Return of CFA: Call-Site Sensitivity Can Be Superior to Object Sensitivity Even for Object-Oriented Programs

Minseok Jeon and Hakjoo Oh

KOREA UNIVERSITY

POPL 2022 @ Philadelphia, USA

Two major camps

A: Call-Site Sensitivity Can

Object Sensitivity Even for

Object-Oriented Programs

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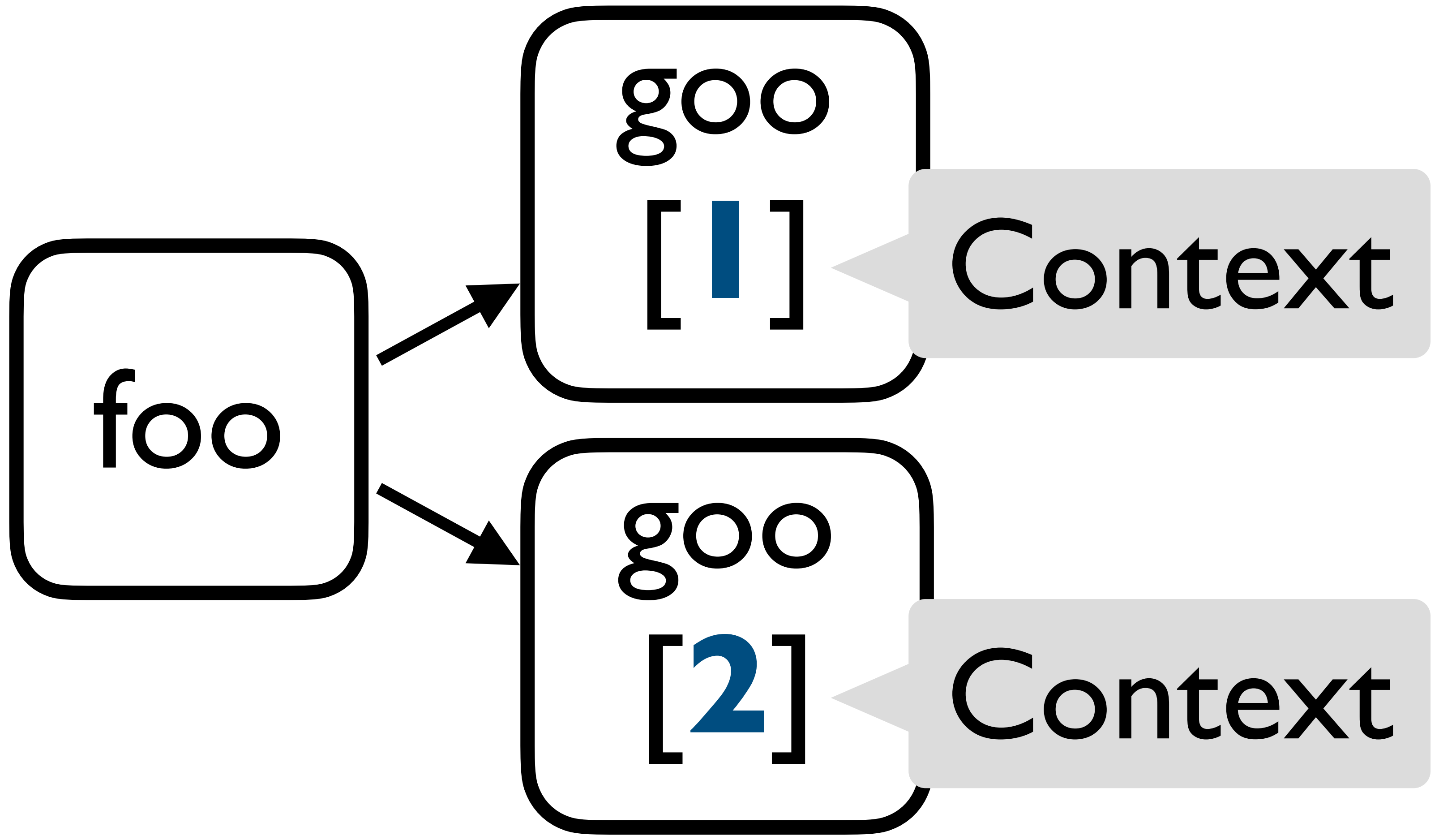
Call-site Sensitivity vs Object Sensitivity

Call-site sensitivity was born in 1981

- Considers "**Where**"

```
0: foo(){
1:   goo();
2:   goo();
3: }
```



Call graph

Call-site sensitivity

1981 2002 2010 2022

Call-site Sensitivity vs Object Sensitivity

Call-site sensitivity was born in 1981

- Considers "**Where**"

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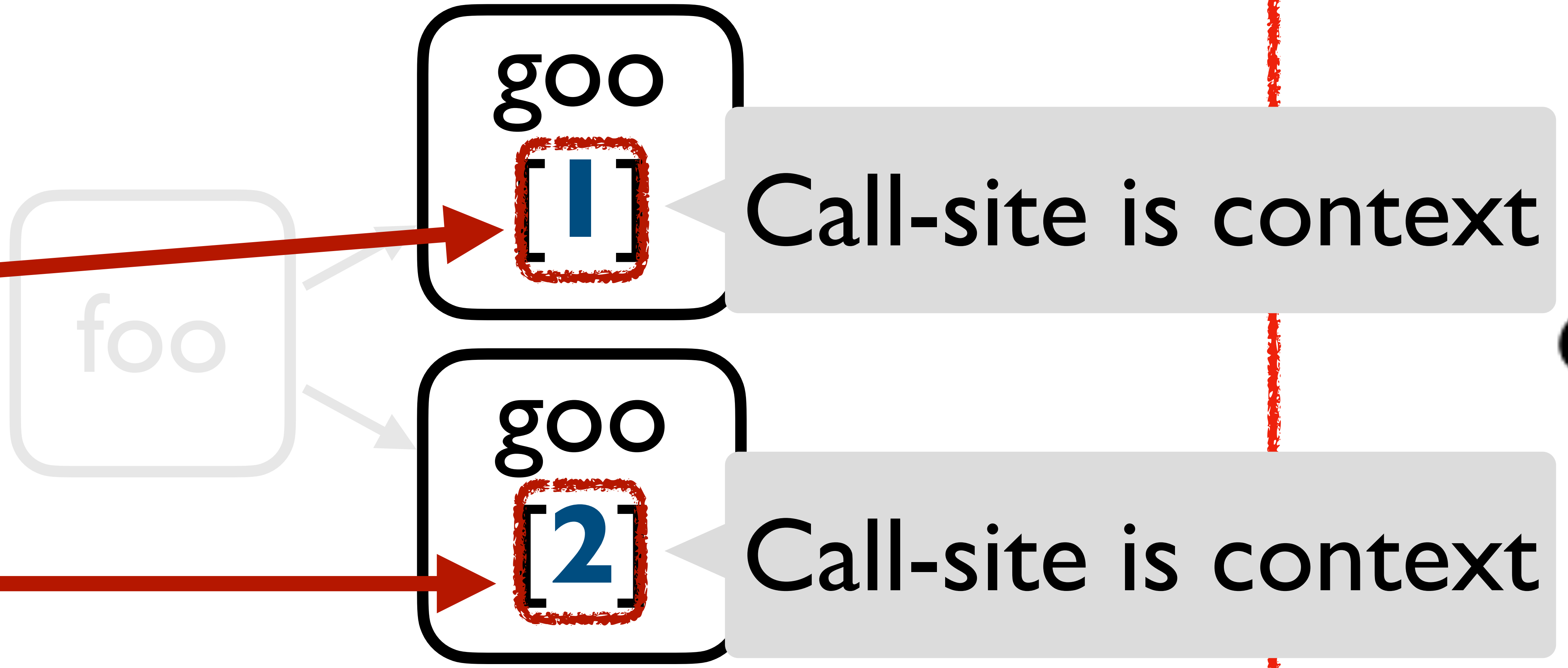
2:    goo();
3: }
```



Call graph

Where is it called from?

Call-site sensitivity

1981 2002 2010 2022

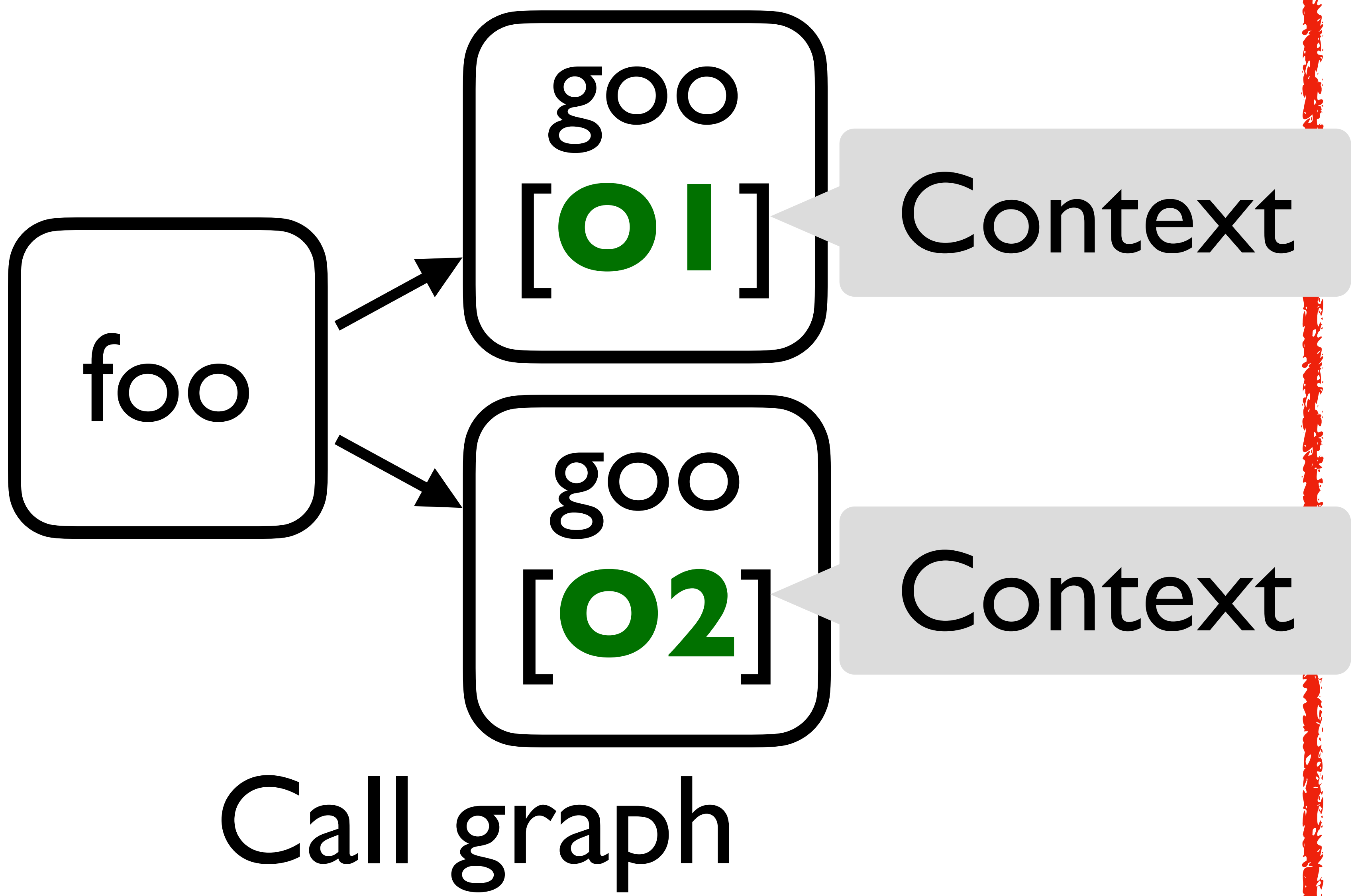
Call-site Sensitivity vs Object Sensitivity

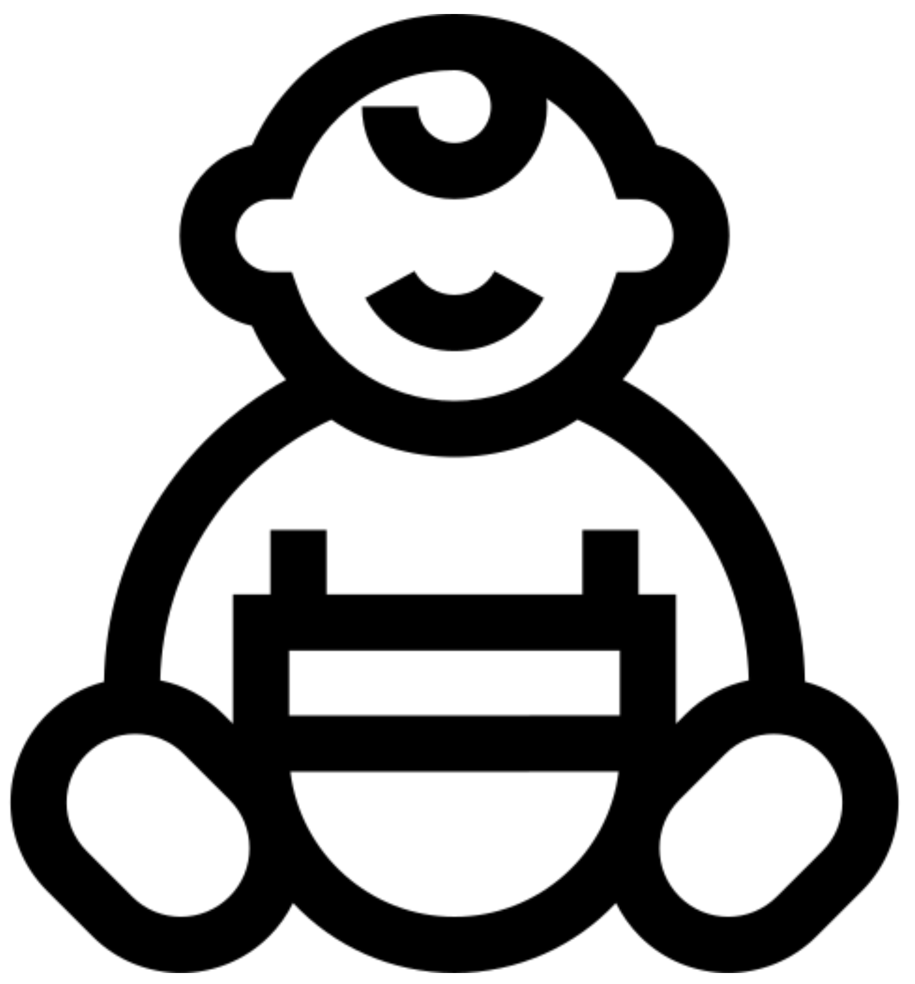
Object sensitivity appeared in 2002

- Considers "**What**"

O1 or **O2**

```
0: foo(p){
1:    p.goo();
2: }
```





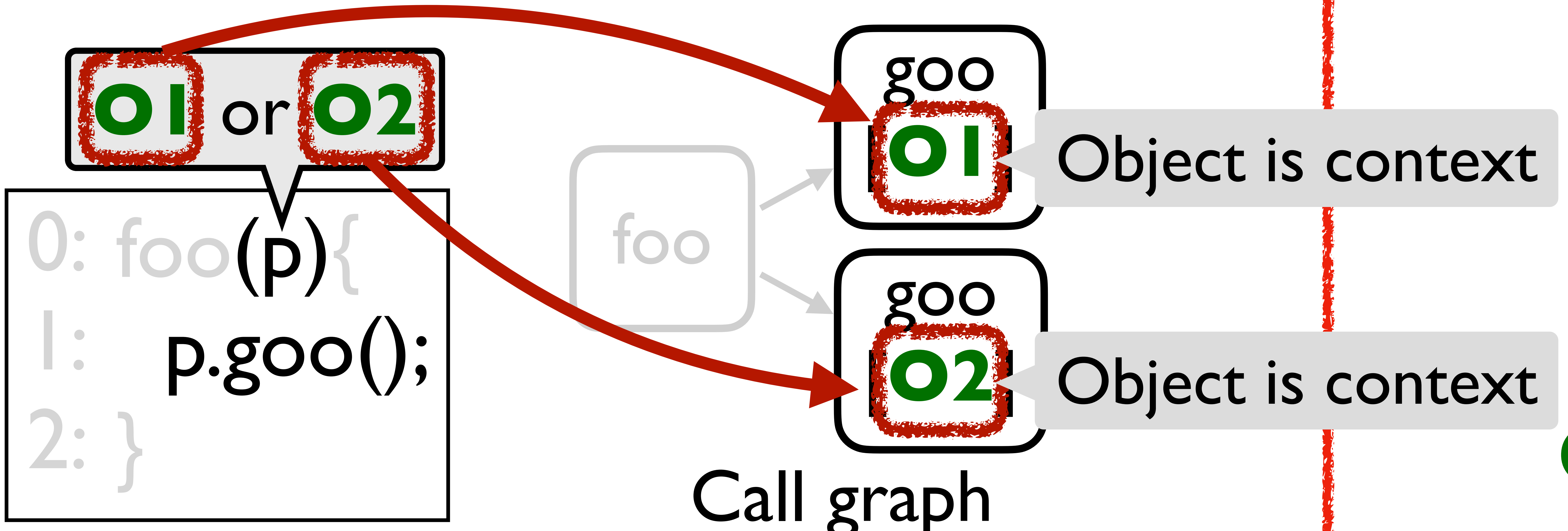
Object sensitivity

1981 **2002** 2010 2022

Call-site Sensitivity vs Object Sensitivity

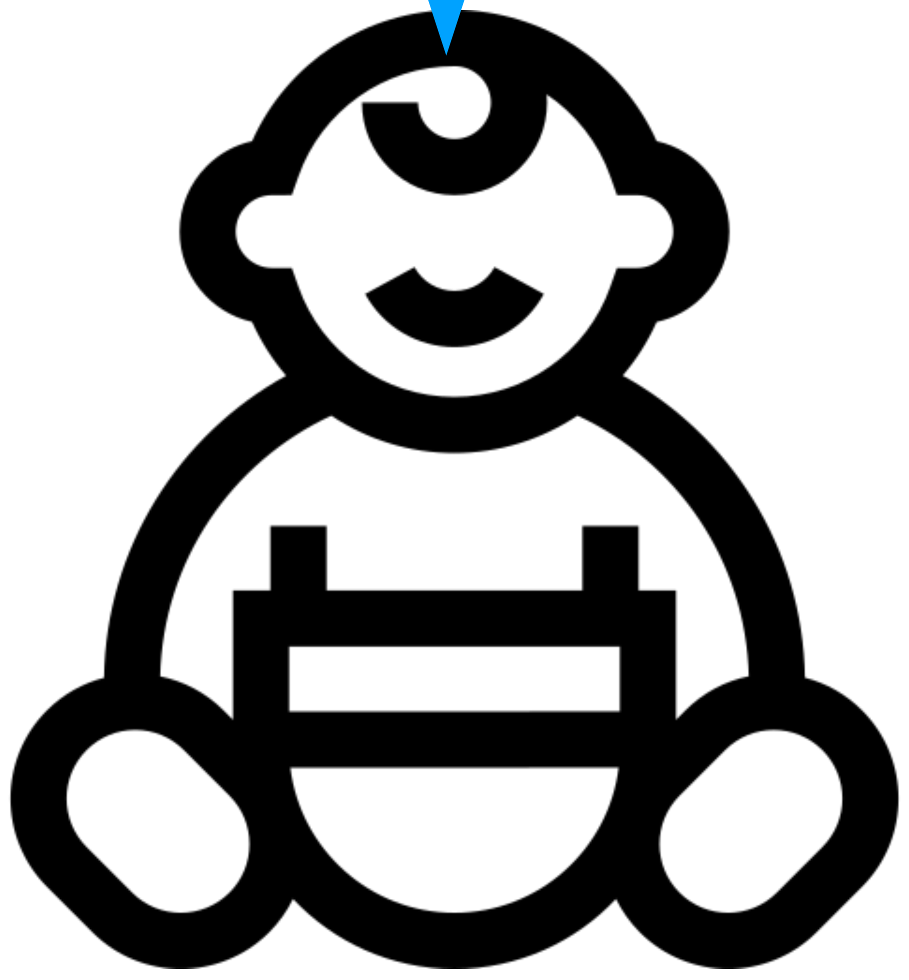
Object sensitivity appeared in 2002

- Considers "**What**"



Call graph

What is it called with?



Object sensitivity

1981 **2002** **2010** **2022**

Call-site Sensitivity vs Object Sensitivity

- An example shows the limitation of CFA and strength of object sensitivity

```
0:  class C{
1:    id(v){
2:      return v;}
3:    id1(v){
4:      return this.id(v);}
5:  }
6:  main(){
7:  c1 = new C();//C1
8:  c2 = new C();//C2
9:  a = (A) c1.id1(new A());//query1
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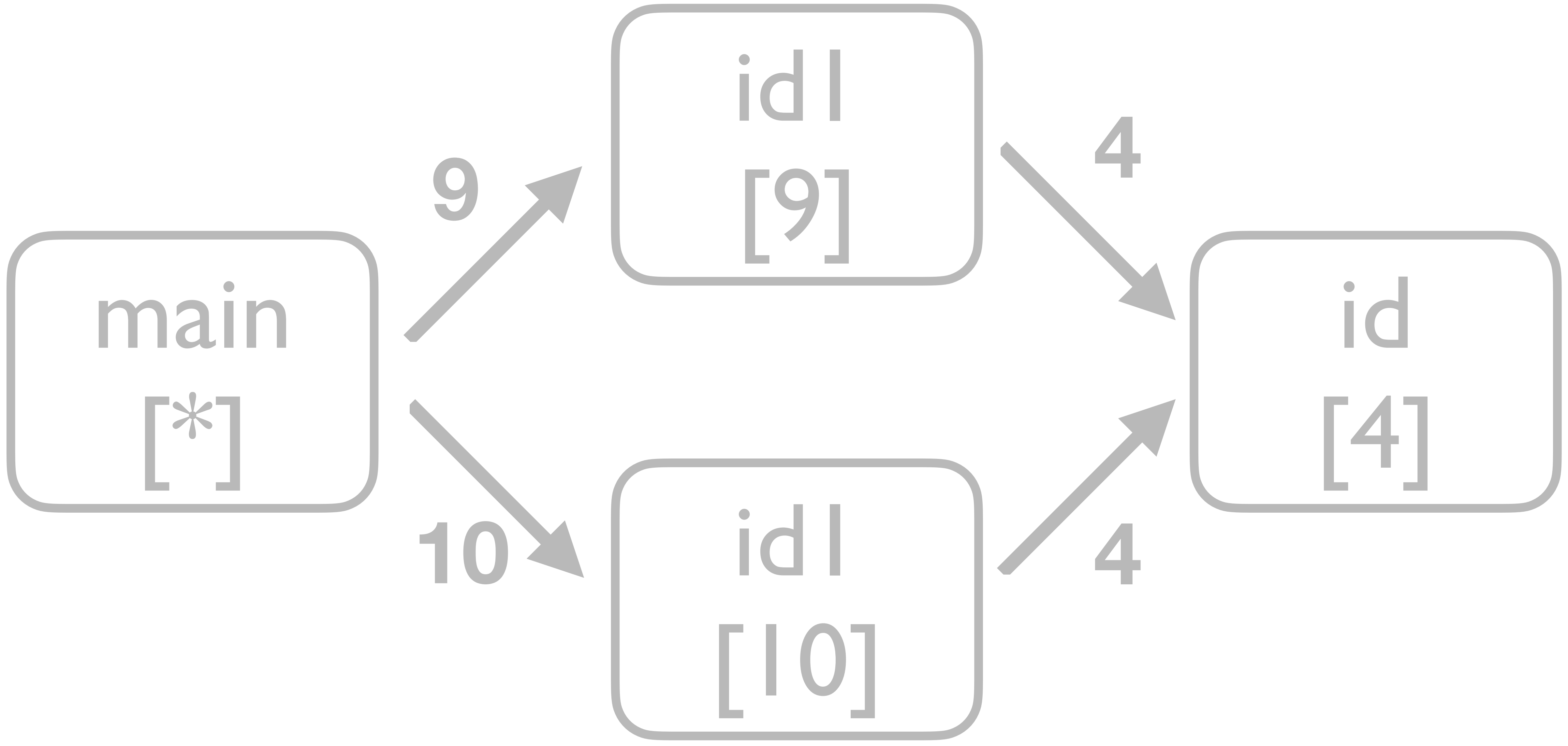
11: }
```



Call-graph of 1-CFA

Call-site Sensitivity vs Object Sensitivity

- An example shows the limitation of CFA and strength of

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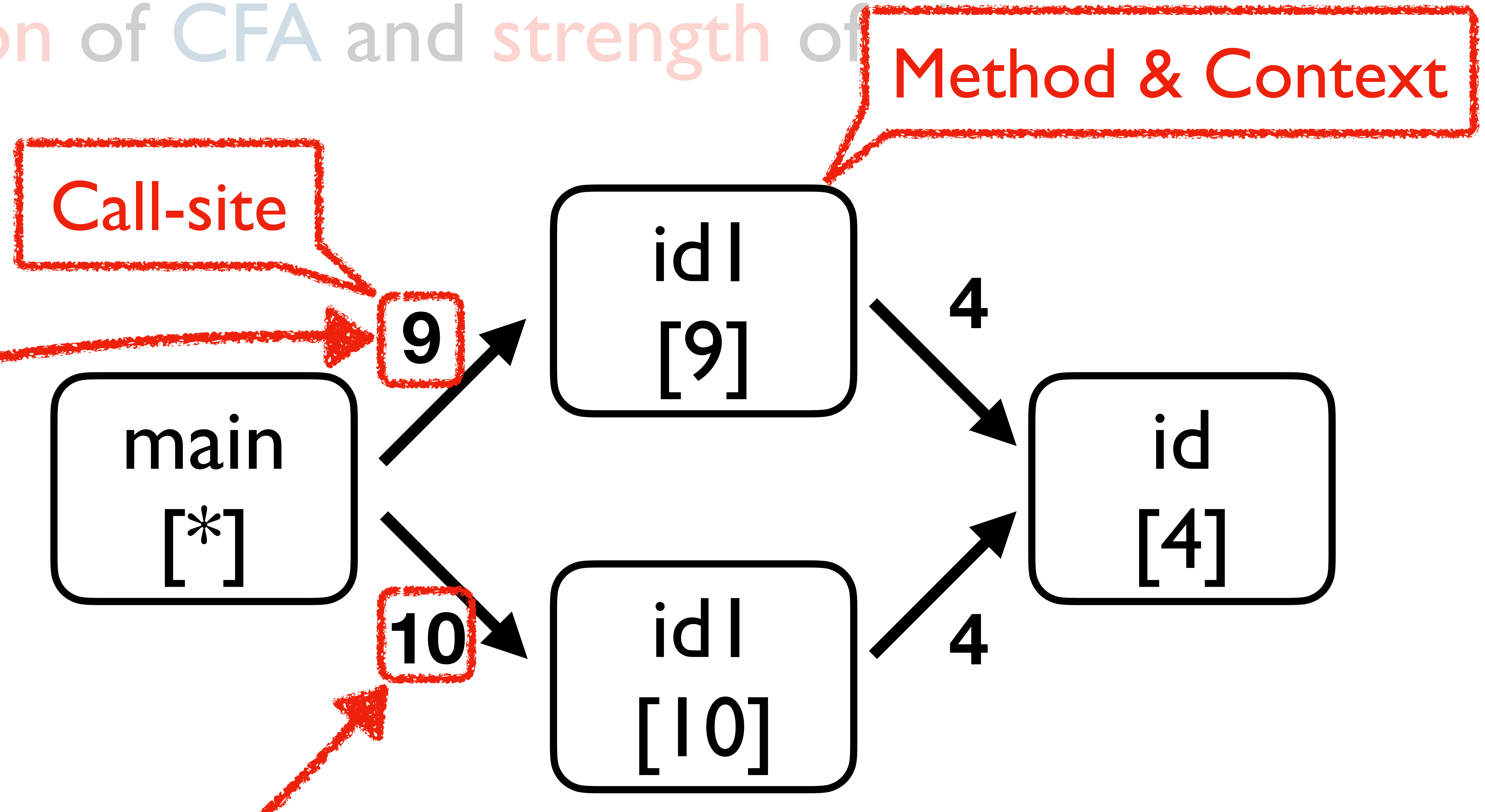

Call-graph of 1-CFA

Call-site Sensitivity vs Object Sensitivity

- An example shows the limitation of CFA and strength of object sensitivity

Limitation of CFA :
Nested method calls

```
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3:    id1(v){
4:      return this.id(v);}
5:  }
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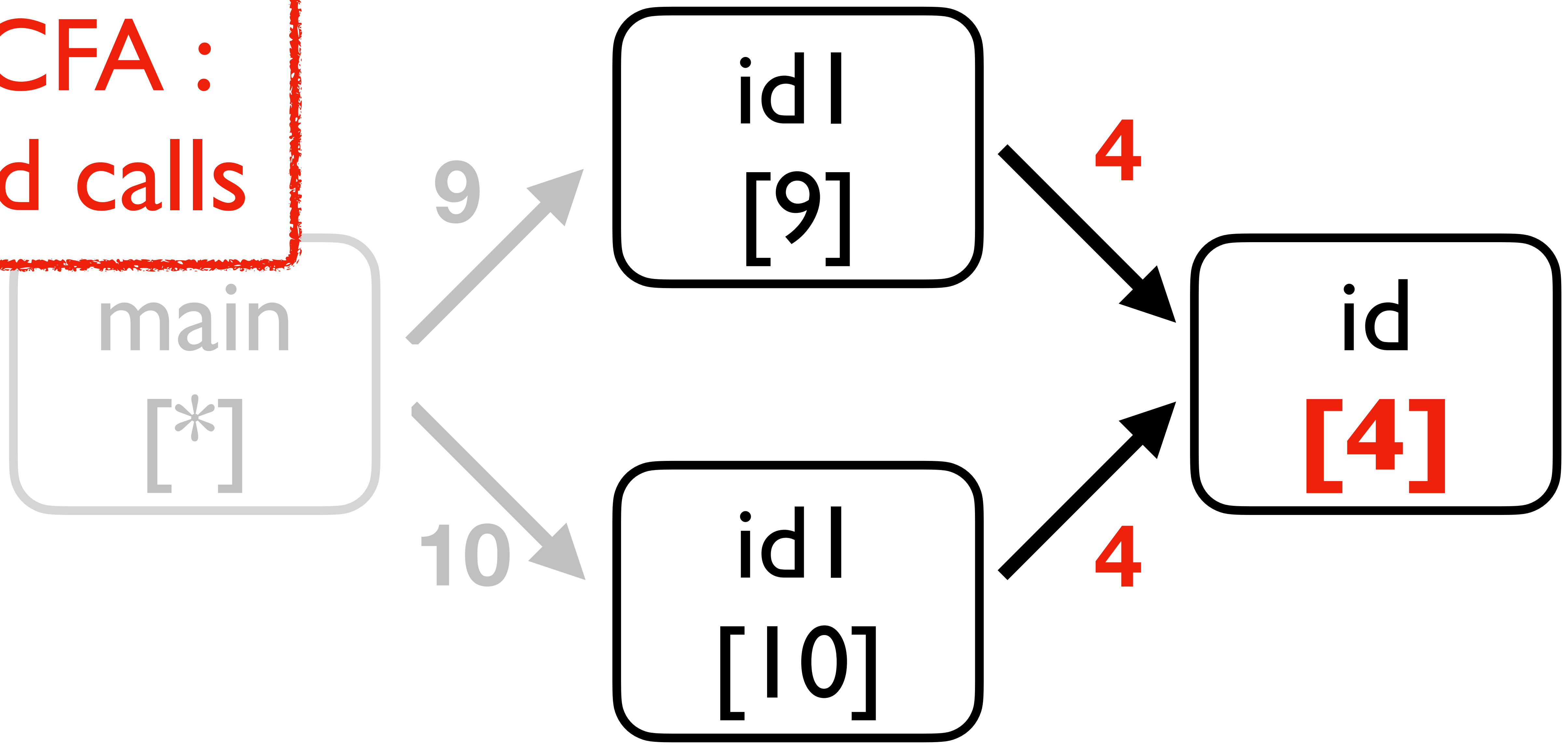

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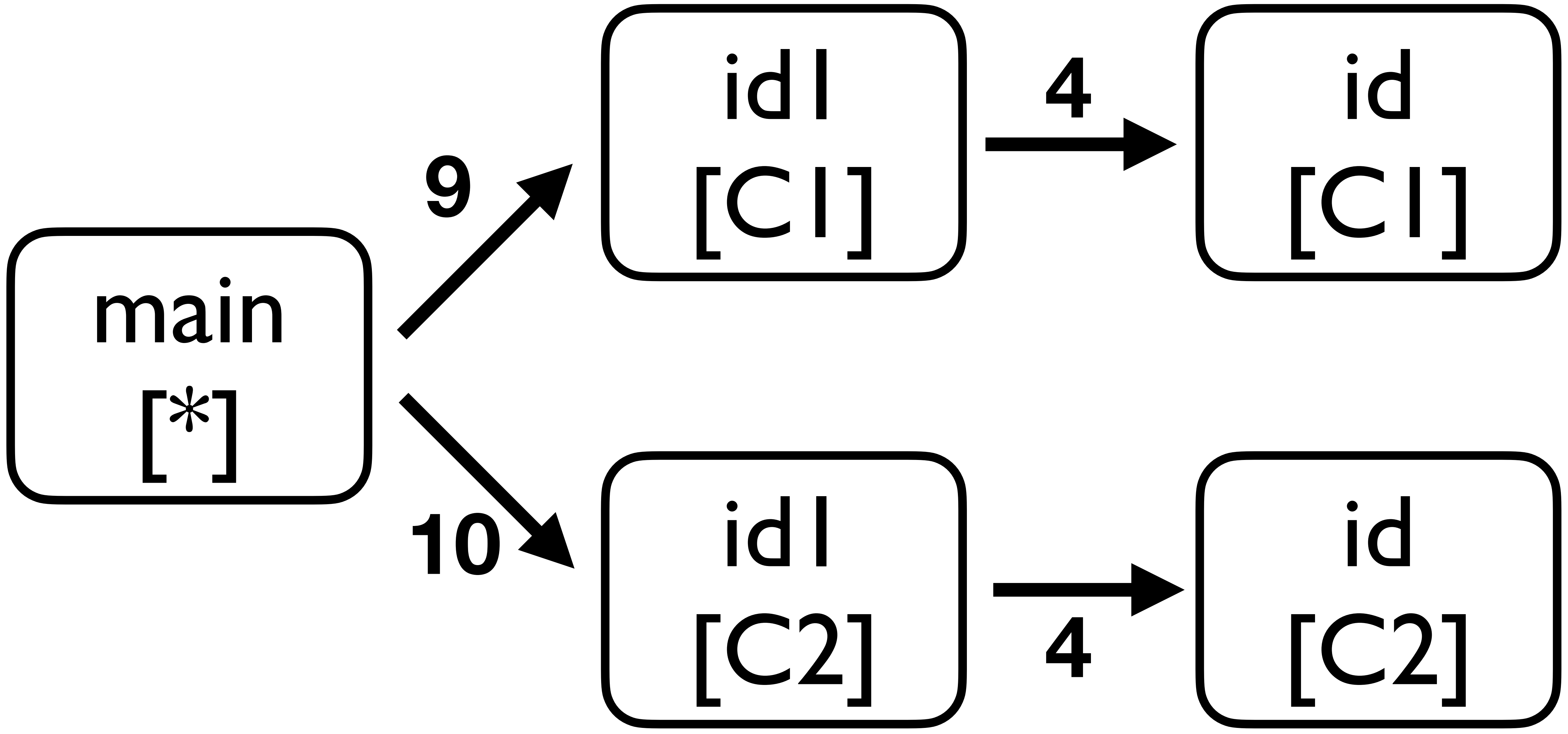

Call-graph of 1-Obj

Call-site Sensitivity vs Object Sensitivity

- An example shows the limitation of CFA and strength of object sensitivity

C1 or C2

```
class C{
  id(v){
    return v;}
  id1(v){
    return this.id(v);}
}
main(){
c1 = new C();//C1
c2 = new C();//C2
a = (A) c1.id1(new A());//query1
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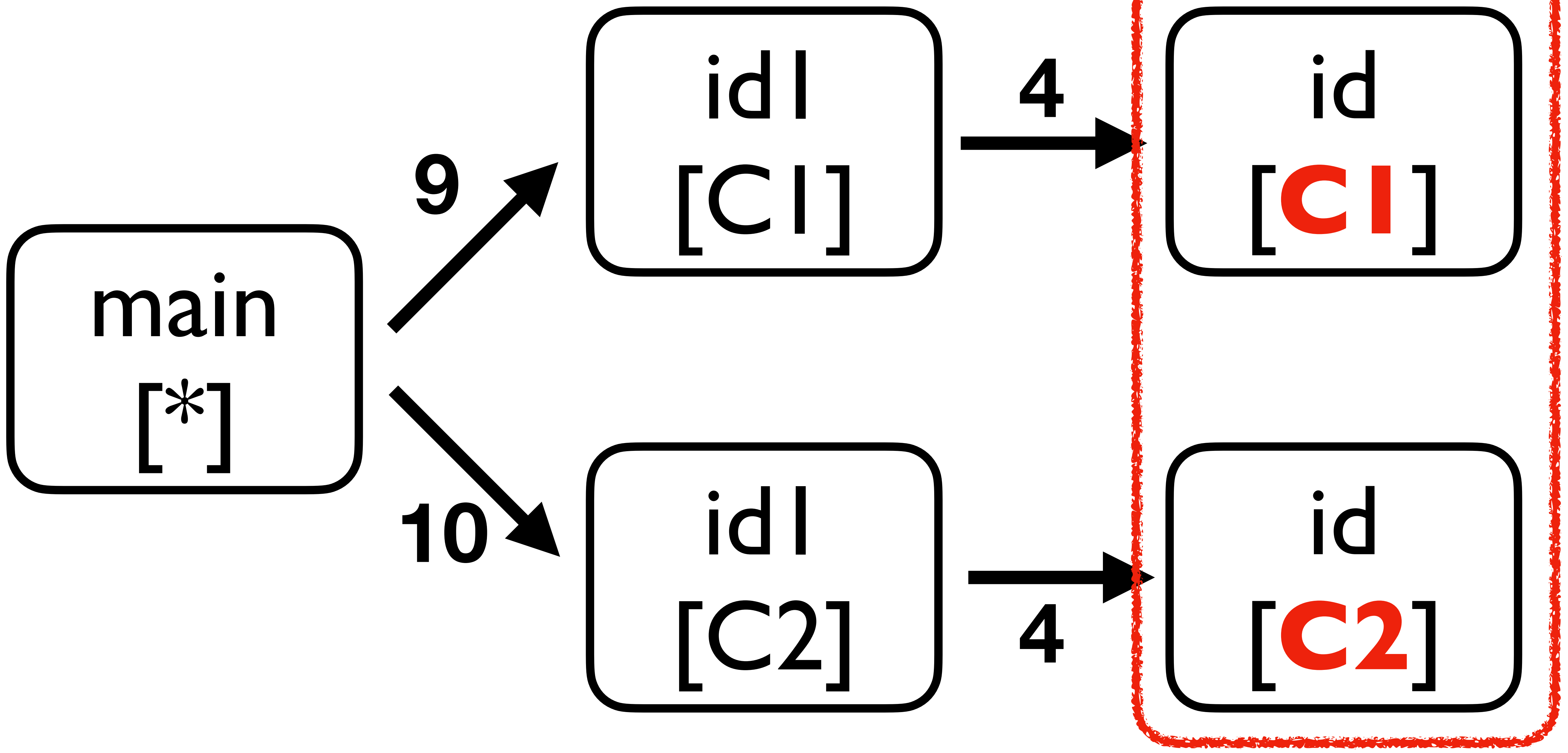
}
```



Call-graph of 1-Obj

Call-site Sensitivity vs Object Sensitivity

- An example shows the limitation of object sensitivity and strength of CFA

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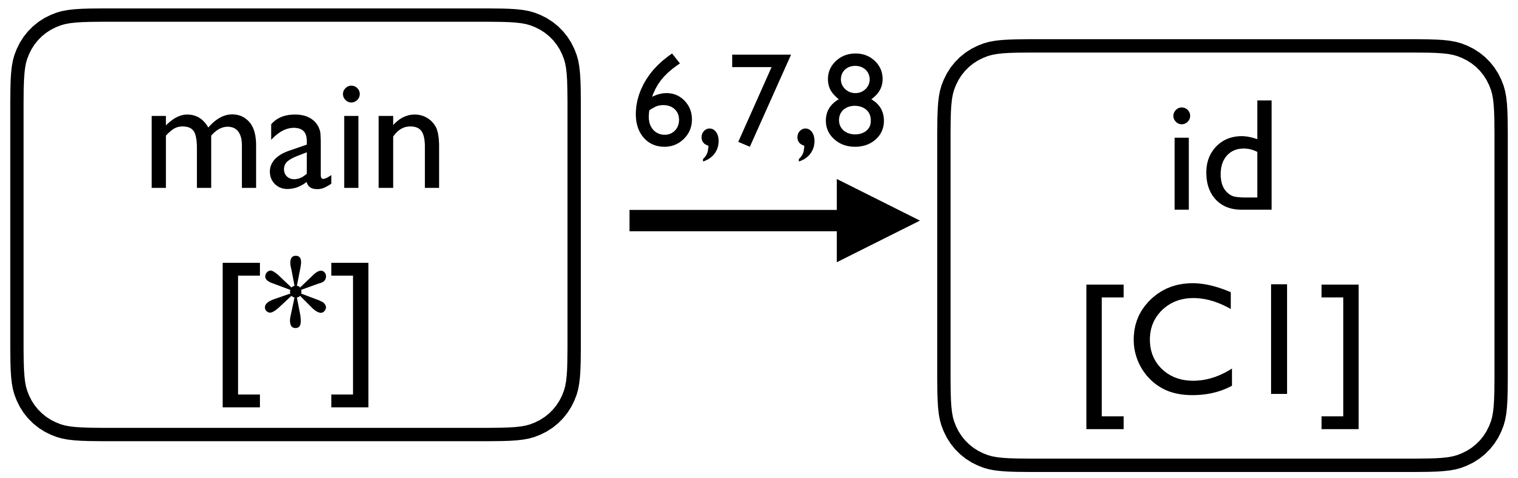

Call-graph of 1-Obj

Call-site Sensitivity vs Object Sensitivity

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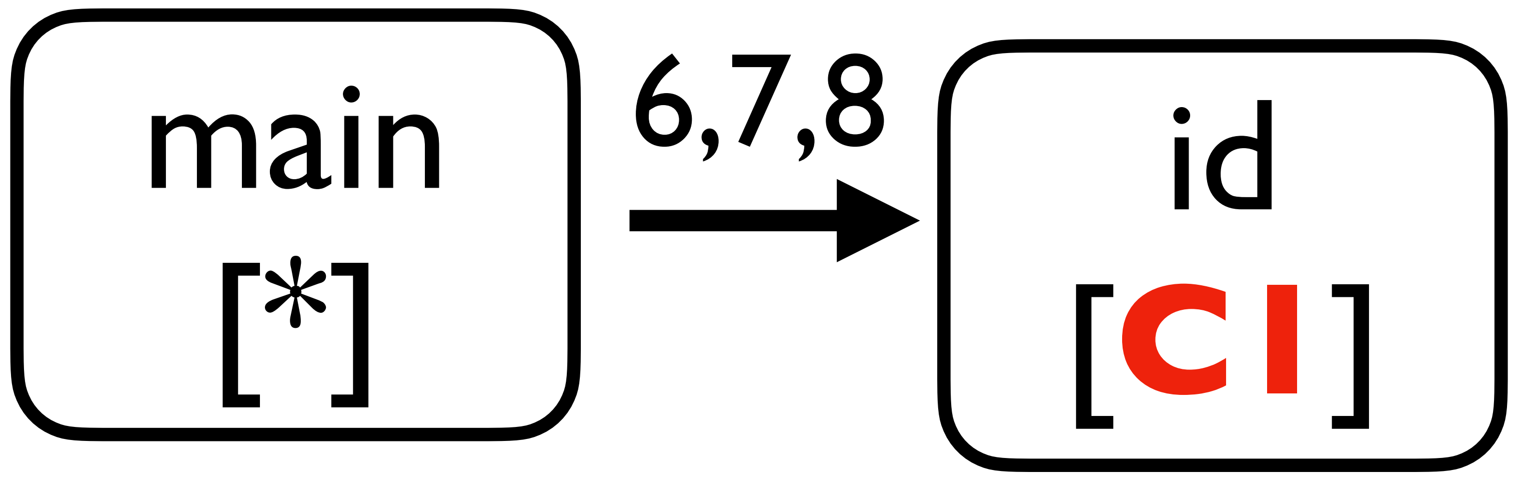

Call-graph of 1-Obj

The three method calls share the same receiver object C1

Call-site Sensitivity vs Object Sensitivity

- An example shows the limitation of object sensitivity and strength of CFA

```
0: class C{
1:   id(v){
2:     return v;}
3: }
4: main(){
5:   c1 = new C();//C1
6:   a = (A) c1.id(new A());//query1
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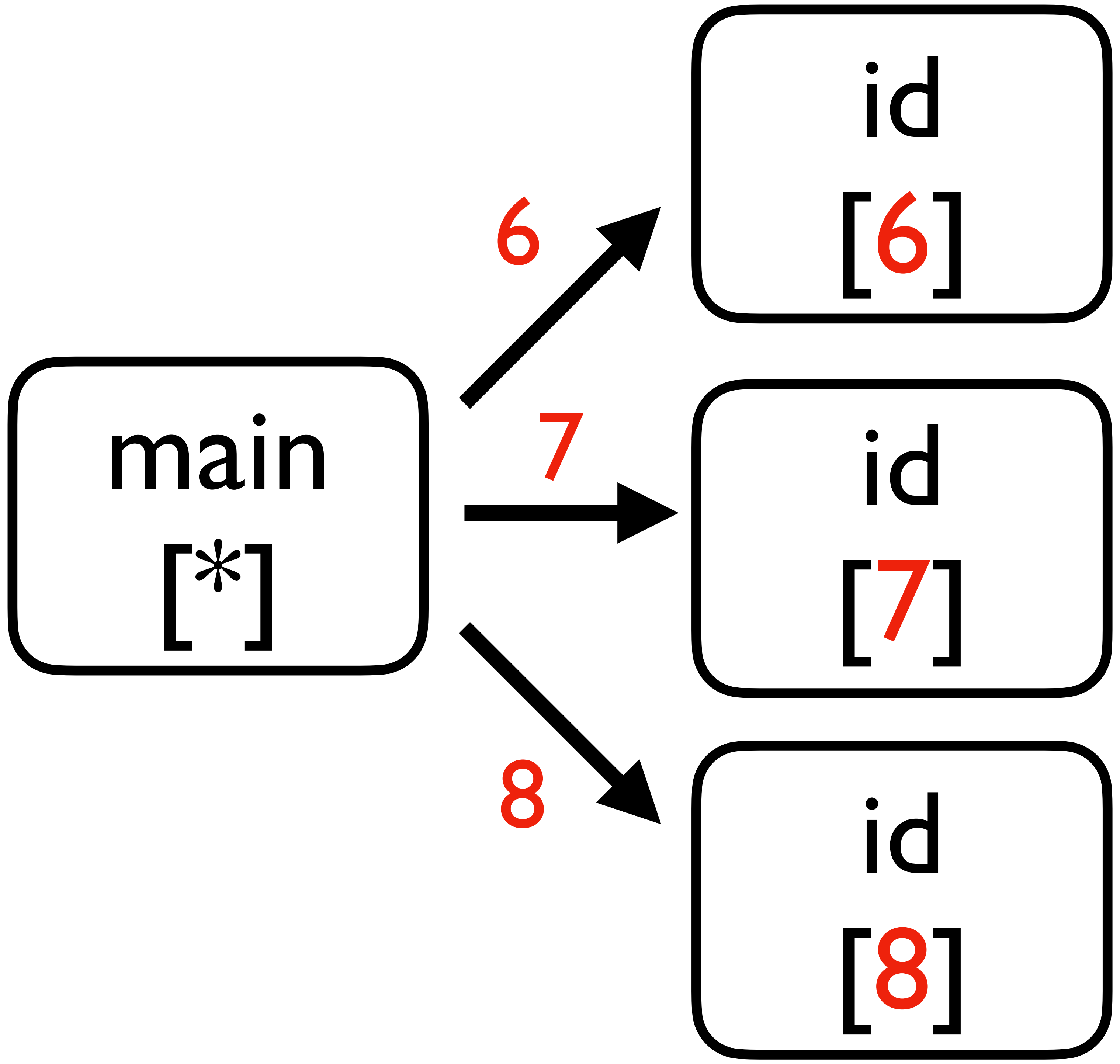


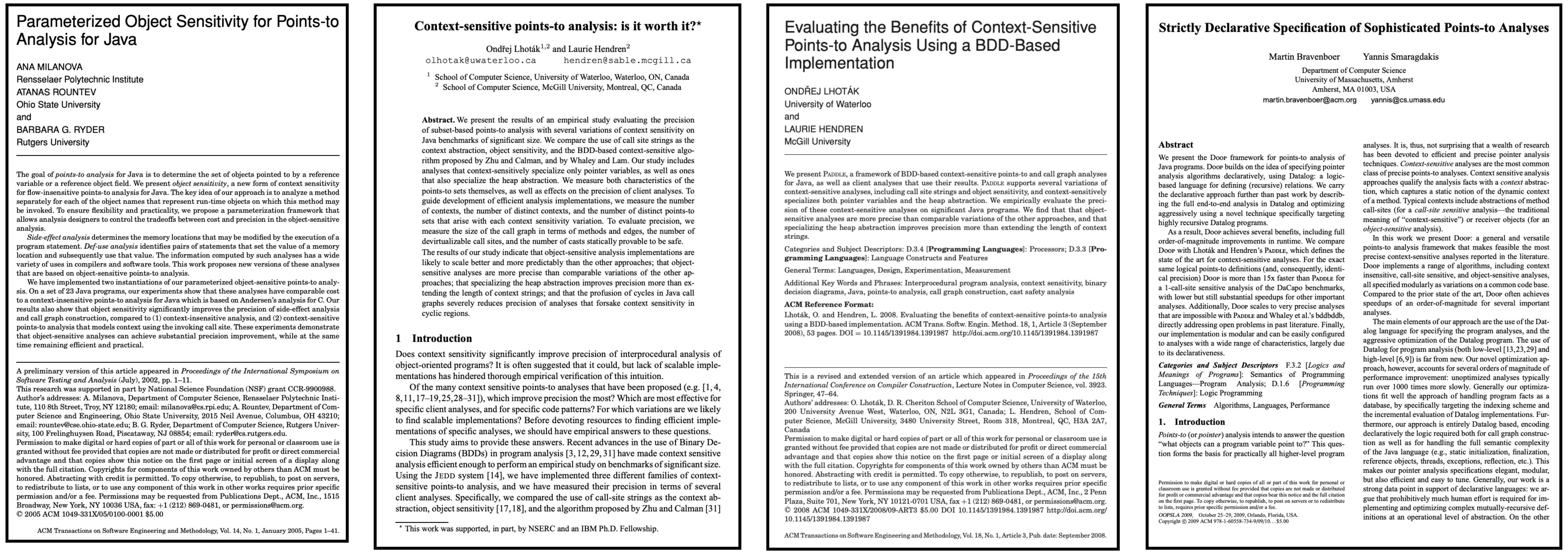
Call-graph of 1-CFA

Call-site sensitivity easily separates the three method calls

Call-site Sensitivity vs Object Sensitivity

- Call-site Sensitivity and Object Sensitivity had been actively compared

Call-site Sensitivity vs Object Sensitivity



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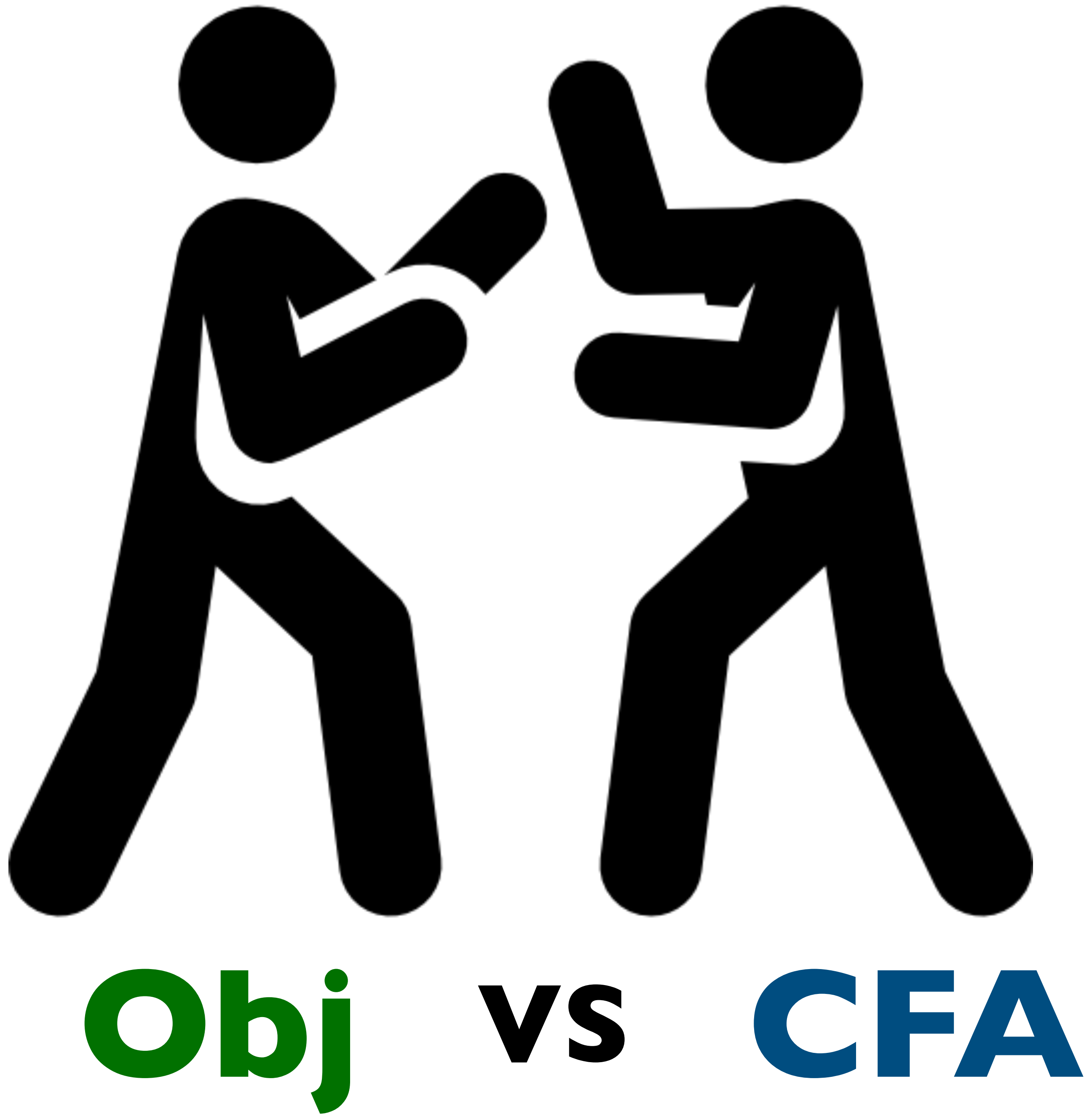


1981 2002 2010 2022

Call-site Sensitivity vs Object Sensitivity

- Object Sensitivity outperformed call-site sensitivity

Call-site Sensitivity vs Object Sensitivity

Parameterized Object Sensitivity for Points-to Analysis for Java — ANA MILANOVA, Rensselaer Polytechnic Institute; ATANAS ROUNTEV, Ohio State University; and BARBARA G. RYDER, Rutgers University

Obj wins

Context-sensitive points-to analysis: is it worth it? — Ondřej Lhoták, Laurie Hendren

Obj wins

Evaluating the Benefits of Context-Sensitive Points-to Analysis Using a BDD-Based Implementation — ONDŘEJ LHOTÁK, University of Waterloo; and LAURIE HENDREN, McGill University

Obj wins

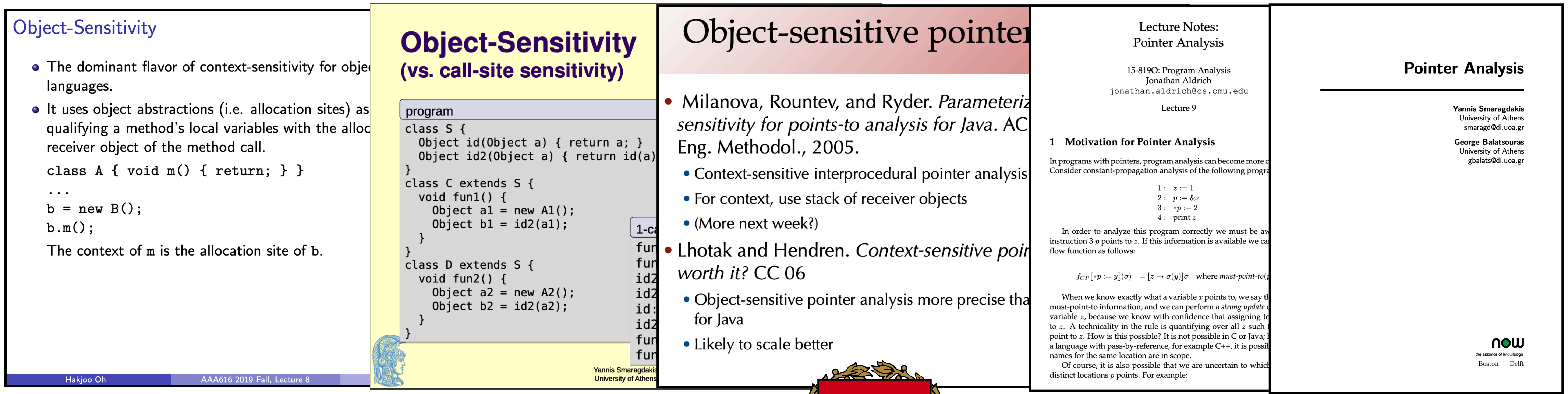
Strictly Declarative Specification of Sophisticated Points-to Analyses — Martin Bravenboer, Yannis Smaragdakis

Obj wins

...

Call-site Sensitivity vs Object Sensitivity

- Lectures have taught the superiority of object sensitivity



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KOREA UNIVERSITY

National and Kapodistrian University of Athens

HARVARD

Carnegie Mellon University

now the essence of knowledge

Obj

1981 — 2002 — 2010 — 2022

Call-site Sensitivity vs Object Sensitivity

- Lectures have taught the superiority of object sensitivity

Object-Sensitivity

- The dominant flavor of context-sensitivity for object-oriented languages.
- It uses object abstractions (i.e. allocation sites) as contexts, qualifying a method's local variables with the allocation site of the receiver object of the method call.

```
class A { void m() { return; } }
...
b = new B();
b.m();
```

The context of m is the allocation site of b.

Hakjoo Oh | AAA616 2019 Fall, Lecture 8 | November 18, 2019 | 27 / 31

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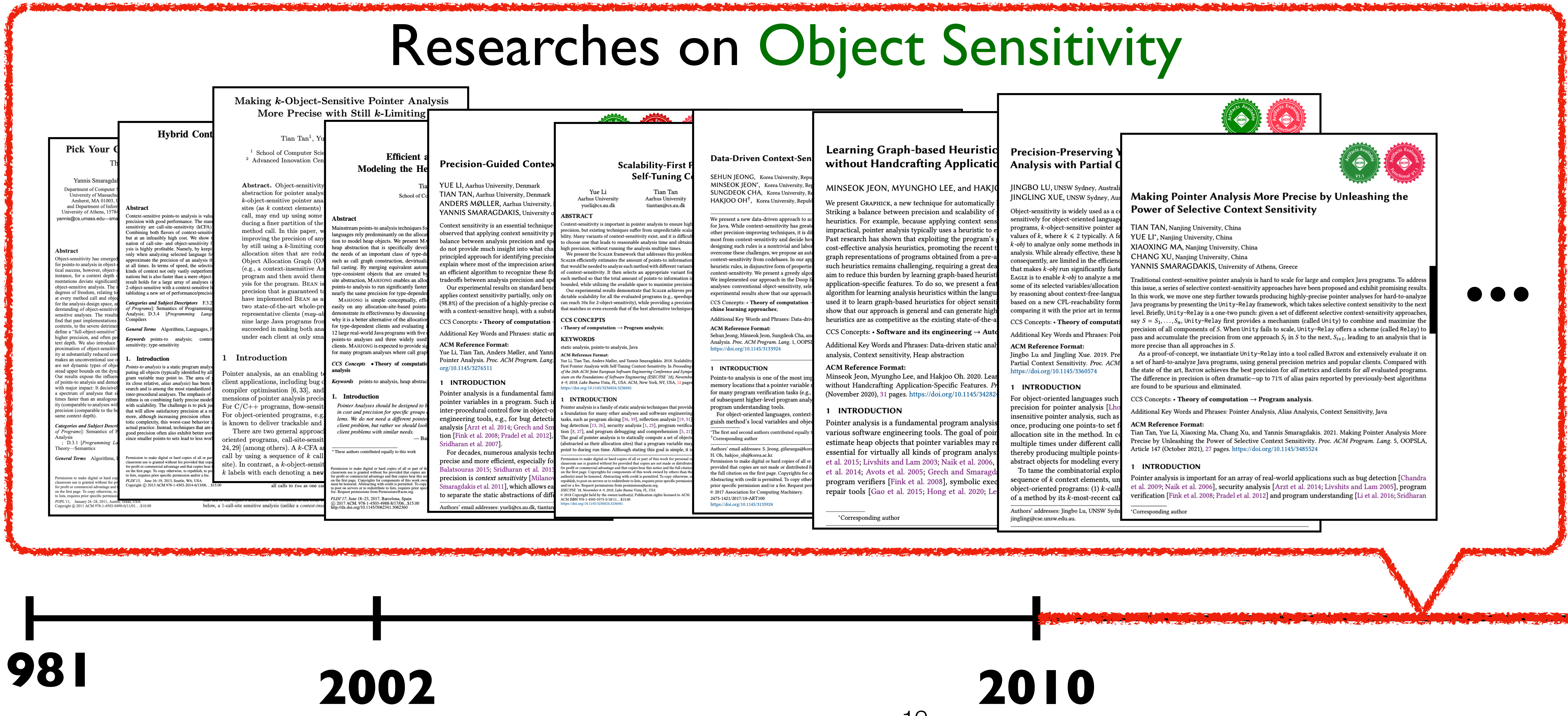
I was also taught like that

Obj

1981 **2002** **2010** **2022**

Call-site Sensitivity vs Object Sensitivity

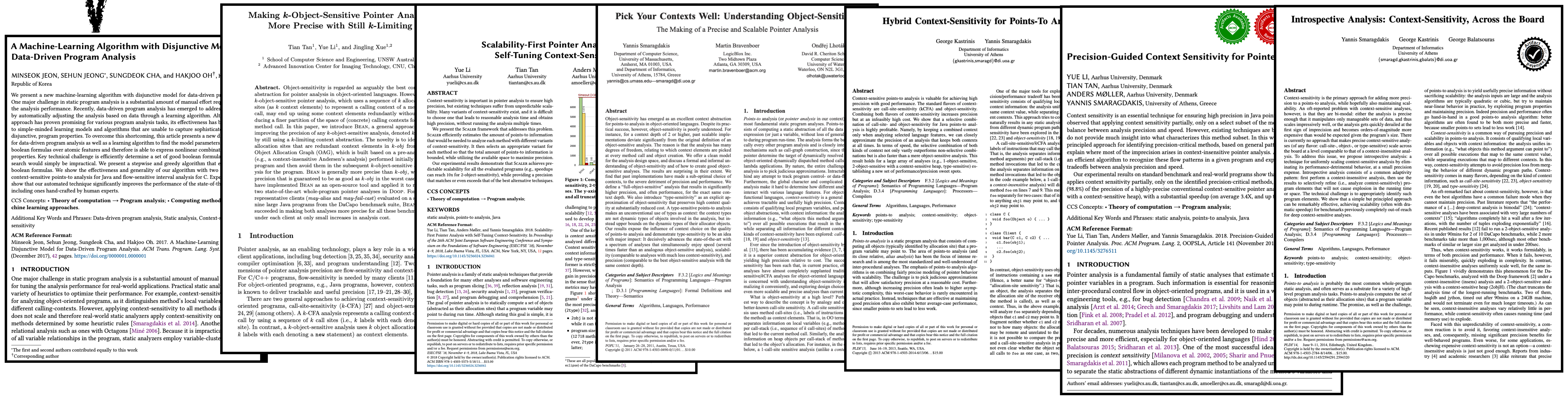
- Researches focused on improving Object Sensitivity



Call-site Sensitivity vs Object Sensitivity

- Call-site Sensitivity has been ignored

> "… call-site-sensitivity is less important than others …"
>
> \- Jeon et al. [2019]



CFA

1981 — 2002 — 2010 — 2022

Call-site Sensitivity vs Object Sensitivity

- Call-site Sensitivity has been ignored

"… call-site-sensitivity is less important than others …"

- Jeon et al. [2019]

I also strongly dismissed call-site sensitivity

CFA

1981 2002 2010 2022

Call-site Sensitivity vs Object Sensitivity

Currently, call-site sensitivity is known as a bad context

1981 **2002** **2010** **2022**

Call-site Sensitivity vs Object Sensitivity

A technique context tunneling is proposed

Precise and Scalable Points-to Analysis via Data-Driven Context Tunneling

MINSEOK JEON, Korea University, Republic of Korea
SEHUN JEONG, Korea University, Republic of Korea
HAKJOO OH*, Korea University, Republic of Korea

We present context tunneling, a new approach for making k-limited context-sensitive points-to analysis precise and scalable. As context-sensitivity holds the key to the development of precise and scalable points-to analysis, a variety of techniques for context-sensitivity have been proposed. However, existing approaches such as k-call-site-sensitivity or k-object-sensitivity have a significant weakness that they unconditionally update the context of a method at every call-site, allowing important context elements to be overwritten by more recent, but not necessarily more important, context elements. In this paper, we show that this is a key limiting factor of existing context-sensitive analyses, and demonstrate that remarkable increase in both precision and scalability can be gained by maintaining important context elements only. Our approach, called context tunneling, updates contexts selectively and decides when to propagate the same context without modification.

We attain context tunneling via a data-driven approach. The effectiveness of context tunneling is very sensitive to the choice of important context elements. Even worse, precision is not monotonically increasing with respect to the ordering of the choices. As a result, manually coming up with a good heuristic rule for context tunneling is extremely challenging and likely fails to maximize its potential. We address this challenge by developing a specialized data-driven algorithm, which is able to automatically search for high-quality heuristics over the non-monotonic space of context tunneling.

We implemented our approach in the Doop framework and applied it to four major flavors of context-sensitivity: call-site-sensitivity, object-sensitivity, type-sensitivity, and hybrid context-sensitivity. In all cases, 1-context-sensitive analysis with context tunneling far outperformed deeper context-sensitivity with $k = 2$ in both precision and scalability.

CCS Concepts: • **Theory of computation → Program analysis**; • **Computing methodologies → Machine learning approaches**;

Additional Key Words and Phrases: Points-to analysis, Context-sensitive analysis, Data-driven program analysis

ACM Reference Format:
Minseok Jeon, Sehun Jeong, and Hakjoo Oh. 2018. Precise and Scalable Points-to Analysis via Data-Driven Context Tunneling. *Proc. ACM Program. Lang.* 2, OOPSLA, Article 140 (November 2018), 30 pages. https://doi.org/10.1145/3276510

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2475-1421/2018/11-ART140
https://doi.org/10.1145/3276510

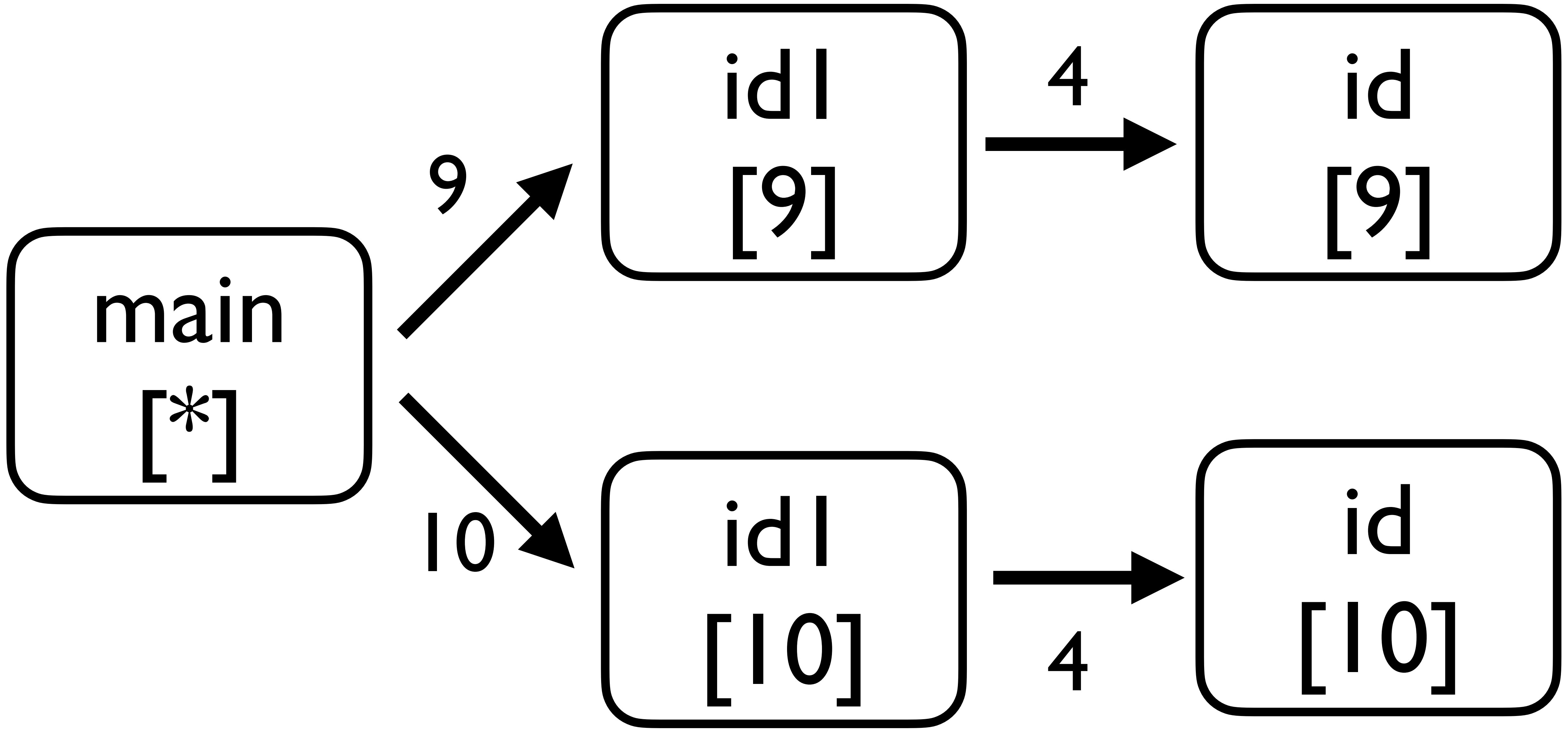
Jeon et al. [2018]

Context tunneling can improve both call-site sensitivity and object sensitivity

Call-site Sensitivity vs Object Sensitivity

- Context tunneling can remove the limitation of call-site sensitivity

```
0:  class C{
1:    id(v){
2:      return v;}
3:    id1(v){
4:      return id0(v);}
5:  }
6:  main(){
7:  c1 = new C();//C1
8:  c2 = new C();//C2
9:  a = (A) c1.id1(new A());//query1
10: b = (B) c2.id1(new B());//query2
11: }
```



1-CFA with context tunneling
(T= {4})

Call-site Sensitivity vs Object Sensitivity

- Context tunneling can remove the limitation of call-site sensitivity

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0: class C{
1:   id(v){
2:     return v;}
3:   id1(v){
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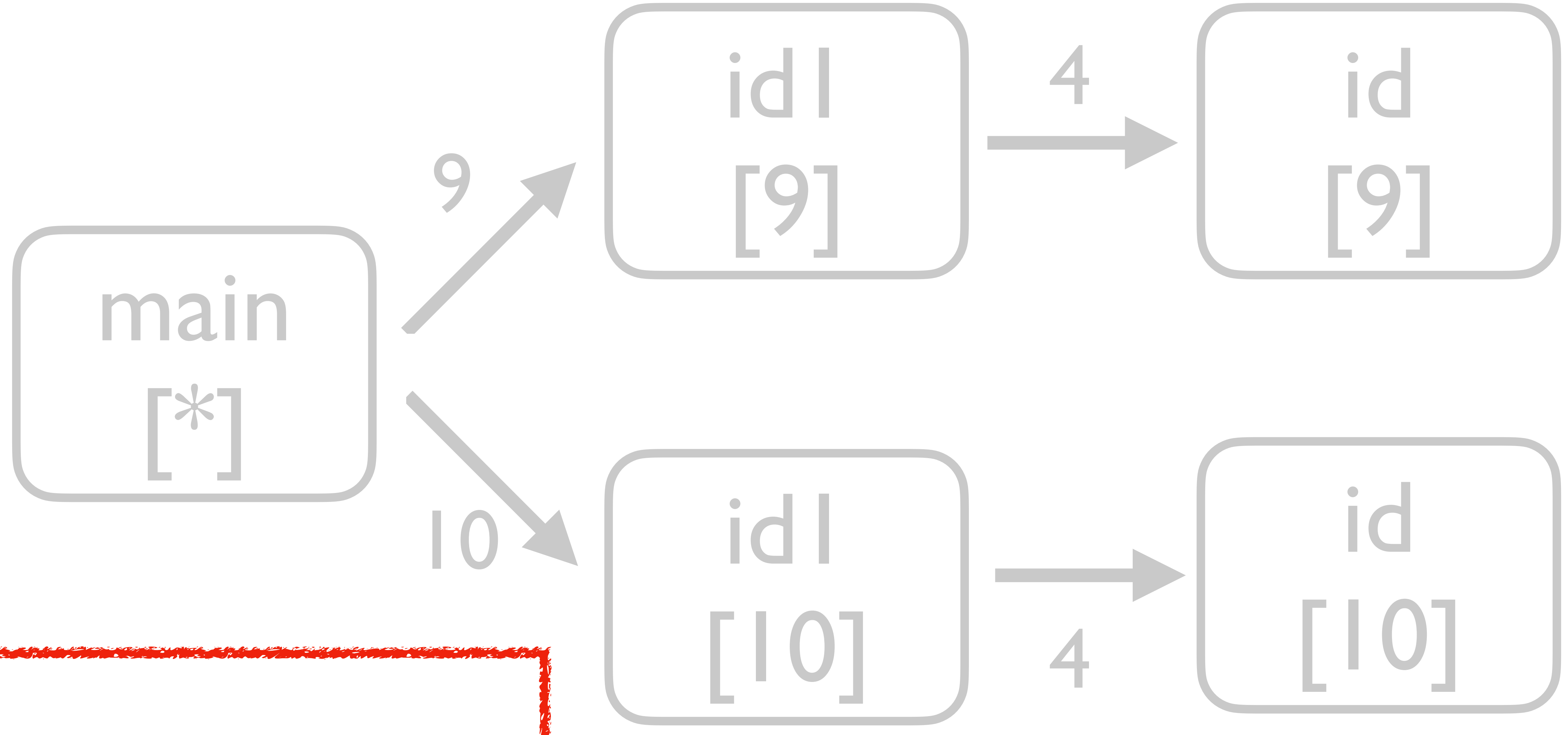
5: }
6: main(){
7:   c1 = new C();//C1
```



th context tunneling
(T= {4})

Tunneling abstraction:
Determines where to apply context tunneling

Call-site Sensitivity vs Object Sensitivity

- Context tunneling can remove the limitation of call-site sensitivity

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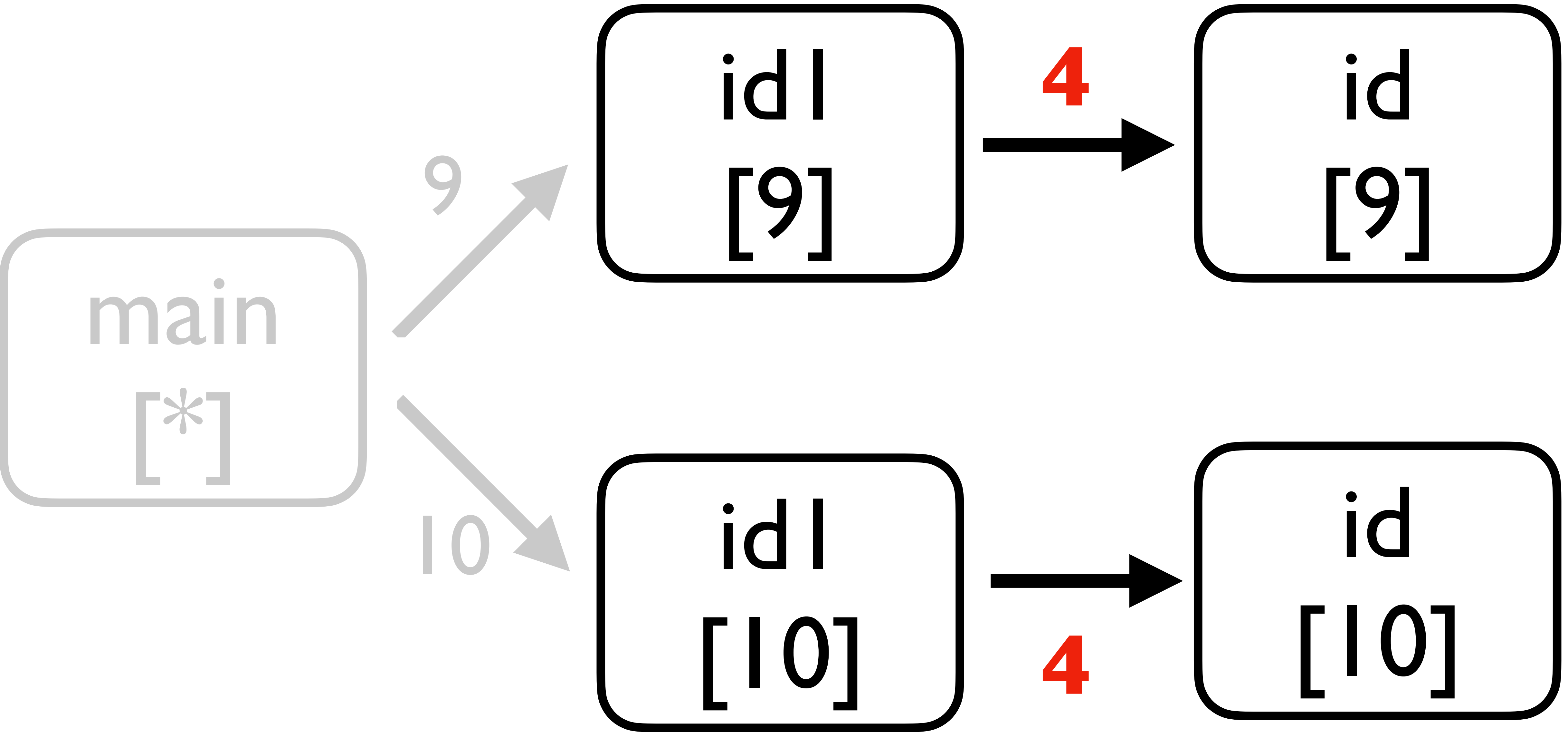

1-CFA with context tunneling
(T= {4})

Unimportant call-sites that should not be used as context elements

Call-site Sensitivity vs Object Sensitivity

- Context tunneling can remove the limitation of call-site sensitivity

```
0:  class C{
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2:      return v;}
3:    id1(v){
4:      return id0(v);}
5:  }
6:  ma
7:  c1
8:  c2        new C();//c2
9:  a = (A) c1.id1(new A());//query1
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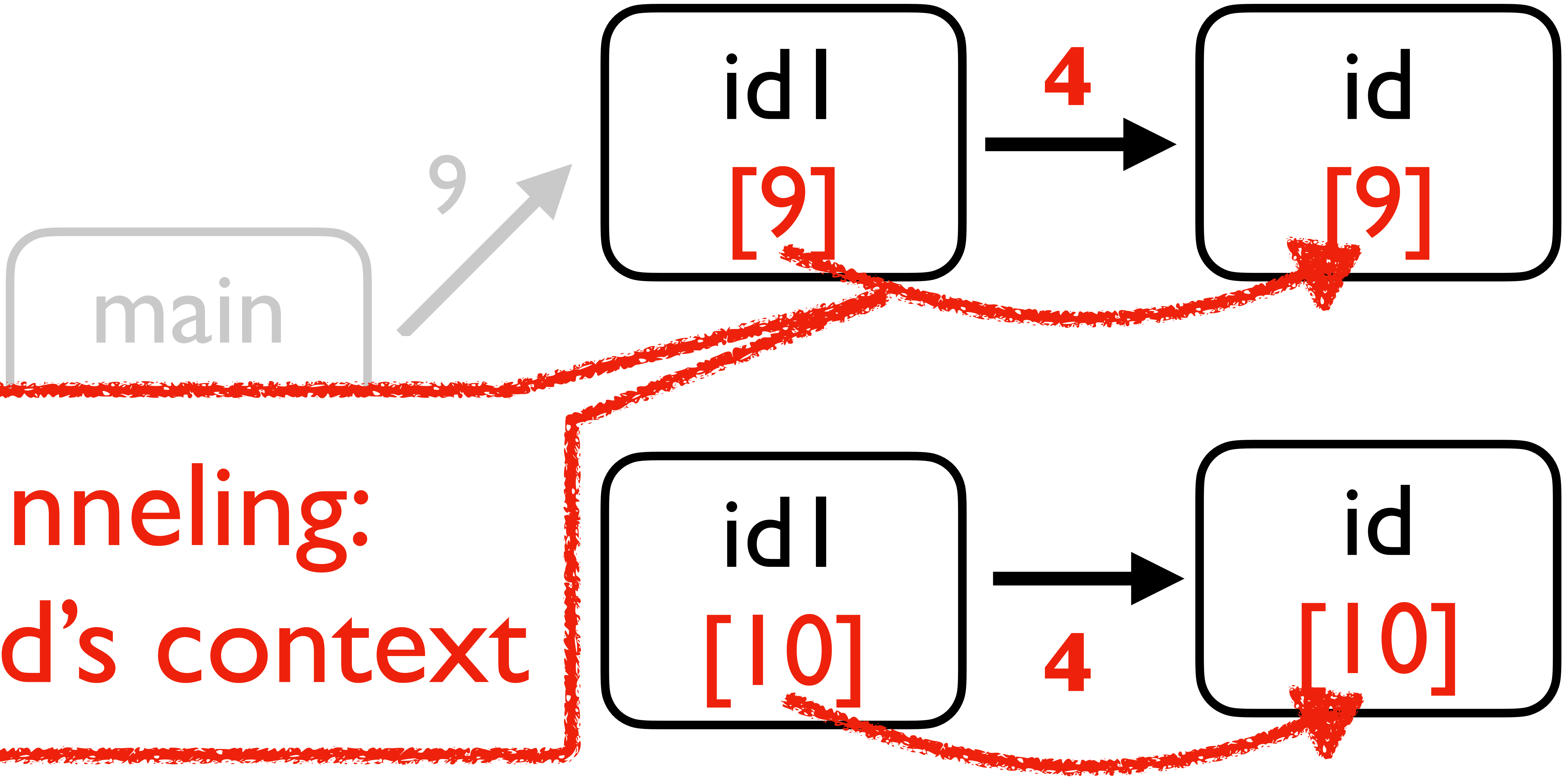
11: }
```

Apply context tunneling:
Inherit caller method's context



1-CFA with context tunneling
(T= {4})

Call-site Sensitivity vs Object Sensitivity

- Context tunneling can remove the limitation of call-site sensitivity

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main(){
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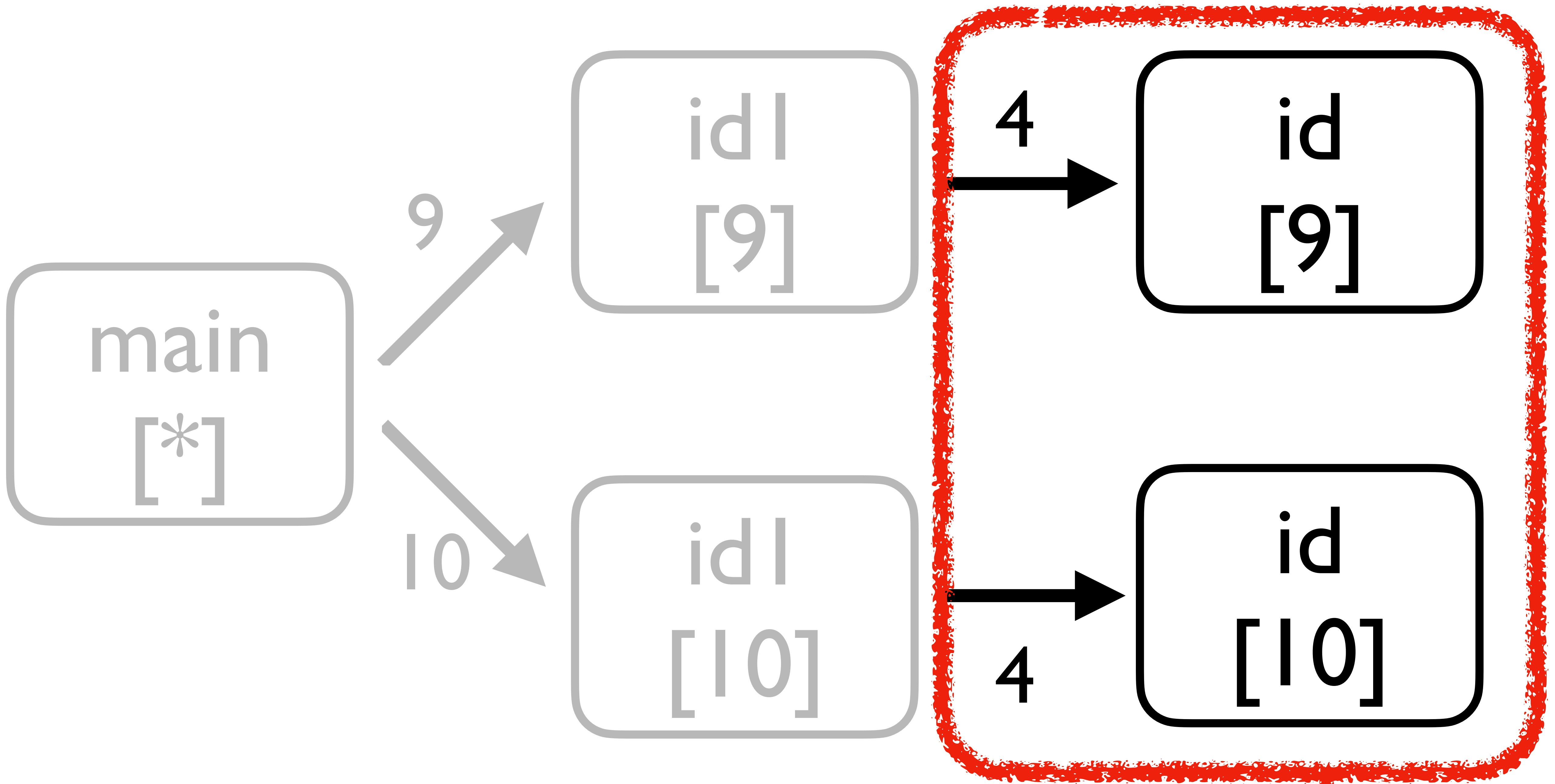

1-CFA with context tunneling
(T= {4})

With tunneling, 1-CFA separates the nested method calls

Call-site Sensitivity vs Object Sensitivity

- Object sensitivity still suffers from its limitation

```
0:  class C{
1:    id(v){
2:      return v;}
3:  }
4:  main(){
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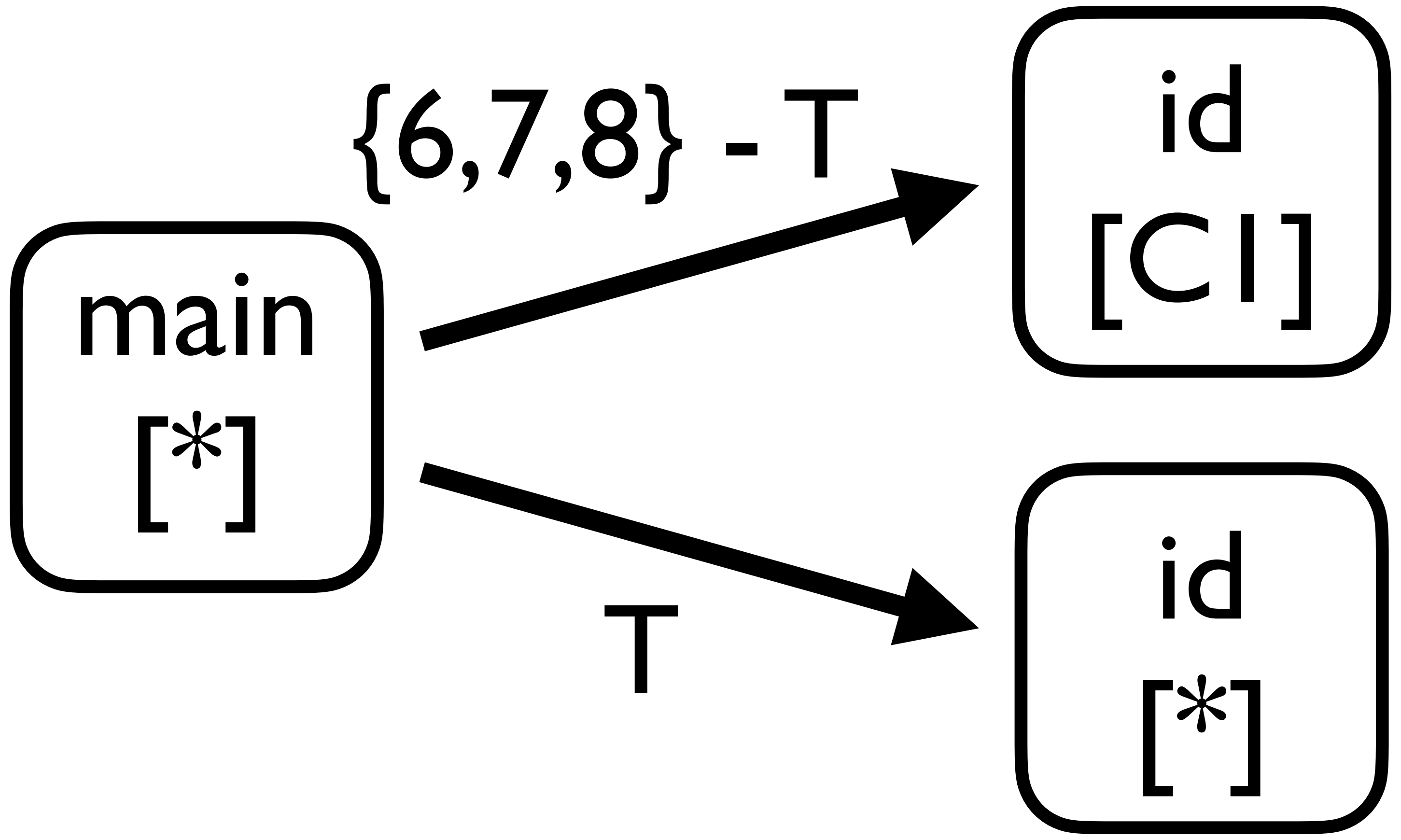

1-Obj + Tunneling
(T = ?)

Call-graph of 1-Obj with tunneling T

Call-site Sensitivity vs Object Sensitivity

- Object sensitivity still suffers from its limitation

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5:    c1 = new C();//C1
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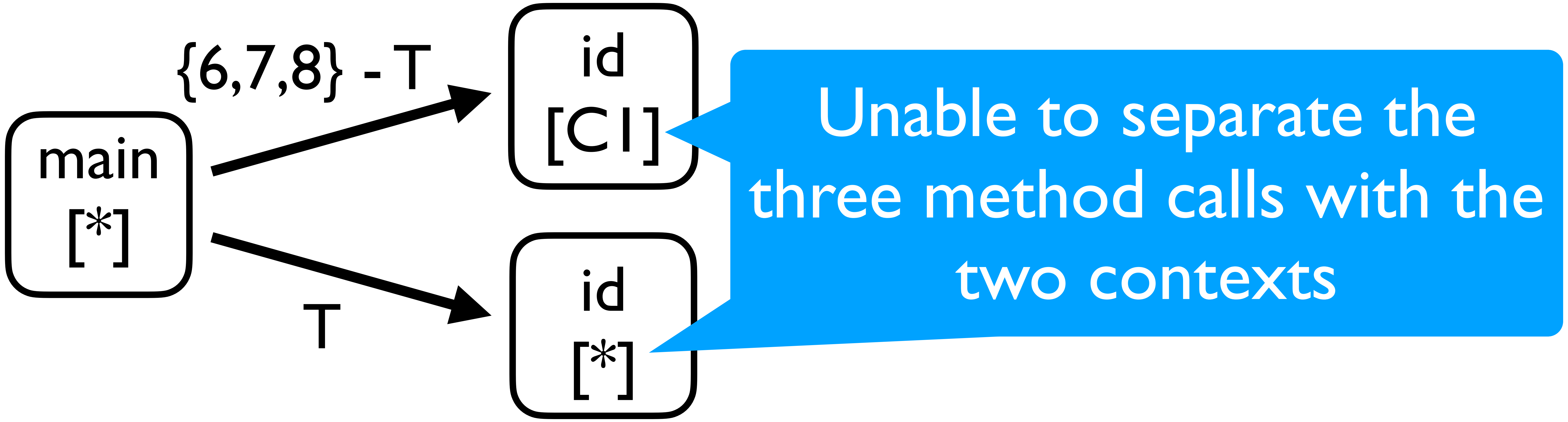

1-Obj + Tunneling
(T = ?)

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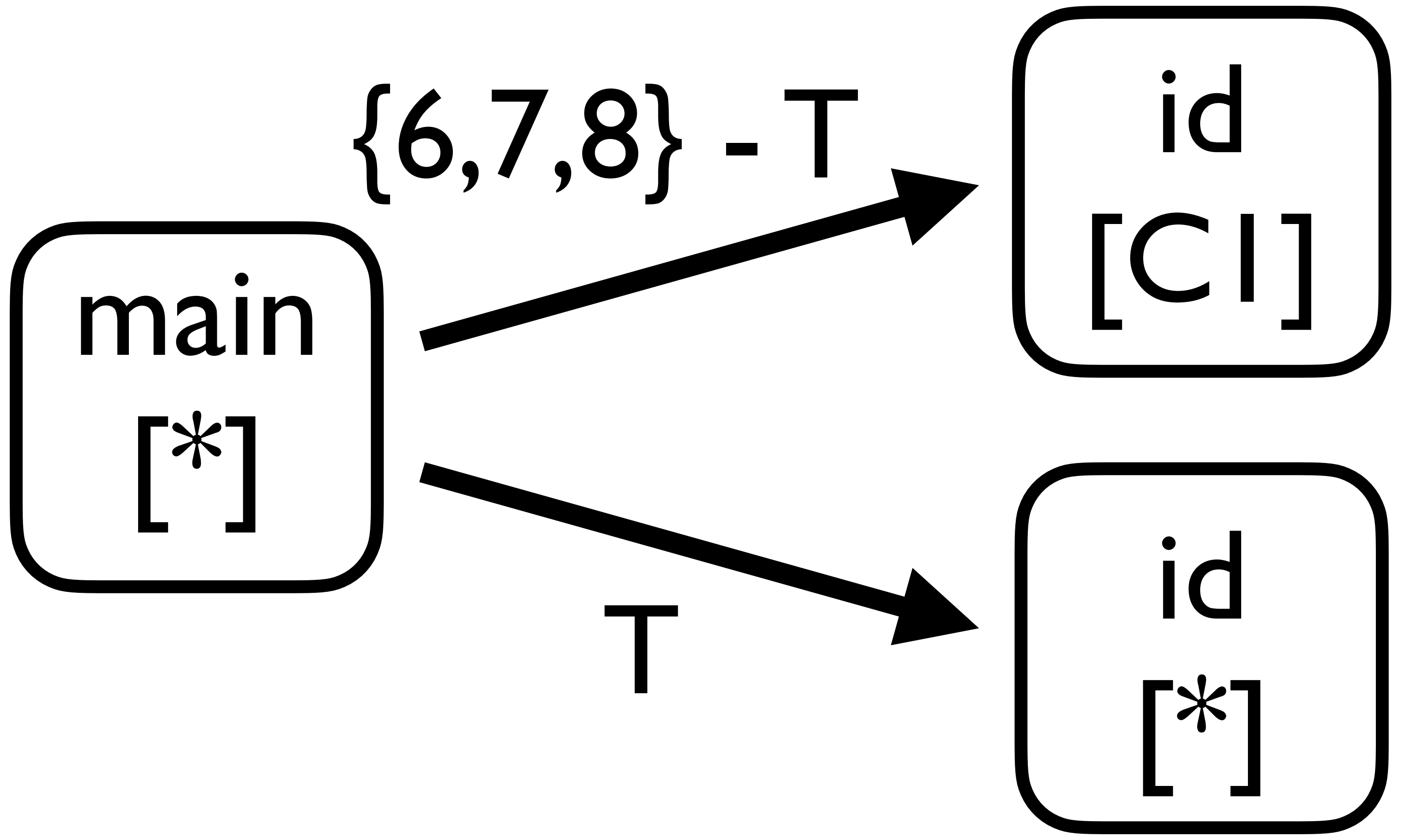

1-Obj + Tunneling
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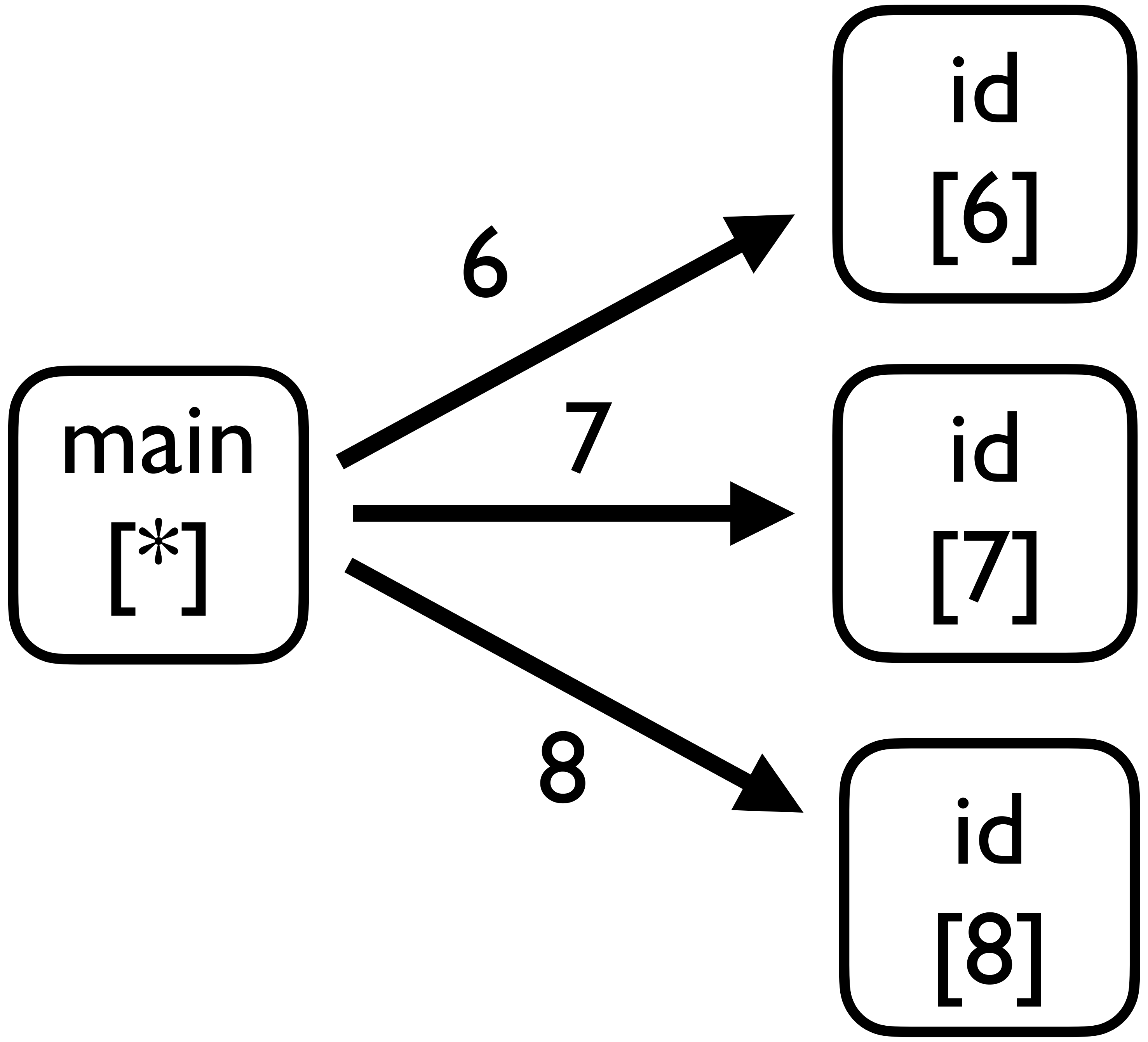


1-CFA

Call-site sensitivity easily separates the three method calls

Call-site Sensitivity vs Object Sensitivity

- Object sensitivity still suffers from its limitation

```
0: c
1:
2:
3: }
4: m
5:
6:   a
7:   b = (B) c1.id(new B());
8:   c = (B) c1.id(new C());
9: }
```

Observation

When context tunneling is included

- Limitation of call-site sensitivity is **removed**
- Limitation of object sensitivity is **not removed**

Call-site Sensitivity vs Object Sensitivity

- Object sensitivity still suffers from its limitation

Observation

When context tunneling is included

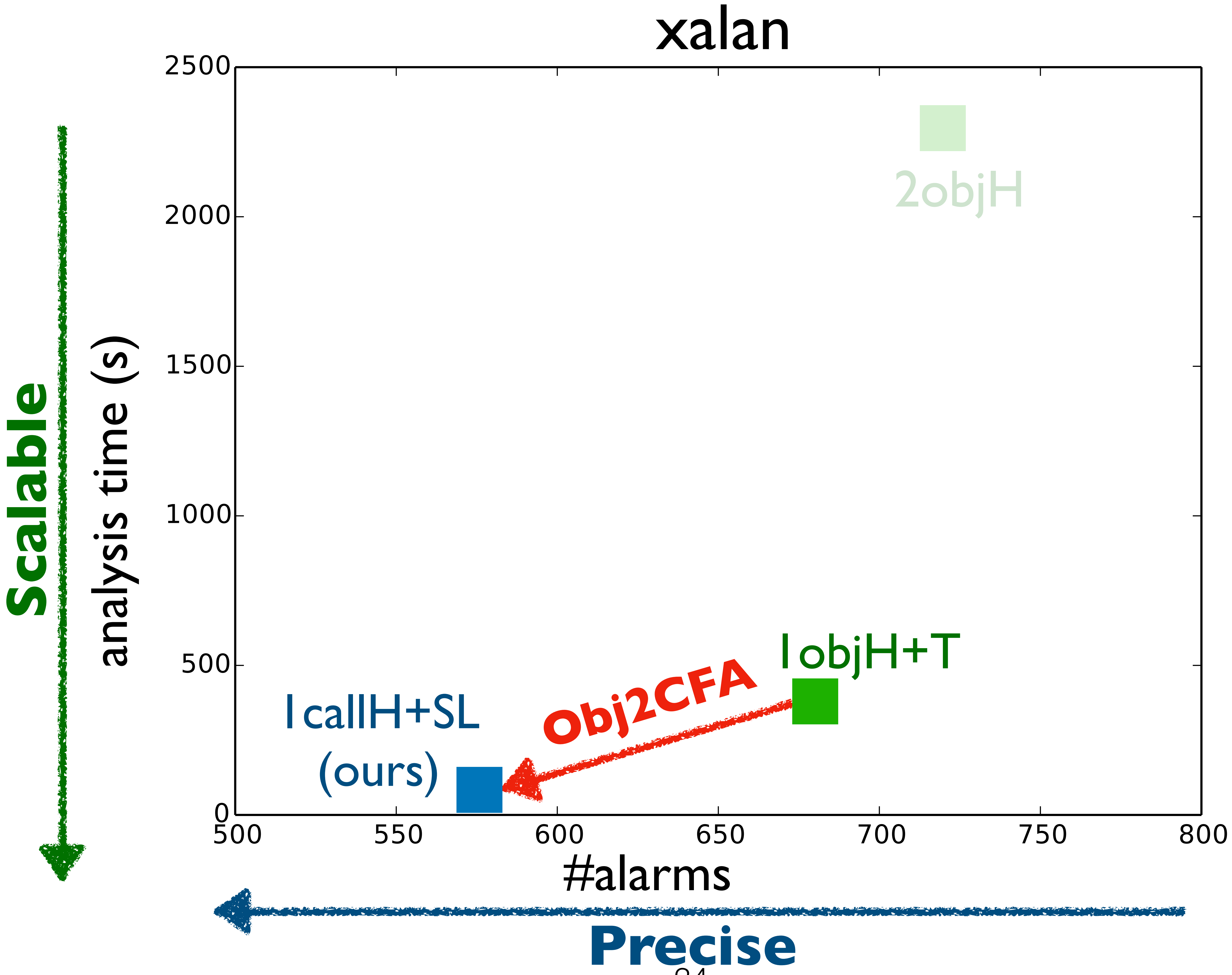
- Limitation of call-site sensitivity is **removed**
- Limitation of object sensitivity is **not removed**

Our claim

If context tunneling is included,
call-site sensitivity is more precise than object sensitivity

Our Technique : **Obj2CFA**

- **Obj2CFA** transforms a given object sensitivity into a more precise CFA



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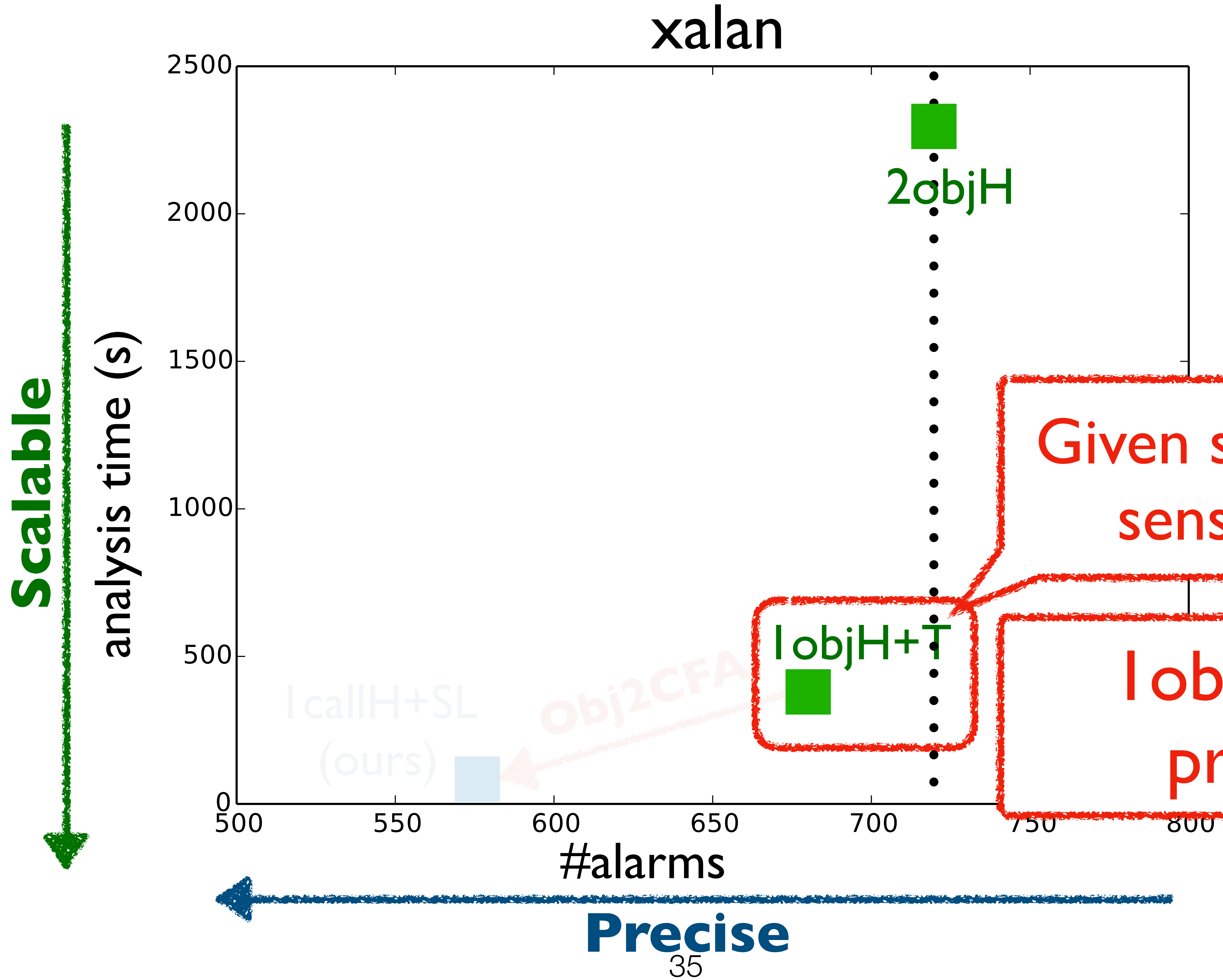
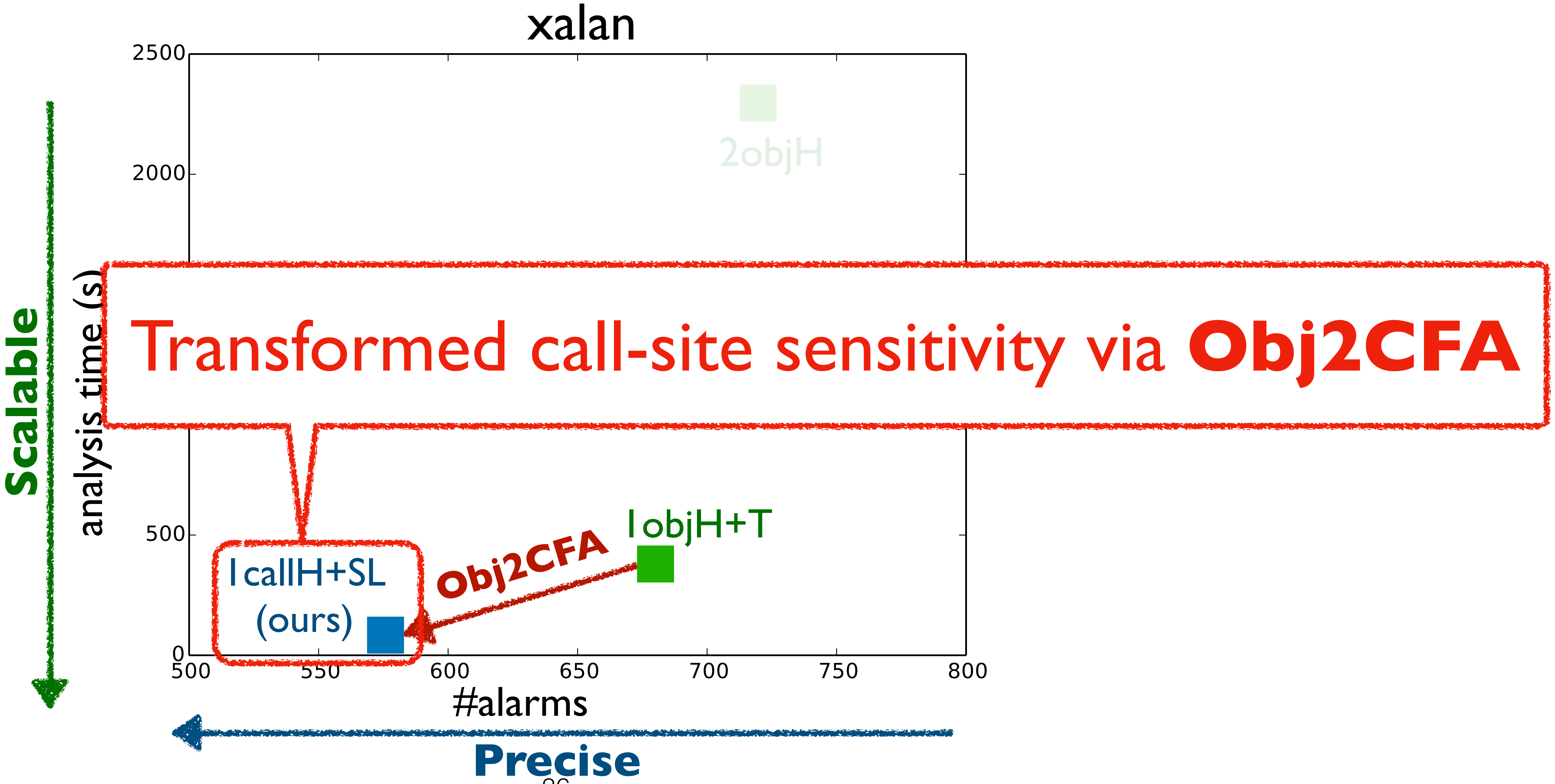


Given state-of-the art 1-object sensitivity with tunneling

1objH+T is even more precise than 2objH

Our Technique : **Obj2CFA**

- **Obj2CFA** transforms a given object sensitivity into a more precise CFA



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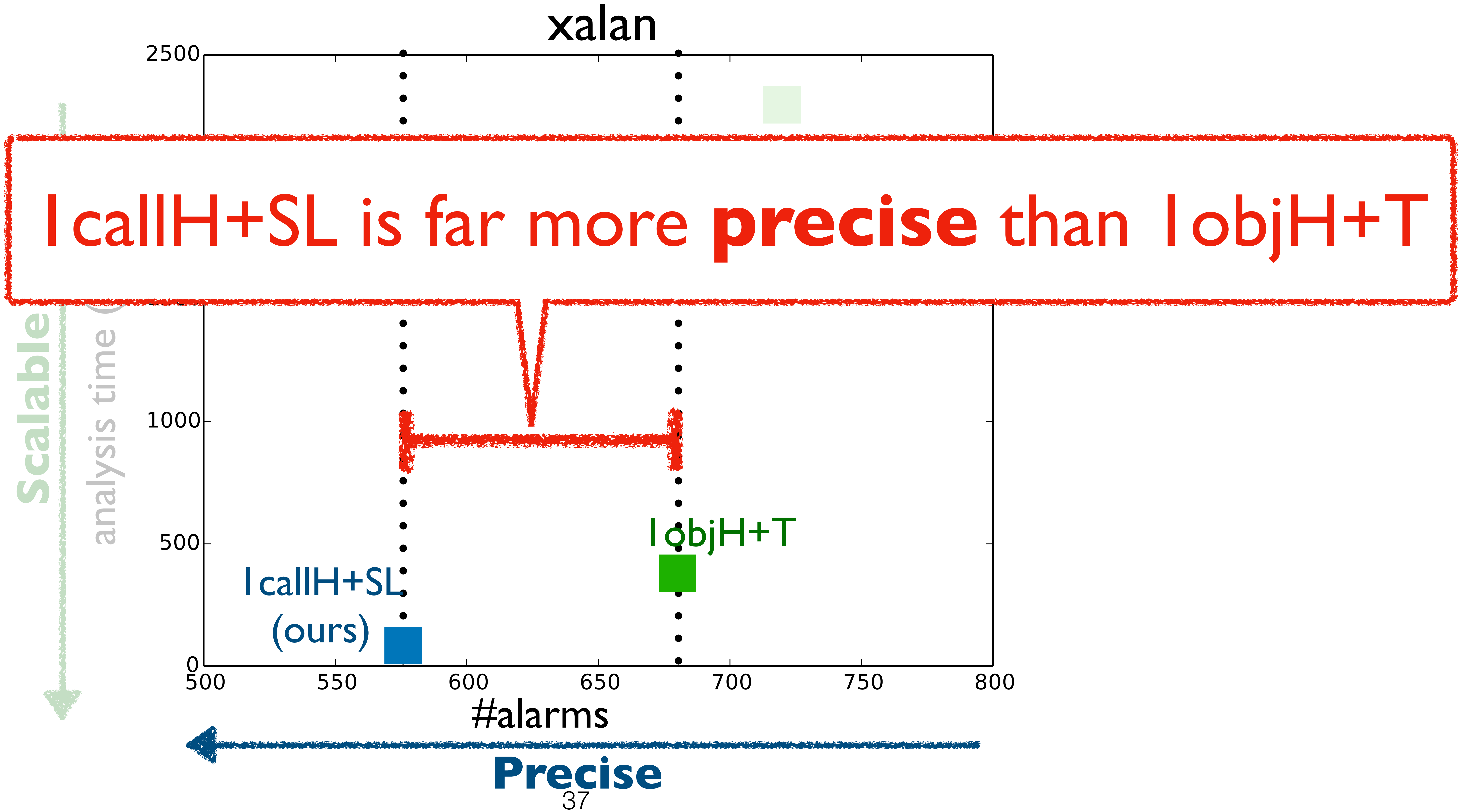

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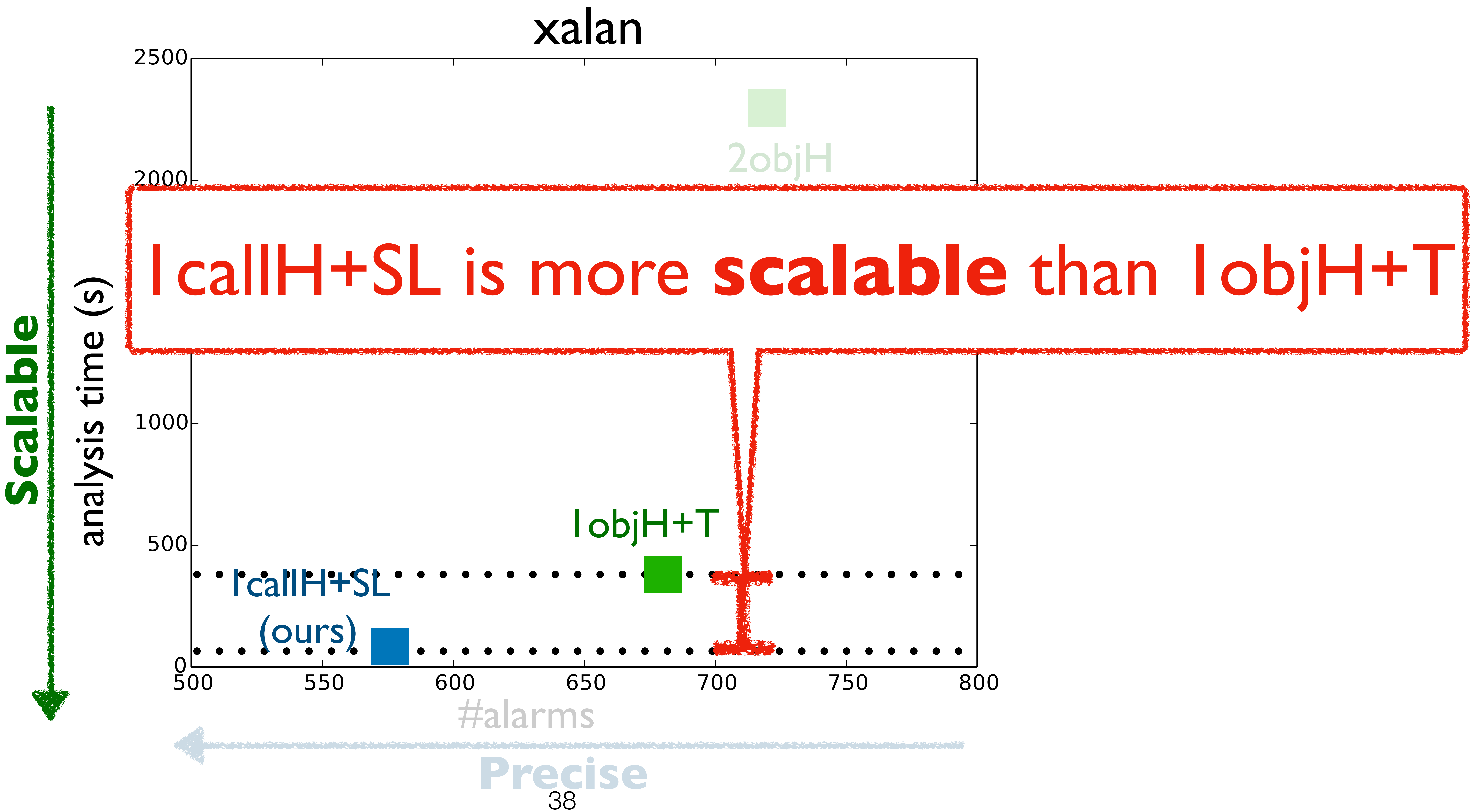
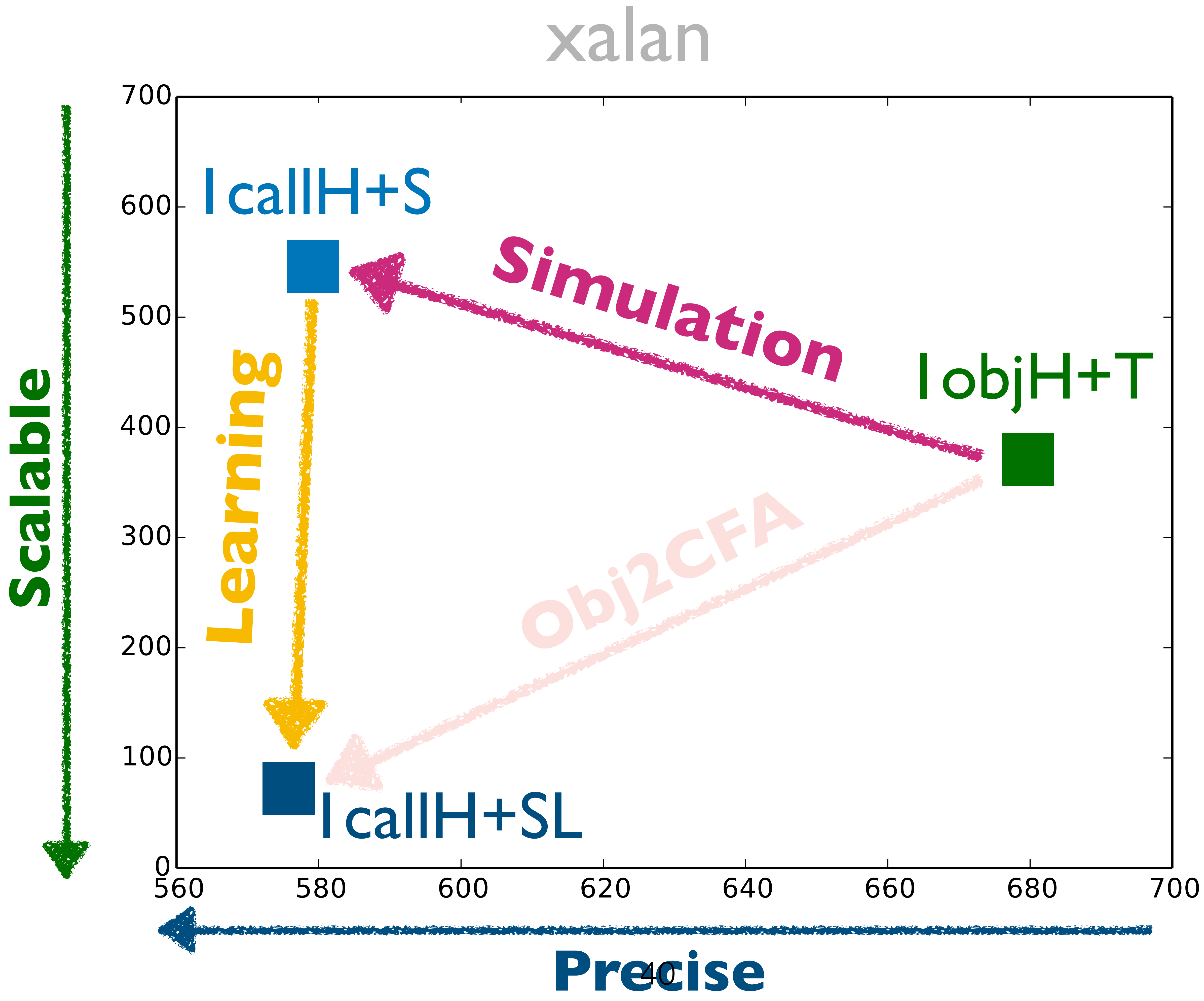


Detail of Obj2CFA

Our Technique : **Obj2CFA**

- **Obj2CFA** consists of **simulation** and simulation-guided **learning**



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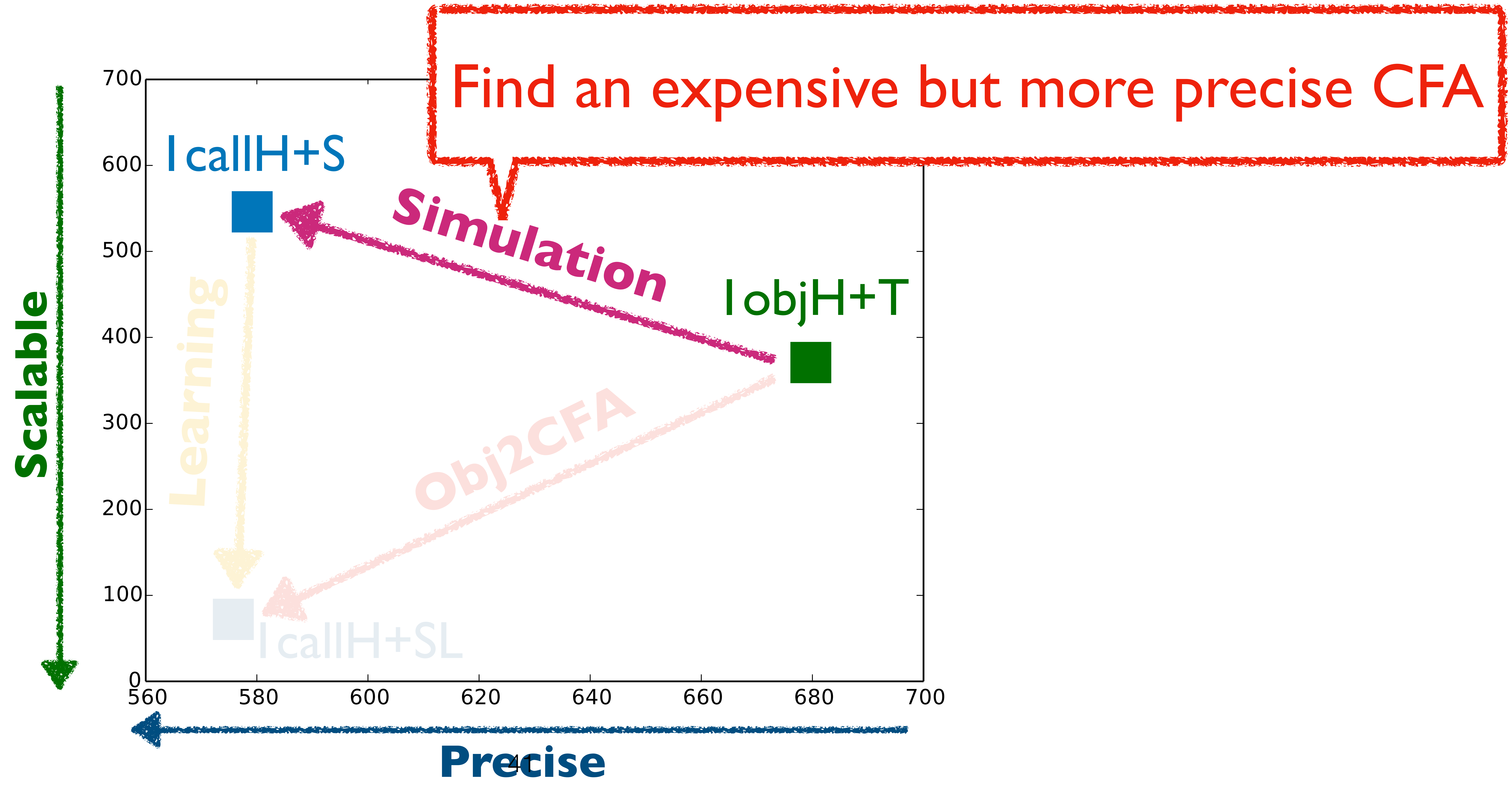

Our Technique : Obj2CFA

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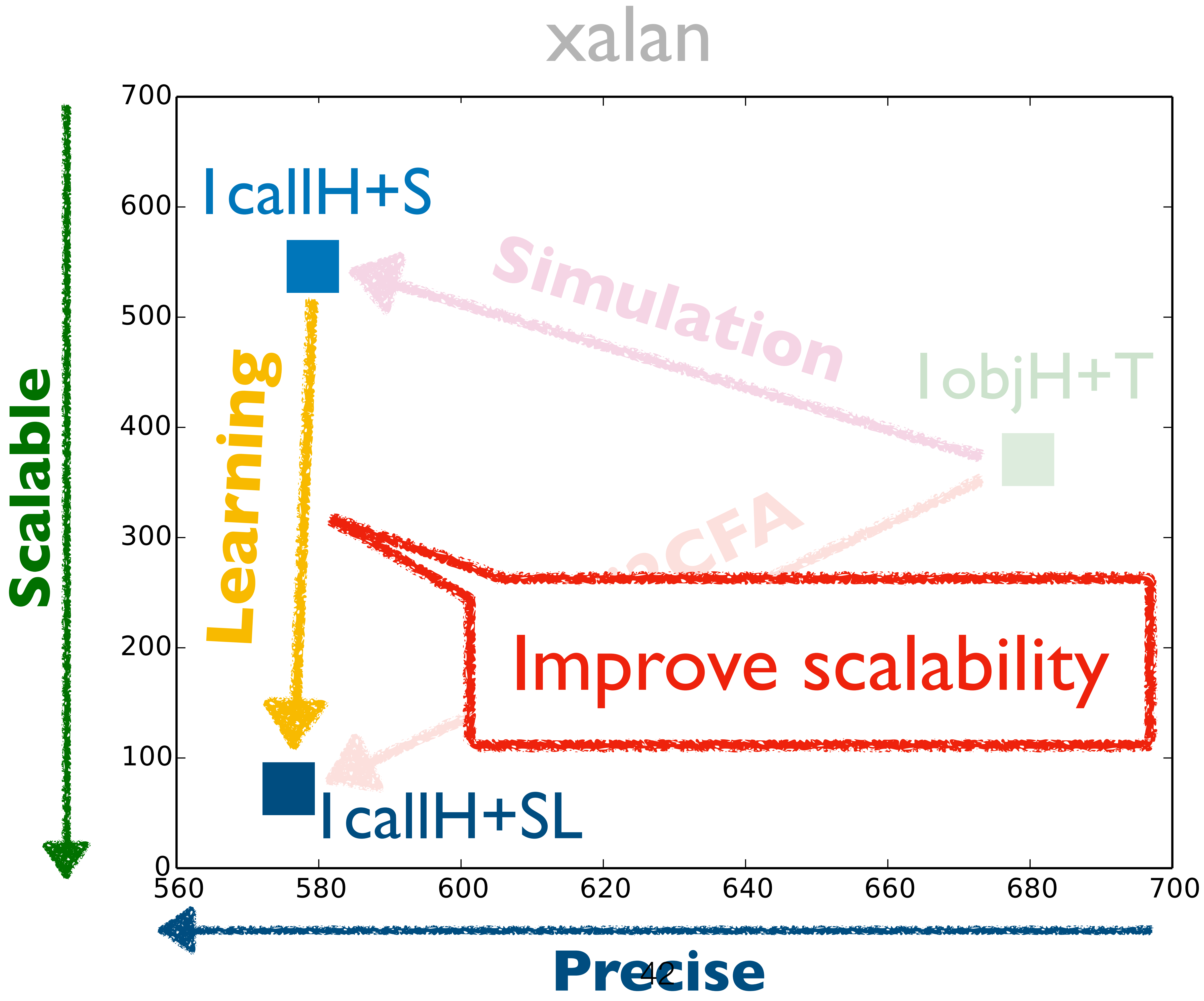

Technique 1: Simulation

- Running example to illustrate Simulation

```
class C{
  id(v){return v;}
  id1(v){return id(v);}
  foo(){
    A a = (A) this.id(new A());}//query1
    B b = (B) this.id(new B());}//query2
}
main(){
  c1 = new C(); //C1
  c2 = new C(); //C2
  c3 = new C(); //C3
  A a = (A) c1.id1(new A());//query3
  B b = (B) c2.id1(new B());//query4
  c3.foo();
}
```

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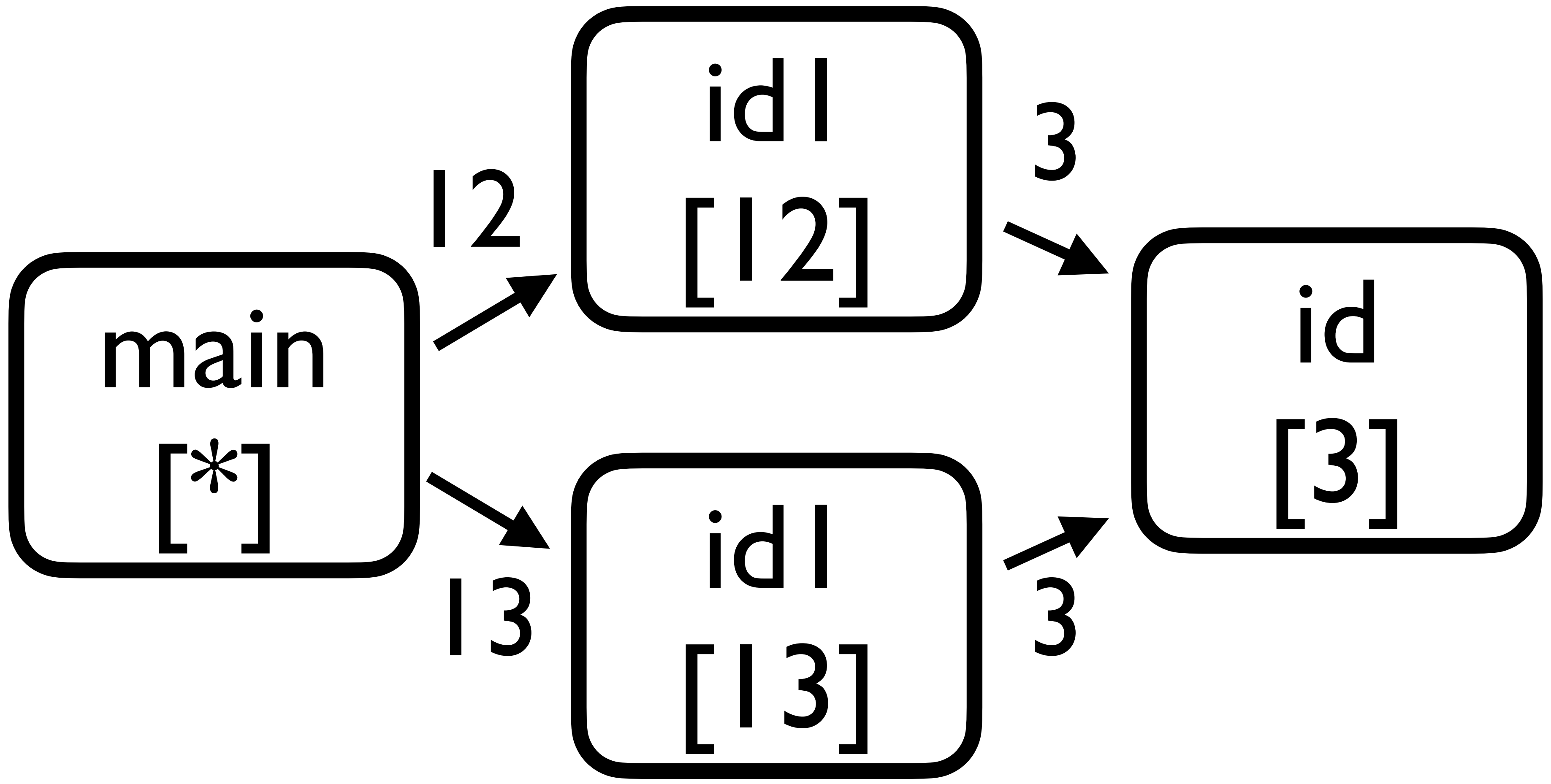
Limitation of conventional 1-CFA



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- Running example to illustrate Simulation

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1:  class C{
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3:    id1(v){return id(v);}
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8:  main(){
9:    c1 = new C(); //C1
10:   c2 = new C(); //C2
11:   c3 = new C(); //C3
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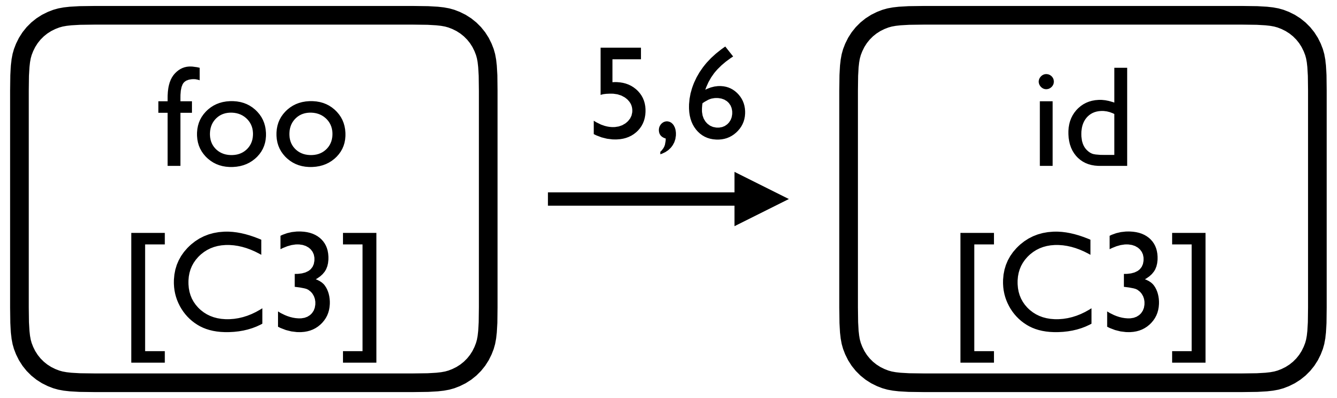
13:   B b = (B) c2.id1(new B());//query4
14:   c3.foo();
15: }
```

Limitation of object sensitivity



Technique 1: Simulation

- Given object sensitivity is conventional 1-object sensitivity (e.g., T = ∅)

```
1:  class C{
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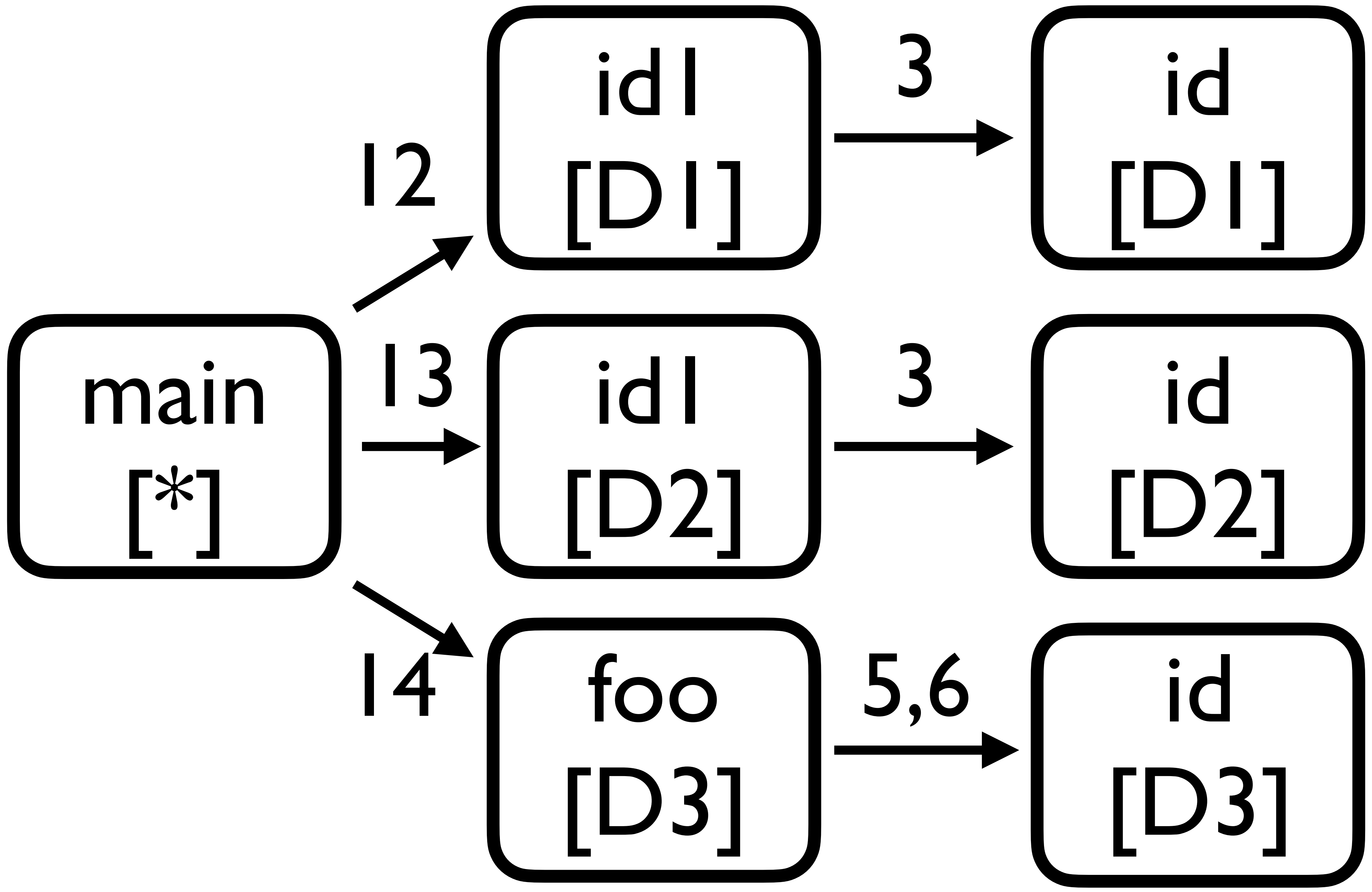


1objH+T (T = ∅)

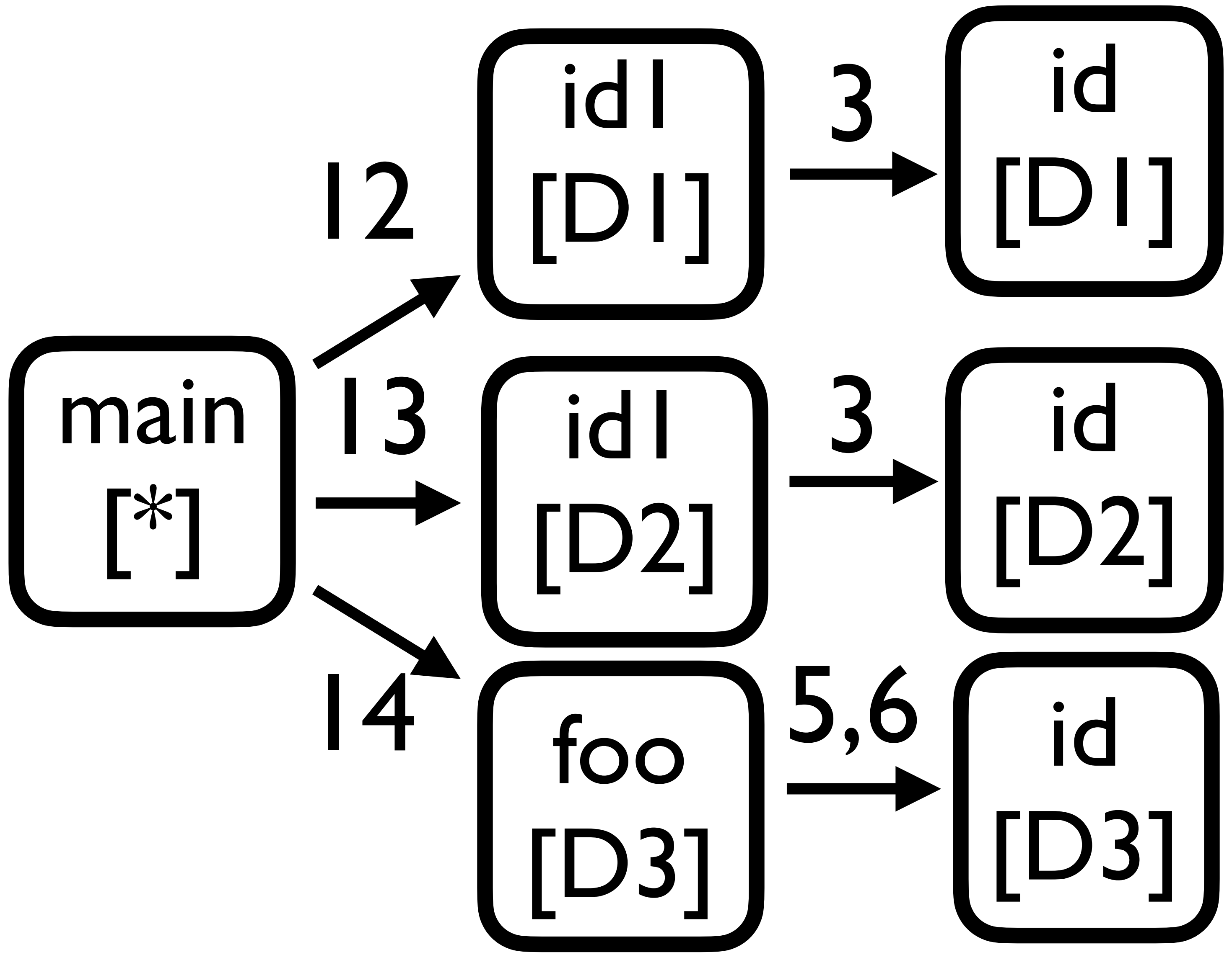
Technique 1: Simulation

- **Simulation** takes a call-graph and produce a tunneling abstraction for CFA

1objH+T (T = ∅)

Technique 1: Simulation

- **Simulation** takes a call-graph and produce a tunneling abstraction for CFA



Simulation

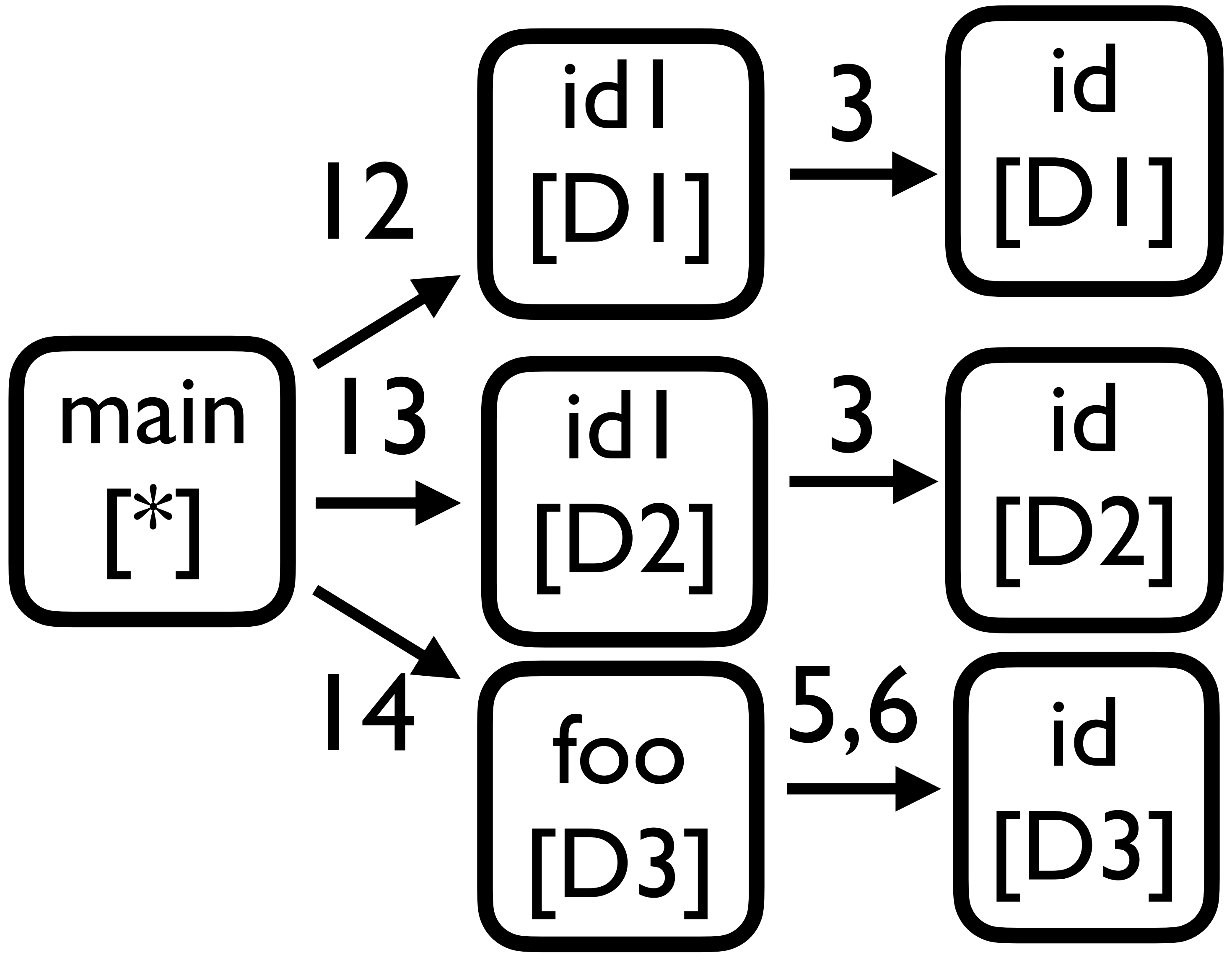
T' = {3}

$$T' = (I_1 \cup I_2) \setminus I_3$$

1objH+T (T = ∅)

Technique 1: Simulation

- **Simulation** takes a call-graph and produce a tunneling abstraction for CFA



1objH+T (T = ∅)

Simulation

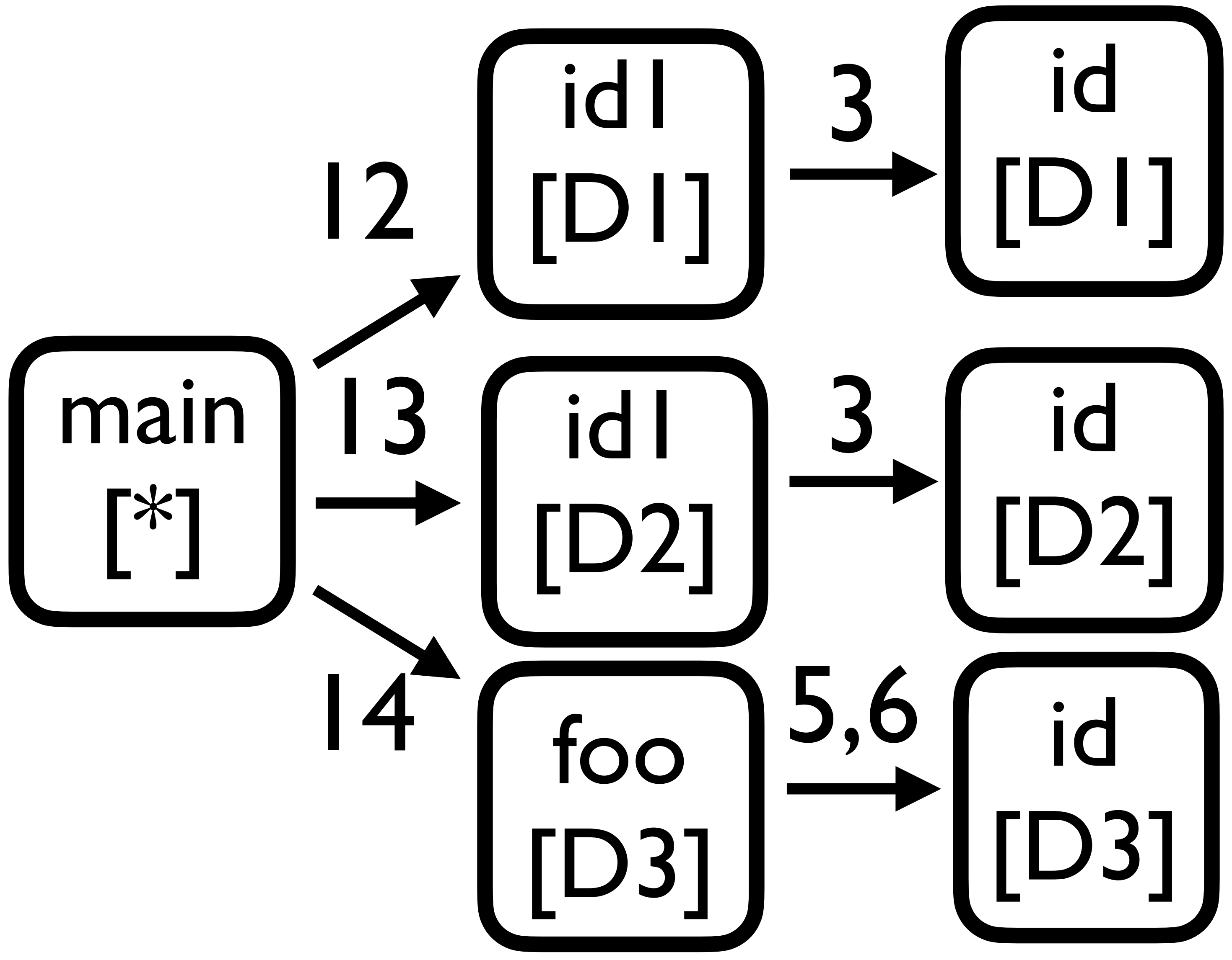
T' = {3}

$T' = \boxed{(I_1 \cup I_2)} \setminus I_3$

Need tunneling to simulate the given object sensitivity

Technique 1: Simulation

- **Simulation** takes a call-graph and produce a tunneling abstraction for CFA



1objH+T (T = ∅)

Simulation

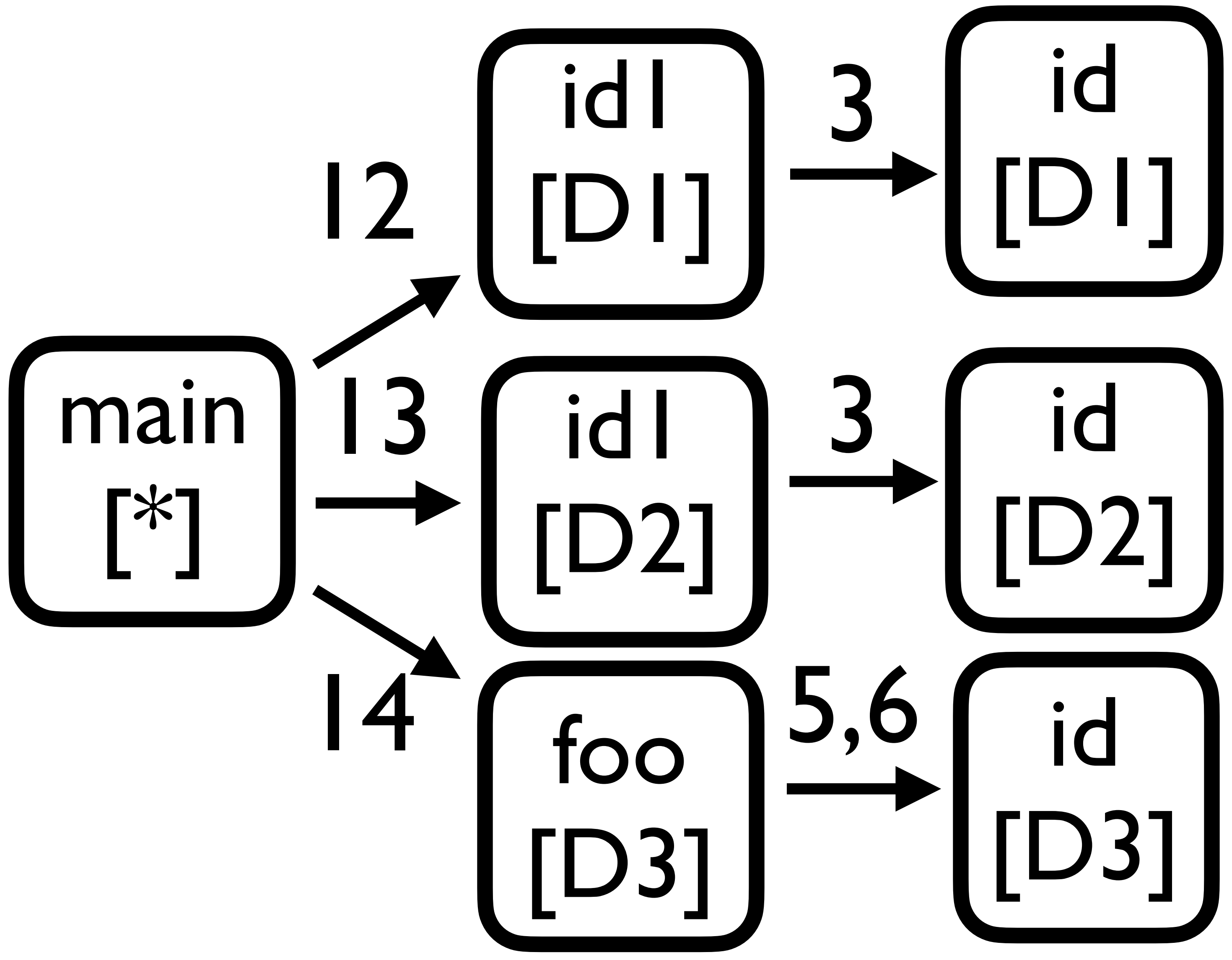
T' = {3}

T' = $(I_1 \cup I_2) \setminus I_3$

Tunneling should be avoided for improving precision

Technique 1: Simulation

- **Simulation** takes a call-graph and produce a tunneling abstraction for CFA



Intuition of Simulation

Suppose the call-graph is produced from 1-CFA + T' and infer the T'

~~1objH+T (T = ∅)~~

1callH+T'

What is T'?

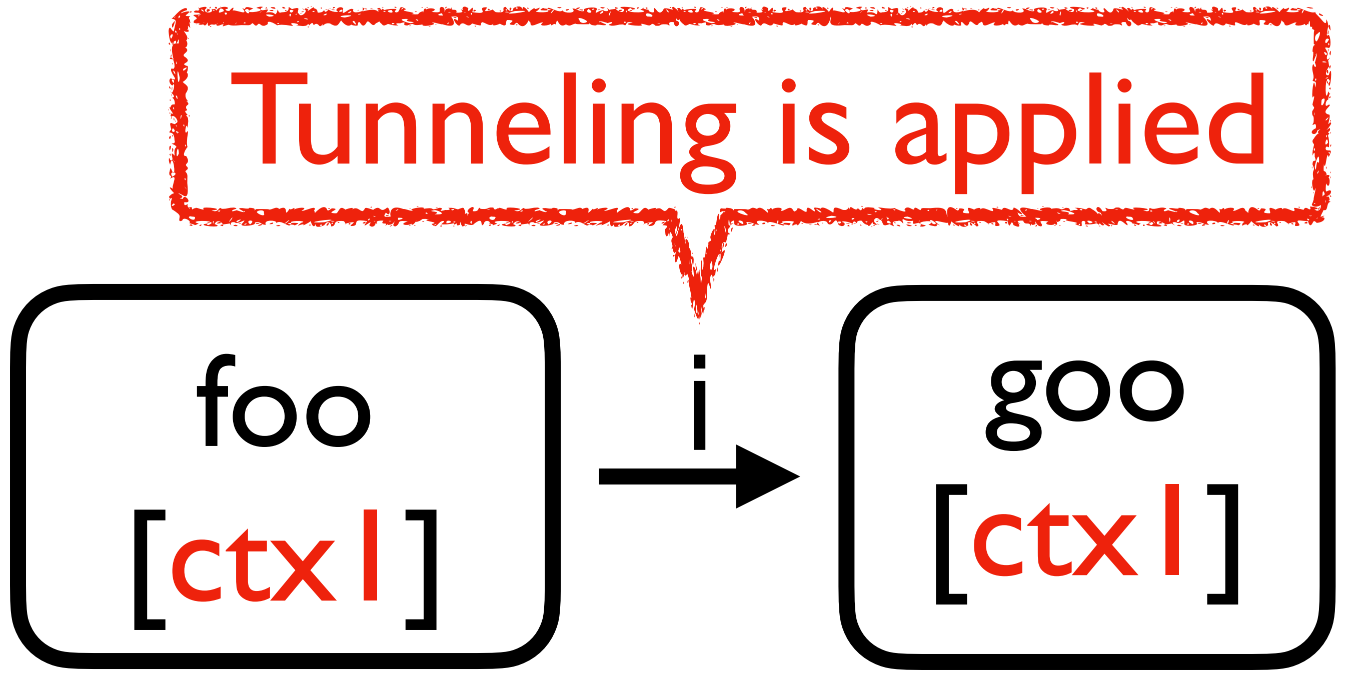
Intuition Behind Simulation $(I_1 \cup I_2)$

- If tunneling is applied to i, two properties inevitably appear at i

We track the two properties to find the T'

Intuition Behind Simulation ($I_1 \cup I_2$)

- If tunneling is applied to i, two properties inevitably appear at i



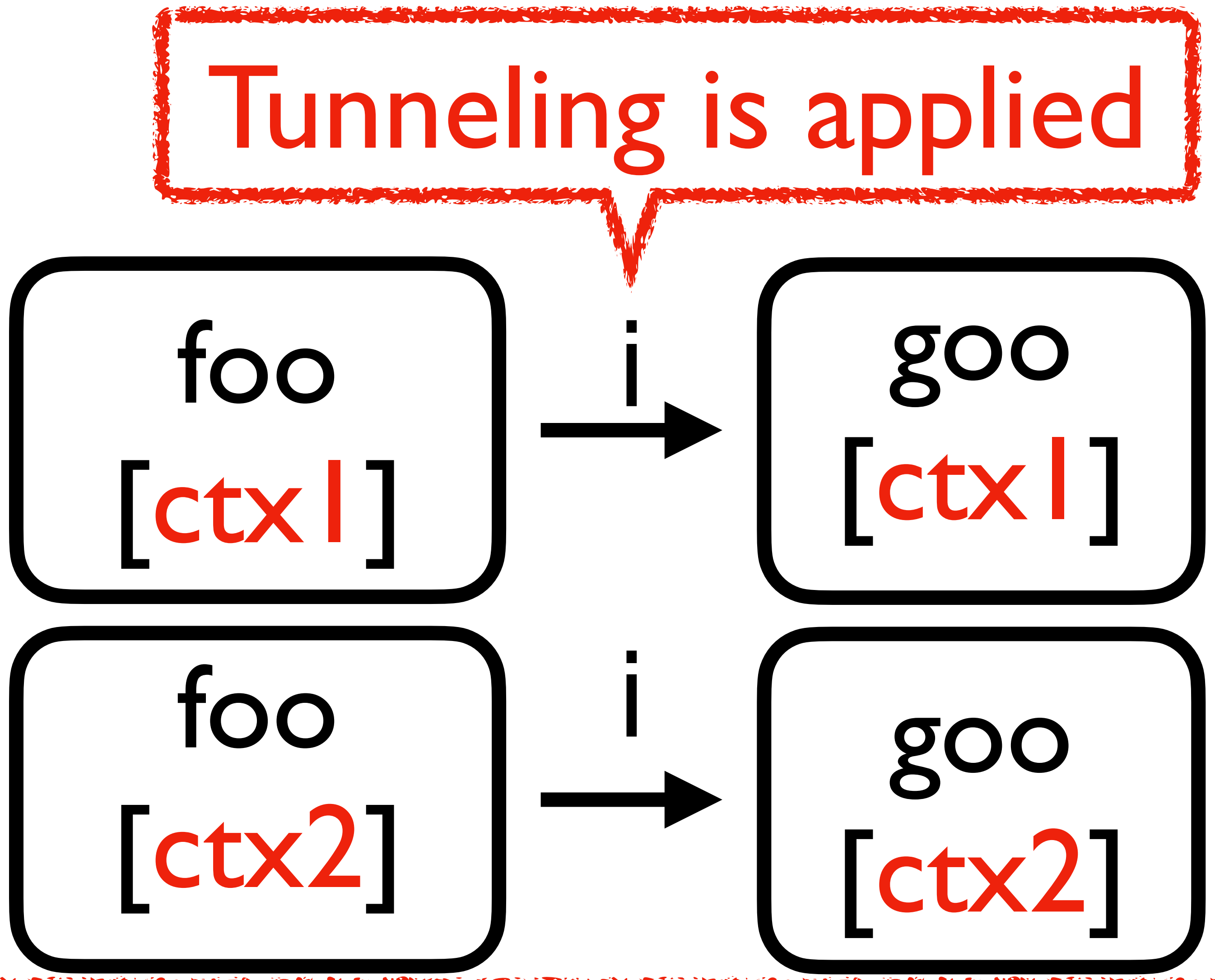
Property of context tunneled call-sites

I_1

- Property 1: caller and callee methods have the same context

Intuition Behind Simulation ($I_1 \cup I_2$)

- If tunneling is applied to i, two properties inevitably appear at i



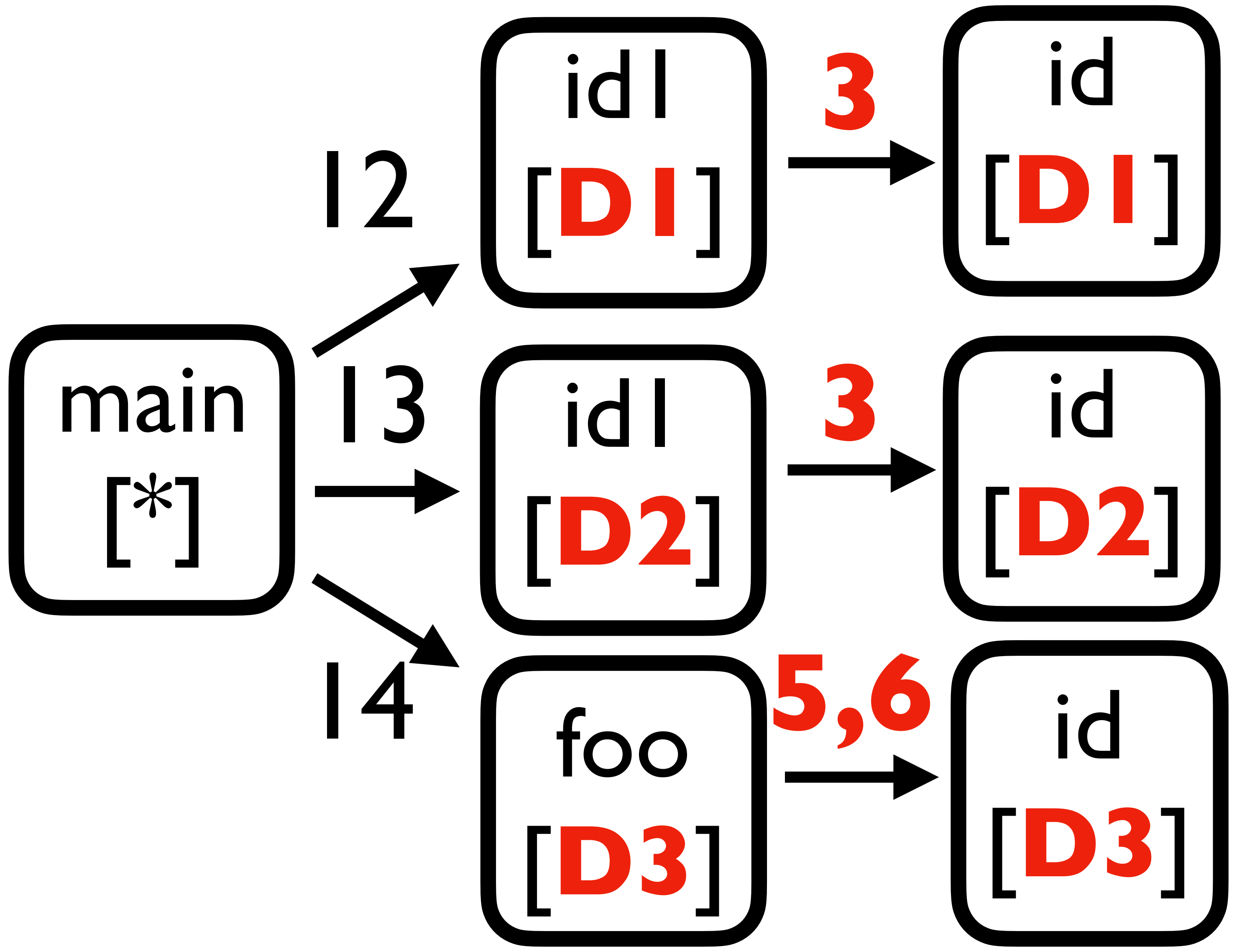
Property of context tunneled invocations

I_2

- Property 2: different caller contexts imply different callee contexts

Intuition Behind Simulation $(I_1 \cup I_2)$

- Suppose given call-graph is produced from 1callH+T' and infer what T' is



- I_1: caller and callee methods have the same context

I_1={3,5,6}

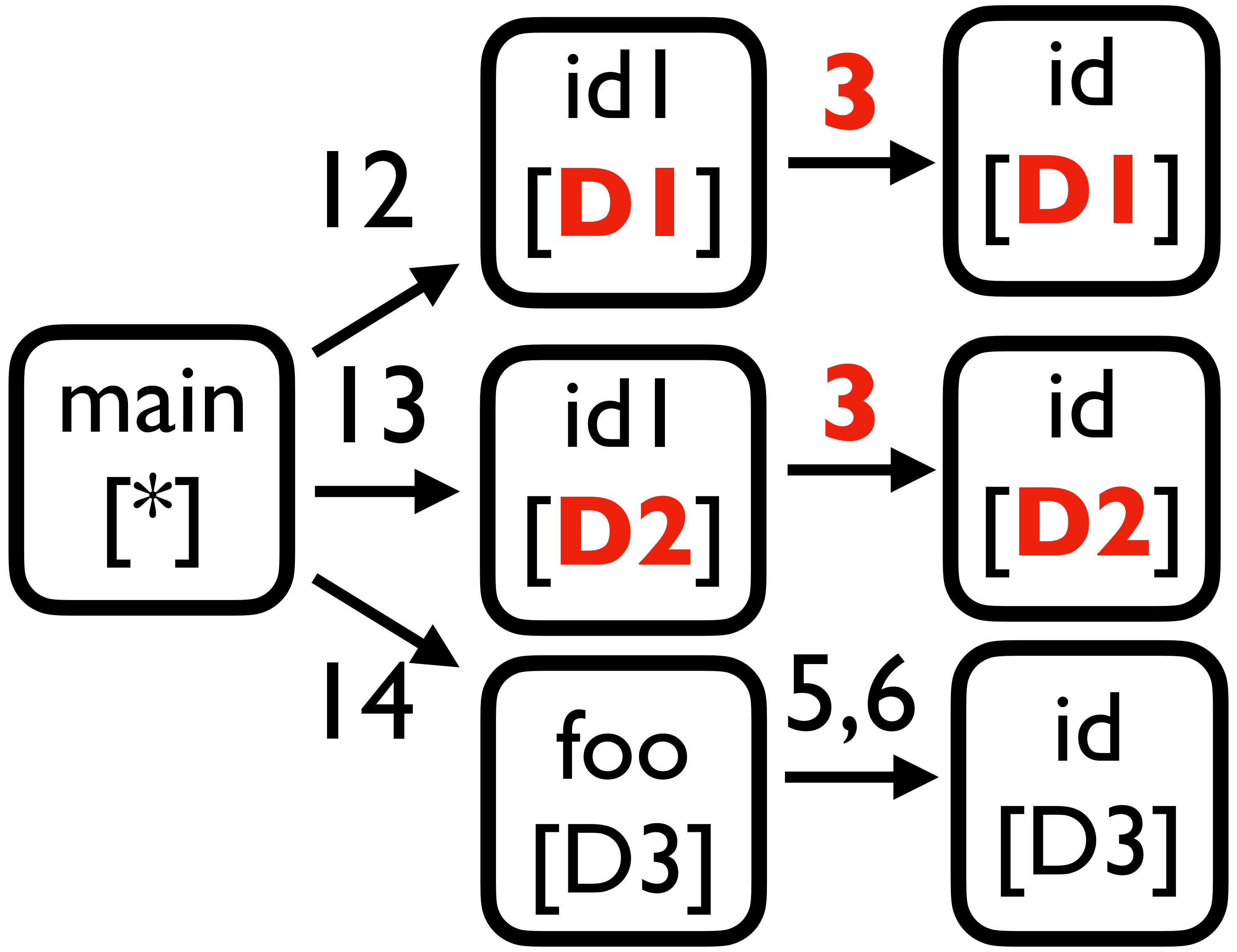
~~1objH+T (T = ∅)~~

1callH+T'

What is T'?

Intuition Behind Simulation $(I_1 \cup I_2)$

- Suppose given call-graph is produced from 1callH+T' and infer what T' is



~~1objH+T (T = ∅)~~

1callH+T'

What is T'?

- I_1: caller and callee methods have the same context

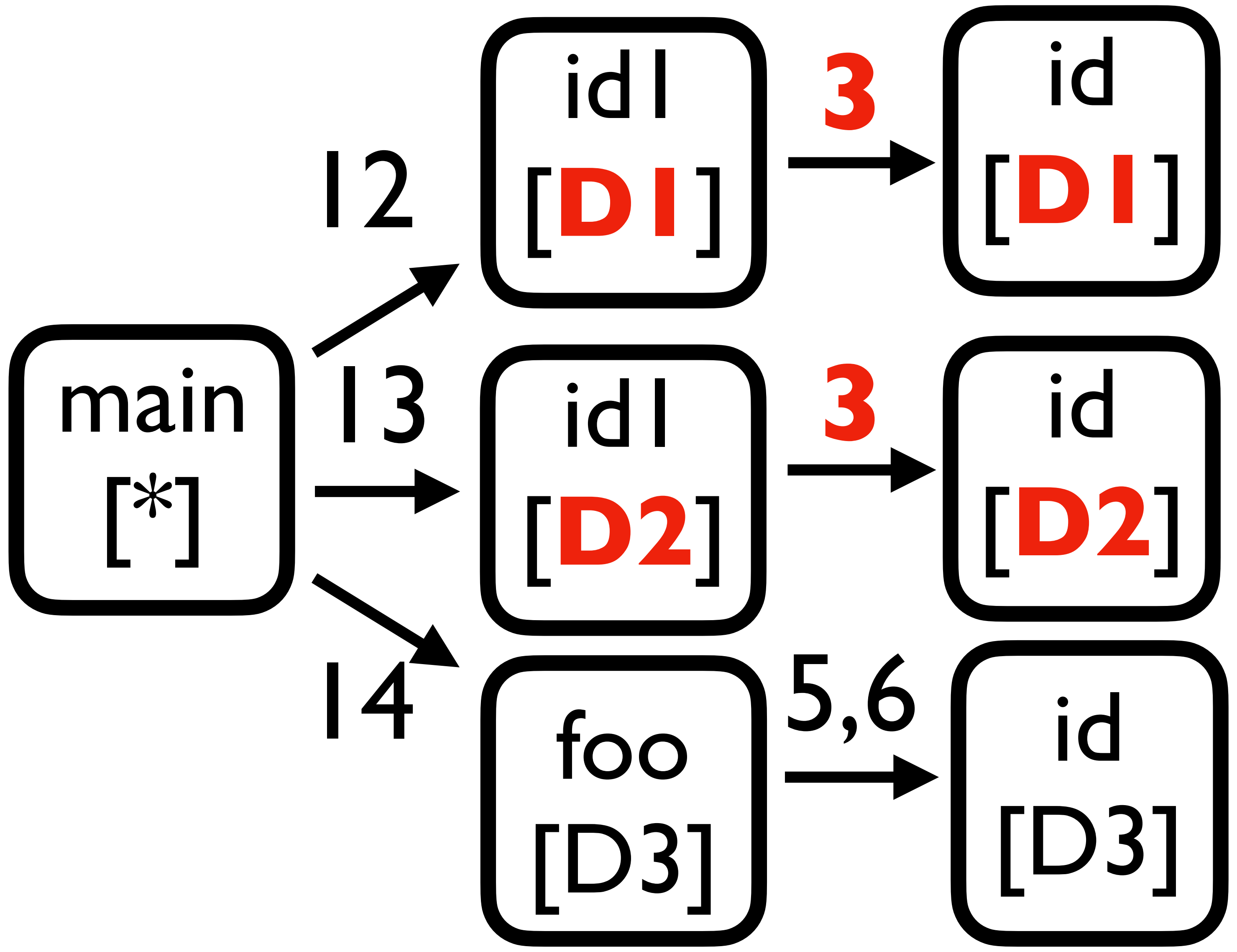
$$I_1=\{3,5,6\}$$

- I_2: different caller ctx imply different callee ctx

$$I_2=\{3\}$$

Intuition Behind Simulation ($I_1 \cup I_2$)

- Suppose given call-graph is produced from 1callH+T' and infer what T' is



~~1objH+T (T = ∅)~~

1callH+T'

What is T'?

- I_1: caller and callee methods have the same context

$$I_1=\{3,5,6\}$$

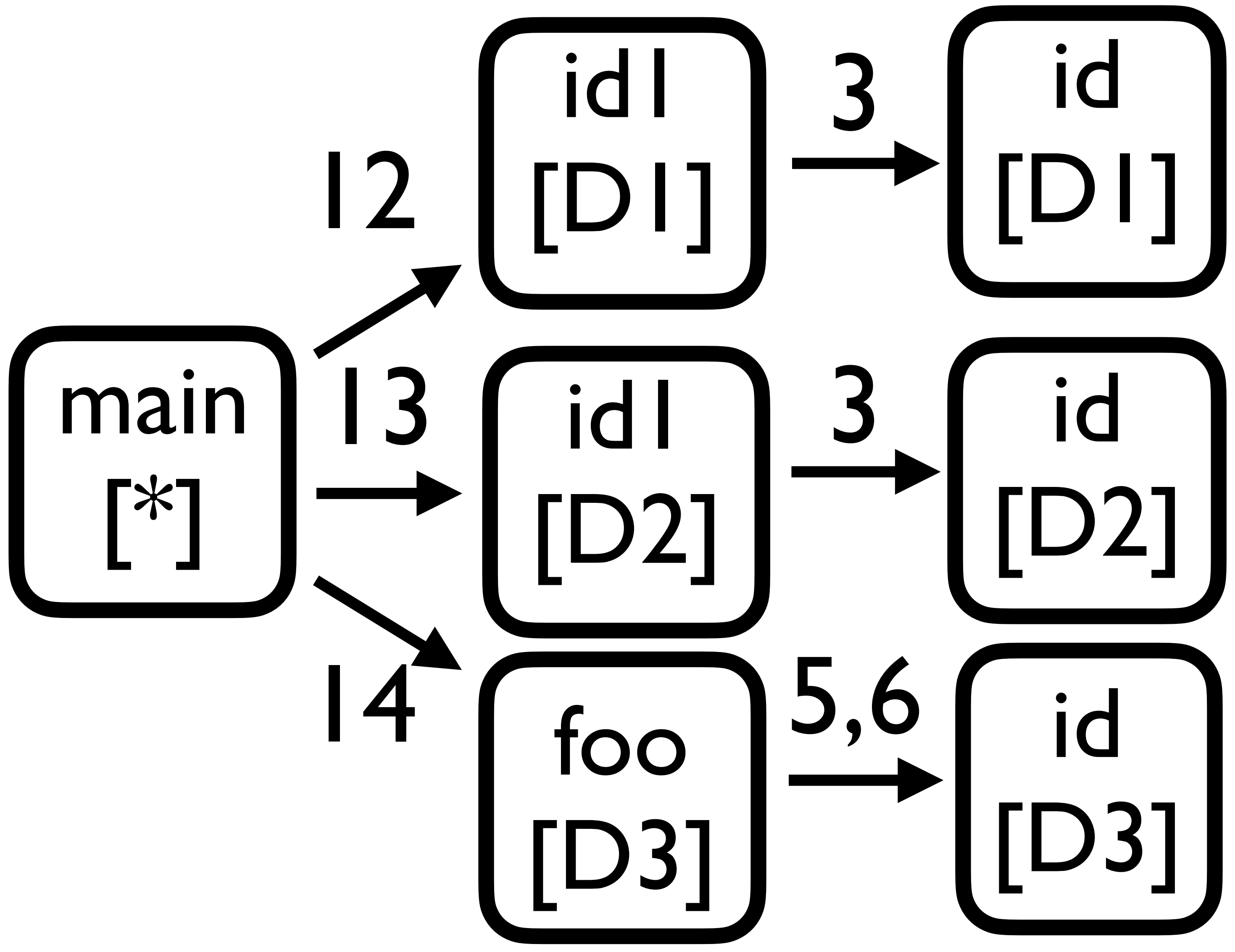
- I_2: different caller ctx imply different callee ctx

$$I_2=\{3\}$$

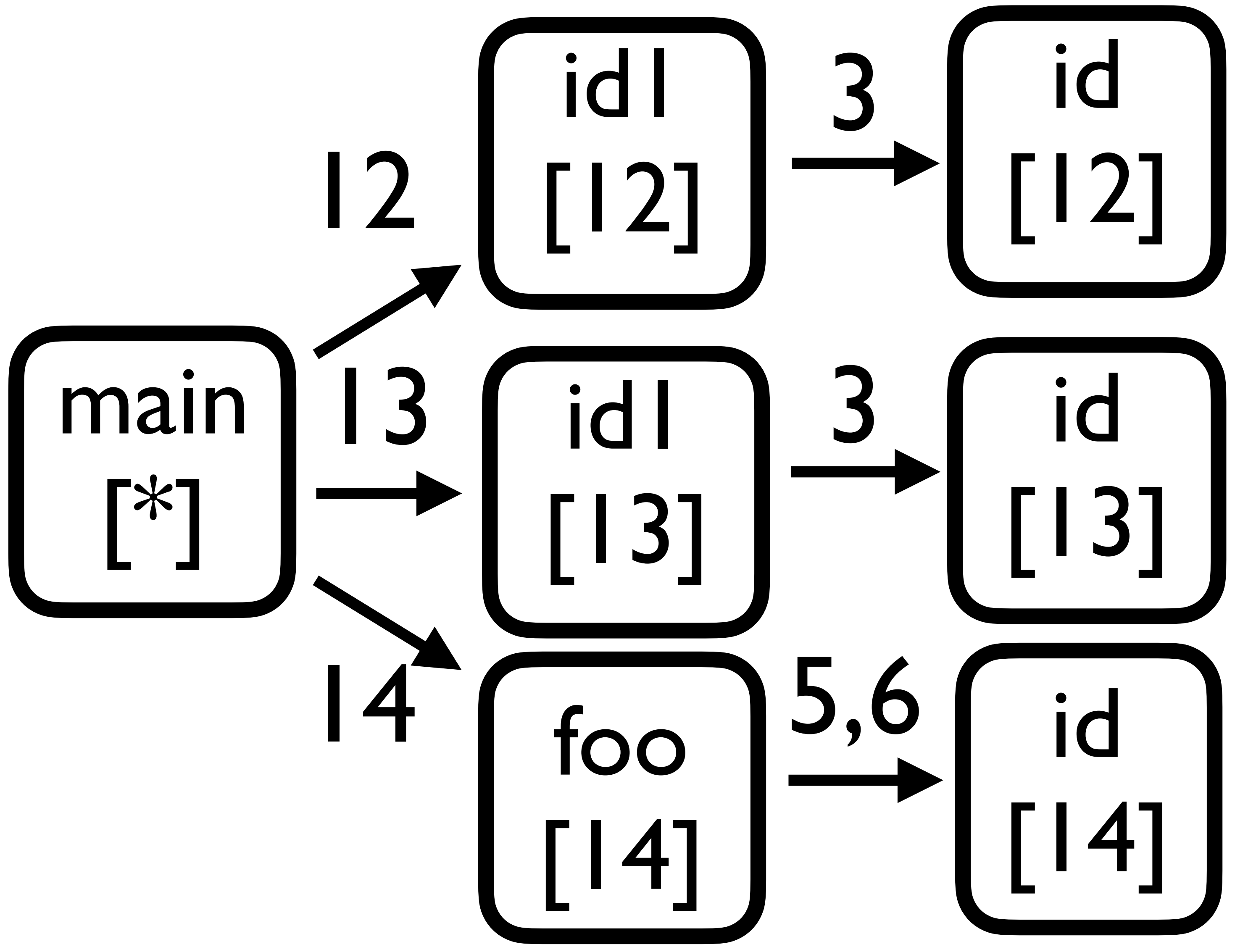
$$\boxed{T' = I_1 \cup I_2 = \{3,5,6\}}$$

Intuition Behind Simulation $(I_1 \cup I_2)$

- Suppose given call-graph is produced from 1callH+T' and infer what T' is



1objH+T (T = ∅)

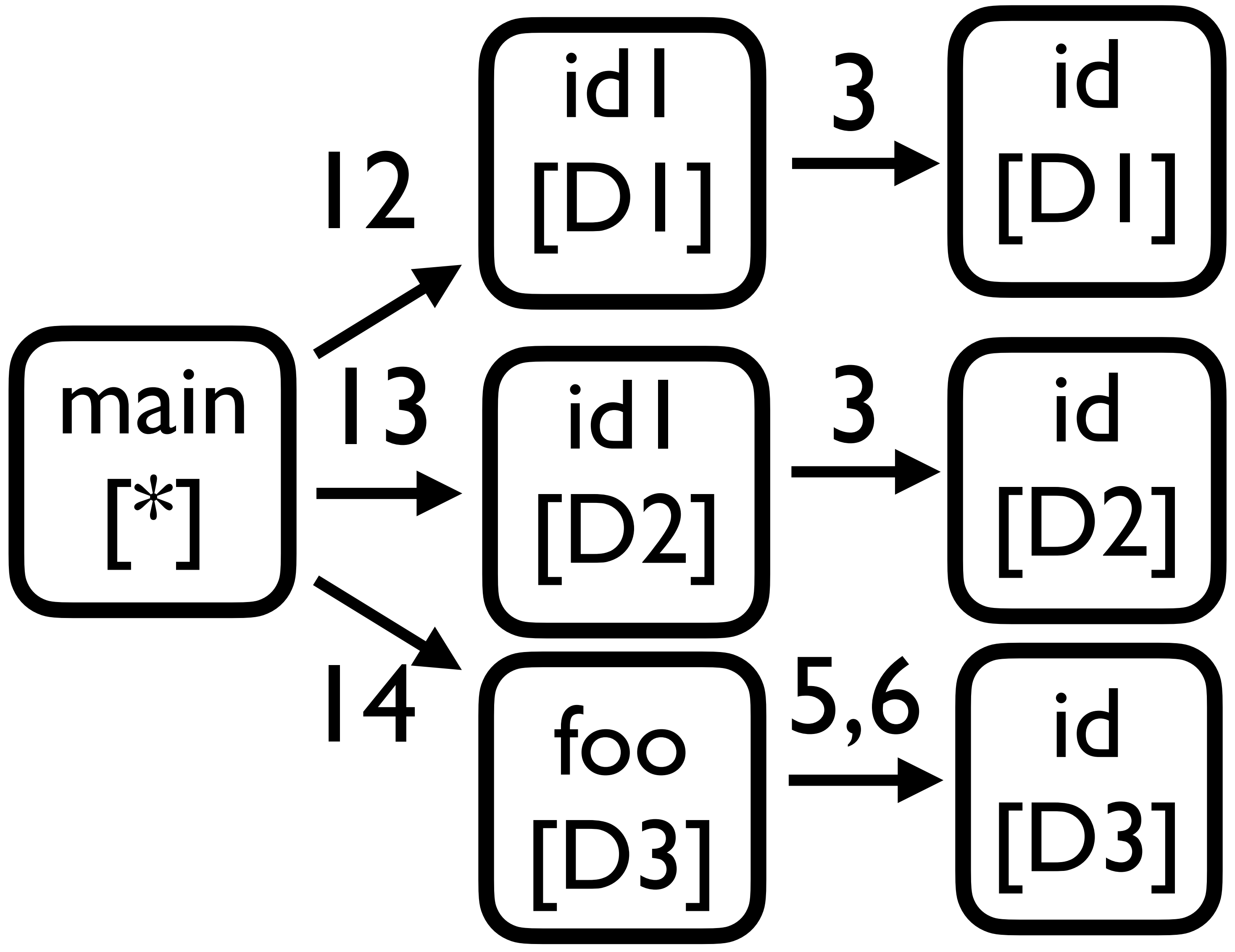


1callH+T' (T' = {3,5,6})

Intuition Behind Simulation $(I_1 \cup I_2)$

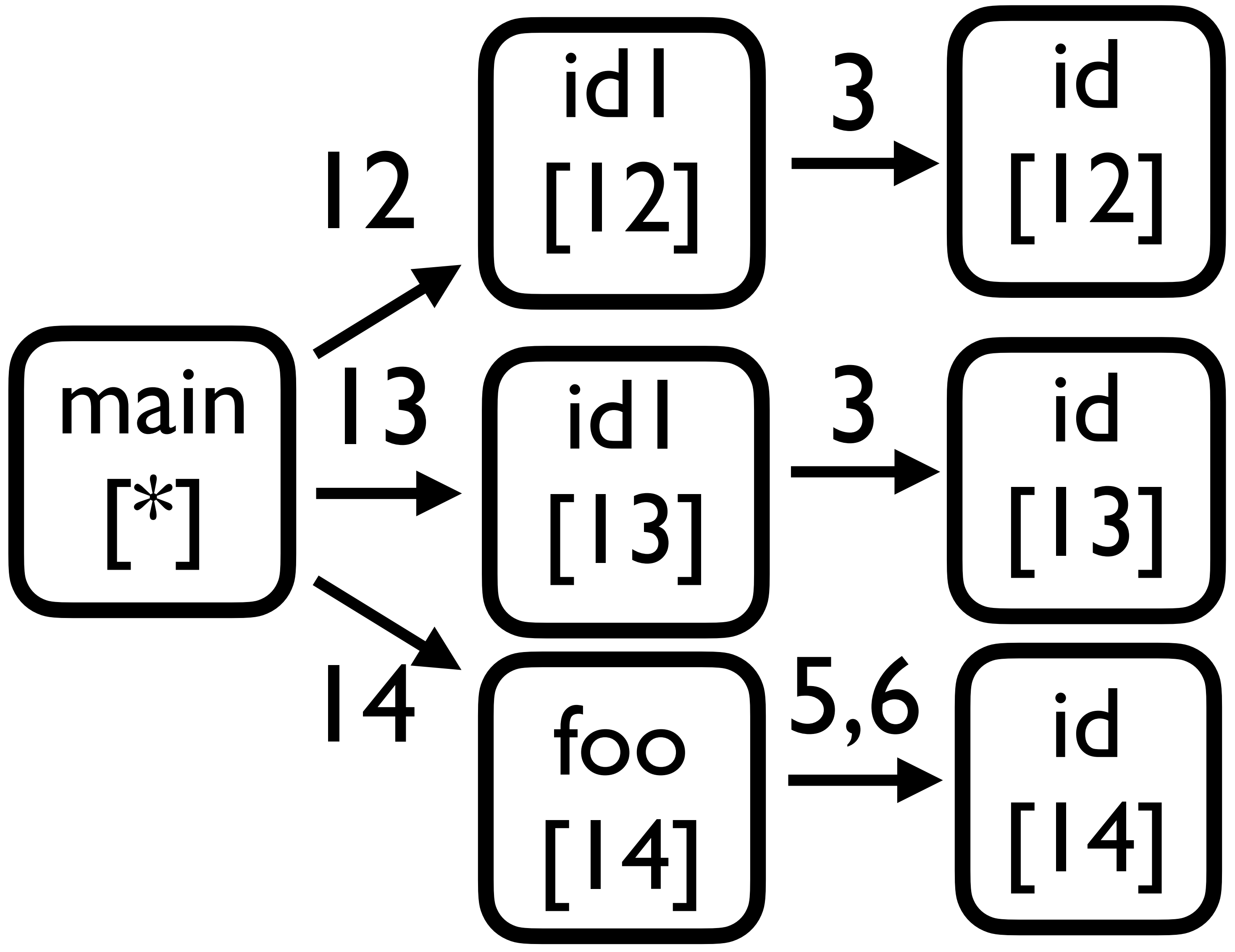
- Suppose given call-g… …d infer what T' is

Exactly the same analyses



1objH+T (T = ∅)

=



1callH+T' (T' = {3,5,6})

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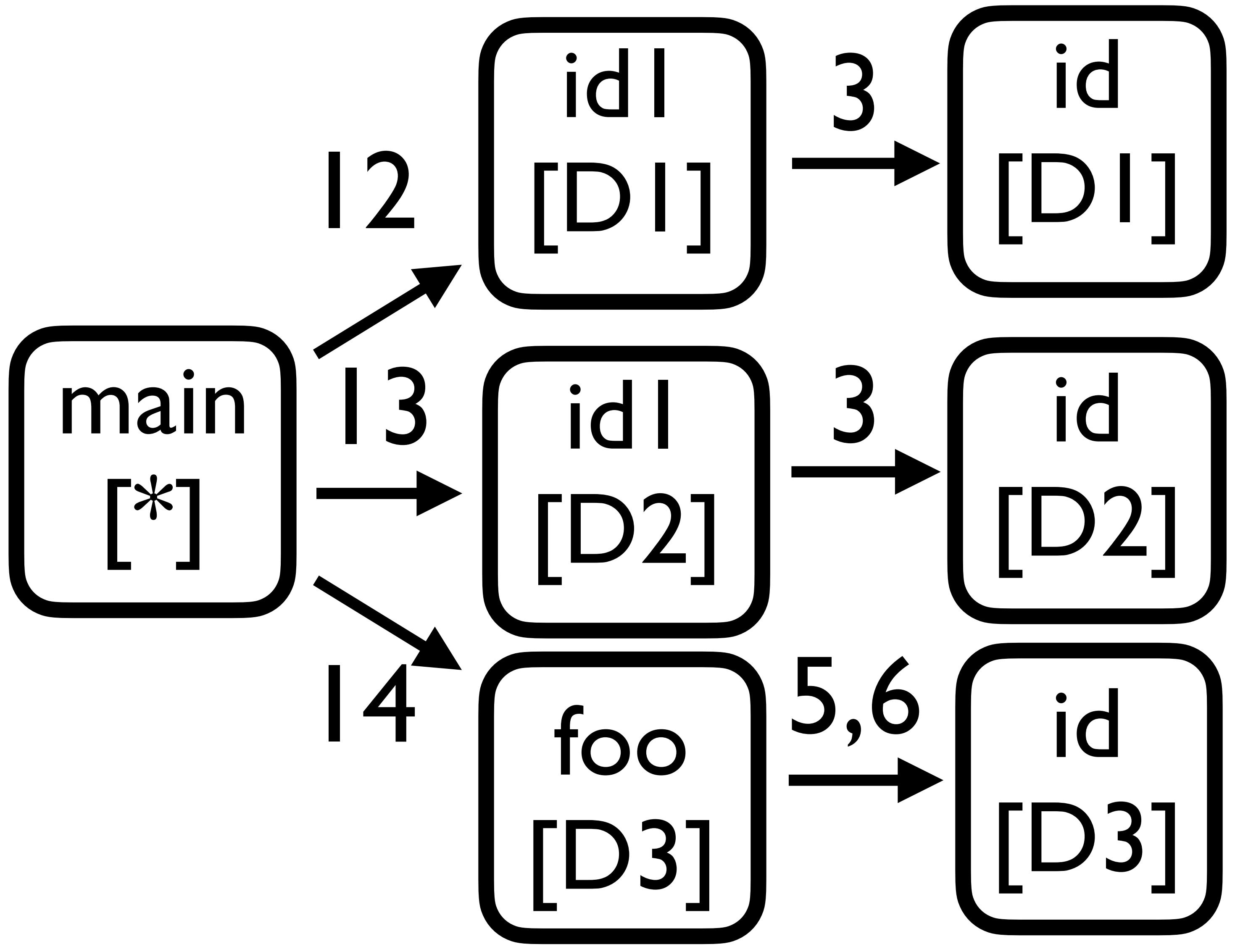
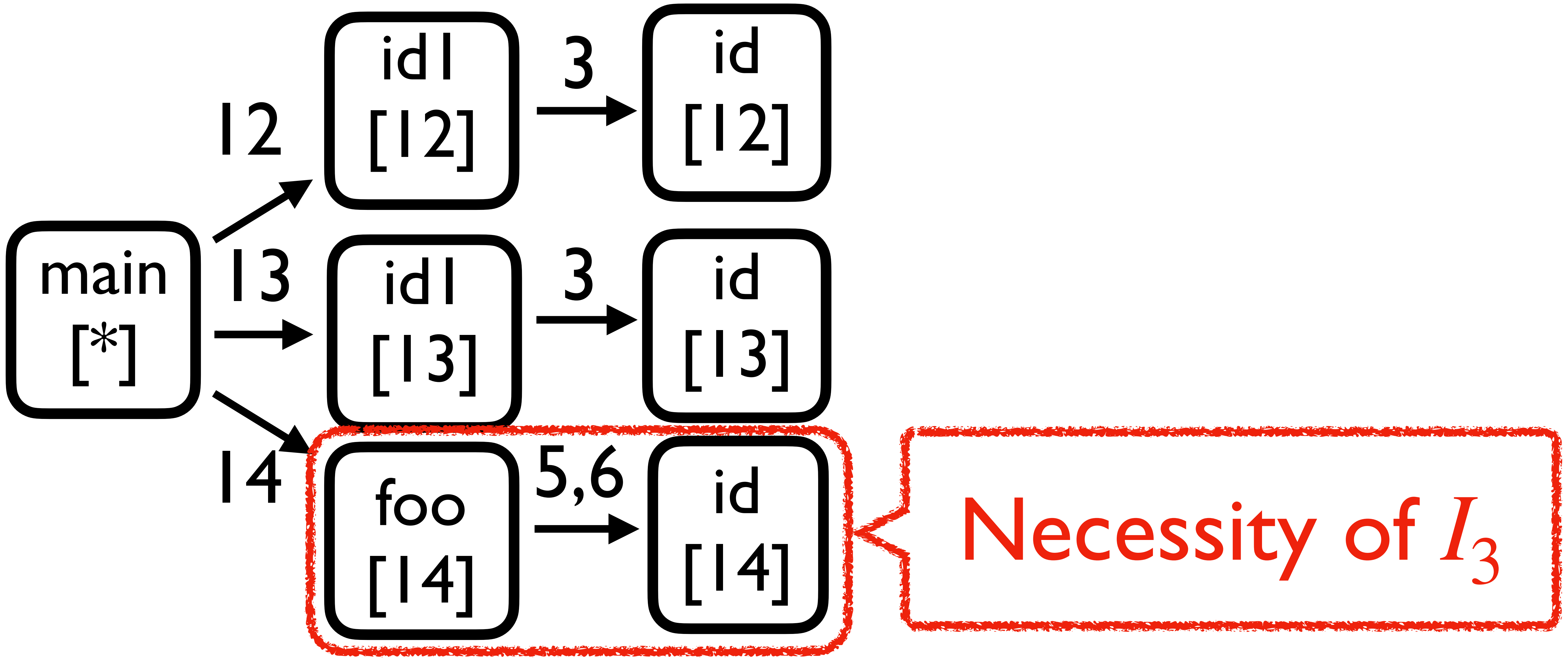


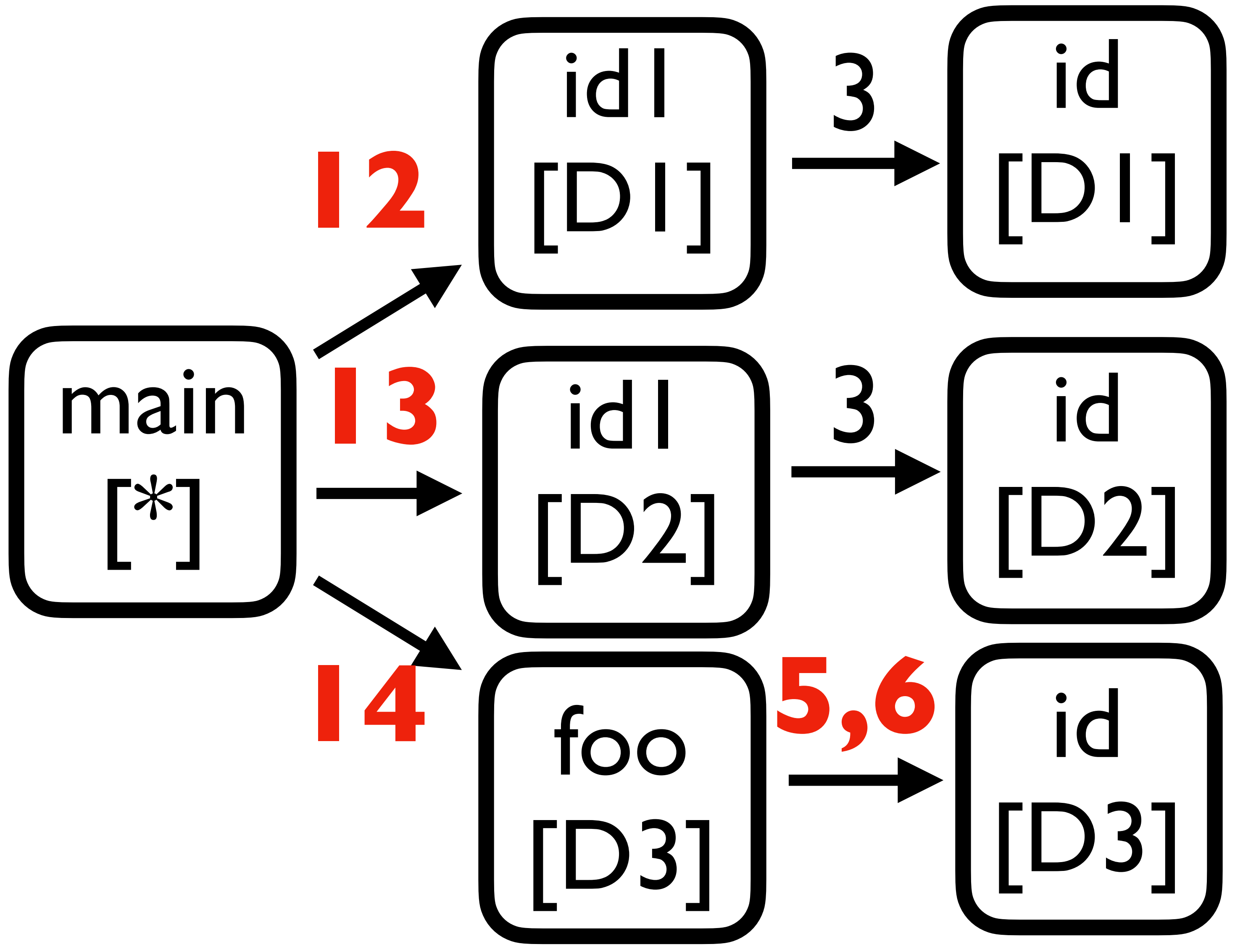
1objH+T (T = ∅)



1callH+T' (T' = {3,5,6})

Intuition Behind Simulation (I_3)

- I_3 : Tunneling should be avoided for improving precision



1objH+T (T = ∅)

- I_1: caller and callee methods have the same context

I_1={3,5,6}

- I_2: different caller ctx imply different callee ctx

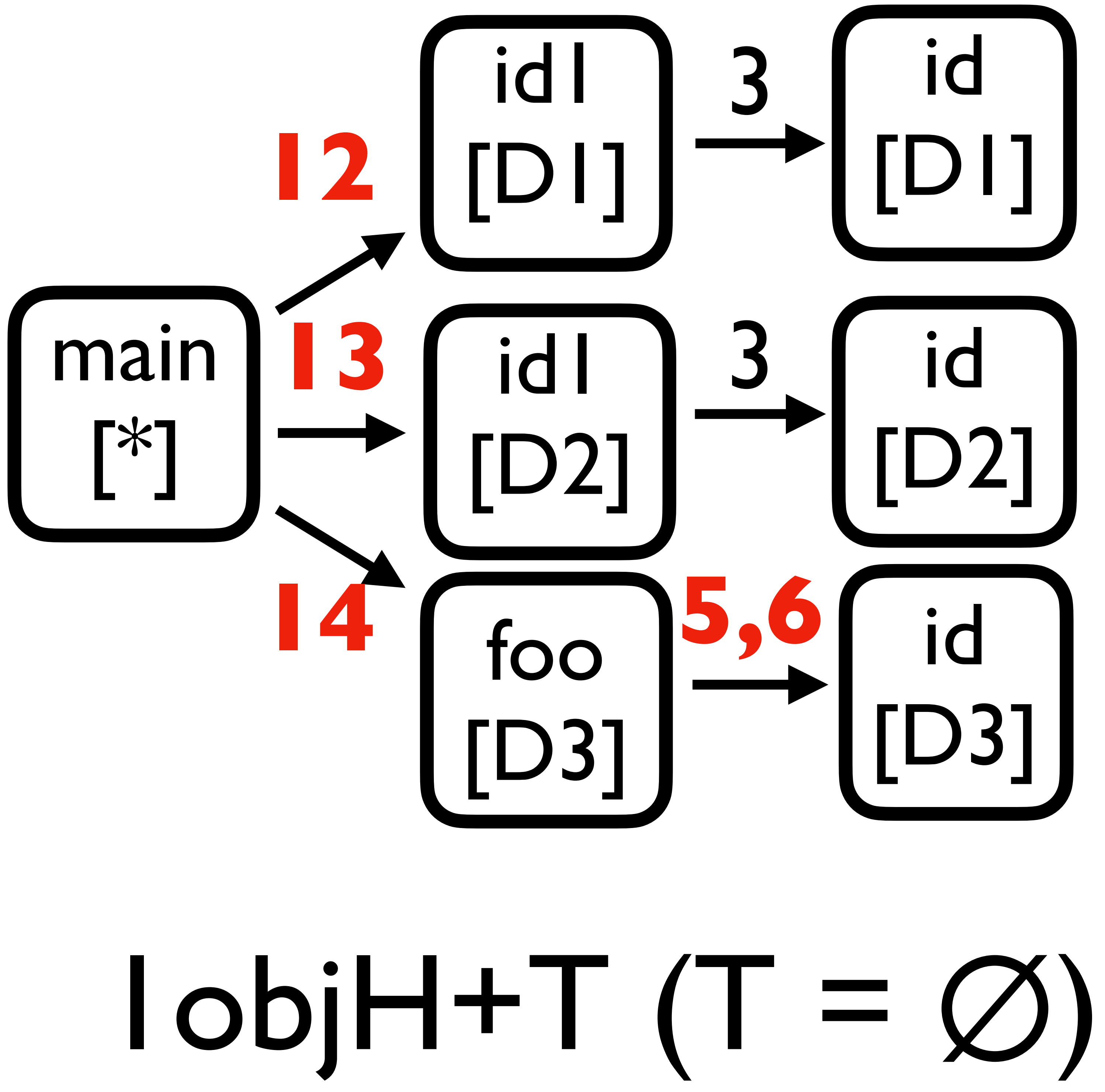
I_2={3}

- I_3: given object sensitivity produced only one context

I_3 = {5,6,12,13,14}

Intuition Behind Simulation

- The inferred tunneling abstraction T' is a singleton set {3}



- I_1: caller and callee methods have the same context

$$I_1=\{3,5,6\}$$

- I_2: different caller ctx imply d

$$I_2=\{3\}$$

$$T' = (I_1 \cup I_2) \backslash I_3 = \{3\}$$

- I_3: given object sensitivity produced only one context

$$I_3 = \{5,6,12,13,14\}$$

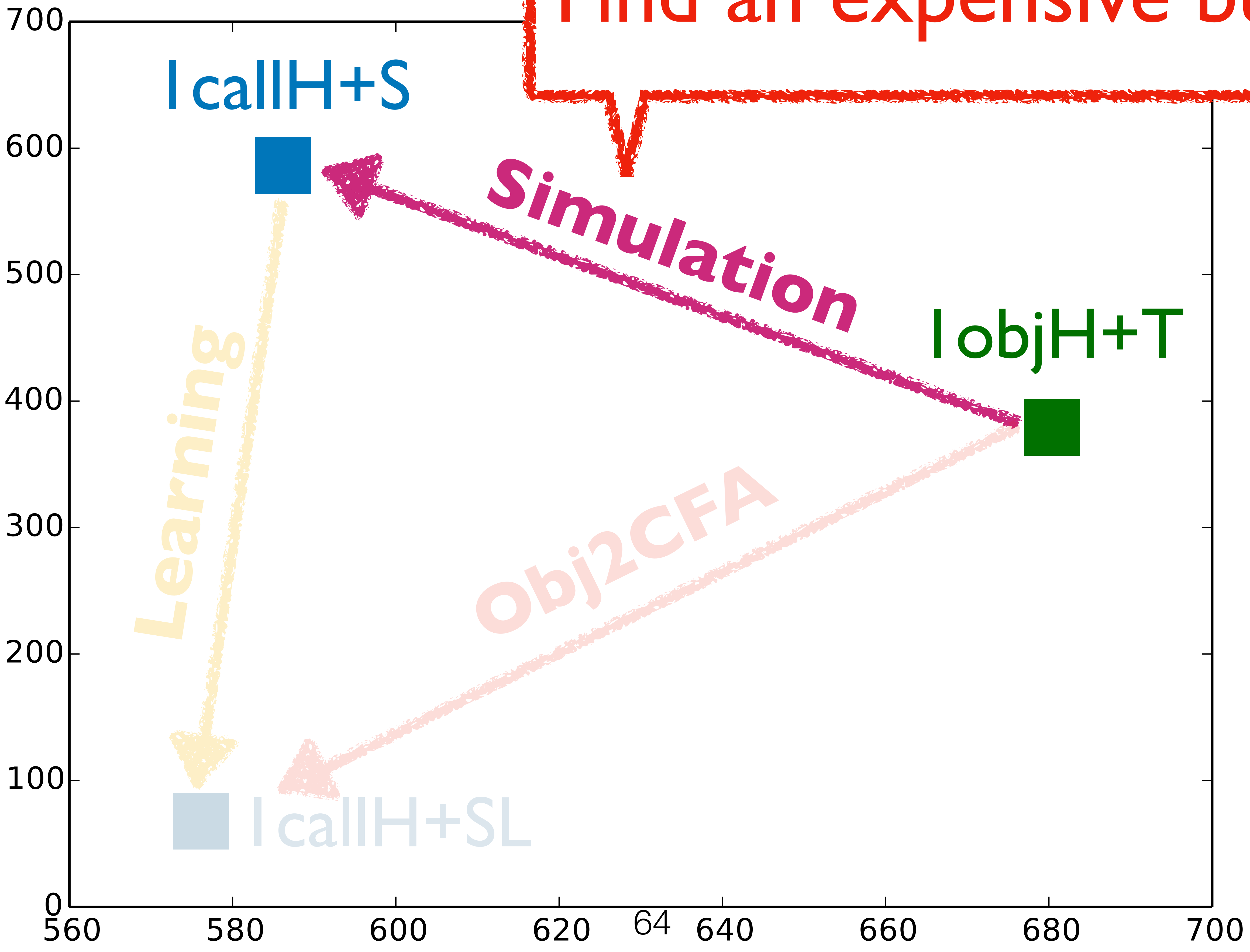
Technique 1: Simulation

- With T', CFA becomes more precise than the given object sensitivity

Our Technique : Obj2CFA

- **Obj2CFA** consists of **simulation** and simulation-guided **learning**

Find an expensive but more precise CFA



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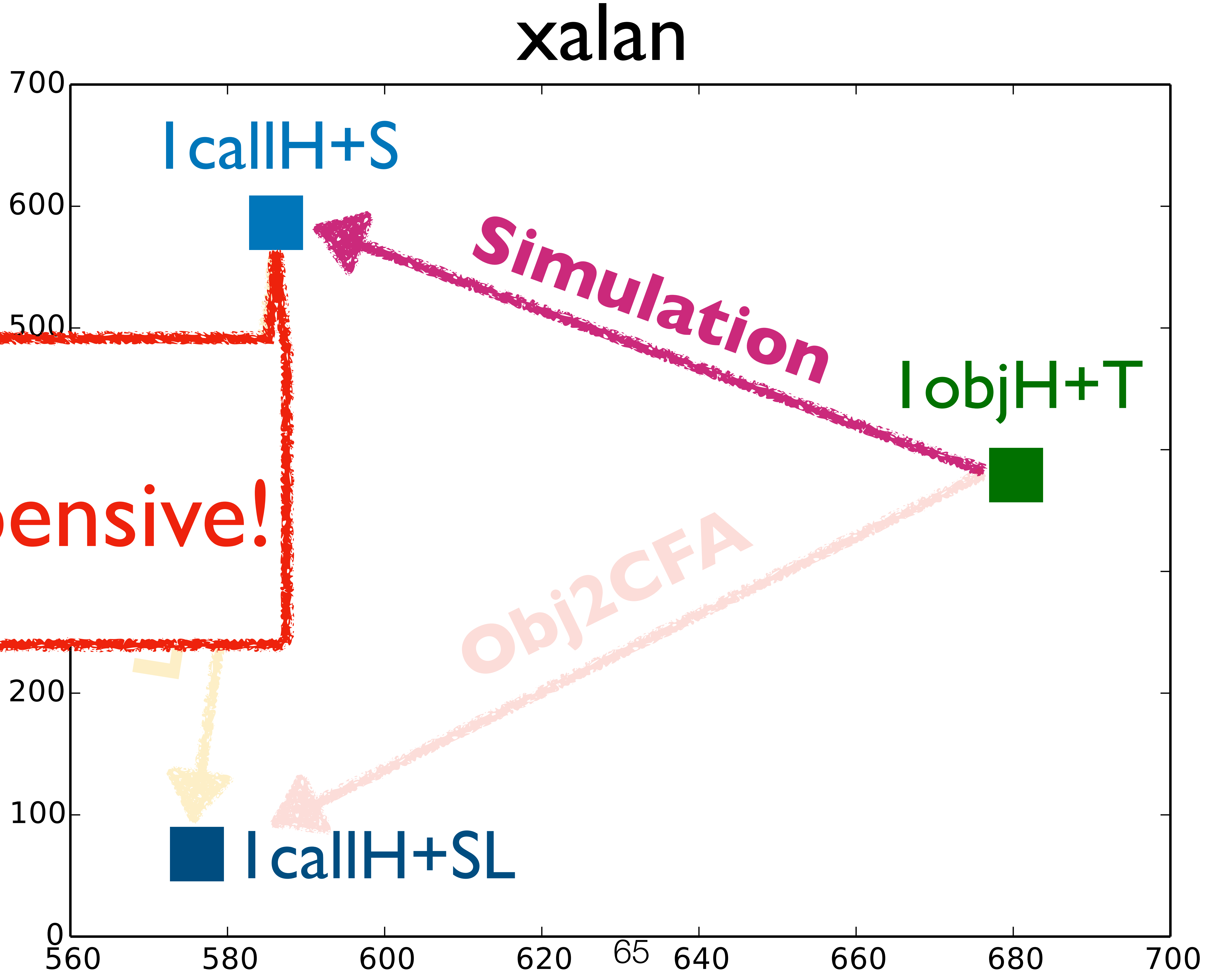
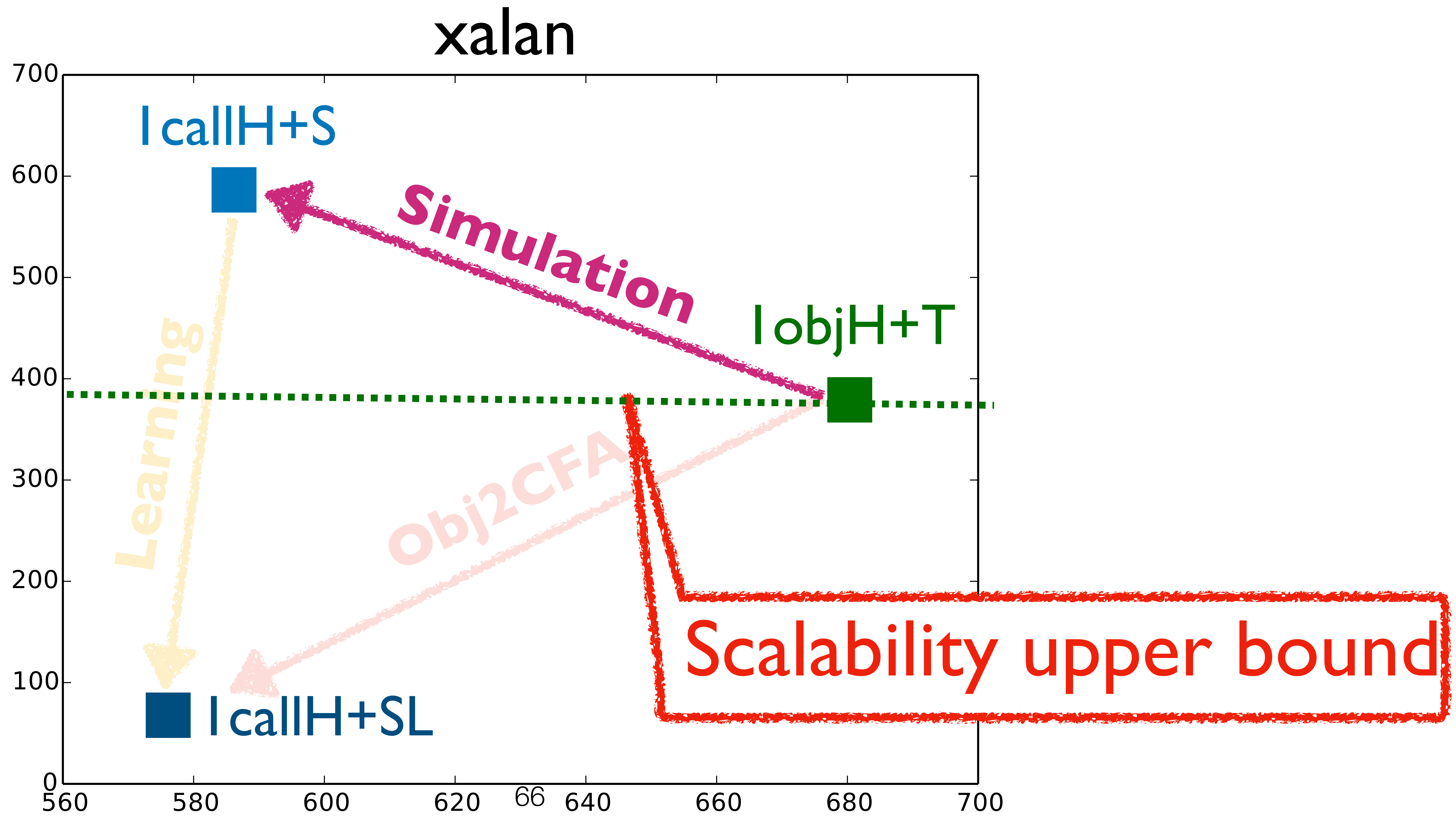


Limitation

Simulation is expensive!

Our Technique : **Obj2CFA**

- **Obj2CFA** consists of **simulation** and simulation-guided **learning**

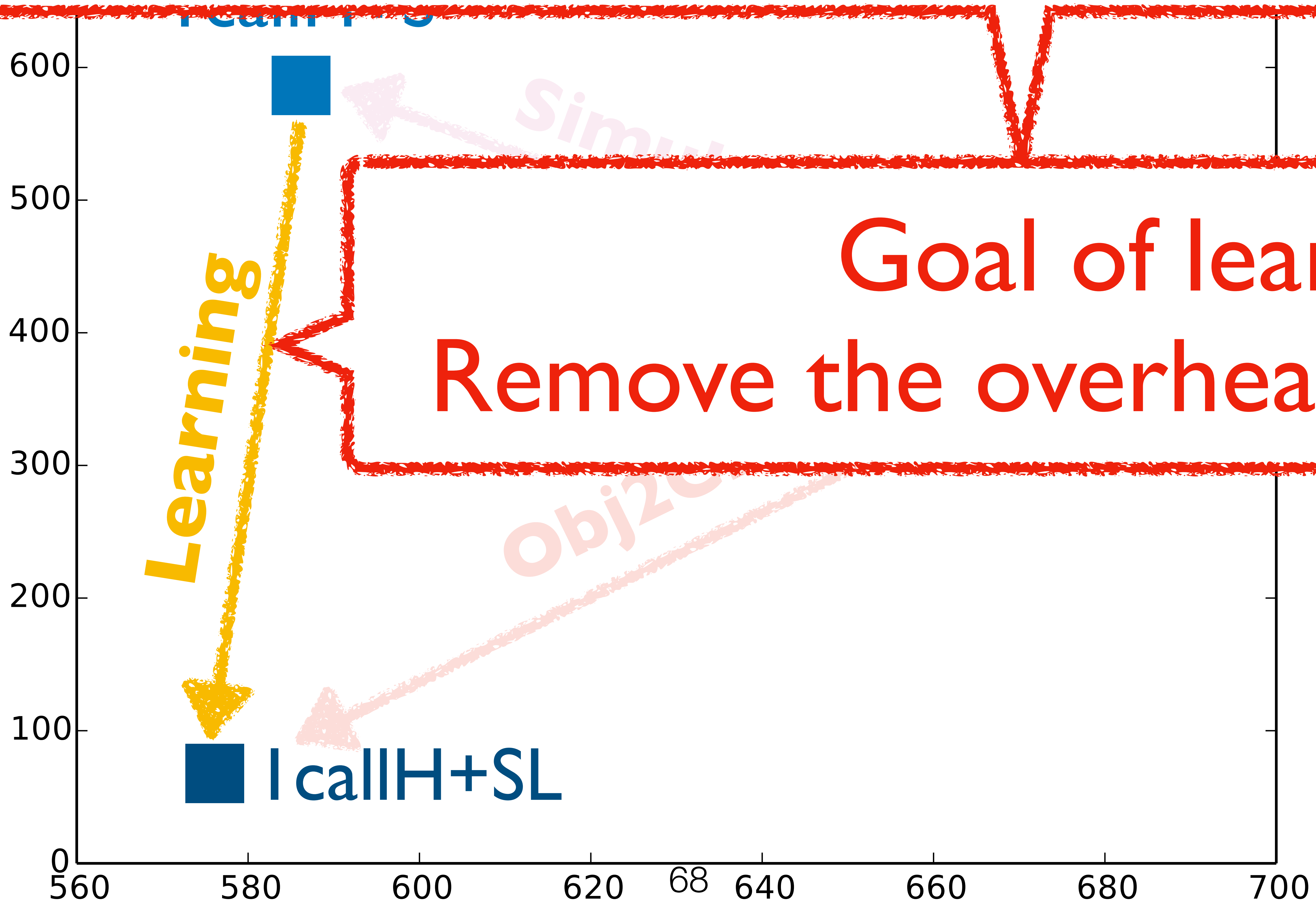


Our Technique : **Obj2CFA**

- **Obj2CFA** consists of **simulation** and simulation-guided **learning**

Our Technique : Obj2CFA

Given training programs and simulated tunneling abstractions, learning aims to find a model that produces similar tunneling abstractions without running the given object sensitivity

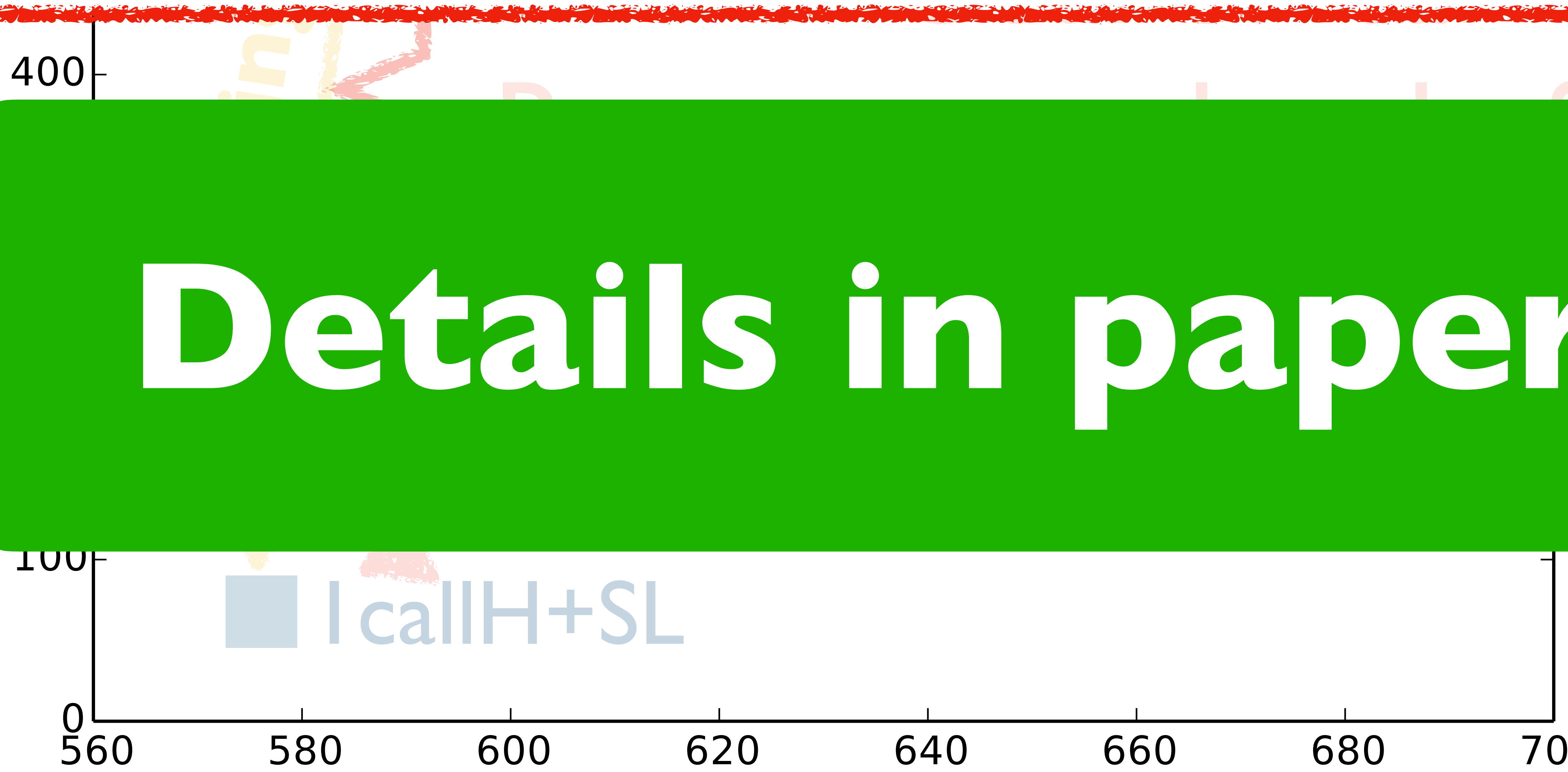


Goal of learning:
Remove the overhead of simulation

Our Technique : Obj2CFA

Given training programs and simulated tunneling abstractions, learning aims to find a model that produces similar tunneling

The learned model will produce tunneling abstractions without running object sensitivity



…ulation

Details in paper

Evaluation

Setting

- Doop
  - Pointer analysis framework for Java

- Research Question: which one is better?

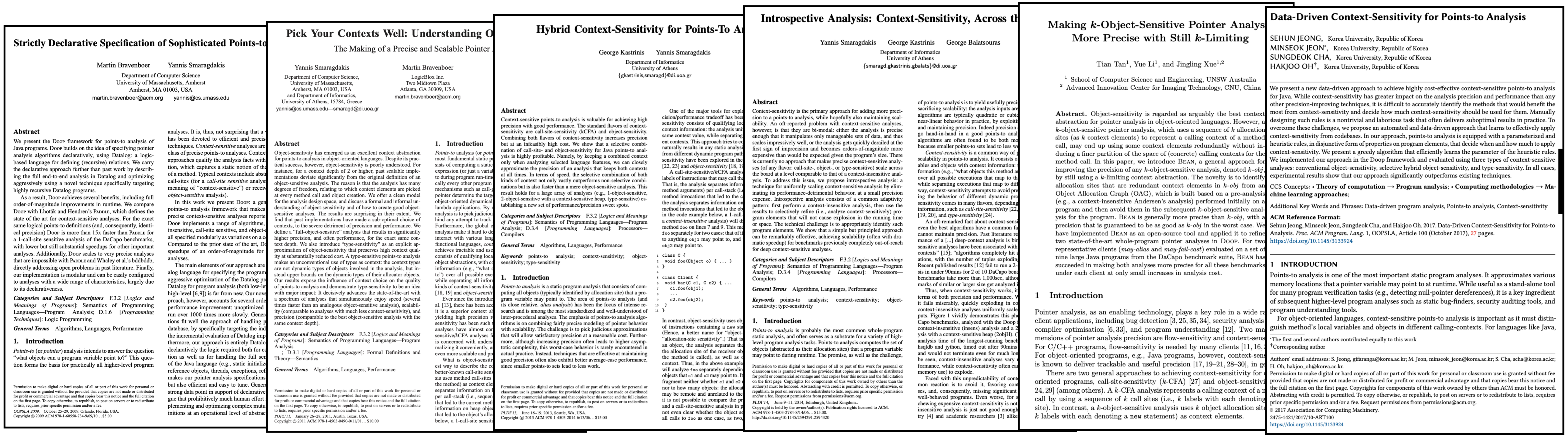
Call-site sensitivity vs Object sensitivity

Context tunneling is included

Setting

- Doop

Negative results on CFA have been **repeatedly** reported on Doop



2009 (OOPSLA) | 2011 (POPL) | 2013 (PLDI) | 2014 (PLDI) | 2016 (SAS) | 2017 (OOPSLA)

...

Setting

- Doop
  - Pointer analysis framework for Java

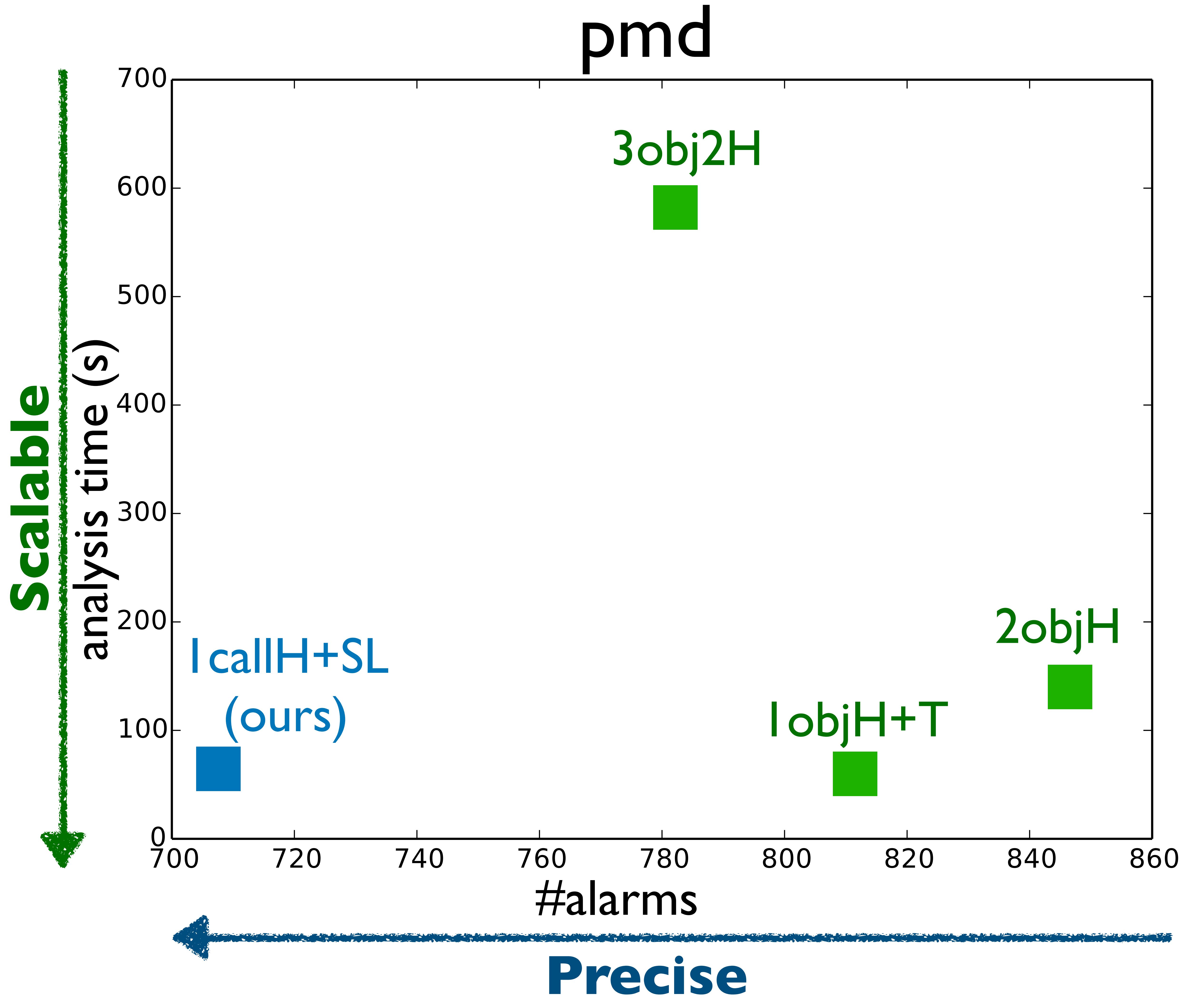
- Research Question: which one is better?

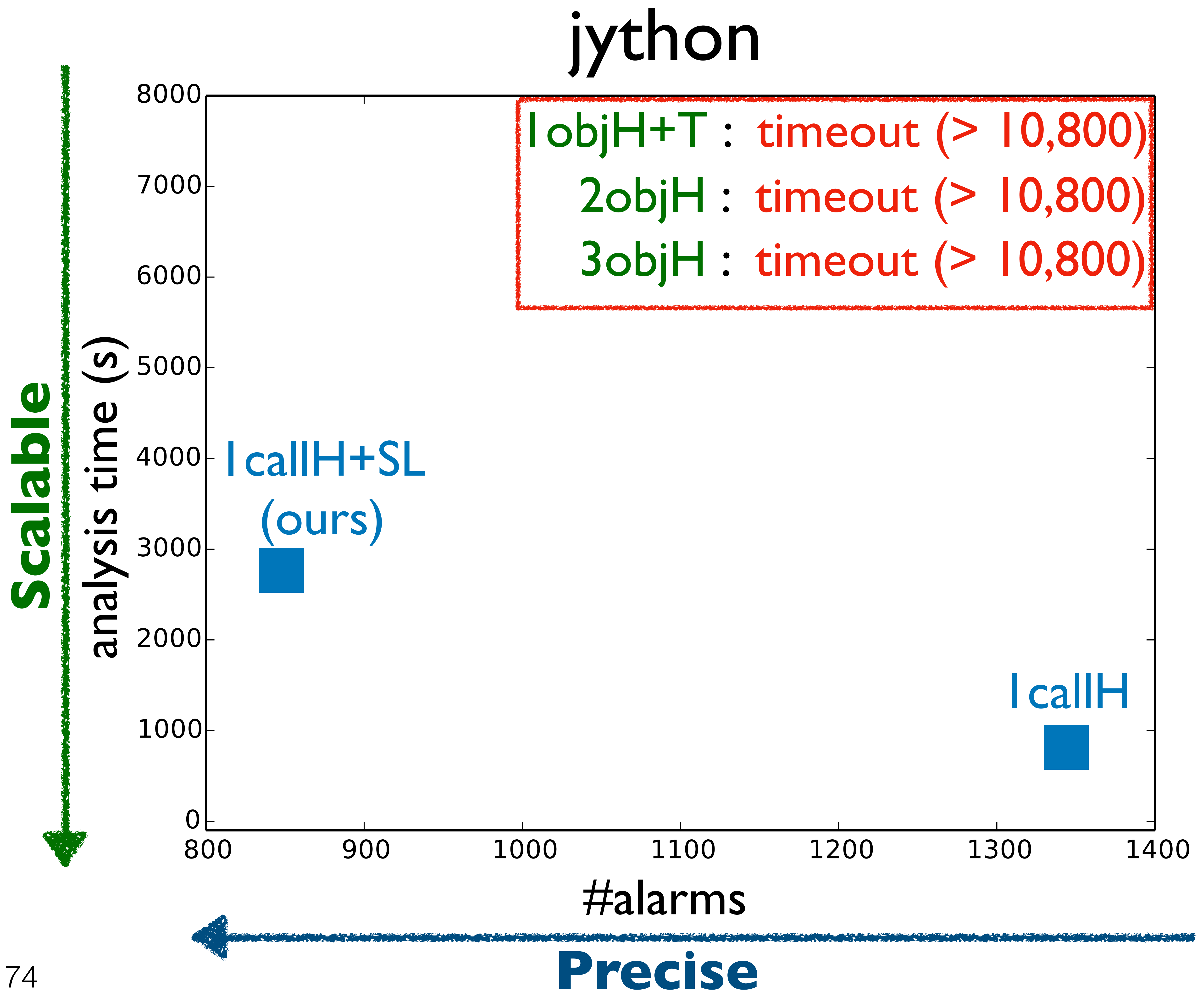
Call-site sensitivity vs Object sensitivity

Context tunneling is included

Call-site Sensitivity vs Object Sensitivity

- 1callH+SL (ours) is more precise and scalable than the existing object sensitivities





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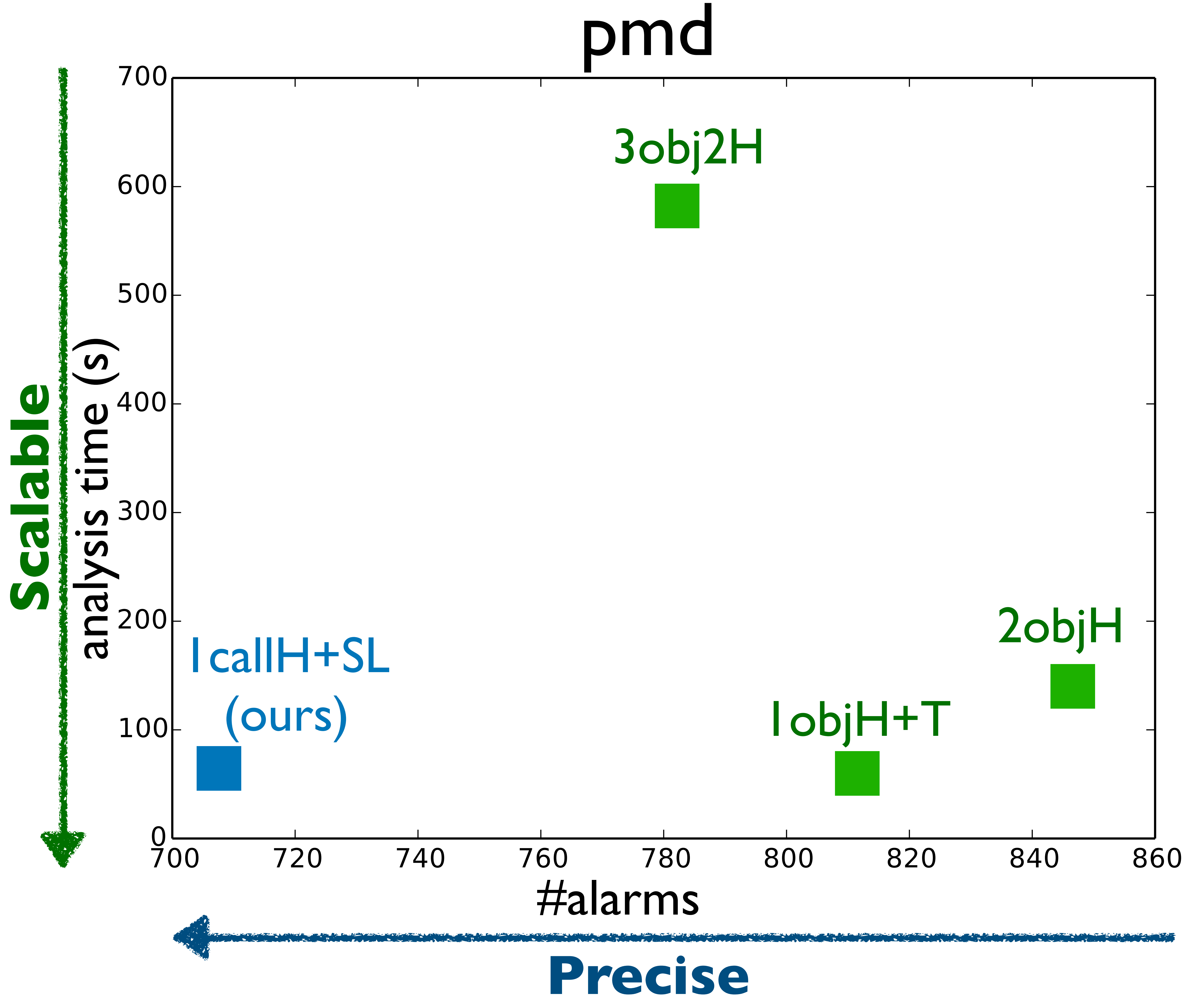

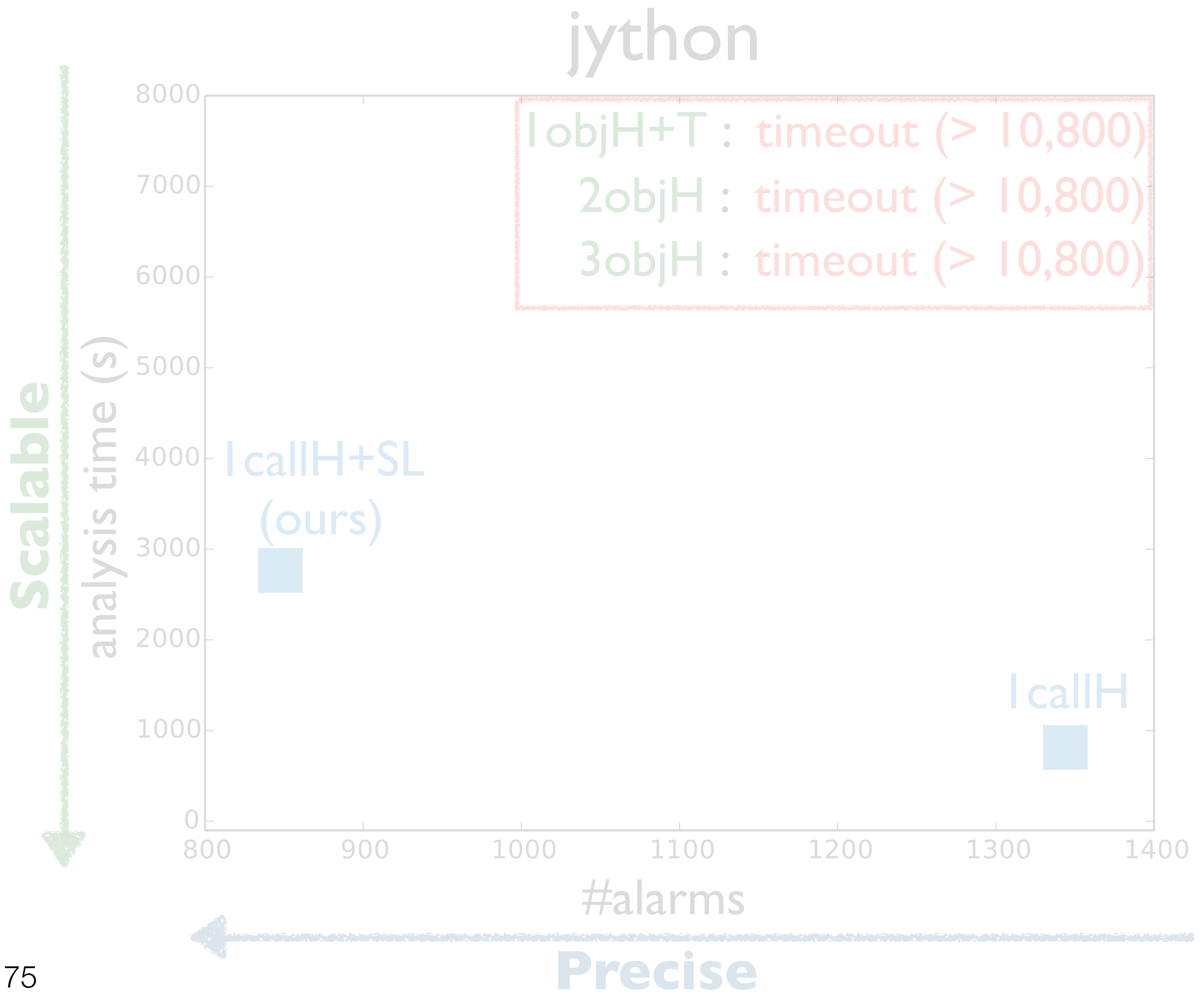

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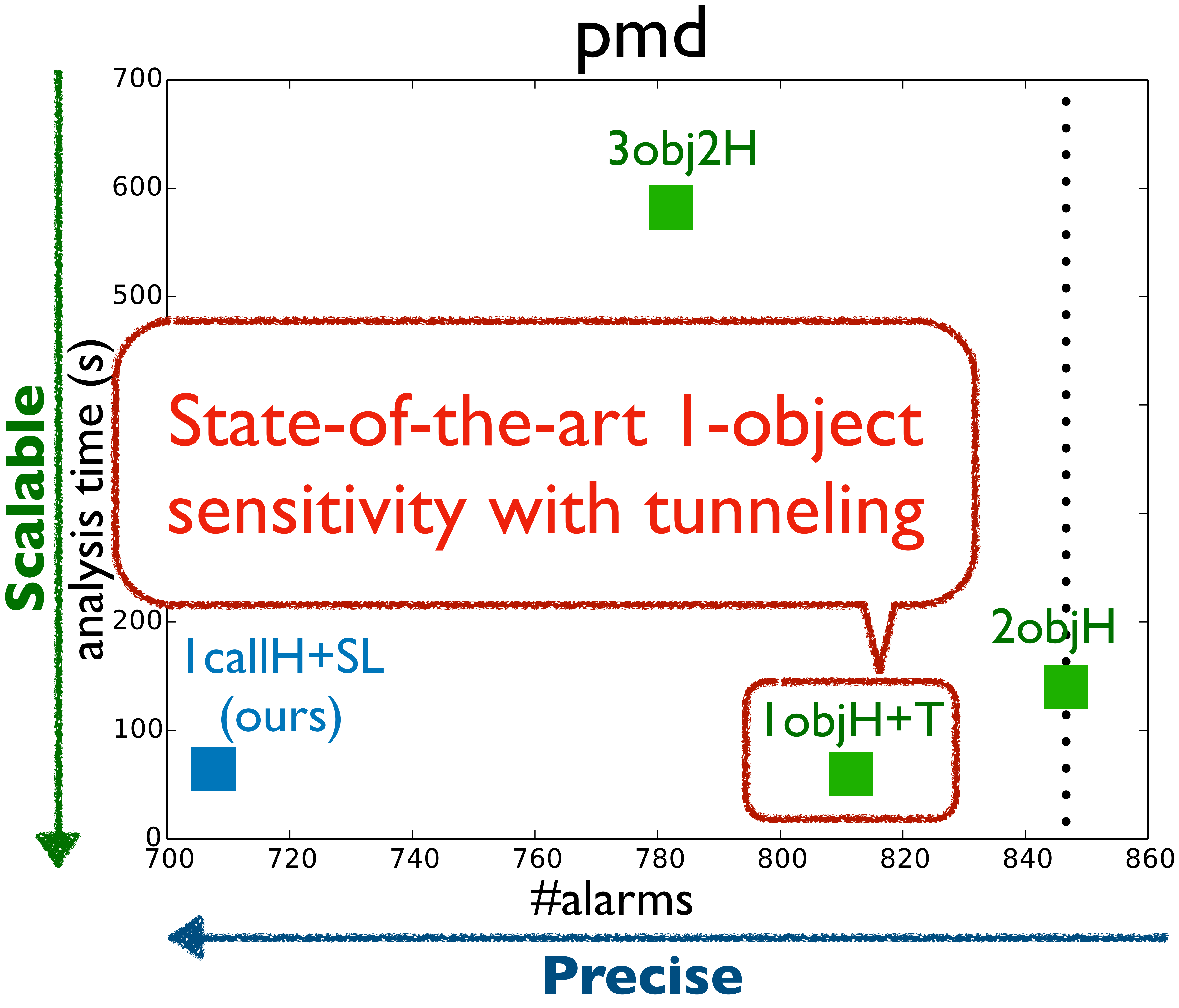

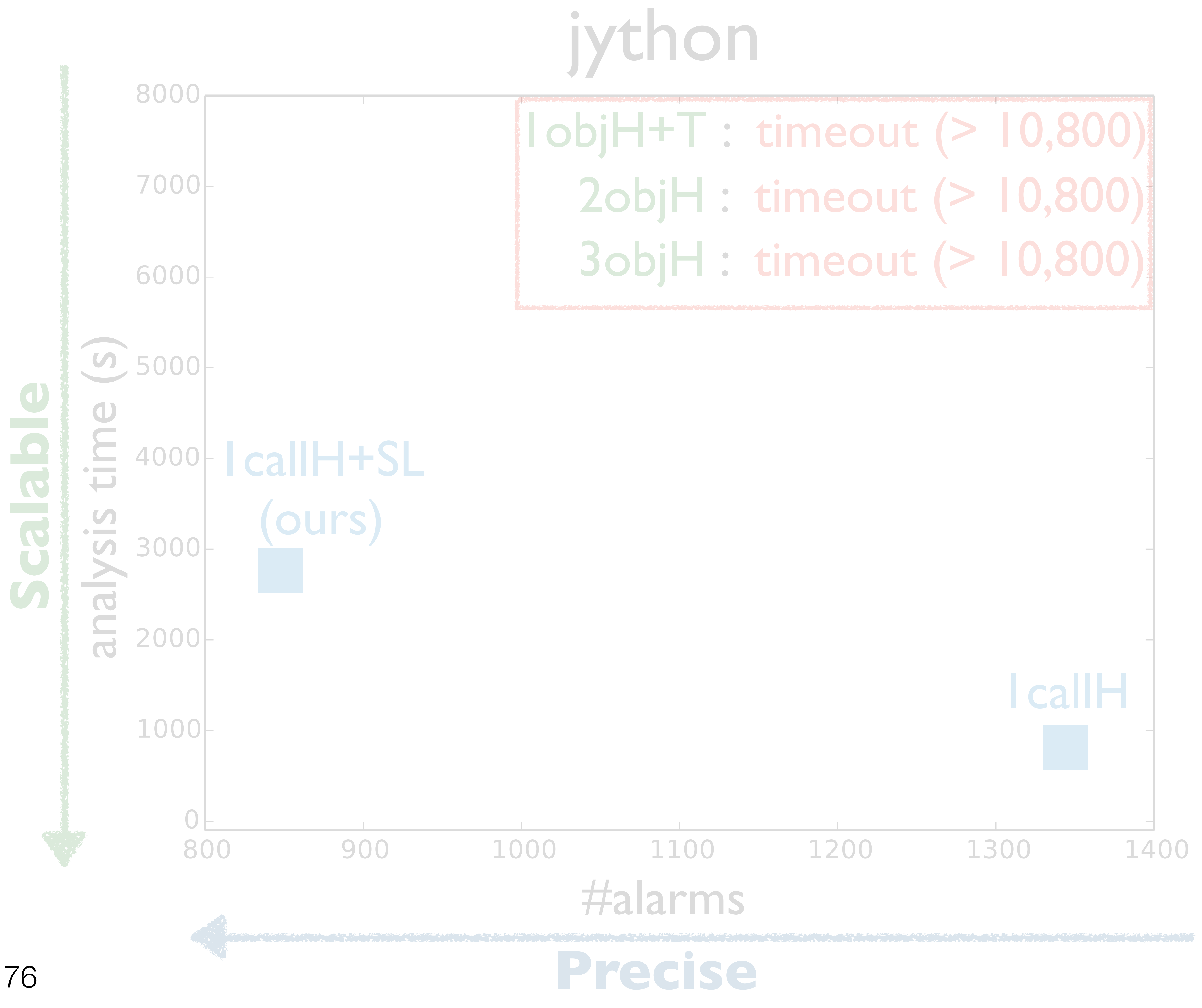

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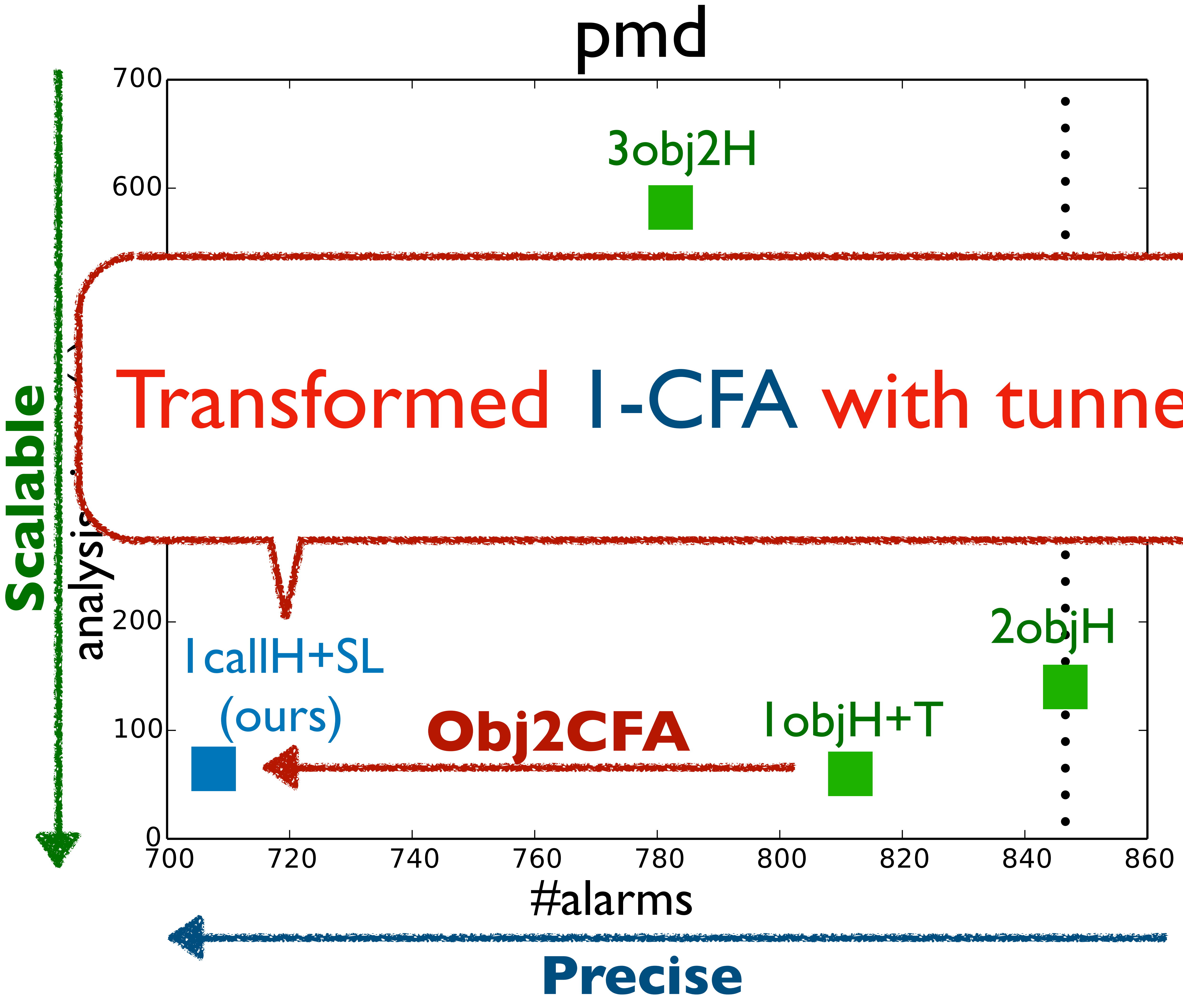
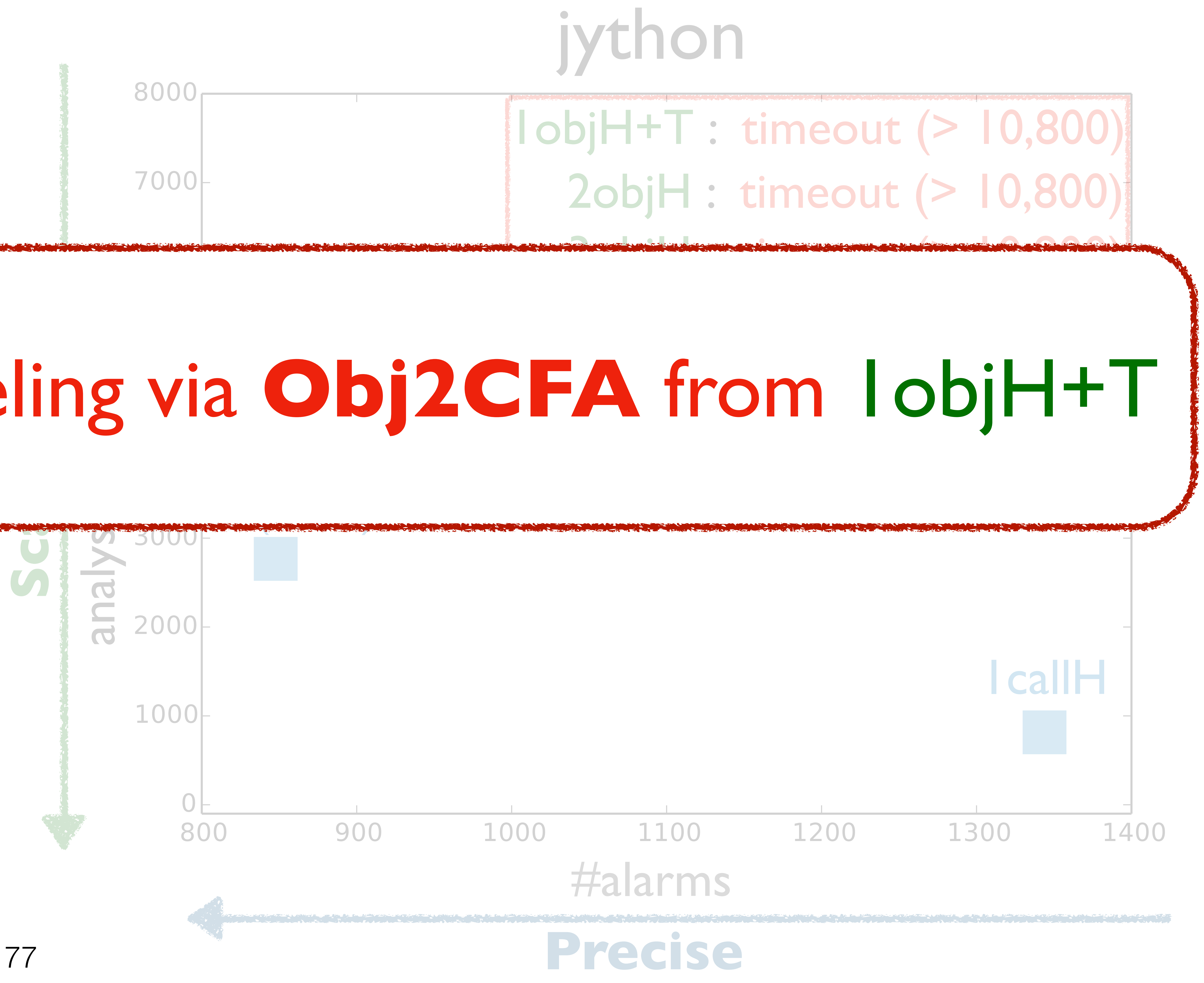
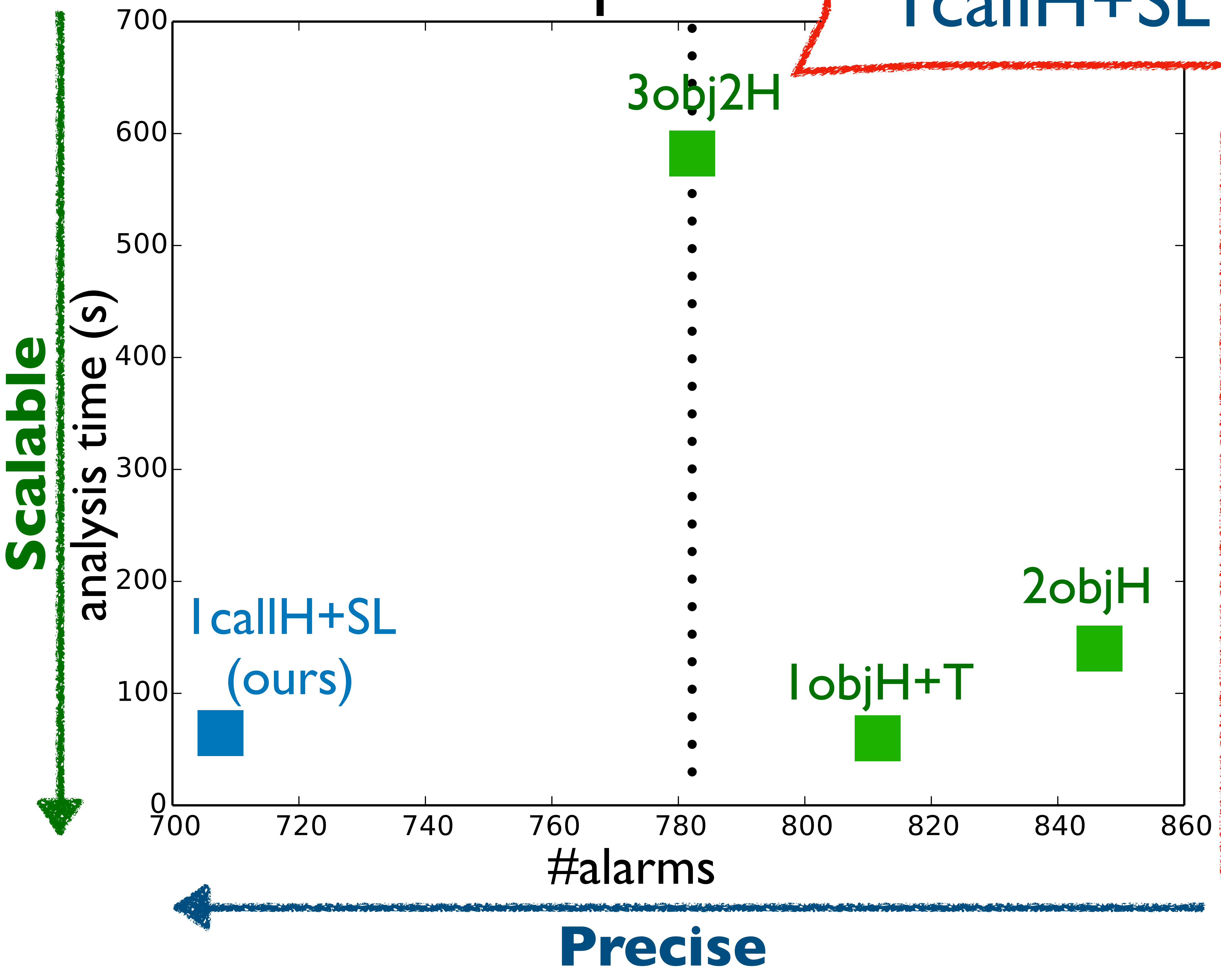




Transformed 1-CFA with tunneling via **Obj2CFA** from 1objH+T

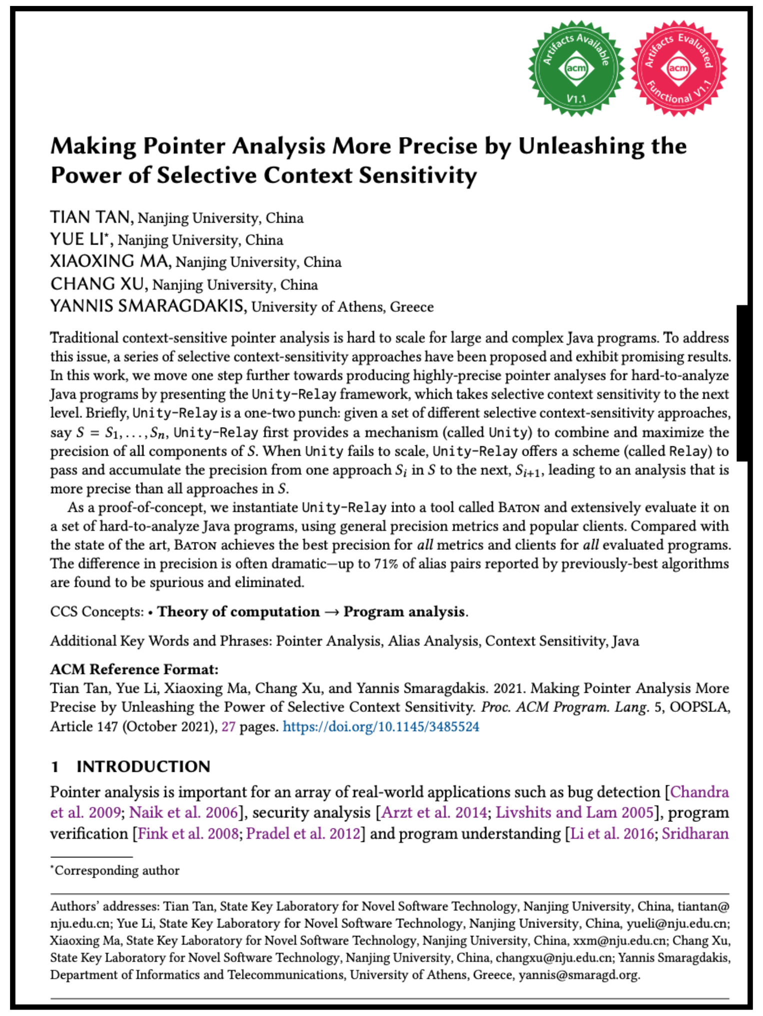
Call-site Sensitivity vs Object Sensitivity

- 1callH+SL (ours) is more precise and scalable than the existing object sensitivities



1callH+SL is even more precise than 3obj2H

Precision upper bound of recent researches on object sensitivity



Making Pointer Analysis More Precise by Unleashing the Power of Selective Context Sensitivity

TIAN TAN, Nanjing University, China
YUE LI*, Nanjing University, China
XIAOXING MA, Nanjing University, China
CHANG XU, Nanjing University, China
YANNIS SMARAGDAKIS, University of Athens, Greece

Traditional context-sensitive pointer analysis is hard to scale for large and complex Java programs. To address this issue, a series of selective context-sensitivity approaches have been proposed and exhibit promising results. In this work, we move one step further towards producing highly-precise pointer analyses for hard-to-analyze Java programs by presenting the Unity-Relay framework, which takes selective context sensitivity to the next level. Briefly, Unity-Relay is a one-two punch: given a set of different selective context-sensitivity approaches, say $S = S_1, \ldots, S_n$, Unity-Relay first provides a mechanism (called Unity) to combine and maximize the precision of all components of S. When Unity fails to scale, Unity-Relay offers a scheme (called Relay) to pass and accumulate the precision from one approach S_i in S to the next, S_{i+1}, leading to an analysis that is more precise than all approaches in S.

As a proof-of-concept, we instantiate Unity-Relay into a tool called Baton and extensively evaluate it on a set of hard-to-analyze Java programs, using general precision metrics and popular clients. Compared with the state of the art, Baton achieves the best precision for *all* metrics and clients for *all* evaluated programs. The difference in precision is often dramatic—up to 71% of alias pairs reported by previously-best algorithms are found to be spurious and eliminated.

CCS Concepts: • **Theory of computation → Program analysis**.

Additional Key Words and Phrases: Pointer Analysis, Alias Analysis, Context Sensitivity, Java

ACM Reference Format:
Tian Tan, Yue Li, Xiaoxing Ma, Chang Xu, and Yannis Smaragdakis. 2021. Making Pointer Analysis More Precise by Unleashing the Power of Selective Context Sensitivity. *Proc. ACM Program. Lang.* 5, OOPSLA, Article 147 (October 2021), 27 pages. https://doi.org/10.1145/3485524

1 INTRODUCTION

Pointer analysis is important for an array of real-world applications such as bug detection [Chandra et al. 2009; Naik et al. 2006], security analysis [Arzt et al. 2014; Livshits and Lam 2005], program verification [Fink et al. 2008; Pradel et al. 2012] and program understanding [Li et al. 2016; Sridharan

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OOPLSA 2021

Precision-Preserving Yet Fast Object-Sensitive Pointer Analysis with Partial Context Sensitivity

JINGBO LU, UNSW Sydney, Australia
JINGLING XUE, UNSW Sydney, Australia

Object-sensitivity is widely used as a context abstraction for computing the points-to information context-sensitively for object-oriented languages like Java. Due to the combinatorial explosion of contexts in large programs, k-object-sensitive pointer analysis (under k-limiting), denoted *k-obj*, is scalable only for small values of k, where $k \leqslant 2$ typically. A few recent solutions attempt to improve its efficiency by instructing *k-obj* to analyze only some methods in the program context-sensitively, determined heuristically by a pre-analysis. While already effective, these heuristics-based pre-analyses do not provide precision guarantees, and consequently, are limited in the efficiency gains achieved. We introduce a radically different approach, Eagle, that makes *k-obj* run significantly faster than the prior art while maintaining its precision. The novelty of Eagle is to enable *k-obj* to analyze a method with partial context-sensitivity, i.e., context-sensitively for only some of its selected variables/allocation sites. Eagle makes these selections during a lightweight pre-analysis by reasoning about context-free-language (CFL) reachability at the level of variables/objects in the program, based on a new CFL-reachability formulation of *k-obj*. We demonstrate the advances made by Eagle by comparing it with the prior art in terms of a set of popular Java benchmarks and applications.

CCS Concepts: • **Theory of computation → Program analysis**.

Additional Key Words and Phrases: Pointer Analysis, Object Sensitivity, CFL Reachability

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1 INTRODUCTION

For object-oriented languages such as Java, context-sensitivity is known to provide highly useful precision for pointer analysis [Lhoták and Hendren 2008; Smaragdakis et al. 2011]. A context-insensitive pointer analysis, such as Andersen's analysis [Andersen 1994], analyzes a method only once, producing one points-to set for every variable and one abstract object for modeling every allocation site in the method. In contrast, its context-sensitive counterpart analyzes a method multiple times under different calling contexts that abstract its different run-time invocations, thereby producing multiple points-to sets for every variable (with one per context) and multiple abstract objects for modeling every allocation site (with one per context) in the method.

To tame the combinatorial explosion of calling contexts, a context is usually represented by a sequence of k context elements, under k-limiting. There are two representative abstractions for object-oriented programs: (1) *k-callsite-sensitivity* [Shivers 1991], which distinguishes the contexts of a method by its k-most-recent callsites, and (2) *k-object-sensitivity* [Milanova et al. 2005], which

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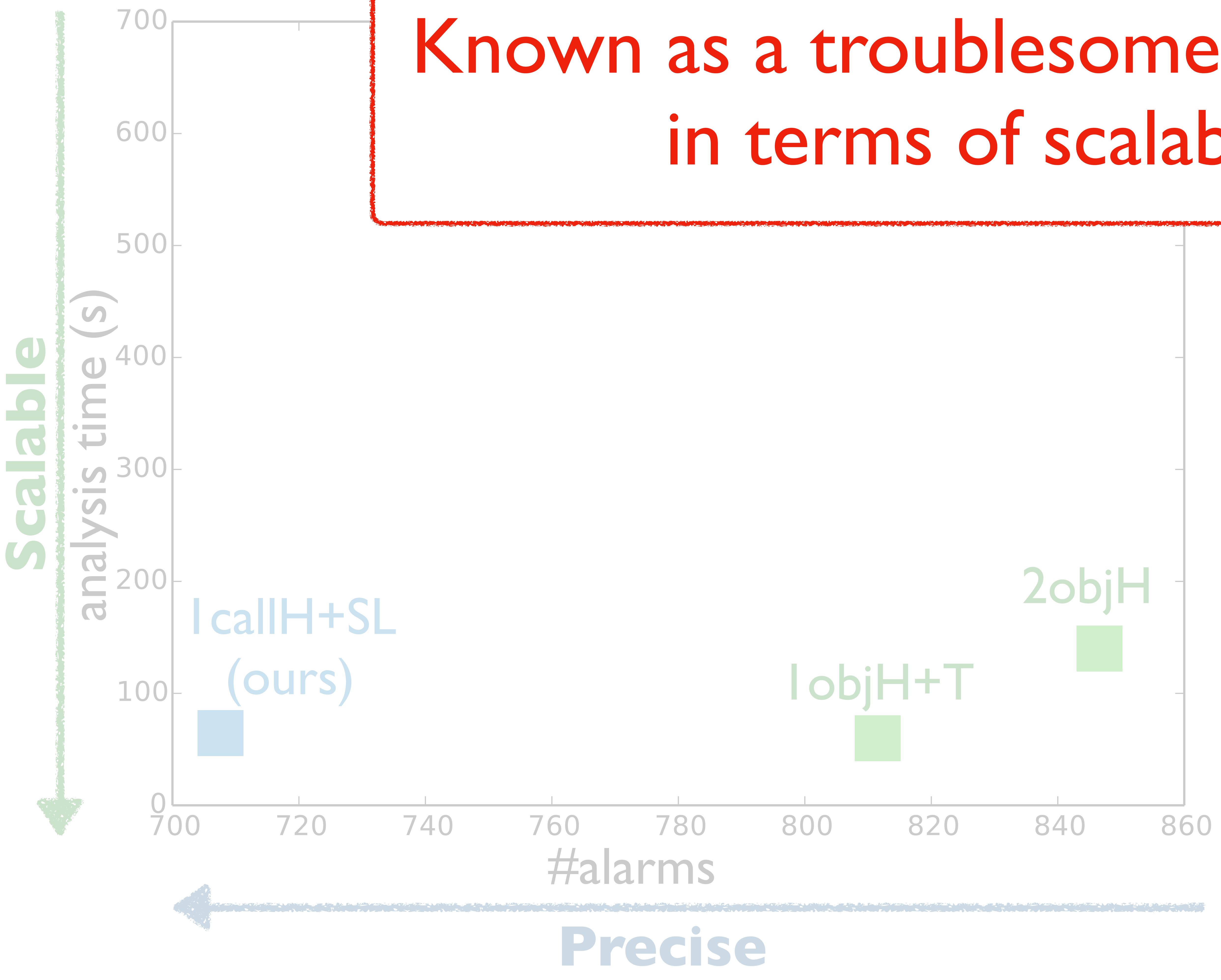
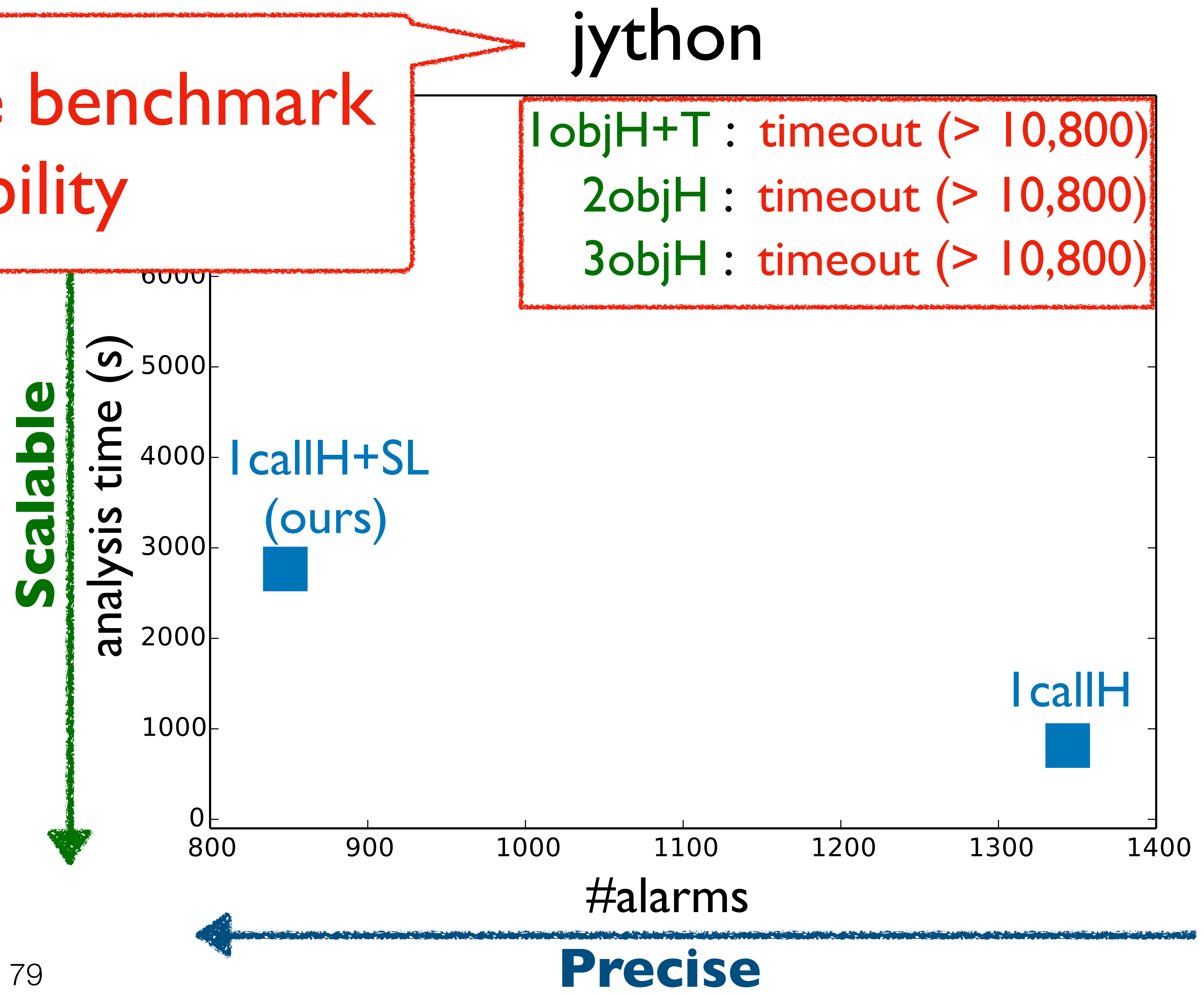
OOPLSA 2019

Call-site Sensitivity vs Object Sensitivity

- 1callH+SL (ours) is more precise and scalable than the existing object sensitivities

Known as a troublesome benchmark in terms of scalability





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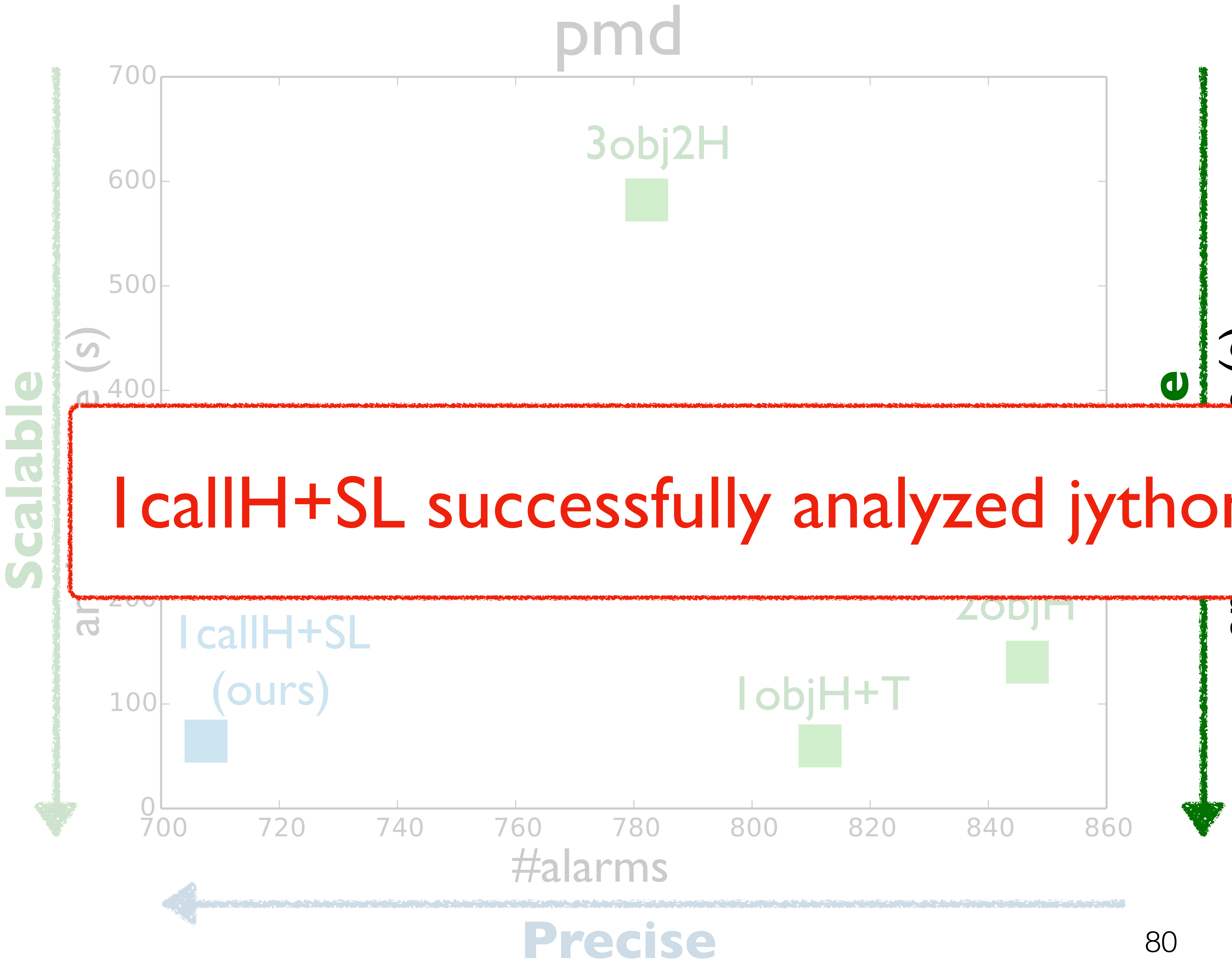
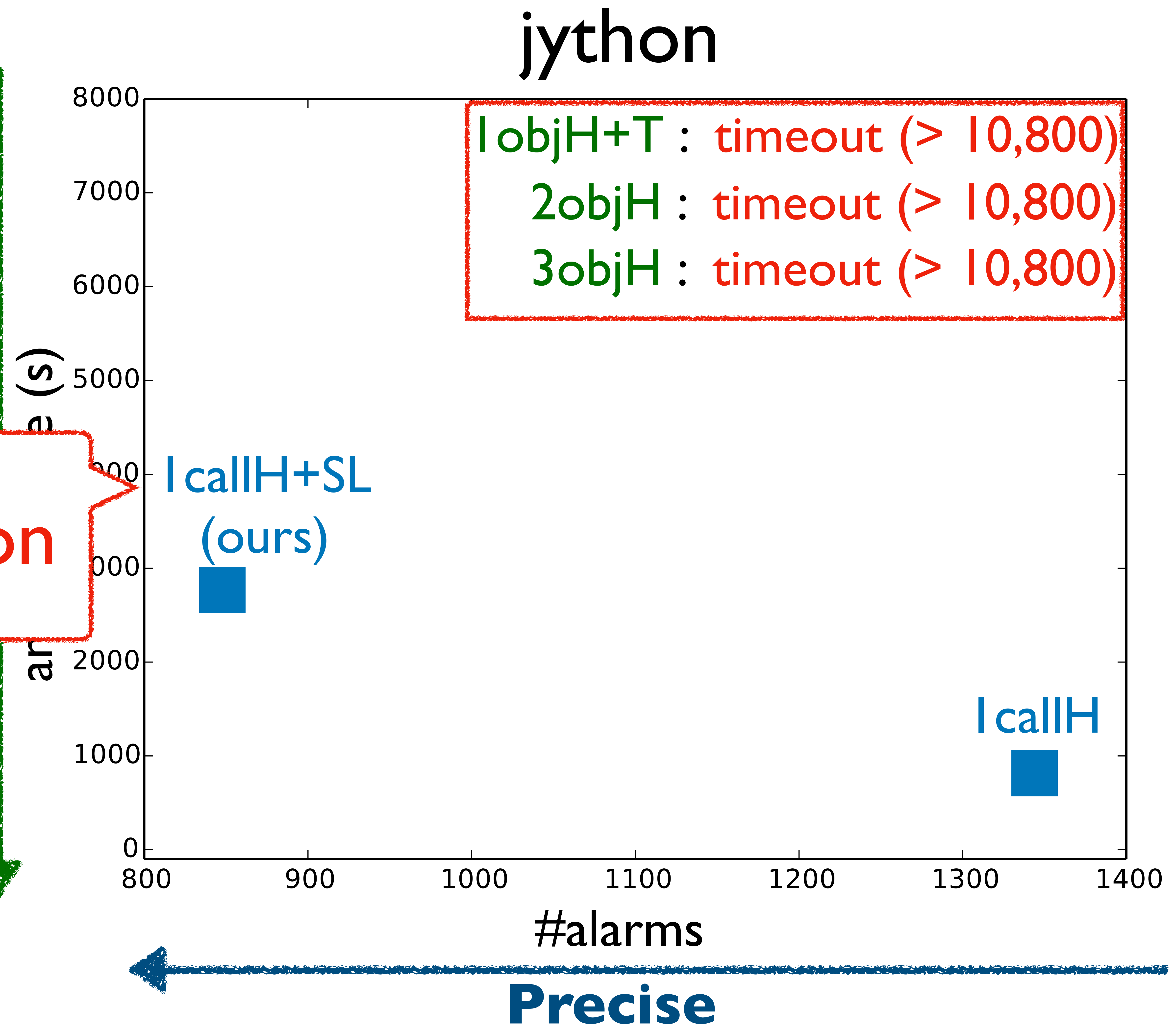


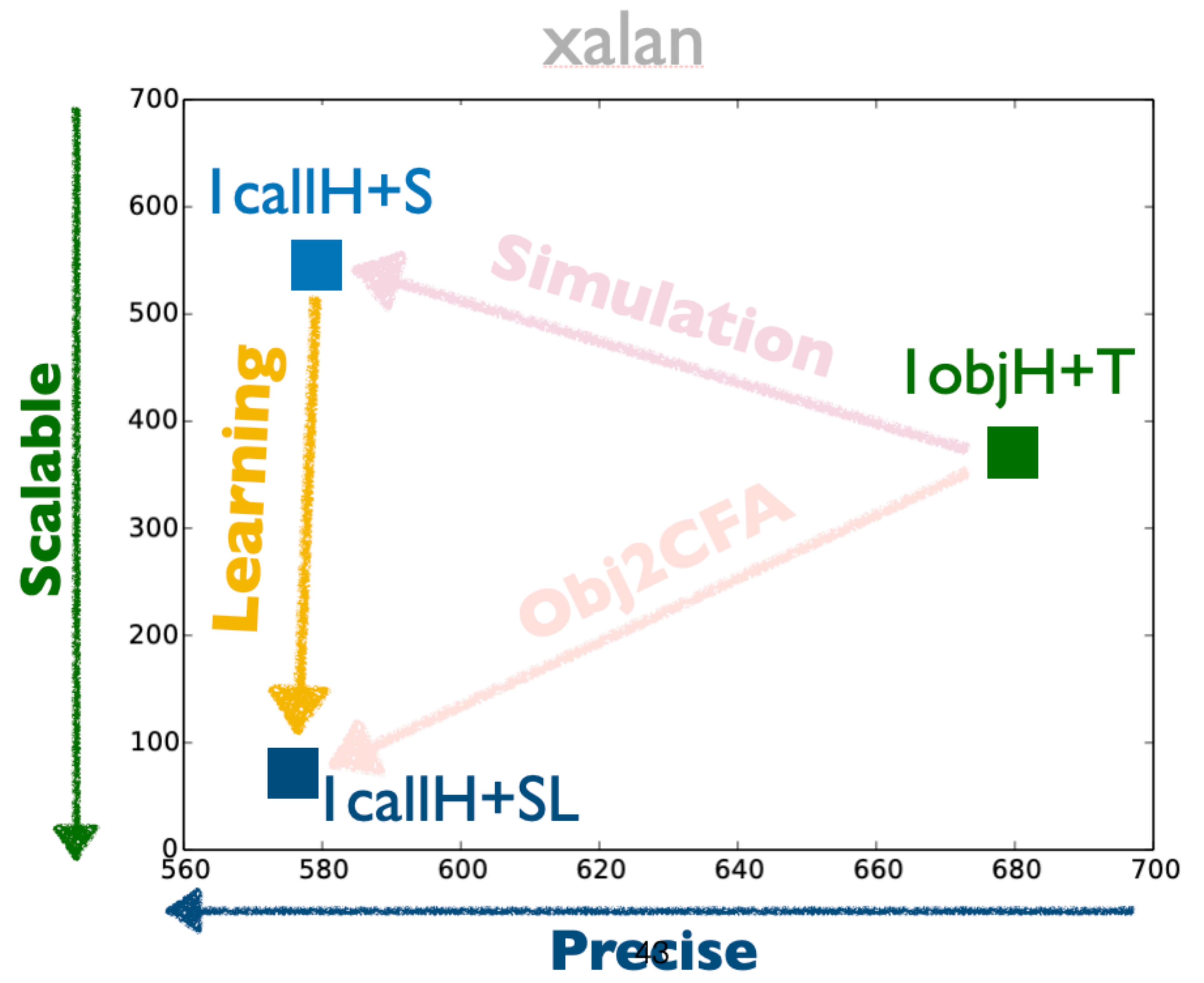
1callH+SL successfully analyzed jython

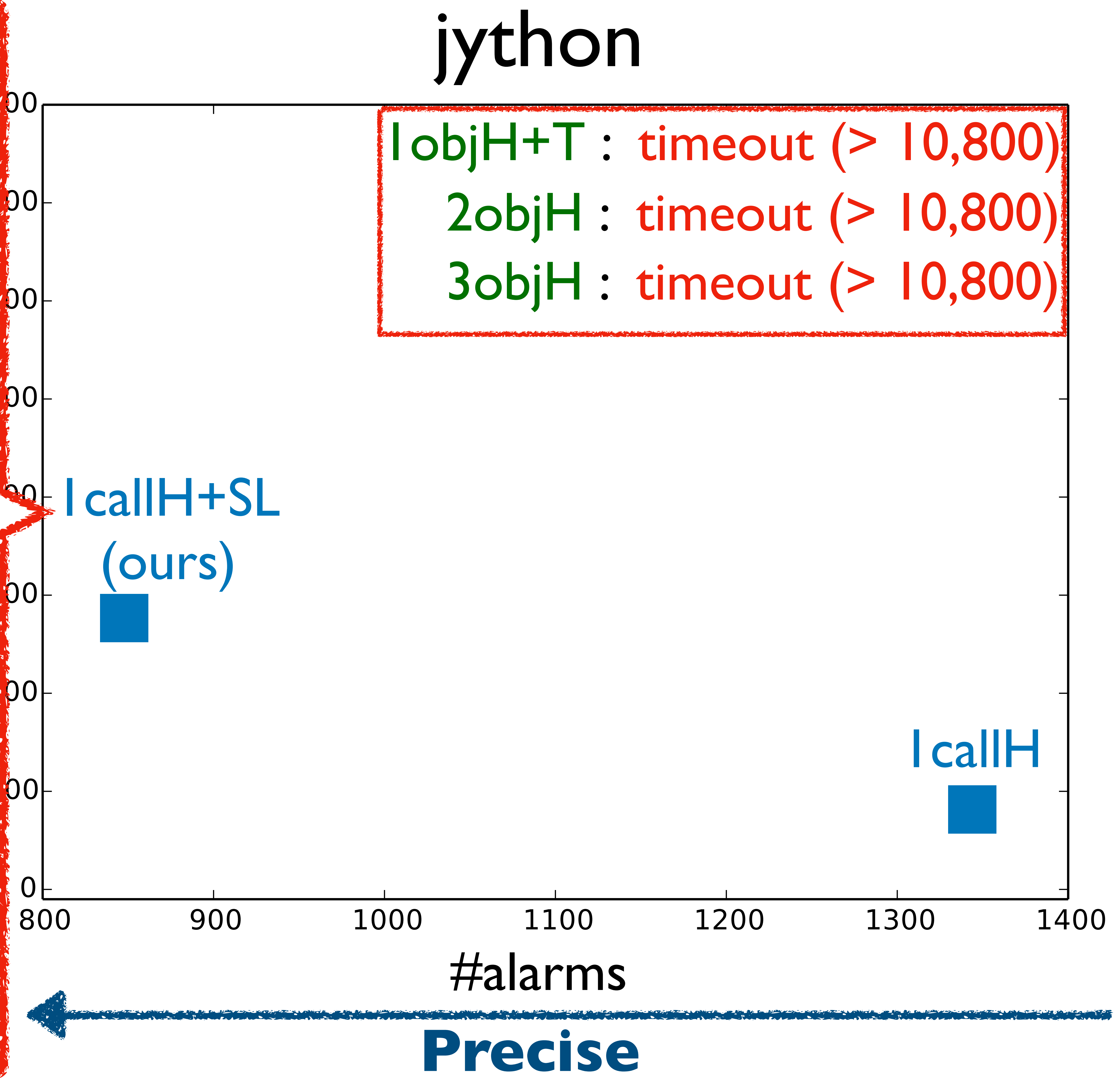


Call-site Sensitivity vs Object Sensitivity

- 1callH+SL (ours) is more precise and scalable than the existing object sensitivities

- Necessity of learning
- 1callH+S is unable to analyze jython





Summary

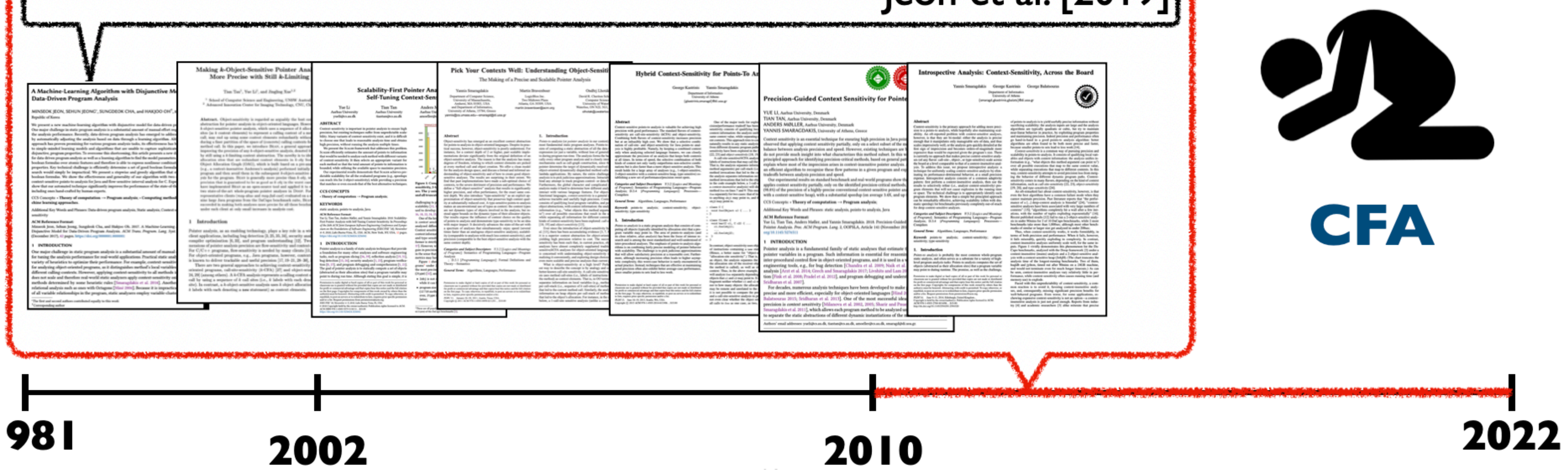
- Currently, CFA is known as a bad context
- However, if context tunneling is included, CFA is not a bad context anymore
- We need to reconsider CFA from now on

Thank you

Summary

- Currently, CFA is known as a bad context
  - Call-site Sensitivity has been ignored

"… call-site-sensitivity is less important than others …"
- Jeon et al. [2019]



Summary

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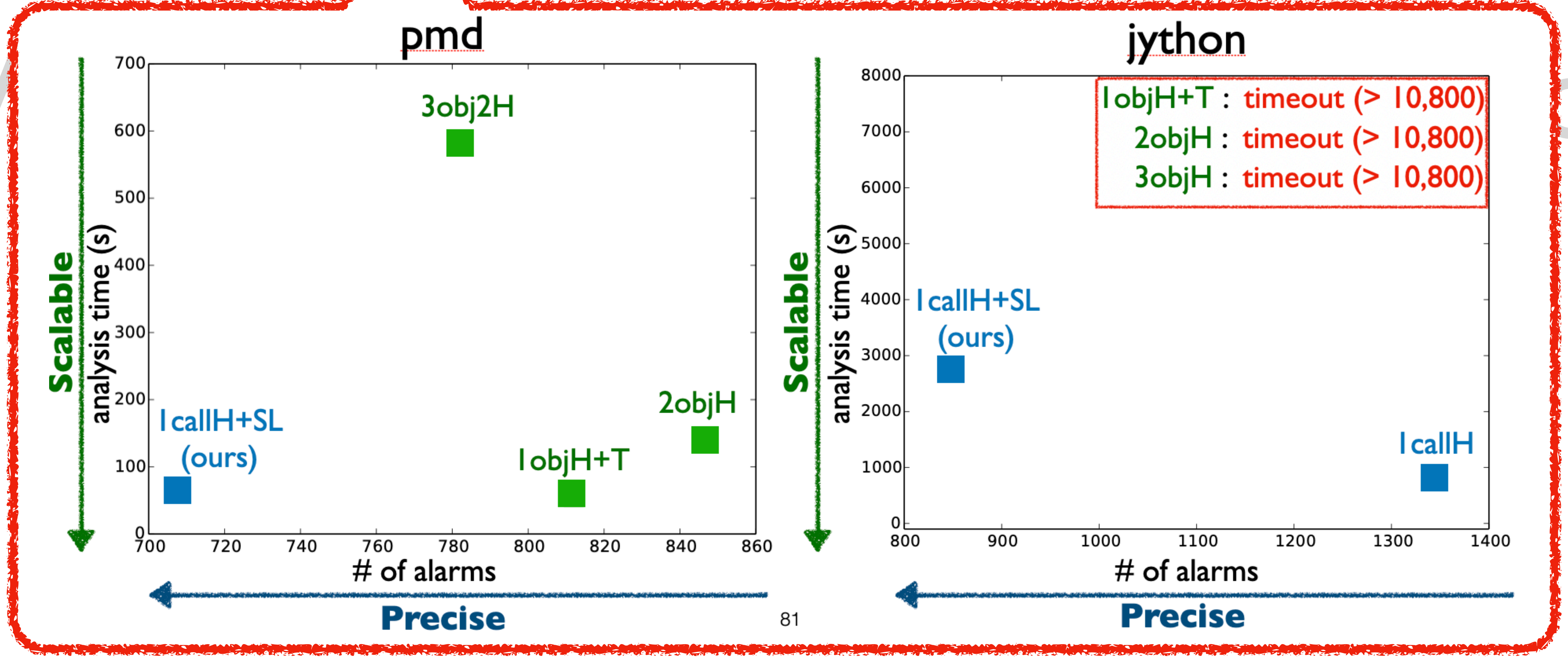
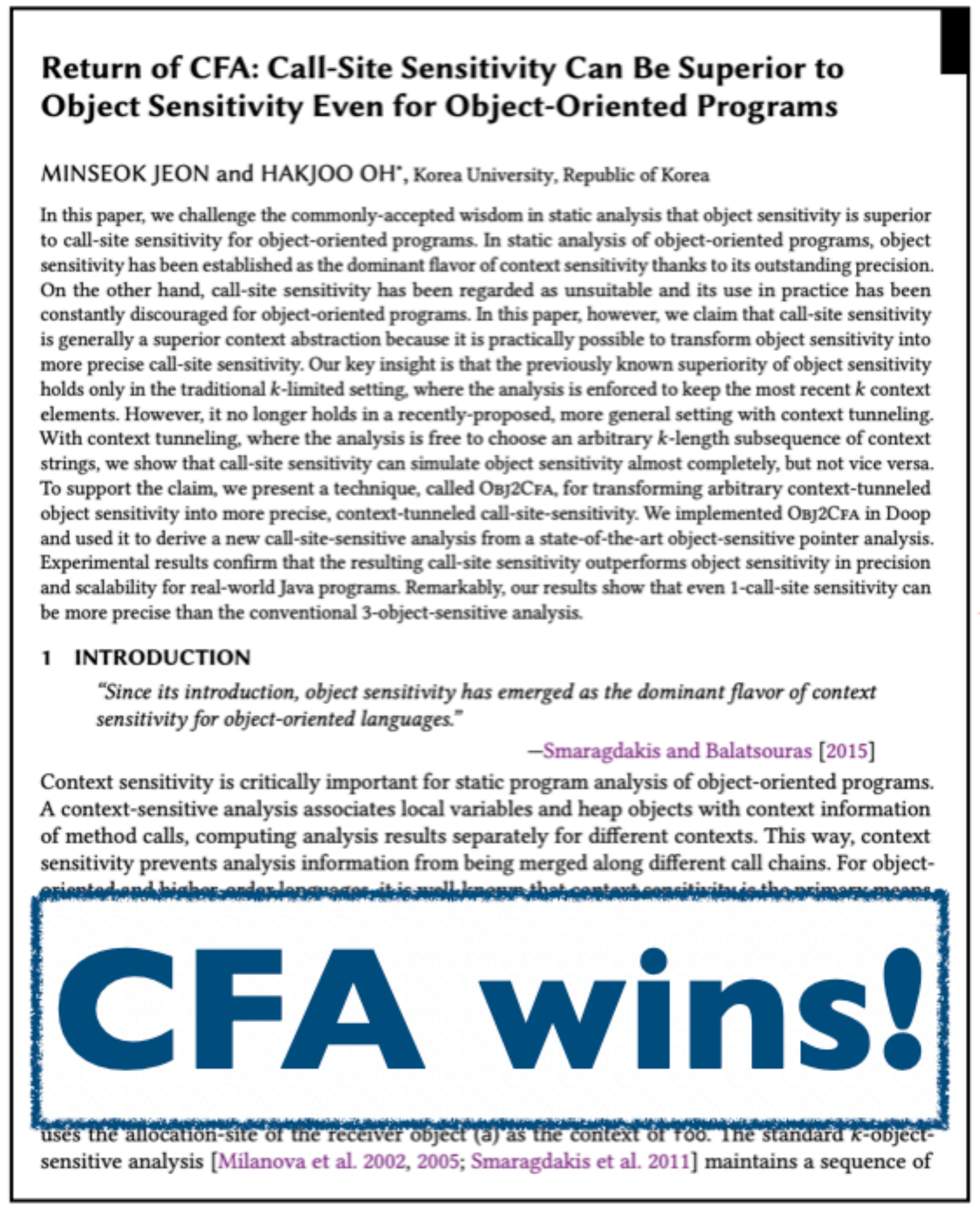


- W... om now on



Return of CFA: Call-Site Sensitivity Can Be Superior to Object Sensitivity Even for Object-Oriented Programs

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In this paper, we challenge the commonly-accepted wisdom in static analysis that object sensitivity is superior to call-site sensitivity for object-oriented programs. In static analysis of object-oriented programs, object sensitivity has been established as the dominant flavor of context sensitivity thanks to its outstanding precision. On the other hand, call-site sensitivity has been regarded as unsuitable and its use in practice has been constantly discouraged for object-oriented programs. In this paper, however, we claim that call-site sensitivity is generally a superior context abstraction because it is practically possible to transform object sensitivity into more precise call-site sensitivity. Our key insight is that the previously known superiority of object sensitivity holds only in the traditional *k*-limited setting, where the analysis is enforced to keep the most recent *k* context elements. However, it no longer holds in a recently-proposed, more general setting with context tunneling. With context tunneling, where the analysis is free to choose an arbitrary *k*-length subsequence of context strings, we show that call-site sensitivity can simulate object sensitivity almost completely, but not vice versa. To support the claim, we present a technique, called Obj2Cfa, for transforming arbitrary context-tunneled object sensitivity into more precise, context-tunneled call-site-sensitivity. We implemented Obj2Cfa in Doop and used it to derive a new call-site-sensitive analysis from a state-of-the-art object-sensitive pointer analysis. Experimental results confirm that the resulting call-site sensitivity outperforms object sensitivity in precision and scalability for real-world Java programs. Remarkably, our results show that even 1-call-site sensitivity can be more precise than the conventional 3-object-sensitive analysis.

1 INTRODUCTION

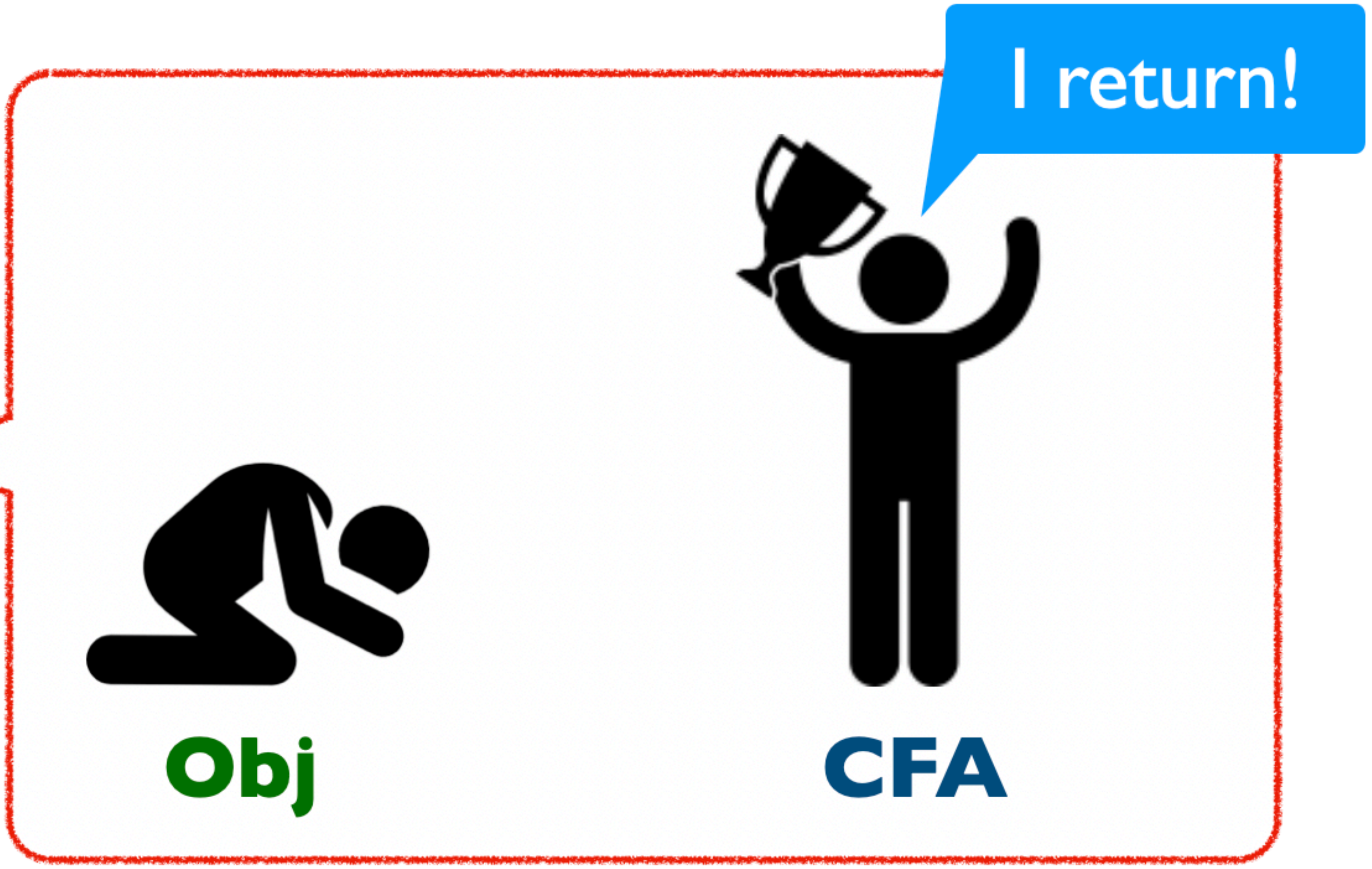
"Since its introduction, object sensitivity has emerged as the dominant flavor of context sensitivity for object-oriented languages."

—Smaragdakis and Balatsouras [2015]

Context sensitivity is critically important for static program analysis of object-oriented programs. A context-sensitive analysis associates local variables and heap objects with context information of method calls, computing analysis results separately for different contexts. This way, context sensitivity prevents analysis information from being merged along different call chains. For object-oriented and higher-order languages, it is well known that context sensitivity is the primary means

CFA wins!

uses the allocation-site of the receiver object (a) as the context of foo. The standard *k*-object-sensitive analysis [Milanova et al. 2002, 2005; Smaragdakis et al. 2011] maintains a sequence of



- We need to reconsider CFA from now on

Thank you