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

Automated Program Analysis: Revisiting Precondition Inference through Constraint Acquisition

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Speaker

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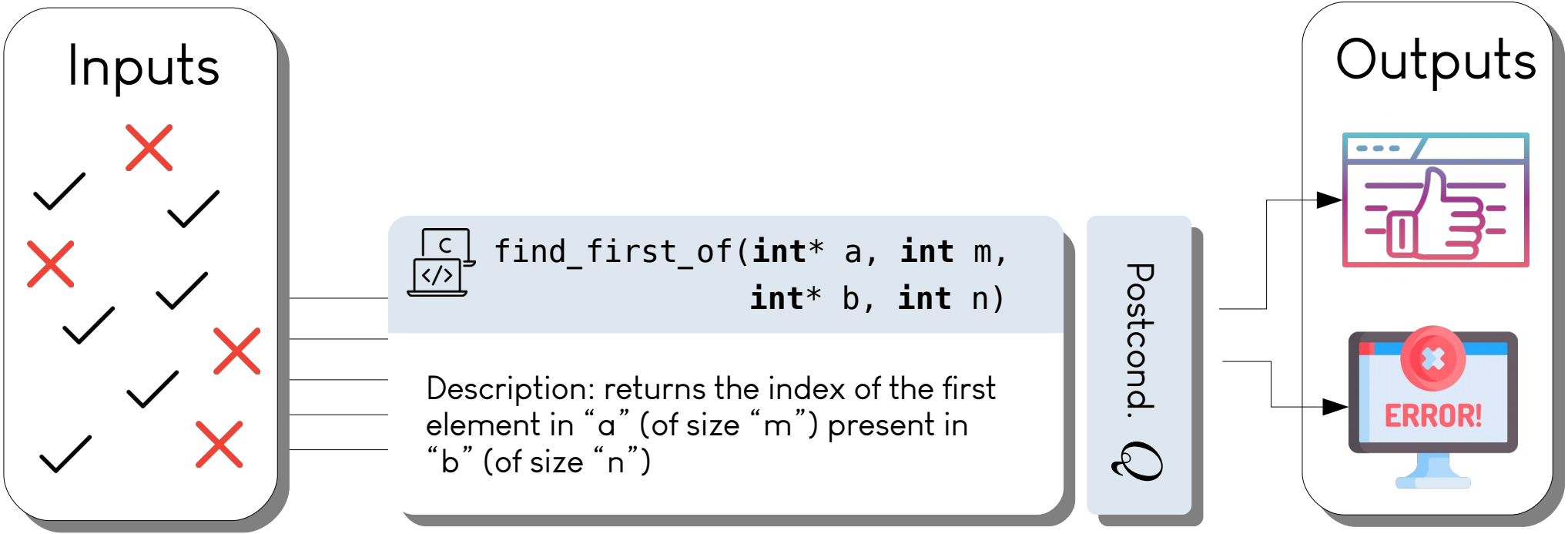
On the Way to Secure Code

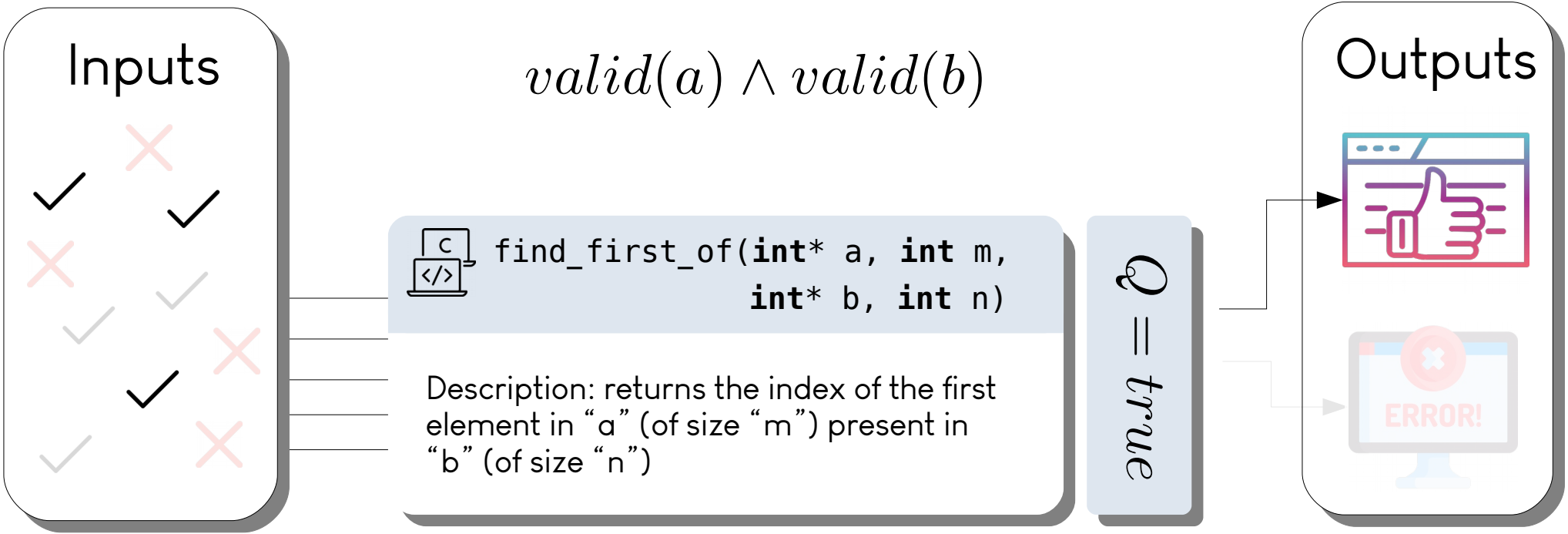
Improve Confidence in Software

- Testing
- Formal Verification
  - E.g., Precondition / postconditon
    - Enable to scale to big code
    - Almost never given in practice

Dream: Infer Preconditions

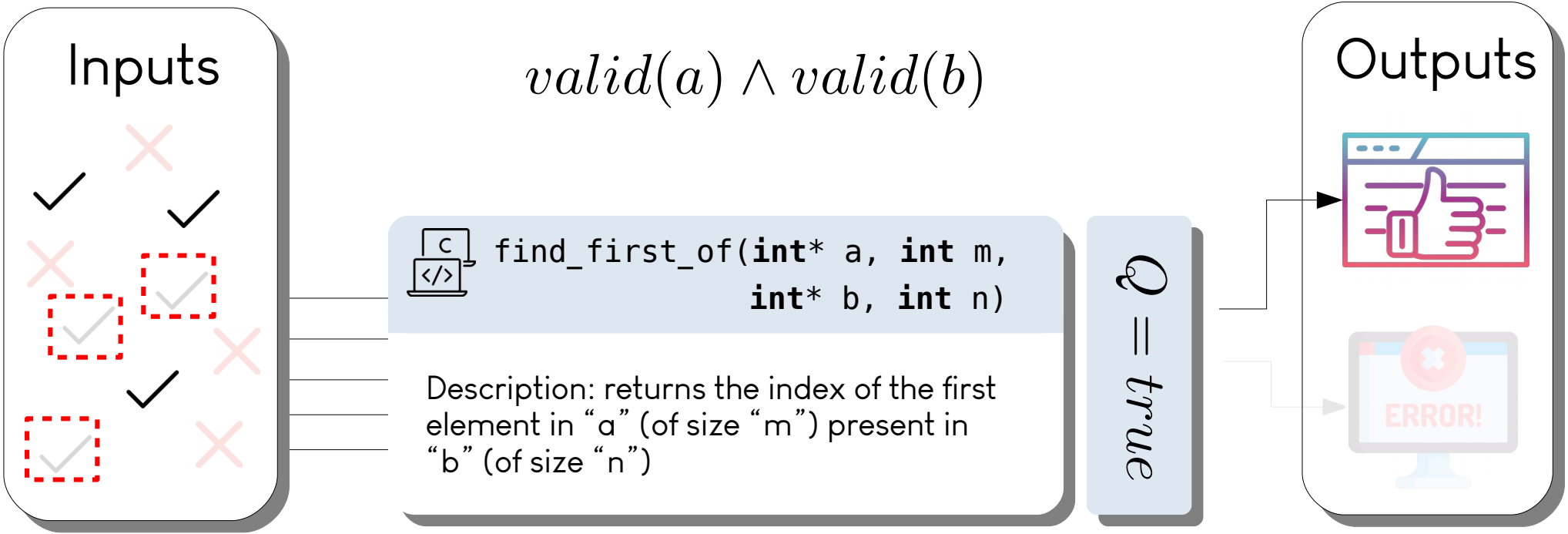


Dream: Infer Preconditions



Undecidable problem: Rice theorem (1953)

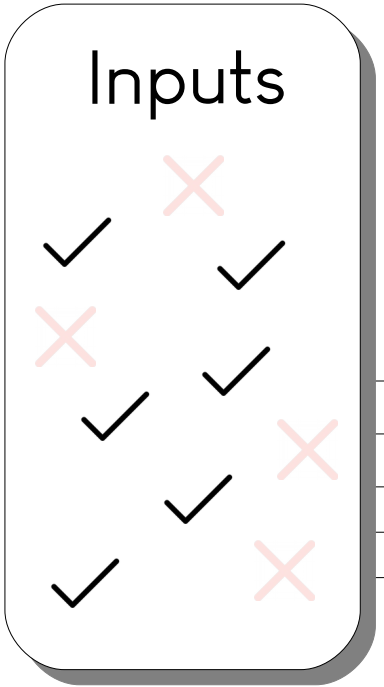
Dream: Infer Preconditions



Undecidable problem: Rice theorem (1953)

Dream: Infer The Weakest Precond.

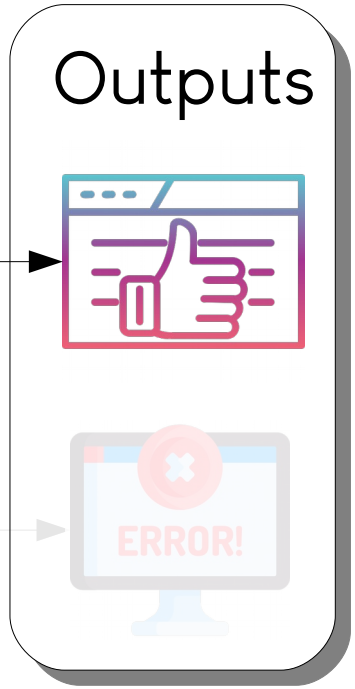
$$[m > 0 \Rightarrow valid(a)]$$
$$\wedge$$
$$[m > 0 \wedge n > 0 \Rightarrow valid(b)]$$




```
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”)

$Q = true$



Undecidable problem: Rice theorem (1953)

State-of-the-art

Execution Based (Daikon, PIE, Gehr et al.):

- 👍 Does not need the source code
- 👎 No clear guarantees

Data-Driven Precondition Inference with Learned Features

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Code Based:

- 👎 Need the source code
  - scalability issues • code not available
- 👍 Clear guarantees

Counterexample-Guided Precondition Inference*

Mohamed Nassim Seghir and Daniel Kroening

Computer Science Department, University of Oxford

Goal

Execution Based (Daikon, PIE, Gehr et al.):

- Does not need the source code
- Clear guarantees

Constraint Acquisition Based Precond. Inference

Code Based:

- Need the source code
  - scalability issues • code not available
- Clear guarantees

Data-Driven Precondition Inference with Learned Features

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Counterexample-Guided Precondition Inference*

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Constraint Acquisition

Constraint Programming

↳ Hard to design models

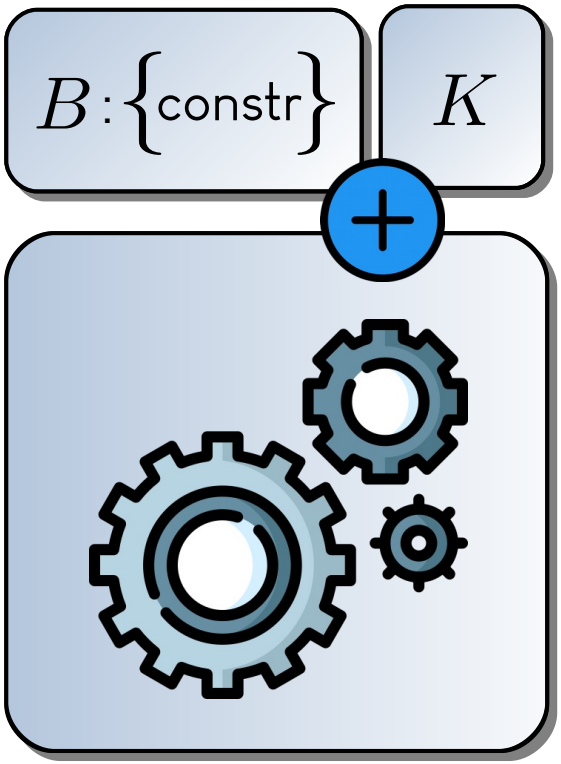
Constraint Acquisition

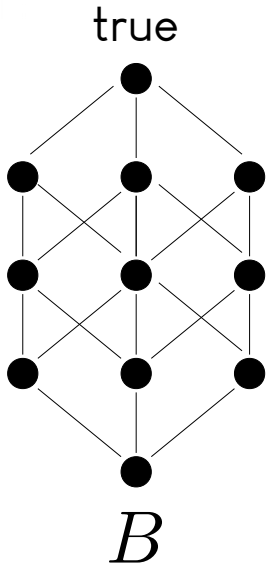
↳ Version Space Learning (Mitchell, 82)

↳ Bessiere, C., Koriche, F., Lazaar, N., & O'Sullivan, B. (2017). Constraint Acquisition. Artificial Intelligence, 244, 315-342.

Active Constraint Acquisition

Background knowledge:
rules to speed up learning





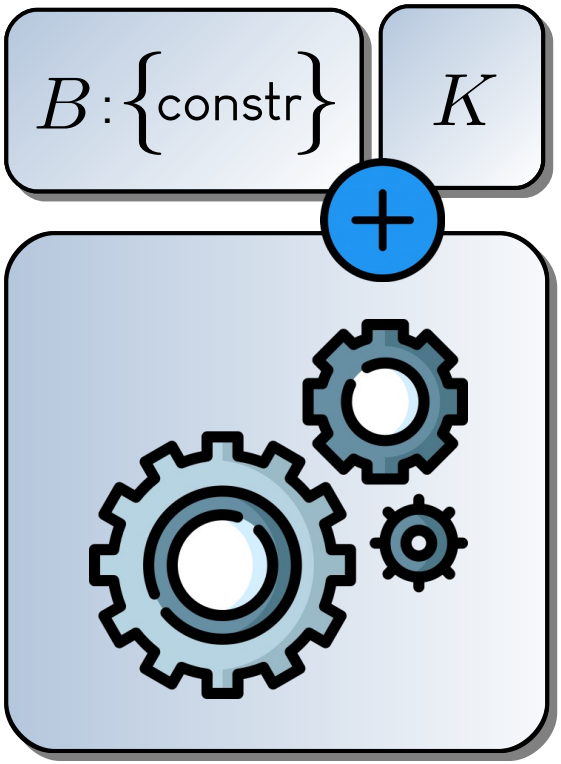
Active Constraint Acquisition

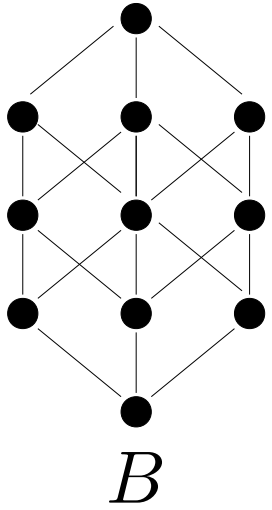
Query

Elise: 8h – 12h

Paul: 10h – 11h

...





Active Constraint Acquisition

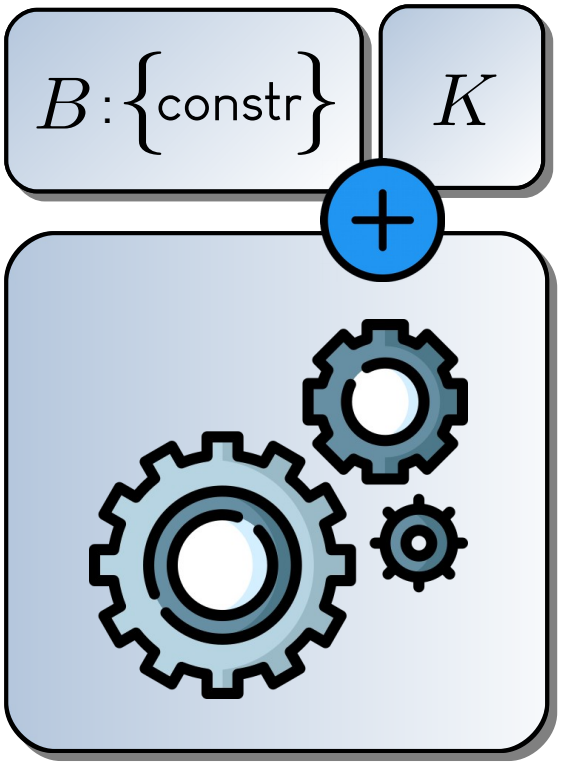
Query

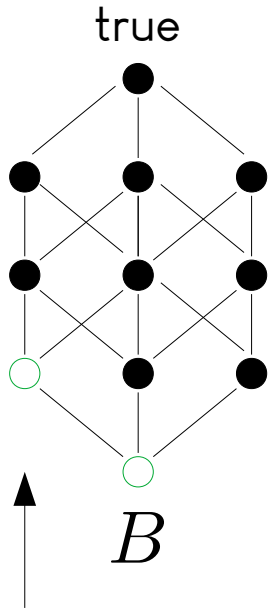
Elise: 8h – 12h

Paul: 10h – 11h

...

yes





yes: Bottom-up

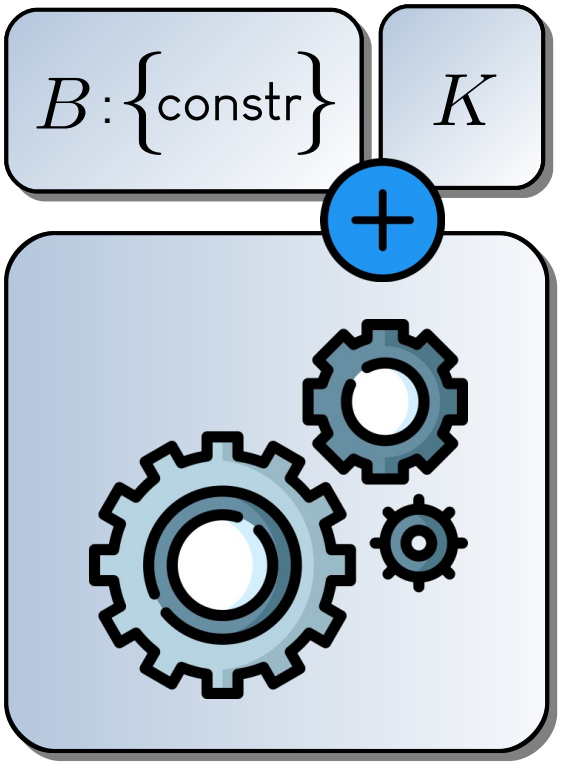
Active Constraint Acquisition

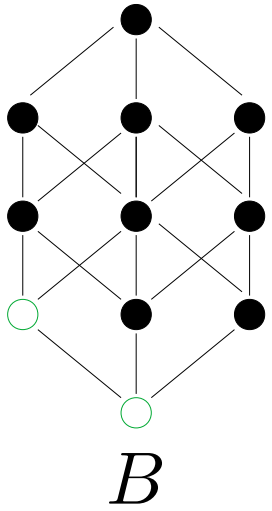
Query

Elise: 8h – 12h

Paul: 10h – 23h

...





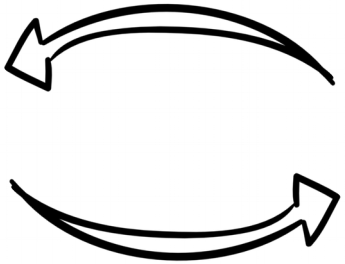
Active Constraint Acquisition

Query

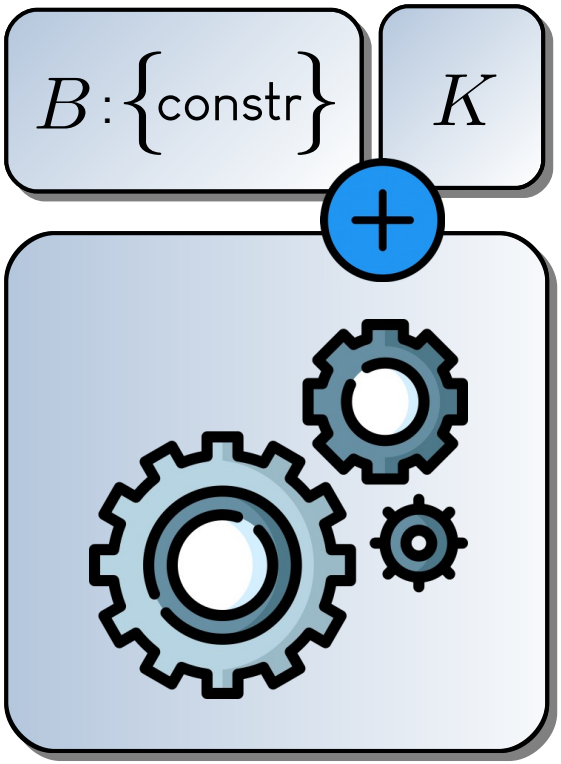
Elise: 8h – 12h

Paul: 10h – 23h

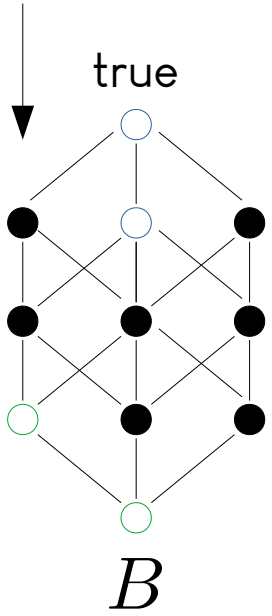
...



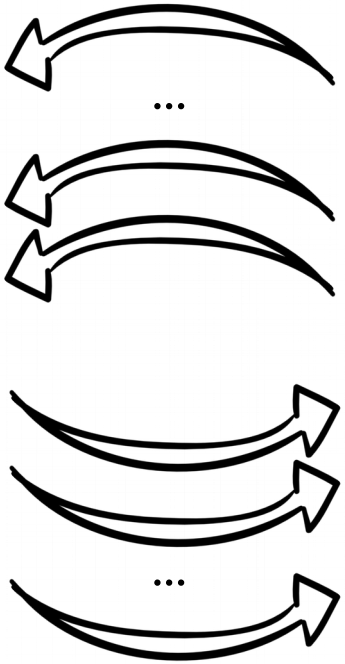
no

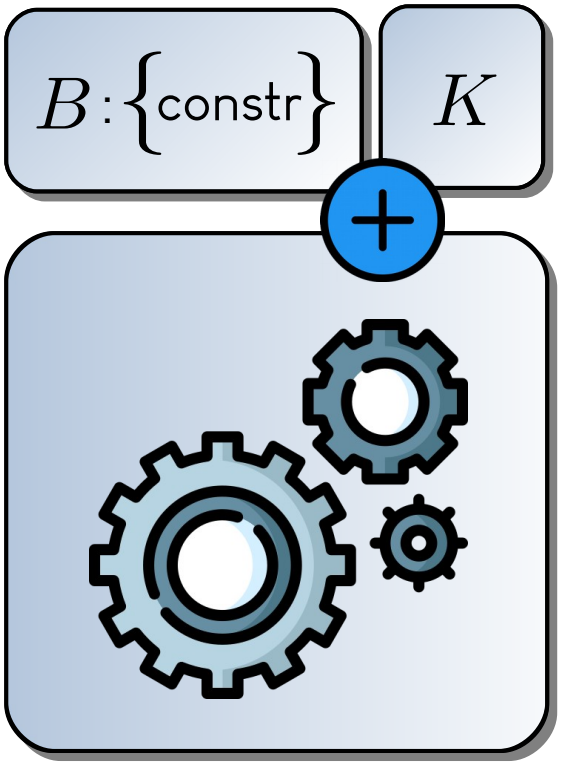


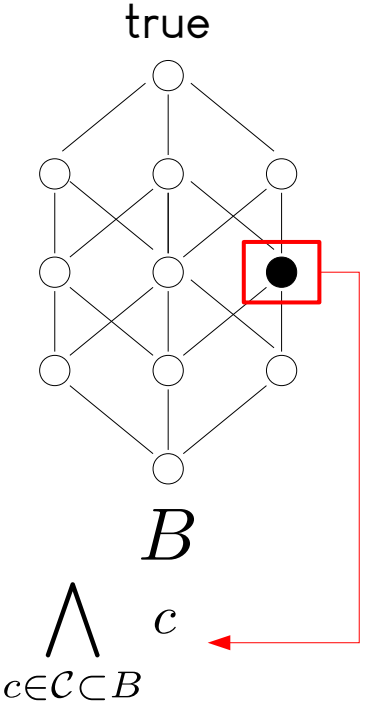
no: Top-down



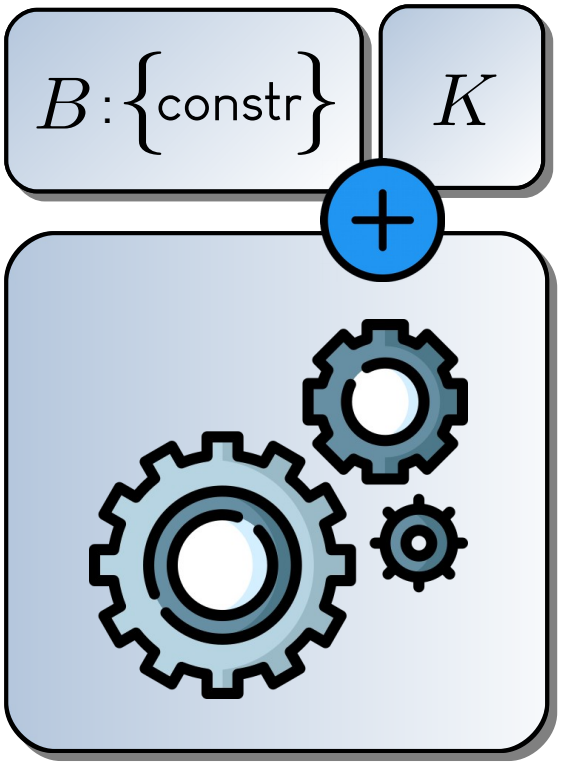
Active Constraint Acquisition

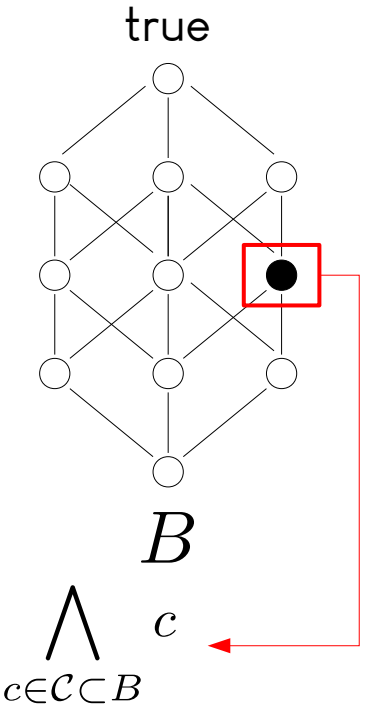






Careful: too many queries





Adapting Constraint Acquisition

Human user → 

Executable under analysis
↳ No limitation on the queries nb.

Query → 
Function inputs (args, global vars)

Constraints → B : Constraints over ptr and int

Background knowledge → K : Background knowledge on pointers


Preprocess (passive mode)
↳ Generates likely to be interesting queries

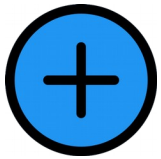
Which constraints ?

Constraints ⟶ B : Constraints over ptr and int

Constraints for memory-related precond.:

$$
\begin{array}{lll}
P & := & C \Rightarrow A \mid A \mid \neg A \\
C & := & C \wedge C \mid A \mid \neg A \\
A & := & valid(p_j) \mid alias(p_j, p_l) \mid deref(p_j, g) \\
 & \mid & i_j = 0 \mid i_j < 0 \mid i_j \leq 0 \mid i_j = i_l \mid i_j < i_l \mid i_j \leq i_l
\end{array}
$$

Method not limited to memory-related precond.



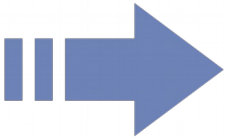
From language to bias B: max. size of horn clauses depending on the function prototype – especially number of integer inputs

Preprocess

Positive (e^+) vs Negative Queries (e^-)

↳ **All constraints** incoherent with e^+ are not in the solution 

↳ **At least one constraint** incoherent with e^- is in the solution 

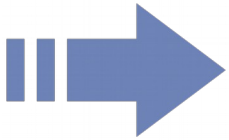


Generate positive queries first to remove a lot of constraints

↳ How to generate positive queries ?

Preprocess

- Goal of developers : software should work
  - Usually they handle well usual cases
- Generate queries where code likely behave correctly



Generate first queries with ≤ 1 one non valid, aliasing or deref pointers

PreCA

NEW

```
Call the preprocess

while true do
    Generate an informative query
    if no-query then «we converged»
    Submit query to the oracle(F, Q)
    if answer is yes then
        Bottom-up-inference()
    else
        Top-down-inference()
```

How Oracle answers queries ?

- Run function F under query
- If $ret \not\models Q$ or 

 ⇢ no
- If  

 ⇢ ukn
- Otherwise ⇢ yes

Back To Our Example

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

Description: returns the index of the first element in “a” present in “b”

Postcondition: $Q = true$

↳ Variables : a, m, b, n

↳ Heuristics : max. Horn clause size = 3

Back To Our Example

```
Fun: find_first_of
In : int* a, int m,
     int* b, int n
```

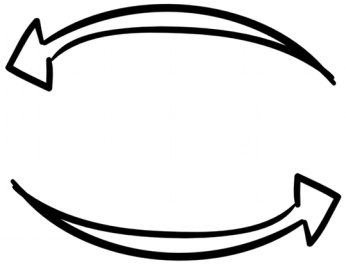
Description: returns the index of the first element in “a” present in “b”

Postcondition: $Q = true$

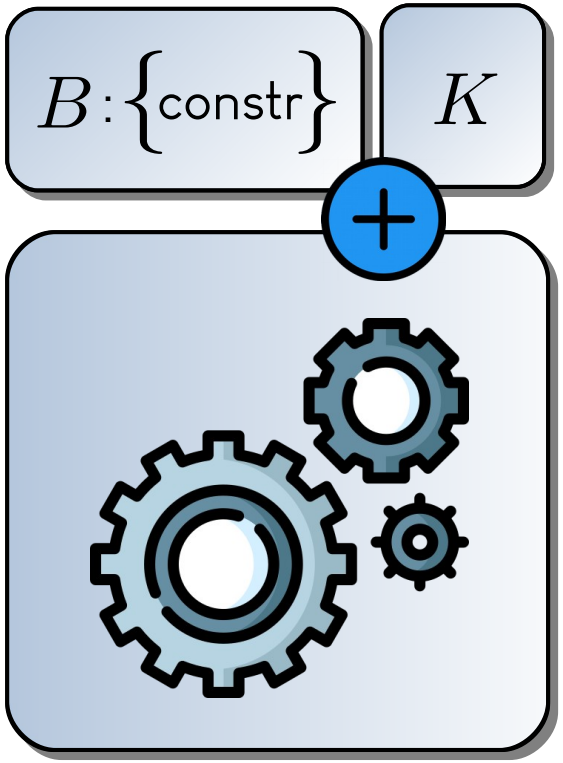
Query

a = NULL, m = 1

b = NULL, n = 3



no



Back To Our Example

```
Fun: find_first_of
In : int* a, int m,
     int* b, int n
```

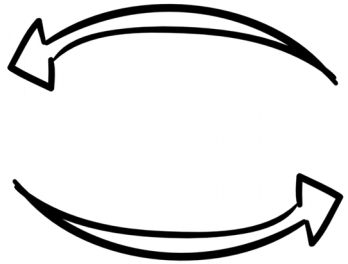
Description: returns the index of the first element in “a” present in “b”

Postcondition: $Q = true$

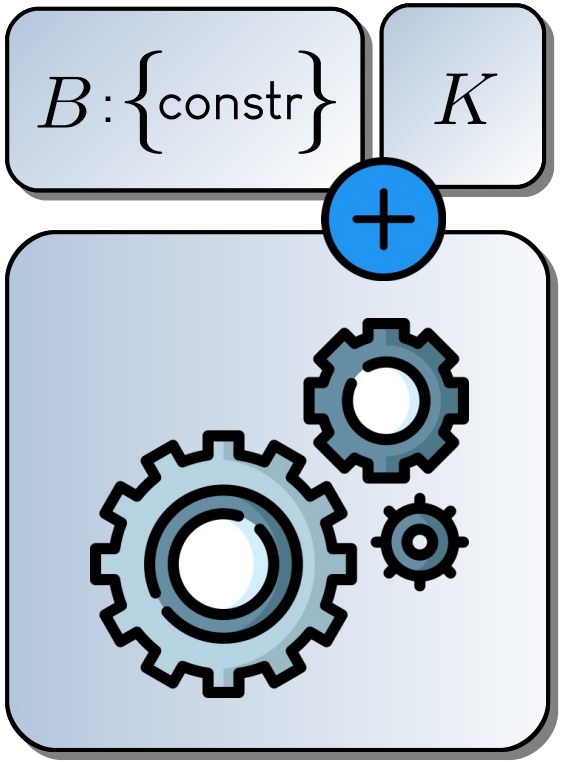
Query

a = NULL, m = 0

b = NULL, n = 0



yes



Back To Our Example

```
Fun: find_first_of
In : int* a, int m,
     int* b, int n
```

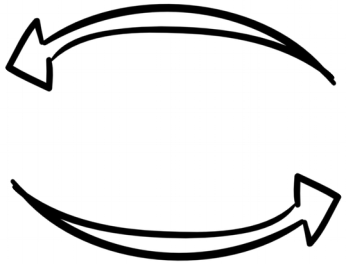
Description: returns the index of the first element in “a” present in “b”

Postcondition: $Q = true$

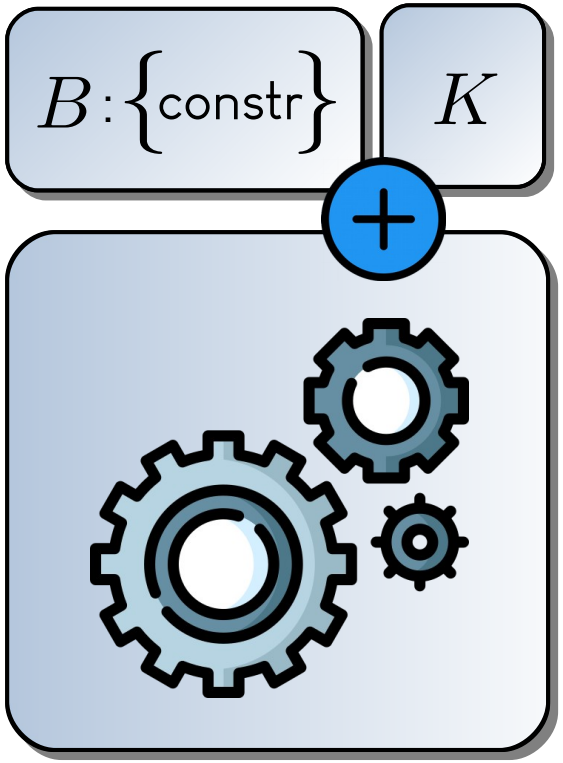
Query

a = @1, m = 3

b = @2, n = 3



yes



Back To Our Example

```
Fun: find_first_of
In : int* a, int m,
     int* b, int n
```

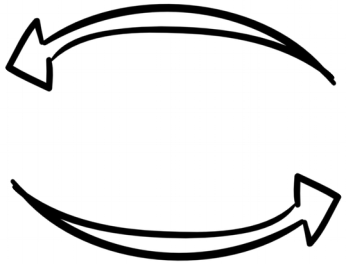
Description: returns the index of the first element in “a” present in “b”

Postcondition: $Q = true$

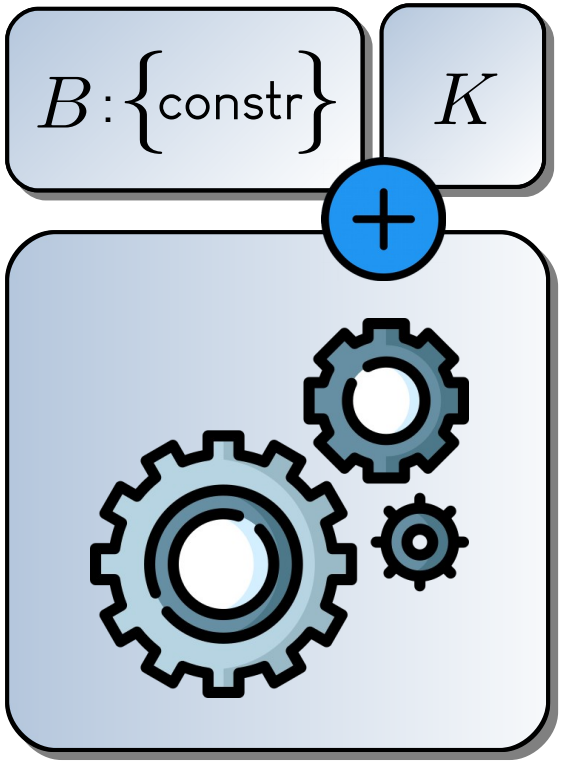
Query

a = @1, m = 3

b = @1, n = 3



yes



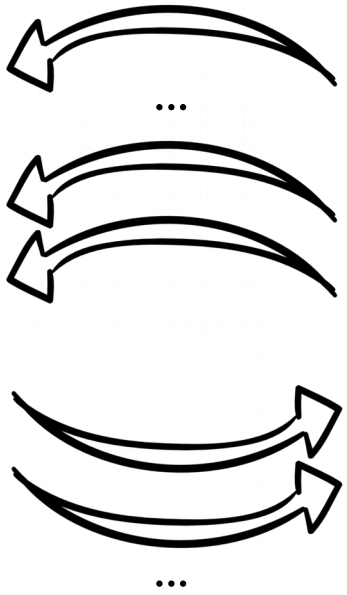
Back To Our Example

```
Fun: find_first_of
In : int* a, int m,
     int* b, int n
```

Description: returns the index of the first element in “a” present in “b”

Postcondition: $Q = true$

45 queries



Result

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

Theoretical Analysis

PreCA guarantees

↳ If B is expressive enough ⇢ ∅ or Precond.

↳ ⊕ If oracle never answers “unk” ⇢ 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:

1 hour

	PreCA		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

AI contributions

- 1st adaptation of CA for prog. analysis
  - new use case for CA
  - no user (no limit for queries nb)
- Translate core concepts :
  - Set of constraints
  - Background knowledge
- Extend CA (ukn, preprocess)

Opens new research directions for CA

Prog. analysis contribs

New efficient precond. inference tool

- Good guarantees
- Outperforms concurrent tools

+

- Does not need the source code

Thank you for your attention

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https://gregoiremenguy.github.io/