FluiDB: Adaptive storage layout using reversible relational operators

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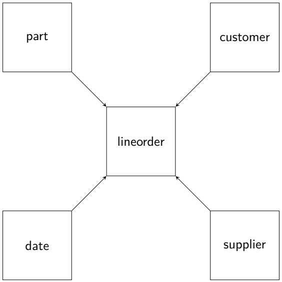
FluiDB at a glance

- 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

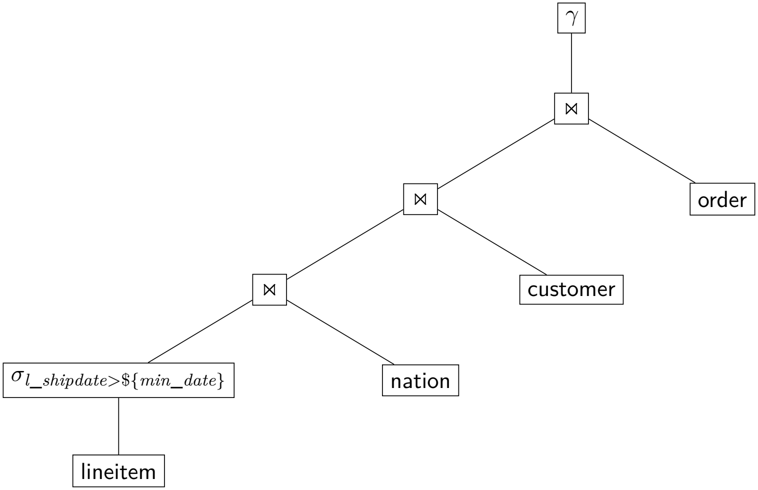
${min_date}is instantiated for each query in the workload.

```
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
```

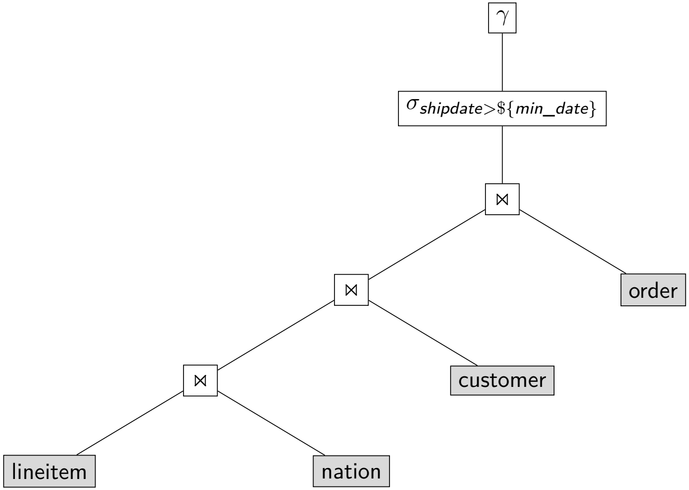


Example 1: Traditional single-query plan

Selection push down



Example 1: Adapt to workload



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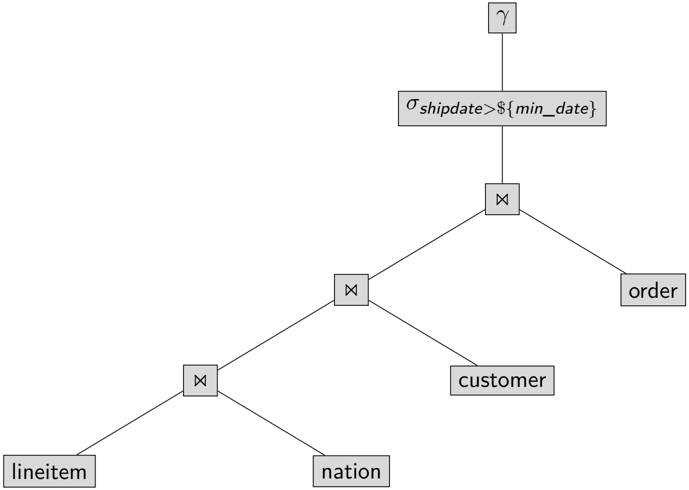

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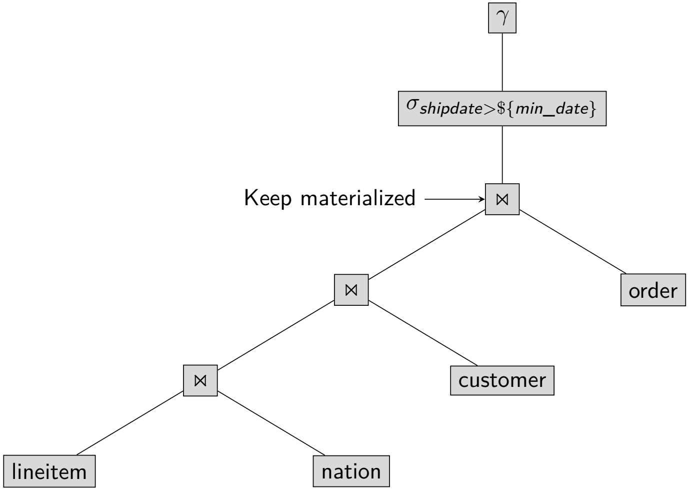

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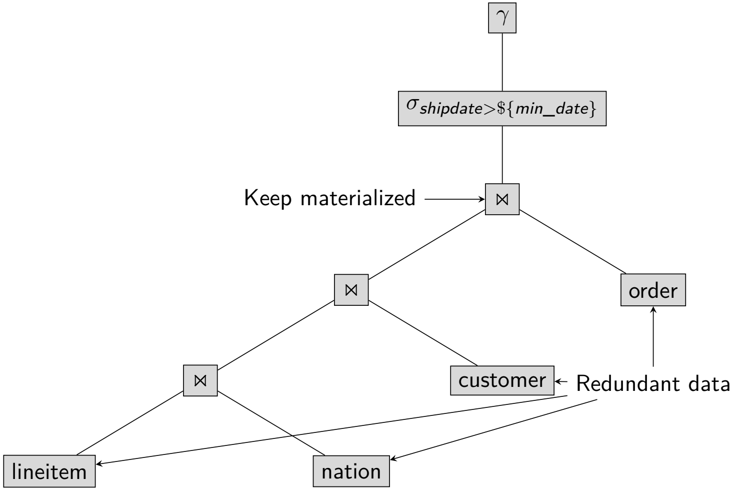

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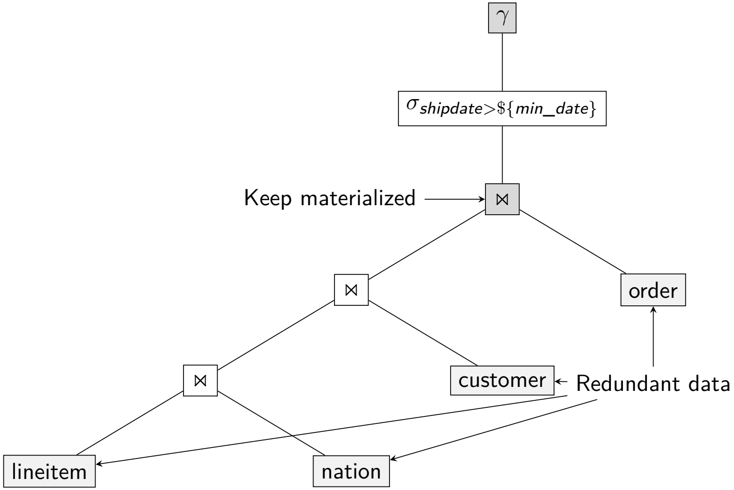
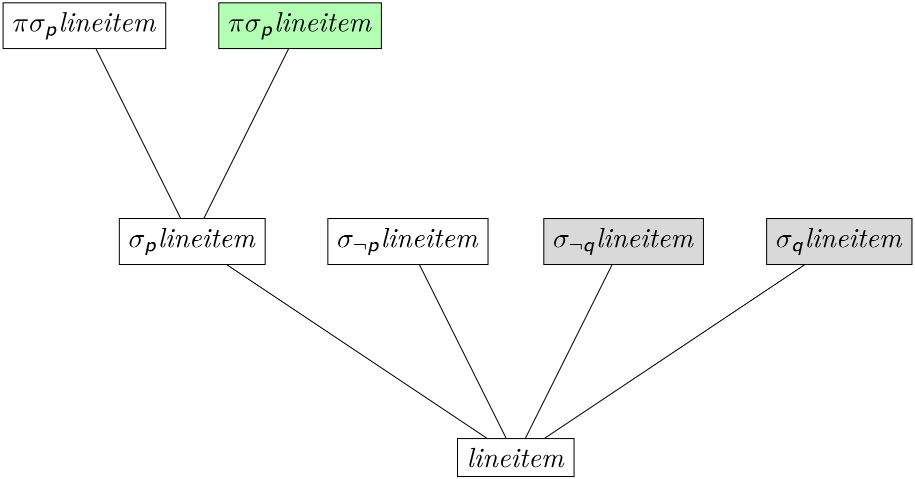


Example 2: Plan with missing primary data



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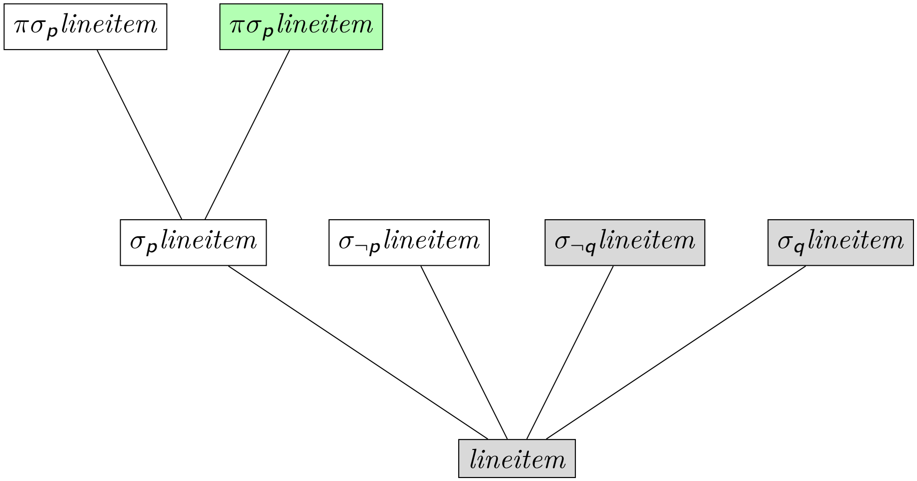

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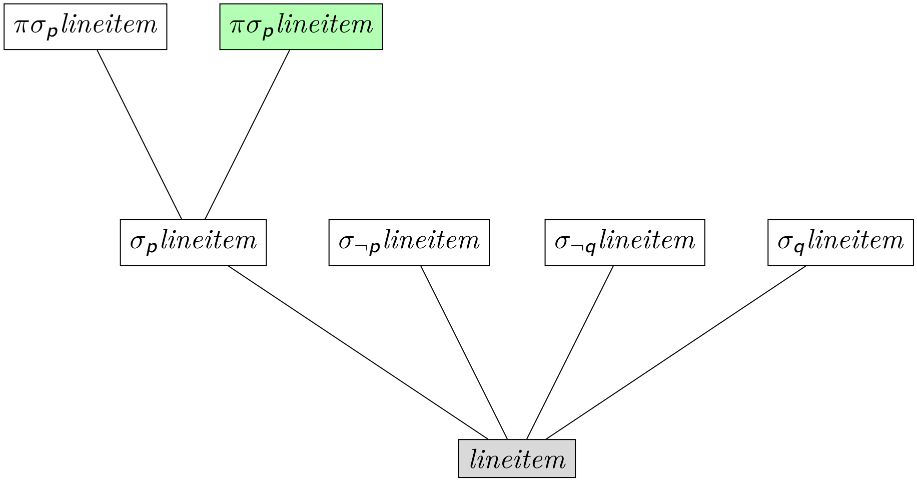

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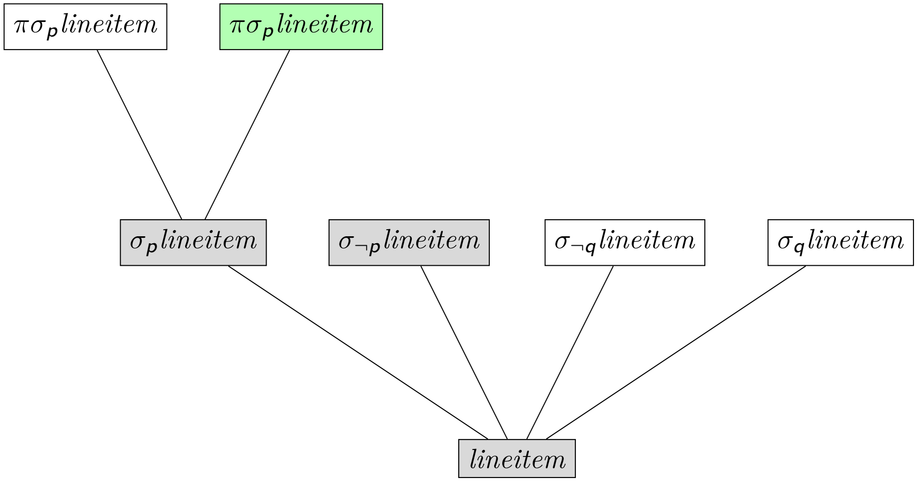

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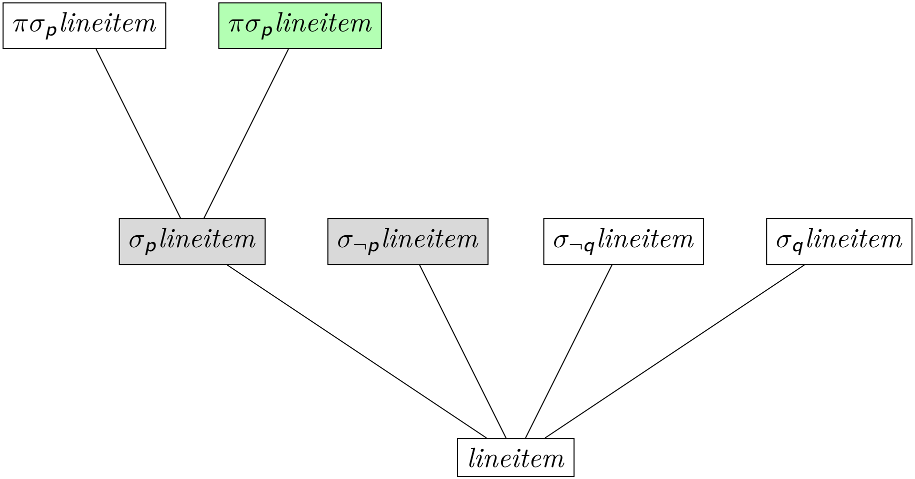

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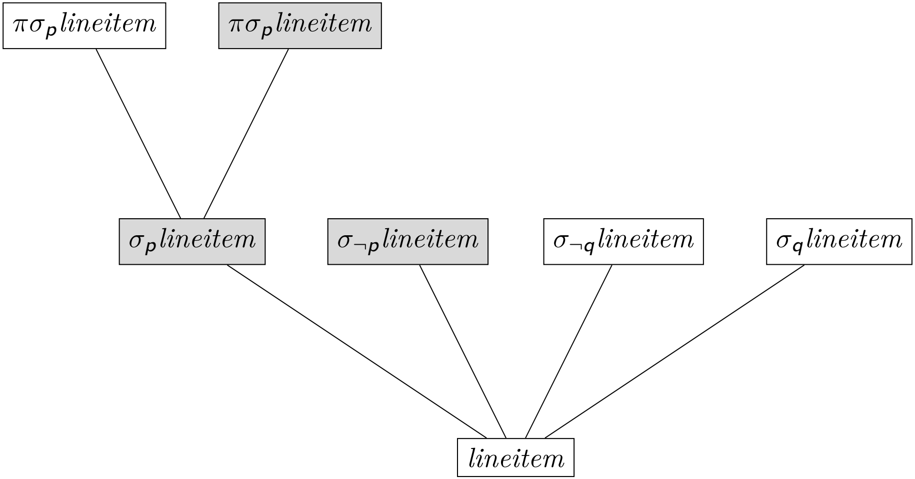
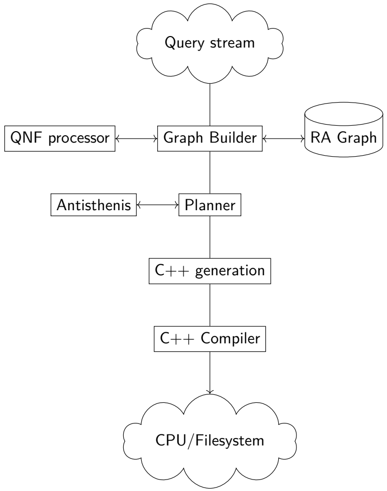


The interesting components

- 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

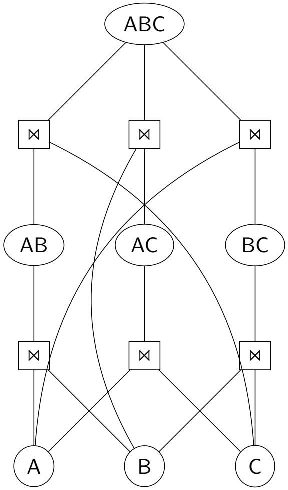
Architecture



Query graph management

- 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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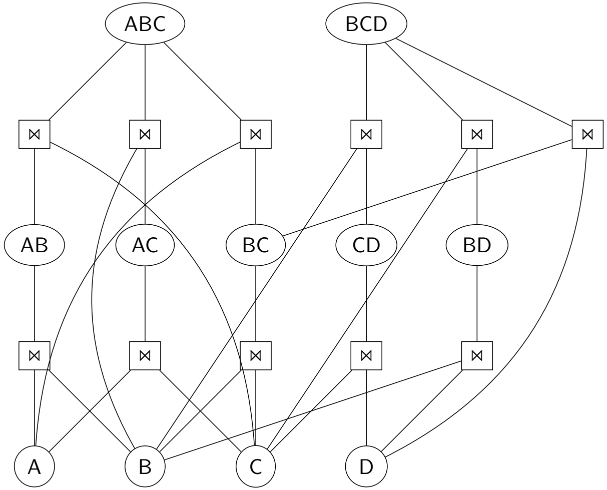
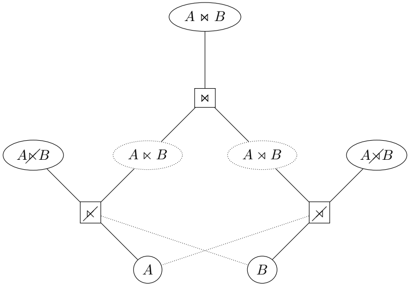
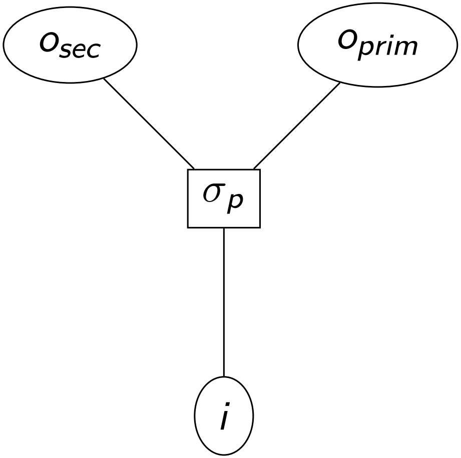
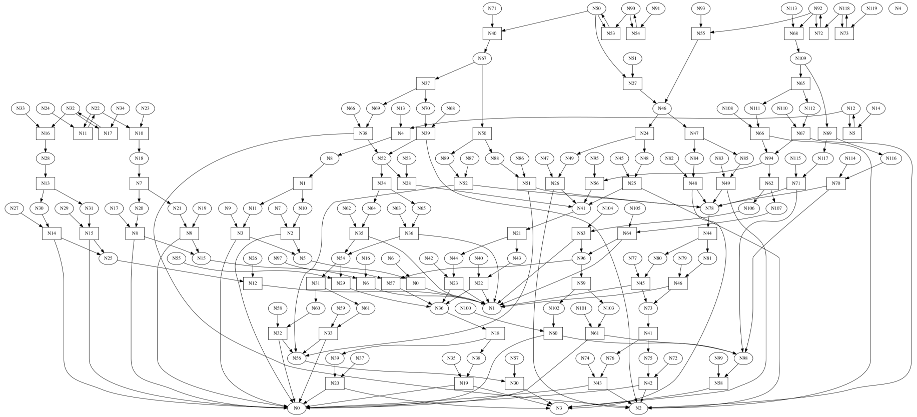


Reversible operators





Reversible operators

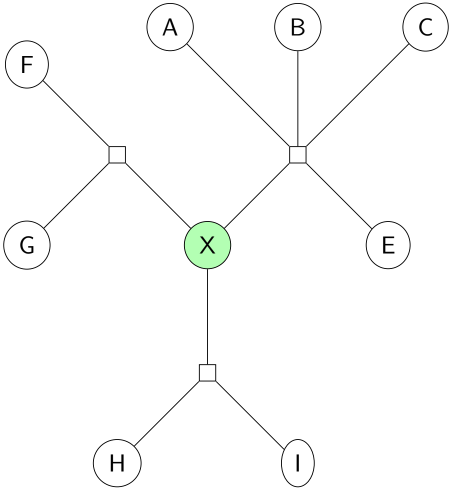


Planning algorithm overview

- A network with reverse nodes
- Check depsets for materializable
- Chose an output set
- Halt by combining
  - Cost of operations so far.
  - Cost of historical costs given the materialized nodes.
  - Expected cost of input.
- Recurse on chosen inputs.
- Garbage collect to make space for the output set
- Mark outputs as materialized and register the operator as tirggered.

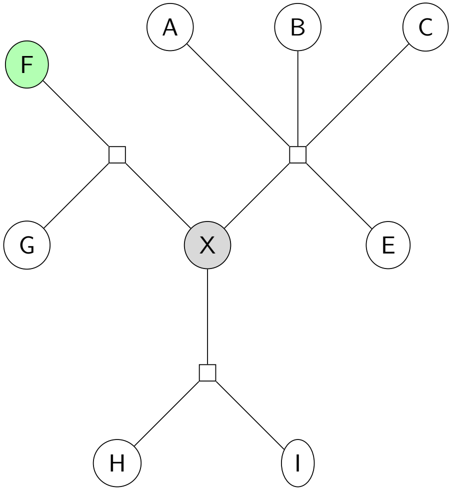
Planning algorithm

Materialize node X (if it is not already materialized)



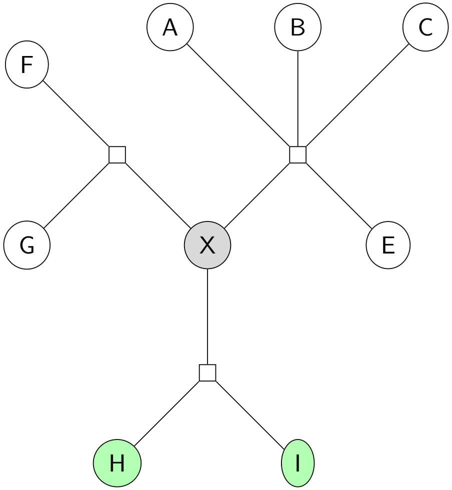
Planning algorithm

For each (materializable) input set



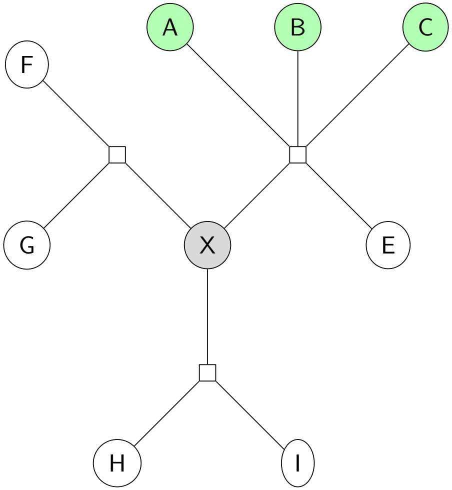
Planning algorithm

For each (materializable) input set



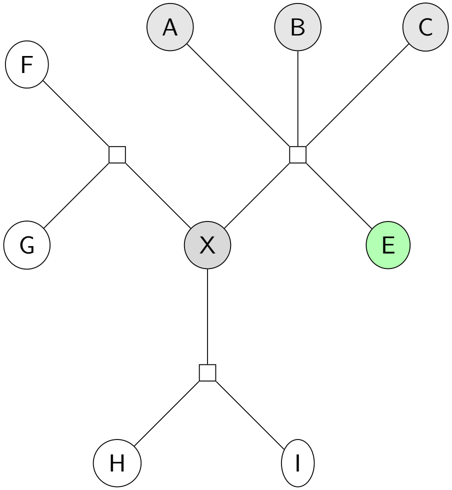
Planning algorithm

For each (materializable) input set



Planning algorithm

For each output set containing the node



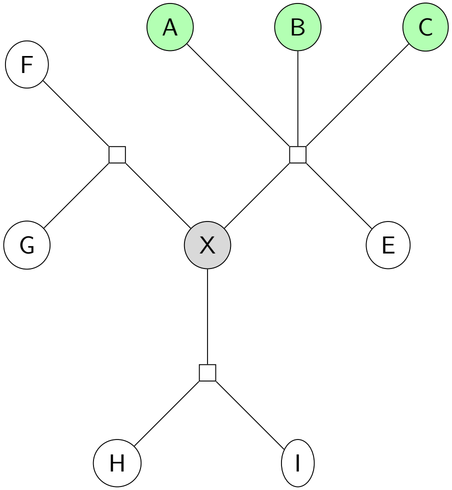
Planning algorithm

Schedule the current branch

$$priority = \sum_{op \in \text{planned ops}} cost(op) + \sum_{h \in hist.} cost_{stoch.}(h) + \sum_{d \in deps} cost_{exp.}(d)$$

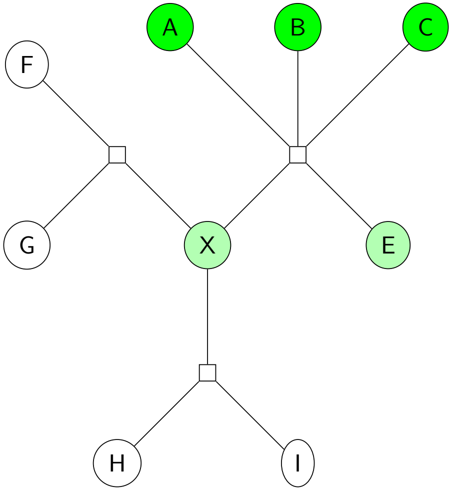
Planning algorithm

Recursively materialize the inputs



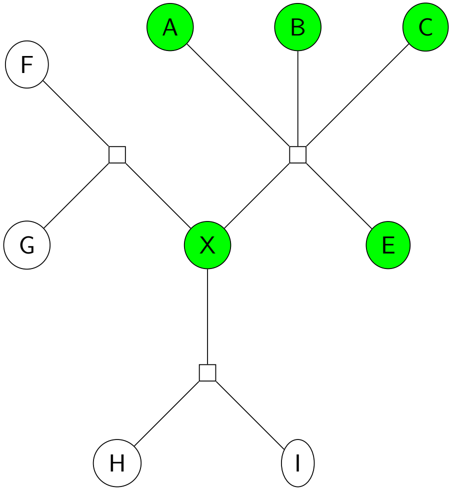
Planning algorithm

Once the inputs are materialized, garbage collect to make room for the outputs



Planning algorithm

Mark the outputs as materialized and register the operator for the plan



Profit!

💰

Antisthenis

Dynamically scheduled incremental computation

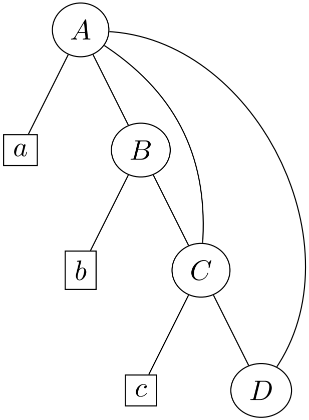
Materializablility and cost inference are numerical operations:

- 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

Variable name $\mapsto$ expression, leaf variables

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



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

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

Kinds of operations: Estimated cost

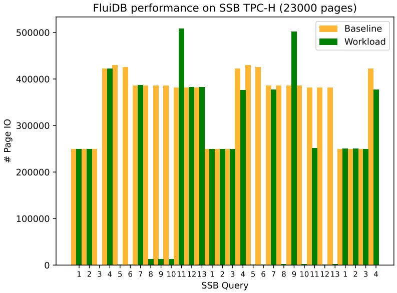
$$cost(n) := \min_{depset \in depsets(n)} \left[cost_{op}(operator(depset)) + \textstyle\sum_{dep \in depset} \neg mat(n) \cdot cost(dep) \right]$$

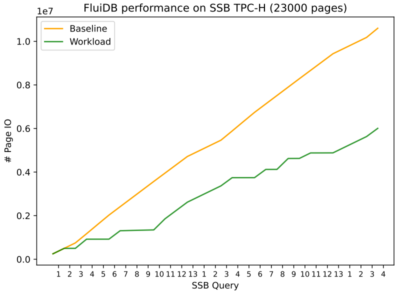
Kinds of operations: Estimated cost

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

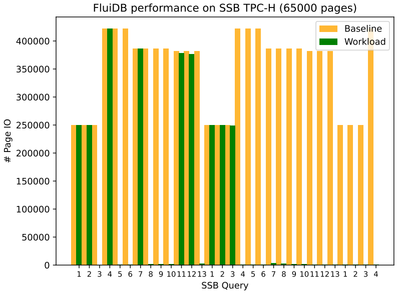
- Recursive – Incremental evaluation is inhibited.
- $\min$ can be exploited for early stopping

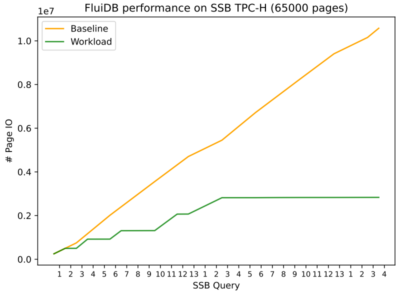
Evaluation: 23K pages budget





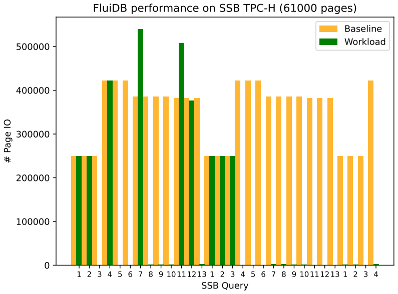
Evaluation: 65K pages budget

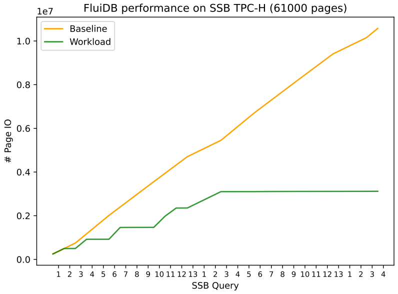




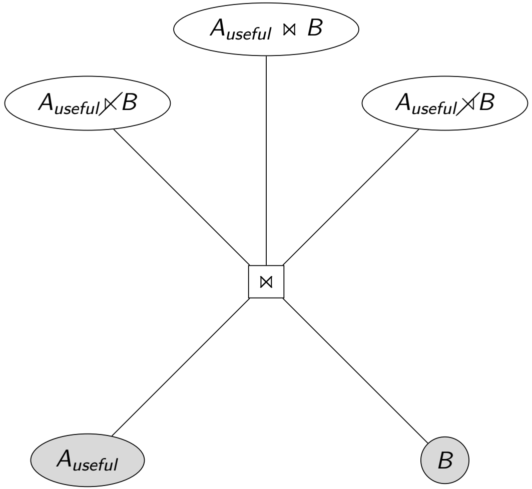
Evaluation: But ... 61K pages budget

lineorder is deleted at 6 because all join outputs were materialized





Plenty of memory



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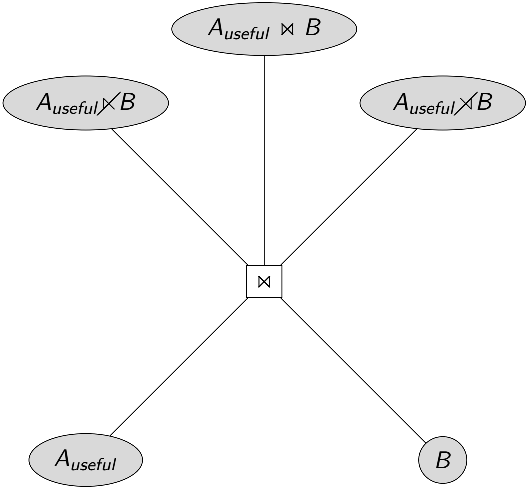

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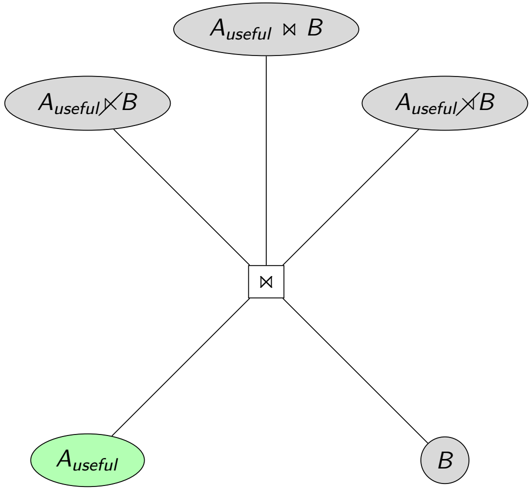
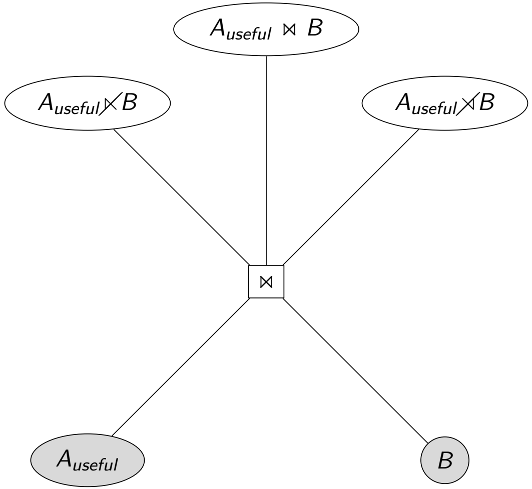


Being on a budget



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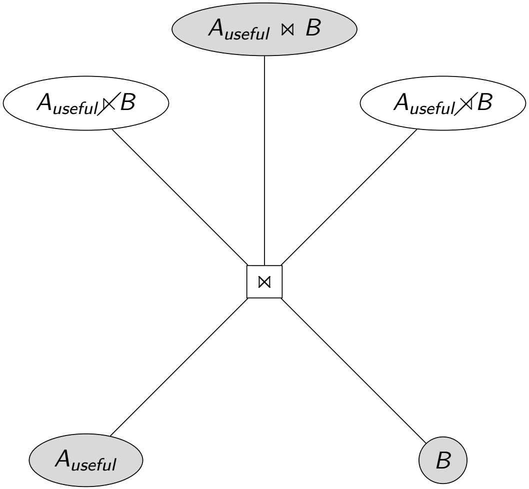

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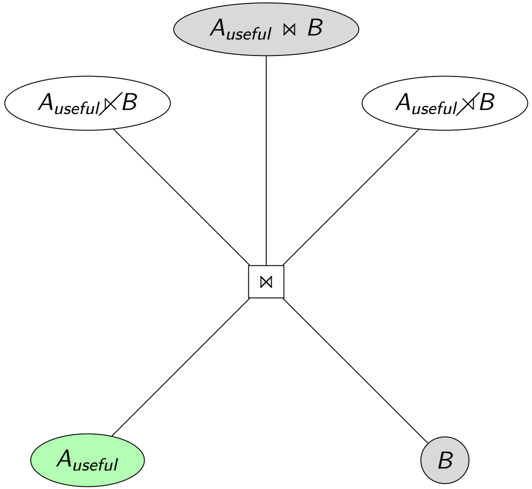
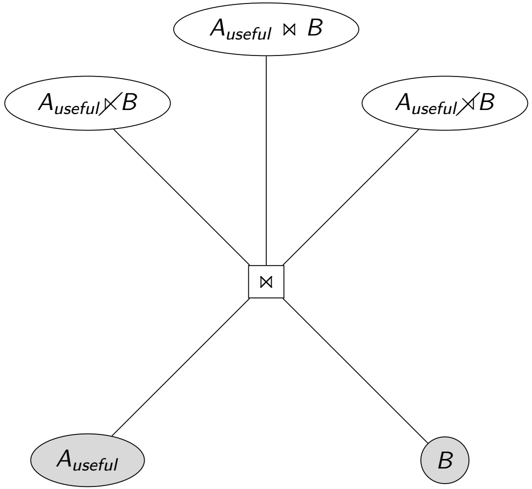


Having just enough rope



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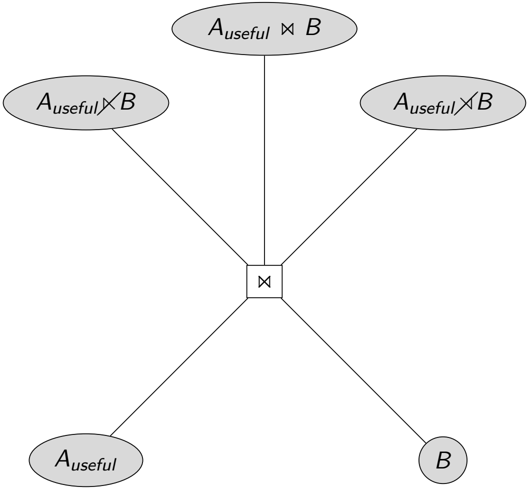

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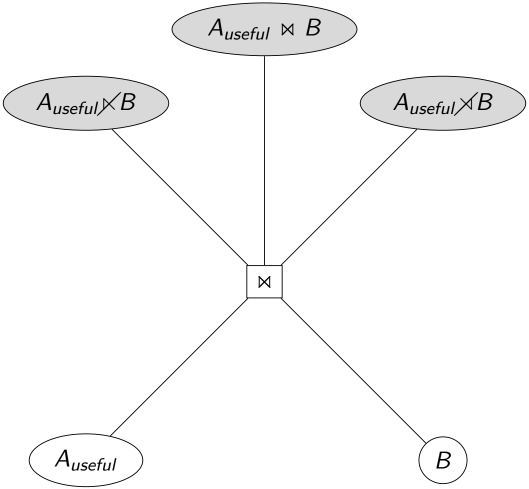

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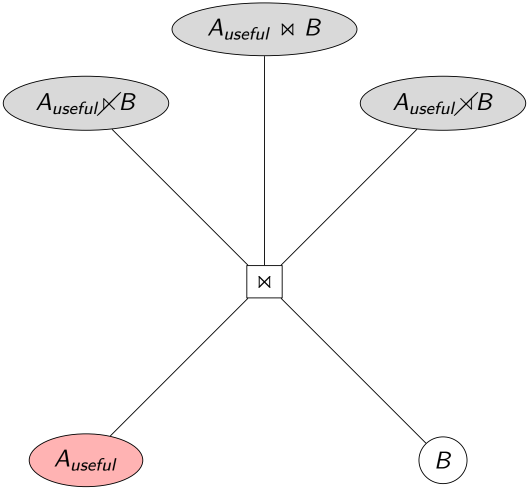

Conclusions

- 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.