FluiDB: Adaptive storage layout using reversible relational operators

<Subtitle>

Christos Perivolaropoulos

University of Edinburgh

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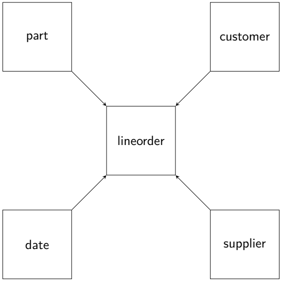
FluiDB at a glance

- FluiDB is an intermediate result (IR) recycling, in-memory RDBMS
- FluiDB materializes all intermediate results and garbage collects when she runs out of space, unifying **query planning and IR recycling**
- Radical approach to IR recycling: **adapt** data layout to the workload:
    - enable **efficient plans**
    - constrained (quality) **budget**
- The main novelty relates to the introduction of **reversible relational operations** which affords a new perspective on query planning and view selection.

Example 1: Workload based on template query

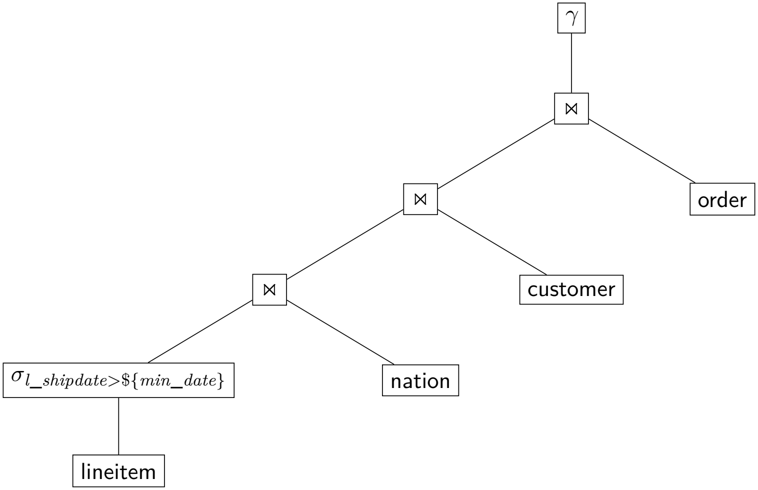
${min_date}is instantiated for each query in the workload.

```
select      n_name, avg(l_discount)
from        lineitem, customer, nation, order
where       l_orderkey = o_orderkey
and         c_custkey = o_custkey
and         c_nationkey = n_nationkey
and         l_shipdate > ${min_date}
group by    n_name
```

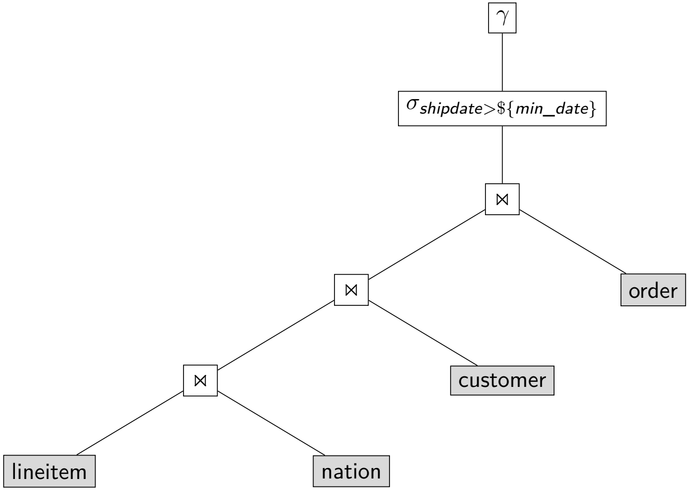


Example 1: Traditional single-query plan

Selection push down



Example 1: Adapt to workload



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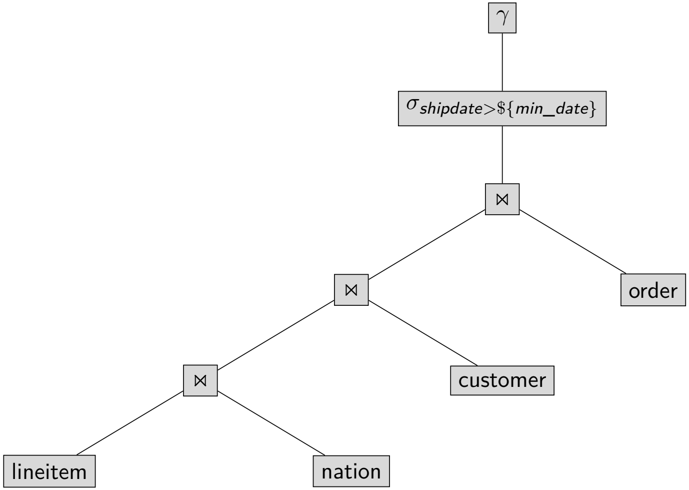

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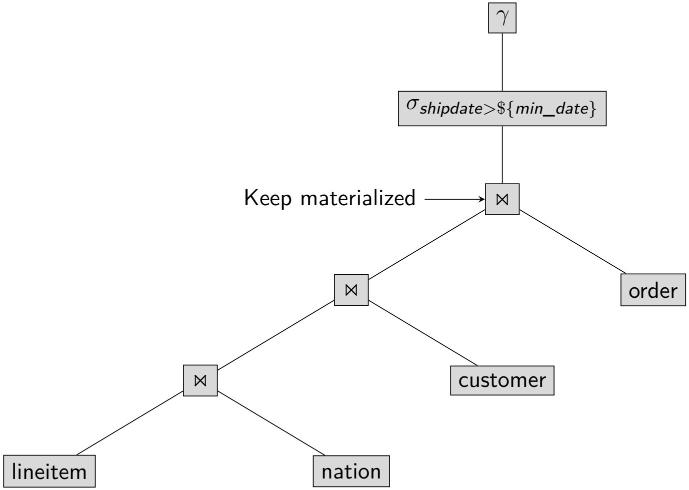

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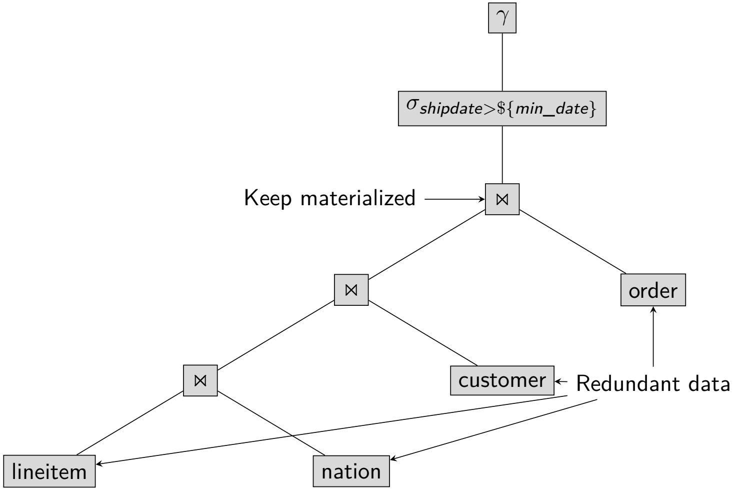

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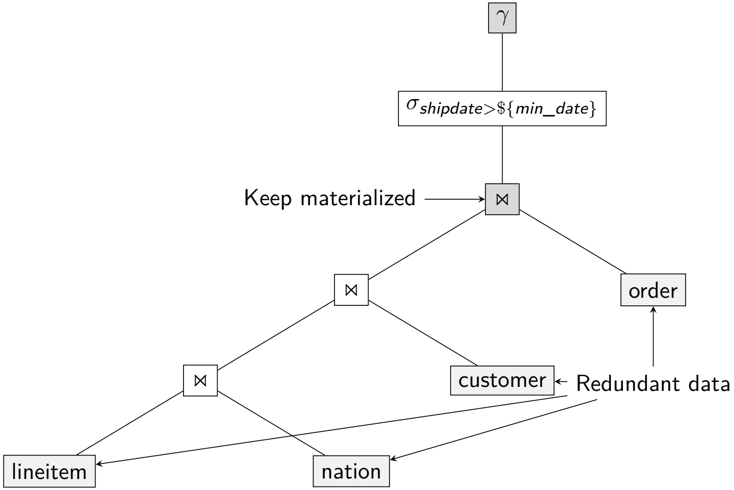
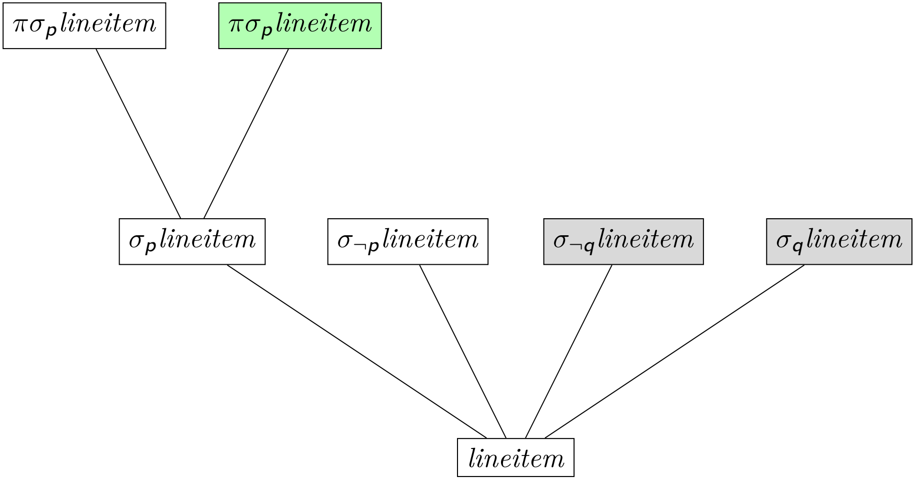


Example 2: Plan with missing primary data



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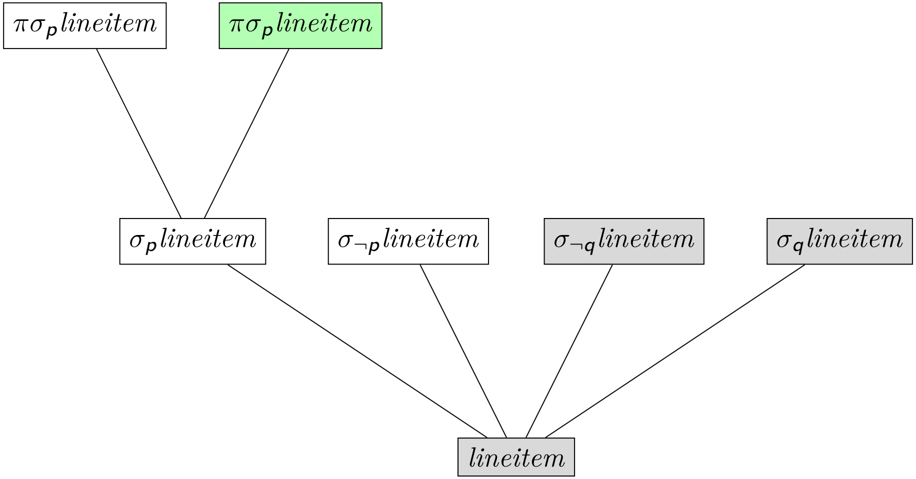

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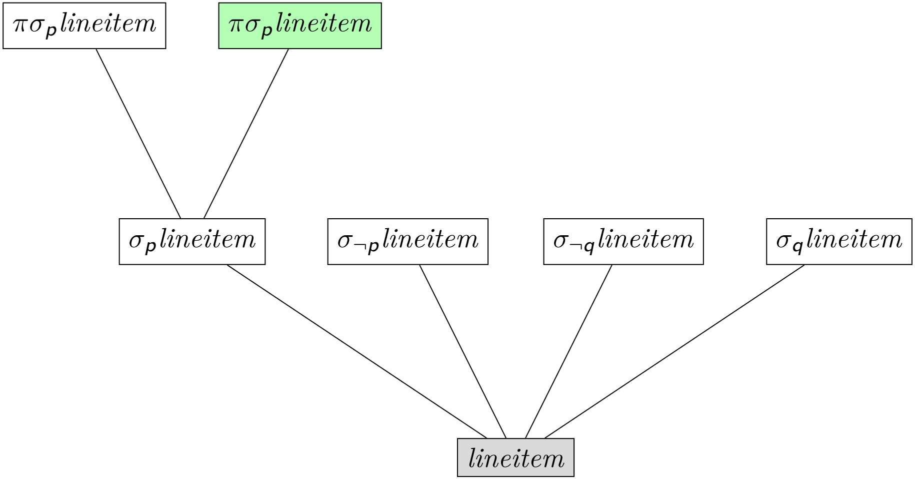

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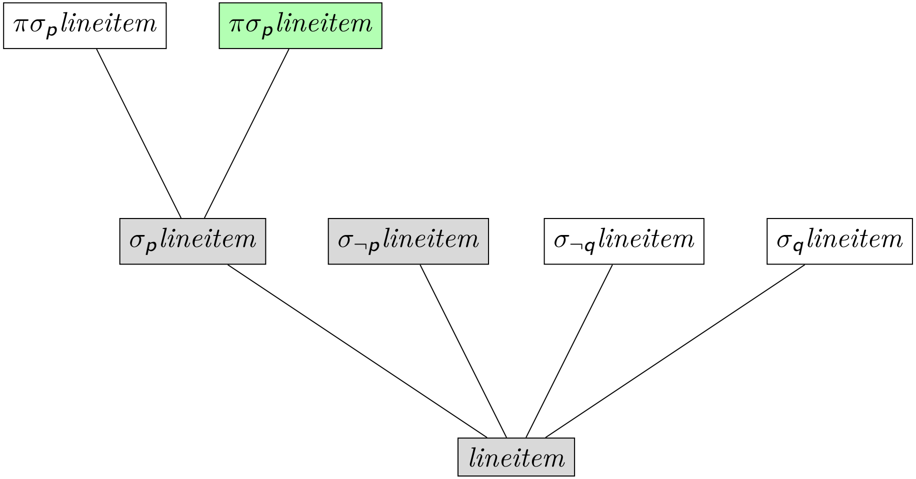

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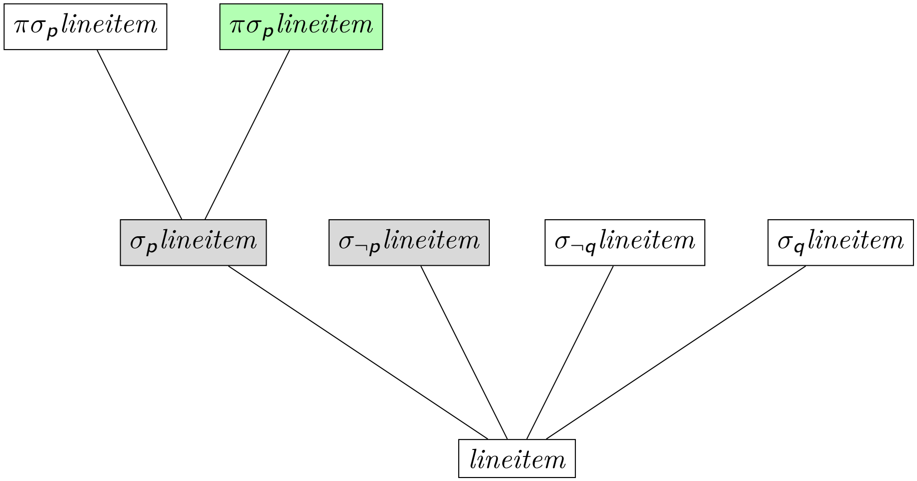

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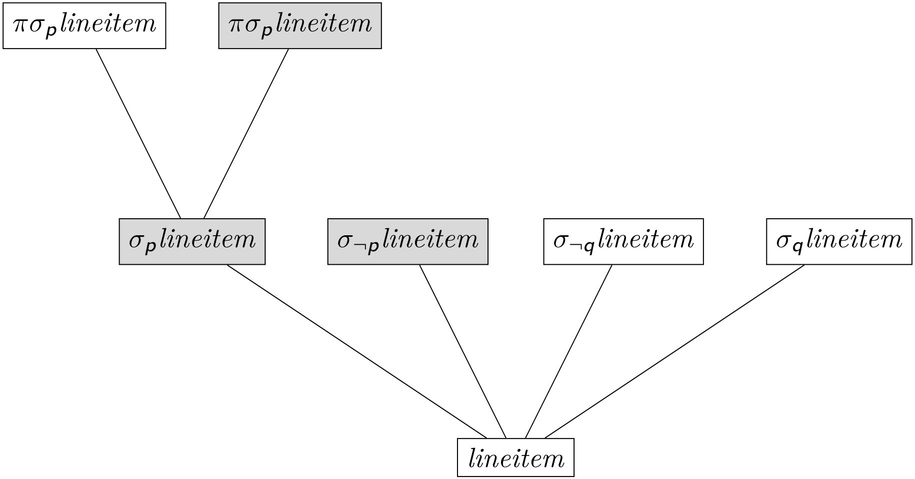
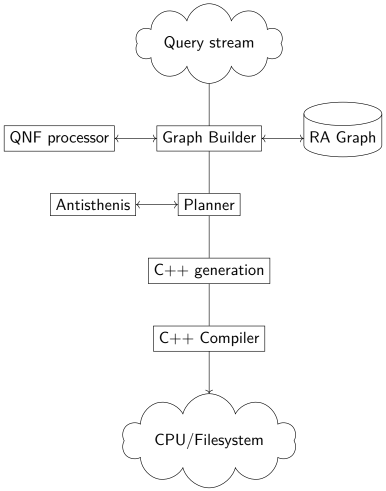


The interesting components

- Graph management and query normal form representation
- Logical planning infrastructure
- Antisthenis: An incremental numeric evaluation system for cost estimation.
- Logical planning algorithm and garbage collector
- Code generation system.

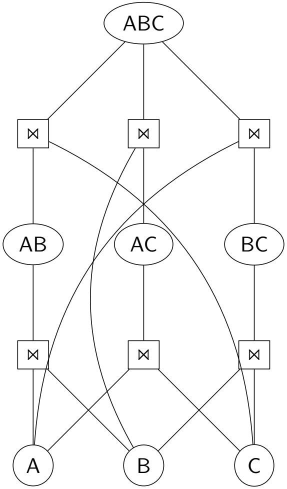
Architecture



Logical planning

- Bipartite query graph – RA operations/relations unified for all queries
- Join ordering enumeration
- QNF – $\pi\sigma(Q_1 \times Q_2 \times \dots)$ or $\gamma\sigma(Q_1 \times Q_2 \times \dots)$

AND/OR DAG (join ordering enumeration)



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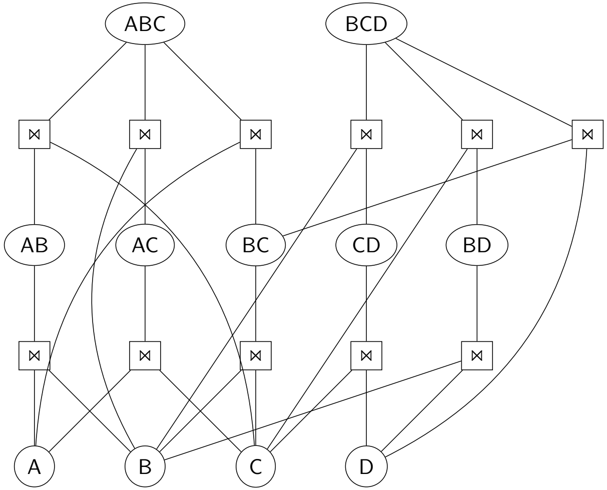
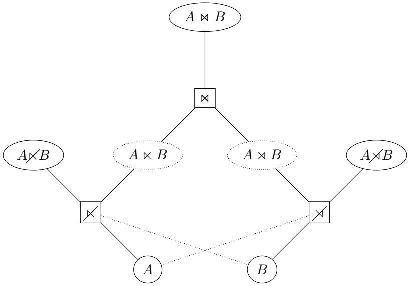
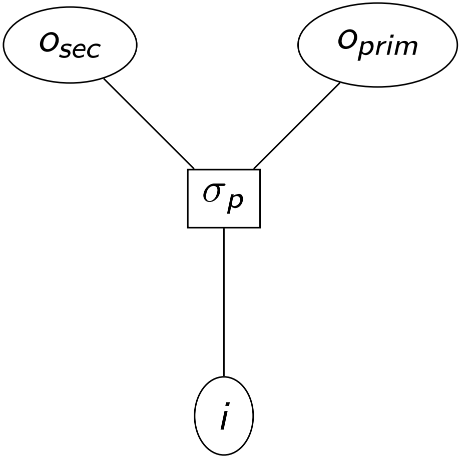
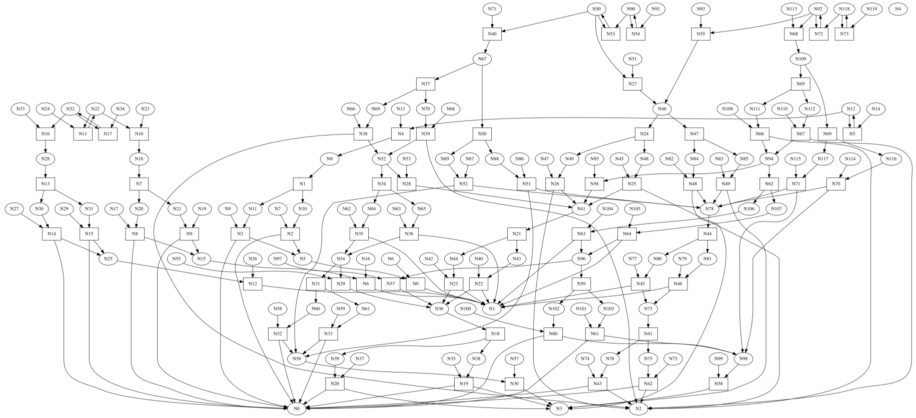


Reversible operators





Reversible operations



Planning algorithm [TODO shapes]

- A network with reverse nodes
- Check depsets for materializable
- Chose an output set
- Garbage collect to create the output set
- Halt by combining
  - History cost
  - Current tirgger
  - Input cost
- Recurse on chosen inputs
- Mark outputs as materialized

Antisthenis

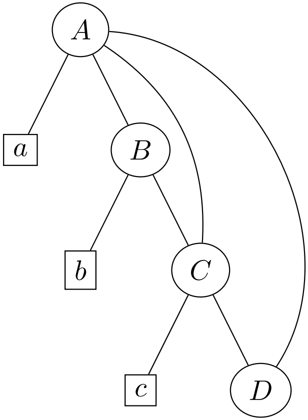
Dynamically scheduled incremental computation

Materializablility and cost inference are numerical operations:

- Input is mostly the same between runs: **incremental**.
- **Order of computation** highly affects the performance (eg absorbig elements, min).
- Self referrential computations may appear earlier than the absorbing element.

Antisthenis: Expression graphs

$$A = a + B + C + D$$
$$B = C \times b$$
$$C = D + c$$
$$D = 0$$



Antisthenis: Absorbing element

$$A = B \times C \times D$$

$$B = \sum_i i$$

$$C = 10 - 10$$

$$D = \sum_i i$$

Antisthenis: Early stopping – recursive expressions

While expressions may be self-referential, we can sometimes still evaluate them.

$$\begin{aligned}
A &= min(B, C, D) \\
B &= b_1 + b_2 \cdot D \\
C &= c_1 + c_2 \cdot A \\
D &= d_1 + d_2 \cdot B
\end{aligned}$$

$$\begin{aligned}
b_1 &= b_2 = d_1 = d_2 = 1 \\
c_1 &= 3 \\
c_2 &= 0
\end{aligned}$$

Kinds of operations: Materializability

$$matable(n) := \bigvee_{depset \in depsets(n)} \bigwedge_{dep \in depset} mat(dep) \vee matable(dep)$$

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- Recursive – normally we would maintain a visited set.
- Incremental evaluation is inhibited.
- Bot $\wedge$ and $\vee$ have absorbing elements.

Kinds of operations: Estimated cost

$$cost(n) := \min_{depset \in depsets(n)} \left[cost_{op}(operator(depset)) + \sum_{dep \in depset} \neg mat(n) \cdot cost(dep) \right]$$

Kinds of operations: Estimated cost

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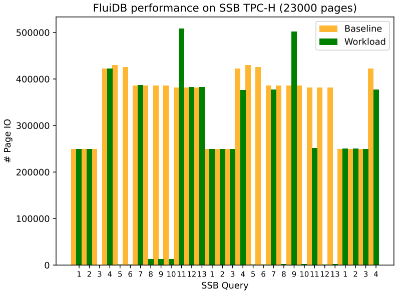
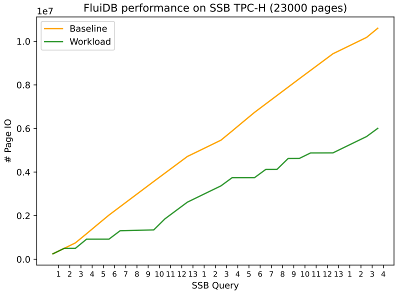
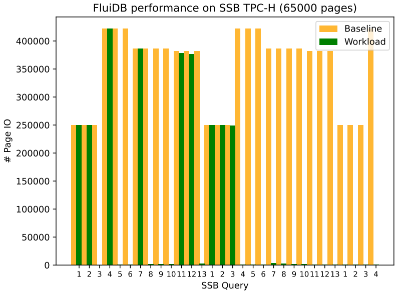
- Recursive – Incremental evaluation is inhibited.
- $\min$ can be exploited for early stopping

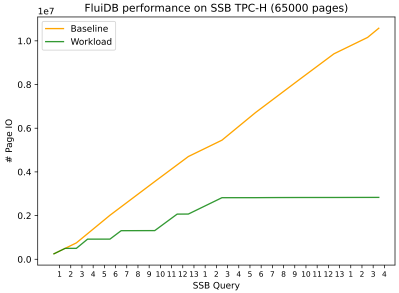
Evaluation: 23K pages budget





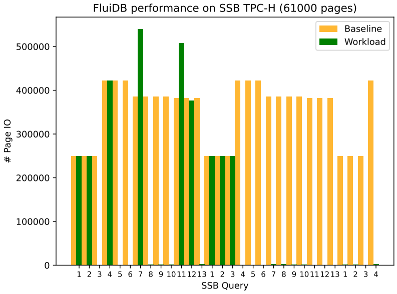
Evaluation: 65K pages budget

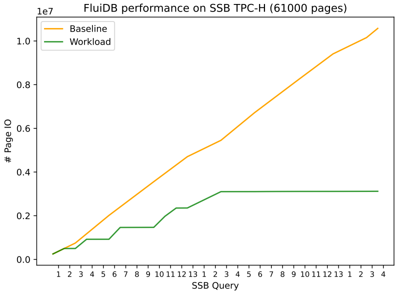




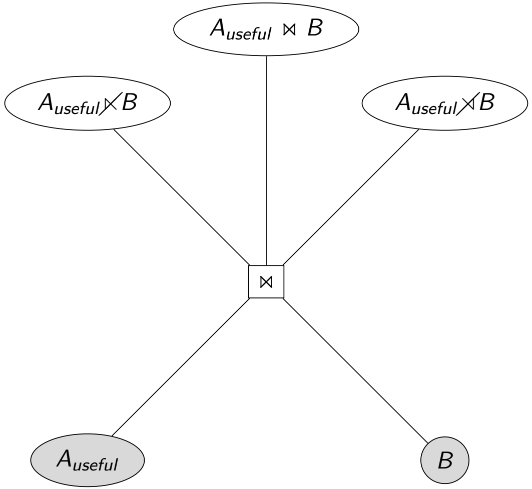
Evaluation: But ... 61K pages budget

lineorder is deleted at 6 because all join outputs were materialized





Plenty of memory



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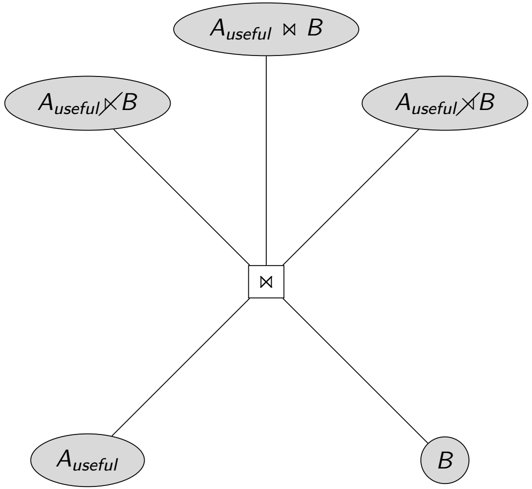

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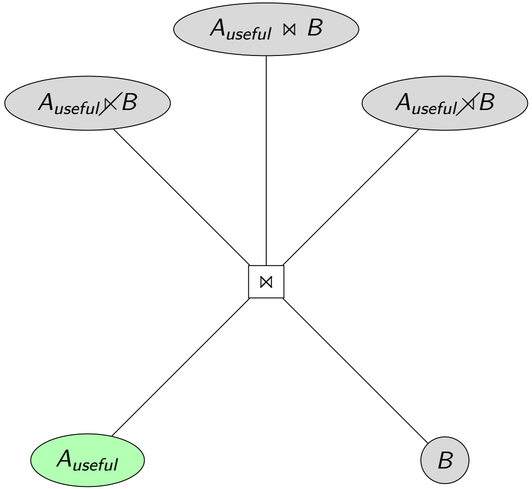
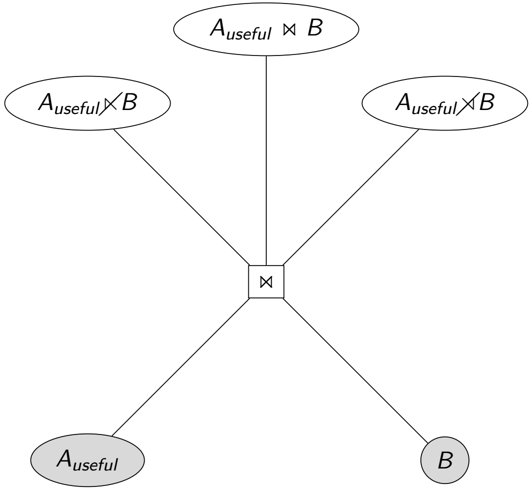


Being on a budget



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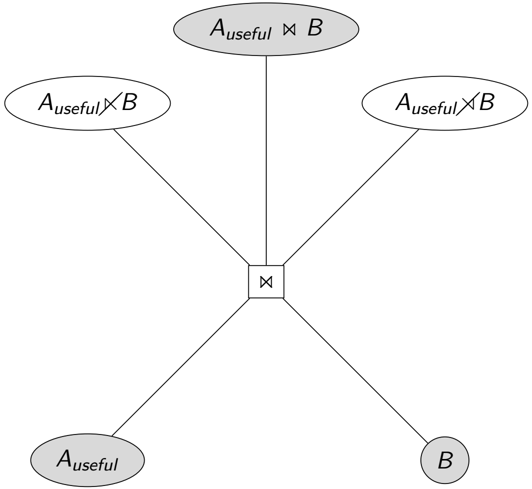

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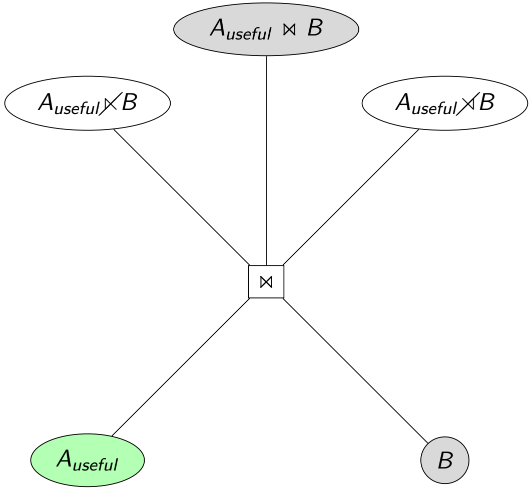
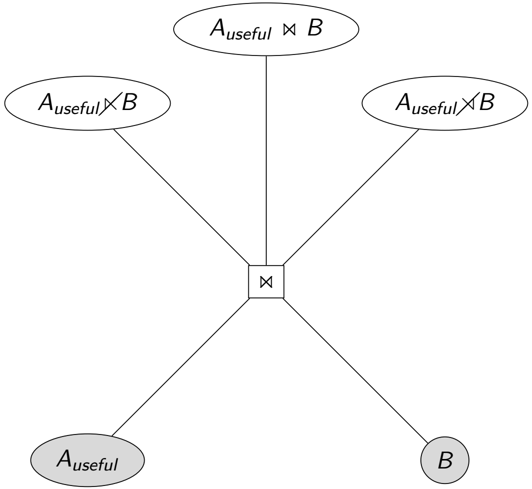


Having just enough rope



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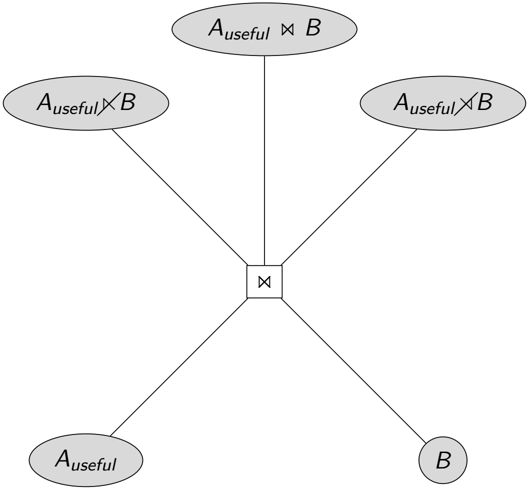

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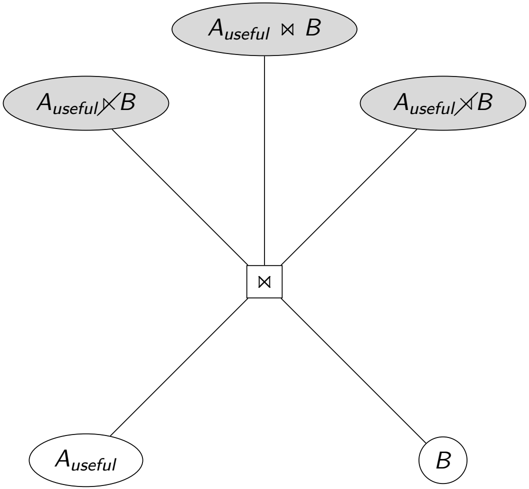

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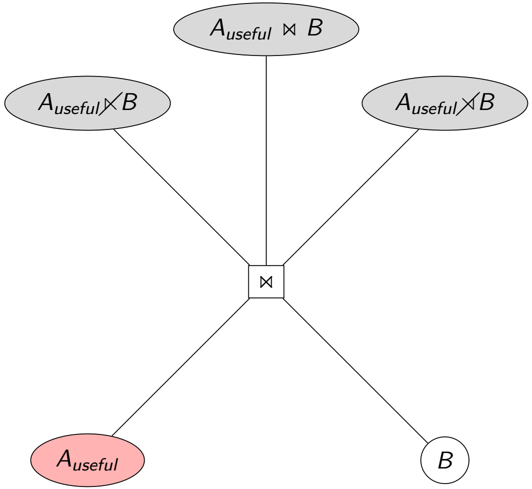

Conclusions

- FluiDB can efficiently use memory budget to store useful intermediate results.
- FluiDB is virtually always better than the naive case.
- FluiDB can incrementally adapt to the workload.