Synthesis of Domain Specific Encoders for Bit-Vector Solvers

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with
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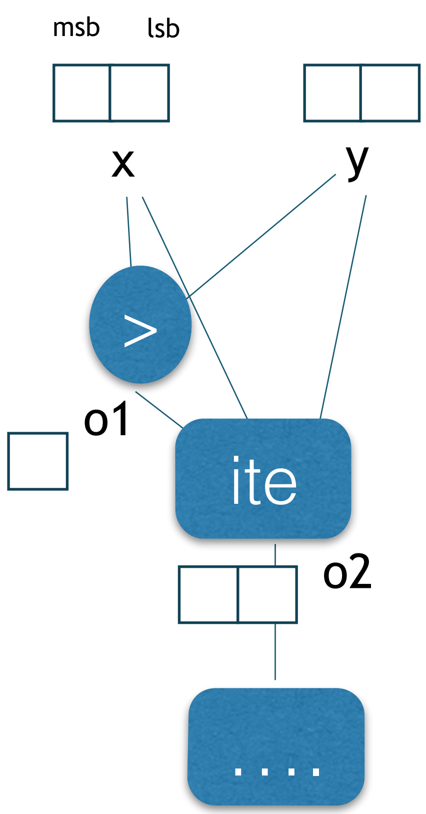
MIT COMPUTER SCIENCE AND ARTIFICIAL INTELLIGENCE LABORATORY

CSAIL

High-level constraint to CNF clauses

SMT solver
High-level constraint

SAT solver
CNF clauses



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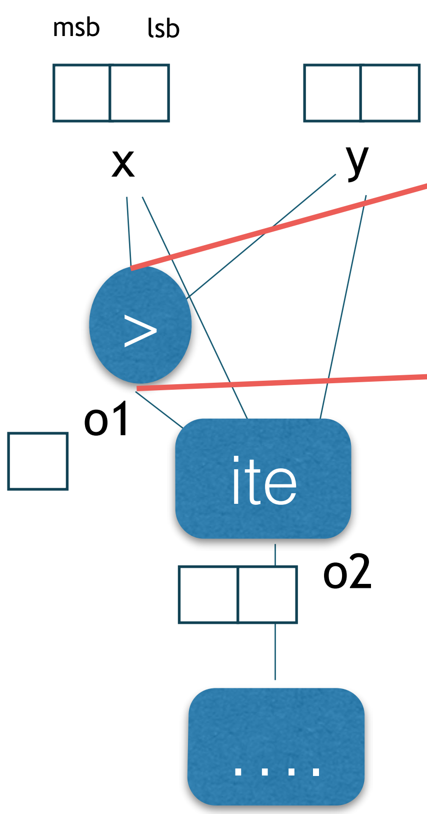

SAT solver
CNF clauses

$\overline{y_1} \lor x_1 \lor \overline{t_1}$

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$\overline{t_2} \lor \overline{y_0}$

$\overline{t_2} \lor x_0$

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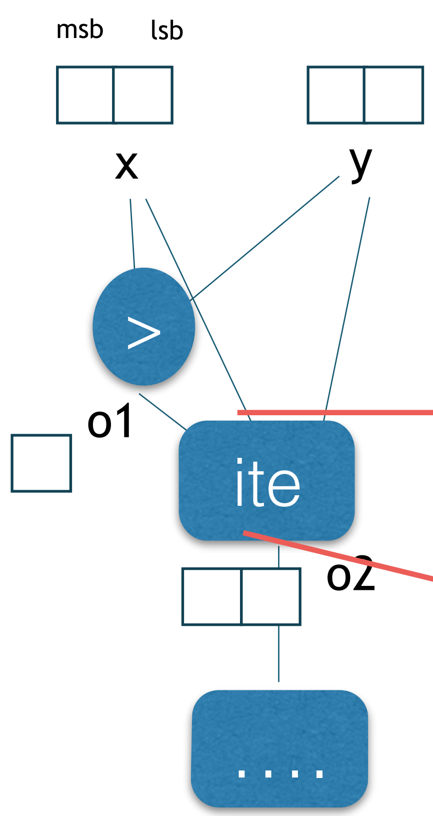

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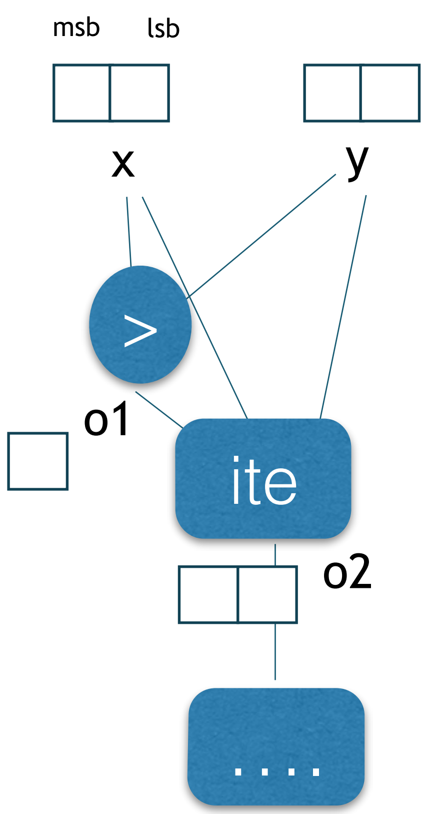

Not the “best” encoding

SAT solver
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....

Goal: Synthesize better code for this translation

What is an optimal encoding?

- Fewer clauses
- Fewer variables
- Maximal propagation

Maximal Propagation

- SAT solvers use unit propagation to infer variable assignments

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Current variables assignment

$$true \rightarrow \overline{x_1},\ x_2,\ \overline{x_3},\ \overline{x_4}$$

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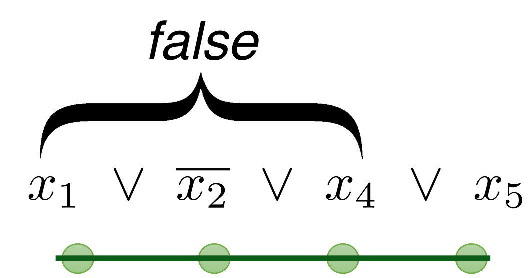


Maximal Propagation

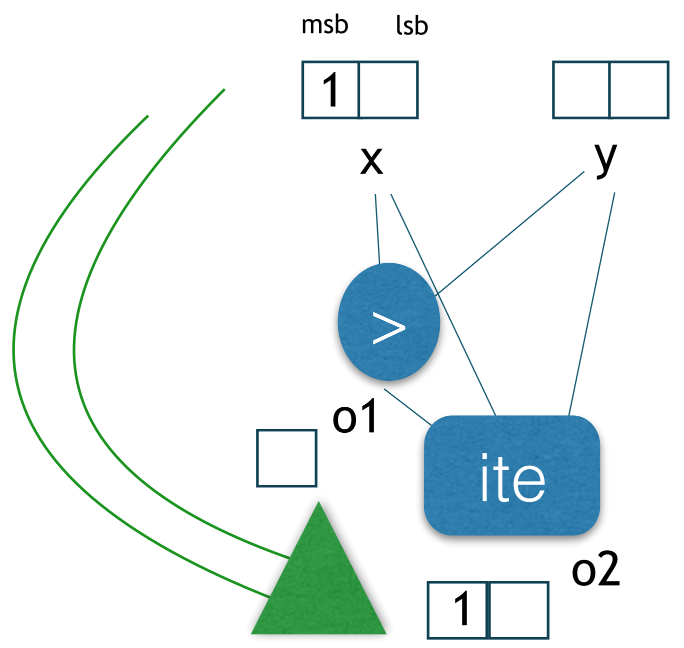
- SAT solvers use unit propagation to infer variable assignments

Current variables assignment

$$true \rightarrow \overline{x_1},\ x_2,\ \overline{x_3},\ \overline{x_4},\ x_5$$

$$x_1 \lor \overline{x_2} \lor x_4 \lor x_5$$

Find an encoding that maximizes what we can learn through unit propagations



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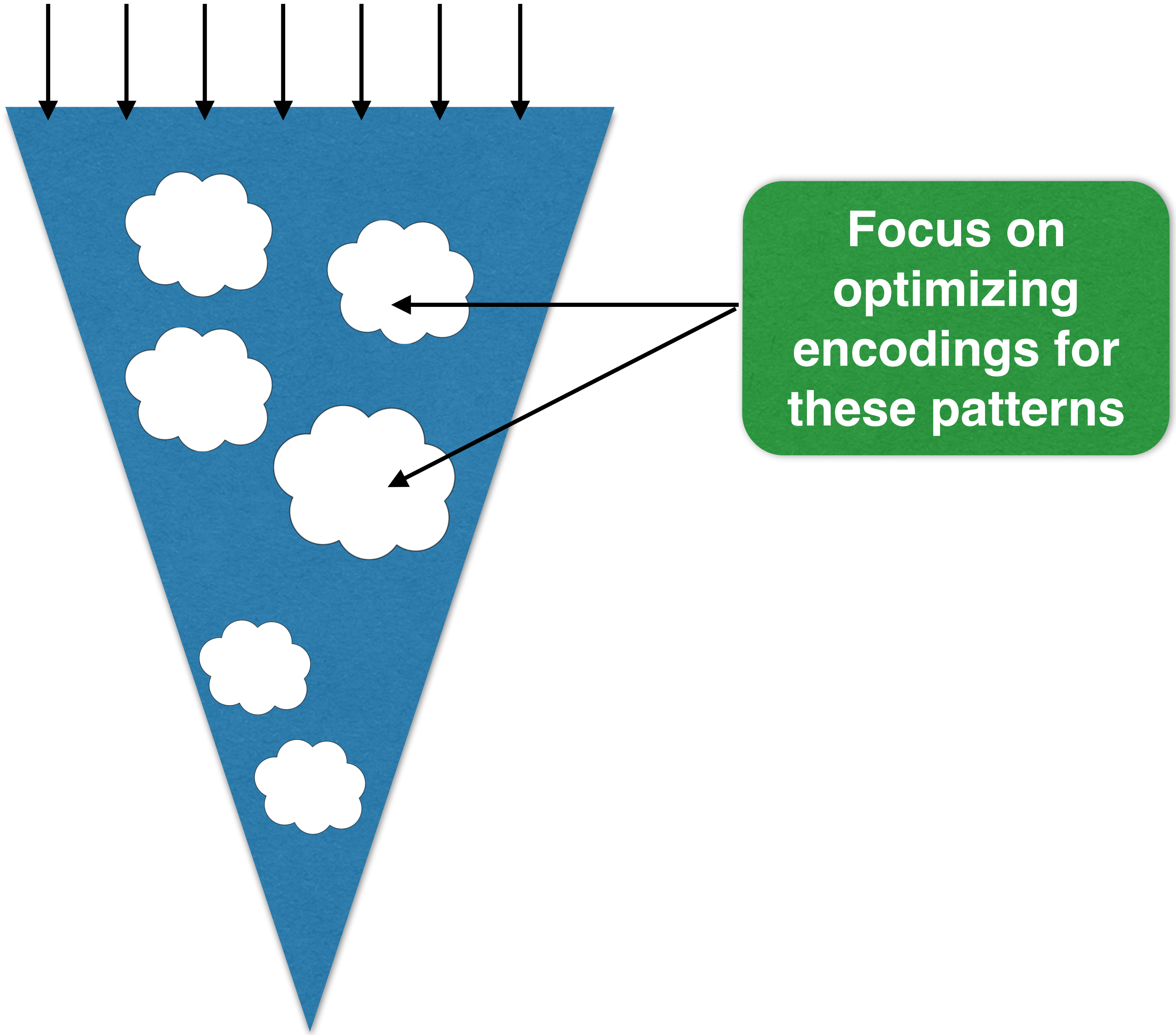
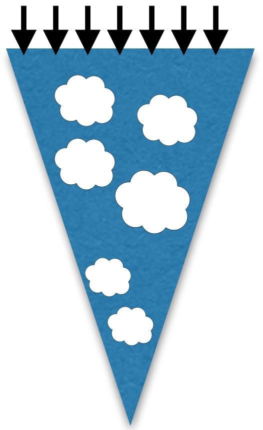
$$x_1 = 1 \xrightarrow{Unit\ prop} o2_1 = 1$$

Composing encodings does not preserve optimality

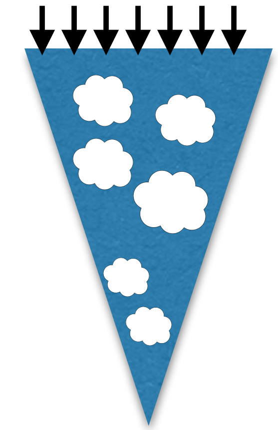

Focus on optimizing encodings for these patterns



What patterns to target?

How do we come up with “optimal” encoding for a pattern?

Do these encodings actually improve the performance?



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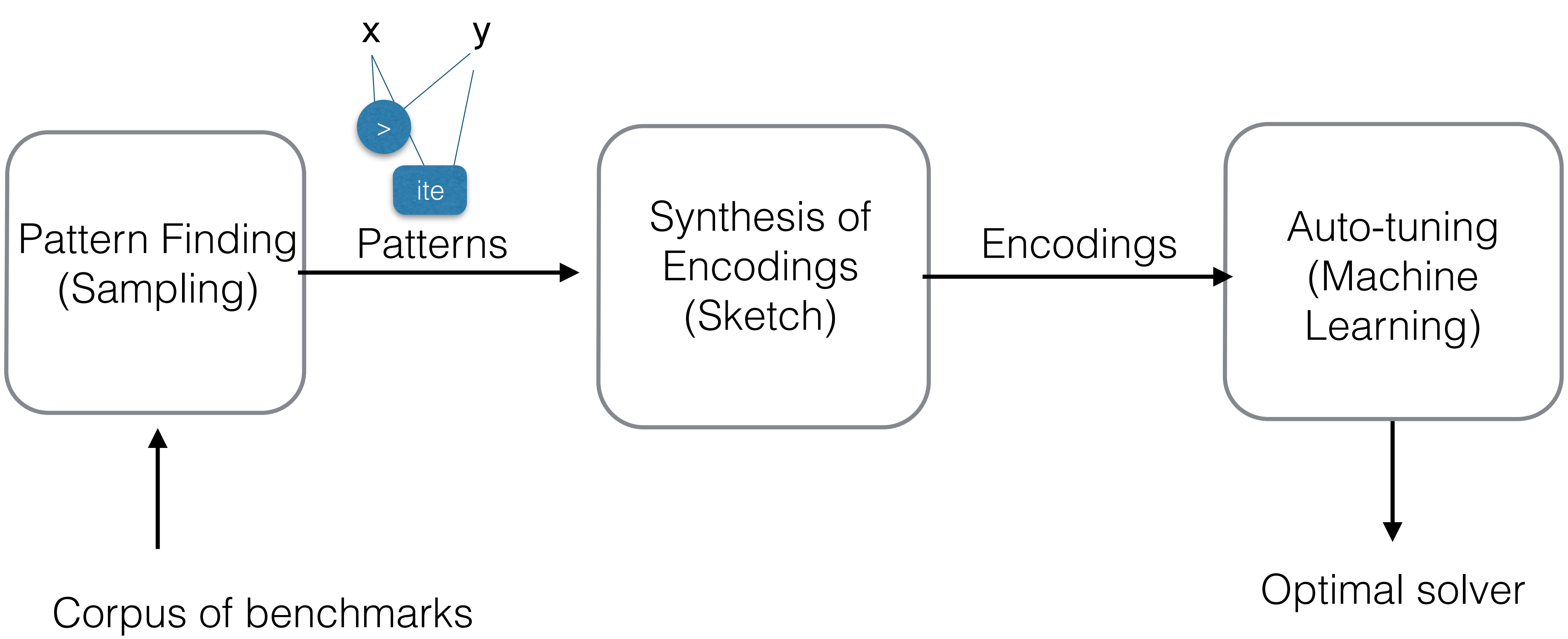

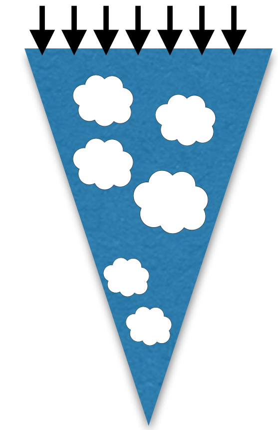

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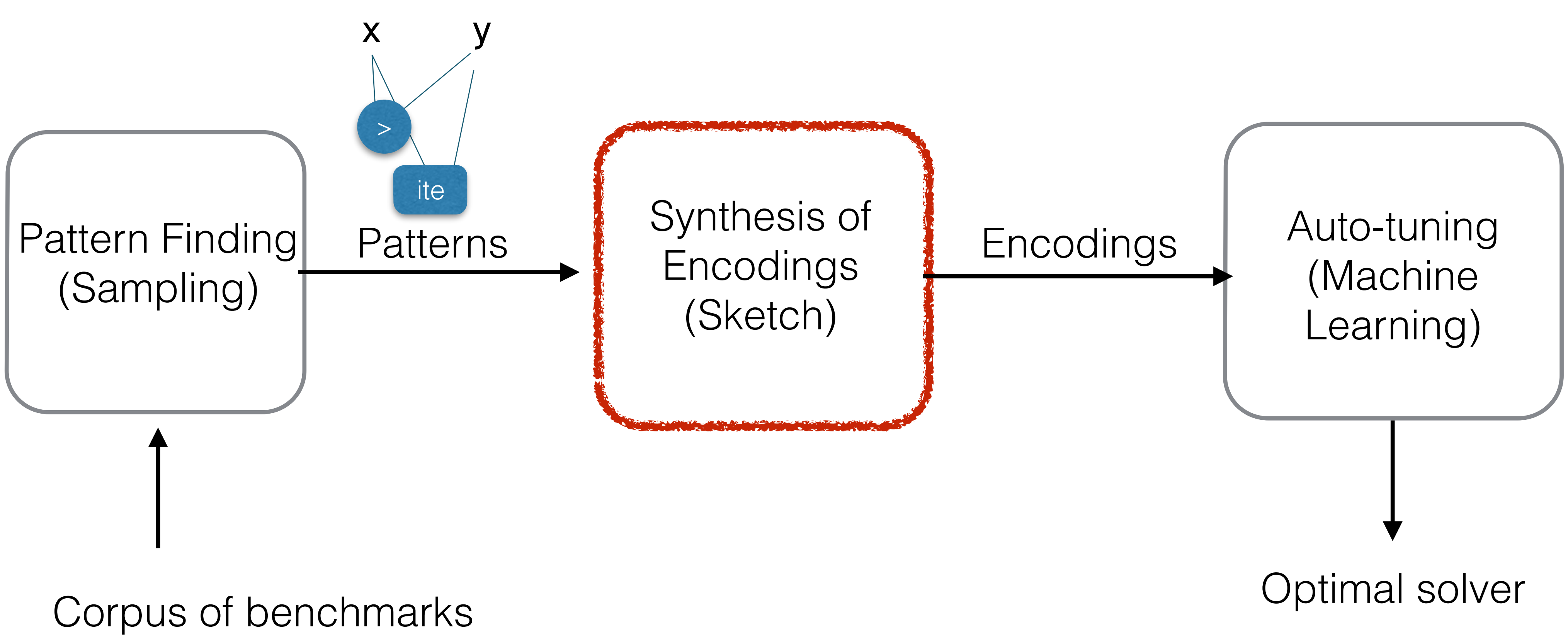
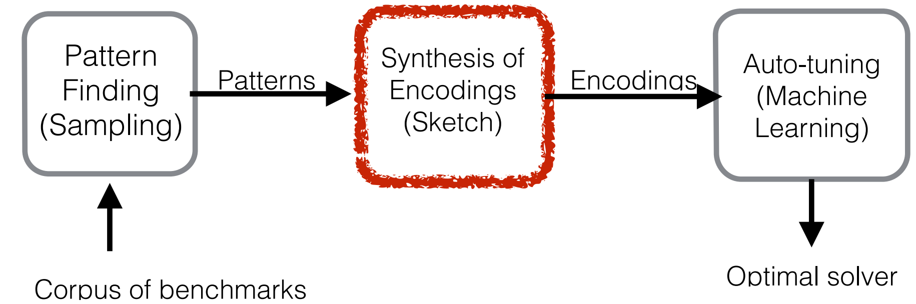
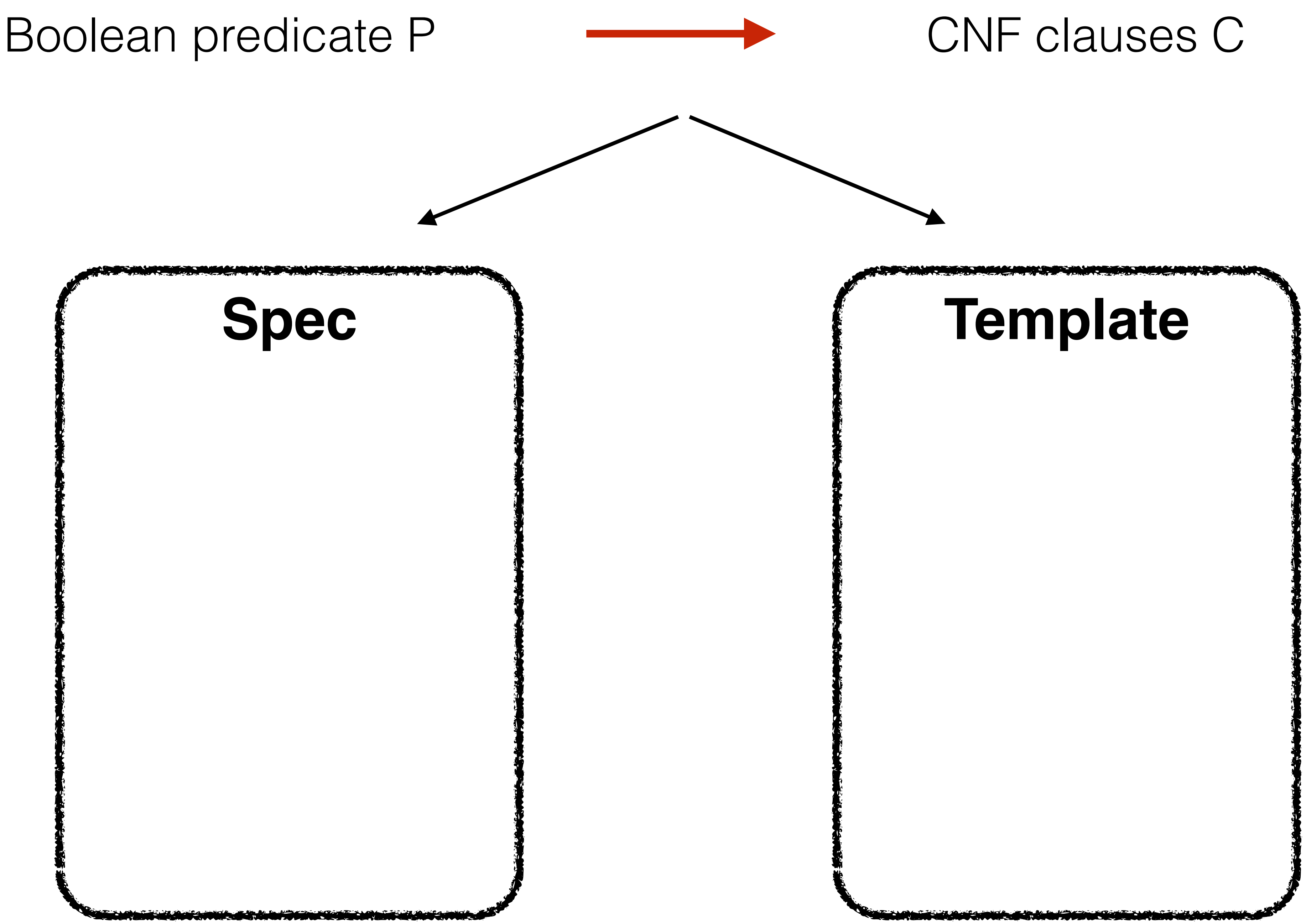


Synthesis as a SyGus problem





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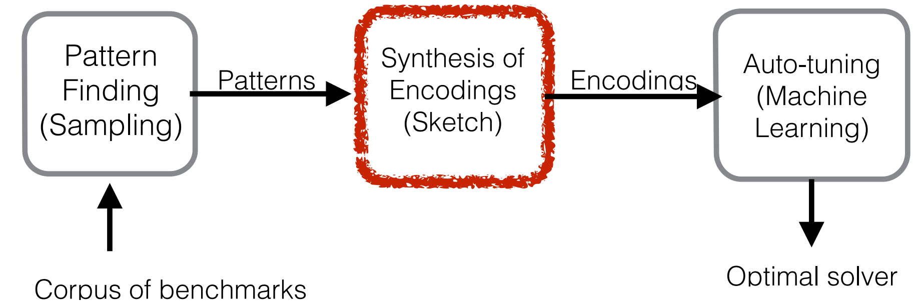


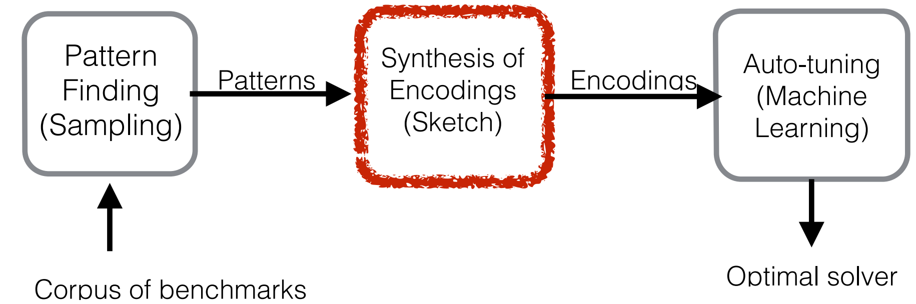
Boolean predicate P → CNF clauses C

Spec

- Involves reasoning about SAT solvers

Template

Synthesis as a SyGus problem



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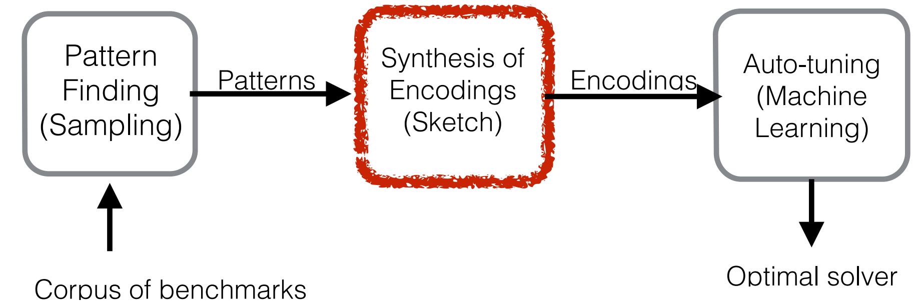

Synthesis as a SyGus problem

Boolean predicate P → CNF clauses C

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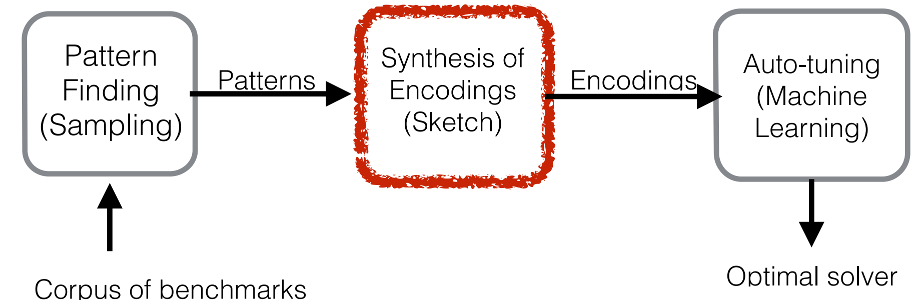

Boolean predicate P → CNF clauses C

Spec

- Involves reasoning about SAT solvers
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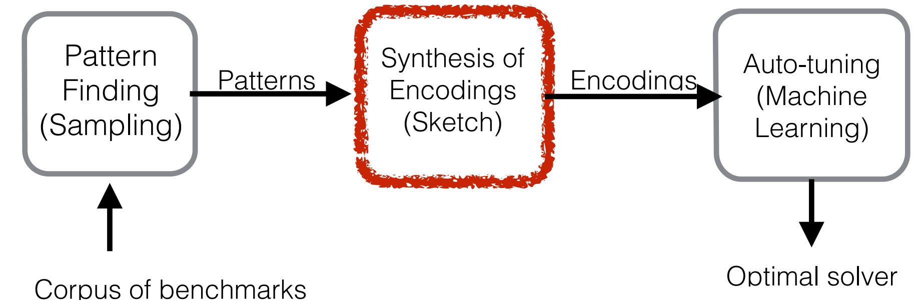
Template

- Huge search space of encodings
- Leverage structure in encodings to design templates

Synthesis as a SyGus problem



Boolean predicate P → CNF clauses C

$$o = ITE_N((GT_N, x, y), x, y)$$

→

$$
\begin{aligned}
&t1 = true\\
&t2 = true\\
&for\ i\ from\ N\ to\ 1:\\
&\quad t3 = newVar\\
&\quad t4 = newVar\\
&\quad clause(\{t1, t2, \overline{t4}\})\\
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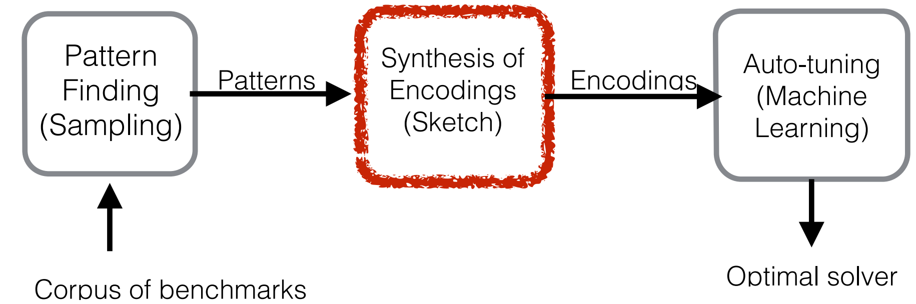

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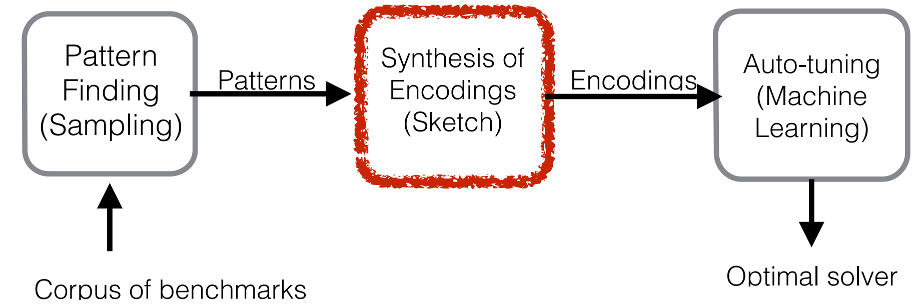

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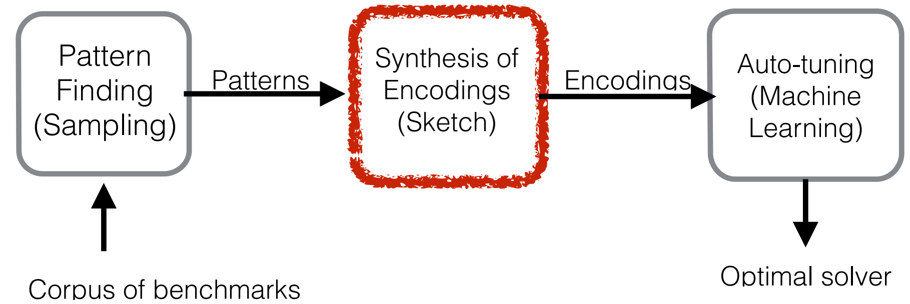

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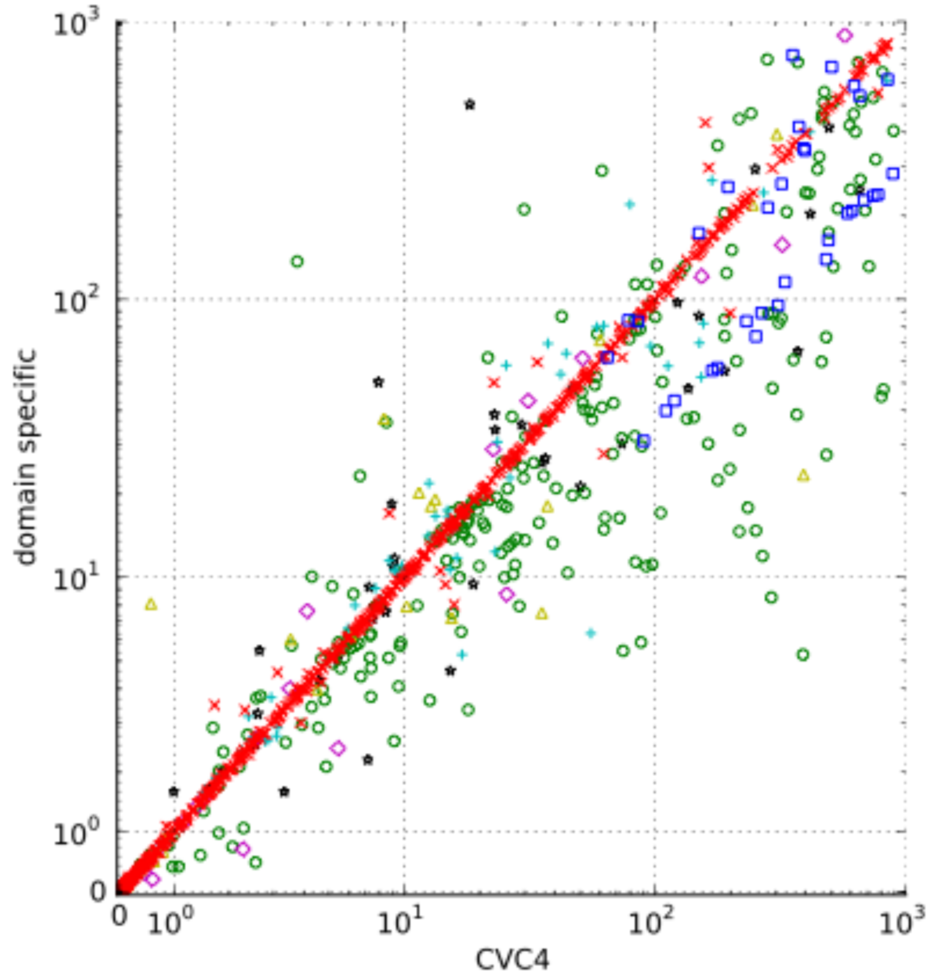
Does this buy you anything?



Solve more problems

Benchmark Family	Solved by CVC4 → Our Solver
Log-slicing (79)	*33 → 62*
ASP (365)	*240 → 288*
Mcm (61)	*40 → 43*
Brummayerbiere2 (33)	*28 → 29*
Float (62)	*59 → 60*
Brummayerbiere3 (40)	*23 → 24*
Bruttomesso (676)	*623 → 623*
TOTAL	***1046 → 1129***

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TOTAL	***1046 → 1129***

83 more problems in total

Cross domain performance

Solver → Domain ↓	log-slicing	asp	mcm	brumma2	float	brumma3	brutto
log-slicing	**62**	**58**	**36**	**59**	**32**	**35**	**35**
asp	**227**	**288**	**255**	**227**	**236**	**253**	**240**
mcm	**39**	**38**	**43**	**40**	**39**	**39**	**41**
brumma2	**29**	**28**	**28**	**29**	**29**	**29**	**29**
float	**57**	**57**	**59**	**57**	**60**	**60**	**59**
brumma3	**22**	**22**	**25**	**22**	**23**	**24**	**23**
brutto	**607**	**606**	**623**	**609**	**623**	**623**	**623**

Best → Worst

What did it take?

- Around 2000 benchmarks across 7 domains
- Over 200 million nodes in the high level SMT constraints
- Sampling generated ~2000 patterns (size <= 5)
- ~2000 SyGus problems to solve
- Generated ~40k to 160k lines of code per domain (30 lines per encoding)
- 8 hours of auto-tuning per domain
- On total, took 10-20 hours per domain with parallelism of 30