UNIT-2

Introduction to the Relational Model, Integrity constraints over relations, Enforcing integrity constraints, Querying relational data, Logical data base design, Introduction to views - destroying /altering tables and views.

Relational Algebra - selection and projection, set operations, renaming, joins, division. Examples of algebra overviews. Relational calculus – Tuple relational calculus, Domain relational calculus.

INTRODUCTION TO THE RELATIONAL MODEL

▪The main construct for representing data in the relational model is a **relation**

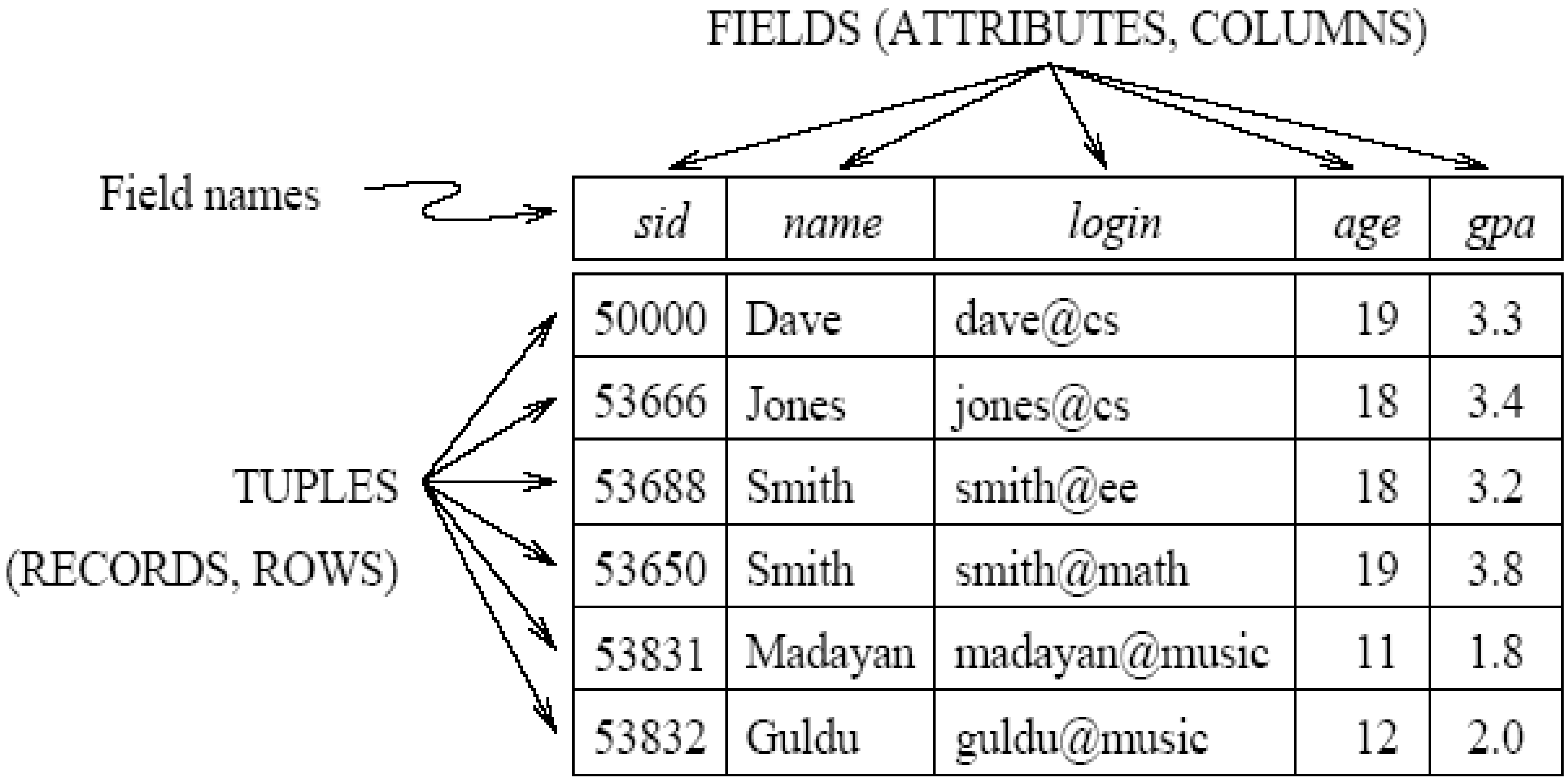
▪A relation consists of a **relation schema** and a **relation instance**

▪The schema specifies the relation's name, the name of each **field** (or **column**, or **attribute**), and the type of each field

Example:

Students(*sid*: string, *name*: string, *login*: string, *age*: integer, *gpa*: real)

- An **instance** of the Students relation appears in Figure 3.1



sid	*name*	*login*	*age*	*gpa*
50000	Dave	dave@cs	19	3.3
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2
53650	Smith	smith@math	19	3.8
53831	Madayan	madayan@music	11	1.8
53832	Guldu	guldu@music	12	2.0

Figure 3.1 An Instance $S1$ of the Students Relation

- The **degree**, also called **arity**, of a relation is the number of fields

- The **cardinality** of a relation instance is the number of tuples in it

- In Figure 3.1, the degree of the relation (the number of columns) is **five**, and the cardinality of this instance is **six**

- A **relational database** is a collection of relations with distinct relation names

- The **relational database schema** is the collection of schemas for the relations in the database

INTEGRITY CONSTRAINTS OVER RELATIONS

- An **integrity constraint (IC)** is a condition that is specified on a database schema, and verified on the data that is to be stored in an instance of the database

- If a database instance satisfies all the integrity constraints specified on the database schema, it is a **legal** instance

- A **DBMS enforces** integrity constraints, in that it permits only legal instances to be stored in the database

- Integrity constraints are **specified** and **enforced** at different times:

1.When the DBA or end user defines a database schema

2.When a database application is run, the DBMS checks for integrity constraints

Key

- Consider the Students relation and the <u>constraint that no two students have the same rollno</u>

- This Integrity Constraint is an example of a key

- A **key** is a *minimal* subset of the fields of a relation that uniquely identifies a tuple

- A set of fields that uniquely identifies a tuple is called a **candidate key** for the relation

- <u>A relation may have several candidate keys</u>

- In the Students relation, **candidate keys** are *login* and *sid*

- Out of all the available candidate keys, a database designer can identify a **primary key**

Constraints
SQL UNIQUE Constraint

- A column can allow unique values. It may allow one null value

- You can have many UNIQUE constraints per table, but only one PRIMARY KEY constraint per table

SQL NOT NULL Constraint

- By default, a column can hold NULL values

- The NOT NULL constraint enforces a column to NOT accept NULL values

Example:

```
CREATE TABLE Students
(
   sid NUMBER(5),
   name VARCHAR2(10) UNIQUE,
   login VARCHAR2(20) NOT NULL,
   age NUMBER(2),
   gpa NUMBER(2,1)
)
```

SQL PRIMARY KEY Constraint

- The PRIMARY KEY constraint uniquely identifies each record in a database table

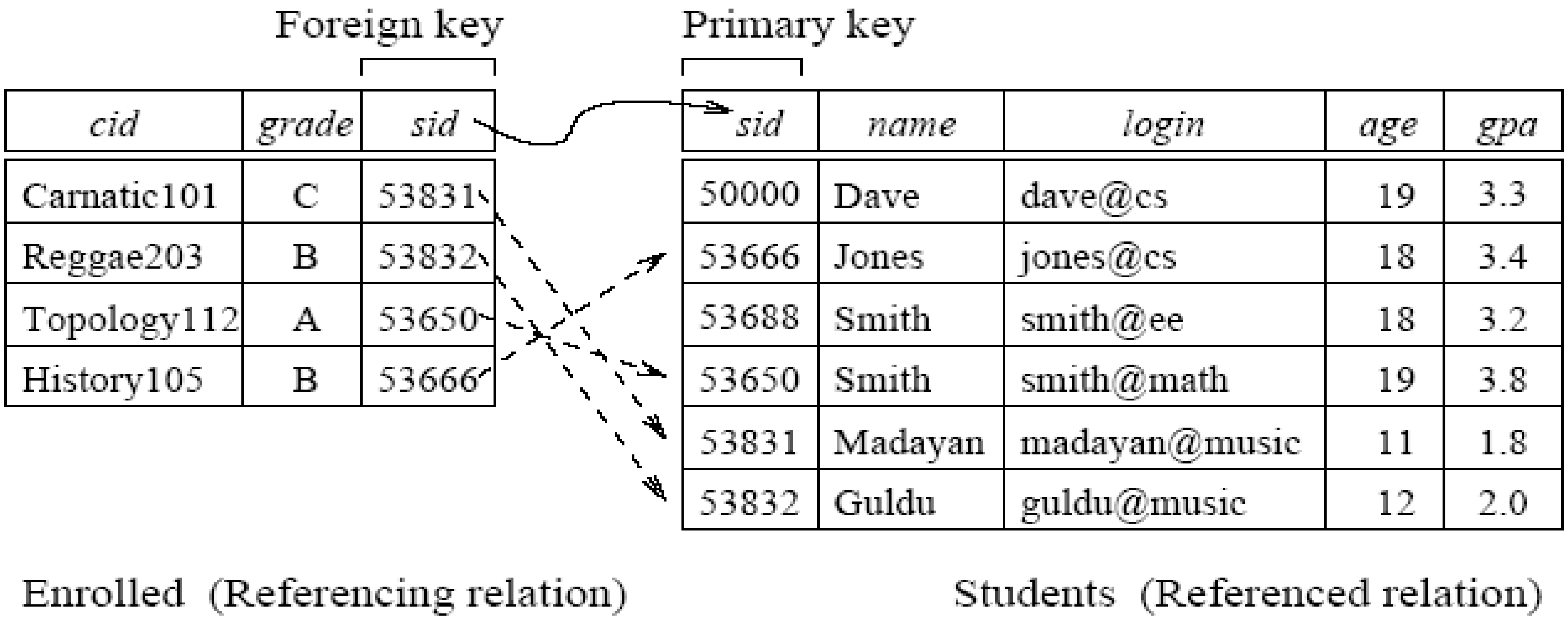
Example:

```
CREATE TABLE Students
(
   sid NUMBER(5) PRIMARY KEY,
   name VARCHAR2(10),
   login VARCHAR2(20),
   age NUMBER(2),
   gpa NUMBER(2,1)
)
```

SQL FOREIGN KEY Constraint

- A FOREIGN KEY in one table points to a PRIMARY KEY in another table

▪The ***sid*** field of **Enrolled** is called a **foreign key** and refers to Students


Foreign key
Primary key
Enrolled (Referencing relation)
Students (Referenced relation)

cid	*grade*	*sid*
Carnatic101	C	53831
Reggae203	B	53832
Topology112	A	53650
History105	B	53666

sid	*name*	*login*	*age*	*gpa*
50000	Dave	dave@cs	19	3.3
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2
53650	Smith	smith@math	19	3.8
53831	Madayan	madayan@music	11	1.8
53832	Guldu	guldu@music	12	2.0

Figure 3.4 Referential Integrity

▪**Foreign kay** value must be one of the values of the **Primary key**

Example:

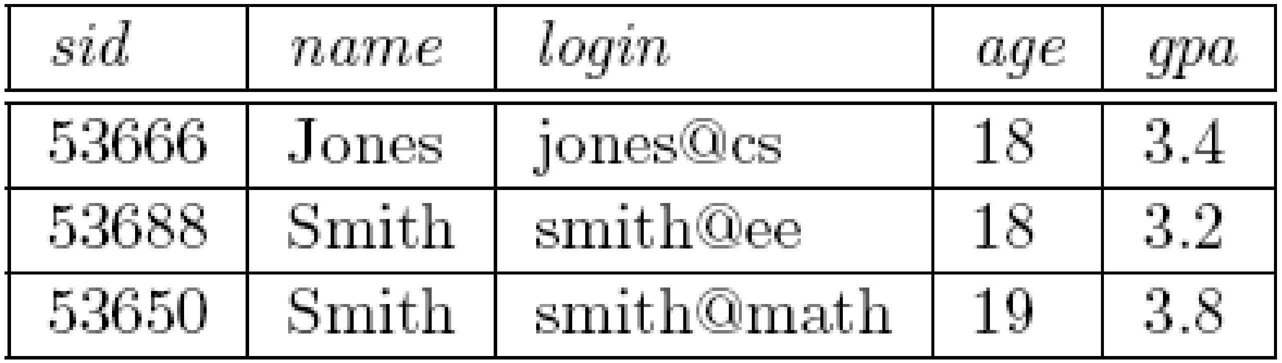
```
CREATE TABLE Enrolled
(
 cid VARCHAR2(20) PRIMARY KEY,
 grade VARCHAR2(2),
 sid NUMBER(5),
 FOREIGN KEY(sid) REFERENCES Students(sid)
 )
```

SQL CHECK constraint

▪CHECK constraint is used to limit the value range that can be placed in a column

Example: All students must be at least 16 years old (Fig 3.5)

```
CREATE TABLE Students
(
  sid NUMBER(5) PRIMARY KEY,
  name VARCHAR2(10),
  login VARCHAR2(20),
  age NUMBER(2) CHECK (age>16),
  gpa NUMBER(2,1)
)
```



sid	*name*	*login*	*age*	*gpa*
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2
53650	Smith	smith@math	19	3.8

Figure 3.5 An Instance $S2$ of the Students Relation

SQL DEFAULT Constraint

- The DEFAULT constraint is used to provide a default value for a field
- The default value will be added to all new records if no other value is specified
- Example:

```
CREATE TABLE Students
(
  sid NUMBER(5) PRIMARY KEY,
  name VARCHAR2(10)  DEFAULT  'Jones',
  login VARCHAR2(20),
  age NUMBER(2),
  gpa NUMBER(2,1)
)
```

ENFORCING INTEGRITY CONSTRAINTS

▪Consider the Students relation shown in Figure 3.1

▪The following insertion violates the primary key constraint because there is already a tuple with the *sid* 53688, and it will be rejected by the DBMS:

INSERT INTO Students VALUES
(53688, 'Mike', 'mike@ee', 17, 3.4)

▪The following insertion violates the constraint that the primary key cannot contain *null:*

INSERT INTO Students VALUES
(*null*, 'Mike', 'mike@ee', 17, 3.4)

- An update can cause violations, similar to an insertion:

UPDATE Students SET sid = 50000 WHERE sid = 53688

- This update violates the primary key constraint because there is already a tuple with *sid* 50000

REFERENTIAL INTEGRITY ENFORCEMENT (ON FOREIGN KEY)

- Deletions of Enrolled tuples do not violate referential integrity, but insertions of Enrolled tuples could

- The following insertion is illegal because there is no student with *sid* 51111:

```
INSERT INTO Enrolled (cid, grade, sid)
VALUES ('Hindi101', 'B', 51111)
```

- On the other hand, insertions of Students tuples do not violate referential integrity although deletions could

- Further, updates on either Enrolled or Students that change the *sid* value could potentially violate referential integrity

```
CREATE TABLE Enrolled
(
 cid VARCHAR2(20) PRIMARY KEY,
 grade VARCHAR2(2),
 sid NUMBER(5),
 FOREIGN KEY(sid) REFERENCES Students(sid)
```

```
  ON DELETE CASCADE
  ON UPDATE NO ACTION
)
```

- The options are specified as part of the foreign key declaration

- The default option is <u>NO ACTION</u>, which means that the action (DELETE or UPDATE) is to be rejected

- The <u>CASCADE</u> keyword says that if a Students row is deleted, all Enrolled rows that refer to it are to be deleted as well

- If the UPDATE clause specified CASCADE, and the *sid* column of a Students row is updated, this update is also carried out in each Enrolled row that refers to the updated Students row

▪If a Students row is deleted, we can switch the enrollment to a 'default' student by using ON DELETE <u>SET DEFAULT</u>

▪The default student is specified as part of the definition of the *sid* field in Enrolled; for example, *sid* NUMBER(5) DEFAULT *'53666'*

▪It is really not appropriate to switch enrollments to a default student

▪The correct solution in this example is to also delete all enrollment tuples for the deleted student (that is, CASCADE), or to reject the update

- SQL also allows the use of *null* as the default value by specifying ON DELETE SET NULL

QUERYING RELATIONAL DATA

- A **relational database query** (query, for short) is a question about the data, and the answer consists of a new relation containing the result

- A **query language** is a language for writing queries

- SQL is the most popular commercial query language for a relational DBMS

Ex:

```
SELECT * FROM Students  WHERE age < 18
```

LOGICAL DATABASE DESIGN: ER TO RELATIONAL

▪The ER model is convenient for representing an initial, high-level database design

Entity Sets to Tables

▪Each attribute of the entity set becomes an attribute of the table

▪Note that we know both the domain of each attribute and the (primary) key of an entity set

- Consider the Employees entity set with attributes *ssn*, *name*, and *lot* shown in Figure 3.8

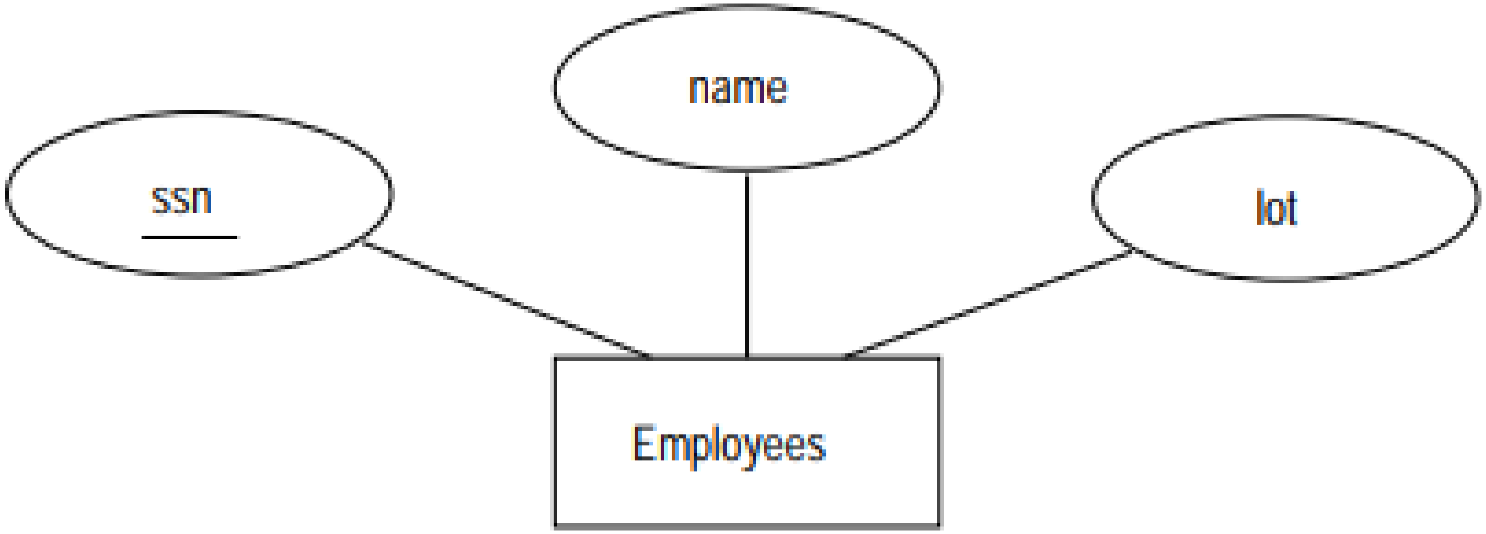


Figure 3.8 The Employees Entity Set

- The following SQL statement captures the preceding information, including the domain constraints and key information:

```
CREATE TABLE Employees
(
  ssn VARCHAR2(11) PRIMARY KEY,
  name VARCHAR2(30),
  lot NUMBER(2)
 )
```

Relationship Sets (without Constraints) to Tables

▪A relationship set, like an entity set, is mapped to a relation in the relational model

▪Thus, <u>the attributes of the relation include</u>:

--The primary key attributes of each participating entity set, as foreign key fields

--The descriptive attributes of the relationship set

▪Consider the Works_In2 relationship set shown in Figure 3.10

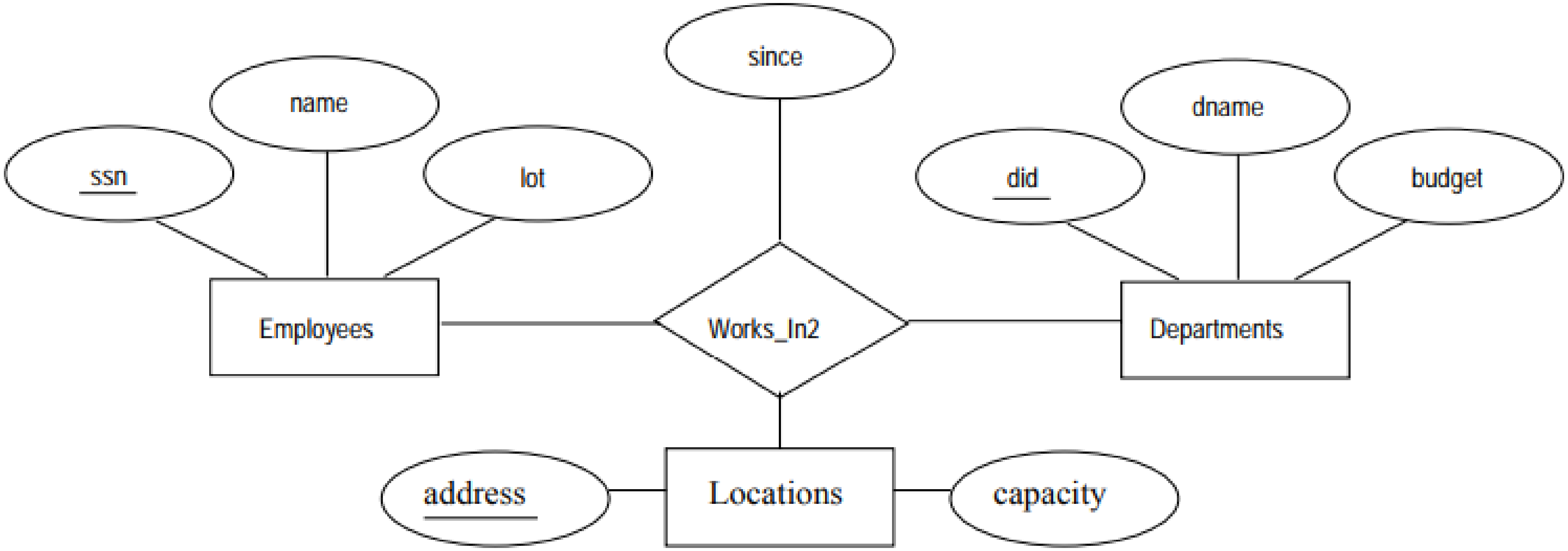


Figure 3.10 A Ternary Relationship Set

▪ All the available information about the Works_In2 table is captured by the following SQL definition:

```
CREATE TABLE Works_In2
(
  ssn VARCHAR2(11),
  did NUMBER(2),
  address VARCHAR2(20),
  since DATE,
  PRIMARY KEY(ssn, did, address),
  FOREIGN KEY(ssn) REFERENCES Employees(ssn),
  FOREIGN KEY(did) REFERENCES Departments(did),
  FOREIGN KEY(address) REFERENCES
  Locations(address) )
```

Translating Relationship Sets with Key Constraints

▪If a relationship set involves *n* entity sets and some m of them are linked via arrows in the ER diagram, the key for any one of these *m* entity sets constitutes a key for the relation to which the relationship set is mapped

▪Thus we have *m* candidate keys, and one of these should be designated as the primary key

▪Consider the relationship set Manages shown in Figure3.12

▪The table corresponding to Manages has the attributes *ssn*, *did*, *since* with *did* as *primary key*

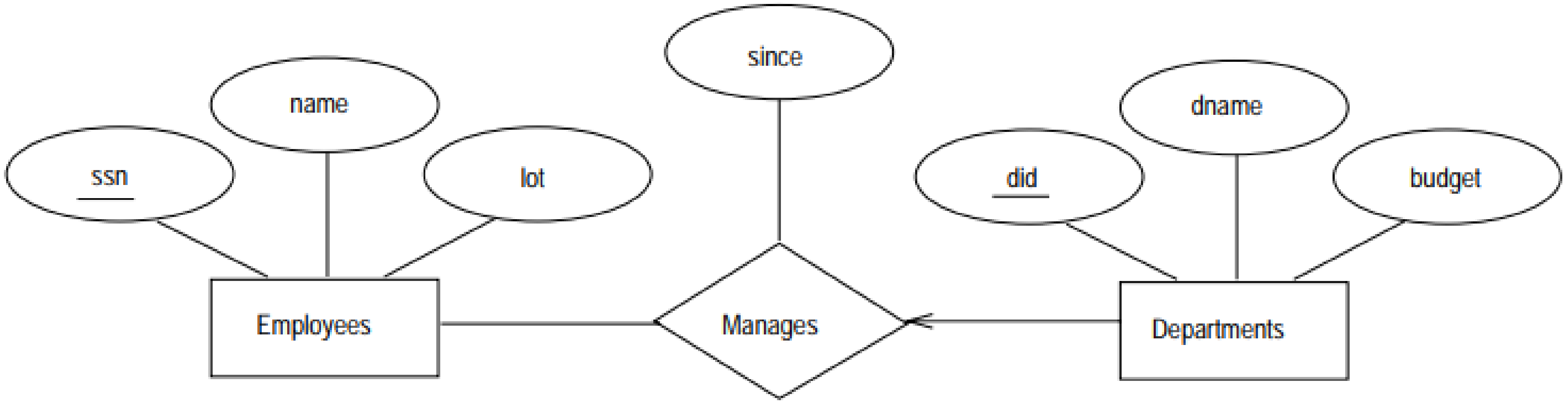


Figure 3.12 Key Constraint on Manages

```
CREATE TABLE Dept_Mgr
(
 did NUMBER(2) PRIMARY KEY,
 dname VARCHAR2(20),
 budget NUMBER(10,2),
 since DATE,
 ssn VARCHAR2(11),
 FOREIGN KEY(ssn) REFERENCES Employees(ssn)
)
```

Translating Relationship Sets with Participation Constraints

- Consider the ER diagram in Figure 3.13, which shows two relationship sets, Manages and Works_In

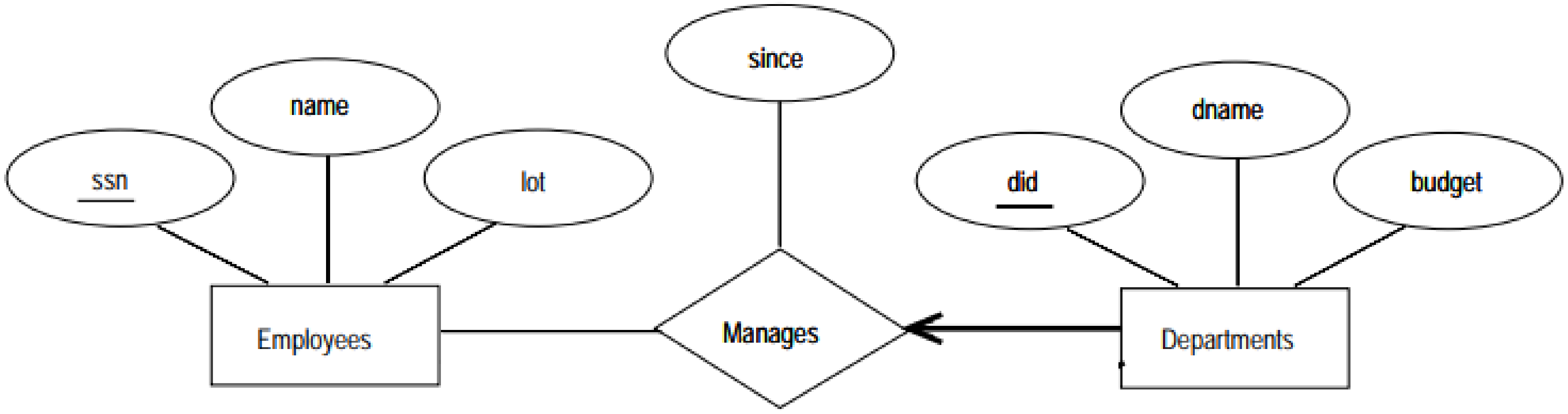


Figure 3.13 Manages and Works_In

```
CREATE TABLE Dept_Mgr
(
 did NUMBER(2) PRIMARY KEY,
 dname VARCHAR2(20),
 budget NUMBER(10,2),
 since DATE,
 ssn VARCHAR2(11) NOT NULL,
 FOREIGN KEY(ssn) REFERENCES Employees(ssn) ON
 DELETE CASCADE
)
```

Translating Weak Entity Sets

▪Consider the Dependents weak entity set shown in Figure 3.14, with partial key *pname*

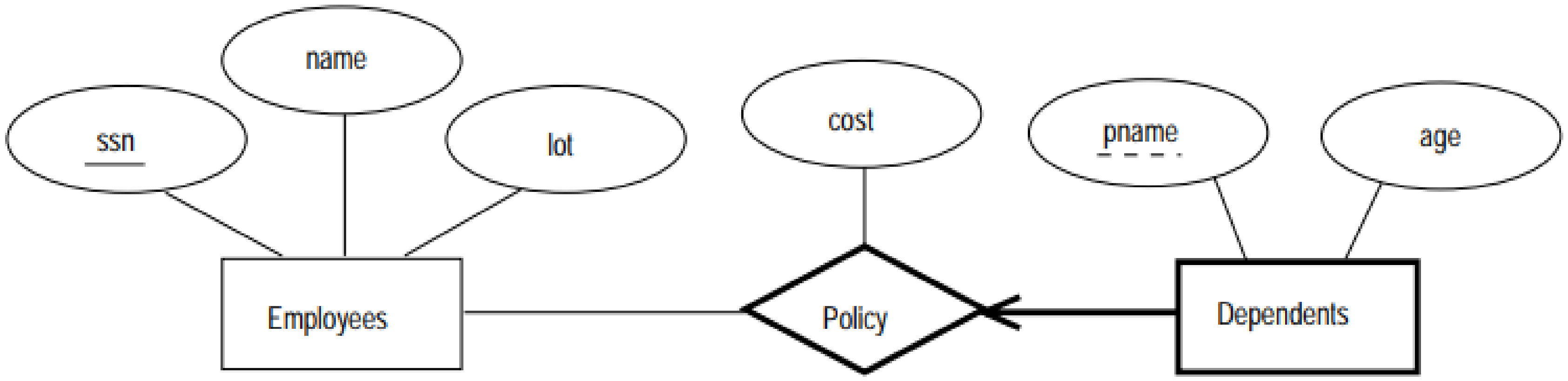


Figure 3.14 The Dependents Weak Entity Set

```
CREATE TABLE Dep_Policy
(
  pname VARCHAR2(20),
  age NUMBER(2),
  cost NUMBER(10,2),
  ssn VARCHAR2(11),
  PRIMARY KEY(ssn,pname)
  FOREIGN KEY(ssn) REFERENCES Employees(ssn) ON
  DELETE CASCADE
)
```

Translating Class Hierarchies

- The two basic approaches to handling ISA hierarchies by applying them to the ER diagram shown in Figure 3.15

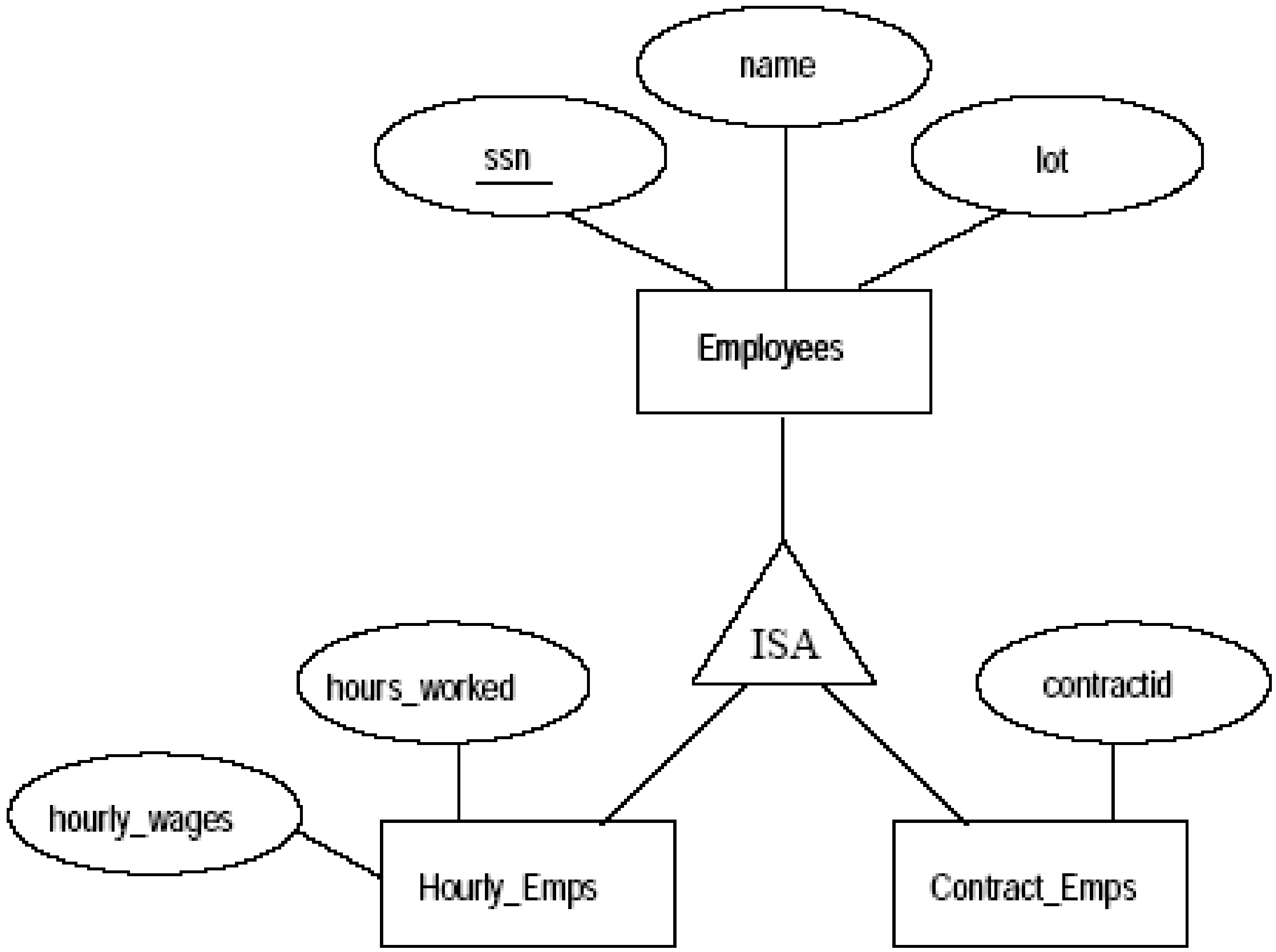


Figure 3.15 Class Hierarchy

Approach1:

- Employees relation contain fields *ssn*, *name* and *lot* with *ssn* as primary key

- Hourly_Emps relation has fileds *hourly_wages*, *hours_worked* and *ssn* with *ssn* as *primary key* as well as *foreign key* referencing the Emplyoyees

- Contract_Emps relation has fileds *contractid* and *ssn* with *ssn* as primary key as well as *foreign key* referencing the Emplyoyees

Approach2:

- Employees relation contain fields *ssn*, *name* and *lot* with *ssn* as primary key

- Hourly_Emps relation has fileds *ssn*, *name*, *lot*, *hourly_wages and hours_worked* with *ssn* as *primary key* as well as *foreign key* referencing the Emplyoyees

- Contract_Emps relation has fileds *ssn*, *name*, *lot*, *contractid* with *ssn* as primary key as well as *foreign key* referencing the Emplyoyees

Translating ER Diagrams with Aggregation

▪Consider the ER diagram shown in Figure 3.16

▪The Employees relation contain fields *ssn*, *name* and *lot* with *ssn* as *primary key*

▪The Projects relation contain fields *pid*, *started_on* and *pbudget* with *pid* as *primary key*

▪The Departments relation contain fields *did*, *dname* and *budget* with *did* as *primary key*

- The <u>Sponsors relation</u> contain fields *did*, *pid* and *since* with (*pid*,*did*) as *primary key* and <u>*pid*</u> as *foreign key* referencing Projects and <u>*did*</u> as *foreign key* referencing Departments

- The <u>Monitors relation</u> contain attributes *ssn*, *did*, *pid* and *until* with (*ssn*,*pid*,*did*) as *primary key* and <u>*pid*</u> as *foreign key* referencing Projects and <u>*did*</u> as *foreign key* referencing Departments and <u>*ssn*</u> as *foreign key* referencing Employees

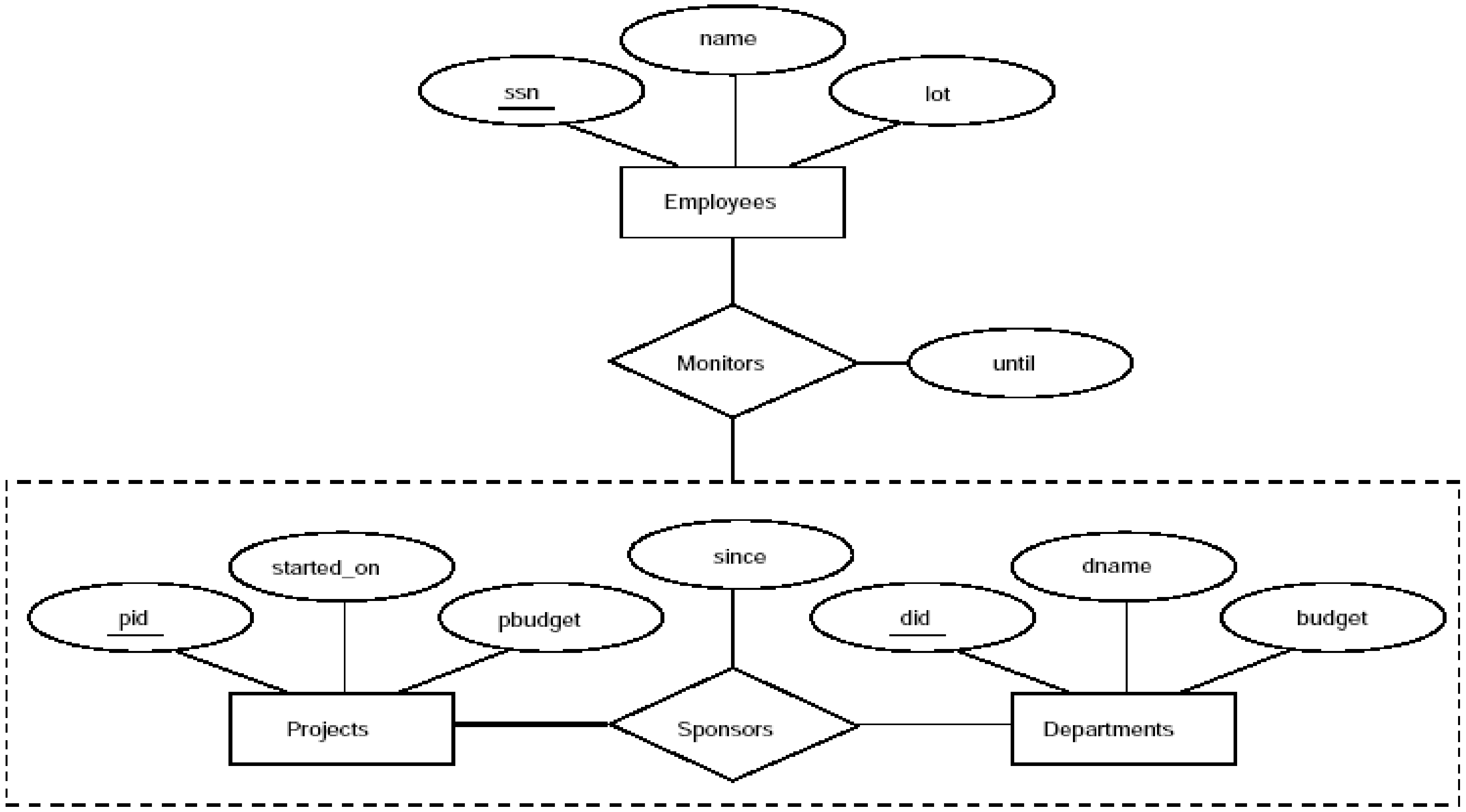


Figure 3.16 Aggregation

INTRODUCTION TO VIEWS

- A **view** is a virtual table whose rows are not explicitly stored in the database
- A view contains no data of it’s own
- A view can be created using the CREATE VIEW statement
- We can create a view from a single table or multiple tables

Syntax:

```
CREATE VIEW view_name AS
SELECT column1, column2, ...
FROM table_name
WHERE condition;
```

Creating View from a single table

```
CREATE VIEW Sailorsdetails AS
SELECT sname, age
FROM Sailors
WHERE rating<7;
```

- Just like table query, we can query the view to view the data

Query: Select * from Sailorsdetails

SNAME	AGE
Brutus	33
Art	25.5
Bob	63.5

Creating View from multiple tables

```
CREATE VIEW Reservationdetails AS
SELECT S.sname, S.age, R.bid, R.day
FROM Sailors S, Reserves R
WHERE S.sid=R.sid;
```

Query: Select * from Reservationdetails

SNAME	AGE	BID	DAY
Dustin	45	101	10-OCT-98
Dustin	45	102	10-OCT-98
Dustin	45	103	10-AUG-98
Dustin	45	104	10-JUL-98
Lubber	55.5	102	11-OCT-98
Lubber	55.5	103	11-JUN-98
Lubber	55.5	104	11-DEC-98
Horatio	35	101	09-MAY-98
Horatio	35	102	09-AUG-98
Horatio	35	103	09-AUG-98

Altering a view or Updating a View

Syntax:

```
CREATE OR REPLACE VIEW view_name AS
SELECT column1, column2, ...
FROM table_name
WHERE condition;
```

Ex:

```
CREATE OR REPLACE VIEW Sailorsdetails AS
SELECT sname, age, rating
FROM Sailors
WHERE rating<7;
```

Query: select * from sailorsdetails;

SNAME	AGE	RATING
Brutus	33	1
Art	25.5	3
Bob	63.5	3

Destroying or Dropping a View

- A view is deleted with the DROP VIEW statement

Syntax: DROP VIEW view_name;

query: drop view sailorsdetails;

output: View dropped

Note: table can be deleted or destroyed using the drop command

drop table sailors;

Note: Like performing operations on the tables, you can perform operations like **insert, delete and update** can be performed on the views but these operations reflect on the **base tables**.

Views, Data Independence, Security

Physical data independence: The ability to modify physical level schema without affecting the logical or view level schema

- For example, if the schema of a stored relation is changed, we can define a view with the old schema, and applications that expect to see the old schema can now use this view

Logical data independence: The ability to change the logical level schema without affecting the view level schemas or application programs

- Views are also valuable in the context of ***security***

- We can define views that give a group of users access to just the information they are allowed to see

- For example, we can define a view that allows students to access other students name and age but not their gpa, and not allowed to access underlying Students table

RELATIONAL ALGEBRA

- Relational algebra is a procedural query language.
- It gives a step by step process to obtain the result of the query.
- Queries in algebra are composed using a collection of operators

- Basic operators (selection, projection, union, cross-product, and difference)

Selection and Projection

- The selection operator (σ) is used to specify the condition

- Consider the instance of the Sailors relation shown in Figure 4.2, denoted as *S2*

sid	*sname*	*rating*	*age*
22	Dustin	7	45.0
31	Lubber	8	55.5
58	Rusty	10	35.0

Figure 4.1 Instance $S1$ of Sailors

sid	*sname*	*rating*	*age*
28	yuppy	9	35.0
31	Lubber	8	55.5
44	guppy	5	35.0
58	Rusty	10	35.0

Figure 4.2 Instance $S2$ of Sailors

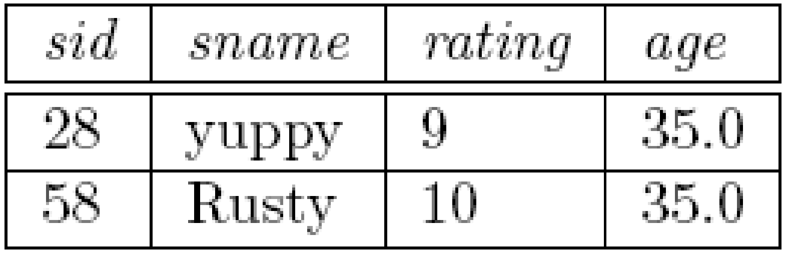
sid	*bid*	*day*
22	101	10/10/96
58	103	11/12/96

Figure 4.3 Instance $R1$ of Reserves

- Ex: Retrieve sailors whose rating is above 8

$$\sigma_{rating>8}(S2)$$

- evaluates to the relation shown in Figure 4.4



sid	*sname*	*rating*	*age*
28	yuppy	9	35.0
58	Rusty	10	35.0

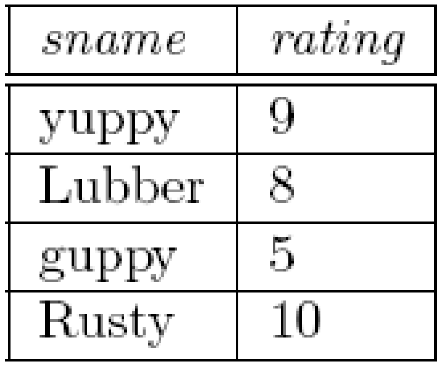
Figure 4.4 $\sigma_{rating>8}(S2)$

▪The projection operator (π) is used to specify the fields of a relation

▪Ex: Find sailor names and ratings

$$\pi_{sname,rating}(S2)$$

▪evaluates to the relation shown in Figure 4.5



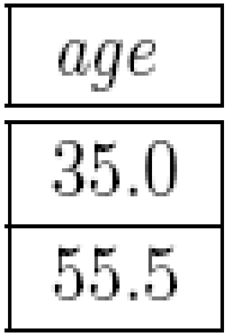
sname	*rating*
yuppy	9
Lubber	8
guppy	5
Rusty	10

Figure 4.5 $\pi_{sname,rating}(S2)$

- Ex: Find ages of sailors

$$\pi_{age}(S2)$$

- evaluates to the relation shown in Figure 4.6



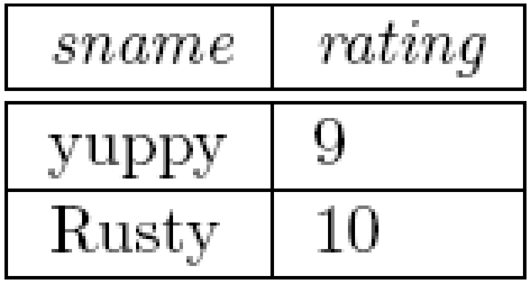
age
35.0
55.5

Figure 4.6 $\pi_{age}(S2)$

- Ex: Find sailor names and ratings, whose rating is above 8

$$\pi_{sname,rating}(\sigma_{rating>8}(S2))$$

- produces the result shown in Figure 4.7



sname	*rating*
yuppy	9
Rusty	10

Figure 4.7 $\pi_{sname,rating}(\sigma_{rating>8}(S2))$

Set Operations

- Union
- Intersection
- Set-difference
- Cross-product

Union Operation($\cup$)

- $R \cup S$ returns a relation instance containing all tuples that occur in either relation instance R or relation instance S (or both)

- The relations R and S must be compatible

Intersection Operation($\cap$)

- $R \cap S$ returns a relation instance containing all tuples that occur in both R and S

- The relations R and S must be compatible

Set-difference Operation($-$)

- $R - S$ returns a relation instance containing all tuples that occur in R but not in S

- The relations R and S must be compatible

Cross-product Operation($\times$)

- $R \times S$ returns a relation instance contains all the fields of R (in the same order as they appear in R) followed by all the fields of S (in the same order as they appear in S)

- The cross-product operation is also called Cartesian product

Examples

1. Find the sid's who are present in S1 and S2

$\pi_{sid}(S1) \cup \pi_{sid}(S2)$

result:

sid
22
28
31
44
58

2. Find the sid's who are present in both S1 and S2

$\pi_{sid}(S1) \cap \pi_{sid}(S2)$

result:

sid
31
58

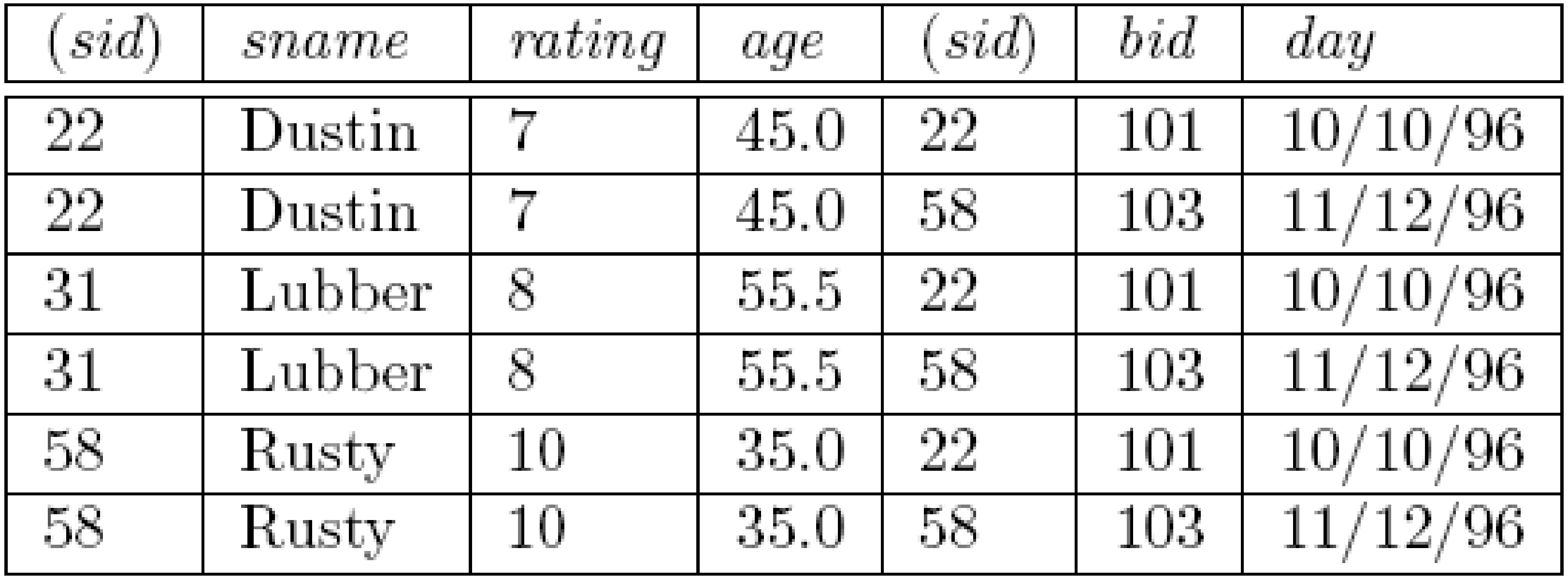
3. Find the sid's who are present in S1 but not in S2

$\pi_{sid}(S1) - \pi_{sid}(S2)$

result:

sid
22

4. The result of the cross-product $S1 \times R1$ is shown in Figure 4.11



(sid)	*sname*	*rating*	*age*	*(sid)*	*bid*	*day*
22	Dustin	7	45.0	22	101	10/10/96
22	Dustin	7	45.0	58	103	11/12/96
31	Lubber	8	55.5	22	101	10/10/96
31	Lubber	8	55.5	58	103	11/12/96
58	Rusty	10	35.0	22	101	10/10/96
58	Rusty	10	35.0	58	103	11/12/96

Figure 4.11 $S1 \times R1$

Renaming

- Field name conflicts can arise in some cases; for example, sid in $S1 \times R1$

- <u>renaming operator(</u> ρ) is used to rename the field

- No two fields in the result table must have the same name

- For example, the expression $\rho(C(1 \rightarrow sid1, 5 \rightarrow sid2),\ S1 \times R1)$ returns a relation that contains the tuples shown in Figure 4.11 and has the following schema:

C(sid1:integer, sname: string, rating: integer, age: real, sid2: integer, bid: integer, day: dates)

- Note: **Renaming** is also used for naming intermediate relations

Joins

- Joins are used to combine two or more relations

Condition Joins (or Theta Joins)

- Join operation accepts a join condition c and a pair of relations as arguments, and returns a relation

- The operation is defined as follows:

$$R \bowtie_c S = \sigma_c(R \times S)$$

▪Ex: $S1 \bowtie_{S1.sid<R1.sid} R1$ is shown in Figure 4.12

(sid)	*sname*	*rating*	*age*	*(sid)*	*bid*	*day*
22	Dustin	7	45.0	58	103	11/12/96
31	Lubber	8	55.5	58	103	11/12/96

Figure 4.12 $S1 \bowtie_{S1.sid<R1.sid} R1$

Equijoin

▪In Equijoin, condition consists of equalities of the form R.name1 = S.name2, that is, equalities between two fields in R and S

▪The result $S1 \bowtie_{R.sid=S.sid} R1$ is shown in Figure 4.13

sid	*sname*	*rating*	*age*	*bid*	*day*
22	Dustin	7	45.0	101	10/10/96
58	Rusty	10	35.0	103	11/12/96

Figure 4.13 $S1 \bowtie_{R.sid=S.sid} R1$

▪Notice that only one *sid* appears in the result

Natural Join

▪The equijoin expression $S1 \bowtie_{R.sid=S.sid} R1$ is actually a **natural join** and can simply be denoted as $S1 \bowtie R1$

▪Relations must have at least one common attribute

▪Note: left outer join is denoted as $⟕$ right outer join is denoted as $⟖$ full outer join is denoted as $⟗$

Division

▪Consider two relations A and B in which A has (exactly) two fields x and y and B has just one field y, with the same domain as in A

▪We define the division operation A/B as the set of all x values such that for every y value in B, there is a tuple $\langle x, y \rangle$ in A

A

sno	*pno*
s1	p1
s1	p2
s1	p3
s1	p4
s2	p1
s2	p2
s3	p2
s4	p2
s4	p4

B1

pno
p2

B2

pno
p2
p4

B3

pno
p1
p2
p4

A/B1

sno
s1
s2
s3
s4

A/B2

sno
s1
s4

A/B3

sno
s1

Figure 4.14 Examples Illustrating Division

Examples of Relational Algebra Queries

sid	*sname*	*rating*	*age*
22	Dustin	7	45.0
29	Brutus	1	33.0
31	Lubber	8	55.5
32	Andy	8	25.5
58	Rusty	10	35.0
64	Horatio	7	35.0
71	Zorba	10	16.0
74	Horatio	9	35.0
85	Art	3	25.5
95	Bob	3	63.5

Figure 4.15 An Instance *S*3 of Sailors

sid	*bid*	*day*
22	101	10/10/98
22	102	10/10/98
22	103	10/8/98
22	104	10/7/98
31	102	11/10/98
31	103	11/6/98
31	104	11/12/98
64	101	9/5/98
64	102	9/8/98
74	103	9/8/98

Figure 4.16 An Instance *R*2 of Reserves

bid	*bname*	*color*
101	Interlake	blue
102	Interlake	red
103	Clipper	green
104	Marine	red

Figure 4.17 An Instance *B*1 of Boats

(Q1) Find the names of sailors who have reserved boat 103

$$\pi_{sname}((\sigma_{bid=103}Reserves) \bowtie Sailors)$$

Result: *Dustin*, *Lubber* and *Horatio*

(OR)

- Using renaming operator

$$\rho(Temp1, \sigma_{bid=103}Reserves)$$

$$\rho(Temp2, Temp1 \bowtie Sailors)$$

$$\pi_{sname}(Temp2)$$

sid	*bid*	*day*
22	103	10/8/98
31	103	11/6/98
74	103	9/8/98

Figure 4.18 Instance of $Temp1$

sid	*sname*	*rating*	*age*	*bid*	*day*
22	Dustin	7	45.0	103	10/8/98
31	Lubber	8	55.5	103	11/6/98
74	Horatio	9	35.0	103	9/8/98

Figure 4.19 Instance of $Temp2$

- Here is another way to write this query:

$$\pi_{sname}(\sigma_{bid=103}(Reserves \bowtie Sailors))$$

- If the user's query is first translated into the expression

$$\pi_{sname}(\sigma_{bid=103}(Reserves \bowtie Sailors))$$

- A good query optimizer will find the equivalent expression

$$\pi_{sname}((\sigma_{bid=103}Reserves) \bowtie Sailors)$$

- Further, the optimizer will recognize that the second expression is likely to be less expensive to compute because the sizes of intermediate relations are smaller

(Q2) Find the names of sailors who have reserved a red boat

$$\pi_{sname}((\sigma_{color='red'} Boats) \bowtie Reserves \bowtie Sailors)$$

Result: *Dustin*, *Lubber* and *Horatio*

(Q3) Find the colors of boats reserved by Lubber

$$\pi_{color}((\sigma_{sname='Lubber'} Sailors) \bowtie Reserves \bowtie Boats)$$

(Q4) Find the names of sailors who have reserved at least one boat

$$\pi_{sname}(Sailors \bowtie Reserves)$$

(Q5) Find the names of sailors who have reserved a red and a green boat

$$\rho(Tempred, \pi_{sid}((\sigma_{color='red'} Boats) \bowtie Reserves))$$

$$\rho(Tempgreen, \pi_{sid}((\sigma_{color='green'} Boats) \bowtie Reserves))$$

$$\pi_{sname}((Tempred \cap Tempgreen) \bowtie Sailors)$$

(Q6) Find the names of sailors who have reserved a red or a green boat

$$\rho(Tempred, \pi_{sid}((\sigma_{color='red'} Boats) \bowtie Reserves))$$

$$\rho(Tempgreen, \pi_{sid}((\sigma_{color='green'} Boats) \bowtie Reserves))$$

$$\pi_{sname}((Tempred \cup Tempgreen) \bowtie Sailors)$$

(Q7) Find the sids of sailors with age over 20 who have not reserved a red boat

$$\pi_{sid}(\sigma_{age>20} Sailors) -$$

$$\pi_{sid}((\sigma_{color='red'} Boats) \bowtie Reserves)$$

(Q8) Find the names of sailors who have reserved all boats

$$\rho(Tempsids, (\pi_{sid,bid} Reserves) / (\pi_{bid} Boats))$$

$$\pi_{sname}(Tempsids \bowtie Sailors)$$

(Q9) Find the names of sailors who have reserved all boats called Interlake

$$\rho(Tempsids, (\pi_{sid,bid} Reserves) / (\pi_{bid}(\sigma_{bname='Interlake'} Boats)))$$

$$\pi_{sname}(Tempsids \bowtie Sailors)$$

RELATIONAL CALCULUS

- Relational calculus is an alternative to relational algebra

- Relational Algebra is procedural language

- Relational Calculus is nonprocedural language

- Relational calculus is of two types

  1. Tuple Relational Calculus(TRC)
  2. Domain Relational Calculus(DRC)

Tuple Relational Calculus

▪A **tuple** variable is a variable that takes tuples of a relation as values

▪A tuple relational calculus query has the form $\{\ T \mid p(T)\ \}$ where ***T*** is a tuple variable and ***p(T)* is a formula** that describes *T*

▪The result of this query is the set of all tuples *t* for which the formula *p(T)* evaluates to true with *T* = *t*

Ex:

(Q) Find all sailors with a rating above 7

$$\{S \mid S \in Sailors \wedge S.rating > 7\}$$

Syntax of TRC Queries

- Let ***Rel*** be a relation name, ***R*** and ***S*** be tuple variables, ***a*** an attribute of ***R***, and ***b*** an attribute of ***S***

- Let ***op*** denote an operator in the set $\{<, >, =, \leq, \geq, \neq\}$

- **Formula** contains the following:
  - $R \in Rel$
  - $R.a \text{ op } S.b$
  - $R.a \text{ op } constant$, or $constant \text{ op } R.a$

- any atomic formula
- $\neg p$, $p \wedge q$, $p \vee q$, or $p \Rightarrow q$
- $\exists R(p(R))$, where R is a tuple variable
- $\forall R(p(R))$, where R is a tuple variable

- In the last two clauses above, the **quantifiers** $\exists$ and $\forall$ are said to **bind** the variable *R*

- A variable is said to be **free** in a formula if the formula does not contain an occurrence of a quantifier that binds it

- A **TRC query** is defined to be expression of the form $\{\ T \mid p(T)\ \}$,where *T* is the only free variable in the formula *p*

Examples of TRC Queries

- Consider the instances *B1* of Boats, *R2* of Reserves, and *S3* of Sailors shown in Figures 4.15, 4.16, and 4.17

(Q)Find the names and ages of sailors with a rating above 7

$$\{P \mid \exists S \in Sailors(S.rating > 7 \wedge P.name = S.sname \wedge P.age = S.age)\}$$

sid	*sname*	*rating*	*age*
22	Dustin	7	45.0
29	Brutus	1	33.0
31	Lubber	8	55.5
32	Andy	8	25.5
58	Rusty	10	35.0
64	Horatio	7	35.0
71	Zorba	10	16.0
74	Horatio	9	35.0
85	Art	3	25.5
95	Bob	3	63.5

Figure 4.15 An Instance *S*3 of Sailors

sid	*bid*	*day*
22	101	10/10/98
22	102	10/10/98
22	103	10/8/98
22	104	10/7/98
31	102	11/10/98
31	103	11/6/98
31	104	11/12/98
64	101	9/5/98
64	102	9/8/98
74	103	9/8/98

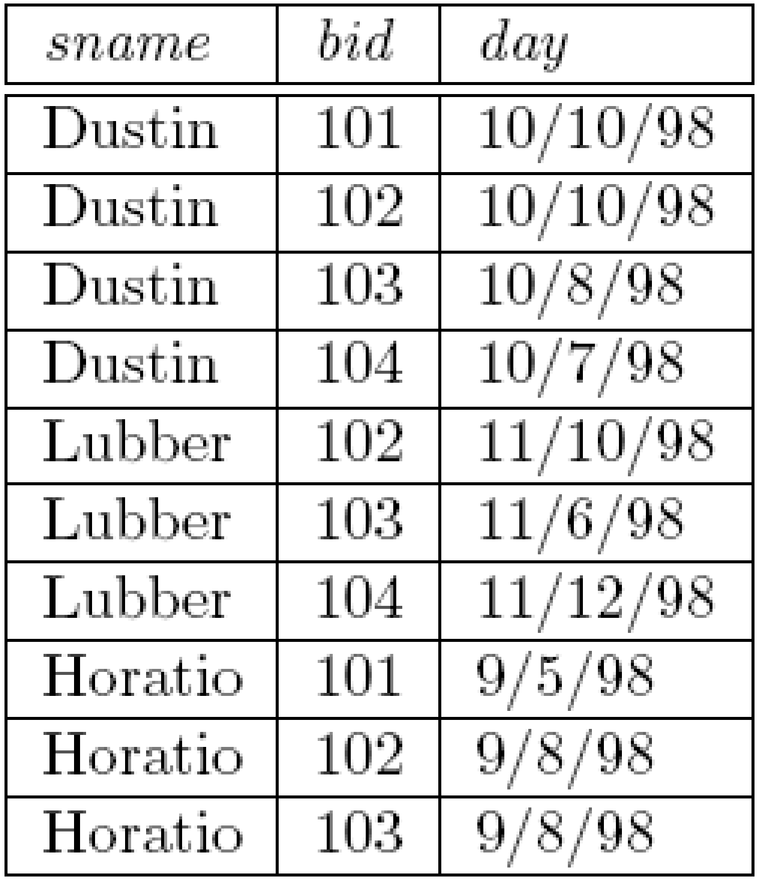
Figure 4.16 An Instance *R*2 of Reserves

bid	*bname*	*color*
101	Interlake	blue
102	Interlake	red
103	Clipper	green
104	Marine	red

Figure 4.17 An Instance *B*1 of Boats

(Q) Find the sailor name, boat id, and reservation date for each reservation

$$\{P \mid \exists R \in Reserves \ \ \exists S \in Sailors$$
$$(R.sid = S.sid \wedge P.bid = R.bid \wedge P.day = R.day \wedge P.sname = S.sname)\}$$



sname	*bid*	*day*
Dustin	101	10/10/98
Dustin	102	10/10/98
Dustin	103	10/8/98
Dustin	104	10/7/98
Lubber	102	11/10/98
Lubber	103	11/6/98
Lubber	104	11/12/98
Horatio	101	9/5/98
Horatio	102	9/8/98
Horatio	103	9/8/98

Figure 4.20 Answer to Query Q

(Q) Find the names of sailors who have reserved boat 103

$$\{P \mid \exists S \in Sailors\ \exists R \in Reserves(R.sid = S.sid \wedge R.bid = 103 \wedge P.sname = S.sname)\}$$

(Q) Find the names of sailors who have reserved a red boat

$$\{P \mid \exists S \in Sailors\ \ \exists R \in Reserves\ \ \exists B \in Boats$$
$$(R.sid = S.sid \wedge B.bid = R.bid \wedge B.color = 'red' \wedge P.sname = S.sname)\}$$

(Q) Find sailors who have reserved all boats

$$\{S \mid S \in Sailors \wedge$$
$$\forall B(\ (B \in Boats) \Rightarrow$$
$$\exists R(R \in Reserves \wedge S.sid = R.sid$$
$$\wedge B.bid = R.bid))\}$$

(Q) Find sailors who have reserved all red boats

$$\{S \mid S \in Sailors \wedge$$
$$\forall B(\ (B \in Boats \wedge B.color = \text{“red”}) \Rightarrow$$
$$\exists R(R \in Reserves \wedge S.sid = R.sid$$
$$\wedge B.bid = R.bid))\}$$

Domain Relational Calculus

- A **domain variable** is a variable that ranges over the values in the domain of some attribute

- Ex: the variable can be assigned an integer if it appears in an attribute whose domain is the set of integers

- A DRC query has the form

$$\{\langle x_1, x_2, \ldots, x_n \rangle \mid p(\langle x_1, x_2, \ldots, x_n \rangle)\}$$

- where each x_i is either a *domain variable* or a constant and $p(\langle x_1, x_2, \ldots, x_n \rangle))\}$ denotes a **DRC formula**

- The result of this query is the set of all tuples for which the formula evaluates to true

- A DRC formula is defined similar to the definition of a TRC formula

- The main difference is that the variables are now domain variables

- Let *op* denote an operator in the set $\{<, >, =, \leq, \geq, \neq\}$ and let *X* and *Y* be domain variables

- **Formula** contains the following:

- $\langle x_1, x_2, \ldots, x_n \rangle \in Rel$, where Rel is a relation with n attributes; each x_i, $1 \leq i \leq n$ is either a variable or a constant.
- X op Y
- X op *constant*, or *constant* op X
- any atomic formula
- $\neg p$, $p \wedge q$, $p \vee q$, or $p \Rightarrow q$
- $\exists X(p(X))$, where X is a domain variable
- $\forall X(p(X))$, where X is a domain variable

Examples of DRC Queries

(Q) Find all sailors with a rating above 7

$$\{\langle I, N, T, A\rangle \mid \langle I, N, T, A\rangle \in Sailors \wedge T > 7\}$$

(Q) Find the names of sailors with a rating above 7

$$\{\langle N\rangle \mid \exists I, T, A(\langle I, N, T, A\rangle \in Sailors \wedge T > 7\}$$

(Q) Find the names of sailors who have reserved boat 103

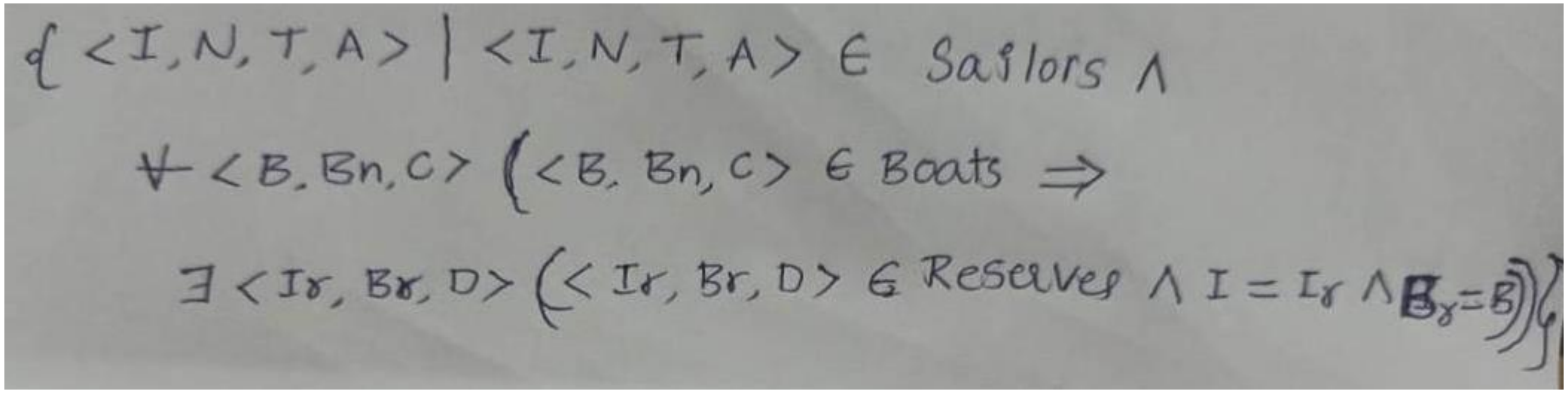
$$\{\langle N\rangle \mid \exists I, T, A(\langle I, N, T, A\rangle \in Sailors$$

$$\wedge \exists Ir, Br, D(\langle Ir, Br, D\rangle \in Reserves \wedge Ir = I \wedge Br = 103))\}$$

(Or)

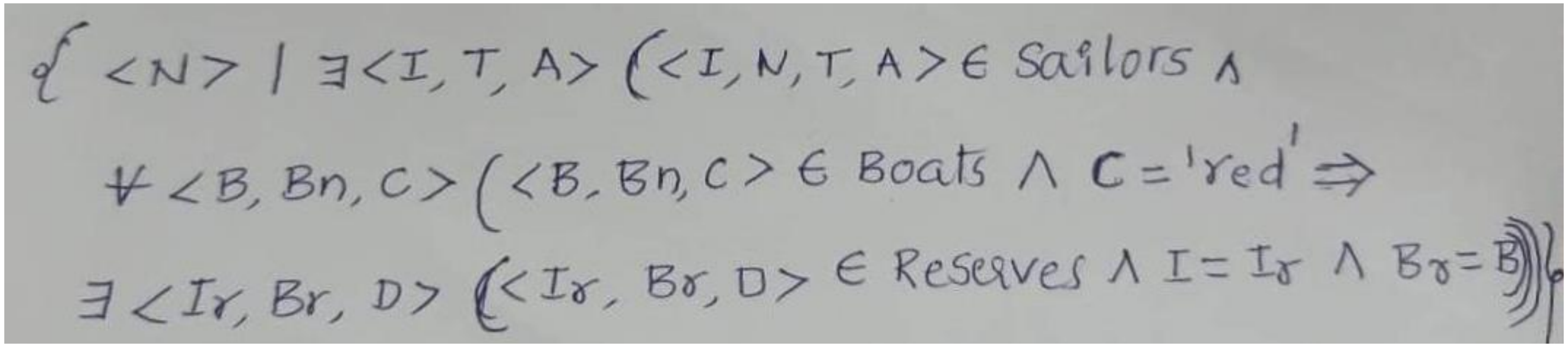
$$\{\langle N\rangle \mid \exists I,T,A(\langle I,N,T,A\rangle \in Sailors \wedge \exists D(\langle I,103,D\rangle \in Reserves))\}$$

(Q) Find sailors who have reserved all boats



$$\{<I,N,T,A> \mid <I,N,T,A> \in Sailors \wedge \forall <B,Bn,C> (<B,Bn,C> \in Boats \Rightarrow \exists <Ir,Br,D> (<Ir,Br,D> \in Reserves \wedge I = Ir \wedge B_r = B))\}$$

(Q) Find the names of sailors who have reserved all red boats



$$\{<N> \mid \exists <I,T,A> (<I,N,T,A> \in Sailors \wedge \forall <B,Bn,C> (<B,Bn,C> \in Boats \wedge C = 'red' \Rightarrow \exists <Ir,Br,D> (<Ir,Br,D> \in Reserves \wedge I = Ir \wedge B_r = B)))\}$$