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

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ER Modeling

Logical Design

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 use sample of queries to optimize for speed/storage

App/Security Design

 prevent security problems

Database Apps Are Complicated

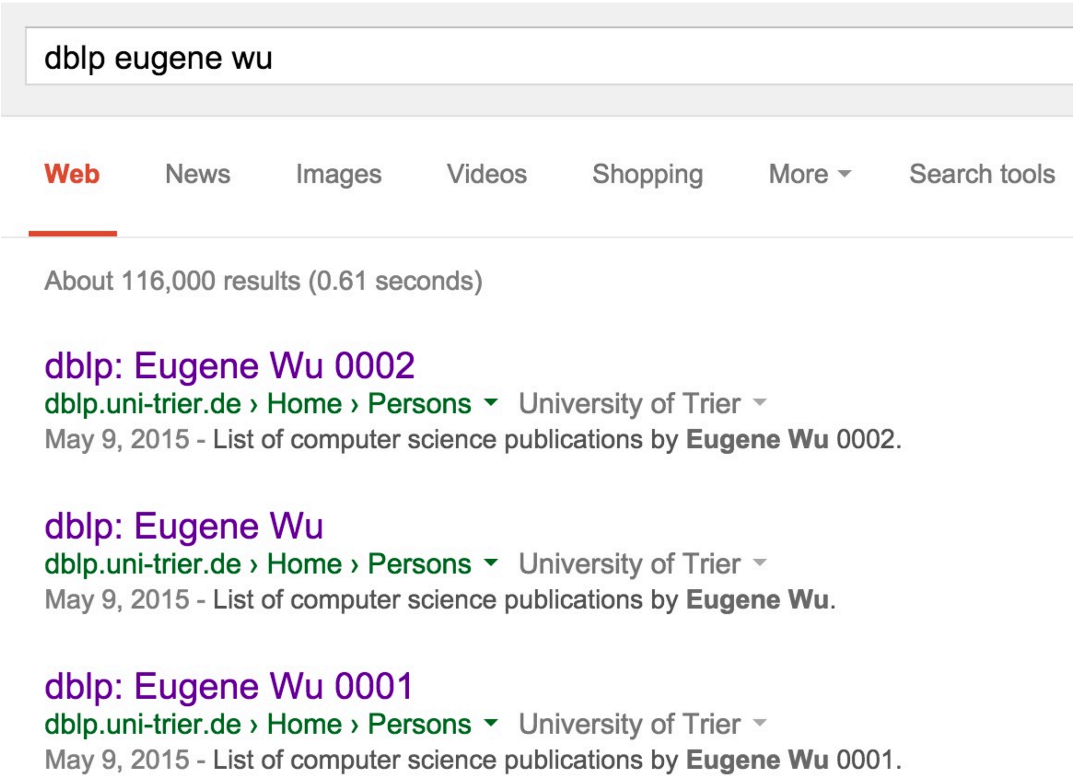
- Typical Fortune 100 Company
  - ~10k different information (data) systems
  - 90% relational databases (DBMSes)
  - Typical database has >100 tables
  - Typical table has 50 – 200 attributes

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



dblp eugene wu

About 116,000 results (0.61 seconds)

dblp: Eugene Wu 0002
dblp.uni-trier.de › Home › Persons University of Trier
May 9, 2015 - List of computer science publications by **Eugene Wu** 0002.

dblp: Eugene Wu
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May 9, 2015 - List of computer science publications by **Eugene Wu**.

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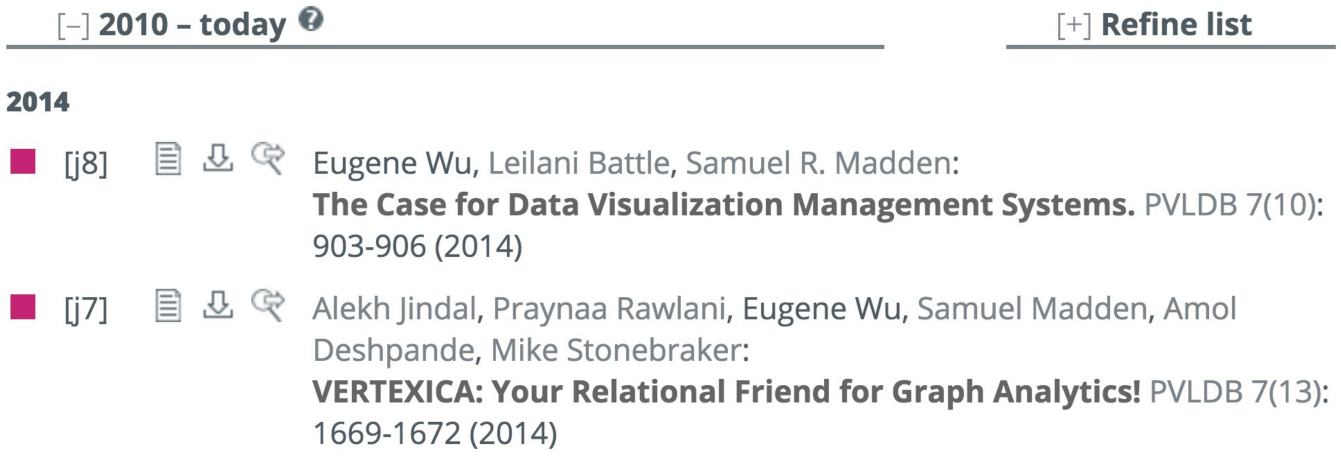
Inconsistencies/Constraint Violations



[–] **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)

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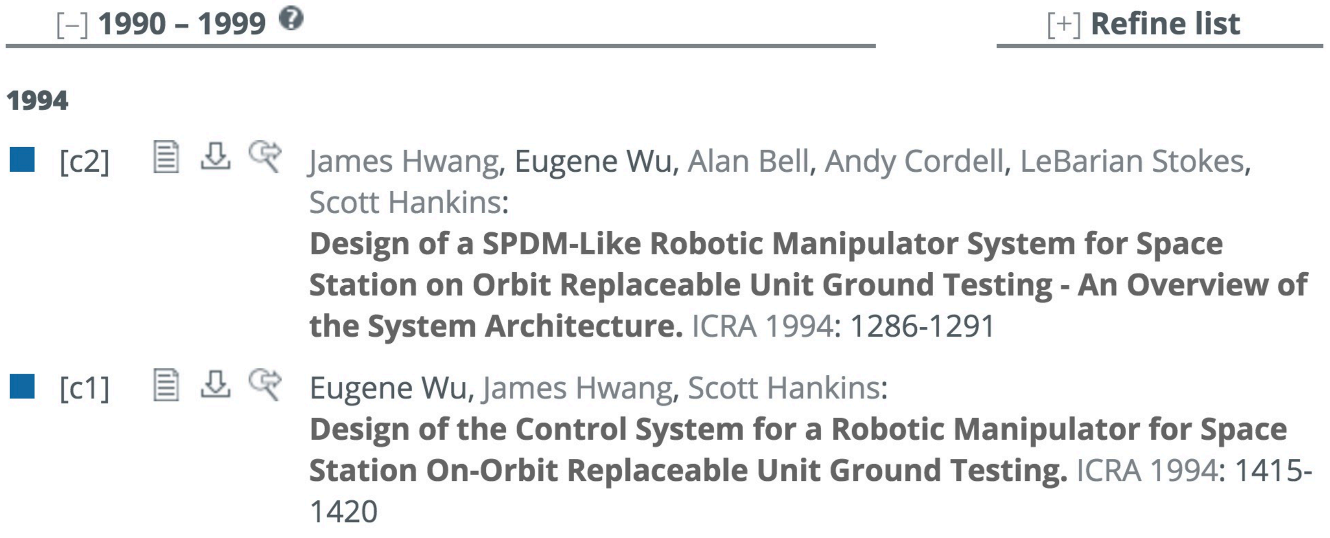
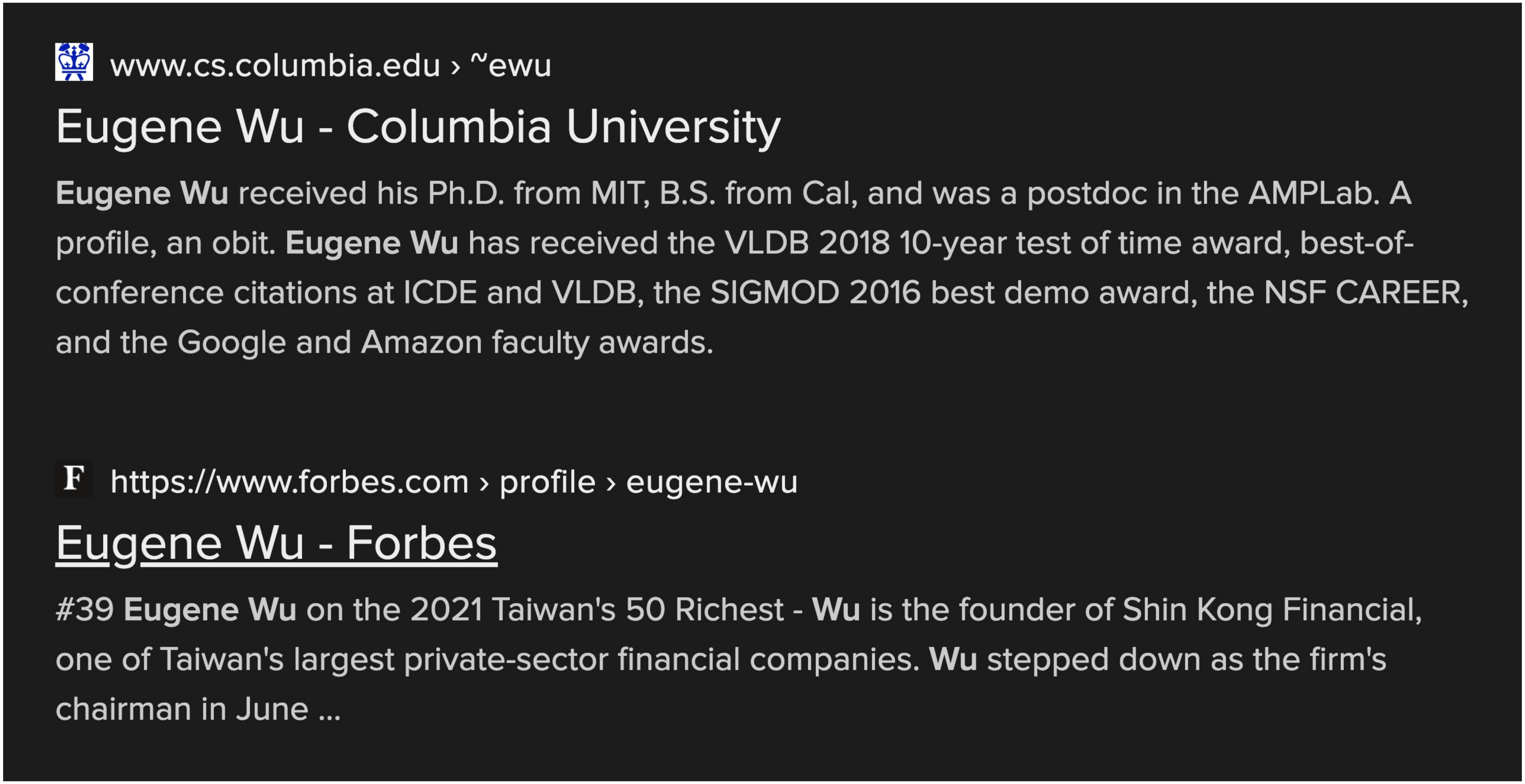


[–] **1990 – 1999** [+] **Refine list**

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

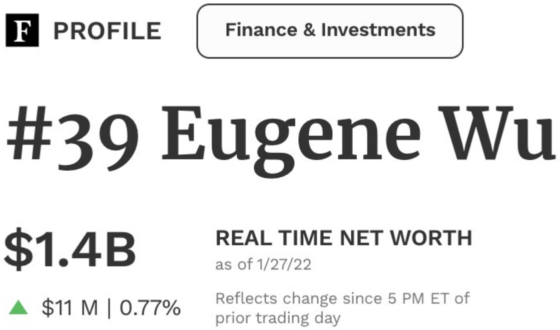
Eugene Wu - Columbia University

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

▲ $11 M | 0.77%

REAL TIME NET WORTH

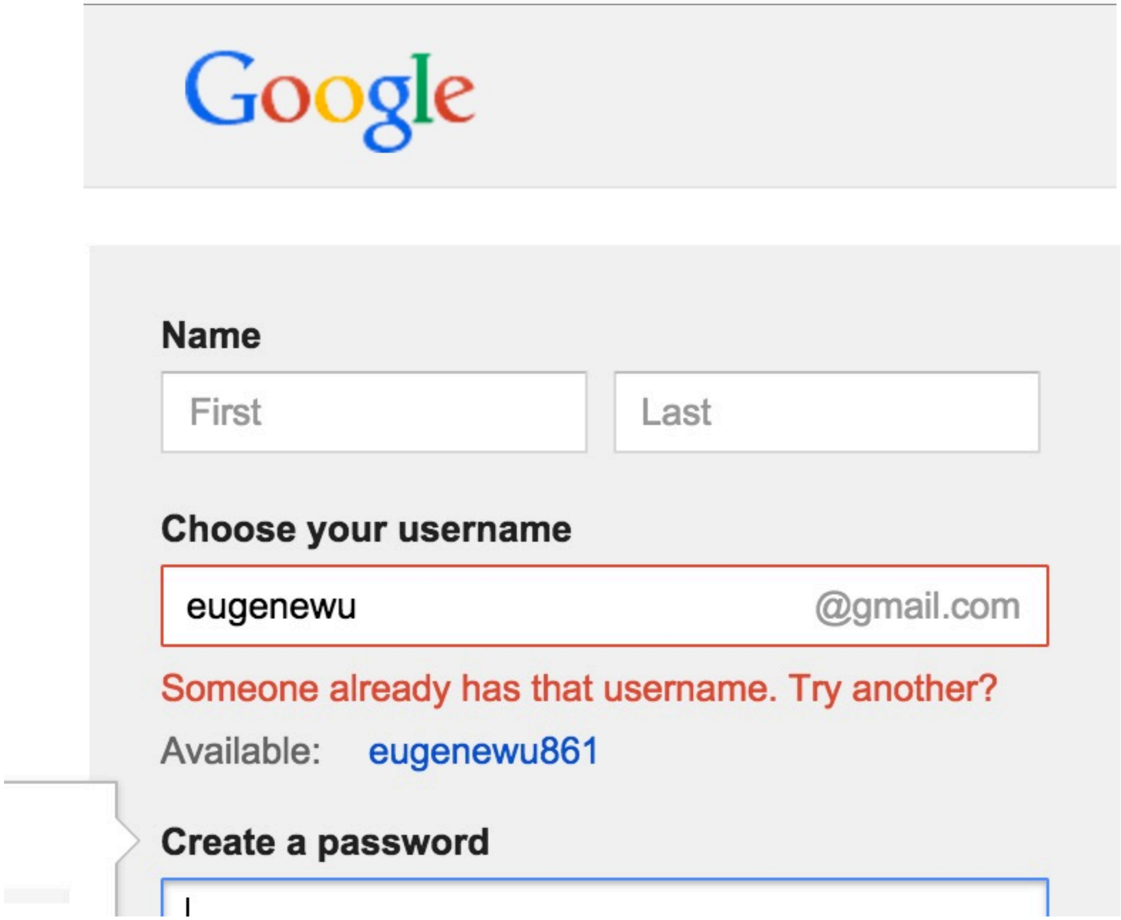
as of 1/27/22

Reflects change since 5 PM ET of prior trading day

Not Teaching 4111!!!

Inconsistencies/Constraint Violations

Check in application code!



Name

Choose your username

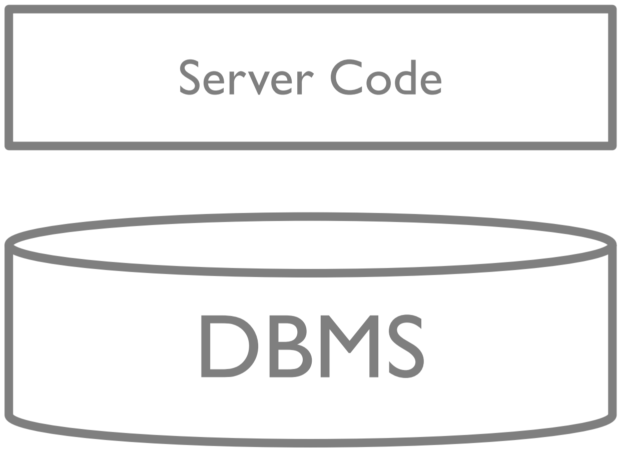
eugenewu @gmail.com

Someone already has that username. Try another?

Available: eugenewu861

Create a password

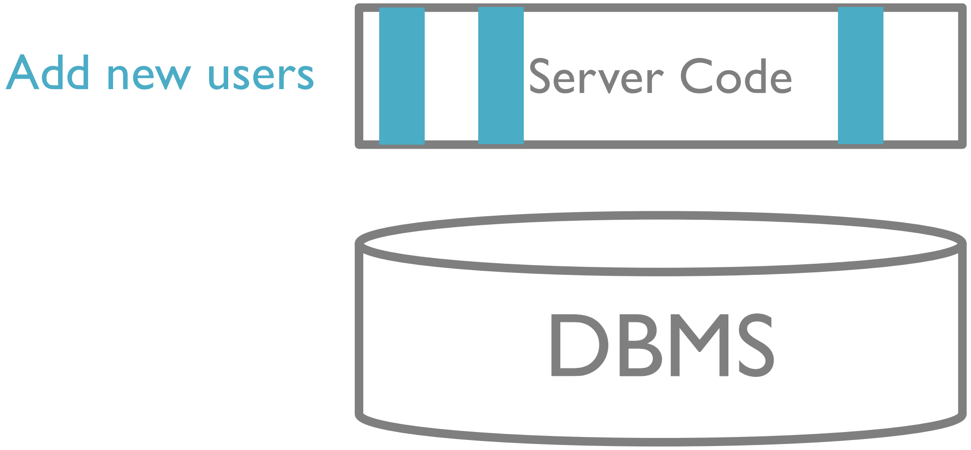
It is Hard to Design Applications



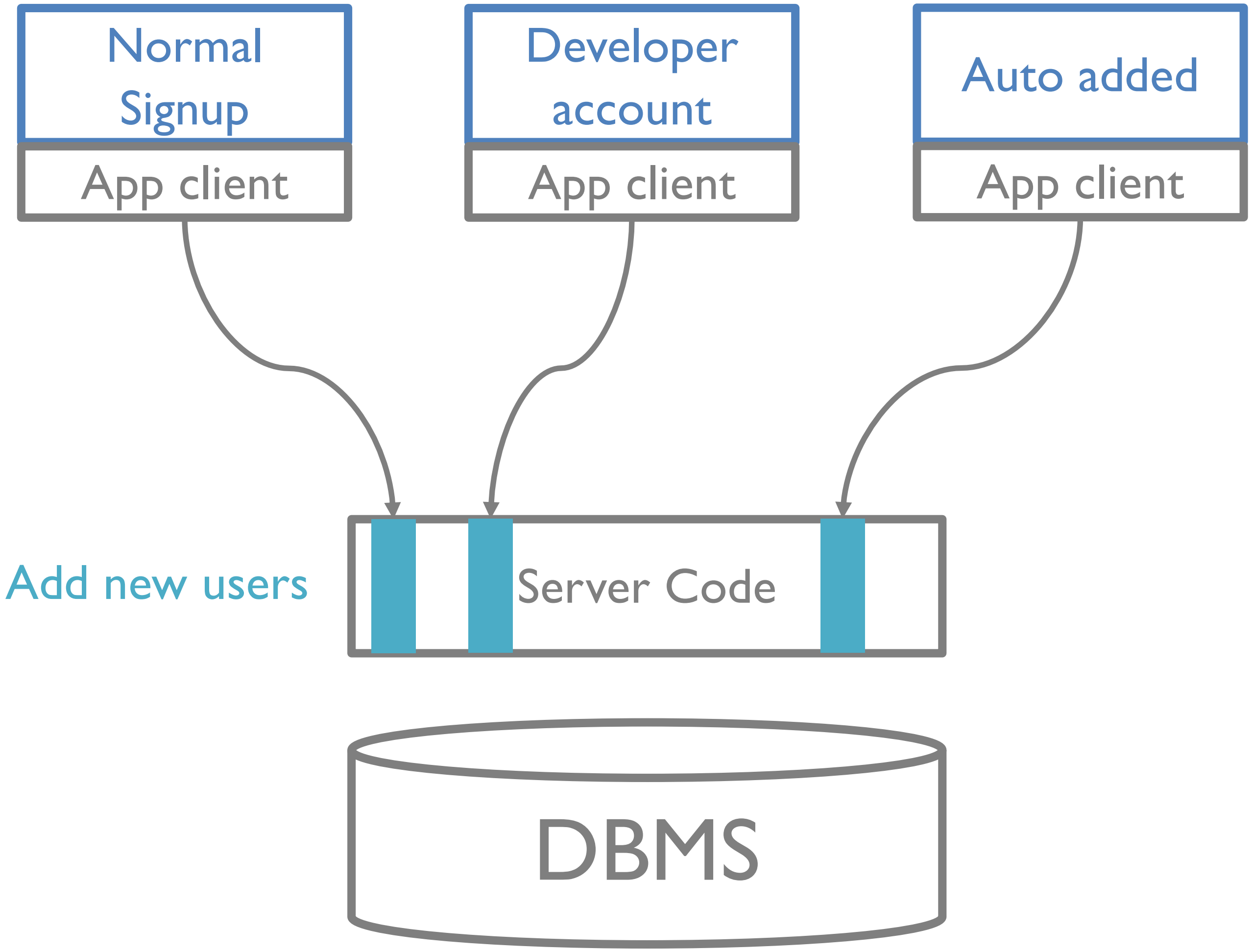
Server Code

DBMS

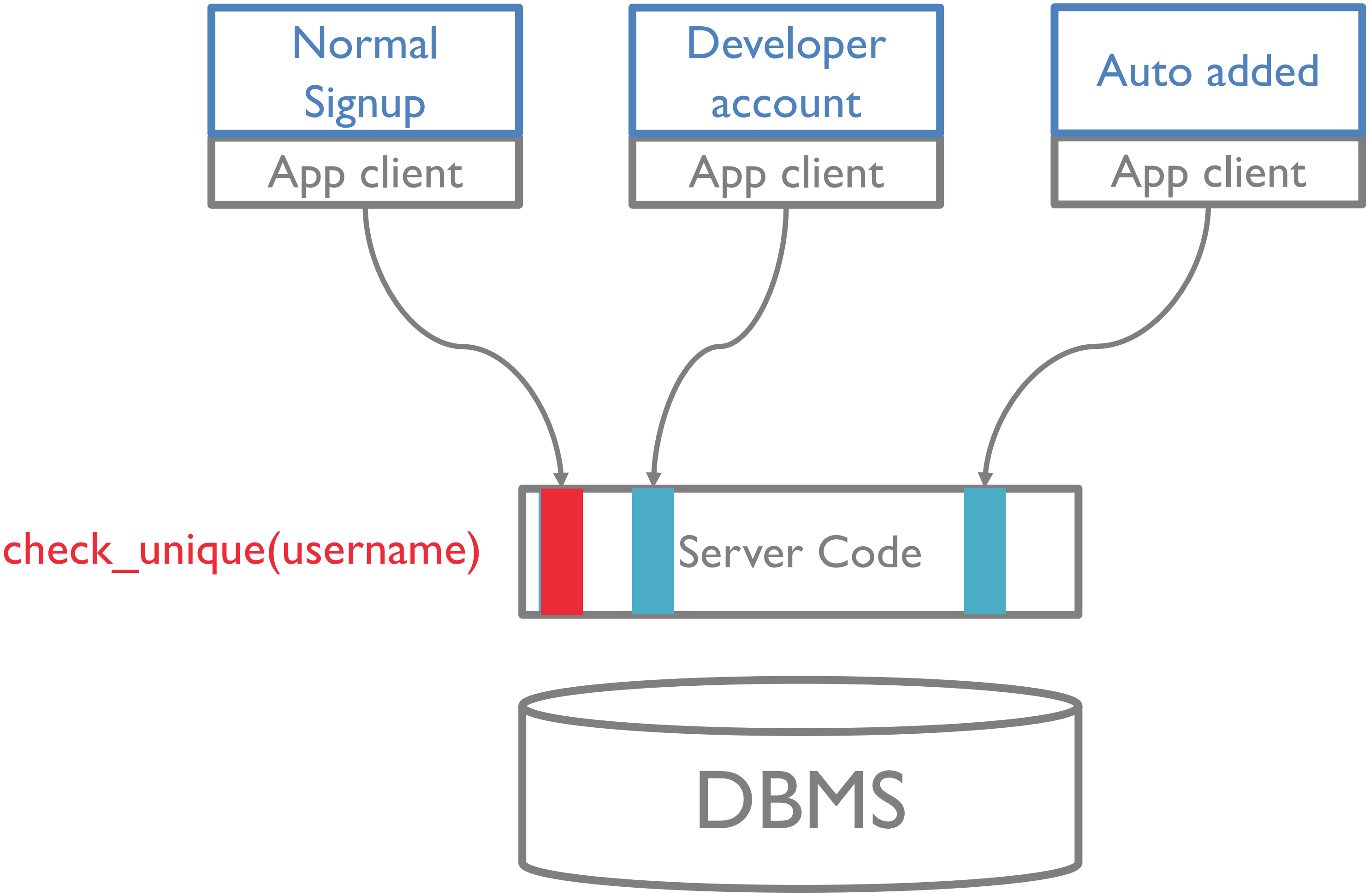
It is Hard to Design Applications



It is Hard to Design Applications



It is Hard to Design Applications



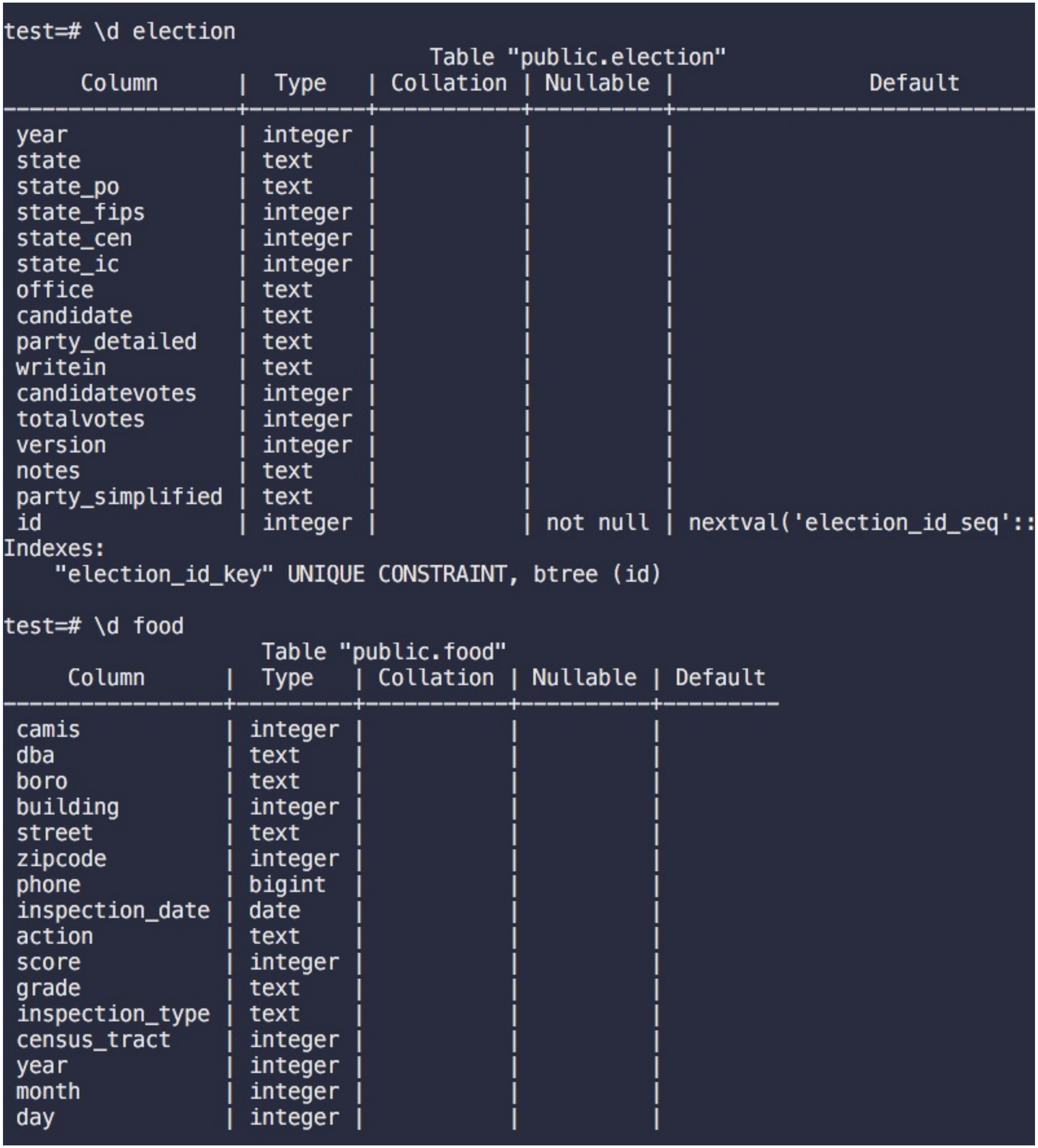
ER Diagrams

What is it?

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

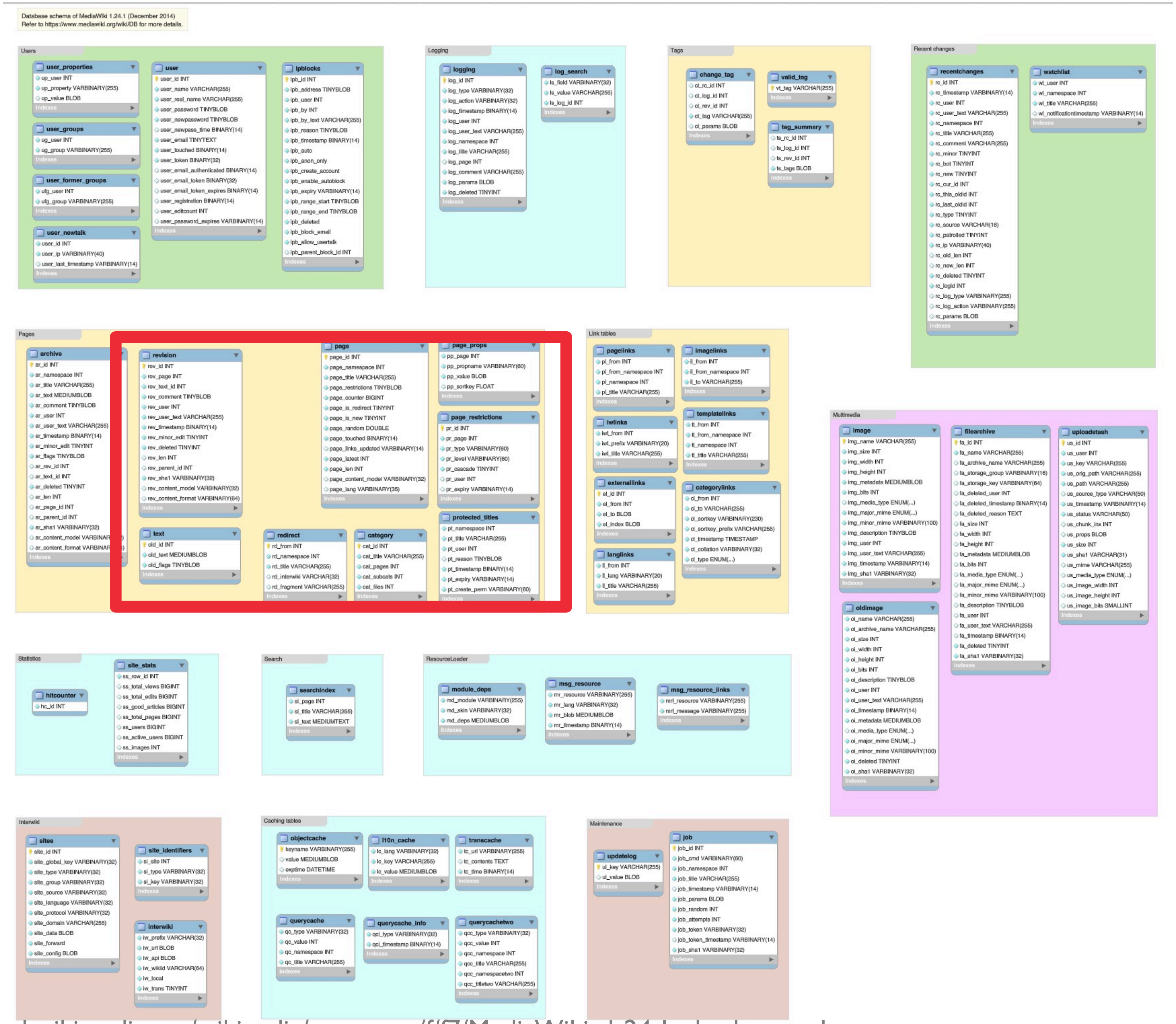
Who cares?

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

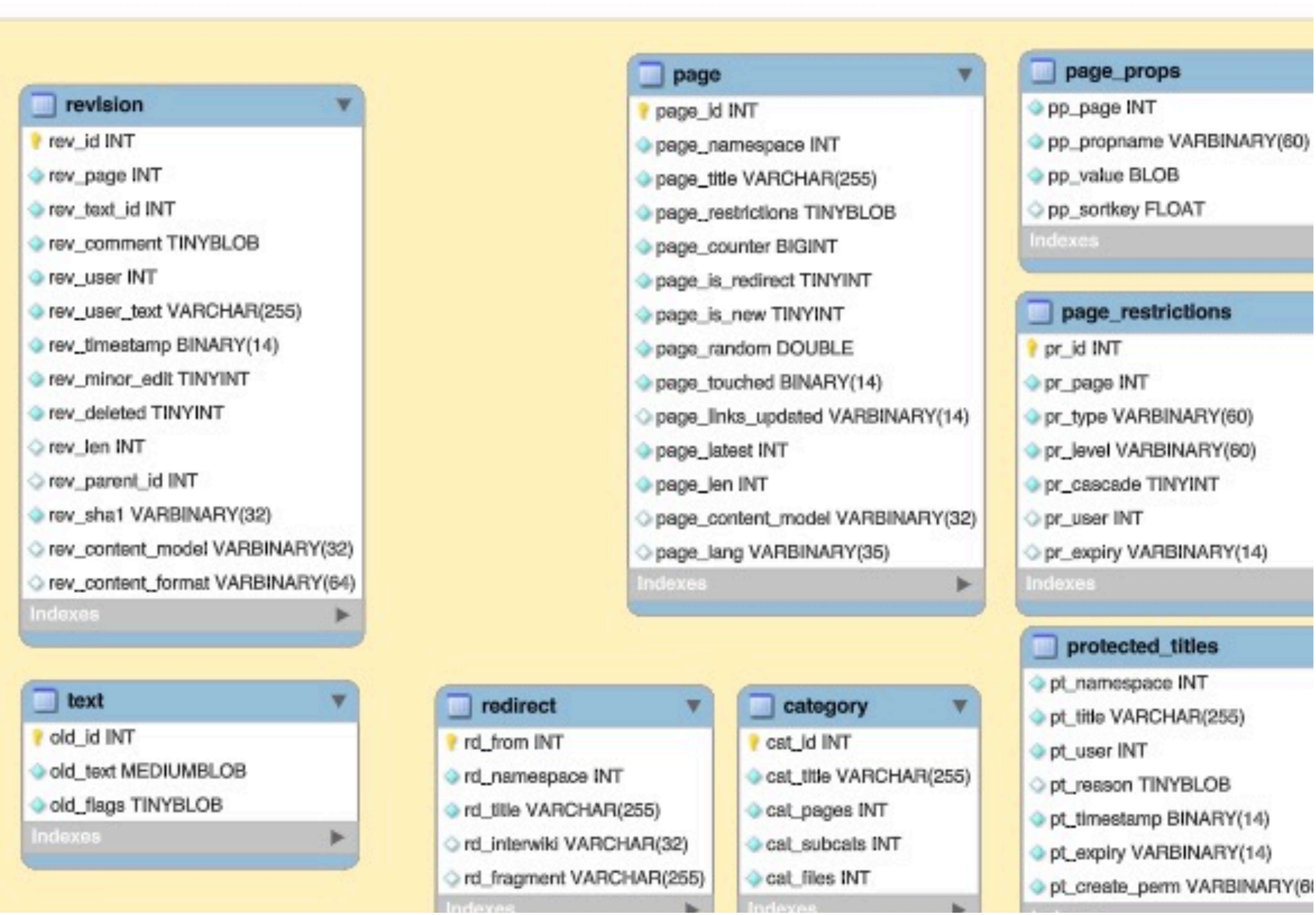


```
test=# \d election
                                 Table "public.election"
      Column       |  Type   | Collation | Nullable |                Default
-------------------+---------+-----------+----------+-----------------------------
 year              | integer |           |          |
 state             | 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



revision
rev_id INT
rev_page INT
rev_text_id INT
rev_comment TINYBLOB
rev_user INT
rev_user_text VARCHAR(255)
rev_timestamp BINARY(14)
rev_minor_edit TINYINT
rev_deleted TINYINT
rev_len INT
rev_parent_id INT
rev_sha1 VARBINARY(32)
rev_content_model VARBINARY(32)
rev_content_format VARBINARY(64)

page
page_id INT
page_namespace INT
page_title VARCHAR(255)
page_restrictions TINYBLOB
page_counter BIGINT
page_is_redirect TINYINT
page_is_new TINYINT
page_random DOUBLE
page_touched BINARY(14)
page_links_updated VARBINARY(14)
page_latest INT
page_len INT
page_content_model VARBINARY(32)
page_lang VARBINARY(35)

page_props
pp_page INT
pp_propname VARBINARY(60)
pp_value BLOB
pp_sortkey FLOAT

page_restrictions
pr_id INT
pr_page INT
pr_type VARBINARY(60)
pr_level VARBINARY(60)
pr_cascade TINYINT
pr_user INT
pr_expiry VARBINARY(14)

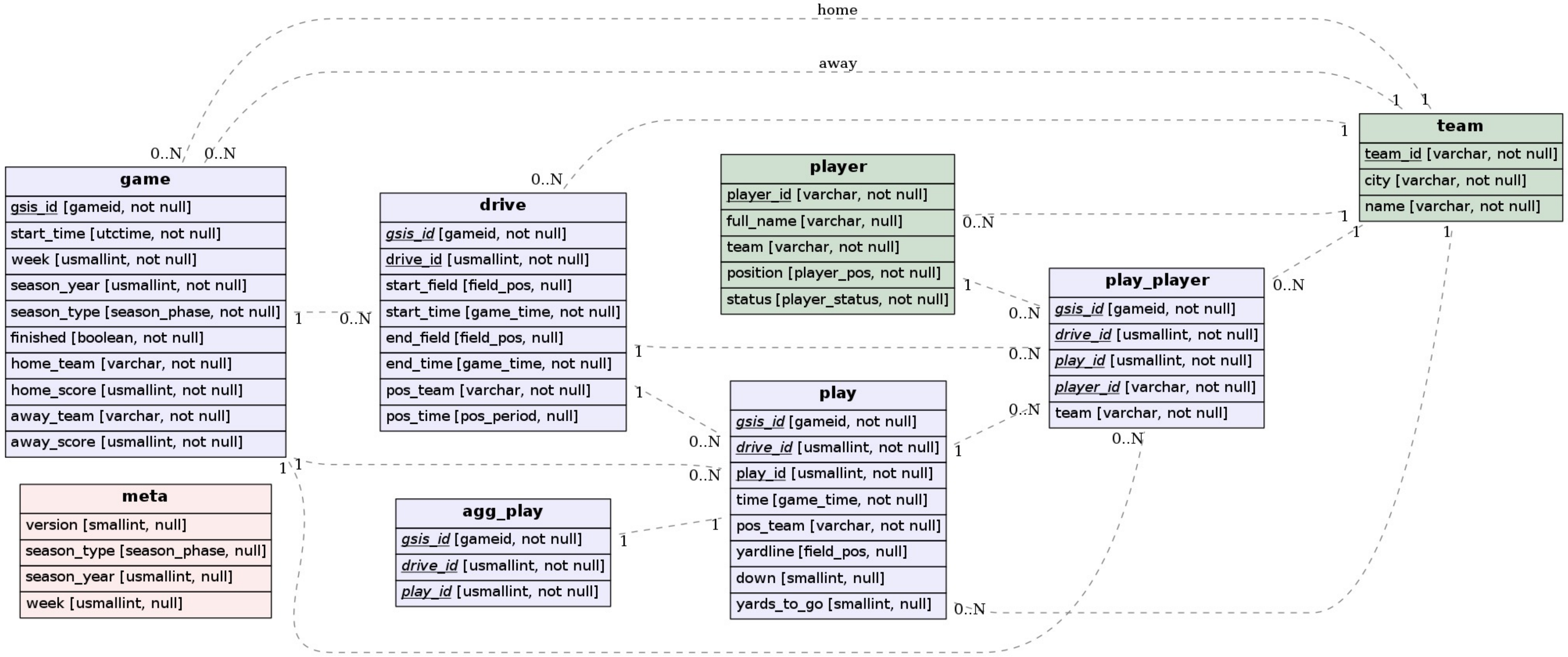
protected_titles
pt_namespace INT
pt_title VARCHAR(255)
pt_user INT
pt_reason TINYBLOB
pt_timestamp BINARY(14)
pt_expiry VARBINARY(14)
pt_create_perm VARBINARY(6

text
old_id INT
old_text MEDIUMBLOB
old_flags TINYBLOB

redirect
rd_from INT
rd_namespace INT
rd_title VARCHAR(255)
rd_interwiki VARCHAR(32)
rd_fragment VARCHAR(255)

category
cat_id INT
cat_title VARCHAR(255)
cat_pages INT
cat_subcats INT
cat_files INT

https://upload.wikimedia.org/wikipedia/commons/f/f7/MediaWiki_1.24.1_database_schema.svg nfldb Entity-Relationship diagram (condensed)



game
gsis_id [gameid, not null]
start_time [utctime, not null]
week [usmallint, not null]
season_year [usmallint, not null]
season_type [season_phase, not null]
finished [boolean, not null]
home_team [varchar, not null]
home_score [usmallint, not null]
away_team [varchar, not null]
away_score [usmallint, not null]

meta
version [smallint, null]
season_type [season_phase, null]
season_year [usmallint, null]
week [usmallint, null]

drive
gsis_id [gameid, not null]
drive_id [usmallint, not null]
start_field [field_pos, null]
start_time [game_time, not null]
end_field [field_pos, null]
end_time [game_time, not null]
pos_team [varchar, not null]
pos_time [pos_period, null]

agg_play
gsis_id [gameid, not null]
drive_id [usmallint, not null]
play_id [usmallint, not null]

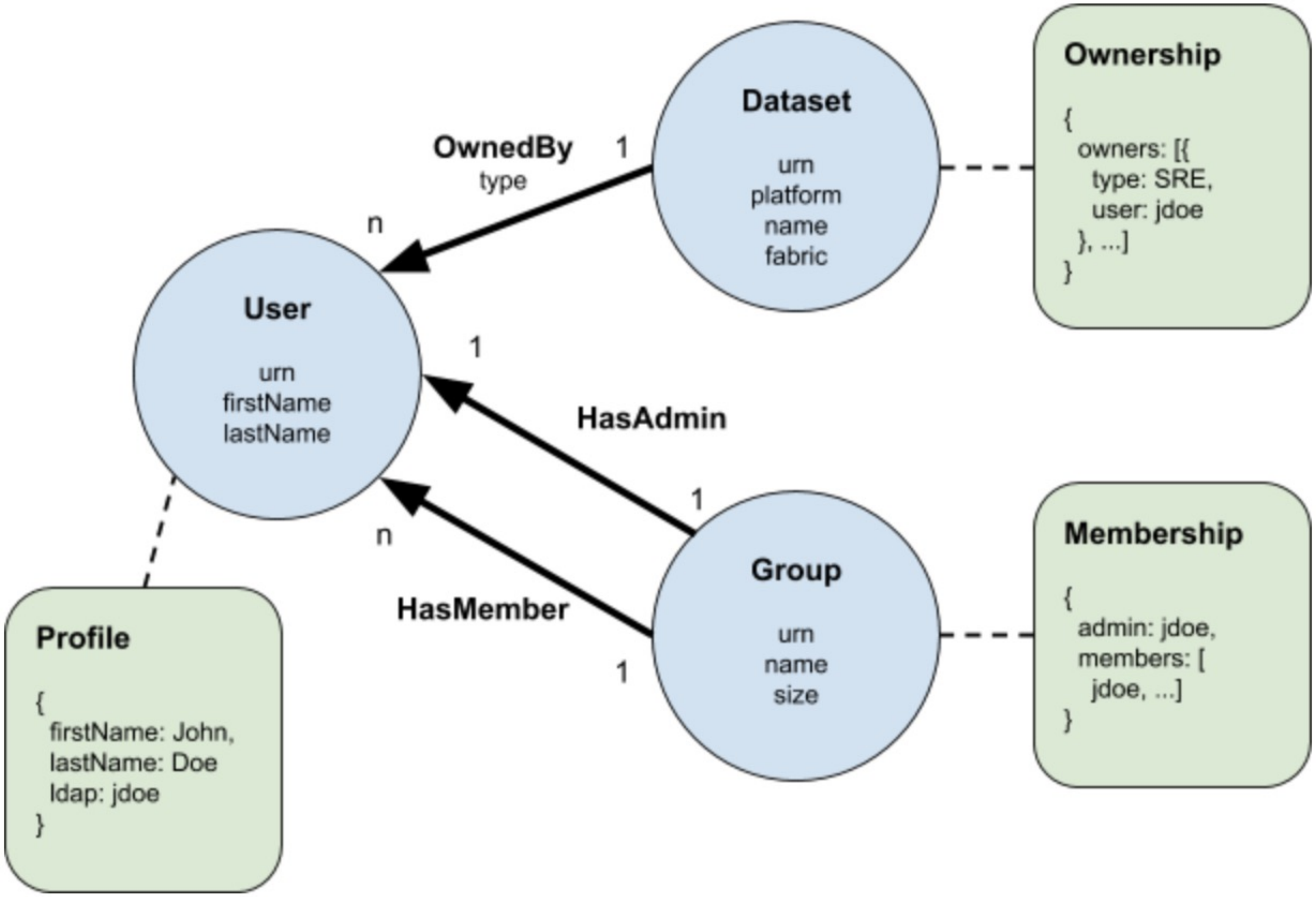
player
player_id [varchar, not null]
full_name [varchar, null]
team [varchar, not null]
position [player_pos, not null]
status [player_status, not null]

play
gsis_id [gameid, not null]
drive_id [usmallint, not null]
play_id [usmallint, not null]
time [game_time, not null]
pos_team [varchar, not null]
yardline [field_pos, null]
down [smallint, null]
yards_to_go [smallint, null]

play_player
gsis_id [gameid, not null]
drive_id [usmallint, not null]
play_id [usmallint, not null]
player_id [varchar, not null]
team [varchar, not null]

team
team_id [varchar, not null]
city [varchar, not null]
name [varchar, not null]

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



Ownership

```
{
  owners: [{
    type: SRE,
    user: jdoe
  }, ...]
}
```

Membership

```
{
  admin: jdoe,
  members: [
    jdoe, ...]
}
```

Profile

```
{
  firstName: John,
  lastName: Doe
  ldap: jdoe
}
```

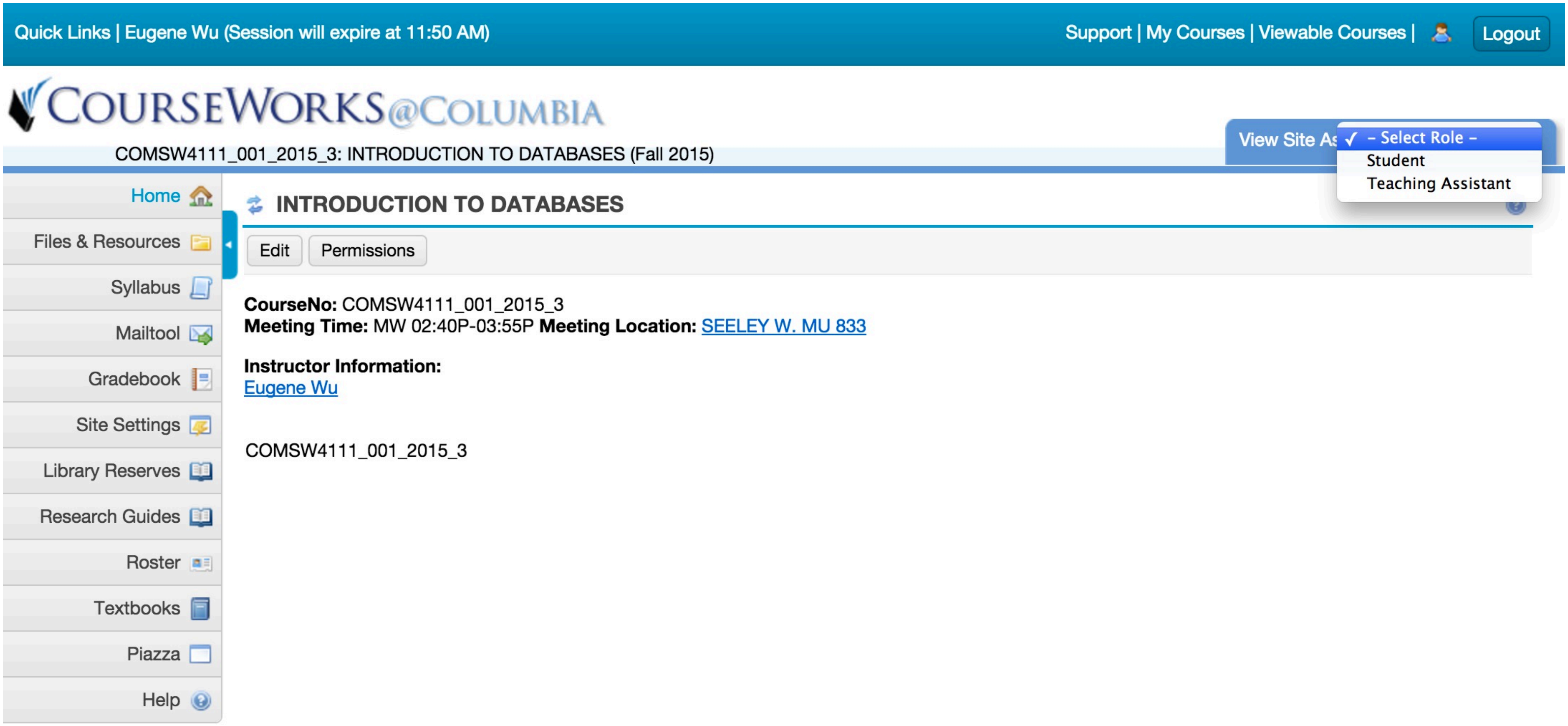
https://engineering.linkedin.com/blog/2019/data-hub

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)



COMSW4111_001_2015_3: INTRODUCTION TO DATABASES (Fall 2015)

INTRODUCTION TO DATABASES

CourseNo: COMSW4111_001_2015_3
Meeting Time: MW 02:40P-03:55P **Meeting Location:** SEELEY W. MU 833

Instructor Information:
Eugene Wu

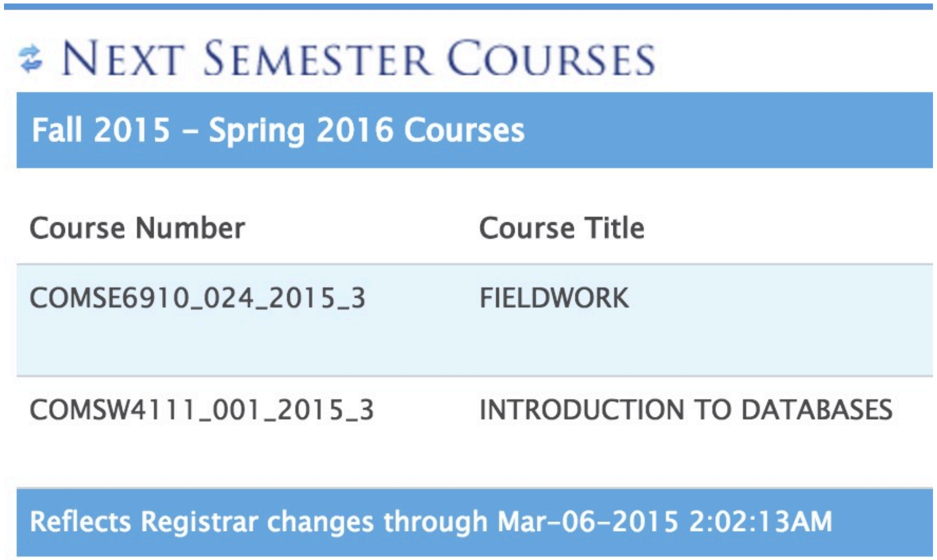
COMSW4111_001_2015_3

Entity-Relationship Modeling

Entities (objects) to store and their attributes

Relationships between entities and their attrs.

Integrity constraints & business rules



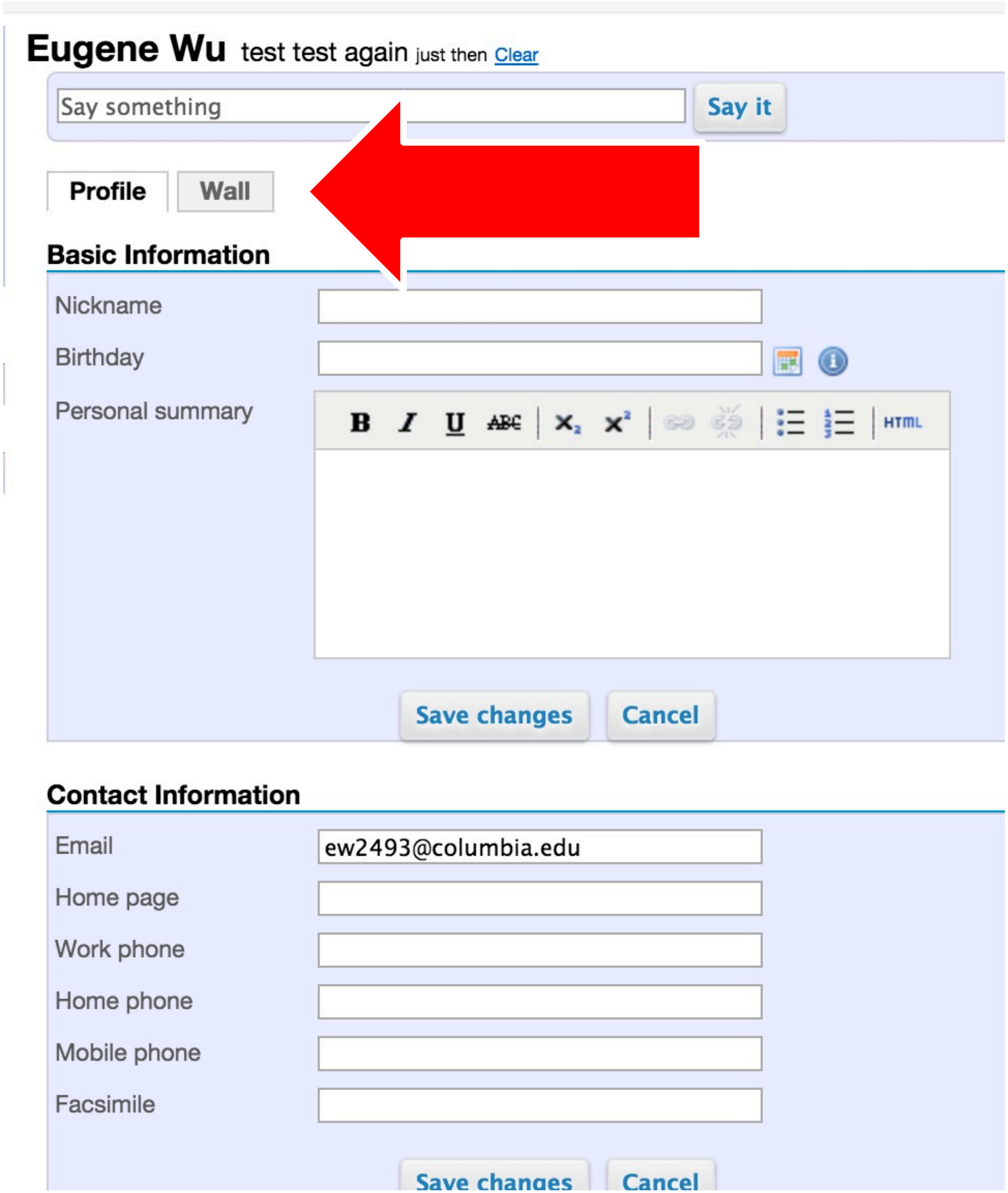
NEXT SEMESTER COURSES

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



Eugene Wu test test again just then Clear

Say something

Basic Information

Nickname

Birthday

Personal summary

Contact Information

Email: ew2493@columbia.edu

Home page

Work phone

Home phone

Mobile phone

Facsimile

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

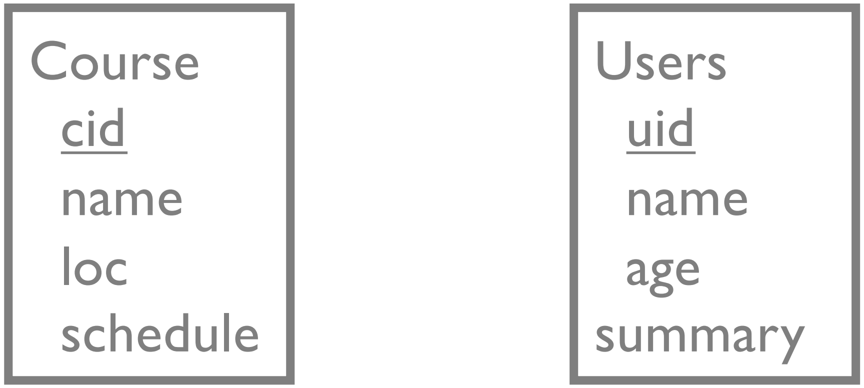
attributes have domains

≈ table

Example: Entity

Keys (cid, uid) are underlined

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



Course
cid
name
loc
schedule

Users
uid
name
age
summary

Basics: Relationships

Relationship: association between 2 or more entities

e.g., alice is taking Introduction to DBs

Relationship Set: collection of similar relationships

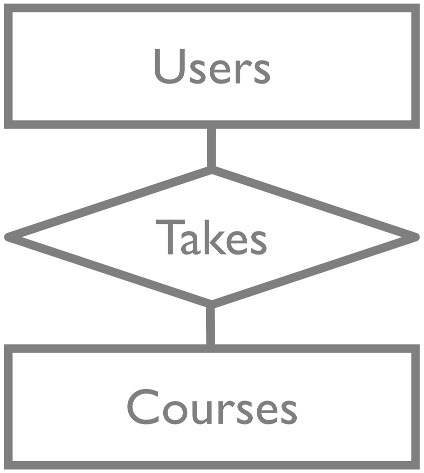
N-ary relationship set R relates N entity sets $E_1 \dots E_n$

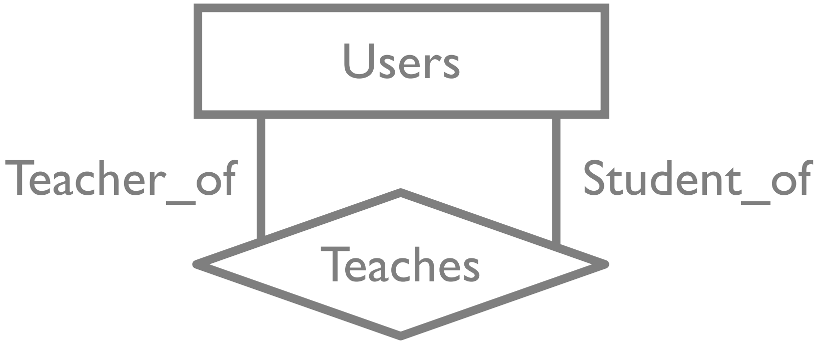
Each $r \in R$ involves entities $e_1 \dots e_n$

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



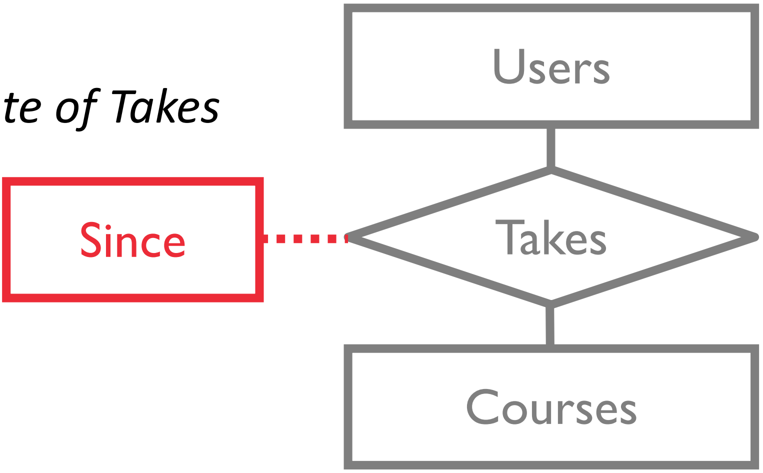


Basics: Relationships

Relationships sets can have descriptive attributes

Denoted with dotted line from diamond to box

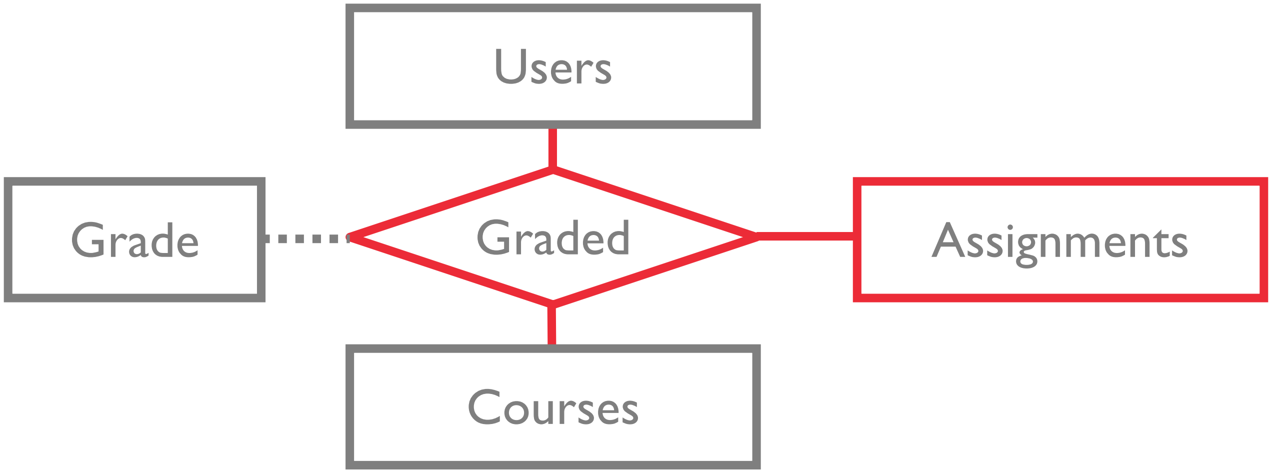
since is attribute of Takes



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

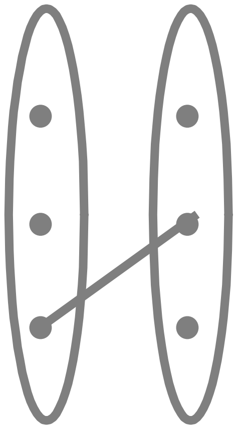
Many to many e.g., *Takes*

a user can take many courses

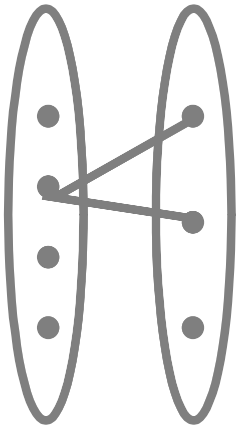
a course can have many users that take the course

One to Many e.g., *Instructs*

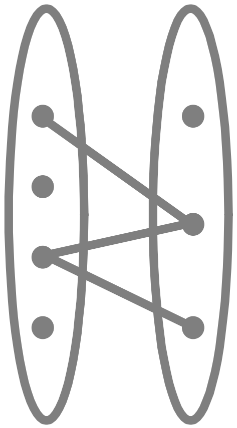
a course has at most one instructor



1-to-1

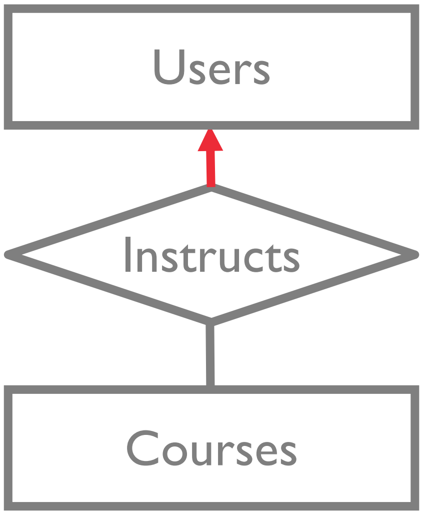


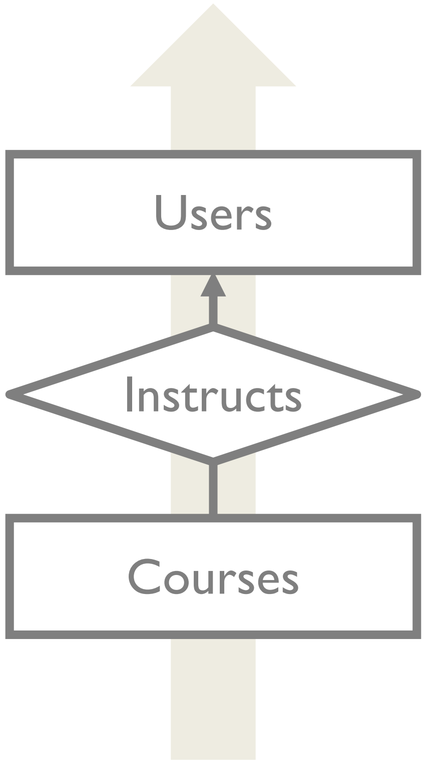
1-to Many



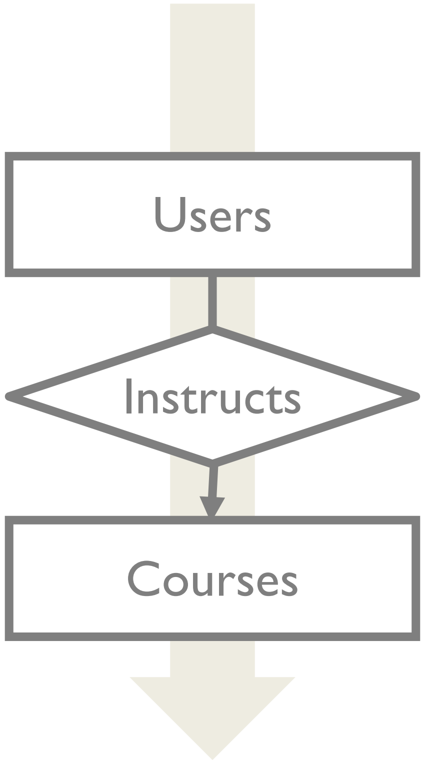
Many-to-Many

Draw arrow from diamond to box

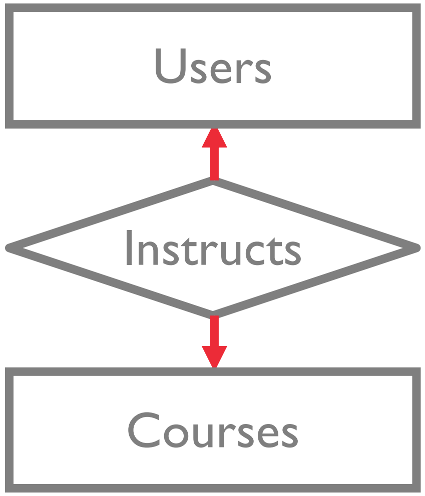




A course is instructed by ≤1 user
(read along the beige arrow)



A user instructs ≤1 course



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

Participation Constraints

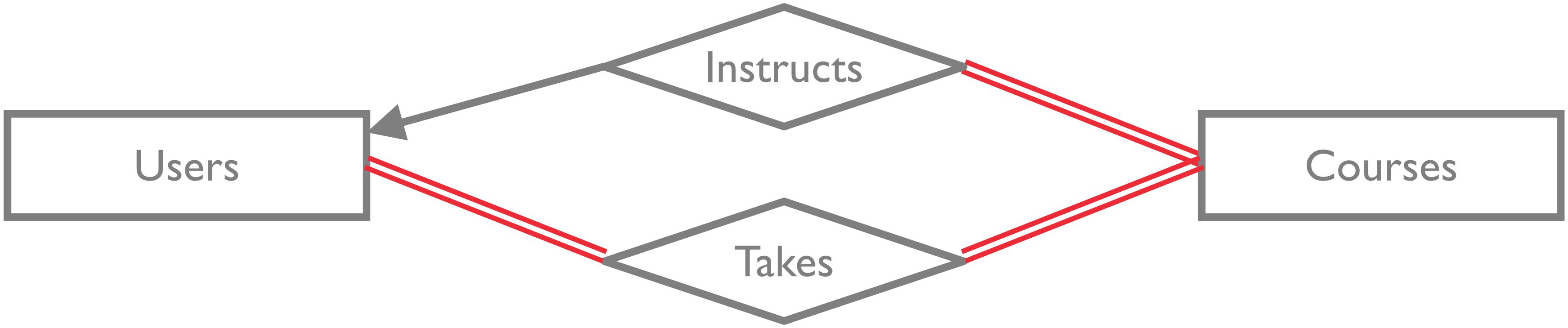
Does every course need an instructor?

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)



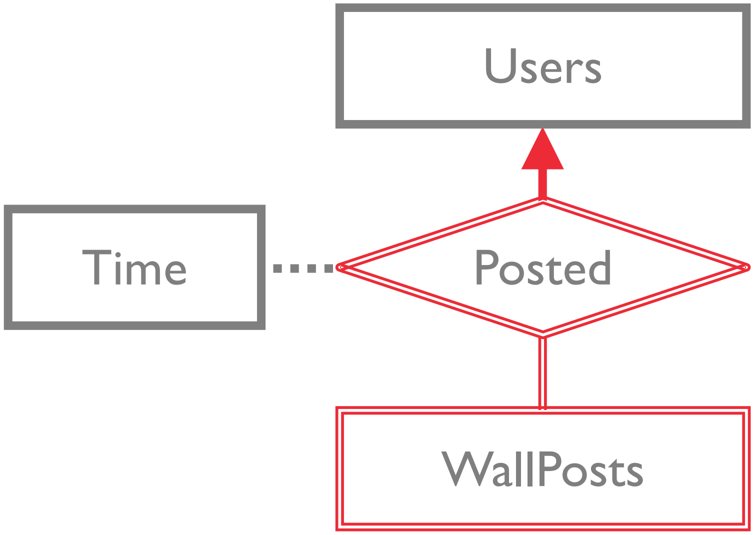
Each user must take at least one course and
Each course must have at least one user (student)

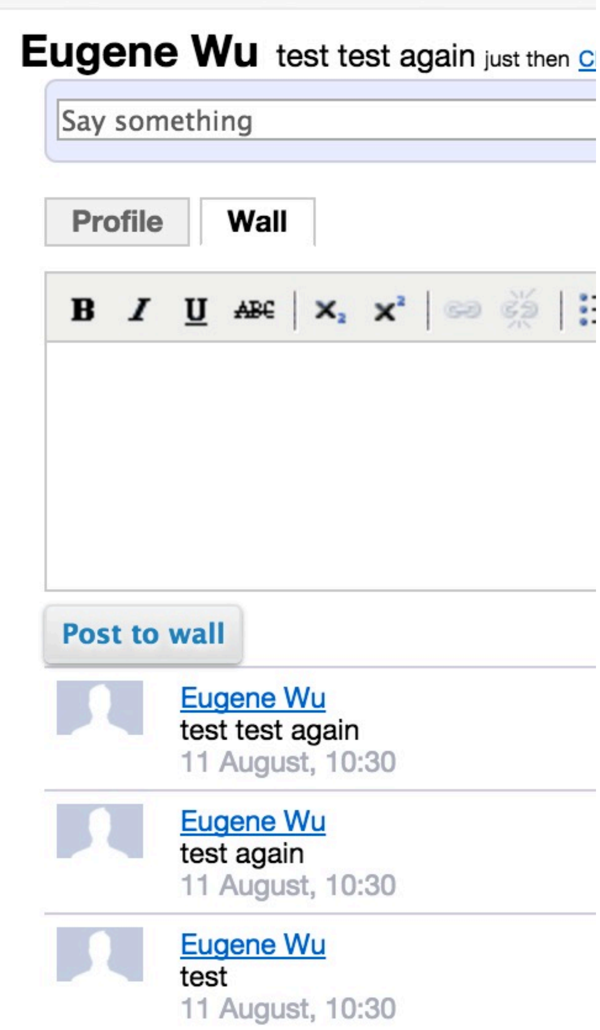
Weak Entities

A *weak entity* can only be uniquely identified by using the primar 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





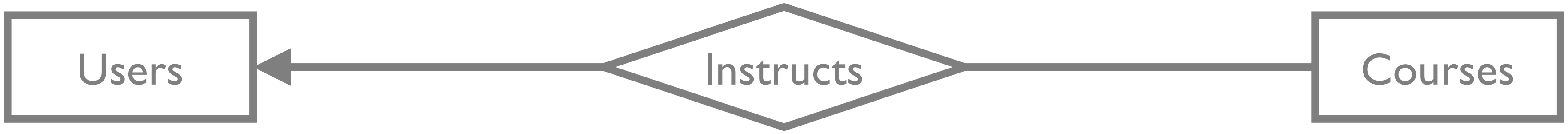
Eugene Wu test test again just then C

Eugene Wu
test test again
11 August, 10:30

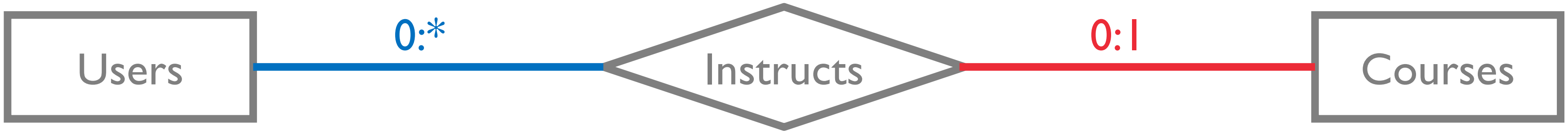
Eugene Wu
test again
11 August, 10:30

Eugene Wu
test
11 August, 10:30

General Cardinality Constraints

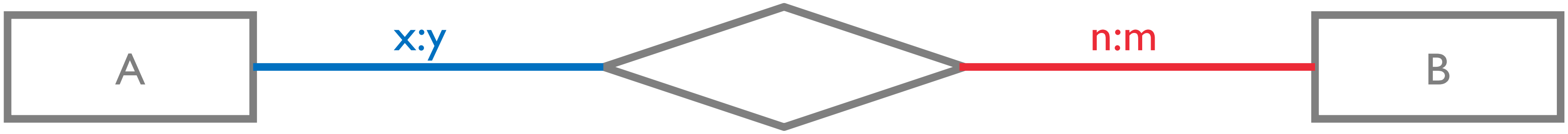


same as



A user instructs 0 to ∞ courses

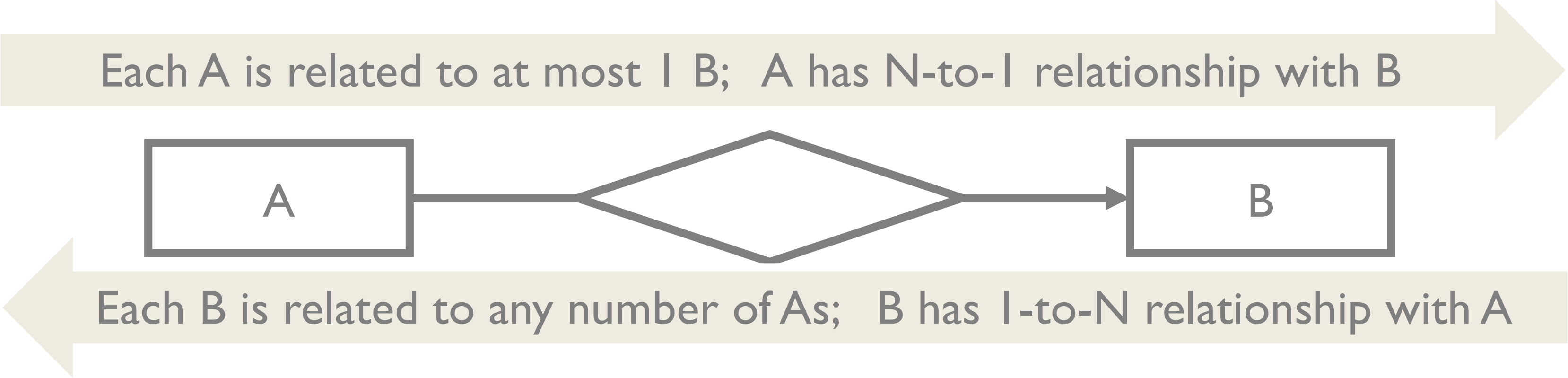
A course has 0 to 1 instructors



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

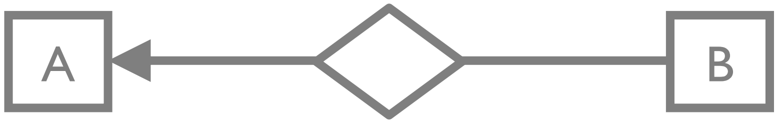
Each B entity has a relationship with between n to m different A entities

Read arrows pointing in the direction from start to end

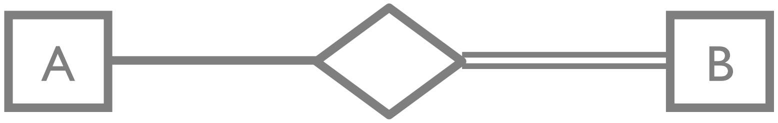


Each A is related to at most 1 B; A has N-to-1 relationship with B

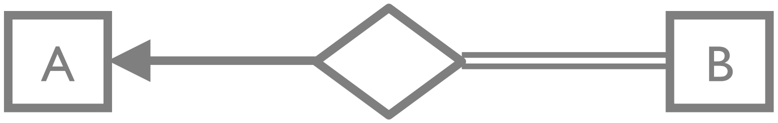
Each B is related to any number of As; B has 1-to-N relationship with A



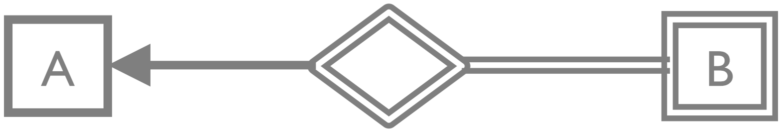
B has at most one A



B has at least one A



B has exactly one A



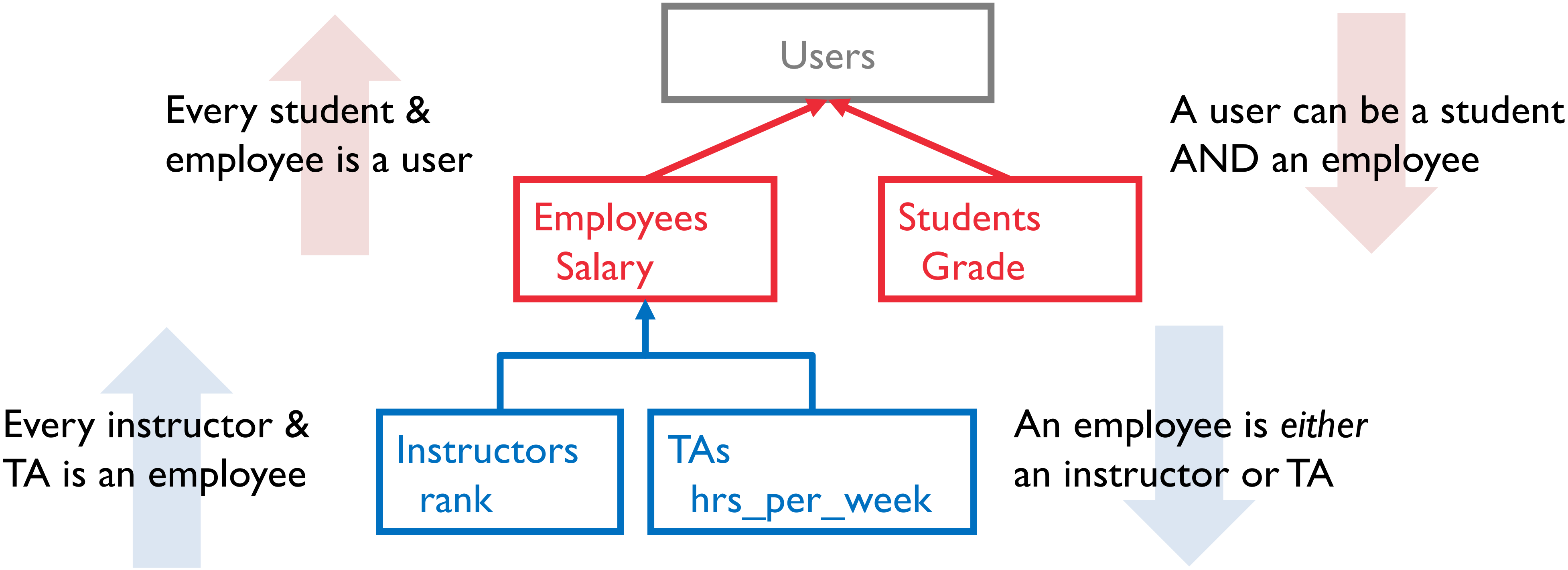
B is a weak entity

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



Every student & employee is a user

A user can be a student AND an employee

Every instructor & TA is an employee

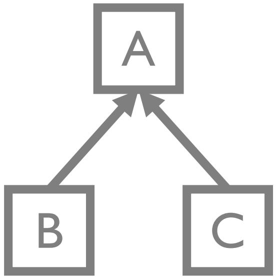
An employee is *either* an instructor or TA

Specialization Hierarchies

Overlap Constraint

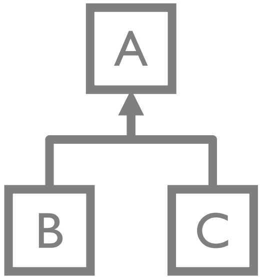
can A be a B *and* a C?

YES



separate arrows

NO

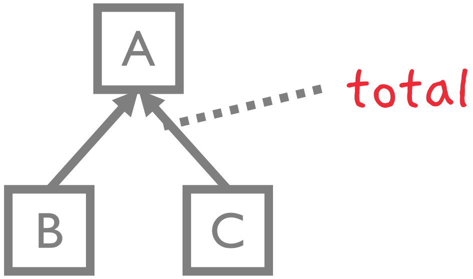


merged into 1 arrow

Total Specialization Constraint

must A be a B or C?

specify as the comment "total" with dashed link to arrows

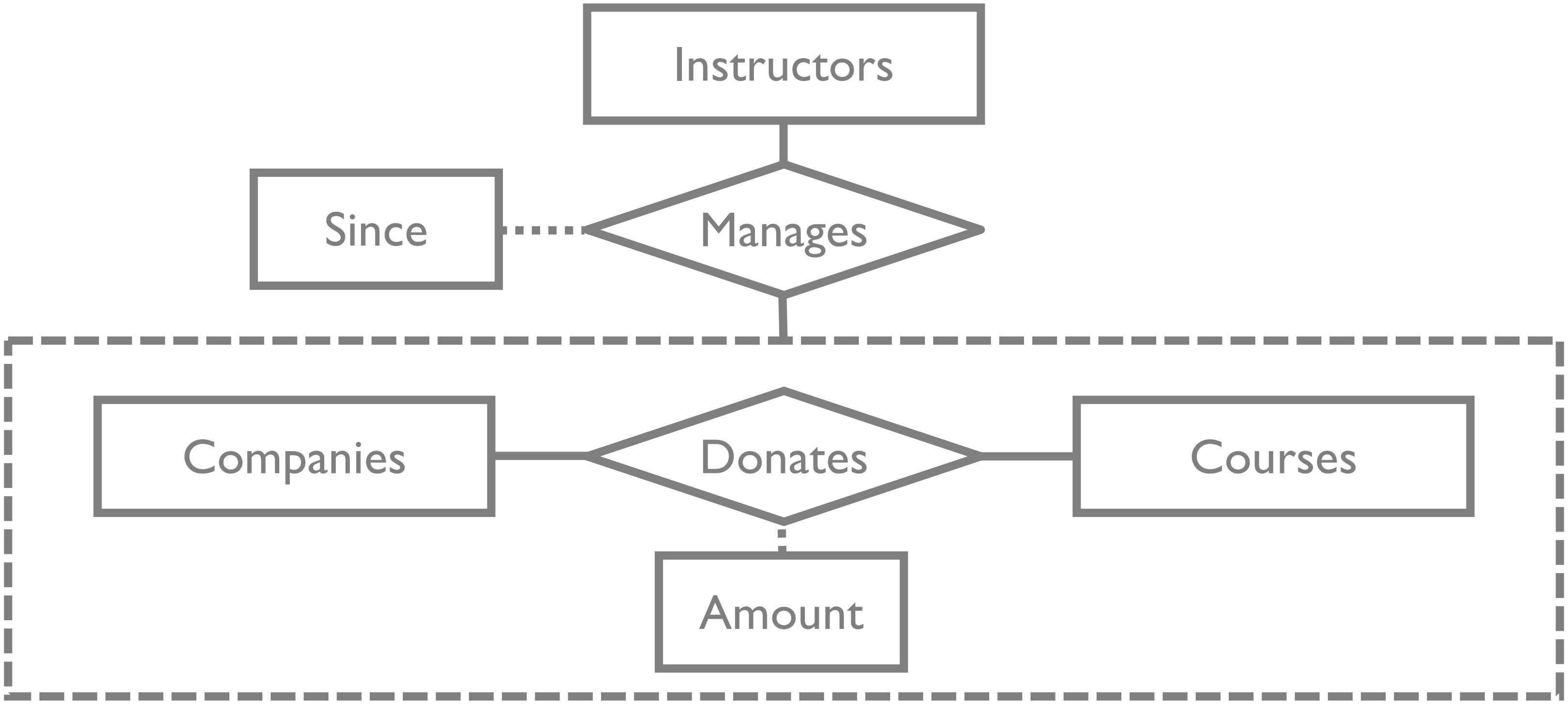


Aggregation

Relationships between (entities – relationships)

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

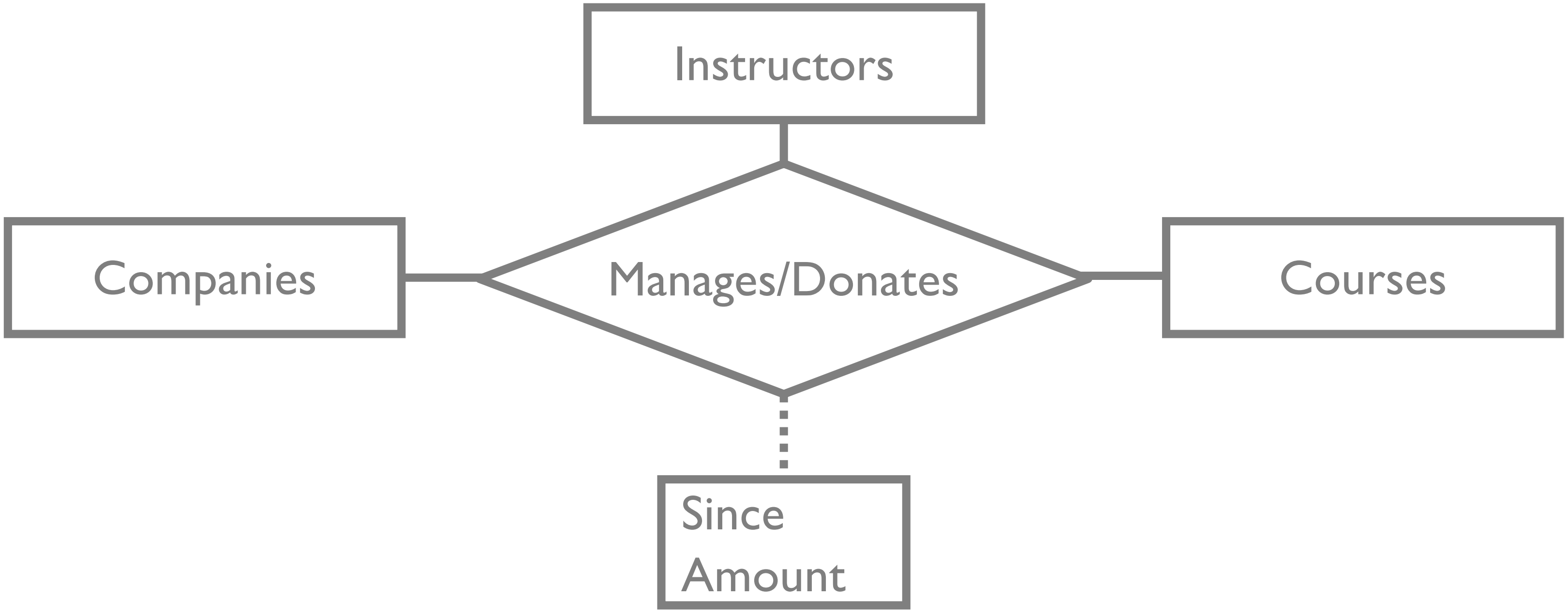
Denoted as dashed line around the relationship set



Aggregation vs Ternary Relationships

Why use aggregation?

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

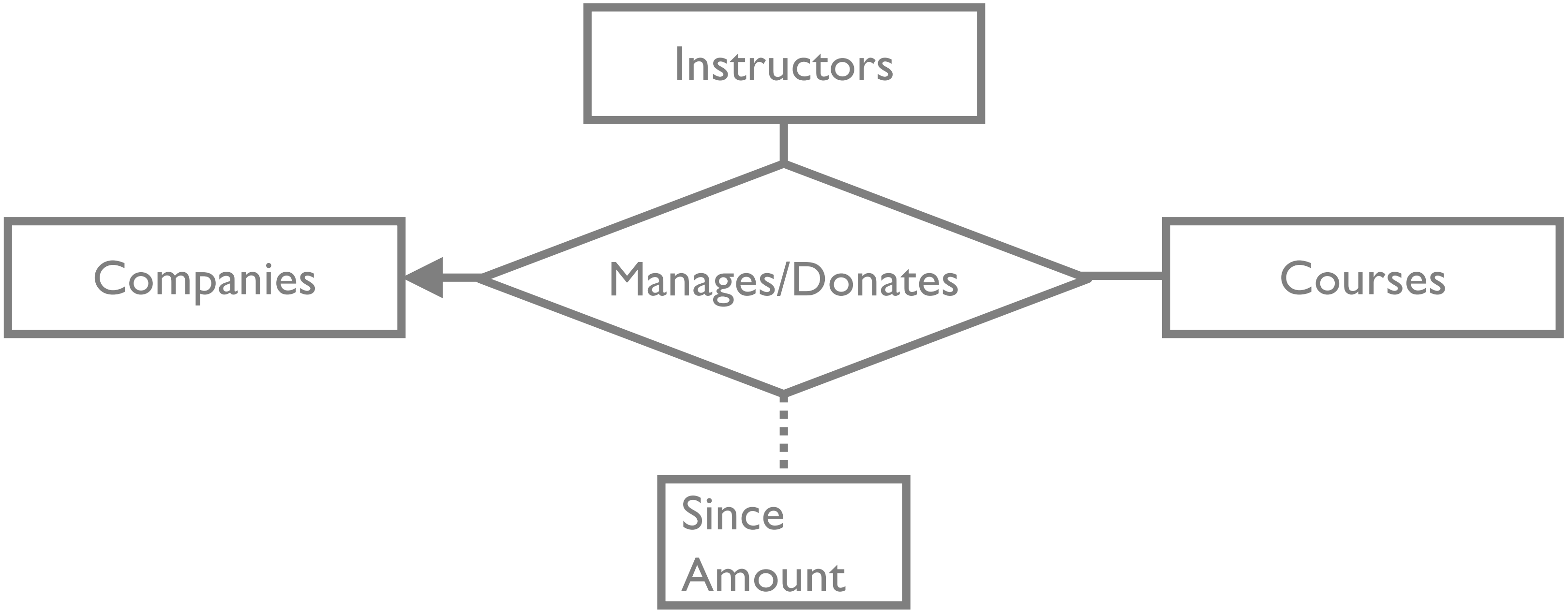


Aggregation vs Ternary Relationships

Constraints apply to all connected entity sets

A donation can be managed by at most one instructor

But also enforces: *A course can have at most one donation*



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?

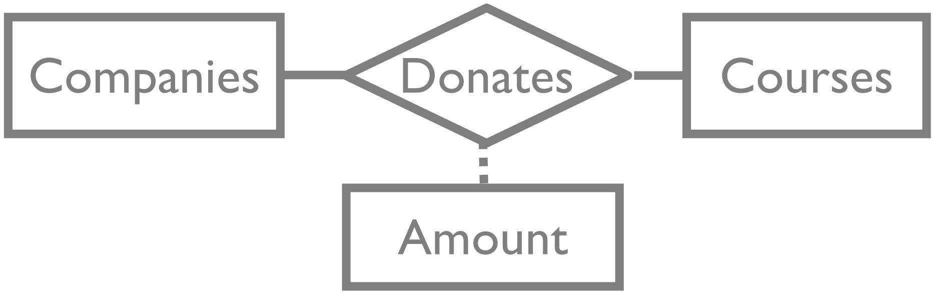
Is users.address an attribute of Users or an entity connected to Users by a relationship?

Depends (and may change over time!)

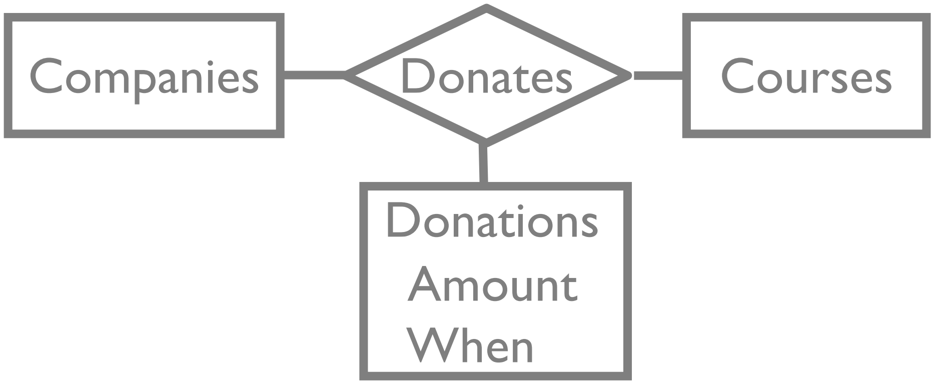
- If a user has >1 addresses, must be an entity
- If an address has attrs (structure), must be entity
- e.g., want to search for users by city, state, or zip

Entity or Attribute?

A company can't donate multiple amounts



Company can make multiple donations

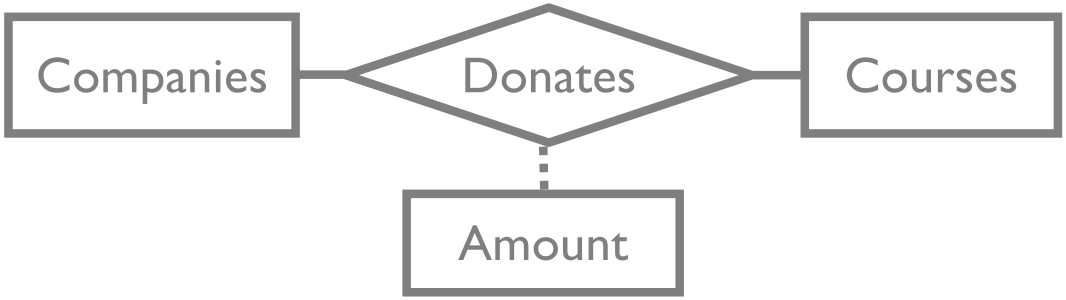


Entity or Relationship?

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



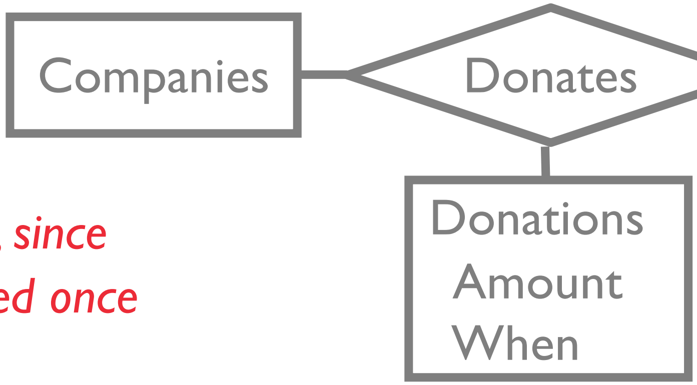
Company	Course	Amount
Amazon	4111	2000
Amazon	4112	2000
Amazon	5111	2000

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

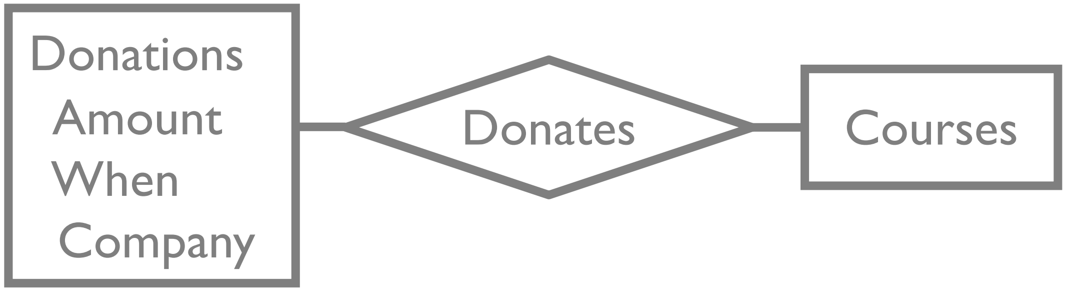
Company	Course	Donation
Amazon	4111	1
Amazon	4112	1
Amazon	5111	1

Donation	When	Amount
1	Today	2000

Entity or Relationship?

If company donates once to school for data related courses.

Refactor amount into an entity

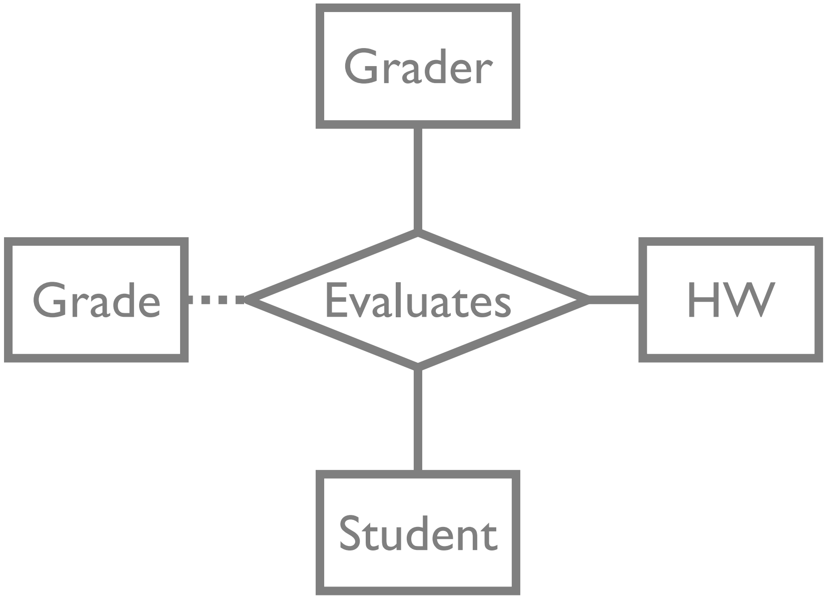


Course	Donation
4111	1
4112	1
5111	1

Donation	When	Amount	Company
1	Today	2000	Amazon

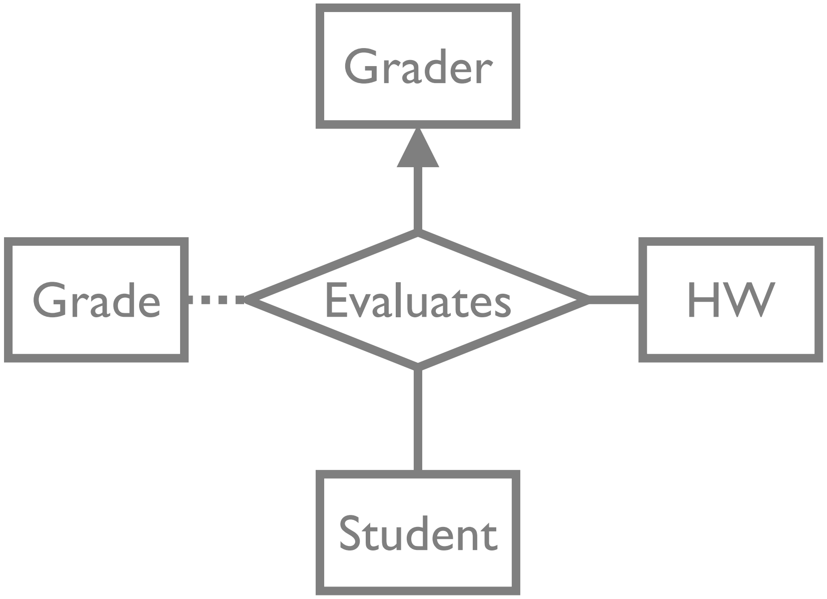
Binary or Ternary Relationship?

What if each HW has at most one grader?

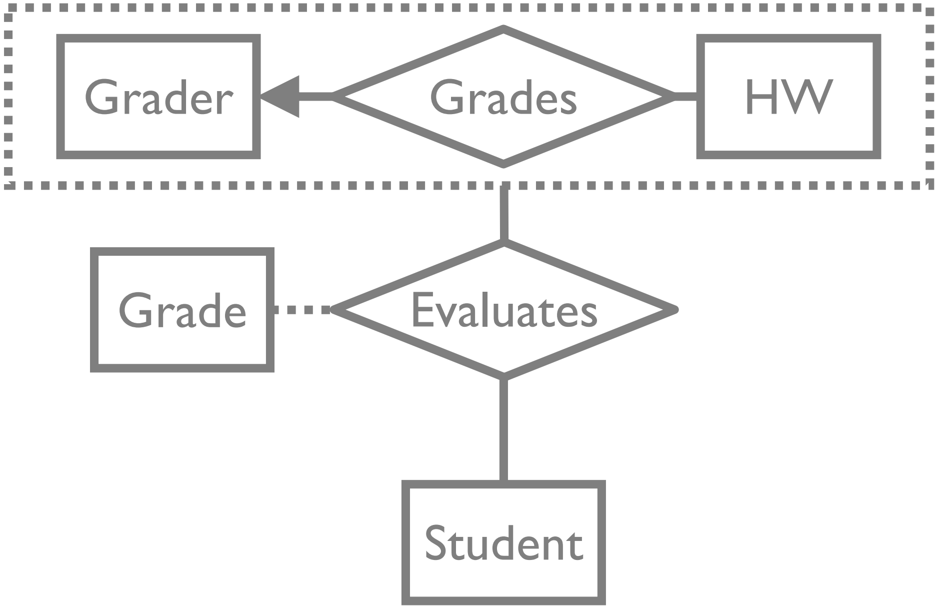


Binary or Ternary Relationship?

What if each HW has at most one grader?



Actually says that each student's HW submission has at most one grader

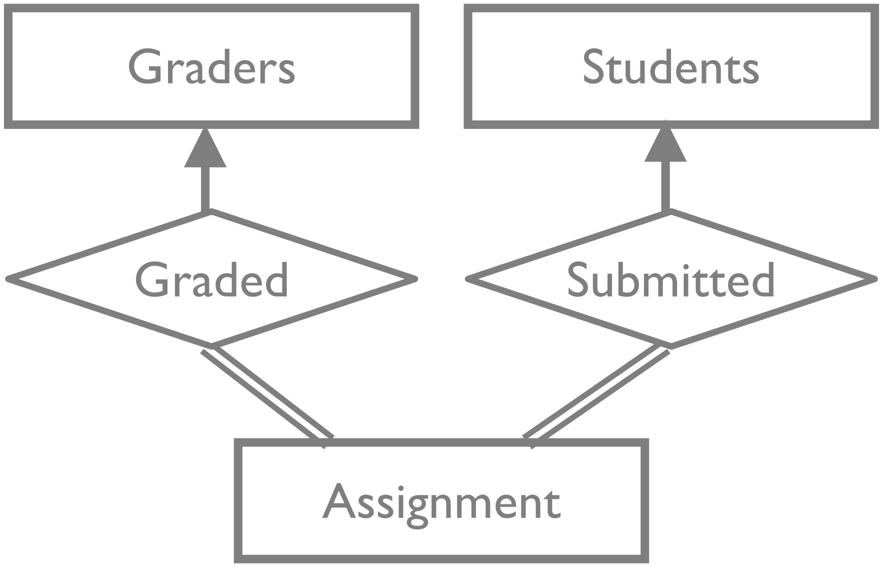


Each HW has at most 1 grader and the grader evaluates student submissions

Binary or Ternary Relationship?

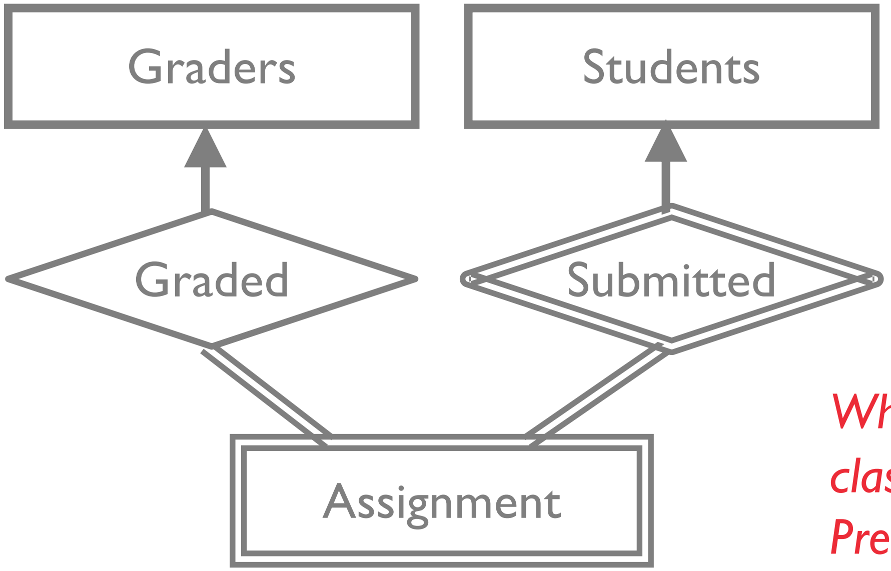
Binary relationships allows additional constraints

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



Binary or Ternary Relationship?

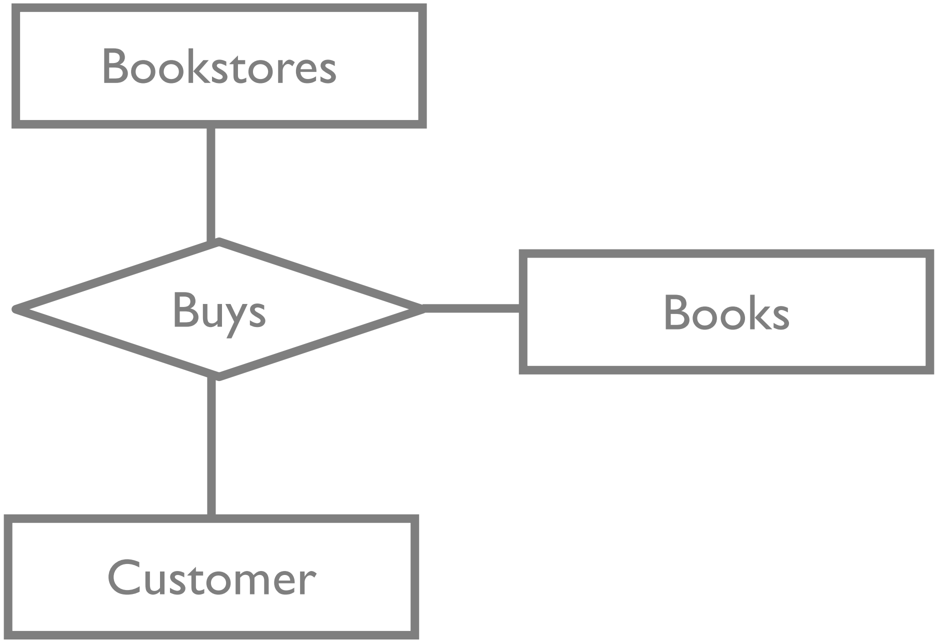
Binary relationships allows additional constraints



When student drops the class, HW0 also disappears! Previous slide was correct

Binary or Ternary Relationship?

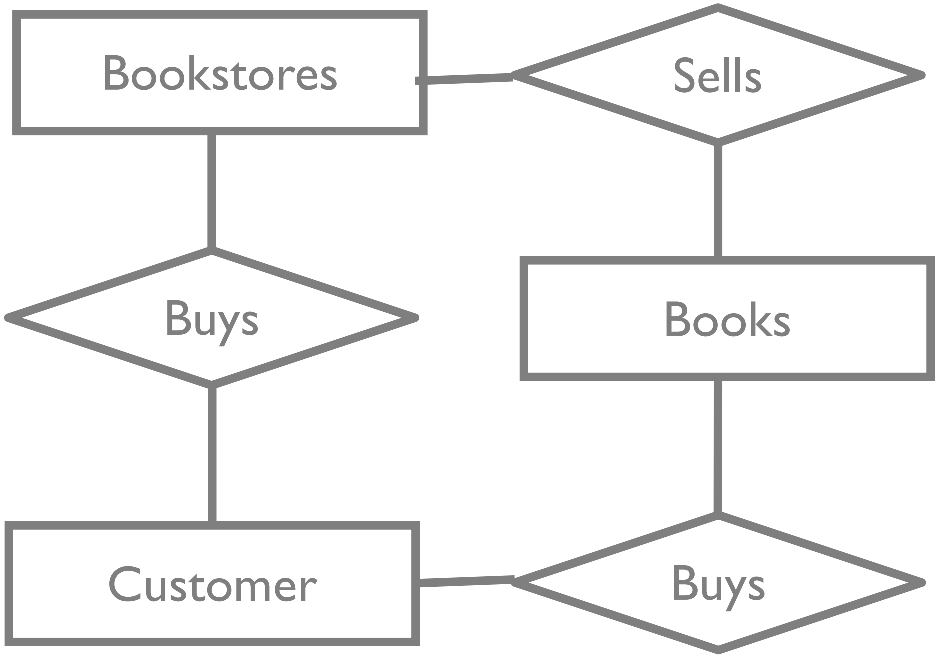
Sometimes have true ternary relationship that is defined by all three entities.



Binary or Ternary Relationship?

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

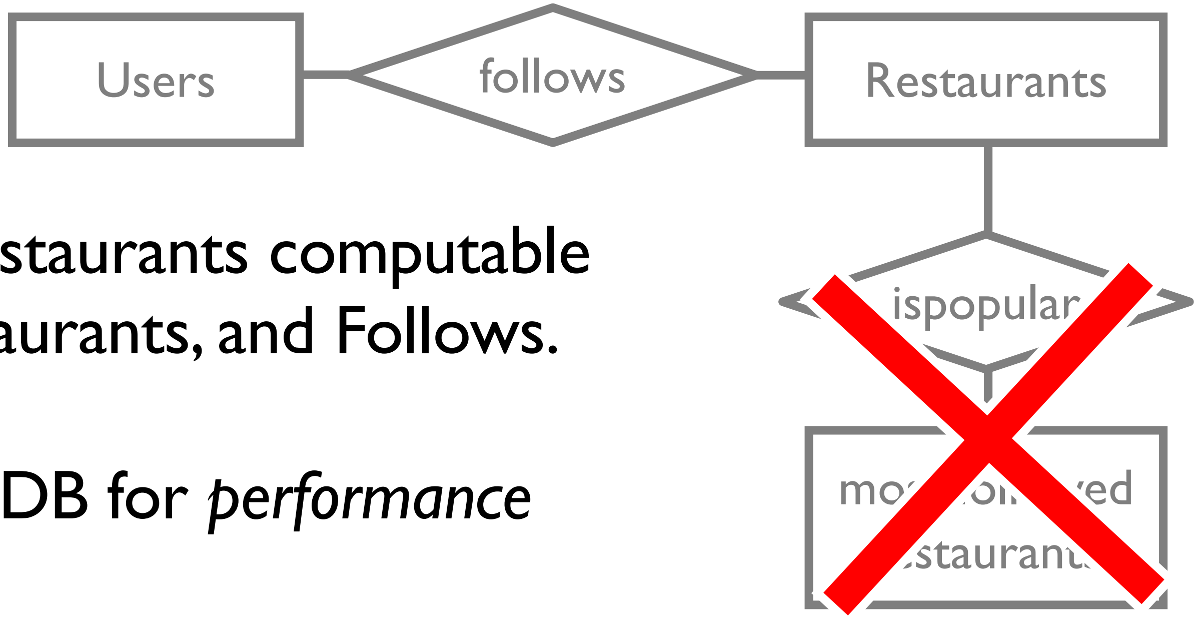
Doesn't Really Work



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