Introduction

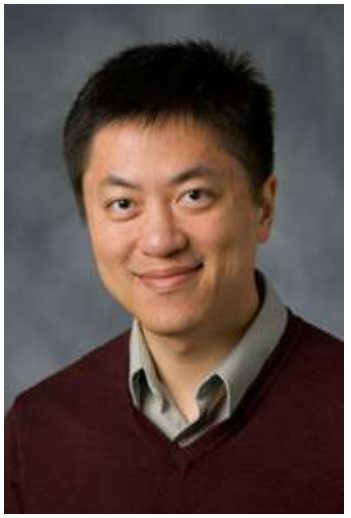
Introduction to Databases

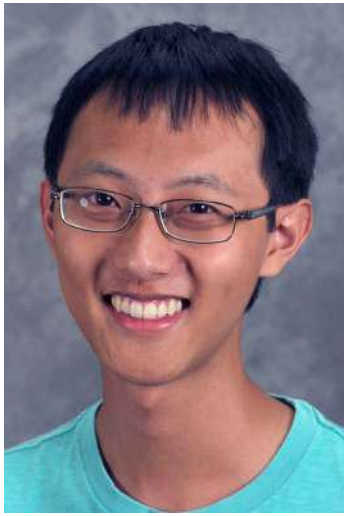
CompSci 316 Fall 2017

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: Andrew Lee
  - PhD student in Computer Science
  - Working on "big data" analysis





About us: UTAs


Seon


Sophie


Amy

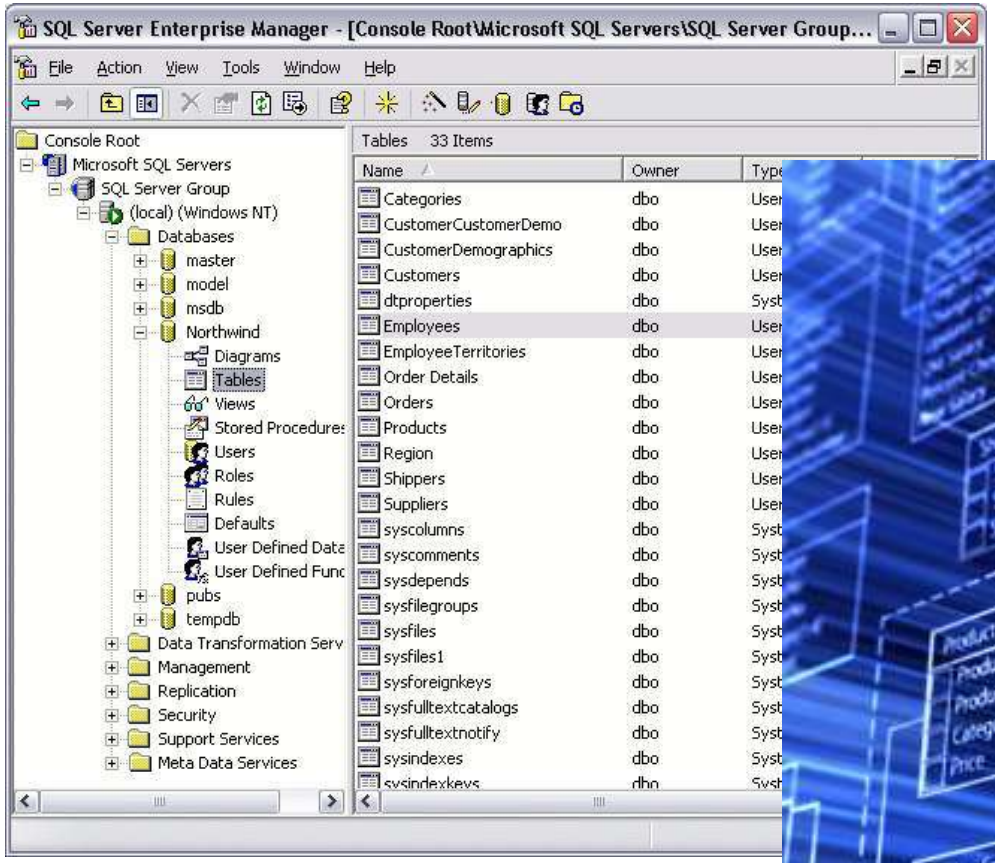

David


Jia

All CompSci 316 veterans!

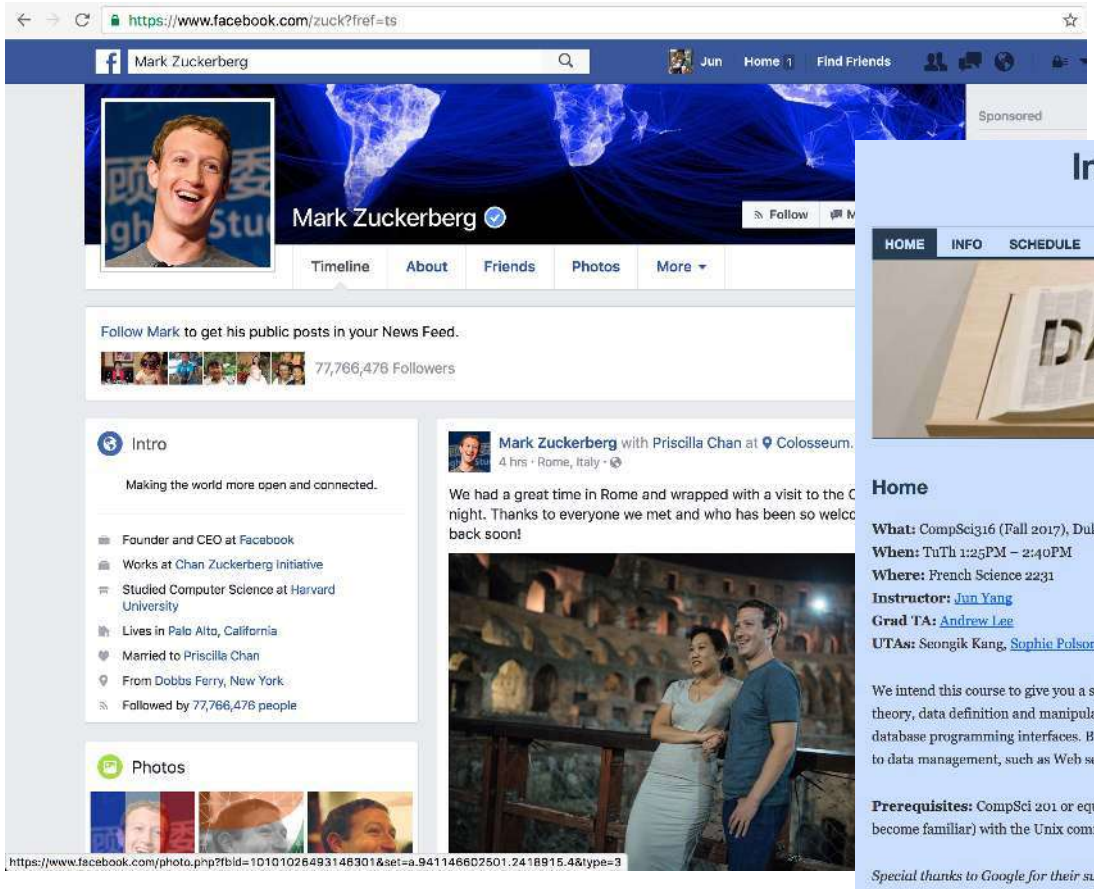
What comes to your mind…

… when you think about “databases”?

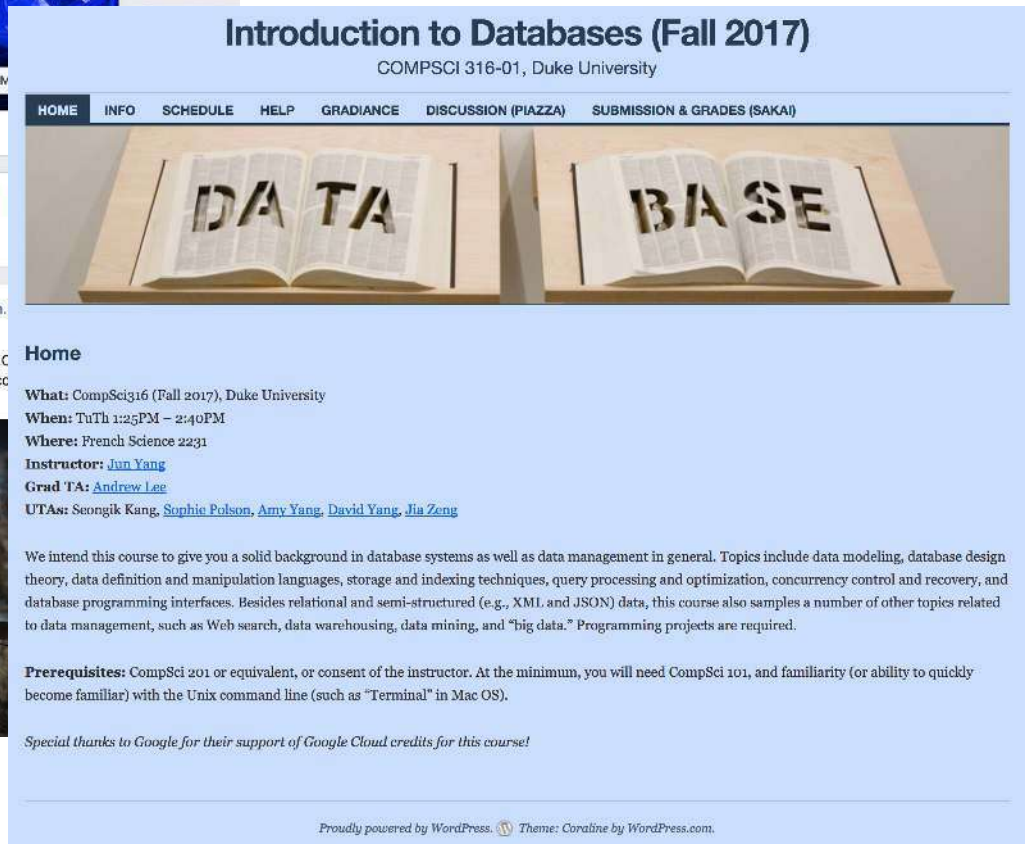


http://www.quackit.com/pix/database/tutorial/dbms_sql_server.gif
http://webstoresltd.com/wp-content/uploads/2013/06/database-design.jpg

But these use databases too…

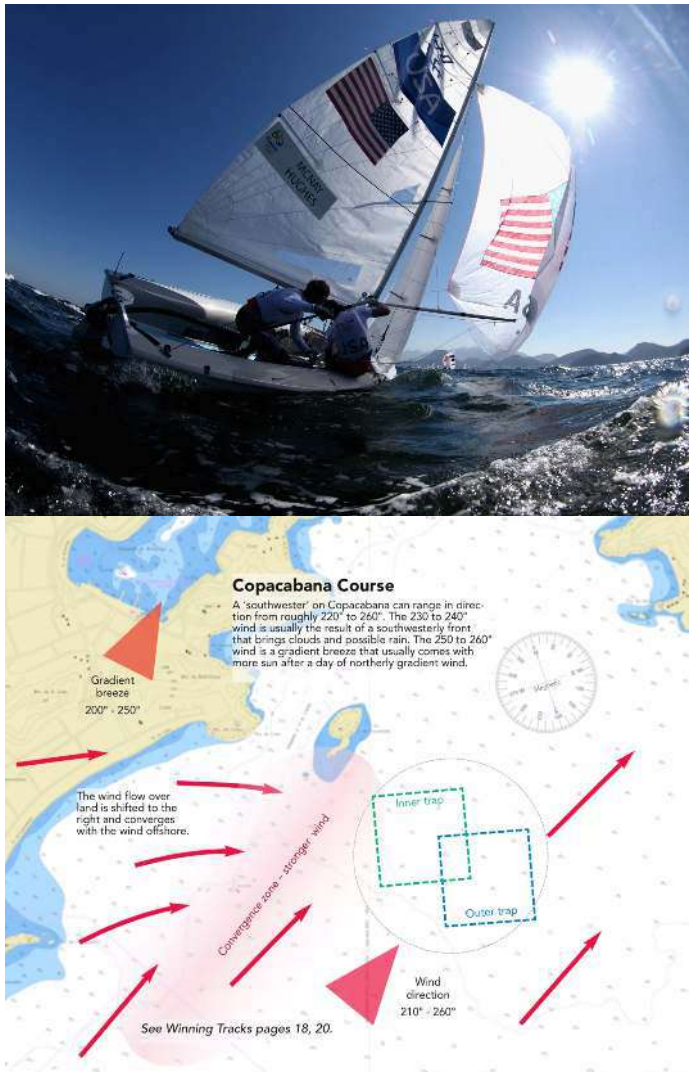


Facebook uses MySQL to store posts, for example



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?"

http://fivethirtyeight.com/features/will-data-help-u-s-sailing-get-back-on-the-olympic-podium/

Data → profit and fun

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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

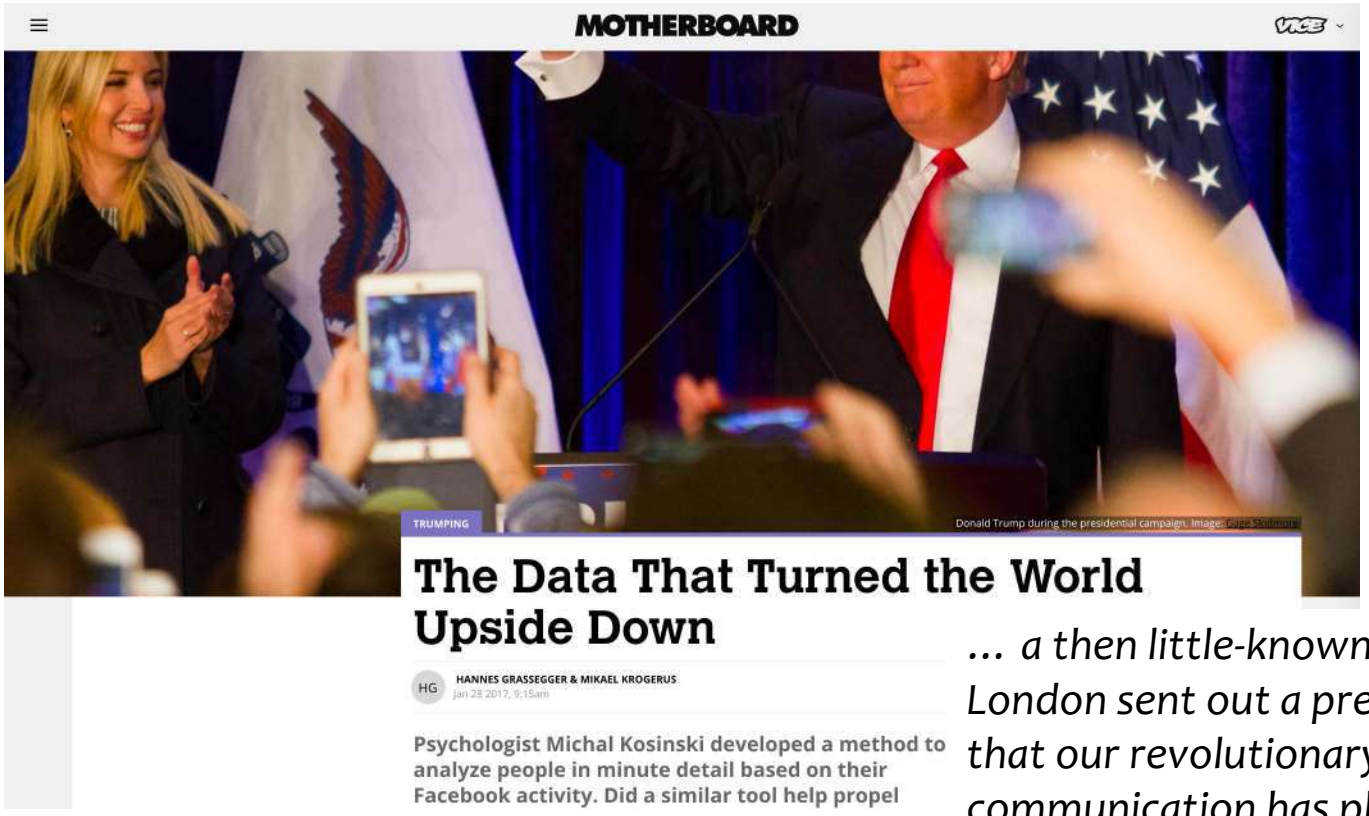
Pokemon Go is displayed on a cell phone. *PHOTO: ASSOCIATED PRESS*

… 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

http://www.wsj.com/articles/pokemon-go-creator-closes-privacy-hole-but-still-collects-user-data-1468363704
http://gizmodo.com/the-silph-road-pokemon-go-1784414758

Data → power

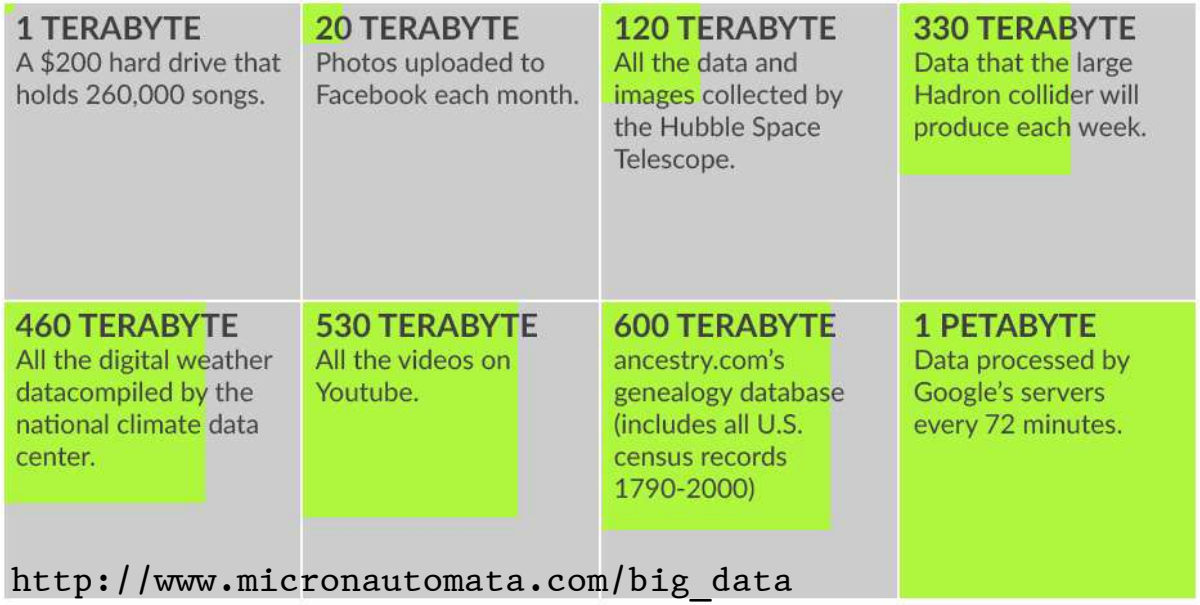


… a then little-known British company based in London sent out a press release: "We are thrilled that our revolutionary approach to data-driven communication has played such an integral part in President-elect Trump's extraordinary win," Alexander James Ashburner Nix was quoted as saying. Nix is British, 41 years old, and CEO of Cambridge Analytica. … His company wasn't just integral to Trump's online campaign, but to the UK's Brexit campaign as well.

https://motherboard.vice.com/en_us/article/mg9vvn/how-our-likes-helped-trump-win

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



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 and processing 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_f2017/`
  - 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
- Submissions, 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

- *Partners for Success* Tutoring App: connecting volunteer tutors to Durham teachers and students
  - Justin Bergkamp, Cosette Goldstein, Sophie Polson (your UTA), Bailey Wall
- *Hunt*: iPhone app for team Scavenger hunt
  - Cody Li, Brian Lin, Andy Wang, David Yang (your UTA)
- *Congress Talking Points*: analyses (sentiment, similarity, etc.) of speeches by members of the Congress
  - Gautam Hathi, Joy Patel, Seon Kang (your UTA), Zoey Zou

Projects from earlier years

- wikiblocks (vimeo.com/147680387): find visualizations for Wiki pages
  - Brooks Mershon, Mark Botros, Manoj Kanagaraj, Davis Treybig, 2015
- 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 Schedulator: 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

http://www.yummymummyclub.ca/sites/default/files/styles/large/public/field/image/teaching_kids_creative_skills.jpg

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

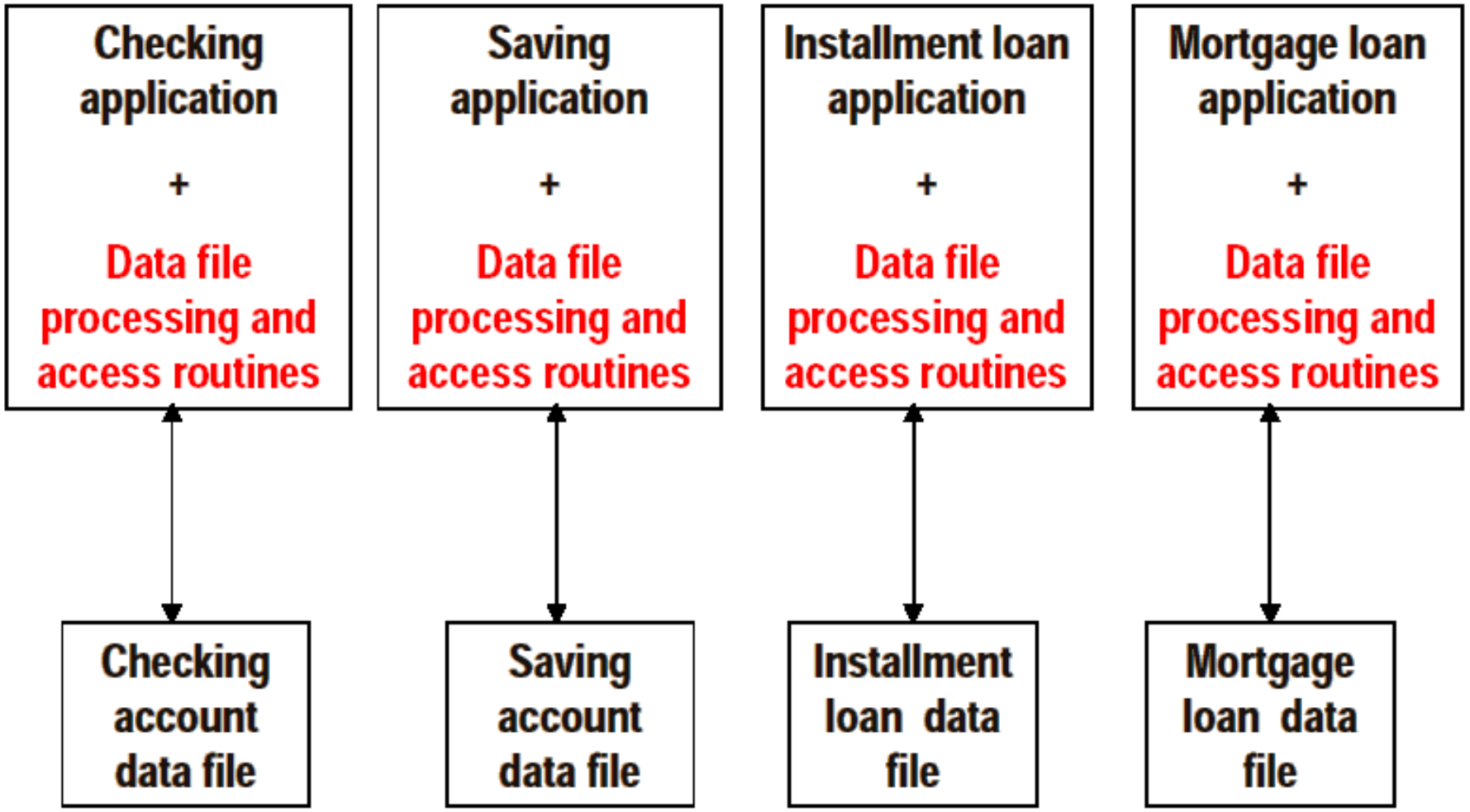
- Tens of thousands of accounts are not Homer's
  - ☞Cluster accounts by owner's initial: those owned by "A..." go into file A; those owned by "B..." go into file B; etc. → decide which file to search using the initial
  - ☞Keep accounts sorted by owner name → binary search?
  - ☞Hash accounts using owner name → compute file offset directly
  - ☞Index accounts by owner name: index entries have the form ⟨*owner_name, file_offset*⟩ → 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

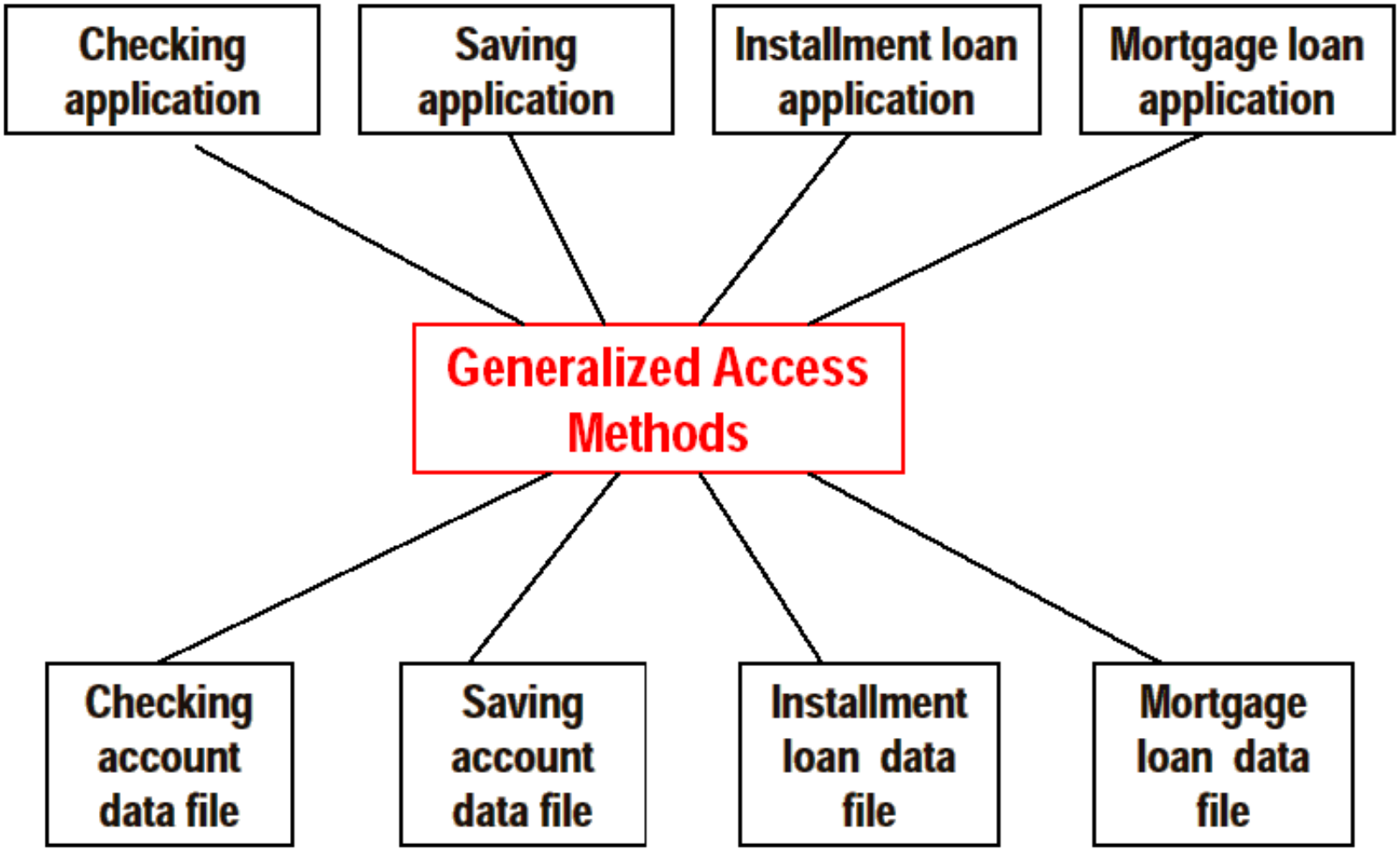
- There are many techniques—not only in storage and query processing, but also in concurrency control, recovery, etc.
- These techniques get used over and over again in different applications
- Different techniques may work better in different usage scenarios

The birth of DBMS – 1



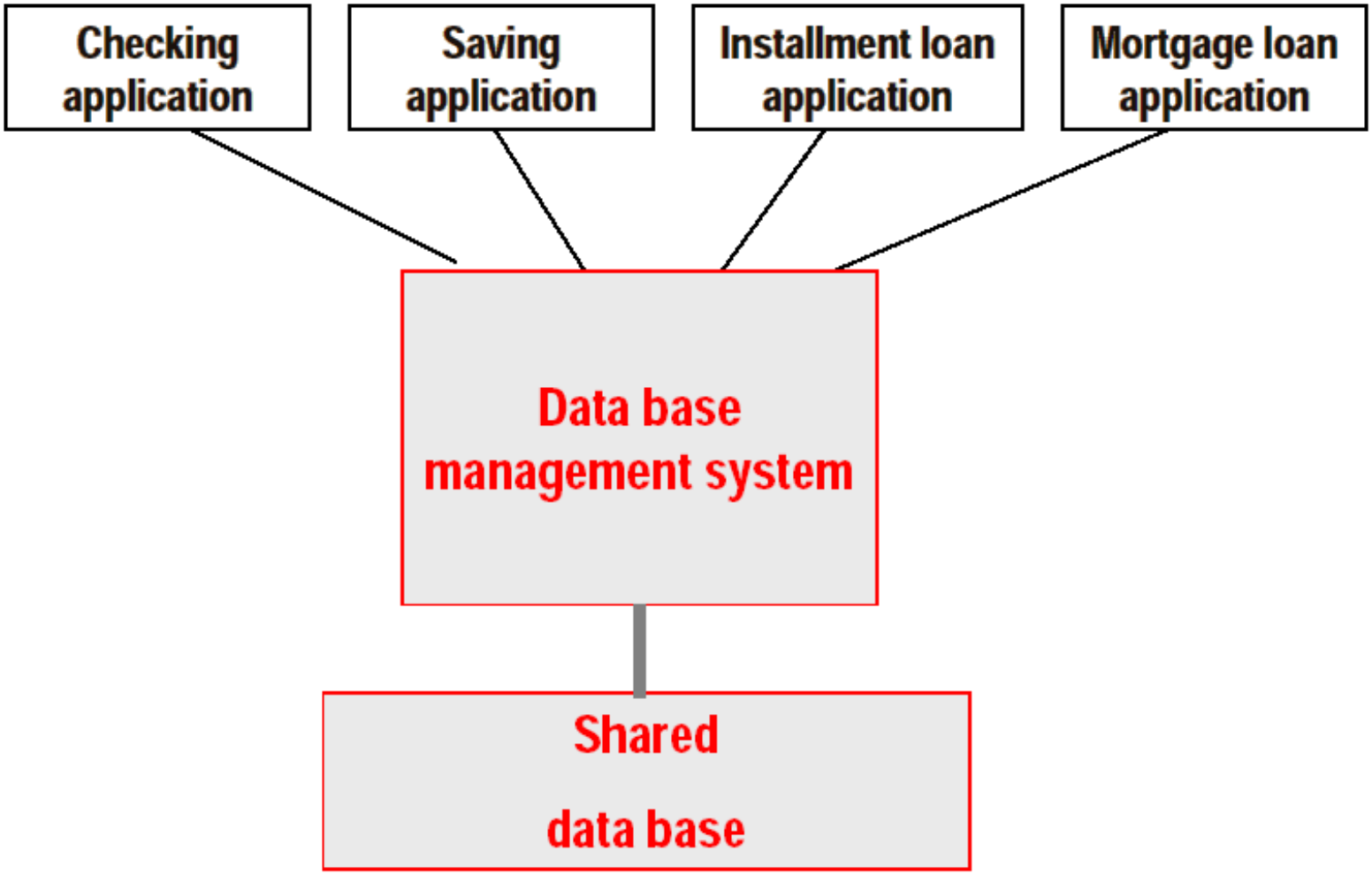
From Hans-J. Schek's *VLDB* 2000 slides

The birth of DBMS – 2



From Hans-J. Schek's *VLDB* 2000 slides

The birth of DBMS – 3



From Hans-J. Schek's *VLDB* 2000 slides

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

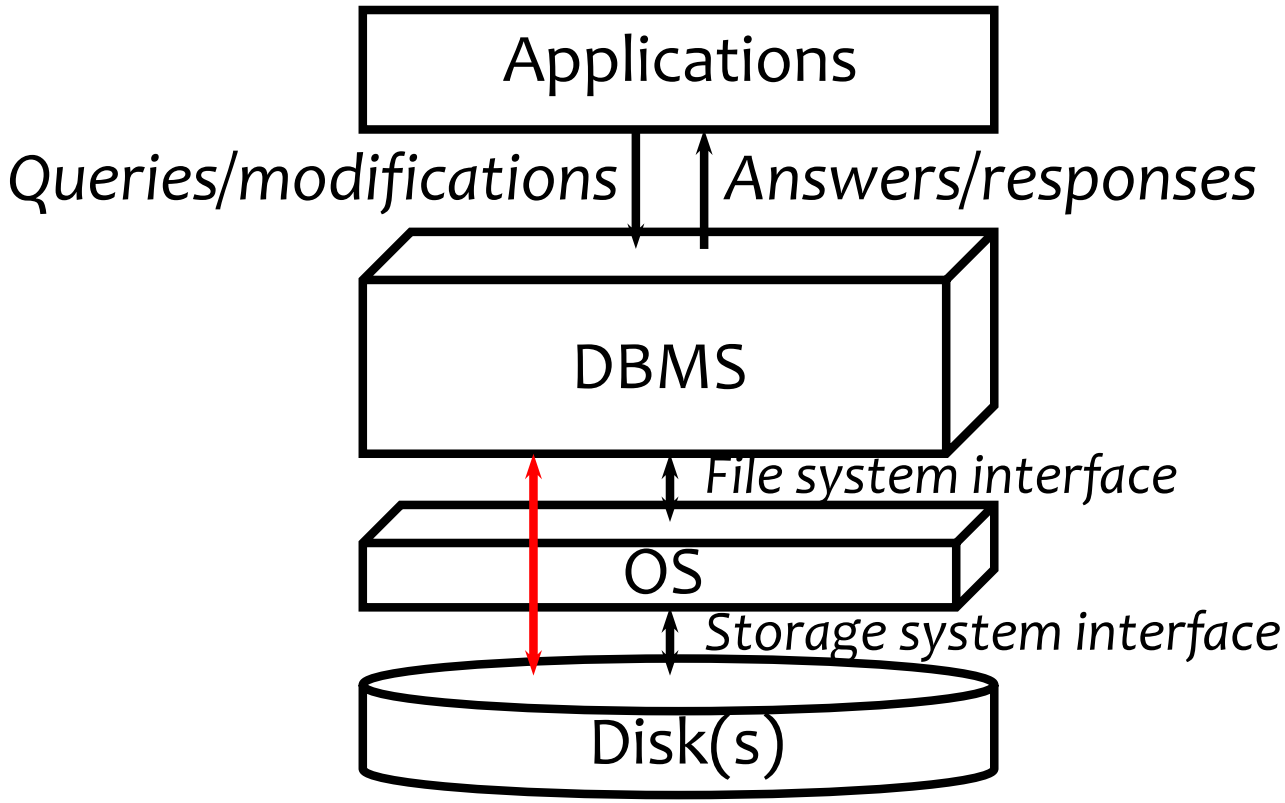
```
decrement the balance of account X by $100;
increment the balance of account Y by $100;
```

- 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 (≥ 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. 29)

- Email me for registration questions
- Thursday
  - Andrew + others will lead the class through the steps of setting up VM for the class on your laptop
    - Bring your laptop, fully charged!
- I will be back to talk about relational algebra next Tuesday!