Administrivia

			Look for teammates	
L2	8-Sep	**ER Models** optional: Textbook Chapter 6 except for Sections 6.7, 6.10, and 6.11.	HW1 Part 1 Project 1 Part 1	HW0 (9/11 11:59PM EST. NO LATE DAYS)
L3	13-Sep	**ER Models** optional: Textbook Chapter 6 except for Sections 6.7, 6.10, and 6.11.		HW 1 Part 1 (9/16 11:59PM EST) Formed Project 1 Team (no submission)
L4	15-Sep	**Relational Model**		Project 1 Part 1 approval

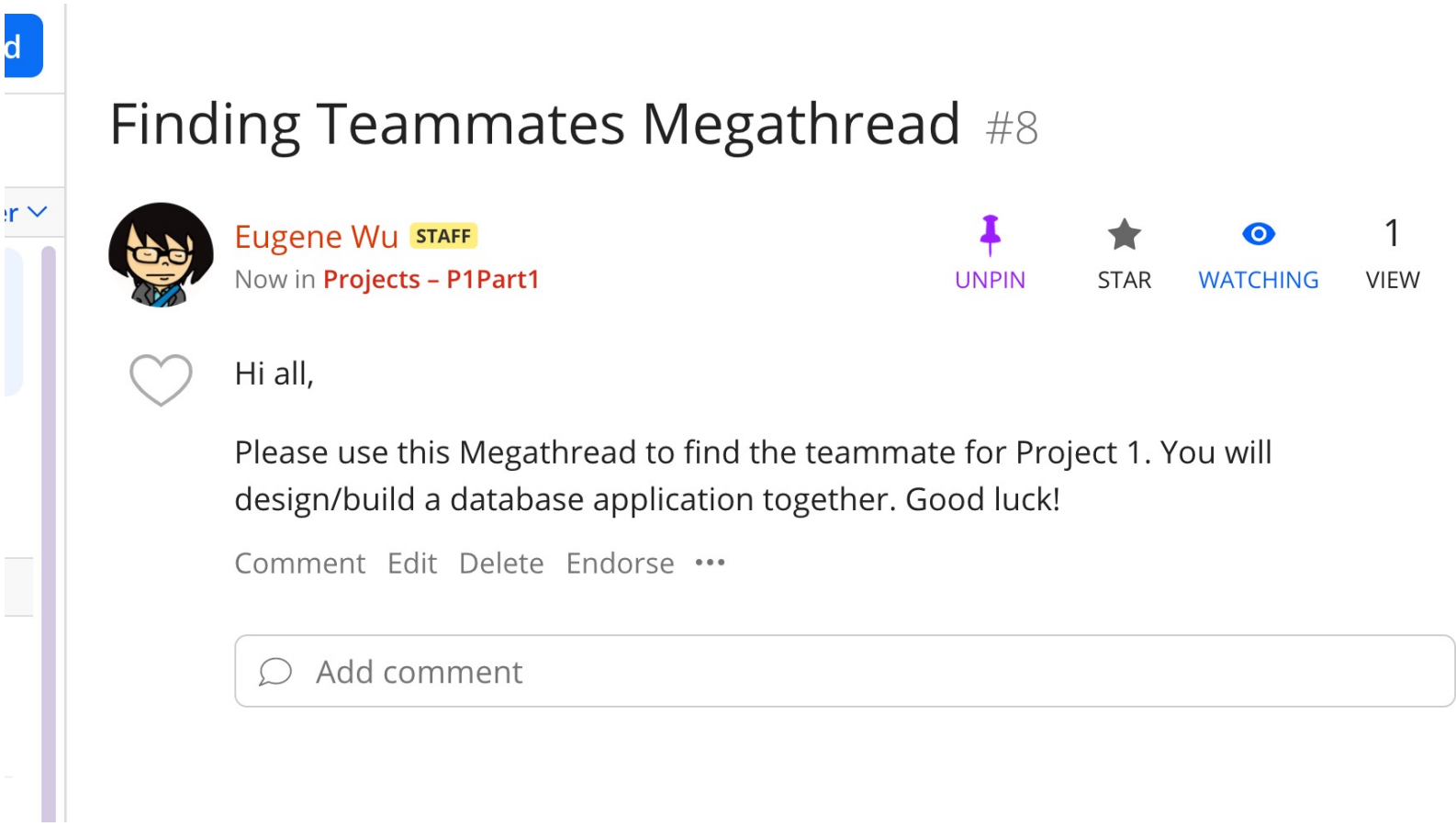
Staff office hours will be up this weekend

Zoom links in discussion board

HW1 out today

Project 1 Part 1 out today

Find a project 1 teammate ASAP!

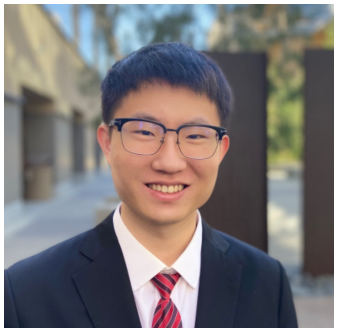


- Auditors OK
  - courseworks set to institutional visibility,
  - all material on website
- Schedule conflicts OK
  - you are responsible for exam conflicts!

Meet the Staff

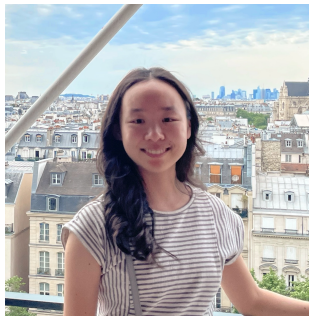
Zachary Huang
Poke Bowl

Lucas Kalejaiye
Emmy burger at Emily (West Village) is the best burger in nyc

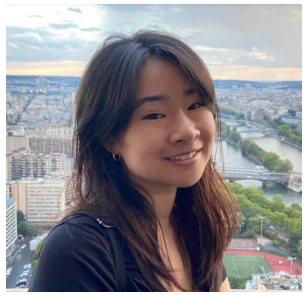


Weisheng Wang
hotpot

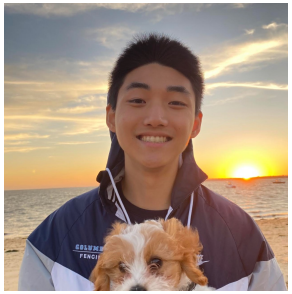
Meet the Staff



Jennifer Wang
Portuguese egg tarts



Lia Chen
Roti Rolls



Andrew Zheng
Uluh on 9th street and 2nd Ave.

Lecture 2
Entity-Relationship Model

Eugene Wu

Steps for a New Application

Requirements
- what are you going to build?

Conceptual Database Design
- pen-and-pencil description

Logical Design
- formal database schema

Schema Refinement:
- fix potential problems, normalization

Physical Database Design
- use sample of queries to optimize for speed/storage

App/Security Design
- prevent security problems

Steps for a New Application

Requirements
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ER Modeling

Logical Design
- formal database schema

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Physical Database Design
- use sample of queries to optimize for speed/storage

App/Security Design
- prevent security problems

Database Apps Are Complicated

Typical Fortune 100 Company

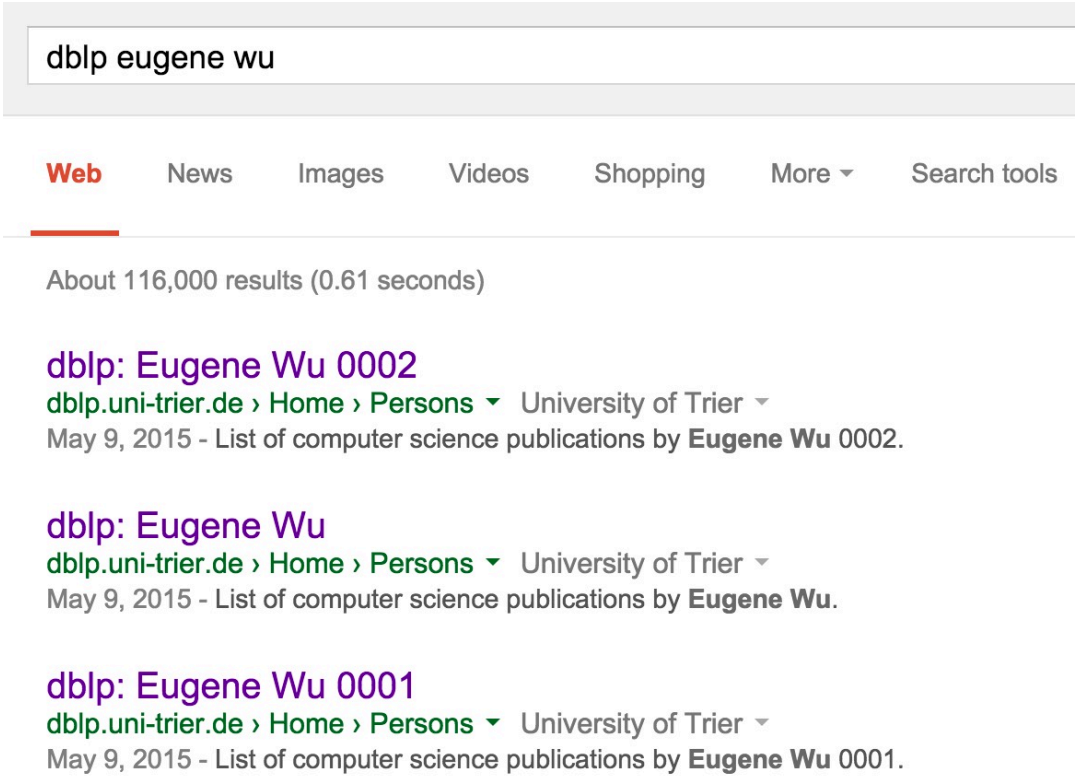
- ~10k different information (data) systems
- 90% relational databases (DBMSes)
- Typical database has >100 tables
- Typical table has 50 – 200 attributes

Inconsistencies/Constraint Violations

Huge amount of effort to avoid inconsistencies

Can data model help us avoid automatically?

DBLP is *the* site for computer science publications



Inconsistencies/Constraint Violations

[–] **2010 – today** [+] **Refine list**

2014

- [j8] Eugene Wu, Leilani Battle, Samuel R. Madden: **The Case for Data Visualization Management Systems.** PVLDB 7(10): 903-906 (2014)
- [j7] Alekh Jindal, Praynaa Rawlani, Eugene Wu, Samuel Madden, Amol Deshpande, Mike Stonebraker: **VERTEXICA: Your Relational Friend for Graph Analytics!** PVLDB 7(13): 1669-1672 (2014)

≠

[–] **1990 – 1999** [+] **Refine list**

1994

- [c2] James Hwang, Eugene Wu, Alan Bell, Andy Cordell, LeBarian Stokes, Scott Hankins: **Design of a SPDM-Like Robotic Manipulator System for Space Station on Orbit Replaceable Unit Ground Testing - An Overview of the System Architecture.** ICRA 1994: 1286-1291
- [c1] Eugene Wu, James Hwang, Scott Hankins: **Design of the Control System for a Robotic Manipulator for Space Station On-Orbit Replaceable Unit Ground Testing.** ICRA 1994: 1415-1420

www.cs.columbia.edu › ~ewu

Eugene Wu - Columbia University

Eugene Wu received his Ph.D. from MIT, B.S. from Cal, and was a postdoc in the AMPLab. A profile, an obit. **Eugene Wu** has received the VLDB 2018 10-year test of time award, best-of-conference citations at ICDE and VLDB, the SIGMOD 2016 best demo award, the NSF CAREER, and the Google and Amazon faculty awards.

https://www.forbes.com › profile › eugene-wu

Eugene Wu - Forbes

#39 **Eugene Wu** on the 2021 Taiwan's 50 Richest - **Wu** is the founder of Shin Kong Financial, one of Taiwan's largest private-sector financial companies. **Wu** stepped down as the firm's chairman in June ...

PROFILE | Finance & Investments

#39 Eugene Wu

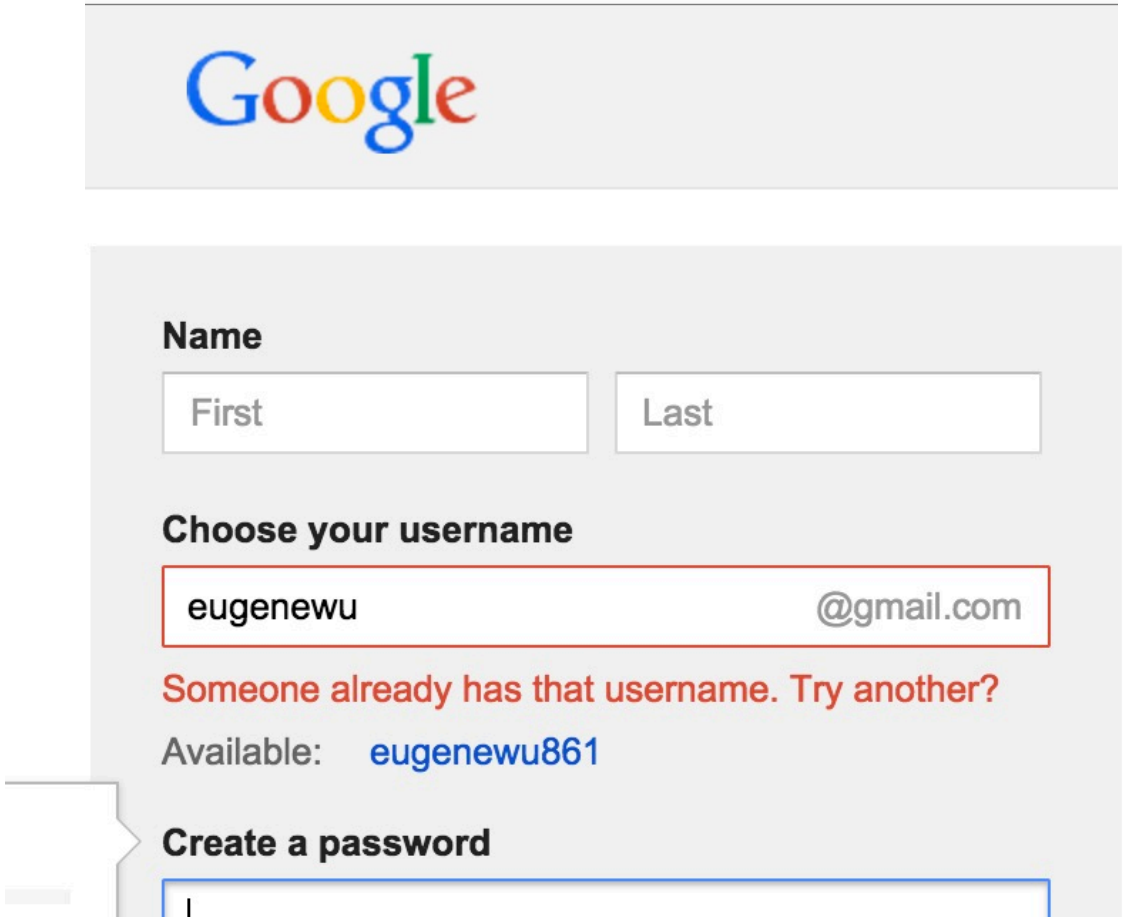
$1.4B REAL TIME NET WORTH
as of 1/27/22

▲ $11 M | 0.77%
Reflects change since 5 PM ET of prior trading day

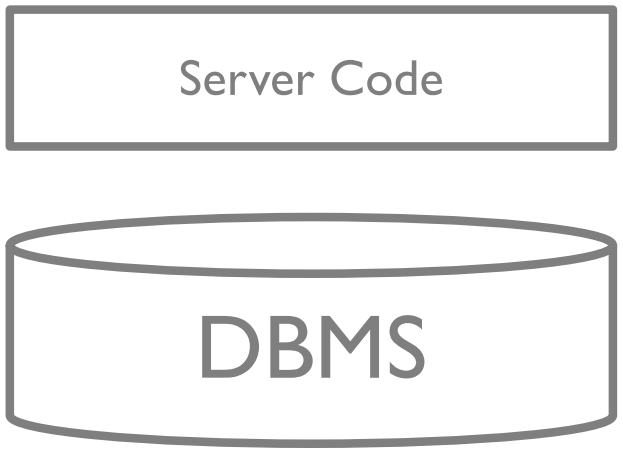
Not Teaching 411!!!

Inconsistencies/Constraint Violations

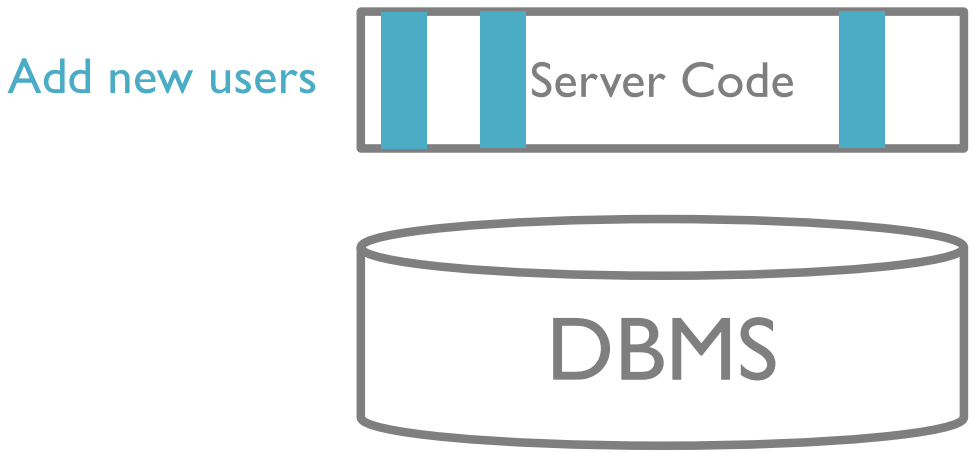
Check in application code!



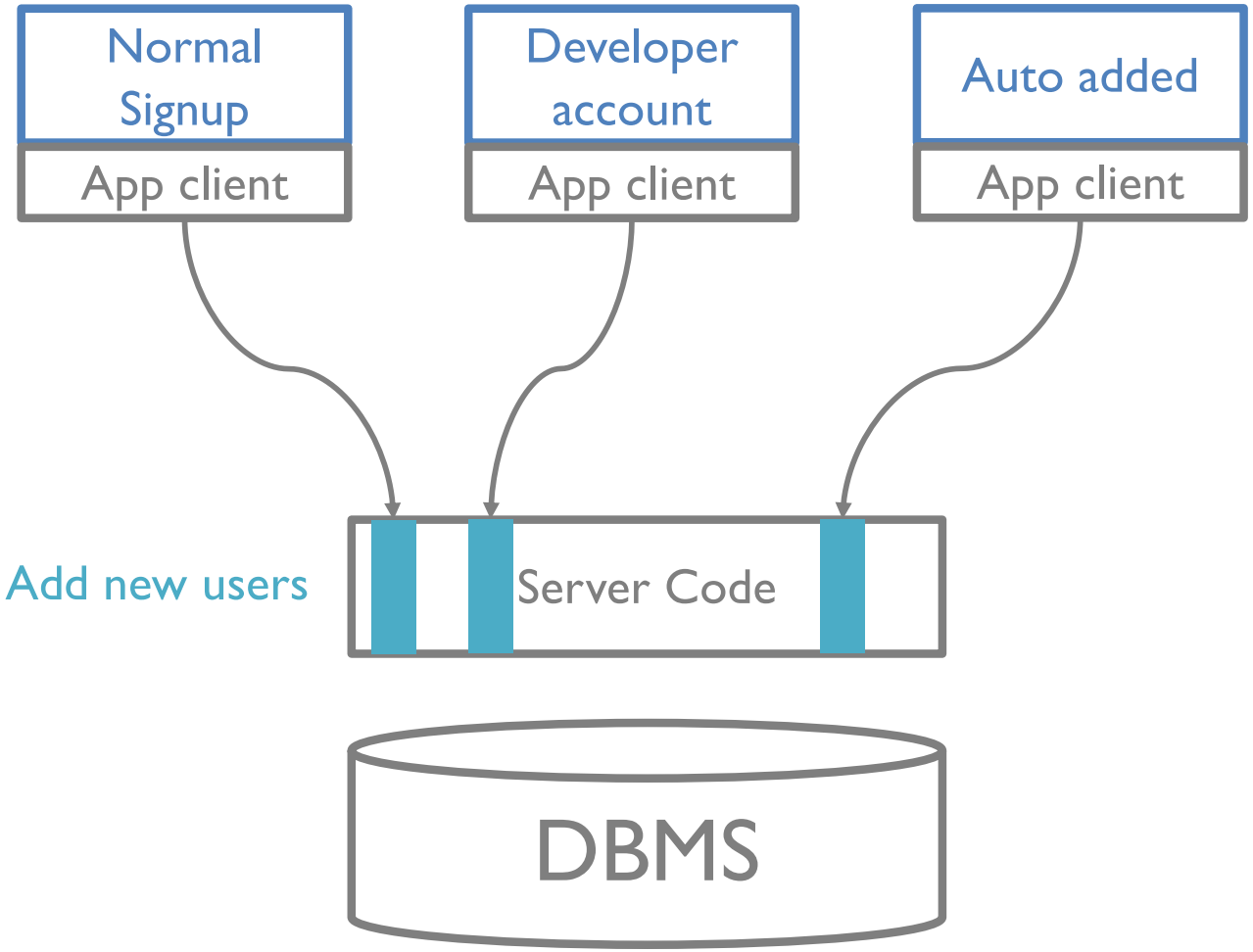
It is Hard to Design Applications



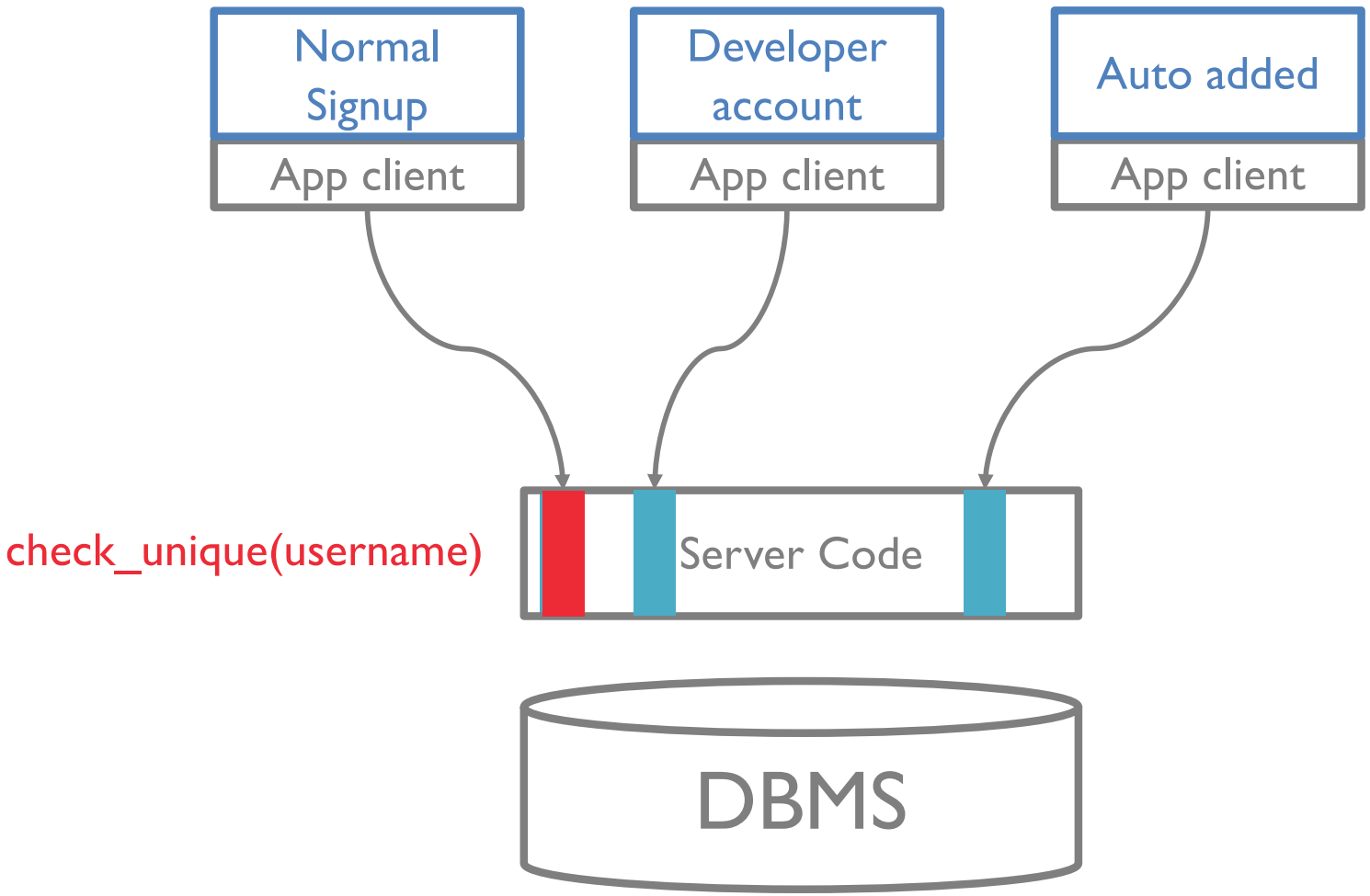
It is Hard to Design Applications



It is Hard to Design Applications



It is Hard to Design Applications



ER Diagrams

What is it?

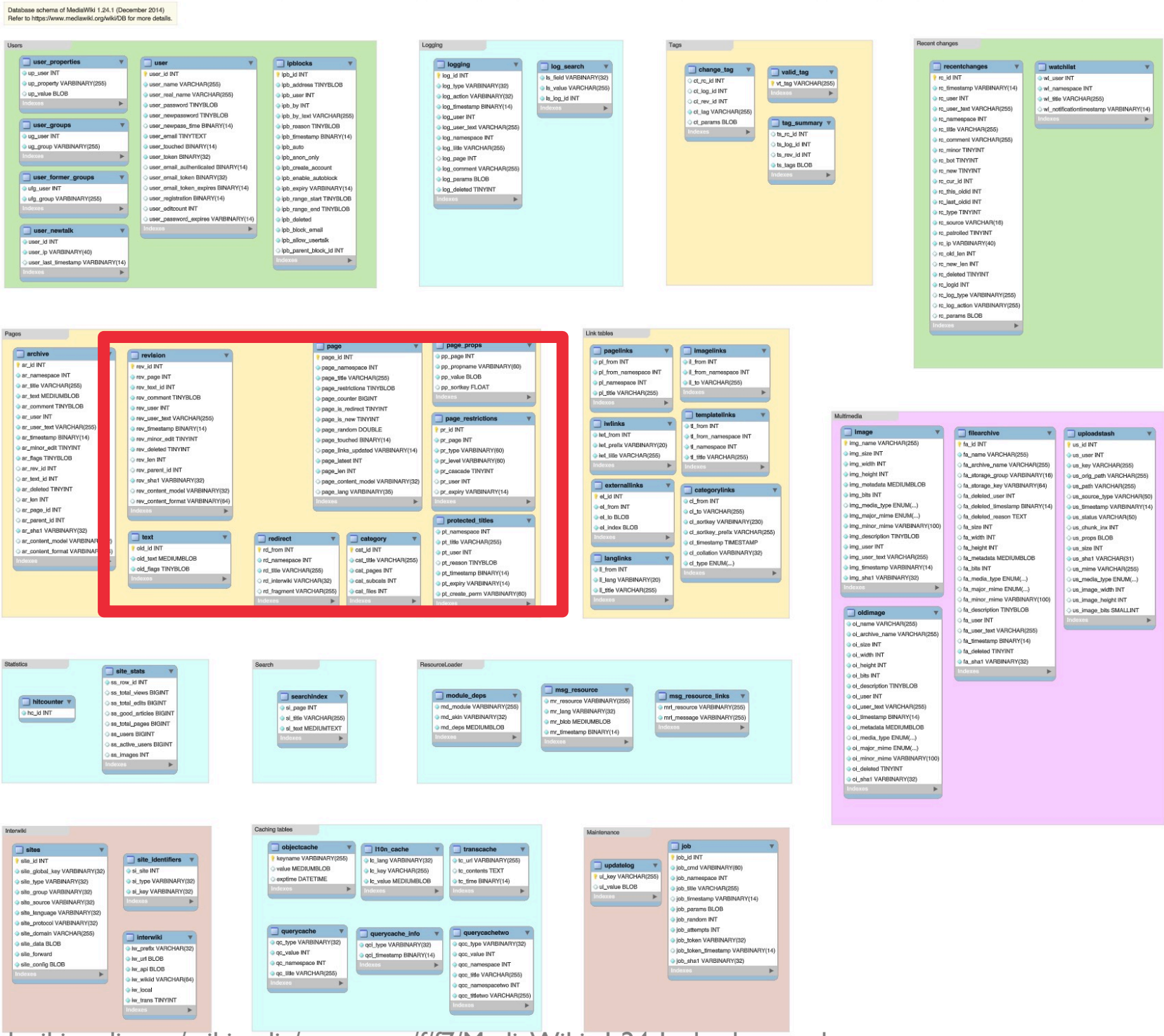
- A way to sketch the core information that your database will eventually store.
- Visually encodes important constraint information

Who cares?

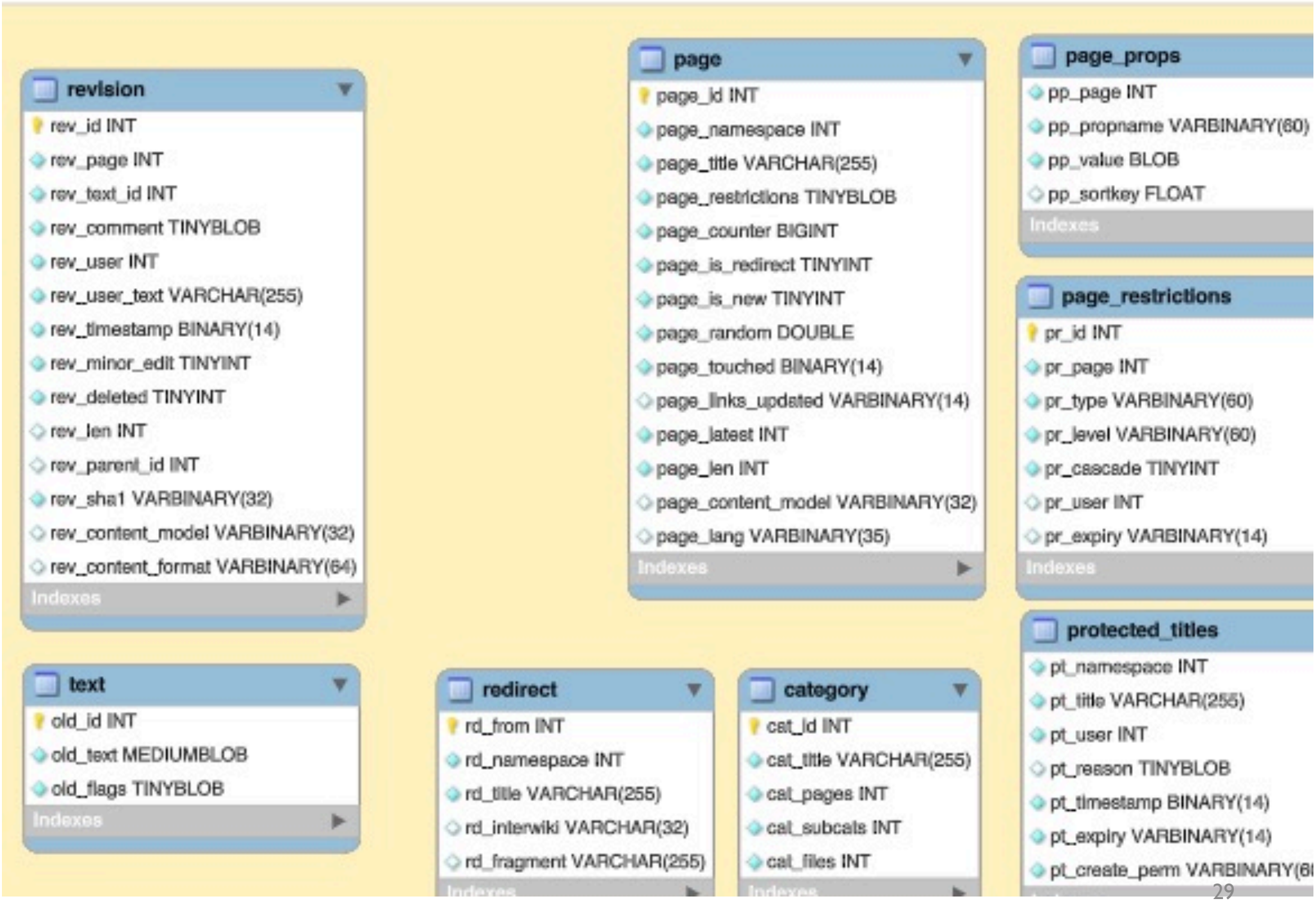
- Good for "white boarding" together
- Good way to share the "gist" of your DB's structure

```
test=# \d election
                                Table "public.election"
      Column       |  Type   | Collation | Nullable |                Default
-------------------+---------+-----------+----------+-------------------------------
 year              | integer |           |          |
 state             | text    |           |          |
 state_po          | text    |           |          |
 state_fips        | integer |           |          |
 state_cen         | integer |           |          |
 state_ic          | integer |           |          |
 office            | text    |           |          |
 candidate         | text    |           |          |
 party_detailed    | text    |           |          |
 writein           | text    |           |          |
 candidatevotes    | integer |           |          |
 totalvotes        | integer |           |          |
 version           | integer |           |          |
 notes             | text    |           |          |
 party_simplified  | text    |           |          |
 id                | integer |           | not null | nextval('election_id_seq'::
Indexes:
    "election_id_key" UNIQUE CONSTRAINT, btree (id)

test=# \d food
                    Table "public.food"
     Column      |  Type   | Collation | Nullable | Default
-----------------+---------+-----------+----------+---------
 camis           | integer |           |          |
 dba             | text    |           |          |
 boro            | text    |           |          |
 building        | integer |           |          |
 street          | text    |           |          |
 zipcode         | integer |           |          |
 phone           | bigint  |           |          |
 inspection_date | date    |           |          |
 action          | text    |           |          |
 score           | integer |           |          |
 grade           | text    |           |          |
 inspection_type | text    |           |          |
 census_tract    | integer |           |          |
 year            | integer |           |          |
 month           | integer |           |          |
 day             | integer |           |          |
```

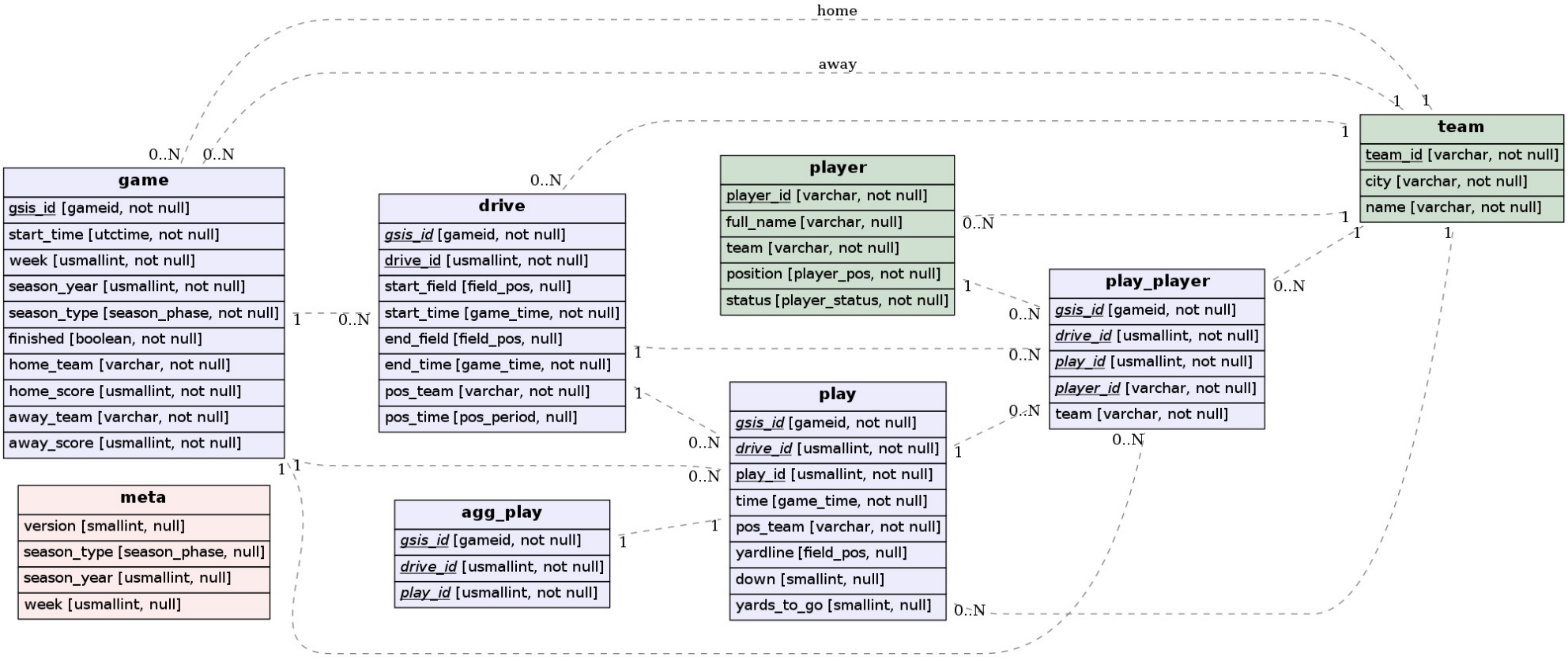


https://upload.wikimedia.org/wikipedia/commons/f/f7/MediaWiki_1.24.1_database_schema.svg



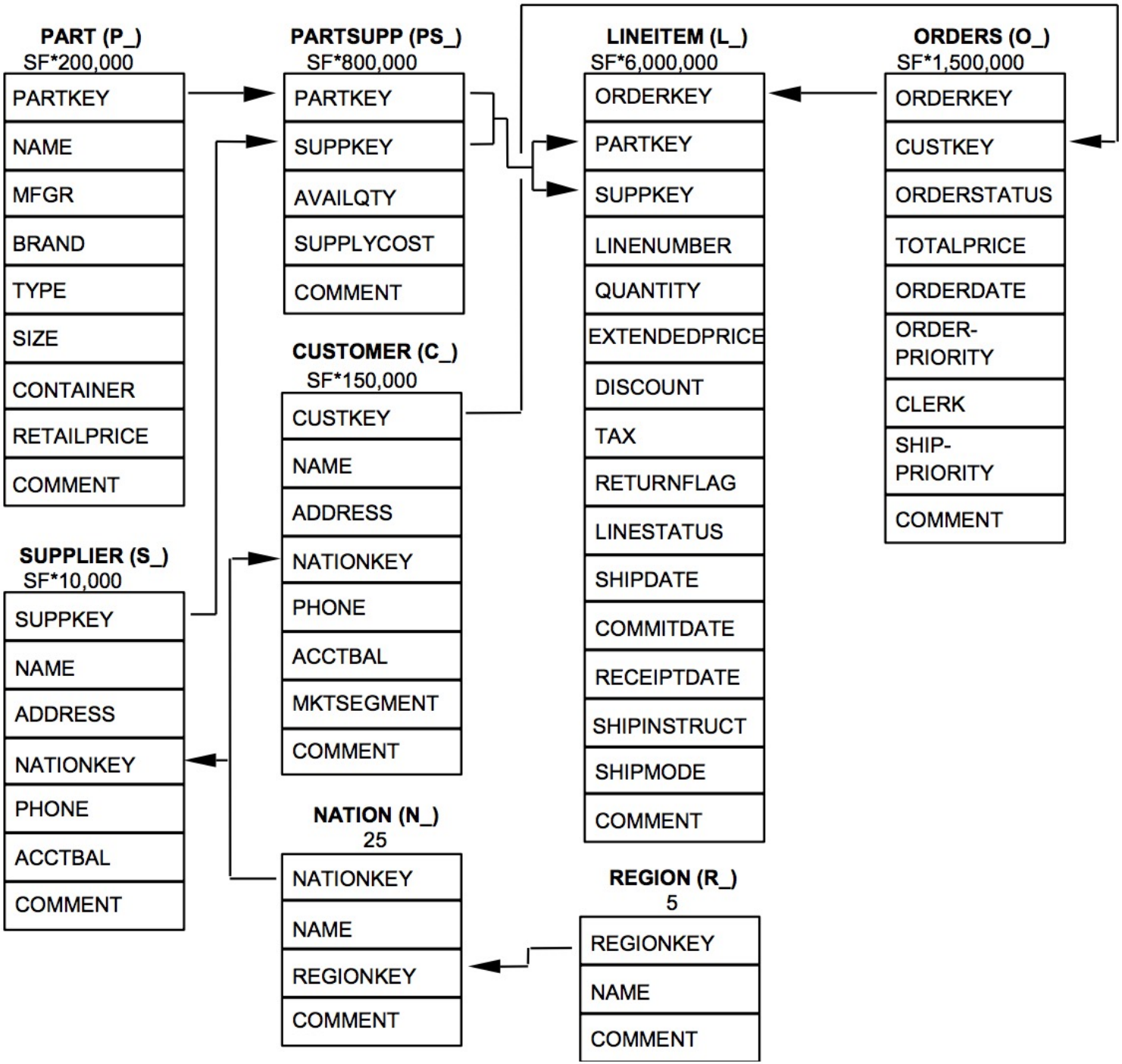
https://upload.wikimedia.org/wikipedia/commons/f/f7/MediaWiki_1.24.1_database_schema.svg

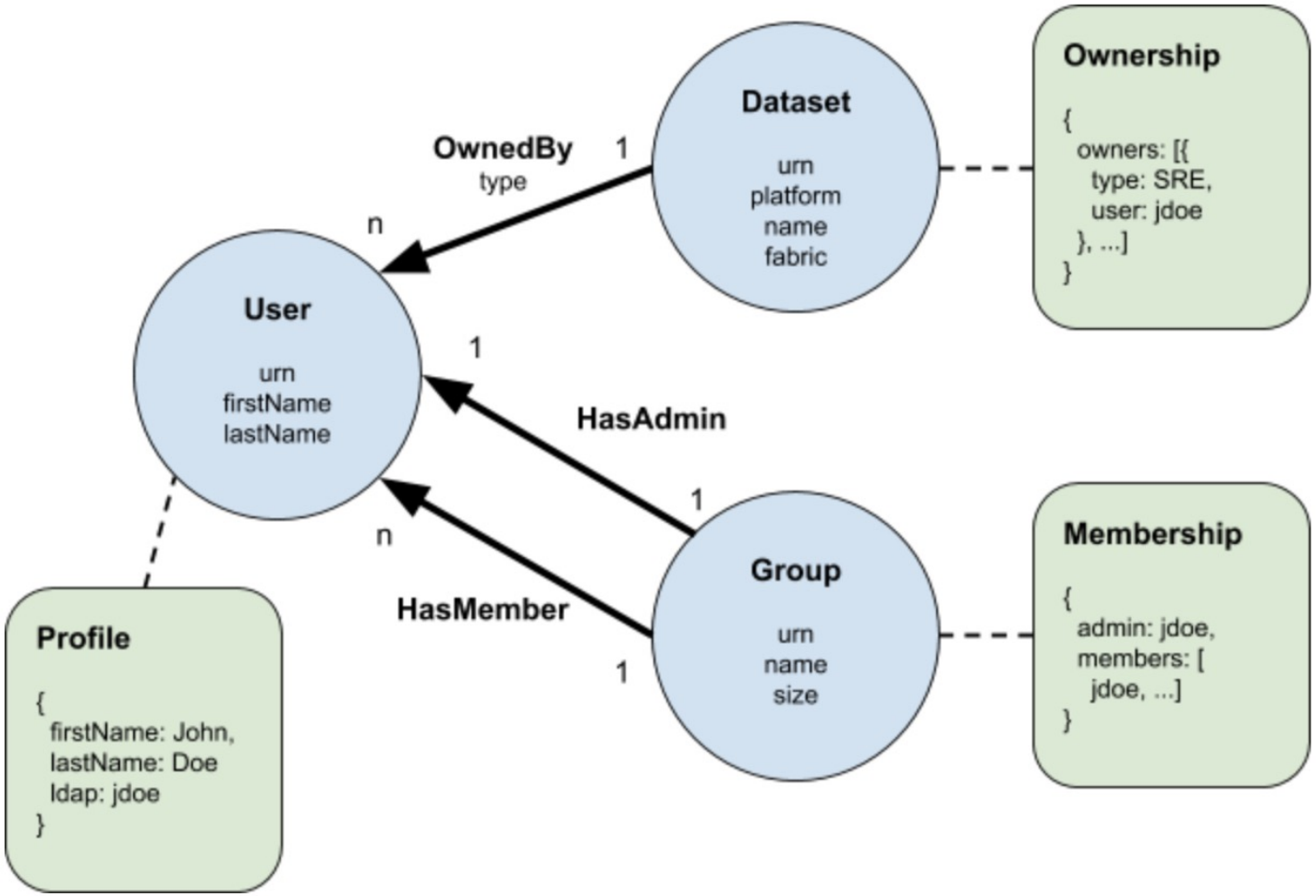
nfldb Entity-Relationship diagram (condensed)



https://github.com/BurntSushi/nfldb/wiki/The-data-model#er-diagrams

Figure 2: The TPC-H Schema





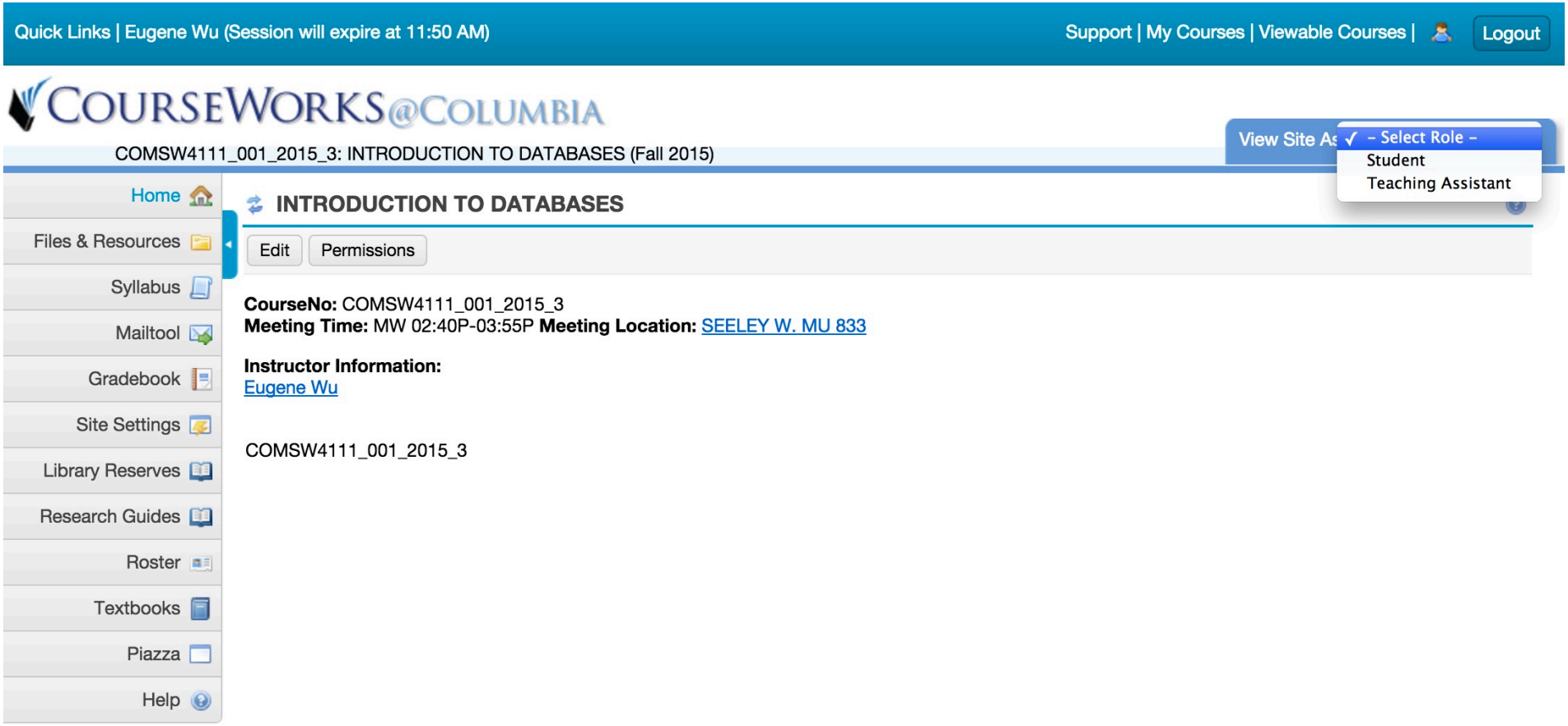
https://engineering.linkedin.com/blog/2019/data-hub

All Variations of ER diagrams

In practice, everyone uses different notations.

What matters are the core *concepts*

(in this class, we will learn a specific notation)

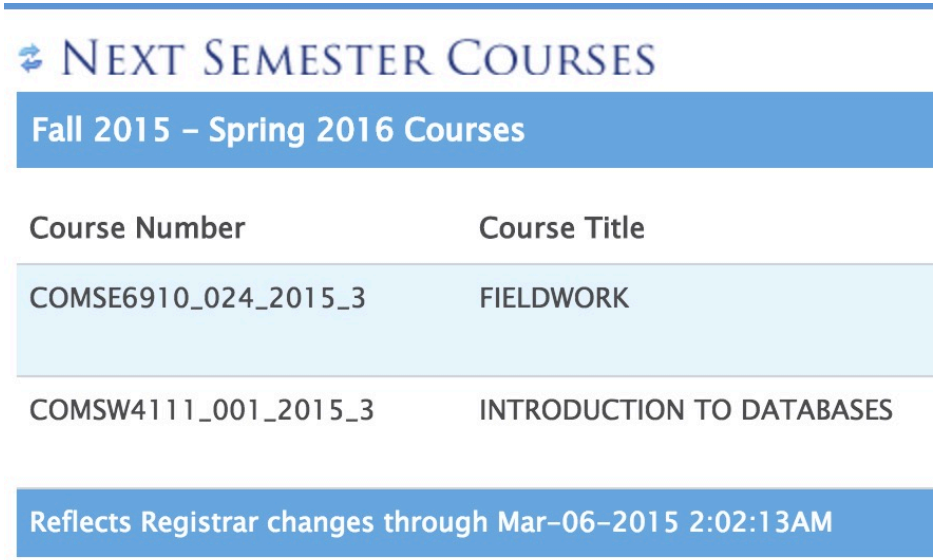

Quick Links | Eugene Wu (Session will expire at 11:50 AM)
Support | My Courses | Viewable Courses |
Logout
COURSEWORKS@COLUMBIA
COMSW4111_001_2015_3: INTRODUCTION TO DATABASES (Fall 2015)
View Site As
– Select Role –
Student
Teaching Assistant
Home
Files & Resources
Syllabus
Mailtool
Gradebook
Site Settings
Library Reserves
Research Guides
Roster
Textbooks
Piazza
Help
INTRODUCTION TO DATABASES
Edit
Permissions
CourseNo: COMSW4111_001_2015_3
Meeting Time: MW 02:40P-03:55P Meeting Location: SEELEY W. MU 833
Instructor Information:
Eugene Wu
COMSW4111_001_2015_3

Entity-Relationship Modeling

Entities (objects) to store and their attributes

Relationships between entities and their attrs.

Integrity constraints & business rules



NEXT SEMESTER COURSES

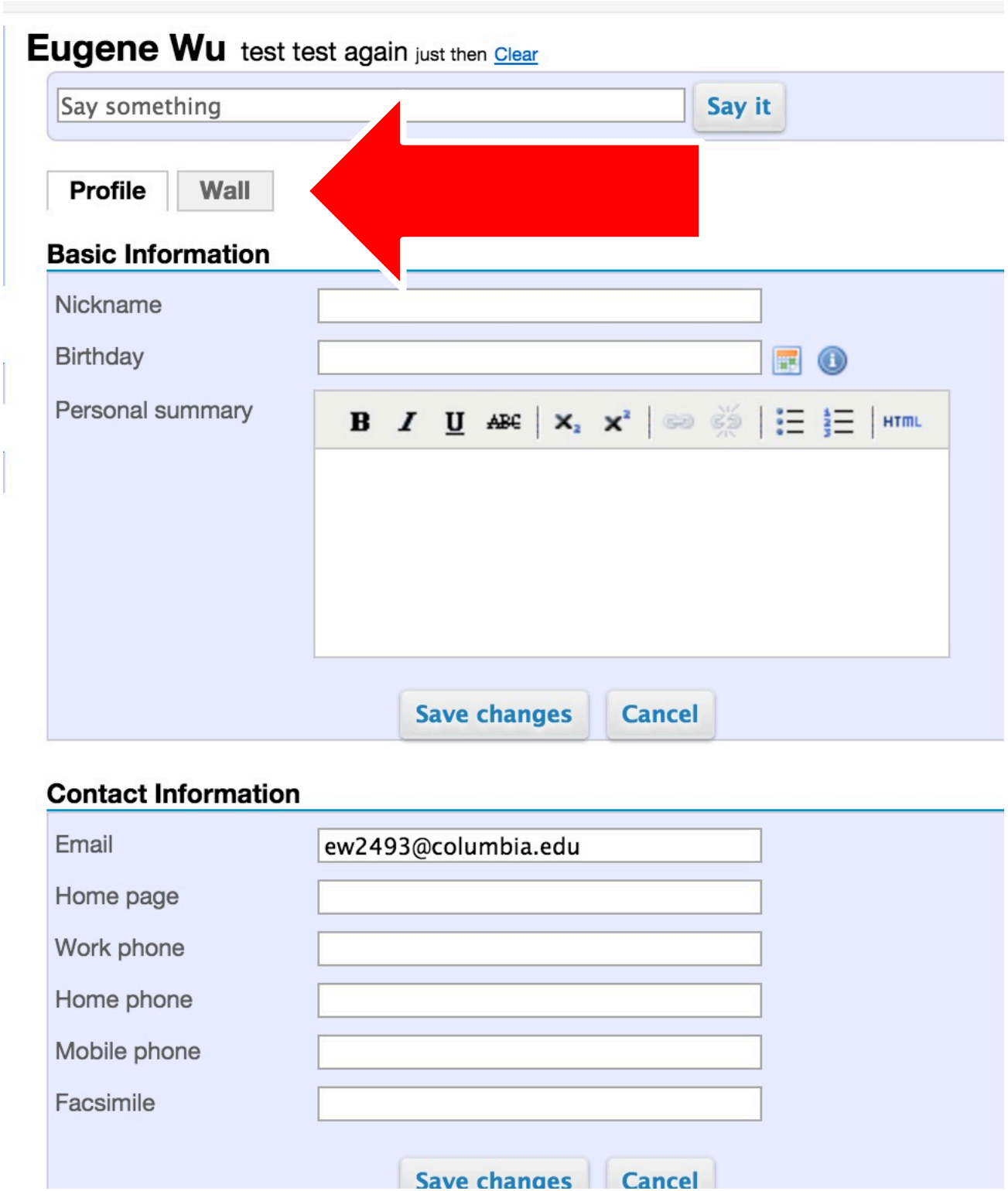
Fall 2015 – Spring 2016 Courses

Course Number	Course Title
COMSE6910_024_2015_3	FIELDWORK
COMSW4111_001_2015_3	INTRODUCTION TO DATABASES

Reflects Registrar changes through Mar-06-2015 2:02:13AM

Courses

- Course Number
- Course Title
- Year
- Semester



Users

- Nickname
- Name
- Birthday
- Summary
- Email
- …

Basics: Entities

Entity e.g., intro to databases

- real-world object distinguishable from other objects
- described as set of attributes & the values
- (think one record)

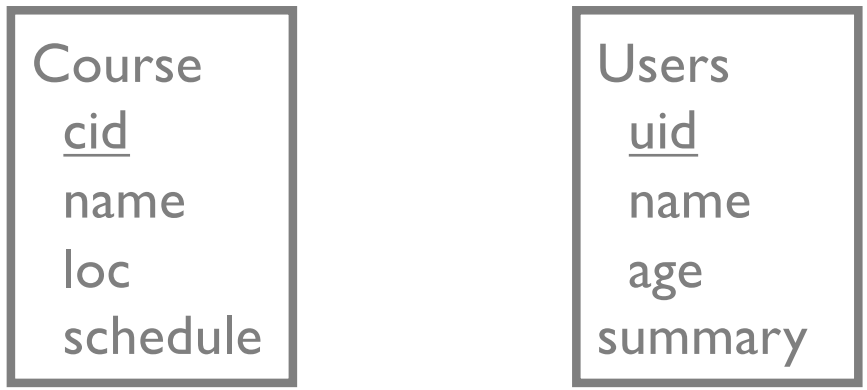
Entity Set e.g., all courses

- collection of similar entities
- all entities have same attributes (unless Is-A)
- must have one or more keys
- attributes have domains
- ≈ table

Example: Entity

Keys (cid, uid) are underlined

- Values must be unique
- (can use as hashtable key to lookup in table)



Basics: Relationships

Relationship: association between 2 or more entities

e.g., alice is taking Introduction to DBs

Relationship Set: collection of similar relationships

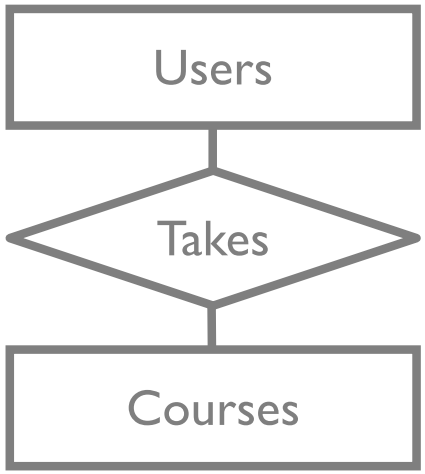
N-ary relationship set R relates N entity sets $E_1 \ldots E_n$

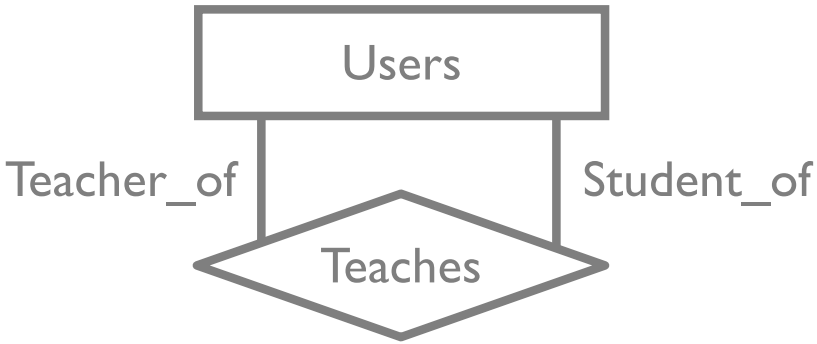
Each $r \in R$ involves entities $e_1 \ldots e_n$

An E_i can be part of diff. relationship sets or diff. roles in same set

Basics: Relationships

Users can have different roles in same relationship set

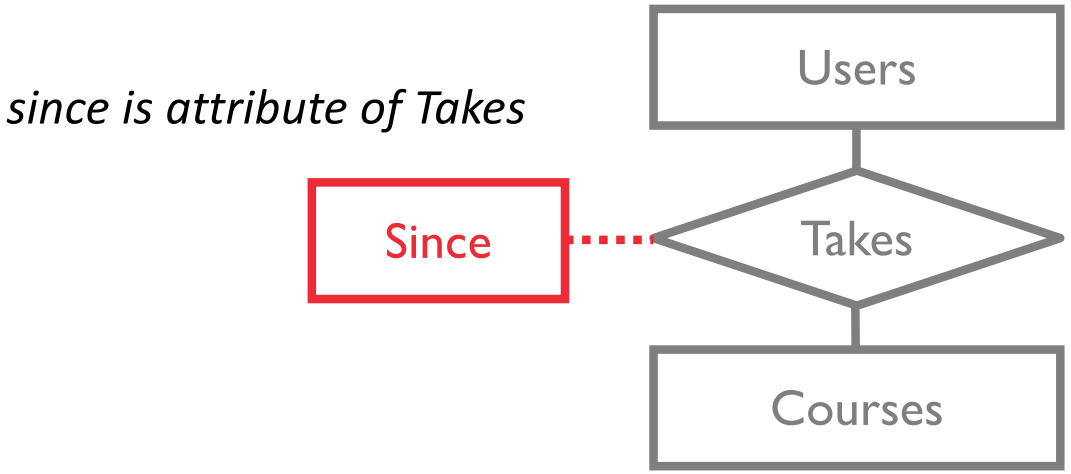




Basics: Relationships

Relationships sets can have descriptive attributes

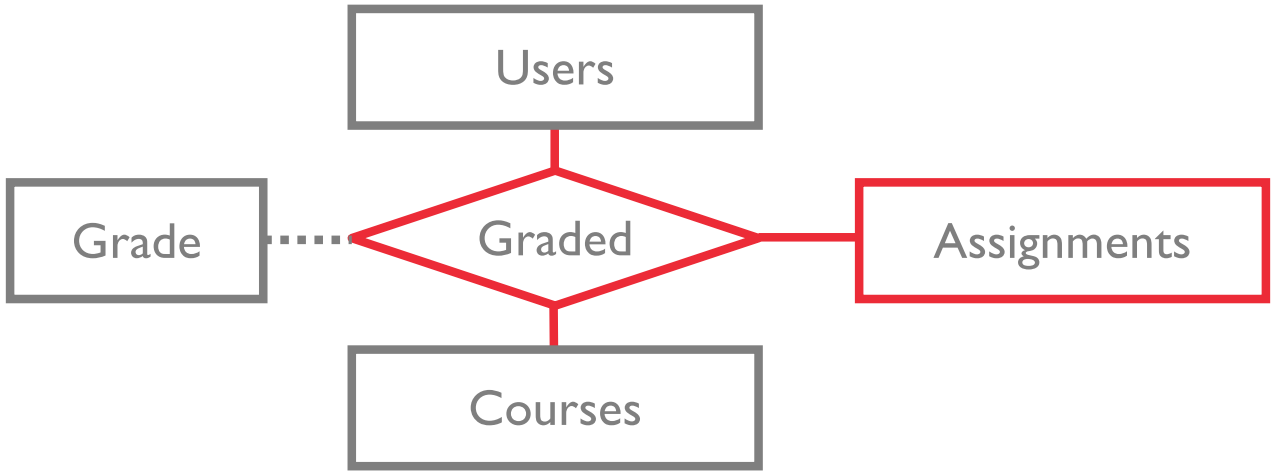
Denoted with dotted line from diamond to box



Basics: Ternary Relationships

Connects three entities

N-ary relationships possible too.



Assignments, Courses, and Users participate in the Graded relationship set

Constraints

Help avoid corruption, inconsistencies

- Key constraints
- Participation constraints
- Weak entities
- Overlap and covering constraints

Key Constraints

Defines cardinality requirements on relationships

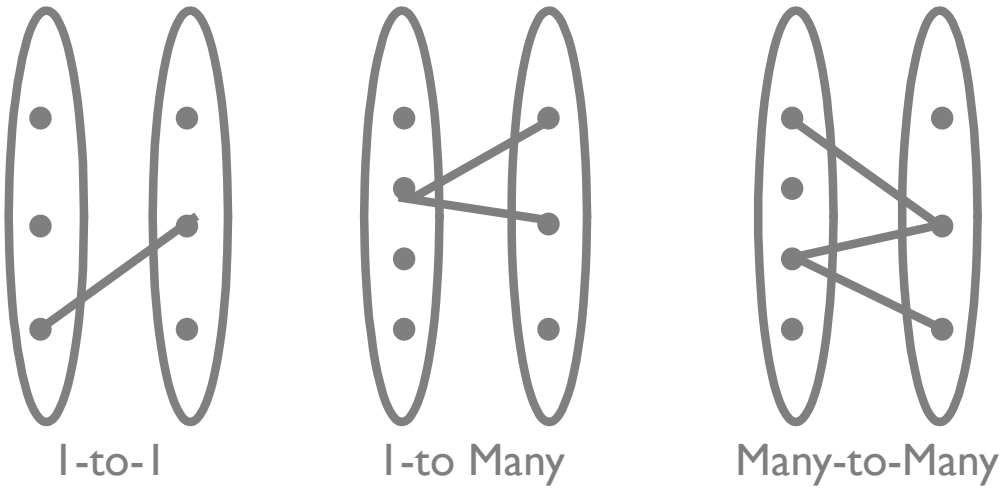
Many to many e.g., *Takes*

a user can take many courses

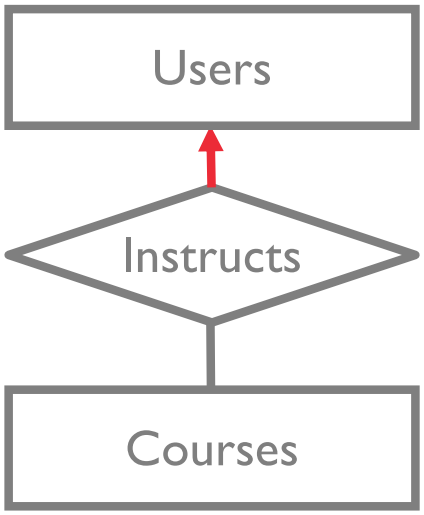
a course can have many users that take the course

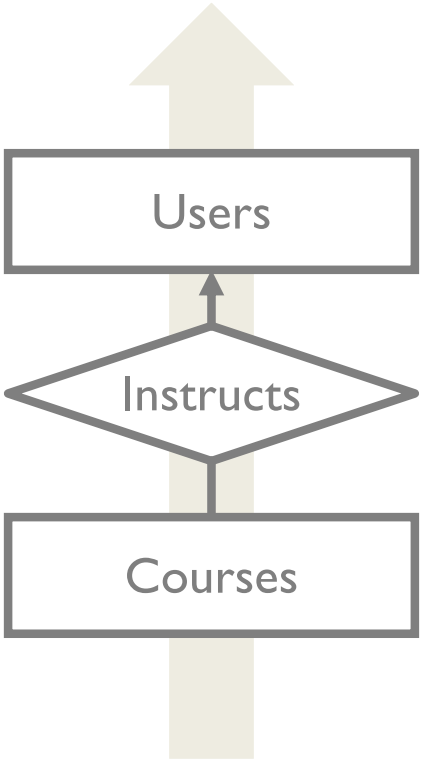
One to Many e.g., *Instructs*

a course has at most one instructor

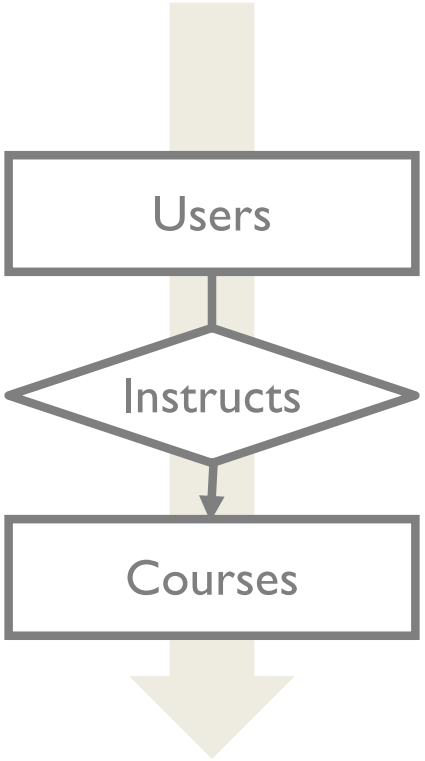


Draw arrow from diamond to box

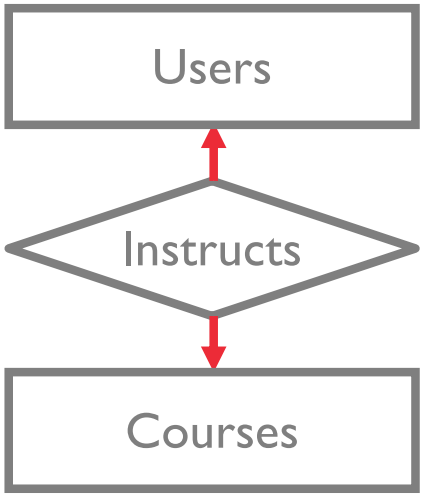




A course is instructed by ≤1 user
(read along the beige arrow)



A user instructs ≤1 course



A course is instructed by ≤1 user
AND
A user instructs ≤1 course

Participation Constraints

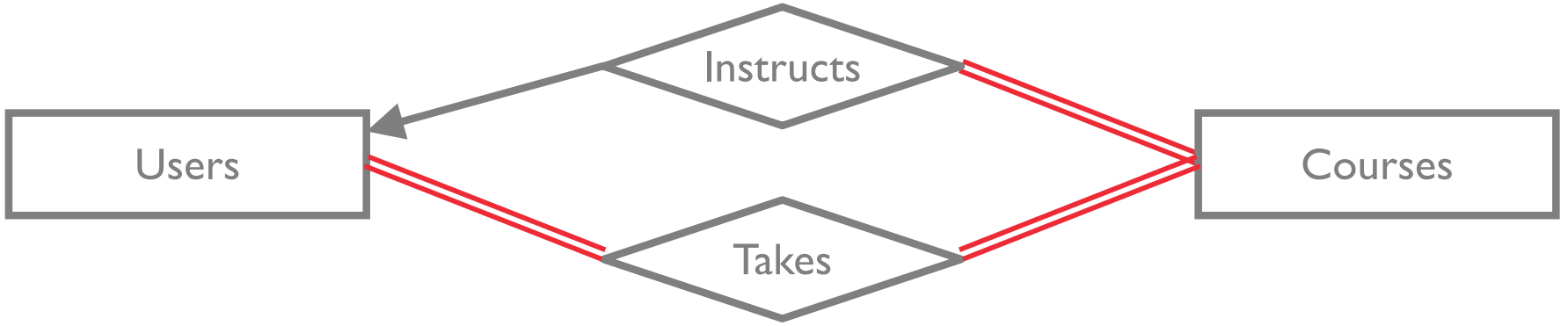
Does every course need an instructor?

If yes, it's a participation constraint

Otherwise, *partial* participation constraint

Denoted by double line between entity set and relationship set

Each course MUST have an instructor
(participation of Courses in instructs is Total)



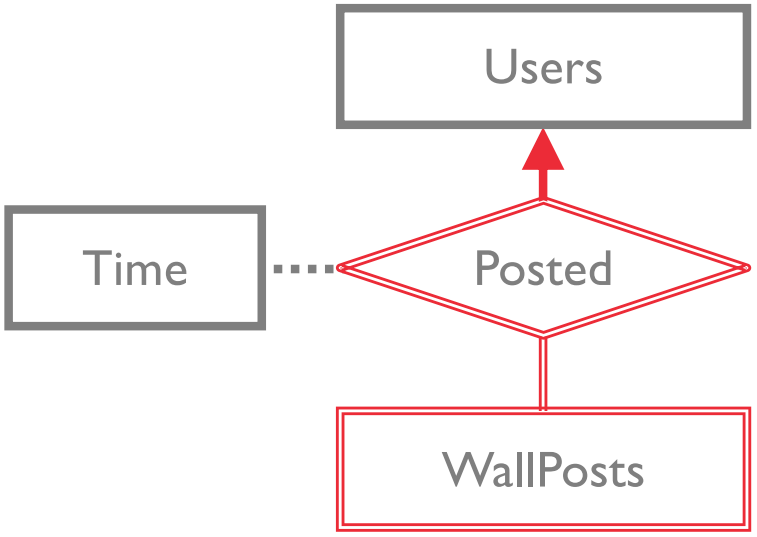
Each user must take at least one course and
Each course must have at least one user (student)

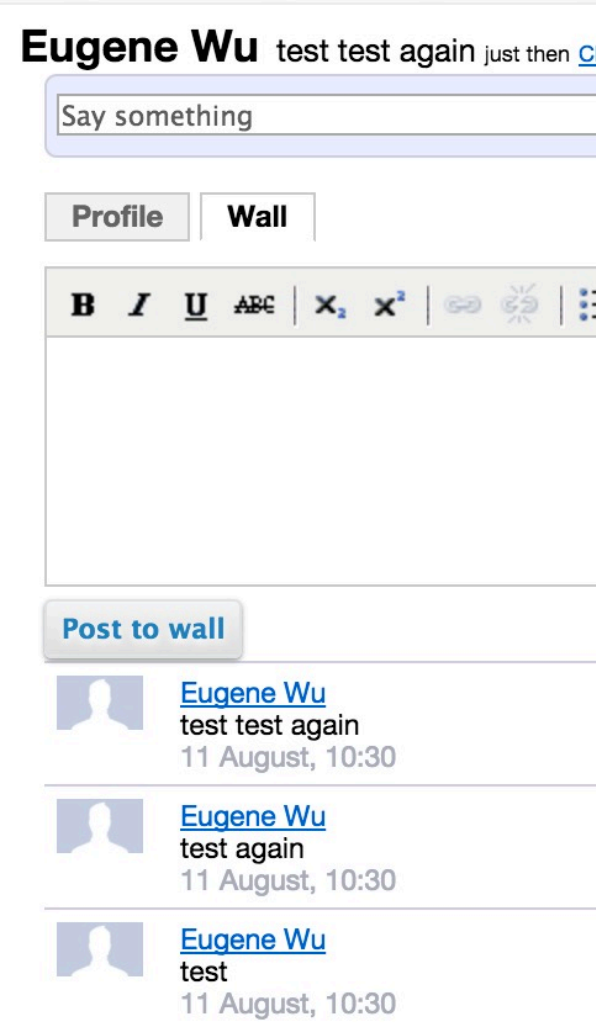
Weak Entities

A *weak entity* can only be uniquely identified by using the primary key of its owner entity

- Owner and weak entity sets must have 1-to-N relationship
- Weak entity set must have total participation in this *identifying* relationships set

Denoted as double line around weak entity, set relationship set, and the edge between them; an arrow to owner entity



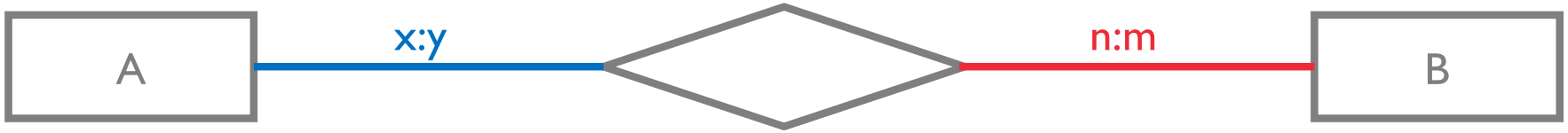


General Cardinality Constraints

same as

A user instructs 0 to ∞ courses

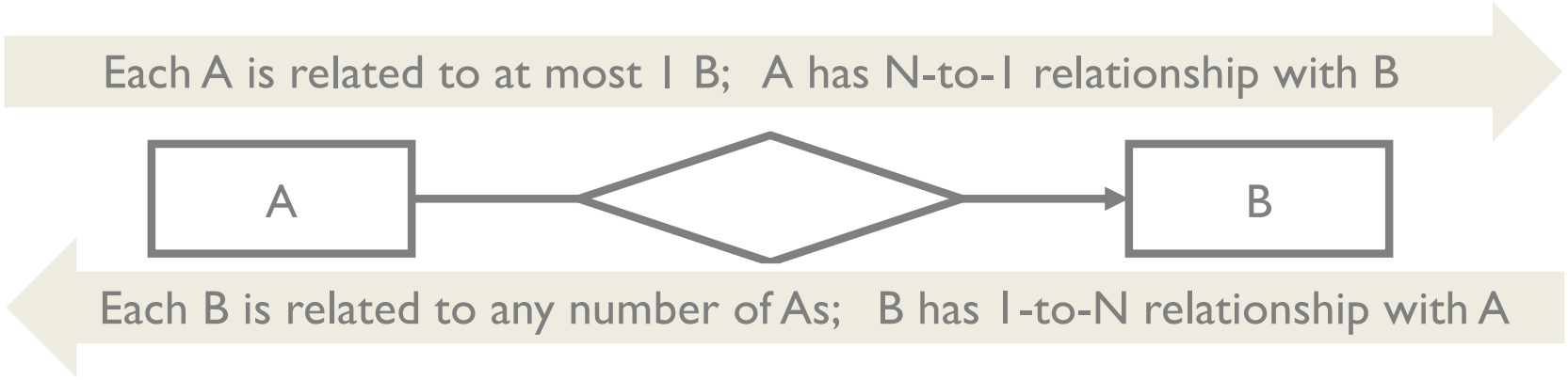
A course has 0 to 1 instructors

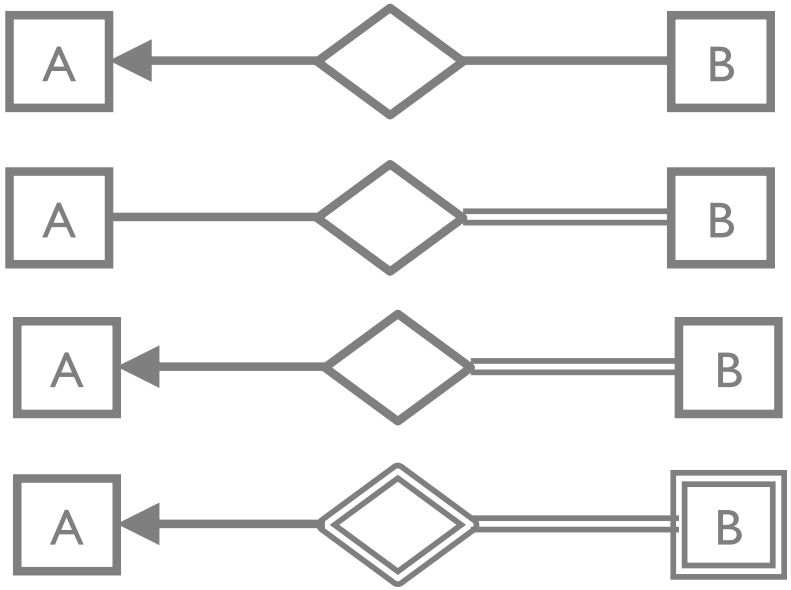


Each A entity has a relationship with between x to y different B entities

Each B entity has a relationship with between n to m different A entities

Read arrows pointing in the direction from start to end





B has at most one A

B has at least one A

B has exactly one A

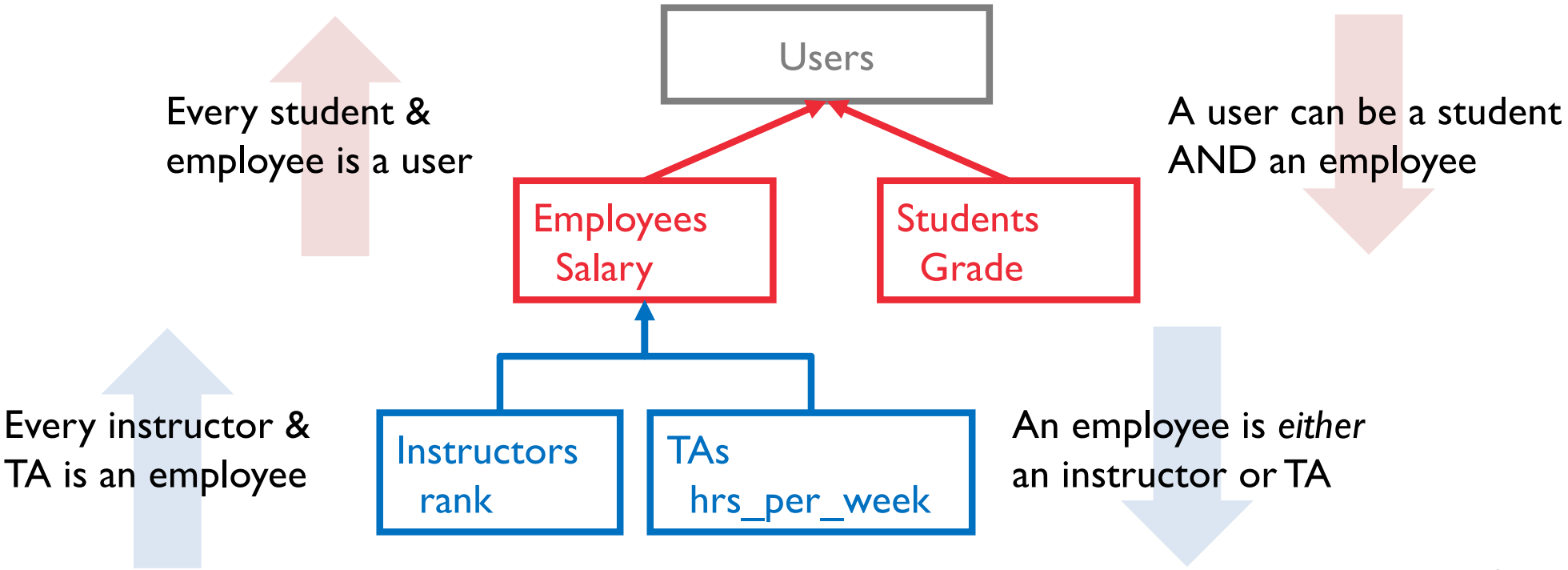
B is a weak entity

Specialization Hierarchies

Inheritance rules similar to programming languages

- add descriptive attributes specific to a subclass e.g., grade
- identify entity set that participate in a relationship

Denoted with arrow from subclass to superclass without a diamond

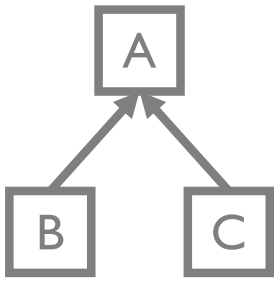


Specialization Hierarchies

Overlap Constraint

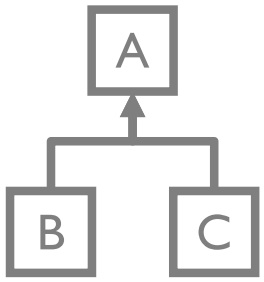
can A be a B *and* a C?

YES



separate arrows

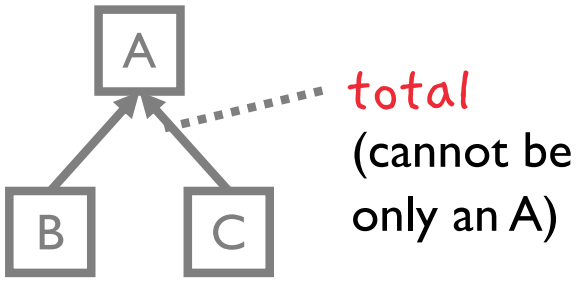
NO



merged into 1 arrow

Total Specialization Constraint

must A be a B or C?
specify as the comment "total"
with dashed link to arrows

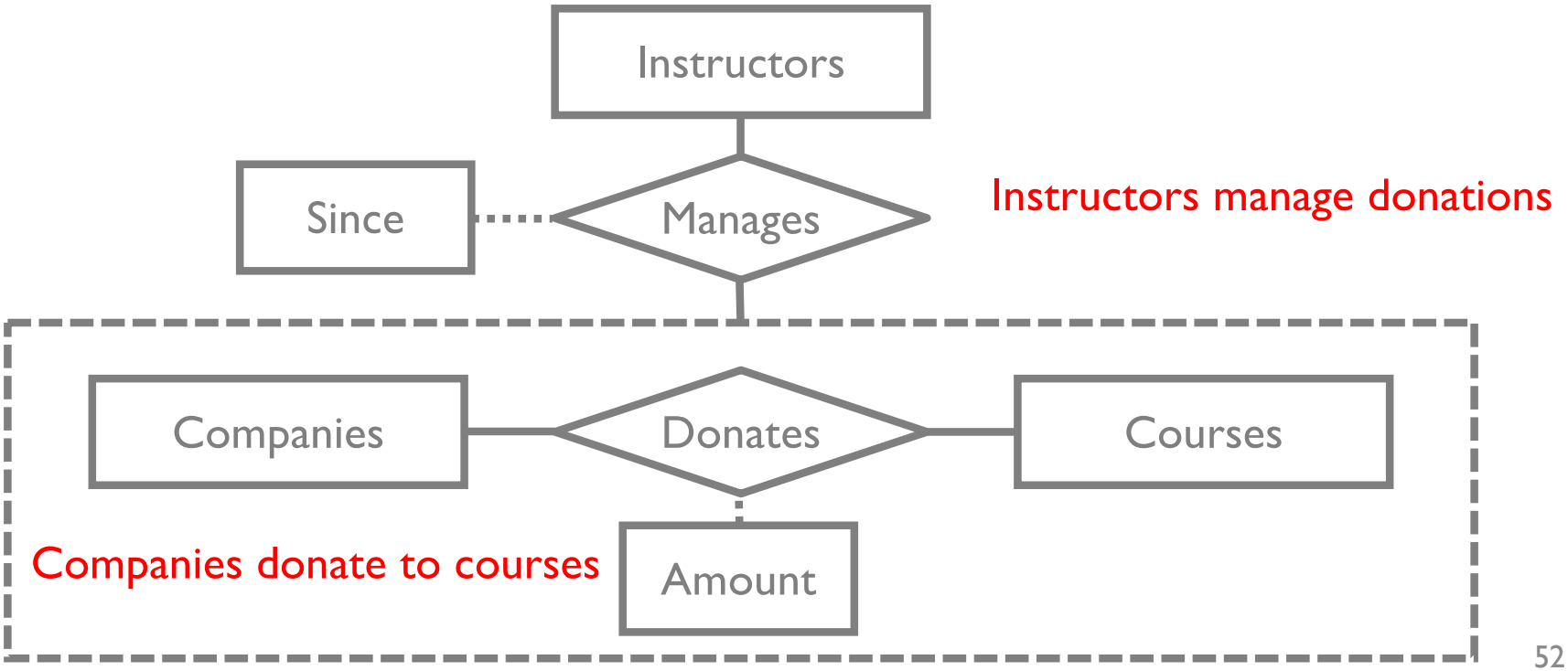


Aggregation

Relationships between (entities – relationships)

Treat Relationship Set like an Entity Set to participate in other relationships

Denoted as dashed line around the relationship set & participating entity sets

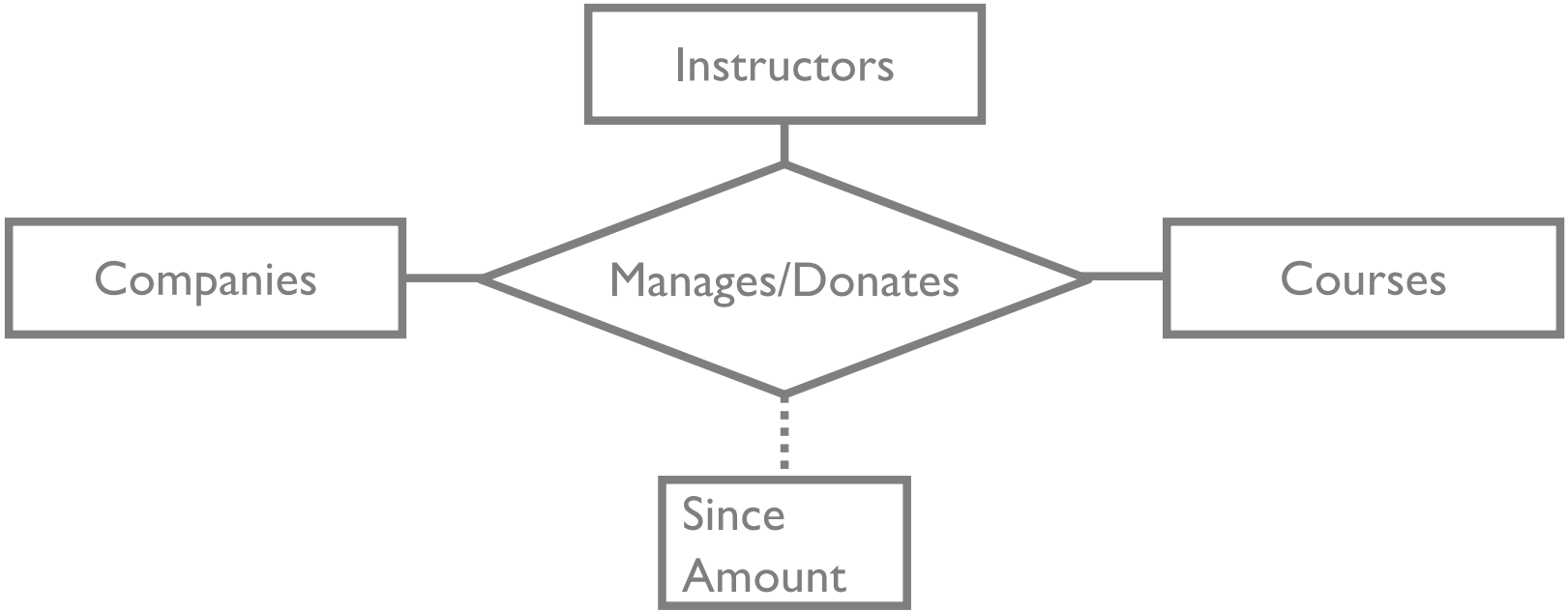


Aggregation vs Ternary Relationships

Why use aggregation?

- Manages and Donates are distinct relationships with own attrs
- Can define constraints on relationship sets

What if we modeled previous slide as ternary relationship?

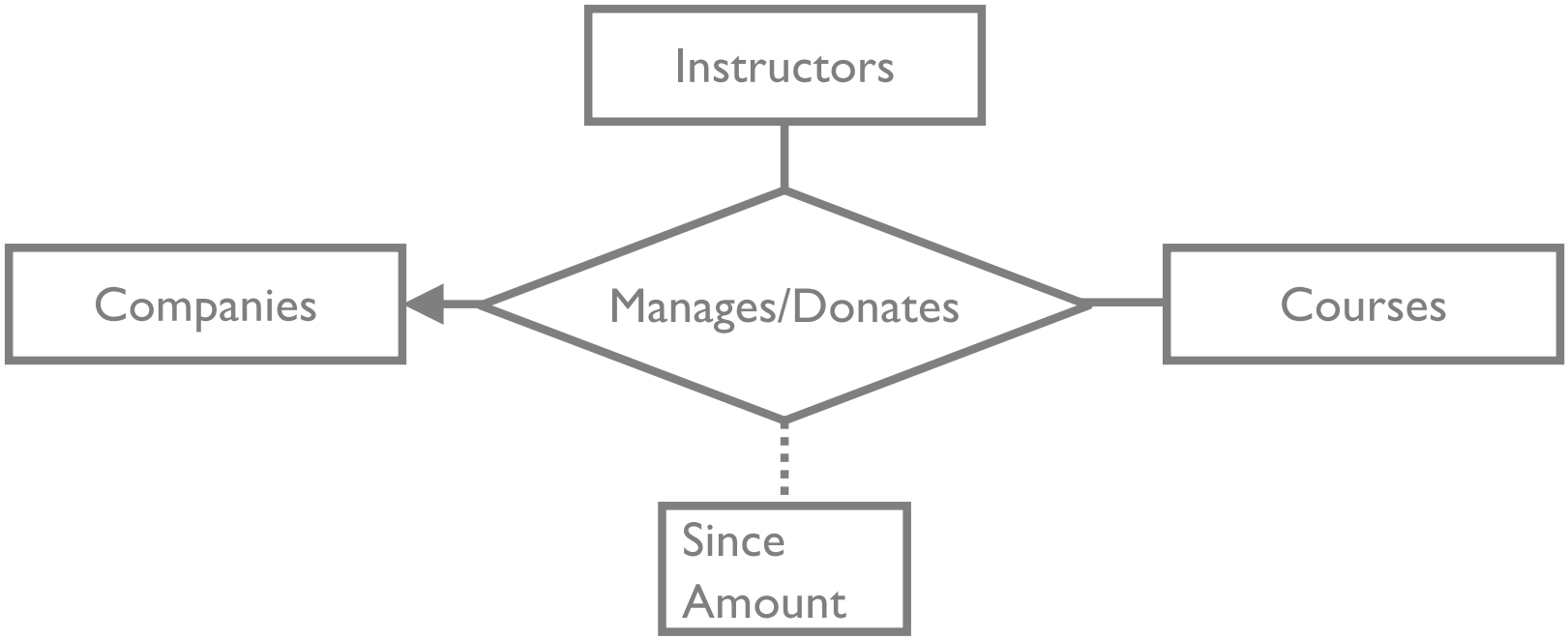


Aggregation vs Ternary Relationships

Suppose we want to model "A course can have at most one donation".

We would draw arrow from diamond to Companies.

Actually reads: "Each *instructor, course combination* can have at most one relationship with Companies" e.g., *Eugene and 4111 can have at most one donation, but Alex and 4111 can have another donation.*



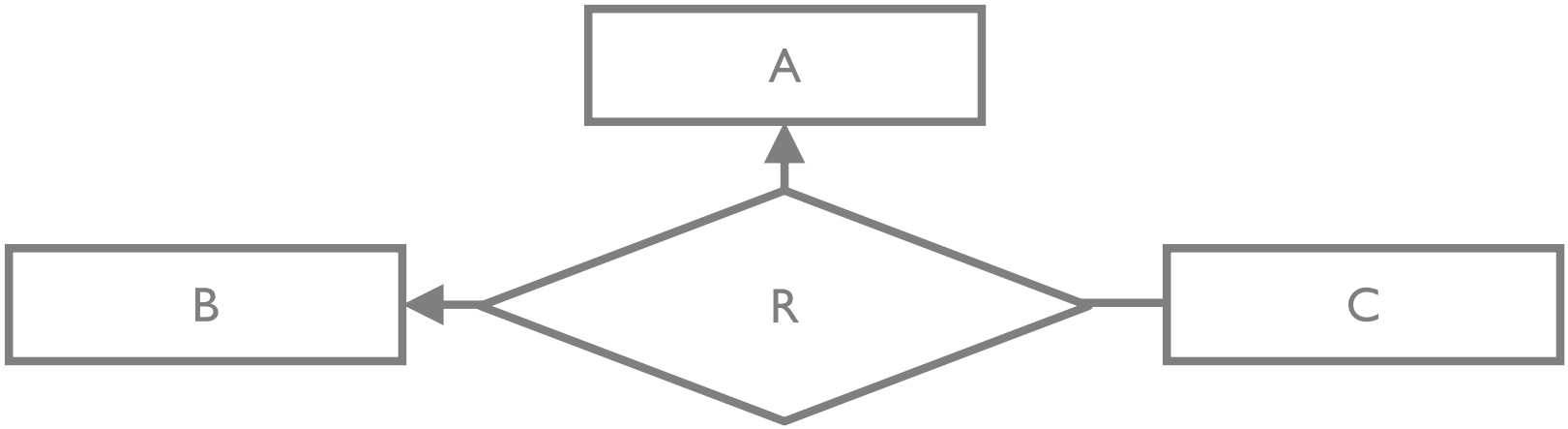
Aggregation vs Ternary Relationships

In general an N-way relationship set can have at most one "at-most-one" constraint (arrow), because multiple constraints (arrows) are ambiguous.

Below could be:

"a C has at most one relationship with a (A, B) pair" OR

"each unique (A,C) pair has at most one relationship with a B, and each unique (B,C) pair has at most one relationship with an A"



Using the ER Model

OK, we've seen the *syntax*.

How to use it involves design choices

Design Choices for a concept

- Entity or Attribute?
- Entity or Relationship?
- Binary or Ternary relationship?
- Aggregation or Ternary relationship?

Entity or Attribute?

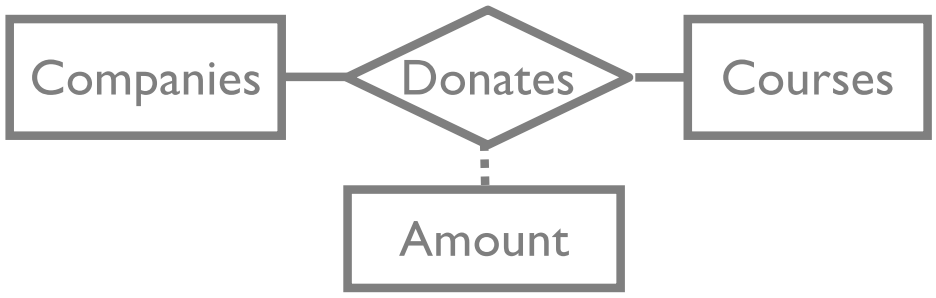
Is users.address an attribute of Users or an entity connected to Users by a relationship?

Depends (and may change over time!)

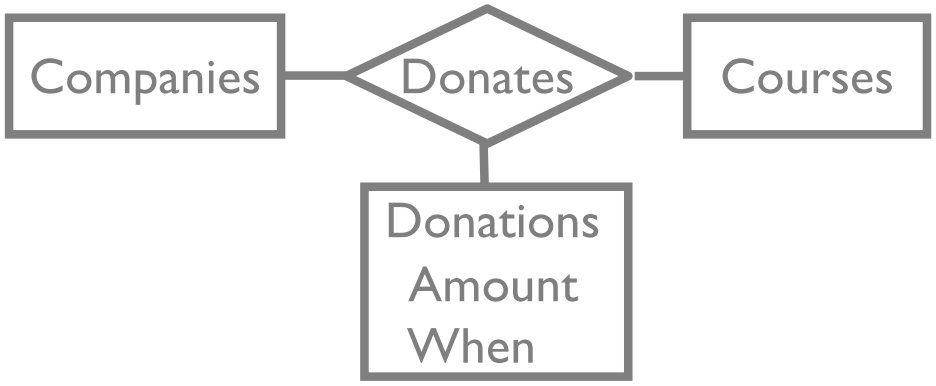
- If a user has >1 addresses, must be an entity
- If an address has attrs (structure), must be entity
  - e.g., want to search for users by city, state, or zip

Entity or Attribute?

A company can't donate multiple amounts



Company can make multiple donations

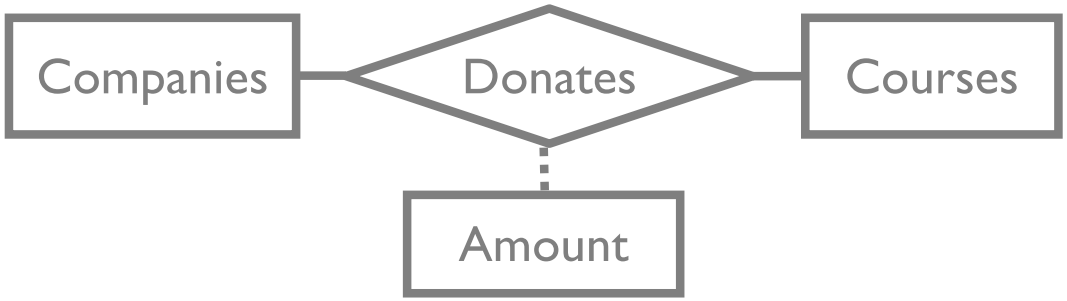


Entity or Relationship?

But what if company donates to school for all data-related courses?

Redundancy of *amount*, need to remember to update every one

Misleading implies *amount* tied to *each* donation individually



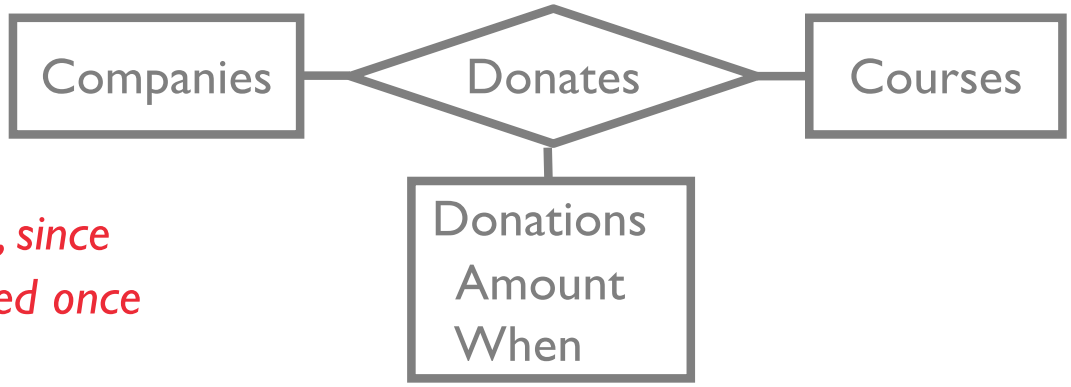
Company	Course	Amount
Amazon	4111	2000
Amazon	4112	2000
Amazon	5111	2000

These amounts are logically the same (redundant)!

Entity or Relationship?

If company donates once to school for data related courses.

Refactor amount into an entity



Company redundant, since company only donated once

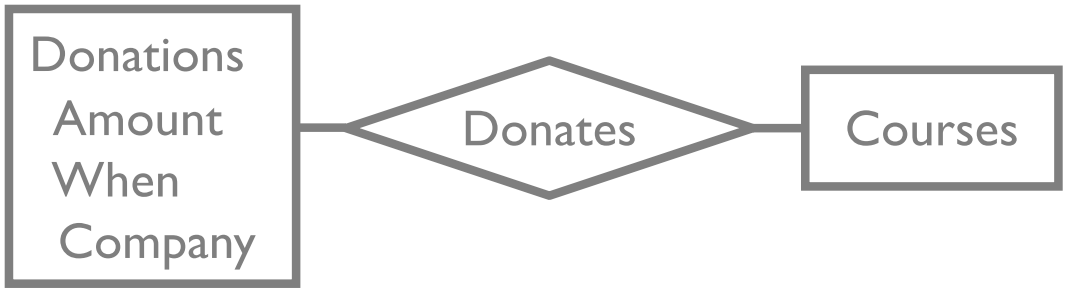
Company	Course	Donation
Amazon	4111	1
Amazon	4112	1
Amazon	5111	1

Donation	When	Amount
1	Today	2000

Entity or Relationship?

If company donates once to school for data related courses.

Refactor amount into an entity



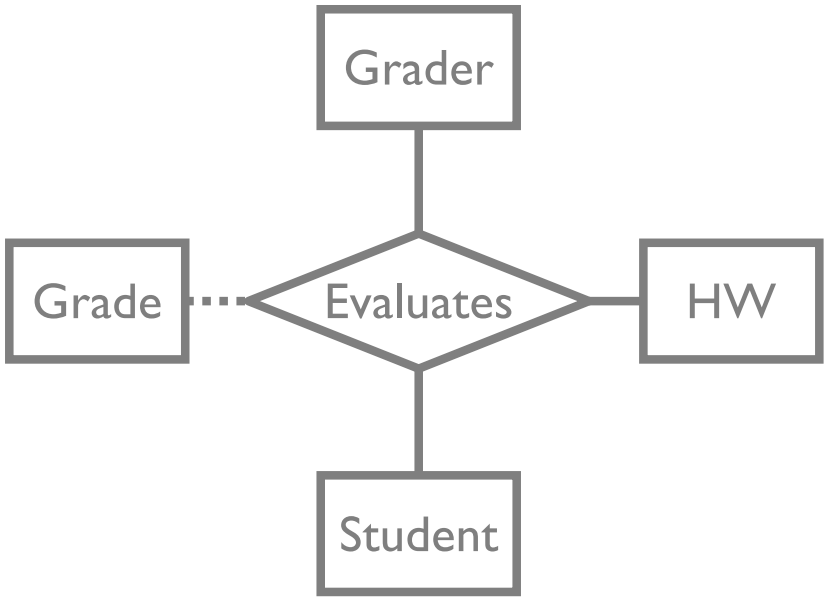
Course	Donation
4111	1
4112	1
5111	1

Donation	When	Amount	Company
1	Today	2000	Amazon

Binary or Ternary Relationship?

HW means a particular released HW, not a submission

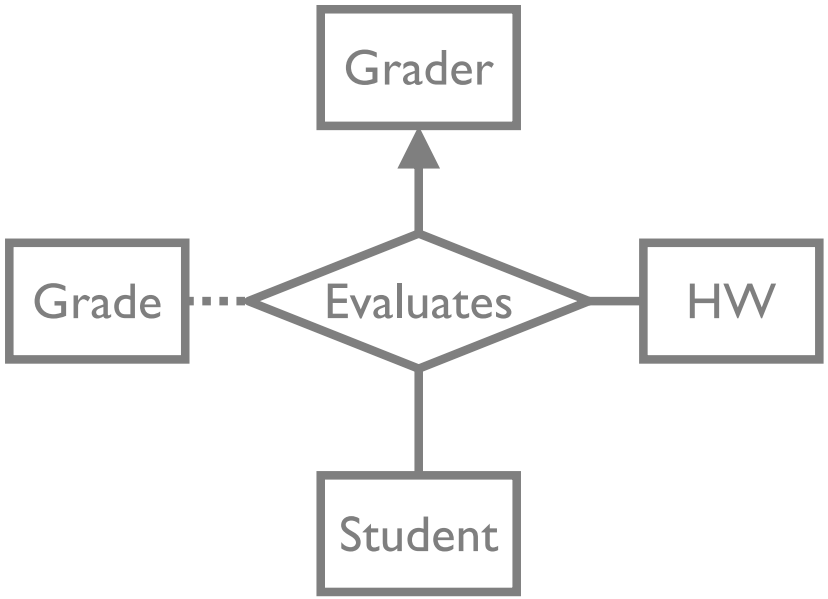
What if each HW has at most one grader? (next slide)



Binary or Ternary Relationship?

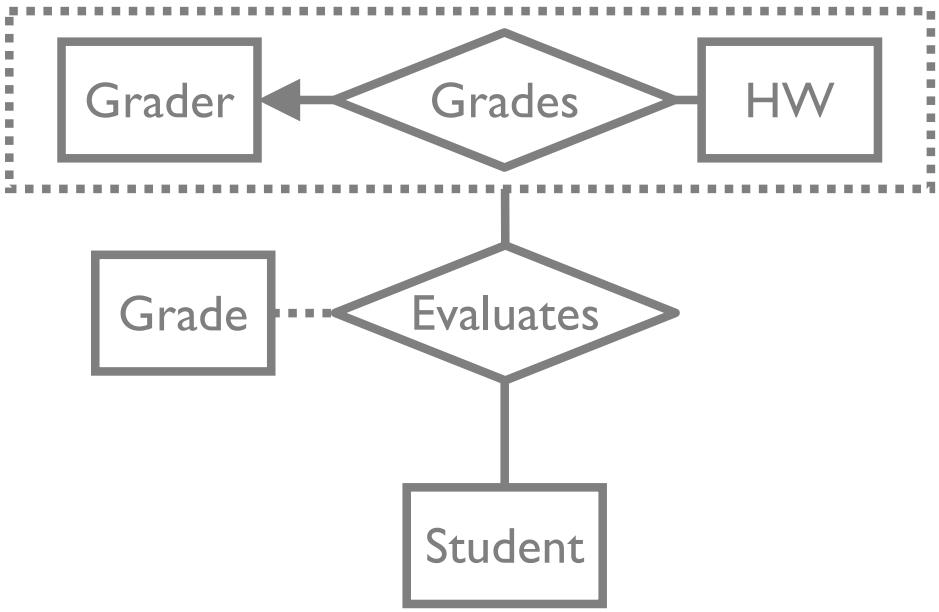
What if each HW has at most one grader?

Option 1: add arrow from evaluates to grader.



Actually says that each student's HW submission (hwid, studentid) has at most one grader

Option 2: aggregation

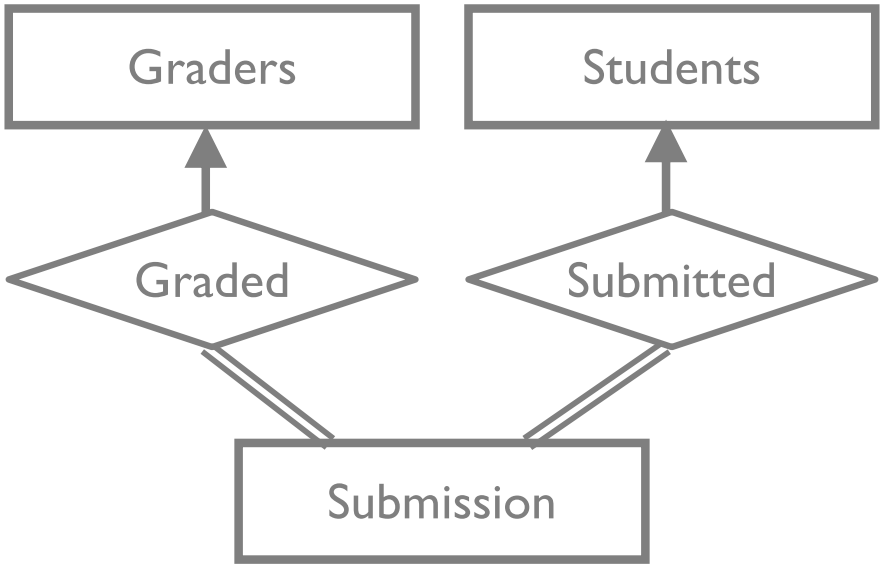


Each HW has at most 1 grader and the grader evaluates each student

Binary or Ternary Relationship?

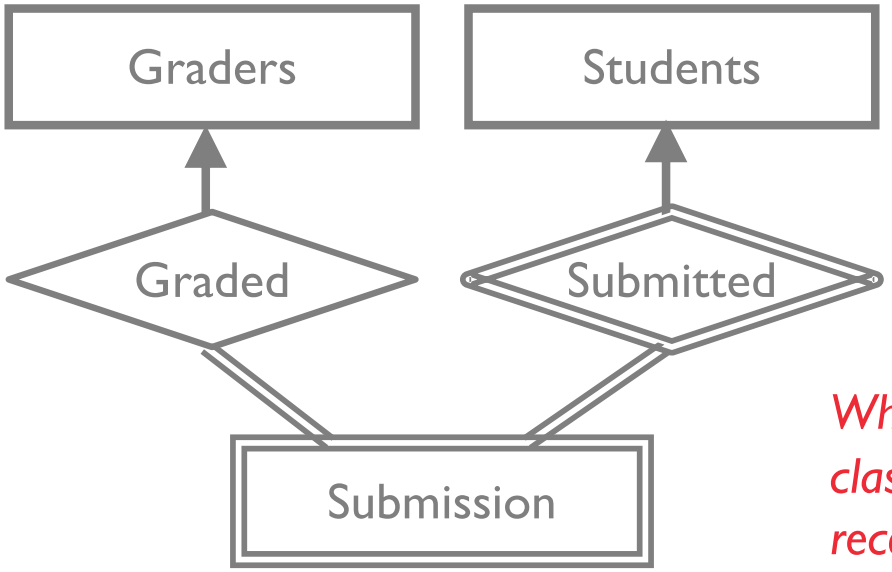
Binary relationships allows additional constraints

What should happen if a student drops the class? (see next slide)



Binary or Ternary Relationship?

Binary relationships allows additional constraints

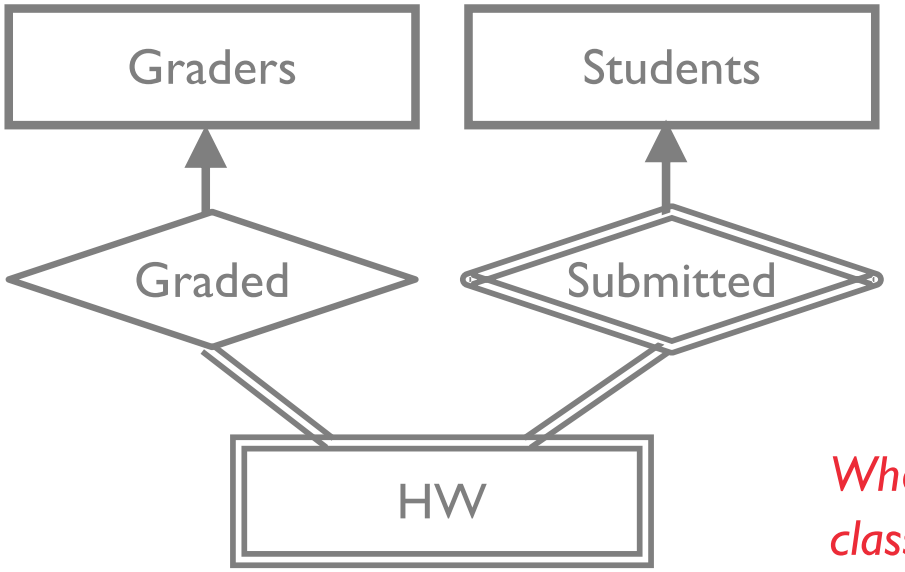


When student drops the class, their submission records also are removed. Makes sense!

Binary or Ternary Relationship?

Binary relationships allows additional constraints

What if we model HW instead of Submission?

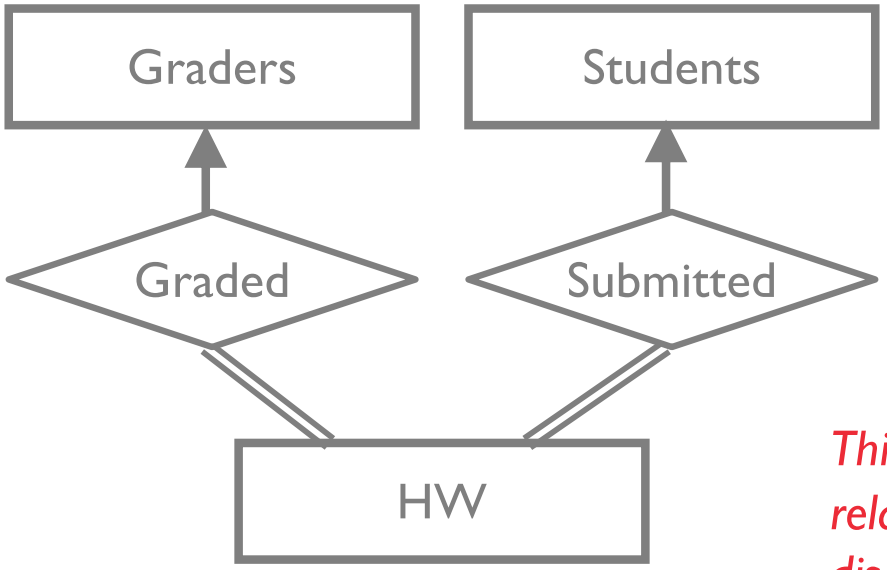


When student drops the class, HW0 also disappears!

Binary or Ternary Relationship?

Binary relationships allows additional constraints

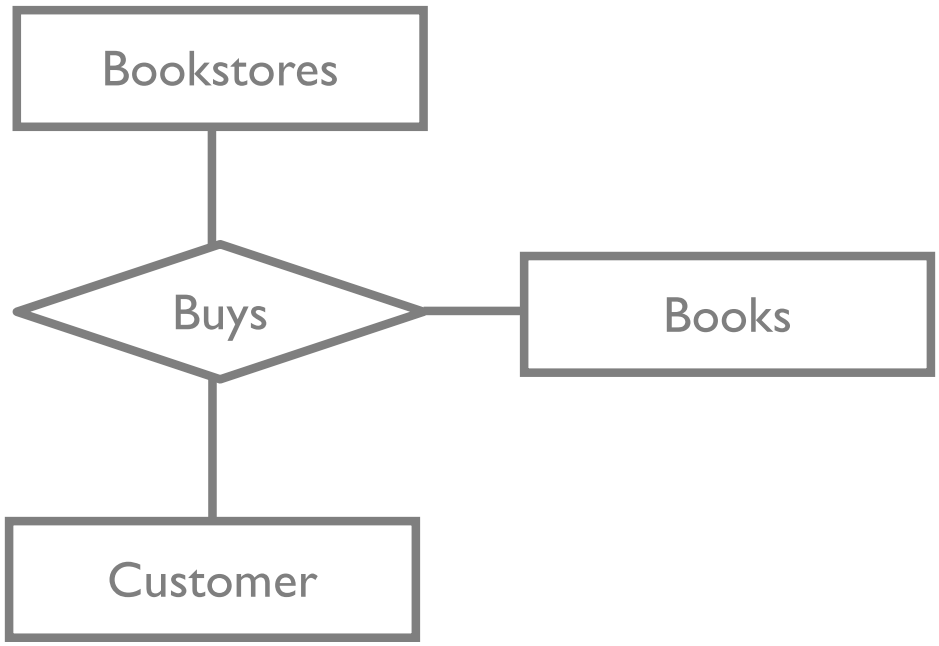
What if we model HW instead of Submission?



This is correct, since the relationship "submitted" will disappear if student is removed

Binary or Ternary Relationship?

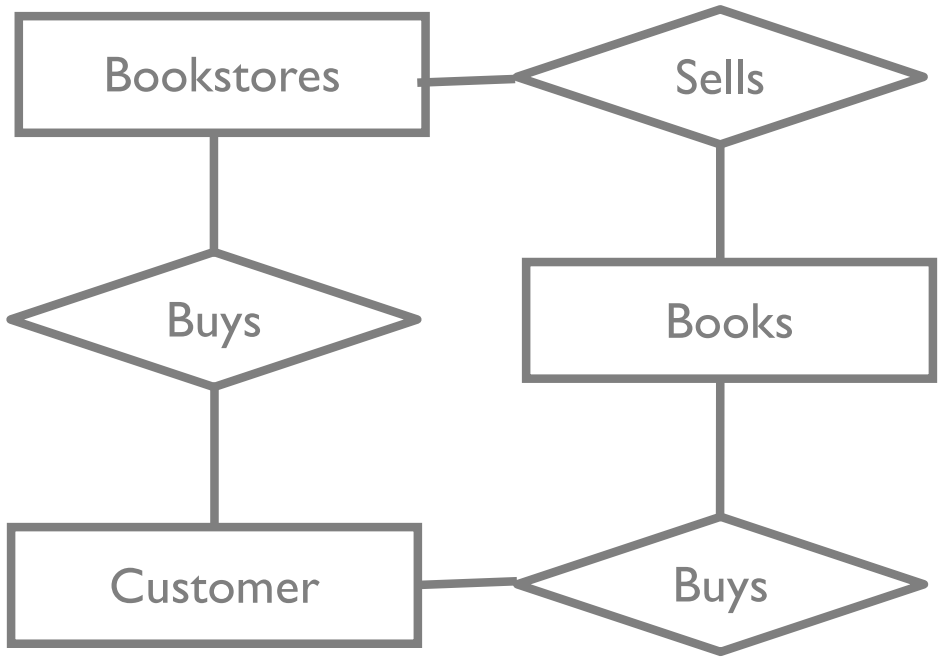
Sometimes have true ternary relationship that is defined by all three entities.



Binary or Ternary Relationship?

Sometimes have true ternary relationship that is defined by all three entities.

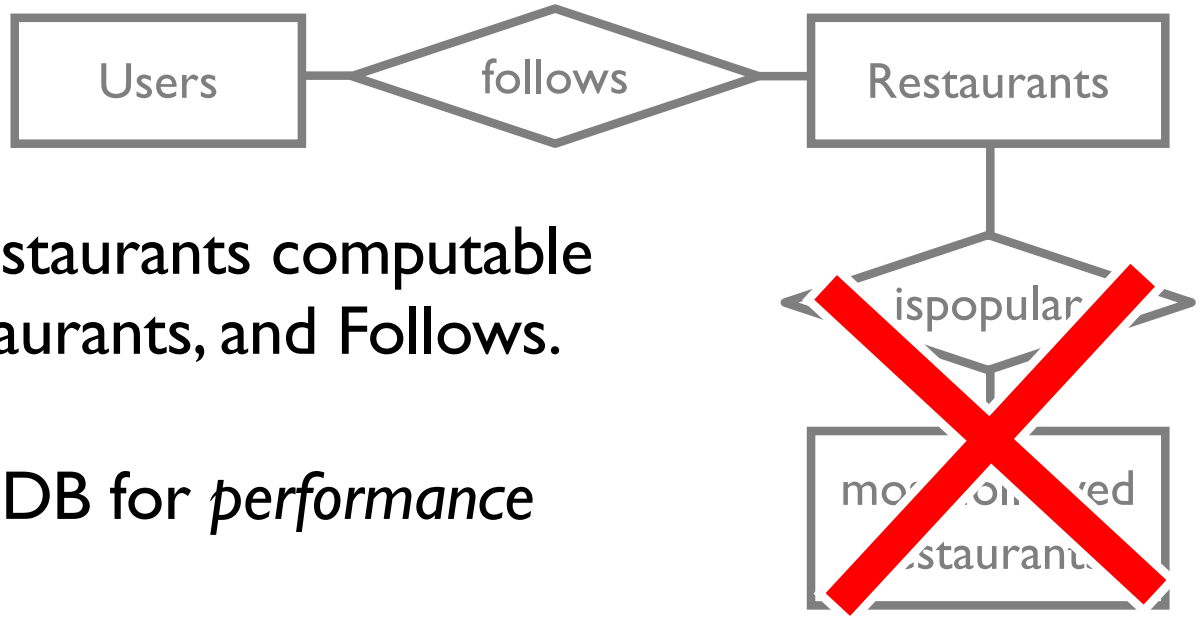
Doesn't Really Work



Advice

The ER diagram (and database) stores the *minimal information* needed for your application.

Everything else (e.g., stats) can be computed



Most followed restaurants computable from Users, Restaurants, and Follows.

May still store in DB for *performance* reasons

Summary

Requirements
- what are you going to build?

Conceptual Database Design
- pen-and-pencil description

(Today) ER Modeling

Logical Design
- formal database schema

Schema Refinement:
- fix potential problems, normalization

Physical Database Design
- use sample of queries to optimize for speed/storage

App/Security Design
- prevent security problems

Summary

Conceptual design follows *requirements analysis*

ER model helpful for conceptual design

- constraints are expressive
- matches how we often think about applications

Core constructs

- entity, relationship, attribute
- weak entities, ISA, aggregation

Many variations beyond today's discussion

Summary

ER design is subjective based on usage+needs

- Today we saw multiple ways to model same idea

ER design is not complete/perfect

- Developed in an enterprise-oriented world (ER First)
- Doesn't capture semantics (what does "instructor" *mean?)*
- Doesn't capture e.g., processes/state machines
- How to combine multiple ER models automatically?
- Limitation of imagination when designing application
- Still needs further refinement
- Open problems!

ER design is a useful way to think

Next Time

Relational Model: de-facto DBMS standard

Set up for ER diagrams → Relational models