Lecture 9 – Regression Testing

AAA705: Software Testing and Quality Assurance

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PLRG

2024 Spring

Recall

- Mutation Testing
  - Fundamental Hypotheses
  - Overall Process
  - Mutation Generation
  - Kill vs Alive
  - Equivalent Mutants
  - How to Kill A Mutant
  - Scalability
  - Higher Order Mutants
  - Tools
- Test Flakiness

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Regression Fault

Inacio Ribeiro Original Poster Jun 1, 2023

Bug after updating Google Chrome to version 114.0.5735.90

After updating Google Chrome to version 114.0.5735.90 my website started experiencing issues with displaying information. It seems to be related to the CSS applied by the browser, but I'm not certain.

The strange thing is that the release notes for this version only mention security updates. Is anyone else facing this same issue?

https://support.google.com/chrome/thread/218644651/

Regression Fault

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The current update of IOS 17.0.2 is full of bugs

device- IPAD 9th generation
I have updated it now while studying when I am opening a pdf it always opens from the 1st page, earlier it used open the same page where I used to leave.
Take a screenshot then copy and delete the screenshot and then paste that in the pdf file.. now it is not getting pasted..earlier it used to get copied.

https://discussions.apple.com/thread/255162058

Regression Fault

- **Regression fault** is a fault that occurs when a **change** in the software introduces a new defect or reactivates a defect that had been previously fixed.

- The term **regression** refers to the fact that the software has **regressed** (gone backwards) to an earlier bad state.

Regression Testing

- You are realizing a **new version** of your software.

Regression Testing

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- You have tried to thoroughly **test the new features**.

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- You want to check if you have created any **regression faults**.

Regression Testing

- You are realizing a **new version** of your software.
- You have tried to thoroughly **test the new features**.
- You want to check if you have created any **regression faults**.
- How would you do that?

Regression Testing – Retest All

- The simplest way is to **retest all** the test cases.

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- You need to run all tests not only for the **new features** but also for the **old existing features**.

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- Its main disadvantage is that it is **time-consuming** to run all the test cases for every new version.

Regression Testing – Retest All

- The simplest way is to **retest all** the test cases.
- You need to run all tests not only for the **new features** but also for the **old existing features**.
- Its main disadvantage is that it is **time-consuming** to run all the test cases for every new version.
- It is **critical** in the modern software development process because software is **continuously and rapidly changing**.

Regression Testing – Retest All

"For example, one of our industrial collaborators reports that for one of its products of about **20,000 lines of code***, the entire test suite requires* **seven weeks** *to run."*

– G.Rothermel, R.H. Untch & M.J. Harrold, *Prioritizing Test Cases for Regression Testing, TSE'21*

Regression Testing – Retest All

"For example, one of our industrial collaborators reports that for one of its products of about **20,000 lines of code**, *the entire test suite requires* **seven weeks** *to run."*

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The **test suite** becomes **larger** and **larger** as the software evolves with the following factors:

- Long Product History
- Different Configurations
- Types of Test Cases

Regression Testing Techniques

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Many techniques have been developed in order to cope with the high cost of retesting all test cases. They can be categorized into:

- **Test Suite Minimization**
- **Test Case Selection**
- **Test Case Prioritization**

Test Suite Minimization

- **Problem** – Regression test suite is **too large**

Test Suite Minimization

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Test Suite Minimization

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- **Idea** – There might be some test cases that are **redundant**
- **Solution** – **Minimize** regression test suite by removing all the redundant test cases

Test Suite Minimization

- **Problem** – Regression test suite is **too large**

- **Idea** – There might be some test cases that are **redundant**

- **Solution** – **Minimize** regression test suite by removing all the redundant test cases

- Then, what is the definition of a **redundant** test case?

Test Suite Minimization

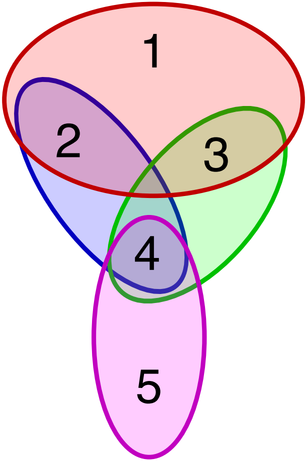
One possible way is to use the **coverage** information.

(e.g., Statements, MC/DC, All-DU-Paths, etc.)

TC	r_1	r_2	r_3	$\cdots$
t_1	✓	✓		$\cdots$
t_2		✓		$\cdots$
t_3		✓	✓	$\cdots$
t_4			✓	$\cdots$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$

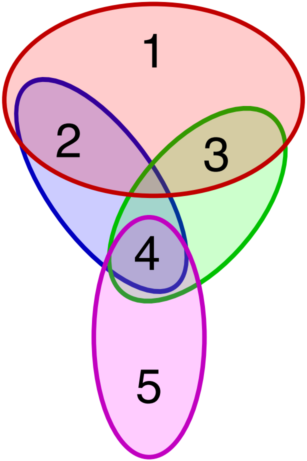
How to **minimize** the test suite as much as possible while **preserving** the coverage information (the set of covered test requirements)?

Test Suite Minimization



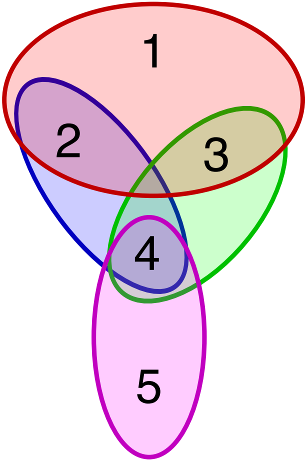
- We can model the **test suite minimization** problem as a **set cover** problem.

Test Suite Minimization



- We can model the **test suite minimization** problem as a **set cover** problem.
- Unfortunately, the set cover problem is **NP-complete**, meaning that there is no known polynomial-time algorithm to solve it.

Test Suite Minimization



- We can model the **test suite minimization** problem as a **set cover** problem.
- Unfortunately, the set cover problem is **NP-complete**, meaning that there is no known polynomial-time algorithm to solve it.
- However, there are many **heuristic** algorithms that can be used to solve the test suite minimization problem.

Greedy Minimization

Algorithm Greedy Minimization

function $\textsc{GreedyMinimization}(T, R)$
    $T' \leftarrow \emptyset$
    while `true` **do**
        $t \leftarrow \text{argmax}_{t \in T} |R \cap \text{TR}(t)|$
        if $|R \cap \text{TR}(t)| = 0$ **then**
            break
        $T' \leftarrow T' \cup \{t\}$
        $R \leftarrow R \setminus \text{TR}(t)$
    return T'

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            break
        T' ← T' ∪ {t}
        R ← R \ TR(t)
    return T'
```

TC	r_1	r_2	r_3	r_4
t_1	✓	✓		
t_2		✓		✓
t_3		✓	✓	✓
t_4			✓	
t_5			✓	✓

$$T' = \varnothing$$
$$R = \{r_1, r_2, r_3, r_4\}$$

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Greedy Minimization with Cost

- However, in fact, test cases have different **costs** to run.

Greedy Minimization with Cost

- However, in fact, test cases have different **costs** to run.
- Is it still $\{t_3, t_1\}$ the best solution?

TC	r_1	r_2	r_3	r_4	*Time*
t_1	✓	✓			3
t_2		✓		✓	5
t_3		✓	✓	✓	10
t_4			✓		2
t_5			✓	✓	8

Greedy Minimization with Cost

Algorithm Greedy Minimization with Cost

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function GreedyMinimization(T, R)
    T' ← ∅
    while true do
        t ← argmax_{t∈T} |R∩TR(t)| / Time(t)
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Greedy Minimization with Score

- Another possible approach is to use the **score** information and keep the **best test case** for each test requirement according to the score.

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- The **score** of each test case can be defined in various ways.

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- For example, consider **conformance test suite** for a JavaScript engines, and each test case is a JavaScript program with assertions.

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- The **score** of each test case can be defined in various ways.
- For example, consider **conformance test suite** for a JavaScript engines, and each test case is a JavaScript program with assertions.
- Then, which test case is better to keep?
- We can define the score of each test case based on the **complexity** of the test case (e.g., **size of the program**, etc.) because a simpler test case is more understandable and maintainable.

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Algorithm Greedy Minimization with Score

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    M ← ∅
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```

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$$T' = \{t_1, t_4, t_5\}$$

Greedy Minimization with Score

We can minimize the test suite even during the **test case generation**.

Greedy Minimization with Score

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RelationalExpression **:** *RelationalExpression* **<=** *ShiftExpression*

1. Let *lref* be ? Evaluation of *RelationalExpression*.
2. Let *lval* be ? GetValue(*lref*).
3. Let *rref* be ? Evaluation of *ShiftExpression*.
4. Let *rval* be ? GetValue(*rref*).
5. Let *r* be ? IsLessThan(*rval*, *lval*, **false**).
6. If *r* is either **true** or **undefined**, return **false**. Otherwise, return **true**.

[ICSE'21] J. Park et al., "JEST: N+1-version Differential Testing of Both JavaScript Engines and Specification"

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Multi-Objective Problem

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- “I have **only 5 hours** as a deadline to run the test suite.”
- “I need to cover **more than one coverage** criterion.”

Multi-Objective Problem

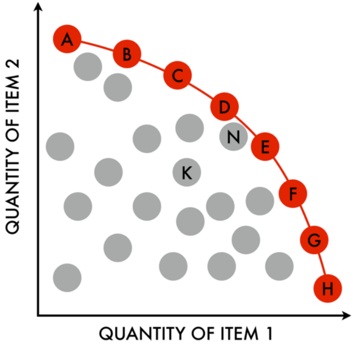
What if the test suite minimization problem has **multiple objectives**?

- "I have **only 5 hours** as a deadline to run the test suite."
- "I need to cover **more than one coverage** criterion."
- "I want to consider the **fault detection capability** of the test suite."

$$\left(1 - \frac{\text{\# Faults Detected by the Minimized Test Suite}}{\text{\# Faults Detected by the Original Test Suite}}\right) \times 100\%$$

Multi-Objective Problem

- Let's consider the **Pareto efficiency** of the test suite minimization.



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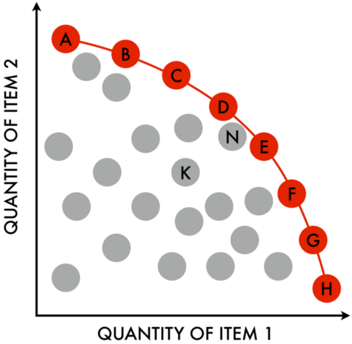
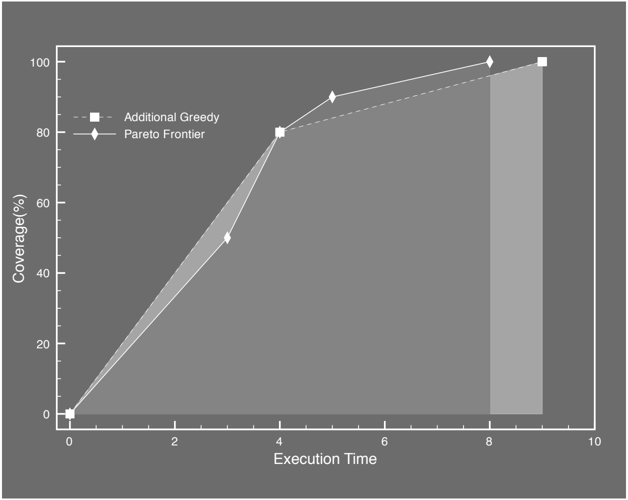


- And, we can consider the **weighted sum** of the objectives.

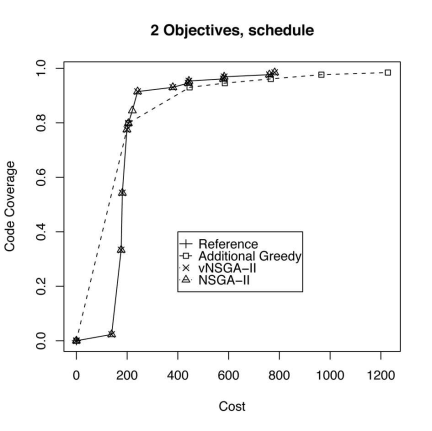
$$o' = \alpha_1 \times o_1 + \alpha_2 \times o_2 + \cdots \alpha_n \times o_n$$

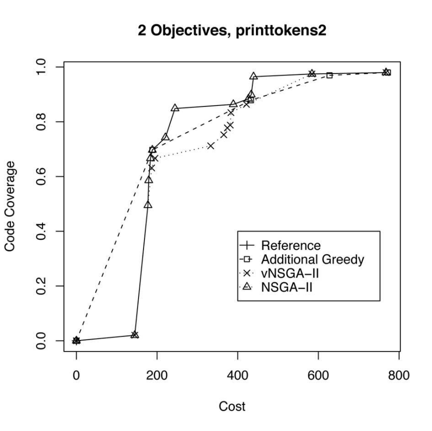
where α_i is the weight of the i-th objective such that $\sum_{1 \leq i \leq n} \alpha_i = 1$, and o_i is the value of the i-th objective.

Multi-Objective Problem



Multi-Objective Problem





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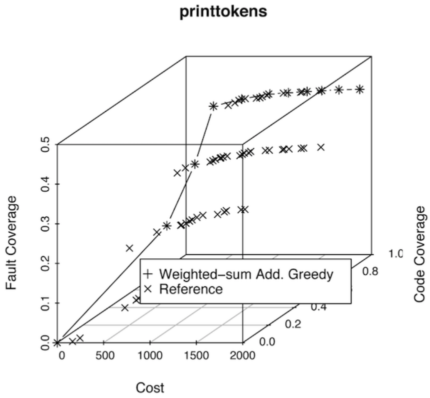

Test Case Selection

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- Then, how can we know which test cases are **related** to the recent changes?

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- We need to keep track of the **execution trace** of the test cases in the original program P to know which parts of the program are executed by each test case.
- Then, we should know the **which parts** of the program are **changed** in the updated program P' compared to the original program P.

Test Case Selection – Textual Diff

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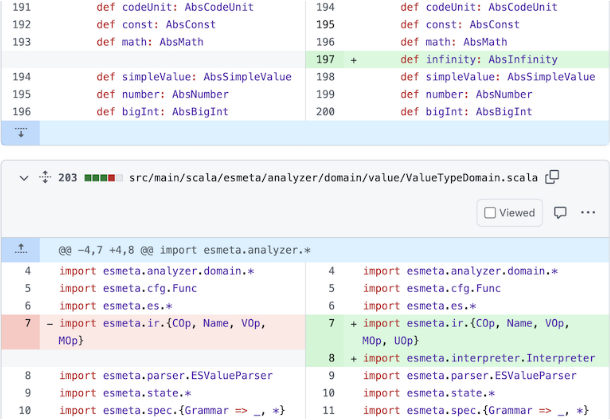
Test Case Selection – Textual Diff

PLRG

- Most of the modern software are developed using the **version control system** (e.g., Git, SVN, etc.).
- The most easiest way is to use the **diff** command provided by the version control system to know the **changed parts** of the program.



Test Case Selection – Control Flow Graph

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P'

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Test Suite

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Test Suite

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Which test case should be **selected**?

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- It is due to that they focus on **safety** (i.e., not missing any tests that are related to the recent modification to avoid regression faults)
- Realistically, we only consider whether each part of the program is **executed** by the test cases or not to check the safety according to their **execution traces**.

Test Case Selection – Difficulties

- **Data Collection** – Collecting the **execution traces** of the test cases is not easy. Especially, when the software is **large** and **complex**, and some programs are written in multiple languages.

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- **Safety can be expensive** What if safe selection is still too **expensive** to run all the selected test cases?

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PLRG

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- Then, how to define the **importance** of each test case?

Simple Approach

Without using any complicated techniques, we can simply prioritize the test using the following criteria:

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If we want to prioritize test cases in a smarter way, what should we consider?

Test Case Prioritization

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- Obviously, we need to run t_3 first and then run t_5 as the next.

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- However, since the full coverage does **not guarantee** full fault detection, we still need to run remaining test cases after **resetting** the coverage information after running t_3 and t_5.
- So, we need to run them in the order of t_2, t_1, and t_4.

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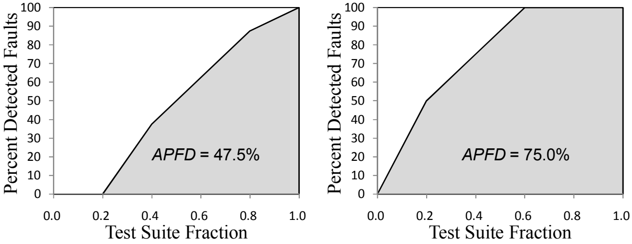
Example on test suite and faults exposed

Test Case	Fault							
	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8
t_A	•		•					•
t_B								
t_C		•		•	•			•
t_D	•	•				•		
t_E			•				•	



(a) *APFD* for test suite T_1 (b) *APFD* for test suite T_2

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- APFDc (by Elbaum et al., 2001) is a variant of APFD that considers the **cost** of the test cases.

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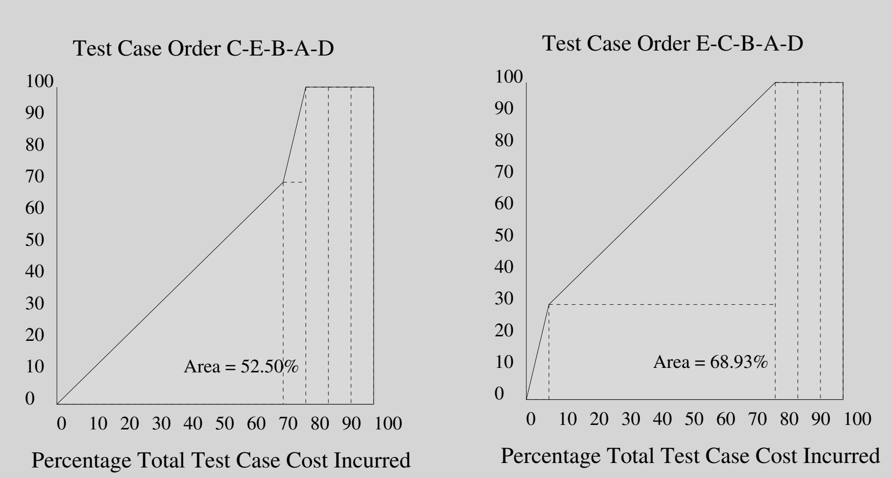

Cost-Cognisant Test Case Prioritisation, ICSE, Malishevsky et al., 2006

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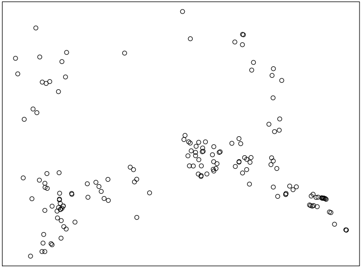
- Reduces the conceptual size of test suites by **clustering** test cases that are similar to each other.
- Provides insights into what is the **most common behavior** of the test cases.
- We can define a **distance** function between test cases based on diverse properties (e.g., coverage, etc.) and **visualize** the clustering results.



Test Case Prioritization – Clustering

[ISSTA'09] Yoo et al., "Clustering Test Cases to Achieve Effective & Scalable Prioritisation Incorporating Expert Knowledge"

Algorithm 1: Agglomerative Hierarchical Clustering
Input: A set of n test cases, T
Output: A dendrogram, D, representing the clusters

```
Form n clusters, each with one test case
C ← {}
Add clusters to C
Insert n clusters as leaf node into D
while there is more than one cluster
    Find a pair of clusters with minimum distance
    Merge the pair into a new cluster, c_new
    Remove the pair of test cases from C
    Add c_new to C
    Insert c_new as a parent node of the pair into D
return D
```

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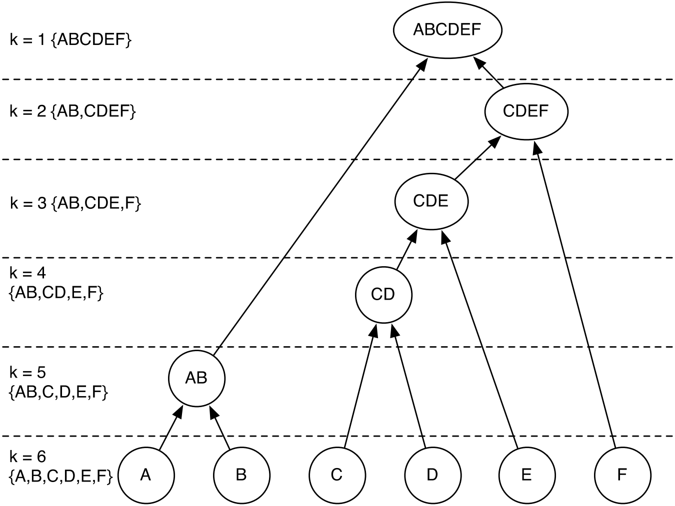

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Algorithm 2: Interleaved Clusters Prioritisation
Input: An ordered set of k ordered clusters, OOC
Output: An ordered set of test cases, OTC

$OTC = <>$
$i \leftarrow 1$
while OOC is not empty
  Append $OOC_i(1)$ to OTC
  Remove $OOC_i(1)$ from OOC_i
  if OOC_i is empty **then** Remove OOC_i from OOC
  $i \leftarrow (i + 1) \bmod k$
return OOC

$$OOC = [\quad \{A, B\}, \quad \{C, D, E\}, \quad \{F\} \quad]$$

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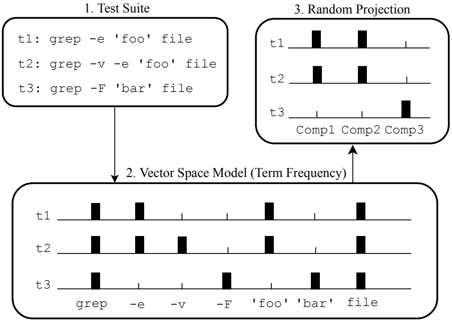

Fig. 1: Visual representation of *FAST-R* preparation phase.

State of the art methods are still largely based on **syntactic** measures (e.g., code coverage, etc.)

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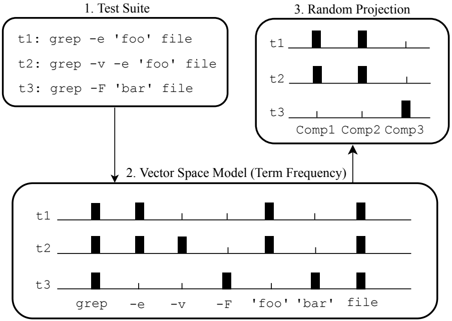

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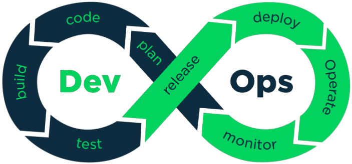
Can we define a **semantic** measure of similarity between test cases?

Regression Testing in Practice



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Regression Testing in Practice

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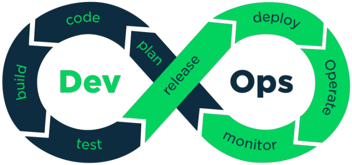

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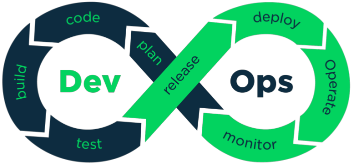

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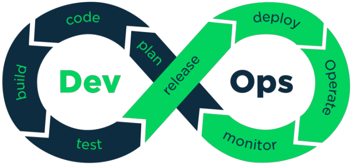

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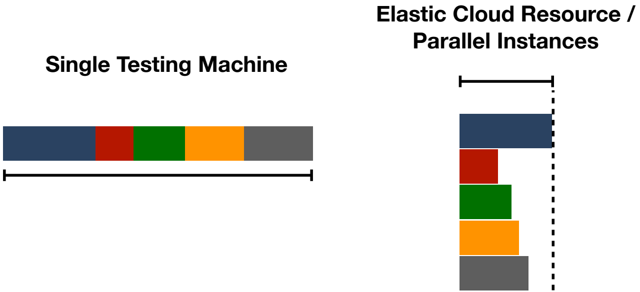
- In practice, we execute test cases in a **distributed** manner to minimize the cost of running the test cases.
- Then, the testing time is only limited by the **slowest** test case.



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- **Prioritising test cases** within test suites makes little impact at this scale.
- Instead, **prioritising commits** to test has been proposed.

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- The proposed technique is essentially history based prioritisation: **commits** relevant to test cases that have **recently failed** are given higher priority. If tests really fail, this ensures **quicker feedback** to the responsible developers.

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- The proposed technique is essentially history based prioritisation: **commits** relevant to test cases that have **recently failed** are given higher priority. If tests really fail, this ensures **quicker feedback** to the responsible developers.
- Assumptions
  - Commits are **independent** from each other. In high volume environment, this is not unrealistic.
  - **Relationships** between code and test cases are known in advance (i.e., which test covers which parts of the code).

Summary

- **Minimization**: Keyword is **redundancy** – **Minimize** test suite by removing redundant test cases according to the definition of redundancy.
- **Selection**: Keyword is **safety** – **Select** test cases that are related to the recent changes conservatively to avoid possible regression faults.
- **Prioritization**: Keyword is **surrogate** – **Prioritize** test cases based on the surrogate for the fault detection capability to maximize the fault detection rate early.

Next Lecture

- Fault Localization

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