Verification of the SQL compilation chain

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Formal guaranties for data-centric applications

Relational databases

well-studied theory [Codd70]

mature implementations

Oracle, DB_2 IBM, SQLServer, Postgresql, MySql, SQLite ...

a standard SQL

SQL: a declarative language

say what but not how

```
select lastname
from people p, director d, role r, movie m
where
  d.mid = r.mid and d.pid = r.pid and p.pid = d.pid and m.mid = d.mid
  and m.year > 1950;
```

SQL: a declarative language

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1. collect all the data, then filter

SQL: a declarative language

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  and m.year > 1950;
```

1. collect all the data, then filter
2. collect only useful data, as fast as possible

Compilation: from solution 1 to solution 2

```sql
select lastname
from people p, director d, role r, movie m
where
  d.mid = r.mid and d.pid = r.pid and p.pid = d.pid and m.mid = d.mid
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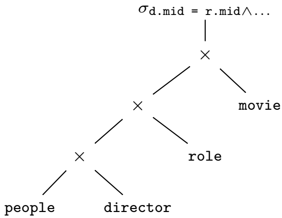
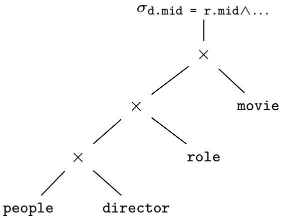
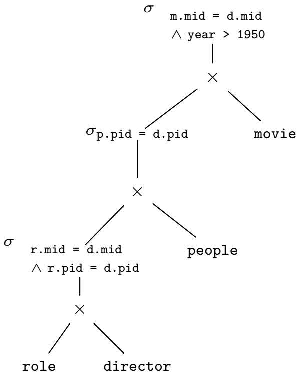


Compilation: from solution 1 to solution 2





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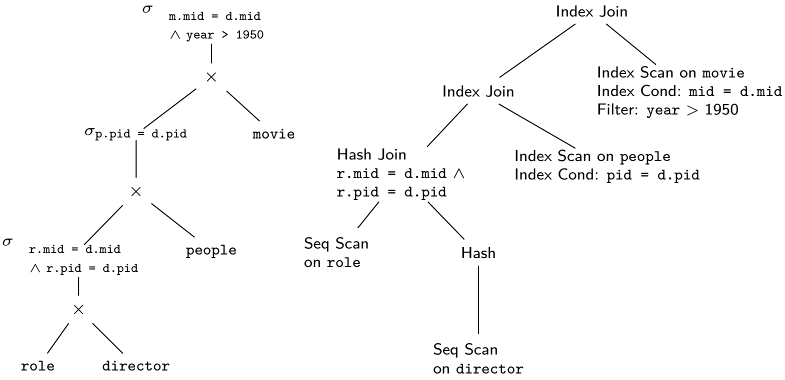
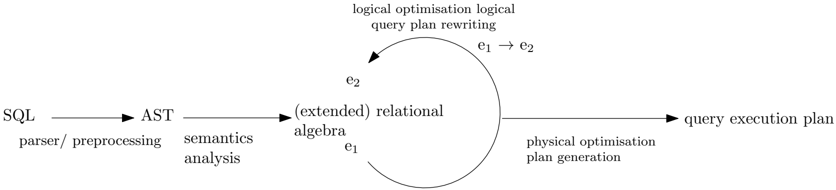
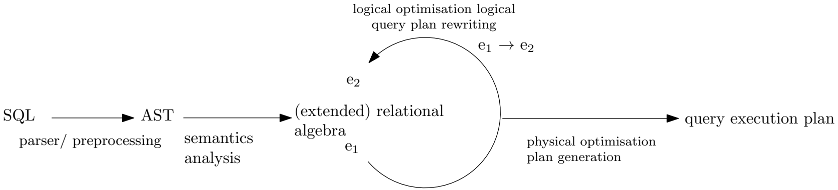


The compilation chain



The compilation chain, verified in Coq



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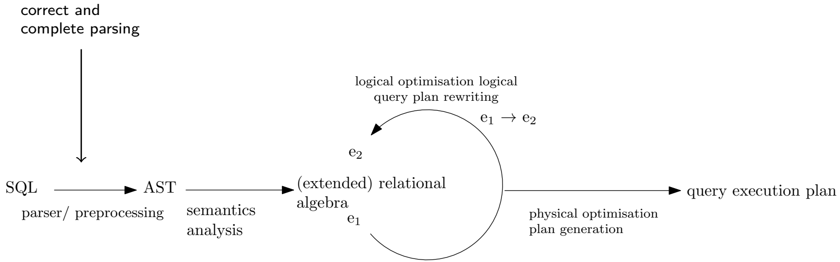

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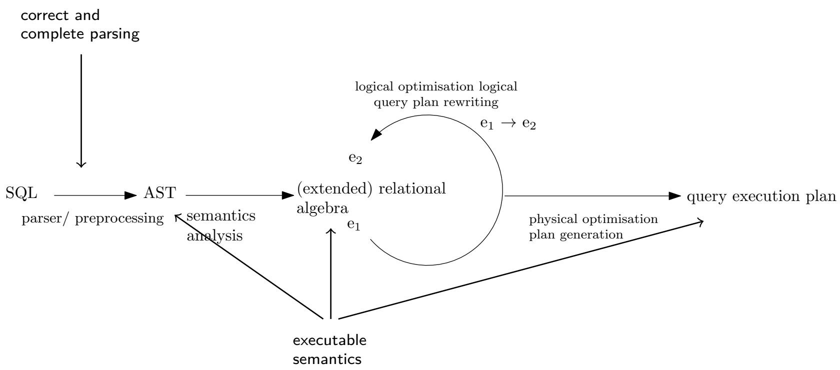

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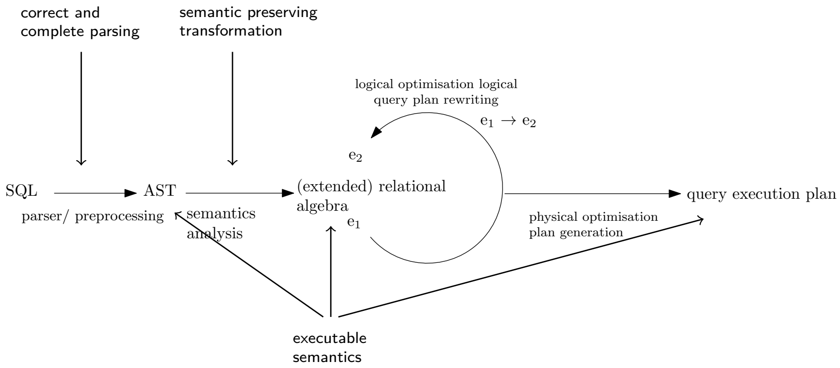

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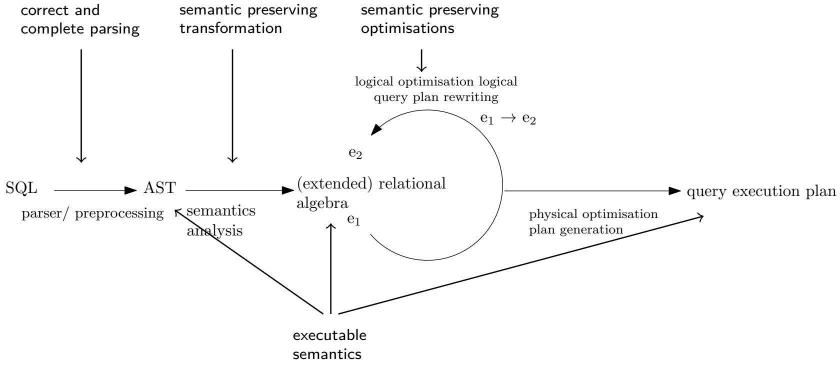

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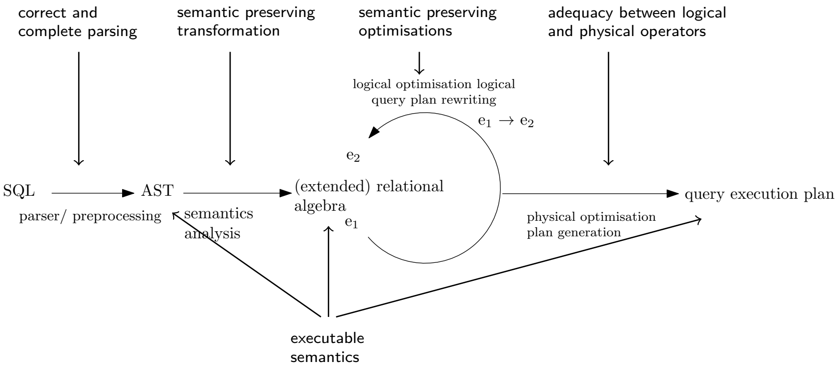

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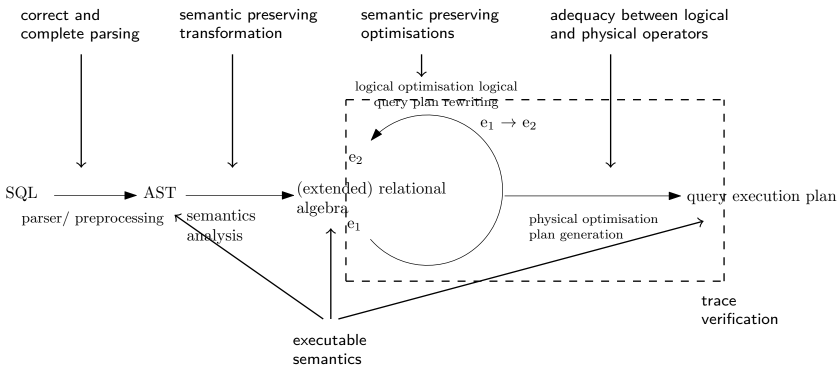
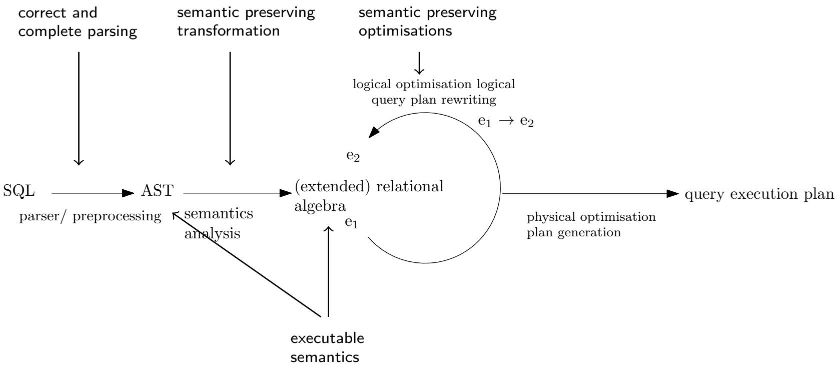
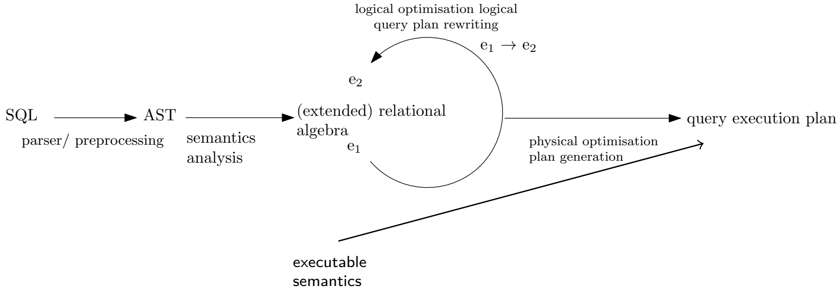


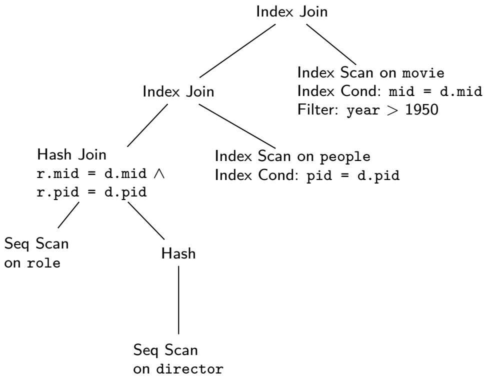
Not detailed parts



Runtime: physical algebra



Iterator interface: online algorithms



Abstract iterator interface

```
Record Cursor (elt : Type) : Type := {
  cursor : Type;
  next : cursor  → result elt * cursor;
  has_next : cursor  → Prop;
  reset : cursor  → cursor;

  collection : cursor  → list elt;
  visited : cursor  → list elt;
  coherent : cursor  → Prop;

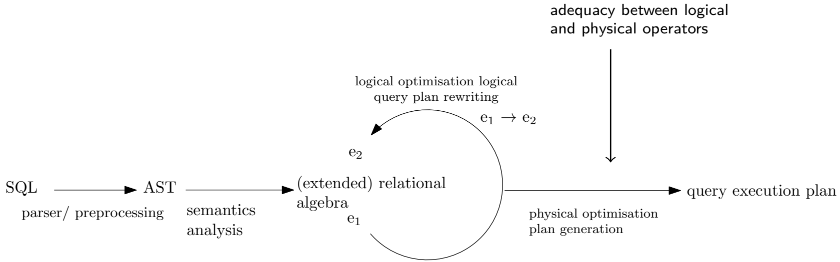
  next_collection : forall c, coherent c  → collection (snd (next c)) = collection c;
  next_coherent : forall c, coherent c  → coherent (snd (next c));
  ...

  ubound : cursor  → nat;
  ubound_complete :
    forall c acc, coherent c  → ∼has_next (fst (iter next (ubound c) c acc));
 }.
```

Implementations and combinations

Iterator interface operators				
	ϕ algebra			
data centric operators	**simple**	**index based**	**sort based**	**sql algebra**
map	Seq Scan	Index scan Bitmap index scan	Sort scan	r, π
join	Nested loop Block nested loop	Hash join Index join	Sort merge join	$\times$
filter	Filter			σ
group	Group			γ
avg count max sum	Aggregate Hash Hash aggregate			aggregate
	Intermediate results storage operators			
	Materialize			

Adequacy between logical and physical operators



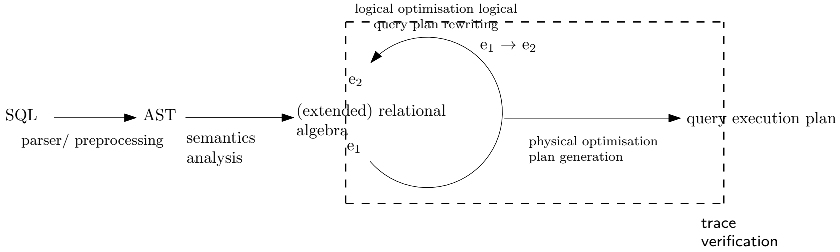
High-level specification of data-centric operators

```
Definition is_a_filter_op (init res : container) (p : A → bool) :=
  forall t, nb_occ t res = (nb_occ t init) * (if p t then 1 else 0).

Lemma Filter_is_a_filter_op c p:
  is_a_filter_op (materialize c) (materialize (mk_Filter c p)) p.

Lemma Sigma_is_computable_by_any_filter_op :
    forall init res p, is_a_filter_op init res p →
    forall q,
      eval_query env q =R= content init →
        eval_query env (Sigma p q) =R= content res.
```

Certification of query execution plans



Using traces

A good query planner is complex software

Instead, call an external planner and check the answer

Oracle, Postgresql

Bonus: *a posteriori* certification of these software

Checking the answer

We adopt a reflexive approach

1. associate a logical operator to each physical operator: adequacy
2. guess which optimisations have been used: “replay” them using the property that they are semantic preserving

Guessing may be hard: no known normal form

Conclusion

The first verification of the full SQL compilation chain

Combines lots of techniques provided by Type Theory

- high degree of abstraction
- "traditional" proofs of algorithms
- reflexive verification of traces
- program extraction
- ...

Perspective: non-relational databases
abstraction should be good enough to handle them