Basic Set Operations

- r ∪ s
- r ∩ s
- r – s

relation **r**

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

relation **s**

A	B	C
b	g	a
d	a	f

- Can we perform ∪, ∩, – between any two relations?
  - They need to be *union compatible*
    - |R| = |S| and
    - corresponding attributes have same domains
- Properties
  - Both ∪ and ∩ are commutative operations
  - Difference is not commutative

Attribute Names?

Basic Set Operations

- r ∪ s
- r ∩ s
- r – s

relation **r**

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

relation **s**

D	E	F
b	g	a
d	a	f

- Can we perform ∪, ∩, – between any two relations?
  - They need to be *union compatible*
    - |R| = |S| and
    - corresponding attributes have same domains
- Properties
  - Both ∪ and ∩ are commutative operations
  - Difference is not commutative

Attribute Names?

Cartesian Product

- r x s

relation **r**

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

α_r

relation **s**

A	B
b	g
d	a

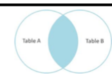
α_s

- Let p(P) = r(R) x s(S)
- |P| = ? and |p| = ?
  - $|P| = |R| + |S| = \alpha_r + \alpha_s$
  - $|p| = |r| * |s|$
- Name conflicts are resolved by using the relations names as prefixes: r.A, r.B, S.A, S.B

Common Query

- Library microDB:
  - Librarian (<u>SSN</u>, Name, SNO)
  - Section (<u>SNO</u>, SName, Head)
- *List the names of head librarians.*
- How?

Equi-Join



- $r \bowtie_{r.A_i = s.A_j} s$
- =-join is a macro of

  $\sigma_{r.A_i = s.A_j} (r \times s)$

- =-join of r(R) and s(S):

  $r \bowtie_{r.B = s.D} s = ?$

relation **r**

A	B	C	D
1	2	3	4
2	4	6	8
1	2	4	8
2	6	6	8
8	2	3	4
2	4	3	4

relation **s**

C	D
3	4
6	8

Θ-Join

- $\Theta = \{=, <, \leq, >, \geq, \neq\}$
- Θ-join of r(R) and s(S)

  on attributes $r.A_i$ and $s.A_j$

  $r \bowtie_{r.A_i\, \theta\, s.A_j} s$

  $= \sigma_{r.A_i\, \theta\, s.A_j} (r \times s)$

- ≥-join of r(R) and s(S):

  $r \bowtie_{r.B \geq s.D} s = ?$

relation **r**

A	B	C	D
1	2	3	4
2	4	6	8
1	2	4	8
2	6	6	8
8	2	3	4
2	4	3	4

relation **s**

C	D
3	4
6	8

Example of Θ-Join

- ≥-join of r(R) and s(S):

  $r \bowtie_{r.B \geq s.D} s = ?$

r.A	r.B	r.C	r.D	s.C	s.D
2	4	6	8	3	4
2	4	3	4	3	4
2	6	6	8	3	4

- $r \bowtie s = r \times s$, $\Theta = \phi$

relation **r**

A	B	C	D
1	2	3	4
2	4	6	8
1	2	4	8
2	6	6	8
8	2	3	4
2	4	3	4

relation **s**

C	D
3	4
6	8

Natural-Join

- Equi-join without duplicate columns

  $r *_P s$

- P=list of attributes: $P = R \cap S$
- $r * s = \Pi_{R \cup S} (r \bowtie_{r.P = s.P} s)$
- $r * s = ?$
- Note other notations & meanings
  - $r \bowtie s = r * s$, $R \cap S \neq \phi$
  - $r * s = r \times s$, $R \cap S = \phi$

relation **r**

A	B	C	D
1	2	3	4
2	4	6	8
1	2	4	8
2	6	6	8
8	2	3	4
2	4	3	4

relation **s**

C	D	E
3	4	6
6	8	8

Examples from Library DB

- Library DB schema:
  - LIBRARIAN(Name, SSN, SNO, BirthPlace)
  - SECTION(SName, SNO, Head)
  - OUTREACH(Pname, PNO, SNUM, Location)
  - WORKSON(LSSN,PNO,Hours)
- For every outreach activity located in PGH, list its project number, the responsible section and its head.
- Find all the librarians (Name, SSN) who work on projects located in their place of birth.

Division

- Let r(R) and s(S) be relations such as S⊂R
- The division of r by s, denoted by r÷s,
  - is relation whose schema is Q=R-S and
  - includes all t such as $t_r[Q] = t$ and $t_r[S] = t$

relation **r**

A	B	C	D
1	2	3	4
2	4	6	8
1	2	6	8
2	4	3	4

relation **s**

C	D
3	4
6	8

r÷s

A	B
1	2
2	4

Division With Remainder

- Let r(R) and s(S) be relations such as S⊂R
- r÷s
  - is relation whose schema is Q=R-S
  - includes all t such as $t_r[Q] = t$ and $t_r[S] = t$

relation **r**

A	B	C	D
1	2	3	4
2	3	3	5
2	4	6	8
1	2	6	8
8	2	3	4
2	4	3	4

relation **s**

C	D
3	4
6	8

r÷s

A	B
1	2
2	4

Division Usage

- Query: "Retrieve the names of students who took *all* the classes that John took."

Q=ENROLL÷CLASS

FN	LN
S	A
K	L

ENROLL

FN	LN	DP	No
S	A	CS	4
M	K	CS	5
K	L	EE	8
S	A	EE	8
F	S	CS	4
K	L	CS	4

CLASS

DP	No
CS	4
EE	8

Note:
Division can be expressed using π, x and – operations: $r \div s = \pi_Q(r) - \pi_Q((\pi_Q(r) \times s) - r)$

Division Usage: Review Example

- Query: "List the names of people who have in common *all* Susan's friends on Facebook."

Relation **Friends**

Username	FNFriend	LNFrind
Susan	Alex	L
Mark	Alex	L
Kirk	Mary	K
Shi	Alex	L
Susan	Mary	K
Shi	Lory	M
Kirk	Chia	S
Kirk	Alex	L

Division Usage: Review Example

- Query: "List the names of people who have in common *all* Susan's friends on Facebook."

Relation **Friends**

Username	FNFriend	LNFrind
Susan	Alex	L
Mark	Alex	L
Kirk	Mary	K
Shi	Alex	L
Susan	Mary	K
Shi	Lory	M
Kirk	Chia	S
Kirk	Alex	L

$SF \leftarrow \sigma_{Username = 'Susan'}(Friends)$

$SSF \leftarrow Friends \div \pi_{FN,LN}(SF)$

$RSLT \leftarrow \sigma_{Username \neq 'Susan'}(SSF)$

Extended Relational Operations

- Extended set and Relational operations:
  - Outer Union
  - Outer Joins
- Aggregate operations:
  - MAX, MIN, AVG, SUM
  - Count
  - Subset: groupping
- Arithmetic operations and other functions:

Outer Union

- it is defined on partially union compatible relations
  - Non union-compatible attributes are kept in $r \cup^* s$
  - Non union-compatible attributes without value are set to NULL
  - Tuples are "matched" over common named attributes like in natural join

relation **r**

FN	LN	MJ
a	b	cs
d	a	ce
c	b	cs

relation **s**

FN	LN	CL
b	g	f
d	a	sr

$r \cup^* s$

FN	LN	MJ	CL
a	b	cs	Null
d	a	ce	sr
c	b	cs	Null
b	g	Null	f

- what about outer intersection or outer difference?

Outer Join

- Join selects only tuples satisfying the join-condition
- ***Outer Join***:
  - Left outer join (r ⟕ s) keeps every tuple in the left relation
  - Right outer join (r ⟖ s) keeps every tuple in the right relation
  - Full outer join (r ⟗ s) keeps every tuple
- Attributes of tuples with no matching tuples are set to NULL
- With out a join-condition they behave like natural join

Outer Join ("natural")

relation **r**

FN	LN	MJ
a	b	cs
d	a	ce
c	b	cs

relation **s**

FN	LN	CL
b	g	f
d	a	sr

r ⟕ s

FN	LN	MJ	CL
a	b	cs	Null
d	a	ce	sr
c	b	cs	Null

r ⟖ s

FN	LN	MJ	CL
d	a	ce	sr
b	g	Null	f

r ⟗ s

FN	LN	MJ	CL
a	b	cs	Null
d	a	ce	sr
c	b	cs	Null
b	g	Null	f

Aggregate Functions

- Mathematical and Statistical aggregate functions on collections of values
  - SUM, MAXIMUM, MINIMUM, AVERAGE
  - COUNT number of tuples (cardinality)

    $\mathfrak{F}_{\text{<function list>}}\ (\text{<relation>})$
  - *Function list* is a list of pairs
    (< *function, attribute* >)
- E.g., $\mathfrak{F}_{\text{count SID, AVERAGE GPA}}\ (\text{STUDENT})$

Aggregate Functions: Example

- RSLT ← $\mathfrak{F}_{\text{count SID, AVERAGE GPA}}\ (\text{STUDENT})$

Student

SID	*Name*	*Age*	*GPA*
546007	Susan	18	3.8
546100	Bob	19	3.65
546500	Bill	20	3.7

RSLT

Count_SID	*AVERAGE_GPA*
3	3.72

Example of Aggregation Query

- Q: *Find the students with the highest GPA.*
- **Student** (SID, Name, Age, GPA)
- A:

MG(MGPA) $\leftarrow \mathfrak{F}_{MAX\ GPA}$ (Student);

RSLT $\leftarrow$ MG $\bowtie_{MGPA\ =\ GPA}$ (Student);

Grouping

- *Grouping* the tuple in a relation

  <grouping attributes> $\mathfrak{F}$ <function list> (<relation>)

  - Tuples are grouped based on the values of *grouping attributes*
- E.g., *major* $\mathfrak{F}$ *count SID, AVERAGE GPA* (STUDENT)

major	*Count_SID*	*AVERAGE_GPA*

Recursive closure

- It is applied to a recursive relationship between tuples of the same relation
- E.g., find all the ancestors or descendants
- How do we express it?
- What about the join operation?
- Need control statements…iteration

Write Queries in Relational Algebra

- Deletion:
  - r $\leftarrow$ r – *Relational_Expression*
  - STUDENT $\leftarrow$ STUDENT – ($\sigma_{\text{Dept = 'CSD'} \wedge \text{QPA<2.5}}$ (STUDENT))
- Insertion:
  - r $\leftarrow$ r $\cup$ *Relational_Expression*
  - STUDENT $\leftarrow$ STUDENT $\cup$ {(365, `Smith', `John')}
- Updating:
  - r $\leftarrow \Pi_{\text{attributes-to-be-updated}}$ (r)
  - STUDENT $\leftarrow \Pi_{\text{Dept = 'CSD'}}$ ($\sigma_{\text{Dept = 'CS'}}$ (STUDENT))

Discussion

- The relational algebra is ***procedural***
- The queries in relational algebra specify ***how*** to produce a result, BUT…
- The ***how*** should be the responsibility of the system
- User queries should be ***declarative*** specifying what is to be retrieved
  - Textual query languages (SQL, QUEL)
  - Graphical query languages (QBE)
  - Visual iconic languages (QBI)
- Other formal query languages:
  - Relational tuple calculus
  - Relational domain calculus

Steps in Processing a Query

SQL statement

↓

Scan, Parse, Validate

↓ Intermediate form of query

Query Optimizer

↓ Execution plan

Query Code Generator

↓ Code to execute query

Runtime DB Processor

↓ Results of running query