THE UNIVERSITY of EDINBURGH

Advanced Database Systems

Spring 2024

Lecture #19:

Query Evaluation: Processing Models

R&G: Chapter 14

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Processing Model

Processing model defines how the DBMS executes a query plan

- Different trade-offs for different workloads

Three main approaches:

- Iterator model
- Vectorised (batch) model
- Materialisation model

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Iterator Model

Each query plan operator implements three functions:

- **open()** – initialise the operator's internal state
- **next()** – return either the next result tuple or a null marker if there are no more tuples
- **close()** – clean up all allocated resources
- Each operator instance maintains an internal state

Any operator can be input to any other (composability)

- Since they all implement the same interface

Also called **Volcano** or **Pipeline** Model

- *Goetz Graefe. Volcano – An Extensible and Parallel Query Evaluation System. IEEE TKDE 1994*

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Iterator Model

Top-down plan processing

- The whole plan is initially reset by calling **open()** on the root operator
- The **open()** call is forwarded through the plan by the operators themselves
- Control returns to the query processor
- The root is requested to produce its **next()** result record
- Operators forward the **next()** request as needed. As soon as the next result record is produced, control returns to the query processor again

Used in almost every DBMS

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Iterator Model

Query processor uses the following routine to evaluate a query plan

```
Function eval(q)
q.open()
r = q.next()
while r != EOF do
  /* deliver record r (print, ship to DB client) */
  emit(r)
  r = q.next()
/* resource deallocation now */
q.close()
```

Output control (e.g., LIMIT) works easily with this model

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Example: Selection σ_p (on-the-fly)

A streaming operator: small amount of work per tuple

Predicate ***p*** stored in internal state

```
open()
child.open()
```

```
close()
child.close()
```

```
next()
while (r = child.next()) != EOF do
  if p(r) return r
return EOF
```

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Example: Heap Scan

Leaf of the query plan, often includes a selection predicate

```
open()
heap = open heap file for this relation       // file handle
cur_page = heap.first_page()                  // first page
cur_slot = cur_page.first_slot()              // first slot on that page
```

```
next()
if cur_page == NULL return EOF
current = tuple at (cur_page, cur_slot)          // tuple to be returned
cur_slot = cur_slot.advance()              // advance slot for subseq. calls
if cur_slot == NULL                     // advance to next page, first slot
  cur_page = cur_page.advance()
  if cur_page != NULL
    cur_slot = cur_page.first_slot()
return current
```

```
close()
heap.close()
```

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Example: Nested Loops Join

Volcano-style implementation of nested loops join $R \bowtie_p S$

```
open()
left_child.open()
right_child.open()
r = left_child.next()
```

```
close()
left_child.close()
right_child.close()
```

```
next()
while r != EOF do
  while (s = right_child.next()) != EOF do
    if p(r,s) return <r,s>
  /* reset inner join input */
  right_child.close()
  right_child.open()
  r = left_child.next()
return EOF
```

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Sort is a blocking operation since we don't know the tuple that should be passed to its parent,
hence we complete sorting in open() function

Example: Sort (2-pass)

open()

```
// first, all of pass 0, a blocking call
child.open()
repeatedly call child.next() and generate the sorted runs on disk, until child gives EOF
// second, set up for pass 1, assumes enough buffers to merge
open each sorted run file and load one page per run into input buffer for pass 1
```

next() // pass 1 merge (assumes enough buffers to merge)

```
output = min tuple across all buffers
if min tuple was last one in its buffer
  fetch next page from that run into buffer
return output          // (or EOF if no tuples remain)
```

close()

```
deallocate the runs files
child.close()
```


Iterator Model

```
for t in child.next():
  emit(projection(t))
```

emit returns control to caller

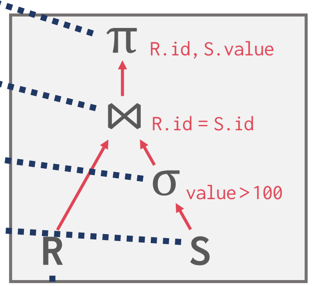
```
SELECT R.id, S.value
  FROM R, S
 WHERE R.id = S.id
   AND S.value > 100
```

```
for t1 in left.next():
  buildHashTable(t1)
for t2 in right.next():
  if probe(t2): emit(t1⋈t2)
```

```
for t in child.next():
  if evalPred(t): emit(t)
```

```
for t in R:
  emit(t)
```

```
for t in S:
  emit(t)
```



Iterator Model

1
```
for t in child.next():
  emit(projection(t))
```

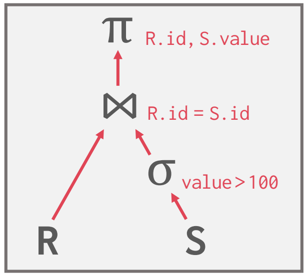
2
```
for t1 in left.next():
  buildHashTable(t1)
for t2 in right.next():
  if probe(t2): emit(t1⋈t2)
```

4
```
for t in child.next():
  if evalPred(t): emit(t)
```

3
```
for t in R:
  emit(t)
```

5
```
for t in S:
  emit(t)
```

```
SELECT R.id, S.value
  FROM R, S
 WHERE R.id = S.id
   AND S.value > 100
```



Iterator Model

Allows for tuple **pipelining**

- The DBMS process a tuple through as many operators as possible before having to retrieve the next tuple
- Reduces memory requirements and response time since each chunk of input is propagated to the output immediately

Some operators will **block** until children emit all of their tuples

- E.g., sorting, hash join, grouping and duplicate elimination over unsorted input, subqueries
- The data is typically buffered ("materialised") on disk

Iterator Model

+ **Nice** & **simple** interface
+ Allows for **easy** combination of operators
– Next called for **every single** tuple & operator
– **Virtual** call via function pointer
  Degrades branch prediction of modern CPUs
– **Poor** code locality and **complex** bookkeeping
  Each operator keeps state to know where to resume

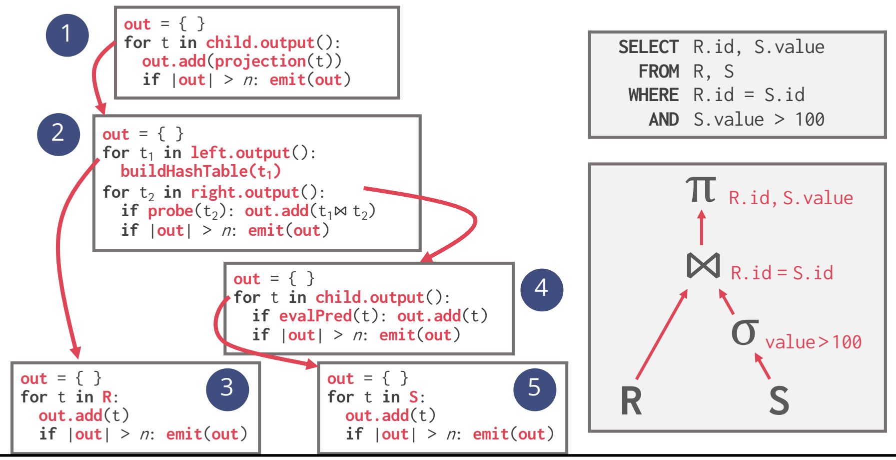
Vectorisation Model

Like Iterator Model, each operator implements a next() function

Each operator emits a batch of tuples instead of a single tuple
- The operator's internal loop processes multiple tuples at a time
- The size of the batch can vary based on hardware and query properties

Ideal for OLAP queries
- Greatly reduces the number of invocations per operator
- Operators can use vectorised (SIMD) instructions to process batches of tuples

Vectorisation Model



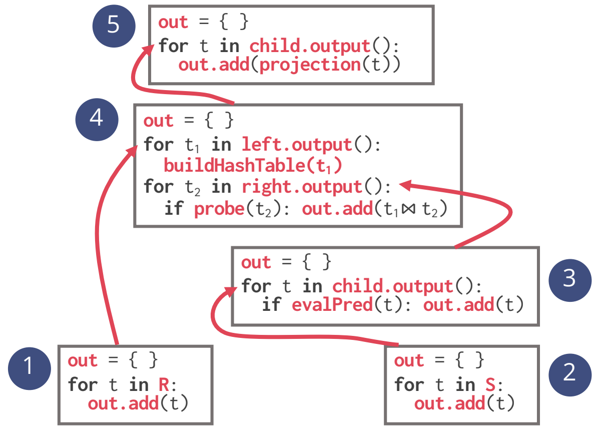
Materialisation Model

Each operator processes its input all at once and then emits its output
- The operator "materialises" its output as a single result

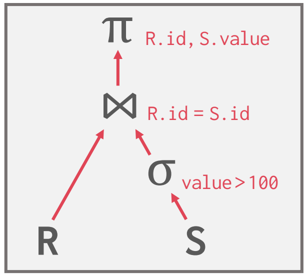
Bottom-up plan processing
- Data not pulled by operators but pushed towards them
- Leads to better code and data locality

Better for OLTP workloads
- OLTP queries typically only access a small number of tuples at a time
- Not good for OLAP queries with large intermediate results

Materialisation Model




```
SELECT R.id, S.value
  FROM R, S
 WHERE R.id = S.id
   AND S.value > 100
```



Processing Models: Summary

Iterator / Volcano

Direction: Top-Down

Emits: Single Tuple

Target: General Purpose

Vectorised

Direction: Top-Down

Emits: Tuple Batch

Target: OLAP

Materialisation

Direction: Bottom-Up

Emits: Entire Tuple Set

Target: OLTP