Incremental Identification of T-Wise Feature Interactions

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Software Engineering
Programming Languages

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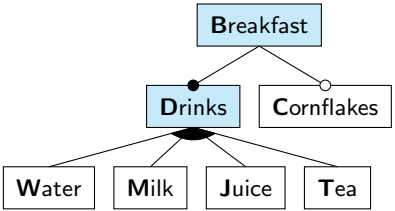
Configurable Software



Cornflakes $\Rightarrow$ **M**ilk

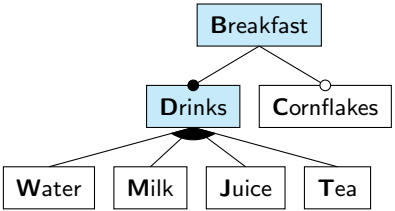
```
1  void main(){
2      // ...
3      #ifdef Milk
4      addMilk();
5      #endif
6
7      #ifdef Cornflakes
8      addCornflakes();
9      #endif
10 }
```

$$c = \{\neg W, M, J, T, \neg C\}$$

Problem Statement

Which feature interaction causes the failing configuration?

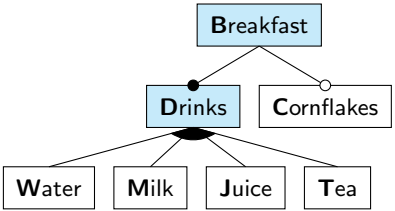
t-wise Feature Interactions: $t = 1$



Cornflakes $\Rightarrow$ **M**ilk

$$W \quad \neg W$$
$$M \quad \neg M$$
$$J \quad \neg J$$
$$T \quad \neg T$$
$$C \quad \neg C$$

t-wise Feature Interactions: $t = 2$



Cornflakes $\Rightarrow$ **M**ilk

$W \wedge M$	$W \wedge \neg M$	$\neg W \wedge M$	$\neg W \wedge \neg M$
$W \wedge J$	$W \wedge \neg J$	$\neg W \wedge J$	$\neg W \wedge \neg J$
$W \wedge T$	$W \wedge \neg T$	$\neg W \wedge T$	$\neg W \wedge \neg T$
$W \wedge C$	$W \wedge \neg C$	$\neg W \wedge C$	$\neg W \wedge \neg C$
$M \wedge J$	$M \wedge \neg J$	$\neg M \wedge J$	$\neg M \wedge \neg J$
$M \wedge T$	$M \wedge \neg T$	$\neg M \wedge T$	$\neg M \wedge \neg T$
$M \wedge C$	$M \wedge \neg C$		$\neg M \wedge \neg C$
$J \wedge T$	$J \wedge \neg T$	$\neg J \wedge T$	$\neg J \wedge \neg T$
$J \wedge C$	$J \wedge \neg C$	$\neg J \wedge C$	$\neg J \wedge \neg C$
$T \wedge C$	$T \wedge \neg C$	$\neg T \wedge C$	$\neg T \wedge \neg C$

or higher-order interactions, e.g., $t = 3$: $W \wedge M \wedge J$, $W \wedge M \wedge \neg J$ ...

Finding Potential Feature Interactions

$$c_{\not\rightarrow} = \{\neg W, M, J, T, \neg C\}$$

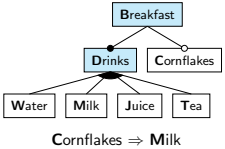
$W \wedge M$	$W \wedge \neg M$	$\neg W \wedge M$	$\neg W \wedge \neg M$
$W \wedge J$	$W \wedge \neg J$	$\neg W \wedge J$	$\neg W \wedge \neg J$
$W \wedge T$	$W \wedge \neg T$	$\neg W \wedge T$	$\neg W \wedge \neg T$
$W \wedge C$	$W \wedge \neg C$	$\neg W \wedge C$	$\neg W \wedge \neg C$
$M \wedge J$	$M \wedge \neg J$	$\neg M \wedge J$	$\neg M \wedge \neg J$
$M \wedge T$	$M \wedge \neg T$	$\neg M \wedge T$	$\neg M \wedge \neg T$
$M \wedge C$	$M \wedge \neg C$		$\neg M \wedge \neg C$
$J \wedge T$	$J \wedge \neg T$	$\neg J \wedge T$	$\neg J \wedge \neg T$
$J \wedge C$	$J \wedge \neg C$	$\neg J \wedge C$	$\neg J \wedge \neg C$
$T \wedge C$	$T \wedge \neg C$	$\neg T \wedge C$	$\neg T \wedge \neg C$

Idea of Inciident

Incremental interaction identification

1. Start with list of all possible t-wise interactions
2. Generate and test new configurations
   - **Fail?** $\Rightarrow$ Keep interactions
   - **Pass?** $\Rightarrow$ Remove interactions
3. Repeat 2. until the remaining interactions cannot be further narrowed down

Example with Random Configurations



$$c_{\lightning} = \{\neg W, M, J, T, \neg C\}$$

$\neg W \wedge M$ $\quad \neg W \wedge J$ $\quad \neg W \wedge T$ $\quad \neg W \wedge \neg C$ $\quad M \wedge J$

$M \wedge T$ $\quad M \wedge \neg C$ $\quad J \wedge T$ $\quad J \wedge \neg C$ $\quad T \wedge \neg C$

configuration $c_1 : \{\neg W, M, \neg J, T, \neg C\}$ 

$\neg W \wedge M$ $\quad \neg W \wedge J$ $\quad \neg W \wedge T$ $\quad \neg W \wedge \neg C$ $\quad M \wedge J$

$M \wedge T$ $\quad M \wedge \neg C$ $\quad J \wedge T$ $\quad J \wedge \neg C$ $\quad T \wedge \neg C$

configuration $c_2 : \{\neg W, M, J, \neg T, C\}$ ✓

$\neg W \wedge M$ $\quad \neg W \wedge T$ $\quad \neg W \wedge \neg C$

$M \wedge T$ $\quad M \wedge \neg C$ $\quad T \wedge \neg C$

$\neg W \wedge T \quad \neg W \wedge \neg C$

$M \wedge T \quad M \wedge \neg C \quad T \wedge \neg C$

configuration c_3 : $\{W, M, \neg J, T, \neg C\}$ ↯

$\neg W \wedge T \quad \neg W \wedge \neg C$

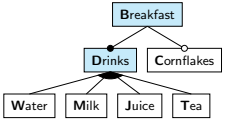
$M \wedge T \quad M \wedge \neg C \quad T \wedge \neg C$

configuration c_4 : $\{\neg W, M, \neg J, \neg T, C\}$ ✓

$M \wedge T \quad M \wedge \neg C \quad T \wedge \neg C$

configuration c_5 : $\{\neg W, M, \neg J, \neg T, \neg C\}$ ↯

$M \wedge T \quad M \wedge \neg C \quad T \wedge \neg C$



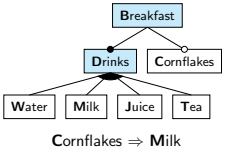
⇒ **Found $M \wedge \neg C$ using five additional configurations**

Optimize Configuration Selection

Goal: Cover about half of the potential interactions in each configuration

$\Rightarrow$ From multiple random configurations choose configuration that is most balanced between included and excluded interactions

Example with Optimized Configurations



configuration $c_1' : \{\neg W, \neg M, J, T, \neg C\}$ ✓

$\neg W \wedge M$ $\quad \neg W \wedge J$ $\quad \neg W \wedge T$ $\quad \neg W \wedge \neg C$ $\quad M \wedge J$

$M \wedge T$ $\quad M \wedge \neg C$ $\quad J \wedge T$ $\quad J \wedge \neg C$ $\quad T \wedge \neg C$

configuration $c_2' : \{W, M, \neg J, T, \neg C\}$ ↯

$\neg W \wedge M$ $\quad M \wedge J$

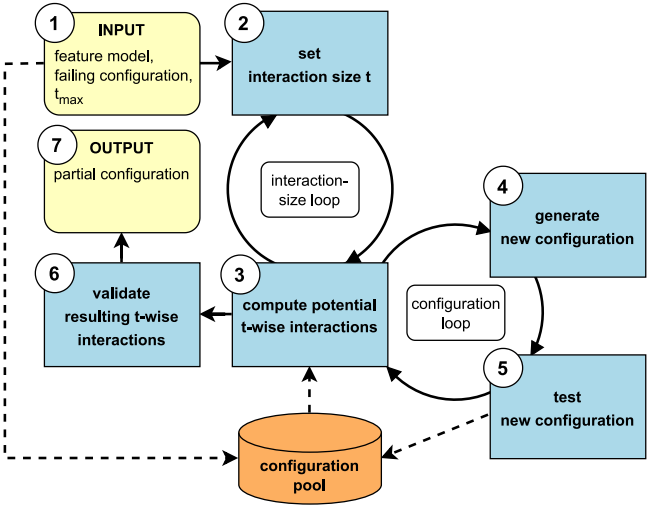
$M \wedge T$ $\quad M \wedge \neg C$

configuration $c_3' : \{\neg W, M, \neg J, \neg T, \neg C\}$ ↯

$M \wedge T$ $\quad M \wedge \neg C$

⇒ **Found $M \wedge \neg C$ using three additional configurations**

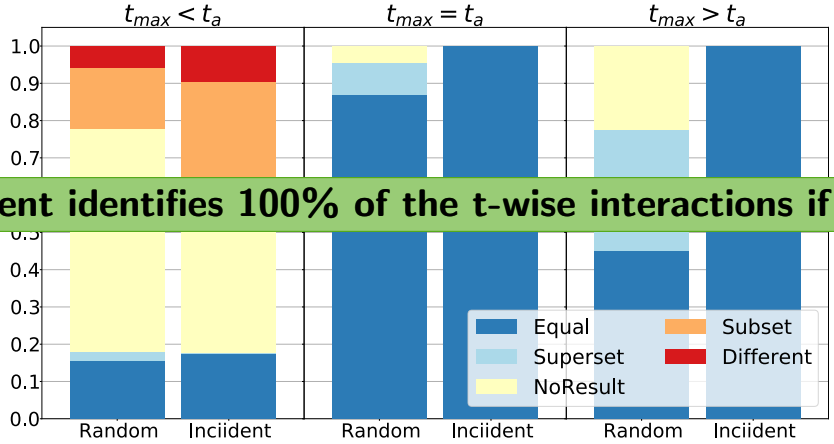
Algorithm Inciident Incremental interaction identification



Evaluation

- 48 real-world feature models
  - $\#features$ between 9 and $3,296$
  - $\#constraints$ between 13 and $15,692$
- 1-wise, 2-wise, and 3-wise simulated interactions
- 10 real-world interaction faults

RQ_1: How effectively can we identify the feature interaction that leads to failing configurations?



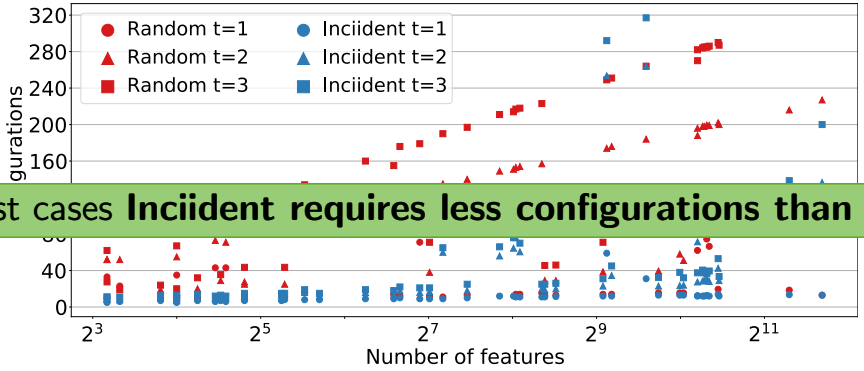
→ **Inciident identifies 100% of the t-wise interactions if $t_{max} \geq t_a$**

RQ_1: How effectively can we identify the feature interaction that leads to failing configurations?

Real-world interaction faults:

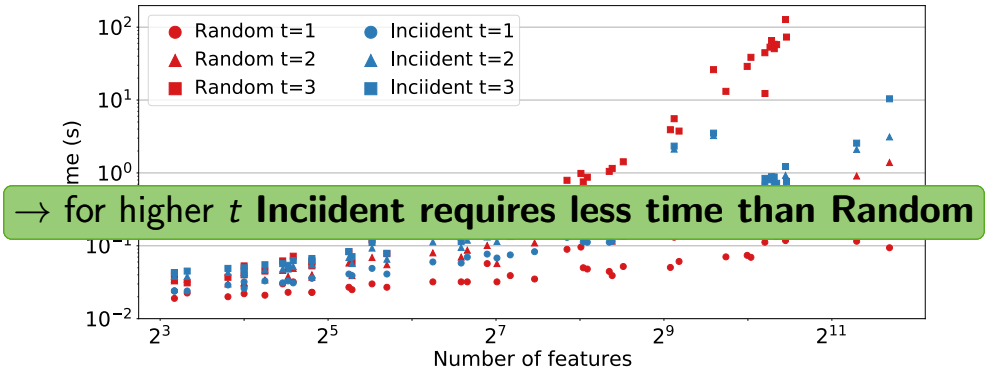
- 8 out of 10 equal
- 2 out of 10 no result
  1. $t_{max} < t_a$ (4-wise interaction)
  2. caused by two interactions (complex feature interaction)

$RQ_{2.1}$: How many configurations have to be tested to identify the feature interaction?



→ in most cases **Inciident requires less configurations than Random**

$RQ_{2.2}$: How much computation time is required to identify the feature interaction?



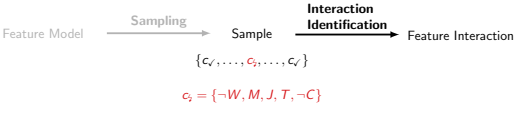
→ for higher t **Inciident requires less time than Random**

Limitations & Future Work

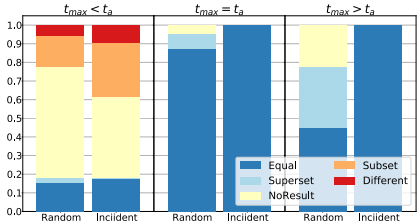
- Failing configurations must be **caused by exactly one** feature interaction
- Feature interaction must be **reliably testable**
- Other errors **must not mask** feature interaction

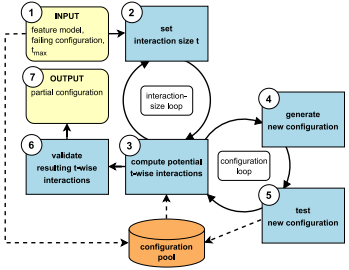
Conclusion

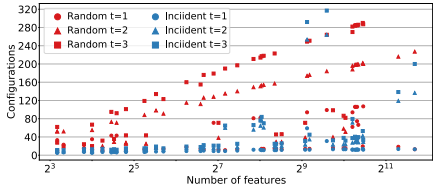
Inciident Incremental interaction identification



Which feature interaction causes the failing configuration?







Incremental Identification of T-Wise Feature Interactions

1. **Motivation**
2. **Background**
3. **Identification of Interactions**
   - Idea
   - Example
   - Inciident
4. **Results**
   - RQ1
   - RQ2
5. **Conclusion**