Database design

Normalization

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Normalization

- Introduction
- Normal form of Boyce Codd
- Decomposition in normal form
- Properties of decompositions
- Lossless decomposition
- Conservation of dependencies

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Normalization

Introduction

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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.

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Normalization and ER model

- 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	CodCourse	CourseName	Vote
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

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Example: constraints

- The primary key is the pair StudentID, CodCourse
- The 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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Redundancy and Anomalies

- In all rows where a student appears, his or her residence is repeated
  - redundancy

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Redundancy and Anomalies

- In all rows where a student appears, his or her residence is repeated
  - redundancy
- If a student's residence changes, all the rows in which it appears must be modified at the same time
  - update anomaly

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Redundancy and Anomalies

- If a new student enrols at university, he or she cannot be entered in the database until he or she passes the first exam
  - insertion anomaly

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Redundancy and Anomalies

- If a new student enrols at university, he or she cannot be entered in the database until he or she passes the first exam
  - insertion anomaly
- If a student withdraws from studies, it is not possible to keep track of his residence
  - deletion anomaly

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Redundancy

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

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Anomalies

- Redundant information must be updated atomically (all at the same time)

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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

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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

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Normalization

Boyce-Codd normal form

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Functional dependence

- It is a special type of integrity constraint
- It describes functional links between the attributes of a relation

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Functional dependence

- It is a special type of integrity constraint
- It describes functional links between the attributes of a relation
- Esxample: the 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

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Functional dependence

- A relation r satisfies the functional dependence $X \rightarrow Y$ if, for each pair t_1, t_2 of tuples of r, having the same values for attributes in X, t_1 and t_2 also have the same values for attributes in Y
  - X determines Y (in r)

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Functional dependence

- A relation r satisfies the functional dependence $X \rightarrow Y$ if, for each pair t_1, t_2 of tuples of r, having the same values for attributes in X, t_1 and t_2 also have the same values for attributes in Y
  - X determines Y (in r)
- Examples

  StudentID → Residence

  StudentID CodCourse → NameCourse

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Non-trivial dependence

- The dependence

  StudentID CodCourse → CodCourse

  The dependency is trivial because CodCourse is part of both sides
- A functional dependence $X \rightarrow Y$ 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 CodCourse → Residence
  - StudentID CodCourse → NameCourse
  - StudentID CodCourse → Vote

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Functional dependencies and anomalies

- Anomalies are caused by attribute properties involved in functional dependencies
  - Examples
    - StudentID → Residence
    - CodCourse → NameCourse

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Functional dependencies and anomalies

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

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Functional dependencies and anomalies

- The anomalies are caused by
  - the inclusion of mutually independent concepts in the same relation

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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 doesn't 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 reports because independent concepts are separated in different reports

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Normalization

Normal form decomposition

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BCNF decomposition

- Normalization
  - process of replacing a non-normalised relation by two or more relations in BCNF

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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

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BCNF decomposition

- The new relationships 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
  - CodCourse → NameCourse
  - StudentID CodCourse → Vote

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Example

- By
  R (StudentID, Residence, CodCourse NameCourse, Vote)
- The relations in BCNF are
  R_1 (StudentID, Residence) = $\pi_{StudentID, Residence} R$
  R_2 (CodCourse, NameCourse) = $\pi_{CodCourse, NameCourse} R$
  R_3 (StudentID, CodCourse, Vote) =
  $\pi_{StudentID, CodCourse, Vote} R$

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Example

R_1

StudentID	Residence
s94539	Milan
s94540	Turin
s94541	Pescara
s94542	Lecce

R_2

CodCourse	NameCourse
04FLYCY	Electronic calculators
01FLTCY	Database design
01KPNCY	Computer network

R_3

StudentID	CodCourse	Vote
s94539	04FLYCY	30
s94540	01FLTCY	26
s94540	01KPNCY	28
s94541	01KPNCY	29
s94542	04FLYCY	25

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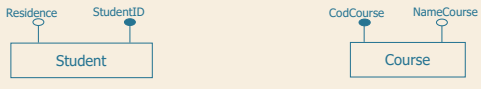
Example: corresponding ER scheme



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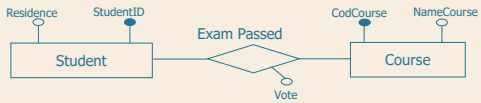
Example: corresponding ER scheme



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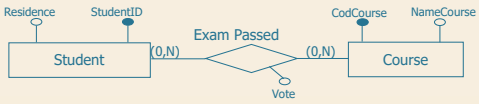
Example: corresponding ER scheme



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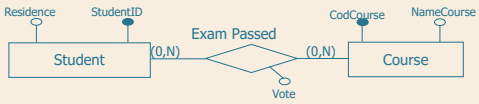
Example: relational logic scheme



Student (StudentID, Residence)
Course (CodCourse, NameCourse)
Exam Passed (StudentID, CodCourse, Vote)

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Normalization

Decomposition properties

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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

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

R (Employee, Category, Salary)

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Example

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

R (Employee, Category, Salary)

Employee → Category

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Example

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

R (Employee, Category, Salary)

Employee → Category
Employee → Salary

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Example

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

R (Employee, Category, Stipendio)

Employee → Category
Employee → Salary
Category → Salary

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Normalization

Lossless Decomposition

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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 (Employee, Category, Salary)

- Decomposing
  R_1 (Employee, Salary) =
  $\pi_{Employee, Salary}$ R

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Example: decomposition (n.1)

R (Employee, Category, Salary)

- Decomposing
  R_1 (Employee, Salary) =
  $\pi_{Employee, Salary}$ R

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

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Example: decomposition (n.1)

R (Employee, Category, Salary)

- Decomposing

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

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

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

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

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Example: recomposition (n.1)

- Recomposing

$R_1 \bowtie R_2$

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Example: recomposition (n.1)

- Recomposing

$R_1 \bowtie R_2$

Employee	Category	Salary
Rossi	2	1800

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Example: recomposition (n.1)

- Recomposing

$R_1 \bowtie R_2$

Employee	Category	Salary
Rossi	2	1800
Rossi	3	1800

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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

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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

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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
...	...	...

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Example: recomposition (n.1)

- Recomposing

$R_1 \bowtie R_2$

Employee	Category	Salary	
Rossi	2	1800	
Rossi	*3*	*1800*	"spurious" tuples
Verdi	*2*	*1800*	"spurious" tuples
Verdi	3	1800	
Bianchi	4	2500	
...	...	...	

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Example: recomposition (n.1)

- Recomposing

$R_1 \bowtie R_2$

Employee	Category	Salary	
Rossi	2	1800	
Rossi	*3*	*1800*	"spurious" tuples
Verdi	*2*	*1800*	"spurious" tuples
Verdi	3	1800	
Bianchi	4	2500	
...	...	...	

- Reconstruction with loss of information

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Decomposition without loss

- The decomposition of a relation r into two sets of attributes X_1 and X_2 is lossless if the join of the projections of r into X_1 and X_2 is equal to r itself (no "spurious" tuples)
- A decomposition performed to normalize must be lossless

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Decomposition without loss

- Given the relation r(X) and sets of attributes X_1 and X_2 such that

  $X = X_1 \cup X_2$

  $X_0 = X_1 \cap X_2$

  if r satisfies the functional dependence

  $X_0 \rightarrow X_1$ o $X_0 \rightarrow X_2$

  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 (Employee, Salary) R_2 (Category, Salary)

- Verification of condition for lossless decomposition

  X_1 = Employee, Salary

  X_2 = Category, Salary

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Example: loss of information

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

- Verification of condition for lossless decomposition

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

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Example: loss of information

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

- Decomposition based on functional dependencies

  Employee→ Category
  Employee→ Salary

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Example: decomposition (n.2)

R (Employee, Category, Salary)

- Decomposing
  R_1 (Employee, Category) =
  $\pi_{Employee, Salary}$ R

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Example: decomposition (n.2)

R (Employee, Category, Salary)

- Decomposing
  R_1 (Employee, Category) =
  $\pi_{Employee, Salary}$ R

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

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Example: decomposition (n.2)

R (Employee, Category, Salary)

- Decomposing
  R_1 (Employee, Category) =
  $\pi_{Employee, Salary}$ R

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

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

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

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Example: decomposition without loss?

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

$R_1 \bowtie R_2$

- Is decomposition without loss?

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Example: decomposition without loss

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

$R_1 \bowtie R_2$

- Verifying the condition for lossless decomposition

X_1 = Employee, Category
X_2 = Employee, Salary

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Example: decomposition without loss

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

$R_1 \bowtie R_2$

- Verifying the condition for lossless decomposition

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

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Example: decomposition without loss

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

$R_1 \bowtie R_2$

- 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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Normalization

Conservation of dependencies

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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

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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

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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

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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

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

Gialli	3

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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

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

Gialli	3

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Example: inserting a new tuple

- What happens if I insert the tuple (Gialli,3500) in R_2?
  - in the original report insertion is prohibited because it causes the violation of the dependency Category → Salary
  - in the decomposition it is no longer possible to recognise any violation, since the attributes Category and Salary are in separate relationships
- The dependence 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

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Example: decomposition (n.3)

R (Employee, Category, Salary)

- Decomposing

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

Employee	Category
Rossi	2
Verdi	3
Bianchi	4
Neri	5
Bruni	6

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Example: decomposition (n.3)

R (Employee, Category, Salary)

- Decomposing

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

Employee	Category
Rossi	2
Verdi	3
Bianchi	4
Neri	5
Bruni	6

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

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

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Example

- Recomposing

$R_1 \bowtie R_2$

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Example: decomposition without loss

- Recomposing

$R_1 \bowtie R_2$

- Condition check for lossless decomposition

X_1 = Employee, Category
X_2 = Category, Salary

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Example: decomposition without loss

- Recomposing

$R_1 \bowtie R_2$

- Condition check for lossless decomposition

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

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Example: decomposition without loss

- 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

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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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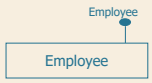
Example: corresponding ER scheme



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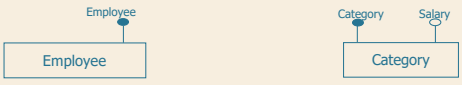
Example: corresponding ER scheme



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Example: corresponding ER scheme

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Example: corresponding ER scheme

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Example: ER schema

Employee (Employee, Category)
Category (Category, Salary)

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Quality of a decomposition

- Decompositions must always satisfy the properties
  - decomposition without loss
    - ensures that the information in the original relation is accurately reconstructed (without spurious tuples) from that 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

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