COMP 322: Fundamentals of Parallel Programming

Lecture 8: Map/Reduce

Mack Joyner and Zoran Budimlić {mjoyner, zoran}@rice.edu

http://comp322.rice.edu



Worksheet #7 solution: Associativity and Commutativity

Recap:

A binary function f is associative if f(f(x,y),z) = f(x,f(y,z)). A binary function f is commutative if f(x,y) = f(y,x).

Worksheet problems:

- 1) Claim: a Finish Accumulator (FA) can only be used with operators that are associative and commutative. Why? What can go wrong with accumulators if the operator is non-associative or non-commutative? You may get different answers in different executions if the operator is non-associative or non-commutative e.g., an accumulator can be implemented using one "partial accumulator" per processor core.
- 2) For each of the following functions, indicate if it is associative and/or commutative.
- a) f(x,y) = x+y, for integers x, y, is associative and commutative
- b) g(x,y) = (x+y)/2, for integers x, y, is commutative but not associative
- c) h(s1,s2) = concat(s1, s2) for strings s1, s2, e.g., h("ab","cd") = "abcd", is associative but not commutative



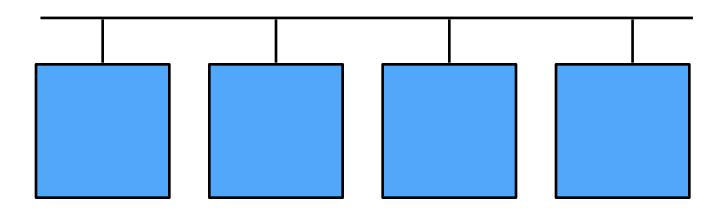
Map/Reduce: Streaming data requirements have skyrocketed

- AT&T processes roughly 168 petabytes per day in 2017 through its telecommunications network
- Google processed roughly 24 petabytes per day in 2009
- Facebook, Amazon, Twitter, etc, have comparable throughputs
- Two Sigma maintains over 100 teraflops of private computing power, continuously computing over 11 petabytes of quantitative data
- In comparison, the IBM Watson knowledge base stored roughly 4 terabytes of data when winning at Jeopardy



Parallelism enables processing of big data

- Continuously streaming data needs to be processed at least as fast as it is accumulated, or we will never catch up
- The bottleneck in processing very large data sets is dominated by the speed of disk access
- More processors accessing more disks enables faster processing





MapReduce Pattern

- Apply Map function f to user supplied record of keyvalue pairs
- Compute set of intermediate key/value pairs
- Apply Reduce operation g to all values that share same key to combine derived data properly
 - —Often produces smaller set of values
- User supplies Map and Reduce operations in functional model so that the system can parallelize them, and also re-execute them for fault tolerance



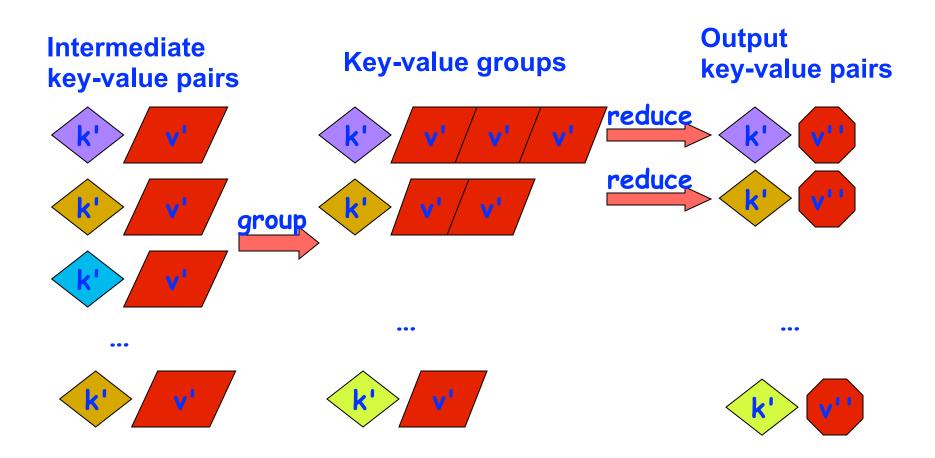
MapReduce: The Map Step

Input set of Flattened intermediate key-value pairs set of key-value pairs

Source: http://infolab.stanford.edu/~ullman/mining/2009/mapreduce.ppt



MapReduce: The Reduce Step



Source: http://infolab.stanford.edu/~ullman/mining/2009/mapreduce.ppt



Map Reduce: Summary

- Input set is of the form {(k1, v1), . . . (kn, vn)}, where (ki, vi) consists of a key, ki, and a value, vi.
 - Assume that the key and value objects are immutable, and that equality comparison is well defined on all key objects.
- Map function f generates sets of intermediate key-value pairs, f(ki,vi) = {(k1',v1'),...(km',vm')}. The km' keys can be different from ki key in the map function.
 - Assume that a flatten operation is performed as a postpass after the map operations, so as to avoid dealing with a set of sets.
- Reduce operation groups together intermediate key-value pairs, {(k', vj')} with the same k', and generates a reduced key-value pair, (k',v"), for each such k', using reduce function g



Google Uses MapReduce For ...

- Web crawl: Find outgoing links from HTML documents, aggregate by target document
- Google Earth: Stitching overlapping satellite images to remove seams and to select high-quality imagery
- Google Maps: Processing all road segments on Earth and render map tile images that display segments



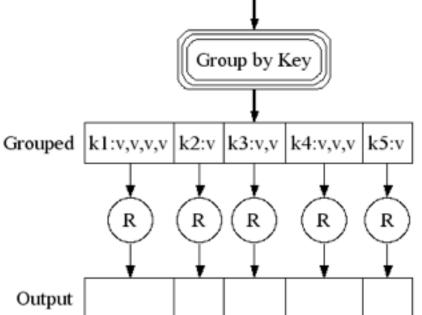
MapReduce Execution

Fine granularity Inputasks: many more map tasks than machines

Intermediate

Bucket sort to get same keys together

2000 servers => ≈ 200,000 Map Tasks, ≈ 5,000 Reduce tasks



WordCount example

In: set of words

Out: set of (word,count) pairs

Algorithm:

- 1. For each in word W, emit (W, 1) as a key-value pair (map step).
- 2. Group together all key-value pairs with the same key (reduce step).
- 3. Perform a sum reduction on all values with the same key(reduce step).
- All map operations in step 1 can execute in parallel with only local data accesses
- Step 2 may involve a major reshuffle of data as all key-value pairs with the same key are grouped together.
- Step 3 performs a standard reduction algorithm for all values with the same key, and in parallel for different keys.



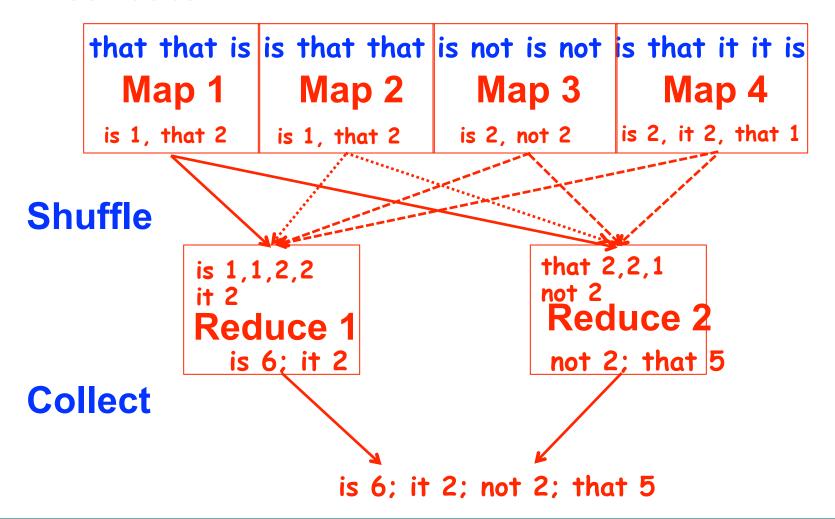
PseudoCode for WordCount

```
<String, Integer> map(String inKey, String inValue):
     // inKey: document name
3.
     // inValue: document contents
4.
     for each word w in inValue:
5.
       emitIntermediate(w, 1) // Produce count of words
6.
7.
   <Integer> reduce(String outKey, Iterator<Integer> values):
8.
     // outKey: a word
9.
     // values: a list of counts
10.
      Integer result = 0
11.
      for each v in values:
12.
        result += v // the value from map was an integer
13.
      emit(result)
```



Example Execution of WordCount Program

Distribute



Announcements & Reminders

IMPORTANT:

- —Watch video & read handout for topic 2.5 and 2.6 for next lecture on Monday, Jan 28th
- HW2 is available and due by Wednesday, Feb 6th
- Quiz for Unit 1 (topics 1.1 1.5) is due by 11:59pm TODAY on Canvas
- See course web site for all work assignments and due dates
- Use Piazza (public or private posts, as appropriate) for all communications re. COMP 322
- See <u>Office Hours</u> link on course web site for latest office hours schedule.

