UNIVERSITY OF WATERLOO

Big Data Infrastructure

CS 489/698 Big Data Infrastructure (Winter 2016)

Week 2: MapReduce Algorithm Design (1/2)

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These slides are available at http://lintool.github.io/bigdata-2016w/

Aside: Cloud Computing

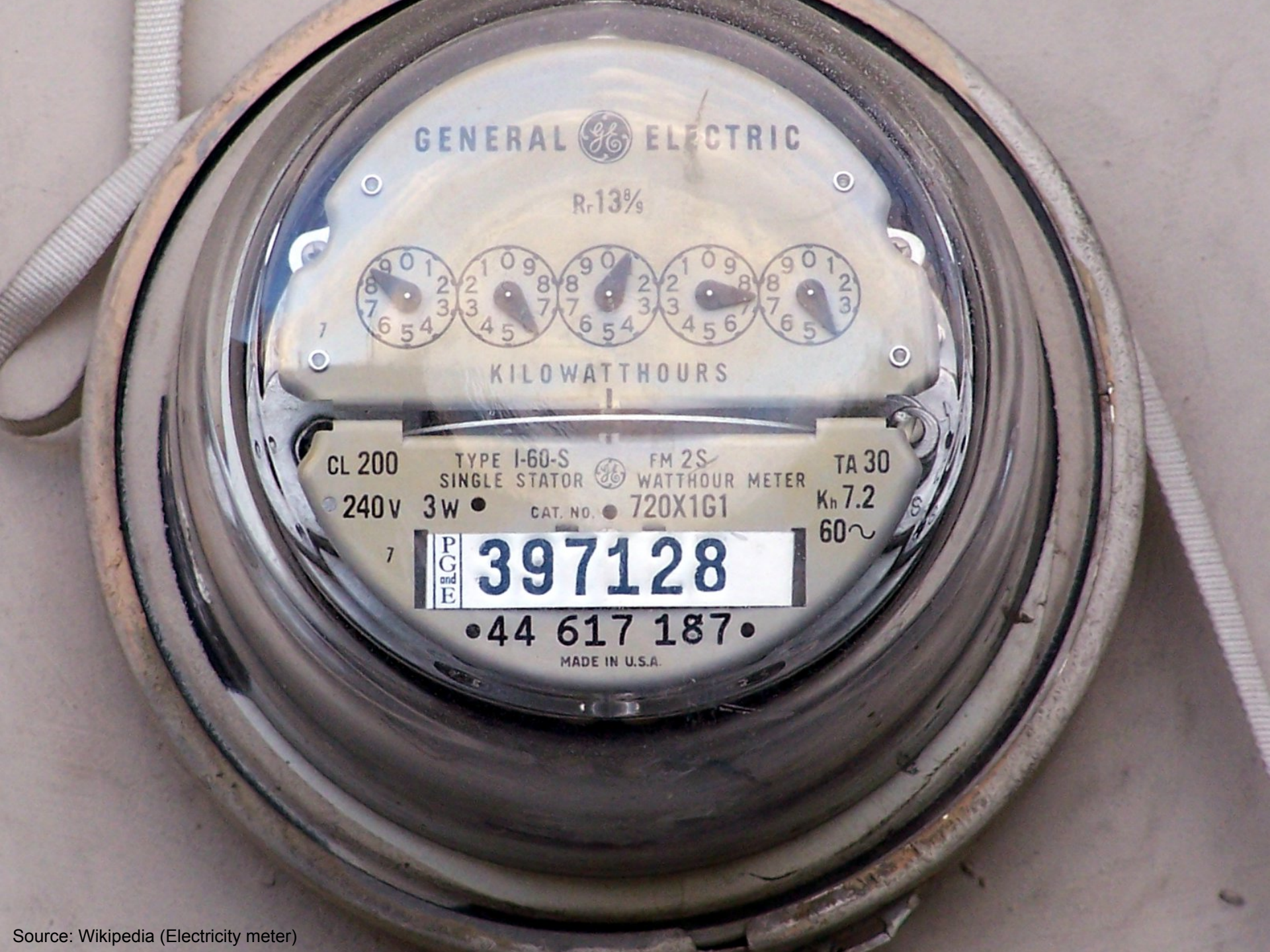
Source: Wikipedia (Clouds)

The best thing since sliced bread?

- Before clouds…
  - Grids
  - Connection machine
  - Vector supercomputers
  - …
- Cloud computing means many different things:
  - Big data
  - Rebranding of web 2.0
  - Utility computing
  - Everything as a service

Rebranding of web 2.0

- Rich, interactive web applications
  - Clouds refer to the servers that run them
  - AJAX as the de facto standard (for better or worse)
  - Examples: Facebook, YouTube, Gmail, …
- "The network is the computer": take two
  - User data is stored "in the clouds"
  - Rise of the tablets, smartphones, etc. ("thin client")
  - Browser *is* the OS



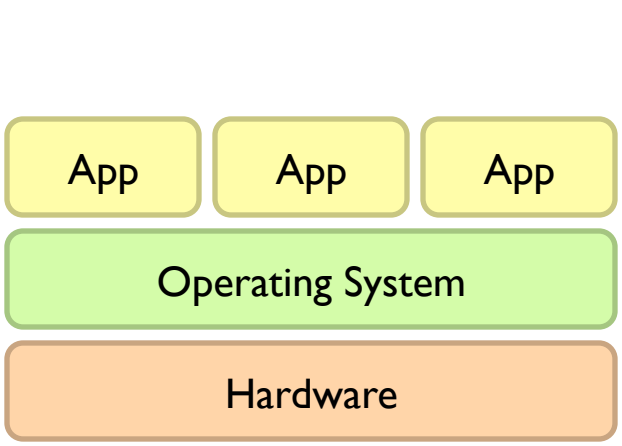
Source: Wikipedia (Electricity meter)

Utility Computing

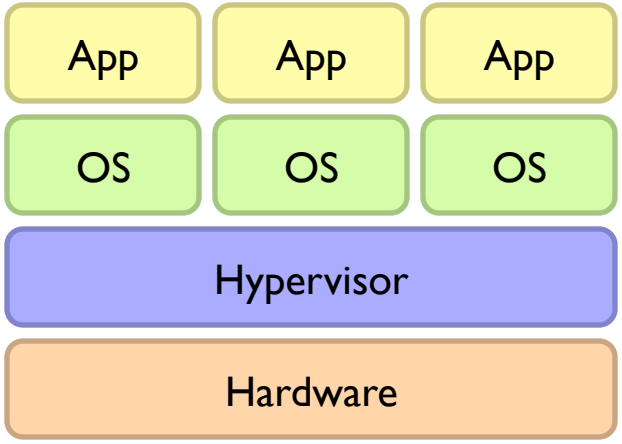
- What?
  - Computing resources as a metered service ("pay as you go")
  - Ability to dynamically provision virtual machines
- Why?
  - Cost: capital vs. operating expenses
  - Scalability: "infinite" capacity
  - Elasticity: scale up or down on demand
- Does it make sense?
  - Benefits to cloud users
  - Business case for cloud providers

I think there is a world market for about five computers.

Enabling Technology: Virtualization



Traditional Stack



Virtualized Stack

Today's buzzword: Docker

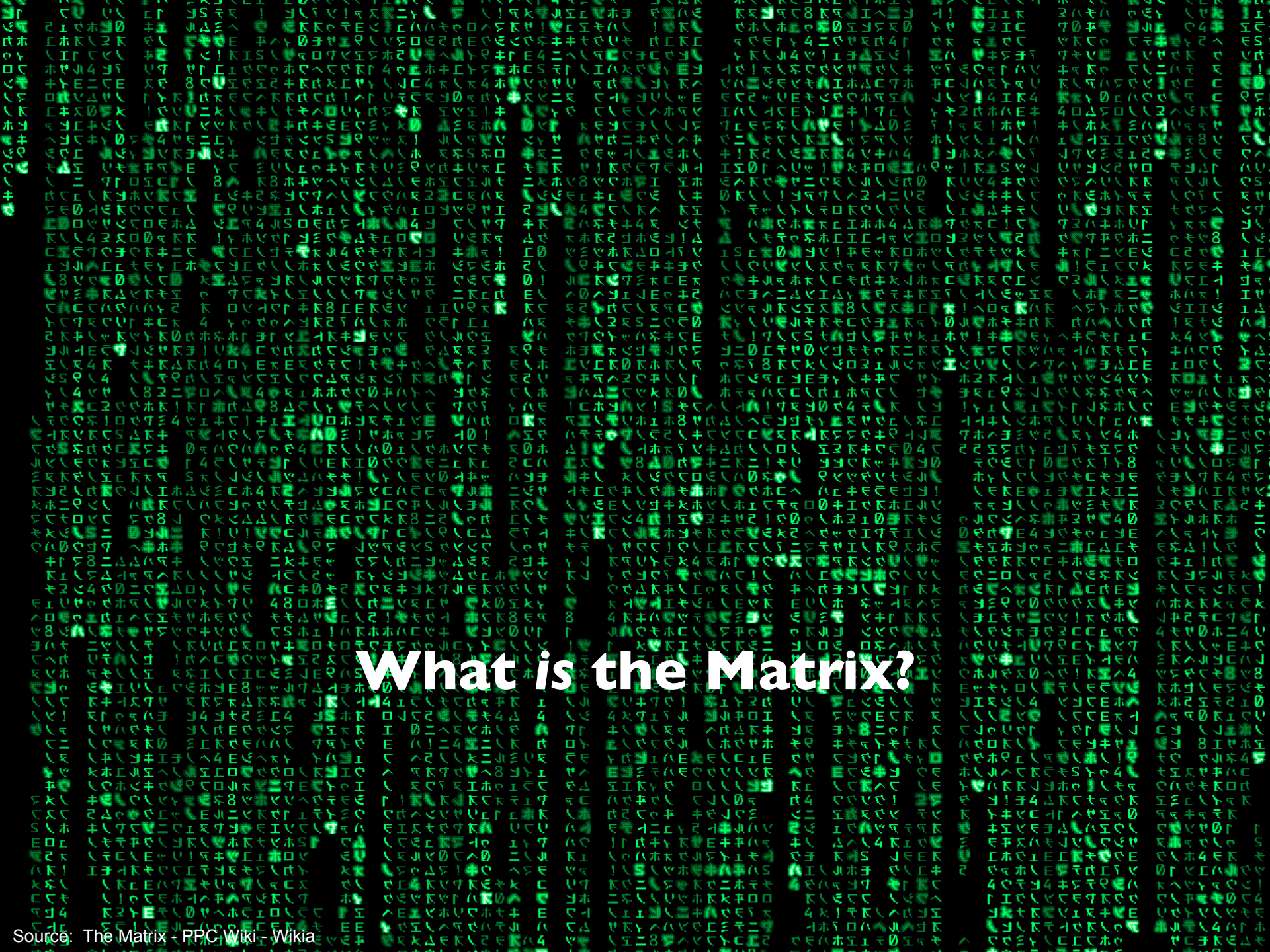
Everything as a Service

- Utility computing = Infrastructure as a Service (IaaS)
  - Why buy machines when you can rent cycles?
  - Examples: Amazon's EC2, Rackspace
- Platform as a Service (PaaS)
  - Give me nice API and take care of the maintenance, upgrades, …
  - Example: Google App Engine, Altiscale
- Software as a Service (SaaS)
  - Just run it for me!
  - Example: Gmail, Salesforce

Who cares?

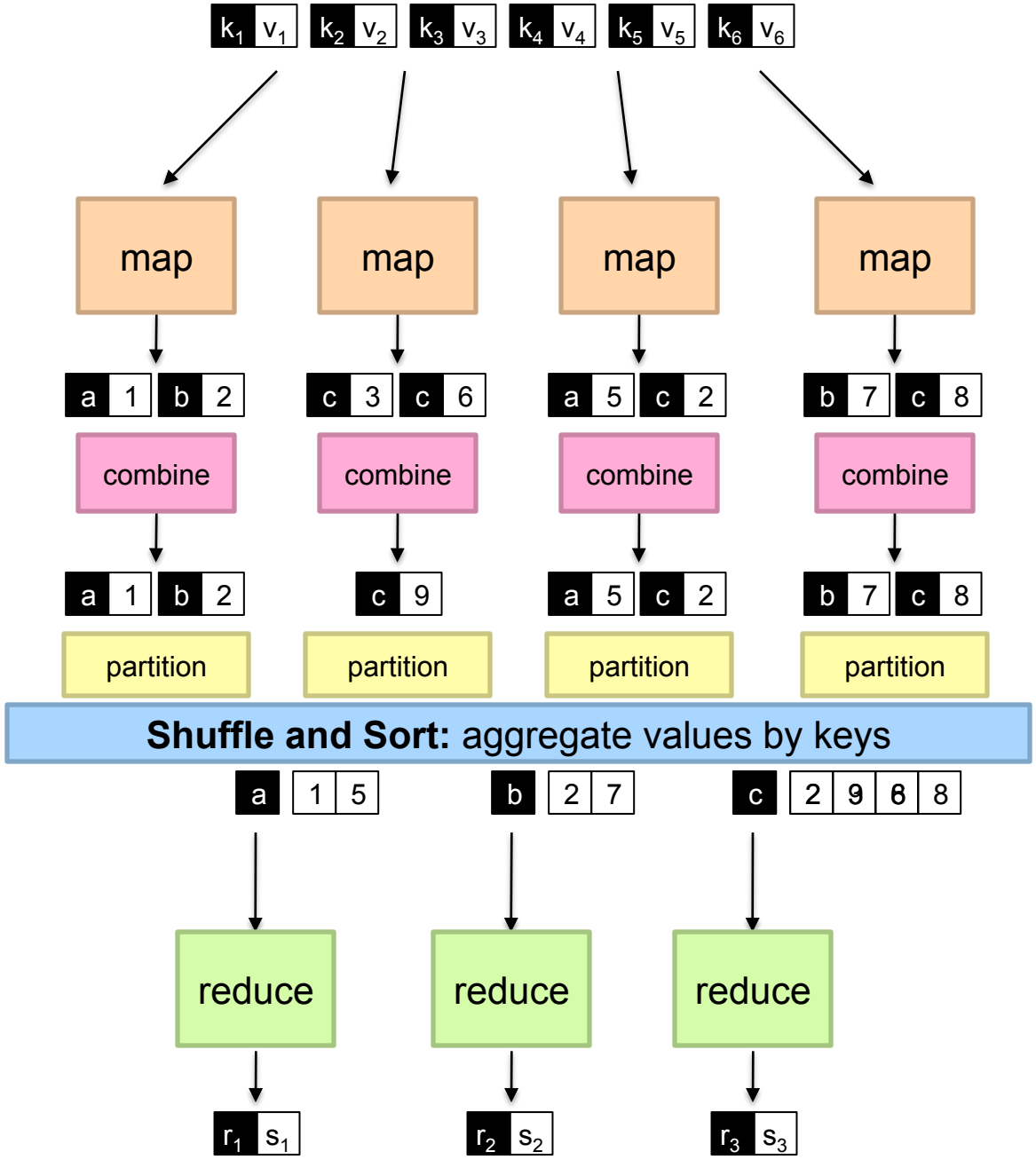
- A source of problems…
  - Cloud-based services *generate* big data
  - Clouds make it easier to start companies that *generate* big data
- As well as a solution…
  - Ability to provision analytics clusters on-demand in the cloud
  - Commoditization and democratization of big data capabilities

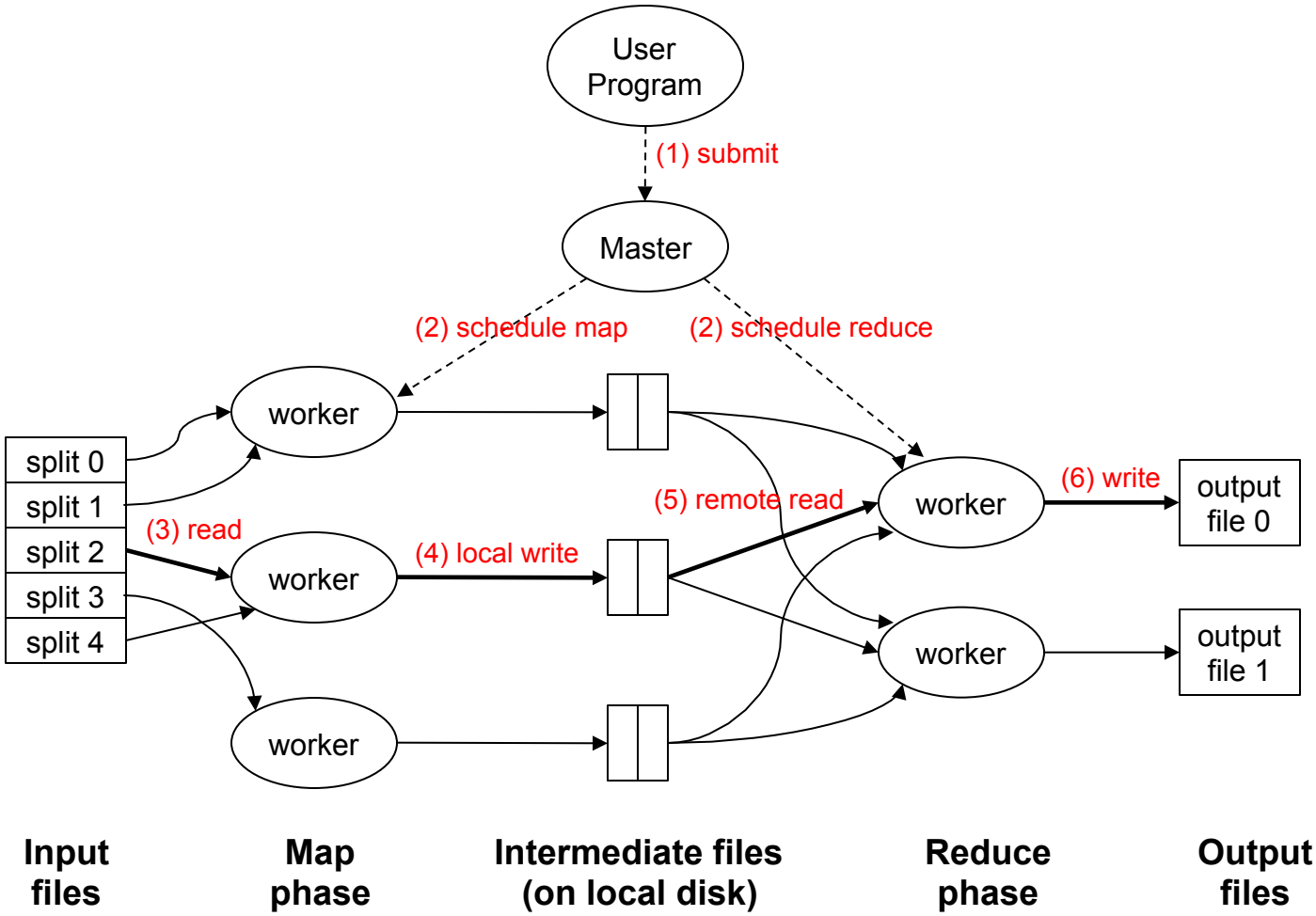
Source: Wikipedia (Clouds)



Source: The Matrix - PPC Wiki - Wikia

Source: Google


k1 v1
k2 v2
k3 v3
k4 v4
k5 v5
k6 v6
map
map
map
map
a 1
b 2
c 3
c 6
a 5
c 2
b 7
c 8
combine
combine
combine
combine
a 1
b 2
c 9
a 5
c 2
b 7
c 8
partition
partition
partition
partition
Shuffle and Sort: aggregate values by keys
a 1 5
b 2 7
c 2 9 6 8
reduce
reduce
reduce
r1 s1
r2 s2
r3 s3



Adapted from (Dean and Ghemawat, OSDI 2004)

Source: Wikipedia (Mahout)

Hadoop API*

- Mapper<K_{in},V_{in},K_{out},V_{out}>
  - void setup(Mapper.Context context)
    Called once at the beginning of the task
  - void map(K_{in} key, V_{in} value, Mapper.Context context)
    Called once for each key/value pair in the input split
  - void cleanup(Mapper.Context context)
    Called once at the end of the task
- Reducer<K_{in},V_{in},K_{out},V_{out}>/Combiner<K_{in},V_{in},K_{out},V_{out}>
  - void setup(Reducer.Context context)
    Called once at the start of the task
  - void reduce(K_{in} key, Iterable<V_{in}> values, Reducer.Context context)
    Called once for each key
  - void cleanup(Reducer.Context context)
    Called once at the end of the task

*Note that there are two versions of the API!

Hadoop API*

- Partitioner
  - int getPartition(K key, V value, int numPartitions)
    Get the partition number given total number of partitions
- Job
  - Represents a packaged Hadoop job for submission to cluster
  - Need to specify input and output paths
  - Need to specify input and output formats
  - Need to specify mapper, reducer, combiner, partitioner classes
  - Need to specify intermediate/final key/value classes
  - Need to specify number of reducers (but not mappers, why?)
  - Don't depend of defaults!

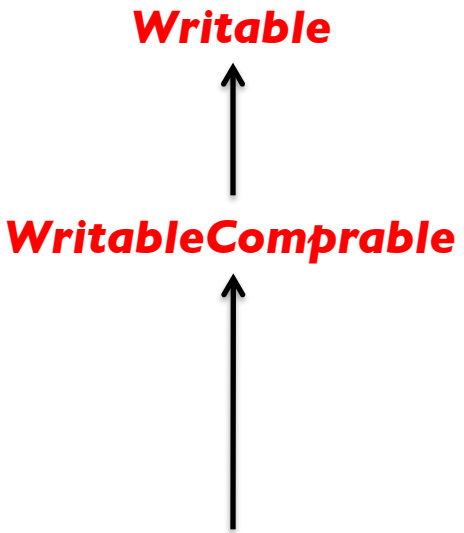
*Note that there are two versions of the API!

A tale of two packages...

org.apache.hadoop.mapreduce
org.apache.hadoop.mapred

Source: Wikipedia (Budapest)

Data Types in Hadoop: Keys and Values



Defines a de/serialization protocol. Every data type in Hadoop is a Writable.

Defines a sort order. All keys must be of this type (but not values).

Concrete classes for different data types.

SequenceFiles

Binary encoded of a sequence of key/value pairs

“Hello World”: Word Count

```
Map(String docid, String text):
    for each word w in text:
        Emit(w, 1);

Reduce(String term, Iterator<Int> values):
    int sum = 0;
    for each v in values:
        sum += v;
    Emit(term, sum);
```

“Hello World”: Word Count

```
private static class MyMapper
    extends Mapper<LongWritable, Text, Text, IntWritable> {

  private final static IntWritable ONE = new IntWritable(1);
  private final static Text WORD = new Text();

  @Override
  public void map(LongWritable key, Text value, Context context)
      throws IOException, InterruptedException {
    String line = ((Text) value).toString();
    StringTokenizer itr = new StringTokenizer(line);
    while (itr.hasMoreTokens()) {
      WORD.set(itr.nextToken());
      context.write(WORD, ONE);
    }
  }
}
```

“Hello World”: Word Count

```
private static class MyReducer
    extends Reducer<Text, IntWritable, Text, IntWritable> {

  private final static IntWritable SUM = new IntWritable();

  @Override
  public void reduce(Text key, Iterable<IntWritable> values,
      Context context) throws IOException, InterruptedException {
    Iterator<IntWritable> iter = values.iterator();
    int sum = 0;
    while (iter.hasNext()) {
      sum += iter.next().get();
    }
    SUM.set(sum);
    context.write(key, SUM);
  }
}
```

Three Gotchas

- Avoid object creation if possible
  - Reuse Writable objects, change the payload
- Execution framework reuses value object in reducer
- Passing parameters via class statics

Getting Data to Mappers and Reducers

- Configuration parameters
  - Directly in the Job object for parameters
- "Side data"
  - DistributedCache
  - Mappers/reducers read from HDFS in setup method

Complex Data Types in Hadoop

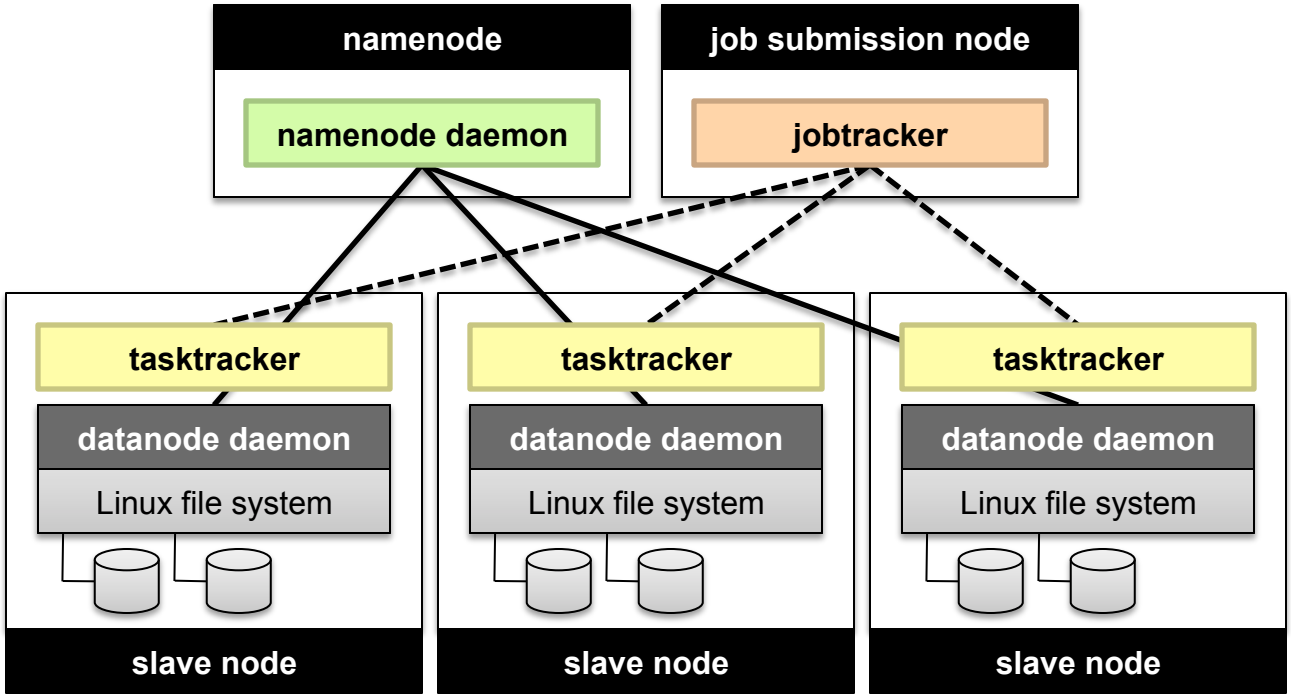
- How do you implement complex data types?
- The easiest way:
  - Encoded it as Text, e.g., (a, b) = “a:b”
  - Use regular expressions to parse and extract data
  - Works, but janky
- The hard way:
  - Define a custom implementation of Writable(Comprable)
  - Must implement: readFields, write, (compareTo)
  - Computationally efficient, but slow for rapid prototyping
  - Implement WritableComparator hook for performance
- Somewhere in the middle:
  - Bespin (via lin.tl) offers JSON support and lots of useful Hadoop types

Basic Cluster Components*

- One of each:
  - Namenode (NN): master node for HDFS
  - Jobtracker (JT): master node for job submission
- Set of each per slave machine:
  - Tasktracker (TT): contains multiple task slots
  - Datanode (DN): serves HDFS data blocks

* Not quite… leaving aside YARN for now

Putting everything together…

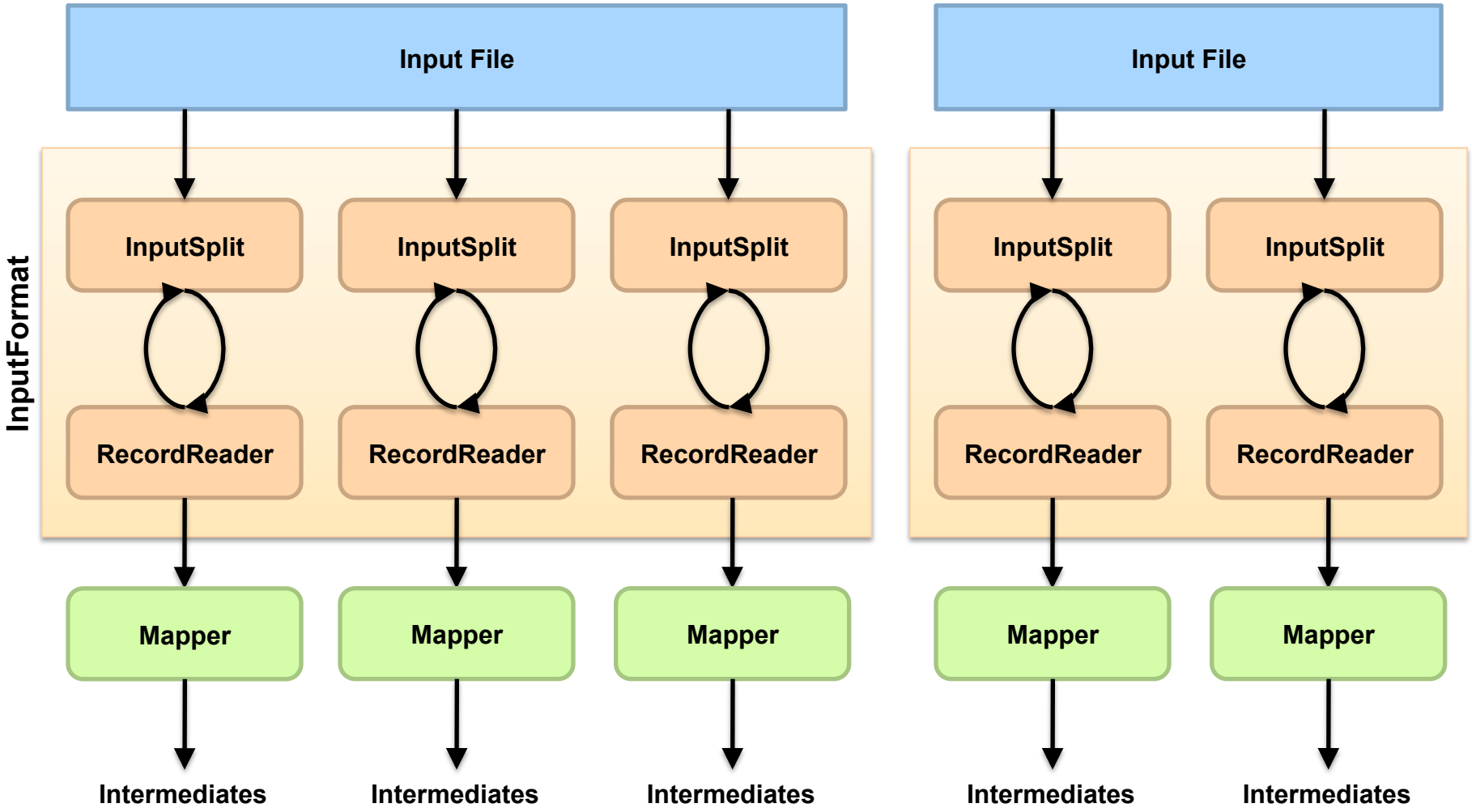


Anatomy of a Job

- MapReduce program in Hadoop = Hadoop job
  - Jobs are divided into map and reduce tasks
  - An instance of running a task is called a task attempt (occupies a slot)
  - Multiple jobs can be composed into a workflow
- Job submission:
  - Client (i.e., driver program) creates a job, configures it, and submits it to jobtracker
  - That's it! The Hadoop cluster takes over…

Anatomy of a Job

- Behind the scenes:
  - Input splits are computed (on client end)
  - Job data (jar, configuration XML) are sent to JobTracker
  - JobTracker puts job data in shared location, enqueues tasks
  - TaskTrackers poll for tasks
  - Off to the races…



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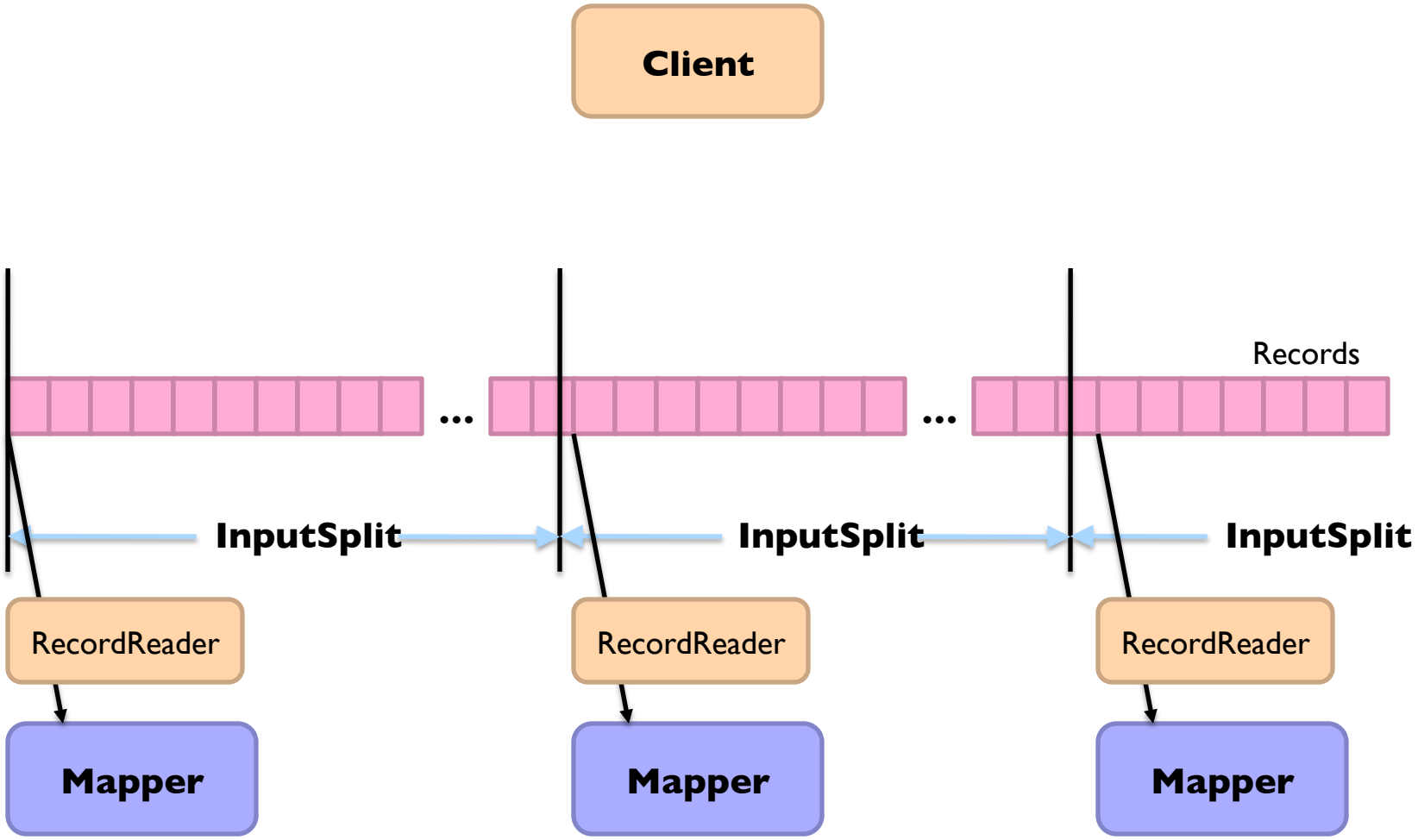
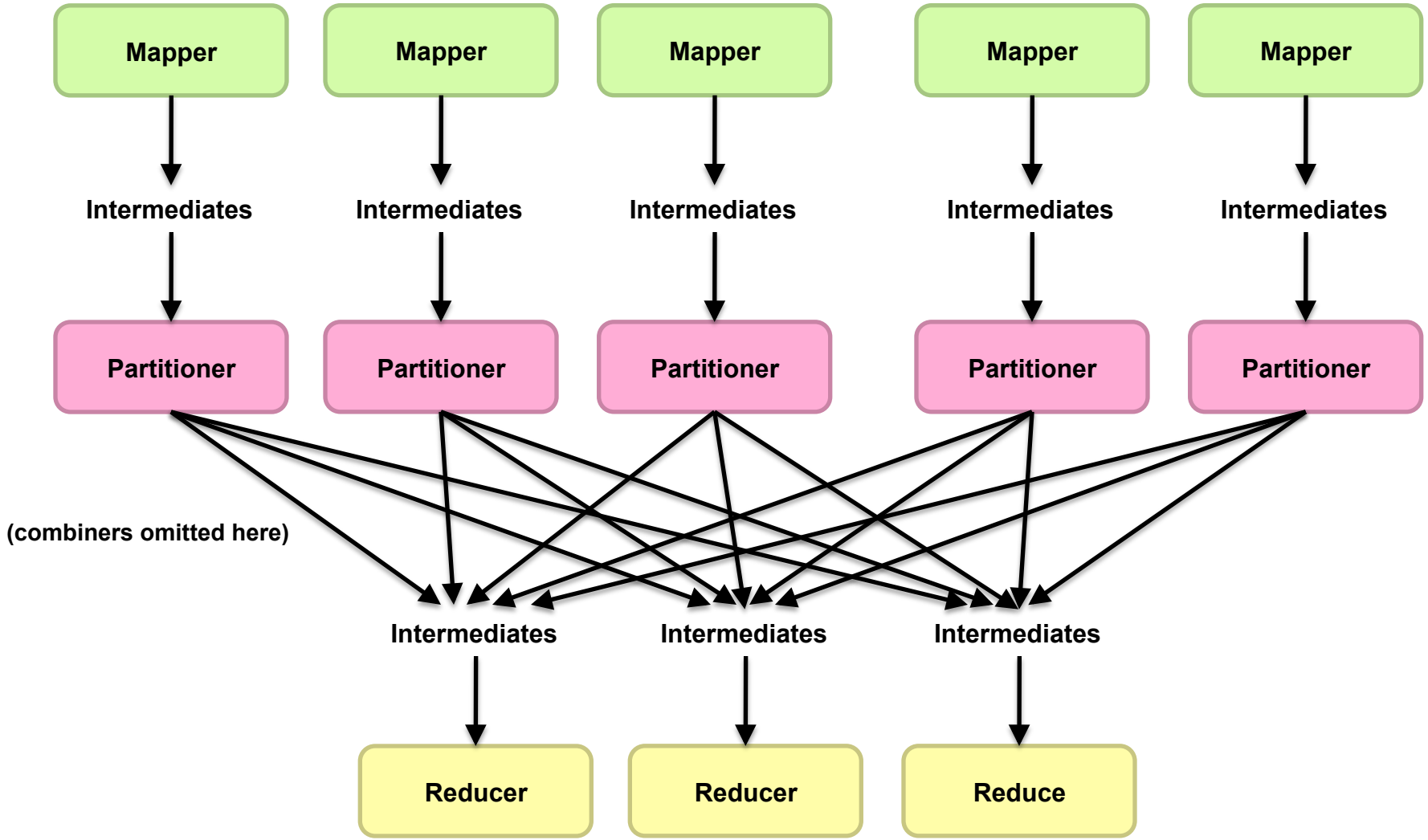

Client
Records
InputSplit
InputSplit
InputSplit
RecordReader
RecordReader
RecordReader
Mapper
Mapper
Mapper



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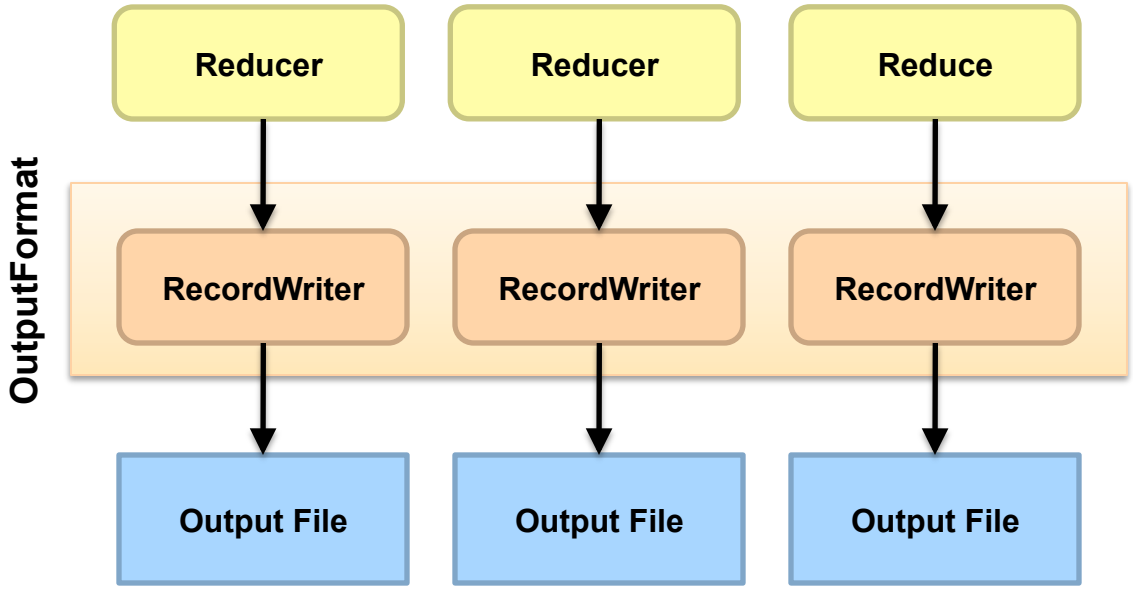

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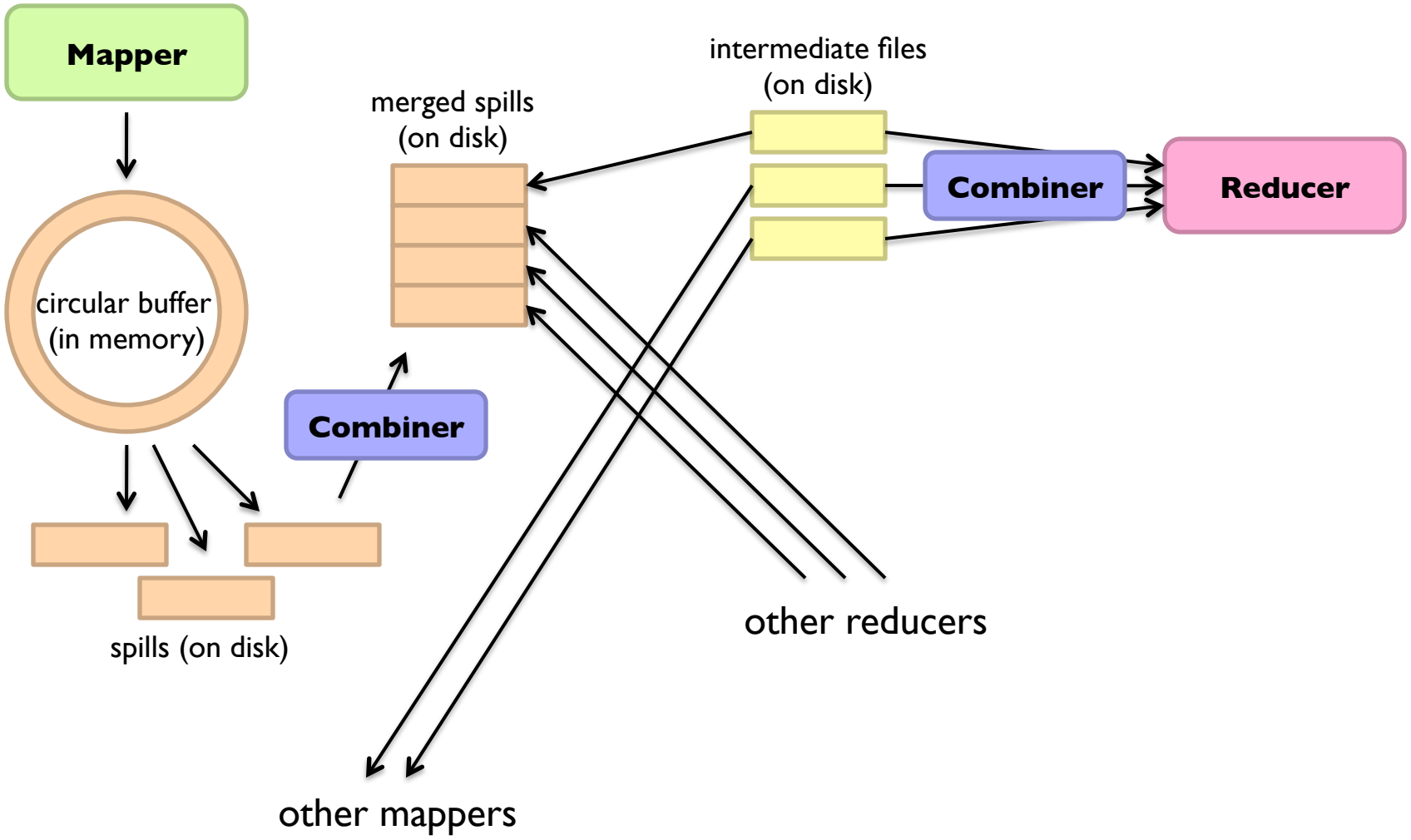
Input and Output

- InputFormat:
  - TextInputFormat
  - KeyValueTextInputFormat
  - SequenceFileInputFormat
  - …
- OutputFormat:
  - TextOutputFormat
  - SequenceFileOutputFormat
  - …

Shuffle and Sort in MapReduce

- Probably the most complex aspect of MapReduce execution
- Map side
  - Map outputs are buffered in memory in a circular buffer
  - When buffer reaches threshold, contents are "spilled" to disk
  - Spills merged in a single, partitioned file (sorted within each partition): combiner runs during the merges
- Reduce side
  - First, map outputs are copied over to reducer machine
  - "Sort" is a multi-pass merge of map outputs (happens in memory and on disk): combiner runs during the merges
  - Final merge pass goes directly into reducer

Shuffle and Sort



Hadoop Workflow

You

Submit node
(workspace)

Hadoop Cluster

Getting data in?
Writing code?
Getting data out?

Debugging Hadoop

- First, take a deep breath
- Start small, start locally
- Build incrementally

Source: Wikipedia (The Scream)

Code Execution Environments

- Different ways to run code:
  - Local (standalone) mode
  - Pseudo-distributed mode
  - Fully-distributed mode
- Learn what's good for what

Hadoop Debugging Strategies

- Good ol' System.out.println
  - Learn to use the webapp to access logs
  - Logging preferred over System.out.println
  - Be careful how much you log!
- Fail on success
  - Throw RuntimeExceptions and capture state
- Programming is still programming
  - Use Hadoop as the "glue"
  - Implement core functionality outside mappers and reducers
  - Independently test (e.g., unit testing)
  - Compose (tested) components in mappers and reducers

Source: Wikipedia (Japanese rock garden)