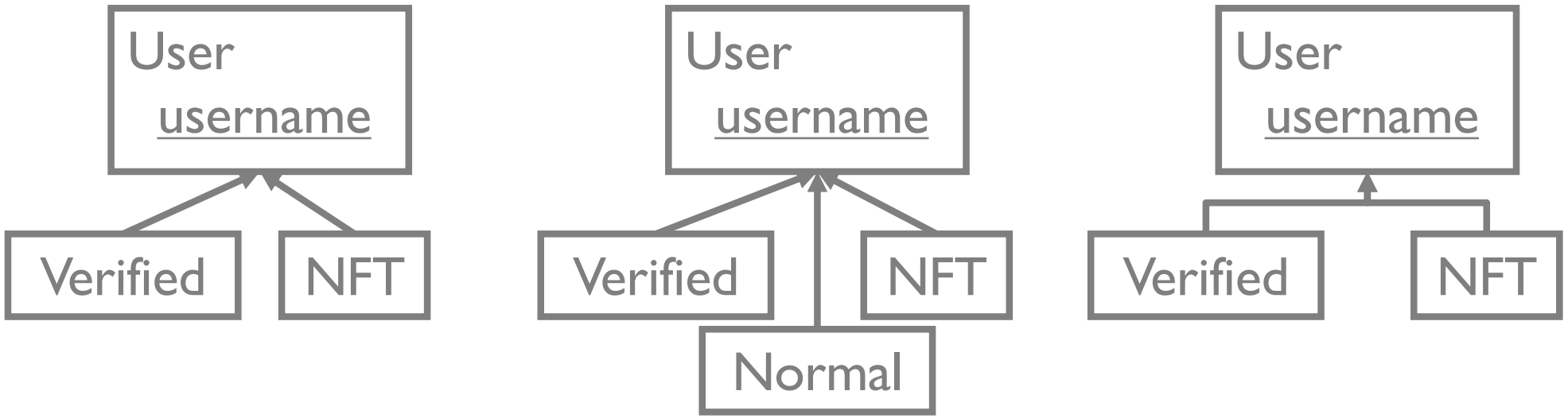
QUIZ TIME!!

http://w4111.github.io/quiz.html

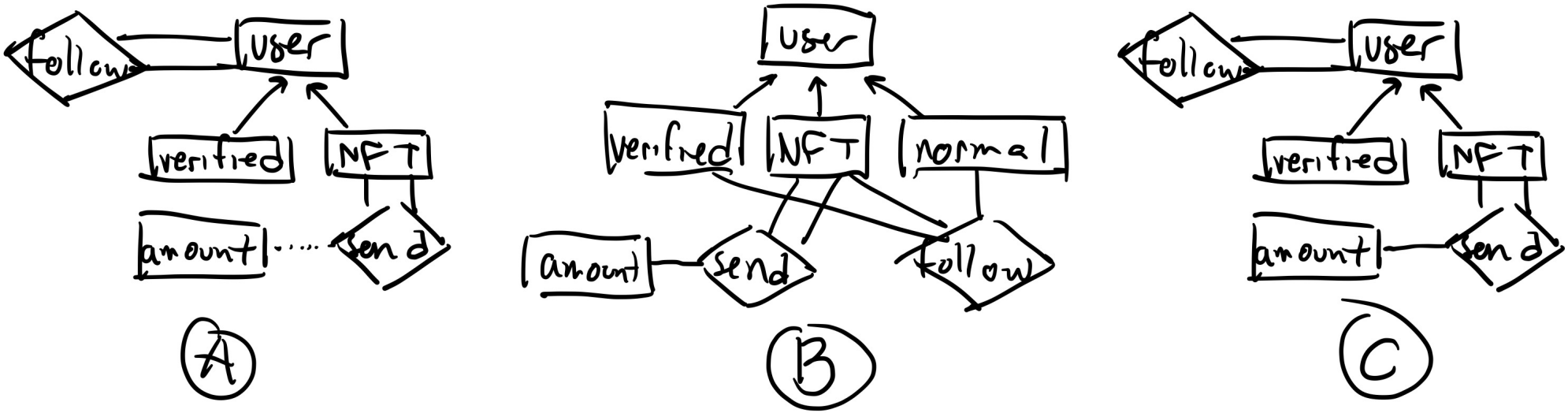
A twitter **user** is identified by username, and can be a **verified user**, an **NFT user**, a **normal** user, or any combination.



A B C

http://w4111.github.io/quiz.html

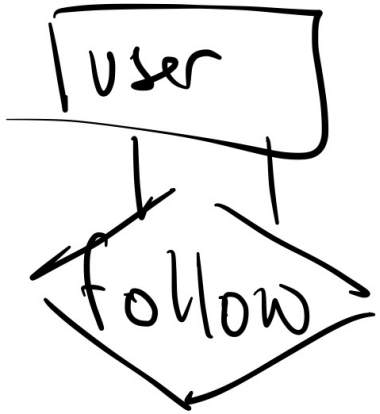
Any **user** can follow another **user**, but only **NFT** users can send **bitcoin** to each other.



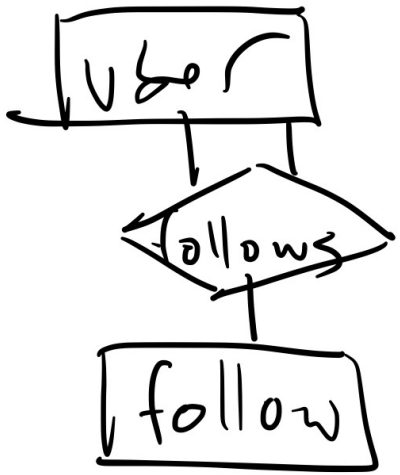
http://w4111.github.io/quiz.html

Suppose Eugene follows BigDataMemes.

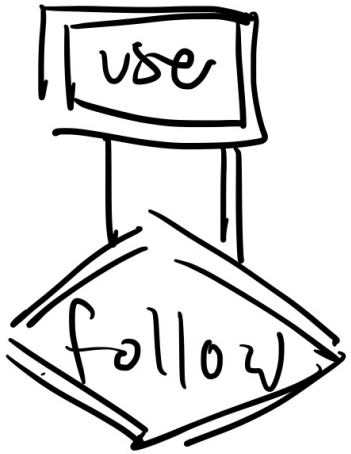
If Eugene deletes his account, BigDataMemes should not have Eugene as a follower.



A



B



C

The Relational Model

Eugene Wu

Background

Relational model: most widely used data model in the world

Legacy Models

- IMS hierarchical/Nested
- CODASYL network

Other common models:

- Key-Val, Matrix, Data frame

Overview of Key Relational Principles

Data redundancy (or how to avoid it)

Physical data independence

- Can change physical storage w/out changing programs

Logical data independence

- Can change schema without changing programs

High level languages

Historical Context

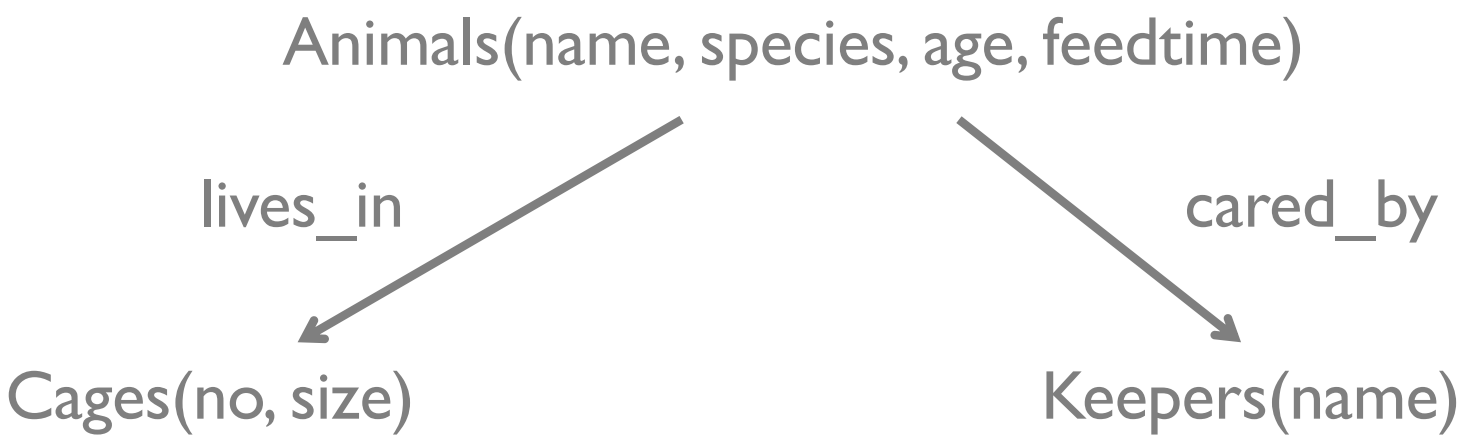
Hierarchical model (IMS)

Network model (CODASYL)

Relational model (SQL/QUEL)

70s

80-90s

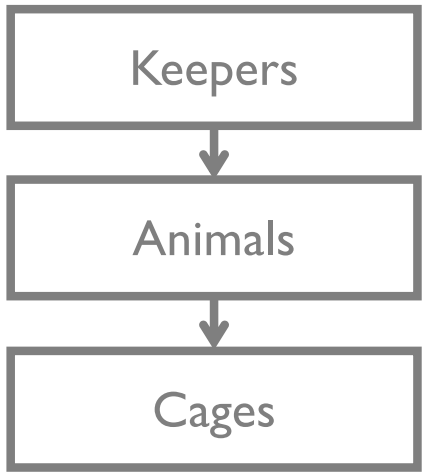


Hierarchical Model (IMS, circa 1968)

Segment types (objects)

Segment instances (records)

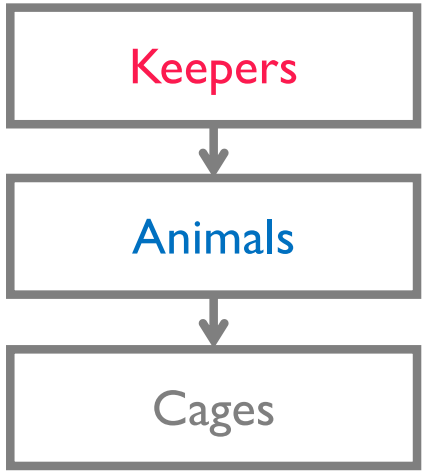
Segment types form a tree



Data Stored Depth First

```
Jane                (HSK 1)
  Bob, iguana,      (2)
    1, 100ft²,      (3)
  Joe, student,     (4)
    1, 100ft²,      (5)
```

```
{ id: 1
  name: Jane
  animals: [
   { id: 2
     name: Bob
     species: iguana,
     cages: [
       {id: 3,
        no: 1,
        size: 100
     }]
  }, ..
```



What's repeated?

Inconsistencies possible, lack of protections

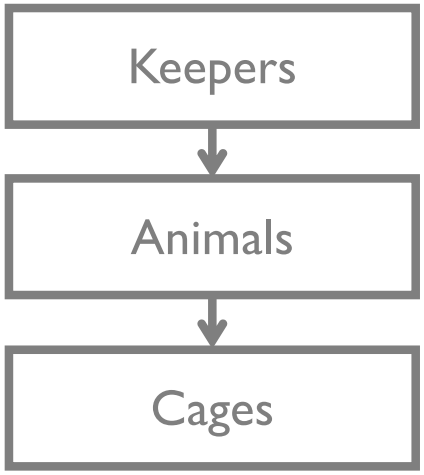
Similar to JSON

Can't Avoid Redundancy

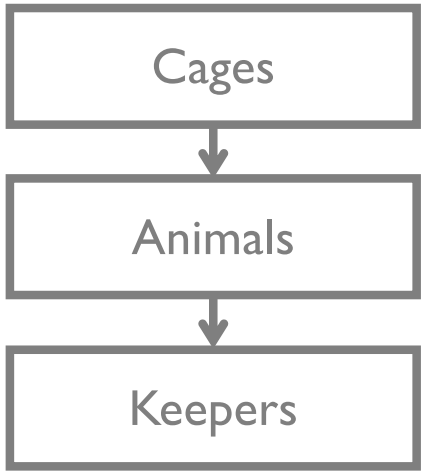
Segment types (objects)

Segment instances (records)

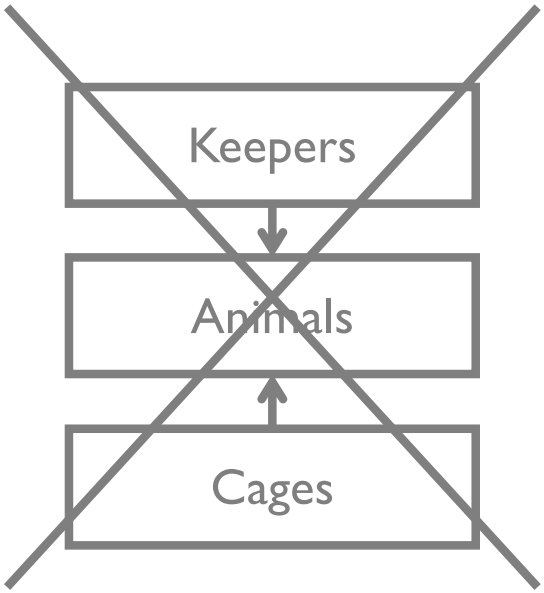
Segment types form a tree



Repeats cage data if >1 animals in a cage



Repeats keeper data if keeper cares for >1 animals



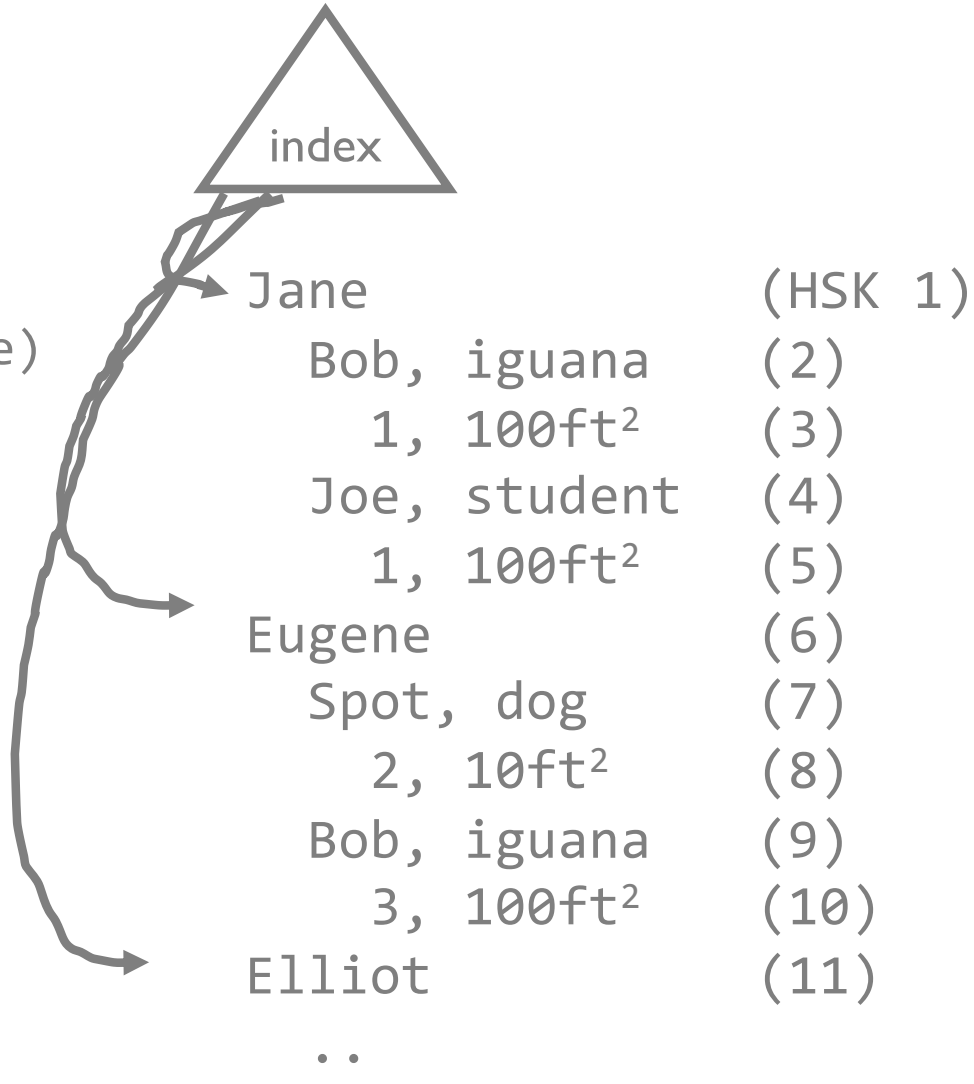
DAG != Tree

Hierarchical "Querying"

Fetch cages that Eugene manages

```
Goto(Keeper, name = Eugene)
Until no more records
    cage = NextInParent(Cage)
    print cage.no
```

Output:



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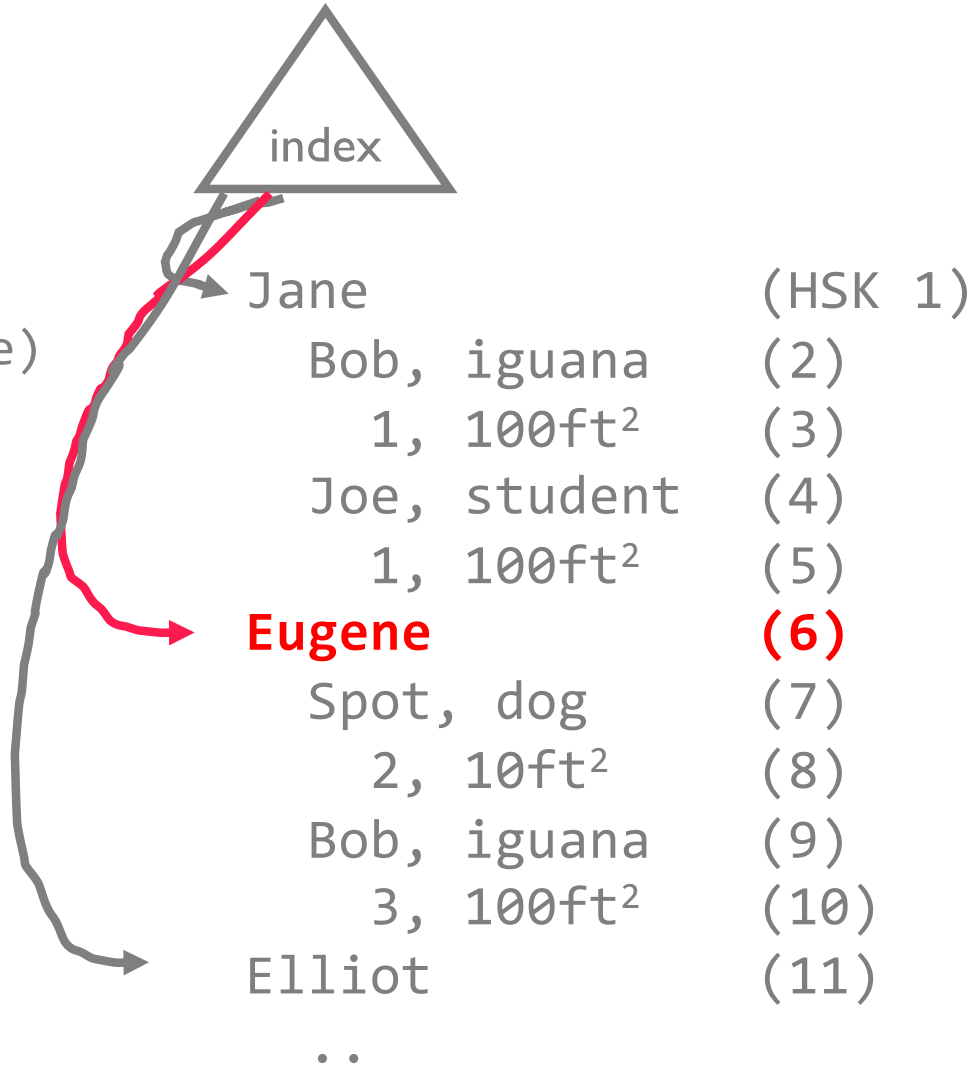

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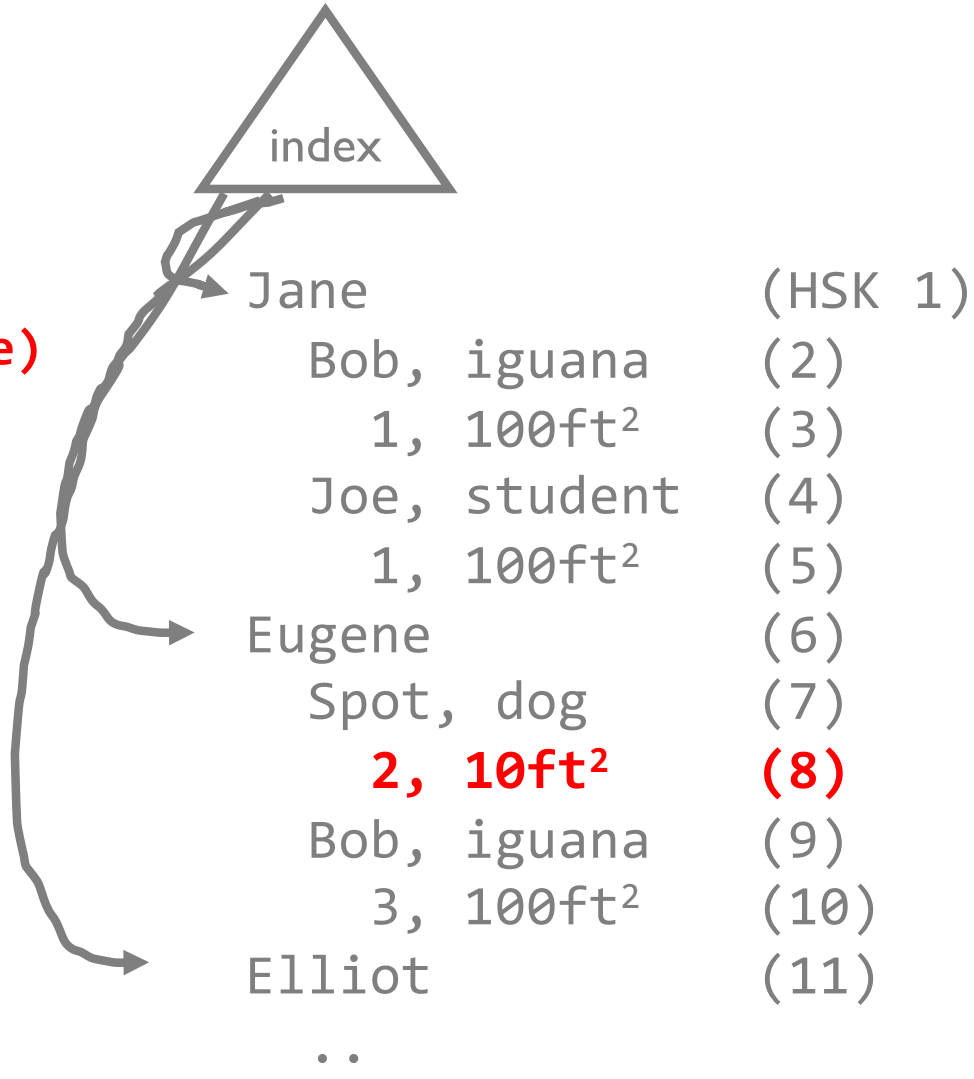
Output:



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```
Goto(Keeper, name = Eugene)
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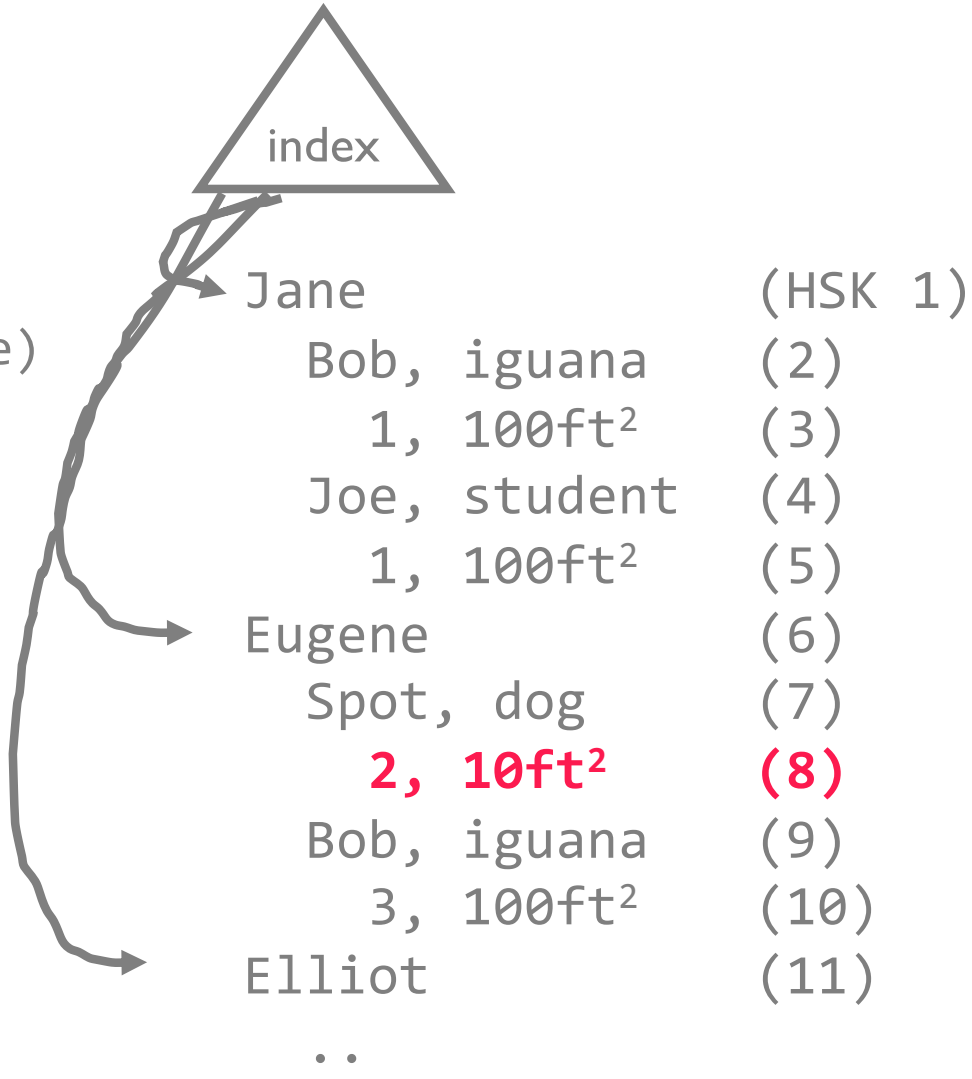
```

Output:

2



Hierarchical "Querying"

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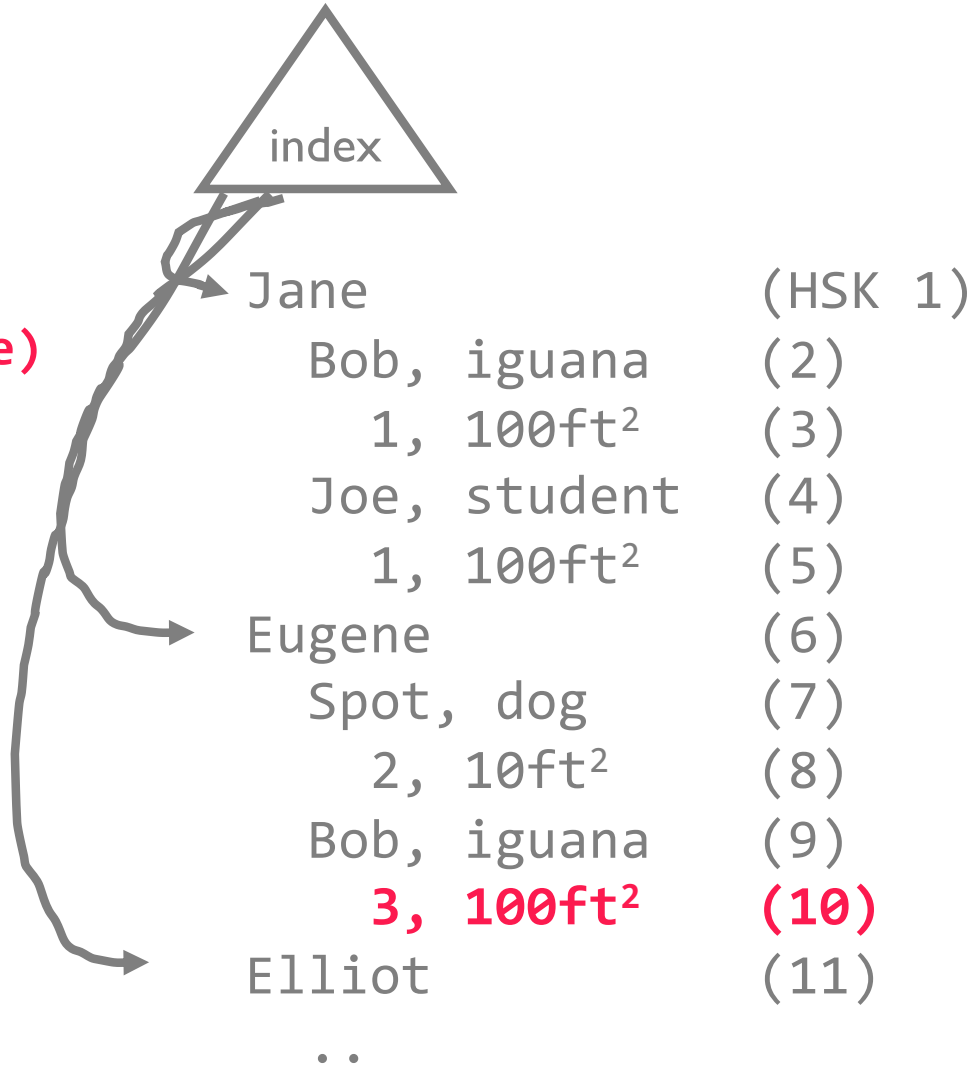
Output:

2



Hierarchical "Querying"

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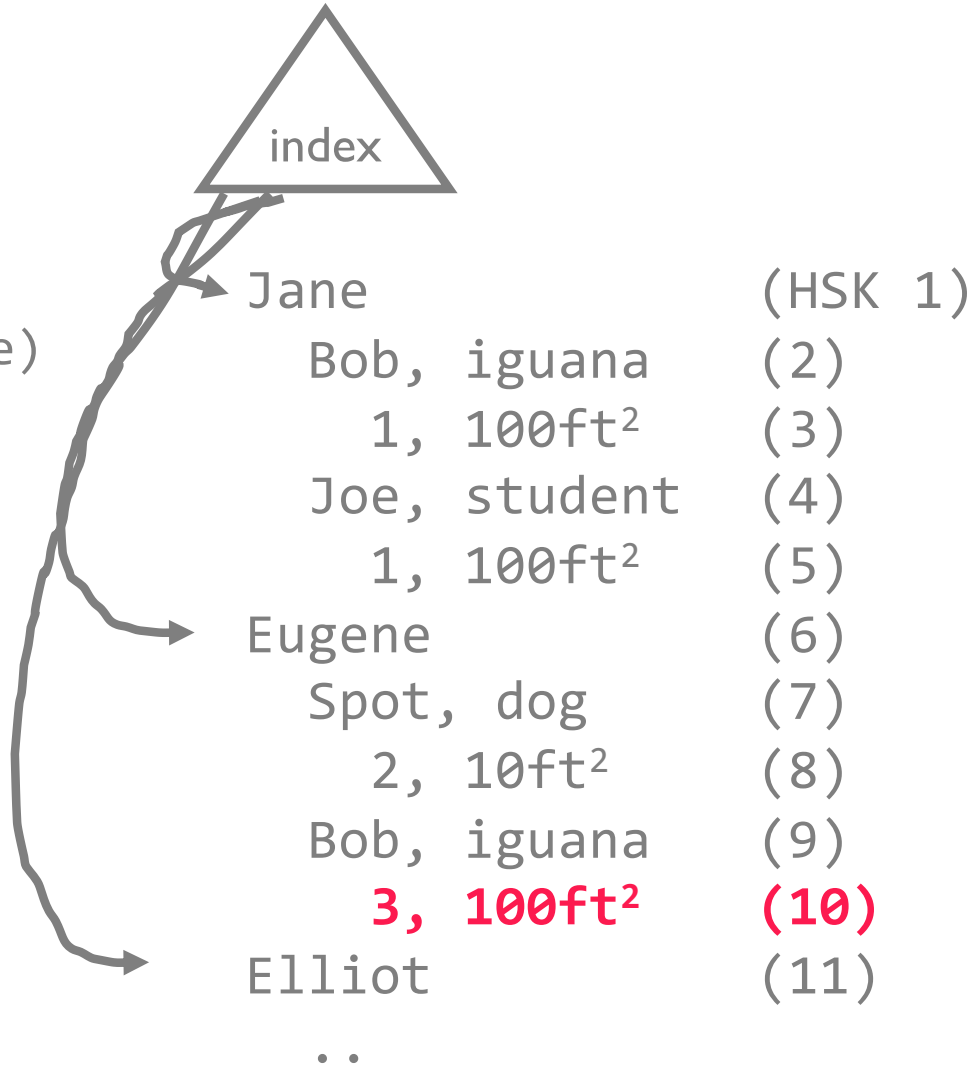
Output:

2

3



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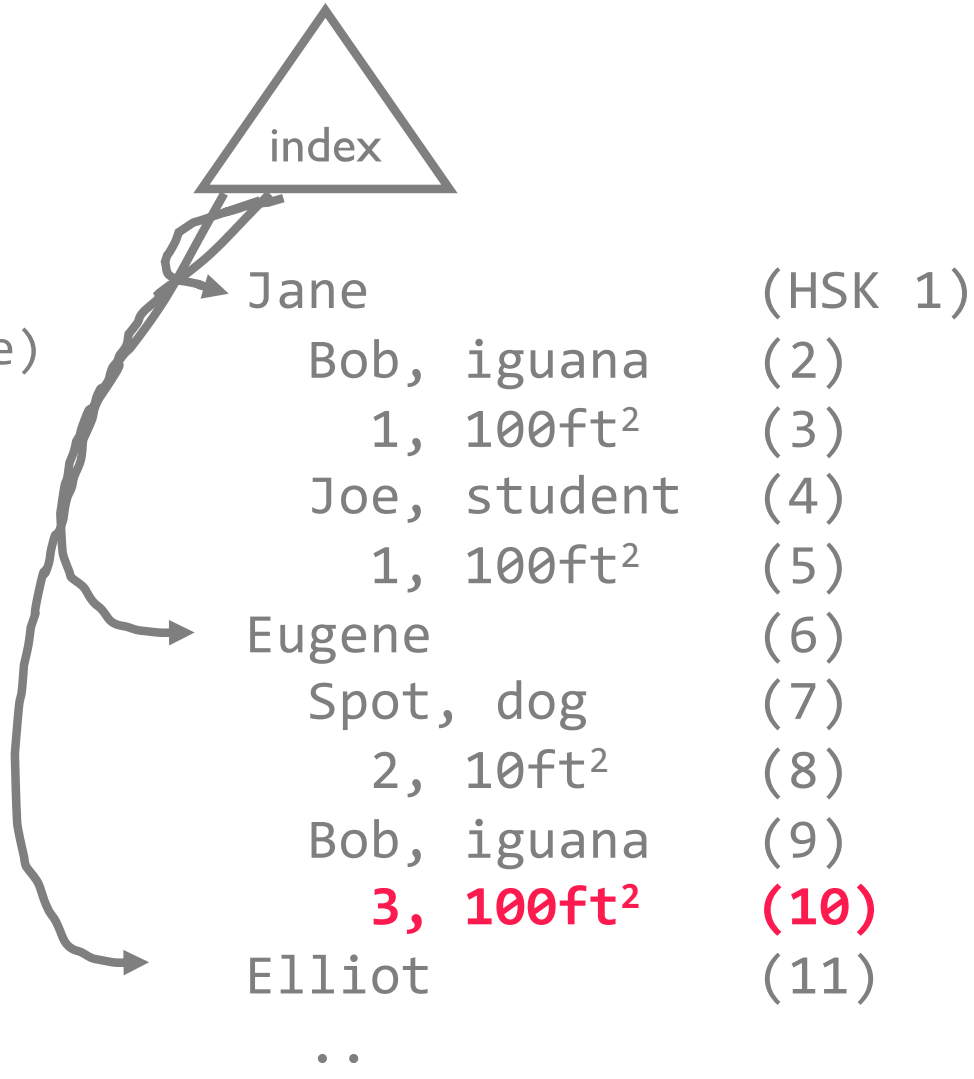

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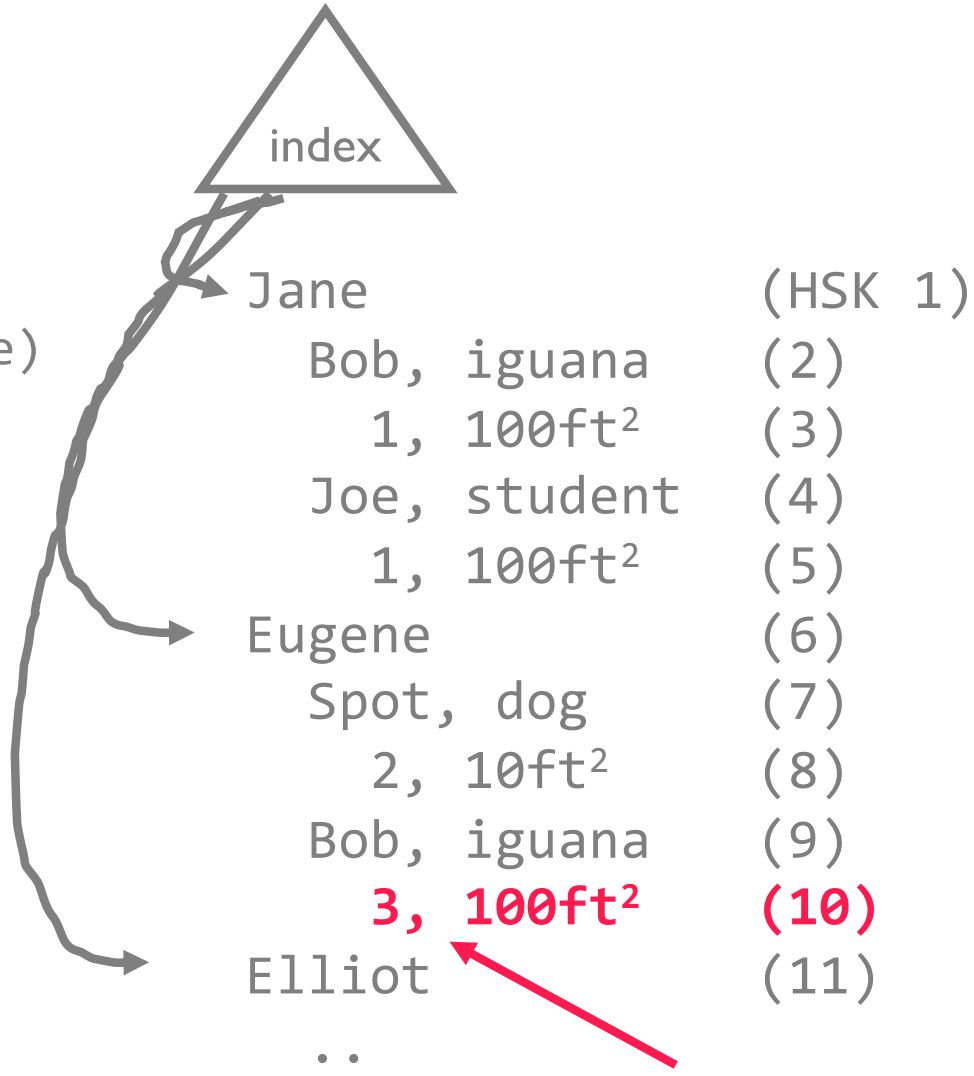
    cage = NextInParent(Cage)
    print cage.no
```

Output:

2

3

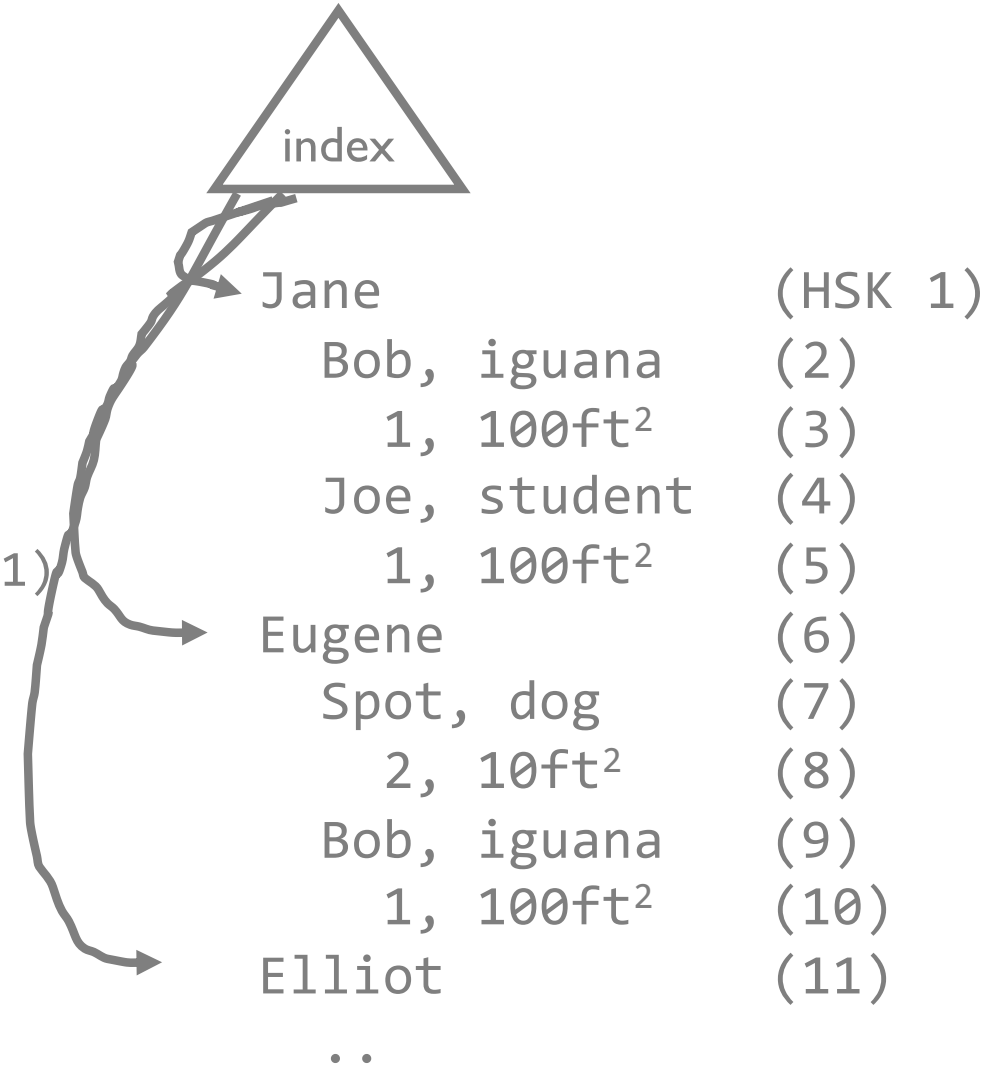


Notice the redundant and inconsistent data

Hierarchical "Querying"

Find Keepers of Cage 1

```
keeper = Goto(Keeper)
NextInParent(Cages, no=1)
print keeper
Until no more records
    keeper = Next(Keeper)
    NextInParent(Cages, no=1)
    print keeper
```



Problems

- Duplicates data
- Low level programming interface
- Almost no physical data independence
  - Change root from tree to hash index causes programs with GN on root to *fail*
  - Inserts into sequential root structures disallowed
- Lacks logical data independence
  - Changing schema requires changing program

Violates many desirable properties
of a proper DBMS

More Problems

Schema changes require program changes because pointers after `GetNext()` calls now different

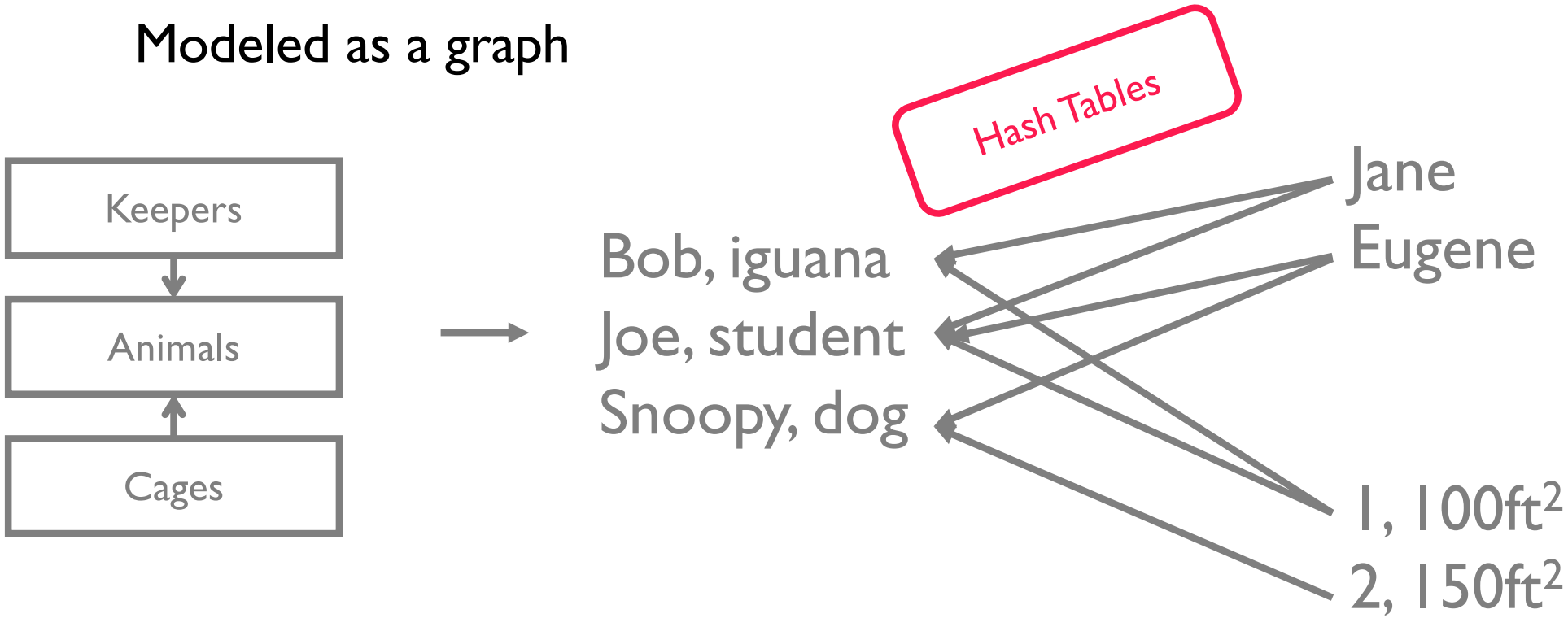
But…schemas change all the time

- Keepers now responsible for a whole cage
- Hummingbirds require multiple feedings
- Merge with another zoo

Network Models (CODASYL, 1969)

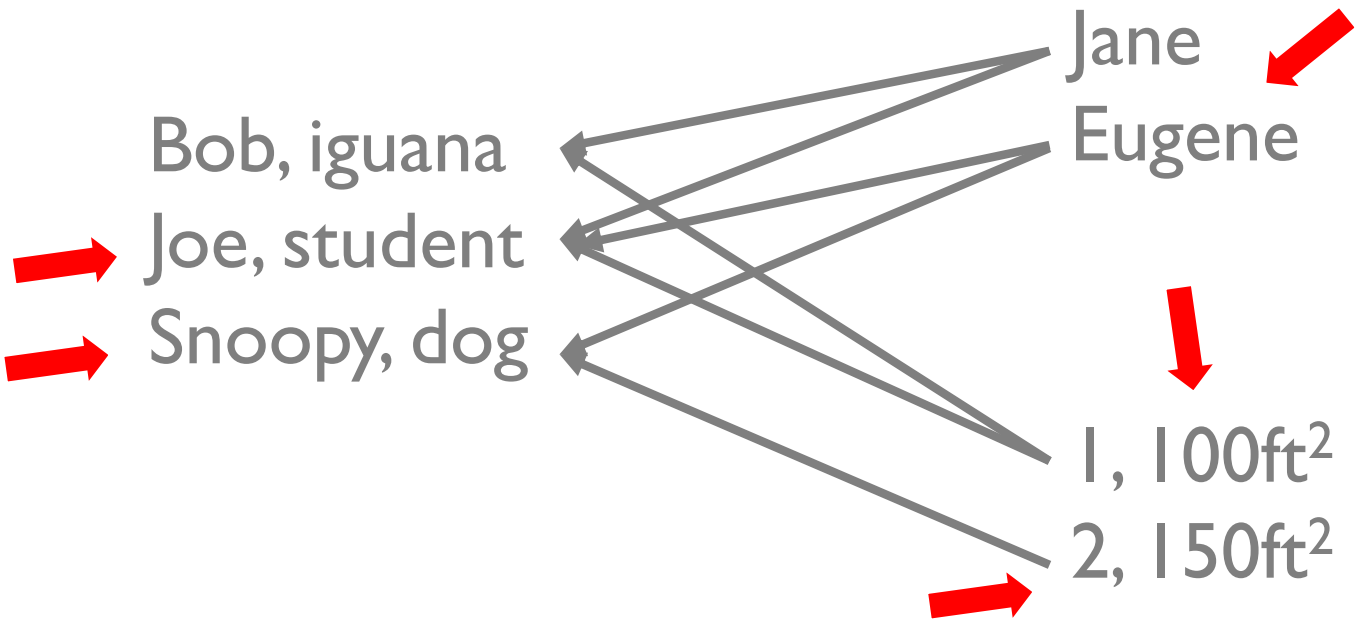
Abstraction

- Types of Records
- Connected by named sets (1-to-N relationships)
- Modeled as a graph



Network Models (CODASYL, 1969)

```
Find Keeper (name = 'Eugene')
until no more
   Find next Animal in cares_for
   Find Cage in lives_in
   Get current record
```



Network Models: Problems

Very complex due to navigational programming

(hard to hire these programmers!)

No data independence

Poor implementations e.g., main memory only

Bad trade off: increased programmer pain in order to model non-hierarchical data

Relational Model (1970)

Ted Codd, 1970

Reaction to CODASYL

Key properties

1. simple representation
2. set oriented model
3. no physical data model needed

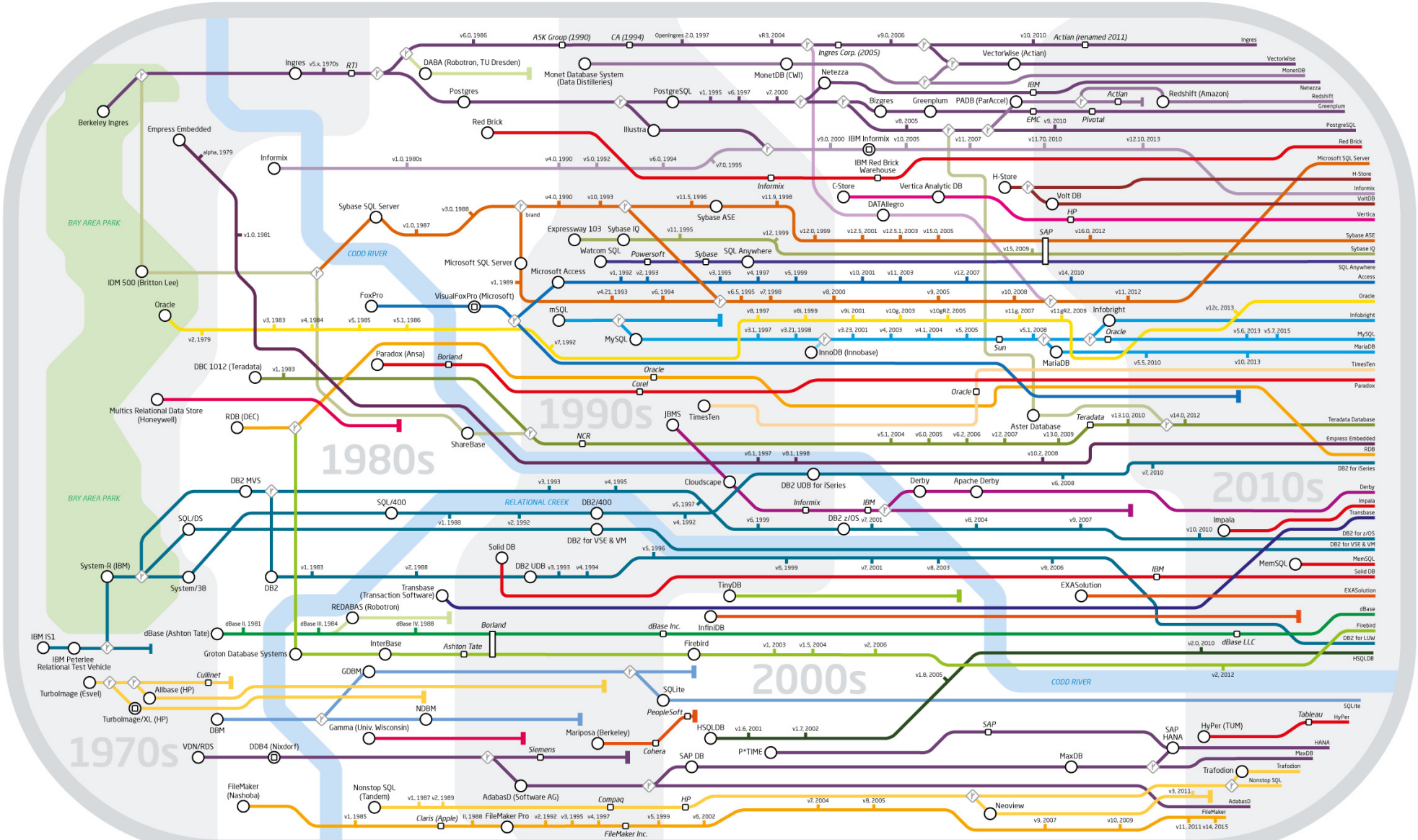
A Relational Model of Data for Large Shared Data Banks

E. F. Codd
IBM Research Laboratory, San Jose, California

Future users of large data banks must be protected from having to know how the data is organized in the machine (the internal representation). A prompting service which supplies such information is not a satisfactory solution. Activities of users at terminals and most application programs should remain unaffected when the internal representation of data is changed and even when some aspects of the external representation are changed. Changes in data representation will often be needed as a result of changes in query, update, and report traffic and natural growth in the types of stored information.

Existing noninferential, formatted data systems provide users with tree-structured files or slightly more general network models of the data. In Section 1, inadequacies of these models

Genealogy of Relational Database Management Systems



HPI Hasso Plattner Institut
Digital Engineering · Universität Potsdam

Key to lines and symbols

DBMS name (Company) | *Acquisition* | v9, 2006 Versions | Discontinued | Branch (intellectual and/or code) | Crossing lines have no special semantics

Felix Naumann, Jana Bauckmann, Claudia Exeler, Jan-Peer Rudolph, Fabian Tschirschnitz
Contact - Hasso Plattner Institut, University of Potsdam, felix.naumann@hpi.de
Design - Alexander Sandt Grafik-Design, Hamburg

Version 6.0 - October 2018
https://hpi.de/naumann/projects/rdbms-genealogy.html

Franck Pachot @FranckPachot · Sep 10

Replying to @MongoDB

Real friends will patiently explain to n00b friends why relational model was invented. #consistency #security #abstraction #encapsulation #normalization #joins #multi-purpose model.
seas.upenn.edu/~zives/03f/cis…

Future users of large data banks must be protected from having to know how the data is organized in the machine (the internal representation). A prompting service which supplies such information is not a satisfactory solution. Activities of users at terminals and most application programs should remain unaffected when the internal representation of data is changed and even when some aspects of the external representation are changed. Changes in data representation will often be needed as a result of changes in query, update, and report traffic and natural growth in the types of stored information.

Existing noninferential, formatted data systems provide users with tree-structured files or slightly more general network models of the data. In Section 1, inadequacies of these models are discussed. A model based on *n*-ary relations, a normal

Roadmap

History lesson

DDLs: Data definition language

Create schemas and constraints

DMLs: Data Manipulation Language Selection
Select, insert, delete, update data

ER → Relational Model

Theory: Relational Model

Relation defined by schema and contains set of tuples

Schema: relation name and **ordered list** of (attribute,type) pairs

an attribute/column

sid	name	login	age	gpa
1	eugene	ewu@cs	20	2.5
2	luis	luis@cs	20	3.5
3	ken	ken@cs	33	3.9

tuples: value for each attribute

Theory: Relational Model

Relation defined by schema and contains set of tuples

students(sid int, name text, login text, age int, gpa float)

an attribute/column

sid	name	login	age	gpa
1	eugene	ewu@cs	20	2.5
2	luis	luis@cs	20	3.5
3	ken	ken@cs	33	3.9

tuples: value for each attribute

Theory: Relational Model

Relation defined by schema and contains set of tuples

Schema is metadata

sid	name	login	age	gpa
1	eugene	ewu@cs	20	2.5
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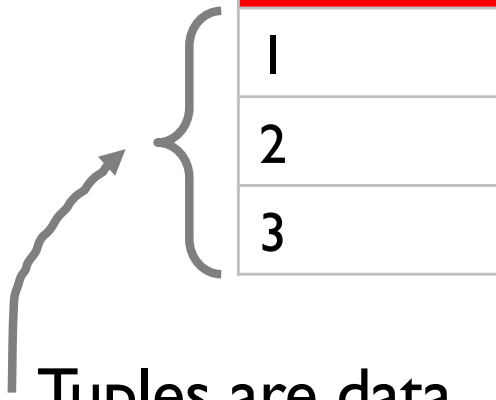
3	ken	ken@cs	33	3.9



Tuples are data

Theory: Relational Model

Relation defined by schema and contains set of tuples

sid	name	login
1	eugene	ewu@cs
2	luis	luis@cs
3	ken	ken@cs

=?

sid	login	name
1	ewu@cs	eugene
2	luis@cs	luis
3	ken@cs	ken

Not Same

Theory: Relational Model

Relation defined by schema and contains set of tuples

"Relation instance": schema and a **set** of specific tuples

unordered, no duplicates

Database set of relations

"Database instance": set of relation instances

relation instance

sid	name	login	age	gpa
1	eugene	ewu@cs	20	2.5
2	luis	luis@cs	20	3.5
3	ken	ken@cs	33	3.9

Can the values of two columns be the same?

Can the values of two rows be the same?

Going Back to the Examples

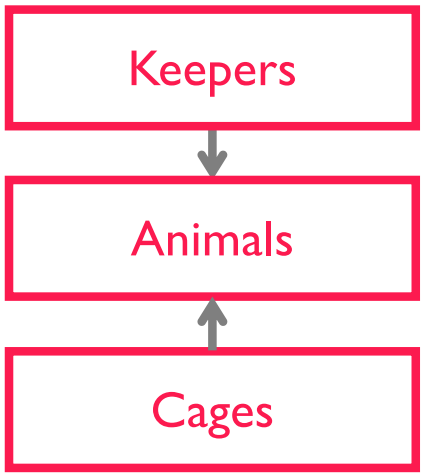
Keepers(id int, name text)

caresfor(keeper_id int, animal_id int)

Animals(id int, name text, species text)

livesin(animal_id int, cage_no)

Cages(no int, size int)



Terminology

Formal Name	Synonyms
Relation	Table
Tuple	Row, Record
Attribute	Column, Field
Domain	Type

Practice

The relational model is set-oriented

In practice, databases allow duplicates (multi-set semantics)

The following slides describe integrity constraints using concrete syntax

DDL: CREATE TABLE

Create the Students Relation

```
CREATE TABLE Students(
    sid int,
    name text,
    login text,
    age int,
    gpa float
)
```

Note: attribute domains are defined & enforced by DBMS

Create the Enrolled relation

```
CREATE TABLE Enrolled(
    sid int,
    cid int,
    grade char(2)
)
```

Integrity Constraints (ICs)

def: a condition that is true for *any* instance of the database

Often specified when defining schema
DBMS enforces ICs at all times

An instance of a relation is legal if it satisfies all declared ICs
Programmer doesn't have to worry about data errors!
    e.g., data entry errors

PostgreSQL documentation great resource
https://www.postgresql.org/docs/current/ddl-constraints.html

Domain Constraints (attr types)

```
CREATE TABLE Students(
    sid int,
    name text,
    login text,
    age int,
    gpa float
)
```

NULL Constraints

```
CREATE TABLE Students(
   sid int NOT NULL,
   name text,
   login text,
   age int,
   gpa float
)
```

Candidate Keys

Set of fields is a *candidate key (or just Key)* for a relation if:

1. No two distinct tuples have same values in all key fields
2. This is untrue if you remove any attribute in the key
3. Key fields cannot be NULL

A set of attributes is a superkey if some subset of its attributes is a key.
What's a trivial superkey?

If >1 candidate keys in relation, developer just picks one as primary key

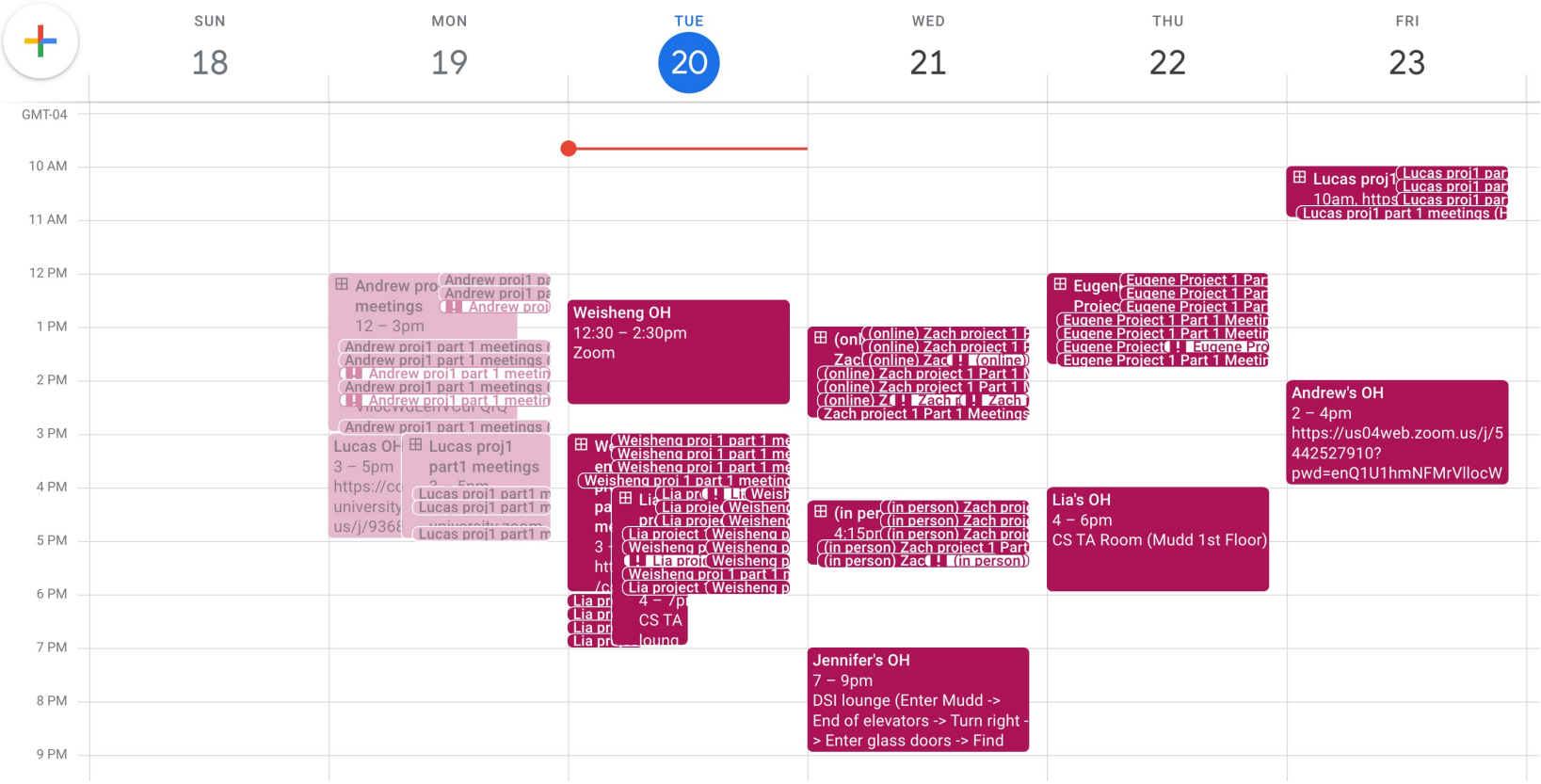
sid is key for Students
is name a key?
what is (sid, gpa)?

Administrivia

HW1 Part 2 out later today.

Project 1 Part 1 meetings this week!!

Will open up more appointment slots.



Primary and Candidate Keys

UNIQUE & PRIMARY KEY key words

Be careful with ICs:

Each student can enroll in a course only once

```
CREATE TABLE Enrolled(
    sid: int,
    cid: int,
    grade: char(2),
    PRIMARY KEY (sid, cid)
)
```

What does this say?

```
CREATE TABLE Enrolled(
    sid: int,
    cid: int,
    grade: char(2),
    PRIMARY KEY (sid),
    UNIQUE (cid, grade)
)
```

Primary and Candidate Keys

UNIQUE + NOT NULL == field is a key

PRIMARY KEY is shorthand for UNIQUE NOT NULL

```
CREATE TABLE Students(
   sid int NOT NULL UNIQUE,
   name text,
   login text,
   age int,
   gpa float,
   PRIMARY KEY (sid)
)
```

Default Candidate Keys

sqlite, duckdb, oracle

`rowid`: "hidden" unique id column

postgreSQL

`ctid`: location of tuple. May change arbitrarily!

Primary Keys IRL

https://twitter.com/jaykreps/status/1302046006679199745?s=20

Foreign Keys

def: set of fields in Relation R_i used to refer to tuple in R_j via R_j's keys (a logical pointer)

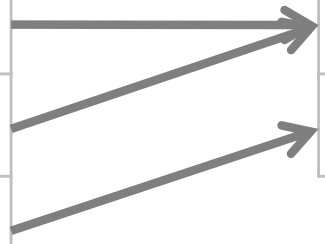
```
CREATE TABLE Enrolled(
    sid: int,  cid: int,  grade: char(2),
    PRIMARY KEY (sid, cid),
    FOREIGN KEY (sid) REFERENCES Students(sid)
)
```

Enrolled

sid	cid	grade
1	2	A
1	3	B
2	2	A+

Students

sid	name
1	eugene
2	luis



Foreign Keys

def: set of fields in Relation R_i used to refer to tuple in R_j via R_j's keys (a logical pointer)

```
CREATE TABLE Donation(
    companyid int,
    classid int,
    amount float,
    PRIMARY KEY(companyid, classid)
)
CREATE TABLE Donation_Admin(
    daid int PRIMARY KEY,
    companyid int,
    classid int,
    FOREIGN KEY (companyid, classid) REFERENCES
                Donation(companyid, classid)
)
```

Referential Integrity

A database instance has *referential integrity* if all foreign key constraints are enforced

no "dangling references"

Examples where referential integrity is not enforced?

- HTML links
- Yellow page listing
- Restaurant menus

CHECK Constraints

Boolean constraint expression added to schema

Very powerful mechanism.

Evaluated over each tuple, rejects tuple if false

```
CREATE TABLE Enrolled(
    sid int,
    cid int,
    grade char(2),
    CHECK (
      grade IN ('A','B','C','D','F')
    )
)
```

How to Enforce Integrity Constraints

Run checks anytime database changes

On INSERT

- What if new Enrolled tuple refers to non-existent student?
  Reject insertion

On DELETE (many options)

- What if Students tuple is deleted?
  - Delete dependent Enrolled tuples
  - Reject deletion
  - Set Enrolled.sid to default value or null
    (null means 'unknown' or 'inapplicable' in SQL)

Where do ICs come from?

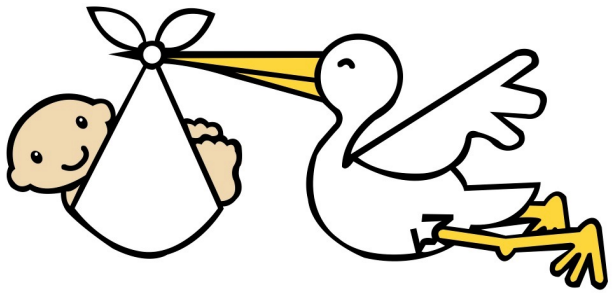
Based on application semantics and use cases

Can check if database instance satisfies ICs

IC is a statement over *all possible instances*

Can't infer ICs by staring at an instance

Key and foreign key ICs are most common, more general table and database constraints possible as well.



(mostly) More Powerful than ER Constraints

Functional dependencies

A dept can't order two distinct parts from the same supplier.

Can't express this wrt ternary Contracts relationship.

Used to further refine ER models (called normalization)

Inclusion dependencies

Special case: ER model can express Foreign keys

At least 1 person must report to each manager.

General constraints

Each donation is less than 10% of the combined donations to all humanities courses. (but can be expensive to enforce)

What Can ER Express?

Key constraints,

participation constraints,

overlap/covering constraints

Some foreign key constraints as part of relationship set

- Some constraints require general CHECK stmts
- ER cannot express e.g., function dependencies at all
- Constraints help determine best database design

Roadmap

History lesson

DDLs: Data definition language
Create schemas and constraints

DMLs: Data Manipulation Language Selection
Select, insert, delete, update data

ER → Relational Model

DML: Introduction to Queries

Key strength of relational model

declarative querying of data

Queries are high level, readable

DBMS makes it fast, user don't need to worry

Precise semantics for relational queries

Lets DBMS choose different ways to run query while ensuring answer is the same

INSERT/DELETE

Add a tuple

```
INSERT INTO Students(sid, name, login, age, gpa)
VALUES (4, ‘wu’, ‘wu@cs’, 20, 5)
```

Delete tuples satisfying a predicate (condition)

```
DELETE FROM Students S
WHERE S.name = ‘wu’
```

Boolean predicate

Bulk Imports

varies by database system, read their docs

Postgresql

```
COPY into Students
FROM ‘/users/ewu/students.csv’ WITH CSV
```

SQLite

```
.mode csv
.import /users/ewu/students.csv Students
```

DuckDB

```
CREATE TABLE Students AS
SELECT * FROM read_csv_auto(‘/users/ewu/students.csv’)
```

Basic SELECT

Get all attributes of students younger than 21

```
SELECT *
FROM Students S
WHERE S.age < 21
```

Get only names

```
SELECT S.name
FROM Students S
WHERE S.age < 21
```

sid	name	login	age	gpa
1	eugene	ewu@cs	20	2.5
2	luis	luis@cs	20	3.5
3	ken	ken@math	33	3.9

Single Table Semantics

A *conceptual evaluation method* for previous query:

```
for row in Students                  // FROM clause
  if predicate(row):                 // WHERE clause
    emit desired fields              // SELECT clause
```

Actual evaluation will be *much* more efficient, but must produce the same answers.

Multi-table SELECT

What does this return?

```
SELECT S.name, E.cid
FROM Students S, Enrolled E
WHERE S.sid = E.sid AND
      E.grade = “A”
```

Enrolled

sid	cid	grade
1	2	A
1	3	B
2	2	A+

Students

sid	name
1	eugene
2	luis

Result

name	cid
eugene	2

Multi-Table Semantics

Modify the FROM clause evaluation

1. FROM clause: compute *cross-product* of Students and Enrolled

Enrolled

sid	cid	grade
1	2	A
1	3	B
2	2	A+

Students

sid	name
1	eugene
2	luis

Cross-product

sid	cid	grade	sid	name
1	2	A	1	eugene
1	3	B	1	eugene
2	2	A+	1	eugene
1	2	A	2	luis
1	3	B	2	luis
2	2	A+	2	luis

Multi-Table Semantics

Modify the FROM clause evaluation

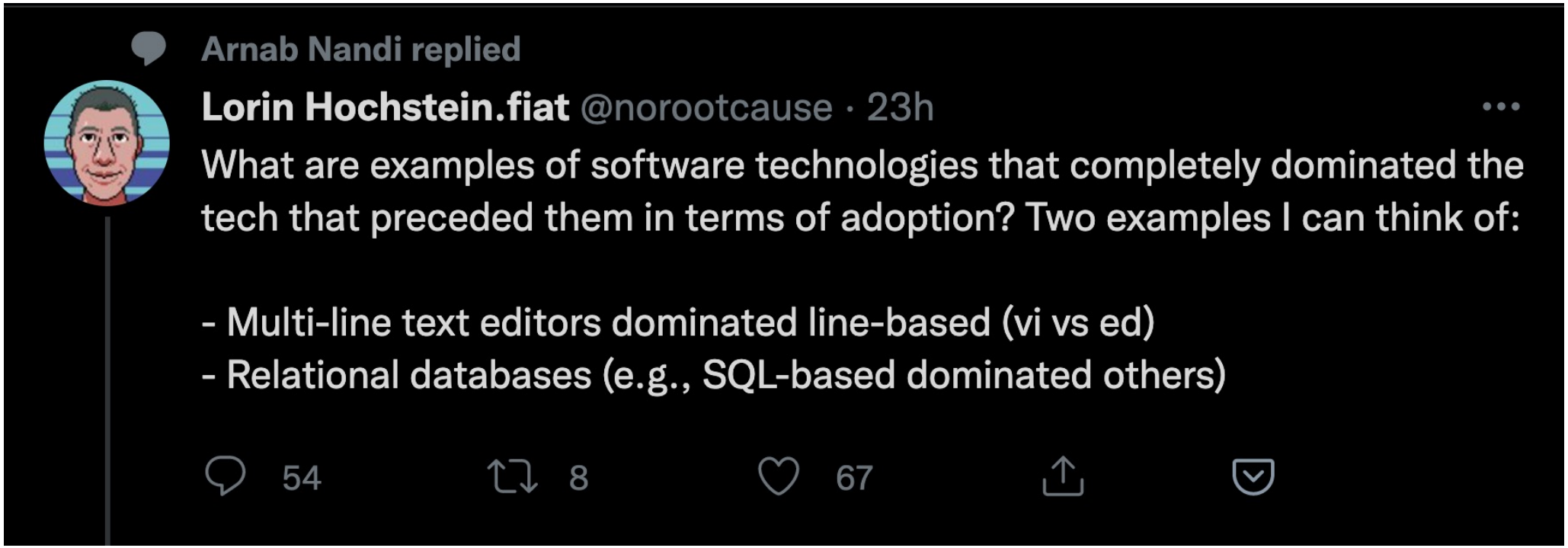
1. FROM clause: compute *cross-product* of Students and Enrolled
2. WHERE clause: check conditions, discard tuples that fail
3. SELECT clause: keep desired fields

Multi-Table Semantics

```
SELECT a1, a2, a3
FROM A, B, C
WHERE A.a1 = B.b1
```

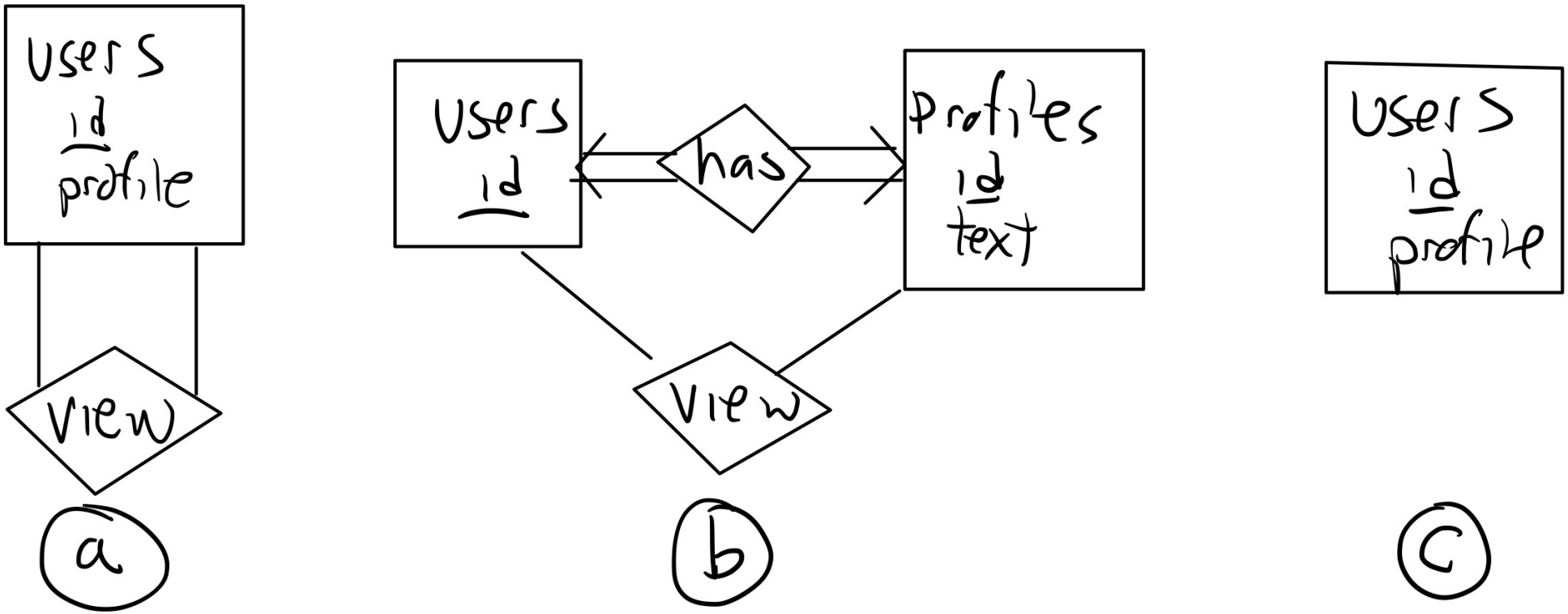
```
for row1 in A
  for row2 in B
    for row3 in C
      if (row1.a1 == row2.b1) {
          yield [row1.a1, row1.a2, row1.a3]
       }
```

Databases are Great



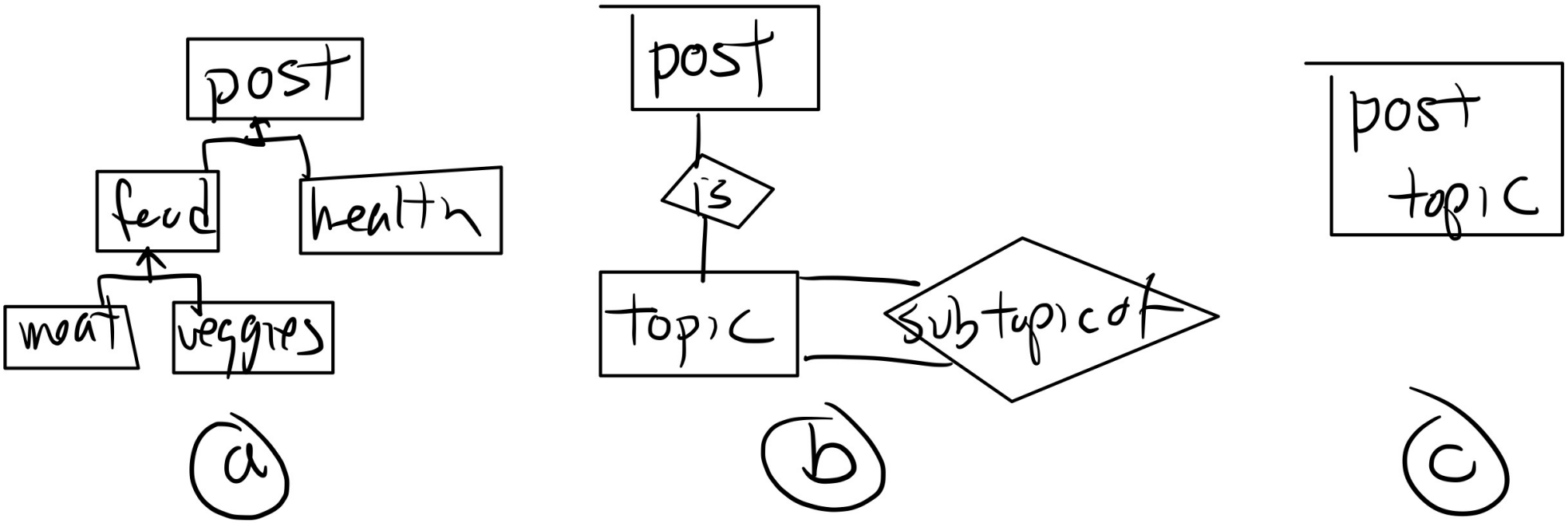
http://w4111.github.io/quiz.html

The applications lets **users view** the **profiles** of other **users**



http://w4111.github.io/quiz

A **post** can be about **food or health** and under **food** it can be about **meat** or **veggies**



http://w4111.github.io/quiz

A user can **enroll** in at most one course.

What should be the constraints?

```
CREATE TABLE enrolls(
  userid int REFERENCES users(id),
  courseid int REFERENCES courses(id),
  term int
)
```

(A)

```
PRIMARY KEY (userid,
             coursed)
```

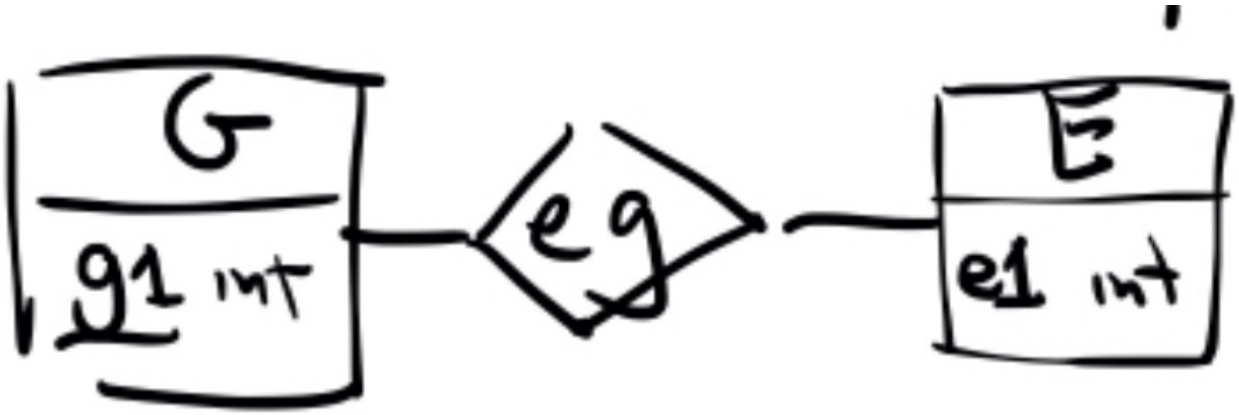
(B)

```
UNIQUE (userid)
NOT NULL userid
```

(C)

```
UNIQUE(userid)
NOT NULL userid
NOT NULL coursed
```

Wu's Clues



Template: G have a relationship with E called eg

Courses have a relationship with Courses called prereq

Users have a relationship with Tickets called purchased

Courses are prereqs of other Courses

Users purchase Tickets

Translating ER → Relational Models

Approach:

Does ER version allow and reject everything that the Relational Model's version allows and rejects?

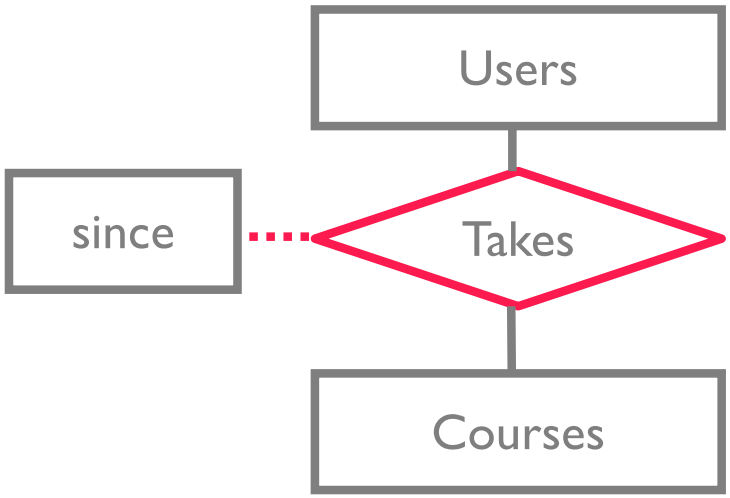
Entity Set → Relation


```
CREATE TABLE Course(
   cid int,
   name text,
   loc text,
   PRIMARY KEY (cid)
)
```

Relationship Set w/out constraint → Relation

Relation must include

- Keys for each entity set as foreign keys
  - these form superkey for relation
- All attributes of the relationship set

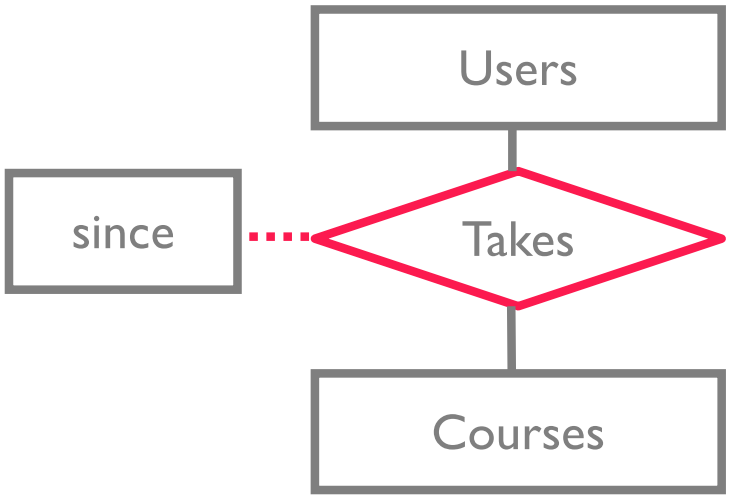



```
CREATE TABLE Takes(
    uid int,
    cid int,
    since date,
    PRIMARY KEY (uid, cid),
    FOREIGN KEY (uid) REFERENCES Users,
    FOREIGN KEY (cid) REFERENCES Courses
)
```

Relationship Set w/out constraint → Relation

Relation must include

- Keys for each entity set as foreign keys
  - these form superkey for relation
- All attributes of the relationship set



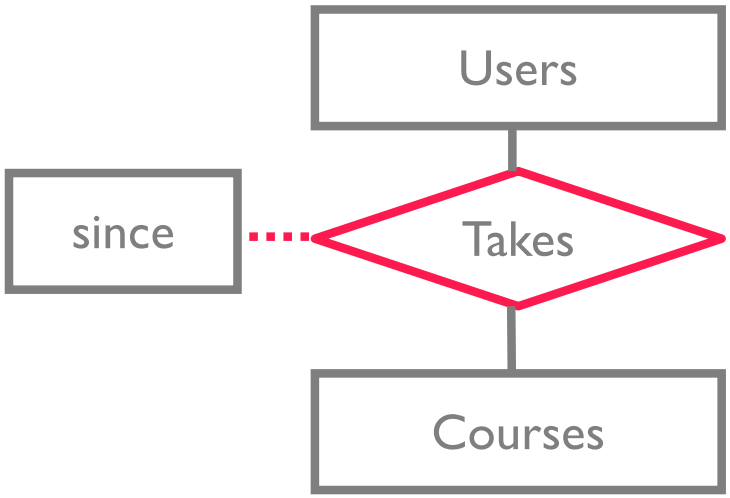

```
CREATE TABLE Takes(
    uid int REFERENCES Users(uid),
    cid int REFERENCES Courses(cid),
    since date,
    PRIMARY KEY (uid, cid)
)
```

Short hand

Relationship Set w/out constraint → Relation

Relation must include

- Keys for each entity set as foreign keys
  - these form superkey for relation
- All attributes of the relationship set



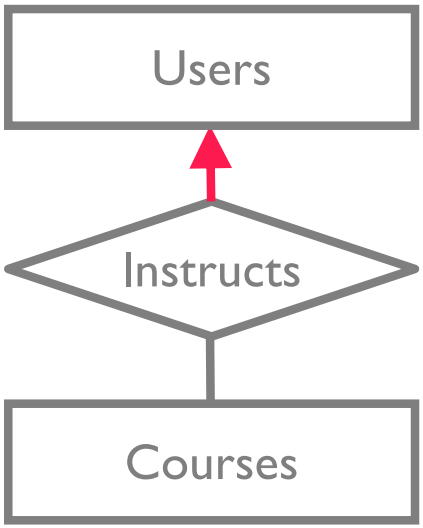

```
CREATE TABLE Takes(
    uid int REFERENCES Users,
    cid int REFERENCES Courses
    since date,
    PRIMARY KEY (uid, cid)
)
```

Shorter hand if
attribute names the same

Key Constraint → Relation

User and Courses are separate relations

Note only cid is a Key… why not UNIQUE(uid, cid)?

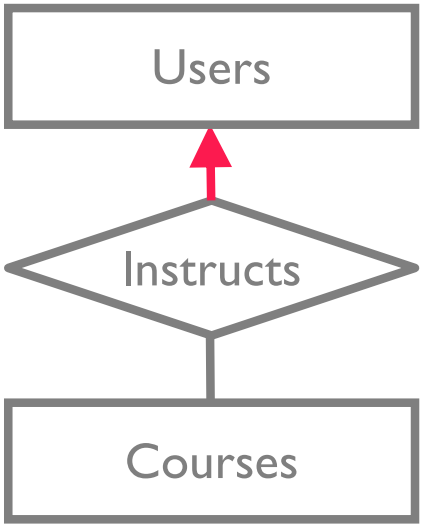



```
CREATE TABLE Instructs(
    uid int NOT NULL,
    cid int,
    PRIMARY KEY (cid),
    FOREIGN KEY (uid) REFERENCES Users,
    FOREIGN KEY (cid) REFERENCES Courses
)
```

Key Constraint → Relation

Alternatively combine Courses and Instructs

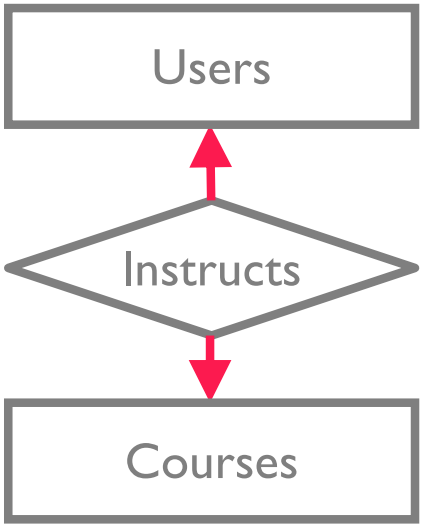
(this is the preferred way)




```
CREATE TABLE Course_Instructs(
    cid int
    uid int,
    name text,     // attr from Courses
    loc text,      // attr from Courses
    PRIMARY KEY (cid),
    FOREIGN KEY (uid) REFERENCES Users
)
```

Key Constraint → Relation

How to translate this ER diagram?

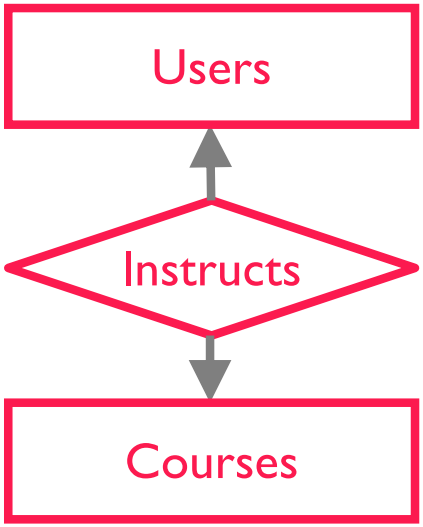



```
CREATE TABLE Course_Instructs(
    ????
)
```

Key Constraint → Relation

Translation 0.5 (wrong!)

Merge Courses and Instructs

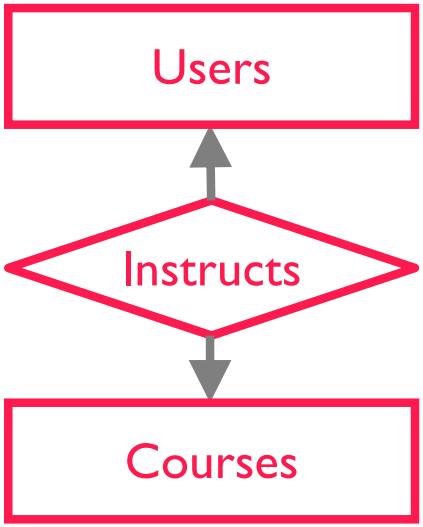



```
CREATE TABLE Course_Instructs(
  cid int
  … courses attributes …
  uid int REFERENCES Users
  PRIMARY KEY (cid)
  PRIMARY KEY (uid)
)
// course cannot have 0 users
// cannot have 2 primary keys
```

Key Constraint → Relation

Translation 1 (wrong!)

Merge Courses and Instructs

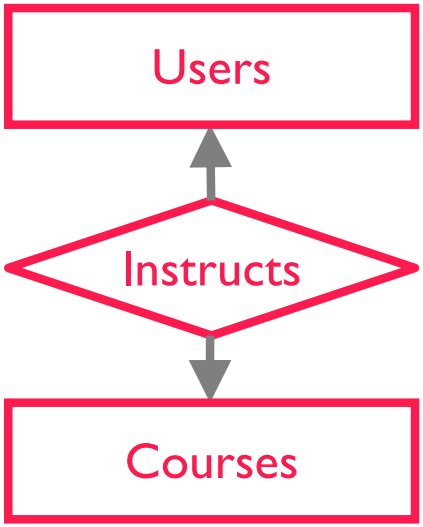



```
CREATE TABLE Course_Instructs(
  cid int
  … courses attributes …
  uid int UNIQUE NOT NULL REFERENCES Users
  PRIMARY KEY (cid)
)
// course cannot have 0 users
```

Key Constraint → Relation

Translation 1.5 (correct)

Merge Courses and Instructs



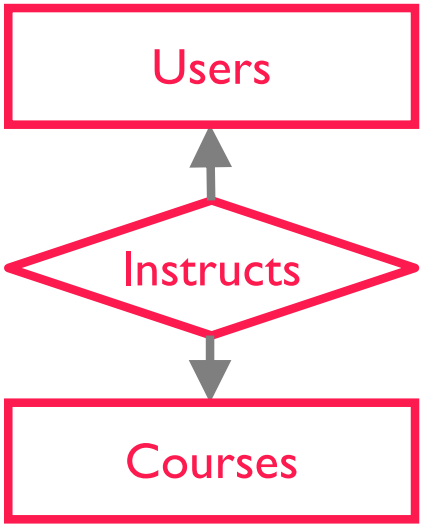

```
CREATE TABLE Course_Instructs(
  cid int PRIMARY KEY,
  … courses attributes …
  uid int UNIQUE REFERENCES Users
)
// course can have 0 users or 1 users
// user can have 0 or 1 course
```

Key Constraint → Relation

Mixing together many attrs can get messy

Translation 2.

Merge all three relations.

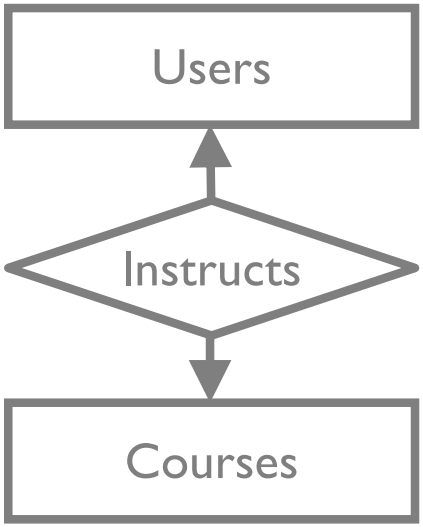



```
CREATE TABLE Course_Instructs_Users(
    cid int
    uid int,
    … courses attributes …
    … users attributes …
    CHECK (cid NOT NULL OR uid NOT NULL)
    UNIQUE uid,
    UNIQUE cid
)
```

Key Constraint → Relation

Translation 3.

Keep all three relations.



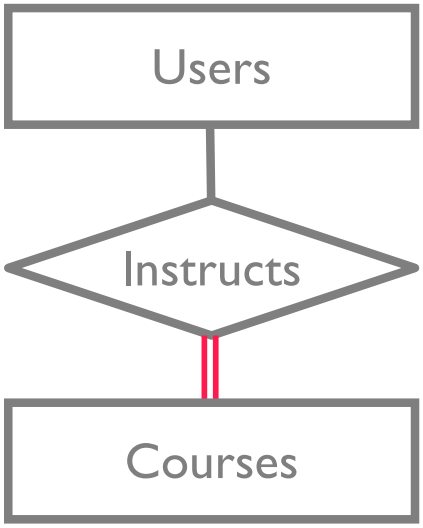

```
CREATE TABLE courses(cid, ...)
CREATE TABLE users(uid, ...)

CREATE TABLE instructs(
  uid int UNIQUE NOT NULL REFERENCES users,
  cid int UNIQUE NOT NULL REFERENCES courses,
  PRIMARY KEY (uid, cid)
)
```

IF there is a relationship, it must satisfy constraints in instructs

Participation Constraint → Relation

We only consider participation constraints with one entity set in binary relationship (others need CHECK constraint)



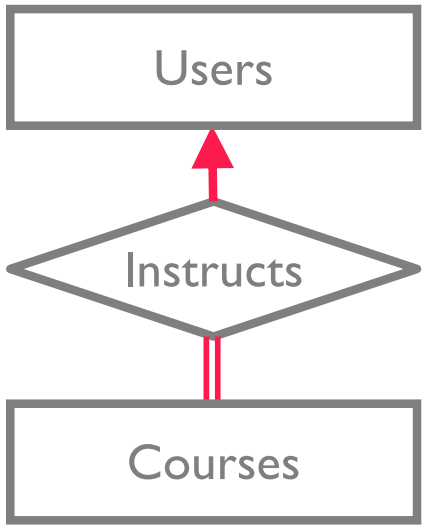

```
CREATE TABLE Course_Instructs(
    cid int
    uid int NOT NULL,
    … courses attributes …
    PRIMARY KEY (cid),
    FOREIGN KEY (uid) REFERENCES Users
        ON DELETE NO ACTION
)
```

Not a fully correct translation. Why?

Participation Constraint → Relation

Actually expresses exactly 1 relationship

Can't express total participation without at-most-one because no way to "force" a relationship tuple to exist.

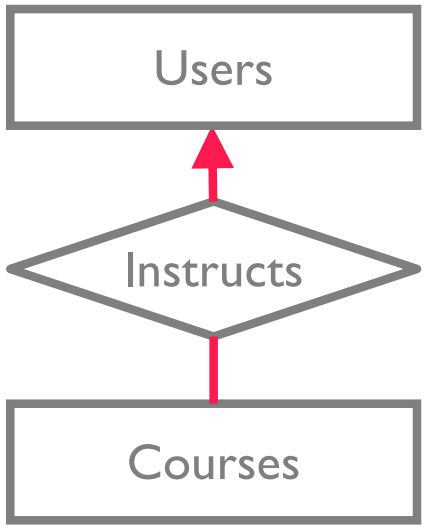



```
CREATE TABLE Course_Instructs(
    cid int
    uid int NOT NULL,
    … courses attributes …
    PRIMARY KEY (cid),
    FOREIGN KEY (uid) REFERENCES Users
        ON DELETE NO ACTION
)
```

Participation Constraint → Relation

Using 3 tables enforces "0 or 1" relationships

Can't express total participation without at-most-one because no way to "force" a relationship tuple to exist.




```
CREATE TABLE Course()
CREATE TABLE Users()

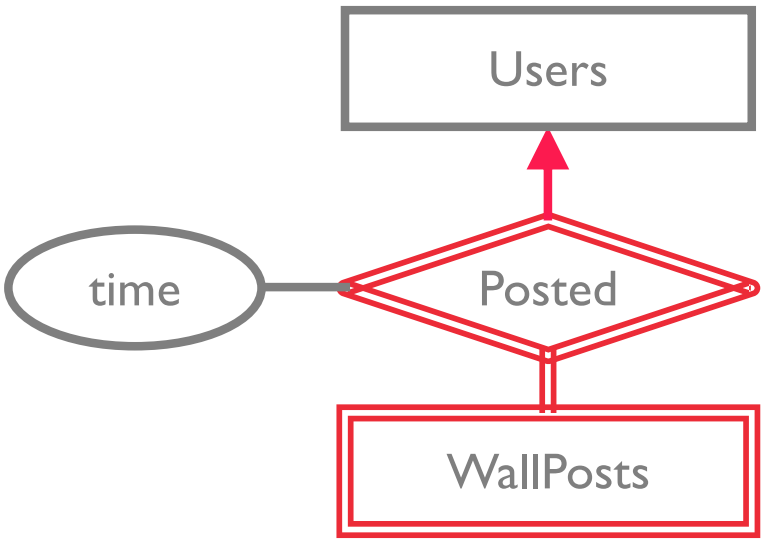
CREATE TABLE Instructs(
    cid int REFERENCES Course,
    uid int REFERENCES Users,
    NOT NULL uid,
    PRIMARY KEY (cid)
)
```

Weak Entity → Relation

Weak entity set and identifying relationship set are translated into a single table.

When owner entity is deleted, all owned weak entities also deleted.

post_title in this example is a partial key: it alone does not identify a given wall post! For example, if each user's first wall post is given post_title 1, then post_title does not uniquely identify a wall post since another user's first post may also be post_title = 1



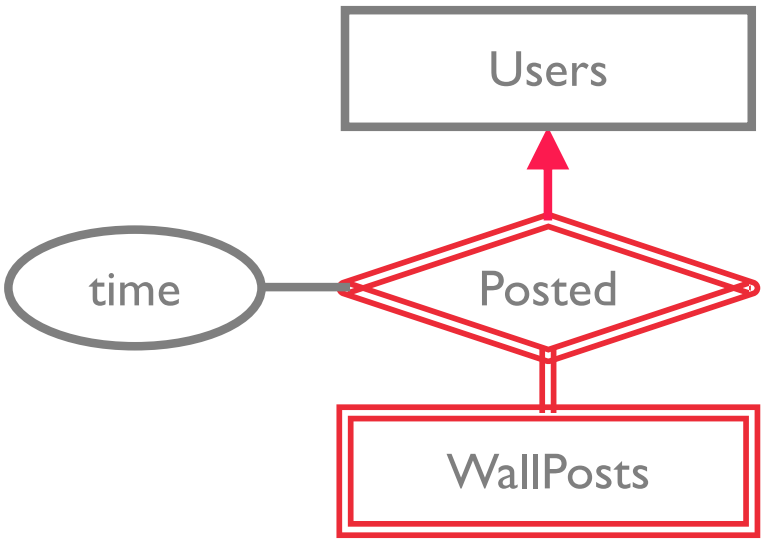

```
CREATE TABLE WallPosts_Posted(
    post_title text,  // partial key
    post_text text,
    time DATE,
    uid int,
    PRIMARY KEY (post_title, uid),
    FOREIGN KEY (uid) REFERENCES Users
        ON DELETE CASCADE
)
```

Weak Entity → Relation

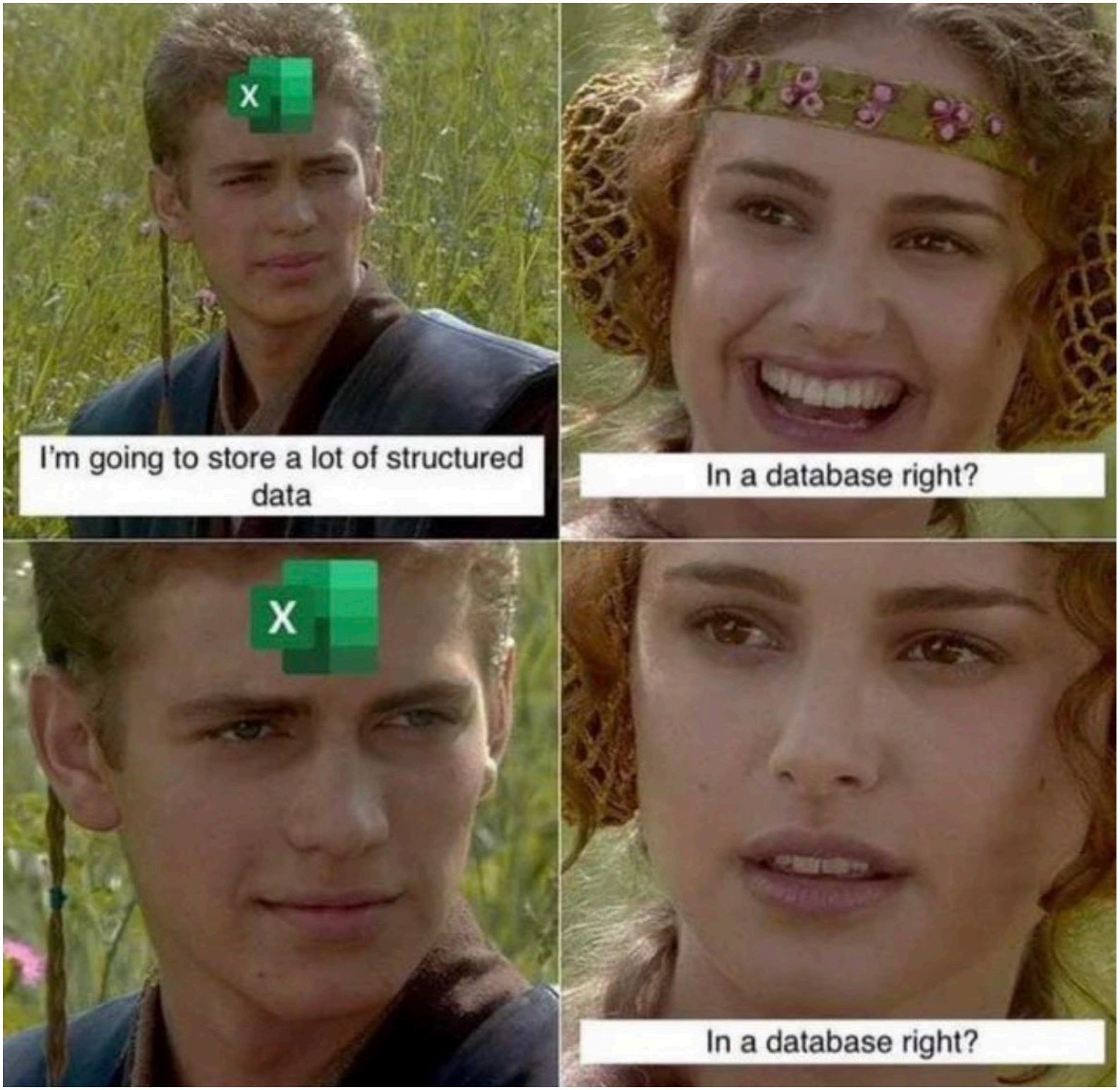
Weak entity set and identifying relationship set are translated into a single table.

When owner entity is deleted, all owned weak entities also deleted.

In practice, easy to make an auto incrementing id that is unique, so the primary key could simply be pid. In PostgreSQL, specified as `serial`. In this case we still need the `ON DELETE CASCADE`.




```
CREATE TABLE Wall_Posted(
    pid int serial,
     post_title text,
    post_text text,
    time DATE,
    uid int NOT NULL,
    PRIMARY KEY (pid),
    FOREIGN KEY (uid) REFERENCES Users
        ON DELETE CASCADE
)
```


I'm going to store a lot of structured data
In a database right?
In a database right?

Specialization Hierarchies

Option 1: Keep parent relation

- B and C's attributes stored in A

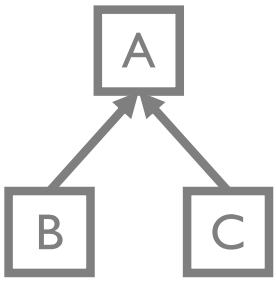
Option 2: Keep parent and child relations

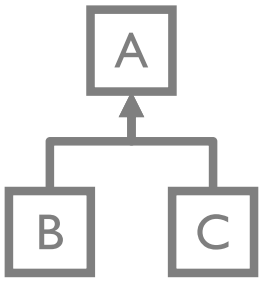
- A stores only attributes of A
- B and C store their own attributes
- JOIN between child and base relations for all attributes

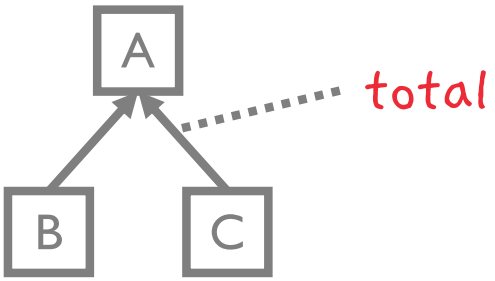
Option 3: Only keep child relations

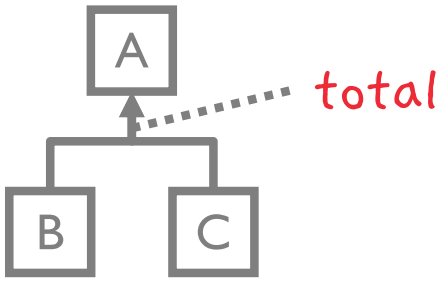
- B and C have copies of A's attributes

} Only under total specialization!









Specialization Hierarchies

Each option has its own trade-offs in terms of

- what constraints it can express
- how complex the resulting schema is

The following examples focus on the main translation designs (number of relations).

Other constraints such as keys, not null, etc should still be considered

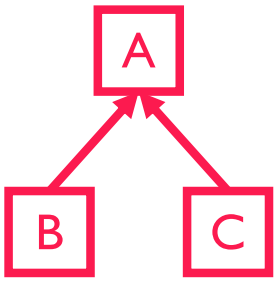
Analyze the consistency of a translation by

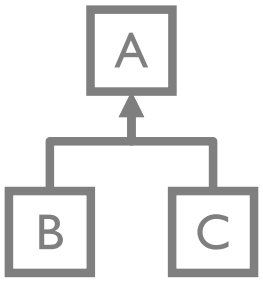
- adding records in the relations and seeing if they are allowed by the ER diagram,
- studying records that the relations disallow and if they are disallowed in the ER diagram
- and vice versa

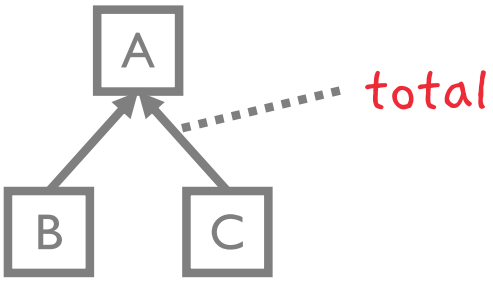
Specialization Hierarchies: Option 1

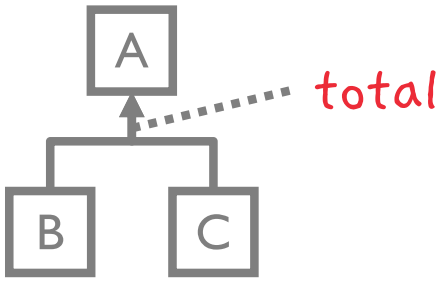
```
A(a int PRIMARY KEY, name text)
B(b int PRIMARY KEY, a int NOT NULL REFERENCES A)
C(c int PRIMARY KEY, a int NOT NULL REFERENCES A)
```

Supports overlap = true, total = no





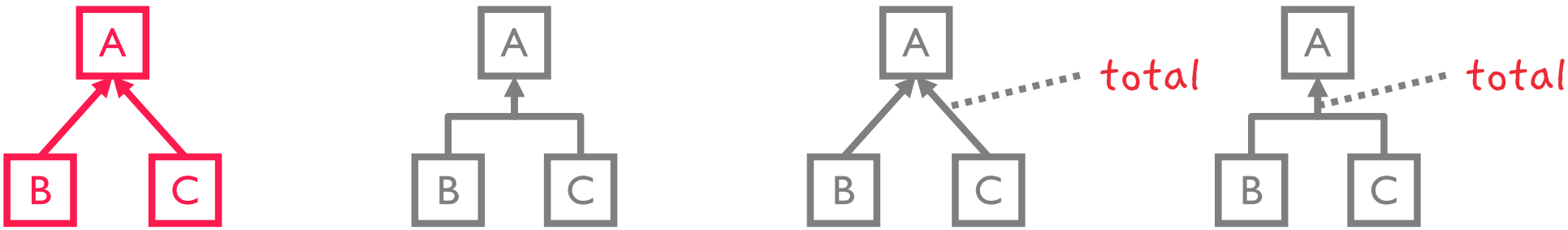




Specialization Hierarchies: Option 1

```
A(
  a int PRIMARY KEY,
  name text,
  b int,
  c int
)
```

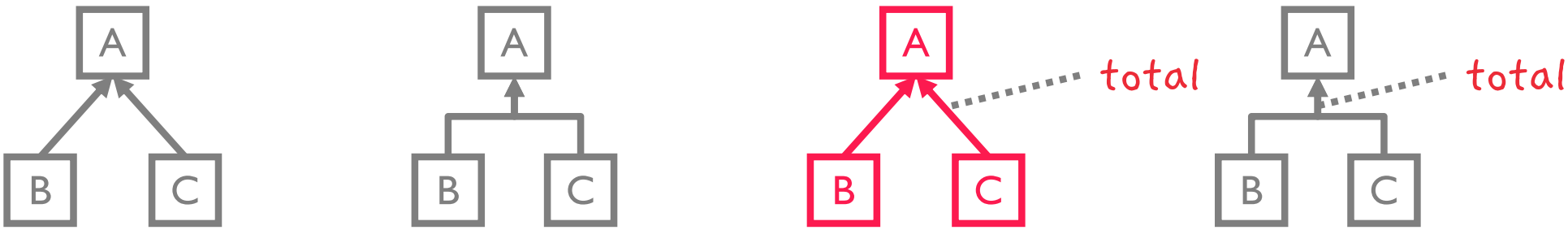
Supports overlap = true, total = no



Specialization Hierarchies: Option 2

```
B(id int PRIMARY KEY, name text)
C(id int PRIMARY KEY, name text)
```

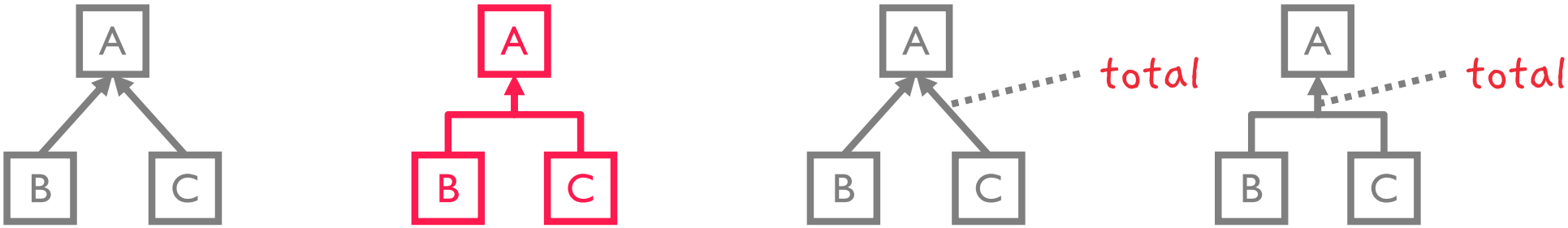
Enforces total specialization.
Cant' have relationship with As in general



Specialization Hierarchies: Option 3

```
A(
  a int PRIMARY KEY,
  name text,
  b int,
  c int,
  CHECK (not (b is not null and c is not null))
)
```

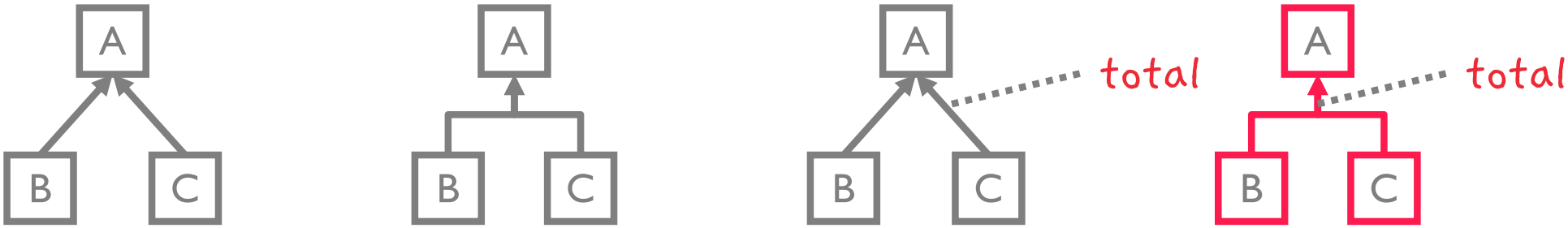
Supports overlap = no, total = no



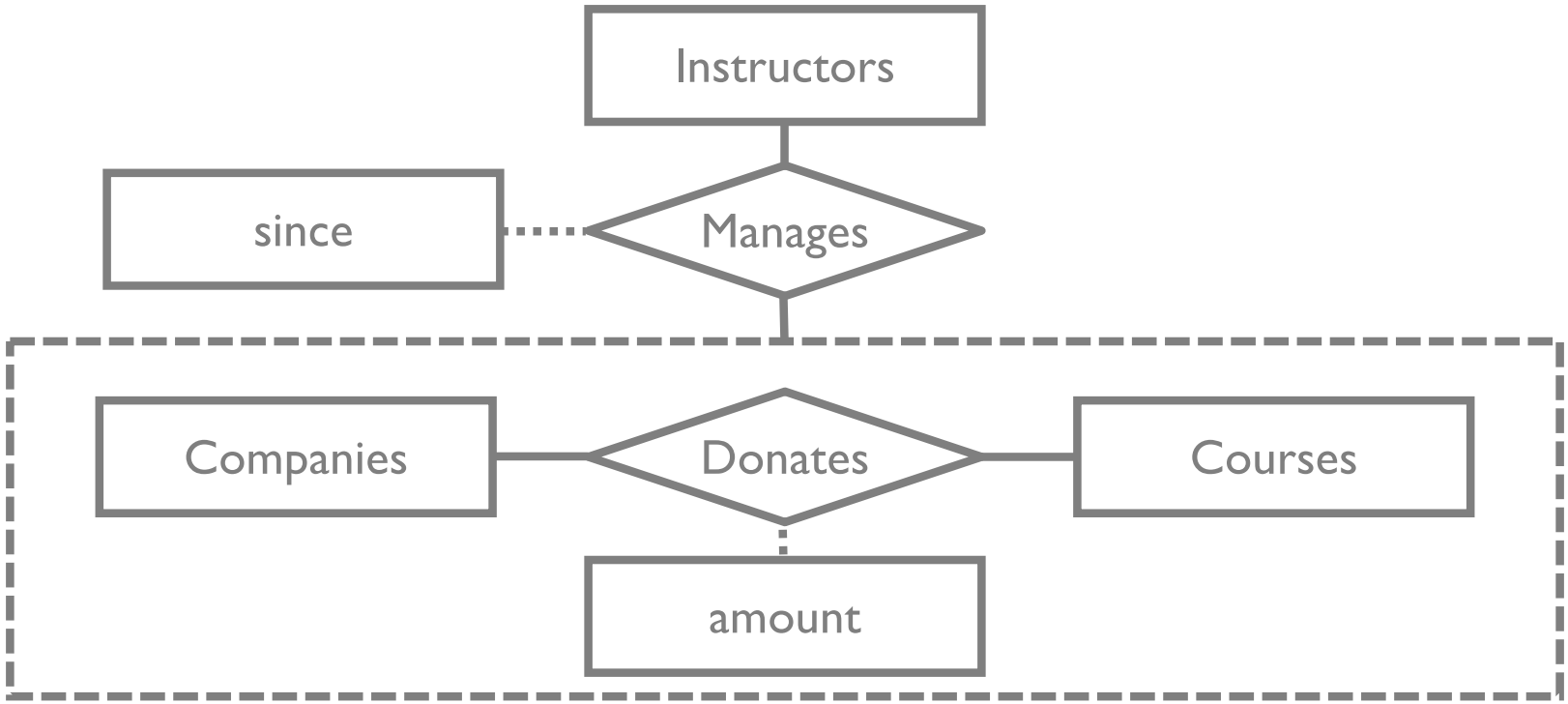
Specialization Hierarchies: Option 4

```
A(
  a int PRIMARY KEY,
  name text,
  b int,
  c int,
  CHECK (b is null or c is null) and
        (b is not null or c is not null)
)
```

Supports overlap = no, total = yes

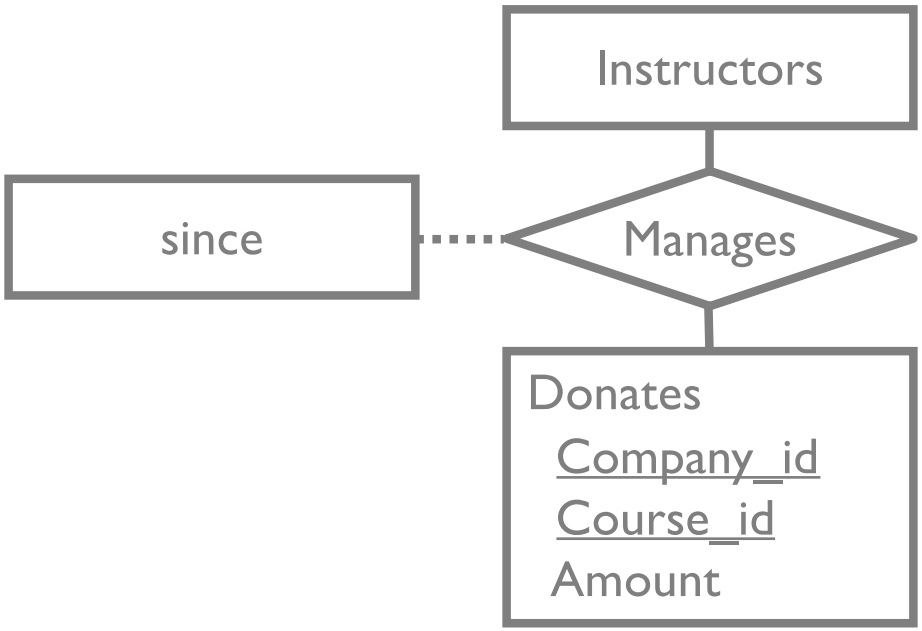


Aggregation



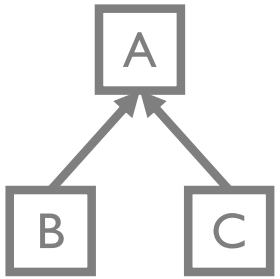
Aggregation

However you translate the donates relationship set is the table you use to model the relationship with instructors.

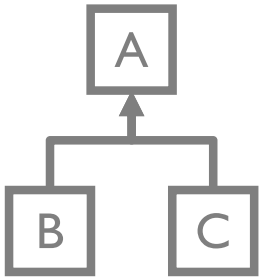


w4111.github.io/quiz.html

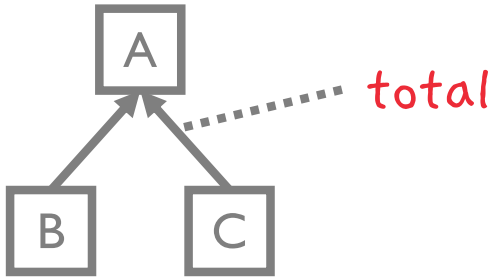
```
A(a int PRIMARY KEY, name text)
B(b int PRIMARY KEY, a int REFERENCES A)
C(c int PRIMARY KEY, a int REFERENCES A)
```



(a)



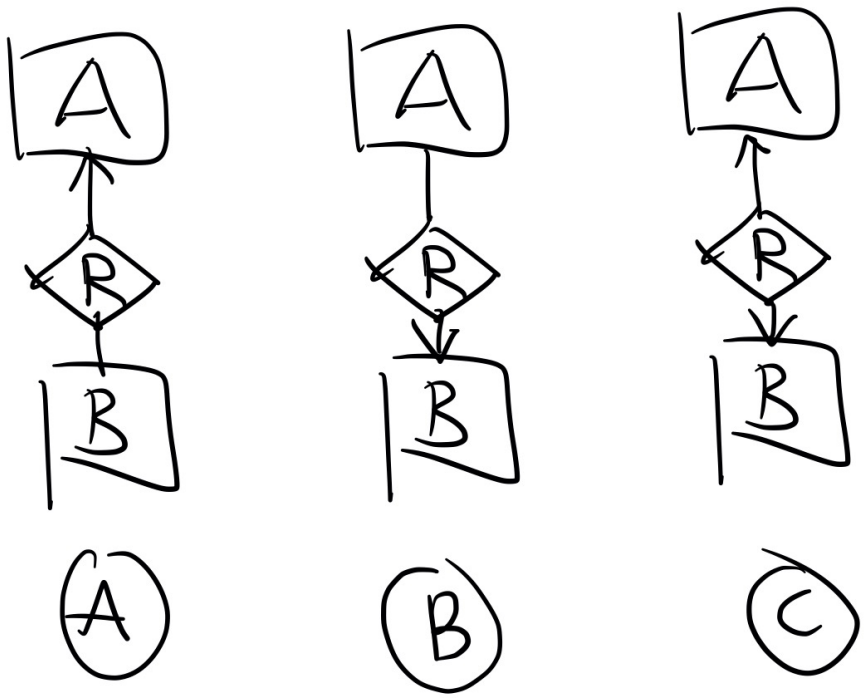
(b)



(c)

w4111.github.io/quiz.html

```
CREATE TABLE R(
   aid int primary key,
   bid int references B(bid)
)
```



w4111.github.io/quiz.html

A(id, a) contains 10 rows
B(id, b) contains 10 rows
How many rows *can* the following query return?

```
SELECT A.id, B.id FROM A, B
 WHERE A.a = B.b
```

0 to 10	10	0 to 100
(a)	(b)	(c)

w4111.github.io/quiz

A(id, a) contains 10 rows

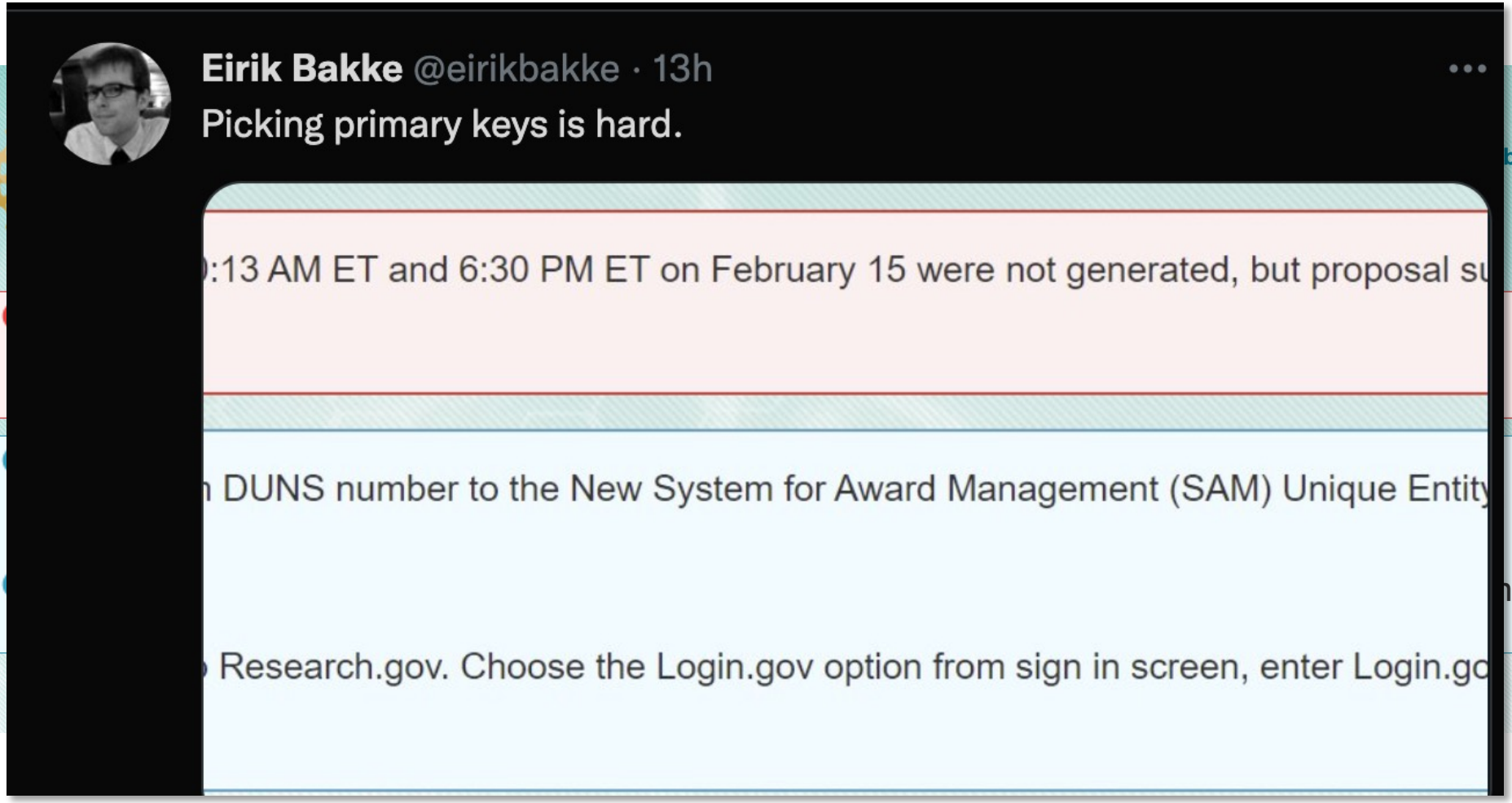
B(id, b) contains 10 rows

How many rows *can* the following query return?

```
SELECT A.id, B.id FROM A, B WHERE A.id = B.id
```

Between 0 and 10	10	Between 0 and 100
(a)	(b)	(c)

Is this class really relevant?


Eirik Bakke @eirikbakke · 13h
Picking primary keys is hard.
:13 AM ET and 6:30 PM ET on February 15 were not generated, but proposal su
DUNS number to the New System for Award Management (SAM) Unique Entity
Research.gov. Choose the Login.gov option from sign in screen, enter Login.go

great_expectations

♡ COMMUNITY EXPECTATIONS DOCUMENTATION CASE STUDIES BLOG

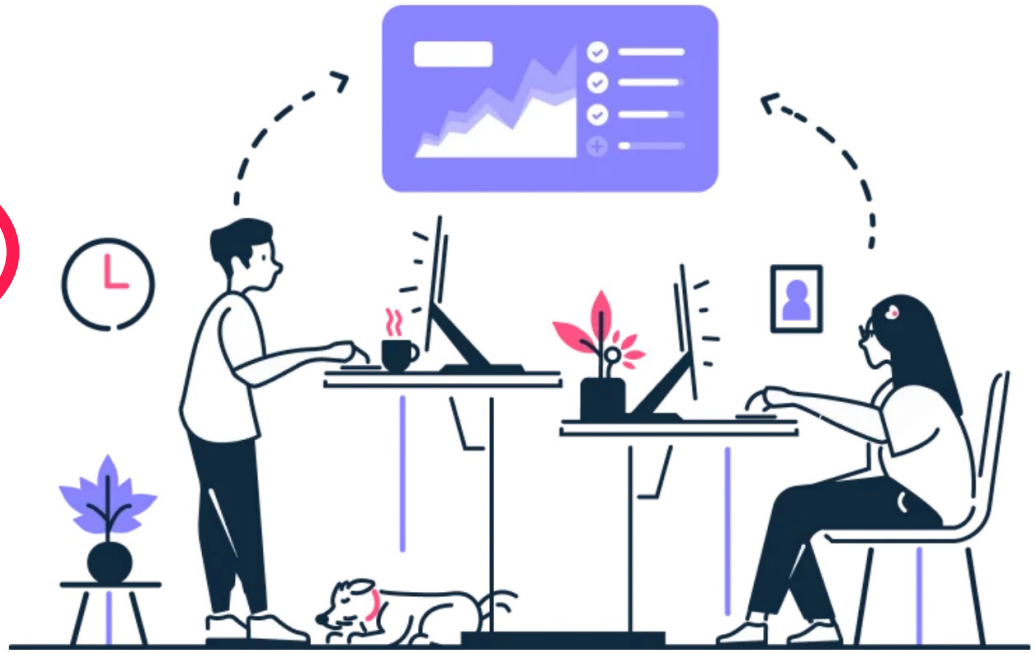
Greetings! We now have a cloud offering Learn More

Welcome to Great Expectations

Always know what to expect from your data

Great Expectations is a shared, open standard for data quality. It helps data teams eliminate pipeline debt, through data testing, documentation, and profiling.

JOIN OUR SLACK!



What is an Expectation?

An Expectation is a statement describing a verifiable property of data. Like assertions in traditional Python unit tests, Expectations provide a flexible, declarative language for describing expected behavior. Unlike traditional unit tests, Great Expectations applies Expectations to data instead of code.

Great Expectations' built-in library includes more than 50 c
Expectations, such as:

- `expect_column_values_to_not_be_null`
- `expect_column_values_to_match_regex`
- `expect_column_values_to_be_unique`
- `expect_column_values_to_match_strftime_format`
- `expect_table_row_count_to_be_between`
- `expect_column_median_to_be_between`

Oh. These are integrity constraints

Recap

Relational Data Model Recap

Relation: schema, contains set of tuples

Schema: list of attribute, type pairs

Keys and integrity constraints

Foreign-key References

Schema

Tuples

sid	name	age	gpa
1	eugene	20	2.5
2	luis	20	3.5
3	ken	33	3.9

Cell

Other Popular Data Models

Matrix

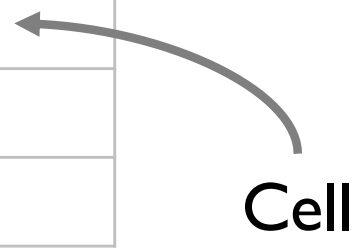
TYPE is a field (+, * obey "usual algebra")

Rows and Cols are ordered and indexed, not named

Values can be missing.

Lots of missing values is "sparse". Else dense

TYPE	1	…	n
1			
…			
m			



Other Popular Data Models

Matrix: expressible as relation?

```
Matrix(
  i int, j int,
  v TYPE,
  primary key (i, j)
)
```

TYPE	1	…	n
1			
…			
m			

Other Popular Data Models

Relation expressible as matrix?

- ML expects matrices.
- Turn attribute types into field (e.g., a number)
- Hot-one encoding, featurization

sid	name	age	gpa
1	eugene	20	2.5
2	luis	20	3.5
3	ken	33	3.9

Other Popular Data Models

Value

TYPE	1
1	

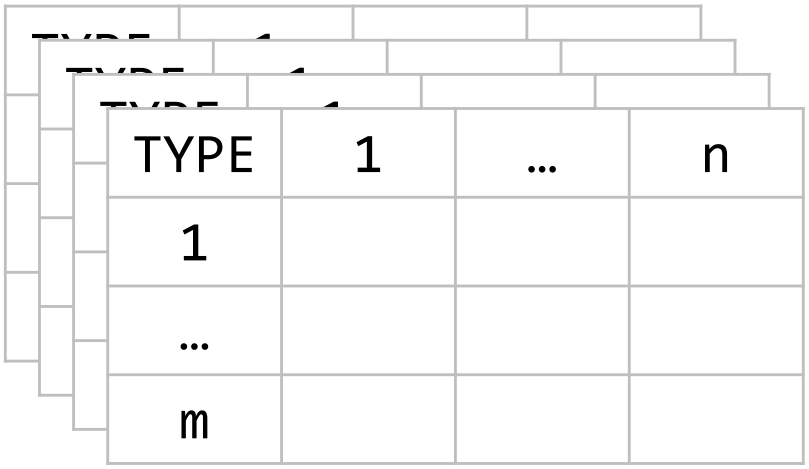
Vector

TYPE	1	2	…	n
1				

Matrix

TYPE	1	…	n
1			
…			
m			

Tensor



Other Popular Data Models

Pandas/R data frame

- only columns have types
- rows and cols are ordered and named
- less mathematically grounded

	$name_1$	$name_2$	…	$name_n$
	$type_1$	$type_2$	…	$type_n$
$name_1$				
…				
$name_m$				

REVIEW OF ER AND RELATIONAL

ER Overview

- Ternary relationships
- Relationships constraints
  - At most one
  - At least one
  - Exactly one
  - Weak entities
- Aggregation
- Is-A

Relational Review

Relations ~= Sets

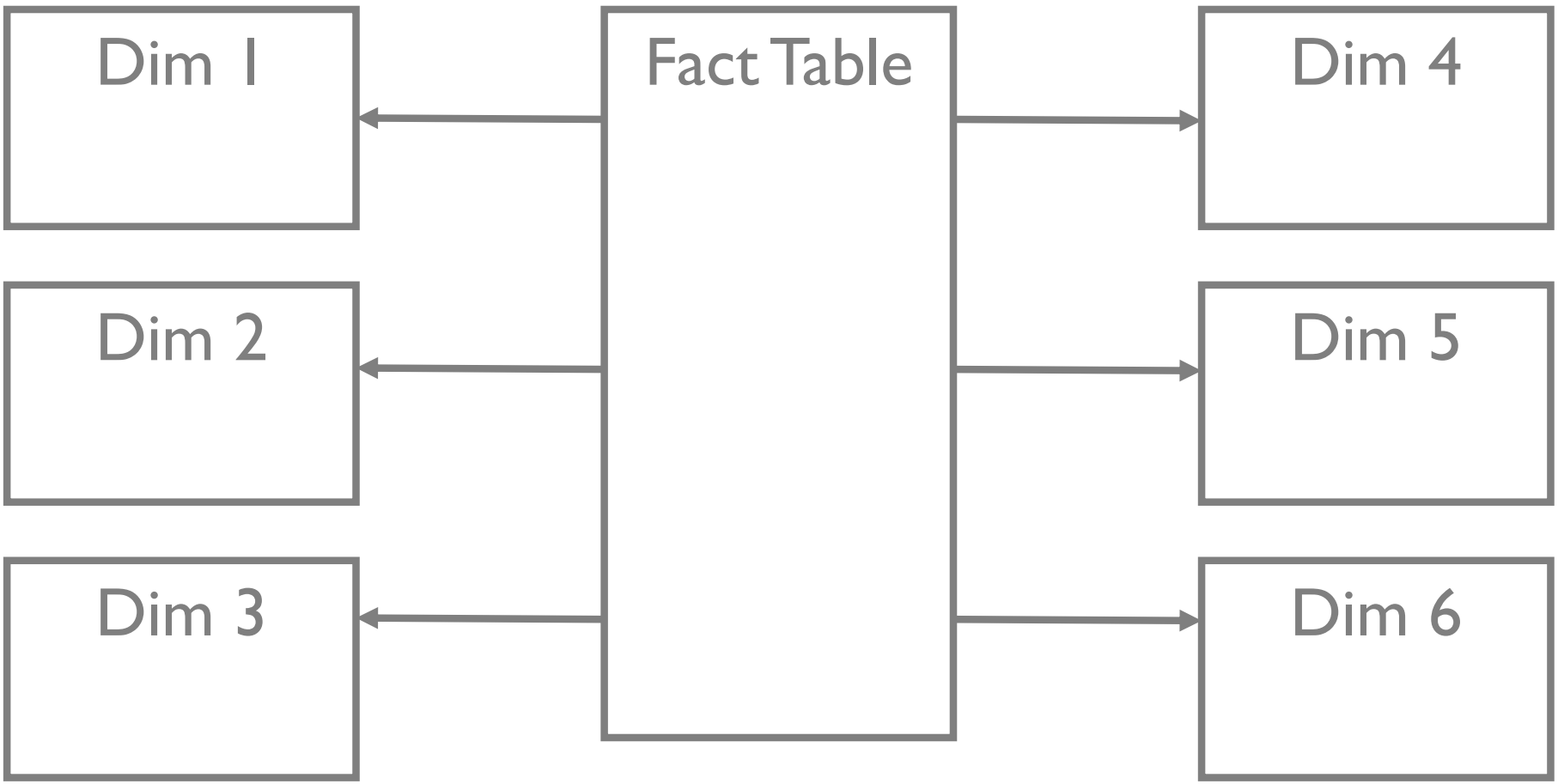
- Schema = structure // like a class definition
- Instance = the data // like an object
- "every relation is guaranteed to have a key"?

Integrity Constraints

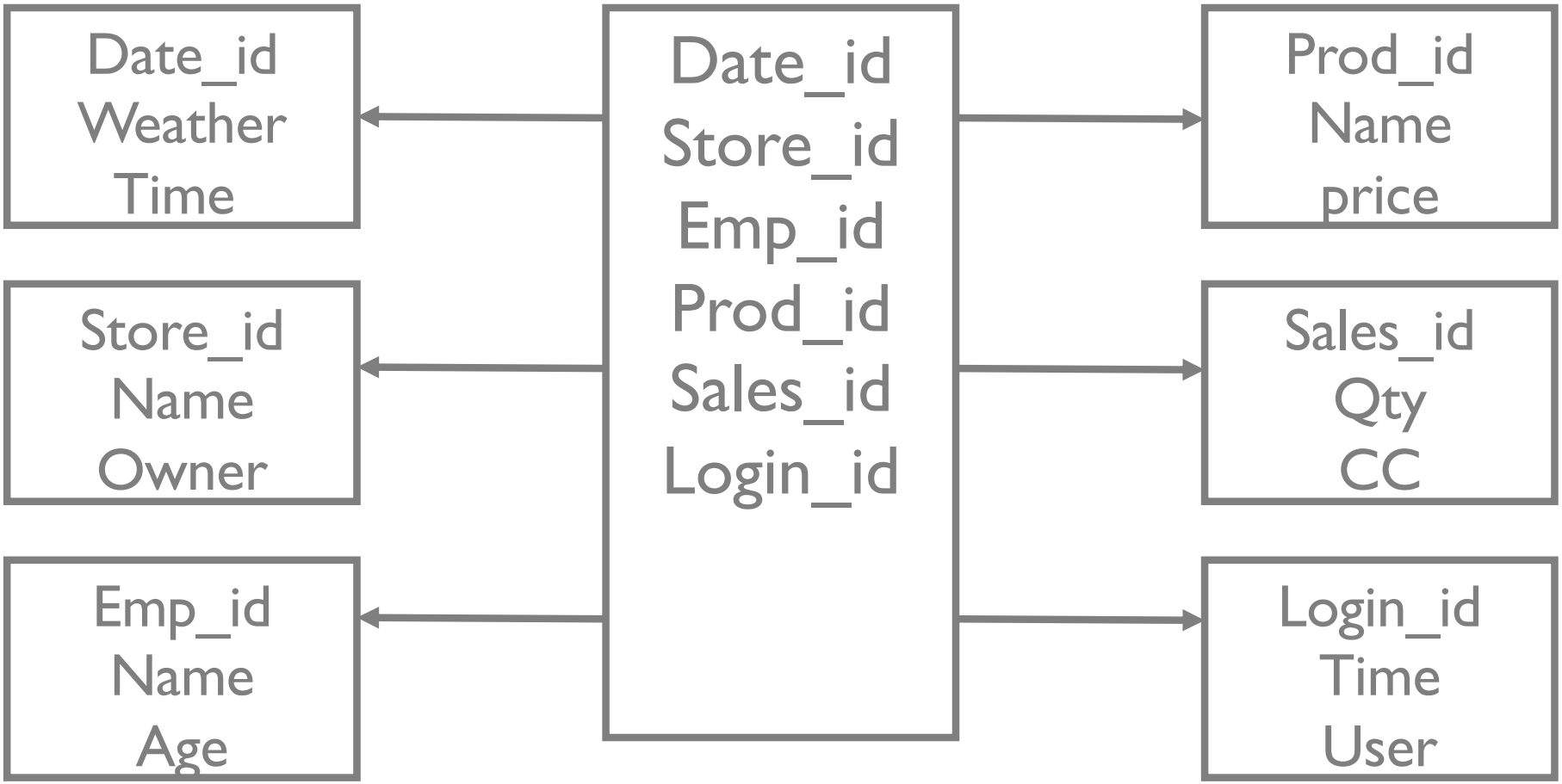
- Candidate and primary keys
- NOT NULL
- Referential integrity

How are foreign keys managed by the DBMS?

Star Schema



Star Schema


Date_id
Weather
Time
Store_id
Name
Owner
Emp_id
Name
Age
Date_id
Store_id
Emp_id
Prod_id
Sales_id
Login_id
Prod_id
Name
price
Sales_id
Qty
CC
Login_id
Time
User

So What Happened?

1970 heated debates about CODASYL vs Relational

Network arguments

- low level languages more efficient (performance)
- relational queries would never be fast (performance)

Relational arguments

- data independence
- high level *simpler* languages

Market spoke.

Other models beyond relational!

Summary

Better than IMS/CODASYL

- allows us to talk about constraints!
- allows us to talk at a logical level
- declarative queries better than navigational programs

Everything is a relation (table)

DBA specifies ICs based on app, DBMS enforces

- Primary and Foreign Keys most used
- Types == Domain constraints

SQL

Next Time

Relational Algebra

- A set-oriented theory for relational data

Finish history lesson