Politecnico di Torino

Normalization

Database design

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Normalization

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Introduction

Normalization

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Normalization

- Normalization is a process which, starting from a non-normalized relational schema, obtains a normalized relational schema
- Normalization is not a design methodology, but a verification tool
- The design methodology based on ER schemas normally produces normalized relational schemas
- Normalization checks can also be applied to ER schemas

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Example

Exam Passed

StudentID	Residence	CourseID	CourseName	Grade
s94539	Milan	04FLYCY	Electronic calculators	30
s94540	Turin	01FLTCY	Database design	26
s94540	Turin	01KPNCY	Computer network	28
s94541	Pescara	01KPNCY	Computer network	29
s94542	Lecce	04FLYCY	Electronic calculators	25

- Constraints
  - The primary key is the pair StudentID, CourseID
  - The place of residence of each student is unique and is an attribute of the student alone, regardless of the exams he or she has passed
  - The name of the course is unique and is a function of the course only, regardless of which students pass the corresponding exam

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Example: Redundancy

Exam Passed

StudentID	Residence	CourseID	CourseName	Grade
s94539	Milan	04FLYCY	Electronic calculators	30
s94540	Turin	01FLTCY	Database design	26
s94540	Turin	01KPNCY	Computer network	28
s94541	Pescara	01KPNCY	Computer network	29
s94542	Lecce	04FLYCY	Electronic calculators	25

- Redundancy
  - In all rows where a student appears, his or her place of residence is repeated
  - In all rows where the same course appears, its name is repeated

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Example: Anomalies

Exam Passed

StudentID	Residence	CourseID	CourseName	Grade
s94539	Milan	04FLYCY	Electronic calculators	30
s94540	Turin	01FLTCY	Database design	26
s94540	Turin	01KPNCY	Computer network	28
s94541	Pescara	01KPNCY	Computer network	29
s94542	Lecce	04FLYCY	Electronic calculators	25

- Update anomaly
  - If a student's place of residence changes, all the rows in which it appears must be modified at the same time
- Insertion anomaly
  - If a new student enrolls at university, he or she cannot be entered in the database until he or she passes the first exam
- Deletion anomaly
  - If a student withdraws from studies, it is not possible to keep track of his place of residence

Redundancy

- A single relation is used to represent heterogeneous information
  - some data are repeated in different tuples without adding new information
    - redundant data

Anomalies

- Redundant information must be updated atomically (all at the same time)
- The deletion of a tuple implies the deletion of all concepts represented in it
  - including those that might still be valid
- The insertion of a new tuple is only possible if at least the complete information about the primary key exists
  - it is not possible to insert the part of the tuple relating to only one concept

Boyce-Codd normal form

Normalization

Functional dependency

- It is a special type of integrity constraint
- It describes functional links between the attributes of a relation
- Example: the place of residence is unique for each student
  - each time the same student appears, the value is repeated
  - the value of StudentID determines the value of Residence

Exam Passed

StudentID	Residence	CourseID	CourseName	Grade
s94539	Milan	04FLYCY	Electronic calculators	30
s94540	Turin	01FLTCY	Database design	26
s94540	Turin	01KPNCY	Computer network	28
s94541	Pescara	01KPNCY	Computer network	29
s94542	Lecce	04FLYCY	Electronic calculators	25

Functional dependency

- A relation r satisfies the functional dependency X → Y if, for each pair t1, t2 of tuples of r, having the same values for attributes in X, t1 and t2 also have the same values for attributes in Y
  - X determines Y (in r)
- Examples

StudentID → Residence
CourseID → CourseName
StudentID CourseID → CourseName

Non-trivial dependency

- The dependency

  StudentID CourseID → CourseID

  is trivial because CourseID is part of both sides
- A functional dependency X → Y is non-trivial if no attribute in X appears among the attributes in Y

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Functional dependencies and keys

- Given a key K of a relation r

  K → any other attribute of r (or set of attributes)
- Examples
  - StudentID CourseID → Residence
  - StudentID CourseID → CourseName
  - StudentID CourseID → Grade

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Functional dependencies and anomalies

- Anomalies are caused by attribute properties involved in functional dependencies
  - Examples
    - StudentID → Residence
    - CourseID → CourseName
- Functional dependencies on keys do not give rise to anomalies
  - Example
    - StudentID CourseID → Grade

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Functional dependencies and anomalies

- The anomalies are caused by
  - the inclusion of mutually independent concepts in the same relation
  - functional dependencies X → Y allowing for multiple tuples with the same value of X
    - X does not contain a key

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Boyce Codd normal form (BCNF)

- BCNF = Boyce Codd Normal Form
- A relation r is in BCNF if, for every (non-trivial) functional dependency X → Y defined on it, X contains a key of r (X is superkey of r)
- Anomalies and redundancies are not present in BCNF relations because independent concepts are separated in different relations

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Normal form decomposition

Normalization

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BCNF decomposition

- Normalization
  - process of replacing a non-normalised relation by two or more relations in BCNF
- Criteria
  - a relation representing several independent concepts is decomposed into smaller relations, one for each concept, by means of functional dependencies
- The new relations are obtained by projections onto the sets of attributes corresponding to the functional dependencies
- The keys of the new relations are the left parts of the functional dependencies
  - the new relations are in BCNF

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Example

- Functional dependencies in the example
  - StudentID → Residence
  - CourseID → CourseName
  - StudentID CourseID → Grade

Exam Passed

StudentID	Residence	CourseID	CourseName	Grade
s94539	Milan	04FLYCY	Electronic calculators	30
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s94540	Turin	01KPNCY	Computer network	28
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s94542	Lecce	04FLYCY	Electronic calculators	25

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Example

- By

  R (StudentID, Residence, CourseID CourseName, Grade)

- Functional dependencies in the example
  - StudentID → Residence
  - CourseID → CourseName
  - StudentID CourseID → Grade

- The relations in BCNF are

  R1 (StudentID, Residence) = $\pi_{\text{StudentID, Residence}} R$

  R2 (CourseID, CourseName) = $\pi_{\text{CourseID, CourseName}} R$

  R3 (StudentID, CourseID, Grade) = $\pi_{\text{StudentID, CourseID, Grade}} R$

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Example

R_1

StudentID	Residence
s94539	Milan
s94540	Turin
s94540	Turin
s94541	Pescara

R_2

CourseID	CourseName
04FLYCY	Electronic calculators
01FLTCY	Database design
01KPNCY	Computer network

R_3

StudentID	CourseID	Grade
s94539	04FLYCY	30
s94540	01FLTCY	26
s94540	01KPNCY	28
s94541	01KPNCY	29
s94542	04FLYCY	25

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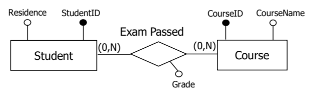
Example: corresponding ER scheme



Student (StudentID, Residence)
Course (CourseID, CourseName)
Exam Passed (StudentID, CourseID, Grade)

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Decomposition properties

Normalization

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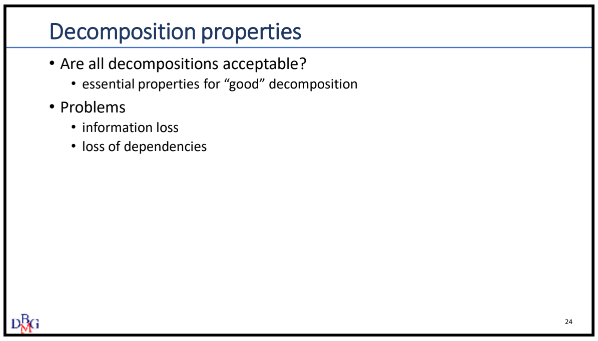

Decomposition properties

- Are all decompositions acceptable?
  - essential properties for "good" decomposition
- Problems
  - information loss
  - loss of dependencies

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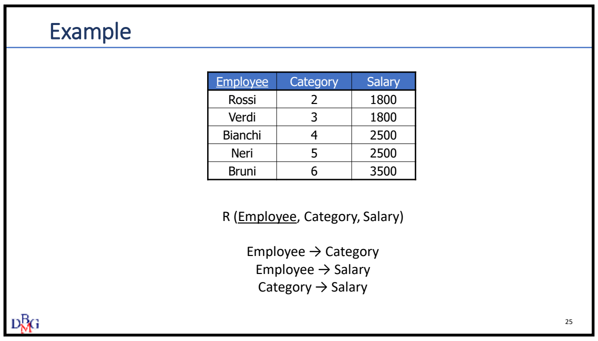

Example

<u>Employee</u>	Category	Salary
Rossi	2	1800
Verdi	3	1800
Bianchi	4	2500
Neri	5	2500
Bruni	6	3500

R (<u>Employee</u>, Category, Salary)

Employee → Category
Employee → Salary
Category → Salary

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Lossless Decomposition

Normalization

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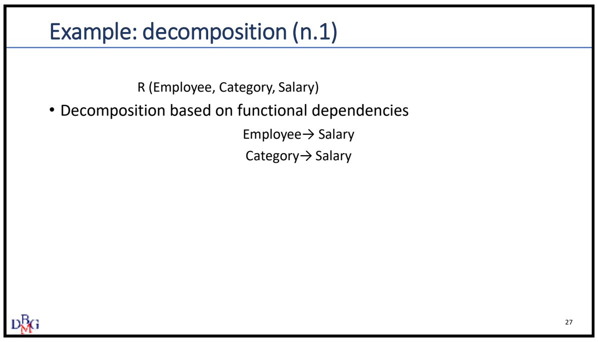

Example: decomposition (n.1)

R (Employee, Category, Salary)

- Decomposition based on functional dependencies

Employee→ Salary
Category→ Salary

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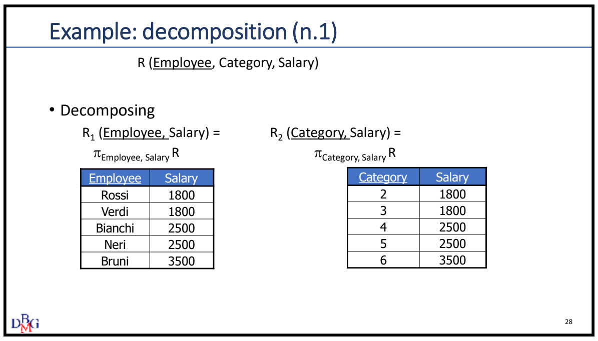

Example: decomposition (n.1)

R (<u>Employee</u>, Category, Salary)

- Decomposing

R_1 (<u>Employee,</u> Salary) = $\pi_{\text{Employee, Salary}}$ R

<u>Employee</u>	Salary
Rossi	1800
Verdi	1800
Bianchi	2500
Neri	2500
Bruni	3500

R_2 (<u>Category,</u> Salary) = $\pi_{\text{Category, Salary}}$ R

Category	Salary
2	1800
3	1800
4	2500
5	2500
6	3500

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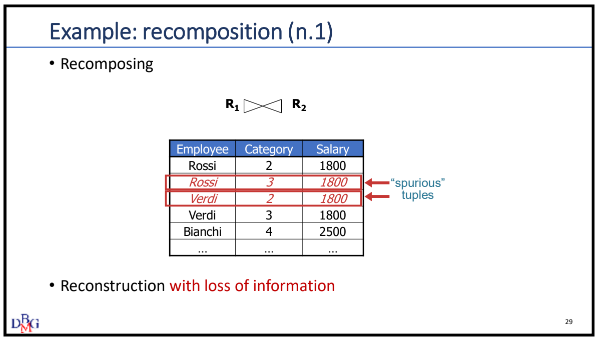

Example: recomposition (n.1)

- Recomposing

$R_1 \bowtie R_2$

Employee	Category	Salary
Rossi	2	1800
Rossi	*3*	*1800*
Verdi	*2*	*1800*
Verdi	3	1800
Bianchi	4	2500
…	…	…

"spurious" tuples

- Reconstruction with loss of information

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Decomposition without loss

- The decomposition of a relation r into two sets of attributes X1 and X2 is lossless if the join of the projections of r into X1 and X2 is equal to r itself (no "spurious" tuples)
- A decomposition performed to normalize a relation must be lossless

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Lossless decomposition

- Given the relation r(X) and sets of attributes X1 and X2 such that

  $X = X_1 \cup X_2$
  $X_0 = X_1 \cap X_2$

  if r satisfies the functional dependency

  $X_0 \rightarrow X_1$ or $X_0 \rightarrow X_2$

  the decomposition of r on X1 and X2 is lossless
- Common attributes form a key to at least one of the decomposed relations

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Example: loss of information

R_1 (<u>Employee,</u> Salary) R_2 (<u>Category,</u> Salary)

- Verification of condition for lossless decomposition

  X_1 = Employee, Salary
  X_2 = Category, Salary
  X_0 = Salary
- The attribute Salary does not satisfy the condition for lossless decomposition

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Example: decomposition (n.2)

R (<u>Employee</u>, Category, Salary)

- Decomposition based on functional dependencies

  Employee→ Category
  Employee→ Salary
- Decomposing

  R_1 (<u>Employee,</u> Category) = $\pi_{\text{Employee, Salary}}$ R

  R_2 (<u>Employee,</u> Salary) = $\pi_{\pi\text{Category, Salary}}$ R

Employee	Category
Rossi	2
Verdi	3
Bianchi	4
Neri	4
Bruni	5

Employee	Salary
Rossi	1800
Verdi	1800
Bianchi	2500
Neri	2500
Bruni	3500

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Example: lossless decomposition?

R_1 (<u>Employee,</u> Category) R_2 (<u>Employee,</u> Salary)

$\mathbf{R_1} \bowtie \mathbf{R_2}$

- Is the decomposition lossless?
- Verifying the condition for lossless decomposition

  X_1 = Employee, Category
  X_2 = Employee, Salary
  X_0 = Employee
- The attribute Employee satisfies the condition for lossless decomposition

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Conservation of dependencies

Normalization

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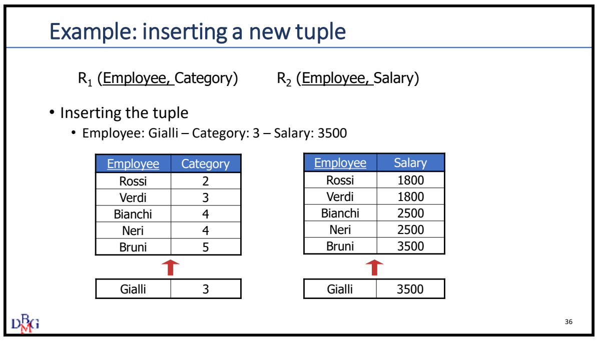

Example: inserting a new tuple

R_1 (Employee, Category) R_2 (Employee, Salary)

- Inserting the tuple
  - Employee: Gialli – Category: 3 – Salary: 3500

Employee	Category
Rossi	2
Verdi	3
Bianchi	4
Neri	4
Bruni	5
Gialli	3

Employee	Salary
Rossi	1800
Verdi	1800
Bianchi	2500
Neri	2500
Bruni	3500
Gialli	3500

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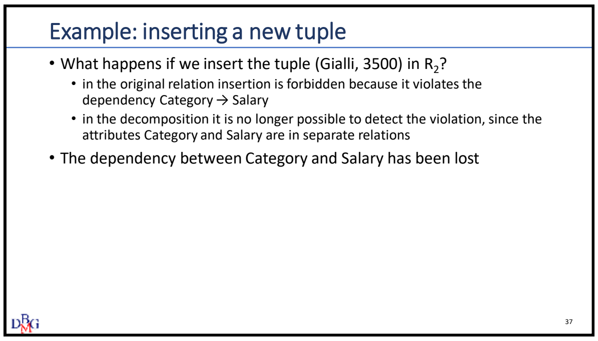

Example: inserting a new tuple

- What happens if we insert the tuple (Gialli, 3500) in R_2?
  - in the original relation insertion is forbidden because it violates the dependency Category → Salary
  - in the decomposition it is no longer possible to detect the violation, since the attributes Category and Salary are in separate relations
- The dependency between Category and Salary has been lost

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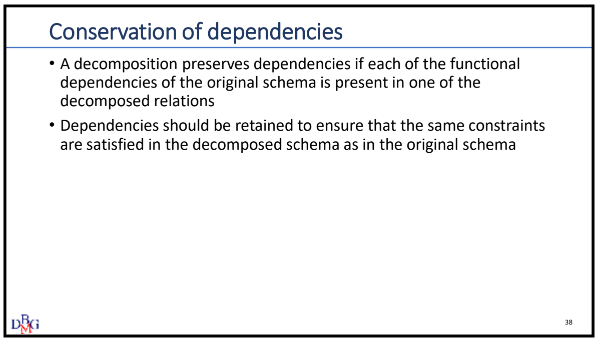

Conservation of dependencies

- A decomposition preserves dependencies if each of the functional dependencies of the original schema is present in one of the decomposed relations
- Dependencies should be retained to ensure that the same constraints are satisfied in the decomposed schema as in the original schema

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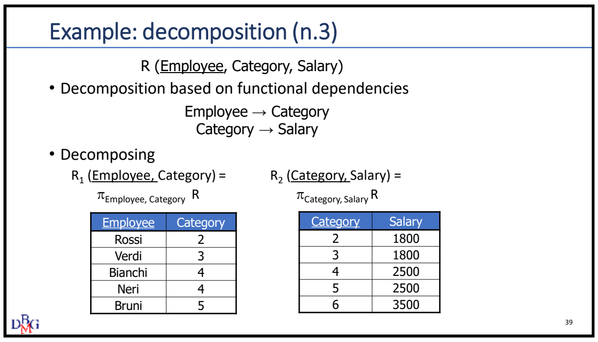

Example: decomposition (n.3)

R (Employee, Category, Salary)

- Decomposition based on functional dependencies

Employee → Category
Category → Salary

- Decomposing

R_1 (Employee, Category) = $\pi_{\text{Employee, Category}}$ R

R_2 (Category, Salary) = $\pi_{\text{Category, Salary}}$ R

Employee	Category
Rossi	2
Verdi	3
Bianchi	4
Neri	4
Bruni	5

Category	Salary
2	1800
3	1800
4	2500
5	2500
6	3500

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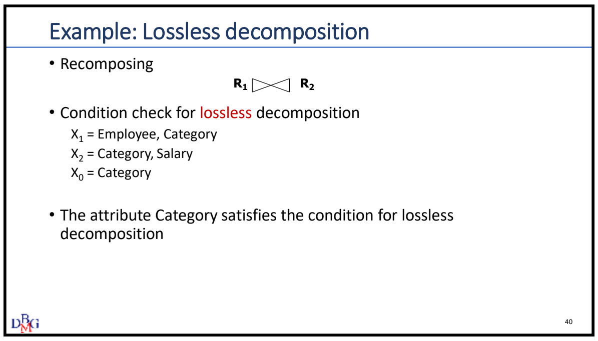

Example: Lossless decomposition

- Recomposing

$$R_1 \bowtie R_2$$

- Condition check for lossless decomposition

X_1 = Employee, Category
X_2 = Category, Salary
X_0 = Category

- The attribute Category satisfies the condition for lossless decomposition

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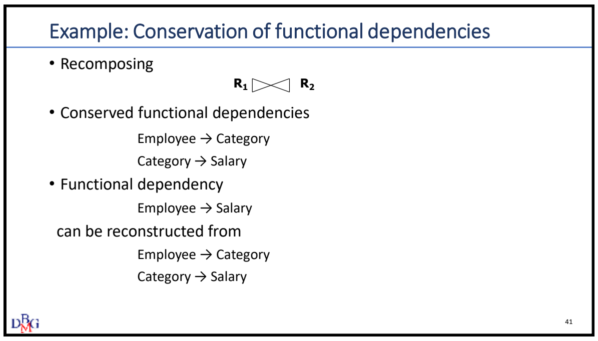

Example: Conservation of functional dependencies

- Recomposing

$$R_1 \bowtie R_2$$

- Conserved functional dependencies

Employee → Category
Category → Salary

- Functional dependency

Employee → Salary

can be reconstructed from

Employee → Category
Category → Salary

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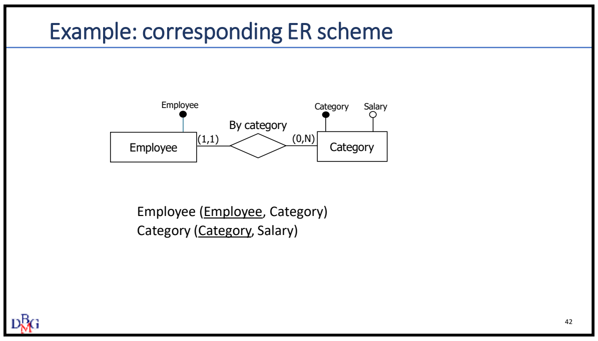
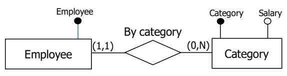
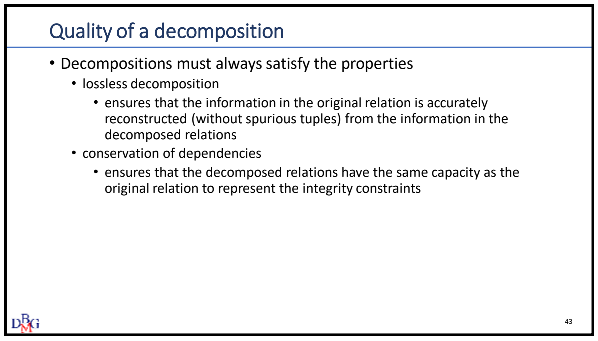


Example: corresponding ER scheme



Employee (<u>Employee</u>, Category)
Category (<u>Category</u>, Salary)



Quality of a decomposition

- Decompositions must always satisfy the properties
  - lossless decomposition
    - ensures that the information in the original relation is accurately reconstructed (without spurious tuples) from the information in the decomposed relations
  - conservation of dependencies
    - ensures that the decomposed relations have the same capacity as the original relation to represent the integrity constraints