UNIVERSITY OF WATERLOO

Big Data Infrastructure

CS 489/698 Big Data Infrastructure (Winter 2017)

Week 1: Introduction (1/2)

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These slides are available at http://lintool.github.io/bigdata-2017w/

Questions for Today

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)

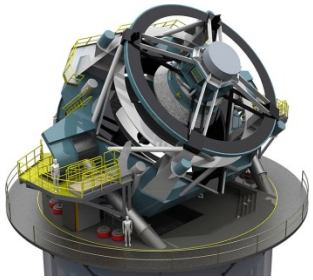
300 PB data in Hive + 600 TB/day (4/2014)

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)

Commerce

Know thy customers

Data → Insights → Profit!

Source: Wikiedia (Shinjuku, Tokyo)

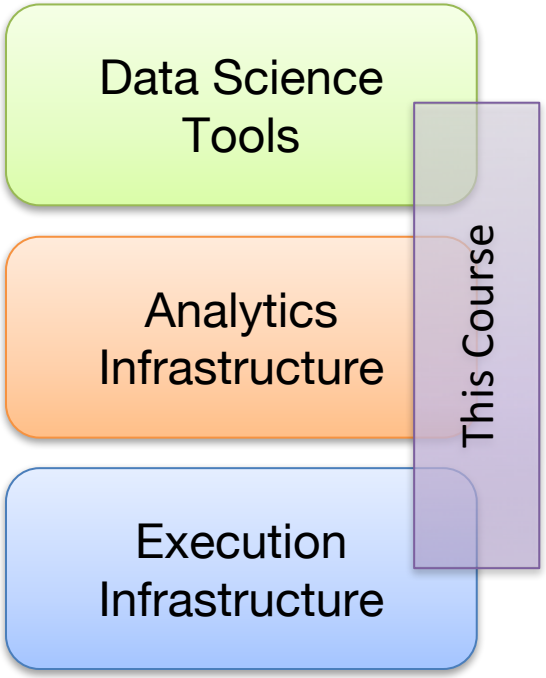
Society

Humans as social sensors

Computational social science

Source: Guardian

What is this course about?

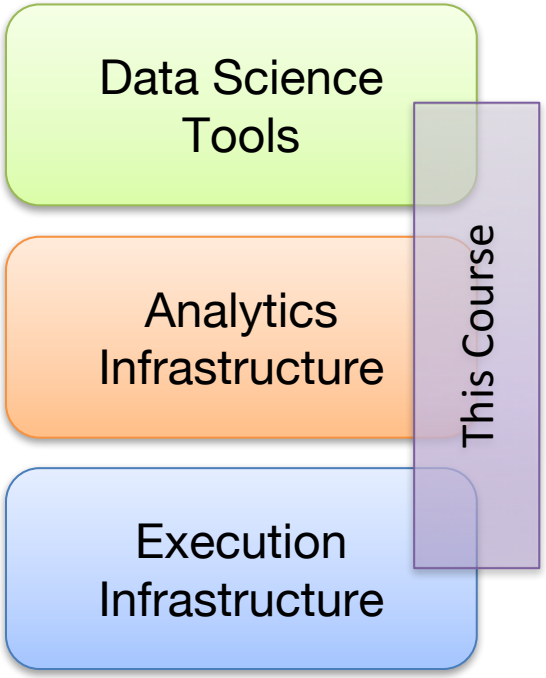


"big data stack"

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

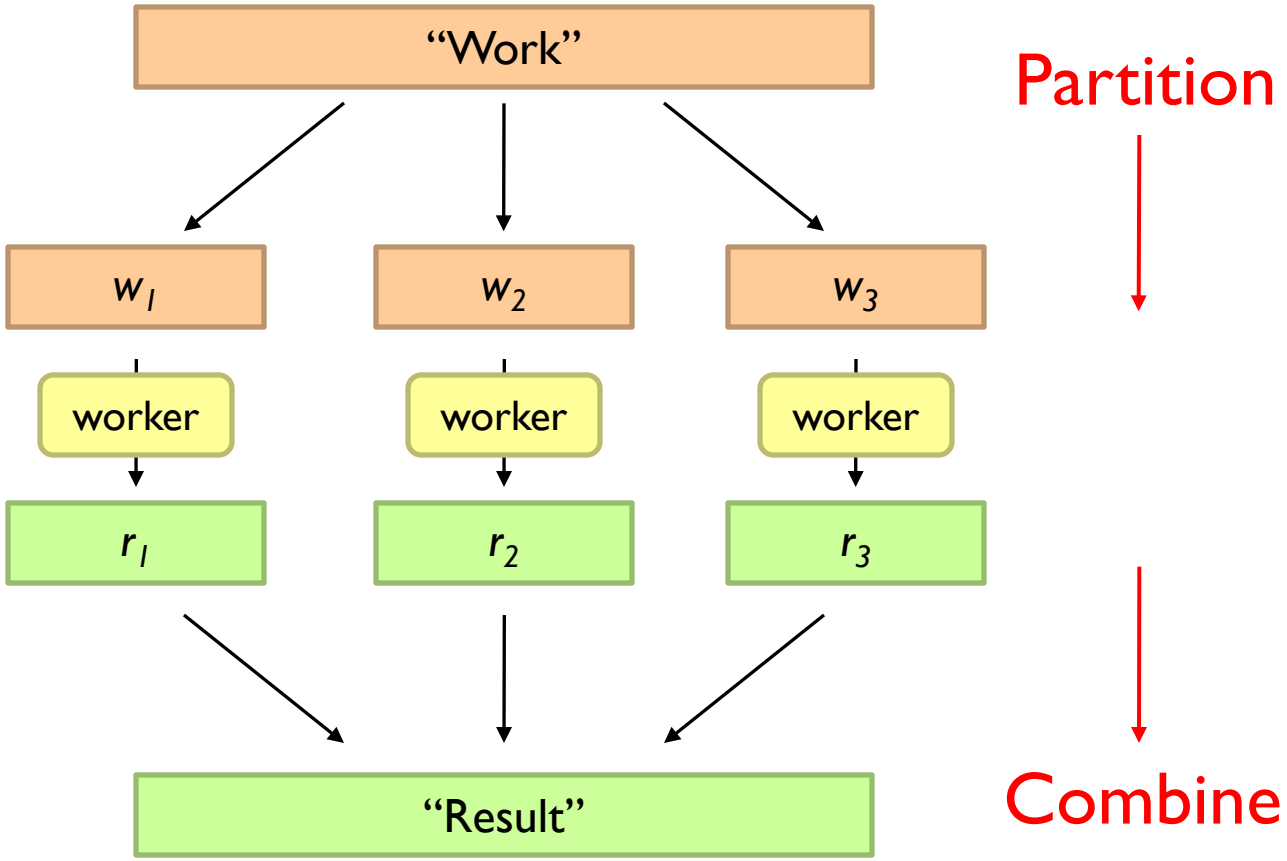
Data mining: hashing, clustering (*k*-means), classification, recommendations

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 when all the workers have finished?
What if workers die?

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 resources…

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)

How do we tackle these challenges?

Current Tools

Basic primitives

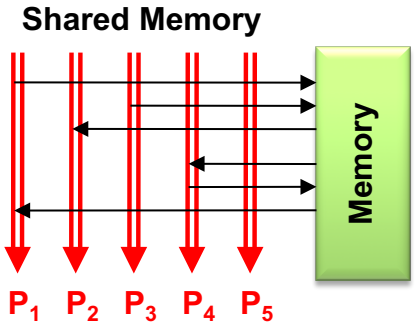
Semaphores (lock, unlock)
Conditional variables (wait, notify, broadcast)
Barriers

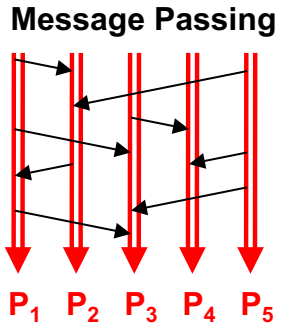
Awareness of Common Problems

Deadlock, livelock, race conditions...
Dining philosophers, sleeping barbers, cigarette smokers...

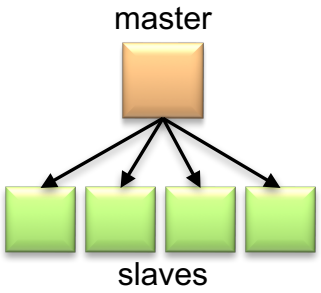
Current Tools

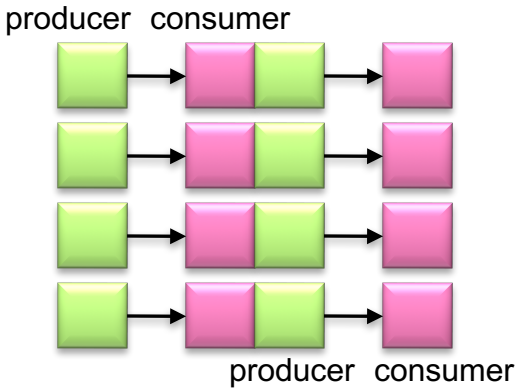
Programming Models

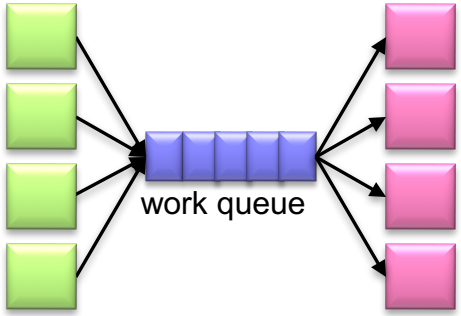




Design Patterns







When Theory Meets Practices

Concurrency is already difficult to reason about…

Now throw in:

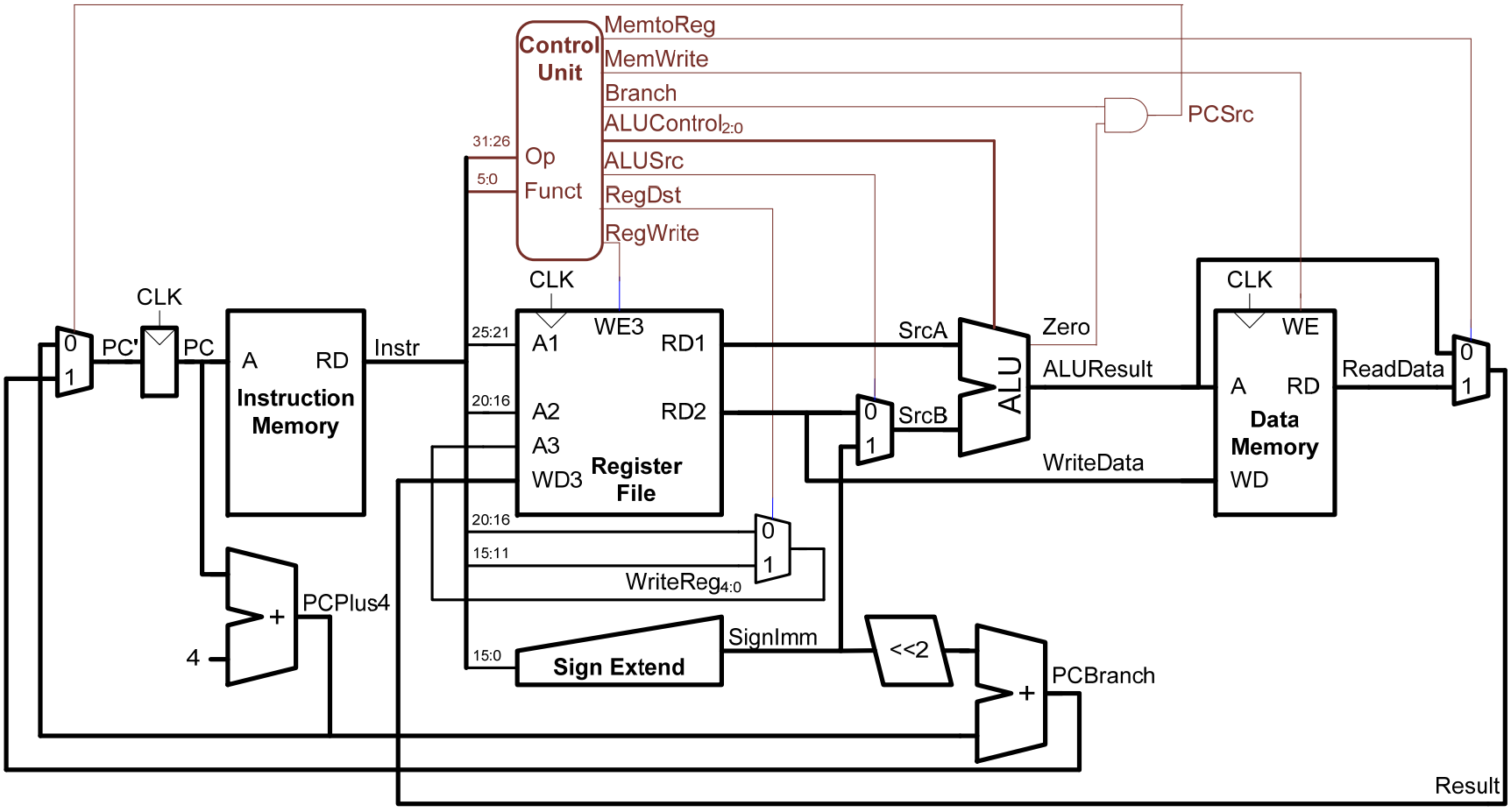
At the scale of datacenters and across datacenters
In the presence of failures
In the presence of multiple interacting services

The reality:

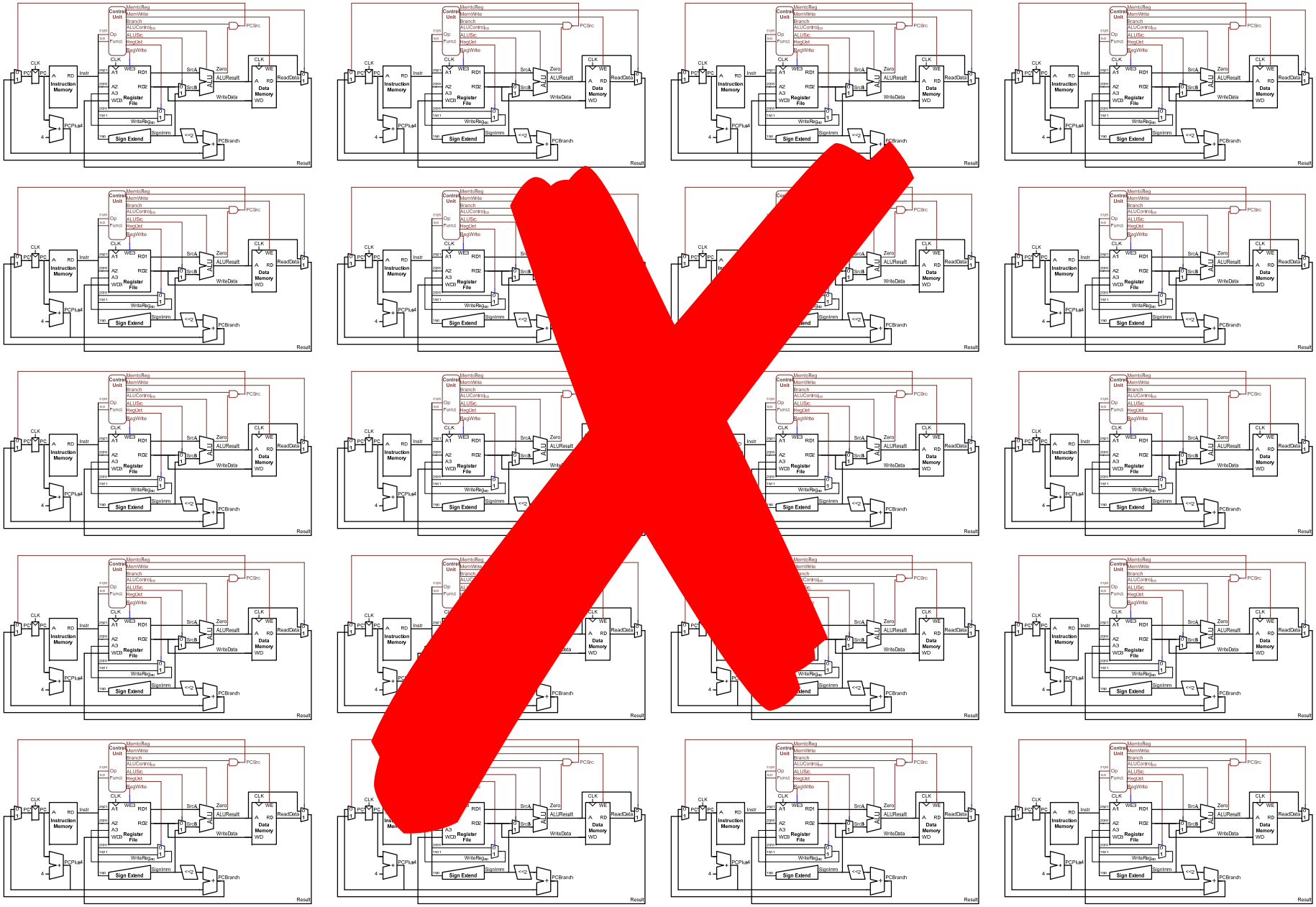
Lots of one-off solutions, custom code
Write you own dedicated library, then program with it
Burden on the programmer to explicitly manage everything

Bottom line: it's hard!

Source: Ricardo Guimarães Herrmann



Source: CS 251



Source: CS 251

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… but not the last!

Source: Google

Typical Big Data Problem

Iterate over a large number of records

Map Extract something of interest from each

Shuffle and sort intermediate results

Aggregate intermediate results Reduce

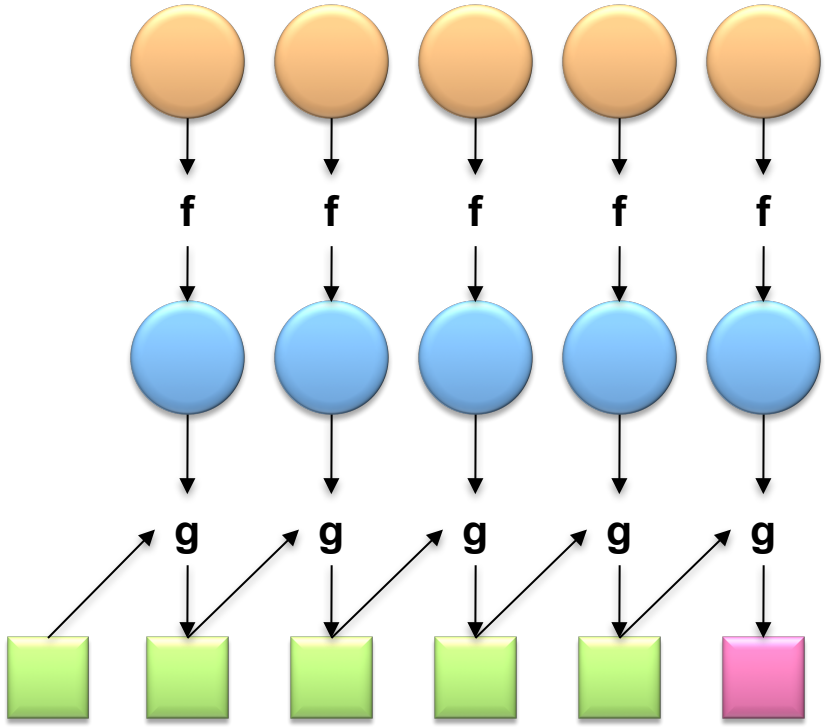
Generate final output

Key idea: provide a functional abstraction for these two operations

Roots in Functional Programming

Map

Fold



Functional Programming in Scala

```
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
```

MapReduce = Functional programming + distributed computing!

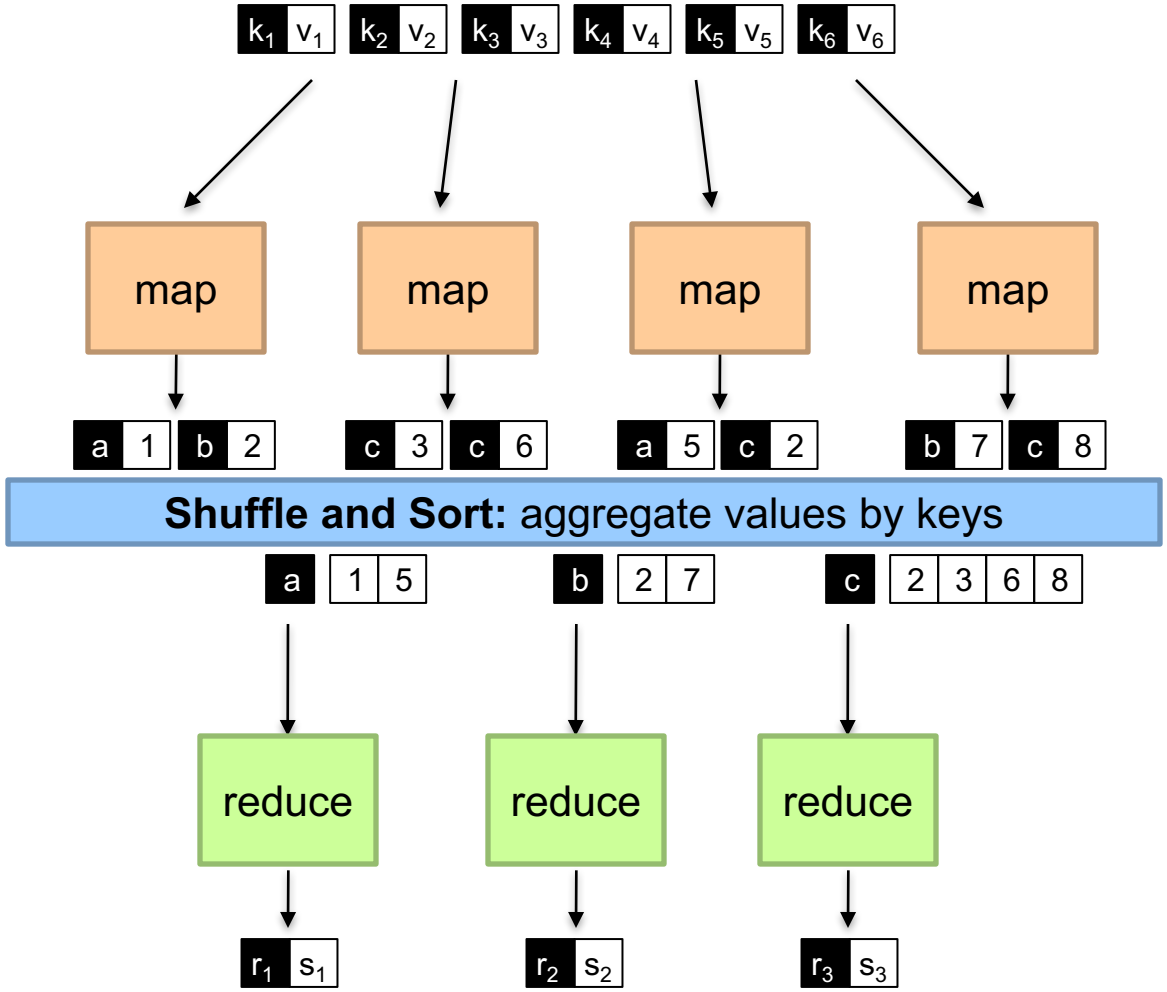
MapReduce

Programmer specifies two functions:

$$\texttt{map}\ (k_1, v_1) \rightarrow [\langle k_2, v_2 \rangle]$$
$$\texttt{reduce}\ (k_2, [v_2]) \rightarrow [\langle k_3, v_3 \rangle]$$

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

Programmer specifies two functions:

$$\texttt{map}\ (k_1, v_1) \rightarrow [\langle k_2, v_2 \rangle]$$
$$\texttt{reduce}\ (k_2, [v_2]) \rightarrow [\langle k_3, v_3 \rangle]$$

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

Programmer specifies two functions:

$$\texttt{map}\ (k_1, v_1) \rightarrow [\langle k_2, v_2 \rangle]$$
$$\texttt{reduce}\ (k_2, [v_2]) \rightarrow [\langle k_3, v_3 \rangle]$$

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

The execution framework handles everything else…

Not quite…

MapReduce

Programmer specifies four 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

`partition (k', p) → 0 ... p-1`

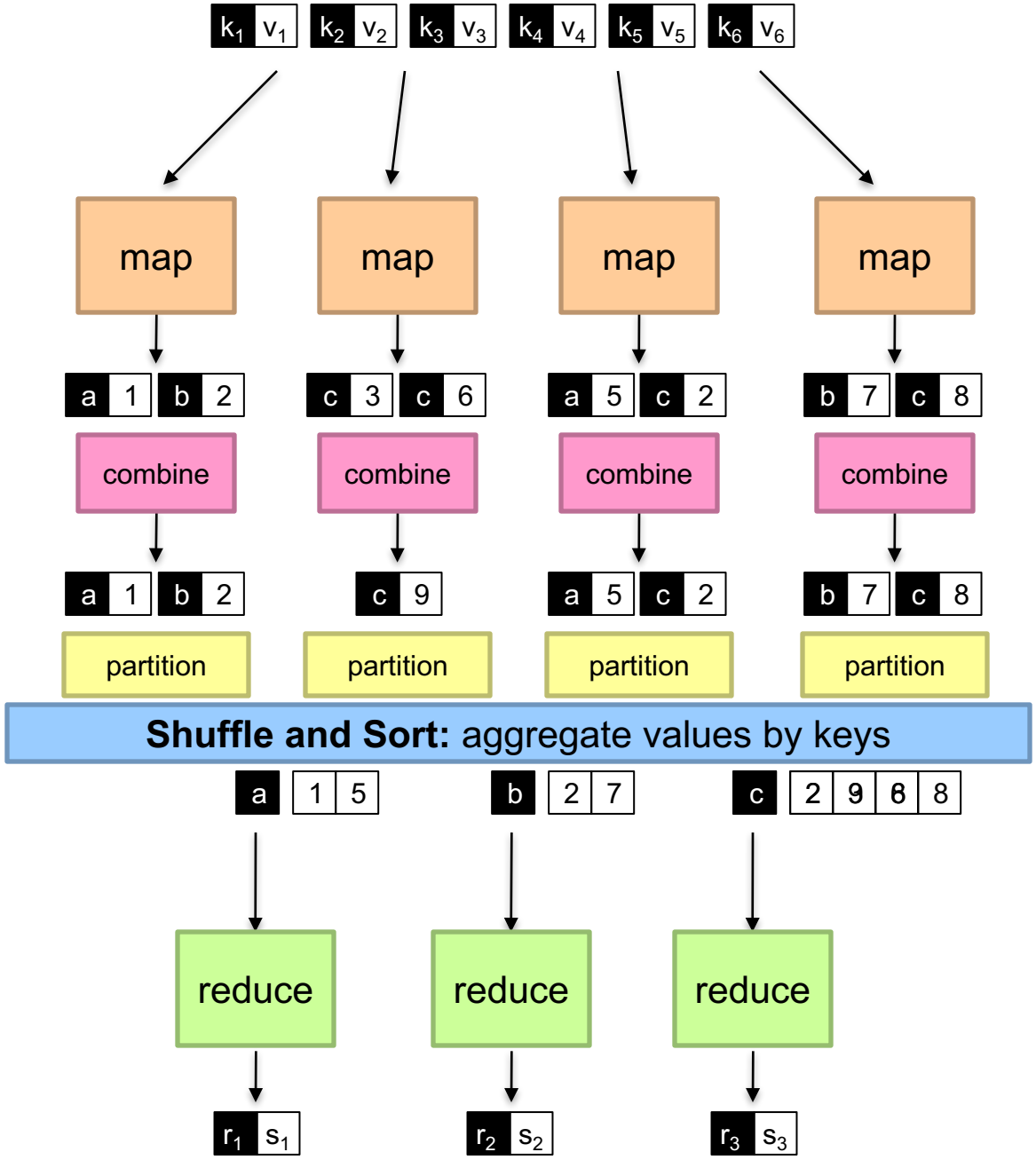
Often a simple hash of the key, e.g., `hash(k') mod n`

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 runtime can begin copying intermediate data earlier

Keys arrive at each reducer in sorted order

No enforced ordering across reducers

“Hello World” MapReduce: 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

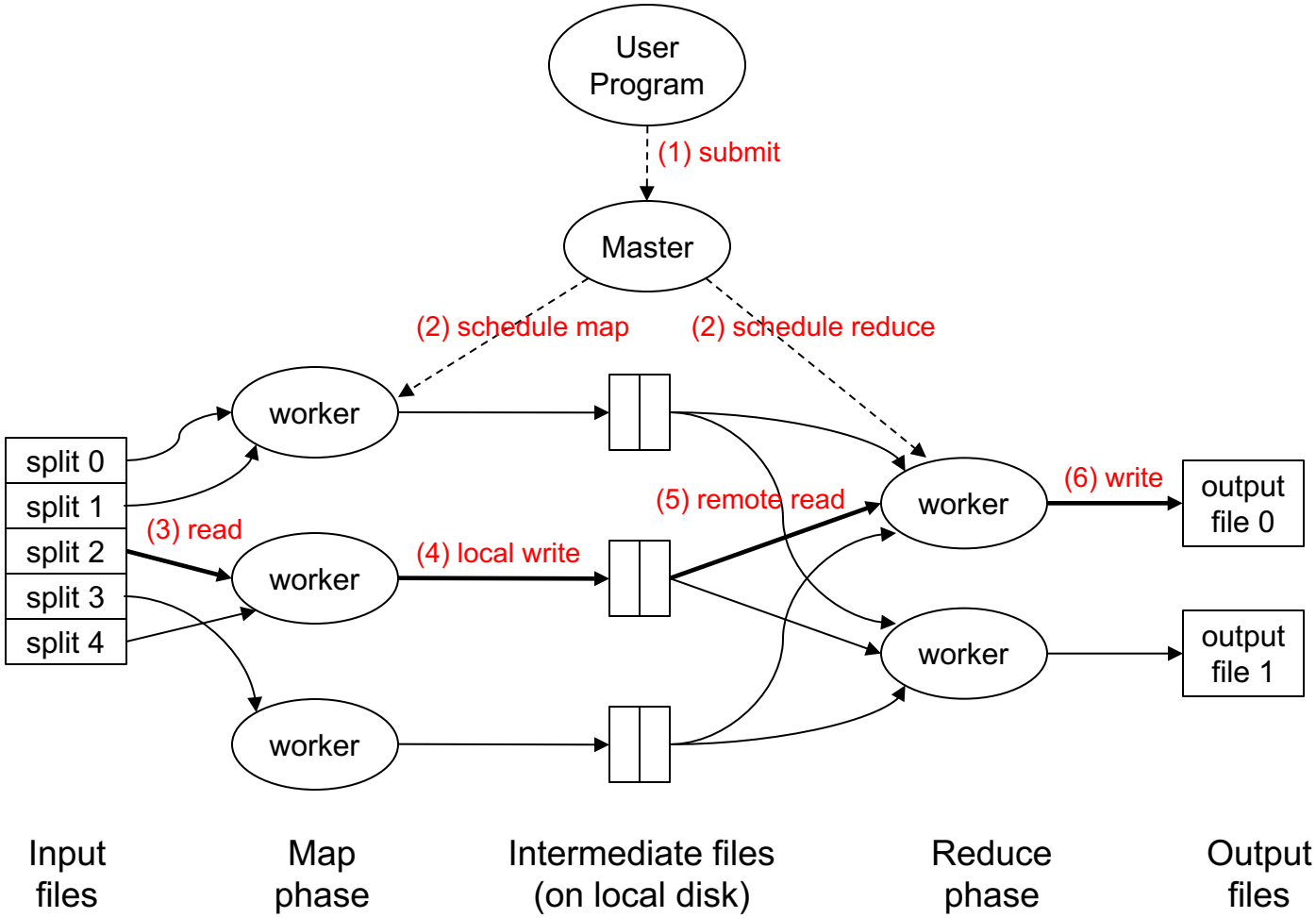
Google has a proprietary implementation in C++

Bindings in Java, Python

Hadoop provides an open-source implementation in Java

Development begun by Yahoo, later an Apache project
Used in production at 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

Your are:

Genuinely interested in the topic
Be prepared to put in the time
Comfortable with immature software

Important Coordinates

Course website:

http://lintool.github.io/bigdata-2016w/

Lots of info there, read it!

("I didn't see it" will not be accepted as an excuse.)

Communicating with us:

Piazza for general questions (link on course homepage)

Personal concerns: uwaterloo-bigdata-2017w-staff@googlegroups.com

(Mailing list reaches me and TAs)

Bespin

http://bespin.io/

Course Design

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

Final exam

CS 698: additional group final project

MapReduce/Spark Environments

See "Software" page in course homepage for instructions

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 and plenty of disk space

Works fine on Mac and Linux, YMMV on Windows

Important: For your convenience only!

We'll provide basic instructions, but not technical support

Altiscale: Hadoop-as-a-Service

You'll be provided an account – watch for the email

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)

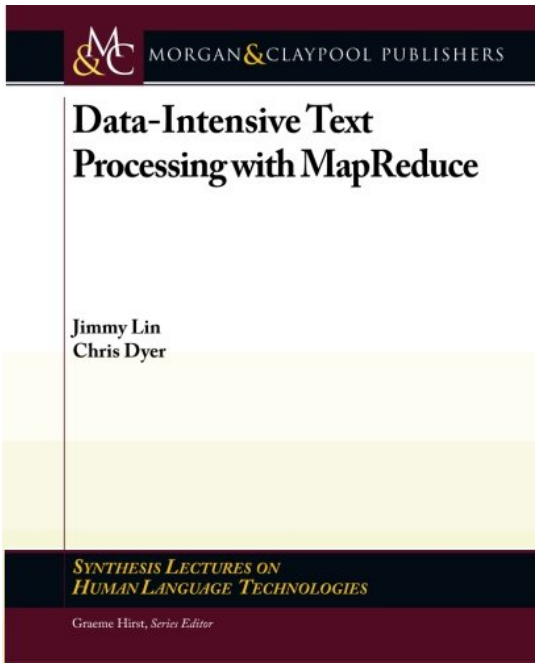
Late by up to 24 hours: 25% reduction in grade
Late 24-48 hours: 50% reduction in grade
Late by more the 48 hours: not accepted

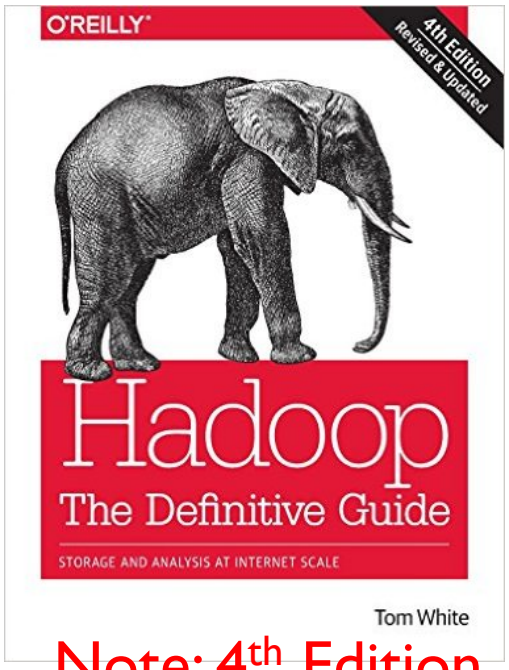
By assumption, we'll pull and mark at deadline:
If you want us to hold off, you must let us know!

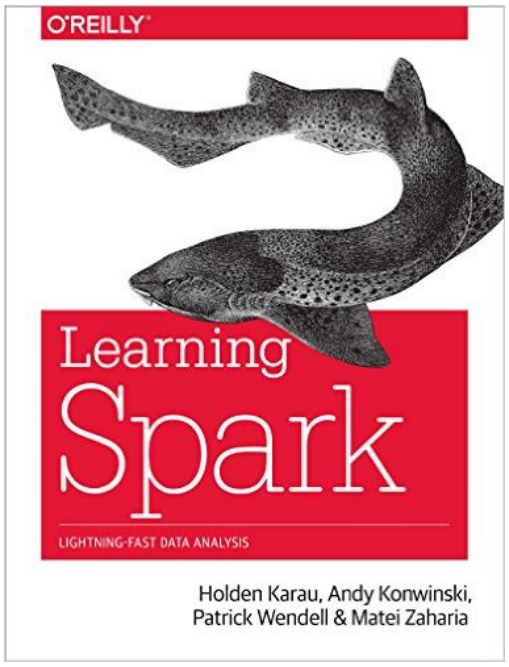
Important: Register for (free) GitHub educational account!
`https://education.github.com/discount_requests/new`

Course Materials

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







Note: 4th Edition

(optional but recommended)

If you're not (yet) registered…


If you’re not (yet) registered…
There’s (some) hope!

If you're not (yet) registered:

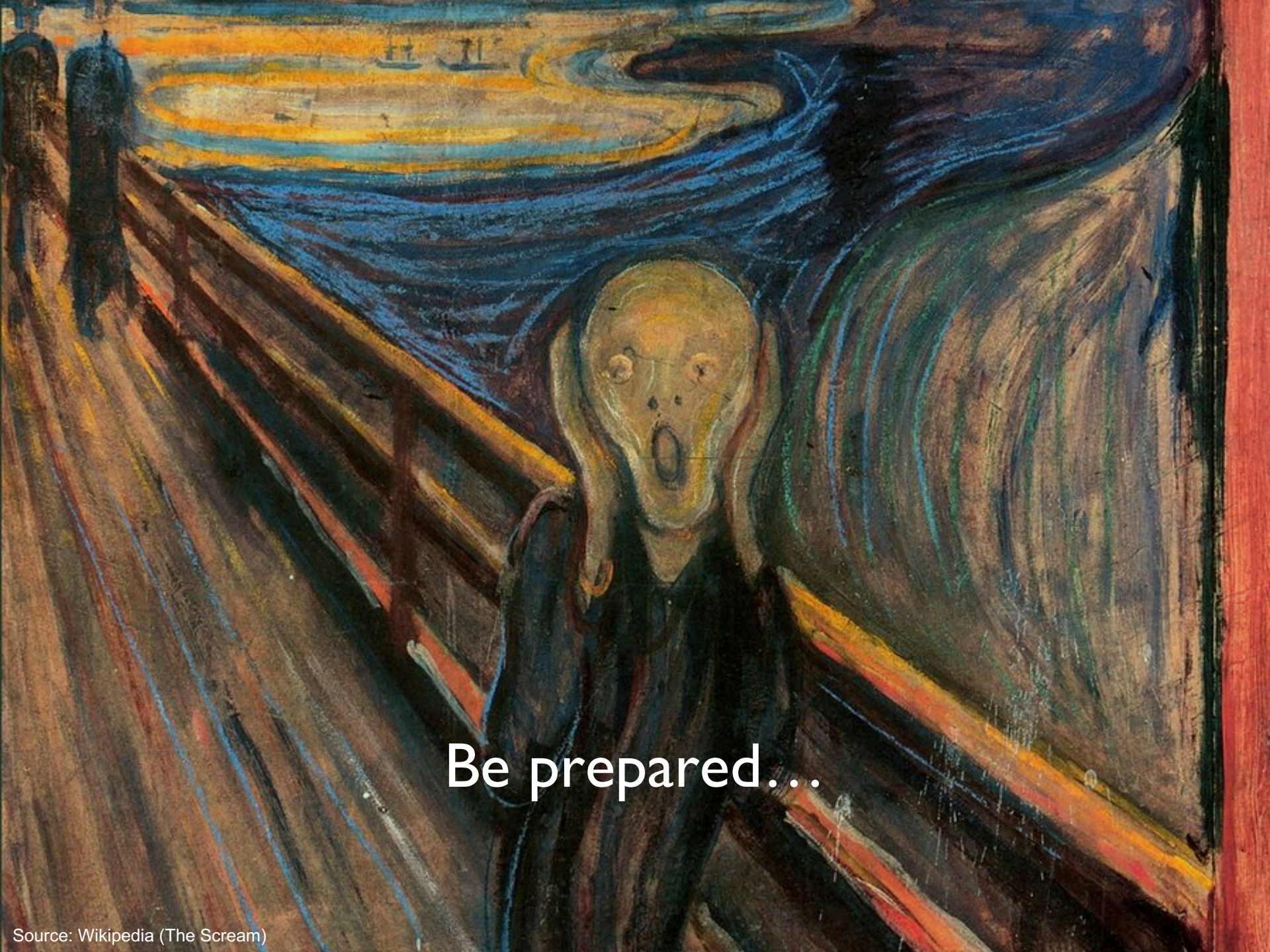
Come and find me after class for the wait list

Continue coming to class, sign in after every class

As spots open up, I'll give preference to those attending class

Note: late registration is not an excuse for late assignments

Luke: I won't fail you. I'm not afraid.
Yoda: You will be. You... will... be.



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

Source: Wikipedia (Japanese rock garden)

Source: Wikipedia (Japanese rock garden)