MapReduce

Questions Answered in this Lecture:

- How do we abstract away details of parallel programs?
- How does MapReduce work?
- When is it useful?

Announcements

- Reading: Google tutorial on MapReduce
  - https://ai.google/research/pubs/pub36249
- Final exam example(s) will be out next week

Acknowledgements

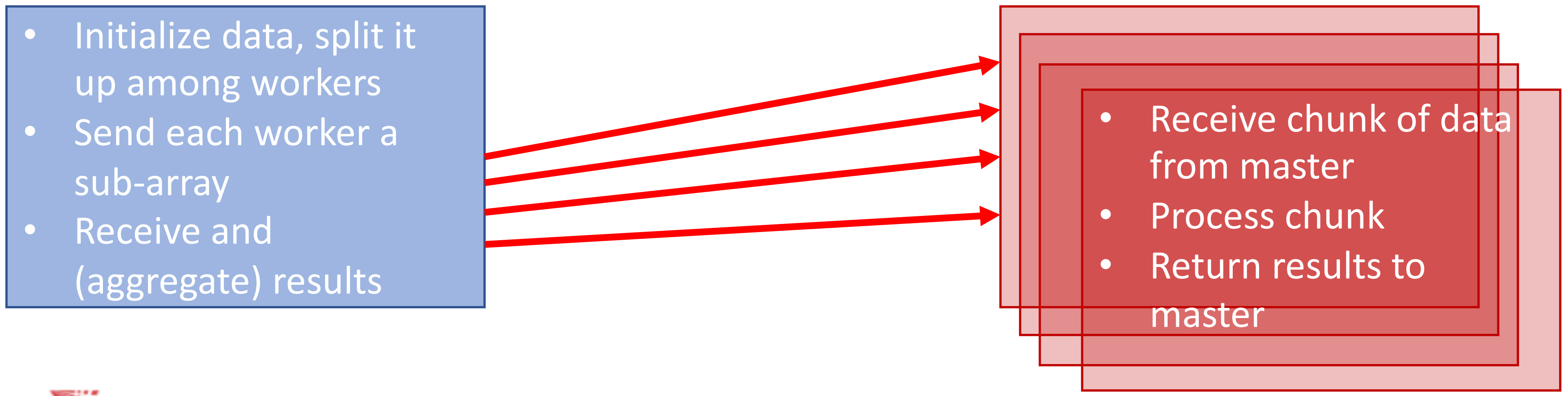
- A lot of this information comes from Google
- Also Paul Krzyzanowski's notes from Rutgers
- See also here https://hadoop.apache.org/docs/r1.2.1/mapred_tutorial.html

Background

- We’ve seen a lot about concurrency and parallelism, and why they make sense to use
- But we also know how it can be hard to get right

Simplest example: *embarrassingly parallel*

- ***No dependencies*** between data
- Split our data into chunks (or shards)
- Distribute chunks among workers (threads, processes, nodes, etc.)
- *Master* process coordinates others (*workers*)



- Initialize data, split it up among workers
- Send each worker a sub-array
- Receive and (aggregate) results
- Receive chunk of data from master
- Process chunk
- Return results to master

The Power of Abstraction

- ***Many* programs work this way** when written with parallelism in mind
- But **they all repeat a lot of work** (creating threads, waiting on barriers, waiting on CV’s, getting intermediate results, terminating workers, etc.)
- Can we abstract away the details? (yes)
- We **build a *framework***, and how we *use* (program to the interface of) that framework we’ll refer to as a *programming model*

MapReduce

- Created by Google in 2004
- Inspired by collection-oriented functions in functional languages (e.g. LISP)
  - **`map(function, collection)`**
    - Applies function to each value in the collection
    - `(map ‘length ‘(() (a) (a b) (a b c))) => (0 1 2 3)`
  - **`reduce(function, collection)`**
    - Combines all values using a binary function (+, *, etc.)
    - `(reduce #’+ ‘(1 2 3 4 5)) => 15`

MapReduce

- Framework for parallel computing (on clusters)
- Programmers use a simple API
- Don’t have to worry about
  - Parallelization – Creating threads, managing them
  - Domain decomposition – who gets what data
  - Load Balancing – When/where to schedule workers
  - Fault Tolerance
- Can use it to process tera/petabytes on big machines

MapReduce

- Map(input chunk) → Intermediate key/value pairs
  - Framework automatically **partitions input data into M chunks**
  - Discard unneeded data and generate (key, value) sets
  - **Framework groups intermediate values** with same key and passes them to *Reduce*
- Reduce(intermediate key/value pairs) → result files
  - Input key & set of values which it maps to
  - **Merge these values together to form a smaller set of values**
- Important: Reducers are distributed by **partitioning key space into R pieces** (using a partitioning function)

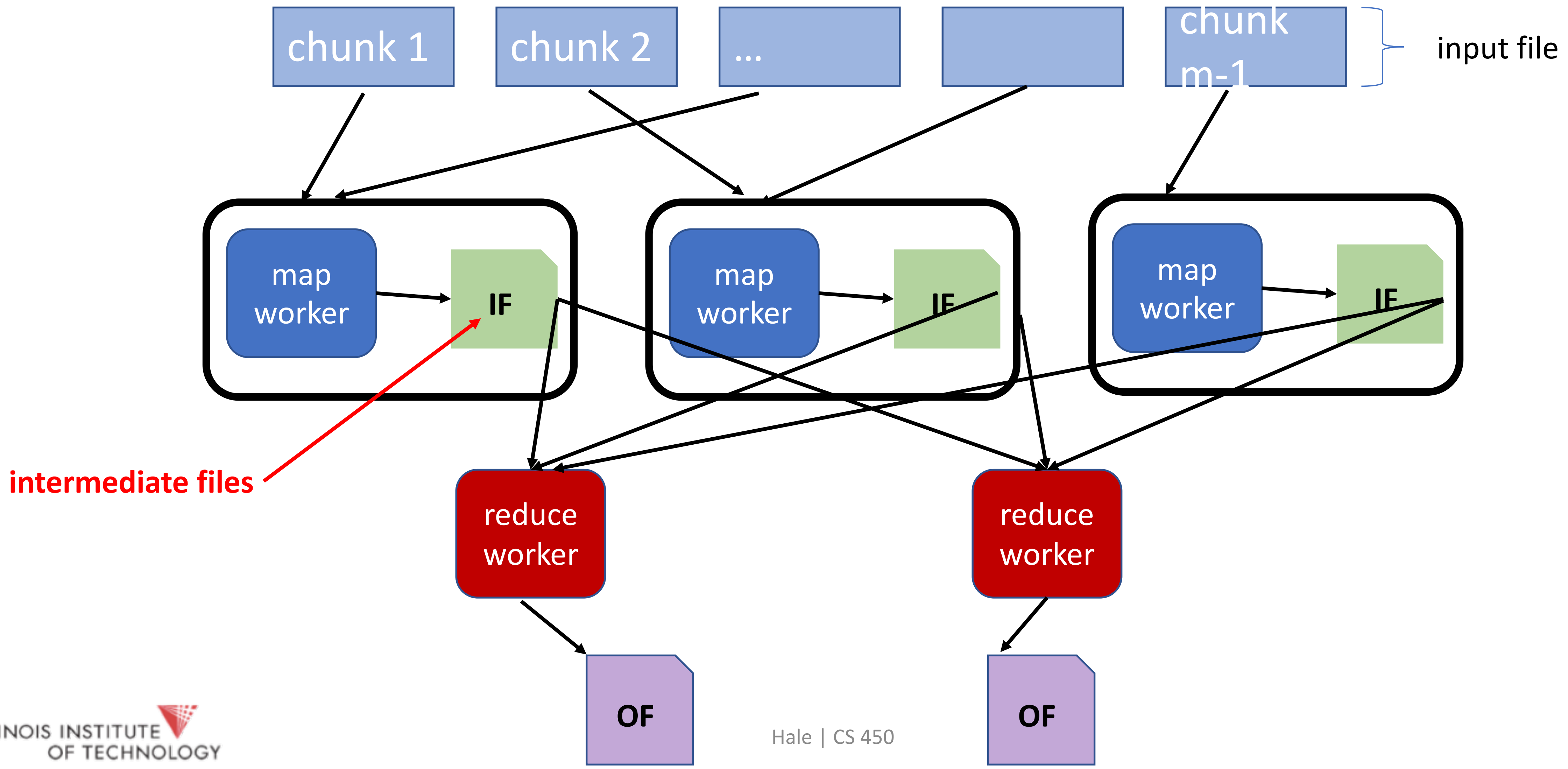
- Map
  - Get source data (parse into key, value pair)
  - Write key to intermediate file (emit)
- Partition
  - Identify which of R reducers will handle which keys
  - Map data to target it to one of the R reducers

Map Worker

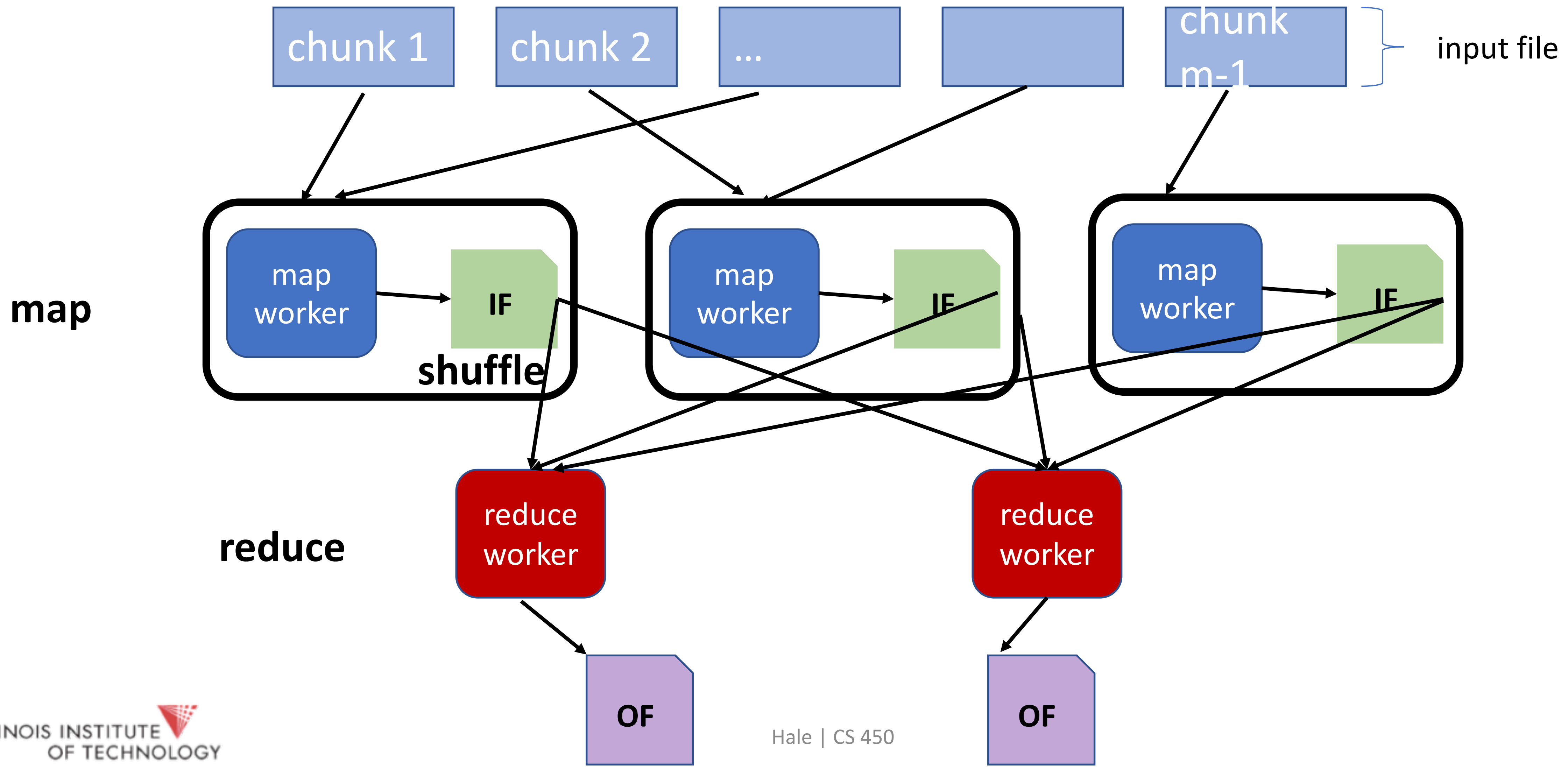
- Shuffle and Sort
  - Shuffle: Fetch the relevant partition of the output from all mappers
  - Sort by keys (note that there may be more than one value for each key)
- Reduce
  - Input is the sorted output of mappers
  - Call Reduce function per key so that reducer can aggregate all values

Reduce Worker

The complete picture



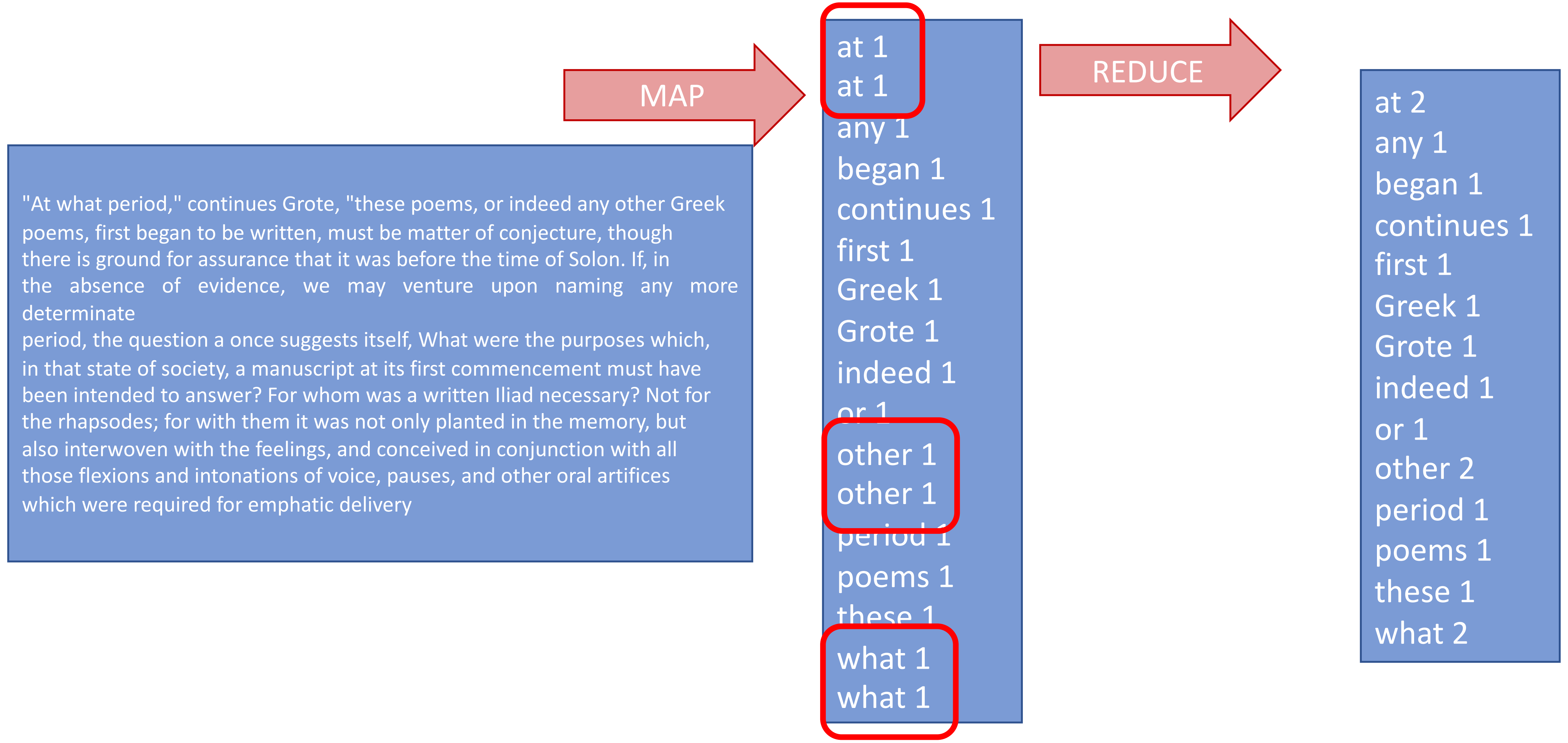
The complete picture



Example: word count

- Map
  - Process data, output each word and a count (1 each occurrence)
- Reduce
  - Sort: sort by keys (words)
  - Reduce: Sum together counts for each key (word)

```
map (String key, String value):
    // key: doc name, value: contents
    for each word w in value:
            EmitIntermediate(w, “1”);
reduce (String key, Iterator values):
    // key: a word; values: a list of counts
    int result = 0;
    for each v in values:
            result += Int(v);
    Emit(String(result));
```



"At what period," continues Grote, "these poems, or indeed any other Greek poems, first began to be written, must be matter of conjecture, though there is ground for assurance that it was before the time of Solon. If, in the absence of evidence, we may venture upon naming any more determinate
period, the question a once suggests itself, What were the purposes which, in that state of society, a manuscript at its first commencement must have been intended to answer? For whom was a written Iliad necessary? Not for the rhapsodes; for with them it was not only planted in the memory, but also interwoven with the feelings, and conceived in conjunction with all those flexions and intonations of voice, pauses, and other oral artifices which were required for emphatic delivery

at 1
at 1
any 1
began 1
continues 1
first 1
Greek 1
Grote 1
indeed 1
or 1
other 1
other 1
period 1
poems 1
these 1
what 1
what 1

at 2
any 1
began 1
continues 1
first 1
Greek 1
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or 1
other 2
period 1
poems 1
these 1
what 2

Fault Tolerance

- How to detect failure?
  - Master pings workers periodically (heartbeats)
  - If they don’t respond, reset map/reduce tasks and give them to someone else

- How can we ensure persistence?

Locality

- MapReduce typically uses a distributed file system for input data (Google File System or BigTable)
- How do we reduce network overhead?
  - Schedule map tasks near their input data!

Other Examples

- Distributed grep
- Map: emit a line if it matches pattern
- Reduce: copy intermediate data to output

Map

```
Input: line of text
if pattern matches
        EmitIntermediate("", line)
```

Reduce

```
Input: "", [lines]
Output: lines
```