HA NOI UNIVERSITY OF SCIENCE AND TECHNOLOGY
SCHOOL OF INFORMATION AND COMMUNICATION TECHNOLOGY

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IT3090E - Databases

Chapter 5: Database design – bottom-up approach
Functional dependencies

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Designing a database

- To design a database, one can start from a data **state**
  - List of data that the database users need

⇒**Bottom-up approach**

- The states can be obtained by
  - The analysis of the existing system (flat files or other ...)
  - An interview with DB users to determine which states they would need

Designing a database

- Example :
  - In the case of a supermarket, you can start with the information on the receipts
  - In the case of a library, you can start from the excel files necessary for the library to function properly
  - In the case of the school service, you can start from the planning sheets...
  -

Designing a database - example 1

- How do I organize a movies collection?
- How to describe a movie??
  - Title, category (sci-fi, comedy...), type (DVD, BluRay, Divx)
  - Lead actor, director
  -

Id	Title	Cat	Type	Director	Actor
1	Indiana Jones	advent	dvd	S. Spielberg	H. Ford
2	Indiana Jones II	advent	dvd	S. Spielberg	H. Ford
3	**Indiana Jones III**	**advent**	**dvd**	**S. Spielberg**	H. Ford
4	**Indi Jones III**	**advent**	**dvd**	**S. Spielberg**	S. Connery

Title cannot be PK -> we need to add an identifier

The values of the attributes **Title**, **Cat**, **Type**, **Director** are the same for multiple records

What if we'd like to…
- Write « Harrison Ford » ?
- Modify the title « Indi III »?
- Delete Indi III ?

We need to do the same thing multiple times -> risk of error

Designing a database - example 2

- How to organize the data?
- Example: Paleontology
  - Information about dinosaurs
    - Name, Era, Beginning, End, Ecosystem, Diet, Weight
  - Information on eras (cretaceous, jurassic…)
    - era (cretaceous, jurassic…), Beginning, End

D (Name, Era, Beginning, End, Ecosystem, Diet, Weight)

Allosaurus	Jurassic	200	145	Ground	carnivore	2.09
Ptéranodon	cretaceous	145	65	Air	carnivore	NULL
Brontosaurus	Jurassic	200	149	Lake	herbivorous	32.48
Tyrannosaurus	Cretqceous	145	65	Ground	carnivore	6.89

Designing a database - example 2

- Problems :
  - Redundencies: information about Eras (Beginning, end)
  - Inconsistencies: Two timeframes for Jurassic; Cretaceous or Cretqceous?
  - Incomplete: No information on the Triassi period if no dinosaur in the DB
  - Difficulties to update or insert new data
  - D (Name, Era, Beginning, End, Ecosystem, Diet, Weight)

Allosaurus	Jurassic	200	145	Ground	carnivore	2.09
Ptéranodon	cretaceous	145	65	Air	carnivore	NULL
Brontosaurus	Jurassic	200	149	Lake	herbivorous	32.48
Tyrannosaurus	Cretqceous	145	65	Ground	carnivore	6.89

Decomposition

- How can we avoid these problems?
  - **By breaking down D into 2 tables + 1 foreign key**

Dinosaur (Name, *Era#*, Ecosystem, Diet, Weight)

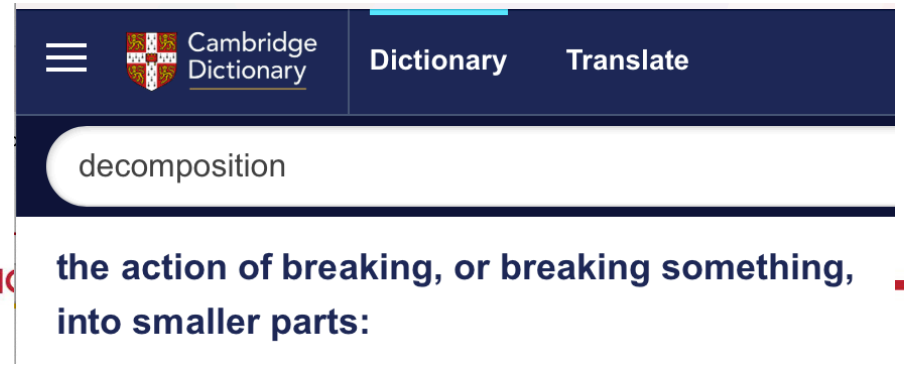
Allosaurus	Jurassic	Ground	carnivore	2.09
Ptéranodon	cretaceous	Air	carnivore	NULL
Brontosaurus	Jurassic	Lake	herbivorous	32.48
Tyrannosaurus	cretaceous	Ground	carnivore	6.89

Era (Era, Beginning, End)

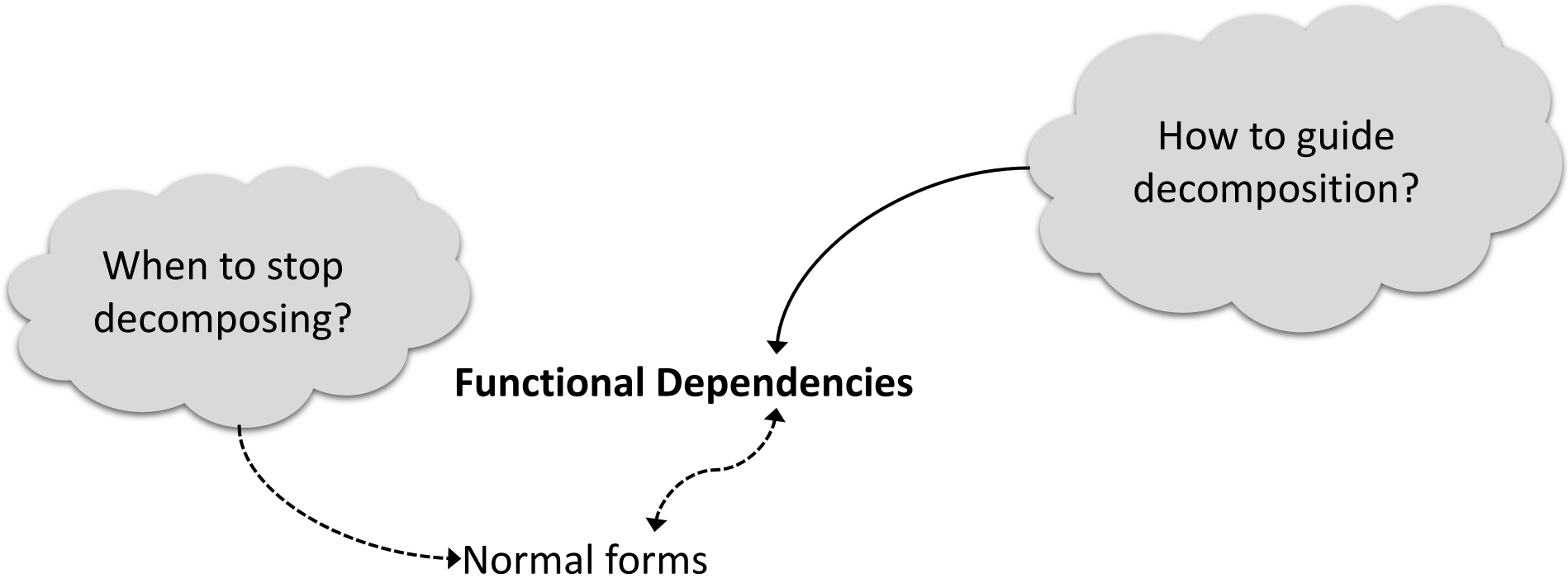
Jurassic	200	145
cretaceous	145	65
triassic	230	200

Decomposition

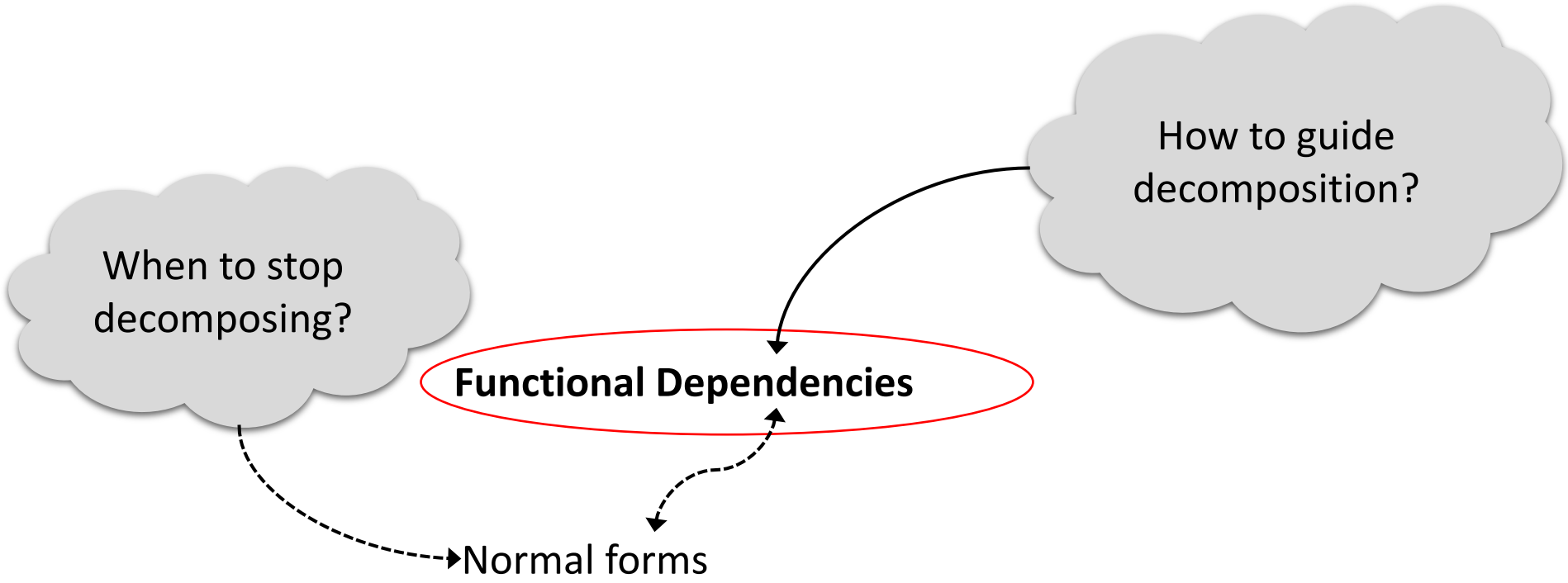
- Designing a « good » relational database
  - No redundancy
  - Easier update
  - Better-assured consistency
  - Easier understanding
  -
- Principle → break down (**decompose**) one table into several tables
  - How to do that?
  - When to stop?
  -



Decomposition



Functional Dependencies (FDs)



Functional Dependencies (FDs)

- Functional Dependencies (FDs) are an expression of:
  - The semantic links between attributes
  - Our choices for representing reality
  -

$$A \rightarrow B$$

A determines B (⇔ B is functionally dependent of A)

If and only of

The value of B ONLY depends on the value of A (⇔ for each value of A, the value of B is always the same)

A is called the **determinant**, B is called the **dependent**

In general, A is a primary key (but not always)

Functional Dependencies (FDs) - examples

- Tax Id → Name?
- Licence plate → Model?
- Colour → Licence plate?

Functional Dependencies (FDs)

- Watch out for the direction of the DF!!
  - The right side (dependent) depends on the left side (determinant)

- Example: if a student has only one grade per course
  - Nguyen Tú, StudentID 100, got A+ in Law and Computer Science
  - StudentID, Grade → Course?
    - 100, A+ → Law ; 100, A+ → Computer Science
  - StudentID, Course → Grade?
    - 100, Law → A+ ; 100, Computer Science → A+

Functional Dependencies (FDs)

- **Example**: **R (OrderID, OrderDetailID, ProductID, Order_Date, Quantity)**

  OrderNo: identifier for the order

  OrderDetailID: identifier for the order line

  ProductID: identifier for the product ordered

  Quantity: ordered quantity (for that product)

  1 order line / product ordered, multiple order lines / order

  Order_date: date of the order

Example of corresponding state: receipt

Order n° 10123
16/04/2021

Product	Unit Price	Qtity	Total Price
USB Key	9.90	2	19.8
USB hub	16.98	1	16.98

N.B. The state does not necessarily contain all the attributes we need in the database (especially PKs…)

Functional Dependencies (FDs)

- **Example**: **R (OrderID, OrderLineID, ProductID, Order_Date, Quantity)**

  OrderID: identifier for the order

  OrderLineID: identifier for the order line

  ProductID: identifier for the product ordered

  Quantity: ordered quantity (for that product)

  1 order line / product ordered, multiple order lines / order

  Order_Date: date of the order

Example of corresponding state: receipt

Order n° 10123
16/04/2021

Product	Unit Price	Qtity	Total Price
USB Key	9.90	2	19.8
USB hub	16.98	1	16.98

Questions - is it true that:

OrderID → Order_Date ??

OrderID → ProductID ??

OrderID → OrderLineID ??

OrderID, OrderLineID → ProductID, Quantity??

Identifying functional dependencies

- Looking at the data in the DB is **not enough!!!**
  - A FD is not linked to the specific state of the database at a given instant
    - A FD is more like a general rule
  - **Beware:** A → B can be verified in practice, without it being a DF (general rule)
    - Example: from this extract, one might think that Title → Type…
      - Until we get Indiana Jones in blue-ray…

Id	Title	Cat	Type	Director	Actor
1	Indiana Jones	advent	dvd	S. Spielberg	H. Ford
2	Indiana Jones II	advent	dvd	S. Spielberg	H. Ford
3	**Indiana Jones III**	**advent**	**dvd**	**S. Spielberg**	H. Ford
4	**Indi Jones III**	**advent**	**dvd**	**S. Spielberg**	S. Connery

Identifying functional dependencies

- Therefore, it is difficult to automatize the identification of FDs…
  - A FD is a general rule that humans can only identify if they understand the DB contents…
  - Usually, you'll need an interview with the DB users to really identify functional dependencies…

Definitions and properties

- The three Armstrong's **axioms** are the following, where:
  - $R = \{A_1, A_2, \dots, A_n\}$, X, Y, Z, W are subsets of R
  - XY denotes $X \cup Y$
- Reflexivity
  - If $Y \subseteq X$ then $X \rightarrow Y$
- Augmentation
  - If $X \rightarrow Y$ then $XZ \rightarrow YZ$
- Transitivity
  - If $X \rightarrow Y$, $Y \rightarrow Z$ then $X \rightarrow Z$

Definitions and properties

- Armstrong's **secondary rules** are the following:
- Union
  - If $X \rightarrow Y$, $X \rightarrow Z$ then $X \rightarrow YZ$.
- Pseudo-transitivity
  - If $X \rightarrow Y$, $WY \rightarrow Z$ then $XW \rightarrow Z$.
- Decomposition
  - If $X \rightarrow Y$, $Z \subseteq Y$ then $X \rightarrow Z$

Exercises

- Consider the following set of FDs on the attributes A,B,C,D,E,F:

$$
\begin{aligned}
A &\rightarrow B \\
A &\rightarrow C \\
CD &\rightarrow E \\
CD &\rightarrow F \\
B &\rightarrow E
\end{aligned}
$$

- Exercise 1: Prove CD → EF by applying Armstrong's Axioms (reflexivity, augmentation, and transitivity)

Exercises

- Solution to exercise 1:

Exercises

- Consider the following set of FDs on the attributes A,B,C,D,E,F:

$$
\begin{aligned}
A &\rightarrow B \\
A &\rightarrow C \\
CD &\rightarrow E \\
CD &\rightarrow F \\
B &\rightarrow E
\end{aligned}
$$

- Exercise 2: Prove AD $\rightarrow$ EF by repeatedly applying Armstrong's Axioms

Exercises

- Solution to exercise 2:

Definitions and properties

- Trivial FDs:
  - A FD $X \rightarrow Y$ is trivial if $X \supseteq Y$
    - In particular, $X \rightarrow X$ and $\{X,Y\} \rightarrow X$ are always true
- Partial FDs:
  - A FD $\{X,Y\} \rightarrow Z$ is partial if $X \rightarrow Z$
  - (In other words, Y is « useless » in that FD)
- Elementary FDs:
  - A FD $X \rightarrow Y$ is elementary if it is nor trivial nor partial
  - If $X \rightarrow Y$ is an elementary FD, then X is a candidate key for the table {X,Y}

Definitions and properties

- In Chapter 5bis (on Teams), you'll find 2 algorithms to find the minimal key of a table
  - Based on the notion of closure of a set of attributes
- Please read it carefully and ask me questions if needed
- In this lecture, we will focus on more hand—on experience for database design: decomposing the tables and until we reach some normal form
  - For finding the keys, we will rely mainly on common sense and semantics

Decomposition - example

Item	Ref	Qty	Supplier	ZIP_code	City
Umbrella	501	50	Labalaine	75000	Paris
Hat	530	100	Lemelon	17000	La Rochelle
Rain jacket	510	100	Labaleine	75000	Paris

- The attributes ZIP_code and City are dependent on the attribute supplier:
  - Supplier → ZIP_code, City

Decomposition - example

- Therefore, we can decompose the initial relation:
  - Supplier → ZIP_code, City

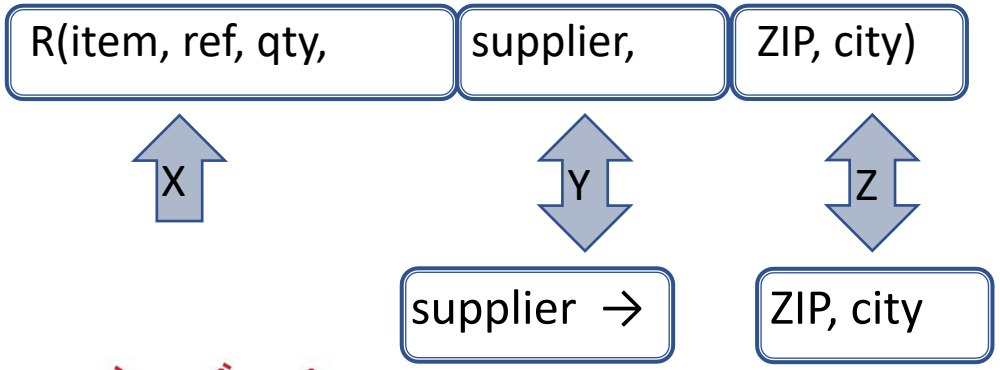
Item	Ref	Qty	Supplier	ZIP_code	City
Umbrella	501	50	Labalaine	75000	Paris
Hat	530	100	Lemelon	17000	La Rochelle
Rain jacket	510	100	Labaleine	75000	Paris

Item	Ref	Qty	Supplier#
Umbrella	501	50	Labalaine
Hat	530	100	Lemelon
Rain jacket	510	100	Labaleine

Supplier	ZIP_code	City
Labalaine	75000	Paris
Lemelon	17000	La Rochelle

Decomposition – general rule

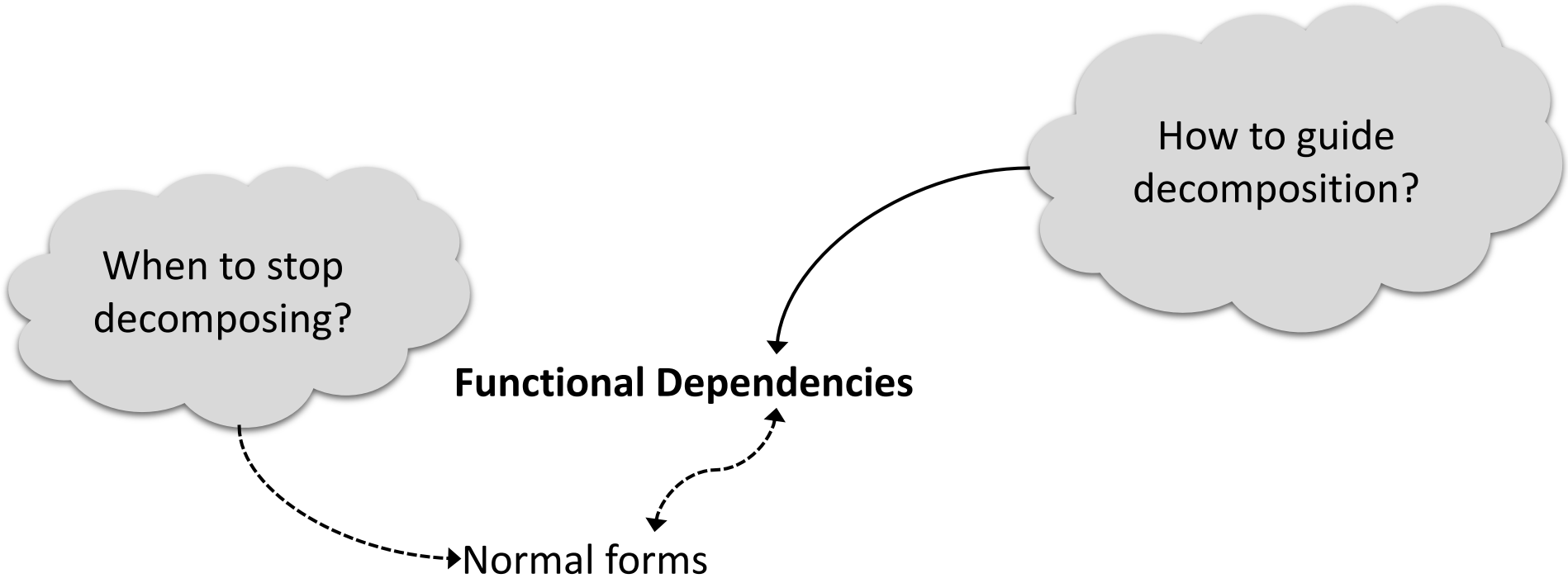
- General rule:
  - If R(X, Y, Z) is a relation
  - And if Y $\rightarrow$ Z is a FD of R
  - Then R(X,Y, Z) = R(X,Y) * R(Y,Z)
- In other words, the right hand-side of the FD can be taken out of the initial relation R



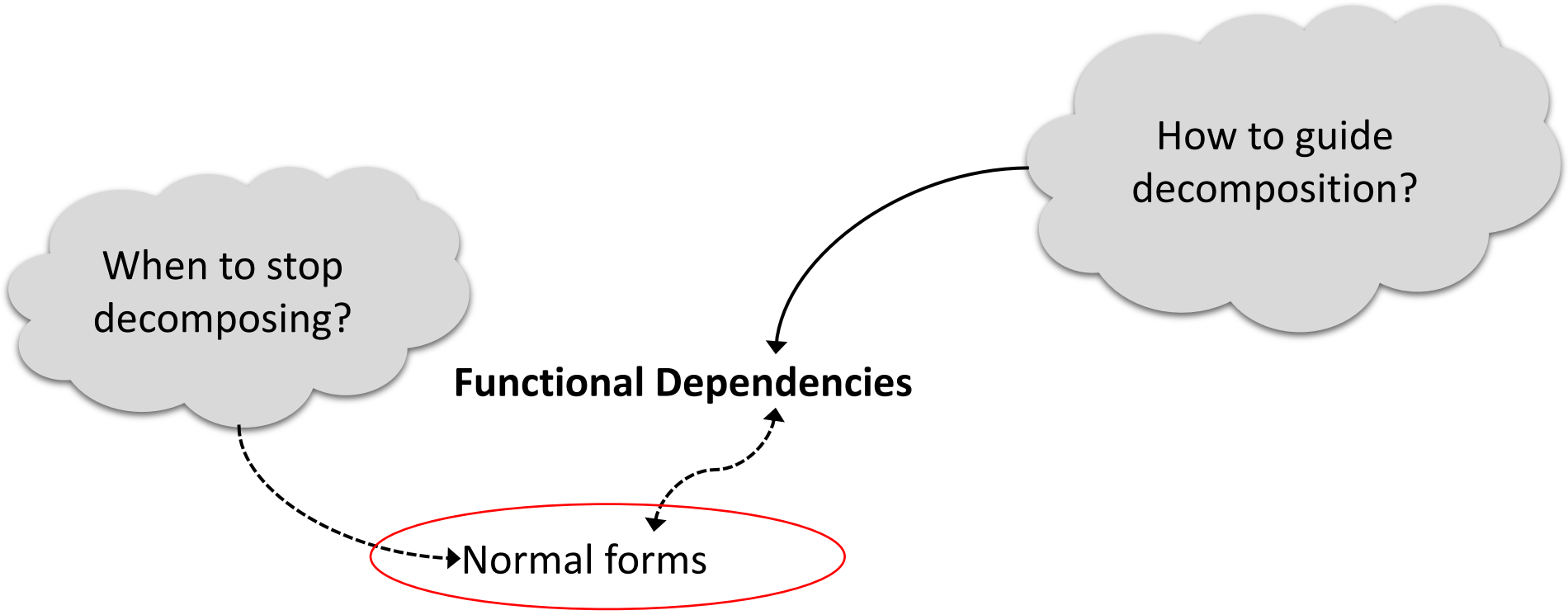
Decomposition – some comments

- If we decompose a table following a DF, then we don't loose any information
  - The **join** between the two tables contain the same information as the initial table
- One can always decompose a table when there exists **at least one** DF
- One cannot decompose a table when there exists **no** DF

Decomposition



Normalization

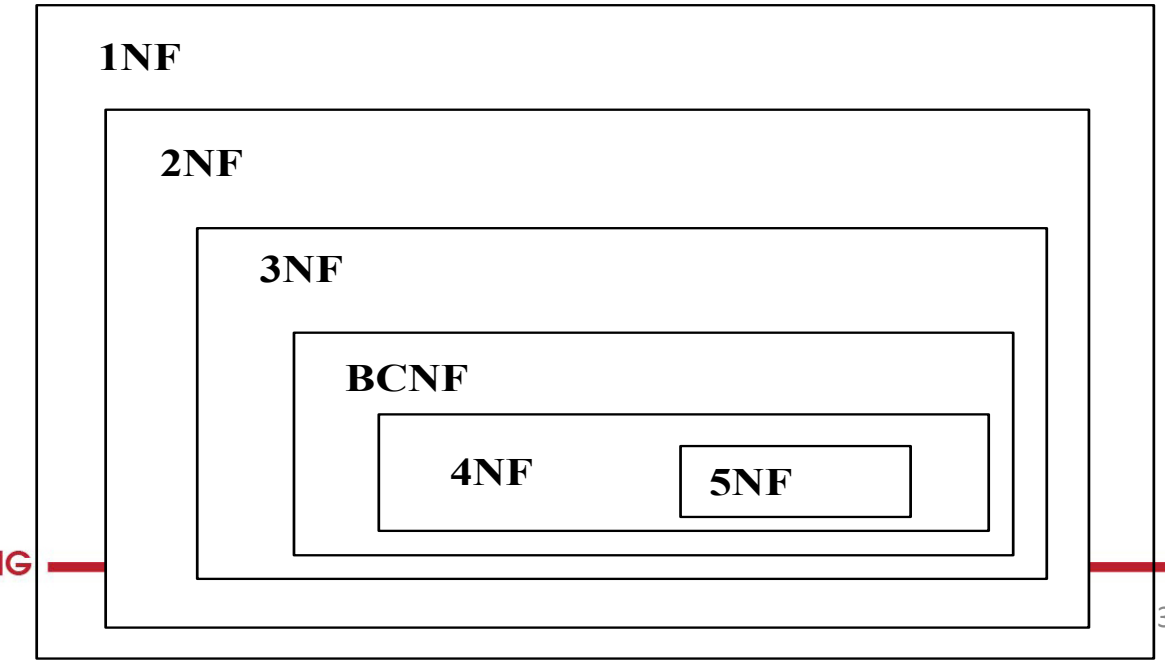


Why normalizing?

- Normalizing a relational schema is replacing it with an equivalent schema where all tables verify certain properties
  - These properties are based on the analysis of FDs inside each table
- Normalizing is useful to:
  - Limit data redundancies
  - Minimize storage space
  - Limiting data loss
  - Limit inconsistencies
  - Improve processing performances
  - Avoid any difficulty (potential source of errors) during updates

Normal forms

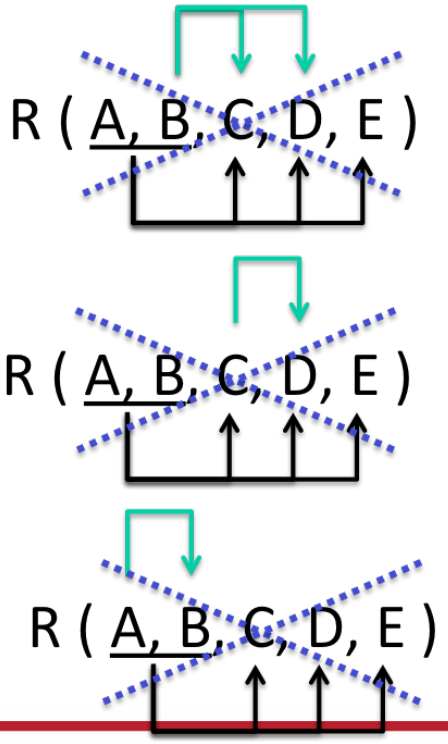
- There exist different levels of normalization
  - 1st, 2nd and 3rd Normal forms (1NF, 2NF, 3NF)
  - Boyce-Codd Normal Form (BCNF)
  - The 4th, 5th normal forms are complex (we'll not study them today)



Normal forms

- 1NF :
  - No calculated or non-atomic attribute
- 2NF :
  - 1NF + No Partial Dependency (PD)
    - PD: when a **non-prime attribute** (attributes which are not part of any candidate key) is dependent on a subset of a candidate key
- 3NF :
  - 2NF + no Transitive Dependency for non-prime attributes
    - TD happens when a non-prime attribute depends on another non-prime attribute
- BCNF :
  - 3NF + in every FD, the determinant is a **super-key**
    - Super-key: set of attributes which identifies uniquely the attributes in the relation (not necessarily minimal)

Illustrations (specific cases)



How to normalize a schema?

- Basically, it is made by:
  - Initialization: putting all attributes in one big table R
  - Identification of all the elementary FDs in the table R
  - Decomposing recursively the table R by applying the FDs…
  - … until we reach the level of normalization that we wish to get
    - Usually, 3NF is enough…

Decomposition algorithm

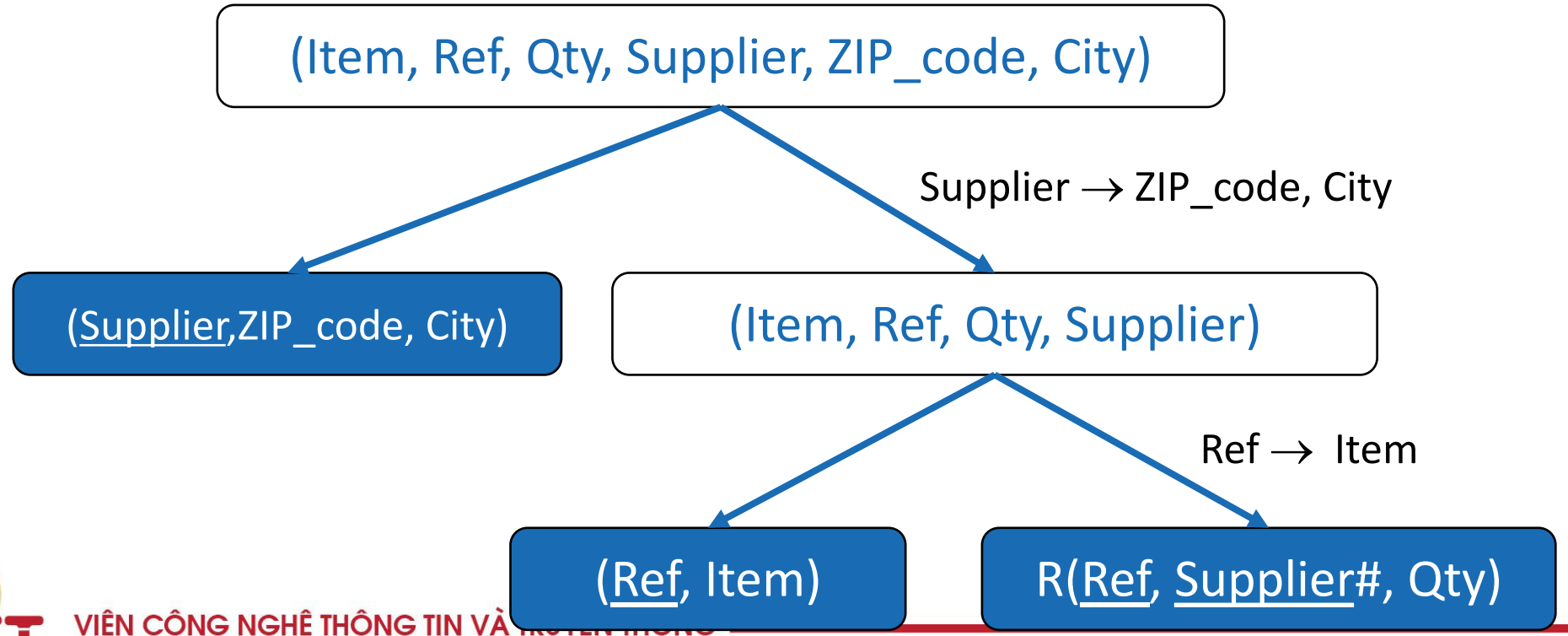
- Input:
  - A relation R to decompose
  - A set of FDs
- Output:
  - Multiple tables which join gives R
- Principle:
  - Recursive algorithm
  - Equivalent to calculating a binary tree which root is R
  - The tree leaves give the final result

Decomposition algorithm

- Recursive decomposition step
- Current node: a relation R(T)
  - Choose a DF $Y \rightarrow Z$ which attributes are in R
    - $\Rightarrow$ T can be decomposed into $T = X \cup Y \cup Z$
  - Add the relation R(Y, Z) as the left child of R
  - Add the relation R(X, Y) as the right child of R
  - Recursively decompose R(X, Y) and R(Y, Z)

Example

- Input:
  - Table: (Item, Ref, Qty, Supplier, ZIP_code, City)
  - FDs: Supplier → ZIP_code, City; Ref → Item



Normal forms

- Exercise 3:
  - Given the relation R (A, B, C, D, E) and the following FD:
    1. A → B
    2. B C → E
    3. D E → A

  Question 1: give the candidate key(s) of R (see slide 25)

  Solution:

  -

Normal forms

- Exercise 3:
  - Given the relation R (A, B, C, D, E) and the following FD:
    1. $A \rightarrow B$
    2. $B\ C \rightarrow E$
    3. $D\ E \rightarrow A$

  Question 2: Let us assume none of the above attributes are calculated, nor non-atomic. Is R in 3NF? If not, then normalize it in 3NF (give the corresponding schema)

  Solution:

Normal forms

- Exercise 3:
  - Given the relation R (A, B, C, D, E) and the following FD:
    1. A → B
    2. B C → E
    3. D E → A

  Question 3: Are the relations which you obtain in BCNF? If not, then normalize them in BCNF (multiple solutions are possible).

  Solution:

  -

Normal forms

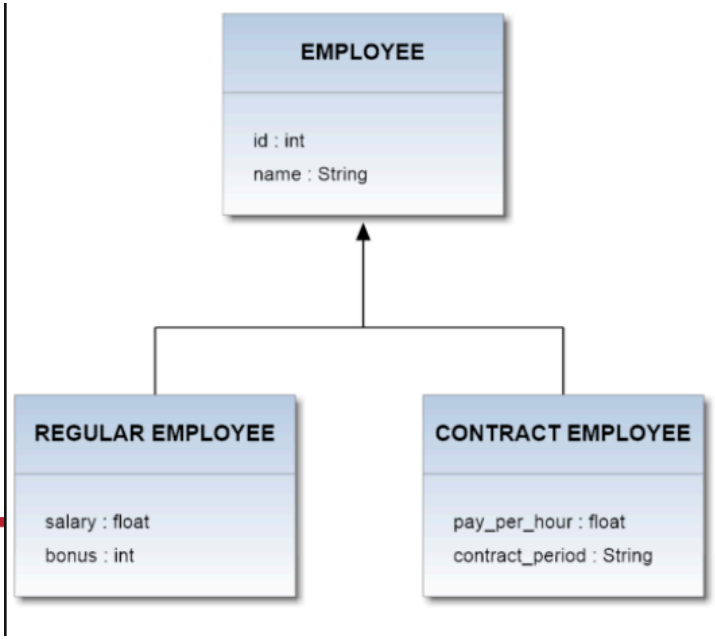
- Exercise 3:
  - Given the relation R (A, B, C, D, E) and the following FD:
    1. $A \rightarrow B$
    2. $B\ C \rightarrow E$
    3. $D\ E \rightarrow A$

  Question 4: Is there a loss of dependencies after you replied to Question 3? If yes, then which are the functional dependencies that are lost?

  Solution:

Some basic rules for a good database design…

- There are several rules for designing good relational databases, among which
  - No calculated attribute
    - *E.g.*: Total price, if it can be deduced from unit_price and qtity
  - Normalized scheme
    - Decompose using the above algorithm until you reach (at least) 3NF (maybe even BCNF, depending on your needs)
  - « Merge » the entities which are semantically close, and share the same attributes (inheritance)
    - *E.g.*: movie_director, movie_producer, actor, viewer



Exercises

- Do the exercise list number 5
  - Assignment due: Sunday, 9th of May, 23h59.

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