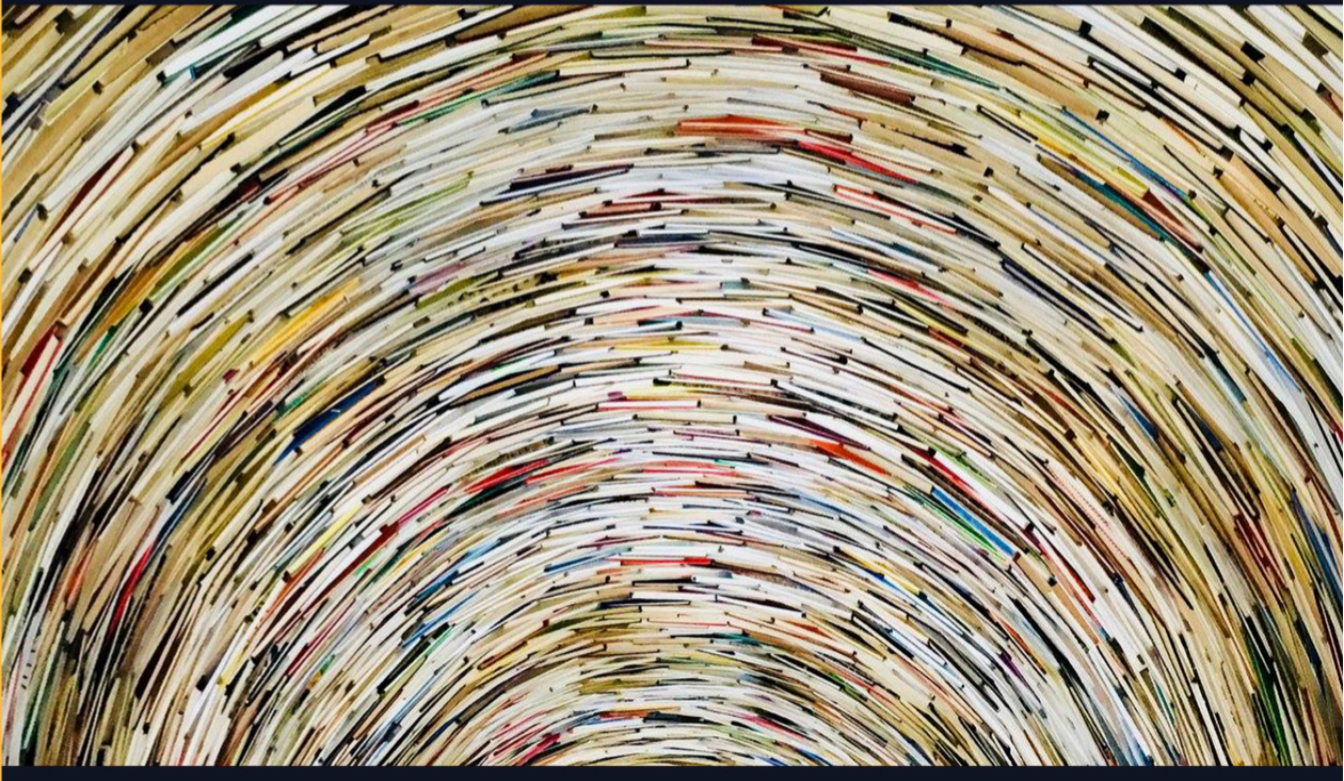
THE APACHE IGNITE BOOK

The next phase of the distributed systems



The complete guide to learning everything you need to know about Apache Ignite

BY SHAMIM BHUIYAN & MICHAEL ZHELUDKOV

The Apache Ignite book

The next phase of the distributed systems

Shamim Bhuiyan and Michael Zheludkov

This book is for sale at http://leanpub.com/ignitebook

This version was published on 2019-03-26

ISBN 978-0-359-43937-9

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To my Mother & Brothers, thank you for your unconditional love.

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Preface

Apache Ignite is one of the most widely used open source memory-centric distributed, caching, and processing platform. This allows the users to use the platform as an in-memory computing framework or a full functional persistence data stores with SQL and ACID transaction support. On the other hand, Apache Ignite can be used for accelerating existing Relational and NoSQL databases, processing events & streaming data or developing Microservices in fault-tolerant fashion.

This book addressed anyone interested in learning in-memory computing and distributed database. This book intends to provide someone with little to no experience of Apache Ignite with an opportunity to learn how to use this platform effectively from scratch taking a practical hands-on approach to learning.

What this book covers

Chapter 1. Introduction: gives an overview of the trends that have made in-memory computing such important technology today. By the end of this chapter, you will have a clear idea of what Apache Ignite is and why use Apache Ignite instead of others frameworks like *HazelCast*, *Ehcache*?

Chapter 2. Getting started with Apache Ignite: is about getting excited. This chapter walks you through the initial setup of an Ignite database and running of some sample application. You will implement your first Ignite application to read and write entries from the Cache at the end of the chapter. Also, you will learn how to install and configure an SQL IDE to run SQL queries against Ignite caches and use Apache Ignite Thin client to working with the Ignite database.

Chapter 3. Apache Ignite use cases: discusses various design decisions and use cases where Ignite can be deployed. These use cases detailed and explained through the rest of the book.

Chapter 4. Architecture deep dive: covers Ignite's internal plumbing. This chapter has a lot of useful design concepts if you have never worked with a distributed system. This chapter introduces Ignite shared nothing architecture, cluster topology, distributed hashing, Ignite replication strategy and durable memory architecture. It is a theoretical chapter; you may skip (not recommended) it and come back later.

Chapter 5. Intelligent caching: presents Ignite smart caching capabilities, Memoization, and Web-session clustering. This chapter covers developments and techniques to improve the performance of your existing web applications without changing any code.

Chapter 6. Database: guides you through the Ignite database features. This massive chapter explores: Ignite tables and index configurations, different Ignite queries, how SQL works under the cover, collocated/Non-collocated distributed joins, Spring data integration, using Ignite with JPA and Ignite native persistence. This chapter is for you if you are planning to use Ignite as a database.

Chapter 7. Distributed computing: focuses on more advanced Ignite features such as distributed computing and how Ignite can help you develop Micro-service like application, which will be performed in parallel fashion to gain high performance, low latency, and linear scalability. You will learn about Ignite inline MapReduce & ForkJoin, distributed closure execution, continuous mapping for data processing across multiple nodes in the cluster.

Chapter 8. Streaming and complex event processing: takes the next step and goes beyond using Apache Ignite to solve complex real-time event processing problem. This chapter covers how Ignite can be used easily with other Big data technologies such as Kafka, flume, storm, and camel to solve various business problems. We will guide you through with complete examples for developing real-time data processing on Apache Ignite.

Chapter 9. Accelerating Big data computing: is a full chapter about how to use Apache Spark Dataframe and RDD for processing massive datasets. We detailed by examples of how to share the application states in memory across multiple Spark jobs by using Ignite.

Chapter 10. Management and monitoring: explain the various tools that you can use to monitor and manage the Ignite cluster. For instance, configuring Zookeeper discovery, scaling up a cluster with Baseline topology. We provide a complete example of using Grafana for monitoring Ignite cluster at the end of this chapter.

Code Samples

All code samples, scripts, and more in-depth examples can be found on the GitHub repository[1].

[1] https://github.com/srecon/the-apache-ignite-book

Readership

The target audiences of this book are IT architect, team leaders or programmer with minimum programming knowledge. No excessive knowledge is required, though it would be good to be familiar with *Java*, *Spring framework* and tools like *Maven*. The book is also useful for any reader, who already familiar with Oracle Coherence, Hazelcast, Infinispan or Memcached.

Conventions

The following typographical conventions are used in this book:

Italic and **Bold** indicates new terms, important words, URL's, filenames, and file extensions.

A block code is set as follows:

Listing 1.1

```
public class MySuperExtractor implements StreamSingleTupleExtractor<SinkRecord, String, S\
tring> {

 @Override public Map.Entry<String, String> extract(SinkRecord msg) {
    String[] parts = ((String)msg.value()).split("_");
    return new AbstractMap.SimpleEntry<String, String>(parts[1], parts[2]+":"+parts[3]);
 }
}
```

Any command-line **input** or **output** is written as follows:

```
[2018-09-30 15:39:04,479] INFO Kafka version : 2.0.0 (org.apache.kafka.common.utils.AppIn\
foParser)
[2018-09-30 15:39:04,479] INFO Kafka commitId : 3402a8361b734732 (org.apache.kafka.common\
.utils.AppInfoParser)
[2018-09-30 15:39:04,480] INFO [KafkaServer id=0] started (kafka.server.KafkaServer)
```

Tip

This icon signifies a tip, suggestion.

Warning

This icon indicates a warning or caution.

Info

This icon signifies general note.

Reader feedback

We would like to hear your comment such as what you think, like or dislike about the content of the book. Your feedback will help us to write a better book and help others to clear all the concepts. To submit your feedback, please use the the feedback link[2].

[2] https://leanpub.com/ignitebook/email_author/new

About the authors

Shamim Bhuiyan is currently working as an Enterprise architect; where he's responsible for designing and building out highly scalable, and high-load middleware solutions. He received his Ph.D. in Computer Science from the University of Vladimir, Russia in 2007. He has been in the IT field for over 18 years and is specialized in Middleware solutions, Big Data and Data science. Also, he is a former SOA solution designer, speaker, and Big data evangelist. Actively participates in the development and designing of high-performance software for IT, telecommunication and the banking industry. In spare times, he usually writes the blog frommyworkshop[3] and shares ideas with others.

Michael Zheludkov is a senior programmer at AT Consulting. He graduated from the *Bauman Moscow State Technical University* in 2002. Lecturer at BMSTU since 2013, delivering course *Parallel programming and distributed systems*.

[3] http://frommyworkshop.blogspot.ru/

Chapter 4. Architecture deep dive

Apache Ignite is an open-source memory-centric distributed database, caching and computing platform. It was designed as an in-memory data grid for developing a high-performance software system from the beginning. So its core architecture design is slightly different from that of the traditional NoSQL databases, able to simplify the building of modern applications with a flexible data model and simpler high availability and high scalability.

To understand how to properly design an application with any databases or framework, you must first understand the architecture of the database or framework itself. By getting a better idea of the system, you can solve different problems in your enterprise architecture landscape, can select a comprehensive database or framework that is appropriate for your application and can get maximum benefits from the system. This chapter gives you a look at the Apache Ignite architecture and core components to help you figure out the key reasons behind Ignite's success over other platforms.

Understanding the cluster topology: shared-nothing architecture

Apache Ignite is a grid technology, and its design implies that the entire system is both inherently available and massively scalable. Grid computing is a technology in which we utilize the resources of many computers (commodity, on-premise, VM, etc.) in a network towards solving a single computing problem in parallel fashion.

Note that there is often some confusion about the difference between grid and cluster. Grid computing is very similar to cluster computing, the big difference being that cluster computing consists of homogeneous resources, while grids are heterogeneous. Computers that are part of a grid can run different operating systems and have different hardware, whereas cluster computers all have the same hardware and OS. A grid can make use of spare computing power on a desktop computer, while the machines in a cluster are dedicated to working as a single unit and nothing else. Throughout this book, we use the terms *grid* and *cluster* interchangeably.

Apache Ignite also provides a shared-nothing architecture[4] where multiple identical nodes

[4] https://en.wikipedia.org/wiki/Shared-nothing_architecture

form a cluster with no *single master* or *coordinator*. All nodes in a shared-nothing cluster are identical and run the exact same process. In the Ignite grid, nodes can be added or removed nondisruptively to increase (or decrease) the amount of RAM available. Ignite internode communication allows all nodes to receive updates quickly without having any master coordinator. Nodes communicate using peer-to-peer message passing. The Apache Ignite grid is sufficiently resilient, allowing the nondisruptive automated detection and recovery of a single node or multiple nodes.

On the most fundamental level, all nodes in the Ignite cluster fall into one of two categories: *client* and *server*. There is a big difference between the two types of nodes, and they can be deployed in different ways. In the rest of this section, we will talk about the topology of the Ignite grid and how it can be deployed in real life.

Client and server node

An Ignite node is a single Ignite process running in a JVM. Apache Ignite nodes have an optional notion of client and server nodes as we mentioned before. Often, an Ignite client node also addresses as a *native client node*. Both client and server nodes are part of Ignite's physical grid and are interconnected with each other. The client and server nodes have the following characteristics.

Node	Description
Server	1. Acts as a container for storing data and computing. A server node contains data, participates in caching, computing and streaming. 2. Generally starts as a standalone Java process.
Client	1. Acts as an entry point to run operations like put/get into the cache. 2. Can store portions of data in the near cache, which is a smaller local cache that stores most recently and most frequently accessed data. 3. It is also used to deploy compute and service tasks to the server nodes and can participate in computation tasks (optional). 4. Usually embedded with the application code.

Tip

You often encounter the term *data node* in the Ignite documentation. The terms *data node* and *server node* refer to the same thing and are used interchangeably.

All nodes in the Ignite grid start as server nodes by default, and client nodes need to be *explicitly* enabled. You can imagine the Ignite client node as a *thick client* (also called a fat client, e.g., Oracle OCI8). Whenever a client node connects to the Ignite grid or cluster, it is

aware of the grid topology (data partitions for each node) and is able to send a request to the particular node to retrieve data. You can configure an Ignite node to be either a client or a server via a Spring or Java configuration, as shown below.

Spring configuration:

Listing 4.1

```
<bean class="org.apache.ignite.configuration.IgniteConfiguration">
    ...
    <!-- Enable client mode. -->
    <property name="clientMode" value="true"/>
    ...
</bean>
```

Java configuration:

Listing 4.2

```
IgniteConfiguration cfg1 = new IgniteConfiguration();
cfg1.setGridName("name1");
// Enable client mode.
cfg1.setClientMode(true);
// Start Ignite node in client mode
Ignite ignite1 = Ignition.start(cfg1);
```

Here is also a special type of logical node called a *compute node* in the Ignite cluster. A compute node is the node that usually participates in computing business logic. Basically, a server node that contains data is also used to execute computing tasks.

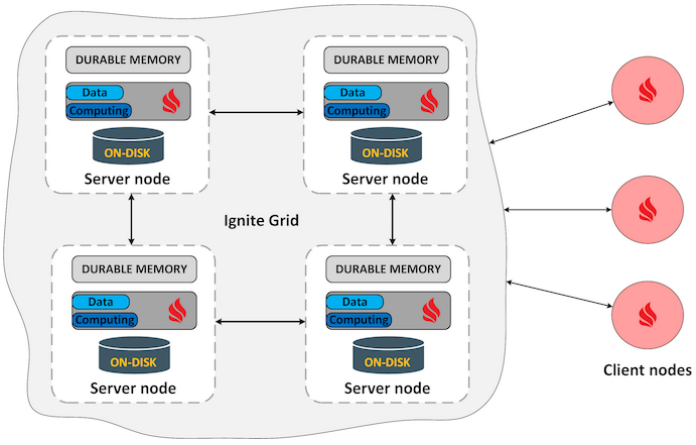


Figure 4.2

However, an Apache Ignite client node can also participate in computing tasks *optionally*. The concept might seem complicated at first glance, but let's try to clarify it.

Server nodes or Data nodes always stores data and participating in any computing task. On the other hand, the Client node can manipulate the server caches, store local data and optionally participate in computing tasks. Usually, client nodes are only used to put or retrieve data from the caches.

Why should you want to run any computing task on client nodes? In some cases (for instance high volume transactions in the server nodes), you do not want to execute any job or computing task on the server nodes. In such a case, you can choose to perform jobs only on client's nodes by creating a cluster group. This way, you can separate the server node (data node) from the nodes that are particular uses for computing in the same grid.

A cluster group is a *logical unit* of a few nodes (server or client node) that group together in a cluster to perform some work. Within a cluster group, you can limit job execution, service deployment, streaming and other tasks to run only within a cluster group. You can create a cluster group based on any predicate. For instance, you can create a cluster group from a group of nodes, where all the nodes are responsible for caching data for a cache named **testCache**. It's enough for now, and we will explore this distinction later in the subsequent section of this chapter.

Ignite nodes can be divided into *two major groups* from the deployment point of view:

1. Embedded with the application.
2. Standalone server node.

Embedded with the application

Apache Ignite as a Java application can be deployed embedded with other applications. It means that Ignite nodes will be runs on the same JVM that uses the application. Ignite node can be embedded with any Java web application artifact like WAR or EAR running on any application server or with any standalone Java application. Our *HelloIgnite* Java application from *chapter 2* is a perfect example of embedded Ignite server. We start our Ignite server as a part of the Spring application running on the same JVM and joins with other nodes of the grids in this example. In this approach, the life cycle of the Ignite node is tightly bound with the life cycle of the entire application itself. Ignite node will also shut down if the application dies or is taken down. This topology is shown in figure 4.3.

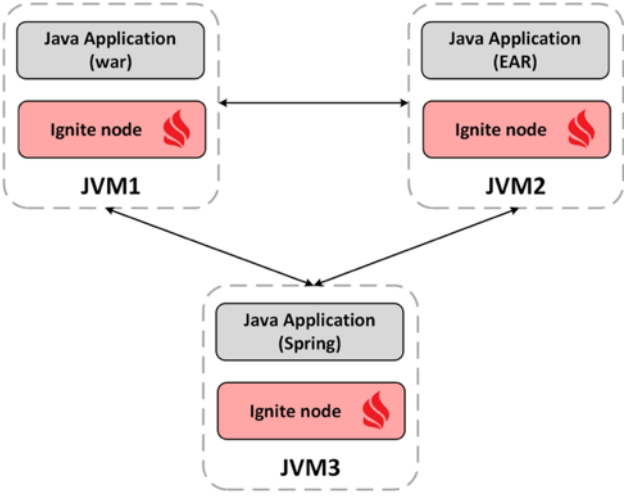


Figure 4.3

If you change the **IgniteConfiguration.setClientMode** property to *false*, and rerun the *HelloIgnite* application, you should see the following:

Figure 4.4

HelloIgnite Java application run and joins to the cluster as a server node. The application exists from the Ignite grid after inserting a few datasets. Another excellent example of using Ignite node as an embedded mode are implementing web session clustering. In this approach, you usually configure (web.xml file) your web application to start an Ignite node

in embedded mode. When multiple application server instances are running, all embedded Ignite nodes connect with each other and forming an Ignite grid. Please see the *chapter 5 Intelligent caching* for more details of using web session clustering.

Client and the server nodes in the same host

This is one of the typical cases when Ignite client and server nodes are running on different JVM in the same host. You can execute Ignite client and server nodes in separate containers such as Docker or OpenVZ if you are using container technology for running JVM. Both containers can be located in the same single host.

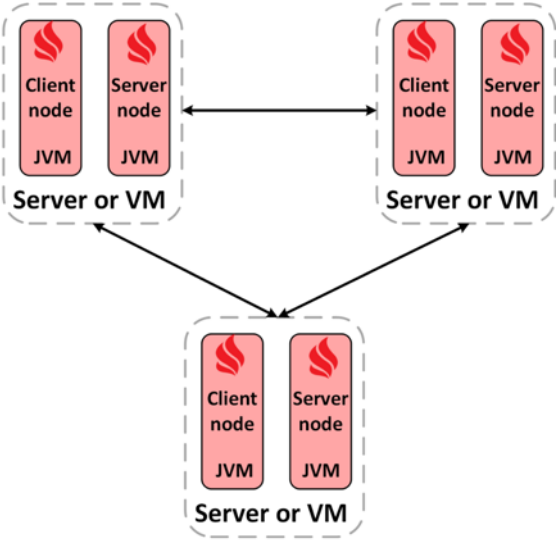


Figure 4.5

The container isolates the resources (CPU, RAM, Network interface) and the JVM only uses isolated resources assigned to this container. Moreover, the Ignite client and server node can be deployed in the separate JVM in the single host without containers, where they all use the shared resourced assigned to this host machine. Host machine could be any on-premise, virtual machine or Kubernates pods.

Running multiple nodes within single JVM

It is possible to start multiple nodes from within a single JVM. This approach is very popular for unit testing among developers. Ignite nodes running on the same JVM connects with each other and forming an Ignite grid.

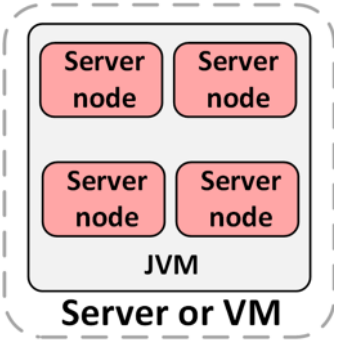


Figure 4.6

One of the *easiest* ways to run a few nodes within a single JVM is by executing the following code::

Listing 4.3

```
IgniteConfiguration cfg1 = new IgniteConfiguration();
cfg1.setGridName("g1");
Ignite ignite1 = Ignition.start(cfg1);
IgniteConfiguration cfg2 = new IgniteConfiguration();
cfg2.setGridName("g2");
Ignite ignite2 = Ignition.start(cfg2);
```

Tip

Such a configuration is only intended for developing process and not recommended for production use.

Real cluster topology

In this approach Ignite client and server nodes are running on different hosts. These are the most common way to deploy a large-scale Ignite cluster for production use because it provides greater flexibilities in term of cluster technics. Individual Ignite server node can be taken down or restarted without any impact to the overall cluster.

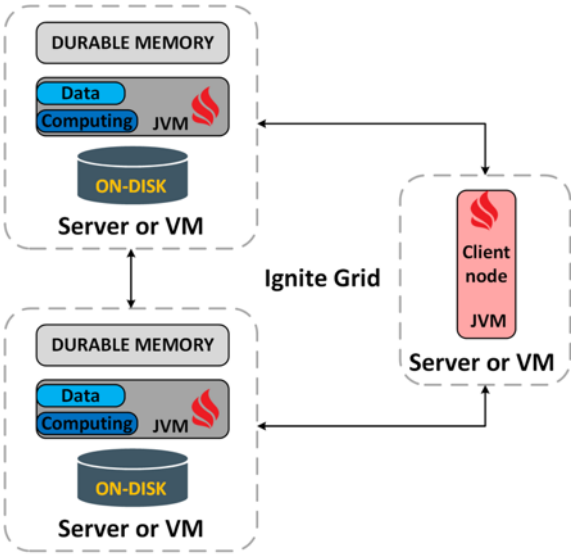


Figure 4.6.1

Such a cluster can be quickly deployed in and maintained by the kubernates[5] which an open source system for automating deployment, scaling, and management of the containerized application. VMWare[6] is another common cluster management system rapidly used for the Ignite cluster.

Data partitioning in Ignite

Data partitioning[7] is one of the fundamental parts of any distributed database despite its storage mechanism. Data partitioning and distribution technics are capable of handling large amounts of data across multiple data centers. Also, these technics allow a database system to become highly available because data has been spread across the cluster.

Traditionally, it has been difficult to make a database highly available and scalable, especially the relational database systems that have dominated the last couple of decades. These systems are most often designed to run on a single large machine, making it challenging to scale out to multiple machines.

At the very high level, there are two styles of data distribution models available:

[5] https://kubernetes.io
[6] https://www.vmware.com/solutions/virtualization.html
[7] https://en.wikipedia.org/wiki/Partition_(database)

1. **Sharding**: it's sometimes called horizontal partitioning. Sharding distributes different data across multiple servers, so each server act as a single source for a subset of data. Shards are called *partitions* in Ignite.
2. **Replication**: replication copies data across multiple servers, so each portion of data can be found in multiple places. Replicating each partition can reduce the chance of a single partition failure and improves the availability of the data.

Tip

There are also two types of partitions available in partitions strategy: *vertical partitioning* and *functional partition.* A detailed description of these partitioning strategies is out of the scope of this book.

Usually, there are several algorithms uses for distributing data across the cluster, a *hashing algorithm* is one of them. We will cover the Ignite data distribution strategy in this section, which will build a deeper understanding of how Ignite manages data across the cluster.

Understanding data distribution: DHT

As you read in the previous section, Ignite shards are called partitions. Partitions are memory segments that can contain a large volume of a dataset, depends on the capacity of the RAM of your system. Partition helps you to spread the load over more nodes, which reduces contention and improves performance. You can scale out the Ignite cluster by adding more partitions that run on different server nodes. The next figure shows an overview of the horizontal partitioning or sharding.

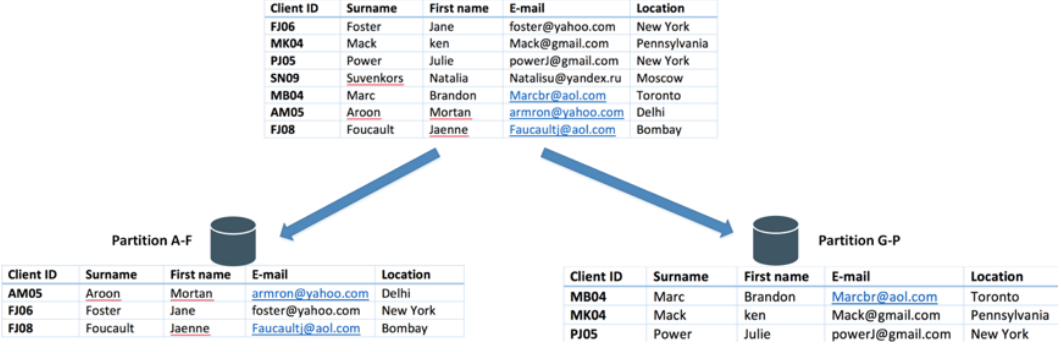


Figure 4.7

In the above example, the client profile's data are divided into partitions based on the client *Id* key. Each partition holds the data for a specified range of partition key, in our case, it's the range of the client ID key. Note that, partitions are shown here for the descriptive purpose. Usually, the partitions are not distributed in any order but are distributed randomly.

Distributed Hash Table[8] or DHT is one of the fundamental algorithms used in the distributed scalable system for partitioning data across the cluster. DHT is often used in web caching, P2P system, and distributed database. The first step to understand the DHT is *Hash Tables*. Hashtable[9] needs *key*, *value*, and one hash *function*, where hash function maps the key to a location (slot) where the value is located. According to this schema, we apply a hash function to some key attribute of the entity we are storing that becomes the partition number. For instance, if we have four Ignite nodes and 100 clients (assume that client Id is a numeric value), then we can apply the hash function `hash (Client Id) % 4`, which will return the node number where we can store or retrieve the data. Let's begin with some basic details of the Hashtable.

The idea behind the Hashtable is straightforward. For each element we insert, we have to have calculated the slot (technically, each position of the hash table is called slot) number of the element into the array, where we would like to put it. Once we need to retrieve the element from the array, we recalculate its slot again and returns it's as a single operation (something like return array [calculated index or slot]). That's why it has O(1)[10] time complexity. In short, O(1) means that the operation takes a certain (constant) amount of times, like 10 nanoseconds or 2 milliseconds. The process of calculating *unique* slot of each element is called *Hashing* and the algorithm how it's done called *Hash function*.

In a typical Hash table design, the Hash function result is divided by the number of array slots and the remainder of the division becomes the slot number of the array. So, the index or slot into the array can be calculated by `hash(o) % n`, where *o* is the object or key, and *n* is the total number of slots into the array. Consider the following illustration below as an example of the hash table.

[8] https://en.wikipedia.org/wiki/Distributed_hash_table
[9] https://en.wikipedia.org/wiki/Hash_table
[10] https://en.wikipedia.org/wiki/Big_O_notation

Figure 4.8

The value on the left represents keys in the preceding diagram, which are being hashed by the hash function for producing the slot where the value is stored. Based on the hash value computed, all the items placed in respective slots. Also, we can look up the client profile of a given client *Id* by calculating its hash and then accessing the resulting slot into the array.

Info

Implementation of the Hash tables has some memory overhead. Hash tables need a lot of memory to accommodate the entire. Even if most of the table is empty, we need to allocate memory for the entire table. Often, this called a time-space tradeoff, and hashing gives the best performance for searching data at the expanse of memory.

Hash table is well suited for storing data set allocated in one machine. However, when you have to accommodate a large number of keys, for instance, millions and millions of keys, DHT comes into play. A DHT is merely a key-value store distributed across many nodes in a cluster. You have to divide the keys into subsets of keys and map those keys to a *bucket*. Each bucket will reside in a sperate node. You can assume a bucket as a sperate hash table. In one word, using buckets to distribute the key-value pairs is DHT.

Another key objective of the hash function in a DHT is to map a key to the node that owns it, such that a request can be made to the correct node. Therefore, there are *two* hash functions for looking up the value of the key across the cluster in DHT. The first hash function will search for the appropriate bucket maps to the key, and the second hash function will return the slot number of the value for the key located in the node. We can visualize the schema as shown in figure 4.9.

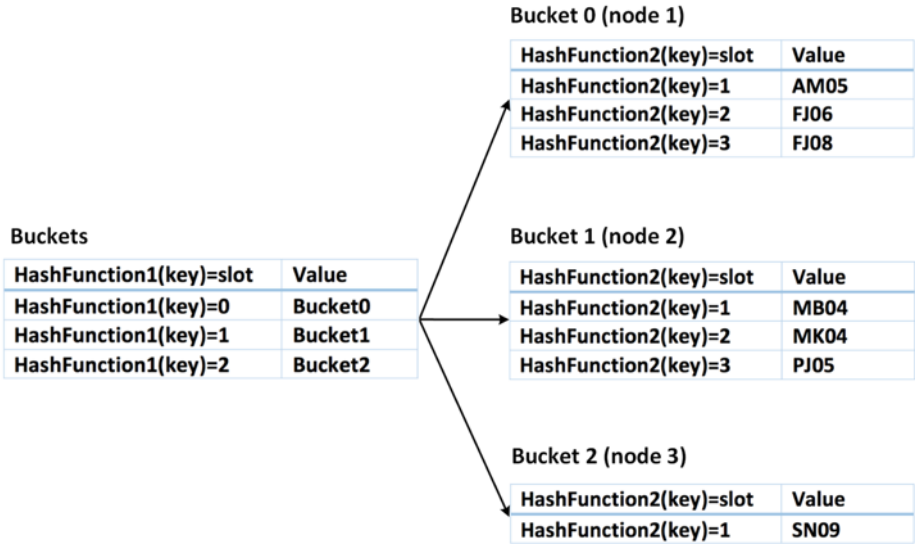


Figure 4.9

To illustrate this, we modified our previous hash table to store pointers to the bucket instead of values. If we have three buckets as shown in the preceding example, then *key=1* should go to the *bucket 1*, *key=2* will go to *bucket 2* and so on. Therefore, we have to need one more hash function to find out the actual value of the key-value pair inside a particular bucket. *HashFucntion2* is the second hash function for looking up the actual key-value pair from the bucket in this case.

Table named **Buckets** on the left-hand side in figure 4.9 sometimes called *partition table*. This tables stores the partition *IDs* and the node associated to that partition. The function of this table is to make all members of the entire cluster aware of this information, making sure that all members know where the data is.

The fundamental problem of DHT is that it effectively fixes the total number of the nodes in the cluster. Adding a new node or removing nodes from the cluster means changing the hash function which would require redistribution of the data and downtime of the cluster. Let's see what happens when we remove the bucket 2 (node 3) from the cluster, the number of buckets is now equal to two, i.e., n=2. This changes the result of the hash function `hash (key) % n`, causing the previous mapping to the node (bucket) unstable. The key=2 which was previously mapped to bucket two now mapped to bucket 0 since key % 2 is equal to 0. We need to move the data between buckets to make it still work, which is going to be expensive in this hashing algorithm.

A workaround for this problem is to use *Consistence Hashing* or *Rendezvous hashing*. Often

Rendezvous hashing is also called *Highest Random Weight (HRW)* hashing. Apache Ignite uses the Rendezvous hashing, which guarantees that only the minimum amount of partitions will be moved to scale out the cluster when topology changes.

Info

Consistence Hashing is also very popular among other distributive systems such as Cassandra, Hazelcast, etc. At the early stage, Apache Ignite also used consistent Hashing to reduce the number of partitions moving to different nodes. Still, you can find Java class *GridConsistentHash* in the Apache Ignite codebase regards to the implementation of the Consistent Hashing.

Rendezvous hashing

Rendezvous hashing[11] (aka highest random weight (HRW) hashing) was introduced by David Thaler and Chinya Ravishankar in 1996 at the University of Michigan. It was first used for enabling multicast clients on the internet to identify rendezvous points in a distributed fashion. It was used by Microsoft corporation for distributed cache coordination and routing a few years later. Rendezvous hashing is an alternative to the ring based, consistent hashing. It allows clients to achieve distributed agreement on which node a given key is to be placed in.

The algorithm is based on a similar idea of consistent hashing[12] where nodes are converted into *numbers* with hash. The basic idea behind the algorithm is that the algorithm uses *weights* instead of projecting nodes and their replicas on a circle. A numeric value is created with a standard hash function hash(Ni, K) to find out which node should store a given key, for each combination of the node (N) and key (K). The node that's picked is the one with the highest number. This algorithm is particularly useful in a system with some replication (we will detail the replication mechanism in the next section, for now, data replication is a term means to have redundancies data for high availability) since it can be used to agree on multiple options.

[11] https://en.wikipedia.org/wiki/Rendezvous_hashing
[12] https://en.wikipedia.org/wiki/Consistent_hashing

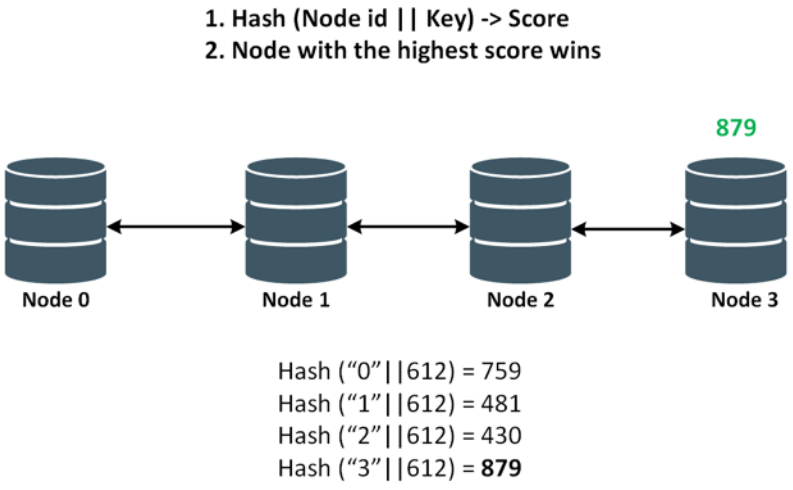


Figure 4.10

Both Consistent hashing and Rendezvous hashing algorithms can be used in a distributed database to decide the home node for any given key, and often can replace each other. However, Rendezvous hashing or HRW have some advantages over Consistent hashing (CH).

1. You do not have to pre-define any tokens for the nodes to create any circle for HRW hashing.
2. The biggest advantage of the HRW hashing is that it provides a very *even distribution* of keys across the cluster, even while nodes are being added or removed. For CH, you have to create a lot of virtual nodes (Vnodes) into each node to provide evenly distribution of keys on a small size of a cluster.
3. HRW hashing doesn't store any additional information for data distribution.
4. Usually, HRW hashing can provide different N servers for a given key K. This makes it very useful to support storing redundant data.
5. Finally, HRW hashing is simple to understand and code.

HRW hashing also has a few *disadvantages* as follows:

1. HRW hashing requires more than one hashing computation per key to maps key to a node. It can make a massive difference if you are using some sort of slow hashing function.

2. HRW hashing can be slower to run hash functions against each key node combinations instead of the just once with the CH algorithms.

Rendezvous Hashing or HRW hashing is the default algorithm in Apache Ignite for a key to node mapping since version 2.0. RendezvousAffinityFunction[13] class is the standard implementation of the Rendezvous Hashing in the Apache Ignite. This class provides affinity information for detecting which node (nodes) are responsible for the particular key in the Ignite grid.

Info

Keys are not directly mapped to the node in Ignite. A given key always maps to the partition first. Then, the partitions are maps into nodes. Also, Ignite doesn't form any circle like network topology defined in *articles or documentation.*

Mapping of a given key in Ignite is a *three steps* operation. First, any given key will get an affinity key by using *CacheAffinityKeyMapper* function. Affinity key will be used to determine a node on which this key will be cached. The second step will map the affinity key to partition using *AffinityFunction.partition(object)* method. Here, a partition is simply a number from a limited set (0 to 1024), 1024 is default. A key to partition mapping does not change over the time. The third step will map an obtained partition to nodes for the current grid topology version. Partition to node mapping is calculated by using *assignPartitions()* method, which assigns a collection of nodes to each partition.

[13] https://github.com/apache/ignite/blob/master/modules/core/src/main/java/org/apache/ignite/cache/affinity/rendezvous/RendezvousAffinityFunction.java

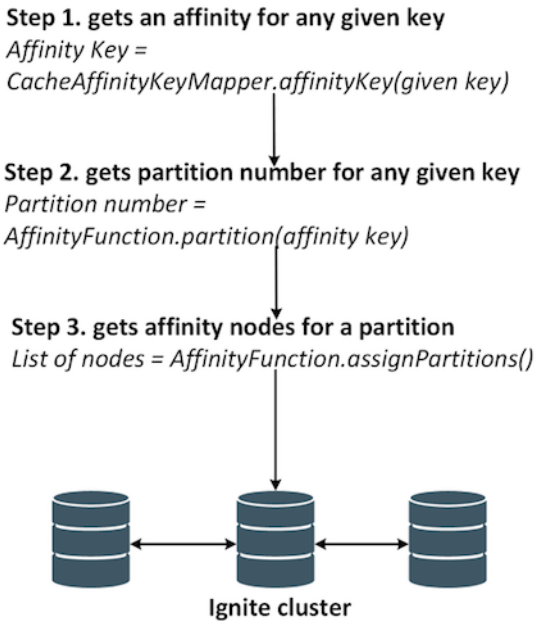


Figure 4.11

Apache Ignite affinity function (key to node mapping) is fully pluggable, and you can implement your version of Rendezvous Hashing or consistent hashing to determine an ideal mapping for the partition to nodes in the grids. You must have implemented the Java interface *AffinityFuction* and configure this function in the cache configuration as shown below:

This part is not available in the sample chapter

Durable memory architecture

The Ignite new memory architecture as well as native persistence was debuted on version 2.0 and distributed from the end of the last year. The data in memory and on disk has the same binary representation. This means that no additional conversion of the data is needed while moving from in memory to disk. Ignite new memory architecture provides off-heap data storage in a page format. Sometimes it's also called *page-based* memory architecture

that is split into pages of fixed size. The pages are allocated in managed off-heap (outside of the Java heap) region of the RAM and organized in a particular hierarchy. Let's start with the basic of the durable memory architecture: page, the smallest unit of the data with a fixed size.

Page

A page is a basic storage unit of data that contains actual data or meta-data. Each page contains a fixed length and has a unique identifier: *FullPageId.* As mentioned earlier, Pages are stored outside the Java heap and organized in RAM. Pages interact with the memory using the *PageMemory* abstraction. It usually helps to read, write a page and even allocate a page *ID*.

When the allocated memory exhausted and the data are pushed to the persistence store, it happens page by page. So, a page size is crucial for performance, it should not be too large, otherwise, the efficiency of swapping will suffer seriously. When page size is small, there could be another problem of storing massive records that do not fit on a single page. Because, to satisfy a read, Ignite have to do a lot of expensive calls to the operating system for getting small pages with 10-15 records.

When the record does not fit in a single page, it spreads across several pages, each of them stores only some fragments of the record. The downside of this approach is that Ignite has to look up the multiple pages to obtain the entire records. So, you can configure the size of the memory page in such cases.

Size of the page can be configured via *DataStorageConfiguration.setPageSize(..)* parameter. It is highly recommended to use the same page size or not less than of your storage device (SSD, Flash, etc.) and the cache page size of your operating system. Try a 4 KB as page size if it's difficult to figure out the size of the cache page size of your operating system,.

Every page contains at least two sections: header and page data. Page header includes the following information's:

1. Type: size 2 bytes, defines the class of the page implementation (ex. DataPageIO, BplusIO)
2. Version: size 2 bytes, defines the version of the page
3. CRC: size 4 bytes, defines the checksum
4. PageId: unique page identifier
5. Reserved: size 3*8 bytes

Ignite memory page structure illustrated in the following figure 4.29.

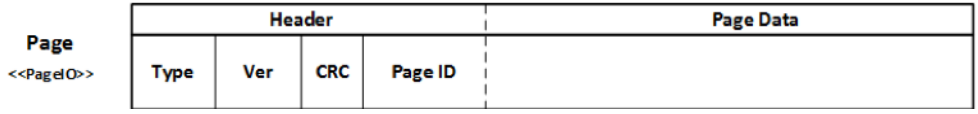


Figure 4.28

Memory pages are divided into several types, and the most important of them are Data Pages and Index Pages. All of them are inherited from the *PageIO*. We are going to details the Data Page and the Index Page in the next two subsections.

Data Page

The data pages store the data you enter into the Ignite caches. If a single record does not fit into a single data page, it will be stored into several data pages. Generally, a single data page holds multiple key-values entries to utilize the memory as efficiently as possible for avoiding memory fragmentation. Ignite looks for an optimal data page that can fit the entire key-value pair when a new key-value entry is being added to the cache. It makes sense to increase the page size if you have many large entries in your application. One thing we have to remember is that data is swapped to disk page by page and the page is either completely located in RAM or into Disk.

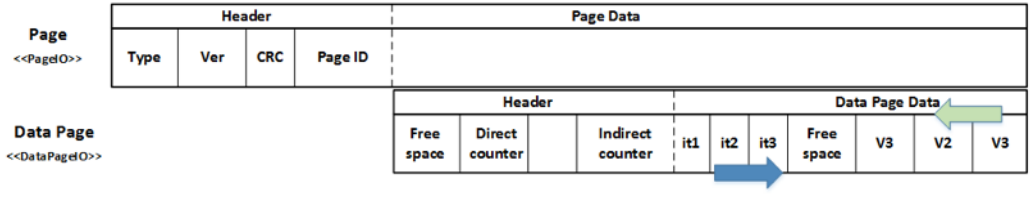


Figure 4.29

During an entry updates, if the entry size exceeds the free space available in the data page, then Ignite will look for a new data page that has enough space to store the entry and the new value will be moved there. Data page has its header information in addition to the abstract page. Data page consist of two major sections: the data page header and data page data. Data page header contains the following information's and the structure of the data page is illustrated in figure 4.29.

1. Free space, refers to the max row size, which is guaranteed to fit into this data page.
2. Direct count.

3. Indirect count.

The next portions of data after the page header is data page data and consists of items and values. Items are linked to the key-value. A link allows reading key-value pair as an N^{th} item in a page. Items are stores from the beginning to the end, and values are stores on reverse order: from the end to beginning.

Index pages and B+ trees

Index pages are stored in a structure known as a B+ tree[14], each of them can be distributed across multiple pages. All SQL and cache indexes are stored and maintained in B+ tree data structure. For every unique index declared in SQL schema, Ignite initialized and managed a dedicated B+ tree instance. Unlike data pages, index pages are always stored in memory for quick access when looking for data.

A B+ tree structure is very similar to a *B tree* with the difference that an additional level is added at the bottom with linked leaves. The purpose of the B+ tree is to link and order the index pages that are allocated and stored within the durable memory. This means that only a small number of pointers or links traversal is necessary to search for value if the number of the keys in a node is very large. Finally, the index pages of the B+ tree all contain a next sibling pointer for fast iteration through a contiguous block of value. This allows for extremely fast range queries.

Info

Key duplication is not possible in B+ tree structure.

In B+ tree binary search is used to find out the required key. To search for an element into the tree, one load up the root nodes finds the adjacent keys that the searched-for value is between. If the required value is not found, it is compared with other values in the tree.

[14] https://en.wikipedia.org/wiki/B%2B_tree

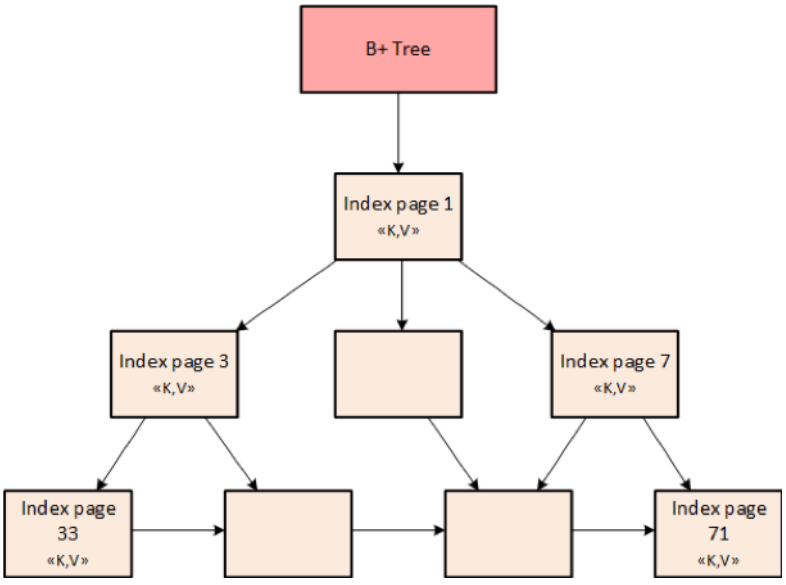


Figure 4.30

There is a high cost of allocating memory for a large number of pages including data or index pages, which solves through the next level of abstraction called *Segments*.

Segments

Segments are a contiguous block of physical memory, which are the atomic units of the allocated memory. When the allocated memory runs out, the operating system is requested for an additional segment. Further, this segment is divided into pages of fixed size. All page types include data or index pages resides in the segment.

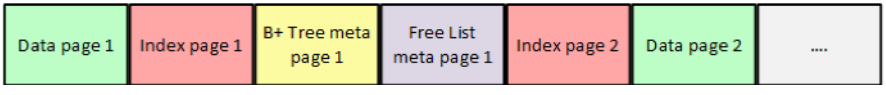


Figure 4.31

It is possible to allocate up to 16 memory segments for one dedicated memory region with the size of the segments at least 256 MB in the current version. Ignite uses a particular component for managing information about pages currently available in memory segment and page Id mapping to region address called *LoadedPagesTable*. LoadedPagesTable or *PageIdTable* manages mapping from Page ID to relative memory segment chunk (unsafe).

LoadedPagesTable uses Robin Hood Hashing[15] algorithm for maintaining HashMap of FullPageId since Ignite version 2.5.

When it comes about memory segment, it is necessary to mention the memory consumption limits. In Apache Ignite data are stored in caches. Obviously, we cannot keep the entire dataset forever in memory. Also, different data may have different storage requirements. To make it possible to set limits at the level of each cache, a hybrid approach was chosen that allows Ignite to define limits for groups of caches, which brings us to the next level of abstraction called memory *Region*.

Region

The top level of the Ignite durable memory storage architecture is the data Region, a logical expandable area. Data region can have a few memory segments and can group segments that share a single storage area with their settings, constraints and so on. Durable memory architecture can consist of *multiple data regions* that can vary in size, evictions policies and can be persisted on disk.

Tip

Ignite allocates a single data region (default data region) occupying up to 20% of the RAM available on a local cluster by default. The default data region is the data region that is used for all the caches that are not explicitly assigned to any other data region.

Data region encapsulates all the data storage configuration for operational and historical data for your utilization in Ignite and can have one or more caches or tables on a single region. With data region configuration you can manage more than one data region, which can be used for storing historical and operation data of your system. There are different cases when you might do this. The most trivial example is that when you have different non-related caches or tables with different limits.

[15] http://codecapsule.com/2013/11/17/robin-hood-hashing-backward-shift-deletion/

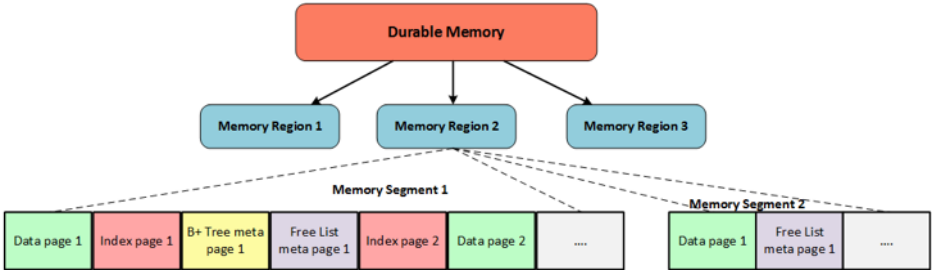


Figure 4.32

Let's assume that in our application we have Product, Purchase history entities stored in *ProductCache* and *PurchaseHistCache* caches respectively. Here, the Product data is operational and access by the application frequently. Moreover, the Purchase History data needed occasionally and not very critical to lose. In this situation, we can define two different regions of memory with different sizes: *Data_region_4GB* and *Data_region_128GB*.

- Data_region_128GB is only 128 GB of memory and will store the operational or frequently access data such as Products.
- Data_region_4GB size is 4 GB and will be allocated for rarely accessed data sets like Purchase history.

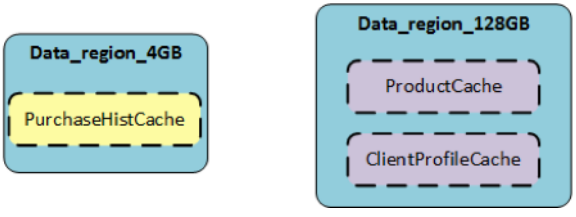


Figure 4.33

When we create caches, we should have specified the region, on which the cache will belong to. The limits here are applied on the data region level. When you put or insert something in your small cache, and if you exceed the maximum size of the data region (ex. 4 GB), you will get out of the memory (*IgniteOutOfMemory*) exception, even when the larger data region is empty. You can't use the memory that is allocated for the Data_region_128GB by the small caches, because it is assigned to the different data region.

So, you should remove or swap the stale data from the data region if you want to avoid this out of memory error. For these circumstances, Ignite provides a few data eviction algorithms to remove unnecessary data from in memory.

This part is not available in the sample chapter

Ignite read/write path

Ignite uses a B+ tree index to find out the potential data pages to fulfil a read. Ignite processes read data at several stages on the read path to discover where the data is stored, starting looking up the key in the B+ tree and finishing with data page:

1. On the client node, a cache method has been called `myCache.get(keyA)`.
2. Client node identifies the server node that is responsible for this given key `keyA` using the built-in affinity function and delegates the request to the server node over the network.
3. The server node determines the memory region that is responsible for the cache `myCache`.
4. In the corresponding memory region, a request goes to the meta page, which contains the entry points to a B+ tree by the key of this cache.
5. Based on the `keyA` hash code, the index page the key belongs to will be located in the B+ tree.
6. Ignite will return a null value if the corresponding index page is not found in the memory or on the disk.
7. If the index page exists, then it contains the reference to the data page of the entry `keyA`.
8. Ignite accesses the data page for keyA and returns the value to the client node.

The above schema for data looks up by the key can be illustrated as shown in figure 4.38.

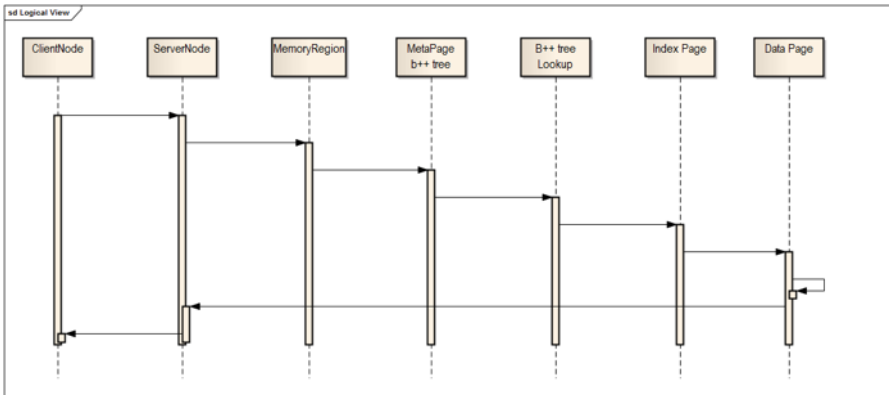


Figure 4.37

Similar to the read path, Ignite processes data at several stages on a write path. The only difference is that, when a write occurs, Ignite looks for the corresponding index page in the B+ tree. If the index page is not found, Ignite requests a new index page from one of the free lists. The same thing happens for the data page. Also, a new data page also requests from the free list.

Free List is a list of pages, structured by an amount of space remained within a page. Ignite manages free lists to solve the problem of fragmentation in pages (not full page). Free lists make the allocation and deallocation operations of the data and index pages straightforward, and allow to keep track of free memory. For instance, the image in figure 4.39 shows a free list that stores all the data pages that have up to 15% free space available. Data and index pages are tracked in separate free lists. The list is traversed, and the data/index page that is large enough to store the data is returned when a request for a data/index pages is sent.

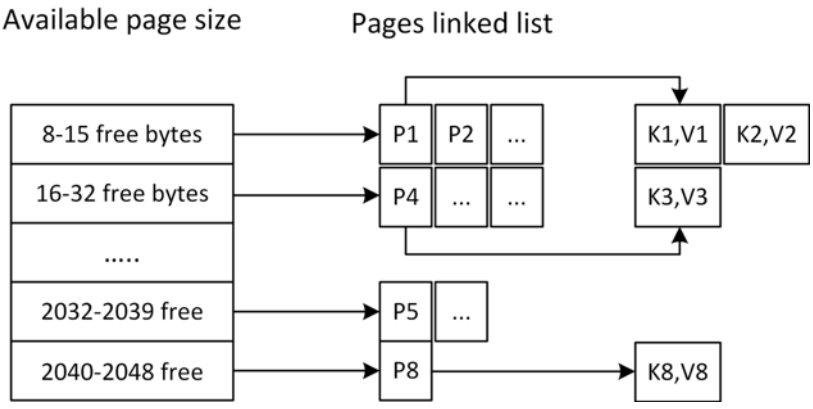


Figure 4.38

Let's see what's going under the hood when a myCache.put(keyA, valueA) request sent to the Ignite node:

1. A cache method myCache.put(keyA, valueA) has been called on the client node.
2. Client node identifies the server node that is responsible for this given key keyA using the built-in affinity function and delegates the request to the server node over the network.
3. The server node determines the memory region that is responsible for the cache myCache.
4. A request goes to the Meta page in the corresponding memory region, which contains the entry points to a B+ tree by the key of this cache.
5. Based on the keyA hash code, the index page the key belongs to will be located in the B+ tree.
6. If the corresponding index page is not found in the memory or on disk, then a new page will be requested from one of the free lists. Once the index page is provided, it will be added to the B+ tree.
7. If the index page is empty (i.e., does not refer to any data page), then the data page will be provided by one of the free lists, depending on the total cache entry size. During the selection of the data page for storing the new key-value pair, Ignite does the following:
    - Consult marshaller about size in bytes of this value pair.
    - Upper-round this value to be divisible by 8 bytes.
    - Use the value from the previous step to get page list from the free list.
    - Select some page from an appropriate list of free pages. This page will have required amount of free space.
    - A reference to the data page will be added to the index page.

8. The cache entry is added to the data page.

The Ignite write path with several stages illustrated in the following sequence diagram.

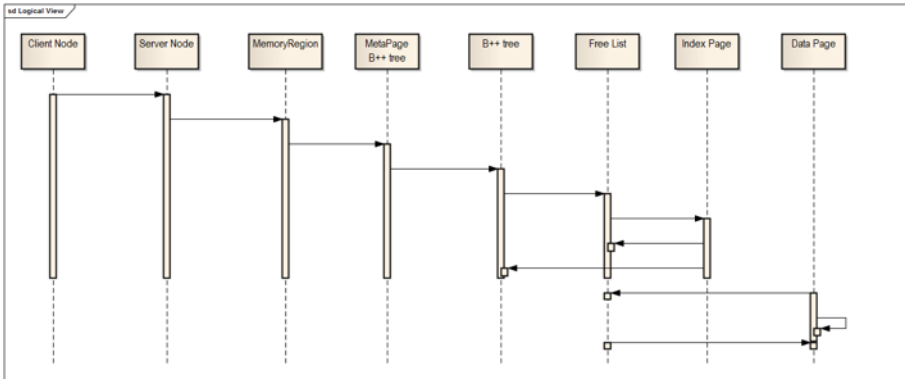


Figure 4.39

Write-Ahead-Log (WAL)

The Write-Ahead-Log or WAL is a commonly used technique in the database system for maintaining atomicity and durability of writes. The key behind the WAL is that before making any changes to database state, first, we have to log the complete set of operations to the nonvolatile storage (e.g., disk). By writing the log into WAL first, we can guarantee the data durability. If the database crash during changes to the disk, we will be able to read and replay the instructions from the WAL to recover the mutation.

Tip

WAL also known as the transaction log or redo log file. Practically every database management system has one.

From the Apache Ignite perspective, WAL is a dedicated partition file stored on each cluster node. The update is not directly written to the appropriate partition file but is appended to the end of the WAL file when data are updated in RAM. WAL provides superior performance when compared to in-place updates.

So, what exactly is a Write-Ahead-Log (WAL) file and how it works? Let's consider an application that's trying to change the value of A and B from the following four key-values:

```
(K, V) = (A, 10);
(K, V) = (B, 10);
(K, V) = (C, 20);
(K, V) = (D, 30);
```

The application is performing an addition of 10 within a single transaction as shown below.

```
A := A+ 10;
B := B + 10;
```

The problem arises when there is a system failure during writing to the disk. Assume that, after *output(A)* on disk, there is a power outage, so output(B) does not get executed, and the value of B is now in the inconsistent state. Value of A on disk is 20, and the value of B is still 10. Therefore, the database system needs a mechanism to handle such failures since they cannot be prevented from any power outage or system crash.

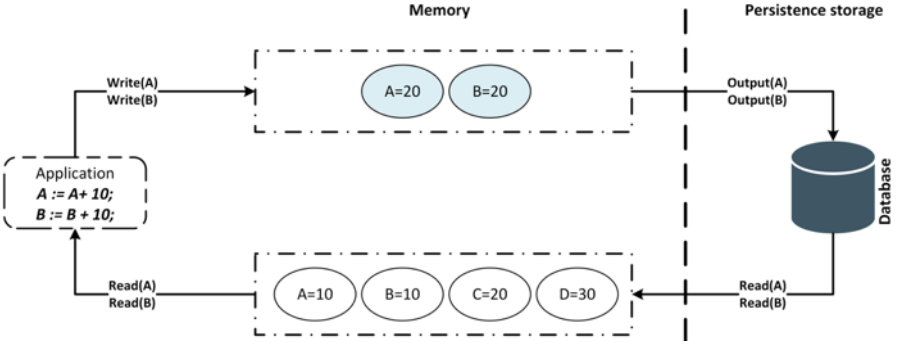


Figure 4.42

Most database system uses a log-based database recovery mechanism to solve the above problem. A *log* is the most commonly used structure for recording database modification. The DBMS has enough information available to recreate the original data changes after a crash after the log file has been flushed to disk.

The first log approach is the **UNDO log**. The purpose of the undo log is to reverse or undo the changes of an incomplete transaction. In our example, during recovery, we have to put the database in the state it was before this transaction, means that changes to A are undone, so A is once again 10 and A=B=10. The undo log file always written to the nonvolatile storage.

Undo logging rules:

1. Record a log in undo log file for every transaction T. Write (start T).

2. For every action, generate an undo log record with the old value. Write (T, X, VOLD).
3. Flush the log to disk.
4. Write all the database changes to disk if transaction T commits.
5. Then write (commit T) to the log on disk as soon as possible.

An undo log looks very similar as shown in the figure 4.43.

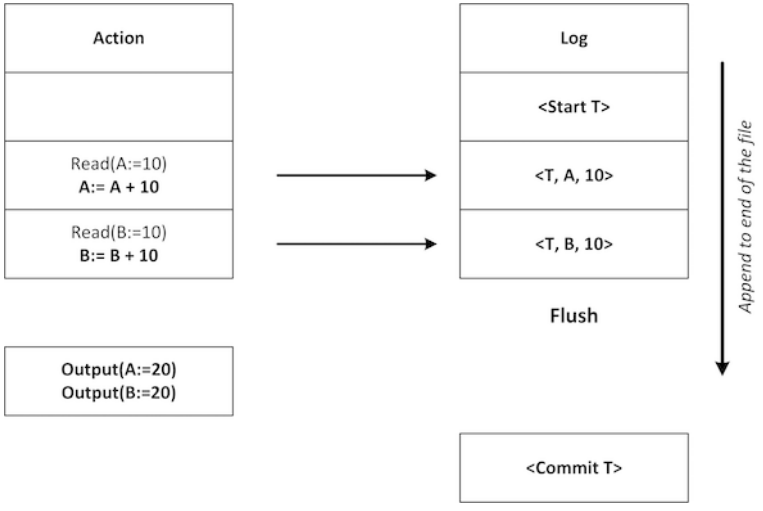


Figure 4.43

We log a record indicates that we have started the transaction before starting the transaction. When we update the value A, we also write a log indicates its old value 10. Similarly, we record its old value of 10 when we change the value of B from 10 to 20. We flush the undo log to disk before outputting values of A and B to disk. Then we output(A) and output(B) to disk, only after that, we can record (commit T) into undo log file.

Undo logging recovery rules:

1. We only undo the failed transaction. If there's already (commit T) or (abort T) record, do nothing.
2. For all (T, X, VOLD):
   - output(VOLD)
3. write (abort T) to undo log.

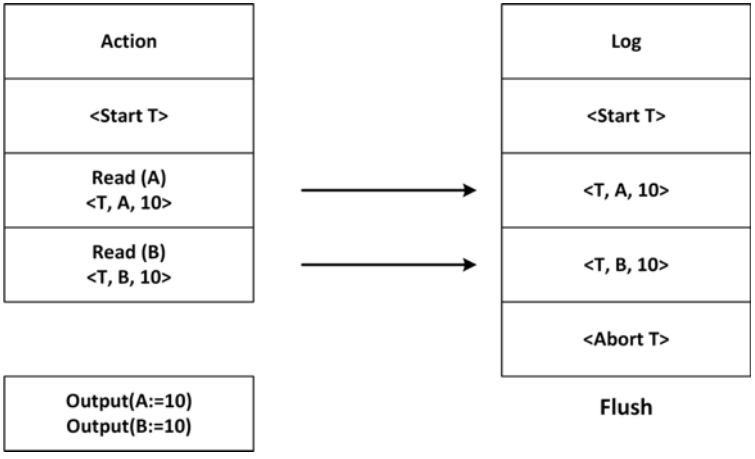


Figure 4.44

We read the undo log from the end to start, and looking for an incomplete transaction during the recovery process. Any records with (commit T) or (abort T) are ignored because we know that (commit T) or (abort T) can only be recorded after a successful output to disk. We cannot be sure that output was successful if there are no (commit T) record, so for every record, we use the old value VOLD to revert the changes. So, (T, B, 10) sets B back to 10 and so on. Undo log records (abort T) to indicate that we aborted the transaction after making the changes.

The main disadvantage of the undo log is that it might be slower for heavy write-intensive application because for every transaction, we have to output the value to the disk before records a (commit T) log in the undo log file.

At this moment, we can get back to our starting point about WAL. The second log approach for protecting data-loss is the write-ahead log or WAL. Instead of undoing a change, WAL tries to reproduce a change. During the transaction, we write all the changes to WAL that we are indented to do, so we can rerun transaction in case of disaster and reapplying the changes if necessary. Before making any output (write to the disk), we must record the (commit T) record.

WAL logging rules:

1. Record a log into undo file for every transaction T. Write (start T) to the log.
2. Set its value to *New* if transaction modifies database record X. Write (T, X, V^{new}) to the log.
3. Write (Commit T) to the log if transaction T commits.
4. Flush the log file to the disk.

5. And then, write the new value V^{new} for X to disk.

A WAL log file looks something like shown in figure 4.45.

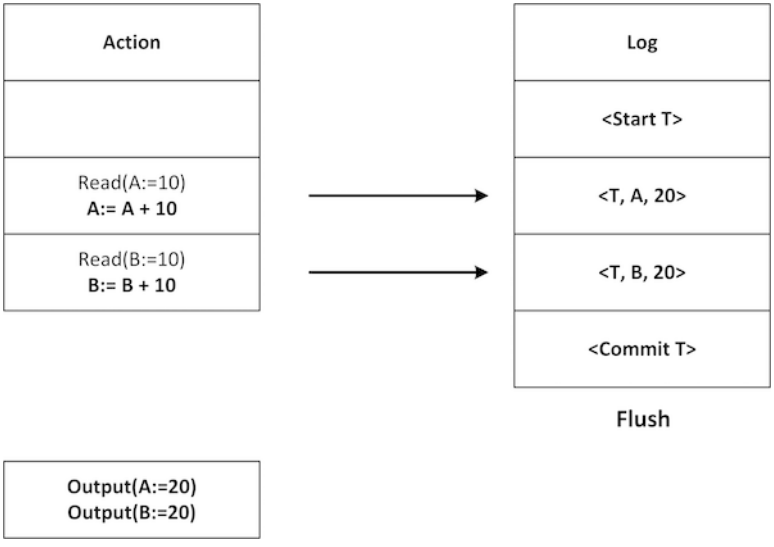


Figure 4.45

We record the new values for A and B then commit and flush the log to disk. Only after that, we output the values of A and B to the disk. This solves two main issues with disk I/O: buffering and randomly output to disk.

WAL logging recovery rules:

1. Do nothing if there's any incomplete transaction (no commit T) record.
2. If there is (commit T), for all (T, X, V^{new}):
    - output(V^{new})

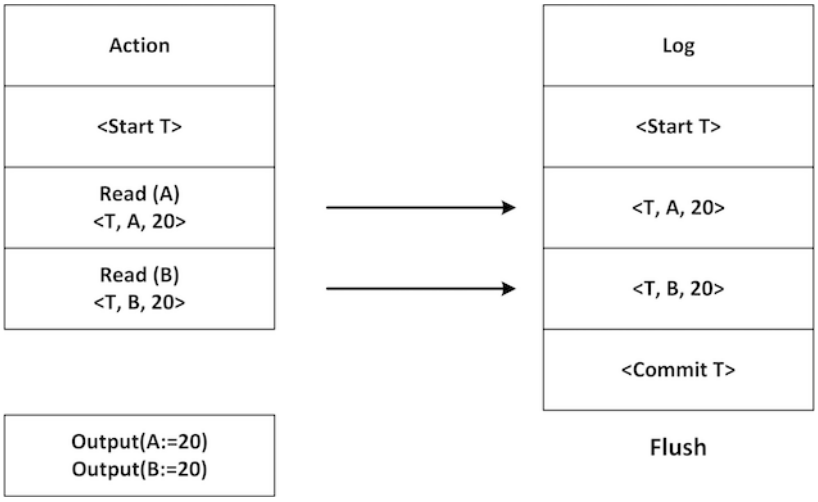


Figure 4.46

To recover with a WAL log file, we start from the beginning of the file scanning forwards (opposite of the undo log file). If we find any incomplete transaction (no commit T), we skip the transaction so that no output was done. We do not know whether the output was successful or not whenever we find any (commit T) record. In this case, we redo the changes, and even it is redundant. In our example, the value of A will be set to 20, and the value of B will also be set to 20.

Now that we have got the basics of the log structure, so let's move on to Ignite's WAL concept to see how the things organized under the cover. From the Ignite perspective, whenever the storage engine wants to make any changes to the data page, it writes the change to the RAM and then appends the changes to the WAL. Storage engine sends an acknowledgment to confirm the operation only after durably written the changes to WAL file on disk.

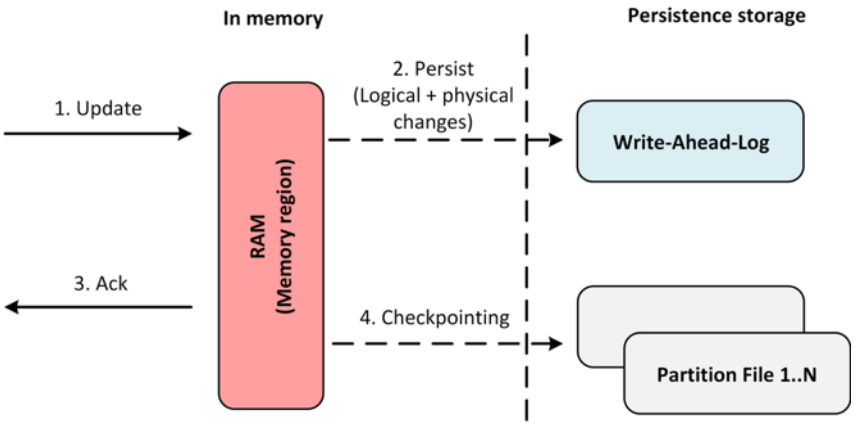


Figure 4.47

This makes the database changes reliably. If the node crashes while data was being appended to the WAL, no problem because dirty data pages have not been copied from RAM to disk. So, storage engine can read and reply WAL using already saved page set if it crashes while the data pages are being modified. The storage engine can restore to state, which was last committed state of the crashed process. In Ignite, restore is based on page store and WAL log. You may notice that Ignite native persistence is slightly different than the classical WAL log concept.

Tip

Data changes are acknowledged only after the cache operations and page changes were logged into the WAL. Dirty data pages will be copied later by another process.

This part is not available in the sample chapter

Baseline topology

Ignite *Baseline Topology* or BLT represents a set of server nodes in the cluster that persists data on disk.

$$\text{Baseline topology} = \{N1, N2, N5\} \subseteq \{N1, N2, N3, N4, N5, N6\}$$

Where,

- N1-2 and N5 server nodes are the member of the Ignite cluster with native persistence enable that persists data on disk.
- N3-4, N6 server nodes are the member of the Ignite cluster but not a part of the baseline topology.

The nodes from the baseline topology are a regular server node, that store's data in memory and on the disk, and also participate in computing tasks. Ignite cluster can have different nodes that are not a part of the baseline topology such as:

- Server nodes that are not used Ignite native persistence to persist data on disk. Usually, they store data in memory or persists data to a 3rd party database or NoSQL. In the above equitation, node N3 or N4 might be one of them.
- Client nodes that are not stored shared data.

Let's start at the beginning and try to understand its goal and which problem it's solved to clear the baseline topology concept.

The database like Ignite is designed to support massive data storage and processing. Ignite database are highly scalable and fault-tolerant. This high scalability feature of the Ignite brings a few challenges for the database administrator, such as:

- how to manage a cluster?
- How to add/remove nodes correctly? or
- how to rebalance data after add/remove nodes?

Ignite cluster with a multitude of nodes can significantly increase the complexity of the data infrastructure. Let's look at it by the example of Apache Ignite. Ignite in-memory *mode* cluster concept is very simple. There are no master or dedicated node in the cluster, and every node is equal. Each node stores a subset of data and can be participated in distributed computing or deploy any services. In case of any node failures, client requests served by the other nodes, and the data of the failed nodes will be no longer available. In this mode, Ignite cluster management operations are very similar as follows:

1. To run a cluster, start all nodes.
2. To expand the cluster topology, add some nodes.
3. To reduce the cluster topology, remove some nodes.

Data redistributes between nodes automatically. Data partitions moves from one node to another depending on the backup copy configuration of the caches.

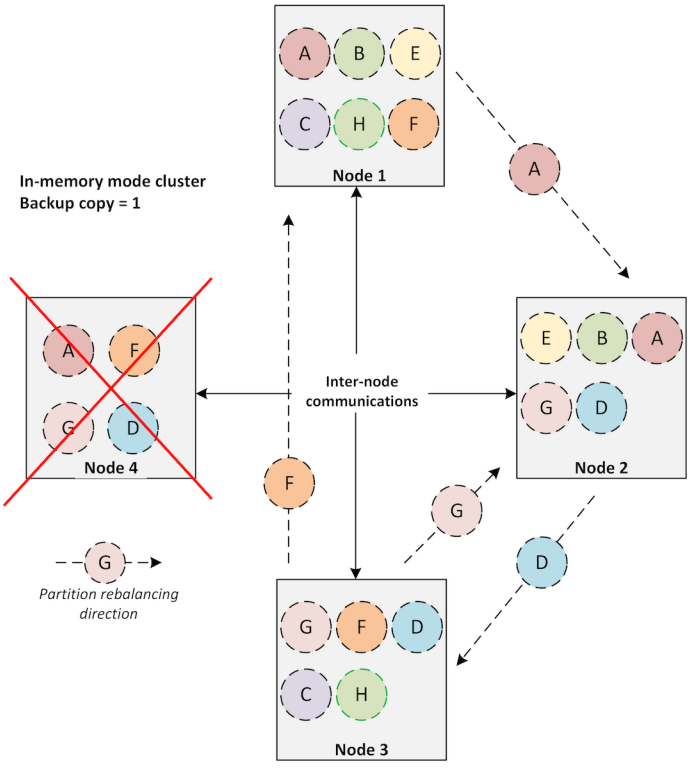


Figure 4.53

In the persistence mode, the node keeps their state even after the restart. Data is read from the disk and restores the node state during any read operation. Therefore, restart of a node in persistence mode does not need to redistributed data from one node to another unlike in-memory mode. The data during node failure will be restored from the disk. This strategy opens up the opportunities to not only preventing of moving a massive amount of data during node failure but also reduce the startup times of the entire cluster after a restart. So, we need to distinguish somehow these nodes that can save their state after restart. In other words, the Ignite baseline topology provides this capability.

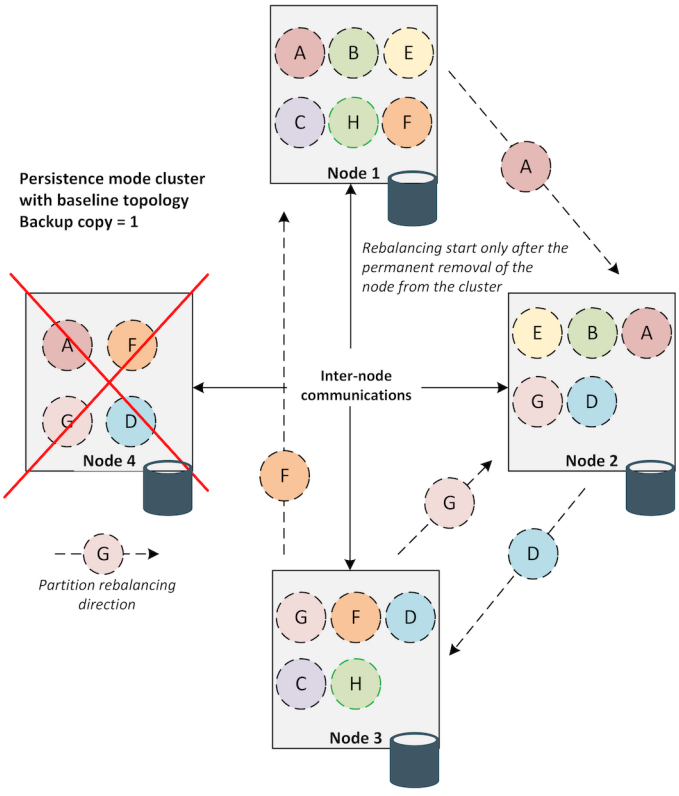


Figure 4.54

In a nutshell, Ignite baseline topology is a collection of nodes that have been configured for storing persistence data on disk. Baseline topology tracks the history of the topology changes and prevents data discrepancies in the cluster during recovery. Let's resume the goals of the baseline topology:

1. Avoid redundant data rebalancing if a node is being rebooted.
2. Automatically activate a cluster once all the nodes of the baseline topology have joined after a cluster restart.
3. Prevent the data inconsistencies in the case of split-brain.

Please note that, you can use persistence caches with the in-memory caches at the same time. In-memory caches will live same as before: consider all nodes are equals and begin redistribution of the partitions whenever a node goes down. Baseline topology will take action only on the persistence caches. Hence, Ignite baseline topology has the following characteristics:

1. Baseline topology defines a list of nodes which intended for storing data, and does not affect other functionalities such as data grid, compute grid etc. If a new node joined to the cluster where baseline topology is already defined, the data partitions is not started moving to the new node until the node is added to the baseline topology manually.
2. On each node, persistence Meta-data repository is used to store the history of the baseline topology.
3. For a newly created cluster (or cluster without baseline topology), a baseline topology is created for the first time during the first activation of the cluster. The administrator must explicitly do all the future changes (add/remove nodes) of the baseline topology.
4. If baseline topology is defined for a cluster, after restarting the cluster, the cluster will be activated automatically whenever all the nodes from the baseline topology are connected.

Now, let's details how Ignite storage engine achieves the abovementioned goals.

Automatic cluster activation

A cluster can make on its own decision to activate the cluster in the persistence mode with baseline topology. After the first activation of the cluster, the first baseline topology is created and saved on the disk, which contains information about all nodes present in the cluster at the time of activation. Each node checks the status of the other nodes within the baseline topology after the cluster is rebooted. The cluster is activated automatically once all the nodes are online. This time the database administrator needs no manual intervention to activate the cluster.

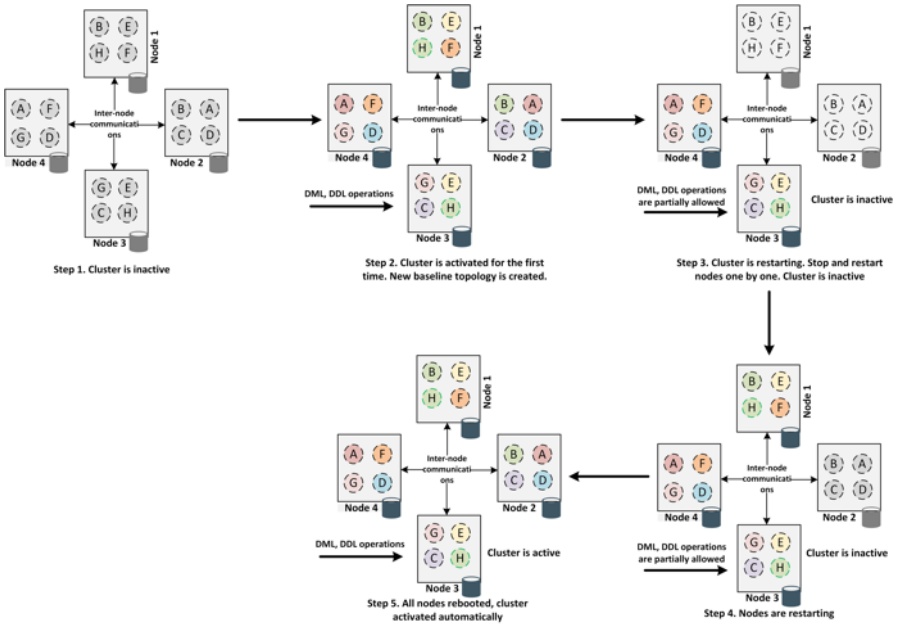


Figure 4.55

Let's go through the details of the automatic cluster activation when **Ignite persistence** is enabled:

- Step 1. All nodes started. The cluster is inactive state and can't handle any DDL/DML operations (SQL, Key-value API).
- Step 2. The cluster is activated by the database administrator manually. First baseline topology is created, added all the currently running server nodes to the baseline topology.
- Step 3. Database administrator decided to restart the entire cluster to perform any software or hardware upgrade. Administrator stopped or restarted each node one by one.
- Step 4. Nodes are started back one by one and joined to the cluster.
- Step 5. Once all the nodes are baseline topology booted, the cluster gets activated automatically.

Although, Apache Ignite is a horizontally scalable database and nodes can be added and removed from the cluster dynamically, baseline topology proceeds from the concept that in persistence mode the user maintains a stable cluster in production.

Split-brain protection

Split-brain[16] is one of the common problems of distributed systems, in which a cluster of nodes gets divided into smaller clusters of equal or nonequal numbers of nodes, each of which believes it is only the active cluster. Commonly, the split-brain situation is created during network interruption or cluster reformation. The cluster reforms itself with the available nodes when one or more node fails in a cluster. Sometimes instead of forming a single cluster, multiple mini clusters with an equal or nonequal of nodes may be formed during this reformation. Moreover, these mini cluster starts handling request from the application, which makes the data inconsistency or corrupted. How it may happen is illustrated in figure 4.56. Here's how it works in more details.

- Step 1. All nodes started. The cluster is inactive state and can't handle any DDL/DML operations (SQL, Key-value API).
- Step 2. The cluster is activated by the database administrator manually. First baseline topology is created, added all the currently running server nodes to the baseline topology.
- Step 3. Now let's say, a network interruption has occurred. Database administrator manually split the entire cluster into two different clusters: cluster A and cluster B. Activated the cluster A with a new baseline topology.
- Step 4. Database administrator activated the cluster B with a new baseline topology.
- Step 5-6. Cluster A and B are started getting updates from the application.
- Step 7. After a while, the administrator resolved the network problem and decided to merge the two different cluster into a single cluster. In this time baseline topology of the cluster A will reject the merge, and an exception will occur as follows:

[16] https://en.wikipedia.org/wiki/Split-brain_(computing)

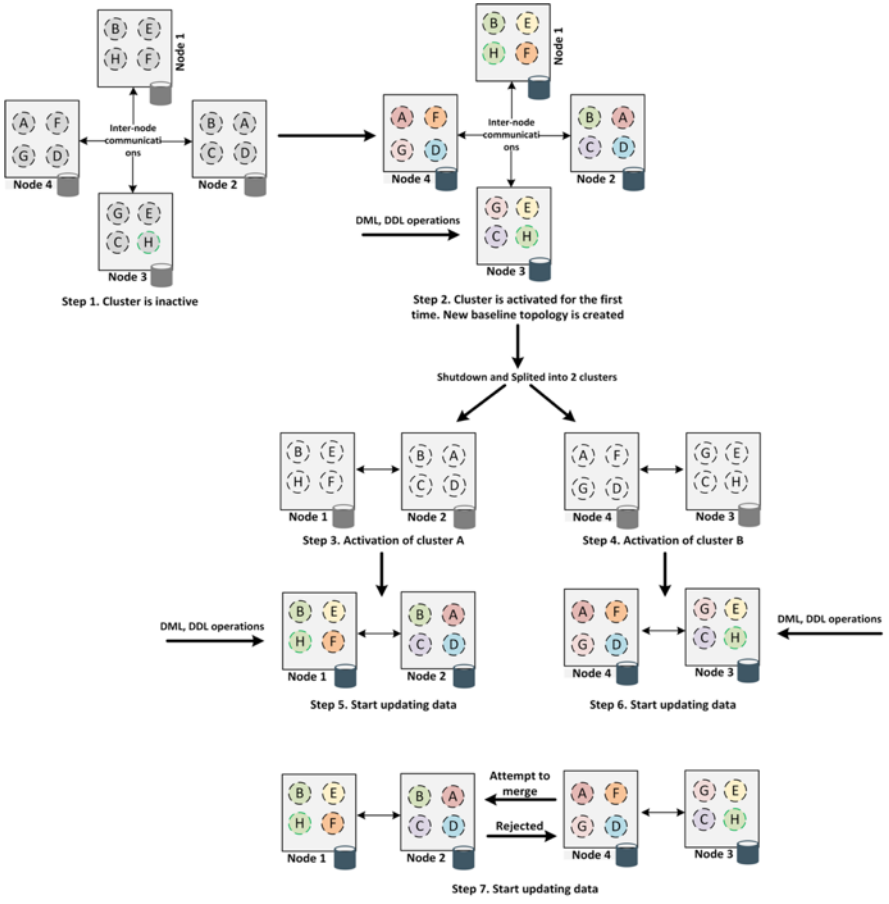


Figure 4.56

Listing 4.15

```
class org.apache.ignite.spi.IgniteSpiException: BaselineTopology of joining node (4,3) is\
 not compatible with BaselineTopology in the cluster. Branching history of cluster BlT ([\
11, 9]) doesn't contain branching point hash of joining node BlT (3). Consider cleaning p\
ersistent storage of the node and adding it to the cluster again.
```

The nodes of the cluster B will store their data during node startup when Ignite works in persistence mode. The data of the cluster B will be available as we started the cluster B again. So, different nodes may have different values for the same key after the cluster is restored to its primary state. Protection from this situation is one the task of baseline topology.

As stated earlier, a new baseline topology is created and saved on the disk, which contains information about all the nodes presents in the cluster at the moment of activation when we activate the cluster first time. This information also includes a hash value based on the identifiers of the online nodes. If some nodes are missing in the topology during subsequent activation (for instance, the cluster was rebooted, and one node was removed permanently for disk outage), the hash value is recalculated for each node, and the previous value is stored in the activation history within the same baseline topology. Such a way, baseline topology supports a chain of hashes describing the cluster structure at the time of each activation.

In steps 3 and 4, the administrator manually activated the two incomplete cluster, and each baseline topology recalculated and updated the hash locally with a new hash. All nodes of each cluster will be able to calculate the same hashes, but they will be different in various groups. Cluster A determined that nodes of the cluster B is activated independently of the node of the cluster A, and access was denied when the administrator tried to merge the two cluster into one. The logic is as follows:

Listing 4.16

```
if (!olderBaselineHistory.contains(newerBaselineHash))
    <join is rejected>
```

Warning

Please note that this validation does not provide full protection against split-brain conflicts. However, it protects against conflicts in case of administrative errors.

Fast rebalancing and it's pitfalls

As described above, the rebalancing event occurs, and data starts moving between the nodes within the baseline topology whenever a new node joins or removes from the baseline topology explicitly by the database administrator. Generally, rebalancing is a time-consuming process, and the process can take quite a while depending on the amount of the data. In this section, we are going into details on the rebalancing process and its pitfalls.

This part is not available in the sample chapter

Chapter 5. Intelligent caching

A cache is a high-speed data storage layer in front of the primary storage location which stores a subset of data so that future requests for that data served up as fast as possible in computer terminology. Primary storage could be any database or a file system that usually stores data on *non-volatile* storage. Caching allows you to reuse previously retrieved or computed data efficiently, and it is one of the secrets of high-scalability and performance of any enterprise level application.

You may wonder why we named the chapter intelligent caching! Because, from the last decades, the unbounded changes of the software architecture need not only correctly used of a caching strategy but also properly configured (cache eviction, expiration) and sizing the cache layer to achieve the maximum performance and high-scalability of an application. Caching can be used for speeding up requests on five main different layers or environments of your application architecture:

1. Client
2. Network
3. Web server
4. Application
5. Database

So, you should consider caching strategies for each layer of your application architecture to accomplish the high-performance of an application, and implements it's correctly. It should be noted that none of the caching platforms or framework are a silver bullet. Cache usages vary for different data sizes and scenarios. Firstly, you should measure the data sizes and requests on each layer, doing various tests to find out the bottleneck and then with the way of experiments you have to define a tool or framework for caching data before implementing any caching platform such as Ignite, Ehcache, Redis or Hazelcast on any application layer.

In this chapter, we want to focus primarily on things you need to know about data caching and demonstrate the use of Apache Ignite for accelerating application performance without changing any business logic code. So, we are going to cover the following topics throughout the entire chapter:

1. Different caching strategies and usage methods as a smart in-memory caching.

2. Read/Write through and write behind strategies examples based on Hibernate and MyBatis for database caching.
3. Memoization or application level caching.
4. Web session clustering.
5. Moreover, a list of recommendations to correctly prepare the caching layer.

Smart caching

I often hear suggestion like this when it comes to a matter of performance: *Need for speed - Caching*. However, I believe that in-memory caching is *the last lines of defense* when all current optimization tricks reach a bottleneck. We have a lot of points for optimizing before considering a separate layer for caching data, such as:

- Optimizing SQL queries; runs a few SQL queries plans to define the bottleneck on the database level.
- Adding *necessary* indexes on tables.
- Optimizing and configuring connection pools on Application servers.
- Optimizing application code, such as fetching data by paging.
- Caching static data such as Java script, Images and CSS files on the Web server and the client side.

Consider the regular N-Tier JEE architecture for optimizing and caching data as shown in figure 5.1.

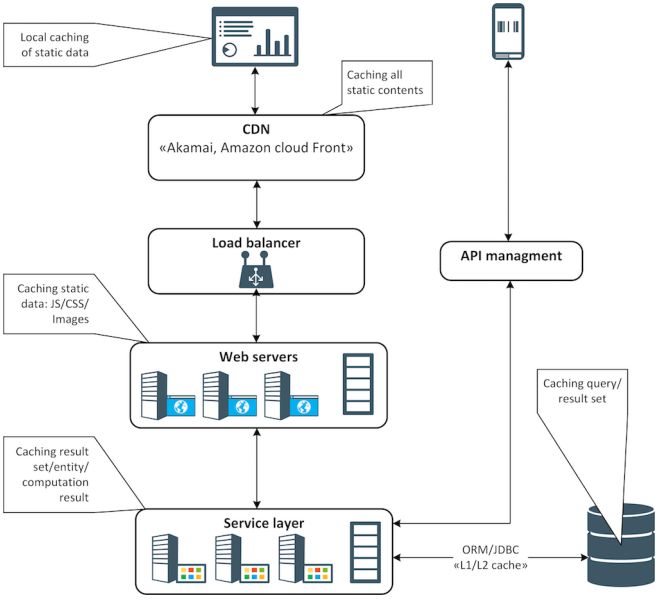


Figure 5.1

Caches can be applied and leveraged throughout the various layers of technology including browsers, network layers (Content delivery network and DNS), web applications and databases as shown in figure 5.1. Cached information can include the result of database queries, computationally intensive calculation, API request/responses, and web artifacts such as HTML, JavaScript, and multi-media files. Therefore, for getting a high throughput of an entire application, you should consider optimization and caches on other layers, and not only the use of in-memory caching layer. These will give you the maximum benefits of caching data and improves the overall performance of the application.

Caching best practices

It's essential to consider a few best practices for using cache *smartly* when implementing a cache on any application layer. A smart caching ensure that you implement all (or most of them) the best practices whenever designing a cache. This subsection describes a few considerations for using a cache

1. **Decide when and which data to cache**. Caching can improve performance; the more data you can cache, the higher the chance to reduce the latency and contention that's associated with handling large volumes of concurrent requests in the original data store. However, server resources are finite, and unfortunately, you could not cache all the resources you want. Consider caching data that are read frequently but modified rarely.
2. **The resilience of the caching layer**. Your application can continue to operate by using the primary data storage if the cache is unavailable, and you won't lose any critical piece of information.
3. **Determine how to cache data effectively**. Most often, caching is less useful for dynamic data. The key to using a cache successfully lies in determining the most appropriate data to cache and caching it in the proper time. The data can be added to the cache on demand the first time it is fetched from the store by the application. Subsequent access to this data can be satisfied by using this cache. On the other hand, you can upload the data into the cache during the application startup, and sometimes it's called cache warm up.
4. **Managing data expiration in caches**. You can maintain a cache entry up-to-date by expiring a cache entry into the cache. When a cached data expires, it's removed from the cache, and a new cache entry will be added into the cache at the next time when it will be fetched from the primary data. You can set a default expiration policy when you configure the cache. However, consider the expiration period for the cache carefully. Cache entry expires too quickly if you make it too short, and you will reduce the

benefits of using the cache. On the other hand, you risk the data becoming stale if you make the period too long. Additionally, you should also consider to configure the cache eviction policy which will help you to evict cache entries from the cache whenever the cache is full and no more places exists to add a new entry.

5. **Update the caches when data changes on the primary data store**. Generally, a middle-tier caching layer duplicates some data from the central database server. Its goal is to avoid redundant queries to the database. The cache entry has to be updated or invalidated when the data updates in the database. You should consider the possibility to maintain a cache entry as up-to-date as possible when designing a caching layer. Many database vendors allow getting a notification whenever any entity updates into the database and updates the caches.
6. **Invalidate data in a client-side cache**. Data that is stored in a client-side cache (browser or any standalone application) is generally considered to be auspices of the service that provides the data to the client. A service cannot directly force a client to add or remove information from a client-side cache. This means that it's possible for a client that poorly configured the cache to continue using the staled information. However, a service that provides cache needs to ensure that each server response provides the correct HTTP header directives to instruct the browser on when and for how long the browser can cache the response.

Design patterns

There might be two different strategies in a distributed computing environment when caching data:

- *Local or private cache.* The data is stored locally on the server that's running an instance of an application or service. Application performance is very high in this strategy, because, most often the cached data stored in the same JVM along with application logic. However, when the cache is resident on the same node as the application utilizing it, scaling may affect the integrity of the cache. Additionally, when local caches are used, they only benefit the local application that consuming the data.
- *Shared or distributed cache.* The cache served as the common caching layer that can be accessed from any application instances and architecture topology. cached data can span multiple cache servers in this strategy, and be stored in a central location for the benefit of all the consumers of the data. This is especially relevant in a system where application nodes can be dynamically scaled in and out.

Tip

With the Apache Ignite you can implement either or both of the above strategies when caching data.

Basic terms

There are a few basic terms related to caching, frequently used throughout this book. I strongly believe that you are already familiar with these terms. However, it will be useful for those who are not familiar with these terms and getting all the information in a single place.

Terms	Description
Cache entry	A single cache value, consists of a key and its mapped data value within the cache.
Cache Hit	When a data entry is requested from the cache, and the entry exists for the given key. A more cache hit means that most of the requests are satisfied by the cache.
Cache Miss	When a data entry is requested from the cache, and the entry does not exists for the given key.
Hot data	Data that has recently been used by an application is very likely to be reassessed soon. Such data is considered hot. A cache may attempt to keep the hottest data most quickly available while trying to choose the least hot data for eviction.
Cache eviction	The removal of entries from the cache in order to make room for newer entries, typically when the cache has run out of data storage capacity.
Cache expiration	The removal of entries from the cache after some amount of time has passed, typically as a strategy to avoid stale data in the cache.

Database caching

There are many challenges that disk-based databases (especially RDBMS) can pose to your application when developing a distributed system that requires low latency and horizontal scaling. A few common challenges are as follows:

1. *Expensive query processing*. Database queries can be slow and require serious system resources because the database system needs to perform some computation to fulfill the query request.

2. *Database hotspots.* It's likely that a small subset of data such as a celebrity profile or popular product (before Christmas) will be accessed more frequently than others in many applications. The SQL queries on such favorite products can result in hot spots in your database and maybe overprovisioning of database resources (CPU, RAM) based on the throughput requirements for the most frequently used data.
3. *The cost to scale.* Most often, RDBMS are only scaling vertically (anyway, Oracle 18c[17] and Postgres-XL[18] can scaling horizontally but needs tremendous effort to configure). Scaling databases for extremely high reads can be costly and may require many databases read replicas to match the current business needs.

Most database servers are configured by default for optimal performance. However, each database vendors provides various optimizations tips and tricks to help engineers get the most out of their databases. These guidelines for database optimization observe a law similar to the funnel law that is illustrated in figure 5.2 and described below:

1. Reducing data access.
2. Returning less data.
3. Reducing interaction with the underlayer.
4. Reducing CPU overhead and using more machine resources.

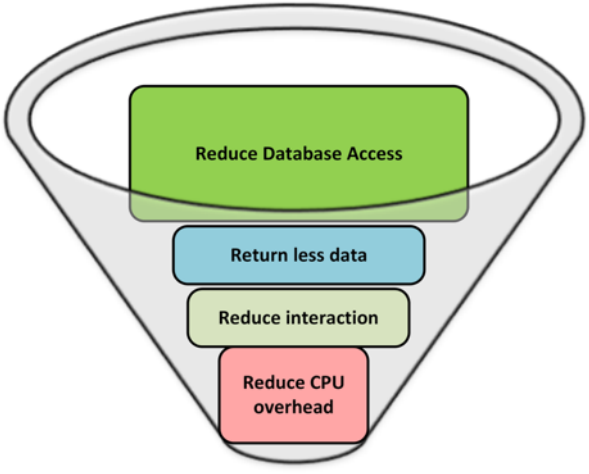


Figure 5.2

[17] https://www.oracle.com/technetwork/database/database-technologies/sharding/overview/index.html
[18] https://www.postgres-xl.org

Architects and engineers should make a great effort in squeezing as much performance as they can out of their database as mentioned earlier, because database caching should be implemented when all existing optimization tools reach a database bottleneck. A database cache supplements your primary database by removing unnecessary pressure on it (very close to the *reduce data access* layer), typically in the form of frequently accessed read data. The cache itself can live in some areas including your database, application or as a standalone layer.

The basic paradigm when querying data from a relational database from an application includes executing SQL statement through ORM tools or JDBC API and iterating over the returned *ResultSet* object cursor to retrieve the database rows. There are a few techniques you can apply based on your data access tools and patterns when wanting to cache the returned data.

We are going to discuss how Ignite in-memory cache can be used as a 2nd level caches in different data access tools such as *Hibernate* and *Mybatis* in this section, which can significantly reduce the data access times of your application and improve overall application performance.

A 2nd level cache is a local or distributed data store of entity data managed by the persistence provider to improve application performance.

A second level cache can improve application performance by avoiding expensive database calls, keeping the data bounded (locally available) to the application. A 2nd level cache is fully managed by the persistence provider and typically transparent to the application. That is, application reads, writes and commits data through the entity manager without knowing about the cache.

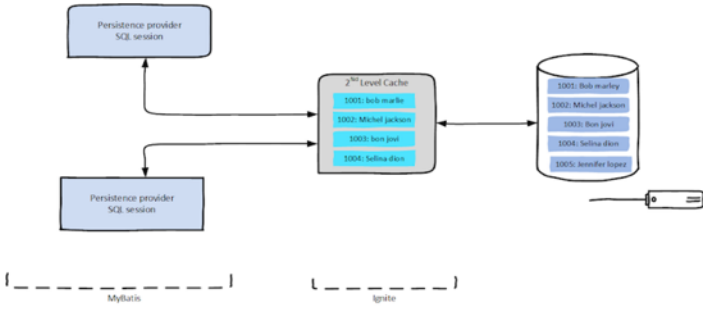


Figure 5.3

There is also a **Level 1** cache based on the persistence provider, such as MyBatis or Hibernate. Level 1 is used to cache objects retrieved from the database within the current database

session. An HTTP session is opened and reused until the service method returns when client-side (web page or web service) invokes a service. All operations performed until the service method return will share the L1 cache, so the same object will not retrieve twice from the database. Objects retrieved from the database will not be available after closing the database session.

Tip

In most persistence providers, *level 1* cache is always enabled *by default.*

So, in a nutshell, the 2nd level cache provides the following benefits:

1. Boost performance by avoiding expensive database calls.
2. Data are kept transparent to the application.
3. CRUD operation can be performed through standard persistence manager functions.
4. You can accelerate applications performance by using 2nd level cache, without changing the code.

This part is not available in the sample chapter

Chapter 6. Database

Starting from version 2.0, Apache Ignite redesigned the storage engine and introduced a new memory-centric architecture that can be used as an In-memory database or a fully functional distributed database with disk durability and strong consistency. Ignite memory-centric storage helps to store data and indexes both in-memory and on-disk in the same data structure. It enables executing SQL queries over data stored in-memory and on-disk and delivers optimal performance while minimizing infrastructure costs.

Apache Ignite data persistence on-disk mechanism is called *Native persistence* and is an *optional choice*. When native persistence is turned on, Ignite can store more data than can fit in the available memory, and act like a complete distributed SQL database. On the other hand, when the whole data set and indexes fit in memory, and the native persistence is disabled, Ignite function as an in-memory database supporting SQL, together with all the existing APIs for memory-only use cases.

Moreover, Apache Ignite supports Spring Data[19] that allows abstracting an underlying data storage from the application layer since 2.0 version. Spring Data also allows using out-of-the-box CRUD operations for accessing the database instead of writing boilerplate code. Additionally, you can use Hibernate OGM[20] that provides JPA (Java Persistence API) supports for Ignite database.

This part is not available in the sample chapter

How SQL queries works in Ignite

In this chapter so far, we have discussed a lot about Ignite SQL capabilities. Perhaps it is the exact time to dive deep into the Ignite distributed SQL engine to explorer how it runs SQL queries under the hood. Most often Ignite executes SQL queries in two or more steps:

[19] https://spring.io/projects/spring-data
[20] http://hibernate.org/ogm/

- Ignite distributed SQL engine parse and analyze the DDL/DML statements, creates appropriate caches from a non-ANSI part of the SQL queries and delegates the ANSI part to the H2 database engine.
- H2 executes a query locally on each node and passes a local result to the distributed Ignite SQL engine for aggregating the result or further processing.

Consequently, Apache Ignite SQL engine is firmly coupled with H2[21] database and uses particular version of the database (for instance, Ignite version 2.6 uses H2 1.4.195 version). Each Ignite node runs one instance of the H2 database in the embedded mode. In this mode, the H2 database instance runs within the same Ignite process as a in-memory database.

Info

H2 SQL engine always executes SQL queries on local Ignite node.

We have already introduced you to the H2 database in *chapter 2*. However, in this section, we are going to answer the following questions:

1. How tables and indexes organize in H2 database?
2. How H2 database uses indexes?
3. How to use SQL statements execution plans for optimizing queries?
4. How SQL queries work for the PARTITIONED and REPLICATED caches?
5. How concurrent modification works?

For simplicity, we use our well-known dataset: *Employee* and *Department* tables. We also use the Ignite *SQLLINE* command line tool and H2 Web console to run SQL queries.

H2 database supplies a web console server to access the local database using a web browser. As we described earlier, the H2 console server provides you to run SQL queries against the embedded node and check how the tables and indexes look like internally. Moreover, with the H2 web console, you can analyze how a query is executed by the database, e.g., whether indexes are used or if the database has done an expensive full scan. This feature is crucial for optimizing the query performance. To do that, you have to start the Ignite local node with IGNITE_H2_DEBUG_CONSOLE system property or an environment variable set to true as shown below:

[21] http://www.h2database.com/html/main.html

Listing 6.38

```
export IGNITE_H2_DEBUG_CONSOLE=true
```

Info

Ignite SQLLINE also supports *SQL execution plan* (EXPLAIN), but through H2 web console you can execute EXPLAIN plan in a *particular* node which is very useful to investigating query performance for specific Ignite node.

Now, start the Ignite node from any terminal.

Listing 6.39

```
$IGNITE_HOME/bin/ignite.sh
```

A web console will be opened in your browser as shown in the next figure. As mentioned earlier, whenever we create any table (through SQLLINE or Ignite SQL JAVA API) in Ignite, a meta-data information of the tables created and displayed in the H2 database. However, the data, as well as the indexes, are always stored in the Ignite caches that execute queries through the h2 database engine.

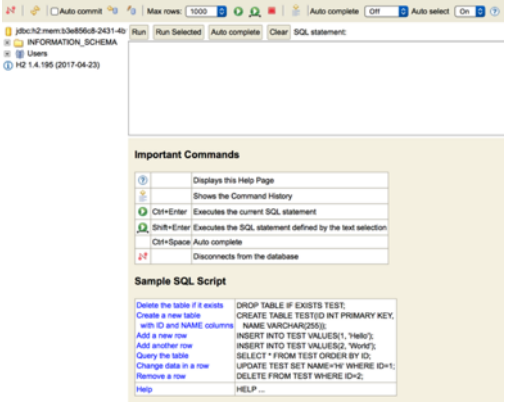


Figure 6.6

Let's create the *EMP* table through the *SQLLINE* tool and observe what happen on the H2 database. Run the following script for running the *SQLLINE* command console to connect to the Ignite cluster:

Listing 6.40

```
$ ./sqlline.sh --color=true --verbose=true -u jdbc:ignite:thin://127.0.0.1/
```

Next, create the *EMP* table with the following DDL script.

Listing 6.41

```
CREATE TABLE IF NOT EXISTS EMP
 (
   empno    LONG,
   ename    VARCHAR,
   job      VARCHAR,
   mgr      INTEGER,
   hiredate DATE,
   sal      LONG,
   comm     LONG,
   deptno   LONG,
   CONSTRAINT pk_emp PRIMARY KEY (empno)
 ) WITH "template=replicated,backups=1,CACHE_NAME=EMPcache";
```

Now, we have a table named *EMP* in Ignite as shown in the following figure.

Figure 6.7

Let's get back to the H2 web console and refresh the H2 database objects panel (you should see a small refresh button on the H2 web console menu bar on the upper left side of the web page). You would probably see a new table with name *EMP* appears on the object panel. Expand the EMP table, and you should get the following picture as shown in figure 6.8.

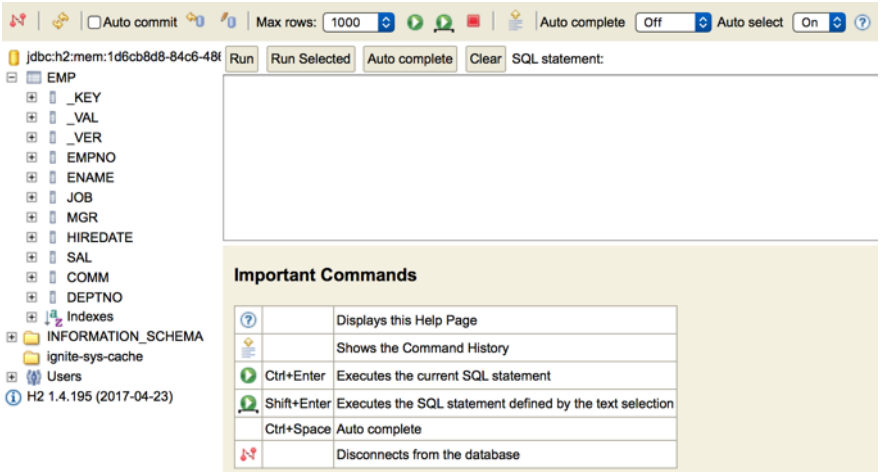


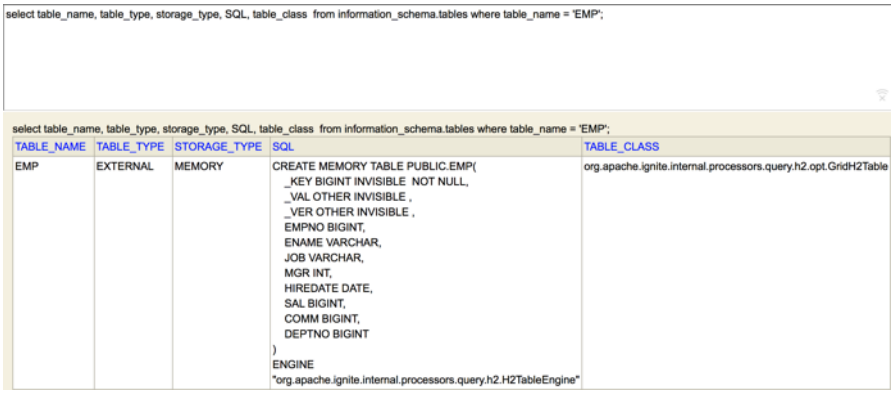
Figure 6.8

From the above screenshot, you can discover that H2 EMP table contains three extra columns with name _KEY, _VAL, _VER. Apache Ignite as a key-value data store, always stores cache keys and values as _KEY and _VAL fields. H2 EMP table column _key and _val corresponded to the Ignite internal _key and _val field of the EMPcache cache. The _VER field assigns the Ignite topology version and the node order. Let's have a look at the DDL scripts that H2 executed for creating the *EMP* table. Execute the following SQL query on the SQL statement panel of the H2 web console as shown below:

Listing 6.42

```
select table_catalog, table_name, table_type, storage_type, SQL from information_schema.t\
ables where table_name = 'EMP';
```

You should have the following query result on the panel.



```
select table_name, table_type, storage_type, SQL, table_class  from information_schema.tables where table_name = 'EMP';
```

select table_name, table_type, storage_type, SQL, table_class from information_schema.tables where table_name = 'EMP';

TABLE_NAME	TABLE_TYPE	STORAGE_TYPE	SQL	TABLE_CLASS
EMP	EXTERNAL	MEMORY	CREATE MEMORY TABLE PUBLIC.EMP(_KEY BIGINT INVISIBLE NOT NULL, _VAL OTHER INVISIBLE , _VER OTHER INVISIBLE , EMPNO BIGINT, ENAME VARCHAR, JOB VARCHAR, MGR INT, HIREDATE DATE, SAL BIGINT, COMM BIGINT, DEPTNO BIGINT) ENGINE "org.apache.ignite.internal.processors.query.h2.H2TableEngine"	org.apache.ignite.internal.processors.query.h2.opt.GridH2Table

Figure 6.9

We used the H2 system table TABLES to get all the meta-data infotmation of the *EMP* table.

Tip

The system tables of the H2 database in the schema INFORMATION_SCHEMA contain the metadata of all tables in the database as well as the current settings. Examples of the system tables are *TABLES*, *INDEXES*, *VIEWS*, etc.

The exciting part of the query result is STORAGE_TYPE, TABLE_CLASS and the SQL itself.

- SQL: See the listing 6.43. The CREATE table DDL statement indicates that the EMP table is a *MEMORY* table. A memory table is a persistence table, but the index of data is kept in the memory, so a memory table cannot be too large. The EMP table also uses custom table implementation which is specified by the ENGINE parameter. H2 uses the H2 table engine implementation of the class org.apache.ignite.internal.processors.query.h2.H2TableEngine to create the EMP table. H2 table engine creates the table using given connection, DDL clause for given type descriptor and list of indexes. Created EMP table has three individual columns with invisible column definition which made the columns hidden, i.e., it will not appear in SELECT * results.
- TABLE_CLASS: org.apache.ignite.internal.processors.query.h2.opt.GridH2Table. The *EMP* table is not an H2 regular table. It's a user-defined or custom designed table which is the type of Ignite *GridH2Table*. The Ignite *H2TableEngine* uses the implementation of the *GridH2Table* for creating tables in the H2 database.
- STORAGE_TYPE: MEMORY. The storage type of the table is MEMORY.

Listing 6.43

```
CREATE MEMORY TABLE PUBLIC.EMP(
    _KEY BIGINT INVISIBLE  NOT NULL,
    _VAL OTHER INVISIBLE ,
    _VER OTHER INVISIBLE ,
    EMPNO BIGINT,
    ENAME VARCHAR,
    JOB VARCHAR,
    MGR INT,
    HIREDATE DATE,
    SAL BIGINT,
    COMM BIGINT,
    DEPTNO BIGINT
)
ENGINE "org.apache.ignite.internal.processors.query.h2.H2TableEngine"
```

Next, execute the following query into the H2 web console SQL statement pane.

Listing 6.44

```
select table_name, non_unique, index_name, column_name, primary_key, SQL, index_class fro\
m information_schema.indexes where table_name = 'EMP';
```

We use the H2 system table *INDEXES* to discover the meta-data information about the indexes used by the *EMP* table. After executing the above SQL, you should have the following output demonstrated in the next table.

TABLE NAME	NON UNIQUE	INDEX NAME	COLUMN NAME	PRIMARY KEY	SQL	INDEX CLASS
EMP	FALSE	_key_PK_hash	_KEY	TRUE	CREATE PRIMARY KEY HASH PUBLIC."_key_-PK_hash" ON PUBLIC.EMP(_-KEY)	H2PkHashIndex
EMP	FALSE	_key_PK	_KEY	TRUE	CREATE PRIMARY KEY PUBLIC."_key_-PK" ON PUBLIC.EMP(_-KEY)	H2TreeIndex

TABLE NAME	NON UNIQUE	INDEX NAME	COLUMN NAME	PRIMARY KEY	SQL	INDEX CLASS
EMP	TRUE	_key_PK_proxy	EMPNO	FALSE	CREATE INDEX PUBLIC."_key_-PK_proxy" ON PUBLIC.EMP(EMPNO)	GridH2ProxyIndex

We have three different indexes generated for the table EMP by the H2 engine: *Hash*, *Tree* and *Proxy* index. Two different primary key indexes _key_PK_hash and _key_PK are created on column _KEY. The main interesting point is that, column EMPNO is not a primary key, rather than a proxy index _key_PK_proxy is created on column EMPNO. A proxy index allows to delegates the calls to the underlying normal index. _key_PK is a Btree primary index created on column _KEY. The _key_PK_hash is an in-memory hash index and usually faster than the regular index. Note that, Hash index does not support range queries similar to a hash table.

Now that we have got an idea about the internal structure of the tables and indexes in H2 database. Let's insert a few rows into the EMP table and run some queries to know how data is organized into a table. First, insert some data into the EMP table as follows.

Listing 6.45

```
insert into emp (empno, ename, job, mgr, hiredate, sal, comm, deptno) values(7839, 'KING'\
, 'PRESIDENT', null, to_date('17-11-1981','dd-mm-yyyy'), 5000, null, 10);
insert into emp (empno, ename, job, mgr, hiredate, sal, comm, deptno) values( 7698, 'BLAK\
E', 'MANAGER', 7839, to_date('1-5-1981','dd-mm-yyyy'), 2850, null, 30);
insert into emp (empno, ename, job, mgr, hiredate, sal, comm, deptno) values(7782, 'CLARK\
', 'MANAGER', 7839, to_date('9-6-1981','dd-mm-yyyy'), 2450, null, 10);
```

Enter the following simple *SELECT* query into the H2 web console SQL statement panel.

Listing 6.46

```
select _key, _val, _ver from EMP;
```

The above query should return you the following output.

KEY	VAL	VER
7698	SQL_PUBLIC_EMP_da74a220_118a_4111_a7d7_-283d55dec3fb [idHash=1526052858, hash=-1417502761, ENAME=BLAKE, JOB=MANAGER, MGR=7839, HIREDATE=1981-05-01, SAL=2850, COMM=null, DEPTNO=30]	GridCacheVersion [topVer=153331122, order=1541851119645, nodeOrder=1]

KEY	VAL	VER
7782	SQL_PUBLIC_EMP_da74a220_118a_4111_a7d7_-283d55dec3fb [idHash=1412584148, hash=1453774085, ENAME=CLARK, JOB=MANAGER, MGR=7839, HIREDATE=1981-06-09, SAL=2450, COMM=null, DEPTNO=10]	GridCacheVersion [topVer=153331122, order=1541851119647, nodeOrder=1]
7839	SQL_PUBLIC_EMP_da74a220_118a_4111_a7d7_-283d55dec3fb [idHash=1343085706, hash=1848897643, ENAME=KING, JOB=PRESIDENT, MGR=null, HIREDATE=1981-11-17, SAL=5000, COMM=null, DEPTNO=10]	GridCacheVersion [topVer=153331122, order=1541851119643, nodeOrder=1]

From the preceding figure, you can notice that every _KEY field hold the actual employee number (EMPNO), and the rest of the information such as job, salary information hold by the _VAL field. H2 EMP table *EMPNO* field maps to the actual _key field of the cache, job field maps to the _VAL field job attribute and so on. Whenever you execute any SQL query, H2 engine uses the regular fields such as *ENAME*, *MGR*, *JOB* fields to fulfill the query request.

Before moving on to the query execution plan, let's clarify how Ignite process SQL queries under the cover. Ignite always uses *Map/Reduce* pattern to process SQL queries. Whenever Ignite SQL engine receives queries, it split the query into two parts: *Map* and *Reduce*. Map query runs on each participating cache node depends on the cache mode (PARTITIONED OR REPLICATED), and Reduce query aggregates results received from all nodes running map query. We can generalize the process of executing SQL queries based on the Cache/Table modes into two categories:

- REPLICATED/LOCAL CACHE/TABLE. If a SQL query is executed against Replicated or Local cache data, Ignite distributed SQL engine knows that all data is available locally and runs a local SQL map query in the H2 database engine, aggregates the result on the same node and returns the query result to the application. Map and Reduce parts executes on the same Ignite node, so the query performance is more impressive. It's worth mentioning that in replicated caches, every node contains a replica data for other nodes.

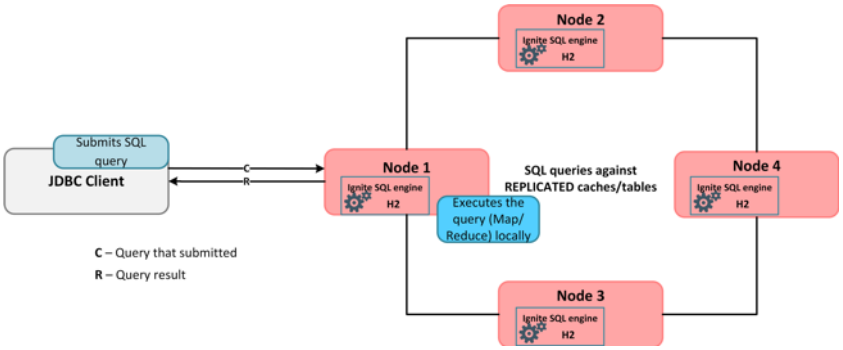


Figure 6.10

- PARTITIONED CACHE/TABLE. SQL queries against partitioned caches/tables is slightly complicated. If you are executing any SQL query against a Partitioned cache, Ignite under the hood splits the query into multiple in-memory map queries and a single reduce query. The number of map queries depends on the size of the partitions and number the partitions (or nodes) in the cluster. Then, all map queries are executed on all data nodes of the participating caches, relaying results to the reducing node, which will, in turn, run the reduce query over these intermediate results. If you are not familiar with the Map-Reduce pattern, you can imagine it as a Java Fork-join process.

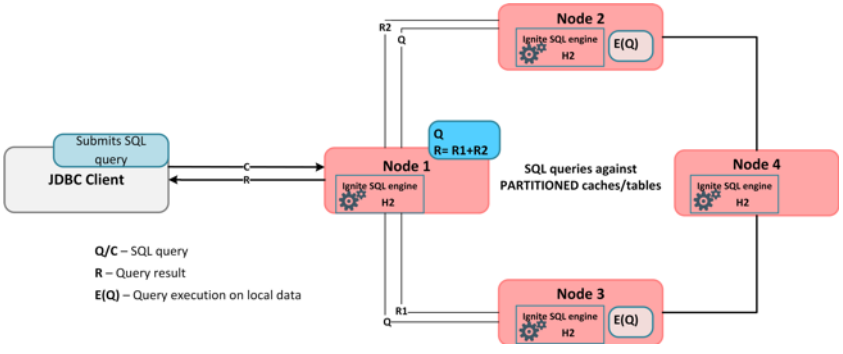


Figure 6.11

In addition, to study the internal structure of the tables and indexes in H2 databases, you can also see query execution plan against local data in H2 web console. Ignite SQLLINE tool also supports the *EXPLAIN* syntax for reading execution plans for the distributed query. In the last part of this sub-section, we use both of them to see how to read query execution plans and how to get benefit from it.

In the last part of this sub-section, we use both H2 and SQLLINE SQL execution plans to see how to read query execution plans and how to get benefit from it.

Let's start from the definition and purpose of the Query Execution plan. A query plan is a set of steps that the DBMS executes to complete the query. The reason we have query plans is that the SQL you write may declare your intentions, but it does not tell the SQL engine the exact logic to follow. When a query is submitted to the database, the query optimizer[22] evaluates some of the different, correct possible plans for executing the query and returns what it considers the best option. In H2 database the process is called statement execution plan and provides two different syntaxes to runs query execution plans: *EXPLAIN* and *EXPLAIN ANALYZE*.

H2 EXPLAIN statement displays the indexes and optimizations the database uses for the given SQL statement. This statement actually does not execute the query, rather than prepare it. Let's run the following query into the SQLLINE tool and then repeat the process into the H2 web console.

Listing 6.47

```
Explain select ename, job from emp where ename='KING';
```

After running the above query into the SQLLINE tool, you should have the following result on the console.

```
+--------------------------------+
|              PLAN              |
+--------------------------------+
| SELECT
    __Z0.ENAME AS __C0_0,
    __Z0.JOB AS __C0_1
FROM PUBLIC.EMP __Z0
    /* PUBLIC.EMP.__SCAN */|
| SELECT
    __C0_0 AS ENAME,
    __C0_1 AS JOB
FROM PUBLIC.__T0
    /* PUBLIC."merge_scan" */ |
+--------------------------------+
```

As we mentioned before, Ignite SQL engine receives the SQL queries and split this query into two parts: *Map* and *Reduce*. Map query runs on the single Ignite node because our *EMP*

[22] https://en.wikipedia.org/wiki/Query_plan

table is replicated. Reduce query aggregate the result received from the H2 database in the same node and return the result. So, in query execution plan we have two parts: Map parts with the Z0 prefix, and a reduce part with C0 prefix. If you run the above query through H2 web console, you should have only one part as shown below. This is because, H2 executes the entire queries as a whole and does not splits into parts.

```
SELECT
  ENAME,
  JOB
FROM PUBLIC.EMP
  /* PUBLIC.EMP.__SCAN_ */
WHERE ENAME = 'KING'
```

Let's get back to our explain plan result from the SQLLINE tool. Comment /*PUBLIC.EMP.__SCAN */ from the Map part of the query result indicates that the query does not use any indexes and executes a full table scan. These are the expected results because we did not create an index on column ENAME. Let's create a user-defined index on column *ENAME* through SQLLINE tool and re-run the explain plan query.

Listing 6.48

```
CREATE INDEX ename_idx ON emp (ename);
```

Now the SQL query to find the employee with name KING will use the index, and the explain plan query should return the following output.

```
+--------------------------------+
|              PLAN              |
+--------------------------------+
| SELECT
  __Z0.ENAME AS __C0_0,
  __Z0.JOB AS __C0_1
FROM PUBLIC.EMP __Z0
  /* PUBLIC.ENAME_IDX: */ |
| SELECT
  __C0_0 AS ENAME,
  __C0_1 AS JOB
FROM PUBLIC.__T0
  /* PUBLIC."merge_scan" */ |
+--------------------------------+
```

H2 SQL engine uses only one index per table. If you create an index on column *SAL* and run the query explain plan using the condition `where ename='KING' and job='PRESIDENT' or sal>3000`. The query process would use a full table scan instead of first using the index on column ENAME and then the index on SAL.

```
+--------------------------------+
|              PLAN              |
+--------------------------------+
| SELECT
    __Z0.JOB AS __C0_0,
    __Z0.SAL AS __C0_1
FROM PUBLIC.EMP __Z0
    /* PUBLIC.EMP.__SCAN_  */|
| SELECT
    __C0_0 AS JOB,
    __C0_1 AS SAL
FROM PUBLIC.__T0
    /* PUBLIC."merge_scan" */ |
+--------------------------------+
```

In such cases, it makes sense to write two queries and combines them using *UNION*. Thus each individual query uses a different index as follows:

Listing 6.49

```
Explain Select job, sal from emp where ename='KING' and job='PRESIDENT'
UNION
select job, sal from emp where sal>3000;
```

The preceding SQL statement should use two different indexes and give us the following query plan as shown in the following screenshot.

```
+--------------------------------+
|              PLAN              |
+--------------------------------+
| SELECT
    __Z0.JOB AS __C0_0,
    __Z0.SAL AS __C0_1
FROM PUBLIC.EMP __Z0
    /* PUBLIC.ENAME_IDX: E */ |
| SELECT
    __Z1.JOB AS __C1_0,
    __Z1.SAL AS __C1_1
FROM PUBLIC.EMP __Z1
    /* PUBLIC.IDX_SALARY:  */ |
| (SELECT
    __C0_0 AS JOB,
    __C0_1 AS SAL
FROM PUBLIC.__T0
    /* PUBLIC."merge_scan" */)
```

Besides to EXPLAIN keywords, you can also use ANALYZE keyword which shows the scanned rows per table. The *EXPLAIN ANALYZE* keyword actually executes the SQL queries unlike *EXPLAIN* which only process it. This execution plan is useful to know how many rows will be affected by the queries. Unfortunately, Ignite SQLLINE tool does not support the *EXPLAIN ANALYZE* keyword. However, you can use this keyword through H2 web console. The following query scanned two rows while executing the plan.

```
SELECT
    ENAME,
    JOB
FROM PUBLIC.EMP
    /* PUBLIC.ENAME_IDX: ENAME = 'KING' */
    /* scanCount: 2 */
WHERE ENAME = 'KING'
```

Warning

Not all execution plan is this simple and sometimes they might be challenging to read and understand.

HOW SQL join works. The internal of any query operation can be reviewed in the query execution plan. There are several factors that involves how the data is extracted and queried from the source tables. Mainly there are two elements you need to be concerned about:

- *Seeks and Scans*. The first step to any query is to extract the data from the source tables. This is performed using one of two actions (and variations within): a *seek* or a *scan*. A seek is where the query engine can leverage an index to narrow down the data retrieval. If no index is available, then the engine must perform a scan of all records in the table. In general, seeks typically perform better than scans.
- *Physical Joins*. Once data is retrieved from the tables, it must be physically joined. Note, this is not the same as logical joins (INNER and OUTER). There are three physical join operators[23] that can be used by the engine: *Hash Join*, *Merge Join* and *Nested loop join*.

The query engine will evaluate several factors to determine which physical join will be the most efficient for the query execution. H2 uses *hash joins* during the query execution.

Another vital part of the query execution is the query optimizer. H2 SQL engine is a cost-based optimizer. Cost-based optimization involves generating multiple execution plans and selecting the lowest cost execution plans to fire and finally execute a query. The CPU, IO, and memory are some of the parameters H2 uses in recognizing the cost, and finally generating the execution plan.

So, then you can better understand how the H2 database handles the SQL queries if you can read and understand execution plans. It will help you to work on query tuning and optimization. In other words, you will understand which objects are in use within the database you are coding against. For more information, please visit the H2 database web site.

This part is not available in the sample chapter

Spring Data integration

When we develop an application which interacts with a database, we write a set of SQL queries and bind them to the Java objects for saving and retrieving them. This standard approach to persistence via Data Access Objects[24] is monotonous and contains a lot of boilerplate code. Spring Data[25] simplifies this process of creating the data-driven application with a new way to access data by removing the DAO implementations entirely.

[23] https://www.periscopedata.com/blog/how-joins-work
[24] https://en.wikipedia.org/wiki/Data_access_object
[25] https://spring.io/projects/spring-data

In a nutshell, Spring Data provides a unified and easy way to access the different persistence store, both relational database systems, and NoSQL data stores. It's adding another layer of abstraction and defining a standards-based design to support the persistence layer in a Spring context. You do not have to write any more code for CRUD operations with Spring Data. Instead, you define an interface, Spring Data generates (no CGLib nor byte-code generation) the actual implementation on the fly for you.

Spring Data introduced the concept of Repository. It acts as an adapter, takes the domain class to manage as well as the id type of the domain class as type arguments. This `Repository` interface is the central interface in Spring data repository concept. The primary purpose of this interface is to capture the domain types to work, intercepts and routes all the calls to the appropriate implementation.

Info

Note that, Spring Data does not generate any code. Instead, a JDK proxy instance is created programmatically using Spring's `ProxyFactory` API to back the interface, and a `MethodInterceptor` intercepts all the method calls and delegates them to the appropriate implementations.

Spring data provides various interfaces (abstraction) that enable you to work or connect with multiple data stores: `CrudRepository`, `PagingAndSortingRepository`. All of them extends the marker interface Repository.

This part is not available in the sample chapter

Chapter 8. Streaming and complex event processing

Probably you often heard the terms: **Data-at-Rest** and **Data-in-Motion** whenever talking about BigData management. Data-at-rest refers mostly at static data collected from one and many data sources and followed by analysis. The Data-in-motion refers to a mode where all the similar data collection method is applied, and data get analyzed at the same time as it is generated. For instance, sensor data processing for the self-driving car from Google. Sometimes, this type of data is also called *stream data*. Analysis of a Data-in-motion is often called *Stream processing*, *Real-time analysis* or *Complex event processing*.

Most often, Streaming data is generated continuously by thousands of data sources, which typically send in the data records simultaneously and in small sizes. Streaming data includes a wide variety and velocities of data such as log files generated by mobile devices, user activities from e-commerce sites, financial trading floors or tracking information from car/bike sharing devices, etc.

This data needs to be processed *sequentially* and *incrementally*, and used for a wide variety of analytics including aggregation, filtering or business intelligence for taking any business decision with latencies measured in microseconds rather than seconds of response time. Apache Ignite allows loading and processing of continuous never-ending streams of data in a scalable and fault-tolerant fashion, rather than analyzing data after it has reached the database. This enables you to correlate relationships and detect meaningful patterns from significantly more data that you can process it faster and much more efficiently.

Apache Ignite streaming and CEP can be employed in a wealth of industries area; the following are some first-class use cases:

- **Financial services**: the ability to perform real-time risk analysis, monitoring ,and reporting of financial trading and fraud detection.
- **Telecommunication**: the ability to perform *real-time* call detail record, SMS monitoring ,and *DDoS* attack.
- **IT systems and infrastructure**: the ability to detect failed or unavailable applications or servers in real-time.

- **Logistics**: the ability to track shipments and order processing in real-time and reports on potential delays on arrival.
- **In-game player activities**: the ability to collects streaming data about player-game interactions, and feeds the data into its gaming platform. It then analyzes the data in real-time, offers incentives and dynamic experiences to engage its players.

Basically, Apache Ignite Streaming technics works as follows:

1. Clients inject streams of data into Ignite cluster.
2. Data is automatically partitioned between Ignite data nodes.
3. Data is concurrently processed across all cluster nodes, such as enrichment, filter extra.
4. Clients perform concurrent *SQL queries* on the streamed data.
5. Clients subscribe to *continuous queries* as data changes.

These above activities can be illustrated as shown in figure 8.1.

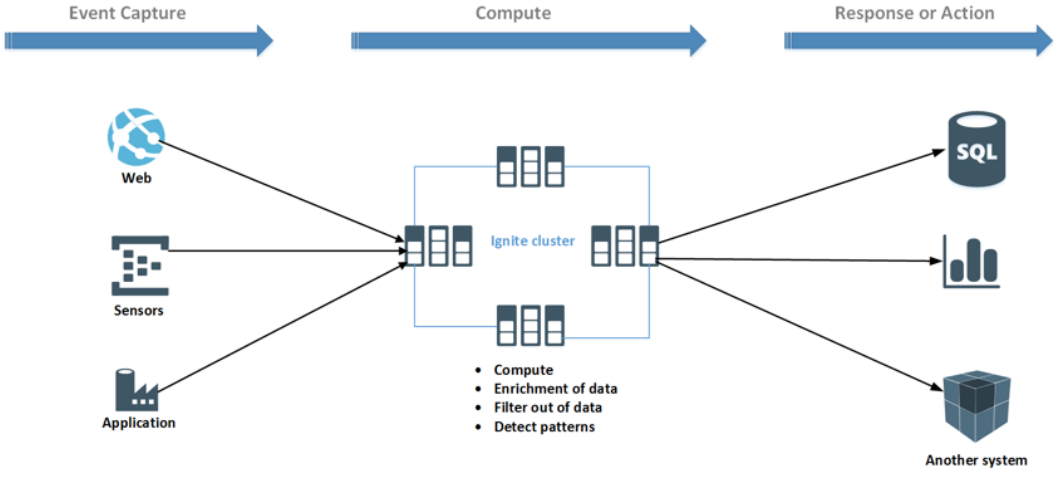


Figure 8.1

Data are ingesting from difference sources. Sources can be any sensors (IoT), web applications or industrial applications. Stream data can be concurrently processed directly on the Ignite cluster in a distributed fashion. Also, data can be computed on third-party CEP application like confluent[26], Apache Storm[27] and then aggregated data can be loaded into the Ignite cluster for visualization or for taking some actions.

[26] https://www.confluent.io/
[27] http://storm.apache.org/

Apache Ignite provides native data streamers for loading and streaming large amounts of data into Ignite cluster. Data streamers are defined by `IgniteDataStreamer` API and are built to ingest large amounts of endless stream data into Ignite caches. IgniteDataStreamer can ingest data from various sources such as files, FTP, queues, etc., but the users must develop the adapter for connecting to the sources. Also, Ignite integrates with major streaming technologies such as Kafka, Camel, Storm or Flume to bring even more advanced streaming capabilities to Ignite-based architectures. At the moment of writing this book, Ignite provides the following data streamers for streaming a large amount of data into Ignite cluster:

- IgniteDataStreamer
- JMS Streamer
- Flume sink
- MQTT Streamer
- Camel Streamer
- Kafka Streamer
- Storm Streamer
- Flink Streamer
- ZeroMQ Streamer
- RocketMQ Streamer

In practice, most developers use the 3rd party framework such as Kafka, Camel, etc. for initial loading and streaming data into Ignite cluster, because they are well known multi-purpose technologies for complex event processing. So, in this chapter, first of all, we will introduce the Kafka streamer and then goes through the rest of the favorite data streamers, and provides some real-world running example for each streamer.

Kafka Streamer

Apache Ignite out-of-the-box provides *Ignite-Kafka* module with three different solutions (API) to achieve a robust data processing pipeline for streaming data from/to Kafka[28] topics into Apache Ignite.

Name	Description
IgniteSinkConnector	Consumes messages from Kafka topics and ingests them into an Ignite node.
KafkaStreamer	Fetching data from Kafka topics and injecting them into Ignite node.
IgniteSourceConnector	Manages source tasks that listens to registered Ignite grid events and forward them to Kafka topics.

This part is not available in the sample chapter

IgniteSourceConnector

The Apache IgniteSourceConnector[29] is used to subscribe to Ignite cache events and stream them to Kafka topic. In other words, it can be used to export data (changed datasets) from an Ignite cache into a Kafka topic. Ignite source connector listens to registered Ignite grid events such as PUT and forward them to Kafka topic. This enables data that has been saved into the Ignite cache to be easily turned into an event stream. Each event stream contains key and two values: *old* and *new*.

The *IgniteSourceConnector* can be used to support the following use cases:

1. To automatically notify any clients when a cache event occurs, for instance whenever there is a new entry into the cache.
2. To use an asynchronous event streaming from an Ignite cache to 1-N destinations. The destination can be any database or another Ignite cluster. *These enable you to data replication between two Ignite cluster through Kafka.*

The Apache *IgniteSourceConnector* ships together with the *IgniteSinkConnector*, and available in ignite-kafka-x.x.x.jar distribution. IgniteSourceConnector requires the following configuration parameters:

[28] https://kafka.apache.org/
[29] https://ignite.apache.org/releases/latest/javadoc/org/apache/ignite/stream/kafka/connect/IgniteSourceConnector.html

Name	Description	Mandatory/optional
igniteCfg	Ignite configuration file path.	Mandatory
cacheName	Name of the Cache.	Mandatory
topicNames	Kafka topics name where event will be streamed.	Mandatory
cacheEvts	Ignite cache events to be listened to, for example PUT.	Mandatory
evtBufferSize	Internal buffer size.	Optional
evtBatchSize	Size of one chunk drained from the internal buffer.	Optional
cacheFilterCls	User-defined filter class.	Optional

A high-level architecture of the *IgniteSinkConnector* is shown in figure 8.6.

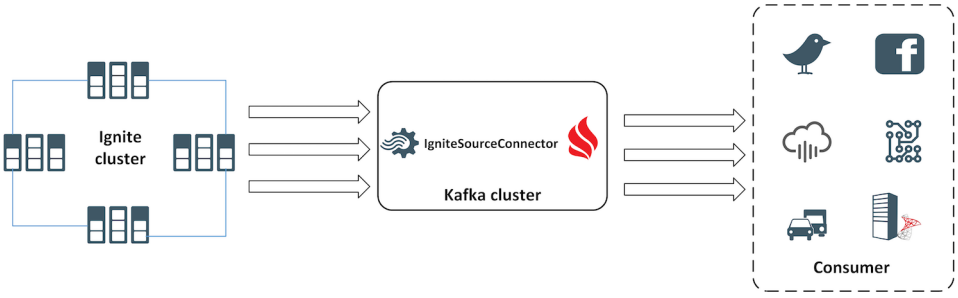


Figure 8.6

In this section, we are going to use both *IgniteSourceConnector* and *IgniteSinkConnector* for streaming event from one Ignite cluster to another. IgniteSourceConnector will stream the event from one Ignite cluster (source cluster) to Kafka topic, and the IgniteSinkConnector will stream the changes from the topic to the another Ignite cluster (target cluster). We will demonstrate the step by step instructions to configure and run both the Source and Sink connectors. To accomplish the data replication between Ignite clusters, we are going do the following:

1. Execute two isolated Ignite cluster in a single machine.
2. Develop a Stream extractor to parse the incoming data before sending to the Ignite target cluster.
3. Configure and start Ignite Source and Sink connectors in different standalone Kafka workers.
4. Add or modify some data into the Ignite source cluster.

After completing all the configurations, you should have a typical pipeline that is streaming data from one Ignite cluster to another as shown in figure 8.7.

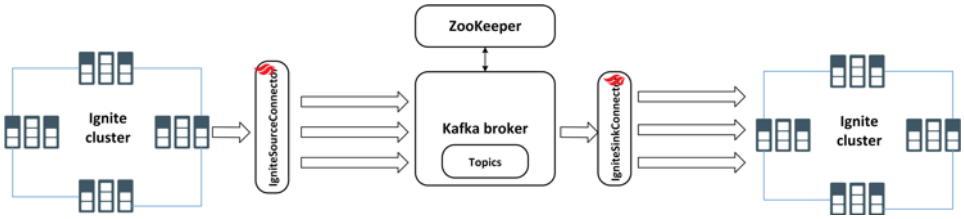


Figure 8.7

We will use the knowledge of Zookeeper and Kafka from the previous section to achieve the task. Let's start from the Ignite cluster configuration.

Step 1. We are going to start two isolated clusters on a single machine. To accomplish this, we have to use a different set of TcpDiscoverySpi and TcpConfigurationSpi to separate the two clusters on a single host. So, for the nodes from the first cluster we proceed to use the following TcpDiscoverySpi and TcpConfigurationSpi configurations:

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Chapter 10. Management and monitoring

As a system or cluster grows, you may start getting hardware or virtual machine failures in your cloud/dedicated infrastructure. In such cases, you may need to do one of these things: add/remove nodes from the cluster or backup/repair nodes. These tasks come as an integral part of a system administrator daily work. Luckily all these tasks are relatively straightforward in Apache Ignite and partially documented in Ignite documentation.

In the last chapter of this book, we will go through Ignite's built-in and 3rd party tools to manage and monitor the Ignite cluster in the production environment. We divided the entire chapter into two parts: management and monitoring. In the management part, we will discuss different tools and technics to configure and manage the Ignite cluster. And we will cover the basic of monitoring Apache Ignite includes logging, inspection of JVM, etc. in the monitoring part.

Managing Ignite cluster

Out-of-the-box Apache Ignite provides several tools for managing cluster. These tools include *web interface* or *command line interface* that allows you to perform various task such as start/stop/restart remote nodes or control cluster states (baseline topology). A table below shows all the built-in tools of the Apache Ignite to configure and managing Ignite cluster.

Name	Description
Ignite Web console	Allows configuring all the cluster properties, and managing the Ignite cluster through a web interface.
Control script	A command line script that allows to monitor and control cluster states includes Ignite baseline topology.

Info

Please note that *Ignite Web console* also uses for monitoring cluster functionality like cache metrics as well as CPU and Memory heap usages.

This part is not available in the sample chapter

Monitoring Ignite cluster

At this point, your Ignite cluster is configured and running. Applications are using the Ignite cluster for writing and reading data to and from it. However, Ignite is not a set-it-and-forget-it system. Ignite is a JVM based system and designed to *fast fail*. So, it requires monitoring for acting on time.

Ignite is built on JVM and JVM can use the JMX[30] or Java Management Extension. In other words, you can manage the system remotely by using JMX, gathering metrics (cache or memory) including the memory, CPU, threads, or any other part of the system that has been instrumented in JMX. Instrumentation enables the application or system to provide application-specific information to be collected by the external tools.

[30] https://docs.oracle.com/javase/8/docs/technotes/guides/jmx/overview/intro.html

Info

JMX was introduced in Java 5.0 release to manage & monitor the resources at runtime. Using JMX, we can monitor memory usage, garbage collection, loaded classes, thread count, etc. over time.

MBeans or Managed Beans are a particular type of JavaBeans that takes a resource inside the application or the JVM available externally. Figure 10.7 shows a high-level architecture of the JMX.

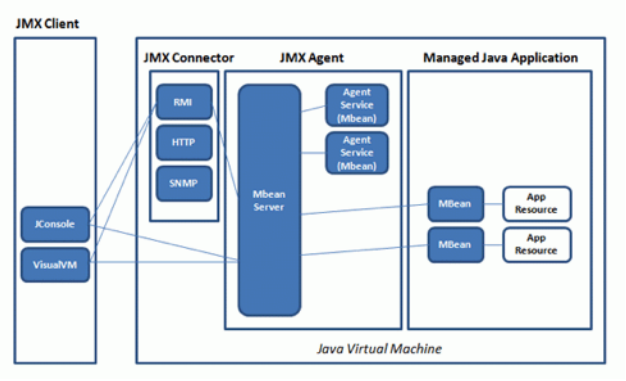

Figure 10.7

Apache Ignite provides a few JMX MBeans for collection and monitoring cache and memory metrics as follows:

- CacheMetricsMXBean. MBean that provides access to cache descriptor.
- CacheGroupMetricsMXBean. MBean that provides metrics for caches associated with a particular CacheGroup.
- DataRegionMetricsMXBean. MBean that provides access to *DataRegionMetrics* of a local Apache Ignite node.
- DataStorageMetricsMXBean. An MBean allowing to monitor and tune persistence metrics.

A few more new MBeans will be added in the subsequent Apache Ignite releases soon.

The standard tools that ships with Java for managing the MBeans is JConsole[31] or VisualVM[32]. In the case of VisualVM you have to install the VisualVM-MBeans plugin[33].

[31] https://docs.oracle.com/javase/7/docs/technotes/guides/management/jconsole.html
[32] https://docs.oracle.com/javase/8/docs/technotes/guides/visualvm/
[33] https://visualvm.github.io/plugins.html

VisualVM is like JConsole but with more advanced monitoring featuring such as CPU profiling and GC visualization.

Tip

Ignite allows running a VisualVM instance from IgniteVisor command. Use the *ignitevisor* `vvm` command to open VisualVM for an Ignite node in the topology.

VisualVM

VisualVM is a GUI tool for monitor JVM. It helps the application developers and architects to track memory leaks, analyze the heap data, monitor the JVM garbage collector and CPU profiling. Moreover, after installing the *VisualVM-MBeans* plugin, you can manage and collect metrics from JMX MBeans provides by the application. VisualVM can be also used for monitoring the local and the remote Java process as well.

As we stated before, for monitoring the Ignite process you can lunch VisualVM with two different ways:

- Use ignitevisor `VVM` command to open a VisualVM instance or
- lunch a VisualVM instance manually by the `jVisualVM.exe|sh` from the `$JAVA_HOME/bin` folder.

IgniteVisor VVM command under the cover uses the default JDK installation to run the local VisualVM tool. Let's execute an Ignite node, create a table and populate some test data into the table. I am going to use the *EMP* table and data from the previous section. If you are having any trouble to create the table, please refer to step 5 of the previous section.

Step 1. Lunch the VisualVM application from the *JDK bin directory*. On top-left corner of the application tab, you can see different options like Local, Remote and Snapshots. Select the `org.apache.ignite.startup.cmdline.CommandLineStartup` application from the *Local* section as shown below.

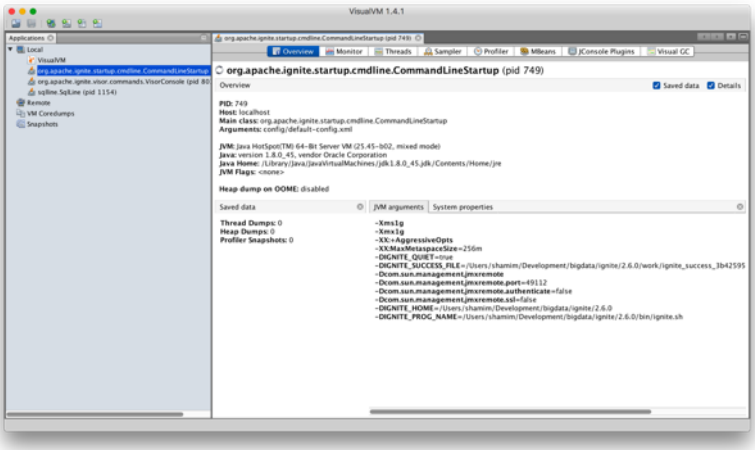

Figure 10.8

By default when Ignite node is started with ignite.sh!bat script, it picks up a random JMX port and binds to it. You can explicitly set the JMX port by setting the IGNITE_JMX_PORT environmental variable. In *nix system it can be done in the following way:

```
export IGNITE_JMX_PORT=55555
```

However, if you run the Ignite node programmatically (i.e., by using Eclipse/IntelliJ IDEA), then the environmental variable IGNITE_JMX_PORT will not work. In such a situation, you need to pass the system parameters to your Java process that calls *Ignition.start* as follows:

```
-Dcom.sun.management.jmxremote -Dcom.sun.management.jmxremote.port={PREFERRED_PORT}
-Dcom.sun.management.jmxremote.authenticate=false -Dcom.sun.management.jmxremote.ssl=fals\
e
```

Step 2. The Memory, anf Threads tabs are sets of graphs that provide insight into the current state of the application. The monitor tab consists of graphs about the current state of the Java heap, CPU, Classes and threads (see Figure 10.8).

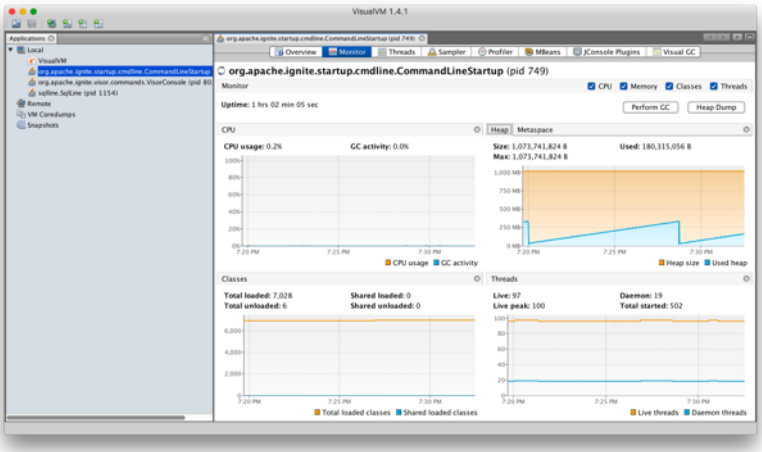

Figure 10.9

The Classes graph is merely a graph of how many classes are loaded into the JVM at the current time. One of the most important metrics to be aware of is your current heap usage. Ignite uses off-heap memory to store data from version 2.0 by default, so it is unnecessary to use a large heap size for Ignite node. By using small heap size, you reduce the memory footprint on the system and possibly speed up the GC process.

Step 3. Let's open the tab MBeans. There are many MBeans that are useful for assessing the state of the Ignite node. You will notice that there are few grouping here that can be expanded. All the Ignite MBeans classpath starts with the org.apache. Expand the group *Cache Group* under *18b4aac2* and click on the *EMPcache MBean* as shown in figure 10.10.

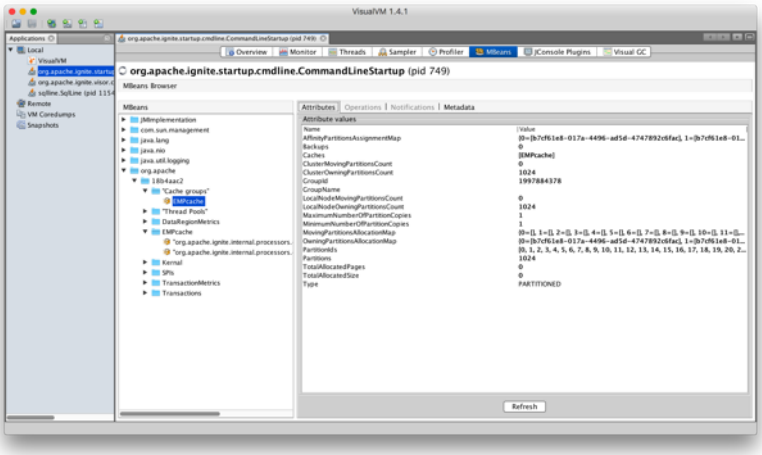

Figure 10.10

You should notice many import attributes shown for the EMPcache cache. Click on the value of the *LocalNodeOwningPartitionsCount* attribute, and a simple chart should pop up and show the current total number of partitions for the cache.

When you select an MBean in the tree, its MBeanInfo and MBean descriptor are displayed on the right-hand side of the window. If any additional attributes, operations or notifications are available, they appear in the tree as well below the selected MBean. As a high-level overview, they are broken down into the following categories:

- *Cache Groups*. The MBeans stored in this section cover everything about the actual data storage part of Ignite. This MBeans provides information about the caches itself: Affinity partitions assignment map, total backups, collections of the partitions as well as total partition number.
- *Kernel*. In the Kernel section, some MBeans cover the basic information about the node. For example, IgniteKernel MBean provides you the information about node Uptime, local node id or Peer class loading option.
- *SPIs*. The MBeans in the SPI's section covers the information about node discovery and internode communication. These include informations such as Node fails, Network timeout.
- *TransactionMetrics*. The metrics available in this section are closely related to transactions. These are things like LockedKeysNumber, TransactionRollbackNumber.

Each one of these sections of MBeans provides access to a large amount of information, giving you insight into both the system as a whole and the individual nodes. There is no

need to cover all of them as you can easily explore them on your own using VisualVm GUI interface.

Using JConsole/VisualVM to monitor a local application or Ignite node is useful for development or prototyping. Monitoring an Ignite cluster over 5 nodes by VisualVM or JConsole is unrealistic and time-consuming. Also, JMX does not provide any historical data. So, it is not recommended for production environments. Nowadays there is a lot of tools/software available for system monitoring. Most famous of them are:

- Nagios[34]
- Zabbix[35]
- Grafana, etc.

In the next sub-section, we cover the Grafana for monitoring Ignite node and provide step-by-step instructions to install and configure the entire stack technology.

Grafana

Grafana[36] is an open-source graphical tool dedicated to query, visualize and alert on for all your metrics. It brings your metrics together and lets you create graphs and dashboards based on data from various sources. Also, you can use Grafana to display data from different monitoring systems like Zabbix. It is lightweight, easy to install, easy configure, and it looks beautiful.

Before we dive into the details, let's discuss the concept of monitoring large-scale production environments. Figure 10.11 illustrated a high-level overview of how the monitoring system looks like on production environments.

[34] https://www.nagios.org
[35] https://www.zabbix.com
[36] https://grafana.com/grafana

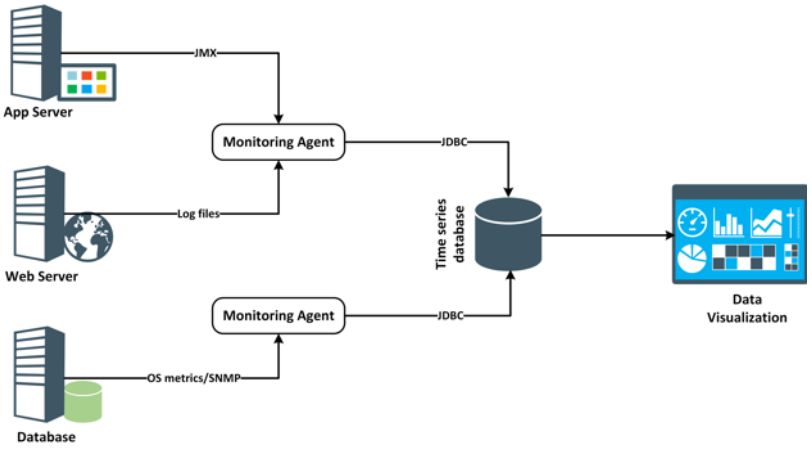

Figure 10.11

In the above architecture, data such as OS metrics, log files, and application metrics are gathering from various hosts through different protocols likes JMX, SNMP into a single time-series database. Next, all the gathered data is used to display on a dashboard for real-time monitoring. However, a monitoring system could be complicated and vary in different environments, but the basic is the same for all.

Let's start at the bottom of the monitoring chain and work our way up. To avoid a complete lesson on monitoring, we will only cover the basics along with what the most common checks should be done as they relate to Ignite and it's operation. The data we are planning to use for monitoring are:

- Ignite node Java Heap.
- Ignite cluster topology version.
- Amount of server or client nodes in cluster.
- Ignite node total up time.

This part is not available in the sample chapter

The sample chapters are ends here. If you are not sure if this book is for you, I encourage you to try it out, and if you don't like the book, you can always ask a 100% refund within 45 days.