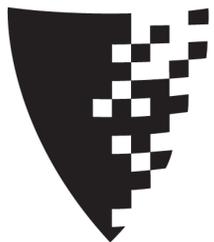


Introduction

Introduction to Databases

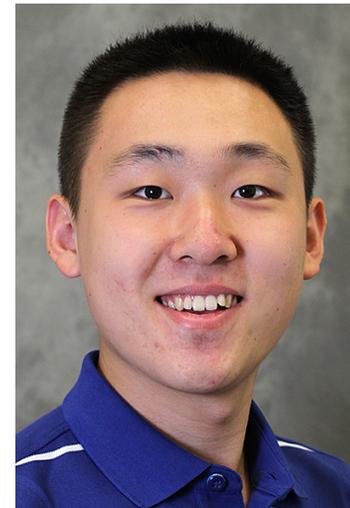
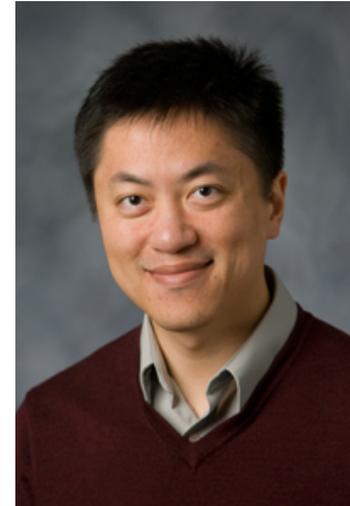
CompSci 316 Fall 2016



DUKE
COMPUTER SCIENCE

About us: instructor and TA

- Instructor: **Jun Yang**
 - Been doing (and enjoying) research in databases ever since grad school (1995)
 - Didn't take any database as an undergrad
 - Now working on data-intensive systems and computational journalism
- Graduate TA: **Yuhao Wen**
 - PhD student in Computer Science
 - Working on data-intensive interactive systems



About us: UTAs



Alex



Callie



Tianyi

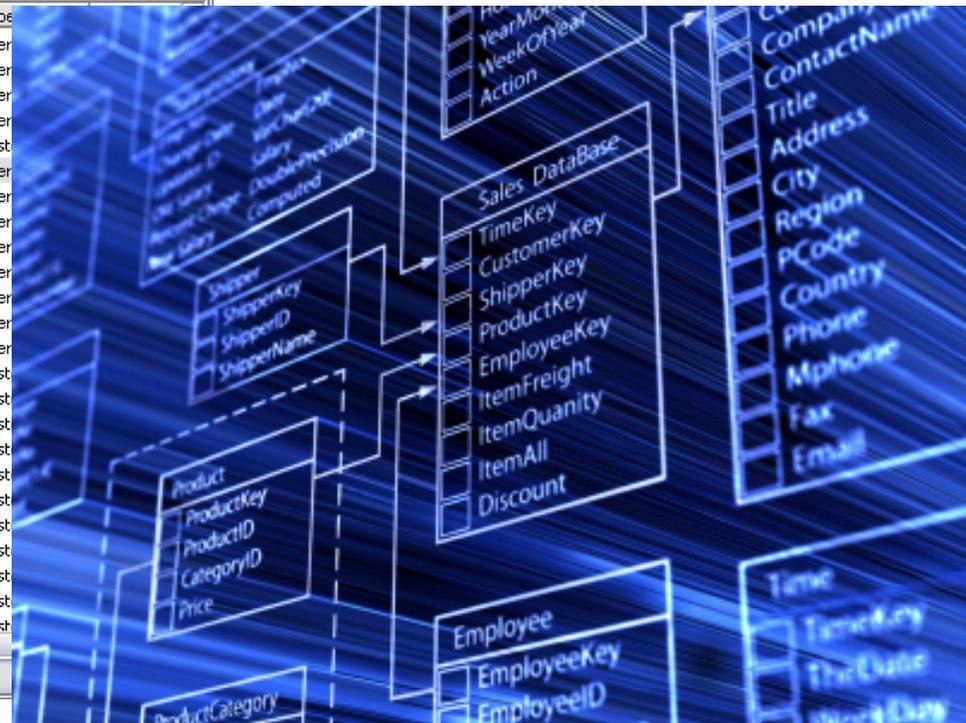
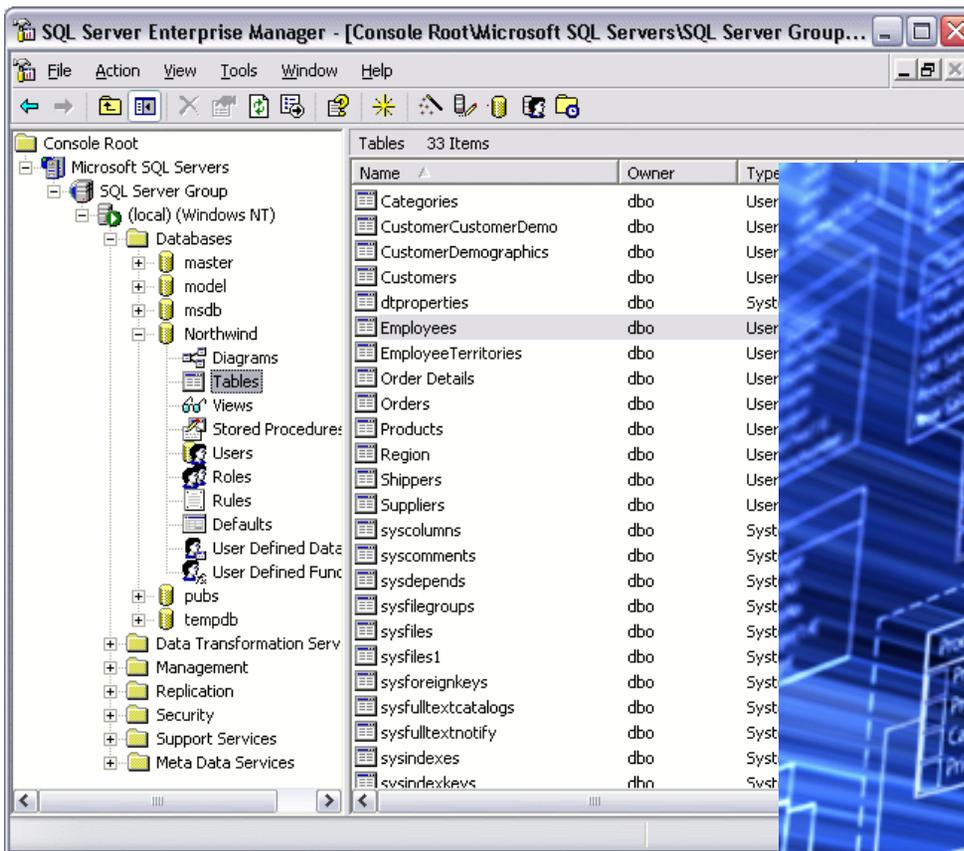


Jia

All CompSci 316 veterans!

What comes to your mind...

... when you think about “databases”?



But these use databases too...

The image shows three overlapping screenshots:

- Facebook Profile:** A screenshot of Mark Zuckerberg's profile on Facebook, showing his name, profile picture, and a post from Rome, Italy.
- WordPress Site:** A screenshot of a WordPress site titled "Introduction to Databases (Fall 2016)". The site has a blue header and a sidebar with a menu including Home, Schedule, Info, Help, Gradiance, Discussion, WebSubmit, and Solutions & Grades.
- Home Page:** A screenshot of a WordPress site titled "Home". It lists course details for "CompSci316 (Fall 2016), Duke University", including the schedule (TuTh 1:25PM - 2:40PM), location (Biological Sciences 111), instructor (Jun Yang), grad TA (Yuhao Wen), and UTAs (Alex Dao, Callie Mao, Tianyi Mu, Jia Zeng).

Facebook uses MySQL to store posts, for example

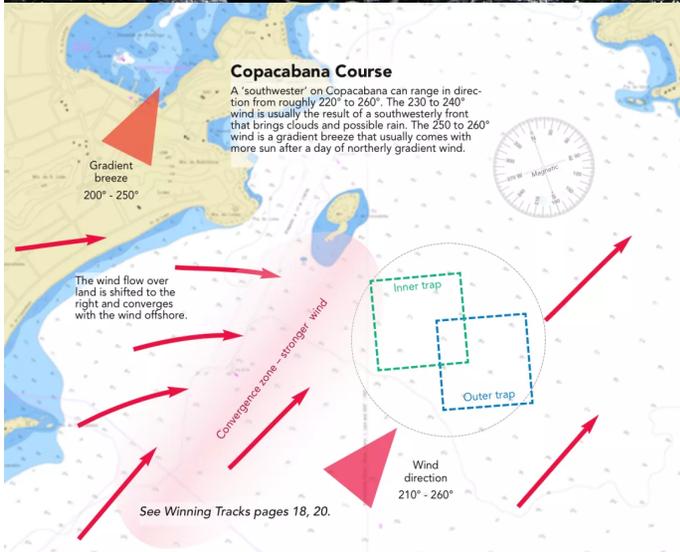
WordPress uses MySQL to manage components of a website (pages, links, menus, etc.)

Data → gold



... The three years of gathering and analyzing data culminated in what U.S. Sailing calls their “Rio Weather Playbook,” a body of critical information about each of the seven courses only available to the U.S. team...

— FiveThirtyEight, “Will Data Help U.S. Sailing Get Back On The Olympic Podium?”



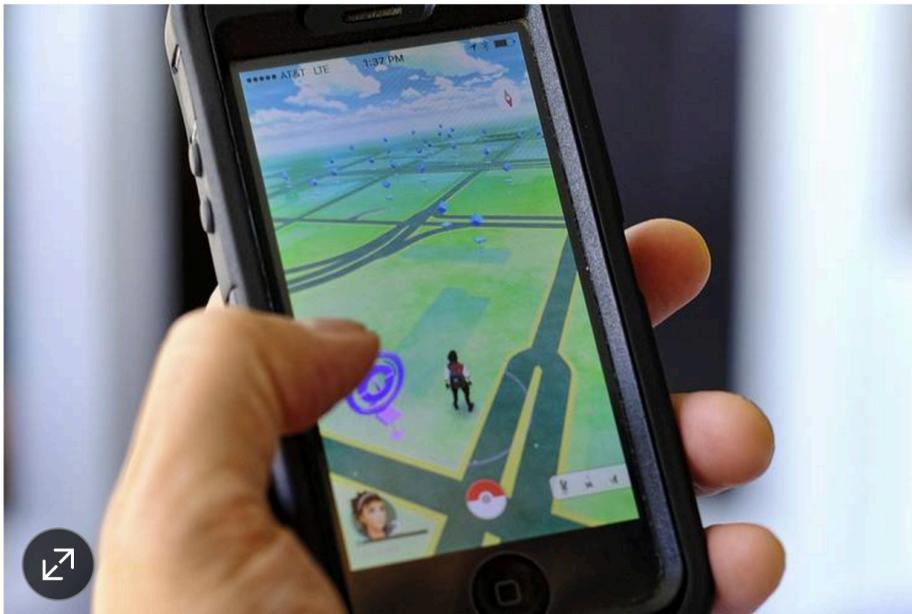
Data → profit and fun



TECH | CONSUMER TECHNOLOGY

‘Pokémon Go’ Creator Closes Privacy Hole But Still Collects User Data

Players with iPhones should log out and download the update; game’s developers say it never snooped



Pokemon Go is displayed on a cell phone. PHOTO: ASSOCIATED PRESS



WHAT HAVE YOU FOUND, TRAVELER?



SIGHTING REPORT »

A NEST (MULTIPLE) »

SIGHTING REPORTS

are normal spawn reports - i.e. when you encounter a Pokémon in your travels, submit a Sighting Report!

NESTS

are our term for repeat spawns or clustered spawns of the same species. Only report a 'Nest' if you see multiples of an uncommon species at once (or a consistently spawning rare 'mon)!

... Silph’s newest initiative is to have travelers log the location of “nests,” spots where a certain species of monster is guaranteed to appear, and sometimes several instances of that species (e.g. Charmanders gather at New York’s Museum of Natural History.)

— GIZMODO

Data → power



Google Trends
@GoogleTrends

Follow

"What is the EU?" is the second top UK question on the EU since the #EURefResults were officially announced

TOP QUESTIONS ON THE EUROPEAN UNION Google Trends
in the UK since Brexit result officially announced

- 1 What does it mean to leave the EU?
- 2 What is the EU?
- 3 Which countries are in the EU?
- 4 What will happen now we've left the EU?
- 5 How many countries are in the EU?

google.com/trends

RETWEETS LIKES
27,305 **18,371**



4:25 AM - 24 Jun 2016

↩️ ↻ 27K ❤️ 18K ⋮

REUTERS

Database of 191 million U.S. voters exposed on Internet: researcher

POLITICS | Mon Dec 28, 2015 4:52pm EST

Database of 191 million U.S. voters exposed on Internet: researcher



By Jim Finkle and Dustin Volz

An independent computer security researcher uncovered a database of information on 191 million voters that is exposed on the open Internet due to an incorrectly configured database, he said on Monday.

The database includes names, addresses, birth dates, party affiliations, phone numbers and emails of voters in all 50 U.S. states and Washington, researcher Chris Vickery said in a phone interview.

... A database with information on all American voters... might go for about \$270,000, according to one marketing firm consulted by researcher Chris Vickery...

— databreaches.net

<http://www.npr.org/sections/alltechconsidered/2016/06/24/480949383/britains-google-searches-for-what-is-the-eu-spike-after-brexit-vote>

<http://www.reuters.com/article/us-usa-voters-breach-idUSKBN0UB1E020151228>

<https://www.databreaches.net/191-million-voters-personal-info-exposed-by-misconfigured-database/>

Challenges

- Moore's Law:
 - Processing power doubles every 18 months*
- But amount of data doubles every 9 months
 - Disk sales (# of bits) doubles every 9 months
 - Parkinson's Law:
 - Data expands to fill the space available for storage*

1 TERABYTE A \$200 hard drive that holds 260,000 songs.	20 TERABYTE Photos uploaded to Facebook each month.	120 TERABYTE All the data and images collected by the Hubble Space Telescope.	330 TERABYTE Data that the large Hadron collider will produce each week.
460 TERABYTE All the digital weather data compiled by the national climate data center.	530 TERABYTE All the videos on Youtube.	600 TERABYTE ancestry.com's genealogy database (includes all U.S. census records 1790-2000)	1 PETABYTE Data processed by Google's servers every 72 minutes.
http://www.micronautomata.com/big_data			

Moore's Law reversed

*Time to process all data
doubles every 18 months!*

- Does your attention span double every 18 months?
 - No, so we need smarter data management techniques

Democratizing data (and analysis)

- **Democratization of data**: more data—relevant to you and the society—are being collected
 - “Smart planet”: sensors for phones and cars, roads and bridges, buildings and forests, ...
 - “Government in the sunshine”: spending reports, school performance, crime reports, corporate filings, campaign contributions, ...
- **But few people know how to analyze them**
- You will learn how to help bridge this divide

Misc. course info

- Website: http://sites.duke.edu/compsci316_01_f2016/
 - Course info; tentative schedule and reference sections in the book; lecture slides, assignments, help docs, ...
- Book: *Database Systems: The Complete Book*, by H. Garcia-Molina, J. D. Ullman, and J. Widom. 2nd Ed.
- Programming: VM required; \$50 worth of credits for VMs in the cloud, courtesy of Google
- Q&A on Piazza; grades, sample solutions on Sakai
- Watch your email for announcements
- Office hours to be posted

Grading

[90%, 100%]	A- / A / A+
[80%, 90%)	B- / B / B+
[70%, 80%)	C- / C / C+
[60%, 70%)	D
[0%, 60%)	F

- No “curves”
- Scale may be adjusted downwards (i.e., grades upwards) if, for example, an exam is too difficult
- Scale will not go upwards—mistake would be mine alone if I made an exam too easy

Duke Community Standard

- See course website for link
- Group discussion for assignments is okay (and encouraged), but
 - Acknowledge any help you receive from others
 - Make sure you “own” your solution
- All suspected cases of violation will be aggressively pursued

Course load

- Four homework assignments (35%)
 - **Gradiance**: immediately and automatically graded
 - Plus written and programming problems
- Course project (25%)
 - Details to be given in the third week of class
- Midterm and final (20% each)
 - Open book, open notes
 - No communication/Internet whatsoever
 - Final is comprehensive, but emphasizes the second half of the course

Projects from last year

- **RA**: next-generation relational algebra interpreter
 - Kevin Do, Michael Han, Jennie Ju, Jordan Ly
 - You may get to try it out for Homework #1!
- **wikiblocks** (<https://vimeo.com/147680387>)
 - Brooks Mershon, Mark Botros, Manoj Kanagaraj, Davis Treybig
 - Automatically finds relevant interactive visualizations when you are browsing a Wikipedia page

Projects from earlier years

- **SMSmart** (4.1 stars on Google Play): search/tweet/Yelp without data
 - Alan Ni, Jay Wang, Ben Schwab, 2014
- **FarmShots**: help farmers with analysis of satellite images
 - Ouwen Huang, Arun Karottu, Yu Zhou Lee, Billy Wan, 2014
- **FoodPointsMaster**: tracks balance & spending habit
 - Howard Chung, Wenjun Mao, William Shelburne, 2014
- **Pickup Coordinator**: app for coordinating carpool/pickups
 - Adam Cue, Kevin Esoda, Kate Yang, 2012
- **Mobile Pay**
 - Michael Deng, Kevin Gao, Derek Zhou, 2012
- **FriendsTracker app**: where are my friends?
 - Anthony Lin, Jimmy Mu, Austin Benesh, Nic Dinkins, 2011

More past examples

- **ePrint iPhone app**
 - Ben Getson and Lucas Best, 2009
- **Making iTunes social**
 - Nick Patrick, 2006; Peter Williams and Nikhil Arun, 2009
- **Duke Scheduler: ditch ACES—plan visually!**
 - Alex Beutel, 2008
- **SensorDB: manage/analyze sensor data from forest**
 - Ashley DeMass, Jonathan Jou, Jonathan Odom, 2007
- **Facebook+**
 - Tyler Brock and Beth Trushkowsky, 2005
- **K-ville tenting management**
 - Zach Marshall, 2005



Your turn to be creative

So, what is a database system?

From Oxford Dictionary:

- **Database**: an organized body of related information
- **Database system, DataBase Management System (DBMS)**: a software system that facilitates the creation and maintenance and use of an electronic database

What do you want from a DBMS?

- Keep data around (**persistent**)
- Answer questions (**queries**) about data
- **Update** data

- Example: a traditional banking application
 - **Data**: Each account belongs to a branch, has a number, an owner, a balance, ...; each branch has a location, a manager, ...
 - **Persistency**: Balance can't disappear after a power outage
 - **Query**: What's the balance in Homer Simpson's account?
What's the difference in average balance between Springfield and Capitol City accounts?
 - **Modification**: Homer withdraws \$100; charge accounts with lower than \$500 balance a \$5 fee

Sounds simple!

```
1001#Springfield#Mr. Morgan
```

```
... ..
```

```
00987-00654#Ned Flanders#2500.00
```

```
00123-00456#Homer Simpson#400.00
```

```
00142-00857#Montgomery Burns#1000000000.00
```

```
... ..
```

- Text files
- Accounts/branches separated by newlines
- Fields separated by #'s

Query by programming

```
1001#Springfield#Mr. Morgan
```

```
... ..
```

```
00987-00654#Ned Flanders#2500.00
```

```
00123-00456#Homer Simpson#400.00
```

```
00142-00857#Montgomery Burns#1000000000.00
```

```
... ..
```

- What's the balance in Homer Simpson's account?
- A simple script
 - Scan through the accounts file
 - Look for the line containing "Homer Simpson"
 - Print out the balance

Query processing tricks

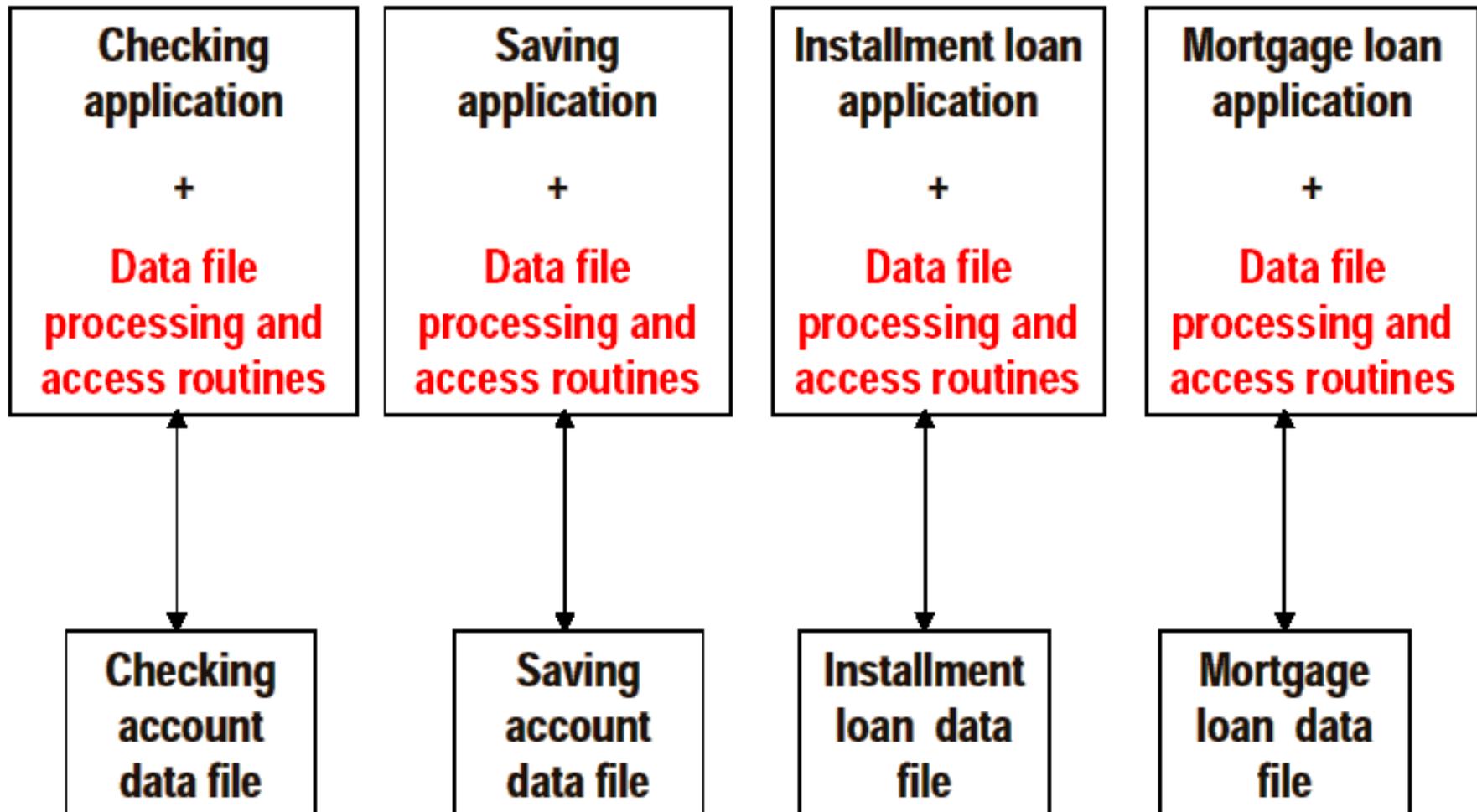
- Tens of thousands of accounts are not Homer's
 - ☞ Cluster accounts by owner's initial: those owned by "A..." go into file A; those owned by "B..." go into file B; etc. → decide which file to search using the initial
 - ☞ Keep accounts sorted by owner name → binary search?
 - ☞ Hash accounts using owner name → compute file offset directly
 - ☞ Index accounts by owner name: index entries have the form $\langle \text{owner_name}, \text{file_offset} \rangle$ → search index to get file offset
 - ☞ And the list goes on...

What happens when the query changes to: *What's the balance in account 00142-00857?*

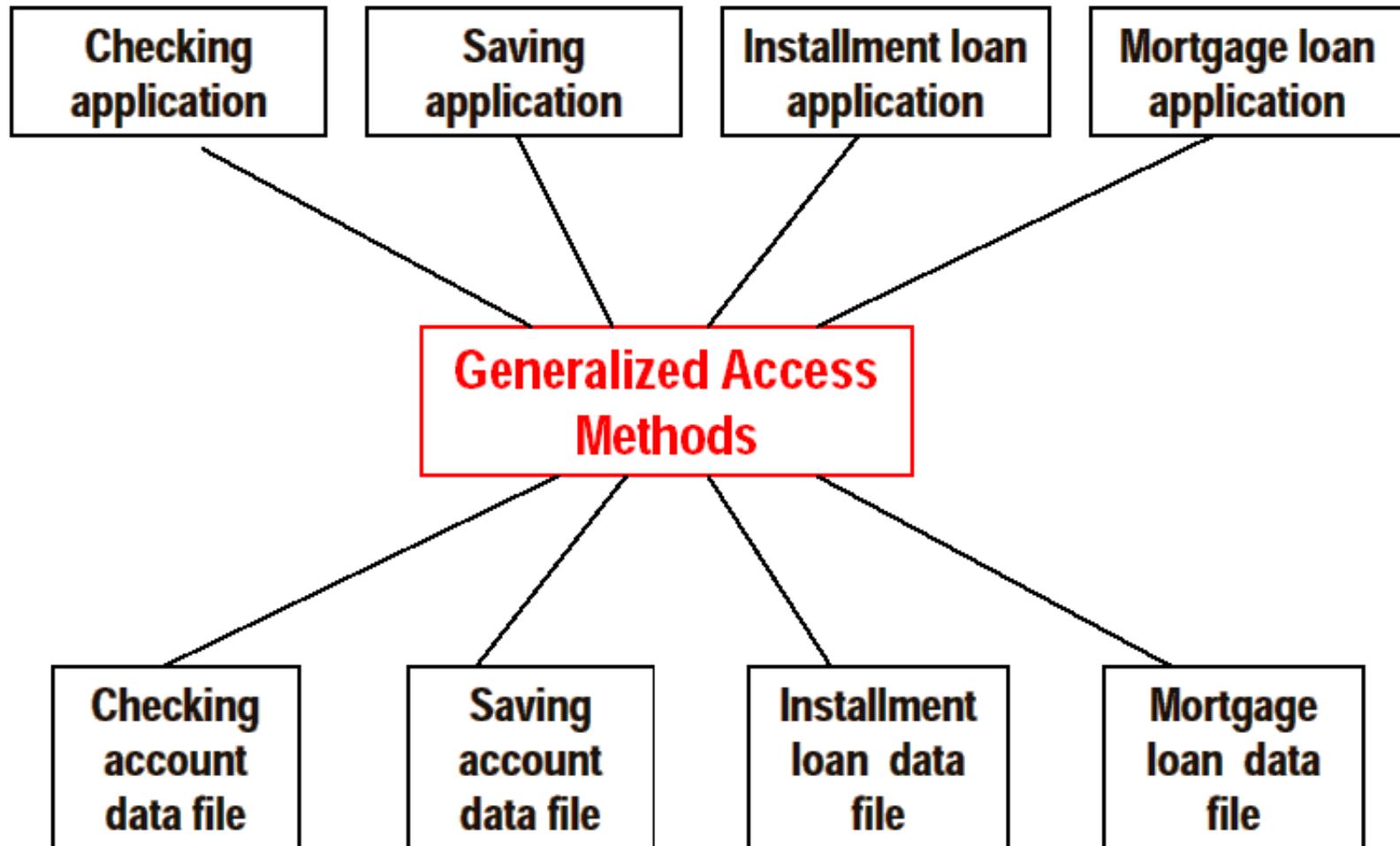
Observations

- There are many techniques—not only in storage and query processing, but also in concurrency control, recovery, etc.
- These techniques get used over and over again in different applications
- Different techniques may work better in different usage scenarios

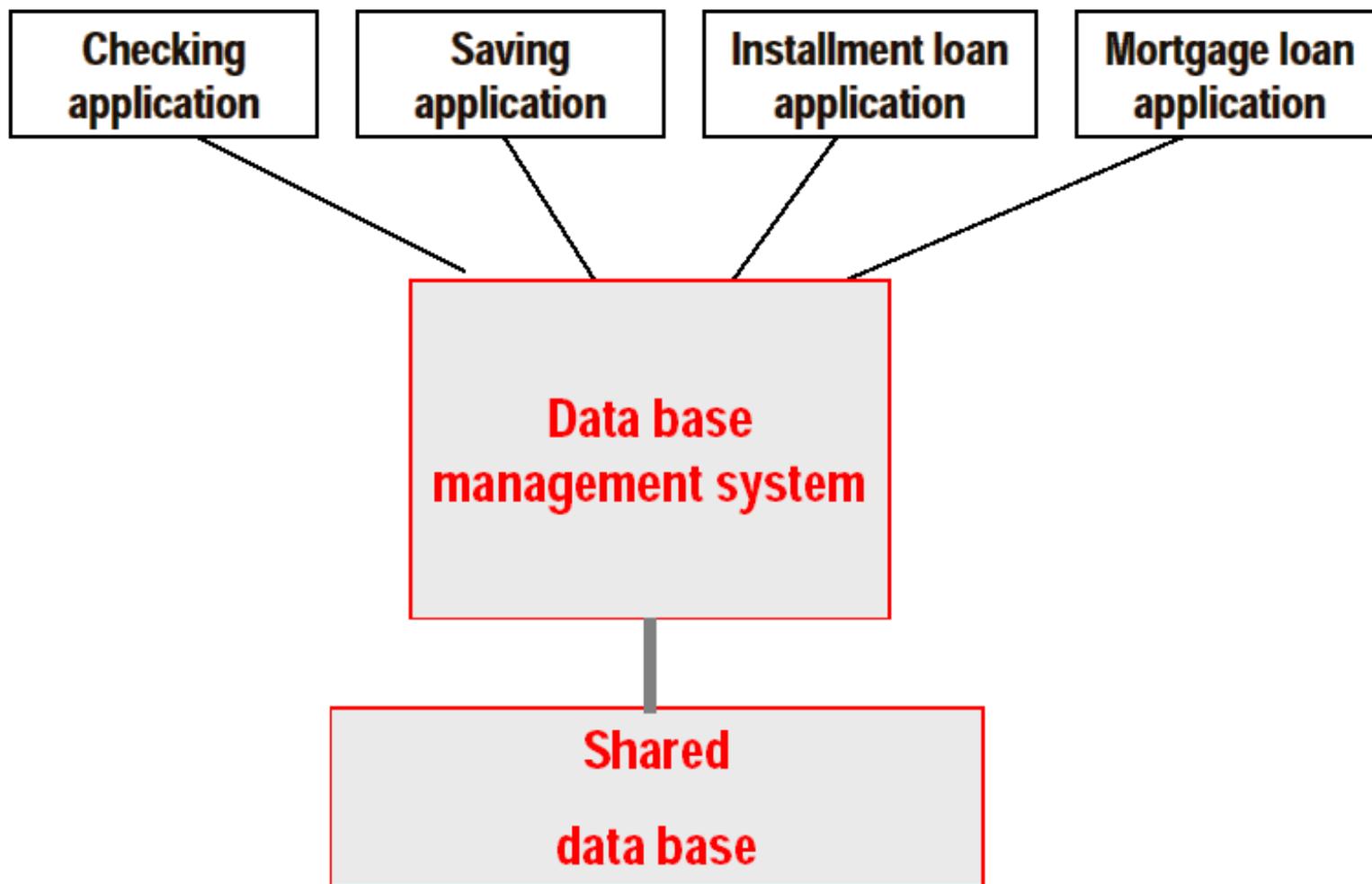
The birth of DBMS – 1



The birth of DBMS – 2



The birth of DBMS – 3



Early efforts

- “Factoring out” data management functionalities from applications and standardizing these functionalities is an important first step
 - CODASYL standard (circa 1960’s)
 - ☞ Bachman got a Turing award for this in 1973
- But getting the abstraction right (the API between applications and the DBMS) is still tricky

CODASYL

- Query: Who have accounts with 0 balance managed by a branch in Springfield?
- Pseudo-code of a CODASYL application:

```
Use index on account(balance) to get accounts with 0 balance;  
For each account record:  
  Get the branch id of this account;  
  Use index on branch(id) to get the branch record;  
  If the branch record's location field reads "Springfield":  
    Output the owner field of the account record.
```

- Programmer controls “navigation”: accounts → branches
 - How about branches → accounts?

What's wrong?

- The best navigation strategy & the best way of organizing the data depend on data/workload characteristics

With the CODASYL approach

- To write correct code, programmers need to know how data is organized physically (e.g., which indexes exist)
- To write efficient code, programmers also need to worry about data/workload characteristics
- ☞ Can't cope with changes in data/workload characteristics

The relational revolution (1970's)

- A simple model: data is stored in **relations** (tables)
- A declarative query language: **SQL**

```
SELECT Account.owner
FROM Account, Branch
WHERE Account.balance = 0
AND Branch.location = 'Springfield'
AND Account.branch_id = Branch.branch_id;
```

- Programmer specifies **what** answers a query should return, but **not how** the query is executed
 - DBMS picks the best execution strategy based on availability of indexes, data/workload characteristics, etc.
- ☞ Provides **physical data independence**

Physical data independence

- Applications should not need to worry about how data is physically structured and stored
- Applications should work with a **logical** data model and **declarative** query language
- Leave the implementation details and optimization to DBMS
- **The single most important reason behind the success of DBMS today**
 - And a Turing Award for E. F. Codd in 1981

Standard DBMS features

- Persistent storage of data
- Logical data model; declarative queries and updates → physical data independence
 - Relational model is the dominating technology today

👉 What else?

DBMS is multi-user

- Example

```
get account balance from database;  
if balance > amount of withdrawal then  
    balance = balance - amount of withdrawal;  
    dispense cash;  
    store new balance into database;
```

- Homer at ATM1 withdraws \$100
- Marge at ATM2 withdraws \$50
- Initial balance = \$400, final balance = ?
 - Should be \$250 no matter who goes first

Final balance = \$300

Homer withdraws \$100:

```
read balance; $400
```

```
if balance > amount then  
    balance = balance - amount; $300  
    write balance; $300
```

Marge withdraws \$50:

```
read balance; $400  
if balance > amount then  
    balance = balance - amount; $350  
    write balance; $350
```

Final balance = \$350

Homer withdraws \$100:

```
read balance; $400
if balance > amount then
  balance = balance - amount; $300
write balance; $300
```

Marge withdraws \$50:

```
read balance; $400
if balance > amount then
  balance = balance - amount; $350
write balance; $350
```

Concurrency control in DBMS

- Similar to concurrent programming problems?
 - But data not main-memory variables
- Similar to file system concurrent access?
 - Lock the whole table before access
 - Approach taken by MySQL in the old days
 - Still used by SQLite (as of Version 3)
 - But want to control at much finer granularity
 - Or else one withdrawal would lock up all accounts!

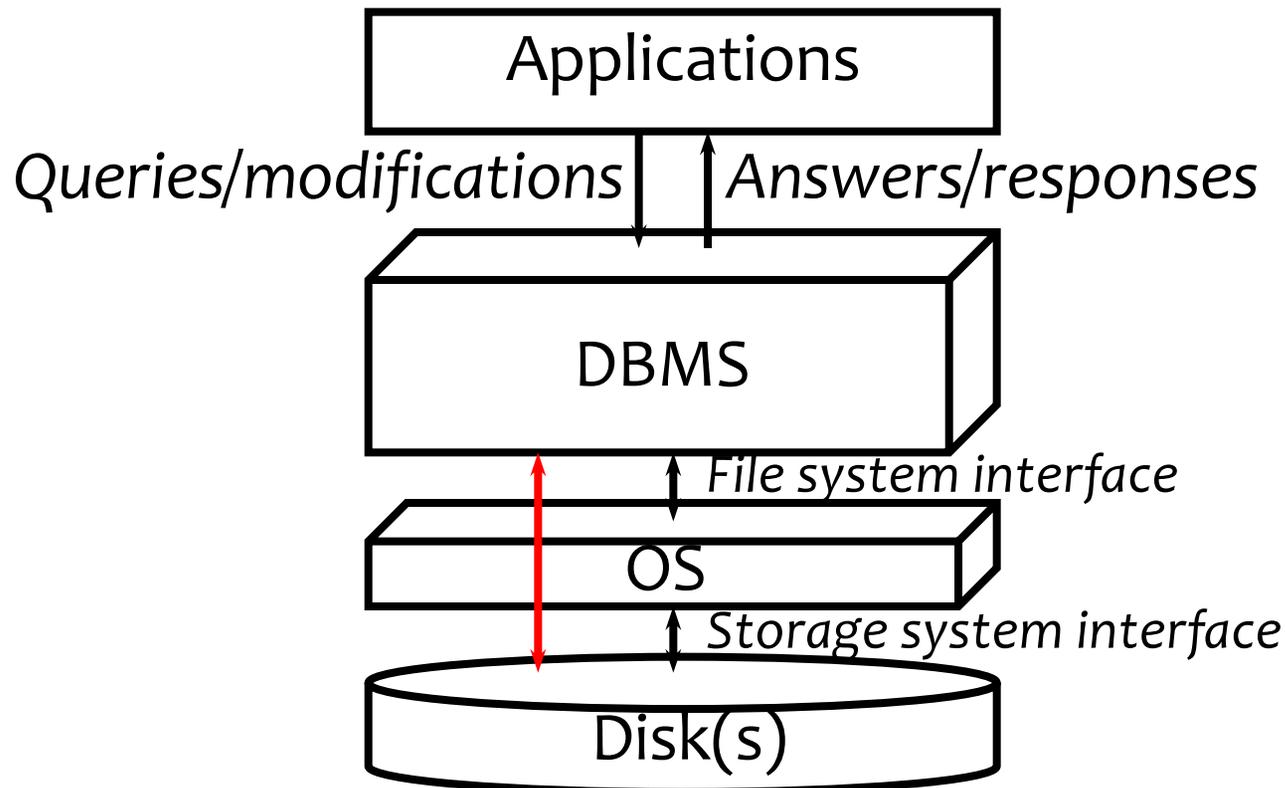
Recovery in DBMS

- Example: balance transfer
decrement the balance of account X by \$100;
increment the balance of account Y by \$100;
- Scenario 1: Power goes out after the first instruction
- Scenario 2: DBMS buffers and updates data in memory (for efficiency); before they are written back to disk, power goes out
- How can DBMS deal with these failures?

Standard DBMS features: summary

- Persistent storage of data
- Logical data model; declarative queries and updates → physical data independence
- Multi-user concurrent access
- Safety from system failures
- Performance, performance, performance
 - Massive amounts of data (terabytes~petabytes)
 - High throughput (thousands~millions transactions/hour)
 - High availability ($\geq 99.999\%$ uptime)

Standard DBMS architecture



- Much of the OS may be bypassed for performance and safety
- We will be filling in many details of the DBMS box throughout the semester

AYBABTU?

“Us” = relational databases

- Most data are not in them!
 - Personal data, web, scientific data, system data, ...
- Text and semi-structured data management
 - XML, JSON, ...
- “NoSQL” and “NewSQL” movement
 - MongoDB, Cassandra, BigTable, HBase, Spanner, HANA...
- This course will look beyond relational databases



Use of AYBABTU inspired by Garcia-Molina

Image: <http://upload.wikimedia.org/wikipedia/en/0/03/Aybabtu.png>

Course components

- Relational databases
 - Relational algebra, database design, SQL, app programming
- XML
 - Data model and query languages, app programming, interplay between XML and relational databases
- Database internals
 - Storage, indexing, query processing and optimization, concurrency control and recovery
- Advanced topics (TBD)
 - Data warehousing and data mining, Web search and indexing, parallel data processing/MapReduce, etc.

Announcements (Tue. Aug. 30)

- We intend to cap the class size at 120
 - Good news: CompSci 316 will be offered again next semester (Spring 2017)
- Thursday
 - Our first language of the semester—relational algebra!
 - Homework #1 to be assigned