

Relational Database Design

CPS 216
Advanced Database Systems

Announcements

- ❖ DB2 accounts have been set up
 - Let me know if you have not received an email from me regarding your account
- ❖ Recitation session this Friday (January 17) on E/R database design and review of relational algebra and design theory
- ❖ Office hours
 - Me (D327): Wed. 3:35-4:35pm & Fri. 2:00-3:00pm
 - TA (D328): Tue. & Thu. 12:00-1:00pm

Database (schema) design

- ❖ Understand the real-world domain being modeled
- ❖ Specify it using a database design model
 - Design models are especially convenient for schema design, but are not necessarily implemented by DBMS
 - Popular ones include
 - Entity/Relationship (E/R) model
 - Object Definition Language (ODL)
- ❖ Translate the design to the data model of DBMS
 - Relational, XML, object-oriented, etc.
- ❖ Apply database design theory to check the design
- ❖ Create DBMS schema

Entity-relationship (E/R) model

- ❖ Historically very popular
 - Primarily a design model; not implemented by any major DBMS nowadays
- ❖ Can think of as a “watered-down” object-oriented design model
- ❖ E/R diagrams represent designs

E/R example



- ❖ Entity: a “thing,” like a record or an object
- ❖ Entity set (rectangle): a collection of things of the same type, like a relation of tuples or a class of objects
- ❖ Relationship: an association among two or more entities
- ❖ Relationship set (diamond): a set of relationships of the same type; an association among two or more entity sets
- ❖ Attributes (ovals): properties of entities or relationships, like attributes of tuples or objects

ODL (Object Definition Language)

- ❖ Standardized by ODMG (Object Data Management Group)
 - Comes with a declarative query language OQL (Object Query Language)
 - Implemented by OODBMS (Object-Oriented DataBase Management Systems)
- ❖ Object oriented
- ❖ Based on C++ syntax
- ❖ Class declarations represent designs

ODL example

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```
class Student {
  attribute integer SID;
  attribute string name;
  relationship Set<Course> enrolledIn inverse Course::students;
};
class Course {
  attribute string CID;
  attribute string title;
  relationship Set<Student> students inverse Student::enrolledIn;
};
```

- ❖ Easy to map them to C++ classes
 - ODL attributes correspond to attributes of objects; complex types are allowed
 - ODL relationships can be mapped to pointers to other objects (e.g., `Set<Course>` → set of pointers to objects of `Course` class)

Not covered in this lecture

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- ❖ E/R and ODL design
- ❖ Translating E/R and ODL designs into relational designs
 - ☞ Reference book (GMUW) has all the details
 - ☞ E/R design and E/R-relational translation will be covered in recitation session this Friday
- ❖ Next: relational design theory

Relational model: review

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- ❖ A database is a collection of relations (or tables)
- ❖ Each relation has a list of attributes (or columns)
- ❖ Each attribute has a domain (or type)
- ❖ Each relation contains a set of tuples (or rows)

Keys

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- ❖ A set of attributes K is a key for a relation R if
 - In no instance of R will two different tuples agree on all attributes of K
 - That is, K is a “tuple identifier”
 - No proper subset of K satisfies the above condition
 - That is, K is minimal
- ❖ Example: *Student* (SID , $name$, age , GPA)
 - SID is a key of *Student*
 - $\{SID, name\}$ is not a key (not minimal)

Schema vs. data

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Student

<i>SID</i>	<i>name</i>	<i>age</i>	<i>GPA</i>
142	Bart	10	2.3
123	Milhouse	10	3.1
857	Lisa	8	4.3
456	Ralph	8	2.3
...

- ❖ Is *name* a key of *Student*?
 - Yes? Seems reasonable for this instance
 - No! Student names are not unique in general
- ❖ Key declarations are part of the schema

More examples of keys

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- ❖ *Enroll* (SID , CID)
 - $\{SID, CID\}$
- ❖ *Address* ($street_address$, $city$, $state$, zip)
 - $\{street_address, city, state\}$
 - $\{street_address, zip\}$
- ❖ *Course* (CID , $title$, $room$, day_of_week , $begin_time$, end_time)
 - $\{CID, day_of_week, begin_time\}$
 - $\{CID, day_of_week, end_time\}$
 - $\{room, day_of_week, begin_time\}$
 - $\{room, day_of_week, end_time\}$
 - ☞ Not a good design, and we will see why later

Usage of keys

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- ❖ More constraints on data, fewer mistakes
- ❖ Look up a row by its key value
 - Many selection conditions are “key = value”
- ❖ “Pointers”
 - Example: *Enroll* (*SID*, *CID*)
 - *SID* is a key of *Student*
 - *CID* is a key of *Course*
 - An *Enroll* tuple “links” a *Student* tuple with a *Course* tuple
 - Many join conditions are “key = key value stored in another table”

Motivation for a design theory

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<i>SID</i>	<i>name</i>	<i>CID</i>
142	Bart	CPS216
142	Bart	CPS214
857	Lisa	CPS216
857	Lisa	CPS230
...

- ❖ Why is this design is bad?
 - This design has redundancy, because the name of a student is recorded multiple times, once for each course the student is taking
- ❖ Why is redundancy bad?
 - Wastes space, complicates updates, and promotes inconsistency
- ❖ How about a systematic approach to detecting and removing redundancy in designs?
 - Dependencies, decompositions, and normal forms

Functional dependencies

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- ❖ A functional dependency (FD) has the form $X \rightarrow Y$, where X and Y are sets of attributes in a relation R
- ❖ $X \rightarrow Y$ means that whenever two tuples in R agree on all the attributes in X , they must also agree on all attributes of Y

X	Y	Z
a	b	c
a	b	?
...

Must be b ← ← Could be anything

FD examples

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Address (*street_address*, *city*, *state*, *zip*)

- ❖ $street_address, city, state \rightarrow zip$
- ❖ $zip \rightarrow city, state$
- ❖ $zip, state \rightarrow zip$?
 - This is a trivial FD
 - Trivial FD: $LHS \supseteq RHS$
- ❖ $zip \rightarrow state, zip$?
 - This is non-trivial, but not completely non-trivial
 - Completely non-trivial FD: $LHS \cap RHS = \emptyset$

Keys redefined using FD's

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A set of attributes K is a key for a relation R if

- ❖ $K \rightarrow$ all (other) attributes of R
 - That is, K is a “super key”
- ❖ No proper subset of K satisfies the above condition
 - That is, K is minimal

Reasoning with FD's

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Given a relation R and a set of FD's \mathcal{F}

- ❖ Does another FD follow from \mathcal{F} ?
 - Are some of the FD's in \mathcal{F} redundant (i.e., they follow from the others)?
- ❖ Is K a key of R ?
 - What are all the keys of R ?

Attribute closure

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- ❖ Given R , a set of FD's \mathcal{F} that hold in R , and a set of attributes Z in R :
The closure of Z (denoted Z^+) with respect to \mathcal{F} is the set of all attributes functionally determined by Z
- ❖ Algorithm for computing the closure
 - Start with closure = Z
 - If $X \rightarrow Y$ is in \mathcal{F} and X is already in the closure, then also add Y to the closure
 - Repeat until no more attributes can be added

A more complex example

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StudentGrade ($SID, name, email, CID, grade$)

- ❖ $SID \rightarrow name, email$
 - ❖ $email \rightarrow SID$
 - ❖ $SID, CID \rightarrow grade$
- ☞ Not a good design, and we will see why later

Example of computing closure

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- ❖ \mathcal{F} includes:
 - $SID \rightarrow name, email$
 - $email \rightarrow SID$
 - $SID, CID \rightarrow grade$
- ❖ $\{CID, email\}^+ = ?$
- ❖ $email \rightarrow SID$
 - Add SID ; closure is now $\{CID, email, SID\}$
- ❖ $SID \rightarrow name, email$
 - Add $name, email$; closure is now $\{CID, email, SID, name\}$
- ❖ $SID, CID \rightarrow grade$
 - Add $grade$; closure is now all the attributes in *StudentGrade*

Using attribute closure

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Given a relation R and set of FD's \mathcal{F}

- ❖ Does another FD $X \rightarrow Y$ follow from \mathcal{F} ?
 - Compute X^+ with respect to \mathcal{F}
 - If $Y \subseteq X^+$, then $X \rightarrow Y$ follow from \mathcal{F}
- ❖ Is K a key of R ?
 - Compute K^+ with respect to \mathcal{F}
 - If K^+ contains all the attributes of R , K is a super key
 - Still need to verify that K is *minimal* (how?)

Useful rules of FD's

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- ❖ 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 $X \rightarrow Y$ and $Y \rightarrow Z$, then $X \rightarrow Z$
- ❖ Rules derived from axioms
 - Splitting: If $X \rightarrow YZ$, then $X \rightarrow Y$ and $X \rightarrow Z$
 - Combining: If $X \rightarrow Y$ and $X \rightarrow Z$, then $X \rightarrow YZ$

Non-key FD's

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- ❖ Consider a non-trivial FD $X \rightarrow Y$ where X is not a super key
 - Since X is not a super key, there are some attributes (say Z) that are not functionally determined by X

X	Y	Z
a	b	$c1$
a	b	$c2$
...

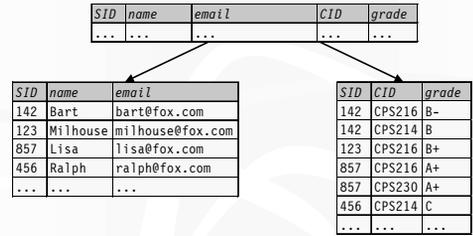
The fact that a is always associated with b is recorded in multiple rows: redundancy!

Example of redundancy

- ❖ *StudentGrade* (*SID*, *name*, *email*, *CID*, *grade*)
- ❖ *SID* → *name*, *email*

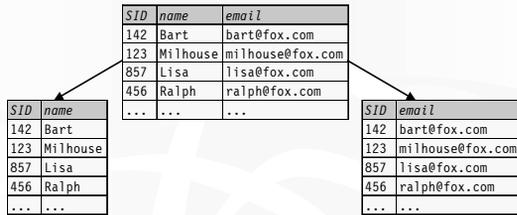
<i>SID</i>	<i>name</i>	<i>email</i>	<i>CID</i>	<i>grade</i>
142	Bart	bart@fox.com	CPS216	B-
142	Bart	bart@fox.com	CPS214	B
123	Milhouse	milhouse@fox.com	CPS216	B+
857	Lisa	lisa@fox.com	CPS216	A+
857	Lisa	lisa@fox.com	CPS230	A+
456	Ralph	ralph@fox.com	CPS214	C
...

Decomposition



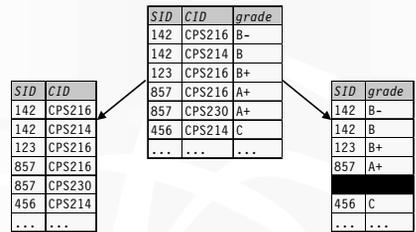
- ❖ Eliminates redundancy
- ❖ To get back to the original relation: ⋈

Unnecessary decomposition



- ❖ Fine: join returns the original relation
- ❖ Unnecessary: no redundancy is removed, and now *SID* is stored twice!

Bad decomposition



- ❖ Association between *CID* and *grade* is lost
- ❖ Join returns more rows than the original relation

Questions about decomposition

- ❖ When to decompose
- ❖ How to come up with a correct decomposition

An answer: BCNF

- ❖ A relation *R* is in Boyce-Codd Normal Form if
 - For every non-trivial FD $X \rightarrow Y$ in *R*, *X* is a super key
 - That is, all FDs follow from “key → other attributes”
- ❖ When to decompose
 - As long as some relation is not in BCNF
- ❖ How to come up with a correct decomposition
 - Always decompose on a BCNF violation
 - ☞ Then it is guaranteed to be a correct decomposition!

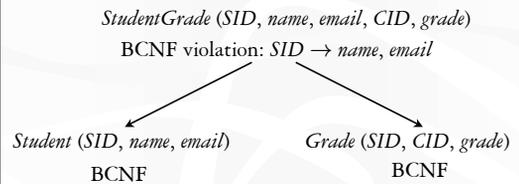
BCNF decomposition algorithm

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- ❖ Find a BCNF violation
 - That is, a non-trivial FD $X \rightarrow Y$ in R where X is not a super key of R
- ❖ Decompose R into R_1 and R_2 , where
 - R_1 has attributes $X \cup Y$
 - R_2 has attributes $X \cup Z$, where Z contains all attributes of R that are in neither X nor Y
- ❖ Repeat until all relations are in BCNF

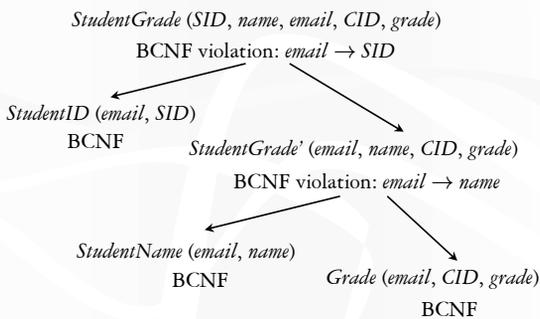
BCNF decomposition example

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Another example

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Recap

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- ❖ Functional dependencies: generalization of keys
- ❖ Non-key functional dependencies: a source of redundancy
- ❖ BCNF decomposition: a method of removing redundancies due to FD's
- ❖ BCNF: schema in this normal form has no redundancy due to FD's
- ☞ Not covered in this lecture: many other types of dependencies (e.g., MVD) and normal forms (e.g., 4NF)
 - GMUW has all the details
 - Relational design theory was a big research area in the 1970's, but there is not much now