W4111
Introduction to Databases
Spring 2019

Computer Science Department

Columbia University

Data

Data

is for serious business

Data

is at the center of most things.

Data

is at the center of *everything*


Data

Data Sizes

Bit
(⅛ byte)

1/8 of a letter

Nibble
(½ byte)

1/2 of a letter

Byte
(1 byte)

1 letter

Megabyte
(1,024 kilobytes)

1 book

Gigabyte
(1,024 megabytes)

1600 books

Terabyte
(1,024 gigabytes)

1,600,000 books

Petabyte
(1,024 terrabytes)

160,000,000 books

1 exabyte is equivalent toabout **3000 times** the entire content of the Library of Congress.

Exabyte
(1,024 petabytes)

Only 10,000 miles short of reaching the moon!

1,600,000,000,000 books

2.5 quintillion bytes of data are created daily, produced by everything from photos uploaded to social media websites, to weather balloons, to the Curiosity rover currently exploring Mars.

Bigger Than Big Data

THE PAST

Digital storage grew annually by 23% between 1986 and 2007.

Most data was stored on **videotapes** such as VHS cassettes in the pre-digital revolution world of the late 1980s, Vinyl LP records, audio cassette tapes, and photography accounted for significant portions as well.

Paper-based storage represented 33% of all data storage on its own in 1986.

25% of all data stored in the world in 2000 was stored digitally.

2002 is the first year that digital storage capacity overtook analog capacity.

94% of all data was stored in digital format by 2007.

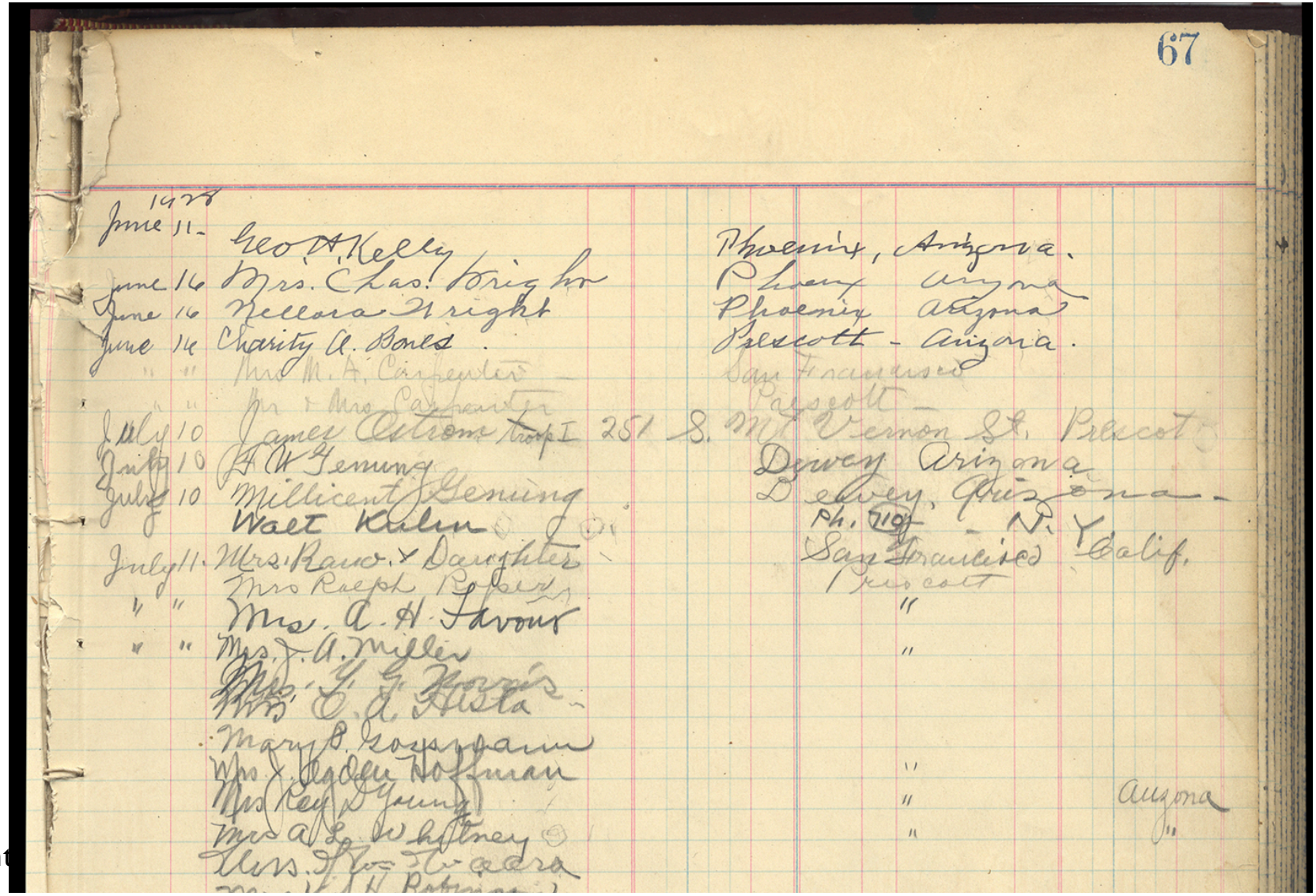
PRESENT

Today, more than 2.5 exabytes (2.5 billion gigabytes) of data is generated every single day. This is expected to continue growing at a significant rate with mobile devices accounting for much of this data.

Some experts have estimated that 90% of all of the data the world today was produced within the last two years.

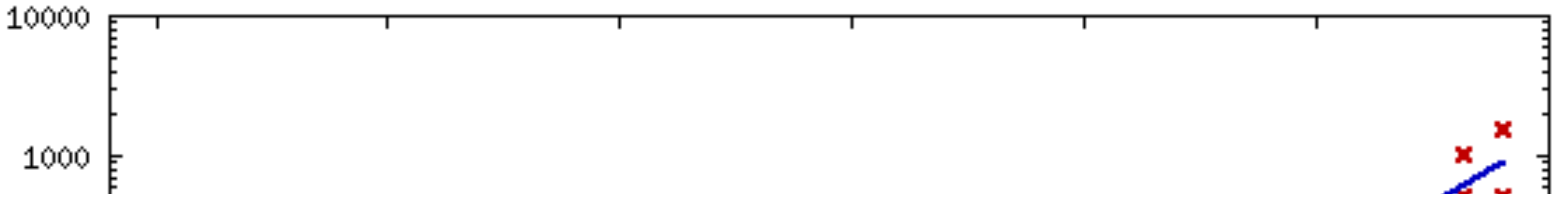
How did we get here?

Data was *Manual*



Data was *Expensive*

Data is *Cheap*



U32 Shadow™ 1TB External USB 3.0 Portable Hard Drive

by Oyen Digital

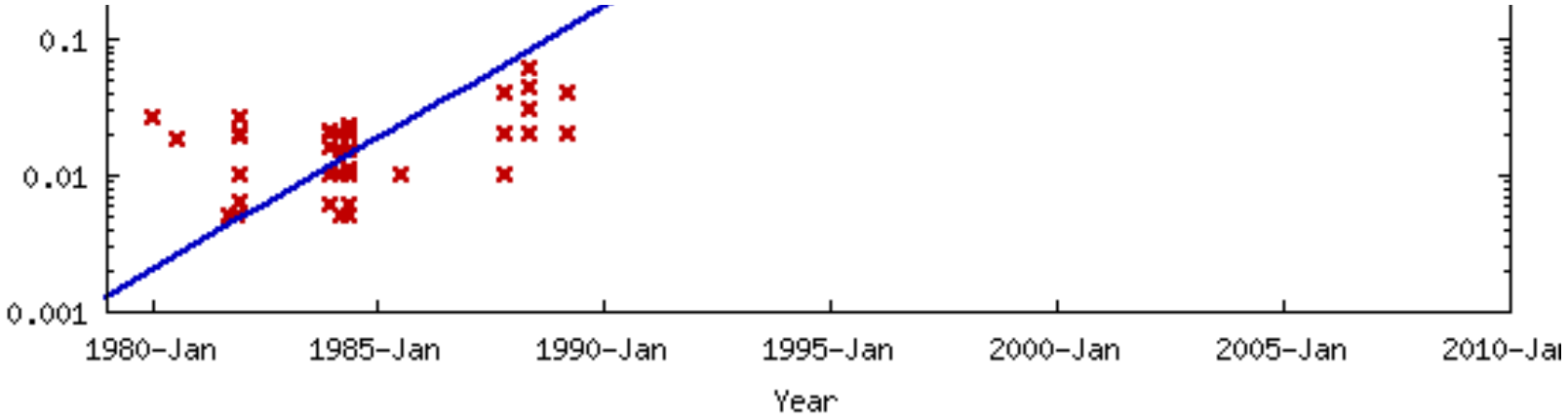
$84.95 Prime

Only 4 left in stock - order soon.

More Buying Choices

$84.95 new (2 offers)

$74.33 used (1 offer)



Data is *Automated*

Physical devices

Data is *Automated*

Physical devices

Software logs

Data is *Ubiquitous*

Physical devices

Software logs

Phones

Data is *Ubiquitous*

Physical devices

Software logs

Phones

GPS/Cars

vodafone ES LTE 6:50 PM 23%

sleepnumber.com

1-888-411-2188 STORES

sleep number

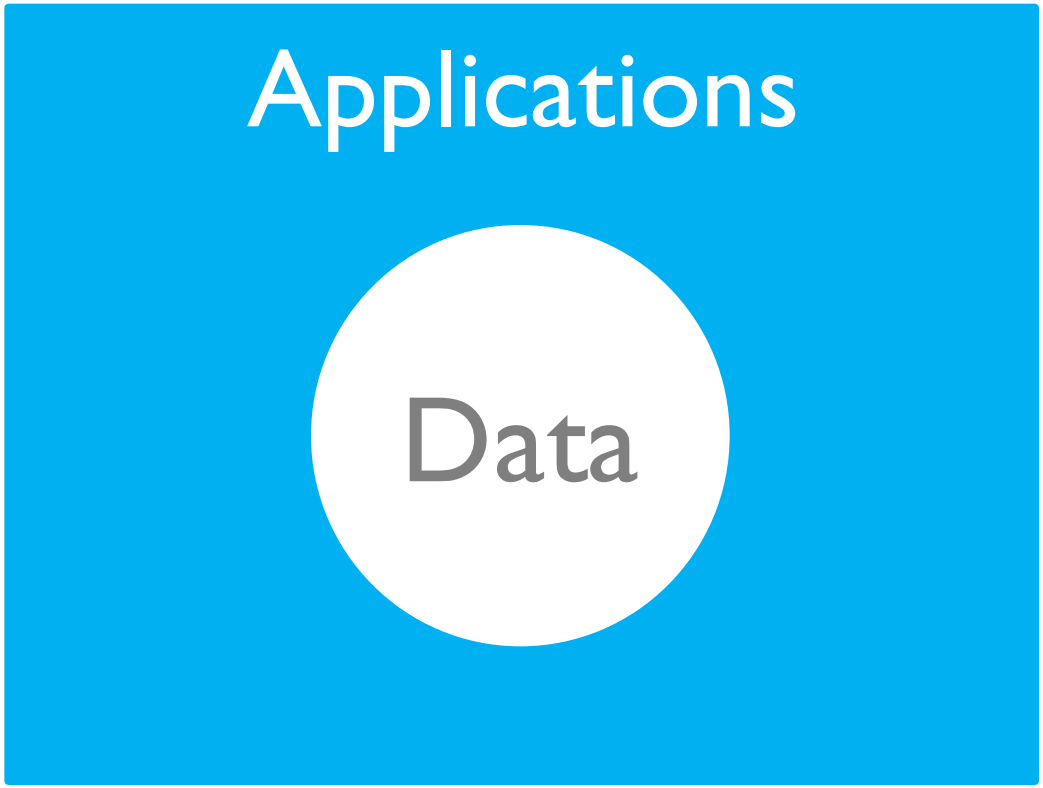
- Information You provide to Us on a financing application
- Information You provide to Us to allow Your participation in a partner's loyalty program

Once You create a User Profile, We also may collect Personal Information, which may include, among other types of information:

- Revised or updated User Profile information
- Biometric and sleep-related data about how You, a Child, and any person that uses the Bed slept, such as that person's movement, positions, respiration, and heart rate while sleeping
- Audio in Your room to detect snoring and similar sleep conditions


Data

What Applications?



What are we doing with data?

Health

What are we doing with data?

Health

What are we doing with data?

Health

Investigative Journalism

What are we doing with data?

Health

Investigative Journalism

Recommendations

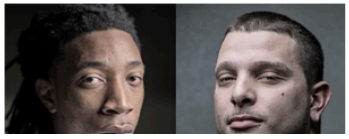
What are we doing with data?

MACHINE BIAS

Besieged Facebook Says New Ad Limits Aren't Response to Lawsuits

The social network is removing 5,000 options that regulators say enable advertisers to discriminate.

by Ariana Tobin and Jeremy B. Merrill, Aug. 23, 12:48 p.m. EDT



Facebook's move to eliminate 5,000 options that enable advertisers on its platform to limit their audiences is unrelated to lawsuits accusing it of fostering housing and

FOLLOW PROPUBLICA

Twitter

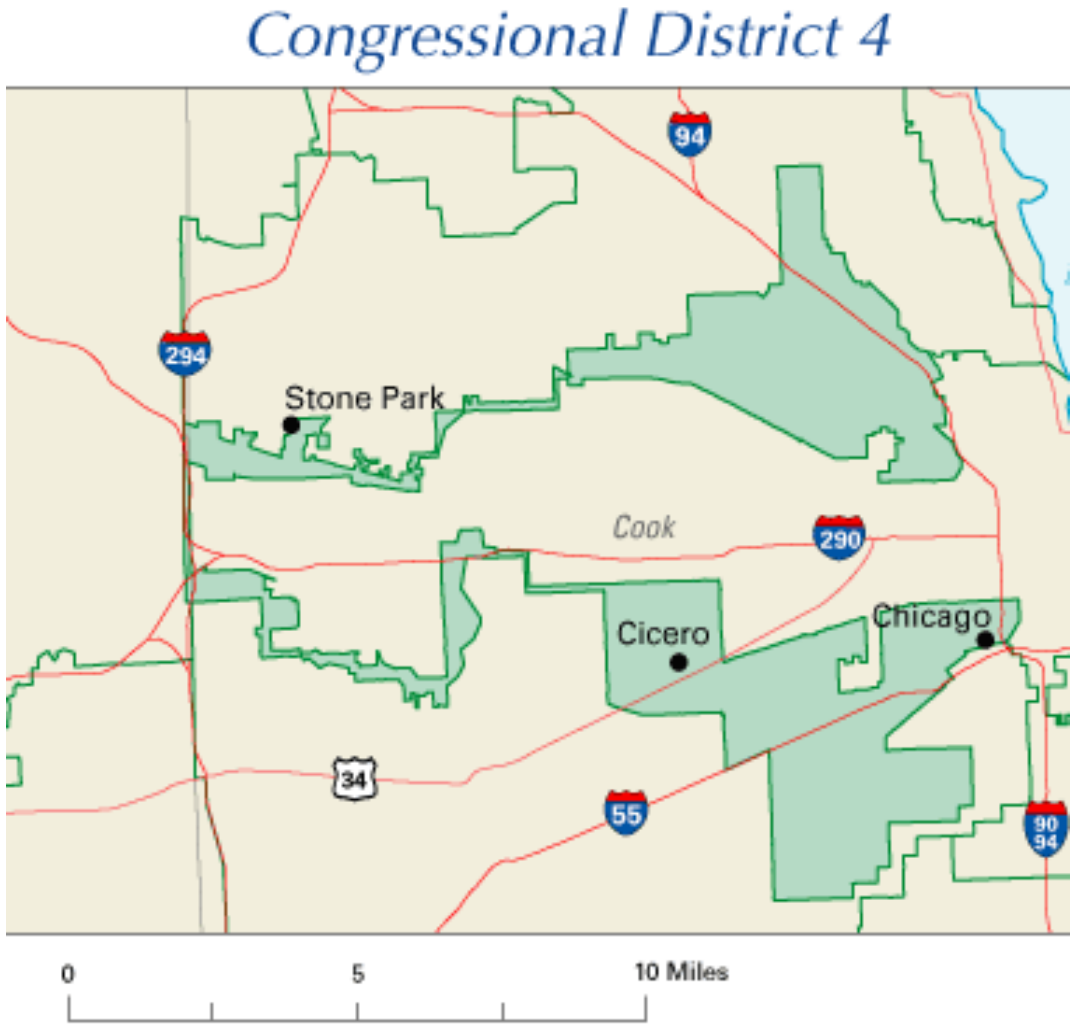
What are we doing with data?

Health

Investigative Journalism

Recommendations

Politics



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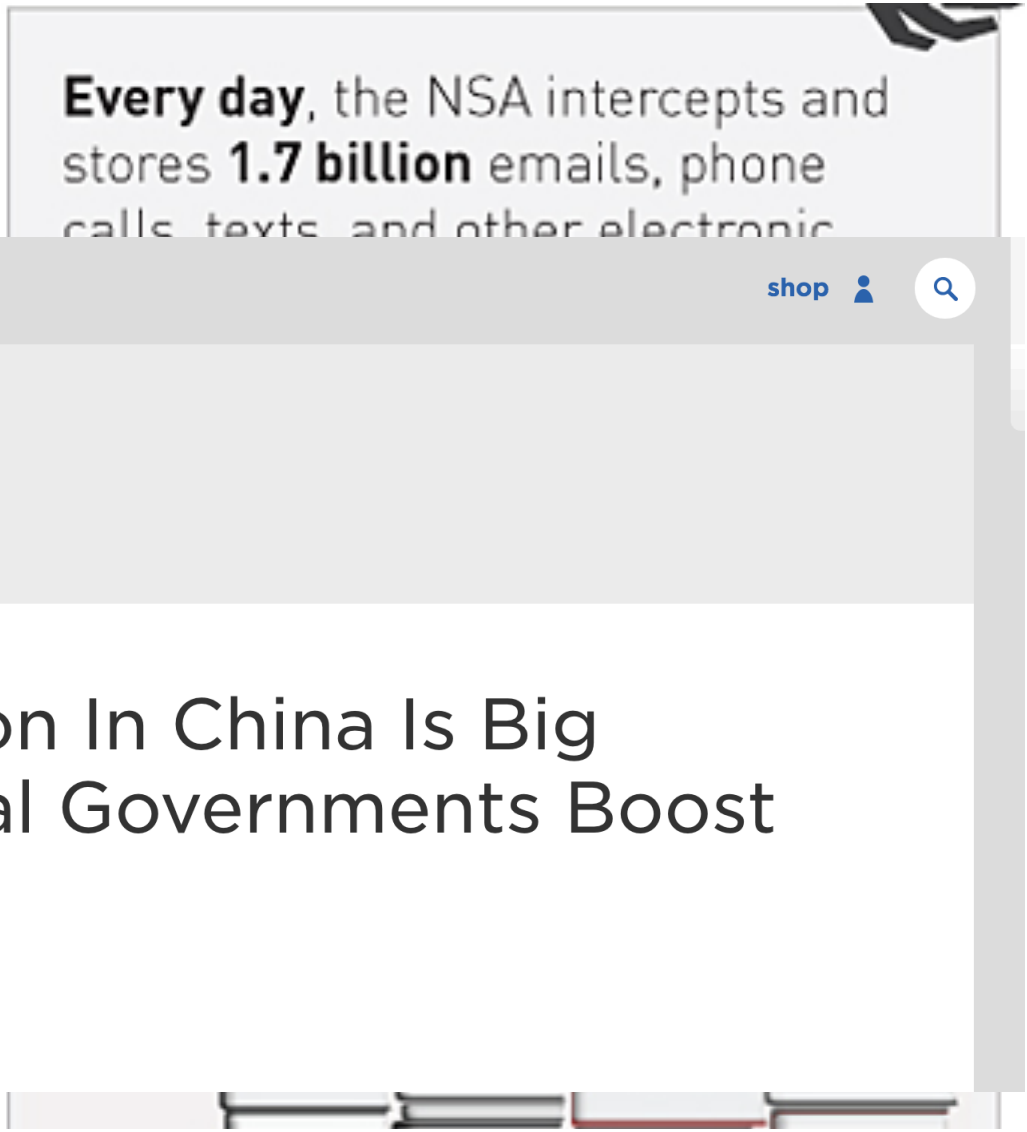


What are we doing with data?

Health

Investigative Journalism

Recommendations

Politics

Surveillance

Identity

HARVARD | BUSINESS | SCHOOL

30 APR 2012 RESEARCH & IDEAS

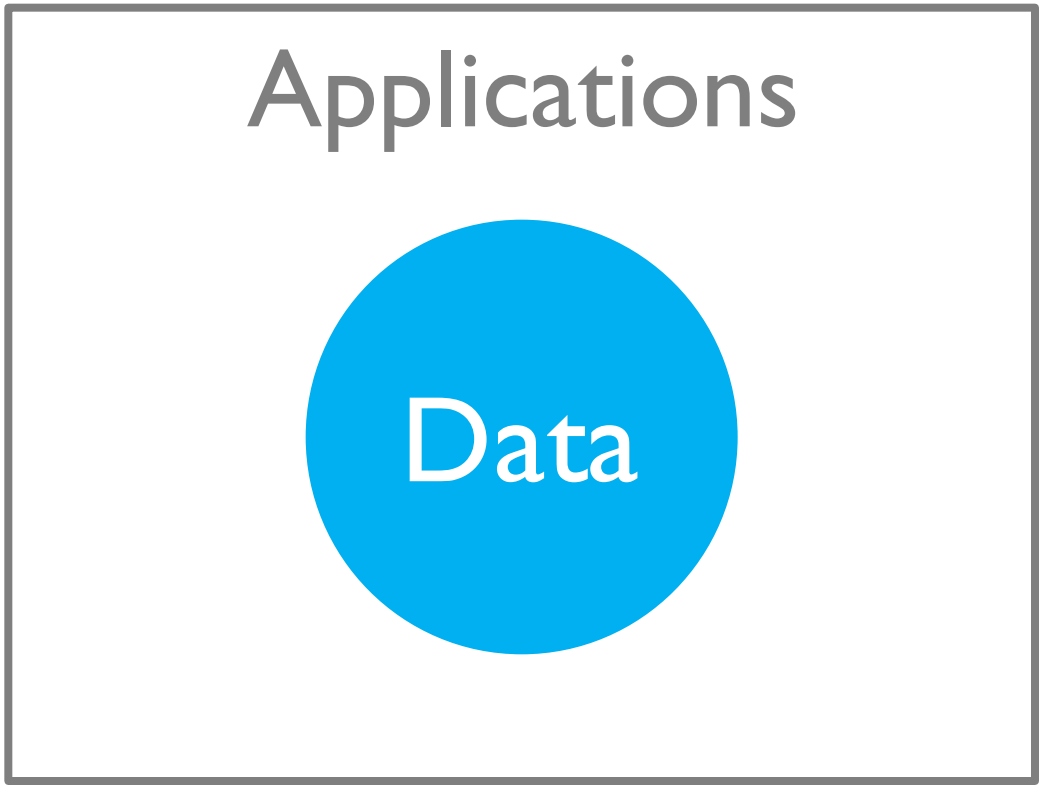
India's Ambitious National Identification Program

Comments 30 Email Print Download Share Recommend Share 92

The Unique Identification Authority of India has been charged with implementing a nationwide program to register and assign a unique 12-digit ID to every Indian resident—some 1.2 billion people—by 2020. In a new case, Professor Tarun Khanna and HBS India Research Center Executive Director Anjali Raina discuss the complexities of this massive data management project.

"YOU ARE BASICALLY DENIED ALMOST EVERYTHING IF YOU CAN'T PROVE WHO YOU ARE."

What data?



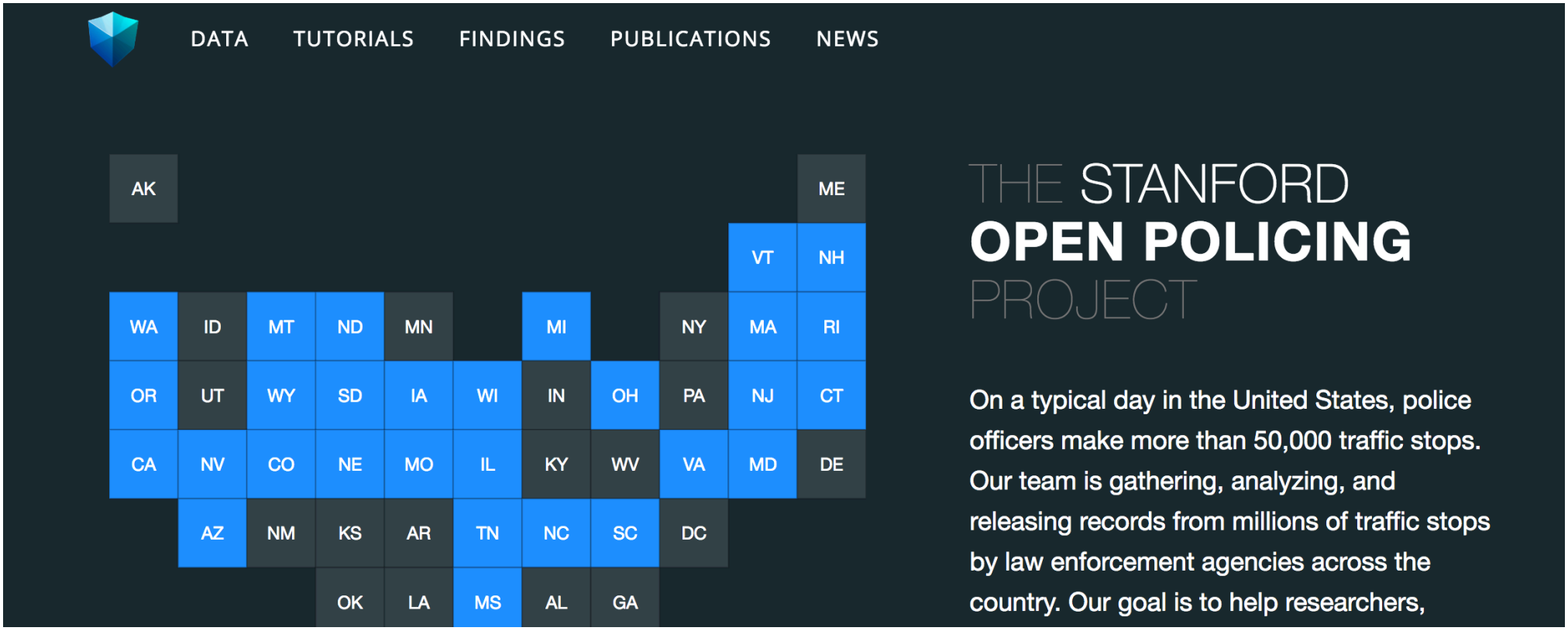
What data?

Fake data

What data?

Fake data

Biased data



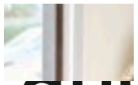
EU may fine political groups misusing personal data to skew elections

It's hoping to prevent another Cambridge Analytica scandal.

Jon Fingas, @jonfingas
08.27.18 in Internet

4 Comments

275 Shares



another record fine from the EU

Chris Smith @chris_writes
August 17th, 2018 at 12:32 AM

Share Tweet

Google has been dealt two huge blows in Europe in recent years, where antitrust investigations have ruled the company abused is position in search as well as in the mobile market. The company received two record fines as a result, which added up to more than €6.74 billion ($7.66 billion). On top of that, a third investigation is in the works and could bring over additional fines.

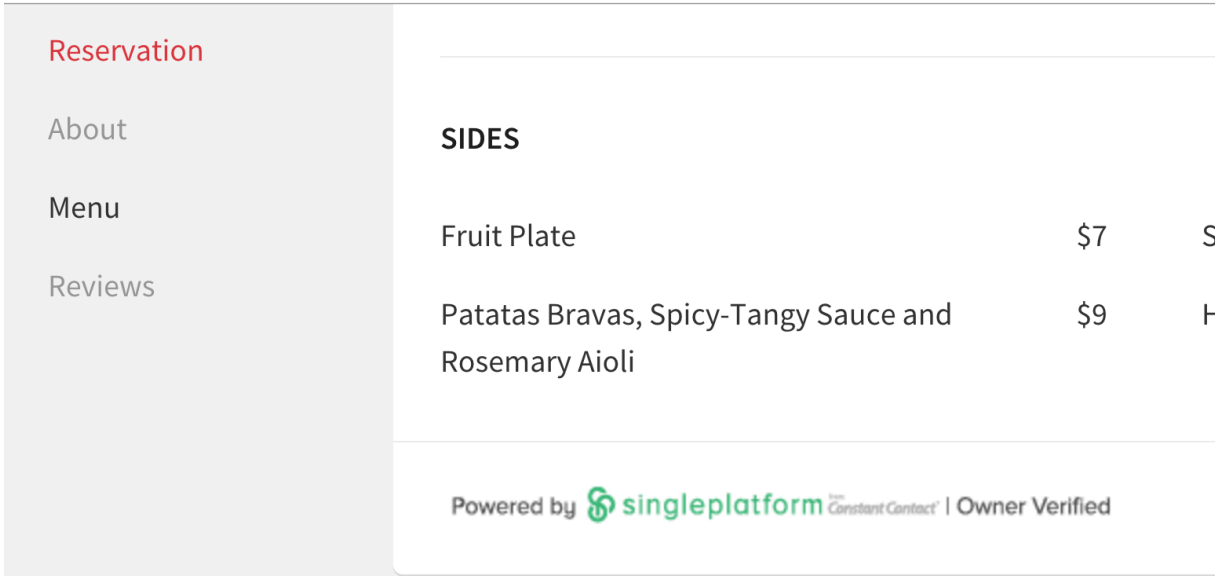
What data?

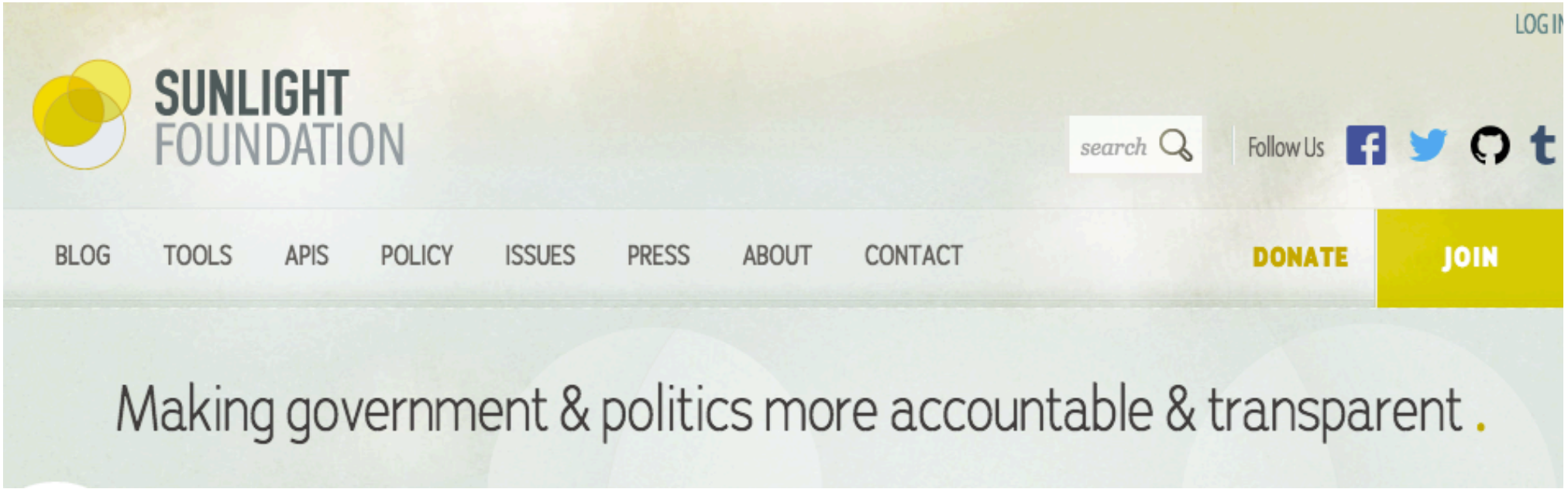
Fake data

Biased data

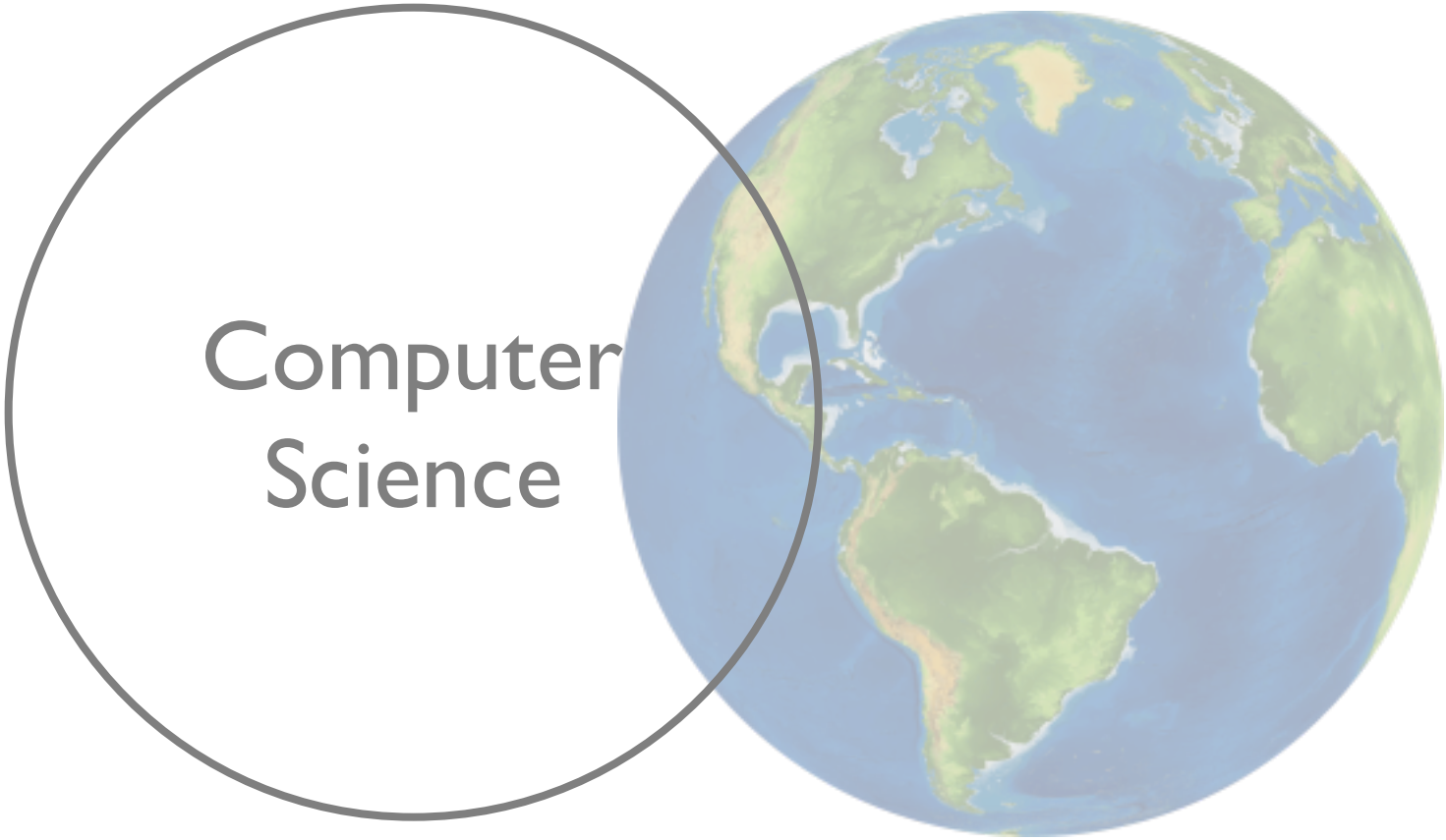
Personal data

Mixed data





Computer Science


Computer
Science


Computer
Science

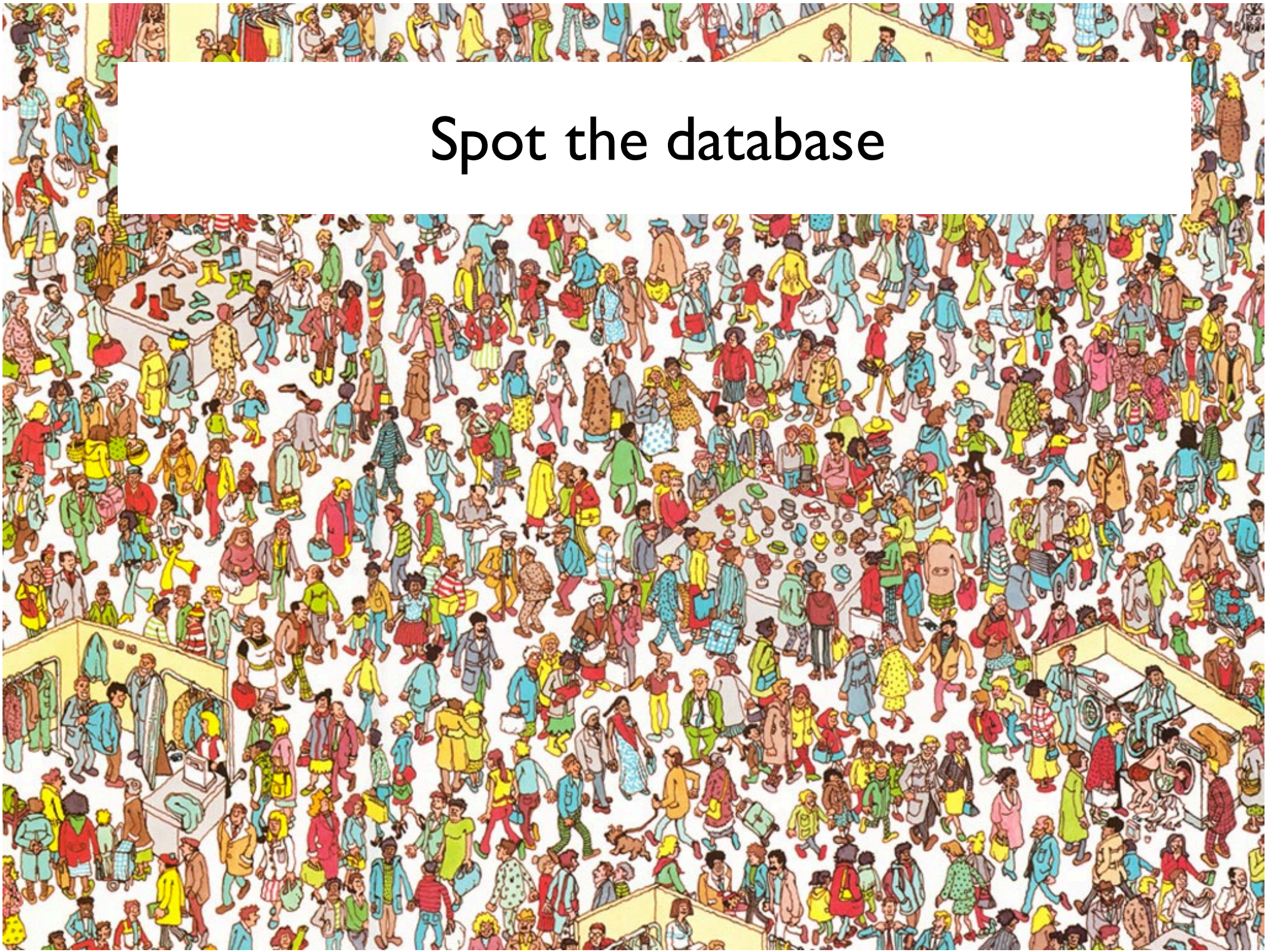
Data will be crucial to
how we live
as individuals and as a society

Data ~~will be~~ **is** crucial to

how we live

as individuals and as a society

Spot the database

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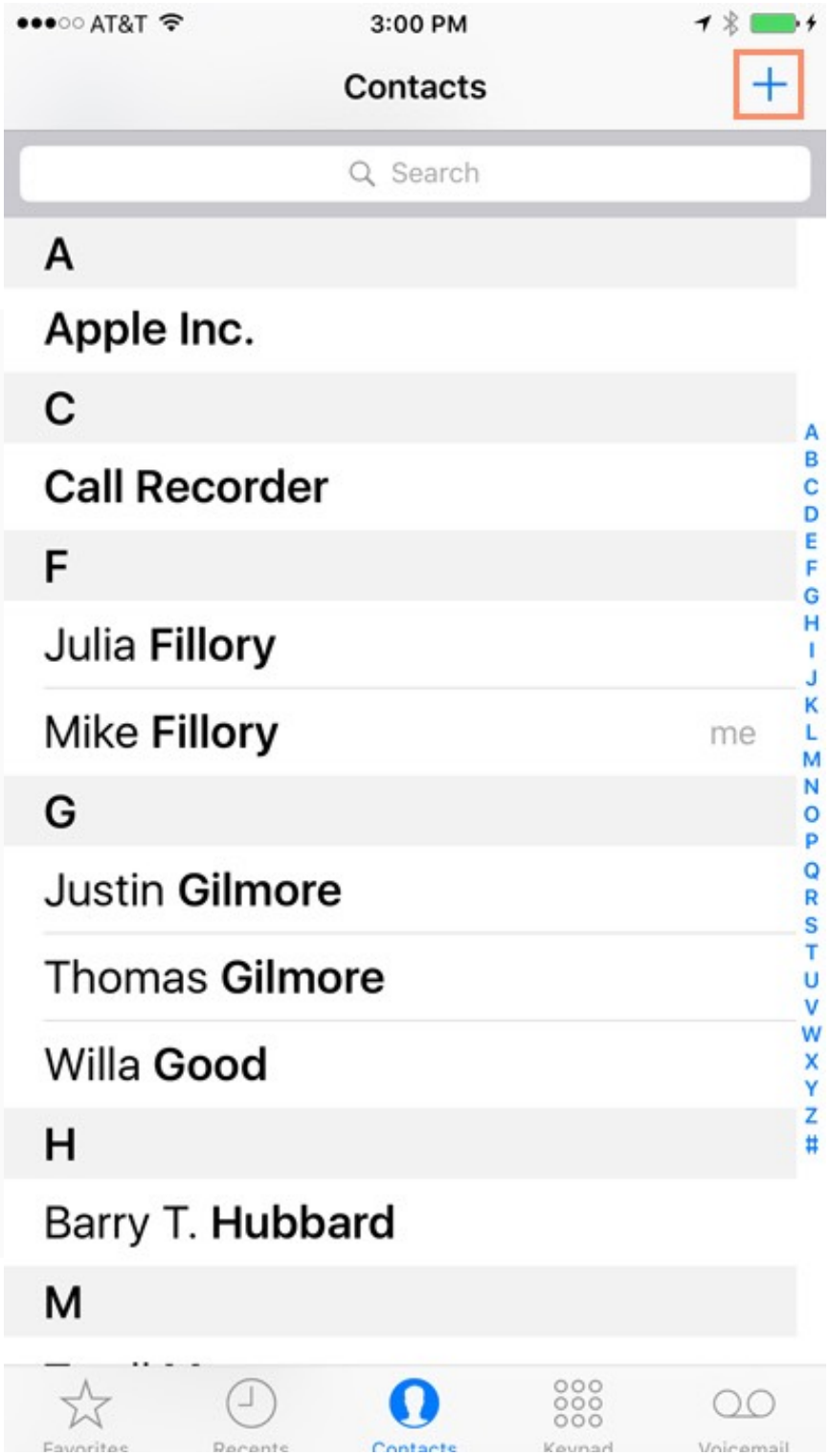
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Julia Fillory
Mike Fillory
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Justin Gilmore
Thomas Gilmore
Willa Good
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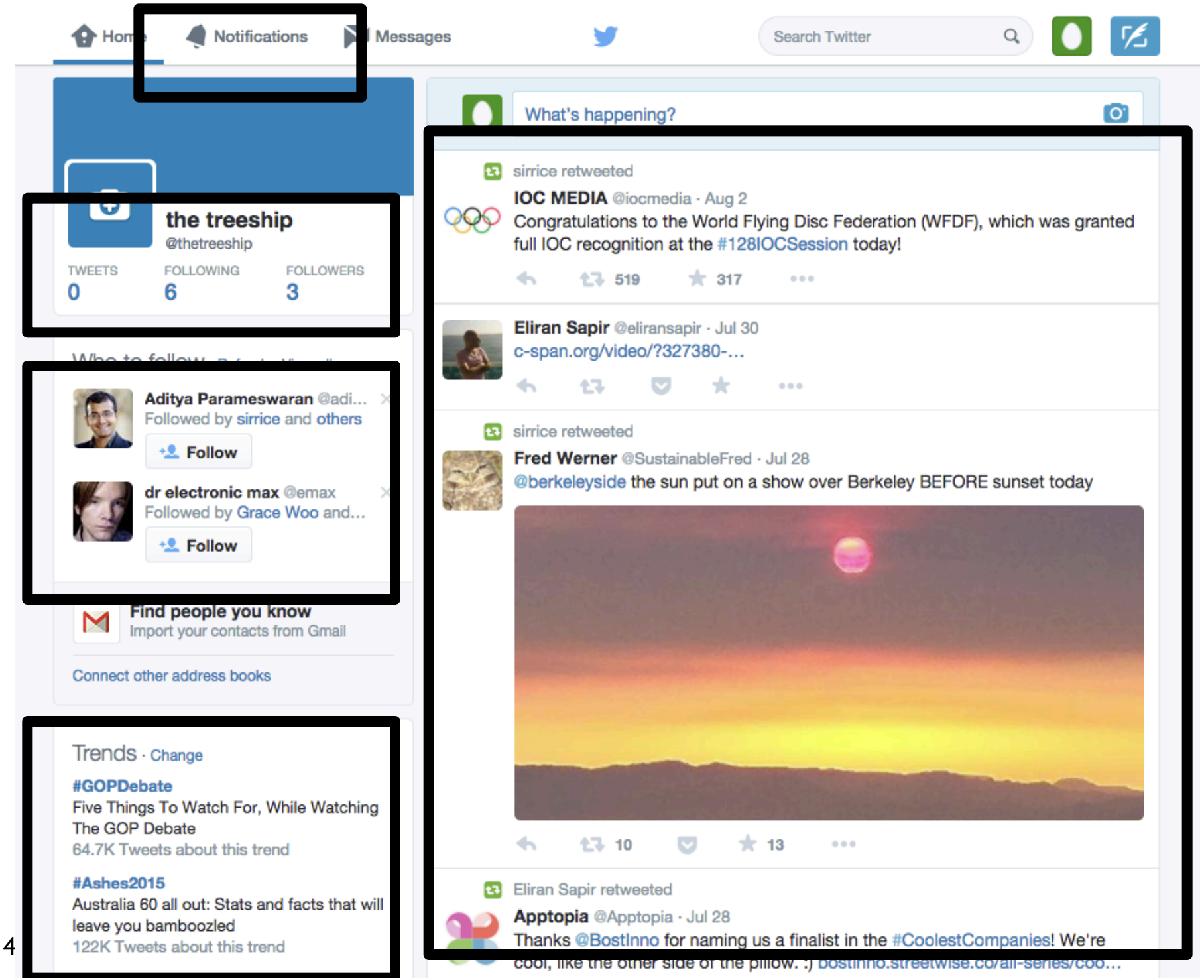
Barry T. Hubbard
M
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z #
Favorites
Recents
Contacts
Keypad
Voicemail


ATM
24 HOUR BANKING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Messages
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What's happening?
the treeship
@thetreeship
TWEETS 0
FOLLOWING 6
FOLLOWERS 3
Aditya Parameswaran @adi...
Followed by sirrice and others
Follow
dr electronic max @emax
Followed by Grace Woo and...
Follow
Find people you know
Import your contacts from Gmail
Connect other address books
Trends · Change
#GOPDebate
Five Things To Watch For, While Watching The GOP Debate
64.7K Tweets about this trend
#Ashes2015
Australia 60 all out: Stats and facts that will leave you bamboozled
122K Tweets about this trend
sirrice retweeted
IOC MEDIA @iocmedia · Aug 2
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519
317
Eliran Sapir @eliransapir · Jul 30
c-span.org/video/?327380-...
sirrice retweeted
Fred Werner @SustainableFred · Jul 28
@berkeleyside the sun put on a show over Berkeley BEFORE sunset today
10
13
Eliran Sapir retweeted
Apptopia @Apptopia · Jul 28
Thanks @BostInno for naming us a finalist in the #CoolestCompanies! We're

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2012-01-04 00:01:23,180 INFO org.apache.hadoop.hdfs.server.datanode.DataNode: Receiving
010
2012-01-04 00:01:23,184 INFO org.apache.hadoop.hdfs.server.datanode.DataNode.clienttrace
 cliID: DFSClient_-603743753, offset: 0, srvID: DS-292194659-127.0.1.1-50010-13247633001
2012-01-04 00:01:23,185 INFO org.apache.hadoop.hdfs.server.datanode.DataNode: PacketResp
2012-01-04 00:01:23,291 INFO org.apache.hadoop.hdfs.server.datanode.DataNode: Receiving
10
2012-01-04 00:01:23,293 INFO org.apache.hadoop.hdfs.server.datanode.DataNode.clienttrace
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2012-01-04 00:01:23,324 INFO org.apache.hadoop.hdfs.server.datanode.DataNode: Receiving
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2012-01-04 00:01:23,326 INFO org.apache.hadoop.hdfs.server.datanode.DataNode.clienttrace
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2012-01-04 00:01:23,327 INFO org.apache.hadoop.hdfs.server.datanode.DataNode: PacketResp
2012-01-04 00:01:23,409 INFO org.apache.hadoop.hdfs.server.datanode.DataNode: Receiving
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2012-01-04 00:01:23,411 INFO org.apache.hadoop.hdfs.server.datanode.DataNode.clienttrace
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2012-01-04 00:01:23,411 INFO org.apache.hadoop.hdfs.server.datanode.DataNode: PacketResp
2012-01-04 00:01:23,433 INFO org.apache.hadoop.hdfs.server.datanode.DataNode.clienttrace
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2012-01-04 00:01:23,494 INFO org.apache.hadoop.hdfs.server.datanode.DataNode: Receiving
10
2012-01-04 00:01:23,498 INFO org.apache.hadoop.hdfs.server.datanode.DataNode.clienttrace
, cliID: DFSClient_-2054881890, offset: 0, srvID: DS-292194659-127.0.1.1-50010-132476330
2012-01-04 00:01:23,498 INFO org.apache.hadoop.hdfs.server.datanode.DataNode: PacketResp
2012-01-04 00:01:23,523 INFO org.apache.hadoop.hdfs.server.datanode.DataNode: Receiving
010
```


To the Reader.
SHAKESPEARES
COMEDIES,
HISTORIES, &
TRAGEDIES.

What is a Database?

Structured data

What is a Database?

Lots of

Structured data

Database Management System (DBMS)

A system to store, manage and access databases

Database Management System (DBMS)

System to safely and reliably store lots of persistent structured data and is convenient for multiple users to efficiently access and modify.

Is a script a DBMS?

Javascript/Python Script

- Data stored in variables (RAM)
- Very fast access

Is Excel a DBMS?

Microsoft office security

Visually access/modify/compute over data cells

Click save to store persistently

Is the file system a DBMS?

Manages files that are persistently stored on disk

Open/read/seek/write access to files

Access via file names

Access control via permissions

Is the file system a DBMS?

You and a friend edit the same text file

Save at the same time

What happens?

1. Your changes survive
2. Friend's changes survive
3. Both changes survive
4. No changes survive
5. ¯_(ツ)_/¯

Is the file system a DBMS?

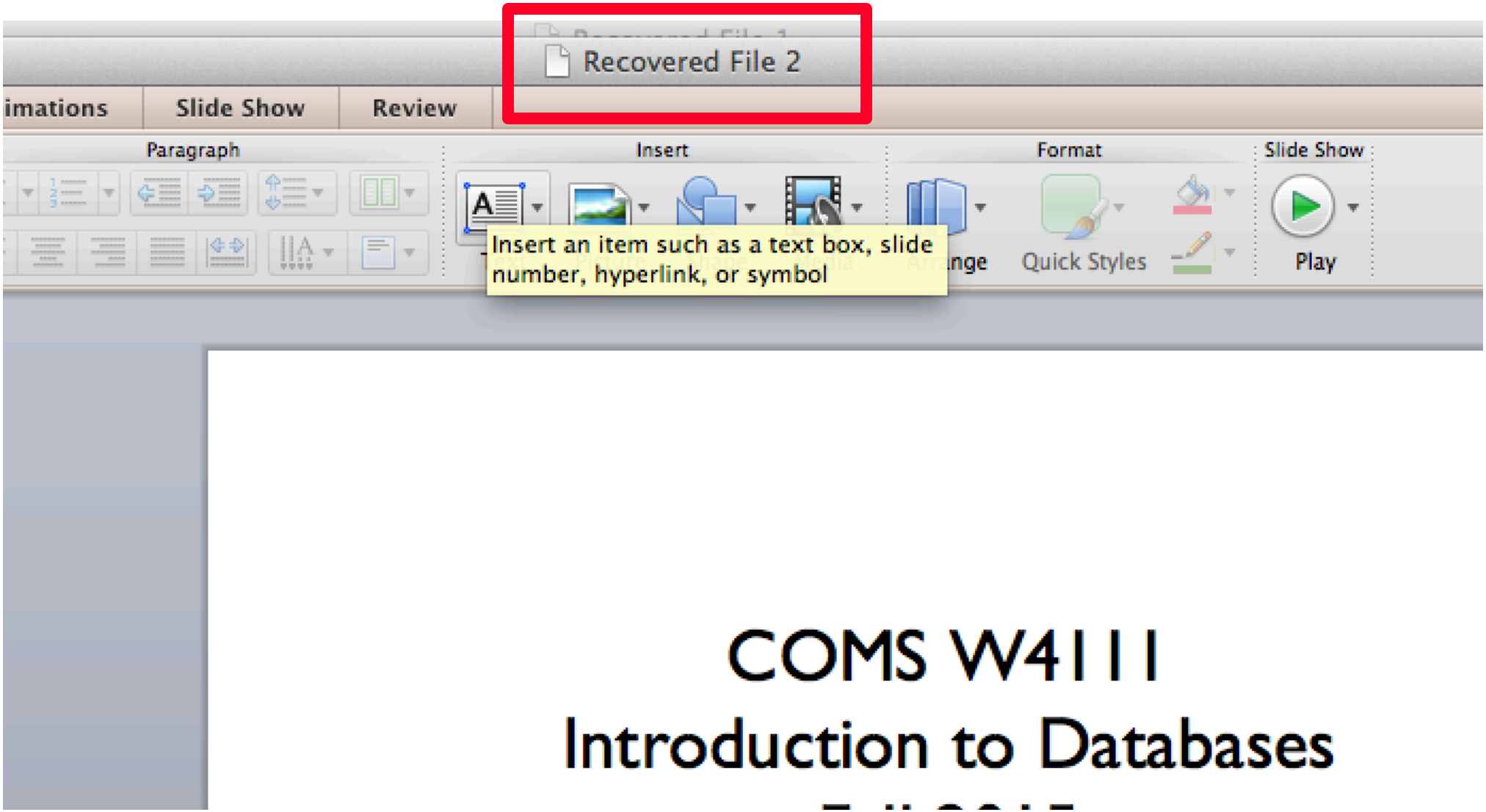
You edit a text file

Computer crashes

What happens?

1. All changes survive
2. No changes survive
3. Changes from last save survive
4. ¯_(ツ)_/¯

Is the file system a DBMS?



Want *Guarantees* from DBMS

You want to write a hot new app on a DBMS.
What do you *not* want to worry about?

Failures disk, machine, human, corruption, deity

Lots of users

Ad-hoc data access

Data formats csv? tsv? custom format?

Database Management System (DBMS)

System to safely and reliably store lots of persistent structured data and is convenient for multiple users to efficiently access and modify.

Database Management System (DBMS)

Safe	Consistent and correct data after failures
Reliable	99.99+% Uptime
Lots	>>RAM (terabytes)
Persistent	Lives longer than DBMS application
Convenient	Physical Independence. Declarative.
Multiple Users	Concurrent access. Access control.
Efficient	*Fast*: 100k+ queries / sec

DBMSes in the Wild

Classic Disk-based Relational

- $$: Oracle, IBM, Microsoft, Teradata, EMC, etc
- Free: MySQL, PostgreSQL, SQLite

New Relational

- In-Memory, Column-store, Streaming

Non-traditional

- Search (Google, Bing, Lucene), Scientific, Geo, Graph

NoSQL

- Big Data: Hadoop, Spark, etc
- Key-value: Mongo, BerkeleyDB, Cassandra, etc

DBMS-as-a-Service

- MS Azure, Google BigQuery, Amazon Redshift/RDS ...

Encompasses most of CS

OS	DBMS directly manages hardware
Languages	SQL is a domain specific language
Theory	Algorithms, models, NP-complete
AI/ML	Knowledge Discovery, KDD
Logic	Relational Algebra = 1st order logic

Scalable Computer Science

Good time to learn!

Cloud programmer

Data science

Data engineer

Machine learning engineer

DATA

Data Scientist: The Sexiest Job of the 21st Century

by Thomas H. Davenport and D.J. Patil

FROM THE OCTOBER 2012 ISSUE

2 Key Concepts

Data Independence

Declarative Languages

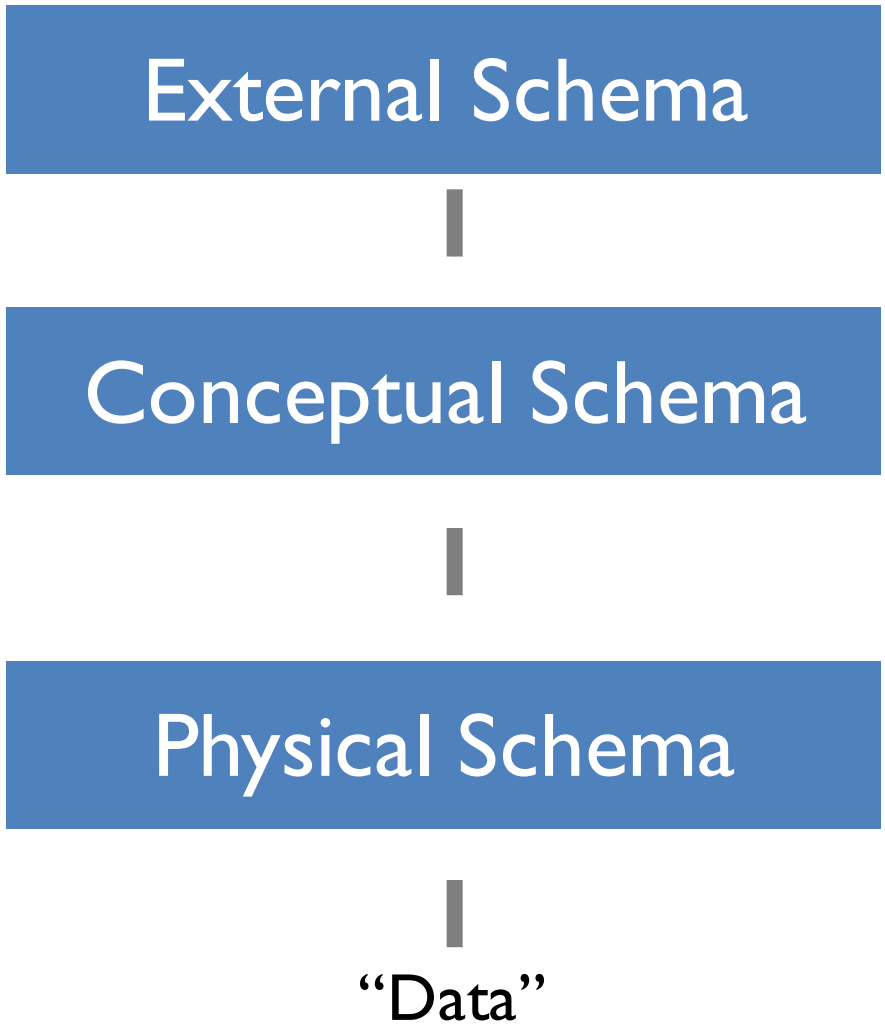
Serve to insulate application programmers from the system implementation

Data Independence

External Schema
Describe how users see data

Conceptual Schema
Describes logical structure

Physical Schema
Describes files and indexes



Example App: Guuber

Users(uid int, name str, age int)

Drivers(did int, name str)

Rides(uid int, did int, distance float, drive_time float)

Data Independence

UID	Name	Age
0	Eugene	17
1	Luis	20
2	Ken	30

0,Eugene,17
1,Luis,20
2,Ken,30

CSV File

What is the number of adults?

Data Independence

UID	Name	Age
0	Eugene	17
1	Luis	20
2	Ken	30

0,Eugene,17
1,Luis,20
2,Ken,30

CSV File

```
n = 0
for line in csv_file:
  attributes = line.split(“,”)
  if attributes[2] >= 18:
    n += 1
```

Data Independence

UID	Name	Age
0	Eugene	17
1	Luis	20
2	Ken	30

0,1,2
Eugene,Luis,Ken
17,20,30

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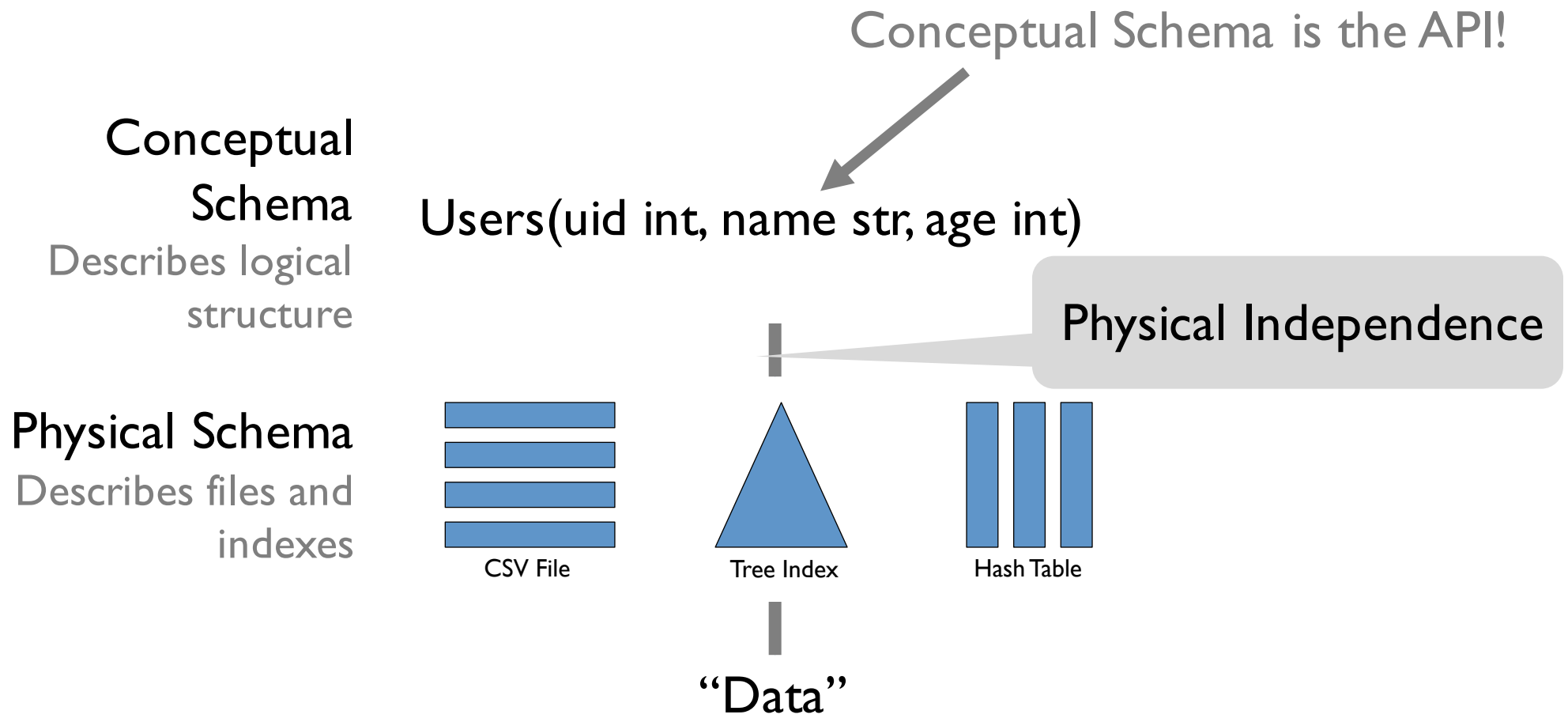


Data Independence

Users(uid int, name str, age int)

Drivers(did int, name str)

Rides(uid int, did int, distance float, drive_time float)

"Welcome back Mr. Wu"

Data Independence

Users(uid int, fname str, lname str, age int)

Drivers(did int, name str)

Rides(uid int, did int, distance float, drive_time float)

"Welcome back Mr. Wu"

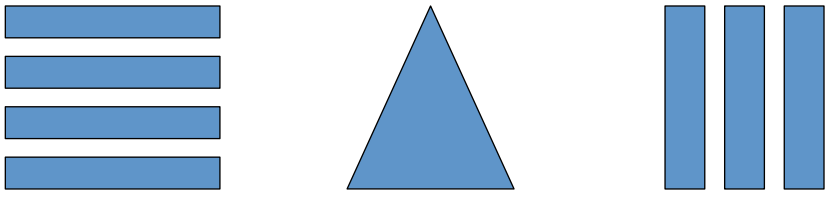
Data Independence

Conceptual Schema
Describes logical structure

Users(uid int, name str, age int)

Physical Independence

Physical Schema
Describes files and indexes



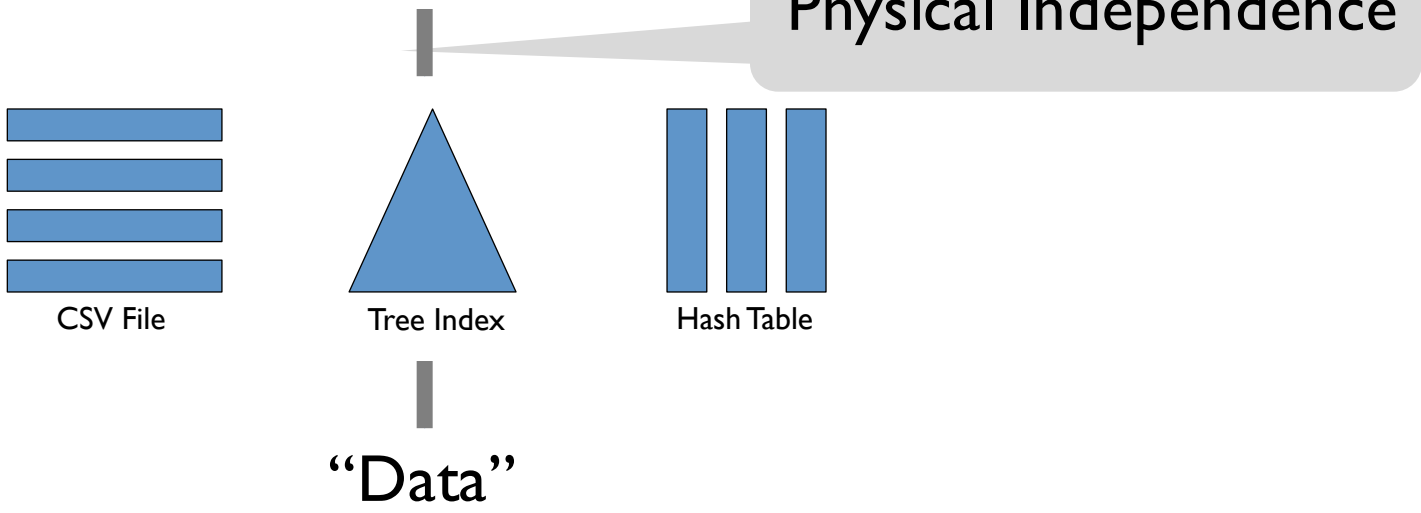
"Data"

Data Independence

Conceptual Schema
Describes logical structure

Users(uid int, fname str, lname str, age int)

Physical Schema
Describes files and indexes



Data Independence

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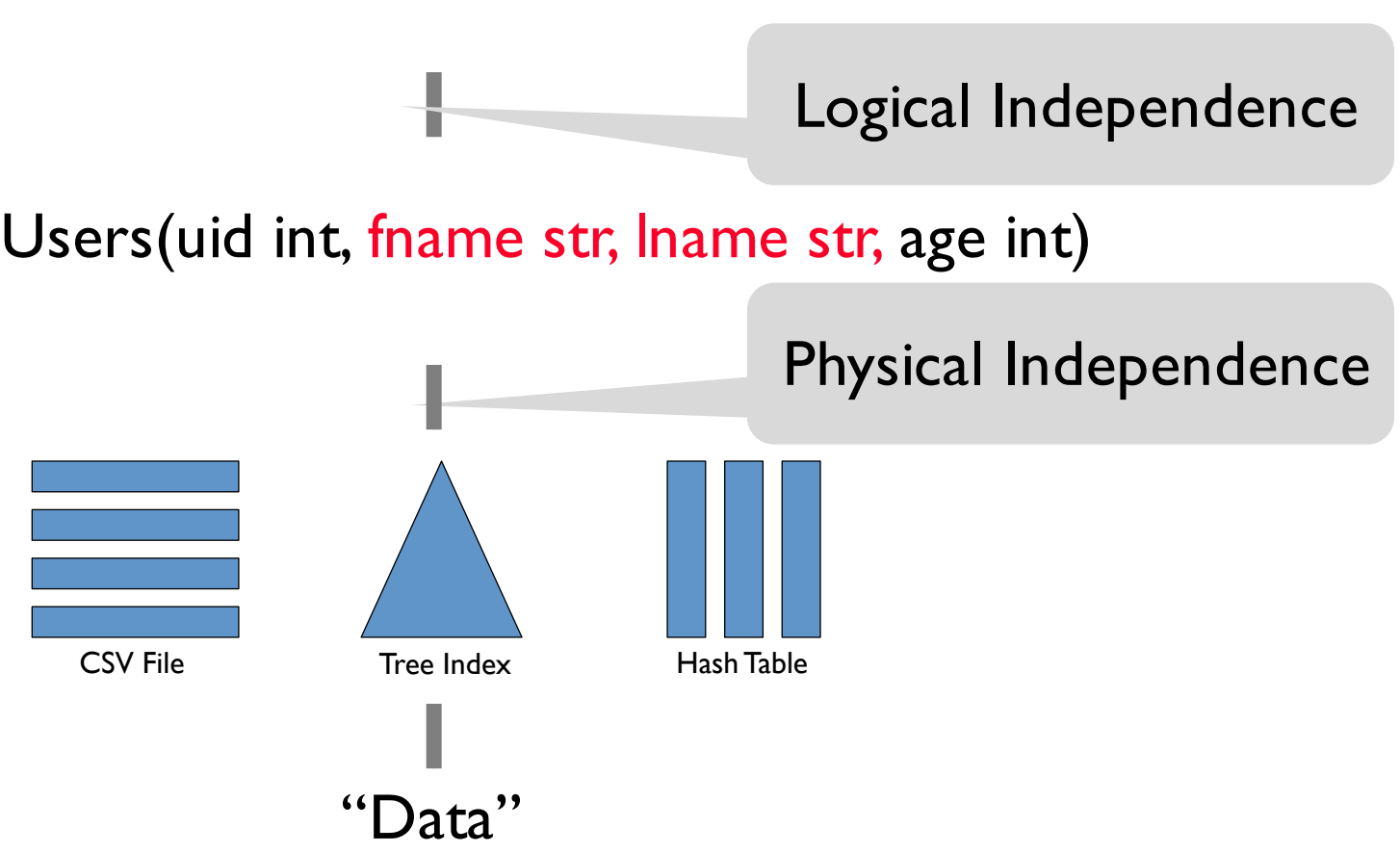


Data Independence

Physical Independence

Protection from changes in physical structure of data

Logical Independence

Protection from changes in logical structure of data

One of most important properties of a DBMS

Declarative

What you want, **not how to do it.**

"Make me a sandwich"

Buy from pb&j store
Make BLT
½ Tuna
Veggie

"Take two slices of wheat bread out of the 2nd shelf, put them next to each other…"

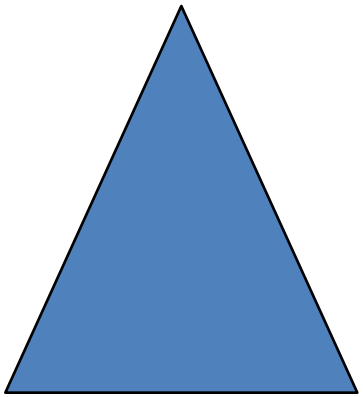
What if on 1st shelf?
Out of wheat bread?
No counter space?

Declarative

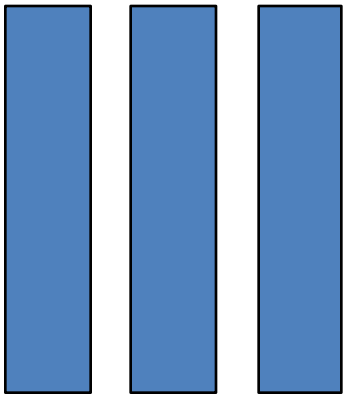
"I want all highly rated fast drivers"

DBMS

CSV File



Tree Index



Hash Table

Declarative

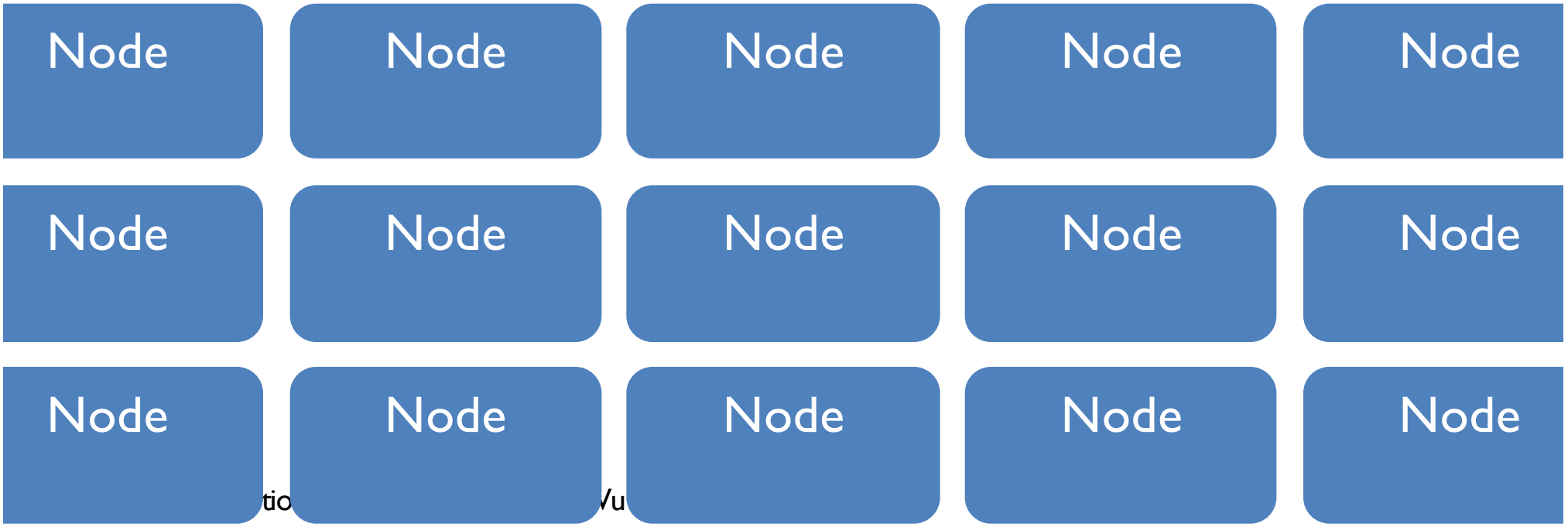
"I want all highly rated fast drivers"

DBMS

Declarative

"I want all highly rated fast drivers"

DBMS



Classic Components in Databases

Concurrency Control

Transactions

Atomicity

Recovery and Logs

Transaction: Execution of a DB Program

Def: *atomic* sequence of DBMS actions

```
Begin;
<read beth's account>
<deduct from beth's account>
<increase eugene's account>
Commit;  (or Abort;)
```

Transaction: Execution of a DB Program

Def: *atomic* sequence of DBMS actions

Each fully executed transaction must leave DB in *consistent state* if DB is consistent before transaction

- Users specify simple *integrity constraints* on data, and DBMS enforces the constraints.
- DBMS does not understand semantics of its data
  e.g., doesn't know how bank interest is computed
- User's responsibility to ensure transaction (run alone) preserves consistency

Concurrency Control

Concurrently running multiple user programs needed for good performance

Disk accesses are frequent & slow. Keep CPU working on several user programs while waiting.

Concurrency can cause inconsistencies

- e.g., check cleared while account balance being computed.
- *Really* hard to program against

DBMS ensures such problems don't arise

- programmers can pretend to use a single-user system.

Scheduling Concurrent Transactions

Transactions T1, …, Tn are run concurrently

Equivalent to a *serial* ordering (as if no concurrency)

Locks: T_i requests and waits for lock before read/write.

e.g., T_i locks the database, updates, then releases

e.g., T_i locks the table, updates, then releases

e.g., T_i locks rows, updates, then releases

Will talk about how this works later in course.

Atomicity

Def: Xact fully completes, or never happened

even after failures e.g., crashes

Record all actions Xact did during execution in a log

1. Write ahead logging: before making any change, ensure the change is safely recorded in log
2. After failure, read log and undo any incomplete Xacts

The Log

A log record contains enough info to undo actions:

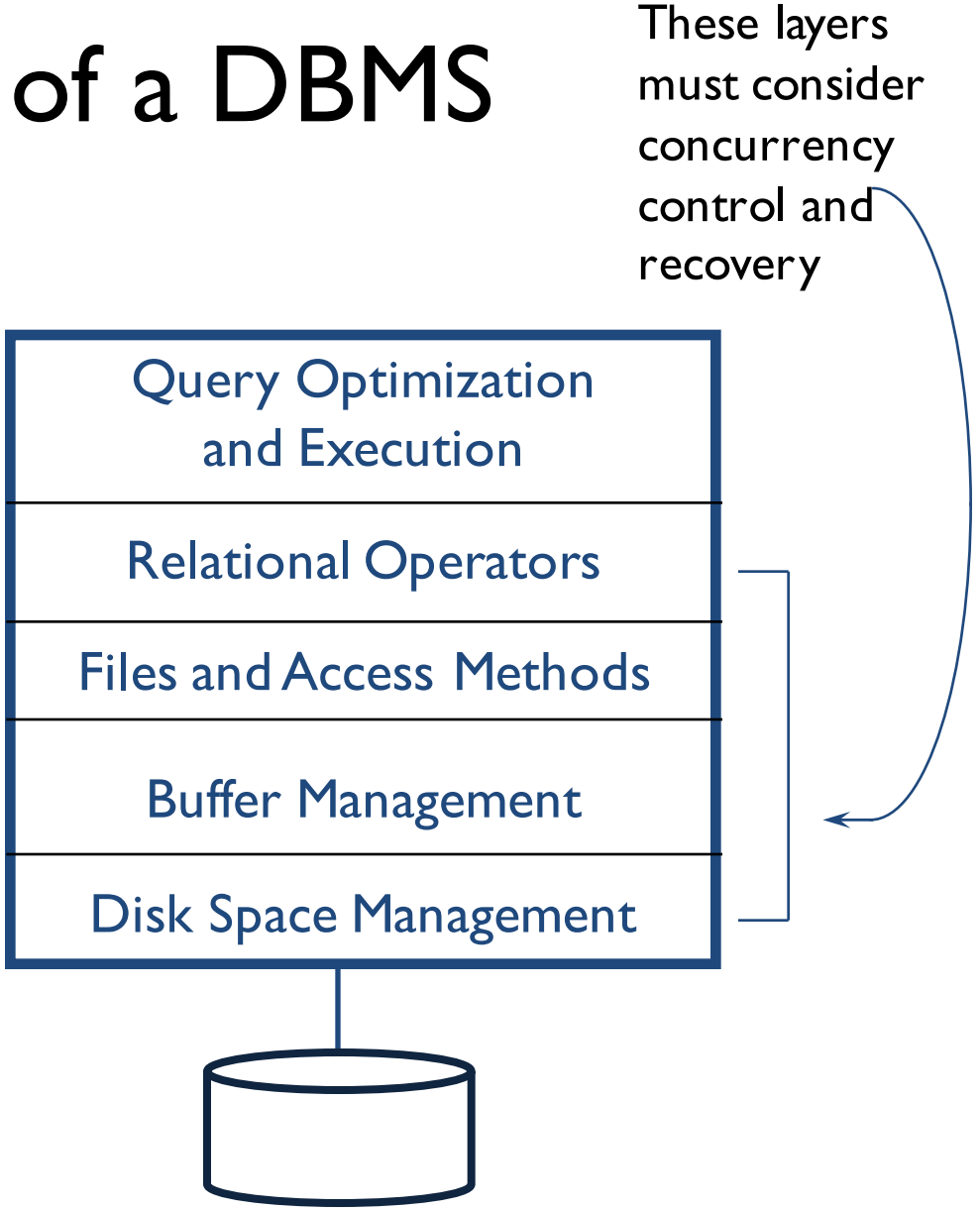
- Transaction id
- T_1 writes an object: old and new values
- Log record *must* be safely stored before the changed data
- T_1 commits/aborts: store commit/abort action

All logging, recovery and concurrency control activities hidden away from user.

Classic Structure of a DBMS

Typical layered architecture
- DBMS, not OS, manages memory and disk

Doesn't show concurrency control & recovery components



Database Courses at Columbia

COMS W4111 - Intro to Databases

Prerequisites: CS3137 or CS3134; fluency in Python

Intro to DBMSes

Data Models Entity-relation, Relational, …

Relational Algebra

SQL

Applications + SQL cursors, APIs, embedded …

Normalization

Peek at DBMS internals:

- Storage and indexing
- Query optimization
- Transaction Processing

COMS W4112-Database Sys. Impl.

Prerequisites: CS3137 or CS3134; fluency in Python

Storage Methods and Indexing

Query Processing and Optimization for 1NF Relations, including external sorting

Materialized Views and Use in Query Optimization

Query Processing and Optimization for ORDBMSs

Transaction Processing and Recovery

Parallel & Distributed DBMSes: Query Proc. and Optimization

Parallel and Distributed Databases: Transaction Processing

Performance Considerations Beyond I/Os

COMS E6111-Advanced Databases

Prerequisites: CS4111; fluency in Java or Python

Information Retrieval
Web Search
Distributed Information Retrieval and Web Search
Data Mining
Data Warehousing, OLAP, Decision Support
Information Extraction
Scalable Visualization and Interaction
Supporting data analysis
Exploration, explanation and exhibition techniques

COMS E6xxx-DB Research Seminars

Prerequisites: CS4111; fluency in Java or Python

6113 Database Research Topics

6998.002 Interactive Data Exploration Systems

6998.005 Database Topics in Research & Practice

Administrivia

Next Up

HW0 is out.

Due by Friday 1/25 10AM sharp.

No Late Submission Accepted

0 in class if not submitted in time

Your Instructor: **Eugene Wu**

B.S. @U.C. Berkeley

Ph.D. @MIT

PostDoc @U.C. Berkeley

Assistant Professor since Fall 2015

Databases, visualization, data analysis

data cleaning, crowdsourcing.

Your Instructor: **Eugene Wu**

Contact

www.eugenewu.net
ewu@cs.columbia.edu
421 Mudd

Office hours

Thurs 3-4PM
By appointment by email

Class Resources

Class web page

w4111.github.io

Discussion board

piazza (linked from website, public)

Announcements from class staff:

Website

Your TAs

Amita Shukla
Yiru Chen
Zhicheng Wu
Ziao Wang

All TA office hours in CS TA Room
TA office hours will be set next week
(see class web page)

Class Information: Prerequisites

COMS W3134 - *Data Structures in Java* or
COMS W3137 - *Data Structures and Algorithms*

(equivalent courses taken elsewhere are acceptable as well)

Fluency in Python

Class Information: Lectures

Tuesdays and Thursdays

8:30-10AM

209 Havemeyer

(here)

An aside: Success

What does succeeding in this course mean?

Timescales

How to encourage a collaborative environment?

What discourages it?

Assessment

Grading Information

Midterm 1:	25%
Midterm 2:	40% cumulative
HW:	15% (4 HWs equally weighed)
Project 1:	15%
Project 2:	5%
Extra credit:	scribe notes + advanced assignments

Median grade: B or slightly higher.
Alternative or make-up exams will not be given.
All homework assignments are equally weighted.
Project 1 has higher weight than Project 2.

Exam Dates

Midterm 1: 3/7, in class

Midterm 2: 4/30 last day of class, in class, cumulative

Makeup exams are not scheduled

Homework

Homeworks usually due at 10AM of due date.

Assignment will specify submission instructions.

No extensions or exceptions.

Three grace late days for hws throughout the semester.

After using all grace days, 25% grade deduction per late day.

Check full details on web site.

Projects (more details soon)

Two projects.

- Teams of two
- Run on cloud infrastructure
- Get CS account if your team doesn't have a computer
- Language is Python

Project 1

- Model and build your own database web application
- Explore "traditional" relational database features.

Project 2

- TBD

Projects (cont.)

3 grace late days total for project parts 1 and 2.

No extensions or exceptions for project part 3 submission.

After using all grace days, 25% grade deduction per late day.

Check full details on web site.

Extra Credit

Added *after* the curve

Scribe notes: 0-5% extra credit

Advanced Assignments:

- ~same value as HW
- Goes into more depth
- Hack on the DataBass system

Collaboration Policy

Read Syllabus on course site for allowed conduct

CS Dept academic honesty policies
http://www.cs.columbia.edu/education/honesty

We will not tolerate *any* cheating

Collaboration Policy

Discussing lectures and course material strongly encouraged

Homework and exams are *individual*. No exceptions
Any libraries or code however minor must be disclosed.

Projects are done in *teams*; no collaboration between teams.

Contact the instructor right away if you have any questions or are falling behind.

Textbook

Raghu Ramakrishnan, Johannes Gehrke: *Database Management Systems*, 3rd edition, McGraw-Hill, 2002

Available from

Bookculture bookstore 536 W. 112th St.

Online retailers

Upperclass-persons

On reserve in Engineering Library

Contests and Rewards

Project 1 contest

- Four best projects chosen as contest winners.
- Winners get:
  - 10% boost in Project 1 grade.
  - If time allows: demo your project in class.

On-going Feedback

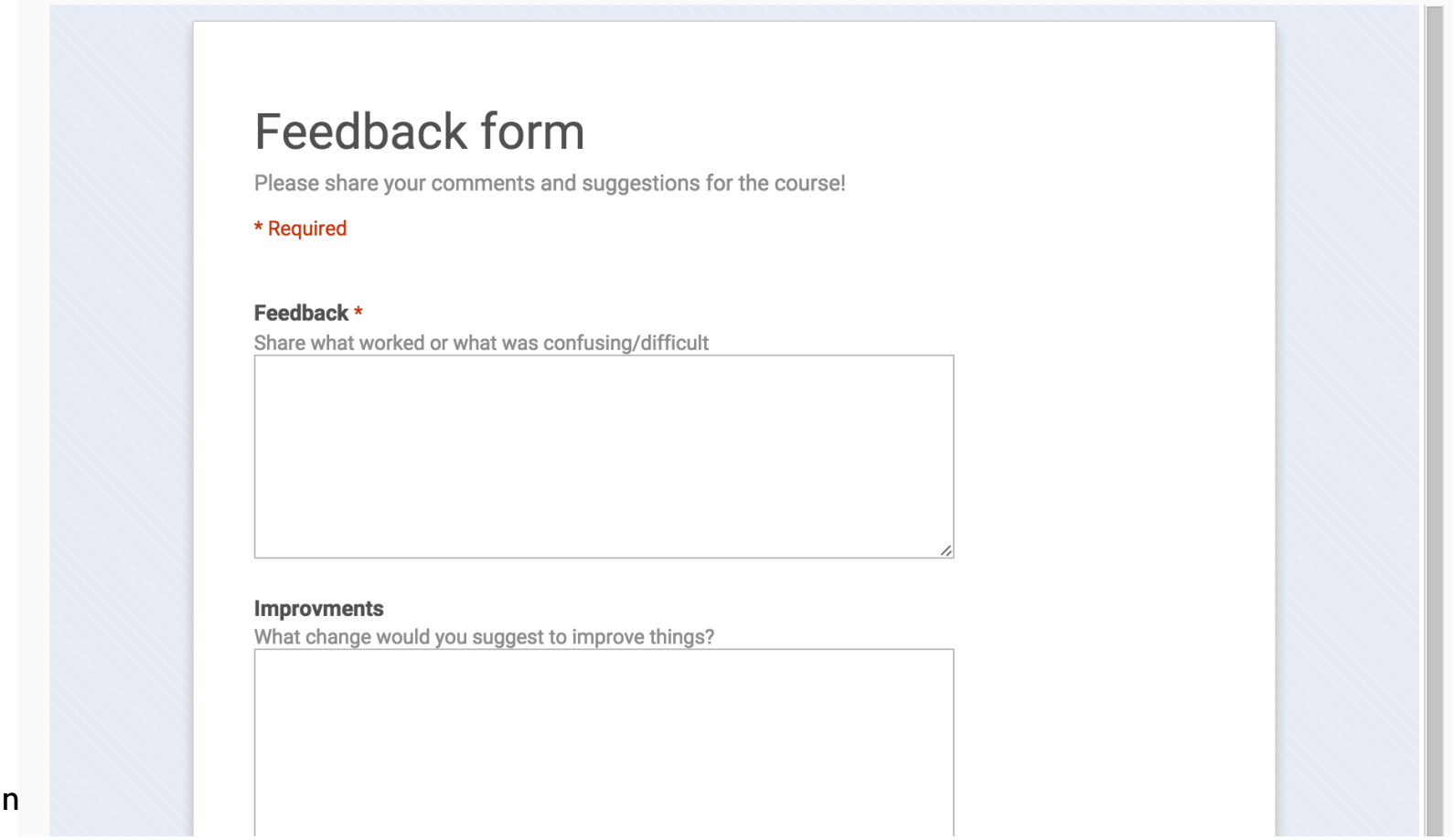
Please provide feedback throughout the course.

- What is useful or confusing in lecture
- Thoughts about software stack
- Thoughts about assignments

Email me, come to office hours, talk to staff or:

On-going Feedback

Use form on website



Slides borrow material from
Prof. Gravano
Prof. Hellerstein & Franklin@Cal
Prof. Madden & Stonebraker@MIT

(and by transitivity Raghu Ramakrishnan and Johannes Gehrke)

w4111.github.io

ewu@cs.columbia.edu

DO HOMEWORK 0!