CompSci 516
Database Systems

Lecture 5
Relational Algebra And Normalization

Guest Lecture: Junyang Gao

Announcements

- Lab-2 on RA on Thursday
  - Do not forget your laptop!
- Homework-1 (Part-1 and 2) have been posted on sakai
  - First deadline next Tuesday: 09/17
  - Parsing XML will take time!
- Next week:
  - Revisit Relational Calculus!
  - New topic: Database internals and indexes!

Today's topic

- Relational Algebra
- Normalization

Acknowledgement:
The following slides have been created adapting the instructor material of the [RG] book provided by the authors Dr. Ramakrishnan and Dr. Gehrke.

A Quick Recap

Likes(drinker, beer)
Frequents(drinker, bar)
Serves(bar, beer)

- The "Drinker-Beer-Bar" example

Query: Find drinkers that like some beer (so much) that they frequent all bars that serve it

$$Q(x) = \exists y.\ Likes(x, y) \wedge \forall z.(Serves(z,y) \Rightarrow Frequents(x,z))$$

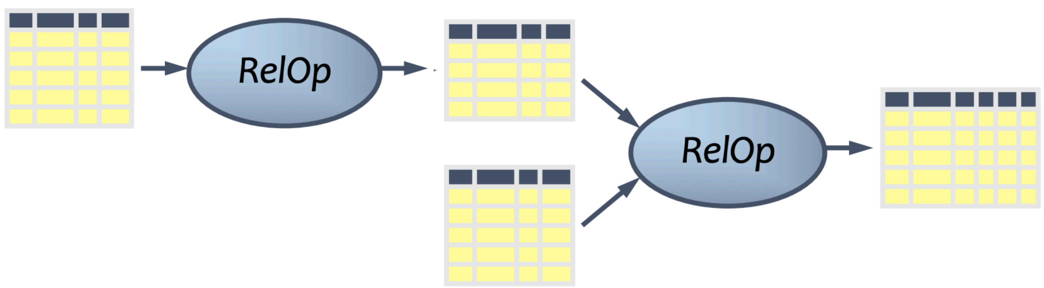
```
SELECT DISTINCT L.drinker
FROM Likes L
WHERE not exists
   (SELECT S.bar
    FROM Serves S
    WHERE L.beer=S.beer
          AND not exists (SELECT *
                          FROM Frequents F
                          WHERE F.drinker=L.drinker
                             AND F.bar=S.bar))
```

Relational Algebra (RA)

Relational Algebra

- A language for querying relational data based on "operators"

- Takes one or more relations as input, and produces a relation as output
  - operator
  - operand
  - semantic
  - so an algebra!



- Since each operation returns a relation, operations can be composed
  - Algebra is "closed"

Relational Algebra

- Basic operations:
  - Selection (σ) Selects a subset of rows from relation
  - Projection (π) Deletes unwanted columns from relation.
  - Cross-product (x) Allows us to combine two relations.
  - Set-difference (-) Tuples in reln. 1, but not in reln. 2.
  - Union (∪) Tuples in reln. 1 or in reln. 2.
- Additional operations:
  - Intersection (∩)
  - **join** ⋈
  - division(/)
  - renaming (ρ)
  - Not essential, but (very) useful, especially join!

Example Schema and Instances

Sailors(sid, sname, rating, age)
Boats(bid, bname, color)
Reserves(sid, bid, day)

S1

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

S2

sid	sname	rating	age
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

R1

sid	bid	day
22	101	10/10/96
58	103	11/12/96

Projection

S2

<u>sid</u>	sname	rating	age
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

- Deletes attributes that are not in projection list.
- Schema of result contains exactly the fields in the projection list, with the same names that they had in the (single) input relation.

sname	rating
yuppy	9
lubber	8
guppy	5
rusty	10

$$\pi_{sname,rating}(S2)$$

age
3[illegible]
5[illegible]5
3[illegible]
35.0

$$\pi_{age}(S2)$$

Projection

S2

sid	sname	rating	age
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

- Deletes attributes that are not in projection list.
- Schema of result contains exactly the fields in the projection list, with the same names that they had in the (single) input relation.
- Projection operator has to eliminate duplicates (Set semantic!)
  - Note: real systems typically don't do duplicate elimination unless the user explicitly asks for it (performance)

sname	rating
yuppy	9
lubber	8
guppy	5
rusty	10

$$\pi_{sname,rating}(S2)$$

age
35.0
55.5

$$\pi_{age}(S2)$$

Selection

- Selects rows that satisfy selection condition
- No duplicates in result
  - Because input is a set!
- Schema of result identical to schema of (single) input relation

S2

sid	sname	rating	age
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

sid	sname	rating	age
28	yuppy	9	35.0
58	rusty	10	35.0

$$\sigma_{rating > 8}(S2)$$

Composition of Operators

- Result relation can be the input for another relational algebra operation
  - Operator composition

S2

sid	sname	rating	age
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

What do we get here?

$$\pi_{sname,rating}(\sigma_{rating>8}(S2))$$

Composition of Operators

- Result relation can be the input for another relational algebra operation
  - Operator composition

S2

sid	sname	rating	age
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

sname	rating
yuppy	9
rusty	10

What do we get here?

$$\pi_{sname,rating}(\sigma_{rating>8}(S2))$$

Union, Intersection, Set-Difference

S1

<u>sid</u>	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

S2

<u>sid</u>	sname	rating	age
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

- All of these operations take two input relations, which must be union-compatible:
  - Same number of fields.
  - "Corresponding" fields must have the same type and same schema as the inputs

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0
44	guppy	5	35.0
28	yuppy	9	35.0

$S1 \cup S2$

You would lose points if your relations in $\cup$, $\cap$, $-$ are not union compatible!

Union, Intersection, Set-Difference

S1

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

S2

sid	sname	rating	age
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

- Note: no duplicate
  - "Set semantic"
  - SQL: UNION
  - But SQL allows "bag semantic" as well: UNION ALL

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0
44	guppy	5	35.0
28	yuppy	9	35.0

$$S1 \cup S2$$

Union, Intersection, Set-Difference

S1

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

S2

sid	sname	rating	age
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

sid	sname	rating	age
22	dustin	7	45.0

$$S1 - S2$$

sid	sname	rating	age
31	lubber	8	55.5
58	rusty	10	35.0

$$S1 \cap S2$$

Cross-Product

- Each row of S1 is paired with each row of R.
- Result schema has one field per field of S1 and R, with field names `inherited' if possible.
  - Conflict: Both S1 and R have a field called sid.

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

sid	bid	day
22	101	10/10/96
58	103	11/12/96

(sid)	sname	rating	age	(sid)	bid	day
22	dustin	7	45.0	22	101	10/10/96
22	dustin	7	45.0	58	103	11/12/96
31	lubber	8	55.5	22	101	10/10/96
31	lubber	8	55.5	58	103	11/12/96
58	rusty	10	35.0	22	101	10/10/96
58	rusty	10	35.0	58	103	11/12/96

Renaming Operator ρ

$(\rho_{sid \rightarrow sid1}\ S1) \times (\rho_{sid \rightarrow sid2}\ R1)$

Different syntaxes are used
You can use any of these

or

$\rho(C(1 \rightarrow sid1,\ 5 \rightarrow sid2),\ S1 \times R1)$

C is the new relation name

sid1 ~~(sid)~~	sname	rating	age	sid2 ~~(sid)~~	bid	day
22	dustin	7	45.0	22	101	10/10/96
22	dustin	7	45.0	58	103	11/12/96
31	lubber	8	55.5	22	101	10/10/96
31	lubber	8	55.5	58	103	11/12/96
58	rusty	10	35.0	22	101	10/10/96
58	rusty	10	35.0	58	103	11/12/96

- In general, can use ρ(<Temp>, <RA-expression>)

Joins

$$R \bowtie_c S = \sigma_c (R \times S)$$

(sid)	sname	rating	age	(sid)	bid	day
22	dustin	7	45.0	58	103	11/12/96
31	lubber	8	55.5	58	103	11/12/96

$$S1 \bowtie_{S1.sid < R1.sid} R1$$

- Result schema same as that of cross-product.
- Fewer tuples than cross-product, might be able to compute more efficiently
  - We will do join algorithms later

Find names of sailors who've reserved boat #103

Sailors(<u>sid</u>, sname, rating, age)

Boats(<u>bid</u>, bname, color)

Reserves(<u>sid, bid, day</u>)

Find names of sailors who've reserved boat #103

Sailors(<u>sid</u>, sname, rating, age)

Boats(<u>bid</u>, bname, color)

Reserves(<u>sid, bid, day</u>)

Find names of sailors who've reserved boat #103

Sailors(sid, sname, rating, age)

Boats(bid, bname, color)

Reserves(sid, bid, day)

- Solution 1: $\pi_{sname}((\sigma_{bid=103} \text{Reserves}) \bowtie Sailors)$

- Solution 2: $\pi_{sname}(\sigma_{bid=103}(\text{Reserves} \bowtie Sailors))$

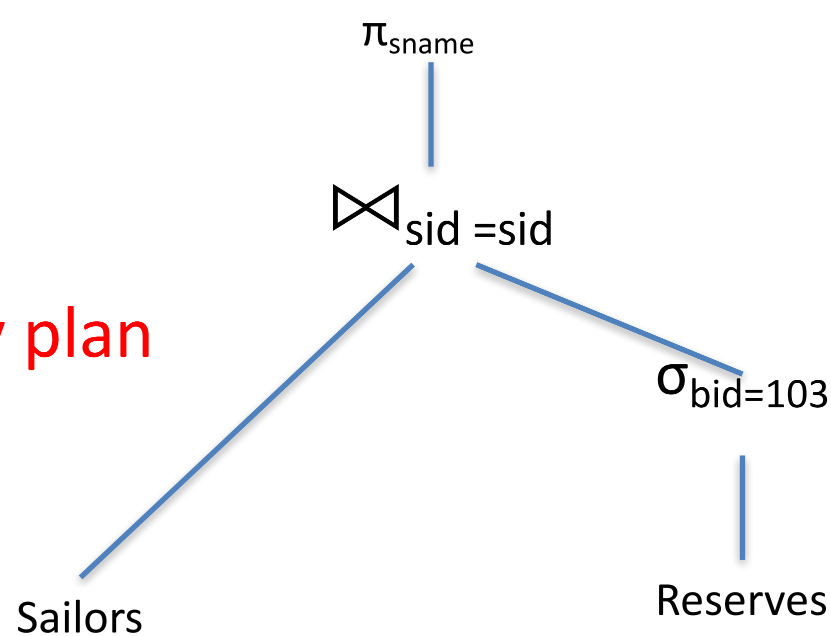
Expressing an RA expression as a Tree

Sailors(sid, sname, rating, age)

Boats(bid, bname, color)

Reserves(sid, bid, day)

Also called a logical query plan



You can use either RA expression or a logical query plan in exams

But in the lab on Thursday you will use RA expressions In RADB and RATest tools

$$\pi_{sname}((\sigma_{bid=103}\,\mathrm{Reserves}) \bowtie \mathit{Sailors})$$

Find sailors who've reserved a red or a green boat

Sailors(<u>sid</u>, sname, rating, age)

Boats(<u>bid</u>, bname, color)

Reserves(<u>sid, bid, day</u>)

Use of rename operation

Find sailors who've reserved a red or a green boat

Sailors(<u>sid</u>, sname, rating, age)
Boats(<u>bid</u>, bname, color)
Reserves(<u>sid, bid, day</u>)

Use of rename operation

- Can identify all red or green boats, then find sailors who've reserved one of these boats:

$$\rho\ (Tempboats, (\sigma_{color='red' \vee color='green'}\ Boats))$$

$$\pi_{sname}(Tempboats \bowtie \mathrm{Re}serves \bowtie Sailors)$$

Can also define Tempboats using union

Try the "AND" version yourself

What about aggregates?

Sailors(<u>sid</u>, sname, rating, age)
Boats(<u>bid</u>, bname, color)
Reserves(<u>sid, bid, day</u>)

- Supported by extended relational algebra
- $\gamma_{\text{age, avg(rating)} \rightarrow \text{avgr}}$ Sailors

- Also extended to "bag semantic": allow duplicates
  - Take into account cardinality
  - R and S have tuple t resp. m and n times
  - $R \cup S$ has t m+n times
  - $R \cap S$ has t min(m, n) times
  - R – S has t max(0, m-n) times
  - sorting(τ), duplicate removal (δ) operators

Example: Aggregates in RA

Sailors(sid, sname, rating, age)

Boats(bid, bname, color)

Reserves(sid, bid, day)

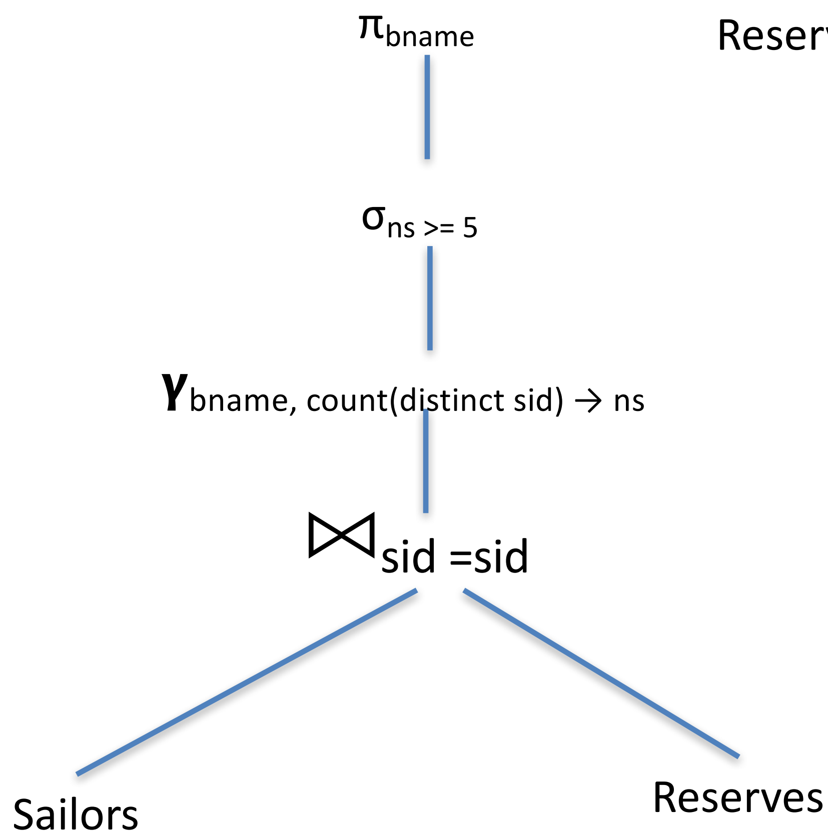
Output bnames that have been reserved by at least 5 sailors

Example: Aggregates in RA

Sailors(sid, sname, rating, age)

Boats(bid, bname, color)

Reserves(sid, bid, day)



Output bnames that have been reserved by at least 5 sailors

Database Normalization

What will we learn?

- What goes wrong if we have redundant info in a database?
- Why and how should you refine a schema?
- Functional Dependencies – a new kind of integrity constraints (IC)
- Normal Forms
- How to obtain those normal forms

Example

The list of hourly employees in an organization

<u>ssn (S)</u>	name (N)	lot (L)	rating (R)	hourly-wage (W)	hours-worked (H)
111-11-1111	Attishoo	48	8	10	40
222-22-2222	Smiley	22	8	10	30
333-33-3333	Smethurst	35	5	7	30
444-44-4444	Guldu	35	5	7	32
555-55-5555	Madayan	35	8	10	40

- key = SSN
- Suppose for a given rating, there is only one hourly_wage value
- Redundancy in the table
- Why is redundancy bad?

Why is redundancy bad? 1/4

The list of hourly employees in an organization

ssn (S)	name (N)	lot (L)	rating (R)	hourly-wage (W)	hours-worked (H)
111-11-1111	Attishoo	48	8	10	40
222-22-2222	Smiley	22	8	10	30
333-33-3333	Smethurst	35	5	7	30
444-44-4444	Guldu	35	5	7	32
555-55-5555	Madayan	35	8	10	40

1. Redundant storage:
   - Some information is stored repeatedly
   - The rating value 8 corresponds to hourly_wage 10, which is stored three times

Why is redundancy bad? 2/4

The list of hourly employees in an organization

<u>ssn (S)</u>	name (N)	lot (L)	rating (R)	hourly-wage (W)	hours-worked (H)
111-11-1111	Attishoo	48	8	10 → 9	40
222-22-2222	Smiley	22	8	10	30
333-33-3333	Smethurst	35	5	7	30
444-44-4444	Guldu	35	5	7	32
555-55-5555	Madayan	35	8	10	40

2. Update anomalies
   - If one copy of data is updated, an inconsistency is created unless all copies are similarly updated
   - Suppose you update the hourly_wage value in the first tuple using UPDATE statement in SQL -- inconsistency

Why is redundancy bad? 3/4

The list of hourly employees in an organization

ssn (S)	name (N)	lot (L)	rating (R)	hourly-wage (W)	hours-worked (H)
111-11-1111	Attishoo	48	8	10	40
222-22-2222	Smiley	22	8	10	30
333-33-3333	Smethurst	35	5	7	30
444-44-4444	Guldu	35	5	7	32
555-55-5555	Madayan	35	8	10	40

3. Insertion anomalies:
   - It may not be possible to store certain information unless some other, unrelated info is stored as well
   - We cannot insert a tuple for an employee unless we know the hourly wage for the employee's rating value

Why is redundancy bad? 4/4

The list of hourly employees in an organization

ssn (S)	name (N)	lot (L)	rating (R)	hourly-wage (W)	hours-worked (H)
111-11-1111	Attishoo	48	8	10	40
222-22-2222	Smiley	22	8	10	30
333-33-3333	Smethurst	35	5	7	30
444-44-4444	Guldu	35	5	7	32
555-55-5555	Madayan	35	8	10	40

4. Deletion anomalies:
   - It may not be possible delete certain information without losing some other information as well
   - If we delete all tuples with a given rating value (Attishoo, Smiley, Madayan), we lose the association between that rating value and its hourly_wage value

Nulls may or may not help

ssn (S)	name (N)	lot (L)	rating (R)	hourly-wage (W)	hours-worked (H)
111-11-1111	Attishoo	48	8	10	40
222-22-2222	Smiley	22	8	10	30
333-33-3333	Smethurst	35	5	7	30
444-44-4444	Guldu	35	5	7	32
555-55-5555	Madayan	35	8	10	40

- Does not help redundant storage or update anomalies
- May help insertion and deletion anomalies
  - can insert a tuple with null value in the hourly_wage field
  - but cannot record hourly_wage for a rating unless there is such an employee (SSN cannot be null) – same for deletion

Summary: Redundancy

- Redundancy arises when the schema forces an association between attributes that is “not natural”
- We want schemas that do not permit redundancy
  – at least identify schemas that allow redundancy to make an informed decision (e.g. for performance reasons)
- Null value may or may not help

- Solution?
  – Decomposition of schema!

Decomposition: Example-1

ssn (S)	name (N)	lot (L)	rating (R)	hourly-wage (W)	hours-worked (H)
111-11-1111	Attishoo	48	8	10	40
222-22-2222	Smiley	22	8	10	30
333-33-3333	Smethurst	35	5	7	30
444-44-4444	Guldu	35	5	7	32
555-55-5555	Madayan	35	8	10	40

Decomposition: Example-1

ssn (S)	name (N)	lot (L)	rating (R)	hourly-wage (W)	hours-worked (H)
111-11-1111	Attishoo	48	8	10	40
222-22-2222	Smiley	22	8	10	30
333-33-3333	Smethurst	35	5	7	30
444-44-4444	Guldu	35	5	7	32
555-55-5555	Madayan	35	8	10	40

ssn (S)	name (N)	lot (L)	rating (R)	hours-worked (H)
111-11-1111	Attishoo	48	8	40
222-22-2222	Smiley	22	8	30
333-33-3333	Smethurst	35	5	30
444-44-4444	Guldu	35	5	32
555-55-5555	Madayan	35	8	40

rating	hourly _wage
8	10
5	7

Decomposition – Example-2

(on twitter)

uid	*uname*	*twitterid*	*gid*	*fromDate*
142	Bart	@BartJSimpson	dps	1987-04-19
123	Milhouse	@MilhouseVan_	gov	1989-12-17
857	Lisa	@lisasimpson	abc	1987-04-19
857	Lisa	@lisasimpson	gov	1988-09-01
456	Ralph	@ralphwiggum	abc	1991-04-25
456	Ralph	@ralphwiggum	gov	1992-09-01
…	…	…	…	…

- User id
- user name
- Twitter id
- Group id
- Joining Date (to a group)
- Both uid and twitterid are keys

uid	uname	twitterid
142	Bart	@BartJSimpson
123	Milhouse	@MilhouseVan_
857	Lisa	@lisasimpson
456	Ralph	@ralphwiggum
…	…	…

uid	gid	fromDate
142	dps	1987-04-19
123	gov	1989-12-17
857	abc	1987-04-19
857	gov	1988-09-01
456	abc	1991-04-25
456	gov	1992-09-01
…	…	…

Unnecessary decomposition

uid	*uname*	*twitterid*
142	Bart	@BartJSimpson
123	Milhouse	@MilhouseVan_
857	Lisa	@lisasimpson
456	Ralph	@ralphwiggum
…	…	…

Why?

uid	uname
142	Bart
123	Milhouse
857	Lisa
456	Ralph
…	…

uid	twitterid
142	@BartJSimpson
123	@MilhouseVan_
857	@lisasimpson
456	@ralphwiggum
…	…

- Still correct: join returns the original relation
- Unnecessary: no redundancy is removed; schema is more complicated (and *uid* is stored twice!)

Bad decomposition

uid	*gid*	*fromDate*
142	dps	1987-04-19
123	gov	1989-12-17
857	abc	1987-04-19
857	gov	1988-09-01
456	abc	1991-04-25
456	gov	1992-09-01
…	…	…

Why bad?

uid	gid
142	dps
123	gov
857	abc
857	gov
456	abc
456	gov
…	…

uid	fromDate
142	1987-04-19
123	1989-12-17
857	1987-04-19
857	1988-09-01
456	1991-04-25
456	1992-09-01
…	…

- Association between *gid* and *fromDate* is lost
- Join returns more rows than the original relation

Lossless join decomposition

- Decompose relation R into relations S and T
  - $attrs(R) = attrs(S) \cup attrs(T)$
  - $S = \pi_{attrs(S)}(R)$
  - $T = \pi_{attrs(T)}(R)$

- The decomposition is a lossless join decomposition if, given known constraints such as FD's, we can guarantee that $R = S \bowtie T$

- $R \subseteq S \bowtie T$ or $R \supseteq S \bowtie T$?

- Any decomposition gives $R \subseteq S \bowtie T$ (why?)
  - A lossy decomposition is one with $R \subset S \bowtie T$

Loss? But I got more rows!

- "Loss" refers not to the loss of tuples, but to the loss of information
  - Or, the ability to distinguish different original relations

uid	*gid*	*fromDate*
142	dps	1987-04-19
123	gov	1989-12-17
857	abc	1988-09-01
857	gov	1987-04-19
456	abc	1991-04-25
456	gov	1992-09-01
…	…	…

No way to tell
which is the original relation

uid	gid
142	dps
123	gov
857	abc
857	gov
456	abc
456	gov
…	…

uid	fromDate
142	1987-04-19
123	1989-12-17
857	1987-04-19
857	1988-09-01
456	1991-04-25
456	1992-09-01
…	…

Decompositions should be used judiciously

1. Do we need to decompose a relation?
   – Several "normal forms" exist to identify possible redundancy at different granularity
   – If a relation is not in one of them, may need to decompose further

2. What are the problems with decomposition?
   – Bad decompositions: e.g., Lossy decompositions
   – Performance issues -- decomposition may both
     • help performance (for updates, some queries accessing part of data), or
     • hurt performance (new joins may be needed for some queries)