UNIVERSITY OF WATERLOO

Big Data Infrastructure

CS 489/698 Big Data Infrastructure (Winter 2016)

Week 1: Introduction (1/2)

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

Questions, questions, questions…

Who am I?
What is big data?
Why big data?
What is this course about?

Source: Wikipedia (All Souls College, Oxford)

... to building sh*t that works

Source: Wikipedia (Factory)

Source: Wikipedia (All Souls College, Oxford)

Source: Wikipedia (Hard disk drive)

Google™

Processes 20 PB a day (2008)
Crawls 20B web pages a day (2012)
Search index is 100+ PB (5/2014)
Bigtable serves 2+ EB, 600M QPS (5/2014)

INTERNET ARCHIVE

400B pages, 10+ PB (2/2014)

YAHOO!®

19 Hadoop clusters: 600 PB, 40k servers (9/2015)

JPMorganChase

150 PB on 50k+ servers running 15k apps (6/2011)

ebay®

Hadoop: 10K nodes, 150K cores, 150 PB (4/2014)

300 PB data in Hive + 600 TB/day (4/2014)

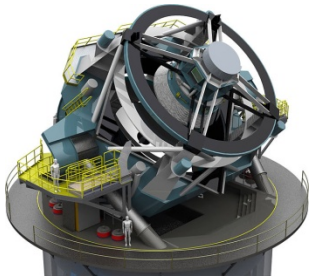
facebook

amazon web services™

S3: 2T objects, 1.1M request/ second (4/2013)

LHC: ~15 PB a year

CERN



LSST: 6-10 PB a year (~2020)

SKA: 0.3 – 1.5 EB per year (~2020)

How much data?

Why big data?

Science
Engineering
Commerce
Society

Source: Wikipedia (Everest)

Science

Emergence of the 4th Paradigm

Data-intensive e-Science

Maximilien Brice, © CERN

Engineering

The unreasonable effectiveness of data

Search, recommendation, prediction, …

Source: Wikipedia (Three Gorges Dam)

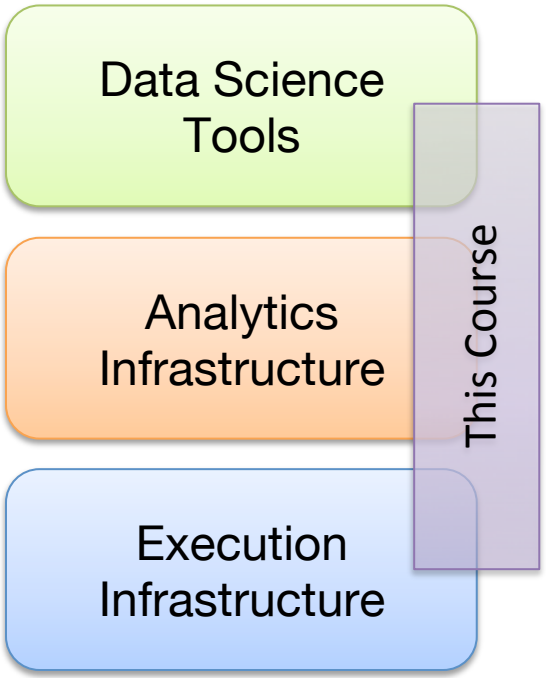

Know thy customers
Data → Insights → Competitive advantages
Commerce
EPSON
PEARL BAR
Source: Wikiedia (Shinjuku, Tokyo)

Society

- Humans as social sensors
- Computational social science

Source: Guardian

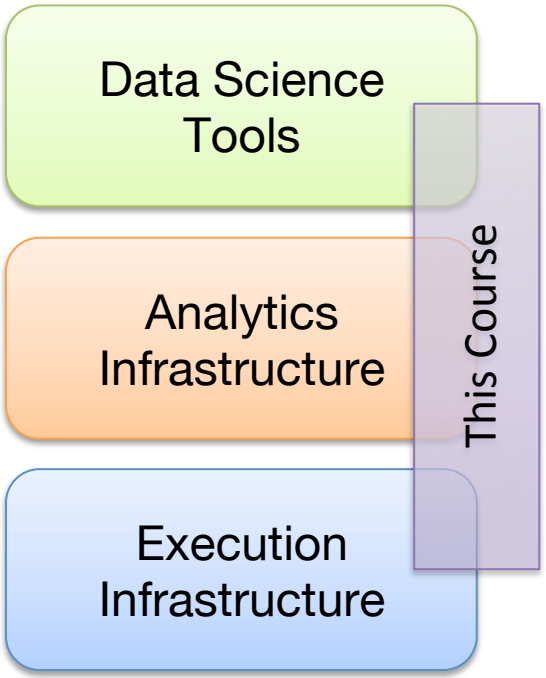
What is this course about?



"big data stack"

Buzzwords

data analytics, business intelligence, OLAP, ETL, data warehouses and data lakes



MapReduce, Spark, noSQL, Flink, Pig, Hive, Dryad, Pregel, Giraph, Storm

"big data stack"

Text: frequency estimation, language models, inverted indexes

Graphs: graph traversals, random walks (PageRank)

Relational data: SQL, joins, column stores

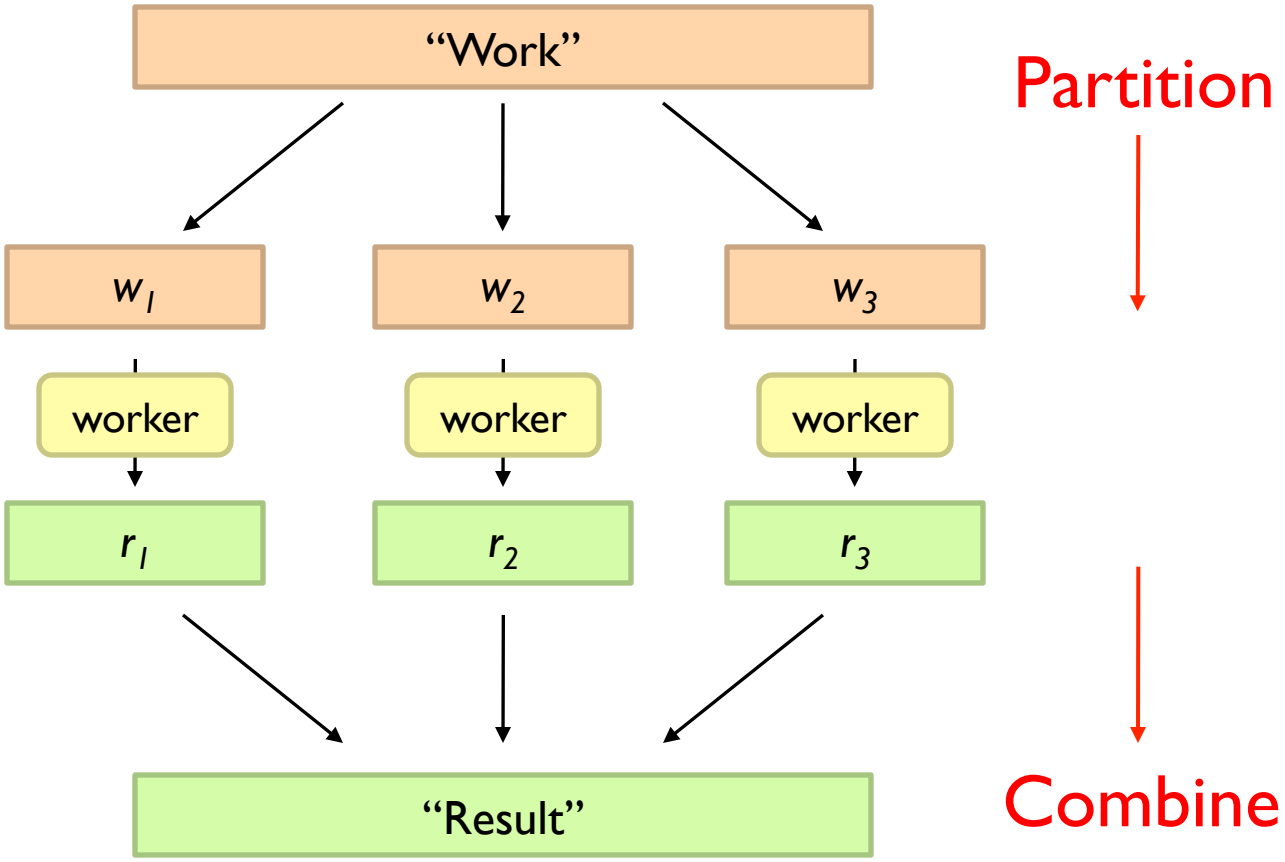
Data mining: hashing, clustering (*k*-means), classification, recommendations

Streams: probabilistic data structures (Bloom filters, CMS, HLL counters)

This course focuses on algorithm design and "thinking at scale"

Source: Google

Divide and Conquer



Parallelization Challenges

- How do we assign work units to workers?
- What if we have more work units than workers?
- What if workers need to share partial results?
- How do we aggregate partial results?
- How do we know all the workers have finished?
- What if workers die?

What's the common theme of all of these problems?

Common Theme?

- Parallelization problems arise from:
  - Communication between workers (e.g., to exchange state)
  - Access to shared resources (e.g., data)
- Thus, we need a synchronization mechanism

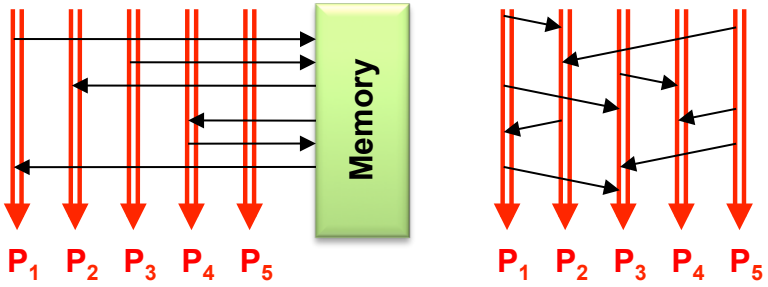
Source: Ricardo Guimarães Herrmann

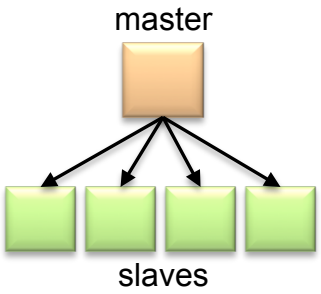
Managing Multiple Workers

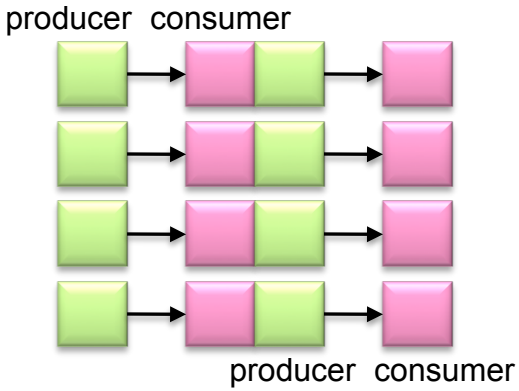
- Difficult because
  - We don't know the order in which workers run
  - We don't know when workers interrupt each other
  - We don't know when workers need to communicate partial results
  - We don't know the order in which workers access shared data
- Thus, we need:
  - Semaphores (lock, unlock)
  - Conditional variables (wait, notify, broadcast)
  - Barriers
- Still, lots of problems:
  - Deadlock, livelock, race conditions...
  - Dining philosophers, sleeping barbers, cigarette smokers...
- Moral of the story: be careful!

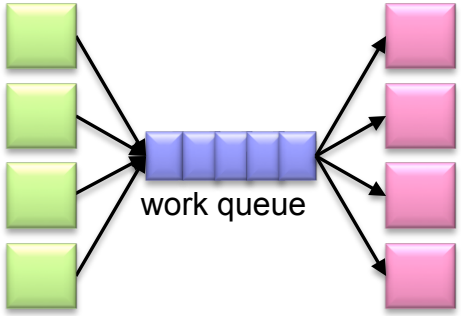
Current Tools

- Programming models
  - Shared memory (pthreads)
  - Message passing (MPI)
- Design Patterns
  - Master-slaves
  - Producer-consumer flows
  - Shared work queues





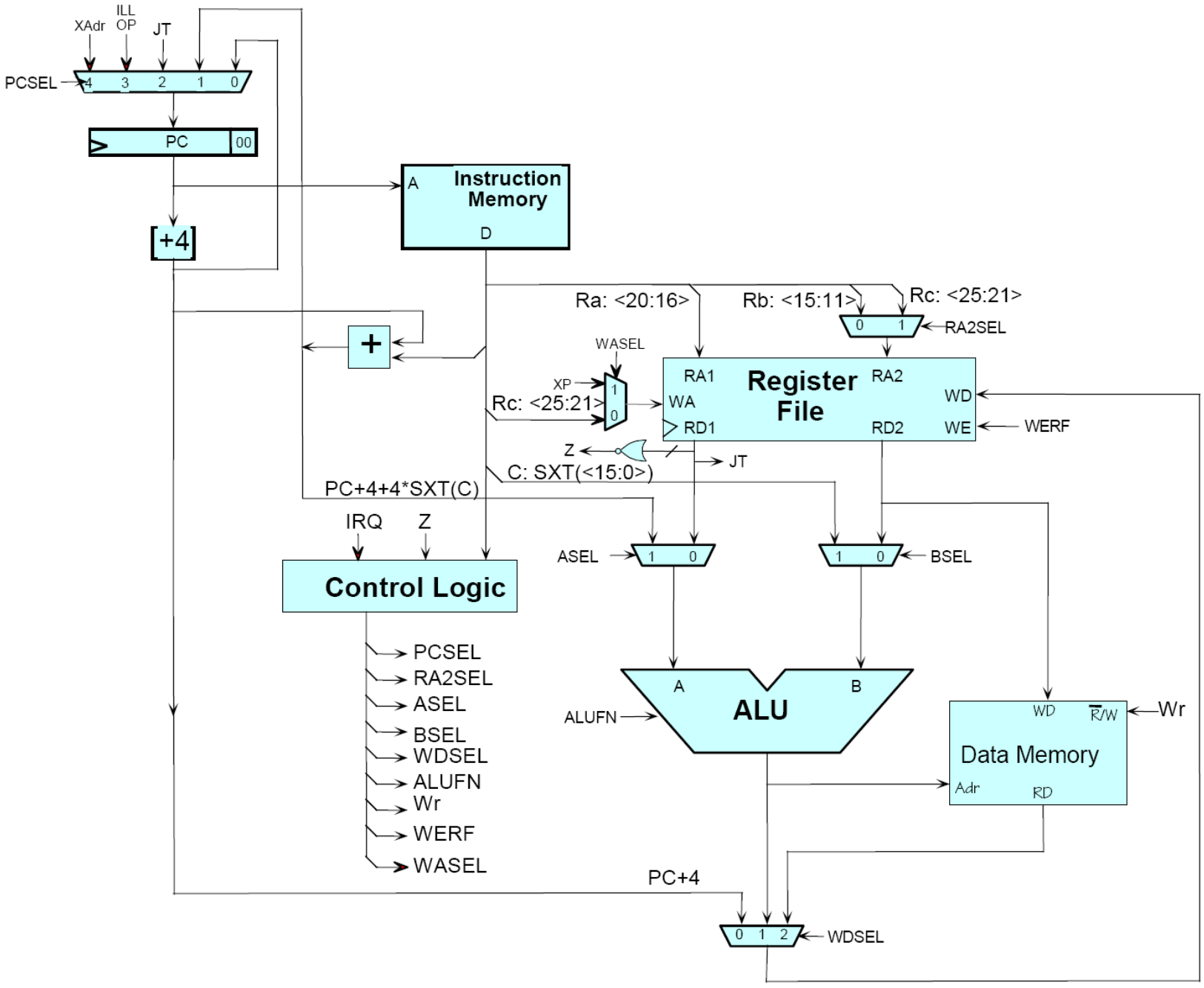




Where the rubber meets the road

- Concurrency is difficult to reason about
- Concurrency is even more difficult to reason about
  - At the scale of datacenters and across datacenters
  - In the presence of failures
  - In terms of multiple interacting services
- Not to mention debugging…
- The reality:
  - Lots of one-off solutions, custom code
  - Write you own dedicated library, then program with it
  - Burden on the programmer to explicitly manage everything

Source: Wikipedia (Flat Tire)



Source: MIT Open Courseware

Source: MIT Open Courseware

Source: Google

The datacenter *is* the computer

- It's all about the right level of abstraction
  - Moving beyond the von Neumann architecture
  - What's the "instruction set" of the datacenter computer?
- Hide system-level details from the developers
  - No more race conditions, lock contention, etc.
  - No need to explicitly worry about reliability, fault tolerance, etc.
- Separating the *what* from the *how*
  - Developer specifies the computation that needs to be performed
  - Execution framework ("runtime") handles actual execution

MapReduce is the first instantiation of this idea…

Source: Google

Typical Big Data Problem

- Iterate over a large number of records
- Extract something of interest from each — Map
- Shuffle and sort intermediate results
- Aggregate intermediate results — Reduce
- Generate final output

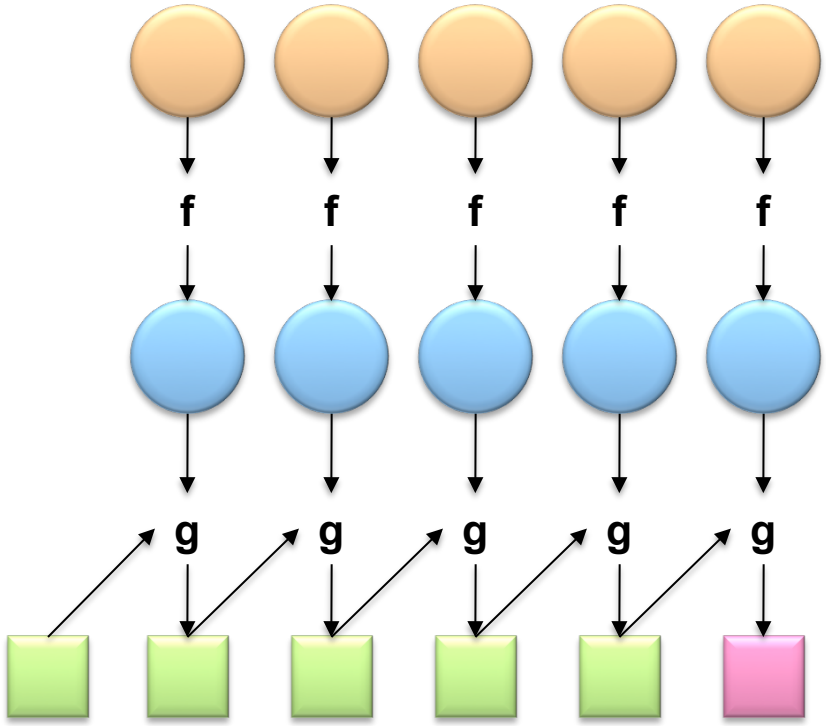
Key idea: provide a functional abstraction for these two operations

(Dean and Ghemawat, OSDI 2004)

Roots in Functional Programming

Map

Fold




```
scala> val t = Array(1, 2, 3, 4, 5)
t: Array[Int] = Array(1, 2, 3, 4, 5)

scala> t.map(n => n*n)
res0: Array[Int] = Array(1, 4, 9, 16, 25)

scala> t.map(n => n*n).foldLeft(0)((m, n) => m + n)
res1: Int = 55
```

Functional programming + distributed computing!

MapReduce

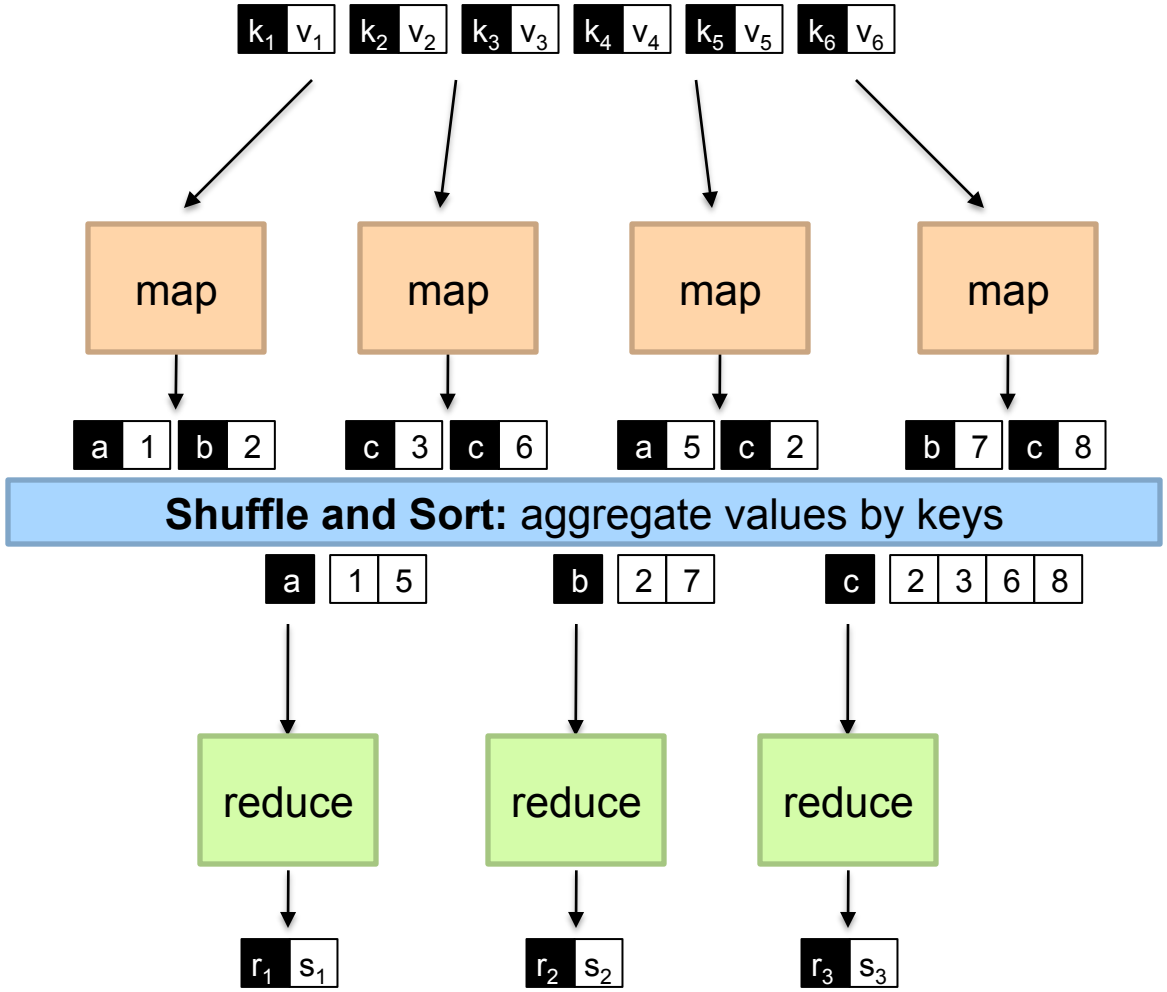
- Programmers specify two functions:

  map $(k_1, v_1) \rightarrow [<k_2, v_2>]$

  reduce $(k_2, [v_2]) \rightarrow [<k_3, v_3>]$

  - All values with the same key are sent to the same reducer

- The execution framework handles everything else…


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
Shuffle and Sort: aggregate values by keys
a 1 5
b 2 7
c 2 3 6 8
reduce
reduce
reduce
r1 s1
r2 s2
r3 s3

MapReduce

- Programmers specify two functions:

  map (k, v) → <k', v'>*

  reduce (k', v') → <k', v'>*

  - All values with the same key are sent to the same reducer
- The execution framework handles everything else…

What's "everything else"?

MapReduce "Runtime"

- Handles scheduling
  - Assigns workers to map and reduce tasks
- Handles "data distribution"
  - Moves processes to data
- Handles synchronization
  - Gathers, sorts, and shuffles intermediate data
- Handles errors and faults
  - Detects worker failures and restarts
- Everything happens on top of a distributed FS (later)

MapReduce

- Programmers specify two functions:

  map (k, v) → <k', v'>*

  reduce (k', v') → <k', v'>*

  - All values with the same key are reduced together

- The execution framework handles everything else…

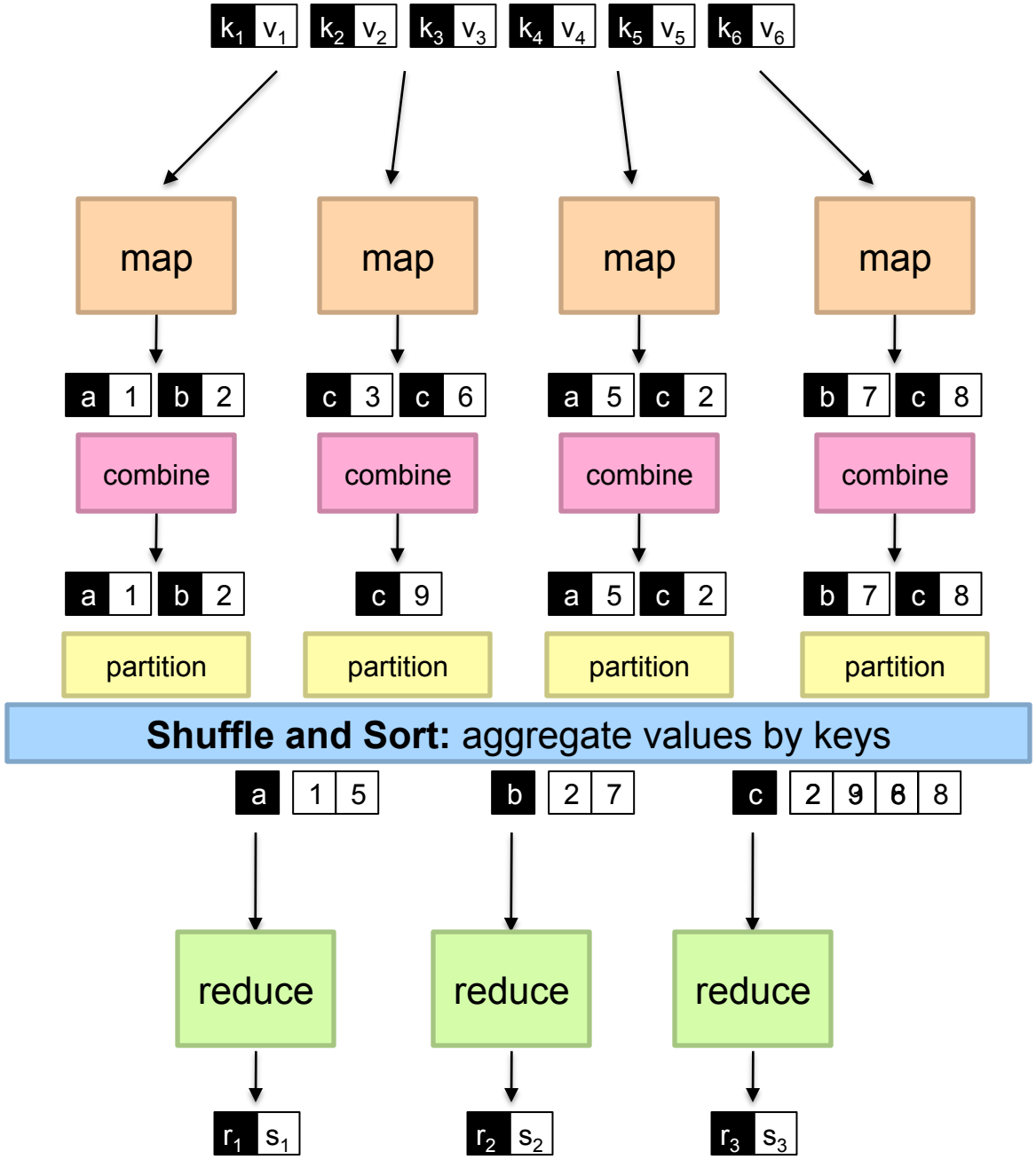
- Not quite…usually, programmers also specify:

  partition (k', number of partitions) → partition for k'

  - Often a simple hash of the key, e.g., hash(k') mod n
  - Divides up key space for parallel reduce operations

  combine (k', v') → <k', v'>*

  - Mini-reducers that run in memory after the map phase
  - Used as an optimization to reduce network traffic


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

Two more details…

- Barrier between map and reduce phases
  - But we can begin copying intermediate data earlier
- Keys arrive at each reducer in sorted order
  - No enforced ordering *across* reducers

“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);
```

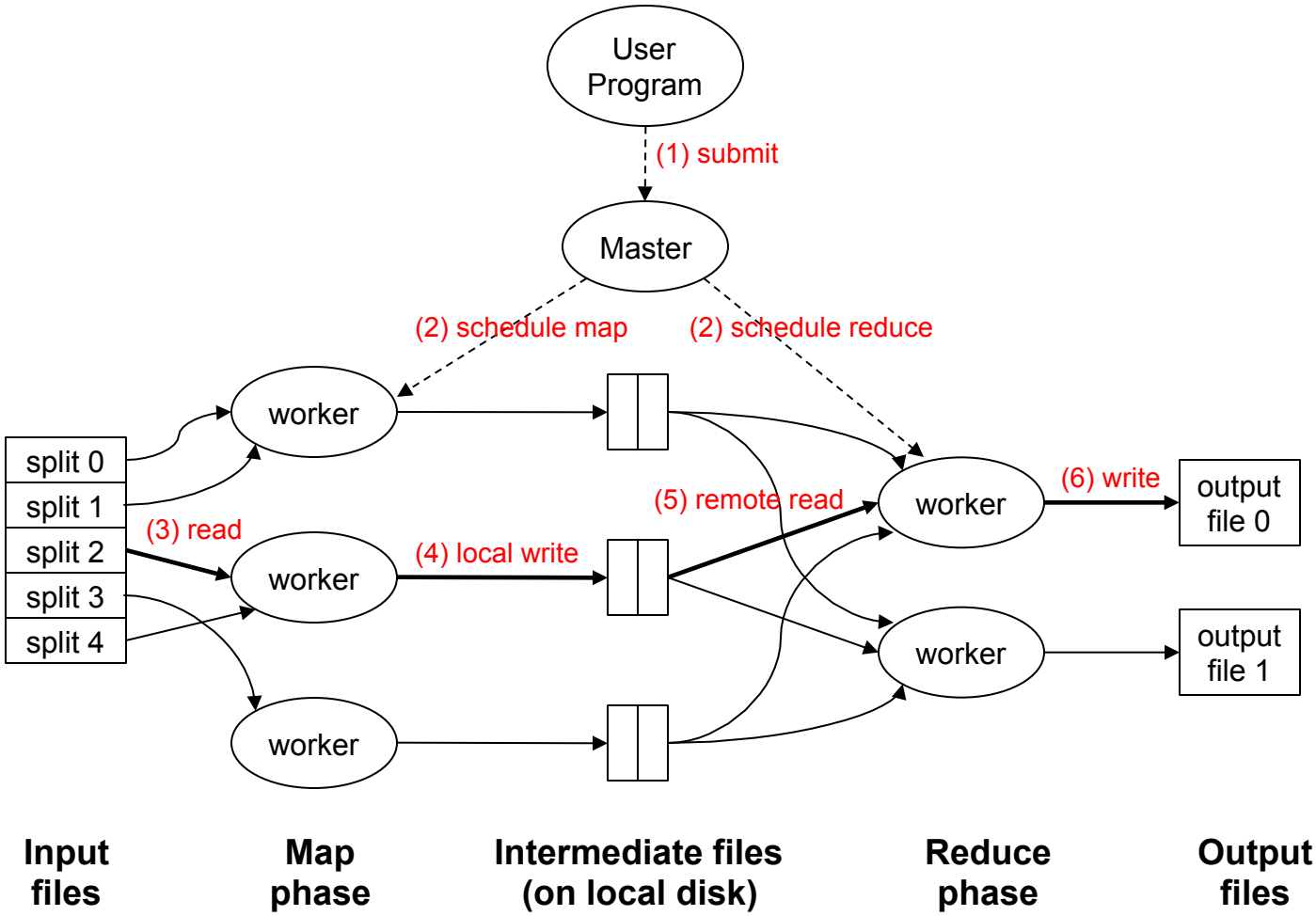
MapReduce can refer to…

- The programming model
- The execution framework (aka “runtime”)
- The specific implementation

Usage is usually clear from context!

MapReduce Implementations

- Google has a proprietary implementation in C++
  - Bindings in Java, Python
- Hadoop provides an open-source implementation in Java
  - Development led by Yahoo, now an Apache project
  - Used in production at Yahoo, Facebook, Twitter, LinkedIn, Netflix, …
  - Large and expanding software ecosystem
  - Potential point of confusion: Hadoop is more than MapReduce today
- Lots of custom research implementations



We'll discuss physical execution in detail later…

Adapted from (Dean and Ghemawat, OSDI 2004)

Course Administrivia

Source: http://www.flickr.com/photos/artmind_etcetera/6336693594/

My Expectations

- Your background:
  - Pre-reqs: CS 341, CS 350, (CS 348)
  - Comfortable in Java and Scala
  - Know how to use Git
  - Reasonable "command-line"-fu skills
  - Experience in compiling, patching, and installing open source software
  - Good debugging skills
- You are:
  - Genuinely interested in the topic
  - Be prepared to put in the time
  - Comfortable with the uncertainty and unpredictability that comes with cutting-edge, immature software

Course Design

- Course website: https://www.student.cs.uwaterloo.ca/~cs489/
  Redirects to: http://lintool.github.io/bigdata-2016w/
- Piazza: https://piazza.com/uwaterloo.ca/winter2016/cs489698/
- Bespin: http://bespin.io/
- This course focuses on algorithm design and "thinking at scale"
  - Not the "mechanics" (API, command-line invocations, et.)
  - You're expected to pick up MapReduce/Spark with minimal help
- Components of the final grade:
  - Eight individual assignments: mix of MapReduce (Java) and Spark (Scala)
  - Final exam
  - CS 698: additional final project

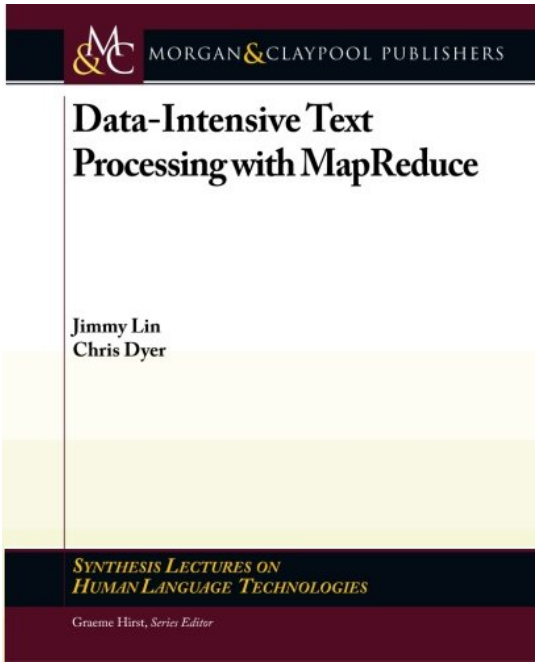
Assignment Mechanics

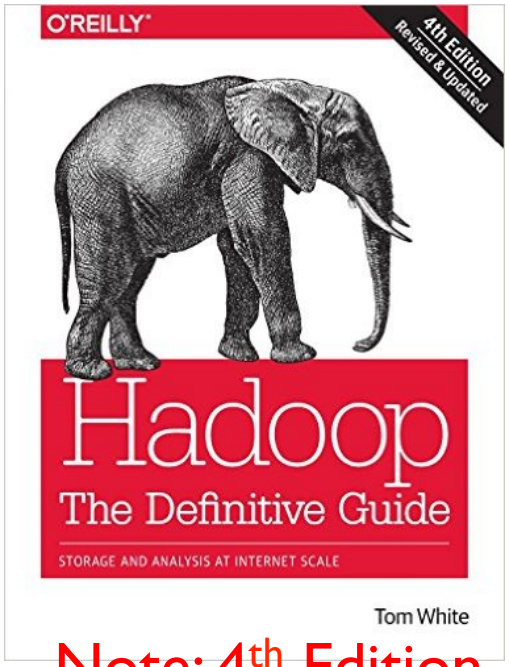
- We'll be using private GitHub repos for assignments
  - Complete your assignments, push to GitHub
  - We'll pull your repos at the deadline and grade
- Note late policy (details on course homepage)
  - Late by up to 24 hours: 25% reduction in grade
  - Late 24-48 hours: 50% reduction in grade
  - Late by more the 48 hours: not accepted
  - By assumption, we'll pull and grade at deadline – if you want us to hold off, you must let us know

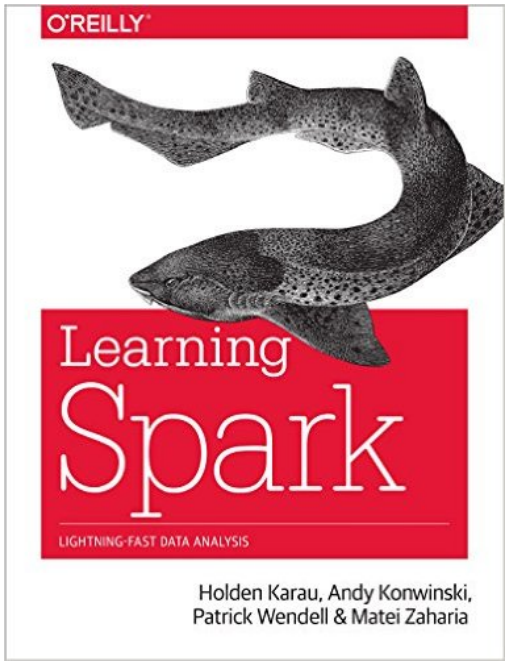
Important: Register for (free) GitHub educational account!
https://education.github.com/discount_requests/new

Course Materials

One (required) textbook +
Two (optional but recommended) books +
Additional readings from research papers as appropriate







Note: 4th Edition

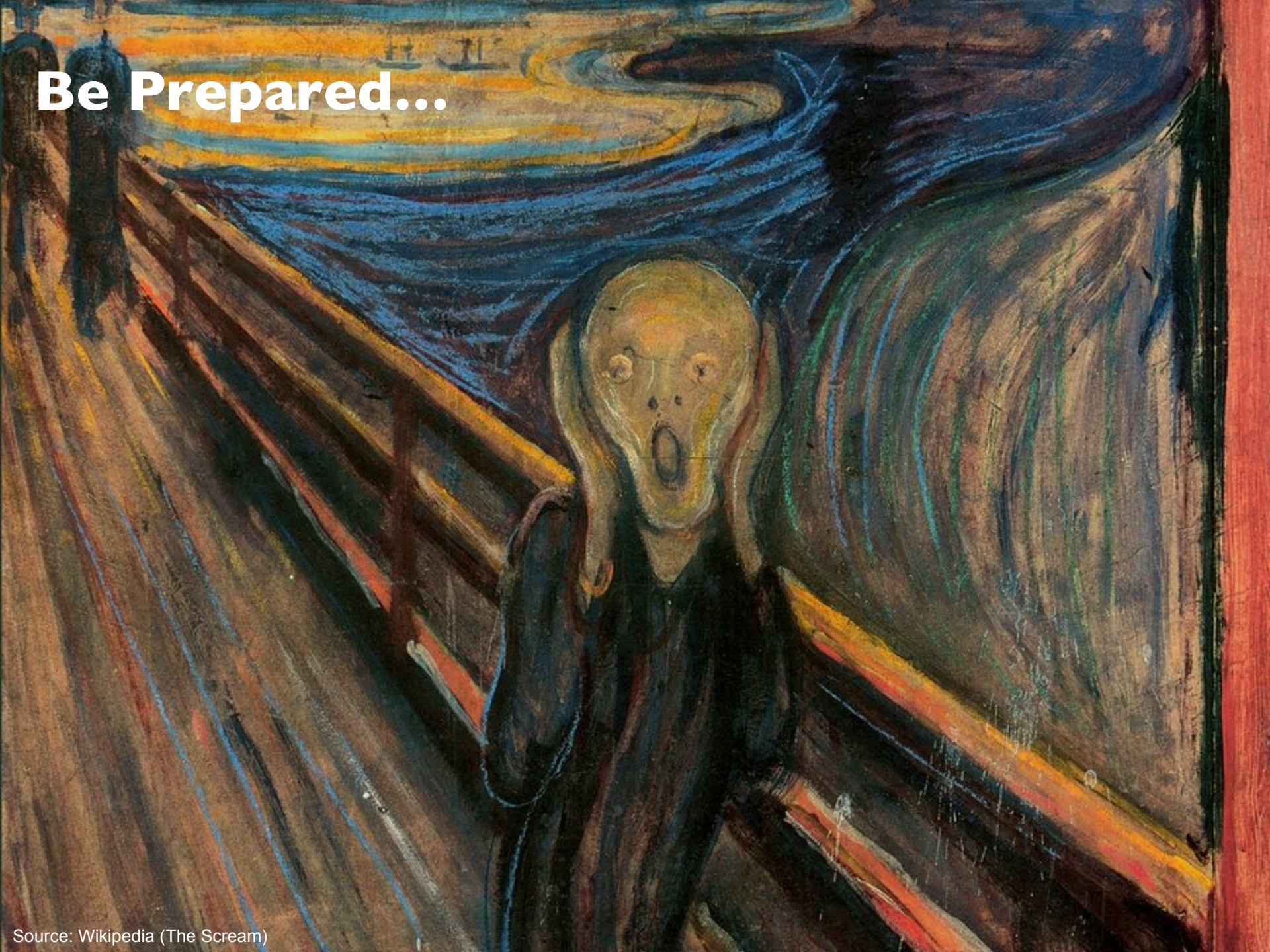
(optional but recommended)

MapReduce/Spark Environments

- Linux Student CS Environment
  - Everything is set up for you, just follow instructions
  - We'll make sure everything works
- Local installations
  - Install all software components on your own machine
  - Requires at least 4GB RAM + 10s GB disk for a good experience
  - Works fine on Mac and Linux, YMMV on Windows
  - We'll provide basic instructions, but not technical support
- Altiscale: Hadoop-as-a-Service
  - You'll be provided an account later

See "Software" page in course homepage for details:
http://lintool.github.io/bigdata-2016w/software.html

Be Prepared...



Source: Wikipedia (The Scream)

“Hadoop Zen”

- Parts of the ecosystem are still immature
  - We’ve come a long way since 2007, but still far to go…
  - Bugs, undocumented “features”, inexplicable behavior, etc.
  - Different versions = major pain
- Don’t get frustrated (take a deep breath)…
  - Those W$*#T@F! moments
- Be patient…
  - We will inevitably encounter “situations” along the way
- Be flexible…
  - We will have to be creative in workarounds
- Be constructive…
  - Tell me how I can make everyone’s experience better

“Hadoop Zen”

Source: Wikipedia (Japanese rock garden)

Source: Wikipedia (Japanese rock garden)