Additional Topics: Big Data

Lecture #1

An overview of “Big Data”

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Course outline

- 0 – Google on Building Large Systems (Mar. 14)
  - David Singleton
- 1 – Overview of Big Data (today)
- 2 – Algorithms for Big Data (April 30)
- 3 – Case studies from Big Data startups (May 2)
  - Pete Warden

Goals after four lectures

- recognise some of the main terminology
- remember that there are many tools available
- realise the potential of Big Data
    - all of you are skilled enough to get involved!

What is Big Data?

Data sets that grow so large that they become awkward to work with using on-hand database management tools? (Wikipedia)

What is Big Data?

- distributed file systems
- NoSQL databases
- grid computing, cloud computing
- MapReduce and other new paradigms
- large-scale machine learning

What is Big Data?

from “Big Data and the Web: Algorithms for Data Intensive Scalable Computing”
PhD Thesis, Gianmarco De Francisci Morales

What is Big Data?

- buzzword?
- bubble?
- gold rush?
- revolution?
- funding fad?
    - DARPA XDATA project, March 2012

Who's profiting?

RapLeaf


```
{
  "age":"21-24",
  "gender":"Male",
  "interests":{
    "Blogging":true,
    "High-End Brand Buyer":true,
    "Sports":true,
  },
  "education":"Completed Graduate School",
  "occupation":"Professional",
  "children":"No",
  "household_income":"75k-100k",
  "marital_status":"Single",
  "home_owner_status":"Rent"
}
```


- 10 TB of user data
- all computation done using local Hadoop cluster

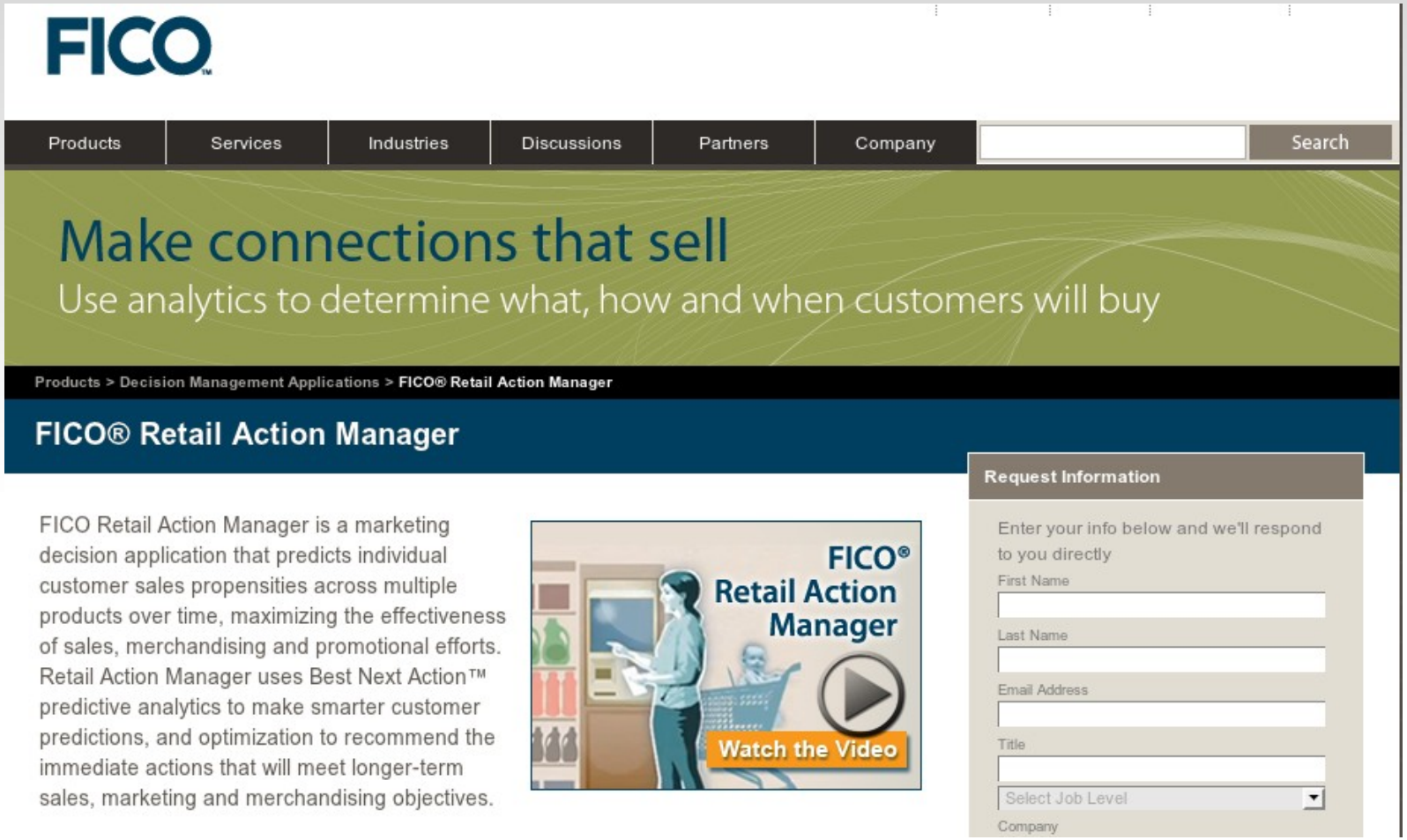
Gnip

- "grand central station" for social web streams
- aggregates several TB of new social data **per day**
- all data stored on Amazon S3

Climate Corporation

- 14 TB of historical weather data
- all computation done using Amazon EC2
- 30 technical staff, including 12 PhDs
- 10,000 sales agents

FICO

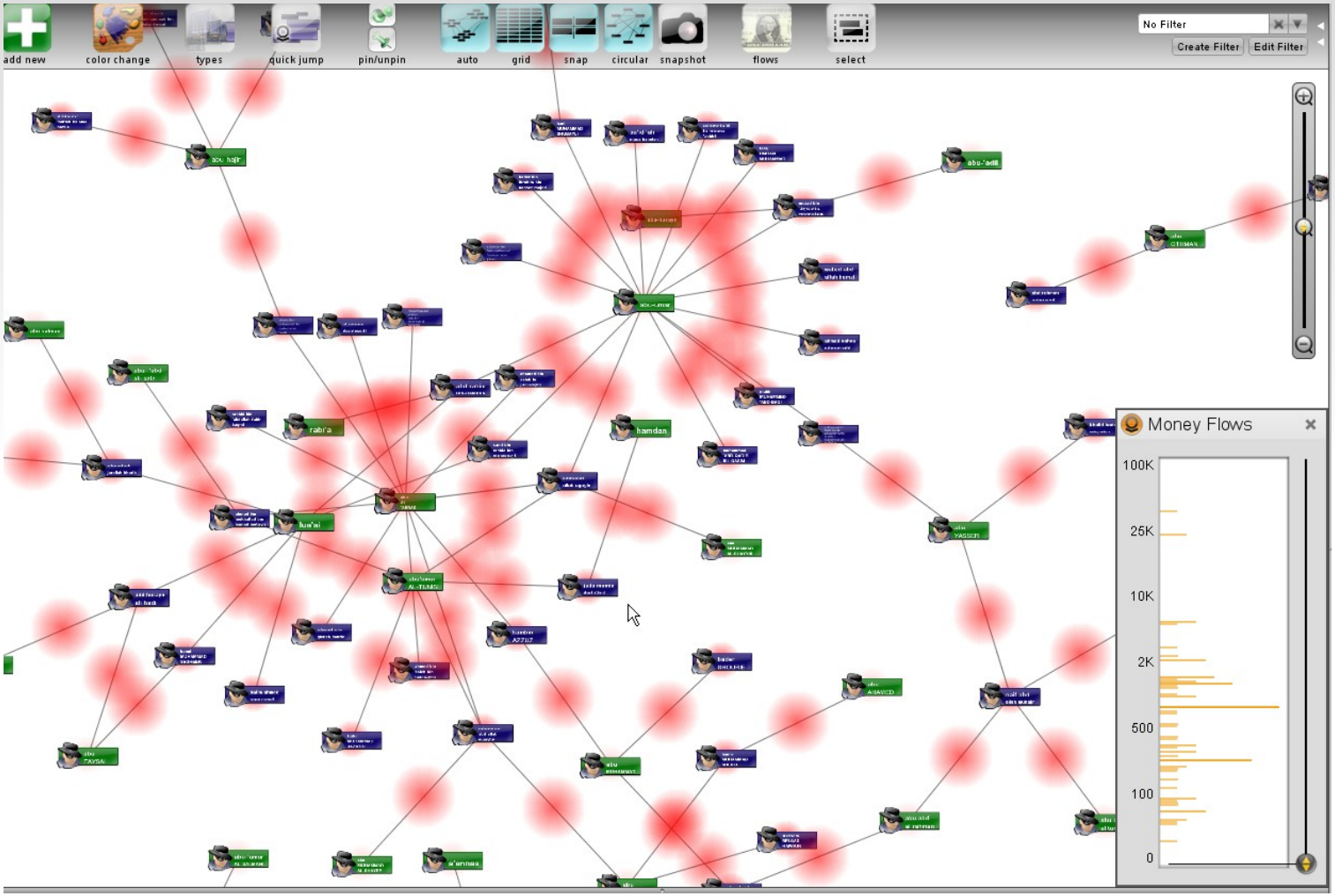


- 50+ years of experience doing credit ratings
- transitioning to predictive analytics

Cloudera

- employs many of the original Hadoop developers
- now facing many competitors

Palantir Technologies



- data analysis, exploration tools for government, finance
- 0-$2 billion in 5 years

The modern data scientist

- Engineer
  - collect & scrub disparate data sources
  - manage a large computing cluster
- Mathematician
  - machine learning
  - statistics
- Artist
  - visualise data beautifully
  - tell a convincing story

Sources of Big Data

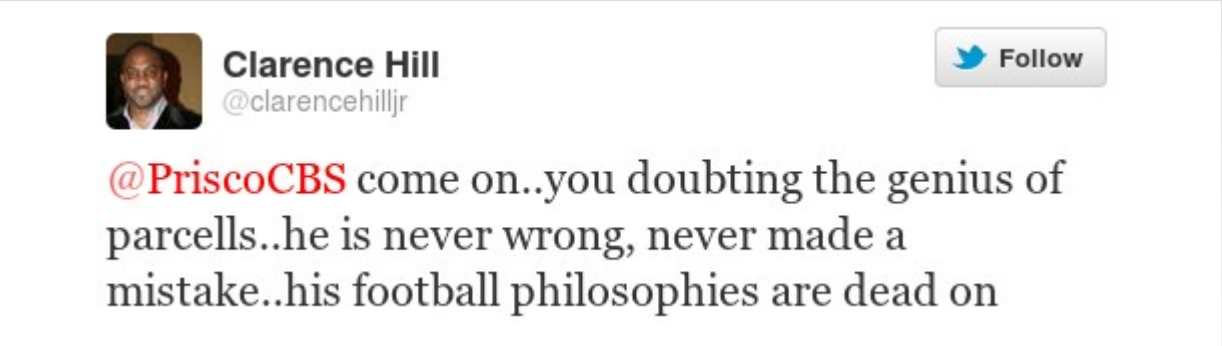
Proprietary data: Facebook

- 40+ billion photos
  - 100 PB
- 6 billion messages **per day**
  - 5-10 TB
- 900 million users
  - 1 trillion connections?

Common Crawl

- covers about 5 million web pages
- 50 TB of data
- available for free, hosted by Amazon

Twitter “Firehose”




```
{  "in_reply_to_status_id_str":null,  "retweet_count":0,  "favorited":false,  "text":"New iPad vs iPad 2: which should
you choose? http://t.co/EpygqtlE Redsn0w 0.9.10b6 i4Siri Proxy Server For Spire GEVEY Ultra S WP7
_83",  "in_reply_to_user_id_str":null,  "in_reply_to_status_id":null,  "created_at":"Mon Mar 19 22:22:32 +0000
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kC"      }    ],    "user_mentions":
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/images/themes/theme1/bg.png",    "utc_offset":null  },  "id":181868286009548802}
```
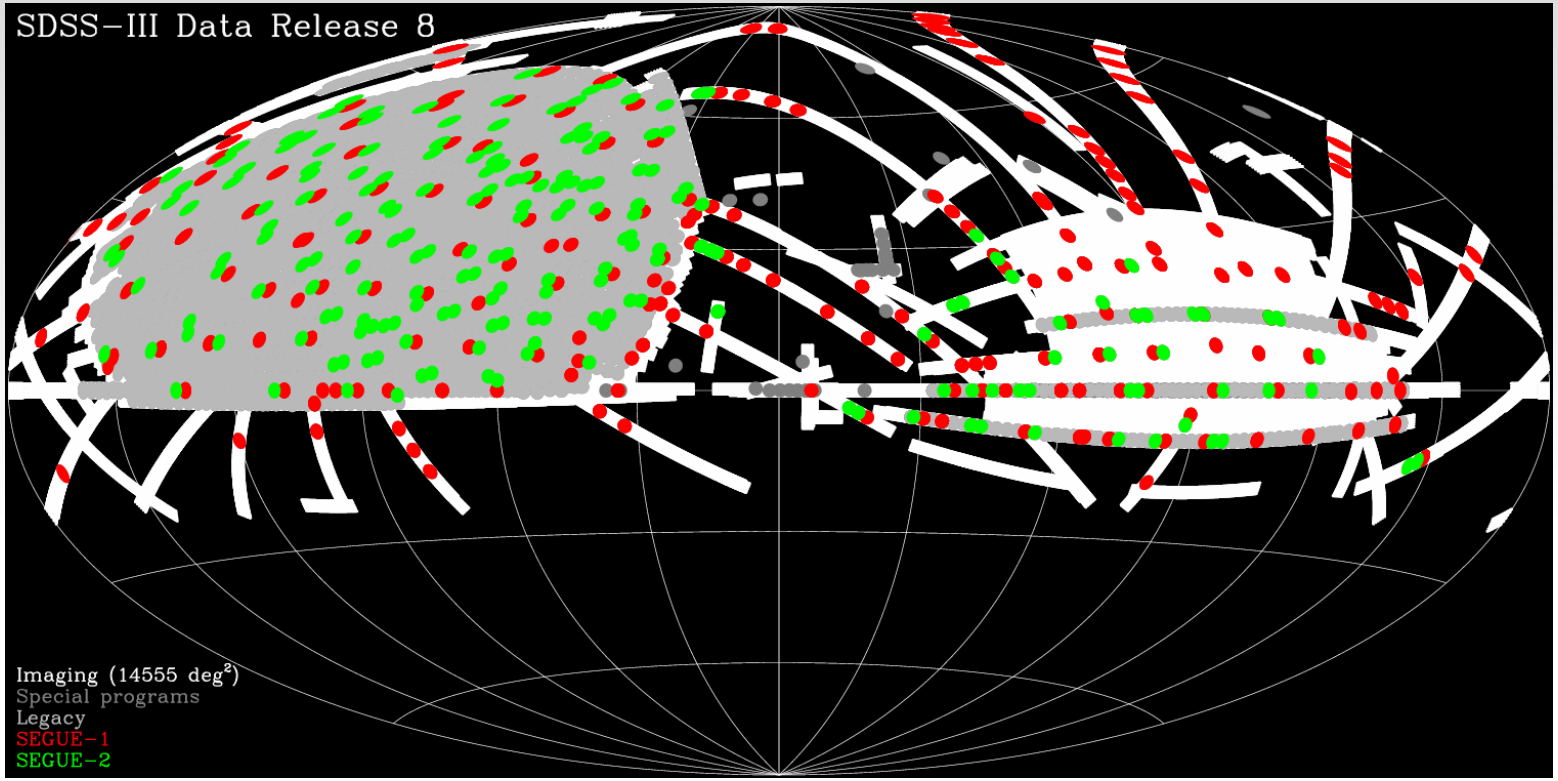


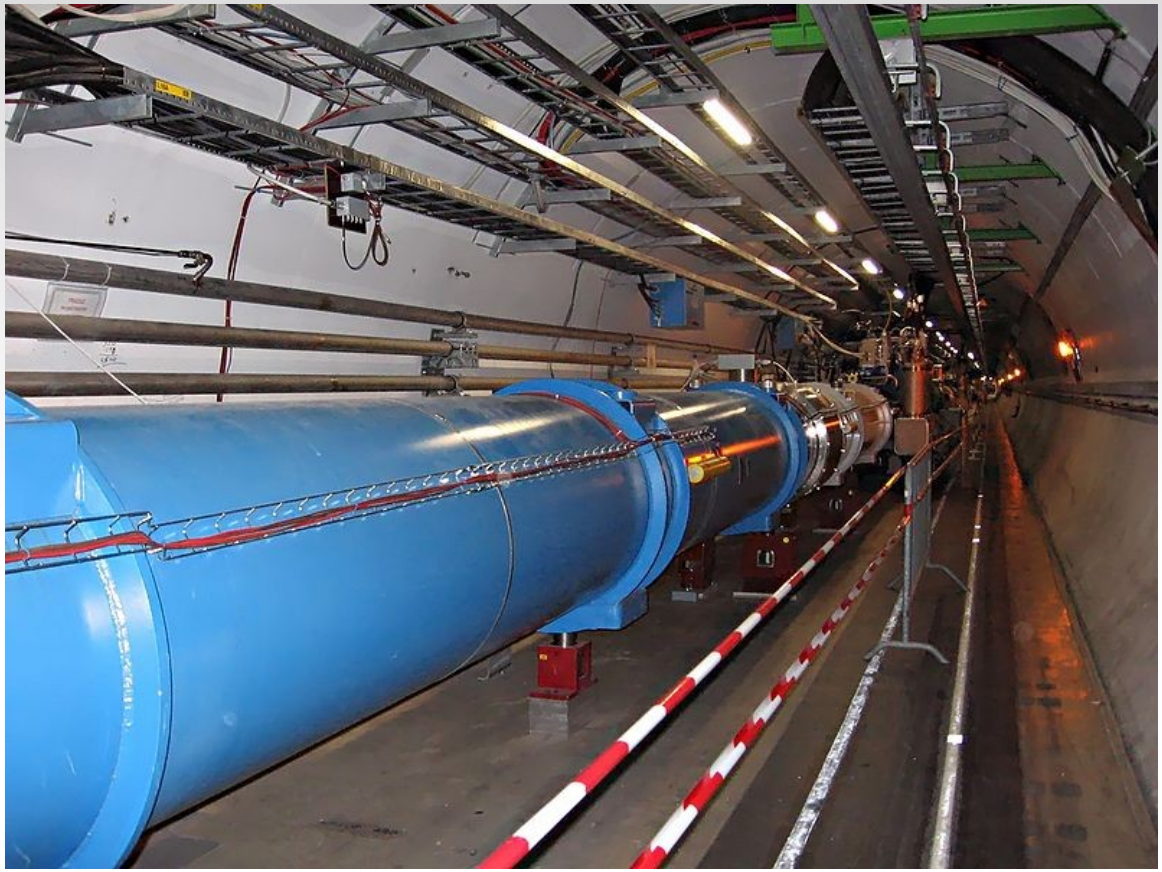
350 M tweets/day x 2-3Kb/tweet ≈ 1 TB/day

Sloan Digital Sky Survey



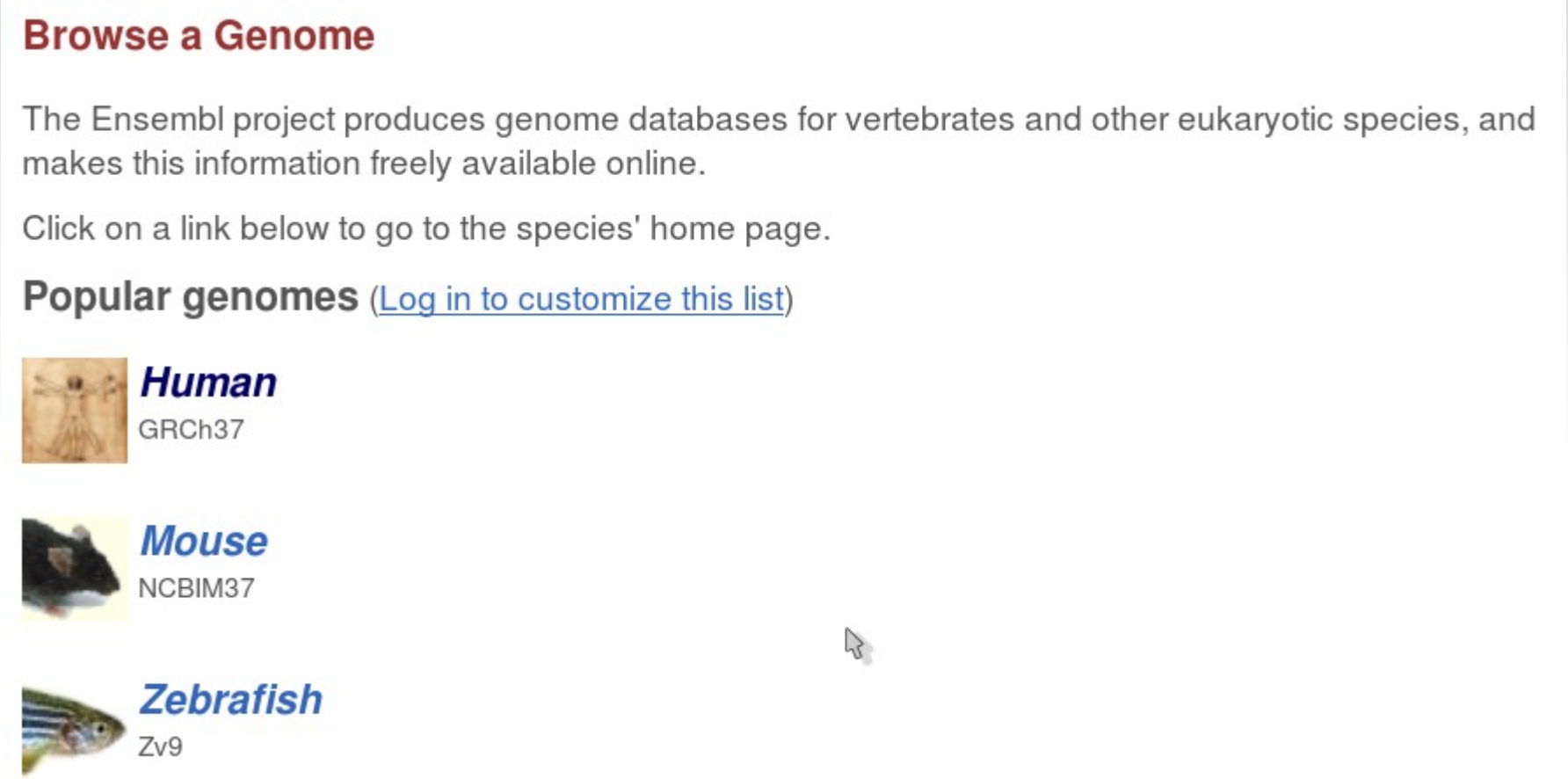
- 35% of the sky mapped
- 500 million objects classified
- 50 TB of data available

Large Hadron Collider



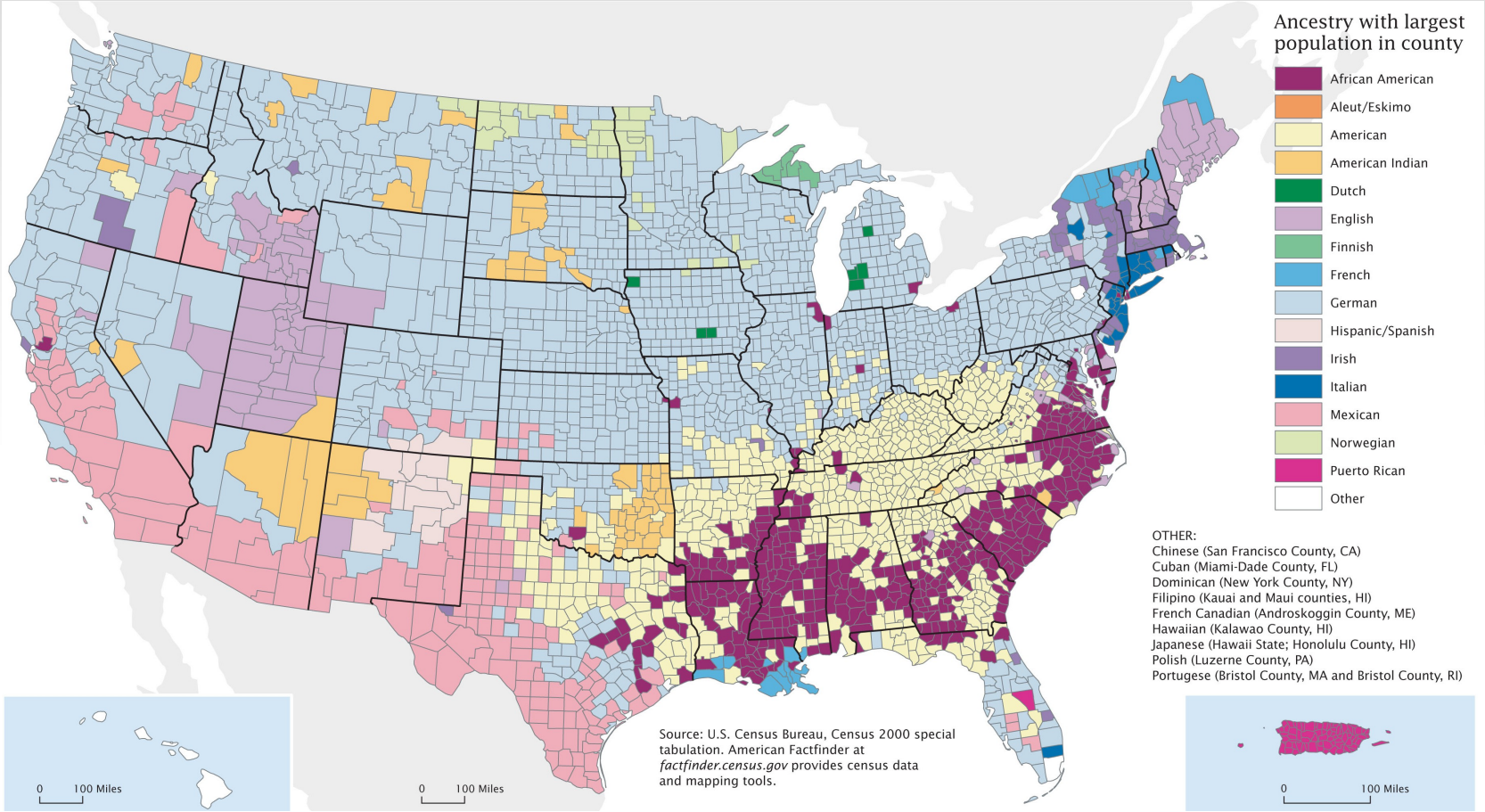
- 15 PB of data generated annually
- mostly stored in Oracle databases (SQL)

Human genome



- humans and 50 other species
- “only” 250 GB

US census data (2000)



- detailed demographic data for small localities
- “only” 200 GB

Roll your own big data

- crawling as a service
- web sites, social profiles, product listings, etc.
- free accounts offer crawls of up to 10k URLs

Roll your own big data

- Needlebase: graphical tagging of website structure

Roll your own big data

- Boilerpipes: remove “clutter” from web pages
  - Metadata, JavaScript, etc.
- Google Refine: clean up human-entered data
  - fix common typos, spacing, etc.
- NLPToolkit: simplify natural language
  - stem words, replace synonyms
- Lucene: index terms for text search
- Amazon MTurk: human analysis

Storing big data

Traditional SQL databases

```
TABLE instructor
+-------+-----------------+
|  ID   | Name            |
+-------+-----------------+
|  14   | David Singleton |
|  27   | Joseph Bonneau  |
|  52   | Pete Warden     |
+-------+-----------------+

TABLE lectures

+-------+--------------------+-------------+
|  ID   | Title              |  Lecturer   |
+-------+--------------------+-------------+
|  1    | BD at Google       |  14         |
|  2    | Overview of BD     |  27         |
|  3    | Algorithms for BD  |  27         |
|  4    | BD at startups     |  14         |
+-------+--------------------+-------------+
```

Traditional SQL databases

TABLE instructor

ID	Name
14	David Singleton
27	Joseph Bonneau
52	Pete Warden

most interesting queries require computing **joins**

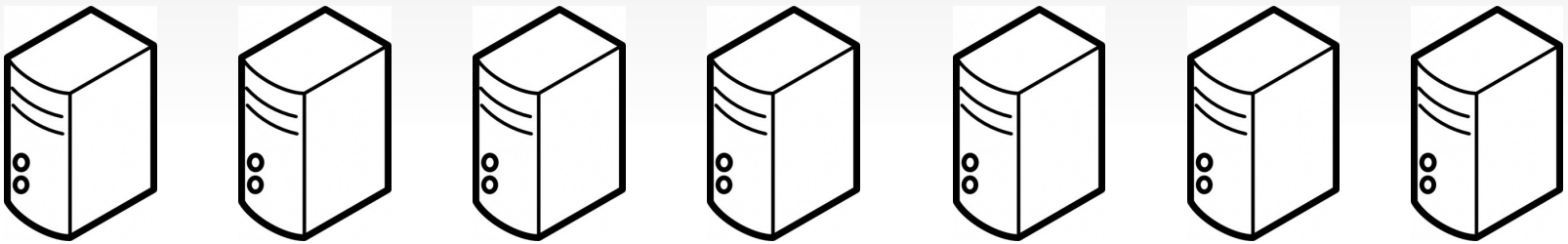
TABLE lectures

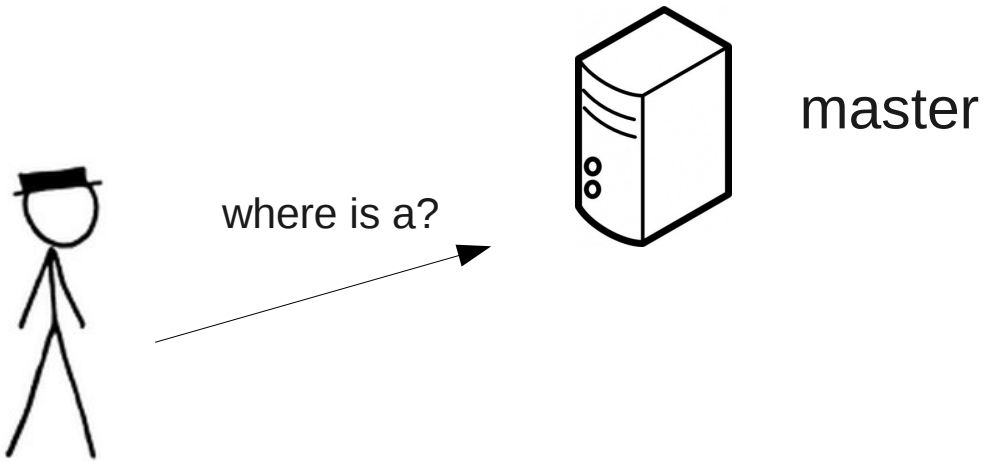
ID	Title	Lecturer
1	BD at Google	14
2	Overview of BD	27
3	Algorithms for BD	27
4	BD at startups	14

Data assumptions

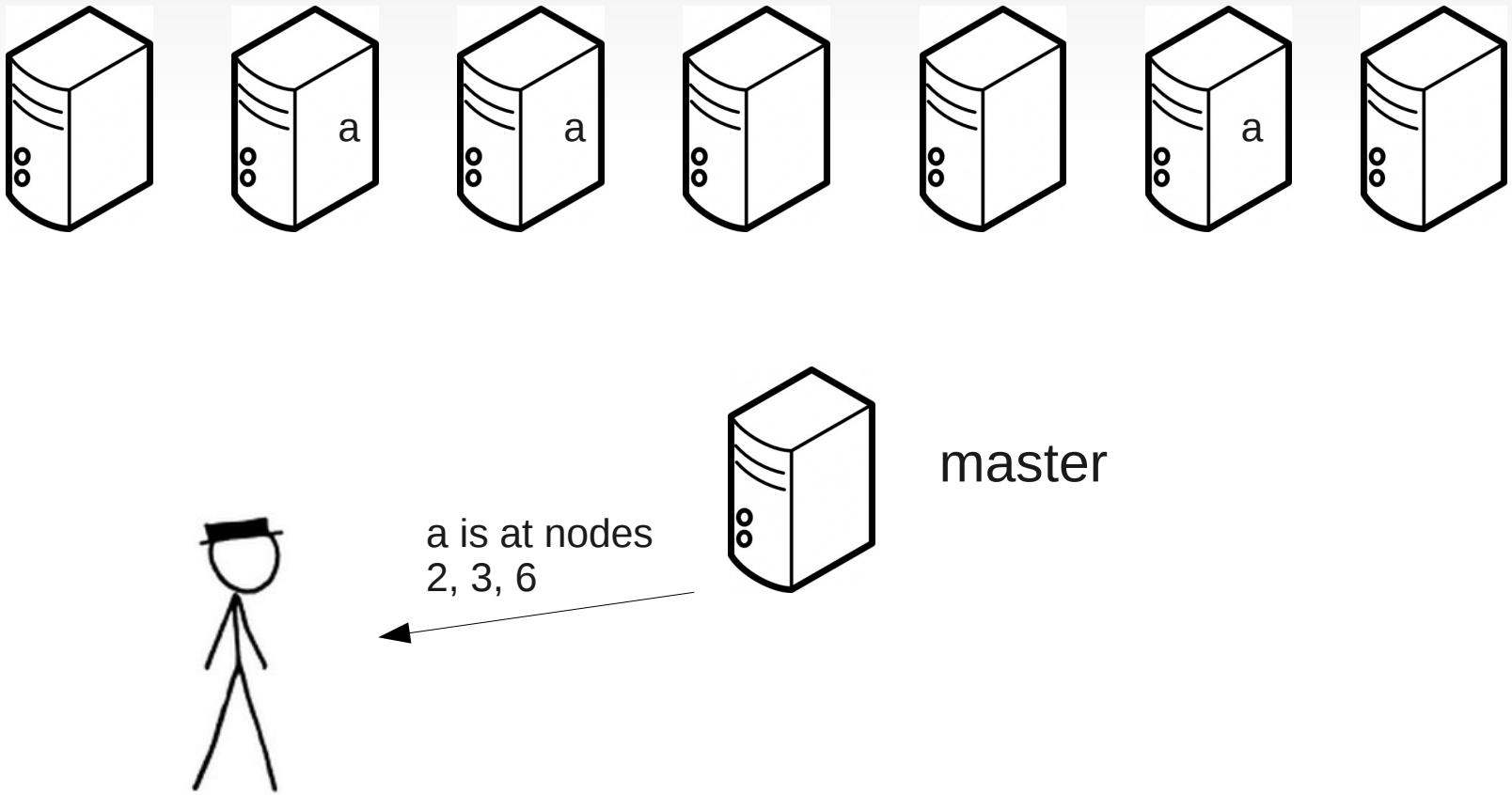
Traditional RDBMS (SQL)	NoSQL
integrity is mission-critical	OK as long as most data is correct
data format consistent, well-defined	data format unknown or inconsistent
data is of long-term value	data will be replaced
data updates are frequent	write-once, ready multiple
predictable, linear growth	unpredictable growth (exponential?)
non-programmers writing queries	only programmers writing queries
regular backup	replication
access through master server	sharding

Replication and sharding

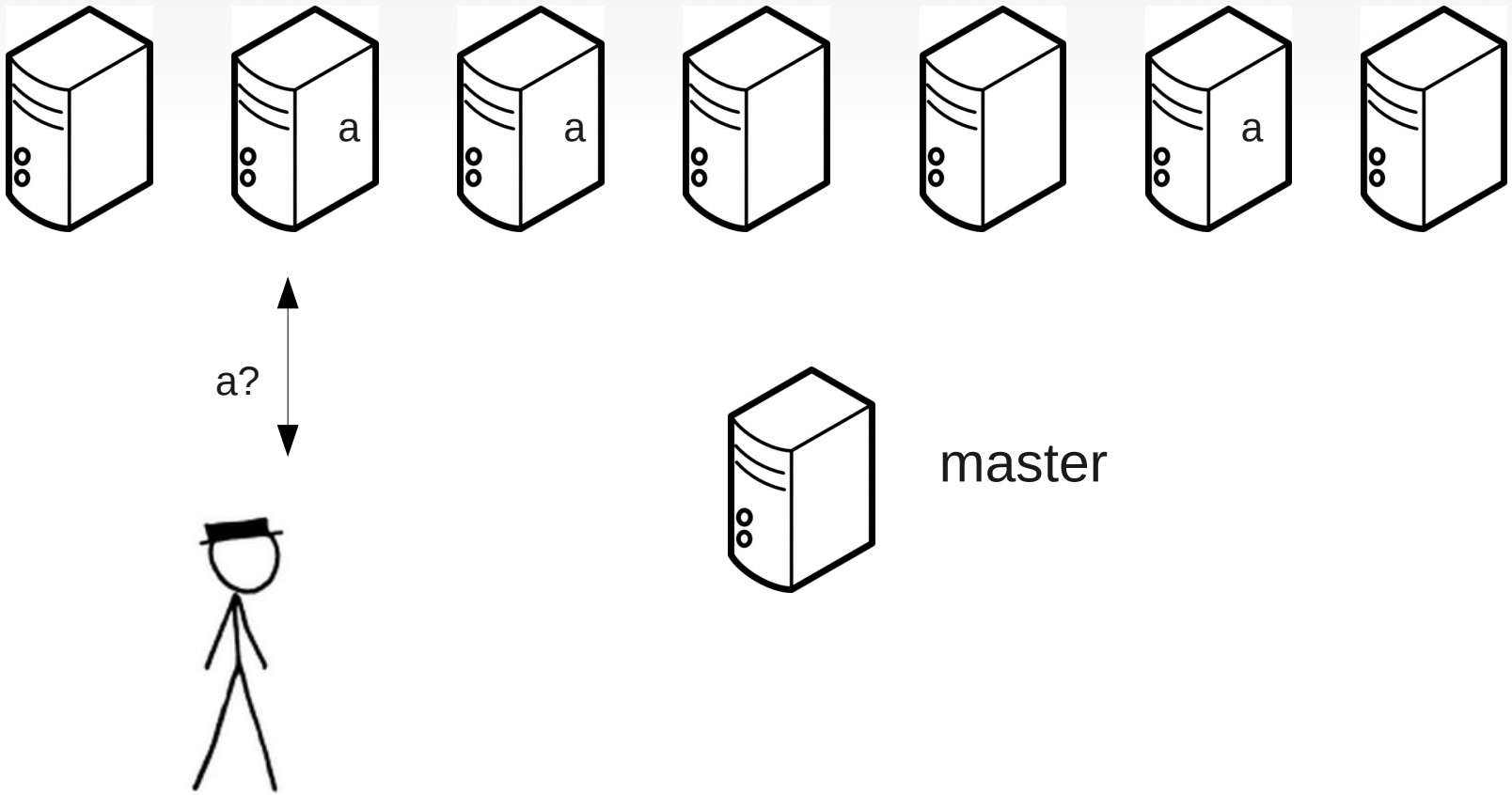




Replication and sharding



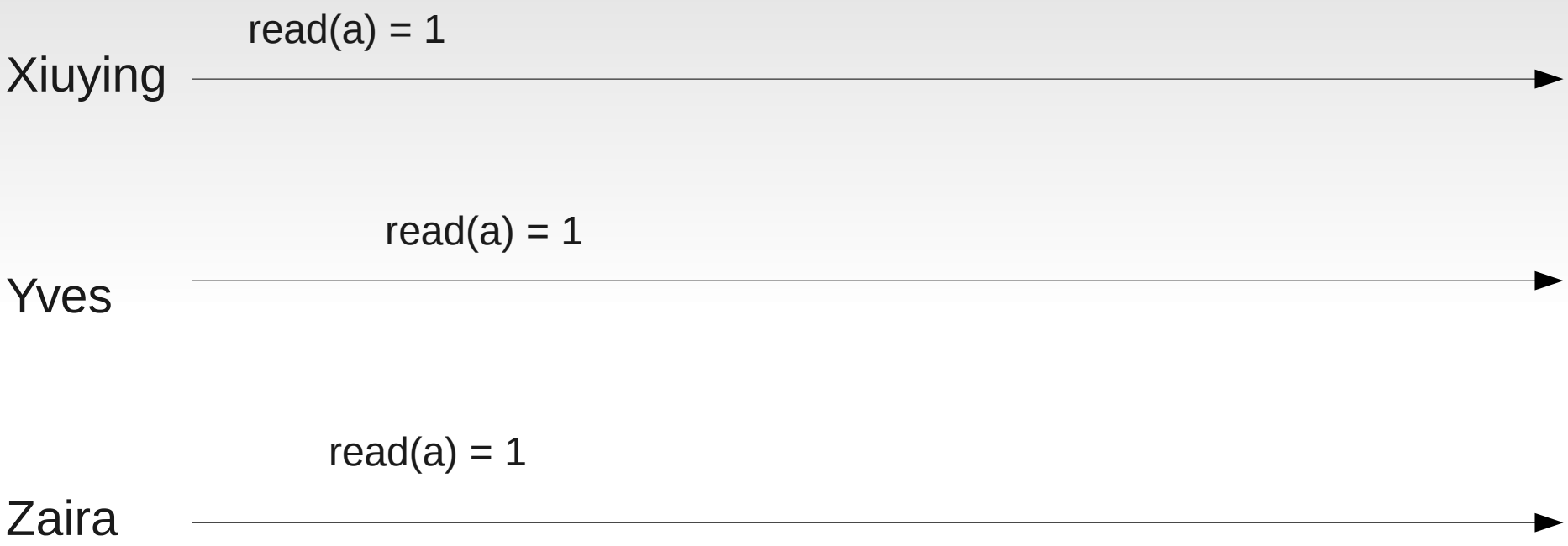
Replication and sharding



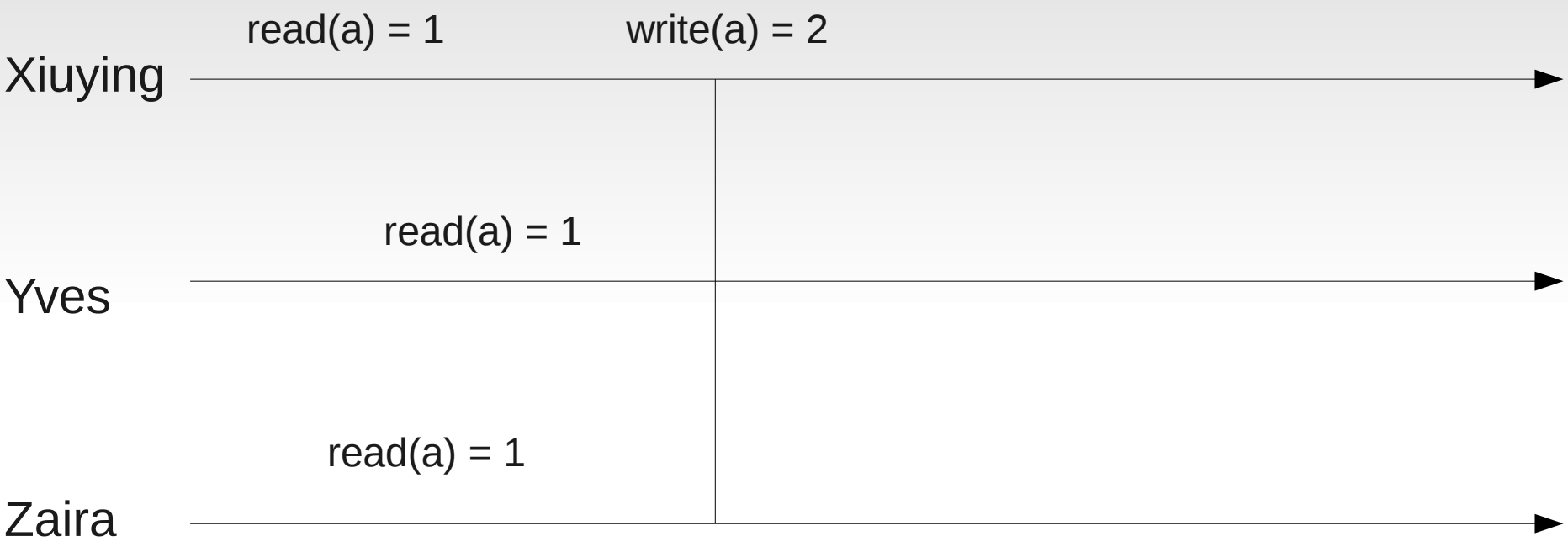
Integrity guarantees

Traditional RDBMS (SQL)	NoSQL
Available	**B**asically
Consistent	**A**vailable
Isolated transactions	**S**oft state
Durable writes	**E**ventually consistent

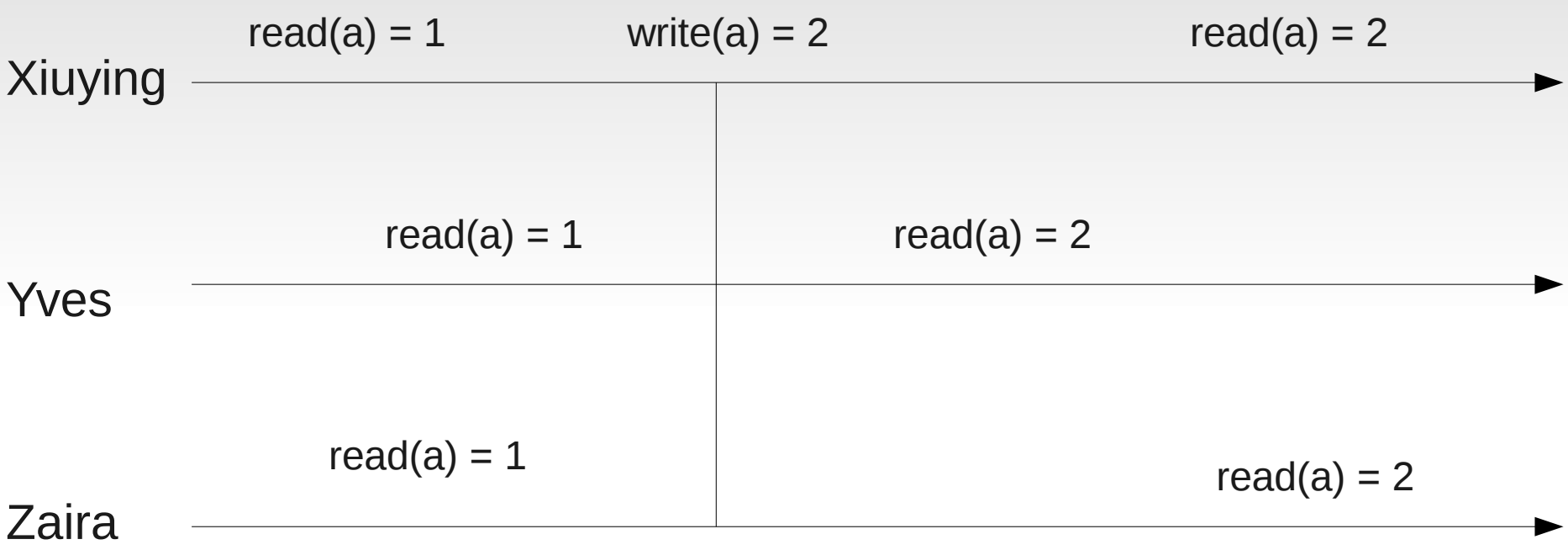
Strong consistency



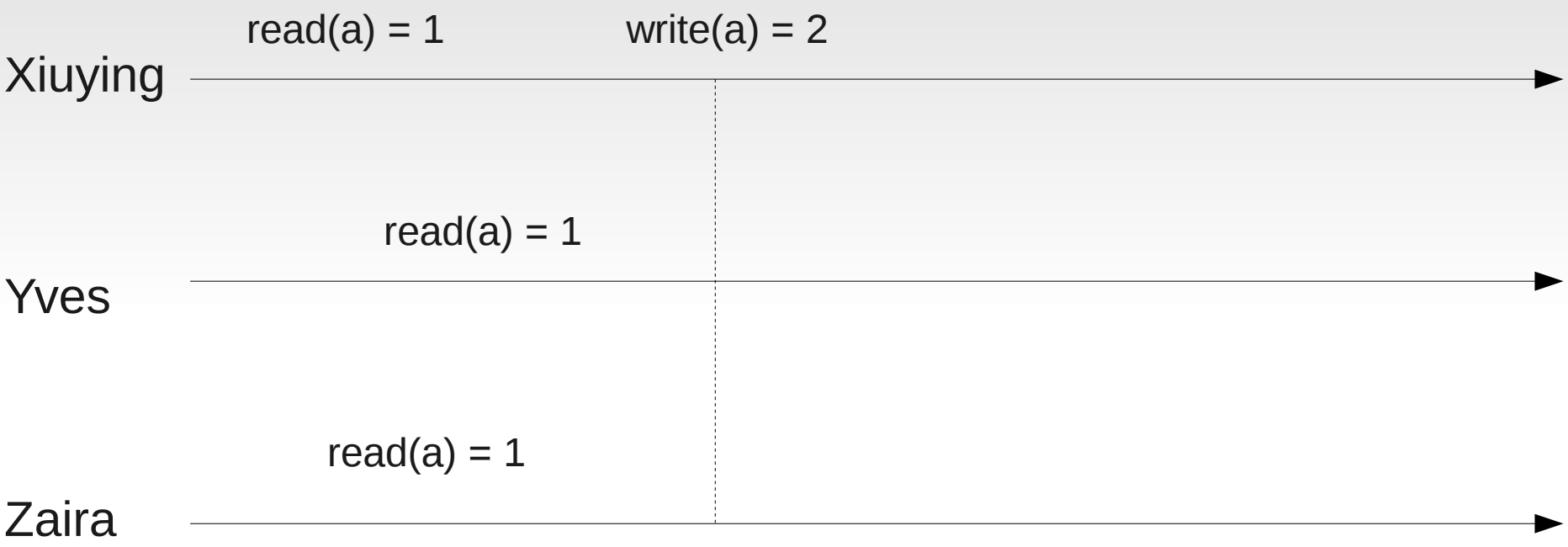
Strong consistency



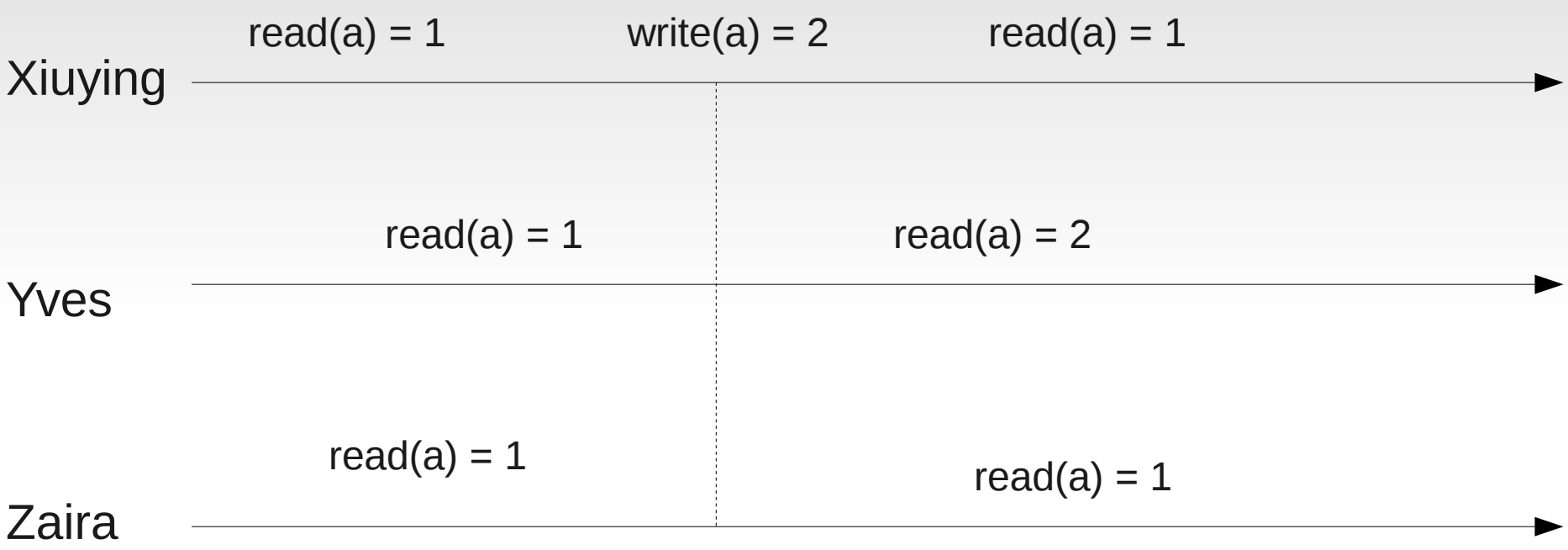
Strong consistency



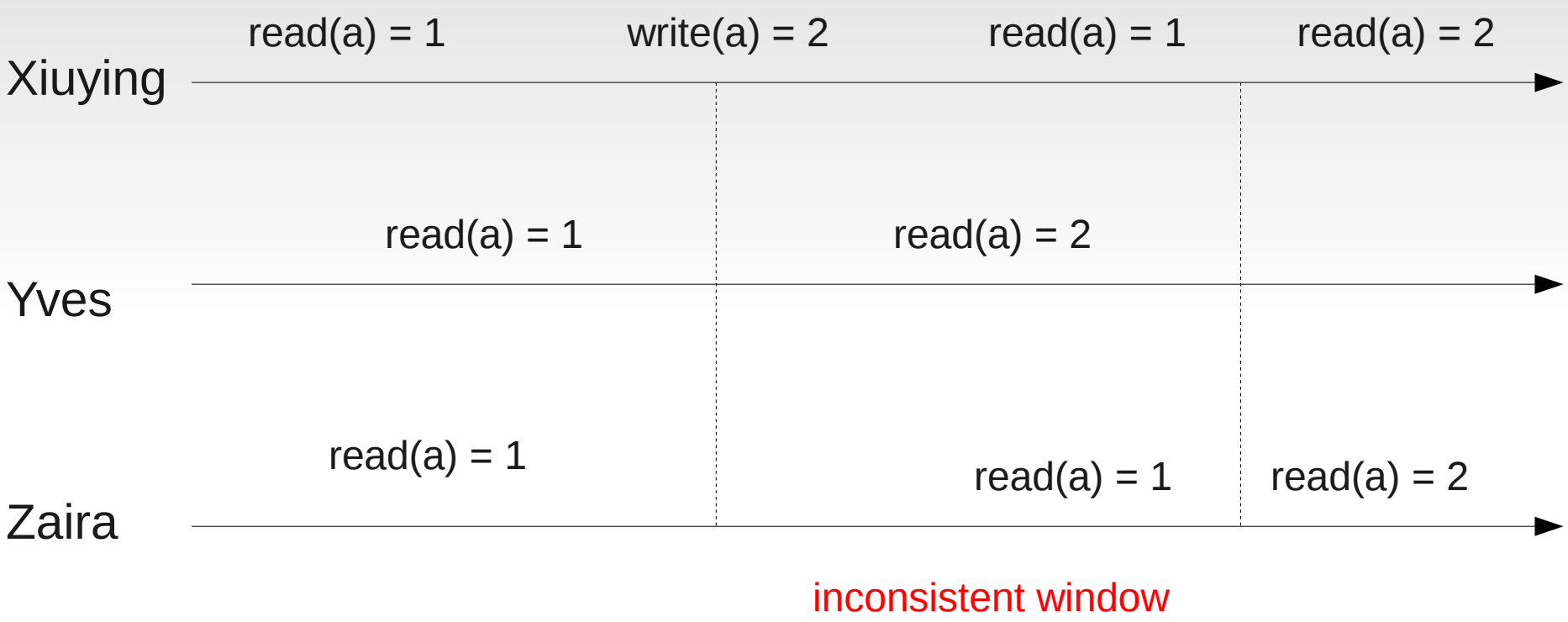
Eventual consistency



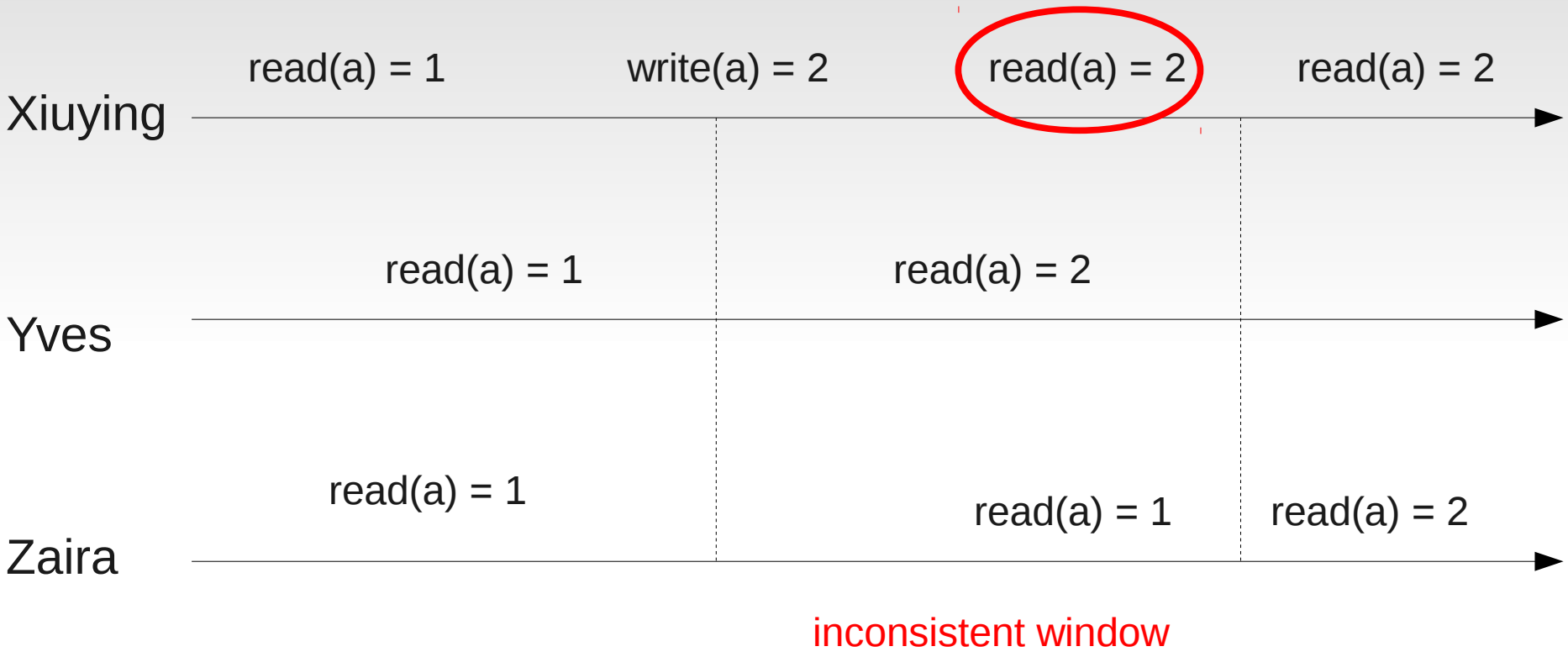
Eventual consistency



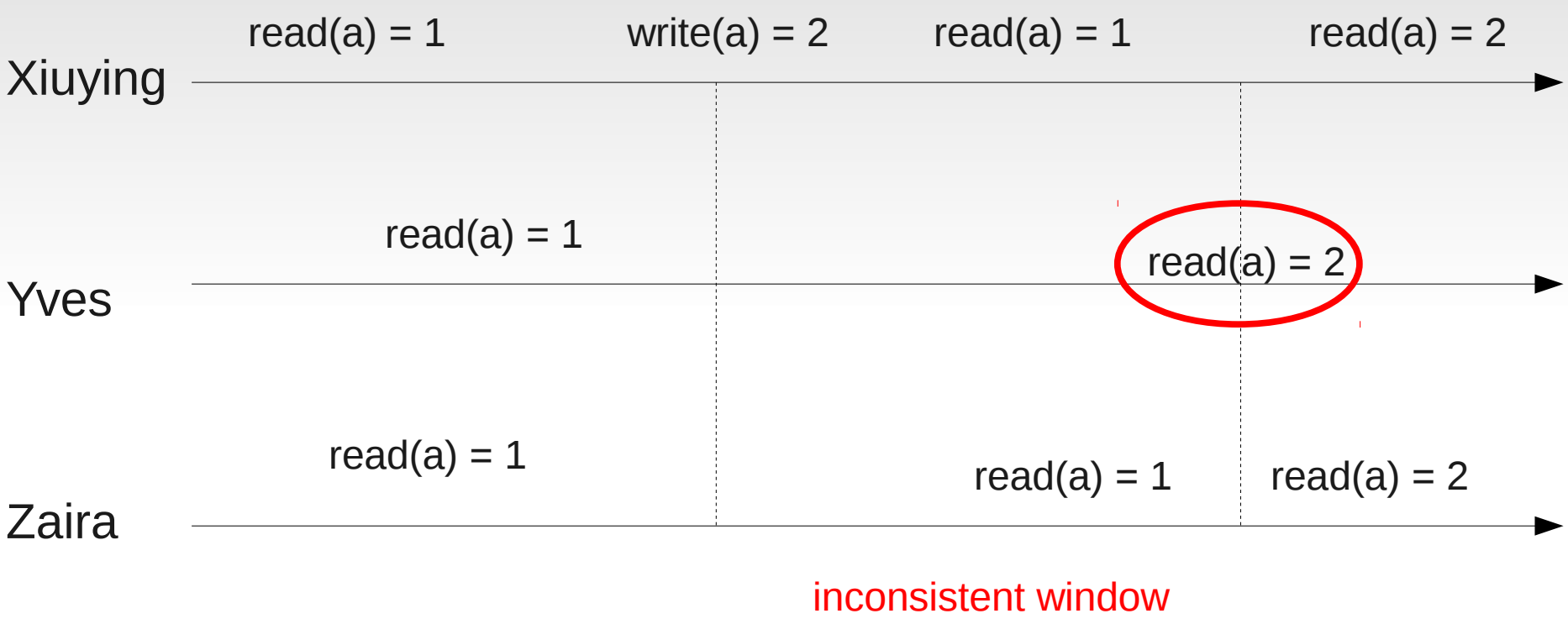
Eventual consistency



Read-own writes consistency



Monotonic read consistency

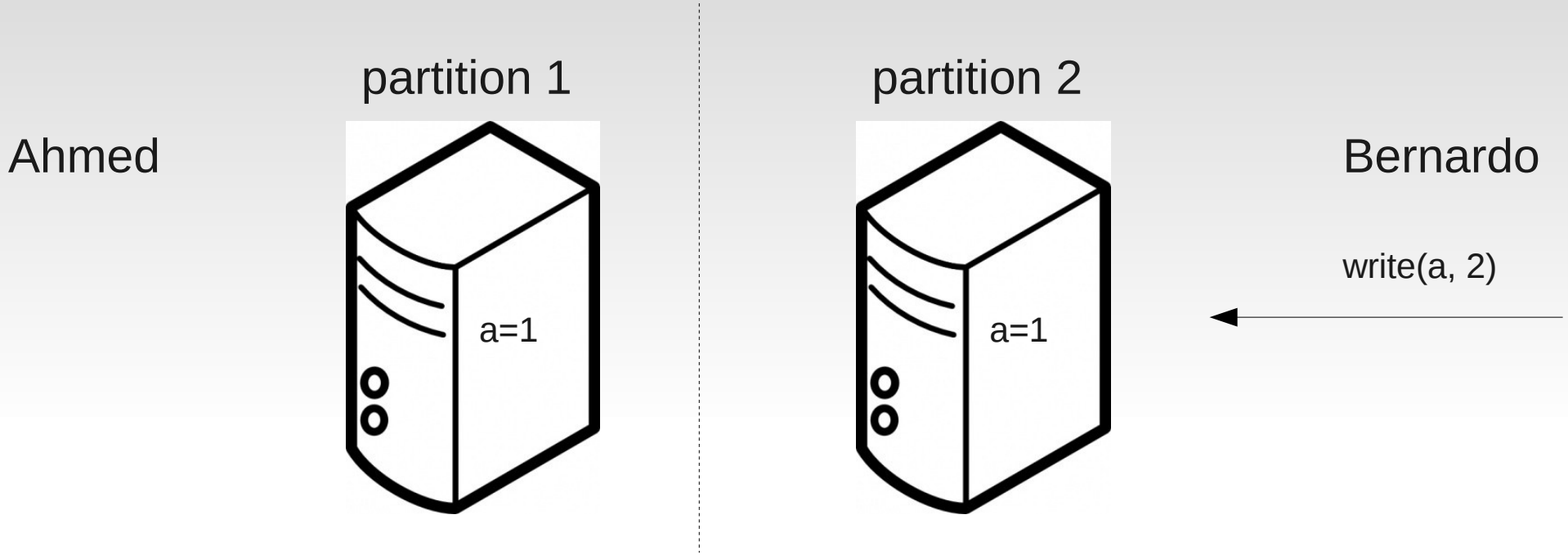


CAP theorem (Brewer)

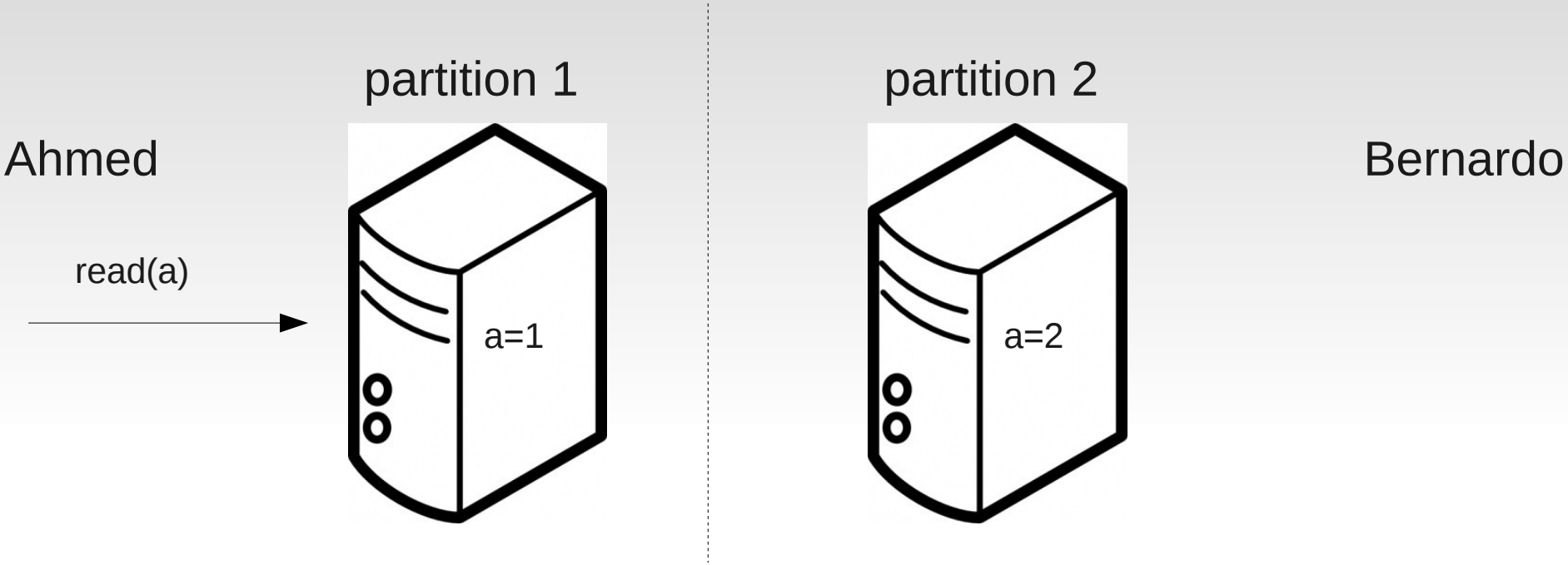
- **C**onsistency
- **A**vailability
- **P**artitioning

Pick any two...

CAP theorem - informal proof

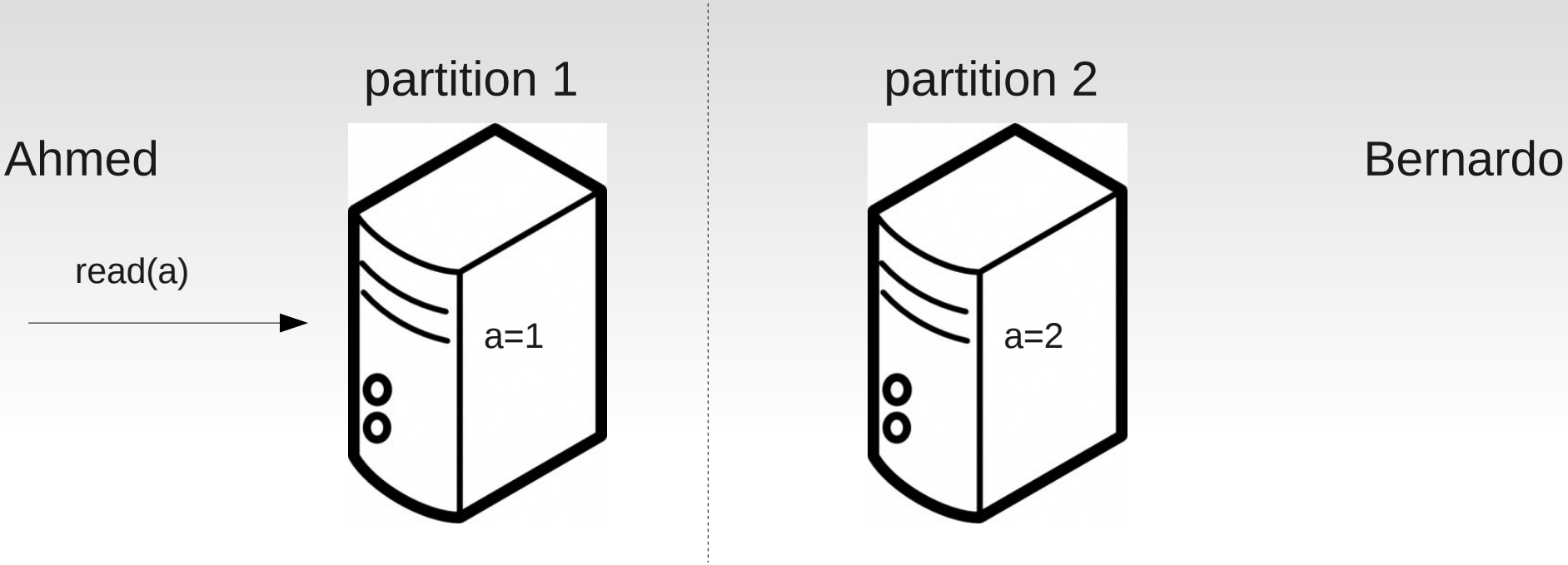


CAP theorem - informal proof



How should P1 respond to Ahmed?

CAP theorem - informal proof



How should P1 respond to Ahmed?

- respond that a = 1 (forgo **consistency**)
- delay (forgo **availability**)
- be in constant contact with P2 (forgo **partitioning**)

Approaches to NoSQL

- key/value
- column-oriented
- document-oriented
- graph-oriented

Key/value stores

- simplest possible interface:
  - put('foo', 'bar')
  - get('foo') will return 'bar'
- dates to at least the 1970s (**dbm**)
- **Memcached/MemcacheDB** as a caching layer
- **BerkeleyDB** (now maintained by Oracle)
- others: Tokyo Cabinet, Voldemort, Redis, Scalaris, Google LevelDB

Column-oriented

RowKey	TimeStamp	ColumnFamily contents	ColumnFamily anchor
com.cnn.www	t1	contents.html = ...	anchor:cnnsi.com = “CNN”
com.cnn.www	t0	contents.html = ...	anchor:cnnsi.com = “News”
...	...	...	...
uk.ac.cam.www	t1	contents.html = ...	anchor:cl.cam.ac.uk = “Home”
uk.ac.cam.cl.www	t1	contents.html = ...	anchor:cl.cam.ac.uk/jcb82 = “My Lab” anchor:cam.ac.uk = “Computer Lab”

Hadoop HBase

Column-oriented

- maintain unique keys per row
- much more complicated multi-valued columns
  - richer querying possible
- Google's BigTable was a pioneer
  - Bigtable: A Distributed Storage System for Structured Data, Chang et al.
- others: Apache Cassandra, Hadoop HBase, Amazon DynamoDB, Hypertable

Document-oriented

- like a key-value store, but stores **documents**
- can be *serialised* objects or binary files
    - can query attributes of serialised objects

XML

```
<person id="11">
   <name>Joseph Bonneau</name>
   <email>jcb82@cam</name>
</person>
```

- can specify separate DTD schema
- can display using XSLT

JSON

```
{
   "id": 11,
   "name":"Joseph Bonneau",
   "email":"jcb82@cam"
}
```

- human readable
- native parsing in JavaScript
- BSON-binary version developed for MongoDB

Protocol buffers

```
message Person {
  required int32 id = 1;
  required string name = 2;
  optional string email = 3;
}
```

- compiles to binary format-not human-readable
- developed by Google – many similar approaches
  - Apache Thrift

Document-oriented: MongoDB

```
{
    "_id": ObjectId("4efa8d2b7d284dad101e4bc9"),
    "name": "Joseph Bonneau",
    "role": "PhD student",
    "office number": 17
},
{
    "_id": ObjectId("4efa8d2b7d284dad101e4bc7"),
    "name": "Ross Anderson",
    "role": "Professor",
    "subject": "Security Engineering"
}
```

```
db.find({"name" : "Joseph Bonneau"});
db.find({"name" : { $regex : '.*Anderson$'} } } );
db.find({"office number" : { $gt: 16 } } );
```

Document-oriented

- MongoDB
  - uses BSON (Binary JSON)
  - open-source, commercially developed
- Apache CouchDB
  - uses vanilla JSON
  - open-source, community developed

Graph-oriented

- developed specifically for large graphs
  - “index-free” lookup of neighbors
- OrientDB is perhaps the best known
  - less practical use than other approaches

Summary of NoSQL

Pros:

- scalable and fast
- flexible
- can be easier for experienced programmers

Cons:

- fewer consistency/concurrency guarantees
- weaker set of queries supported
- less mature

Big Data stacks

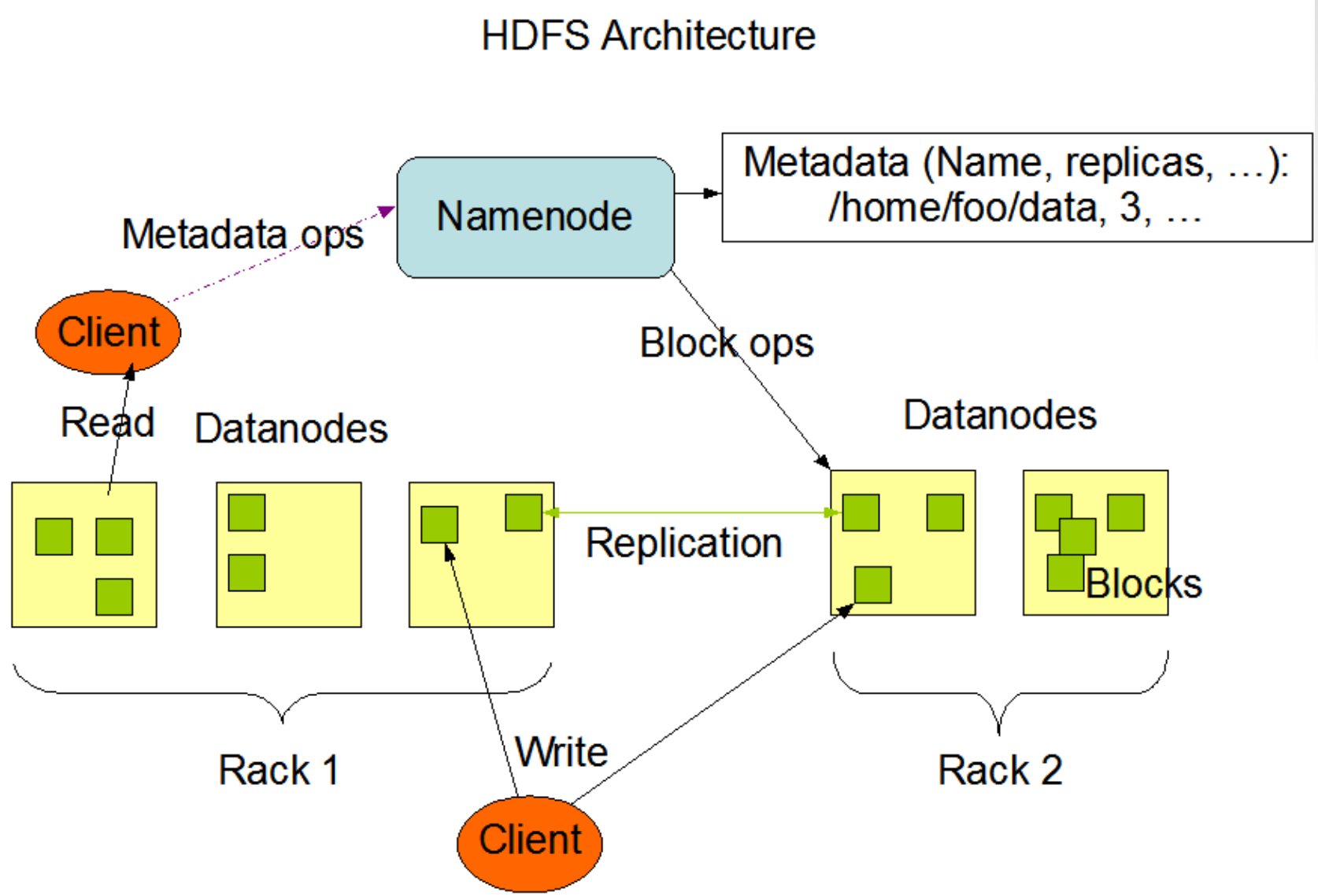
Big Data stacks

- Google
  - proprietary but influential
- Apache Hadoop
  - totally open-source
- Amazon Web Services (AWS)
  - mixed-source, including some Hadoop

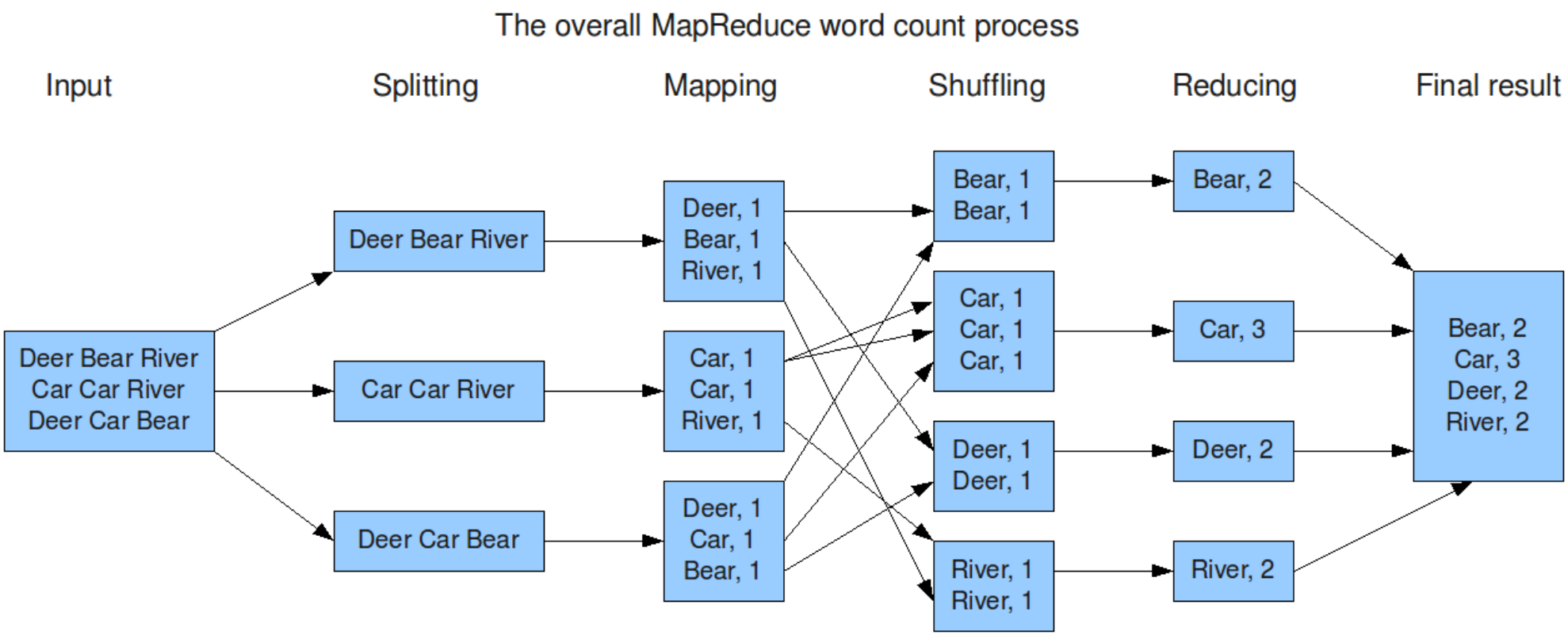
Hadoop

- founded in 2004 by a Yahoo! employee
- spun into open-source Apache project
- general-purpose framework for Big Data
  - MapReduce implementation
  - supporting tools (distributed storage, concurrency)
- used by everybody...
  - Yahoo!, Facebook, Amazon, Microsoft, Apple

Hadoop Distributed File Sys.



Review: MapReduce



Example from rapidgremlin.com

Hadoop MapReduce example

```
public 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);
        }
    }
}
```

Example from rapidgremlin.com

Hadoop MapReduce example

```
public class Reduce 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));
    }

}
```

Example from rapidgremlin.com

Hadoop MapReduce example

```
public class WordCount {
   public static void main(String[] args) throws Exception {
      JobConf conf = new JobConf(WordCount.class);
      conf.setJobName("wordcount");

      conf.setOutputKeyClass(Text.class);
      conf.setOutputValueClass(IntWritable.class);

      conf.setMapperClass(Map.class);
      conf.setCombinerClass(Reduce.class);
      conf.setReducerClass(Reduce.class);

      conf.setInputFormat(TextInputFormat.class);
      conf.setOutputFormat(TextOutputFormat.class);

      FileInputFormat.setInputPaths(conf, new Path(args[0]));
      FileOutputFormat.setOutputPath(conf, new Path(args[1]));
      JobClient.runJob(conf);
   }
}
```

Example from rapidgremlin.com

Hadoop JobTracker

Quick Links

10 Hadoop Map/Reduce Administration

State: RUNNING
Started: Tue May 10 17:11:39 GMT 2011
Version: 0.21.0, 985326
Compiled: Tue Aug 17 01:02:28 EDT 2010 by tomwhite from branches/branch-0.21
Identifier: 201105101711

Cluster Summary (Heap Size is 106.12 MB/1.56 GB)

Queues	Running Map Tasks	Running Reduce Tasks	Total Submissions	Nodes	Occupied Map Slots	Occupied Reduce Slots	Reserved Map Slots	Reserved Reduce Slots	Map Slot Capacity	Reduce Slot Capacity	Avg. Slots/Node	Blacklisted Nodes	Excluded Nodes
1	6	1	1	4	6	1	0	0	8	8	4.00	0	0

Filter (Jobid, Priority, User, Name)
Example: 'user:smith 3200' will filter by 'smith' only in the user field and '3200' in all fields

Running Jobs

Jobid	Priority	User	Name	Map % Complete	Map Total	Maps Completed	Reduce % Complete	Reduce Total	Reduces Completed	Job Scheduling Information
job_201105101711_0001	NORMAL	hadoop	QuasiMonteCarlo	50.00%	20	10	0.00%	1	0	NA

Retired Jobs

none

Local Logs

Log directory, Job Tracker History

Hadoop, 2011.

MapReduce alternative: Pig

```
lines = LOAD '../data/words.txt' USING TextLoader() AS
(sentence:chararray);

words = FOREACH lines GENERATE FLATTEN(TOKENIZE(sentence)) AS
word;

groupedWords = GROUP words BY word;

counts = FOREACH groupedWords GENERATE group, COUNT(words);

STORE counts INTO 'output/wordcounts' USING PigStorage();
```

Example from rapidgremlin.com

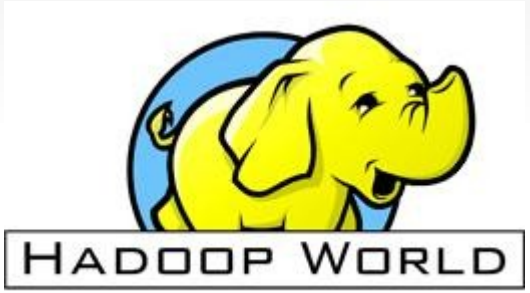
MapReduce alternative: Hive

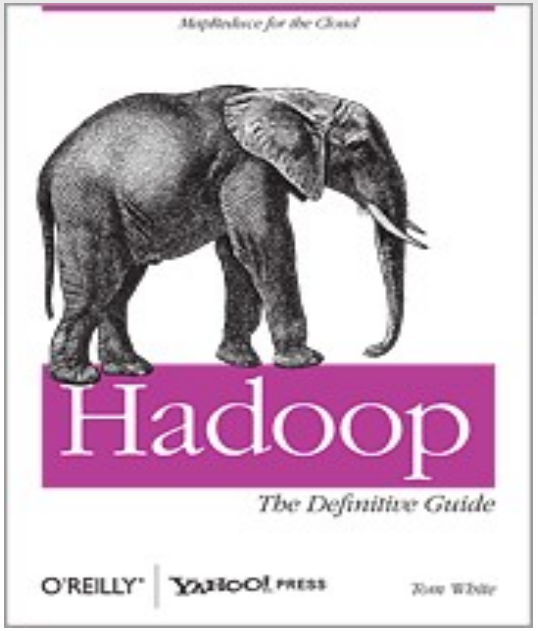
```
create table textlines(text string);

load data local inpath
'C:\work\ClearPoint\Data20\data\words.txt' overwrite into table
textlines;

create table words(word string);

insert overwrite table words select explode(split(text, '[ \t]
+')) word from textlines;

select word, count(*) from words group by word;
```

Example from rapidgremlin.com

The Hadoop Industry

cloudera





Amazon web services

- launched 2006
- largest, most popular cloud computing platform
  - others: Rackspace, Azure, Google App Engine

Elastic Compute Cloud (EC2)

- rent “Elastic compute units” by the hour
  - one ECU = one 1 GHz processor machine
- can choose Linux, FreeBSD, Solaris, Windows
- virtual private servers running on Xen
- pricing: US$0.02-2.50 per hour
  - varies by machine capacity
  - spot pricing-varies by demand

Simple Storage Service (S3)

- store arbitrary files (objects)
- index by “bucket” and “key”
  - http://s3.amazonaws.com/bucket/key
- accessible via HTTP, SOAP, BitTorrent
- directly readable from EC2 machines
- over 1 trillion objects now uploaded
- pricing: US$0.05-0.10 per GB per month
  - wimilar rates for transfer out, free transfer in

Other AWS elements

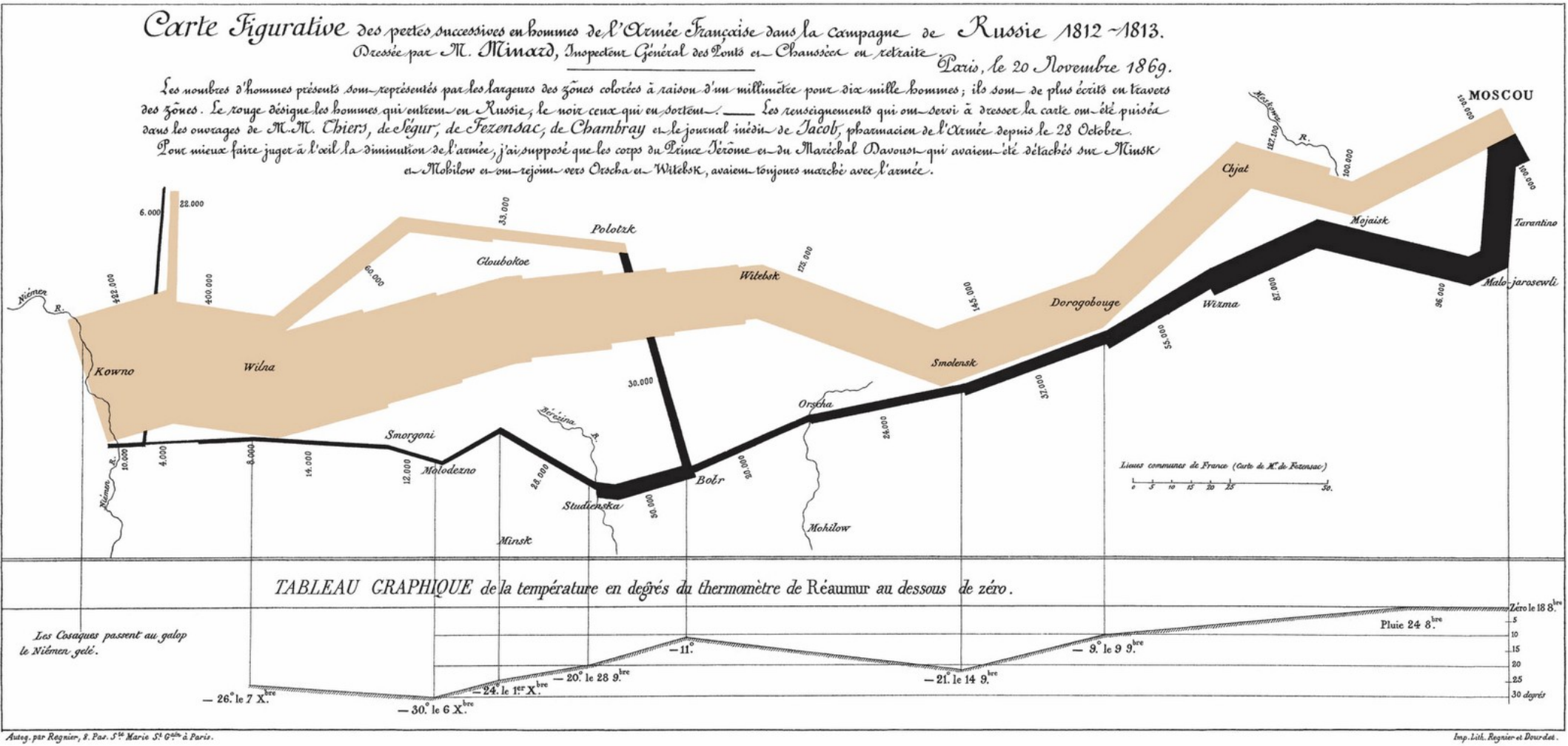
- elastic MapReduce
  - run Hadoop on EC2 machines with S3 storage
  - free data transfer
- relational Database Service
  - SQL database
- many features for running a data-driven website
  - content delivery networks, caches, etc.

Comparison

	Google	Hadoop	Amazon WS
storage	GoogleFS	HDFS	S3
caching	memcacheg		ElastiCache
locking	chubby	Zookeeper	
key-value	LevelDB		
column-oriented	BigTable	Cassandra	DynamoDB
document-oriented		CouchDB	SimpleDB

Visualisation

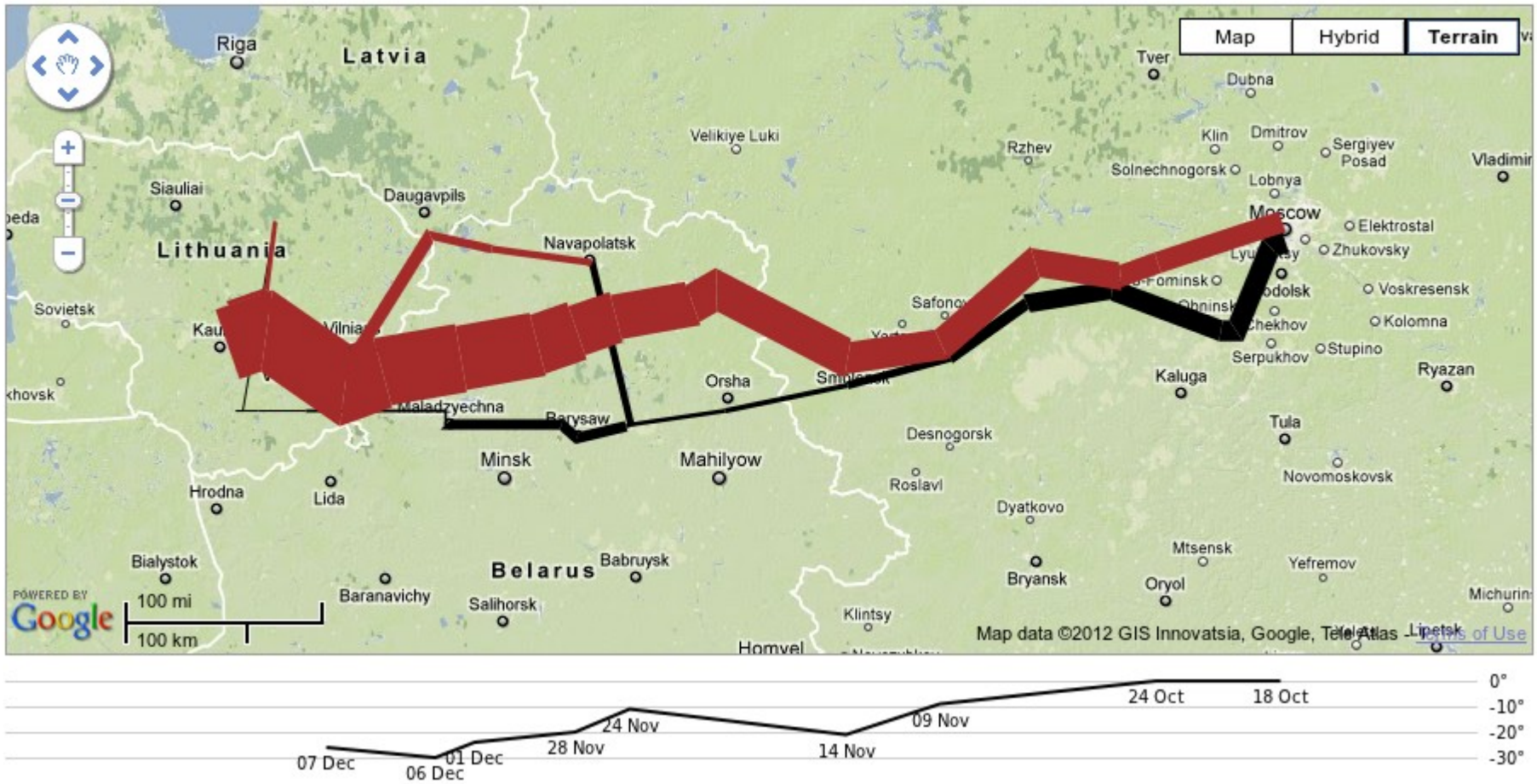
Visualisation



Charles Minard 1869

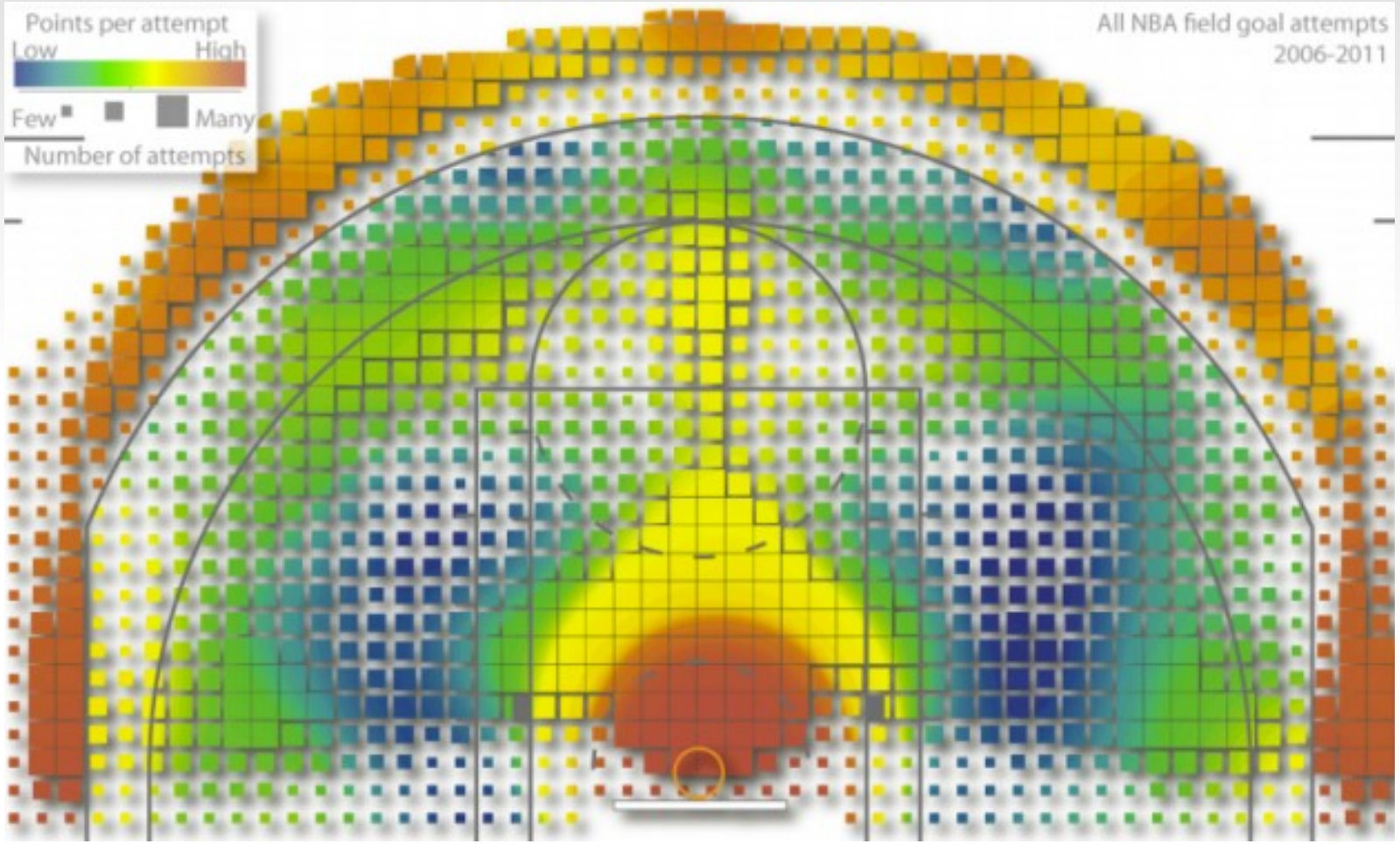
Visualisation

Minard's Napoleon



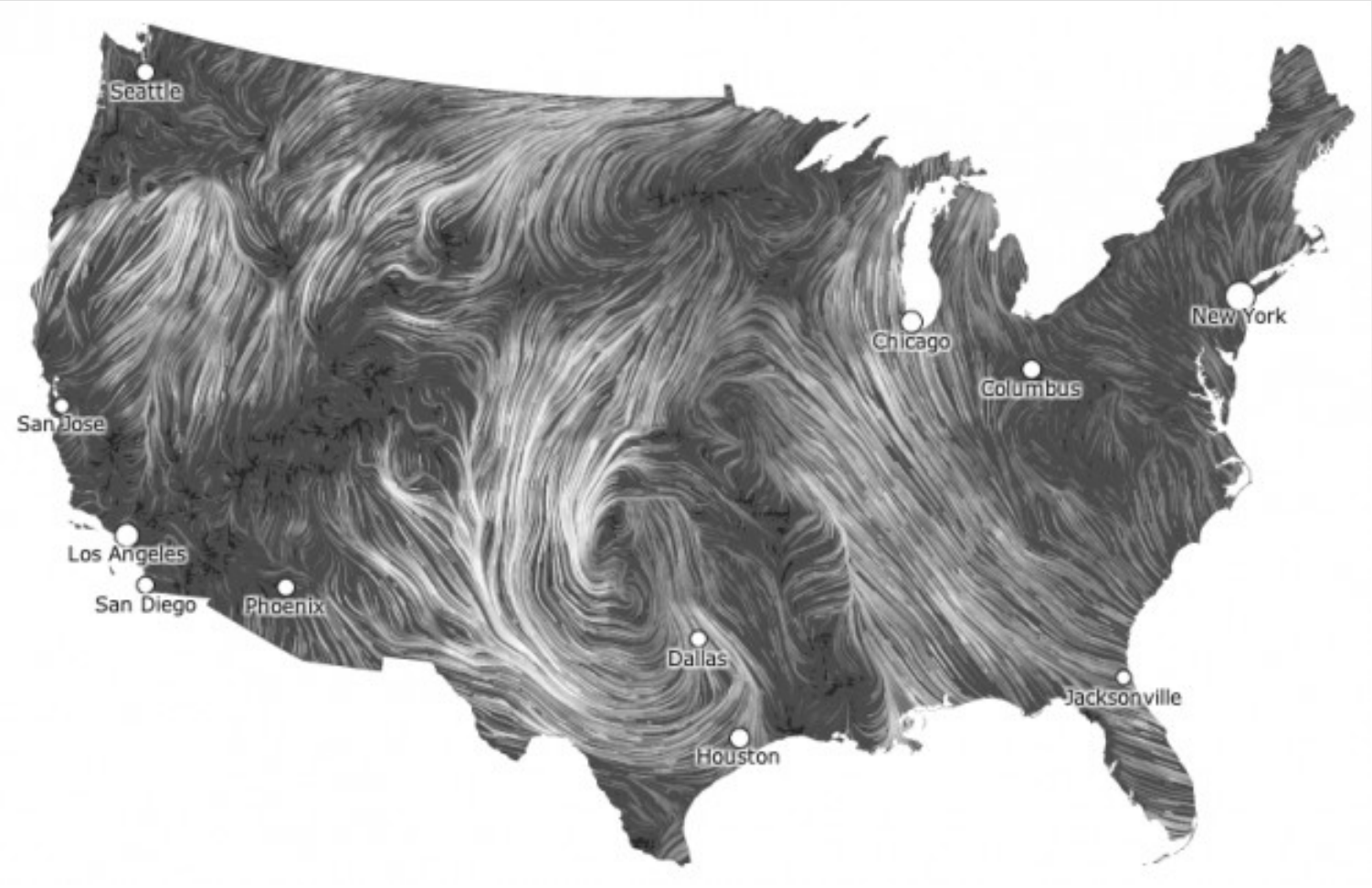
re-creation with Protovis, Google Maps

Visualisation



Kirk Goldberry

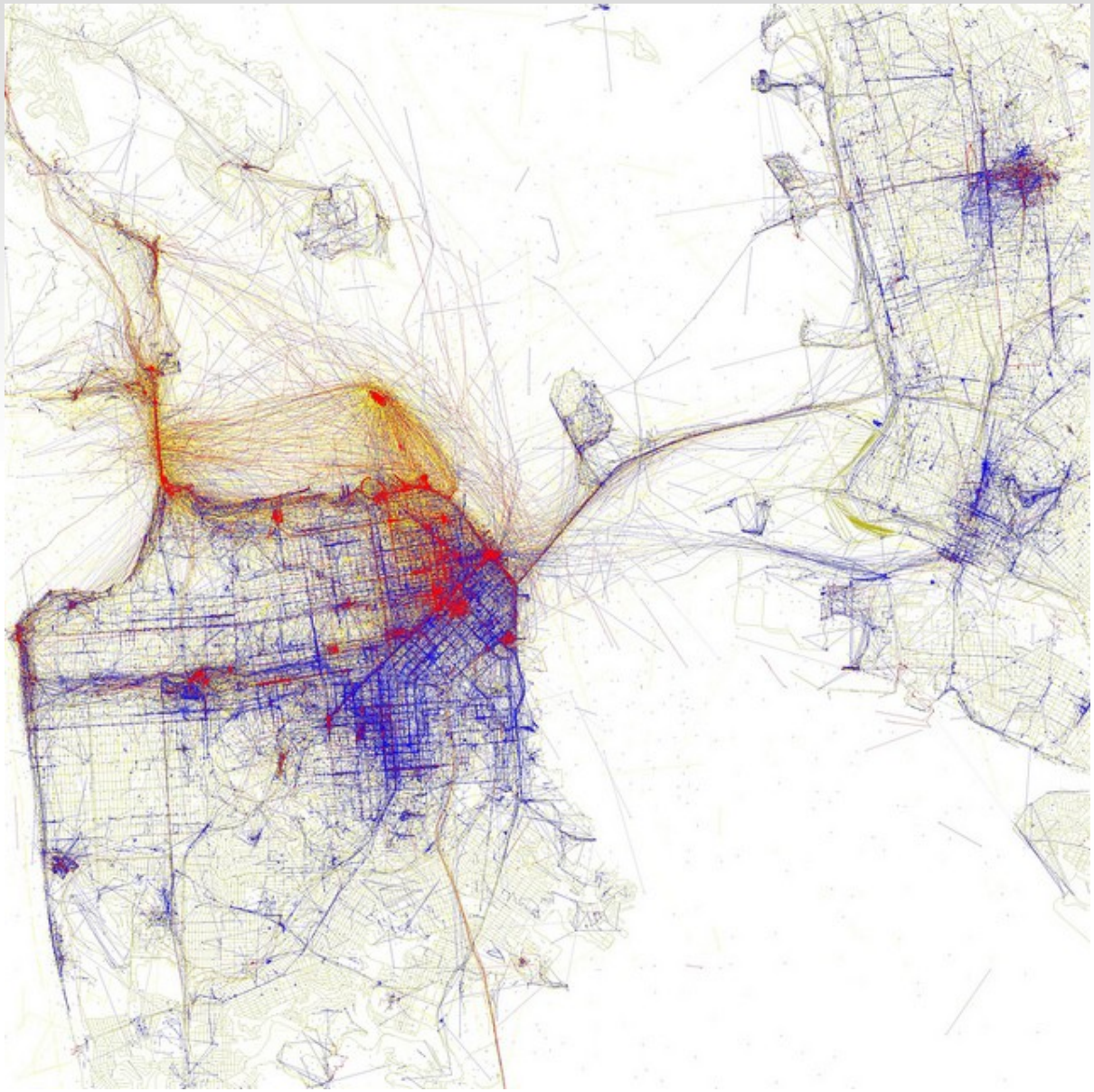
Visualisation



http://hint.fm/wind/

Martin Wattenburg
Fernanda Viegas

Visualisation

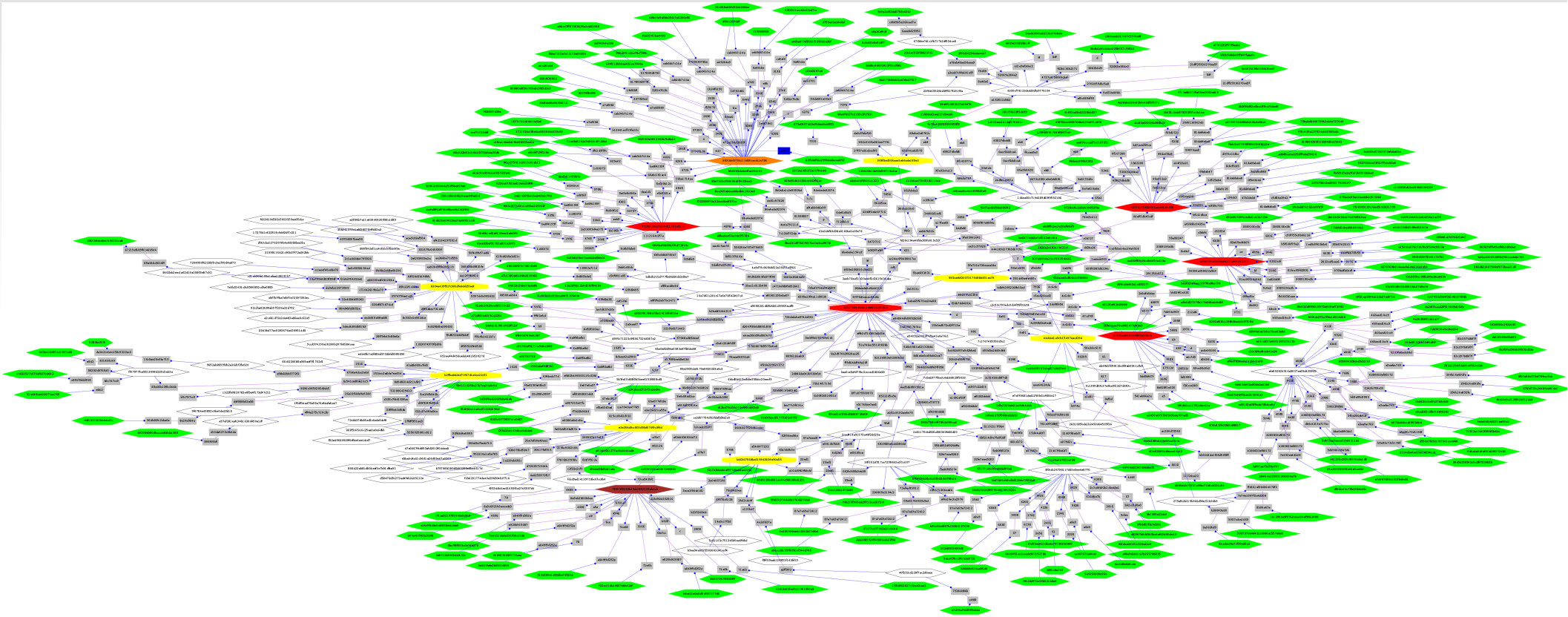


Eric Fischer

Visualisation challenges

- 2 spacial dimensions + 3 colour dimensions
- big data sets can have thousands!
- animation/interactivity often necessary

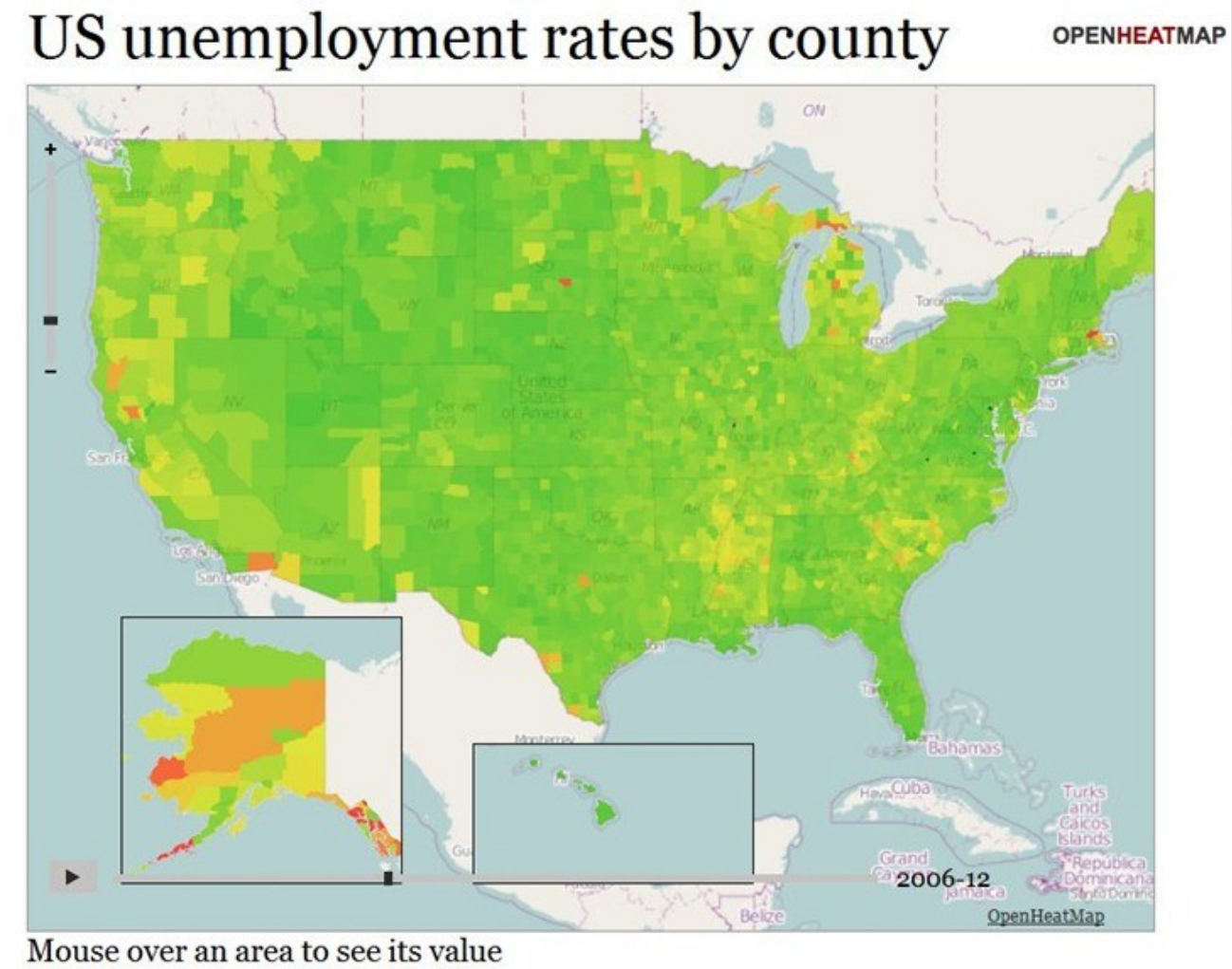
Graph visualisation tools



GraphViz

See also: Protovis, Gephi, Processing,

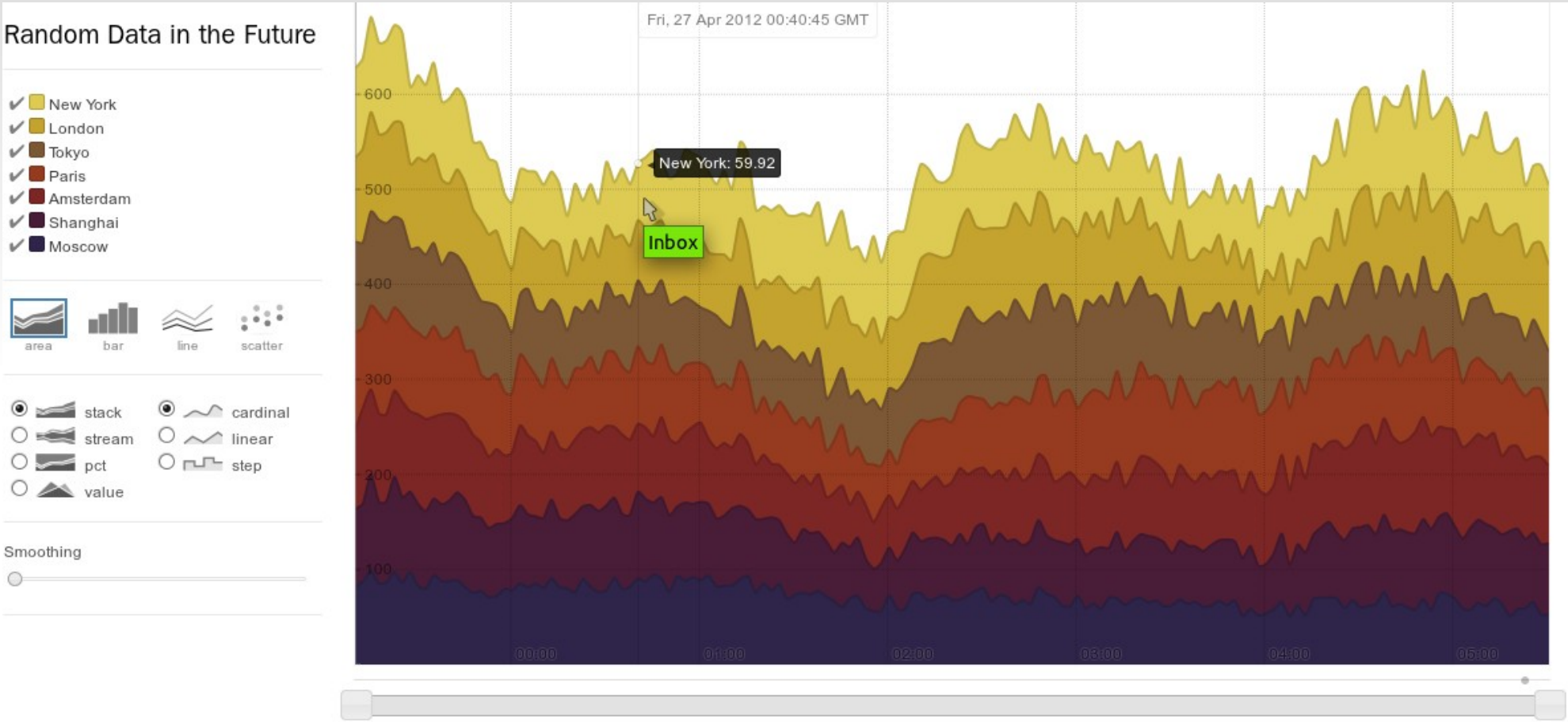
Geographic visualisation tools



OpenHeatMap

See also: FusionTables, GoogleMaps API

Interactive chart tools



Rickshaw

See also: Tableau, Highcharts JS, ExtJS, Raphaël, flot, dojox.charting

Privacy

Privacy

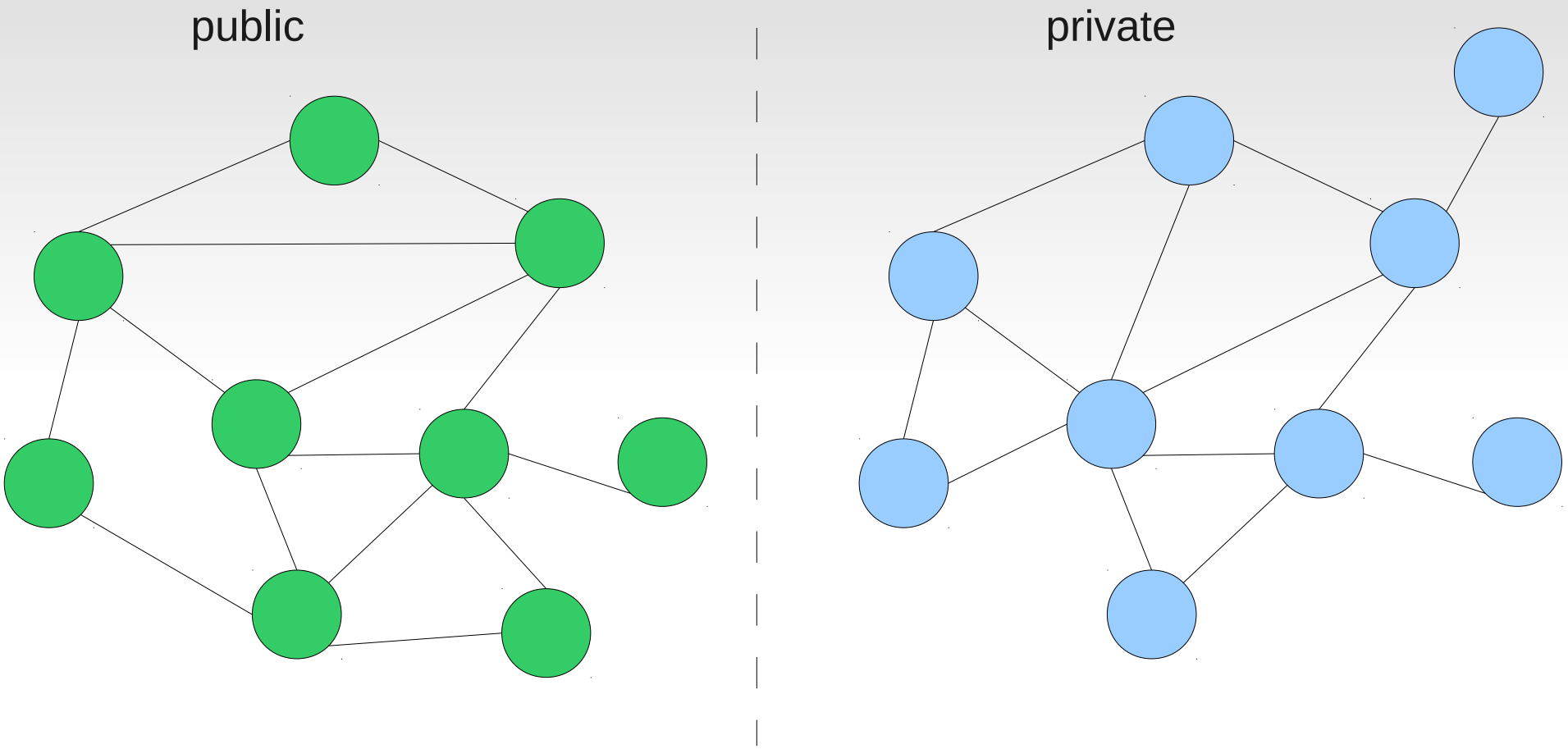
Technology is neither good nor bad, it is neutral

- big data is often generated by people
- obtaining consent is often impossible
- anonymisation is very hard...

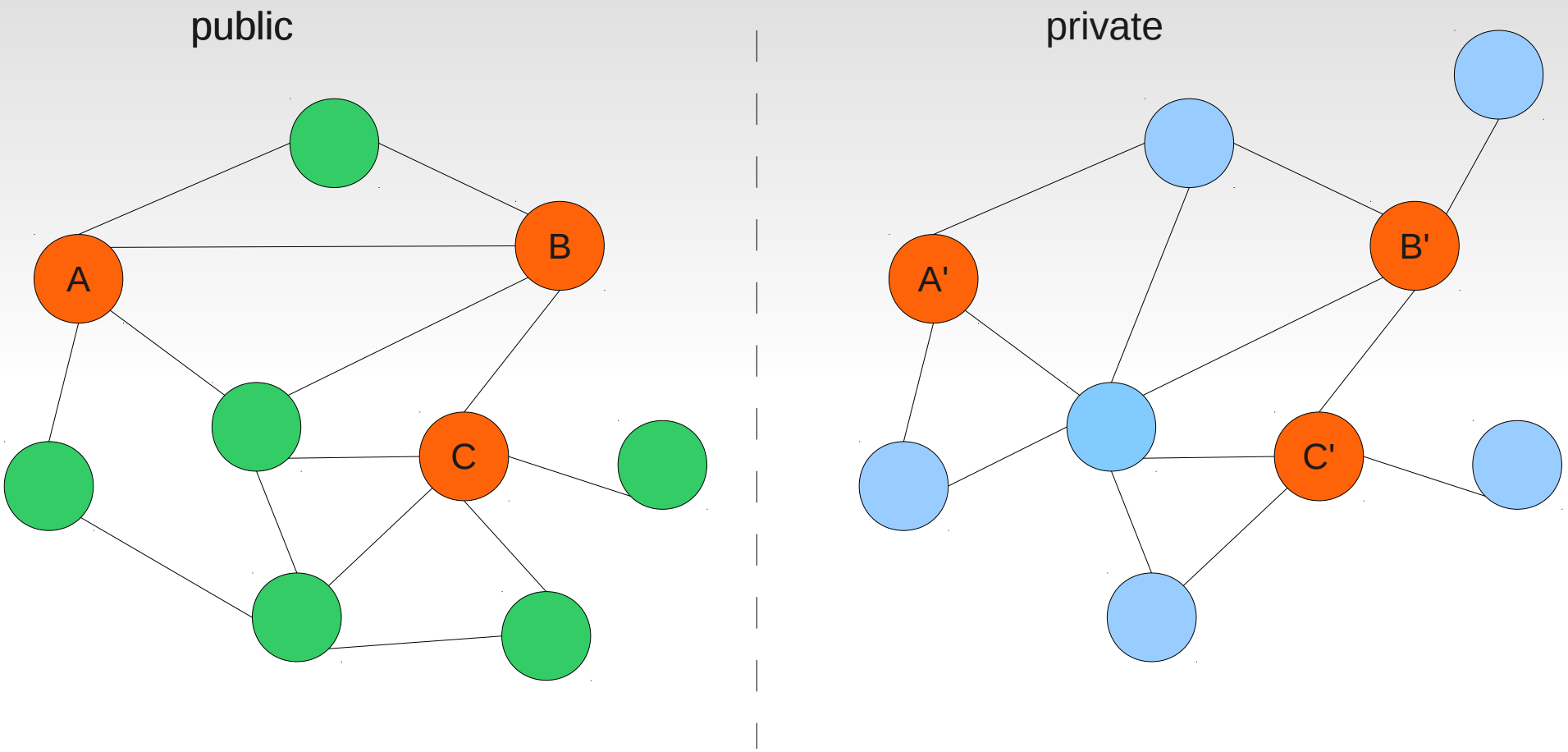
You only need 33 bits...

- birth date, postcode, gender
  - Unique for 87% of US population (Sweeney 1997)
- preference in movies
  - 99% of 500k with 8 ratings (Narayanan 2007)
- web browser
  - 94% of 500k users (Eckersley 2010)
- writing style
  - 20% accurate out of 100k useres (Naraynanan 2012)

Cross-graph de-anonymisation

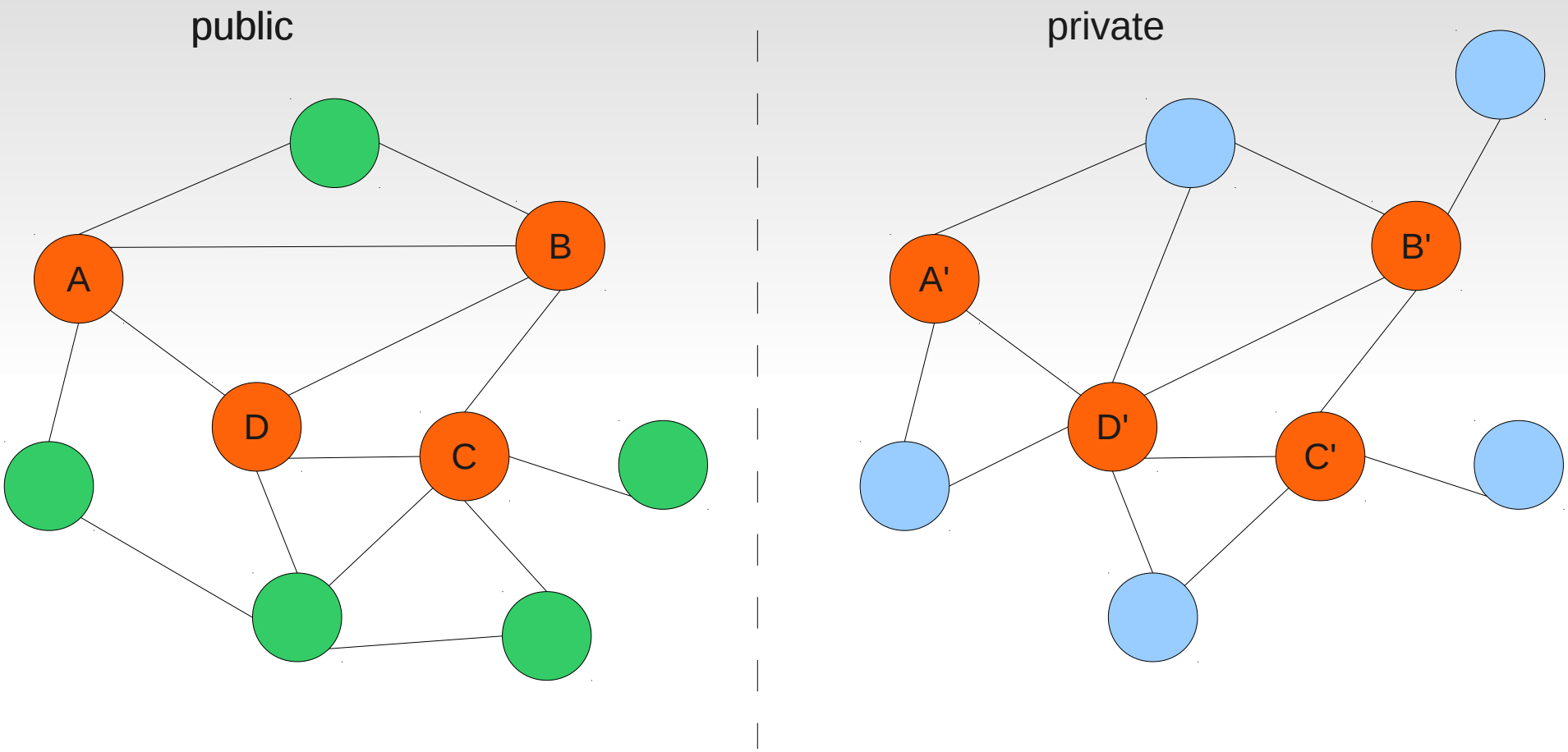


Cross-graph de-anonymisation



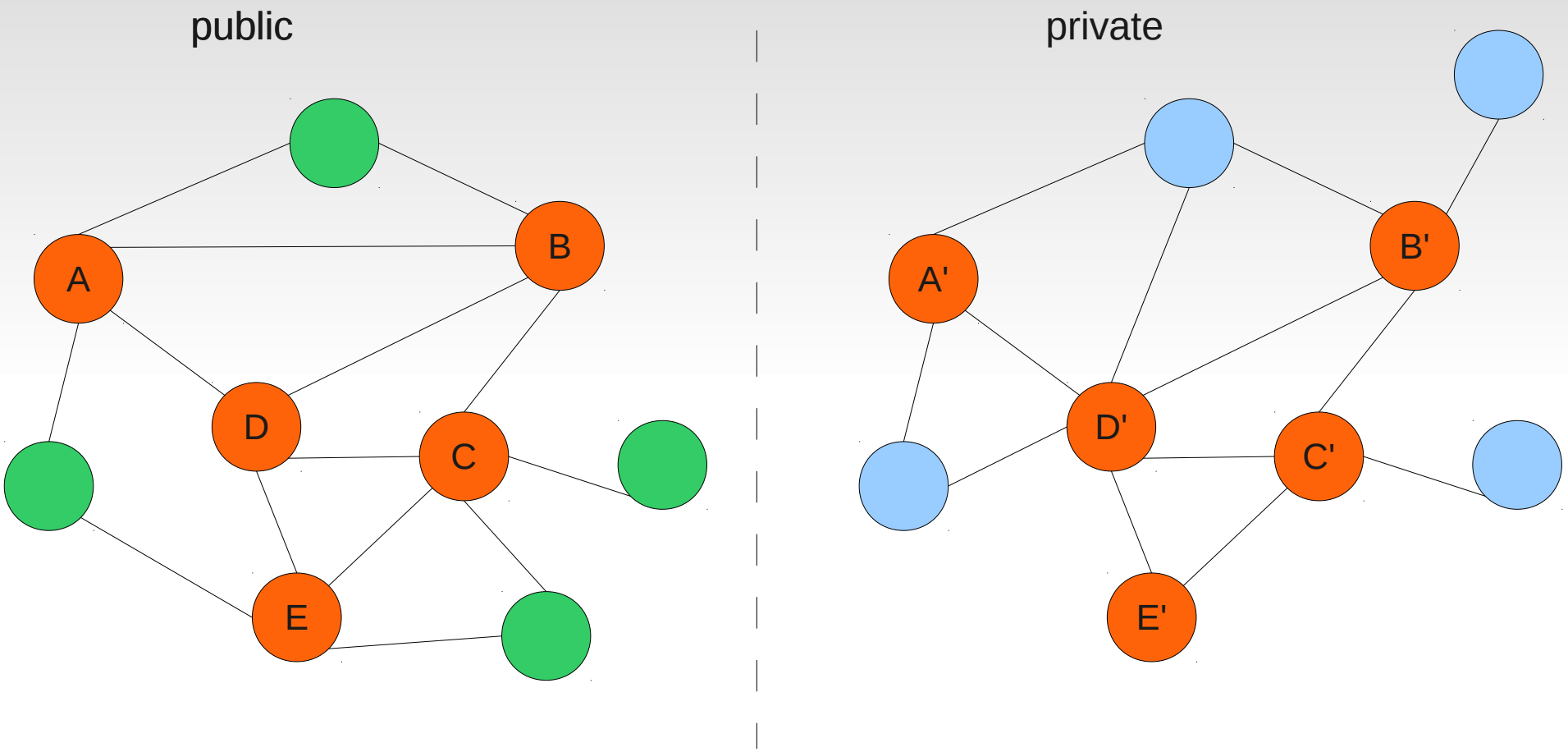
Step 1: identify seed nodes

Cross-graph de-anonymisation



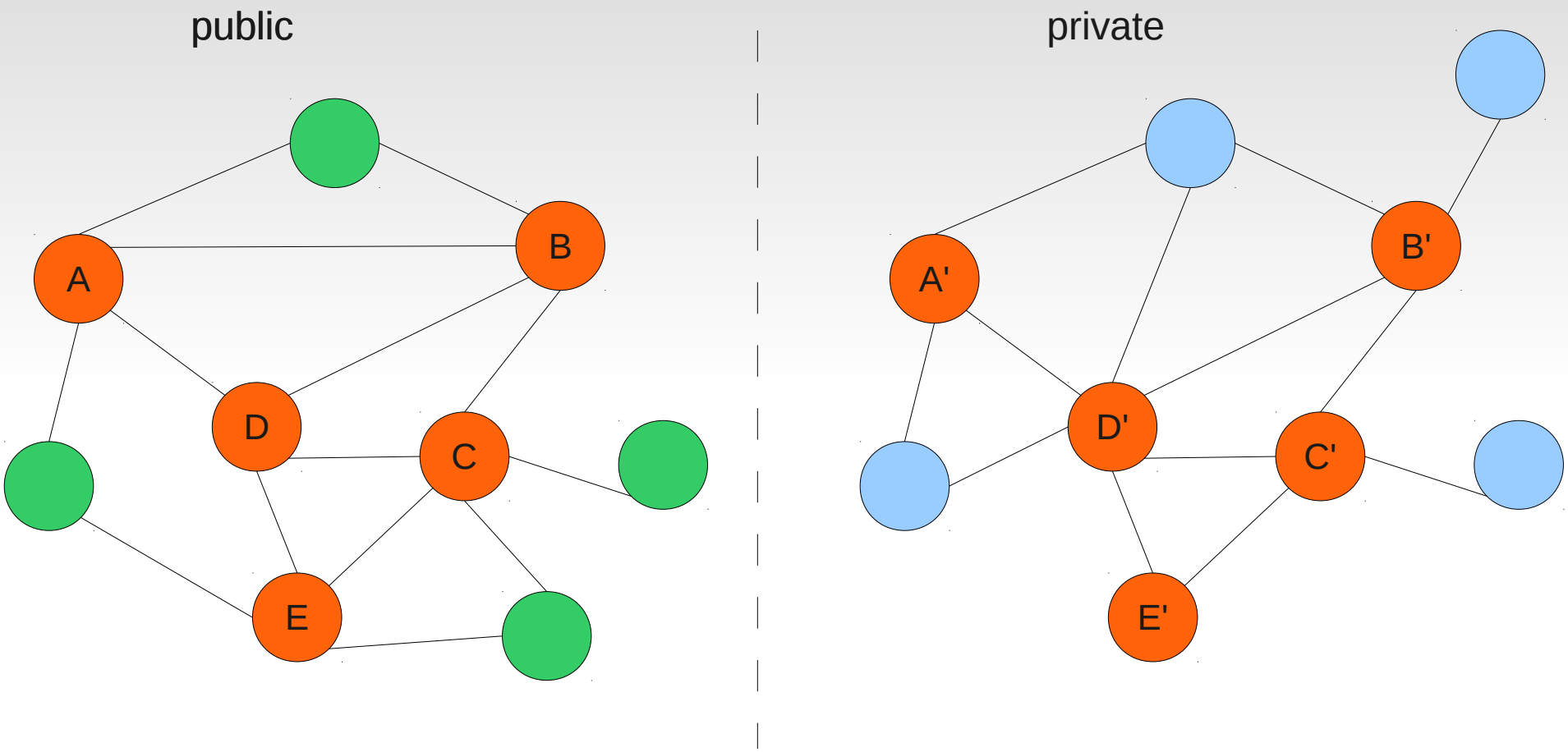
Step 2: assign mappings based on mapped neighbors

Cross-graph de-anonymisation



Step 3: iterate

Cross-graph de-anonymisation



Step 3: Iterate

31% of common Twitter/Flickr users found given **30** seeds!

Homophily

Birds of a feather link together

- age
- gender
- political orientation
- sexual orientation

Thank you