High-level Programming Languages

Apache Pig and Pig Latin

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Apache Pig

See also the 4 segments on Pig on coursera:

`https://www.coursera.org/course/datasci`

Introduction

- **Collection and analysis of enormous datasets is at the heart of innovation in many organizations**
  - E.g.: web crawls, search logs, click streams

- **Manual inspection before batch processing**
  - Very often engineers look for exploitable trends in their data to drive the design of more sophisticated techniques
  - This is difficult to do in practice, given the sheer size of the datasets

- **The MapReduce model has its own limitations**
  - One input
  - Two-stage, two operators
  - Rigid data-flow

MapReduce limitations

- **Very often tricky workarounds are required**[1]
  - This is very often exemplified by the difficulty in performing `JOIN` operations
- **Custom code required even for basic operations**
  - Projection and Filtering need to be “rewritten” for each job

$\rightarrow$ Code is difficult to reuse and maintain

$\rightarrow$ Semantics of the analysis task are obscured

$\rightarrow$ Optimizations are difficult due to opacity of `Map` and `Reduce`

[1] The term workaround should not only be intended as negative.

Use Cases

Rollup aggregates

- **Compute aggregates against user activity logs, web crawls, etc.**
  - Example: compute the frequency of search terms aggregated over days, weeks, month
  - Example: compute frequency of search terms aggregated over geographical location, based on IP addresses

- **Requirements**
  - Successive aggregations
  - Joins followed by aggregations

- **Pig vs. OLAP systems**
  - Datasets are too big
  - **Data curation** is too costly

Use Cases

Temporal Analysis

- **Study how search query distributions change over time**
  - Correlation of search queries from two distinct time periods (groups)
  - Custom processing of the queries in each correlation group

- **Pig supports operators that minimize memory footprint**
  - Instead, in a RDBMS such operations typically involve `JOINS` over very large datasets that do not fit in memory and thus become slow

Use Cases

Session Analysis

- **Study sequences of page views and clicks**
- **Example of typical aggregates**
  - Average length of user session
  - Number of links clicked by a user before leaving a website
  - Click pattern variations in time
- **Pig supports advanced data structures, and UDFs**

Pig Latin

- **Pig Latin, a high-level programming language initially developed at Yahoo!, now at HortonWorks**
  - Combines the best of both declarative and imperative worlds
    - High-level declarative querying in the spirit of SQL
    - Low-level, procedural programming á la MapReduce

- **Pig Latin features**
  - Multi-valued, nested data structures instead of flat tables
  - Powerful data transformations primitives, including joins

- **Pig Latin program**
  - Made up of a series of operations (or transformations)
  - Each operation is applied to input data and produce output data

  → A Pig Latin program describes a data flow

Example 1

Pig Latin premiere

- **Assume we have the following table:**

```
urls:  (url, category, pagerank)
```

- Where:
  - `url`: is the url of a web page
  - `category`: corresponds to a pre-defined category for the web page
  - `pagerank`: is the numerical value of the pagerank associated to a web page

→ *Find, for each sufficiently large category, the average page rank of high-pagerank urls in that category*

Example 1

SQL

```
SELECT category, AVG(pagerank)
FROM urls WHERE pagerank > 0.2
GROUP BY category HAVING COUNT(*) > 10^6
```

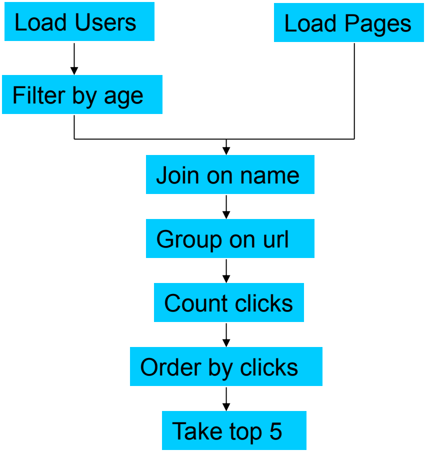
Example 1

Pig Latin

```
good_urls = FILTER urls BY pagerank > 0.2;
groups = GROUP good_urls BY category;
big_groups = FILTER groups BY COUNT(good_urls) > 10^6;
output = FOREACH big_groups GENERATE
category, AVG(good_urls.pagerank);
```

Example 2

- User data in one file, website data in another
- Find the top 5 most visited sites
- Group by users aged in the range (18,25)



Example 2: in MapReduce

```
import java.io.IOException;
import java.util.ArrayList;
import java.util.Iterator;
import java.util.List;

import org.apache.hadoop.fs.Path;
import org.apache.hadoop.io.LongWritable;
import org.apache.hadoop.io.Text;
import org.apache.hadoop.io.Writable;
import org.apache.hadoop.io.WritableComparable;
import org.apache.hadoop.mapred.FileInputFormat;
import org.apache.hadoop.mapred.FileOutputFormat;
import org.apache.hadoop.mapred.JobConf;
import org.apache.hadoop.mapred.KeyValueTextInputFormat;
import org.apache.hadoop.mapred.Mapper;
import org.apache.hadoop.mapred.MapReduceBase;
import org.apache.hadoop.mapred.OutputCollector;
import org.apache.hadoop.mapred.RecordReader;
import org.apache.hadoop.mapred.Reducer;
import org.apache.hadoop.mapred.Reporter;
import org.apache.hadoop.mapred.SequenceFileInputFormat;
import org.apache.hadoop.mapred.SequenceFileOutputFormat;
import org.apache.hadoop.mapred.TextInputFormat;
import org.apache.hadoop.mapred.jobcontrol.Job;
import org.apache.hadoop.mapred.jobcontrol.JobControl;
import org.apache.hadoop.mapred.lib.IdentityMapper;

public class MRExample {
    public static class LoadPages extends MapReduceBase
        implements Mapper<LongWritable, Text, Text, Text> {

        public void map(LongWritable k, Text val,
                OutputCollector<Text, Text> oc,
                Reporter reporter) throws IOException {
            // Pull the key out
            String line = val.toString();
            int firstComma = line.indexOf(',');
            String key = line.substring(0, firstComma);
            String value = line.substring(firstComma + 1);
            Text outKey = new Text(key);
            // Prepend an index to the value so we know which file
            // it came from.
            Text outVal = new Text("1" + value);
            oc.collect(outKey, outVal);
        }
    }
    public static class LoadAndFilterUsers extends MapReduceBase
        implements Mapper<LongWritable, Text, Text, Text> {

        public void map(LongWritable k, Text val,
                OutputCollector<Text, Text> oc,
                Reporter reporter) throws IOException {
            // Pull the key out
            String line = val.toString();
            int firstComma = line.indexOf(',');
            String value = line.substring(firstComma + 1);
            int age = Integer.parseInt(value);
            if (age < 18 || age > 25) return;
            String key = line.substring(0, firstComma);
            Text outKey = new Text(key);
            // Prepend an index to the value so we know which file
            // it came from.
            Text outVal = new Text("2" + value);
            oc.collect(outKey, outVal);
        }
    }
    public static class Join extends MapReduceBase
        implements Reducer<Text, Text, Text, Text> {

        public void reduce(Text key,
                Iterator<Text> iter,
                OutputCollector<Text, Text> oc,
                Reporter reporter) throws IOException {
            // For each value, figure out which file it's from and
store it
            // accordingly.
            List<String> first = new ArrayList<String>();
            List<String> second = new ArrayList<String>();

            while (iter.hasNext()) {
                Text t = iter.next();
                String value = t.toString();
                if (value.charAt(0) == '1')
first.add(value.substring(1));
                else second.add(value.substring(1));
                reporter.setStatus("OK");
            }

            // Do the cross product and collect the values
            for (String s1 : first) {
                for (String s2 : second) {
                    String outval = key + "," + s1 + "," + s2;
                    oc.collect(null, new Text(outval));
                    reporter.setStatus("OK");
                }
            }
        }
    }
    public static class LoadJoined extends MapReduceBase
        implements Mapper<Text, Text, Text, LongWritable> {

        public void map(
                Text k,
                Text val,
                OutputCollector<Text, LongWritable> oc,
                Reporter reporter) throws IOException {
            // Find the url
            String line = val.toString();
            int firstComma = line.indexOf(',');
            int secondComma = line.indexOf(',', firstComma);
            String key = line.substring(firstComma, secondComma);
            // drop the rest of the record, I don't need it anymore,
            // just pass a 1 for the combiner/reducer to sum instead.
            Text outKey = new Text(key);
            oc.collect(outKey, new LongWritable(1L));
        }
    }
    public static class ReduceUrls extends MapReduceBase
        implements Reducer<Text, LongWritable, WritableComparable,
Writable> {

        public void reduce(
                Text key,
                Iterator<LongWritable> iter,
                OutputCollector<WritableComparable, Writable> oc,
                Reporter reporter) throws IOException {
            // Add up all the values we see

            long sum = 0;
            while (iter.hasNext()) {
                sum += iter.next().get();
                reporter.setStatus("OK");
            }

            oc.collect(key, new LongWritable(sum));
        }
    }
    public static class LoadClicks extends MapReduceBase
        implements Mapper<WritableComparable, Writable, LongWritable,
Text> {

        public void map(
                WritableComparable key,
                Writable val,
                OutputCollector<LongWritable, Text> oc,
                Reporter reporter) throws IOException {
            oc.collect((LongWritable)val, (Text)key);
        }
    }
    public static class LimitClicks extends MapReduceBase
        implements Reducer<LongWritable, Text, LongWritable, Text> {

        int count = 0;
        public void reduce(
            LongWritable key,
            Iterator<Text> iter,
            OutputCollector<LongWritable, Text> oc,
            Reporter reporter) throws IOException {

            // Only output the first 100 records
            while (count < 100 && iter.hasNext()) {
                oc.collect(key, iter.next());
                count++;
            }
        }
    }
    public static void main(String[] args) throws IOException {
        JobConf lp = new JobConf(MRExample.class);
        lp.setJobName("Load Pages");
        lp.setInputFormat(TextInputFormat.class);
        lp.setOutputKeyClass(Text.class);
        lp.setOutputValueClass(Text.class);
        lp.setMapperClass(LoadPages.class);
        FileInputFormat.addInputPath(lp, new
Path("/user/gates/pages"));
        FileOutputFormat.setOutputPath(lp,
            new Path("/user/gates/tmp/indexed_pages"));
        lp.setNumReduceTasks(0);
        Job loadPages = new Job(lp);

        JobConf lfu = new JobConf(MRExample.class);
        lfu.setJobName("Load and Filter Users");
        lfu.setInputFormat(TextInputFormat.class);
        lfu.setOutputKeyClass(Text.class);
        lfu.setOutputValueClass(Text.class);
        lfu.setMapperClass(LoadAndFilterUsers.class);
        FileInputFormat.addInputPath(lfu, new
Path("/user/gates/users"));
        FileOutputFormat.setOutputPath(lfu,
            new Path("/user/gates/tmp/filtered_users"));
        lfu.setNumReduceTasks(0);
        Job loadUsers = new Job(lfu);

        JobConf join = new JobConf(MRExample.class);
        join.setJobName("Join Users and Pages");
        join.setInputFormat(KeyValueTextInputFormat.class);
        join.setOutputKeyClass(Text.class);
        join.setOutputValueClass(Text.class);
        join.setMapperClass(IdentityMapper.class);
        join.setReducerClass(Join.class);
        FileInputFormat.addInputPath(join, new
Path("/user/gates/tmp/indexed_pages"));
        FileInputFormat.addInputPath(join, new
Path("/user/gates/tmp/filtered_users"));
        FileOutputFormat.setOutputPath(join, new
Path("/user/gates/tmp/joined"));
        join.setNumReduceTasks(50);
        Job joinJob = new Job(join);
        joinJob.addDependingJob(loadPages);
        joinJob.addDependingJob(loadUsers);

        JobConf group = new JobConf(MRExample.class);
        group.setJobName("Group URLs");
        group.setInputFormat(KeyValueTextInputFormat.class);
        group.setOutputKeyClass(Text.class);
        group.setOutputValueClass(LongWritable.class);
        group.setOutputFormat(SequenceFileOutputFormat.class);
        group.setMapperClass(LoadJoined.class);
        group.setCombinerClass(ReduceUrls.class);
        group.setReducerClass(ReduceUrls.class);
        FileInputFormat.addInputPath(group, new
Path("/user/gates/tmp/joined"));
        FileOutputFormat.setOutputPath(group, new
Path("/user/gates/tmp/grouped"));
        group.setNumReduceTasks(50);
        Job groupJob = new Job(group);
        groupJob.addDependingJob(joinJob);

        JobConf top100 = new JobConf(MRExample.class);
        top100.setJobName("Top 100 sites");
        top100.setInputFormat(SequenceFileInputFormat.class);
        top100.setOutputKeyClass(LongWritable.class);
        top100.setOutputValueClass(Text.class);
        top100.setOutputFormat(SequenceFileOutputFormat.class);
        top100.setMapperClass(LoadClicks.class);
        top100.setCombinerClass(LimitClicks.class);
        top100.setReducerClass(LimitClicks.class);
        FileInputFormat.addInputPath(top100, new
Path("/user/gates/tmp/grouped"));
        FileOutputFormat.setOutputPath(top100, new
Path("/user/gates/top100sitesforusers18to25"));
        top100.setNumReduceTasks(1);
        Job limit = new Job(top100);
        limit.addDependingJob(groupJob);

        JobControl jc = new JobControl("Find top 100 sites for users
18 to 25");
        jc.addJob(loadPages);
        jc.addJob(loadUsers);
        jc.addJob(joinJob);
        jc.addJob(groupJob);
        jc.addJob(limit);
        jc.run();
    }
}
```

- Hundreds lines of code; hours to write

Example 2: in Pig

```
Users = load 'users' as (name, age);
Fltrd = filter Users by age >= 18 and age <= 25;
Pages = load 'pages' as (user, url);
Jnd = join Fltrd by name, Pages by user; Grpd = group Jnd by
url;
Smmd = foreach Grpd generate group, COUNT(Jnd) as clicks;
Srtd = order Smmd by clicks desc; Top5 = limit Srtd 5;
store Top5 into 'top5sites';
```

- Few lines of code; few minutes to write

Pig Execution environment

- **How do we go from Pig Latin to MapReduce?**
  - The Pig system is in charge of this
  - Complex execution environment that interacts with Hadoop MapReduce

  → The programmer focuses on the data and analysis

- **Pig Compiler**
  - Pig Latin operators are translated into MapReduce code
  - NOTE: in some cases, hand-written MapReduce code performs better

- **Pig Optimizer**[2]
  - Pig Latin data flows undergo an (automatic) optimization phase[3]
  - These optimizations are borrowed from the RDBMS community

[2] Currently, rule-based optimization only.

[3] Optimizations can be selectively disabled.

Pig and Pig Latin

- **Pig is not a RDBMS!**
  - This means it is not suitable for all data processing tasks
- **Designed for batch processing**
  - Of course, since it compiles to MapReduce
  - Of course, since data is materialized as files on HDFS
- **NOT designed for random access**
  - Query selectivity does not match that of a RDBMS
  - Full-scans oriented!

Comparison with RDBMS

- **It may seem that Pig Latin is similar to SQL**
  - We'll see several examples, operators, etc. that resemble SQL statements
- **Data-flow vs. declarative programming language**
  - Data-flow:
    - Step-by-step set of operations
    - Each operation is a single transformation
  - Declarative:
    - Set of constraints
    - Applied together to an input to generate output

$\rightarrow$ **With Pig Latin it's like working at the query planner**

Comparison with RDBMS

- **RDBMS store data in tables**
  - Schema are predefined and strict
  - Tables are flat
- **Pig and Pig Latin work on more complex data structures**
  - Schema can be defined at run-time for readability
  - *Pigs eat anything!*
  - UDF and streaming together with nested data structures make Pig and Pig Latin more flexible

Dataflow Language

- **A Pig Latin program specifies a series of steps**
  - Each step is a single, high level data transformation
  - Stylistically different from SQL
- **With reference to Example 1**
  - The programmer supply an order in which each operation will be done
- **Consider the following snippet**

```
spam_urls = FILTER urls BY isSpam(url);
culprit_urls = FILTER spam_urls BY pagerank > 0.8;
```

Dataflow Language

- **Data flow optimizations**
  - Explicit sequences of operations can be overridden
  - Use of high-level, relational-algebra-style primitives (`GROUP`, `FILTER`,...) allows using traditional RDBMS optimization techniques

→ **NOTE: it is necessary to check whether such optimizations are beneficial or not, by hand**

- **Pig Latin allows Pig to perform optimizations that would otherwise by a tedious manual exercise if done at the MapReduce level**

Quick Start and Interoperability

- **Data I/O is greatly simplified in Pig**
  - No need to curate, bulk import, parse, apply schema, create indexes that traditional RDBMS require
  - Standard and ad-hoc “readers” and “writers” facilitate the task of ingesting and producing data in arbitrary formats

- **Pig can work with a wide range of other tools**

- **Why RDBMS have stringent requirements?**
  - To enable transactional consistency guarantees
  - To enable efficient point lookup (using physical indexes)
  - To enable data curation on behalf of the user
  - To enable other users figuring out what the data is, by studying the schema

Quick Start and Interoperability

- **Why is Pig so flexible?**
  - Supports read-only workloads
  - Supports scan-only workloads (no lookups)
  - → No need for transactions nor indexes

- **Why data curation is not required?**
  - Very often, Pig is used for ad-hoc data analysis
  - Work on temporary datasets, then throw them out!
  - → Curation is an overkill

- **Schemas are optional**
  - Can apply one on the fly, at runtime
  - Can refer to fields using positional notation
  - E.g.: `good_urls = FILTER urls BY $2 > 0.2`

Nested Data Model

- **Easier for "programmers" to think of nested data structures**
  - E.g.: capture information about positional occurrences of terms in a collection of documents
  - `Map<documnetId, Set<positions> >`

- **Instead, RDBMS allows only fat tables**
  - Only atomic fields as columns
  - Require normalization
  - From the example above: need to create two tables
  - `term_info: (termId, termString, ...)`
  - `position_info: (termId, documentId, position)`

  → Occurrence information obtained by joining on `termId`, and grouping on `termId, documentId`

Nested Data Model

- **Fully nested data model (see also later in the presentation)**
  - Allows complex, non-atomic data types
  - E.g.: set, map, tuple
- **Advantages of a nested data model**
  - More natural than normalization
  - Data is often already stored in a nested fashion on disk
    - E.g.: a web crawler outputs for each crawled url, the set of outlinks
    - Separating this in normalized form imply use of joins, which is an overkill for web-scale data
  - Nested data allows to have an algebraic language
    - E.g.: each tuple output by `GROUP` has one non-atomic field, a nested set of tuples from the same group
  - Nested data makes life easy when writing UDFs

User Defined Functions

- **Custom processing is often predominant**
  - E.g.: users may be interested in performing natural language stemming of a search term, or tagging urls as spam
- **All commands of Pig Latin can be customized**
  - Grouping, filtering, joining, per-tuple processing
- **UDFs support the nested data model**
  - Input and output can be non-atomic

Example 3

- **Continues from Example 1**
  - Assume we want to find for each category, the top 10 urls according to pagerank

```
groups = GROUP urls BY category;
output = FOREACH groups GENERATE category,
top10(urls);
```

- `top10()` is a UDF that accepts a set of urls (for each group at a time)
- it outputs a set containing the top 10 urls by pagerank for that group
- final output contains non-atomic fields

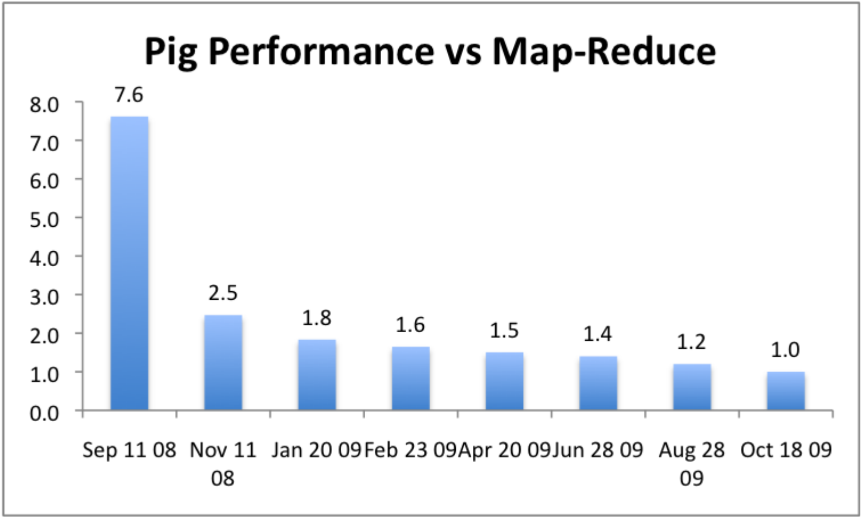
User Defined Functions

- **UDFs can be used in all Pig Latin constructs**
- **Instead, in SQL, there are restrictions**
  - Only scalar functions can be used in `SELECT` clauses
  - Only set-valued functions can appear in the `FROM` clause
  - Aggregation functions can only be applied to `GROUP BY` or `PARTITION BY`
- **UDFs can be written in Java, Python and Javascript**
  - With streaming, we can use also C/C++, Python, ...

Handling parallel execution

- **Pig and Pig Latin are geared towards parallel processing**
  - Of course, the underlying execution engine is MapReduce
  - SPORK = Pig on Spark $\rightarrow$ the execution engine need not be MapReduce
- **Pig Latin primitives are chosen such that they can be easily parallelized**
  - Non-equi joins, correlated sub-queries,... are not directly supported
- **Users may specify parallelization parameters at run time**
  - Question: Can you specify the number of maps?
  - Question: Can you specify the number of reducers?

A note on Performance



Pig Latin

Introduction

- **Not a complete reference to the Pig Latin language**: refer to [1]
  - Here we cover some interesting/useful aspects
- **The focus here is on some language primitives**
  - Optimizations are treated separately
  - How they can be implemented (in the underlying engine) is not covered
- **Examples are taken from [2, 3]**

Data Model

- **Supports four types**
  - *Atom:* contains a simple atomic value as a string or a number, e.g. `‘alice’`
  - *Tuple:* sequence of *fields*, each can be of any data type, e.g., `(‘alice’, ‘lakers’)`
  - *Bag:* collection of tuples with possible duplicates. Flexible schema, no need to have the same number and type of fields

$$\left\{ \begin{array}{c} \texttt{('alice','lakers')} \\ \texttt{('alice',('iPod','apple'))} \end{array} \right\}$$

    The example shows that tuples can be nested

Data Model

- **Supports four types**
  - *Map:* collection of data items, where each item has an associated key for lookup. The schema, as with bags, is flexible.
    - NOTE: keys are required to be data atoms, for efficient lookup.

$$\left[\begin{array}{c}\texttt{`fan of'} \rightarrow \left\{\begin{array}{c}\texttt{(`lakers')}\\ \texttt{(`iPod')}\end{array}\right\}\\ \texttt{`age'} \rightarrow \texttt{20}\end{array}\right]$$

    - The key `'fan of'` is mapped to a bag containing two tuples
    - The key `'age'` is mapped to an atom
  - Maps are useful to model datasets in which schema may be dynamic (over time)

Structure

- **Pig Latin programs are a sequence of steps**
  - Can use an interactive shell (called `grunt`)
  - Can feed them as a "script"
- **Comments**
  - In line: with double hyphens (`- -`)
  - C-style for longer comments (`/* ... */`)
- **Reserved keywords**
  - List of keywords that can't be used as identifiers
  - Same old story as for any language

Statements

- **As a Pig Latin program is executed, each statement is *parsed***
  - The interpreter builds a **logical plan** for every relational operation
  - The logical plan of each statement is added to that of the program so far
  - Then the interpreter moves on to the next statement

- **IMPORTANT: No data processing takes place during construction of logical plan → Lazy Evaluation**
  - When the interpreter sees the first line of a program, it confirms that it is syntactically and semantically correct
  - Then it adds it to the logical plan
  - It does not even check the existence of files, for data load operations

Statements

→ **It makes no sense to start any processing until the whole flow is defined**
  - Indeed, there are several optimizations that could make a program more efficient (e.g., by avoiding to operate on some data that later on is going to be filtered)

- **The trigger for Pig to start execution are the `DUMP` and `STORE` statements**
  - It is only at this point that the logical plan is compiled into a physical plan

- **How the physical plan is built**
  - Pig prepares a series of MapReduce jobs
    - ★ In *Local mode*, these are run locally on the JVM
    - ★ In *MapReduce mode*, the jobs are sent to the Hadoop Cluster
  - IMPORTANT: The command `EXPLAIN` can be used to show the MapReduce plan

Statements

Multi-query execution

- **There is a difference between `DUMP` and `STORE`**
  - Apart from diagnosis, and interactive mode, in batch mode `STORE` allows for program/job optimizations

- **Main optimization objective: minimize I/O**
  - Consider the following example:

```
A = LOAD 'input/pig/multiquery/A';
B = FILTER A BY $1 == 'banana';
C = FILTER A BY $1 != 'banana';
STORE B INTO 'output/b';
STORE C INTO 'output/c';
```

Statements

Multi-query execution

- **In the example, relations `B` and `C` are both derived from `A`**
  - Naively, this means that at the first `STORE` operator the input should be read
  - Then, at the second `STORE` operator, the input should be read again
- **Pig will run this as a single MapReduce job**
  - Relation `A` is going to be read only once
  - Then, each relation `B` and `C` will be written to the output

Expressions

- **An expression is something that is evaluated to yield a value**
  - Lookup on [3] for documentation

$$\texttt{t} = \left(\texttt{'alice'}, \left\{ \begin{array}{c} (\texttt{'lakers'}, \ 1) \\ (\texttt{'iPod'}, \ 2) \end{array} \right\}, \left[\texttt{'age'} \rightarrow 20 \right] \right)$$

Let fields of tuple `t` be called `f1, f2, f3`

Expression Type	Example	Value for `t`
Constant	'bob'	Independent of `t`
Field by position	\$0	'alice'
Field by name	f3	$\left[\texttt{'age'} \rightarrow 20 \right]$
Projection	f2.\$0	$\left\{ \begin{array}{c} (\texttt{'lakers'}) \\ (\texttt{'iPod'}) \end{array} \right\}$
Map Lookup	f3#'age'	20
Function Evaluation	SUM(f2.\$1)	1 + 2 = 3
Conditional Expression	f3#'age'>18? 'adult':'minor'	'adult'
Flattening	FLATTEN(f2)	'lakers', 1 'iPod', 2

Schemas

- **A relation in Pig may have an associated schema**
  - This is optional
  - A schema gives the fields in the relations names and types
  - Use the command `DESCRIBE` to reveal the schema in use for a relation

- **Schema declaration is flexible but reuse is awkward**[4]
  - A set of queries over the same input data will often have the same schema
  - This is sometimes hard to maintain (unlike HIVE) as there is no external components to maintain this association

HINT:: You can write a UDF function to perform a personalized load operation which encapsulates the schema

[4] Current developments solve this problem: HCatalogs. We will not cover this in this course.

Validation and nulls

- **Pig does not have the same power to enforce constraints on schema at load time as a RDBMS**
  - If a value cannot be cast to a type declared in the schema, then it will be set to a `null` value
  - This also happens for corrupt files
- **A useful technique to partition input data to discern good and bad records**
  - Use the `SPLIT` operator

```
SPLIT records INTO good_records IF temperature is
not null, bad _records IF temperature is NULL;
```

Other relevant information

- **Schema propagation and merging**
  - How schema are propagated to new relations?
  - Advanced, but important topic
- **User-Defined Functions**
  - Use [3] for an introduction to designing UDFs

Data Processing Operators

Loading and storing data

- **The first step in a Pig Latin program is to load data**
  - Accounts for what input files are (e.g. csv files)
  - How the file contents are to be deserialized
  - An input file is assumed to contain a sequence of tuples

- Data loading is done with the `LOAD` command

```
queries = LOAD 'query_log.txt'
USING myLoad()
AS (userId, queryString, timestamp);
```

Data Processing Operators

Loading and storing data

- **The example above specifies the following:**
  - The input file is `query_log.txt`
  - The input file should be converted into tuples using the custom `myLoad` deserializer
  - The loaded tuples have three fields, specified by the schema
- **Optional parts**
  - `USING` clause is optional: if not specified, the input file is assumed to be plain text, tab-delimited
  - `AS` clause is optional: if not specified, must refer to fileds by position instead of by name

Data Processing Operators

Loading and storing data

- Return value of the `LOAD` command
  - Handle to a bag
  - This can be used by subsequent commands
  - → bag handles are only logical
  - → no file is actually read!

- The command to write output to disk is `STORE`
  - It has similar semantics to the `LOAD` command

Data Processing Operators

Loading and storing data: Example

```
A = LOAD 'myfile.txt' USING PigStorage(',') AS
(f1,f2,f3);
```

```
<1, 2, 3>
<4, 2, 1>
<8, 3, 4>
<4, 3, 3>
<7, 2, 5>
<8, 4, 3>
```

Data Processing Operators

Per-tuple processing

- **Once you have some data loaded into a relation, a possible next step is, e.g., to filter it**
  - This is done, e.g., to remove unwanted data
  - HINT: By filtering early in the processing pipeline, you minimize the amount of data flowing trough the system

- **A basic operation is to apply some processing over every tuple of a data set**
  - This is achieved with the `FOREACH` command

```
expanded_queries = FOREACH queries GENERATE
userId, expandQuery(queryString);
```

Data Processing Operators

Per-tuple processing

- **Comments on the example above:**
  - Each tuple of the bag `queries` should be processed independently
  - The second field of the output is the result of a UDF

- **Semantics of the `FOREACH` command**
  - There can be no dependence between the processing of different input tuples
  - → This allows for an efficient parallel implementation

- **Semantics of the `GENERATE` clause**
  - Followed by a list of expressions
  - Also *flattening* is allowed
    - ★ This is done to eliminate nesting in data
    - → Allows to make output data independent for further parallel processing
    - → Useful to store data on disk

Data Processing Operators

Per-tuple processing: example

```
X = FOREACH A GENERATE f0, f1+f2;
Y = GROUP A BY f0;
Z = FOREACH Y GENERATE group, Y.($1, $2);
```

```
A=
<1, 2, 3>
<4, 2, 1>
<8, 3, 4>
<4, 3, 3>
<7, 2, 5>
<8, 4, 3>
```

```
X=
<1, 5>
<4, 3>
<8, 7>
<4, 6>
<7, 7>
<8, 7>
```

```
Z=
<1, {<2, 3>}>
<4, {<2, 1>, <3, 3>}>
<7, {<2, 5>}>
<8, {<3, 4>, <4, 3>}>
```

Data Processing Operators

Per-tuple processing: Discarding unwanted data

- **A common operation is to retain a portion of the input data**
  - This is done with the `FILTER` command

    ```
    real_queries = FILTER queries BY userId neq
    'bot';
    ```

- **Filtering conditions involve a combination of expressions**
  - Comparison operators
  - Logical connectors
  - UDF

Data Processing Operators

Filtering: example

```
Y = FILTER A BY f1 == '8';
```

```
A=
<1, 2, 3>
<4, 2, 1>
<8, 3, 4>
<4, 3, 3>
<7, 2, 5>
<8, 4, 3>
```

```
Y=
<8, 3, 4>
<8, 4, 3>
```

Data Processing Operators

Per-tuple processing: Streaming data

- **The `STREAM` operator allows transforming data in a relation using an external program or script**
  - This is possible because Hadoop MapReduce supports “streaming”
  - Example:
    `C = STREAM A THROUGH ‘cut -f 2’;`
    which use the Unix `cut` command to extract the second filed of each tuple in `A`
- **The `STREAM` operator uses `PigStorage` to serialize and deserialize relations to and from `stdin/stdout`**
  - Can also provide a custom serializer/deserializer
  - Works well with python

Data Processing Operators

Getting related data together

- **It is often necessary to *group* together tuples from one or more data sets**
  - We will explore several nuances of “grouping”

Data Processing Operators

The GROUP operator

- **Sometimes, we want to operate on a single dataset**
  - This is when you use the GROUP operator

- **Let's continue from Example 3:**
  - Assume we want to find the total revenue for each query string. This writes as:

```
grouped_revenue = GROUP revenue BY queryString;
query_revenue = FOREACH grouped_revenue GENERATE
queryString, SUM(revenue.amount) AS totalRevenue;
```

  - Note that `revenue.amount` refers to a projection of the nested bag in the tuples of `grouped_revenue`

Data Processing Operators

`GROUP ... BY ...`: Example

```
X = GROUP A BY f1;
```

```
A=
<1, 2, 3>
<4, 2, 1>
<8, 3, 4>
<4, 3, 3>
<7, 2, 5>
<8, 4, 3>
```

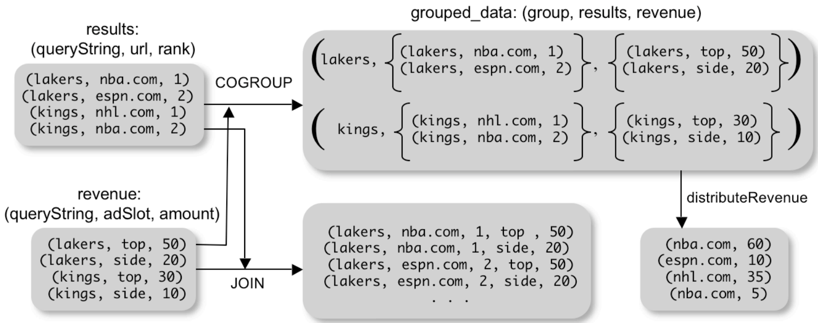
```
X=
<1, <1, 2, 3>>
<4, <4, 2, 1>, <4, 3, 3>>
<7, <7, 2, 5>>
<8, <8, 3, 4>, <8, 4, 3>>
```

Data Processing Operators

Getting related data together

- **Suppose we want to group together all search results data and revenue data for the same query string**

```
grouped_data = COGROUP results BY queryString,
revenue BY queryString;
```



Data Processing Operators

The `COGROUP` command

- **Output of a `COGROUP` contains one tuple for each group**
  - First field (`group`) is the group identifier (the value of the `queryString`)
  - Each of the next fields is a bag, one for each group being co-grouped
- **Grouping can be performed according to UDFs**
- **Next: a clarifying example**

Data Processing Operators

```
C = COGROUP A BY f1, B BY $0;
```

```
A=
<1, 2, 3>
<4, 2, 1>
<8, 3, 4>
<4, 3, 3>
<7, 2, 5>
<8, 4, 3>
```

```
B=
<2, 4>
<8, 9>
<1, 3>
<2, 7>
<2, 9>
<4, 6>
<4, 9>
```

```
C=
<1, {<1, 2, 3>}, {<1, 3>}>
<2, { }, {<2, 4>, <2, 7>, <2, 9>}>
<4, {<4, 2, 1>, <4, 3, 3>}, {<4, 6>,<4, 9>}>
<7, {<7, 2, 5>}, { }>
<8, {<8, 3, 4>, <8, 4, 3>}, {<8, 9>}>
```

Data Processing Operators

`COGROUP` vs `JOIN`

- `JOIN` vs. `COGROUP`
  - Their are equivalent: `JOIN == COGROUP` followed by a cross product of the tuples in the nested bags

- **Example 3: Suppose we try to attribute search revenue to search-results urls → compute monetary worth of each url**

```
grouped_data = COGROUP results BY queryString,
revenue BY queryString;
url_revenues = FOREACH grouped_data GENERATE
FLATTEN(distrubteRevenue(results, revenue));
```

  - Where `distrubteRevenue` is a UDF that accepts search results and revenue information for each query string, and outputs a bag of urls and revenue attributed to them

Data Processing Operators

COGROUP vs JOIN

- **More details on the UDF distribute Revenue**
  - Attributes revenue from the top slot entirely to the first search result
  - The revenue from the side slot may be equally split among all results

- **Let's see how to do the same with a `JOIN`**
  - `JOIN` the tables `results` and `revenues` by `queryString`
  - `GROUP BY queryString`
  - Apply a custom aggregation function

- **What happens behind the scenes**
  - During the `JOIN`, the system computes the cross product of the search and revenue information
  - Then the custom aggregation needs to undo this cross product, because the UDF specifically requires so

Data Processing Operators

`COGROUP` in details

- **The `COGROUP` statement conforms to an algebraic language**
  - The operator carries out only the operation of grouping together tuples into nested bags
  - The user can the decide whether to apply a (custom) aggregation on those tuples or to cross-product them and obtain a `JOIN`

- **It is thanks to the nested data model that `COGROUP` is an independent operation**
  - Implementation details are tricky
  - Groups can be very large (and are redundant)

Data Processing Operators

`JOIN` in Pig Latin

- **In many cases, the typical operation on two or more datasets amounts to an equi-join**
  - IMPORTANT NOTE: large datasets that are suitable to be analyzed with Pig (and MapReduce) are generally **not normalized**
  - → `JOIN`s are used more infrequently in Pig Latin than they are in SQL

- **The syntax of a `JOIN`**

```
join_result = JOIN results BY queryString,
revenue BY queryString;
```

  - This is a classic inner join (actually an equi-join), where each match between the two relations corresponds to a row in the `join_result`

Data Processing Operators

`JOIN` in Pig Latin

- **JOINs lend themselves to optimization opportunities**
  - Active development of several join flavors is on-going

- **Assume we join two datasets, one of which is considerably smaller than the other**
  - For instance, suppose a dataset fits in memory

- **Fragment replicate join**
  - Syntax: append the clause `USING "replicated"` to a `JOIN` statement
  - Uses a distributed cache available in Hadoop
  - All mappers will have a copy of the small input

  $\rightarrow$ This is a Map-side join

Data Processing Operators

MapReduce in Pig Latin

- **It is trivial to express MapReduce programs in Pig Latin**
  - This is achieved using `GROUP` and `FOREACH` statements
  - A map function operates on one input tuple at a time and outputs a bag of key-value pairs
  - The reduce function operates on all values for a key at a time to produce the final result

- **Example**

```
map_result = FOREACH input GENERATE
FLATTEN(map(*));
key_groups = GROUP map_results BY $0;
output = FOREACH key_groups GENERATE reduce(*);
```

  - where `map()` and `reduce()` are UDFs

The Pig Execution Engine

Pig Execution Engine

- **Pig Latin Programs are compiled into MapReduce jobs, and executed using Hadoop**[5]

- **Overview**
  - How to build a logical plan for a Pig Latin program
  - How to compile the logical plan into a physical plan of MapReduce jobs

- **Optimizations**

[5] Other execution engines are allowed, but require a lot of implementation effort.

Building a Logical Plan

- **As clients issue Pig Latin commands (interactive or batch mode)**
  - The Pig interpreter parses the commands
  - Then it verifies validity of input files and bags (variables)
    - E.g.: if the command is `c = COGROUP a BY ..., b BY ...;`, it verifies if `a` and `b` have already been defined

- **Pig builds a logical plan for every bag**
  - When a new bag is defined by a command, the new logical plan is a combination of the plans for the input and that of the current command

Building a Logical Plan

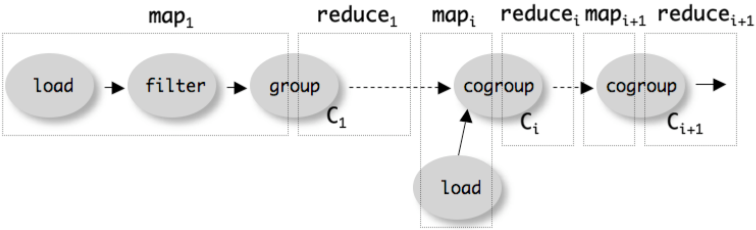
- **No processing is carried out when constructing the logical plans**
  - Processing is triggered only by `STORE` or `DUMP`
  - At that point, the logical plan is compiled to a physical plan
- **Lazy execution model**
  - Allows in-memory pipelining
  - File reordering
  - Various optimizations from the traditional RDBMS world
- **Pig is (potentially) platform independent**
  - Parsing and logical plan construction are platform oblivious
  - Only the compiler is specific to Hadoop

Building the Physical Plan

- **Compilation of a logical plan into a physical plan is “simple”**
  - MapReduce primitives allow a parallel `GROUP BY`
    - Map assigns keys for grouping
    - Reduce process a group at a time (actually in parallel)

- **How the compiler works**
  - Converts each `(CO)GROUP` command in the logical plan into distinct MapReduce jobs
  - *Map function* for `(CO)GROUP` command *C* initially assigns keys to tuples based on the `BY` clause(s) of *C*
  - *Reduce function* is initially a `no-op`

Building the Physical Plan



- **MapReduce boundary is the COGROUP command**
  - The sequence of FILTER and FOREACH from the LOAD to the first COGROUP C_1 are pushed in the Map function
  - The commands in later COGROUP commands C_i and C_{i+1} can be pushed into:
    - the Reduce function of C_i
    - the Map function of C_{i+1}

Building the Physical Plan

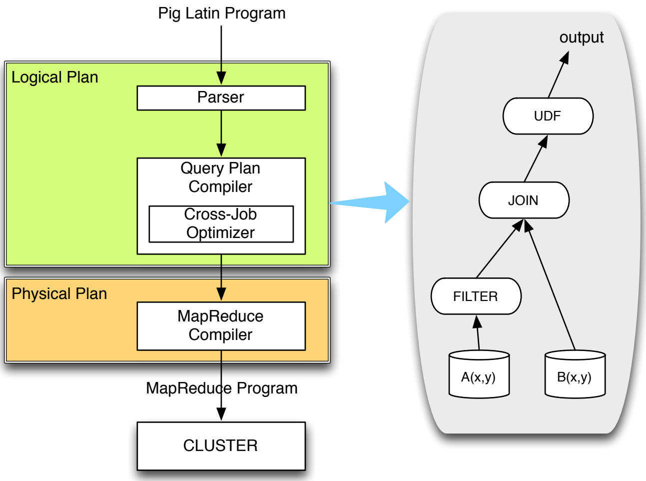
- **Pig optimization for the physical plan**
  - Among the two options outlined above, the first is preferred
  - Indeed, grouping is often followed by aggregation
  - $\rightarrow$ reduces the amount of data to be materialized between jobs

- **`COGROUP` command with more than one input dataset**
  - Map function appends an extra field to each tuple to identify the dataset
  - Reduce function decodes this information and inserts tuple in the appropriate nested bags for each group

Building the Physical Plan

- **How parallelism is achieved**
  - For `LOAD` this is inherited by operating over HDFS
  - For `FILTER` and `FOREACH`, this is automatic thanks to MapReduce framework
  - For `(CO)GROUP` uses the `SHUFFLE` phase
- **A note on the `ORDER` command**
  - Translated in two MapReduce jobs
  - First job: Samples the input to determine quantiles of the sort key
  - Second job: Range partitions the input according to quantiles, followed by sorting in the reduce phase
- **Known overheads due to MapReduce inflexibility**
  - Data materialization between jobs
  - Multiple inputs are not supported well

Summary


Pig Latin Program
Logical Plan
Parser
Query Plan Compiler
Cross-Job Optimizer
Physical Plan
MapReduce Compiler
MapReduce Program
CLUSTER
output
UDF
JOIN
FILTER
A(x,y)
B(x,y)

Single-program Optimizations

- **Logical optimizations: query plan**
  - Early projection
  - Early filtering
  - Operator rewrites
- **Physical optimization: execution plan**
  - Mapping of logical operations to MapReduce
  - Splitting logical operations in multiple physical ones
  - Join execution strategies

Efficiency measures

- **`(CO)GROUP` command places tuples of the same group in nested bags**
  - Bag materialization (I/O) can be avoided
  - This is important also due to memory constraints
  - Distributive or algebraic aggregation facilitate this task

- **What is an algebraic function?**
  - Function that can be structured as a tree of sub-functions
  - Each leaf sub-function operates over a subset of the input data

  → If nodes in the tree achieve data reduction, then the system can reduce materialization
  - Examples: `COUNT`, `SUM`, `MIN`, `MAX`, `AVERAGE`, ...

Efficiency measures

- **Pig compiler uses the combiner function of Hadoop**
  - A special API for algebraic UDF is available
- **There are cases in which `(CO)GROUP` is inefficient**
  - This happens with non-algebraic functions
  - Nested bags can be spilled to disk
  - Pig provides a disk-resident bag implementation
    - Features external sort algorithms
    - Features duplicates elimination

References

References I

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