Cauliflower: A Solver-Generator for Context-Free Language Reachability

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What Is CFL-R?

A Datalog Fragment

- Formulated originally by Yannakakis [**?**]
- A subclass of Datalog:
  - Binary relations (EDB & IDB)
  - Chain rules:

$$H(v_0, v_k) \rightarrow B_1(v_0, v_1), B_2(v_1, v_2), \ldots, B_k(v_{k-1}, v_k).$$

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- Rephrased as a graph problem:
  - Binary predicates $\Leftrightarrow$ labelled graph edges
  - Chain rules $\Leftrightarrow$ context-free grammar

$$H \rightarrow B_1 B_2 \ldots B_k$$

- A generalisation of two well-known computational problems

Recognition +

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- Given a context-free language
- Determine if a string is a member of the language
- CYK (cubic time)
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- By coincidence, both are equivalent to matrix multiplication

CFL-R Applications

- Points-to analysis [**?**, **?**, **?**, **?**, **?**]
- Dataflow analysis [**?**, **?**]
- Shape analysis [**?**]
- Constant propagation [**?**]
- Inter-procedural slicing [**?**]
- Some logic fragments [**?**]
- Set Constraints [**?**, **?**]
- Security verification [**?**, **?**]
- Control-flow analysis [**?**]

Application: Points-To

```
a = new F1();
b = new F2();
d = c.f;
b.f = a;
c = b;
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- Which program variables refer to which (abstract) heap locations at runtime

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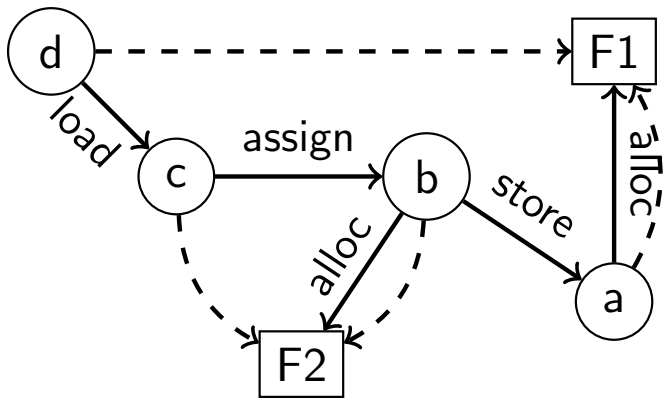

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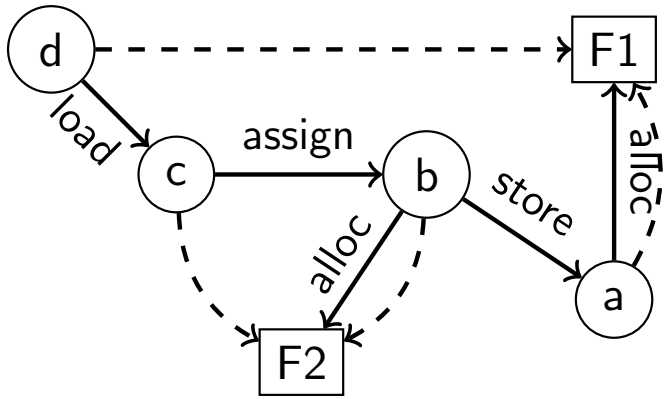

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$pt \rightarrow load \quad pt\ \overline{pt}\ store \quad pt$

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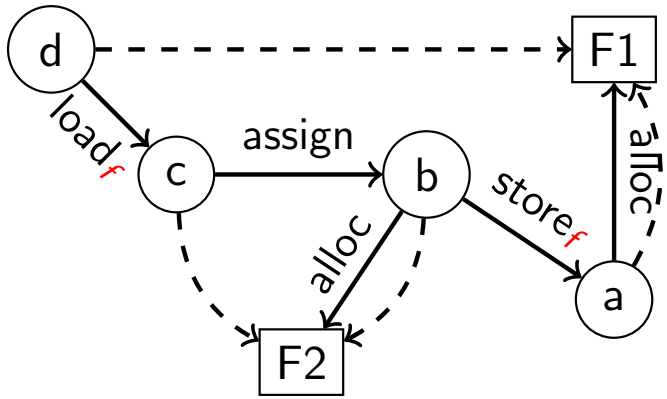

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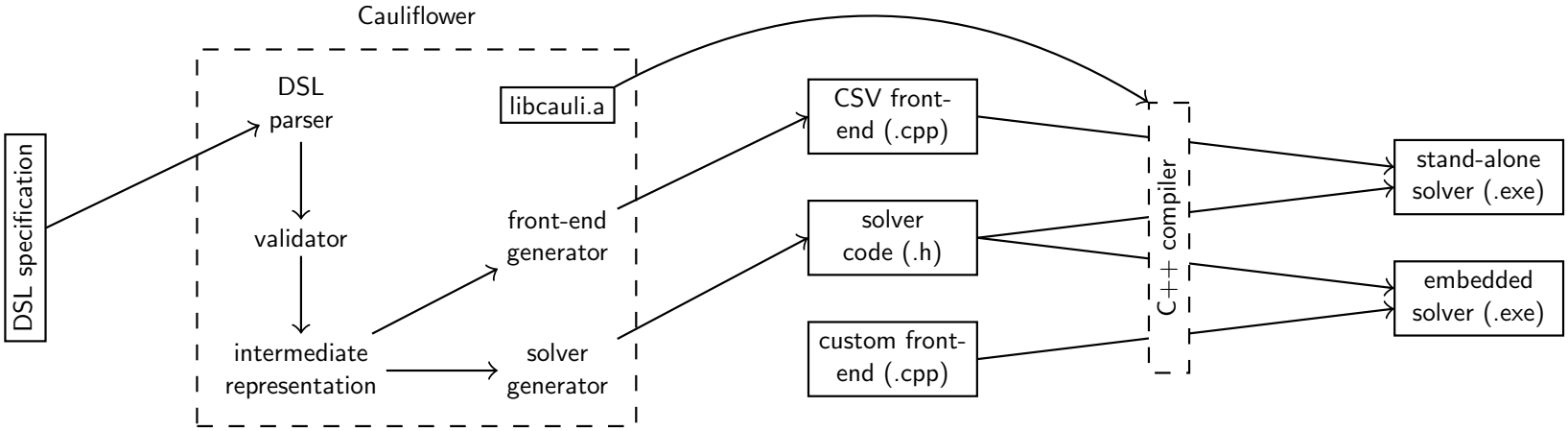
- Which program variables refer to which (abstract) heap locations at runtime
- Field sensitivity, improve precision by treating object fields distinctly

Improving CFL-R

Cauliflower



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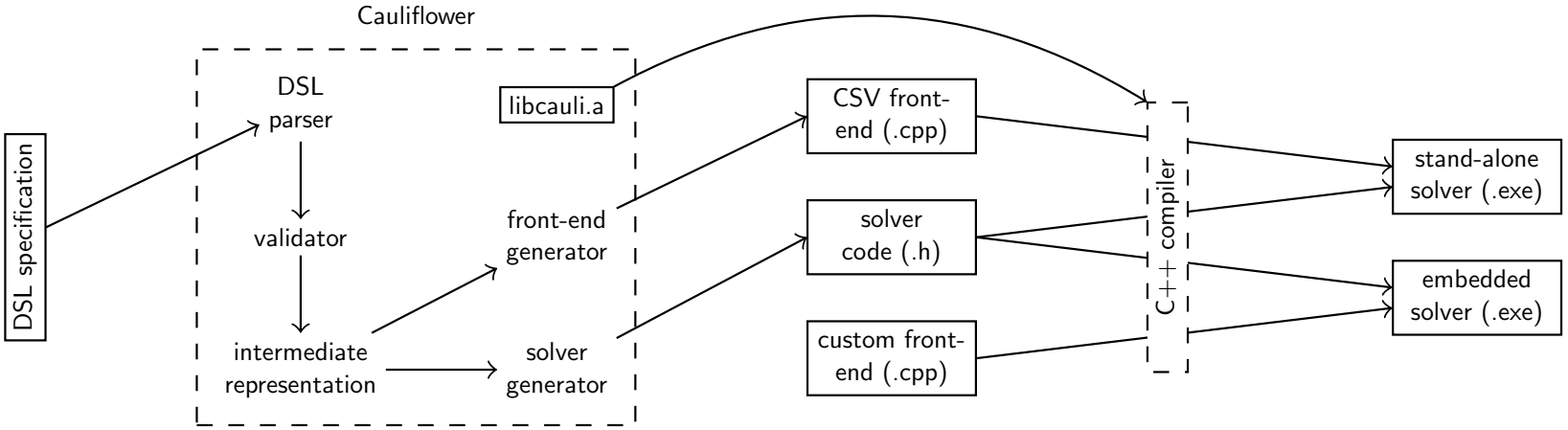
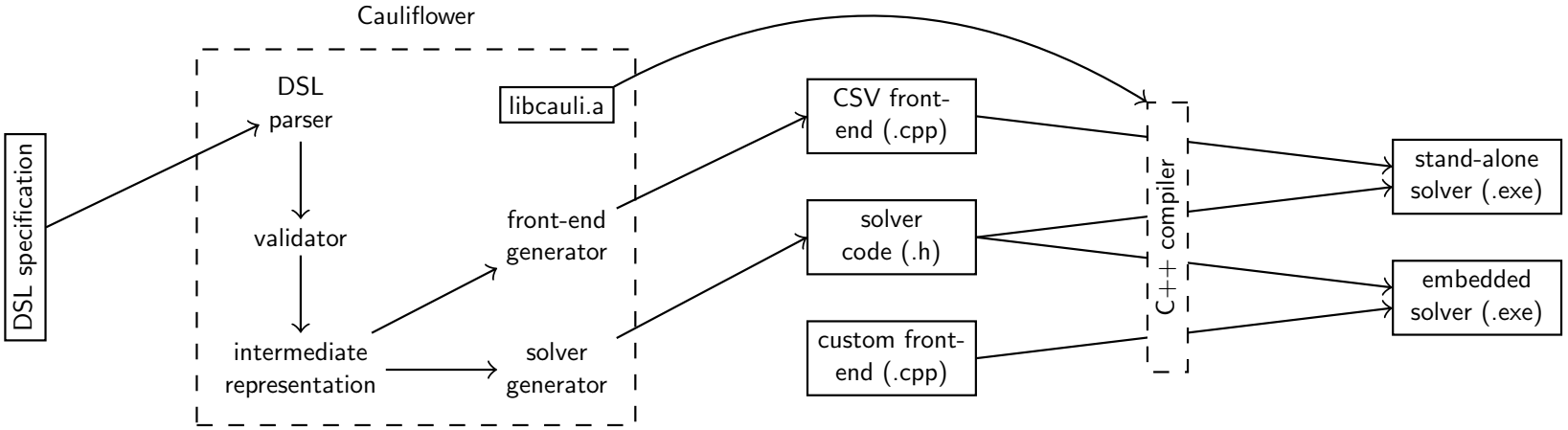


- Solver generator
  - Typical use-case: one grammar many graphs
  - Problems encoded in a Domain-Specific language
  - Specialised solvers for the given problem
  - Static code generator (C++)
    - Avoids dynamic execution planning
    - Leverage c++ compiler optimisations

Cauliflower



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- Optimiser?
  - Soon^{TM}

Enhanced Semantics

- In the literature, CFL-R alone is not enough
  - Points-to: $pt \rightarrow load_f \ pt \ \overline{pt} \ store_f \ pt$

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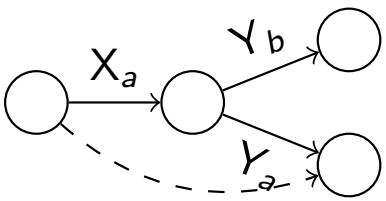
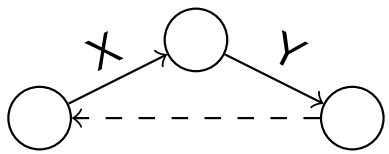


X[f], Y[f]



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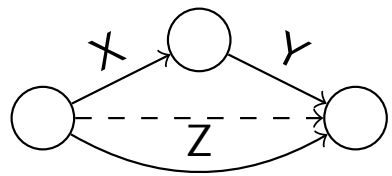

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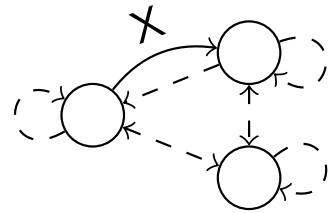

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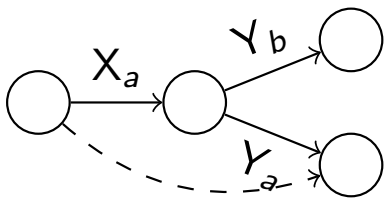

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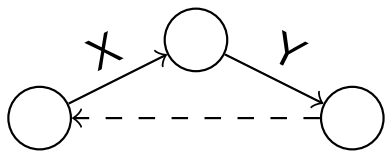

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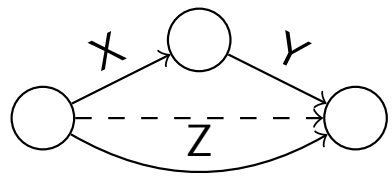

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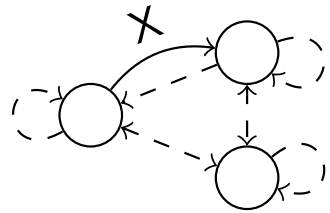

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- Capture more problems in CFL-R
- Develop a DSL for CFL-R specifications
  - Rapid prototyping

CFL-R Domain-Specific Language

- Type declarations
  - Semantic correctness
  - Performance - partitioning

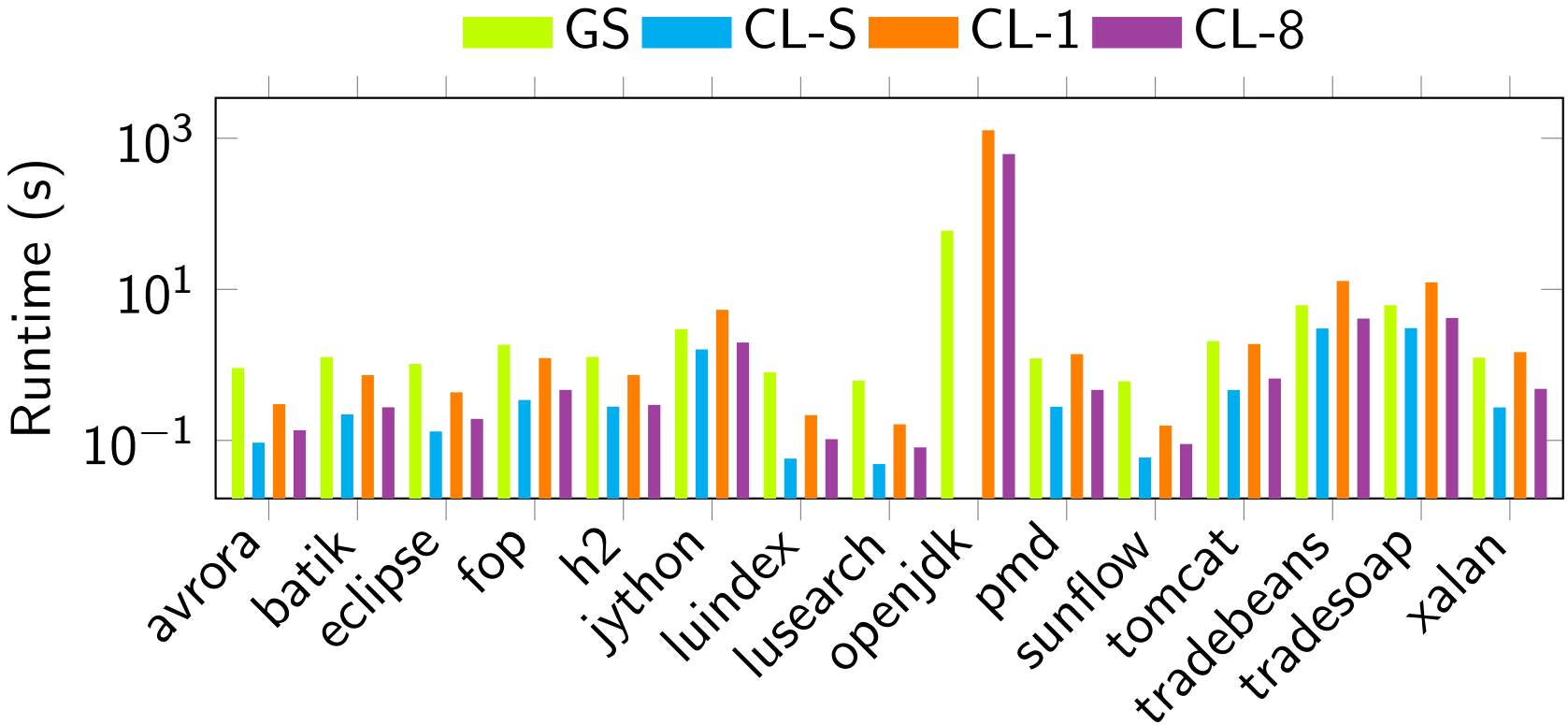
```
Alloc <- v . h;
Assign <- v . v;
Cast[t] <- v . v;
Load[f] <- v . v;
Store[f] <- v . v;
Bridge <- v . v;
VPT <- v . h;
LVPT[f] <- v . h;
SVPT[f] <- v . h;
```

- Rule declarations
  - BNF syntax
  - Enhanced semantics

```
Assign -> Cast[type];
VPT -> Alloc;
VPT -> -Assign, VPT;
VPT -> Bridge, VPT;
LVPT[f] -> -Load[f], VPT;
SVPT[f] -> Store[f], VPT;
Bridge -> LVPT[f],
          -SVPT[f];
```

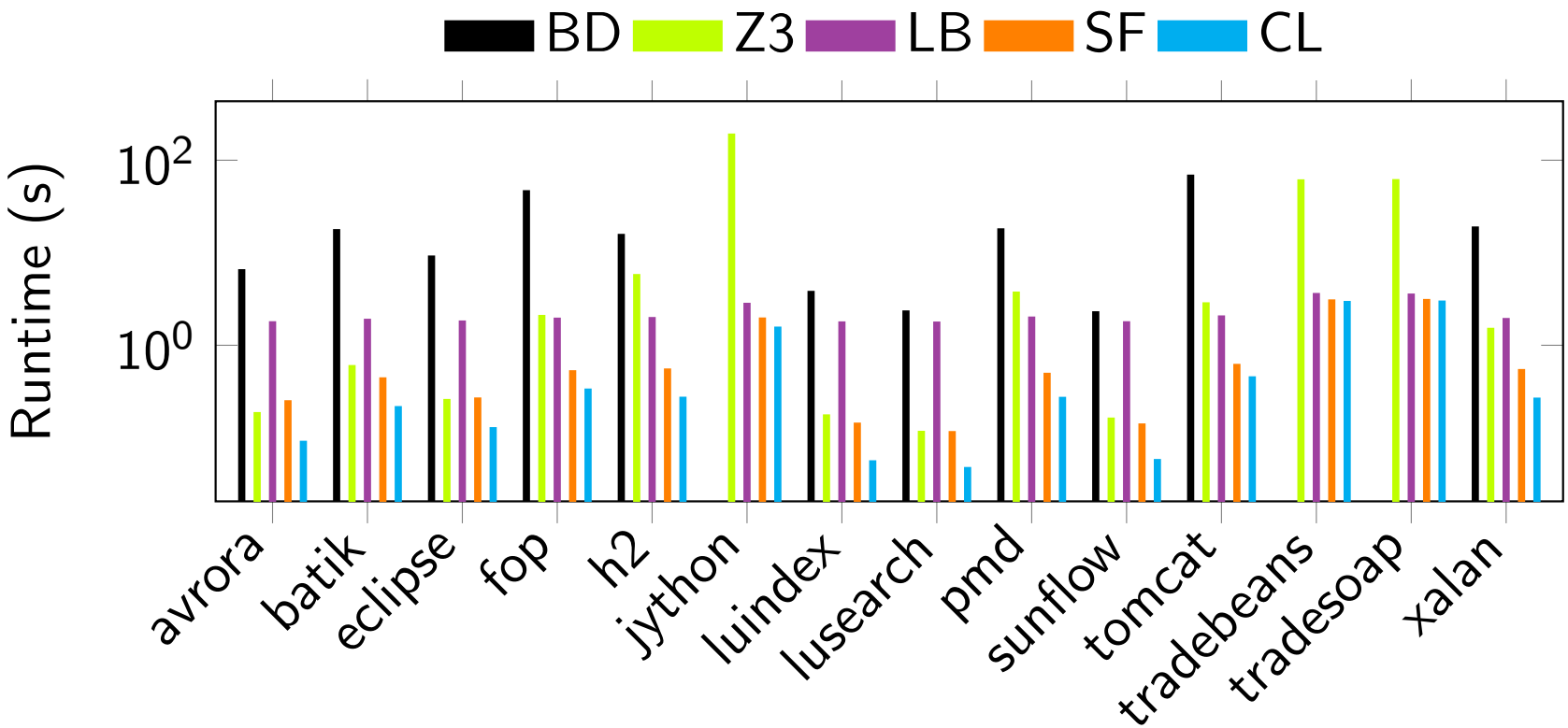
Experimental Validation

Comparison vs Gigascale



- Gigascale, high performance field-sensitive points-to analysis
- 1 hour timeout
- Cauliflower is more efficient on small cases
- Cauliflower solves large instance, but not as efficiently

Comparison vs Datalog



- Points to analysis - 1 hour timeout
- Datalog exhibits overheads/inefficiencies Cauliflower doesn't

Live Demo

Summary

Cauliflower

- CFL-R
  - Generalisation of Recognition and Reachability
  - Ubiquitous in program analysis
  - Notably points-to analysis
- Cauliflower
  - Solver generator
  - Parallel
  - Enhanced semantics
    - Fields, Reversal, Branching, Disconnection
  - DSL for rapid prototyping

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