Administrivia

HW3 is out.

Project 1 is due next week

L7
Normalization is a Good Idea

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Fall 2015

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 — Normalization
- fix potential problems, normalization

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

App/Security Design
- prevent security problems

Information Retrieval

A Relational Model of Data for Large Shared Data Banks

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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

Redundancy is no good

Update/insert/delete anomalies. Wastes space

sid	name	address	hobby	cost
1	Eugene	amsterdam	trucks	$$
1	Eugene	amsterdam	cheese	$
2	Bob	40th	paint	$$$
3	Bob	40th	cheese	$
4	Shaq	florida	swimming	$

people have names and addrs

hobbies have costs

people many-to-many with hobbies
- What's primary key? sid? sid + hobby?

Anomalies (Inconsistencies)

Update Anomaly
- change one address, need to change all

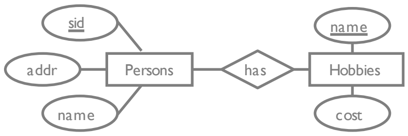
Insert Anomaly
- add person without hobby?
- not allowed? dummy hobby?

Delete Anomaly
- if delete a hobby. Delete the person?

Theory Can Fix This!

A Possible Approach

ER diagram was a heuristic



We have decomposed example table into:

person(sid, addr, name)
hobby(name, cost)
personhobby(hobbyname, sid)

A Possible Approach

What if decompose into:

person(sid, name, address, cost)
personhobby(sid, hobbyname)

sid	name	address	cost
1	Eugene	amsterdam	$$
1	Eugene	amsterdam	$
2	Bob	40th	$$$
3	Bob	40th	$
4	Shaq	florida	$

sid	hobby
1	trucks
1	cheese
2	paint
3	cheese
4	swimming

but… which cost goes with which hobby?

lost information: *lossy decomposition*

Decomposition

Replace schema R with 2+ smaller schemas that

1. each contain subset of attrs in R
2. together include all attrs in R

ABCD replaced with AB, BCD or AB, BC, CD

Not free – may introduce problems!

1. lossy-join: able to recover R from smaller relations
2. non-dependency-preserving: constraints on R hold by only enforcing constraints on smaller schemas
3. performance: additional joins, may affect performance

Can we systematically decompose our relation to

prevent decomposition problems & remove redundancy?

Functional Dependencies (FD)

sid	name	address	hobby	cost
1	Eugene	amsterdam	trucks	$$
1	Eugene	amsterdam	cheese	$
2	Bob	40th	paint	$$$
3	Bob	40th	cheese	$
4	Shaq	florida	swimming	$

sid sufficient to identify name and addr, but not hobby

e.g., exists a function f(sid) → name, addr

sid → name, addr is a functional dependency

"sid determines name, addr"
"name, addr are functionally dependent on sid"
"if 2 records have the same sid, their name and addr are the same"

Functional Dependencies (FD)

$X \rightarrow Y$

holds on R

if $t_1.X = t_2.X$ then $t_1.Y = t_2.Y$

where X,Y are subsets of attrs in R

Examples of FDs in person-hobbies table

sid, hobby → name, address cost
hobby → cost
sid → name, address

Fun Facts

Functional Dependency is an integrity constraint
- statement about all instances of relation
- Generalizes key constraints
  - if K is candidate key of R, then K → R

Given FDs, simple definition of redundancy
- when left side of FD is not table key

Where do FDs come from?
- thinking really hard aka application semantics
- can't stare at database to derive (like ICs)

Fun Facts

Functional Dependency is an integrity constraint
- statement about all instances of relation
- Generalizes key constraints
  - if K is candidate key of R, then K → R

Functional Dependency Discovery:
An Experimental Evaluation of Seven Algorithms

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Normal Forms

Criteria met by a relation R wrt functional dependencies

Boyce Codd Normal Form (BCNF)
- No redundancy, may lose dependencies

Third Normal Form (3NF)
- May have redundancy, no decomposition problems

Redundancy depends on FDs
- consider R(ABC)
- no FDs: no redundancy
- if A→B: tuples with same A value means B is duplicated!

BCNF

Relation R in BCNF has *no redundancy* wrt FDs
(only FDs are key constraints)

```
F: set of functional dependencies over relation R
   for (X→Y) in F
      Y is in X OR
      X is a superkey of R
```

Is this in BCNF?

sid → name

sid	hobby	name
x	y_1	z
x	y_2	?

BCNF

Relation R in BCNF has *no redundancy* wrt FDs
(only FDs are key constraints)

```
F: set of functional dependencies over relation R
   for (X→Y) in F
      Y is in X OR
      X is a superkey of R
```

Functional Dependencies
- SH → NAC (sid, hobby → name, addr, cost)
- H → C
- S → NA

What's in BCNF?

SHNAC	NO
SNA, SHC	NO
SNA, HC, SH	YES

BCNF

Suppose we have
- Client, Office → Account
- Account → Office

What's in BCNF?
- R(Account, Client, Office)
- R(Account, Office) R(Client, Account)

Where did CO→A go? *Lost Dependency*
Can we preserve FDs *and* remove most redundancy?

3rd Normal Form (3NF)

Relax BCNF (e.g.,BCNF ⊆ 3NF)

```
F: set of functional dependencies over relation R
        for (X→Y) in F
            Y is in X OR
            X is a superkey of R
```

3rd Normal Form (3NF)

Relax BCNF (e.g.,BCNF ⊆ 3NF)

```
F: set of functional dependencies over relation R
        for (X→Y) in F
            Y is in X OR
            X is a superkey of R OR
            Y is part of a key in R
```

Is new condition trivial? NO! key is minimal

Nice properties

lossless join ^ dependency preserving decomposition to 3NF always possible

3rd Normal Form (3NF)

Relax BCNF (e.g.,BCNF ⊆ 3NF)

```
F: set of functional dependencies over relation R
        for (X→Y) in F
            Y is in X OR
            X is a superkey of R OR
            Y is part of a key in R
```

FDs

Client, Office → A

Account → Office

(Account, Office), (Client,Account) split up key in CO→A

R(Client, Office,Account) is in 3NF!

3rd Normal Form (3NF)

Relax BCNF (e.g.,BCNF ⊆ 3NF)

```
F: set of functional dependencies over relation R
        for (X→Y) in F
            Y is in X OR
            X is a superkey of R OR
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```

Reservations(Sailor, Boat, Day, CreditCard) SBDC

FDs: SBD→C, S→C

Reservations not in 3NF

FDs: SBD→C, S→C, C→S

Reservations in 3NF (hint: CBD is a key)

In both cases, (Sailors, CreditCard) stored redundantly

We're going to need some theory

Closure of FDs

armstrong's axioms

Minimal FD Set

Principled Decomposition

BCNF & 3NF

Closure of FDs

If I know

Name → Bday and Bday → age

Then it implies

Name → age

f' is implied by set F if f' is true when F is true

F^+ closure of F is all FDs implied by F

Can we construct this closure automatically? YES

Closure of FDs

Inference rules called Armstrong's Axioms

Reflexivity if $Y \subseteq X$ then $X \rightarrow Y$

Augmentation if $X \rightarrow Y$ then $XZ \rightarrow YZ$ for any Z

Transitivity if $X \rightarrow Y$ & $Y \rightarrow Z$ then $X \rightarrow Z$

These are sound and complete rules

sound doesn't produce FDs not in the closure

complete doesn't miss any FDs in the closure

Closure of FDs

Can we compute the closure? YES. slowly

expensive. exponential in # attributes

Can we *check* if $X \rightarrow Y$ is in the closure of F?

X^+ = *attribute closure* of X (expand X using axioms)

check if Y is implied in the attribute closure

Closure of FDs

F = {A→B, B→C, CB→E}

Is A→E in the closure?

A → B	given
A → AB	augmentation A
A → BB	apply A→B
A → BC	apply B→C
BC → E	given
A → E	transitivity

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Minimum Cover of FDs

Closures let us compare sets of FDs meaningfully

F1 = {A → B, A → C, A → BC}

F2 = {A → B, A → C}

F1 equivalent to F2

If there's a closure (a maximally expanded FD), there's a *minimal* FD. Let's find it

Minimum Cover of FDs

1. Turn FDs into *standard form*
   decompose each FD so single attr on the right side
2. Minimize left side of each FD
   for each FD, check if can delete left attr w/out changing closure
   given ABC → D, B→C can reduce to AB→D, B→C
3. Delete redundant FDs
   check each remaining FD and see if it can be deleted
   e.g., in closure of the other FDs

2 must happen before 3!

Minimum Cover of FDs

A→B,ABC→E, EF→G,ACF→EG

Standard form

A→B, ABC→E, EF→G, ACF→E, ACF→G

Minimize left side

A→B, AC→E, EF→G, ACF→E, ACF→G

reason: AC→E + A→B implies ABC→E

Delete Redundant FDs

A→B, AC→E, EF→G, ~~ACF→E, ACF→G~~

reason: ACF→E implied by AC→E, EF→G

We're going to need some theory

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Principled Decomposition

BCNF & 3NF

Decomposition

Eventually want to decompose R into $R_1 \ldots R_n$ wrt F

We've seen issues with decomposition.

Lost Joins: Can't recover R from $R_1 \ldots R_n$

Lost dependencies

Principled way of avoiding these?

Lossless Join Decomposition

join the decomposed tables to get *exactly the* original

e.g., decompose R into tables X,Y

$\pi_X(R) \bowtie \pi_Y(R) = R$

Lossless wrt F if and only if F^+ contains

$X \cap Y \rightarrow X$ or $Y \cap X \rightarrow Y$

intersection of X, Y is a key for one of them

Lossless Join Decomposition

Lossless wrt F if and only if F^+ contains

$X \cap Y \rightarrow X$ or $Y \cap X \rightarrow Y$

intersection of X, Y is a key for one of them

FDs: A→C,A→B

A	B	C
1	2	1
5	3	4
9	2	6

→

A	B
1	2
5	3
9	2

B	C
2	1
3	4
2	6

→

A	B	C
1	2	1
5	3	4
9	2	6
1	2	6
9	2	1

Lossy! AB ∩ BC = B doesn't determine anything

Lossless Join Decomposition

Lossless wrt F if and only if F^+ contains

$X \cap Y \rightarrow X$ or $Y \cap X \rightarrow Y$

intersection of X, Y is a key for one of them

FDs: A→C,A→B

A	B	C
1	2	1
5	3	4
9	2	6

→

A	B
1	2
5	3
9	2

A	C
1	1
5	4
9	6

→

A	B	C
1	2	1
5	3	4
9	2	6

OK

Dependency-preserving Decomposition

Terminology: F_X = Projection of F onto R
FDs U→V in F^+ s.t. U and V are in R

If R decompose to X, Y.
FDs that hold on X, Y equivalent to all FDs on R
$(F_X \cup F_Y)^+ = F^+$

Consider ABCD, C is key, AB→C, D→A
BCNF decomposition: BCD, DA
AB→C doesn't apply to either table!

We're going to need some theory

Closure of FDs
armstrong's axioms

Minimal FD Set

Principled Decomposition

BCNF & 3NF

BCNF

```
while BCNF is violated
  R with FDs F
  if X→Y violates BCNF
    turn R into R-Y & XY
```

ABCDE key A, BC→A, D→B, C→D
DB, ACDE using D→B
DB, CD, ACE using C→D

uh oh, lost BC→A

3NF

F^{min} = minimal cover of F
Run BCNF using F^{min}
for X→Y in F^{min} not in projection onto $R_1 \ldots R_N$
create relation XY

ABCDE key A, BC→A, D→B, C→D
DB, ACDE
DB, CD, ACE
add ABC

Summary

Normal Forms: BCNF and 3NF
FD closures: Armstrong's axioms
Proper Decomposition

Summary

Accidental redundancy is really really bad
Adding lots of joins can hurt performance

Can be at odds with each other
Normalization good starting point, relax as needed

People usually think in terms of entities and keys, usually ends up reasonable

What you should know

- Purpose of normalization
  - Anomalies
  - Decomposition problems
  - Functional dependencies & axioms
- 3NF
  - properties
  - algorithm