Introduction to Big Data with Apache Spark

This Lecture

Structured Data and Relational Databases

The Structured Query Language (SQL)

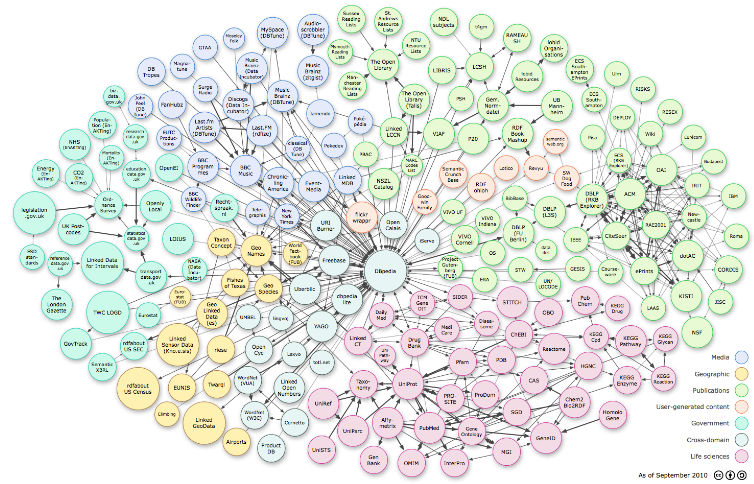
SQL and pySpark Joins

Review: Key Data Management Concepts

- A ***data model*** is a collection of concepts for describing data
- A ***schema*** is a description of a particular collection of data, using a given data model

Whither Structured Data?

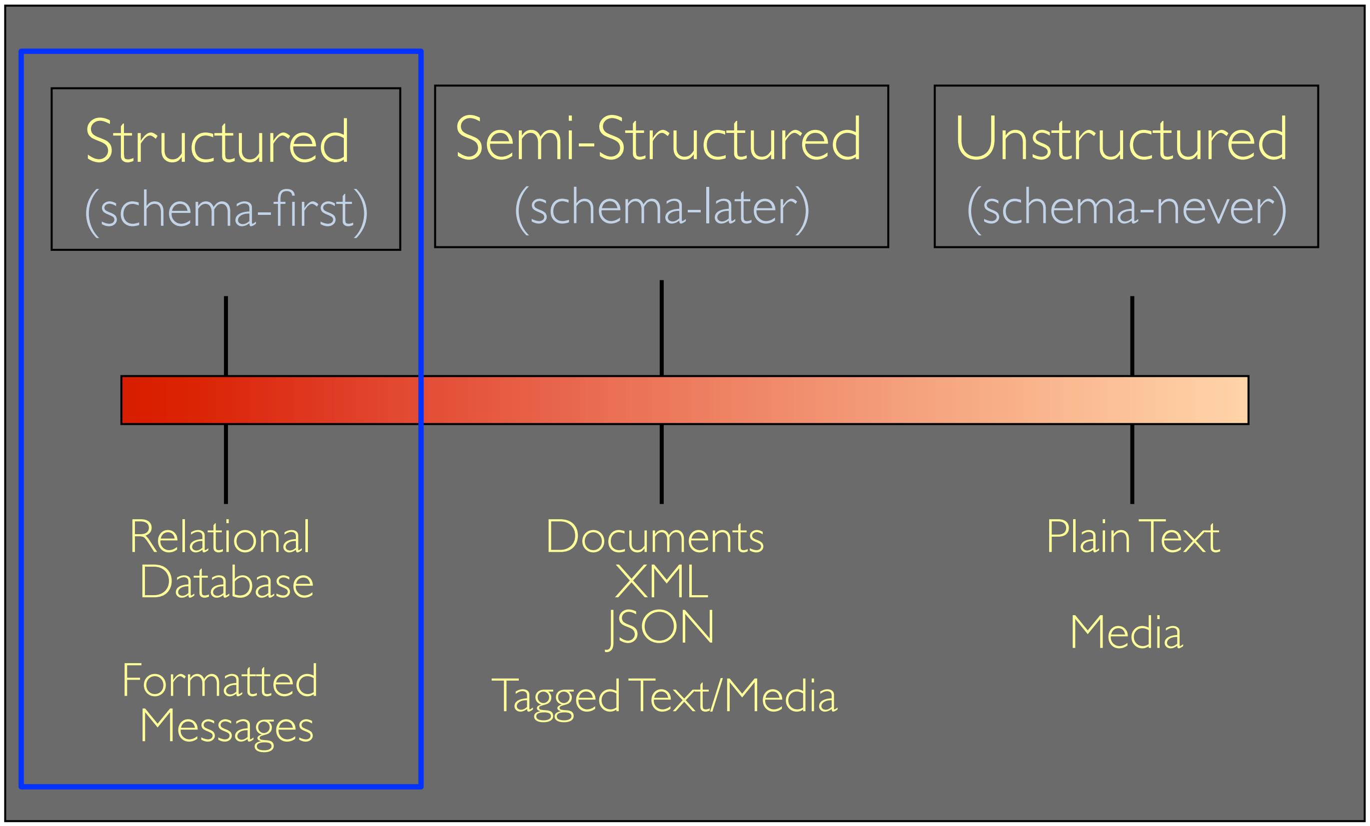
- Conventional Wisdom:
  - » Only 20% of data is structured.



- Decreasing due to:
  - » Consumer applications
  - » Enterprise search
  - » Media applications

http://upload.wikimedia.org/wikipedia/commons/2/23/Lod-datasets_2010-09-22_colored.png

The Structure Spectrum



This lecture

Relational Database: Definitions

- *Relational database:* a set of *relations*
- Two parts to a *Relation*:

Schema: specifies name of relation, plus each column's name and type

```
Students(sid: string, name: string, email: string,
         age: integer, gpa: real)
```

Instance: the actual data at a given time

- #rows = *cardinality*
- #fields = *degree*

Review: Key Data Management Concepts

- A *data model* is a collection of concepts for describing data
- A *schema* is a description of a particular collection of data, using a given data model
- A *relational data model* is the most used data model
  - » *Relation*, a table with rows and columns
  - » Every relation has a *schema* defining fields in columns

What is a Database?

- A large organized collection of data
  - » Transactions used to modify data

- Models real world, e.g., enterprise
  - » Entities (e.g., teams, games)
  - » Relationships, e.g.,
  - » A plays against B in The World Cup

Large Databases

- US Internal Revenue Service: 150 Terabytes
- Australian Bureau of Stats: 250 Terabytes
- AT&T call records: 312 Terabytes
- eBay database: 1.4 Petabytes
- Yahoo click data: 2 Petabytes
- *What matters for these databases?*

Large Databases

- US Internal Revenue Service: [150 Terabytes] ← Accuracy, Consistency, Durability, Rich queries
- Australian Bureau of Stats: [250 Terabytes] ← Fast, Rich queries
- AT&T call records: [312 Terabytes] ← Accuracy, Consistency, Durability
- eBay database: [1.4 Petabytes] ← Availability, Timeliness
- Yahoo click data: [2 Petabytes] ← Availability, Timeliness
- *What matters for these databases?*

Example: Instance of Students Relation

`Students(`*`sid`*`:string, `*`name`*`:string, `*`login`*`:string, `*`age`*`:integer, `*`gpa`*`:real)`

sid	name	login	age	gpa
53666	Jones	jones@eecs	18	3.4
53688	Smith	smith@statistics	18	3.2
53650	Smith	smith@math	19	3.8

- Cardinality = 3 (rows)
- Degree = 5 (columns)
- All rows (tuples) are distinct

Relational Databases

- Advantages
  - » Well-defined structure
  - » Maintains indices for high performance
  - » Consistency maintained by transactions
- Disadvantages
  - » Limited, rigid structure
  - » Most of disk space is taken up by large indices
  - » Transactions are slow
  - » Poor support for sparse data

Sparse Data

- Very sparse data is common today
  - » Want to store data with thousands of columns
  - » But, not all rows have values for all columns
- Typical database tables might have dozens of columns
- Tables are very wasteful for sparse data

SQL - A language for Relational DBs

- SQL = Structured Query Language
- Supported by pySpark DataFrames (SparkSQL)
- Some of the functionality SQL provides:
  - » Create, modify, delete relations
  - » Add, modify, remove tuples
  - » *Specify queries to find tuples matching criteria*

Queries in SQL

- Single-table queries are straightforward
- To find all 18 year old students, we can write:

```
SELECT *
  FROM Students S
 WHERE S.age=18
```

- To find just names and logins:

```
SELECT S.name, S.login
  FROM Students S
 WHERE S.age=18
```

Querying Multiple Relations

- Can specify a *join* over two tables as follows:

```
SELECT S.name, E.cid
 FROM Students S, Enrolled E
 WHERE S.sid=E.sid
```

Enrolled

E

E.sid	E.cid	E.grade
53831	Physics203	A
53650	Topology112	A
53341	History105	B

Students

S

S.sid	S.name	S.login	S.age	S.gpa
53341	Jones	jones@cs	18	3.4
53831	Smith	smith@ee	18	3.2

- First, combine the two tables, S and E

Cross Join

- Cartesian product of two tables (E x S):

Enrolled

E

E.sid	E.cid	E.grade
53831	Physics203	A
53650	Topology112	A
53341	History105	B

Students

S

S.sid	S.name	S.login	S.age	S.gpa
53341	Jones	jones@cs	18	3.4
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Cross Join

- Cartesian product of two tables (E x S):

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E

E.sid	E.cid	E.grade
53831	Physics203	A
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Students

S

S.sid	S.name	S.login	S.age	S.gpa
53341	Jones	jones@cs	18	3.4
53831	Smith	smith@ee	18	3.2

E.sid	E.cid	E.grade	S.sid	S.name	S.login	S.age	S.gpa
53831	Physics203	A	53341	Jones	jones@cs	18	3.4
53650	Topology112	A	53341	Jones	jones@cs	18	3.4
53341	History105	B	53341	Jones	jones@cs	18	3.4
53831	Physics203	A	53831	Smith	smith@ee	18	3.2
53650	Topology112	A	53831	Smith	smith@ee	18	3.2
53341	History105	B	53831	Smith	smith@ee	18	3.2

Where Clause

- Choose matching rows using Where clause:

```
SELECT S.name, E.cid
 FROM Students S, Enrolled E
 WHERE S.sid=E.sid
```

E.sid	E.cid	E.grade	S.sid	S.name	S.login	S.age	S.gpa
53831	Physics203	A	53341	Jones	jones@cs	18	3.4
53650	Topology112	A	53341	Jones	jones@cs	18	3.4
53341	History105	B	53341	Jones	jones@cs	18	3.4
53831	Physics203	A	53831	Smith	smith@ee	18	3.2
53650	Topology112	A	53831	Smith	smith@ee	18	3.2
53341	History105	B	53831	Smith	smith@ee	18	3.2

Select Clause

- Filter columns using Select clause:

```
SELECT S.name, E.cid
 FROM Students S, Enrolled E
 WHERE S.sid=E.sid
```

E.sid	E.cid	E.grade	S.sid	S.name	S.login	S.age	S.gpa
53831	Physics203	A	53341	Jones	jones@cs	18	3.4
53650	Topology112	A	53341	Jones	jones@cs	18	3.4
53341	History105	B	53341	Jones	jones@cs	18	3.4
53831	Physics203	A	53831	Smith	smith@ee	18	3.2
53650	Topology112	A	53831	Smith	smith@ee	18	3.2
53341	History105	B	53831	Smith	smith@ee	18	3.2

Result

- Can specify a *join* over two tables as follows:

```
SELECT S.name, E.cid
 FROM Students S, Enrolled E
 WHERE S.sid=E.sid
```

Enrolled

E

E.sid	E.cid	E.grade
53831	Physics203	A
53650	Topology112	A
53341	History105	B

Students

S

S.sid	S.name	S.login	S.age	S.gpa
53341	Jones	jones@cs	18	3.4
53831	Smith	smith@ee	18	3.2

Result =

S.name	E.cid
Jones	History105
Smith	Physics203

Explicit SQL Joins

```
SELECT S.name, E.classid
 FROM Students S INNER JOIN Enrolled E ON S.sid=E.sid
```

S

S.name	S.sid
Jones	11111
Smith	22222
Brown	33333

E

E.sid	E.classid
11111	History105
11111	DataScience194
22222	French150
44444	English10

Result

S.name	E.classid
Jones	History105
Jones	DataScience194
Smith	French150

Equivalent SQL Join Notations

- Explicit Join notation (preferred):

```
SELECT S.name, E.classid
 FROM Students S INNER JOIN Enrolled E ON S.sid=E.sid
```

```
SELECT S.name, E.classid
 FROM Students S JOIN Enrolled E ON S.sid=E.sid
```

- Implicit join notation (deprecated):

```
SELECT S.name, E.cid
 FROM Students S, Enrolled E
 WHERE S.sid=E.sid
```

SQL Types of Joins

```
SELECT S.name, E.classid
 FROM Students S INNER JOIN Enrolled E ON S.sid=E.sid
```

S

S.name	S.sid
Jones	11111
Smith	22222
Brown	33333

E

E.sid	E.classid
11111	History105
11111	DataScience194
22222	French150
44444	English10

Result

S.name	E.classid
Jones	History105
Jones	DataScience194
Smith	French150

Unmatched keys

The type of join controls how unmatched keys are handled

SQL Joins: Left Outer Join

```
SELECT S.name, E.classid
 FROM Students S LEFT OUTER JOIN Enrolled E ON S.sid=E.sid
```

S

S.name	S.sid
Jones	11111
Smith	22222
Brown	33333

E

E.sid	E.classid
11111	History105
11111	DataScience194
22222	French150
44444	English10

Result

S.name	E.classid
Jones	History105
Jones	DataScience194
Smith	French150
Brown	<NULL>

Unmatched keys

SQL Joins: Right Outer Join

```
SELECT S.name, E.classid
 FROM Students S RIGHT OUTER JOIN Enrolled E ON S.sid=E.sid
```

S

S.name	S.sid
Jones	11111
Smith	22222
Brown	33333

E

E.sid	E.classid
11111	History105
11111	DataScience194
22222	French150
44444	English10

Result

S.name	E.classid
Jones	History105
Jones	DataScience194
Smith	French150
<NULL>	English10

Unmatched keys

Spark Joins

- SparkSQL and Spark DataFrames **`join()`** supports:
  - » inner, outer, left outer, right outer, semijoin

- For Pair RDDs, pySpark supports:
  - » inner join(), leftOuterJoin(), rightOuterJoin(), fullOuterJoin()

Pair RDD Joins

- X.join(Y)
  - » Return RDD of all pairs of elements with matching keys in X and Y
  - » Each pair is (k, (v1, v2)) tuple, where (k, v1) is in X and (k, v2) is in Y

```
>>> x = sc.parallelize([("a", 1), ("b", 4)])
>>> y = sc.parallelize([("a", 2), ("a", 3)])
>>> sorted(x.join(y).collect())

Value: [('a', (1, 2)), ('a', (1, 3))]
```

Pair RDD Joins

- [X.leftOuterJoin(Y)]
  » For each element (k, v) in X, resulting RDD will either contain
  - All pairs (k, (v, w)) for w in Y,
  - Or the pair (k, (v, *None*)) if no elements in Y have key k

```
>>> x = sc.parallelize([("a", 1), ("b", 4)])
>>> y = sc.parallelize([("a", 2)])
>>> sorted(x.leftOuterJoin(y).collect())

Value: [('a', (1, 2)), ('b', (4, None))]
```

Pair RDD Joins

- `Y.rightOuterJoin(X)`
  » For each element (k, w) in X, resulting RDD will either contain
  - All pairs (k, (v, w)) for v in Y,
  - Or the pair (k, (*None*, w)) if no elements in Y have key k

```
>>> x = sc.parallelize([("a", 1), ("b", 4)])
>>> y = sc.parallelize([("a", 2)])
>>> sorted(y.rightOuterJoin(x).collect())

Value: [('a', (2, 1)), ('b', (None, 4))]
```

Pair RDD Joins

- [`X.fullOuterJoin(Y)`]
  » For each element (k, v) in X, resulting RDD will either contain
    - All pairs (k, (v, w)) for w in Y, or (k, (v, *None*)) if no elements in Y have k

  » For each element (k, w) in Y, resulting RDD will either contain
    - All pairs (k, (v, w)) for v in X, or (k, (*None*, w)) if no elements in X have k

```
>>> x = sc.parallelize([("a", 1), ("b", 4)])
>>> y = sc.parallelize([("a", 2), ("c", 8)])
>>> sorted(x.fullOuterJoin(y).collect())

Value: [('a', (1, 2)), ('b', (4, None)) , ('c', (None, 8))]
```