Black-box Code Analysis for Reverse Engineering

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Speaker

Grégoire Menguy

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Context

Software size +

- Hard to verify code
- Hard to test code
- Hard to understand code

Need for automatic software analysis

White vs Black-box

White-box analysis

- Rely on the syntax
  - Symbolic exec.
  - Abstract interp.
- Scale issues

Black-box analysis

- Rely on code executions
- **Insensitive to syntactic complexity**

Scenarios

Deobfuscation

- Malware analysis
- Assess obfuscation strength

30 MIN

Contract inference

- Core refactoring
- Code understanding

10 MIN

Search-based Local Blackbox Deobfuscation: Understand, Improve and Mitigate

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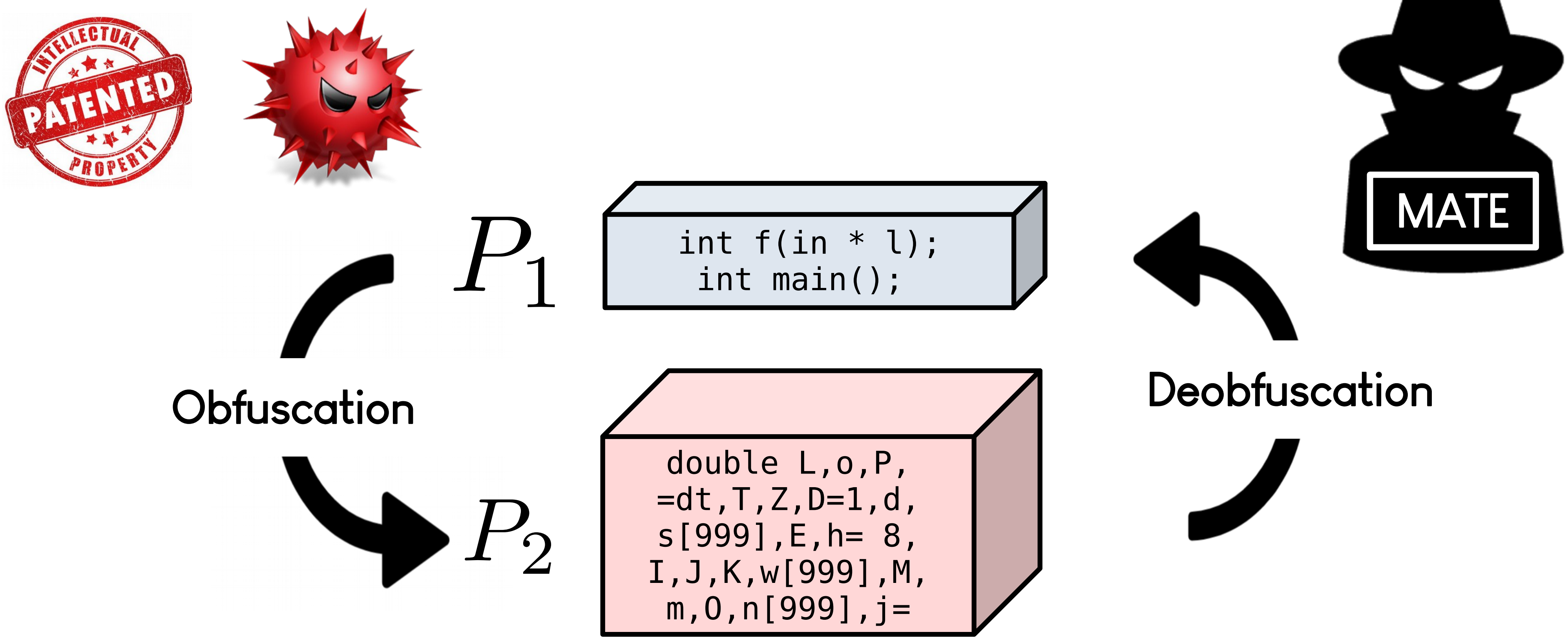
Obfuscation



Deobfuscation

Protecting Software through Obfuscation: Can It Keep Pace with Progress in Code Analysis?

SEBASTIAN SCHRITTWIESER, St. Pölten University of Applied Sciences, Austria
STEFAN KATZENBEISSER, Technische Universität Darmstadt, Germany
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A Generic Approach to Automatic Deobfuscation of Executable Code

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Symbolic deobfuscation: from virtualized code back to the original*

Jonathan Salwan[1], Sébastien Bardin[2], and Marie-Laure Potet[3]

Backward-Bounded DSE: Targeting Infeasibility Questions on Obfuscated Codes*

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BINSEC

TRITON
Dynamic Binary Analysis

MIASM

Deobfuscation

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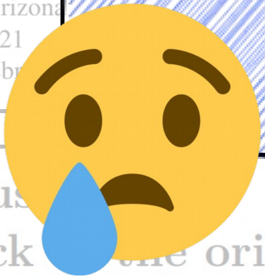
SEC

TRITON
Dynamic Binary Analysis

MIASM

White-box deobfuscation is highly efficient



Anti-White-Box Deobfuscation

But efficient countermeasures

Information Hiding in Software with Mixed Boolean-Arithmetic Transforms

Yongxin Zhou, Alec Main, Yuan X. Gu, and Harold Johnson

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How to Kill Symbolic Deobfuscation for Free
(or: Unleashing the Potential of Path-Oriented Protections)

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Probabilistic Obfuscation through Covert Channels

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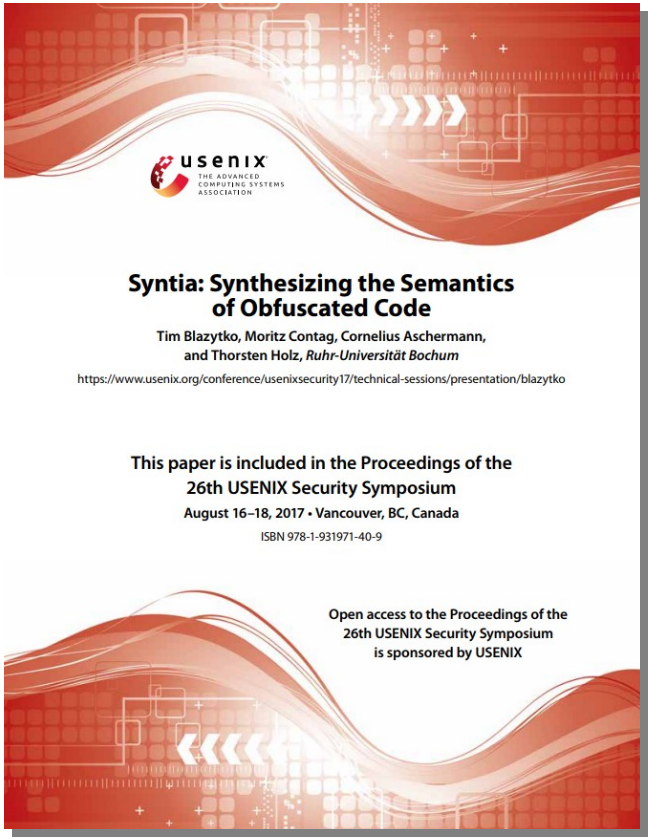
New Threat: Black-box Deobfuscation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THE ADVANCED COMPUTING SYSTEMS ASSOCIATION

Syntia: Synthesizing the Semantics of Obfuscated Code

Tim Blazytko, Moritz Contag, Cornelius Aschermann, and Thorsten Holz, *Ruhr-Universität Bochum*

https://www.usenix.org/conference/usenixsecurity17/technical-sessions/presentation/blazytko

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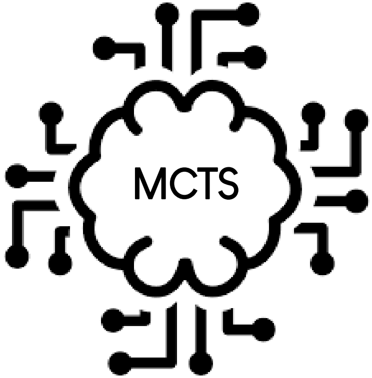


Bypasses white-box methods limitations

Open Questions

Understand

- Strenghts ?
- Weaknesses ?
- Why ?

Improve

- Why MCTS ?
- Can be improved ?
- Impacted by SOTA protections ?

Mitigate

- How to protect ?

Contributions

Understand

- Propose missing formalisation
- Refine Syntia Xps: new strenghs & weaknesses
- Show & explain why MCTS not appropriate

Improve

- S-metaheursitics > MCTS
- Implement our approach: Xyntia
- Evaluation of Xyntia

Mitigate

- Propose 2 protections
- Evaluate them against Xyntia and Syntia

Black-box deobfuscation
What's that ?

Black-box Deobfuscation

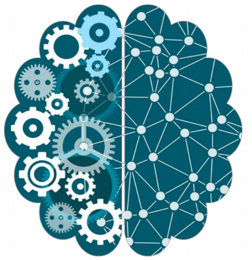
1. Sample

(t = 1, T = 2)
(t = 2, T = 5)
(t = 0, T = 6)
...

-1
-3
-6
...

2. Learn

(t = 1, T = 2) → -1
(t = 2, T = 5) → -3
(t = 0, T = 6) → -6
...



$$t - T$$

Learning Engine

$U \times U$ $t + T$ $t - U$

$\longrightarrow$ $expr$ $\longrightarrow$

$$\Delta\begin{pmatrix} expr(t=1, T=2), -1 \\ expr(t=2, T=5), -3 \\ expr(t=0, T=6), -6 \\ \dots \end{pmatrix}$$

Expression grammar

U := U + U | U – U | U * U …
| t | T | 1

Why Black-box ?

Given a language L and an expression "e" in L

Syntactic complexity	Semantic complexity
Size of the expression "e"	Size of the smallest expr. in L equivalent to "e"

Example

$t - T$ is syntactically simpler than $(t \vee -2T) \times 2 - (t \oplus -2T) + T$

but they share the same semantic complexity (being equivalent)

Why Black-box ?

Given a language L and an expression "e" in L

Syntactic complexity	Semantic complexity
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Example

$t - T$ is syntactically simpler than $(t \vee -2T) \times 2 - (t \oplus -2T) + T$

but they share the same semantic complexity (being equivalent)

Obfuscation increases syntactitc complexity
→ **No impact on black-box methods**

Understand

Zoom of SOTA: Syntia

Dig into Syntia and deepen its evaluation

– RQ1: stability of Syntia

– RQ2: efficiency of Syntia

– RQ3: impact of operators set

Syntia: New Results

Stable

Quality

Correctness

Speed

Robustness

Experimental Design

B1 (Syntia)

- 500 expressions
- Up to 3 inputs
- redundancy
- Unbalances w.r.t. type

B2 (ours)

- 1110 expressions
- 2 to 6 inputs
- No redundancy
- Balances w.r.t. type

	Type			# Inputs				
	Bool.	Arith.	MBA	2	3	4	5	6
#Expr.	370	370	370	150	600	180	90	90

Table 1: Distribution of samples in benchmark B2

Evaluation of Syntia

B1 (Syntia)

– With a 60 s/expr. timeout: 75% of success rate

– With a 1 h/expr. timeout: 88% of success rate

– With a **12 h/expr. timeout: 97% of success rate**

B2 (Ours)

Table 2: Syntia depending on the timeout per expression (B2)

	1s	10s	60s	600s
Succ. Rate	16.5%	25.6%	34.5%	42.3%
Equiv. Range	16.3%	25.1 - 25.3%	33.7 - 34.0%	41.4 - 41.6%
Mean Qual	0.35	0.49	0.59	0.67

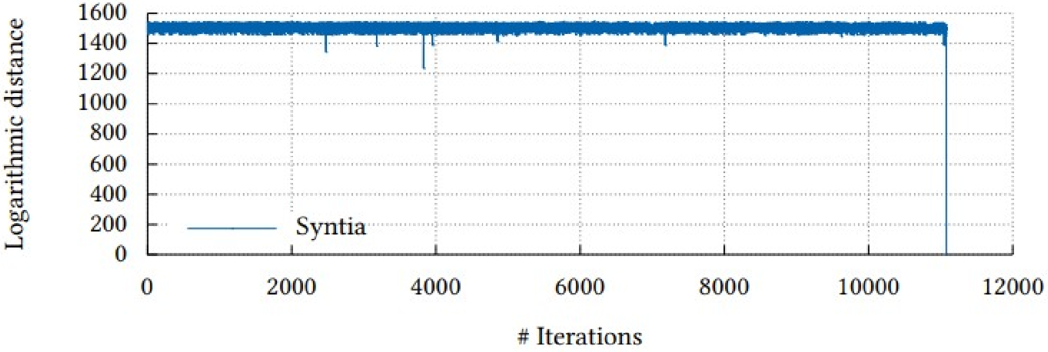
Why ?

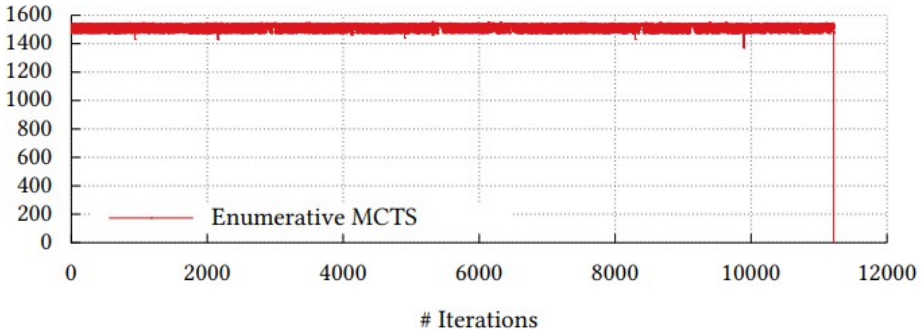
- Syntia manipulates non terminal expressions, e.g., $U - V$
- Scoring of non terminal expressions can be misleading

 $t - T$

$$U - V \rightsquigarrow \begin{cases} t - T \\ t - 1 \\ 1 - 1 \end{cases}$$

- Syntia (i.e., MCTS) = “almost BFS”

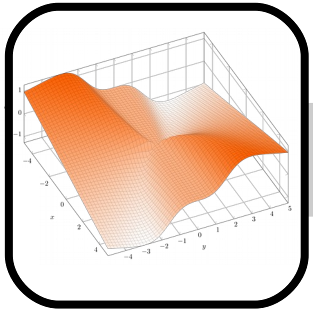




Improve

Black-box Deobf: An Optimization Pb

Syntia sees blackbox deobfuscation as a **single player game**

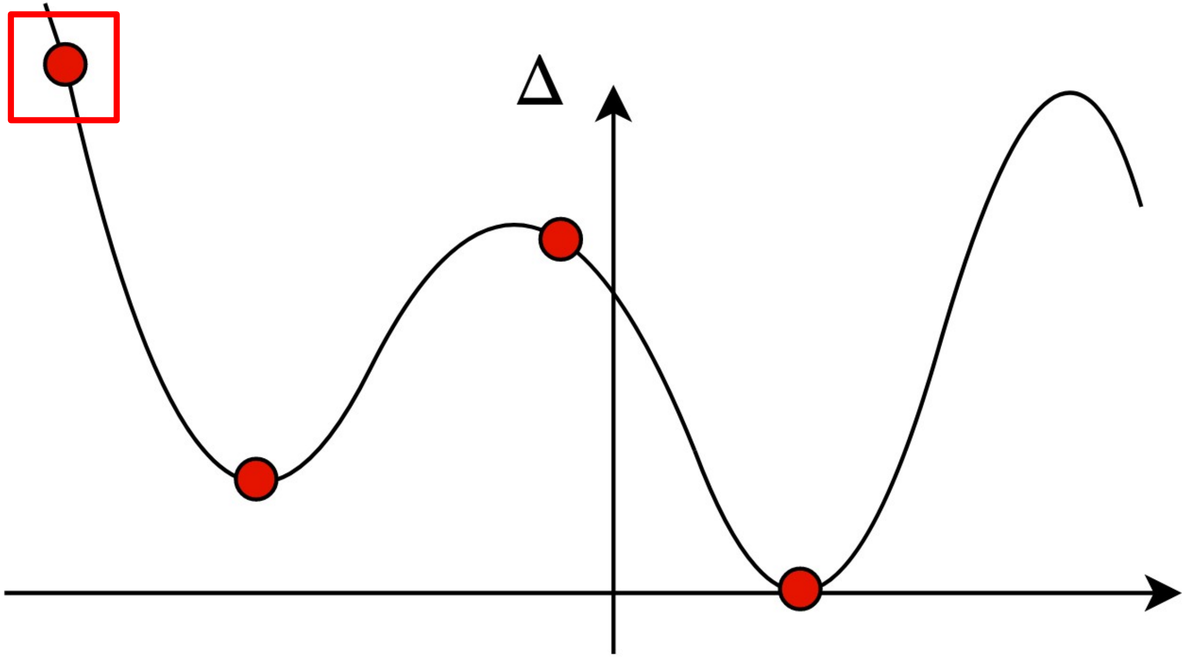


We propose to see it as an **optimization problem**

Goal : find $\underbrace{s^*}_{\text{An expr.}}$ s.t. $\underbrace{f}_{\Delta}(s^*) \leq f(s), \forall s \in S$

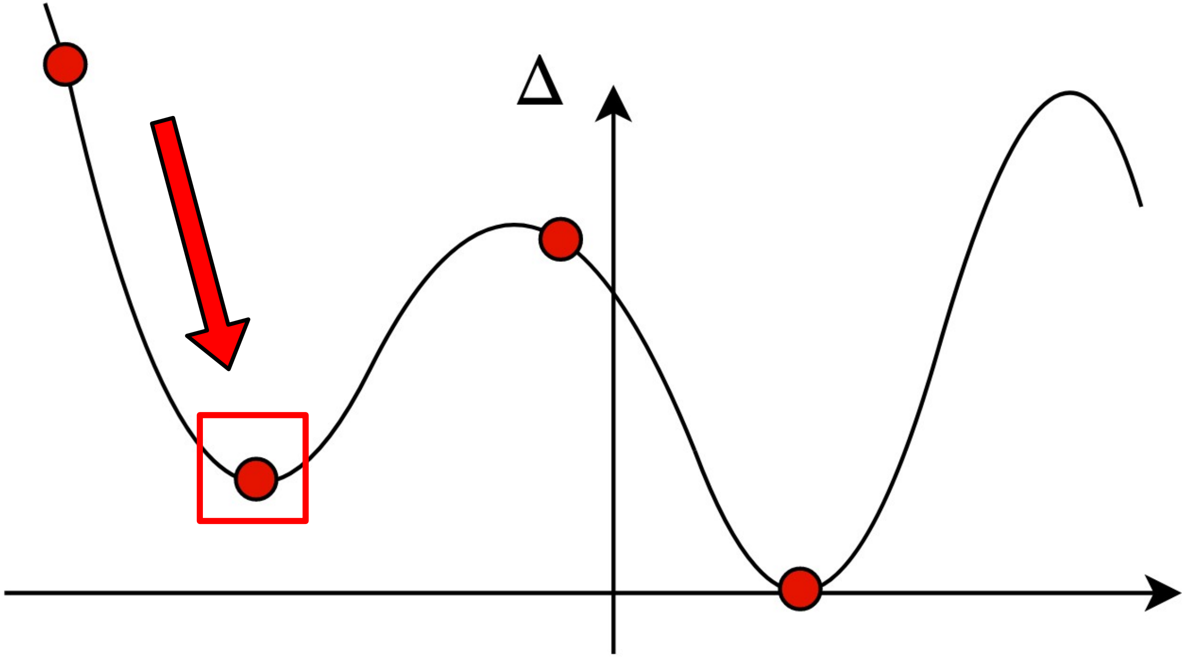
S-metaheuristics

– Solve optimization problems



S-metaheuristics

– Solve optimization problems



S-metaheuristics

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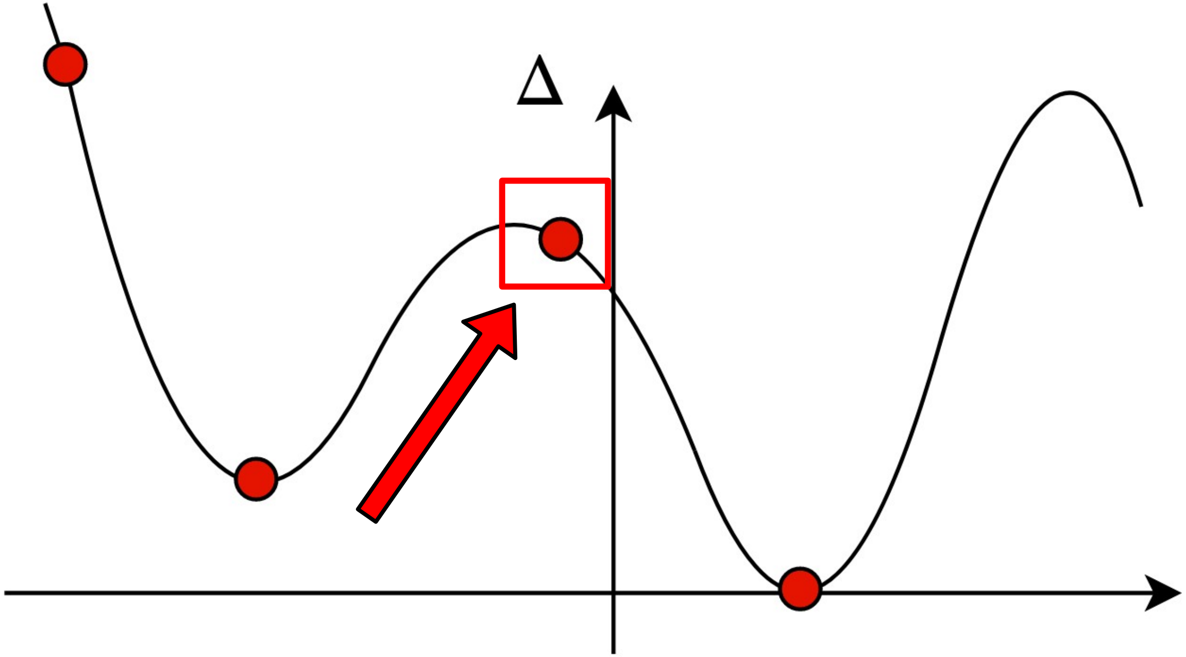

S-metaheuristics

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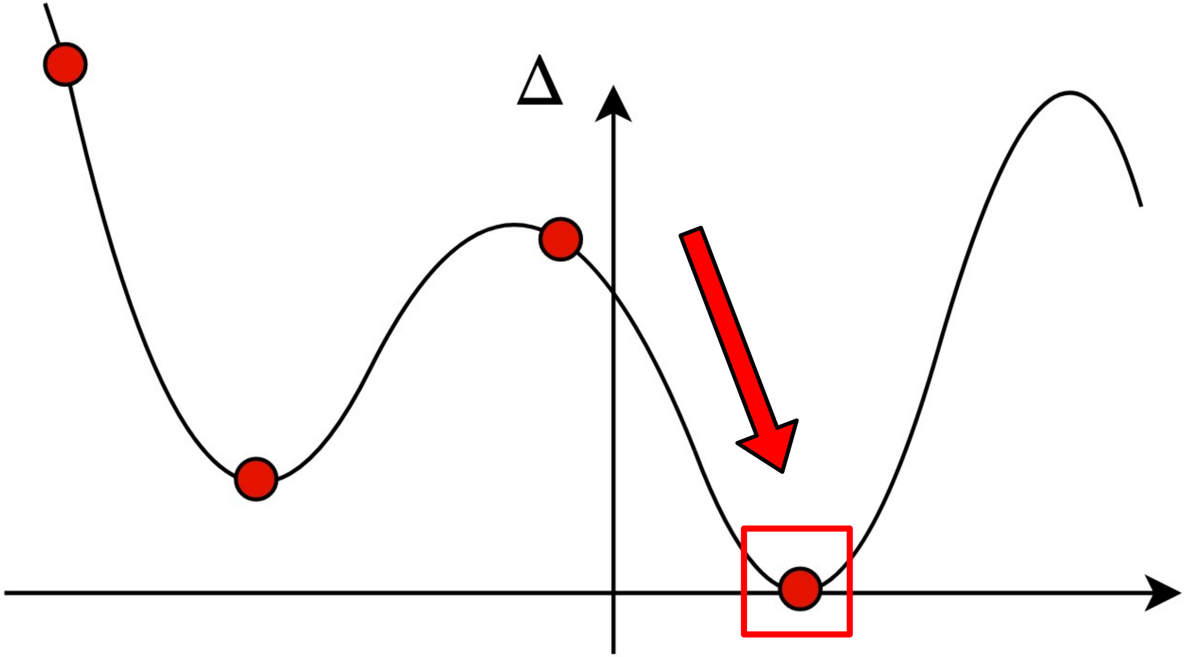
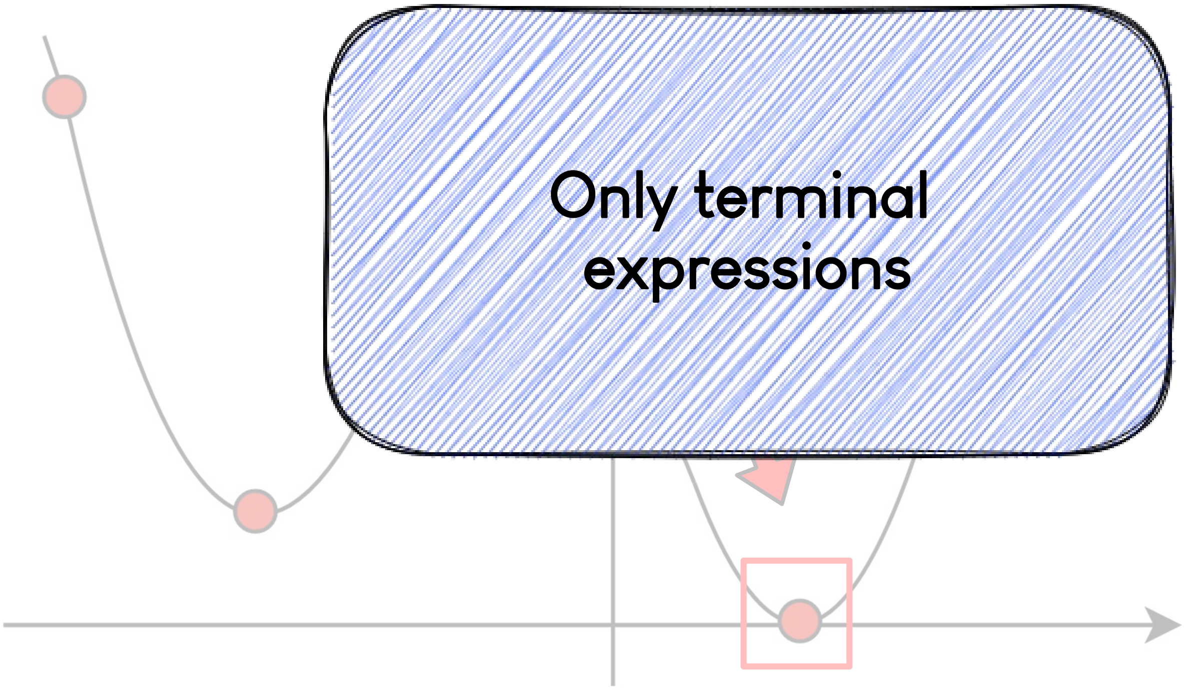
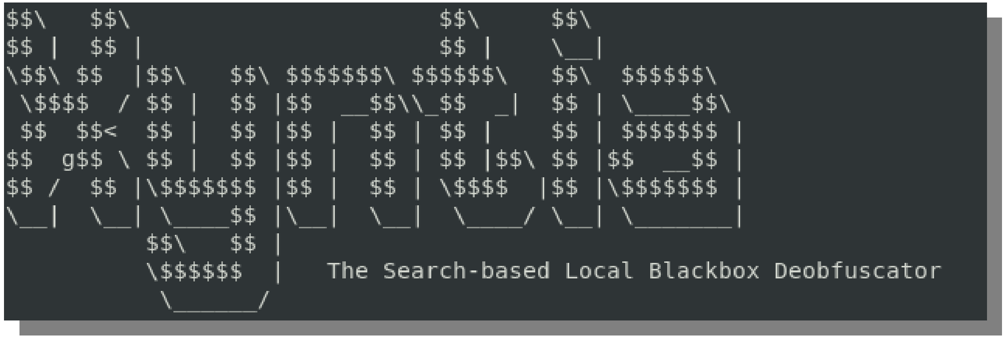


S-metaheuristics

– Solve optimization problems



New Prototype: Xyntia



↳ **S-metaheuristics**

↳ **Can choose between:**
- Hill Climbing
- Simulated Annealing
- Metropolis Hasting
- Iterated Local Search

} > **MCTS**

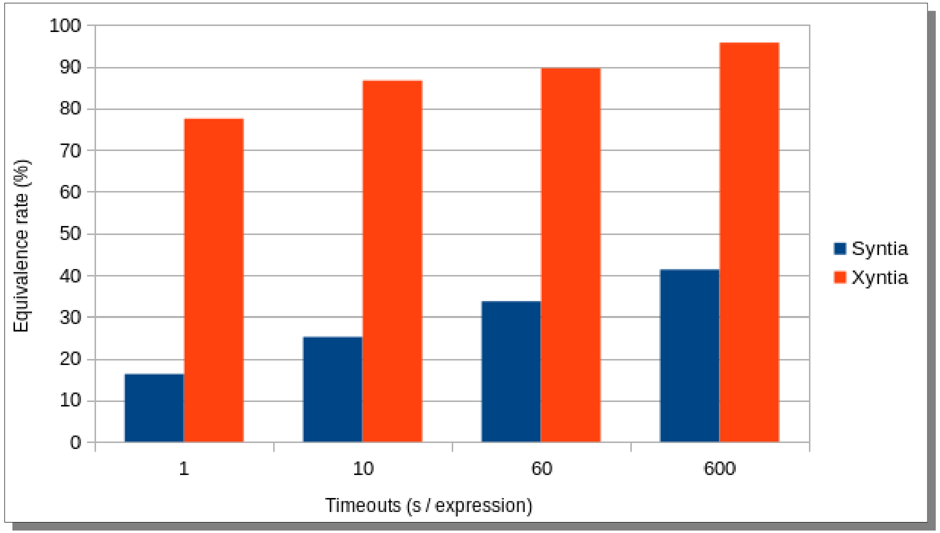
Xyntia vs Syntia

B1 (Syntia)

– 100 % success rate in 1s/expr.

Syntia: 75% in 60 s/expr.

B2 (Ours)



Xyntia vs Syntia

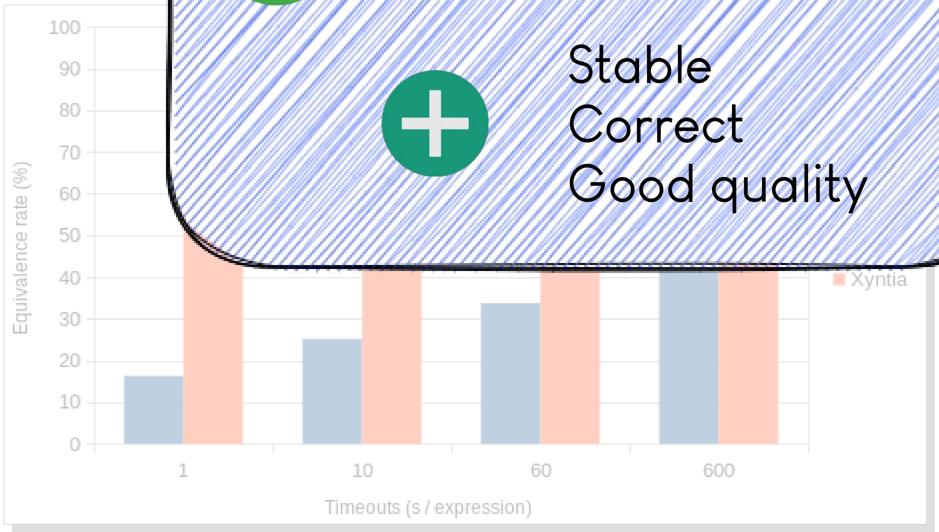
B1 (Syntia)

– 100 % success rate in 1s/expr

Syntia: 75% in 60 s/expr.

Robust & Fast

Stable
Correct
Good quality



Other Experiments

– Xyntia vs Qsynth

– Xyntia vs “compiler like simplifications”

– Xyntia vs program synthesizer CVC4

– Xyntia vs superoptimizer STOKE

404

Not Found

The resource requested could not be found on this server!

– Use-cases
 - ↳ State-of-the-art protections
 - ↳ VM-based obfuscation

What's Next ?


PROTECTIONS ARE BROKEN!


DON'T WORRY...
I HAVE A PLAN
memegenerator.net

Mitigate

Context: Virtualization

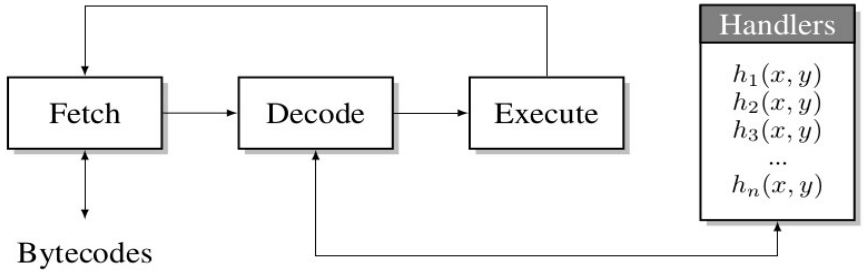


Fig. 1: Virtualization based obfuscation

Proved to be sensitive to black-box deobfuscation

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Why VM-based Obf. Is Vulnerable ?

- Handlers are too semantically simple
  - ↳ e.g., $+, -, \times, \wedge, \vee$
- Obfuscation increases syntactic complexity
  - ↳ Black-box deobf. is **not impacted**

We need to move ...

From syntactic to semantic complexity

Semantically Complex Expressions

Goal

- ↳ Increase the semantic complexity of each handlers
- ↳ Keep a Turing complete set of handlers

Example

$$
\begin{array}{rrcl}
 & h_0 & = & (x+y) + -((a-x^2) - (xy)) \\
+ & h_1 & = & (a-x^2) - xy + (-(y-(a \wedge x)) \times (y \otimes x)) \\
+ & h_2 & = & (y-(a \wedge x)) \times (y \otimes x) \\
\hline
 & h & = & x+y
\end{array}
$$

Merged Handlers

Goal : Increase handlers semantic complexity + sampling harder

Example : $h_1(x, y) = x + y$ and $h_2(x, y) = x \wedge y$

$$\longrightarrow h(x, y, c) = \text{if } (c = cst) \text{ then } h_1(x, y) \text{ else } h_2(x, y)$$

Hide conditionals :

```c
int32_t h(int32_t a, int32_t b, int32_t c) {
    // if (c == cst) then h1(a,b,c) else h2(a,b,c);
    int32_t res = c - cst ;
    int32_t s = res >> 31;
    res = (-((res ^ s) -s) >> 31) & 1;
    return h1(a, b, c)*(1 - res) + res*h2(a, b, c);
}
```

Semantically Complex Handlers: Results

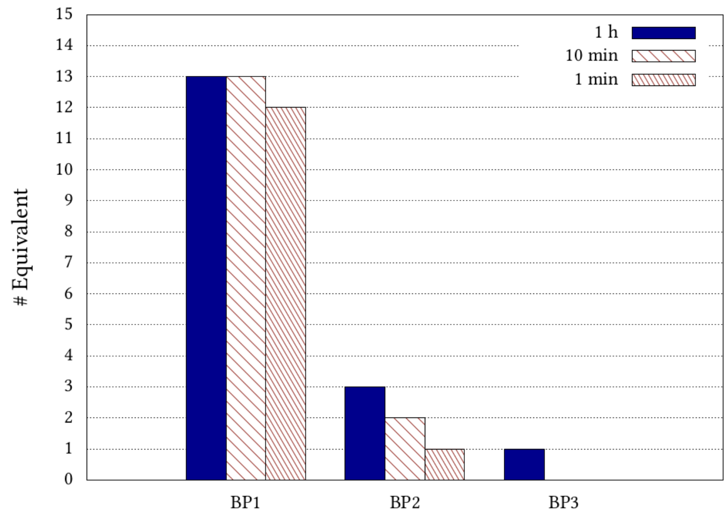

Figure 8: Xyntia ($\text{Xyntia}_{\text{OPT}}$) on BP1,2, 3 – varying timeouts

More results: Syntia with 12h/exprs. → 1/15 on BP1

Merged Handlers: Results

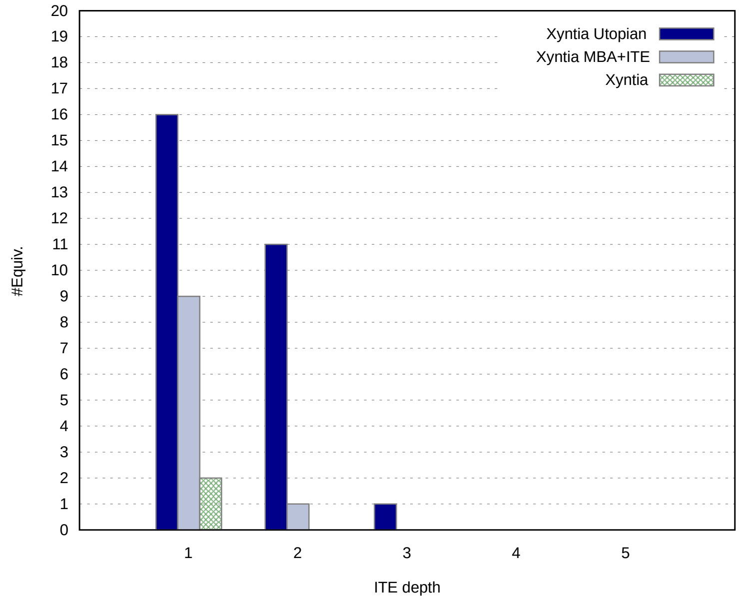

Figure 10: Merged handlers: Xyntia (timeout=60s)

More results: Syntia finds nothing for ≥ 2 nested ITE

Xyntia: The Recap

MCTS is not appropriate for blackbox deobfuscation
→ Search space too unstable
→ Estimation of non terminal expressions pertinence is misleading

S-metaheuristics yields a significant improvement
→ More robust
→ Much Faster

Moving for syntactic to semantic complexity
→ 2 efficient methods to protect against blackbox deobfuscation

Discussion: No Guarantees

– Xyntia & Syntia have **no correctness guarantees**

– But **some contexts need it:**

↳ Code verification

↳ Code refactoring

Can black-box approaches have clear guarantees ?

H2020 TAILOR -Foundations of Trustworthy AI -
Integrating Reasoning, Learning and Optimization

Automated Program Analysis: Revisiting Precondition Inference through Constraint Acquisition

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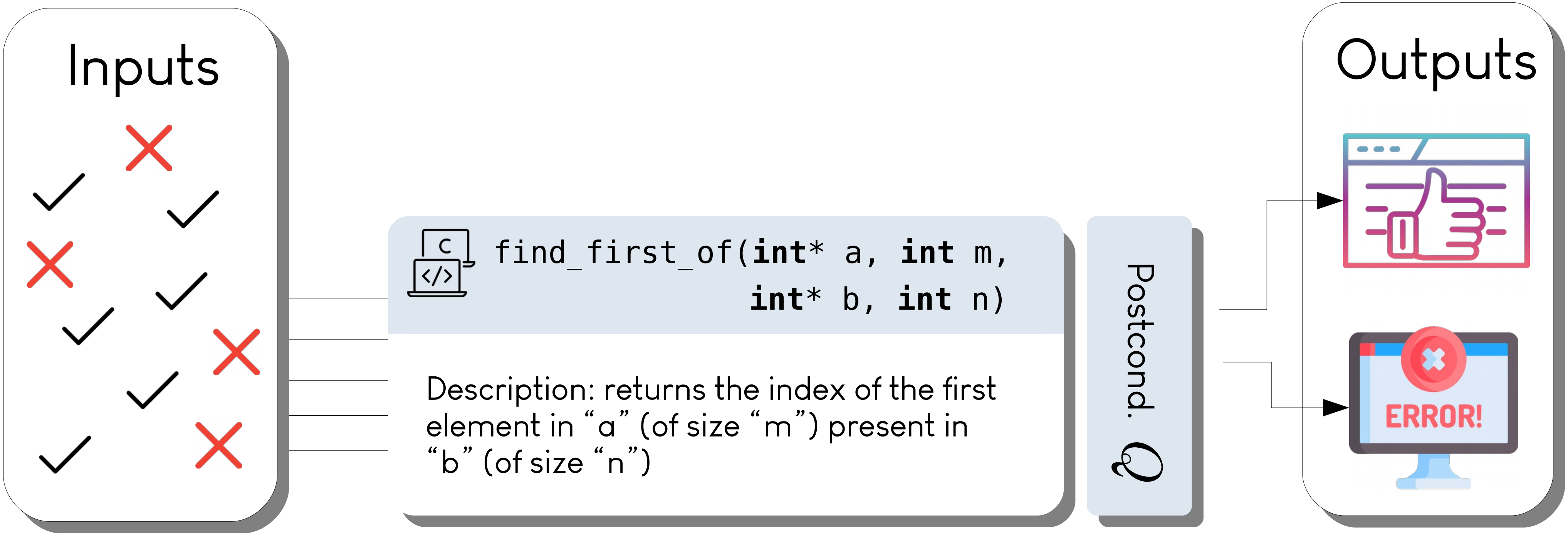
Dream: Infer Preconditions



Dream: Infer Preconditions

Inputs

$$[m > 0 \Rightarrow valid(a)]$$
$$\wedge$$
$$[m > 0 \wedge n > 0 \Rightarrow valid(b)]$$

```c
find_first_of(int* a, int m,
              int* b, int n)
```

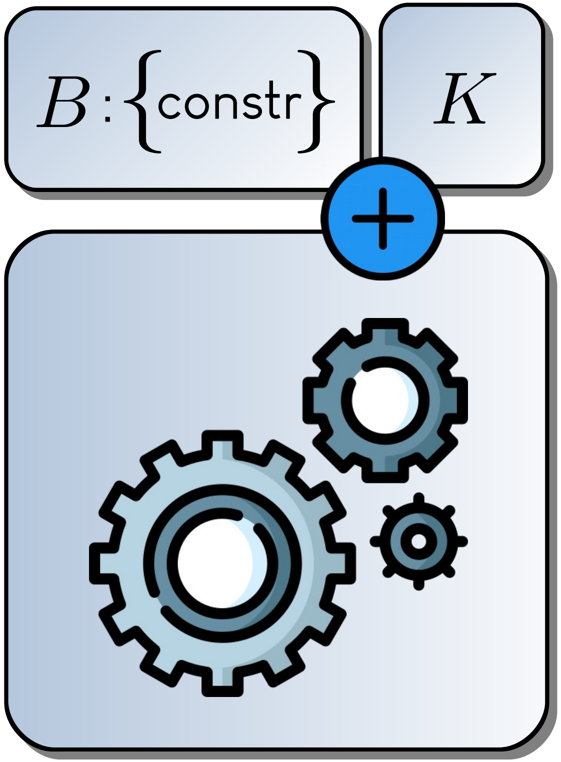
Description: returns the index of the first element in “a” (of size “m”) present in “b” (of size “n”)

$Q = true$

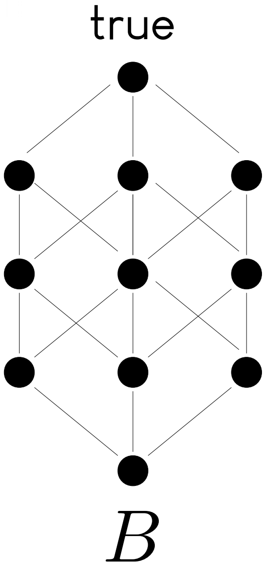
Outputs

Undecidable problem: Rice theorem (1953)

Active Constraint Acquisition



Background knowledge:
rules to speed up learning



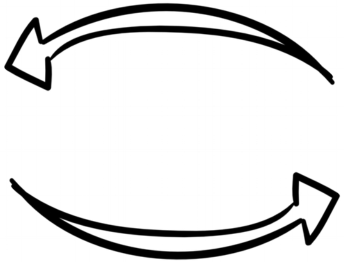
Active Constraint Acquisition

Query

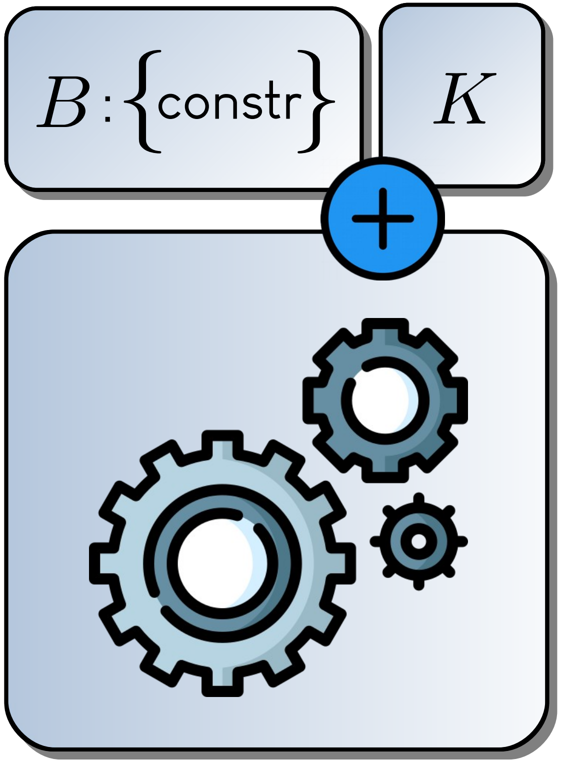
Elise: 8h – 12h

Paul: 10h – 11h

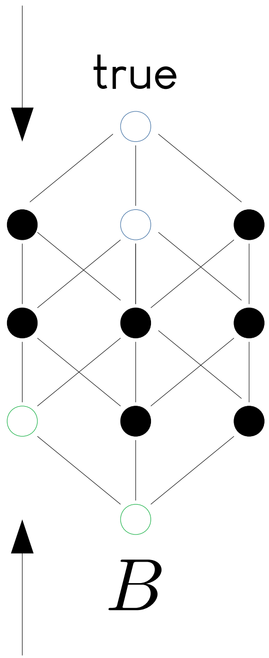
...



yes /no

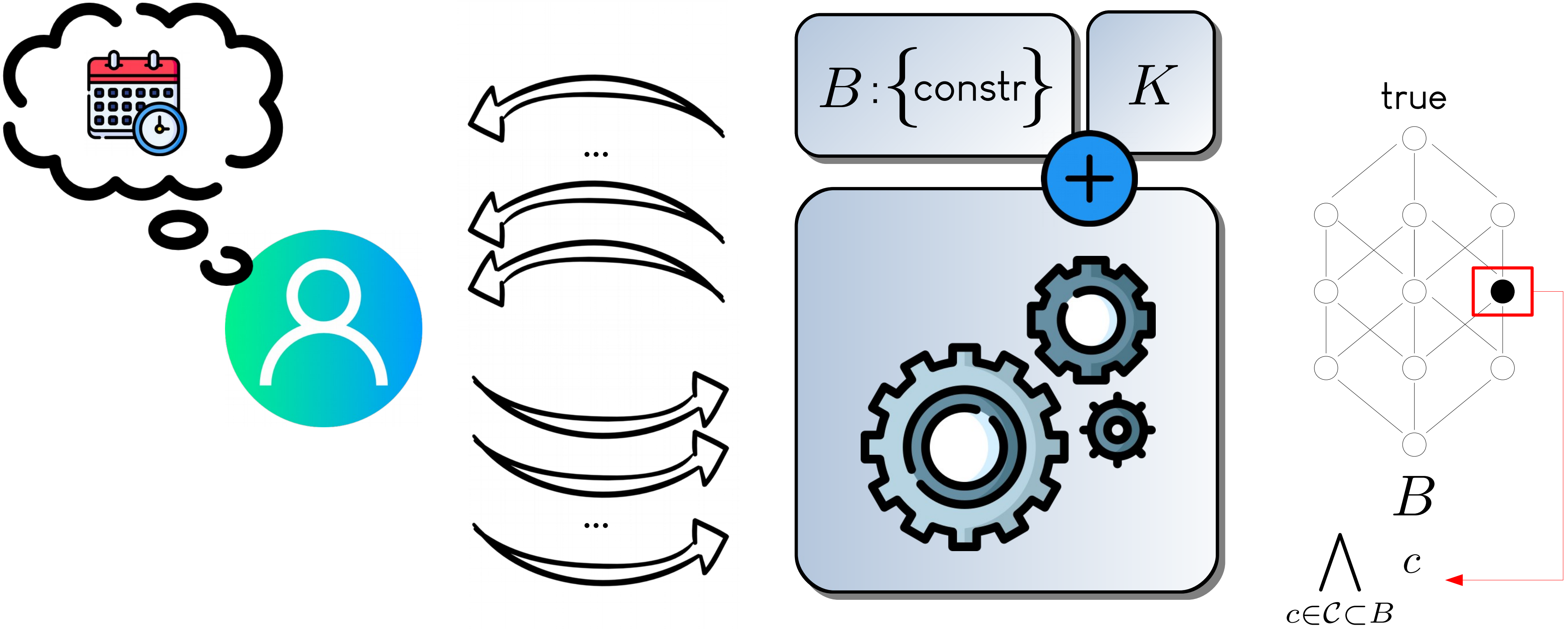


no: Top-down

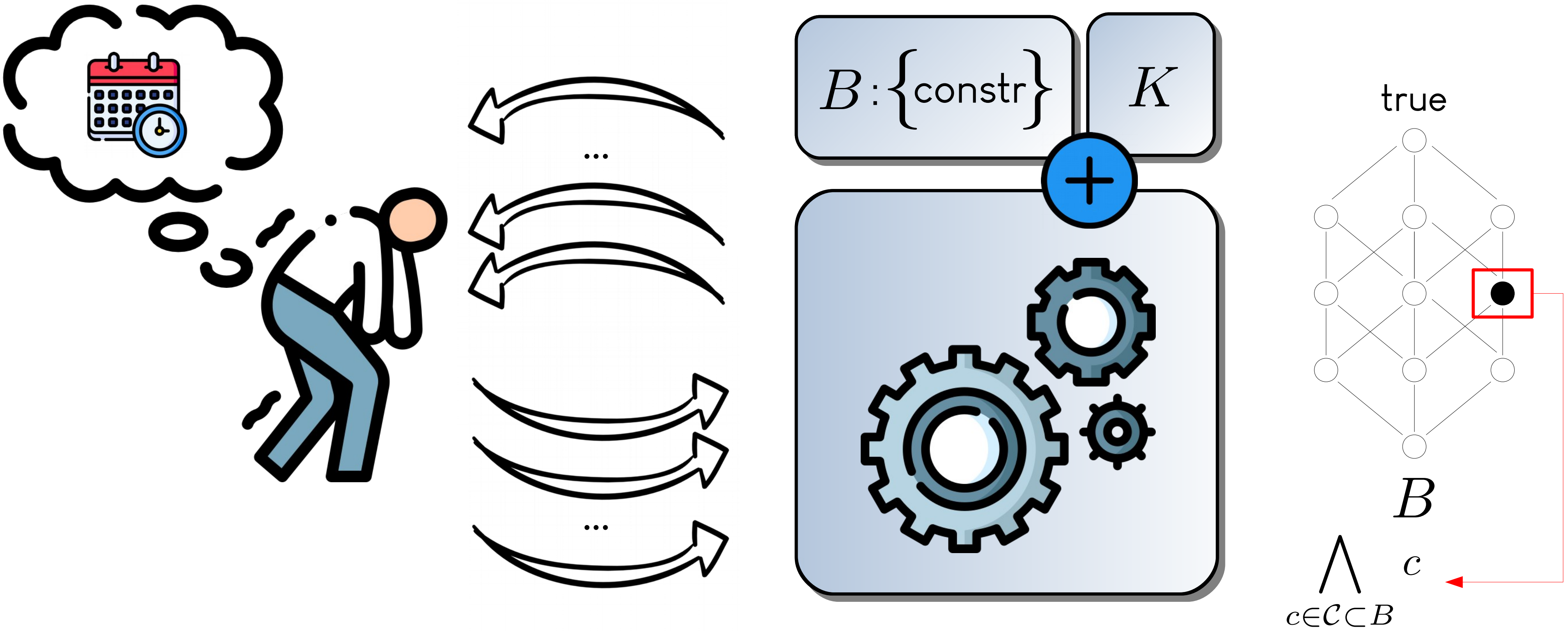


yes: Bottom-up

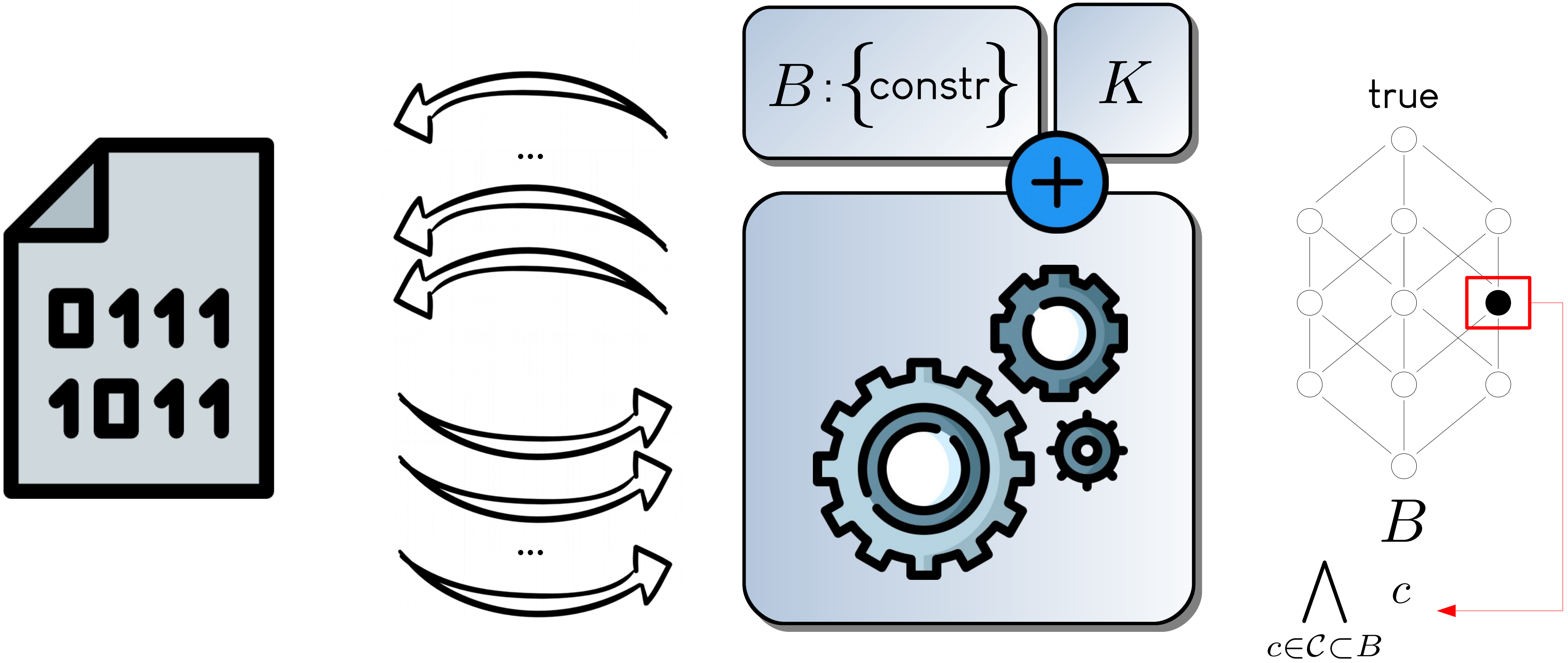
Active Constraint Acquisition



Careful: too many queries



PreCA: Precondition Constr. Acq.



Theoretical Analysis

PreCA guarantees

↳ If B is expressive enough → ∅ or Precond.

↳ ⊕ If code exec. always terminates → The most general precondition

These are good theoretical guarantees

↳ SOTA executions based methods, from programming language community, have no clear guarantees

Evaluation

Dataset: 94 learning tasks • compiled C functions (string.h, arrays, arithmetic ...)

Evaluation:

	PreCA		1 hour Daikon, PIE, Gehr et al		P-Gen
$Q = true$	92%	VS	At most 52%	VS	74%
$Q \neq true$	41%		At most 23%		34%

⊕ PreCA better in 5s than concurrent tools in 1 hour

Conclusion

Black-box methods can be used in broad contexts

↪ Deobfuscation – Contracts inference

Balance between robustness and guarantees

Thank you for your attention

@grmenguy

https://gregoiremenguy.github.io/