Distributed data processing on the Cloud – Lecture 3

MapReduce Algorithms

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Outline

• MapReduce algorithms
• How to write MR algorithms
Shuffle and Sort: aggregate values by keys
Hadoop Usage Patterns

• Extract, transform, and load (ETL)
  – Perform aggregations, transformation, normalizations on the data (e.g. Log files) and load into RDBMS/ data mart

• Reporting and analytics
  – Run ad-hoc queries, analytics and data mining operations on large data

• Data processing pipelines

• Machine learning & Graph algorithms
  – Implement machine learning algorithms on huge data sets
  – Traverse large graphs and data sets, building models and classifiers
MapReduce Examples

- Distributed Grep
- Count of URL Access Frequency
- Reverse Web-Link Graph
- Term-Vector per Host
- Inverted Index
- Distributed Sort
MapReduce Jobs

- Tend to be very short, code-wise
  - IdentityReducer is very common
- “Utility” jobs can be composed
- Represent a data flow, more so than a procedure
Count of URL Access Frequency

• Processing web access logs
• Very similar to word count
• Map
  – processes logs of web page requests and outputs <URL, 1>
• Reduce
  – adds together all values
  – emits a <URL, total count> pairs
Distributed Grep

• Map
  – Emits a line if it matches a supplied pattern

• Reduce
  – Identity function
  – Just copies the supplied intermediate data to the output
Reverse Web-Link Graph

• Map
  – Outputs \(<\text{target}, \text{source}>\) pairs
  – for each link to a \textit{target} URL found in a page named \textit{source}.

• Reduce
  – Concatenates the list of all source URLs
  – Returns \(<\text{target}, \text{list(source)}>\)
Sort: Inputs

- A set of files, one value per line.
- Mapper key is file name, line number
- Mapper value is the contents of the line
Sort Algorithm

• Takes advantage of reducer properties:
  – (key, value) pairs are processed in order by key; reducers are themselves ordered
• Mapper: Identity function for value
  (k, v) -> (v, _)
• Reducer: Identity function (k’, _) -> (k’, “”)
Sort: The Trick

• (key, value) pairs from mappers are sent to a particular reducer based on hash(key)
• Must pick the hash function for your data such that
  – K1 < K2 => hash(K1) < hash(K2)
• Used as a test of Hadoop’s raw speed
Inverted Index: Inputs

- A set of files containing lines of text
- Mapper key is file name, line number
- Mapper value is the contents of the line
Inverted Index Algorithm

• Mapper: For each word in (file, words), map to (word, file)

• Reducer: Identity function
Index MapReduce

- `map(pageName, pageText):`
  - `foreach` word `w` in `pageText`:
    - `emit Intermediate(w, pageName);`
  - `Done`

- `reduce(word, values):`
  - `foreach` pageName in `values`:
    - `AddToOutputList(pageName);`
  - `Done`
  - `emitFinal(FormattedPageListForWord);`
Index: Data Flow

Page A
This page contains so much of text

A map output
This : A
page : A
contains : A
so : A
much : A
of : A
text : A

Page B
This page too contains some text

B map output
This : B
page : B
too : B
contains : B
some : B
text : B

Reduced output
This : A, B
page : A, B
too : B
contains : A, B
so : A
much : A
of : A
text : A, B
some : B
Let us focus much bigger problems
Managing Dependencies

• Remember: Mappers run in isolation
  – You have no idea in what order the mappers run
  – You have no idea on what node the mappers run
  – You have no idea when each mapper finishes

• Tools for synchronization:
  – Ability to hold state in reducer across multiple key-value pairs
  – Sorting function for keys
  – Partitioner
  – Cleverly-constructed data structures
Motivating Example

• Term co-occurrence matrix for a text collection
  – $M = N \times N$ matrix ($N =$ vocabulary size)
  – $M_{ij}$: number of times $i$ and $j$ co-occur in some context
    (for concreteness, let’s say context = sentence)

• Why?
  – Distributional profiles as a way of measuring semantic distance
  – Semantic distance useful for many language processing tasks

“You shall know a word by the company it keeps” (Firth, 1957)
MapReduce: Large Counting Problems

- Term co-occurrence matrix for a text collection = specific instance of a large counting problem
  - A large event space (number of terms)
  - A large number of events (the collection itself)
  - Goal: keep track of interesting statistics about the events

- Basic approach
  - Mappers generate partial counts
  - Reducers aggregate partial counts

How do we aggregate partial counts efficiently?
First Try: “Pairs”

• Each mapper takes a sentence:
  – Generate all co-occurring term pairs
  – For all pairs, emit \((a, b) \rightarrow \text{count}\)
• Reducers sums up counts associated with these pairs
• Use combiners!
“Pairs” Analysis

• Advantages
  – Easy to implement, easy to understand

• Disadvantages
  – Lots of pairs to sort and shuffle around (upper bound?)
Another Try: “Stripes”

- Idea: group together pairs into an associative array
  - \((a, b) \rightarrow 1\)
  - \((a, c) \rightarrow 2\)
  - \((a, d) \rightarrow 5\)
  - \((a, e) \rightarrow 3\)
  - \((a, f) \rightarrow 2\)
  - \(a \rightarrow \{ b: 1, c: 2, d: 5, e: 3, f: 2 \}\)

- Each mapper takes a sentence:
  - Generate all co-occurring term pairs
  - For each term, emit \(a \rightarrow \{ \text{count}_b, \text{count}_c, \text{count}_d \ldots \}\)

-Reducers perform element-wise sum of associative arrays
  - \(a \rightarrow \{ b: 1, d: 5, e: 3 \}\)
  - \(a \rightarrow \{ b: 1, c: 2, d: 2, f: 2 \}\)
  - \(a \rightarrow \{ b: 2, c: 2, d: 7, e: 3, f: 2 \}\)
“Stripes” Analysis

• Advantages
  – Far less sorting and shuffling of key-value pairs
  – Can make better use of combiners

• Disadvantages
  – More difficult to implement
  – Underlying object is more heavyweight
  – Fundamental limitation in terms of size of event space
Efficiency comparison of approaches to computing word co-occurrence matrices

- "stripes" approach
- "pairs" approach

Cluster size: 38 cores
Data Source: Associated Press Worldstream (APW) of the English Gigaword Corpus (v3), which contains 2.27 million documents (1.8 GB compressed, 5.7 GB uncompressed)
Conditional Probabilities

- How do we compute conditional probabilities from counts?

$$P(B \mid A) = \frac{\text{count}(A, B)}{\text{count}(A)} = \frac{\text{count}(A, B)}{\sum_{B'} \text{count}(A, B')}$$

- How do we do this with MapReduce?
P(B | A): “Pairs”

For this to work:

- Must emit extra (a, *) for every $b_n$ in mapper
- Must make sure all a’s get sent to same reducer (use Partitioner)
- Must make sure (a, *) comes first (define sort order)

Reducer holds this value in memory:

<table>
<thead>
<tr>
<th>(a, b)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a, b₁)</td>
<td>3</td>
</tr>
<tr>
<td>(a, b₂)</td>
<td>12</td>
</tr>
<tr>
<td>(a, b₃)</td>
<td>7</td>
</tr>
<tr>
<td>(a, b₄)</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(a, *)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a, *)</td>
<td>32</td>
</tr>
</tbody>
</table>
P(B | A): “Stripes”

a → {b_1:3, b_2:12, b_3:7, b_4:1, ... }

• Easy!
  – One pass to compute (a, *)
  – Another pass to directly compute P(B | A)
Synchronization in Hadoop

• Approach 1: turn synchronization into an ordering problem
  – Sort keys into correct order of computation
  – Partition key space so that each reducer gets the appropriate set of partial results
  – Hold state in reducer across multiple key-value pairs to perform computation
  – Illustrated by the “pairs” approach

• Approach 2: construct data structures that “bring the pieces together”
  – Each reducer receives all the data it needs to complete the computation
  – Illustrated by the “stripes” approach
Issues and Tradeoffs

• Number of key-value pairs
  – Object creation overhead
  – Time for sorting and shuffling pairs across the network

• Size of each key-value pair
  – De/serialization overhead

• Combiners make a big difference!
  – RAM vs. disk and network
  – Arrange data to maximize opportunities to aggregate partial results
Complex Data Types in Hadoop

• How do you implement complex data types?
• The easiest way:
  – Encoded it as Text, e.g., (a, b) = “a:b”
  – Use regular expressions to parse and extract data
  – Works, but pretty hack-ish

• The hard way:
  – Define a custom implementation of WritableComparable
  – Must implement: readFields, write, compareTo
  – Computationally efficient, but slow for rapid prototyping
This week in lab

• MapReduce for data analysis

• Writing your first MapReduce algorithms
Next Lecture

- MapReduce in Information Retrieval
References


• Data-Intensive Text Processing with MapReduce
  Authors: Jimmy Lin and Chris Dyer
  Pages 50-57: Pairs and Stripes problem