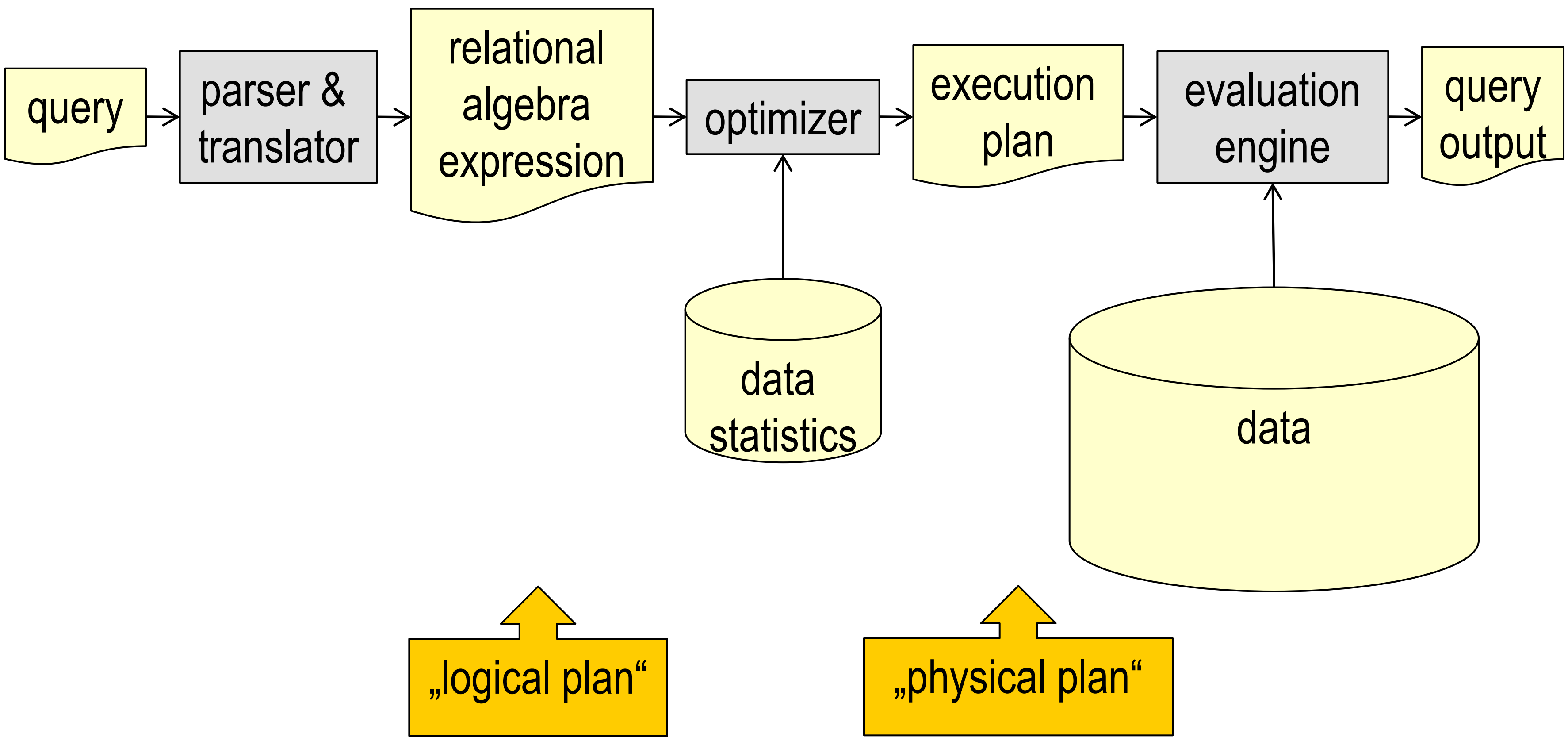
Query Processing and Optimization

Jennifer Widom

Ramakrishnan/Gehrke Chapters 10, 12

Steps in Database Query Processing

Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution



Steps in Database Query Processing

Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution

Query string
→ **Parser** →
Query tree
→ Checker →
Valid query tree
→ View expander →
Valid tree w/o views
→ **Logical query plan generator** →
Logical query plan
→ Query rewriter (heuristic) →
Better logical plan
→ **Physical query plan generator** (cost-based)
Selected physical plan
→ Code generator →
Executable code
→ **Execution engine**

Running Example

Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution

- Tables (what are the keys?):

  Student(ID, Name, Major)

  Course(Num, Dept)

  Taking(ID, Num)

- Query to find all EE students taking at least one CS course:

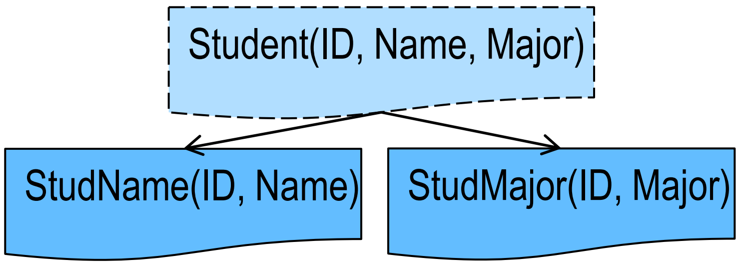
SELECT	Name	π
FROM	Student, Course, Taking	$\times$
WHERE	Taking.ID = Student.ID	$\bowtie$
AND	Taking.Num = Course.Num	$\bowtie$
AND	Major = 'EE'	σ
AND	Dept = 'CS'	σ

View Expander

Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution

- Suppose Student is view:

```
CREATE VIEW Student AS
SELECT StudName.ID, Name, Major
FROM   StudName, StudMajor
WHERE  StudName.ID = StudMajor.ID
```




```
SELECT Name
FROM   Student, Course, Taking
WHERE  Taking.ID = Student.ID
   AND Taking.Num = Course.Num
   AND Major = 'EE'
   AND Dept = 'CS'
```

- Via view expander original query becomes:

```
SELECT Name
FROM   Course, Taking, Student AS ( SELECT StudName.ID, Name, Major
FROM StudName, StudMajor WHERE  StudName.ID = StudMajor.ID )
WHERE  Taking.ID = Student.ID AND Taking.Num = Course.Num AND
          Student.Major = 'EE' AND Course.Dept = 'CS‘ AND StudName.ID = StudMajor.ID
```

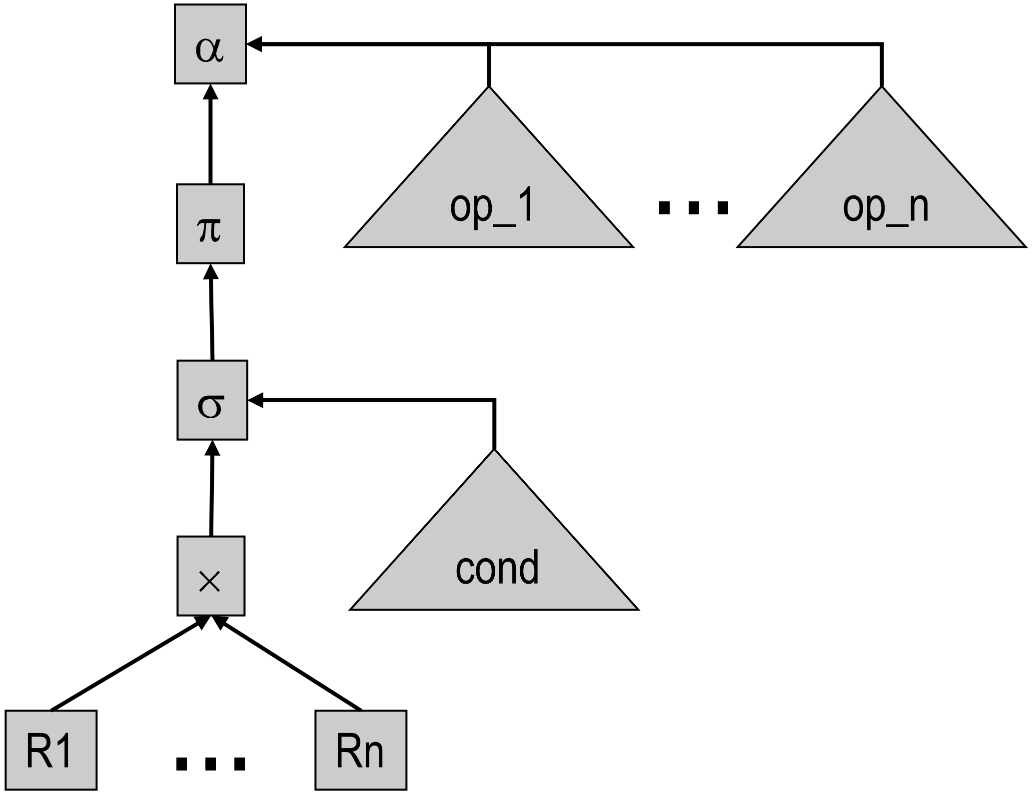
- "flattened":

```
SELECT Name
FROM   Course, Taking, StudName, StudMajor
WHERE  Taking.ID = StudName.ID AND Taking.Num = Course.Num AND
StudMajor.Major = 'EE' AND Course.Dept = 'CS' AND StudName.ID = StudMajor.ID
```

Logical Query Tree: Notation Overview

Parser – Checker - Views - Logical plan - Rewriter - Physical plan - Code gen. - Execution

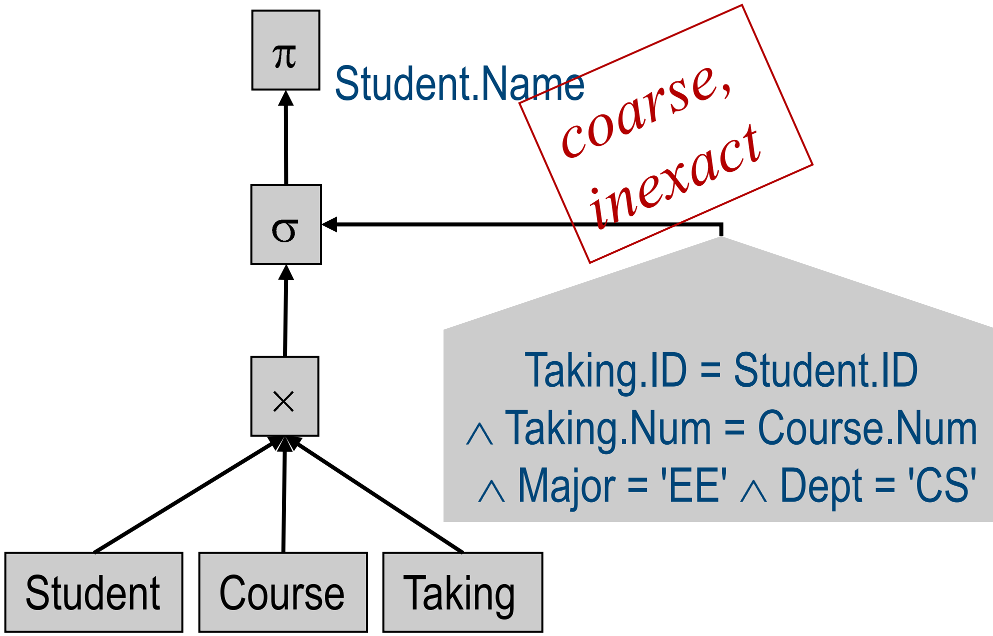
- Logical query tree
  = Logical plan = parsed query,
  translated into relational algebra
- Equivalent to relational algebra expression (why not calculus?) using:
  - $\times$ cross product
  - σ selection from set, based on condition *cond*
  - π projection to attributes
  - α application of an expression to arguments
  - $\triangleright\triangleleft$ joins...



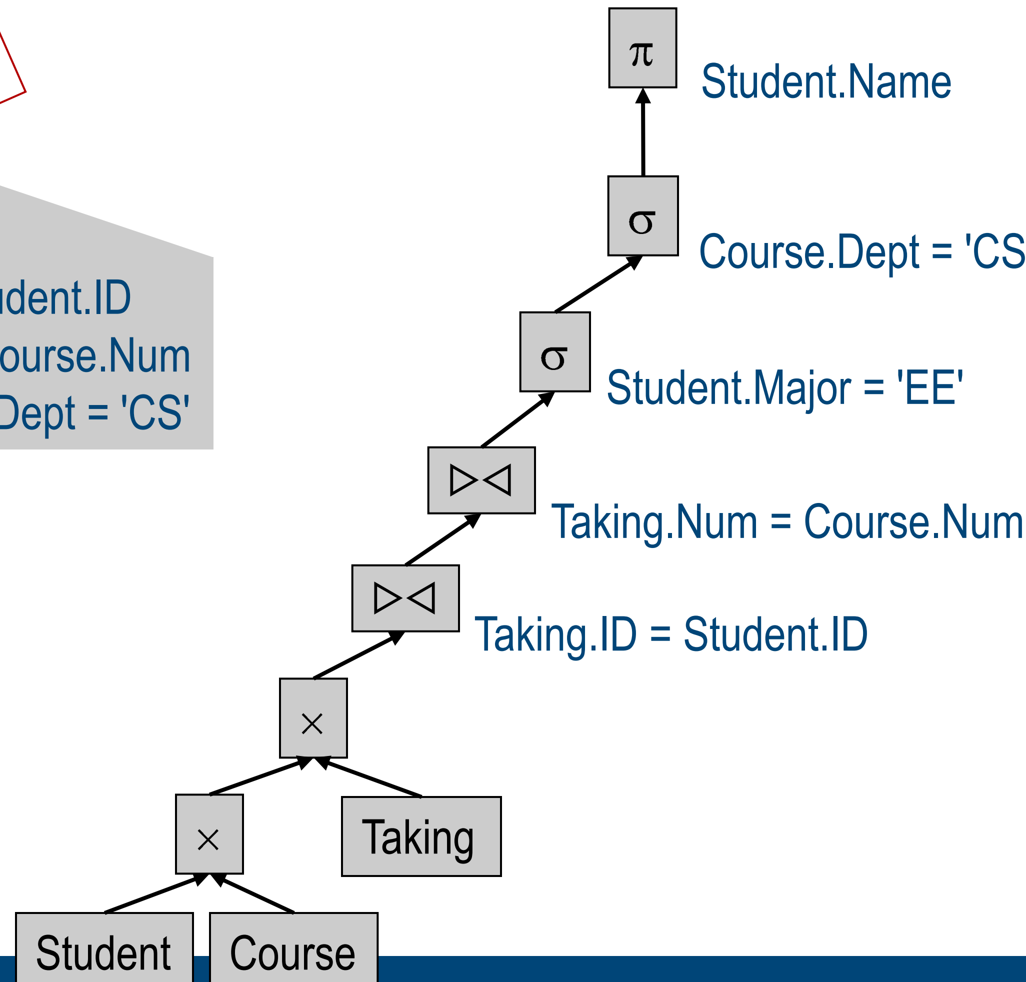
SELECT α(op_1(R1,R2,…)),op_2(R1,R2,…), …)
FROM R1, R2, …
WHERE σ(R1,R2,…)

Logical Query Plan

Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution




```
SELECT  Name
FROM    Student, Course, Taking
WHERE   Taking.ID = Student.ID
   AND  Taking.Num = Course.Num
   AND  Major = 'EE'
   AND  Dept = 'CS'
```



Logical vs Physical Query Plan

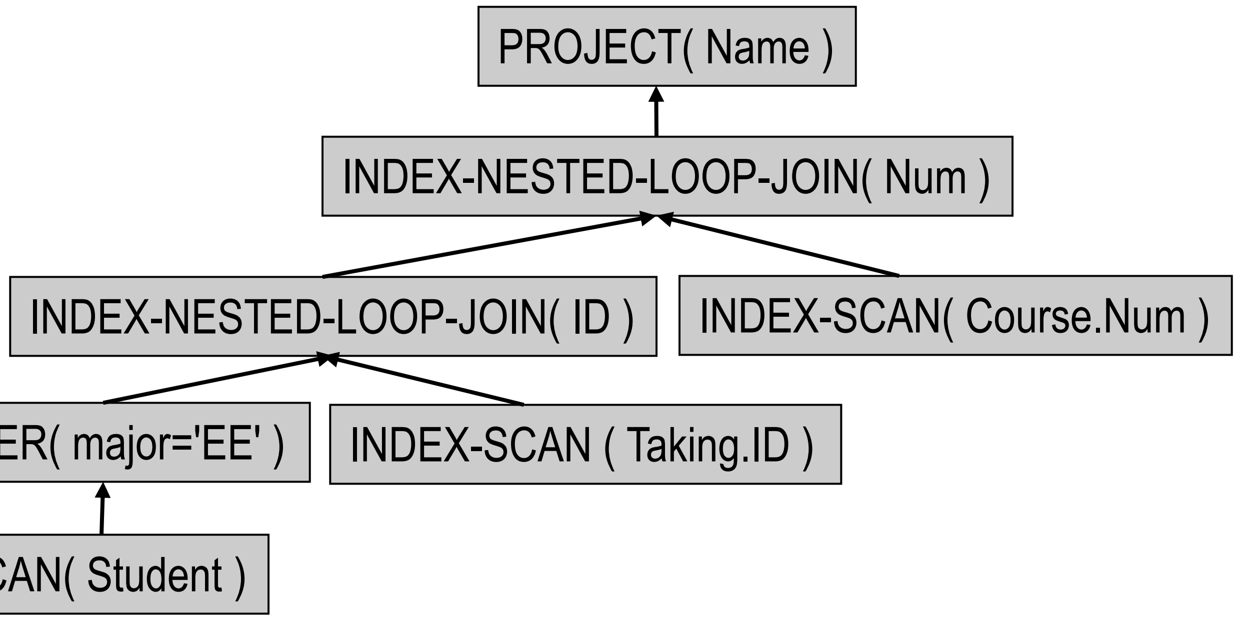
Parser – Checker - Views - Logical plan - Rewriter - Physical plan - Code gen. - Execution

- Commonalities:
  - Trees representing query evaluation
  - Leaves = data (table vs table/index)
  - Internal nodes = "operators" over data
- Differences:

	Level	**Operators**
Logical plan	higher-level, algebraic	query language constructs
Physical plan	lower-level, operational	"access methods"

Physical Query Plan

Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution




```
SELECT  Name
FROM    Student, Course, Taking
WHERE   Taking.ID = Student.ID
   AND  Taking.Num = Course.Num
   AND  Major = 'EE'
   AND  Dept = 'CS'
```

one of manyManyMany possible plans, assumes particular index situation.

Sample Operator: Nested Loop Join

Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution

- Consider this equi-join query:

```
SELECT   *
FROM     Sailor S, Reserves R
WHERE    S.sid = R.sid
```

- Naïve, straightforward approach: combine all tuples, pick good ones

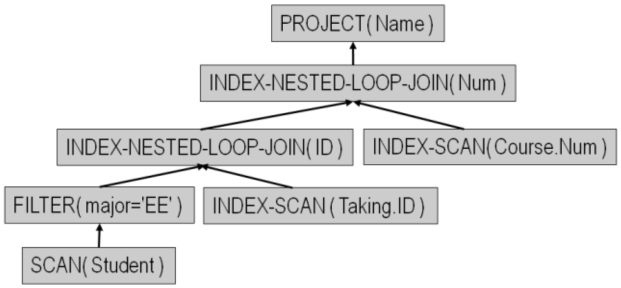
```
foreach tuple r in R do
    foreach tuple s in S do
        if r_i == s_j then add <r,s> to result
```

  - Assume there is no index, R small, S big: better R inner or S?
  - What if hash index on S?
  - *…this is what cost-based optimization considers!*

Physical Plan Generation

Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution

- ManyManyMany possible physical query plans for a given logical plan
- physical plan generator tries to select "optimal" one
  - Optimal wrt. response time, throughput
- How are intermediate results passed from children to parents?
  - Temporary files
    - *Evaluate tree bottom-up*
    - *Children write intermediate results to temporary files*
    - *Parents read temporary files*
  - Iterator interface (next)



Sample Query Plan

Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution

```
SET EXPLAIN ON AVOID_EXECUTE;
SELECT  C.customer_num, O.order_num
FROM    customer C, orders O, items I
WHERE   C.customer_num = O.customer_num
        AND O.order_num = I.order_num
```

```
for each row in the customer table do:
  read the row into C
  for each row in the orders table do:
    read the row into O
    if O.customer_num = C.customer_num then
      for each row in the items table do:
        read the row into I
        if I.order_num = O.order_num then
          accept the row and send to user
        end if
      end for
    end if
  end for
end for
```

IBM Informix Dynamic Server

Iterator Interface

Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution

- "ONC protocol":
  Every operator maintains own execution state, implements the following methods:
  - open( ):
    Initialize state, get ready for processing
  - getNext( ):
    Return next tuple in result (or null if no more tuples); adjust state for delivering subsequent tuples
  - close( ):
    Clean up

Ex: Iterator for Table Scan

Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution

Sailors: 22|Dustin|7|45.0|31|Lubber|8|55.5|58|Rusty|10|35.0…

- open( )
  - Allocate buffer space
- getNext( )
  - If no block of R has been read yet:
    read first block from disk
    return (R==empty ? null : first tuple in block)
  - If no more tuple left in current block:
    read next block of R from disk
    return (R exhausted ? null : first tuple in block)
  - Return next tuple in block
- close( )
  - Deallocate buffer space

Ex: Iterator for Nested-Loop Join

- open()
  - R.open(); S.open();
  - r = R.getNext();
- getNext()
  - repeat until r and s join:

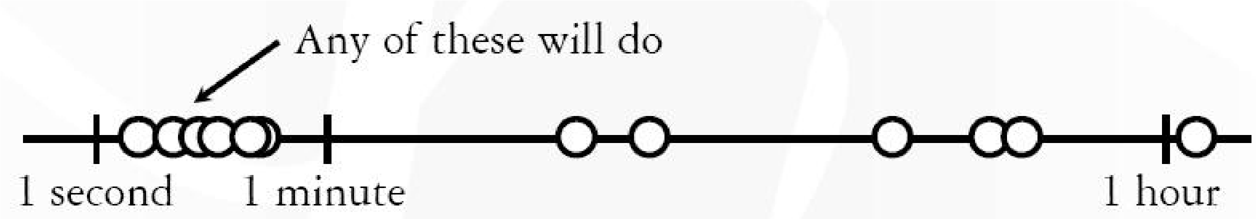
```
s = S.getNext();
if (s = = null)
{       S.close(); S.open(); s = S.getNext();
        if (s = = null) return null;
        r = R.getNext();
        if (r = = null) return null;
}
```

  - return <r,s>;
- close()
  - R.close(); S.close();

Query Optimization

Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution

- Optimization = find better, equivalent plan
  - Equivalent = produces same result
  - Logical level optimization = aka heuristic optimization
  - Physical level optimization = aka cost-based optimization
- Two main issues:
  - For a given query, how to find cheapest plans?
  - How is cost of a plan estimated?



(I) Heuristic Optimization

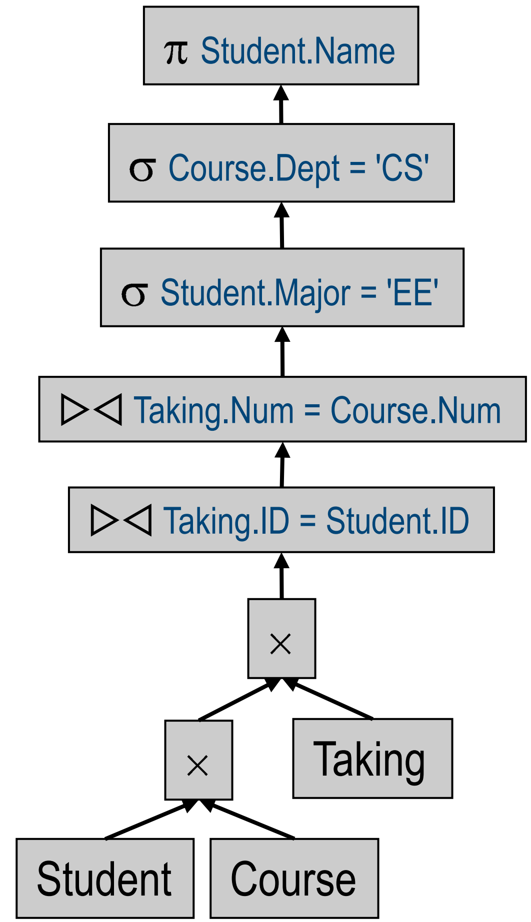
Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution

- logical tree $\rightarrow$ (more efficient) logical tree
  - heuristically apply algebraic equivalences
    - *heuristics = "looks good, let's try it!"*
- Ex: "push down predicates"

$$\sigma_{major='EE'}(\bowtie_{Taking.ID=Student.ID}(Taking,Student))$$

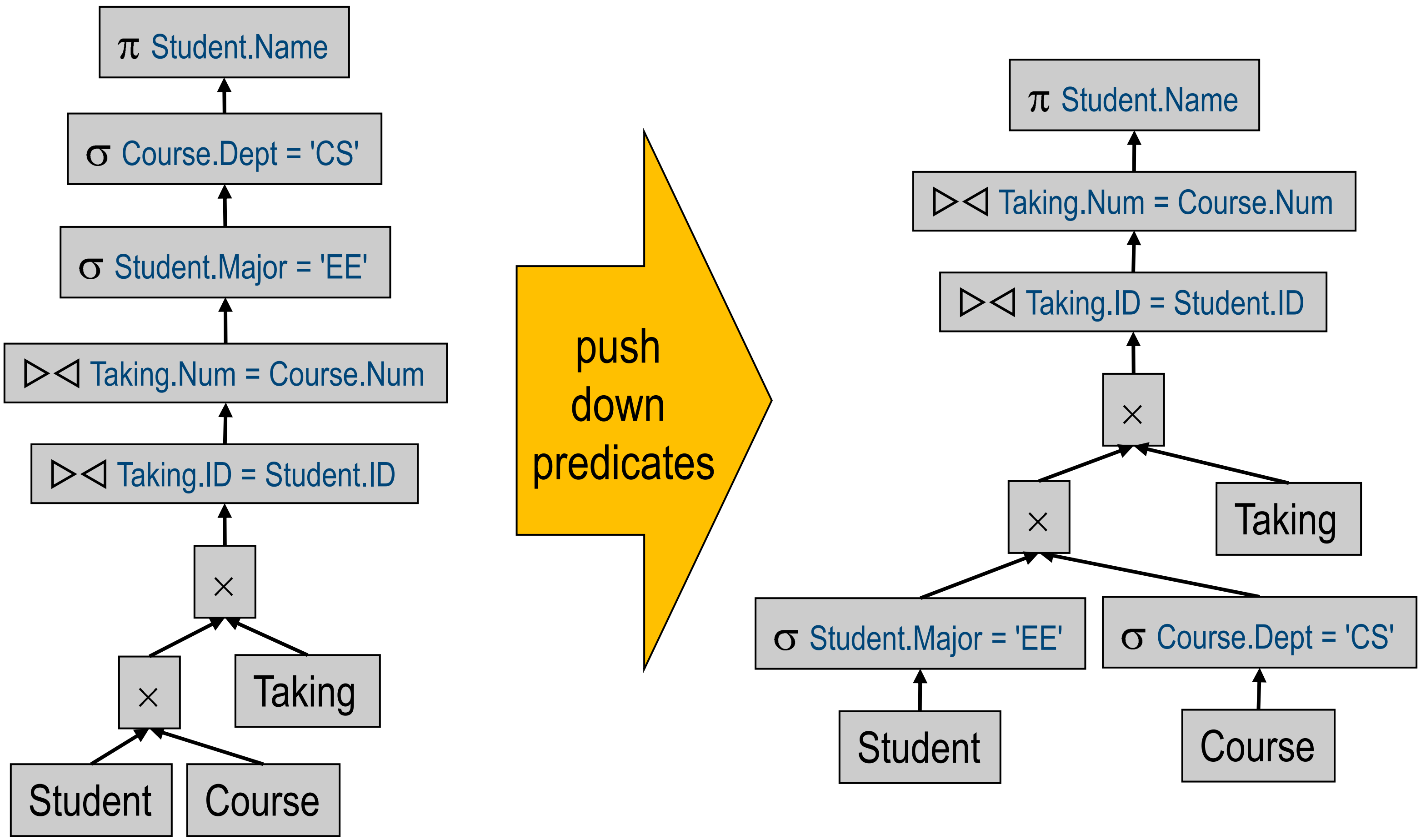
$$\equiv$$

$$\bowtie_{Taking.ID=Student.ID}(\sigma_{major='EE'}(Taking),Student)$$



(I) Heuristic Optimization

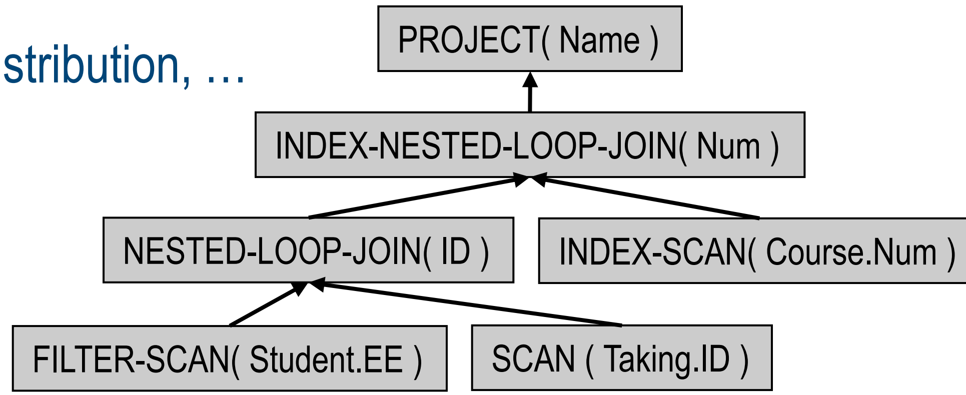
Parser – Checker - Views - Logical plan – **Optim1** - Physical plan – Optim2 - Execution

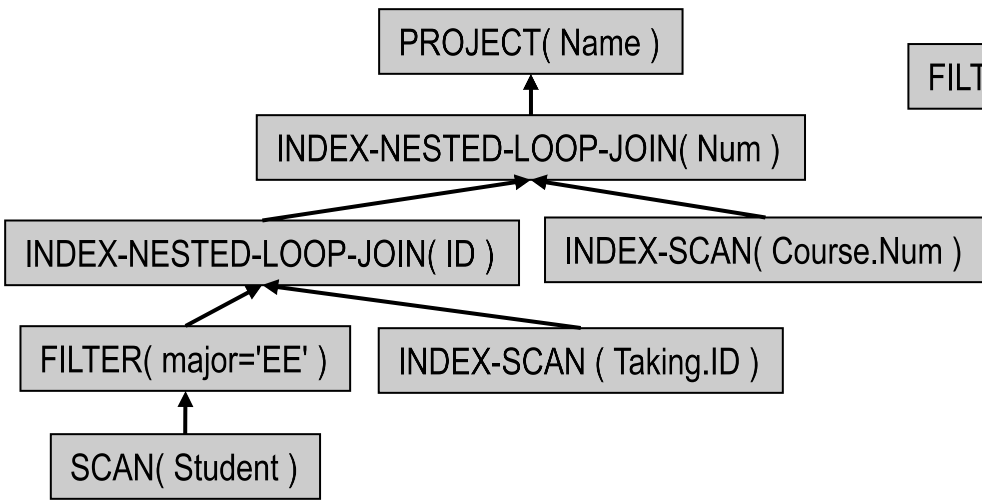


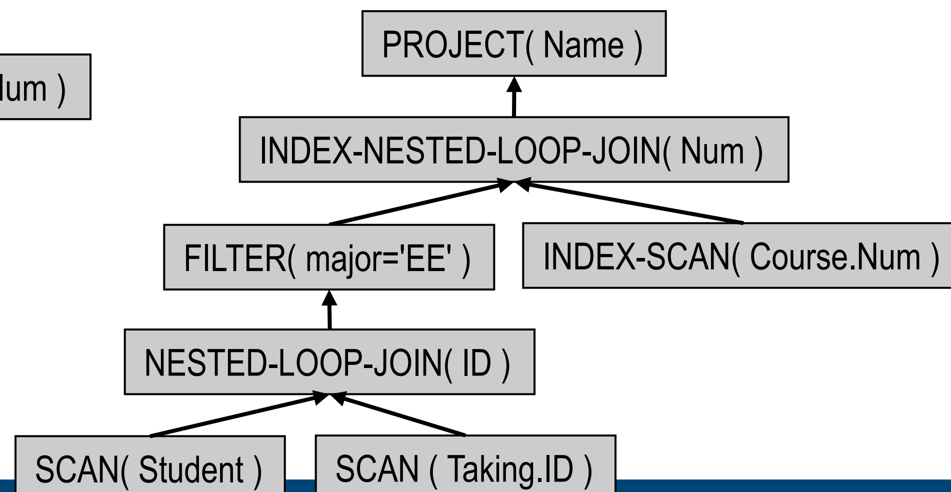
(II) Cost-Based Optimization

Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution

- Estimate costs, based on physical situation
  - concrete table sizes, indexes, data distribution, …
  - Find cheapest plan



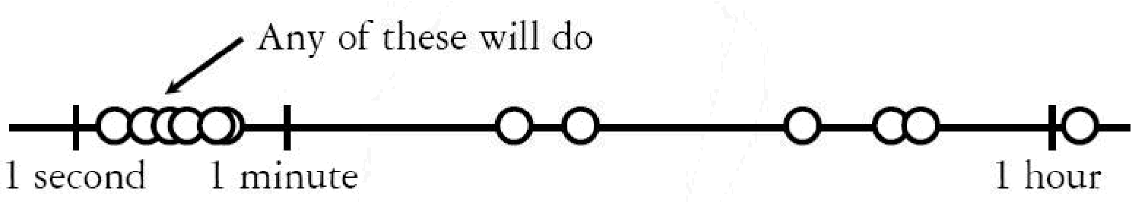




(II) Cost-Based Optimization

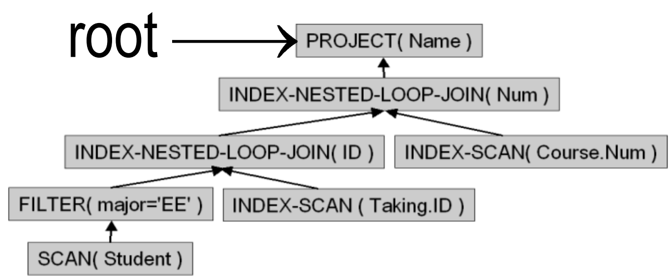
Parser – Checker - Views - Logical plan – Optim1 - Physical plan – Optim2 - Execution

- Approach:
  - enumerate all (?) possible physical plans that can be derived from given logical plan
  - estimate cost for each plan
  - pick best (i.e., least cost) alternative
- Ideally: Want to find best plan; practically: Avoid worst plans!



Finale: Execution of Tree

Parser – Checker - Views - Logical plan - Rewriter - Physical plan - Optim. - Execution




```
result = {};
root.open();
do
{
        tmp = root.getNext();
        result += tmp;
} while (tmp != NULL);
root.close();
return result;
```

- Recursive evaluation of tree
  - Requests go down
  - Intermediate result tuples go up
- Often instead: compile into "database machine code" program
  - CPU, GPU, FPGA, ...

System Catalogs

JACOBS UNIVERSITY

- For each relation:
  - name, file name, file structure (e.g., Heap file)
  - attribute name and type, for each attribute
  - index name, for each index
  - integrity constraints
- For each index:
  - structure (e.g., B+ tree) and search key fields
- For each view:
  - view name and definition
- Plus statistics, authorization, buffer pool size, etc.

Catalogs themselves stored as relations!

Sample Catalog Table

Attribute_Cat:

attr_name	rel_name	type	position
attr_name	Attribute_Cat	string	1
rel_name	Attribute_Cat	string	2
type	Attribute_Cat	string	3
position	Attribute_Cat	integer	4
sid	Students	string	1
name	Students	string	2
login	Students	string	3
age	Students	integer	4
gpa	Students	real	5
fid	Faculty	string	1
fname	Faculty	string	2
sal	Faculty	real	3

1st entry?
Key(s)?

Summary

- Query tree = internal representation of query
  - Logical tree: based on relational algebra
  - Physical tree: concrete algorithms („access plans“)
- Optimization = modify tree to perform better
  - Logical optimization = heuristic optimization = query rewriting
  - Physical optimization = cost-based optimization = black magic