Data Model

- Set of concepts and constructs used to describe and organize data and their relationships
- Basic feature: structuring mechanism (also: type constructor) as in programming languages
- *Example*: in the relational DB model, ***relation*** constructor organizes data as sets of homogeneous (same type) records
- Two main types of data model:
  - ***Logical models***: used for organization of data at a level that abstracts from physical structures

    Examples: relational, network, hierarchical (traditional ones), object (more recent)

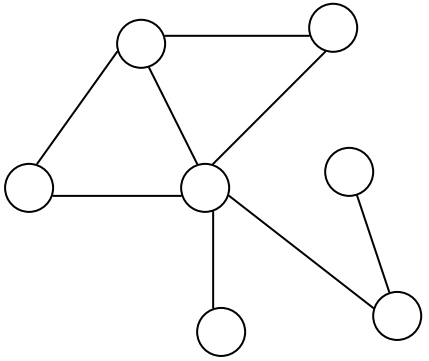
  - ***Conceptual models***: used to describe data in a way that is completely independent of any system, with the goal of representing the concepts of the real world; used in the early stages of DB design

    Most popular: Entity-Relationship model

Network Data Model

Characteristics:

- Data represented as collection of *records*
- Binary relationships represented as *links* (also called *sets,* and implemented as pointers)
- The model is represented by means of graph structures where:
  - Nodes=records
  - Edges=links



Relational Model

Characteristics:

- Data and relationships represented as values (relations)
- No explicit references, i.e., pointers as in the network model

=> higher level representation, while network model is closer to the physical structure of the DB

EXAMPLE: A Relational Database

STUDENTS

RegNum	Surname	FirstName	BirthDate
276545	Smith	Mary	25/11/1990
485745	Black	Anna	23/04/1991
200768	Verdi	Paolo	12/02/1991
587614	Smith	Lucy	10/10/1990
937653	Brown	Mavis	01/12/1990

EXAMS

Student	Grade	Course
276545	C	01
276545	B	04
937653	B	01
200768	B	04

COURSES

Code	Title	Tutor
01	Physics	Grant
03	Chemistry	Beale
04	Chemistry	Clark

EXAMPLE: A Network Database

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	C	
	B	
	B	
	B	

COURSES

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Relational Model

- Proposed by E. F. Codd in 1970 in order to support data independence
- Used in almost all commercial DBMS since 1981
- It provides simple and declarative languages that are powerful and allow to express operations for access and manipulation of data
- It is based on the concept of **relation**;
  theoretical basis that allows to formally prove properties of data and operations

Relational Model

- A relation is a set of data elements and it can be seen as a **table** in which each row (also called **tuple**) is a data element and each column corresponds to a component of the element
- Columns have associated names, called **attribute names** and associated **domains (data types)**
- **Domain**: a set (possibly infinite) of values;

  examples:

  - the set of integers is a domain;
  - the set of strings of characters with length=20 is a domain

- The pair (attribute name, domain) is called an **attribute**
- The set of attributes of a relation is called **schema**
- If a relation has name ***R*** and attribute names $A_1, A_2, \ldots, A_k$, the schema is often indicated by

  $R(A_1, A_2, \ldots, A_k)$

- The **degree** of a relation is the number of attributes (columns) of that relation, the **cardinality** of a relation is the number of tuples (rows) contained in the relation

Example:

Relation ***Info_City***

City	*Region*	*Population*
Roma	Lazio	3,000,000
Milano	Lombardia	1,500,000
Genova	Liguria	800,000
Pisa	Toscana	150,000

schema ***Info_City***(*City, Region, Population*)

Info_City has degree 3 and cardinality 4.

Relational Model

- let ***R***($A_1, A_2, ..., A_k$) be a relation schema, a tuple t on such a schema can be represented by the notation:

[$A_1 : v_1, \ A_2 : v_2, ..., A_k : v_k$] or by ($v1, v2, \ldots, vk$)

where v_i is a value belonging to the domain of A_i (denoted $dom(A_i)$) for $i=1,....,k$

$t[A_i]$ indicates the value of the attribute named A_i of tuple t

- Example:

  t = [City : Roma, Region : Lazio, Population : 3,000,000] or t = (Roma, Lazio, 3,000,000)

  is a tuple defined on schema Info_City(*City, Region, Population*)

  t[City] = Roma

Relational Value

Null Values

- sometimes no information is available on some components of entities represented in the DB

  i.e., no value is known for some attributes of some rows (tuples)

- special value (**null value**) denotes no value (often denoted '?')

Relational Model: Key

- The **key** of a relation is the set of attributes that uniquely identifies tuples of the relation
- More precisely, a set X of attributes of a relation R, is a *key* of R if it satisfies the following properties:

  1. for each status of R, no pair of distinct rows (tuples) *t'* and *t''* exist in R such that *t'* and *t''* have same value for all attributes in X;

  2. no proper subset (*) of X satisfies property (1).

- In the previous example:
  key(Info_City) = {City}
  there cannot be multiple cities with same name

  key(Info_City) = {City, Region}
  different cities with same name can exist but only in different regions

---

(*)S' is a proper subset of S, if it is a subset of S and S'≠S.

Relational Model: Key

- A key cannot have null values
- There can be more than one set X in a relation that satisfies the two properties (several possible keys)
- Sometimes it is necessary to choose one key if the system does not support multiple keys.
- **Primary key** is the selected key
- A possible selection criterion is to choose the key most frequently used in queries
- Another criterion: choose the key with least number of attributes

Relational Model: Foreign Key

- Let R and R' be two relations such that

  - R has a set of attributes X;

  - R' has a set Y of attributes as key;

  Y is **foreign key** of R on R' if Y is a subset of X

- In other words, if R has among its attributes a set Y of attributes that is key of a relation R', we say that Y is an external key of R on R'

- R' is said **referenced relation**

- Foreign keys allow to link tuples of different relations and provide a mechanism to model associations between entities

- A tuple t that references another tuple t' includes, among its attributes, one or more attributes whose value is the value of the key of t'

Relational Model: Example

We define two relations that contain information about employees of a company and the departments in which the company is organized

Employees (Emp#, Name, Job, Start_Date,Salary, Bonus, Dept#)

key(Employees) = {Emp#}

foreign-key(Employees) = {Dept#}

(referenced relation: Departments)

Departments(Dept#, Name_Dept, Office#, Division#, Manager)

key (Departments) = {Dept#}

Example

Employees

Emp#	Name	Job	Start_Date	Salary	Bonus	Dept#
7369	Rossi	engineer	17-Dec-90	1600,00	500,00	20
7499	Andrei	technician	20-Feb-91	800,00	?	30
7521	Bianchi	technician	20-Feb-91	800,00	100,00	30
7566	Rosi	manager	02-Apr-91	2975,00	?	20
7654	Martini	secretary	28-Sep-91	800,00	?	30
7698	Blacchi	manager	01-May-91	2850,00	?	30
7782	Neri	engineer	01-Jun-91	2450,00	200,00	10
7788	Scotti	secretary	09-Nov-91	800,00	?	20
7839	Dare	engineer	17-Nov-91	2600,00	300,00	10
7844	Turni	technician	08-Sep-91	1500,00	?	30
7876	Adami	engineer	28-Sep-91	1100,00	500,00	20
7900	Gianni	engineer	03-Dec-91	1950,00	?	30
7902	Fordi	secretary	03-Dec-91	1000,00	?	20
7934	Milli	engineer	23-Jan-92	1300,00	150,00	10
7977	Verdi	manager	10-Dec-90	3000,00	?	10

Departments

Dept#	Name_Dept	Office	Division	Manager
10	Civil Engineering	1100	D1	7977
20	R&D	2200	D1	7566
30	Surveying	5100	D2	7698

Relational Model: Referential Integrity Constraints

- imposed to guarantee that values refer to actual values in the referenced relation
- if a tuple t references $v_1,.....,v_n$ as values of a foreign key, there must be a tuple t' in the referenced relation with key values $v_1,.....,v_n$
- relations Employees and Departments verify this property
- consider the following tuple and assume it is inserted in relation Employees

  [Emp#: 7899, Name: Smith, Job: technician,
  Start_Date_A:03-Dec-91, Salary:2000,
  Bonus: 100, Dept#: 50]

  this tuple violates referential integrity as there is no department in relation Departments with number = 50

- DB languages (SQL) allow the user to specify for which relations and attributes it is necessary to preserve referential integrity (and what to do when there is violation)

Query Languages for Relational DB

- Operations on DB:

  1. queries: read from the DB
  2. updates: change the content of the DB

- Formal query language: *relational algebra*
- Relational algebra is a “procedural” language: queries are expressed by applying operators to relations, i.e., to formulate a query as an algebraic expression, we indicate operations (steps) that must be performed to generate the query result

- Later, we will see SQL: practical language for queries and updates

Relational Algebra

- 5 basic operations:
  - *union*
  - *difference*
  - *Cartesian product*
  - *projection*
  - *selection*
- these operations completely define relational algebra

- every operation returns a relation as result; it is then possible to apply an operation to the result of another operation (closure property)

- there are additional operations that can be expressed in terms of the 5 basic operations; these operations do not add expressive power to the set of basic operations but they are useful shortcuts and they are called “derived operations”

- the most important derived operation: *join*

- *renaming:* to modify names of attributes

Union

- Union of two relations R and S, indicated R ∪ S:

  set of tuples that are in R, or in S, or in both

- Union of two relations is possible only if the two relations have same degree; also: the first attribute of R must be compatible with the first attribute of S, the second attribute of R must be compatible with the second attribute of S and so on.

- if the two relations have different attribute names, in the returned relation by convention the names from the first relation (in this case R) are used, unless renaming is applied

- duplicate tuples are eliminated

- the degree of the returned relation is the same as the degree of the two original relations

Union

Example

A	B	C
a	b	c
d	a	f
c	b	d

relation R

D	E	F
b	g	a
d	a	f

relation S

A	B	C
a	b	c
d	a	f
c	b	d
b	g	a

$R \cup S$

Difference

- Difference of two relations R and S, indicated R – S:

  set of tuples that are in R, but not in S

- difference (like union) of two relations is possible only if the two relations have same degree and attributes are compatible

- if the two relations have different attribute names, in the returned relation by convention the names from the first relation (in this case R) are used, unless renaming is applied

- the degree of the returned relation is the same as the degree of the two original relations

Difference

Example

A	B	C
a	b	c
d	a	f
c	b	d

relation R

D	E	F
b	g	a
d	a	f

relation S

A	B	C
a	b	c
c	b	d

R – S

Cartesian Product

- Cartesian product of two relations R and S, with degree k_1 and k_2, respectively, indicated

  R X S

  is a relation with degree $k_1 + k_2$ composed of all possible tuples such that:

  - their first k_1 components are tuples of R, and
  - their last k_2 components are tuples of S

- in the returned relation the names of the first k_1 attributes are the names of attributes of relation R and the names of the last k_2 attributes are the names of the attributes of relation S

- if the two relations have attributes with same name it is necessary to rename those attributes in one of the two relations

Example

A	B	C
a	b	c
d	a	f
c	b	d

relation R

D	E	F
b	g	a
d	a	f

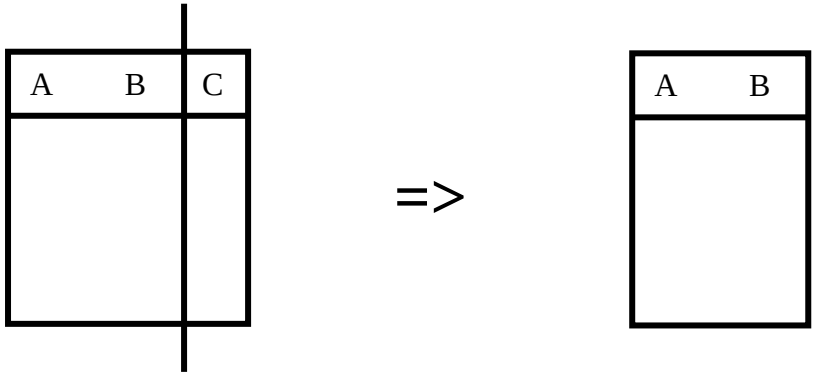
relation S

A	B	C	D	E	F
a	b	c	b	g	a
a	b	c	d	a	f
d	a	f	b	g	a
d	a	f	d	a	f
c	b	d	b	g	a
c	b	d	d	a	f

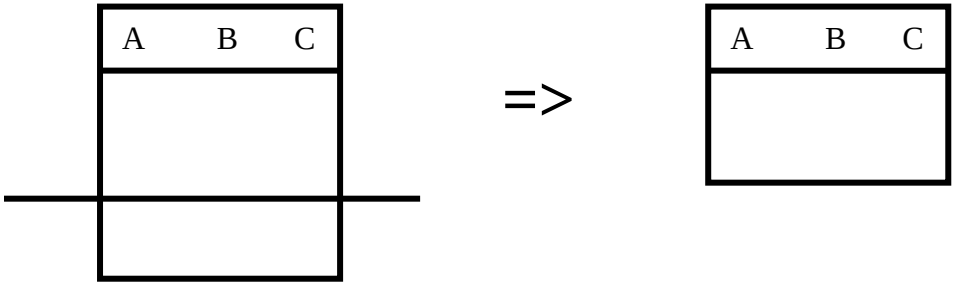
R x S

Projection and Selection

Projection = vertical decomposition



Selection = horizontal decomposition



Projection

- projection of a relation R on a set $A=\{A_1, A_2,....,A_m\}$ of attributes, indicated

$$\Pi_{A1,\ A2,....,Am}(R)$$

  is a relation of degree *m* whose tuples have only attributes specified in A

- projection operation generates a set T of m-tuples (i.e., tuples with m attributes)

- projection generates, from a given relation, a relation containing only a subset of attributes
- in the returned relation attributes are ordered according to the order specified in A

Example

A	B	C
a	b	c
d	a	f
c	b	d

Relation R

A	C
a	c
d	f
c	d

$\Pi_{A,C}(R)$

B	A
b	a
a	d
b	c

$\Pi_{B,A}(R)$

Selection: predicates

- a predicate F on a relation can be one of the following:
  - simple predicate
  - Boolean combination of simple predicates by means of logical connectives

    $\wedge$ (AND), $\vee$ (OR), $\neg$ (NOT)

- a *simple predicate* can be
  (i) A *op constant*
  (ii) A *op* A'

  where A and A' are attributes of R;
  op is a comparison operator: <, >, $\leq$, $\geq$, =, etc.
  constant is a constant value compatible with the domain of A

- examples:

B=b	simple predicate (i)
A=C	simple predicate (ii)
B=b $\vee$ A=C	Boolean combination
B=b $\wedge$ A=C	Boolean combination
$\neg$B=b	Boolean combination

Selection

- Selection on a relation R, given a predicate F, indicated σ_F (R)

  is a relation that contains all tuples satisfying predicate F
- the degree of the returned relation is the same as the degree of the original relation; the names of its attributes are the same as the name of the original relation
- if no tuple of R satisfies F, the result is an empty relation (indicated 0 or Ø)
- if k is the degree of R, selection generates a set T of k-tuples

Example

A	B	C
a	b	c
d	a	f
c	b	d

relation R

A	B	C
a	b	c
c	b	d

$\sigma_{B=b}(R)$

A	B	C
d	a	f

$\sigma_{\neg(B=b)}(R)$

A	B	C
a	b	c
c	b	d

$\sigma_{B=b \vee A=C}(R)$

$\sigma_{B=b \wedge A=C}(R) = \varnothing$

Example

Employees

Emp#	Name	Job	Start_Date	Salary	Bonus	Dept#
7369	Rossi	engineer	17-Dec-90	1600,00	500,00	20
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7521	Bianchi	technician	20-Feb-91	800,00	100,00	30
7566	Rosi	manager	02-Apr-91	2975,00	?	20
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EXAMPLES

- **Q1: find the name of employees that have salary greater than 2000**

$$\Pi_{Name}(\sigma_{Salary>2000}(Employees))$$

Name
Rosi
Blacchi
Neri
Dare
Verdi

- **Q2: find the name and numbers of department of employees that are engineers and have salary greater than 2000**

$$\Pi_{Name,Dept\#}(\sigma_{Salary>2000 \wedge Job= \text{'engineer'}} (Employees))$$

Name	Dep#
Neri	10
Dare	10

- **Q3: find the employee number of employees that:** (a) work in department 30 and (b) are engineers or technicians

$$\Pi_{Emp\#}(\sigma_{Dept\#=30 \wedge (Job= 'engineer' \vee Job= 'technician')}(Employees))$$

Emp#
7499
7521
7844
7900

Renaming

Renaming of a relation R with respect to a list of pairs of names of attributes

$$(A_1, B_1), (A_2, B_2), \ldots\ldots, (A_m, B_m)$$

such that A_i (i=1,...,m) is a name of an attribute in R, is denoted

$$\rho_{A1, A2, \ldots, Am \leftarrow B1, B2, \ldots, Bm}(R)$$

and renames attribute named A_i (i=1,...,m) with name B_i

Renaming is correct if the attributes of the new schema of relation R all have distinct names

Example:

R(A,B,C)

$$\rho_{A, B, C \leftarrow AA, BB, CC}(R)$$

modifies the schema of relation R to R(AA,BB,CC)

Derived operation: Join

- join of two relations R and S on attributes A of R and A' of S, indicated

$$R \underset{A\theta A'}{\bowtie} S$$

  is defined $\sigma_{A\theta A'}(R \times S)$

- join is a Cartesian product followed by a selection; $A\theta A'$ is called *join predicate*

- the degree of the resulting relation is the sum of the degrees of the original relations

Examples

A	B	C
1	2	3
4	5	6
7	8	9

relation R

D	E
3	1
6	2

relation S

A	B	C	D	E
1	2	3	3	1

$R \bowtie S$
A=E

A	B	C	D	E
1	2	3	3	1
1	2	3	6	2
4	5	6	6	2

$R \bowtie S$
B<D

A	B	C	D	E
1	2	3	3	1
1	2	3	6	2
4	5	6	3	1
4	5	6	6	2
7	8	9	3	1
7	8	9	6	2

RXS

A	B	C	D	E
1	2	3	3	1

$\sigma_{A=E}(RXS)$

$R \bowtie_{A=E} S$

Natural Join

- Natural join is a particular case of join
- Example: “find the name of all employees and the office in which they work”

  We can express this query by joining Employees and Departments with the predicate:

  Employees.Dept# = Departments.Dept#

- this particular case of join is based on the equality of all attributes common to the two relations
- joins based on equality of attributes are very frequently used

Natural Join

We can express the previous query as: $\Pi_{\text{Name, Office}}$ (Employees $\bowtie$ Departments)

- natural join performs a join based on the equality of attributes common to the two relations and then eliminates all duplicate attributes – ie. in this case only one of the columns Dept# appears in the result (and there is no need to use Renaming)

Example

A	B	C
a	b	c
d	b	c
b	b	f
c	a	d

R

B	C	D
b	c	d
b	c	e
a	d	b

S

A	B	C	D
a	b	c	d
a	b	c	e
d	b	c	d
d	b	c	e
c	a	d	b

R ⋈ S

Derived operations: Intersection

$R \cap S = R - (R - S)$ (same constraints apply as for difference)

Example

A	B	C
a	b	c
d	a	f
c	b	d

relation R

D	E	F
b	g	a
d	a	f

relation S

A	B	C
a	b	c
c	b	d

relation R – S

A	B	C
d	a	f

relation R – (R – S)

Semantic Integrity Constraints

A constraint is a property that a set of data must satisfy. One possible classification of constraints:

- *immediate*: verified immediately after each modification of the DB
- *deferred*: verified only at the end of a series of operations (transaction)

- constraints can also be classified depending on the objects they access:

  - on a single relation
    - (i) on a single tuple:
      - * attribute constraints
      - * multiple attribute constraints
    - (ii) on multiple tuples of the same relation
      - * functional dependencies
      - * cardinality constraints
    - (iii) aggregation constraints
  - on multiple relations: referential integrity

Examples:

- on a single attribute

  salary of an employee must be between 500 and 1000

- on multiple attributes

  bonus of an employee must always be less than the salary

- cardinality constraints

  there must be at least 3 technicians (ie. 3 employees whose job = “technician”)

- aggregation constraints

  the average salary for a technician must be greater than 500

- constraints on multiple relations

  the sum of salaries of employees that work on project P must be less than the budget for P