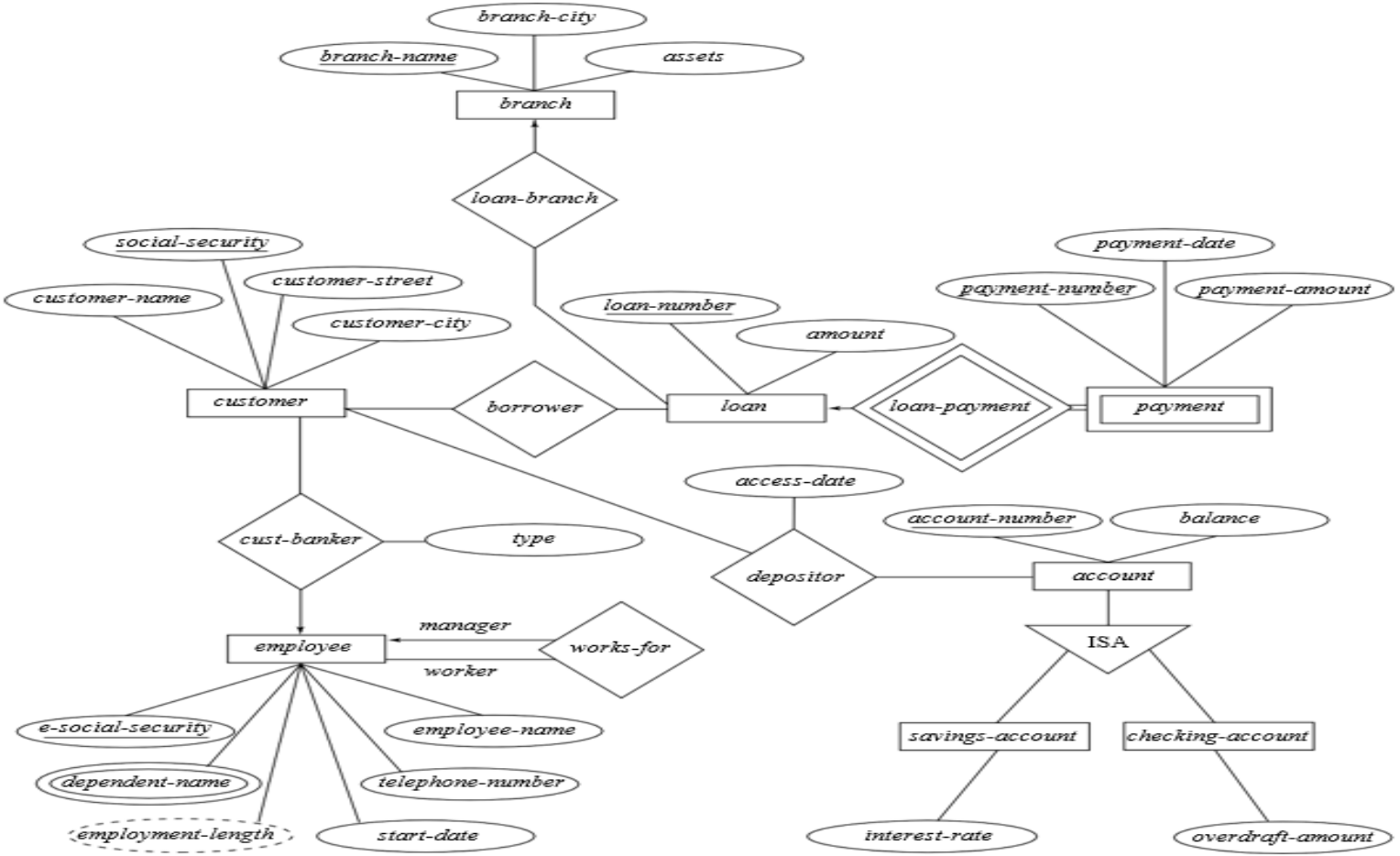
ELSEWEDY UNIVERSITY OF TECHNOLOGY
- POLYTECHNIC OF EGYPT -

Database Management Systems

Lecture 7: Normalization

© Spring 2023 – **Dr. Alyaa Hamza**
alyaa.hamza@sut.edu.eg

E-R Diagram for Banking Enterprise



Reduction of an E-R Schema to Tables (rational model)

- Primary keys allow entity sets and relationship sets to be expressed uniformly as *tables* which represent the contents of the database.
- A database which conforms to an E-R diagram can be represented by a collection of tables.
- For each entity set and relationship set there is a unique table which is assigned the name of the corresponding entity set or relationship set.
- Each table has a number of columns (generally corresponding to attributes), which have unique names.
- Converting an E-R diagram to a table format is the basis for deriving a relational database design from an E-R diagram.

Representing Entity Sets as Tables

- A strong entity set reduces to a table with the same attributes.

customer-name	*social-security*	*c-street*	*c-city*
Jones	321-12-3123	Main	Harrison
Smith	019-28-3746	North	Rye
Hayes	677-89-9011	Main	Harrison

The *customer* table

- A weak entity set becomes a table that includes a column for the primary key of the identifying strong entity set.

loan-number	*payment-number*	*payment-date*	*payment-amount*
L-17	5	10 May 1996	50
L-23	11	17 May 1996	75
L-15	22	23 May 1996	300

The *payment* table

Representing Entity Sets as Tables

- A many-to-many relationship set is represented as a table with columns for the primary keys of the two participating entity sets, and any descriptive attributes of the relationship set.

social-security	*account-number*	*access-date*
...	...	...

The *depositor* table

- The table corresponding to a relationship set linking a weak entity set to its identifying strong entity set is redundant.

  The *payment* table already contains the information that would appear in the *loan-payment* table (i.e., the columns
  loan-number and *payment-number*).

Representing Entity Sets as Tables

- Method 1: Form a table for the generalized entity ***account*** Form a table for each entity set that is generalized (include primary key of generalized entity set)

table	table attributes
account	*account-number, balance, account-type*
savings-account	*account-number, interest-rate*
checking-account	*account-number, overdraft-amount*

- Method 2: Form a table for each entity set that is generalized

table	table attributes
savings-account	*account-number, balance, interest-rate*
checking-account	*account-number, balance, overdraft-amount*

Method 2 has no table for generalized entity *account*

Relations Corresponding to Aggregation

customer

customer-name	*cust-social-security*	*customer-street*	*customer-city*

loan

loan-number	*amount*

borrower

cust-social-security	*loan-number*

employee

emp-social-security	*employee-name*	*phone-number*

loan-officer

emp-social-security	*cust-social-security*	*loan-number*

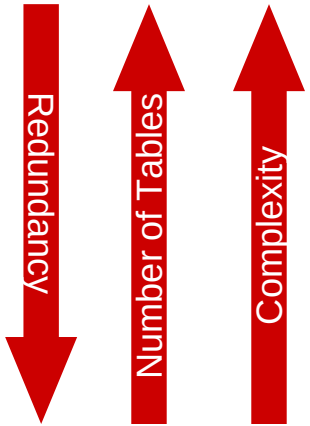
Normalization

Definition

- This is the process which allows you to winnow out redundant data within your database.
- This involves restructuring the tables to successively meeting higher forms of Normalization.
- A properly normalized database should have the following characteristics
  - Scalar values in each fields
  - Absence of redundancy.
  - Minimal use of null values.
  - Minimal loss of information.

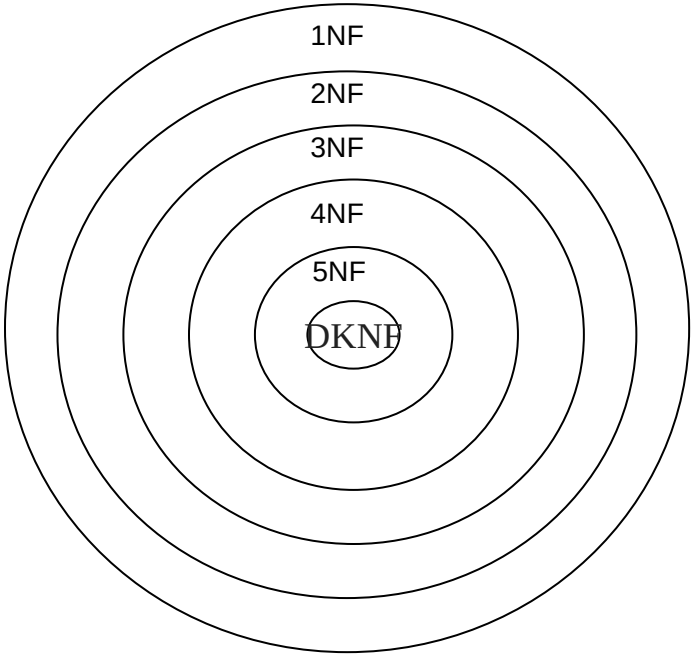
Levels of Normalization

- Levels of normalization based on the amount of redundancy in the database.
- Various levels of normalization are:
  - First Normal Form (1NF)
  - Second Normal Form (2NF)
  - Third Normal Form (3NF)
  - Boyce-Codd Normal Form (BCNF)
  - Fourth Normal Form (4NF)
  - Fifth Normal Form (5NF)
  - Domain Key Normal Form (DKNF)



Most databases should be 3NF or BCNF in order to avoid the database anomalies.

Levels of Normalization



Each higher level is a subset of the lower level

First Normal Form (1NF)

First Normal Form (1NF)

A table is considered to be in 1NF if all the fields contain only scalar values (as opposed to list of values).

Example (Not 1NF)

ISBN	Title	AuName	AuPhone	PubName	PubPhone	Price
0-321-32132-1	Balloon	Sleepy, Snoopy, Grumpy	321-321-1111, 232-234-1234, 665-235-6532	Small House	714-000-0000	$34.00
0-55-123456-9	Main Street	Jones, Smith	123-333-3333, 654-223-3455	Small House	714-000-0000	$22.95
0-123-45678-0	Ulysses	Joyce	666-666-6666	Alpha Press	999-999-9999	$34.00
1-22-233700-0	Visual Basic	Roman	444-444-4444	Big House	123-456-7890	$25.00

Author and AuPhone columns are not scalar

1NF - Decomposition

1. Place all items that appear in the repeating group in a new table
2. Designate a primary key for each new table produced.
3. Duplicate in the new table the primary key of the table from which the repeating group was extracted or vice versa.

Example (1NF)

ISBN	Title	PubName	PubPhone	Price
0-321-32132-1	Balloon	Small House	714-000-0000	$34.00
0-55-123456-9	Main Street	Small House	714-000-0000	$22.95
0-123-45678-0	Ulysses	Alpha Press	999-999-9999	$34.00
1-22-233700-0	Visual Basic	Big House	123-456-7890	$25.00

ISBN	AuName	AuPhone
0-321-32132-1	Sleepy	321-321-1111
0-321-32132-1	Snoopy	232-234-1234
0-321-32132-1	Grumpy	665-235-6532
0-55-123456-9	Jones	123-333-3333
0-55-123456-9	Smith	654-223-3455
0-123-45678-0	Joyce	666-666-6666
1-22-233700-0	Roman	444-444-4444

Functional Dependencies

Functional Dependencies

1. If one set of attributes in a table determines another set of attributes in the table, then the second set of attributes is said to be functionally dependent on the first set of attributes.

Example 1

ISBN	Title	Price
0-321-32132-1	Balloon	$34.00
0-55-123456-9	Main Street	$22.95
0-123-45678-0	Ulysses	$34.00
1-22-233700-0	Visual Basic	$25.00

Table Scheme: {ISBN, Title, Price}

Functional Dependencies:

{ISBN} → {Title}

{ISBN} → {Price}

Functional Dependencies

Example 2

PubID	PubName	PubPhone
1	Big House	999-999-9999
2	Small House	123-456-7890
3	Alpha Press	111-111-1111

Table Scheme: {PubID, PubName, PubPhone}

Functional Dependencies:

{PubId} → {PubPhone}

{PubId} → {PubName}

{PubName, PubPhone} → {PubID}

Example 3

AuID	AuName	AuPhone
1	Sleepy	321-321-1111
2	Snoopy	232-234-1234
3	Grumpy	665-235-6532
4	Jones	123-333-3333
5	Smith	654-223-3455
6	Joyce	666-666-6666
7	Roman	444-444-4444

Table Scheme: {AuID, AuName, AuPhone}

Functional Dependencies:

{AuId} → {AuPhone}

{AuId} → {AuName}

{AuName, AuPhone} → {AuID}

FD – Example

Database to track reviews of papers submitted to an academic conference. Prospective authors submit papers for review and possible acceptance in the published conference proceedings. Details of the entities

- Author information includes a unique author number, a name, a mailing address, and a unique (optional) email address.
- Paper information includes the primary author, the paper number, the title, the abstract, and review status (pending, accepted, rejected)
- Reviewer information includes the reviewer number, the name, the mailing address, and a unique (optional) email address
- A completed review includes the reviewer number, the date, the paper number, comments to the authors, comments to the program chairperson, and ratings (overall, originality, correctness, style, clarity)

FD – Example

Functional Dependencies

- AuthNo → AuthName, AuthEmail, AuthAddress
- AuthEmail → AuthNo
- PaperNo → Primary-AuthNo, Title, Abstract, Status
- RevNo → RevName, RevEmail, RevAddress
- RevEmail → RevNo
- RevNo, PaperNo → AuthComm, Prog-Comm, Date, Rating1, Rating2, Rating3, Rating4, Rating5

Second Normal Form (2NF)

Second Normal Form (2NF)

For a table to be in 2NF, there are two requirements

- The database is in first normal form
- All **nonkey** attributes in the table must be functionally dependent on the entire primary key

Note: *Remember that we are dealing with non-key attributes*

Example 1 (Not 2NF)

Scheme → {Title, PubId, AuId, Price, AuAddress}

1. **Key → {Title, PubId, AuId}**
2. **{Title, PubId, AuID} → {Price}**
3. **{AuID} → {AuAddress}**
4. **AuAddress does not belong to a key**
5. **AuAddress functionally depends on AuId which is a subset of a key**

Second Normal Form (2NF)

Example 2 (Not 2NF)

Scheme → {City, Street, HouseNumber, HouseColor, CityPopulation}

1. **key → {City, Street, HouseNumber}**
2. **{City, Street, HouseNumber} → {HouseColor}**
3. **{City} → {CityPopulation}**
4. **CityPopulation does not belong to any key.**
5. **CityPopulation is functionally dependent on the City which is a proper subset of the key**

Example 3 (Not 2NF)

Scheme → {studio, movie, budget, studio_city}

1. **Key → {studio, movie}**
2. **{studio, movie} → {budget}**
3. **{studio} → {studio_city}**
4. **studio_city is not a part of a key**
5. **studio_city functionally depends on studio which is a proper subset of the key**

2NF - Decomposition

1. If a data item is fully functionally dependent on only a part of the primary key, move that data item and that part of the primary key to a new table.
2. If other data items are functionally dependent on the same part of the key, place them in the new table also
3. Make the partial primary key copied from the original table the primary key for the new table. Place all items that appear in the repeating group in a new table

Example 1 (Convert to 2NF)

Old Scheme → {Title, PubId, AuId, Price, AuAddress}

New Scheme → {Title, PubId, AuId, Price}

New Scheme → {AuId, AuAddress}

2NF - Decomposition

Example 2 (Convert to 2NF)

Old Scheme → {Studio, Movie, Budget, StudioCity}

New Scheme → {Movie, Studio, Budget}

New Scheme → {Studio, City}

Example 3 (Convert to 2NF)

Old Scheme → {City, Street, HouseNumber, HouseColor, CityPopulation}

New Scheme → {City, Street, HouseNumber, HouseColor}

New Scheme → {City, CityPopulation}

Third Normal Form (3NF)

Third Normal Form (3NF)

This form dictates that all **non-key** attributes of a table must be functionally dependent on a candidate key i.e. there can be no interdependencies among non-key attributes.

For a table to be in 3NF, there are two requirements

- The table should be second normal form
- No attribute is transitively dependent on the primary key

Example (Not in 3NF)

Scheme → {Title, PubID, PageCount, Price }

1. **Key → {Title, PubId}**
2. **{Title, PubId} → {PageCount}**
3. **{PageCount} → {Price}**
4. **Both Price and PageCount depend on a key hence 2NF**
5. **Transitively {Title, PubID} → {Price} hence not in 3NF**

Third Normal Form (3NF)

Example 2 (Not in 3NF)

Scheme → {Studio, StudioCity, CityTemp}

1. **Primary Key → {Studio}**
2. **{Studio} → {StudioCity}**
3. **{StudioCity} → {CityTemp}**
4. **{Studio} → {CityTemp}**
5. **Both StudioCity and CityTemp depend on the entire key hence 2NF**
6. **CityTemp transitively depends on Studio hence violates 3NF**

Example 3 (Not in 3NF)

Scheme → {BuildingID, Contractor, Fee}

1. **Primary Key → {BuildingID}**
2. **{BuildingID} → {Contractor}**
3. **{Contractor} → {Fee}**
4. **{BuildingID} → {Fee}**
5. **Fee transitively depends on the BuildingID**
6. **Both Contractor and Fee depend on the entire key hence 2NF**

BuildingID	Contractor	Fee
100	Randolph	1200
150	Ingersoll	1100
200	Randolph	1200
250	Pitkin	1100
300	Randolph	1200

3NF - Decomposition

1. Move all items involved in transitive dependencies to a new entity.
2. Identify a primary key for the new entity.
3. Place the primary key for the new entity as a foreign key on the original entity.

Example 1 (Convert to 3NF)

Old Scheme → {Title, PubID, PageCount, Price }

New Scheme → {PubID, PageCount, Price}

New Scheme → {Title, PubID, PageCount}

3NF - Decomposition

Example 2 (Convert to 3NF)

Old Scheme → {Studio, StudioCity, CityTemp}

New Scheme → {Studio, StudioCity}

New Scheme → {StudioCity, CityTemp}

Example 3 (Convert to 3NF)

Old Scheme → {BuildingID, Contractor, Fee}

New Scheme → {BuildingID, Contractor}

New Scheme → {Contractor, Fee}

BuildingID	Contractor
100	Randolph
150	Ingersoll
200	Randolph
250	Pitkin
300	Randolph

Contractor	Fee
Randolph	1200
Ingersoll	1100
Pitkin	1100

Boyce-Codd Normal Form (BCNF)

Boyce-Codd Normal Form (BCNF)

- BCNF does not allow dependencies between attributes that belong to candidate keys.
- BCNF is a refinement of the third normal form in which it drops the restriction of a non-key attribute from the 3rd normal form.
- Third normal form and BCNF are not same if the following conditions are true:
  - The table has two or more candidate keys
  - At least two of the candidate keys are composed of more than one attribute
  - The keys are not disjoint i.e. The composite candidate keys share some attributes

Example 1 - Address (Not in BCNF)

Scheme → {City, Street, ZipCode }

1. **Key1 → {City, Street }**
2. **Key2 → {ZipCode, Street}**
3. **No non-key attribute hence 3NF**
4. **{City, Street} → {ZipCode}**
5. **{ZipCode} → {City}**
6. **Dependency between attributes belonging to a key**

Boyce Codd Normal Form (BCNF)

Example 2 - Movie (Not in BCNF)

Scheme → {MovieTitle, MovieID, PersonName, Role, Payment }

1. **Key1 → {MovieTitle, PersonName}**
2. **Key2 → {MovieID, PersonName}**
3. **Both role and payment functionally depend on both candidate keys thus 3NF**
4. **{MovieID} → {MovieTitle}**
5. **Dependency between MovieID & MovieTitle Violates BCNF**

Example 3 - Consulting (Not in BCNF)

Scheme → {Client, Problem, Consultant}

1. **Key1 → {Client, Problem}**
2. **Key2 → {Client, Consultant}**
3. **No non-key attribute hence 3NF**
4. **{Client, Problem} → {Consultant}**
5. **{Client, Consultant} → {Problem}**
6. **Dependency between attributes belonging to keys violates BCNF**

BCNF - Decomposition

1. Place the two candidate primary keys in separate entities
2. Place each of the remaining data items in one of the resulting entities according to its dependency on the primary key.

Example 1 (Convert to BCNF)

Old Scheme → {City, Street, ZipCode }

New Scheme1 → {ZipCode, Street}

New Scheme2 → {City, Street}

- **Loss of relation {ZipCode} → {City}**

Alternate New Scheme1 → {ZipCode, Street }

Alternate New Scheme2 → {ZipCode, City}

Decomposition – Loss of Information

1. If decomposition does not cause any loss of information it is called a **lossless** decomposition.
2. If a decomposition does not cause any dependencies to be lost it is called a **dependency-preserving** decomposition.
3. Any table scheme can be decomposed in a lossless way into a collection of smaller schemas that are in BCNF form. However the dependency preservation is not guaranteed.
4. Any table can be decomposed in a lossless way into 3rd normal form that also preserves the dependencies.
   - 3NF may be better than BCNF in some cases

Use your own judgment when decomposing schemas

BCNF - Decomposition

Example 2 (Convert to BCNF)

Old Scheme → {MovieTitle, MovieID, PersonName, Role, Payment }

New Scheme → {MovieID, PersonName, Role, Payment}

New Scheme → {MovieTitle, PersonName}

- **Loss of relation {MovieID} → {MovieTitle}**

New Scheme → {MovieID, PersonName, Role, Payment}

New Scheme → {MovieID, MovieTitle}

- **We got the {MovieID} → {MovieTitle} relationship back**

Example 3 (Convert to BCNF)

Old Scheme → {Client, Problem, Consultant}

New Scheme → {Client, Consultant}

New Scheme → {Client, Problem}

Fourth Normal Form (4NF)

Fourth Normal Form (4NF)

- **Fourth normal form eliminates independent many-to-one relationships between columns.**
- **To be in Fourth Normal Form,**
  - **a relation must first be in Boyce-Codd Normal Form.**
  - **a given relation may not contain more than one multi-valued attribute.**

Example (Not in 4NF)

Scheme → {MovieName, ScreeningCity, Genre)

Primary Key: {MovieName, ScreeningCity, Genre)

1. **All columns are a part of the only candidate key, hence BCNF**
2. **Many Movies can have the same Genre**
3. **Many Cities can have the same movie**
4. **Violates 4NF**

Movie	ScreeningCity	Genre
Hard Code	Los Angles	Comedy
Hard Code	New York	Comedy
Bill Durham	Santa Cruz	Drama
Bill Durham	Durham	Drama
The Code Warrier	New York	Horror

Fourth Normal Form (4NF)

Example 2 (Not in 4NF)

Scheme → {Manager, Child, Employee}

1. **Primary Key → {Manager, Child, Employee}**
2. **Each manager can have more than one child**
3. **Each manager can supervise more than one employee**
4. **4NF Violated**

Manager	Child	Employee
Jim	Beth	Alice
Mary	Bob	Jane
Mary	NULL	Adam

Example 3 (Not in 4NF)

Scheme → {Employee, Skill, ForeignLanguage}

1. **Primary Key → {Employee, Skill, Language }**
2. **Each employee can speak multiple languages**
3. **Each employee can have multiple skills**
4. **Thus violates 4NF**

Employee	Skill	Language
1234	Cooking	French
1234	Cooking	German
1453	Carpentry	Spanish
1453	Cooking	Spanish
2345	Cooking	Spanish

4NF - Decomposition

1. Move the two multi-valued relations to separate tables
2. Identify a primary key for each of the new entity.

Example 1 (Convert to 3NF)

Old Scheme → {MovieName, ScreeningCity, Genre}

New Scheme → {MovieName, ScreeningCity}

New Scheme → {MovieName, Genre}

Movie	Genre
Hard Code	Comedy
Bill Durham	Drama
The Code Warrier	Horror

Movie	ScreeningCity
Hard Code	Los Angles
Hard Code	New York
Bill Durham	Santa Cruz
Bill Durham	Durham
The Code Warrier	New York

4NF - Decomposition

Example 2 (Convert to 4NF)

Old Scheme → {Manager, Child, Employee}

New Scheme → {Manager, Child}

New Scheme → {Manager, Employee}

Manager	Child
Jim	Beth
Mary	Bob

Manager	Employee
Jim	Alice
Mary	Jane
Mary	Adam

Example 3 (Convert to 4NF)

Old Scheme → {Employee, Skill, ForeignLanguage}

New Scheme → {Employee, Skill}

New Scheme → {Employee, ForeignLanguage}

Employee	Skill
1234	Cooking
1453	Carpentry
1453	Cooking
2345	Cooking

Employee	Language
1234	French
1234	German
1453	Spanish
2345	Spanish

Fifth Normal Form (5NF)

Fifth Normal Form (5NF)

- **Fifth normal form is satisfied when all tables are broken into as many tables as possible in order to avoid redundancy. Once it is in fifth normal form it cannot be broken into smaller relations without changing the facts or the meaning.**

Domain Key Normal Form (DKNF)

- **The relation is in DKNF when there can be no insertion or deletion anomalies in the database.**


Question
&
Answer