Database Design Principles

CPS352: Database Systems

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Agenda

- Check-in
- Design Project ERD Presentations
- Database Design Principles
  - Decomposition
  - Functional Dependencies
  - Closures
  - Canonical Cover
- Homework 3

Check-in

Datatabases

...of the Bible

The Entities and Relationships of the Psalms

Psalm 30, 31, and 32 (NIV)

Some Assertions about Psalm Data

- Each psalm is identified by a number, has a text, and may have a type, recipient, and zero or more instruments
- An author is identified by a name and has a position. An author may write multiple psalms, but every author must be associated with at least one psalm.
- An occasion is identified by a name and has a location. A single psalm can be used for multiple occasions, but it doesn't make sense to have an occasion without a psalm. (How boring would that be!)
- A psalm can describe one or more acts of God, and multiple psalms can describe a single act of God.

Design Project ERD Presentations

Milestone II

Database Design Principles

Introduction

- Terminology review
  - Relation scheme – set of attributes for some relation (R, R_1, R_2)
  - Relation – the actual data stored in some relation scheme (r, r_1, r_2)
  - Tuple – a single actual row in the relation (t, t_1, t_2)
- Changes to the library database schema
  - We make the following updates for this discussion
    - Add the following attributes to the book relation
      - copy_number – a library can have multiple copies of a book
      - accession_number – unique number (ID) assigned to a copy of a book when the library acquires it
  - New book and checked_out relation scheme
    - Book(<u>call_number</u>, <u>copy_number</u>, accession_number, title, author)
    - Checked_out(<u>borrower_id</u>, <u>call_number</u>, <u>copy_number</u>, date_due)

The Art of Database Design

- Designing a database is a balancing act
- On the one extreme, you can have a *universal relation* (in which all attributes reside within a single relation scheme)
  - Everything(

    ```
        borrower_id, last_name, first_name,  // from borrower
        call_number, copy_number,
        accession_number, title, author       // from book
        date_due                              // from checked_out
    )
    ```
- Leads to numerous anomalies with changing data in the database

Break Up Relations with Decomposition

- *Decomposition* is the process of breaking up an original scheme into two or more schemes
  - Each attribute of the original scheme appears in at least one of the new schemes
- But this can be taken too far
  - Borrower(borrower_id, last_name, first_name)
  - Book(call_number, copy_number, accession_number, title, author)
  - Checked_out(date_due)
- Leads to *lossy-join* problems

We Want Lossless-Join Decompositions

- Part of the middle ground in the balancing act
  - Allows decomposition of the Everything relation
  - Preserves connections between the tuples of the participating relations
  - So that the natural join of the new relations = the original Everything relation

- Formal definition
  - For some relation scheme R decomposed into two or more schemes (R_1, R_2, … R_n)
  - Where $R = R_1 \cup R_2 \cup \ldots \cup R_n$
  - A *lossless-join decomposition* means that for every legal instance r of R decomposed into r_1, r_2, … r_n of R_1, R_2, and R_n
  - $r = r_1 \ |X|\ r_2 \ |X|\ \ldots \ |X|\ r_n$

Database Design Goal: Create "Good" Relations

- We want to be able to determine whether a particular relation *R* is in "good" form.
  - We'll talk about how to do this shortly
- In the case that a relation *R* is not in "good" form, decompose it into a set of relations $\{R_1, R_2, \ldots, R_n\}$ such that
  - each relation is in good form
  - the decomposition is a lossless-join decomposition
- Our theory is based on:
  - functional dependencies
  - multivalued dependencies

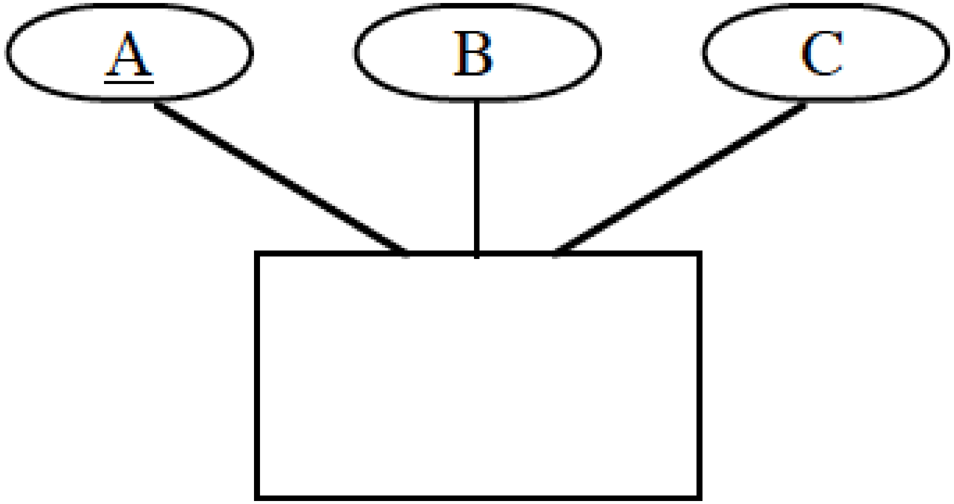
Functional Dependency (FD)

- When the value of a certain set of attributes uniquely determines the value for another set of attributes
  - Generalization of the notion of a key
  - A way to find “good” relations
  - $A \rightarrow B$ (read: A determines B)
- Formal definition
  - For some relation scheme R and attribute sets A ($A \subseteq R$) and B ($B \subseteq R$)
  - $A \rightarrow B$ if for any legal relation on R
    - If there are two tuples t_1 and t_2 such that $t_1(A) = t_2(A)$
    - It must be the case that $t_2(B) = t_2(B)$

Finding Functional Dependencies

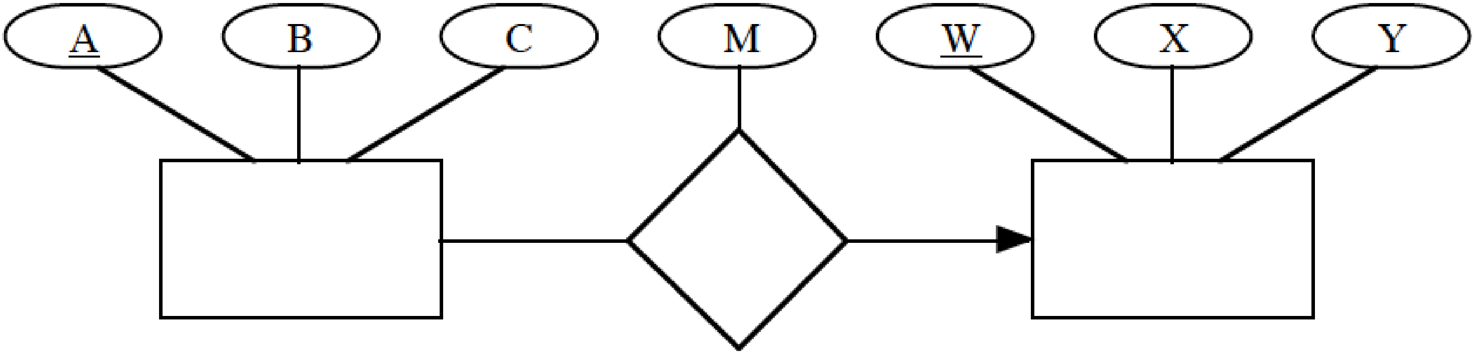
- From keys of an entity
- From relationships between entities
- Implied functional dependencies

FDs from Entity Keys



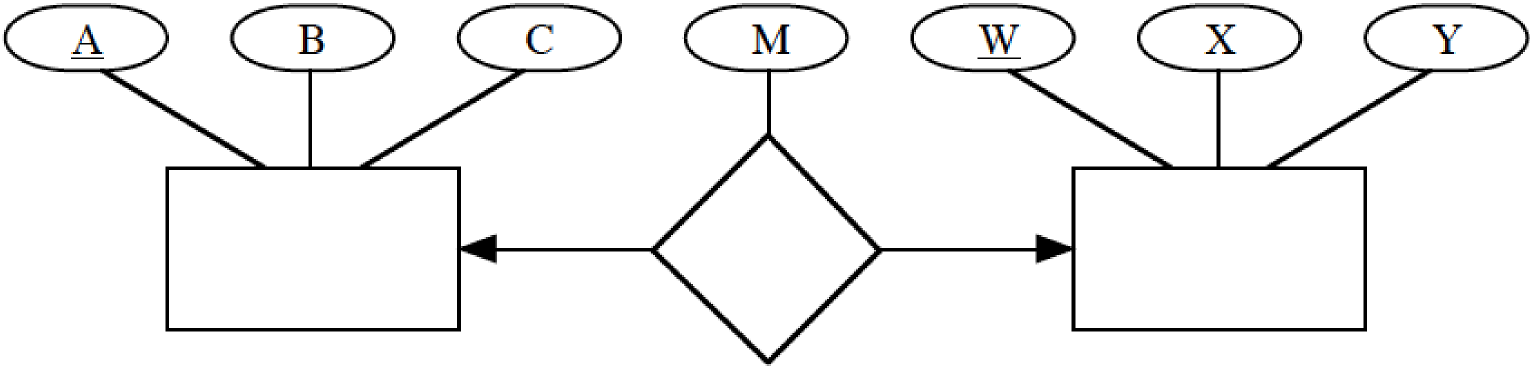
A → BC

FDs from One to Many / Many to One Relationships



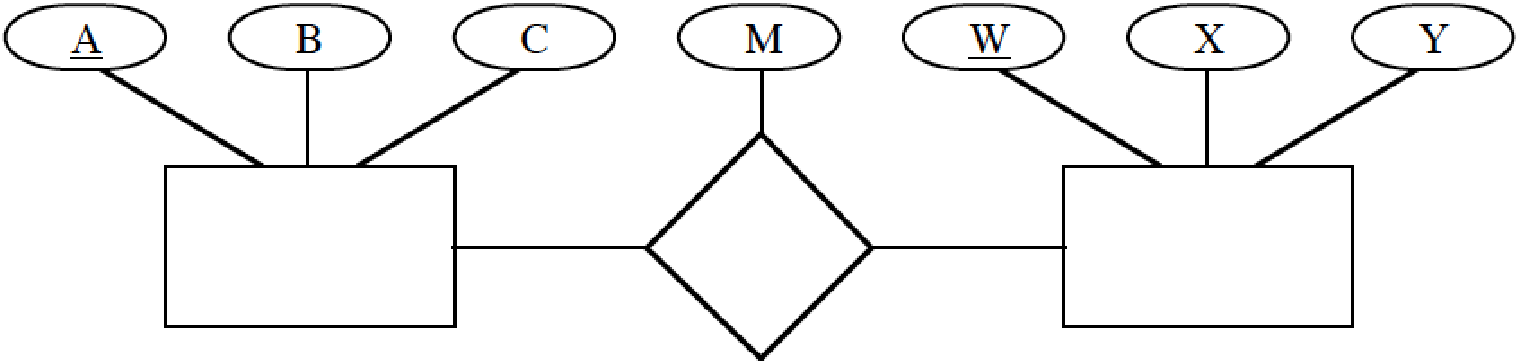
A → BC
W → XY
A → BCMWXY

FDs from One to One Relationships



A → BC
W → XY
A → BCMWXY
W → XYMABC

FDs from Many to Many Relationships



A → BC
W → XY
AW → M

Implied Functional Dependencies

- Initial set of FDs *logically implies* other FDs
  - If A → B and B → C, then A → C
- Closure
  - If F is the set of functional dependencies we develop from the logic of the underlying reality
  - Then F+ (the *transitive closure* of F) is the set consisting of all the dependencies of F, plus all the dependencies they imply

Rules for Computing F+

- We can find F^{+}, the closure of F, by repeatedly applying **Armstrong's Axioms:**
  - if $\beta \subseteq \alpha$, then $\alpha \rightarrow \beta$ **(reflexivity)**
    - *Trivial dependency*
  - if $\alpha \rightarrow \beta$, then $\gamma \alpha \rightarrow \gamma \beta$ **(augmentation)**
  - if $\alpha \rightarrow \beta$, and $\beta \rightarrow \gamma$, then $\alpha \rightarrow \gamma$ **(transitivity)**
- Additional rules (inferred from Armstrong's Axioms)
  - If $\alpha \rightarrow \beta$ *and* $\alpha \rightarrow \gamma$, then $\alpha \rightarrow \beta\gamma$ **(union)**
  - If $\alpha \rightarrow \beta\gamma$, then $\alpha \rightarrow \beta$ and $\alpha \rightarrow \gamma$ **(decomposition)**
  - If $\alpha \rightarrow \beta$ *and* $\gamma \beta \rightarrow \delta$, then $\alpha \gamma \rightarrow \delta$ **(pseudotransitivity)**

Applying the Axioms

- $R = (A, B, C, G, H, I)$
  $F = \{ A \rightarrow B$
  $A \rightarrow C$
  $CG \rightarrow H$
  $CG \rightarrow I$
  $B \rightarrow H\}$

- some members of F^+
  - $A \rightarrow H$
    - by transitivity from $A \rightarrow B$ *and* $B \rightarrow H$
  - $AG \rightarrow I$
    - by augmenting $A \rightarrow C$ with G, to get $AG \rightarrow CG$
      and then transitivity with $CG \rightarrow I$
  - $CG \rightarrow HI$
    - by augmenting $CG \rightarrow I$ to infer $CG \rightarrow \mathrm{CG}I$,
      and augmenting of $CG \rightarrow H$ to infer $CGI \rightarrow HI$,
      and then transitivity
    - or by the union rule

Algorithm to Compute F+

- To compute the closure of a set of functional dependencies F:

```
$F^+ = F$
repeat
    for each functional dependency $f$ in $F^+$
        apply reflexivity and augmentation rules on $f$
        add the resulting functional dependencies to $F^+$
    for each pair of functional dependencies $f_1$ and $f_2$ in $F^+$
        if $f_1$ and $f_2$ can be combined using transitivity
            then add the resulting functional dependency to $F^+$
until $F^+$ does not change any further
```

Algorithm to Compute the Closure of Attribute Sets

- Given a set of attributes α, define the ***closure*** of α **under** F (denoted by α^+) as the set of attributes that are functionally determined by α under F

- Algorithm to compute α^+, the closure of α under F

```
result := α;
while (changes to result) do
    for each β → γ in F do
      begin
        if β ⊆ result then  result := result ∪ γ
      end
```

Example of Attribute Set Closure

- $R = (A, B, C, G, H, I)$
- $$F = \{\begin{aligned}&A \rightarrow B\\ &A \rightarrow C\\ &CG \rightarrow H\\ &CG \rightarrow I\\ &B \rightarrow H\}\end{aligned}$$
- $(AG)^+$
  1. $result = AG$
  2. $result = ABCG$ $(A \rightarrow C$ and $A \rightarrow B)$
  3. $result = ABCGH$ $(CG \rightarrow H$ and $CG \subseteq AGBC)$
  4. $result = ABCGHI$ $(CG \rightarrow I$ and $CG \subseteq AGBCH)$
- Is AG a candidate key?
  1. Is AG a super key?
     1. Does $AG \rightarrow R?$ == Is $(AG)^+ \supseteq R$
  2. Is any subset of AG a superkey?
     1. Does $A \rightarrow R$? == Is $(A)^+ \supseteq R$
     2. Does $G \rightarrow R$? == Is $(G)^+ \supseteq R$

Canonical Cover

- Sets of functional dependencies may have redundant dependencies that can be inferred from the others
  - For example: $A \rightarrow C$ is redundant in: $\{A \rightarrow B, \quad B \rightarrow C, A \rightarrow C\}$
  - Parts of a functional dependency may be redundant
    - E.g.: on RHS: $\{A \rightarrow B, \quad B \rightarrow C, \quad A \rightarrow CD\}$ can be simplified to
      $\{A \rightarrow B, \quad B \rightarrow C, \quad A \rightarrow D\}$
    - E.g.: on LHS: $\{\mathrm{A} \rightarrow B, \quad B \rightarrow C, \quad AC \rightarrow D\}$ can be simplified to
      $\{\mathrm{A} \rightarrow B, \quad B \rightarrow C, \quad A \rightarrow D\}$

- Intuitively, a canonical cover of F is a "minimal" set of functional dependencies equivalent to F, having no redundant dependencies or redundant parts of dependencies

Definition of Canonical Cover

- A **canonical cover** for *F* is a set of dependencies F_c such that
  - *F* logically implies all dependencies in $F_{c,}$ and
  - F_c logically implies all dependencies in *F,* and
  - No functional dependency in F_c contains an extraneous attribute, and
  - Each left side of functional dependency in F_c is unique.

- To compute a canonical cover for *F*:

```
repeat
        Use the union rule to replace any dependencies in $F$
                $\alpha_1 \rightarrow \beta_1$ and $\alpha_1 \rightarrow \beta_2$ with $\alpha_1 \rightarrow \beta_1 \beta_2$
        Find a functional dependency $\alpha \rightarrow \beta$ with an
                extraneous attribute either in $\alpha$ or in $\beta$
                /* Note: test for extraneous attributes done using $F_{c,}$ not F*/
        If an extraneous attribute is found, delete it from $\alpha \rightarrow \beta$
until $F$ does not change
```

- Note: Union rule may become applicable after some extraneous attributes have been deleted, so it has to be re-applied

How to Find a Canonical Cover

- Another algorithm
  - Write F as a set of dependencies where each has a single attribute on the **right hand side**
  - Eliminate trivial dependencies
    - In which $\alpha \rightarrow \beta$ and $\beta \subseteq \alpha$ (reflexivity)
  - Eliminate redundant dependencies (implied by other dependencies)
  - Combine dependencies with the same left hand side
- For any given set of FDs, the canonical cover is not necessarily unique

Uses of Functional Dependencies

- Testing for lossless-join decomposition
- Testing for dependency preserving decompositions
- Defining keys

Testing for Lossless-Join Decomposition

- The closure of a set of FDs can be used to test if a decomposition is lossless-join

- For the case of $R = (R_1, R_2)$, we require that for all possible relations r on schema R

$$r = \prod_{R1}(r) \quad \prod_{R2}(r)$$

- A decomposition of R into R_1 and R_2 is lossless join if at least one of the following dependencies is in F^+:
  - $R_1 \cap R_2 \rightarrow R_1$
  - $R_1 \cap R_2 \rightarrow R_2$

- Does the intersection of the decomposition satisfy at least one FD?

Testing for Dependency Preserving Decompositions

- The closure of a set of FDs allows us to test a new tuple being inserted into a table to see if it satisfies all relevant FDs without having to do a join
  - This is desirable because joins are expensive
- Let F_i be the set of dependencies F^+ that include only attributes in R_i.
  - A decomposition is **dependency preserving**, if

    $(F_1 \cup F_2 \cup \ldots \cup F_n)^+ = F^+$
  - If it is not, then checking updates for violation of functional dependencies may require computing joins, which is expensive.
- The closure of a dependency preserving decomposition equals the closure of the original set
- Can all FDs be tested (either directly or by implication) without doing a join?

Keys and Functional Dependencies

- Given a relation scheme R with attribute set $K \subseteq R$
  - K is a superkey if $K \rightarrow R$
  - K is a candidate key if there is no subset L of K such that $L \rightarrow R$
    - A superkey with one attribute is always a candidate key
  - Primary key is the candidate key K chosen by the designer
- Every relation must have a superkey (possibly the entire set of attributes)
- *Key attribute* – an attribute that is or is part of a candidate key

Homework 3