Semantic Bug Seeding: A Learning-Based Approach for Creating Realistic Bugs

Michael Pradel

Software Lab – University of Stuttgart

Joint work with Jibesh Patra

Why Seed Bugs?

Large set of known, realistic bugs

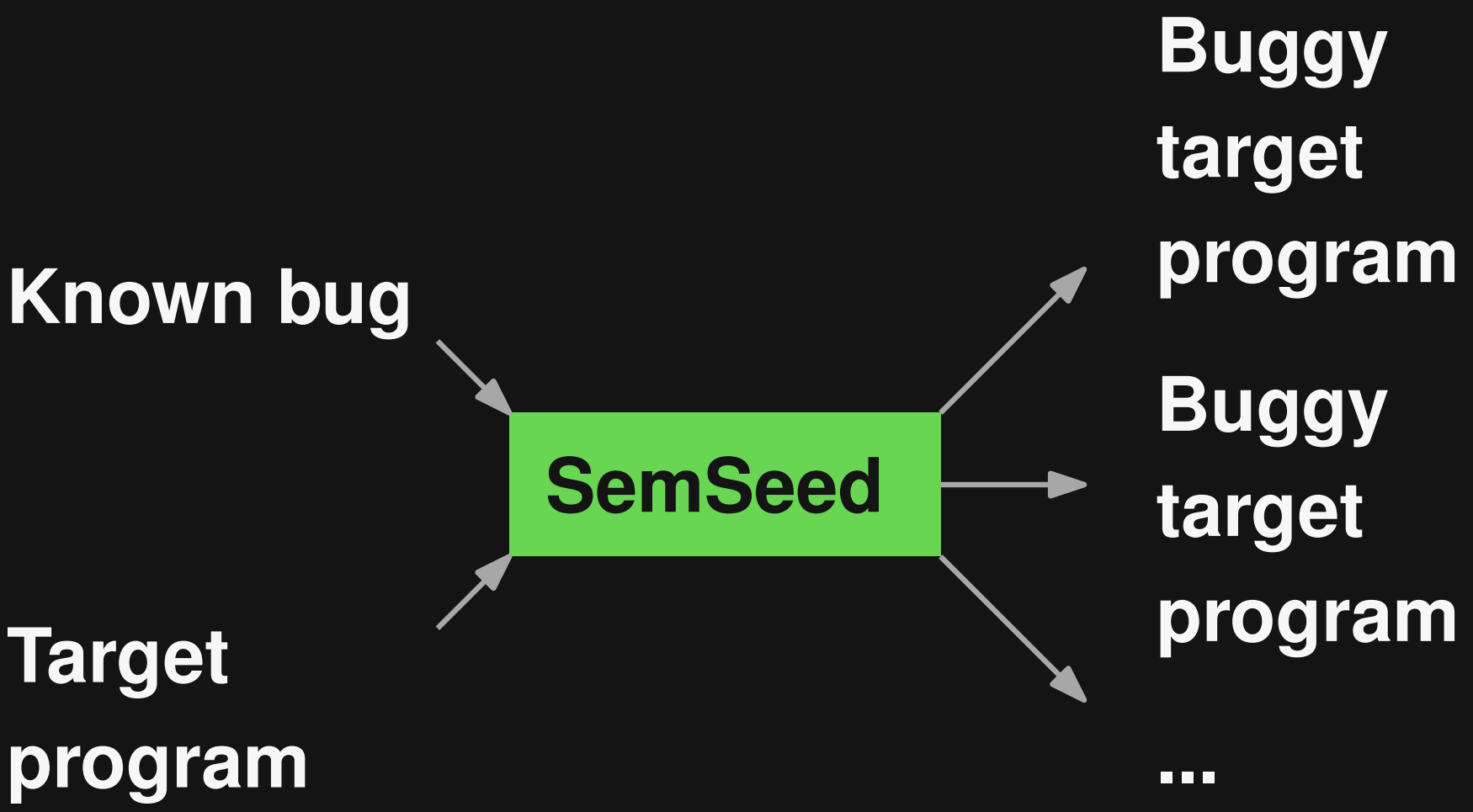
Benchmark for

- Test suites
- Bug detectors
- Repair tools

Training data for

- Learning-based bug detectors
- Learning-based repair tools

Idea: Imitate a Known Bug



Example and Challenges

```
if (process.platform === "darwin")
   ...
```

Known bug fix

```
if (process.platform !== "win32")
   ...
```

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Challenge 1: Where in the target program to seed this kind of bug?

Example and Challenges

```
if (process.platform === "darwin")
   ...
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```
if (process.platform !== "win32")
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Challenge 2: How to adapt the bug to the target program?

Example and Challenges

```
if (process.platform === "darwin")
   ...
```


```
if (process.platform !== "win32")
   ...
```

Challenge 3: How to handle “unbound” tokens?

Step 1: Abstraction to Bug Pattern

```
if (process.platform === "darwin")
  ...
```


```
if (process.platform !== "win32")
  ...
```

- **Reduce** to smallest AST subtree that contains all changed tokens
- **Abstract** identifiers and literals

Step 1: Abstraction to Bug Pattern

```
process.platform === "darwin"
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- **Reduce** to smallest AST subtree that contains all changed tokens
- **Abstract** identifiers and literals

Step 1: Abstraction to Bug Pattern

```
id1.id2 === lit1
```


```
id1.id2 !== lit2
```

- **Reduce** to smallest AST subtree that contains all changed tokens
- **Abstract** identifiers and literals

Step 2: Semantic Matching

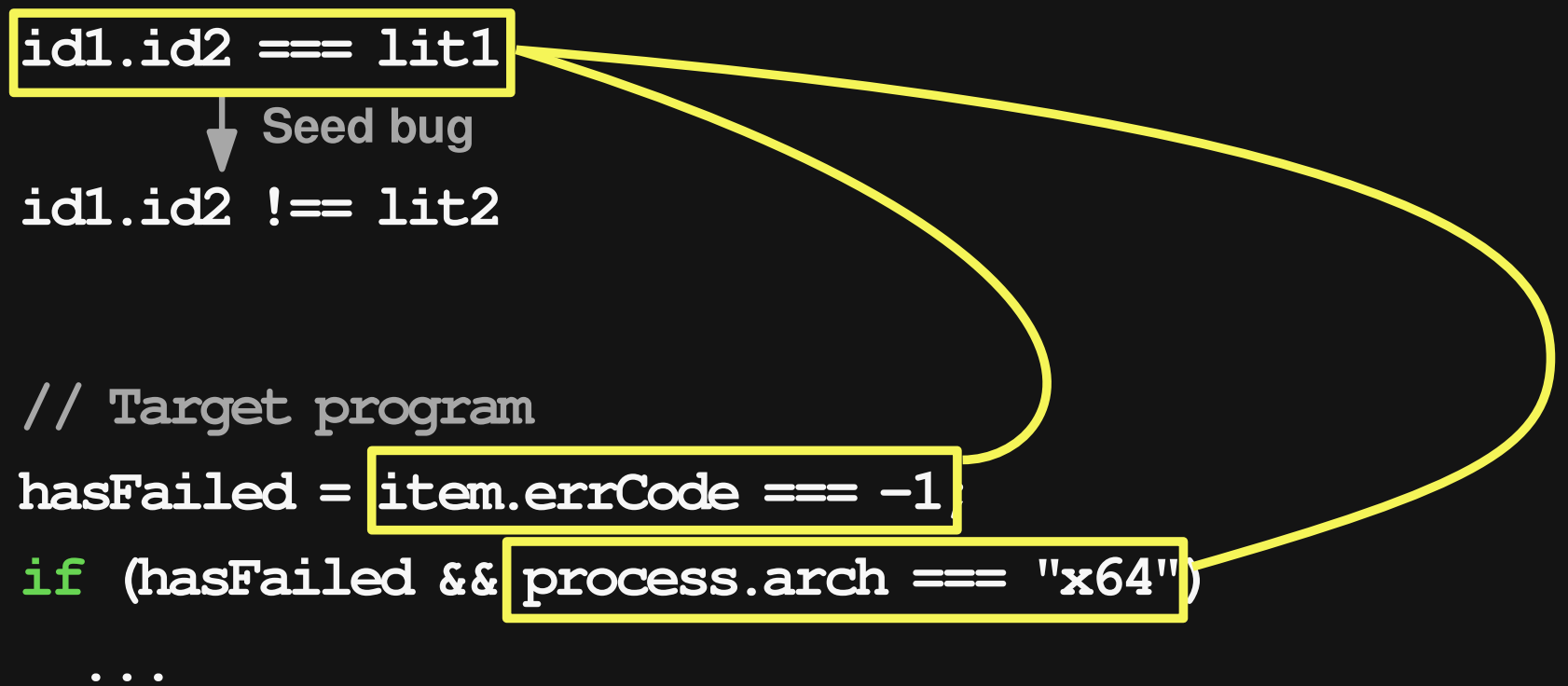
```
id1.id2 === lit1
```


```
id1.id2 !== lit2
```

```
// Target program
hasFailed = item.errCode === -1;
if (hasFailed && process.arch === "x64")
  ...
```

- **Syntactic** matching
- **Semantic** matching based on **learned token embeddings**

Step 2: Semantic Matching



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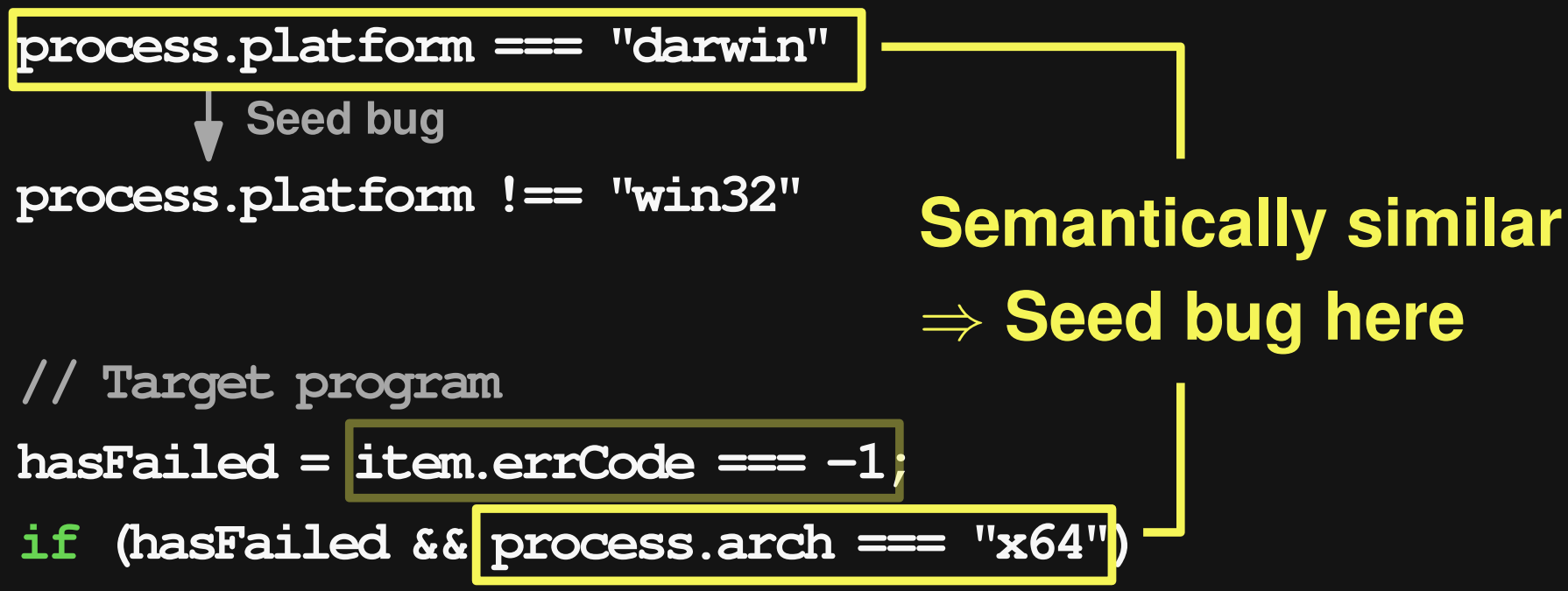

- **Syntactic** matching
- **Semantic** matching based on **learned token embeddings**

Step 3: Apply Pattern

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```
process.platform !== "win32"
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```
hasFailed = item.errCode === -1;
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  ..
```


```
hasFailed = item.errCode === -1;
if (hasFailed && process.arch !== ???)
  ...
```

Step 3: Apply Pattern

```
process.platform === "darwin"
```

Seed bug

```
process.platform !== "win32"
```

What literal to use?

```
hasFailed = item.errCode === -1;
if (hasFailed && process.arch === "x64")
  ..
```

Seed bug

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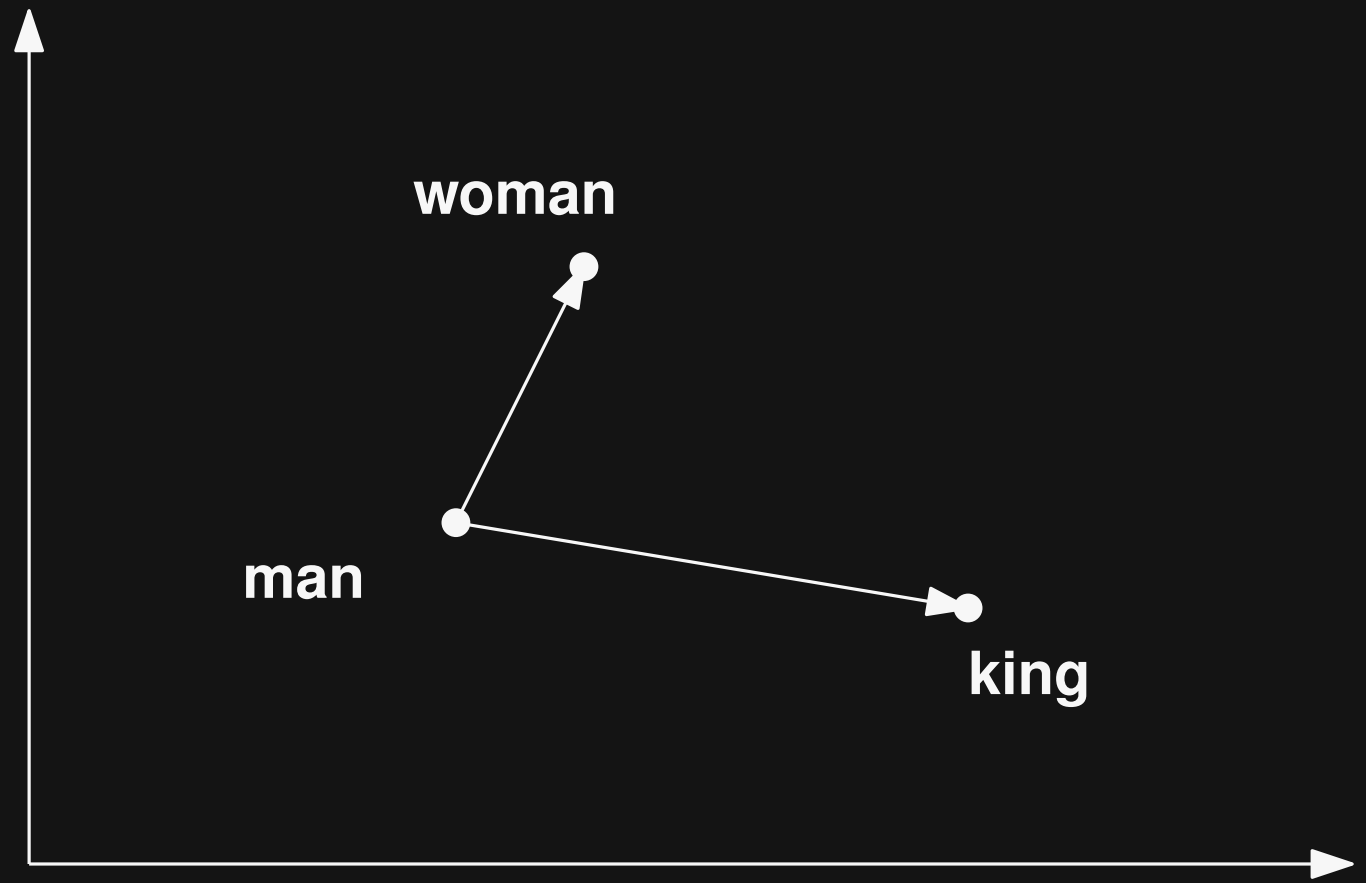
Step 3: Apply Pattern

Bind unbound tokens via analogy queries in token embedding space:



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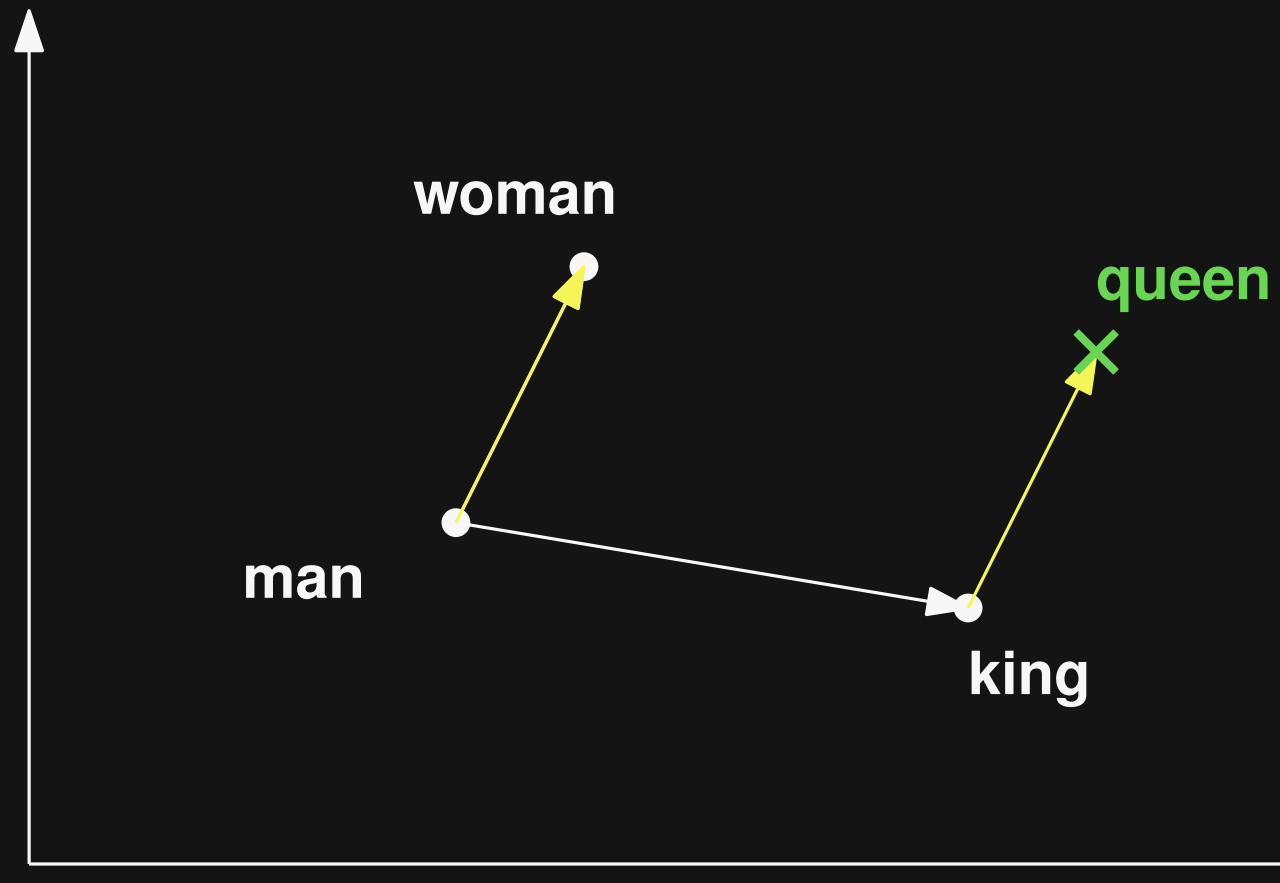

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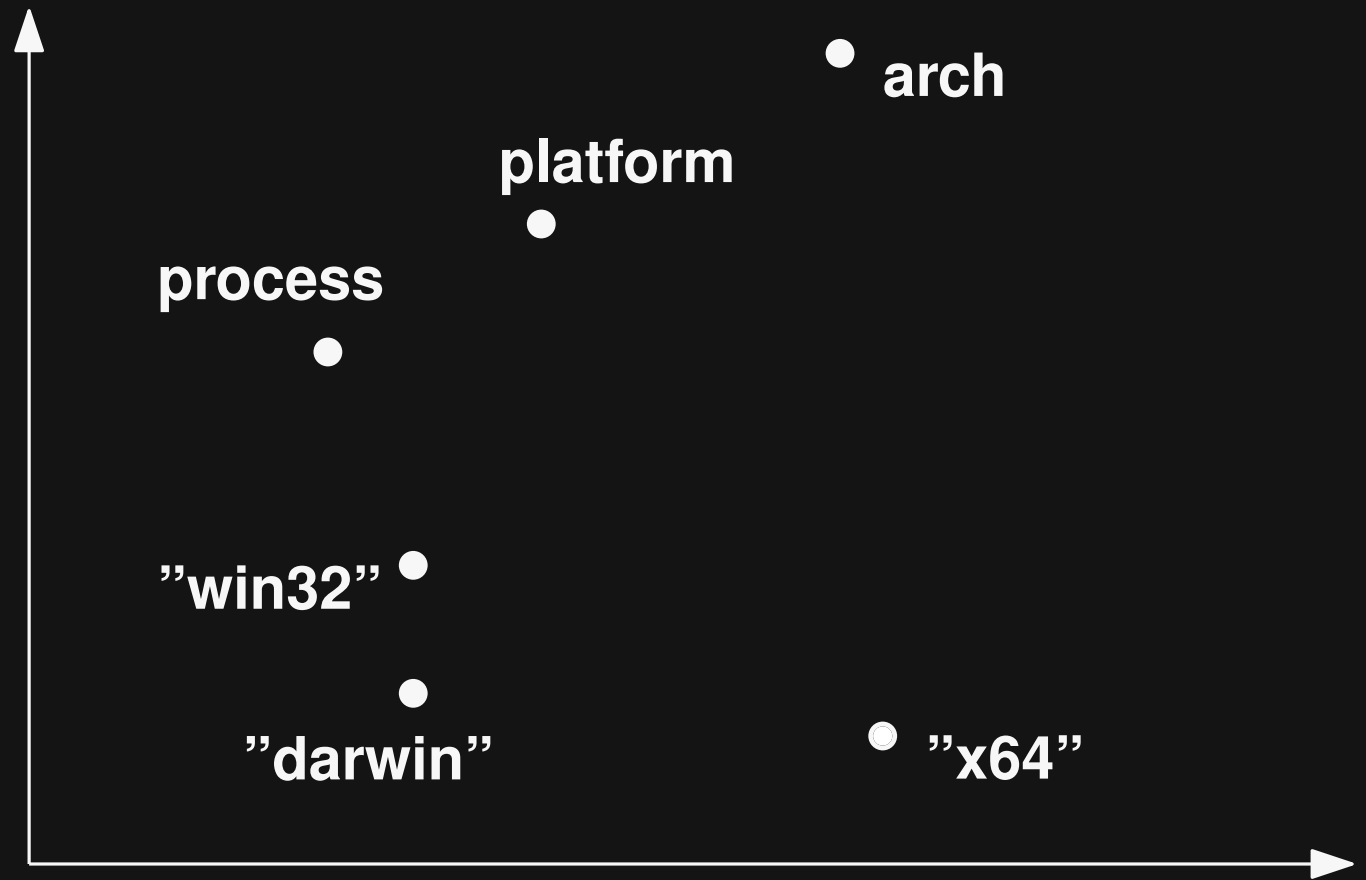

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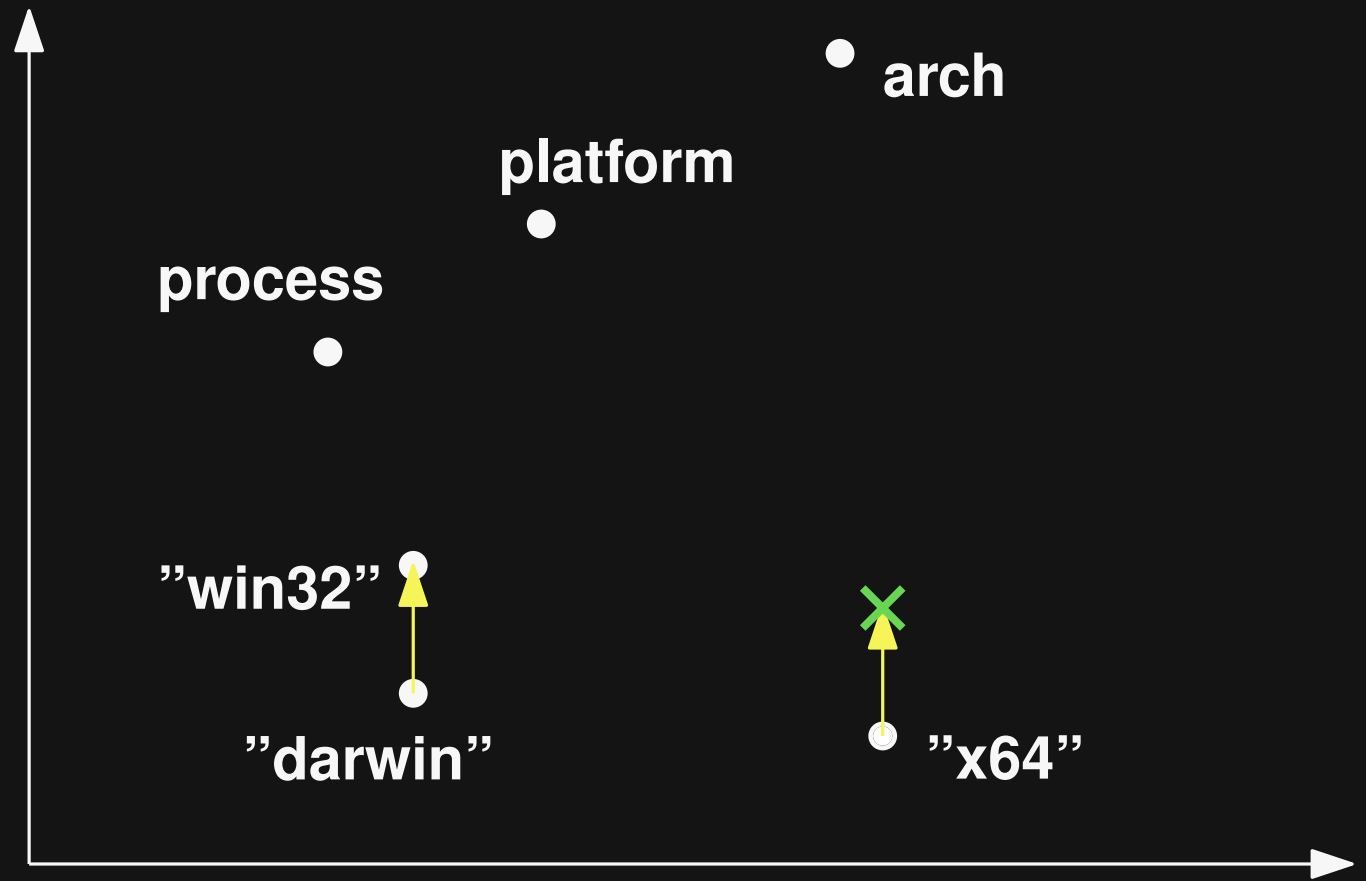

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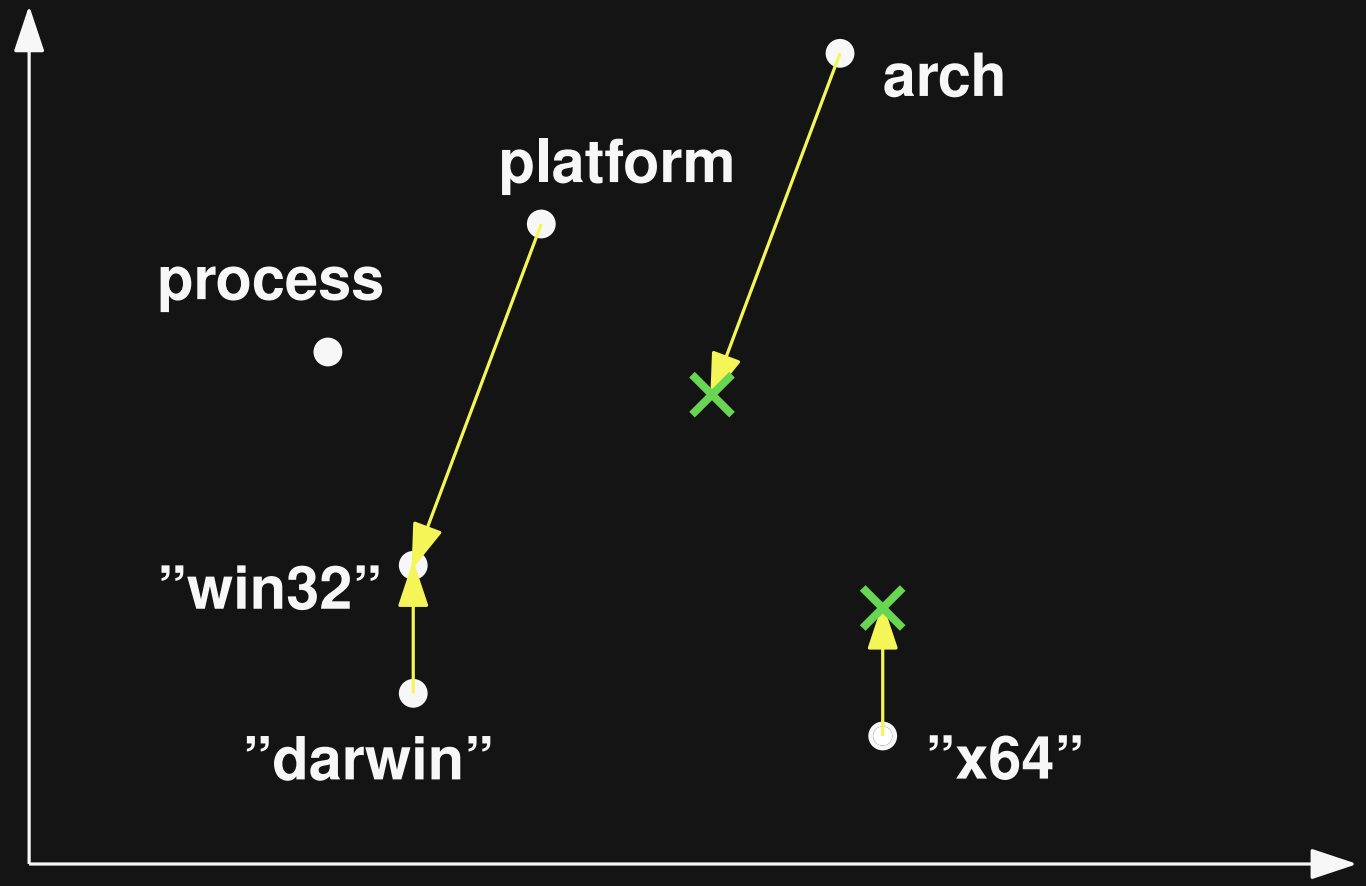

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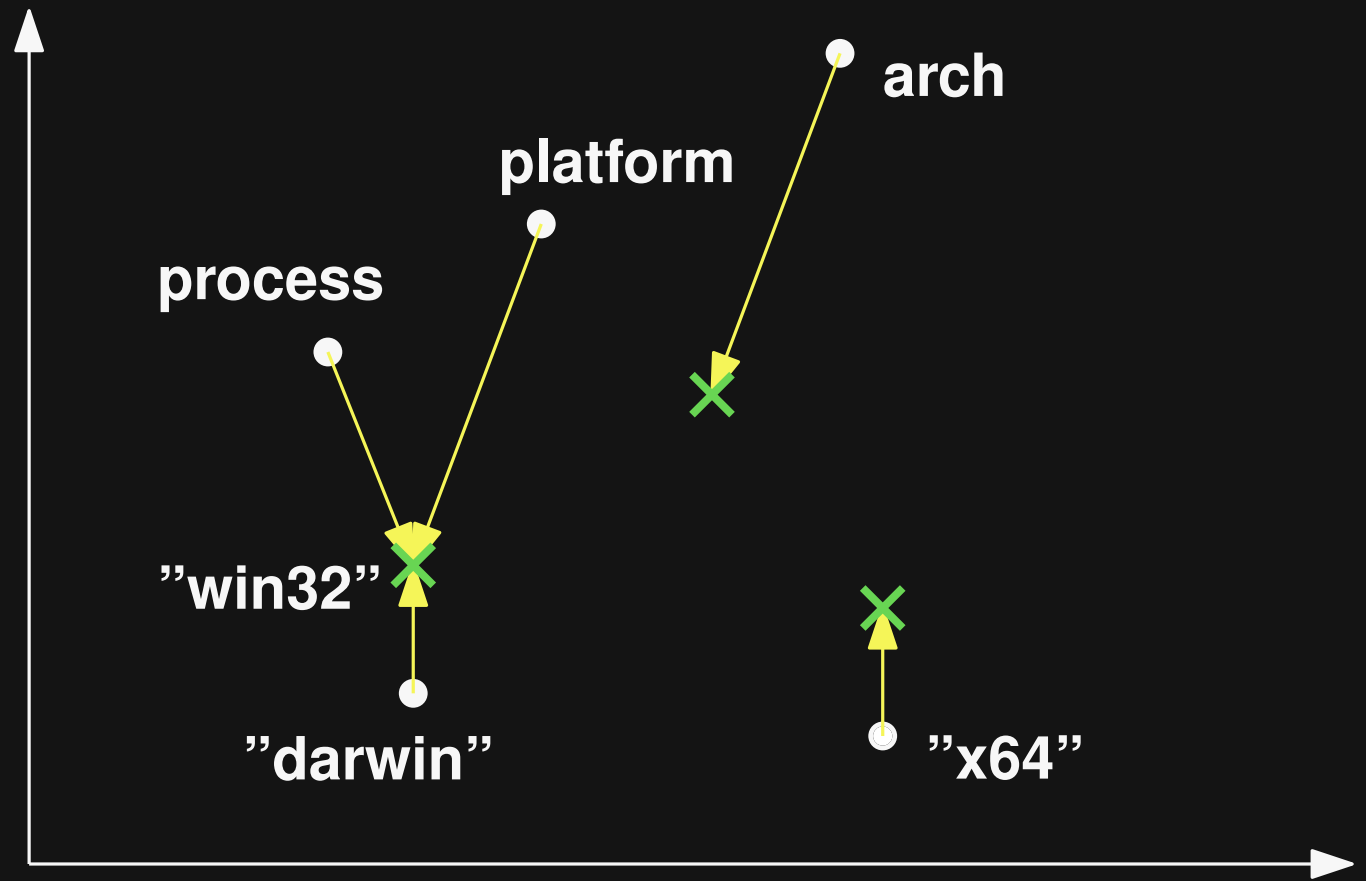

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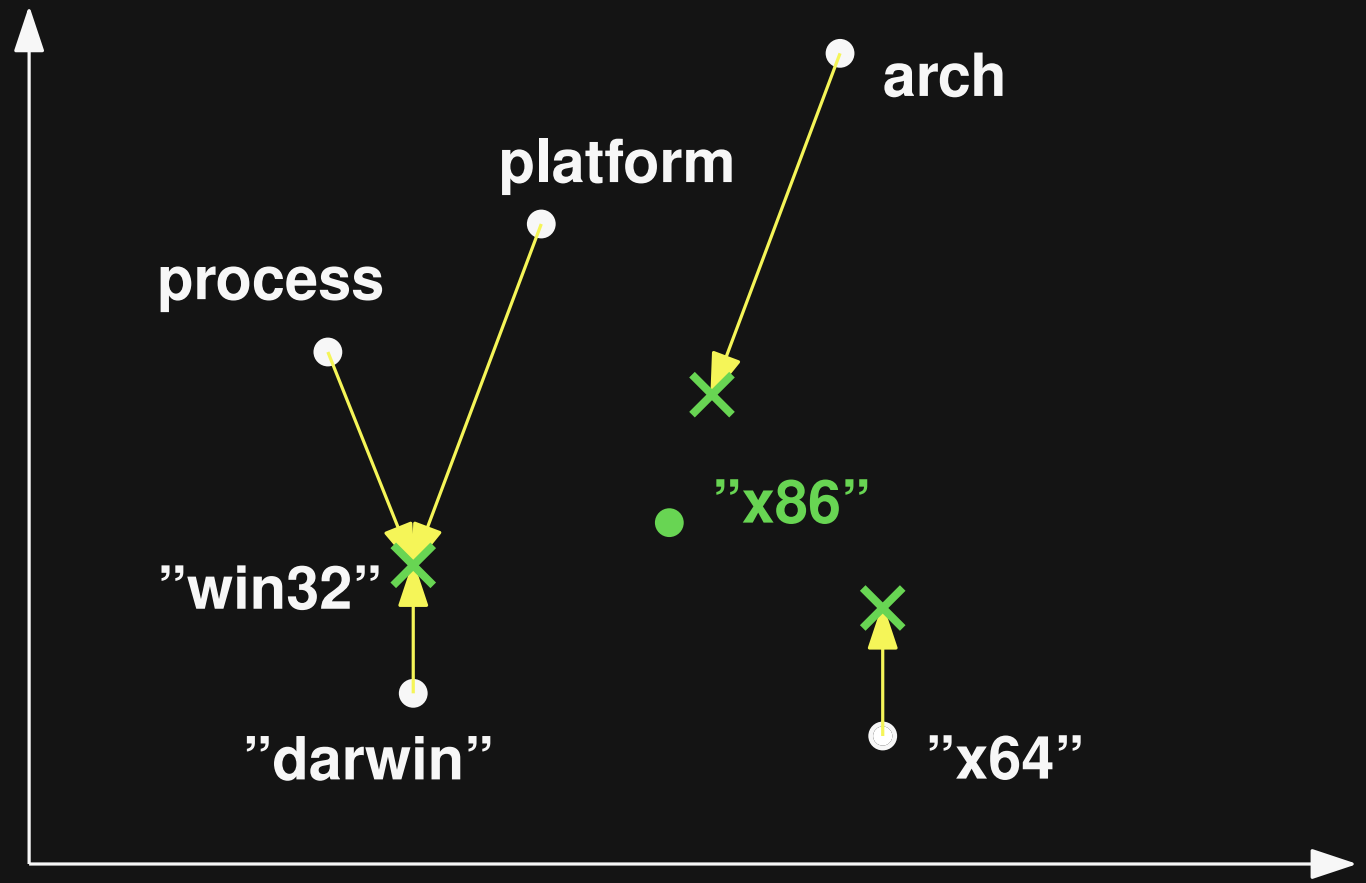

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hasFailed = item.errCode === -1;
if (hasFailed && process.arch !== "x86")
  ...
```

Evaluation

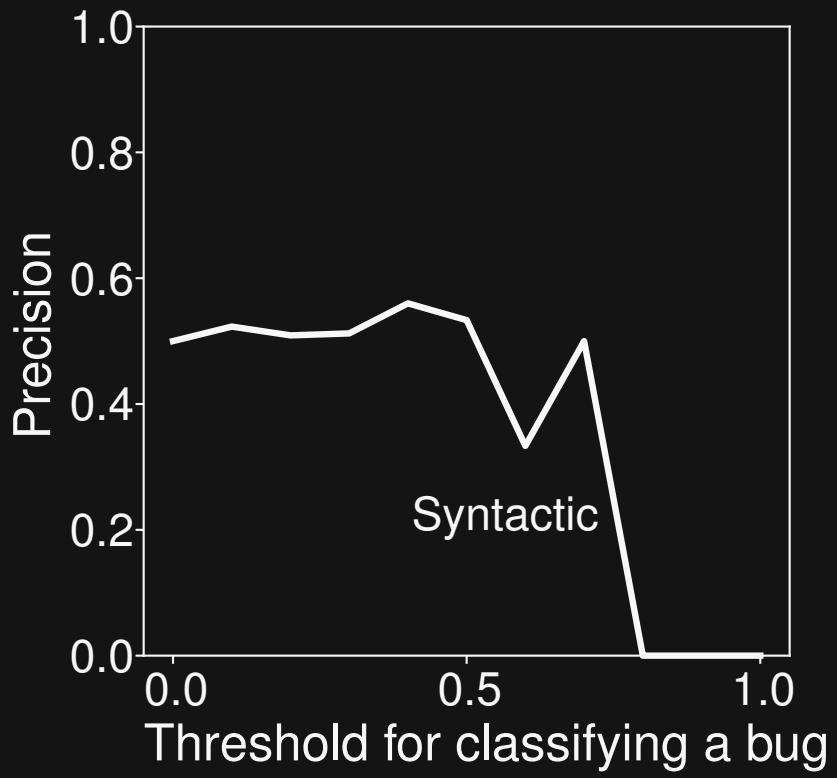
- **3,600 bug fixes from 100 popular JavaScript repositories**
  - Single-line changes with “bug”, “fix”, etc. in commit message
- **2,201 bug seeding patterns**
  - 62% have at least one unbound token

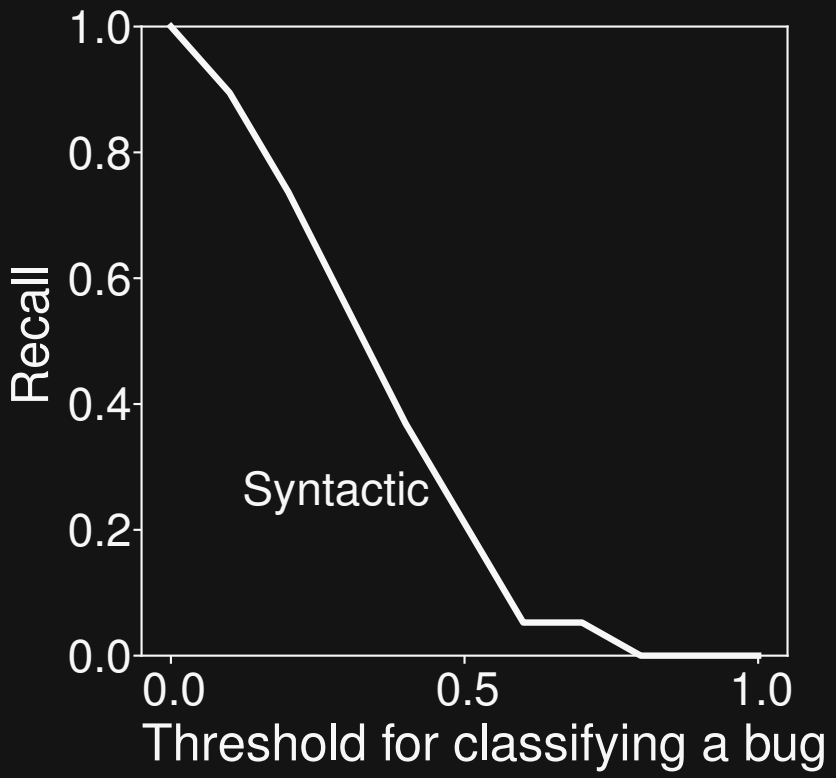
Reproducing Real Bugs

- **Seed 10 bugs per matching location**
- **Can reproduce held-out, real bugs?**
  - SemSeed reproduces 47/53 bugs
  - Syntactic baseline: 16/53 bugs
    - Main reason: Fails to guess unbound tokens

Learning Bug Detectors

Use seeded bugs as training data for learning bug detectors [DeepBugs, OOPSLA'18]





Incorrect assignment bugs, corpus of 120K files.

Artificial seeds 1.1M bugs, SemSeed seeds 248K bugs.

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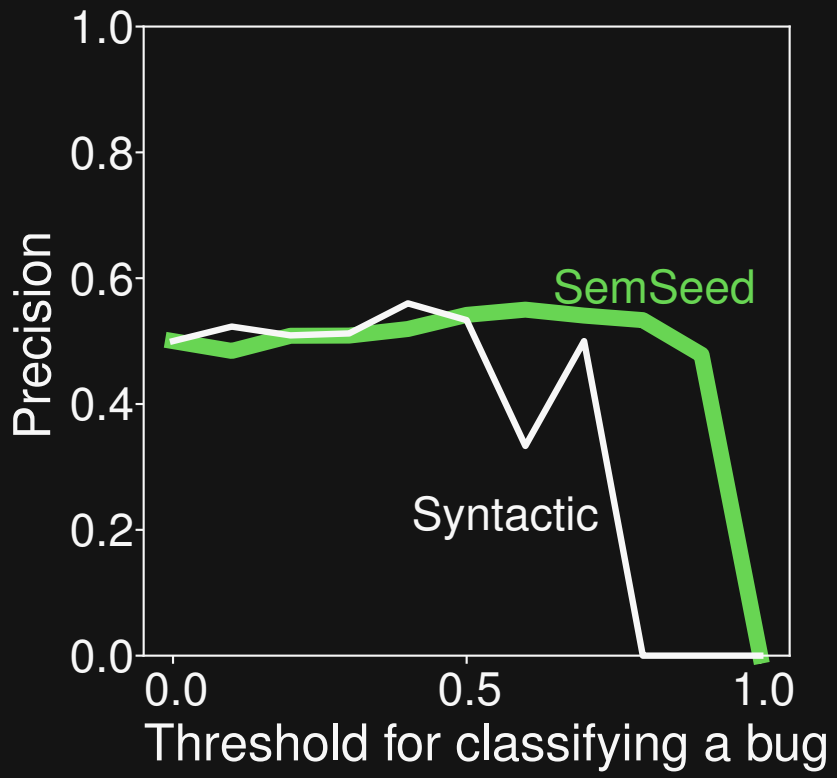

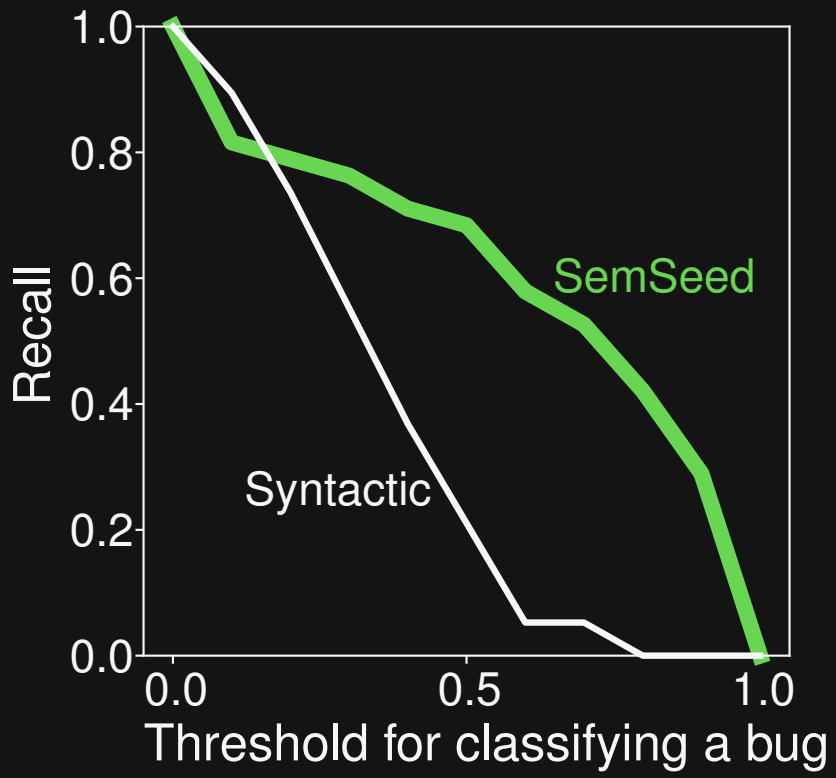

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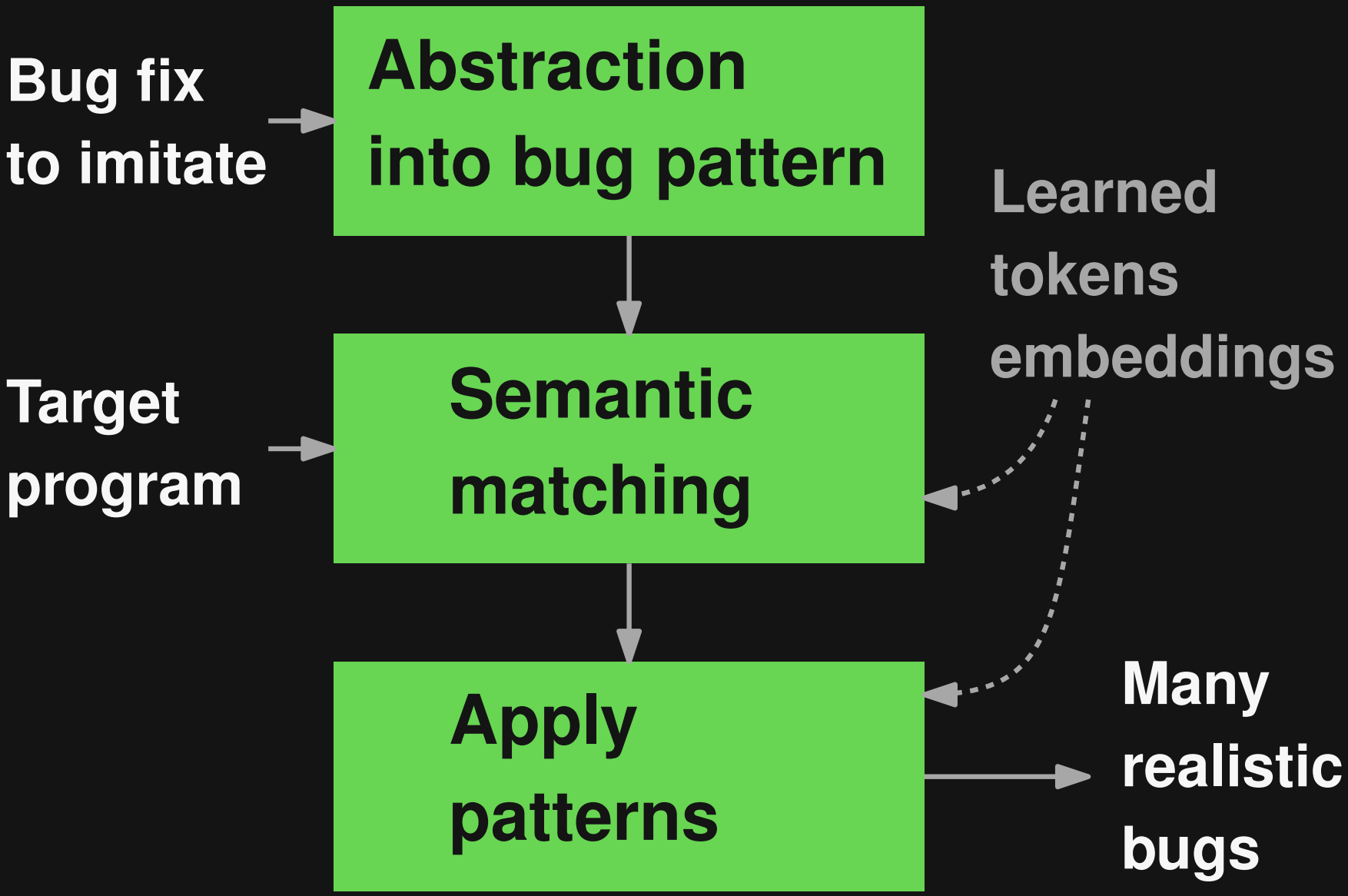
Summary


Bug fix
to imitate
Abstraction
into bug pattern
Learned
tokens
embeddings
Target
program
Semantic
matching
Apply
patterns
Many
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bugs

Comparison: Mutation Operators

- **Comparison with 23 mutation operators in Mutandis** [ICST'13]
  - SemSeed supports 16/23 mutation operators
  - 98.2% of SemSeed-generated bugs go beyond the 23 operators
- **Complementary to traditional mutation operators**