Lecture 22
GFS and MapReduce

Administration

- Last call for the datacenter tour!
  - Thurs @2:30PM, or Fri @10:30AM
  - Sign up at the Ctools-posted URL
  - Directions have been posted
  - Take a bus, drive, or get a ride
- Alpha Release this Friday @ 6PM
  - Please keep your sites up till 10AM Sat
- Midterm #2
  - Still being graded
  - Early results: better than MT#1

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GFS and MapReduce

- Search engines were among first apps to address Web's scale directly
  - We spoke about distributing search queries
  - Also, distributing index construction
- Search engines were first, but not last
  - Social networks
  - Web-analysis and intelligence
  - Log processing
- Traditional data systems inappropriate; Google first to build somewhat general solutions

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A Little Math

- How hard is indexing the Web really?
  - Say, 10B pages in 1 week
  - 10B in ~10K minutes
  - 1M pages every minute!
  - Disk scan rate 50MB/sec
  - Page takes average 25kb
  - 2000 pages/sec, or,
  - 120,000 pages/min *just to read off disk*
- What if we wanted to do it in a day?
  - An hour?
- Want to use clusters of 100s-1000s of machines, with local disks and some network

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Distributed Programming

- Unlike distributed databases, many CPUs needed. 1000s, not dozens
  - Programmer cannot know how many machines at program-time or runtime
  - Even so, job is very long-lasting compared to most db queries
  - Machines die, machines depart; job must survive
- Also, cannot express program in SQL

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MapReduce

- MapReduce system provides:
  - Automatic parallelization & distribution
  - Fault-tolerance
  - Status & monitoring tools
  - Clean abstraction for programmers

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MapReduce

- Many data programs can be written as *map* and *reduce* functions
- *map* transforms **key, value** inputs into new **key', value'**
  - `Map(k, v) => (k', v') list`
- *reduce* receives all the vals for a given key' and can output to disk file
  - `Reduce(k', v' list) => (out-key, out-val) list`

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Example: Filter

- ```
  Map(k, v)=>
  if (prime(k)) then emit(k, v)
  ```
- ("foo", 7) => ("foo", 7)
- ("bar", 10) => *nothing*

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Example: Sum

- ```
  Reduce(k, vals)=>
  sum = 0
  foreach int v in vals:
    sum += v
  emit(k, sum)
  ```
- `("A", [42, 100, 312]) => ("A", 454)`
- `("B", [12, 6, -2]) => ("B", 16)`

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Word counting

- ```
  Map(lineNo, textStr)
      for each word w in textStr:
        emit(w, 1)
  ```
- ```
  Reduce(outKey, interm-vals)
      int result = 0
      for each v in interm-vals:
        result += v
  ```
- `Emit(output-key, result)`

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Applications

- What else can be an MR program?
  - URL counting in logs, Reverse Web graph
  - Inverted index construction, Sorting
  - Massive image conversion, others

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Shuffle/Sort

- What happens between map & reduce?
  - Data collated and grouped for map
- Execution goes as follows:
  - Break input into M chunks
  - Process each chunk w/ *map* process
  - Group map outputs into R chunks
  - Process each chunk w/ *reduce* process
  - *reduce* fn's outputs go to disk

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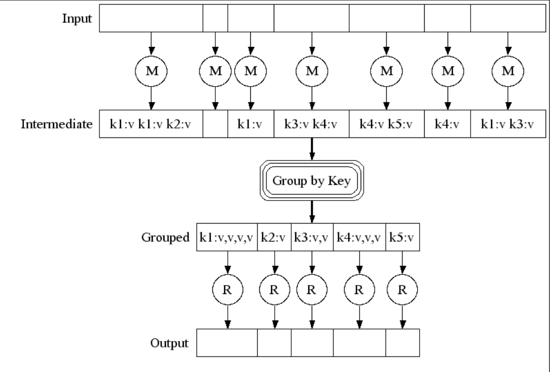

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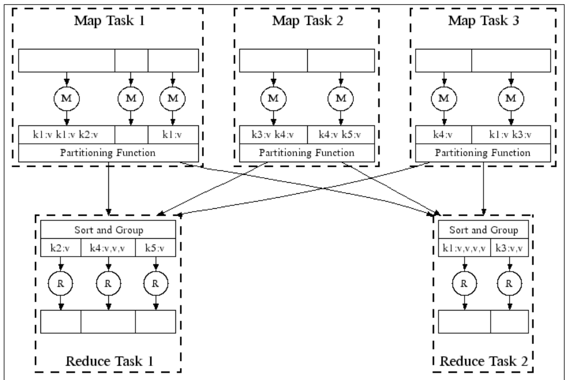

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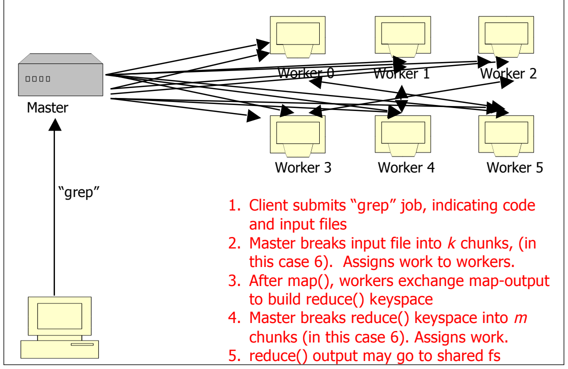
Map/Reduce Job Processing



1. Client submits "grep" job, indicating code and input files
2. Master breaks input file into *k* chunks, (in this case 6). Assigns work to workers.
3. After map(), workers exchange map-output to build reduce() keyspace
4. Master breaks reduce() keyspace into *m* chunks (in this case 6). Assigns work.
5. reduce() output may go to shared fs

A few nice features

- What about slow, not dead, machines?
  - Speculative execution for stragglers
- What about data placement?
  - Use distributed filesystem across cluster disks; start tasks where the target data already lies
- Isn't the intermediate data size large?
  - Use a "local reducer" called a Combiner at each map
  - Compress data between map and reduce

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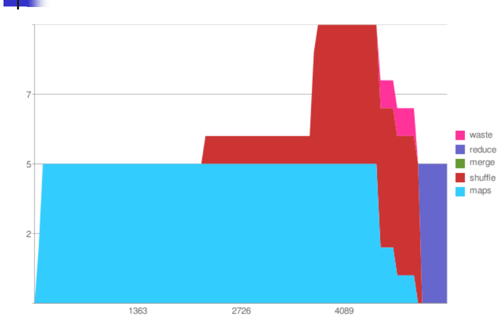
MapReduce Timelines



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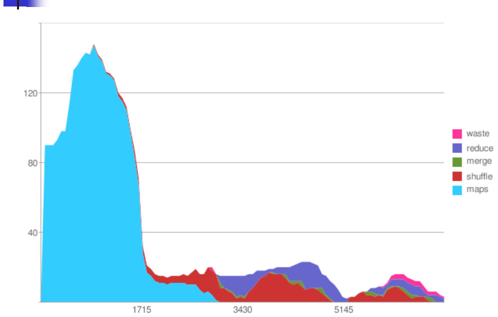
MapReduce Timelines



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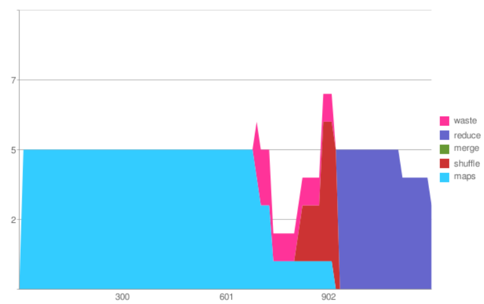
MapReduce Timelines



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Performance

- The TeraSort benchmark measures time to sort 1TB (10B 100-byte records)
  - In 1998, record holder did it in 151 mins
  - In 2009, Yahoo/Hadoop MapReduce did it in 209 seconds
  - Then a few months later, Google did it in 68 seconds (on about 1,000 machines)
- MapReduce also holds the record for sorting a petabyte
  - (That's 10 trillion 100-byte records)
  - 6 hours, 2 mins on 4,000 machines

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Intermission

- MapReduce has become extremely trendy. Any problem, no matter how unrelated, is now treated as a good target for MapReduce programming

- That said, it has its uses. For a different opinion, do a search for "MapReduce: A Major Step Backwards"

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Google File System

- The distributed filesystem that stores data across a MapReduce cluster
- As with MR, Google had strange requirements and came up with strange design
- Has not proved as generally-useful as MapReduce

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Weird Requirements

- High component failure rates
  - Inexpensive commodity components fail all the time
- "Modest" number of HUGE files
  - Just a few million
  - Each is 100MB or larger; multi-GB files typical
- Files are append-only
- Large streaming reads
- High sustained throughput favored over low latency

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Design solution

- Files stored as chunks
  - Much larger size than most filesystems (default is 64MB)
- Reliability through replication
  - Each chunk replicated across 3+ *Chunkservers*
- Single master coordinates access, metadata
  - Simple centralized management
- No data caching
  - Little benefit due to large data sets, streaming reads
- Familiar interface, but customize the API
  - Simplify the problem; focus on distributed apps

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Design Details

- Chunks can be copied, replicated
- Chunkservers hold and serve chunks
- Master holds metainfo
  - Filename → chunk list
  - Chunk → chunkserver-location
- Chunkservers report in to master every few seconds
- Data/task co-location is extremely important

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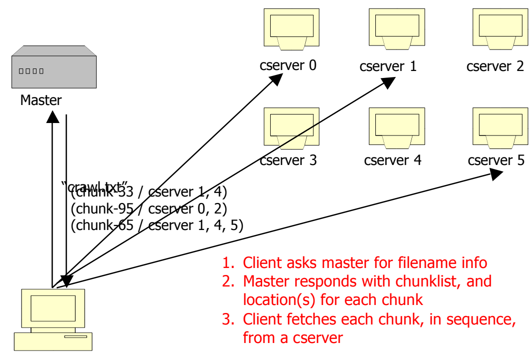
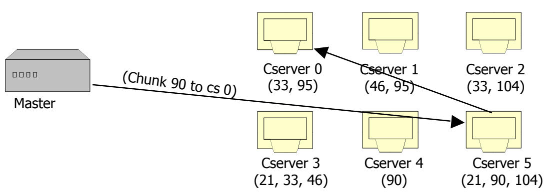
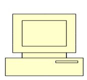
GFS File Read



1. Client asks master for filename info
2. Master responds with chunklist, and location(s) for each chunk
3. Client fetches each chunk, in sequence, from a cserver

GFS Replication





1. Always keep at least *k* copies of each chunk
2. Imagine cserver 4 dies; #90 lost
3. Master loses heartbeat, decrements #90's reference count. Asks cserver 5 to replicate #90 to cserver 0
4. Choosing replication target is tricky