Computer Science 425
Distributed Systems

CS 425 / ECE 428

Fall 2013

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Sep 3, 2013

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!
  - Spun off into startup HortonWorks
- 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 Languages (e.g., Lisp)**

Sum of squares:

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

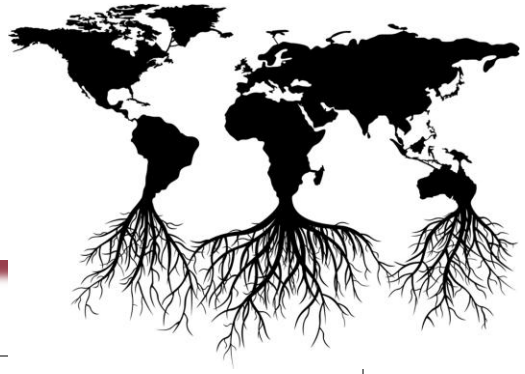
  [processes each record sequentially and independently]

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

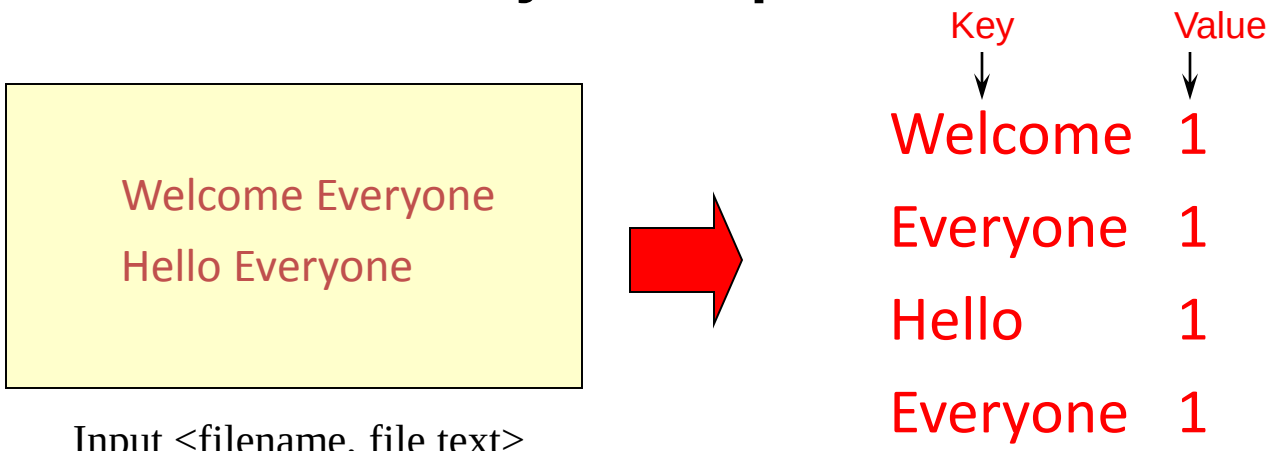
  [processes set of all records in groups]

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

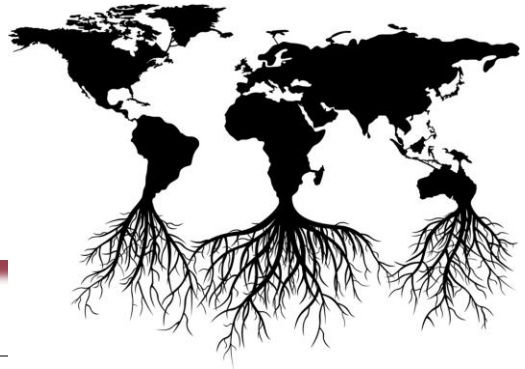
Map



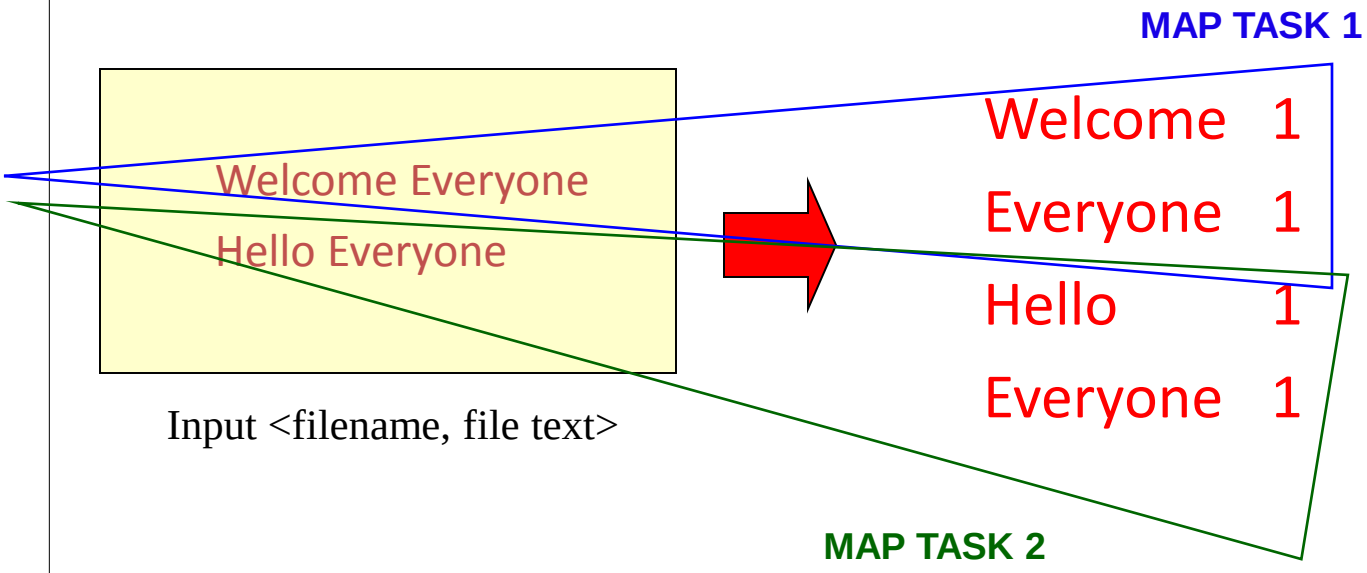
- **Process individual records to generate intermediate key/value pairs.**



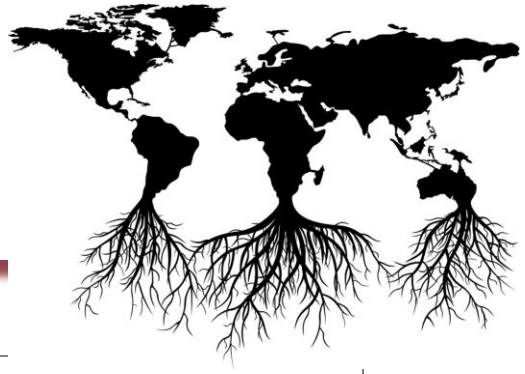
Map



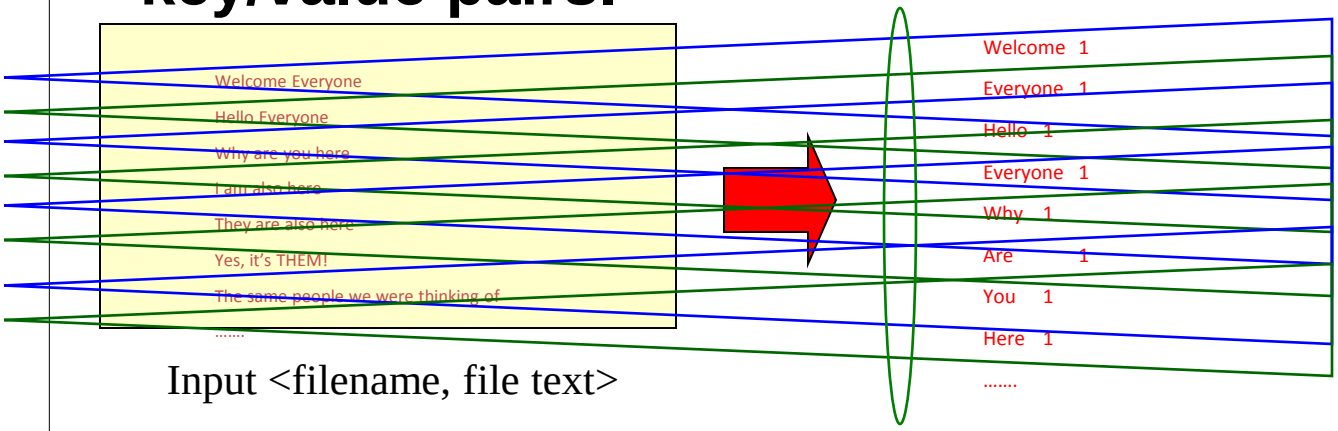
- **Parallelly Process individual records to generate intermediate key/value pairs.**



Map



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



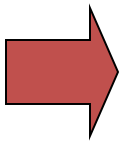
Input <filename, file text>

MAP TASKS

Reduce

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

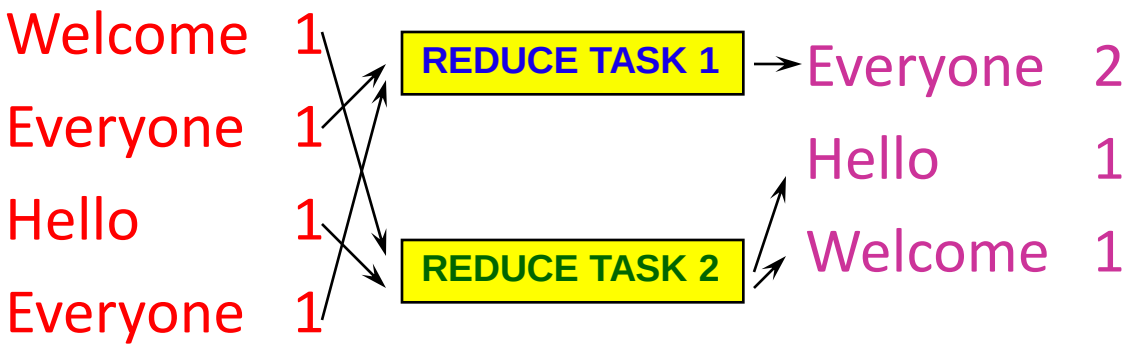
Welcome	1
Everyone	1
Hello	1
Everyone	1



Key	Value
Everyone	2
Hello	1
Welcome	1

Reduce

- **Parallelly Processes and merges all intermediate values by partitioning keys**



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 –** ***Simply copies the intermediate data (key-value pairs) to output***
- **Partitioner –** ***Default (hash-based)***

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 for each <source, target> it outputs <target, source>***
- **Reduce -** ***emits <target, list(source)>***
- **Partitioner –** ***Default (hash-based)***

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

(all use default partitioners)

- 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 task – Sums up *URL_count's* to calculate overall_count.

Outputs <URL, URL_count/overall_count> pairs

Some Other Applications of MapReduce (4)

Sort

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

- Map – *<key, value> -> <key,value> (identity)*
- Reducer – *<key, value> -> <key, value> (identity)*
- Partitioner – identity. For load-balance, assign equal number of keys to each reduce
  - » Take data distribution into account to split key ranges across reduce tasks

- *Why does this work?*
  - Map task's output is (always) auto-sorted (e.g., quicksort)
  - Reduce task's input is (always) auto-sorted (e.g., mergesort)

Programming MapReduce

- **Externally: For user**
  1. **Write a Map program (short), write a Reduce program (short)**
  2. **Specifiy number of tasks and submit job in configuration; wait for result**
  3. **Need to know practically 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
     - » Intermediate data - Map output: to local disk (at Map node); uses local file system
     - » Intermediate data - 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

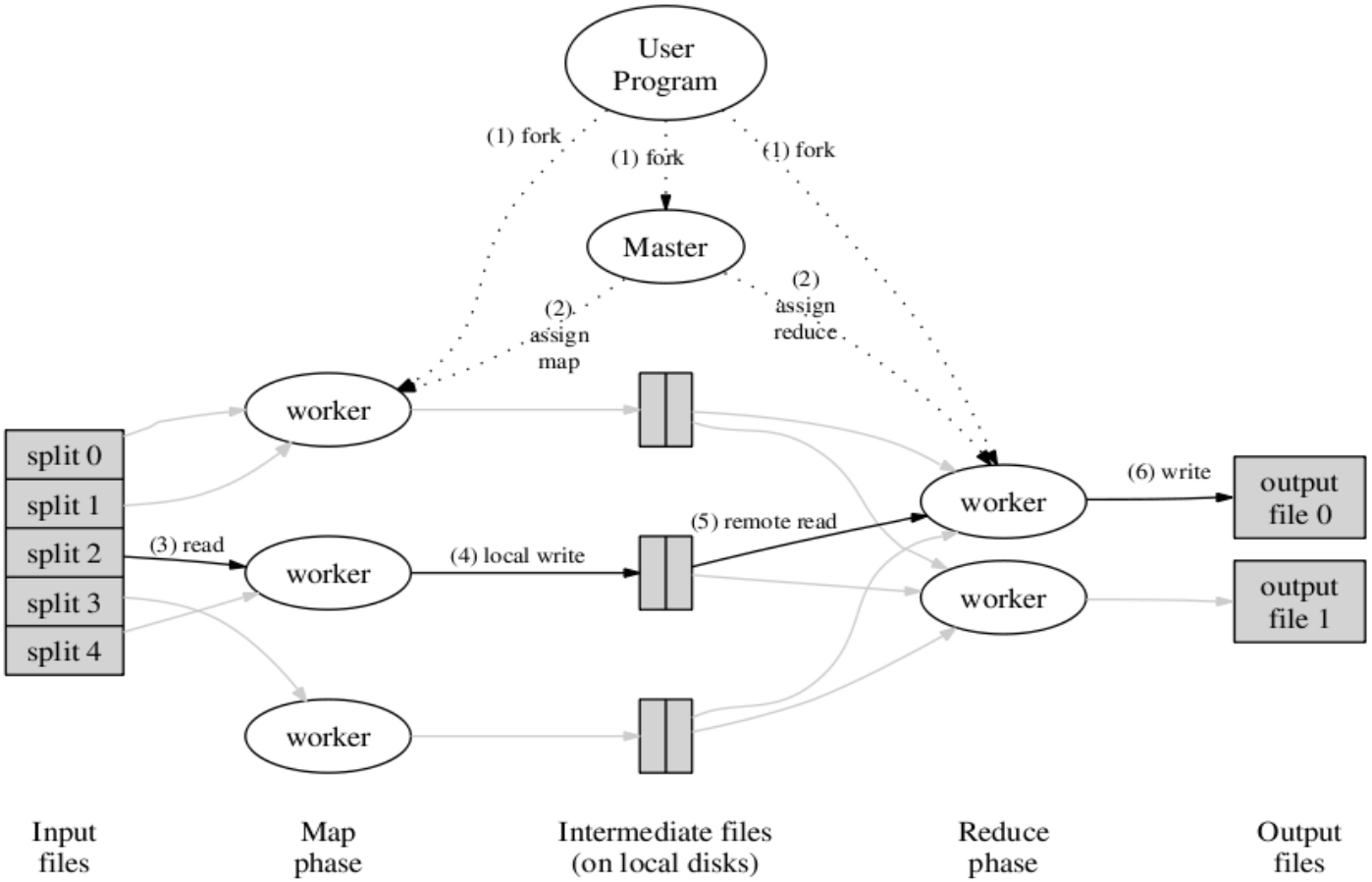


Figure 1: Execution overview

From the original MapReduce paper (OSDI 2004)

Barriers and Speculation

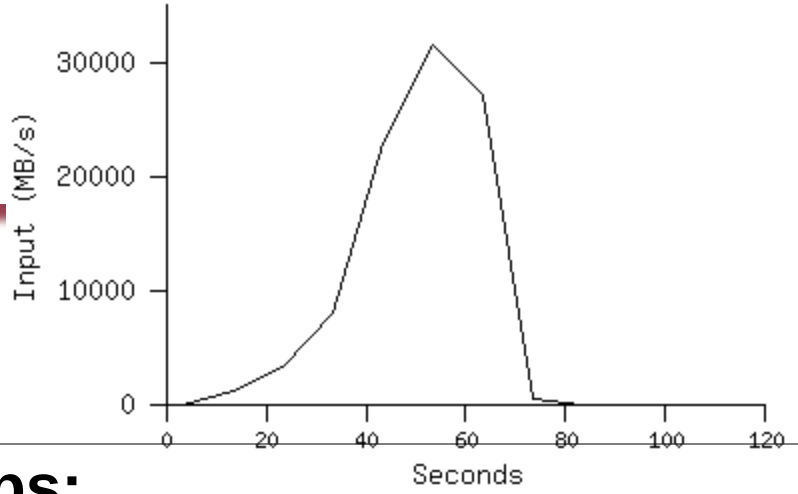
- *Hadoop's internal scheduler runs at master*
- *A Reduce task cannot start until all Map tasks done, and all its (Reduce's) data has been fetched*
  - » *Barrier between Map phase and Reduce phase*
  - » *As a result, the slowest Map slows down the entire Map phase (and thus the entire job)*
  - » *The slowest Reduce slows down the entire Reduce phase (and thus the entire job)*
- **Stragglers (slow nodes)**
  - – **The slowest machine slows the entire job down**
  - – **Due to Bad Disk, Network Bandwidth, CPU, or Memory**
  - – **Solution: Speculative Execution.**
    - » **Keep track of "progress" of each task (% done)**
    - » **Replicate straggler task on other available machines – fastest machine wins (and other task replicas are then killed)**

Etcetera

- **Locality**
  - Needed to avoid network traffic bottlenecks, since cloud has hierarchical topology (e.g., racks)
  - GFS stores 3 replicas of each of 64MB chunks
    - » Maybe on different racks, e.g., 2 on a rack, 1 on a different rack
  - Scheduler attempts to schedule a map task on a machine that contains a replica of corresponding input data: why?
    - » Failing this, it tries scheduling map on the same rack as data
    - » Failing this, schedule map task anywhere
- **Failures**
  - Master tracks progress of each task
  - Similar to speculative execution, reschedules task with stopped progress or on failed machine
  - Highly simplified explanation here – failure-handling is more sophisticated (next lecture!)

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

Grep

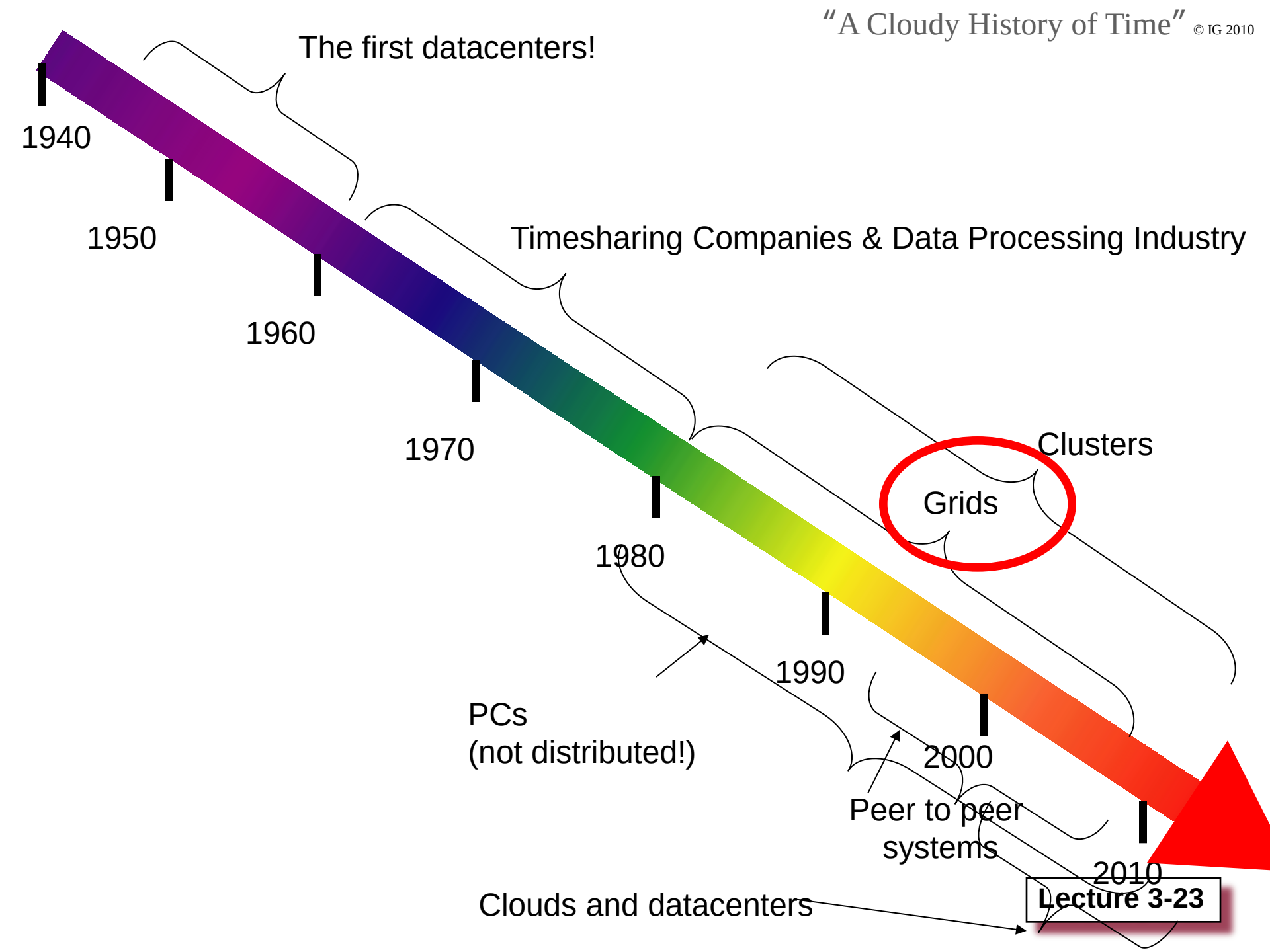


Locality optimization helps:

- **1800 machines read 1 TB at peak ~31 GB/s**
- **W/out this, rack switches would limit to 10 GB/s**

Startup overhead is significant for short jobs

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


The first datacenters!
1940
1950
Timesharing Companies & Data Processing Industry
1960
1970
Clusters
Grids
1980
1990
PCs
(not distributed!)
2000
Peer to peer
systems
2010
Clouds and datacenters
Lecture 3-23

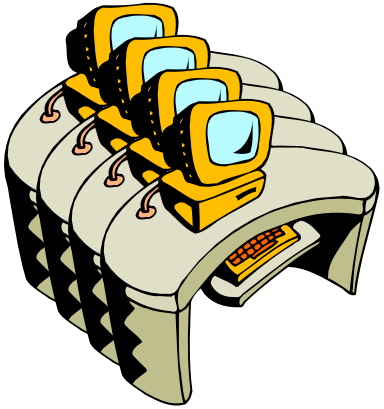
Clouds are data-intensive while …
<u>Grids</u> are/were computation-intensive

What is a Grid?

Example: Rapid Atmospheric Modeling System, ColoState U

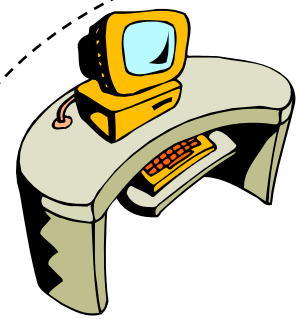
- **Hurricane Georges, 17 days in Sept 1998**
  - **"RAMS modeled the mesoscale convective complex that dropped so much rain, in good agreement with recorded data"**
  - **Used 5 km spacing instead of the usual 10 km**
  - **Ran on 256+ processors**
- **Computation-intensive application rather than data-intensive**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

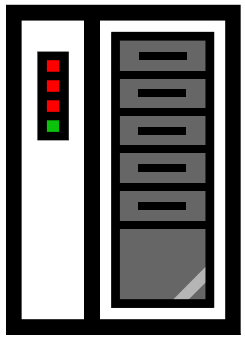
Wisconsin



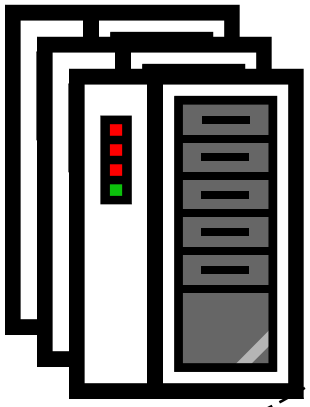
Distributed Computing Resources

MIT

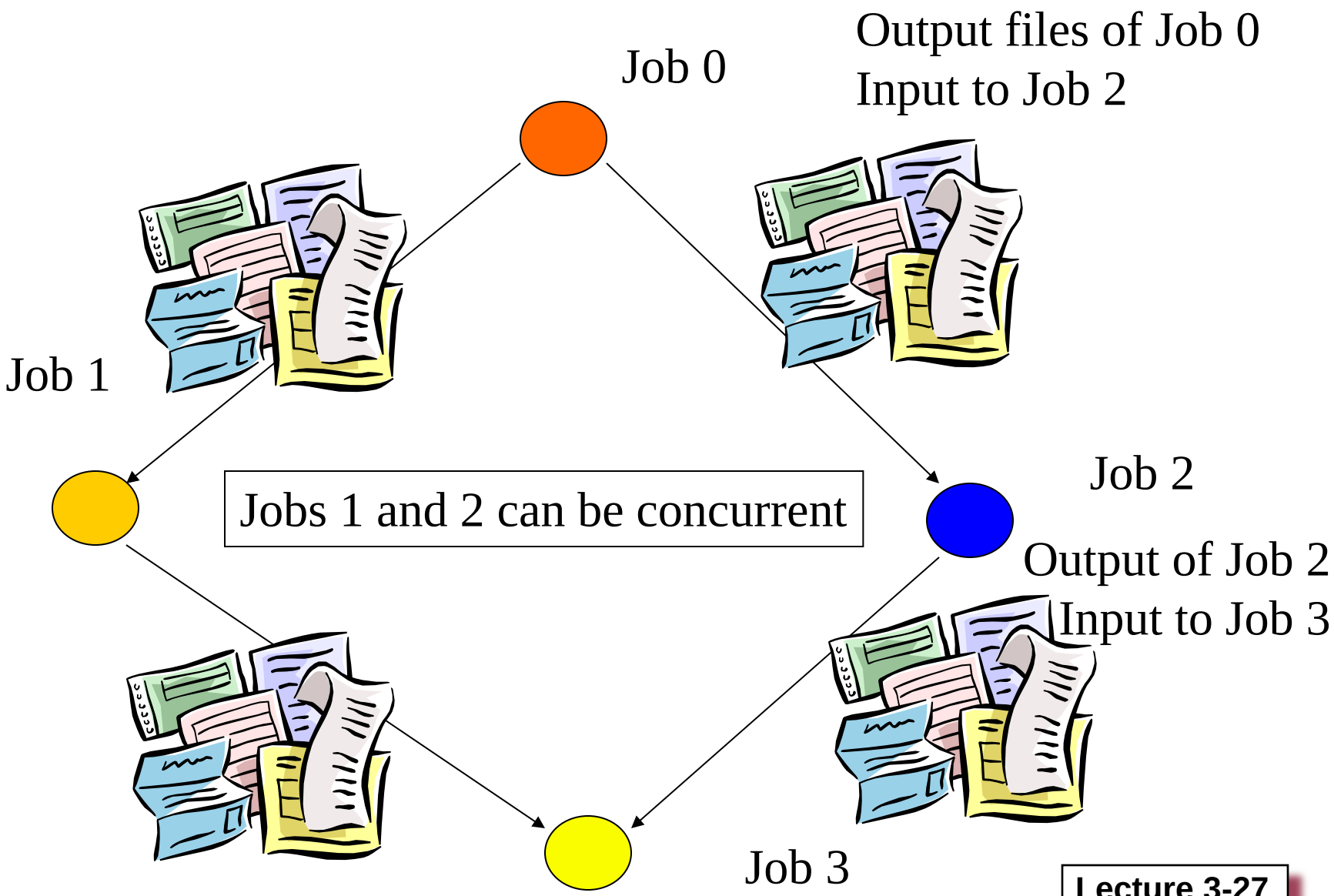




NCSA



An Application Coded by a Physicist



An Application Coded by a Physicist

Output files of Job 0
Input to Job 2

Several GBs

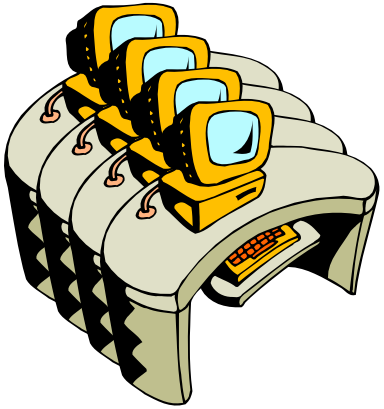
May take several hours-days
4 stages of a job
- Init
- Stage in
- Execute
- Stage out
- Publish

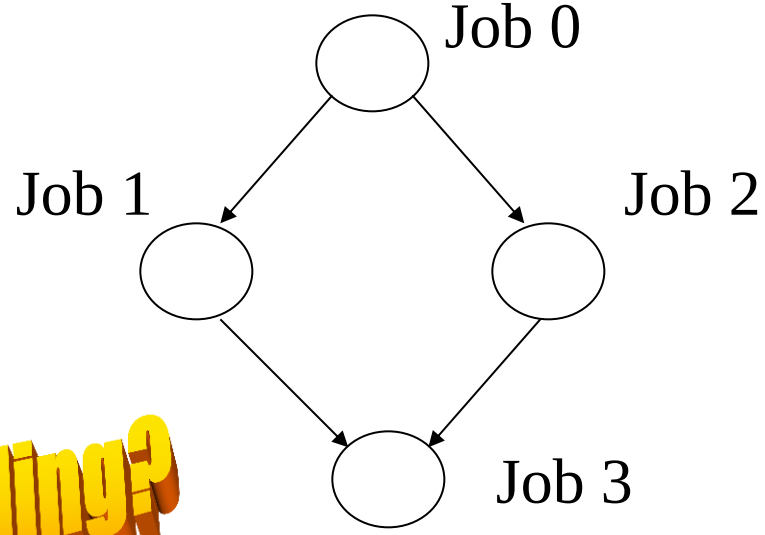
Computation Intensive,
so Massively Parallel

Job 2

Output of Job 2
Input to Job 3

Wisconsin

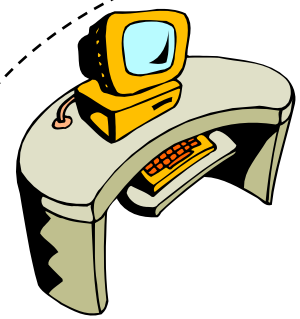


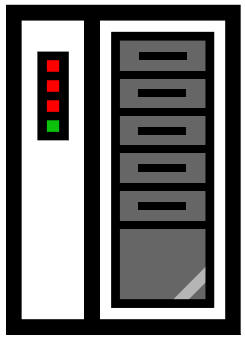


Allocation?

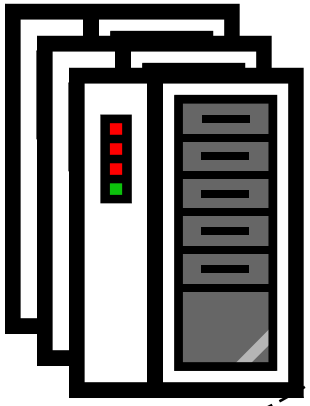
Scheduling?

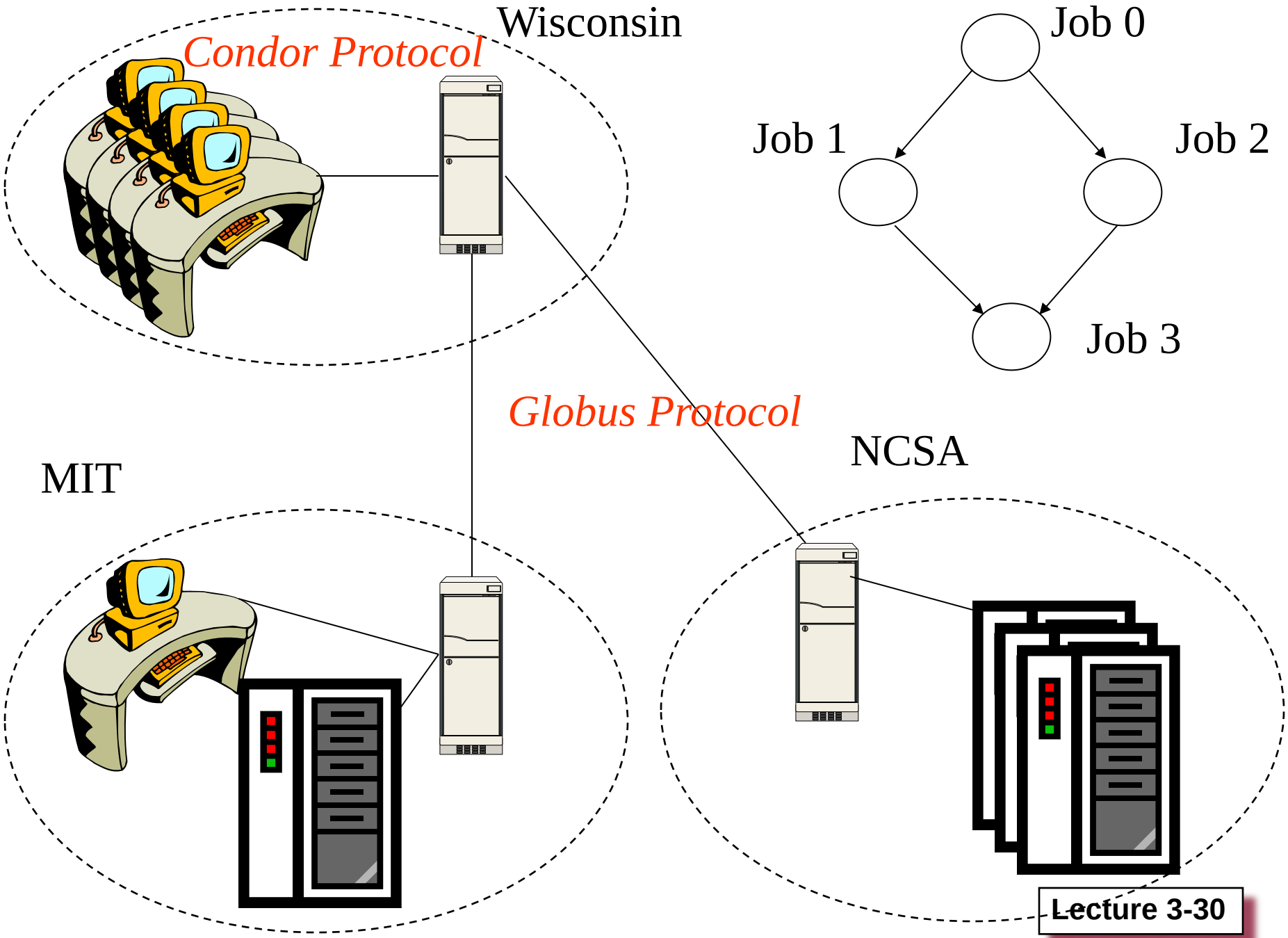
MIT

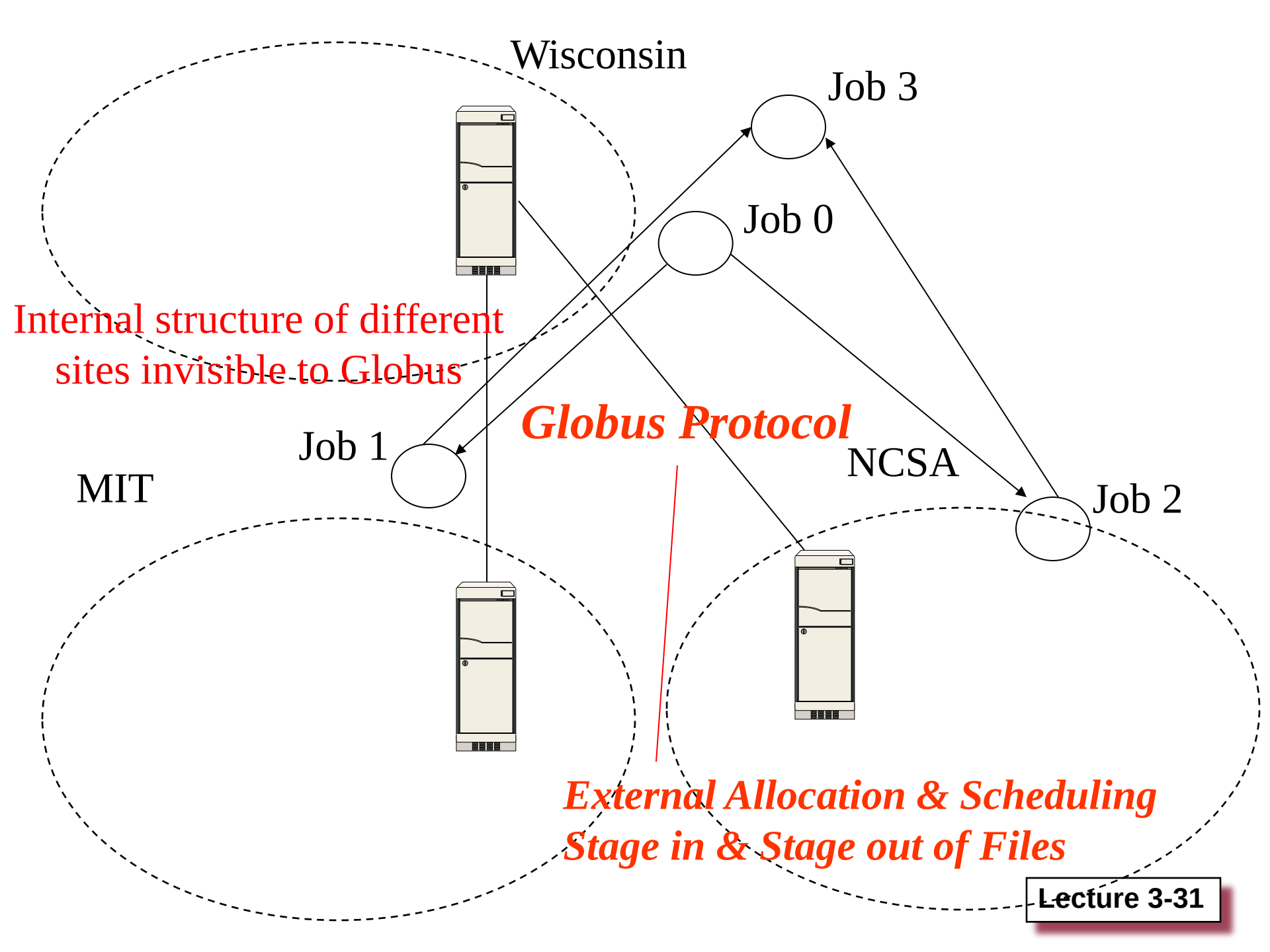


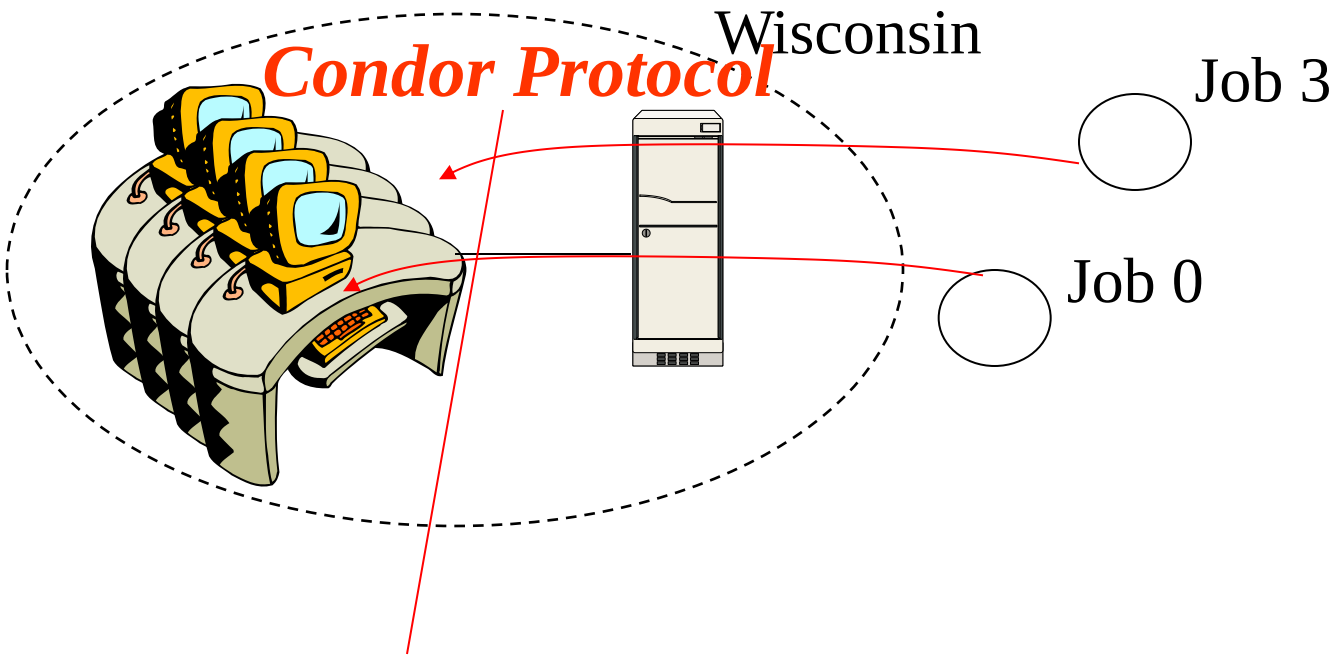


NCSA




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

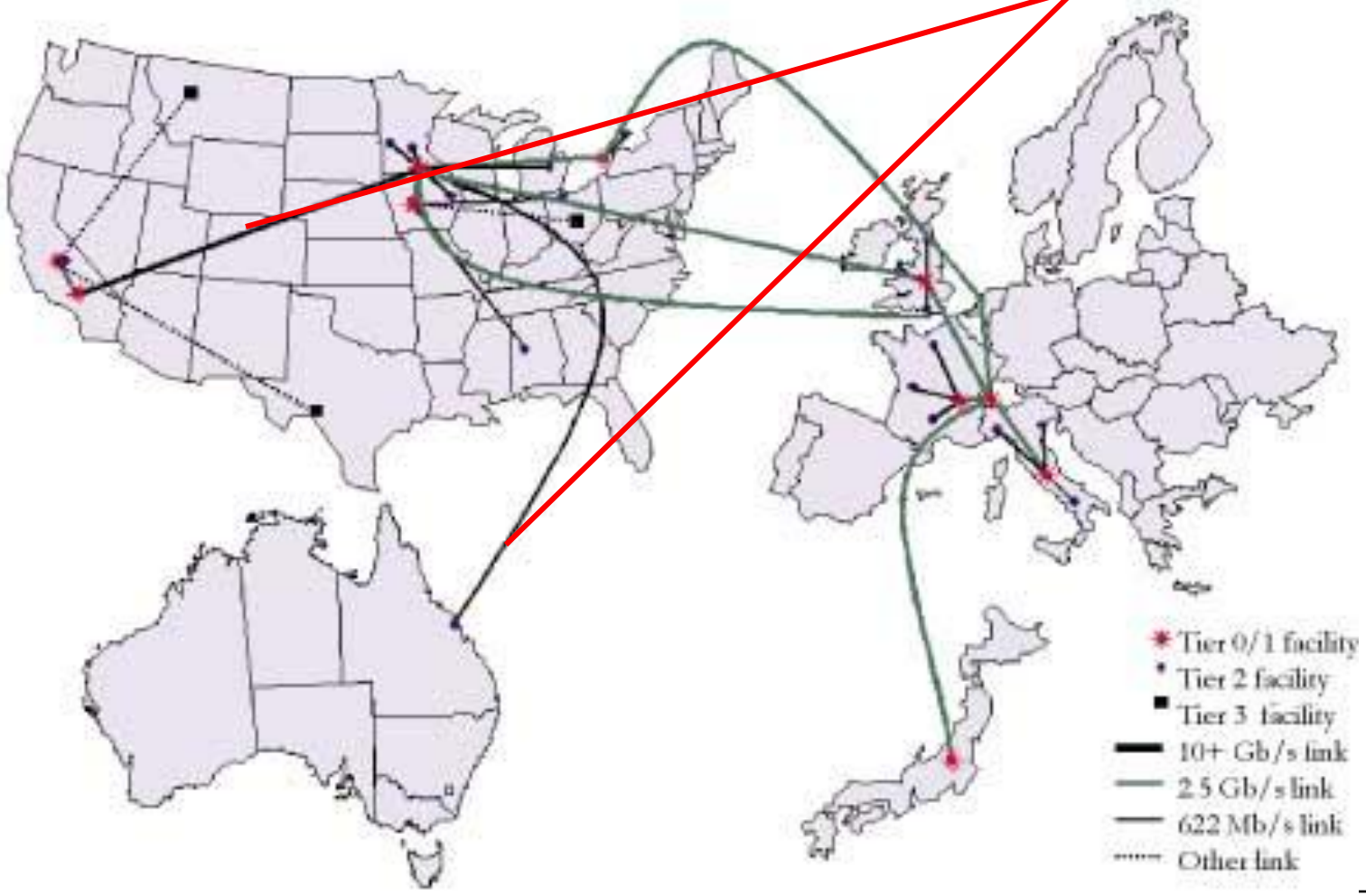

Wisconsin
Job 3
Job 0
Internal structure of different sites invisible to Globus
Globus Protocol
Job 1
NCSA
MIT
Job 2
External Allocation & Scheduling
Stage in & Stage out of Files



Internal Allocation & Scheduling
Monitoring
Distribution and Publishing of Files

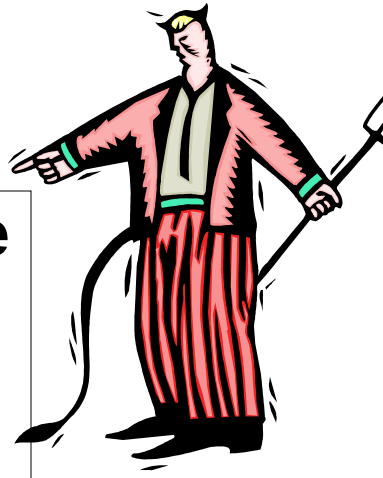
The Grid Recently

Some are 40Gbps links.
(The TeraGrid links)

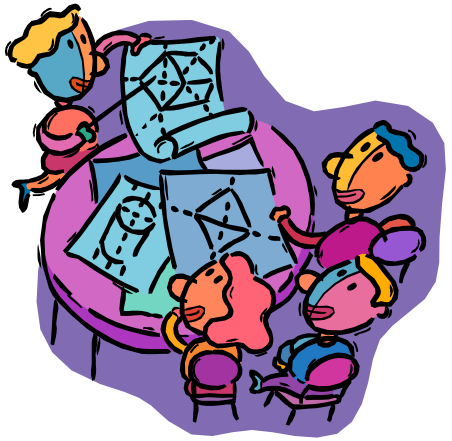


"A parallel Internet"

Question to Ponder



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



MP1, HW1

- **MP1, HW1 out today**
  - **MP1 due 9/15 (Sun midnight). Demos soon after (likely Monday 9/16)**
  - **HW1 due 9/19 (hand-in at beginning of class)**
- **Effort**
  - **For HW: Individual effort only. 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 an MP partner, hang around after class today (or use Piazza)**
    - **» Please report groups to us by this Thursday 9/15. Subject line: "425 MP group" to cs425-ece428@mx.uillinois.edu**
  - **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)
- Each line is a key-value pair
- Read the doc – it is very detailed
- 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**