Testing the Binding Code of Scripting Languages with Cooperative Mutation

Peng Xu Yanhao Wang **Hong Hu** Purui Su

PennState

Scripting Language

Scripting Language

Scripting Language integrated to documents

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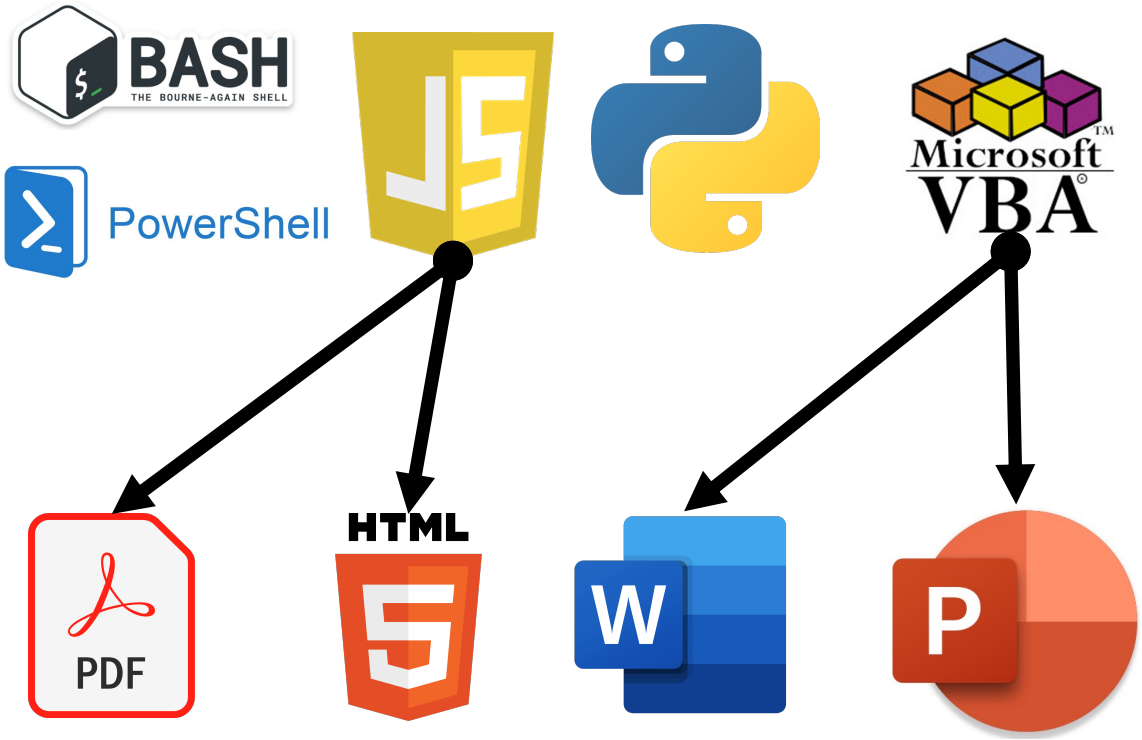

Vulnerability in Embedded Scripting Language

- Dangerous and Common

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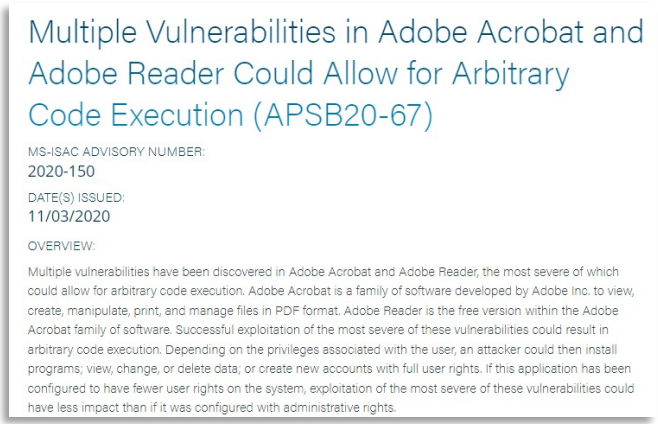

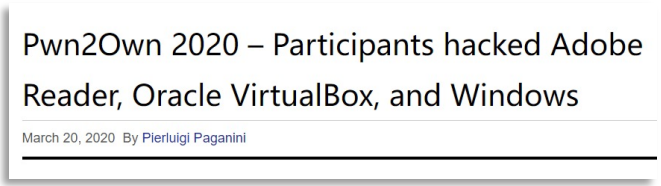

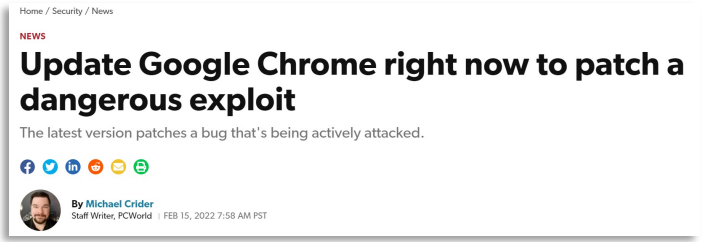

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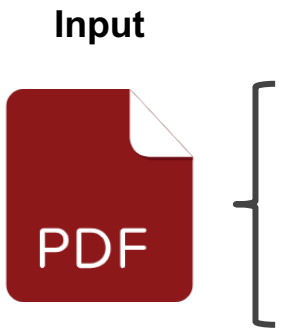
- Open-sourced at: https://github.com/TCA-ISCAS/Cooper

Document processing programs

- Input: Native objects + Scripts code



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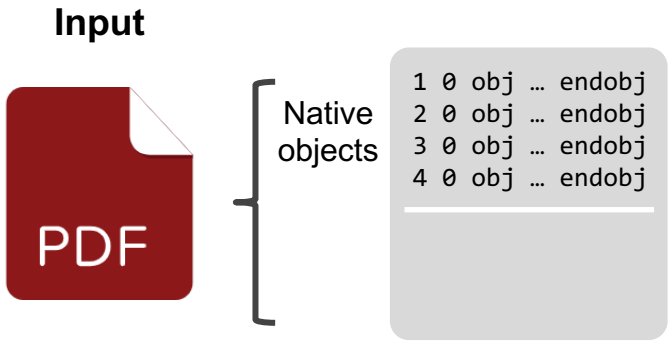

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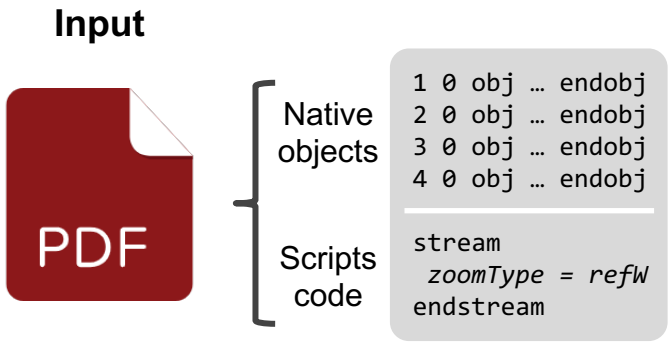

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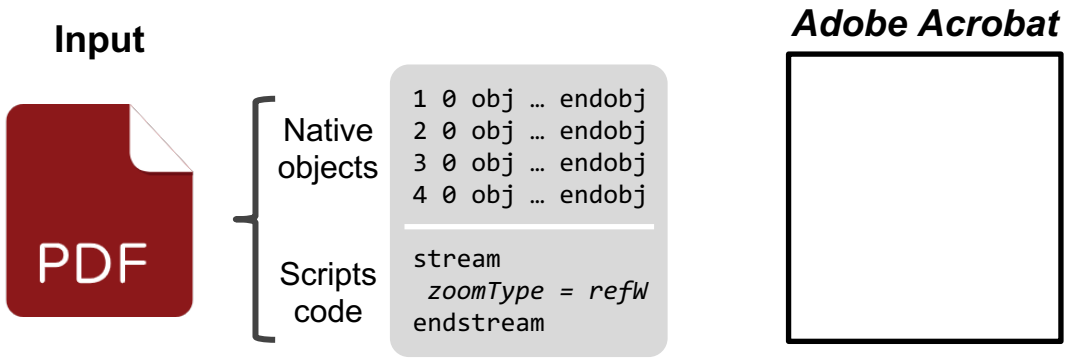

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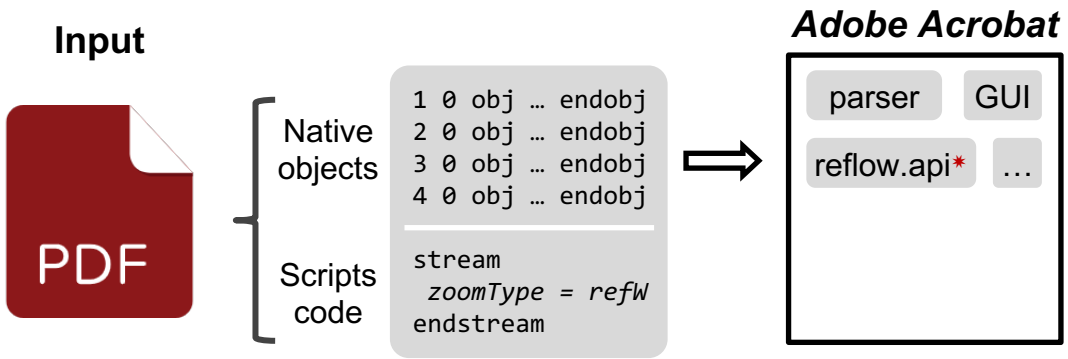

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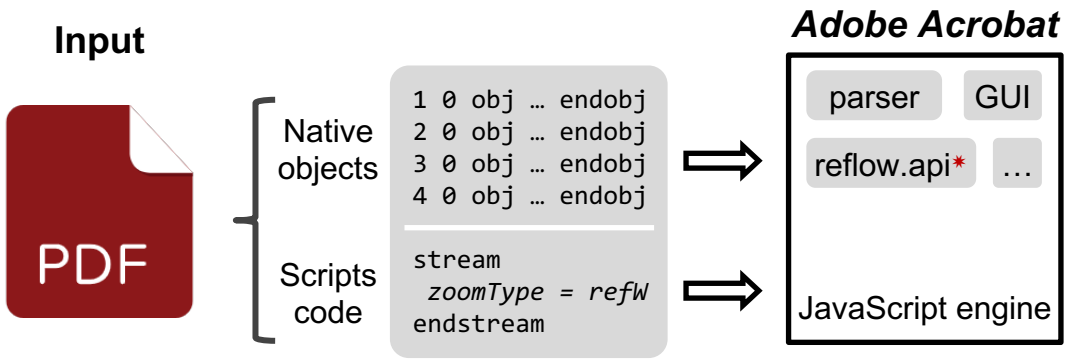

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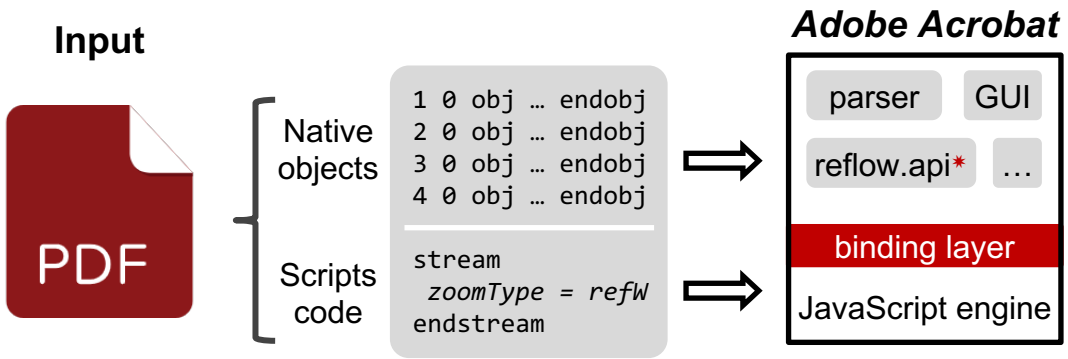

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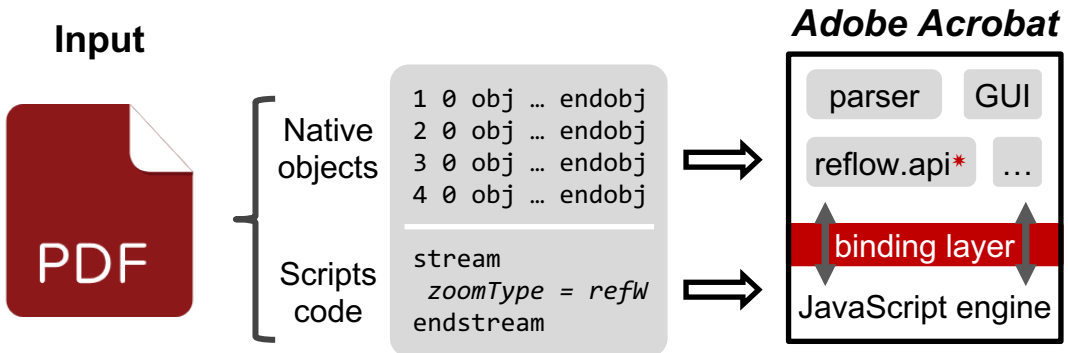

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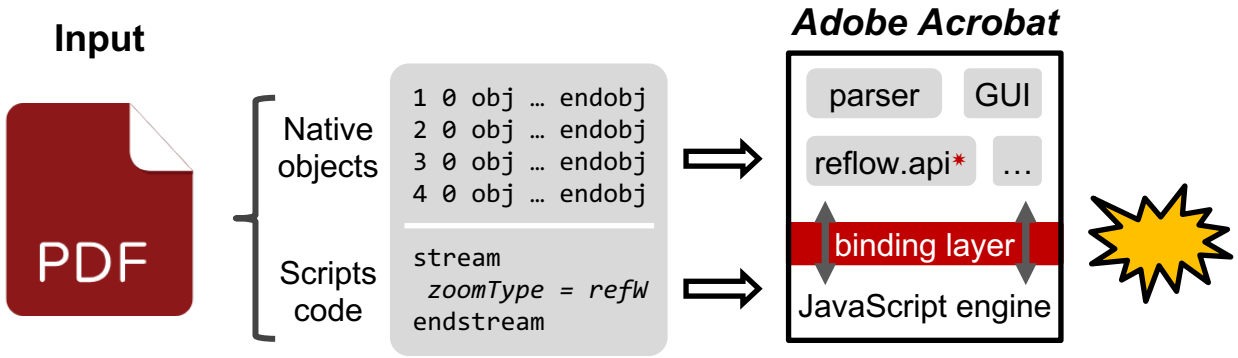

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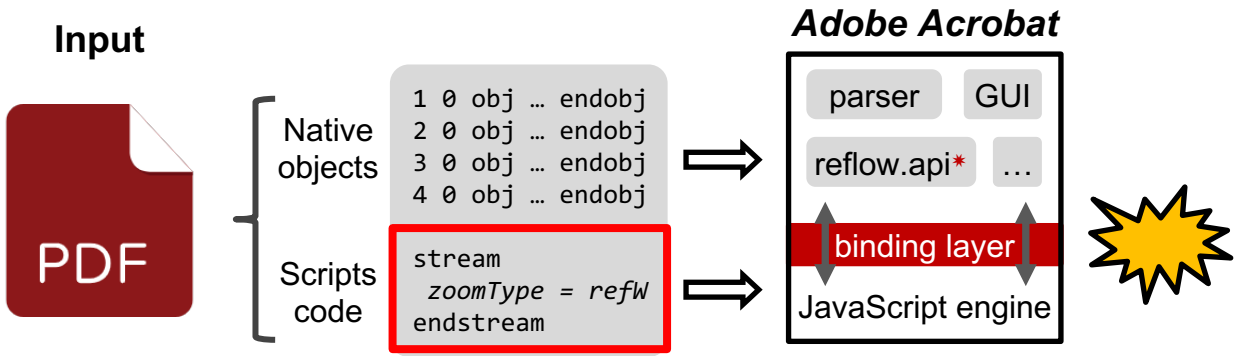

Previous work only mutates scripts code

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Motivating Example

- Heap Overflow in Adobe Acrobat
- Remote Code Execution
- $2.5K bounty

```
%PDF-1.3
1 0 obj << /Pages 2 0 R >> endobj
2 0 obj << /Kids [ 3 0 R ] >> endobj
3 0 obj << /Resources << /Font << /TT1 4 0 R >> >>
          /AA << /O << /S /JavaScript
                       /JS 5 0 R >> >> >> endobj
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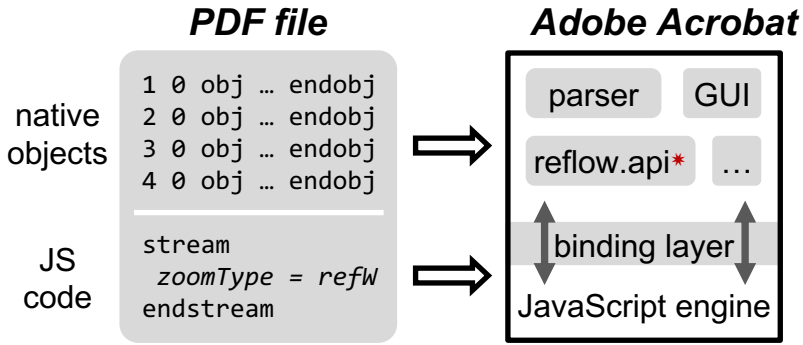
One-dimension-mutation cannot trigger this vulnerability

Our Solution: Cooperative Mutation

Cooperative Mutation



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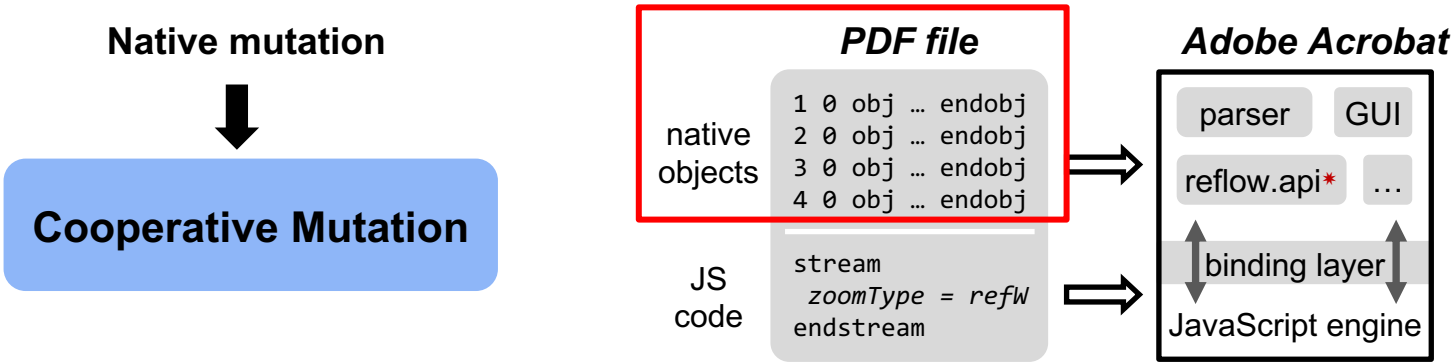

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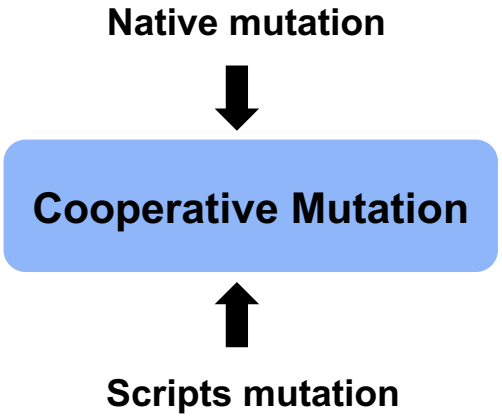

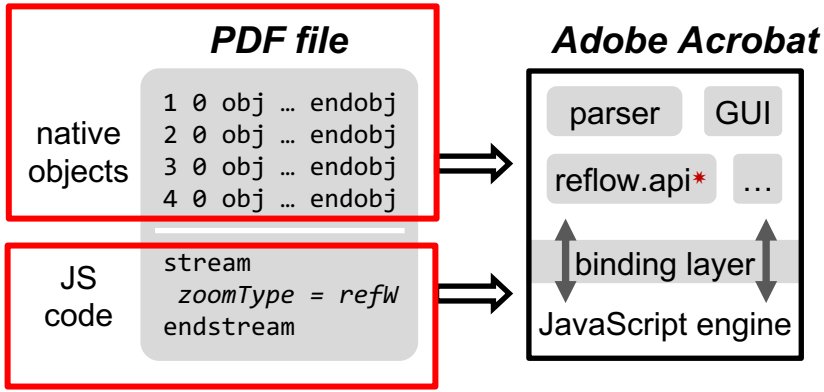

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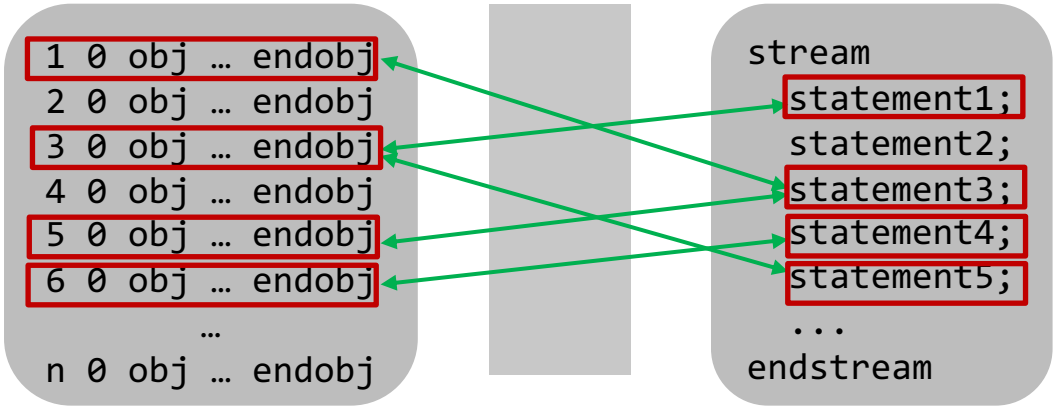
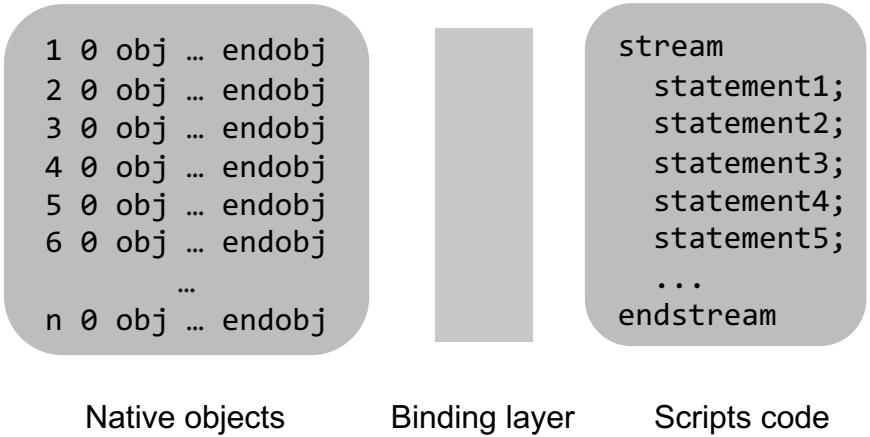


Challenges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endstream
Native objects
Binding layer
Scripts code

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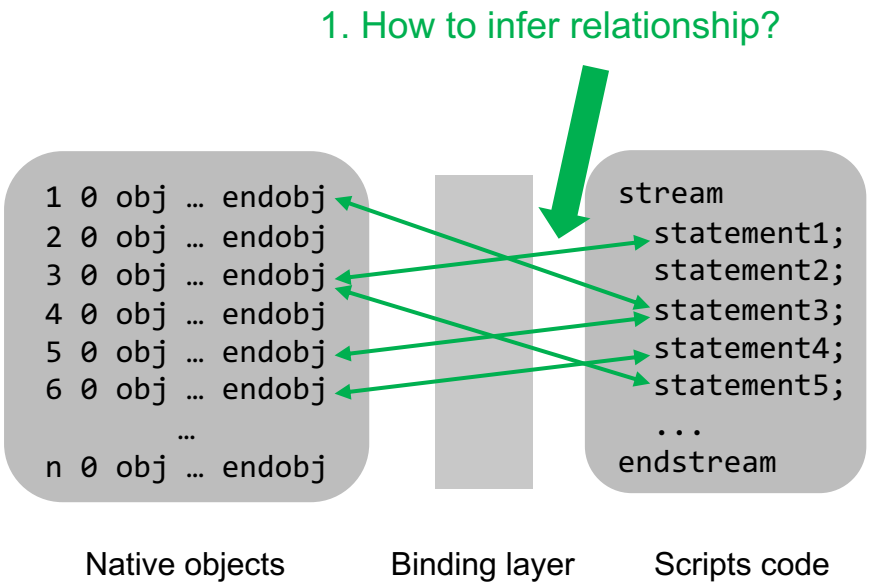
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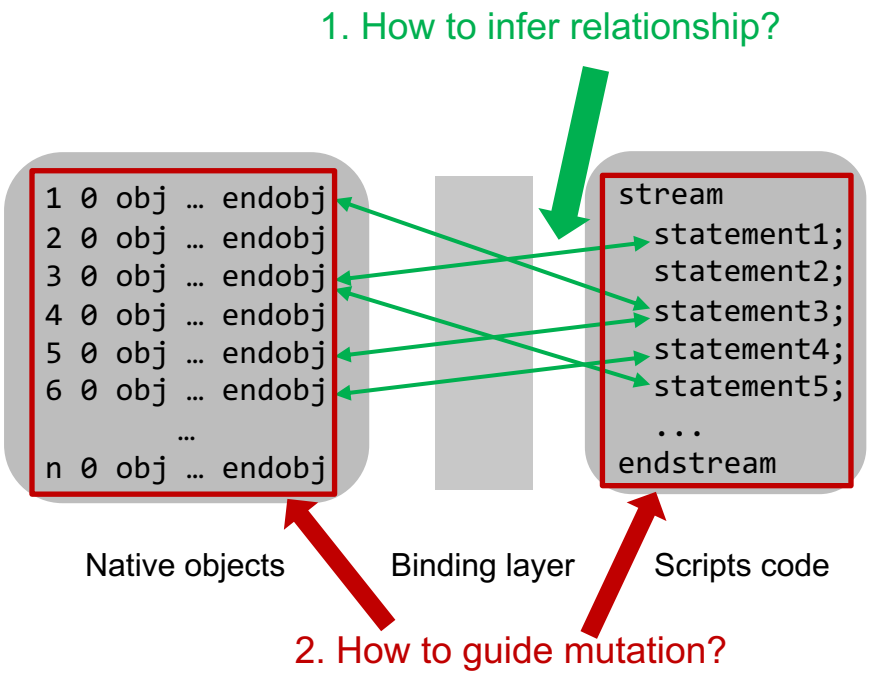
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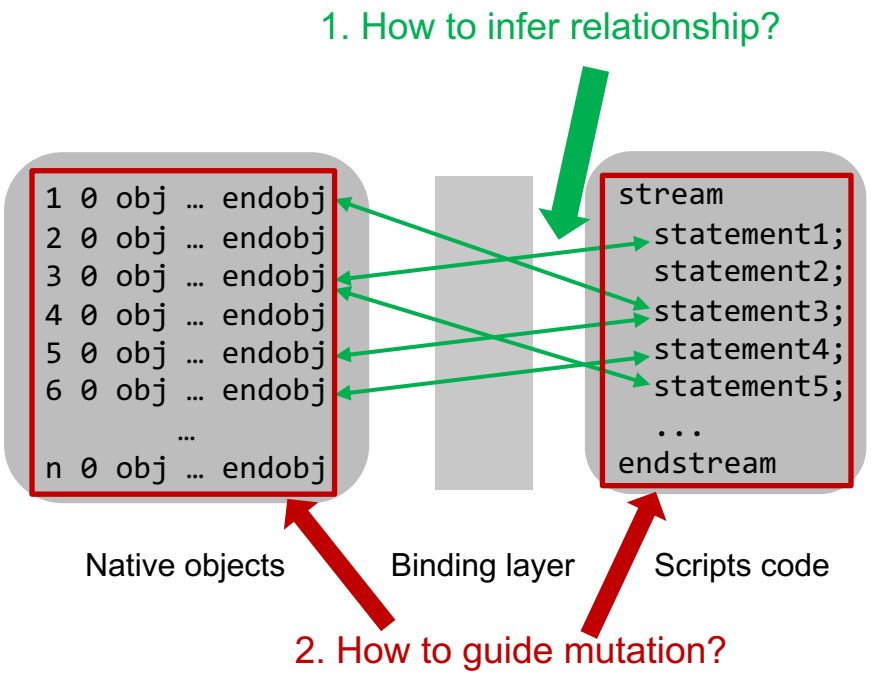
2. How to guide mutation?

Challenges

Too many objects!!! Makes it hard for inferring and mutation



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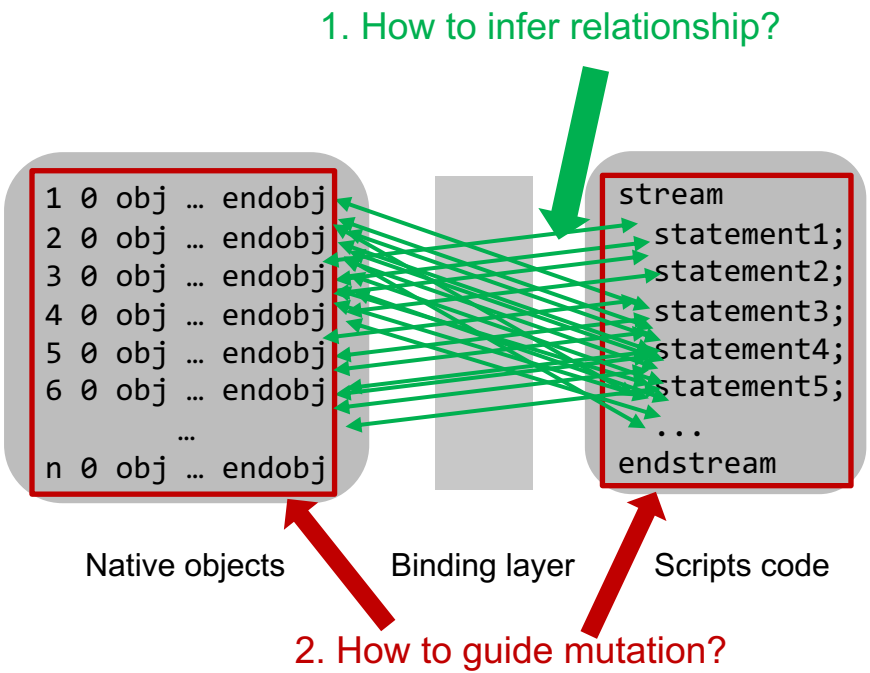

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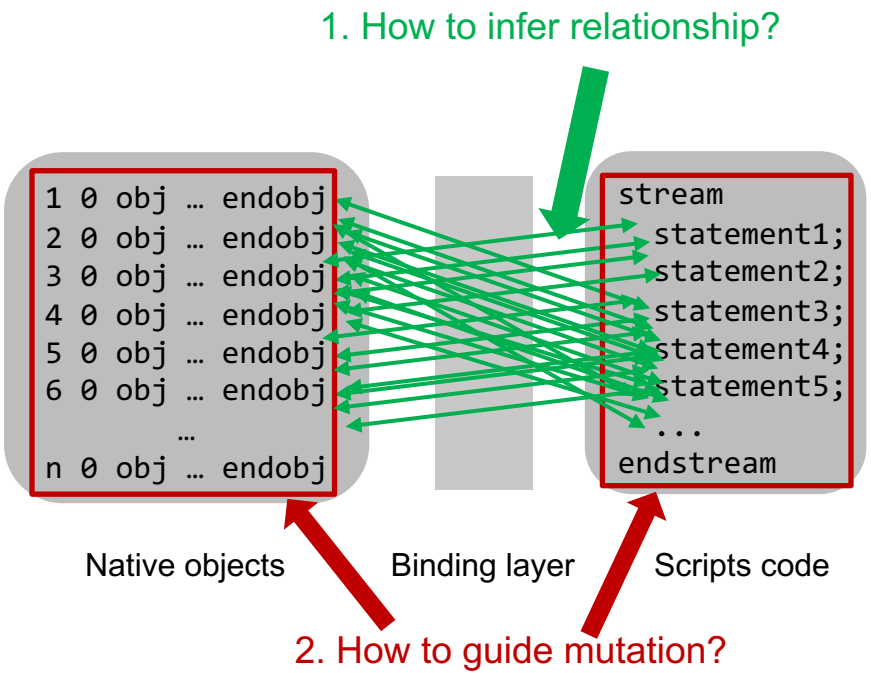
We need to reduce the search space of native objects.



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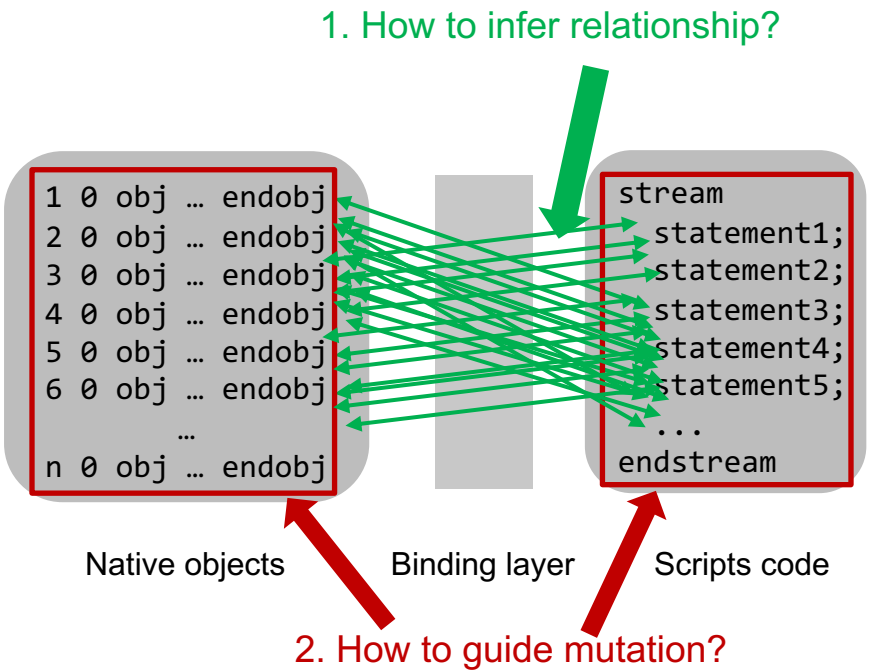
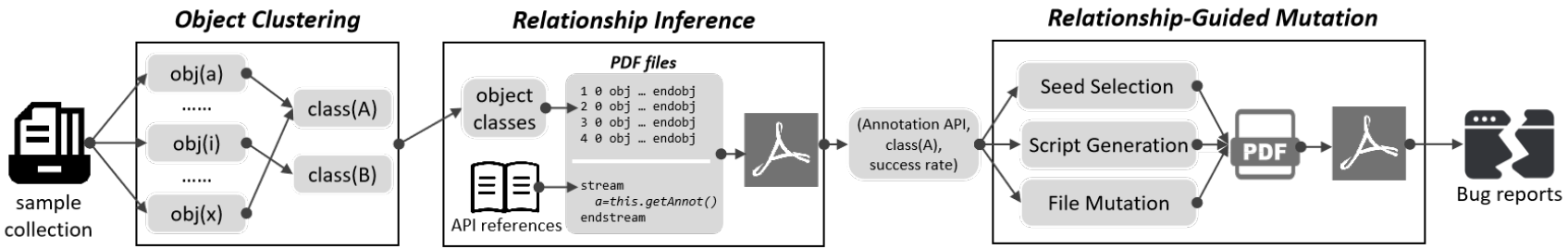


0. How to cluster native objects?

Cooper Overview



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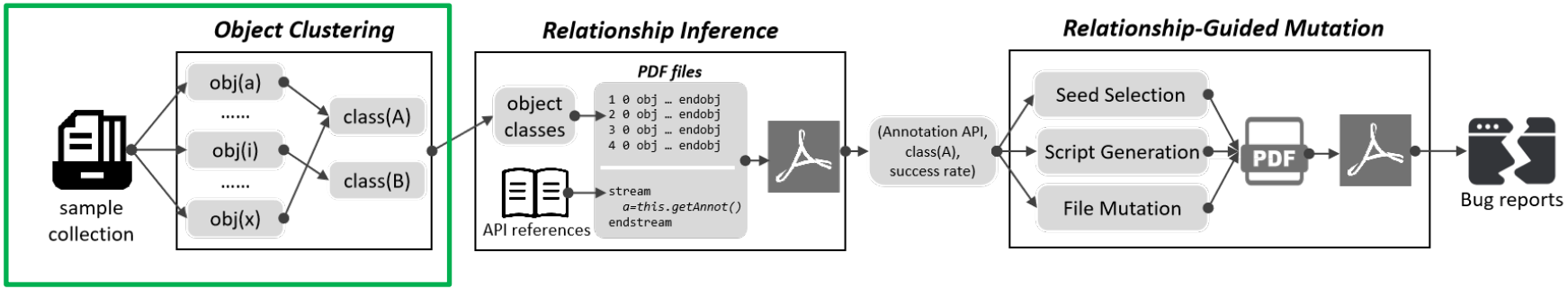

cluster input objects to semantic-similar classes

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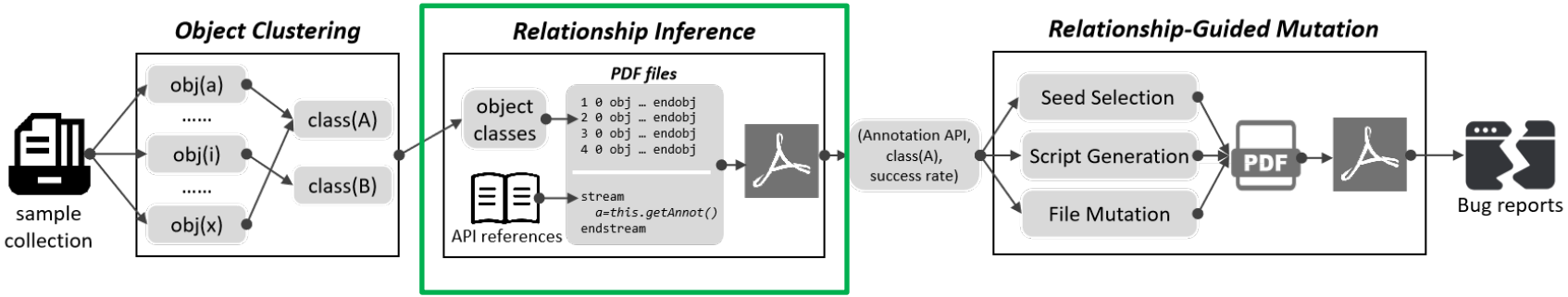

infer relation between native input and script code

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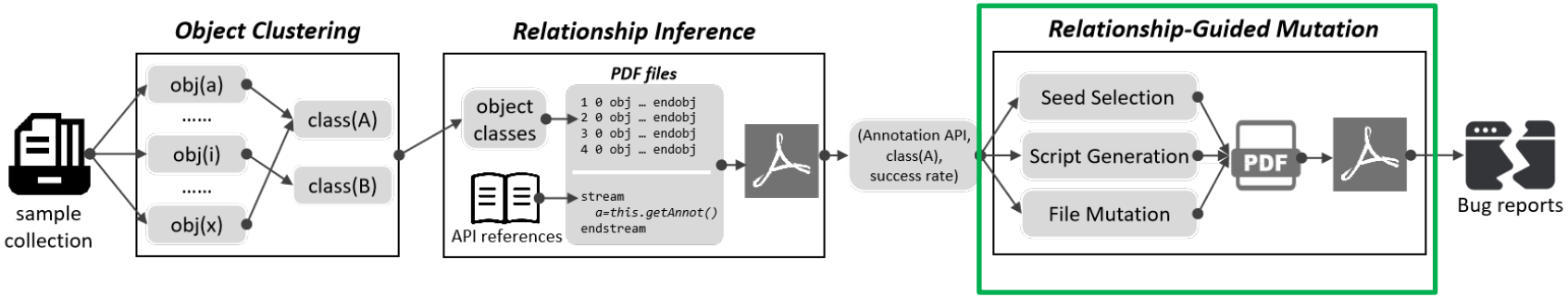

use the inferred relation
to guide mutation

Object Clustering

Object Clustering

$$O\text{:object} = \left\{ \begin{array}{l} A_0\text{: } \mathbf{name_0} = \text{object}_0, \\ A_1\text{: } \mathbf{name_1} = \text{object}_1, \\ A_2\text{: } \mathbf{name_2} = \text{object}_2, \\ \quad \ldots = \ldots \end{array} \right\}$$

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- Clustering objects with **name**

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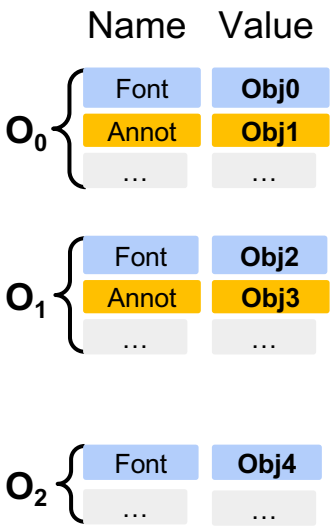

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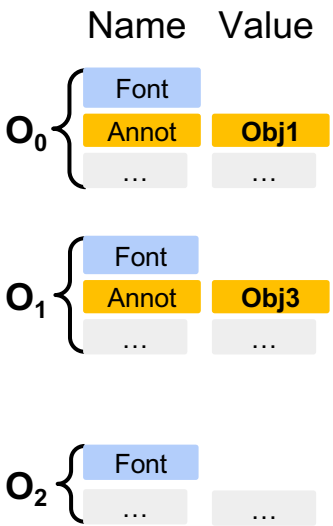

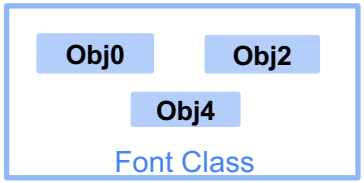

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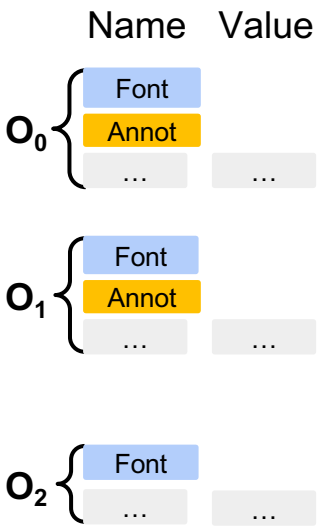

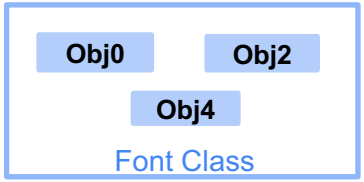

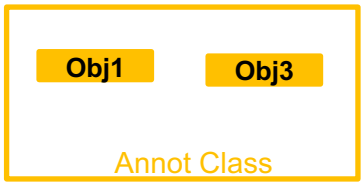

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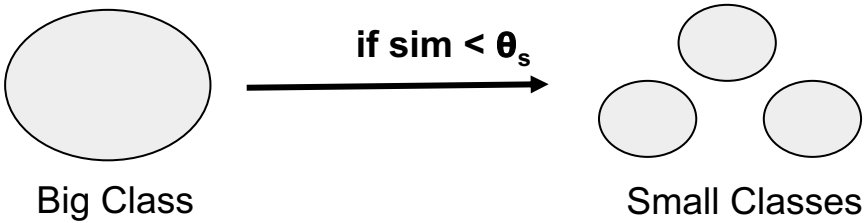
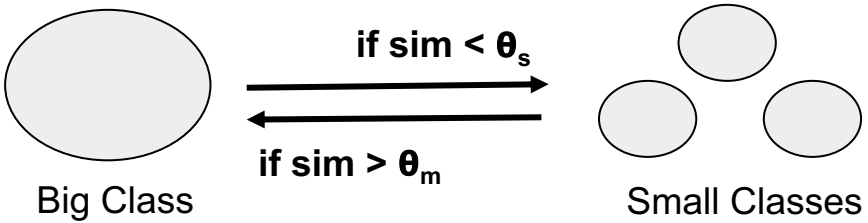


Object Clustering

- Spliting and merging classes with attribute similarity

$$Sim(A, B) = \frac{2(|A \cap B|)}{|A|+|B|}$$



Relationship Inference

- Run & Record

Relationship Inference

- Run & Record

```
1  0  obj  …  endobj
2  0  obj  …  endobj
3  0  obj  …  endobj

4  0  obj  …  endobj
5  0  obj  …  endobj
6  0  obj  …  endobj
```

Relationship Inference

- Run & Record

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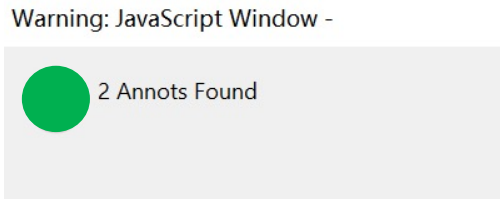
Relationship Inference

- Run & Record

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6  0  obj  …  endobj
```
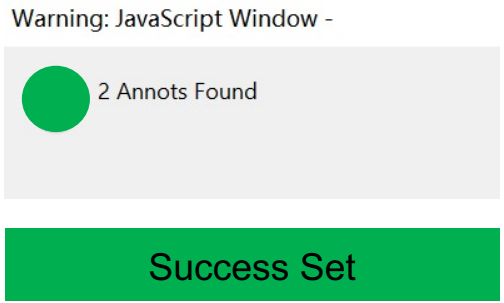

Relationship Inference

- Run & Record

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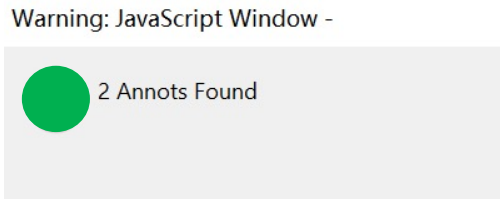
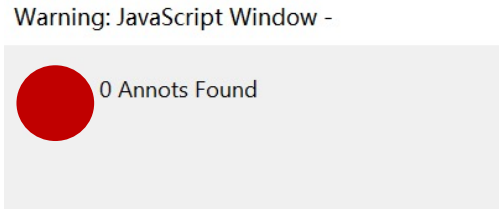
Relationship Inference

- Run & Record



Success Set

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1  0  obj  …  endobj
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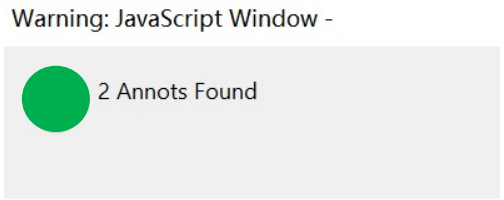
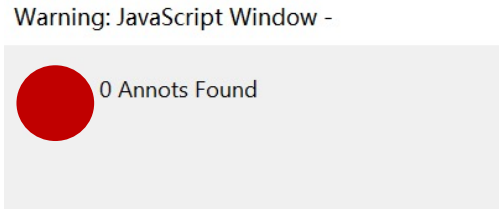
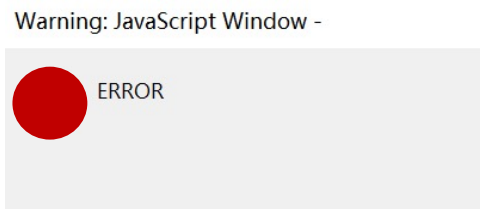
Relationship Inference

- Run & Record



Success Set



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2  0  obj  …  endobj
3  0  obj  …  endobj
```

```
try{
   var annots = this.getAnnot();
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}catch(e){ app.alert("ERROR" + e); }
```

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4  0  obj  …  endobj
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```

Relationship Inference

- Run & Record

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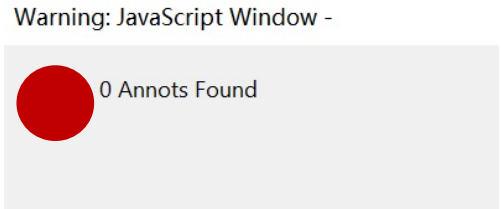
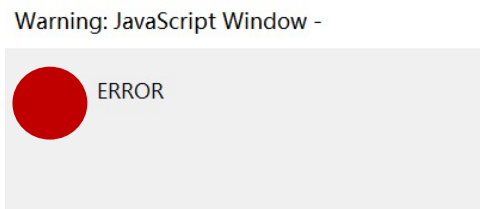




Failure Set

Relationship Inference

- Run & Record

Warning: JavaScript Window -

2 Annots Found

Success Set

```
1  0  obj  …  endobj
2  0  obj  …  endobj
3  0  obj  …  endobj
```

```
try{
   var annots = this.getAnnot();
   app.alert(annots.length+" Annots Found");
}catch(e){ app.alert("ERROR" + e); }
```

```
4  0  obj  …  endobj
5  0  obj  …  endobj
6  0  obj  …  endobj
```

Warning: JavaScript Window -

0 Annots Found

Warning: JavaScript Window -

ERROR

Failure Set

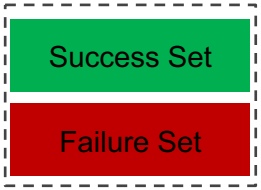
Samples

Success Set

Failure Set

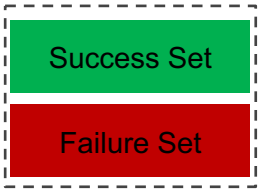
Relationship Inference

- Run & Record
- Statistical Inference



Relationship Inference

- Run & Record
- Statistical Inference



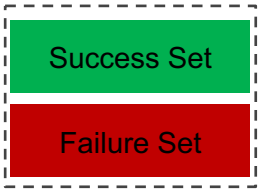
Statistical Inference

	API_0			API_1			API_2			…
	Success Rate	**Failure Rate**	**Diff**	**Success Rate**	**Failure Rate**	**Diff**	**Success Rate**	**Failure Rate**	**Diff**	**…**
Class0	0.9	0.1	0.8	1.0	0.0	1.0	1.0	0.1	0.9	…
Class1	0.8	0.2	0.6	0.3	0.3	0.0	0.9	0.0	0.9	…
Class2	1.0	0.0	1.0	0.9	0.1	0.8	0.2	0.1	0.1	…
…	…	…	…	…	…	…	…	…	…	…
Classn	0.3	0.3	0.0	0.8	0.2	0.6	1.0	0.2	0.8	…

Relation Map

Relationship Inference

- Run & Record
- Statistical Inference



Statistical Inference

	API_0			API_1			API_2			...
	Success Rate	**Failure Rate**	**Diff**	**Success Rate**	**Failure Rate**	**Diff**	**Success Rate**	**Failure Rate**	**Diff**	**...**
Class0	0.9	0.1	0.8	1.0	0.0	1.0	1.0	0.1	0.9	...
Class1	0.8	0.2	0.6	0.3	0.3	0.0	0.9	0.0	0.9	...
Class2	1.0	0.0	1.0	0.9	0.1	0.8	0.2	0.1	0.1	...
...	...	...	...	...	...	...	...	...	...	...
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Relation Map

Relationship Inference

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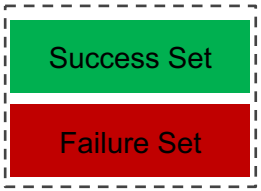

Statistical Inference

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Class2	1.0	0.0	1.0	0.9	0.1	0.8	0.2	0.1	0.1	…
…	…	…	…	…	…	…	…	…	…	…
Classn	0.3	0.3	0.0	0.8	0.2	0.6	1.0	0.2	0.8	…

Relation Map

Relationship Inference

- Run & Record
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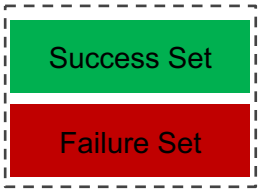

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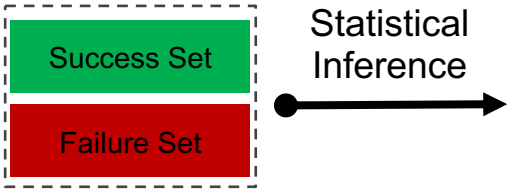
Class2	1.0	0.0	1.0	0.9	0.1	0.8	0.2	0.1	0.1	…
…	…	…	…	…	…	…	…	…	…	…
Classn	0.3	0.3	0.0	0.8	0.2	0.6	1.0	0.2	0.8	…

Relation Map

Relationship Inference

- Run & Record
- Statistical Inference



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Relation Map

Relationship Guided Mutation

	API_0	**API_1**	**API_2**	**…**
Class0	0.8	1.0	0.9	…
Class1	0.6	0.0	0.9	…
Class2	1.0	0.8	0.1	…
…	**…**	**…**	**…**	**…**

Relation Map

Relationship Guided Mutation

	API_0	**API_1**	**API_2**	**…**
Class0	0.8	1.0	0.9	…
Class1	0.6	0.0	0.9	…
Class2	1.0	0.8	0.1	…
…	**…**	**…**	**…**	**…**

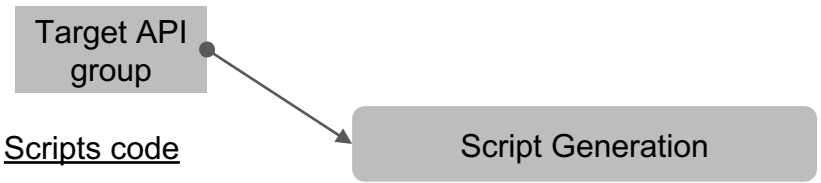
Relation Map

Target API group

Relationship Guided Mutation

	API_0	API_1	API_2	…
Class0	0.8	1.0	0.9	…
Class1	0.6	0.0	0.9	…
Class2	1.0	0.8	0.1	…
…	**…**	**…**	**…**	**…**

Relation Map



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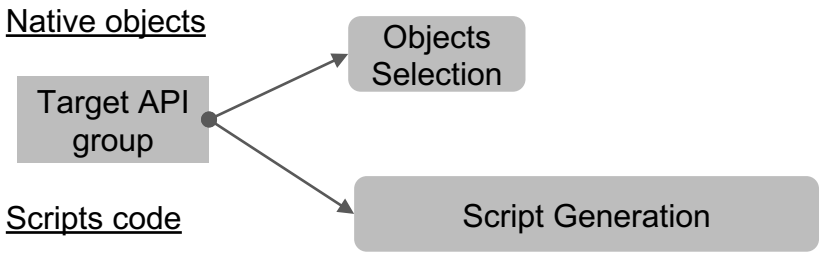
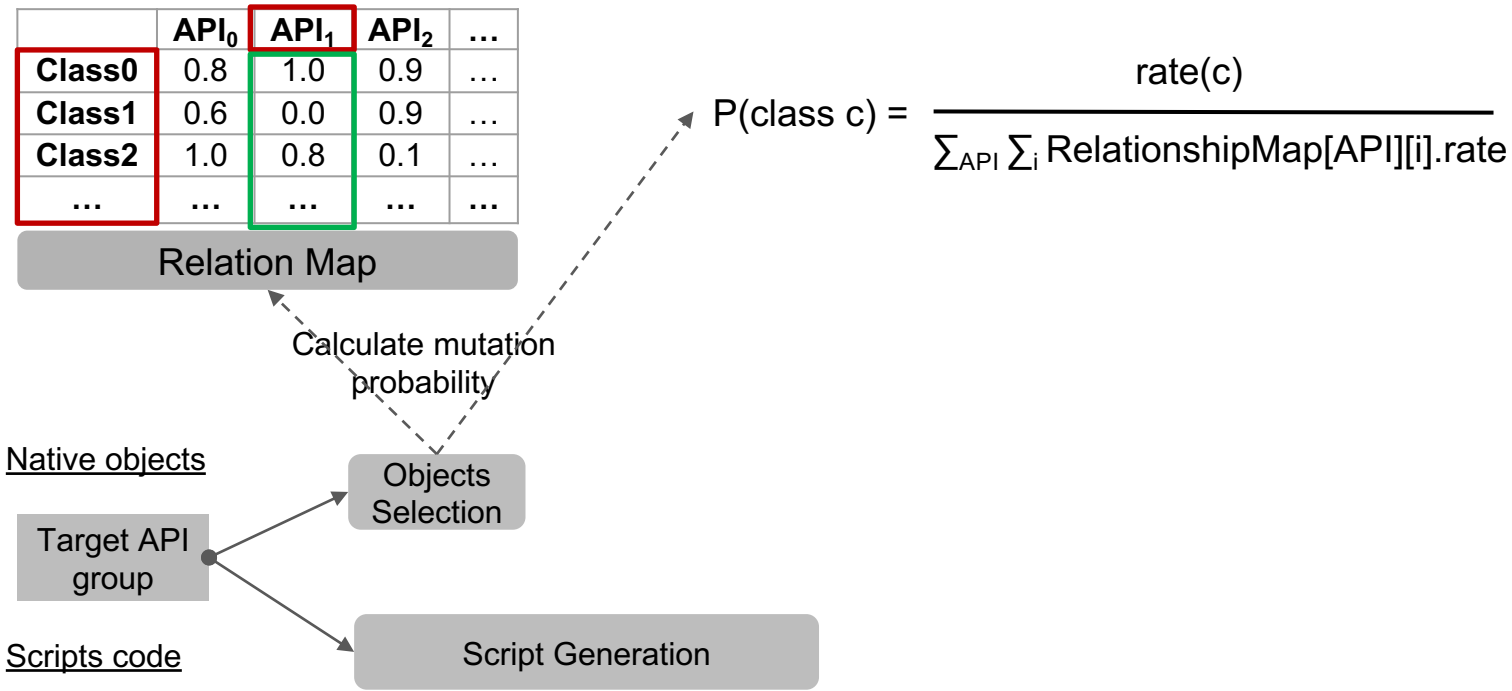
…	**…**	**…**	**…**	**…**

Relation Map



Relationship Guided Mutation



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Class1	0.6	0.0	0.9	…
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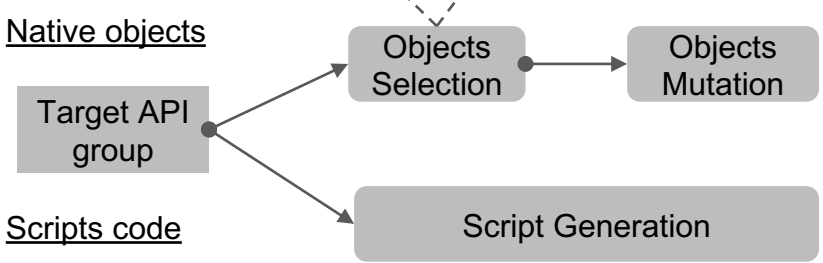
…	…	…	…	…

Relation Map

$$P(\text{class } c) = \frac{\text{rate}(c)}{\sum_{API} \sum_{i} \text{RelationshipMap}[API][i].\text{rate}}$$

Calculate mutation probability



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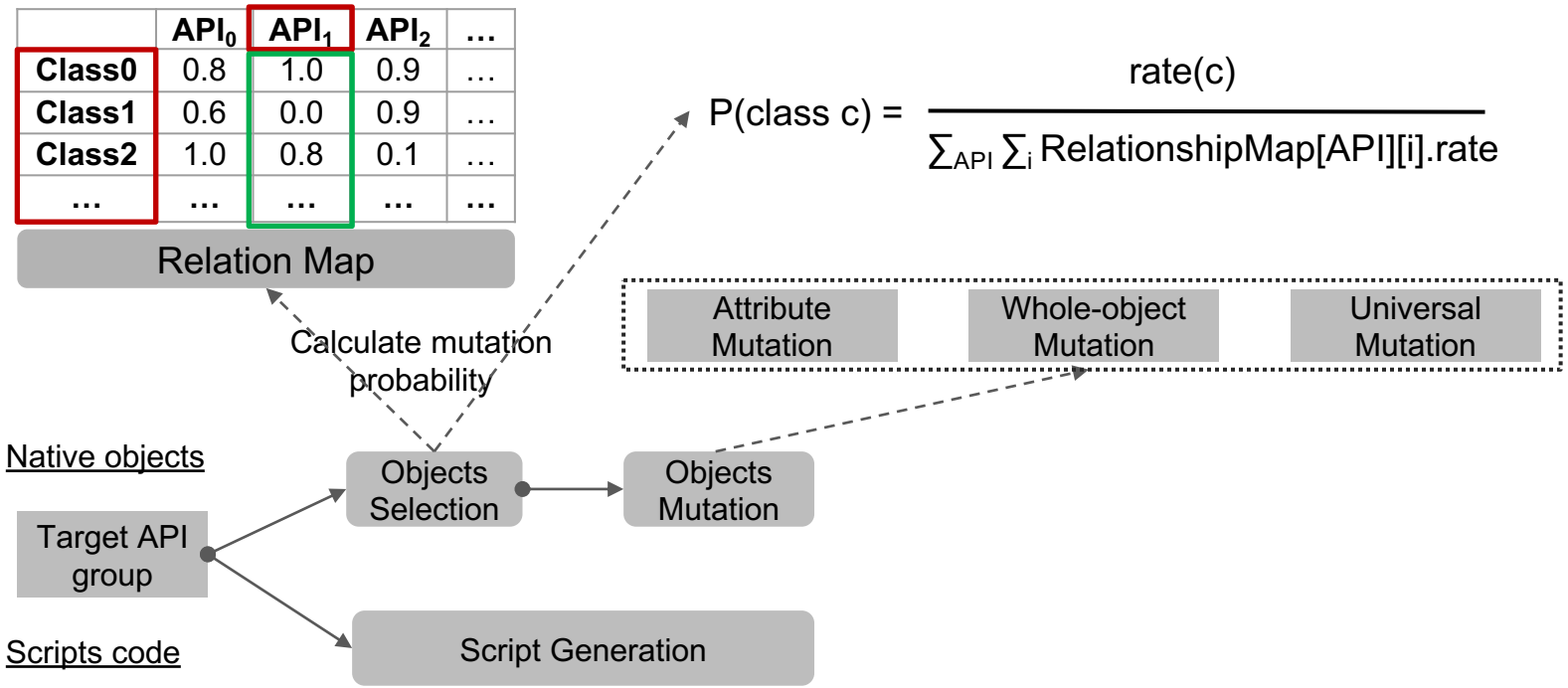

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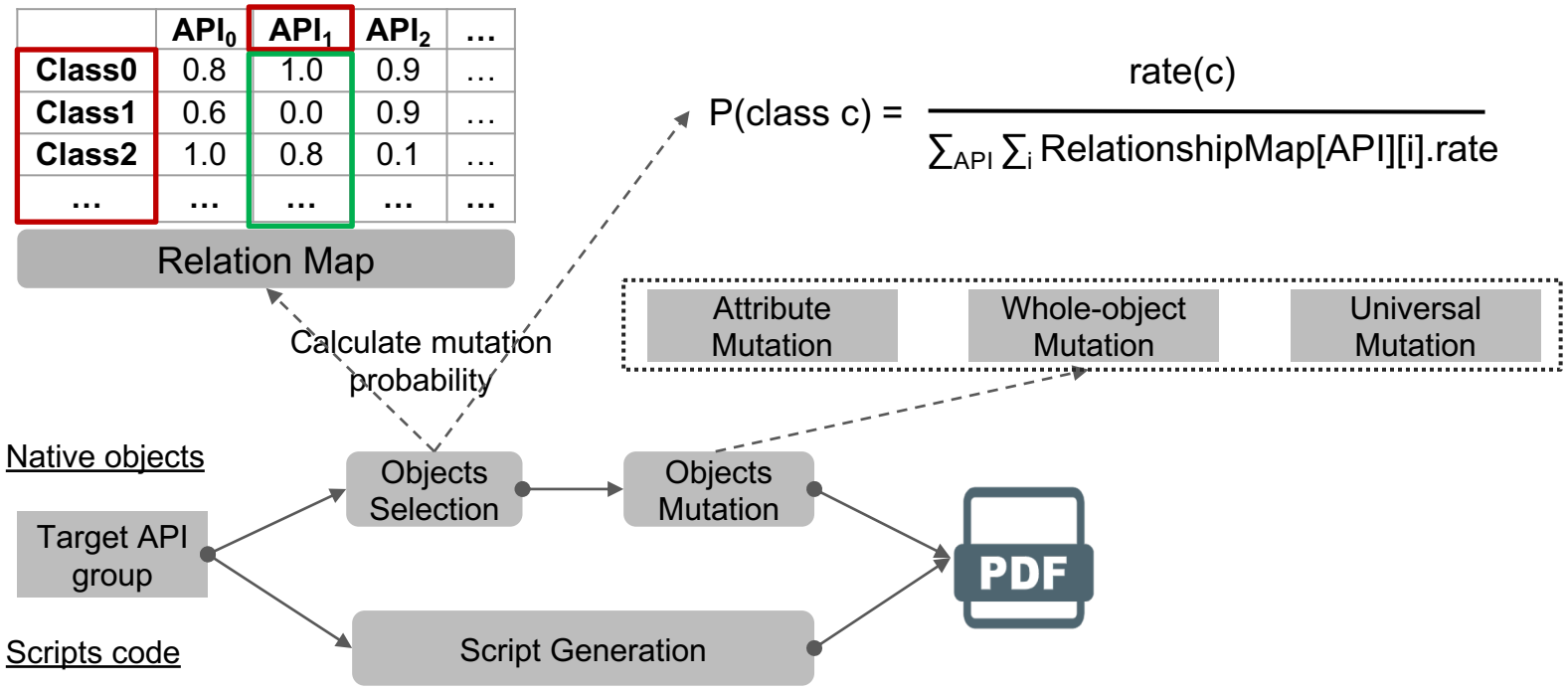

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- Currently support
  - PDF: use PyPDF2 for parsing
  - Word: use zipfile and xml for parsing
- For scripts generation
  - modify Domato, and add block-level template
- Extensible and Portable

Evaluations

- New bugs
- Comparison
  - Bug finding
  - Branch coverage

New Bugs (in four months)

	Adobe Acrobat	Foxit Reader	Microsoft Word	**Total**
use-after-free	12	18	3	**33**
buffer overflow	4	8	5	**17**
buffer error	6	1	0	**7**
null ptr deref	30	22	8	**60**
stack exhaustion	6	4	0	**10**
access violation	2	2	1	**5**
others	0	1	1	**2**
Total	**60**	**56**	**18**	**134**

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Total	**60**	**56**	**18**	**134**

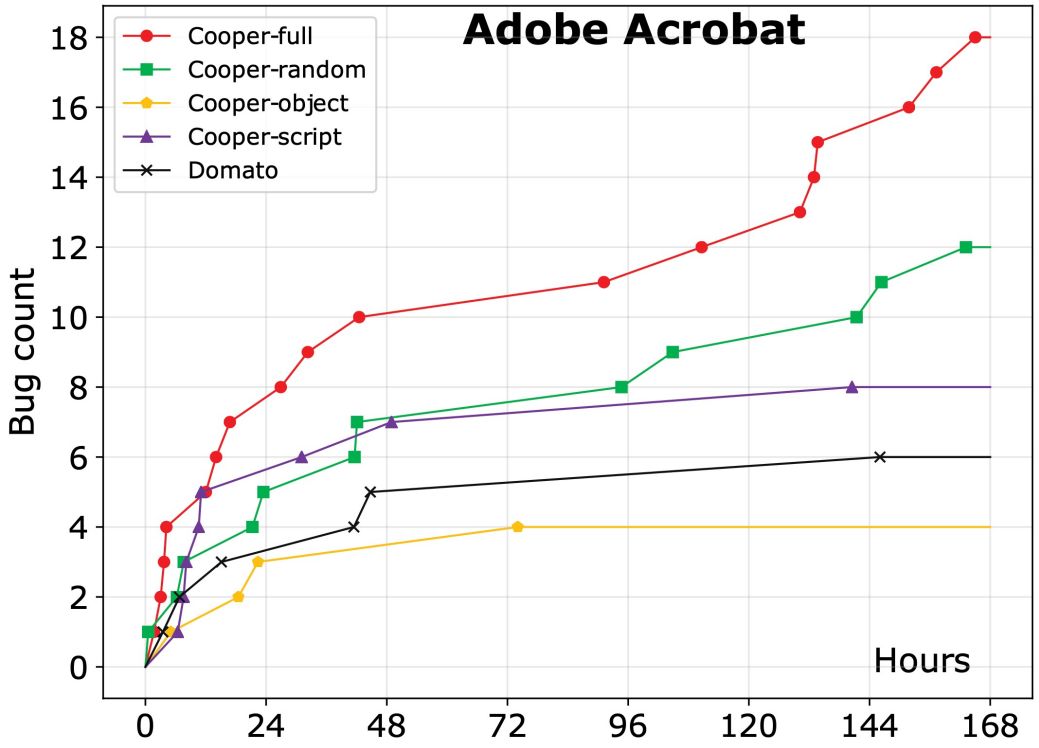
- 33 CVE, 59 fixed
- 22K dollars bounty
- 90 APIs &

  11 object classes

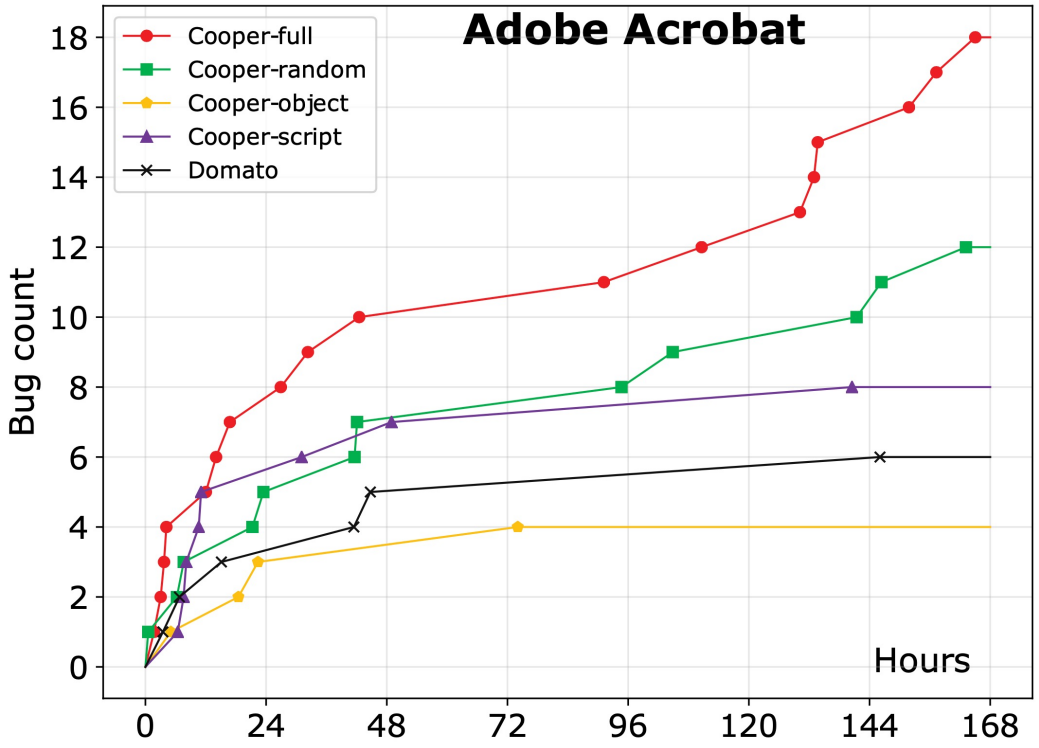
Comparing different configurations and tools

Experiment	Relation Guidance	Object Mutation	Script Generation
Cooper-full	●	●	●
Cooper-random	○	●	●
Cooper-object	●	●	○
Cooper-script	○	○	●
Domato	○	○	◐

Bug finding with different configurations (one week)

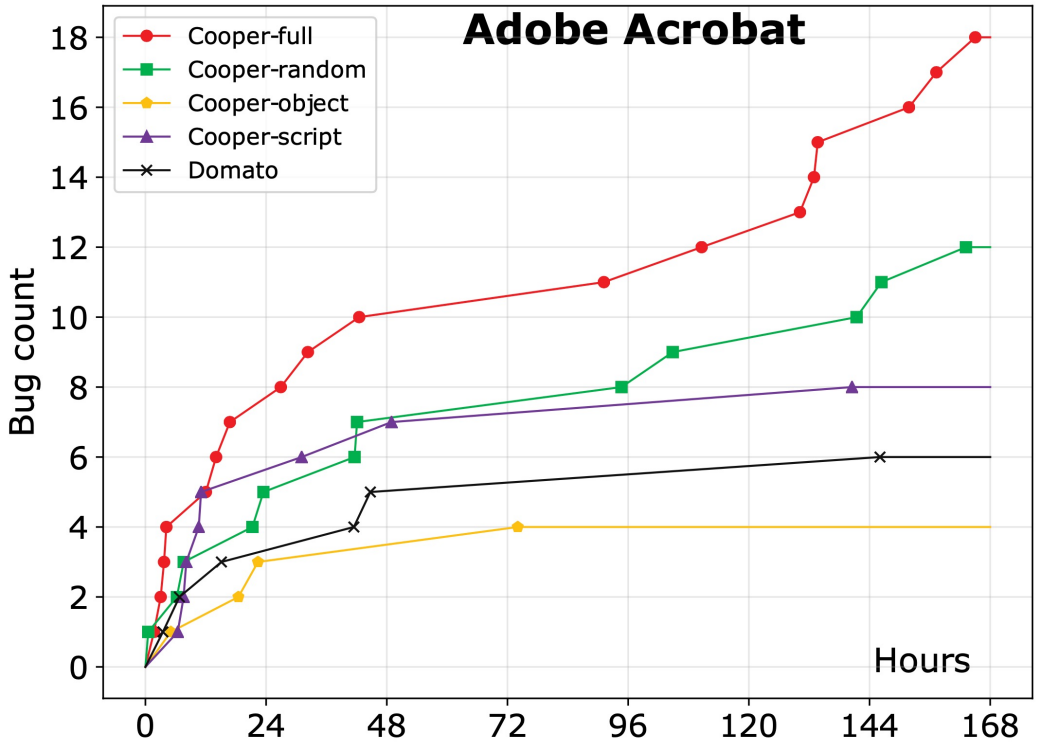


Bug finding with different configurations (one week)



Cooper-full: 18 bugs

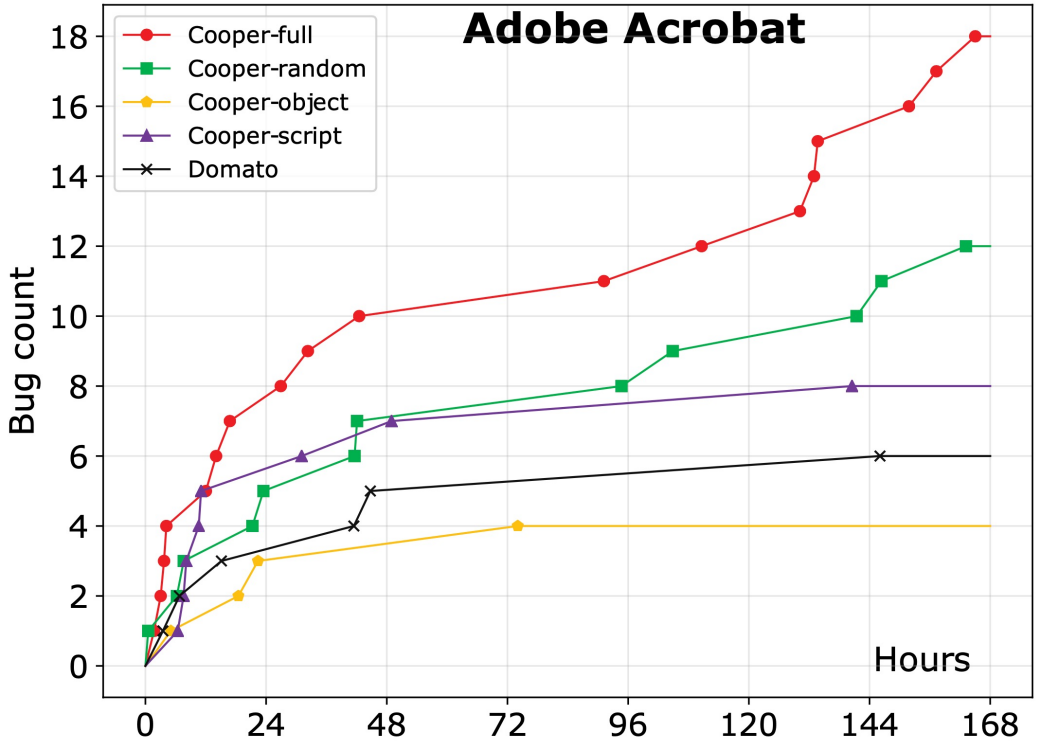
Bug finding with different configurations (one week)



Cooper-full: 18 bugs

w/o relation: 12 bugs

Bug finding with different configurations (one week)



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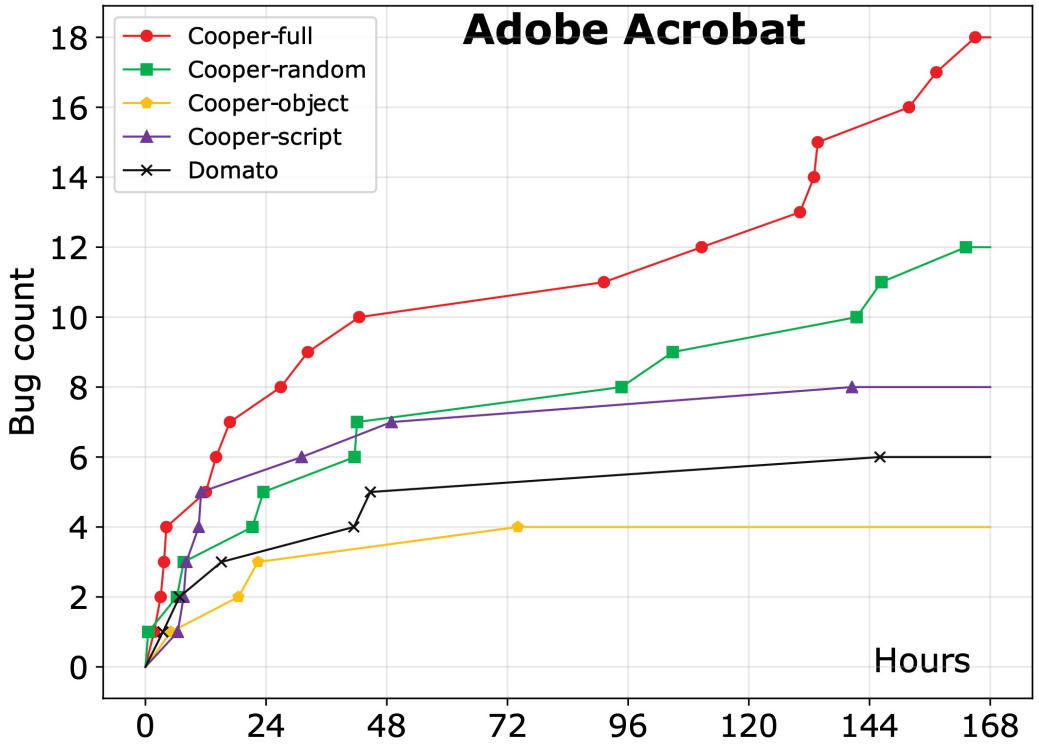
Script-only: 8 bugs

Bug finding with different configurations (one week)



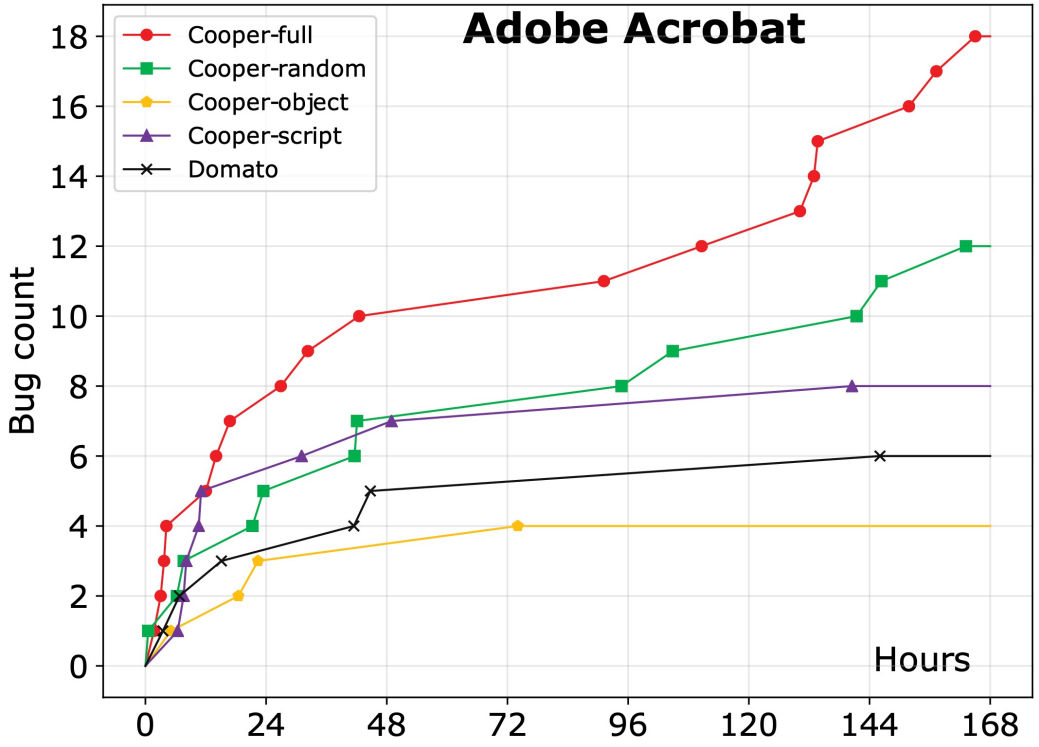
Cooper-full: 18 bugs

w/o relation: 12 bugs

Script-only: 8 bugs

Domato: 6 bugs

Bug finding with different configurations (one week)



Cooper-full: 18 bugs

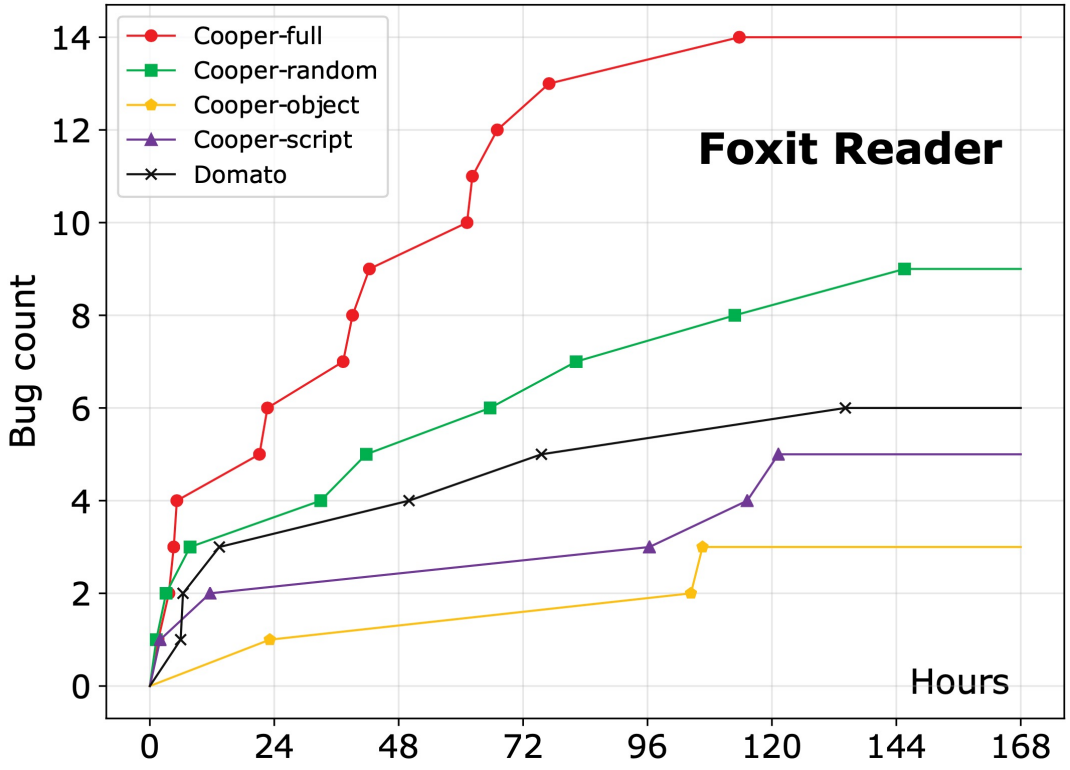
w/o relation: 12 bugs

Script-only: 8 bugs

Domato: 6 bugs

Object-only: 4 bugs

Bug finding with different configurations (one week)



Cooper-full: 14 bugs

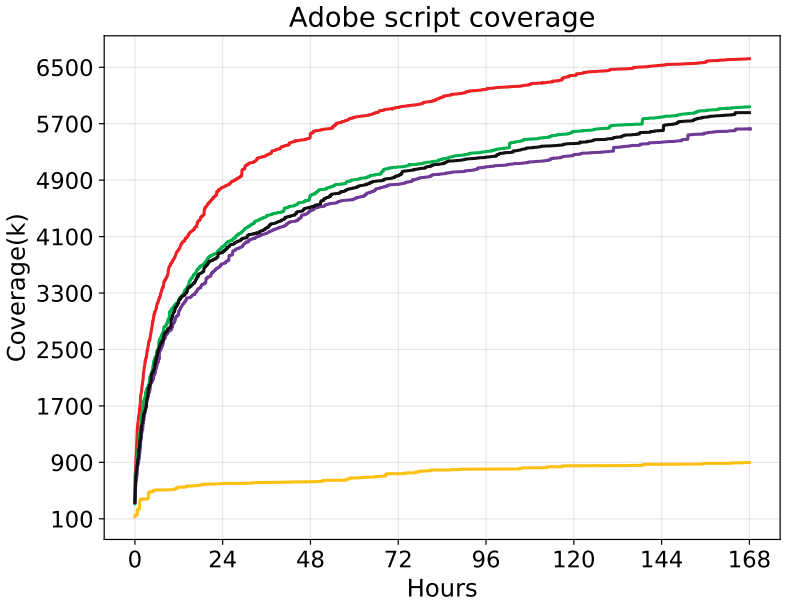
w/o relation: 9 bugs

Domato: 6 bugs

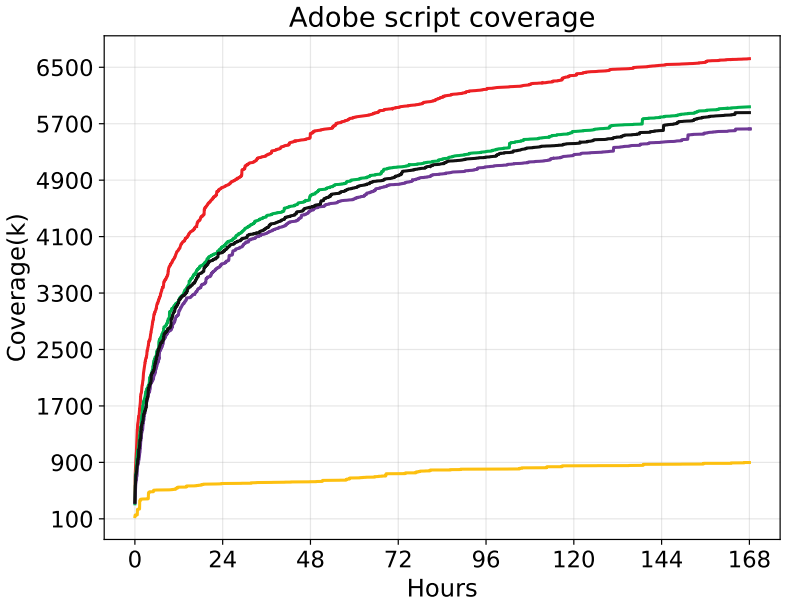
Script-only: 5 bugs

Object-only: 3 bugs

Branch Coverage (one week)

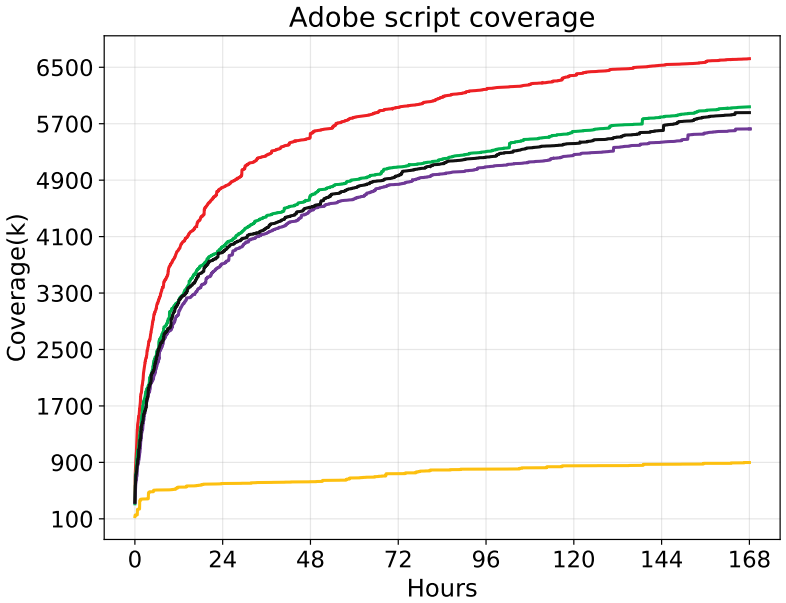


Branch Coverage (one week)



Cooper-full

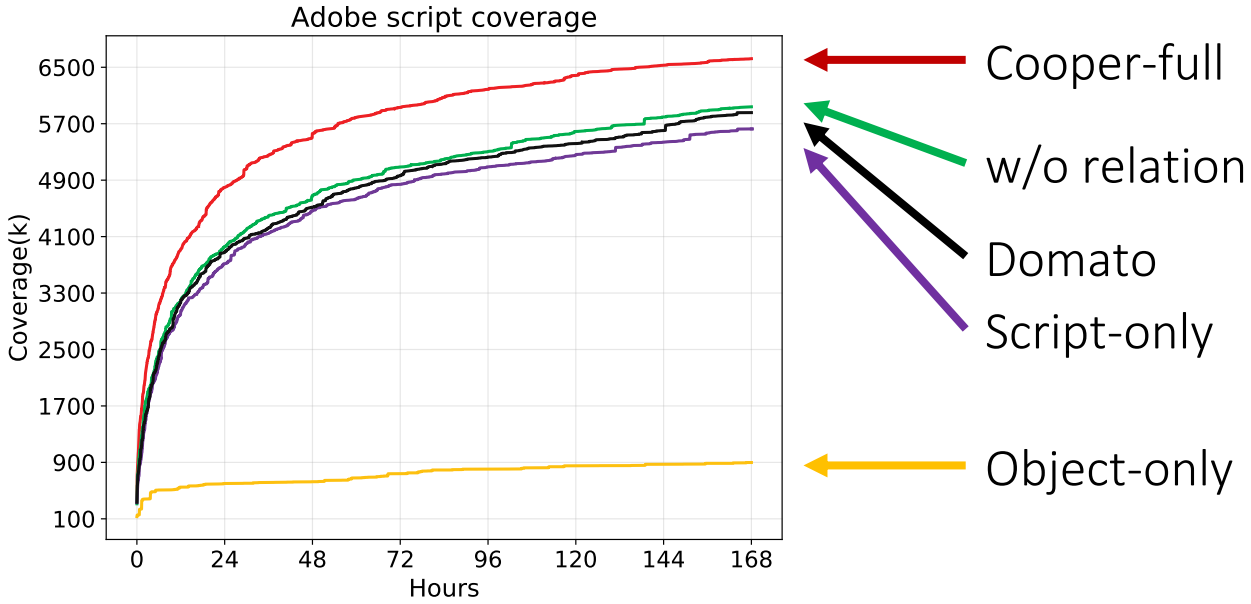
Branch Coverage (one week)



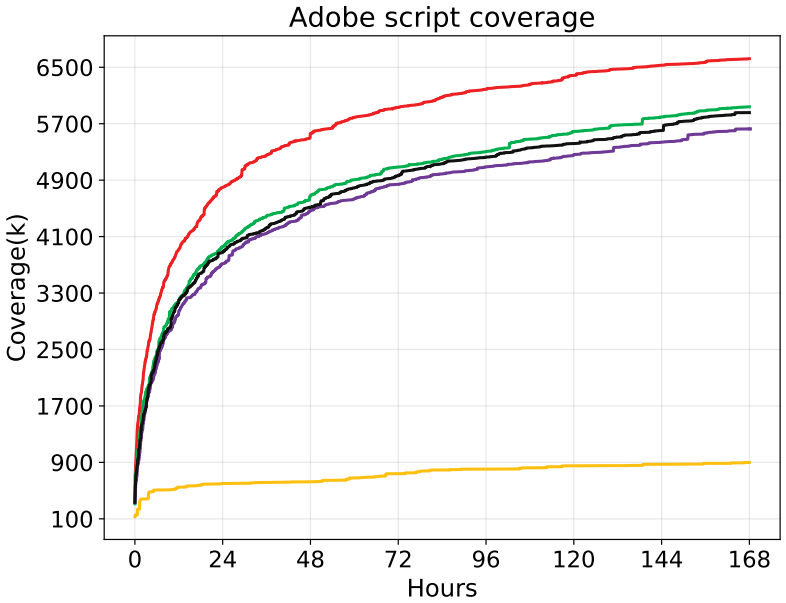
Cooper-full

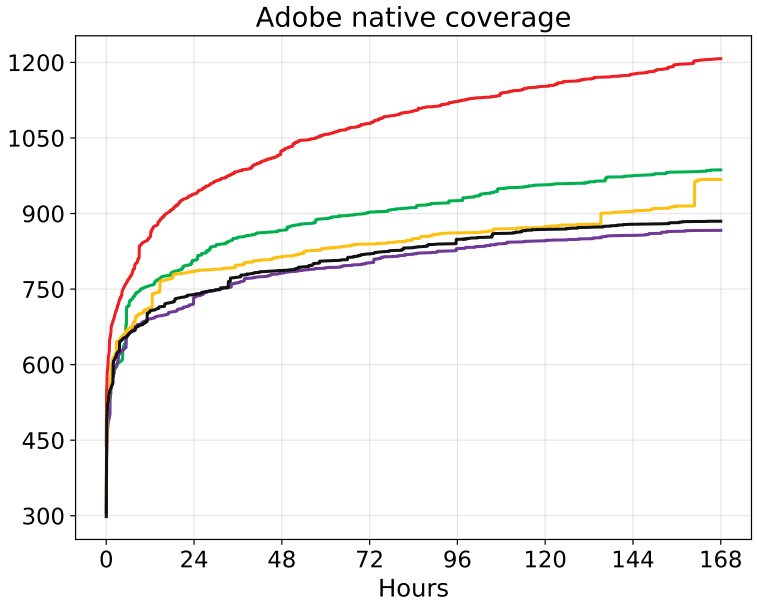
Object-only

Branch Coverage (one week)

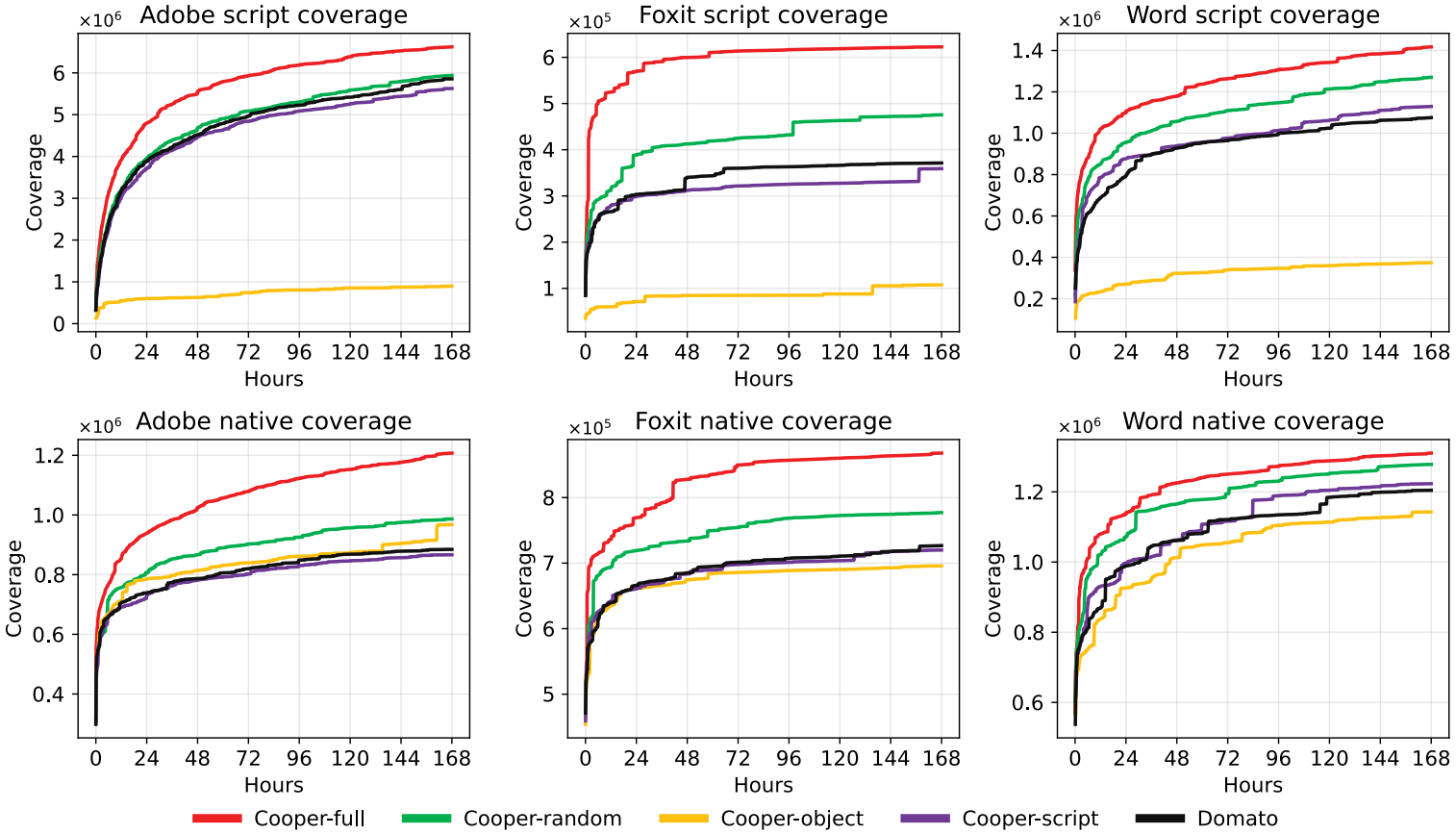


Branch Coverage (one week)





Branch Coverage (one week)



Conclusion

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- Code at: https://github.com/TCA-ISCAS/Cooper

Question?