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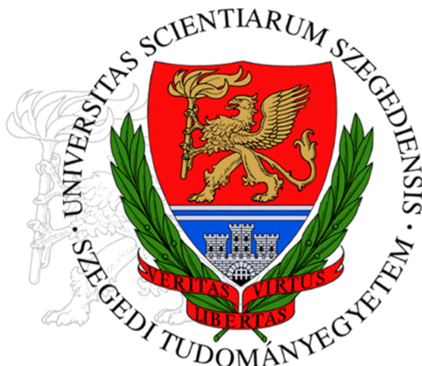
Fault Detection and Localisation in Reduced Test Suites



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Overview

- University of Szeged, Department of Software Engineering
- Part I – Redundancy in testing
- Part II – Research on fault detection and fault localisation. Test reduction

Redundancy in testing

Avoiding redundancy is the basis for practical testing

- Testing is about partitioning the testing space based on various assumptions

Yet, there are many repetitions

- Test automation, regression testing, etc.

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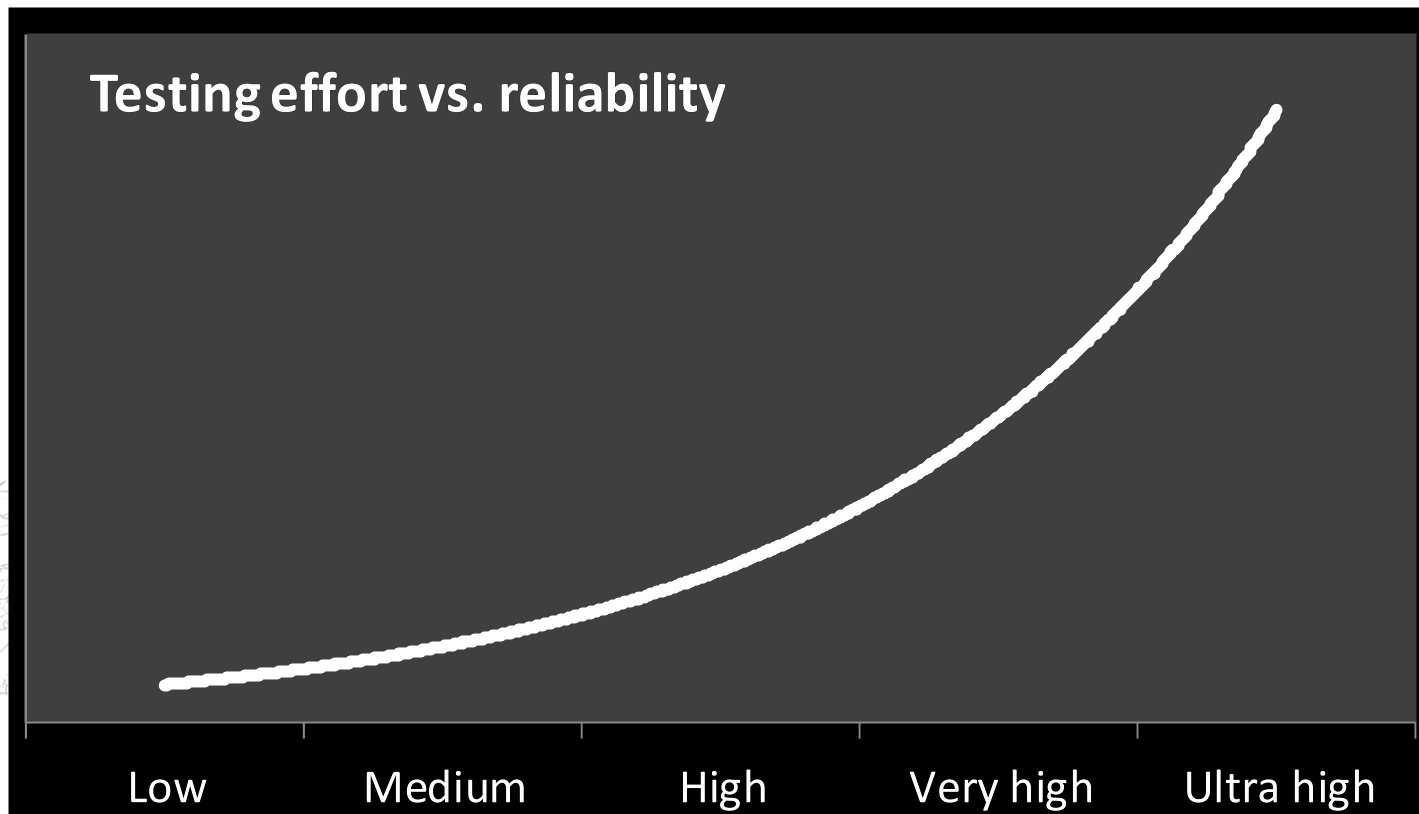
Goal of testing

To find (as many as possible) bugs

Using (as least as possible) effort



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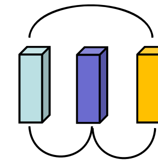
Exhaustive testing is impossible

- Theoretically, each execution is unique
  - You wouldn't try all 2^64 combinations of summing up two integers
  - Try out the "interesting" cases
- Testers are practical: don't do "redundant" testing because that will cost much and will bring little value
- But what are the "interesting" cases?

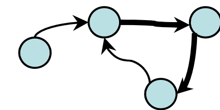
Testers make assumptions

- Equivalence partitioning

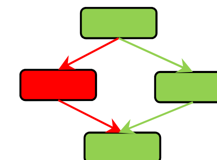
- Pairwise testing



- n-switch state-based testing



- Statement / branch / path coverage



- Etc.

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Repetitions in testing

- What is a unique/redundant test case?
- Definition phase:
  - Two test cases with common steps
  - Test execution procedure or script
  - “Data/keyword-driven” testing
- Execution phase:
  - Confirmation testing
  - Regression testing

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Regression test selection

- If used properly, there should be many regression tests
  - Test suite increases and evolves with the system
- Test selection based on changes and/or risks
- When are two regression tests redundant?

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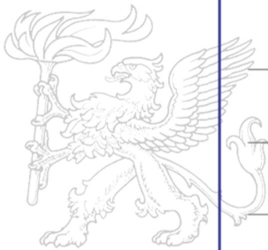
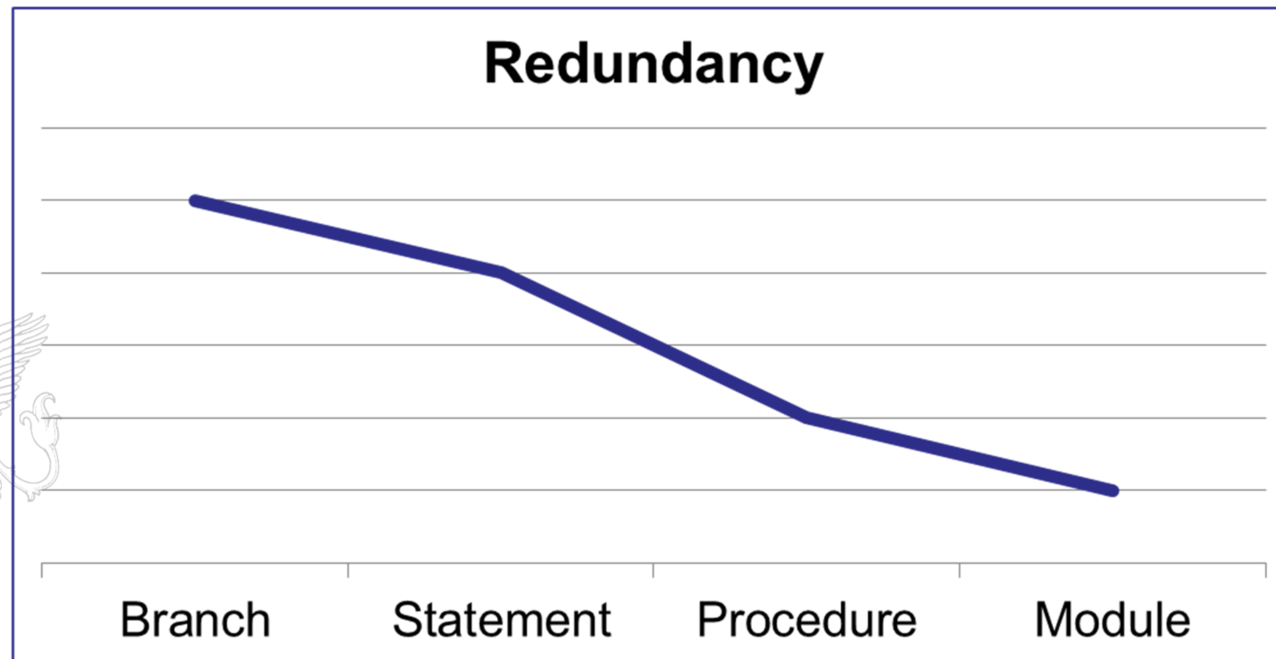


White-box testing

- If test cases exercise the same statements/paths/functions are they redundant?
  - Probability decreases as we relax coverage criterion



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Some redundancy data

Program	kLOC	# TCs	Unique statement-level coverage vectors
space (SIR)	6.2	13 570	88%
tcas (Siemens)	0.1	1 608	4.9%
tot_info (Siemens)	0.5	1 052	31.8%

Program	kLOC	# TCs	Unique procedure-level coverage vectors
space (SIR)	6.2	13 570	30%
tcas (Siemens)	0.1	1 608	0.4%
tot_info (Siemens)	0.5	1 052	0.6%
GCC	6 200	128 230	44.6%
WebKit	4 500	21 987	88.4%

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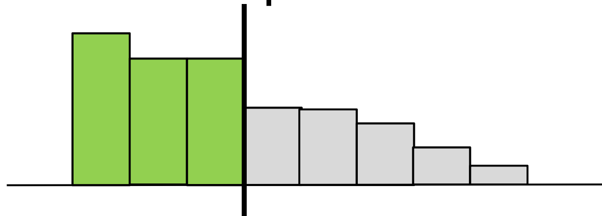
Test reduction

- Test suite reduction
  - Find a representative subset satisfying certain properties of the full suite
  - Also called minimisation (finding the minimal subset is NP-complete)
  - Either permanently or temporary eliminate the test cases
- Test case prioritisation
  - Finding the optimal sequence permutation
- Test case selection: Which test cases to use instead of the full suite?
  1. Satisfy the desired property (e.g. 100% statement coverage)
  2. Select the first N in the prioritised list



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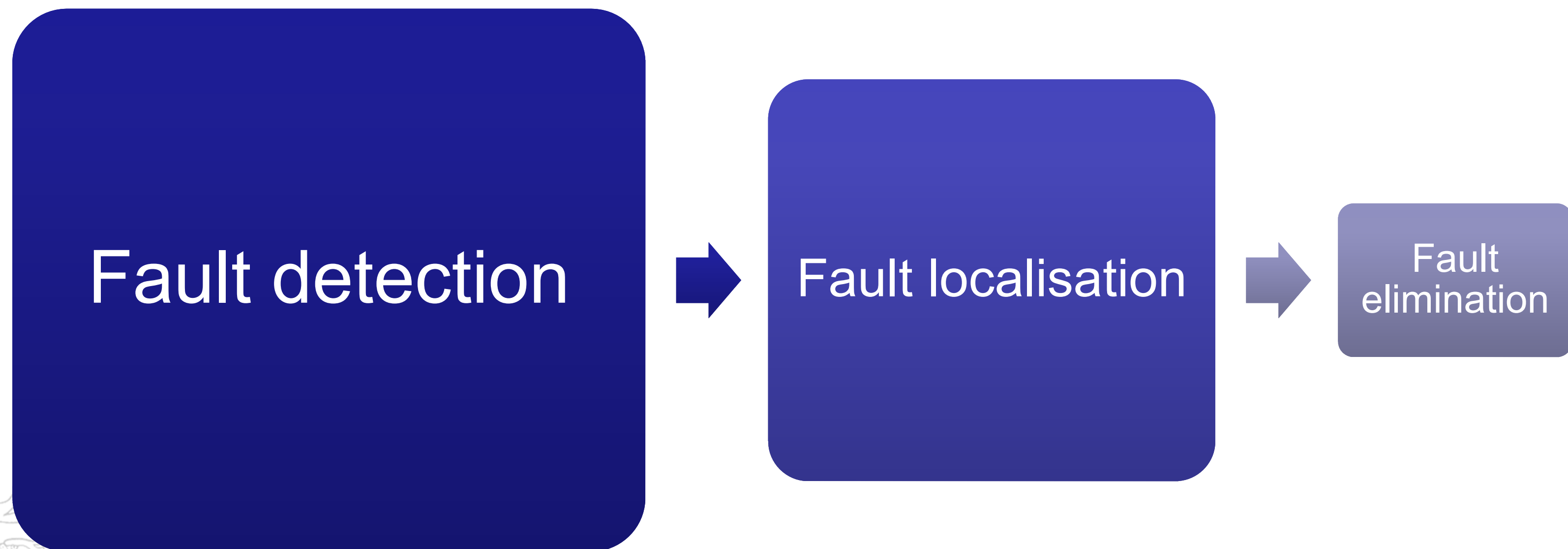
Detect-fix lifecycle



Fault detection and -localisation

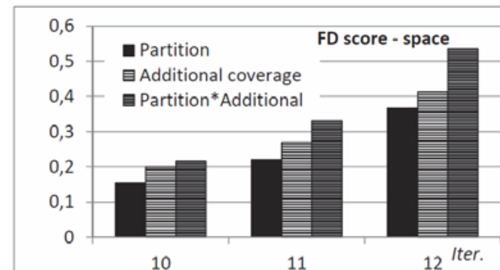
- Fault detection:
  - Use failing tests to shed light on defects
  - Prime task of testing
- Fault localisation:
  - Diagnose the actual cause of the defective behaviour, i.e. pinpoint program elements containing defects
  - Prime task of debugging
- Fault detection capability:
  - ***~high (code) coverage***
- Fault localisation capability:
  - ***~???***

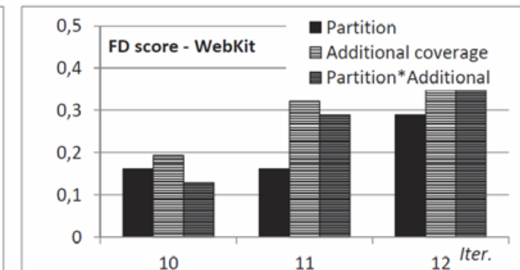
Test reduction

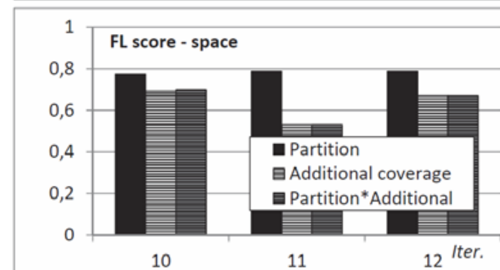
- Traditionally investigated in the context of fault detection
  - For instance, aim at maximal code coverage
- However, this strategy could be bad for fault localisation

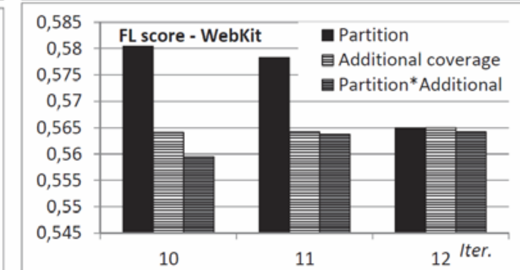
print_tokens	4.934
print_tokens2	4.597
replace	4.747
schedule	8.805
schedule2	6.081
space	0.024
tcas	6.854
tot_info	4.895
Summary	4.767

Increase in fault-localisation expense %
(Yu, Jones and Harrold. An empirical study of the effects of test-suite reduction on fault localization, ICSE '08)









FD=fault detection rate, FL=fault localisation rate
…for different reductions sizes (1k, 2k and 4k test cases)

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Fault localisation using Spectra

- "Spectrum-based" approach
  - Spectrum: signature of program behaviour on the test cases (count or hit)
  - Idea: look at which tests fail/pass and compare this to the spectrum
  - Program elements that usually produce failing tests when executed and passing tests when not are "suspicious"

$$CFM(p_i) = \begin{cases} 1 & \text{if } \mathbf{C}(p_i) = \mathbf{e}, \\ 0 & \text{otherwise.} \end{cases}$$

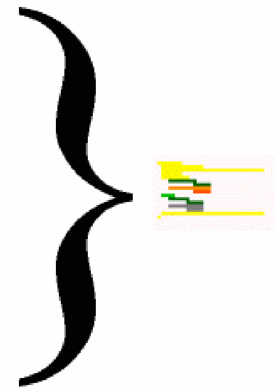
$$\mathbf{C} = t_j \left\{ \overbrace{\begin{bmatrix} 0/1 & 0/1 & \cdots & 0/1 & 0/1 \\ 0/1 & 0/1 & \cdots & 0/1 & 0/1 \\ & & \ddots & & \\ 0/1 & 0/1 & \cdots & 0/1 & 0/1 \\ 0/1 & 0/1 & \cdots & 0/1 & 0/1 \end{bmatrix}}^{p_i} \right. \quad \mathbf{e} = \begin{bmatrix} 0/1 \\ 0/1 \\ \vdots \\ 0/1 \\ 0/1 \end{bmatrix}$$

Suspiciousness assessment

- "Consistent Faults Method"
  1. Only one fails assumption
  2. Always fails assumption
  - Find the matching coverage vector with the fault vector
  - Rarely satisfied, especially the second assumption
- Similarity-based methods:
  - Tarantula: failing test vs. all hitting test
  - Ochiai: a cosine similarity

```
mid() {
  int x,y,z,m;
  read("Enter 3 numbers:",x,y,z);
  m = z;
  if (y<z)
    if (x<y)
      m = y;
    else if (x<z)
      m = y;
  else
    if (x>y)
      m = y;

  print("Middle number is:", m);
}
```



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Fault Localisation Capability

- How “variable” are test cases in terms of their coverage vectors?
- Partitioning based on coverage vectors
- Number and sizes of partitions

	p1	p2	p3	p4	p5
t1	1	1	1	1	1
t2	1	1	0	0	1
t3	0	0	1	1	1

π_1 (p1, p2) π_2 (p3, p4) π_3 (p5)

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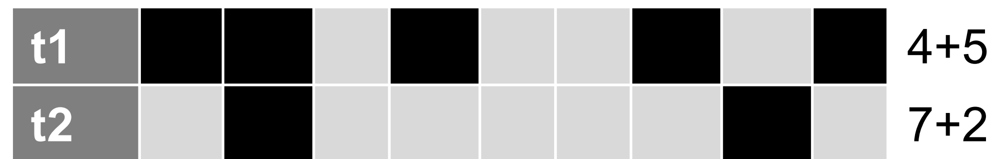
Reduction for fault localisation

- A possible metric: $$FL\ metric = \sum_{i=1}^{K} |\pi_i|(|\pi_i| - 1)$$
  - Or entropy
- Greedy algorithm
  - Selects test cases that improve the fault localization capability best
  - Repeat iteratively until a fixed size or the original localisation capability metric is achieved
- I.e. tests that separate procedures best into different partitions



- t1 should be preferred because it produces smaller partitions

Results

→1 is good

FD - space

Partition
Naive coverage
Additional coverage
Partition*Naive
Partition*Additional

→0 is good

FL - space

Iterations

1 2 3 4 5 6 7 8 9 10 11 12 13 14

0 0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8 0,9 1

Reduction sizes: 1,3,7,15, …

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