Computer Science 425
Distributed Systems

CS 425 / CSE 424 / ECE 428

Fall 2012

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Lecture 3

Cloud Computing - 2

Recap

- **Last Thursday's Lecture**
  - **Clouds vs. Clusters**
    - » **At least 3 differences**
  - **A Cloudy History of Time**
    - » **Clouds are the latest in a long generation of distributed systems**
- **Today's Lecture**
  - **Cloud Programming: MapReduce (the heart of Hadoop)**
  - **Grids**

Programming Cloud Applications - New Parallel Programming Paradigms: MapReduce

- Highly-Parallel Data-Processing
- Originally designed by Google (OSDI 2004 paper)
- Open-source version called Hadoop, by Yahoo!
  - Hadoop written in Java. Your implementation could be in Java, or any executable
- Google (MapReduce)
  - Indexing: a chain of 24 MapReduce jobs
  - ~200K jobs processing 50PB/month (in 2006)
- Yahoo! (Hadoop + Pig)
  - WebMap: a chain of 100 MapReduce jobs
  - 280 TB of data, 2500 nodes, 73 hours
- Annual Hadoop Summit: 2008 had 300 attendees, now close to 1000 attendees

What is MapReduce?

- **Terms are borrowed from Functional Language (e.g., Lisp)**

Sum of squares:

- **(**map **square ‘(1 2 3 4))**
  - **Output: (1 4 9 16)**

  [processes each record sequentially and independently]

- **(**reduce **+ ‘(1 4 9 16))**
  - **(+ 16 (+ 9 (+ 4 1)))**
  - **Output: 30**

  [processes set of all records in groups]

- **Let’s consider a sample application: Wordcount**
  - **You are given a <u>huge</u> dataset (e.g., collection of webpages) and asked to list the count for each word appearing in the dataset**

Map

- **Process individual records to generate intermediate key/value pairs.**

Welcome Everyone

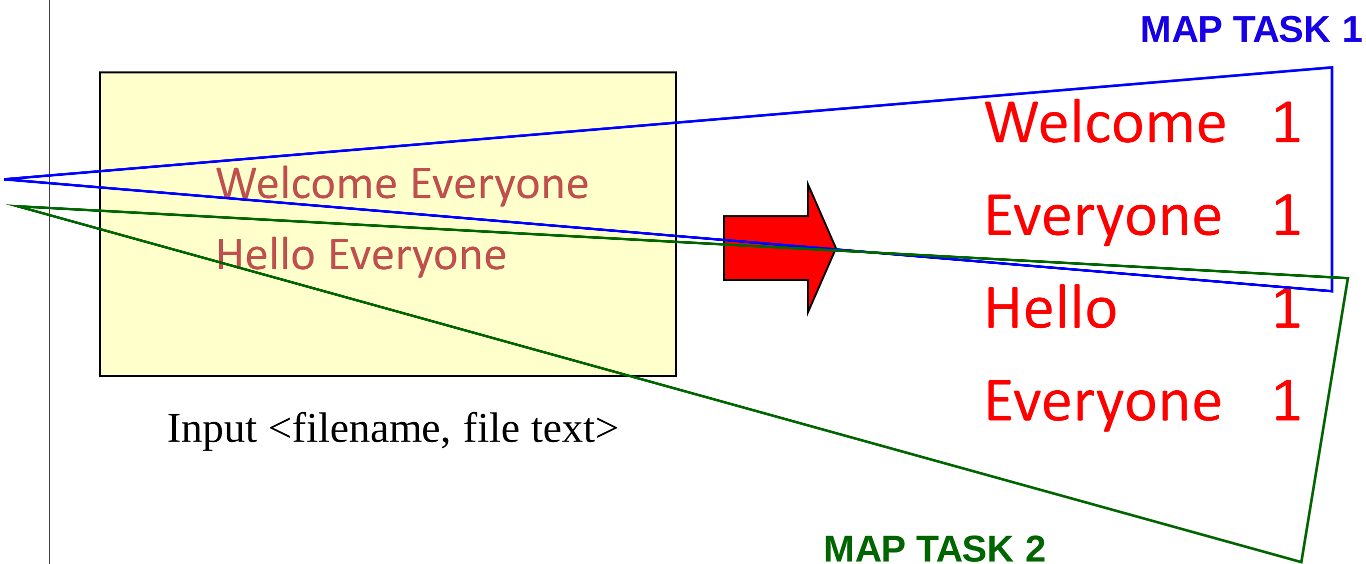
Hello Everyone

Input <filename, file text>

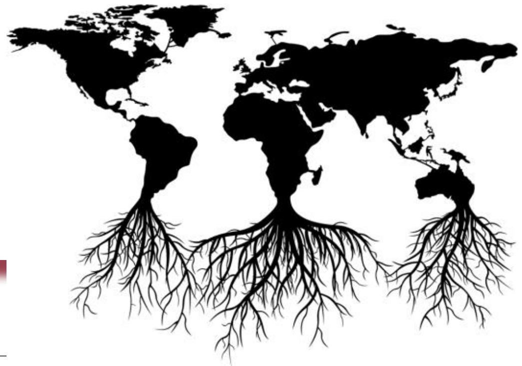
Key	Value
Welcome	1
Everyone	1
Hello	1
Everyone	1

Map

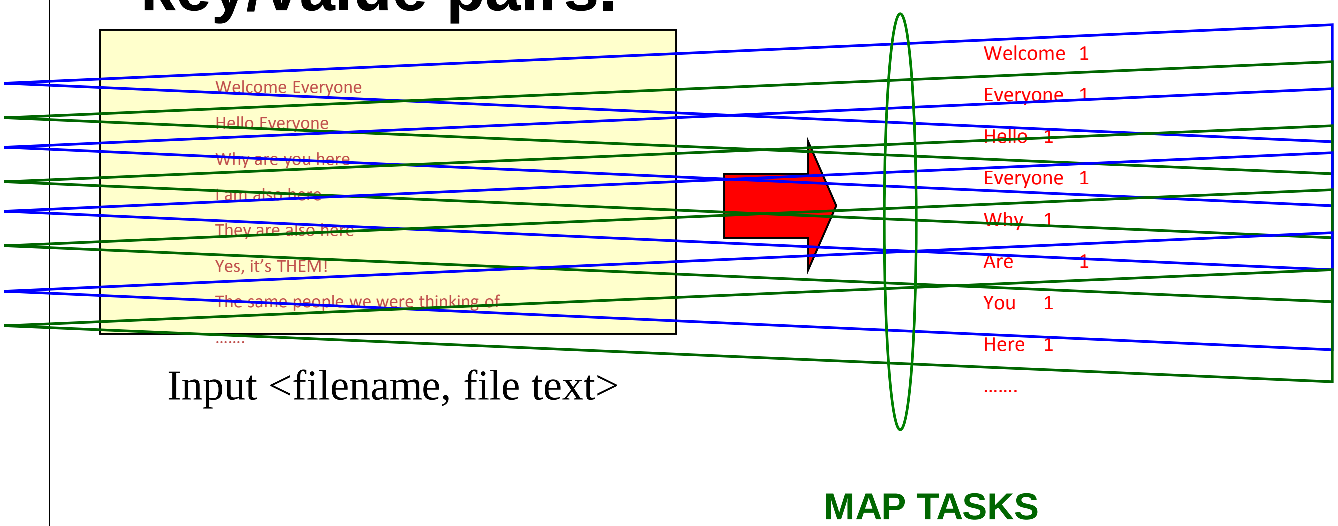
- <u>**Parallelly**</u> **Process individual records to generate intermediate key/value pairs.**



Map



- **Parallelly Process a large number of individual records to generate intermediate key/value pairs.**



Reduce

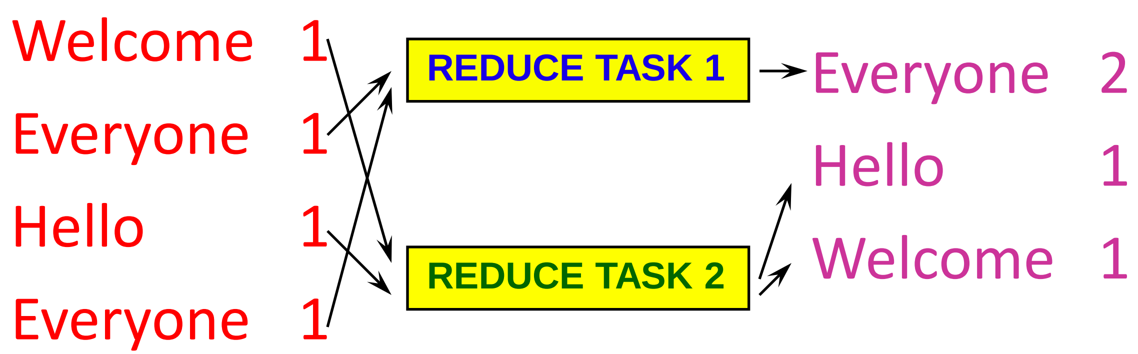
- **Processes and merges all intermediate values associated per key (that's the group)**

Welcome	1
Everyone	1
Hello	1
Everyone	1

Key	Value
Everyone	2
Hello	1
Welcome	1

Reduce

- **<u>Parallelly</u> Processes and merges all intermediate values <u>by partitioning keys</u>**



Hadoop Code - Map

```
public static class MapClass extends MapReduceBase
      implements Mapper<LongWritable, Text, Text,
        IntWritable> {
  private final static IntWritable one =
    new IntWritable(1);
  private Text word = new Text();

  public void map( LongWritable key, Text value,
      OutputCollector<Text, IntWritable> output,
      Reporter reporter)
    throws IOException {
    String line = value.toString();
    StringTokenizer itr = new StringTokenizer(line);
    while (itr.hasMoreTokens()) {
      word.set(itr.nextToken());
      output.collect(word, one);
    }
  }
} // Source: http://developer.yahoo.com/hadoop/tutorial/module4.html#wordcount
```

Hadoop Code - Reduce

```
public static class ReduceClass extends MapReduceBase
        implements Reducer<Text, IntWritable, Text,
        IntWritable> {
  public void reduce(
        Text key,
        Iterator<IntWritable> values,
        OutputCollector<Text, IntWritable> output,
        Reporter reporter)
     throws IOException {
        int sum = 0;
        while (values.hasNext()) {
          sum += values.next().get();
        }
        output.collect(key, new IntWritable(sum));
  }
}
```

Hadoop Code - Driver

```
// Tells Hadoop how to run your Map-Reduce job
public void run (String inputPath, String outputPath)
       throws Exception {
  // The job. WordCount contains MapClass and Reduce.
  JobConf conf = new JobConf(WordCount.class);
  conf.setJobName(”mywordcount");
  // The keys are words
  (strings) conf.setOutputKeyClass(Text.class);
  // The values are counts (ints)
  conf.setOutputValueClass(IntWritable.class);
  conf.setMapperClass(MapClass.class);
  conf.setReducerClass(ReduceClass.class);
  FileInputFormat.addInputPath(
       conf, newPath(inputPath));
  FileOutputFormat.setOutputPath(
       conf, new Path(outputPath));
  JobClient.runJob(conf);
}
```

Some Other Applications of MapReduce

Distributed Grep:

- **Input: large set of files**
- **Output: lines that match pattern**

- **Map –** ***Emits a line if it matches the supplied pattern***
- **Reduce -** ***Copies the intermediate data to output***

Some Other Applications of MapReduce (2)

Reverse Web-Link Graph

- Input: Web graph: tuples (a, b) where (page a → page b)
- Output: For each page, list of pages that link *to* it

- Map – *process web log and outputs <target, source>*
- Reduce - *emits <target, list(source)>*

Some Other Applications of MapReduce (3)

Count of URL access frequency

- **Input: Log of accessed URLs from proxy server**
- **Output: For each URL, % of total accesses for that URL**

- **Map –** ***Process web log and outputs <URL, 1>***
- **Multiple Reducers -** ***Emits <URL, URL_count>***

(So far, like Wordcount. But still need %)

- **Chain another MapReduce job after above one**
- **Map –** ***Processes <URL, URL_count>*** **and outputs** ***<1, (<URL, URL_count>)>***
- **1 Reducer – Sums up** ***URL_count's*** **to calculate overall_count.**

Emits <URL, URL_count/overall_count>

Some Other Applications of MapReduce (4)

Map task’s output is sorted (e.g., quicksort)
Reduce task’s input is sorted (e.g., mergesort)

Sort

- **Input: Series of (key, value) pairs**
- **Output: Sorted <value>s**

- **Map –** ***<key, value> -> <value, _> (identity)***
- **Reducer –** ***<key, value> -> <key, value> (identity)***
- **Partitioning function – partition keys across reducers based on ranges**
  - » **Take data distribution into account to balance reducer tasks**

Programming MapReduce

- **Externally: For user**
  1. Write a Map program (short), write a Reduce program (short)
  2. Decide number of tasks and submit job; wait for result
  3. Need to know nothing about parallel/distributed programming!
- **Internally: For the cloud (and for us distributed systems researchers)**
  1. Parallelize Map
  2. Transfer data from Map to Reduce
  3. Parallelize Reduce
  4. Implement Storage for Map input, Map output, Reduce input, and Reduce output

Inside MapReduce

X-Ray

- For the cloud (and for us distributed systems researchers)
  1. Parallelize Map: easy! Shard the data equally into requested map tasks.
  2. Transfer data from Map to Reduce:
     - » All Map output tuples with same key assigned to same Reduce task
     - » use partitioning function: example is to hash the key of the tuple, modulo number of reduce jobs, or identity function for sort
  3. Parallelize Reduce: easy! Assign keys uniformly across requested reduce tasks. Reduce task knows its assigned keys (through master).
  4. Implement Storage for Map input, Map output, Reduce input, and Reduce output
     - » Map input: from distributed file system
     - » Map output: to local disk (at Map node); uses local file system
     - » Reduce input: from (multiple) remote disks; uses local file systems
     - » Reduce output: to distributed file system

     local file system = Linux FS, etc.

     distributed file system = GFS (Google File System), HDFS (Hadoop Distributed File System)

Internal Workings of MapReduce - Example

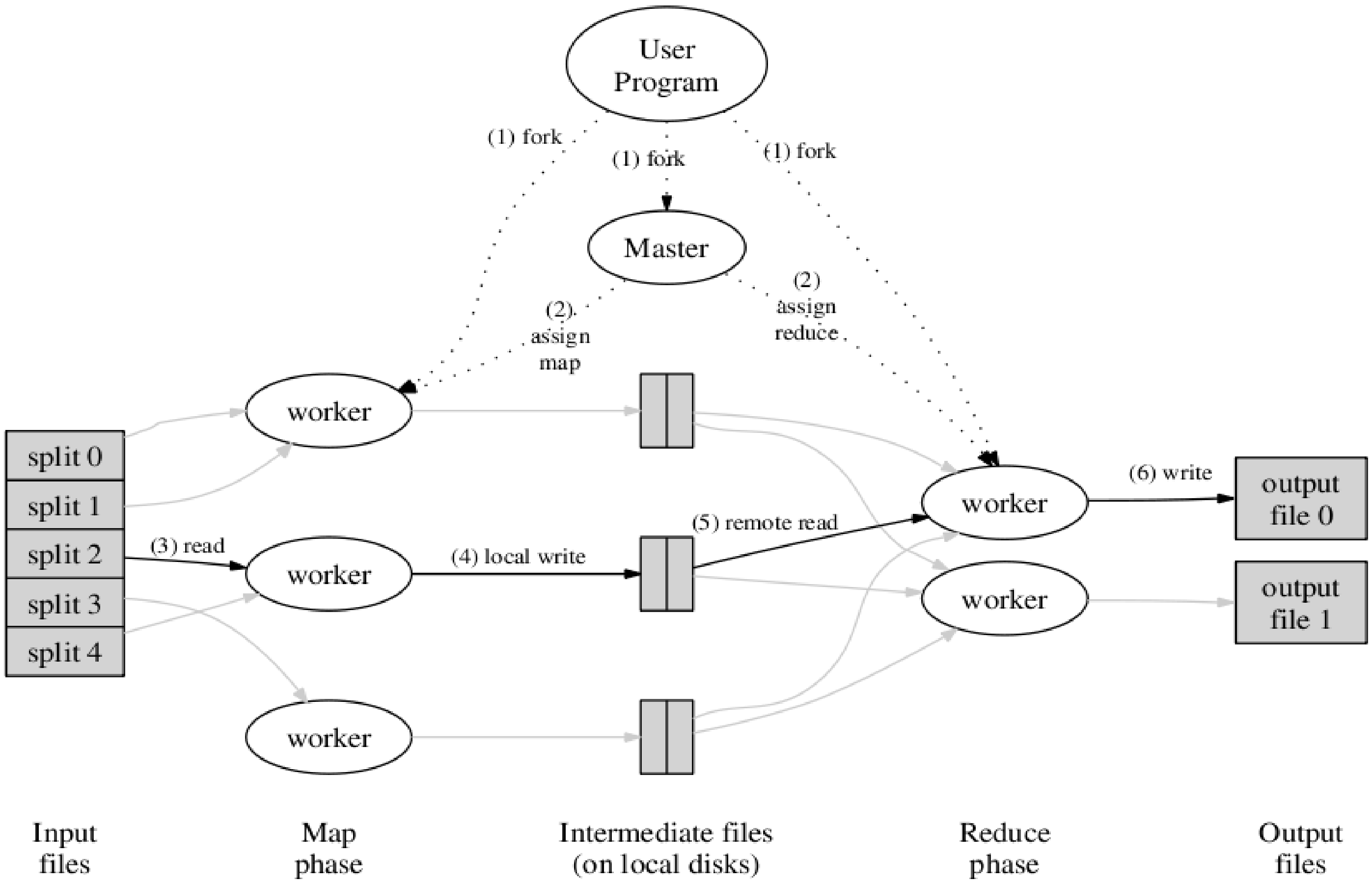


Figure 1: Execution overview

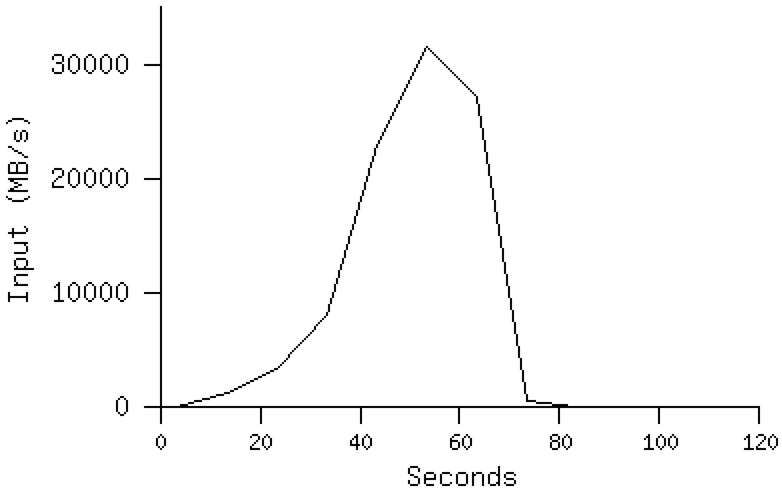
From the original MapReduce paper (OSDI 2004)

Etcetera

- **Failures**
  - Master tracks progress of each task
  - reschedules task with stopped progress or on failed machine
  - Highly simplified explanation here – failure-handling is more sophisticated (next lecture!)
- **Slow tasks**
  - The slowest machine slows the entire job down
  - Hadoop Speculative Execution: Spawn multiple copies of tasks that have a slow progress. When one finishes, stop other copies.
- **What about bottlenecks within the datacenter?**
  - CPUs? Disks? Switches?

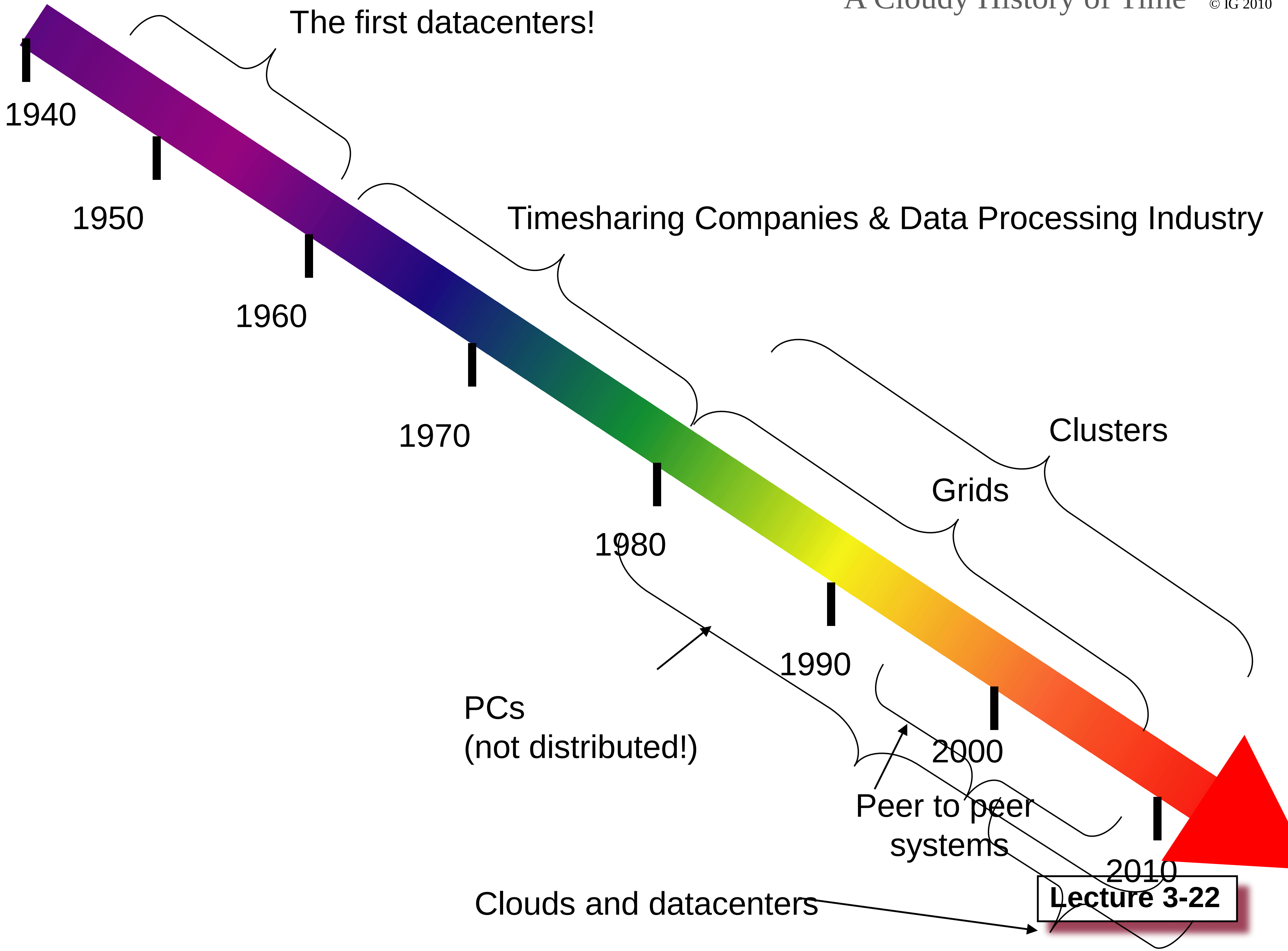
Testbed: 1800 servers each with 4GB RAM, dual 2GHz Xeon, dual 169 GB IDE disk, 100 Gbps, Gigabit ethernet per machine

Grep



Workload: 10^{10} 100-byte records to extract records matching a rare pattern (92K matching records)

From the original MapReduce paper (OSDI 2004)


The first datacenters!
1940
1950
1960
1970
1980
1990
2000
2010
Timesharing Companies & Data Processing Industry
Clusters
Grids
PCs
(not distributed!)
Peer to peer
systems
Clouds and datacenters

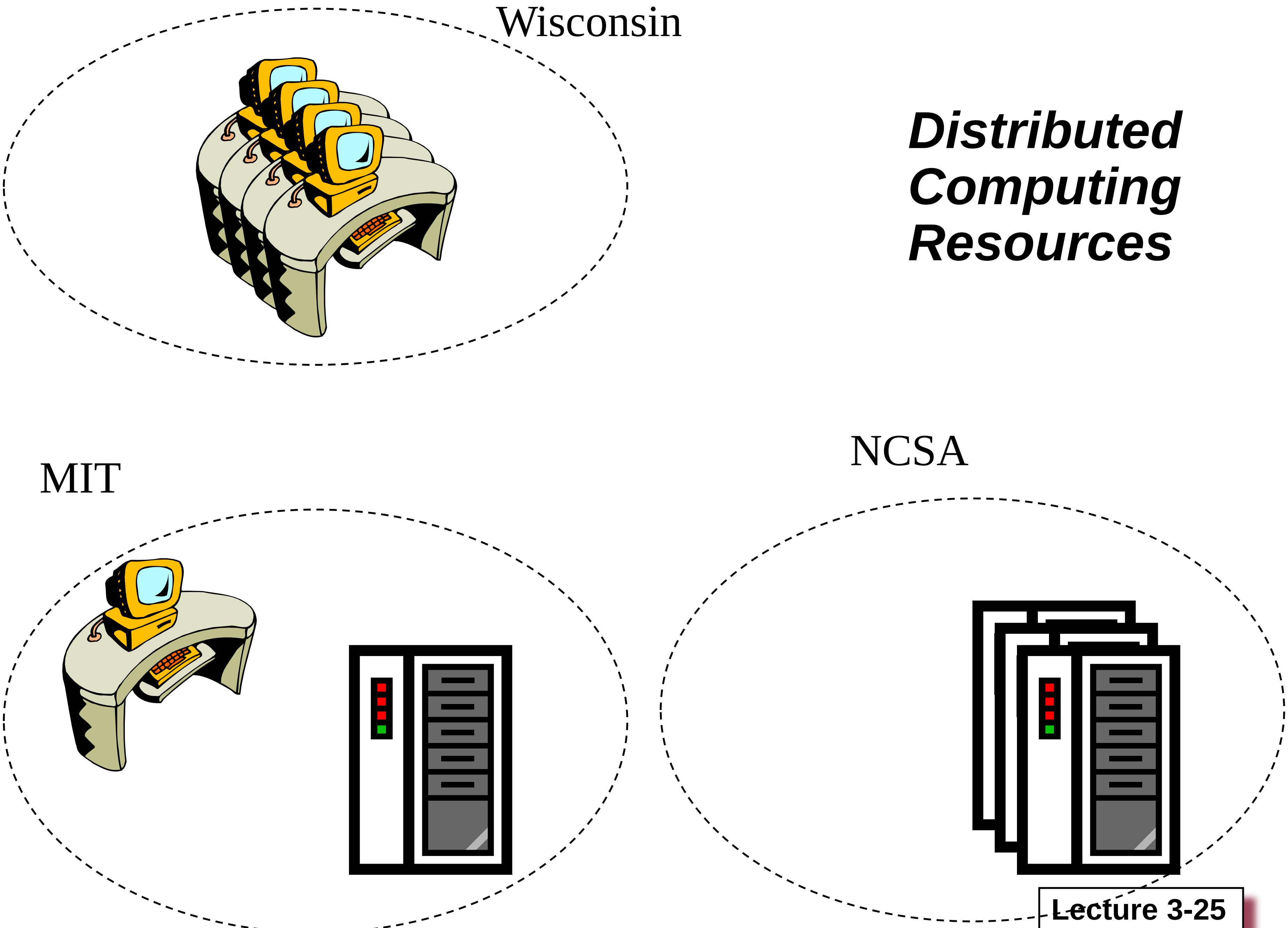
Clouds are data-intensive
Grids are/were computation-intensive

What is a Grid?

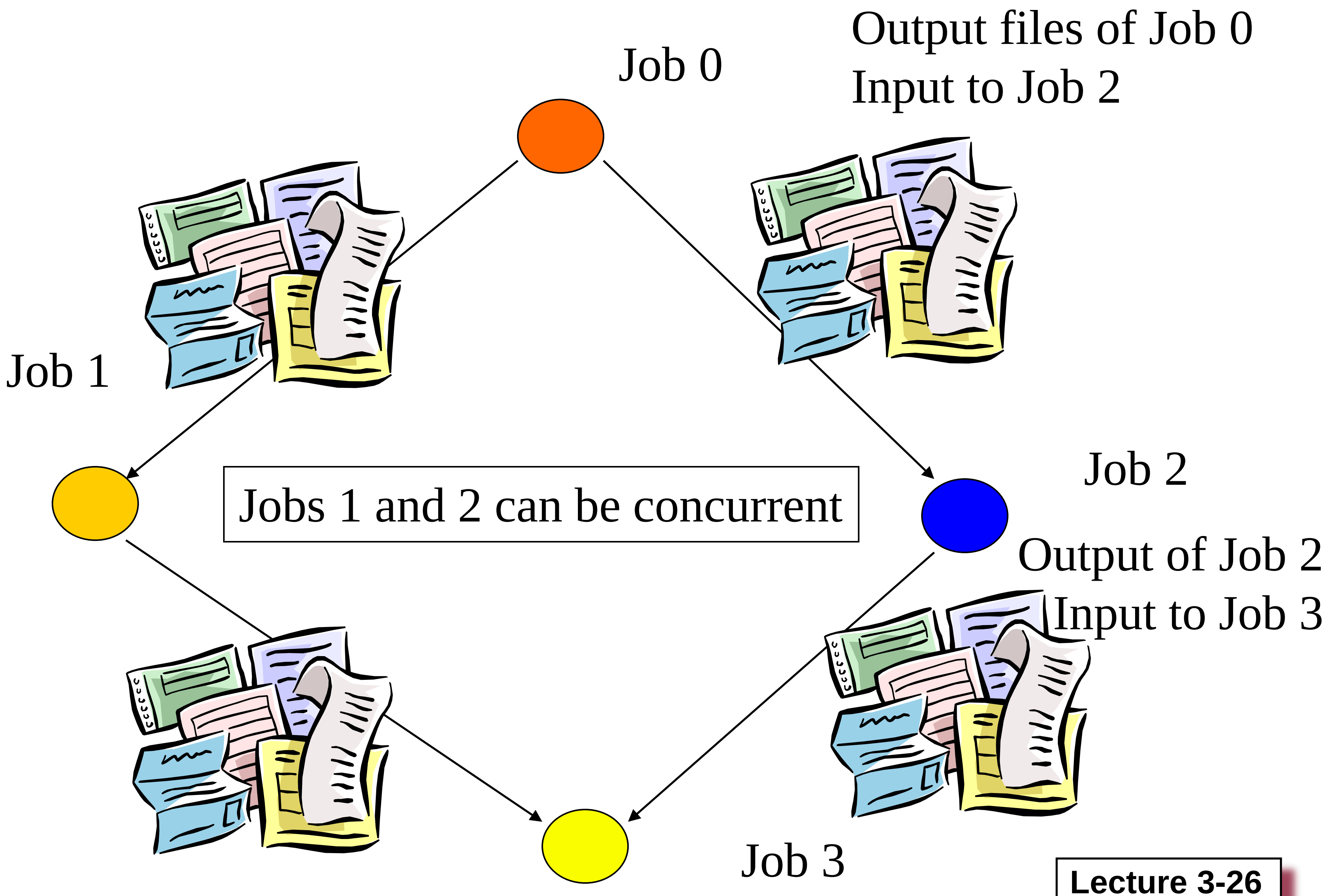
Example: Rapid Atmospheric Modeling System, ColoState U

- Hurricane Georges, 17 days in Sept 1998
  - "RAMS modeled the mesoscale convective complex that dropped so much rain, in good agreement with recorded data"
  - Used 5 km spacing instead of the usual 10 km
  - Ran on 256+ processors
- Computation-intensive application rather than data-intensive
- *Can one run such a program without access to a supercomputer?*

Distributed Computing Resources



An Application Coded by a Physicist



An Application Coded by a Physicist

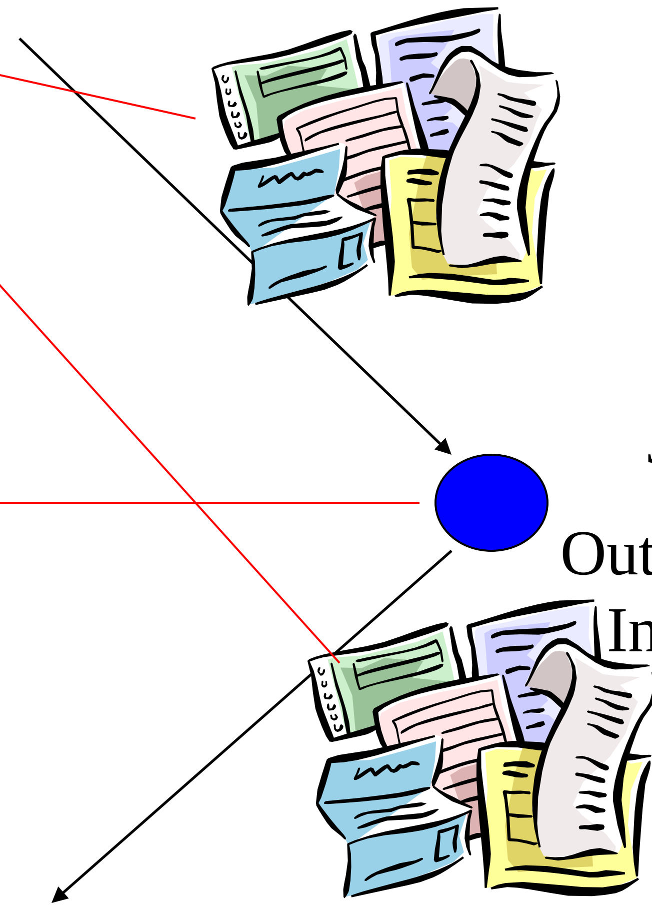
Several GBs

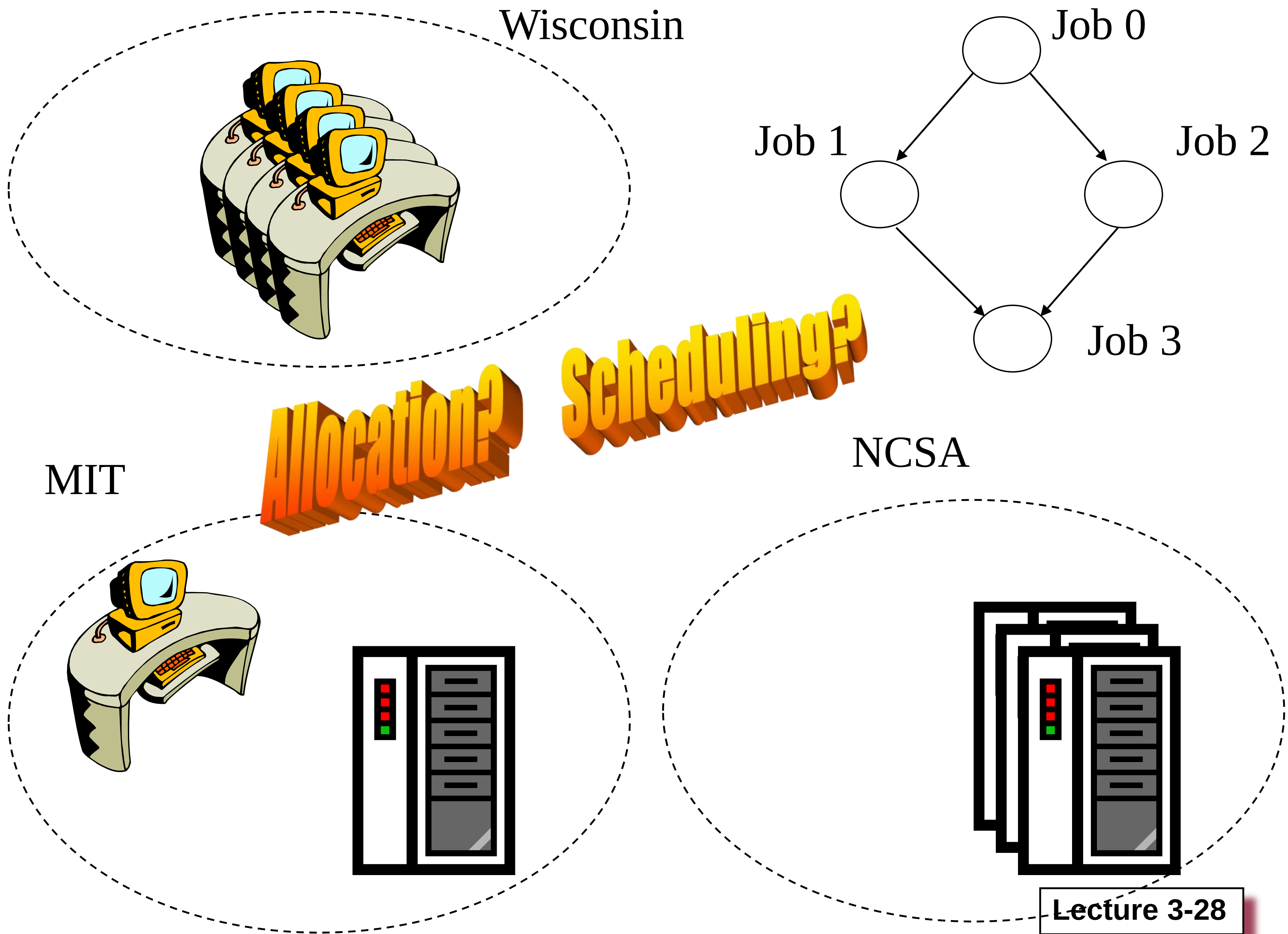
May take several hours/days

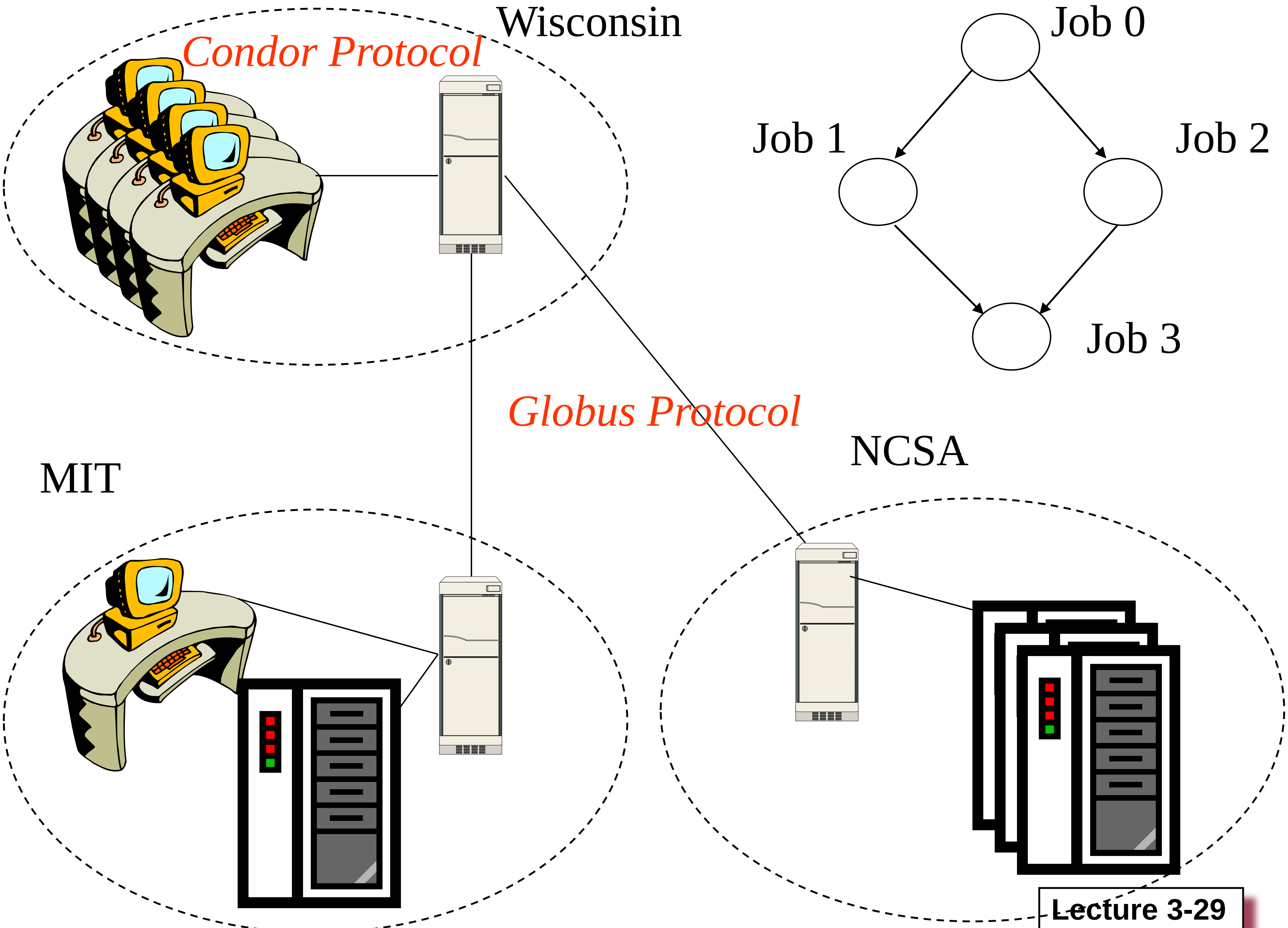
4 stages of a job

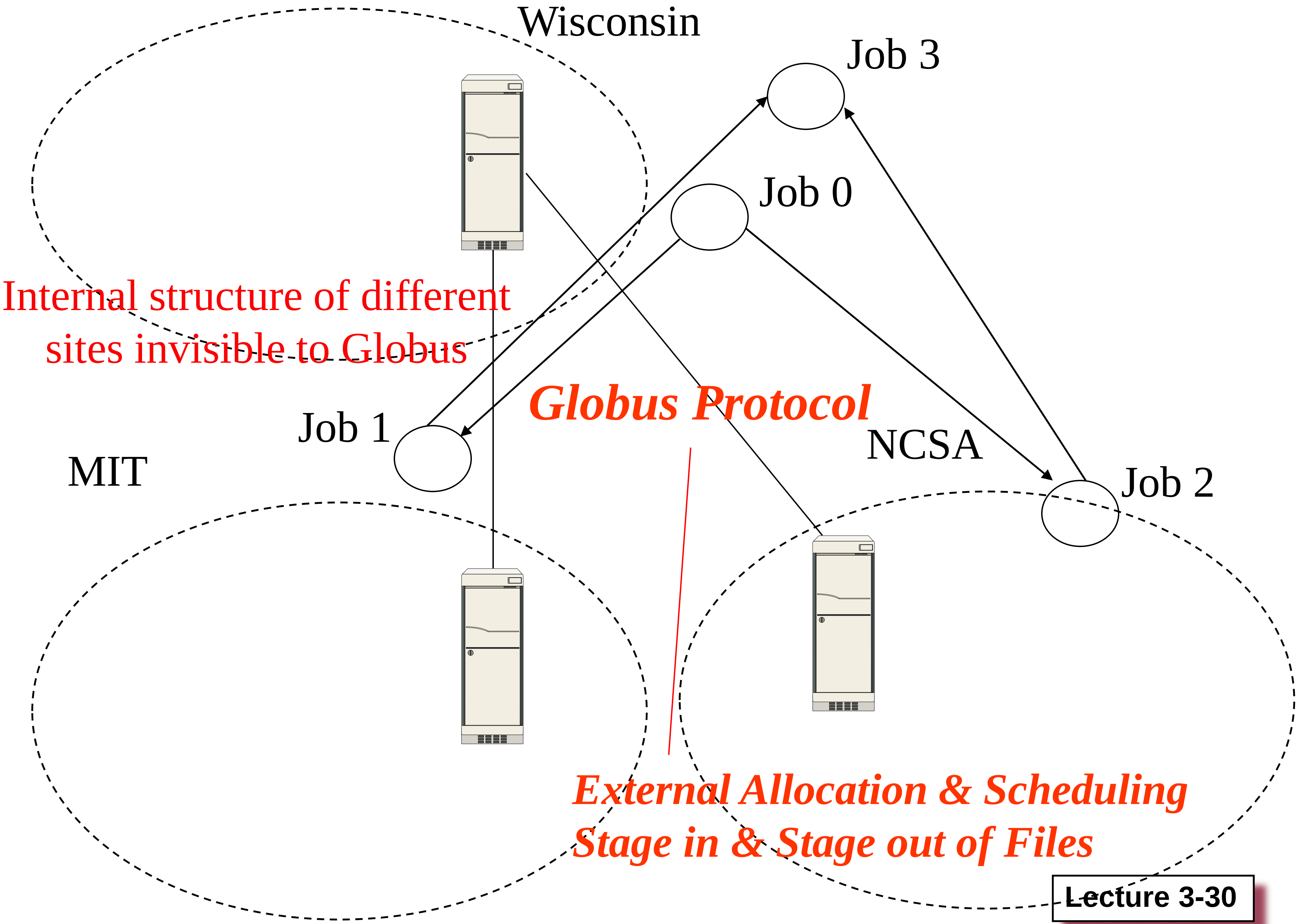
- Init
- Stage in
- Execute
- Stage out
- Publish

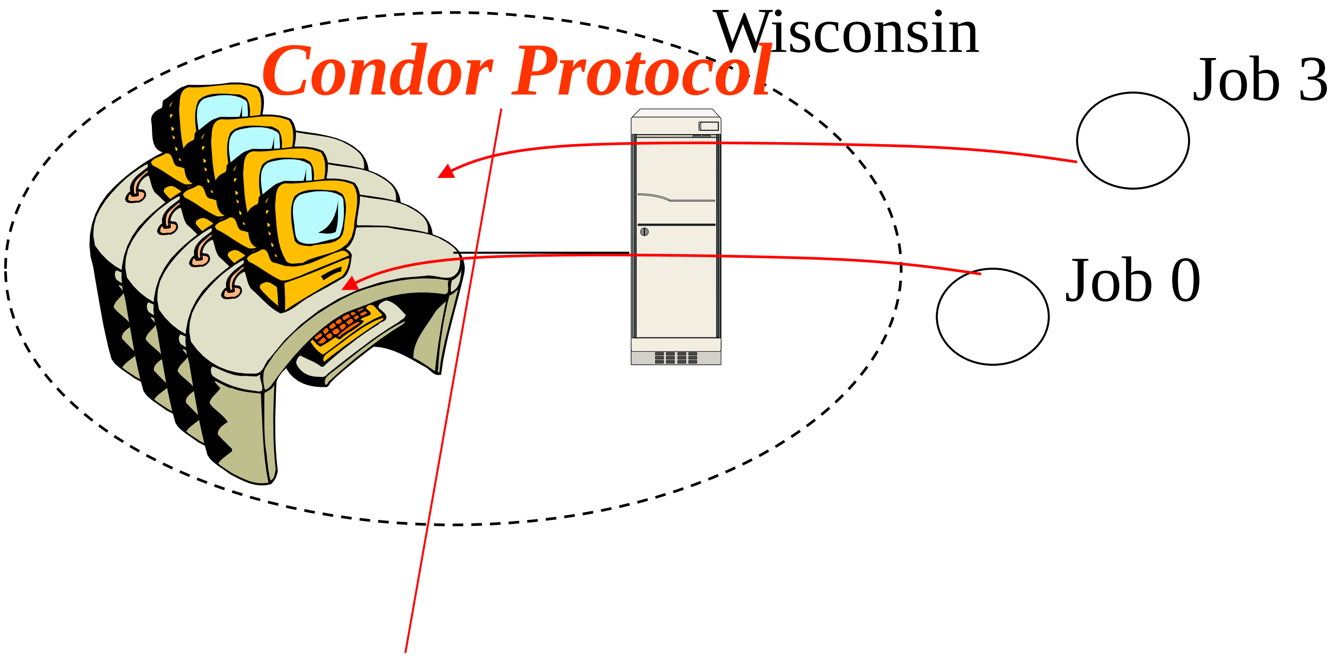
Computation Intensive,
so Massively Parallel




Wisconsin
Job 0
Job 1
Job 2
Job 3
Allocation?
Scheduling?
MIT
NCSA


Wisconsin
Condor Protocol
Job 0
Job 1
Job 2
Job 3
Globus Protocol
NCSA
MIT

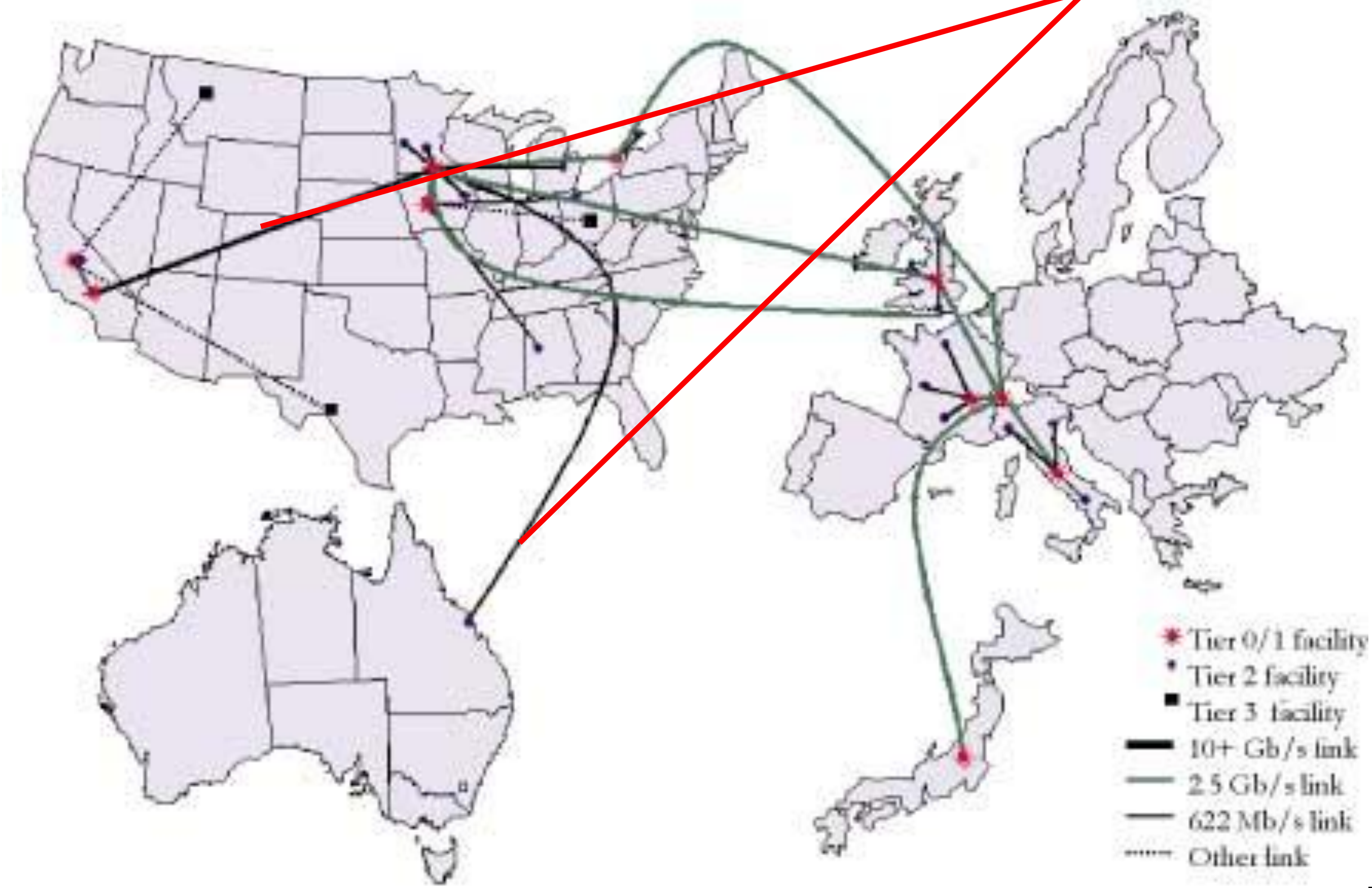

Wisconsin
Job 3
Job 0
Internal structure of different sites invisible to Globus
Globus Protocol
Job 1
MIT
NCSA
Job 2
External Allocation & Scheduling
Stage in & Stage out of Files



Internal Allocation & Scheduling
Monitoring
Distribution and Publishing of Files

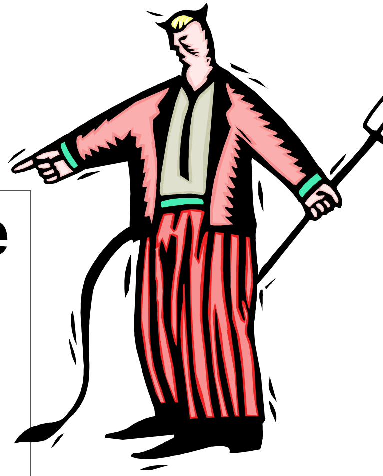
The Grid Recently

Some are 40Gbps links!
(The TeraGrid links)

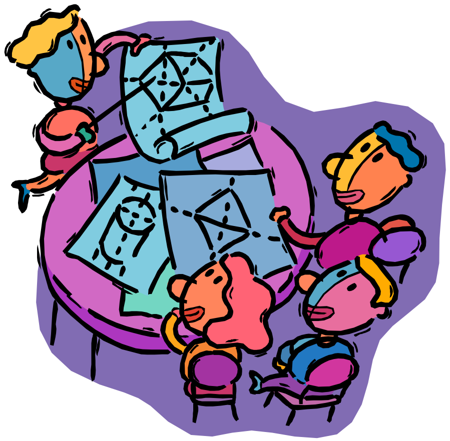


"A parallel Internet"

Question to Ponder



- **Cloud computing vs. Grid computing: what are the differences?**



MP1, HW1

- **MP1, HW1 out today**
  - **MP1 due 9/16 (Sun midnight)**
  - **HW1 due 9/20 (in class)**
  - **For HW: Individual. You are allowed to discuss the *problem* and *concepts* (e.g., in study groups), but you cannot discuss the *solution*.**
  - **For MP: Groups of 2 students (pair up with someone taking class for same # credits)**
    - **If you don't have a partner, hang around after class today**
    - **Please report groups to us by this Thursday 9/16. Subject line: "425 MP group"**
  - **Please read instructions carefully!**
  - **Start NOW**

MP1: Logging + Testing

- Distributed Systems hard to debug (you'll know soon!)
- Creating log files at each machine to tabulate important messages/errors/status is critical to debugging
- MP1: Write a distributed program that lets you grep (+ regexp's) all the log files across a set of machines (from any of those machines)
- How do you know your program works?
  - Write unit tests
  - E.g., Generate non-identical logs at each machine, then run grep from one of them and automatically verify that you receive the answer you expect
  - Writing tests can be hard work, but it is industry standard
  - We encourage (but don't require) that you write tests for MP2 onwards

Readings

- **For next lecture**
  - **Failure Detection**
  - **Readings: Section 15.1, parts of Section 2.4.2**