Relational Database Design Theory
Part II

CPS 116
Introduction to Database Systems

Announcements (October 13)

- Midterm graded; sample solution available
  - Please verify your grades on Blackboard
- Project milestone #1 due today

Review

- Functional dependencies
  - $X \rightarrow Y$: If two rows agree on X, they must agree on Y
  - ☞A generalization of the key concept
- Non-key functional dependencies: a source of redundancy
  - Non-trivial $X \rightarrow Y$ where X is not a superkey
  - ☞Called a BCNF violation
- BCNF decomposition: a method for removing redundancies
  - Given $R(X, Y, Z)$ and a BCNF violation $X \rightarrow Y$, decompose R into $R_1(X, Y)$ and $R_2(X, Z)$
  - ☞A lossless join decomposition
- Schema in BCNF has no redundancy due to FD's

Next

- 3NF (BCNF is too much)
- Multivalued dependencies: another source of redundancy
- 4NF (BCNF is not enough)

Motivation for 3NF

- *Address* (*street_address*, *city*, *state*, *zip*)
  - *street_address*, *city*, *state* $\rightarrow$ *zip*
  - *zip* $\rightarrow$ *city*, *state*
- Keys
  - {*street_address*, *city*, *state*}
  - {*street_address*, *zip*}
- BCNF?

To decompose or not to decompose

$Address_1$ (*zip*, *city*, *state*)

$Address_2$ (*street_address*, *zip*)

- FD's in $Address_1$
  - *zip* $\rightarrow$ *city*, *state*
- FD's in $Address_2$
  - None!
- Hey, where is *street_address*, *city*, *state* $\rightarrow$ *zip*?
  - Cannot check without joining $Address_1$ and $Address_2$ back together
- Problem: Some lossless join decomposition is not dependency-preserving
- Dilemma: Should we get rid of redundancy at the expense of making constraints harder to enforce?

3NF

7

- R is in Third Normal Form (3NF) if for every non-trivial FD $X \rightarrow A$ (where A is single attribute), either
  - X is a superkey of R, or
  - A is a member of at least one key of R
  - ☞Intuitively, BCNF decomposition on $X \rightarrow A$ would "break" the key containing A
- So *Address* is already in 3NF
- Tradeoff:
  - Can enforce all original FD's on individual decomposed relations
  - Might have some redundancy due to FD's

BNCF = no redundancy?

8

- *Student* (*SID*, *CID*, *club*)
  - Suppose your classes have nothing to do with the clubs you join
  - FD's?
  - BNCF?
  - Redundancies?

SID	*CID*	*club*
142	CPS116	ballet
142	CPS116	sumo
142	CPS114	ballet
142	CPS114	sumo
123	CPS116	chess
123	CPS116	golf
...	...	...

Multivalued dependencies

9

- A multivalued dependency (MVD) has the form $X \twoheadrightarrow Y$, where X and Y are sets of attributes in a relation R
- $X \twoheadrightarrow Y$ means that whenever two rows in R agree on all the attributes of X, then we can swap their Y components and get two new rows that are also in R

X	Y	Z	
a	*b1*	*c1*	
a	*b2*	*c2*	
a	*b1*	*c2*	Must be in R too
a	*b2*	*c1*	
...	...	...	

10

MVD examples

Student (*SID*, *CID*, *club*)

- $SID \twoheadrightarrow CID$

11

Complete MVD + FD rules

- FD reflexivity, augmentation, and transitivity
- MVD complementation:
  If $X \twoheadrightarrow Y$, then $X \twoheadrightarrow attrs(R) - X - Y$
- MVD augmentation:
  If $X \twoheadrightarrow Y$ and $V \subseteq W$, then $XW \twoheadrightarrow YV$
- MVD transitivity:
  If $X \twoheadrightarrow Y$ and $Y \twoheadrightarrow Z$, then $X \twoheadrightarrow Z - Y$
- Replication (FD is MVD):
  If $X \rightarrow Y$, then $X \twoheadrightarrow Y$
- Coalescence:
  If $X \twoheadrightarrow Y$ and $Z \subseteq Y$ and there is some W disjoint from Y such that $W \rightarrow Z$, then $X \rightarrow Z$

Try proving things using these!

12

An elegant solution: chase

- Given a set of FD's and MVD's $\mathcal{D}$, does another dependency d (FD or MVD) follow from $\mathcal{D}$?
- Procedure
  - Start with the hypothesis of d, and treat them as "seed" tuples in a relation
  - Apply the given dependencies in $\mathcal{D}$ repeatedly
    - If we apply an FD, we infer equality of two symbols
    - If we apply an MVD, we infer more tuples
  - If we infer the conclusion of d, we have a proof
  - Otherwise, if nothing more can be inferred, we have a counterexample

Proof by chase

- In $R(A, B, C, D)$, does $A \twoheadrightarrow B$ and $B \twoheadrightarrow C$ imply that $A \twoheadrightarrow C$?

Have

	A	B	C	D
	a	b1	c1	d1
	a	b2	c2	d2
$A \twoheadrightarrow B$	a	b2	c1	d1
	a	b1	c2	d2
$B \twoheadrightarrow C$	a	b2	c1	d2
	a	b2	c2	d1
$B \twoheadrightarrow C$	a	b1	c2	d1
	a	b1	c1	d2

Need

A	B	C	D
a	b1	c2	d1
a	b2	c1	d2

Another proof by chase

- In $R(A, B, C, D)$, does $A \rightarrow B$ and $B \rightarrow C$ imply that $A \rightarrow C$?

Have

A	B	C	D
a	b1	c1	d1
a	b2	c2	d2

Need

$c1 = c2$

$A \rightarrow B$ $\quad b1 = b2$

$B \rightarrow C$ $\quad c1 = c2$

In general, both new tuples and new equalities may be generated

Counterexample by chase

- In $R(A, B, C, D)$, does $A \twoheadrightarrow BC$ and $CD \rightarrow B$ imply that $A \rightarrow B$?

Have

	A	B	C	D
	a	b1	c1	d1
	a	b2	c2	d2
$A \twoheadrightarrow BC$	a	b2	c2	d1
	a	b1	c1	d2

Counterexample!

Need

$b1 = b2$

4NF

- A relation R is in Fourth Normal Form (4NF) if
  - For every non-trivial MVD $X \twoheadrightarrow Y$ in R, X is a superkey
  - That is, all FD's and MVD's follow from "key $\rightarrow$ other attributes" (i.e., no MVD's, and no FD's besides key functional dependencies)
- 4NF is stronger than BCNF
  - Because every FD is also a MVD

4NF decomposition algorithm

- Find a 4NF violation
  - A non-trivial MVD $X \twoheadrightarrow Y$ in R where X is not a superkey
- Decompose R into R_1 and R_2, where
  - R_1 has attributes $X \cup Y$
  - R_2 has attributes $X \cup Z$ (Z contains attributes not in X or Y)
- Repeat until all relations are in 4NF
- Almost identical to BCNF decomposition algorithm
- Any decomposition on a 4NF violation is lossless

4NF decomposition example

SID	*CID*	*club*
142	CPS116	ballet
142	CPS116	sumo
142	CPS114	ballet
142	CPS114	sumo
123	CPS116	chess
123	CPS116	golf
...	...	...

Student (*SID*, *CID*, *club*)

4NF violation: $SID \twoheadrightarrow CID$

Enroll (*SID*, *CID*)

4NF

SID	*CID*
142	CPS116
142	CPS114
123	CPS116
...	...

Join (*SID*, *club*)

4NF

SID	*club*
142	ballet
142	sumo
123	chess
123	golf
...	...

3NF, BCNF, 4NF, and beyond

Anomaly/normal form	3NF	BCNF	4NF
Lose FD's?	No	Possible	Possible
Redundancy due to FD's	Possible	No	No
Redundancy due to MVD's	Possible	Possible	No

- Of historical interests
  - 1NF: All column values must be atomic
  - 2NF: Slightly more relaxed than 3NF

Summary

- Philosophy behind BCNF, 4NF:
  Data should depend on the key, the whole key, and nothing but the key!

- Philosophy behind 3NF:
  … But not at the expense of more expensive constraint enforcement!