Improved Software Fault Detection with Graph Mining

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Locating Bugs in Software

- Software is almost never shipped bug-free, even if tested extensively.
- Particularly challenging are:
  - **Noncrashing bugs** – no stack trace available
  - **Occasional bugs** – occur just with some input data
- Some resources are available, but software projects are way too large for a complete review.

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- Idea:
  - Locate **noncrashing occasional bugs** with **data mining** techniques.
  - Using a **weighted graph mining** approach

Outline

Data Mining in Software Engineering

- Traditional data mining techniques process feature vectors of numerical and categorical data.
- In software engineering, this can be
  - different code metrics (static analysis)
  - data gained from instrumentation (dynamic analysis)

	METRIC 1	METRIC 2	METRIC 3	...
Software artefact 1	123	5	12	...
Software artefact 2	222	8	12	...
...	...	...	...	...

- Searched are patterns or properties which are more likely in buggy software.

Challenges with Software Metrics

- Shortcomings of relational metric collections:
  - Static analysis
    - Even hundreds of metrics
      describe a program insufficiently.
    - Static code metrics help little for locating bugs.
  - Dynamic analysis (instrumentation)
    - Tradeoff: runtime vs. amount of relevant data

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  - Dynamic analysis (instrumentation)
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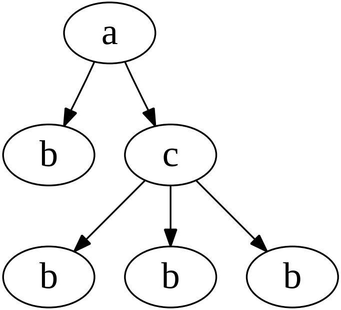
- Idea:
  - Look at **program executions** represented as **call graph** and analyse its structure.
  - Identify substructures typical for failing executions.
    - Requires a test oracle, which is typically available.
  - Analyse the **call frequencies** (**edge weights**) as well!

Call Graphs

- Call graphs are rooted ordered trees.
- Program executions as call graphs:
  - Methods → nodes
  - Method calls → edges
- Bugs in the call tree:



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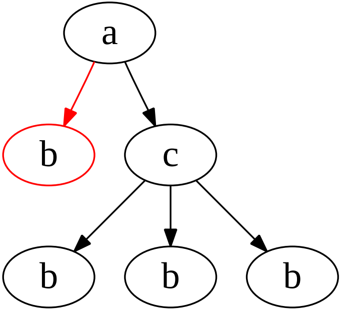

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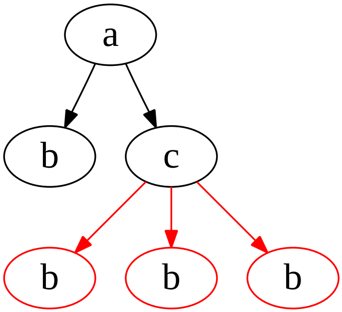
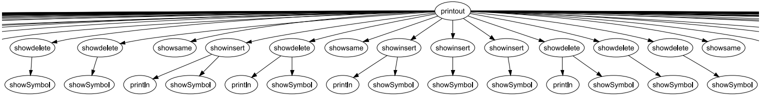
  - **Call frequency affecting**
    - E.g., a bug in a loop-condition in `c`



Reduction of Call Graphs



- Millions of method calls are very common!

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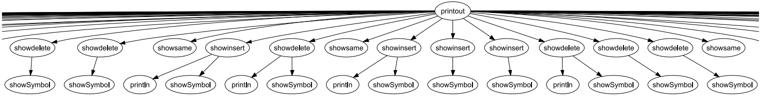
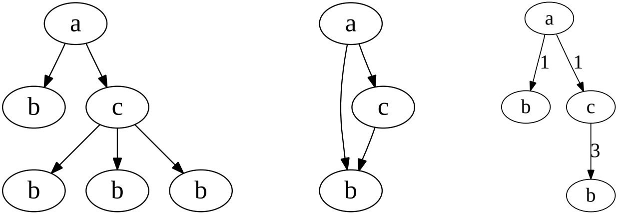


- Millions of method calls are very common!
- Several reduction techniques exist, e.g.:

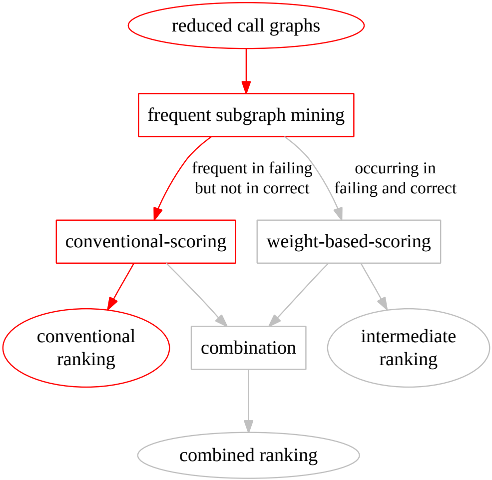


Conventional Approach (di Fatta et al., 2006)

1. Input data:
   - Collection of call graphs classified as **correct** or **failing**.
2. Search for frequent subgraphs with an arbitrary algorithm.
3. Identify discriminative subgraphs: frequent within the **faulty** but not within the **correct** executions.
   - The methods within these subgraphs display an increased likelihood of containing a bug.

→ Here, only structural differences are considered – no call frequencies of graphs occurring in both sets.

Framework for Locating Bugs



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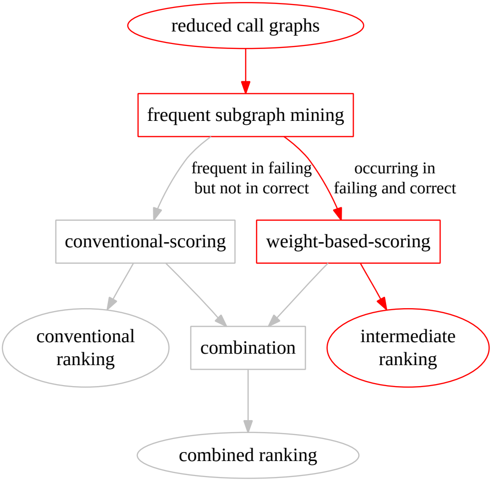

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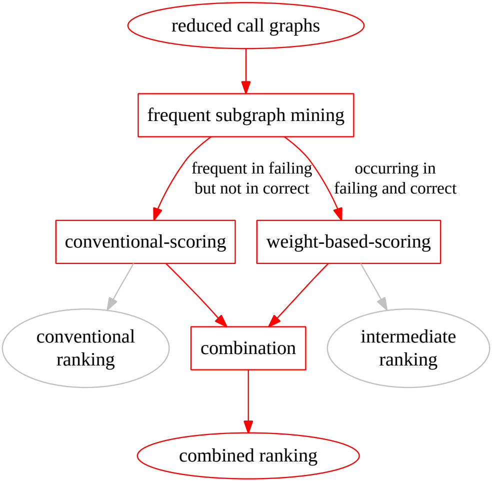

- Both types of bugs are considered: structure and call frequency affecting ones
- Integration of the traditional approach

Entropy-based Ranking of Edge Weights

- Identification of edge weights which most differentiate between the two classes
- Every edge in every frequent subgraph is considered:

	SG_1 $a \to b$	SG_1 $a \to c$	SG_2 $a \to b$	$\cdots$	$Class$
$Graph_1$	2	1	6	$\cdots$	$failing$
$Graph_2$	0	0	4	$\cdots$	$correct$
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$

- Application of an entropy-based feature selection algorithm to the table.
- Result: Ranking of the columns (edges)

Results

- Example output:

	METHOD	SCORE
1	`inputscan()`	0.9833
2	`showinsert()`	0.9204
3	`showdelete()`	0.4876
4	`oldconsume()`	0.4876
5	`addSymbol()`	0.2428

Results

- Example output:

	METHOD	SCORE
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- The bug was instrumented in `showinsert()`.
- A software developer has to check two methods only.
- Low line numbers are better!

Experiments

- Setting:
  - Open source Java tool, 25 methods
  - 9 artificial but realistic bugs
  - 100 program executions each
- Experimental results:
  - Displayed is the number of methods to be reviewed.

Exp. \ Bug No.	1	2	3	4	5	6	7	8	9
Conventional	3	–	1	4	6	4	3	3	1
Intermediate	3	3	1	1	1	3	3	1	–
Combined	1	3	1	2	2	1	2	1	3

- Localisation precision increased by 2.4.

Conclusion

- Summary of contributions
  - New call graph reduction variant
  - Mining of weighted graphs in a classification scenario
    - Combining structural and numerical techniques
    - Applicable in other domains
  - Considering weights of non-discriminative patterns
- Results in software engineering
  - Ability to detect a new important class of bugs
  - Doubled precision of bug localisations
- Current and future work
  - Weight based constraints
  - Mining of large graphs/large software projects
  - Other fields of application

Questions?

Thank you for your attention!