

Announcements (October 13)

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

Review

- * Functional dependencies
 - $X \to Y$: 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 $X \to Y$ where X is not a superkey
 - Called a BCNF violation
- $\boldsymbol{\diamond}$ BCNF decomposition: a method for removing redundancies
 - Given R(X, Y, Z) and a BCNF violation $X \to Y$, decompose R into $R_1(X, Y)$ and $R_2(X, Z)$
 - TA 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?
 - Violation: $zip \rightarrow city$, state

To decompose or not to decompose

Address₁ (zip, city, state)

Address₂ (street_address, zip)

- FD's in $Address_1$
- $zip \rightarrow city$, state
- ✤ FD's in Address₂
 - None!
- ♦ Hey, where is street_address, city, state → zip?
 Cannot check without joining Address₁ and Address₂ 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

- 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
 - ^{*The Problem Problem}* 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

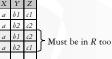
BNCF = no redundancy?

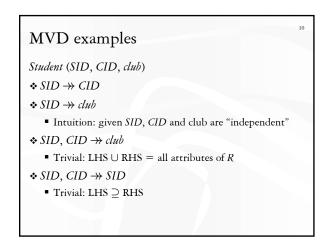
♦ Student (SID, CID, club)

- Suppose your classes have nothing to do with the clubs you join
- FD's?
- None BNCF?
- Yes
- Redundancies? • Tons!

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

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





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): Try proving things using these! If $X \to Y$, then $X \twoheadrightarrow Y$ ✤ Coalescence:

If $X \twoheadrightarrow Y$ and $Z \subseteq Y$ and there is some W disjoint from Ysuch that $W \to Z$, then $X \to Z$

An elegant solution: chase \bullet Given a set of FD's and MVD's \mathcal{D} , does another

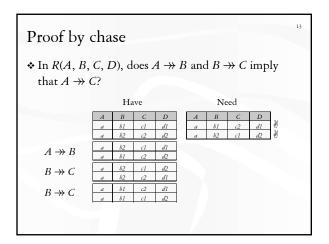
- dependency d (FD or MVD) follow from \mathcal{D} ?
- * Procedure

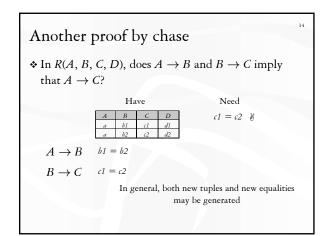
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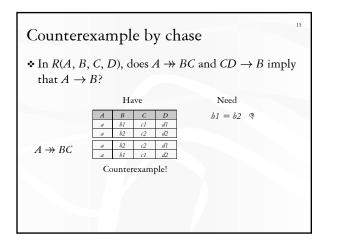
• Start with the hypothesis of *d*, and treat them as "seed" tuples in a relation

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- Apply the given dependencies in 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







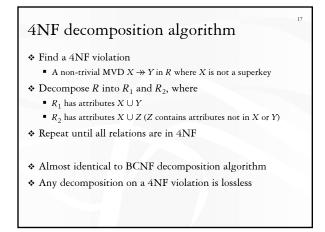
4NF

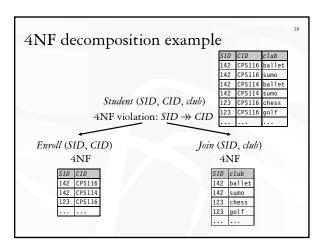
* A relation R is in Fourth Normal Form (4NF) if

- 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 → 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





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

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

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