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Some Cloud Computing Topics

CSE 454

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About me

- Aaron Kimball (M.S. 2008)
- Designed/taught CSE 490H
  - “Problem solving on large-scale clusters” a.k.a. “The Hadoop course” a.k.a. “The Google course”
- I now work for Cloudera (“The Commercial Hadoop Company”)

A lecture about…

“I suspect that an overview on cloud computing that hits highlights on GFS, hadoop, bigtable, Ec2 would be great. (Or a subset or extended subset of those topics) would be appreciated by the students.”

– email from Dan 10/29/09

An outline?

- Big Data (Corporations are packrats)
- Big Computations (If you want it done right…)
- Big Computing Environments

Databases

- MySQL, Oracle, SQL Server…
- Store *structured data* along with large amount of *metadata*
  - A finite set of fields per record with well-defined types
  - Lots of bookkeeping information (table statistics, indices over one or more columns, constraints on data integrity…)
    - Really cool data structures! (e.g., B-Trees)
- **Pro:** REALLY FAST queries of certain types
  - Metadata can be tuned to make certain queries better
- **Con:** Metadata has time and space costs to create, maintain. Must also predict / control the *schema* of the information
- ... Take CSE 444 for more information

Example table

```
mysql> use corp;
Database changed

mysql> describe employees;
+------------+-------------+------+-----+---------+----------------+
| Field      | Type        | Null | Key | Default | Extra          |
+------------+-------------+------+-----+---------+----------------+
| id         | int(11)     | NO   | PRI | NULL    | auto_increment |
| firstname  | varchar(32) | YES  |     | NULL    |                |
| lastname   | varchar(32) | YES  |     | NULL    |                |
| jobtitle   | varchar(64) | YES  |     | NULL    |                |
| start_date | date        | YES  |     | NULL    |                |
| dept_id    | int(11)     | YES  |     | NULL    |                |
+------------+-------------+------+-----+---------+----------------+
```

Some things databases are good at

- Using an index to look up a particular row
- Grouping together rows with a shared key
  - And applying “aggregation” functions (SUM, AVG, STDDEV…)
- Enforcing data quality
  - e.g.: no duplicates; type-safety; other business-logic constraints

The problems…

- A hard drive writes at 50—60 MB/sec.
  - … but only if you’re writing in a straight line
  - Maintaining indexed data may drop this by 10x or more
  - Buffering / delayed writes can help recover this
- Performing database operations in parallel is complicated, and scalability is challenging to implement correctly
- Databases hold max 10 TB; queries can scan ~10%

Bigger data, better processing

- How do we store 1,000x as much data?
- How do we process data where we don't know the schema in advance?
- How do we perform more complicated processing?
  - Natural language processing, machine learning, image processing, web mining…
- How do we do this at the rate of TB/hour?

What we need

- An **efficient** way to decompose problems into parallel parts
- A way to read and write data **in parallel**
- A way to **minimize** bandwidth usage
- A **reliable** way to get computation done

What does it mean to be reliable?

Ken Arnold, CORBA designer*:

“Failure is the defining difference between distributed and local programming”

*(Serious Über-hacker)

Reliability Demands

- Support partial failure
  - Total system must support graceful decline in application performance rather than a full halt

Reliability Demands

- Data Recoverability
  - If components fail, their workload must be picked up by still-functioning units

Reliability Demands

- Individual Recoverability
  - Nodes that fail and restart must be able to rejoin the group activity without a full group restart

Reliability Demands

- Consistency
  - Concurrent operations or partial internal failures should not cause externally visible nondeterminism

Reliability Demands

- Scalability
  - Adding increased load to a system should not cause outright failure, but a graceful decline
  - Increasing resources should support a proportional increase in load capacity

A Radical Way Out…

- Nodes talk to each other as little as possible – maybe never
  - “Shared nothing” architecture
- Programmer should not explicitly be allowed to communicate between nodes
- Data is spread throughout machines in advance, computation happens where it’s stored.

Locality

- Master program divvies up tasks based on location of data: tries to have map tasks on same machine as physical file data, or at least same rack
- Map task inputs are divided into 64—128 MB blocks: same size as filesystem chunks
  - Process components of a single file in parallel

Fault Tolerance

- Tasks designed for independence
- Master detects worker failures
- Master re-executes tasks that fail while in progress
- Restarting one task does not require communication with other tasks
- Data is replicated to increase availability, durability

How MapReduce is Structured

- Functional programming meets distributed computing
- A batch data processing system
- Factors out many reliability concerns from application logic

MapReduce Provides:

- Automatic parallelization & distribution
- Fault-tolerance
- Status and monitoring tools
- A clean abstraction for programmers

Programming Model

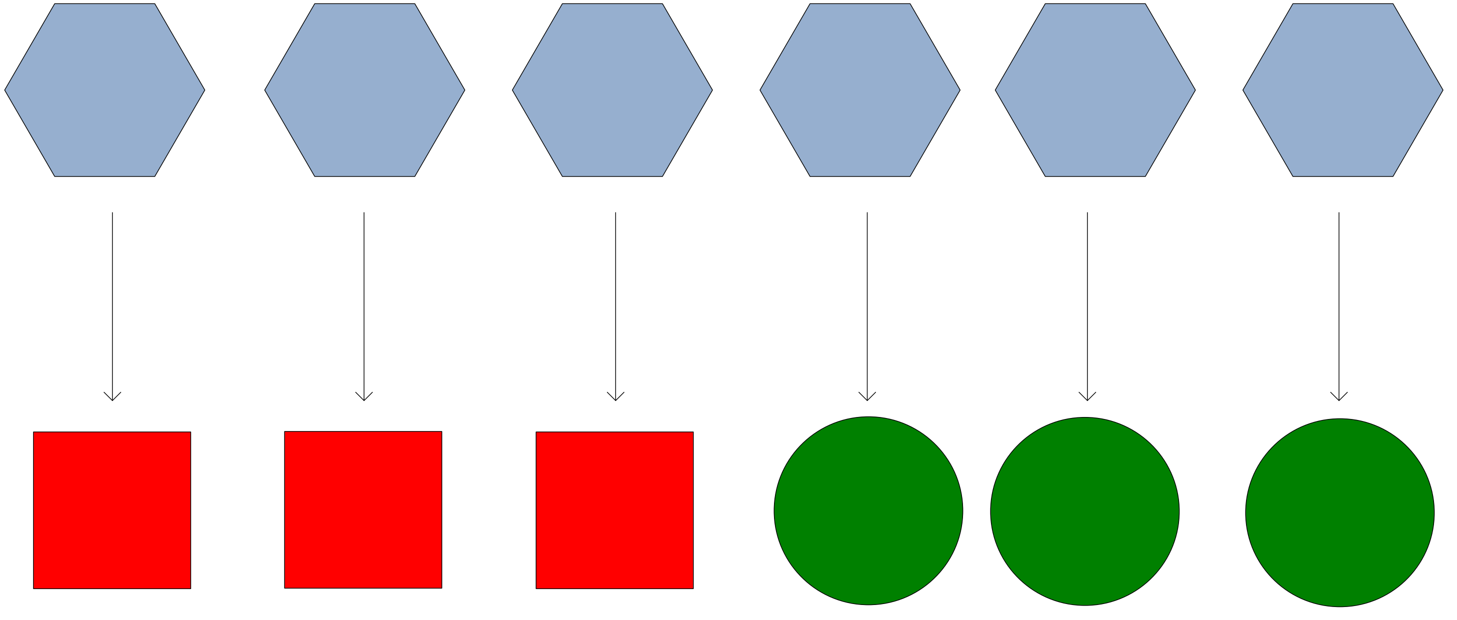
- Borrows from functional programming
- Users implement interface of two functions:

  - **`map (in_key, in_value) ->`**
    `(intermediate_key, int_value) list`

  - **`reduce (intermediate_key, int_value list) ->`**
    `(out_key, out_value) list`

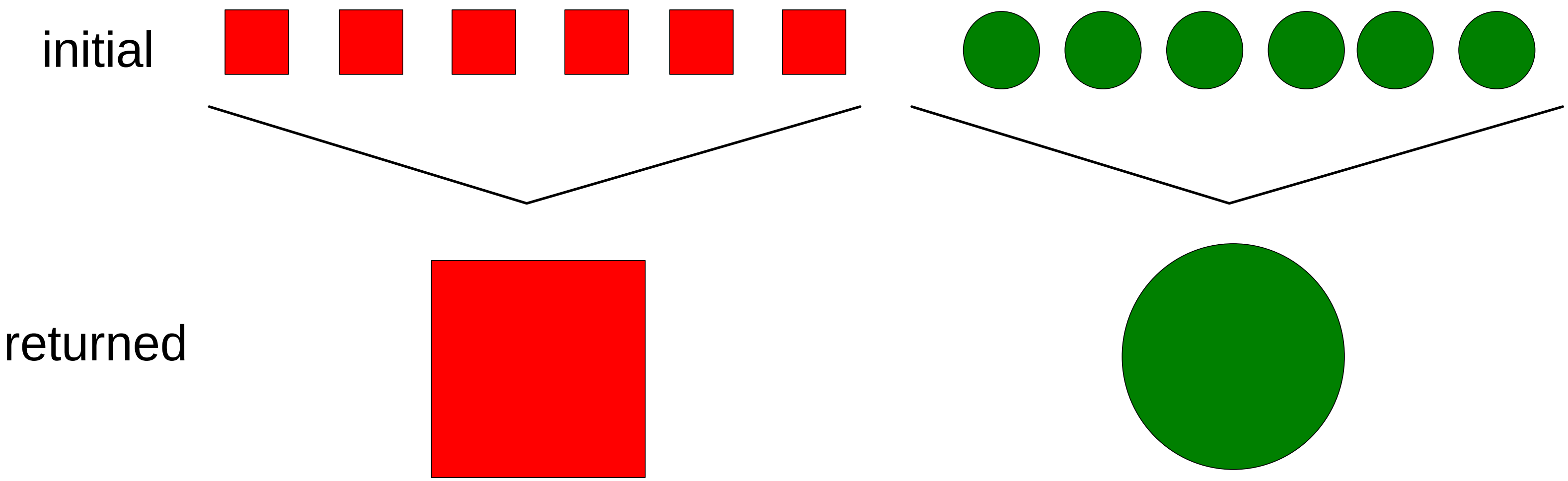
map

```
map  (in_key, in_value) ->
   (intermediate_key, int_value) list
```



reduce

```
reduce (intermediate_key, int_value list) ->
         (out_key, out_value) list
```



Example: Filter Mapper

```
let map(k, v) =
  if (isPrime(v)) then emit(k, v)
```

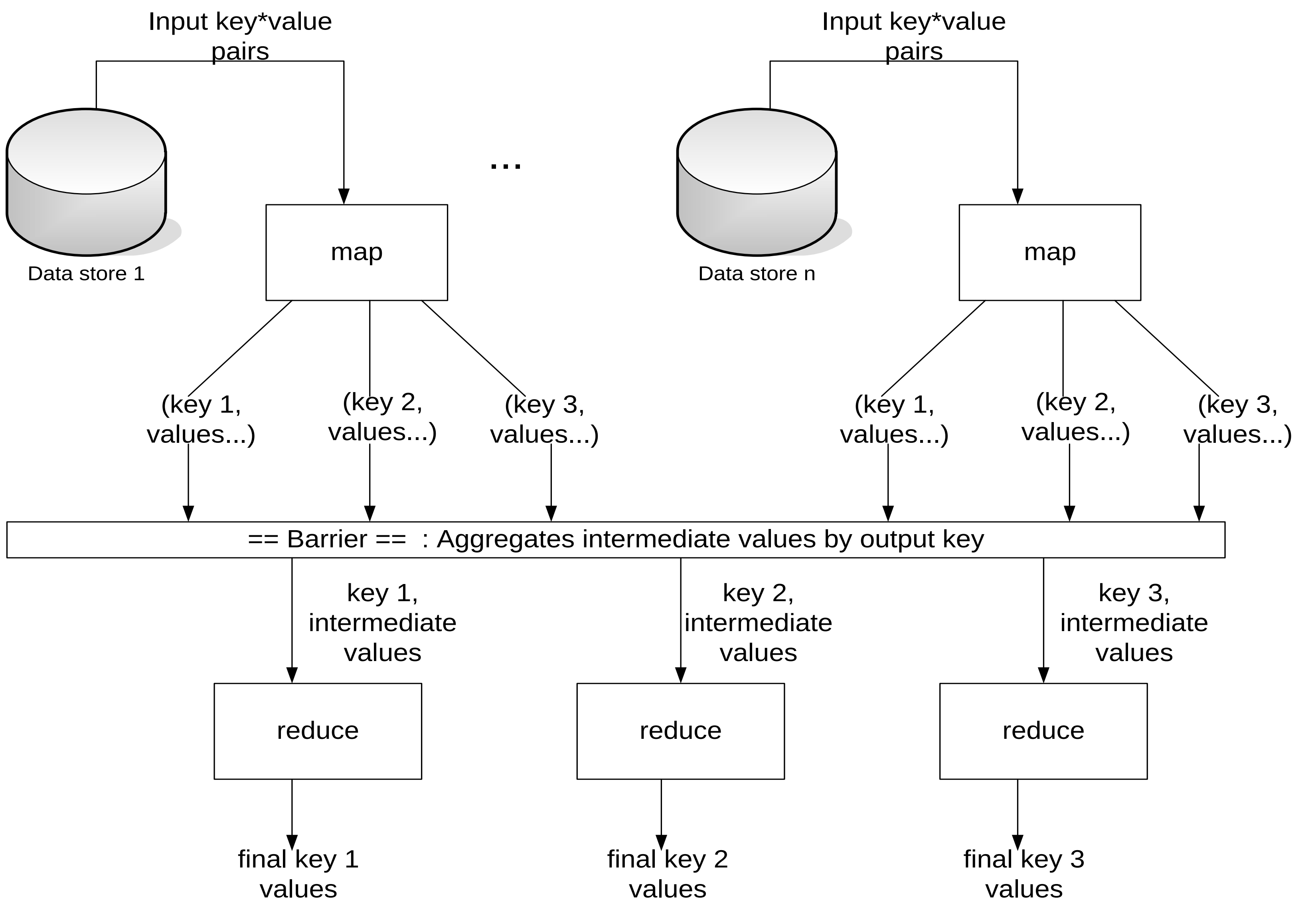
("foo", 7) ➔ ("foo", 7)

("test", 10) ➔ *(nothing)*

Example: Sum Reducer

```
let 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)
```


Input key*value pairs
Input key*value pairs
...
map
Data store 1
Data store n
map
(key 1, values...)
(key 2, values...)
(key 3, values...)
(key 1, values...)
(key 2, values...)
(key 3, values...)
== Barrier == : Aggregates intermediate values by output key
key 1, intermediate values
key 2, intermediate values
key 3, intermediate values
reduce
reduce
reduce
final key 1 values
final key 2 values
final key 3 values

Example: Count word occurrences

```
map(String input_key, String input_value):
  // input_key: document name
  // input_value: document contents
  for each word w in input_value:
    emit(w, 1);

reduce(String output_key, Iterator<int>
   intermediate_values):
  // output_key: a word
  // output_values: a list of counts
  int result = 0;
  for each v in intermediate_values:
    result += v;
  emit(output_key, result);
```

That’s how to process data in parallel

- … How to store all this data?
  - HDFS / GFS

Storage assumptions

- 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 write-once (maybe appended-to)
- Large streaming reads
- High sustained throughput favored over low latency

GFS/HDFS Design Decisions

- Files stored as blocks
  - Much larger size than most filesystems (default is 64MB)
- Reliability through replication
  - Each block replicated across 3+ *DataNodes*
- Single master (NameNode) 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

GFS Architecture

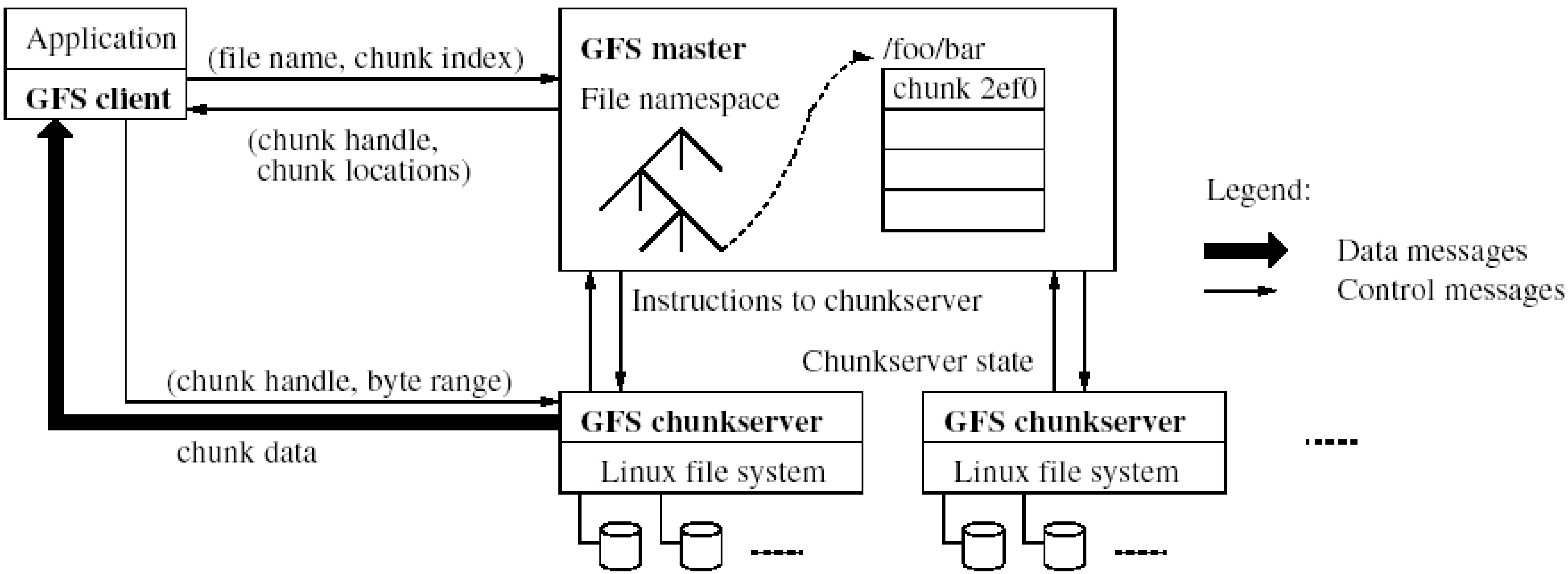


Figure from “The Google File System,”
Ghemawat et. al., SOSP 2003

The key insight…

- DataNodes (storing blocks of files) are the **same machines** as MapReduce worker nodes

- When scheduling tasks, MapReduce picks nodes based on **where data already is resident**
  - Data replication increases durability, also improves scheduling efficiency

Cloud computing: broader than any one app

Cloud computing is a method to address scalability and availability concerns for enterprise applications.

An evolving ecosystem

Application Infrastructure

Platform Infrastructure

Language-level Infrastructure

Hardware Infrastructure

Breadth of applicability

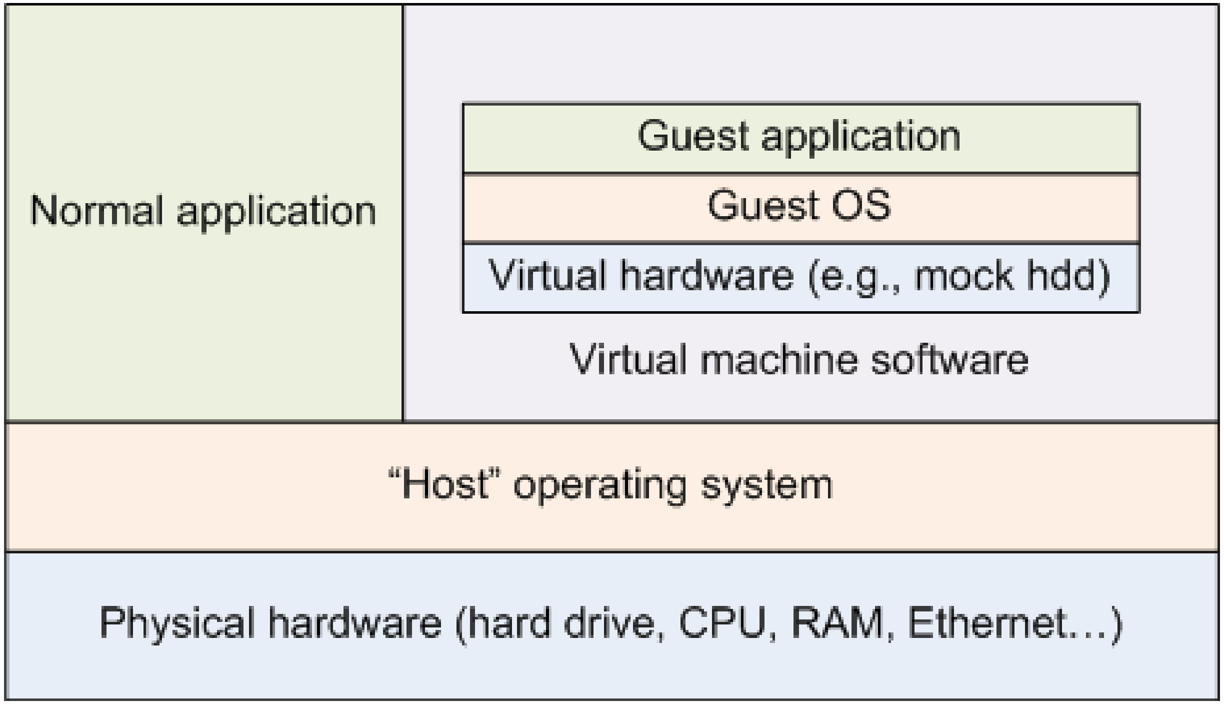
Rapid development in domain

Hardware as a service: virtualization

- Amazon EC2: Machines for rent by the hour, on demand.
  - But you don’t necessarily get a full machine (maybe just a slice)
- Google AppEngine: We give you “cycles,” who knows where

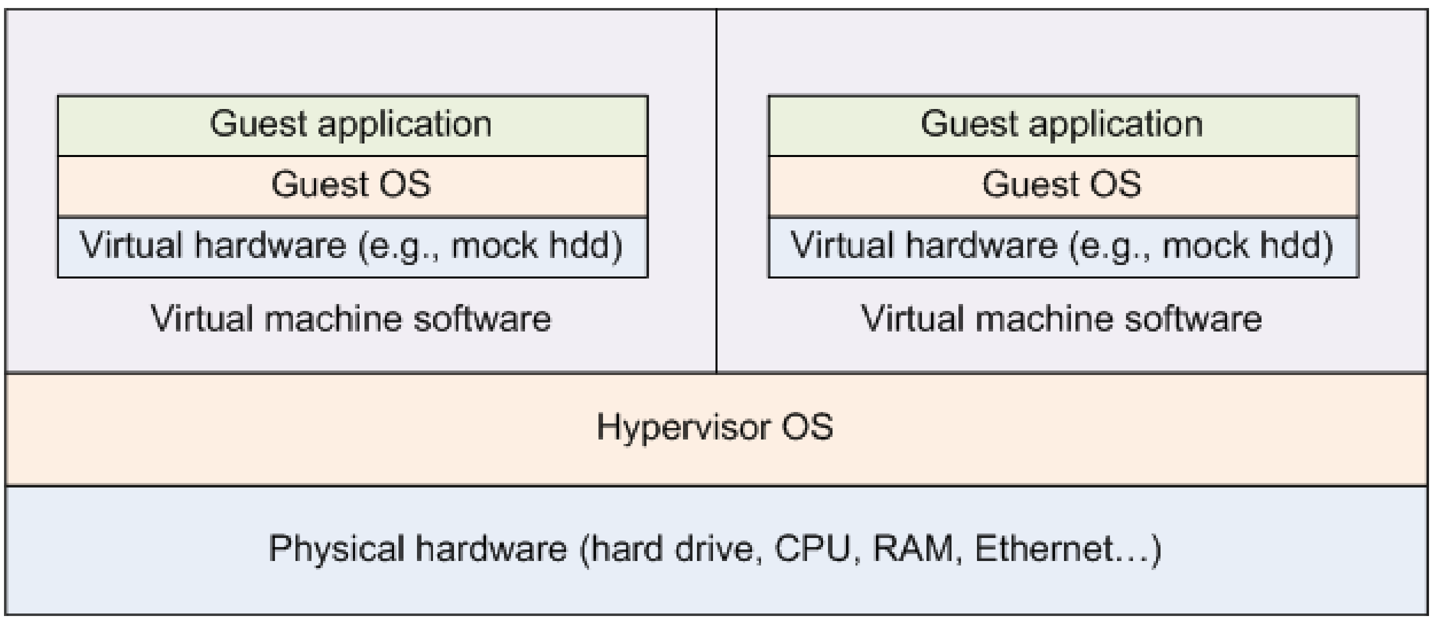
Virtualization in a nutshell

- Just a layer of software that responds to device drivers (hard drive, Ethernet, graphics) like the drivers/OS expect
- Software layer then does “something reasonable” with underlying actual resources

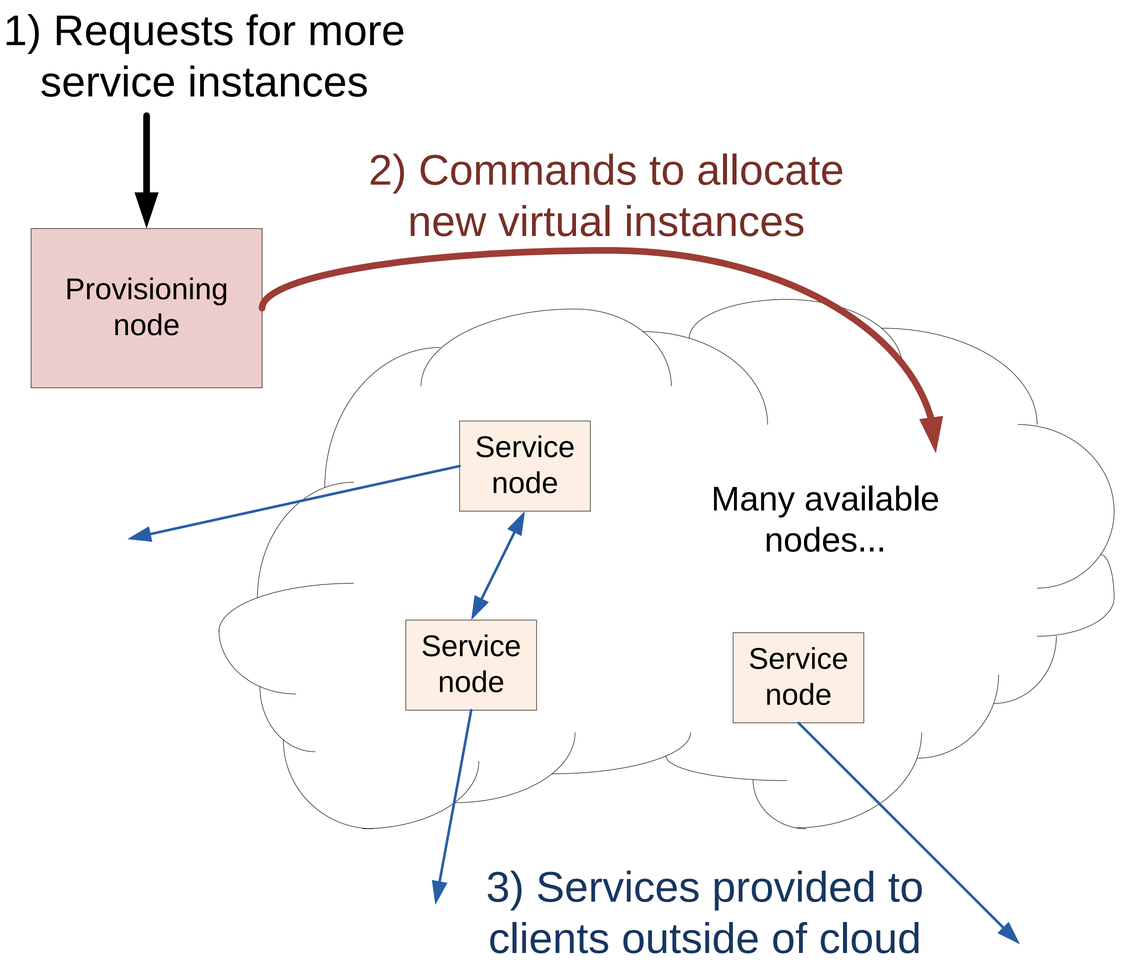


A fully-virtualized machine

- All applications run in a VM
- One or more VMs may share machine



Clouds: high-level



Key promises of virtualization

- Users can get more machines in on-demand fashion
- Interface to new virtual nodes is through software API
  - So software on existing nodes can recognize over/underloading and make requests to provider to adjust on the fly.
- EC2 gives you more explicit control in terms of virtual nodes
- AppEngine takes this to the next level and does not expose any hardware to you whatsoever
  - Makes web application development simpler. Makes high-performance system design nearly impossible
- My next wish: explicit network topology control…

Some concluding summary…

- Processing lots of data requires lots of machines
- Using lots of machines in parallel requires
  - Some infrastructure to manage it for you (Hadoop)
  - The ability to decompose a problem into independent subtasks
- High performance requires data locality
  - (It’s not processing data that’s slow. It’s **moving** data that is.)

Want to play with Hadoop?

- We’ve got a virtual machine available online
  - Eclipse, and Hadoop, some exercises, and a tutorial all set up
  - Download: http://cloudera.com/hadoop-training-virtual-machine
- You’ll need VMWare Player/Fusion to run it
- It’s about a 1 GB download, 4 GB unpacked (so get this in 002) ;)

Want a job this summer?

- No promises but last year we had a bunch of interns
  - We’ll probably need some more
- You get to play with Hadoop, other distributed systems, EC2…
- The catch: We’re pretty bad at making commitments this far out. Talk to us again around March/April.
- Want a full-time job? We’ve got a bunch of those :)
- Send resumes/inquiries/etc to aaron@cloudera.com

Thanks for listening

Questions: aaron@cloudera.com