Towards Formally Verified Rule Language Compilers

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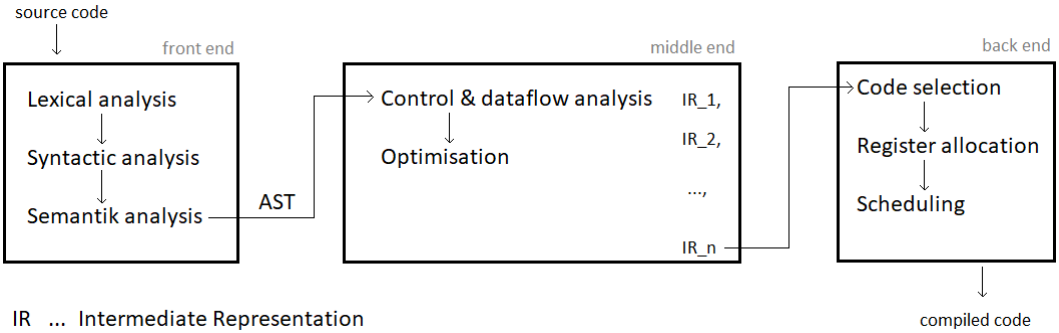
What is the problem

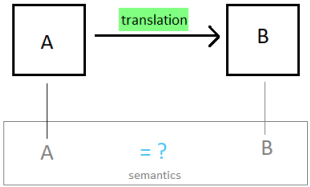
- optimisations need formal verification
  - search for a fixpoint may not terminate, e.g. Skolem chase
  - some algorithms optimize based on edge cases
- correctness guarantees should not compromise efficiency

Short trip to the world of compilers



Formally verified compilers

- 2 approaches
  - internally verified - directly from scratch
  - external verification aka. translation validation (more flexible)



- formalize representations; formalize transitions; show preservation of semantics

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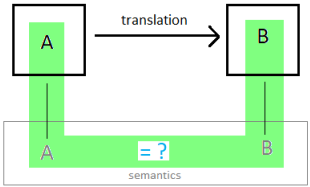

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Semantic preservation

- formalize representations; formalize transitions; show preservation of semantics
- theorem provers like Coq or Lean can be used

"If the compiler produces compiled code C from source code S, without reporting compile-time errors, then every observable behavior (B) of C is either identical to an allowed behavior of S, or improves over such an allowed behavior of S by replacing undefined behaviors with more defined behaviors." [2]

Semantic preservation

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- theorem provers like Coq or Lean can be used

$$S \texttt{ safe} \Rightarrow \forall B, S \Downarrow B \iff C \Downarrow B$$

Semantic preservation

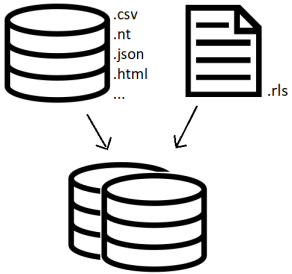
- formalize representations; formalize transitions; show preservation of semantics
- theorem provers like Coq or Lean can be used

$$\forall S, C, \mathit{Comp}(S) = \texttt{OK}(C) \Rightarrow S \approx C$$

Rule reasoning systems

1. logic programming systems
2. KG and deductive database engines
3. specialised data-analytics systems
4. data management frameworks

according to *Nemo: Your Friendly and Versatile Rule Reasoning Toolkit* [0]



[1]

Rule reasoning systems

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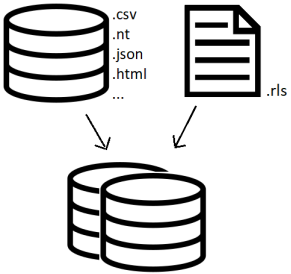
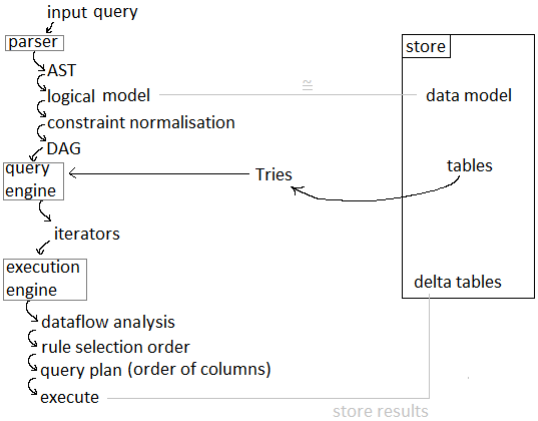


[1]

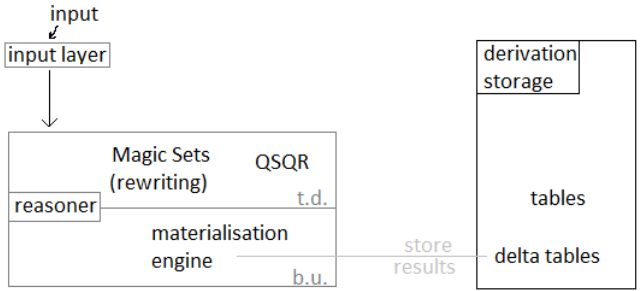
Nemo


input query
parser
AST
logical model
constraint normalisation
DAG
query engine
Tries
iterators
execution engine
dataflow analysis
rule selection order
query plan (order of columns)
execute
store
data model
tables
delta tables
store results

Nemo

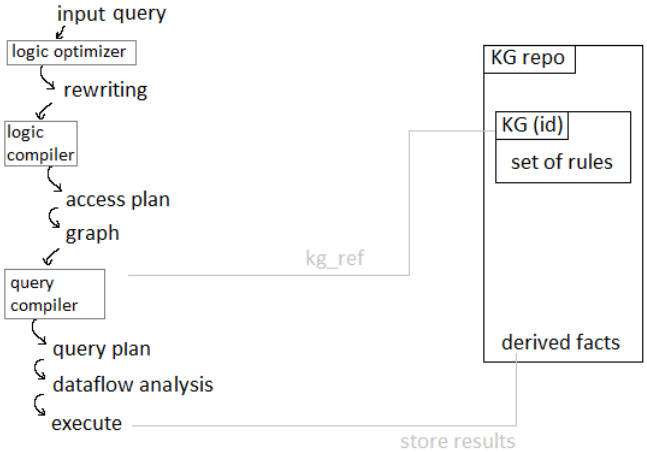
```
a(x) :- b("foo", x).
a(x) :- b(var, x), var = "foo").
```

VLog

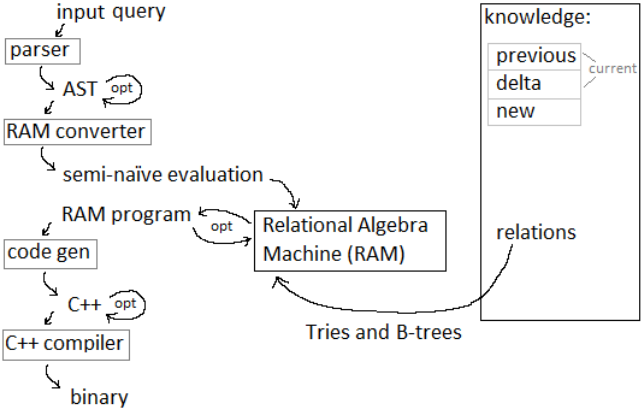


t.d. = top-down (query-driven reasoning)
b.u. = bottom-up (materialisation)

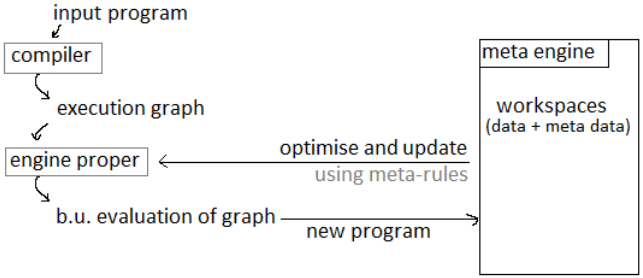
Vadalog


input query
logic optimizer
rewriting
logic compiler
access plan
graph
query compiler
query plan
dataflow analysis
execute
kg_ref
KG repo
KG (id)
set of rules
derived facts
store results

Soufflé


input query
parser
AST
opt
RAM converter
semi-naïve evaluation
RAM program
opt
code gen
C++
opt
C++ compiler
binary
Relational Algebra Machine (RAM)
knowledge:
previous
delta
new
current
relations
Tries and B-trees

LogicBlox


input program
compiler
execution graph
engine proper
b.u. evaluation of graph
optimise and update
using meta-rules
new program
meta engine
workspaces
(data + meta data)

Structural similarities

- top-down evaluation (query-driven reasoning) and/or bottom-up (materialisation)
- distinction between IDB and EDB (e.g. delta tables)
- some initial parsing into an AST
- rewriting (e.g. constraint normalisation)
- a graph representation of the database and some structure to access it
- query engine or materialisation engine
- usage of relational algebra to process tables

Concrete plans for verification

- semi-naive evaluation (since it's optimized)
- LFTJ (since it's optimized)
- 1-parallel restricted chase
- (skolem chase)

References

[0] **classification of rule reasoning systems** from *Nemo: Your Friendly and Versatile Rule Reasoning Toolkit*, Alex Ivliev and Lukas Gerlach and Simon Meusel and Jakob Steinberg and Markus Krötzsch, https://iccl.inf.tu-dresden.de/w/images/f/fb/KR-2024-CR.pdf
[1] **database icon** https://linearicons.com/, created by https://perxis.com/ - https://cdn.linearicons.com/free/1.0.0/Linearicons-Free-v1.0.0.zip, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=77236210;
note icon SimpleIcon http://www.simpleicon.com/, CC BY 3.0 https://creativecommons.org/licenses/by/3.0, via Wikimedia Commons; changes were made to the graphics
[2] **definition of semantic preservation** taken from *CompCert - A Formally Verified Optimizing Compiler*, Leroy, Xavier and Blazy, Sandrine and Kästner, Daniel and Schommer, Bernhard and Pister, Markus and Ferdinand, Christian, https://inria.hal.science/hal-01238879/file/erts2016_compcert.pdf