DB 2

13 – Plan Evaluation

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Torsten Grust
Universität Tübingen, Germany

1 ┆ Evaluating Query Plan Trees

The evaluation of a (complex) query plan requires a coordinated execution of the plan's operators:

- Is data **pushed** from the leaves (*e.g.*, Seq Scan, Index Scan) towards the plan root?
- Or does an operator **pull** the intermediate results from its upstream child operators?
- What kind of data flows across the plan's edges? **Entire tables or columns**? **Single rows**?
- Does the plan execute in one shot or can we **demand** the "next result row" when we are ready to consume it?
    - Can operators remember/resume from their current state?

Query Q_{12} and its (Moderately Complex) Plan

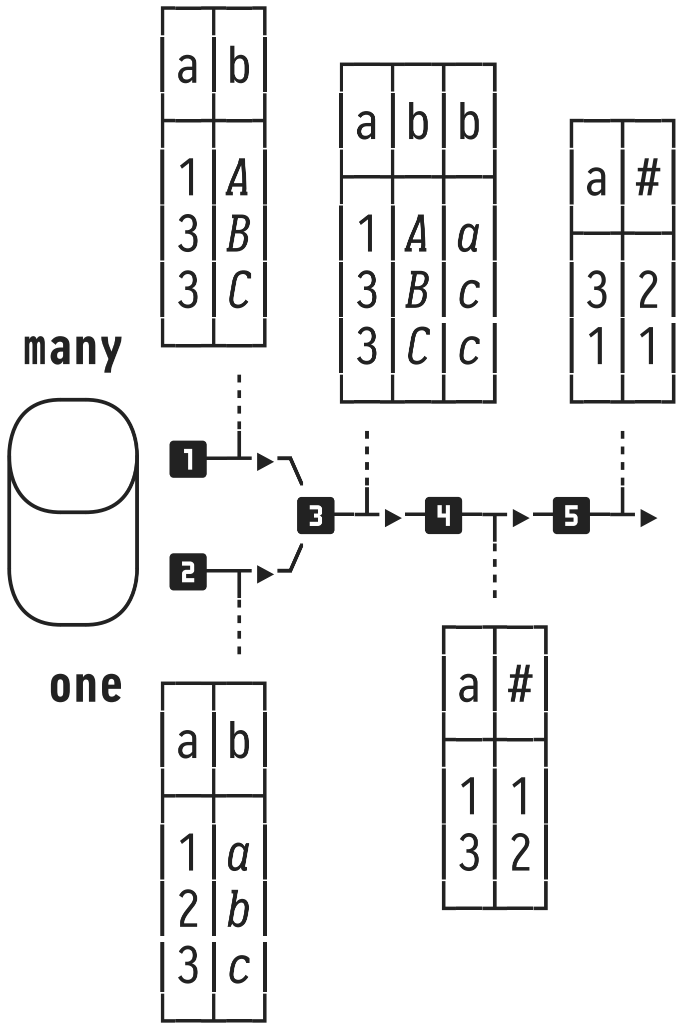
- ***Q***$_{12}$:

```
SELECT o.a, COUNT(*) AS "#"
FROM   one AS o, many AS m
WHERE  o.a = m.a
GROUP BY o.a
ORDER BY o.a DESC
```

- Plan operators:

  ❶ Seq Scan on **many** (outer of ❸)
  ❷ Seq Scan on **one** (inner of ❸)
  ❸ Nested Loop (Join Filter: o.a = m.a)
  ❹ HashAggregate (Group Key: o.a)
  ❺ Sort (Sort Key: o.a DESC)

  —▸— ≡ direction of data flow
  ❶ … ❺ ≡ evaluation order



MonetDB: Full Materialization

MonetDB generates MAL programs that evaluate operators following a post-order traversal[1] of the query plan tree.

- Leaf nodes evaluated first, downstream nodes consume BATs generated by child nodes. Root operator evaluated last.
- Each operator consumes entire BATs, generates and **fully materializes** its result BAT(s) [cf. previous slide].
  - Tight code loops process entire columns. **Instruction *and* data locality**, predictable memory access.
  - **Size of intermediate results** may exceed available RAM ⇒ OS-level paging and thus disk I/O.

[1] Recall: data-flow dependency analysis enables the // evaluation of ❶ and ❷.

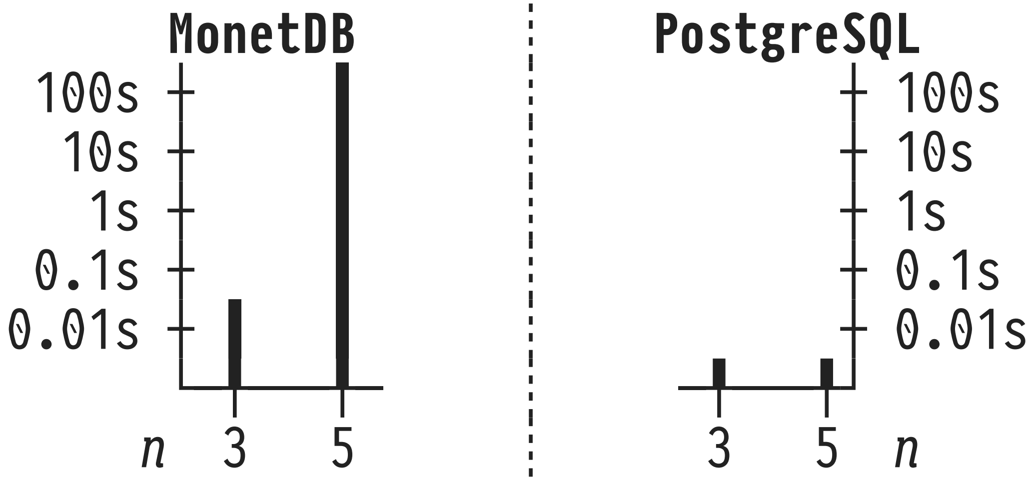
Data Dependencies in MAL Program for Q_{12}

```
one     :bat[:oid] := sql.tid(sql, "sys", "one");                              } 1 Scan one.a
one_a0 :bat[:int] := sql.bind(sql, "sys", "one", "a", 0:int);
one_a   :bat[:int] := algebra.projection(one, one_a0);
                                                                                1 // 2
many   :bat[:oid] := sql.tid(sql, "sys", "many");                              } 2 Scan many.a
many_a0:bat[:int] := sql.bind(sql, "sys", "many", "a", 0:int);
many_a :bat[:int] := algebra.projection(many, many_a0);

(left, right) := algebra.join(one_a, many_a, nil:bat, nil:bat, false, nil:lng);  } 3 Equi-Join
joined_one_a:bat[:int] := algebra.projection(left, one_a);

(grouped_one_a, group_keys, group_sizes) := group.groupdone(joined_one_a);       } 4 Group + Agg
keys_a:bat[:int] := algebra.projection(group_keys, joined_one_a);
count :bat[:lng] := aggr.subcount(grouped_one_a, grouped_one_a, group_keys, false);

(sorted_a, oidx, gidx) := algebra.sort(keys_a, true, true, false);              } 5 Sort
result_a    :bat[:int] := algebra.projection(oidx, keys_a);
result_count:bat[:lng] := algebra.projection(oidx, count);
```

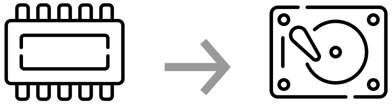
2 ┆ Materialization vs. Demand-Driven Pipelining

Consider Q_{13}, returning the single value 42:

```
SELECT 42 AS fortytwo
FROM   hundred AS h₁, …, hundred AS hₙ   -- ⚠ 100ⁿ rows
LIMIT  1
```



Volcano-Style Demand-Driven Pipelining



PostgreSQL implements the **Volcano Iterator Model:**

- Operator **demands** its subplan to produce the next row (*i.e.*, the plan root drives the query evaluation).
- Operator delivers results **one row at a time**, avoids intermediate result materialization (if possible ⚠️):
  - Reduces query *response* time (first row delivered immediately, do not wait until result is complete). 👍
  - Reduces memory requirements (pass data row-by-row, not table at a time). 👍

Demand-Driven Evaluation and Call by Need

Volcano-style **demand-driven** pipelining bears some resemblance with **call-by-need** evaluation of (functional) programming languages:

- If function $f(e_1,e_2)$ does not (always) need the value of expression e_2, then $f(42,1/0)$ may evaluate just fine.
- With the demand-driven evaluation in Haskell[2], consider:

```
sum [x/0 | x <- [1..10], x > 42]              ⇢ 0.0
length [x/0 | x <- [1..10]]                   ⇢ 10
take 1 [(x,y) | x <- [1..], y <- [1..]]  ⇢ [(1,1)] ⬅ Q13
```

[2] Haskell is a *lazily* evaluated functional programming language, see http://haskell.org.

Query Response vs. Evaluation Time

In PostgreSQL's EXPLAIN output, query **response** (first row) and **evaluation time** (all rows) are distinguished:

```
⋮
Seq Scan on many m (actual time=0.747..139.172 rows=502867 …)
```

$\underbrace{0.747}_{\textbf{response}}..\underbrace{139.172}_{\textbf{evaluation}\text{ time}}$

response/evaluation time

- Both times may…
  - … differ substantially (pipelined evaluation),
  - … coincide (**blocking** operators—*e.g.*, Sort—evaluate in full first, then deliver all rows from intermediate result buffer).

Volcano Iterator Model: API

In Volcano-style demand-driven query evaluation, operators implement a simple API of three main methods:

1. **open()**: Initialize operator and its internal state, forward open() request to upstream subplans as well.
2. **next()**: If required, forward next() upstream to request more input rows. Then deliver next output row (or NUL if result complete).
3. **close()**: Release operator-internal state, forward close() request to upstream subplans as well.

Volcano-style call protocol: (open() next()* close())+.

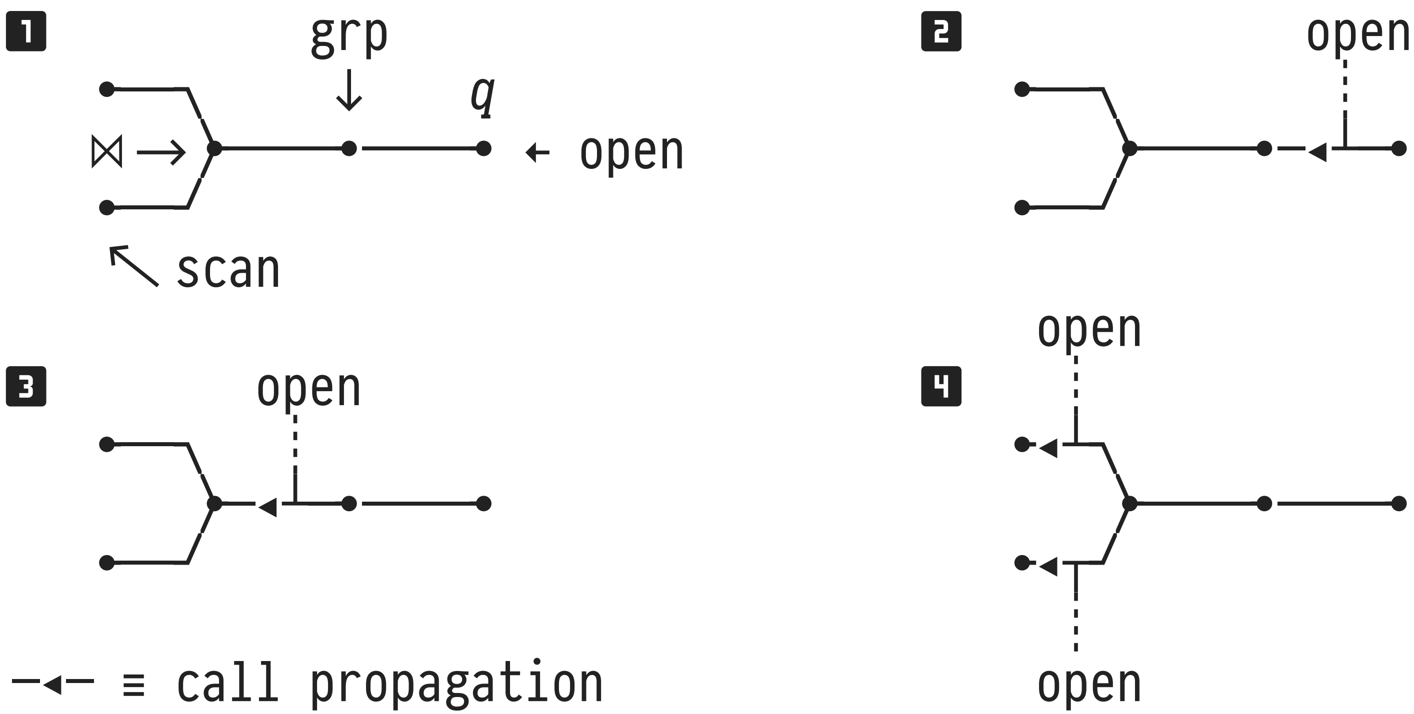
Volcano Iterator Model: Query Evaluation Driver

Use the Volcano iterator model API to *fully* evaluate a query. Operator q denotes the root of the query plan:

```
Eval(q):
  open(q);
  t ← next(q);
  while t ≠ NULL            } iterate while still rows to consume
  | emit(t);                } ship current row to application
  | t ← next(q);
  close(q);
```

- To retrieve next result row only, simply call next(q).
- May/must use close(q) to cancel query evaluation midway.

Volcano Iterator Model: Forwarding open()/close()



- Each operator instance (•) allocates and releases its own copy of state that is kept between method invocations.

Pipelined Nested Loop Join (NLJ)

Implement open() and close() for the Nested Loop Join operator:

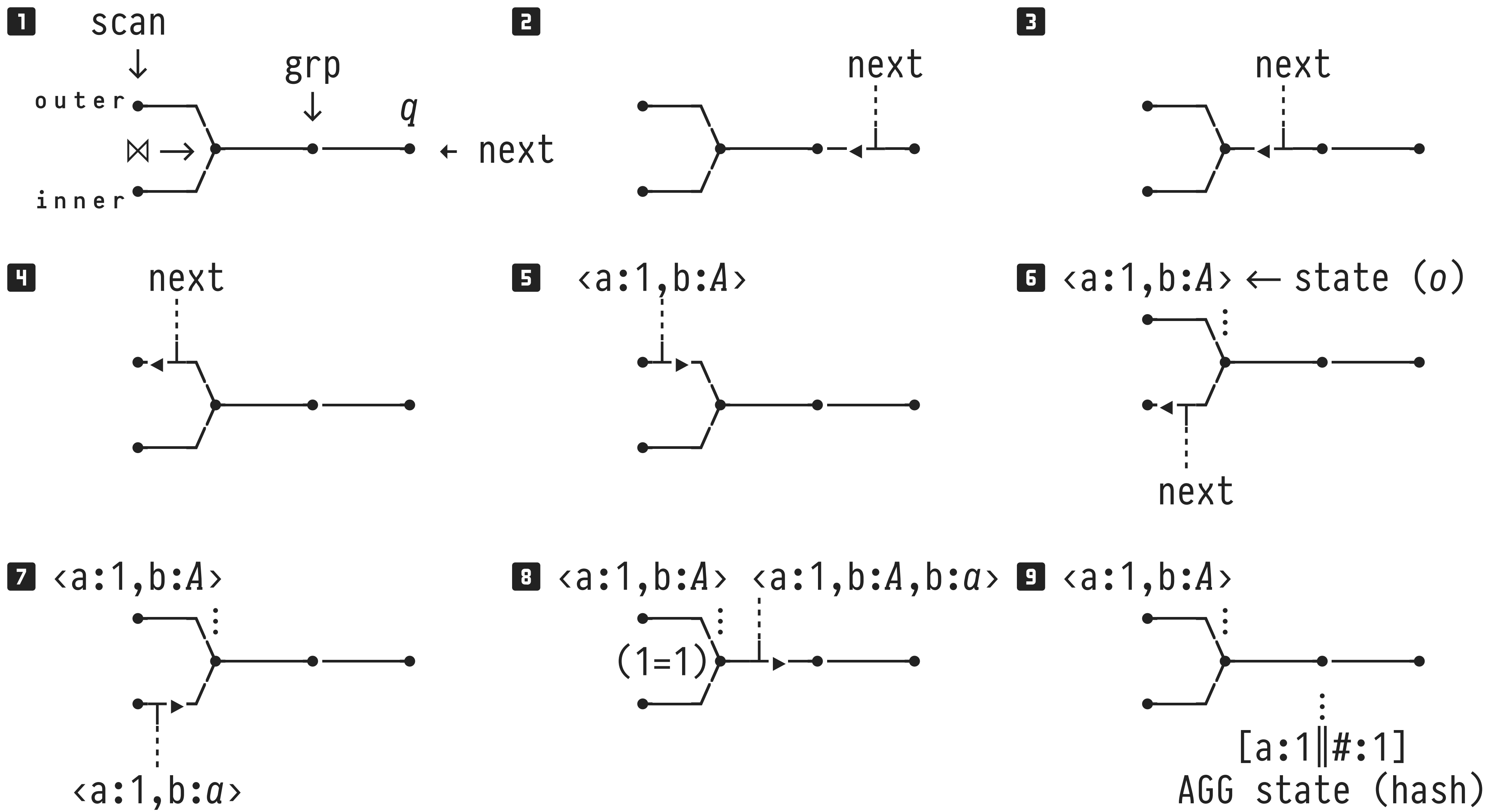
```
NLJ.open(outer,inner,θ):
  open(outer);                 } may open() in ∥:
  open(inner);                 }                   outer  inner

  needNewOuter ← true;         } local NLJ state
  o            ← NULL;         }
```

```
NLJ.close(outer,inner,θ):
  close(outer);
  close(inner);
```

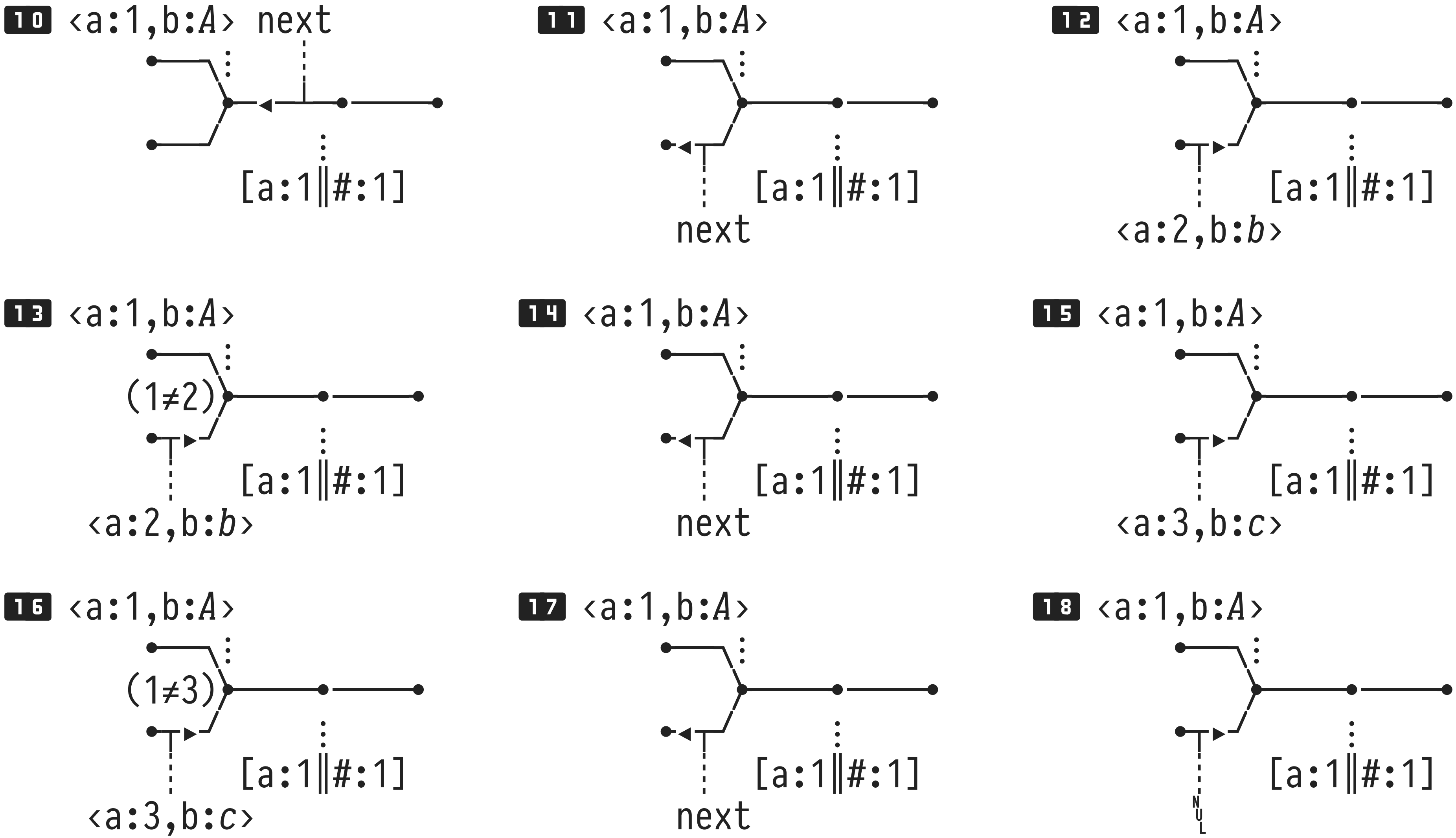
Pipelined Nested Loop Join (NLJ, cont'd)

```
NLJ.next(outer,inner,θ):
  forever
    if needNewOuter
      o ← next(outer);                 } o: current outer row
      if o = NULL                      } no more outer rows
        return NULL;                   }  ⇒ join complete
      needNewOuter ← false;
      close(inner);                    } reset/rescan
      open(inner);                     }  inner input

    i ← next(inner);                   } i: current inner row
    if i = NULL                        } no more inner rows,
      needNewOuter ← true;             }  next time: read new outer
    else if o θ i                      } join condition satisfied?
           return <o,i>;               } return single joined pair
```

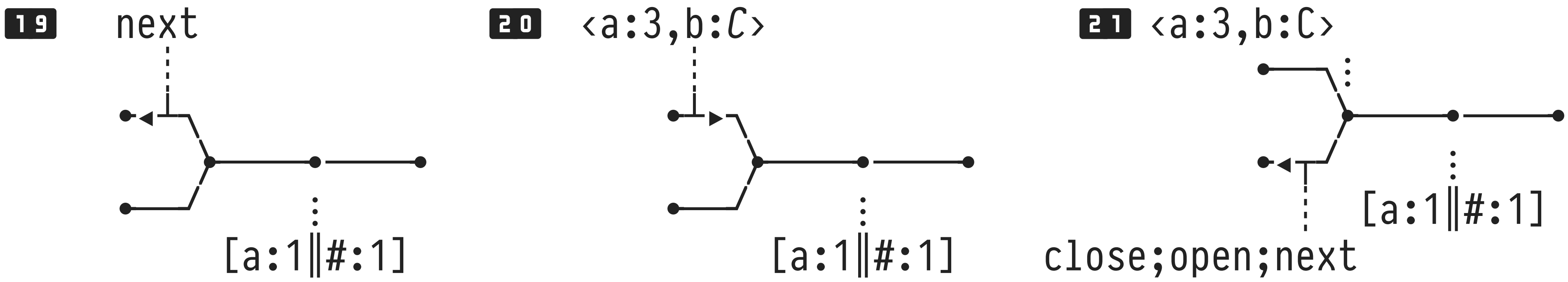
Volcano Iterator Model: Evaluating a NLJ Plan



Volcano Iterator Model: Evaluating a NLJ Plan



Volcano Iterator Model: Evaluating a NLJ Plan



Quiz/Exercise: Think about how to implement the following plan operators in the Volcano iterator model:

- Seq Scan (with Filter condition),
- Limit (given a row limit *n*),
- GroupAggregate (over input sorted by the Group Key),
- Append (SQL: UNION ALL).

Volcano Iterator Model at the SQL Level

Via **cursors**, the SQL standard exposes the Volcano-style open/next/close API at the level of (Embedded) SQL:

```
-- Generate query plan, no evaluation yet
❶ DECLARE ‹cursor› [ SCROLL ] CURSOR FOR ‹query›
--                          ⬑ cursor can move backwards

-- Evaluate plan to deliver the next/prior row (‹n› rows)
❷ FETCH [ NEXT | [ FORWARD | BACKWARD ] ‹n› ] FROM ‹cursor›

-- Release plan/intermediate buffers
❸ CLOSE ‹cursor›
```

- Statements need to be issued within an SQL transaction.

Volcano-Style Iteration has its Cost

- Effectively, **multiple operators are active at one time.**
  - Aggregate intermediate state (memory) may be large.
  - Method call forwarding incurs function call overhead.
  - Frequent switches between code blocks due to row-by-row processing, CPU instruction cache misses are likely.

- 💡 Modern RDBMSs (*e.g.*, *VectorWise*[3], *Umbra*) seek middle ground between full materialization and pipelining:
  - Build demand-driven pipeline between operators, but…
  - … pass **vectors of rows**—typically the size of the CPU's data cache—between operators.

[3] See *MonetDB/X100—A DBMS In The CPU Cache* and *MonetDB/X100: Hyper-Pipelining Query Execution*.