SWAPPER: A Framework for Automatic Generation of Formula Simplifiers based on Conditional Rewrite Rules

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Mountain View, CA, USA

General Constraint Solvers

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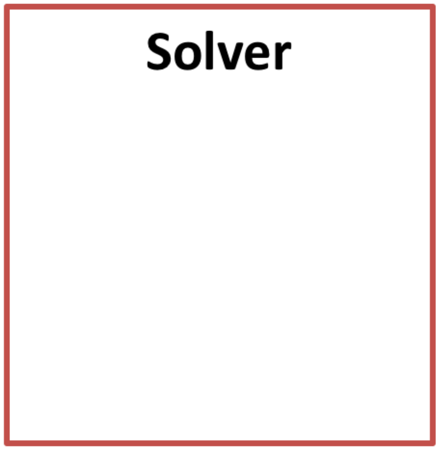

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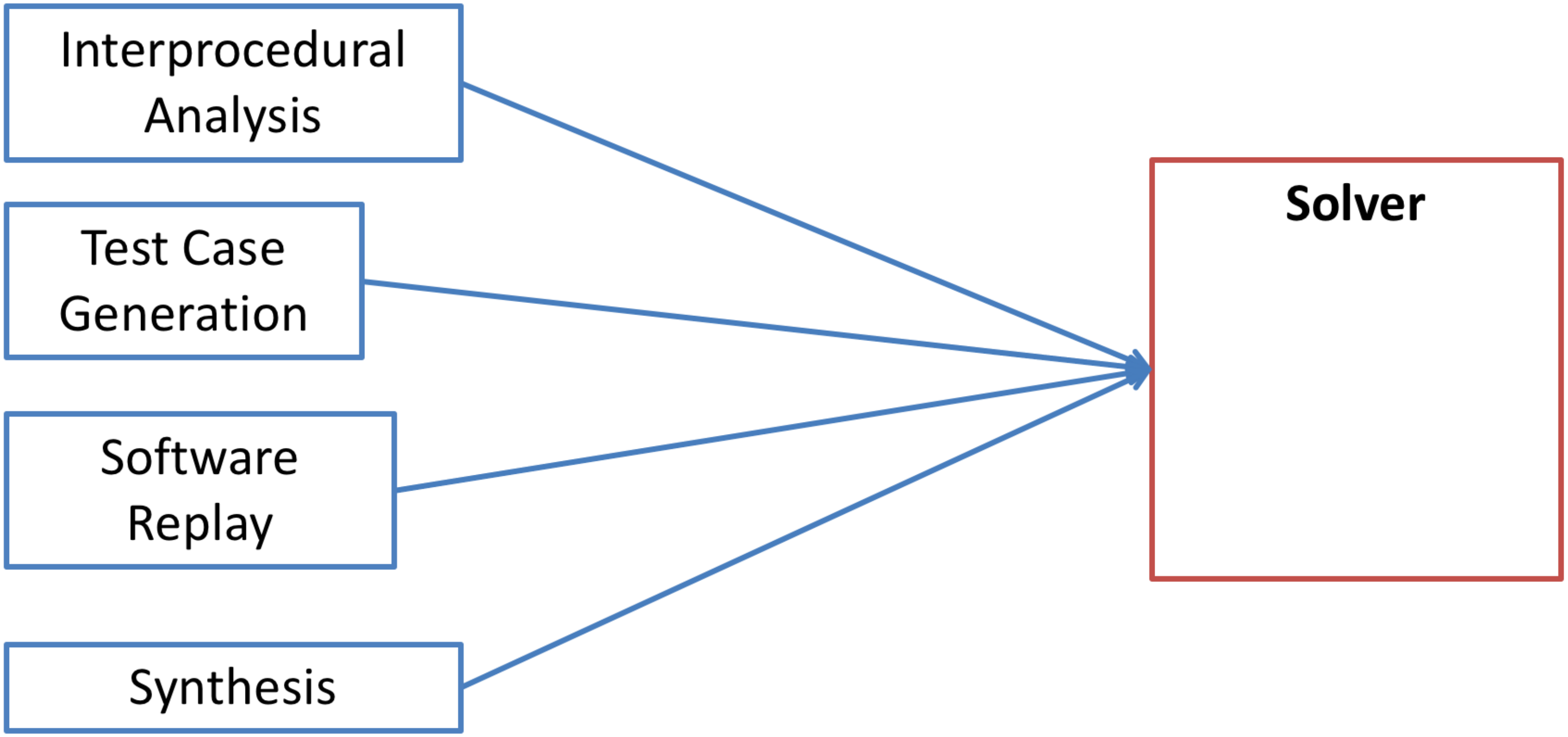

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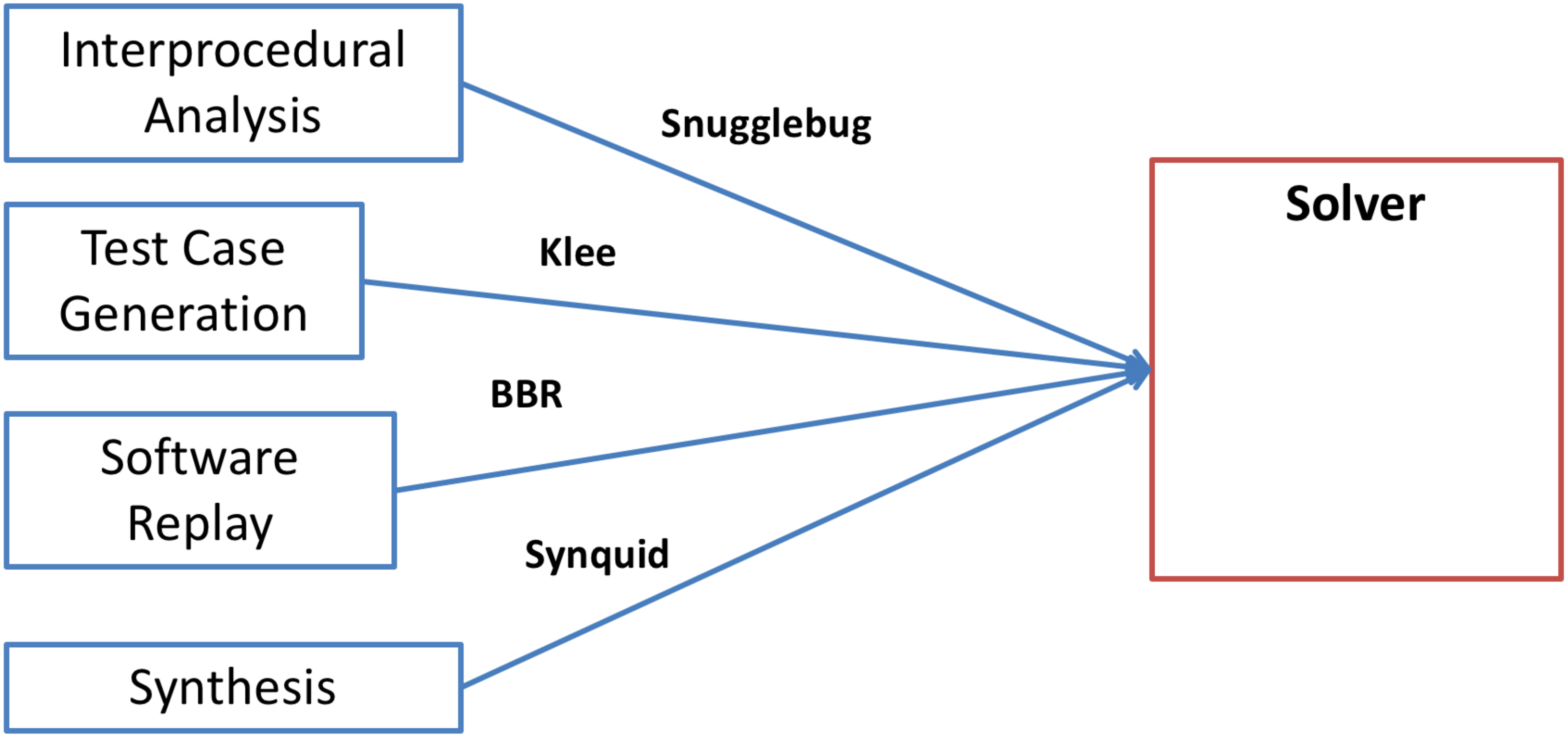

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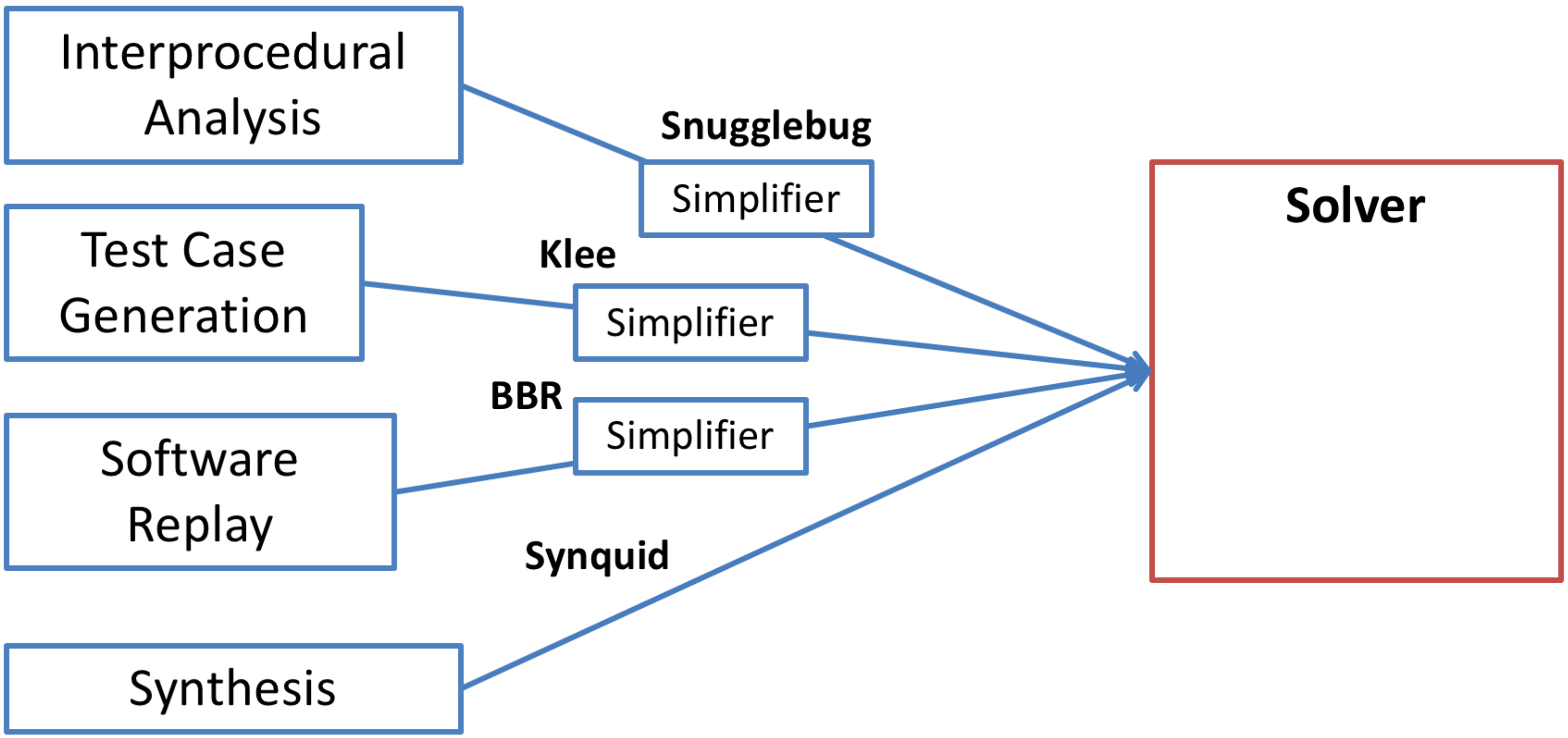

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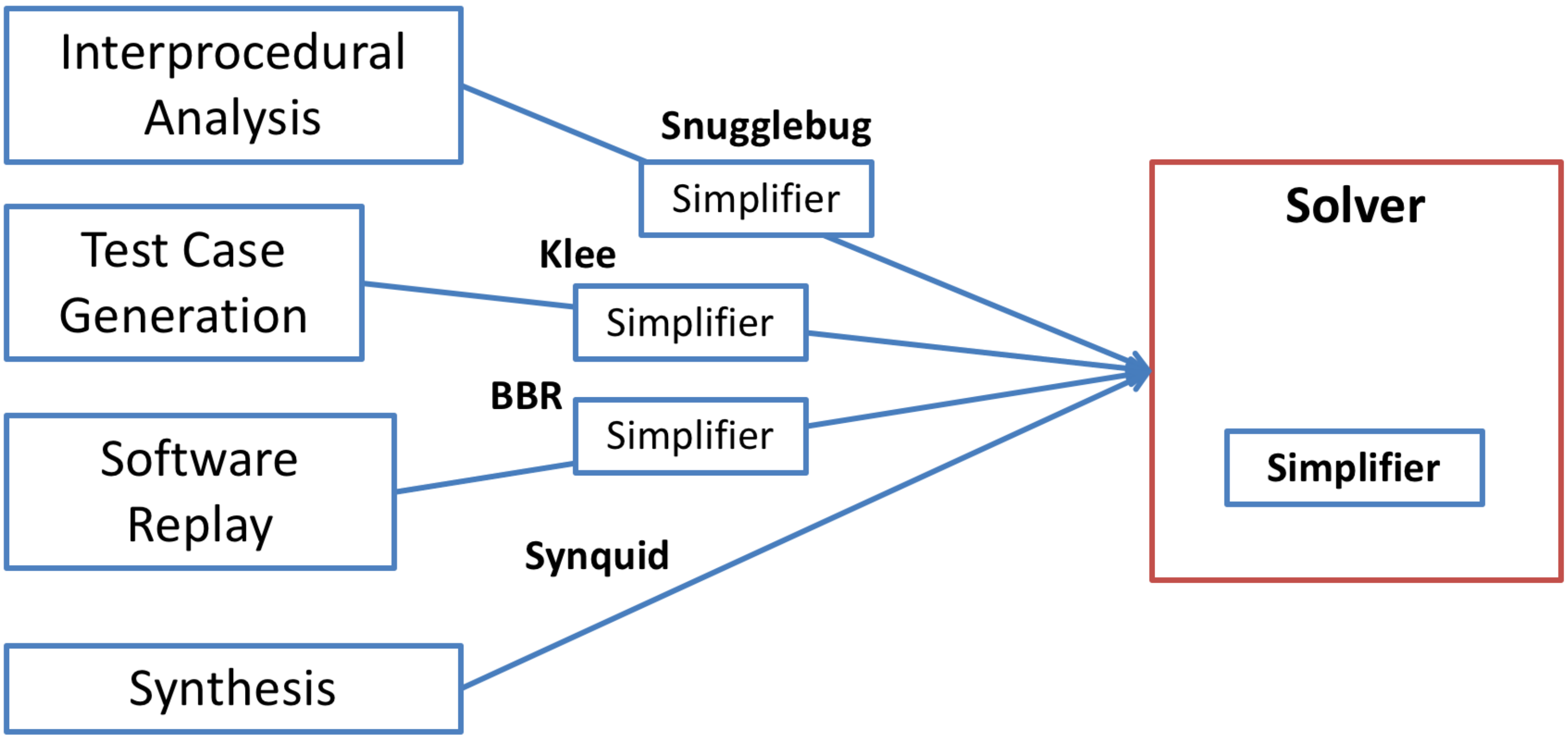

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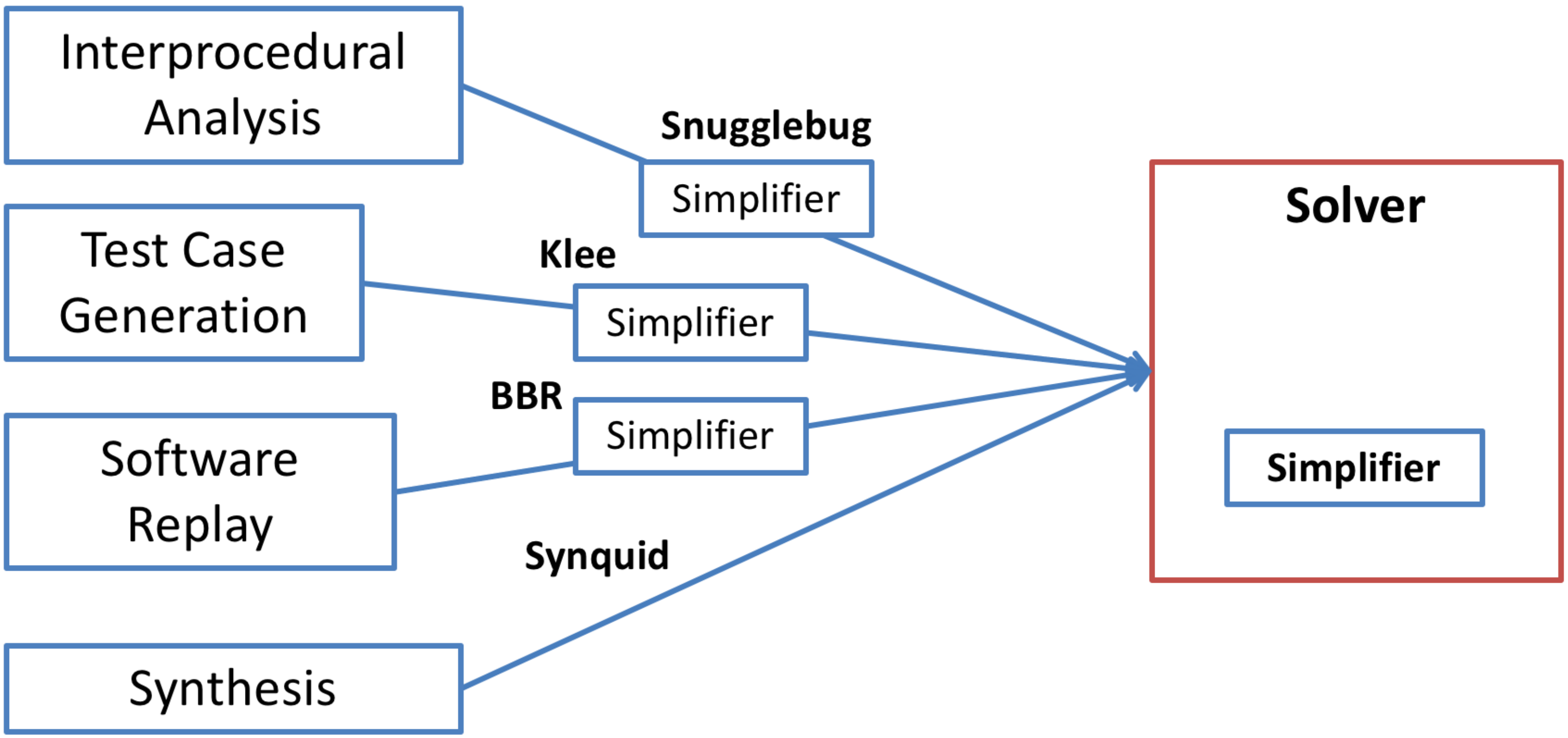

Simplifiers are very application specific

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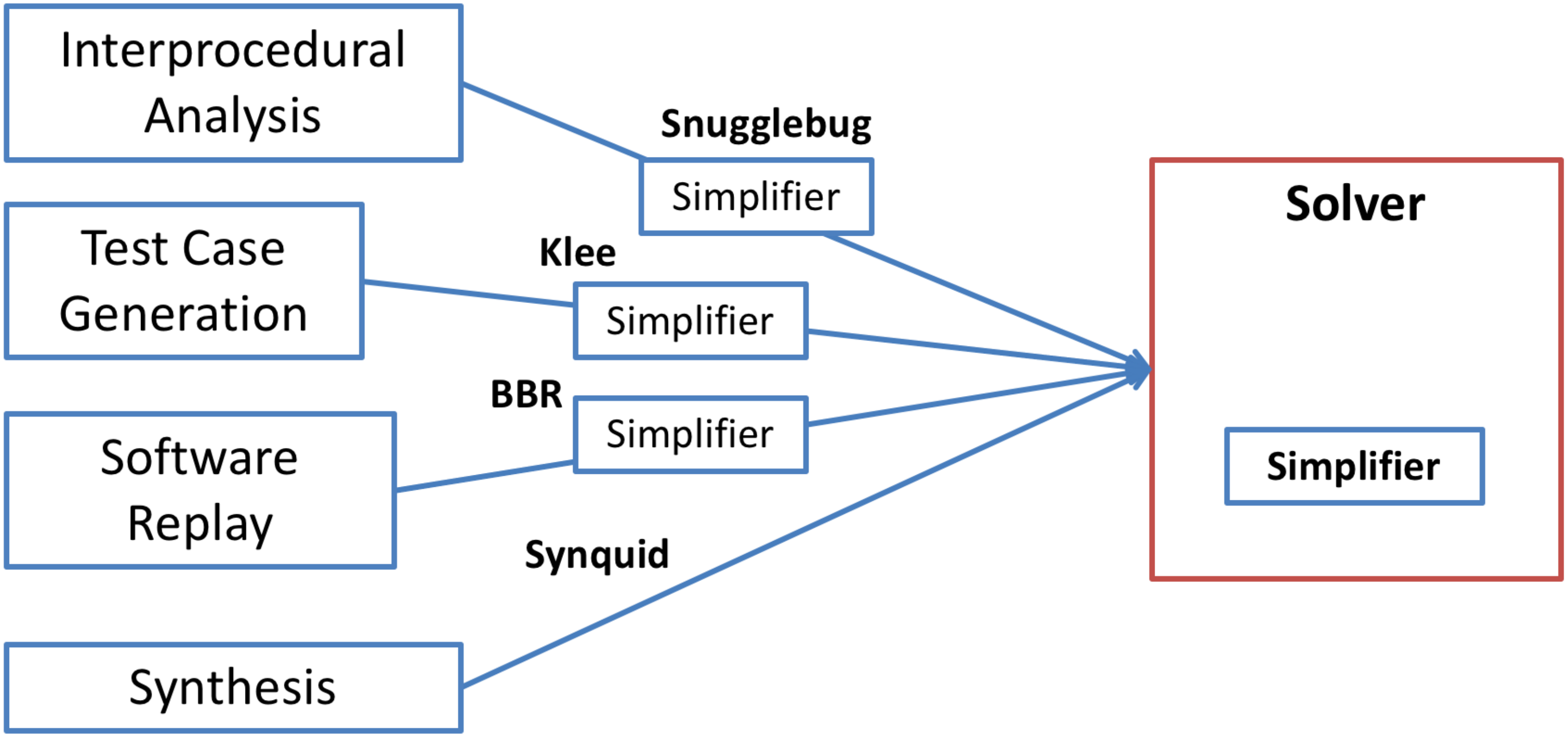

Simplifiers are very application specific

Not every tool can afford a custom simplifier

Custom simplifiers are expensive

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Trial and Error

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Trial and Error

Each Try is hard

Target: Sketch Solver

Sketch
∃∀ formulas

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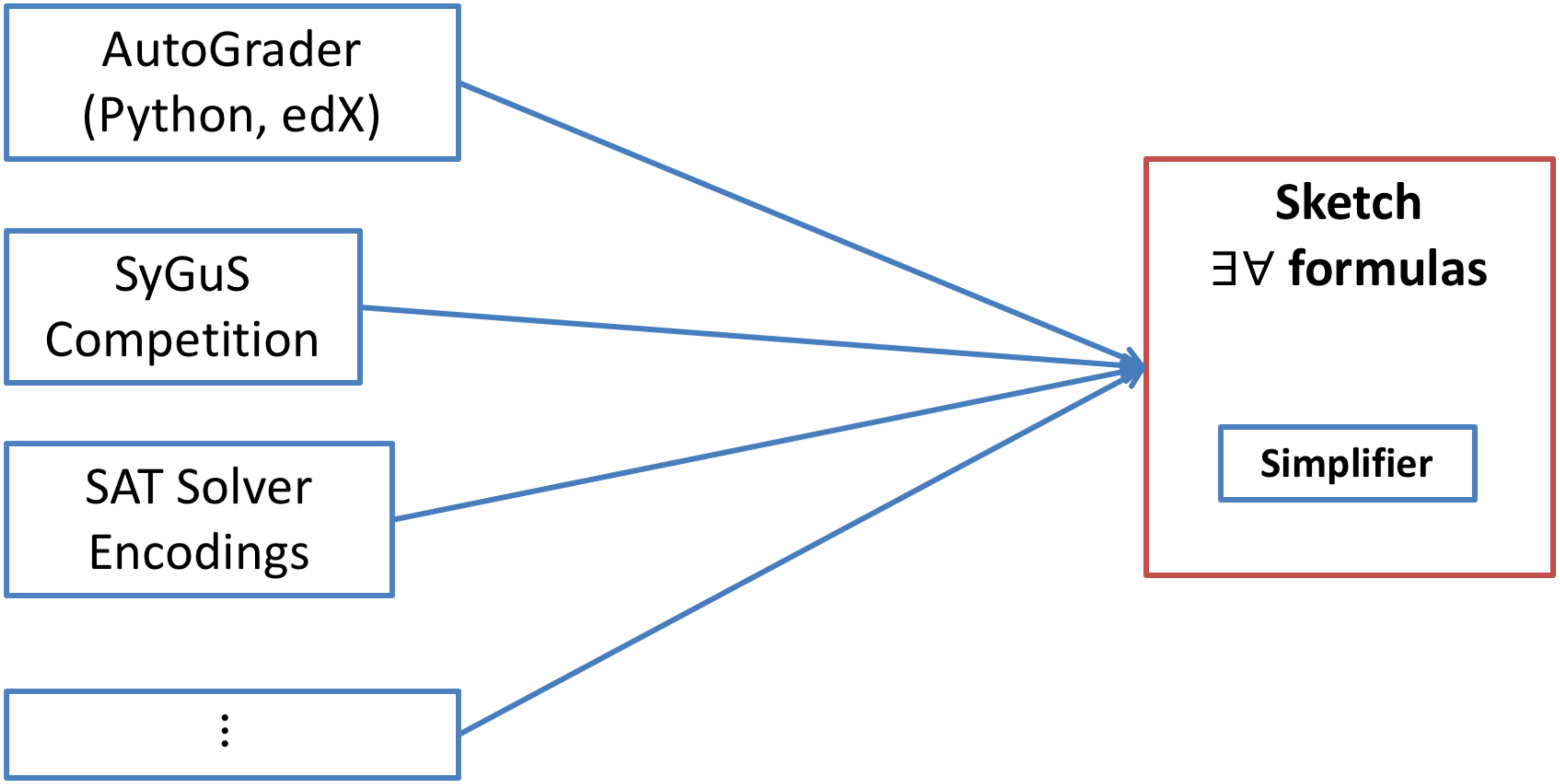

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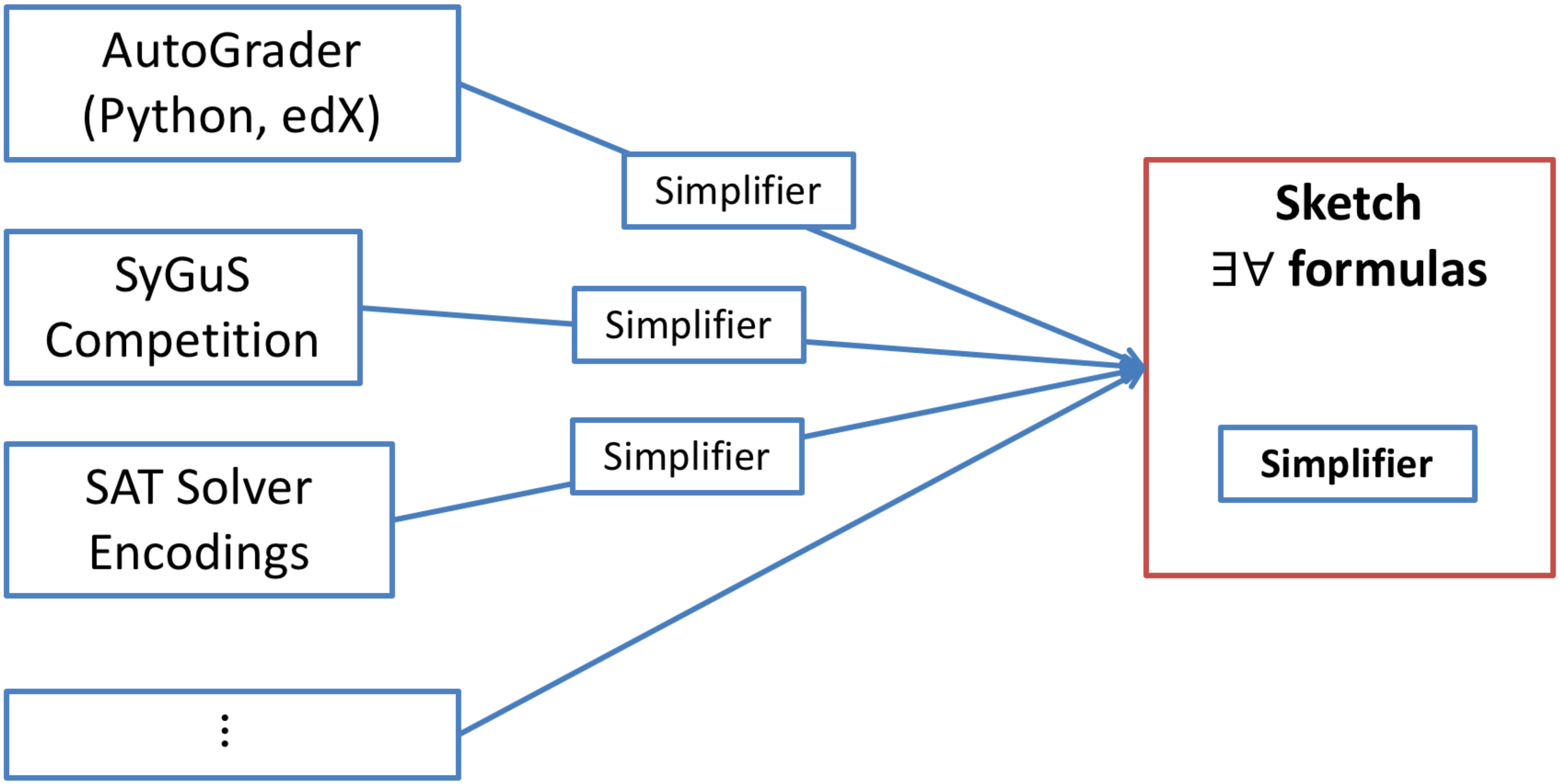

Auto-generate efficient domain-specific simplifiers

Sketch Simplifier

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Messy low-level C++ code

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Employs simple declarative *Rewrite rules*

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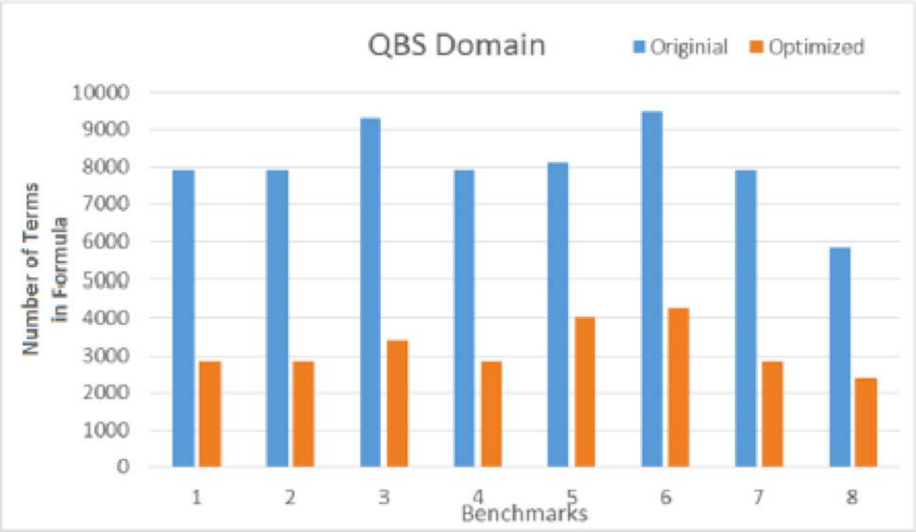
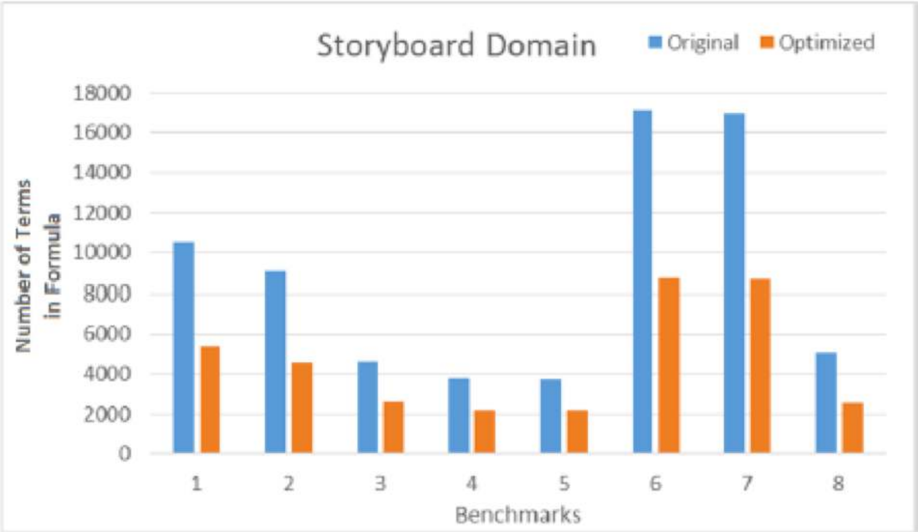
Messy low-level C++ code

Employs simple declarative *Rewrite rules*

Huge impact on performance





Internal Representation

- Internal language for constraints
- Theory of Arrays, booleans and integer arithmetic

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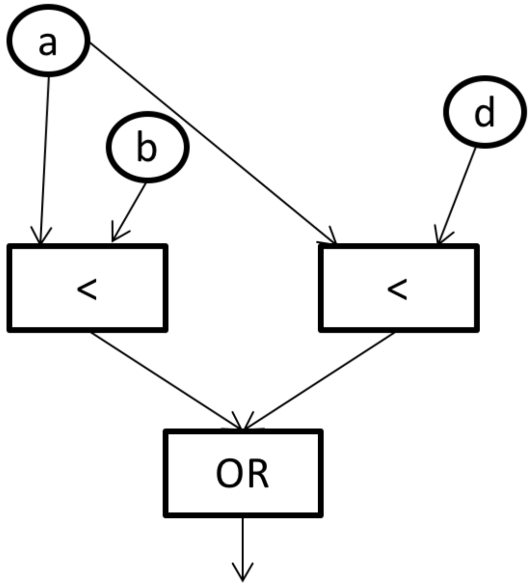
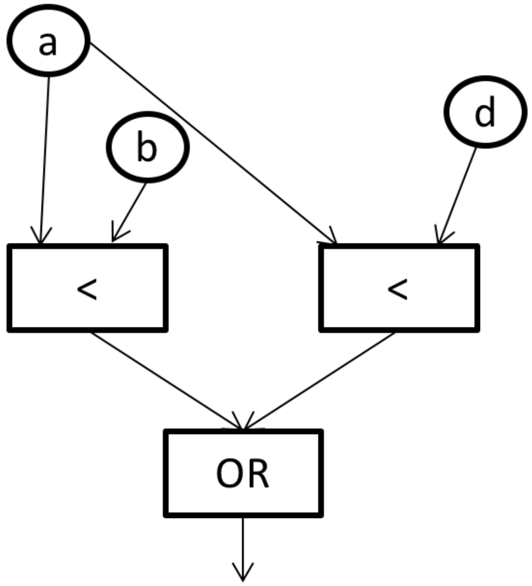


Directed Acyclic Graphs

Internal Representation

- Internal language for constraints
- Theory of Arrays, booleans and integer arithmetic

$$or(lt(a, b), lt(a, d))$$



Directed Acyclic Graphs

Conditional Rewrite Rules

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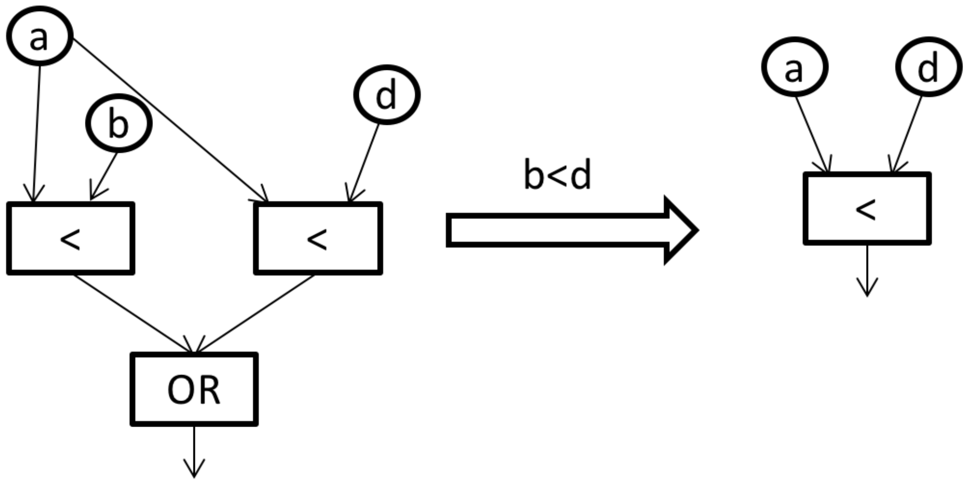

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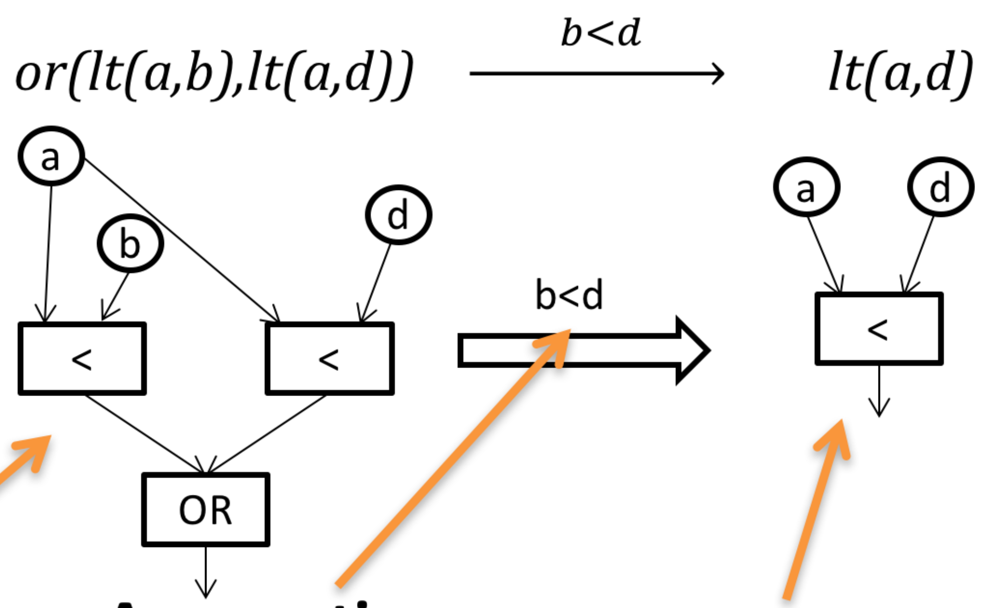

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Conditional Rewrite Rules

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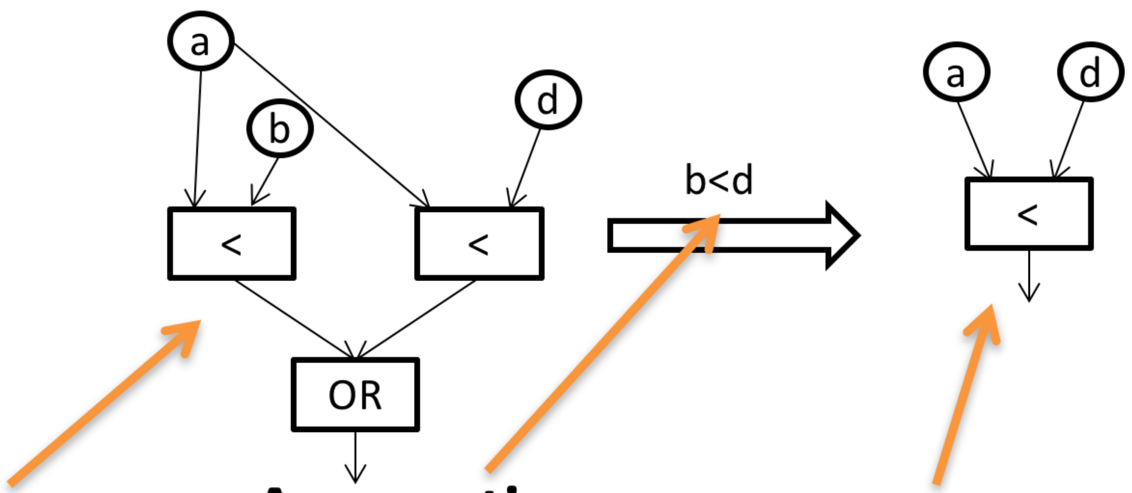

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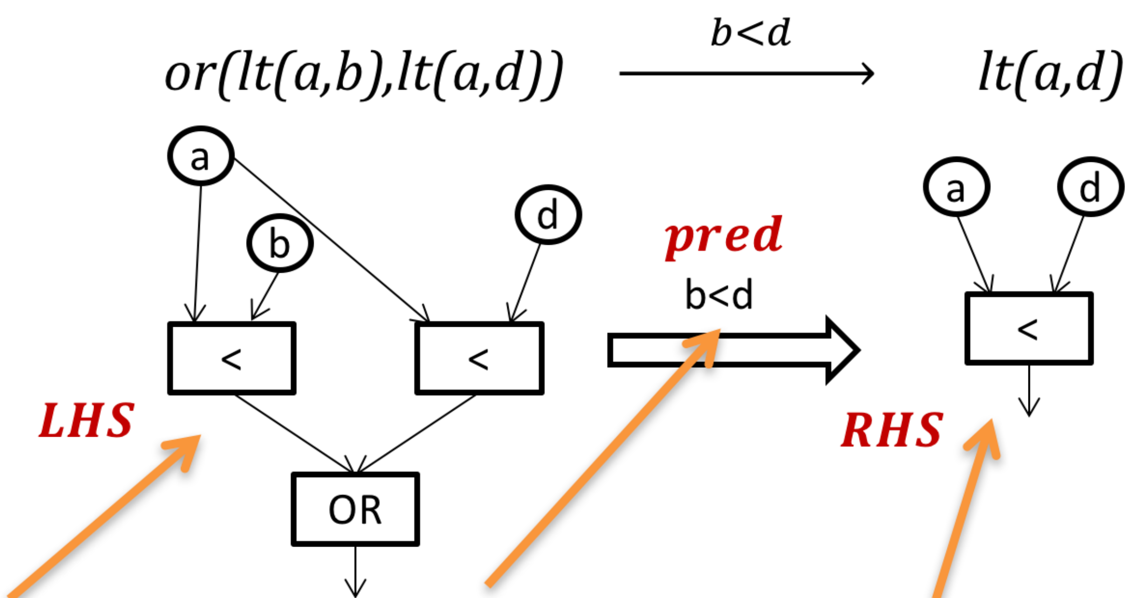
Conditional Rewrite Rules



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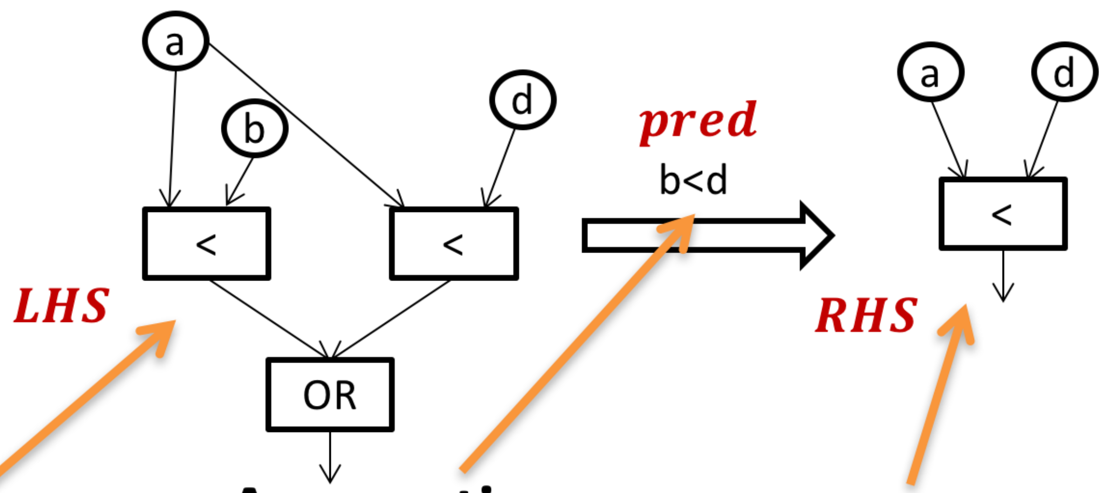

- **Pattern** $\xrightarrow{\textbf{Assumptions}}$ **Pattern**
- **Inputs :** 

- $\forall x \; pred(x) \Rightarrow \big(LHS(x) == RHS(x)\big)$
- Sketch Simplifier: apply in order at each node

Rule application code

Code for implementing Rewrite Rules

$$and(lt(plus(a,e),x), \quad lt(plus(e,b),x)\ ) \xrightarrow{b<a} lt(plus(a,e),x)$$

Rule application code

Code for implementing Rewrite Rules

```
if(nfather->type == LT && nmother->type == LT){
  // (a+e<x) & (b+e<x) ---> a+e<x when b<a
  if(nfather->mother->type == PLUS && nmother->mother-
>type == PLUS){
    bool_node* nfm = nfather->mother;
    bool_node* nmm = nmother->mother;

    bool_node* nmmConst = nmm->mother;
    bool_node* nmmExp = nmm->father;
    if(isConst(nmmExp)){
      bool_node* tmp = nmmExp;
      nmmExp = nmmConst;
      nmmConst = tmp;
    }
    bool_node* nfmConst = nfm->mother;
    bool_node* nfmExp = nfm->father;
    if(isConst(nfmExp)){
      bool_node* tmp = nfmExp;
      nfmExp = nfmConst;
      nfmConst = tmp;
    }
if(isConst(nfmConst) && isConst(nmmConst) && nfmExp== nmmExp){
      if(val(nfmConst) < val(nmmConst)){
        return nmother;
      }else{
        return nfather;
      }
    }
  }
}
```

$$and(lt(plus(a,e),x),\ lt(plus(e,b),x))\ \xrightarrow{b<a}\ lt(plus(a,e),x)$$

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Given a corpus of benchmark problems (formulas) from a domain:

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Solution: **SWAPPER** framework

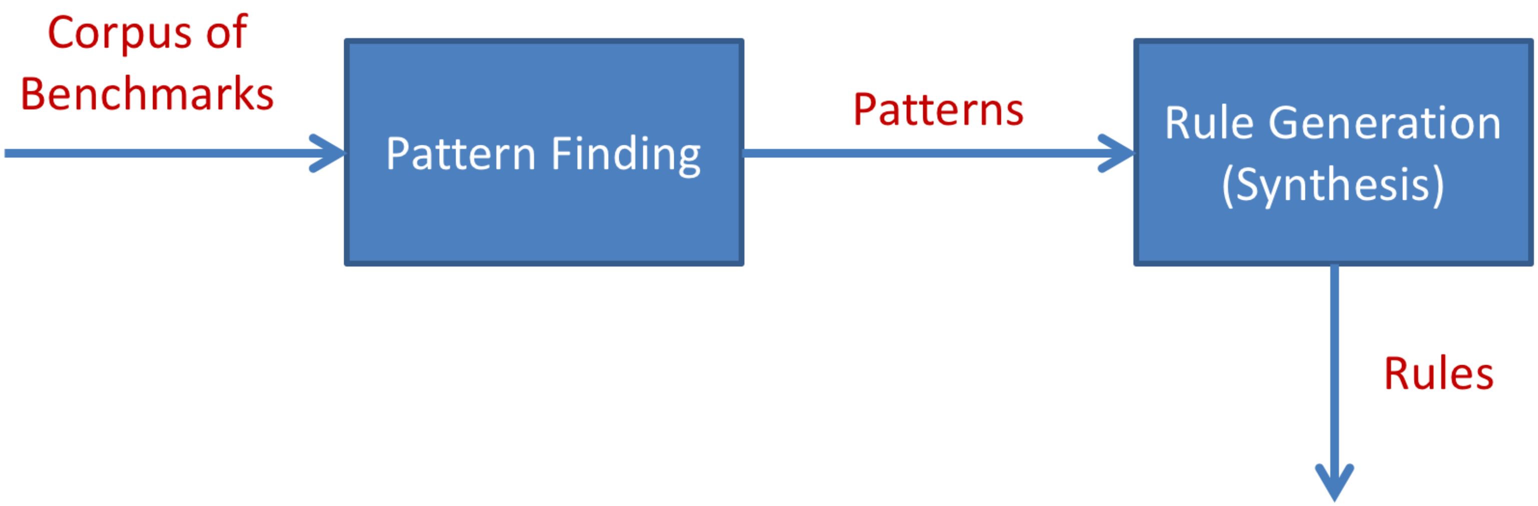
SWAPPER framework

SWAPPER framework

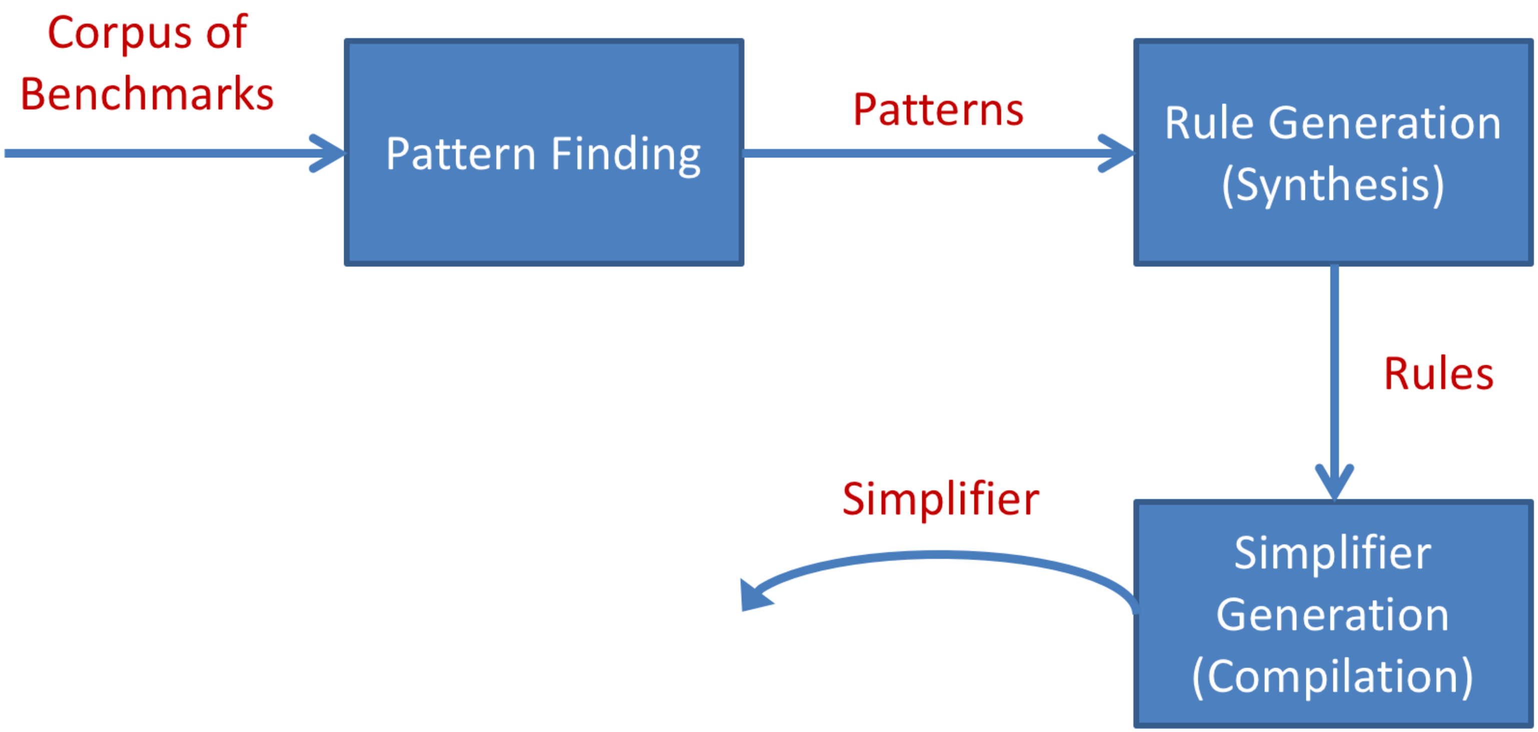
Corpus of Benchmarks

SWAPPER framework

SWAPPER framework



SWAPPER framework



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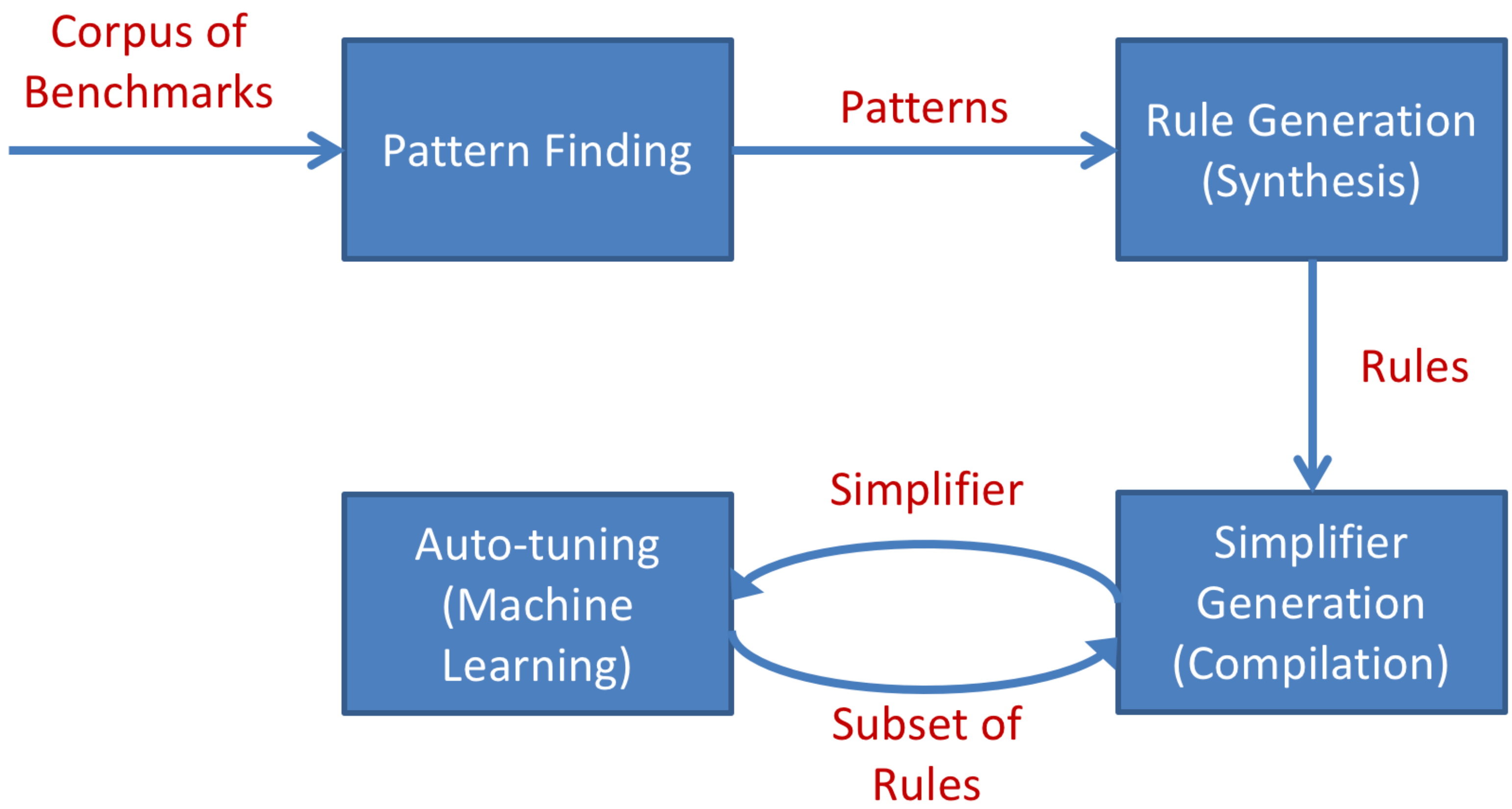

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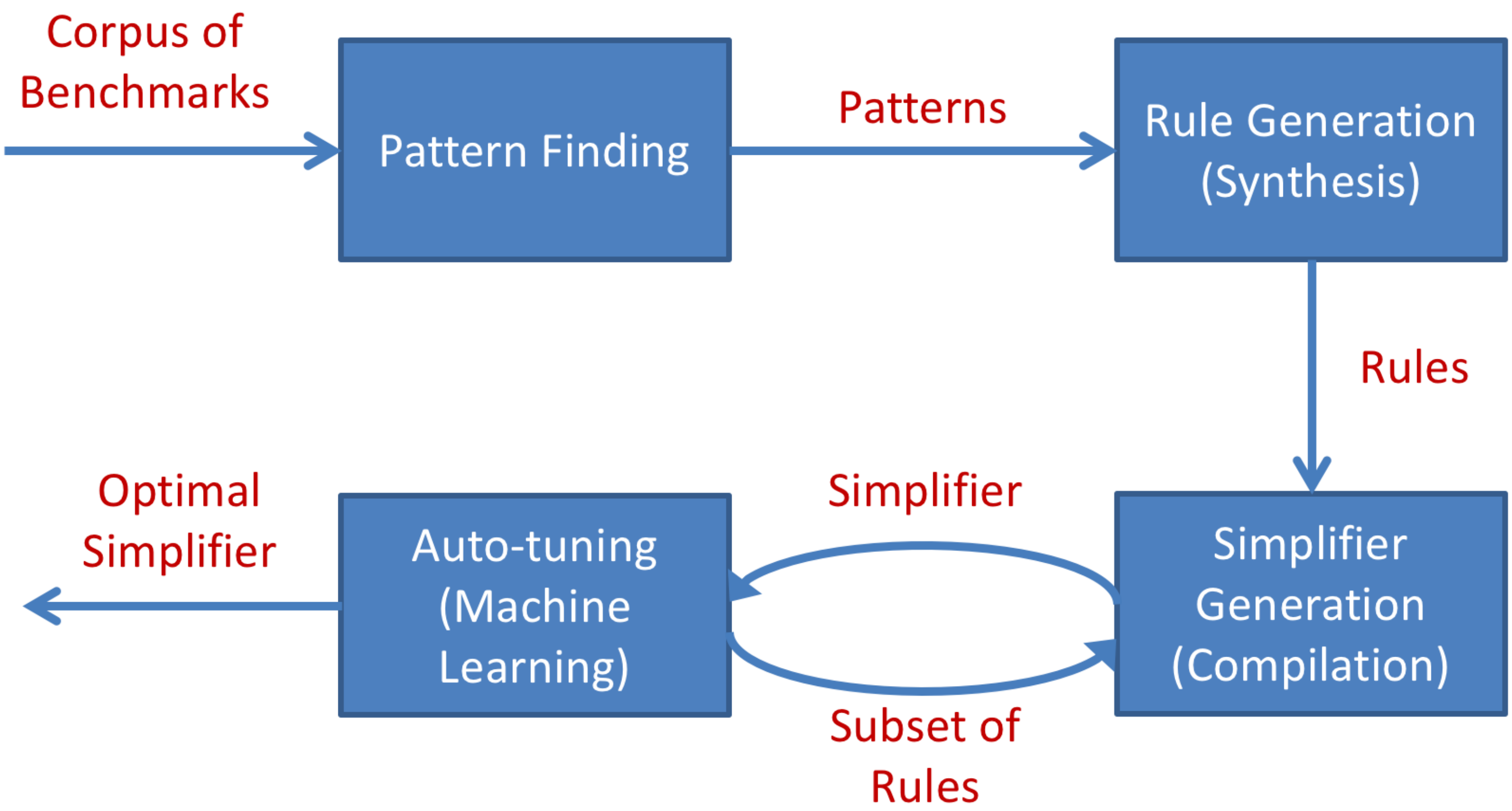

Related Work

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- Peephole optimizations
  - Alive DSL [PLDI 15] : no synthesis of rules
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  - Alive DSL [PLDI 15] : no synthesis of rules
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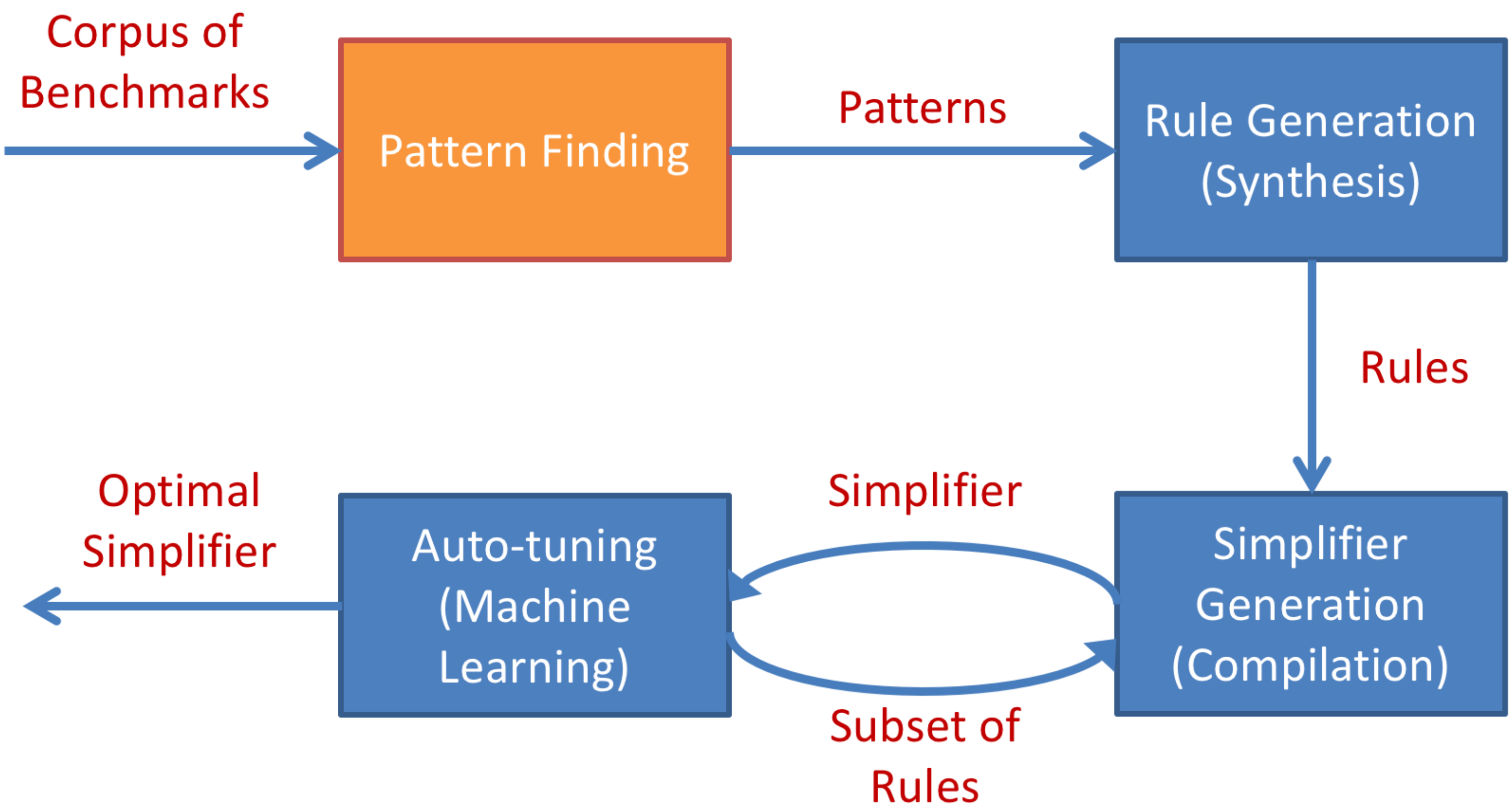
- Term/Graph Rewriting:
  - Stratego/XT [ASF+SDF 97], GrGen

SWAPPER framework



Pattern Finding

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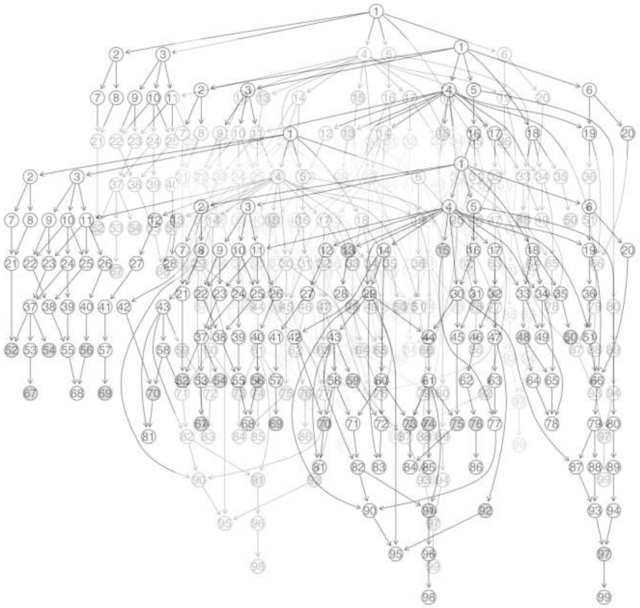
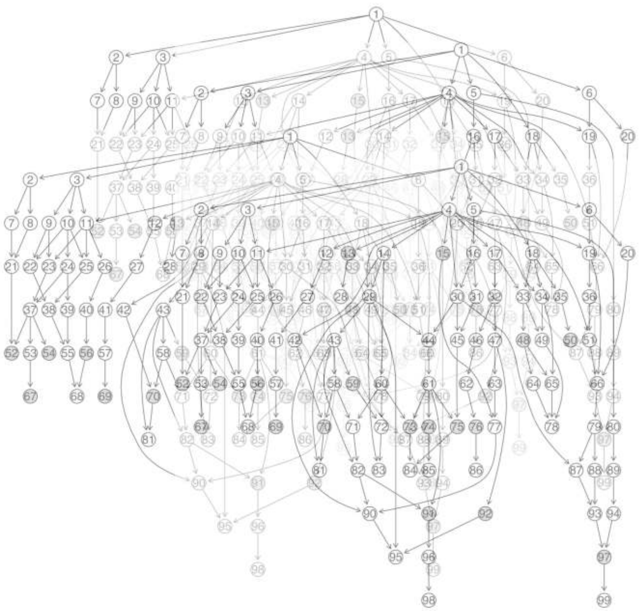
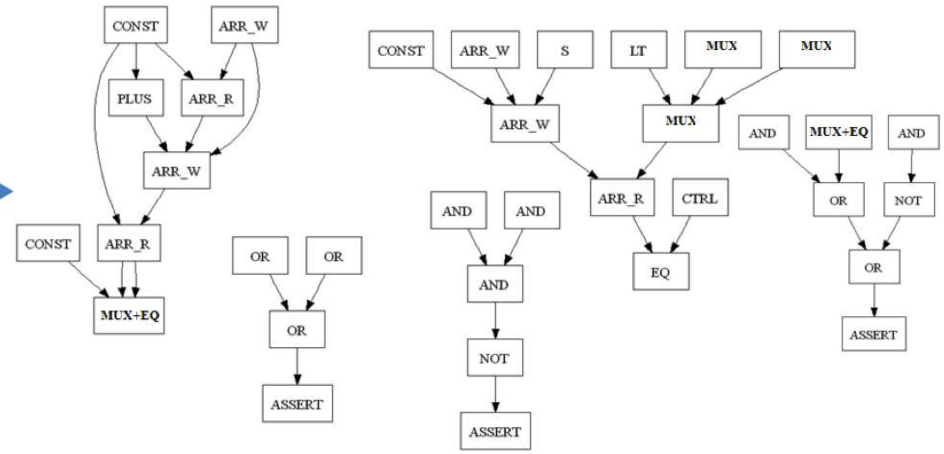


Corpus of Formulas (DAGs)

Pattern Finding





Corpus of Formulas (DAGs)

Patterns (Sub-formulas)

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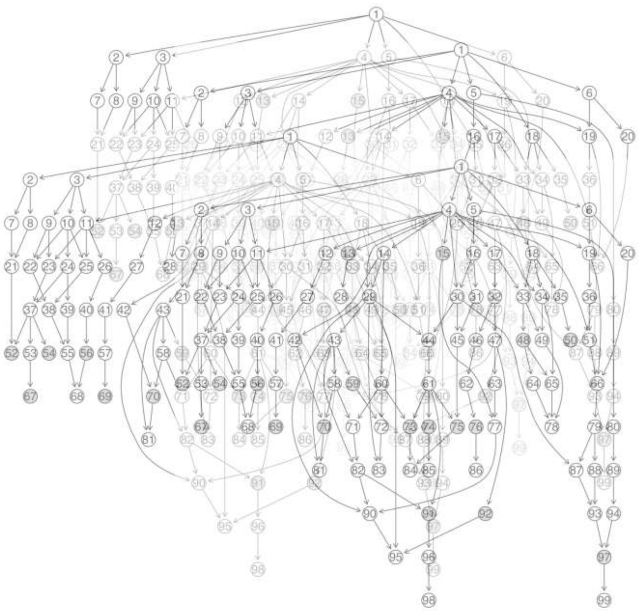

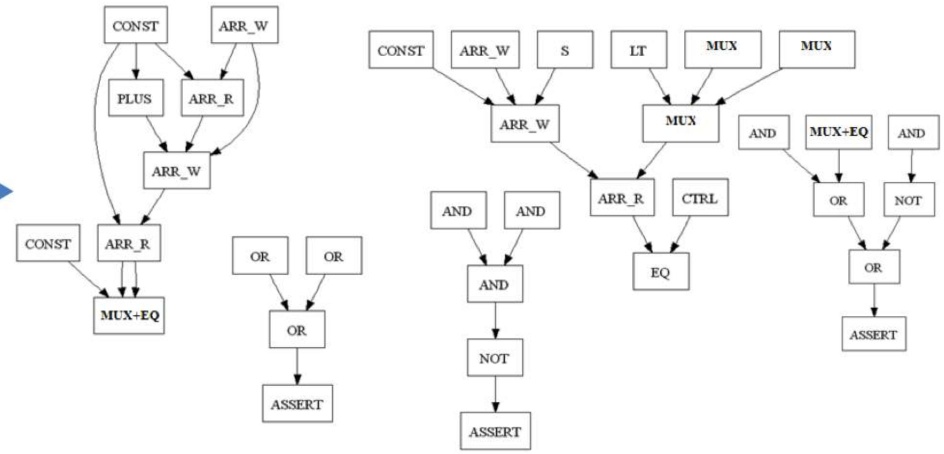

Corpus of Formulas (DAGs)

Patterns (Sub-formulas)

Commonly Occurring Patterns ⇒ More applicable rules

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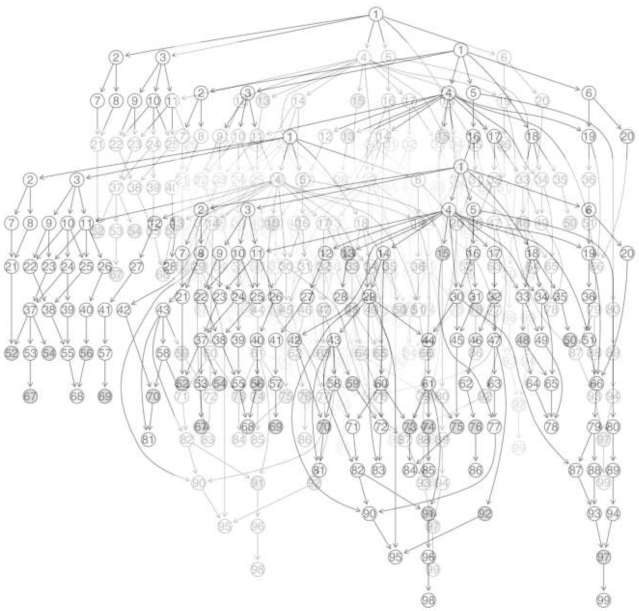

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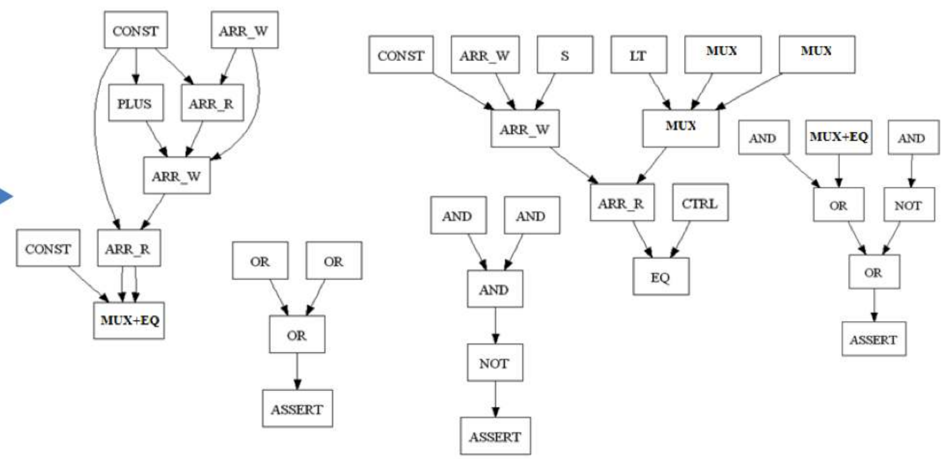

Patterns
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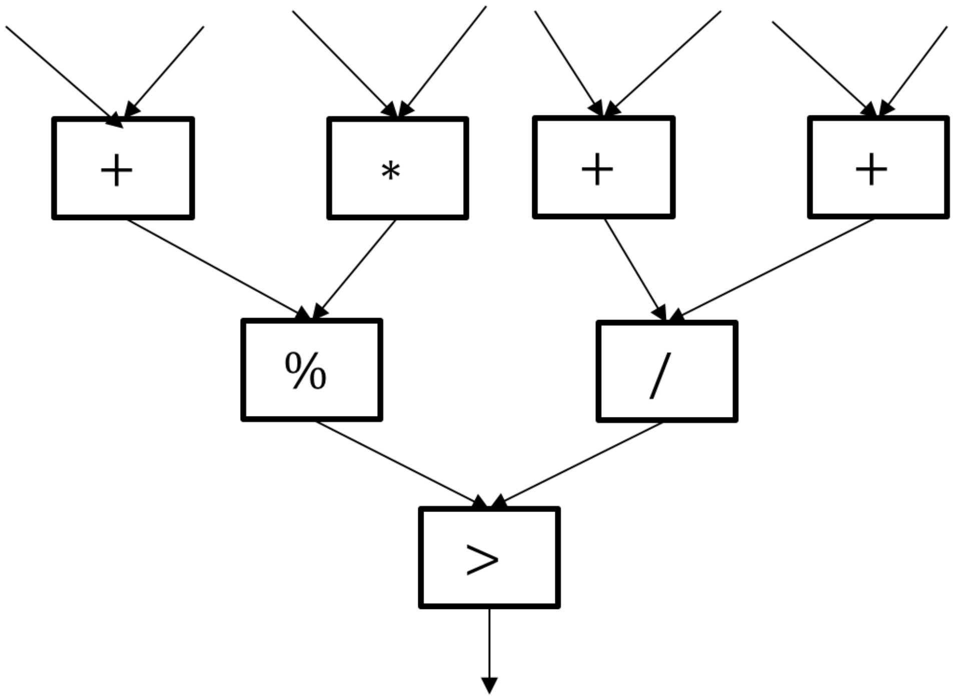
Commonly Occurring Patterns ⇒ More applicable rules

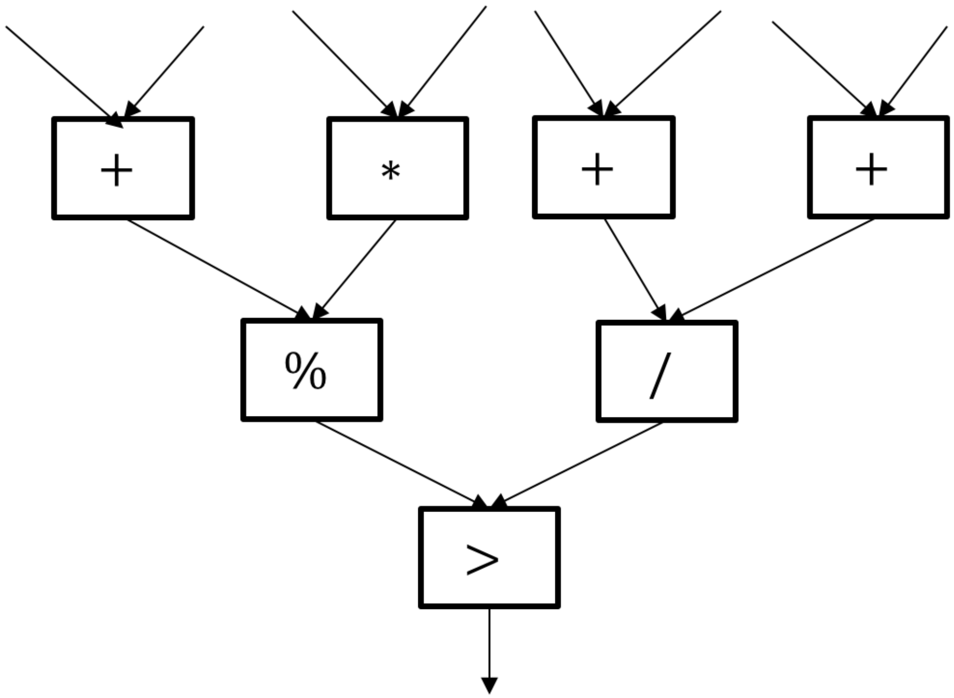
Different from Motif Discovery

Representative Sampling



Formula Trees

Representative Sampling



$$\frac{1}{|nodes|}$$

Formula Trees

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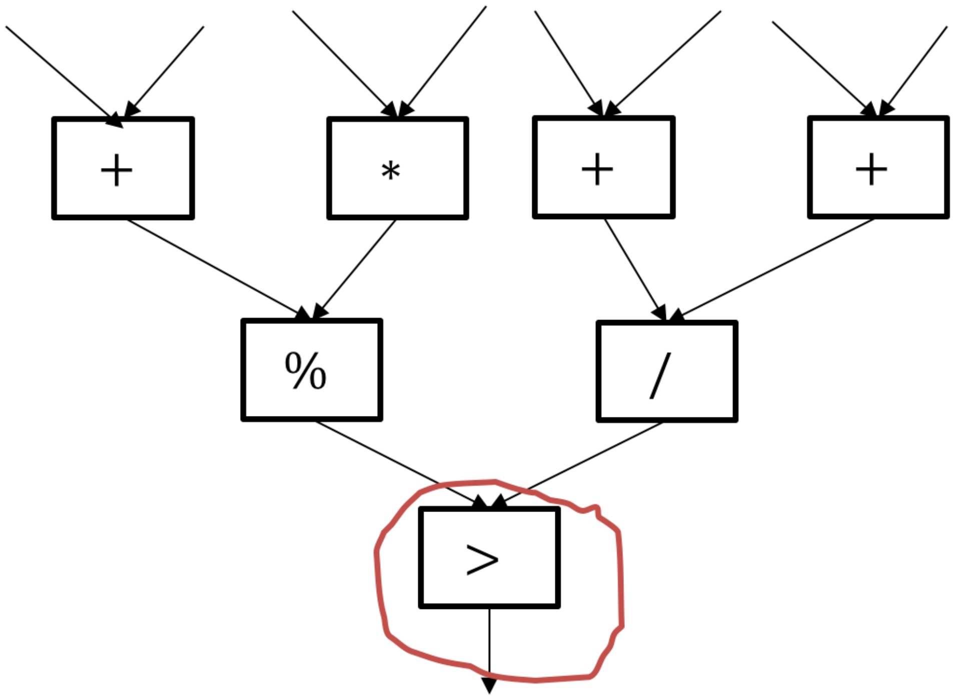

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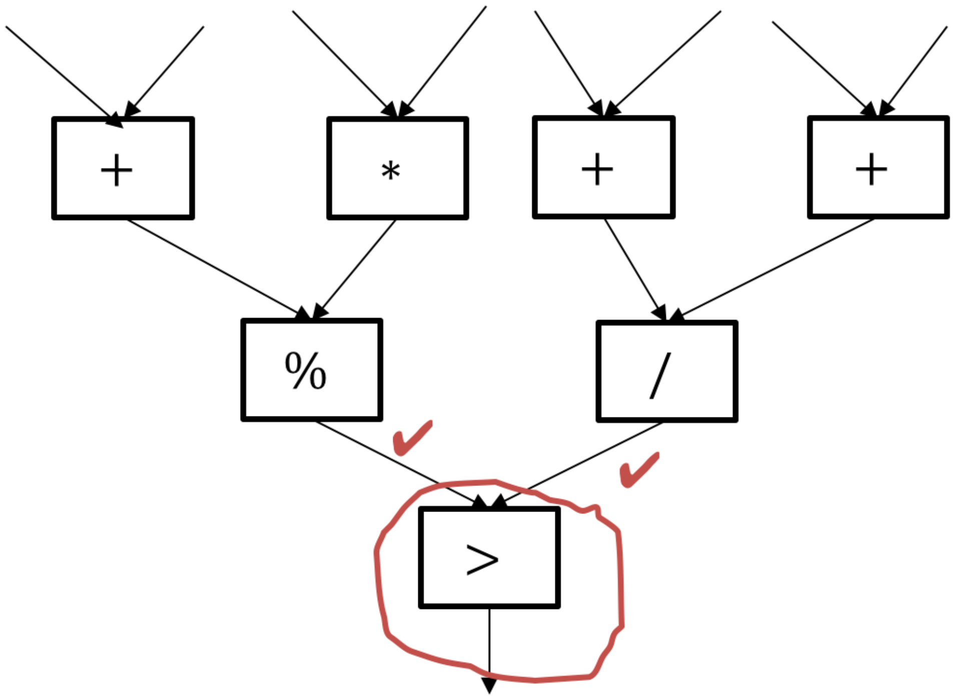

$$\frac{1}{|nodes|} \times \frac{1}{2}$$

Formula Trees

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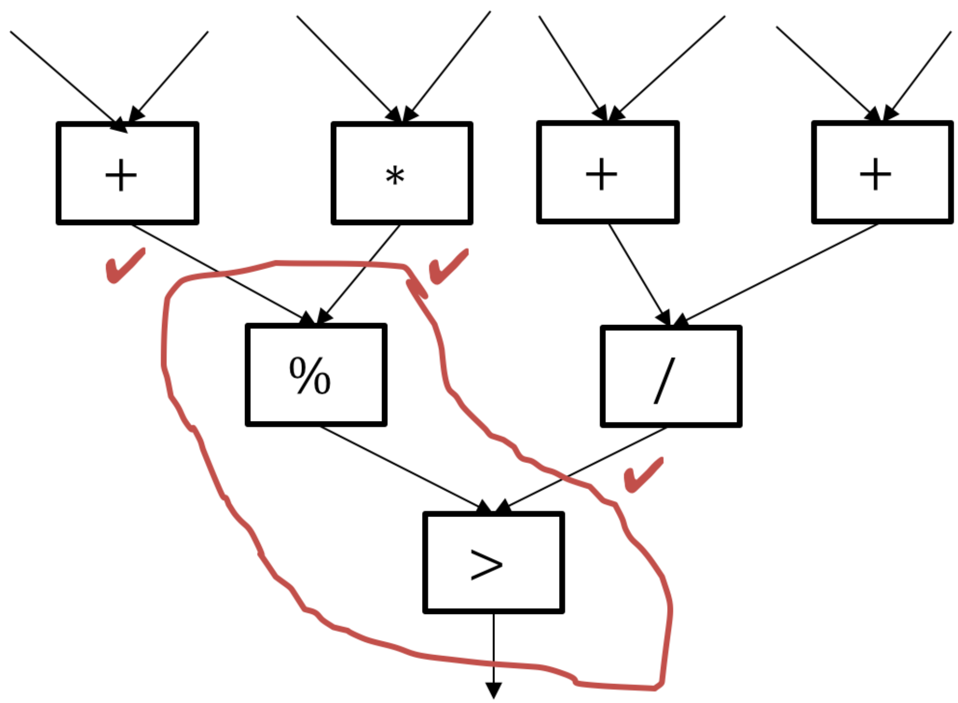

$$\frac{1}{|nodes|} \times \frac{1}{2} \times \frac{1}{3}$$

Formula Trees

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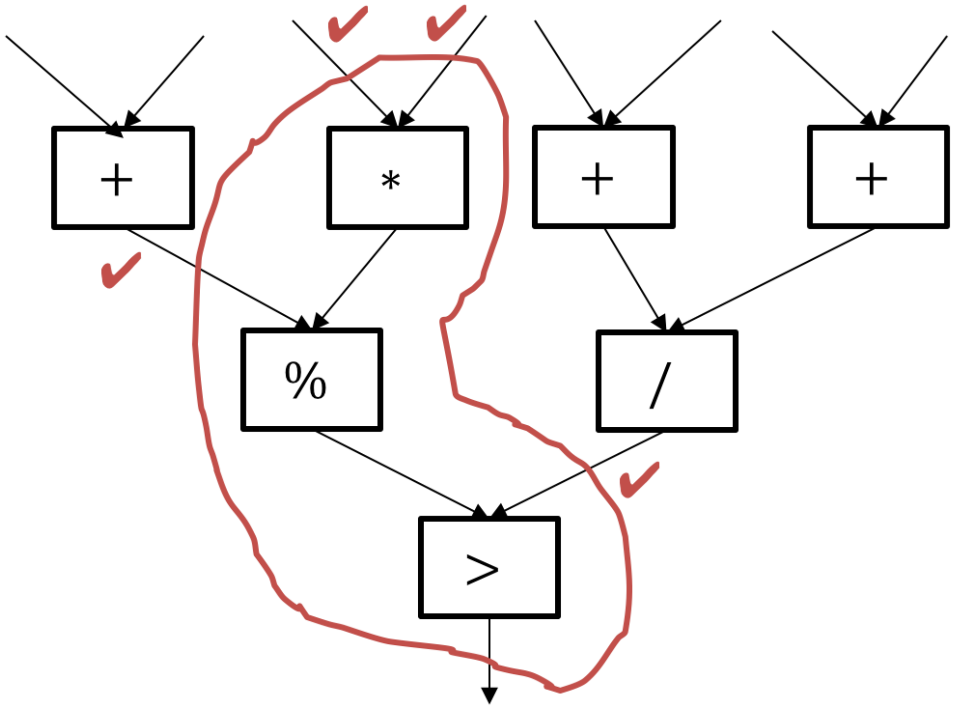

$$\frac{1}{|nodes|} \times \frac{1}{2} \times \frac{1}{3} \times \frac{1}{4} \cdots$$

Formula Trees

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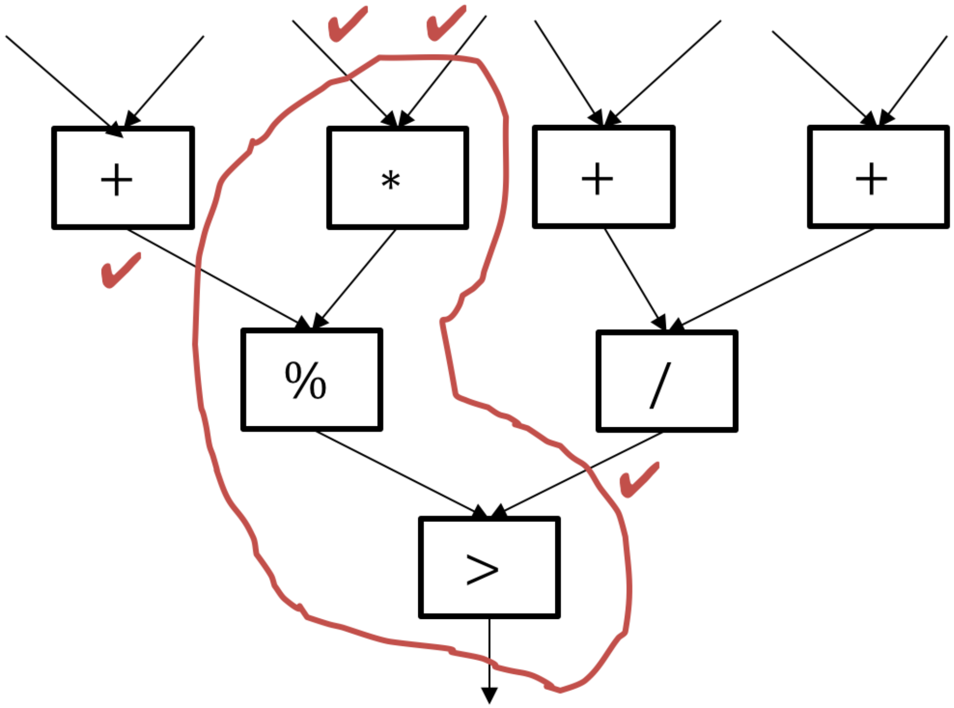

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Formula Trees

Probability independent of structure

Representative Sampling

- Naïve algorithm
  - Sample a node at random
  - Maintain a set of "boundary" edges
  - Sample from the boundary and repeat

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  - Sample a node at random
  - Maintain a set of “boundary” edges
  - Sample from the boundary and repeat
- Works for K-ary trees

Pattern Finding: Sampling

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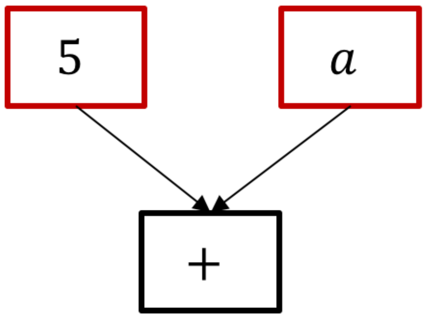

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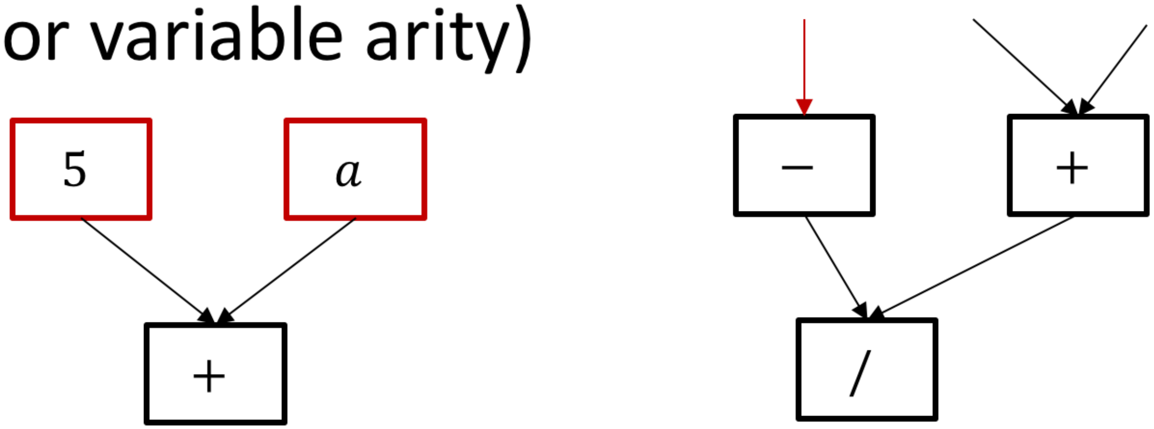

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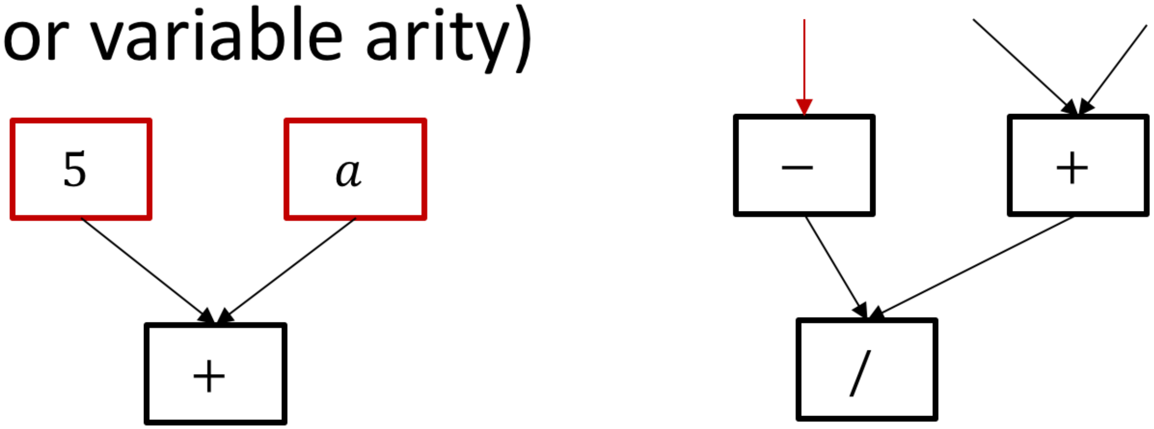

  - For DAGs, Finding same pattern in multiple ways

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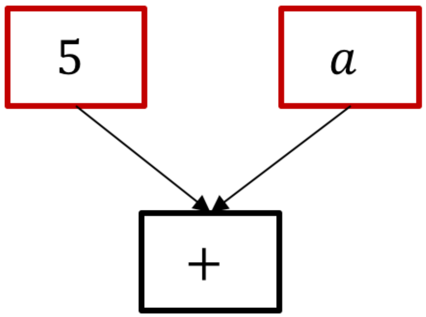

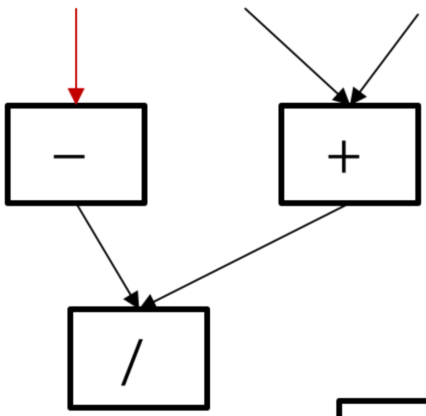

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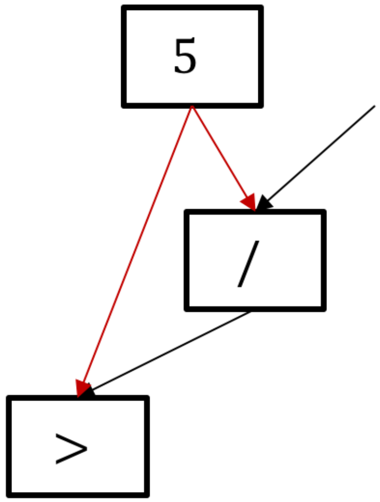

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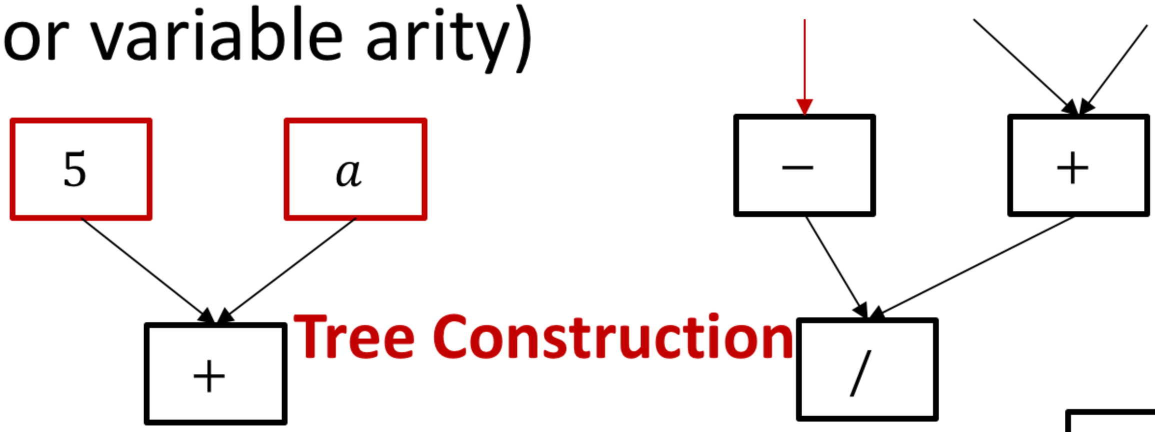

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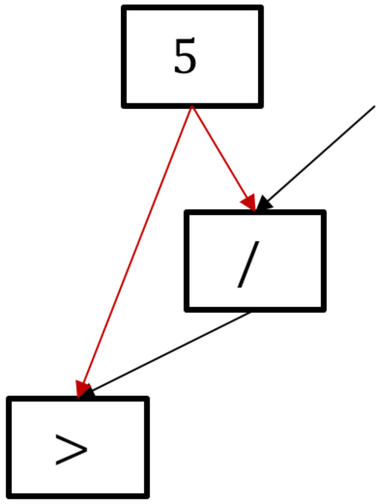

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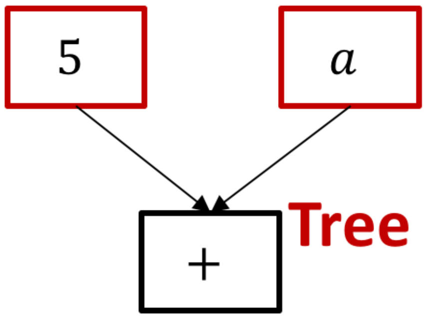
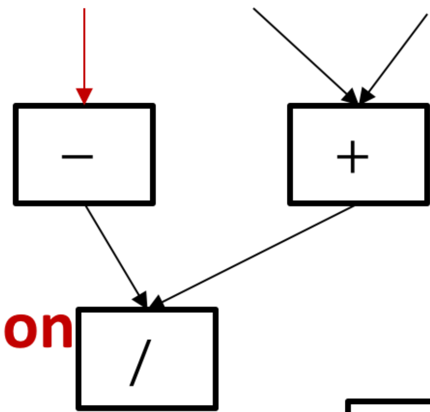


Tree Construction



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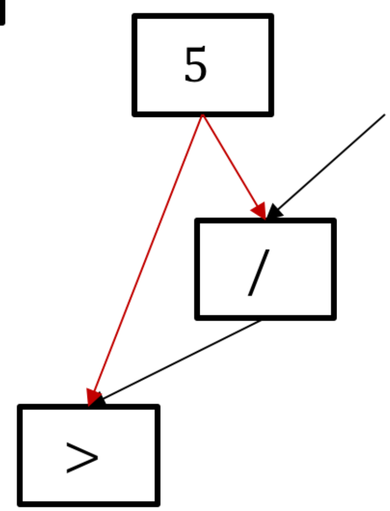
BFS Ordering



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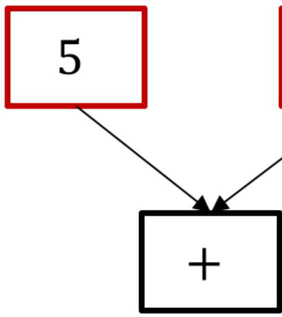

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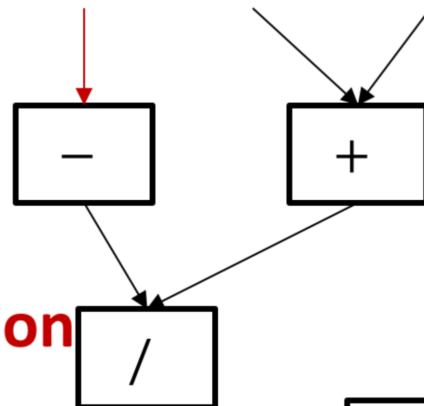

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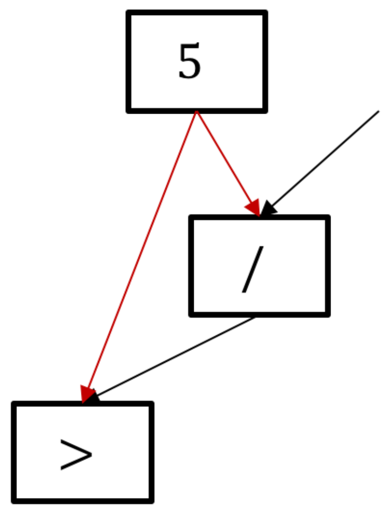
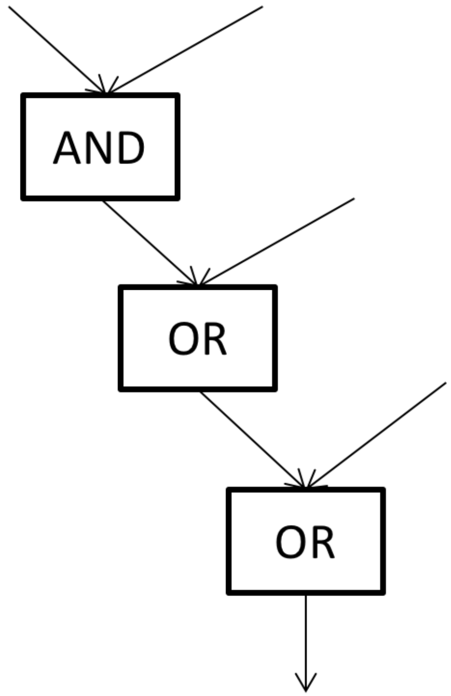


BFS Ordering

Use Rejection Sampling

Pattern Finding: Book-keeping



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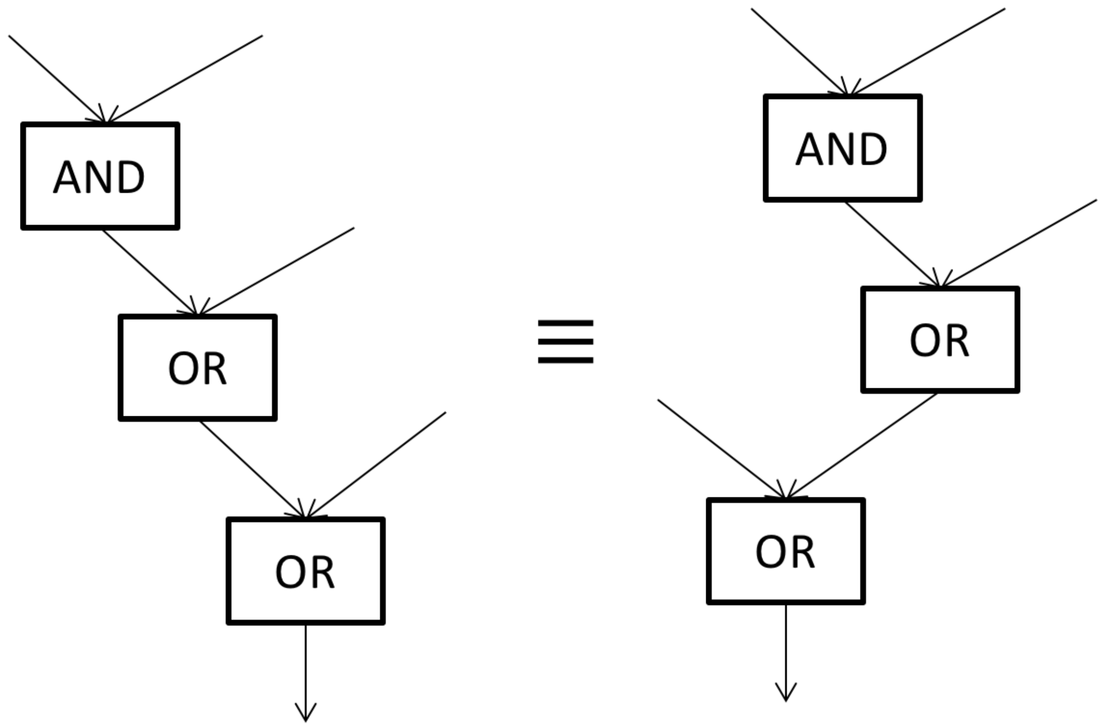
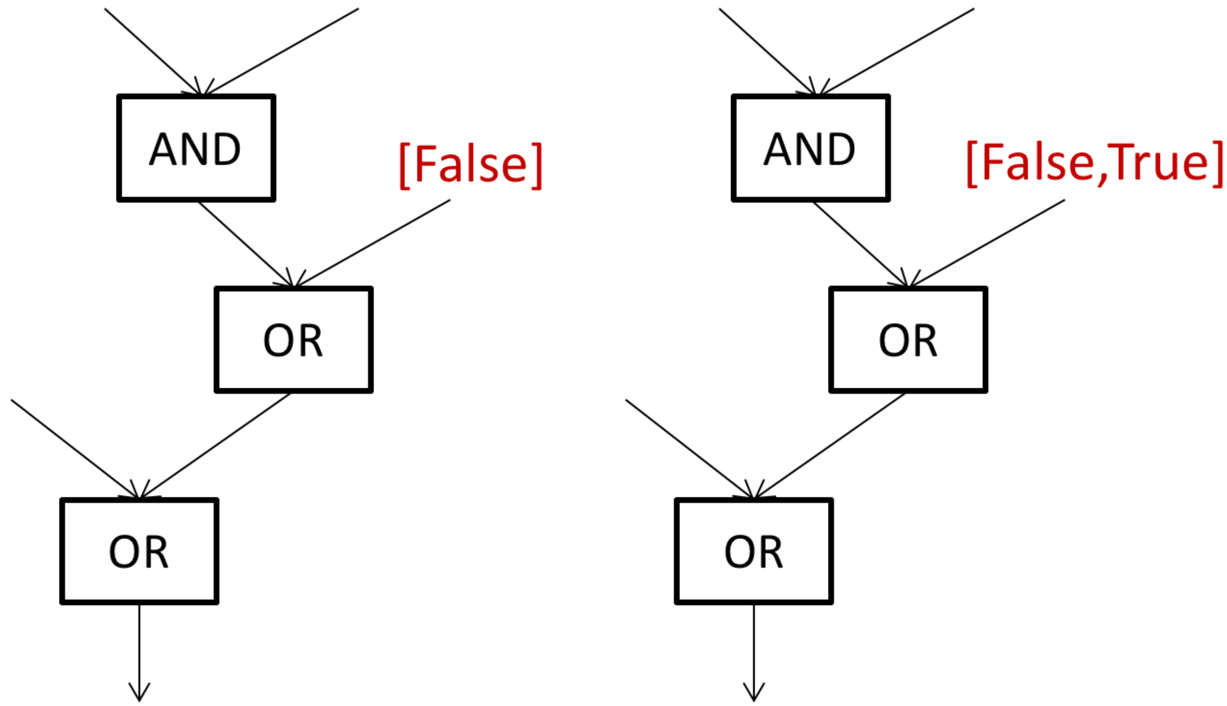


- Aggregation modulo symmetries

Pattern Finding: Book-keeping



- Aggregation modulo symmetries
- Handling contextual information around formulas

Contextual Information: *static()*

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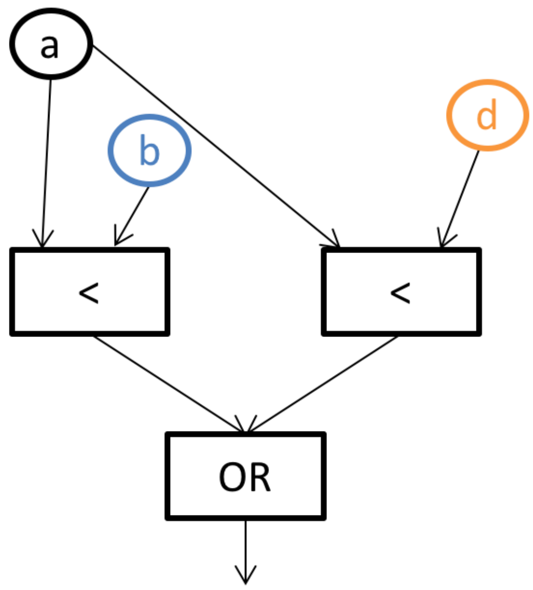

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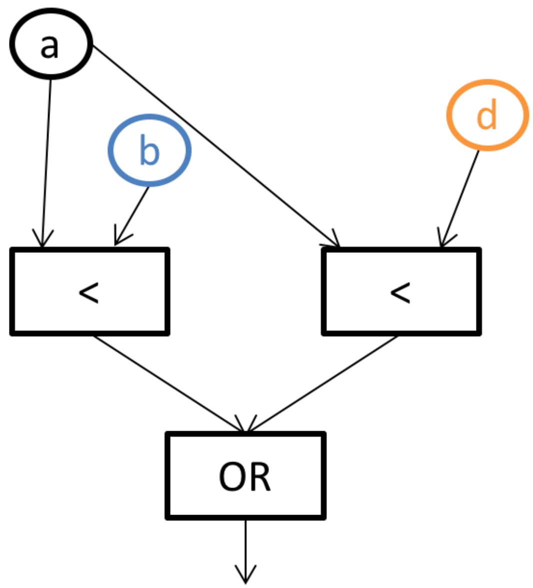

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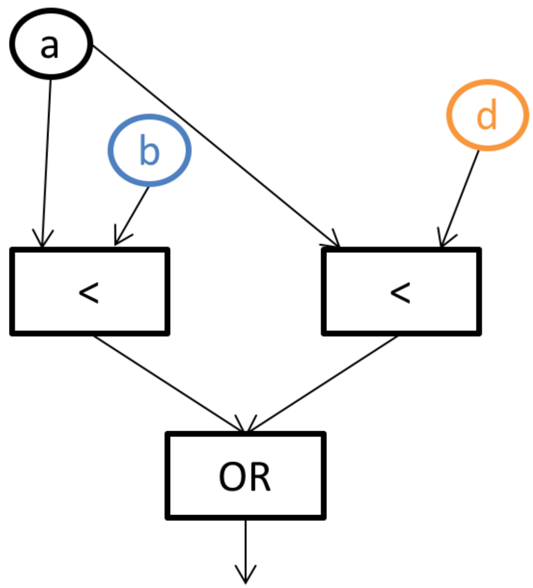

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Can infer strong assumptions like:

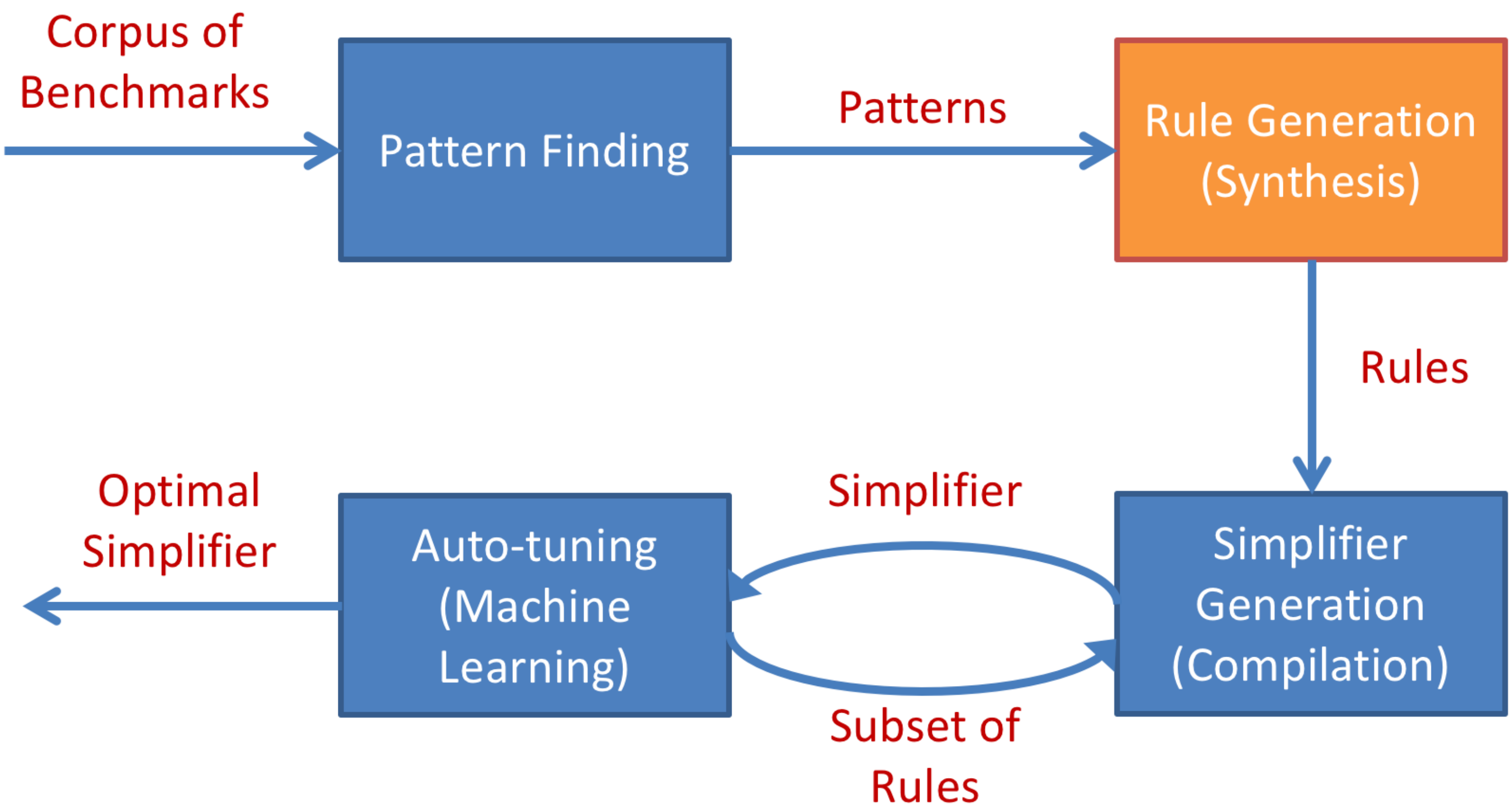
$b < d$

$b \neq d$

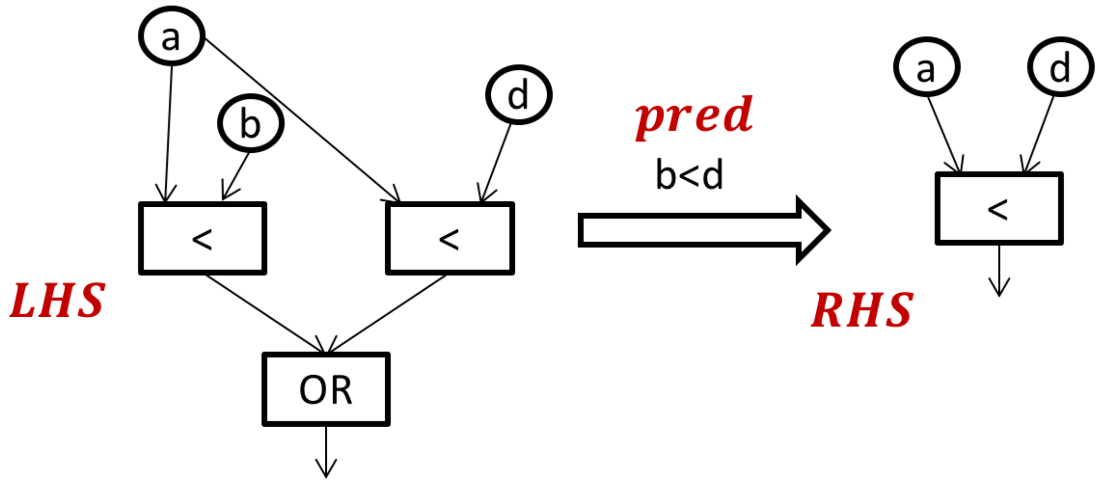
$b \leq 0$

$0 < d$

SWAPPER framework



Conditional Rewrite Rules



- **Inputs (x) :** ⓐ ⓑ ⓓ
- $\forall x \; pred(x) \Rightarrow \big(LHS(x) == RHS(x)\big)$

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Classic Syntax-guided synthesis problem (Sketch)

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+ Enumerative predicate refinement

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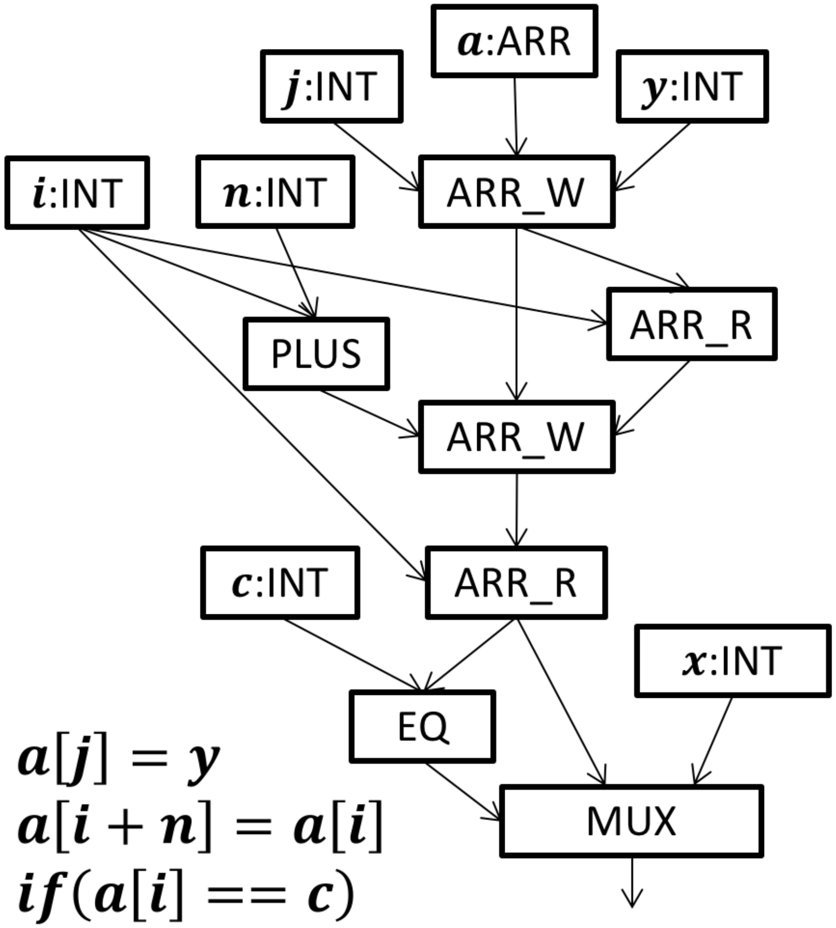

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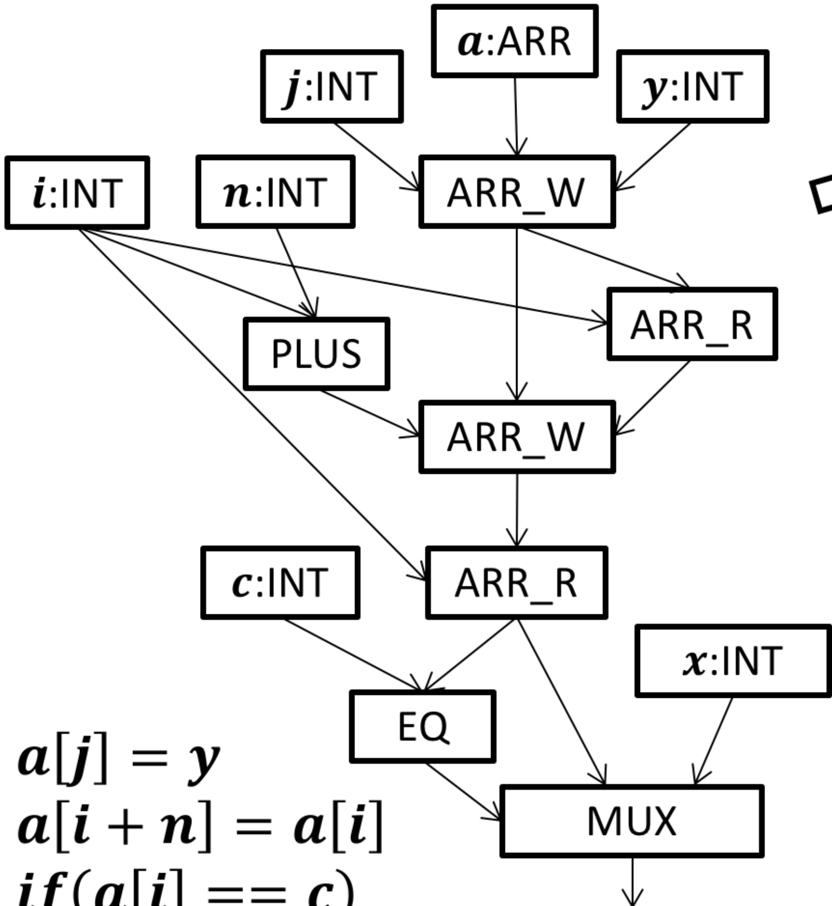

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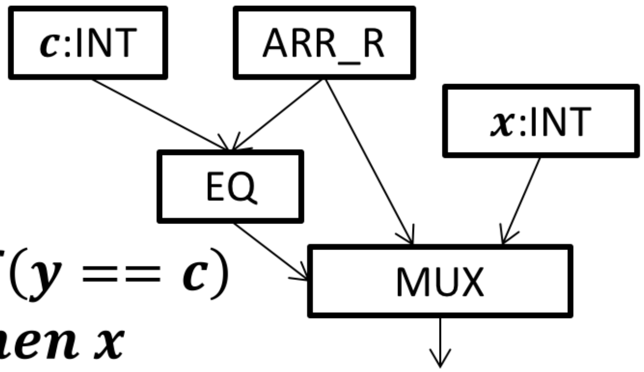

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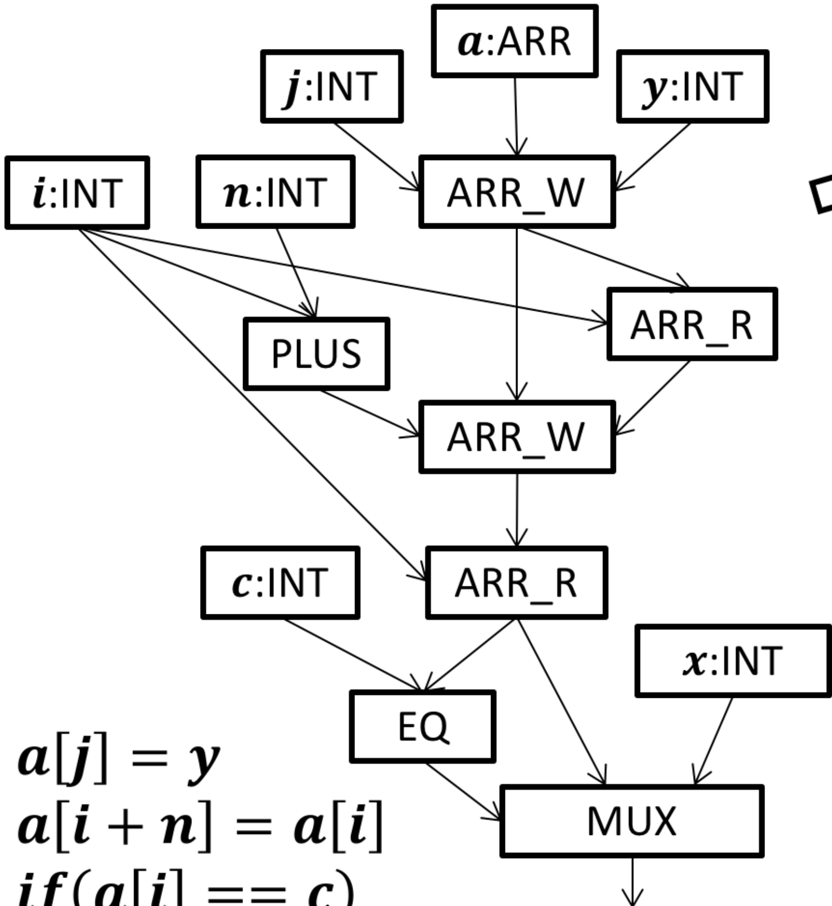

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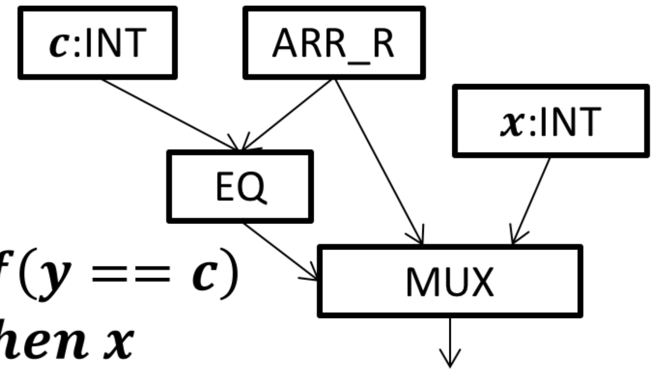

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True

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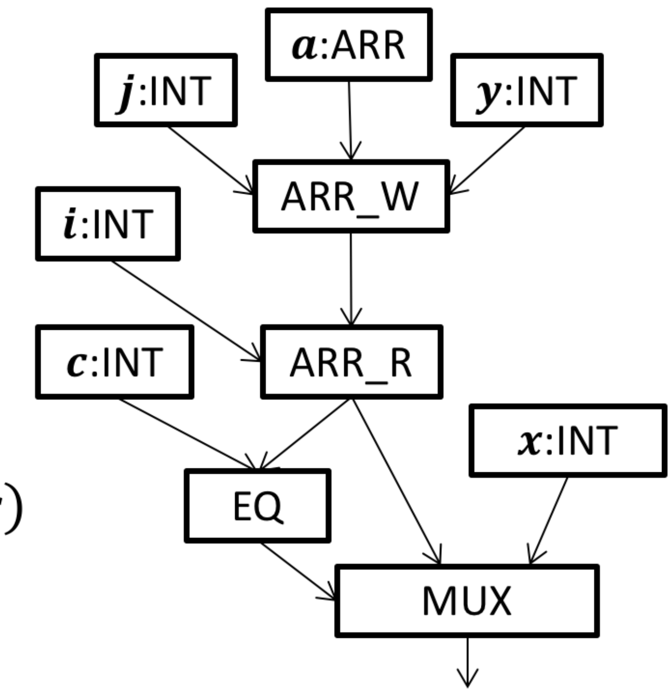
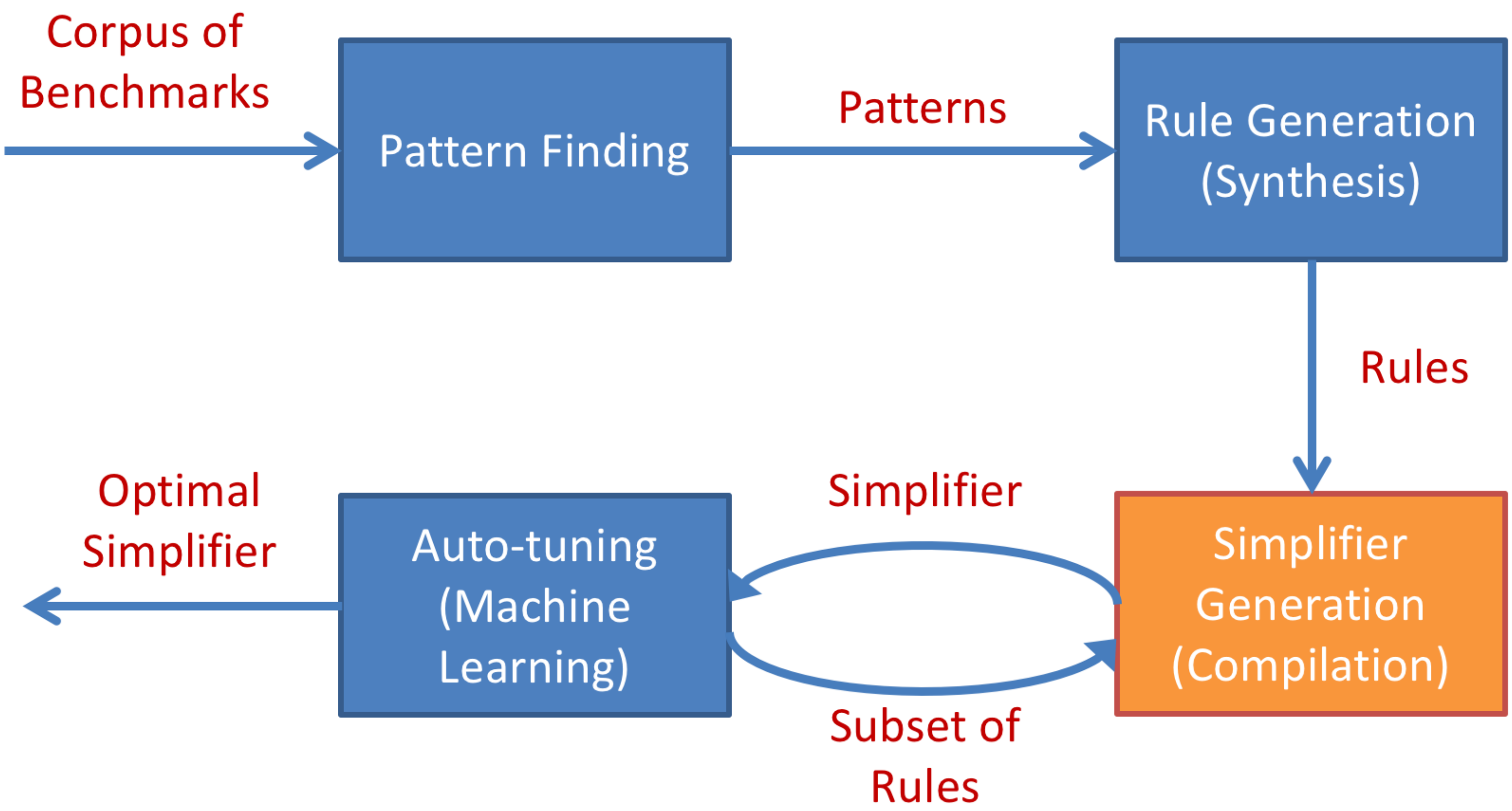


SWAPPER framework



Simplifier Generation

- Default node traversal and rule application strategy
- Generate efficient C++ code

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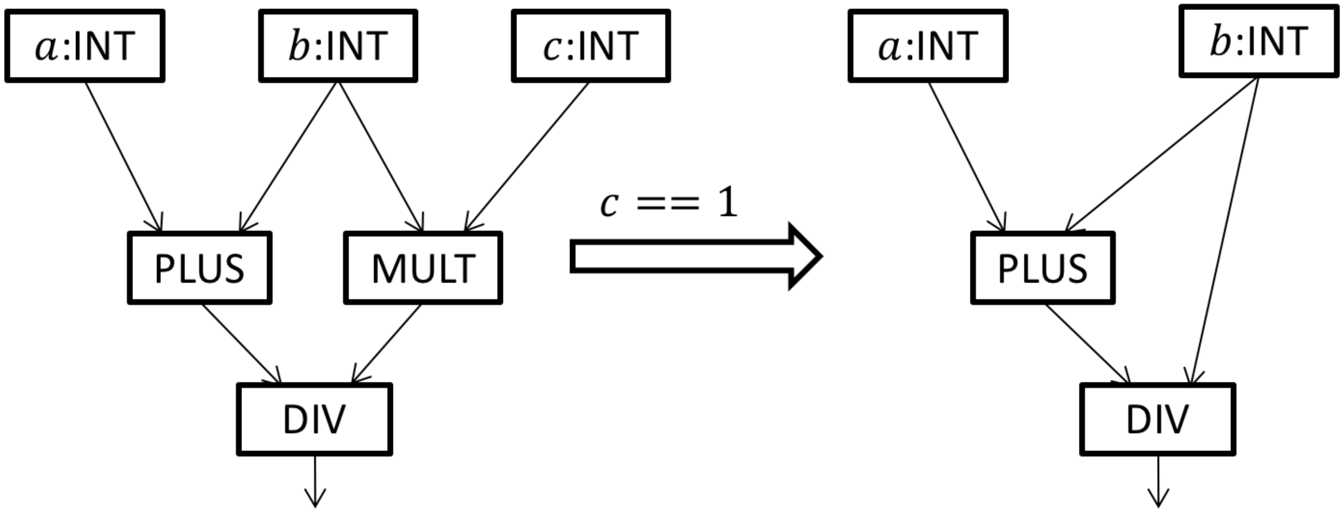

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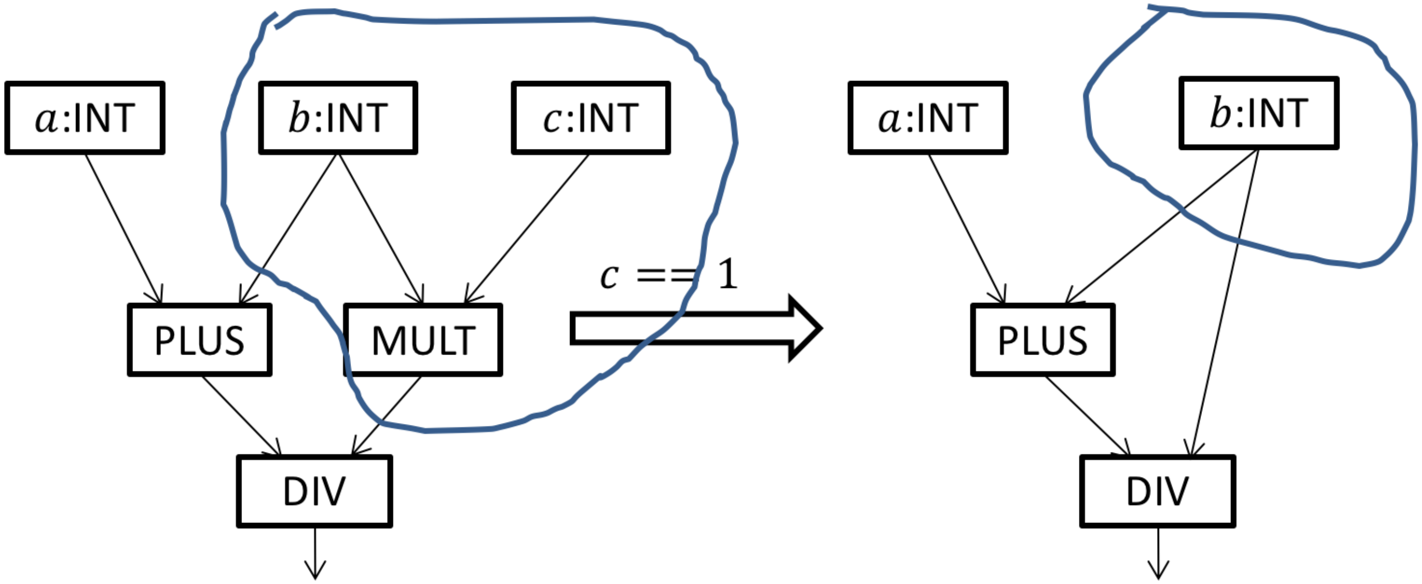

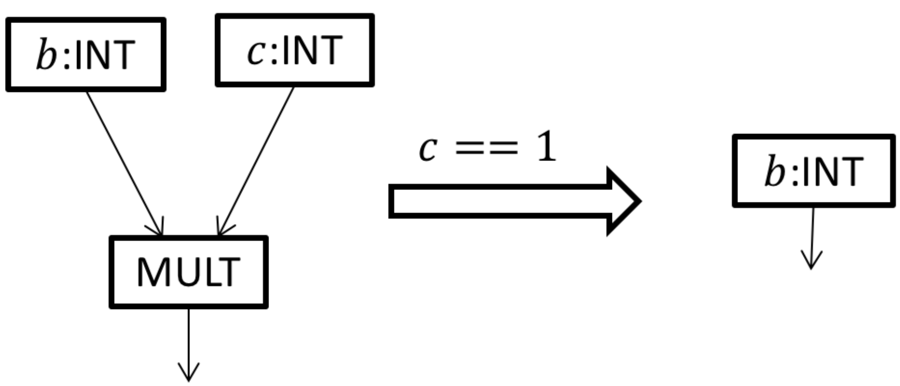

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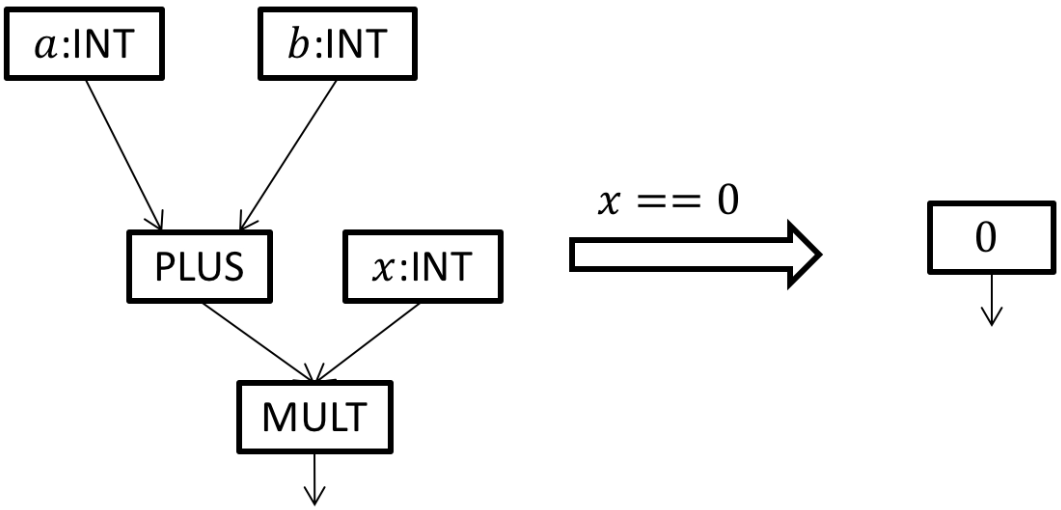

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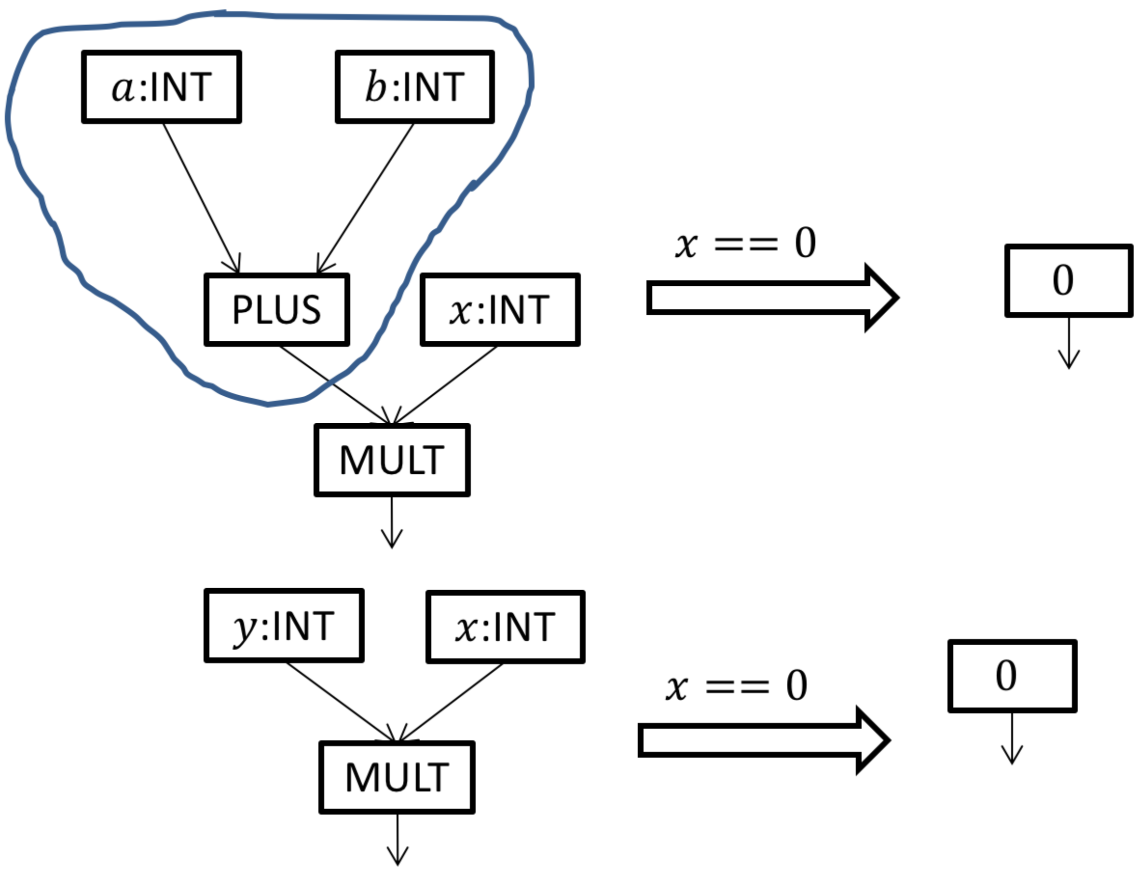

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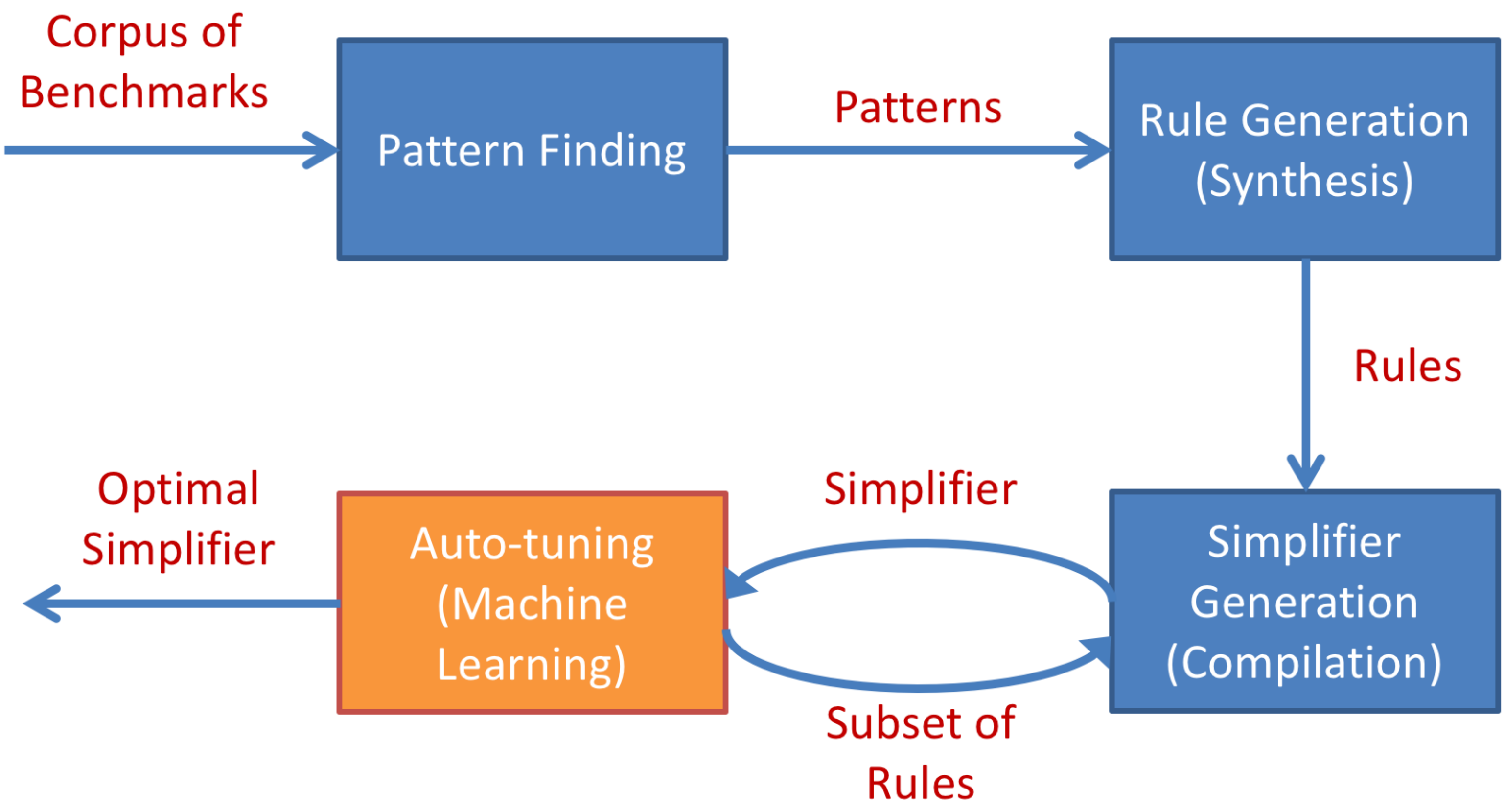

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Ansel et al, PACT 2014
http://opentuner.org

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- Problem Setup:
  - Search space parameters:
    - Permutation of rules
    - Number of rules to be used
  - Optimization Function: Weighted Solution time

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Experiments

Domains & Benchmarks

Domain	Benchmark DAGs Used	Avg. Number of Terms
AutoGrader	45	23289
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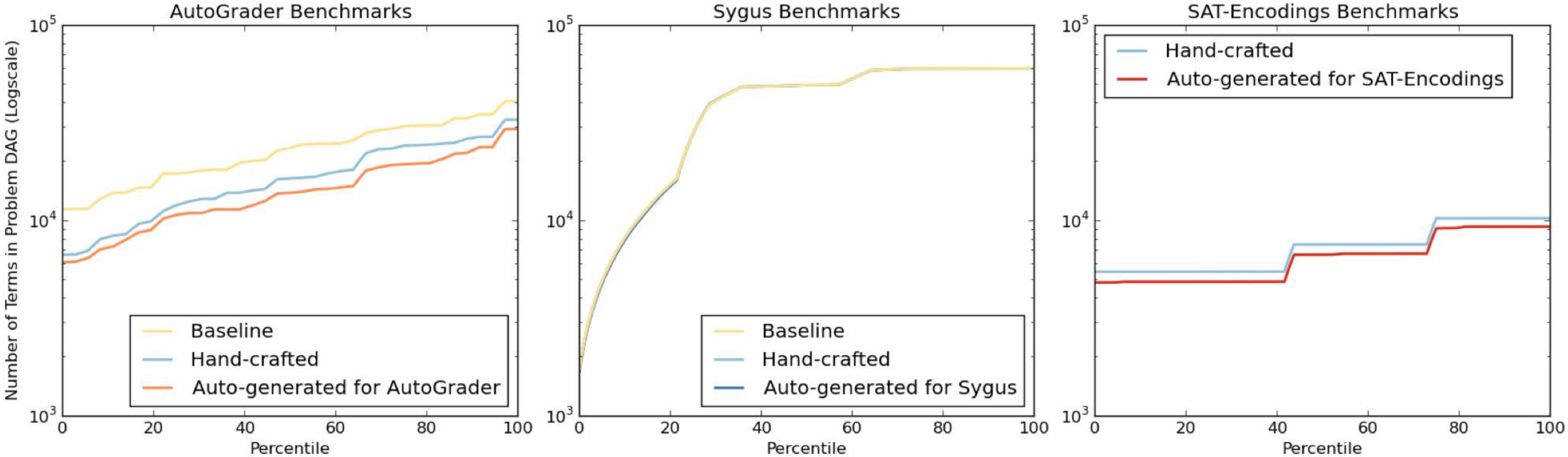
    - For **AutoGrader** and **Sygus** domains

SWAPPER : Generated Rules

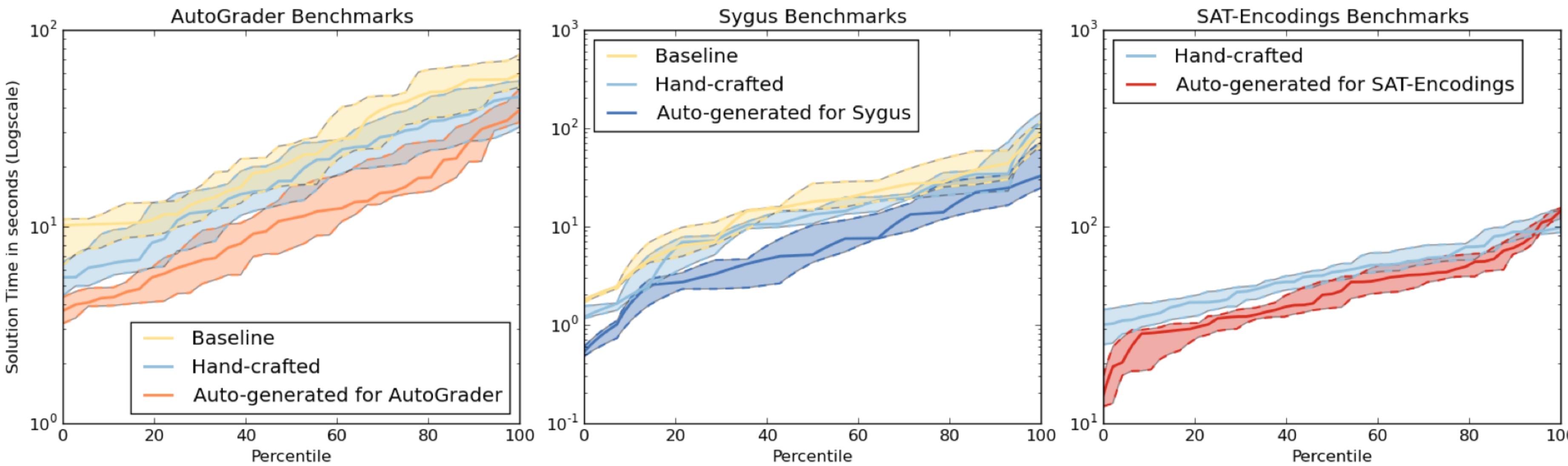
	AutoGrader	Sygus	SAT Encodings
Obtained	**201**	**163**	**117**
Optimal	**135**	**65**	**68**

Impact on Sizes



- **AutoGrader**: 13.8% reduction
- **Sygus**: 1.1% reduction
- **SAT Encodings**: 11% reduction

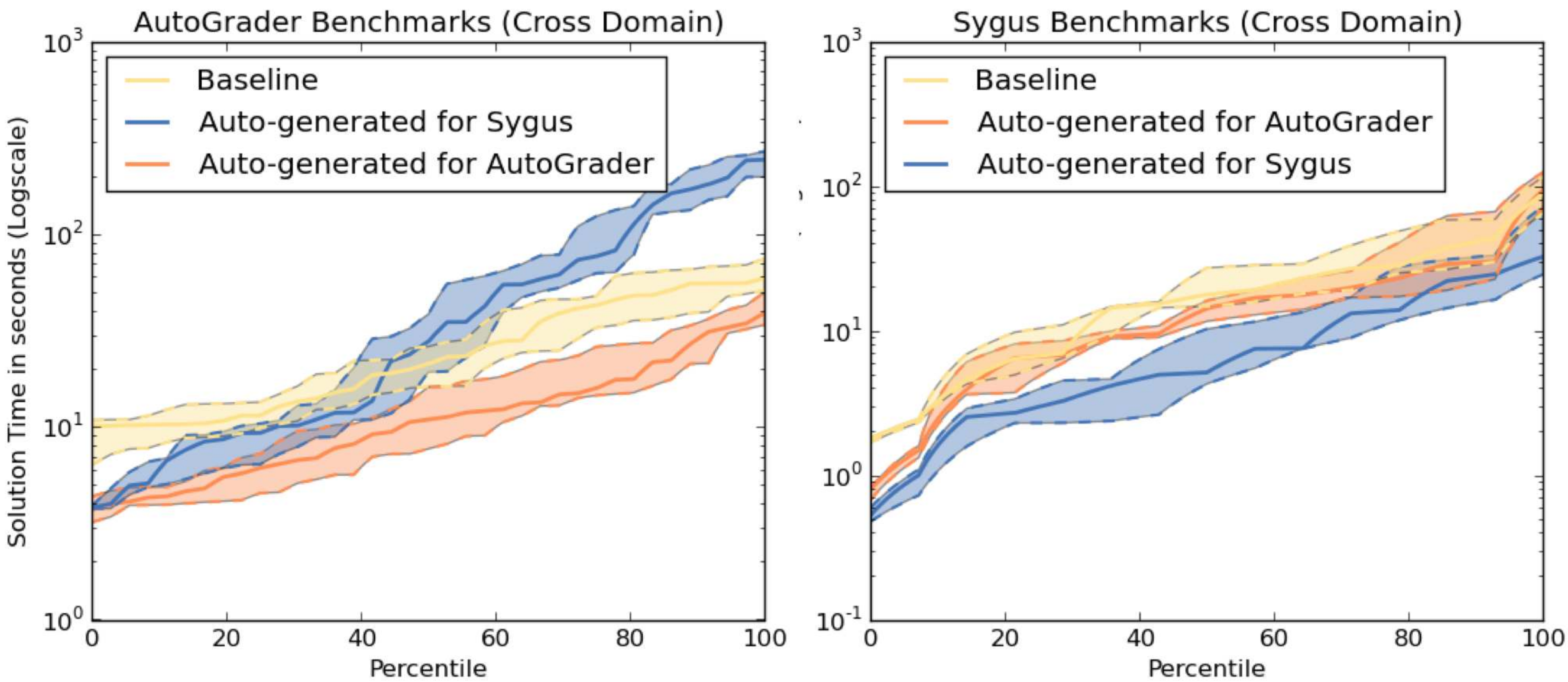
Impact on Running times



- Medians with quartile confidence intervals
- **AutoGrader**: 21s → 13s average times
- **Sygus**: 20s → 8s average times
- **SAT Encodings**: 59s → 51s average times

Domain Specificity

Impact on times across domains



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Time and Cost Estimation (on AWS, parallelism of 40 threads)

Domain	Pattern Finding	Rule Generation	Auto-Tuning	Total Time (in hours)	Cost
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Can reduce time by increasing parallelism or smarter evaluations with timeouts

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Thank You!