

DB 2

08 – Predicate Evaluation

Summer 2020

Torsten Grust
Universität Tübingen, Germany

1 | Q₇ — Predicate (or Filter) Evaluation

SQL's **WHERE/HAVING/FILTER** clauses use **expressions of type Boolean (predicates)** to filter rows. Predicates may use Boolean connectives (**AND, OR, NOT**) to build complex filters from simple predicate building blocks:

```
SELECT t.a, t.b
FROM   ternary AS t
WHERE  t.a % 2 = 0 AND [OR] t.c < 1  -- either AND or OR
```

Evaluate predicate for every row **t** scanned. Here:
assume that evaluation of the predicate is *not*
supported by a specific index. (⚠ Index support for
predicates is essential → see upcoming chapters.)



Using **EXPLAIN** on *Q₇*

EXPLAIN ANALYZE VERBOSE

```
SELECT t.a, t.b
FROM   ternary AS t           -- 1000 rows
WHERE  t.a % 2 = 0 AND t.c < 1;
```

QUERY PLAN

```
Seq Scan on ternary t (cost=... rows=1 ...) (actual time=... rows=4 ...)
  Filter: ((c < '1'::double precision) AND ((a % 2) = 0))
  Rows Removed by Filter: 996
Planning time: 2.125 ms
Execution time: 1.894 ms
```

- Filter predicate evaluated during **Seq Scan**.
- Estimated **selectivity** of predicate $1/1000$ (real: $4/1000$).



`t.a % 2 = 0 AND t.c < 1`: An Expression of Type `bool`

- In the absence of index support, use the regular expression interpreter to evaluate predicates:

```

SCAN_FETCHSOME(t, [a, c])
SCAN_VAR(c)
CONST(1)
? FUNCEXPR_STRICT(<, •, •)
  BOOL_AND_STEP_FIRST(•)
    SCAN_VAR(a)
    CONST(2)
    FUNCEXPR_STRICT(%, •, •)
    CONST(0)
    FUNCEXPR_STRICT(=, •, •)
  ↓
  BOOL_AND_STEP_LAST(•)

```


if • = *false*, immediately yield *false*
 # (∧ semantics: *false* ∧ *p* = *false*)

yield • (∧ semantics: *true* ∧ *p* = *p*)

- Uses jumps (....) in program to implement **Boolean shortcut**.



Heuristic Predicate Simplification

- Predicate evaluation effort is multiplied by the number of rows processed. **Even small simplifications add up.**
- PostgreSQL performs basic predicate simplifications:
 - Reduce constant expressions to `true/false`.
 - Apply basic identities (e.g., `NOT(NOT(p)) ≡ p` and `(p AND q) OR (p AND r) ≡ p AND (q OR r)`).
 - Remove duplicate clauses (e.g., `p AND p ≡ p`)
 - Apply De Morgan's laws.
-  These are **heuristics** (expected to improve evaluation time): selectivity is *not yet* taken into account.

Machine-Generated Queries and Predicate Simplification

Automatically generated SQL text may differ significantly from human-authored queries. Consider a web search form:

⊗ Search ternary...

a:

c:

1. User enters search keys for columns **a** and/or **c**.
2. Web form maps missing keys to **NULL** (interpret as wildcard).
3. DBMS executes parameterized query:

```

SELECT t.*
FROM   ternary AS t
WHERE  (t.a = :a OR :a IS NULL)
        AND (t.c = :c OR :c IS NULL)
  
```



Heuristics May Not Be Enough

- Heuristics only go so far. The (estimated) **cost** of evaluation may suggest better predicate rewrites:

SELECT t.* FROM ternary_10m AS t WHERE	length(btrim(t.b, '0...9')) < length(t.b) OR t.a % 1000 <> 0	(expected) cost
p_1	p_2	<div style="display: inline-block; width: 100px; height: 10px; background-color: black; margin-bottom: 5px;"></div> <div style="display: inline-block; width: 100px; height: 10px; background-color: black;"></div>

- With Boolean shortcut it makes a difference which disjunct is evaluated first. (Both predicates not selective, p_1 : 85.9%, p_2 : 99.9% of 10^7 rows pass.)

⇒ Many optimizer decisions indeed *are* **cost-based**.

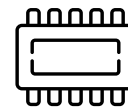
2 : Q_7 — Predicate (or Filter) Evaluation



```
SELECT t.a, t.b
FROM   ternary AS t
WHERE  t.a % 2 = 0 AND [OR] t.c < 1  -- either AND or OR
```

MonetDB can evaluate basic predicates on individual column BATs (here: **a** and **c**) ❶ but then needs to

1. derive the result of composite predicates ❷ and
2. propagate the filter effect to all output columns (here: **a**, **b**) ❸ to form the final selection result.

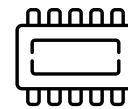


Using **EXPLAIN** on Q_7 (Boolean Connective: **OR**)

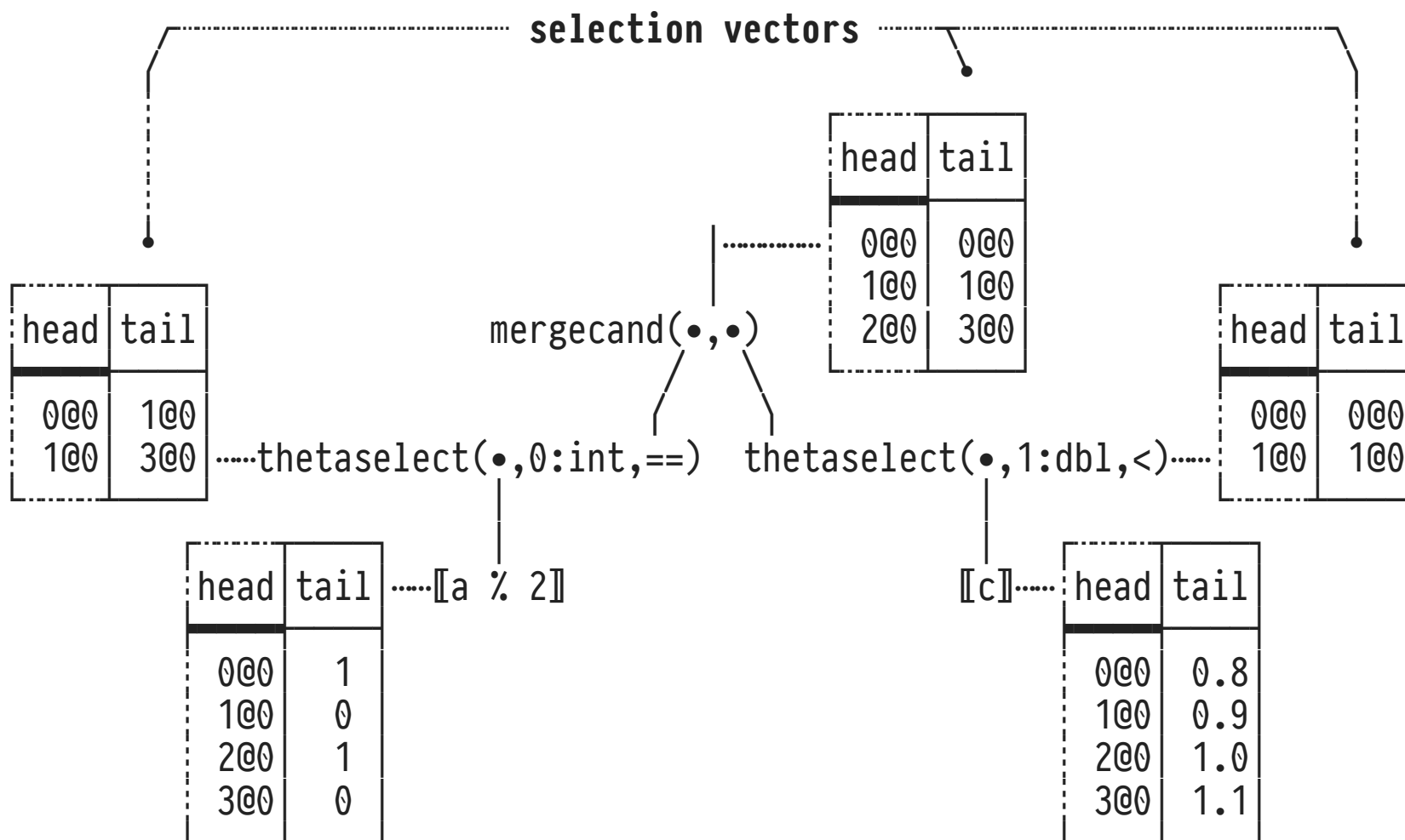
```

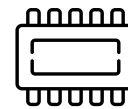
sql> EXPLAIN SELECT t.a, t.b
      FROM   ternary AS t
      WHERE  t.a % 2 = 0 OR t.c < 1;
:
ternary :bat[:oid] := sql.tid(sql, "sys", "ternary");
a0      :bat[:int] := sql.bind(sql, "sys", "ternary", "a", 0:int);
a       :bat[:int] := algebra.projection(ternary, a0);
e1      :bat[:int] := batcalc.%(a, 2:int);           ─ a % 2
1 p1    :bat[:oid] := algebra.thetaselect(e1, 0:int, "=="); ─ p1 ≡ a % 2 = 0
c0      :bat[:dbl] := sql.bind(sql, "sys", "ternary", "c", 0:int);
c       :bat[:dbl] := algebra.projection(ternary, c0);
1 p2    :bat[:oid] := algebra.thetaselect(c, 1:dbl, "<");   ─ p2 ≡ c < 1
2 or    :bat[:oid] := bat.mergeconj(p1, p2);             ─ p1 ∨ p2
b0      :bat[:str] := sql.bind(sql, "sys", "ternary", "b", 0:int);
3 bres  :bat[:str] := algebra.projectionpath(or, ternary, b0); ─ result col b
3 ares  :bat[:int] := algebra.projection(or, a);          ─ result col a
:

```



Result of a Predicate \equiv Selection Vectors





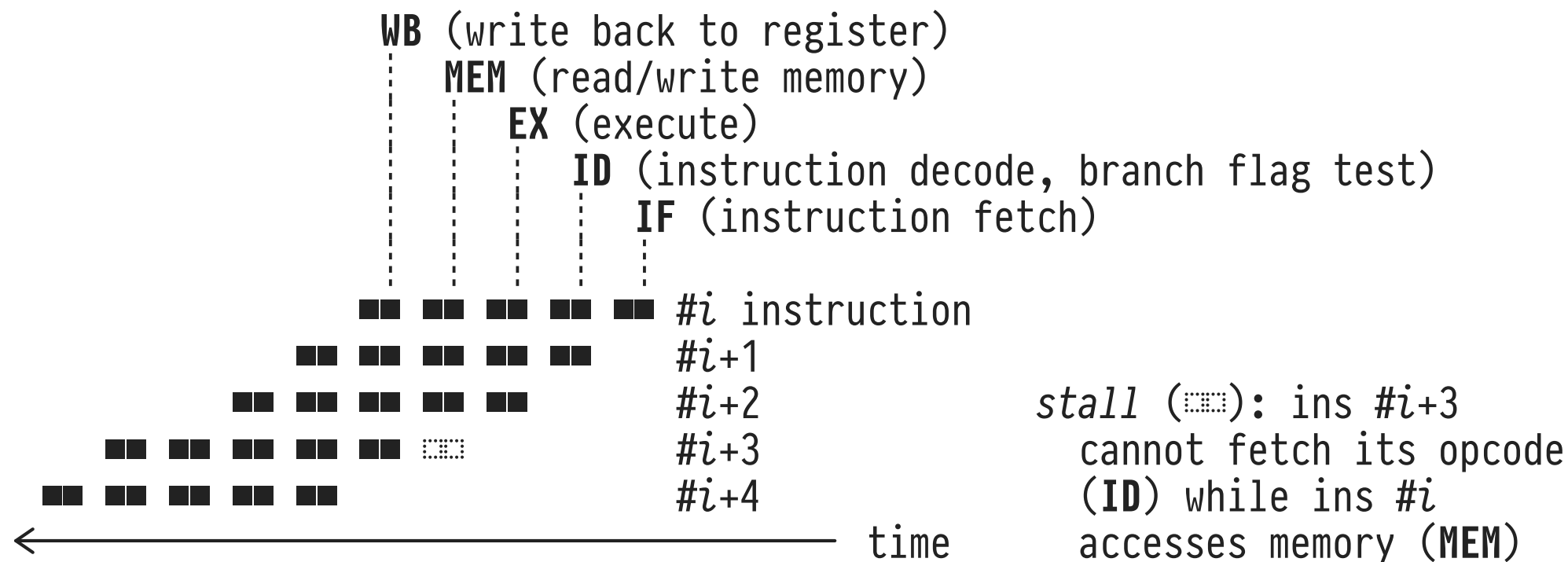
Selection Vectors (also: Candidate Lists)

- **Selection vector** `sv`: BAT of type `bat[:oid]`.
 $i@0 \in sv \iff i\text{th input row satisfies filter predicate.}$
- Use `algebra.projection(sv, col)` to propagate filter effect to column `col`.
- Implement Boolean connectives for predicate p_i with sv_i :
 - p_1 OR p_2 : `bat.mergecand(sv1, sv2)`
 - p_1 AND p_2 : `algebra.projectionpath(sv2, sv1, •)` with

$$\text{algebra.projectionpath}(sv_2, sv_1, \bullet) \equiv \text{algebra.projection}(sv_2, \text{algebra.projection}(sv_1, \bullet)).$$

Instruction Pipelining in Modern CPUs

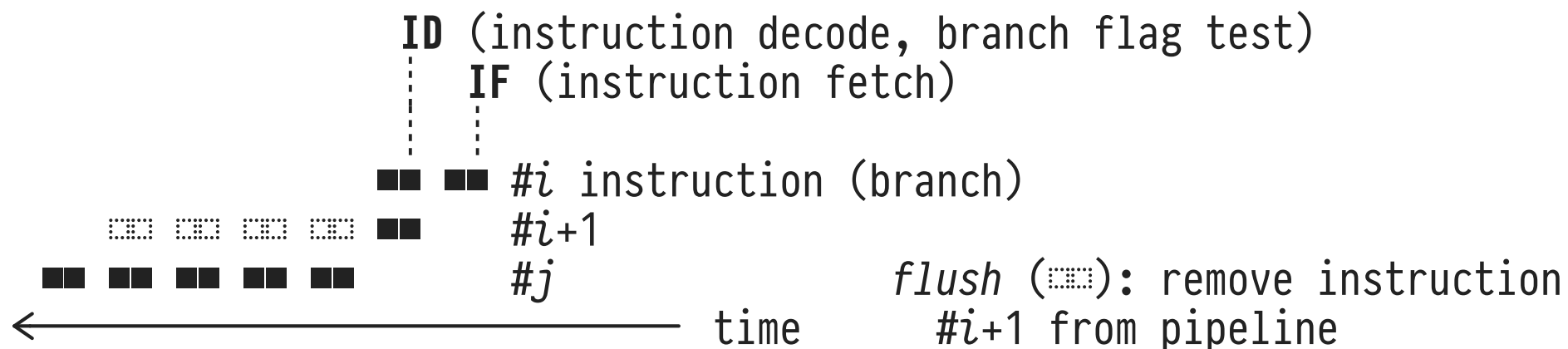
Control flow branches (**for**, but particularly **if**) are a challenge for modern pipelining CPUs:



Branch Taken? Yes, Flush Pipeline

This pipeline decides the outcome of branch $\#i$ (end of **ID**) only *after* instruction $\#i+1$ has already been fetched (**IF**):

- If the branch is taken, **flush** instruction $\#i+1$ from pipeline ☹, instead fetch instruction $\#j$ at jump target:



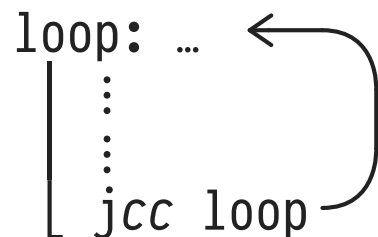
Branch Prediction: History and Heuristics

CPUs thus try to **predict the outcome of a branch #i** based on **earlier recorded outcomes** of the same branch:

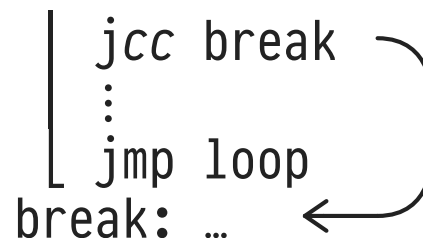
Branch prediction	Fetch instruction
<i>taken</i>	<i>#j</i>
<i>not taken</i>	<i>#i+1</i>

- Also: **heuristics** based on typical control flow patterns:


Predicted *taken*

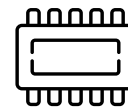


Predicted *not taken*



Avoiding Branch Mispredictions

- A **mispredicted branch**  leads to
 1. pipeline flushes—effectively a stall—and
 2. (possibly) instruction cache misses.
- The resulting runtime penalty indeed is significant \Rightarrow DBMSs aim to avoid branch mispredictions in tight inner loops:
 - prefer branch-less implementations of query logic,
 - reduce number of random/hard-to-predict branches.

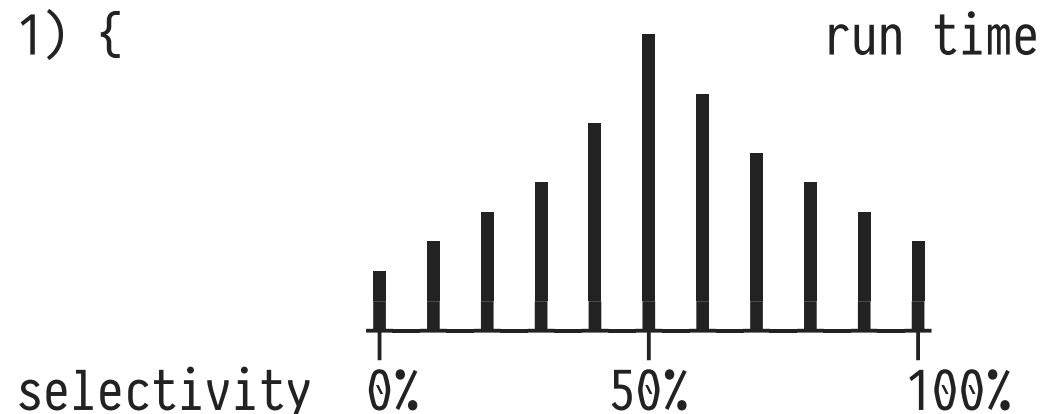


MonetDB: Branch-Less Selection ②

```

1 for (int i = 0; i < SIZE; i += 1) {
    if (col[i] < v) {
        sv[out] = i;
        out += 1;
    }
}

```

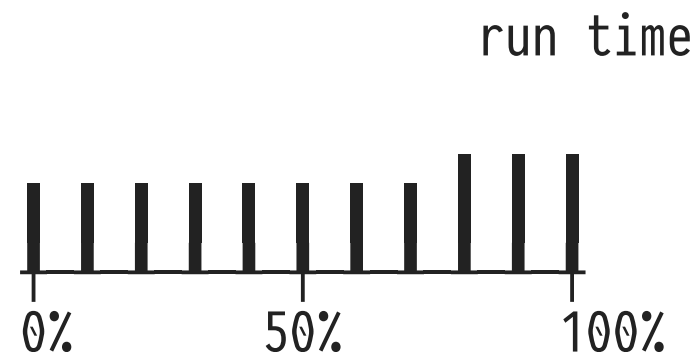


```

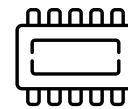
2 for (int i = 0; i < SIZE; i += 1) {
    sv[out] = i;
    out += (col[i] < v);
}

```

$\equiv 1$ if predicate satisfied, else 0



②: Only well-predictable loop control flow (**for**) remains.



Mixed-Mode Selection

There is an entire space of possibilities to implement composite predicates (e.g., the conjunction p_1 AND p_2):

- Use branch-less selection via $\text{out} += p_1 \ \& \ p_2$ (note use of C's bit-wise *and* operator $\&$).
- Identify the *more selective*¹ (and thus more predictable) conjunct p_1 , say, then use

```
if ( $p_1$ ) {  
    sv[out] = i;  
    out += ( $p_2$ );  
}
```

¹ This is important. Using $\text{if } (p_2) \dots$ instead, where p_2 is unpredictable, immediately ruins the plan.