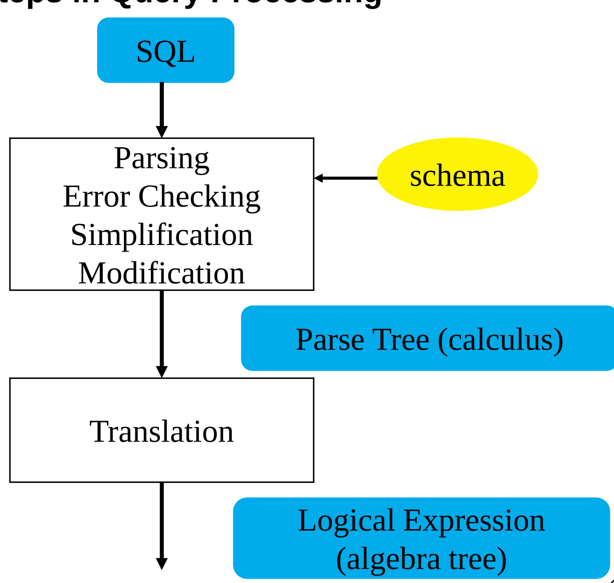
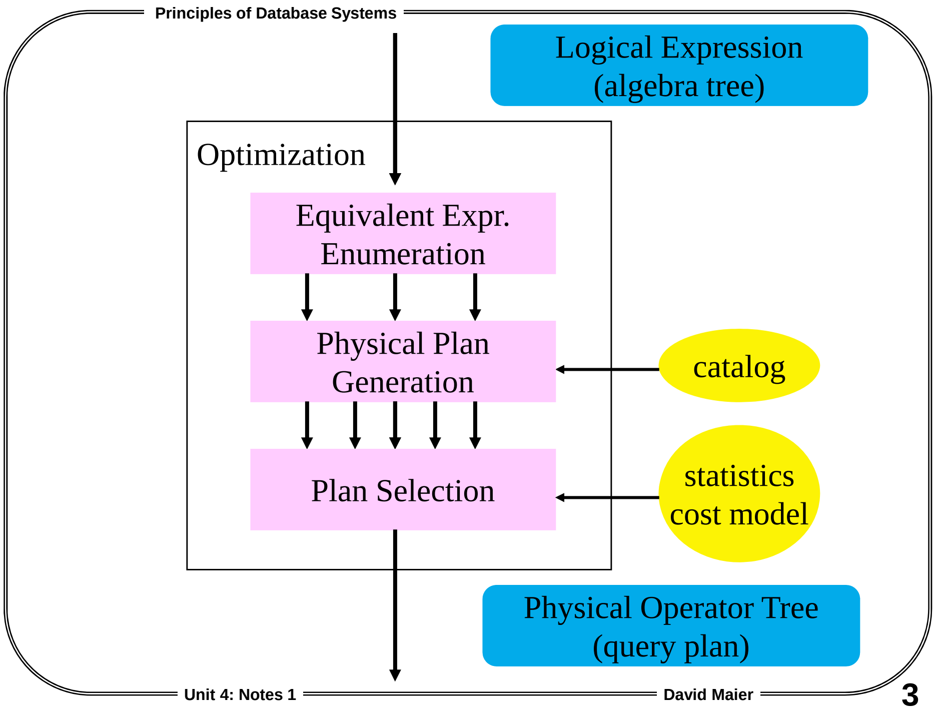
CS 589, Principles of Database Systems, Lecture 3-1

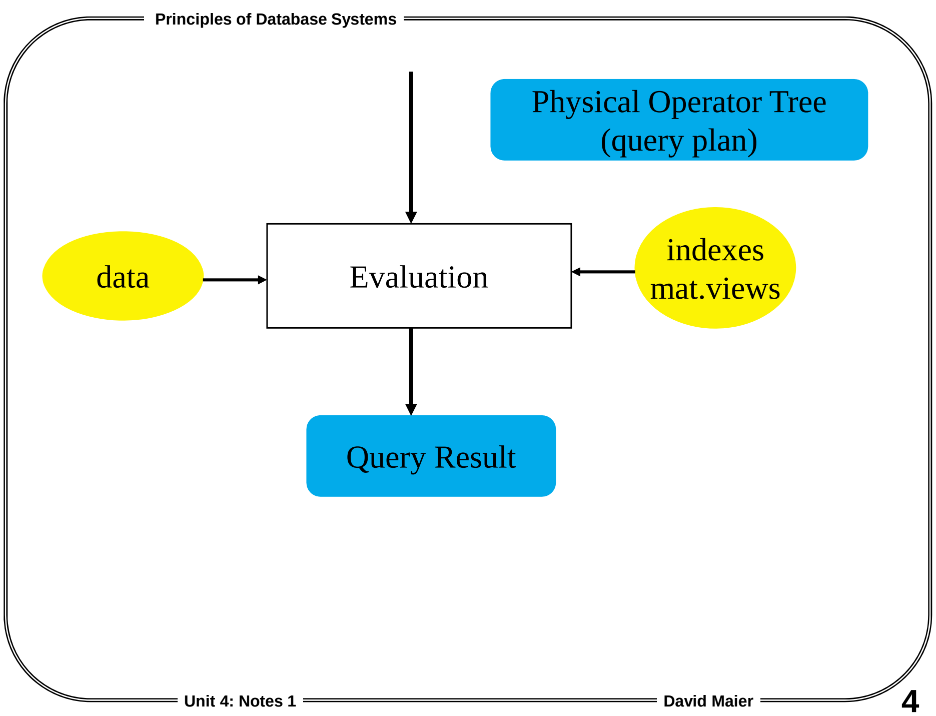
Unit 3
Query Optimization

Steps in Query Processing




Principles of Database Systems
Logical Expression
(algebra tree)
Optimization
Equivalent Expr.
Enumeration
Physical Plan
Generation
catalog
Plan Selection
statistics
cost model
Physical Operator Tree
(query plan)
Unit 4: Notes 1
David Maier

3


Principles of Database Systems
Physical Operator Tree
(query plan)
data
Evaluation
indexes
mat.views
Query Result
Unit 4: Notes 1
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4

Topics

Simplification, tableau optimization calculus

Role of algebra and algebraic equivalences in query optimization algebra

Algebra issues:

- bags versus sets
- additional operators (e.g., group-by)
- transformations
- logical versus physical ops.
- alternative interpretations of operators
  - size
  - cost

Simplification

There is some work more easily done in a calculus form

Rewrite of query conditions

flights(F**L**IGHT **D**ATE **B**US **E**CON)

```
select f.L, f.D
from flights as f
where f.B > 60 and f.B > 40
```

More Examples

select f.L, f.D
from flights **as** f
where ~~(f.B > 60 **and** f.E > f.B~~
~~**and** f.E < 30) **or**~~ f.B < 40

select f.L, f.D
from flights **as** f
where f.B = f.E **and** ~~f.E = 40~~
and f.B = 40

Rewrite Doesn’t Always “Simplify”

select f1.L, f2.L
from flights **as** f1, f2
where f1.B = f2.B
and f1.B = f2.E

Some query systems rewrite the condition to:

where f1.B = f2.B
and f1.B = f2.E
and f2.B = f2.E] only mentions f2

Why?

Tableau Query Minimization

Reduce the number of joins in SPJ queries

Query containment
Query p is *contained by* query q, $p \subseteq q$, if for all database instances I, $p(I) \subseteq q(I)$

Tableau as a Query

Have tableau T (possibly with constants) with *result row* w

answer on r(R)
$\{\rho(w) \mid \rho(T) \subseteq r\}$

ρ is a *valuation*: maps variables to constants
(and constants to themselves)

David Maier & Lois Delcambre

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Tableau Query Example: q = (T, w)

```
 r (F    D     B     E)  T  (F   D   B   E )
t1 176  6Oct 15 160   w1  f1  d1  20  e1
t2 185  6Oct 20 150   w2  f2  d1  b2  e2
t3 192  6Oct 35 174   w   f2      b2
t4 176  7Oct 20  95
t5 176  8Oct 17 152

     v    f1   d1    e1   f2   b2   e2
 ρ1(v)  176  6Oct  160  185  20  150
So
ρ1(w1)  = <176  6Oct  20  160> ∉ r
ρ1(w2)  = <185  6Oct  20  150> = t2 ∈ r
Adds no tuple to q(r)
```


Other Valuations

```
     v    f1   d1    e1   f2   b2   e2
 ρ2(v)  185  6Oct  150  176  15  160
So
ρ2(w1)  = <185  6Oct  20  150> = t2 ∈ r
ρ2(w2)  = <176  6Oct  15  160> = t1 ∈ r
Adds ρ2(w)= <176 15> to q(r)

ρ3(w1)  = <185  6Oct  20  150> = t2 ∈ r
ρ3(w2)  = <192  6Oct  35  174> = t3 ∈ r
Adds ρ3(w)= <192 35> to q(r)
```

More Valuations

ρ4(w1) = <185 6Oct 20 150> = t2 ∈ r
ρ4(w2) = <185 6Oct 20 150> = t2 ∈ r
Adds ρ4(w)= <185 20> to q(r)

ρ5(w1) = <176 7Oct 20 95> = t4 ∈ r
ρ5(w2) = <176 7Oct 20 95> = t4 ∈ r
Adds ρ5(w)= <176 20> to q(r)

ρ6(w1) = ?< 8Oct 20 > no
ρ6(w2) = <176 8Oct 17 152> = t5 ∈ r

Final Result

q(r)

F	B
176	15
185	20
192	35
176	20

Substitution

Need something like a valuation that goes from one tableau query to another.

Substitution θ:maps variables to variables or constants
(and constants to themselves)

Mapping Tableau Queries

Interested in substitution that maps one tableau to another

q1 T1(L A)

	L	A
	f	a
w1	f	a

q2 T2(L A)

	L	A
	f	a1
	f1	a
	f1	a1
w2	f	a

<183 ()← ρ — θ

Want a substitution θ where
θ(T2) ⊆ T1
θ(w2) = w1

Means q1 ⊆ q2

v	f	f1	a	a1
θ(v)	f	f	a	a

Example of Containment

Suppose t=<115 747> in q1(r)

Must be ρ, ρ(T1) ⊆ r and ρ(w1) = t

Want to show t in q2(r)

Let ρ′=ρ°θ $\rho'(v) = \rho(\theta(v))$

Have θ(T2) ⊆ T1 so

ρ(θ(T2)) ⊆ ρ(T1) or ρ′(T2) ⊆ ρ(T1)

Also know ρ(T1) ⊆ r

So ρ′(T2) ⊆ ρ(T1) ⊆ r

What is ρ′(w2)?

ρ′(w2) = ρ(θ(w2)) = ρ(w1) = t

So t in q2(r)!

Homomorphism Theorem

Given tableau queries q1 = <T1, w1> and q2 = <T2, w2>;

q1 ⊆ q2 if and only if there is a substitution θ such that T1 ⊇ θ(T2) and w1 = θ(w2).

Such a substitution is called a *query homomorphism*.

What's Containment Good For?

Containment itself isn't that interesting.

Equivalence: $q1 \equiv q2$ if $q1(I) = q2(I)$ for all instances I.

Observation: $q1 \equiv q2$ if and only if $q1 \subseteq q2$ and $q2 \subseteq q1$.

Query Minimization

The real use of the Homomorphism Theorem is in finding a *minimum equivalent* query.

Given tableau query q, want a query q′ with fewest rows such that $q \equiv q'$.

Remarkable fact: You can always get to a minimum equivalent query by removing rows.

(Maybe 0 rows if already minimum.)

Example

θ

q1	T1	A	B	C
	w1	a2	b1	c
	w2	a	b1	c1
	w3	a	b2	c2
	w4	a1	$\bar{b}$	$\bar{c}1$
	w5	a2	b2	c
	wr	a	b	c

q2	T2	A	B	C
	w1	a2	b1	c
	w2	a	b1	c1
	w4	a1	b	c1
	wr	a	b	c

Id = Identity Subs

Id (T2) ⊆ T1

Id (wr) = Id (wr)

- q2 ⊇ q1 (why?)
- q1 ⊇ q2

v	a	a1	a2	b	b1	b2	c	c1	c2
θ(v)	a	a1	a2	b	b1	**b1**	c	c1	**c1**

- so q1 ≡ q2

Query Translation

What are some features of SQL that are not easily expressed using the relational algebra operators introduced so far?

Duplicates

Table is a *bag* of tuples, rather than a set.

Need operators that keep duplicates and an operator to remove them

- $\cup^+$ union-all: don't remove duplicates
- π^+ project-all: don't remove duplicates
- DE duplicate-elim: convert bag to set

DISTIN DISTINCT

Beware: Some authors assume duplicate-preserving ops without telling you.

Example

flights(FLIGHT DATE BUS ECON)

FLIGHT	DATE	BUS	ECON
115	1 Nov	10	80
115	2 Nov	15	70
115	3 Nov	10	60
116	1 Nov	20	75
116	2 Nov	15	90

π^+_{BUS}(flights) (BUS)

BUS
10
15
10
20
15

π_{BUS}(flights) (BUS)

BUS
10
15
20

$DE(\pi^+_{BUS}(\text{flights})) = \pi_{BUS}(\text{flights})$

Group-by

Scalar: one row summary of whole relation: G1

Vector: one row per group: G

G1[F] - F is aggregate functions

```
select sum(B) as SB, sum(E) as SE
from flights
```

```
G1[sum(B) as SB, sum(E) as SE](flights)
```

SB	SE
70	375

Vector Group-by

G[A; F] - A is grouping attributes, F is aggregate functions

```
select L, sum(B) as SB, sum(E)
 as SE
from flights
group by L
```

```
G[L;sum(B) as SB, sum(E) as SE](flights)
```

L	SB	SE
115	35	210
116	35	165

Other aggregates: count, avg, min, max

Join Variants

Outer-join: used when you want to preserve all tuples from one input in the result (even if some don't connect with tuples in the other input)

- LOJ: Left outer-join, include all of left input
- ROJ: Right outer-join, include all of right input
- FOJ: Full outer-join, include all of both inputs

Need to pad with nulls

Outer-join Example

capacity(AIRCRAFT MAXBUS MAXECON)

AIRCRAFT	MAXBUS	MAXECON
707	25	100
737	30	120
747	80	300
757	50	250 no match

uses(FLIGHT AIRCRAFT)

FLIGHT	AIRCRAFT
115	707
116	737
80	747
81	737

[Natural] Left Outer-Join

```
capacity LOJ[A=A] uses
```

AIRCRAFT	MAXBUS	MAXECON	FLIGHT
707	25	100	115
737	30	120	116
737	30	120	81
747	80	300	80
757	50	250	$\perp$

Semi-Join

translate EXISTS

Find the tuples in one relation that join with those in another.

Have r(R), s(S), common attributes X

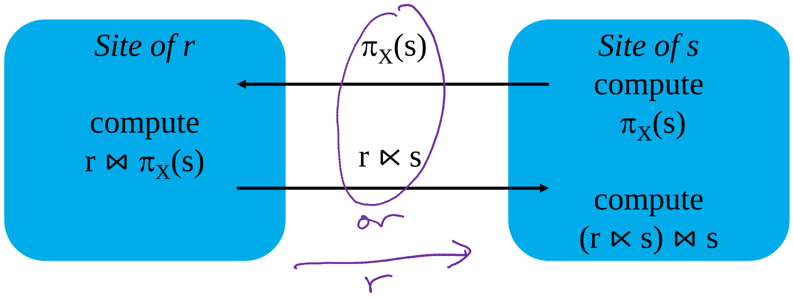
$r \ltimes s = \{t \mid t \text{ in } r \text{ and } \exists u \text{ in } s,\ t[X] = u[X]\}$

$r \ltimes s = \pi_R(r \bowtie s)$

capacity $\ltimes$ uses

Note: $r \ltimes s = r \bowtie \pi_X(s)$

Semi-Join is Useful in Distributed Query Processing



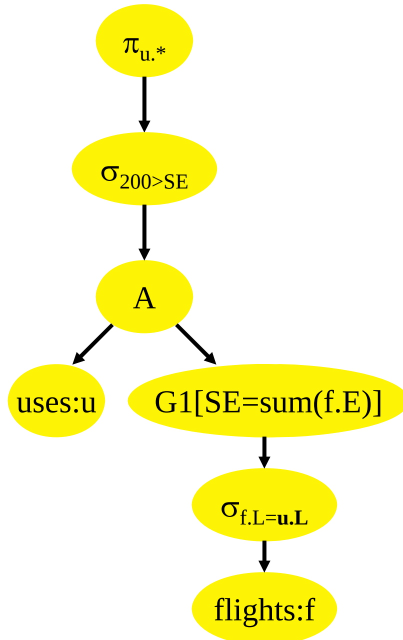
$(r \ltimes s) \bowtie s = r \bowtie s$

Apply (Map, Do-all)

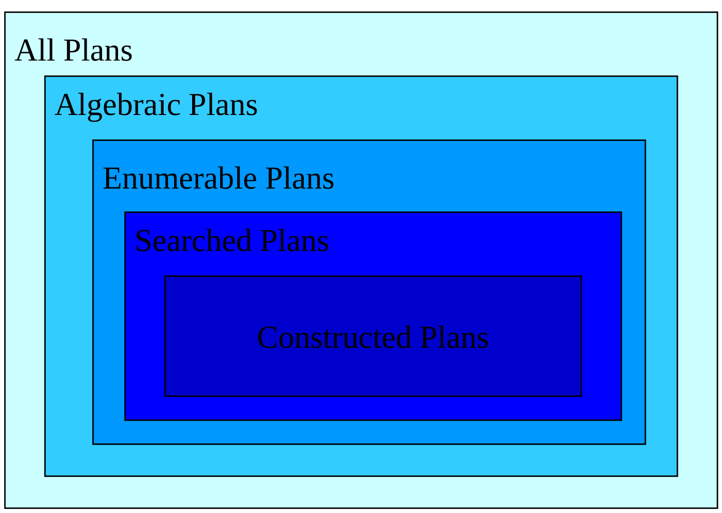
concat

r A e(x) = {t++u | t in r and u in e(t)}

```
select u.*
from uses as u
where 200 >
   (select sum(f.E)
    from flights as f
    where u.L = f.L)
```



Optimization: Logical Expression Enumeration



Search

Search can be limited by

- *Plan shape*: no Cartesian products, no bushy joins
- *Heuristics*: abandon subplans with cost over 80% of current best plan
- *Time*: stop when optimization time = estimated execution time

3 sec ≥

2.4 sec

Optimality Principle

Bellman's Principle

Subplans of an optimal plan are themselves optimal

If $((r \bowtie s) \bowtie u) \bowtie v)$ is best for joining r,s,u & v, then $(r \bowtie s) \bowtie u$ is best for joining r,s & u

Dynamic Programming for join ordering (System R)

- Find best order for every join of k-1 or fewer tables
- Use those results to find best order for k tables

Example Metrics

\# rows

size(E ⋈ F) = size(E)*size(F)/10

cost(E ⋈ F) = size(E ⋈ F) + cost(E) + cost(F)

cost(scan(r)) = 0

Principles of Database Systems

1-joins and 2-joins

1-joins relation:size
cost

```
r:10    s:100    u:50    v:10
  0        0       0      0
```

2-joins

size (10 * 50)/10 = 50 + cost(r) + cost(u)
0 0

```
(r,s):100    (r,u):50    (r,v):10
    100          50          10

(s,u):500    (s,v):100   (u,v):50
    500          100         50
```

3-joins

```
(r,s,u):500               (r,s,v):100
  (rs)u  +100+0=600         (rs)v  +100+0=200
 *(ru)s  +50+0=550         *(rv)s  +10+0=110
  (su)r  +500+0=1000        (sv)r  +100+0=200
```

size(s⋈u⋈v)

```
(r,u,v):50                (s,u,v):500
  (ru)v  +50+0=100          (su)v  +500+0=1000
 *(rv)u  +10+0=60           (sv)u  +100+0=600
  (uv)r  +50+0=100         *(uv)s  +50+0=550
```

cost left   cost right

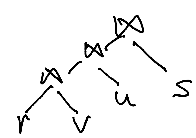
4-join

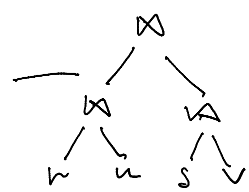
```
(r,s,u,v):500

  (rsu)v  +550+0=1050
 *(ruv)s  +60+0=560
  (rsv)u  +110+0=610
  (suv)r  +550+0=1050

  (rs)(uv)  +100+50=650
  (ru)(sv)  +50+100=650
  (rv)(su)  +10+500=1010
```

vine
left-deep





bushy