CS 525: Advanced Database Organisation

08: Query Processing Parsing and Analysis

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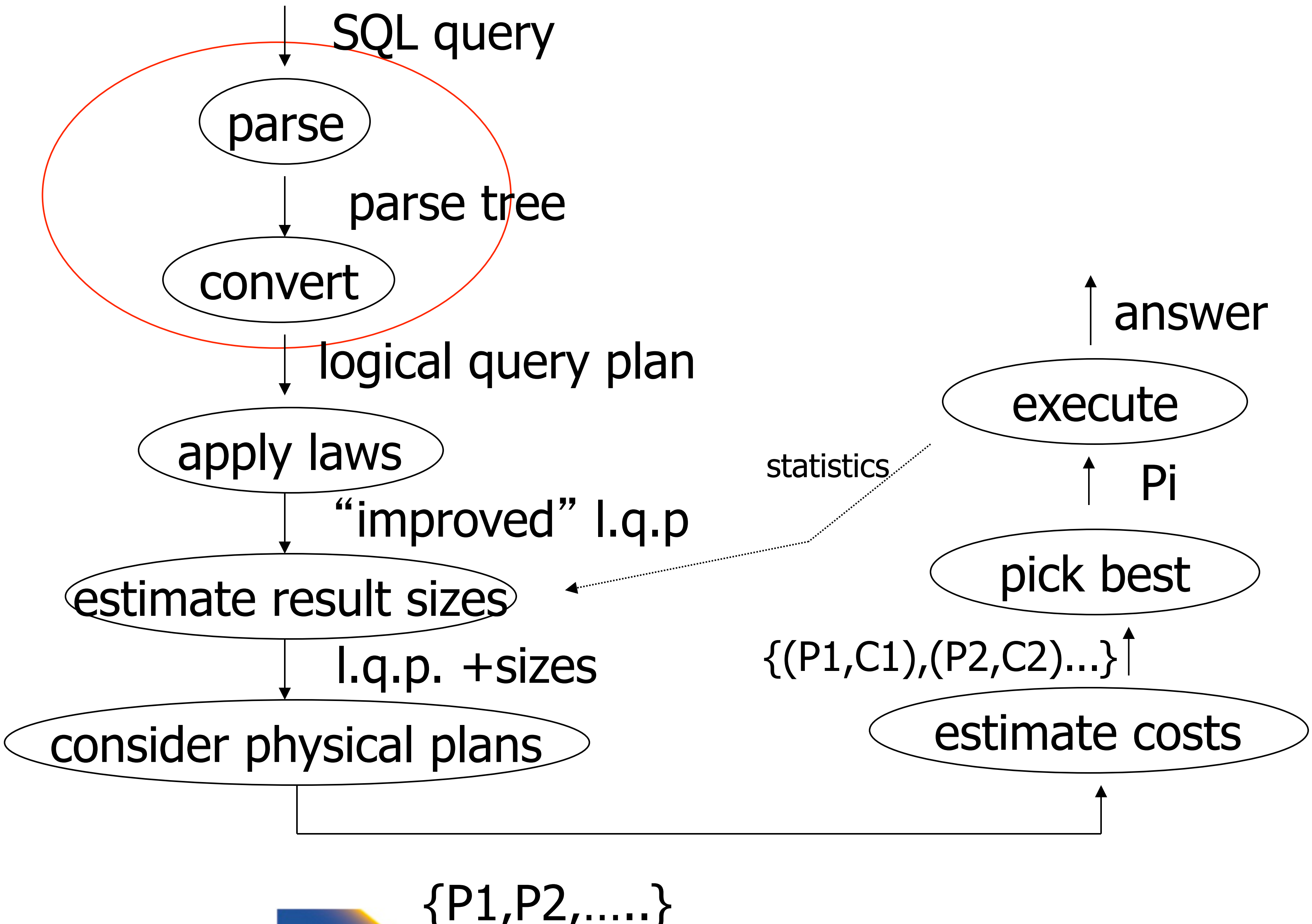
Slides: adapted from a course taught by Hector Garcia-Molina, Stanford InfoLab


SQL query
parse
parse tree
convert
logical query plan
apply laws
"improved" l.q.p
estimate result sizes
statistics
l.q.p. +sizes
consider physical plans
{P1,P2,…..}
estimate costs
{(P1,C1),(P2,C2)...}
pick best
Pi
execute
answer

Parsing, Analysis, Conversion

1. Parsing
   – Transform SQL text into syntax tree
2. Analysis
   – Check for semantic correctness
   – Use database catalog
   – E.g., unfold views, lookup functions and attributes, check scopes
3. Conversion
   – Transform into internal representation
   – Relational algebra or QBM

Analysis and Conversion

- Usually intertwined
- The internal representation is used to store analysis information
- Create an initial representation and complete during analysis

Parsing, Analysis, Conversion

1. Parsing
2. Analysis
3. Conversion

Parsing

- SQL -> Parse Tree
- Covered in compiler courses and books
- Here only short overview

SQL Standard

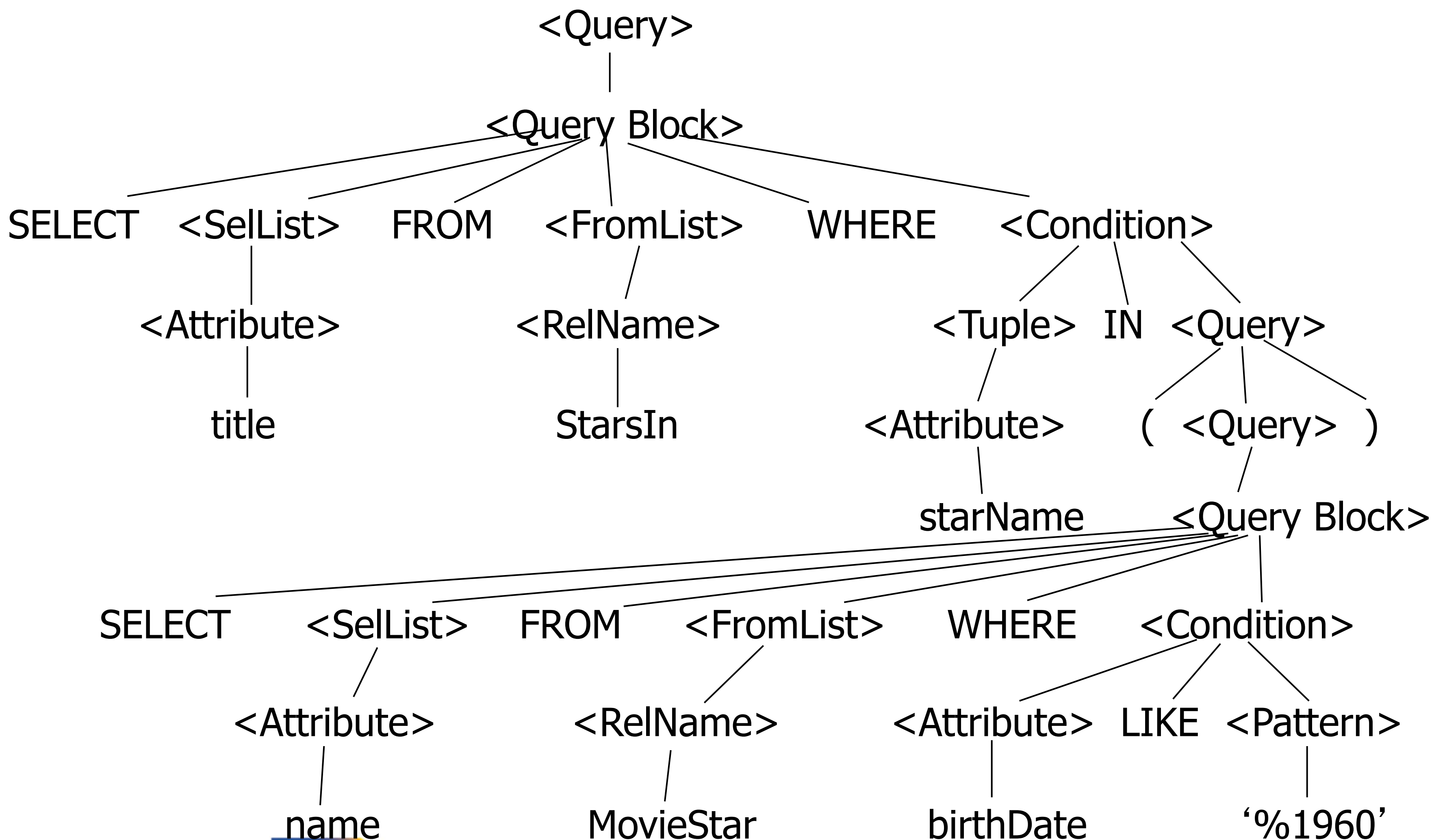
- Standardized language
  - 86, 89, 92, 99, 03, 06, 08, 11
- DBMS vendors developed their own dialects

Example: SQL query

```
SELECT title
FROM StarsIn
WHERE starName IN (
     SELECT name
     FROM MovieStar
     WHERE birthdate LIKE '%1960'
);
```

(Find the movies with stars born in 1960)

Example: Parse Tree



SQL Query Structure

- Organized in Query blocks

```
SELECT <select_list>
FROM <from_list>
WHERE <where_condition>
GROUP BY <group_by_expressions>
HAVING <having_condition>
ORDER BY <order_by_expressions>
```

Query Blocks

- Only **SELECT** clause is mandatory
  - Some DBMS require **FROM**

SELECT (1 + 2) AS result

result
3

SELECT clause

- List of expressions and optional name assignment + optional **DISTINCT**
  - Attribute references: R.a, b
  - Constants: 1, ‘hello’, ‘2008-01-20’
  - Operators: (R.a + 3) * 2
  - Functions (maybe UDF): substr(R.a, 1,3)
    - Single result or **set functions**
  - Renaming: (R.a + 2) AS x

SELECT clause - example

```
SELECT substring(p.name,1,1) AS initial
       p.name
FROM person p
```

person

name	gender
Joe	male
Jim	male

result

initial	name
J	Joe
J	Jim

SELECT clause – set functions

- Function `extrChar(string)`

```
SELECT extrChar(p.name) AS n
FROM person p
```

result

n
J
o
e
J
i
m

person

name	gender
Joe	male
Jim	male

SELECT clause – DISTINCT

```
SELECT DISTINCT gender
FROM person p
```

person

name	gender
Joe	male
Jim	male

result

gender
male

FROM clause

- List of table expressions
  - Access to relations
  - Subqueries (need alias)
  - Join expressions
  - Table functions
  - Renaming of relations and columns

FROM clause examples

```
FROM R
```

-access table R

```
FROM R, S
```

-access tables R and S

```
FROM R JOIN S ON (R.a = S.b)
```

-join tables R and S on condition (R.a = S.b)

```
FROM R x
FROM R AS x
```

-Access table R and assign alias 'x'

FROM clause examples

```
FROM R x(c,d)
FROM R AS x(c,d)
```
-using aliases x for R and c,d for its attribues

```
FROM (R JOIN S t ON (R.a = t.b)), T
```
-join R and S, and access T

```
FROM (R JOIN S ON (R.a = S.b)) JOIN T
```
-join tables R and S and result with T

```
FROM create_sequence(1,100) AS seq(a)
```
-call table function

FROM clause examples

```
FROM
      (SELECT count(*) FROM employee)
      AS empcnt(cnt)
```

-count number of employee in subquery

FROM clause examples

```
SELECT *
FROM create_sequence(1,3) AS seq(a)
```

result

a
1
2
3

FROM clause examples

```
SELECT dep, headcnt
FROM (SELECT count(*) AS headcnt, dep
      FROM employee
      GROUP BY dep)
WHERE headcnt > 100
```

employee

name	dep
Joe	IT
Jim	Marketing
…	…

result

dep	headcnt
IT	103
Support	2506
…	…

FROM clause - correlation

- Correlation
  - Reference attributes from other FROM clause item
  - Attributes of i^{th} entry only available in j > I
  - Semantics:
    - For each row in result of i^{th} entry:
    - Substitute correlated attributes with value from current row and evaluate query

Correlation - Example

```
SELECT name, chr
FROM employee AS e,
     extrChar(e.name) AS c(chr)
```

result

name	chr
Joe	J
Joe	o
Joe	e
Jim	J
Jim	i
…	…

employee

name	dep
Joe	IT
Jim	Marketing
…	…

Correlation - Example

```
SELECT name
FROM (SELECT max(salary) maxsal
      FROM employee) AS m,
      (SELECT name
      FROM employee x
      WHERE x.salary = m.salary) AS e
```

employee

name	salary
Joe	20,000
Jim	30,000
…	…

result

name
Jim

WHERE clause

- A condition
  - Attribute references
  - Constants
  - Operators (boolean)
  - Functions
  - Nested subquery expressions
- Result has to be boolean

WHERE clause examples

```
WHERE R.a = 3
```

-comparison between attribute and constant

```
WHERE (R.a > 5) AND (R.a < 10)
```

-range query using boolean AND

```
WHERE R.a = S.b
```

-comparison between two attributes

```
WHERE (R.a * 2) > (S.b – 3)
```

-using operators

Nested Subqueries

- Nesting a query within an expression
- Correlation allowed
  - Access FROM clause attributes
- Different types of nesting
  - Scalar subquery
  - Existential quantification
  - Universal quantification

Nested Subqueries Semantics

- For each tuple produced by the FROM clause execute the subquery
  - If correlated attributes replace them with tuple values

Scalar subquery

- Subquery that returns one result tuple
  - How to check?
  - -> Runtime error

```
SELECT *
FROM R
WHERE R.a = (SELECT count(*) FROM S)
```

Existential Quantification

- `<expr> IN <subquery>`
  - Evaluates to true if <expr> equals at least one of the results of the subquery

```
SELECT *
FROM users
WHERE name IN (SELECT name FROM
                       blacklist)
```

Existential Quantification

- EXISTS <subquery>
  - Evaluates to true if <subquery> returns at least one tuple

```
SELECT *
FROM users u
WHERE EXISTS (SELECT * FROM
              blacklist
             WHERE b.name = u.name)
```

Existential Quantification

- `<expr> <op> ANY <subquery>`
  - Evaluates to true if <expr> <op> <tuple> evaluates to true for **at least one** result tuple
  - Op is any comparison operator: =, <, >, …

```
SELECT *
FROM users
WHERE name = ANY (SELECT name FROM
                    blacklist)
```

Universal Quantification

- `<expr> <op> ALL <subquery>`
  - Evaluates to true if <expr> <op> <tuple> evaluates to true for **all** result tuples
  - Op is any comparison operator: =, <, >, …

```
SELECT *
FROM nation
WHERE nname = ALL (SELECT nation FROM
                          blacklist)
```

Nested Subqueries Example

```
SELECT dep,name
FROM employee e
WHERE salary >= ALL (SELECT salary
                     FROM employee d
                     WHERE e.dep = d.dep)
```

employee

name	dep	salary
Joe	IT	2000
Jim	IT	300
Bob	HR	100
Alice	HR	10000
Patrice	HR	10000

result

dep	Name
IT	Joe
HR	Alice
HR	Patrice

GROUP BY clause

- A list of expressions
  - Same as WHERE
  - No restriction to boolean
  - DBMS has to know how to compare = for data type
- Results are grouped by values of the expressions
- -> usually used for aggregation

GROUP BY restrictions

- If group-by is used then
  - SELECT clause can only use group by expressions or aggregation functions

GROUP BY clause examples

```
GROUP BY R.a
```
-group on single attribute

```
GROUP BY (1+2)
```
-allowed but useless (single group)

```
GROUP BY salary / 1000
```
-groups of salary values in buckets of 1000

```
GROUP BY R.a, R.b
```
-group on two attributes

```
SELECT count(*) AS numP,
     (SELECT count(*)
      FROM friends o
      WHERE o.with = f.name) AS numF
FROM (SELECT DISTINCT name FROM friends) f
GROUP BY (SELECT count(*)
          FROM friends o
          WHERE o.with = f.name)
```

friends

name	with
Joe	Jim
Joe	Peter
Jim	Joe
Jim	Peter
Peter	Joe

result

numP	numF
1	1
2	2

HAVING clause

- A boolean expression
- Applied after grouping and aggregation
  - Only references aggregation expressions and group by expressions

HAVING clause examples

```
HAVING sum(R.a) > 100
```

-only return tuples with sum bigger than 100

```
GROUP BY dep
```

HAVING dep = ‘IT’ AND sum(salary) > 1000000

-only return group ‘IT’ and sum threshold

ORDER BY clause

- A list of expressions
- Semantics: Order the result on these expressions

ORDER BY clause examples

```
ORDER BY R.a ASC
ORDER BY R.a
```
-order ascending on R.a

```
ORDER BY R.a DESC
```
-order descending on R.a

```
ORDER BY salary + bonus
```
-order by sum of salary and bonus

New and Non-standard SQL features (excerpt)

- LIMIT / OFFSET
  - Only return a fix maximum number of rows
  - FETCH FIRST n ROWS ONLY (DB2)
  - row_number() (Oracle)
- Window functions
  - More flexible grouping
  - Return both aggregated results and input values

Parsing, Analysis, Conversion

1. Parsing
2. Analysis
3. Conversion

Analysis Goals

- Semantic checks
  - Table column exists
  - Operator, function exists
  - Determine type casts
  - Scope checks
- Rewriting
  - Unfolding views

Semantic checks

```
SELECT *
FROM R
WHERE R.a + 3 > 5
```

- Table R exists?
- Expand *: which attributes in R?
- R.a is a column?
- Type of constants 3, 5?
- Operator + for types of R.a and 3 exists?
- Operator > for types of result of + and 5 exists?

Database Catalog

- Stores information about database objects
- Aliases:
  - Information Schema
  - System tables
  - Data Dictionary

Typical Catalog Information

- Tables
  - Name, attributes + data types, constraints
- Schema, DB
  - Hierarchical structuring of data
- Data types
  - Comparison operators
  - physical representation
  - Functions to (de)serialize to string

Typical Catalog Information

- Functions (including aggregate/set)
  - Build-in
  - User defined (UDF)
- Triggers
- Stored Procedures
- …

Type Casts

- Similar to automatic type conversion in programming languages
- Expression: R.a + 3.0
  - Say R.a is of type integer
    - Search for a function +(int,float)
  - Does not exist?
    - Try to find a way to cast R.a, 3.0 or both to new data type
    - So that a function + exists for new types

Scope checks

- Check that references are in correct scope
- E.g., if GROUP BY is present than SELECT clause expression can only reference group by expressions or aggregated values

View Unfolding

- SQL allows for stored queries using CREATE VIEW
- Afterwards a view can be used in queries
- If view is not materialized, then need to replace view with its definition

View Unfolding Example

```
CREATE VIEW totalSalary AS
SELECT name, salary + bonus AS total
FROM employee

SELECT *
FROM totalSalary
WHERE total > 10000
```

View Unfolding Example

```
CREATE VIEW totalSalary AS
SELECT name, salary + bonus AS total
FROM employee

SELECT *
FROM (SELECT name,
             salary + bonus AS total
     FROM employee) AS totalSalary
WHERE total > 10000
```

Analysis Summary

- Perform semantic checks
  - Catalog lookups (tables, functions, types)
  - Scope checks
- View unfolding
- Generate internal representation during analysis

Parsing, Analysis, Conversion

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Conversion

- Create an internal representation
  - Should be useful for analysis
  - Should be useful optimization
- Internal representation
  - Relational algebra
  - Query tree/graph models
    - E.g., QGM (Query Graph Model) in Starburst

Relational Alegbra

- Formal language
- Good for studying logical optimization and query equivalence (containment)
- Not informative enough for analysis
  - No datatype representation in algebra expressions
  - No meta-data

Other Internal Representations

- Practical implementations
  - Mostly following structure of SQL query blocks
  - Store data type and meta-data (where necessary)

Canonical Translation to Relational Algebra

- TEXTBOOK version of conversion
- Given an SQL query
- Return an equivalent relational algebra expression

Relational Algebra Recap

- Formal query language
- Consists of operators
  - Input(s): relation
  - Output: relation
  - -> Composable
- Set and Bag semantics version

- Relation Schema
  - A set of attribute name-datatype pairs
- Relation (instance)
  - A (multi-)set of tuples with the same schema
- Tuple
  - List of attribute value pairs (or function from attribute name to value)

Set- vs. Bag semantics

- Set semantics:
  - Relations are Sets
  - Used in most theoretical work
- Bag semantics
  - Relations are Multi-Sets
    - Each element (tuple) can appear more than once
  - SQL uses bag semantics

Bag semantics notation

- We use $\mathbf{t^m}$ to denote tuple t appears with multiplicity **m**

Set- vs. Bag semantics

Set

Name	Purchase
Peter	Guitar
Joe	Drum
Alice	Bass

Bag

Name	Purchase
Peter	Guitar
Peter	Guitar
Joe	Drum
Alice	Bass
Alice	Bass

Operators

- Selection
- Renaming
- Projection
- Joins
  - Theta, natural, cross-product, outer, anti
- Aggregation
- Duplicate removal
- Set operations

Selection

- Syntax: $\sigma_c(R)$
  - R is input
  - C is a condition
- Semantics:
  - Return all tuples that match condition C
  - Set: $\{ t \mid t \in R \text{ AND } t \text{ fulfills } C \}$
  - Bag: $\{ t^n \mid t^n \in R \text{ AND } t \text{ fulfills } C \}$

Selection Example

- $\sigma_{a<5}$ (R)

R

a	b
1	13
3	12
6	14

Result

a	b
6	14

Renaming

- Syntax: $\rho_A(R)$
  - R is input
  - A is list of attribute renamings $b \leftarrow a$
- Semantics:
  - Applies renaming from A to inputs
  - Set: $\{ t.A \mid t \in R \}$
  - Bag: $\{ (t.A)^n \mid t^n \in R \}$

Renaming Example

- $\rho_{c \leftarrow a}$ (R)

R

a	b
1	13
3	12
6	14

Result

c	b
1	13
3	12
6	14

Projection

- Syntax: $\Pi_A (R)$
  - R is input
  - A is list of projection expressions
  - Standard: only attribute in A
- Semantics:
  - Project all inputs on projection expressions
  - Set: $\{ t.A \mid t \in R \}$
  - Bag: $\{ (t.A)^n \mid t^n \in R \}$

Projection Example

- Π_b (R)

R

a	b
1	13
3	12
6	14

Result

b
13
12
14

Cross Product

- Syntax: R X S
  - R and S are inputs
- Semantics:
  - All combinations of tuples from R and S
  - = mathematical definition of cross product
  - Set: $\{ (t,s) \mid t \ \varepsilon\ R \text{ AND } s\ \varepsilon\ S \}$
  - Bag: $\{ (t,s)^{n*m} \mid t^n\ \varepsilon\ R \text{ AND } s^m\ \varepsilon\ S \}$

Cross Product Example

- R X S

R

a	b
1	13
3	12

S

c	d
a	5
b	3
c	4

Result

a	b	c	d
1	13	a	5
1	13	b	3
1	13	c	4
3	12	a	5
3	12	b	3
3	12	c	4

Join

- Syntax: $R \bowtie_C S$
  - R and S are inputs
  - C is a condition
- Semantics:
  - All combinations of tuples from R and S that match C
  - Set: { (t,s) | t ε R AND s ε S AND (t,s) matches C}
  - Bag: { $(t,s)^{n*m}$ | t^n ε R AND s^m ε S AND (t,s) matches C}

Join Example

- $R \bowtie_{a=d} S$

R

a	b
1	13
3	12

S

c	d
a	5
b	3
c	4

Result

a	b	c	d
3	12	b	3

Natural Join

- Syntax: $R \bowtie S$
  - R and S are inputs
- Semantics:
  - All combinations of tuples from R and S that match on common attributes
  - A = common attributes of R and S
  - C = exclusive attributes of S
  - Set: $\{ (t,s.C) \mid t \ \varepsilon \ R \text{ AND } s \ \varepsilon \ S \text{ AND } t.A=s.A\}$
  - Bag: $\{ (t,s.C)^{n*m} \mid t^{n} \ \varepsilon \ R \text{ AND } s^{m} \ \varepsilon \ S \text{ AND } t.A=s.A\}$

Natural Join Example

- R ⋈ S

R

a	b
1	13
3	12

S

c	a
a	5
b	3
c	4

Result

a	b	c
3	12	b

Left-outer Join

- Syntax: $R ⟕_C S$
  - R and S are inputs
  - C is condition
- Semantics:
  - R join S
  - t ε R without matches fill S attributes with NULL

{ (t,s) | t ε R AND s ε S AND (t,s) matches C}

union

{ (t, NULL(S)) | t ε R AND NOT exists s ε S: (t,s) matches C }

Left-outer Join Example

- R ⟕$_{a=d}$ S

R

a	b
1	13
3	12

S

c	d
a	5
b	3
c	4

Result

a	b	c	d
1	13	NULL	NULL
3	12	b	3

Right-outer Join

- Syntax: R $⟖_C$ S
  - R and S are inputs
  - C is condition
- Semantics:
  - R join S
  - s ε S without matches fill R attributes with NULL

{ (t,s) | t ε R AND s ε S AND (t,s) matches C}

union

{ (NULL(R),s) | s ε S AND NOT exists t ε R: (t,s) matches C }

Right-outer Join Example

- $R ⟖_{a=d} S$

R

a	b
1	13
3	12

S

c	d
a	5
b	3
c	4

Result

a	b	c	d
NULL	NULL	a	5
3	12	b	3
NULL	NULL	c	4

Full-outer Join

- Syntax: $R ⟗_C S$
  - R and S are inputs and C is condition
- Semantics:

  { (t,s) | t ε R AND s ε S AND (t,s) matches C}

  union

  { (NULL(R),s) | s ε S AND NOT exists t ε R: (t,s) matches C }

  union

  { (t, NULL(S)) | t ε R AND NOT exists s ε S: (t,s) matches C }

Full-outer Join Example

- $R ⟗_{a=d} S$

R

a	b
1	13
3	12

S

c	d
a	5
b	3
c	4

Result

a	b	c	d
1	13	NULL	NULL
NULL	NULL	a	5
3	12	b	3
NULL	NULL	c	4

Semijoin

- Syntax: R ⋉ S and R ⋊ S
  - R and S are inputs
- Semantics:
  - All tuples from R that have a matching tuple from relation S on the common attributes A

{ t | t ε R AND exists s ε S: t.A = s.A}

Semijoin Example

- $R \ltimes S$

R

a	b
1	13
3	12

S

c	a
a	5
b	3
c	4

Result

a	b
3	12

Antijoin

- Syntax: $R \triangleright S$
  - R and S are inputs
- Semantics:
  - All tuples from R that have no matching tuple from relation S on the common attributes A

{ t | t ε R AND NOT exists s ε S: t.A = s.A}

Antijoin Example

- $R \triangleright S$

R

a	b
1	13
3	12

S

c	a
a	5
b	3
c	4

Result

a	b
1	13

Aggregation

– Syntax: ${}_{A}\alpha_{G}(R)$
  - A is list of aggregation functions
  - G is list of group by attributes
– Semantics:
  - Build groups of tuples according G and compute the aggregation functions from each group
  - $\{ (t.G, agg(G(t)) \mid t \in R \}$
  - $G(t) = \{ t' \mid t' \in R \text{ AND } t'.G = t.G \}$

Aggregation Example

- ${}_{b}\alpha_{sum(a)}$ (R)

R

a	b
1	1
3	1
6	2
3	2

Result

sum(a)	b
4	1
9	2

Duplicate Removal

- Syntax: δ (R)
  - R is input
- Semantics:
  - Remove duplicates from input
  - Set: N/A
  - Bag: $\{ t^1 \mid t^n \varepsilon R \}$

Duplicate Removal Example

- δ (R)

R

a	b
1	13
1	13
6	14

Result

a	b
1	13
6	14

Set operations

- Input: R and S
  - Have to have the same schema
    - Union compatible
  - Modulo attribute names
- Types
  - Union
  - Intersection
  - Set difference

Union

- Syntax: $R \cup S$
  - R and S are union-compatible inputs
- Semantics:
  - Set: $\{ (t) \mid t \in R \text{ OR } t \in S\}$
  - Bag: $\{ (t,s)^{n+m} \mid t^n \in R \text{ AND } s^m \in S \}$
    - Assumption t^n with $n < 1$ for tuple not in relation

Union Example

- R ∪ S

R

a
1
3

S

b
1
2
3

Result

a
1
2
3
1
3

Intersection

- Syntax: $R \cap S$
  - R and S are union-compatible inputs
- Semantics:
  - Set: $\{ (t) \mid t \in R \text{ AND } t \in S \}$
  - Bag: $\{ (t,s)^{min(n,m)} \mid t^n \in R \text{ AND } s^m \in S \}$

Intersection Example

- R ∩ S

R

a
1
3

S

b
1
2
3

Result

a
1
3

Set Difference

– Syntax: R - S
  - R and S are union-compatible inputs
– Semantics:
  - Set: { (t) | t ε R AND NOT t ε S}
  - Bag: { $(t,s)^{n-m}$ | t^n ε R AND s^m ε S }

Set Difference Example

- R - S

R

a
1
5

S

b
1
2
3

Result

a
5

Canonical Translation to Relational Algebra

- TEXTBOOK version of conversion
- Given an SQL query
- Return an equivalent relational algebra expression

Canonical Translation

- **FROM** clause into joins and cross-products
  - Cross-product between list items
  - Joins into their algebra counter-part
- **WHERE** clause into selection
- **SELECT** clause into projection and renaming
  - If it has aggregation functions use aggreation
  - **DISTINCT** into duplicate removal

Canonical Translation

- **GROUP BY** clause into aggregation
- **HAVING** clause into selection
- **ORDER BY** – no counter-part

- Then turn joins into crossproducts and selections

Set Operations

- **UNION ALL** into union
- **UNION** duplicate removal over union
- **INTERSECT ALL** into intersection
- **INTERSECT** add duplicate removal
- **EXCEPT ALL** into set difference
- **EXCEPT** apply duplicate removal to inputs and then apply set difference

Example: Relational Algebra Translation

```
SELECT sum(R.a)
FROM R
GROUP BY b
```

$$\Pi_{sum(a)}$$

$$_{B}\alpha_{sum(a)}$$

$$R$$

Example: Relational Algebra Translation

```
SELECT dep, headcnt
FROM (SELECT count(*) AS headcnt, dep
      FROM employee
      GROUP BY dep)
WHERE headcnt > 100
```

$$\Pi_{dep,\ headcnt}$$

$$\sigma_{headcnt > 100}$$

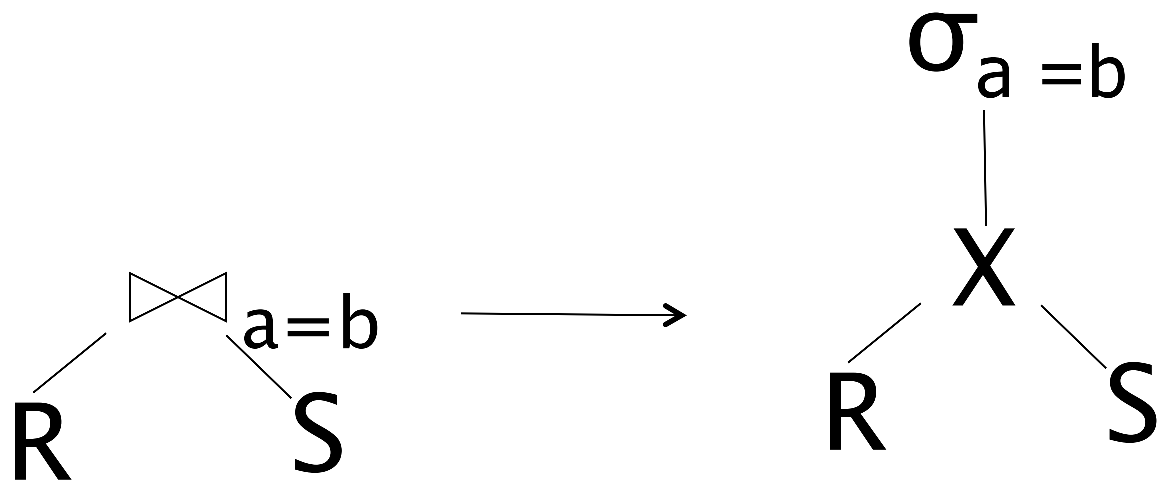
$$\rho_{headcnt \leftarrow count(*)}$$

$${}_{dep}\alpha_{count(*)}$$

$$Employee$$

Example: Relational Algebra Translation

```
SELECT *
FROM R JOIN S ON (R.a = S.b)
```



Parsing and Analysis Summary

- SQL text -> Internal representation
- Semantic checks
- Database catalog
- View unfolding