Balancing Soundness and Efficiency for Practical Testing of Configurable Systems

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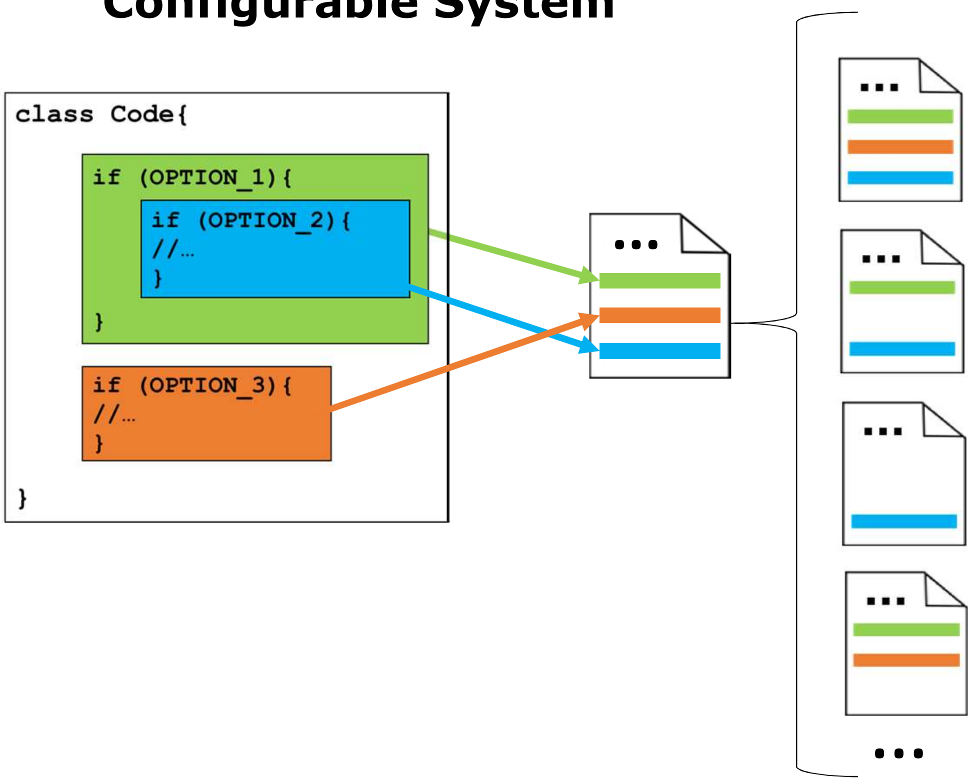
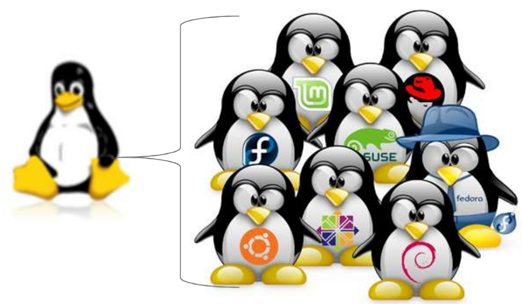
Configurable Systems

Configurations

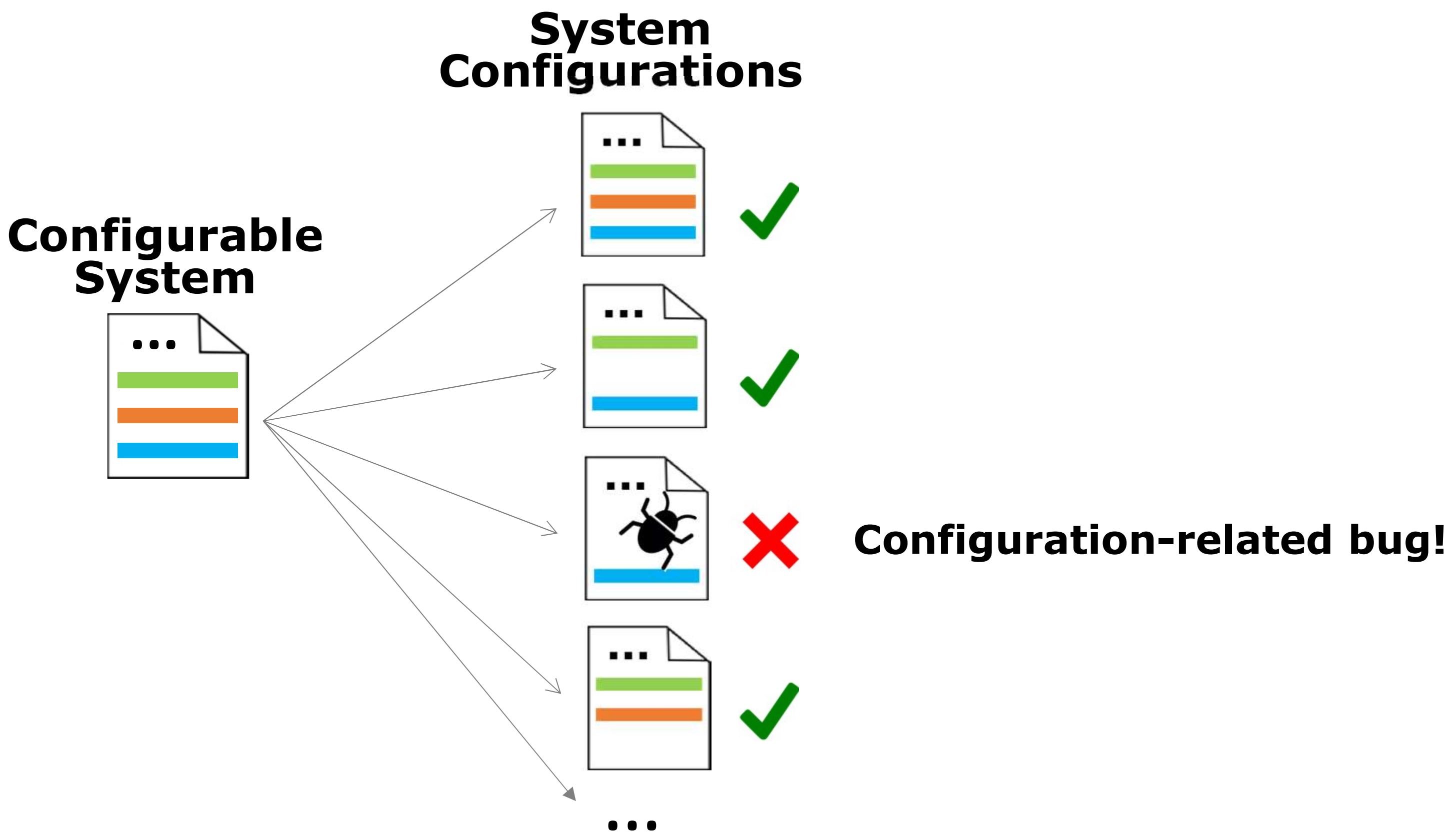
Configurable System



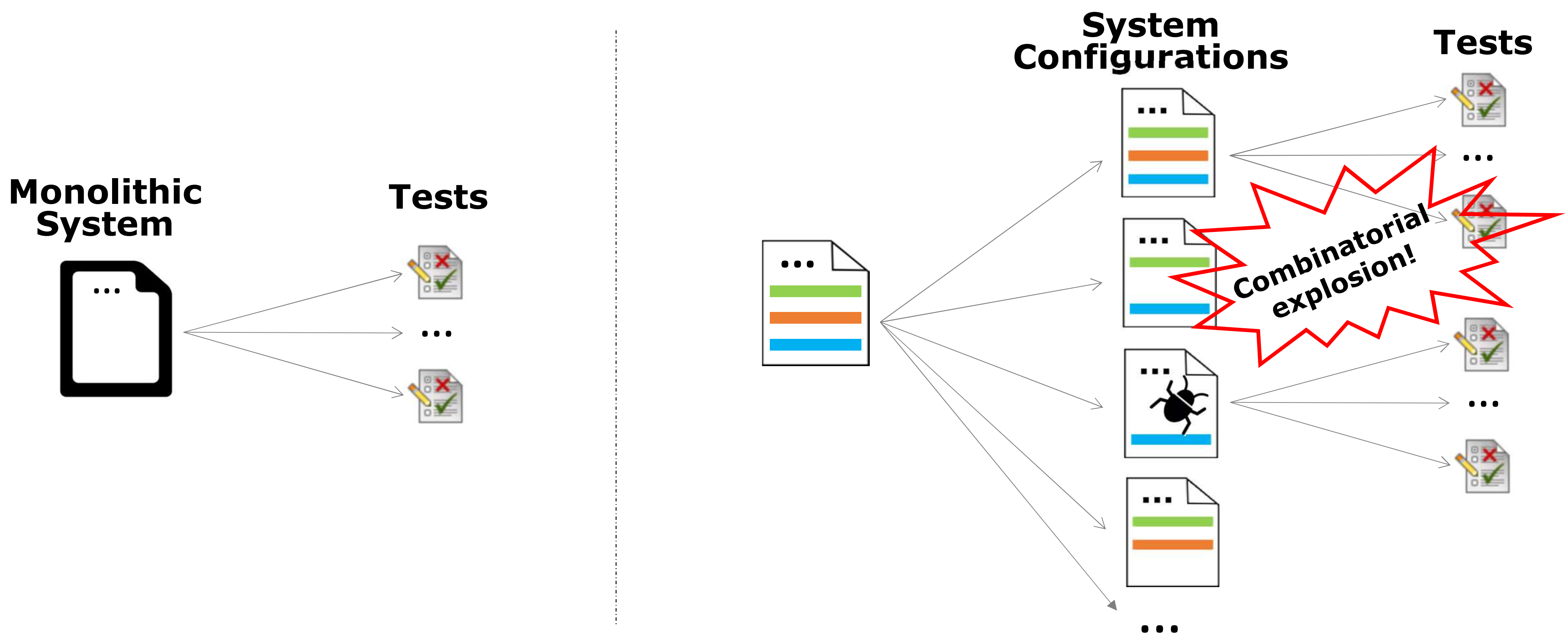


Many other examples!

Bugs in Configurable Systems



Testing Configurable Systems



Limitations of Existing Techniques

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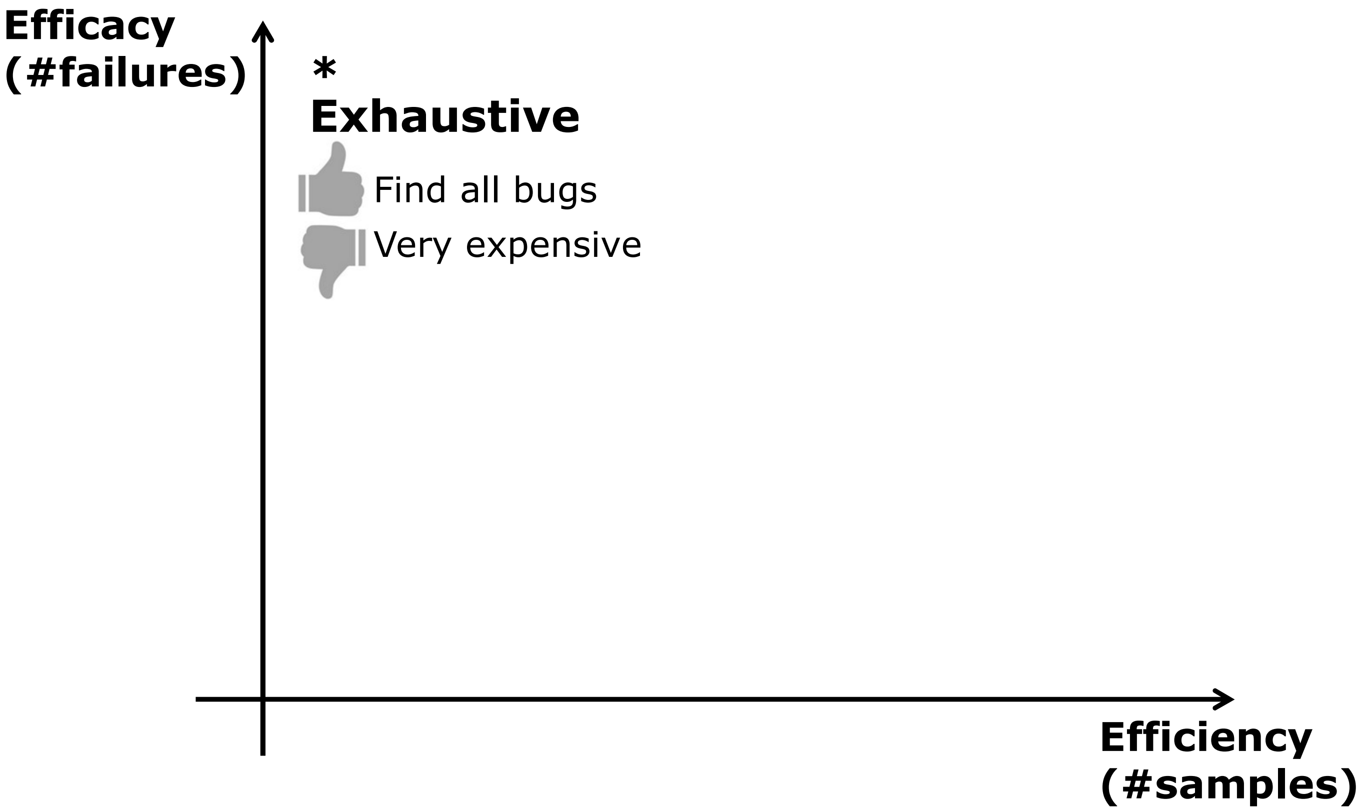
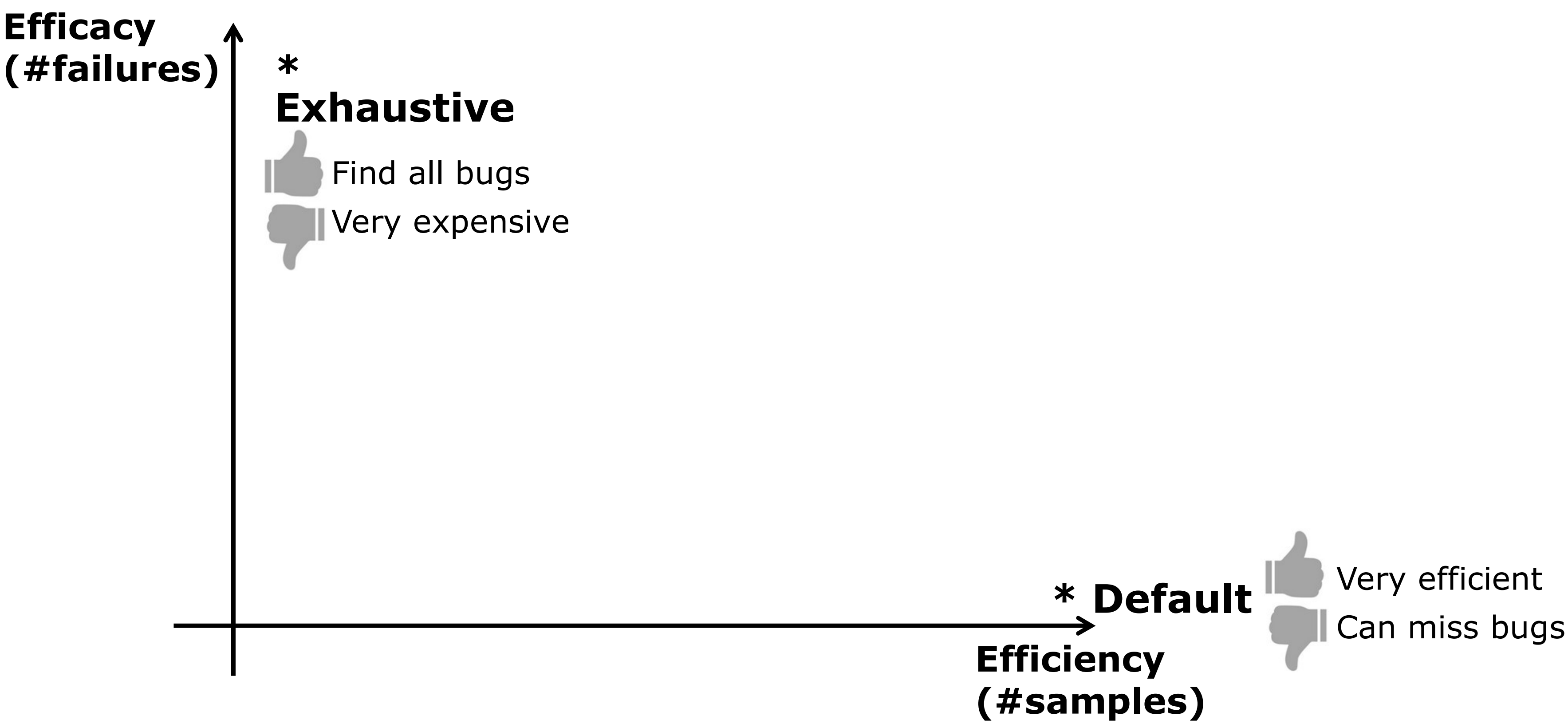
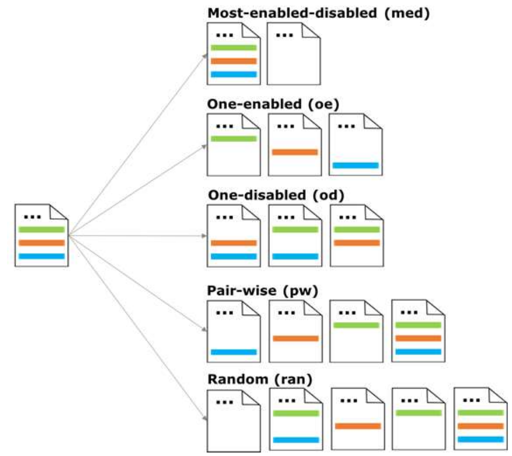


Limitations of Existing Techniques



Limitations of Existing Techniques



Efficacy (#failures)

*** Exhaustive**

Find all bugs

Very expensive

*** Sampling**

Try to find bugs with less samples

False positives and false negatives

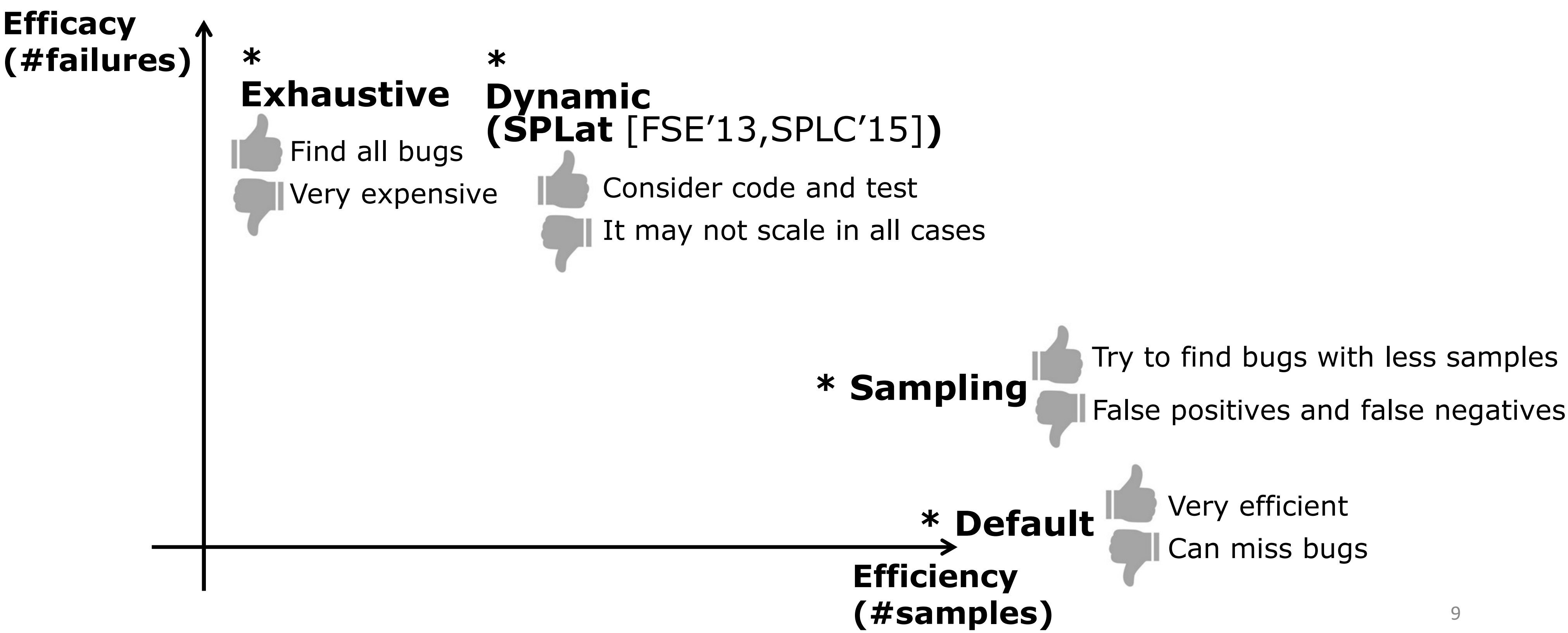
*** Default**

Very efficient

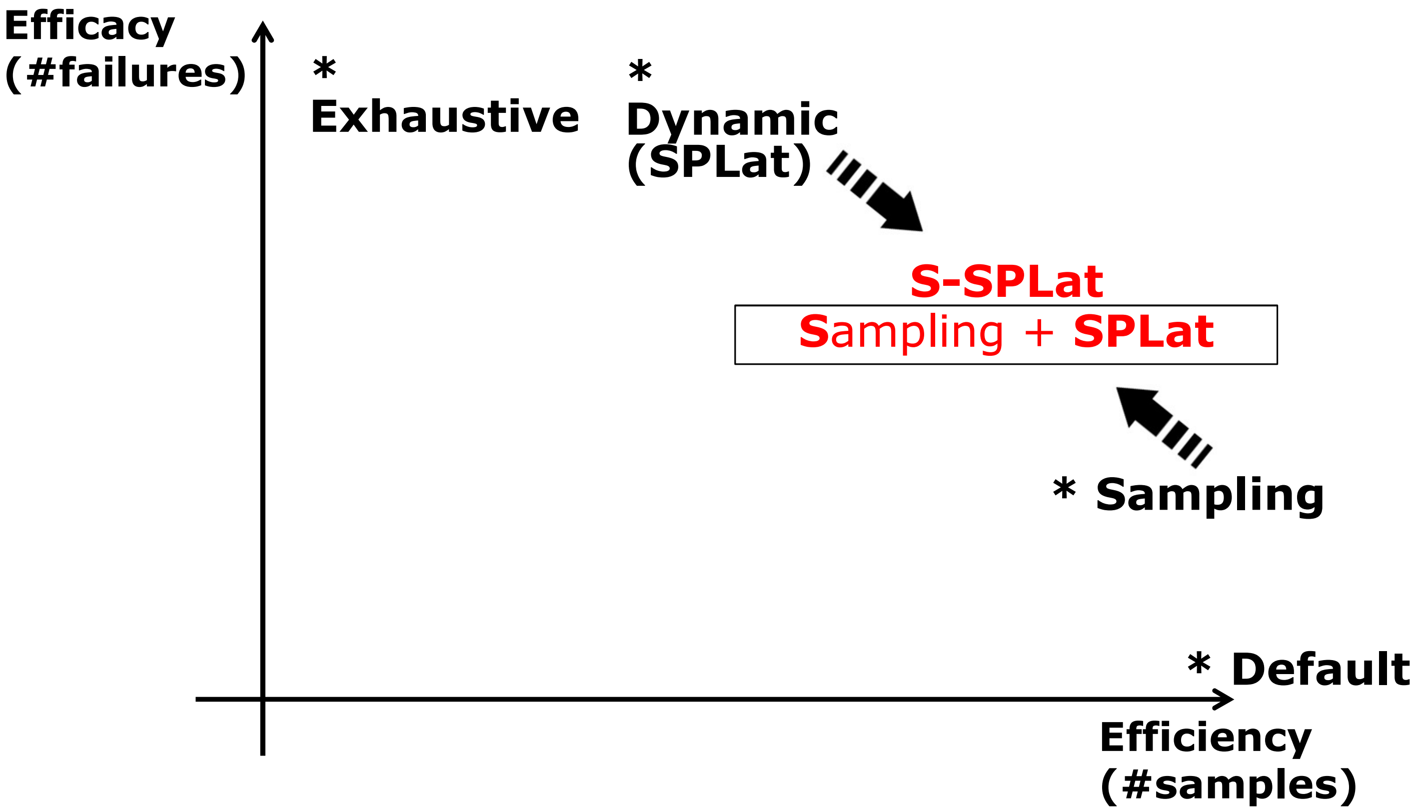
Can miss bugs

Efficiency (#samples)

Limitations of Existing Techniques



Limitations of Existing Techniques



Example

Sampling (one-enabled)

SPLat

S-SPLat (one-enabled)

Example

Notepad

- **17** configuration variables
- Only 3 are reached by toolbar()

Test

```
class Notepad {
    void toolbar() {
        if (TOOLBAR) {
            //...
            if (WORDCOUNT) {
                //...
            }
        }

        if (MENUBAR) {
        //...
        }
    }
    //...
}
```

Sampling (one-enabled)

SPLat

S-SPLat (one-enabled)

Example

Notepad
- **17** configuration variables
- Only 3 are reached by toolbar()

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Sampling (one-enabled)

17 configurations

SPLat

S-SPLat (one-enabled)

Example

Notepad

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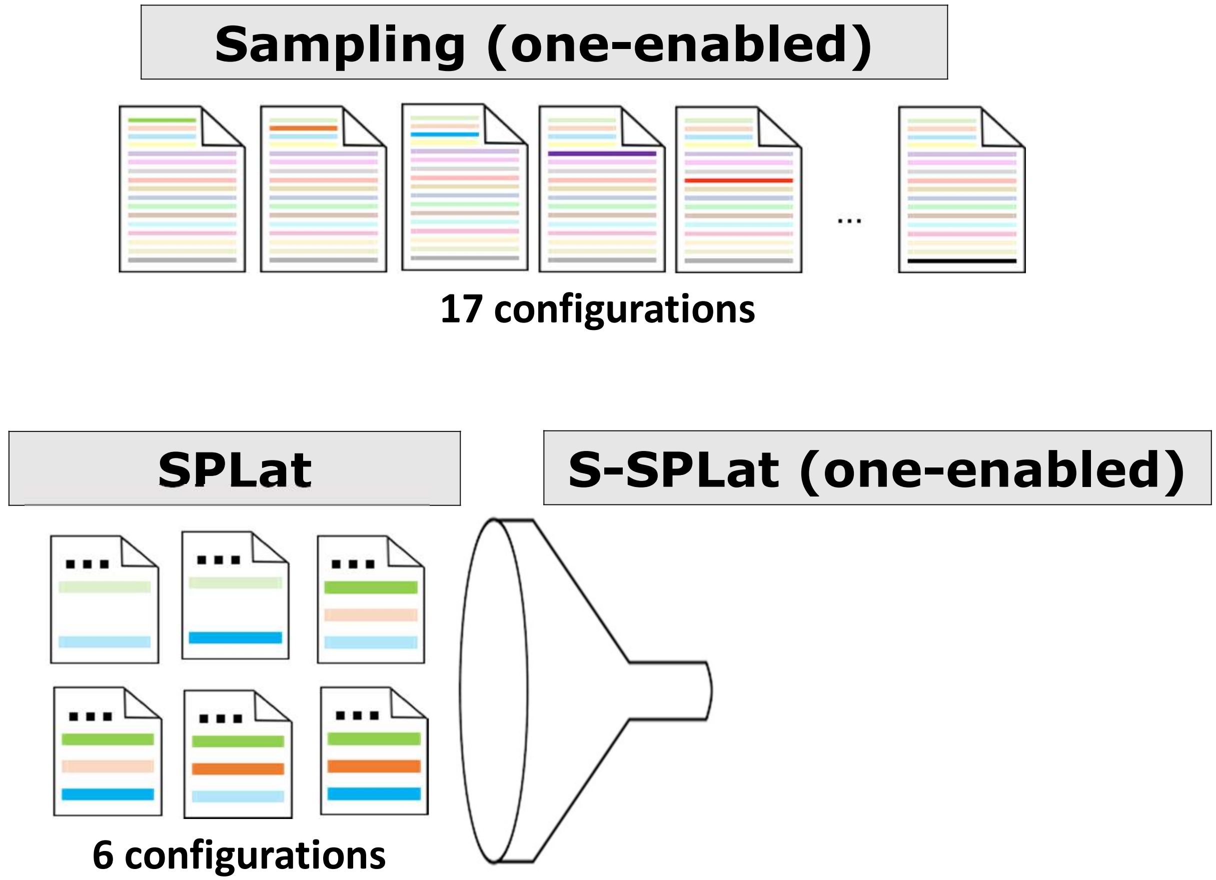

Example

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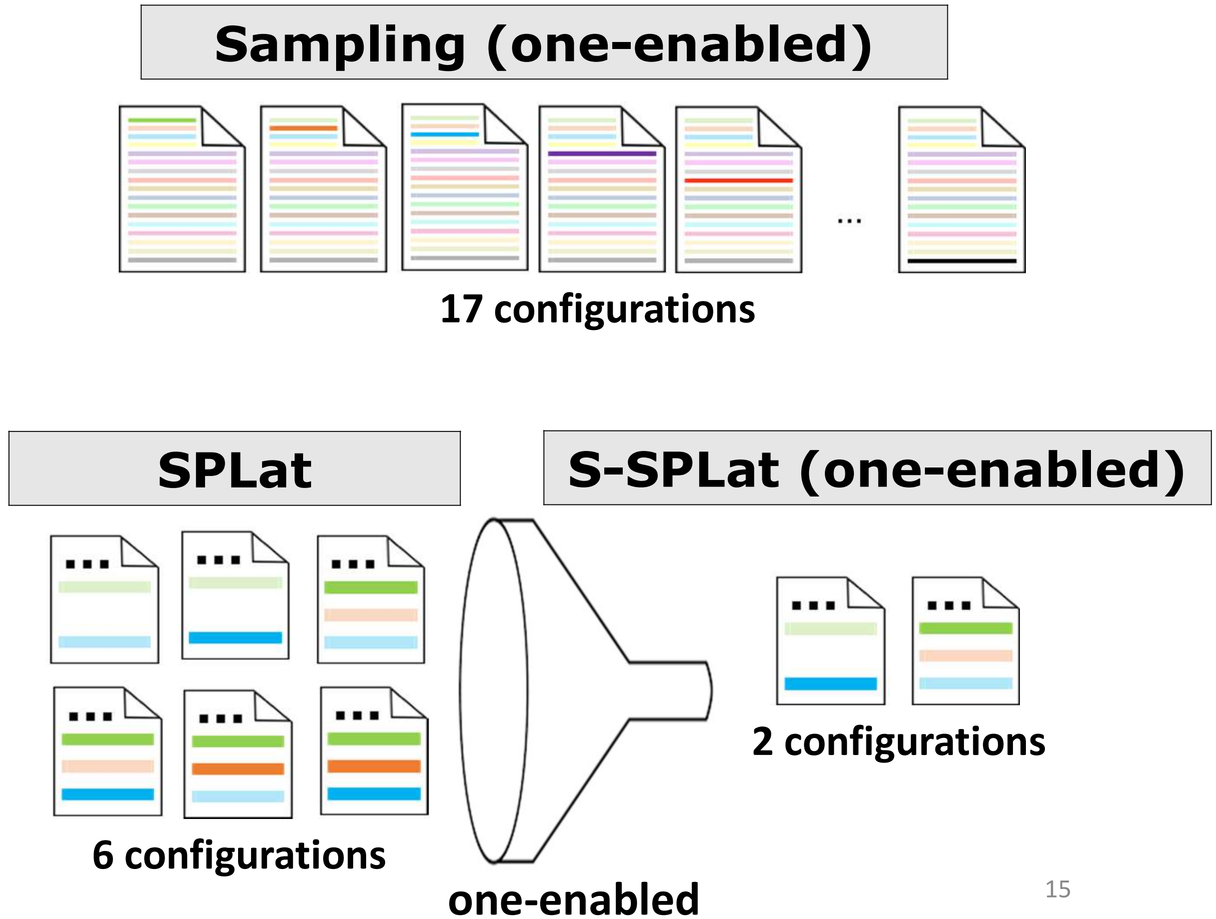
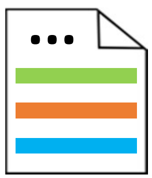


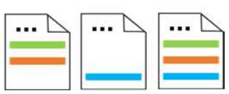
S-SPLat

Input

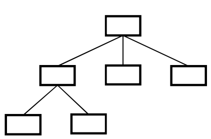


Instrumented Configurable System

Tests



Sampling Heuristic

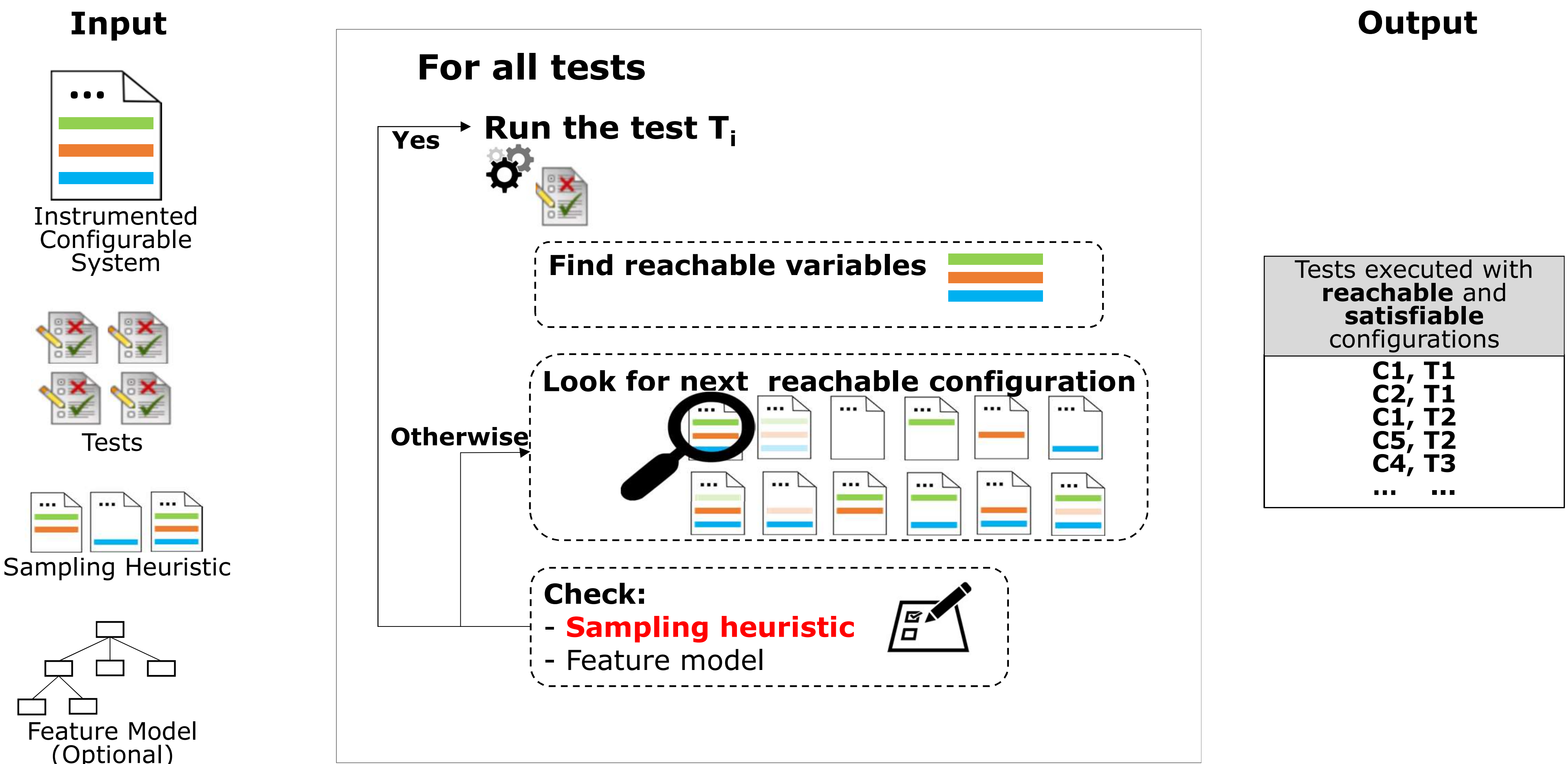


Feature Model (Optional)

Output

Tests executed with **reachable** and **satisfiable** configurations
C1, T1
C2, T1
C1, T2
C5, T2
C4, T3
… …

S-SPLat



Input
Instrumented Configurable System
Tests
Sampling Heuristic
Feature Model (Optional)
For all tests
Yes
Run the test T_i
Find reachable variables
Otherwise
Look for next reachable configuration
Check:
- Sampling heuristic
- Feature model
Output
Tests executed with **reachable** and **satisfiable** configurations
C1, T1
C2, T1
C1, T2
C5, T2
C4, T3
... ...

EVALUATION

Research Questions

RQ1 → Which heuristics maximize efficiency (#samples)?

RQ2 → Which heuristics maximize efficacy (#failures)?

RQ3 → Which heuristics (basic or combination) maximize efficiency and efficacy?

Scenarios

- **17K+ tests**
- **2k+ variables**

GCC

Software Product Lines (SPLs)

8 subjects

- All existing tests
- All existing options

Version 6.1

Version 4.8.2

- 3,557 tests
- 50 most frequently cited options in bug reports

Evaluation

SPLs

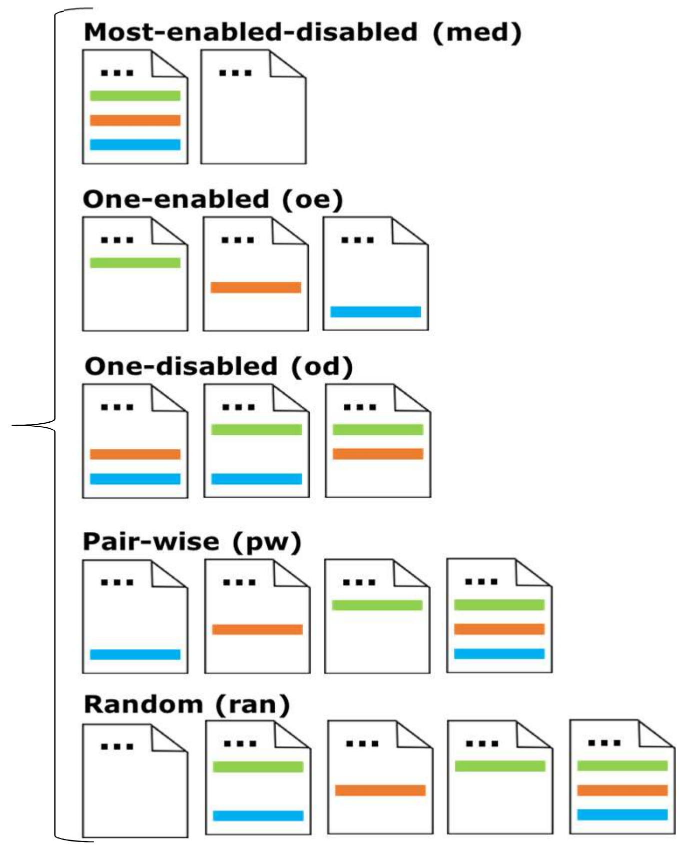
Evaluation Techniques

[ICSE’16,ASE’14]

SPLs

8 subjects

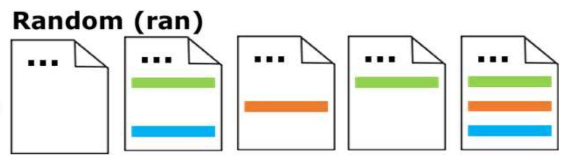
Techniques:
1. SPLat
2. SPLat + med
3. SPLat + oe
4. SPLat + od
5. SPLat + pw
6. SPLat + ran



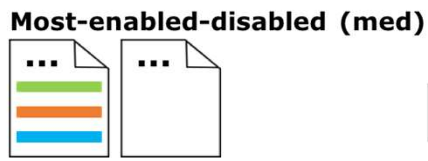
Findings

RQ1: Which heuristics maximize efficiency (#samples)?

SPLat and **SPLat+**



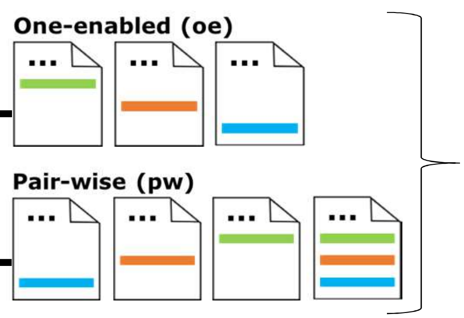
SPLat+



RQ2: Which heuristics maximize efficacy (#failures)?

SPLat+

SPLat+



Findings

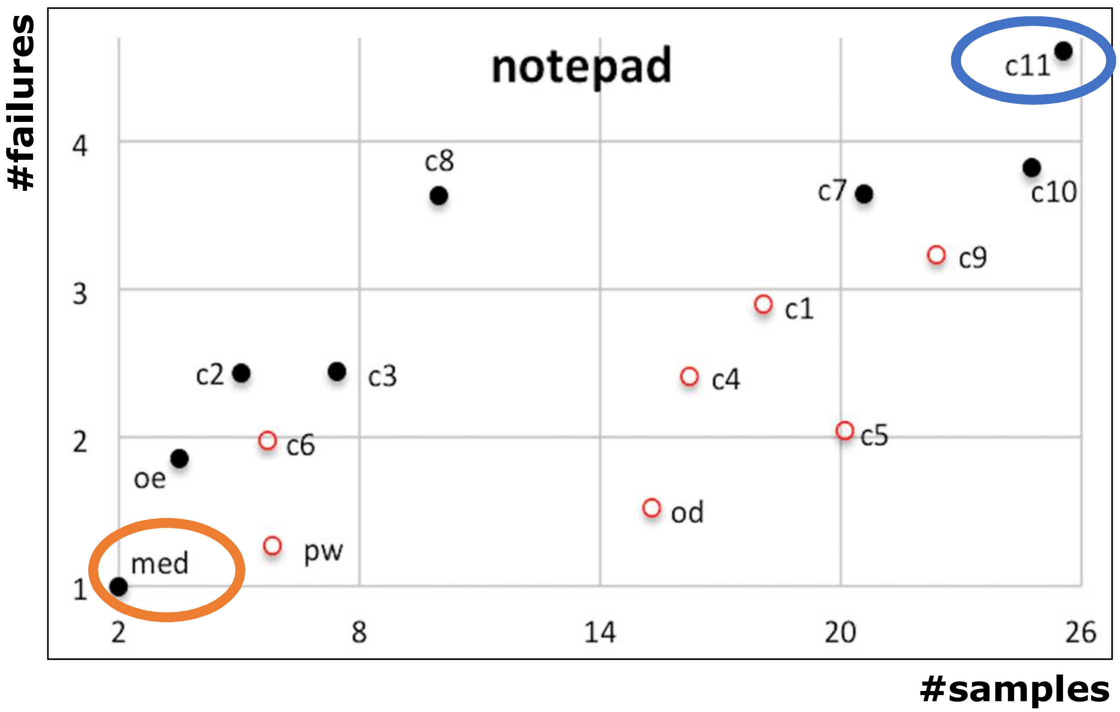
RQ3: Which heuristics maximize efficiency (#samples) and efficacy (#failures)?

Combinations of heuristics

- **oe x od x med x pw**
  - **c1** = oe+od
  - **c2** = oe+med
  - **c3** = oe+pw **...**
  - **c11** = oe+od+med+pw

Findings

RQ3: Which heuristics maximize efficiency (#samples) and efficacy (#failures)?



- **SPLat+Most-enabled-disabled** optimized #samples at the expense of #failures
- **SPLat+c11** (oe + od + med + pw) optimized #failures at the expense of #samples
- **SPLat** did not scale for some subjects

The sampling heuristics **reduced the number of samples** explored by SPLat yet retaining their ability to **reveal failures**.

Evaluation

Evaluation Techniques

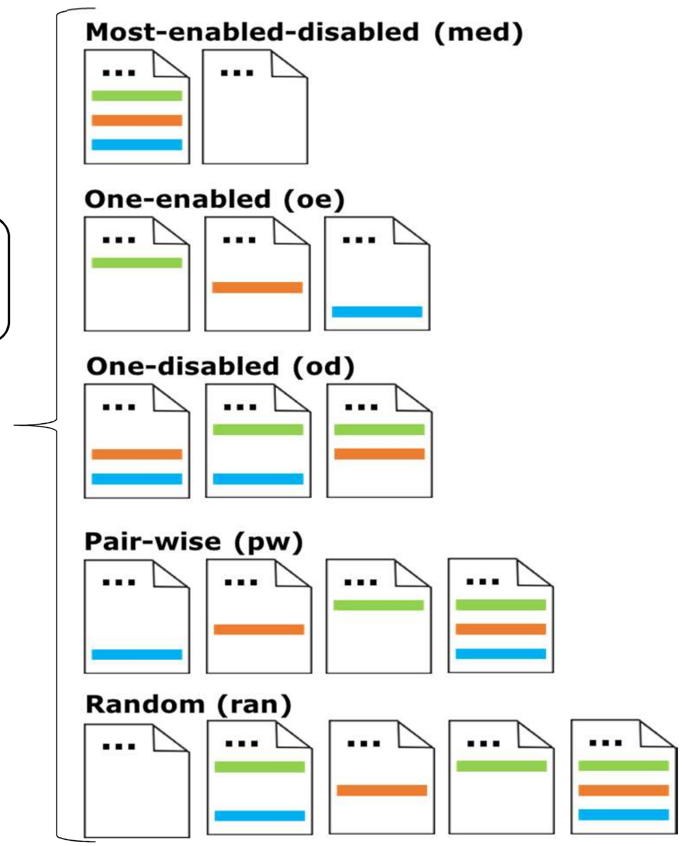
[ICSE'16,ASE'14]

Version 6.1

Version 4.8.2

Techniques:

1. SPLat
2. SPLat + med
3. SPLat + oe
4. SPLat + od
5. SPLat + pw
6. SPLat + ran



Findings

Evaluation SPLs

Evaluation

GCC

Version 6.1

RQ1: Which heuristics maximize efficiency (#samples)?

Random (ran)

SPLat+ and **SPLat+**

Pair-wise (pw)

Most-enabled-disabled (med)

SPLat+

RQ2: Which heuristics maximize efficacy (#failures)?

One-enabled (oe)

SPLat+

One-disabled (od)

SPLat+

Findings

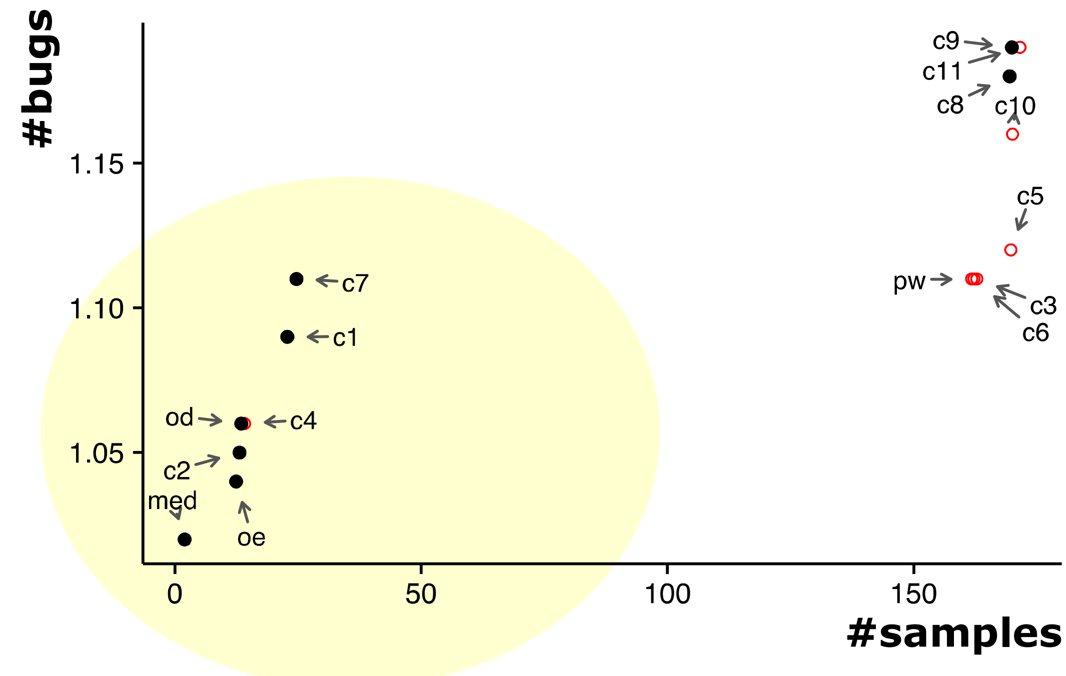
Evaluation SPLs

Evaluation

GCC

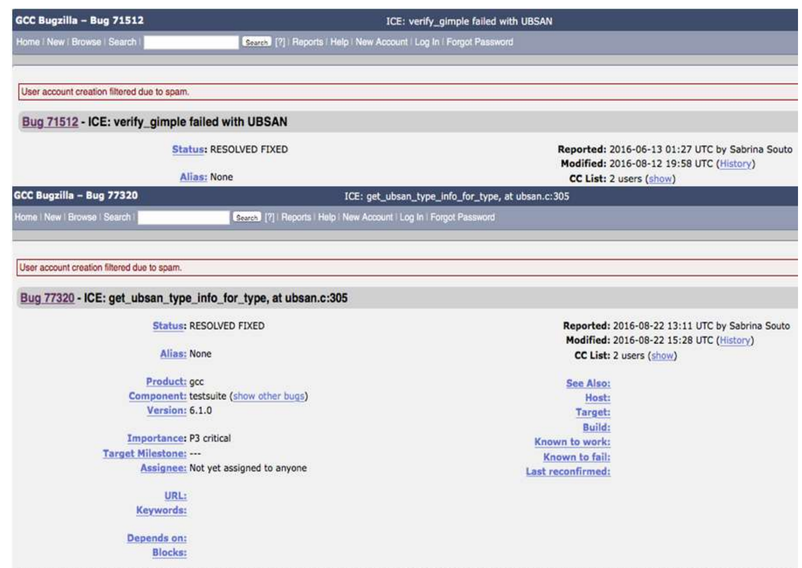
Version 6.1

RQ3: Which heuristics maximize efficiency (#samples) and efficacy (#failures)?



It is preferable to pick the best performing heuristics in the leftmost group → **the best choices**!

Bugs found



2 new bugs reported.

Evaluation SPLs

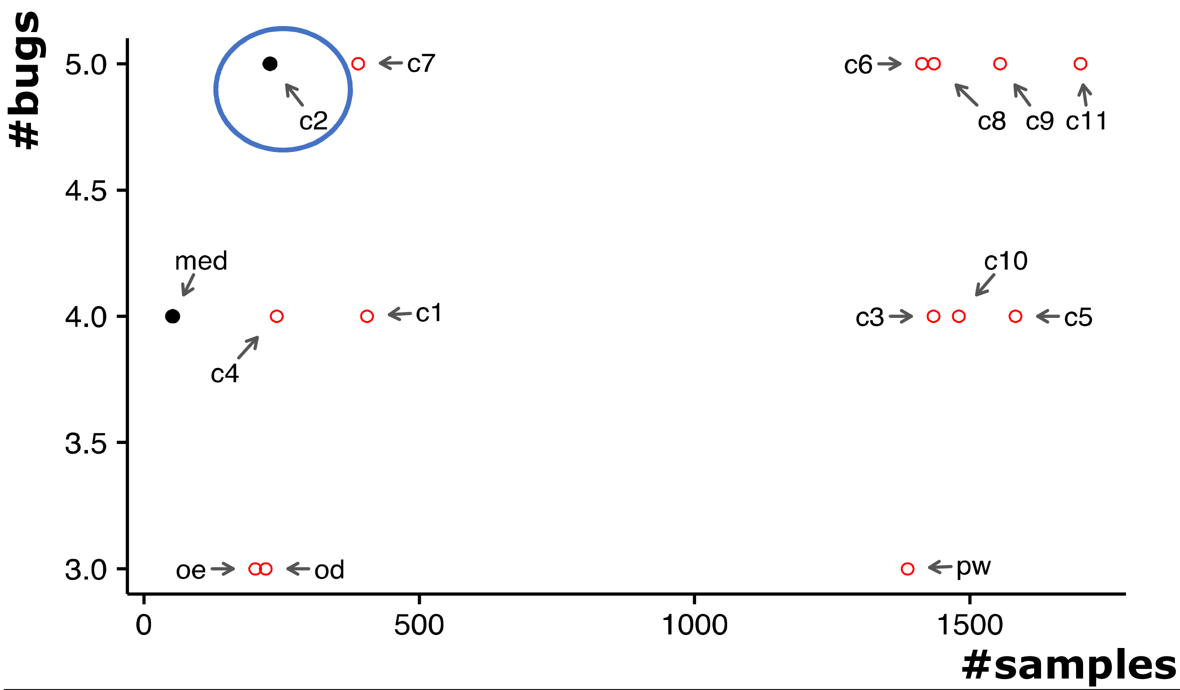
Evaluation

GCC

Version 4.8.2

Findings

RQ3: Which heuristics maximize efficiency (#samples) and efficacy (#failures)?



Bugs found

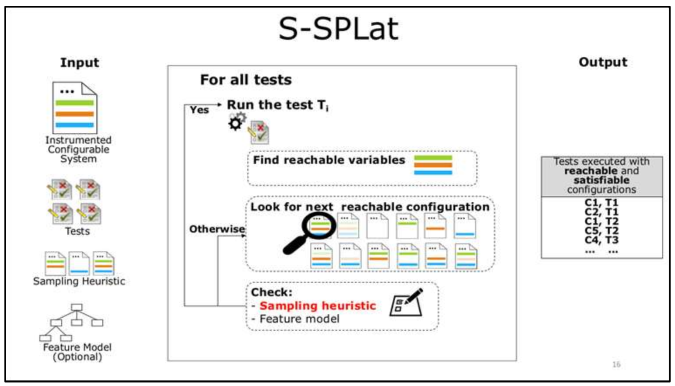
Basic Technique	Crash Id 1	2	3	4	5
med	✓	✓		✓	✓
oe	✓	✓	✓		
od	✓	✓			✓
pw	✓	✓	✓		

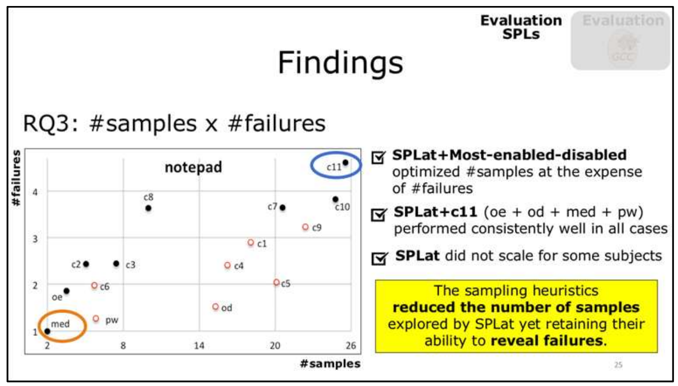
All five bugs were captured.
SPLat+c2(oe+med) found all bugs with a relatively small number of samples.

Lessons Learned

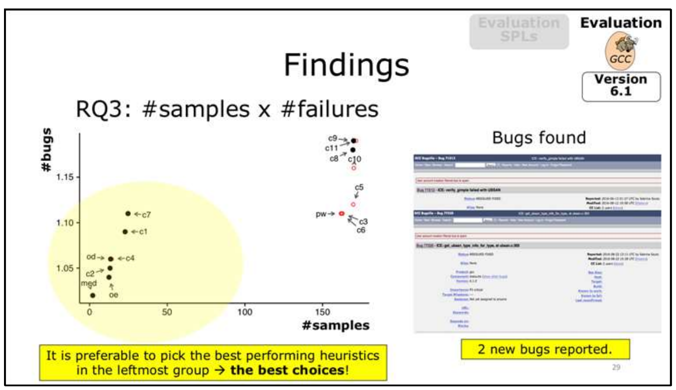
- For SPLs → c11 (oe+od+med+pw)
- For GCC → c2(oe+med)
- For SPLs and GCC → c7 (oe+od+med)
    - [ICSE 2016] **A comparison of 10 sampling algorithms for configurable systems**.
- Combine different simple heuristics
- Avoid heuristics with a large number of requirements

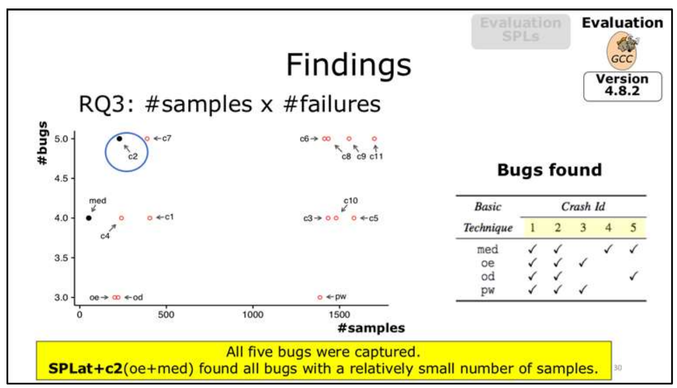
- **S-SPLat found a good balance between bugs and samples**
  - The sampling heuristics helped to reduced the number of samples explored by SPLat without loss the ability to find bugs
- **S-SPLat could deal with scalability**
  - It revealed bugs in potentially large configuration spaces





https://sabrinadfs.github.io/s-splat/





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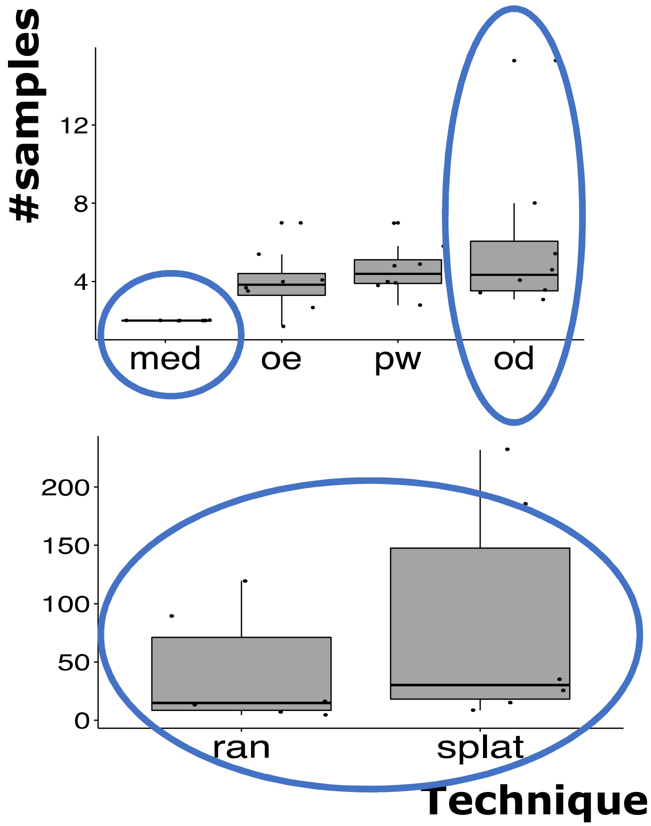
BACKUP SLIDES

Evaluation SPLs | Evaluation GCC

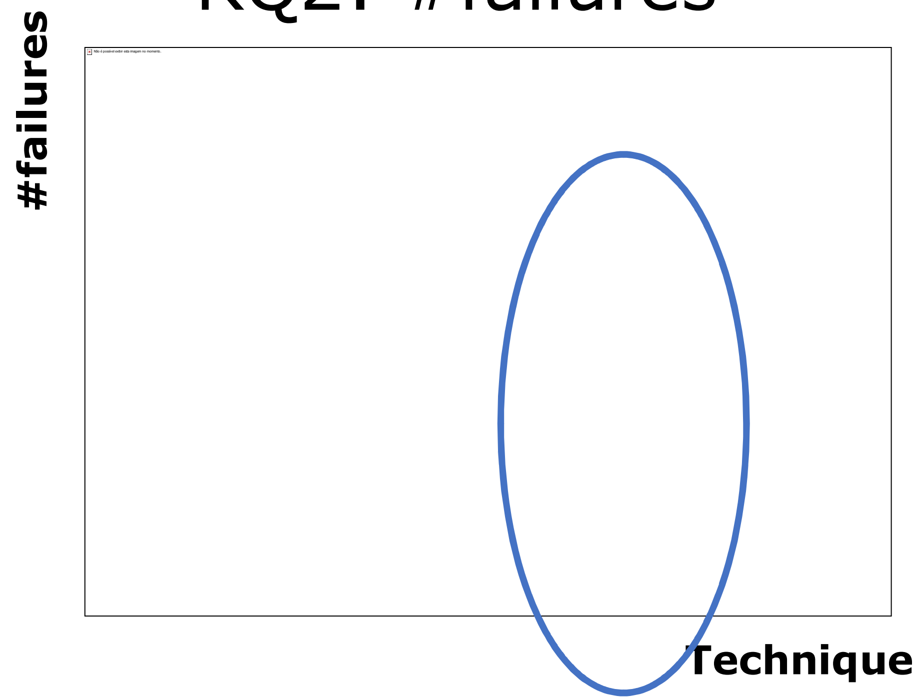
RQ1: #samples



SPLat and **ran** explored much samples.

med explored the smallest sample sets.
od explored the largest sample sets.

RQ2: #failures

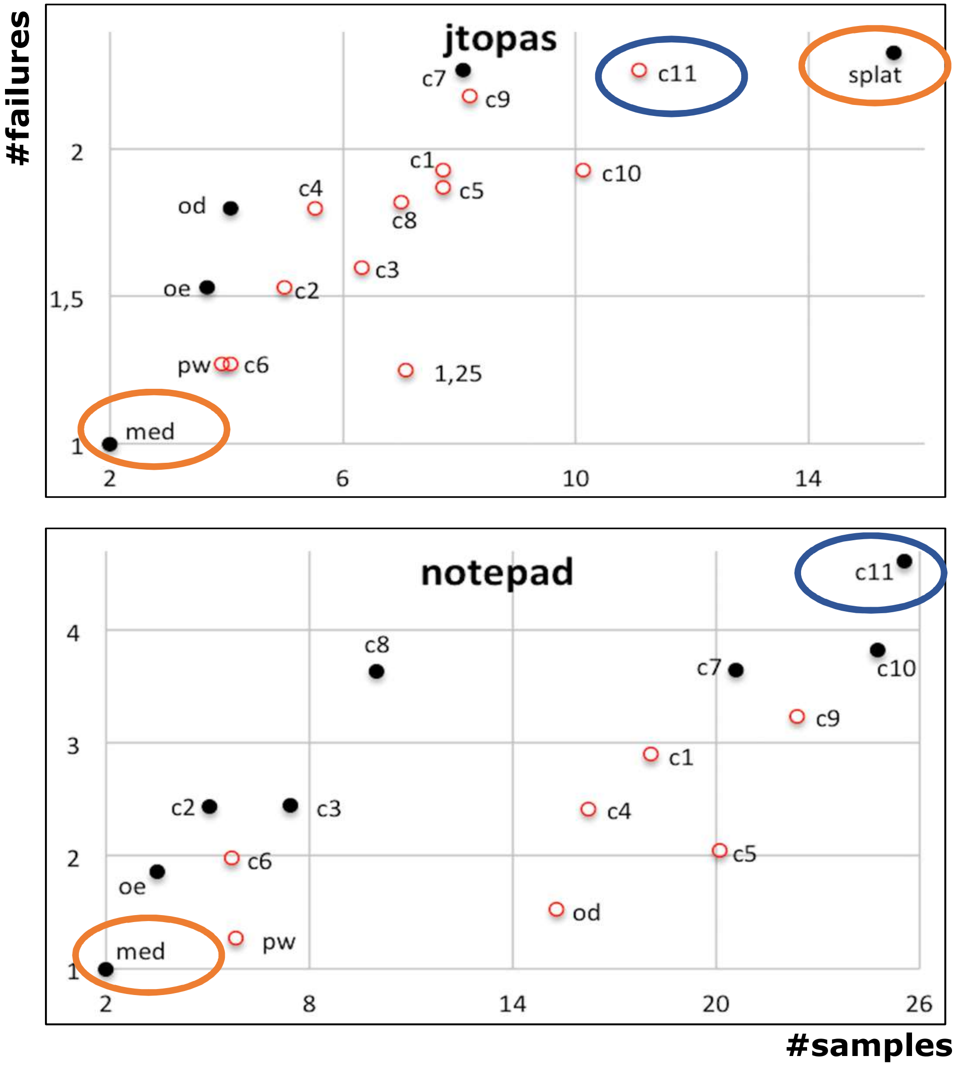


od and **pw** found almost the same number of failures as **splat** but they required much fewer samples.

RQ3: #samples x #failures

Evaluation SPLs

Evaluation GCC



- Combinations of heuristics
  - **oe x od x med x pw**
    - **c1** = oe+od
    - **c2** = oe+med
    - **c3** = oe+pw**…**
    - **c11** = oe+od+med+pw

SPLat and **med** optimize one dimension at the expense of the other.

c11 (oe + od + med + pw) performed consistently well in all cases.

The sampling heuristics **reduced the number of samples** explored by SPLat yet retaining their ability to **reveal failures**.

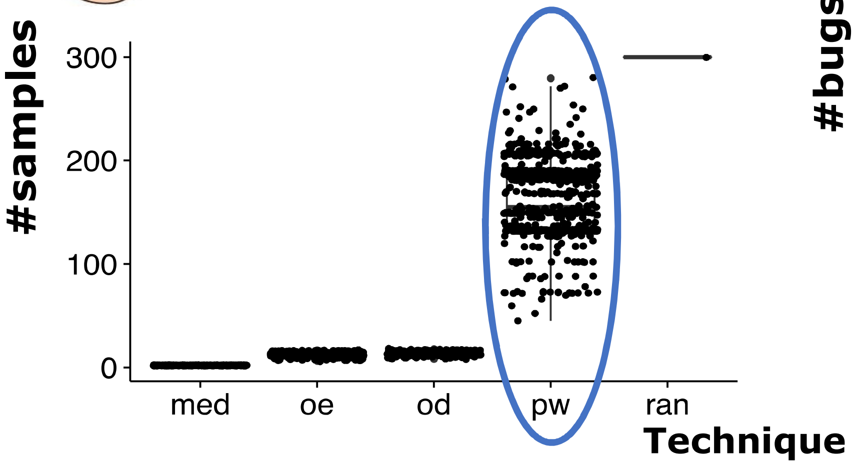
Evaluation SPLs

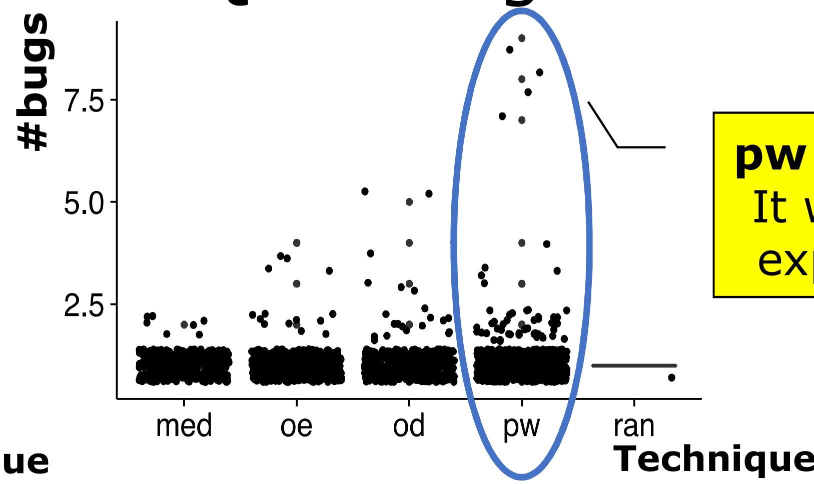
Evaluation GCC

Version 6.1

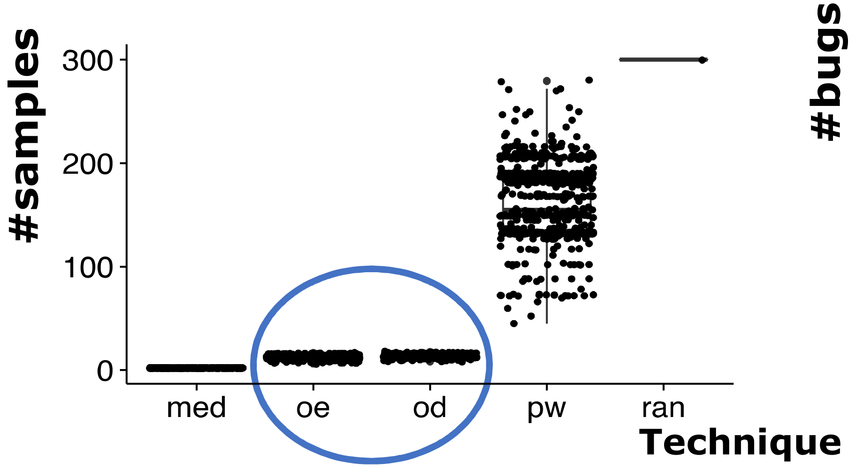
RQ1: #samples

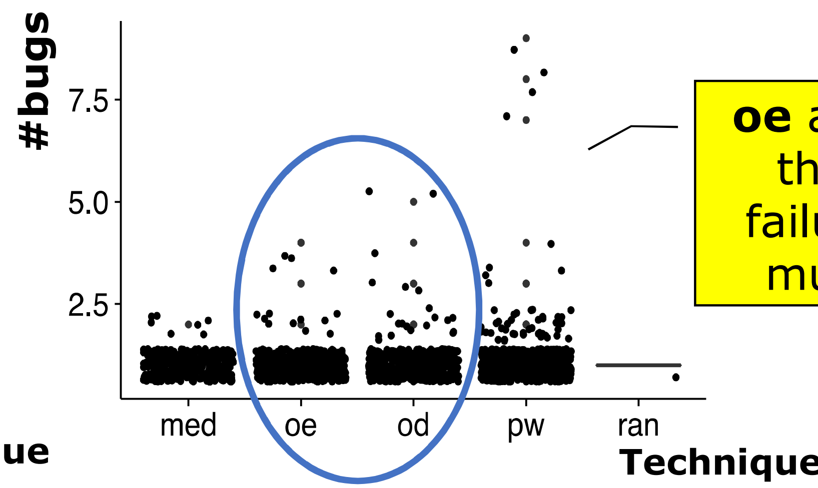
RQ2: #bugs





pw found more failures. It was one of the most expensive techniques.





oe and **od** found almost the same number of failures as **pw** but with much fewer samples.

Evaluation SPLs

Evaluation GCC

Discussion

- **c2** found all crashes with a relatively low number of configurations
- **c7** performed better, it detected most failures and crashes through a relatively small number of configurations
- Combine different simple heuristics instead of using one that entails a larger number of test requirements
- **S-SPLat** is promising to reveal errors in potentially large configuration spaces

Handling Constraints

SPLs

Complex models

- 54% of the selected configurations are invalid
- 43% of failures are false positives

GCC

The use of validation is not necessary

- Crashes was only revealed in valid configurations

The techniques performed consistently with and without feature constraints

Evaluation SPLs **Evaluation GCC**

Additional Evaluations

S-SPLat
x
Regular Sampling

Regular Sampling detected the same bugs as S-SPLat with more configurations.

Random Sampling with more rates: 10% and 30%

New results are proportional to the change in the sampling rates of random.

Threats to Validity and Limitations

- The selection of subjects
  - We used subjects from a variety of sources, including a large configurable system with hundreds of options
- Eventual implementation errors
  - We thoroughly checked our implementation and our experimental results
  - Our datasets and implementations are publicly available: https://sabrinadfs.github.io/s-splat/
- SPLat currently only supports systems with dynamically bound feature variables])
  - It remains to investigate how SPLat and S-SPLat would perform on systems with #ifdef variability