COMP9120

Week 8: Schema Refinement and Normalisation

Semester 1, 2025

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THE UNIVERSITY OF SYDNEY

Contents co-developed with Dr Lijun Chang

Warming up

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Acknowledgement of Country

I would like to acknowledge the Traditional Owners of Australia and recognise their continuing connection to land, water and culture. I am currently on the land of the Gadigal people of the Eora nation and pay my respects to their Elders, past, present and emerging.

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Assignment 2

- Released **tonight**
- **Focus:** Database Application Development
  - Gain practical experience in interacting with a relational database management system using an Application Programming Interface (API) (Python DB-API).
  - This assignment additionally provides an opportunity to use more advanced features of a database such as functions.
  - **Choice**: Java or Python
- **Deadline: Sunday 18 May 2025 23:59** (1 month)

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Outline

- **Redundancy**
  - Update/Insertion/Deletion anomalies
- **Functional Dependencies and Normal Forms**
  - Functional dependencies
  - Attribute closure, candidate keys
  - 1NF, 2NF, 3NF, BCNF
  - Multivalued dependencies and 4NF
- **Schema Decomposition**
  - How to decompose a relation into BCNF relations
    - Lossless decomposition
    - Dependency-preservation

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Redundant Data Can Cause Anomalies

Student	UnitOfStudy	Room
Mary	COMP9120	
Joe	COMP9120	
Sam	COMP9120	
..	..	..

If a unit of study is in only one single room, this table contains ***redundant*** information!

Student	UnitOfStudy	Room
Mary	COMP9120	R203
Joe	COMP9120	R101
Sam	COMP9120	R203
..	..	..

If we update the room number for *all but one* tuple, we get inconsistent data => an ***update* anomaly**

If everyone drops the unit of study, *we lose what room this unit is in* => a ***delete* anomaly**

Similarly, we cannot reserve a room for *a unit of study without students* => an ***insert* anomaly**

Redundant Data Can Cause Anomalies

Alternatively:

Student	UnitOfStudy
Mary	COMP9120
Joe	COMP9120
Sam	COMP9120
..	..

UnitOfStudy	Room
COMP9120	R101
..	..

Is this better in terms of

- Redundancy?
- Update anomaly?
- Delete anomaly?
- Insert anomaly?

YES!

Bad and good database design

- **Bad design** usually means
  - *Redundancy* (waste of disk space)
  - Update/insertion/deletion *anomalies*
- **Good design** usually means
  - *Minimal* redundancy
  - *No* update/insertion/deletion *anomalies*

What is the **Aim** of **Good Design**?

1. Develop a ***theory*** to understand *whether* a relation *must* be ***decomposed*** to address the *redundancy* and *update*/*insertion*/*deletion* anomalies.

2. Provide a ***foundational framework*** on *how* to ***decompose*** the relation.

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Normalization

Solution to bad design: *Normalize* the design to avoid the mentioned *anomalies*.

Normalization is the process that defines what is *acceptable as good relational design.*

- Geared towards resolving issues surrounding ***changes*** (*updates, insertion, deletions*) to the database

Before learning about the normalization process, we need to define a *key effective tool* we will use:

- **Functional Dependencies (FDs)** - a tool to:
  - ***Capture semantic relationships between attributes***
  - ***Detect*** and ***eliminate bad design***

In database design:

- we use **FDs** to *identify redundancies*.
- we ***also*** use **FDs** to *decompose* relations *to eliminate* the related *update/insertion/delete* issues.

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Functional Dependencies

› **Informal** definition of a **Functional Dependency** (FD):

Value of attribute X **determines** *the value of attribute Y*

- Every UoS is taught in a single room
  - E.g., COMP9120 is always held in Room R101

› **Formal** definition of a **Functional Dependency** (FD):

$$\mathbf{X \rightarrow Y}$$

and we say "X (functionally) **determines** Y"

- Assuming that X and Y are two sets of attributes, the relationship between X and Y values is modelled using a ***function***.
  - A *function* essentially *means* that ***a value of X cannot be mapped to more than one value of Y***. **Only** (n-1) (and **thus** (1-1)) relationships may exist between X and Y.
    - Example: UoS $\rightarrow$ Room

Functional Dependencies

- **How** do we determine **functional dependencies**?
- Two ways
  - By considering:
    - ***Semantic meaning*** of the attributes

    or

    - ***Actual data*** in tables
- In most cases, we use the *former* (i.e., *semantic meaning* of attributes).
- In the *latter* case (considering *data*), the process is called *knowledge mining*.

Another example

- Let us now look at how *data* can be used to *derive FDs* in the relation *Lending*.

branch_name	assests	city	loan_no	customer_name	amount
Mall St	9000000	Sydney	17	Jones	1000
Logan	5000000	Melbourne	23	Smith	2000
Queen	500000	Perth	15	Hayes	1500
Mall St	9000000	Sydney	14	Jackson	1500
King George	10000000	Brisbane	93	Carry	500
Queen	500000	Perth	25	Glenn	2500
Bondi	15000000	Adelaide	10	Brooks	2500
Logan	5000000	Melbourne	30	Johnson	750

- There is a functional dependency:

$$\text{branch\_name} \rightarrow \text{city}$$

Functional Dependencies

branch_name	assests	city	loan_no	customer_name	amount
Mall St	9000000	Sydney	17	Jones	1000
Logan	5000000	Melbourne	23	Smith	2000
Queen	500000	Perth	15	Hayes	1500
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Logan	5000000	Melbourne	30	Johnson	750

- Do you see any other functional dependency?
  - For instance, are the following FDs correct?

loan_no → customer_name, amount? **YES**

loan_no → branch_name? **YES**

city → customer_name? **NO**

city → assets? **YES**

Functional Dependencies

Consider the following table called *PhD*:

SID	first	last	dept	advisor	award	description
1234	Brian	Cox	IT	Codd	Rejected	Work not deemed sufficient
3456	Albert	Einstein	IT	Boyce	Conditional	Accepted with minor corrections
3456	Albert	Einstein	Physics	Newton	Accepted	Accepted with no corrections
7546	Alan	Turing	IT	Codd	Accepted	Accepted with no corrections
4879	Brian	Cox	Physics	Newton	Conditional	Accepted with minor corrections
4879	Brian	Cox	Media	Attenborough	Accepted	Accepted with no corrections

What *functional dependencies* might exist in the **PhD relation** above?

Determining FDs based on data

- Note that
  - We might be able to tell that a certain FD does ***not*** hold by just looking at an instance of a relation
  - However, we can **never** deduce that an FD *does* hold by looking at any number of instances of a relation.
  - Why?
    - Because an FD **is a statement** about *all possible legal instances* of the relation.

FD Inference Rules

› **Armstrong's Axioms** (*A, B, C* are sets of attributes):

Axiom definition: *An axiom is a statement that is taken to be true and serves as a premise or starting point for further reasoning and arguments*[1].

1. **Reflexivity:** If $B \subseteq A$, then $A \rightarrow B$

- Example: *cpoints, uos_name* $\rightarrow$ *uos_name*

These are called **Trivial FDs**: When all RHS attributes appear on LHS. *All reflexive* FDs are *trivial*.

2. **Augmentation:** If $A \rightarrow B$, then $AC \rightarrow BC$ for any set of attributes C

- Example: *cpoints* $\rightarrow$ *wload* **implies** *cpoints, uos_name* $\rightarrow$ wload, *uos_name*

3. **Transitivity:** If $A \rightarrow B$ and $B \rightarrow C$, then $A \rightarrow C$

- Example: *uos_code* $\rightarrow$ *cpoints*, *cpoints* $\rightarrow$ *wload* **implies** *uos_code* $\rightarrow$ *wload*

[1]Wikipedia

Inferring Functional Dependency

› Example

Products

Name	Color	Category	Dept	Price
Gizmo	Green	Gadget	Toys	49
Widget	Black	Gadget	Toys	59
Gizmo	Green	Whatsit	Garden	99

Functional Dependencies:

Name → Color
Category → Dept
Color, Category → Price

Given the above FDs, we *deduce* that *Name, Category → Price* must also hold on **any instance:** Let us use *augmentation* and *transitivity* as a proof

Name, Category → Color, Category
Color, Category → Price

Augmentation

Inferring Functional Dependency

› Example

Products

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Functional Dependencies:

Name → Color
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Name, Category → Price

Transitivity

Closure of a set of FDs

- ***Closure*** of a set of FDs ***F*** is the set ***F⁺***:
  - the set of *all* FDs that *can be deduced* from the set F using the inference rules (Armstrong's axioms): *reflexivity*, *augmentation*, and *transitivity* inference rules.

- More formally, the closure of a **set F** is the **set F^+** defined by:

$$\mathbf{F^+ = \{X \rightarrow Y \mid F \models X \rightarrow Y\}}$$

- In general, the calculation of the closure of **F** is, in the worst case, *exponential* in the number of attributes in **F**.

Closure of a set

Algorithm for finding the **closure** of a set of FDs:

Initialize $F^+ = F$

Repeat

For each functional dependency FD in F^+

*Apply **reflexivity** and **augmentation** rules on F^+*

Add the result 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***

Add the result to F^+

Until F^+ does not change.

FD Closure Example

Assume that we have three attributes A, B, C in a relation R.

- With the following FDs, F = {A → B, B → C}.

› Using the previous algorithm, F^+ includes the following FDs:

A → A,	AB → A,	ABC → A,
A → B,	AB → B,	ABC → B,
A → C,	AB → C,	ABC → C,
B → B,	AC → A,	………. etc
B → C ,	AC → B,	
C → C	AC → C,	
	BC → B,	
	BC → C	
	…….	

FD Closure

- A few additional rules (that follow from Armstrong's Axioms):
  - **Decomposition**

    If $A \rightarrow BC$, then $A \rightarrow B$ and $A \rightarrow C$

  - **Union**

    If $A \rightarrow B$ and $A \rightarrow C$, then $A \rightarrow BC$

Proof:
$A \rightarrow$ BC
$BC \rightarrow$ B [Reflexivity]
$A \rightarrow B$ [Transitivity]

A $\rightarrow$ BC
BC $\rightarrow$ C [Reflexivity]
A $\rightarrow$ C [Transitivity]

Proof:
$A \rightarrow B$
AA $\rightarrow$ AB [Augmentation]
A$\rightarrow$ AB [definition of a set, i.e., A=AA]
and
$A \rightarrow C$
AB $\rightarrow$ BC[Augmentation]
$A \rightarrow BC$ [Transitivity]

- Note that Armstrong's Axioms are
  - ***Sound***
    - they generate ***only*** *FDs* in F^+ when applied to a set F of FDs
  - ***Complete***
    - repeated application of these rules will generate ***all*** FDs in the closure F^+

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Functional Dependency and Keys

- A **superkey** is a set of attributes that *uniquely* identify each tuple in a relation
  - If K is a superkey for a relation R, then **K → R** i.e., K ***determines all*** the attributes of R
- A candidate **key** (or just **key**) is a minimal superkey, i.e.,
  - ***No subset*** of a candidate key is a candidate key itself
  - There may be ***many candidate*** keys for a relation, but ***only 1 primary key***.

- Example: Given a relation R, with attributes **ABCDE** (each letter denotes an attribute) where:
  - **A** *uniquely identifies* each row in R
  - **BC** also *uniquely identifies* each row in R (but *not B or C alone*)
  - **A** is a superkey (*and candidate* key) for R
  - **BC** is a superkey (*and candidate* key) for R
  - **BCE** is a superkey (but ***not** a candidate key*)
    - because it is ***not*** minimal!

Attribute Closure

- **Attribute Closure of a set of attributes *X* denoted as *X⁺* :**
  - Given a set ***F*** of FDs and a set of attributes ***X***, ***X⁺*** *(called closure of **X**)* is the *set of all attributes* that *are determined by **X** under **F**.* It is denoted

$$X \rightarrow X^+$$

- Attribute closure helps to ***check*** whether an attribute (or a set of attributes) is a key for the relation.
- How?
  1. Any set of attributes, whose **attribute closure** is the whole relation, is a **superkey**
  2. A *superkey* is a *candidate key* if it is **minimal** (i.e., **none** of its subset is a superkey)

Compute Attribute Closure: Algorithm

Starting with a given set of attributes ***X***, we repeatedly expand the set by adding the *right side* of an FD as soon as the *left side* is present:

Algorithm to compute the closure X^+ of a set of attribute X:

1. Initialise *result* with the *given set* of attributes, i.e., $X^+ = \{A_1, \ldots, A_n\}$ *(reflexivity rule)*
2. Repeatedly search for some *FD* $A_1 A_2 \ldots A_m \rightarrow C$ such that all $A_1, \ldots, A_m$ are already in the set of attributes *result*, but C is *not.*
3. Add *C* to the set *result. (transitivity and decomposition rules)*
4. Repeat steps 2-3 until *no more attributes* can be added to *result*
5. The set *result* is then the correct value of X^+

Exercise: Candidate Keys*

What are the keys of the following relation:

PhD(sid, first, last, dept, advisor, award, description)

Given the FDs

a) sid → first, last

b) advisor → dept

c) description → award

d) sid, dept → advisor, description

(sid, dept)$^+$ → sid,dept
→ sid,dept,first,last
→ sid,dept,first,last,advisor,description
→ sid,dept,first,last, advisor,description,award

(sid, dept)$^+$= R, therefore, it **is a superkey**.

Is it a *candidate* key? Let's check its subsets.

{sid}$^+$={sid, first, last} **not key**
{dept}$^+$={dept} **not key**

YES, (sid, dept) is a candidate key.

Let's try (sid, dept)?

What about (sid, description)? Is it a candidate key?

Short break

please stand up and stretch

Let us also menti….

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Normal Forms

- **Normal Forms**
  - The goal of normal forms is to **reduce** *different types of redundancies*
  - Note: In what follows, a **key** refers to a **candidate key**, unless otherwise stated. Without loss of generality, we assume that we have ***one single candidate key*** in all examples, unless specified otherwise.
  - Each *normal form* is characterized by *a specific set of conditions*.
    - For a relation to be in *a normal form*, it must satisfy the *conditions associated* with that form.

› We focus on **1NF, 2NF, 3NF, BCNF,** and **4NF**

- Based on ***Functional Dependencies (FDs)*** and ***MultiValued Dependencies(MVDs)*.**

› **Normalisation** is the process of *meeting* a design *goal* which may require *breaking down* relations into smaller relations to *reduce* specific types of *redundancies*

First Normal Forms

- A relation *R* is in **First Normal Form (1NF)** if the *domains* of *all attributes* of *R* are *atomic*.
  - *multivalued attributes* are an example of *non-atomic* domains

Important note: Objective of 1NF is ***not the same*** *as the other normal forms*:

According to its creator, Ted Codd, the *goal is to allow data to be queried and manipulated using a "universal data sub-language"* that is *grounded in first-order logic.*

Student	UnitOfStudy
Mary	{COMP9120,COMP5318}
Joe	{COMP9120,COMP5313}

Violates 1NF

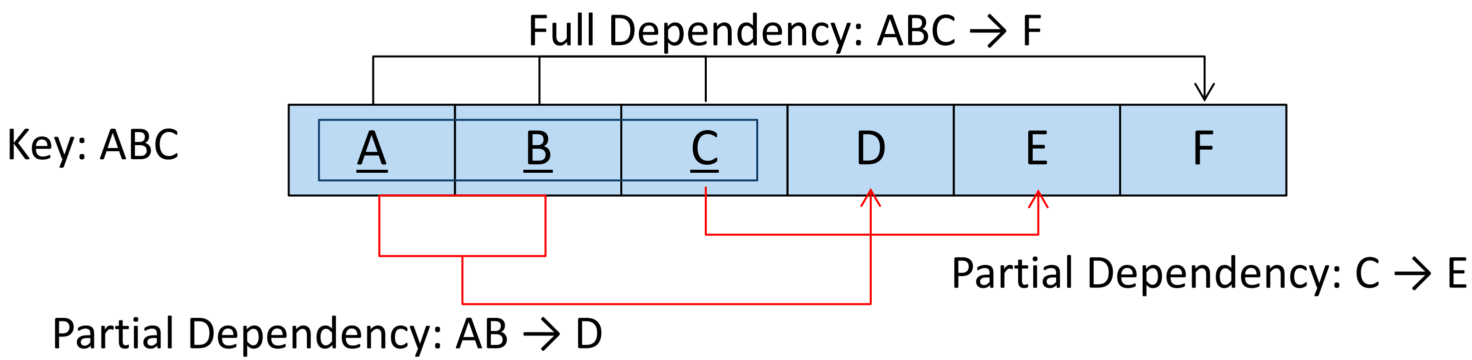
Student	UnitOfStudy
Mary	COMP9120
Mary	COMP5318
Joe	COMP9120
Joe	COMP5313

In 1NF

Second Normal Form (2NF)

› 1NF + ***No partial dependencies***

- A *partial dependency* is a *non-trivial* FD ***X*** $\longrightarrow$ ***Y*** in **R** where ***X*** is a *strict (proper) subset* of some key for **R** and ***Y*** *is not part of a key*:
  - *There cannot be a functional dependency between a subset of a key to non-key attributes*. This is applicable only when the key consists of *more* than *one* attribute.



Partial Dependency

<u>Teacher_name</u>	<u>UnitOfStudy</u>	Teacher_position
Mary	COMP9120	Lecturer
Mary	COMP5313	Lecturer

Violates 2NF

Second Normal Form (2NF)

- Problem: redundancy.

  In the example above, the *teacher* ***position*** would have *to be* ***repeated*** *for* ***all units*** *of study that the teacher teaches*!

- More formally,

  A relation is in the 2NF if the closure F^+ contains ***no*** functional dependency of the form: $X \rightarrow Y$ where Y is *nonprime* (i.e., not part of a candidate key) and X is *a proper subset* of a candidate key. In this case, Y is said to be *fully functionally dependent* on the key.

- What is the possible solution to the above *violation*?

  Decompose the relation into *two relations* such that *X and Y are in one relation* and *X is in the remaining relation*. The next step is to *check* that the *resulting relations are in 2NF*.

  Example above: Decompose R(Teach_name, UnitOfStudy, Teacher_position) into two relations: R1(Teacher_name, Teacher_position) and

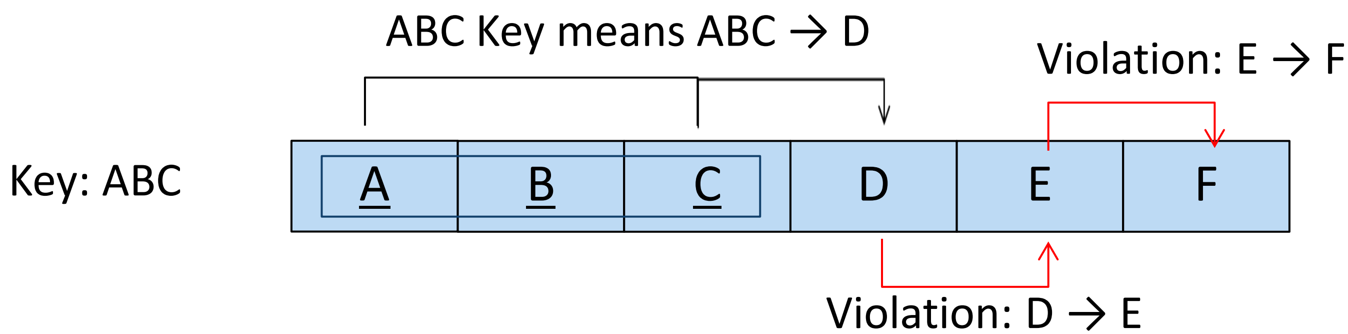
  R2(Teacher_name, UnitOfStudy)

  Teacher_name $\rightarrow$ Teacher_position

Third Normal Form

- **Third Normal Form (3NF)**
- Formal definition: a relation R is in 3NF *if for each dependency X→ Y in F^+, at least one of the following conditions holds*:
  - X → Y is a trivial FD (Y ⊆ X)
  - X is a superkey for R
  - Y ⊂ (is a proper subset of) a candidate key for R
- A plain English definition of 3NF is: A relation is in 3NF *if and only if* (denoted *iff*) it is in 2NF and *every non-key* attribute is *not transitively* functionally dependent on a key.

Third Normal Form



Employee_name	department	location
Jim	Research	Brisbane
John	Manufacturing	Melbourne
Mary	Research	Brisbane
Sue	Manufacturing	Melbourne

Violates 3NF

- There is a *functional dependency* between *Department* and *Location* (thus *transitive dependency*).

Third Normal Form

- Problem: redundancy

  The department's location is *repeated* with *every employee* working in that department.

- Solution: split up the relation into two relations:
  - R1(<u>Employee</u>, Department) and R2(<u>Department</u>, Location)

<u>Employee</u>	**Department**

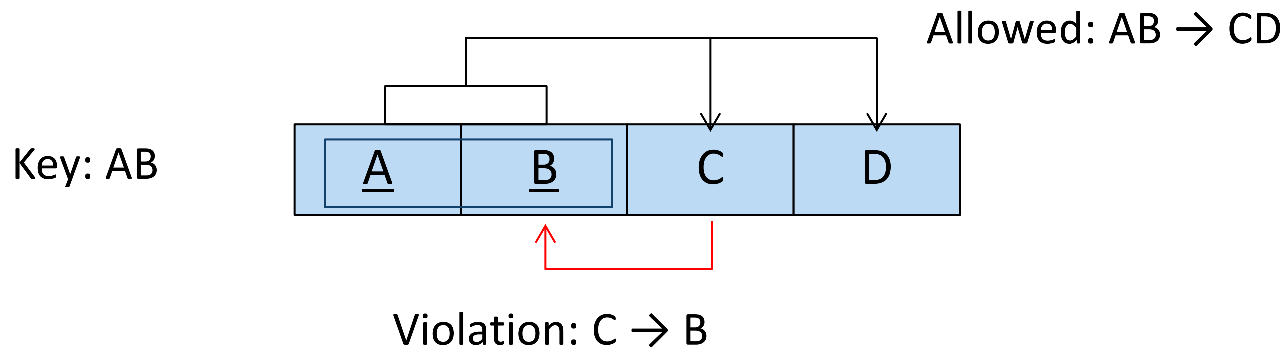
<u>Department</u>	**Location**

Boyce-Codd Normal Form

- Boyce-Codd Normal Form (BCNF) is a **stronger form** of 3NF

  Problem: 3NF *allows functional dependencies* between *non-prime attributes to prime attributes.*

- A relation *R* is in **BCNF** if **all** *non-trivial FDs* over *R,* **have** a superkey of R on the Left Hand Side (LHS). In other words, a relation is in BCNF *iff* every attribute *is dependent on the key, the whole key and nothing but the key*.
  - Formally: For all *non-trivial* $X \rightarrow Y$ *for R*: *X is a superkey for R*
  - Informally: *All dependency arrows are from superkeys*



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- A relation *R* is in **BCNF** if **all** *non-trivial FDs* over *R,* **have** a superkey of R on the Left Hand Side (LHS). In other words, a relation is in BCNF *iff* every attribute *is dependent on the key, the whole key and nothing but the key*.
  - Formally: For all *non-trivial* $X \rightarrow Y$ *for R*: *X is a superkey for R*
  - Informally: *All dependency arrows come out of superkeys*

Teacher_name	**UnitOfStudy**	**Address**
Mary	COMP9120	One Street
Mary	COMP5313	One Street

Violation: Address $\rightarrow$ Teacher_name

Boyce-Codd Normal Form

› Problem: redundancy

A teacher's name is repeated for every address of that teacher teaching a unit of study.

› Solution: split up the relation into two relations:

- R1(<u>Address</u>, Teacher_name) and R2(Address, <u>UnitofStudy</u>)

<u>Address</u>	Teacher_name

<u>UnitOfStudy</u>	Address

Example: Is the relation in BCNF?

Enrol(<u>sid</u>, <u>uosCode</u>, title, credits, hours, lecturer, grade)
Key = (sid, uosCode)

1. uosCode → title, credits, lecturer
2. credits → hours

NO:

1. violates 2NF, therefore it violates BCNF
2. violates 3NF, therefore it violates BCNF

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Issues with 1NF

- Because the 1NF *does not allow more than one value* for each attribute, here is an example of how we can deal with *multiple* values for an attribute.

name	profession	Language
John	{Electrician, Plumber}	French, Korean
Mary	{Doctor, Author}	Spanish, Chinese

name	profession	Language
John	Electrician	French
Mary	Doctor	Spanish
John	Plumber	Korean
Mary	Author	Chinese

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Issues with 1NF

- Because the 1NF *does not allow more than one value* for each attribute, here is an example of how we can deal with *multiple* values for an attribute.

name	profession	Language
John	Electrician	French
Mary	Doctor	Spanish
John	Plumber	Korean
Mary	Author	Chinese

However, these values suggest that whenever

- John is electrician, he speaks French.
- John is plumber, he speaks Korean.

Same for Mary. The values suggest that whenever

- Mary is an author, she speaks Chinese
- Mary is a doctor, she speaks Spanish

This table data is implying that there is a relationship between the *Profession* John is engaged in **and** the *Language* that he speaks!

*This is of course **semantically incorrect**. John and Mary speak these languages irrespective of the professions they are engaged in!*

Fixing the 1NF issue

name	profession	Language
John	Electrician	French
Mary	Doctor	Spanish
John	Plumber	Korean
Mary	Author	Chinese

*So **not to infer** such an incorrect semantic relationship*, there is a need to ***repeat all combinations*** of these attributes.

name	profession	Language
John	Electrician	French
Mary	Doctor	Spanish
John	Plumber	Korean
Mary	Author	Chinese
John	Plumber	French
Mary	Author	Spanish
John	Electrician	Korean
Mary	Doctor	Chinese

This means that

John will have both languages occurring with both of his professions!

Mary will have both languages occurring with both of her professions!

MultiValued Dependency (MVD)

- Informal definition: A **multivalued dependency** between X and Y *exists* if *no relationship can be inferred* between X and Z, i.e., they are *independent* of each other.

- More formally, let R (X, Y, Z) be a relation and X, Y and Z are sets of attributes of R, there is a *multivalued dependency*, noted:

$$X \twoheadrightarrow Y \text{ (X } \textit{multidermines} \text{ Y)}$$

if for all tuples t_1 and t_2 that agree in X, i.e., $t_1[X] = t_2[X]$, there exist tuples t_3 and t_4 such that:

1. $t_1[X] = t_2[X] = t_3[X] = t_4[X]$ and
2. $t_3[Y] = t_1[Y]$ and $t_4[Y] = t_2[Y]$ and
3. $t_3[Z] = t_2[Z]$ and $t_4[Z] = t_1[Z]$

tuples	X	Y	Z
t_1	a_1………a_i	a_{i+1}………a_j	a_{j+1}………a_n
t_2	a_1………a_i	b_{i+1}………b_j	b_{j+1}………b_n
t_3	a_1………a_i	a_{i+1}………a_j	b_{j+1}………b_n
t_4	a_1………a_i	b_{i+1}………b_j	a_{j+1}………a_n

MultiValued Dependency (MVD): Example

Example:

UoS ↠ *Textbook* ?

Note that according to the values in the relation, the relationship between the UoS and Textbook is ***independent*** from the relationship between UoS and Tutor. *This means that there is an MVD between UoS and Textbook*. This also implies that the textbook of a UoS is set *independently*.

Assume a *new textbook* by *Ramakrishnan* is added to the UoS COMP9120. *What should happen to maintain this independence (i.e., MVD)*?

- ***Add one row for each Tutor of that UoS.***

UoS	Textbook	Tutor
COMP9120	Silberschatz	Ying Z
COMP9120	Widom	Ying Z
COMP9120	Silberschatz	Mohammad P
COMP9120	Widom	Mohammad P
COMP9120	Silberschatz	Alan F
COMP9120	Widom	Alan F
COMP5110	Silberschatz	Ying Z
COMP5110	Silberschatz	Mohammad P
COMP9120	**Ramakrishnan**	**Alan F**
COMP9120	**Ramakrishnan**	**Ying Z**
COMP9120	**Ramakrishnan**	**Mohammad P**

Fourth Normal Form (4NF)

Fourth Normal Form (4NF)

Redundancy problem in MVDs:

- For the first example: should list *all professions* for *every language* a person speaks.
- For the second example: should *list all tutors* for *each textbook* that a UoS has listed.

4NF deals with *redundancies* created by ***multivalued dependencies***.

Formally:

R is in **4NF** *if* for **all MVDs** of the form $\mathbf{X \twoheadrightarrow Y}$ in F^+, at least one of the following conditions holds:

- $X \twoheadrightarrow Y$ is *a trivial MVD* (i.e., *either* $Y \subseteq X$ *or* $X \cup Y = R$)
- X is a *superkey* for R

Fourth Normal Form (4NF)

Assuming the *only key* to the following relation is the set : (Project-id, Personal-phone#):

employee_name	project_id	personal_phone_number
Bob	P1	047012345
Bob	P3	046098765
Bob	P1	046098765
Bob	P3	047012345
Lily	P1	045067543
Fiona	P7	043085432

Is this relation in 4NF?

No: There is at least *one non-trivial multivalued dependency*

employee_name ↠ Project-id (Note that employee_name is *not* a superkey).

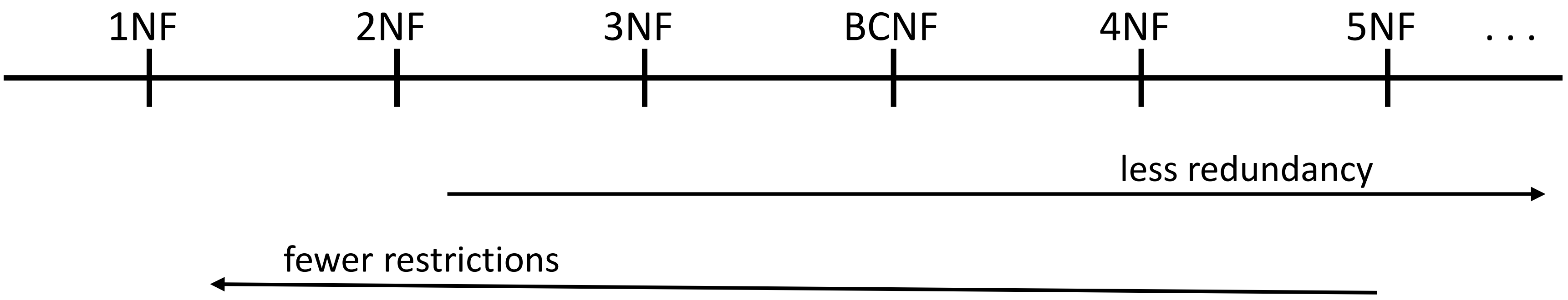
Solution: split the above relation into two relations:

employee_name	Project_id

employee_name	Personal_phone_number

Now the two relations are in 4NF!

Beyond 4NF



- Higher normal forms
  - 5NF, 6NF/DKNF
  - They also exploit other types of dependencies
    - Join dependencies
    - Inclusion dependencies

Outline

- **Redundancy**
  - Update/Insertion/deletion anomalies
- **Functional Dependencies and Normal Forms**
  - Functional dependencies
  - Attribute closure, candidate keys
  - 1NF, 2NF, 3NF, BCNF
  - Multivalued dependencies and 4NF
- **Schema Decomposition**
  - ***Dependency-preservation*** and ***lossless decomposition*** into BCNF

Decomposition: Example 1

uosCode → uosName

Student	UoSCode	UoSName	Grade
Alice	COMP5138	Database Management Systems	CR
Alice	COMP5338	Advanced Data Models	D
Bob	COMP5138	Database Management Systems	P
Clare	COMP5338	Advanced Data Models	HD
David	COMP5338	Advanced Data Models	CR

⋈

Student	UoSCode	Grade
Alice	COMP5138	CR
Alice	COMP5338	D
Bob	COMP5138	P
Clare	COMP5338	HD
David	COMP5338	CR

UoSCode	UoSName
COMP5138	Database Management Systems
COMP5338	Advanced Data Models

Decomposition: Example 2

uosCode → uosName

Student	UoSCode
Alice	COMP5138
Alice	COMP5338
Bob	COMP5138
Clare	COMP5338
David	COMP5338

UoSCode	UoSName	Grade
COMP5138	Database Management Systems	CR
COMP5138	Database Management Systems	P
COMP5338	Advanced Data Models	CR
COMP5338	Advanced Data Models	D
COMP5338	Advanced Data Models	HD

$\bowtie$

Student	UoSCode	UoSName	Grade
Alice	COMP5138	Database Management Systems	CR
Alice	COMP5138	Database Management Systems	P
Alice	COMP5338	Advanced Data Models	CR
Alice	COMP5338	Advanced Data Models	D
Alice	COMP5338	Advanced Data Models	HD
Bob	COMP5138	Database Management Systems	CR
Bob	COMP5138	Database Management Systems	P
Clare	COMP5338	Advanced Data Models	CR
Clare	COMP5338	Advanced Data Models	D
Clare	COMP5338	Advanced Data Models	HD
David	COMP5338	Advanced Data Models	CR
David	COMP5338	Advanced Data Models	D
David	COMP5338	Advanced Data Models	HD

Schema Decomposition

- A <u>decomposition</u> of R **replaces** R by two or more *distinct* relations:
  - Each new relation schema contains a subset of the attributes of R, and
  - Every attribute of R appears as an attribute in *at least one* of the new relations.
  - Many possible decompositions – however, *not all equally* good/correct

- Need strong decomposition *properties*:
  - **Dependency preservation**: ***No FDs are lost*** in the decomposition
  - **Lossless-join (also called non-additive) decomposition**: *Re-joining a decomposition* of R should give us back R!

Dependency preservation

- **Dependency preservation**

  When decomposing a relation, we may require that *dependencies be preserved* in the resulting component relations because dependencies are also used to *express the constraints* on the database. If they are *not preserved*, to check whether the *dependencies still hold,* a solution would be to perform *costly joins* .

- Assuming a relation R is decomposed into relations R_1 R_2 .... R_{n-1} R_n

  First check whether a "lost" dependency *can be deduced* across relations. If it *cannot be deduced*, we have no other choice but to perform *joins* to check whether a functional dependency still holds every time we *have an update*.

- How do we check?

  Let $F' = F_1 \cup F_2 \cup ...... \cup F_{n-1} \cup F_n$ be the *union* of sets of FDs of the *decomposed* relations. F_i is that subset of F' that is applicable (i.e., projection) to R_i .

  If $F' \neq F$, run a simple algorithm that checks whether $F'^+ = F^+$.

Dependency preservation: An Example

- Assume we have the following relation and FDs:
- R = (A, B, C), F = {A→B, B→C, A→C}

with Key = {A}

This relation is *not* in 3NF because of the transitive FD derived from B → C. We therefore split the relation R into R_1 = (B, C) and R_2 = (A, B). Both relations *are now in 3NF* because there is no transitive FD.

However, is this decomposition *dependency preserving*?

Let F_1 be the projection of F' on R_1 and F_2 the projection of F' on R_2. To be dependency preserving, the above decomposition would have to satisfy either $F' = F_1 \cup F_2$ or $F'^+ = (F_1 \cup F_2)^+$ (i.e., the *closure of F'* is equal to the *closure of* $(F_1 \cup F_2)$).

For the relation R_1, F_1={B→C}, omitting all trivial FDs. For R_2, F_2={A→B}, omitting all trivial FDs. Therefore F≠ {$F_1 \cup F_2$) because we lost the FD: A → C! Let us know check whether F^+ is equal $(F_1 \cup F_2)^+$. The answer is YES.

This means that this decomposition is *dependency preserving*.

› Lossless join decomposition

The loss here refers *to the loss of information* and *not to the loss of tuples*!

When joining back the resulting relations, *we may be losing information by adding extra tuples as we saw before! Remember the example:*

Student	UoSCode
Alice	COMP5138
Alice	COMP5338
Bob	COMP5138
Clare	COMP5338
David	COMP5338

UoSCode	UoSName	Grade
COMP5138	Database Management Systems	CR
COMP5138	Database Management Systems	P
COMP5338	Advanced Data Models	CR
COMP5338	Advanced Data Models	D
COMP5338	Advanced Data Models	HD

$\bowtie$

Student	UoSCode	UoSName	Grade
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Alice	COMP5138	Database Management Systems	P
Alice	COMP5338	Advanced Data Models	CR
Alice	COMP5338	Advanced Data Models	D
Alice	COMP5338	Advanced Data Models	HD
Bob	COMP5138	Database Management Systems	CR
Bob	COMP5138	Database Management Systems	P
Clare	COMP5338	Advanced Data Models	CR
Clare	COMP5338	Advanced Data Models	D
Clare	COMP5338	Advanced Data Models	HD
David	COMP5338	Advanced Data Models	CR
David	COMP5338	Advanced Data Models	D
David	COMP5338	Advanced Data Models	HD

Lossless join decomposition

- A decomposition *is not always lossless*. We may have *more than one choice* to *split up* a relation *in the course of normalization* as we saw in the previous example.

  For example, *if the decomposition is on a non-key attribute, the decomposition may be lossy.*

To ensure lossless join decomposition use *Functional Dependencies.*

Lossless join decomposition using FDs

- If R is a relation decomposed into relations $R_1, R_2, \ldots, R_{n-1}, R_n$ and F is a set of functional dependencies. This *decomposition* is *lossless* (with respect to F) *if* for every relation R that satisfies F, the following equation is true:
  - $R = \Pi R_1(R) \infty \Pi R_2(R) \ldots \infty \Pi R_{n-1}(R) \infty \Pi R_n(R)$ where Π and ∞ are the symbols for *projection* and *natural join*, respectively.
- More formally: Let R be a relation and R_1 and R_2 be a decomposition of R. Let F be the set of functional dependencies. This decomposition is a lossless-join decomposition if at least one of the following FDs are in F^+.
  - $R_1 \cap R_2 \rightarrow R_1$
  - $R_1 \cap R_2 \rightarrow R_2$
- In plain English, this means that if the *intersection* of the set of attributes between R_1 and R_2 functionally determines either R_1 or R_2 (i.e., the intersection is a key to at least one of the resulting relations), then the composition is *lossless*.

Decomposing a Schema into BCNF

- Suppose we have a schema R and a non-trivial dependency $X \rightarrow Y$ which causes a violation of BCNF. We decompose R into:

$$R_1 = X \cup Y$$

$$R_2 = R - Y$$

- Example schema that is *not* in BCNF:

loan_info = (<u>*customer_id*</u>, <u>*loan_number*</u>, *amount*) with *loan_number* → *amount*

but *loan_number* is *not a superkey*

- Assume,
  - X = *loan_number*
  - *Y* = *amount*

So, the relation *loan_info* is replaced by the following relations:

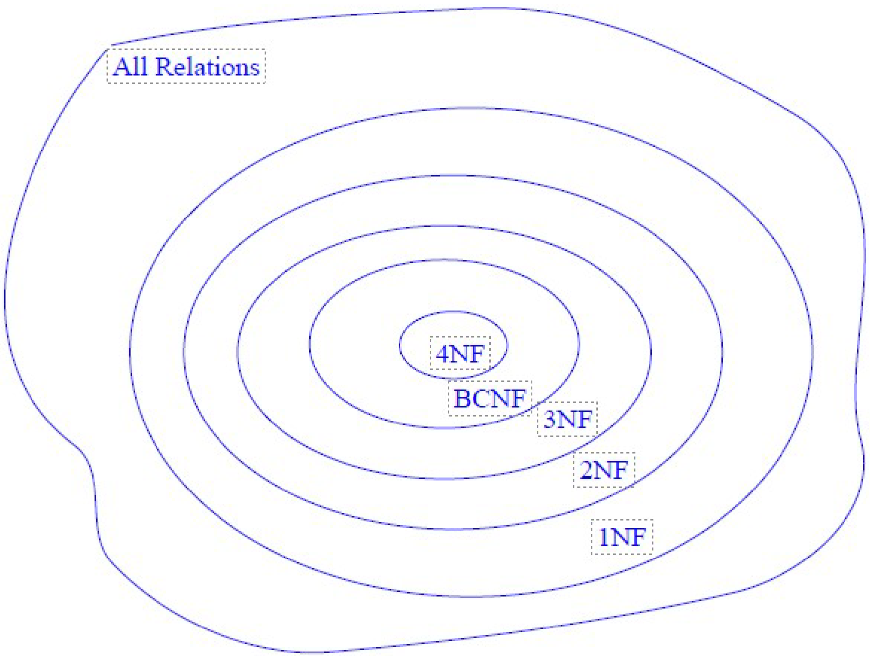
R_1 = (X ∪ Y) = (<u>*loan_number*</u>, *amount*)

R_2 = (*R* - *Y*) = (<u>*customer_id*</u>, <u>*loan_number*</u>)

Now both are in BCNF

Relationships of normal forms

Relationship between Normal Forms:



Remember that normalization is

- Geared *towards changes/updates in the database*
- Not *necessarily good* for *mostly retrieval* operations

This means that it *is not always good* to *normalize up to the 4NF normal* form: e.g., archives, historical databases, etc.

Key Skills

You should be able to perform the following tasks

- Identify and interpret functional dependencies for a database schema
- Identify the candidate keys and normal form (up to 4NF) of a relation schema using its functional and multivalued dependencies
  - Identify whether a set of attributes forms a minimal superkey
  - Determine all possible candidate keys
- Decompose a relational instance into a set of BCNF relational instances
  - Determine a lossless join decomposition of a relational schema
  - Correctly determine the decomposed relation instances

Next Lecture

- **Transaction Management**
  - Transaction Concept
  - Serializability

- Readings:
  - **Ramakrishnan/Gehrke, Chapter 16**
  - Kifer/Bernstein/Lewis book, Chapter 18
  - Ullman/Widom, Chapter 6.6 onwards

Have a nice break!

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