Relational Algebra

Outline

1. Introduction
2. Selection, Projection, Extended Projection
3. Product, Theta-Join, Natural Join
4. Renaming
5. Building Complex Expressions

What is an "Algebra"

- Mathematical system consisting of:
  - *Operands* --- variables or values from which new values can be constructed.
  - *Operators* --- symbols denoting procedures that construct new values from given values.

What is Relational Algebra?

- An algebra whose operands are relations or variables that represent relations.
- Operators are designed to do the most common things that we need to do with relations in a database.
  - The result is an algebra that can be used as a *query language* for relations.

Core Relational Algebra

- Union, intersection, and difference.
  - Usual set operations, but both operands must have the same relation schema.
- Selection: picking certain rows.
- Projection: picking certain columns.
- Products and joins: compositions of relations.
- Renaming of relations and attributes.

Selection

- R1 := σ_C(R2)
  - *C* is a condition (as in "if" statements) that refers to attributes of R2.
  - R1 is all those tuples of R2 that satisfy *C*.

Example: Selection

Relation Sells:

bar	beer	price
Joe's	Bud	2.50
Joe's	Miller	2.75
Sue's	Bud	2.50
Sue's	Miller	3.00

JoeMenu := $\sigma_{bar=\text{“Joe's”}}$(Sells):

bar	beer	price
Joe's	Bud	2.50
Joe's	Miller	2.75

Projection

- R1 := π_L (R2)
  - L is a list of attributes from the schema of R2.
  - R1 is constructed by looking at each tuple of R2, extracting the attributes on list L, in the order specified, and creating from those components a tuple for R1.
  - Eliminate duplicate tuples, if any.

Example: Projection

Relation Sells:

bar	beer	price
Joe's	Bud	2.50
Joe's	Miller	2.75
Sue's	Bud	2.50
Sue's	Miller	3.00

Prices := $\pi_{beer,price}$(Sells):

beer	price
Bud	2.50
Miller	2.75
Miller	3.00

Extended Projection

- Using the same π_L operator, we allow the list L to contain arbitrary expressions involving attributes:
  1. Arithmetic on attributes, e.g., $A+B\text{->}C$.
  2. Duplicate occurrences of the same attribute.

Example: Extended Projection

R =

A	B
1	2
3	4

$\pi_{A+B\text{->}C,A,A}$ (R) =

C	A1	A2
3	1	1
7	3	3

Product

- R3 := R1 X R2
  - Pair each tuple t1 of R1 with each tuple t2 of R2.
  - Concatenation t1t2 is a tuple of R3.
  - Schema of R3 is the attributes of R1 and then R2, in order.
  - But beware attribute *A* of the same name in R1 and R2: use R1.*A* and R2.*A*.

Example: R3 := R1 X R2

R1(

A,	B
1	2
3	4

)

R2(

B,	C
5	6
7	8
9	10

)

R3(

A,	R1.B,	R2.B,	C
1	2	5	6
1	2	7	8
1	2	9	10
3	4	5	6
3	4	7	8
3	4	9	10

)

Theta-Join

- R3 := R1 $\bowtie_C$ R2
  - Take the product R1 X R2.
  - Then apply σ_C to the result.
- As for σ, C can be any boolean-valued condition.
  - Historic versions of this operator allowed only A θ B, where θ is =, <, etc.; hence the name "theta-join."

Example: Theta-Join

Sells(

bar,	beer,	price
Joe's	Bud	2.50
Joe's	Miller	2.75
Sue's	Bud	2.50
Sue's	Coors	3.00

)

Bars(

name,	addr
Joe's	Maple St.
Sue's	River Rd.

)

BarInfo := Sells $\bowtie_{\text{Sells.bar = Bars.name}}$ Bars

BarInfo(

bar,	beer,	price,	name,	addr
Joe's	Bud	2.50	Joe's	Maple St.
Joe's	Miller	2.75	Joe's	Maple St.
Sue's	Bud	2.50	Sue's	River Rd.
Sue's	Coors	3.00	Sue's	River Rd.

)

Natural Join

- A useful join variant (natural join) connects two relations by:
  - Equating attributes of the same name, and
  - Projecting out one copy of each pair of equated attributes.
- Denoted R3 := R1 $\bowtie$ R2.

Example: Natural Join

Sells(

bar,	beer,	price
Joe's	Bud	2.50
Joe's	Miller	2.75
Sue's	Bud	2.50
Sue's	Coors	3.00

)

Bars(

bar,	addr
Joe's	Maple St.
Sue's	River Rd.

)

Note: Bars.name has become Bars.bar to make the natural join "work."

BarInfo := Sells $\bowtie$ Bars

BarInfo(

bar,	beer,	price,	addr
Joe's	Bud	2.50	Maple St.
Joe's	Millller	2.75	Maple St.
Sue's	Bud	2.50	River Rd.
Sue's	Coors	3.00	River Rd.

)

Note: only one *bar* column is kept (the other one is projected out)

Outerjoin

- Suppose we join *R* and *S* :
  - $R \bowtie_C S$ (theta-join)
  - or $R \bowtie S$ (natural join)
- A tuple of *R* that has no tuple of *S* with which it joins is said to be dangling.
  - Similarly for a tuple of *S*.
- Outerjoin preserves dangling tuples by padding them NULL.

Example: Outerjoin

R = (

A	B
1	2
4	5

)

S = (

B	C
2	3
6	7

)

(1,2) joins with (2,3), but the other two tuples are dangling.

R OUTERJOIN S =

A	B	C
1	2	3
4	5	NULL
NULL	6	7

Example: Outerjoin (2)

- Note:
  - The example involves a natural join, but the same applies to theta-joins
  - An outerjoin contains all the tuples of the matching inner join, *plus* dangling tuples
  - To retain only dangling tuples, we need to filter on a non-null column of the opposite table

Renaming

- The ρ operator gives a new schema to a relation.
- R1 := $\rho_{R1(A1,\ldots,An)}$(R2) makes R1 be a relation with attributes A1,…,A*n* and the same tuples as R2.
- Simplified notation: R1(A1,…,A*n*) := R2.

Example: Renaming

Bars(

name,	addr
Joe's	Maple St.
Sue's	River Rd.

)

R(bar, addr) := Bars

R(

bar,	addr
Joe's	Maple St.
Sue's	River Rd.

)

Building Complex Expressions

- Combine operators with parentheses and precedence rules.
- Three notations, just as in arithmetic:
  1. Sequences of assignment statements.
  2. Expressions with several operators.
  3. Expression trees.

Sequences of Assignments

- Create temporary relation names.
- Renaming can be implied by giving relations a list of attributes.
- Example: R3 := R1 $\bowtie_C$ R2 can be written:

  R4 := R1 X R2

  R3 := σ_C(R4)

Expressions in a Single Assignment

- Example: the theta-join R3 := R1 $\bowtie_C$ R2 can be written: R3 := σ_C(R1 X R2)
- Precedence of relational operators:
  1. [σ, π, ρ] (highest).
  2. [x, $\bowtie$].
  3. $\cap$.
  4. [$\cup$, —]

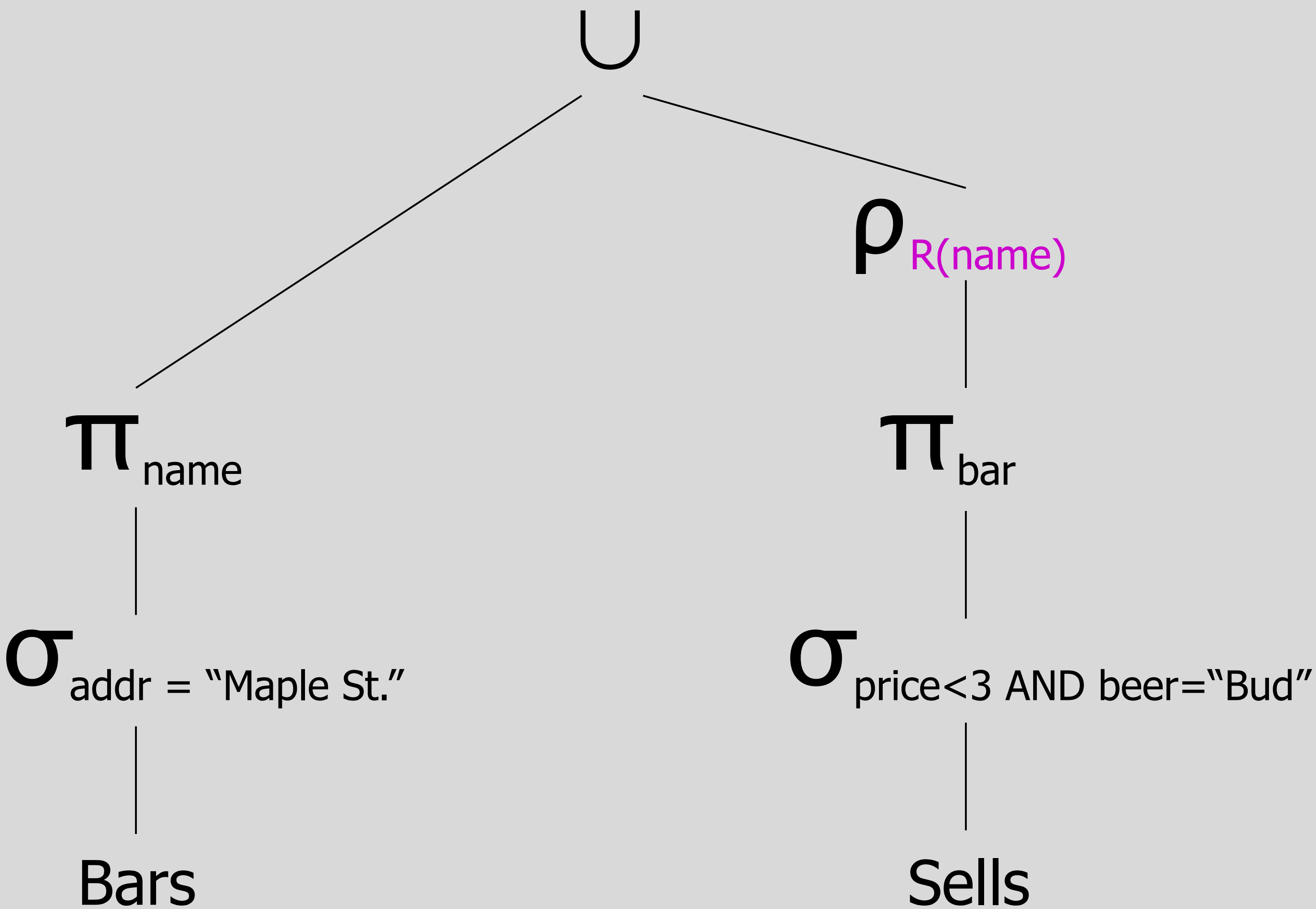
Expression Trees

- Leaves are operands --- either variables standing for relations or particular, constant relations.
- Interior nodes are operators, applied to their child or children.

Example: Tree for a Query

- Using the relations Bars(name, addr) and Sells(bar, beer, price), find the names of all the bars that are either on Maple St. or sell Bud for less than $3.

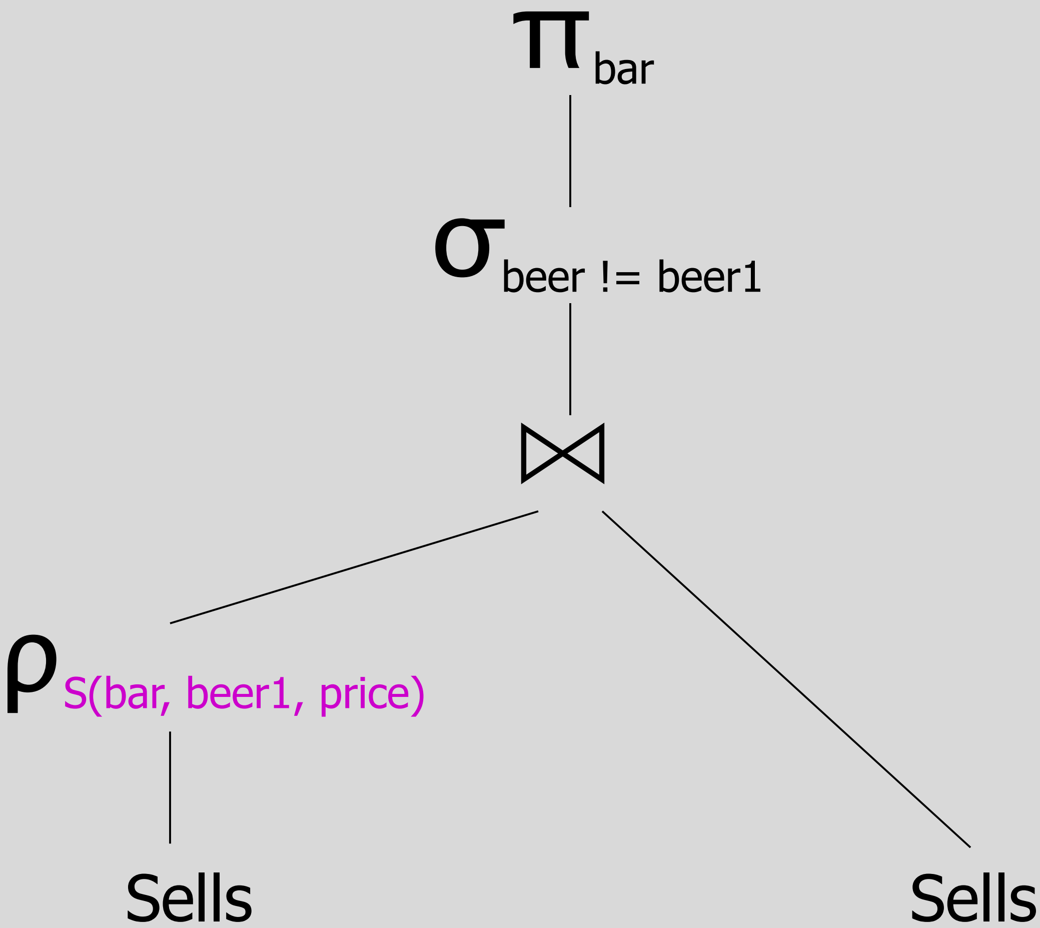
As a Tree:


∪
ρ R(name)
π name
π bar
σ addr = “Maple St.”
σ price<3 AND beer=“Bud”
Bars
Sells

Example: Self-Join

- Using Sells(bar, beer, price), find the bars that sell two different beers at the same price.
- Strategy: by renaming, define a copy of Sells, called S(bar, beer1, price). The natural join of Sells and S consists of quadruples (bar, beer, beer1, price) such that the bar sells both beers at this price.

The Tree



Schemas for Results

- Union, intersection, and difference: the schemas of the two operands must be the same, so use that schema for the result.
- Selection: schema of the result is the same as the schema of the operand.
- Projection: list of attributes tells us the schema.

Schemas for Results --- (2)

- Product: schema is the attributes of both relations.
  - Use R.*A*, etc., to distinguish two attributes named *A*.
- Theta-join: same as product, since theta-join = product + selection.
- Natural join: union of the attributes of the two relations.
- Renaming: the operator tells the schema.

Extended Relational Algebra

Outline

1. Relational Algebra on Bags
2. Duplicate Elimination
3. Sorting
4. Grouping

Relational Algebra on Bags

- A bag (or multiset) is like a set, but an element may appear more than once.
- Example: {1,2,1,3} is a bag.
- Example: {1,2,3} is also a bag that happens to be a set.

Why Bags?

- Relational algebra considers relations as sets (hence duplicate elimination after projection)
- SQL, the most important query language for relational databases, is actually a bag language.
- Some operations, like projection, are *more efficient* on bags than sets.

Operations on Bags

- Selection applies to each tuple, so its effect on bags is like its effect on sets.
- Projection also applies to each tuple, but as a bag operator, *we do not eliminate duplicates*.
- Products and joins are done on each pair of tuples, so duplicates in bags have no effect on how we operate.

Example: Bag Selection

R(

A,	B)
1	2
5	6
1	2

$\sigma_{A+B<5}$ (R) =

A	B
1	2
1	2

Example: Bag Projection

R(

A,	B
1	2
5	6
1	2

)

π_A (R) =

A
1
5
1

Example: Bag Product

R(

A,	B
1	2
5	6
1	2

)

S(

B,	C
3	4
7	8

)

R X S =

A	R.B	S.B	C
1	2	3	4
1	2	7	8
5	6	3	4
5	6	7	8
1	2	3	4
1	2	7	8

Example: Bag Theta-Join

R(

A,	B
1	2
5	6
1	2

)

S(

B,	C
3	4
7	8

)

$R \bowtie_{R.B<S.B} S =$

A	R.B	S.B	C
1	2	3	4
1	2	7	8
5	6	7	8
1	2	3	4
1	2	7	8

Bag Union

- An element appears in the union of two bags the sum of the number of times it appears in each bag.
- Example: $\{1,2,1\} \cup \{1,1,2,3,1\} = \{1,1,1,1,1,2,2,3\}$

Bag Intersection

- An element appears in the intersection of two bags the minimum of the number of times it appears in either.
- Example: $\{1,2,1,1\} \cap \{1,2,1,3\} = \{1,1,2\}$.

Bag Difference

- An element appears in the difference $A - B$ of bags as many times as it appears in A, minus the number of times it appears in B.
  - But never less than 0 times.
- Example: {1,2,1,1} – {1,2,3} = {1,1}.

Beware: Bag Laws != Set Laws

- Some, but *not all* algebraic laws that hold for sets also hold for bags.
- Example: the commutative law for union ($R \cup S = S \cup R$) *does* hold for bags.
  - Since addition is commutative, adding the number of times x appears in R and S doesn't depend on the order of R and S.

Example: A Law That Fails

- Set union is idempotent, meaning that $S \cup S = S$.
- However, for bags, if x appears n times in S, then it appears $2n$ times in $S \cup S$.
- Thus $S \cup S$!= S in general.
  - e.g., {1} ∪ {1} = {1,1} != {1}.

The Extended Algebra

δ = eliminate duplicates from bags.

τ = sort tuples.

γ = grouping and aggregation.

Duplicate Elimination

- R1 := δ(R2).
- R1 consists of one copy of each tuple that appears in R2 one or more times.

Example: Duplicate Elimination

R = (

A	B
1	2
3	4
1	2

)

$\delta(R)$ =

A	B
1	2
3	4

Sorting

- R1 := τ_L (R2).
  - L is a list of some of the attributes of R2.
- R1 is the list of tuples of R2 sorted first on the value of the first attribute on L, then on the second attribute of L, and so on.
  - Break ties arbitrarily.
- τ is the only operator whose result is neither a set nor a bag.

Example: Sorting

R = (

A	B
1	2
3	4
5	2

)

$\tau_B(R) = [(5,2), (1,2), (3,4)]$

Aggregation Operators

- Aggregation operators are not operators of relational algebra.
- Rather, they apply to entire columns of a table and produce a single result.
- The most important examples: SUM, AVG, COUNT, MIN, and MAX.

Example: Aggregation

R = (

A	B
1	3
3	4
3	2

)

SUM(A) = 7
COUNT(A) = 3
MAX(B) = 4
AVG(B) = 3

Grouping Operator

- R1 := γ_L (R2). L is a list of elements that are either:
  1. Individual (grouping) attributes.
  2. AGG(A), where AGG is one of the aggregation operators and A is an attribute.
     - An arrow and a new attribute name renames the component.

Applying $\gamma_L(R)$

- Group *R* according to all the grouping attributes on list *L*.
  - That is: form one group for each distinct list of values for those attributes in *R*.
- Within each group, compute AGG(*A*) for each aggregation on list *L*.
- Result has one tuple for each group:

1. The grouping attributes and
2. Their group's aggregations.

Example: Grouping/Aggregation

R = (

A	B	C
4	null	4
1	2	3
4	5	6
1	2	5
4	null	2

)

$\gamma_{A,B,\text{AVG(C)->X}}$ (R) = ?

Example: Grouping/Aggregation

First, group *R* by *A* and *B* :

A	B	C
1	2	3
1	2	5
4	5	6
4	null	2
4	null	4

Then, average *C* within groups:

A	B	X
1	2	4
4	5	6
4	null	3

Note: null values make up a distinct group