Chapter 3. Apache Spark's Structured APIs

In this chapter, we will explore the principal motivations behind adding structure to Apache Spark, how those motivations led to the creation of high-level APIs (DataFrames and Datasets), and their unification in Spark 2.x across its components. We'll also look at the Spark SQL engine that underpins these structured high-level APIs.

When Spark SQL was first introduced in the early Spark 1.x releases, followed by DataFrames as a successor to SchemaRDDs in Spark 1.3, we got our first glimpse of structure in Spark. Spark SQL introduced high-level expressive operational functions, mimicking SQL-like syntax, and DataFrames, which laid the foundation for more structure in subsequent releases, paved the path to performant operations in Spark's computational queries.

But before we talk about the newer Structured APIs, let's get a brief glimpse of what it's like to not have structure in Spark by taking a peek at the simple RDD programming API model.

Spark: What's Underneath an RDD?

The RDD is the most basic abstraction in Spark. There are three vital characteristics associated with an RDD:

- Dependencies
- Partitions (with some locality information)

- Compute function: Partition => `Iterator[T]`

All three are integral to the simple RDD programming API model upon which all higher-level functionality is constructed. First, a list of *dependencies* that instructs Spark how an RDD is constructed with its inputs is required. When necessary to reproduce results, Spark can recreate an RDD from these dependencies and replicate operations on it. This characteristic gives RDDs resiliency.

Second, *partitions* provide Spark the ability to split the work to parallelize computation on partitions across executors. In some cases—for example, reading from HDFS—Spark will use locality information to send work to executors close to the data. That way less data is transmitted over the network.

And finally, an RDD has a *compute function* that produces an `Iterator[T]` for the data that will be stored in the RDD.

Simple and elegant! Yet there are a couple of problems with this original model. For one, the compute function (or computation) is opaque to Spark. That is, Spark does not know what you are doing in the compute function. Whether you are performing a join, filter, select, or aggregation, Spark only sees it as a lambda expression. Another problem is that the `Iterator[T]` data type is also opaque for Python RDDs; Spark only knows that it's a generic object in Python.

Furthermore, because it's unable to inspect the computation or expression in the function, Spark has no way to optimize the expression—it has no comprehension of its intention. And finally, Spark has no knowledge of the specific data type in `T`. To Spark it's an opaque object; it has no idea if you are accessing a column of a certain type within an object. Therefore, all Spark can do is serialize the opaque object as a series of bytes, without using any data compression techniques.

This opacity clearly hampers Spark's ability to rearrange your computation into an efficient query plan. So what's the solution?

Structuring Spark

Spark 2.x introduced a few key schemes for structuring Spark. One is to express computations by using common patterns found in data analysis. These patterns are expressed as high-level operations such as filtering, selecting, counting, aggregating, averaging, and grouping. This provides added clarity and simplicity.

This specificity is further narrowed through the use of a set of common operators in a DSL. Through a set of operations in DSL, available as APIs in Spark's supported languages (Java, Python, Spark, R, and SQL), these operators let you tell Spark what you wish to compute with your data, and as a result, it can construct an efficient query plan for execution.

And the final scheme of order and structure is to allow you to arrange your data in a tabular format, like a SQL table or spreadsheet, with supported structured data types (which we will cover shortly).

But what's all this structure good for?

Key Merits and Benefits

Structure yields a number of benefits, including better performance and space efficiency across Spark components. We will explore these benefits further when we talk about the use of the DataFrame and Dataset APIs shortly, but for now we'll concentrate on the other advantages: expressivity, simplicity, composability, and uniformity.

Let's demonstrate expressivity and composability first, with a simple code snippet. In the following example, we want to aggregate all the ages for each name, group by name, and then average the ages—a common pattern in data analysis and discovery. If we were to use the low-level RDD API for this, the code would look as follows:

```
# In Python
# Create an RDD of tuples (name, age)
dataRDD = sc.parallelize([("Brooke", 20), ("Denny", 31), ("Jules", 30),
  ("TD", 35), ("Brooke", 25)])
# Use map and reduceByKey transformations with their lambda
# expressions to aggregate and then compute average

agesRDD = (dataRDD
  .map(lambda x: (x[0], (x[1], 1)))
  .reduceByKey(lambda x, y: (x[0] + y[0], x[1] + y[1]))
  .map(lambda x: (x[0], x[1][0]/x[1][1])))
```

No one would dispute that this code, which tells Spark *how to* aggregate keys and compute averages with a string of lambda functions, is cryptic and hard to read. In other words, the code is instructing Spark how to compute the query. It's completely opaque to Spark, because it doesn't communicate the intention. Furthermore, the equivalent RDD code in Scala would look very different from the Python code shown here.

By contrast, what if we were to express the same query with high-level DSL operators and the DataFrame API, thereby instructing Spark *what to do*? Have a look:

```
# In Python
from pyspark.sql import SparkSession
from pyspark.sql.functions import avg
# Create a DataFrame using SparkSession
spark = (SparkSession
  .builder
  .appName("AuthorsAges")
  .getOrCreate())
# Create a DataFrame
data_df = spark.createDataFrame([("Brooke", 20), ("Denny", 31), ("Jules", 30),
  ("TD", 35), ("Brooke", 25)], ["name", "age"])
# Group the same names together, aggregate their ages, and compute an average
avg_df = data_df.groupBy("name").agg(avg("age"))
# Show the results of the final execution
avg_df.show()

+------+--------+
|  name|avg(age)|
+------+--------+
|Brooke|    22.5|
| Jules|    30.0|
|    TD|    35.0|
| Denny|    31.0|
+------+--------+
```

This version of the code is far more expressive as well as simpler than the earlier version, because we are using high-level DSL operators and APIs to tell Spark what to do. In effect, we have employed these operators to compose our query. And because Spark can inspect or parse this query and understand our intention, it can optimize or arrange the operations for efficient execution. Spark knows exactly *what* we wish to do: group people by their names, aggregate their ages, and then compute the average age of all people with the same name. We've composed an entire computation using high-level operators as a single simple query—how expressive is that?

Some would contend that by using only high-level, expressive DSL operators mapped to common or recurring data analysis patterns to introduce order and structure, we are limiting the scope of the developers' ability to instruct the compiler or control how their queries should be computed. Rest assured that you are not confined to these structured patterns; you can switch back at any time to the unstructured low-level RDD API, although we hardly ever find a need to do so.

As well as being simpler to read, the structure of Spark's high-level APIs also introduces uniformity across its components and languages. For example, the Scala code shown here does the same thing as the previous Python code—and the API looks nearly identical:

```
// In Scala
import org.apache.spark.sql.functions.avg
import org.apache.spark.sql.SparkSession
// Create a DataFrame using SparkSession
val spark = SparkSession
  .builder
  .appName("AuthorsAges")
  .getOrCreate()
// Create a DataFrame of names and ages
val dataDF = spark.createDataFrame(Seq(("Brooke", 20), ("Brooke", 25),
  ("Denny", 31), ("Jules", 30), ("TD", 35))).toDF("name", "age")
// Group the same names together, aggregate their ages, and compute an average
val avgDF = dataDF.groupBy("name").agg(avg("age"))
// Show the results of the final execution
```

```
avgDF.show()

+------+--------+
|  name|avg(age)|
+------+--------+
|Brooke|    22.5|
| Jules|    30.0|
|    TD|    35.0|
| Denny|    31.0|
+------+--------+
```

NOTE

Some of these DSL operators perform relational-like operations that you'll be familiar with if you know SQL, such as selecting, filtering, grouping, and aggregation.

All of this simplicity and expressivity that we developers cherish is possible because of the Spark SQL engine upon which the high-level Structured APIs are built. It is because of this engine, which underpins all the Spark components, that we get uniform APIs. Whether you express a query against a DataFrame in Structured Streaming or MLlib, you are always transforming and operating on DataFrames as structured data. We'll take a closer look at the Spark SQL engine later in this chapter, but for now let's explore those APIs and DSLs for common operations and how to use them for data analytics.

The DataFrame API

Inspired by pandas DataFrames in structure, format, and a few specific operations, Spark DataFrames are like distributed in-memory tables with named columns and schemas, where each column has a specific data type: integer, string, array, map, real, date, timestamp, etc. To a human's eye, a Spark DataFrame is like a table. An example is shown in Table 3-1.

Table 3-1. The table-like format of a DataFrame

Id (Int)	First (String)	Last (String)	Url (String)	Published (Date)	Hits (Int)	Campaigns (List[Strings])
1	Jules	Damji	https://tinyurl.1	1/4/2016	4535	[twitter, LinkedIn]
2	Brooke	Wenig	https://tinyurl.2	5/5/2018	8908	[twitter, LinkedIn]
3	Denny	Lee	https://tinyurl.3	6/7/2019	7659	[web, twitter, FB, LinkedIn]
4	Tathagata	Das	https://tinyurl.4	5/12/2018	10568	[twitter, FB]
5	Matei	Zaharia	https://tinyurl.5	5/14/2014	40578	[web, twitter, FB,

Id (Int)	First (String)	Last (String)	Url (String)	Published (Date)	Hits (Int)	Campaigns (List[Strings])
						LinkedIn]
6	Reynold	Xin	https://tinyurl.6	3/2/2015	25568	[twitter, LinkedIn]

When data is visualized as a structured table, it's not only easy to digest but also easy to work with when it comes to common operations you might want to execute on rows and columns. Also recall that, as you learned in Chapter 2, DataFrames are immutable and Spark keeps a lineage of all transformations. You can add or change the names and data types of the columns, creating new DataFrames while the previous versions are preserved. A named column in a DataFrame and its associated Spark data type can be declared in the schema.

Let's examine the generic and structured data types available in Spark before we use them to define a schema. Then we'll illustrate how to create a DataFrame with a schema, capturing the data in Table 3-1.

Spark's Basic Data Types

Matching its supported programming languages, Spark supports basic internal data types. These data types can be declared in your Spark application or defined in your schema. For example, in Scala, you can define or declare a particular column name to be of type `String`, `Byte`, `Long`, or Map, etc. Here, we define variable names tied to a Spark data type:

```
$SPARK_HOME/bin/spark-shell
scala> import org.apache.spark.sql.types._
import org.apache.spark.sql.types._
scala> val nameTypes = StringType
nameTypes: org.apache.spark.sql.types.StringType.type = StringType
scala> val firstName = nameTypes
firstName: org.apache.spark.sql.types.StringType.type = StringType
scala> val lastName = nameTypes
lastName: org.apache.spark.sql.types.StringType.type = StringType
```

Table 3-2 lists the basic Scala data types supported in Spark. They all are subtypes of the class `DataTypes`, except for `DecimalType`.

Table 3-2. Basic Scala data types in Spark

Data type	Value assigned in Scala	API to instantiate
ByteType	Byte	DataTypes.ByteType
ShortType	Short	DataTypes.ShortType
IntegerType	Int	DataTypes.IntegerType
LongType	Long	DataTypes.LongType
FloatType	Float	DataTypes.FloatType
DoubleType	Double	DataTypes.DoubleType
StringType	String	DataTypes.StringType
BooleanType	Boolean	DataTypes.BooleanType
DecimalType	java.math.BigDecimal	DecimalType

Spark supports similar basic Python data types, as enumerated in Table 3-3.

Table 3-3. Basic Python data types in Spark

Data type	Value assigned in Python	API to instantiate
`ByteType`	`int`	`DataTypes.ByteType`
`ShortType`	`int`	`DataTypes.ShortType`
`IntegerType`	`int`	`DataTypes.IntegerType`
`LongType`	`int`	`DataTypes.LongType`
`FloatType`	`float`	`DataTypes.FloatType`
`DoubleType`	`float`	`DataTypes.DoubleType`
`StringType`	`str`	`DataTypes.StringType`
`BooleanType`	`bool`	`DataTypes.BooleanType`
`DecimalType`	`decimal.Decimal`	`DecimalType`

Spark's Structured and Complex Data Types

For complex data analytics, you won't deal only with simple or basic data types. Your data will be complex, often structured or nested, and you'll need Spark to handle these complex data types. They come in many forms: maps, arrays, structs, dates, timestamps, fields, etc. Table 3-4 lists the Scala structured data types that Spark supports.

Table 3-4. Scala structured data types in Spark

Data type	Value assigned in Scala	API to instantiate
`BinaryType`	`Array[Byte]`	`DataTypes.BinaryType`
`TimestampType`	`java.sql.Timestamp`	`DataTypes.TimestampType`
`DateType`	`java.sql.Date`	`DataTypes.DateType`
`ArrayType`	`scala.collection.Seq`	`DataTypes.createArrayType(ElementType)`
`MapType`	`scala.collection.Map`	`DataTypes.createMapType(keyType, valueType)`
`StructType`	`org.apache.spark.sql.Row`	`StructType(ArrayType[fieldTypes])`
`StructField`	A value type corresponding to the type of this field	`StructField(name, dataType, [nullable])`

The equivalent structured data types in Python that Spark supports are enumerated in Table 3-5.

Table 3-5. Python structured data types in Spark

Data type	Value assigned in Python	API to instantiate
`BinaryType`	`bytearray`	`BinaryType()`
`TimestampType`	`datetime.datetime`	`TimestampType()`
`DateType`	`datetime.date`	`DateType()`
`ArrayType`	List, tuple, or array	`ArrayType(dataType, [nullable])`
`MapType`	`dict`	`MapType(keyType, valueType, [nullable])`
`StructType`	List or tuple	`StructType([fields])`
`StructField`	A value type corresponding to the type of this field	`StructField(name, dataType, [nullable])`

While these tables showcase the myriad types supported, it's far more important to see how these types come together when you define a schema for your data.

Schemas and Creating DataFrames

A *schema* in Spark defines the column names and associated data types for a DataFrame. Most often, schemas come into play when you are reading structured data from an external data source (more on this in the next chapter). Defining a schema up front as opposed to taking a schema-on-read approach offers three benefits:

- You relieve Spark from the onus of inferring data types.
- You prevent Spark from creating a separate job just to read a large portion of your file to ascertain the schema, which for a large data file can be expensive and time-consuming.
- You can detect errors early if data doesn't match the schema.

So, we encourage you to always define your schema up front whenever you want to read a large file from a data source. For a short illustration, let's define a schema for the data in Table 3-1 and use that schema to create a DataFrame.

Two ways to define a schema

Spark allows you to define a schema in two ways. One is to define it programmatically, and the other is to employ a Data Definition Language (DDL) string, which is much simpler and easier to read.

To define a schema programmatically for a DataFrame with three named columns, `author`, `title`, and `pages`, you can use the Spark DataFrame API. For example:

```
// In Scala
import org.apache.spark.sql.types._
val schema = StructType(Array(StructField("author", StringType, false),
  StructField("title", StringType, false),
  StructField("pages", IntegerType, false)))
```

```
# In Python
from pyspark.sql.types import *
schema = StructType([StructField("author", StringType(), False),
  StructField("title", StringType(), False),
  StructField("pages", IntegerType(), False)])
```

Defining the same schema using DDL is much simpler:

```
// In Scala
val schema = "author STRING, title STRING, pages INT"
```

```
# In Python
schema = "author STRING, title STRING, pages INT"
```

You can choose whichever way you like to define a schema. For many examples, we will use both:

```
# In Python
from pyspark.sql import SparkSession

# Define schema for our data using DDL
schema = "`Id` INT, `First` STRING, `Last` STRING, `Url` STRING,
```

```
  `Published` STRING, `Hits` INT, `Campaigns` ARRAY<STRING>"

# Create our static data
data = [[1, "Jules", "Damji", "https://tinyurl.1", "1/4/2016", 4535, ["twitter",
"LinkedIn"]],
       [2, "Brooke","Wenig", "https://tinyurl.2", "5/5/2018", 8908, ["twitter",
"LinkedIn"]],
       [3, "Denny", "Lee", "https://tinyurl.3", "6/7/2019", 7659, ["web",
"twitter", "FB", "LinkedIn"]],
       [4, "Tathagata", "Das", "https://tinyurl.4", "5/12/2018", 10568,
["twitter", "FB"]],
       [5, "Matei","Zaharia", "https://tinyurl.5", "5/14/2014", 40578, ["web",
"twitter", "FB", "LinkedIn"]],
       [6, "Reynold", "Xin", "https://tinyurl.6", "3/2/2015", 25568,
["twitter", "LinkedIn"]]
      ]

# Main program
if __name__ == "__main__":
   # Create a SparkSession
   spark = (SparkSession
     .builder
     .appName("Example-3_6")
     .getOrCreate())
   # Create a DataFrame using the schema defined above
   blogs_df = spark.createDataFrame(data, schema)
   # Show the DataFrame; it should reflect our table above
   blogs_df.show()
   # Print the schema used by Spark to process the DataFrame
   print(blogs_df.printSchema())
```

Running this program from the console will produce the following output:

```
$ spark-submit Example-3_6.py
...
+-------+---------+-------+-----------------+---------+-----+------------------+
|Id     |First    |Last   |Url              |Published|Hits |Campaigns         |
+-------+---------+-------+-----------------+---------+-----+------------------+
|1      |Jules    |Damji  |https://tinyurl.1|1/4/2016 |4535 |[twitter,...]     |
|2      |Brooke   |Wenig  |https://tinyurl.2|5/5/2018 |8908 |[twitter,...]     |
|3      |Denny    |Lee    |https://tinyurl.3|6/7/2019 |7659 |[web, twitter...] |
|4      |Tathagata|Das    |https://tinyurl.4|5/12/2018|10568|[twitter, FB]     |
|5      |Matei    |Zaharia|https://tinyurl.5|5/14/2014|40578|[web, twitter,...]|
|6      |Reynold  |Xin    |https://tinyurl.6|3/2/2015 |25568|[twitter,...]     |
+-------+---------+-------+-----------------+---------+-----+------------------+

root
 |-- Id: integer (nullable = false)
 |-- First: string (nullable = false)
 |-- Last: string (nullable = false)
 |-- Url: string (nullable = false)
 |-- Published: string (nullable = false)
 |-- Hits: integer (nullable = false)
 |-- Campaigns: array (nullable = false)
 |    |-- element: string (containsNull = false)
```

If you want to use this schema elsewhere in your code, simply execute `blogs_df.schema` and it will return the schema definition:

```
StructType(List(StructField("Id",IntegerType,false),
StructField("First",StringType,false),
StructField("Last",StringType,false),
StructField("Url",StringType,false),
StructField("Published",StringType,false),
```

```
StructField("Hits",IntegerType,false),
StructField("Campaigns",ArrayType(StringType,true),false)))
```

As you can observe, the DataFrame layout matches that of Table 3-1 along with the respective data types and schema output.

If you were to read the data from a JSON file instead of creating static data, the schema definition would be identical. Let's illustrate the same code with a Scala example, this time reading from a JSON file:

```
// In Scala
package main.scala.chapter3

import org.apache.spark.sql.SparkSession
import org.apache.spark.sql.types._

object Example3_7 {
 def main(args: Array[String]) {

   val spark = SparkSession
     .builder
     .appName("Example-3_7")
     .getOrCreate()

   if (args.length <= 0) {
     println("usage Example3_7 <file path to blogs.json>")
     System.exit(1)
   }
   // Get the path to the JSON file
   val jsonFile = args(0)
   // Define our schema programmatically
```

```
    val schema = StructType(Array(StructField("Id", IntegerType, false),
      StructField("First", StringType, false),
      StructField("Last", StringType, false),
      StructField("Url", StringType, false),
      StructField("Published", StringType, false),
      StructField("Hits", IntegerType, false),
      StructField("Campaigns", ArrayType(StringType), false)))

    // Create a DataFrame by reading from the JSON file
    // with a predefined schema
    val blogsDF = spark.read.schema(schema).json(jsonFile)
    // Show the DataFrame schema as output
    blogsDF.show(false)
    // Print the schema
    println(blogsDF.printSchema)
    println(blogsDF.schema)
  }
}
```

Not surprisingly, the output from the Scala program is no different than that from the Python program:

```
+---+---------+-------+-----------------+---------+-----+----------------------+
|Id |First    |Last   |Url              |Published|Hits |Campaigns             |
+---+---------+-------+-----------------+---------+-----+----------------------+
|1  |Jules    |Damji  |https://tinyurl.1|1/4/2016 |4535 |[twitter, LinkedIn]   |
|2  |Brooke   |Wenig  |https://tinyurl.2|5/5/2018 |8908 |[twitter, LinkedIn]   |
|3  |Denny    |Lee    |https://tinyurl.3|6/7/2019 |7659 |[web, twitter,...]    |
|4  |Tathagata|Das    |https://tinyurl.4|5/12/2018|10568|[twitter, FB]         |
|5  |Matei    |Zaharia|https://tinyurl.5|5/14/2014|40578|[web, twitter, FB,...]|
|6  |Reynold  |Xin    |https://tinyurl.6|3/2/2015 |25568|[twitter, LinkedIn]   |
+---+---------+-------+-----------------+---------+-----+----------------------+
```

```
root
 |-- Id: integer (nullable = true)
 |-- First: string (nullable = true)
 |-- Last: string (nullable = true)
 |-- Url: string (nullable = true)
 |-- Published: string (nullable = true)
 |-- Hits: integer (nullable = true)
 |-- Campaigns: array (nullable = true)
 |    |-- element: string (containsNull = true)

StructType(StructField("Id",IntegerType,true),
    StructField("First",StringType,true),
    StructField("Last",StringType,true),
    StructField("Url",StringType,true),
    StructField("Published",StringType,true),
    StructField("Hits",IntegerType,true),
    StructField("Campaigns",ArrayType(StringType,true),true))
```

Now that you have an idea of how to use structured data and schemas in DataFrames, let's focus on DataFrame columns and rows and what it means to operate on them with the DataFrame API.

Columns and Expressions

As mentioned previously, named columns in DataFrames are conceptually similar to named columns in pandas or R DataFrames or in an RDBMS table: they describe a type of field. You can list all the columns by their names, and you can perform operations on their values using relational or computational expressions. In

Spark's supported languages, columns are objects with public methods (represented by the `Column` type).

You can also use logical or mathematical expressions on columns. For example, you could create a simple expression using `expr("columnName * 5")` or `(expr("columnName - 5") > col(anothercolumnName))`, where `columnName` is a Spark type (integer, string, etc.). `expr()` is part of the `pyspark.sql.functions` (Python) and `org.apache.spark.sql.functions` (Scala) packages. Like any other function in those packages, `expr()` takes arguments that Spark will parse as an expression, computing the result.

NOTE

Scala, Java, and Python all have public methods associated with columns. You'll note that the Spark documentation refers to both `col` and `Column`. `Column` is the name of the object, while `col()` is a standard built-in function that returns a `Column`.

Let's take a look at some examples of what we can do with columns in Spark. Each example is followed by its output:

```
// In Scala
scala> import org.apache.spark.sql.functions._
scala> blogsDF.columns
res2: Array[String] = Array(Campaigns, First, Hits, Id, Last, Published, Url)

// Access a particular column with col and it returns a Column type
scala> blogsDF.col("Id")
res3: org.apache.spark.sql.Column = id
```

```
// Use an expression to compute a value
scala> blogsDF.select(expr("Hits * 2")).show(2)
// or use col to compute value
scala> blogsDF.select(col("Hits") * 2).show(2)

+----------+
|(Hits * 2)|
+----------+
|      9070|
|     17816|
+----------+

// Use an expression to compute big hitters for blogs
// This adds a new column, Big Hitters, based on the conditional expression
blogsDF.withColumn("Big Hitters", (expr("Hits > 10000"))).show()

+---+---------+-------+---+---------+-----+--------------------+-----------+
| Id|    First|   Last|Url|Published| Hits|           Campaigns|Big Hitters|
+---+---------+-------+---+---------+-----+--------------------+-----------+
|  1|    Jules|  Damji|...| 1/4/2016| 4535| [twitter, LinkedIn]|      false|
|  2|   Brooke|  Wenig|...| 5/5/2018| 8908| [twitter, LinkedIn]|      false|
|  3|    Denny|    Lee|...| 6/7/2019| 7659|[web, twitter, FB...|      false|
|  4|Tathagata|    Das|...|5/12/2018|10568|       [twitter, FB]|       true|
|  5|    Matei|Zaharia|...|5/14/2014|40578|[web, twitter, FB...|       true|
|  6|  Reynold|    Xin|...| 3/2/2015|25568| [twitter, LinkedIn]|       true|
+---+---------+-------+---+---------+-----+--------------------+-----------+

// Concatenate three columns, create a new column, and show the
// newly created concatenated column
blogsDF
  .withColumn("AuthorsId", (concat(expr("First"), expr("Last"), expr("Id"))))
  .select(col("AuthorsId"))
  .show(4)
```

```
+-------------+
|    AuthorsId|
+-------------+
|  JulesDamji1|
| BrookeWenig2|
|    DennyLee3|
|TathagataDas4|
+-------------+

// These statements return the same value, showing that
// expr is the same as a col method call
blogsDF.select(expr("Hits")).show(2)
blogsDF.select(col("Hits")).show(2)
blogsDF.select("Hits").show(2)

+-----+
| Hits|
+-----+
| 4535|
| 8908|
+-----+

// Sort by column "Id" in descending order
blogsDF.sort(col("Id").desc).show()
blogsDF.sort($"Id".desc).show()

+--------------------+---------+-----+---+-------+---------+-----------------+
|           Campaigns|    First| Hits| Id|   Last|Published|              Url|
+--------------------+---------+-----+---+-------+---------+-----------------+
| [twitter, LinkedIn]|  Reynold|25568|  6|    Xin| 3/2/2015|https://tinyurl.6|
|[web, twitter, FB...|    Matei|40578|  5|Zaharia|5/14/2014|https://tinyurl.5|
|       [twitter, FB]|Tathagata|10568|  4|    Das|5/12/2018|https://tinyurl.4|
```

```
|[web, twitter, FB...|    Denny| 7659|  3|    Lee| 6/7/2019|https://tinyurl.3|
| [twitter, LinkedIn]|   Brooke| 8908|  2|  Wenig| 5/5/2018|https://tinyurl.2|
| [twitter, LinkedIn]|    Jules| 4535|  1|  Damji| 1/4/2016|https://tinyurl.1|
+-------------------+---------+-----+---+-------+---------+-----------------+
```

In this last example, the expressions `blogs_df.sort(col("Id").desc)` and `blogsDF.sort($"Id".desc)` are identical. They both sort the DataFrame column named `Id` in descending order: one uses an explicit function, `col("Id")`, to return a `Column` object, while the other uses `$` before the name of the column, which is a function in Spark that converts column named `Id` to a `Column`.

NOTE

We have only scratched the surface here, and employed just a couple of methods on `Column` objects. For a complete list of all public methods for `Column` objects, we refer you to the Spark documentation.

`Column` objects in a DataFrame can't exist in isolation; each column is part of a row in a record and all the rows together constitute a DataFrame, which as we will see later in the chapter is really a `Dataset[Row]` in Scala.

Rows

A row in Spark is a generic `Row` object, containing one or more columns. Each column may be of the same data type (e.g., integer or string), or they can have different types (integer, string, map, array, etc.). Because `Row` is an object in Spark and an ordered collection of fields, you can instantiate a `Row` in each of Spark's supported languages and access its fields by an index starting at 0:

```
// In Scala
import org.apache.spark.sql.Row
// Create a Row
val blogRow = Row(6, "Reynold", "Xin", "https://tinyurl.6", 255568, "3/2/2015",
  Array("twitter", "LinkedIn"))
// Access using index for individual items
blogRow(1)
res62: Any = Reynold
```

```
# In Python
from pyspark.sql import Row
blog_row = Row(6, "Reynold", "Xin", "https://tinyurl.6", 255568, "3/2/2015",
  ["twitter", "LinkedIn"])
# access using index for individual items
blog_row[1]
'Reynold'
```

`Row` objects can be used to create DataFrames if you need them for quick interactivity and exploration:

```
# In Python
rows = [Row("Matei Zaharia", "CA"), Row("Reynold Xin", "CA")]
authors_df = spark.createDataFrame(rows, ["Authors", "State"])
authors_df.show()
```

```
// In Scala
val rows = Seq(("Matei Zaharia", "CA"), ("Reynold Xin", "CA"))
val authorsDF = rows.toDF("Author", "State")
authorsDF.show()
```

```
+-------------+-----+
|       Author|State|
+-------------+-----+
|Matei Zaharia|   CA|
|  Reynold Xin|   CA|
+-------------+-----+
```

In practice, though, you will usually want to read DataFrames from a file as illustrated earlier. In most cases, because your files are going to be huge, defining a schema and using it is a quicker and more efficient way to create DataFrames.

After you have created a large distributed DataFrame, you are going to want to perform some common data operations on it. Let's examine some of the Spark operations you can perform with high-level relational operators in the Structured APIs.

Common DataFrame Operations

To perform common data operations on DataFrames, you'll first need to load a DataFrame from a data source that holds your structured data. Spark provides an interface, `DataFrameReader`, that enables you to read data into a DataFrame from myriad data sources in formats such as JSON, CSV, Parquet, Text, Avro, ORC, etc. Likewise, to write a DataFrame back to a data source in a particular format, Spark uses `DataFrameWriter`.

Using DataFrameReader and DataFrameWriter

Reading and writing are simple in Spark because of these high-level abstractions and contributions from the community to connect to a wide variety of data sources, including common NoSQL stores, RDBMSs, streaming engines such as Apache Kafka and Kinesis, and more.

To get started, let's read a large CSV file containing data on San Francisco Fire Department calls.[1] As noted previously, we will define a schema for this file and use the `DataFrameReader` class and its methods to tell Spark what to do. Because this file contains 28 columns and over 4,380,660 records,[2] it's more efficient to define a schema than have Spark infer it.

NOTE

If you don't want to specify the schema, Spark can infer schema from a sample at a lesser cost. For example, you can use the `samplingRatio` option:

```
// In Scala
val sampleDF = spark
  .read
  .option("samplingRatio", 0.001)
  .option("header", true)
  .csv("""/databricks-datasets/learning-spark-v2/
  sf-fire/sf-fire-calls.csv""")
```

Let's take a look at how to do this:

```python
# In Python, define a schema
from pyspark.sql.types import *

# Programmatic way to define a schema
fire_schema = StructType([StructField('CallNumber', IntegerType(), True),
                StructField('UnitID', StringType(), True),
                StructField('IncidentNumber', IntegerType(), True),
                StructField('CallType', StringType(), True),
                StructField('CallDate', StringType(), True),
                StructField('WatchDate', StringType(), True),
                StructField('CallFinalDisposition', StringType(), True),
                StructField('AvailableDtTm', StringType(), True),
                StructField('Address', StringType(), True),
                StructField('City', StringType(), True),
                StructField('Zipcode', IntegerType(), True),
                StructField('Battalion', StringType(), True),
                StructField('StationArea', StringType(), True),
                StructField('Box', StringType(), True),
                StructField('OriginalPriority', StringType(), True),
                StructField('Priority', StringType(), True),
                StructField('FinalPriority', IntegerType(), True),
                StructField('ALSUnit', BooleanType(), True),
                StructField('CallTypeGroup', StringType(), True),
                StructField('NumAlarms', IntegerType(), True),
                StructField('UnitType', StringType(), True),
                StructField('UnitSequenceInCallDispatch', IntegerType(), True),
                StructField('FirePreventionDistrict', StringType(), True),
                StructField('SupervisorDistrict', StringType(), True),
                StructField('Neighborhood', StringType(), True),
                StructField('Location', StringType(), True),
                StructField('RowID', StringType(), True),
                StructField('Delay', FloatType(), True)])
```

```
# Use the DataFrameReader interface to read a CSV file
sf_fire_file = "/databricks-datasets/learning-spark-v2/sf-fire/sf-fire-calls.csv"
fire_df = spark.read.csv(sf_fire_file, header=True, schema=fire_schema)


// In Scala it would be similar
val fireSchema = StructType(Array(StructField("CallNumber", IntegerType, true),
                   StructField("UnitID", StringType, true),
                   StructField("IncidentNumber", IntegerType, true),
                   StructField("CallType", StringType, true),
                   StructField("Location", StringType, true),
                   ...
                   ...
                   StructField("Delay", FloatType, true)))

// Read the file using the CSV DataFrameReader
val sfFireFile="/databricks-datasets/learning-spark-v2/sf-fire/sf-fire-calls.csv"
val fireDF = spark.read.schema(fireSchema)
  .option("header", "true")
  .csv(sfFireFile)
```

The `spark.read.csv()` function reads in the CSV file and returns a DataFrame of rows and named columns with the types dictated in the schema.

To write the DataFrame into an external data source in your format of choice, you can use the `DataFrameWriter` interface. Like `DataFrameReader`, it supports multiple data sources. Parquet, a popular columnar format, is the default format; it uses snappy compression to compress the data. If the DataFrame is written as Parquet, the schema is preserved as part of the Parquet metadata. In this case, subsequent reads back into a DataFrame do not require you to manually supply a schema.

Saving a DataFrame as a Parquet file or SQL table

A common data operation is to explore and transform your data, and then persist the DataFrame in Parquet format or save it as a SQL table. Persisting a transformed DataFrame is as easy as reading it. For example, to persist the DataFrame we were just working with as a file after reading it you would do the following:

```
// In Scala to save as a Parquet file
val parquetPath = ...
fireDF.write.format("parquet").save(parquetPath)
```

```
# In Python to save as a Parquet file
parquet_path = ...
fire_df.write.format("parquet").save(parquet_path)
```

Alternatively, you can save it as a table, which registers metadata with the Hive metastore (we will cover SQL managed and unmanaged tables, metastores, and DataFrames in the next chapter):

```
// In Scala to save as a table
val parquetTable = ... // name of the table
fireDF.write.format("parquet").saveAsTable(parquetTable)
```

```
# In Python
parquet_table = ... # name of the table
fire_df.write.format("parquet").saveAsTable(parquet_table)
```

Let's walk through some common operations to perform on DataFrames after you have read the data.

Transformations and actions

Now that you have a distributed DataFrame composed of San Francisco Fire Department calls in memory, the first thing you as a developer will want to do is examine your data to see what the columns look like. Are they of the correct types? Do any of them need to be converted to different types? Do they have `null` values?

In "Transformations, Actions, and Lazy Evaluation" in Chapter 2, you got a glimpse of how transformations and actions are used to operate on DataFrames, and saw some common examples of each. What can we find out from our San Francisco Fire Department calls using these?

Projections and filters

A *projection* in relational parlance is a way to return only the rows matching a certain relational condition by using filters. In Spark, projections are done with the `select()` method, while filters can be expressed using the `filter()` or `where()` method. We can use this technique to examine specific aspects of our SF Fire Department data set:

```
# In Python
few_fire_df = (fire_df
  .select("IncidentNumber", "AvailableDtTm", "CallType")
  .where(col("CallType") != "Medical Incident"))
few_fire_df.show(5, truncate=False)
```

```
// In Scala
val fewFireDF = fireDF
  .select("IncidentNumber", "AvailableDtTm", "CallType")
  .where($"CallType" =!= "Medical Incident")
fewFireDF.show(5, false)

+--------------+----------------------+--------------+
|IncidentNumber|AvailableDtTm         |CallType      |
+--------------+----------------------+--------------+
|2003235       |01/11/2002 01:47:00 AM|Structure Fire|
|2003235       |01/11/2002 01:51:54 AM|Structure Fire|
|2003235       |01/11/2002 01:47:00 AM|Structure Fire|
|2003235       |01/11/2002 01:47:00 AM|Structure Fire|
|2003235       |01/11/2002 01:51:17 AM|Structure Fire|
+--------------+----------------------+--------------+
only showing top 5 rows
```

What if we want to know how many distinct `CallType` s were recorded as the causes of the fire calls? These simple and expressive queries do the job:

```
# In Python, return number of distinct types of calls using countDistinct()
from pyspark.sql.functions import *
(fire_df
  .select("CallType")
  .where(col("CallType").isNotNull())
  .agg(countDistinct("CallType").alias("DistinctCallTypes"))
  .show())
```

```
// In Scala
import org.apache.spark.sql.functions._
```

```
fireDF
  .select("CallType")
  .where(col("CallType").isNotNull)
  .agg(countDistinct('CallType) as 'DistinctCallTypes)
  .show()

+-----------------+
|DistinctCallTypes|
+-----------------+
|                32|
+-----------------+
```

We can list the distinct call types in the data set using these queries:

```
# In Python, filter for only distinct non-null CallTypes from all the rows
(fire_df
  .select("CallType")
  .where(col("CallType").isNotNull())
  .distinct()
  .show(10, False))


// In Scala
fireDF
  .select("CallType")
  .where($"CallType".isNotNull())
  .distinct()
  .show(10, false)

Out[20]: 32

+-----------------------------------+
```

```
|CallType                           |
+-----------------------------------+
|Elevator / Escalator Rescue        |
|Marine Fire                        |
|Aircraft Emergency                 |
|Confined Space / Structure Collapse|
|Administrative                     |
|Alarms                             |
|Odor (Strange / Unknown)           |
|Lightning Strike (Investigation)   |
|Citizen Assist / Service Call      |
|HazMat                             |
+-----------------------------------+
only showing top 10 rows
```

Renaming, adding, and dropping columns

Sometimes you want to rename particular columns for reasons of style or convention, and at other times for readability or brevity. The original column names in the SF Fire Department data set had spaces in them. For example, the column name `IncidentNumber` was `Incident Number`. Spaces in column names can be problematic, especially when you want to write or save a DataFrame as a Parquet file (which prohibits this).

By specifying the desired column names in the schema with `StructField`, as we did, we effectively changed all names in the resulting DataFrame.

Alternatively, you could selectively rename columns with the `withColumnRenamed()` method. For instance, let's change the name of our

`Delay` column to `ResponseDelayed inMins` and take a look at the response times that were longer than five minutes:

```
# In Python
new_fire_df = fire_df.withColumnRenamed("Delay", "ResponseDelayedinMins")
(new_fire_df
  .select("ResponseDelayedinMins")
  .where(col("ResponseDelayedinMins") > 5)
  .show(5, False))
```

```
// In Scala
val newFireDF = fireDF.withColumnRenamed("Delay", "ResponseDelayedinMins")
newFireDF
  .select("ResponseDelayedinMins")
  .where($"ResponseDelayedinMins" > 5)
  .show(5, false)
```

This gives us a new renamed column:

```
+---------------------+
|ResponseDelayedinMins|
+---------------------+
|5.233333             |
|6.9333334            |
|6.116667             |
|7.85                 |
|77.333336            |
+---------------------+
only showing top 5 rows
```

NOTE

Because DataFrame transformations are immutable, when we rename a column using `withColumnRenamed()` we get a new DataFrame while retaining the original with the old column name.

Modifying the contents of a column or its type are common operations during data exploration. In some cases the data is raw or dirty, or its types are not amenable to being supplied as arguments to relational operators. For example, in our SF Fire Department data set, the columns `CallDate`, `WatchDate`, and `AlarmDtTm` are strings rather than either Unix timestamps or SQL dates, both of which Spark supports and can easily manipulate during transformations or actions (e.g., during a date- or time-based analysis of the data).

So how do we convert them into a more usable format? It's quite simple, thanks to some high-level API methods. `spark.sql.functions` has a set of to/from date/timestamp functions such as `to_timestamp()` and `to_date()` that we can use for just this purpose:

```
# In Python
fire_ts_df = (new_fire_df
  .withColumn("IncidentDate", to_timestamp(col("CallDate"), "MM/dd/yyyy"))
  .drop("CallDate")
  .withColumn("OnWatchDate", to_timestamp(col("WatchDate"), "MM/dd/yyyy"))
  .drop("WatchDate")
  .withColumn("AvailableDtTS", to_timestamp(col("AvailableDtTm"),
  "MM/dd/yyyy hh:mm:ss a"))
  .drop("AvailableDtTm"))

# Select the converted columns
```

```
(fire_ts_df
  .select("IncidentDate", "OnWatchDate", "AvailableDtTS")
  .show(5, False))


// In Scala
val fireTsDF = newFireDF
  .withColumn("IncidentDate", to_timestamp(col("CallDate"), "MM/dd/yyyy"))
  .drop("CallDate")
  .withColumn("OnWatchDate", to_timestamp(col("WatchDate"), "MM/dd/yyyy"))
  .drop("WatchDate")
  .withColumn("AvailableDtTS", to_timestamp(col("AvailableDtTm"),
  "MM/dd/yyyy hh:mm:ss a"))
  .drop("AvailableDtTm")

// Select the converted columns
fireTsDF
  .select("IncidentDate", "OnWatchDate", "AvailableDtTS")
  .show(5, false)
```

Those queries pack quite a punch—a number of things are happening. Let's unpack what they do:

1. Convert the existing column's data type from string to a Spark-supported timestamp.
2. Use the new format specified in the format string `"MM/dd/yyyy"` or `"MM/dd/yyyy hh:mm:ss a"` where appropriate.
3. After converting to the new data type, `drop()` the old column and append the new one specified in the first argument to the `withColumn()` method.
4. Assign the new modified DataFrame to `fire_ts_df`.

The queries result in three new columns:

```
+-------------------+-------------------+-------------------+
|IncidentDate       |OnWatchDate        |AvailableDtTS      |
+-------------------+-------------------+-------------------+
|2002-01-11 00:00:00|2002-01-10 00:00:00|2002-01-11 01:58:43|
|2002-01-11 00:00:00|2002-01-10 00:00:00|2002-01-11 02:10:17|
|2002-01-11 00:00:00|2002-01-10 00:00:00|2002-01-11 01:47:00|
|2002-01-11 00:00:00|2002-01-10 00:00:00|2002-01-11 01:51:54|
|2002-01-11 00:00:00|2002-01-10 00:00:00|2002-01-11 01:47:00|
+-------------------+-------------------+-------------------+
only showing top 5 rows
```

Now that we have modified the dates, we can query using functions from `spark.sql.functions` like `dayofmonth()`, `dayofyear()`, and `dayofweek()` to explore our data further. We could find out how many calls were logged in the last seven days, or we could see how many years' worth of Fire Department calls are included in the data set with this query:

```
# In Python
(fire_ts_df
  .select(year('IncidentDate'))
  .distinct()
  .orderBy(year('IncidentDate'))
  .show())
```

```
// In Scala
fireTsDF
  .select(year($"IncidentDate"))
  .distinct()
```

```
  .orderBy(year($"IncidentDate"))
  .show()
+------------------+
|year(IncidentDate)|
+------------------+
|              2000|
|              2001|
|              2002|
|              2003|
|              2004|
|              2005|
|              2006|
|              2007|
|              2008|
|              2009|
|              2010|
|              2011|
|              2012|
|              2013|
|              2014|
|              2015|
|              2016|
|              2017|
|              2018|
+------------------+
```

So far in this section, we have explored a number of common data operations: reading and writing DataFrames; defining a schema and using it when reading in a DataFrame; saving a DataFrame as a Parquet file or table; projecting and filtering selected columns from an existing DataFrame; and modifying, renaming, and dropping columns.

One final common operation is grouping data by values in a column and aggregating the data in some way, like simply counting it. This pattern of grouping and counting is as common as projecting and filtering. Let's have a go at it.

Aggregations

What if we want to know what the most common types of fire calls were, or what zip codes accounted for the most calls? These kinds of questions are common in data analysis and exploration.

A handful of transformations and actions on DataFrames, such as `groupBy()`, `orderBy()`, and `count()`, offer the ability to aggregate by column names and then aggregate counts across them.

NOTE

For larger DataFrames on which you plan to conduct frequent or repeated queries, you could benefit from caching. We will cover DataFrame caching strategies and their benefits in later chapters.

Let's take our first question: what were the most common types of fire calls?

```
# In Python
(fire_ts_df
  .select("CallType")
  .where(col("CallType").isNotNull())
  .groupBy("CallType")
  .count()
```

```
  .orderBy("count", ascending=False)
  .show(n=10, truncate=False))


// In Scala
fireTsDF
  .select("CallType")
  .where(col("CallType").isNotNull)
  .groupBy("CallType")
  .count()
  .orderBy(desc("count"))
  .show(10, false)

+-------------------------------+-------+
|CallType                       |count  |
+-------------------------------+-------+
|Medical Incident               |2843475|
|Structure Fire                 |578998 |
|Alarms                         |483518 |
|Traffic Collision              |175507 |
|Citizen Assist / Service Call  |65360  |
|Other                          |56961  |
|Outside Fire                   |51603  |
|Vehicle Fire                   |20939  |
|Water Rescue                   |20037  |
|Gas Leak (Natural and LP Gases)|17284  |
+-------------------------------+-------+
```

From this output we can conclude that the most common call type is Medical Incident.

NOTE

The DataFrame API also offers the `collect()` method, but for extremely large DataFrames this is resource-heavy (expensive) and dangerous, as it can cause out-of-memory (OOM) exceptions. Unlike `count()`, which returns a single number to the driver, `collect()` returns a collection of all the `Row` objects in the entire DataFrame or Dataset. If you want to take a peek at some `Row` records you're better off with `take(n)`, which will return only the first *n* `Row` objects of the DataFrame.

Other common DataFrame operations

Along with all the others we've seen, the DataFrame API provides descriptive statistical methods like `min()`, `max()`, `sum()`, and `avg()`. Let's take a look at some examples showing how to compute them with our SF Fire Department data set.

Here we compute the sum of alarms, the average response time, and the minimum and maximum response times to all fire calls in our data set, importing the PySpark functions in a Pythonic way so as not to conflict with the built-in Python functions:

```
# In Python
import pyspark.sql.functions as F
(fire_ts_df
  .select(F.sum("NumAlarms"), F.avg("ResponseDelayedinMins"),
   F.min("ResponseDelayedinMins"), F.max("ResponseDelayedinMins"))
  .show())
```

```
// In Scala
import org.apache.spark.sql.{functions => F}
fireTsDF
  .select(F.sum("NumAlarms"), F.avg("ResponseDelayedinMins"),
  F.min("ResponseDelayedinMins"), F.max("ResponseDelayedinMins"))
  .show()

+--------------+--------------------------+--------------------------+---------+
|sum(NumAlarms)|avg(ResponseDelayedinMins)|min(ResponseDelayedinMins)|max(...) |
+--------------+--------------------------+--------------------------+---------+
|       4403441|         3.902170335891614|               0.016666668|1879.6167|
+--------------+--------------------------+--------------------------+---------+
```

For more advanced statistical needs common with data science workloads, read the API documentation for methods like `stat()`, `describe()`, `correlation()`, `covariance()`, `sampleBy()`, `approxQuantile()`, `frequentItems()`, and so on.

As you can see, it's easy to compose and chain expressive queries with DataFrames' high-level API and DSL operators. We can't imagine the opacity and comparative unreadability of the code if we were to try to do the same with RDDs!

End-to-End DataFrame Example

There are many possibilities for exploratory data analysis, ETL, and common data operations on the San Francisco Fire Department public data set, above and beyond what we've shown here.

For brevity we won't include all the example code here, but the book's GitHub repo provides Python and Scala notebooks for you to try to complete an end-to-end DataFrame example using this data set. The notebooks explore and answer the following common questions that you might ask, using the DataFrame API and DSL relational operators:

- What were all the different types of fire calls in 2018?
- What months within the year 2018 saw the highest number of fire calls?
- Which neighborhood in San Francisco generated the most fire calls in 2018?
- Which neighborhoods had the worst response times to fire calls in 2018?
- Which week in the year in 2018 had the most fire calls?
- Is there a correlation between neighborhood, zip code, and number of fire calls?
- How can we use Parquet files or SQL tables to store this data and read it back?

So far we have extensively discussed the DataFrame API, one of the Structured APIs that span Spark's MLlib and Structured Streaming components, which we cover later in the book.

Next, we'll shift our focus to the Dataset API and explore how the two APIs provide a unified, structured interface to developers for programming Spark. We'll then examine the relationship between the RDD, DataFrame, and Dataset APIs, and help you determine when to use which API and why.

The Dataset API

As stated earlier in this chapter, Spark 2.0 unified the DataFrame and Dataset APIs as Structured APIs with similar interfaces so that developers would only have to learn a single set of APIs. Datasets take on two characteristics: *typed and untyped* APIs, as shown in Figure 3-1.

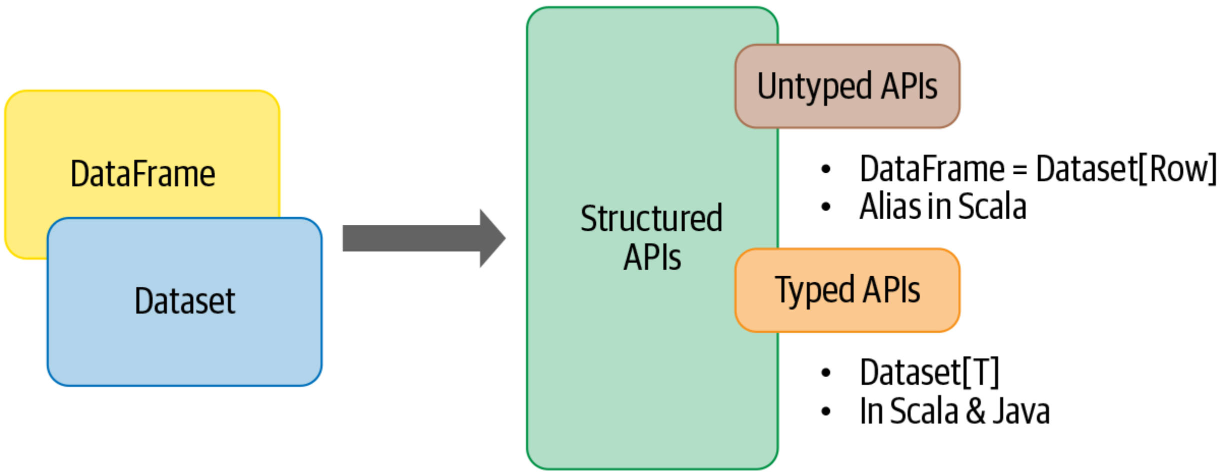


Figure 3-1. Structured APIs in Apache Spark

Conceptually, you can think of a DataFrame in Scala as an alias for a collection of generic objects, `Dataset[Row]`, where a `Row` is a generic untyped JVM object that may hold different types of fields. A Dataset, by contrast, is a collection of strongly typed JVM objects in Scala or a class in Java. Or, as the Dataset documentation puts it, a Dataset is:

> *a strongly typed collection of domain-specific objects that can be transformed in parallel using functional or relational operations. Each Dataset [in Scala] also has an untyped view called a DataFrame, which is a Dataset of* `Row`.

Typed Objects, Untyped Objects, and Generic Rows

In Spark's supported languages, Datasets make sense only in Java and Scala, whereas in Python and R only DataFrames make sense. This is because Python and R are not compile-time type-safe; types are dynamically inferred or assigned during execution, not during compile time. The reverse is true in Scala and Java: types are bound to variables and objects at compile time. In Scala, however, a DataFrame is just an alias for untyped `Dataset[Row]`. Table 3-6 distills it in a nutshell.

Table 3-6. Typed and untyped objects in Spark

Language	Typed and untyped main abstraction	Typed or untyped
Scala	`Dataset[T]` and DataFrame (alias for `Dataset[Row]`)	Both typed and untyped
Java	`Dataset<T>`	Typed
Python	DataFrame	Generic `Row` untyped
R	DataFrame	Generic `Row` untyped

`Row` is a generic object type in Spark, holding a collection of mixed types that can be accessed using an index. Internally, Spark manipulates `Row` objects, converting them to the equivalent types covered in Table 3-2 and Table 3-3. For example, an `Int` as one of your fields in a `Row` will be mapped or converted to `IntegerType` or `IntegerType()` respectively for Scala or Java and Python:

```
// In Scala
import org.apache.spark.sql.Row
val row = Row(350, true, "Learning Spark 2E", null)
```

```
# In Python
from pyspark.sql import Row
row = Row(350, True, "Learning Spark 2E", None)
```

Using an index into the `Row` object, you can access individual fields with its public *getter* methods:

```
// In Scala
row.getInt(0)
res23: Int = 350
row.getBoolean(1)
res24: Boolean = true
row.getString(2)
res25: String = Learning Spark 2E
```

```
# In Python
row[0]
Out[13]: 350
row[1]
Out[14]: True
```

```
row[2]
Out[15]: 'Learning Spark 2E'
```

By contrast, typed objects are actual Java or Scala class objects in the JVM. Each element in a Dataset maps to a JVM object.

Creating Datasets

As with creating DataFrames from data sources, when creating a Dataset you have to know the schema. In other words, you need to know the data types. Although with JSON and CSV data it's possible to infer the schema, for large data sets this is resource-intensive (expensive). When creating a Dataset in Scala, the easiest way to specify the schema for the resulting Dataset is to use a case class. In Java, JavaBean classes are used (we further discuss JavaBean and Scala case class in Chapter 6).

Scala: Case classes

When you wish to instantiate your own domain-specific object as a Dataset, you can do so by defining a case class in Scala. As an example, let's look at a collection of readings from Internet of Things (IoT) devices in a JSON file (we use this file in the end-to-end example later in this section).

Our file has rows of JSON strings that look as follows:


```
{"device_id": 198164, "device_name": "sensor-pad-198164owomcJZ", "ip":
"80.55.20.25", "cca2": "PL", "cca3": "POL", "cn": "Poland", "latitude":
53.080000, "longitude": 18.620000, "scale": "Celsius", "temp": 21,
```

```
"humidity": 65, "battery_level": 8, "c02_level": 1408,"lcd": "red",
"timestamp" :1458081226051}
```

To express each JSON entry as `DeviceIoTData`, a domain-specific object, we can define a Scala case class:

```
case class DeviceIoTData (battery_level: Long, c02_level: Long,
cca2: String, cca3: String, cn: String, device_id: Long,
device_name: String, humidity: Long, ip: String, latitude: Double,
lcd: String, longitude: Double, scale:String, temp: Long,
timestamp: Long)
```

Once defined, we can use it to read our file and convert the returned `Dataset[Row]` into `Dataset[DeviceIoTData]` (output truncated to fit on the page):

```
// In Scala
val ds = spark.read
 .json("/databricks-datasets/learning-spark-v2/iot-devices/iot_devices.json")
 .as[DeviceIoTData]

ds: org.apache.spark.sql.Dataset[DeviceIoTData] = [battery_level...]

ds.show(5, false)

+-------------|---------|----|----|-------------|---------|---+
|battery_level|c02_level|cca2|cca3|cn           |device_id|...|
+-------------|---------|----|----|-------------|---------|---+
|8            |868      |US  |USA |United States|1        |...|
|7            |1473     |NO  |NOR |Norway       |2        |...|
```

```
|2            |1556     |IT  |ITA |Italy        |3        |...|
|6            |1080     |US  |USA |United States|4        |...|
|4            |931      |PH  |PHL |Philippines  |5        |...|
+-------------|---------|----|----|-------------|---------|---+
only showing top 5 rows
```

Dataset Operations

Just as you can perform transformations and actions on DataFrames, so you can with Datasets. Depending on the kind of operation, the results will vary:

```
// In Scala
val filterTempDS = ds.filter({d => {d.temp > 30 && d.humidity > 70})

filterTempDS: org.apache.spark.sql.Dataset[DeviceIoTData] = [battery_level...]

filterTempDS.show(5, false)

+-------------|---------|----|----|-------------|---------|---+
|battery_level|c02_level|cca2|cca3|cn           |device_id|...|
+-------------|---------|----|----|-------------|---------|---+
|0            |1466     |US  |USA |United States|17       |...|
|9            |986      |FR  |FRA |France       |48       |...|
|8            |1436     |US  |USA |United States|54       |...|
|4            |1090     |US  |USA |United States|63       |...|
|4            |1072     |PH  |PHL |Philippines  |81       |...|
+-------------|---------|----|----|-------------|---------|---+
only showing top 5 rows
```

In this query, we used a function as an argument to the Dataset method `filter()`. This is an overloaded method with many signatures. The version we used, `filter(func: (T) > Boolean): Dataset[T]`, takes a lambda function, `func: (T) > Boolean`, as its argument.

The argument to the lambda function is a JVM object of type `DeviceIoTData`. As such, we can access its individual data fields using the dot (`.`) notation, like you would in a Scala class or JavaBean.

Another thing to note is that with DataFrames, you express your `filter()` conditions as SQL-like DSL operations, which are language-agnostic (as we saw earlier in the fire calls examples). With Datasets, we use language-native expressions as Scala or Java code.

Here's another example that results in another, smaller Dataset:

```
// In Scala
case class DeviceTempByCountry(temp: Long, device_name: String, device_id: Long,
  cca3: String)
val dsTemp = ds
  .filter(d => {d.temp > 25})
  .map(d => (d.temp, d.device_name, d.device_id, d.cca3))
  .toDF("temp", "device_name", "device_id", "cca3")
  .as[DeviceTempByCountry]
dsTemp.show(5, false)

+----+---------------------+---------+----+
|temp|device_name          |device_id|cca3|
+----+---------------------+---------+----+
|34  |meter-gauge-1xbYRYcj |1        |USA |
|28  |sensor-pad-4mzWkz    |4        |USA |
```

```
|27   |sensor-pad-6al7RTAobR|6        |USA |
|27   |sensor-pad-8xUD6pzsQI|8        |JPN |
|26   |sensor-pad-10BsywSYUF|10       |USA |
+----+--------------------+---------+----+
only showing top 5 rows
```

Or you can inspect only the first row of your Dataset:

```
val device = dsTemp.first()
println(device)

device: DeviceTempByCountry =
DeviceTempByCountry(34,meter-gauge-1xbYRYcj,1,USA)
```

Alternatively, you could express the same query using column names and then cast to a `Dataset[DeviceTempByCountry]`:

```
// In Scala
val dsTemp2 = ds
  .select($"temp", $"device_name", $"device_id", $"device_id", $"cca3")
  .where("temp > 25")
  .as[DeviceTempByCountry]
```

NOTE

Semantically, `select()` is like `map()` in the previous query, in that both of these queries select fields and generate equivalent results.

To recap, the operations we can perform on Datasets— `filter()` , `map()` , `groupBy()` , `select()` , `take()` , etc.—are similar to the ones on DataFrames. In a way, Datasets are similar to RDDs in that they provide a similar interface to its aforementioned methods and compile-time safety but with a much easier to read and an object-oriented programming interface.

When we use Datasets, the underlying Spark SQL engine handles the creation, conversion, serialization, and deserialization of the JVM objects. It also takes care of off-Java heap memory management with the help of Dataset encoders. (We will talk more about Datasets and memory management in Chapter 6.)

End-to-End Dataset Example

In this end-to-end Dataset example you'll conduct similar exploratory data analysis, ETL (extract, transform, and load), and data operations as in the DataFrame example, using the IoT data set. This data set is small and fake, but our main goal here is to illustrate the clarity with which you can express queries with Datasets and the readability of those queries, just as we did with DataFrames.

Again, for brevity, we won't include all the example code here; however, we have furnished the notebook in the GitHub repo. The notebook explores common operations you might conduct with this data set. Using the Dataset API, we attempt to do the following:

1. Detect failing devices with battery levels below a threshold.
2. Identify offending countries with high levels of CO2 emissions.
3. Compute the min and max values for temperature, battery level, CO2, and humidity.
4. Sort and group by average temperature, CO2, humidity, and country.

DataFrames Versus Datasets

By now you may be wondering why and when you should use DataFrames or Datasets. In many cases either will do, depending on the languages you are working in, but there are some situations where one is preferable to the other. Here are a few examples:

- If you want to tell Spark *what to do*, not *how to do it*, use DataFrames or Datasets.
- If you want rich semantics, high-level abstractions, and DSL operators, use DataFrames or Datasets.
- If you want strict compile-time type safety and don't mind creating multiple case classes for a specific `Dataset[T]`, use Datasets.
- If your processing demands high-level expressions, filters, maps, aggregations, computing averages or sums, SQL queries, columnar access, or use of relational operators on semi-structured data, use DataFrames or Datasets.
- If your processing dictates relational transformations similar to SQL-like queries, use DataFrames.
- If you want to take advantage of and benefit from Tungsten's efficient serialization with Encoders, use Datasets.
- If you want unification, code optimization, and simplification of APIs across Spark components, use DataFrames.
- If you are an R user, use DataFrames.
- If you are a Python user, use DataFrames and drop down to RDDs if you need more control.
- If you want space and speed efficiency, use DataFrames.
- If you want errors caught during compilation rather than at runtime, choose the appropriate API as depicted in Figure 3-2.

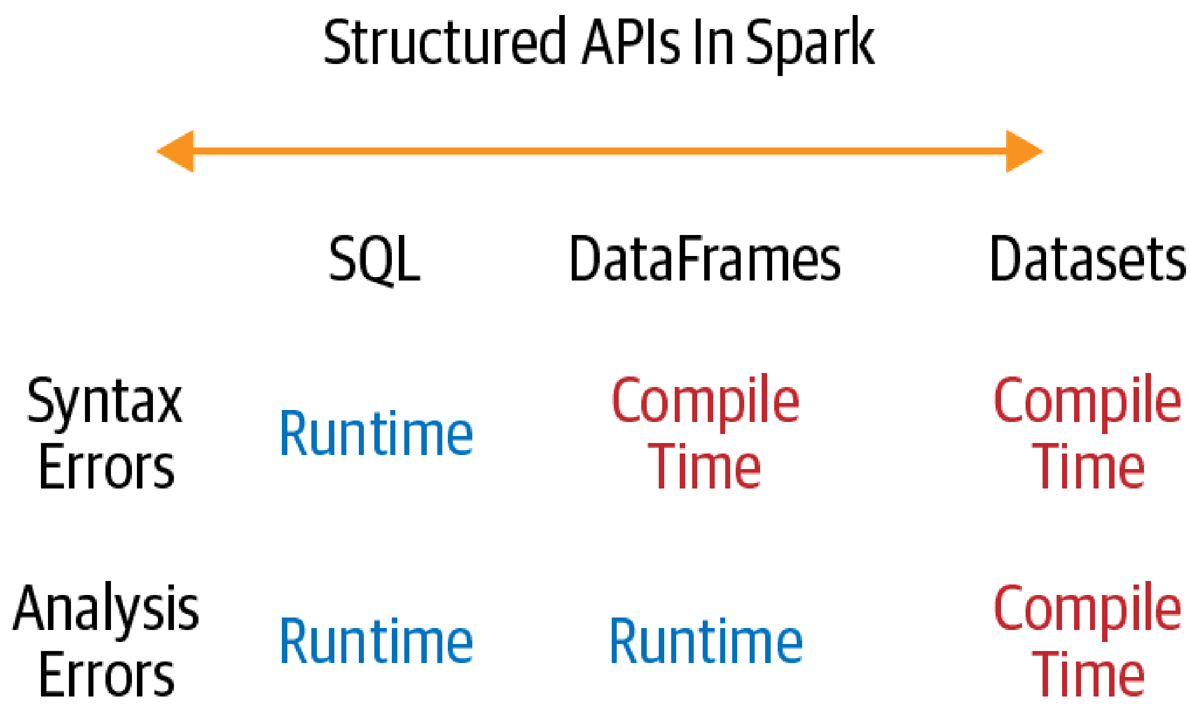


Figure 3-2. When errors are detected using the Structured APIs

When to Use RDDs

You may ask: Are RDDs being relegated to second-class citizens? Are they being deprecated? The answer is a resounding *no*! The RDD API will continue to be supported, although all future development work in Spark 2.x and Spark 3.0 will continue to have a DataFrame interface and semantics rather than using RDDs.

There are some scenarios where you'll want to consider using RDDs, such as when you:

- Are using a third-party package that's written using RDDs

- Can forgo the code optimization, efficient space utilization, and performance benefits available with DataFrames and Datasets
- Want to precisely instruct Spark *how to do* a query

What's more, you can seamlessly move between DataFrames or Datasets and RDDs at will using a simple API method call, `df.rdd`. (Note, however, that this does have a cost and should be avoided unless necessary.) After all, DataFrames and Datasets are built on top of RDDs, and they get decomposed to compact RDD code during whole-stage code generation, which we discuss in the next section.

Finally, the preceding sections provided some intuition on how Structured APIs in Spark enable developers to use easy and friendly APIs to compose expressive queries on structured data. In other words, you tell Spark *what to do*, not *how to do it*, using high-level operations, and it ascertains the most efficient way to build a query and generates compact code for you.

This process of building efficient queries and generating compact code is the job of the Spark SQL engine. It's the substrate upon which the Structured APIs we've been looking at are built. Let's peek under the hood at that engine now.

Spark SQL and the Underlying Engine

At a programmatic level, Spark SQL allows developers to issue ANSI SQL:2003–compatible queries on structured data with a schema. Since its introduction in Spark 1.3, Spark SQL has evolved into a substantial engine upon which many high-level structured functionalities have been built. Apart from allowing you to issue SQL-like queries on your data, the Spark SQL engine:

- Unifies Spark components and permits abstraction to DataFrames/Datasets in Java, Scala, Python, and R, which simplifies working with structured data sets.
- Connects to the Apache Hive metastore and tables.
- Reads and writes structured data with a specific schema from structured file formats (JSON, CSV, Text, Avro, Parquet, ORC, etc.) and converts data into temporary tables.
- Offers an interactive Spark SQL shell for quick data exploration.
- Provides a bridge to (and from) external tools via standard database JDBC/ODBC connectors.
- Generates optimized query plans and compact code for the JVM, for final execution.

Figure 3-3 shows the components that Spark SQL interacts with to achieve all of this.

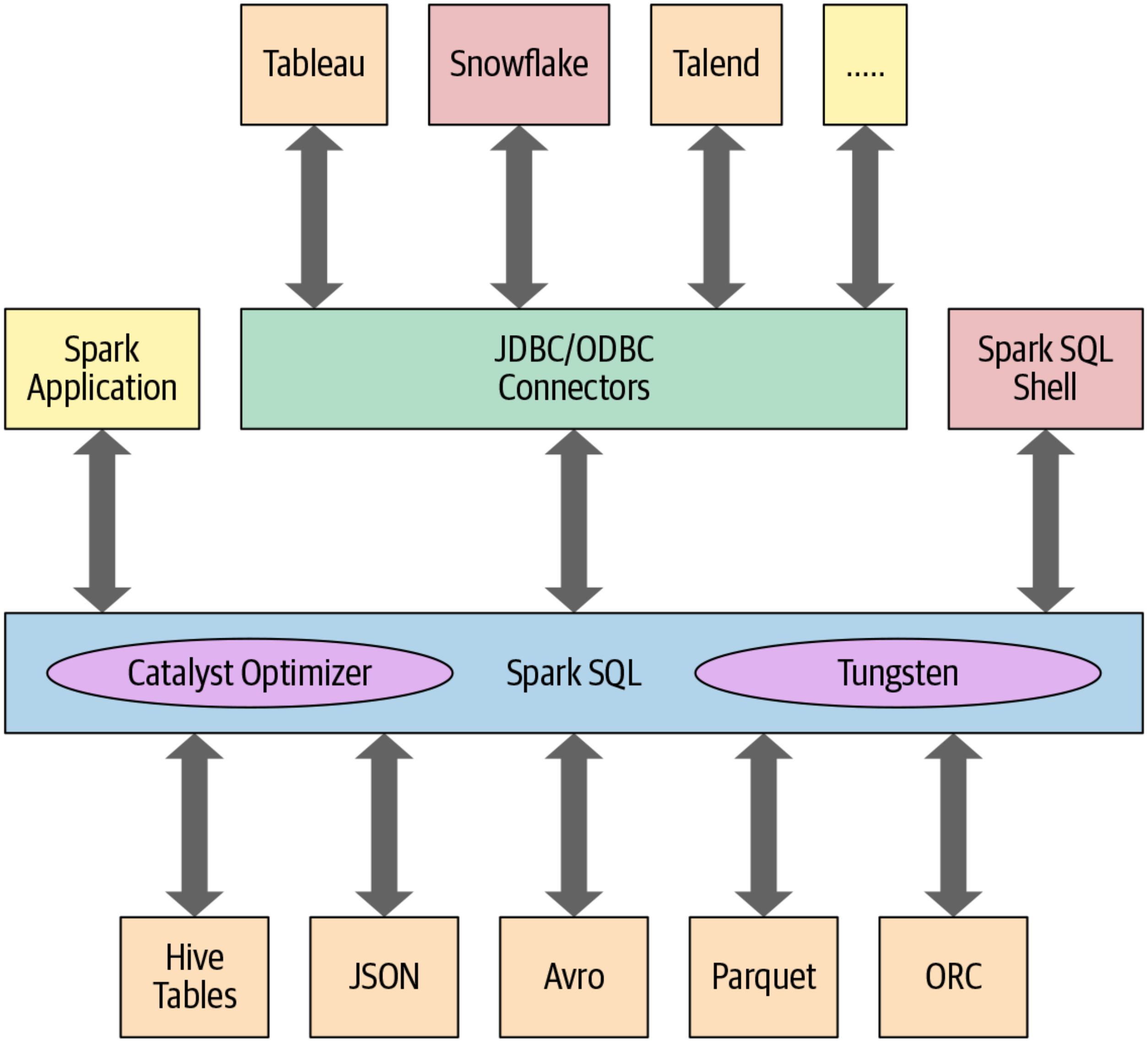


Figure 3-3. Spark SQL and its stack

At the core of the Spark SQL engine are the Catalyst optimizer and Project Tungsten. Together, these support the high-level DataFrame and Dataset APIs and SQL queries. We'll talk more about Tungsten in Chapter 6; for now, let's take a closer look at the optimizer.

The Catalyst Optimizer

The Catalyst optimizer takes a computational query and converts it into an execution plan. It goes through four transformational phases, as shown in Figure 3-4:

1. Analysis
2. Logical optimization
3. Physical planning
4. Code generation

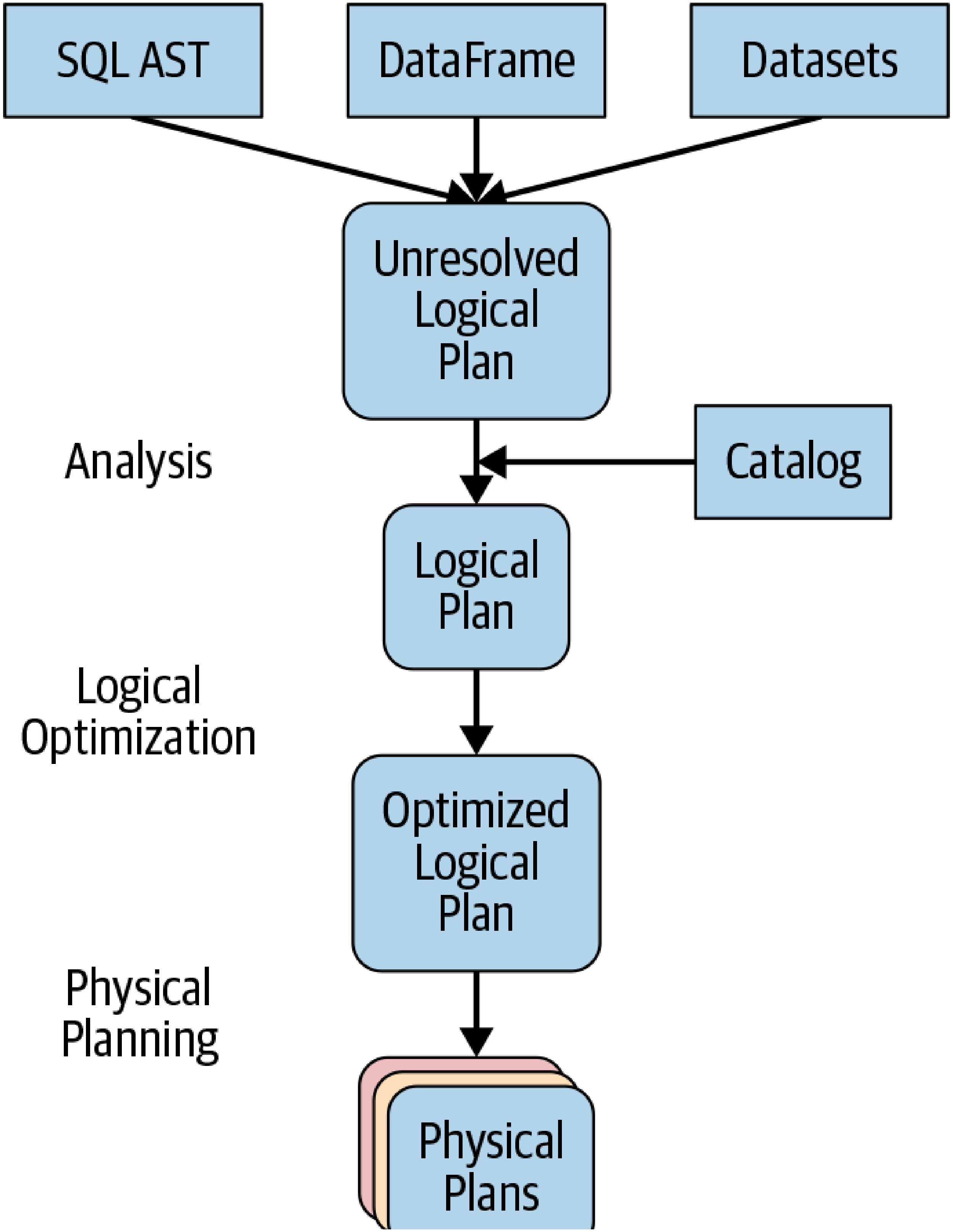

SQL AST
DataFrame
Datasets
Unresolved Logical Plan
Analysis
Catalog
Logical Plan
Logical Optimization
Optimized Logical Plan
Physical Planning
Physical Plans

Figure 3-4. A Spark computation's four-phase journey

For example, consider one of the queries from our M&Ms example in Chapter 2. Both of the following sample code blocks will go through the same process, eventually ending up with a similar query plan and identical bytecode for execution. That is, regardless of the language you use, your computation undergoes the same journey and the resulting bytecode is likely the same:

```
# In Python
count_mnm_df = (mnm_df
    .select("State", "Color", "Count")
    .groupBy("State", "Color")
    .agg(sum("Count")
    .alias("Total"))
    .orderBy("Total", ascending=False))
```

```
-- In SQL
SELECT State, Color, sum(Count) AS Total
FROM MNM_TABLE_NAME
GROUP BY State, Color
ORDER BY Total DESC
```

To see the different stages the Python code goes through, you can use the `count_mnm_df.explain(True)` method on the DataFrame. Or, to get a look at the different logical and physical plans, in Scala you can call `df.queryExecution.logical` or `df.queryExecution.optimizedPlan`. (In Chapter 7, we will discuss more about tuning and debugging Spark and how to read query plans.) This gives us the following output:

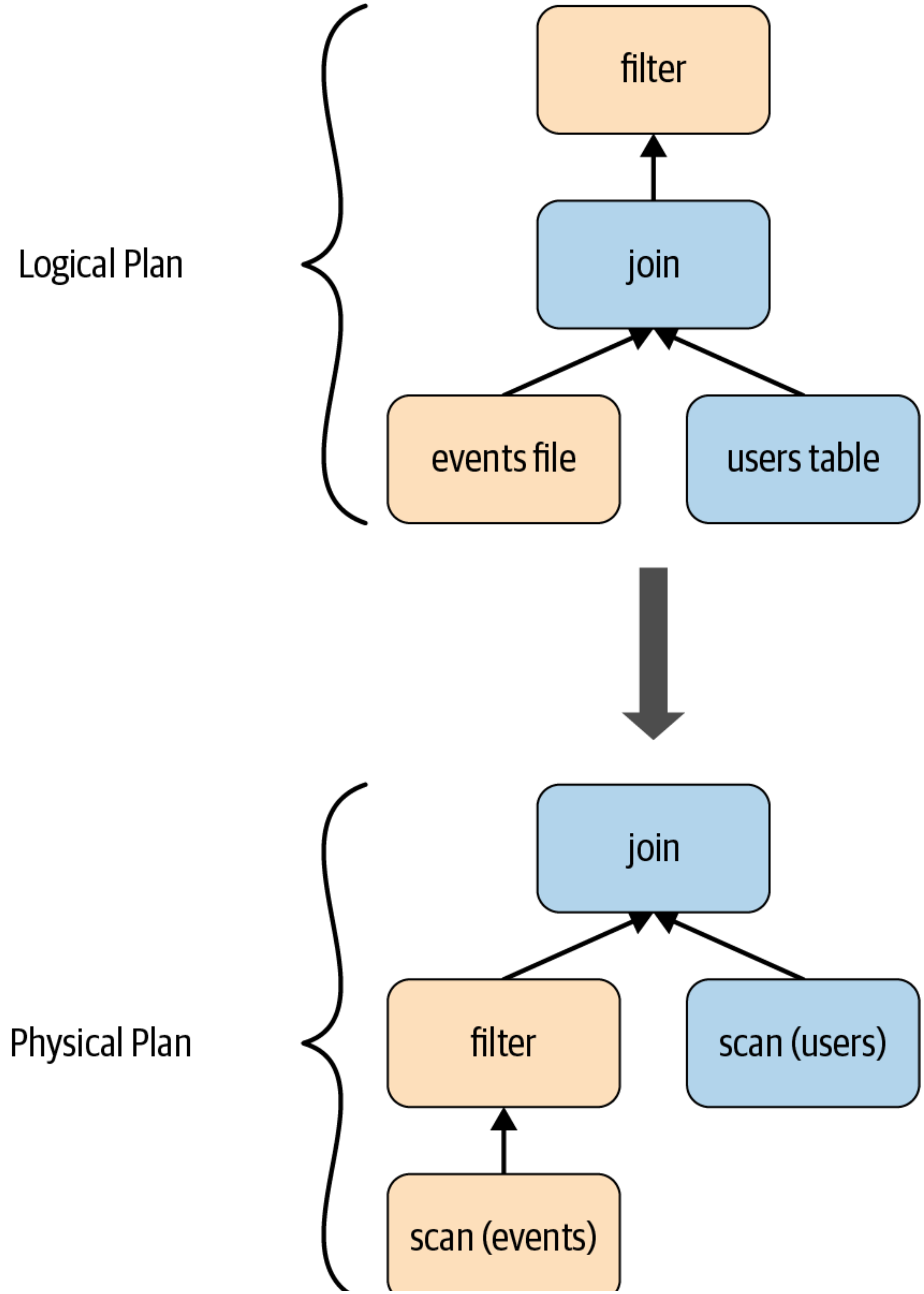
```
count_mnm_df.explain(True)

== Parsed Logical Plan ==
'Sort ['Total DESC NULLS LAST], true
+- Aggregate [State#10, Color#11], [State#10, Color#11, sum(Count#12) AS...]
   +- Project [State#10, Color#11, Count#12]
      +- Relation[State#10,Color#11,Count#12] csv

== Analyzed Logical Plan ==
State: string, Color: string, Total: bigint
Sort [Total#24L DESC NULLS LAST], true
+- Aggregate [State#10, Color#11], [State#10, Color#11, sum(Count#12) AS...]
   +- Project [State#10, Color#11, Count#12]
      +- Relation[State#10,Color#11,Count#12] csv

== Optimized Logical Plan ==
Sort [Total#24L DESC NULLS LAST], true
+- Aggregate [State#10, Color#11], [State#10, Color#11, sum(Count#12) AS...]
   +- Relation[State#10,Color#11,Count#12] csv

== Physical Plan ==
*(3) Sort [Total#24L DESC NULLS LAST], true, 0
+- Exchange rangepartitioning(Total#24L DESC NULLS LAST, 200)
   +- *(2) HashAggregate(keys=[State#10, Color#11], functions=[sum(Count#12)],
output=[State#10, Color#11, Total#24L])
      +- Exchange hashpartitioning(State#10, Color#11, 200)
         +- *(1) HashAggregate(keys=[State#10, Color#11],
functions=[partial_sum(Count#12)], output=[State#10, Color#11, count#29L])
            +- *(1) FileScan csv [State#10,Color#11,Count#12] Batched: false,
Format: CSV, Location:
InMemoryFileIndex[file:/Users/jules/gits/LearningSpark2.0/chapter2/py/src/...
```

```
dataset.csv], PartitionFilters: [], PushedFilters: [], ReadSchema:
struct<State:string,Color:string,Count:int>
```

Let's consider another DataFrame computation example. The following Scala code undergoes a similar journey as the underlying engine optimizes its logical and physical plans:

```scala
// In Scala
// Users DataFrame read from a Parquet table
val usersDF  = ...
// Events DataFrame read from a Parquet table
val eventsDF = ...
// Join two DataFrames
val joinedDF = users
  .join(events, users("id") === events("uid"))
  .filter(events("date") > "2015-01-01")
```

After going through an initial analysis phase, the query plan is transformed and rearranged by the Catalyst optimizer as shown in Figure 3-5.


Logical Plan
filter
join
events file
users table
Physical Plan
join
filter
scan (users)
scan (events)

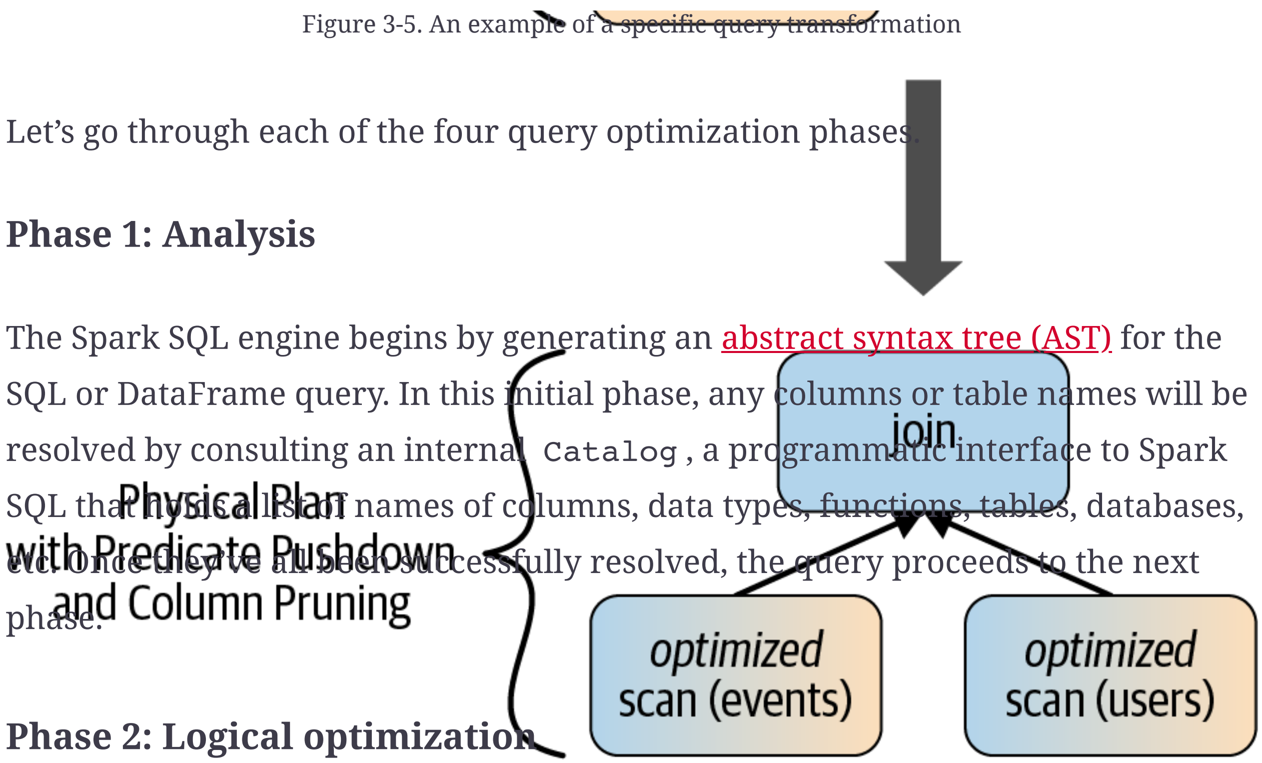


Figure 3-5. An example of a specific query transformation

Let's go through each of the four query optimization phases.

Phase 1: Analysis

The Spark SQL engine begins by generating an abstract syntax tree (AST) for the SQL or DataFrame query. In this initial phase, any columns or table names will be resolved by consulting an internal `Catalog`, a programmatic interface to Spark SQL that holds a list of names of columns, data types, functions, tables, databases, etc. Once they've all been successfully resolved, the query proceeds to the next phase.

Phase 2: Logical optimization

As Figure 3-4 shows, this phase comprises two internal stages. Applying a standard-rule based optimization approach, the Catalyst optimizer will first construct a set of multiple plans and then, using its cost-based optimizer (CBO), assign costs to each plan. These plans are laid out as operator trees (like in Figure 3-5); they may include, for example, the process of constant folding, predicate pushdown, projection pruning, Boolean expression simplification, etc. This logical plan is the input into the physical plan.

Phase 3: Physical planning

In this phase, Spark SQL generates an optimal physical plan for the selected logical plan, using physical operators that match those available in the Spark execution engine.

Phase 4: Code generation

The final phase of query optimization involves generating efficient Java bytecode to run on each machine. Because Spark SQL can operate on data sets loaded in memory, Spark can use state-of-the-art compiler technology for code generation to speed up execution. In other words, it acts as a compiler. Project Tungsten, which facilitates whole-stage code generation, plays a role here.

Just what is whole-stage code generation? It's a physical query optimization phase that collapses the whole query into a single function, getting rid of virtual function calls and employing CPU registers for intermediate data. The second-generation Tungsten engine, introduced in Spark 2.0, uses this approach to generate compact RDD code for final execution. This streamlined strategy significantly improves CPU efficiency and performance.

NOTE

We have talked at a conceptual level about the workings of the Spark SQL engine, with its two principal components: the Catalyst optimizer and Project Tungsten. The internal technical workings are beyond the scope of this book; however, for the curious, we encourage you to check out the references in the text for in-depth technical discussions.

Summary

In this chapter, we took a deep dive into Spark's Structured APIs, beginning with a look at the history and merits of structure in Spark.

Through illustrative common data operations and code examples, we demonstrated that the high-level DataFrame and Dataset APIs are far more expressive and intuitive than the low-level RDD API. Designed to make processing of large data sets easier, the Structured APIs provide domain-specific operators for common data operations, increasing the clarity and expressiveness of your code.

We explored when to use RDDs, DataFrames, and Datasets, depending on your use case scenarios.

And finally, we took a look under the hood to see how the Spark SQL engine's main components—the Catalyst optimizer and Project Tungsten—support structured high-level APIs and DSL operators. As you saw, no matter which of the Spark-supported languages you use, a Spark query undergoes the same optimization journey, from logical and physical plan construction to final compact code generation.

The concepts and code examples in this chapter have laid the groundwork for the next two chapters, in which we will further illustrate the seamless interoperability between DataFrames, Datasets, and Spark SQL.

1 This public data is available at https://oreil.ly/iDzQK.

2 The original data set has over 60 columns. We dropped a few unnecessary columns, removed records with null or invalid values, and added an extra Delay column.