Grep

- Find all lines matching some pattern
- No need to combine anything
  - Reduce is not needed, i.e., just identity function
- Map takes line and outputs it if it matches the pattern
- Map could also take an entire document and emit all matching lines
  - Not a good idea if there is a single large document, but works well if there are many documents

URL Access Frequency

- Web log shows individual URL accesses
- Essentially the same Word Count
- Map can work with individual URL access records, or with an entire log file
  - Word Count analogy: work with individual words or with documents
- Reduce combines the partial counts for each URL

Reverse Web-Link Graph

- For each URL, find all pages (URLs) pointing to it (incoming links)
- Problem: Web page has only outgoing links
- Need all (anySource, P) links for each page P
  - Suggests Reduce with P as the key, source as value
- Map: for page *source*, create all (*target*, *source*) pairs for each link to a *target* found in page
- Reduce: since *target* is key, will receive all sources pointing to that target

Inverted Index

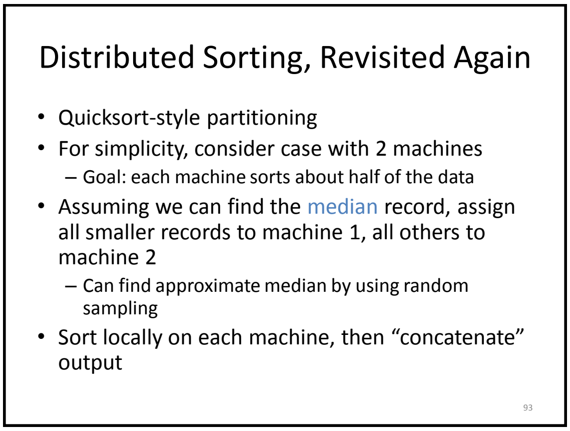
- For each word, create list of documents (document IDs) containing it
- Same as reverse Web-link graph problem
  - "Source URL" is now "document ID"
  - "Target URL" is now "word"
- Can augment this to create list of (document ID, position) pairs for each word
  - Map emits (word, (document ID, position)) while parsing a document

Distributed Sorting

- Does not look like a good match for MapReduce
- Send arbitrary data subset to reduce task?
  - How to merge them? Need another MapReduce phase.
- Can Map do pre-sorting and Reduce the merging?
  - Use *set* of input records as Map input
  - Map pre-sorts it and single reducer merges them
  - Does not scale!
- We need to get multiple reducers involved
  - What should we use as the intermediate key?

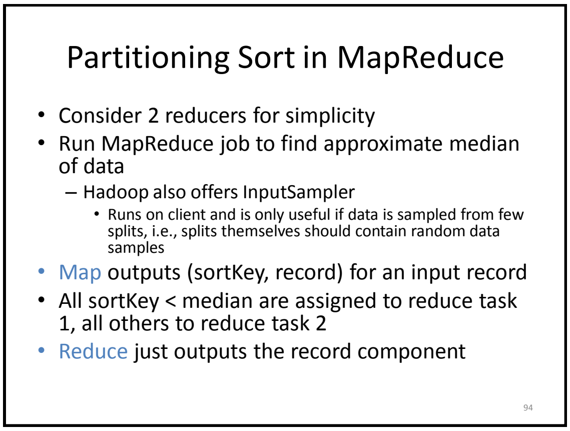
Distributed Sorting, Revisited

- MapReduce environment guarantees that for each reduce task the assigned set of intermediate keys is processed in key order
  - After receiving all (key2, val2) pairs from mappers, reducer sorts them by key2, then calls Reduce on each (key2, list(val2)) group
- Can leverage this guarantee for sorting
  - Map outputs (sortKey, record) for each record
  - Reduce simply emits the records unchanged
  - Make sure there is only a single reducer machine
- So far so good, but this still does not scale



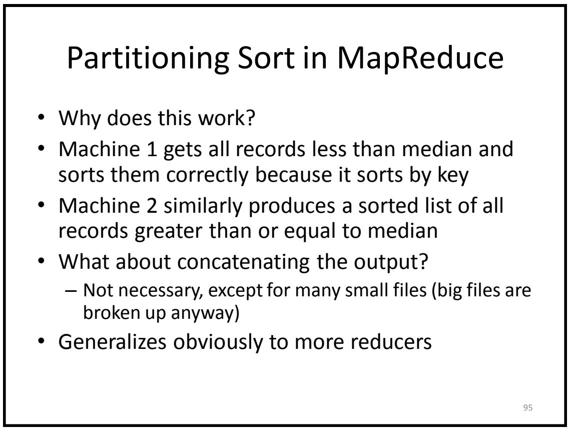
Distributed Sorting, Revisited Again

- Quicksort-style partitioning
- For simplicity, consider case with 2 machines
  - Goal: each machine sorts about half of the data
- Assuming we can find the median record, assign all smaller records to machine 1, all others to machine 2
  - Can find approximate median by using random sampling
- Sort locally on each machine, then “concatenate” output



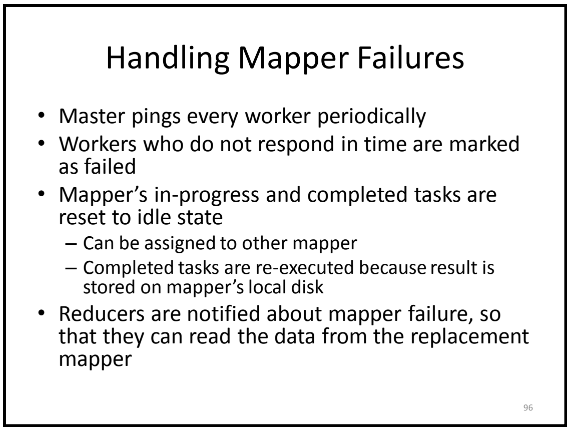
Partitioning Sort in MapReduce

- Consider 2 reducers for simplicity
- Run MapReduce job to find approximate median of data
  - Hadoop also offers InputSampler
    - Runs on client and is only useful if data is sampled from few splits, i.e., splits themselves should contain random data samples
- Map outputs (sortKey, record) for an input record
- All sortKey < median are assigned to reduce task 1, all others to reduce task 2
- Reduce just outputs the record component



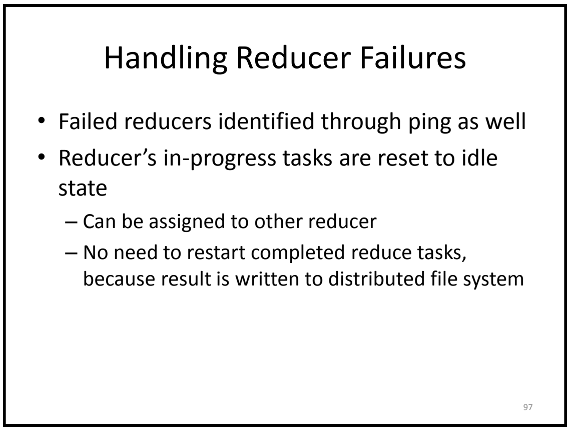
Partitioning Sort in MapReduce

- Why does this work?
- Machine 1 gets all records less than median and sorts them correctly because it sorts by key
- Machine 2 similarly produces a sorted list of all records greater than or equal to median
- What about concatenating the output?
  - Not necessary, except for many small files (big files are broken up anyway)
- Generalizes obviously to more reducers



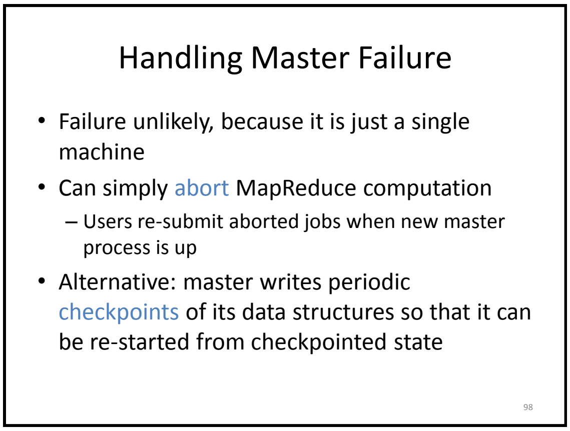
Handling Mapper Failures

- Master pings every worker periodically
- Workers who do not respond in time are marked as failed
- Mapper’s in-progress and completed tasks are reset to idle state
  - Can be assigned to other mapper
  - Completed tasks are re-executed because result is stored on mapper’s local disk
- Reducers are notified about mapper failure, so that they can read the data from the replacement mapper



Handling Reducer Failures

- Failed reducers identified through ping as well
- Reducer’s in-progress tasks are reset to idle state
  - Can be assigned to other reducer
  - No need to restart completed reduce tasks, because result is written to distributed file system



Handling Master Failure

- Failure unlikely, because it is just a single machine
- Can simply abort MapReduce computation
  - Users re-submit aborted jobs when new master process is up
- Alternative: master writes periodic checkpoints of its data structures so that it can be re-started from checkpointed state