5. Physical Properties

- Why Properties
- Distributed Queries
- Ordering
- Grouping
- DAGs

Why Properties

- query optimizer chooses the cheapest equivalent plan
- join ordering: the cheapest plan with the same set of relations
- but: plans might produce the same result but behave differently
- for example sort-merge vs. hash join
- hash join could be cheaper, but sort-merge still pay of later
- not directly comparable

Why Properties (2)

How to handle logical equivalent but un-comparable plans?

- one alternative: encode differences into search space
- for example, different plans for sorting vs. hashing
- but: search space explodes
- some aspects like "sorting" consist of many alternatives
- further: if sorting is cheaper than hashing, we usually prefer sorting
- direct encoding into search space too wasteful
- use (physical) properties instead

Using Properties

A physical property P defines a partial relation $\leq_P$ with the following characteristics among plans:

If two plans p_1 and p_2 are logically equivalent,

- $p_1 \leq_P p_2$ if p_2 dominates p_1 concerning P
- $p_1 =_P p_2$ is p_1 and p_2 are comparable concerning P $(p_1 \leq_P p_2 \wedge p_2 \leq_P p_1)$

A plan can only be pruned if it is dominated or comparable

Using Properties (2)

With properties, the query optimizer does not maintain a single solution but a set of solutions for each subproblem:

storeSolution(S,p)
  $P = dpTable[S]$
  $P' = \emptyset$
  for $\forall p' \in P$ {
    if $p \leq p' \wedge C(p) \geq C(p')$
      return
    if $\neg(p' \leq p \wedge C(p') \geq C(p))$
      $P' = P' \cup \{p'\}$
  }
  $dpTable[S] = P' \cup \{p\}$

Using Properties (3)

- algorithm too simple
- properties can be *enforced*
- Enforcers make plans comparable
- allows for more pruning
- will see examples for this
- combination of multiple properties needs some care

Distributed Queries

- distributed query processing keeps track of the *site*
- intermediate results can be computed at different sites
- a physical property is therefore the site of the intermediate result
- very simple property, site is either the same or different
- more plans comparable with enforcers

Distributed Queries - Comparing Plans

Two plans are comparable, if they produce their result on the same site or the difference is larger than the shipment costs:

prune(p_1,p_2)
  if $p_1.site = p_2.site$
    return $(C(p_1) \leq C(P_2))?p_1 : p_2$
  if $C(p_1) + C(\text{transfer } p_1) \leq C(P_2)$
    return p_1
  if $C(p_2) + C(\text{transfer } p_2) \leq C(P_1)$
    return p_2
  return $\{p_1, p_2\}$

Distributed Queries - Effect on Search organization

- previous slide described how to compare plans, but not how to generate them
- plans must be generated for desired sites
- one possibility: generate plans for all sites
- can be quite wasteful
- alternative: generate plans (for sites) on demand
- difficult to do bottom-up
- usual technique: determine relevant sites beforehand and generate plans for them
- this sites would be called *interesting*

Ordering

- physical tuple order is the classical physical property
- equivalent plans produce the same tuples, but (potentially) in different order
- tuple ordering is very important for many operators
- sort-merge, group by etc.
- explicit order by
- access optimization

Ordering (2)

An ordering O is a list of attributes $(A_1, \ldots, A_n)$

A tuple stream satisfied an ordering O, if the tuples are sorted according to A_1 and for each $1 < i \leq n$ the tuples are sorted on A_i for identical values of $A_1, \ldots, A_{i-1}$.

Interesting Orderings

- optimizer uses existing orderings, or creates new ones (enforcers)
- set of potential orderings very large
- too many orderings increase the search space
- concentrate on relevant orderings: *interesting orderings*

ordering is interesting, if

- requested by the user
- physically available
- useful for a planed operator

Interesting Orderings (2)

- ordering is characterized by a list of attributes
- if a tuple stream is ordered on $a_1, \ldots, a_n, a_{n+1}$, it is also ordered on $a_1, \ldots, a_n$
- orderings are affected by operators, in particular they can grow
- therefore, each prefix of an interesting ordering is also interesting
- (somewhat implementation dependent)
- non-interesting orderings are "forgotten" by the optimizer to reduce the search space

Physical vs. Logical Ordering

- the *physical* ordering is the actual order of tuples on disk/in a tuple stream
- the *logical* ordering is the ordering satisfied by the tuples
- the query optimizer can usually only reason about the logical ordering
- a tuple stream may satisfy multiple logical orderings
- the logical ordering can change, although the physical ordering did not!

Functional Dependencies

Logical Ordering is affected by functional dependencies:

- induces by operators
- $\sigma_{a=\cos(b)} \Rightarrow \{b \rightarrow a\}$
- $\sigma_{a=b} \Rightarrow \{a \rightarrow b, b \rightarrow a\}$ (even stronger)
- $\sigma_{a=10} \Rightarrow \{\emptyset \rightarrow a\}$
- complex operators can induce multiple FDs
- FDs allow for deriving new logical orderings

Example

```
select a,b,c
from   s a,
       (select b:b,c:count(*),d:max(d)
       from tablefunc(a) group by b)
order  by a,b,c
```

Interesting ordering:	(a), (b), (a,b) and (a,b,c)
Interesting groupings:	$\{b\}$
Functional dependencies:	$b \rightarrow c$, $b \rightarrow d$

- Note: for $\{b\}$ grouping is sufficient (next section)

Materializing Orderings

- the query optimizer might just maintain a set of all orderings satisfied by a plan
- but FDs increase the set
- $\texttt{sort}(a) \rightarrow \texttt{select}(a = b)$
- is compatible with $(a), (a, b), (b), (b, a)$
- set can grow exponentially
- maintaining set of orderings not feasible

Reducing Orderings

Simmen et al. [10] proposed the following scheme:

- remember the base ordering
- remember all functional dependencies
- whenever testing for an ordering, reduce by base ordering and functional dependency
- apply prefix test after this

Reducing Orderings - Example

Ordering (b, d, e), test for (a, b, c, e), FDs $\{a \rightarrow c, \emptyset \rightarrow a, b \rightarrow d\}$

1. reduce ordering to (b, e)
2. reduce test to (a, b, e)
3. reduce test to (b, e)
4. test for prefix

but:

- what would happen if we applied $\emptyset \rightarrow a$ first?
- reductions must be applied back to front

Reducing Orderings - Discussion

- back-to-front rule is not enough ((a),(a, b, c),$\{a \rightarrow b, a, b \rightarrow c\}$)
- avoiding this requires normalizing the FDs, which is very expensive
- reduction has to be done for each test
- tests happen very frequently (nearly each operator tests)
- memory management is a problem
- better than materializing orderings, but not optimal

Required Interface for Orderings

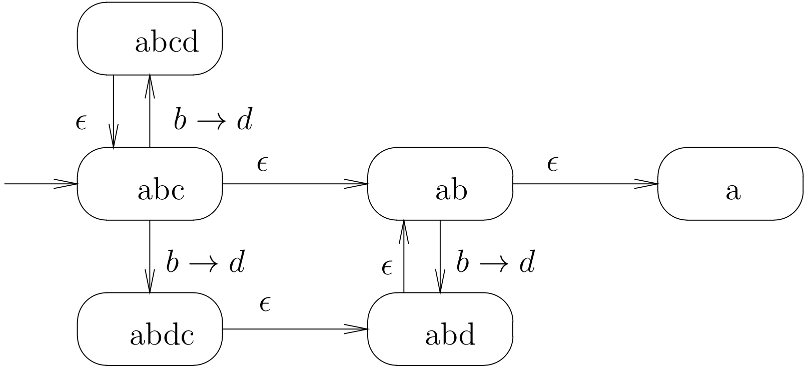
Query optimizer just requires few operations:

- initialization
- test for an ordering
- apply function dependency

Concrete ordering not required

Encoding Orderings as FSMs

Use an FSM (ordering (a, b, c), FD $\{b \rightarrow d\}$)

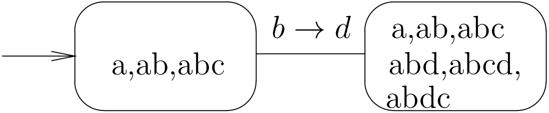


Encoding Orderings as FSMs (2)

- FSM described physical orderings
- pretends that FD changes physical ordering
- might be non-deterministic
- has to become deterministic
- conversion in DFSM (via NFA→DFA)

Encoding Orderings as FSMs (3)

DFSM



- node contains all possible physical orderings $\Longrightarrow$ logical orderings
- operating on the DFSM is very efficient
- only problem: how to construct it (efficiently)

Ordering FSM Construction - Overview

1. Determine the input
   1.1 Determine interesting orders
   1.2 Determine sets of functional dependencies
2. Construct the NFSM
   2.1 Construct nodes of the NFSM
   2.2 Filter functional dependencies
   2.3 Add edges to the NFSM
   2.4 Prune the NFSM
   2.5 Add artificial start node and edges
3. Construct the DFSM - convert the NFSM into a DFSM
4. Precompute values
   4.1 Precompute the compatibility matrix
   4.2 Precompute the transition table

Ordering FSM Construction - Determining the Input

- interesting orders (requested, required, index)
- $O_I = O_P \cup O_T$ (produced vs. tested, allows pruning)
- functional dependencies (operators, keys)
- handles for O(1) comparisons

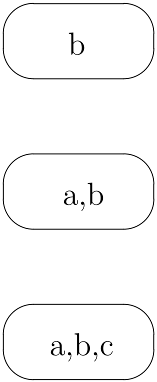
E.g.

$$\mathcal{F} = \{\{b \rightarrow c\}, \{b \rightarrow d\}\}$$

$$O_I = \{(b), (a, b)\} \cup \{(a, b, c)\}$$

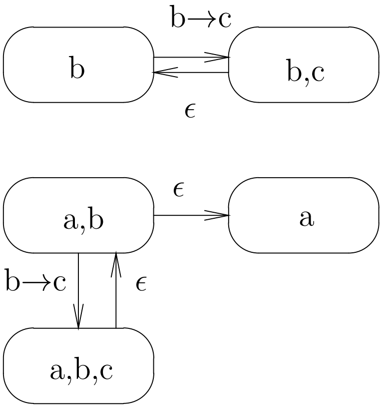
Ordering FSM Construction - Constructing the NFSM

Initial nodes for O_I



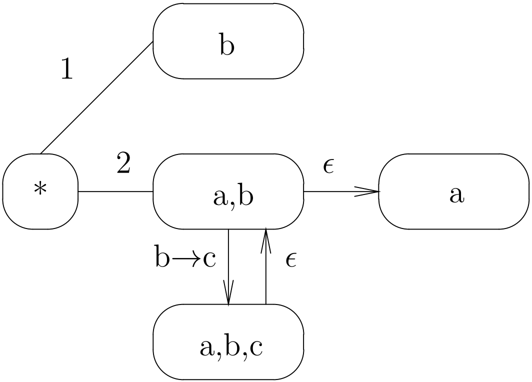
Ordering FSM Construction - Constructing the NFSM (2)

Edges for F. Creates artificial node (can be pruned)



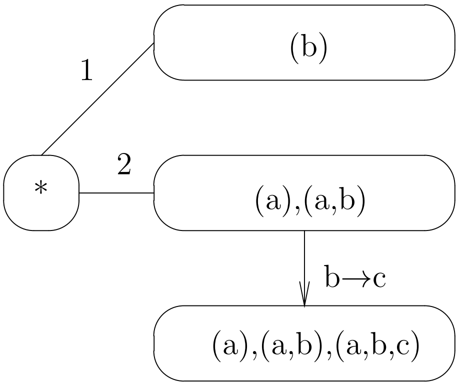
Ordering FSM Construction - Constructing the NFSM (3)

Edges for initialization. (b, c) was pruned.



Ordering FSM Construction - Constructing the DFSM

Standard conversion algorithm



- tests for O_T are precomputed (materialized)

Pruning Techniques

- reducing the NFSM reduces conversion time
- reducing the DFSM reduces search space
- FDs can be removed if no interesting orderings reachable
- artificial nodes can be merged if the behave identical
- artificial nodes can be removed it they only have ϵ edges

Note: search space reduction is a major benefit!

Discussion

- orderings essential for query optimizations
- but orderings increase the search space
- management involved
- FSM representation needs $O(1)$ time and space during optimization
- queried very often, but also very fast
- help reduce the search space

Grouping

- sometimes ordering is a too strong requirement
- some operators do not need an order, they just want continuous blocks for values
- group by operators are a typical example
- therefore: grouping property
- exploiting groupings is similar to exploiting orderings

Grouping (2)

A grouping G is a set of attributes $\{A_1, \ldots, A_n\}$

A tuple stream satisfies a grouping G, if tuples with the same values for $A_1, \ldots, A_n$ are placed next to each other.

Note that the attributes within a grouping are unordered

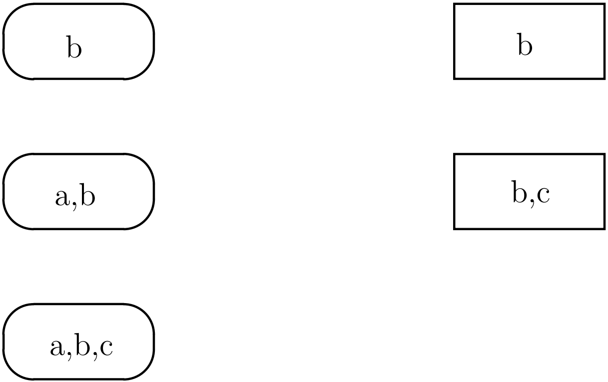
Ordering vs. Grouping

- ordering is a much stronger requirement than grouping
- every tuple stream that satisfies an ordering $O = (A_1, \ldots, A_n)$ also satisfies the grouping $G = \{A_1, \ldots, A_n\}$
- but there is not prefix deduction for groupings
- a tuple stream satisfying $\{A_1, A_2\}$ does not necessarily satisfy $\{A_1\}$
- could be derived from ordering information
- both types should be handled simultaneously

Integrating Grouping into Ordering Processing

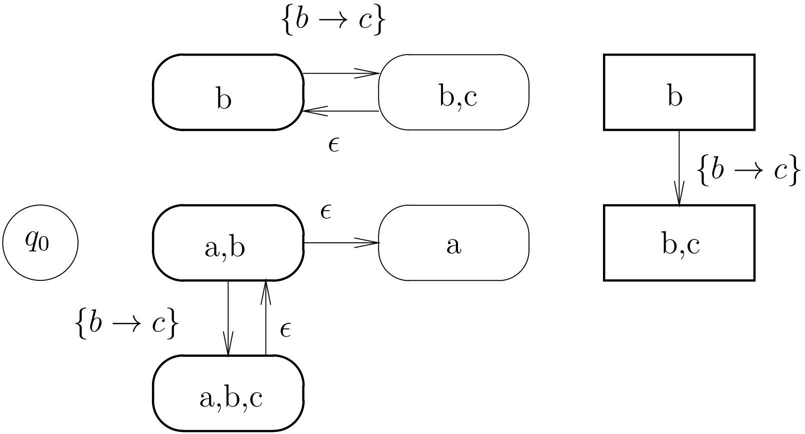
- groupings are similar to orderings
- can be modelled as FSMs, too (less edges, though)
- idea: build one big integrated FSM
- edges from orderings to corresponding groupings
- unifies these properties, makes pruning etc. much easier

Constructing a Unified FSM



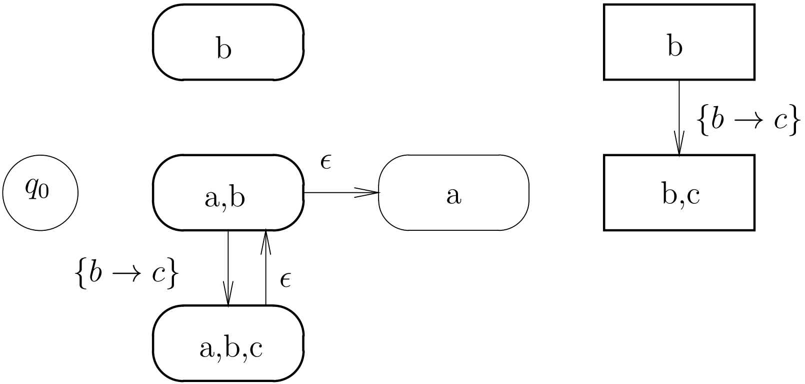
- create states for interesting orderings/groupings

Constructing a Unified FSM (2)



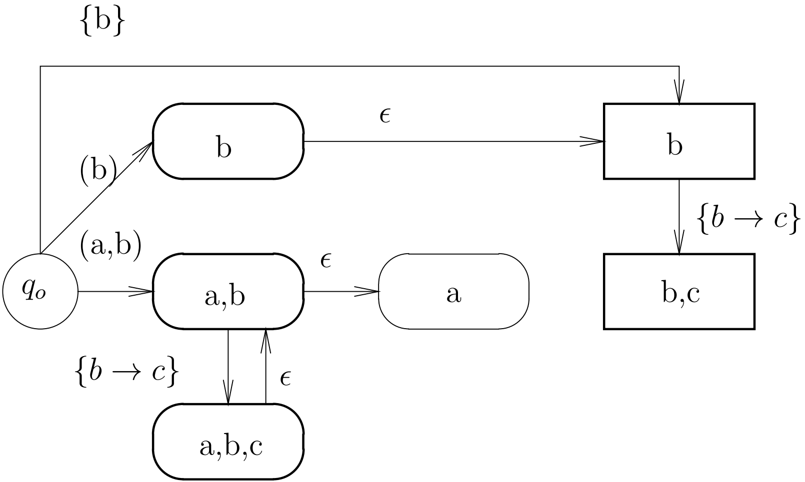
- consider functional dependencies
- note: no ϵ edge between groupings

Constructing a Unified FSM (3)



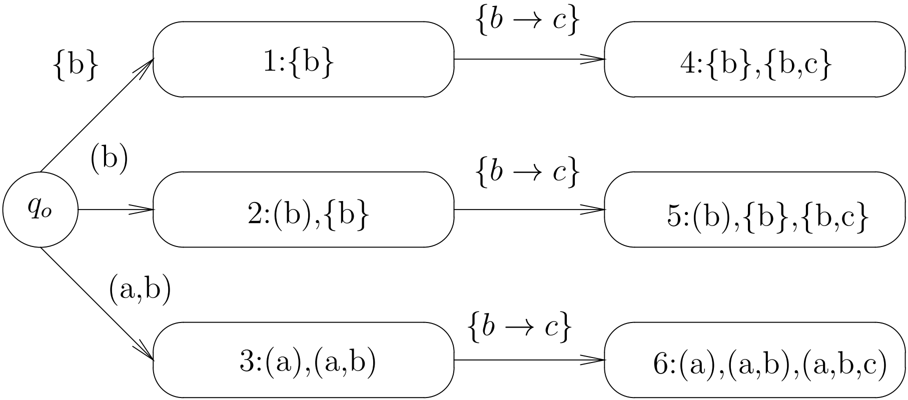
- prune artificial nodes

Constructing a Unified FSM (4)



- add additional edges for initialization

Constructing a Unified FSM (4)



- construct final DFSM

Discussion

- algorithm for groupings similar to orderings
- include pruning etc.
- unified handling very nice
- easy integration of both into the query optimizer
- FSM representation very fast
- only constant space per plan

DAGs

- execution plans until now were trees
- each operator has one consumer (except the root)
- no overlap
- very easy data flow
- but too limited in expressiveness
- a generalized plan structure requires some care (in this case a new kind of properties)

DAGs (2)

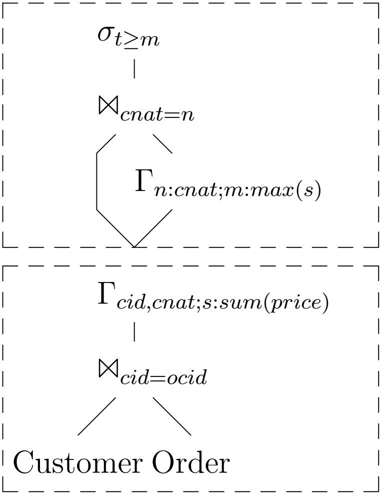
DAG - directed acyclic graph

More general than a tree, an operator can have more than one parent.
Allows for more efficient plans.

Motivation for DAGs

common: views or shared expressions

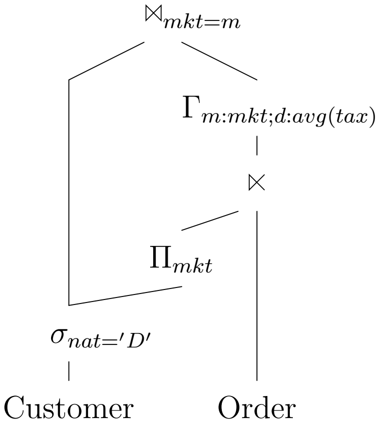
- recognized e.g. by DB2
- uses buffering
- parts optimized independently
- not really a DAG then



Motivation for DAGs (2)

magic sets

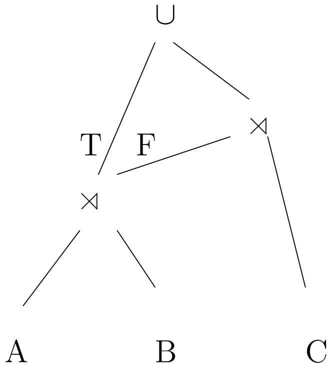
- propagate domain information
- nice optimization, but requires DAGs



Motivation for DAGs (3)

bypass plans

- handle tuples different depending on predicates
- more efficient for disjunctive queries
- more complex data flow

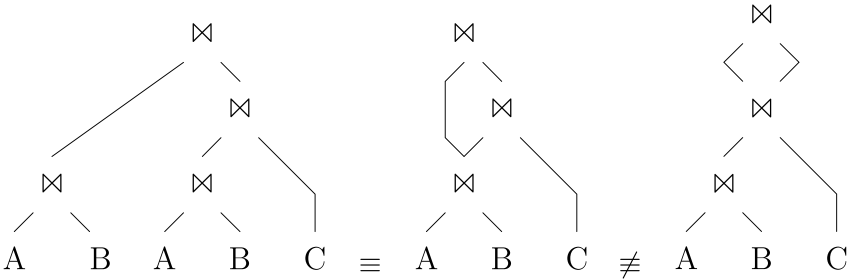


Motivation for DAGs (4)

- also XPath/XQuery evaluation, distributed queries, dependent join optimizations, ...
- optimizations not always beneficial, proper plan generation required
- buffering/temp reduces benefit, "real" execution required

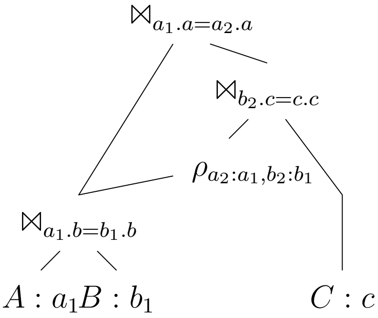
goal: generic DAG support

DAG Generation - Correctness Problems



- equivalences difficult to check
- here joins (apparently) not freely reorderable
- known equivalences not directly applicable

DAG Generation - Correctness Problems (2)



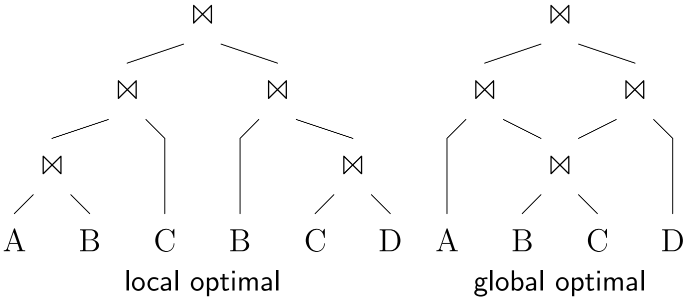
- idea: sharing through renaming $\Longrightarrow$ *share equivalence*
- formal criteria to detect equivalent subproblems
- create logical trees, allows for reusing known equivalences

Share Equivalence

$$A \equiv_S B \text{ iff } \exists_{\delta_{A,B}:\mathcal{A}(A)\to\mathcal{A}(B) \textit{ bijective}} \rho_{\delta_{A,B}}(A) = B$$

- difficult to test in general
- but constructive definition simple
- can be computed easily
- will be the base of a property (next slides)

DAG Generation - Optimal Substructure



- shared plans destroy optimal substructure
- idea: encode sharing into the search space
- *share equivalence* for operators
- creates equivalence classes, describes possibilities to share

DAG Generation - Optimal Substructure (2)

- generalize share equivalence from plans to operators
- would create share equivalent plans if the input were share equivalent
- classifies operators into equivalence classes
- only one operator from an equivalence class is relevant (representative)
- annotate each plan with the equivalence class (property)
- keep plans if they offer more classes (more sharing)
- note: only whole trees can be shared

DAG Generation - Search

Search component has to be adjusted:

- incorporate share equivalence
- try to rewrite problems as representatives
- if completely possible (whole tree) only use representatives
- creates implicit renames
- allows for reusing results
- adjust pruning, too

Discussion

- DAGs allow for much better plans
- generation somewhat involved
- share equivalence as property guarantees optimal solution
- many details omitted here
- cost model
- execution