# Relational Model

## Introduction

- Proposed by Edgar. F. Codd (1923-2003) in the early seventies. [ Turing Award – 1981 ]
- Most of the modern DBMS are relational.
- Simple and elegant model with a mathematical basis.
- Led to the development of a theory of data dependencies and database design.
- Relational algebra operations –
  crucial role in query optimization and execution.
- Laid the foundation for the development of
  - Tuple relational calculus and then
  - Database standard SQL

## Relation Scheme

- Consists of relation name, and a set of attributes or field names or column names. Each attribute has an associated domain.
- *Example:*

```
student ( studentName      : string,
          rollNumber       : string,
          phoneNumber      : integer,
          yearOfAdmission  : integer,
          branchOfStudy    : string )
```

**Relation name**

Attribute names

domains

- *Domain* – set of *atomic* (or *indivisible* ) values – data type

## Relation Instance

- A finite *set* of tuples constitute a relation instance.
- A tuple of relation with scheme $R = (A_1, A_2, \ldots, A_m)$ is an ordered sequence of values $(v_1, v_2, \ldots, v_m)$ such that $v_i \in$ domain $(A_i)$, $1 \leq i \leq m$

student

| **studentName** | **rollNumber** | **yearOf Admission** | **phoneNumber** | **branch Of Study** |
|---|---|---|---|---|
| Ravi Teja | CS05B015 | 2005 | 9840110489 | CS |
| Rajesh | CS04B125 | 2004 | 9840110490 | CS |
| | | ⋮ | | |

No duplicate tuples ( or rows ) in a relation instance.

We shall later see that in SQL, duplicate rows would be allowed in tables.

## Another Relation Example

enrollment (studentName, rollNo, courseNo, sectionNo)

enrollment

| studentName | rollNumber | courseNo | sectionNo |
|---|---|---|---|
| Rajesh | CS04B125 | CS320 | 2 |
| Rajesh | CS04B125 | CS370 | 1 |
| Suresh | CS04B130 | CS320 | 2 |
| | | ⋮ | |

## Keys for a Relation (1/2)

- **Key**: A set of attributes K, whose values uniquely identify a tuple in any instance. And none of the proper subsets of K has this property

  Example: {*rollNumber*} is a key for *student* relation.

  {*rollNumber, name*} – values can uniquely identify a tuple

    - but the set is not *minimal*
    - not a Key
- A key can not be determined from any particular instance data
  - it is an intrinsic property of a scheme
  - it can only be determined from the meaning of attributes

## Keys for a Relation (2/2)

- A relation can have more than one key.
- Each of the keys is called a *candidate* key

  Example: *book* (*isbnNo, authorName, title, publisher, year*)
  (Assumption : books have only one author )
  *Keys*: {*isbnNo*}, {*authorName, title*}
- A relation has at least one key

  - the set of all attributes, in case no proper subset is a key.
- **Superkey**: A set of attributes that contains a key as a subset.
  - A key can also be defined as a *minimal superkey*
- **Primary Key**: One of the candidate keys chosen for indexing purposes ( More details later…)

## Relational Database Scheme and Instance

**Relational database scheme**: *D* consist of a finite no. of relation schemes and a set *I* of integrity constraints.

**Integrity constraints**: Necessary conditions to be satisfied by the data values in the relational instances so that the set of data values constitute a meaningful database

- domain constraints
- key constraints
- referential integrity constraints

**Database instance**: Collection of relational instances satisfying the integrity constraints.

## Domain and Key Constraints

- **Domain Constraints**: Attributes have associated domains

  *Domain* – set of atomic data values of a specific type.

  *Constraint* – stipulates that the actual values of an attribute in any tuple must belong to the declared domain.

- **Key Constraint**: Relation scheme – associated keys

  Constraint – if $K$ is supposed to be a key for scheme $R$, any relation instance $r$ on $R$ should not have two tuples that have identical values for attributes in $K$.

  Also, none of the key attributes can have null value.

## Foreign Keys

- Tuples in one relation, say $r_1(R_1)$, often need to refer to tuples in another relation, say $r_2(R_2)$
  - to capture relationships between entities
- Primary Key of $R_2$ : $K = \{B_1, B_2, \ldots, B_j\}$
- A set of attributes $F = \{A_1, A_2, \ldots, A_j\}$ of $R_1$ such that

  $$\text{dom}(A_i) = \text{dom}(B_i), \quad 1 \leq i \leq j \text{ and}$$

  whose values are used to refer to tuples in $r_2$ is called a *foreign key* in $R_1$ *referring* to $R_2$.

- $R_1$, $R_2$ can be the same scheme also.
- There can be more than one foreign key in a relation scheme

## Foreign Key – Examples(1/2)

Foreign key attribute *deptNo* of *course* relation refers to Primary key attribute *deptID* of *department* relation

Course

| courseId | name | credits | deptNo |
|---|---|---|---|
| CS635 | ALGORITHMS | 3 | 1 |
| CS636 | A.I | 4 | 1 |
| ES456 | D.S.P | 3 | 2 |
| ME650 | AERO DYNAMIC | 3 | 3 |

Department

| deptId | name | hod | phone |
|---|---|---|---|
| 1 | COMPUTER SCIENCE | CS01 | 22576235 |
| 2 | ELECTRICAL ENGG | ES01 | 22576234 |
| 3 | MECHANICAL ENGG | ME01 | 22576233 |

## Foreign Key – Examples(2/2)

It is possible for a foreign key in a relation
to refer to the primary key of the relation itself

An Example:

univEmployee ( <u>empNo</u>, name, sex, salary, dept, reportsTo)

*reportsTo* is a foreign key referring to *empNo* of the same relation

Every employee in the university reports to some other employee for administrative purposes
- except the *vice-chancellor*, of course!

## Referential Integrity Constraint (RIC)

- Let *F* be a foreign key in scheme $R_1$ referring to scheme $R_2$ and let *K* be the primary key of $R_2$.
- **RIC**: any relational instance $r_1$on $R_1$, $r_2$ on $R_2$ must be s.t for any tuple *t* in $r_1$, either its *F*-attribute values are *null* or they are identical to the *K*-attribute values of *some* tuple in $r_2$.
- RIC ensures that references to tuples in $r_2$ are for *currently existing* tuples.
  - That is, there are no *dangling* references.

## Referential Integrity Constraint (RIC) - Example

COURSE

| **courseId** | **name** | **credits** | **deptNo** |
|---|---|---|---|
| CS635 | ALGORITHMS | 3 | 1 |
| CS636 | A.I | 4 | 1 |
| ES456 | D.S.P | 3 | 2 |
| ME650 | AERO DYNAMIC | 3 | 3 |
| CE751 | MASS TRANSFER | 3 | 4 |

DEPARTMENT

| **deptId** | **name** | **hod** | **phone** |
|---|---|---|---|
| 1 | COMPUTER SCIENCE | CS01 | 22576235 |
| 2 | ELECTRICAL ENGG. | ES01 | 22576234 |
| 3 | MECHANICAL ENGG. | ME01 | 22576233 |

The new course refers to a non-existent department and thus violates the RIC

## Example Relational Scheme

student (rollNo, name, degree, year, sex, deptNo, advisor)

Here, *degree* is the program ( B Tech, M Tech, M S, Ph D etc) for which the student has joined. *Year* is the year of admission and *advisor* is the EmpId of a faculty member identified as the student's advisor.

department (deptId, name, hod, phone)

Here, *phone* is that of the department's office.

professor (empId, name, sex, startYear, deptNo, phone)

Here, *startYear* is the year when the faculty member has joined the department *deptNo*.

## Example Relational Scheme

course (<u>courseId</u>, cname, credits, deptNo)

Here, *deptNo* indicates the department that offers the course.

enrollment (<u>rollNo, courseId, sem, year</u>, grade)

Here, *sem* can be either "odd" or "even" indicating the two semesters of an academic year. The value of *grade* will be null for the current semester and non-null for past semesters.

teaching (<u>empId, courseId, sem, year</u>, classRoom)

preRequisite (<u>preReqCourse, courseID</u>)

Here, if (c1, c2) is a tuple, it indicates that c1 should be successfully completed before enrolling for c2.

## Example Relational Scheme

student (rollNo, name, degree, year, sex, deptNo, advisor)

department (deptId, name, hod, phone)

professor (empId, name, sex, startYear, deptNo, phone)

course (courseId, cname, credits, deptNo)

enrollment (rollNo, courseId, sem, year, grade)

teaching (empId, courseId, sem, year, classRoom)

preRequisite (preReqCourse, courseId)

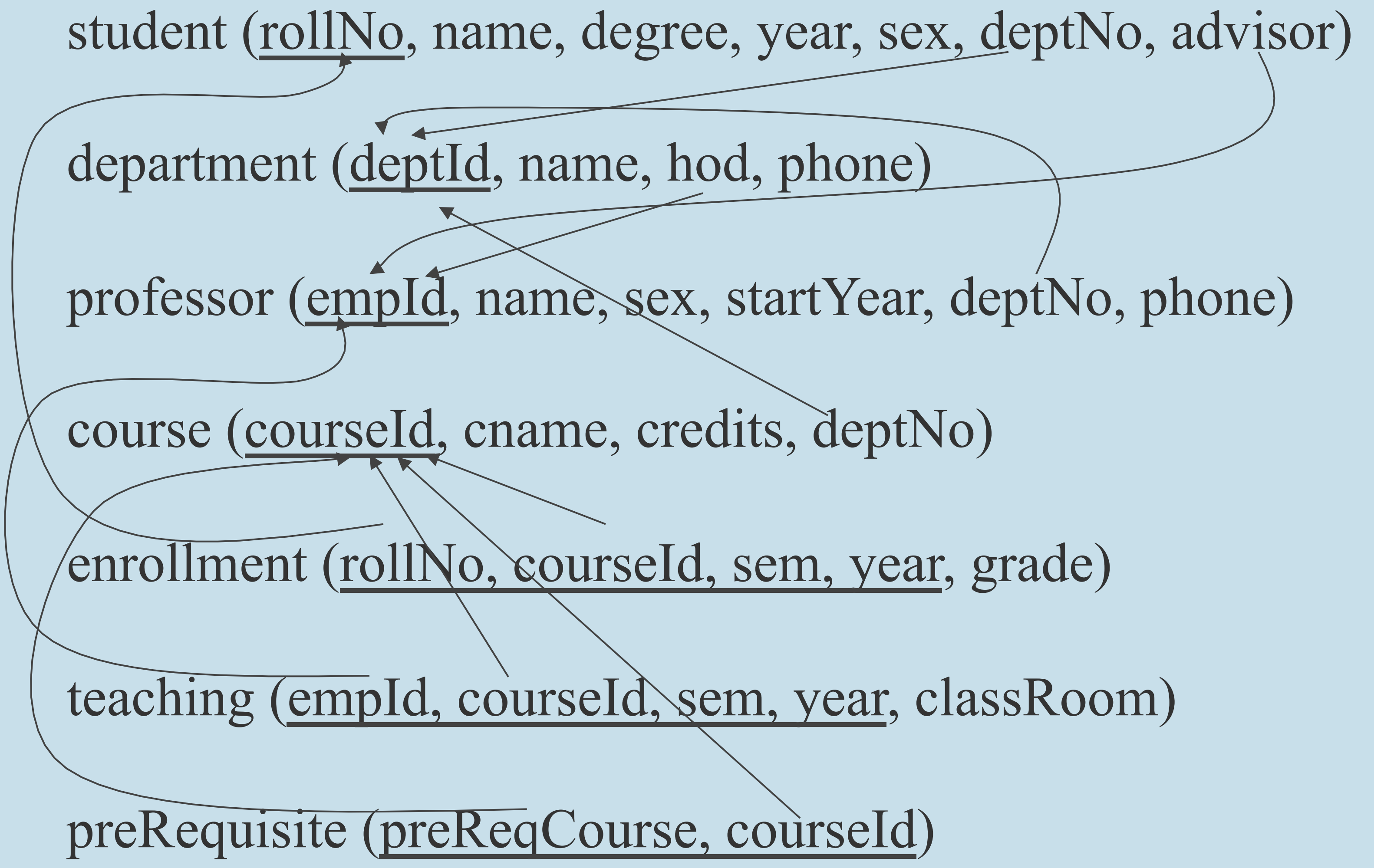
queries-1

queries-2

queries-3

TCQuery

# Example Relational Scheme with RIC’s shown



student (rollNo, name, degree, year, sex, deptNo, advisor)

department (deptId, name, hod, phone)

professor (empId, name, sex, startYear, deptNo, phone)

course (courseId, cname, credits, deptNo)

enrollment (rollNo, courseId, sem, year, grade)

teaching (empId, courseId, sem, year, classRoom)

preRequisite (preReqCourse, courseId)

## Relational Algebra

- A set of operators (unary and binary) that take relation instances as arguments and return new relations.
- Gives a procedural method of specifying a retrieval query.
- Forms the core component of a relational query engine.
- SQL queries are internally translated into RA expressions.
- Provides a framework for query optimization.

**RA operations**: *select* ($\sigma$), *project* ($\pi$), *cross product* ($\times$), *union* ($\cup$), *intersection* ($\cap$), *difference* ($-$), *join* ( $\bowtie$ )

## The *select* Operator

- Unary operator.
- can be used to *select* those tuples of a relation that satisfy a given condition.
- *Notation*: $\sigma_\theta ( r )$

  $\sigma$ : select operator ( read as *sigma*)

  $\theta$ : selection condition

  $r$ : relation name
- Result: a relation with the same schema as $r$ consisting of the tuples in $r$ that satisfy condition $\theta$
- Select operation is commutative:

  $\sigma_{c1} (\sigma_{c2} ( r ) ) = \sigma_{c2} (\sigma_{c1} ( r ) )$

## Selection Condition

- *Select condition*:
  Basic condition or Composite condition
- *Basic condition*:
  Either $A_i$ <compOp> $A_j$ or $A_i$ <compOp> c
- *Composite condition*:
  Basic conditions combined with logical operators AND, OR and NOT appropriately.
- Notation:

  <compOp> : one of $<, \leq, >, \geq, =, \neq$

  $A_i$, $A_j$ : attributes in the scheme *R* of *r*

  c : constant of appropriate data type

## Examples of *select* expressions

1. Obtain information about a professor with name "Giridhar"

$$\sigma_{\text{name} = \text{“Giridhar”}} (\text{professor})$$

2. Obtain information about professors who joined the university between 1980 and 1985, both inclusive

$$\sigma_{\text{startYear} \geq 1980 \wedge \text{startYear} \leq 1985} (\text{professor})$$

## The *project* Operator

- Unary operator.
- Can be used to keep only the required attributes of a relation instance and throw away others.
- *Notation*: $\pi_{A_1, A_2, \ldots, A_k}(r)$ where $A_1, A_2, \ldots, A_k$ is a list L of desired attributes in the scheme of r.
- Result = $\{ (v_1, v_2, \ldots, v_k) \mid v_i \in dom(A_i),\ 1 \le i \le k$ and there is some tuple t in r *s.t* $t.A_1 = v_1, t.A_2 = v_2, \ldots, t.A_k = v_k \}$
- If $r_1 = \pi_L(r_2)$ then scheme of $r_1$ is L

## Examples of *project* expressions

student

| rollNo | name | degree | year | sex | deptNo | advisor |
|---|---|---|---|---|---|---|
| CS04S001 | Mahesh | M.S | 2004 | M | 1 | CS01 |
| CS03S001 | Rajesh | M.S | 2003 | M | 1 | CS02 |
| CS04M002 | Piyush | M.E | 2004 | M | 1 | CS01 |
| ES04M001 | Deepak | M.E | 2004 | M | 2 | ES01 |
| ME04M001 | Lalitha | M.E | 2004 | F | 3 | ME01 |
| ME03M002 | Mahesh | M.S | 2003 | M | 3 | ME01 |

$\pi_{\text{rollNo, name}}$ (student)

| rollNo | name |
|---|---|
| CS04S001 | Mahesh |
| CS03S001 | Rajesh |
| CS04M002 | Piyush |
| ES04M001 | Deepak |
| ME04M001 | Lalitha |
| ME03M002 | Mahesh |

$\pi_{\text{name}}\ (\sigma_{\text{degree = “M.S”}}$ (student))

| name |
|---|
| Mahesh |
| Rajesh |

Note: Mahesh is displayed only once because project operation results in a set.

## Size of *project* expression result

- If $r_1 = \pi_L(r_2)$ then scheme of $r_1$ is L
- What about the number of tuples in $r_1$?
- Two cases arise:
  - Projection List L contains some key of $r_2$
    - Then $|r_1| = |r_2|$
  - Projection List L does not contain any key of $r_2$
    - Then $|r_1| \leq |r_2|$

## Set Operators on Relations

- As relations are sets of tuples, set operations are applicable to them; but not in all cases.
- **Union Compatibility** : Consider two schemes $R_1$, $R_2$ where $R_1 = (A_1, A_2, \ldots, A_k)$ ; $R_2 = (B_1, B_2, \ldots, B_m)$
- $R_1$ and $R_2$ are called *union-compatible* if
  - $k = m$ and
  - $dom(A_i) = dom(B_i)$ for $1 \leq i \leq k$
- **Set operations** – *union, intersection, difference*
  - Applicable to two relations if their schemes are union-compatible
- If $r_3 = r_1 \cup r_2$ , scheme of $r_3$ is $R_1$ (as a convention)

## Set Operations

$r_1$ - relation with scheme $R_1$
$r_2$ - relation with scheme $R_2$ - union compatible with $R_1$

$$r_1 \cup r_2 = \{t \mid t \in r_1 \text{ or } t \in r_2\};$$
$$r_1 \cap r_2 = \{t \mid t \in r_1 \text{ and } t \in r_2\}$$
$$r_1 - r_2 = \{t \mid t \in r_1 \text{ and } t \notin r_2\};$$

By convention, in all the cases, the scheme of the result is that of the first operand i.e $r_1$.

## *Cross product* Operation

| $r_1$ $A_1$ | $A_2$ | ... | $A_m$ |
|---|---|---|---|
| $a_{11}$ | $a_{12}$ | ... | $a_{1m}$ |
| $a_{21}$ | $a_{22}$ | ... | $a_{2m}$ |
| $a_{s1}$ | $a_{s2}$ | ... | $a_{sm}$ |

$r_1$ : *s* tuples

| $r_2$ $B_1$ | $B_2$ | ... | $B_n$ |
|---|---|---|---|
| $b_{11}$ | $b_{12}$ | ... | $b_{1n}$ |
| $b_{21}$ | $b_{22}$ | ... | $b_{2n}$ |
| $b_{t1}$ | $b_{t2}$ | ... | $b_{tn}$ |

$r_2$ : *t* tuples

$r_1 \times r_2$

| $A_1$ | $A_2$ | ... | $A_m$ | $B_1$ | $B_2$ | ... | $B_n$ |
|---|---|---|---|---|---|---|---|
| $a_{11}$ | $a_{12}$ | ... | $a_{1m}$ | $b_{11}$ | $b_{12}$ | ... | $b_{1n}$ |
| $a_{11}$ | $a_{12}$ | ... | $a_{1m}$ | $b_{21}$ | $b_{22}$ | ... | $b_{2n}$ |
| | : | | | | : | | |
| $a_{11}$ | $a_{12}$ | ... | $a_{1m}$ | $b_{t1}$ | $b_{t2}$ | ... | $b_{tn}$ |
| $a_{21}$ | $a_{22}$ | ... | $a_{2m}$ | $b_{11}$ | $b_{12}$ | ... | $b_{1n}$ |
| $a_{21}$ | $a_{22}$ | ... | $a_{2m}$ | $b_{21}$ | $b_{22}$ | ... | $b_{2n}$ |
| | : | | | | : | | |
| $a_{21}$ | $a_{22}$ | ... | $a_{2m}$ | $b_{t1}$ | $b_{t2}$ | ... | $b_{tn}$ |

⋮

$r_1 \times r_2$ : $s \times t$ tuples

## Example Query using *cross product*

Obtain the list of professors (Id and Name) along with the *name* of their respective departments

- profDetail (eId, pname,deptno) $\leftarrow \pi_{\text{empId, name, deptNo}}$ (professor)
- deptDetail (dId,dname) $\leftarrow \pi_{\text{deptId, name}}$ (department)
- profDept $\leftarrow$ profDetail $\times$ deptDetail
- desiredProfDept $\leftarrow \sigma_{\text{deptno = dId}}$ (profDept)
- result $\leftarrow \pi_{\text{eld, pname, dname}}$ (desiredProfDept)

## *Join* Operation

- ***Cross product*** : produces all combinations of tuples
    - often only certain combinations are meaningful
    - cross product is usually followed by selection

- ***Join*** : combines tuples from two relations provided they satisfy a specified condition (join condition)
    - equivalent to performing *cross product* followed by *selection*
    - a very useful operation

- Depending on the type of condition we have
    - *theta join*
    - *equi join*

## *Theta* join

- Let $r_1$ - relation with scheme $R_1 = (A_1, A_2, \ldots, A_m)$
  $r_2$ - relation with scheme $R_2 = (B_1, B_2, \ldots, B_n)$
  and $R_1 \cap R_2 = \phi$
- Notation for join expression : $r_1 \bowtie_\theta r_2$ , $\theta$ - join condition
  $\theta$ is of the form : $C_1 \wedge C_2 \wedge \ldots \wedge C_s$
  $C_i$ is of the form : $A_j$ <CompOp> $B_k$
  <CompOp> : $=$ , $\neq$, $<$ , $\leq$ , $>$ , $\geq$
- Scheme of the result relation
  $Q = (A_1, A_2, \ldots, A_m, B_1, B_2, \ldots, B_n)$
- $r = \{(a_1,a_2,\ldots,a_m,b_1,b_2,\ldots,b_n) \mid (a_1,a_2,\ldots,a_m) \in r_1, (b_1,b_2, \ldots,b_n) \in r_2$ and $(a_1,a_2,\ldots,a_m , b_1,b_2,\ldots,b_n)$ satisfies $\theta\}$

Professor

| empId | name | sex | startYear | deptNo | phone |
|---|---|---|---|---|---|
| CS01 | GIRIDHAR | M | 1984 | 1 | 22576345 |
| CS02 | KESHAV MURTHY | M | 1989 | 1 | 22576346 |
| ES01 | RAJIV GUPTHA | M | 1980 | 2 | 22576244 |
| ME01 | TAHIR NAYYAR | M | 1999 | 3 | 22576243 |

Courses

| courseId | cname | credits | deptNo |
|---|---|---|---|
| CS635 | Algorithms | 3 | 1 |
| CS636 | A.I | 4 | 1 |
| ES456 | D.S.P | 3 | 2 |
| ME650 | Aero Dynamics | 3 | 3 |

Department

| deptId | name | hod | phone |
|---|---|---|---|
| 1 | Computer Science | CS01 | 22576235 |
| 2 | Electrical Engg. | ES01 | 22576234 |
| 3 | Mechanical Engg. | ME01 | 22576233 |

## Examples

For each department, find its name and the name, sex and phone number of the head of the department.

Prof (empId, p-name, sex, deptNo, prof-phone)

$$\leftarrow \pi_{\text{empId, name, sex, deptNo, phone}} \text{(professor)}$$

Result $\leftarrow$

$$\pi_{\text{DeptId, name, hod, p-name, sex, prof-phone}} (\text{Department} \bowtie_{(\text{empId} = \text{hod}) \wedge (\text{deptNo} = \text{deptId})} \text{Prof})$$

| deptId | name | hod | p-name | sex | prof-phone |
|---|---|---|---|---|---|
| 1 | Computer Science | CS01 | Giridher | M | 22576235 |
| 2 | Electrical Engg. | EE01 | Rajiv Guptha | M | 22576234 |
| 3 | Mechanical Engg. | ME01 | Tahir Nayyar | M | 22576233 |

## *Equi-join* and *Natural join*

- *Equi-join* : Equality is the only comparison operator used in the join condition
- *Natural join* : $R_1$, $R_2$ - have common attributes, say $X_1,X_2,X_3$
  - Join condition:

    $(R_1.X_1 = R_2.X_1) \wedge (R_1.X_2 = R_2.X_2) \wedge (R_1.X_3 = R_2.X_3)$

    - values of common attributes should be equal
  - Schema for the result $Q = R_1 \cup (R_2 - \{X_1, X_2, X_3\})$
    - Only one copy of the common attributes is kept

- Notation for natural join : $r = r_1 * r_2$

## Examples – Equi-join

Find courses offered by each department

$$\pi_{\text{deptId, name, courseId, cname, credits}} (\text{Department} \bowtie_{(\text{deptId} = \text{deptNo})} \text{Courses})$$

| deptId | name | courseId | cname | credits |
|---|---|---|---|---|
| 1 | Computer Science | CS635 | Algorithms | 3 |
| 1 | Computer Science | CS636 | A.I | 4 |
| 2 | Electrical Engg. | ES456 | D.S.P | 3 |
| 3 | Mechanical Engg. | ME650 | Aero Dynamics | 3 |

Teaching

| **empId** | **courseId** | **sem** | **year** | **classRoom** |
|---|---|---|---|---|
| CS01 | CS635 | 1 | 2005 | BSB361 |
| CS02 | CS636 | 1 | 2005 | BSB632 |
| ES01 | ES456 | 2 | 2004 | ESB650 |
| ME650 | ME01 | 1 | 2004 | MSB331 |

To find the courses handled by each professor

Professor * Teaching

result

| **empId** | **name** | **sex** | **startYear** | **deptNo** | **phone** | **courseId** | **sem** | **year** | **classRoom** |
|---|---|---|---|---|---|---|---|---|---|
| CS01 | Giridhar | M | 1984 | 1 | 22576345 | CS635 | 1 | 2005 | BSB361 |
| CS02 | Keshav Murthy | M | 1989 | 1 | 22576346 | CS636 | 1 | 2005 | BSB632 |
| ES01 | Rajiv Guptha | M | 1989 | 2 | 22576244 | ES456 | 2 | 2004 | ESB650 |
| ME01 | Tahir Nayyar | M | 1999 | 3 | 22576243 | ME650 | 1 | 2004 | MSB331 |

## Division operator

- The necessary condition to determine $r \div s$ on instances $r(R)$ and $s(S)$ is $S \subset R$
- The relation $r \div s$ is a relation on schema $R - S$.

  A tuple t is in $r \div s$ if and only if

  1) t is in $\pi_{R-S}(r)$
  2) For every tuple $t_s$ in s, there is $t_r$ in r satisfying both
     a) $t_r[S] = t_s$
     b) $t_r[R - S] = t$

- Another Definition $r = r_1 \div r_2$

  Division operator produces a relation $R(X)$ that includes all tuples $t[X]$ in $R_1(Z)$ that appear in $R_1$ in combination with every tuple from $R_2(Y)$ where $Z = X \cup Y$

R = (A, B, C, D), S = (A, B), X = (C, D)

$x = r \div s$

s

| A | B |
|---|---|
| $a_1$ | $b_1$ |
| $a_2$ | $b_2$ |

r

| A | B | C | D |
|---|---|---|---|
| $a_1$ | $b_1$ | $c_1$ | $d_1$ |
| $a_2$ | $b_2$ | $c_1$ | $d_1$ |
| $a_1$ | $b_1$ | $c_2$ | $d_2$ |
| $a_1$ | $b_1$ | $c_3$ | $d_3$ |
| $a_2$ | $b_2$ | $c_3$ | $d_3$ |

x

| C | D |
|---|---|
| $c_1$ | $d_1$ |
| $c_3$ | $d_3$ |

($c_2$, $d_2$) is not present in the result of division as it does not appear in combination with <u>all</u> the tuples of s in r

## Query using division operation

Find those students who have enrolled for *all* courses offered in the dept of Computer Science.

Step1: Get the course enrollment information for all students

studEnroll $\leftarrow \pi_{\text{rollNo, name, courseId}}$ (student * enrollment)

Step2: Get the course Ids of all courses offered by CS dept

csCourse $\leftarrow \pi_{\text{courseId}}(\sigma_{\text{dname = "computer science"}}(\text{courses} \bowtie_{\text{deptId = deptNo}} \text{dept}))$

Result : studEnroll $\div$ csCourse

Schema

## Suppose result of step 1 is

studEnroll

| name | courseId |
|---|---|
| Mahesh | CS635 |
| Mahesh | CS636 |
| Rajesh | CS635 |
| Piyush | CS636 |
| Piyush | CS635 |
| Deepak | ES456 |
| Lalitha | ME650 |
| Mahesh | ME650 |

## result of step 2

csCourse

| courseId |
|---|
| CS635 |
| CS636 |

studEnroll ÷ csCourse

result

| name |
|---|
| Mahesh |
| Piyush |

Let's assume for a moment that student names are unique!

## Complete Set of Operators

- Are all Relational Algebra operators essential ?

  Some operators can be realized through other operators

- What is the minimal set of operators ?
  - The operators $\{\sigma , \pi, \times , \cup , -\}$ constitute a *complete* set of operators
  - Necessary and sufficient set of operators.
  - Intersection – union and difference
  - Join – cross product followed by selection
  - Division – project, cross product and difference

## Example Queries

Schema

Retrieve the list of female PhD students

$\sigma_{\text{degree} = \text{'phD'} \wedge \text{sex} = \text{'F'}}$ (student)

Obtain the name and rollNo of all female Btech students

$\pi_{\text{rollNo, name}}(\sigma_{\text{degree} = \text{'BTech'} \wedge \text{sex} = \text{'F'}}$ (student))

Obtain the rollNo of students who never obtained an 'E' grade

$\pi_{\text{rollNo}}(\sigma_{\text{grade} \neq \text{'E'}}$ (enrollment))

is incorrect!!

(what if some student gets E in one course and A in another?)

$\pi_{\text{rollNo}}$ (student) – $\pi_{\text{rollNo}}(\sigma_{\text{grade} = \text{'E'}}$ (enrollment))

## More Example Queries

Obtain the department Ids for departments with no lady professor

$$\pi_{\text{deptId}}(\text{dept}) - \pi_{\text{deptId}}(\sigma_{\text{sex} = \text{'F'}}(\text{professor}))$$

Obtain the rollNo of male students who have obtained at least one S grade

$$\pi_{\text{rollNo}}(\sigma_{\text{sex} = \text{'M'}}(\text{student})) \cap \pi_{\text{rollNo}}(\sigma_{\text{grade} = \text{'S'}}(\text{enrollment}))$$

## Another Example Query

Schema

Obtain the names, roll numbers of students who have got S grade in the CS3700 course offered in 2012 odd semester along with his/ her advisor name.

reqStudsRollNo $\leftarrow$

$\pi_{\text{rollNo}}(\sigma_{\text{courseId = 'CS370' \& year = '2012' \& semester = 'odd' \& grade= 'S'}}(\text{enrollment}))$

reqStuds-Name-AdvId ( rollNo, sName, advId) $\leftarrow$

$\pi_{\text{rollNo, name, advisor}}(\text{reqStudsRollNo} * \text{student})$

result( rollNo, studentName, advisorName) $\leftarrow$

$\pi_{\text{rollNo, sName, name}}(\text{reqStuds-Name-AdvId} \bowtie_{\text{advId=empId}} \text{professor})$

## Transitive Closure Queries

Schema

Obtain the courses that are either direct or indirect prerequisites of the course CS767.

- Indirect prerequisite – (prerequisite of $)^+$ a prerequisite course
- Prerequisites at all levels are to be reported

$$\text{levelOnePrereq(cId1)} \leftarrow \pi_{\text{preReqCourse}}(\sigma_{\text{courseId = 'CS767'}}(\text{preRequisite}))$$

$$\text{levelTwoPrereq(cId2)} \leftarrow \pi_{\text{preReqCourse}}(\text{preRequisite} \bowtie_{\text{courseId = cId1}} \text{levelOnePrereq}))$$

Similarly, level *k* prerequisites can be obtained.
But, prerequisites at all levels can not be obtained as there is no looping mechanism.

## Outer Join Operation (1/2)

- Theta join, equi-join, natural join are all called *inner joins* . The result of these operations contain only the matching tuples

- The set of operations called *outer joins* are used when <u>all</u> tuples in relation *r* or relation *s* or both in *r* and *s* have to be in result.

There are 3 kinds of outer joins:

Left outer join ⟕

Right outer join ⟖

Full outer join ⟗

## Outer Join Operation (2/2)

Left outer join: $r$ ⟕ $s$

It keeps all tuples in the first, or left relation *r* in the result. For some tuple *t* in *r*, if no matching tuple is found in *s* then S-attributes of *t* are made null in the result.

Right outer join: $r$ ⟖ $s$

Same as above but tuples in the second relation are all kept in the result. If necessary, R-attributes are made null.

Full outer join: $r$ ⟗ $s$

All the tuples in both the relations *r* and *s* are in the result.

## Instance Data for Examples

Student

| rollNo | name | degree | year | sex | deptNo | advisor |
|---|---|---|---|---|---|---|
| CS04S001 | Mahesh | M.S | 2004 | M | 1 | CS01 |
| CS05S001 | Amrish | M.S | 2003 | M | 1 | null |
| CS04M002 | Piyush | M.E | 2004 | M | 1 | CS01 |
| ES04M001 | Deepak | M.E | 2004 | M | 2 | null |
| ME04M001 | Lalitha | M.E | 2004 | F | 3 | ME01 |
| ME03M002 | Mahesh | M.S | 2003 | M | 3 | ME01 |

Professor

| empId | name | sex | startYear | deptNo | phone |
|---|---|---|---|---|---|
| CS01 | GIRIDHAR | M | 1984 | 1 | 22576345 |
| CS02 | KESHAV MURTHY | M | 1989 | 1 | 22576346 |
| ES01 | RAJIV GUPTHA | M | 1980 | 2 | 22576244 |
| ME01 | TAHIR NAYYAR | M | 1999 | 3 | 22576243 |

## Left outer join

$\text{temp} \leftarrow (\text{student} ⟕_{\text{advisor} = \text{empId}} \text{professor})$

$\rho_{\text{rollNo, name, advisor}} (\pi_{\text{rollNo, student.name, professor.name}} (\text{temp}))$

Result

| rollNo | name | advisor |
|---|---|---|
| CS04S001 | Mahesh | Giridhar |
| CS05S001 | Amrish | Null |
| CS04M002 | Piyush | Giridhar |
| ES04M001 | Deepak | Null |
| ME04M001 | Lalitha | Tahir Nayyer |
| ME03M002 | Mahesh | Tahir Nayyer |

## Right outer join

$\text{temp} \leftarrow (\text{student} ⟖_{\text{advisor = empId}} \text{professor})$

$\rho_{\text{rollNo, name, advisor}} (\pi_{\text{rollNo, student.name, professor.name}} (\text{temp}))$

Result

| rollNo | name | advisor |
|---|---|---|
| CS04S001 | Mahesh | Giridhar |
| CS04M002 | Piyush | Giridhar |
| null | null | Keshav Murthy |
| null | null | Rajiv Guptha |
| ME04M001 | Lalitha | Tahir Nayyer |
| ME03M002 | Mahesh | Tahir Nayyer |

## Full outer join

$$\text{temp} \leftarrow (\text{student} ⟗_{\text{advisor} = \text{empId}} \text{professor})$$

$$\rho_{\text{rollNo, name, advisor}} (\pi_{\text{rollNo, student.name, professor.name}} (\text{temp}))$$

Result

| rollNo | name | advisor |
|---|---|---|
| CS04S001 | Mahesh | Giridhar |
| CS04M002 | Piyush | Giridhar |
| CS05S001 | Amrish | Null |
| null | null | Keshav Murthy |
| ES04M001 | Deepak | Null |
| null | null | Rajiv Guptha |
| ME04M001 | Lalitha | Tahir Nayyer |
| ME03M002 | Mahesh | Tahir Nayyer |

## E/R diagrams to Relational Schema

- E/R model and the relational model are logical representations of real world enterprises
- An E/R diagram can be converted to a collection of relations
- For each entity set and relationship set in E/R diagram we can have a corresponding relational table with the same name as entity set / relationship set
- Each table will have multiple columns whose names are obtained from the attributes of entity types/relationship types

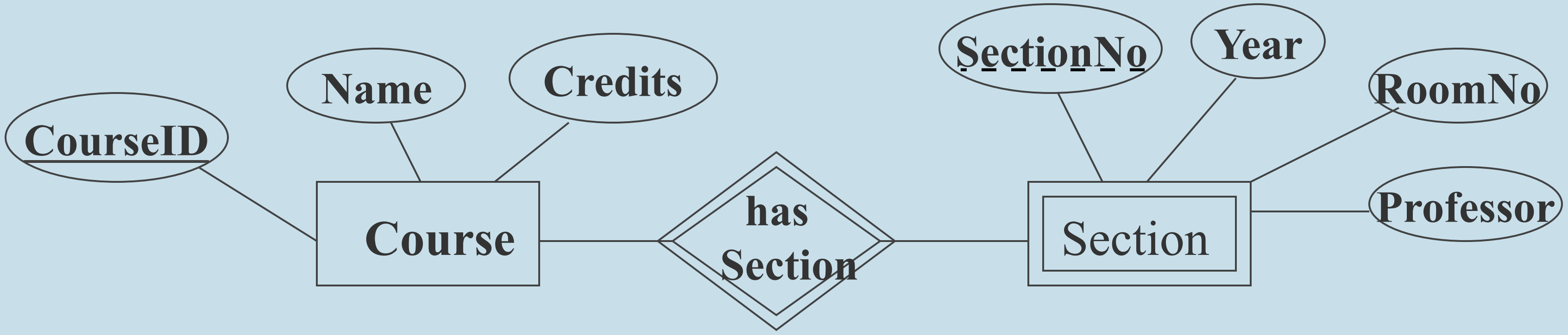
## Relational representation of strong entity sets

- Create a table $T_i$ for each strong entity set $E_{i.}$
- Include simple attributes and simple components of composite attributes of entity set $E_i$ as attributes of $T_i$.
    - Multi-valued attributes of entities are dealt with separately.
- The primary key of $E_i$ will also be the primary key of $T_i$.
- The primary key can be referred to by other tables via foreign keys in them to capture relationships as we see later

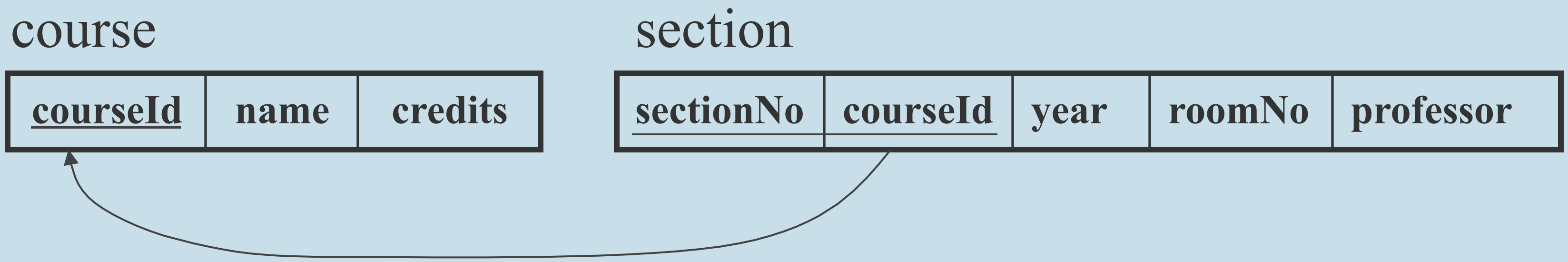
## Relational representation of weak entity sets

- Let E' be a weak entity owned by a strong/weak entity E
- E' is converted to a table, say R'
- Attributes of R' will be
  - Attributes of the weak entity set E' and
  - Primary key attributes of the identifying strong entity E
  - (Or, partial key of E + primary key of the owner of E, if E is itself a weak entity)
    - These attributes will also be a foreign key in R' referring to the table corresponding to E
- Key of R' : partial key of E' + Key of E
- Multi-valued attributes are dealt separately as described later

## Example



Corresponding tables are



course

| <u>courseId</u> | name | credits |
|---|---|---|

section

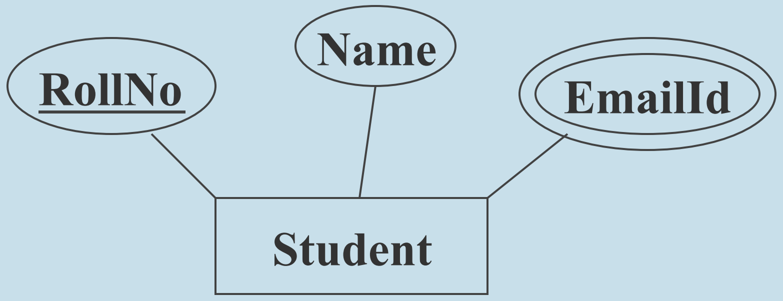
| <u>sectionNo</u> | <u>courseId</u> | year | roomNo | professor |
|---|---|---|---|---|

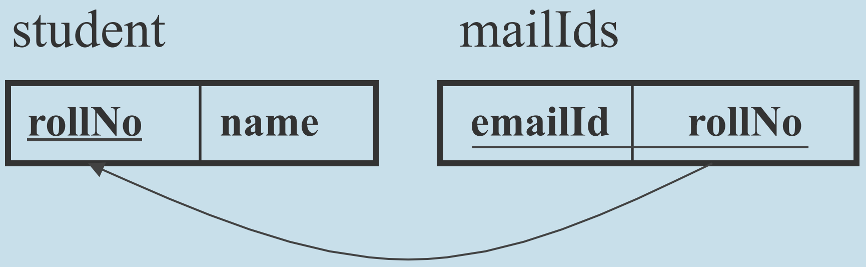
Primary key of *section* = {courseId, sectionNo}

## Relational representation of multi-valued attributes

- One table for each multi-valued attribute
- One column for this attribute and
- One column for the primary key attribute of entity / relationship set for which this is an attribute.

e.g.,

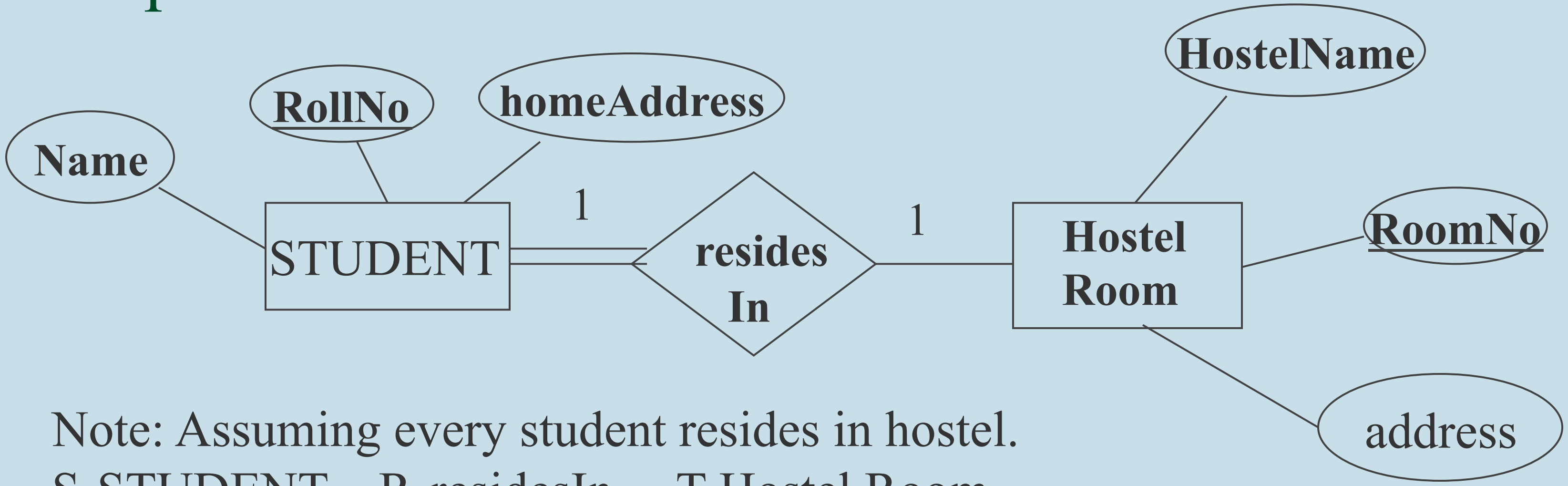




## Handling Binary 1:1 Relationship

- Let S and T be entity sets in relationship R and S', T' be the tables corresponding to these entity sets
- Choose an entity set which has total participation if there is one (says, S)
- Include the primary key of T' as a foreign key in S' referring to relation T'
- Include all simple attributes (and simple components of composite attributes) of R as attributes of S'
- We can do the other way round too
  – lot of null values

# Example



Note: Assuming every student resides in hostel.
S-STUDENT R-residesIn T-Hostel Room

Student

| <u>RollNo</u> | Name | homeAddress | RoomId |
|---|---|---|---|

Hostel

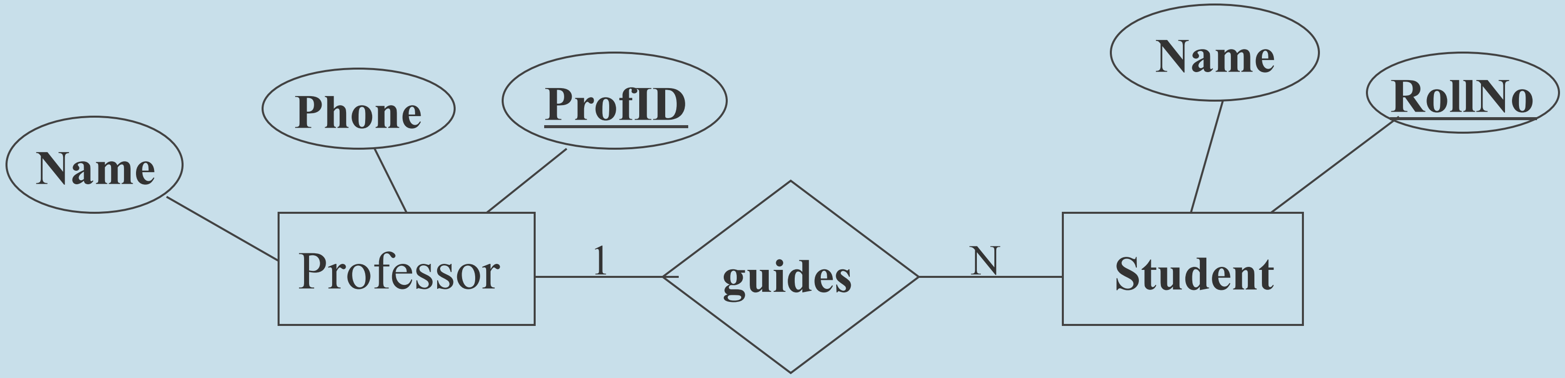
| <u>RoomNo</u> | HostelName | address |
|---|---|---|

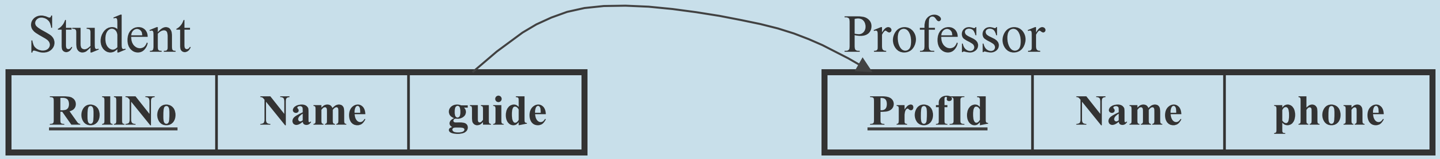
Foreign key name need
not be same as primary key
of the other relation

## Handling 1:N Relationship

- Let S be the participating entity on the N-side and T the other entity. Let S' and T' be the corresponding tables.
- Include primary key of T' as foreign key in S'
- Include any simple attribute (and simple components of composite attributes) of 1:N relation type as attributes of S'

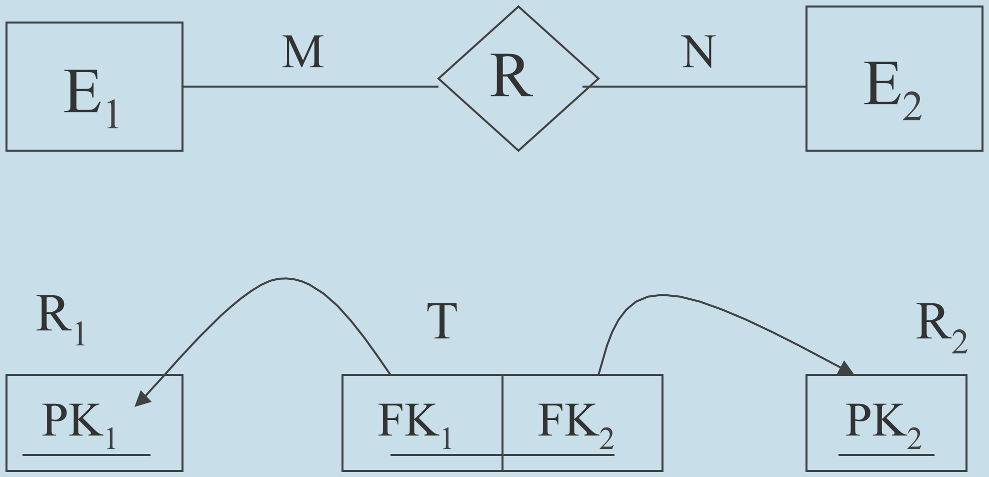
## Example


Name
Phone
ProfID
Professor
1
guides
N
Student
Name
RollNo

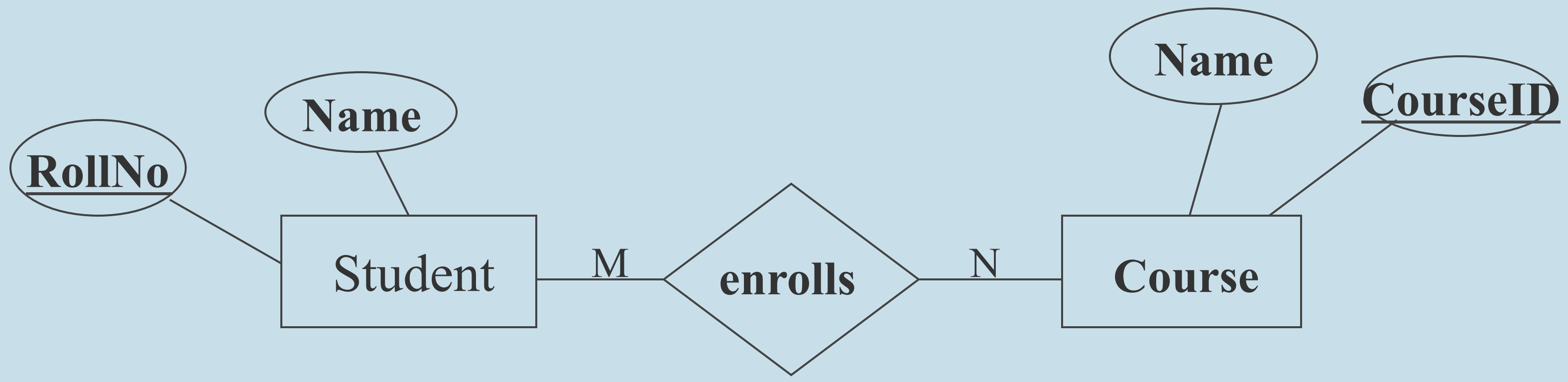

Student
RollNo
Name
guide
Professor
ProfId
Name
phone

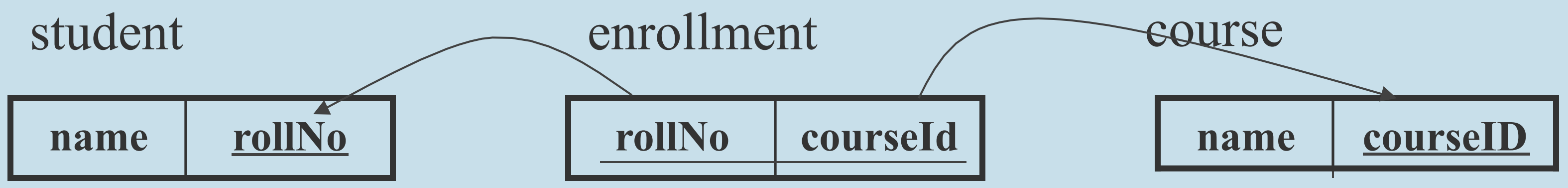
## Handling M:N relationship

- Make a separate table T for this relationship R between entity sets $E_1$ and $E_2$.
  Let $R_1$ and $R_2$ be the tables corresponding to $E_1$ and $E_2$.
- Include primary key attributes of $R_1$ and $R_2$ as foreign keys in T. Their combination is the primary key in T.



## Example



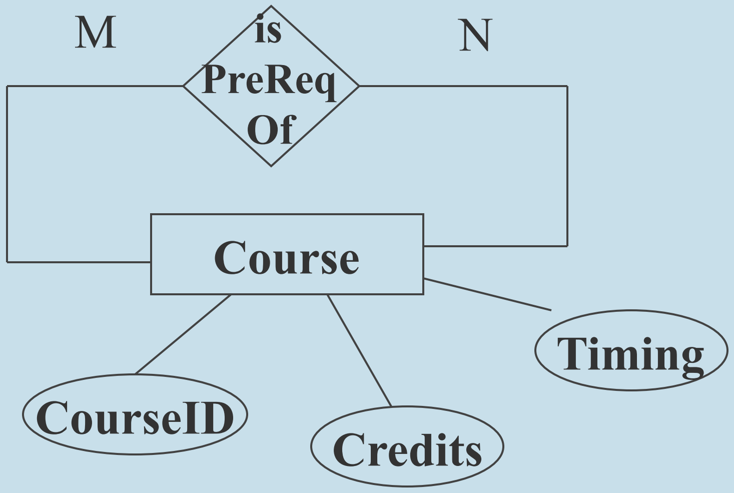


Primary key of *enrollment* table is {RollNo, CourseID}

## Handling Recursive relationships

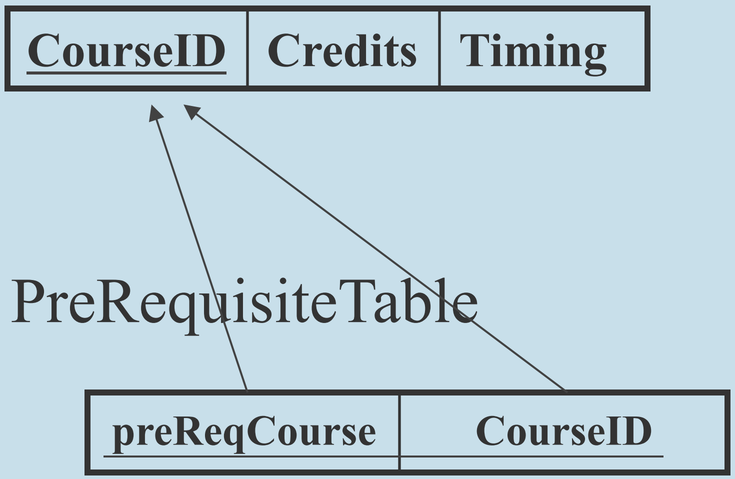
- Make a table T for the participating entity set E ( this might already be existing) and one table for recursive relationship R.

Example



CourseTable

PreRequisiteTable


CourseID
Credits
Timing
preReqCourse
CourseID