Query Processing: Systems Perspective

Introduction to Databases

CompSci 316 Spring 2017

DUKE COMPUTER SCIENCE

Announcements (Mon., Mar. 20)

- Homework #3
  - 3.1 and 3.2 due today
  - Remaining parts to be posted today
  - Due on Monday
- Project
  - Milestone 2 due next Monday March 27

QP so far

- Scan-based algorithms
  - Nested loop join (tuple nested, block nested)
- Sort-based algorithms
  - External merge sort
  - Sort-merge join
- Hash-based algorithms
  - Hash join

- Can be adapted to
  - Selection, projection, aggregate

Recall: Performance of SMJ

- If SMJ completes in two passes:
  - I/O's: $3 \cdot \left(B(R) + B(S)\right)$
  - Memory requirement
    - We must have enough memory to accommodate one block from each run: $M > \frac{B(R)}{M} + \frac{B(S)}{M}$
    - $M > \sqrt{B(R) + B(S)}$
- If SMJ cannot complete in two passes:
  - Repeatedly merge to reduce the number of runs as necessary before final merge and join

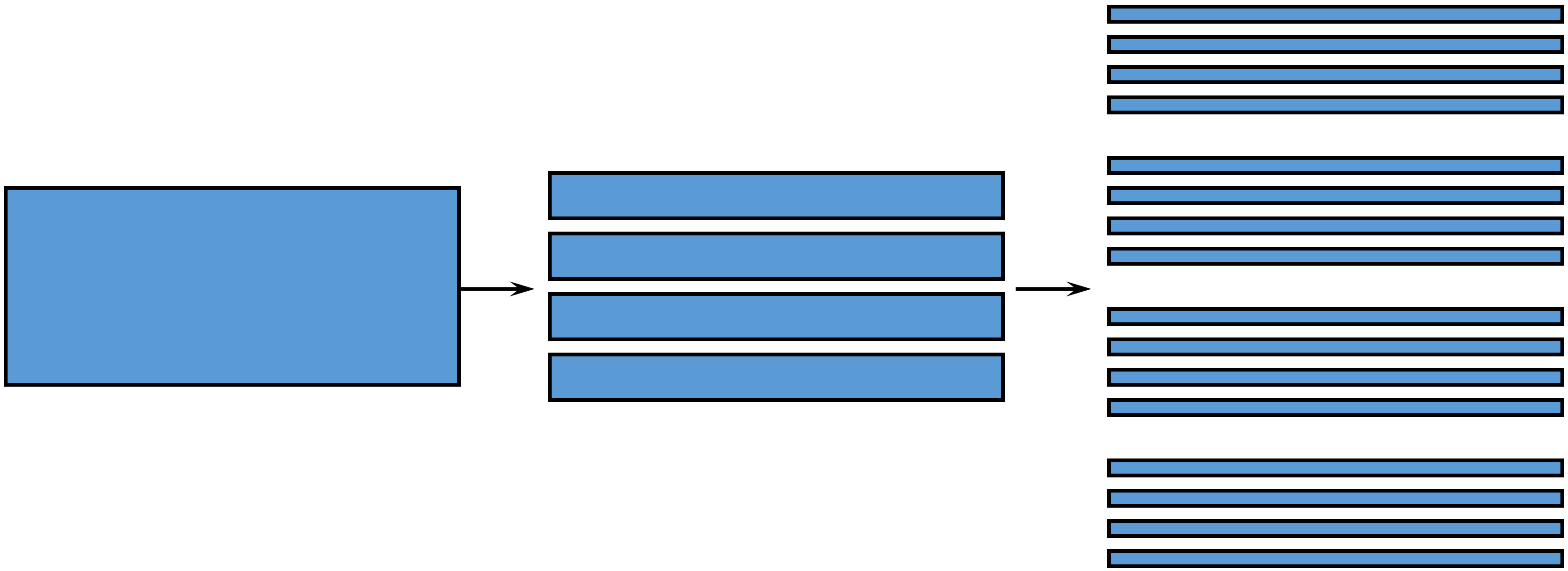
Recall: Performance of (two-pass) hash join

- If hash join completes in two passes:
  - I/O's: $3 \cdot \left(B(R) + B(S)\right)$
  - Memory requirement:
    - In the probing phase, we should have enough memory to fit one partition of R: $M - 1 > \frac{B(R)}{M-1}$
    - $M > \sqrt{B(R)} + 1$
    - We can always pick R to be the smaller relation, so:

$$M > \sqrt{\min\left(B(R), B(S)\right)} + 1$$

Generalizing for larger inputs

- What if a partition is too large for memory?
  - Read it back in and partition it again!
    - See the duality in multi-pass merge sort here?



Hash join versus SMJ

Pros? Cons?

(Assuming two-pass)

- I/O's: same
- Memory requirement: hash join is lower
  - $\sqrt{\min\left(B(R), B(S)\right)} + 1 < \sqrt{B(R) + B(S)}$
  - Hash join wins when two relations have very different sizes
- Other factors
  - Hash join performance depends on the quality of the hash
    - Might not get evenly sized buckets
  - SMJ can be adapted for inequality join predicates
  - SMJ wins if R and/or S are already sorted
  - SMJ wins if the result needs to be in sorted order

What about nested-loop join?

- May be best if many tuples join
  - Example: non-equality joins that are not very selective
- Necessary for black-box predicates
  - Example: WHERE $user\_defined\_pred(R.A, S.B)$

Other hash-based algorithms

- Union (set), difference, intersection
  - More or less like hash join
- Duplicate elimination
  - Check for duplicates within each partition/bucket
- Grouping and aggregation
  - Apply the hash functions to the group-by columns
  - Tuples in the same group must end up in the same partition/bucket
  - Keep a running aggregate value for each group
    - May not always work

Duality of sort and hash

- Divide-and-conquer paradigm
  - Sorting: physical division, logical combination
  - Hashing: logical division, physical combination
- Handling very large inputs
  - Sorting: multi-level merge
  - Hashing: recursive partitioning
- I/O patterns
  - Sorting: sequential write, random read (merge)
  - Hashing: random write, sequential read (partition)

Index-based algorithms

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Selection using index

- Equality predicate: $\sigma_{A=v}(R)$
  - Use an ISAM, B+-tree, or hash index on $R(A)$
- Range predicate: $\sigma_{A>v}(R)$
  - Use an ordered index (e.g., ISAM or B+-tree) on $R(A)$
  - Hash index is not applicable

- Indexes other than those on $R(A)$ may be useful
  - Example: B+-tree index on $R(A, B)$
  - How about B+-tree index on $R(B, A)$?

Index versus table scan

Situations where index clearly wins:

- Index-only queries which do not require retrieving actual tuples
    - Example: $\pi_A\left(\sigma_{A>v}(R)\right)$
- Primary index clustered according to search key
    - One lookup leads to all result tuples in their entirety

Index versus table scan (cont'd)

BUT(!):

- Consider $\sigma_{A>v}(R)$ and a secondary, non-clustered index on $R(A)$
  - Need to follow pointers to get the actual result tuples
  - Say that 20% of R satisfies $A > v$
    - Could happen even for equality predicates
  - I/O's for index-based selection: lookup + 20% $|R|$
  - I/O's for scan-based selection: $B(R)$
  - Table scan wins if a block contains more than 5 tuples!

Index nested-loop join

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

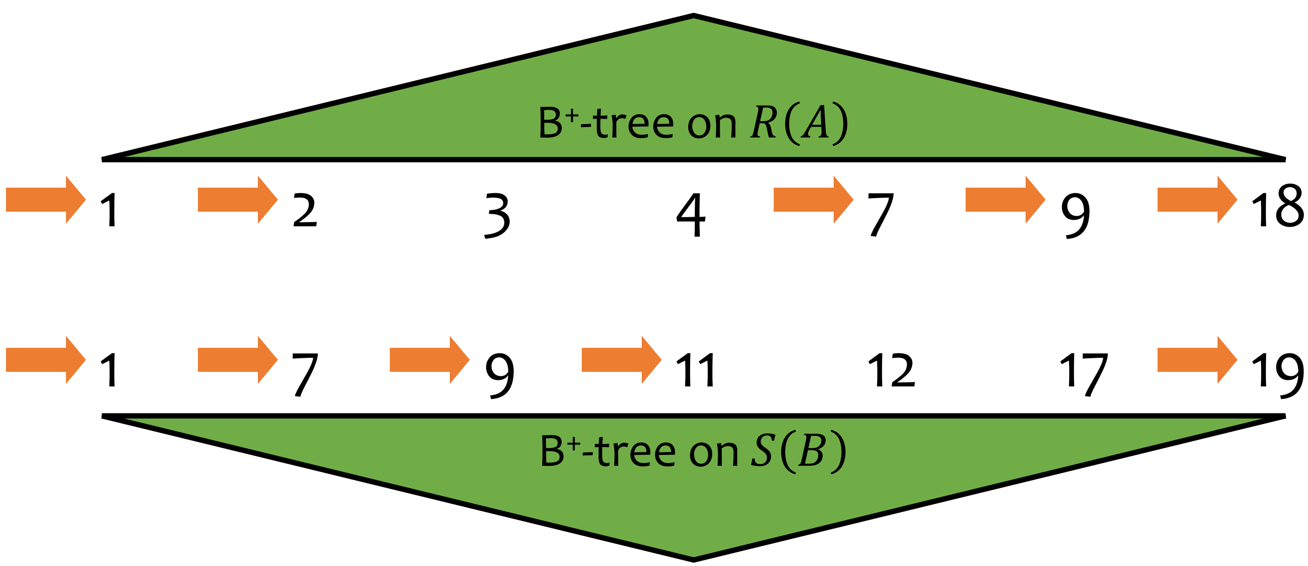
Suppose there is an index on S(B): S is outer or inner?

- Idea: use a value of $R.A$ to probe the index on $S(B)$
- For each block of R, and for each r in the block:
  Use the index on $S(B)$ to retrieve s with $s.B = r.A$
  Output rs
- I/O's: $B(R) + |R| \cdot (\text{index lookup})$
  - Typically, the cost of an index lookup is 2-4 I/O's
  - Beats other join methods if $|R|$ is not too big
  - Better pick R to be the smaller relation
- Memory requirement: 3

Zig-zag join using ordered indexes

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

- Idea: use the ordering provided by the indexes on $R(A)$ and $S(B)$ to eliminate the sorting step of sort-merge join
- Use the larger key to probe the other index
    - Possibly skipping many keys that don't match



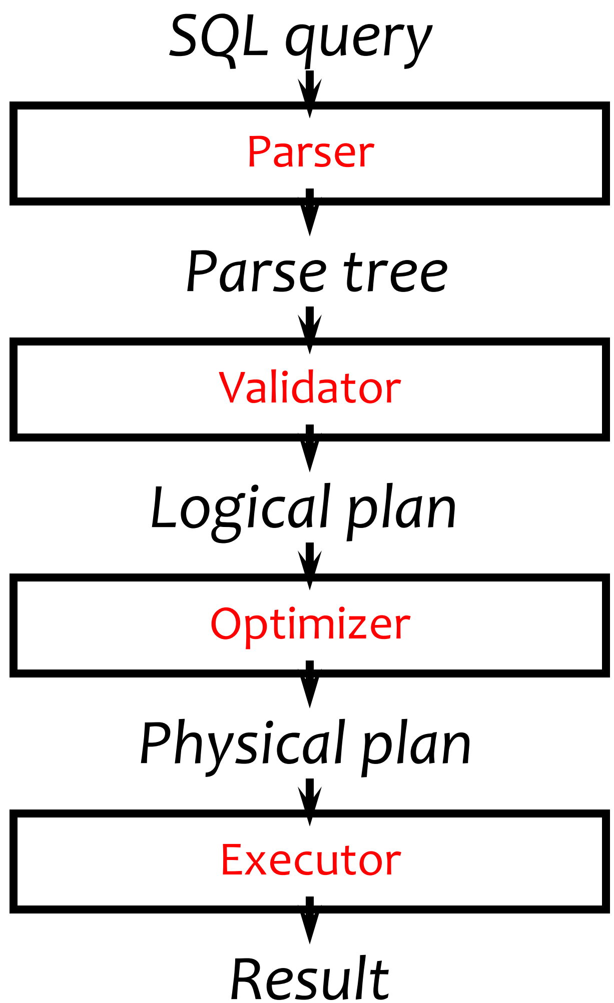
Summary of techniques

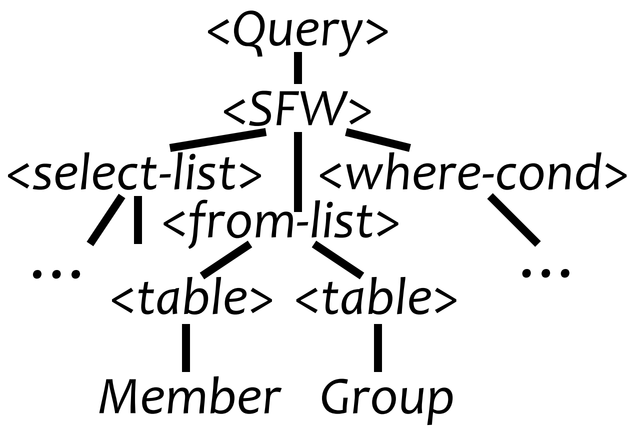
- Scan
  - Selection, duplicate-preserving projection, nested-loop join
- Sort
  - External merge sort, sort-merge join, union (set), difference, intersection, duplicate elimination, grouping and aggregation
- Hash
  - Hash join, union (set), difference, intersection, duplicate elimination, grouping and aggregation
- Index
  - Selection, index nested-loop join

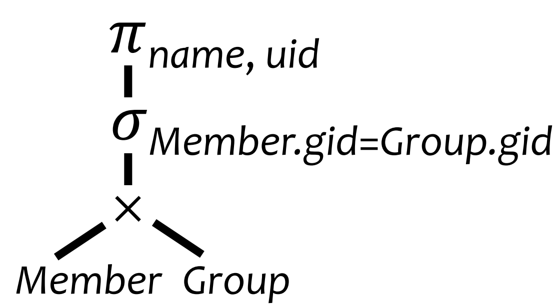
Query Processing: Systems aspects

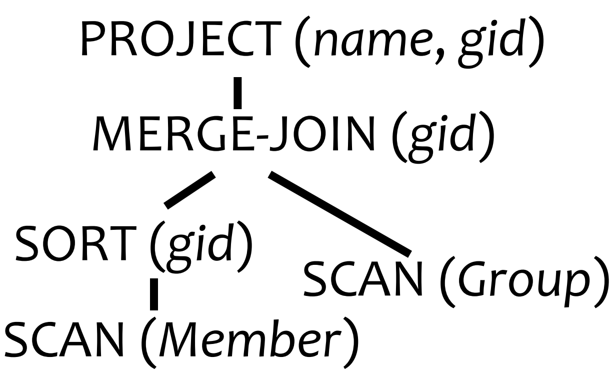
A query's trip through the DBMS

```
SELECT name, uid
FROM Member, Group
WHERE Member.gid =
      Group.gid;
```







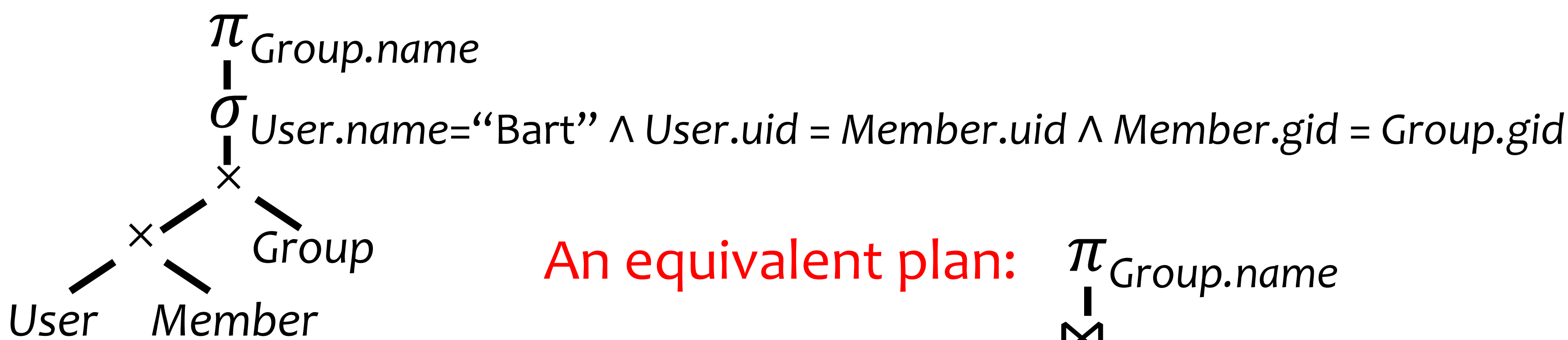


Parsing and validation

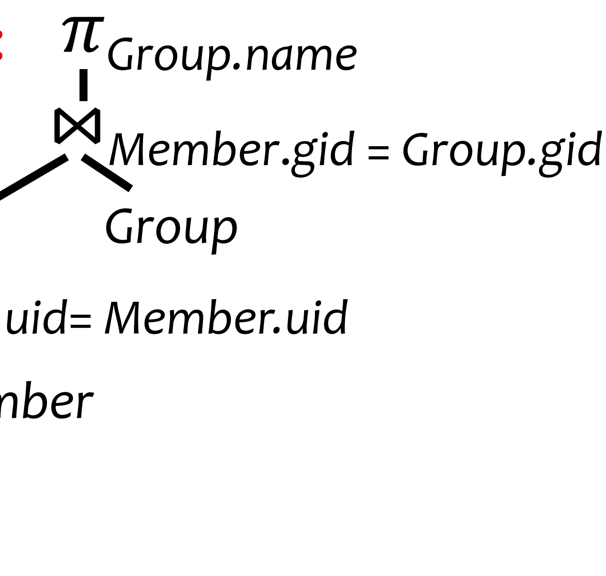
- Parser: SQL → parse tree
  - Detect and reject syntax errors
- Validator: parse tree → logical plan
  - Detect and reject semantic errors
    - Nonexistent tables/views/columns?
    - Insufficient access privileges?
    - Type mismatches?
      - Examples: AVG(name), name + pop, User UNION Member
  - Also
    - Expand *
    - Expand view definitions
  - Information required for semantic checking is found in system catalog (which contains all schema information)

Logical plan

- Nodes are logical operators (often relational algebra operators)
- There are many equivalent logical plans



An equivalent plan:

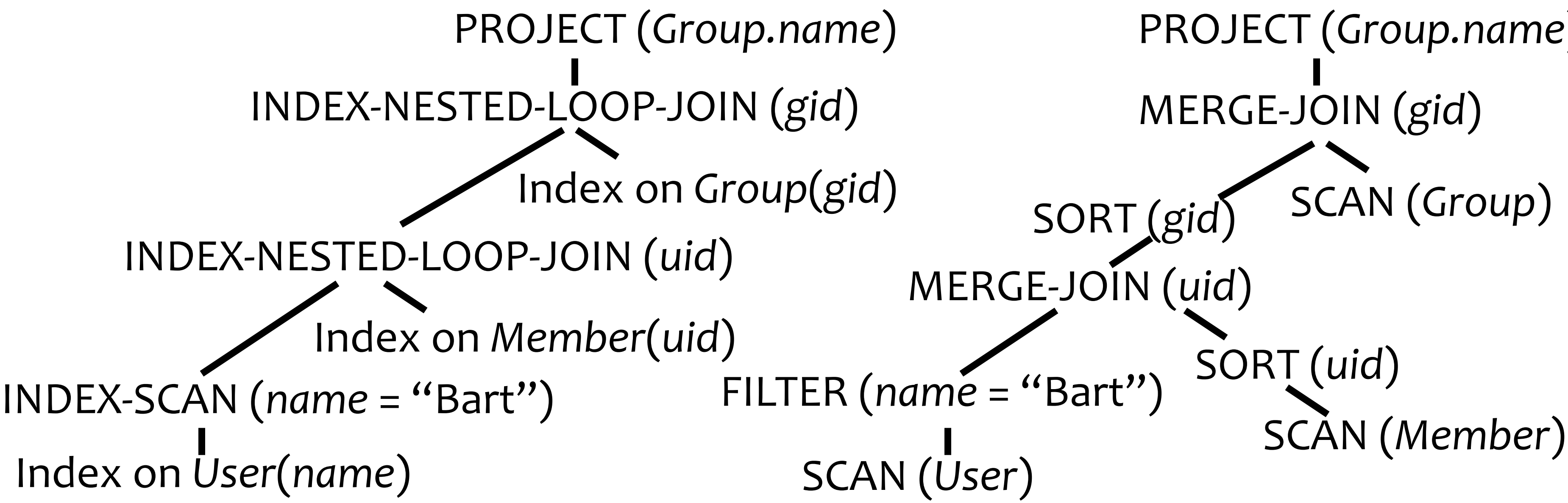


Physical (execution) plan

- A complex query may involve multiple tables and various query processing algorithms
  - E.g., table scan, index nested-loop join, sort-merge join, hash-based duplicate elimination…
- A physical plan for a query tells the DBMS query processor how to execute the query
  - A tree of physical plan operators
  - Each operator implements a query processing algorithm
  - Each operator accepts a number of input tables/streams and produces a single output table/stream

Examples of physical plans

SELECT Group.name
FROM User, Member, Group
WHERE User.name = 'Bart'
AND User.uid = Member.uid AND Member.gid = Group.gid;

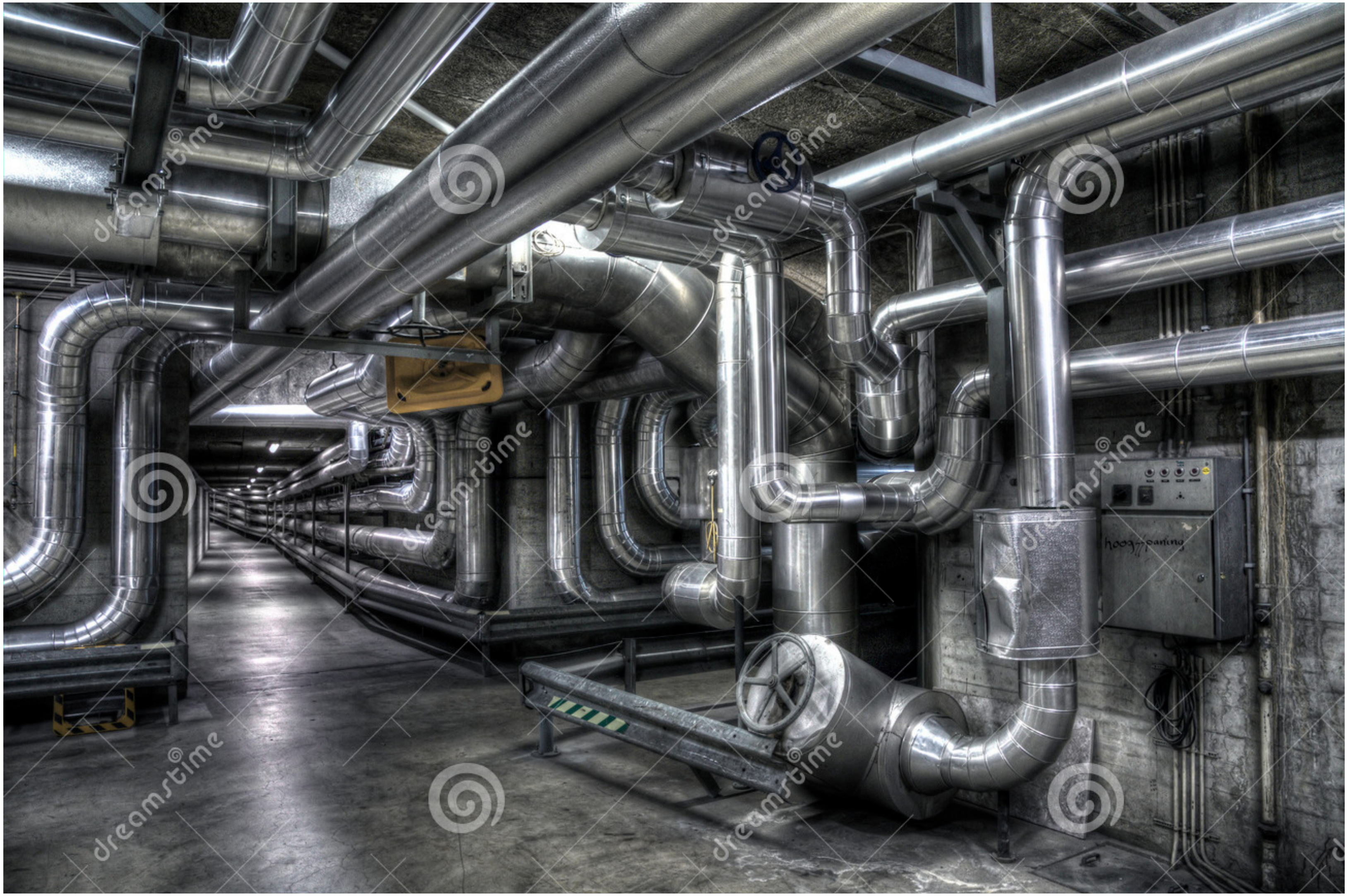


- Many physical plans for a single query
  - Equivalent results, but different costs and assumptions!

☞DBMS query optimizer picks the "best" possible physical plan

Physical plan execution

- How are intermediate results passed from child operators to parent operators?
  - Temporary files
    - Compute the tree bottom-up
    - Children write intermediate results to temporary files
    - Parents read temporary files
  - Iterators
    - Do not materialize intermediate results
    - Children pipeline their results to parents



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Iterator interface

- Every physical operator maintains its own execution state and implements the following methods:
  - open(): Initialize state and get ready for processing
  - getNext(): Return the next tuple in the result (or a null pointer if there are no more tuples); adjust state to allow subsequent tuples to be obtained
  - close(): Clean up

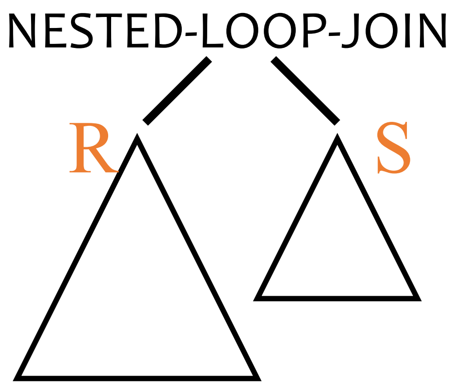
An iterator for table scan

- State: a block of memory for buffering input R; a pointer to a tuple within the block
- open(): allocate a block of memory
- getNext()
  - If no block of R has been read yet, read the first block from the disk and return the first tuple in the block
    - Or null if R is empty
  - If there is no more tuple left in the current block, read the next block of R from the disk and return the first tuple in the block
    - Or null if there are no more blocks in R
  - Otherwise, return the next tuple in the memory block
- close(): deallocate the block of memory

An iterator for nested-loop join

R: An iterator for the left subtree

S: An iterator for the right subtree



- open()

```
R.open()
S.open()
r = R.getNext()
```

- getNext()
  - To output just the next (r, s) tuple from R Join S

```
while True:
    s = S.getNext()
    if s is null: # no more tuple from S to join with the current R-tuple
        S.close()
    r = R.getNext() # move on to next r
    if r is null: # no more tuple from R
        return null
    # otherwise we are at current r
    S.open() # reopen S
    s = S.getNext()
    if s is null: # S is empty!
        return null
    if joins(r, s):
    return concat(r, s)
```

- close()

```
R.close()
S.close()
```

An iterator for 2-pass merge sort

- open()
  - Allocate a number of memory blocks for sorting
  - Call open() on child iterator
- getNext()
  - If called for the first time
    - Call getNext() on child to fill all blocks, sort the tuples, and output a run
    - Repeat until getNext() on child returns null
    - Read one block from each run into memory, and initialize pointers to point to the beginning tuple of each block
  - Return the smallest tuple and advance the corresponding pointer; if a block is exhausted bring in the next block in the same run
- close()
  - Call close() on child
  - Deallocate sorting memory and delete temporary runs

Blocking vs. non-blocking iterators

- A blocking iterator must call getNext() exhaustively (or nearly exhaustively) on its children before returning its first output tuple
  - Examples: sort, aggregation
- A non-blocking iterator expects to make only a few getNext() calls on its children before returning its first (or next) output tuple
  - Examples: dup-preserving projection, filter, merge join with sorted inputs

Execution of an iterator tree

- Call root.open()
- Call root.getNext() repeatedly until it returns null
- Call root.close()

☞ Requests go down the tree

☞ Intermediate result tuples go up the tree

☞ No intermediate files are needed

- But maybe useful if an iterator is opened many times
  - Example: complex inner iterator tree in a nested-loop join; "cache" its result in an intermediate file