* though compare custom settings, such as the used `Description` key, modified from the original to the new value during the operation.

Schema Operations

Besides using the `modifyTable()` call, there are dedicated methods provided by the `Admin` class to modify specific aspects of the current table schema. As usual, you need to make sure the table to be modified is disabled first. The whole set of column-related methods is as follows:

```

voidaddColumn(final TableName tableName, final HColumnDescriptor
column)
voiddeleteColumn(final TableName tableName, final byte[] colum-
nName)
voidmodifyColumn(final TableName tableName,
final HColumnDescriptor descriptor)

```

You can add, delete, and modify columns. Adding or modifying a column requires that you first prepare a `HColumnDescriptor` instance, as described in detail in “[Column Families](#)” (page 362). Alternatively, you could use the `getTableDescriptor()` call to retrieve the current table schema, and subsequently invoke `getColumnFamilies()` on the returned `HTableDescriptor` instance to retrieve the existing columns. Otherwise, you supply the table name, and optionally the column

name for the delete calls. All of these calls are asynchronous, so as mentioned before, caveat emptor.

Use Case: Hush

An interesting use case for the administrative API is to create and alter tables and their schemas based on an external configuration file. Hush is making use of this idea and defines the table and column descriptors in an XML file, which is read and the contained schema compared with the current table definitions. If there are any differences they are applied accordingly. The following example has the core of the code that does this task:

Example 5-14. Creating or modifying table schemas using the HBase administrative API

```
private void createOrChangeTable(final HTableDescriptor schema)
throws IOException {
    HTableDescriptor desc = null;
    if (tableExists(schema.getTableName(), false)) {
        desc = getTable(schema.getTableName(), false);
        LOG.info("Checking table " + desc.getNameAsString() +
"...");
    }

    final List<HColumnDescriptor> modCols =
        new ArrayList<HColumnDescriptor>();
    for (final HColumnDescriptor cd : desc.getFamilies()) {
        final HColumnDescriptor cd2 = schema.getFamily(cd.getName());
        if (cd2 != null && !cd.equals(cd2)) { ❶
            modCols.add(cd2);
        }
    }
    final List<HColumnDescriptor> delCols =
        new ArrayList<HColumnDescriptor>(desc.getFamilies());
    delCols.removeAll(schema.getFamilies());
    final List<HColumnDescriptor> addCols =
        new ArrayList<HColumnDescriptor>(schema.getFamilies());
    addCols.removeAll(desc.getFamilies());

    if (modCols.size() > 0 || addCols.size() > 0 || del-
    Col.size() > 0 || ❷
        !hasSameProperties(desc, schema)) {
        LOG.info("Disabling table...");
        admin.disableTable(schema.getTableName());
        if (modCols.size() > 0 || addCols.size() > 0 || del-
    Col.size() > 0) {
            for (final HColumnDescriptor col : modCols) {
                LOG.info("Found different column -> " + col);
                admin.modifyColumn(schema.getTableName(), col); ❸
            }
        }
    }
}
```

```

    }
    for (final HColumnDescriptor col : addCols) {
        LOG.info("Found new column -> " + col);
        admin.addColumn(schema.getTableName(), col); ④
    }
    for (final HColumnDescriptor col : delCols) {
        LOG.info("Found removed column -> " + col);
        admin.deleteColumn(schema.getTableName(), col.getName()); ⑤
    }
} else if (!hasSameProperties(desc, schema)) {
    LOG.info("Found different table properties...");
    admin.modifyTable(schema.getTableName(), schema); ⑥
}
LOG.info("Enabling table...");
admin.enableTable(schema.getTableName());
LOG.info("Table enabled");
getTable(schema.getTableName(), false);
LOG.info("Table changed");
} else {
    LOG.info("No changes detected!");
}
} else {
    LOG.info("Creating table " + schema.getNameAsString() +
"...");
    admin.createTable(schema); ⑦
    LOG.info("Table created");
}
}

```

- ① Compute the differences between the XML based schema and what is currently in HBase.
- ② See if there are any differences in the column and table definitions.
- ③ Alter the columns that have changed. The table was properly disabled first.
- ④ Add newly defined columns.
- ⑤ Delete removed columns.
- ⑥ Alter the table itself, if there are any differences found.
- ⑦ In case the table did not exist yet create it now.

Cluster Operations

After the operations for the namespace, table, and column family schemas within a table, there are a list of methods provided by the Admin implementation for operations on the regions and tables them-

selves. They are used much more from an operator's point of view, as opposed to the schema functions, which will very likely be used by the application developer. The cluster operations split into *region*, *table*, and *server* operations, and we will discuss them in that order.

Region Operations

First are the region-related calls, that is, those concerned with the state of a region. (to come) has the details on regions and their life cycle. Also, recall the details about the server and region name in “[Server and Region Names](#)” (page 356), as many of the calls below will need one or the other.

Many of the following operations are for advanced users, so please handle with care.

`List<HRegionInfo> getOnlineRegions(final ServerName sn)`

Often you need to get a list of regions before operating on them, and one way to do that is this method, which returns all regions hosted by a given server.

```
void closeRegion(final String regionname, final String
serverName)
void closeRegion(final byte[] regionname, final String
serverName)
boolean closeRegionWithEncodedRegionName(final String en
codedRegionName, final String serverName)
void closeRegion(final ServerName sn, final HRegionInfo
hri)
```

Use these calls to close regions that have previously been deployed to region servers. Any enabled table has all regions enabled, so you could actively close and undeploy one of those regions.

You need to supply the exact regionname as stored in the system tables. Further, you may optionally supply the `serverName` parameter, that overrides the server assignment as found in the system tables as well. Some of the calls want the full name in text form, others the hash only, while yet another is asking for objects encapsulating the details.

Using this close call does bypass any master notification, that is, the region is directly closed by the region server, unseen by the master node.

```
void flush(final TableName tableName)
void flushRegion(final byte[] regionName)
```

As updates to a region (and the table in general) accumulate the MemStore instances of the region servers fill with unflushed modifications. A client application can use these synchronous methods to flush such pending records to disk, before they are implicitly written by hitting the memstore flush size (see “[Table Properties](#)” ([page 358](#)) at a later time.

There is a method for flushing all regions of a given table, named `flush()`, and another to flush a specific region, called `flushRegion()`.

```
void compact(final TableName tableName)
void compact(final TableName tableName, final byte[] columnFamily)
void compactRegion(final byte[] regionName)
void compactRegion(final byte[] regionName, final byte[] columnFamily)
void compactRegionServer(final ServerName sn, boolean major)
```

As storage files accumulate the system is compacting them in the background to keep the number of files low. With these calls you can explicitly trigger the same operation for an entire server, a table, or one specific region. When you specify a column family name, then the operation is applied to that family only. Setting the `major` parameter to `true` promotes the region server-wide compaction to a major one.

The call itself is asynchronous, as compactions can potentially take a long time to complete. Invoking these methods queues the table(s), region(s), or column family for compaction, which is executed in the background by the server hosting the named region, or by all servers hosting any region of the given table (see “[Auto-Sharding](#)” ([page 26](#)) for details on compactations).

```
CompactionState getCompactionState(final TableName tableName)
CompactionState getCompactionStateForRegion(final byte[] regionName)
```

These are a continuation from the above, available to query the status of a running compaction process. You either ask the status for an entire table, or a specific region.

```
void majorCompact(TableName tableName)
void majorCompact(TableName tableName, final byte[] col
```

```
umnFamily)
void majorCompactRegion(final byte[] regionName)
void majorCompactRegion(final byte[] regionName, final
byte[] columnFamily)
```

These are the same as the `compact()` calls, but they queue the column family, region, or table, for a major compaction instead. In case a table name is given, the administrative API iterates over all regions of the table and invokes the compaction call implicitly for each of them.

```
void split(final TableName tableName)
void split(final TableName tableName, final byte[] split
Point)
void splitRegion(final byte[] regionName)
void splitRegion(final byte[] regionName, final byte[]
splitPoint)
```

Using these calls allows you to split a specific region, or table. In case of the table-scoped call, the system iterates over all regions of that table and implicitly invokes the `split` command on each of them.

A noted exception to this rule is when the `splitPoint` parameter is given. In that case, the `split()` command will try to split the given region at the provided row key. In the case of using the table-scope call, all regions are checked and the one containing the `splitPoint` is split at the given key.

The `splitPoint` must be a valid row key, and—in case you use the region specific method—be part of the region to be split. It also must be greater than the region's start key, since splitting a region at its start key would make no sense. If you fail to give the correct row key, the split request is ignored without reporting back to the client. The region server currently hosting the region will log this locally with the following message:

```
2015-04-12 20:39:58,077 ERROR [PriorityRpcServer.han-
dler=4,queue=0,port=62255]
regionserver.HRegion: Ignoring invalid split
org.apache.hadoop.hbase.regionserver.WrongRegionException: Re-
quested row out
of range for calculated split on HRegion testtable.,
1428863984023.
2d729d711208b37629baf70b5f17169c., startKey='', getEnd-
Key()='ABC', row='ZZZ'
at org.apache.hadoop.hbase.regionserver.HRegion.check-
Row(HRegion.java)
```

```
void mergeRegions(final byte[] encodedNameOfRegionA, final byte[] encodedNameOfRegionB, final boolean forcible)
```

This method allows you to merge previously split regions. The operation usually requires adjacent regions to be specified, but setting the `forcible` flag to `true` overrides this safety latch.

```
void assign(final byte[] regionName)
void unassign(final byte[] regionName, final boolean force)
void offline(final byte[] regionName)
```

When a client requires a region to be deployed or undeployed from the region servers, it can invoke these calls. The first would assign a region, based on the overall assignment plan, while the second would unassign the given region, triggering a subsequent automatic assignment. The third call allows you to offline a region, that is, leave it unassigned after the call.

The `force` parameter set to `true` for `unassign()` means that a region already marked to be unassigned—for example, from a previous call to `unassign()`--is forced to be unassigned again. If `force` were set to `false`, this would have no effect.

```
void move(final byte[] encodedRegionName, final byte[] destServerName)
```

Using the `move()` call enables a client to actively control which server is hosting what regions. You can move a region from its current region server to a new one. The `destServerName` parameter can be set to `null` to pick a new server at random; otherwise, it must be a valid server name, running a region server process. If the server name is wrong, or currently not responding, the region is deployed to a different server instead. In a worst-case scenario, the move could fail and leave the region unassigned.

The `destServerName` must comply with the rules explained in “[Server and Region Names](#)” (page 356), that is, it must have a hostname, port, and timestamp component.

```
boolean setBalancerRunning(final boolean on, final boolean synchronous)
boolean balancer()
```

The first method allows you to switch the region balancer on or off. When the balancer is enabled, a call to `balancer()` will start the process of moving regions from the servers, with more deployed to those with less deployed regions. (to come) explains how this works in detail.

The `synchronous` flag allows to run the operation in said mode, or in asynchronous mode when supplying `false`.

Example 5-15 assembles many of the above calls to showcase the administrative API and its ability to modify the data layout within the cluster.

Example 5-15. Shows the use of the cluster operations

```
Connection connection = ConnectionFactory.createConnection(conf);
Admin admin = connection.getAdmin();

TableName tableName = TableName.valueOf("testtable");
HColumnDescriptor coldef1 = new HColumnDescriptor("colfam1");
HTableDescriptor desc = new HTableDescriptor(tableName)
    .addFamily(coldef1)
    .setValue("Description", "Chapter 5 - ClusterOperationExample");
byte[][][] regions = new byte[][][] { Bytes.toBytes("ABC"),
    Bytes.toBytes("DEF"), Bytes.toBytes("GHI"), Bytes.to-
Bytes("KLM"),
    Bytes.toBytes("OPQ"), Bytes.toBytes("TUV")
};
admin.createTable(desc, regions); ①

BufferedMutator mutator = connection.getBufferedMutator(table-
Name);
for (int a = 'A'; a <= 'Z'; a++)
    for (int b = 'A'; b <= 'Z'; b++)
        for (int c = 'A'; c <= 'Z'; c++) {
            String row = Character.toString((char) a) +
                Character.toString((char) b) + Character.toString((char)
c); ②
            Put put = new Put(Bytes.toBytes(row));
            put.addColumn(Bytes.toBytes("colfam1"), Bytes.to-
Bytes("col1"),
                Bytes.toBytes("val1"));
            System.out.println("Adding row: " + row);
            mutator.mutate(put);
        }
mutator.close();

List<HRegionInfo> list = admin.getTableRegions(tableName);
int numRegions = list.size();
HRegionInfo info = list.get(numRegions - 1);
System.out.println("Number of regions: " + numRegions); ③
System.out.println("Regions: ");
printRegionInfo(list);

    System.out.println("Splitting region: " + info.getRegionNameAs-
String());
    admin.splitRegion(info.getRegionName()); ④
do {
```

```

list = admin.getTableRegions(tableName);
Thread.sleep(1 * 1000L);
System.out.print(".");
} while (list.size() <= numRegions); ⑤
numRegions = list.size();
System.out.println();
System.out.println("Number of regions: " + numRegions);
System.out.println("Regions: ");
printRegionInfo(list);

System.out.println("Retrieving region with row ZZZ..."); 
RegionLocator locator = connection.getRegionLocator(tableName);
HRegionLocation location =
    locator.getRegionLocation(Bytes.toBytes("ZZZ")); ⑥
System.out.println("Found cached region: " +
    location.getRegionInfo().getRegionNameAsString());
location = locator.getRegionLocation(Bytes.toBytes("ZZZ"), true);
System.out.println("Found refreshed region: " +
    location.getRegionInfo().getRegionNameAsString());

List<HRegionInfo> online =
    admin.getOnlineRegions(location.getServerName());
online = filterTableRegions(online, tableName);
int numOnline = online.size();
System.out.println("Number of online regions: " + numOnline);
System.out.println("Online Regions: ");
printRegionInfo(online);

HRegionInfo offline = online.get(online.size() - 1);
System.out.println("Offlining region: " + offline.getRegionNameAs-
String());
admin.offline(offline.getRegionName()); ⑦
int revs = 0;
do {
    online = admin.getOnlineRegions(location.getServerName());
    online = filterTableRegions(online, tableName);
    Thread.sleep(1 * 1000L);
    System.out.print(".");
    revs++;
} while (online.size() <= numOnline && revs < 10);
numOnline = online.size();
System.out.println();
System.out.println("Number of online regions: " + numOnline);
System.out.println("Online Regions: ");
printRegionInfo(online);

HRegionInfo split = online.get(0); ⑧
System.out.println("Splitting region with wrong key: " + split.ge-
tRegionNameAsString());
        admin.splitRegion(split.getRegionName(), Bytes.to-
Bytes("ZZZ")); // triggers log message

```

```

        System.out.println("Assigning region: " + offline.getRegionNameAs-
String());
        admin.assign(offline.getRegionName()); ⑨
        revs = 0;
        do {
            online = admin.getOnlineRegions(location.getServerName());
            online = filterTableRegions(online, tableName);
            Thread.sleep(1 * 1000L);
            System.out.print(".");
            revs++;
        } while (online.size() == numOnline && revs < 10);
        numOnline = online.size();
        System.out.println();
        System.out.println("Number of online regions: " + numOnline);
        System.out.println("Online Regions: ");
        printRegionInfo(online);

        System.out.println("Merging regions...");
        HRegionInfo m1 = online.get(0);
        HRegionInfo m2 = online.get(1);
        System.out.println("Regions: " + m1 + " with " + m2);
        admin.mergeRegions(m1.getEncodedNameAsBytes(), ⑩
            m2.getEncodedNameAsBytes(), false);
        revs = 0;
        do {
            list = admin.getTableRegions(tableName);
            Thread.sleep(1 * 1000L);
            System.out.print(".");
            revs++;
        } while (list.size() >= numRegions && revs < 10);
        numRegions = list.size();
        System.out.println();
        System.out.println("Number of regions: " + numRegions);
        System.out.println("Regions: ");
        printRegionInfo(list);
    }
}

```

- ① Create a table with seven regions, and one column family.
- ② Insert many rows starting from “AAA” to “ZZZ”. These will be spread across the regions.
- ③ List details about the regions.
- ④ Split the last region this table has, starting at row key “TUV”. Adds a new region starting with key “WEI”.
- ⑤ Loop and check until the operation has taken effect.
- ⑥ Retrieve region infos cached and refreshed to show the difference.
- ⑦ Offline a region and print the list of all regions.

- ⑧ Attempt to split a region with a split key that does not fall into boundaries. Triggers log message.
- ⑨ Reassign the offline region.
- ⑩ Merge the first two regions. Print out result of operation.

Table Operations: Snapshots

The second set of cluster operations revolve around the actual tables. These are low-level tasks that can be invoked from the administrative API and be applied to the entire given table. The primary purpose is to archive the current state of a table, referred to as *snapshots*. Here are the admin API methods to create a snapshot for a table:

```
void snapshot(final String snapshotName, final TableName tableName)
void snapshot(final byte[] snapshotName, final TableName tableName)
void snapshot(final String snapshotName, final TableName tableName,
             Type type)
void snapshot(SnapshotDescription snapshot)
SnapshotResponse takeSnapshotAsync(SnapshotDescription snapshot)
boolean isSnapshotFinished(final SnapshotDescription snapshot)
```

You need to supply a unique name for each snapshot, following the same rules as enforced for table names. This is caused by snapshots being stored in the underlying file system the same way as tables are, though in a specific location (see (to come) for details). For example, you could make use of the `TableName.isLegalTableQualifierName()` method to verify if a given snapshot name is matching the requirements. In addition, you have to name the table you want to perform the snapshots on.

Besides the obvious snapshot calls asking for name and table, there are a few more involved ones. The third call in the list above allows you hand in another parameter, called `type`. It specifies the type of snapshot you want to create, with these choices being available:

Table 5-7. Choices available for snapshot types

Type	Table State	Description
FLUSH	Enabled	This is the default and is used to force a <i>flush</i> operation on online tables before the snapshot is taken.
SKIPFLUSH	Enabled	If you do not want to cause a <i>flush</i> to occur, you can use this option to immediately snapshot all persisted files of a table.
DISABLED	Disabled	This option is not for normal use, but might be returned if a snapshot was created on a disabled table.

The same enumeration is used for the objects returned by the `listSnapshot()` call, that is why the `DISABLED` value is a possible snapshot type: it depends when you take the snapshot, that is, if the snapshotted table is enabled or disabled at that time. And obviously, if you hand in a type of `FLUSH` or `SKIPFLUSH` on a disabled table they will have no effect. On the contrary, the snapshot will go through and is listed as `DISABLED` no matter what you have specified.

Once you have created one or more snapshot, you are able to retrieve a list of the available snapshots using the following methods:

```
List<SnapshotDescription> listSnapshots()
List<SnapshotDescription> listSnapshots(String regex)
List<SnapshotDescription> listSnapshots(Pattern pattern)
```

The first call lists all snapshots stored, while the other two filter the list based on a regular expression pattern. The output looks similar to this, but of course depends on your cluster and what has been snapshotted so far:

```
[name: "snapshot1"
table: "testtable"
creation time: 1428924867254
type: FLUSH
version: 2
, name: "snapshot2"
table: "testtable"
creation_time: 1428924870596
type: DISABLED
version: 2]
```

Highlighted are the discussed *types* of each snapshot. The `listSnapshots()` calls return a list of `SnapshotDescription` instances, which give access to the snapshot details. There are the obvious `getName()` and `getTable()` methods to return the snapshot and table name. In addition, you can use `getType()` to get access to the highlighted snapshot type, and `getCreationTime()` to retrieve the timestamp when the snapshot was created. Lastly, there is `getVersion()` returning the internal format version of the snapshot. This number is used to read older snapshots with newer versions of HBase, so expect this number to increase over time with major version of HBase. The description class has a few more getters for snapshot details, such as the amount of storage it consumes, and convenience methods to retrieve the described information in other formats.

When it is time to restore a previously taken snapshot, you need to call one of these methods:

```
void restoreSnapshot(final byte[] snapshotName)
void restoreSnapshot(final String snapshotName)
```

```

void restoreSnapshot(final byte[] snapshotName,
    final boolean takeFailSafeSnapshot)
void restoreSnapshot(final String snapshotName,
    boolean takeFailSafeSnapshot)

```

Analogous, you specify a snapshot name, and the table is recreated with the data contained in the snapshot. Before you can run a *restore* operation on a table though, you need to *disable* it first. The restore operation is essentially a drop operation, followed by a recreation of the table with the archived data. You need to provide the table name either as a string, or as a byte array. Of course, the snapshot has to exist, or else you will receive an error.

The optional `takeFailSafeSnapshot` flag, set to `true`, will instruct the servers to *first* perform a snapshot of the specified table, *before* restoring the saved one. Should the restore operation fail, the failsafe snapshot is restored instead. On the other hand, if the restore operation completes successfully, then the failsafe snapshot is removed at the end of the operation. The name of the failsafe snapshot is specified using the `hbase.snapshot.restore.failsafe.name` configuration property, and defaults to `hbase-failsafe-{snapshot.name}-{restore.timestamp}`. The possible variables you can use in the name are:

Variable	Description
{snapshot.name}	The name of the snapshot.
{table.name}	The name of the table the snapshot represents.
{restore.timestamp}	The timestamp when the snapshot is taken.

The default value for the failsafe name ensures that the snapshot is uniquely named, by adding the name of the snapshot that triggered its creation, plus a timestamp. There should be no need to modify this to something else, but if you want to you can use the above pattern and configuration property.

You can also *clone* a snapshot, which means you are recreating the table under a new name:

```

void cloneSnapshot(final byte[] snapshotName, final TableName ta-
bleName)
void cloneSnapshot(final String snapshotName, final TableName ta-
bleName)

```

Again, you specify the snapshot name in one or another form, but also supply a new table name. The snapshot is restored in the newly named table, like a restore would do for the original table.

Finally, removing a snapshot is accomplished using these calls:

```
void deleteSnapshot(final byte[] snapshotName)
void deleteSnapshot(final String snapshotName)
void deleteSnapshots(final String regex)
void deleteSnapshots(final Pattern pattern)
```

Like with the delete calls for tables, you can either specify an exact snapshot by name, or you can apply a regular expression to remove more than one in a single call. Just as before, be very careful what you hand in, there is no coming back from this operation (as in, there is *no* undo)! [Example 5-16](#) runs these commands across a single original table, that contains a single row only, named "row1":

Example 5-16. Example showing the use of the admin snapshot API

```
admin.snapshot("snapshot1", tableName); ❶

List<HBaseProtos.SnapshotDescription> snaps = admin.listSnapshots();
System.out.println("Snapshots after snapshot 1: " + snaps);

Delete delete = new Delete(Bytes.toBytes("row1"));
    delete.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual1")); ❷
table.delete(delete);

admin.snapshot("snapshot2", tableName,
    HBaseProtos.SnapshotDescription.Type.SKIPFLUSH);
admin.snapshot("snapshot3", tableName,
    HBaseProtos.SnapshotDescription.Type.FLUSH);

snaps = admin.listSnapshots();
System.out.println("Snapshots after snapshot 2 & 3: " + snaps);

Put put = new Put(Bytes.toBytes("row2"))
    .addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("qual10"),
        Bytes.toBytes("val10")); ❸
table.put(put);

HBaseProtos.SnapshotDescription snapshotDescription =
    HBaseProtos.SnapshotDescription.newBuilder()
        .setName("snapshot4")
        .setTable(tableName.getNameAsString())
        .build();
admin.takeSnapshotAsync(snapshotDescription);

snaps = admin.listSnapshots();
System.out.println("Snapshots before waiting: " + snaps);

System.out.println("Waiting...");
while (!admin.isSnapshotFinished(snapshotDescription)) { ❹
    Thread.sleep(1 * 1000);
```

```

        System.out.print(".");
    }
    System.out.println();
    System.out.println("Snapshot completed.");
    snaps = admin.listSnapshots();
    System.out.println("Snapshots after waiting: " + snaps);

    System.out.println("Table before restoring snapshot 1");
    helper.dump("testtable", new String[]{"row1", "row2"}, null,
null);

    admin.disableTable(tableName);
    admin.restoreSnapshot("snapshot1"); ⑤
    admin.enableTable(tableName);

    System.out.println("Table after restoring snapshot 1");
    helper.dump("testtable", new String[]{"row1", "row2"}, null,
null);

    admin.deleteSnapshot("snapshot1"); ⑥
    snaps = admin.listSnapshots();
    System.out.println("Snapshots after deletion: " + snaps);

    admin.cloneSnapshot("snapshot2", TableName.valueOf("testtable2"));
    System.out.println("New table after cloning snapshot 2");
    helper.dump("testtable2", new String[]{"row1", "row2"}, null,
null);
    admin.cloneSnapshot("snapshot3", TableName.valueOf("testta-
ble3")); ⑦
    System.out.println("New table after cloning snapshot 3");
    helper.dump("testtable3", new String[]{"row1", "row2"}, null,
null);

```

- ① Create a snapshot of the initial table, then list all available snapshots next.
- ② Remove one column and do two more snapshots, one without first flushing, then another with a preceding flush.
- ③ Add a new row to the table and take yet another snapshot.
- ④ Wait for the asynchronous snapshot to complete. List the snapshots before and after the waiting.
- ⑤ Restore the first snapshot, recreating the initial table. This needs to be done on a disabled table.
- ⑥ Remove the first snapshot, and list the available ones again.
- ⑦ Clone the second and third snapshot into a new table, dump the content to show the difference between the “skipflush” and “flush” types.

The output (albeit a bit lengthy) reveals interesting things, please keep an eye out for snapshot number #2 and #3:

```
Before snapshot calls...
Cell: row1/colfam1:qual1/2/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
...
Cell: row1/colfam2:qual3/6/Put/vlen=4/seqid=0, Value: val3
Cell: row1/colfam2:qual3/5/Put/vlen=4/seqid=0, Value: val3

Snapshots after snapshot 1: [name: "snapshot1"
table: "testtable"
creation_time: 1428918198629
type: FLUSH
version: 2
]

Snapshots after snapshot 2 & 3: [name: "snapshot1"
table: "testtable"
creation_time: 1428918198629
type: FLUSH
version: 2
, name: "snapshot2"
table: "testtable"
creation_time: 1428918200818
type: SKIPFLUSH
version: 2
, name: "snapshot3"
table: "testtable"
creation_time: 1428918200931
type: FLUSH
version: 2
]

Snapshots before waiting: [name: "snapshot1"
table: "testtable"
creation_time: 1428918198629
type: FLUSH
version: 2
, name: "snapshot2"
table: "testtable"
creation_time: 1428918200818
type: SKIPFLUSH
version: 2
, name: "snapshot3"
table: "testtable"
creation_time: 1428918200931
type: FLUSH
version: 2
]

Waiting...
```

```

.
Snapshot completed.
Snapshots after waiting: [name: "snapshot1"
table: "testtable"
creation_time: 1428918198629
type: FLUSH
version: 2
, name: "snapshot2"
table: "testtable"
creation_time: 1428918200818
type: SKIPFLUSH
version: 2
, name: "snapshot3"
table: "testtable"
creation_time: 1428918200931
type: FLUSH
version: 2
, name: "snapshot4"
table: "testtable"
creation_time: 1428918201570
version: 2
]

Table before restoring snapshot 1
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual2/4/Put/vlen=4/seqid=0, Value: val2
...
Cell: row1/colfam2:qual3/5/Put/vlen=4/seqid=0, Value: val3
Cell: row2/colfam1:qual10/1428918201565/Put/vlen=5/seqid=0, Value: val10

Table after restoring snapshot 1
Cell: row1/colfam1:qual1/2/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
...
Cell: row1/colfam2:qual3/6/Put/vlen=4/seqid=0, Value: val3
Cell: row1/colfam2:qual3/5/Put/vlen=4/seqid=0, Value: val3

Snapshots after deletion: [name: "snapshot2"
table: "testtable"
creation_time: 1428918200818
type: SKIPFLUSH
version: 2
, name: "snapshot3"
table: "testtable"
creation_time: 1428918200931
type: FLUSH
version: 2
, name: "snapshot4"
table: "testtable"
creation_time: 1428918201570
version: 2

```

```

]

New table after cloning snapshot 2
Cell: row1/colfam1:qual1/2/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual2/4/Put/vlen=4/seqid=0, Value: val2
...
Cell: row1/colfam2:qual3/6/Put/vlen=4/seqid=0, Value: val3
Cell: row1/colfam2:qual3/5/Put/vlen=4/seqid=0, Value: val3

New table after cloning snapshot 3
Cell: row1/colfam1:qual1/1/Put/vlen=4/seqid=0, Value: val1
Cell: row1/colfam1:qual2/4/Put/vlen=4/seqid=0, Value: val2
Cell: row1/colfam1:qual2/3/Put/vlen=4/seqid=0, Value: val2
...
Cell: row1/colfam2:qual3/6/Put/vlen=4/seqid=0, Value: val3
Cell: row1/colfam2:qual3/5/Put/vlen=4/seqid=0, Value: val3

```

Since we performed snapshot #2 while *skipping* flushes, we do not see the preceding delete being applied: the delete has been applied to the WAL and memstore, but not the store files yet. Snapshot #3 does the same snapshot, but *forces* the flush to occur beforehand. The output in `testtable2` and `testtable3` confirm that the former still contains the deleted data, and the latter does not.

Some parting notes on snapshots:

- You can only have one snapshot or restore in progress per table. In other words, if you have two separate tables, you can snapshot them at the same time, but you cannot run two concurrent snapshots on the same table—or run a snapshot while a restore is in progress. The second operation would fail with an error message (for example: "Rejected taking <snapshotname> because we are already running another snapshot...").
- You can increase the snapshot concurrency from the default of 1 by setting a higher value with the `hbase.snapshot.master.threads` configuration property. The default means only one snapshot operation runs at any given time in the entire cluster. Subsequent operations would be queued and executed sequentially.
- Turning off snapshot support for the entire cluster is handled by `hbase.snapshot.enabled`. It is set to true, that is, snapshot support is enabled on a cluster installed with default values.

Server Operations

The third group of methods provided by the Admin interface address the entire cluster. They are either generic calls, or very low-level operations, so please again, be very careful with what you are doing.

`ClusterStatus getClusterStatus()`

The `getClusterStatus()` call allows you to retrieve an instance of the `ClusterStatus` class, containing detailed information about the cluster status. See “[Cluster Status Information](#)” (page 411) for what you are provided with.

`Configuration getConfiguration()`

`void updateConfiguration(ServerName server)`

`void updateConfiguration()`

These calls allow the application to access the current configuration, and to reload that configuration from disk. The latter is done for either all servers, when no parameter is specified, or one given server only. You need to provide a server name, as discussed throughout this chapter. Not all configuration properties are supported as reloadable during the runtime of the servers. See (to come) for a list of those that can be reloaded.

Using the `getConfiguration()` gives access to the client configuration instance, that is, what was loaded, or set later on, from disk. Since HBase is a distributed system it is very likely that the client-side settings are not the same as the server-side ones. And using any of the `set()` methods of the returned `Configuration` instance is just modifying the client-side settings. If you want to update the servers, you need to deploy an updated `hbase-site.xml` to the servers and invoke the `updateConfiguration()` call instead.

`int getMasterInfoPort()`

Returns the current web-UI port of the HBase Master. This value is set with the `hbase.master.info.port` property, but might be dynamically reassigned when the server starts.

`int getOperationTimeout()`

Returns the value set with the `hbase.client.operation.timeout` property. It defines how long the client should wait for the servers to respond, and defaulting to `Integer.MAX_VALUE`, that is, indefinitely.

`void rollWALWriter(ServerName serverName)`

Instructs the named server to close the current WAL file and create a new one.

```
boolean enableCatalogJanitor(boolean enable)
int runCatalogScan()
boolean isCatalogJanitorEnabled()
```

The HBase Master process runs a background housekeeping task, the *catalog janitor*, which is responsible to clean up region operation remnants. For example, when a region splits or is merged, the janitor will clean up the left-over region details, including meta data and physical files. By default, the task runs on every standard cluster. You can use these calls to stop that task to run, invoke a run manually with `runCatalogScan()`, and check the status of the task.

```
String[] getMasterCoprocessors()
CoprocessorRpcChannel coprocessorService()
CoprocessorRpcChannel coprocessorService(ServerName sn)
```

Provides access to the list of coprocessors loaded into the master process, and the RPC channel (which is derived from a Protobuf superclass) for the active master, when not providing any parameter, or a given region server. See “[Coprocessors](#)” (page 282), and especially “[The Service Interface](#)” (page 299), on how to make use of the RPC endpoint.

```
void execProcedure(String signature, String instance,
Map<String, String> props)
byte[] execProcedureWithRet(String signature, String instance,
Map<String, String> props)
boolean isProcedureFinished(String signature, String instance,
Map<String, String> props)
```

HBase has a server-side *procedure* framework, which is used by, for example, the master to distribute an operation across many or all region servers. If a flush is triggered, the procedure representing the flush operation is started on the cluster. There are calls to do this as a one-off call, or with a built-in retry mechanism. The latter call allows to retrieve the status of a procedure that was started beforehand.

```
void shutdown()
void stopMaster()
void stopRegionServer(final String hostnamePort)
```

These calls either shut down the entire cluster, stop the master server, or stop a particular region server only. Once invoked, the affected servers will be stopped, that is, there is no delay nor a way to revert the process.

Chapters (to come) and (to come) have more information on these advanced—yet very powerful—features. Use with utmost care!

Cluster Status Information

When you query the cluster status using the `Admin.getClusterStatus()` call, you will be given a `ClusterStatus` instance, containing all the information the master server has about the current state of the cluster. [Table 5-8](#) lists the methods of the `ClusterStatus` class.

Table 5-8. Overview of the information provided by the ClusterStatus class

Method	Description
<code>getAverageLoad()</code>	The total average number of regions per region server. This is computed as <i>number of regions/number of servers</i> .
<code>getBackupMasters()</code>	Returns the list of all known backup HBase Master servers.
<code>getBackupMastersSize()</code>	The size of the list of all known backup masters.
<code>getBalancerOn()</code>	Provides access to the internal Boolean instance, reflecting the balancer tasks status. Might be <code>null</code> .
<code>getClusterId()</code>	Returns the unique identifier for the cluster. This is a UUID generated when HBase starts with an empty storage directory. It is stored in <code>hbase.id</code> under the HBase root directory.
<code>getDeadServerNames()</code>	A list of all server names currently considered dead. The names in the collection are <code>ServerName</code> instances, which contain the hostname, RPC port, and start code.
<code>getDeadServers()</code>	The number of servers listed as dead. This does not contain the live servers.
<code>getHBaseVersion()</code>	Returns the HBase version identification string.
<code>getLoad(ServerName sn)</code>	Retrieves the status information available for the given server name.
<code>getMaster()</code>	The server name of the current master.
<code>getMasterCoprocessors()</code>	A list of all loaded master coprocessors.
<code>getRegionsCount()</code>	The total number of regions in the cluster.
<code>getRegionsInTransition()</code>	Gives you access to a map of all regions currently in transition, e.g., being moved, assigned, or unassigned. The key of the map is the encoded region name (as returned by <code>HRegionInfo.getEncodedName()</code> , for example), while the value is an instance of <code>RegionState</code> . ^a
<code>getRequestsCount()</code>	The current number of requests across all region servers in the cluster.
<code>getServers()</code>	The list of live servers. The names in the collection are <code>ServerName</code> instances, which contain the hostname, RPC port, and start code.

Method	Description
getServersSize()	The number of region servers currently live as known to the master server. The number does not include the number of dead servers.
getVersion()	Returns the format version of the ClusterStatus instance. This is used during the serialization process of sending an instance over RPC.
isBalancerOn()	Returns true if the balancer task is enabled on the master.
toString()	Converts the entire cluster status details into a string.

^a See (to come) for the details.

Accessing the overall cluster status gives you a high-level view of what is going on with your servers—as a whole. Using the getServers() array, and the returned ServerName instances, lets you drill further into each actual live server, and see what it is doing currently. See “[Server and Region Names](#)” (page 356) again for details on the ServerName class.

Each server, in turn, exposes details about its load, by offering a ServerLoad instance, returned by the getLoad() method of the Cluster Status instance. Using the aforementioned ServerName, as returned by the getServers() call, you can iterate over all live servers and retrieve their current details. The ServerLoad class gives you access to not just the load of the server itself, but also for each hosted region. [Table 5-9](#) lists the provided methods.

Table 5-9. Overview of the information provided by the ServerLoad class

Method	Description
getCurrentCompactedKVs()	The number of cells that have been compacted, while compactions are running.
getInfoServerPort()	The web-UI port of the region server.
getLoad()	Currently returns the same value as getNumberofRegions().
getMaxHeapMB()	The configured maximum Java Runtime heap size in megabytes.
getMemStoreSizeInMB()	The total size of the in-memory stores, across all regions hosted by this server.
getNumberofRegions()	The number of regions on the current server.
getNumberofRequests()	Returns the accumulated number of requests, and counts all API requests, such as gets, puts, increments, deletes, and so on. ^a
getReadRequestsCount()	The sum of all read requests for all regions of this server. ^a

Method	Description
getRegionServerCoprocessors()	The list of loaded coprocessors, provided as a string array, listing the class names.
getRegionsLoad()	Returns a map containing the load details for each hosted region of the current server. The key is the region name and the value an instance of the RegionsLoad class, discussed next.
getReplicationLoadSink()	If replication is enabled, this call returns an object with replication statistics.
getReplicationLoadSourceList()	If replication is enabled, this call returns a list of objects with replication statistics.
getRequestsPerSecond()	Provides the computed requests per second value, accumulated for the entire server.
getRootIndexSizeKB()	The summed up size of all root indexes, for every storage file, the server holds in memory.
getRsCoprocessors()	The list of coprocessors in the order they were loaded. Should be equal to getRegionServerCoprocessors().
getStorefileIndexSizeInMB()	The total size in megabytes of the indexes—the block and meta index, to be precise—across all store files in use by this server.
getStorefiles()	The number of store files in use by the server. This is across all regions it hosts.
getStorefileSizeInMB()	The total size in megabytes of the used store files.
getStores()	The total number of stores held by this server. This is similar to the number of all column families across all regions.
getStoreUncompressedSizeMB()	The raw size of the data across all stores in megabytes.
getTotalCompactingKVs()	The total number of cells currently compacted across all stores.
getTotalNumberOfRequests()	Returns the total number of all requests received by this server. ^a
getTotalStaticBloomSizeKB()	Specifies the combined size occupied by all Bloom filters in kilobytes.
getTotalStaticIndexSizeKB()	Specifies the combined size occupied by all indexes in kilobytes.
getUsedHeapMB()	The currently used Java Runtime heap size in megabytes, if available.
getWriteRequestsCount()	The sum of all read requests for all regions of this server. ^a
hasMaxHeapMB()	Check if the value with same name is available during the accompanying getxyz() call.

Method	Description
hasNumberOfRequests()	Check if the value with same name is available during the accompanying getxyz() call.
hasTotalNumberOfRequests()	Check if the value with same name is available during the accompanying getxyz() call.
hasUsedHeapMB()	Check if the value with same name is available during the accompanying getxyz() call.
obtainServerLoadPB()	Returns the low-level Protobuf version of the current server load instance.
toString()	Converts the state of the instance with all above metrics into a string for logging etc.

^a Accumulated within the last hbase.regionserver.metrics.period

Finally, there is a dedicated class for the region load, aptly named RegionLoad. See [Table 5-10](#) for the list of provided information.

Table 5-10. Overview of the information provided by the Region Load class

Method	Description
getCompleteSequenceId()	Returns the last completed sequence ID for the region, used in conjunction with the MVCC.
getCurrentCompactedKVs()	The currently compacted cells for this region, while a compaction is running.
getDataLocality()	A ratio from 0 to 1 (0% to 100%) expressing the locality of store files to the region server process.
getMemStoreSizeMB()	The heap size in megabytes as used by the MemStore of the current region.
getName()	The region name in its raw, byte[] byte array form.
getNameAsString()	Converts the raw region name into a String for convenience.
getReadRequestsCount()	The number of read requests for this region, since it was deployed to the region server. This counter is not reset.
getRequestsCount()	The number of requests for the current region.
getRootIndexSizeKB()	The sum of all root index details help in memory for this region, in kilobytes.
getStorefileIndexSizeMB()	The size of the indexes for all store files, in megabytes, for this region.
getStorefiles()	The number of store files, across all stores of this region.
getStorefileSizeMB()	The size in megabytes of the store files for this region.
getStores()	The number of stores in this region.

Method	Description
getStoreUncompressedSizeMB()	The size of all stores in megabyte, before compression.
getTotalCompactingKVs()	The count of all cells being compacted within this region.
getTotalStaticBloomSizeKB()	The size of all Bloom filter data in kilobytes.
getTotalStaticIndexSizeKB()	The size of all index data in kilobytes.
getWriteRequestsCount()	The number of write requests for this region, since it was deployed to the region server. This counter is not reset.
toString()	Converts the state of the instance with all above metrics into a string for logging etc.

[Example 5-17](#) shows all of the getters in action.

Example 5-17. Example reporting the status of a cluster

```
ClusterStatus status = admin.getClusterStatus(); ①

System.out.println("Cluster Status:\n-----");
System.out.println("HBase Version: " + status.getHBaseVersion());
System.out.println("Version: " + status.getVersion());
System.out.println("Cluster ID: " + status.getClusterId());
System.out.println("Master: " + status.getMaster());
System.out.println("No. Backup Masters: " +
    status.getBackupMastersSize());
System.out.println("Backup Masters: " + status.getBackupMasters());

System.out.println("No. Live Servers: " + status.getServerSize());
System.out.println("Servers: " + status.getServers());
System.out.println("No. Dead Servers: " + status.getDeadServers());
System.out.println("Dead Servers: " + status.getDeadServerNames());
System.out.println("No. Regions: " + status.getRegionsCount());
System.out.println("Regions in Transition: " +
    status.getRegionsInTransition());
System.out.println("No. Requests: " + status.getRequestsCount());
System.out.println("Avg Load: " + status.getAverageLoad());
System.out.println("Balancer On: " + status.getBalancerOn());
System.out.println("Is Balancer On: " + status.isBalancerOn());
System.out.println("Master Coprocessors: " +
    Arrays.asList(status.getMasterCoprocessors()));

System.out.println("\nServer Info:\n-----");
for (ServerName server : status.getServers()) { ②
    System.out.println("Hostname: " + server.getHostname());
```

```

System.out.println("Host and Port: " + server.getHostAndPort());
System.out.println("Server Name: " + server.getServerName());
System.out.println("RPC Port: " + server.getPort());
System.out.println("Start Code: " + server.getStartcode());

ServerLoad load = status.getLoad(server); ③

System.out.println("\nServer Load:\n-----");
System.out.println("Info Port: " + load.getInfoServerPort());
System.out.println("Load: " + load.getLoad());
System.out.println("Max Heap (MB): " + load.getMaxHeapMB());
System.out.println("Used Heap (MB): " + load.getUsedHeapMB());
System.out.println("Memstore Size (MB): " +
    load.getMemstoreSizeInMB());
System.out.println("No. Regions: " + load.getNumberOfRegions());
    System.out.println("No. Requests: " + load.getNumberOfRe-
quests());
    System.out.println("Total No. Requests: " +
        load.getTotalNumberOfRequests());
    System.out.println("No. Requests per Sec: " +
        load.getRequestsPerSecond());
    System.out.println("No. Read Requests: " +
        load.getReadRequestsCount());
    System.out.println("No. Write Requests: " +
        load.getWriteRequestsCount());
    System.out.println("No. Stores: " + load.getStores());
    System.out.println("Store Size Uncompressed (MB): " +
        load.getStoreUncompressedSizeMB());
    System.out.println("No. Storefiles: " + load.getStorefiles());
    System.out.println("Storefile Size (MB): " +
        load.getStorefileSizeInMB());
    System.out.println("Storefile Index Size (MB): " +
        load.getStorefileIndexSizeInMB());
    System.out.println("Root Index Size: " + load.getRootIndexSi-
zeKB());
    System.out.println("Total Bloom Size: " +
        load.getTotalStaticBloomSizeKB());
    System.out.println("Total Index Size: " +
        load.getTotalStaticIndexSizeKB());
    System.out.println("Current Compacted Cells: " +
        load.getCurrentCompactedKVs());
    System.out.println("Total Compacting Cells: " +
        load.getTotalCompactingKVs());
    System.out.println("Coprocessors1: " +
        Arrays.asList(load.getRegionServerCoprocessors()));
    System.out.println("Coprocessors2: " +
        Arrays.asList(load.getRsCoprocessors()));
    System.out.println("Replication Load Sink: " +
        load.getReplicationLoadSink());
    System.out.println("Replication Load Source: " +
        load.getReplicationLoadSourceList());

```

```

System.out.println("\nRegion Load:\n-----");
for (Map.Entry<byte[], RegionLoad> entry : ④
    load.getRegionsLoad().entrySet()) {
    System.out.println("Region: " + Bytes.toStringBinary(en-
try.getKey()));
    RegionLoad regionLoad = entry.getValue(); ⑤

    System.out.println("Name: " + Bytes.toStringBinary(
        regionLoad.getName()));
    System.out.println("Name (as String): " +
        regionLoad.getNameAsString());
    System.out.println("No. Requests: " + regionLoad.getRequests-
Count());
    System.out.println("No. Read Requests: " +
        regionLoad.getReadRequestsCount());
    System.out.println("No. Write Requests: " +
        regionLoad.getWriteRequestsCount());
    System.out.println("No. Stores: " + regionLoad.getStores());
    System.out.println("No. Storefiles: " + regionLoad.getStore-
files());
    System.out.println("Data Locality: " + regionLoad.getDataLo-
cality());
    System.out.println("Storefile Size (MB): " +
        regionLoad.getStorefileSizeMB());
    System.out.println("Storefile Index Size (MB): " +
        regionLoad.getStorefileIndexSizeMB());
    System.out.println("Memstore Size (MB): " +
        regionLoad.getMemStoreSizeMB());
    System.out.println("Root Index Size: " +
        regionLoad.getRootIndexSizeKB());
    System.out.println("Total Bloom Size: " +
        regionLoad.getTotalStaticBloomSizeKB());
    System.out.println("Total Index Size: " +
        regionLoad.getTotalStaticIndexSizeKB());
    System.out.println("Current Compacted Cells: " +
        regionLoad.getCurrentCompactedKVs());
    System.out.println("Total Compacting Cells: " +
        regionLoad.getTotalCompactingKVs());
    System.out.println();
}
}

```

- ① Get the cluster status.
- ② Iterate over the included server instances.
- ③ Retrieve the load details for the current server.
- ④ Iterate over the region details of the current server.
- ⑤ Get the load details for the current region.

On a standalone setup, and running the *Performance Evaluation* tool (see (to come)) in parallel, you should see something like this:

```
Cluster Status:  
-----  
HBase Version: 1.0.0  
Version: 2  
Cluster ID: 25ba54eb-09da-4698-88b5-5acdfeccf0005  
Master: srv1.foobar.com,63911,1428996031794  
No. Backup Masters: 0  
Backup Masters: []  
No. Live Servers: 1  
Servers: [srv1.foobar.com,63915,1428996033410]  
No. Dead Servers: 2  
Dead Servers: [srv1.foobar.com,62938,1428669753889, \  
    srv1.foobar.com,60813,1428991052036] ❶  
No. Regions: 7  
Regions in Transition: {}  
No. Requests: 56047  
Avg Load: 7.0  
Balancer On: true  
Is Balancer On: true  
Master Coprocessors: [MasterObserverExample] ❷  
  
Server Info:  
-----  
Hostname: srv1.foobar.com  
Host and Port: srv1.foobar.com:63915  
Server Name: srv1.foobar.com,63915,1428996033410  
RPC Port: 63915  
Start Code: 1428996033410  
  
Server Load:  
-----  
Info Port: 63919  
Load: 7  
Max Heap (MB): 12179  
Used Heap (MB): 1819  
Memstore Size (MB): 651  
No. Regions: 7  
No. Requests: 56047  
Total No. Requests: 14334506  
No. Requests per Sec: 56047.0  
No. Read Requests: 2325  
No. Write Requests: 1239824  
No. Stores: 7  
Store Size Uncompressed (MB): 491  
No. Storefiles: 7  
Storefile Size (MB): 492  
Storefile Index Size (MB): 0  
Root Index Size: 645  
Total Bloom Size: 644
```



```

Region: TestTable,00000000000000000000419430,1429009449882 \
    .08acdaa21909f0085d64c1928afbf144.
Name: TestTable,00000000000000000000419430,1429009449882 \
    .08acdaa21909f0085d64c1928afbf144.
Name          (as      String):           TestTable,
00000000000000000000419430,1429009449882 \
    .08acdaa21909f0085d64c1928afbf144.
No. Requests: 247868
No. Read Requests: 0
No. Write Requests: 247868
No. Stores: 1
No. Storefiles: 1
Data Locality: 1.0
Storefile Size (MB): 101
Storefile Index Size (MB): 0
Memstore Size (MB): 125
Root Index Size: 133
Total Bloom Size: 128
Total Index Size: 80
Current Compacted Cells: 0
Total Compacting Cells: 0

Region: TestTable,00000000000000000000629145,1429009449882 \
    .aaa91cddbfe2ed65bb35620f034f0c66.
Name: TestTable,00000000000000000000629145,1429009449882 \
    .aaa91cddbfe2ed65bb35620f034f0c66.
Name          (as      String):           TestTable,
00000000000000000000629145,1429009449882 \
    .aaa91cddbfe2ed65bb35620f034f0c66.
No. Requests: 247971
No. Read Requests: 0
No. Write Requests: 247971
No. Stores: 1
No. Storefiles: 1
Data Locality: 1.0
Storefile Size (MB): 88
Storefile Index Size (MB): 0
Memstore Size (MB): 151
Root Index Size: 116
Total Bloom Size: 128
Total Index Size: 70
Current Compacted Cells: 0
Total Compacting Cells: 0

Region: TestTable,00000000000000000000838860,1429009449882 \
    .5a4243a8d734836f4818f115370fc089.
Name: TestTable,00000000000000000000838860,1429009449882 \
    .5a4243a8d734836f4818f115370fc089.
Name          (as      String):           TestTable,
00000000000000000000838860,1429009449882 \
    .5a4243a8d734836f4818f115370fc089.
No. Requests: 247453

```

```
No. Read Requests: 0
No. Write Requests: 247453
No. Stores: 1
No. Storefiles: 1
Data Locality: 1.0
Storefile Size (MB): 113
Storefile Index Size (MB): 0
Memstore Size (MB): 99
Root Index Size: 148
Total Bloom Size: 132
Total Index Size: 89
Current Compacted Cells: 0
Total Compacting Cells: 0

Region: hbase:meta,,1
Name: hbase:meta,,1
Name (as String): hbase:meta,,1
No. Requests: 2481
No. Read Requests: 2321
No. Write Requests: 160
No. Stores: 1
No. Storefiles: 1
Data Locality: 1.0
Storefile Size (MB): 0
Storefile Index Size (MB): 0
Memstore Size (MB): 0
Root Index Size: 0
Total Bloom Size: 0
Total Index Size: 0
Current Compacted Cells: 51
Total Compacting Cells: 51

Region: 1428669937904.0cfcd0834931f1aa683c765206e8fc0a.          hbase:namespace,,,
Name: 1428669937904.0cfcd0834931f1aa683c765206e8fc0a.          hbase:namespace,,,
Name (as String): hbase:namespace,,1428669937904 \
.0cfcd0834931f1aa683c765206e8fc0a.
No. Requests: 4
No. Read Requests: 4
No. Write Requests: 0
No. Stores: 1
No. Storefiles: 1
Data Locality: 1.0
Storefile Size (MB): 0
Storefile Index Size (MB): 0
Memstore Size (MB): 0
Root Index Size: 0
Total Bloom Size: 0
Total Index Size: 0
Current Compacted Cells: 0
Total Compacting Cells: 0
```

- ❶ The region server process was restarted and therefore all previous instance are now listed in the dead server list.
- ❷ The example HBase Master coprocessor from earlier is still loaded.
- ❸ In this region all pending cells are compacted (51 out of 51). Other regions have no currently running compactions.
- ❹ Data locality is 100% since only one server is active, since this test was run on a local HBase setup.

The *data locality* for newer regions might return "0.0" because none of the cells have been flushed to disk yet. In general, when no information is available the call will return zero. But eventually you should see the locality value reflect the respective ratio. The servers count all blocks that belong to all store file managed, and divide the ones local to the server by the total number of blocks. For example, if a region has three column families, it has an equal amount of stores, namely three. And if each holds two files with 2 blocks each, that is, four blocks per store, and a total of 12 blocks, then if 6 of these blocks were stored on the same physical node as the region server process, then the ration would 0.5, or 50%. This assumes that the region server is colocated with the HDFS data node, or else the locality would always be zero.

ReplicationAdmin

HBase provides a separate administrative API for all replication purposes. Just to clarify, we are referring here to cluster-to-cluster replication, not the aforementioned region replicas. The internals of cluster replication is explained in (to come), which means that we here are mainly looking at the API side of it. If you want to fully understand the inner workings, or one of the methods is unclear, then please refer to the referenced section.

The class exposes one constructor, which can be used to create a connection to the cluster configured within the supplied configuration instance:

```
ReplicationAdmin(Configuration conf) throws IOException
```

Once you have created the instance, you can use the following methods to set up the replication between the current and remote clusters:

```
void addPeer(String id, String clusterKey) throws ReplicationException
void addPeer(String id, String clusterKey, String tableCFs)
void addPeer(String id, ReplicationPeerConfig peerConfig, Map<Ta-
```

```

bleName,
    ? extends Collection<String>> tableCfs) throws ReplicationException
void removePeer(String id) throws ReplicationException
void enablePeer(String id) throws ReplicationException
void disablePeer(String id) throws ReplicationException
boolean getPeerState(String id) throws ReplicationException

```

A *peer* is a remote cluster as far as the current cluster is concerned. It is referenced by a unique *ID*, which is an arbitrary number, and the *cluster key*. The latter comprises the following details from the peer's configuration:

```
<hbase.zookeeper.quorum>:<hbase.zookeeper.property.client-  
Port>:<zookeeper.znode.parent>
```

An example might be: zk1.foo.com,zk2.foo.com,zk3.foo.com:2181:/hbase. There are three hostnames for the remote ZooKeeper ensemble, the client port they are listening on, and the root path HBase is storing its data in. This implies that the current cluster is able to communicate with the listed remote servers, and the port is not blocked by, for example, a firewall.

Peers can be added or removed, so that replication between clusters are dynamically configurable. Once the relationship is established, the actual replication can be enabled, or disabled, without having to remove the peer details to do so. The `enablePeer()` method starts the replication process, while the `disablePeer()` is stopping it for the named peer. The `getPeerState()` lets you check the current state, that is, is replication to the named peer active or not.

Note that both clusters need additional configuration changes for replication of data to take place. In addition, any column family from a specific table that should possibly be replicated to a peer cluster needs to have the replication scope set appropriately. See [Table 5-5](#) when using the administrative API, and (to come) for the required cluster wide configuration changes.

Once the relationship between a cluster and its peer are set, they can be queried in various ways, for example, to determine the number of peers, and the list of peers with their details:

```

int getPeersCount()
Map<String, String> listPeers()
Map<String, ReplicationPeerConfig> listPeerConfigs()
ReplicationPeerConfig getPeerConfig(String id)

```

```
    throws ReplicationException
List<HashMap<String, String>> listReplicated() throws IOException
```

We discussed how you have to enable the cluster wide replication support, then indicate for every table which column family should be replicated. What is missing is the *per peer* setting that defines which of the replicated families is send to which peer. In practice, it would be unreasonable to ship all replication enabled column families to all peer clusters. The following methods allow the definition of per peer, per column family relationships:

```
String getPeerTableCFs(String id) throws ReplicationException
void setPeerTableCFs(String id, String tableCFs)
    throws ReplicationException
void setPeerTableCFs(String id,
    Map<TableName, ? extends Collection<String>> tableCFs)
void appendPeerTableCFs(String id, String tableCFs)
    throws ReplicationException
void appendPeerTableCFs(String id,
    Map<TableName, ? extends Collection<String>> tableCFs)
void removePeerTableCFs(String id, String tableCF)
    throws ReplicationException
void removePeerTableCFs(String id,
    Map<TableName, ? extends Collection<String>> tableCFs)
static Map<TableName, List<String>> parseTableCFsFromConfig(
    String tableCFsConfig)
```

You can set and retrieve the list of replicated column families for a given peer ID, and you can add to that list without replacing it. The latter is done by the `appendPeerTablesCFs()` calls. Note how the earlier `addPeer()` is also allowing you to set the desired column families as you establish the relationship. We brushed over it, since more explanation was needed.

The static `parseTableCFsFromConfig()` utility method is used internally to parse string representations of the tables and their column families into appropriate Java objects, suitable for further processing. The `setPeerTableCFs(String id, String tableCFs)` for example is used by the shell commands (see “[Replication Commands](#)” (page 496)) to hand in the table and column family details as text, and the utility method parses them subsequently. The allowed syntax is:

```
<tablename>[:<column family>,<column family> ...] \
[;<tablename>[:<column family>,<column family> ...] ...]
```

Each table name is followed—optionally—by a colon, which in turn is followed by a comma separated list of column family names that should be part of the replication for the given peer. Use a semicolon to separate more than one of such declarations within the same string. Space between any of the parts should be handled fine, but

common advise is to not use any of them, just to avoid unnecessary parsing issues. As noted, the column families are optional, if they are not specified then all column families that are enabled to replicate (that is, with a replication scope of 1) are selected to ship data to the given peer.

Finally, when done with the replication related administrative API, you should—as with any other API class—close the instance to free any resources it may have accumulated:

```
void close() throws IOException
```


Chapter 6

Available Clients

HBase comes with a variety of clients that can be used from various programming languages. This chapter will give you an overview of what is available.

Introduction

Access to HBase is possible from virtually every popular programming language and environment. You either use the client API directly, or access it through some sort of proxy that translates your request into an API call. These proxies wrap the native Java API into other protocol APIs so that clients can be written in any language the external API provides. Typically, the external API is implemented in a dedicated Java-based server that can internally use the provided Table client API. This simplifies the implementation and maintenance of these gateway servers.

On the other hand, there are tools that hide away HBase and its API as much as possible. You talk to specific interface, or develop against a set of libraries that generalize the access layer, for example, providing a persistency layer with *data access objects* (DAOs). Some of these abstractions are even active components themselves, acting like an application server or middleware framework to implement data applications that can talk to any storage backend. We will discuss these various approaches in order.

Gateways

Going back to the gateway approach, the protocol between them and their clients is driven by the available choices and requirements of the remote client. An obvious choice is *Representational State Transfer*

(REST),¹ which is based on existing web-based technologies. The actual transport is typically HTTP—which is *the* standard protocol for web applications. This makes REST ideal for communicating between heterogeneous systems: the protocol layer takes care of transporting the data in an interoperable format.

REST defines the semantics so that the protocol can be used in a generic way to address remote resources. By not changing the protocol, REST is compatible with existing technologies, such as web servers, and proxies. Resources are uniquely specified as part of the request URI—which is the opposite of, for example, SOAP-based² services, which define a new protocol that conforms to a standard.

However, both REST and SOAP suffer from the verbosity level of the protocol. Human-readable text, be it plain or XML-based, is used to communicate between client and server. Transparent compression of the data sent over the network can mitigate this problem to a certain extent.

As a result, companies with very large server farms, extensive bandwidth usage, and many disjoint services felt the need to reduce the overhead and implemented their own RPC layers. One of them was Google, which implemented the already mentioned *Protocol Buffers*. Since the implementation was initially not published, Facebook developed its own version, named *Thrift*.

They have similar feature sets, yet vary in the number of languages they support, and have (arguably) slightly better or worse levels of encoding efficiencies. The key difference with Protocol Buffers, when compared to Thrift, is that it has no RPC stack of its own; rather, it generates the RPC definitions, which have to be used with other RPC libraries subsequently.

HBase ships with auxiliary servers for REST and Thrift.³ They are implemented as standalone gateway servers, which can run on shared or dedicated machines. Since Thrift has its own RPC implementation, the gateway servers simply provide a wrapper around them. For REST, HBase has its own implementation, offering access to the stored data.

1. See “[Architectural Styles and the Design of Network-based Software Architectures](#)” by Roy T. Fielding, 2000.
2. See the official [SOAP specification](#) online. SOAP—or *Simple Object Access Protocol*-also uses HTTP as the underlying transport protocol, but exposes a different API for every service.
3. HBase used to also include a gateway server for Avro, but due to lack of interest and support it was abandoned subsequently in HBase 0.96 (see [HBASE-6553](#)).

The supplied *RESTServer* actually supports Protocol Buffers. Instead of implementing a separate RPC server, it leverages the Accept header of HTTP to send and receive the data encoded in Protocol Buffers. See “[REST](#)” (page 433) for details.

[Figure 6-1](#) shows how dedicated gateway servers are used to provide endpoints for various remote clients.

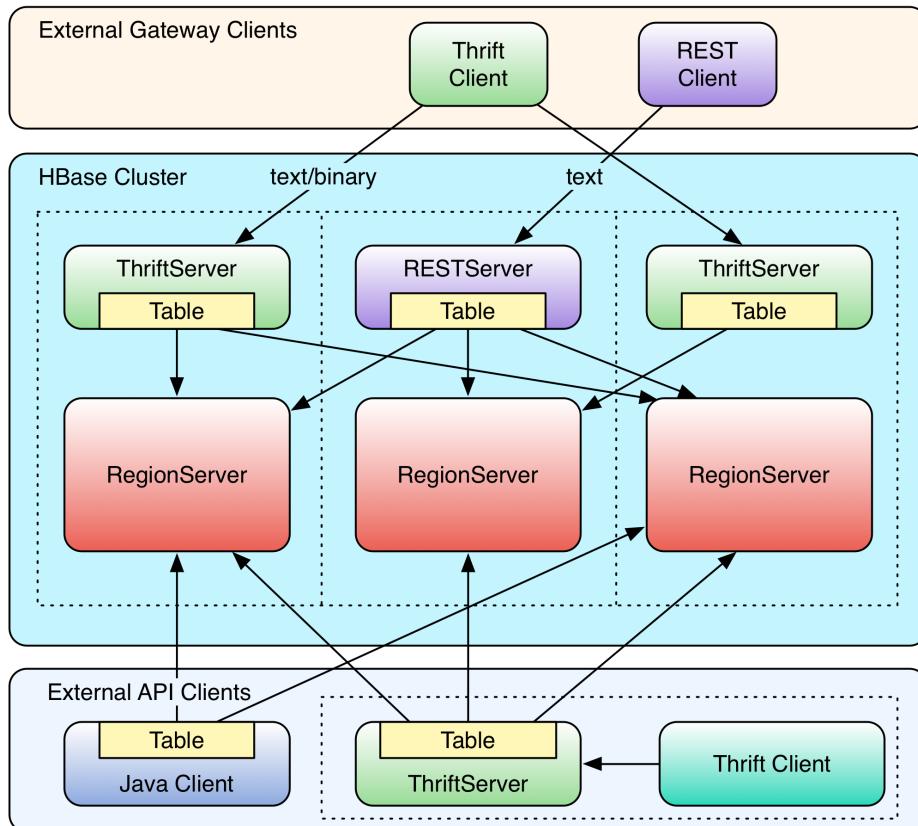


Figure 6-1. Clients connected through gateway servers

Internally, these servers use the common Table or BufferedMutator-based client API to access the tables. You can see how they are started on top of the region server processes, sharing the same physical

machine. There is no one true recommendation for how to place the gateway servers. You may want to colocate them, or have them on dedicated machines.

Another approach is to run them directly on the client nodes. For example, when you have web servers constructing the resultant HTML pages using PHP, it is advantageous to run the gateway process on the same server. That way, the communication between the client and gateway is local, while the RPC between the gateway and HBase is using the native protocol.

Check carefully how you access HBase from your client, to place the gateway servers on the appropriate physical machine. This is influenced by the load on each machine, as well as the amount of data being transferred: make sure you are not starving either process for resources, such as CPU cycles, or network bandwidth.

The advantage of using a server as opposed to creating a new connection for every request goes back to when we discussed “[Resource Sharing](#)” ([page 119](#))—you need to reuse connections to gain maximum performance. Short-lived processes would spend more time setting up the connection and preparing the metadata than in the actual operation itself. The caching of region information in the server, in particular, makes the reuse important; otherwise, every client would have to perform a full row-to-region lookup for every bit of data they want to access.

Selecting one server type over the others is a nontrivial task, as it depends on your use case. The initial argument over REST in comparison to the more efficient Thrift, or similar serialization formats, shows that for high-throughput scenarios it is advantageous to use a purely binary format. However, if you have few requests, but they are large in size, REST is interesting. A rough separation could look like this:

REST Use Case

Since REST supports existing web-based infrastructure, it will fit nicely into setups with reverse proxies and other caching technologies. Plan to run many REST servers in parallel, to distribute the load across them. For example, run a server on every application server you have, building a *single-app-to-server* relationship.

Thrift/Avro Use Case

Use the compact binary protocols when you need the best performance in terms of throughput. You can run fewer servers—for ex-

ample, one per region server—with a *many-apps-to-server* cardinality.

Frameworks

There is a long trend in software development to modularize and decouple specific units of work. You might call this *separation of responsibilities* or other, similar names, yet the goal is the same: it is better to build a commonly used piece of software only once, not having to reinvent the wheel again and again. Many programming languages have the concept of modules, in Java these are JAR files, providing shared code to many consumers. One set of those libraries is for persistency, or data access in general. A popular choice is [Hibernate](#), providing a common interface for all object persistency.

There are also dedicated languages just for data manipulation, or such that make this task as seamless as possible, so as not to distract from the business logic. We will look into *domain-specific languages* (DSLs) below, which cover these aspects. Another, newer trend is to also abstract away the application development, first manifested in *platform-as-a-service* (PaaS). Here we are provided with everything that is needed to write applications as quick as possible. There are application servers, accompanying libraries, databases, and so on.

With PaaS you still need to write the code and deploy it on the provided infrastructure. The logical next step is to provide data access APIs that an application can use with no further setup required. The Google App Engine services is one of those, where you can talk to a datastore API, that is provided as a library. It limits the freedom of an application, but assuming the storage API is powerful enough, and imposing no restrictions on the application developers creativity, it makes deployment and management of applications much easier.

Hadoop is a very powerful and flexible system. In fact, any component in Hadoop could be replaced, and you still have Hadoop, which is more of an ideology than a collection of specific technologies. With this flexibility and likely change comes the opposing wish of developers to stay clear of any hard dependency. For that reason, it is apparent how a new kind of active framework is emerging. Similar to the Google App Engine service, they provide a server component which accepts applications being deployed into, and with abstracted interfaces to underlying services, such as storage.

Interesting is that these kinds of frameworks, we will call them *data application servers*, or *data-as-a-service* (DaaS), embrace the nature of Hadoop, which is *data first*. Just like a smart phone, you install applications that implement business use cases and run where the

shared data resides. There is no need to costly move large amounts of data around to produce a result. With HBase as the storage engine, you can expect these frameworks to make best use of many built-in features, for example server-side coprocessors to push down selection predicates and analytical functionality. One example here is [Cask](#).

Common to libraries and frameworks is the notion of an abstraction layer, be it a generic data API or DSL. This is also apparent with yet another set of frameworks atop HBase, and other storage layers in general, implementing SQL capabilities. We will discuss them in a separate section below (see “[SQL over NoSQL](#)” (page 459)), so suffice it to say that they provide a varying level of SQL conformity, allowing access to data under the very popular idiom. Examples here are [Impala](#), [Hive](#), and [Phoenix](#).

Finally, what is hard to determine is where some of these libraries and frameworks really fit, as they can be employed on various backends, some suitable for batch operations only, some for interactive use, and yet other for both. The following will group them by that property, though that means we may have to look at the same tool more than ones. On the other hand, HBase is built for interactive access, but can equally be used within long running batch processes, for example, scanning analytical data for aggregation or model building. The grouping therefore might be arbitrary, though helps with covering both sides of the coin.

Gateway Clients

The first group of clients consists of the *gateway* kind, those that send client API calls on demand, such as get, put, or delete, to servers. Based on your choice of protocol, you can use the supplied gateway servers to gain access from your applications. Alternatively, you can employ the provided, storage specific API to implement generic, possibly hosted, data-centric solutions.

Native Java

The native Java API was discussed in [Chapter 3](#) and [Chapter 4](#). There is no need to start any gateway server, as your client using `Table` or `BufferedMutator` is directly communicating with the HBase servers, via the native RPC calls. Refer to the aforementioned chapters to implement a native Java client.

REST

HBase ships with a powerful REST server, which supports the complete client and administrative API. It also provides support for different message formats, offering many choices for a client application to communicate with the server.

Operation

For REST-based clients to be able to connect to HBase, you need to start the appropriate gateway server. This is done using the supplied scripts. The following commands show you how to get the command-line help, and then start the REST server in a non-daemonized mode:

```
$ bin/hbase rest
usage: bin/hbase rest start [--infoport <arg>] [-p <arg>] [-ro]
      --infoport <arg>    Port for web UI
      -p,--port <arg>       Port to bind to [default: 8080]
      -ro,--readonly        Respond only to GET HTTP method requests
[default:
           false]
```

To run the REST server as a daemon, execute `bin/hbase-daemon.sh start|stop`
`rest [--infoport <port>] [-p <port>] [-ro]`

```
$ bin/hbase rest start
^C
```

You need to press Ctrl-C to quit the process. The help stated that you need to run the server using a different script to start it as a background process:

```
$ bin/hbase-daemon.sh start rest
starting rest, logging to /var/lib/hbase/logs/hbase-larsgeorge-
rest-<servername>.out
```

Once the server is started you can use `curl`⁴ on the command line to verify that it is operational:

```
$ curl http://<servername>:8080/
testtable

$ curl http://<servername>:8080/version
rest 0.0.3 [JVM: Oracle Corporation 1.7.0_51-24.51-b03] [OS: Mac
OS X \
10.10.2 x86_64] [Server: jetty/6.1.26] [Jersey: 1.9]
```

4. `curl` is a command-line tool for transferring data with URL syntax, supporting a large variety of protocols. See the project's [website](#) for details.

Retrieving the root URL, that is "/" (slash), returns the list of available tables, here testtable. Using "/version" retrieves the REST server version, along with details about the machine it is running on.

Alternatively, you can open the web-based UI provided by the REST server. You can specify the port using the above mentioned --infoport command line parameter, or by overriding the hbase.rest.info.port configuration property. The default is set to 8085, and the content of the page is shown in [Figure 6-2](#).

Attribute Name	Value	Description
HBase Version	1.0.0, revision=6c98bff7b719efdb16f71606f3b7d8229445eb81	HBase version and revision
HBase Compiled	Sat Feb 14 19:49:22 PST 2015, enis	When HBase version was compiled and by whom
REST Server Start Time	Sat Apr 18 16:34:17 CEST 2015	Date stamp of when this REST server was started

[Apache HBase Wiki on REST](#)

Figure 6-2. The web-based UI for the REST server

The UI has functionality that is common to many web-based UIs provided by HBase. The middle part provides information about the server and its status. For the REST server there is not much more but the HBase version, compile information, and server start time. At the bottom of the page there is a link to the HBase [Wiki](#) page explaining the REST API. At the top of the page there are links offering extra functionality:

Home

Links to the Home page of the server.

Local logs

Opens a page that lists the local log directory, providing web-based access to the otherwise inaccessible log files.

Log Level

This page allows to query and set the log levels for any class or package loaded in the server process.

Metrics Dump

All servers in HBase track activity as metrics (see (to come)), which can be accessed as JSON using this link.

HBase Configuration

Prints the current configuration as used by the server process.

See “[Shared Pages](#)” (page 551) for a deeper discussion on these shared server UI links.

Stopping the REST server, when running as a daemon, involves the same script, just replacing `start` with `stop`:

```
$ bin/hbase-daemon.sh stop rest  
stopping rest..
```

The REST server gives you all the operations required to work with HBase tables.

The current documentation for the REST server is available [online](#). Please refer to it for all the provided operations. Also, be sure to carefully read the [XML schemas documentation](#) on that page. It explains the schemas you need to use when requesting information, as well as those returned by the server.

You can start as many REST servers as you like, and, for example, use a load balancer to route the traffic between them. Since they are stateless—any state required is carried as part of the request—you can use a round-robin (or similar) approach to distribute the load.

The `--readonly`, or `-ro` parameter switches the server into *read-only* mode, which means it only responds to HTTP GET operations. Finally, use the `-p`, or `--port`, parameter to specify a different port for the server to listen on. The default is 8080. There are additional configura-

tion properties that the REST server is considering as it is started. [Table 6-1](#) lists them with default values.

Table 6-1. Configuration options for the REST server

Property	Default	Description
hbase.rest.dns.nameserver	default	Defines the DNS server used for the name lookup. ^a
hbase.rest.dns.interface	default	Defines the network interface that the name is associated with. ^a
hbase.rest.port	8080	Sets the HTTP port the server will bind to. Also settable per instance with the -p and --port command-line parameter.
hbase.rest.host	0.0.0.0	Defines the address the server is listening on. Defaults to the wildcard address.
hbase.rest.info.port	8085	Specifies the port the web-based UI will bind to. Also settable per instance using the --infoport parameter.
hbase.rest.info.bindAddress	0.0.0.0	Sets the IP address the web-based UI is bound to. Defaults to the wildcard address.
hbase.rest.readonly	false	Forces the server into normal or read-only mode. Also settable by the --readonly, or -ro options.
hbase.rest.threads.max	100	Provides the upper boundary of the thread pool used by the HTTP server for request handlers.
hbase.rest.threads.min	2	Same as above, but sets the lower boundary on number of handler threads.
hbase.rest.connection.cleanup-interval	10000 (10 secs)	Defines how often the internal housekeeping task checks for expired connections to the HBase cluster.
hbase.rest.connection.max-idletime	600000 (10 mins)	Amount of time after which an unused connection is considered expired.
hbase.rest.support.proxyuser	false	Flags if the server should support proxy users or not. This

Property	Default	Description
		is used to enable secure impersonation.

^aThese two properties are used in tandem to look up the server's hostname using the given network interface and name server. The default value mean it uses whatever is configured on the OS level.

The connection pool configured with the above cleanup task settings is required since the server needs to keep a separate connection for each authenticated user, when security is enabled. This also applies to the proxy user settings, and both are explained in more detail in (to come).

Supported Formats

Using the HTTP Content-Type and Accept headers, you can switch between different formats being sent or returned to the caller. As an example, you can create a table and row in HBase using the shell like so:

```
hbase(main):001:0> create 'testtable', 'colfam1'
0 row(s) in 0.6690 seconds

=> Hbase::Table - testtable
hbase(main):002:0> put 'testtable', "\x01\x02\x03", 'colfam1:col1', 'value1'
0 row(s) in 0.0230 seconds

hbase(main):003:0> scan 'testtable'
ROW          COLUMN+CELL
\x01\x02\x03    column=colfam1:col1, timestamp=1429367023394, val-
ue=value1
1 row(s) in 0.0210 seconds
```

This inserts a row with the binary row key `0x01 0x02 0x03` (in hexadecimal numbers), with one column, in one column family, that contains the value `value1`.

Plain (text/plain)

For some operations it is permissible to have the data returned as plain text. One example is the aforementioned /version operation:

```
$ curl -H "Accept: text/plain" http://<servername>:8080/version
rest 0.0.3 [JVM: Oracle Corporation 1.7.0_45-24.45-b08] [OS:
Mac OS X \
10.10.2 x86_64] [Server: jetty/6.1.26] [Jersey: 1.9]
```

On the other hand, using plain text with more complex return values is not going to work as expected:

```
$ curl -H "Accept: text/plain" \
http://<servername>:8080/testtable/%01%02%03/colfam1:col1

<html>
<head>
<meta http-equiv="Content-Type" content="text/html;
charset=ISO-8859-1"/>
<title>Error 406 Not Acceptable</title>
</head>
<body><h2>HTTP ERROR 406</h2>
<p>Problem accessing /testtable/%01%02%03/colfam1:col1. Reason:
<pre>    Not Acceptable</pre></p>
<br /><i><small>Powered by Jetty://</small></i><br />
<br />
...
<br />
</body>
</html>
```

This is caused by the fact that the server cannot make any assumptions regarding how to format a complex result value in plain text. You need to use a format that allows you to express nested information natively.

The row key used in the example is a binary one, consisting of three bytes. You can use REST to access those bytes by encoding the key using *URL encoding*,⁵ which in this case results in %01%02%03. The entire URL to retrieve a cell is then:

```
http://<servername>:8080/testtable/%01%02%03/
colfam1:col1
```

See the online documentation referred to earlier for the entire syntax.

XML (text/xml)

When storing or retrieving data, XML is considered the default format. For example, when retrieving the example row with no particular Accept header, you receive:

```
$ curl http://<servername>:8080/testtable/%01%02%03/
colfam1:col1
```

5. The basic idea is to encode any unsafe or unprintable character code as "%" + *ASCII Code*. Because it uses the percent sign as the prefix, it is also called *percent encoding*. See the Wikipedia page on [percent encoding](#) for details.

```

<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<CellSet>
  <Row key="AQID">
    <Cell column="Y29sZmFtMTpjB2wx" \
          timestamp="1429367023394">dmFsdWUx</Cell>
  </Row>
</CellSet>

```

The returned format defaults to XML. The column name and the actual value are encoded in [Base64](#), as explained in the online schema documentation. Here is the respective part of the schema:

```

<element name="Row" type="tns:Row"></element>

<complexType name="Row">
  <sequence>
    <element name="key" type="base64Binary"></element>
    <element name="cell" type="tns:Cell" maxOccurs="unbounded"
  \
    minOccurs="1"></element>
  </sequence>
</complexType>

<element name="Cell" type="tns:Cell"></element>

<complexType name="Cell">
  <sequence>
    <element name="value" maxOccurs="1" minOccurs="1">
      <simpleType><restriction base="base64Binary">
        </simpleType>
    </element>
  </sequence>
  <attribute name="column" type="base64Binary" />
  <attribute name="timestamp" type="int" />
</complexType>

```

All occurrences of `base64Binary` are where the REST server returns the encoded data. This is done to safely transport the binary data that can be contained in the keys, or the value. This is also true for data that is sent to the REST server. Make sure to read the schema documentation to encode the data appropriately, including the payload, in other words, the actual data, but also the column name, row key, and so on.

A quick test on the console using the `base64` command reveals the proper content:

```
$ echo AQID | base64 -D | hexdump
00000000 01 02 03
```

```
$ echo Y29sZmFtMTpjB2wx | base64 -D
colfam1:col1
```

```
$ echo dmFsdWUx | base64 -D  
value1
```

This is obviously useful only to verify the details on the command line. From within your code you can use any available Base64 implementation to decode the returned values.

JSON (application/json)

Similar to XML, requesting (or setting) the data in JSON simply requires setting the Accept header:

```
$ curl -H "Accept: application/json" \  
http://<servername>:8080/testtable/%01%02%03/colfam1:col1  
  
{  
    "Row": [  
        {"key": "AQID",  
         "Cell": [  
            {"column": "Y29sZmFtMTpjB2wx",  
             "timestamp": 1429367023394,  
             "$": "dmFsdWUx"  
         ]  
     ]  
}
```

The preceding JSON result was reformatted to be easier to read. Usually the result on the console is returned as a single line, for example:

```
{"Row": [{"key": "AQID", "Cell": [{"column": "Y29sZmFtMTpjB2wx",  
                           "timestamp": 1429367023394, "$": "dmFsdWUx"}]}]}
```

The encoding of the values is the same as for XML, that is, Base64 is used to encode any value that potentially contains binary data. An important distinction to XML is that JSON does not have nameless data fields. In XML the cell data is returned between Cell tags, but JSON *must* specify *key/value* pairs, so there is no immediate counterpart available. For that reason, JSON has a special field called "\$" (the dollar sign). The value of the *dollar* field is the cell data. In the preceding example, you can see it being used:

```
"$": "dmFsdWUx"
```

You need to query the dollar field to get the Base64-encoded data.

Protocol Buffer (application/x-protobuf)

An interesting application of REST is to be able to switch encodings. Since Protocol Buffers have no native RPC stack, the HBase REST server offers support for its encoding. The schemas are documented [online](#) for your perusal.

Getting the results returned in Protocol Buffer encoding requires the matching Accept header:

```
$ curl -H "Accept: application/x-protobuf" \
http://<servername>:8080/testtable/%01%02%03/colfam1:col1 | 
hexdump -C
...
00000000  0a 24 0a 03 01 02 03 12  1d 12 0c 63 6f 6c 66 61  | .
$.....colfa|
00000010  6d 31 3a 63 6f 6c 31 18  a2 ce a7 e7 cc 29 22 06  | 
m1:col1.....|.|
00000020  76 61 6c 75 65 31          |
value1|
```

The use of *hexdump* allows you to print out the encoded message in its binary format. You need a Protocol Buffer decoder to actually access the data in a structured way. The ASCII printout on the righthand side of the output shows the column name and cell value for the example row.

Raw binary (application/octet-stream)

Finally, you can dump the data in its raw form, while omitting structural data. In the following console command, only the data is returned, as stored in the cell.

```
$ curl -H "Accept: application/octet-stream" \
http://<servername>:8080/testtable/%01%02%03/colfam1:col1 | 
hexdump -C
00000000  76 61 6c 75 65 31          |
value1|
```

Depending on the format request, the REST server puts structural data into a custom header. For example, for the raw get request in the preceding paragraph, the headers look like this (adding -D- to the curl command):

```
HTTP/1.1 200 OK
Content-Length: 6
X-Timestamp: 1429367023394
Content-Type: application/octet-stream
```

The timestamp of the cell has been moved to the header as X-Timestamp. Since the row and column keys are part of the request URI, they are omitted from the response to prevent unnecessary data from being transferred.

REST Java Client

The REST server also comes with a comprehensive Java client API. It is located in the `org.apache.hadoop.hbase.rest.client` package. The central classes are `RemoteHTable` and `RemoteAdmin`. [Example 6-1](#) shows the use of the `RemoteHTable` class.

Example 6-1. Example of using the REST client classes

```
Cluster cluster = new Cluster();
cluster.add("localhost", 8080); ①

Client client = new Client(cluster); ②

RemoteHTable table = new RemoteHTable(client, "testtable"); ③

Get get = new Get(Bytes.toBytes("row-30")); ④
get.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("col-3"));
Result result1 = table.get(get);

System.out.println("Get result1: " + result1);

Scan scan = new Scan();
scan.setStartRow(Bytes.toBytes("row-10"));
scan.setStopRow(Bytes.toBytes("row-15"));
scan.addColumn(Bytes.toBytes("colfam1"), Bytes.toBytes("col-5"));
ResultScanner scanner = table.getScanner(scan); ⑤

for (Result result2 : scanner) {
    System.out.println("Scan row[" + Bytes.toString(result2.get-
    Row()) +
    "]: " + result2);
}
```

- ① Set up a cluster list adding all known REST server hosts.

- ② Create the client handling the HTTP communication.
- ③ Create a remote table instance, wrapping the REST access into a familiar interface.
- ④ Perform a get operation as if it were a direct HBase connection.
- ⑤ Scan the table, again, the same approach as if using the native Java API.

Running the example requires that the REST server has been started and is listening on the specified port. If you are running the server on a different machine and/or port, you need to first adjust the value added to the `Cluster` instance.

Here is what is printed on the console when running the example:

```
Adding rows to table...
Get result1:
  keyvalues={row-30/colfam1:col-3/1429376615162/Put/vlen=8/seqid=0}
Scan row[row-10]:
  keyvalues={row-10/colfam1:col-5/1429376614839/Put/vlen=8/seqid=0}
Scan row[row-100]:
  keyvalues={row-100/colfam1:col-5/1429376616162/Put/vlen=9/
seqid=0}
Scan row[row-11]:
  keyvalues={row-11/colfam1:col-5/1429376614856/Put/vlen=8/seqid=0}
Scan row[row-12]:
  keyvalues={row-12/colfam1:col-5/1429376614873/Put/vlen=8/seqid=0}
Scan row[row-13]:
  keyvalues={row-13/colfam1:col-5/1429376614891/Put/vlen=8/seqid=0}
Scan row[row-14]:
  keyvalues={row-14/colfam1:col-5/1429376614907/Put/vlen=8/seqid=0}
```

Due to the lexicographical sorting of row keys, you will receive the preceding rows. The selected columns have been included as expected.

The `RemoteHTable` is a convenient way to talk to a number of REST servers, while being able to use the normal Java client API classes, such as `Get` or `Scan`.

The current implementation of the Java REST client is using the Protocol Buffer encoding internally to communicate with the remote REST server. It is the most compact protocol the server supports, and therefore provides the best bandwidth efficiency.

Thrift

Apache Thrift is written in C++, but provides schema compilers for many programming languages, including Java, C++, Perl, PHP, Python, Ruby, and more. Once you have compiled a schema, you can exchange messages transparently between systems implemented in one or more of those languages.

Installation

Before you can use Thrift, you need to install it, which is preferably done using a binary distribution package for your operating system. If that is not an option, you need to compile it from its sources.

HBase ships with pre-built Thrift code for Java and all the included demos, which means that there should be no need to install Thrift. You still will need the Thrift source package, because it contains necessary code that the generated classes rely on. You will see in the example below (see “[Example: PHP](#) (page 452) how for some languages that is required, while for others it may now.

Download the source tarball from the website, and unpack it into a common location:

```
$ wget http://www.apache.org/dist/thrift/0.9.2/thrift-0.9.2.tar.gz  
$ tar -xzvf thrift-0.9.2.tar.gz -C /opt  
$ rm thrift-0.9.2.tar.gz
```

Install the dependencies, which are Automake, LibTool, Flex, Bison, and the Boost libraries:

```
$ sudo apt-get install build-essential automake libtool flex bison  
libboost
```

Now you can build and install the Thrift binaries like so:

```
$ cd /opt/thrift-0.9.2  
$ ./configure  
$ make  
$ sudo make install
```

Alternative, on OS X you could, for example, use the [Homebrew](#) package manager for installing the same like so:

```
$ brew install thrift  
==> Installing dependencies for thrift: boost, openssl  
...
```

```
==> Summary  
/usr/local/Cellar/thrift/0.9.2: 90 files, 5.4M
```

When installed, you can verify that everything succeeded by calling the main `thrift` executable:

```
$ thrift -version  
Thrift version 0.9.2
```

Once you have Thrift installed, you need to compile a schema into the programming language of your choice. HBase comes with a schema file for its client and administrative API. You need to use the Thrift binary to create the wrappers for your development environment.

The supplied schema file exposes the majority of the API functionality, but is lacking in a few areas. It was created when HBase had a different API and that is noticeable when using it. Newer features might be not supported yet, for example the newer *durability* settings. See “[Thrift2](#)” ([page 458](#)) for a replacement service, implementing the current HBase API verbatim.

Before you can access HBase using Thrift, though, you also have to start the supplied `ThriftServer`.

Thrift Operations

Starting the Thrift server is accomplished by using the supplied scripts. You can get the command-line help by adding the `-h` switch, or omitting all options:

```
$ bin/hbase thrift  
usage: Thrift [-b <arg>] [-c] [-f] [-h] [-hsha | -nonblocking |  
      -threadedselector | -threadpool] [--infoport <arg>] [-k  
<arg>] [-m  
<arg>] [-p <arg>] [-q <arg>] [-w <arg>]  
-b,--bind <arg>           Address to bind the Thrift server to.  
[default:  
          0.0.0.0]  
-c,--compact               Use the compact protocol  
-f,--framed                Use framed transport  
-h,--help                  Print help information  
-hsha                      Use the THsHaServer This implies the  
framed  
                           transport.  
--infoport <arg>          Port for web UI  
-k,--keepAliveSec <arg>   The amount of time in seconds to keep a  
thread  
                           alive when idle in TBoundedThreadPool-
```

```

Server
  -m,--minWorkers <arg>      The minimum number of worker threads for
                                TThreadPoolServer
  -nonblocking                 Use the TNonblockingServer This implies
                                the
  -p,--port <arg>              Port to bind to [default: 9090]
  -q,--queue <arg>            The maximum number of queued requests in
                                TThreadPoolServer
  -threadedselector            Use the TThreadedSelectorServer This im-
                                plies
  -threadpool                  the framed transport.
                                Use the TThreadPoolServerThis is
                                the
  -W,--workers <arg>          default.
                                The maximum number of worker threads for
                                TThreadPoolServer
To start the Thrift server run 'bin/hbase-daemon.sh start thrift'
To shutdown the thrift server run 'bin/hbase-daemon.sh stop
thrift' or
send a kill signal to the thrift server pid

```

There are many options to choose from. The type of server, protocol, and transport used is usually enforced by the client, since not all language implementations have support for them. From the command-line help you can see that, for example, using the *nonblocking* server implies the *framed transport*.

Using the defaults, you can start the Thrift server in non-daemonized mode:

```
$ bin/hbase thrift start
^C
```

You need to press Ctrl-C to quit the process. The help stated that you need to run the server using a different script to start it as a background process:

```
$ bin/hbase-daemon.sh start thrift
starting thrift, logging to /var/lib/hbase/logs/
\hbase-larsgeorge-thrift-<servername>.out
```

Stopping the Thrift server, running as a daemon, involves the same script, just replacing `start` with `stop`:

```
$ bin/hbase-daemon.sh stop thrift
stopping thrift..
```

Once started either way, you can open the web-based UI provided by the Thrift server. You can specify the port using the above listed `--infoport` command line parameter, or by overriding the `hbase.thrift.info.port` configuration property. The default is set to 9095, and the content of the page is shown in [Figure 6-3](#).

ThriftServer 9090

Software Attributes

Attribute Name	Value	Description
HBase Version	1.0.0, r6c98bff7b719efdb16f71606f3b7d8229445eb81	HBase version and revision
HBase Compiled	Sat Feb 14 19:49:22 PST 2015, enis	When HBase version was compiled and by whom
Thrift Server Start Time	Sun Apr 19 15:23:51 CEST 2015	Date stamp of when this Thrift server was started
Thrift Impl Type	threadpool	Thrift RPC engine implementation type chosen by this Thrift server
Compact Protocol	false	Thrift RPC engine uses compact protocol
Framed Transport	false	Thrift RPC engine uses framed transport

[Apache HBase Wiki on Thrift](#)

Figure 6-3. The web-based UI for the Thrift server

The UI has functionality that is common to many web-based UIs provided by HBase. The middle part provides information about the server and its status. For the Thrift server there is not much more but the HBase version, compile information, server start time, and Thrift specific details, such as the server type, protocol and transport options configured. At the bottom of the page there is a link to the HBase [Wiki](#) page explaining the Thrift API. At the top of the page there are links offering extra functionality:

Home

Links to the Home page of the server.

Local logs

Opens a page that lists the local log directory, providing web-based access to the otherwise inaccessible log files.

Log Level

This page allows to query and set the log levels for any class or package loaded in the server process.

Metrics Dump

All servers in HBase track activity as metrics (see (to come)), which can be accessed as JSON using this link.

HBase Configuration

Prints the current configuration as used by the server process.

See “[Shared Pages](#)” (page 551) for a deeper discussion on these shared server UI links.

The current documentation for the Thrift server is available [online](#) (also see the [package info](#)). You should refer to it for all the provided operations. It is also advisable to read the provided `$HBASE_HOME/hbase-thrift/src/main/resources/org/apache/hadoop/hbase/thrift/Hbase.thrift` schema definition file for the authoritative documentation of the available functionality.

The Thrift server provides you with all the operations required to work with HBase tables. You can start as many Thrift servers as you like, and, for example, use a load balancer to route the traffic between them. Since they are stateless, you can use a round-robin (or similar) approach to distribute the load. Use the `-p`, or `--port`, parameter to specify a different port for the server to listen on. The default is `9090`.

There are additional configuration properties that the Thrift server is considering as it is started. [Table 6-2](#) lists them with default values.

Table 6-2. Configuration options for the Thrift server

Property	Default	Description
<code>hbase.thrift.dns.nameserver</code>	<code>default</code>	Defines the DNS server used for the name lookup. ^a
<code>hbase.thrift.dns.interface</code>	<code>default</code>	Defines the network interface that the name is associated with. ^a

Property	Default	Description
hbase.regionserver.thrift.port	9090	Sets the port the server will bind to. Also settable per instance with the -p or --port command-line parameter.
hbase.regionserver.thrift.ipaddress	0.0.0.0	Defines the address the server is listening on. Defaults to the wildcard address. Set with -b, --bind per instance on the command-line.
hbase.thrift.info.port	9095	Specifies the port the web-based UI will bind to. Also settable per instance using the --infoport parameter.
hbase.thrift.info.bindAddress	0.0.0.0	Sets the IP address the web-based UI is bound to. Defaults to the wildcard address.
hbase.regionserver.thrift.server.type	threadpool	Sets the Thrift server type in non-HTTP mode. See below for details.
hbase.regionserver.thrift.compact	false	Enables the <i>compact</i> protocol mode if set to true. Default means <i>binary</i> mode instead. Also settable per instance with -c, or --compact.
hbase.regionserver.thrift.framed	false	Sets the transport mode to <i>framed</i> . Otherwise the standard transport is used. Framed cannot be used in secure mode. When using the hsha or nonblocking server type, framed transport is always used irrespective of this configuration property. Also settable per instance with -f, or --framed.

Property	Default	Description
hbase.regionserver.thrift.framed.max_frame_size_in_mb	2097152 (2MB)	The maximum frame size when <i>framed</i> transport mode is enabled.
hbase.thrift.minWorkerThreads	16	Sets the minimum amount of worker threads to keep, should be increased for production use (for example, to 200). Settable on the command-line with <code>-m</code> , or <code>--minWorkers</code> .
hbase.thrift.maxWorkerThreads	1000	Sets the upper limit of worker threads. Settable on the command-line with <code>-w</code> , or <code>--workers</code> .
hbase.thrift.maxQueuedRequests	1000	Maximum number of request to queue when workers are all busy. Can be set with <code>-q</code> , and <code>--queue</code> per instance.
hbase.thrift.threadKeepAliveTimeSec	60 (secs)	Amount of time an extraneous idle worker is kept before it is discarded. Also settable with <code>-k</code> , or <code>--keepAliveSec</code> .
hbase.regionserver.thrift.http	false	Flag that determines if the server should run in HTTP or native mode.
hbase.thrift.http_threads.max	100	Provides the upper boundary of the thread pool used by the HTTP server for request handlers.
hbase.thrift.http_threads.min	2	Same as above, but sets the lower boundary on number of handler threads.
hbase.thrift.ssl.enabled	false	When HTTP mode is enabled, this flag sets the SSL mode.
hbase.thrift.ssl.keystore.store	""	When SSL is enabled, sets the key store file.

Property	Default	Description
hbase.thrift.ssl.keystore.password	null	When SSL is enabled, sets the password to unlock the key store file.
hbase.thrift.ssl.keystore.keypassword	null	When SSL is enabled, sets the password to retrieve the keys from the key store.
hbase.thrift.security.qop	""	Can be one of auth, auth-int, or auth-conf to set the SASL <i>quality-of-protection</i> (QoP). See (to come) for details.
hbase.thrift.support.proxyuser	false	Flags if the server should support proxy users or not. This is used to enable secure impersonation.
hbase.thrift.kerberos.principal	<hostname>	Can be used to set the Kerberos principal to use in secure mode.
hbase.thrift.keytab.file	""	Specifies the Kerberos keytab file for secure operation.
hbase.regionserver.thrift.coalesceIncrement	false	Enables the <i>coalesce</i> mode for increments, which is a delayed, batch increment operation.
hbase.thrift.filters	""	Loads filter classes into the server process for subsequent use.
hbase.thrift.connection.cleanupInterval	10000 (10 secs)	Defines how often the internal housekeeping task checks for expired connections to the HBase cluster.
hbase.thrift.connection.max-idletime	600000 (10 mins)	Amount of time after which an unused connection is considered expired.

^aThese two properties are used in tandem to look up the server's hostname using the given network interface and name server. The default value mean it uses whatever is configured on the OS level.

There are a few choices for the *server type* in Thrift native mode (that is, non-HTTP), which are:

nonblocking

Uses the `TNonblockingServer` class, which is based on Java NIO's *non-blocking I/O*, where the selector thread also processes the actual request. Settable per server instance with the `-nonblocking` parameter.

hsha

Uses the `THsHaServer` class, implementing a *Half-Sync/Half-Async* (HsHa) server. The difference to the *non-blocking* server is that it has a single thread accepting connections, but a thread pool for the processing workers. Settable per server instance with the `-hsha` parameter.

threadedselector

Extends on the *HsHa* server by maintaining two thread pools, one for network I/O (selection), and another for processing (workers). Uses the `TThreadedSelectorServer` class. Settable per server instance with the `-threadedselector` parameter.

threadpool

Has a single thread to accept connections, which are then scheduled to be worked on in an `ExecutorService`. Each connection is dedicated to one client, therefore potentially many threads are needed in highly concurrent setups. Uses the `TBoundedThreadPoolServer` class, which is a customized implementation of the Thrift `TThreadPoolServer` class. Also settable per server instance with the `-threadpool` parameter.

The default of type `threadpool` is a good choice for production use, as it combines many proven techniques.⁶

Example: PHP

HBase not only ships with the required Thrift schema file, but also with an example client for many programming languages. Here we will enable the PHP implementation to demonstrate the required steps.

Before we start though, a few notes:

- You need to enable PHP support for your web server! Follow your server documentation to do so. On OS X, for example, you need to

6. See this [blog post](#) for a comparison.

edit the `/etc/apache2/httpd.conf` and uncomment the following line, and (re)start the server with `$ sudo apachectl restart`:

```
LoadModule php5_module libexec/apache2/libphp5.so
```

- HBase ships with a precompiled PHP Thrift module, so you are free to skip the part below (that is, step #1) where we generate the module anew. Either way should get you to the same result. The code shipped with HBase is in the ``hbase-examples`
- The included `DemoClient.php` is not up-to-date, for example, it tests with an empty row key, which is *not* allowed, and using a non-UTF8 row key, which *is* allowed. Both checks fail, and you need to fix the PHP file taking care of the changes.
- Apache Thrift has changed the layout of the PHP scaffolding files it ships with. In earlier releases it only had a `$THRIFT_SRC_HOME/lib/php/src` directory, while newer versions have a `../src` and `../lib` folder.

Step 1

Optionally: The first step is to copy the supplied schema file and compile the necessary PHP source files for it:

```
$ cp -r $HBASE_HOME/hbase-thrift/src/main/resources/org/apache/ \
  hadoop/hbase/thrift ~/thrift_src
$ cd thrift_src/
$ thrift -gen php Hbase.thrift
```

The call to `thrift` should complete with no error or other output on the command line. Inside the `thrift_src` directory you will now find a directory named `gen-php` containing the two generated PHP files required to access HBase:

```
$ ls -l gen-php/Hbase/
total 920
-rw-r--r-- 1 larsgeorge staff 416357 Apr 20 07:46 Hbase.php
-rw-r--r-- 1 larsgeorge staff 52366 Apr 20 07:46 Types.php
```

If you decide to skip this step, you can copy the supplied, pre-generated PHP files from the `hbase-examples` module in the HBase source tree:

```
$ ls -lr $HBASE_HOME/hbase-examples/src/main/php
total 24
-rw-r--r-- 1 larsgeorge admin 8438 Jan 25 10:47 DemoClient.php
drwxr-xr-x 3 larsgeorge admin 102 May 22 2014 gen-php

/usr/local/hbase-1.0.0-src/hbase-examples/src/main/php/gen-php:
total 0
drwxr-xr-x 4 larsgeorge admin 136 Jan 25 10:47 Hbase
```

```
/usr/local/hbase-1.0.0-src/hbase-examples/src/main/php/gen-php/
Hbase:
total 800
-rw-r--r-- 1 larsgeorge admin 366528 Jan 25 10:47 Hbase.php
-rw-r--r-- 1 larsgeorge admin 38477 Jan 25 10:47 Types.php
```

Step 2

The generated files require the Thrift-supplied PHP harness to be available as well. They need to be copied into your web server's *document root* directory, along with the generated files:

```
$ cd /opt/thrift-0.9.2
$ sudo mkdir $DOCUMENT_ROOT/thrift/
$ sudo cp src/*.php $DOCUMENT_ROOT/thrift/
$ sudo cp -r lib/Thrift/* $DOCUMENT_ROOT/thrift/
$ sudo mkdir $DOCUMENT_ROOT/thrift/packages
$ sudo cp -r ~/thrift_src/gen-php/Hbase $DOCUMENT_ROOT/thrift/packages/
```

The generated PHP files are copied into a packages subdirectory, as per the Thrift documentation, which needs to be created if it does not exist yet.

The \$DOCUMENT_ROOT in the preceding commands could be /var/www, for example, on a Linux system using Apache, or /Library/WebServer/Documents/ on an Apple Mac OS X machine. Check your web server configuration for the appropriate location.

HBase ships with a DemoClient.php file that uses the generated files to communicate with the servers. This file is copied into the same document root directory of the web server:

```
$ sudo cp $HBASE_HOME/hbase-examples/src/main/php/DemoClient.php
$DOCUMENT_ROOT/
```

You need to edit the DemoClient.php file and adjust the following fields at the beginning of the file:

```
# Change this to match your thrift root
$GLOBALS['THRIFT_ROOT'] = 'thrift';
...
# According to the thrift documentation, compiled PHP thrift libraries should
# reside under the THRIFT_ROOT/packages directory. If these compiled
# libraries are not present in this directory, move them there from gen-php/.
require_once( $GLOBALS['THRIFT_ROOT'].'/packages/Hbase/
Hbase.php' );
```

```
...
$socket = new TSocket( 'localhost', 9090 );
...
```

Usually, editing the first line is enough to set the `THRIFT_ROOT` path. Since the `DemoClient.php` file is also located in the document root directory, it is sufficient to set the variable to `thrift`, that is, the directory copied from the Thrift sources earlier.

The last line in the preceding excerpt has a hardcoded server name and port. If you set up the example in a distributed environment, you need to adjust this line to match your environment as well. After everything has been put into place and adjusted appropriately, you can open a browser and point it to the demo page. For example:

```
http://<webserver-address>/DemoClient.php
```

This should load the page and output the following details (abbreviated here for the sake of brevity):⁷

```
scanning tables...
  found: testtable
creating table: demo_table
column families in demo_table:
  column: entry:, maxVer: 10
  column: unused:, maxVer: 3
Starting scanner...
...
```

The same *Demo Client* client is also available in C++, Java, Perl, Python, and Ruby. Follow the same steps to start the Thrift server, compile the schema definition into the necessary language, and start the client. Depending on the language, you will need to put the generated code into the appropriate location first.

Example: Java

HBase already ships with the generated Java classes to communicate with the Thrift server, though you can always regenerate them again from the schema file. The book's online code repository provides a script to generate them directly within the example directory for this chapter. It is located in the `bin` directory of the repository root path, and is named `dothrift.sh`. It requires you to hand in the HBase Thrift definition file, since that can be anywhere:

```
$ bin/dothrift.sh
Missing thrift file parameter!
```

7. As of this writing, the supplied `DemoClient.php` is slightly outdated, running into a script error during evaluation. This results in not all of the included tests being executed. This is tracked in [HBASE-13522](#).

```

Usage: bin/dothrift.sh <thrift-file>

$ bin/dothrift.sh $HBASE_HOME/hbase-thrift/src/main/resources/org/
 \
  apache/hadoop/hbase/thrift/Hbase.thrift
compiling   thrift:    /usr/local/hbase-1.0.0-src/hbase-thrift/src/
main/ \
  resources/org/apache/hadoop/hbase/thrift/Hbase.thrift
done.

```

After running the script, the generated classes can be found in the `ch06/src/main/java/org/apache/hadoop/hbase/thrift/` directory. [Example 6-2](#) uses these classes to communicate with the Thrift server. Make sure the gateway server is up and running and listening on port 9090.

Example 6-2. Example using the Thrift generated client API

```

private static final byte[] TABLE = Bytes.toBytes("testtable");
private static final byte[] ROW = Bytes.toBytes("testRow");
private static final byte[] FAMILY1 = Bytes.toBytes("testFamily1");
private static final byte[] FAMILY2 = Bytes.toBytes("testFamily2");
private static final byte[] QUALIFIER = Bytes.toBytes
  ("testQualifier");
private static final byte[] COLUMN = Bytes.toBytes(
  "testFamily1:testColumn");
private static final byte[] COLUMN2 = Bytes.toBytes(
  "testFamily2:testColumn2");
private static final byte[] VALUE = Bytes.toBytes("testValue");

public static void main(String[] args) throws Exception {
  TTransport transport = new TSocket("0.0.0.0", 9090, 20000);
  TProtocol protocol = new TBinaryProtocol(transport, true, true);
①  Hbase.Client client = new Hbase.Client(protocol);
  transport.open();

  ArrayList<ColumnDescriptor> columns = new
    ArrayList<ColumnDescriptor>();
  ColumnDescriptor cd = new ColumnDescriptor(); ②
  cd.name = ByteBuffer.wrap(FAMILY1);
  columns.add(cd);
  cd = new ColumnDescriptor();
  cd.name = ByteBuffer.wrap(FAMILY2);
  columns.add(cd);

  client.createTable(ByteBuffer.wrap(TABLE), columns); ③

  ArrayList<Mutation> mutations = new ArrayList<Mutation>();
  mutations.add(new Mutation(false, ByteBuffer.wrap(COLUMN),
    ByteBuffer.wrap(VALUE), true));
  mutations.add(new Mutation(false, ByteBuffer.wrap(COLUMN2),

```

```

        ByteBuffer.wrap(VALUE), true));
client.mutateRow(ByteBuffer.wrap(TABLE), ByteBuffer.wrap(ROW), ❸
    mutations, null);

TScan scan = new TScan();
    int scannerId = client.scannerOpenWithScan(ByteBuff-
er.wrap(TABLE), ❹
    scan, null);
for (TRowResult result : client.scannerGet(scannerId)) {
    System.out.println("No. columns: " + result.getColumnsSize());
    for (Map.Entry<ByteBuffer, TCell> column :
        result.getColumns().entrySet()) {
        System.out.println("Column name: " + Bytes.toString(
            column.getKey().array()));
        System.out.println("Column value: " + Bytes.toString(
            column.getValue().getValue()));
    }
}
client.scannerClose(scannerId);

ArrayList<ByteBuffer> columnNames = new ArrayList<ByteBuffer>();
columnNames.add(ByteBuffer.wrap(FAMILY1));
scannerId = client.scannerOpen(ByteBuffer.wrap(TABLE), ❺
    ByteBuffer.wrap(Bytes.toBytes("")), columnNames, null);
for (TRowResult result : client.scannerGet(scannerId)) {
    System.out.println("No. columns: " + result.getColumnsSize());
    for (Map.Entry<ByteBuffer, TCell> column :
        result.getColumns().entrySet()) {
        System.out.println("Column name: " + Bytes.toString(
            column.getKey().array()));
        System.out.println("Column value: " + Bytes.toString(
            column.getValue().getValue()));
    }
}
client.scannerClose(scannerId);

System.out.println("Done.");
transport.close(); ❻
}

```

- ❶ Create a connection using the Thrift boilerplate classes.
- ❷ Create two column descriptor instances.
- ❸ Create the test table.
- ❹ Insert a test row.
- ❺ Scan with an instance of TScan. This is the most convenient approach. Print the results in a loop.
- ❻ Scan again, but with another Thrift method. In addition, set the columns to a specific family only. Also print out the results in a loop.

- ⑦ Close the connection after everything is done.

The console output is:

```
No. columns: 2
Column name: testFamily1:testColumn
Column value: testValue
Column name: testFamily2:testColumn2
Column value: testValue
No. columns: 1
Column name: testFamily1:testColumn
Column value: testValue
Done.
```

Please consult the supplied classes, examples, and online documentation for more details.

Thrift2

Since the client API of HBase was changed significantly in version 0.90, it is apparent in many places how the Thrift API is out of sync. An effort was started to change this by implementing a new version of the Thrift gateway server, named *Thrift2*. It mirrors the current client API calls and therefore feels more natural to the HBase developers familiar with the native, Java based API. On the other hand, unfortunately, it is still *work in progress* and is lacking various features.

Overall the Thrift2 server is used the same way as the original Thrift server is, which means we can skip the majority of the explanation. Read about the operations of the server in “[Thrift Operations](#)” (page 445). You can see all command line options running the `thrift2` option like so:

```
$ bin/hbase thrift2
usage: Thrift [-b <arg>] [-c] [-f] [-h] [-hsha | -nonblocking |
      -threadpool] [--infoport <arg>] [-p <arg>]
      -b,--bind <arg>      Address to bind the Thrift server to. [de-
                           fault: 0.0.0.0]
      -c,--compact          Use the compact protocol
      -f,--framed           Use framed transport
      -h,--help              Print help information
      -hsha                 Use the THsHaServer. This implies the framed
                           transport.
      --infoport <arg>       Port for web UI
      -nonblocking          Use the TNonblockingServer. This implies
                           the framed
                           transport.
      -p,--port <arg>        Port to bind to [default: 9090]
      -threadpool           Use the TThreadPoolServer. This is the de-
```

```
fault.  
To start the Thrift server run 'bin/hbase-daemon.sh start thrift2'  
To shutdown the thrift server run 'bin/hbase-daemon.sh stop  
thrift2' or  
send a kill signal to the thrift server pid
```

Using the defaults, you can start the Thrift server in non-daemonized mode:

```
$ bin/hbase thrift2 start  
^C
```

You need to press Ctrl-C to quit the process. The help stated that you need to run the server using a different script to start it as a background process:

```
$ bin/hbase-daemon.sh start thrift2  
starting thrift2, logging to /var/lib/hbase/logs/ \  
hbase-larsgeorge-thrift2-<servername>.out
```

Stopping the Thrift server, running as a daemon, involves the same script, just replacing `start` with `stop`:

```
$ bin/hbase-daemon.sh stop thrift2  
stopping thrift2.
```

Once started either way, you can open the web-based UI provided by the Thrift server, the same way as explained for the original Thrift server earlier. Obviously, the main difference between Thrift2 and its predecessor is the changes in API calls. Consult the Thrift service definition file, that is, `$HBASE_HOME/hbase-thrift/src/main/resources/org/apache/hadoop/hbase/thrift/Hbase.thrift`, for the details on the provided services and data structures.

SQL over NoSQL

An interesting spin on NoSQL is the recent rise of SQL frameworks that make HBase look like any other RDBMS: you have transactions, indexes, referential integrity, and other well-known features—all atop an inherently non-SQL system. These frameworks have varying levels of integration, adding several service around HBase itself to re-add all (or some) of the database relevant features. Some notable projects are:

Phoenix

The most native integration into HBase is provided by the [Apache Phoenix](#) project. It is available as open-source and under the Apache ASF license. The framework uses many advanced features to optimize generic SQL queries executed against HBase tables, including coprocessors for secondary indexes, and filtering.

Trafodion

Developed as open-source software by HP, [Trafodion](#) is a system that combines existing database technology with HBase as the storage layer.

Impala

Another open-source, and Apache licensed, project is [Impala](#). Primary built to perform interactive queries against data stored in HDFS, it has the ability to directly access HBase tables too. Impala shared

Hive with Tez/Spark

We will discuss Hive in detail in “[Hive](#)” (page 460), because originally it used the Hadoop batch framework to execute the data processing. With the option to replace MapReduce with other engines, such as the more recent *Tez* or *Spark*, you can also run HiveQL based queries interactively over HBase tables.

Framework Clients

After the more direct gateway clients, we are now going to talk about the second class of clients, referred to collectively as *frameworks*. They are offering a higher level of abstraction, usually in the form of a *domain specific language* (DSL). This includes, for example, SQL, the *lingua franca* of relational database system with external clients, and also MapReduce, the original processing framework (and SDK) to write and execute longer running batch jobs.

MapReduce

The Hadoop MapReduce framework is built to process petabytes of data, in a reliable, deterministic, yet easy-to-program way. There are a variety of ways to include HBase as a source and target for MapReduce jobs.

Native Java

The Java-based MapReduce API for HBase is discussed in [Chapter 7](#).

Hive

The [Apache Hive](#) project offers a data warehouse infrastructure atop Hadoop. It was initially developed at Facebook, but is now part of the open source Hadoop ecosystem. Hive can be used to run structured queries against HBase tables, which we will discuss now.

Introduction

Hive offers an SQL-like query language, called *HiveQL*, which allows you to query the semistructured data stored in Hadoop. The query is eventually turned into a processing job, traditionally MapReduce, which is executed either locally or on a distributed cluster. The data is parsed at job execution time and Hive employs a *storage handler*⁸ abstraction layer that allows for data not to just reside in HDFS, but other data sources as well. A storage handler transparently makes arbitrarily stored information available to the HiveQL-based user queries.

Since version 0.6.0, Hive also comes with a handler for HBase.⁹ You can define Hive tables that are backed by HBase tables or snapshots, mapping columns between them and the query schema as required. The row key can be exposed as one or more extra column when needed, supporting composite keys.

HBase Version Support

As of this writing, the latest release of Hive, version 1.2.1, includes support for HBase 0.98.x. There is a problem using this version with HBase 1.x, because a class signature has changed, causing the HBase handler JAR shipped with Hive to throw a runtime exception when confronted with the HBase 1.x libraries:

```
15/07/03 04:38:09 [main]: ERROR exec.DDLTask: java.lang.NoSuchMethodError: org.apache.hadoop.hbase.HTableDescriptor.addFamily(\n    Lorg/apache/hadoop/hbase/HColumnDescriptor;)V\n    at org.apache.hadoop.hive.hbase.HBaseStorageHandler.preCreateTable(...)\n    at org.apache.hadoop.hive.metastore.HiveMetaStoreClient.createTable(...)\n    at org.apache.hadoop.hive.metastore.HiveMetaStoreClient.createTable(...)
```

The only way currently to resolve this problem is to build Hive from source, and update the HBase dependencies to 1.x in the process. The steps are:

1. Clone the source repository of Hive
2. Edit the `pom.xml`, adjusting the used HBase version
3. Build Hive with final packaging option for Hadoop 2

8. See the Hive [wiki](#) for more details on storage handlers.

9. The Hive [wiki](#) has a full explanation of the HBase integration into Hive.

4. Install this custom version of Hive

In more concrete steps, here are the shell commands:

```
$ git clone https://github.com/apache/hive.git
$ cd hive/
$ vi pom.xml

...
<hbase.hadoop1.version>0.98.9-hadoop1</hbase.hadoop1.version>
<hbase.hadoop2.version>1.1.0</hbase.hadoop2.version>
<!--hbase.hadoop2.version>0.98.9-hadoop2</
hbase.hadoop2.version-->
...

$ mvn clean install -Phadoop-2,dist -DskipTests
...
[INFO]
-----
[INFO] Building Hive HBase Handler 2.0.0-SNAPSHOT
[INFO]

-----
[INFO] --- maven-install-plugin:2.4:install (default-install)
@ \
  hive-hbase-handler ---
[INFO] Installing /home/larsgeorge/hive/hbase-handler/target/ \
  hive-hbase-handler-2.0.0-SNAPSHOT.jar  to  /home/lars-
george/.m2/ \
  repository/org/apache/hive/hive-hbase-handler/2.0.0-
SNAPSHOT/ \
  hive-hbase-handler-2.0.0-SNAPSHOT.jar
...
[INFO]
-----
[INFO] Reactor Summary:
[INFO]
[INFO] Hive ..... SUCCESS [ 8.843 s]
...
[INFO] Hive HBase Handler ..... SUCCESS [ 8.179 s]
...
[INFO] Hive Packaging ..... SUCCESS [01:02 min]
[INFO]
-----
[INFO] BUILD SUCCESS
[INFO]

-----
[INFO] Total time: 08:11 min
[INFO] Finished at: 2015-07-03T06:16:43-07:00
[INFO] Final Memory: 210M/643M
```

```
[INFO]
```

```
$ sudo tar -zxvf packaging/target/apache-hive-2.0.0-SNAPSHOT-bin.tar.gz \
-C /opt/
```

The build process will take a while, since Maven needs to download all required libraries, and that depends on your Internet connection speed. Once the build is complete, you can start using the HBase handler with the new version of HBase.

After you have installed Hive itself, you have to edit its configuration files so that it has access to the HBase JAR file, and the accompanying configuration. Modify `$HIVE_CONF_DIR/hive-env.sh` to contain these lines, while using the appropriate paths for your installation:

```
# Set HADOOP_HOME to point to a specific hadoop install directory
HADOOP_HOME=/opt/hadoop
HBASE_HOME=/opt/hbase

# Hive Configuration Directory can be controlled by:
# export HIVE_CONF_DIR=
export HIVE_CONF_DIR=/etc/opt/hive/conf
export HIVE_LOG_DIR=/var/opt/hive/log

# Folder containing extra libraries required for hive compilation/
execution
# can be controlled by:
export HIVE_AUX_JARS_PATH=/usr/share/java/mysql-connector-
java.jar: \
$HBASE_HOME/lib/hbase-client-1.1.0.jar
```

You may have to copy the supplied `$HIVE_CONF_DIR/hive-env.sh.template` file, and save it in the same directory, but without the `.template` extension. Once you have copied the file, you can edit it as described.

Also note that the used `{HADOOP|HBASE}_HOME` directories for Hadoop and HBase need to be set to match your environment. The shown `/opt/` parent directory is used throughout the book for exemplary purposes.

Part of the Hive setup is to configure the metastore database, which is then pointed to with the `hive-site.xml`, for example:

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<?xml-stylesheet type="text/xsl" href="configuration.xsl"?>
```

```

<configuration>
  <property>
    <name>javax.jdo.option.ConnectionURL</name>
    <value>jdbc:mysql://master-2.internal.larsgeorge.com/meta-store_db</value>
  </property>
  <property>
    <name>javax.jdo.option.ConnectionDriverName</name>
    <value>com.mysql.jdbc.Driver</value>
  </property>
  <property>
    <name>javax.jdo.option.ConnectionUserName</name>
    <value>dbuser</value>
  </property>
  <property>
    <name>javax.jdo.option.ConnectionPassword</name>
    <value>dbuser</value>
  </property>
  <property>
    <name>datanucleus.autoCreateSchema</name>
    <value>false</value>
  </property>
  <property>
    <name>hive.mapred.reduce.tasks.speculative.execution</name>
    <value>false</value>
  </property>
</configuration>

```

There is more work needed to get Hive working, including the creation of the warehouse and temporary work directory within HDFS, and so on. We refrain here to go into all the details, but refer you to the aforementioned Hive wiki for all the details. Note that there is no need for any extra processes to run for Hive to execute queries over HBase (or HDFS). The *Hive Metastore Server* and *Hive Server* daemons are only needed for access to Hive by external clients.

Mapping Managed Tables

Once Hive is installed and operational, you can begin using the HBase handler. First start the Hive command-line interface, create a native Hive table, and insert data from the supplied example files:

Should you run into issue with the commands shown, you can start the Hive CLI overriding the logging level to print details on the console using `$ hive --hiveconf hive.root.logger=INFO,console` (or even DEBUG instead of INFO, printing many more details).¹⁰

```
$ hive
...
hive> CREATE TABLE pokes (foo INT, bar STRING);
OK
Time taken: 1.835 seconds

hive> LOAD DATA LOCAL INPATH '/opt/hive/examples/files/kv1.txt' \
      OVERWRITE INTO TABLE pokes;
Loading data to table default.pokes
Table default.pokes stats: [numFiles=1, numRows=0, totalSize=5812,
rawDataSize=0]
OK
Time taken: 2.695 seconds
```

This is using the pokes example table, as described in the Hive [Getting Started](#) guide, with two columns named foo and bar. The data loaded is provided as part of the Hive installation, containing a key and value field, separated by the Ctrl-A ASCII control code (hexadecimal x01), which is the default for Hive:

```
$ head /opt/hive/examples/files/kv1.txt | cat -v
238^Aval_238
86^Aval_86
311^Aval_311
27^Aval_27
165^Aval_165
409^Aval_409
255^Aval_255
278^Aval_278
98^Aval_98
484^Aval_484
```

Next you create a HBase-backed table like so:

```
hive> CREATE TABLE hbase_table_1(key int, value string) \
      STORED BY 'org.apache.hadoop.hive.hbase.HBaseStorageHandler' \
      WITH SERDEPROPERTIES ("hbase.columns.mapping" = ":key,cf1:val") \
      TBLPROPERTIES ("hbase.table.name" = "hbase_table_1");
OK
Time taken: 2.369 seconds
```

10. If you get an error starting the Hive CLI indicating an issue with JLine, please see [HIVE-8609](#). Hadoop 2.7.0 and later should work fine.

This DDL statement creates and maps a HBase table, defined using the `TBLPROPERTIES` and `SERDEPROPERTIES` parameters, using the provided HBase handler, to a Hive table named `hbase_table_1`. The `hbase.columns.mapping` property has a special feature, which is mapping the column with the name "`:key`" to the HBase row key. You can place this special column to perform row key mapping anywhere in your definition. Here it is placed as the first column, thus mapping the values in the key column of the Hive table to be the row key in the HBase table.

The `hbase.table.name` in the table properties is optional and only needed when you want to use different names for the tables in Hive and HBase. Here it is set to the same value, and therefore could be omitted. It is particularly useful when the target HBase table is part of a non-default namespace. For example, you could map the Hive `hbase_table_1` to a HBase table named "`warehouse:table1`", which would place the table in the named `warehouse` namespace (you would need to create that first of course, for example, using the HBase Shell's `create_namespace` command).

Loading the table from the previously filled `pokes` Hive table is done next. According to the mapping, this will save the `pokes.foo` values in the row key, and the `pokes.bar` data in the column `cf1:val`:

```
hive> INSERT OVERWRITE TABLE hbase_table_1 SELECT * FROM pokes;
Query ID = larsgeorge_20150704102808_6172915c-2053-473b-9554-c9ea972e0634
Total jobs = 1
Launching Job 1 out of 1
Number of reduce tasks is set to 0 since there's no reduce operator
Starting Job = job_1433933860552_0036, Tracking URL = \
    http://master-1.internal.larsgeorge.com:8088/ \
    proxy/application_1433933860552_0036/
Kill Command = /opt/hadoop/bin/hadoop job -kill
job_1433933860552_0036
Hadoop job information for Stage-0: number of mappers: 1; \
    number of reducers: 0
2015-07-04 10:28:23,743 Stage-0 map = 0%, reduce = 0%
2015-07-04 10:28:34,377 Stage-0 map = 100%, reduce = 0%, \
    Cumulative CPU 3.43 sec
MapReduce Total cumulative CPU time: 3 seconds 430 msec
Ended Job = job_1433933860552_0036
MapReduce Jobs Launched:
Stage-Stage-0: Map: 1 Cumulative CPU: 3.43 sec \
    HDFS Read: 15942 HDFS Write: 0 SUCCESS
Total MapReduce CPU Time Spent: 3 seconds 430 msec
OK
Time taken: 27.153 seconds
```

This starts the first MapReduce job in this example. You can see how the Hive command line prints out the parameters it is using. The job copies the data from the HDFS-based Hive table into the HBase-backed one. The execution time of around 30 seconds for this, and any subsequent job shown, is attributed to the inherent work YARN and MapReduce have to perform, which includes distributing the job JAR files, spinning up the Java processes on the processing worker nodes, and persist any intermediate results.

In certain setups, especially in the local, pseudo-distributed mode, the Hive job may fail with an obscure error message. Before trying to figure out the details, try running the job in Hive *local* MapReduce mode. In the Hive CLI enter:¹¹

```
hive> SET mapreduce.framework.name=local;
```

The advantage is that you completely avoid the overhead of and any inherent issue with the processing framework—which means you have one less part to worry about when debugging a failed Hive job.

Loading the data using a table to table copy as shown in the example is good for limited amounts of data, as it uses the standard HBase client APIs, here with `put()` calls, to insert the data. This is not the most efficient way to load data at scale, and you may want to look into *bulk loading* of data instead (see below). Another, rather dangerous option is to use the following parameter in the Hive CLI:

```
set hive.hbase.wal.enabled=false;
```

Be advised that this is effectively disabling the use of the write-ahead log, your one place to keep data safe during server failures. In other words, disabling the WAL is only advisable in very specific situations, for example, when you do not worry about some data missing from the table loading operation. On the other hand it removes one part of the write process, and will certainly speed up loading data.

The following counts the rows in the `pokes` and `hbase_table_1` tables (the CLI output of the job details are omitted for the second and all subsequent queries):

¹¹. Before YARN, using the original MapReduce framework, this variable was named `mapred.job.tracker` and was set in the Hive CLI with `SET mapred.job.tracker=local;`.

```

hive> SELECT COUNT(*) FROM pokes;
Query ID = larsgeorge_20150705121407_ddc2ddfa-8cd6-4819-9460-5a88fdcf2639
Total jobs = 1
Launching Job 1 out of 1
Number of reduce tasks determined at compile time: 1
In order to change the average load for a reducer (in bytes):
  set hive.exec.reducers.bytes.per.reducer=<number>
In order to limit the maximum number of reducers:
  set hive.exec.reducers.max=<number>
In order to set a constant number of reducers:
  set mapreduce.job.reduces=<number>
Starting Job = job_1433933860552_0045, Tracking URL = \
  http://master-1.internal.larsgeorge.com:8088/proxy/ \
  application_1433933860552_0045/
Kill Command = /opt/hadoop/bin/hadoop job -kill
job_1433933860552_0045
Hadoop job information for Stage-1: number of mappers: 1; \
  number of reducers: 1
2015-07-05 12:14:21,938 Stage-1 map = 0%,  reduce = 0%
2015-07-05 12:14:30,443 Stage-1 map = 100%,  reduce = 0%, \
  Cumulative CPU 2.08 sec
2015-07-05 12:14:40,017 Stage-1 map = 100%,  reduce = 100%, \
  Cumulative CPU 4.23 sec
MapReduce Total cumulative CPU time: 4 seconds 230 msec
Ended Job = job_1433933860552_0045
MapReduce Jobs Launched:
Stage-Stage-1: Map: 1 Reduce: 1 Cumulative CPU: 4.23 sec \
  HDFS Read: 12376 HDFS Write: 4 SUCCESS
Total MapReduce CPU Time Spent: 4 seconds 230 msec
OK
500
Time taken: 33.268 seconds, Fetched: 1 row(s)

hive> SELECT COUNT(*) FROM hbase_table_1;
...
OK
309
Time taken: 46.218 seconds, Fetched: 1 row(s)

```

What is interesting to note is the difference in the actual count for each table. They differ by more than 100 rows, where the HBase-backed table is the shorter one. What could be the reason for this? In HBase, you cannot have duplicate row keys, so every row that was copied over, and which had the same value in the originating `pokes.foo` column, is saved as the same row. This is the same as performing a `SELECT DISTINCT` on the source table:

```

hive> SELECT COUNT(DISTINCT foo) FROM pokes;
...
OK

```

```
309
Time taken: 30.512 seconds, Fetched: 1 row(s)
```

This is now the same outcome and proves that the previous results are correct. Finally, drop both tables, which also removes the underlying HBase table:

```
hive> DROP TABLE pokes;
OK
Time taken: 0.85 seconds

hive> DROP TABLE hbase_table_1;
OK
Time taken: 3.132 seconds

hive> EXIT;
```

Mapping Existing Tables

You can also map an existing HBase table into Hive, or even map the table into multiple Hive tables. This is useful when you have very distinct column families, and querying them is done separately. This will improve the performance of the query significantly, since it uses a Scan internally, selecting only the mapped column families. If you have a sparsely set family, this will only scan the much smaller files on disk, as opposed to running a job that has to scan everything just to filter out the sparse data.

Another reason to map unmanaged, existing HBase tables into Hive is the ability to fine-tune the tables properties. For example, let's create a Hive table that is backed by a managed HBase table, using a non-direct table name mapping, and subsequently use the HBase shell with its describe command to print the table properties:

```
hive> CREATE TABLE dwitems(key int, value string) \
    STORED BY 'org.apache.hadoop.hive.hbase.HBaseStorageHandler' \
    WITH SERDEPROPERTIES ("hbase.columns.mapping" = ":key,cf1:val") \
    TBLPROPERTIES ("hbase.table.name" = "warehouse:items");
OK
Time taken: 1.961 seconds

hbase(main):001:0> describe 'warehouse:items'
Table warehouse:items is ENABLED
warehouse:items
COLUMN FAMILIES DESCRIPTION
{NAME => 'cf1', DATA_BLOCK_ENCODING => 'NONE', BLOOMFILTER =>
'ROW', \
  REPLICATION_SCOPE => '0', VERSIONS => '1', COMPRESSION =>
'NONE', \
  MIN_VERSIONS => '0', TTL => 'FOREVER', KEEP_DELETED_CELLS =>
'FALSE', \
```

```
BLOCKSIZE => '65536', IN_MEMORY => 'false', BLOCKCACHE => 'true'}  
1 row(s) in 0.2520 seconds
```

The managed table uses the properties provided by the cluster-wide configuration, without the ability to override any of them from the Hive CLI. This is very limiting in practice, so you would usually create the table in the HBase shell first, and then map it into Hive as an existing table. This requires the Hive EXTERNAL keyword, which is also used in other places to access data stored in *unmanaged* Hive tables, that is, those that are not under Hive's control. The following example first creates a namespace and table on the HBase side, and then a mapping within Hive:

```
hbase(main):002:0> create_namespace 'salesdw'  
0 row(s) in 0.0700 seconds  
hbase(main):003:0> create 'salesdw:itemdescs', { NAME => 'meta',  
VERSIONS => 5, \  
    COMPRESSION => 'Snappy', BLOCKSIZE => 8192 }, { NAME => 'data', \  
    COMPRESSION => 'GZ', BLOCKSIZE => 262144, BLOCKCACHE => 'false' }  
0 row(s) in 1.3590 seconds  
  
=> Hbase::Table - salesdw:itemdescs  
hbase(main):004:0> describe 'salesdw:itemdescs'  
Table salesdw:itemdescs is ENABLED  
salesdw:itemdescs  
COLUMN FAMILIES DESCRIPTION  
{NAME => 'data', DATA_BLOCK_ENCODING => 'NONE', BLOOMFILTER =>  
'ROW', \  
    REPLICATION_SCOPE => '0', VERSIONS => '1', COMPRESSION => 'GZ', \  
    MIN_VERSIONS => '0', TTL => 'FOREVER', KEEP_DELETED_CELLS =>  
'FALSE', \  
    BLOCKSIZE => '262144', IN_MEMORY => 'false', BLOCKCACHE =>  
'false'}  
{NAME => 'meta', DATA_BLOCK_ENCODING => 'NONE', BLOOMFILTER =>  
'ROW', \  
    REPLICATION_SCOPE => '0', VERSIONS => '5', COMPRESSION => 'SNAP-  
PY', \  
    MIN_VERSIONS => '0', TTL => 'FOREVER', KEEP_DELETED_CELLS =>  
'FALSE', \  
    BLOCKSIZE => '8192', IN_MEMORY => 'false', BLOCKCACHE => 'true'}  
2 row(s) in 0.0440 seconds  
  
hive> CREATE EXTERNAL TABLE salesdwitemdescs(id string, \  
        title string, createdate string)  
      STORED BY 'org.apache.hadoop.hive.hbase.HBaseStorageHandler'  
      WITH SERDEPROPERTIES ("hbase.columns.mapping" = ":key, meta:title, meta:date")  
      TBLPROPERTIES("hbase.table.name" = "salesdw:itemdescs");  
OK  
Time taken: 0.33 seconds
```

The example HBase table overwrites a few properties, for example, the compression type and block sizes to use, based on the assumption that the meta family is going to contain very small columns, while the data family is holding a larger chunk of information. Before we are going to look into further aspects of the Hive integration with HBase, let us use the HBase Shell to insert some random data (see “[Scripting](#)” (page 497) for details on how to use the Ruby based shell to its full potential):

```
hbase(main):003:0> require 'date';
import java.lang.Long
import org.apache.hadoop.hbase.util.Bytes

def randomKey
  rowKey = Long.new(rand * 100000).to_s
  cdate = (Time.local(2011, 1, 1) + rand * (Time.now.to_f - \
    Time.local(2011, 1, 1).to_f)).to_i.to_s
  recId = (rand * 10).to_i.to_s
  rowKey + "|" + cdate + "|" + recId
end

1000.times do
  put 'salesdw:itemdescs', randomKey, 'meta:title', \
    ('a'..'z').to_a.shuffle[0,16].join
end

0 row(s) in 0.0150 seconds

0 row(s) in 0.0070 seconds
...
0 row(s) in 0.0070 seconds

=> 1000

hbase(main):004:0> scan 'salesdw:itemdescs'
...
73240|1340109585|0      column=meta:title, timestamp=1436194770461,
  value=owadqizytesfxjpk
7331|1320411151|5      column=meta:title, timestamp=1436194770291,
  value=ygskbquxrhfjdzl
73361|1333773850|1      column=meta:title, timestamp=1436194771546,
  value=xvwpahoderlmkzyc
733|1322342049|7       column=meta:title, timestamp=1436194768921,
  value=lxbewcargdkzhqnf
73504|1374527239|8      column=meta:title, timestamp=1436194773800,
  value=knweopyzcfjmbxag
73562|1294318375|0      column=meta:title, timestamp=1436194770200,
  value=cdhorqwpatjvykx
73695|1415147780|1      column=meta:title, timestamp=1436194772545,
  value=hjevgfwtscoiqxbm
73862|1358685650|7      column=meta:title, timestamp=1436194773488,
```

```
value=fehuajtyxsbcikn
73943|1324759091|0      column=meta:title, timestamp=1436194773597,
    value=gvdentsxayhfropj
7400|1369244556|8      column=meta:title, timestamp=1436194774953,
    value=hacgrvwbnsfieopy
74024|1363079462|3      column=meta:title, timestamp=1436194775155,
    value=qsfjpabywuovmnrt...
```

Please note that for the row key this creates a compound key, that also varies in length. We will discuss how this can be mapped into Hive next. The value for the `meta:title` column is randomized, for the sake of simplicity. We can now query the table on the Hive side like so:

```
hive> SELECT * FROM salesdwitemdescs LIMIT 5;
hive> select * from salesdwitemdescs limit 5;
OK
10106|1415138651|1      wbnajpegdfiouzrk      NULL
10169|1429568580|9      nwlujxsyvperhqac      NULL
1023|1397904134|5      srcbzdyavleoptq      NULL
10512|1419127826|0      xnyctsefodmzgaju      NULL
10625|1435864853|2      ysqovchlwptibru      NULL
Time taken: 0.239 seconds, Fetched: 5 row(s)
```

Finally, external tables are *not* deleted when the table is dropped from inside Hive. It simply removes the metadata information about the table.

Advanced Column Mapping Features

You have the option to map any HBase column directly to a Hive column, or you can map an entire column family to a Hive MAP type. This is useful when you do not know the column qualifiers ahead of time: map the family and iterate over the columns from within the Hive query instead.

HBase columns you do not map into Hive are not accessible for Hive queries.

Since storage handlers work transparently for the higher-level layers in Hive, you can also use any *user-defined function* (UDF) supplied with Hive—or your own custom functions.

There are a few shortcomings in the current version, though:

No custom serialization

HBase only stores `byte[]` arrays, so Hive is simply converting every column value to `String`, and serializes it from there. For ex-

ample, an INT column set to 12 in Hive would be stored as if using Bytes.toBytes("12").

Check with the Hive project site to see if these features have since been added.

Mapping Existing Table Snapshots

On top of mapping existing HBase tables into Hive, you can do the same with HBase snapshots. You initially do the same things, that is, define a table schema over a HBase table. This sets the table name using the hbase.table.name property as shown above. When you execute a query it is reading from the named table as expected. For reading from a snapshot instead, you have to set its name just *before* you issue the same query as before, using the hive.hbase.snapshot.name property interactively in the Hive shell. For example, first we snapshot the previously created warehouse:itemdescs table, and then add another 1000 rows into it, bringing it to a total of 2000 rows:

```
hbase(main):005:0> snapshot 'salesdw:itemdescs', 'itemdescs-snap1'
0 row(s) in 0.7180 seconds
hbase(main):006:0> 1000.times do
  put 'salesdw:itemdescs', randomKey, 'meta:title', \
    ('a'..'z').to_a.shuffle[0,16].join
end
...
0 row(s) in 0.0060 seconds

=> 1000

hbase(main):007:0> count 'salesdw:itemdescs'
Current count: 1000, row: 55291|1419780087|4
Current count: 2000, row: 999|1358386653|5
2000 row(s) in 0.6280 seconds

=> 2000
```

We can now assume that the snapshot itemdescs-snap1 has 1000 rows, while the live table has 2000. We switch to the Hive CLI and confirm the table count next:

```
hive> SELECT COUNT(*) FROM salesdw:itemdescs;
...
OK
2000
Time taken: 41.224 seconds, Fetched: 1 row(s)
```

Before we can use the snapshot, we have to switch to the HBase super user (the one owning the HBase files in HDFS, here hadoop) to be able to read the snapshot at all. This is explained in detail in “[MapReduce](#)

over Snapshots” (page 620), but suffice it to say that you have to exit the Hive CLI and set a Hadoop variable to indicate the user like so:

```
$ export HADOOP_USER_NAME=hadoop  
$ hive
```

Reading from a HBase snapshot requires the creation of a temporary table structure somewhere in HDFS, which defaults to /tmp. You can override this from within Hive’s shell using the `hive.hbase.snapshot.restoredir` property, if you want to use a different path. Now we are ready to query the snapshot, instead of the table:

```
hive> SET hive.hbase.snapshot.name=itemdescs-snap1;  
//hive> SET hbase.bucketcache.ioengine=;  
hive> SELECT COUNT(*) FROM salesdwitemdescs;  
...  
OK  
1000  
Time taken: 34.672 seconds, Fetched: 1 row(s)
```

As expected, we are returned a row count of 1000, matching the table as it was when the snapshot was taken.

Block Load Data

Pig

The [Apache Pig](#) project provides a platform to analyze large amounts of data. It has its own high-level query language, called *Pig Latin*, which uses an imperative programming style to formulate the steps involved in transforming the input data to the final output. This is the opposite of Hive’s declarative approach to emulate SQL.

The nature of Pig Latin, in comparison to HiveQL, appeals to everyone with a procedural programming background, but also lends itself to significant parallelization. When it is combined with the power of Hadoop and the MapReduce framework, you can process massive amounts of data in reasonable time frames.

Version 0.7.0 of Pig introduced the `LoadFunc`/`StoreFunc` classes and functionality, which allows you to load and store data from sources other than the usual HDFS. One of those sources is HBase, implemented in the `HBaseStorage` class.

Pigs’ support for HBase includes reading and writing to existing tables. You can map table columns as Pig *tuples*, which optionally include the row key as the first field for read operations. For writes, the first field is always used as the row key.

The storage also supports basic filtering, working on the row level, and providing the comparison operators explained in “[Comparison Operators](#)” (page 221).¹²

Pig Installation

You should try to install the prebuilt binary packages for the operating system distribution of your choice. If this is not possible, you can download the source from the project website and build it locally. For example, on a Linux-based system you could perform the following steps.¹³

Download the source tarball from the website, and unpack it into a common location:

```
$ wget http://www.apache.org/dist/pig/pig-0.8.1/
pig-0.8.1.tar.gz
$ tar -xzvf pig-0.8.1.tar.gz -C /opt
$ rm pig-0.8.1.tar.gz
```

Add the *pig* script to the shell’s search path, and set the `PIG_HOME` environment variable like so:

```
$ export PATH=/opt/pig-0.8.1/bin:$PATH
$ export PIG_HOME=/opt/pig-0.8.1
```

After that, you can try to see if the installation is working:

```
$ pig -version
Apache Pig version 0.8.1
compiled May 27 2011, 14:58:51
```

You can use the supplied tutorial code and data to experiment with Pig and HBase. You do have to create the table in the HBase Shell first to work with it from within Pig:

```
hbase(main):001:0> create 'excite', 'colfam1'
```

Starting the Pig Shell, aptly called *Grunt*, requires the *pig* script. For local testing add the `-x local` switch:

```
$ pig -x local
grunt>
```

Local mode implies that Pig is not using a separate MapReduce installation, but uses the `LocalJobRunner` that comes as part of Hadoop. It

12. Internally it uses the `RowFilter` class; see “[RowFilter](#)” (page 223).

13. The full details can be found on the [Pig setup page](#).

runs the resultant MapReduce jobs within the same process. This is useful for testing and prototyping, but should not be used for larger data sets.

You have the option to write the script beforehand in an editor of your choice, and subsequently specify it when you invoke the *pig* script. Or you can use Grunt, the Pig Shell, to enter the Pig Latin statements interactively. Ultimately, the statements are translated into one or more MapReduce jobs, but not all statements trigger the execution. Instead, you first define the steps line by line, and a call to DUMP or STORE will eventually set the job in motion.

The Pig Latin functions are case-insensitive, though commonly they are written in uppercase. Names and fields you define are case-sensitive, and so are the Pig Latin functions.

The Pig tutorial comes with a small data set that was published by Excite, and contains an anonymous user ID, a timestamp, and the search terms used on its site. The first step is to load the data into HBase using a slight transformation to generate a compound key. This is needed to enforce uniqueness for each entry:

```
grunt> raw = LOAD 'tutorial/data/excite-small.log' \
  USING PigStorage('\t') AS (user, time, query);
T = FOREACH raw GENERATE CONCAT(CONCAT(user, '\u0000'), time),
query;
grunt> STORE T INTO 'excite' USING \
org.apache.pig.backend.hadoop.hbase.HBaseStorage('colfam1:query');
...
2011-05-27 22:55:29,717 [main] INFO org.apache.pig.backend.hadoop. \
executionengine.mapReduceLayer.MapReduceLauncher - 100% complete
2011-05-27 22:55:29,717 [main] INFO org.apache.pig.tools.pig- \
stats.PigStats \
- Detected Local mode. Stats reported below may be incomplete
2011-05-27 22:55:29,718 [main] INFO org.apache.pig.tools.pig- \
stats.PigStats \
- Script Statistics:

HadoopVersion PigVersion        UserId  StartedAt      FinishedAt
Features
0.20.2      0.8.1    larsgeorge   2011-05-27 22:55:22  2011-05-27
22:55:29 UNKNOWN

Success!
```

```
Job Stats (time in seconds):
JobId Alias Feature Outputs
job_local_0002 T,raw MAP_ONLY           excite,
Input(s):
Successfully read records from: "file:///opt/pig-0.8.1/tutorial/
data/excite-small.log"
Output(s):
Successfully stored records in: "excite"

Job DAG:
job_local_0002
```

You can use the `DEFINE` statement to abbreviate the long Java package reference for the `HBaseStorage` class. For example:

```
grunt> DEFINE LoadHBaseUser org.apache.pig.backend.ha-
doop.hbase.HBaseStorage( \
'data:roles', '-loadKey');
grunt> U = LOAD 'user' USING LoadHBaseUser;
grunt> DUMP U;
...
```

This is useful if you are going to reuse the specific load or store function.

The `STORE` statement started a MapReduce job that read the data from the given logfile and copied it into the HBase table. The statement in between is changing the *relation* to generate a compound row key—which is the first field specified in the `STORE` statement afterward—which is the user and time fields, separated by a zero byte.

Accessing the data involves another `LOAD` statement, this time using the `HBaseStorage` class:

```
grunt> R = LOAD 'excite' USING \
org.apache.pig.backend.hadoop.hbase.HBaseStorage('colfam1:query',
'-loadKey') \
AS (key: chararray, query: chararray);
```

The parameters in the brackets define the column to field mapping, as well as the extra option to load the row key as the first field in relation `R`. The `AS` part explicitly defines that the row key and the `col fam1:query` column are converted to `chararray`, which is Pig's string type. By default, they are returned as `bytearray`, matching the way they are stored in the HBase table. Converting the data type allows you, for example, to subsequently split the row key.

You can test the statements entered so far by dumping the content of R, which is the result of the previous statement.

```
grunt> DUMP R;
...
Success!
...
(002BB5A52580A8ED970916150445,margaret laurence the stone angel)
(002BB5A52580A8ED970916150505,margaret laurence the stone angel)
...
```

The row key, placed as the first field in the tuple, is the concatenated representation created during the initial copying of the data from the file into HBase. It can now be split back into two fields so that the original layout of the text file is re-created:

```
grunt> S = foreach R generate FLATTEN(STRSPLIT(key, '\u0000', 2))
AS \
  (user: chararray, time: long), query;
grunt> DESCRIBE S;
S: {user: chararray, time: long, query: chararray}
```

Using DUMP once more, this time using relation S, shows the final result:

```
grunt> DUMP S;
(002BB5A52580A8ED,970916150445,margaret laurence the stone angel)
(002BB5A52580A8ED,970916150505,margaret laurence the stone angel)
...
```

With this in place, you can proceed to the remainder of the Pig tutorial, while replacing the LOAD and STORE statements with the preceding code. Concluding this example, type in QUIT to finally exit the Grunt shell:

```
grunt> QUIT;
$
```

Pig's support for HBase has a few shortcomings in the current version, though:

No version support

There is currently no way to specify any version details when handling HBase cells. Pig always returns the most recent version.

Fixed column mapping

The row key must be the first field and cannot be placed anywhere else. This can be overcome, though, with a subsequent FOREACH...GENERATE statement, reordering the relation layout.

Check with the Pig project site to see if these features have since been added.

Cascading

Cascading is an alternative API to MapReduce. Under the covers, it uses MapReduce during execution, but during development, users don't have to think in MapReduce to create solutions for execution on Hadoop.

The model used is similar to a real-world *pipe assembly*, where data sources are *taps*, and outputs are *sinks*. These are *piped* together to form the processing flow, where data passes through the pipe and is transformed in the process. Pipes can be connected to larger *pipe assemblies* to form more complex processing pipelines from existing pipes.

Data then *streams* through the pipeline and can be split, merged, grouped, or joined. The data is represented as *tuples*, forming a *tuple stream* through the assembly. This very visually oriented model makes building MapReduce jobs more like construction work, while abstracting the complexity of the actual work involved.

Cascading (as of version 1.0.1) has support for reading and writing data to and from a HBase cluster. Detailed information and access to the source code can be found on the Cascading Modules page (<http://www.cascading.org/modules.html>).

Example 6-3 shows how to *sink* data into a HBase cluster. See the GitHub repository, linked from the modules page, for more up-to-date API information.

Example 6-3. Using Cascading to insert data into HBase

```
// read data from the default filesystem
// emits two fields: "offset" and "line"
Tap source = new Hfs(new TextLine(), inputFileLhs);

// store data in a HBase cluster, accepts fields "num", "lower", and
// "upper"
// will automatically scope incoming fields to their proper family-
// name,
// "left" or "right"
Fields keyFields = new Fields("num");
String[] familyNames = {"left", "right"};
Fields[] valueFields = new Fields[] {new Fields("lower"),
    new Fields("upper") };
Tap hBaseTap = new HBaseTap("multitable", new HBaseScheme(keyFields,
    familyNames, valueFields), SinkMode.REPLACE);

// a simple pipe assembly to parse the input into fields
// a real app would likely chain multiple Pipes together for more com-
plex
```

```

// processing
Pipe parsePipe = new Each("insert", new Fields("line"),
    new RegexSplitter(new Fields("num", "lower", "upper"), " "));

// "plan" a cluster executable Flow
// this connects the source Tap and hBaseTap (the sink Tap) to the
parsePipe
Flow parseFlow = new FlowConnector(properties).connect(source, hBase-
Tap,
    parsePipe);

// start the flow, and block until complete
parseFlow.complete();

// open an iterator on the HBase table we stuffed data into
TupleEntryIterator iterator = parseFlow.openSink();

while(iterator.hasNext()) {
    // print out each tuple from HBase
    System.out.println( "iterator.next() = " + iterator.next() );
}

iterator.close();

```

Cascading to Hive and Pig offers a Java API, as opposed to the domain-specific languages (DSLs) provided by the others. There are add-on projects that provide DSLs on top of Cascading.

Other Clients

There are other client libraries that allow you to access a HBase cluster. They can roughly be divided into those that run directly on the Java Virtual Machine, and those that use the gateway servers to communicate with a HBase cluster. Here are some examples:

Clojure

The HBase-Runner project (<https://github.com/mudphone/hbase-runner/>) offers support for HBase from the functional programming language Clojure. You can write MapReduce jobs in Clojure while accessing HBase tables.

JRuby

The HBase Shell is an example of using a JVM-based language to access the Java-based API. It comes with the full source code, so you can use it to add the same features to your own JRuby code.

HBql

HBql adds an SQL-like syntax on top of HBase, while adding the extensions needed where HBase has unique features. See the project's [website](#) for details.

HBase-DSL

This project gives you dedicated classes that help when formulating queries against a HBase cluster. Using a builder-like style, you can quickly assemble all the options and parameters necessary. See its [wiki](#) online for more information.

JPA/JPO

You can use, for example, [DataNucleus](#) to put a JPA/JPO access layer on top of HBase.

PyHBase

The [PyHBase project](#) offers a HBase client through the Avro gateway server.

AsyncHBase

AsyncHBase offers a completely asynchronous, nonblocking, and thread-safe client to access HBase clusters. It uses the native RPC protocol to talk directly to the various servers. See the project's [website](#) for details.

Note that some of these projects have not seen any activity for quite some time. They usually were created to fill a need of the authors, and since then have been made public. You can use them as a starting point for your own projects.

Shell

The *HBase Shell* is the command-line interface to your HBase cluster(s). You can use it to connect to local or remote servers and interact with them. The shell provides both client and administrative operations, mirroring the APIs discussed in the earlier chapters of this book.

Basics

The first step to experience the shell is to start it:

```
$ $HBASE_HOME/bin/hbase shell
HBase Shell; enter 'help<RETURN>' for list of supported commands.
Type "exit<RETURN>" to leave the HBase Shell
Version 1.0.0, r6c98bfff7b719efdb16f71606f3b7d8229445eb81, \
  Sat Feb 14 19:49:22 PST 2015

hbase(main):001:0>
```

The shell is based on *JRuby*, the Java Virtual Machine-based implementation of [Ruby](#). More specifically, it uses the *Interactive Ruby Shell* (IRB), which is used to enter Ruby commands and get an immediate response. HBase ships with Ruby scripts that extend the IRB with specific commands, related to the Java-based APIs. It inherits the built-in support for command history and completion, as well as all Ruby commands.

There is no need to install Ruby on your machines, as HBase ships with the required JAR files to execute the JRuby shell. You use the supplied script to start the shell on top of Java, which is already a necessary requirement.

Once started, you can type in `help`, and then press Return, to get the help text (shown abbreviated):

```
hbase(main):001:0> help
HBase          Shell,           version      1.0.0,
r6c98bff7b719efdb16f71606f3b7d8229445eb81, \
Sat Feb 14 19:49:22 PST 2015
Type 'help "COMMAND"', (e.g. 'help "get"' -- the quotes are necessary) \
    for help on a specific command.
Commands are grouped. Type 'help "COMMAND_GROUP"', (e.g. 'help "general"' ) \
    for help on a command group.

COMMAND GROUPS:
Group name: general
Commands: status, table_help, version, whoami

Group name: ddl
Commands: alter, alter_async, alter_status, create, describe,
disable, \
    disable_all, drop, drop_all, enable, enable_all, exists,
get_table, \
    is_disabled, is_enabled, list, show_filters
...

SHELL USAGE:
Quote all names in HBase Shell such as table and column names.
Commas
delimit command parameters. Type <RETURN> after entering a command to
run it.
Dictionaries of configuration used in the creation and alteration
of tables
```

are Ruby Hashes. They look like this:

...

As stated, you can request help for a specific command by adding the command when invoking help, or print out the help of all commands for a specific group when using the group name with the `help` command. The optional *command* or *group name* has to be enclosed in quotes.

You can leave the shell by entering `exit`, or `quit`:

```
hbase(main):002:0> exit
$
```

The shell also has specific command-line options, which you can see when adding the `-h`, or `--help`, switch to the command:

```
$ $HBASE_HOME/bin/hbase shell -h
Usage: shell [OPTIONS] [SCRIPTFILE [ARGUMENTS]]

--format=OPTION           Formatter for outputting results.
                          Valid options are: console, html.
                          (Default: console)

-d | --debug              Set DEBUG log levels.
-h | --help                This help.
```

Debugging

Adding the `-d`, or `--debug` switch, to the shell's start command enables the *debug* mode, which switches the logging levels to DEBUG, and lets the shell print out any *backtrace* information—which is similar to *stacktraces* in Java.

Once you are inside the shell, you can use the `debug` command to toggle the debug mode:

```
hbase(main):001:0> debug
Debug mode is ON

hbase(main):002:0> debug
Debug mode is OFF
```

You can check the status with the `debug?` command:

```
hbase(main):003:0> debug?
Debug mode is OFF
```

Without the debug mode, the shell is set to print only ERROR-level messages, and no backtrace details at all, on the console.

There is an option to switch the formatting being used by the shell. As of this writing, only `console` is available, though, albeit the CLI help (using `-h` for example) stating that `html` is supported as well. Trying to set anything but `console` will yield an error message.

The shell start script automatically uses the configuration directory located in the same `$HBASE_HOME` directory. You can override the location to use other settings, but most importantly to connect to different clusters. Set up a separate directory that contains an `hbase-site.xml` file, with an `hbase.zookeeper.quorum` property pointing to another cluster, and start the shell like so:

```
$ HBASE_CONF_DIR="/<your-other-config-dir>/" bin/hbase shell
```

Note that you have to specify an entire directory, *not* just the `hbase-site.xml` file.

Commands

The commands are grouped into five different categories, representing their semantic relationships. When entering commands, you have to follow a few guidelines:

Quote Names

Commands that require a table or column name expect the name to be quoted in either single or double quotes. Common advice is to use single quotes.

Quote Values

The shell supports the output and input of binary values using a hexadecimal—or octal—representation. You *must* use double quotes or the shell will interpret them as literals.

```
hbase> get 't1', "key\x00\x6c\x65\x6f\x6e"  
hbase> get 't1', "key\000\154\141\165\162\141"  
hbase> put 't1', "test\xef\xff", 'f1:', "\x01\x33\x70"
```

Note the mixture of quotes: you need to make sure you use the correct ones, or the result might not be what you had expected. Text in single quotes is treated as a literal, whereas double-quoted text is *interpolated*, that is, it transforms the octal or hexadecimal values into bytes.

Comma Delimiters for Parameters

Separate command parameters using commas. For example:

```
hbase(main):001:0> get 'testtable', 'row-1', 'colfam1:qual1'
```

Ruby Hashes for Properties

For some commands, you need to hand in a map with *key/value* properties. This is done using Ruby hashes:

```
{'key1' => 'value1', 'key2' => 'value2', ...}
```

The keys/values are wrapped in curly braces, and in turn are separated by "`=>`" (the *hash rocket*, or *fat comma*). Usually keys are predefined constants such as `NAME`, `VERSIONS`, or `COMPRESSION`, and do not need to be quoted. For example:

```
hbase(main):001:0> create 'testtable', { NAME => 'colfam1', VERSIONS => 1, \ TTL => 2592000, BLOCKCACHE => true }
```

Restricting Output

The `get` command has an optional parameter that you can use to restrict the printed values by length. This is useful if you have many columns with values of varying length. To get a quick overview of the actual columns, you could suppress any longer value being printed in full—which on the console can get unwieldy very quickly otherwise.

In the following example, a very long value is inserted and subsequently retrieved with a restricted length, using the `MAXLENGTH` parameter:

The **MAXLENGTH** is counted from the start of the row, that is, it includes the column name. Set it to the width (or slightly less) of your console to fit each column into one line.

For any command, you can get detailed help by typing in `help <command>`. Here is an example:

```
hbase(main):001:0> help 'status'  
Show cluster status. Can be 'summary', 'simple', 'detailed', or
```

```
'replication'. The  
default is 'summary'. Examples:
```

```
hbase> status  
hbase> status 'simple'  
hbase> status 'summary'  
hbase> status 'detailed'  
hbase> status 'replication'  
hbase> status 'replication', 'source'  
hbase> status 'replication', 'sink'
```

The majority of commands have a direct match with a method provided by either the client or administrative API. Next is a brief overview of each command and the matching API functionality. They are grouped by their purpose, and aligned with how the shell groups the command:

Table 6-3. Command Groups in HBase Shell

Group	Description
<i>general</i>	Comprises general commands that do not fit into any other category, for example <code>status</code> .
<i>configuration</i>	Some configuration properties can be changed at runtime, and reloaded with these commands.
<i>ddl</i>	Contains all commands for <i>data-definition</i> tasks, such as creating a table.
<i>namespace</i>	Similar to the former, but for namespace related operations.
<i>dml</i>	Has all the <i>data-manipulation</i> commands, which are used to insert or delete data, for example.
<i>snapshots</i>	Tables can be saved using snapshots, which are created, deleted, restored, etc. using commands from this group.
<i>tools</i>	There are tools supplied with the shell that can help run expert-level, cluster wide operations.
<i>replication</i>	All replication related commands are within this group, for example, adding a peer cluster.
<i>security</i>	The contained commands handle security related tasks.
<i>visibility labels</i>	These commands handle cell label related functionality, such as adding or listing labels.

You can use any of the group names to get detailed help using the same help '`<groupname>`' syntax, as shown above for the help of a specific command. For example, typing in `help ddl` will print out the full help text for the data-definition commands.

General Commands

The *general* commands are listed in [Table 6-4](#). They allow you, for example, to retrieve details about the status of the cluster itself, and the version of HBase it is running.

Table 6-4. General Shell Commands

Command	Description
status	Returns various levels of information contained in the <code>ClusterStatus</code> class. See the help to get the <code>simple</code> , <code>summary</code> , and <code>detailed</code> status information.
version	Returns the current version, repository revision, and compilation date of your HBase cluster. See <code>ClusterStatus.getHBaseVersion()</code> in Table 5-8 .
table_help	Prints a help text explaining the usage of table references in the Ruby shell.
whoami	Shows the current OS user and group membership known to HBase about the shell user.

Running `status` without any qualifier is the same as executing `status 'summary'`, both printing the number of active and dead servers, as well as the average load. The latter is the average number of regions each region server holds. The `status 'simple'` prints out details about the active and dead servers, which is their unique name, and for the active ones also their high-level statistics, similar to what is shown in the region server web-UI, containing the number of requests, heap details, disk- and memstore information, and so on. Finally, the *detailed* version of the `status` is, in addition to the above, printing details about every region currently hosted by the respective servers. See the `ClusterStatus` class in [“Cluster Status Information” \(page 411\)](#) for further details.

We will look into the features shown with `table_help` in [“Scripting” \(page 497\)](#). The `whoami` command is particularly useful when the cluster is running in secure mode (see [\(to come\)](#)). In non-secure mode the output is very similar to running the `id` and `whoami` commands in a terminal window, that is, they print out the ID of the current user and associated groups:

```
hbase(main):001:0> whoami
larsgeorge (auth:SIMPLE)
groups: staff, ..., admin, ...
```

Another set of general commands are related to updating the server configurations at runtime. [Table 6-5](#) lists the available shell commands.

Table 6-5. Configuration Commands

Commands	Description
update_config	Update the configuration for a particular server. The name must be given as a valid server name.
update_all_config	Updates all region servers.

You can use the `status` command to retrieve a list of servers, and with those names invoke the update command. Note though, that you need to slightly tweak the formatting of the emitted names: the components of a server name (as explained in “[Server and Region Names](#)” ([page 356](#))) are divided by *commas*, not colon or space. The following example shows this used together:

```
hbase(main):001:0> status 'simple'
1 live servers
  127.0.0.1:62801 1431177060772
...
Aggregate load: 0, regions: 4

hbase(main):002:0> update_config '127.0.0.1,62801,1431177060772'
0 row(s) in 0.1290 seconds

hbase(main):003:0> update_all_config
0 row(s) in 0.0560 seconds
```

Namespace and Data Definition Commands

The *namespace* group of commands provides the shell functionality explained in “[Namespaces](#)” ([page 347](#)), which is handling the creation, modification, and removal of namespaces. [Table 6-6](#) lists the available commands.

Table 6-6. Namespace Shell Commands

create_namespace	Creates a namespace with the provided name.
drop_namespace	Removes the namespace, which must be empty, that is, it must <i>not</i> contain any tables.
alter_namespace	Changes the namespace details by altering its configuration properties.
describe_namespace	Prints the details of an existing namespace.
list_namespace	Lists all known namespaces.
list_namespace_tables	Lists all tables contained in the given namespace.

The *data definition* commands are listed in [Table 6-7](#). Most of them stem from the administrative API, as described in [Chapter 5](#).

Table 6-7. Data Definition Shell Commands

Command	Description
alter	Modifies an existing table schema using <code>modifyTable()</code> . See “ Schema Operations ” (page 391) for details.
alter_async	Same as above, but returns immediately without waiting for the changes to take effect.
alter_status	Can be used to query how many regions have the changes applied to them. Use this after making asynchronous alterations.
create	Creates a new table. See the <code>createTable()</code> call in “ Table Operations ” (page 378) for details.
describe	Prints the <code>HTableDescriptor</code> . See “ Tables ” (page 350) for details. A shortcut for this command is <code>desc</code> .
disable	Disables a table. See “ Table Operations ” (page 378) and the <code>disableTable()</code> method.
disable_all	Uses a regular expression to disable all matching tables in a single command.
drop	Drops a table. See the <code>deleteTable()</code> method in “ Table Operations ” (page 378).
drop_all	Drops all matching tables. The parameter is a regular expression.
enable	Enables a table. See the <code>enableTable()</code> call in “ Table Operations ” (page 378) for details.
enable_all	Using a regular expression to enable all matching tables.
exists	Checks if a table exists. It uses the <code>tableExists()</code> call; see “ Table Operations ” (page 378).
is_disabled	Checks if a table is disabled. See the <code>isTableDisabled()</code> method in “ Table Operations ” (page 378).
is_enabled	Checks if a table is enabled. See the <code>isTableEnabled()</code> method in “ Table Operations ” (page 378).
list	Returns a list of all user tables. Uses the <code>listTables()</code> method, described in “ Table Operations ” (page 378).
show_filters	Lists all known filter classes. See “ Filter Parser Utility ” (page 269) for details on how to register custom filters.
get_table	Returns a table reference that can be used in scripting. See “ Scripting ” (page 497) for more information.

The commands ending in `_all` accept a regular expression that applies the command to all matching tables. For example, assuming you have one table in the system named `test` and using the catch-all regular expression of `".*"` you will see the following interaction:

```
hbase(main):001:0> drop_all '.*'
test
```

```

Drop the above 1 tables (y/n)?
y
1 tables successfully dropped

hbase(main):002:0> drop_all '.*'
No tables matched the regex .*

```

Note how the command is confirming the operation before executing it—better safe than sorry.

Data Manipulation Commands

The *data manipulation* commands are listed in [Table 6-8](#). Most of them are provided by the client API, as described in Chapters [Chapter 3](#) and [Chapter 4](#).

Table 6-8. Data Manipulation Shell Commands

Command	Description
put	Stores a cell. Uses the Put class, as described in “Put Method” (page 122) .
get	Retrieves a cell. See the Get class in “Get Method” (page 146) .
delete	Deletes a cell. See “Delete Method” (page 168) and the Delete class.
deleteall	Similar to delete but does not require a column. Deletes an entire family or row. See “Delete Method” (page 168) and the Delete class.
append	Allows to append data to cells. See “Append Method” (page 181) for details.
incr	Increments a counter. Uses the Increment class; see “Counters” (page 273) for details.
get_counter	Retrieves a counter value. Same as the get command but converts the raw counter value into a readable number. See the Get class in “Get Method” (page 146) .
scan	Scans a range of rows. Relies on the Scan class. See “Scans” (page 193) for details.
count	Counts the rows in a table. Uses a Scan internally, as described in “Scans” (page 193) .
truncate	Truncates a table, which is the same as executing the disable and drop commands, followed by a create, using the same schema. See “Table Operations” (page 378) and the truncateTable() method for details.
truncate_preserve	Same as the previous command, but retains the regions with their start and end keys.

Many of the commands have extensive optional parameters, please make sure you consult their help within the shell. Some of the commands support *visibility labels*, which will be covered in (to come).

Formatting Binary Data

When printing cell values during a get operation, the shell implicitly converts the binary data using the `Bytes.toStringBinary()` method. You can change this behavior on a per column basis by specifying a different formatting method. The method has to accept a `byte[]` array and return a printable representation of the value. It is defined as part of the column *name*, which is handed in as an optional parameter to the get call:

```
<column family>[:<column qualifier>[:format method]]
```

For a get call, you can omit *any* column details, but if you do add them, they can be as detailed as just the column family, or the family and the column qualifier. The third optional part is the format method, referring to either a method from the `Bytes` class, or a custom class and method. Since this implies the presence of both the family and qualifier, it means you can only specify a format method for a specific column—and not for an entire column family, or even the full row. [Table 6-9](#) lists the two options with examples.

Table 6-9. Possible Format Methods

Method	Examples	Description
<i>Bytes Method</i>	<code>toInt</code> , <code>toLong</code>	Refers to a known method from the <code>Bytes</code> class.
<i>Custom Method</i>	<code>c(CustomFormat Class).format</code>	Specifies a custom class and method converting <code>byte[]</code> to text.

The *Bytes Method* is simply shorthand for specifying the `Bytes` class explicitly, for example, `colfam:qual:c(org.apache.hadoop.hbase.util.Bytes).toInt` is the same as `colfam:qual:toInt`. The following example uses a variety of commands to showcase the discussed:

```
hbase(main):001:0> create 'testtable', 'colfam1'
0 row(s) in 0.2020 seconds

=> Hbase::Table - testtable

hbase(main):002:0> incr 'testtable', 'row-1', 'colfam1:cnt1'
0 row(s) in 0.0580 seconds
```

```

hbase(main):003:0> get_counter 'testtable', 'row-1', 'col
fam1:cnt1', 1
COUNTER VALUE = 1

hbase(main):004:0> get 'testtable', 'row-1', 'colfam1:cnt1'
COLUMN          CELL
    colfam1:cnt1           timestamp=...,      value=
\x00\x00\x00\x00\x00\x00\x00\x01
1 row(s) in 0.0150 seconds

hbase(main):005:0> get 'testtable', 'row-1', { COLUMN => 'col
fam1:cnt1' }
COLUMN          CELL
    colfam1:cnt1           timestamp=...,      value=
\x00\x00\x00\x00\x00\x00\x00\x01
1 row(s) in 0.0160 seconds

hbase(main):006:0> get 'testtable', 'row-1', \
{ COLUMN => ['colfam1:cnt1:toLong'] }
COLUMN          CELL
    colfam1:cnt1 timestamp=..., value=1
1 row(s) in 0.0050 seconds

hbase(main):007:0> get 'testtable', 'row-1', 'colfam1:cnt1:tol
ong'
COLUMN          CELL
    colfam1:cnt1 timestamp=..., value=1
1 row(s) in 0.0060 seconds

```

The example shell commands create a table, and increment a counter, which results in a Long value of 1 stored inside the increment column. When we retrieve the column we usually see the eight bytes comprising the value. Since counters are supported by the shell we can use the `get_counter` command to retrieve a readable version of the cell value. The other option is to use a `format` method to convert the binary value. By adding the `:toLong` parameter, we instruct the shell to print the value as a human readable number instead. The example commands also show how `{ COLUMN => 'colfam1:cnt1' }` is the same as its shorthand `'colfam1:cnt1'`. The former is useful when adding other options to the column specification.

Snapshot Commands

These commands reflect the administrative API functionality explained in “[Table Operations: Snapshots](#)” (page 401). They allow to take a snapshot of a table, restore or clone it subsequently, list all available snapshots, and more. The commands are listed in [Table 6-10](#).

Table 6-10. Snapshot Shell Commands

Command	Description
snapshot	Creates a snapshot. Use the SKIP_FLUSH => true option to <i>not</i> flush the table before the snapshot.
clone_snapshot	Clones an existing snapshot into a new table.
restore_snapshot	Restores a snapshot under the same table name as it was created.
delete_snapshot	Deletes a specific snapshot. The given name must match the name of a previously created snapshot.
delete_all_snapshot	Deletes all snapshots using a regular expression to match any number of names.
list_snapshots	Lists all snapshots that have been created so far.

Creating a snapshot lets you specify the *mode* like the API does, that is, if you want to first force a *flush* of the table's in-memory data (the default behavior), or if you want to only snapshot the files that are already on disk. The following example shows this using a test table:

```

hbase(main):001:0> create 'testtable', 'colfam1'
0 row(s) in 0.4950 seconds

=> Hbase::Table - testtable

hbase(main):002:0> for i in 'a'..'z' do \
    for j in 'a'..'z' do put 'testtable', "row-#{i}#{j}", "col
fam1:#{j}", \
    "#{j}" end end

0 row(s) in 0.0830 seconds

0 row(s) in 0.0070 seconds

...
hbase(main):003:0> count 'testtable'
676 row(s) in 0.1620 seconds

=> 676

hbase(main):004:0> snapshot 'testtable', 'snapshot1', \
    { SKIP_FLUSH => true }
0 row(s) in 0.4300 seconds

hbase(main):005:0> snapshot 'testtable', 'snapshot2'
0 row(s) in 0.3180 seconds

hbase(main):006:0> list_snapshots
SNAPSHOT      TABLE + CREATION TIME

```

```

snapshot1      testtable (Sun May 10 20:05:11 +0200 2015)
snapshot2      testtable (Sun May 10 20:05:18 +0200 2015)
2 row(s) in 0.0560 seconds

=> ["snapshot1", "snapshot2"]

hbase(main):007:0> disable 'testtable'
0 row(s) in 1.2010 seconds

hbase(main):008:0> restore_snapshot 'snapshot1'
0 row(s) in 0.3430 seconds

hbase(main):009:0> enable 'testtable'
0 row(s) in 0.1920 seconds

hbase(main):010:0> count 'testtable'
0 row(s) in 0.0130 seconds

=> 0

hbase(main):011:0> disable 'testtable'
0 row(s) in 1.1920 seconds

hbase(main):012:0> restore_snapshot 'snapshot2'
0 row(s) in 0.4710 seconds

hbase(main):013:0> enable 'testtable'
0 row(s) in 0.3850 seconds

hbase(main):014:0> count 'testtable'
676 row(s) in 0.1670 seconds

=> 676

```

Note how we took two snapshots, first one with the `SKIP_FLUSH` option set, causing the table to not be flushed before the snapshot is created. Since the table is new and not flushed at all yet, the snapshot will have no data in it. The second snapshot is taken with the default flushing enabled, and subsequently we test both snapshots by recreating the table in place with the `restore_snapshot` command. Using the `count` command we test both and see how the first is indeed empty, and the second contains the correct amount of rows.

Tool Commands

The `tools` commands are listed in [Table 6-11](#). These commands are provided by the administrative API; see “[Cluster Operations](#)” ([page 393](#)) for details. Many of these commands are very low-level, that is, they may apply disruptive actions. Please make sure to carefully read the shell help for each command to understand their impact.

Table 6-11. Tools Shell Commands

Command	Description
assign	Assigns a region to a server. See “Cluster Operations” (page 393) and the <code>assign()</code> method.
balance_switch	Toggles the balancer switch. See “Cluster Operations” (page 393) and the <code>balanceSwitch()</code> method.
balancer	Starts the balancer. See “Cluster Operations” (page 393) and the <code>balancer()</code> method.
close_region	Closes a region. Uses the <code>closeRegion()</code> method, as described in “Cluster Operations” (page 393).
compact	Starts the asynchronous compaction of a region or table. Uses <code>compact()</code> , as described in “Cluster Operations” (page 393).
compact_rs	Compact all regions of a given region server. The optional boolean flag decided between major and minor compactions.
flush	Starts the asynchronous flush of a region or table. Uses <code>flush()</code> , as described in “Cluster Operations” (page 393).
major_compact	Starts the asynchronous major compaction of a region or table. Uses <code>majorCompact()</code> , as described in “Cluster Operations” (page 393).
move	Moves a region to a different server. See the <code>move()</code> call, and “Cluster Operations” (page 393) for details.
split	Splits a region or table. See the <code>split()</code> call, and “Cluster Operations” (page 393) for details.
merge_region	Merges two regions, specified as hashed names. The optional boolean flag allows merging of non-subsequent regions.
unassign	Unassigns a region. See the <code>unassign()</code> call, and “Cluster Operations” (page 393) for details.
wal_roll	Rolls the WAL, which means close the current and open a new one. ^a
catalogjanitor_run	Runs the system catalog janitor process, which operates in the background and cleans out obsolete files etc. See “Server Operations” (page 409) for details.
catalogjanitor_switch	Toggles the system catalog janitor process, either enabling or disabling it. See “Server Operations” (page 409) for details.
catalogjanitor_enabled	Returns the status of the catalog janitor background process. See “Server Operations” (page 409) for details.
zk_dump	Dumps the ZooKeeper details pertaining to HBase. This is a special function offered by an internal class. The web-based UI of the HBase Master exposes the same information.
trace	Starts or stops a trace, using the <i>HTrace</i> framework. See (to come) for details.

^a Renamed from `hlog_roll` in earlier versions.

Replication Commands

The replication commands are listed in [Table 6-12](#), and are explained in detail in “[ReplicationAdmin](#)” (page 422) and (to come).

Table 6-12. Replication Shell Commands

Command	Description
add_peer	Adds a replication peer.
remove_peer	Removes a replication peer.
enable_peer	Enables a replication peer.
disable_peer	Disables a replication peer.
list_peers	List all previously added peers.
list_replicated_tables	Lists all tables and column families that have replication enabled on the current cluster.
set_peer_tableCFs	Sets specific column families that should be replicated to the given peer.
append_peer_tableCFs	Adds the given column families to the specified peer’s list of replicated column families.
remove_peer_tableCFs	Removes the given list of column families from the list of replicated families for the given peer.
show_peer_tableCFs	Lists the currently replicated column families for the given peer.

Some commands have been removed recently, namely `start_replication` and `stop_replication` (as of HBase 0.98.0 and 0.95.2, see [HBASE-8861](#)), and others added, like the column families per table options (as of HBase 1.0.0 and 0.98.1, see [HBASE-8751](#)).

The majority of the commands expect a peer ID, to apply the respective functionality to a specific peer configuration. You can add a peer, remove it subsequently, enable or disable the replication for an existing peer, and list all known peers or replicated tables. In addition, you can set the desired column families per table per peer that should be replicated. This only applies to column families with the replication scope set to 1, and allows to limit which are shipped to a specific peer. The remaining commands add column families to an exiting per table per peer list, remove some or all from it, and list the current configuration.

The `list_replicated_tables` accepts an optional regular expression that allows to filter the matching tables. It uses the `listReplicated()`

method of the `ReplicationAdmin` class to retrieve the list first. It either prints all contained tables, or the ones matching the given expression.

Security Commands

This group of commands can be split into two, first the *access control list*, and then the *visibility label* related ones. With the former group you can grant, revoke, and list the user permissions. Note though that these commands are only applicable if the `AccessController` coprocessor was enabled. See (to come) for all the details on these commands, how they work, and the required cluster configuration.

Table 6-13. Security Shell Commands

Command	Description
<code>grant</code>	Grant the named access rights to the given user.
<code>revoke</code>	Revoke the previously granted rights of a given user.
<code>user_permission</code>	Lists the current permissions of a user. The optional regular expression filters the list.

The second group of security related commands address the cell-level visibility labels, explained in (to come). Note again that you need some extra configuration to make these work, here the addition of the `VisibilityController` coprocessor to the server processes.

Table 6-14. Visibility Label Shell Commands

Command	Description
<code>add_labels</code>	Adds a list of visibility labels to the system.
<code>list_labels</code>	Lists all previously defined labels. An optional regular expression can be used to filter the list.
<code>set_auths</code>	Assigns the given list of labels to the provided user ID.
<code>get_auths</code>	Returns the list of assigned labels for the given user.
<code>clear_auths</code>	Removes all or only the specified list of labels from the named user.
<code>set_visibility</code>	Adds a visibility expression to one or more cell.

Scripting

Inside the shell, you can execute the provided commands interactively, getting immediate feedback. Sometimes, though, you just want to send one command, and possibly script this call from the scheduled maintenance system (e.g., cron or at). Or you want to send a command in response to a check run in Nagios, or another monitoring tool. You can do this by *piping* the command into the shell:

```
$ echo "status" | bin/hbase shell
HBase Shell; enter 'help<RETURN>' for list of supported commands.
Type "exit<RETURN>" to leave the HBase Shell
Version 1.0.0, r6c98bfff7b719efdb16f71606f3b7d8229445eb81, \
Sat Feb 14 19:49:22 PST 2015

status
1 servers, 2 dead, 3.0000 average load
```

Once the command is complete, the shell is closed and control is given back to the caller. Finally, you can hand in an entire script to be executed by the shell at startup:

```
$ cat ~/hbase-shell-status.rb
status
$ bin/hbase shell ~/hbase-shell-status.rb
1 servers, 2 dead, 3.0000 average load

HBase Shell; enter 'help<RETURN>' for list of supported commands.
Type "exit<RETURN>" to leave the HBase Shell
Version 1.0.0, r6c98bfff7b719efdb16f71606f3b7d8229445eb81, Sat Feb
14 19:49:22 PST 2015

hbase(main):001:0> exit
```

Once the script has completed, you can continue to work in the shell or exit it as usual. There is also an option to execute a script using the raw JRuby interpreter, which involves running it directly as a Java application. The `hbase` script sets up the class path to be able to use any Java class necessary. The following example simply retrieves the list of tables from the remote cluster:

```
$ cat ~/hbase-shell-status-2.rb
include Java
import org.apache.hadoop.hbase.HBaseConfiguration
import org.apache.hadoop.hbase.client.HBaseAdmin
import org.apache.hadoop.hbase.client.ConnectionFactory

conf = HBaseConfiguration.create
connection = ConnectionFactory.createConnection(conf)

admin = connection.getAdmin
tables = admin.listTables
tables.each { |table| puts table.getNameAsString() }
```

\$ bin/hbase org.jruby.Main ~/hbase-shell-status-2.rb
testtable

Since the shell is based on JRuby's IRB, you can use its built-in features, such as command completion and history. Enabling or configuring them is a matter of creating an `.irbrc` in your home directory, which is read when the shell starts:

```
$ cat ~/.irbrc
require 'irb/ext/save-history'
IRB.conf[:SAVE_HISTORY] = 100
IRB.conf[:HISTORY_FILE] = "#{ENV['HOME']}/.irb-save-history"
Kernel.at_exit do
  IRB.conf[:AT_EXIT].each do |i|
    i.call
  end
end
```

This enables the command history to save across shell starts. The command completion is already enabled by the HBase scripts. An additional advantage of the interactive interpreter is that you can use the HBase classes and functions to perform, for example, something that would otherwise require you to write a Java application. Here is an example of binary output received from a `Bytes.toBytes()` call that is converted into an integer value:

```
hbase(main):001:0>
org.apache.hadoop.hbase.util.Bytes.toInt( \
"\x00\x01\x06[".to_java_bytes)
=> 67163
```

Note how the shell encoded the first three unprintable characters as hexadecimal values, while the fourth, the "[", was printed as a character. Another example is to convert a date into a Linux epoch number, and back into a human-readable date:

```
hbase(main):002:0> java.text.SimpleDateFormat.new("yyyy/MM/dd
HH:mm:ss"). \
parse("2015/05/12 20:56:29").getTime
=> 1431456989000

hbase(main):002:0> java.util.Date.new(1431456989000).toString
=> "Tue May 12 20:56:29 CEST 2015"
```

You can also add many cells in a loop—for example, to populate a table with test data (which we used earlier but did not explain):

```
hbase(main):003:0> for i in 'a'..'z' do for j in 'a'..'z' do \
  put 'testtable', "row-#{i}##{j}", "colfam1:#{j}", "#{j}" end end
```

A more elaborate loop to populate counters could look like this:

```
hbase(main):004:0> require 'date';
import java.lang.Long
import org.apache.hadoop.hbase.util.Bytes
(Date.new(2011, 01, 01)..Date.today).each { |x| put "testtable",
"daily", \
"colfam1:" + x.strftime("%Y%m%d"), Bytes.toBytes(Long.new(rand *
4000).longValue).to_a.pack("CCCCCCCC") }
```

The shell's JRuby code wraps many of the Java classes, such as Table or Admin, into its own versions, making access to their functionality more amenable. A result is that you can use these classes to your advantage when performing more complex scripting tasks. If you execute the `table_help` command you can access the built-in help text on how to make use of the shell's wrapping classes, and in particular the `table` reference. You may have wondered up to now why the shell sometimes responds with the ominous hash rocket, or fat comma, when executing certain commands like `create`:

```
hbase(main):005:0> create 'testtable', 'colfam1'  
0 row(s) in 0.1740 seconds  
  
=> Hbase::Table - testtable
```

The `create` command really returns a reference to you, pointing to an instance of `Hbase::Table`, which in turn references the newly created `testtable`. We can make use of this reference by storing it in a variable and using the shell's *double tab* feature to retrieve all the possible functions it exposes:

You will have to remove the test table between these steps, or keep adding new tables by adding a number post-fix, to prevent the (obvious) error message that the table already exists. For the former, use `disable 'testtable'` and `drop 'testtable'` to remove the table between these steps, or to clean up from earlier test.

```
hbase(main):006:0> tbl = create 'testtable', 'colfam1'  
0 row(s) in 0.1520 seconds  
  
=> Hbase::Table - testtable  
hbase(main):006:0> tbl. TAB TAB  
...  
tbl.append                      tbl.close  
tbl.delete                       tbl.describe  
tbl.deleteall                     ...  
tbl.disable  
  
...  
tbl.help                         tbl.incr  
tbl.name                          ...  
tbl.put                           ...  
tbl.table                         ...  
...  
...
```

The above is shortened and condensed for the sake of readability. You can see though how the `table` Ruby class (here printed under its vari-

able name `tbl`) is exposing all of the shell commands with the same name. For example, the `put` command really is a shortcut to the `table.put` method. The `table.help` prints out the same as `table_help`, and the `table.table` is the reference to the Java Table instance. We will use the later to access the native API when no other choice is left.

Another way to retrieve the same Ruby table reference is using the `get_table` command, which is useful if the table already exists:

```
hbase(main):006:0> tbl = get_table 'testtable'
0 row(s) in 0.0120 seconds

=> Hbase::Table - testtable
```

Once you have the reference you can invoke any command using the matching method, without having to enter the table name again:

```
hbase(main):007:0> tbl.put 'row-1', 'colfam1:qual1', 'val1'
0 row(s) in 0.0050 seconds
```

This inserts the given value into the named row and column of the test table. The same way you can access the data:

```
hbase(main):008:0> tbl.get 'row-1'
COLUMN           CELL
 colfam1:qual1  timestamp=1431506646925, value=val1
1 row(s) in 0.0390 seconds
```

You can also invoke `tbl.scan` etc. to read the data. All the commands that are table related, that is, they start with a table name as the first parameter, should be available using the table reference syntax. Type in `tbl.help '<command>'` to see the shell's built-in help for the command, which usually includes examples for the reference syntax as well.

General administrative actions are also available directly on a table, for example, enable, disable, flush, and drop by typing `tbl.enable`, `tbl.flush`, and so on. Note that after dropping a table, your reference to it becomes useless and further usage is undefined (and not recommended).

And lastly, another example around the custom serialization and formatting. Assume you have saved Java objects into a table, and want to recreate the instance on-the-fly, printing out the textual representation of the stored object. As you have seen above, you can provide a custom format method when retrieving columns with the `get` command. In addition, HBase already ships with the [Apache Commons Lang](#) artifacts to use the included `SerializationUtils` class. It has a static `serialize()` and `deserialize()` method, which can handle any

Java object that implements the `Serializable` interface. The following example goes deep into the bowls of the shell, since we have to create our own `Put` instance. This is needed, because the provided `put` shell command assumes the value is a string. For our example to work, we need access to the raw `Put` class methods instead:

```
hbase(main):004:0> import org.apache.commons.lang.SerializationU  
tills  
=> Java:::OrgApacheCommonsLang::SerializationUtils  
  
hbase(main):002:0> create 'testtable', 'colfam1'  
0 row(s) in 0.1480 seconds  
  
hbase(main):003:0> p = org.apache.hadoop.hbase.client. \  
Put.new("row-1000".to_java_bytes)  
=> #<Java:::OrgApacheHadoopHbaseClient::Put:0x6d6bc0eb>  
  
hbase(main):004:0> p.addColumn("colfam1".to_java_bytes,  
"qual1".to_java_bytes, \  
SerializationUtils.serialize(java.util.ArrayList.new([1,2,3])))  
=> #<Java:::OrgApacheHadoopHbaseClient::Put:0x6d6bc0eb>  
  
hbase(main):005:0> t.table.put(p)  
  
hbase(main):006:0> scan 'testtable'  
ROW COLUMN+CELL  
row-1000 column=colfam1:qual1, timestamp=1431353253936, \  
value=\xAC\xED\x00\x05sr\x00\x13java.util.ArrayList\x81\xD2\x1D  
\x99... \  
\x03sr\x00\x0Ejava.lang.Long;\x8B\xE4\x90\xCC\x8F#\xFDF  
\x02\x00\x01... \  
\x10java.lang.Number\x86\xAC\x95\x1D\x0B\x94\xE0\x8B  
\x02\x00\x00xp...  
1 row(s) in 0.0340 seconds  
  
hbase(main):007:0> get 'testtable', 'row-1000', \  
'colfam1:qual1:c(SerializationUtils).deserialize'  
COLUMN CELL  
colfam1:qual1 timestamp=1431353253936, value=[1, 2, 3]  
1 row(s) in 0.0360 seconds  
  
hbase(main):008:0> p.addColumn("colfam1".to_java_bytes, \  
"qual1".to_java_bytes, SerializationUtils.serialize( \  
java.util.ArrayList.new(["one", "two", "three"])))  
=> #<Java:::OrgApacheHadoopHbaseClient::Put:0x6d6bc0eb>  
hbase(main):009:0> t.table.put(p)  
hbase(main):010:0> scan 'testtable'  
ROW COLUMN+CELL  
row-1000 column=colfam1:qual1, timestamp=1431353620544, \  
value=\xAC\xED\x00\x05sr\x00\x13java.util.ArrayList\x81\xD2\x1D  
\x99 \  
\xC7a\x9D\x03\x00\x01I\x00\x04sizep\x00\x00\x00\x03w
```

```

\x04\x00\x00\x00 \
\x03t\x00\x03onet\x00\x03twot\x00\x05threex
1 row(s) in 0.4470 seconds

hbase(main):011:0> get 'testtable', 'row-1000', \
  'colfam1:qual1:c(SerializationUtils).deserialize'
COLUMN          CELL
  colfam1:qual1  timestamp=1431353620544, value=[one, two, three]
1 row(s) in 0.0190 seconds

```

First we import the already known (that is, they are already on the class path of the HBase Shell) Apache Commons Lang class, and then create a test table, followed by a custom Put instance. We set the put instance twice, once with a serialized array list of numbers, and then with an array list of strings. After each we call the `put()` method of the wrapped Table instance, and scan the content to verify the serialized content.

After each serialization we call the `get` command, with the custom format method pointing to the `deserialize()` method. It parses the raw bytes back into a Java object, which is then printed subsequently. Since the shell applies a `toString()` call, we see the original content of the array list printed out that way, for example, `[one, two, three]`. This confirms that we can recreate the serialized Java objects (and even set it as shown) directly within the shell.

This example could be ported, for example, to Avro, so that you can print the content of a serialized column value directly within the shell. What is needed is already on the class path, including the Avro artifacts. Obviously, this is getting very much into Ruby and Java itself. But even with a little bit of programming skills in another language, you might be able to use the features of the IRB-based shell to your advantage. Start easy and progress from there.

Web-based UI

The HBase processes expose a web-based *user interface* (UI), which you can use to gain insight into the cluster's state, as well as the tables it hosts. The majority of the functionality is read-only, but a few selected operations can be triggered through the UI. On the other hand, it is possible to get very detailed information, short of having to resort to the full-fidelity metrics (see (to come)). It is therefore very helpful to be able to navigate through the various UI components, being able to quickly derive the current status, including memory usage, number of regions, cache efficiency, coprocessor resources, and much more.

Master UI Status Page

HBase also starts a web-based information service of vital attributes. By default, it is deployed on the master host at port 16010, while region servers use 16030.¹⁴ If the master is running on a host named `master.foo.com` on the default port, to see the master's home page, you can point your browser at <http://master.foo.com:16010>.

The ports used by the embedded information servers can be set in the `hbase-site.xml` configuration file. The properties to change are:

```
hbase.master.info.port  
hbase.regionserver.info.port
```

Note that many of the information shown on the various status pages are fed by the underlaying server metrics, as, for example, exposed by the cluster information API calls explained in “[Cluster Status Information](#)” (page 411).

Main Page

The first page you will see when opening the master's web UI is shown in [Figure 6-4](#). It consists of multiple sections that give you insight into the cluster status itself, the tables it serves, what the region servers are, and so on.

14. This has changed from 60010 and 60030 in HBase 1.0 (see [HBASE-10123](#) for details). Version 1.0.0 of HBase had an odd state where the master would use the region server ports for RPC, and the UI would redirect to a random port. [HBASE-13453](#) fixes this in 1.0.1 and later.

The screenshot shows the Apache HBase master interface. At the top, there's a navigation bar with links for Home, Table Details, Local Logs, Log Level, Debug Dump, Metrics Dump, and HBase Configuration. The title "Master master-1.internal.larsgeorge.com" is displayed prominently. Below the title, there's a section titled "Region Servers" with tabs for Base Stats (which is selected), Memory, Requests, Storefiles, and Compactions. A table lists region servers with their start times, requests per second, and number of regions. It includes entries for slave-1, slave-2, slave-3, and a summary row for Total:3.

Master master-1.internal.larsgeorge.com

Region Servers

ServerName	Start time	Requests Per Second	Num. Regions
slave-1.internal.larsgeorge.com,16020,1432833667280	Thu May 28 10:21:07 PDT 2015	0	2
slave-2.internal.larsgeorge.com,16020,1432835159618	Thu May 28 10:45:59 PDT 2015	0	0
slave-3.internal.larsgeorge.com,16020,1432833668231	Thu May 28 10:21:08 PDT 2015	0	0
Total:3		0	2

Backup Masters

ServerName	Port	Start Time
master-2.internal.larsgeorge.com	16000	Thu May 28 10:20:42 PDT 2015
master-3.internal.larsgeorge.com	16000	Thu May 28 10:21:05 PDT 2015
Total:2		

Tables

User Tables	System Tables	Snapshots

Tasks

Show All Monitored Tasks Show non-RPC Tasks Show All RPC Handler Tasks Show Active RPC Calls Show Client Operations View as JSON
No tasks currently running on this node.

Software Attributes

Attribute Name	Value	Description
HBase Version	1.1.0, revision=e860c66d41ddc8231004b646098a58abca7fb523	HBase version and revision
HBase Compiled	Tue May 12 13:07:08 PDT 2015, ndimiduk	When HBase version was compiled and by whom
HBase Source Checksum	6424fcab95bfff8337780a181ad7c78	HBase source MD5 checksum
Hadoop Version	2.5.1, revision=2e18d179e4a8065b6a9f29cf2de9451891265cce	Hadoop version and revision
Hadoop Compiled	2015-03-26T16:58Z, ndimiduk	When Hadoop version was compiled and by whom
Zookeeper Quorum	master-1.internal.larsgeorge.com:2181 master-2.internal.larsgeorge.com:2181 master-3.internal.larsgeorge.com:2181	Addresses of all registered ZK servers. For more, see zk dump .
Zookeeper Base Path	/hbase	Root node of this cluster in ZK.
HBase Root Directory	hdfs://master-1.internal.larsgeorge.com:9000/hbase	Location of HBase home directory
HMMaster Start Time	Thu May 28 10:21:02 PDT 2015	Date stamp of when this HMMaster was started
HMMaster Active Time	Thu May 28 10:21:07 PDT 2015	Date stamp of when this HMMaster became active
HBase Cluster ID	d11df898-b760-412d-92a7-71b42444822c	Unique identifier generated for each HBase cluster
Load average	0.67	Average number of regions per regionserver. Naive computation.
Coprocessors	[]	Coprocessors currently loaded by the master
LoadBalancer	org.apache.hadoop.hbase.master.balancer.StochasticLoadBalancer	LoadBalancer to be used in the Master

Figure 6-4. The HBase Master user interface

First we will look into the various parts of the page at a high level, followed by a more detailed description in the subsequent sections. The details of the main Master UI page can be broken up into the following groups:

Shared Header

At the very top there is a header with hyperlinks that is shared by many pages of the HBase UIs. They contain references to specific subpages, such as *Table Details*, plus generic pages that dump logs, let you set the logging levels, and dump debug, metric, and configuration details.

Warnings

Optional — In case there are some issues with the current setup, there are optional warning messages displayed at the very top of the page.

Region Servers

Lists the actual region servers the master knows about. The table lists the address, which you can click on to see more details. The tabbed table is containing additional useful information about each server, grouped by topics, such as *memory*, or *requests*.

Dead Region Servers

Optional — This section only appears when there are servers that have previously been part of the cluster, but are now considered dead.

Backup Masters

This section lists all configured and started backup master servers. It is obviously empty if you have none of them.

Tables

Lists all the user and system tables HBase knows about. In addition it also lists all known snapshots of tables.

Regions in Transition

Optional — Any region that is currently *in change* of its state is listed here. If there is no region that is currently transitioned by the system, then this entire section is omitted.

Tasks

The next group of details on the master's main page is the list of *currently running tasks*. Every internal operation performed by the master, such as region or log splitting, is listed here while it is running, and for another minute after its completion.

Software Attributes

You will find cluster-wide details in a table at the bottom of the page. It has information on the version of HBase and Hadoop that you are using, where the root directory is located, the overall load average, and so on.

As mentioned above, we will discuss each of them now in that same order in the next sections.

Warning Messages

As of this writing, there are three checks the Master UI page performs and reports on, in case a violation is detected: the JVM version, as well as the catalog janitor and balancer status. [Figure 6-5](#) shows the latter two of them.

The screenshot shows the Apache HBase Master UI. At the top, there is a navigation bar with links: Home, Table Details, Local Logs, Log Level, Debug Dump, Metrics Dump, and HBase Configuration. Below the navigation bar, the title "Master" is displayed along with the host "master-1.internal.larsgeorge.com". A message box contains the text: "Please note that your cluster is running with the CatalogJanitor disabled. It can be re-enabled from the hbase shell by running the command 'catalogjanitor_switch true'". Another message box below it states: "The Load Balancer is not enabled which will eventually cause performance degradation in HBase as Regions will not be distributed across all RegionServers. The balancer is only expected to be disabled during rolling upgrade scenarios." At the bottom, there is a section titled "Region Servers" with a table showing server statistics. The table has columns: ServerName, Start time, Requests Per Second, and Num. Regions. The data includes three slave servers and a total row.

ServerName	Start time	Requests Per Second	Num. Regions
slave-1.internal.larsgeorge.com,16020,1432570700425	Mon May 25 09:18:20 PDT 2015	348	4
slave-2.internal.larsgeorge.com,16020,1432570737921	Mon May 25 09:18:57 PDT 2015	360	2
slave-3.internal.larsgeorge.com,16020,1432570860756	Mon May 25 09:21:00 PDT 2015	238	3
Total:		946	9

Figure 6-5. The optional Master UI warnings section

There are certain Java JVM versions that are known to cause issues when running as the basis for HBase. Again, as of this writing, there only one tested for is 1.6.0_18, which was unstable. This might be extended on the future, if more troublesome Java versions are detected. If the test is finding such a blacklisted JVM version a message is

displayed at the very top of the page, just below the header, stating: “Your current JVM version <version> is known to be unstable with HBase. Please see the HBase wiki for details.”

The other two tests performed are more about the state of background operations, the so-called *chores*. First the catalog janitor, explained in “[Server Operations](#)” (page 409), which is required to keep a HBase cluster clean. If you disable the janitor process with the API call, or the shell command shown in “[Tool Commands](#)” (page 494), you will see the message in the Master UI page as shown in the screen shot. It reminds you to enable it again some time soon.

The check for the balancer status is very similar, as it checks if someone has deactivated the background operation previously, and reminds you to reenable it in the future — or else your cluster might get skewed as region servers join or leave the collective.

Region Servers

The region server section of the Master UI page is divided into multiple subsections, represented as *tabs*. Each shows a set of information pertaining to a specific topic. The first tab is named *Base Stats* and comprises generic region server details, such as the *server name* (see “[Server and Region Names](#)” (page 356) again for details), that also acts as a hyperlink to the dedicated region server status page, explained in “[Region Server UI Status Page](#)” (page 532). The screen shot in [Figure 6-6](#) lists three region servers, named *slave-1* to *slave-3*. The table also states, for each active regions server, the *start time*, number of *requests per second* observed in the last few seconds (more on the timing of metrics can be found in [\(to come\)](#)), and *number of regions* hosted.

Region Servers

Base Stats	Memory	Requests	Storefiles	Compactions
ServerName	Start time		Requests Per Second	Num. Regions
slave-1.internal.larsgeorge.com,16020,1432833667280	Thu May 28 10:21:07 PDT 2015		0	4
slave-2.internal.larsgeorge.com,16020,1432835159618	Thu May 28 10:45:59 PDT 2015		1607	6
slave-3.internal.larsgeorge.com,16020,1432833668231	Thu May 28 10:21:08 PDT 2015		0	5
Total:3			1607	15

Figure 6-6. The region server section on the master page - Base Stats

Please observe closely in the screen shot how there is one server, namely `slave-2`, that seems to receive all the current requests only. This is—if sustained for a long time—potentially a problem called *hotspotting*. We will use this later to show you how to identify which table is causing this imbalance.

The second tab contains memory related details. You can see the currently *used heap* of the Java process, and the configured *maximum heap* it may claim. The *memstore size* states the accumulated memory occupied by all in-memory stores on each server. It can act as an indicator of how many writes you are performing, influenced by how many regions are currently opened. As you will see in (to come), each table is at least one region, and each region comprises one or more column families, with each requiring a dedicated in-memory store. [Figure 6-7](#) shows an example for our three current cluster with three region servers.

Region Servers

Base Stats	Memory	Requests	Storefiles	Compactions
ServerName		Used Heap	Max Heap	Memstore Size
slave-1.internal.larsgeorge.com,16020,1432728017580		99m	941m	96m
slave-2.internal.larsgeorge.com,16020,1432728017307		70m	941m	64m
slave-3.internal.larsgeorge.com,16020,1432728017634		105m	941m	105m

Figure 6-7. The region server section on the master page - Memory

It is interesting to note that the *used heap* is close or even equal to the *memstore size*, which is really only one component of the Java heap used. This can be attributed to the size metrics being collected at different points in time and should therefore only be used as an approximation.

The third tab, titled *Requests*, contains more specific information about the current number of *requests per second*, and also the observed total *read request* and *write request* counts, accumulated across the life time of the region server process. [Figure 6-8](#) shows another example of the same three node cluster, but with an even usage.

Region Servers

Base Stats	Memory	Requests	Storefiles	Compactions
ServerName		Request Per Second	Read Request Count	Write Request Count
slave-1.internal.larsgeorge.com,16020,1432728017580		307	352637	39628
slave-2.internal.larsgeorge.com,16020,1432728017307		115	224652	26453
slave-3.internal.larsgeorge.com,16020,1432728017634		342	440377	43943

Figure 6-8. The region server section on the master page - Requests

The *Storefiles* tab, which is the number four, shows information about the underlying store files of each server. The *number of stores* states the total number of column families served by that server—since each column family internally is represented as a *store* instance. The actual *number of files* is the next column in the table. Once the in-memory stores have filled up (or the dedicated heap for them is filled up) they are *flushed* out, that is, written to disk in the store they belong to, creating a new store file.

Since each store file is containing the actual cells of a table, they require the most amount of disk space as far as HBase's storage architecture is concerned. The *uncompressed size* states their size *before* any file compression is applied, but including any per-column family encodings, such as prefix encoding. The *storefile size* column then contains the actual file size on disk, that is, after any optional file compression has been applied.

Each file also stores various indexes to find the cells contained, and these indexes require storage capacity too. The last two columns show the size of the block and Bloom filter indices, as currently held in memory for all open store files. Dependent on how you compress the data, the size of your cells and file blocks, this number will vary. You can use it as an indicator to estimate the memory needs for your server processes after running your workloads for a while. [Figure 6-9](#) shows an example.

Region Servers

Base Stats	Memory	Requests	Storefiles	Compactions				
ServerName			Num. Stores	Num. Storefiles	Storefile Size Uncompressed	Storefile Size	Index Size	Bloom Size
slave-	1.internal.larsgeorge.com,16020,1432728017580		4	8	54m	54mb	45k	51k
slave-	2.internal.larsgeorge.com,16020,1432728017307		5	5	36m	36mb	30k	34k
slave-	3.internal.larsgeorge.com,16020,1432728017634		5	9	59m	59mb	49k	60k

Figure 6-9. The region server section on the master page - Storefiles

The final and fifth tab shows details about *compactions*, which are one of the background housekeeping tasks a region server is performing on your behalf.¹⁵ The table lists the *number of current cells* that have been scheduled for compactions. The *number of compacted cells* trails the former count, as each of them is processed by the server process. The *remaining cells* is what is left of the scheduled cells, counting towards zero. Lastly, the *compaction progress* shows the scheduled versus remaining as a percentage. Figure 6-10 shows that all compactions have been completed, that is, nothing is remaining and therefore we reached 100% of the overall compaction progress.

Region Servers

Base Stats	Memory	Requests	Storefiles	Compactions		
ServerName			Num. Compacting KVs	Num. Compacted KVs	Remaining KVs	Compaction Progress
slave-	1.internal.larsgeorge.com,16020,1432728017580		361780	361780	0	100.00%
slave-	2.internal.larsgeorge.com,16020,1432728017307		241100	241100	0	100.00%
slave-	3.internal.larsgeorge.com,16020,1432728017634		397120	397120	0	100.00%

Figure 6-10. The region server section on the master page - Compactions

15. As a side note, you will find that the columns are titled with *KV* in them, an abbreviation of *KeyValue* and synonym for *cell*. The latter is the official term as of HBase version 1.0 going forward.

As a cluster is being written to, or compactions are triggered by API or shell calls, the information in this table will vary. The percentage will drop back down as soon as new cells are scheduled, and go back to 100% as the background task is catching up with the compaction queue.

Dead Region Servers

This is an optional section, which only appears if there is a server that was active once, but is now considered inoperational, or *dead*. [Figure 6-11](#) shows an example, which has all three of our exemplary slave servers with a now non-operational process. This might happen if servers are restarted, or crash. In both cases the new process will have a new, unique server name, containing the new start time.

Region Servers

Dead Region Servers

ServerName	Stop time
slave-1.internal.larsgeorge.com,16020,1432727655790	Wed May 27 04:55:01 PDT 2015
slave-2.internal.larsgeorge.com,16020,1432727655709	Wed May 27 04:55:01 PDT 2015
slave-3.internal.larsgeorge.com,16020,1432727656004	Wed May 27 04:55:01 PDT 2015
Total:	servers: 3

Figure 6-11. The optional dead region server section on the master page

If you have no such defunct process in your cluster, the entire section will be omitted.

Backup Masters

The Master UI page further lists all the known *backup masters*. These are HBase Master processes started on the other servers. While it would be possible to start more than one Master on the same physical machine, it is common to spread them across multiple servers, in case the entire server becomes unavailable. [Figure 6-12](#) shows an example where two more backup masters have been started, on `master-2` and `master-3`.

Backup Masters

ServerName	Port	Start Time
master-2.internal.larsgeorge.com	16000	Mon May 25 07:29:33 PDT 2015
master-3.internal.larsgeorge.com	16000	Mon May 25 07:29:52 PDT 2015

Total:2

Figure 6-12. The backup master section on the Master page

The table has three columns, where the first has the hostname of the server running the backup master process. The other two columns state the port and start time of that process. Note that the port really is the RPC port, not the one for the information server. The server name acts as a hyperlink to that said information server though, which means you can click on any of them to open the Backup Master UI page, as shown in “Backup Master UI” (page 521).

Tables

The next major section on the Master UI page are the known tables and snapshots, comprising user and system created ones. For that the *Tables* section is split into three tabs: *User Tables*, *System Tables*, and *Snapshots*.

User Tables

Here you will see the list of all tables known to your HBase cluster. These are the ones you—or your users—have created using the API, or the HBase Shell. The list has many columns that state, for every user table, the namespace it belongs to, the name, region count details, and a description. The latter gives you a printout of the table descriptor, just listing the changed properties; see “Schema Definition” (page 347) for an explanation of how to read them. See Figure 6-13 for an example screen shot.

If you want more information about a user table, there are two options. First, next to the number of user tables found, there is a link titled *Details*. It takes you to another page that lists the same tables, but with their full table descriptors, including all column family descriptions as well. Second, the table names are links to another page with details on the selected table. See “Table Information Page” (page 524) for an explanation of the contained information.

The region counts holds more information about how the regions are distributed across the tables, or, in other words, how many re-

gions a table is divided into. The *online regions* lists all currently active regions. The *offline regions* column should be always zero, as otherwise a region is not available to serve its data. *Failed regions* is usually zero too, as it lists the regions that could not be opened for some reason. See [Figure 6-18](#) for an example showing a table with a failed region.

Tables

The screenshot shows the 'User Tables' section of the HBase Admin UI. At the top, there are tabs for 'User Tables' (which is selected), 'System Tables', and 'Schemas'. Below the tabs, it says '3 table(s) in set. [Details]'. The table has the following data:

Namespace	Table Name	Online Regions	Offline Regions	Failed Regions	Split Regions	Other Regions	Description
default	ltttable	2	0	0	1	0	'ltttable', {NAME => 'test_cf'}
testqauat	testtable	1	0	0	0	0	'testqauat:testtable', {NAME => 'cf1'}
default	usertable	11	0	0	0	0	'usertable', {NAME => 'cf1'}

Figure 6-13. The user tables

The *split region* count is the number of regions for which currently a log splitting process is underway. They will eventually be opened and move the count from this column into the online region one. Lastly, there is an *other regions* counter, which lists the number of regions in any *other* state from the previous columns. (to come) lists all possible states, including the named and other ones accounted for here.

System Tables

This section lists all the catalog—or system—tables, usually `hbase:meta` and `hbase:namespace`. There are additional, yet optional, tables, such as `hbase:acl`, `hbase:labels`, and `hbase:quotas`, which are created when the accompanying feature is enabled or used for the first time. You can click on the name of the table to see more details on the table regions—for example, on what server they are currently hosted. As before with the user tables, see [“Table Information Page” \(page 524\)](#) for more information. The final column in the information table is a fixed description for the given system table. [Figure 6-14](#) is an example for a basic system table list.

Tables

User Tables	System Tables	Snapshots
Table Name	Description	
hbase:meta	The hbase:meta table holds references to all User Table regions	
hbase:namespace	The .NAMESPACE. table holds information about namespaces.	

Figure 6-14. The system tables

Snapshots

The third and final tab available is listing all the known *snapshots*. Figure 6-15 shows an example, with three different snapshots that were taken previously. It lists the snapshot name, the table it was taken from, and the creation time. The table name is a link to the table details page, as already seen earlier, and explained in “Table Information Page” (page 524). The snapshot name links to yet another page, which lists details about the snapshot, and also offers some related operations directly from the UI. See “Snapshot” (page 530) for details.

Tables

User Tables	System Tables	Snapshots
3 snapshot(s) in set.		
Snapshot Name	Table	Creation Time
qa-post-stage1	testqauat:testtable	Tue May 26 03:07:00 PDT 2015
qa-pre-stage1	testqauat:testtable	Tue May 26 03:06:52 PDT 2015
uat-post-stage4	testqauat:testtable	Tue May 26 03:07:10 PDT 2015

Figure 6-15. The list of known snapshots

Optional Table Fragmentation Information

There is a way to enable an additional detail about user and system tables, called *fragmentation*. It is enabled by adding the following configuration property to the cluster configuration file, that is, *hbase_site.xml*:

```
<property>
  <name>hbase.master.ui.fragmentation.enabled</name>
  <value>true</value>
</property>
```

Once you have done so, the server will poll the storage file system to check how many store files per store are currently present. If each store only has one file, for example, after a major compaction of all tables, then the fragmentation amounts to zero. If you have more than a single store file in a store, it is considered fragmented. In other words, not the amount of files matters, but that there is more than one. For example, if you have 10 stores and 5 have more than one file in them, then the fragmentation is 50%.

Figure 6-16 shows an example for a table with 11 regions, where 9 have more than one file, that is, 9 divided by 11, and results in 0.8181 rounded up to 82%.

Tables

Namespace	Table Name	Frag.	Online Regions	Offline Regions	Failed Regions	Split Regions	Other Regions	Description
default	usertable	82%	11	0	0	0	0	'usertable', {NAME => 'cf1'}

Figure 6-16. The optional table fragmentation information

Once enabled, the fragmentation is added to the user and system table information, and also to the list of software attributes at the bottom of the page. The per-table information lists the fragmentation for each table separately, while the one in the table at the end of the page is summarizing the *total* fragmentation of the cluster, that is, across all known tables.

A word of caution about this feature: it polls the file system details on page load, which in a cluster under duress might increase the latency of the UI page load. Because of this it is disabled by default, and needs to be enabled explicitly.

Regions in Transition

As regions are managed by the master and region servers to, for example, balance the load across servers, they go through short phases of transition. This applies to, for example, opening, closing, and splitting a region. Before the operation is performed, the region is added to the list of *regions in transition*, and once the operation is complete,

it is removed. (to come) describes the possible states a region can be in.

When there is no region operation in progress, this section is omitted completely. Otherwise it should look similar to the example in [Figure 6-17](#), listing the regions with their encoded name, the current state, and the time elapsed since the transition process started. As of this writing, there is a hard limit of 100 entries being shown only, since this list could be very large for larger clusters. If that happens, then a message like “*<N> more regions in transition not shown*”, where *<N>* is the number of omitted entries.

Regions in Transition

Region	State	RIT time (ms)
3b2f59fc4275a0ff14141c94e8b4362ee	usertable,user4.1433255423788.3b2f59fc4275a0ff14141c94e8b4362ee.state=SPLITTING_NEW,ts=Tue Jun 02 07:30:23 PDT 2015 (1s ago),server=slave-3.internal.larsgeorge.com,16020,1433242321236	1294
1ec0fa1a46465fa144d20f27becbd452	usertable,user4499913112365217994.1433255423788.1ec0fa1a46465fa144d20f27becbd452.state=SPLITTING_NEW,ts=Tue Jun 02 07:30:23 PDT 2015 (1s ago),server=slave-3.internal.larsgeorge.com,16020,1433242321236	1294
8bc711686a36ef5baaf4285292369a6c	usertable,user4.1432841648880.8bc711686a36ef5baaf4285292369a6c.state=SPLITTING,ts=Tue Jun 02 07:30:23 PDT 2015 (1s ago),server=slave-3.internal.larsgeorge.com,16020,1433242321236	1294
ec3b9fb63b71a8132987cab25d76e5a	usertable,user7499400206646301952.1433255424637.ec3b9fb63b71a8132987cab25d76e5a.state=SPLITTING_NEW,ts=Tue Jun 02 07:30:24 PDT 2015 (0s ago),server=slave-1.internal.larsgeorge.com,16020,1433242321477	438
9edae4b0ff69b67b16be8725624856f6	usertable,user7.1432841648880.9edae4b0ff69b67b16be8725624856f6.state=SPLITTING,ts=Tue Jun 02 07:30:24 PDT 2015 (0s ago),server=slave-1.internal.larsgeorge.com,16020,1433242321477	438
2412bad12d01100ff4fd4c040bab29a	usertable,user7.1433255424637.2412bad12d01100ff4fd4c040bab29a.state=SPLITTING_NEW,ts=Tue Jun 02 07:30:24 PDT 2015 (0s ago),server=slave-1.internal.larsgeorge.com,16020,1433242321477	438
Total number of Regions in Transition for more than 60000 milliseconds	0	
Total number of Regions in Transition	6	

Figure 6-17. The regions in transitions table

Usually the regions in transition should be appearing only briefly, as region state transitioning is a short operation. In case you have an issue that persists, you may see a region stuck in transition for a very long time, or even forever. If that is the case there is a threshold (set by the `hbase.metrics.rit.stuck.warning.threshold` configuration property and defaulting to one minute) that counts those regions in excess regarding their time in the list. [Figure 6-18](#) shows an example, which was created by deliberately replacing a valid store file with one that was corrupt. The server keeps trying to open the region for this table, but will fail until an operator either deletes (or repairs) the file in question.

default	testtable2	0	0	1	0	0	'testtable2', {NAME => 'colfam1', BLOOMFILTER => 'NONE', VERSIONS => '3', BLOCKCACHE => 'false'}
default	usable	20	0	0	9	0	'usable', {NAME => 'cf1'}

Regions in Transition

Region	State	RIT time (ms)
7ba0fe55fc86829fd293f584ba5112f2	testtable2,,1433253497963.7ba0fe55fc86829fd293f584ba5112f2, state=FAILED_OPEN, ts=Wed Jun 03 07:00:31 PDT 2015 (217s ago), server=slave-3.internal.larageorge.com,16020,1433242321236	217983
Total number of Regions in Transition for more than 60000 milliseconds	1	
Total number of Regions in Transition	1	

Figure 6-18. A failed region is stuck in the transition state

You will have noticed how the stuck region is counted in both summary lines, the last two lines of the table. The screen shot also shows an example of a region counted into the *failed regions* in the preceding user table list. In any event, the row containing the oldest region in the list (that is, the one with the largest *RIT time*) is rendered with a red background color, while the first summary row at the bottom of the table is rendered with a green-yellow background.

Tasks

HBase manages quite a few automated operations and background tasks to keep the cluster healthy and operational. Many of these tasks involve a complex set of steps to be run through, often across multiple, distributed set of servers. These tasks include, for example, any region operation, such as opening and closing them, or splitting the WAL files during a region recovery. The tasks save their state so that they also can be recovered should the current server carrying out one or more of the steps fail. The HBase UIs show the currently running tasks and their state in the *tasks* section of their status pages.

The information about tasks applies to the UI status pages for the HBase Master and Region Servers equally. In fact, they share the same HTML template to generate the content. The listed tasks though are dependent on the type of server. For example, a get operation is only sent to the region servers, not the master.

A row with a green background indicates a completed task, while all other tasks are rendered with a white background. This includes entries that are currently running, or have been aborted. The latter can happen when an operation failed due to an inconsistent state. [Figure 6-19](#) shows a completed and a running.

Tasks

Show All Monitored Tasks **Show non-RPC Tasks** Show All RPC Handler Tasks Show Active RPC Calls Show Client Operations
[View as JSON](#)

Start Time	Description	State	Status
Tue May 26 02:41:00 PDT 2015	Doing distributed log split in [] for serverName=[slave-3.internal.larsgeorge.com,16020,1432570860756]	COMPLETE (since 54sec ago)	finished splitting (more than or equal to) 0 bytes in 0 log files in [] in 1ms (since 54sec ago)
Tue May 26 02:40:51 PDT 2015	Master startup	RUNNING (since 1mins, 4sec ago)	Starting namespace manager (since 53sec ago)

Figure 6-19. The list of currently running, general tasks on the master

When you start a cluster you will see quite a few tasks show up and disappear, which is expected, assuming they all turn green and age out. Once a task is not running anymore, it will still be listed for 60 seconds, before it is removed from the UI.

The table itself starts out on the second tab, named *non-RPC tasks*. It filters specific tasks from the full list, which is accessible on the first tab, titled *all monitored tasks*. The next two tabs filter all RPC related tasks, that is, all of them, or only the active ones respectively. The last tab is named *view as JSON* and returns the content of the second tab (the non-RPC tasks) as a JSON structure. It really is not a tab per-se since it replaces the entire page with just the JSON output. Use the browser's *back* to return to the UI page.

The difference between RPC and non-RPC tasks is their origin. The former originate from a remote call, while the latter are something triggered directly within the server process. [Figure 6-20](#) shows two RPC tasks, which also list their origin, that is, the remote client that invoked the task. The previous screen shot in [Figure 6-19](#) differs from this one, as the displayed tasks are non-RPC ones, like the start of the namespace manager, and therefore have no caller info.

Tasks

Show All Monitored Tasks	Show non-RPC Tasks	Show All RPC Handler Tasks	Show Active RPC Calls	Show Client Operations	View as JSON
Start Time	Description	State	Status		
Tue Jun 02 05:05:38 PDT 2015	RpcServer.reader=5,bindAddress=slave-1.internal.larsgeorge.com,port=16020	RUNNING (since 0sec ago)	Servicing call from 10.0.0.20:57684: Scan (since 0sec ago)		
Tue Jun 02 03:52:43 PDT 2015	RpcServer.reader=2,bindAddress=slave-1.internal.larsgeorge.com,port=16020	RUNNING (since 0sec ago)	Servicing call from 10.0.0.20:57686: Scan (since 0sec ago)		

Figure 6-20. The list of currently running RPC tasks on the master

Software Attributes

This section of the Master UI status page lists cluster wide settings, such as the installed HBase and Hadoop versions, the root ZooKeeper path and HBase storage directory¹⁶, and the cluster ID. The table lists the *attribute name*, the current *value*, and a short *description*. Since this page is generated on the current master, it lists what it assumes to be the authoritative values. If you have some misconfiguration on other servers, you may be misled by what you see here. Make sure you cross-check the attributes and settings on *all* servers.

The table also lists the ZooKeeper quorum used, which has a link in its description allowing you to see the information for your current HBase cluster stored in ZooKeeper. “[ZooKeeper page](#)” (page 528) discusses its content. The screen shot in Figure 6-21 shows the current attributes of the test cluster used throughout this part of the book.

16. Recall that this should not be starting with `/tmp`, or you may lose your data during a machine restart. Refer to “[Quick-Start Guide](#)” (page 39) for details.

Software Attributes

Attribute Name	Value	Description
HBase Version	1.1.0, revision=e860c66d41ddc8231004b646098a58abca7fb523	HBase version and revision
HBase Compiled	Tue May 12 13:07:08 PDT 2015, ndimiduk	When HBase version was compiled and by whom
HBase Source Checksum	6424fcab95bfff8337780a181ad7c78	HBase source MD5 checksum
Hadoop Version	2.5.1, revision=2e18d179e4a8065b6a9f29cf2de9451891265cce	Hadoop version and revision
Hadoop Compiled	2015-03-26T16:58Z, ndimiduk	When Hadoop version was compiled and by whom
Zookeeper Quorum	master-1.internal.larsgeorge.com:2181 master-2.internal.larsgeorge.com:2181 master-3.internal.larsgeorge.com:2181	Addresses of all registered ZK servers. For more, see zk dump .
Zookeeper Base Path	/hbase	Root node of this cluster in ZK.
HBase Root Directory	hdfs://master-1.internal.larsgeorge.com:9000/hbase	Location of HBase home directory
HMMaster Start Time	Mon May 25 02:57:37 PDT 2015	Date stamp of when this HMMaster was started
HMMaster Active Time	Mon May 25 02:57:41 PDT 2015	Date stamp of when this HMMaster became active
HBase Cluster ID	2aae930c-66bc-4e3e-bbd2-6eb0818936c0	Unique identifier generated for each HBase cluster
Load average	3.00	Average number of regions per regionserver. Naive computation.
Coprocessors	[]	Coprocessors currently loaded by the master
LoadBalancer	org.apache.hadoop.hbase.master.balancer.StochasticLoadBalancer	LoadBalancer to be used in the Master

Figure 6-21. The list of attributes on the Master UI page

Master UI Related Pages

The following pages are related to the Master UI page, as they are directly linked from it. This includes the detailed table, table information, and snapshot information pages.

Backup Master UI

If you have more than one HBase Master process started on your cluster (for more on how to do that see (to come)), then the active Master UI will list them. Each of the server names is a link to the respective backup master, providing its dedicated status page, as shown in [Figure 6-22](#). The content of each backup master is pretty much the same, since they do nothing else but wait for a chance to take over the

lead. This happens of course only if the currently active master server disappears.

At the top the page links to the currently active master, which makes it easy to navigate back to the root of the cluster. This is followed by the list of tasks, as explained in “[Tasks](#)” (page 518), though here we will only ever see one entry, which is the long running tasks to wait for the master to complete its startup—which is only happening in the above scenario.

Master

master-1.internal.larsgeorge.com

Tasks

[Show All Monitored Tasks](#) [Show non-RPC Tasks](#) [Show All RPC Handler Tasks](#) [Show Active RPC Calls](#) [Show Client Operations](#)
[View as JSON](#)

Start Time	Description	State	Status
Tue May 26 04:34:22 PDT 2015	Master startup	RUNNING (since 5mins, 28sec ago)	Another master is the active master, master-1.internal.larsgeorge.com, 16000, 1432640063230; waiting to become the next active master (since 5mins, 28sec ago)

Software Attributes

Attribute Name	Value	Description
HBase Version	1.1.0, revision=e860c66d41ddc8231004b646098a58abca7fb523	HBase version and revision
HBase Compiled	Tue May 12 13:07:08 PDT 2015, ndimiduk	When HBase version was compiled and by whom
HBase Source Checksum	6424fcab95bfff8337780a181ad7c78	HBase source MD5 checksum
Hadoop Version	2.5.1, revision=2e18d179e4a8065b6a9f29cf2de9451891265cce	Hadoop version and revision
Hadoop Compiled	2015-03-26T16:58Z, ndimiduk	When Hadoop version was compiled and by whom
Zookeeper Quorum	master-1.internal.larsgeorge.com:2181 master-2.internal.larsgeorge.com:2181 master-3.internal.larsgeorge.com:2181	Addresses of all registered ZK servers. For more, see zk dump .
Zookeeper Base Path	/hbase	Root node of this cluster in ZK.
HBase Root Directory	hdfs://master-1.internal.larsgeorge.com:9000/hbase	Location of HBase home directory
HMaster Start Time	Tue May 26 04:34:18 PDT 2015	Date stamp of when this HMaster was started

Figure 6-22. The backup master page

The page also lists an abbreviated list of software attributes. It is missing any current values, such as the loaded coprocessors, or the region load. These values are only accessible when the master process is started fully and active. Otherwise you have seen the list of attributes before, in “[Software Attributes](#)” (page 520).

Table Information Page

When you click on the name of a user or system table in the master's web-based user interface, you have access to the information pertaining to the selected table. [Figure 6-23](#) shows an example of a user table.

Table testqauat:accounts**Table Attributes**

Attribute Name	Value	Description
Enabled	true	Is the table enabled
Compaction	NONE	Is the table compacting

Table Regions

Name	Region Server	Start Key	End Key	Locality	Requests
testqauat:accounts,,1433440760111.2fdae1893e2f4c8533e05e0dbcea1e43.	slave-3.internal.larsgeorge.com:16020	A	0.0	0	
testqauat:accounts,A,1433440760111.7b30ff1c78352b617ab2cd093ddf0bd6.	slave-3.internal.larsgeorge.com:16020	A	D	0.0	2975
testqauat:accounts,D,1433440760111.bcef7a6d064dc87fec9040d7e0241f77.	slave-1.internal.larsgeorge.com:16020	D	G	0.0	3009
testqauat:accounts,G,1433440760111.88a93828ed99adac0e5a9144743a90a4.	slave-3.internal.larsgeorge.com:16020	G	J	0.0	3018
testqauat:accounts,J,1433440760111.e2af71fb052aeaab50b086ae93209214.	slave-2.internal.larsgeorge.com:16020	J	M	0.0	3078
testqauat:accounts,M,1433440760111.5aec2da331856edd4187d4a71a20e6e3.	slave-3.internal.larsgeorge.com:16020	M	P	0.0	3091
testqauat:accounts,P,1433440760111.1577952c5d86cd00f5b0742f4724c4.	slave-2.internal.larsgeorge.com:16020	P	S	0.0	3085
testqauat:accounts,S,1433440760111.9e59b62fce5f259ddb395c92be343941.	slave-1.internal.larsgeorge.com:16020	S	V	0.0	2915
testqauat:accounts,V,1433440760111.b47beea1cfb679d8f433b52c73594bc1.	slave-2.internal.larsgeorge.com:16020	V	Y	0.0	2998
testqauat:accounts,Y,1433440760111.148a0d5b7ab655c286a1e926f6ae8d6f.	slave-1.internal.larsgeorge.com:16020	Y		0.0	2024

Regions by Region Server

Region Server	Region Count
slave-1.internal.larsgeorge.com:16020	3
slave-2.internal.larsgeorge.com:16020	3
slave-3.internal.larsgeorge.com:16020	4

Actions:

Compact

Region Key (optional):

This action will force a compaction of all regions of the table, or, if a key is supplied, only the region containing the given key.

Split

Region Key (optional):

This action will force a split of all eligible regions of the table, or, if a key is supplied, only the region containing the given key. An eligible region is one that does not contain any references to other regions. Split requests for noneligible regions will be ignored.

Figure 6-23. The Table Information page with information about the selected table

The following groups of information are available on the *Table Information* page:

Table Attributes

Here you can find details about the table itself. First, it lists the *table status*, that is, if it is enabled or not. See “[Table Operations](#)” (page 378), and the `disableTable()` call especially. The boolean value states whether the table is enabled, so when you see a `true` in the *Value* column, this is the case. On the other hand, a value of `false` would mean the table is currently disabled.

Second, the table shows if there are any compactions currently running for this table. It either states *NONE*, *MINOR*, *MAJOR*, *MAJOR_AND_MINOR*, or *Unknown*. The latter is rare but might show when, for example, a table with a single region splits and no compaction state is known to the Master for that brief moment. You may wonder how a table can have a minor and major compaction running at the same time, but recall how compactions are triggered per region, which means it is possible for a table with many regions to have more than one being compacted (minor and/or major) at the same time.

Lastly, if you have the optional fragmentation information enabled, as explained in “[Optional Table Fragmentation Information](#)” (page 515), you have a third line that lists the current fragmentation level of the table.

Table Regions

This list can be rather large and shows all regions of a table. The *name* column has the region name itself, and the *region server* column has a link to the server hosting the region. Clicking on the link takes you to the page explained in “[Region Server UI Status Page](#)” (page 532).

- + The *start key* and *end key* columns show the region’s start and end keys as expected. The *locality* column indicates, in terms of a percentage, if the storage files are local to the server which needs it, or if they are accessed through the network instead. See “[Cluster Status Information](#)” (page 411) and the `getDataLocality()` call for details
- + Finally, the *requests* column shows the total number of requests, including all read (get, scan, etc.) and write (put, delete, etc.) operations, since the region was deployed to the hosting server.

Regions by Region Server

The last group on the Table Information page lists which region server is hosting how many regions of the selected table. This number is usually distributed evenly across all available servers. If not, you can use the HBase Shell or administrative API to initiate the balancer, or use the `move` command to manually balance the table regions (see “[Cluster Operations](#)” (page 393)).

By default, the Table Information page also offers some actions that can be used to trigger administrative operations on a specific region, or the entire table. These actions can be hidden by setting the `hbase.master.ui.readonly` configuration property to `true`. See “[Cluster Operations](#)” (page 393) again for details about the actions, and (to come) for information on when you want to use them. The available operations are:

Compact

This triggers the `compact` functionality, which is asynchronously running in the background. Specify the optional name of a region to run the operation more selectively. The name of the region can be taken from the table above, that is, the entries in the `name` column of the *Table Regions* table.

Make sure to copy the entire region name *as-is*. This includes the trailing “`.`” (the dot)!

If you do *not* specify a region name, the operation is performed on all regions of the table instead.

Split

Similar to the `compact` action, the `split` action triggers the `split` command, operating on a table or region scope. Not all regions may be splittable—for example, those that contain no, or very few, cells, or one that has already been split, but which has not been compacted to complete the process.

Once you trigger one of the operations, you will receive a confirmation page; for example, for a split invocation, you will see:

Table action request accepted

Split request accepted.

[Go Back](#), or wait for the redirect.

As directed, use the *Back* button of your web browser, or simply wait a few seconds, to go back to the previous page, showing the table information.

ZooKeeper page

This page shows the same information as invoking the `zk_dump` command of the HBase Shell. It shows you the root directory HBase is using inside the configured filesystem. You also can see the currently assigned master, the known backup masters, which region server is hosting the `hbase:meta` catalog table, the list of region servers that have registered with the master, replication details, as well as ZooKeeper internal details. [Figure 6-24](#) shows an exemplary output available on the ZooKeeper page (abbreviated for the sake of space).

Zookeeper Dump

```
HBase is rooted at /hbase
Active master address: master-1.internal.larsgeorge.com,16000,1432547857293
Backup master addresses:
  master-3.internal.larsgeorge.com,16000,1432564192057
  master-2.internal.larsgeorge.com,16000,1432564173968
Region server holding hbase:meta: slave-3.internal.larsgeorge.com,16020,1432508715491
Region servers:
  slave-3.internal.larsgeorge.com,16020,1432508715491
  slave-2.internal.larsgeorge.com,16020,1432508713180
  slave-1.internal.larsgeorge.com,16020,1432508695103
/hbase/replication:
/hbase/replication/peers:
/hbase/replication/rs:
/hbase/replication/rs/slave-1.internal.larsgeorge.com,16020,1432508695103:
/hbase/replication/rs/slave-2.internal.larsgeorge.com,16020,1432508713180:
/hbase/replication/rs/slave-3.internal.larsgeorge.com,16020,1432508715491:
Quorum Server Statistics:
  master-1.internal.larsgeorge.com:2181
  Zookeeper version: 3.4.6-1569965, built on 02/20/2014 09:09 GMT
Clients:
  /10.0.10.11:52001[1](queued=0,recv=1612,sent=1612)
  /10.0.10.1:42498[1](queued=0,recv=1524,sent=1528)
  /10.0.10.2:34868[1](queued=0,recv=4,sent=4)
  /10.0.10.10:51690[1](queued=0,recv=1612,sent=1612)
  /10.0.10.1:42499[1](queued=0,recv=1229,sent=1229)
  /10.0.10.12:37562[1](queued=0,recv=1612,sent=1612)
  /10.0.10.11:52000[1](queued=0,recv=1647,sent=1649)
  /10.0.10.11:51999[1](queued=0,recv=1612,sent=1612)
  /10.0.10.1:43306[0](queued=0,recv=1,sent=0)
  /10.0.10.12:37561[1](queued=0,recv=1647,sent=1649)
  /10.0.10.12:37563[1](queued=0,recv=1612,sent=1612)
  /10.0.10.10:51689[1](queued=0,recv=1656,sent=1658)
  /10.0.10.10:51691[1](queued=0,recv=1612,sent=1612)

Latency min/avg/max: 0/0/97
Received: 19092
Sent: 19101
Connections: 13
Outstanding: 0
Zxid: 0x10000002a
Mode: leader
Node count: 42
master-2.internal.larsgeorge.com:2181
Zookeeper version: 3.4.6-1569965, built on 02/20/2014 09:09 GMT
Clients:
  /10.0.10.1:39706[0](queued=0,recv=1,sent=0)
  /10.0.10.1:38904[1](queued=0,recv=1507,sent=1507)
  /10.0.10.1:38903[1](queued=0,recv=1227,sent=1227)
```

Figure 6-24. The ZooKeeper page, listing HBase and ZooKeeper details

While you will rarely use this page, which is linked to from the Master UI page, it is useful in case your cluster is unstable, or you need to reassure yourself of its current configuration and state. The information is very low-level in parts, but as you grow more accustomed to HBase and how it is operated, the values reported might give you clues as to what is happening inside the cluster.

Snapshot

Every snapshot name, listed on the Master UI status page, is a link to a dedicated page with information about the snapshot. [Figure 6-25](#) is an example screen shot, listing the table it was taken from (which is a link back to the table information page), the creation time, the type of snapshot, the format version, and state. You can refresh your knowledge about the meaning of each in [“Table Operations: Snapshots” \(page 401\)](#).

The screenshot shows the Apache HBase Master UI interface. At the top, there's a navigation bar with links: Home, Table Details, Local Logs, Log Level, Debug Dump, Metrics Dump, and HBase Configuration. Below the navigation bar, the title "Snapshot: qa-post-stage1" is displayed. Underneath the title, the section "Snapshot Attributes" is shown with a table:

Table	Creation Time	Type	Format Version	State
testqauat:testtable	Wed Jun 03 07:43:24 PDT 2015	FLUSH	2	ok

Below the table, a message states: "1 HFiles (0 in archive), total size 29.4 K (100.0% 29.4 K shared with the source table) 0 Logs, total size 0".

Under the "Actions:" heading, there are two buttons: "Clone" and "New Table Name (clone)". A tooltip for "Clone" says: "This action will create a new table by cloning the snapshot content. There are no copies of data involved. And writing on the newly created table will not influence the snapshot data." Below these buttons is another button labeled "Restore". A tooltip for "Restore" says: "Restore a specified snapshot. The restore will replace the content of the original table, bringing back the content to the snapshot state. The table must be disabled."

Figure 6-25. The snapshot details page

The page also shows some information about the files involved in the snapshot, for example:

```
36 HFiles (20 in archive), total size 250.9 M (45.3% 113.7 M  
shared with the source table)  
0 Logs, total size 0
```

Here we have 36 storage files in the snapshot, and 20 of those are already replaced by newer files, which means they have been archived to keep the snapshot consistent. Should you have had any severe issues with the cluster and experienced data loss, it might happen that you see something similar to what [Figure 6-26](#) shows. The snapshot is corrupt because a file is missing (which I have manually removed to

just to show you this screen shot—do not try this unless you know what you are doing), as listed in the *CORRUPTED Snapshot* section of the page.

Snapshot: before-test-334

Snapshot Attributes

Table	Creation Time	Type	Format Version	State
usertable	Fri Jun 05 05:26:28 PDT 2015	FLUSH	2	CORRUPTED

35 HFiles (35 in archive), total size 248.2 M (0.0% 0 shared with the source table)
0 Logs, total size 0

CORRUPTED Snapshot

1 hfile(s) and 0 log(s) missing.

Figure 6-26. A corrupt snapshot example

There are also actions you can perform—assuming you have not disabled them using the `hbase.master.ui.readonly` configuration property as explained—based on the currently displayed snapshot. You can either *clone* the snapshot into a new table, or *restore* it by replacing the originating table. Both actions will show a confirmation message (or an error in case something is wrong, for example, when specifying a non-existent namespace for a new table), similar to this:

Snapshot action request...

Clone from Snapshot request accepted.

Go [Back](#), or wait for the redirect.

More elaborate functionality is only available through the API, which is mostly exposed through the HBase Shell (as mentioned, see “[Table Operations: Snapshots](#)” (page 401)).

Region Server UI Status Page

The region servers have their own web-based UI, which you usually access through the master UI, by clicking on the server name links provided. You can access the page directly by entering

`http://<region-server-address>:16030`

into your browser (while making sure to use the configured port, here using the default of 16030).

Main page

The main page of the region servers has details about the server, the tasks it performs, the regions it is hosting, and so on. [Figure 6-27](#) shows an example of this page.

RegionServer slave-1.internal.larsgeorge.com,16020,1433763003488

Server Metrics

Base Stats	Memory	Requests	WALs	Storefiles	Queues
Requests Per Second	Num. Regions	Block locality	Block locality (Secondary replicas)		Slow WAL Append Count
0	4	100	0		0

Tasks

Show All Monitored Tasks Show non-RPC Tasks Show All RPC Handler Tasks Show Active RPC Calls Show Client Operations View as JSON

No tasks currently running on this node.

Block Cache

Base Info	Config	Stats	L1	L2
Attribute	Value	Description		
Implementation	CombinedBlockCache	Block cache implementing class		

See [block cache](#) in the HBase Reference Guide for help.

Regions

Base Info	Request metrics	Storefile Metrics	Memstore Metrics	Compaction Metrics	Coprocessor Metrics
Region Name				Start Key	End Key
testquat:usertable2,,1433747096735.74776c3370f2bf20dd7ace5b8ba4a2e8a.				0	
testquat:usertable,user2,1433747062257.b79c02b2cfbc11a5bc128e702a80d09.				user2	user3
testquat:usertable,user6,1433747062257.aa53422259fe19b63b76128ec8cebf2.				user6	user7
testquat:usertable,user9,1433747062257.606be03d837f5bcc12242833557704.				user9	0

Region names are made of the containing table's name, a comma, the start key, a comma, and a randomly generated region id. To illustrate, the region named `domains.apache.org,5464829424211263407` is part of the table `domains`, has an id of `5464829424211263407` and the first key in the region is `apache.org`. The `hbase:meta` 'table' is an internal system table (or a 'catalog' table in db-speak). The `hbase:meta` table keeps a list of all regions in the system. The empty key is used to denote table start and table end. A region with an empty start key is the first region in a table. If a region has both an empty start key and an empty end key, it's the only region in the table. See [HBase Home](#) for further explication.

Software Attributes

Attribute Name	Value	Description
HBase Version	1.1.0, revision=e860c66d41ddc8231004b646098a58abca7fb523	HBase version and revision
HBase Compiled	Tue May 12 13:07:08 PDT 2015, ndimiduk	When HBase version was compiled and by whom
HBase Source Checksum	6424fcab95bfff8337780a181ad7c78	HBase source MD5 checksum
Hadoop Version	2.5.1, revision=2e18d179e4a8065b6a9f29cf2de9451891265cce	Hadoop version and revision
Hadoop Compiled	2015-03-26T16:58Z, ndimiduk	When Hadoop version was compiled and by whom
Zookeeper Quorum	master-1.internal.larsgeorge.com:2181, master-2.internal.larsgeorge.com:2181, master-3.internal.larsgeorge.com:2181	Addresses of all registered ZK servers
Coprocessors	[SequentialIdGeneratorObserver]	Coprocessors currently loaded by this regionserver
RS Start Time	Mon Jun 08 04:30:03 PDT 2015	Date stamp of when this region server was started
HBase Master	master-1.internal.larsgeorge.com:16010	Address of HBase Master

Figure 6-27. The Region Server main page Web-based UI

The page can be broken up into the following groups of distinct information, which we will—if they have not been explained before—discuss in detail in the subsequent sections:

Server Metrics

First, there are statistics about the current state of the server, its memory usage, number of requests observed, and more.

Tasks

The table lists all currently running tasks, as explained in “[Tasks](#)” ([page 518](#)). The only difference is that region servers will work on different tasks compared to the master. The former are concerned about data and region operations, while the latter will manage the region servers and WALs, among many other things.

Block Cache

When data is read from the storage files, it is loaded in blocks. These are usually cached for subsequent use, speeding up the read operations. The block cache has many configuration options, and dependent on those this part of the region server page will vary in its content.

Regions

Here you can see all the regions hosted by the currently selected region server. The table has many tabs that contain basic information, as well as request, store file, compaction, and coprocessor metrics.

Software Attributes

This group of information contains, for example, the version of HBase you are running, when it was compiled, the ZooKeeper quorum used, server start time, and a link back to the active HBase Master server. The content is self-explanatory, has a description column, and is similar to what was explained in “[Software Attributes](#)” ([page 520](#)).

Server Metrics

The first part on the status page of a region server relates to summary statistics about the server itself. This includes the number of region it holds, the memory used, client requests observed, number of store files, WALs, and length of queues. [Figure 6-28](#) combines them all into one screen shot since they are all very short.

Many of the values are backed by the server metrics framework (see (to come)) and do refresh on a slower cadence. Even if you reload the page you will see changes only every now and so often. The metrics update period is set by the `hbase.regionserver.metrics.period` configuration property and defaults to 5 seconds. Metrics collection is a complex process, which means that even with an update every 5 seconds, there are some values which update at a slower rate. In other words, use the values displayed with caution, as they might trail the actual current values.

The first tab, named *base stats*, lists the most high level details, so that you can have a quick glimpse at the overall state of the process. It lists the *requests per second*, the *number of region* hosted, the *block locality* percentage, the same for the replicas—if there are any--, and the number of *slow WAL append* operations. The latter is triggered if writing to the write-ahead log is delayed for some reason (most likely I/O pressure).¹⁷

¹⁷. As of this writing, covering version 1.1.0 of HBase, the “Slow WAL Append” value is hardcoded to be zero.

Server Metrics

Base Stats	Memory	Requests	WALs	Storefiles	Queues
Requests Per Second	Num. Regions	Block locality	Block locality (Secondary replicas)	Slow WAL Append Count	
16	4	100	0	0	

Server Metrics

Base Stats	Memory	Requests	WALs	Storefiles	Queues
Used Heap	Max Heap	Direct Memory Used		Direct Memory Configured	Memstore Size
447.3 M	941.4 M	1.0 G		2 G	310.5 M

Server Metrics

Base Stats	Memory	Requests	WALs	Storefiles	Queues
Request Per Second		Read Request Count			Write Request Count
16		6271360			78620

Server Metrics

Base Stats	Memory	Requests	WALs	Storefiles	Queues
Num. WAL Files					Size. WAL Files (bytes)
5					518310640

Server Metrics

Base Stats	Memory	Requests	WALs	Storefiles	Queues
Num. Stores		Root Index Size (bytes)		Index Size (bytes)	Bloom Size (bytes)
4		890.7 K		1.5 M	586 K

Server Metrics

Base Stats	Memory	Requests	WALs	Storefiles	Queues
Compaction Queue Size					Flush Queue Size
2					0

Figure 6-28. All tabs in the Server Metrics section

The second tab, titled *memory*, shows details of the currently used memory, both on-heap and off-heap. It shows the current and maximum configured Java heap, and the same for the off-heap memory, called *direct memory*. All of these are configured in the cluster wide hbase-env.sh configuration file for the Java process environment. The tab also lists the current combined memory occupied by all the in-

memory stores hosted by this server. The *region statistics* further down the page shows them separately.

The third tab is called *requests* and shows the combined, server-wide number of *requests per second* served, and the total read and write *request count* since the server started. The request per seconds are over the configured time to collect metrics, which is explained in (to come).

The tab named *WALs* lists write-ahead log metrics, here the number of *WALs* this server is keeping around for recovery purposes. It also lists the combined size of these files, as occupied on the underlying storage system.

Next is the *store files* tab, which lists information about the actual storage files. First the *number of stores* is stated, currently served by this region server. Since a store can have zero to many storage files, the next columns lists the *number of store files*, plus their combined sizes regarding the various indices contained in them. There are the *root index*, and the *total index sizes*, both addressing the block index structure. The root index points to blocks in the overall block index, and therefore is much smaller. Only the root index is kept in memory, while the block index blocks are loaded and cached on demand. There is also the Bloom filter, which—if enabled for the column family—is occupying space in the persisted store files. The value state in the table is the combined size as needed for all the store files together. Note that it is cached on demand too, so not all of that space is needed in memory.

The last and sixth tab titled *queues* lists the current size of the compaction and flush queues. These are vital resources for a region server, and a high as well as steadily increasing queue size indicates that the server is under pressure and has difficulties to keep up with the background housekeeping tasks.

Block Cache

The first tab, named *base info*, lists the selected cache implementation class, as shown in [Figure 6-29](#).

Block Cache

Attribute	Value	Description
Implementation	CombinedBlockCache	Block cache implementing class

See [block cache](#) in the HBase Reference Guide for help.

Figure 6-29. The base info of the Block Cache section

The block cache was configured as a *combined cache*, which uses the purely in-memory LRU cache as L1 (first level) cache, and the bucket cache as L2 (second level) cache (see (to come)). The LRU cache is set to use %20 of the maximum Java heap, not the default 40%. The block cache is configured as an *off-heap* cache, set to 1GB, using the following configuration settings:

```
<property>
  <name>hbase.bucketcache.combinedcache.enabled</name>
  <value>true</value>
</property>
<property>
  <name>hfile.block.cache.size</name>
  <value>0.2</value>
</property>
<property>
  <name>hbase.bucketcache.ioengine</name>
  <value>offheap</value>
</property>
<property>
  <name>hbase.bucketcache.size</name>
  <value>1024</value>
</property>
```

The next tab shows the cluster wide configuration values, regarding the cache properties. [Figure 6-30](#) is an example screen shot.

Block Cache

Attribute	Value	Description
Cache DATA on Read	true	True if DATA blocks are cached on read (INDEX & BLOOM blocks are always cached)
Cache DATA on Write	false	True if DATA blocks are cached on write.
Cache INDEX on Write	false	True if INDEX blocks are cached on write
Cache BLOOM on Write	false	True if BLOOM blocks are cached on write
Evict blocks on Close	false	True if blocks are evicted from cache when an HFile reader is closed
Cache DATA in compressed format	false	True if DATA blocks are cached in their compressed form
Prefetch on Open	false	True if blocks are prefetched into cache on open

Figure 6-30. The configuration tab of the Block Cache section

These values are set with the following configuration properties (see (to come) for the default values, their type, and description):

```
hfile.block.cache.size  
hbase.rs.cacheblocksonwrite  
hfile.block.index.cacheonwrite  
hfile.block.bloom.cacheonwrite  
hbase.rs.evictblocksonclose  
hbase.block.data.cachecompressed  
hbase.rs.prefetchblocksonopen
```

The first key, `hfile.block.cache.size`, sets the percentage used by the LRU cache, and if it is set to 0% or less, the cache is completely disabled. In practice it is very unlikely that you would ever go that far, since without any caching the entire I/O is purely based on the backing storage. Even with SATA SSDs or PCIe flash memory cards, the incumbent x86-64 based architecture can operate on DRAM a magnitude faster in comparison.

The majority of these options are turned off, which means you need to deliberately turn them on within your cluster. See (to come) for an in-depth discussion of cache configurations. The next tab is titled *statistics*, and shows the overall cache state. Since there are quite a few options available to configure the block cache, that is, with L1 only, or L1 and L2 together, the statistics combine the values if necessary. Figure 6-31 shows an example.

Block Cache

Attribute	Value	Description
Size	867.8 M	Current size of block cache in use (bytes)
Free	344.4 M	The total free memory currently available to store more cache entries (bytes)
Count	10,348	Number of blocks in block cache
Evicted	12,361	The total number of blocks evicted
Evictions	34,096	The total number of times an eviction has occurred
Hits	418,795	Number requests that were cache hits
Hits Caching	417,307	Cache hit block requests but only requests set to cache block if a miss
Misses	44,690	Block requests that were cache misses but set to cache missed blocks
Misses Caching	44,690	Block requests that were cache misses but only requests set to use block cache
Hit Ratio	90.36%	Hit Count divided by total requests count

If block cache is made up of more than one cache -- i.e. a L1 and a L2 -- then the above are combined counts. Request count is sum of hits and misses.

Figure 6-31. The statistics tab of the Block Cache section

As with many of the values the status pages show, you can access them in various ways. Here, for example, you can also use the metrics API, explained in (to come). The advantage of the web-based UI pages is that they can nicely group the related attributes, format their value human-readable, and add a short description for your perusal.

The screen shot was taken during a load test using YCSB (see (to come)). After the test table was filled with random data, a subsequent read load-test was executed (workload B or C). You might see with some of the statistics the expected effect, for example, the L1 being 100% effective, because with a combined cache configuration, the L1 only caches index data, which fits easily into the in-memory space for our test setup. This is also the reason that we decreased the dedicated heap space allocated for the on-heap LRU cache—it is not needed and the space can be used for other purposes. Figure 6-32 shows this on the next tab, titled *L1*.

Block Cache

Attribute	Value	Description
Implementation	LruBlockCache	Class implementing this block cache Level
Count	14	Count of Blocks
Count	0	Count of DATA Blocks
Size	804.5 K	Size of Blocks
Size	0	Size of DATA Blocks
Evicted	20	The total number of blocks evicted
Evictions	34,095	The total number of times an eviction has occurred
Mean	318,526	Mean age of Blocks at eviction time (seconds)
StdDev	39,331,296	Standard Deviation for age of Blocks at eviction time
Hits	240,772	Number requests that were cache hits
Hits Caching	240,767	Cache hit block requests but only requests set to cache block if a miss
Misses	0	Block requests that were cache misses but set to cache missed blocks
Misses Caching	0	Block requests that were cache misses but only requests set to use block cache
Hit Ratio	100.00%	Hit Count divided by total requests count

[View block cache as JSON](#) | [Block cache as JSON by file](#)

Figure 6-32. The L1 tab of the Block Cache section

The tab lists again many attributes, their values, and a short description. From these values you can determine the amount of blocks cached, divided into *all blocks* and *data blocks* respectively. Since we are not caching data blocks in L1 with an active L2, the count states the index blocks only. Same goes for the *size* of these blocks. There are further statistics, such as the number of *evicted* blocks, and the number of times an *eviction* check has run. The *mean age* and *standard deviation* lets you determine how long blocks stay in the cache before they are removed. This is related to the churn on the cache, because the LRU cache evicts the oldest blocks first, and if these are relatively young, you will have a high churn on the cache. The remaining numbers state the hits (the total number, and only those that are part of requests that had caching enabled), misses, and the ration between them.

The L2 cache is more interesting in this example, as it does the heavy lifting to cache all data blocks. Figure 6-33 shows the matching screen shot in tab number five, labeled appropriately *L2*. It contains a list similar to that of the L1 cache, showing attributes, their current values, and a short description. The link in the first line of the table is

pointing to the online API documentation for the configured class, here a `BucketCache` instance. You can further see the number of blocks cached, their total size, the same eviction details as before, and again the same for hits, misses, and the ratio. Some extra info here are the *hits per second* and *time per hit* values. They show how stressed the cache is and how quickly it can deliver contained blocks.

Block Cache

Base Info	Config	Stats	L1	L2
Attribute	Value	Description		
Implementation	<code>BucketCache</code>	Class implementing this block cache Level		
Implementation	<code>ioengine=ByteBufferIOEngine, capacity=1,073,741,824, direct=true</code>	IOEngine		
Count	10,334	Count of Blocks		
Size	683.3 M	Size of Blocks		
Evicted	12,341	The total number of blocks evicted		
Evictions	1	The total number of times an eviction has occurred		
Mean	318,203	Mean age of Blocks at eviction time (seconds)		
StdDev	60,855,283	Standard Deviation for age of Blocks at eviction time		
Hits	178,029	Number requests that were cache hits		
Hits Caching	176,546	Cache hit block requests but only requests set to cache block if a miss		
Misses	44,690	Block requests that were cache misses but set to cache missed blocks		
Misses Caching	44,690	Block requests that were cache misses but only requests set to use block cache		
Hit Ratio	79.93%	Hit Count divided by total requests count		
Hits per Second	67425	Block gets against this cache per second		
Time per Hit	0.07648498564958572	Time per cache hit		

[View block cache as JSON](#) | [Block cache as JSON by file](#)

`BucketCache` does not discern between DATA and META blocks so we do not show DATA counts (If deploy is using `CombinedBlockCache`, `BucketCache` is only DATA blocks)

Figure 6-33. The L2 tab of the Block Cache section

When you switch the Block Cache section to the last tab, the L2 tab, you will be presented with an additional section right below the Block Cache one, named *bucketcache buckets*, listing all the buckets the cache maintains, and for each the configured *allocation size*, and the

size of the *free* and *used* blocks within.¹⁸ See [Figure 6-34](#) for an example.

BucketCache Buckets

Bucket Offset	Allocation Size	Free Count	Used Count
0	5120	2088960	10240
2101248	9216	1981440	119808
4202496	17408	2088960	0
6303744	33792	2027520	67584
8404992	41984	2099200	0
10506240	50176	2057216	0
12607488	58368	2042880	58368
14708736	66560	0	2063360
16809984	99328	2085888	0
18911232	132096	1981440	0
21012480	197632	1976320	0
23113728	263168	1842176	0
25214976	394240	1971200	0
27316224	99328	2085888	0
29417472	66560	0	2063360
31518720	66560	0	2063360
33619968	66560	0	2063360
35721216	66560	0	2063360

Figure 6-34. The extra bucket cache section

Since in this example the cache is configured to use 1GB of off-heap memory, you see buckets spreading from offset 0, all the way close to the maximum of 1073741824 bytes. The space is divided equally based on the largest configured bucket size, and within each the space is divided into blocks mentioned by the allocation size, which varies to be flexible when it comes to assigning data to them. You can read more about this in aforementioned (to come).

Lastly, the Block Cache section has an additional *as JSON* link on some of the tabs, that lets you access the summary statistics as a JSON structure. This can be done by opening the JSON as a web page,

18. As of this writing, the labels are wrong for the BucketCache Buckets, the last two columns are actually *sizes*, not counts. See [HBASE-13861](#) for details.

or as a direct download to your local machine (*JSON by file* option). [Figure 6-35](#) has an example JSON output.

```
[  
  - {  
    - stats: {  
      hitCount: 4558066,  
      hitCachingCount: 4558066,  
      missCount: 0,  
      missCachingCount: 0,  
      evictionCount: 3759,  
      requestCount: 4558066,  
      hitRatio: 1,  
      requestCachingCount: 4558066,  
      hitCachingRatio: 1,  
      evictedCount: 2,  
      missRatio: 0,  
      missCachingRatio: 0,  
      sumHitCountsPastNPeriods: 0,  
      sumRequestCountsPastNPeriods: 0,  
      sumHitCachingCountsPastNPeriods: 0,  
      sumRequestCachingCountsPastNPeriods: 0,  
      hitRatioPastNPeriods: 0,  
      hitCachingRatioPastNPeriods: 0,  
      - ageAtEvictionSnapshot: {  
        stdDev: 2736159.5892962823,  
        max: 7689929233154,  
        999thPercentile: 7689929233154,  
        98thPercentile: 7689929233154,  
        95thPercentile: 7689929233154,  
        99thPercentile: 7689929233154,  
        min: 7689925363640,  
        mean: 7689927298397,  
        75thPercentile: 7689929233154  
      },  
      maxSize: 197420656,  
      freeSize: 195997312,  
      currentSize: 1423344,  
      blockCount: 13,  
      blockCaches: null  
    },  
    - {  
      count: 13,  
      size: 1215064,  
      dataSize: 0,  
      full: false,  
      - agoInCacheSnapshot: {  
        stdDev: 11487980859388.65,  
        max: 29918027999535,  
        999thPercentile: 29687326608894.184,  
        98thPercentile: 29638263717229.9,  
        95thPercentile: 29609328022236.4,  
        99thPercentile: 29652493335815.64,  
        min: -40020215,  
        mean: 11330928157574.643,  
        75thPercentile: 16216086158638.5  
      },  
      dataCount: 0  
    }  
  }  
]
```

Figure 6-35. Output of cache metrics as JSON

Regions

The next major information section on the region server's web-based UI status page is labeled *Regions*, listing specific metrics for every region currently hosted by the server showing you its status page. It has six tabs, with a lot of fine-grained data points, explained in order next. First is the tab titled *base info*, showing you a brief overview of each region. [Figure 6-36](#) has an exemplary screen shot. You can see the *region name*, the *start* and *end* keys, as well as the *replica ID*. The latter

is a number different from zero if the region is a read replica. We will look into this in (to come).

Regions

Region Name	Start Key	End Key	ReplicaID
testqauat:usable2,,1433747096735.7476c3370f2bf20dd7ace5b8ba4a2e8a.			0
testqauat:usable,user2,1433747062257.b79c02b2cfbc11a5bc128e702a80d09.	user2	user3	0
testqauat:usable,user6,1433747062257.aa53422259fee19b63b76128ec8cebf2.	user6	user7	0
testqauat:usable,user9,1433747062257.606be03d837f5cbcc122428335557704.	user9		0

Region names are made of the containing table's name, a comma, the start key, a comma, and a randomly generated region id. To illustrate, the region named `domains,apache.org,5464829424211263407` is part to the table `domains`, has an id of `5464829424211263407` and the first key in the region is `apache.org`. The `hbase:meta` table is an internal system table (or a 'catalog' table in db-speak). The `hbase:meta` table keeps a list of all regions in the system. The empty key is used to denote table start and table end. A region with an empty start key is the first region in a table. If a region has both an empty start key and an empty end key, it's the only region in the table. See [HBase Home](#) for further explication.

Figure 6-36. The regions details, basic information tab

The next tab, tab two titled *request metrics*, retains the region name column—all further tabs do that, so they will not be mentioned again—but then prints the total *read request*, and *write request* counts. These are accumulated in-memory on the region server, that is, restarting the server will reset the counters. Figure 6-37 shows a screen shot where three tables of one table are busy, while the remaining one region from another has not been used at all.

Regions

Region Name	Read Request Count	Write Request Count
testqauat:usable2,,1433747096735.7476c3370f2bf20dd7ace5b8ba4a2e8a.	0	0
testqauat:usable,user2,1433747062257.b79c02b2cfbc11a5bc128e702a80d09.	2771435	34391
testqauat:usable,user6,1433747062257.aa53422259fee19b63b76128ec8cebf2.	2698841	34243
testqauat:usable,user9,1433747062257.606be03d837f5cbcc122428335557704.	801084	10427

Figure 6-37. The regions details, request metrics tab

Then there is the *storefile metrics* tab, number three, which lists the summary statistics about the store files contained in each region. Recall that each *store* is equivalent to a column family, and each can have zero (before anything was flushed) to many data files in them.

The page also lists the combined size of these files, both uncompresssed and compressed, though the latter is optional and here we see not much difference because of that (see (to come) to learn more about compression of data). The next two columns state the *block index* and *Bloom filter* size required by all the store files in the given region. Lastly, you can see the *data locality* ratio, which is expressed as a percentage from 0.0 to 1.0, meaning 0% to 100%. The screen shot in [Figure 6-38](#) shows the four regions with their respective store file metrics.

Regions

Region Name	Num. Stores	Num. Storefiles	Storefile Size Uncompressed	Storefile Size	Index Size	Bloom Size	Data Locality
testqauat:usable2,,1433747096735.7476c3370f2bf20dd7ace5b8ba4a2e8a.	1	1	212m	213m	191k	192k	1.0
testqauat:usable,user2,1433747062257.b79c02b2cfbc11a5bc128e702a80d09.	1	4	811m	812m	675k	166k	1.0
testqauat:usable,user6,1433747062257.aa53422259fee19b63b76128ec8cebf2.	1	4	811m	812m	675k	166k	1.0
testqauat:usable,user9,1433747062257.606be03d837f5cbcc122428335557704.	1	2	183m	183m	148k	66k	1.0

Figure 6-38. The regions details, storefile metrics tab

The fourth tab, named *memstore metrics*, lists the accumulated, combined amount of memory occupied by the in-memory stores, that is, the Java heap backed structures keeping the mutations (the put and delete records) before they are written to disk. The default flush size is 128MB, which means the sizes shown in this tab—assuming for a second that you have only one memstore—should grow from 0m (zero megabyte) to somewhere around 128m and then after being flushed in the background drop back down to zero. If you have more than one memstore then you should expect the upper boundary to be a multiple of the flush size. [Figure 6-39](#) shows an example.

Regions

Region Name	Memstore Size
testqauat:usable2,,1433747096735.7476c3370f2bf20dd7ace5b8ba4a2e8a.	0m
testqauat:usable,user2,1433747062257.b79c02b2cfbc11a5bc128e702a80d09.	14m
testqauat:usable,user6,1433747062257.aa53422259fee19b63b76128ec8cebf2.	15m
testqauat:usable,user9,1433747062257.606be03d837f5cbcc122428335557704.	67m

Figure 6-39. The regions details, memstore metrics tab

On tab five, the *compaction metrics* shows the summary statistics about the cells currently *scheduled* for compaction, the number of cells that has been already *compacted*, and a *progress* percentage. The screen shot in [Figure 6-40](#) shows an example.

Regions

Region Name	Num. Compacting KVs	Num. Compacted KVs	Compaction Progress
testqauat:usable2,,1433747096735.7476c3370ff2bf20dd7ace5b8ba4a2e8a.	0	0	
testqauat:usable,user2,1433747062257.b79c02b2cfbc11a5bc128e702a80d09.	1322494	1256589	95.02%
testqauat:usable,user6,1433747062257.aa53422259fee19b63b76128ec8cebf2.	1290375	1290375	100.00%
testqauat:usable,user9,1433747062257.606be03d837f5cbcc122428335557704.	389129	389129	100.00%

Figure 6-40. The regions details, compaction metrics tab

Finally, the sixth tab, named *coprocessor metrics*, displays the time spent in each coprocessor that was invoked for any hosted region. As an example, the online code repository for this book includes a coprocessor that does add a generated ID into each record that is written. [Example 6-4](#) shows the code, which, when you read it carefully, also shows how the callback for `prePut()` is artificially delaying the call. We just use this here to emulate a heavier processing task embedded in a coprocessor.

Example 6-4. Adds a coprocessor local ID into the operation

```
private static String KEY_ID = "X-ID-GEN";
private byte[] family;
private byte[] qualifier;
private String regionName;

private Random rnd = new Random();
private int delay;

@Override
public void start(CoprocessorEnvironment e) throws IOException {
    if (e instanceof RegionCoprocessorEnvironment) {
        RegionCoprocessorEnvironment env = (RegionCoprocessorEnvironment) e;
        Configuration conf = env.getConfiguration(); ①
        this.regionName = env.getRegionInfo().getEncodedName();
        String family = conf.get("com.larsgeorge.copro.seqidgen.family", "cf1");
        this.family = Bytes.toBytes(family);
```

```

        String qualifier = conf.get("com.larsgeorge.copro.seqidgen.qualifier", ②
            "GENID");
        this.qualifier = Bytes.toBytes(qualifier);
        int startId = conf.getInt("com.larsgeorge.copro.seqidgen.startId", 1);
        this.delay = conf.getInt("com.larsgeorge.copro.seqidgen.delay", 100);
        env.getSharedData().putIfAbsent(KEY_ID, new AtomicInteger(startId)); ③
    } else {
        LOG.warn("Received wrong context.");
    }
}

@Override
public void stop(CoprocessorEnvironment e) throws IOException {
    if (e instanceof RegionCoprocessorEnvironment) {
        RegionCoprocessorEnvironment env = (RegionCoprocessorEnvironment) e;
        AtomicInteger id = (AtomicInteger) env.getSharedData().get(KEY_ID);
        LOG.info("Final ID issued: " + regionName + "-" + id.get()); ④
    } else {
        LOG.warn("Received wrong context.");
    }
}

@Override
public void prePut(ObserverContext<RegionCoprocessorEnvironment> e,
Put put,
WALEdit edit, Durability durability) throws IOException {
    RegionCoprocessorEnvironment env = e.getEnvironment();
    AtomicInteger id = (AtomicInteger) env.getSharedData().get(KEY_ID);
    put.addColumn(family, qualifier, Bytes.toBytes(regionName + "-" +
⑤
        id.incrementAndGet()));

    try {
        Thread.sleep(rnd.nextInt(delay)); ⑥
    } catch (InterruptedException e1) {
        e1.printStackTrace();
    }
}

```

- ① Get environment and configuration instances.
- ② Retrieve the settings passed into the configuration.
- ③ Set up generator if this has not been done yet on this region server.

- ④ Log the final number generated by this coprocessor.
- ⑤ Set the shared ID for this instance of put.
- ⑥ Sleep for 0 to “delay” milliseconds.

After compiling the project (see (to come)), the generated JAR file is placed into the /opt/hbase-book directory on the test cluster used throughout this section. We can then add the coprocessor to one of the test tables, here one that is used with YCSB (see (to come)), so that during a load test we can measure the impact of the callback. The class is added using the HBase shell, and after running the load test, a scan is performed to print the generated IDs—here a concatenation of the encoded region name and a shared, continuously increasing ID:

```

hbase(main):001:0> alter 'testqauat:usertable', \
  METHOD => 'table_att', 'coprocessor' => \
  'file:///opt/hbase-book/hbase-book-ch05-2.0.jar| \
  coprocessor.SequentialIdGeneratorObserver|'
Updating all regions with the new schema...
1/11 regions updated.
11/11 regions updated.
Done.
0 row(s) in 3.5360 seconds

hbase(main):002:0> scan 'testqauat:usertable', \
  { COLUMNS => [ 'cf1:GENID' ], LIMIT => 2 }
ROW                                COLUMN+CELL
  user1000257404909208451          column=cf1:GENID,      time-
  stamp=1433763441150, \
  value=dcd5395044732242dfed39b09aa05c36-15853
  user1000863415447421507          column=cf1:GENID,      time-
  stamp=1433763396342, \
  value=dcd5395044732242dfed39b09aa05c36-14045
2 row(s) in 4.5070 seconds

```

While running the load test using YCSB (workload A) the example screen shot shown in [Figure 6-41](#) was taken. Since the coprocessor delays the processing between 1 and 100 milliseconds, you will find the values in the *execution time statistics* column reflect that closely. For every region every active coprocessor is listed, and for each you will see the various timing details, showing minimum, average, and maximum time observed. There is also a list of the 90th, 95th, and 99th percentile.

Regions

Region Name	Coprocessor	Execution Time Statistics												
testqauat:usable,user2,1433747062257.b79c02b2cfbc11a5bc128e702a80d09.	SequentialIdGeneratorObserver	<table><tr><td>Min Time</td><td>0.001 ms</td></tr><tr><td>Avg Time</td><td>2.287 ms</td></tr><tr><td>Max Time</td><td>71.259 ms</td></tr><tr><td>90th percentile</td><td>0.020 ms</td></tr><tr><td>95th percentile</td><td>27.788 ms</td></tr><tr><td>99th percentile</td><td>71.059 ms</td></tr></table>	Min Time	0.001 ms	Avg Time	2.287 ms	Max Time	71.259 ms	90th percentile	0.020 ms	95th percentile	27.788 ms	99th percentile	71.059 ms
Min Time	0.001 ms													
Avg Time	2.287 ms													
Max Time	71.259 ms													
90th percentile	0.020 ms													
95th percentile	27.788 ms													
99th percentile	71.059 ms													
testqauat:usable,user6,1433747062257.aa53422259fee19b63b76128ec8cebf2.	SequentialIdGeneratorObserver	<table><tr><td>Min Time</td><td>0.003 ms</td></tr><tr><td>Avg Time</td><td>3.750 ms</td></tr><tr><td>Max Time</td><td>98.212 ms</td></tr><tr><td>90th percentile</td><td>0.040 ms</td></tr><tr><td>95th percentile</td><td>42.095 ms</td></tr><tr><td>99th percentile</td><td>98.173 ms</td></tr></table>	Min Time	0.003 ms	Avg Time	3.750 ms	Max Time	98.212 ms	90th percentile	0.040 ms	95th percentile	42.095 ms	99th percentile	98.173 ms
Min Time	0.003 ms													
Avg Time	3.750 ms													
Max Time	98.212 ms													
90th percentile	0.040 ms													
95th percentile	42.095 ms													
99th percentile	98.173 ms													
testqauat:usable,user9,1433747062257.606be03d837f5cbcc122428335557704.	SequentialIdGeneratorObserver	<table><tr><td>Min Time</td><td>0.003 ms</td></tr><tr><td>Avg Time</td><td>5.068 ms</td></tr><tr><td>Max Time</td><td>89.824 ms</td></tr><tr><td>90th percentile</td><td>0.054 ms</td></tr><tr><td>95th percentile</td><td>61.838 ms</td></tr><tr><td>99th percentile</td><td>89.658 ms</td></tr></table>	Min Time	0.003 ms	Avg Time	5.068 ms	Max Time	89.824 ms	90th percentile	0.054 ms	95th percentile	61.838 ms	99th percentile	89.658 ms
Min Time	0.003 ms													
Avg Time	5.068 ms													
Max Time	89.824 ms													
90th percentile	0.054 ms													
95th percentile	61.838 ms													
99th percentile	89.658 ms													

Figure 6-41. The regions details, coprocessor metrics tab

Software Attributes

This section of the Region Server UI status page lists cluster wide settings, such as the installed HBase and Hadoop versions, the ZooKeeper quorum, the loaded coprocessor classes, and more. The table lists the *attribute name*, the current *value*, and a short *description*. Since this page is generated on the current region server, it lists what it assumes to be the authoritative values. If you have some misconfiguration on other servers, you may be misled by what you see here. Make sure you cross-check the attributes and settings on *all* servers. The screen shot in [Figure 6-42](#) shows the current attributes of the test cluster used throughout this part of the book.

Software Attributes

Attribute Name	Value	Description
HBase Version	1.1.0, revision=e860c66d41ddc8231004b646098a58abca7fb523	HBase version and revision
HBase Compiled	Tue May 12 13:07:08 PDT 2015, ndimiduk	When HBase version was compiled and by whom
HBase Source Checksum	6424fcab95bfff8337780a181ad7c78	HBase source MD5 checksum
Hadoop Version	2.5.1, revision=2e18d179e4a8065b6a9f29cf2de9451891265cce	Hadoop version and revision
Hadoop Compiled	2015-03-26T16:58Z, ndimiduk	When Hadoop version was compiled and by whom
Zookeeper Quorum	master-1.internal.larsgeorge.com:2181, master-2.internal.larsgeorge.com:2181, master-3.internal.larsgeorge.com:2181	Addresses of all registered ZK servers
Coprocessors	[SequentialIdGeneratorObserver]	Coprocessors currently loaded by this regionserver
RS Start Time	Mon Jun 08 04:30:03 PDT 2015	Date stamp of when this region server was started
HBase Master	master-1.internal.larsgeorge.com:16010	Address of HBase Master

Figure 6-42. The list of attributes on the Region Server UI

Shared Pages

On the top of the master, region server, and table pages there are also a few generic links that lead to subsequent pages, displaying or controlling additional details of your setup:

Local Logs

This link provides a quick way to access the logfiles without requiring access to the server itself. It firsts list the contents of the *log* directory where you can select the logfile you want to see. Click on a log to reveal its content. (to come) helps you to make sense of what you may see. [Figure 6-43](#) shows an example page.

Directory: /logs/

SecurityAuth.audit	7973 bytes	May 26, 2015 3:38:44 AM
hbase-hadoop-master-master-1.internal.larsgeorge.com.log	236953 bytes	May 26, 2015 4:16:33 AM
hbase-hadoop-master-master-1.internal.larsgeorge.com.out	465 bytes	May 26, 2015 3:01:57 AM
hbase-hadoop-master-master-1.internal.larsgeorge.com.out.1	22578 bytes	May 26, 2015 2:58:45 AM
hbase-hadoop-master-master-1.internal.larsgeorge.com.out.2	465 bytes	May 25, 2015 11:44:34 PM
hbase-hadoop-master-master-1.internal.larsgeorge.com.out.3	22578 bytes	May 25, 2015 11:35:56 PM

Figure 6-43. The Local Logs page

Log Level

This link leads you to a small form that allows you to retrieve and set the logging levels used by the HBase processes. More on this is provided in (to come). [Figure 6-44](#) shows the form, already filled in with org.apache.hadoop.hbase as the log hierarchy point to check the level for.

Log Level

Get / Set

Log:

Log: Level:

[Hadoop](#), 2015.

Figure 6-44. The Log Level page

When you click on the *Get Log Level* button, you should see a result similar to that shown in [Figure 6-45](#).

Log Level

Results

Submitted Log Name: org.apache.hadoop.hbase
Log Class: org.apache.commons.logging.impl.Log4JLogger
Effective level: INFO

Get / Set

Log: Get Log Level

Log: Level: Set Log Level

[Hadoop](#), 2015.

Figure 6-45. The Log Level Result page

Debug Dump

For debugging purposes, you can use this link to dump many details of the current Java process, including the stack traces of the running threads. You can find more details in (to come). The following details are included, with the difference between HBase Master and Region Server mentioned (the Master has a few more sections listed in the debug page):

Version Info

Lists some of the information shown at the bottom of the status pages, that is, the HBase and Hadoop version, and who compiled them. See “[Software Attributes](#)” (page 520) or “[Software Attributes](#)” (page 550).

Tasks

Prints all of the monitored tasks running on the server. Same as explained in, for example, “[Tasks](#)” (page 518).

Servers

Master Only—Outputs the name and server load of each known online region server (see “[Cluster Status Information](#)” (page 411) for details on the server load records).

Regions in Transition

Master Only—Lists the regions in transition, if there are any. See “[Regions in Transition](#)” (page 516) for details.

Executors

Shows all the currently configured executor threads, working on various tasks.

Stacks

Dumps the stack traces of all Java threads.

Configuration

Prints the configuration as loaded by the current server.

Recent Region Server Aborts

Master Only—Lists the reasons of the last region server aborts, that is, the reasons why a slave server was abandoned or stopped.

Logs

The log messages of the server's log are printed in this section. Lists the last 100KBs, but can be changed per request by adding the tailkb parameter with the desired number of kilobytes to the URL.

Region Server Queues

Shows detailed information about the compaction and flush queues. This includes the different types of compaction entries (small, or large), as well as splits, and region merges. Can be disabled setting the `hbase.regionserver.servelet.show.queuedump` configuration property to false.

Figure 6-46 shows an abbreviated example output for a region server. The full pages are usually very long, as the majority of the emitted information is very verbose.

```
RegionServer status for slave-1.internal.larsgeorge.com,16020,1432728017580 as of Wed May 27 08:53:03 PDT 2015
```

Version Info:

```
HBase 1.1.0
Source code repository git://hw11397.local/Volumes/hbase-1.1.0RC2/hbase revision=e860c66d41ddc8231004b646098a50abca7fb523
Compiled by ndminiduk on Tue May 12 13:07:08 PDT 2015
From source with checksum bcf4ec64372fbd348e6a97dc281c3b0f
Hadoop 2.5.1
Source code repository Unknown revision=2e10d179e4a8065b6a9ff29cf2de9451891265cce
Compiled by ndminiduk on 2015-03-26T16:58Z
```

Tasks:

```
Task: RpcServer.reader=1,bindAddress=slave-1.internal.larsgeorge.com,port=16020
Status: WAITING:Waiting for a call
Running for 13962s

Task: RpcServer.reader=2,bindAddress=slave-1.internal.larsgeorge.com,port=16020
Status: WAITING:Waiting for a call
Running for 13960s

Task: RpcServer.reader=3,bindAddress=slave-1.internal.larsgeorge.com,port=16020
Status: WAITING:Waiting for a call
Running for 13959s

Task: RpcServer.reader=4,bindAddress=slave-1.internal.larsgeorge.com,port=16020
Status: WAITING:Waiting for a call
Running for 13959s

Task: RpcServer.reader=5,bindAddress=slave-1.internal.larsgeorge.com,port=16020
Status: WAITING:Waiting for a call
Running for 13959s

Task: RpcServer.reader=6,bindAddress=slave-1.internal.larsgeorge.com,port=16020
Status: WAITING:Waiting for a call
Running for 13844s

Task: RpcServer.reader=7,bindAddress=slave-1.internal.larsgeorge.com,port=16020
Status: WAITING:Waiting for a call
Running for 13844s

Task: RpcServer.reader=8,bindAddress=slave-1.internal.larsgeorge.com,port=16020
Status: WAITING:Waiting for a call
Running for 13844s

Task: RpcServer.reader=9,bindAddress=slave-1.internal.larsgeorge.com,port=16020
Status: WAITING:Waiting for a call
Running for 13844s

Task: RpcServer.reader=0,bindAddress=slave-1.internal.larsgeorge.com,port=16020
Status: WAITING:Waiting for a call
Running for 13844s
```

Executors:

```
=====
Status for executor: Executor-5-RS_LOG_REPLAY_OPS-slave-1:16020
=====
0 events queued, 0 running
```

Figure 6-46. The Debug Dump page for a Region Server

Metrics Dump

Emits the current server metrics—as explained in (to come)—as a JSON structure. [Figure 6-47](#) shows an abbreviated example.

```

{
  "beans" : [ {
    "name" : "java.lang:type=Memory",
    "modelerType" : "sun.management.MemoryImpl",
    "ObjectPendingFinalizationCount" : 0,
    "NonHeapMemoryUsage" : {
      "committed" : 136773632,
      "init" : 136773632,
      "max" : 184549376,
      "used" : 48938744
    },
    "Verbose" : false,
    "HeapMemoryUsage" : {
      "committed" : 60751872,
      "init" : 62764800,
      "max" : 995819520,
      "used" : 30352928
    },
    "ObjectName" : "java.lang:type=Memory"
  }, {
    "name" : "Hadoop:service=HBase,name=MetricsSystem,sub=Control",
    "modelerType" : "org.apache.hadoop.metrics2.impl.MetricsSystemImpl"
  }, {
    "name" : "Hadoop:service=HBase,name=Master,sub=AssignmentManger",
    "modelerType" : "Master,sub=AssignmentManger",
    "tag.Context" : "master",
    "tag.Hostname" : "master-1.internal.larsgeorge.com",
    "ritOldestAge" : 0,
    "ritCount" : 0,
    "BulkAssign_num_ops" : 12,
    "BulkAssign_min" : 0,
    "BulkAssign_max" : 276,
    "BulkAssign_mean" : 52.75,
    "BulkAssign_median" : 14.0,
    "BulkAssign_75th_percentile" : 80.75,
    "BulkAssign_95th_percentile" : 276.0,
    "BulkAssign_99th_percentile" : 276.0,
    "ritCountOverThreshold" : 0,
    "Assign_num_ops" : 2,
    "Assign_min" : 172,
    "Assign_max" : 191,
    "Assign_mean" : 181.5,
    "Assign_median" : 181.5,
    "Assign_75th_percentile" : 191.0,
    "Assign_95th_percentile" : 191.0,
    "Assign_99th_percentile" : 191.0
  }, {
    "name" : "Hadoop:service=HBase,name=HwiMetrics"
  }
}

```

Figure 6-47. The Metrics Dump page

HBase Configuration

Last but not least, this shared link lets you output the current server configuration as loaded by the process. This is not necessarily what is on disk in the configuration directory, but what has been loaded at process start time, and possibly modified by dynamically reloading the configuration. [Figure 6-48](#) is an example XML output this link produces. Depending on your browser (here Chrome) the rendering will vary.

This XML file does not appear to have any style information associated with it. The document tree is shown below.

```
<configuration>
  <property>
    <name>dfs.journalnode.rpc-address</name>
    <value>0.0.0.0:8485</value>
    <source>hdfs-default.xml</source>
  </property>
  <property>
    <name>io.storefile.bloom.block.size</name>
    <value>131072</value>
    <source>hbase-default.xml</source>
  </property>
  <property>
    <name>yarn.ipc.rpc.class</name>
    <value>org.apache.hadoop.yarn.ipc.HadoopYarnProtoRPC</value>
    <source>yarn-default.xml</source>
  </property>
  <property>
    <name>mapreduce.job.maxtaskfailures.per.tracker</name>
    <value>3</value>
    <source>mapred-default.xml</source>
  </property>
  <property>
    <name>hbase.rest.threads.min</name>
    <value>2</value>
    <source>hbase-default.xml</source>
  </property>
  <property>
    <name>hbase.rs.cacheblocksonwrite</name>
    <value>false</value>
    <source>hbase-default.xml</source>
  </property>
  <property>
    <name>hbase.health-monitor.connect-retry-interval</name>
```

Figure 6-48. The HBase Configuration page

The web-based UI provided by the HBase servers is a good way to quickly gain insight into the cluster, the hosted tables, the status of regions and tables, and so on. The majority of the information can also be accessed using the HBase Shell, but that requires console access to the cluster.

You can use the UI to trigger selected administrative operations; therefore, it might not be advisable to give everyone access to it: similar to the shell, the UI should be used by the operators and administrators of the cluster.

If you want your users to create, delete, and display their own tables, you will need an additional layer on top of HBase, possibly using Thrift or REST as the gateway server, to offer this functionality to end users.

Chapter 7

Hadoop Integration

Hadoop consists of two major components at heart: the *file system* (HDFS) and the *processing framework* (YARN). We have discussed in earlier chapters how HBase is using HDFS (if not configured otherwise) to keep the stored data safe, relying on the built-in replication of data blocks, transparent checksumming, as well as access control and security (the latter you will learn about in (to come)). In this chapter we will look into how HBase is fitting nicely into the processing side of Hadoop as well.

Framework

The primary purpose of Hadoop is to store data in a reliable and scalable manner, and in addition provide means to process the stored data efficiently. That latter task is usually handed to YARN, which stands for *Yet Another Resource Negotiator*, replacing the monolithic *MapReduce* framework in Hadoop 2.2. MapReduce is still present in Hadoop, but was split into two parts: a resource management framework named YARN, and a MapReduce application running on top of YARN.

The difference is that in the past (before Hadoop 2.2), MapReduce was the only native processing framework in Hadoop. Now with YARN you can execute any processing methodology, as long as it can be implemented as a YARN application. MapReduce's processing architecture has been ported to YARN as *MapReduce v2*, and effectively runs the same code as it always did. What became apparent though over time is that there is a need for more complex processing, one that allows to solve other classes of computational problems. One very common one are *iterative* algorithms used in *machine learning*, with the prominent example of *Page Rank*, made popular by Google's search engine. The

idea is to compute a graph problem that iterates over approximations of solutions until a sufficiently stable one has been found.

MapReduce, with its two step, disk based processing model, is too rigid for these types of problems, and new processing engines have been developed to fit that gap. Apache Giraph, for example, can compute graph workloads, based on the Bulk Synchronous Parallel (BSP) model of distributed computation introduced by Leslie Valiant. Another is Apache Spark, which is using a Directed Acyclic Graphs (DAG) based engine, allowing the user to express many different algorithms, including MapReduce and iterative computations.

No matter how you use HBase with one of these processing engines, the common approach is to use the Hadoop provided mechanisms to gain access to data stored in HBase tables. There are shared classes revolving around `InputFormat` and `OutputFormat`, which can (and should) be used in a generic way, independent of how you process the data. In other words, you can use MapReduce v1 (the one before Hadoop 2.2 and YARN), MapReduce v2, or Spark, while all of them use the same lower level classes to access data stored in HDFS, or HBase. We will use the traditional MapReduce framework to explain these classes, though their application in other frameworks is usually the same. Before going into the application of HBase with MapReduce, we will first have a look at the building blocks.

MapReduce Introduction

MapReduce as a process was designed to solve the problem of processing in excess of terabytes of data in a scalable way. There should be a way to build such a system that increases in performance linearly with the number of physical machines added. That is what MapReduce strives to do. It follows a divide-and-conquer approach by splitting the data located on a distributed filesystem, or other data sources, so that the servers (or rather CPUs, or, more modern, “cores”) available can access these chunks of data and process them as fast as they can. The problem with this approach is that you will have to consolidate the data at the end. Again, MapReduce has this built right into it. [Figure 7-1](#) gives a high-level overview of the process.

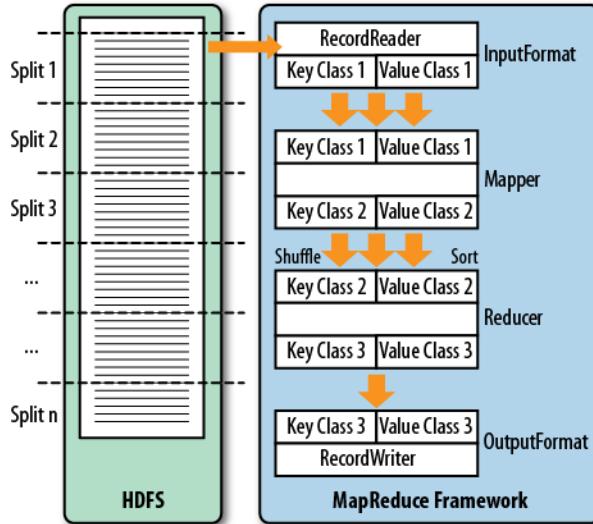


Figure 7-1. The MapReduce process

This (rather simplified) figure of the MapReduce process shows you how the data is processed. The first thing that happens is the *split*, which is responsible for dividing the input data into reasonably sized chunks that are then processed by one server at a time. This splitting has to be done in a somewhat smart way to make best use of available servers and the infrastructure in general. In this example, the data may be a very large log file that is divided into pieces of equal size. This is good, for example, for Apache HTTP Server log files. Input data may also be binary, though, in which case you may have to write your own `getSplits()` method—but more on that shortly.

The basic principle of MapReduce (and a lot of other processing engines or frameworks) is to extract *key/value* pairs from the input data. Depending on the processing engine, they might be called tuples, feature vectors, or records, and so. MapReduce refers to them as records (see [The MapReduce counters showing the records processed](#)), though the idea is the same: we have data points that need to be processed. In MapReduce there is an extra emphasis on the *key* part of each record, since it is used to route and group the values as part of the processing algorithm. Each key and value also have a defined type, which reflect their nature and makes processing less ambiguous. As part of the setup of each MapReduce workflow, the job designer has to assign the types to each key/value as it is passed through the processing stages.

The MapReduce counters showing the records processed.

```
...
Map-Reduce Framework
  Map input records=289
  Map output records=2157
  Map output bytes=22735
  Map output materialized bytes=10992
  Input split bytes=137
  Combine input records=2157
  Combine output records=755
  Reduce input groups=755
  Reduce shuffle bytes=10992
  Reduce input records=755
  Reduce output records=755
...
...
```

Processing Classes

Figure 7-1 also shows you the classes that are involved in the Hadoop implementation of MapReduce. Let us look at them and also at the specific implementations that HBase provides in addition.

MapReduce versus Mapred, versus MapReduce v1 and v2

Hadoop version 0.20.0 introduced a new MapReduce API. Its classes are located in the package named `mapreduce`, while the existing classes for the previous API are located in `mapred`. The older API was deprecated and should have been dropped in version 0.21.0—but that did not happen. In fact, the old API was un-deprecated since the adoption of the new one was hindered by its initial incompleteness.

HBase also has these two packages, which started to differ more and more over time, with the new API being the actively supported one. This chapter will only refer to the new API, that is, when you need to use the `mapred` package instead, you will have to replace the respective classes. Some are named slightly different, but fulfil the same purpose (for example, `TableMap` versus `TableMapper`). Yet others are not available in the older API, and would need to be ported by manually. Most of the classes are self-contained or have little dependencies, which means you can copy them into your own source code tree and compile them with your job archive file.

On the other hand—not to complicate matters presumably--, there is the difference between MapReduce v1 and v2, mentioned earli-

er. The differences in v1 and v2 are not the API, but their implementations, with v1 being a single, monolithic framework, and v2 being an application executed by YARN. This change had no impact on the provided APIs by MapReduce, and both, v1 and v2, offer the `mapreduce` and `mapred` packages. Since YARN is the official processing framework as of Hadoop 2.2 (released in 2013), and since both expose the same API, this chapter will use YARN to execute the MapReduce examples.

InputFormat

The first hierarchy of classes to deal with is based on the `InputFormat` class, shown in [Figure 7-2](#). They are responsible for two things: first, split the input data into chunks, and second, return a `RecordReader` instance that defines the types of the `key` and `value` objects, and also provides a `nextKeyValue()` method that is used to iterate over each input record.¹

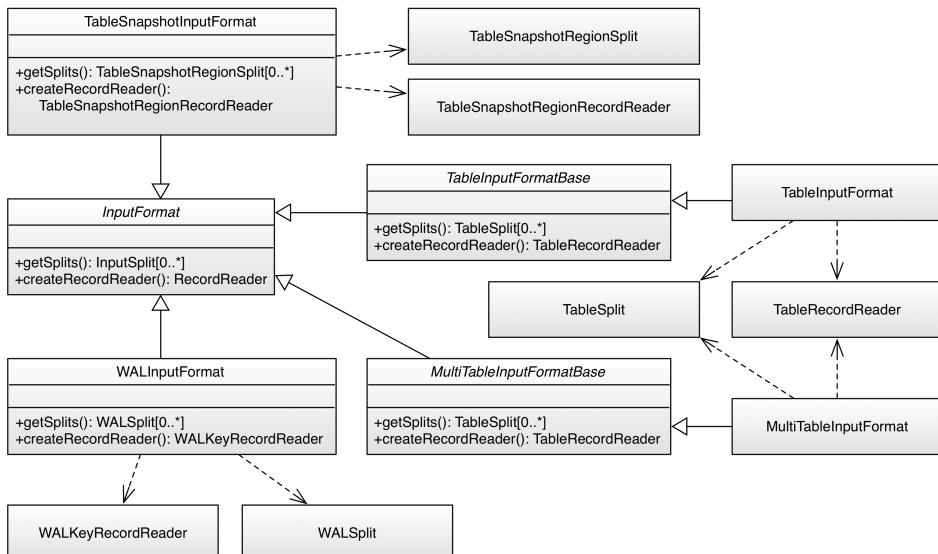


Figure 7-2. The InputFormat hierarchy

1. Note the switch of language here: sometimes Hadoop refers to the processed data as *records*, sometimes as *KeyValues*. These are used interchangeably.

As far as HBase is concerned, there are the following special implementations:

TableInputFormat

This class is based on `TableInputFormatBase`, which implements the majority of the functionality but remains abstract. `TableInputFormat` is used by many supplied examples, tools, and real MapReduce classes, as it provides the most generic functionality to iterate over data stored in a HBase table.

You either have to provide a `Scan` instance that you can prepare in any way you want: specify start and stop keys, add filters, specify the number of versions, and so on, or you have to hand in these parameters separately and the framework will set up the `Scan` instance internally. See [Table 7-1](#) for a list of all the basic properties.

Table 7-1. The basic `TableInputFormat` configuration properties

Property	Description
<code>hbase.mapreduce.inputtable</code>	Specifies the name of the table to read.
<code>hbase.mapreduce.splittable</code>	Specifies an optional table to use for split boundaries. This is useful when you are preparing data for bulkload.
<code>hbase.mapreduce.scan</code>	A fully configured, base-64 encoded scanner. All other scan properties are ignored if this is specified. See <code>TableMapReduceUtil.convertScanToString(Scan)</code> for more details.
<code>hbase.mapreduce.scan.row.start</code>	The optional start row key of the scan (see <code>Scan.setStartRow()</code>).
<code>hbase.mapreduce.scan.row.stop</code>	The optional stop row key for the scan (see <code>Scan.setStopRow()</code>).
<code>hbase.mapreduce.scan.column.family</code>	When given, specifies the column family to scan (see <code>Scan.addFamily()</code>).
<code>hbase.mapreduce.scan.columns</code>	Optional space character-delimited list of columns to include in scan (see <code>Scan.addColumn()</code>).
<code>hbase.mapreduce.scan.timestamp</code>	Allows to set a specific timestamp for the scan to return only those exact versions (see <code>Scan.setTimestamp()</code>).
<code>hbase.mapreduce.scan.time.range.start/hbase.mapreduce.scan.timerange.end</code>	The starting and ending timestamp used to filter columns with a specific range of versions (see <code>Scan.setTimeRange()</code>). Both must be set to take effect.

Property	Description
hbase.mapreduce.scan.maxversions	The maximum number of version to return (see Scan.setMaxVersions()).
hbase.mapreduce.scan.cacheblocks	Set to false to disable server-side caching of blocks for this scan (see Scan.setCacheBlocks()).
hbase.mapreduce.scan.cachetrows	The number of rows for caching that will be passed to scanners (see Scan.setCaching()).
hbase.mapreduce.scan.batchsize	Set the maximum number of values to return for each call to next() (see Scan.setBatch()).

Some of these properties are assignable through dedicated setter methods, for example, the `setScan()` or `configureSplitTable()` calls. You will see examples of that in “[Supporting Classes](#)” (page 575) and “[MapReduce over Tables](#)” (page 586).

The `TableInputFormat` splits the table into proper blocks for you and hands them over to the subsequent classes in the MapReduce process. See “[Table Splits](#)” (page 583) for details on how the table is split. The provided, concrete implementations of the inherited `getSplits()` and `createRecordReader()` methods return the special `TableSplit` and `TableRecordReader` classes, respectively. They wrap each region of a table into a split record, and return the rows and columns as configured by the scan parameters.

MultiTableInputFormat

Since a `TableInputFormat` is only handling a single table with a single scan instance, there is another class extending the same idea to more than one table and scan, aptly named `MultiTableInputFormat`. It is *only* accepting a single configuration property, named `hbase.mapreduce.scans`, which holds the configured scan instance. Since the `Configuration` class used allows to specify the same property more than once, you can add more than one into the current job instance, for example:

```
List<Scan> scans = new ArrayList<Scan>();

Scan scan = new Scan();
scan.setAttribute(Scan.SCAN_ATTRIBUTES_TABLE_NAME,
    Bytes.toBytes("prodretail:users"));
scans.add(scan);

scan = new Scan();
scan.setAttribute(Scan.SCAN_ATTRIBUTES_TABLE_NAME,
    Bytes.toBytes("prodchannel1:users"));
scan.setTimeRange(...);
scans.add(scan);
...
TableMapReduceUtil.initTableMapperJob(scans, ReportMap-
```

```
per.class,
    ImmutableBytesWritable.class, ImmutableBytesWritable.class,
job);
```

This uses an up until now unmentioned public constant, exposed by the Scan class:

```
static public final String SCAN_ATTRIBUTES_TABLE_NAME = \
"scan.attributes.table.name";
```

It is needed for the MultiTableInputFormat to determine the scanned tables. The previous TableInputFormat works the other way around by explicitly setting the scanned table, because there is only one. Here we assign the tables to the one or more scans handed into the MultiTableInputFormat configuration, and then let it iterate over those implicitly.

TableSnapshotInputFormat

This input format class allows you to read a previously taken table snapshot. What has been omitted from the class diagram is the relationship to another class in the mapreduce package, the TableSnapshotInputFormatImpl. It is shared between the two API implementations, and provides generic, API independent functionality. For example, it wraps a special InputSplit class, which is then further wrapped into a TableSnapshotRegionSplit class by the TableSnapshotInputFormat class. It also has the getSplits() method that understands the layout of a snapshot within the HBase root directory, and is able to wrap each contained region into a split instance. Since this is the same no matter which MapReduce API is used, the functionality is implemented in the shared class.

The dedicated snapshot input format also has a setter named setInput() that allows you to assign the snapshot details. You can access this method directly, or use the utility methods provided by TableMapReduceUtil, explained in “[Supporting Classes](#)” (page 575). The setInput() also asks for the name of a temporary directory, which is used internally to restore the snapshot, before it is read from. The user running the MapReduce job requires write permissions on this directory, or the job will fail. This implies that the directory must be, for example, outside the HBase root directory.

WALInputFormat

If you ever need to read the binary write-ahead logs that HBase generates, you can employ this class to access them.² It is primari-

2. As of this writing, there is also a deprecated class named HLogInputFormat that only differs from WALInputFormat in that it handles the equally deprecated HLogKey class, as opposed to the newer WALKey.

ly used by the `WALPlayer` class and tool to reply write-ahead logs using MapReduce. Since WALs are rolled by default when they approach the configured HDFS block size, it is not necessary to calculate splits. Instead, each WAL is mapped to one split. The only exposed configuration properties for the WAL input format are:

```
public static final String START_TIME_KEY = "wal.start.time";
public static final String END_TIME_KEY = "wal.end.time";
```

They allow the user to specify which entries should be read from the logs. Any record before the start, and after the end time will be ignored. Of course, these properties are optional, and if not given the entire logs are read and each record handed to the processing function.

With all of these classes, you can always decide to create your own, or extend the given ones and add your custom business logic as needed. The supplied classes also provide methods (some have their Java scope set as `protected`) that you can override to slightly change the behavior without the need of implementing the same functionality again. The classes ending `Base` are also a good starting point for your own implementations, since they offer many features, and thus form the basis for the provided concrete classes, and could do the same for your own.

Mapper

The `Mapper` class(es) is for the next stage of the MapReduce process and one of its namesakes ([Figure 7-3](#)). In this step, each record read using the `RecordReader` is processed using the `map()` method. [Figure 7-1](#) also shows that the `Mapper` reads a specific type of key/value pair, but emits possibly another type. This is handy for converting the raw data into something more useful for further processing.

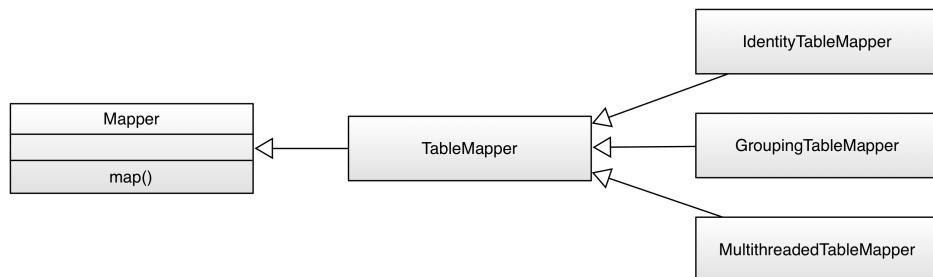


Figure 7-3. The Mapper hierarchy

HBase provides the `TableMapper` class that enforces *key class 1* to be an `ImmutableBytesWritable`, and *value class 1* to be a `Result` type—since that is what the `TableRecordReader` and `TableSnapshotRecordReader` are returning. There are multiple implementations of derived mapper classes available:

IdentityTableMapper

One subclass of the `TableMapper` is the `IdentityTableMapper`, which is also a good example of how to add your own functionality to the supplied classes. The `TableMapper` class itself does not implement anything but only adds the signatures of the actual key/value pair classes. The `IdentityTableMapper` is simply passing on the keys/values to the next stage of processing.

GroupingTableMapper

This is a special subclass that needs a list of columns before it can be used. The mapper code checks each row it is given by the framework in form of a `Result` instance, and if the given columns exists, it creates a new key as a concatenation of all values assigned to each named column. If any of the columns is missing in the row the entire row is skipped.

You can set the key columns using the static `initJob()` method of this class, or assign it to the following configuration property, provided as a public constant in the mapper class:

```
public static final String GROUP_COLUMNS =
    "hbase.mapred.groupingtablemap.columns";
```

The class expects the columns to be specified as a space character-delimited string, for example "`colfam1:col1 colfam1:col2`". If these columns are found in the row, the row key is replaced by a space character-delimited new key, for example:

```
Input:
    "row1" -> cf1:col1 = "val1", cf1:col2 = "val2", cf1:col3 =
    "val3"

Output:
    "val1 val2" -> cf1:col1 = "val1", cf1:col2 = "val2",
    cf1:col3 = "val3"
```

The purpose of this change of the map output key value is the subsequent reduce phase, which receives key/values grouped based on the key. The shuffle and sort steps of the MapReduce framework ensure that the records are sent to the appropriate Reducer instance, which is usually another server somewhere in the cluster. By being able to group the rows using some column values you

can send related rows to a single reducer and therefore perform some processing function across all of them.

MultiThreadedTableMapper

One of the basic principles of the MapReduce framework is that the map and reduce functions are executed by a single thread, which simplifies the implementation because there is no need to take care of thread-safety. Often—for performance reasons—class instances are reused to process data as fast as can be read from disk, and not being slowed down by object instantiation. This is especially true for very small data points.

On the other hand, sometimes the processing in the map function is requiring an excessive amount of time, for example when data is acquired from an external resource, over the network. An example is a web crawling map function, which loads the URL from one HBase table, retrieves the page over the Internet, and writes the fetch content into another HBase table. In this case you mostly wait for the external operation.

Since each map takes up a slot of the processing framework, it is considered scarce, and is limited to what the scheduler is offering to your job. In other words, you can only crawl the web so fast as you receive processing capacities, but then wait for an external resource most of the time. The `MultiThreadedTableMapper` is available for exactly that reason, enabling you to turbo-charge your map function by executing it in a parallel fashion using a thread pool. The pool is controlled by the following configuration property, or the respective getter and setter:

```
public static final String NUMBER_OF_THREADS = \
    "hbase.mapreduce.multithreadedmapper.threads";\n\npublic static int getNumberOfThreads(JobContext job)
public static void setNumberOfThreads(Job job, int threads)
```

Since you effectively bypass the number of threads assigned to you by the scheduler and instead multiply that number at your will, you must take care not to exhaust any vital resources in the process. For example, if you were to use the multithreaded mapper implementation to just read from, and/or write to HBase, you can easily overload the disk I/O. Even with YARN using Linux control groups (cgroups), or other such measures to guard system resources, you have to be very careful.

The number of threads to use is dependent on your external wait time, for example, if you fetch web pages as per the example above, you may want to gradually increase the thread pool to reach CPU or network I/O saturation. The default size of the thread pool is 10, which is conservative start point. Before you can use the threaded class you need to assign the actual map function to run. This is done using the following configuration property, or again using the provided getter and setter methods:

```
public static final String MAPPER_CLASS = \  
    "hbase.mapreduce.multithreadedmapper.mapclass";  
  
public static <K2, V2> Class<Mapper<ImmutableBytesWritable, Re-  
sult, K2, V2>> \  
    getMapperClass(JobContext job)  
public static <K2, V2> void setMapperClass(Job job, \  
    Class<? extends Mapper<ImmutableBytesWritable, Result, K2,  
    V2>> cls)
```

The only difference to a normal map method is that you have to implement it in a thread-safe manner, just as any other Runnable based Java thread executable. This implies that you cannot reuse simple instance variables, unless they refer to an object that itself is thread-safe as well.

Reducer

The Reducer stage and class hierarchy ([Figure 7-4](#)) is very similar to the Mapper stage. This time we get the output of a Mapper class and process it after the data has been *shuffled* and *sorted*.

In the implicit shuffle between the Mapper and Reducer stages, the intermediate data is copied from different Map servers to the Reduce servers and the sort combines the shuffled (copied) data so that the Reducer sees the intermediate data as a nicely sorted set where each unique key is now associated with all of the possible values it was found with.

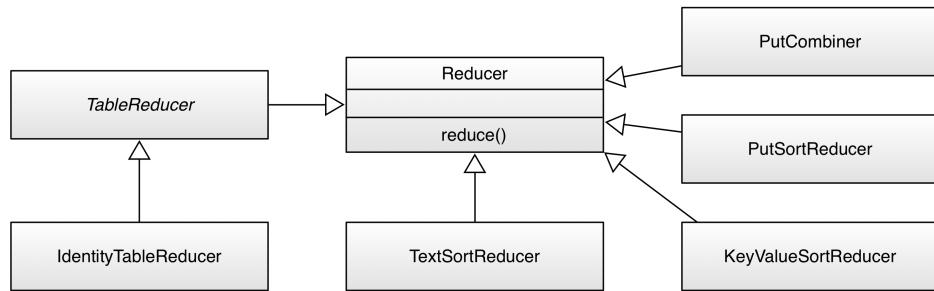


Figure 7-4. The Reducer hierarchy

There are again a set of derived classes available, though for direct table operations there is only one: the `TableReducer` class. It has a subclass called `IdentityTableReducer`, and all it does is make the former abstract class a concrete, usable one. In other words, the basic functionality of a `Reducer` based class is to pass on the data unchanged. If you want anything else, you need to implement your own.

Then there are a few more classes directly subclassing `Reducer`. These are all needed for *bulk loading* data into HBase, as discussed in (to come). Dependent on the type of data being loaded, one of `TextSortReducer`, `PutSortReducer`, or `KeyValueSortReducer` is used to emit the bulk loader data in a sorted manner. The `PutCombiner` is an optimization used in the `ImportTsv` tool to combine many smaller puts into one larger one. This is close to the recommended Combiner usage within Hadoop, reducing transfer of data between Mapper and Reducer instances during the shuffle phase. There could potentially be hundred or thousands of `Put` objects that would need to be serialized and sent to the reducer process on a remote server. Combining these into one does not reduce the size of the data, but reduces class overhead.

OutputFormat

The final stage is the `OutputFormat` class hierarchy ([Figure 7-5](#)), and the job of these classes is to persist the data in various locations. There are specific implementations that allow output to files, or to HBase tables, and we are going to discuss each of them subsequently.

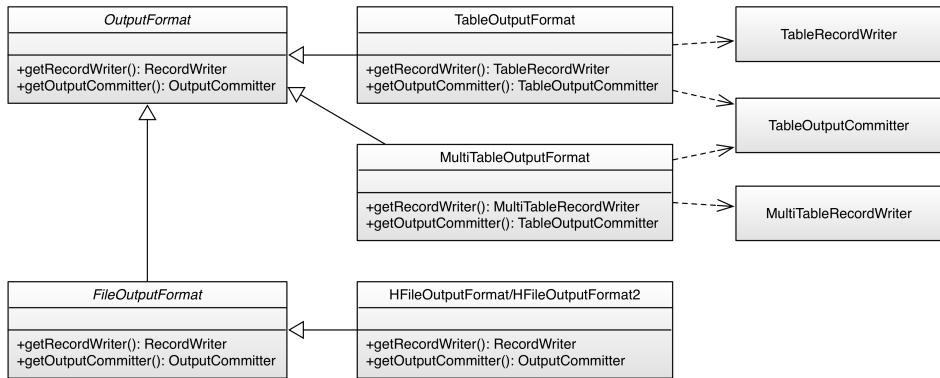


Figure 7-5. The OutputFormat hierarchy

TableOutputFormat

This class is the default output format for many MapReduce jobs that need to write data back into HBase tables. It uses a `TableRecordWriter` to write the data into the specific HBase output table. The latter uses a `BufferedMutator` instance to buffer writes before sending them in batches to the servers. The provided `write()` method expects to receive either a `Put` or a `Delete` instance, and uses the `BufferedMutator.mutate()` method to persist them. If you hand in something else, for example a `Get` or `Increment` instance an error is thrown instead. The `close()` method of the record writer class closes the mutator, enforcing the flush of any pending write operation to the servers.

It is important to note the cardinality as well. Although many Map pers are handing records to many Reducers, only one `OutputFor mat` instance takes the output records from its assigned Reducer subsequently. It is the final class that handles the key/value pairs and writes them to their final destination, this being a file or a table. You need to configure the output format using the configuration properties shown in [Table 7-2](#).

Table 7-2. The TableOutputFormat configuration properties

Property	Description
<code>hbase.mapred.outputtable</code>	The table to write into (required).
<code>hbase.mapred.output.quorum</code>	Optional parameter to specify a peer cluster. Used to specifying a remote cluster when copying between hbase clusters (the source cluster is picked up from <code>hbase-site.xml</code>).

Property	Description
hbase.mapred.out.put.quorum.port	Optional parameter to specify the peer cluster's ZooKeeper client port.
hbase.mapred.out.put.rs.class	Optional specification of the RegionServer class name of the peer cluster.
hbase.mapred.out.put.rs.impl	Optional specification of the RegionServer implementation name of the peer cluster.

These properties are exposed as public constants, allowing you to refer to them as needed, or you can use, for example, the `initTableReducerJob()` method of the `TableMapReduceUtil` helper class to set the table name implicitly. The name of the output table must be specified when the job is set up. Otherwise, the `TableOutputFormat` does not add much more complexity.

The four optional properties allow you to set up a job that reads from one cluster—configured by the current configuration instance—and write to another. The above `initTableReducerJob()` call (one of the overloaded version) has facilities for assigning these properties as well.

MultiTableOutputFormat

An extension to the direct `TableOutputFormat` is the ability to write to more than one single output table. For that matter, the dedicated `MultiTableRecordWriter` uses a need “trick” to coax in the table name for every record emitted by the map or reduce task: it defines the types of the writer as `RecordWriter<ImmutableBytesWritable, Mutation>`, using the `key` as the table name. Usually the key is not needed for the HBase mutations to be written to a table, as the name of the latter is set in the configuration of the job. In fact, the `TableOutputFormat` with its `TableRecordWriter` completely ignore the key, while simply persisting the handed in `put` or `delete` object into the globally configured buffered mutator.

In other words, the change in usage is that a map or reduce task needs to take care of what to emit by specifying the destination table name, and the mutation (the `put` or `delete`). For example, usually you would emit a mutation in a map or reduce method using the `TableOutputFormat` like so:

```
context.write(new ImmutableBytesWritable(rowkey), put);
```

Instead, you switch the key out to name the table instead:

```
context.write(new ImmutableBytesWritable(tableName), put);
```

Internally the class uses a `BufferedMutator` instance for every named table. In addition, the following constants are exposed by the class:

```
public static final String WAL_PROPERTY = \  
    "hbase.mapreduce.multitableoutputformat.wal";  
public static final boolean WAL_ON = true;  
public static final boolean WAL_OFF = false;
```

They allow you to influence the durability settings for the write operation, as explained in “[Durability, Consistency, and Isolation](#)” ([page 108](#)).

A few more general notes on the output formats and their supporting classes:

1. The `TableOutputCommitter` class, used by both the above output formats, is required for the Hadoop framework to do its job. For HBase integration, this class is not needed. In fact, it is a dummy and does not do anything. Other implementations of `OutputFormat` do require a specific output committer, but for HBase an empty implementation is all that is needed.
2. The `BufferedMutator` instances used have no explicit setter or getter regarding their configuration. Instead, you have to set the configuration properties influencing the buffered mutators before you set up the MapReduce job. The settings will be passed into the wrapping output formats through the job context. [Table 7-3](#) lists the properties with their default values. Especially the write buffer should be tuned based on the use-case, where its size should account for a decent amount of mutations to save on the batched network roundtrips.

Table 7-3. Important configuration settings influencing the `BufferedMutator` behavior

Property	Default	Description
<code>hbase.client.write.buffer</code>	2097152 (2MB)	Configures the local write buffer in bytes.
<code>hbase.client.keyvalue.maxsize</code>	10485760 (10MB)	Limits the maximum cell size a client can write.
<code>hbase.client.retries.number</code>	35	Number of retries before failing the operation.
<code>hbase.client.pause</code>	100 (ms)	Initial pause between retries. Increases incrementally for retries.
<code>hbase.rpc.timeout</code>	60000 (1 min)	The connection timeout for the remote server call.

Finally, there is a third class of input format, which is not directly based on `OutputFormat`, but `FileOutputFormat` instead. The reason to rather extend `FileOutputFormat` is based on the built in features of that class and the need to write HBase storage files, called *HFile*, directly into the configured file storage layer, usually HDFS.

`HFileOutputFormat/HFileOutputFormat2`

This output format is used to stage *HFile*'s before they are loaded into the tables, as explained in (to come). The difference between these two classes is that the former is for the now deprecated `KeyValue` class, for legacy reasons, and the latter is for the newer `Cell` classes. The class exposes a static, overloaded method named `configureIncrementalLoad()` which simplifies setting up a Map-Reduce job using this output format.

Part of setting up the *HFile* specific `RecordWriter` is to set the appropriate table properties, including maximum file size, compression format, Bloom filter type, the *HFile* block size, and block encoding format. Many are optional, and will default to what the provided `hbase-site.xml` file on the Java class path specifies. The emitted `Cell` will define which column families are generated, thus there is no need of specifying them explicitly. For the bulk load to work, there are quite a few steps involved, for example, sorting and routing the written `Cells` at a cluster-wide scale, using the `TotalOrderPartitioner` provided by Hadoop. This ensure that the cells for a specific row all end up being written in the expected sort-order by one reducer.

Supporting Classes

The MapReduce support comes with the `TableMapReduceUtil` class that helps in setting up MapReduce jobs over HBase. It has static methods that configure a job so that you can run it with HBase as the source and/or the target. It also has other helper methods to configure various aspects of working with the MapReduce framework. They can be grouped as such:

Class Path Setup

There are two variants of the `addDependencyJars()` method, with one finding all the containing JAR files given a list of classes. It adds the found JAR files to the provided configuration instance using the `tmpjars` property. This is honored by the MapReduce system which includes these JARs into the job setup using the Hadoop distributed cache. In other words, you will *not* have to do anything else to run the job.

The method is powerful enough to work in development environment, checking each named class file, and if it is *not* contained in a JAR file already (that is, it was loaded from a JAR before the check ran) it creates a JAR file on the fly and adds it to the configuration. The temporary file is created using the `File.createTempFile()` method, and used "hadoop-" as its name prefix. The location is set by the `test.build.dir` configuration property, and defaults to `target/test-dir`.

The second variant of the `addDependencyJars()` call just asks for a Job instance, and adds all HBase and user JARs necessary for the job execution, using the previous method. It looks at every class named in the job configuration, for example, the mapper and reducer classes, and adds them to the job configuration. Implicitly it calls a third class path related method named `addHBaseDependencies()`, which does the same for all HBase JARs a client may possibly need. The end result is that all required JAR files, from HBase or your own, are specified in the supplied configuration instance.

Lastly, the `buildDependencyClasspath()` method uses the `tmpjars` property, retrieving all of the configured JARs, and returning a string suitable for an operating system specific search path definition. For example, on Linux this may return something of the following pattern: `<path-to-jar>/<jarname1>.jar:<path-to-jar>/<jarname2>.jar:....` It is using the path and directory divider symbols configured for the platform it executes on.

Security Configuration

These calls allow you to set security credentials, but only do something useful when security is enabled (see (to come)). There is `initCredentials()` which passes on the details about the configured Hadoop delegation tokens and configures the users credentials. This is done by authenticating and retrieving the valid tokens to the job configuration. Before though the method also configures the appropriate ZooKeeper properties within the configuration, since it is needed to determine the unique cluster ID. Eventually the method sends a request to the authentication coprocessor of that cluster to retrieve the tokens, and assign them to the job configuration. This is done for the source *and* target cluster, if configured with the `hbase.mapred.output.quorum` property (as explained in "[OutputFormat](#)" (page 571)).

The `initCredentialsForCluster()` always assumes an external cluster, and asks for ZooKeeper quorum details explicitly. After that it does the same thing, that is, it authenticates the user by

sending a request to the coprocessor, and adding the returned token information to the job configuration.

Configure Table as Input

The `initTableMapperJob()` call comes in many variations. They are essential in setting up MapReduce jobs where the HBase table acts as an input to a Map instance. Here an example signature of one variant:

```
public static void initTableMapperJob(String table, Scan scan,
    Class<? extends TableMapper> mapper, Class<?> outputKeyClass,
    Class<?> outputValueClass, Job job, boolean addDependency-
Jars,
    boolean initCredentials, Class<? extends InputFormat> input-
FormatClass)
throws IOException
```

The calls add more or less details to the job configuration, so that you can choose which is the most suitable to your task at hand. In general, the calls do the following:

1. Configure the job with the given `InputFormat` class
2. If given, overwrite the output key and value class types
3. Assign the given mapper class to the job
4. Optionally, set the `PutCombiner` as combiner class, when the output value type is `Put`
5. Merge the currently visible Hadoop and HBase configuration into the job configuration
6. Set the given table name in the configuration
7. Serialize the configured `Scan` instance and assign it to the configuration
8. Overwrite the default Hadoop `Writable` based serialization with a custom HBase one, based on Protobufs:

```
conf.setStrings("io.serializations", conf.get("io.seriali-
zations"),
    MutationSerialization.class.getName(),
    ResultSerialization.class.getName(),
    KeyValueSerialization.class.getName());
```

9. Optionally, call `addDependencyJars()` to add all JARs to the class path
10. Optionally, set up the security credentials using `initCreden-
tials()`

The mentioned `Serialization` classes are also part of the `map-
reduce` package, and handle the conversion of mutations,

query result, and cells in a platform independent manner, using Google’s Protocol Buffers, and discussed in depth in “[Serialization](#)” (page 353). They are not used explicitly anywhere else, so their implicit use by the `initTableMapperJob()` is somewhat hidden. Especially if you do not use the utility methods provided, you would need to set these classes manually, as shown in the code excerpt above.

Configure Table as Output

The counterpart of the previous set of methods is this one, and it configures a `TableOutputFormat` to use a HBase table as the target for data emitted from the MapReduce job.

Keep in mind that the MapReduce `OutputFormat` is used in combination with a single Reducer instance. In case of a *map-only* job though the output format is called directly by the map function.

The provided `initTableReducerJob()` call again comes in multiple versions, offering fewer to more parameters. Here is the fully specified variant for your perusal:

```
public static void initTableReducerJob(String table,
    Class<? extends TableReducer> reducer, Job job,
    Class partitioner, String quorumAddress, String serverClass,
    String serverImpl, boolean addDependencyJars) throws IOException
```

The following tasks are performed when invoking these methods:

1. Merge the currently visible Hadoop and HBase configuration into the job configuration
2. Assign the given output format class to the job
3. If given, set the reducer class for the job
4. Set the output table name in the configuration
5. Overwrite the default Hadoop `Writable` based serialization with a custom HBase one, based on Protobufs
6. Optionally, set the target cluster ZooKeeper quorum information
7. Optionally, assign the region server interface and implementation class name
8. Set the output key type to `ImmutableBytesWritable` and output value type to `Writable`

9. Assign the given partitioner to the job
 - a. In case of the supplied `HRegionPartitioner`, also limit the number of reduce tasks to run to be not greater than the number of regions in the output table
10. Optionally, call `addDependencyJars()` to add all JARs to the class path
11. Set up the security credentials using `initCredentials()`
This is very similar to the above `initTableMapperJob()`, but with a few difference to match the different purpose of writing into a table, instead of reading from it. Again, if you decide *not* to use this helper method, please study carefully what it does and make sure you do everything required for your use-case as well.

Configure Snapshot as Input

The supplied `initTableSnapshotMapperJob()` sets the name and temporary directory required using the `setInput()` method of the `TableSnapshotInputFormat` class, and then proceeds to invoke `initTableMapperJob()` while mostly passing on the parameters given by the caller. It also assigns the `TableSnapshotInputFormat` as the input format class for the job. One special function it performs is to overrides any block cache configuration that could cause the MapReduce task to exhaust its (usually scarce) resources.

Miscellaneous Tasks

The utility class `TableMapReduceUtil` has a few more generic methods, which are called from the other helpers, or can be called by your own code as necessary. The `limitNumReduceTasks()` ensures the number of requested reduce tasks for the MapReduce job does not exceed the number of available regions. `setNumReduceTasks()`, on the other hand, sets the number of reduce tasks to be the matching number of regions for the given table. This allows you to set up a job where you have a single reduce task responsible for exactly one region of the output table.

The already mentioned `resetCacheConfig()` overrides the cache configuration for the sake of memory limitations. And `setScannerCaching()` sets the `hbase.client.scanner.caching` property of the job configuration to the given value. With that you can influence for the particular job how many rows are fetched from the servers in one RPC. It obviously overwrites any existing value, including the default value.

There are a few more classes that are used implicitly but are required for proper results.

HRegionPartitioner

As mentioned when we discussed the `initTableReducerJob()` method of the `TableMapReduceUtil` utility class, this Hadoop Partitioner implementation serves the purpose of routing the mutations to the `TableOutputFormat` handling a specific region of the output table. It uses a `RegionLocator` instance configured with the specified output table to decide where each put or delete has to be sent. Obviously, this implies to carefully pre-split a new table to achieve proper load distribution across all region servers. If you load into an existing table, it still is frugal to ensure the table has enough regions to make, for example, the staging of the bulk loading efficient.

CellCreator

This class is used internally as part of the bulk loading process with `HFileOutputFormat`, and more specifically the `TextSortReducer` that receives the cells in text format and uses a parser to separate out the details. Once the parsing is complete for a cell, the `CellCreator` is used to convert the information into a `Cell` instance, which is then handed to the output format. Internally there is also made use of the supplied `VisibilityExpressionResolver` and `DefaultVisibilityExpressionResolver` classes, to convert security information into cell tags.

JarFinder

The mentioned `addDependencyJars()` uses this helper class to find, and optionally wrap development classes into JAR files, for adding them to the job configuration.

SimpleTotalOrderPartitioner

You can use this class to distribute mutations in your own MapReduce jobs, based on a configurable key range. The range is specified with the static `setStartKey()` and `setEndKey()` methods of this class, where the end key must be *exclusive*, that is, at least one byte greater than the biggest key you will use. It uses the `BigDecimal` class to convert the specified keys into numbers, splitting them into equally sized partitions using the `Bytes.split()` utility method.

The package provides a few more classes, with one group serving the bulk import feature discussed in (to come). The `ImportTsv`, `TsvImporterMapper`, `TsvImporterTextMapper`, and `LoadIncrementalHFiles` classes are all used as part of that process. The remaining classes are used in other HBase tools, explained in (to come).

MapReduce Locality

One of the more ambiguous things in Hadoop is block replication: it happens automatically and you should not have to worry about it. HBase relies on it to provide durability as it stores its files into the distributed filesystem. Although block replication works completely transparently, users sometimes ask how it affects performance.

This question usually arises when the user starts writing MapReduce jobs against either HBase or Hadoop directly. Especially when larger amounts of data are being stored in HBase, how does the system take care of placing the data close to where it is needed? This concept is referred to as *data locality*, and in the case of HBase using the Hadoop File System (HDFS), users may have doubts as to whether it is working.

First let us see how Hadoop handles this: the MapReduce documentation states that tasks run close to the data they process. This is achieved by breaking up large files in HDFS into smaller chunks, or blocks, with a default setting of 128 MB. Each block is assigned to a map task to process the contained data. This means larger block sizes equal fewer map tasks to run as the number of mappers is driven by the number of blocks that need processing.

Hadoop knows where blocks are located, and runs the map tasks directly on the node that hosts the block. Since block replication ensures that we have (by default) three copies on three different physical servers, the framework has the choice of executing the code on any of those three, which it uses to balance workloads. This is how it guarantees data locality during the MapReduce process.

Back to HBase. Once you understand that Hadoop can process data locally, you may start to question how this may work with HBase. As discussed in (to come), HBase transparently stores files in HDFS. It does so for the actual data files (HFile) as well as the logs (WAL). And if you look into the code, it uses the Hadoop API call `FileSystem.create(Path path)` to create these files.

If you do not co-share your cluster with Hadoop and HBase, but instead employ a separate Hadoop as well as a standalone HBase cluster, there is *no* data locality—there can't be. This is the same as running a separate MapReduce cluster that would not be able to execute tasks directly on the data node. It is imperative for data locality to have the Hadoop and HBase processes running on the same cluster.

How does Hadoop figure out where data is located as HBase accesses it? The most important factor is that HBase servers are not restarted frequently and that they perform housekeeping on a regular basis. These so-called compactions rewrite files as new data is added over time. All files in HDFS, once written, are immutable (for all sorts of reasons). Because of that, data is written into new files, and as their number grows, HBase compacts them into another set of new, consolidated files.

And here is the kicker: HDFS is smart enough to put the data where it is needed! It has a block placement policy in place that enforces all blocks to be written first on a colocated server. The receiving data node compares the server name of the writer with its own, and if they match, the block is written to the local filesystem. Then a replica is placed on a server within a remote rack, and another on a different server in the remote rack—all assuming you have rack-awareness configured within HDFS. If not, the additional copies get placed on the least loaded data node in the cluster.

If you have configured a higher replication factor, more replicas are stored on distinct machines. The important factor here, though, is that you now have a local copy of the block available. For HBase, this means that if the region server stays up for long enough (which is what you want), after a major compaction on all tables—which can be invoked manually or is triggered by a configuration setting—it has the files stored locally on the same host. The data node that shares the same physical host has a copy of all data the region server requires. If you are running a scan or get or any other use case, you can be sure to get the best performance.

An issue to be aware of is region movements during load balancing, or server failures. In that case, the data is no longer local, but over time it will be once again. The master also takes this into consideration when a cluster is restarted: it assigns all regions to the original region

servers. If one of them is missing, it has to fall back to the random region assignment approach.

The HDFS balancer is another factor that potentially could wreak havoc on block locality when run without the knowledge that HBase needs specific blocks to be kept on a specific server. See [HDFS-6133](#) for the feature required to skip HBase blocks during balancer executions. It is available in Hadoop 2.7 and later.

Table Splits

When running a MapReduce job in which you read from a table, you are typically using the `TableInputFormat`. It fits into the framework by overriding the required public methods `getSplits()` and `createRecordReader()`. Before a job is executed, the framework calls `getSplits()` to determine how the data is to be separated into chunks, because it sets the number of map tasks the job requires.

For HBase, the `TableInputFormat` uses the information about the table it represents—based on the `Scan` instance you provided—to divide the table at region boundaries. Since it has no direct knowledge of the effect of the optional filter, it uses the start and stop keys to narrow down the number of regions. The number of splits, therefore, is equal to all regions between the start and stop keys. If you do not set the start and/or stop key, all are included.³

When the job starts, the framework is calling `createRecordReader()` as many times as it has splits. It iterates over the splits and creates a new `TableRecordReader` by calling `createRecordReader()` with the current split. In other words, each `TableRecordReader` handles exactly one region, reading and mapping every row between the region's start and end keys.

The split also contains the server name hosting the region. This is what drives locality for MapReduce jobs over HBase: the framework checks the server name, and if a YARN worker node process is running on the same machine, it will preferably run it on that server. Because the region server is also colocated with the data node on that

3. This is not entirely true, the shared `TableInputFormatBase` class has a protected method named `includeRegionInSplit()` which by default returns `true`. A custom subclass could override the method and *not* include all regions belonging to the configured scan.

same node, the scan of the region will be able to retrieve all data from the local disk.

When running MapReduce over HBase, it is strongly advised that you turn *off speculative execution* mode. It will only create more load on the same region and server, and also works against locality: the speculative task is executed on a different machine, and therefore will not have the region server local, which is hosting the region. This results in all data being sent over the network, adding negatively to the overall I/O load.

There are two more advanced features available while the table splitting is performed: balancing for skewed tables, and shuffling the splits:

Auto-balance Splits

The split function iterates over the regions in their natural order, using their boundaries to set up the start and end of each split. What it does *not* check by default is if all the region actually contain the same amount of data. This is where the *auto-balance* feature comes in, controlled by the following configuration properties, exposed by the `TableInputFormatBase` class:

```
public static final String MAPREDUCE_INPUT_AUTOBALANCE = \  
    "hbase.mapreduce.input.autobalance";  
public static final String INPUT_AUTOBALANCE_MAXSKEWRATIO = \  
    "hbase.mapreduce.input.autobalance.maxskewratio";  
public static final String TABLE_ROW_TEXTKEY = \  
    "hbase.table.row.textkey";
```

Setting `hbase.mapreduce.input.autobalance` to true enables the feature, triggering an additional check that is performed after the usual split function has run. It consults the `hbase.mapreduce.input.autobalance.maxskewratio` property, defaulting to 3, to compare the size of each region against a skew ratio. First it computes the *average region size* and multiplies that by the specified *skew ratio* to determine the *maximum skew threshold*. It then iterates over all regions checking if it exceeds the maximum skew threshold, and, if it does, separates it into two splits. In other words, now two processing tasks will process one half of the larger region each, instead of a single one doing all the work alone.

If the region size is less than the threshold, but *greater* than the average size, it is added as-is. Should the region size be *smaller* than the average, it attempts to combine this region plus all subse-

quent one until it reaches (but not exceed) the maximum skew threshold value. Here there will be one process function reading more than one region. Obviously, this is counterproductive in regards to locality, as the combined split is retaining the locality information of the first small region. The remaining regions fold into the same split, and will most likely be read across the network—unless coincidentally the subsequent region is colocated on the same region server. You will need to weigh up the advantages of splits being of similar size for a skewed table against the cost of read some data over the network.

The `hbase.table.row.textkey` property is needed for those large regions that are split in two, and helps the method to compute the key that is in the middle of the start and end key of the region—assuming the data within is distributed uniformly. The default is `true`, which retains a human readable split key. If set to `false`, the split is done on a binary level, which could result in non-printable characters. [Table 7-4](#) shows some examples.

Table 7-4. Example keys for auto-balanced splits

Start Key	End Key	Text	Split Point
aaabcdefg	aaaffff	Yes	aaad
111000	1125790	Yes	111b
1110	1120	Yes	111_
{ 13, -19, 126, 127 }	{ 13, -19, 127, 0 }	No	{ 13, -19, 127, -64 }

Set the text key flag appropriately for your use-case when you enable the auto-balance functionality.

Shuffle Splits

The `TableInputFormat` class exposes another advanced property, allowing you to shuffle the splits and therefore the map order:

```
public static final String SHUFFLE_MAPS = \
    "hbase.mapreduce.inputtable.shufflemaps";
```

If set to `true`, this features runs after all the other split steps have been performed. It takes the final list of splits and shuffles their order. This is useful in the context of copying data from a table with many regions to a table with much fewer regions. Since all splits are initially ordered by their regions, which are subsequent, it may cause the processing tasks to stress out the target region server hosting the larger (in terms of key space) target region.

For example, assume you copy some data from a table with 100 regions to a table with 10 regions. Both have the same key space

with the difference that in the target table a single region covers the same key range as do 10 regions in the originating table. Also assume we had 10 parallel processing tasks available, so now the regions 1 to 10 would be read in parallel and written to the single region covering the same key range. This would cause hotspotting, and is discussed in detail in (to come).

The supplied CopyTable tool has a `--shuffle` option that allows you to enable this feature.

MapReduce over Tables

The following sections will introduce you to using HBase in combination with MapReduce. Before you can use HBase as a source or sink, or both, for data processing jobs, you have to first decide how you want to prepare the support by Hadoop.

Preparation

There are two vital steps required to execute MapReduce jobs:

1. Provide all necessary JAR files for the processing task to run.
2. Set all configuration parameters needed for the JARs to work as expected.

Since running a MapReduce job needs classes from libraries not shipped with Hadoop or the MapReduce framework, as well as their configuration properties, you will need to make both available before the job is executed. You have two choices: *static* preparation of all task nodes, or *dynamically* supplying everything needed with the job at submission time. We will discuss both in that order, but before we do, there is the need of figuring out what has to be made available to a processing job, no matter how it is provided.

Provision Libraries

Adding HBase support requires a fair amount of JAR files, comprising HBase, ZooKeeper, and other supporting libraries. The best way to figure out which classes are needed is employing the HBase command line script like so:

```
$ hbase mapredcp | sed 's/:/\n/g'  
...  
/opt/hbase-1.1.0/lib/hbase-protocol-1.1.0.jar  
/opt/hbase-1.1.0/lib/htrace-core-3.1.0-incubating.jar  
/opt/hbase-1.1.0/lib/hbase-common-1.1.0.jar  
/opt/hbase-1.1.0/lib/zookeeper-3.4.6.jar
```

```
/opt/hbase-1.1.0/lib/hbase-client-1.1.0.jar  
/opt/hbase-1.1.0/lib/hbase-hadoop-compat-1.1.0.jar  
/opt/hbase-1.1.0/lib/netty-all-4.0.23.Final.jar  
/opt/hbase-1.1.0/lib/guava-12.0.1.jar  
/opt/hbase-1.1.0/lib/protobuf-java-2.5.0.jar  
/opt/hbase-1.1.0/lib/hbase-server-1.1.0.jar
```

The `hbase` shell script has two of these helper commands, `classpath` and `mapredcp`. The difference is that the `classpath` command is printing *all* classes needed by HBase to operate, assuming you are on a machine that is able to run any of the HBase processes. Included in this list are:

- The HBase configuration directory, as set in `$HBASE_CONF_DIR`
- For the web applications (UIs), the directory containing `hbase-webapps` (usually `$HBASE_HOME`)
- Optionally, if HBase is in a development environment, all Maven dependencies
- All JAR files supplied by HBase, located in the `$HBASE_HOME/lib` directory
- If available, all *known* Hadoop class path details, as returned by `hadoop classpath`
- Any optional JAR file configured with `$HBASE_CLASSPATH` in the `hbase-env.sh` configuration file

In addition, if there is a `$HBASE_CLASSPATH_PREFIX` variable defined, its content is inserted at the very end, but before any other `$CLASSPATH` content. This allows you to inject some dependencies that would otherwise clash with the already included JAR files. Also, for the Hadoop class path info to be set, you need to configure the `$HADOOP_HOME` variable, or otherwise ensure the `hadoop` script is accessible to the `hbase` script.

As you can imagine, the resulting list is very long and most likely to verbose. Instead, using the `$hbase mapredcp` command, you can retrieve a minimal list of JARs needed for a client application, including MapReduce jobs. What you might also note from the above is that the `classpath` command includes the configuration directory, while the `mapredcp` does not. We will discuss the difference next.

Setting Configuration Properties

For many libraries there is an option to provide custom configuration files that modify, or fine tune, their behavior. This is also true for HBase clients, which need to at least define the ZooKeeper quorum of the cluster to contact. There are a few ways of doing that, for exam-

ple, set the property as a command line argument or in code, as shown in “[Fully distributed mode](#)” (page 81) or “[API Building Blocks](#)” (page 117). The most practical way is do have a local HBase configuration directory that contains a `hbase-site.xml` file with the ZooKeeper quorum set in it. You can also use this file then to set other properties, such as number of retries for failed operations, or the connection timeout. Note that the servers already have such a directory, and you could simply copy one over to the client to make it available there.

Once you have a configuration directory, you usually assign its location to the `$HBASE_CONF_DIR` environment variable. The task is now to make its content available to the job submission application, that is, the *job driver* code. One of the first lines in that code is this:

```
Configuration conf = HBaseConfiguration.create();
```

The instantiation of the HBase configuration object triggers the load of the HBase default values, and then the load of any custom `hbase-site.xml` with settings that override the defaults. For that to work, you *must* have the configuration directory on the class path of the job driver application. As you have just seen, the `hbase classpath` command does this for you, based on where `$HBASE_CONF_DIR` is pointing to. For the `hbase mapredcp` command you will need to manually specify the path as well, or it will not be known when the code executes. Falling back to the default values will assume that the cluster is located at `localhost`, which is only good for local test setups.

Specifying the configuration properties is a matter of setting the `$HADOOP_CLASSPATH` to include the directory containing the `hbase-site.xml` file. Once the job driver code runs, it uses the above code to load the information, which is subsequently handed into the job context:

```
Job job = Job.getInstance(conf, "<job-name>");
```

This line merges the HBase configuration settings into the configuration stored inside the instantiated job. From here the MapReduce framework will take care of serializing the properties and shipping them with the job to the processing nodes. Once the tasks execute there, the configuration is further merged with the one available on the servers itself. This implies that you could also have HBase settings available in the server-side configuration files, and thus be able to omit them during the job submission. This is all part of the mentioned deployment models, static or dynamic, which are explained now.

Static Provisioning

For a library that is used often, it can be useful to permanently install its JAR file(s) locally on the YARN worker machines, that is, those machines that run the MapReduce tasks. This is achieved by doing the following:

1. Copy the JAR files into a common location on all nodes.
2. Add the JAR files with full location into the `hadoop-env.sh` configuration file, into the `$HADOOP_CLASSPATH` variable:

```
# Extra Java CLASSPATH elements. Optional.  
# export HADOOP_CLASSPATH=<extra_entries>:$HADOOP_CLASSPATH
```

1. Restart all task trackers for the changes to be effective.

Obviously this technique is quite static, and every update (for example, to add new libraries, or update an existing one) requires a restart of the processing daemons. If you decide to use this approach, edit the `hadoop-env.sh` to contain, for example, the following:

```
export HADOOP_CLASSPATH="opt/hbase-1.1.0/lib/hbase-  
protocol-1.1.0.jar: \/  
    /opt/hbase-1.1.0/lib/htrace-core-3.1.0-incubating.jar: /opt/  
    hbase-1.1.0/ \  
        lib/hbase-common-1.1.0.jar: /opt/hbase-1.1.0/lib/  
        zookeeper-3.4.6.jar: \  
            /opt/hbase-1.1.0/lib/hbase-client-1.1.0.jar: /opt/hbase-1.1.0/  
            lib/ \  
                hbase-hadoop-compat-1.1.0.jar: /opt/hbase-1.1.0/lib/netty-  
                all-4.0.23. \  
                Final.jar: /opt/hbase-1.1.0/lib/guava-12.0.1.jar: /opt/hbase-1.1.0/  
                lib/ \  
                    protobuf-java-2.5.0.jar: /opt/hbase-1.1.0/lib/hbase-  
                    server-1.1.0.jar: \  
$HADOOP_CLASSPATH"
```

Obviously the paths shown here are dependent on where HBase was installed. If you have configured the `$HBASE_HOME` environment variable you could also use `export HADOOP_CLASSPATH="$HBASE_HOME/lib/hbase-protocol-1.1.0.jar:... and so on, replacing the absolute path with the variable instead.`

Note that this fixes the versions of these globally provided libraries to whatever is specified on the servers and in their configuration files.

The content of the `$HADOOP_CLASSPATH` is taken from the `$hbase mapredcp` output. You could even add this to the Hadoop configuration file as an embedded command:

```
export HADOOP_CLASSPATH=$(hbase mapredcp):$HBASE_CONF_DIR:$HADOOP_CLASSPATH
```

This executes the HBase script (which of course needs to be available when the Hadoop script is evaluated) every time the server processes are started. It also adds the HBase configuration directory to the class path, which was not done in the previous example. You will need to decide based on your use-case, if you want to configure only one or both statically. In practice, adding the HBase JARs and configuration path to the server class path seems reasonable, as they often go together.

The issue of locking into specific versions of required libraries can be circumvented with the dynamic provisioning approach, explained next.

Dynamic Provisioning

In case you need to provide different libraries to each job you want to run, or you want to update the library versions along with your job classes, then using the dynamic provisioning approach is more useful. There are more than one way of deploying libraries dynamically alongside processing jobs: *fat jars*, using *libjars*, or *adding dependencies* within the Java code, each discussed in order next.

Note that you still need to hand in the configuration files for a job to succeed. This is accomplished by adding the HBase configuration directory to the Hadoop class path during job submission, as explained in “[Preparation](#)” (page 586). The easiest way is to interactively set the class path environment variable Hadoop supports, and launch a job like so:

```
$ export HADOOP_CLASSPATH=$(hbase mapredcp):$HBASE_CONF_DIR  
$ hadoop jar ch07/target/hbase-book-ch07-2.0.jar ImportFromFile -t  
testtable \  
-i test-data.txt -c data:json
```

The other option to add the HBase configuration to the Hadoop environment was described above in the static provisioning section, that is, you could edit the `hadoop-env.sh` file as mentioned. This can be done on both the local client, or the remote processing servers. The difference is that applying the edit locally will use the job submission code to ship the configuration per job, while the server-side modification will apply to all jobs. You can still override settings using the job submission process though.

Fat JARs

Hadoop's JAR file support has a special feature: it reads all libraries from an optional `/lib` directory contained in the job archive. You can use this feature to generate so-called *fat* JAR files, as they ship not just with the actual job code, but also with all libraries needed. This results in considerably larger job JAR files, but on the other hand, represents a complete, self-contained processing job.

Using Maven

The example code for this book uses Maven to build the JAR files (see (to come)). Maven allows you to create the JAR files not just with the example code, but also to build the enhanced fat JAR file that can be deployed to the MapReduce framework as-is. This avoids editing the server-side configuration files.

Maven has support for so-called *profiles*, which can be used to customize the build process. The `pom.xml` for this chapter makes use of this feature to add a `fatjar` profile that creates the required `/lib` directory inside the final job JAR, and copies all required libraries into it. For this to work properly, some of the dependencies need to be defined with a *scope* of `provided` so that they are not included in the copy operation. This is done by adding the appropriate tag to all libraries that are already available on the server, for instance, the Hadoop JARs:

```
<dependency>
    <groupId>org.apache.hadoop</groupId>
    <artifactId>hadoop-mapreduce-client-core</artifactId>
    <version>2.6.0</version>
    <scope>provided</scope>
    ...
</dependency>
```

This is done in the parent POM file, located in the root directory of the book repository, as well as inside the POM for the chapter, depending on where a dependency is added. One example is the Apache Commons CLI library, which is also part of Hadoop.

The `fatjar` profile uses the Maven Assembly plug-in with an accompanying `src/main/assembly/job.xml` file that specifies what should, and what should not, be included in the generated target JAR (for example, it skips the provided libraries). With the profile in place, you can compile a *lean* JAR—one that only contains the job classes—like so:

```
$ mvn package
```

This will build a JAR that can be used to execute any of the included MapReduce, using the `hadoop jar` command:

```
$ hadoop jar ch07/target/hbase-book-ch07-2.0.jar
An example program must be given as the first argument.
Valid program names are:
  AnalyzeData: Analyze imported JSON
  ImportFromFile: Import from file
  ImportFromFileWithDeps: Import from file (with dependencies)
  ParseJson: Parse JSON into columns
  ParseJson2: Parse JSON into columns (map only)
  ParseJsonMulti: Parse JSON into multiple tables
```

The command will list all possible job names. It makes use of the Hadoop ProgramDriver class, which is prepared with all known job classes and their names. The Maven build takes care of adding the custom Driver class—which is the one wrapping the Program Driver instance—as the main class of the JAR file; hence, it is automatically executed by the `hadoop jar` command.

Building a *fat* JAR only requires the addition of the profile name:

```
$ mvn package -Dfatjar
```

The generated JAR file has an added postfix to distinguish it, but that is just a matter of taste (you can simply override the lean JAR if you prefer, although I refrain from explaining it here):

```
$ hadoop jar ch07/target/hbase-book-ch07-2.0-job.jar
```

It behaves exactly like the lean JAR, and you can launch the same jobs with the same parameters. The difference is that it includes the required libraries, avoiding the configuration change on the servers:

```
$ unzip -l ch07/target/hbase-book-ch07-2.0-job.jar
Archive: ch07/target/hbase-book-ch07-2.0-job.jar
      Length      Date    Time     Name
----- -----
          0  06-28-2015 07:25   META-INF/
      165  06-28-2015 07:25   META-INF/MANIFEST.MF
          0  06-28-2015 07:25   mapreduce/
     4876  06-28-2015 07:25   mapreduce/ImportJsonFrom-
File.class
     1699  06-28-2015 07:25   mapreduce/InvalidReducerOverride
 \
                               $InvalidOverrideReduce.class
    1042  06-28-2015 07:25   mapreduce/ImportFromFile$Coun-
ters.class
      ...
          0  06-28-2015 07:25   lib/
    7912  06-27-2015 10:57   lib/hbase-book-common-2.0.jar
   2556  06-27-2015 10:41   lib/hadoop-client-2.6.0.jar
```

```

3360985 06-27-2015 10:42 lib/hadoop-common-2.6.0.jar
2172168 06-27-2015 10:43 lib/guava-15.0.jar
792964 06-27-2015 10:41 lib/zookeeper-3.4.6.jar
67167 06-27-2015 10:41 lib/hadoop-auth-2.6.0.jar
32119 06-27-2015 10:42 lib/slf4j-api-1.7.10.jar
17035 06-27-2015 10:41 lib/hadoop-annotations-2.6.0.jar
1095441 06-27-2015 10:41 lib/hbase-client-1.0.0.jar
507776 06-27-2015 10:41 lib/hbase-common-1.0.0.jar
...
24409 06-27-2015 10:59 lib/log4j-over-slf4j-1.7.10.jar
44333 06-28-2015 07:25 lib/hbase-book-ch07-2.0.jar
16886830 05-14-2015 00:44 lib/jdk.tools-1.7.jar
-----
39321170 59 files

```

Maven is not the only way to generate different job JARs; you can also use Apache Ant, for example. What matters is not how you build the JARs, but that they contain the necessary information (either just the code, or the code and its required libraries).

Once you build a fat job JAR, you can set the configuration and submit the job like so:

```
$ export HADOOP_CLASSPATH=$(hbase mapredcp):$HBASE_CONF_DIR
$ hadoop jar ch07/target/hbase-book-ch07-2.0-job.jar ImportFrom
File -t testtable \
-i test-data.txt -c data:json
```

Since all necessary JARs are shipped inside the job JAR, the processing nodes can run the tasks successfully without any further work.

Using “libjars”

Another way to dynamically provide the necessary libraries is the *libjars* feature of Hadoop’s MapReduce framework. When you create a MapReduce job using the supplied `GenericOptionsParser` harness, you get support for the `libjars` parameter for free. Here is the documentation of the parser class:

```
public class GenericOptionsParser extends java.lang.Object

GenericOptionsParser is a utility to parse command line arguments
generic to the Hadoop framework. GenericOptionsParser recognizes
several standard command line arguments, enabling applications to
easily specify a namenode, a ResourceManager, additional configura-
tion resources etc.
```

Generic Options

The supported generic options are:

-conf <configuration file>	specify a configuration file
----------------------------	------------------------------

```

-D <property=value>           use value for given property
-fs <local|namenode:port>     specify a namenode
-jt <local|resourcemanager:port>   specify a ResourceManager
er
    -files <comma separated list of files>   specify comma sep-
arated
                                                files to be copied to the map reduce
cluster
    -libjars <comma separated list of jars>   specify comma sep-
arated
                                                jar files to include in the class-
path.
    -archives <comma separated list of archives>   specify comma
ma
                                                separated archives to be unarchived on the compute
machines.

```

The general command line syntax is:

```

bin/hadoop command [genericOptions] [commandOptions]
...

```

The reason to carefully read the documentation is that it not only states the `libjars` parameter, but also how and where to specify it on the command line. Failing to add the `libjars` parameter properly will result in the MapReduce job to fail. See [“Debugging Job Submission Problems” \(page 596\)](#) for a detailed discussion on fixing submission errors.

The following command line example shows a job submission that first sets up the required Hadoop class path, including all necessary JARs and configuration files. It then proceeds to add the same list of JAR files to the `-libjars` parameter, replacing all colon characters (“：“) the `mapredcp` command emits with the necessary commas (“,”). This will ensure all of the needed JARs are shipped with the job to the worker nodes:

```

$ export HADOOP_CLASSPATH=$(hbase mapredcp):$HBASE_CONF_DIR
$ hadoop jar ch07/target/hbase-book-ch07-2.0.jar ImportFromHDFS \
-libjars $(hbase mapredcp | tr ':' ',') -t testtable \
-i test-data.txt -c data:json
...
15/06/28 13:12:28 INFO client.RMProxy: Connecting to ResourceManager \
at master-1.internal.larsgeorge.com/10.0.10.1:8032
15/06/28 13:12:31 INFO input.FileInputFormat: Total input paths to
process : 1
15/06/28 13:12:32 INFO mapreduce.JobSubmitter: number of splits:1
15/06/28 13:12:32 INFO mapreduce.JobSubmitter: Submitting tokens
for job: \
job_1433933860552_0018

```

```

15/06/28 13:12:32 INFO impl.YarnClientImpl: Submitted application \
  application_1433933860552_0018
...
15/06/28 13:12:33   INFO mapreduce.Job:     Running    job:
job_1433933860552_0018
15/06/28 13:12:42 INFO mapreduce.Job: Job job_1433933860552_0018
running \
  in uber mode : false
15/06/28 13:12:42 INFO mapreduce.Job: map 0% reduce 0%
15/06/28 13:12:51 INFO mapreduce.Job: map 100% reduce 0%
15/06/28 13:12:52 INFO mapreduce.Job: Job job_1433933860552_0018 \
  completed successfully
15/06/28 13:12:52 INFO mapreduce.Job: Counters: 31
...
mapreduce.ImportFromFile$Counters
  LINES=993
...

```

Adding Dependencies inside the Code

Finally, as discussed in “[Supporting Classes](#)” (page 575), the HBase helper class `TableMapReduceUtil` comes with a set of methods that you can use from your own code to dynamically provision additional JAR and configuration files with your job:

```

static void addDependencyJars(Job job) throws IOException
static void addDependencyJars(Configuration conf, Class... classes)
  throws IOException

```

The former uses the latter function to add all the necessary libraries for HBase, ZooKeeper, job classes, and so on to the job configuration. You can see in the source code of the `ImportTsv` class how this is used:

```

public static Job createSubmittableJob(Configuration conf,
String[] args)
throws IOException, ClassNotFoundException {
  Job job = null;
  ...
  job = Job.getInstance(conf, jobName);
  ...
  TableMapReduceUtil.addDependencyJars(job);
  TableMapReduceUtil.addDependencyJars(job.getConfiguration(),
    com.google.common.base.Function.class /* Guava used by TsvParser */);
  ...
  return job;
}

```

The first call to `addDependencyJars()` adds the job and its necessary classes, including the input and output format, the various key and value types, and so on. The second call adds the Google *Guava* JAR, which is needed on top of the others already added. Note how this

method does not require you to specify the actual JAR file. It uses the Java ClassLoader API and the supplied JarFinder utility class to determine the name of the JAR containing the class in question. This might resolve to the same JAR, but that is irrelevant in this context.

It is important that you have access to these classes in your Java CLASSPATH; otherwise, these calls will fail with a `ClassNotFoundException` error, as discussed in “[Debugging Job Submission Problems](#)” ([page 596](#)). You are still required to at least add the `HADOOP_CLASSPATH` as shown above to the command line for an unprepared Hadoop setup, or else you will not be able to run the job. In other words, the `addDependencyJars()` is a programmatic way of omitting the `-libjars` parameter on the job submission command line. Both do the same thing though.

Which approach you take is your choice. The fat JAR has the advantage of containing everything that is needed for the job to run on a generic Hadoop setup. The other approaches require at least a prepared class path.

As far as this book is concerned, for the sake of simplicity, we will be using the fat JAR to build and launch MapReduce jobs.

Debugging Job Submission Problems

There are three types of issues to check first when submitting a MapReduce job and seeing them fail: the *local* class path, the *remote* class path, and *inclusion* of JARs and/or configuration into the job task attempts. Before you can even submit a job, it has to load JAR files locally to set up the Hadoop and HBase environments. When you do not add one or both of them to the Java class path, you see the following:

```
$ unset HADOOP_CLASSPATH
$ hadoop jar ch07/target/hbase-book-ch07-2.0.jar \
  ImportFromFile -t testtable -i test-data.txt -c data:json
Exception in thread "main" java.lang.NoClassDefFoundError: \
  org/apache/hadoop/hbase/HBaseConfiguration
  at mapreduce.ImportFromFile.main(ImportFromFile.java:157)
  ...
  at org.apache.hadoop.util.ProgramDriver.run(ProgramDriver.java:144)
  at org.apache.hadoop.util.ProgramDriver.driver(ProgramDriver.java:152)
  at mapreduce.Driver.main(Driver.java:28)
  ...
  at org.apache.hadoop.util.RunJar.run(RunJar.java:221)
```

```

        at org.apache.hadoop.util.RunJar.main(RunJar.java:136)
Caused by: java.lang.ClassNotFoundException: \
org.apache.hadoop.hbase.HBaseConfiguration
    ...
    ... 15 more

```

The submission fails to even set up the local application responsible for lodging the job. The reason is clear, the HBase configuration class is missing locally. Hadoop does not know about HBase (without any extra measures, like the static deployment option mentioned above) and therefore fails to start the Java application. This is fixed by adding the libraries to the local \$HADOOP_CLASSPATH environment variable, either within the currently running interactive shell, or by modifying the `hadoop-env.sh` in use, as explained above.

The following sets the class path as a shell variable interactively, and then submits the job again:

```

$ export HADOOP_CLASSPATH=$(hbase mapredcp)
$ hadoop jar ch07/target/hbase-book-ch07-2.0.jar \
  ImportFromFile -t testtable -i test-data.txt -c data:json
15/06/28 05:12:34 INFO client.RMProxy: Connecting to ResourceManager at \
  master-1.internal.larsgeorge.com/10.0.10.1:8032
15/06/28 05:12:35 INFO input.FileInputFormat: Total input paths to process : 1
15/06/28 05:12:35 INFO mapreduce.JobSubmitter: number of splits:1
15/06/28 05:12:35 INFO mapreduce.JobSubmitter: Submitting tokens for job: \
  job_1433933860552_0010
15/06/28 05:12:36 INFO impl.YarnClientImpl: Submitted application \
  application_1433933860552_0010
15/06/28 05:12:36 INFO mapreduce.Job: The url to track the job: \
  http://master-1.internal.larsgeorge.com:8088/proxy/ \
  application_1433933860552_0010/
15/06/28 05:12:36 INFO mapreduce.Job: Running job: \
  job_1433933860552_0010
15/06/28 05:12:49 INFO mapreduce.Job: Job job_1433933860552_0010 \
running \
  in uber mode : false
15/06/28 05:12:49 INFO mapreduce.Job: map 0% reduce 0%
15/06/28 05:12:49 INFO mapreduce.Job: Job job_1433933860552_0010 \
failed \
  with state FAILED due to: Application application_1433933860552_0010 \
  failed 2 times due to AM Container for appattempt_1433933860552_0010_000002 \
  exited with exitCode: 1
For more detailed output, check application tracking \
  page:http://master-1.internal.larsgeorge.com:8088/proxy/ \
  application_1433933860552_0010/Then, click on links to logs of each attempt.

```

```

Diagnostics: Exception from container-launch.
Container id: container_1433933860552_0010_02_000001
Exit code: 1
Stack trace: ExitCodeException exitCode=1:
    at org.apache.hadoop.util.Shell.runCommand(Shell.java:538)
    at org.apache.hadoop.util.Shell.run(Shell.java:455)
    at org.apache.hadoop.util.Shell$ShellCommandExecutor.execute(...)
    at org.apache.hadoop.yarn.server.nodemanager.DefaultContainer...
    at org.apache.hadoop.yarn.server.nodemanager.containermanager...
    at org.apache.hadoop.yarn.server.nodemanager.containermanager...
    at java.util.concurrent.FutureTask.run(FutureTask.java:262)
    at java.util.concurrent.ThreadPoolExecutor.runWorker(ThreadPo...
    at java.util.concurrent.ThreadPoolExecutor$Worker.run(ThreadP...
    at java.lang.Thread.run(Thread.java:745)

Container exited with a non-zero exit code 1
Failing this attempt. Failing the application.
15/06/28 05:12:49 INFO mapreduce.Job: Counters: 0

```

The issue is here that the submission clearly failed, stating that the "container exited" and so on. But what happened? How can you figure out what the true error is, since the root cause is apparently not reported? This is where YARN and its scripts help, they have a facility to access the underlying, low-level logs on the command line:

The YARN UI is complex, making it difficult to find the proper logs that hold the true cause of the failure. This is caused by YARN delegating work to an ApplicationMaster, which then runs the actual MapReduce job. In addition logs are available in YARN, the application master, the MapReduce job, its task attempts, and the MapReduce history server (if configured). Using the shell scripts in the examples makes it slightly easier to see the errors, but your mileage may vary. Both should get you to the same information nevertheless.

```

$ yarn logs -applicationId application_1433933860552_0010

15/06/28 05:19:22 INFO client.RMProxy: Connecting to ResourceManager at \
master-1.internal.larsgeorge.com/10.0.10.1:8032

```

```

Container: container_1433933860552_0010_02_000001 on \
    slave-1.internal.larsgeorge.com_53706
=====
LogType:stderr
Log Upload Time:28-Jun-2015 05:12:50
LogLength:240
Log Contents:
...
LogType:stdout
Log Upload Time:28-Jun-2015 05:12:50
LogLength:0
Log Contents:

LogType:syslog
Log Upload Time:28-Jun-2015 05:12:50
LogLength:3112
Log Contents:
2015-06-28 05:13:06,563 INFO [main] org.apache.hadoop.mapre-
duce.v2.app. \
    MRAppMaster: Created MRAppMaster for application \
    appattempt_1433933860552_0010_000002
...
2015-06-28 05:13:08,645 INFO [main] org.apache.hadoop.service. \
    AbstractService: Service org.apache.hadoop.mapre-
duce.v2.app.MRAppMaster \
    failed in state INITED; cause: org.apache.hadoop.yarn.excep-
tions. \
    YarnRuntimeException: java.lang.RuntimeException: \
        java.lang.ClassNotFoundException: Class org.apache.ha-
        doop.hbase.mapreduce \
            .TableOutputFormat not found
    org.apache.hadoop.yarn.exceptions.YarnRuntimeException: java.lang. \
    \
        RuntimeException: java.lang.ClassNotFoundException: Class \
        org.apache.hadoop.hbase.mapreduce.TableOutputFormat not found
            at org.apache.hadoop.mapreduce.v2.app.MRAppMaster
$1.call(...)
...
Caused by: java.lang.RuntimeException: java.lang.ClassNotFoundException: \
    Class org.apache.hadoop.hbase.mapreduce.TableOutputFormat not
found
...

```

The `yarn logs` command with the ID of the application prints the logs captured from the task JVM, showing the root cause being the HBase class `TableOutputFormat` missing. This is expected as we submitted a job that needs these classes, but have not supplied them in any form. The submission worked, since locally the class path is functional, but on the remote servers it is not. We fix this using the `-libjars` parameter interactively:

```

$ hadoop jar ch07/target/hbase-book-ch07-2.0.jar \
  ImportFromHDFS -libjars $(hbase mapredcp | tr ':' ',' ) -t testtable \
  -i testdata.txt -c data:json
15/06/28 10:14:11 INFO client.RMProxy: Connecting to ResourceManager at \
  master-1.internal.larsgeorge.com/10.0.10.1:8032
15/06/28 10:14:13 INFO input.FileInputFormat: Total input paths to process : 1
15/06/28 10:14:13 INFO mapreduce.JobSubmitter: number of splits:1
15/06/28 10:14:14 INFO mapreduce.JobSubmitter: Submitting tokens for job: \
  job_1433933860552_0015
15/06/28 10:14:14 INFO impl.YarnClientImpl: Submitted application \
  application_1433933860552_0015
15/06/28 10:14:14 INFO mapreduce.Job: The url to track the job: \
  http://master-1.internal.larsgeorge.com:8088/proxy/ \
  application_1433933860552_0015/
15/06/28 10:14:14 INFO mapreduce.Job:     map 0% reduce 0%
15/06/28 10:14:25 INFO mapreduce.Job:     map 100% reduce 0%
15/06/28 10:25:23 INFO mapreduce.Job: Task Id : \
  attempt_1433933860552_0015_m_000000_0, Status : FAILED
AttemptID:attempt_1433933860552_0015_m_000000_0 Timed out after
600 secs
...
15/06/28 10:56:54 INFO mapreduce.Job: Job job_1433933860552_0015
failed \
  with state FAILED due to: Task failed
task_1433933860552_0015_m_000000
Job failed as tasks failed. failedMaps:1 failedReduces:0

15/06/28 10:56:54 INFO mapreduce.Job: Counters: 9
  Job Counters
    Failed map tasks=4
    Launched map tasks=4
    Other local map tasks=3
    Data-local map tasks=1
      Total time spent by all maps in occupied slots
(ms)=20339752
    Total time spent by all reduces in occupied slots (ms)=0
    Total time spent by all map tasks (ms)=2542469
    Total vcore-seconds taken by all map tasks=2542469
    Total megabyte-seconds taken by all map tasks=2603488256

```

This now makes both class paths complete, locally and on the remote servers. As discussed above, the `-libjars` parameter pulls the specified JAR files into the job configuration, which then triggers the use of

the *distributed cache* to copy the JARs with the job submission to every worker node. There are actually two ways of fixing this problem: using `-libjars` on the command line, or use `addDependencyJars()` within the code. [Example 7-1](#) is amending the example we have (without explaining it, which we will do in “[Table as a Data Sink](#)” [\(page 603\)](#) though soon) used so far, adding a call to `addDependencyJars()`. In doing so, we make the job set up the JARs on the remote site the same way as the interactive `-libjars` does. Suffice it to say, the job submits fine and passes the class path issue.

Example 7-1. MapReduce job that reads from a file and writes into a table.

```
Job job = Job.getInstance(conf, "Import from file " + input +  
    " into table " + table);  
job.setJarByClass(ImportFromFile2.class);  
job.setMapperClass(ImportMapper.class);  
job.setOutputFormatClass(TableOutputFormat.class);  
job.getConfiguration().set(TableOutputFormat.OUTPUT_TABLE, table);  
job.setOutputKeyClass(ImmutableBytesWritable.class);  
job.setOutputValueClass(Writable.class);  
job.setNumReduceTasks(0);  
FileInputFormat.addInputPath(job, new Path(input));  
TableMapReduceUtil.addDependencyJars(job); ①
```

① Add dependencies to the configuration.

You can try for yourself using the following command, replacing the driver parameter for the job with `ImportFromFileWithDeps`:

```
$ hadoop jar ch07/target/hbase-book-ch07-2.0.jar \  
  ImportFromFileWithDeps -t testtable -i test-data.txt -c data:json
```

But when you check the result of the earlier job shown above, it still fails! This is attributed to the last piece of the puzzle, the HBase configuration. It is missing in the examples so far, and now since everything else is resolved we are stuck with connection issues, as apparent by the logs again:

```
$ yarn logs -applicationId application_1433933860552_0015  
...  
LogType:syslog  
Log Upload Time:28-Jun-2015 10:57:00  
LogLength:1019903  
Log Contents:  
...  
2015-06-28 10:25:32,882 INFO [main] org.apache.zookeeper.ZooKeeper: \  
 Initiating client connection, connectString=localhost:2181 \  
 sessionTimeout=90000 watcher=hconnection-0x5033d21
```

```

e0x0, quorum=localhost:2181, baseZNode=/hbase
2015-06-28 10:25:32,921 INFO [main-SendThread(localhost:2181)] \
    org.apache.zookeeper.ClientCnxn: Opening socket connection to
server \
    localhost/127.0.0.1:2181. Will not attempt to
    authenticate using SASL (unknown error)
2015-06-28 10:25:32,924 WARN [main-SendThread(localhost:2181)] \
    org.apache.zookeeper.ClientCnxn: Session 0x0 for server null, un-
expected \
    error, closing socket connection and attempting reconnect
java.net.ConnectException: Connection refused
    at sun.nio.ch.SocketChannelImpl.checkConnect(Native Method)
    at sun.nio.ch.SocketChannelImpl.finishConnect(...)
        at org.apache.zookeeper.ClientCnxnSocketNIO.doTrans-
port(...)
        at org.apache.zookeeper.ClientCnxn$SendThread.run(...)
...
2015-06-28 10:25:49,878 WARN [main] org.apache.hadoop.hbase.zoo-
keeper. \
    RecoverableZooKeeper: Possibly transient ZooKeeper, quorum=local-
host:2181, \
    exception=org.apache.zookeeper.KeeperException$ConnectionLossEx-
ception: \
    KeeperErrorCode = ConnectionLoss for /hbase/hbaseid
2015-06-28 10:25:49,878 ERROR [main] org.apache.hadoop.hbase.zoo-
keeper. \
    RecoverableZooKeeper: ZooKeeper exists failed after 4 attempts
2015-06-28 10:25:49,878 WARN [main] org.apache.hadoop.hbase.zoo-
keeper. \
    ZKUtil: hconnection-0x5033d21e0x0, quorum=localhost:2181, \
    baseZNode=/hbase Unable to set watcher on znode (
/hbase/hbaseid)
org.apache.zookeeper.KeeperException$ConnectionLossException: \
    KeeperErrorCode = ConnectionLoss for /hbase/hbaseid
        at org.apache.zookeeper.KeeperException.create(...)
        at org.apache.zookeeper.KeeperException.create(...)
        at org.apache.zookeeper.ZooKeeper.exists(...)
        at org.apache.hadoop.hbase.zookeeper.RecoverableZooKeep-
er.exists(...)
        at org.apache.hadoop.hbase.zookeeper.ZKUtil.checkEx-
ists(...)
        at org.apache.hadoop.hbase.zookeeper.ZKClusterId.readClus-
terIdZNode(..)
        at org.apache.hadoop.hbase.client.ZooKeeperRegistry.get-
ClusterId(...)
...
        at org.apache.hadoop.security.UserGroupInforma-
tion.doAs(UserGroupInformation.java:1628)
        at org.apache.hadoop.mapred.YarnChild.main(YarnChild.java:
158)
2015-06-28 10:25:49,879 ERROR [main] org.apache.hadoop.hbase.zoo-
keeper. \

```

```
ZooKeeperWatcher: hconnection-0x5033d21e0x0, quorum=localhost:  
2181, \  
    baseZNode=/hbase Received unexpected KeeperException, re-  
    throwing exception  
org.apache.zookeeper.KeeperException$ConnectionLossException: \  
    KeeperErrorCode = ConnectionLoss for /hbase/hbaseid  
        at org.apache.zookeeper.KeeperException.create(...)  
        at org.apache.zookeeper.KeeperException.create(...)  
        at org.apache.zookeeper.ZooKeeper.exists(...)  
...  
...
```

You can see the I/O errors logged, and above shows just a tiny excerpt. In the logs there will be hundreds of them, since the connection attempts are retried a few times before giving up eventually. The fix needed is to add the HBase configuration directory to the local class path, so that it can be found by the job submission application. For example:

```
$ export HADOOP_CLASSPATH=$(hbase mapredcp):$HBASE_CONF_DIR
```

This assumes the HBase configuration directory is specified in the \$HBASE_CONF_DIR environment variable. Equally, you could specify an absolute path. The launcher application loads the configuration as part of the `HBaseConfiguration.create()` call, which is usually one of the first steps in setting up the job. Once loaded, the properties are merged into the job configuration, which in turn is serialized and shipped with the job submission.

Table as a Data Sink

Subsequently, we will go through various MapReduce jobs that use HBase to read from, or write to, as part of the process. The first use case explained is using HBase as a *data sink*. This is facilitated by the `TableOutputFormat` class and demonstrated in [Example 7-2](#).

The example data used is based on the public RSS feed offered by [Delicious](#). Arvind Narayanan used the feed to collect a sample data set, which he published on his [blog](#).

There is no inherent need to acquire the data set, or capture the RSS feed (<http://feeds.delicious.com/v2/rss/recent>); if you prefer, you can use any other source, including JSON records. On the other hand, the Delicious data set provides records that can be used nicely with Hush: every entry has a link, user name, date, categories, and so on.

The `test-data.txt` included in the book's repository is a small subset of the public data set. For testing, this subset is sufficient, but you can obviously execute the jobs with the full data set just as well.

The code, shown here in nearly complete form, includes some sort of standard template, and the subsequent examples will not show these *boilerplate* parts. This includes, for example, the command line parameter parsing.

Example 7-2. MapReduce job that reads from a file and writes into a table.

```
public class ImportFromFile {
    public static final String NAME = "ImportFromFile"; ①
    public enum Counters { LINES }

    static class ImportMapper
        extends Mapper<LongWritable, Text, ImmutableBytesWritable, Mutation> { ②

        private byte[] family = null;
        private byte[] qualifier = null;

        @Override
        protected void setup(Context context)
            throws IOException, InterruptedException {
            String column = context.getConfiguration().get("conf.column");
            byte[][] colkey = KeyValue.parseColumn(Bytes.toBytes(column));
            family = colkey[0];
            if (colkey.length > 1) {
                qualifier = colkey[1];
            }
        }

        @Override
        public void map(LongWritable offset, Text line, Context context)
```

```

③    throws IOException {
      try {
        String lineString = line.toString();
        byte[] rowkey = DigestUtils.md5(lineString); ④
        Put put = new Put(rowkey);
        put.addColumn(family, qualifier, Bytes.toBytes(lineString));
⑤      context.write(new ImmutableBytesWritable(rowkey), put);
      context.getCounter(Counters.LINES).increment(1);
    } catch (Exception e) {
      e.printStackTrace();
    }
  }
}

private static CommandLine parseArgs(String[] args) throws ParseException { ⑥
  Options options = new Options();
  Option o = new Option("t", "table", true,
    "table to import into (must exist)");
  o.setArgName("table-name");
  o.setRequired(true);
  options.addOption(o);
  o = new Option("c", "column", true,
    "column to store row data into (must exist)");
  o.setArgName("family:qualifier");
  o.setRequired(true);
  options.addOption(o);
  o = new Option("i", "input", true,
    "the directory or file to read from");
  o.setArgName("path-in-HDFS");
  o.setRequired(true);
  options.addOption(o);
  options.addOption("d", "debug", false, "switch on DEBUG log level");
  CommandLineParser parser = new PosixParser();
  CommandLine cmd = null;
  try {
    cmd = parser.parse(options, args);
  } catch (Exception e) {
    System.err.println("ERROR: " + e.getMessage() + "\n");
    HelpFormatter formatter = new HelpFormatter();
    formatter.printHelp(NAME + " ", options, true);
    System.exit(-1);
  }
  return cmd;
}

public static void main(String[] args) throws Exception {
  Configuration conf = HBaseConfiguration.create();
  String[] otherArgs =

```

```

        new GenericOptionsParser(conf, args).getRemainingArgs(); ⑦
CommandLine cmd = parseArgs(otherArgs);
String table = cmd.getOptionValue("t");
String input = cmd.getOptionValue("i");
String column = cmd.getOptionValue("c");
conf.set("conf.column", column);

Job job = Job.getInstance(conf, "Import from file " + input +
    " into table " + table); ⑧
job.setJarByClass(ImportFromFile.class);
job.setMapperClass(ImportMapper.class);
job.setOutputFormatClass(TableOutputFormat.class);
job.getConfiguration().set(TableOutputFormat.OUTPUT_TABLE, table);
job.setOutputKeyClass(ImmutableBytesWritable.class);
job.setOutputValueClass(Writable.class);
job.setNumReduceTasks(0); ⑨
FileInputFormat.addInputPath(job, new Path(input));

System.exit(job.waitForCompletion(true) ? 0 : 1);
}
}

```

- ① Define a job name for later use.
- ② Define the mapper class, extending the provided Hadoop class.
- ③ The map() function transforms the key/value provided by the InputFormat to what is needed by the OutputFormat.
- ④ The row key is the MD5 hash of the line to generate a random key.
- ⑤ Store the original data in a column in the given table.
- ⑥ Parse the command line parameters using the Apache Commons CLI classes. These are already part of HBase and therefore are handy to process the job specific parameters.
- ⑦ Give the command line arguments to the generic parser first to handle “-Dxyz” properties.
- ⑧ Define the job with the required classes.
- ⑨ This is a map only job, therefore tell the framework to bypass the reduce step.

The code sets up the MapReduce job in its `main()` class by first parsing the command line, which determines the target table name and column, as well as the name of the input file. This could be hardcoded here as well, but it is good practice to write your code in a configurable way. The next step is setting up the job instance, assigning the variable details from the command line, as well as all fixed parameters, such as class names. One of those is the mapper class, set to Im

`portMapper`. This class is located in the same source code file, implementing what should be done during the map phase of the job.

The `main()` code also assigns the output format class, which is the aforementioned `TableOutputFormat` class. It is provided by HBase and allows the job to easily write data into a table. The key and value types needed by this class are implicitly fixed to `ImmutableBytesWritable` for the key, and `Mutation` for the value. Before you can execute the job, you first have to create a target table, for example, using the HBase Shell:

```
hbase(main):001:0> create 'testtable', 'data'  
0 row(s) in 0.5330 seconds
```

Once the table is ready you can launch the job:

```
$ hdfs dfs -put ch07/test-data.txt .  
$ export HADOOP_CLASSPATH=$(hbase mapredcp):$HBASE_CONF_DIR  
$ hadoop jar ch07/target/hbase-book-ch07-2.0-job.jar ImportFrom  
File \  
-t testtable -i test-data.txt -c data:json  
15/06/29 01:15:43 INFO client.RMProxy: Connecting to ResourceManag-  
er at \  
master-1.internal.larsgeorge.com/10.0.10.1:8032  
15/06/29 01:15:45 INFO input.FileInputFormat: Total input paths to  
process : 1  
15/06/29 01:15:45 INFO mapreduce.JobSubmitter: number of splits:1  
15/06/29 01:15:45 INFO mapreduce.JobSubmitter: Submitting tokens  
for job: \  
job_1433933860552_0019  
15/06/29 01:15:46 INFO impl.YarnClientImpl: Submitted application \  
application_1433933860552_0019  
15/06/29 01:15:46 INFO mapreduce.Job: The url to track the job: \  
http://master-1.internal.larsgeorge.com:8088/proxy/ \  
application_1433933860552_0019/  
15/06/29 01:15:46 INFO mapreduce.Job: Running job:  
job_1433933860552_0019  
15/06/29 01:15:55 INFO mapreduce.Job: Job job_1433933860552_0019  
running \  
in uber mode : false  
15/06/29 01:15:55 INFO mapreduce.Job: map 0% reduce 0%  
15/06/29 01:16:04 INFO mapreduce.Job: map 100% reduce 0%  
15/06/29 01:16:05 INFO mapreduce.Job: Job job_1433933860552_0019 \  
completed successfully  
15/06/29 01:16:05 INFO mapreduce.Job: Counters: 31  
File System Counters  
    FILE: Number of bytes read=0  
    FILE: Number of bytes written=130677  
    FILE: Number of read operations=0  
    FILE: Number of large read operations=0  
    FILE: Number of write operations=0  
    HDFS: Number of bytes read=1015549
```

```

HDFS: Number of bytes written=0
HDFS: Number of read operations=2
HDFS: Number of large read operations=0
HDFS: Number of write operations=0
Job Counters
    Launched map tasks=1
    Data-local map tasks=1
        Total time spent by all maps in occupied slots
(ms)=61392
    Total time spent by all reduces in occupied slots
(ms)=0
        Total time spent by all map tasks (ms)=7674
        Total vcore-seconds taken by all map tasks=7674
        Total megabyte-seconds taken by all map
tasks=7858176
Map-Reduce Framework
    Map input records=993
    Map output records=993
    Input split bytes=139
    Spilled Records=0
    Failed Shuffles=0
    Merged Map outputs=0
    GC time elapsed (ms)=48
    CPU time spent (ms)=1950
    Physical memory (bytes) snapshot=182571008
    Virtual memory (bytes) snapshot=1618432000
    Total committed heap usage (bytes)=173015040
mapreduce.ImportFromFile$Counters
    LINES=993
File Input Format Counters
    Bytes Read=1015410
File Output Format Counters
    Bytes Written=0

```

The first command, `hdfs dfs -put`, stores the sample data in the user's home directory in HDFS. The second command sets up the class path, and the third launches the job itself, which completes in a short amount of time. The data is read using the default `TextInputFormat`, as provided by Hadoop and its MapReduce framework. This input format can read text files that have *newline* characters at the end of each line. For every line read, it calls the `map()` function of the defined mapper class. This triggers our `ImportMapper.map()` function.

As shown in [Example 7-2](#), the `ImportMapper` defines two methods, overriding the ones with the same name from the parent `Mapper` class.

Override Woes

It is *highly* recommended to add `@Override` annotations to your methods, so that wrong signatures can be detected at compile

time. Otherwise, the implicit `map()` or `reduce()` methods might be called and do an identity function. For example, consider this `reduce()` method:

```
public void reduce(Writable key, Iterator<Writable> values,
    Reducer.Context context) throws IOException, InterruptedException {
    ...
}
```

While this looks correct, it does *not*, in fact, override the `reduce()` method of the `Reducer` class, but instead defines a new version of the method. The MapReduce framework will silently ignore this method and execute the default implementation as provided by the `Reducer` class.

The reason is that the actual signature of the method is this:

```
protected void reduce(KEYIN key, Iterable<VALUEIN> values, \
    Reducer.Context context) throws IOException, InterruptedException
```

This is a common mistake; the `Iterable` was erroneously replaced by an `Iterator` class. This is all it takes to make for a new signature. Adding the `@Override` annotation to an overridden method in your code will make the compiler (and hopefully your background compilation check of your IDE) throw an error—before you run into what you might perceive as *strange* behavior during the job execution. Adding the annotation to the previous example:

```
@Override
public void reduce(Writable key, Iterator<Writable> values,
    Reducer.Context context) throws IOException, InterruptedException {
    ...
}
```

The IDE you are using should already display an error, but at a minimum the compiler will report the mistake:

```
...
[INFO]
-----
[INFO] BUILD FAILURE
[INFO]
-----
...
[ERROR] Failed to execute goal org.apache.maven.plugins:maven-
compiler- \
    plugin:3.2:compile (default-compile) on project hbase-book-
ch07: \
    Compilation failure
```

```
[ERROR]      ch07/src/main/java/mapreduce/InvalidReducerOverr-
ide.java:[14,5] \
    method does not override or implement a method from a super-
type
...

```

The `setup()` method of `ImportMapper` overrides the method called once when the class is instantiated by the framework. Here it is used to parse the given column into a column family and qualifier. The `map()` of that same class is doing the actual work. As noted, it is called for every row in the input text file, each containing a JSON record. The code creates a HBase row key by using an MD5 hash of the line content. It then stores the line content as-is in the provided column, titled `data:json`.

The example makes use of the implicit write buffer set up by the `TableOutputFormat` class. The call to `context.write()` issues an internal `mutator.mutate()` with the given instance of `Put`. The `TableOutputFormat` takes care of calling `close()` when the job is complete—saving the remaining data from the write buffer to the HBase target table.

The `map()` method *writes* `Put` instances to store the input data. You can also write `Delete` instances to delete data from the target table. This is also the reason why the output value type of the job is set to `Mutation`, instead of the explicit `Put` class.

The `TableOutputFormat` can (currently) only handle `Put` and `Delete` instances. Passing anything else will raise an `IOException` with the message set to "Pass a `Delete` or a `Put`".

Finally, note how the job is just using the map phase, and no reduce is needed. This is fairly typical with MapReduce jobs in combination with HBase: since data is already stored in sorted tables, or the raw data already has unique keys, you can avoid the more costly `sort`, `shuffle`, and `reduce` phases in the process.

Table as a Data Source

After importing the raw data into the table, we can use the contained data to parse the JSON records and extract information from it. This is accomplished using the `TableInputFormat` class, the counterpart to

`TableOutputFormat`. It sets up a table as an input to the MapReduce process. [Example 7-3](#) makes use of the provided `InputFormat` subclass.

Example 7-3. MapReduce job that reads the imported data and analyzes it.

```
static class AnalyzeMapper extends TableMapper<Text, IntWritable>
{ ❶

    private JSONParser parser = new JSONParser();
    private IntWritable ONE = new IntWritable(1);

    @Override
    public void map(ImmutableBytesWritable row, Result columns, Context context)
        throws IOException {
        context.getCounter(Counters.ROWS).increment(1);
        String value = null;
        try {
            for (Cell cell : columns.listCells()) {
                context.getCounter(Counters.COLS).increment(1);
                value = Bytes.toStringBinary(cell.getValueArray(),
                    cell.getValueOffset(), cell.getValueLength());
                JSONObject json = (JSONObject) parser.parse(value);
                String author = (String) json.get("author"); ❷
                context.write(new Text(author), ONE);
                context.getCounter(Counters.VALID).increment(1);
            }
        } catch (Exception e) {
            e.printStackTrace();
            System.err.println("Row: " + Bytes.toStringBinary(row.get()) +
                ", JSON: " + value);
            context.getCounter(Counters.ERROR).increment(1);
        }
    }

    static class AnalyzeReducer
        extends Reducer<Text, IntWritable, Text, IntWritable> { ❸

        @Override
        protected void reduce(Text key, Iterable<IntWritable> values,
            Context context) throws IOException, InterruptedException {
            int count = 0;
            for (IntWritable one : values) count++; ❹
            context.write(key, new IntWritable(count));
        }
    }

    public static void main(String[] args) throws Exception {
        ...
    }
}
```

```

Scan scan = new Scan(); ⑤
if (column != null) {
    byte[][] colkey = KeyValue.parseColumn(Bytes.toBytes(column));
    if (colkey.length > 1) {
        scan.addColumn(colkey[0], colkey[1]);
    } else {
        scan.addFamily(colkey[0]);
    }
}

Job job = Job.getInstance(conf, "Analyze data in " + table);
job.setJarByClass(AnalyzeData.class);
TableMapReduceUtil.initTableMapperJob(table, scan, AnalyzeMapper.class,
    Text.class, IntWritable.class, job); ⑥
job.setReducerClass(AnalyzeReducer.class);
job.setOutputKeyClass(Text.class); ⑦
job.setOutputValueClass(IntWritable.class);
job.setNumReduceTasks(1);
FileOutputFormat.setOutputPath(job, new Path(output));

System.exit(job.waitForCompletion(true) ? 0 : 1);
}

```

- ① Extend the supplied TableMapper class, setting your own output key and value types.
- ② Parse the JSON data, extract the author and count the occurrence.
- ③ Extend a Hadoop Reducer class, assigning the proper types.
- ④ Count the occurrences and emit sum.
- ⑤ Create and configure a Scan instance.
- ⑥ Set up the table mapper phase using the supplied utility.
- ⑦ Configure the reduce phase using the normal Hadoop syntax.

This job runs as a full MapReduce process, where the map phase is reading the JSON data from the input table, and the reduce phase is aggregating the counts for every user. This is very similar to the Word Count example⁴ that ships with Hadoop: the mapper emits counts of ONE, while the reducer counts those up to the sum per key (which in Example 7-3 is the *Author*). Executing the job on the command line is done like so (leaving out the configuration of the \$HADOOP_CLASSPATH variable, for the sake of space, and assuming you have done so for the previous example):

4. See the Hadoop wiki [page](#) for details.

```

$ hadoop jar ch07/target/hbase-book-ch07-2.0-job.jar AnalyzeData \
-t testtable -c data:json -o analyze1
...
15/06/29 02:02:35 INFO client.RMProxy: Connecting to ResourceManager at \
master-1.internal.larsgeorge.com/10.0.10.1:8032
...
15/06/29 02:02:40 INFO mapreduce.JobSubmitter: number of splits:1
...
15/06/29 02:02:41 INFO mapreduce.Job:     Running    job:
job_1433933860552_0021
...
15/06/29 02:02:50 INFO mapreduce.Job:   map 0% reduce 0%
15/06/29 02:03:02 INFO mapreduce.Job:   map 100% reduce 0%
15/06/29 02:03:10 INFO mapreduce.Job:   map 100% reduce 100%
15/06/29 02:03:11 INFO mapreduce.Job: Job job_1433933860552_0021 \
completed successfully
15/06/29 02:03:11 INFO mapreduce.Job: Counters: 53
...
mapreduce.AnalyzeData$Counters
  COLS=993
  ERROR=6
  ROWS=993
  VALID=987
...

```

The end result is a list of counts per author, and can be accessed from the command line using, for example, the `hdfs dfs -text` command:

```

$ hdfs dfs -text analyze1/part-r-00000
10sr      1
13tohl    1
14bcps    1
21721725      1
2centime   1
33rpm     1
3sunset    1
52050361    1
6630nokia  1
...

```

The example also shows how to use the `TableMapReduceUtil` class, with its static methods, to quickly configure a job with all the required classes. Since the job also needs a reduce phase, the `main()` code adds the Reducer classes as required, once again making implicit use of the default value when no other is specified (in this case, the `TextOutputFormat` class).

Obviously, this is a simple example, and in practice you will have to perform more involved analytical processing. But even so, the template shown in the example stays the same: you read from a table, ex-

tract the required information, and eventually output the results to a specific target.

Table as both Data Source and Sink

As already shown, the source or target of a MapReduce job can be a HBase table, but it is also possible for a job to use HBase as both input and output. In other words, a third kind of MapReduce template uses a table for the input and output types. This involves setting the `TableInputFormat` and `TableOutputFormat` classes into the respective fields of the job configuration. This also implies the various key and value types, as shown before. [Example 7-4](#) shows this in context.

Example 7-4. MapReduce job that parses the raw data into separate columns.

```
static class ParseMapper
  extends TableMapper<ImmutableBytesWritable, Mutation> {

    private JSONParser parser = new JSONParser();
    private byte[] columnFamily = null;

    @Override
    protected void setup(Context context)
      throws IOException, InterruptedException {
      columnFamily = Bytes.toBytes(
        context.getConfiguration().get("conf.columnfamily"));
    }

    @Override
    public void map(ImmutableBytesWritable row, Result columns, Context context)
      throws IOException {
      context.getCounter(Counters.ROWS).increment(1);
      String value = null;
      try {
        Put put = new Put(row.get());
        for (Cell cell : columns.listCells()) {
          context.getCounter(Counters.COLS).increment(1);
          value = Bytes.toStringBinary(cell.getValueArray(),
            cell.getValueOffset(), cell.getValueLength());
          JSONObject json = (JSONObject) parser.parse(value);
          for (Object key : json.keySet()) {
            Object val = json.get(key);
            put.addColumn(columnFamily, Bytes.toBytes(key.toString()),
              Bytes.toBytes(val.toString()));
          }
        }
        context.write(row, put);
        context.getCounter(Counters.VALID).increment(1);
      }
    }
}
```

```

        } catch (Exception e) {
            e.printStackTrace();
            System.err.println("Error: " + e.getMessage() + ", Row: " +
                Bytes.toStringBinary(row.get()) + ", JSON: " + value);
            context.getCounter(Counters.ERROR).increment(1);
        }
    }

public static void main(String[] args) throws Exception {
    ...
    Scan scan = new Scan();
    if (column != null) {
        byte[][] colkey = KeyValue.parseColumn(Bytes.toBytes(column));
        if (colkey.length > 1) {
            scan.addColumn(colkey[0], colkey[1]);
            conf.set("conf.columnfamily", Bytes.toStringBinary(col-
key[0])); ❶
            conf.set("conf.columnqualifier", Bytes.toStringBinary(col-
key[1]));
        } else {
            scan.addFamily(colkey[0]);
            conf.set("conf.columnfamily", Bytes.toStringBinary(col-
key[0]));
        }
    }

    Job job = Job.getInstance(conf, "Parse data in " + input +
        ", write to " + output);
    job.setJarByClass(ParseJson.class);
    TableMapReduceUtil.initTableMapperJob(input, scan, ParseMap-
per.class, ❷
        ImmutableBytesWritable.class, Put.class, job);
    TableMapReduceUtil.initTableReducerJob(output, ❸
        IdentityTableReducer.class, job);

    System.exit(job.waitForCompletion(true) ? 0 : 1);
}

```

- ❶ Store the top-level JSON keys as columns, with their value set as the column value.
- ❷ Store the column family in the configuration for later use in the mapper.
- ❸ Setup map phase details using the utility method.
- ❹ Configure an identity reducer to store the parsed data.

The example uses the utility methods to configure the map and reduce phases, specifying the `ParseMapper`, which extracts the details from the raw JSON, and an `IdentityTableReducer` to store the data in the

target table. Note that both—that is, the input and output table—can be the same. Launching the job from the command line can be done like this:

```
$ hadoop jar ch07/target/hbase-book-ch07-2.0-job.jar ParseJson \
-i testtable -c data:json -o testtable
...
15/06/29 05:21:21 INFO impl.YarnClientImpl: Submitted application /
application_1433933860552_0022
...
15/06/29 05:21:21 INFO mapreduce.Job:     Running    job:
job_1433933860552_0022
...
15/06/29 05:21:31 INFO mapreduce.Job:   map 0% reduce 0%
15/06/29 05:21:42 INFO mapreduce.Job:   map 100% reduce 0%
15/06/29 05:21:53 INFO mapreduce.Job:   map 100% reduce 100%
15/06/29 05:21:54 INFO mapreduce.Job: Job job_1433933860552_0022 \
completed successfully
15/06/29 05:21:54 INFO mapreduce.Job: Counters: 53
...
mapreduce.ParseJson$Counters
  COLS=993
  ERROR=6
  ROWS=993
  VALID=987
...
```

The percentages show that both the map and reduce phases have been completed, and that the job overall completed subsequently. Using the `IdentityTableReducer` to store the extracted data is not necessary, and in fact the same code with one additional line turns the job into a map-only one. [Example 7-5](#) shows the added line.

Example 7-5. MapReduce job that parses the raw data into separate columns (map phase only).

```
...
Job job = Job.getInstance(conf, "Parse data in " + input +
  ", write to " + output + "(map only)");
job.setJarByClass(ParseJson2.class);
TableMapReduceUtil.initTableMapperJob(input, scan, ParseMapper-
per.class,
  ImmutableBytesWritable.class, Put.class, job);
TableMapReduceUtil.initTableReducerJob(output,
  IdentityTableReducer.class, job);
job.setNumReduceTasks(0);
...
```

Running the job from the command line shows that the reduce phase has been skipped:

```
$ hadoop jar ch07/target/hbase-book-ch07-1.0-job.jar ParseJson2 \
-i testtable -c data:json -o testtable
...
15/06/29 05:29:17 INFO mapreduce.Job: map 0% reduce 0%
15/06/29 05:29:29 INFO mapreduce.Job: map 100% reduce 0%
15/06/29 05:29:30 INFO mapreduce.Job: Job job_1433933860552_0023 \
completed successfully
...
```

The reduce stays at 0%, even when the job has completed. You can also use the Hadoop MapReduce UI to confirm that no reduce task have been executed for this job. The advantage of bypassing the reduce phase is that the job will complete much faster, since no additional processing of the data by the framework is required. Both variations of the ParseJson job performed the same work. The result can be seen using the HBase Shell (omitting the repetitive row key output for the sake of space):

```
hbase(main):001:0> scan 'testtable'
...
\xFB!Nn\x8F\x89}\xD8\x91+\xB9o9\xB3E\xD0
  column=data:author, timestamp=1435580953962, value=bookrdr3
  column=data:comments, timestamp=1435580953962,
    value=http://delicious.com/url/409839abddbce807e4db07bf7d9cd7ad
  column=data:guidislink, timestamp=1435580953962, value=false
  column=data:id, timestamp=1435580953962,
    value=http://delicious.com/url/
409839abddbce807e4db07bf7d9cd7ad#bookrdr3
...
  column=data:link, timestamp=1435580953962,
    value=http://sweetsassafras.org/2008/01/27/how-to-alter-a-wool-
sweater
...
  column=data:updated, timestamp=1435580953962,
    value=Mon, 07 Sep 2009 18:22:21 +0000
...
...
993 row(s) in 1.7070 seconds
```

The import makes use of the arbitrary column names supported by HBase: the JSON keys are converted into qualifiers, and form new columns on the fly.

Custom Processing

You do not have to use any classes supplied by HBase to read and/or write to a table. In fact, these classes are quite lightweight and only act as helpers to make dealing with tables easier. [Example 7-6](#) converts the previous example code to split the parsed JSON data into two target tables. The link key and its value is stored in a separate

table, named `linktable`, while all other fields are stored in the table named `infotable`.

Example 7-6. MapReduce job that parses the raw data into separate tables.

```
static class ParseMapper
extends TableMapper<ImmutableBytesWritable, Writable> {

    private Connection connection = null;
    private BufferedMutator infoTable = null;
    private BufferedMutator linkTable = null;
    private JSONParser parser = new JSONParser();
    private byte[] columnFamily = null;

    @Override
    protected void setup(Context context)
    throws IOException, InterruptedException {
        connection = ConnectionFactory.createConnection(
            context.getConfiguration());
        infoTable = connection.getBufferedMutator(TableName.valueOf(
            context.getConfiguration().get("conf.infotable"))); ①
        linkTable = connection.getBufferedMutator(TableName.valueOf(
            context.getConfiguration().get("conf.linktable")));
        columnFamily = Bytes.toBytes(
            context.getConfiguration().get("conf.columnfamily"));
    }

    @Override
    protected void cleanup(Context context)
    throws IOException, InterruptedException {
        infoTable.flush(); ②
        linkTable.flush();
    }

    @Override
    public void map(ImmutableBytesWritable row, Result columns,
        Context context)
    throws IOException {
        context.getCounter(Counters.ROWS).increment(1);
        String value = null;
        try {
            Put infoPut = new Put(row.get());
            Put linkPut = new Put(row.get());
            for (Cell cell : columns.listCells()) {
                context.getCounter(Counters.COLS).increment(1);
                value = Bytes.toStringBinary(cell.getValueArray(),
                    cell.getValueOffset(), cell.getValueLength());
                JSONObject json = (JSONObject) parser.parse(value);
                for (Object key : json.keySet()) {
                    Object val = json.get(key);
                    if ("link".equals(key)) {
```

```

        linkPut.addColumn(columnFamily, Bytes.toBytes(key.toString()),
                           Bytes.toBytes(val.toString()));
    } else {
        infoPut.addColumn(columnFamily, Bytes.toBytes(key.toString()),
                           Bytes.toBytes(val.toString()));
    }
}
infoTable.mutate(infoPut); ③
linkTable.mutate(linkPut);
context.getCounter(Counters.VALID).increment(1);
} catch (Exception e) {
    e.printStackTrace();
    System.err.println("Error: " + e.getMessage() + ", Row: " +
        Bytes.toStringBinary(row.get()) + ", JSON: " + value);
    context.getCounter(Counters.ERROR).increment(1);
}
}
}

public static void main(String[] args) throws Exception {
    ...
    conf.set("conf.infotable", cmd.getOptionValue("o")); ④
    conf.set("conf.linktable", cmd.getOptionValue("l"));
    ...
    Job job = Job.getInstance(conf, "Parse data in " + input +
        ", into two tables");
    job.setJarByClass(ParseJsonMulti.class);
    TableMapReduceUtil.initTableMapperJob(input, scan, ParseMapper.class,
        ImmutableBytesWritable.class, Put.class, job);
    job.setOutputFormatClass(NullOutputFormat.class); ⑤
    job.setNumReduceTasks(0);

    System.exit(job.waitForCompletion(true) ? 0 : 1);
}
}

```

- ① Create and configure both target tables in the setup() method.
- ② Flush all pending commits when the task is complete.
- ③ Save parsed values into two separate tables.
- ④ Store table names in configuration for later use in the mapper.
- ⑤ Set the output format to be ignored by the framework.

You need to create two more tables, using, for example, the HBase Shell:

```

hbase(main):001:0> create 'infotable', 'data'
hbase(main):002:0> create 'linktable', 'data'

```

These two new tables will be used as the target tables for the current example. Executing the job is done on the command line, and emits the following output:

```
$ hadoop jar target/hbase-book-ch07-1.0-job.jar ParseJsonMulti \
-i testtable -c data:json -o infotable -l linktable
11/08/08 21:13:57 INFO mapred.JobClient: Running job:
job_201108081021_0033
11/08/08 21:13:58 INFO mapred.JobClient: map 0% reduce 0%
11/08/08 21:14:06 INFO mapred.JobClient: map 100% reduce 0%
11/08/08 21:14:08 INFO mapred.JobClient: Job complete:
job_201108081021_0033
...
```

So far, this is the same as the previous `ParseJson` examples. The difference is the resulting tables, and their content. You can use the HBase Shell and the `scan` command to list the content of each table after the job has completed. You should see that the `link` table contains only the links, while the `info` table contains the remaining fields of the original JSON.

Writing your own MapReduce code allows you to perform whatever is needed during the job execution. You can, for example, read lookup values from a different table while storing a combined result in yet another table. There is no limit as to where you read from, or where you write to. The supplied classes are helpers, nothing more or less, and serve well for a large number of use cases. If you find yourself limited by their functionality, simply extend them, or implement generic MapReduce code and use the API to access HBase tables in any shape or form.

MapReduce over Snapshots

Up to this point we have operated directly on active, live HBase tables, either as a source, target, or both. An additional mode of operation using the supplied input formats is to iterate over a table snapshot instead. It allows you to freeze a table at a specific point in time, and then iterate over its persisted content. This is useful for archival purposes, or for analytical workloads that need to process subset of the data, or while the table is not allowed to change while the processing is underway. You could copy a table, or disable all write operations to it somehow, but by far the easiest way is to use the snapshot API HBase provides (see “[Table Operations: Snapshots](#)” (page 401) again for a refresher).

The utility class `TableMapReduceUtil` provides an easy to use helper method for setting up the MapReduce job, named `initTableSnapshotMapperJob()`. “[Supporting Classes](#)” (page 575) discussed this method

in more detail, but suffice it to say that all you have to do is provide an existing snapshot name, and a writable location to stage the snapshot as temporary table. The full signature of the method is:

```
public static void initTableSnapshotMapperJob(String snapshotName,
    Scan scan, Class<? extends TableMapper> mapper,
    Class<?> outputKeyClass, Class<?> outputValueClass, Job job,
    boolean addDependencyJars, Path tmpRestoreDir) throws IOException
```

In addition, as with the other examples shown in this section, you can set a specific mapper class to process the data, configure a Scan instance to limit and/or filter the data, set the output types, and optionally add the necessary JAR file names to the job configuration. In fact, this is very similar to a usual *table as a data source* approach, as shown in “[Table as a Data Source](#)” (page 610). This is because all the snapshot based input format does is create a temporary table from the snapshot, and then iterate over it as if it is like any other normal table.

Well, at least in a nutshell. There is a lot going on behind the scenes, that is, the snapshot information is read, the layout for the temporary table created within the specified directory, the snapshot storage files are linked into the temporary location, and then the processing can begin. For the staging you need to have write access to both the temporary directory *and* the HBase root directory. This implies that you need to run the MapReduce job using the snapshot backed input format as the hbase user. In other words, this is an administrative operation, and requires elevated privileges.

Splits are done at region boundaries, with the system trying to send the tasks to the servers with the most storage files local. Keep in mind that reading the low level store files might involve reading their underlying store blocks from HDFS across different machines. The TableSnapshotInputFormat first determines the locality of the store file regarding the region they are in. Assuming there was one region server writing the data for a while, you should find at least one server—the one with the region server and data node colocated—that has close, or exactly, 100% locality. It also checks the remaining block replicas, using a *cutoff multiplier* to include them into the list of preferred processing nodes. It is controlled by `hbase.tablesnapshotinputformat.locality.cutoff.multiplier`, with a default value of 0.8 (80%), with all regions passing that threshold to be included into the split locality host list.

Favored Block Placement in HDFS

As of HDFS version 2.7.0 there is a feature allowing clients to specify preferred nodes for block replica placement. This was add-

ed in [HDFS-2576](#), and enables a DFS client to specify a list of host names that are considered for replica placement. The matching HBase work to support that is implemented in [HBASE-4755](#), and its related subtasks, such as [HBASE-7942](#).

There is a second part to this feature, the balancers, both for HDFS and HBase, need to honor the special block placement and ensure they do not wreak havoc by moving blocks or regions to the wrong servers. The JIRA issue for the HDFS side is [HDFS-6133](#). For HBase the work to enhance the load balancer was done in [HBASE-7932](#), which places the regions on the configured preferred nodes.

By default this feature is disabled, but can be switched on with the `hbase.master.loadbalancer.class` configuration property, setting it to `org.apache.hadoop.hbase.master.balancer.FavoredNodeLoadBalancer`. The assignment of regions then follows the Hadoop rack-awareness, optionally placing servers into racks, and choosing random servers across those racks to create full region copies. Given that all blocks of all files for a region are now located on more than one server, the cluster can reassign regions to those preferred nodes while retaining the locality benefits. The same advantage can be reaped by the `TableSnapshotInputFormat`, which can add the info to the splits returned by its `getSplits()` method.

[Example 7-7](#) shows an example that uses the earlier table with the imported test data in JSON format. Here we first snapshot the table, and then iterate over it using a MapReduce job. The set up and execution of the job is a bit different from before.

Example 7-7. MapReduce job that reads the data from a snapshot and analyzes it.

```
Configuration conf = HBaseConfiguration.create();
String[] otherArgs =
    new GenericOptionsParser(conf, args).getRemainingArgs();
CommandLine cmd = parseArgs(otherArgs);
if (cmd.hasOption("d")) conf.set("conf.debug", "true");
String table = cmd.getOptionValue("t");
long time = System.currentTimeMillis();
String tmpName = "snapshot-" + table + "-" + time; ①
String snapshot = cmd.getOptionValue("s", tmpName);
Path restoreDir = new Path(cmd.getOptionValue("b", "/tmp/" +
tmpName));
String column = cmd.getOptionValue("c");
String output = cmd.getOptionValue("o");
boolean cleanup = Boolean.valueOf(cmd.getOptionValue("x"));
```

```

...
Connection connection = ConnectionFactory.createConnection(conf);
Admin admin = connection.getAdmin();
LOG.info("Performing snapshot of table " + table + " as " + snapshot);
admin.snapshot(snapshot, TableName.valueOf(table)); ②

LOG.info("Setting up job");
Job job = Job.getInstance(conf, "Analyze data in snapshot " +
table);
job.setJarByClass(AnalyzeSnapshotData.class);
TableMapReduceUtil.initTableSnapshotMapperJob(snapshot, scan,
    AnalyzeMapper.class, Text.class, IntWritable.class, job, true,
    restoreDir); ③
TableMapReduceUtil.addDependencyJars(job.getConfiguration(),
    JSONParser.class);
job.setReducerClass(AnalyzeReducer.class);
job.setOutputKeyClass(Text.class);
job.setOutputValueClass(IntWritable.class);
job.setNumReduceTasks(1);
FileOutputFormat.setOutputPath(job, new Path(output));

System.exit(job.waitForCompletion(true) ? 0 : 1);

if (cleanup) {
    LOG.info("Cleaning up snapshot and restore directory");
    admin.deleteSnapshot(snapshot); ④
    restoreDir.getFileSystem(conf).delete(restoreDir, true);
}
admin.close();
connection.close();

```

- ① Compute a name for the snapshot and restore directory, if not specified otherwise.
- ② Create a snapshot of the table.
- ③ Set up the snapshot mapper phase using the supplied utility.
- ④ Optionally clean up after the job is complete.

For this job to complete successfully, you need to do a few things differently:

1. Stage the class path with all HBase and project libraries, to fulfil the dependency requirements.
2. Switch the user to the owner of the HBase files, here hadoop.

As explained above, since there is a need for the `TableSnapshotInputFormat` to write into the HBase root and temporary table directories,

you need to switch the user executing the job. We do this by setting the `$HADOOP_USER_NAME` environment variable to `hadoop`. Do not forget to unset it at the end or your subsequent cluster interaction might be affected!

We also need to stage the class path variable with more details, as this job is needing additional, non-HBase (or Hadoop) libraries. Using `hbase classpath` gives us all the HBase ones, more than the previous `hbase mapredcp` call we used. This is caused by the `TableSnapshotIn` `putFormat` to interact deeper with HBase and Hadoop, thus requiring more libraries than the minimal set. In addition we add all the JAR files that are part of the code repository build, using the `mvn dependency:build-classpath` call triggering a Maven plugin that emits all libraries needed. This includes the JSON libraries this example needs. An alternative approach would have been to use the *fat jar* as done above, which includes the dependent JARs within the job jar. In that case we would still have to use the `hbase classpath` output, but not the additional Maven command.

```
$ export HADOOP_CLASSPATH=$(hbase classpath):$(mvn -f ch07/pom.xml
 \
  dependency:build-classpath | grep -v INFO)
$ export HADOOP_USER_NAME=hadoop
$ hadoop jar ch07/target/hbase-book-ch07-2.0.jar \
  AnalyzeSnapshotData -t testtable -c data:json -o analyze2 -x
...
15/06/30 03:39:23 INFO mapreduce.AnalyzeSnapshotData: Performing
snapshot \
  of table testtable as snapshot-testtable-1435660759657
15/06/30 03:39:24 INFO mapreduce.AnalyzeSnapshotData: Setting up
job
15/06/30 03:39:25 INFO snapshot.RestoreSnapshotHelper: \
  region to add: 0be6bdf04700fa055129e69fff7790d2
15/06/30 03:39:25 INFO snapshot.RestoreSnapshotHelper: clone re-
gion= \
  0be6bdf04700fa055129e69fff7790d2           as
0be6bdf04700fa055129e69fff7790d2
15/06/30 03:39:25 INFO regionserver.HRegion: creating HRegion test-
table \
  HTD == 'testtable', {NAME => 'data', DATA_BLOCK_ENCODING =>
'NONE', \
  BLOOMFILTER => 'ROW', REPLICATION_SCOPE => '0', VERSIONS => '1',
 \
  COMPRESSION => 'NONE', MIN_VERSIONS => '0', TTL => 'FOREVER', \
  KEEP_DELETED_CELLS => 'FALSE', BLOCKSIZE => '65536', IN_MEMORY
=> 'false', \
  BLOCKCACHE => 'true'} RootDir = \
  /tmp/snapshot-testtable-1435660759657/
a2dd6a0c-0f1e-473f-8118-50028a88d945 \
  Table name == testtable
```

```

15/06/30 03:39:25 INFO snapshot.RestoreSnapshotHelper: Adding HFi-
leLink \
    8b66d40caffd424099c21b7abbeda62c to table=testtable
15/06/30 03:39:25 INFO regionserver.HRegion: Closed \
    testtable,,1435431398921.0be6bd04700fa055129e69fff7790d2.
15/06/30 03:39:26 INFO client.RMProxy: Connecting to ResourceManager at \
    master-1.internal.larsgeorge.com/10.0.10.1:8032
15/06/30 03:39:29 INFO mapreduce.JobSubmitter: number of splits:1
15/06/30 03:39:30 INFO mapreduce.JobSubmitter: Submitting tokens
for job: \
    job_1433933860552_0026
15/06/30 03:39:30 INFO impl.YarnClientImpl: Submitted application \
    application_1433933860552_0026
...
15/06/30 03:39:30 INFO mapreduce.Job: Running job:
job_1433933860552_0026
...
15/06/30 03:39:40 INFO mapreduce.Job: map 0% reduce 0%
15/06/30 03:39:50 INFO mapreduce.Job: map 100% reduce 0%
15/06/30 03:39:59 INFO mapreduce.Job: map 100% reduce 100%
15/06/30 03:40:00 INFO mapreduce.Job: Job job_1433933860552_0026 \
    completed successfully
15/06/30 03:40:00 INFO mapreduce.Job: Counters: 53
...
mapreduce.AnalyzeSnapshotData$Counters
    COLS=993
    ERROR=6
    ROWS=993
    VALID=987
...
$ hdfs dfs -text analyze2/part-r-00000 | head -n 5

10sr    1
13tohl  1
14bcps  1
21721725      1
2centime   1

$ unset HADOOP_USER_NAME

```

Using the snapshot based input format requires write access to the HBase root directory because it keeps reference of who is using what snapshot files. While no data is copied to stage the temporary table, and only links are created, you still have to allow write access to both locations. If you miss to switch the user to the administrative one, you will encounter errors like the one show here:

```

...
15/06/30 02:30:35 INFO regionserver.HRegion: Closed \
    testtable,,1435431398921.0be6bd04700fa055129e69fff7790d2.

```

```

Exception in thread "main" java.io.IOException: \
    java.util.concurrent.ExecutionException: \
        org.apache.hadoop.security.AccessControlException: Permission
denied: \
            user=larsgeorge, access=WRITE, \
            inode="/hbase/archive/data/default":hadoop:supergroup:drwxr-xr-
x
                at org.apache.hadoop.hdfs.server.namenode.FSPermission-
Checker \
                    .checkFsPermission(FSPermissionChecker.java:271)
                        at org.apache.hadoop.hdfs.server.namenode.FSPermission-
Checker....
...

```

Figure 7-6 shows the YARN main page with the applications list. You can see how the earlier jobs were run as user `larsgeorge`, and then the latter ones as `hadoop` using the approach shown above.

Cluster Metrics																
Apps Submitted	Apps Pending	Apps Running	Apps Completed	Containers Running	Memory Total	Memory Used	Memory Reserved	Vcores Used	Vcores Total	Vcores Reserved	Active Nodes	Decommissioned Nodes	Lost Nodes	Unhealthy Nodes	Rebooted Nodes	
30	0	30	0	0	6 GB	0 B	6 GB	0	3	0	3	0	0	0	0	
Show 20 → entries																
ID	User	Name	Application Type	Queue	StartTime		FinishTime	State	FinalStatus	Progress	Tracking UI					
application_1433933860552_0030	hadoop	Analyze data in snapshottestable	MAPREDUCE	default	Tue, 30 Jun 2015 13:54:52 GMT		Tue, 30 Jun 2015 13:55:21 GMT	FINISHED	SUCCEEDED		History					
application_1433933860552_0029	hadoop	Analyze data in snapshottestable	MAPREDUCE	default	Tue, 30 Jun 2015 13:48:57 GMT		Tue, 30 Jun 2015 13:49:33 GMT	FINISHED	FAILED		History					
application_1433933860552_0028	hadoop	Analyze data in snapshottestable	MAPREDUCE	default	Tue, 30 Jun 2015 13:47:22 GMT		Tue, 30 Jun 2015 13:47:50 GMT	FINISHED	SUCCEEDED		History					
application_1433933860552_0027	hadoop	Analyze data in snapshottestable	MAPREDUCE	default	Tue, 30 Jun 2015 13:01:46 GMT		Tue, 30 Jun 2015 13:02:15 GMT	FINISHED	SUCCEEDED		History					
application_1433933860552_0026	hadoop	Analyze data in snapshottestable	MAPREDUCE	default	Tue, 30 Jun 2015 10:39:30 GMT		Tue, 30 Jun 2015 10:39:59 GMT	FINISHED	SUCCEEDED		History					
application_1433933860552_0025	hadoop	Analyze data in snapshottestable	MAPREDUCE	default	Tue, 30 Jun 2015 10:01:12 GMT		Tue, 30 Jun 2015 10:01:42 GMT	FINISHED	SUCCEEDED		History					
application_1433933860552_0024	hadoop	Analyze data in snapshottestable	MAPREDUCE	default	Tue, 30 Jun 2015 09:50:40 GMT		Tue, 30 Jun 2015 09:51:15 GMT	FINISHED	FAILED		History					
application_1433933860552_0023	larsgeorge	Parse data in testtable, write to testtable(map only)	MAPREDUCE	default	Mon, 29 Jun 2015 12:29:07 GMT		Mon, 29 Jun 2015 12:29:28 GMT	FINISHED	SUCCEEDED		History					
application_1433933860552_0022	larsgeorge	Parse data in testtable, write to testtable	MAPREDUCE	default	Mon, 29 Jun 2015 12:21:20 GMT		Mon, 29 Jun 2015 12:21:52 GMT	FINISHED	SUCCEEDED		History					
application_1433933860552_0021	larsgeorge	Analyze data in testtable	MAPREDUCE	default	Mon, 29 Jun 2015 09:02:40 GMT		Mon, 29 Jun 2015 09:03:10 GMT	FINISHED	SUCCEEDED		History					
application_1433933860552_0020	larsgeorge	Import from file test-data.txt into table testtable	MAPREDUCE	default	Mon, 29 Jun 2015 09:00:06 GMT		Mon, 29 Jun 2015 09:00:25 GMT	FINISHED	SUCCEEDED		History					

Figure 7-6. The class hierarchy of the basic client API data classes

An option to avoid write access to the HBase root is using the ExportS snapshot tool (see (to come)). Obviously, this tool has to copy the data from the active or archive location into the target directory. At scale this is a costly operation and should be carefully evaluated. Also, since you copy into an arbitrary HDFS location, you are ultimately responsible for managing that data. This includes keeping the files while jobs

are executing, and removing them when they are not required anymore.

Finally, another reason for using snapshots as a data source instead of tables for MapReduce processing is that it avoids RPCs and other inherent overhead of the server processes. This alone can speed up the overall runtime of the job by a substantial margin. The JIRA adding this input format class (see [HBASE-8369](#)) reports a factor of 5 to 6 times faster scanning performance for single scanners.

Bulk Loading Data

Instead of going through the API using `put()` calls to insert data—or `delete()` to remove it subsequently—, especially when you need to bootstrap a cluster with large amounts of existing data, you can also stage and bulk load that data without going through the HBase servers. This is a bit of a conundrum with HBase, as it is made for small data points, and optimized for writes, with its sequential, Log-Structured Merge Tree based architecture (more about this in (to come)). Yet, the cost for maintaining said small data points is not negligible. Filling the in-memory stores during write operation and flushing them subsequently, the compaction of data asynchronously in an effort to keep the number of files in check, while handling explicit or predicate deletes, is adding a non-trivial amount of *noise* to the system. Not to even speak of memory management pressure during intense writing, due to Java heap fragmentation. What if you could avoid all of that, because you have the data already in some amenable format and all you need doing is transform it into HBase data? That is exactly what bulk loading is: an ETL job that stages and loads the data into HBase in its native format.

What is misleading here it to speak of *loading* data into HBase. What really happens is that after the staging of the data in native HBase store files, the so called HFfiles, you atomically *move* them into the HBase storage location, making them and the contained data immediately available. Before you can do that though you have to do the staging part, and that is an interesting one as well. Usually this is done by a MapReduce job which extracts the records from the original data, then converts them into Put or Delete instances, which are then stored in HFfiles. This implies sorting the data into rows and columns, *exactly* the way HBase would have done if you had used the client API.

And to complicate things, you often want to stage the store files in the same layout as the target table is *currently*. You need to read the target table's region details, to separate the staged files in the same granularity. Then once you complete the bulk load, you have to ensure

that this layout is still the same, which means if a region has split since the initial region check, you may have to split the staged files too to follow the new table layout. All of this is done by the supplied `ImportTsv` and `LoadIncrementalHFiles` tools, as explained from an operations side in (to come). Here we are going to look more into the MapReduce integration, as it might help you stage other sources, or create HFiles with a different processing framework, while using the same principles, and output format classes.

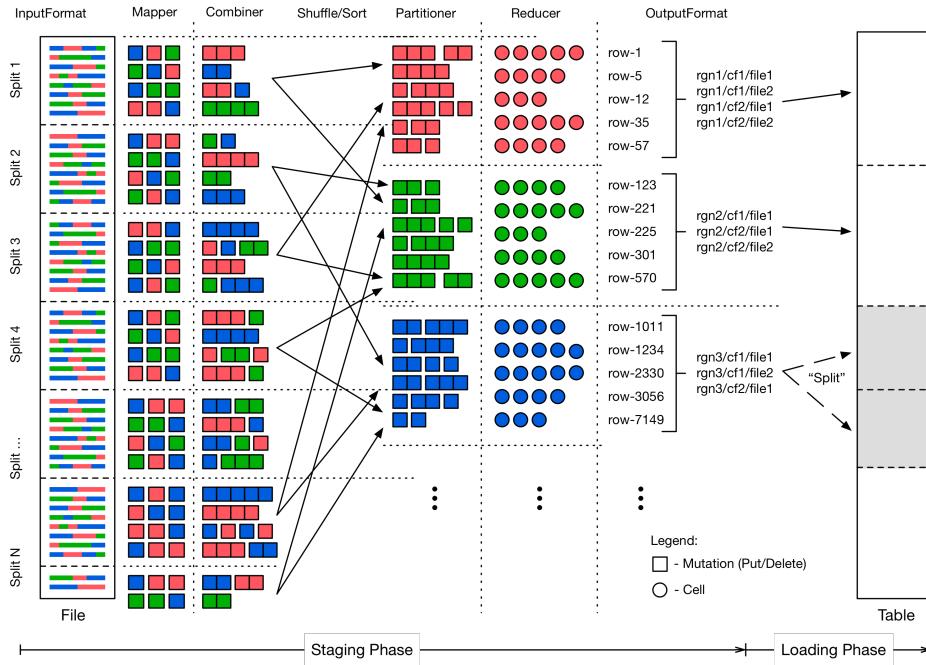


Figure 7-7. The bulk loading process

The `ImportTsv` tool can be used as a template for the first phase of bulk loading: the staging of data. Once this step has completed you use the `LoadIncrementalHFiles` tool to do any final region split adjustments, and then move the data files into place. Figure 7-7 shows a high level view of how the bulk load process works. We will focus here

on the first phase, which employs many techniques to create the staged data files:

The ImportTsv Helper Tool

The `ImportTsv` tool *only* supports inserting data into the table. In other words, many used (and provided) classes are solely supporting `Put` instances only. There is no inherent reason to extend the idea to `Deletes`, but that has not been implemented yet. Adding support for other mutations would not change the overall process.

The `ImportTsv` implementation has another special feature, it can delay the creation of `Put` instances to coincide with the reduce function—referred to as *text-mode* hereafter. In other words, instead of emitting `Put` objects from the mapper, then combining, and shipping them to the reducer, you can keep the data in text form and do the work at the end of the process. This was implemented in [HBASE-8768](#) and available since HBase 0.98.0. You need to enable that feature by overriding the mapper class using the command line parameter:

```
-Dimporttsv.mapper.class=org.apache.hadoop.hbase.mapreduce.TsvImporterTextMapper
```

The tool will then switch out the appropriate classes as needed during the job submission phase.

Read the Input Data

The first step is to read the original data, which is parsed into `Put` or `Delete` (referred to collectively as *mutation* hereafter, for the sake of simplicity) instance at the available granularity. This could be one mutation for every column, or one for the entire row—all dependent on what your input data looks like. You might even get data for one row spread across the input files, which creates mutation instances at random times during the processing, spread across random worker nodes in the cluster. All of these need to be grouped subsequently.

The mapper is expected to emit the mutations as values, while the row key of each mutation is used as the key for each record. This will trigger the built-in shuffle and sorting functionality of the MapReduce framework, grouping all mutations by row key. We will see below how this is a boon and a bane (of sorts), since the default hash function used to route the records would randomly distribute them to matching reducer tasks. It would mean that the

rows would not be contiguous across all partitions, but only within each.

For `ImportTsv` see the `TsvImporterMapper` (or `TsvImporterTextMapper` for text-mode) as an example mapper implementation.

Combine Mutations

As an optimization, we can combine the mutations for the same row emitted by the same mapper task. We might not have the entire row on this server, but if we have more than one mutation for a specific row, we can combine them into a single one, saving object overhead before the shuffle and sort take place.

Note that for `ImportTsv` this is provided by the `PutCombiner` class, and only supports `Put` instances, as the name implies. The supplied class uses an implicit upper size boundary to not run into memory pressure when combining puts. It is set to 1GB and can be modified by setting the `putcombiner.row.threshold` property in the configuration. For text-mode there is no combiner used.

Route Mutations

This is where we get the grouping of rows within region boundaries working. The default hash partitioner class is replaced with the `TotalOrderPartitioner` class, provided by Hadoop. It requires a list of *partitions*, based on user provided boundaries. For bulk loading we use the target table's region boundaries and hand that list over to the special partitioner class. Any mutation that is emitted is then sent to the reducer handling the key subrange. This also implies that we have to run as many reducers as we have regions in the target table.

Sort Rows

There is not much that needs to be done for the rows to be sorted within a region (or partition, both are used synonymously here), as the MapReduce framework is taking care of that. This is one of the fundamental tasks of the framework, sending the records to the proper partition (based on the used partitioner implementation), and sorting them by their key component. This is why the key type `ImmutableBytesWritable` is derived from the Hadoop `WritableComparable` class, allowing for a natural sorting of records by keys.

Sort Columns

While records are grouped and sorted by key, it leaves the associated values to be ordered, that is, the mutations and the contained columns forming a logical row in the resulting HBase table. The `PutSortReducer` (or `TextSortReducer` for text-mode) class handles

this task, being provided with all mutations for a given row key, it sorts the contained columns just like HBase would have done during an organic write operation using the client API.

The `putsortreducer.row.threshold` (or `reducer.row.threshold` for text-mode) property, set to 1GB, defines an upper boundary to avoid memory issues in extreme cases, with very memory intense rows (those that contain many columns, or very large cells). The output of the reducer are the actual columns (the cells) as the value, and not a Put or Delete, while the key stays unchanged and set as the row key. [Figure 7-7](#) shows the difference by switching from boxes to circles in the *reducer* step.

Write Files

The already discussed `HFileOutputFormat2` class is responsible for writing the actual storage files, that is, the HFiles. Its provided, static helper method `configureIncrementalLoad()` can be used to configure all the output format related aspects of the ETL job. This includes setting the above reducer and partitioner classes (along with its custom partition information), as well as the HFile related properties, such as compression type, Bloom filter settings, block sizes and encodings. Otherwise, the output format is honoring many the usual storage related configuration properties, such as `hbase.hregion.max.filesize` (set to 10GB by default) to specify the maximum file size.

These are, from a generic viewpoint, all of the steps involved in staging the bulk load data. The new HFiles are created in a temporary location, which needs to be set per staging job, and obviously requires read and write access for the user running the job. For `ImportTsv` you can specify the location on the command line, using the `importtsv.bulk.output` parameter. The mentioned `LoadIncrementalHFiles` utility performs the second stage of the bulk loading, by moving the new files into the existing table directory, while ensuring any short term region boundary changes are resolved in the process.

One caveat needs to be mentioned: loading potentially very large files into a region can trigger splits right after the process completes. You saw above that the staging process is creating files up to the maximum configured size. If you already have storage files in the region, you will trigger region splits if the combined new size of loaded files plus existing ones exceeds the configured store maximum (which is what the `hbase.hregion.max.filesize` really configures). This is OK of course, because that is part of what makes HBase special, that is, it does the housekeeping work for you asynchronously. On the other hand, that again adds background I/O load to your cluster. It is advisa-

ble to calculate the sizes carefully, and maybe split regions at a slower pace (say at off-peak times) *before* you do the loading.

Loading data into an existing table is a common exercise, and if that table has a decent number of regions you will be able to efficiently load data into them. This is attributed by the number of reducers matching the number of regions, allowing for parallelizing the work into as many concurrent tasks your MapReduce cluster can afford. But what about a bootstrap process, that is, when you want to bulk load new data in a not-yet-existent table? You can certainly use the `create` shell command to quickly create a table, but that will only have one region, and resulting into a single reducer task doing all the data staging. Here is where *presplitting* a table comes in, discussed in detail in (to come). Suffice it to say that you create a certain number of regions at the time you create the table. These regions will be empty, but then fill with data as it is being written to.

If presplitting a new table is the answer to avoid hotspotting on a single region for staging the bulk load, then how splits do you need? And at what boundaries do you split them? This requires detailed knowledge of the key space, which you may not have when faced with an arbitrary set of input data. The common approach is to sample or parse the data at least once, tracking the size of each record and building equally sized partitions. This is only possible if you know where data will eventually be located in the resulting table, and thus you may have to run the same staging logic twice, once to determine the number of regions and their boundaries based on size, and then again to do the actual file staging. An alternative approach is to sample the import data first, trying to extrapolate the region sizes and count from what you have access to. This is a common analytical task and not specific to Hadoop or HBase. You need to calculate the possible error rate to decide which sample rate works best for you. Either way, once you have computed the split points based on the used row keys, you hand this list into first the shell's `create` command to presplit the new table, and second the `TotalOrderPartitioner`, which will do the rest.

Appendix A

Upgrade from Previous Releases

Upgrading HBase involves careful planning, especially when the cluster is currently in production. With the addition of *rolling restarts* (see (to come)), it has become much easier to update HBase with no downtime.

Depending on the version of HBase you are using or upgrading to, you may need to upgrade the underlying Hadoop version first so that it matches the required version for the new version of HBase you are installing. Follow the upgrade guide found on the Hadoop website.

Upgrading to HBase 0.90.x

Depending on the versions you are upgrading from, a different set of steps might be necessary to update your existing cluster to a newer version. The following subsections address the more common update scenarios.

From 0.20.x or 0.89.x

This version of 0.90.x HBase can be started on data written by HBase 0.20.x or HBase 0.89.x, and there is no need for a migration step. HBase 0.89.x and 0.90.x do write out the names of region directories differently—they name them with an MD5 hash of the region name

rather than a Jenkins hash, which means that once you have started, there is no going back to HBase 0.20.x.

Be sure to remove the *hbase-default.xml* file from your *conf* directory when you upgrade. A 0.20.x version of this file will have suboptimal configurations for HBase 0.90.x. The *hbase-default.xml* file is now bundled into the HBase JAR and read from there. If you would like to review the content of this file, you can find it in the *src* directory at `$HBASE_HOME/src/main/resources/hbase-default.xml` or see (to come).

Finally, if upgrading from 0.20.x, check your *.META.* schema in the shell. In the past, it was recommended that users run with a 16 KB `MEMSTORE_FLUSHSIZE`. Execute

```
hbase(main):001:0> scan '-ROOT-'
```

in the shell. This will output the current *.META.* schema. Check if the `MEMSTORE_FLUSHSIZE` size is set to 16 KB (16384). If that is the case, you will need to change this. The new default value is 64 MB (67108864). Run the script `$HBASE_HOME/bin/set_meta_memstore_size.rb`. This will make the necessary changes to your *.META.* schema. Failure to run this change will cause your cluster to run more slowly.¹

Within 0.90.x

You can use a rolling restart during any of the minor upgrades. Simply install the new version and restart the region servers using the procedure described in (to come).

Upgrading to HBase 0.92.0

No rolling restart is possible, as the wire protocol has changed between versions. You need to prepare the installation in parallel, then shut down the cluster and start the new version of HBase. No migration is needed otherwise.

1. See “HBASE-3499 Users upgrading to 0.90.0 need to have their *.META.* table updated with the right `MEMSTORE_SIZE`” (<http://issues.apache.org/jira/browse/HBASE-3499>) for details.

Upgrading to HBase 0.98.x

Migrate API to HBase 1.0.x

TBD.

Table A-1. List of deprecated API methods and classes with their replacement

Name	Type	Replacement	Type
HTable	Class	Table	Interface
HConnection	Interface	Connection	Interface
HConnectionManager	Class	ConnectionFactory	Class
HTableFactory	Class	ConnectionFactory.createConnection()	Method
HTableInterface	Interface	Table	Interface
HTablePool	Class	Connection.getTable()	Method
<tablename>	String	TableName	Class
HTable.getWriteToWAL()	Method	Table.getDurability()	Method
HTable.setWriteToWAL()	Method	Table.setDurability()	Method
HTable.getFamilyMap()	Method	Table.getFamilyCellMap()	Method
HTable.setFamilyMap()	Method	Table.setFamilyCellMap()	Method
Delete.deleteColumn()	Method	Delete.addColumn()	Method
Delete.deleteColumns()	Method	Delete.addColumn()	Method
Delete.deleteFamily()	Method	Delete.addFamily()	Method
Delete.deleteFamilyVersion()	Method	Delete.addFamilyVersion()	Method
Table.batch(List<? extends Row>)	Method	Table.batch(List<? extends Row>, Object[])	Method
Table.batchCallback(List<? extends Row>, Callback<R>)	Method	Table.batchCallback(List<? extends Row>, Object[], Callback<R>)	Method
Batch.forMethod()	Method	dropped, no replacement	n/a

Migrate Coprocessors to post HBase 0.96

Here are the steps needed to convert a Writable based coprocessor implementation into a new [Protocol Buffer](#) based one. This is needed since as of HBase 0.96 (nicknamed *the Singularity*) the entire RPC communication has been replaced by a proper, versioned serialization protocol. With that the old format is not acceptable anymore, and a few changes had to take place. The following uses the RowCount exam-

ple from the first revision of the book, and how it was converted to the new API.

Step 1

The first thing to do is to drop the custom protocol class in favor of a Protocol Buffer definition. You can delete the entire class file that implements the protocol interface, which looks like this:

```
public interface RowCountProtocol extends CoprocessorProtocol {  
    long getRowCount() throws IOException;  
    long getRowCount(Filter filter) throws IOException;  
    long getKeyValueCount() throws IOException;  
}
```

You need to create the replacement Protocol Buffer definition file, and following Maven project layout rules, they go into `${PROJECT_HOME}/src/main/protobuf`, here with the name `RowCountService.proto`.

```
option java_package = "coprocessor.generated";  
option java_outer_classname = "RowCounterProtos";  
option java_generic_services = true;  
option java_generate_equals_and_hash = true;  
option optimize_for = SPEED;  
  
message CountRequest {}  
  
message CountResponse {  
    required int64 count = 1 [default = 0];  
}  
  
service RowCountService {  
    rpc getRowCount(CountRequest)  
        returns (CountResponse);  
    rpc getCellCount(CountRequest)  
        returns (CountResponse);  
}
```

The file defines the output class name, the package to use during code generation and so on. The last thing in step #1 is to compile the definition file into code. This is done using the Protocol Buffer `protoc` tool, as described in more detail in [“Custom Filters” \(page 259\)](#). Executing the command-line compiler will place the generated class file in the source directory, as specified.

Step 2

The next step is to convert `Endpoint` to new API, which involves removing the old custom RPC interface, and adding the new Protocol

Buffer based one (see the `RowCountEndpoint` class in the code repository). The old way to integrate the custom calls looked like this:

```
public class RowCountEndpoint extends BaseEndpointCoprocessor
    implements RowCountProtocol {
```

The new replaces the custom interface with the generated one from step #1 above:

```
public class RowCountEndpoint extends RowCounterProtos.RowCountService
    implements Coprocessor, CoprocessorService {
```

We also implement two more coprocessor related interface directly: there is no `BaseEndpointProcessor` anymore. The `Coprocessor` and `CoprocessorService` interfaces add vital lifecycle methods to our class. We need the `start()` call to retrieve the coprocessor environment like so:

```
@Override
public void start(CoprocessorEnvironment env) throws IOException {
    if (env instanceof RegionCoprocessorEnvironment) {
        this.env = (RegionCoprocessorEnvironment) env;
    } else {
        throw new CoprocessorException("Must be loaded on a table region!");
    }
}
```

In the past the boilerplate `BaseEndpointProcessor` gave us a `getEnvironment()` method to retrieve the same. We now need to do this on our own. On top of that we need to change the RPC call handlers, where the old once simply implemented the custom RPC interface methods:

```
@Override
public long getRowCount() throws IOException {
    return getRowCount(new FirstKeyOnlyFilter());
}
```

In the new API style we have to add a bit more wiring, especially around the marshalling of the result—or error—and how it is returned to the framework (see the [online](#) documentation). Due to the use of the Protocol Buffer library, we need to accept a `request` object and return a `response` like so:

```
@Override
public void getCellCount(RpcController controller, ❶
    RowCounterProtos.CountRequest request,
    RpcCallback<RowCounterProtos.CountResponse> done) {
    RowCounterProtos.CountResponse response = null;
    try {
        long count = getCount(null, true); ❷
    }
```

```

        response = RowCounterProtos.CountResponse.newBuilder()
            .setCount(count).build(); ③
    } catch (IOException ioe) {
        ResponseConverter.setControllerException(controller, ioe); ④
    }
    done.run(response);
}

```

- ① Custom RPC call with specific handler classes, such as the controller, and request/response pair.
- ② Call the internal helper to scan and summarize per region aggregates as usual.
- ③ Hand in resulting count into the response wrapper.
- ④ Handle exceptions by wrapping the error and returning it via the controller.

Apart from that there are more changes, unrelated to coprocessors, that are required to make the old code work. For example, we need to change from `KeyValue` to `Cell` types, and adjust how we do comparisons. The new code looks very similar, but has a few slight changes:

```

try ( ①
    InternalScanner scanner = env.getRegion().getScanner(scan);
) {
    List<Cell> results = new ArrayList<Cell>(); ②
    boolean hasMore = false;
    byte[] lastRow = null;
    do {
        hasMore = scanner.next(results);
        for (Cell cell : results) { ③
            if (!countCells) {
                if (lastRow == null || !CellUtil.matchingRow(cell, las-
tRow)) { ④
                    lastRow = CellUtil.cloneRow(cell); ⑤
                    count++;
                }
            } else count++;
        }
        results.clear();
    } while (hasMore);
}

```

- ① Use of the new `try-with-resource` pattern to simplify resources handling.
- ② ③ The new `Cell` interface is used to retrieve the data and iterate over it.
- ④ Comparing changed to use the `CellUtil.matchingRow()` method, for convenience.

- ➅ The byte array has to be memorized, use again the CellUtil helper to clone the row key.

Apart from that, no further code changes on the server-side code were necessary.

Step 3

From here you need to do the same as before, that is deploy the coprocessor as a JAR file on the servers, add the class name to the hbase-site.xml file, add the JAR name to the class path in the hbase-env.sh file, and restart the servers.

Step 4

Last step is invoking the server-side code. This is now client API code that has to be adjusted. This is located in the EndpointExample class, and looks like this for the old style API:

```
Map<byte[], Long> results = table.coprocessorExec(
    RowCountProtocol.class, null, null,
    new Batch.Call<RowCountProtocol, Long>() {
        @Override
        public Long call(RowCountProtocol counter) throws IOException {
            return counter.getRowCount();
        }
    });
}
```

For the new one there are a few changes, analog to what we have seen on the server-side code. There is more wiring for the Protocol Buffer based RPC handling:

```
final RowCounterProtos.CountRequest request =
    RowCounterProtos.CountRequest.getDefaultInstance(); ①
Map<byte[], Long> results = table.coprocessorService( ②
    RowCounterProtos.RowCountService.class, null, null,
    new Batch.Call<RowCounterProtos.RowCountService, Long>() { ③
        public Long call(RowCounterProtos.RowCountService counter)
            throws IOException {
            BlockingRpcCallback<RowCounterProtos.CountResponse> rpcCallback =
                new BlockingRpcCallback<RowCounterProtos.CountResponse>();
        ④
            counter.getRowCount(null, request, rpcCallback); ⑤
            RowCounterProtos.CountResponse response = rpcCallback.get();
        ⑥
            return response.hasCount() ? response.getCount() : 0;
        }
    });
}
```

- ➊ Create a request instance using the generated RPC class.

- ❷ Call the new coprocessorService() method (the older coprocessorEc() has been removed).
- ❸ Use the generated classes to parameterize the call.
- ❹ Set up an RPC callback for the specific call and types.
- ❺ Invoke the remote call.
- ❻ Retrieve the response and, subsequently, the payload value (our row count).

These are all the changes that were needed to run the existing example using the new API.

Migrate Custom Filters to post HBase 0.96

Here are the steps needed to convert a Writable based filter implementation into a new [Protocol Buffer](#) based one. This is needed since as of HBase 0.96 (nicknamed *the Singularity*) the entire RPC communication has been replaced by a proper, versioned serialization protocol. With that the old format is not acceptable anymore, and a few changes had to take place. The following uses the `CustomFilter` example from the first revision of the book, and how it was converted to the new API.

Step 1

First you need to create a Protocol Buffer definition, which covers all the internal fields of the filter, setting its state. Following Maven project layout rules, they go into `${PROJECT_HOME}/src/main/proto` `buf`, here with the name `CustomFilters.proto`. The content is the following:

```
option java_package = "filters.generated";
option java_outer_classname = "FilterProtos";
option java_generic_services = true;
option java_generate_equals_and_hash = true;
option optimize_for = SPEED;

message CustomFilter {
    required bytes value = 1;
}
```

The file defines the output class name, the package to use during code generation and so on. The last thing in step #1 is to compile the definition file into code. This is done using the Protocol Buffer `protoc` tool, as described in more detail in “[Custom Filters](#)” (page 259). Executing the command-line compiler will place the generated class file in the source directory, as specified.

Step 2

Next step is the conversion of the existing, `Writable` based, serialization methods, over to the new Protocol Buffer ones. For that we need to change to methods, here the old version:

```
@Override  
public void write(DataOutput dataOutput) throws IOException {  
    Bytes.writeByteArray(dataOutput, this.value);  
}  
  
@Override  
public void readFields(DataInput dataInput) throws IOException {  
    this.value = Bytes.readByteArray(dataInput);
```

Both of those methods can be dropped, and are replaced by the following two:

```
@Override  
public byte [] toByteArray() {  
    FilterProtos.CustomFilter.Builder builder =  
        FilterProtos.CustomFilter.newBuilder();  
    if (value != null) builder.setValue(ByteStringer.wrap(value));  
    return builder.build().toByteArray();  
}  
  
public static Filter parseFrom(final byte[] pbBytes)  
throws DeserializationException {  
    FilterProtos.CustomFilter proto;  
    try {  
        proto = FilterProtos.CustomFilter.parseFrom(pbBytes);  
    } catch (InvalidProtocolBufferException e) {  
        throw new DeserializationException(e);  
    }  
    return new CustomFilter(proto.getValue().toByteArray());  
}
```

The look more complicated, but that is attributed to the Protocol Buffer handling, which is not as *hidden* as the `Writable` version. The `toByteArray()` serialized the filter fields inside a Protocol Buffer message. For that it creates a `Builder` instance that was generated in step #1. The builder is then executed and the resulting byte array returned.

On the deserialization side the `parseFrom()` receives the byte array, which is then parse by the generated code into a message instance. The contained data is handed into the filter constructor, which is returned to the caller in due course.

Step 3

From here you need to do the same as before, that is deploy the coprocessor as a JAR file on the servers, add the class name to the `hbase-site.xml` file, add the JAR name to the class path in the `hbase-env.sh` file, and restart the servers. See “[Custom Filters](#)” (page 259) for details on the deployment options.

Step 4

Last step is invoking the filter as part of a read operation. This stays the same as well as before, since we only adjusted the internal serialization process, which is otherwise not exposed to the client. The usage and rest of the filter implementation stays the same (see [Example 4-24](#) for an example).