An Empirical Study of the Effects of Test-Suite Reduction on Fault Localization

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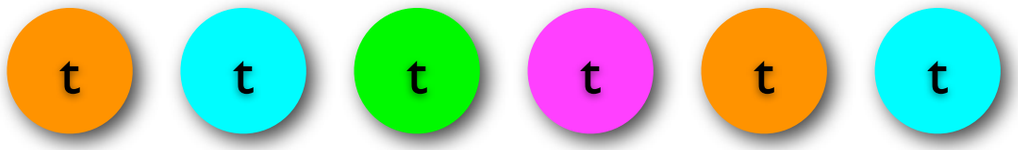
Research Question

Coverage-based
Fault Localization

Research Question



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Fault Localization

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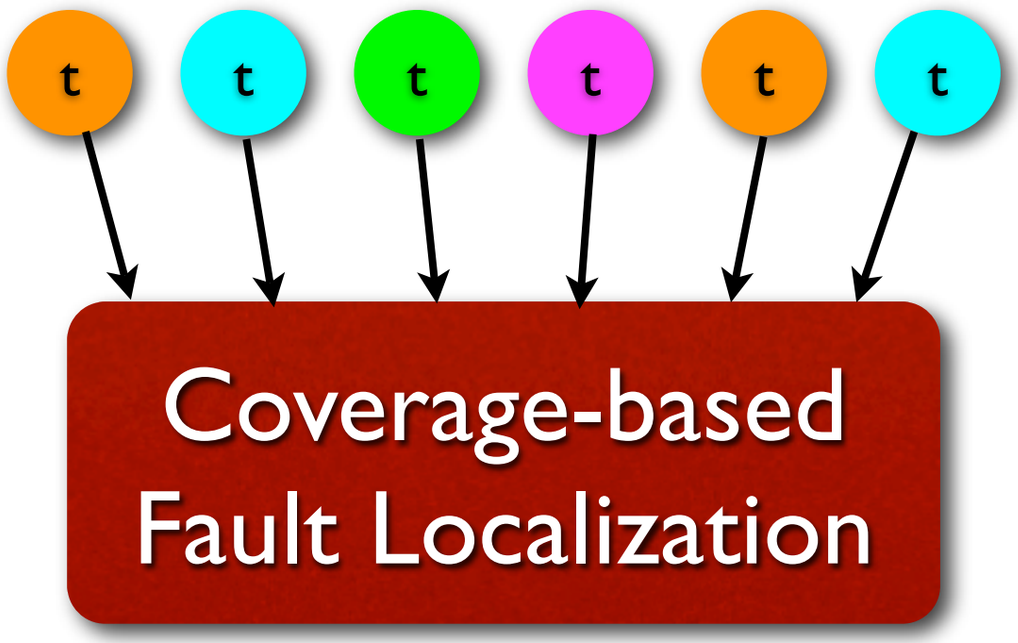

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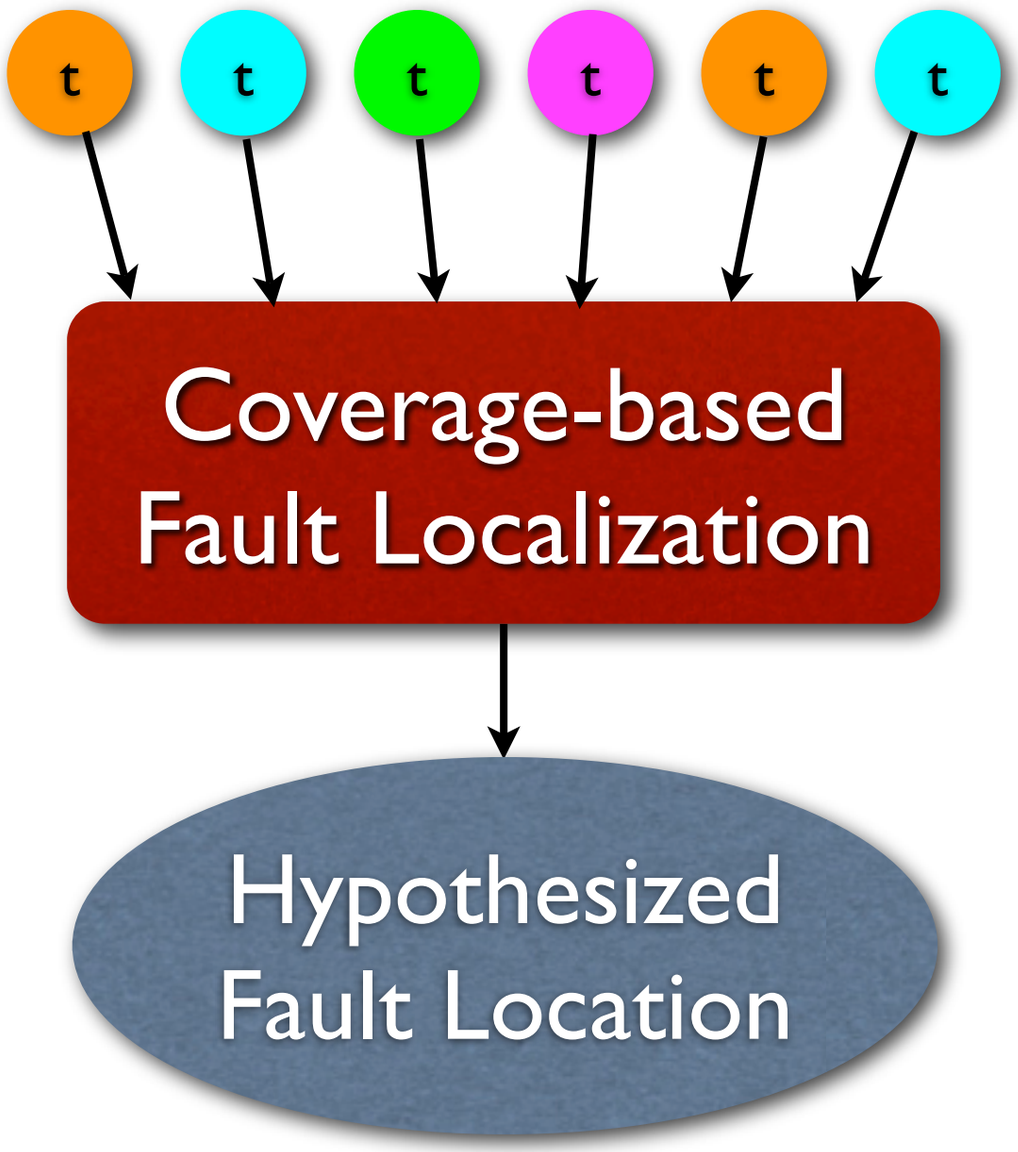

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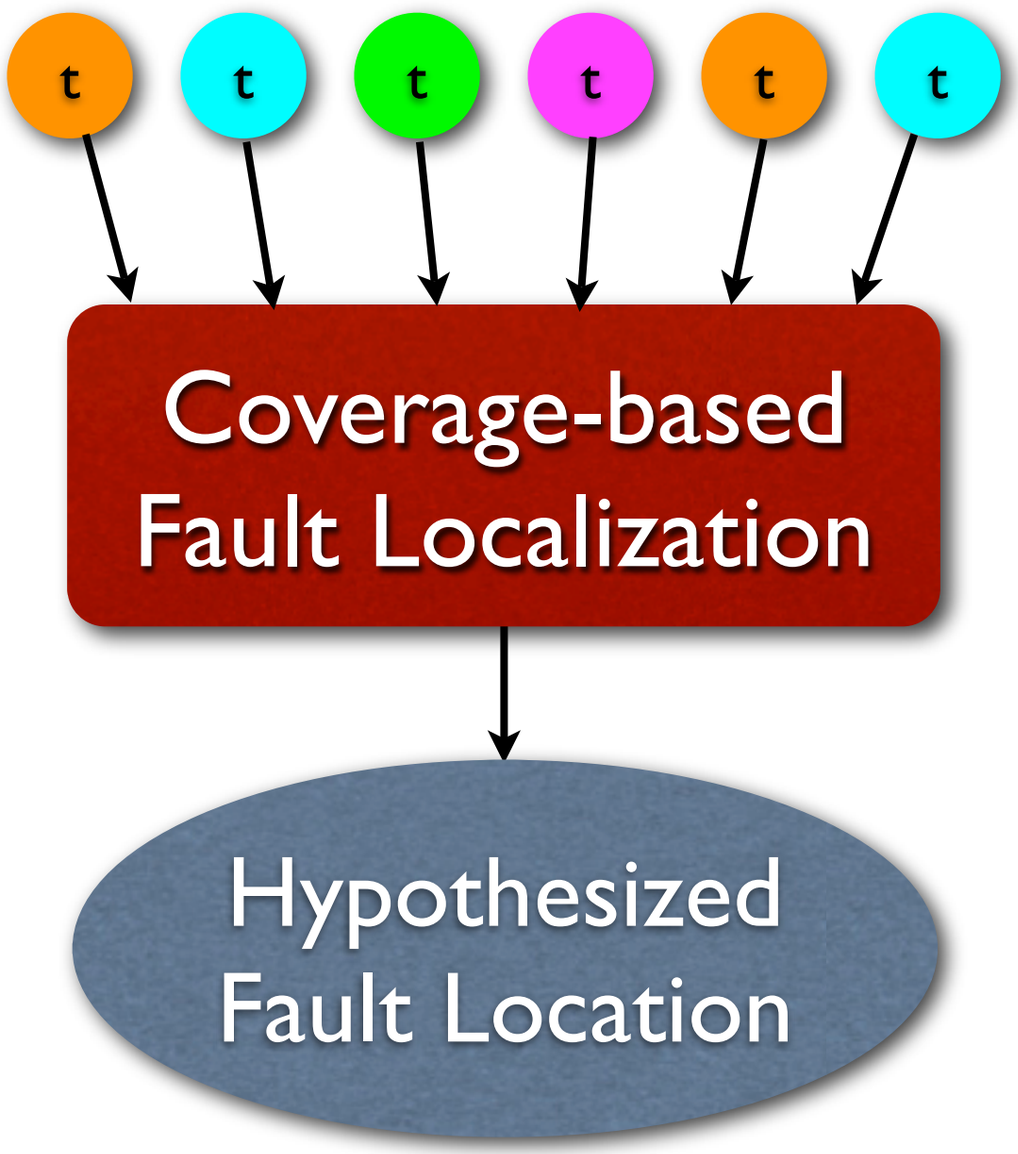

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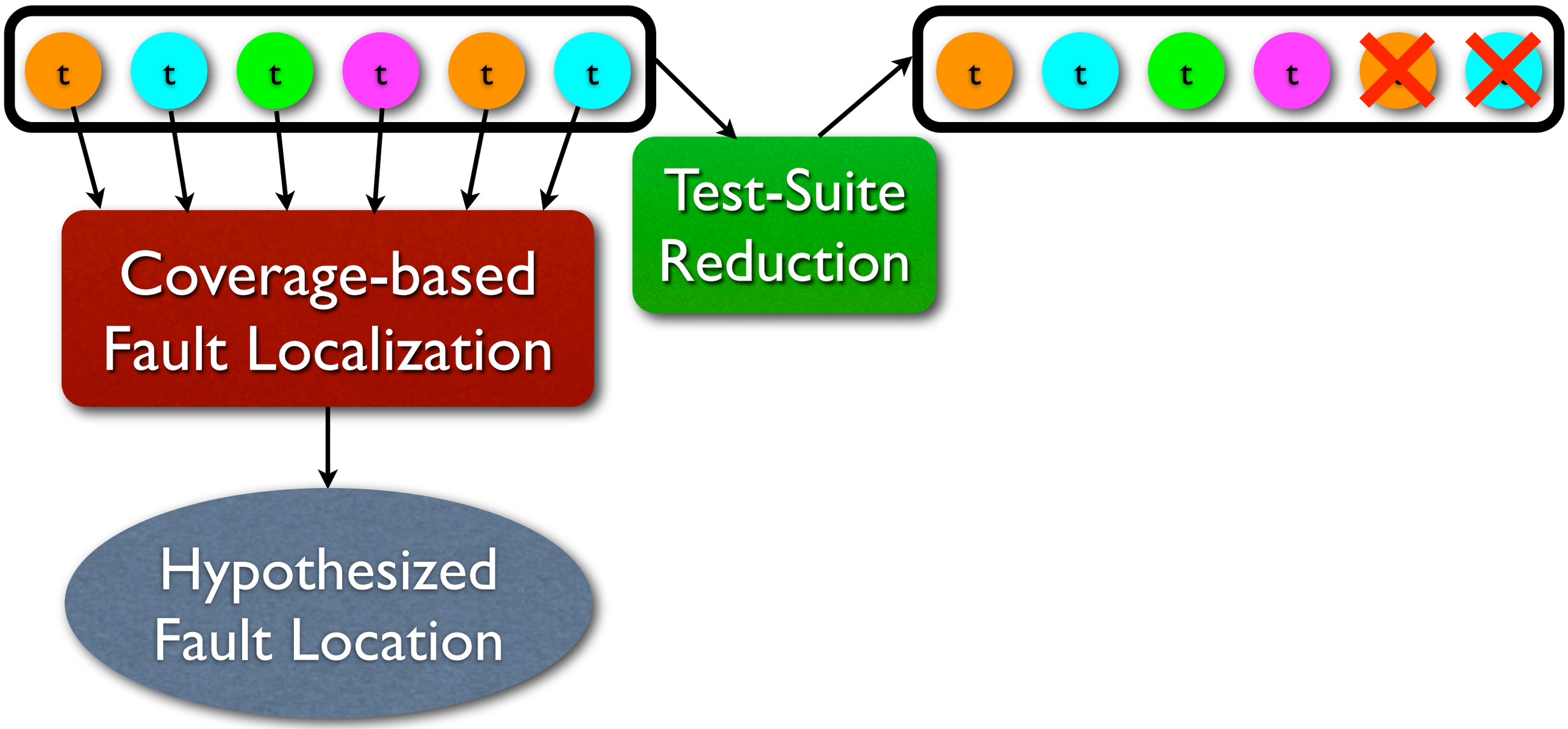

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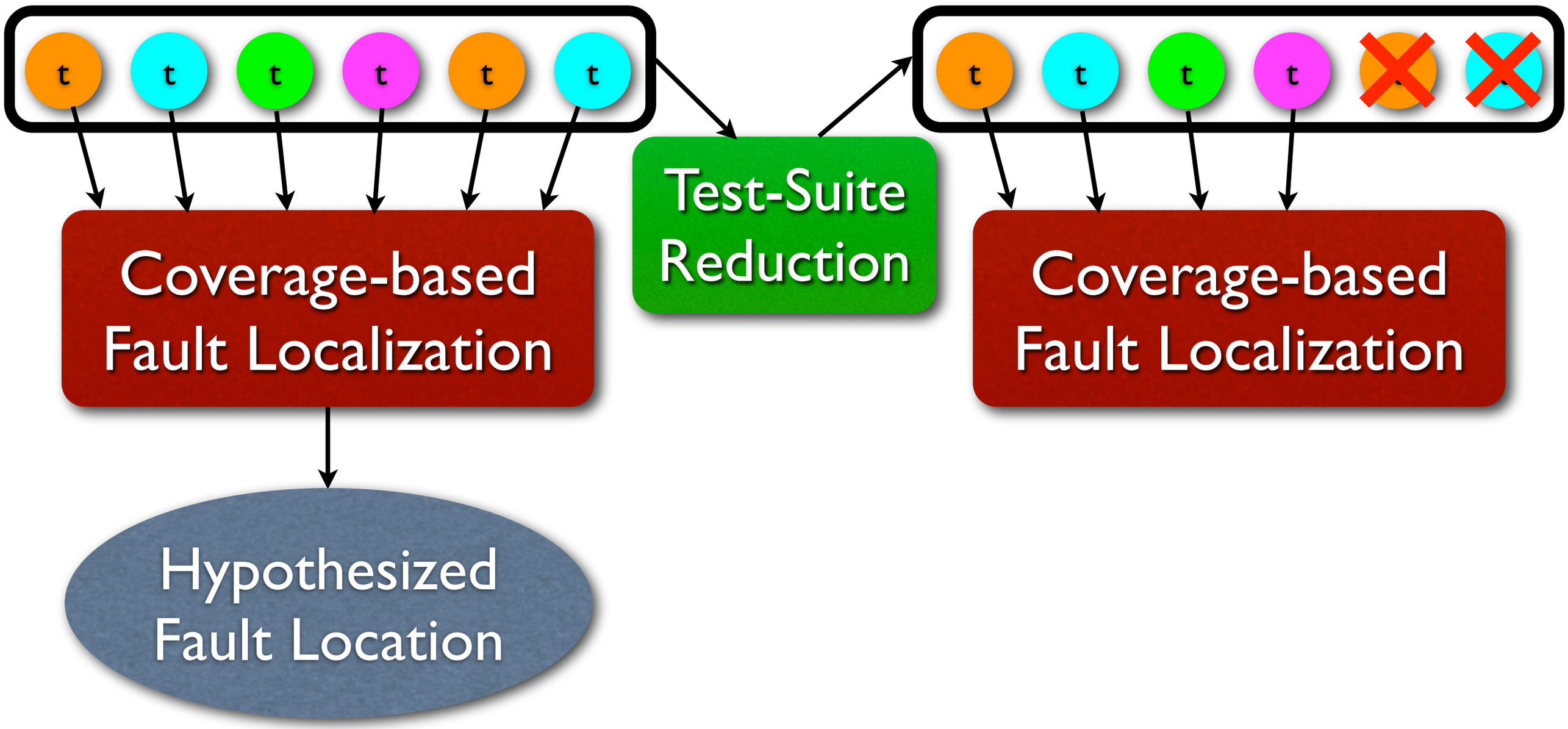
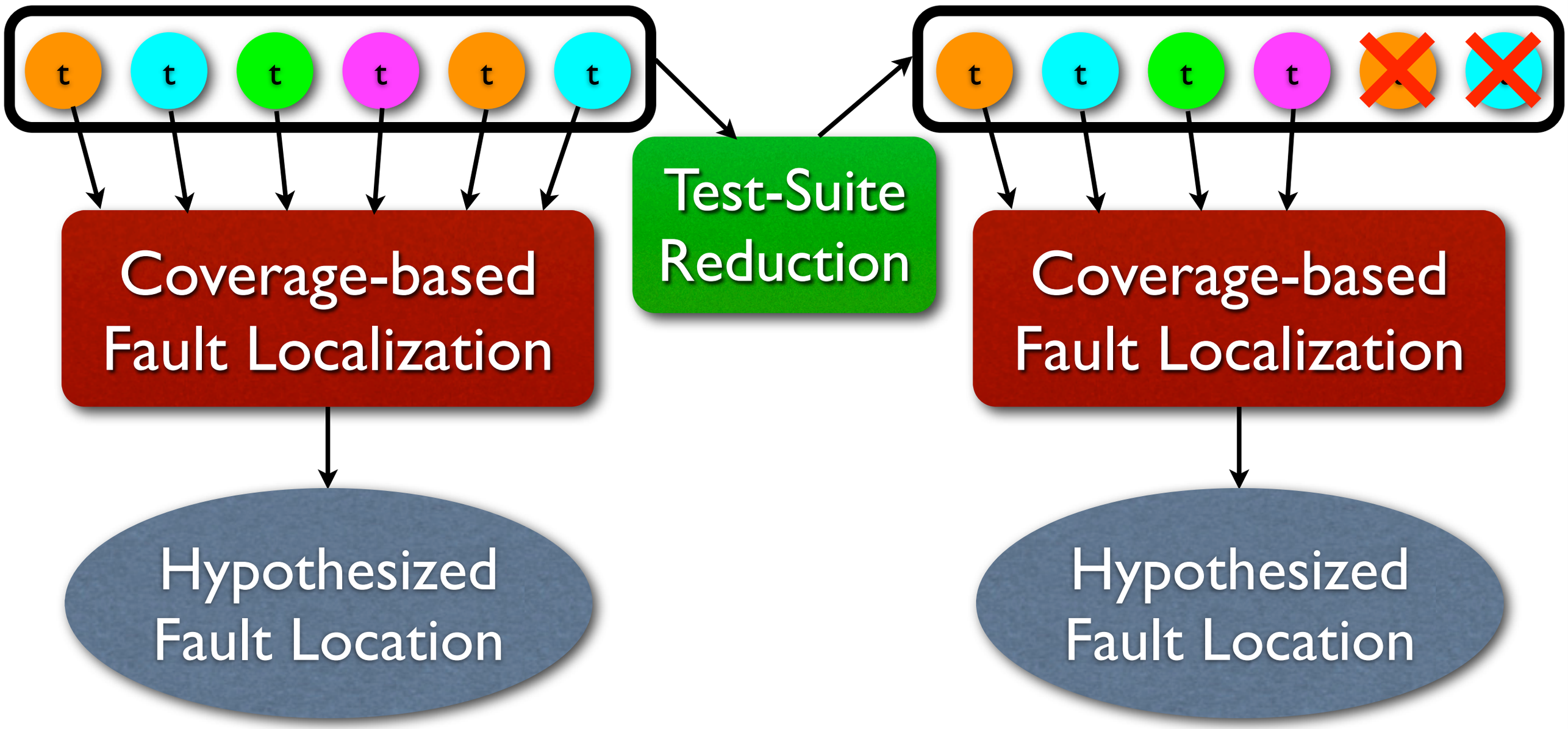


Research Question



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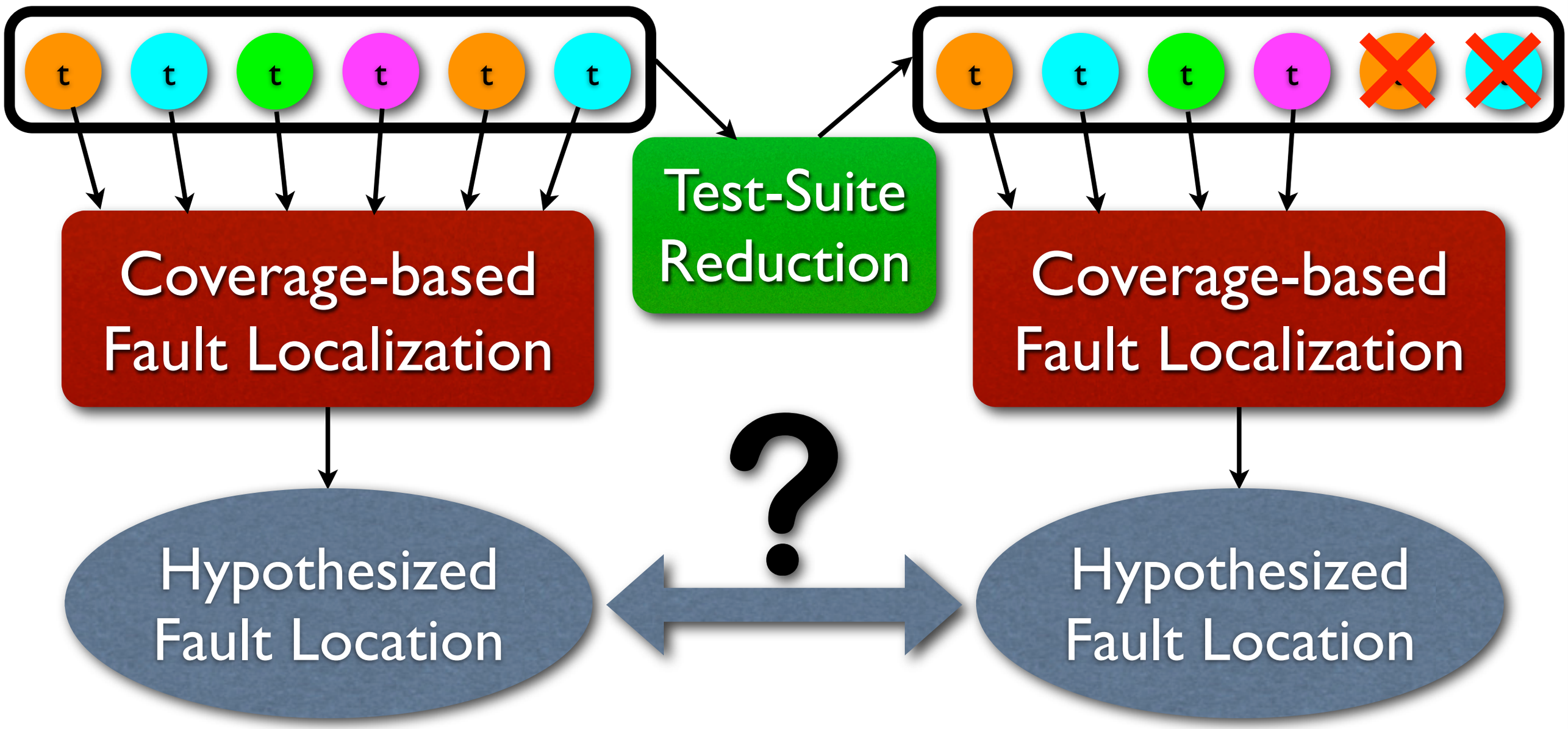


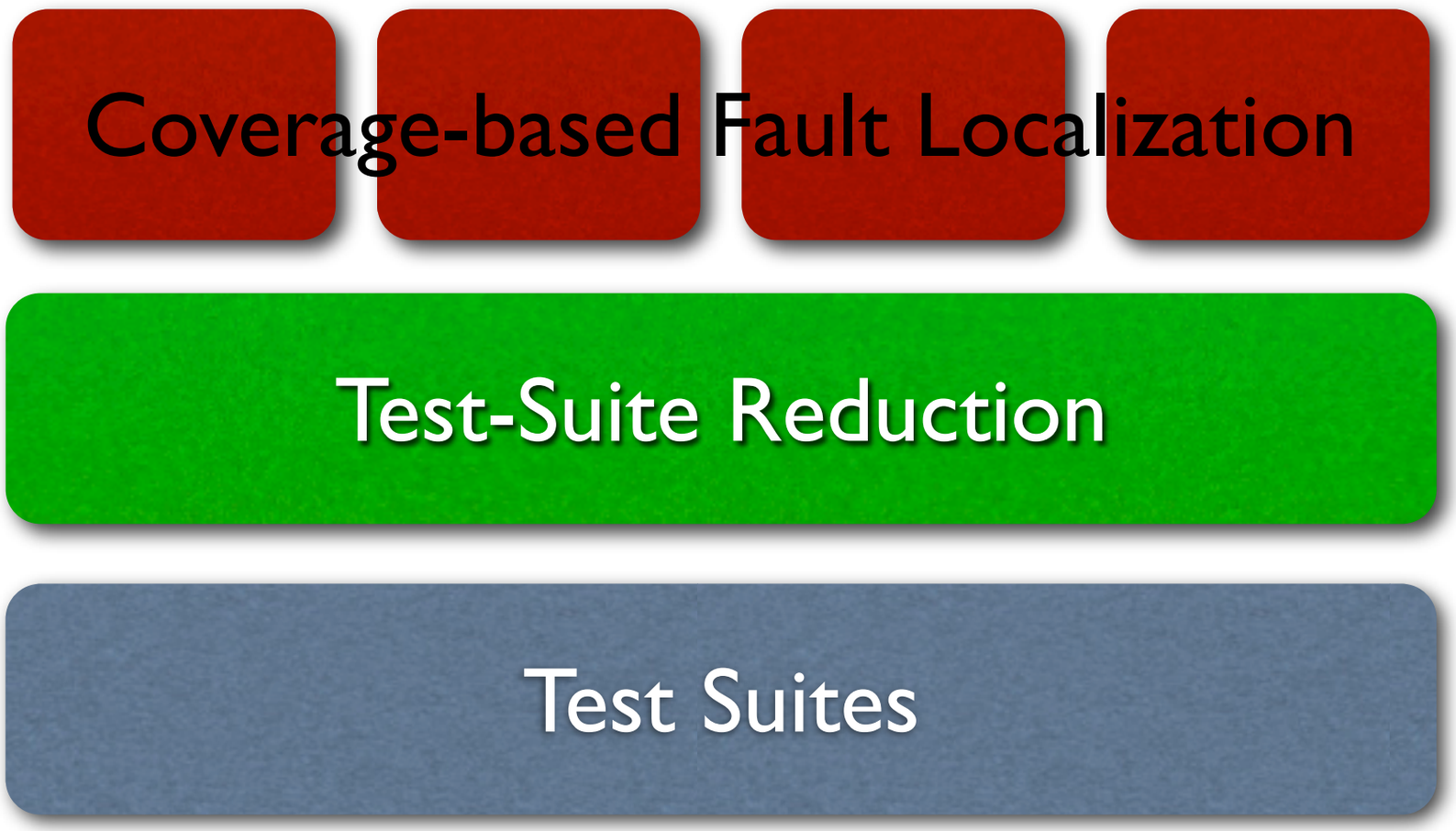
Overview

Coverage-based Fault Localization

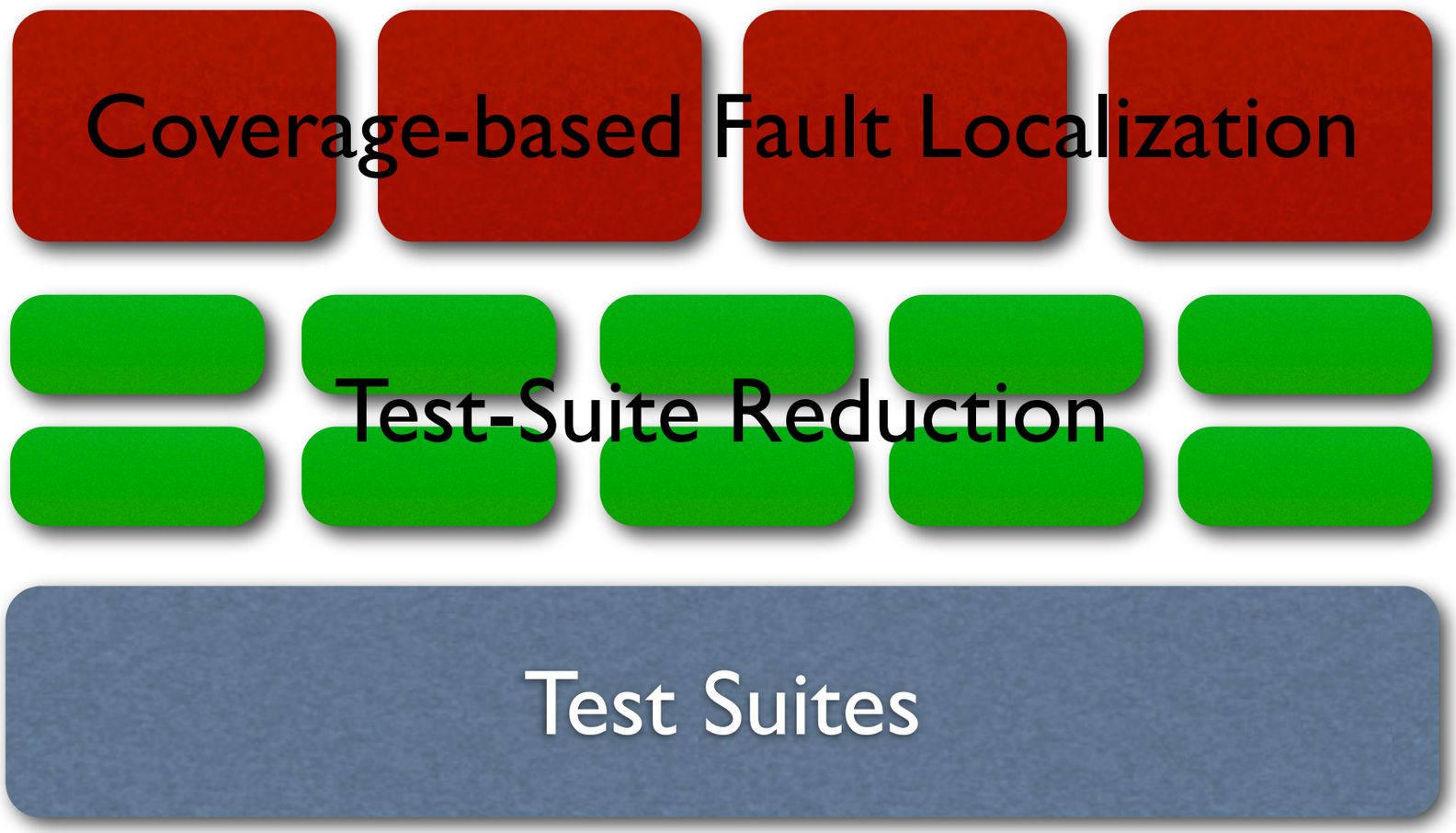
Test-Suite Reduction

Test Suites

Overview


Coverage-based Fault Localization
Test-Suite Reduction
Test Suites

Overview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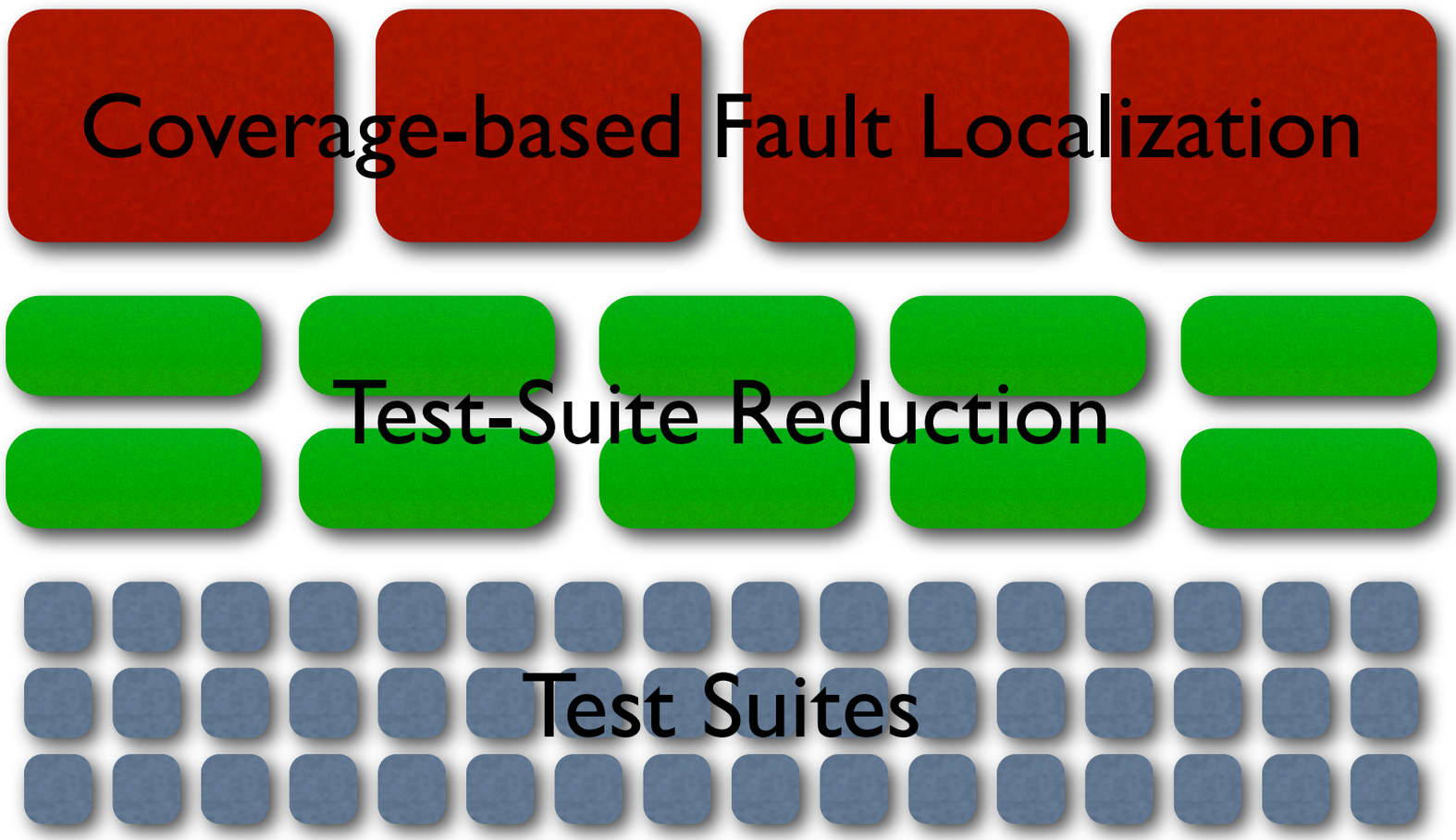
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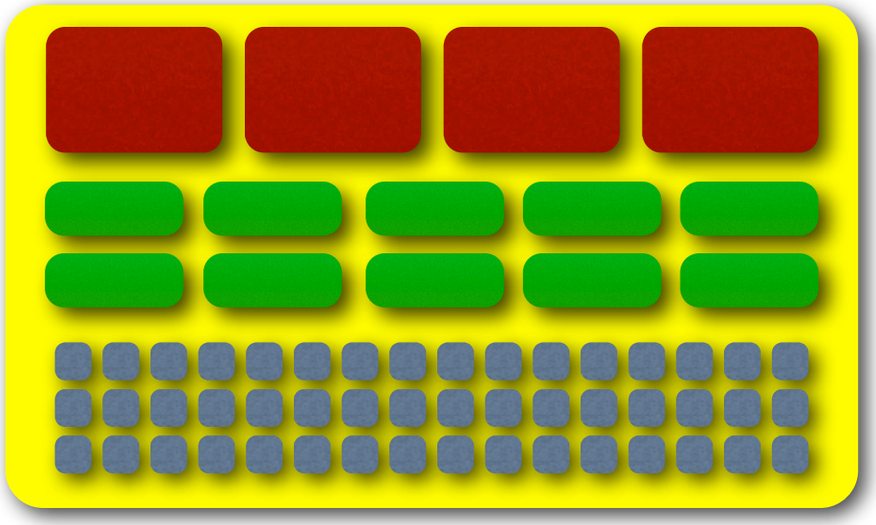
Overview

Background



Experiment

Results & Analysis

Background: Coverage-Based Fault Localization

Examples: Tarantula [Jones '02], Nearest Neighbors [Renieris '03], SBI [Liblit '05], SOBER [Liu '05], Jaccard [Abreu '07], ...

Example: Tarantula

$$suspiciousness(s) = \frac{\frac{failed(s)}{totalfailed}}{\frac{failed(s)}{totalfailed} + \frac{passed(s)}{totalpassed}}$$

```
   mid() {
     int x,y,z,m;
1:   read("Enter 3 numbers:",x,y,z);
2:   m = z;
3:   if (y<z)
4:     if (x<y)
5:           m = y;
6:     else if (x<z)
7:           m = y; // fault
8:   else
9:     if (x>y)
10:          m = y;
11:    else if (x>z)
12:          m = x;
13: print("Middle number is:", m);
   }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5	suspiciousness
1:	•	•	•	•	•	•	•	•	
2:	•	•	•	•	•	•	•	•	
3:	•	•	•	•	•	•	•	•	
4:	•	•			•		•	•	
5:		•							
6:	•				•		•	•	
7:	•						•	•	
8:			•	•		•			
9:			•	•		•			
10:			•			•			
11:				•					
12:									
13:	•	•	•	•	•	•	•	•	
Pass Status	P	P	P	P	P	P	F	F	

Example: Tarantula

$$suspiciousness(s) = \frac{\frac{failed(s)}{totalfailed}}{\frac{failed(s)}{totalfailed} + \frac{passed(s)}{totalpassed}}$$

		3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5	suspiciousness
	`mid() {`									
	`int x,y,z,m;`									
1:	`read("Enter 3 numbers:",x,y,z);`	•	•	•	•	•	•	•	•	
2:	`m = z;`	•	•	•	•	•	•	•	•	
3:	`if (y<z)`	•	•	•	•	•	•	•	•	
4:	`if (x<y)`	•	•			•		•	•	
5:	`m = y;`		•							
6:	`else if (x<z)`	•				•		•	•	
7:	`m = y; // fault`	•						•	•	
8:	`else`			•	•		•			
9:	`if (x>y)`			•	•		•			
10:	`m = y;`			•			•			
11:	`else if (x>z)`				•					
12:	`m = x;`									
13:	`print("Middle number is:", m);`	•	•	•	•	•	•	•	•	
	`}`									
	Pass Status	P	P	P	P	P	P	F	F	

Example: Tarantula

$$suspiciousness(s) = \frac{\frac{failed(s)}{totalfailed}}{\frac{failed(s)}{totalfailed} + \frac{passed(s)}{totalpassed}}$$

```
    mid() {
      int x,y,z,m;
1:    read("Enter 3 numbers:",x,y,z);
2:    m = z;
3:    if (y<z)
4:      if (x<y)
5:            m = y;
6:      else if (x<z)
7:            m = y; // fault
8:    else
9:      if (x>y)
10:           m = y;
11:     else if (x>z)
12:           m = x;
13:   print("Middle number is:", m);
    }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5	suspiciousness
1	•	•	•	•	•	•	•	•	.5
2	•							•	
3	•								
4	•								
5		•							
6	•				•		•	•	
7	•						•	•	
8			•	•		•			
9			•	•		•			
10			•			•			
11				•					
12									
13	•	•	•	•	•	•	•	•	
Pass Status	P	P	P	P	P	P	F	F	

$$susp(1) = \frac{\frac{2}{2}}{\frac{2}{2} + \frac{6}{6}} = 0.5$$

Example: Tarantula

$$suspiciousness(s) = \frac{\frac{failed(s)}{totalfailed}}{\frac{failed(s)}{totalfailed} + \frac{passed(s)}{totalpassed}}$$

```
    mid() {
      int x,y,z,m;
1:    read("Enter 3 numbers:",x,y,z);
2:    m = z;
3:    if (y<z)
4:      if (x<y)
5:            m = y;
6:      else if (x<z)
7:            m = y; // fault
8:    else
9:      if (x>y)
10:           m = y;
11:     else if (x>z)
12:           m = x;
13:   print("Middle number is:", m);
    }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5	suspiciousness
1	•	•	•	•	•	•	•	•	.5
2	•	•	•	•	•	•	•	•	
3	•	•	•	•	•	•	•	•	
4	•	•			•		•	•	
5		•							
6	•				•		•	•	
7	•						•	•	.9
13	•	•	•	•	•	•	•	•	
Pass Status	P	P	P	P	P	P	F	F	

$$susp(7) = \frac{\frac{2}{2}}{\frac{2}{2} + \frac{1}{6}} = 0.9$$

Example: Tarantula

$$suspiciousness(s) = \frac{\frac{failed(s)}{totalfailed}}{\frac{failed(s)}{totalfailed} + \frac{passed(s)}{totalpassed}}$$

		3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5	suspiciousness
	`mid() {`									
	`int x,y,z,m;`									
1:	`read("Enter 3 numbers:",x,y,z);`	•	•	•	•	•	•	•	•	.5
2:	`m = z;`	•	•	•	•	•	•	•	•	.5
3:	`if (y<z)`	•	•	•	•	•	•	•	•	.5
4:	`if (x<y)`	•	•			•		•	•	.7
5:	`m = y;`		•							.0
6:	`else if (x<z)`	•				•		•	•	.8
7:	`m = y; // fault`	•						•	•	.9
8:	`else`			•	•		•			.0
9:	`if (x>y)`			•	•		•			.0
10:	`m = y;`			•			•			.0
11:	`else if (x>z)`				•					.0
12:	`m = x;`									.0
13:	`print("Middle number is:", m);`	•	•	•	•	•	•	•	•	.5
	`}`									
	Pass Status	P	P	P	P	P	P	F	F	

Example: Tarantula

$$suspiciousness(s) = \frac{\frac{failed(s)}{totalfailed}}{\frac{failed(s)}{totalfailed} + \frac{passed(s)}{totalpassed}}$$

		3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5	suspiciousness
	`mid() {`									
	`int x,y,z,m;`									
1:	`read("Enter 3 numbers:",x,y,z);`	•	•	•	•	•	•	•	•	.5
2:	`m = z;`	•	•	•	•	•	•	•	•	.5
3:	`if (y<z)`	•	•	•	•	•	•	•	•	.5
4:	`if (x<y)`	•	•			•		•	•	.7
5:	`m = y;`		•							.0
6:	`else if (x<z)`	•				•		•	•	.8
7:	`m = y; // fault`	•						•	•	.9
8:	`else`			•	•		•			.0
9:	`if (x>y)`			•	•		•			.0
10:	`m = y;`			•			•			.0
11:	`else if (x>z)`				•					.0
12:	`m = x;`									.0
13:	`print("Middle number is:", m);`	•	•	•	•	•	•	•	•	.5
	`}`									
	Pass Status	P	P	P	P	P	P	F	F	

Example: Tarantula

$$suspiciousness(s) = \frac{\frac{failed(s)}{totalfailed}}{\frac{failed(s)}{totalfailed} + \frac{passed(s)}{totalpassed}}$$

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5	suspiciousness
`mid() {`									
`int x,y,z,m;`									
1: `read("Enter 3 numbers:",x,y,z);`	•	•	•	•	•	•	•	•	.5
2: `m = z;`	•	•	•	•	•	•	•	•	.5
3: `if (y<z)`	•	•	•	•	•	•	•	•	.5
4: `if (x<y)`	•	•			•		•	•	.7
5: `m = y;`		•							.0
6: `else if (x<z)`	•				•		•	•	.8
7: `m = y; // fault`	•						•	•	.9
8: `else`			•	•		•			.0
9: `if (x>y)`			•	•		•			.0
10: `m = y;`			•			•			.0
11: `else if (x>z)`				•					.0
12: `m = x;`									.0
13: `print("Middle number is:", m);`	•	•	•	•	•	•	•	•	.5
`}`									
Pass Status	P	P	P	P	P	P	F	F	

Example: Tarantula

$$suspiciousness(s) = \frac{\frac{failed(s)}{totalfailed}}{\frac{failed(s)}{totalfailed} + \frac{passed(s)}{totalpassed}}$$

		3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5	suspiciousness
	`mid() {`									
	`int x,y,z,m;`									
1:	`read("Enter 3 numbers:",x,y,z);`	•	•	•	•	•	•	•	•	.5
2:	`m = z;`	•	•	•	•	•	•	•	•	.5
3:	`if (y<z)`	•	•	•	•	•	•	•	•	.5
4:	`if (x<y)`	•	•			•		•	•	.7
5:	`m = y;`		•							.0
6:	`else if (x<z)`	•				•		•	•	.8
7:	`m = y; // fault`	•						•	•	.9
8:	`else`			•	•		•			.0
9:	`if (x>y)`			•	•		•			.0
10:	`m = y;`			•			•			.0
11:	`else if (x>z)`				•					.0
12:	`m = x;`									.0
13:	`print("Middle number is:", m);`	•	•	•	•	•	•	•	•	.5
	`}`									
	Pass Status	P	P	P	P	P	P	F	F	

Background: Coverage-Based Test-Suite Reduction

Examples: Harrold '93, Rothermel '98, Jones '02, Elbaum '02

Example: Test-Suite Reduction

```
   mid() {
     int x,y,z,m;
1:   read("Enter 3 numbers:",x,y,z);
2:   m = z;
3:   if (y<z)
4:     if (x<y)
5:           m = y;
6:     else if (x<z)
7:           m = y; // bug
8:   else
9:     if (x>y)
10:          m = y;
11:    else if (x>z)
12:          m = x;
13: print("Middle number is:", m);
   }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: Test-Suite Reduction

```
    mid() {
      int x,y,z,m;
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```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

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```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: Test-Suite Reduction

```
   mid() {
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```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: Test-Suite Reduction

```
   mid() {
     int x,y,z,m;
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```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: Test-Suite Reduction

```
   mid() {
     int x,y,z,m;
1:   read("Enter 3 numbers:",x,y,z);
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8:   else
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11:    else if (x>z)
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   }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: Test-Suite Reduction

```
    mid() {
      int x,y,z,m;
1:    read("Enter 3 numbers:",x,y,z);
2:    m = z;
3:    if (y<z)
4:      if (x<y)
5:            m = y;
6:      else if (x<z)
7:            m = y; // bug
8:    else
9:      if (x>y)
10:           m = y;
11:     else if (x>z)
12:           m = x;
13:   print("Middle number is:", m);
    }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: Test-Suite Reduction

```
mid() {
  int x,y,z,m;
1:  read("Enter 3 numbers:",x,y,z);
2:  m = z;
3:  if (y<z)
4:    if (x<y)
5:          m = y;
6:    else if (x<z)
7:          m = y; // bug
8:  else
9:    if (x>y)
10:         m = y;
11:   else if (x>z)
12:         m = x;
13: print("Middle number is:", m);
}
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

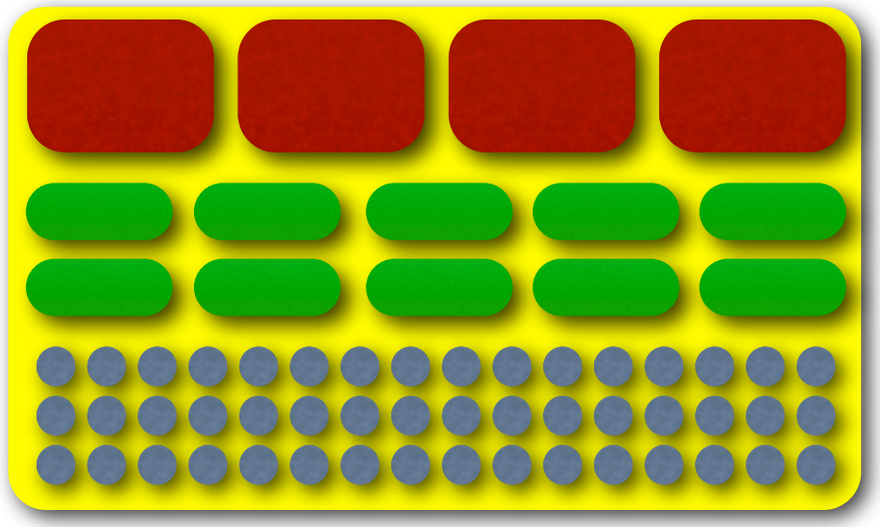
Example: Test-Suite Reduction

```
    mid() {
      int x,y,z,m;
1:    read("Enter 3 numbers:",x,y,z);
2:    m = z;
3:    if (y<z)
4:      if (x<y)
5:            m = y;
6:      else if (x<z)
7:            m = y; // bug
8:    else
9:      if (x>y)
10:           m = y;
11:     else if (x>z)
12:           m = x;
13:   print("Middle number is:", m);
    }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Overview

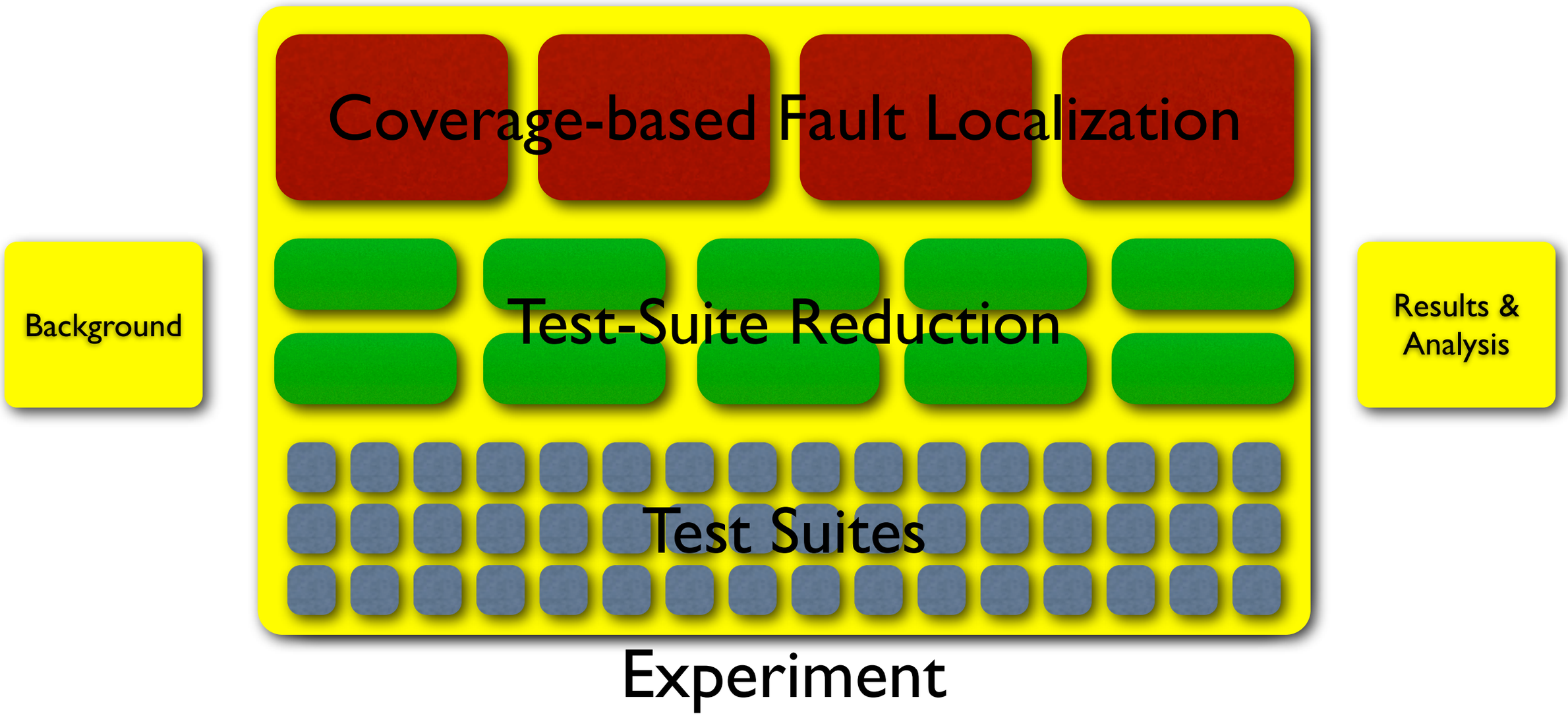
Background



Experiment

Results & Analysis

Overview


Coverage-based Fault Localization
Test-Suite Reduction
Test Suites
Background
Results & Analysis
Experiment

Experiment

Goal: Determine the effect of test-suite reduction on fault-localization effectiveness

Approach: Evaluate the effectiveness of four coverage-based fault-localization techniques with ten test-suite reduction strategies

Coverage-based Fault-Localization Techniques

Tarantula
[Jones et al. '02]

$$suspiciousness_T(s) = \frac{\%\text{failed}(s)}{\%\text{failed}(s) + \%\text{passed}(s)}$$

SBI*
[Liblit et al. '05]

$$suspiciousness_S(s) = \frac{failed(s)}{failed(s) + passed(s)}$$

Jaccard
[Abreu et al. '07]

$$suspiciousness_J(s) = \frac{failed(s)}{totalfailed + passed(s)}$$

Ochiai
[Abreu et al. '07]

$$suspiciousness_O(s) = \frac{failed(s)}{\sqrt{totalfailed * (failed(s) + passed(s))}}$$

Test-Suite Reduction Strategies

	All	Passing	Failing	Passing & Failing	All with Failing Preference
Statement	S-A	S-P	S-F	S-PF	S-R
Vector	V-A	V-P	V-F	V-PF	V-R

Test-Suite Reduction Strategies

Coverage Type	All	Passing	Failing	Passing & Failing	All with Failing Preference
Statement	S-A	S-P	S-F	S-PF	S-R
Vector	V-A	V-P	V-F	V-PF	V-R

Example: Statement Versus Vector Coverage

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
`mid() {`								
`int x,y,z,m;`								
`1: read("Enter 3 numbers:",x,y,z);`	•	•	•	•	•	•	•	•
`2: m = z;`	•	•	•	•	•	•	•	•
`3: if (y<z)`	•	•	•	•	•	•	•	•
`4: if (x<y)`	•	•			•		•	•
`5: m = y;`		•						
`6: else if (x<z)`	•				•		•	•
`7: m = y; // bug`	•						•	•
`8: else`			•	•		•		
`9: if (x>y)`			•	•		•		
`10: m = y;`			•			•		
`11: else if (x>z)`				•				
`12: m = x;`								
`13: print("Middle number is:", m);`	•	•	•	•	•	•	•	•
`}`								
Pass Status	P	P	P	P	P	P	F	F

Example: Statement Versus Vector Coverage

Statement

		3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
	`mid() {`								
	`int x,y,z,m;`								
1:	`read("Enter 3 numbers:",x,y,z);`	•	•	•	•	•	•	•	•
2:	`m = z;`	•	•	•	•	•	•	•	•
3:	`if (y<z)`	•	•	•	•	•	•	•	•
4:	`if (x<y)`	•	•			•		•	•
5:	`m = y;`		•						
6:	`else if (x<z)`	•				•		•	•
7:	`m = y; // bug`	•						•	•
8:	`else`			•	•		•		
9:	`if (x>y)`			•	•		•		
10:	`m = y;`			•			•		
11:	`else if (x>z)`				•				
12:	`m = x;`								
13:	`print("Middle number is:", m);`	•	•	•	•	•	•	•	•
	`}`								
	Pass Status	P	P	P	P	P	P	F	F

Example: Statement Versus Vector Coverage

Statement

		3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
	`mid() {`								
	`int x,y,z,m;`								
1:	`read("Enter 3 numbers:",x,y,z);`	•	•	•	•	•	•	•	•
2:	`m = z;`	•	•	•	•	•	•	•	•
3:	`if (y<z)`	•	•	•	•	•	•	•	•
4:	`if (x<y)`	•	•			•		•	•
5:	`m = y;`		•						
6:	`else if (x<z)`	•				•		•	•
7:	`m = y; // bug`	•						•	•
8:	`else`			•	•		•		
9:	`if (x>y)`			•	•		•		
10:	`m = y;`			•			•		
11:	`else if (x>z)`				•				
12:	`m = x;`								
13:	`print("Middle number is:", m);`	•	•	•	•	•	•	•	•
	`}`								
	Pass Status	P	P	P	P	P	P	F	F

Example: Statement Versus Vector Coverage

Statement

```
    mid() {
      int x,y,z,m;
1:    read("Enter 3 numbers:",x,y,z);
2:    m = z;
3:    if (y<z)
4:      if (x<y)
5:            m = y;
6:      else if (x<z)
7:            m = y; // bug
8:    else
9:      if (x>y)
10:           m = y;
11:     else if (x>z)
12:           m = x;
13:   print("Middle number is:", m);
    }
```

redundant

	7,5,4	2,1,3	4,3,5
1:	•	•	•
2:	•	•	•
3:	•	•	•
4:	•	•	•
5:	•		
6:	•	•	•
7:	•	•	•
8:	•	•	
9:	•	•	
10:	•	•	
11:	•		
12:			
13:	•	•	•
Pass Status	P	P	P
	P	P	P
	P	F	F
	P	P	P
	P	P	P
	P	P	P
	P	F	F
	P	F	F

Example: Statement Versus Vector Coverage

Vector

		3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
	`mid() {`								
	`int x,y,z,m;`								
1:	`read("Enter 3 numbers:",x,y,z);`	•	•	•	•	•	•	•	•
2:	`m = z;`	•	•	•	•	•	•	•	•
3:	`if (y<z)`	•	•	•	•	•	•	•	•
4:	`if (x<y)`	•	•			•		•	•
5:	`m = y;`		•						
6:	`else if (x<z)`	•				•		•	•
7:	`m = y; // bug`	•						•	•
8:	`else`			•	•		•		
9:	`if (x>y)`			•	•		•		
10:	`m = y;`			•			•		
11:	`else if (x>z)`				•				
12:	`m = x;`								
13:	`print("Middle number is:", m);`	•	•	•	•	•	•	•	•
	`}`								
	Pass Status	P	P	P	P	P	P	F	F

Example: Statement Versus Vector Coverage

Vector

```
    mid() {
      int x,y,z,m;
1:    read("Enter 3 numbers:",x,y,z);
2:    m = z;
3:    if (y<z)
4:      if (x<y)
5:            m = y;
6:      else if (x<z)
7:            m = y; // bug
8:    else
9:      if (x>y)
10:           m = y;
11:     else if (x>z)
12:           m = x;
13:   print("Middle number is:", m);
    }
```

redundant

•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•
•	•			•		•	•
	•						
•				•		•	•
•						•	•
		•	•		•		
		•	•		•		
		•			•		
			•				
•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Test-Suite Reduction Strategies

	All	Passing	Failing	Passing & Failing	All with Failing Preference
Statement	S-A	S-P	S-F	S-PF	S-R
Vector	V-A	V-P	V-F	V-PF	V-R

Example: S-A

S-A: Reduce All Test Cases

```
    mid() {
      int x,y,z,m;
1:    read("Enter 3 numbers:",x,y,z);
2:    m = z;
3:    if (y<z)
4:      if (x<y)
5:            m = y;
6:      else if (x<z)
7:            m = y; // bug
8:    else
9:      if (x>y)
10:           m = y;
11:     else if (x>z)
12:           m = x;
13:   print("Middle number is:", m);
    }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: S-P

S-P: Reduce Passing, Keep Failing

```
    mid() {
      int x,y,z,m;
1:    read("Enter 3 numbers:",x,y,z);
2:    m = z;
3:    if (y<z)
4:      if (x<y)
5:            m = y;
6:      else if (x<z)
7:            m = y; // bug
8:    else
9:      if (x>y)
10:           m = y;
11:     else if (x>z)
12:           m = x;
13:   print("Middle number is:", m);
    }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1: read("Enter 3 numbers:",x,y,z);	•	•	•	•	•	•	•	•
2: m = z;	•	•	•	•	•	•	•	•
3: if (y<z)	•	•	•	•	•	•	•	•
4: if (x<y)	•	•			•		•	•
5: m = y;		•						
6: else if (x<z)	•				•		•	•
7: m = y; // bug	•						•	•
8: else			•	•		•		
9: if (x>y)			•	•		•		
10: m = y;			•			•		
11: else if (x>z)				•				
12: m = x;								
13: print("Middle number is:", m);	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: S-P

S-P: Reduce Passing, Keep Failing

```
   mid() {
     int x,y,z,m;
1:   read("Enter 3 numbers:",x,y,z);
2:   m = z;
3:   if (y<z)
4:     if (x<y)
5:           m = y;
6:     else if (x<z)
7:           m = y; // bug
8:   else
9:     if (x>y)
10:          m = y;
11:    else if (x>z)
12:          m = x;
13: print("Middle number is:", m);
   }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: S-P

S-P: Reduce Passing, Keep Failing

```
   mid() {
     int x,y,z,m;
1:   read("Enter 3 numbers:",x,y,z);
2:   m = z;
3:   if (y<z)
4:     if (x<y)
5:           m = y;
6:     else if (x<z)
7:           m = y; // bug
8:   else
9:     if (x>y)
10:          m = y;
11:    else if (x>z)
12:          m = x;
13: print("Middle number is:", m);
   }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: S-F

S-F: Reduce Failing, Keep Passing

```
   mid() {
     int x,y,z,m;
1:   read("Enter 3 numbers:",x,y,z);
2:   m = z;
3:   if (y<z)
4:     if (x<y)
5:           m = y;
6:     else if (x<z)
7:           m = y; // bug
8:   else
9:     if (x>y)
10:          m = y;
11:    else if (x>z)
12:          m = x;
13: print("Middle number is:", m);
   }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1: read("Enter 3 numbers:",x,y,z);	•	•	•	•	•	•	•	•
2: m = z;	•	•	•	•	•	•	•	•
3: if (y<z)	•	•	•	•	•	•	•	•
4: if (x<y)	•	•			•		•	•
5: m = y;		•						
6: else if (x<z)	•				•		•	•
7: m = y; // bug	•						•	•
8: else			•	•		•		
9: if (x>y)			•	•		•		
10: m = y;			•			•		
11: else if (x>z)				•				
12: m = x;								
13: print("Middle number is:", m);	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: S-F

S-F: Reduce Failing, Keep Passing

```
   mid() {
     int x,y,z,m;
1:   read("Enter 3 numbers:",x,y,z);
2:   m = z;
3:   if (y<z)
4:     if (x<y)
5:           m = y;
6:     else if (x<z)
7:           m = y; // bug
8:   else
9:     if (x>y)
10:          m = y;
11:    else if (x>z)
12:          m = x;
13: print("Middle number is:", m);
   }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: S-F

S-F: Reduce Failing, Keep Passing

```
   mid() {
     int x,y,z,m;
1:   read("Enter 3 numbers:",x,y,z);
2:   m = z;
3:   if (y<z)
4:     if (x<y)
5:           m = y;
6:     else if (x<z)
7:           m = y; // bug
8:   else
9:     if (x>y)
10:          m = y;
11:    else if (x>z)
12:          m = x;
13: print("Middle number is:", m);
   }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: S-PF

S-PF: Reduce Passing, Reduce Failing

		3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
	`mid() {`								
	`int x,y,z,m;`								
1:	`read("Enter 3 numbers:",x,y,z);`	•	•	•	•	•	•	•	•
2:	`m = z;`	•	•	•	•	•	•	•	•
3:	`if (y<z)`	•	•	•	•	•	•	•	•
4:	`if (x<y)`	•	•			•		•	•
5:	`m = y;`		•						
6:	`else if (x<z)`	•				•		•	•
7:	`m = y; // bug`	•						•	•
8:	`else`			•	•		•		
9:	`if (x>y)`			•	•		•		
10:	`m = y;`			•			•		
11:	`else if (x>z)`				•				
12:	`m = x;`								
13:	`print("Middle number is:", m);`	•	•	•	•	•	•	•	•
	`}`								
	Pass Status	P	P	P	P	P	P	F	F

Example: S-PF

S-PF: Reduce Passing, Reduce Failing

```
   mid() {
     int x,y,z,m;
1:   read("Enter 3 numbers:",x,y,z);
2:   m = z;
3:   if (y<z)
4:     if (x<y)
5:           m = y;
6:     else if (x<z)
7:           m = y; // bug
8:   else
9:     if (x>y)
10:          m = y;
11:    else if (x>z)
12:          m = x;
13: print("Middle number is:", m);
   }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

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	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1: read("Enter 3 numbers:",x,y,z);	•	•	•	•	•	•	•	•
2: m = z;	•	•	•	•	•	•	•	•
3: if (y<z)	•	•	•	•	•	•	•	•
4: if (x<y)	•	•			•		•	•
5: m = y;		•						
6: else if (x<z)	•				•		•	•
7: m = y; // bug	•						•	•
8: else			•	•		•		
9: if (x>y)			•	•		•		
10: m = y;			•			•		
11: else if (x>z)				•				
12: m = x;								
13: print("Middle number is:", m);	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: S-PF

S-PF: Reduce Passing, Reduce Failing

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   }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: S-PF

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```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: S-R

S-R: Reduce All with Preference for Failing

```
    mid() {
      int x,y,z,m;
1:    read("Enter 3 numbers:",x,y,z);
2:    m = z;
3:    if (y<z)
4:      if (x<y)
5:            m = y;
6:      else if (x<z)
7:            m = y; // bug
8:    else
9:      if (x>y)
10:           m = y;
11:     else if (x>z)
12:           m = x;
13: print("Middle number is:", m);
    }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
4	•	•			•		•	•
5		•						
6	•				•		•	•
7	•						•	•
8			•	•		•		
9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: S-R

S-R: Reduce All with Preference for Failing

```
    mid() {
      int x,y,z,m;
1:    read("Enter 3 numbers:",x,y,z);
2:    m = z;
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4:      if (x<y)
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8:    else
9:      if (x>y)
10:           m = y;
11:     else if (x>z)
12:           m = x;
13:   print("Middle number is:", m);
    }
```

	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	7,5,4	2,1,3	4,3,5
1:	•	•	•	•	•	•	•	•
2:	•	•	•	•	•	•	•	•
3:	•	•	•	•	•	•	•	•
4:	•	•			•		•	•
5:		•						
6:	•				•		•	•
7:	•						•	•
8:			•	•		•		
9:			•	•		•		
10:			•			•		
11:				•				
12:								
13:	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Example: S-R

S-R: Reduce All with Preference for Failing

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1	•	•	•	•	•	•	•	•
2	•	•	•	•	•	•	•	•
3	•	•	•	•	•	•	•	•
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9			•	•		•		
10			•			•		
11				•				
12								
13	•	•	•	•	•	•	•	•
Pass Status	P	P	P	P	P	P	F	F

Test-Suite Reduction Strategies

	All	Passing	Failing	Passing & Failing	All with Failing Preference
Statement	S-A	S-P	S-F	S-PF	S-R
Vector	V-A	V-P	V-F	V-PF	V-R

Subject Programs

Program	LOC	Faulty Versions	Test Cases	Description
Print_tokens	472	5	4056	Lexical analyzer
Print_tokens2	399	9	4071	Lexical analyzer
Replace	512	30	5542	Pattern replacement
Schedule	292	6	2650	Priority scheduler
Schedule2	301	9	2680	Priority scheduler
Tcas	141	41	1578	Altitude separation
Tot_info	440	23	1054	Information measure
Space (1-, 2-, 3-faults)	6218	46	13585	Array Definition Interpreter

= 169 faulty versions

Test Runs

- For each of the 169 faulty versions, we used test suites of sizes

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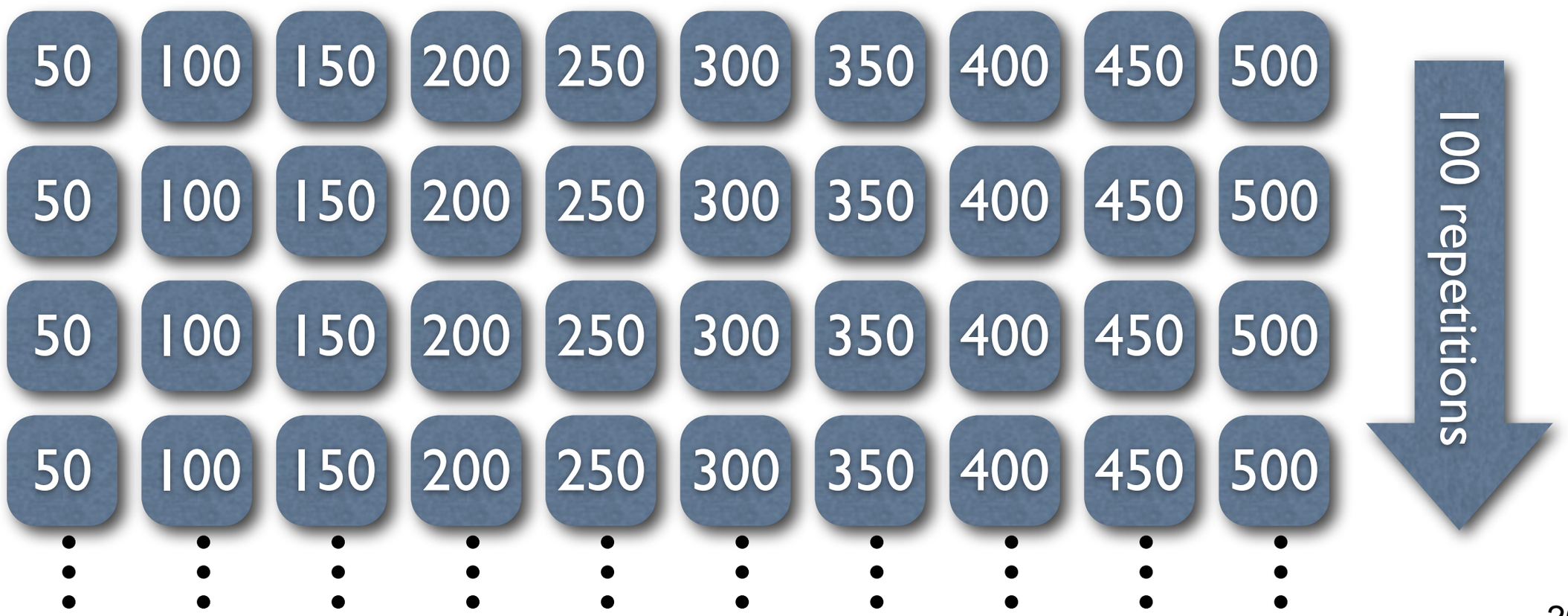

Test Runs

- For each of the 169 faulty versions, we used test suites of sizes
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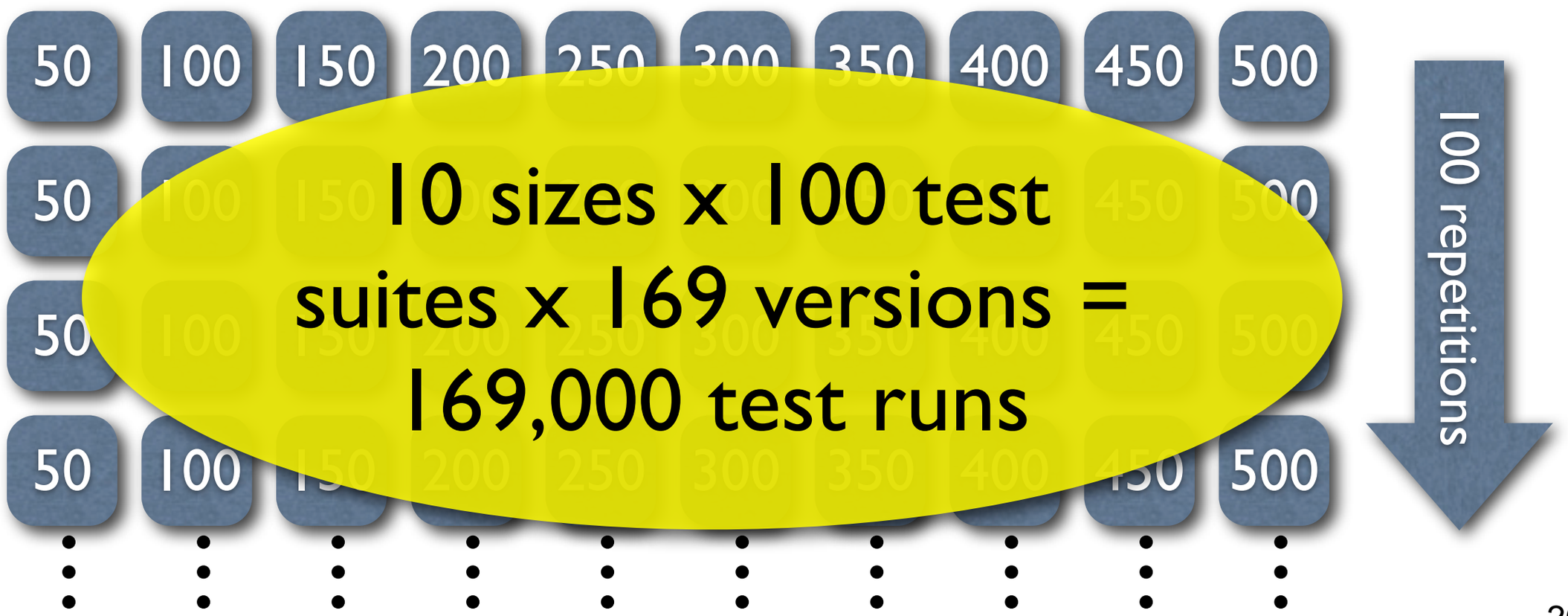


Experimental Method

Fault Localization:
4 techniques

x

Reduction:
1 original test suite
+2 coverage types
x 5 test sets
=11

x

Test Runs:
169 versions
x 10 suite sizes
x 100 repetitions
=169,000

= 7,436,000 fault-localization results

Metrics

- Fault-Localization Expense

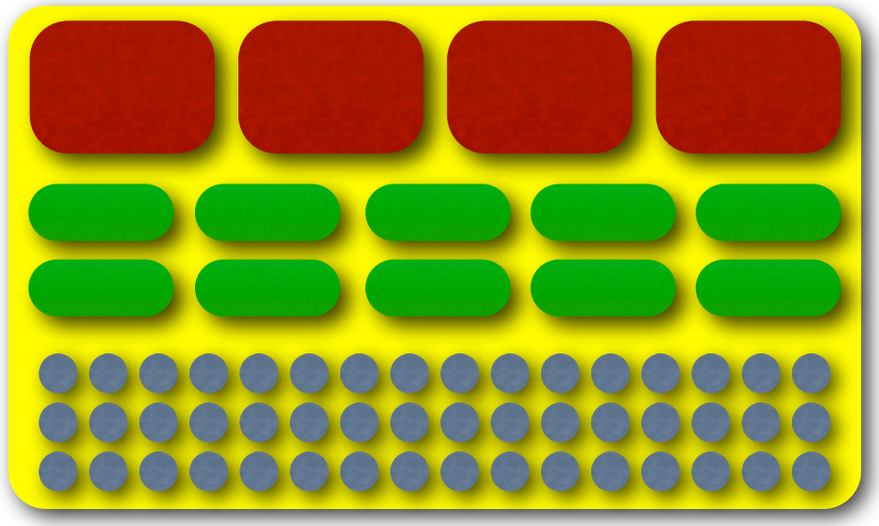
$$Expense = \frac{\text{number of examined statements to fault}}{\text{number of executable statements}} * 100$$

- Test-Suite Reduction

$$Reduction = \left(1 - \frac{\text{size of reduced test suite}}{\text{size of unreduced test suite}}\right) * 100$$

Overview

Background



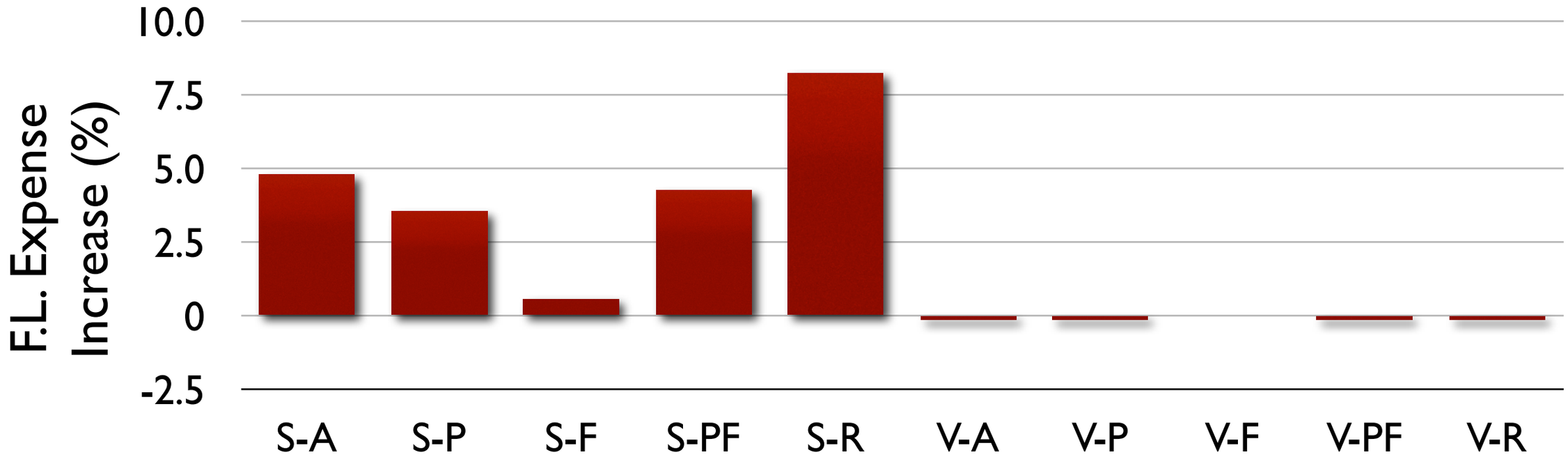
Experiment

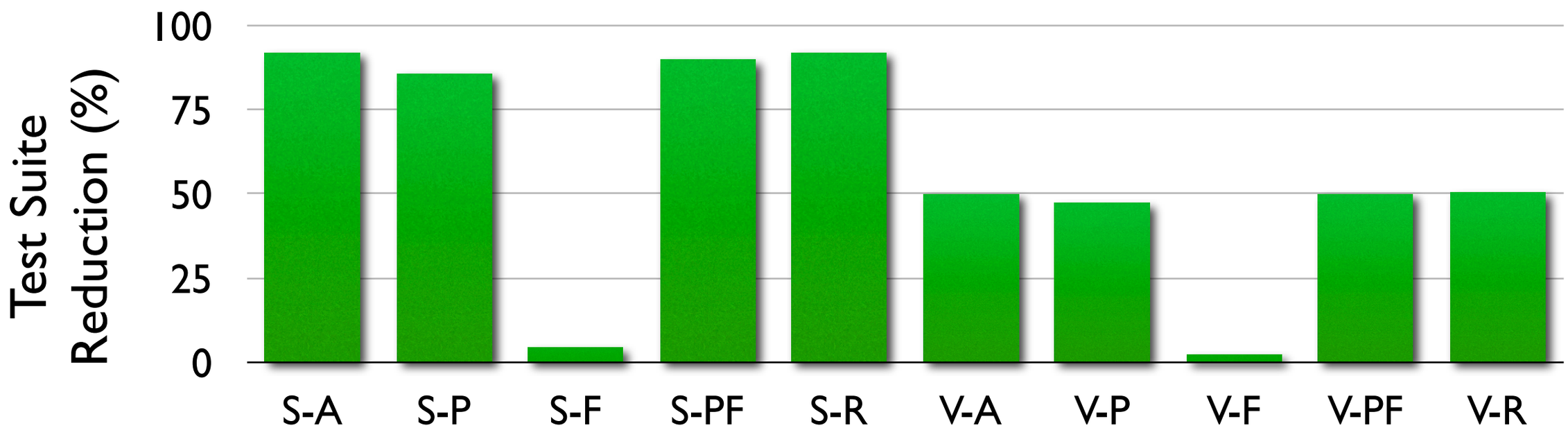
Results & Analysis

Results

F.L. Expense Increase (%)
10.0
7.5
5.0
2.5
0
-2.5
S-A
S-P
S-F
S-PF
S-R
V-A
V-P
V-F
V-PF
V-R

Results


F.L. Expense Increase (%)
10.0
7.5
5.0
2.5
0
-2.5
S-A
S-P
S-F
S-PF
S-R
V-A
V-P
V-F
V-PF
V-R


Test Suite Reduction (%)
100
75
50
25
0
S-A
S-P
S-F
S-PF
S-R
V-A
V-P
V-F
V-PF
V-R

Analysis: Case Study

Goal: Investigate whether test suite size accounts for all of the results

Analysis: Case Study

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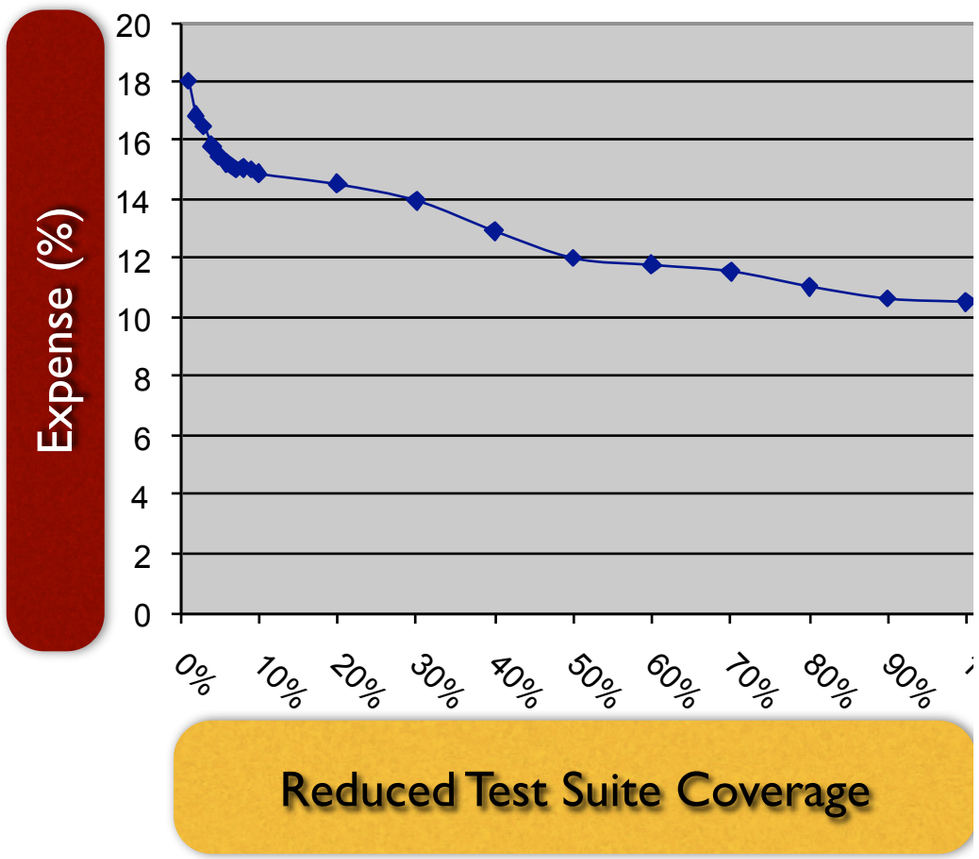
Approach: Incrementally build test suites to see how redundancy affects fault-localization expense

Analysis: Case Study

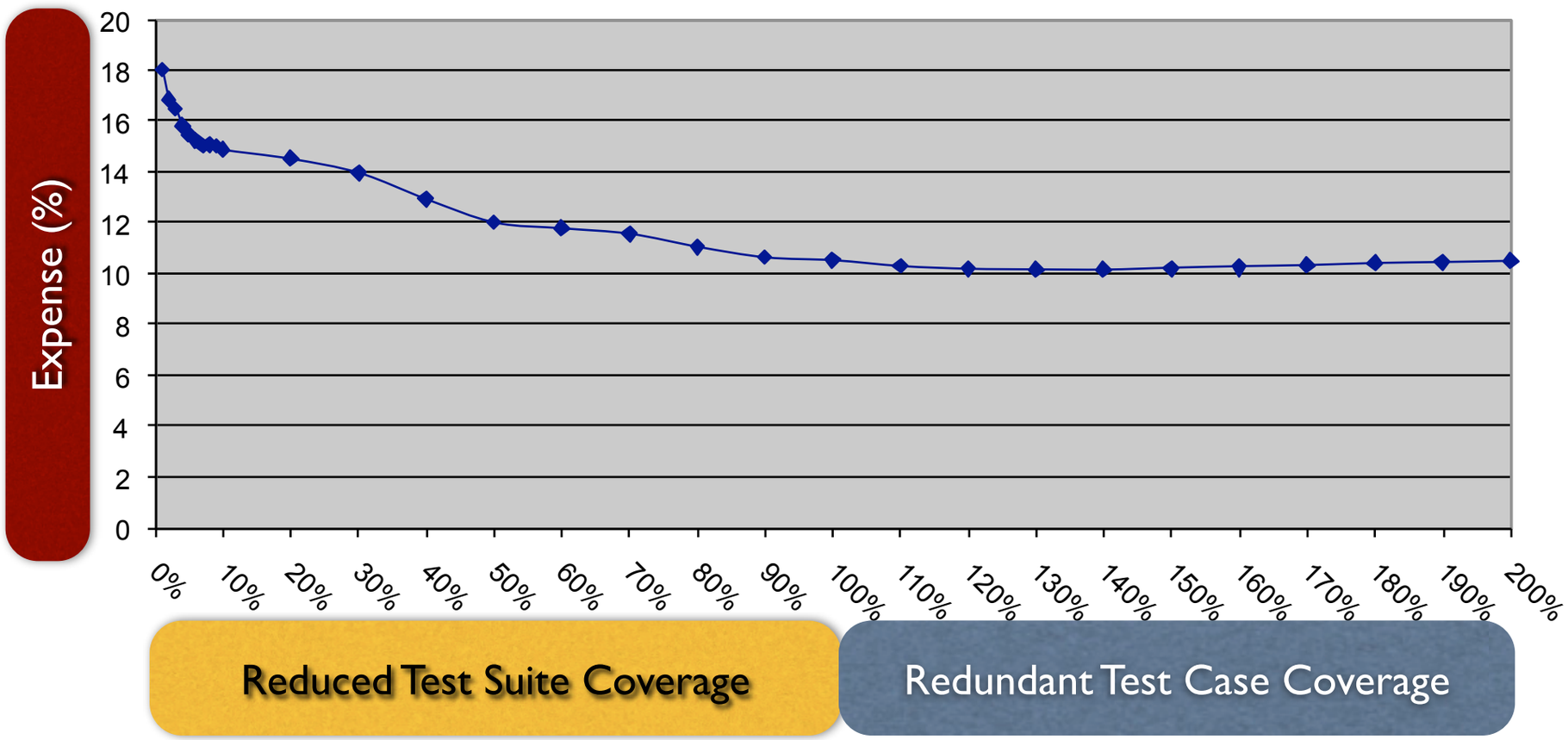
- Question: Are these results due to test-suite composition or size?

Analysis: Case Study Results (Siemens)



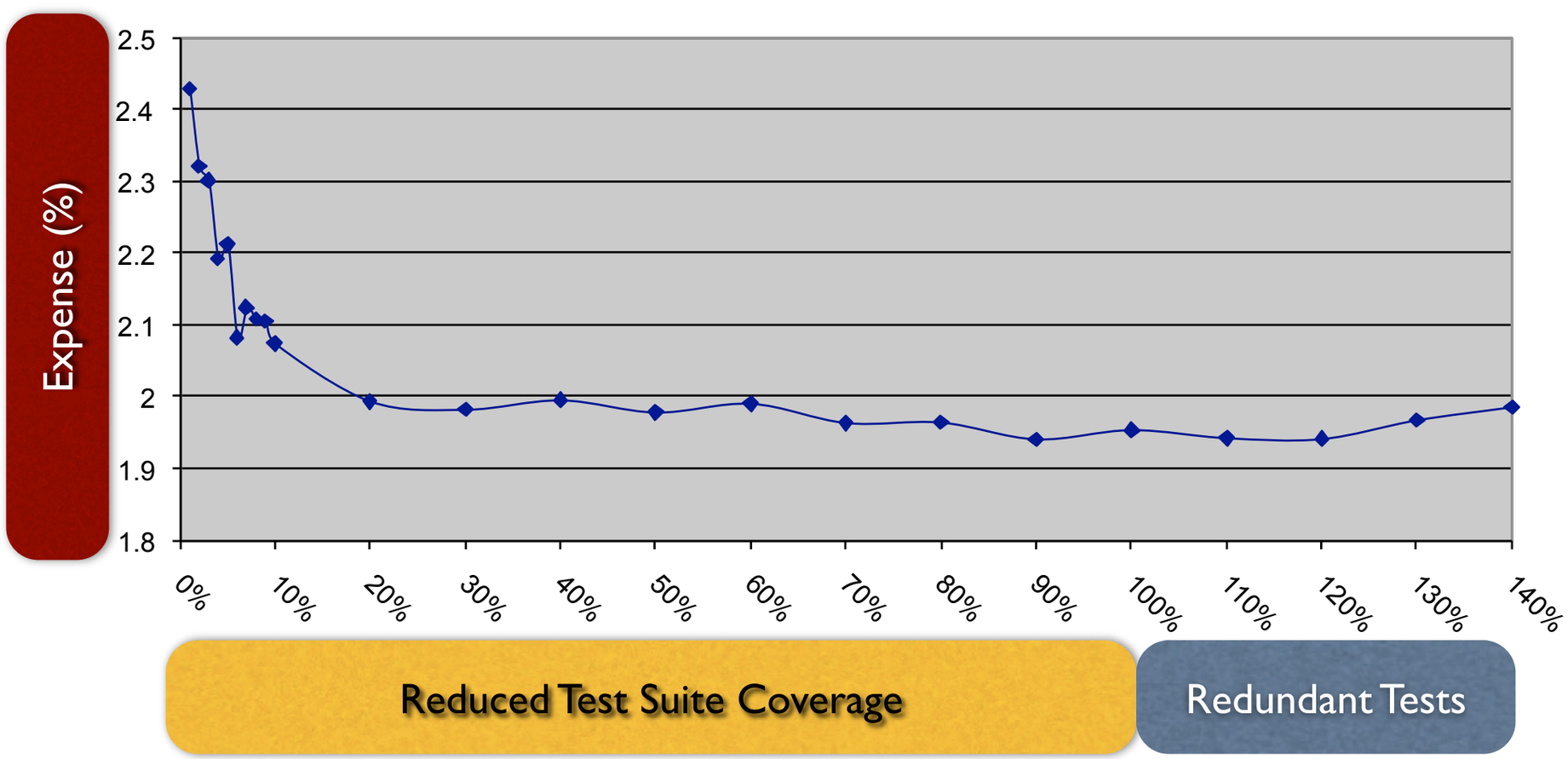
Analysis: Case Study Results (Siemens)

- Size does play a factor, but not the only factor



Analysis: Case Study Results (Space)

- `Space` shows that there may be a criterion stronger than statement, but weaker than vector



Future Work

- Experiment with more, larger subjects
- Consider other coverage entities including branches and data-flow
- Investigate testing criteria that are stronger than statement-based but weaker than vector-based
- Investigate other aspects of test-suite composition

Conclusions

- Composition of test suite affects fault-localization effectiveness
- Definition of redundancy affects fault-localization effectiveness. In particular,
  - Statement-reduction negatively affects
  - Vector-reduction does not diminish

Questions?