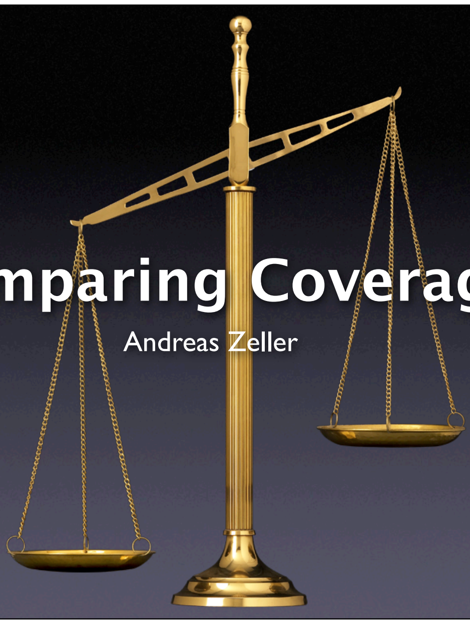
Comparing Coverage



Andreas Zeller

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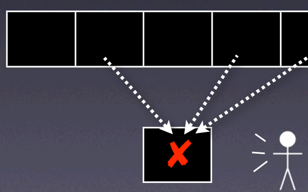
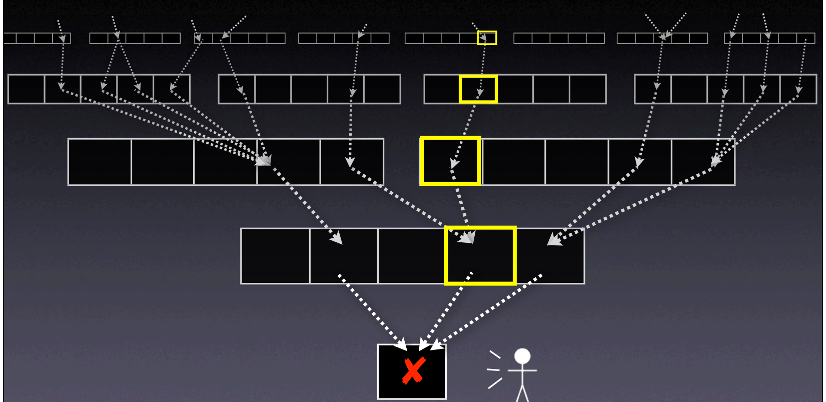
Tracing Infections

- For every infection, we must find the *earlier infection* that *causes* it.
- Which origin should we focus upon?

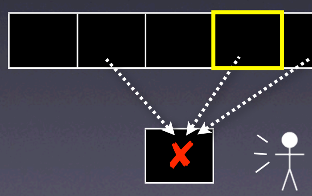


Tracing Infections



Focusing on Anomalies

- Examine origins and locations where something *abnormal* happens



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What's normal?

- General idea: Use *induction* – reasoning from the particular to the general
- Start with a *multitude* of runs
- Determine *properties* that are common across all runs

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What's abnormal?

- Suppose we determine common properties of all *passing* runs.
- Now we examine a run which *fails* the test.
- Any difference in properties *correlates with failure* – and is likely to hint at failure causes

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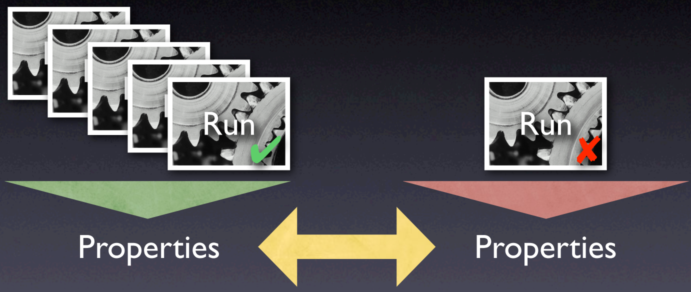
Detecting Anomalies



Differences correlate with failure

Properties

Data properties that hold in all runs:

- "At f(), x is odd"
- "$0 \leq x \leq 10$ during the run"

Code properties that hold in all runs:

- "f() is always executed"
- "After open(), we eventually have close()"

Comparing Coverage

1. Every failure is caused by an infection, which in turn is caused by a defect
2. The defect must be *executed* to start the infection
3. Code that is executed *in failing runs only* is thus likely to cause the defect

The middle program

```
$ middle 3 3 5
middle: 3

$ middle 2 1 3
middle: 1
```

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```
int main(int arc, char *argv[])
{
    int x = atoi(argv[1]);
    int y = atoi(argv[2]);
    int z = atoi(argv[3]);
    int m = middle(x, y, z);

    printf("middle: %d\n", m);

    return 0;
}
```

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```
int middle(int x, int y, int z) {
    int m = z;
    if (y < z) {
        if (x < y)
            m = y;
        else if (x < z)
            m = y;
    } else {
        if (x > y)
            m = y;
        else if (x > z)
            m = x;
    }
    return m;
}
```

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Obtaining Coverage

for C programs

13

13

Obtaining Coverage

for Python programs

```
if __name__ == "__main__":
    sys.settrace(tracer)
    x = sys.argv[1]
    y = sys.argv[2]
    z = sys.argv[3]
    m = middle(x, y, z)

    print "middle:", m
```

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Obtaining Coverage

for Python programs

```
def tracer(frame, event, arg):
    code = frame.f_code
    function = code.co_name
    filename = code.co_filename
    line = frame.f_lineno
    print filename + ":" + `line` + \
        ":" + function + "():", \
        event, arg
    return tracer
```

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Obtaining Coverage

for Python programs

```
$ ./middle.py 3 3 5
./middle.py:13:middle(): call None
./middle.py:14:middle(): line None
./middle.py:15:middle(): line None
./middle.py:16:middle(): line None
./middle.py:18:middle(): line None
./middle.py:19:middle(): line None
./middle.py:26:middle(): line None
./middle.py:26:middle(): return 3
middle: 3
```

For remaining steps, see new project

x	3	1	3	5	5	2
y	3	2	2	5	3	1
z	5	3	1	5	4	3
`int middle(int x, int y, int z) {`	•	•	•	•	•	•
`int m = z;`	•	•	•	•	•	•
`if (y < z) {`	•	•	•	•	•	•
`if (x < y)`		•				
`m = y;`		•				
`else if (x < z)`	•				•	•
`m = y;`	•					•
`} else {`	•		•	•		
`if (x > y)`			•			
`m = y;`			•			
`else if (x > z)`						
`m = x;`						
`}`						
`return m;`	•	•	•	•	•	•
`}`	✔	✔	✔	✔	✔	✘

Discrete Coloring

- (red) executed only in failing runs
  highly suspect
- (yellow) executed in passing and failing runs
  ambiguous
- (green) executed only in passing runs
  likely correct

	x	3	1	3	5	5	2
	y	3	2	2	5	3	1
	z	5	3	1	5	4	3
`int middle(int x, int y, int z) {`		•	•	•	•	•	•
`int m = z;`		•	•	•	•	•	•
`if (y < z) {`		•	•	•	•	•	•
`if (x < y)`			•				
`m = y;`			•				
`else if (x < z)`		•				•	•
`m = y;`		•					•
`} else {`		•		•	•		
`if (x > y)`				•			
`m = y;`				•			
`else if (x > z)`							
`m = x;`							
`}`							
`return m;`		•	•	•	•	•	•
`}`		✔	✔	✔	✔	✔	✘

	x	3	1	3	5	5	2
	y	3	2	2	5	3	1
	z	5	3	1	5	4	3
`int middle(int x, int y, int z) {`		•	•	•	•	•	•
`int m = z;`		•	•	•	•	•	•
`if (y < z) {`		•	•	•	•	•	•
`if (x < y)`			•				
`m = y;`			•				
`else if (x < z)`		•				•	•
`m = y;`		•					•
`} else {`		•		•	•		
`if (x > y)`				•			
`m = y;`				•			
`else if (x > z)`							
`m = x;`							
`}`							
`return m;`		•	•	•	•	•	•
`}`		✔	✔	✔	✔	✔	✘

Continuous Coloring

- executed only in failing runs
- passing and failing runs
- executed only in passing runs

Hue

$$hue(s) = red\ hue + \frac{\%passed(s)}{\%passed(s) + \%failed(s)} \times hue\ range$$

0% passed — 100% passed

Brightness

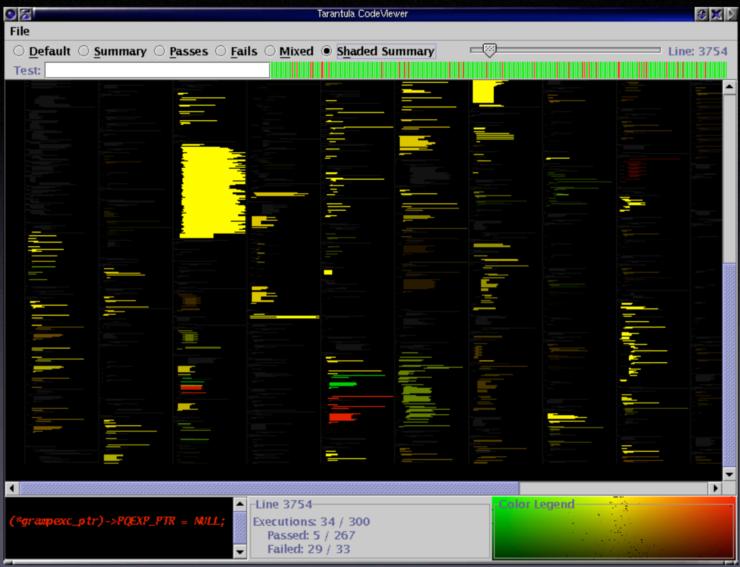
frequently executed

$$bright(s) = \max(\%passed(s), \%failed(s))$$

rarely executed

x	3	1	3	5	5	2
y	3	2	2	5	3	1
z	5	3	1	5	4	3
`int middle(int x, int y, int z) {`	•	•	•	•	•	•
`int m = z;`	•	•	•	•	•	•
`if (y < z) {`	•	•	•	•	•	•
`if (x < y)`		•				
`m = y;`		•				
`else if (x < z)`	•				•	•
`m = y;`	•					•
`} else {`	•		•	•		
`if (x > y)`			•			
`m = y;`			•			
`else if (x > z)`						
`m = x;`						
`}`						
`return m;`	•	•	•	•	•	•
`}`	✔	✔	✔	✔	✔	✘

Source: Jones et al., ICSE 2002



Source: Jones et al., ICSE 2002

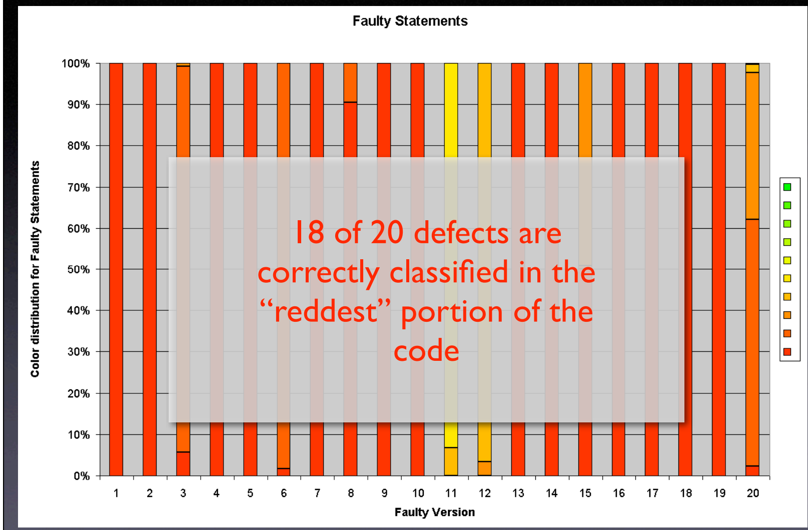
Evaluation

How well does comparing coverage detect anomalies?

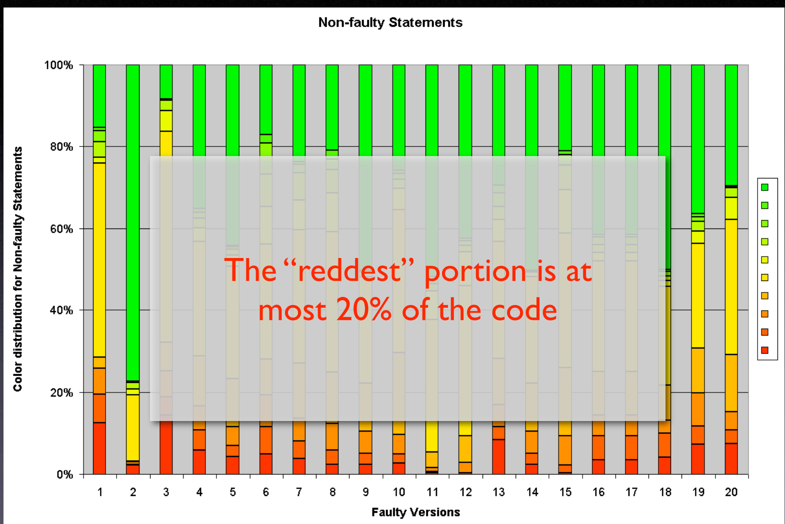
- How green are the defects? *(false negatives)*
- How red are non-defects? *(false positives)*

Space

- 8000 lines of executable code
- 1000 test suites with 156–4700 test cases
- 20 defective versions with one defect each (corrected in subsequent version)



Source: Jones et al., ICSE 2002



Source: Jones et al., ICSE 2002

Siemens Suite

- 7 C programs, 170–560 lines
- 132 variations with one defect each
- 108 all yellow (i.e., useless)
- 1 with one red statement (at the defect)

Source: Renieris and Reiss, ASE 2003

Nearest Neighbor
Run
Run
31

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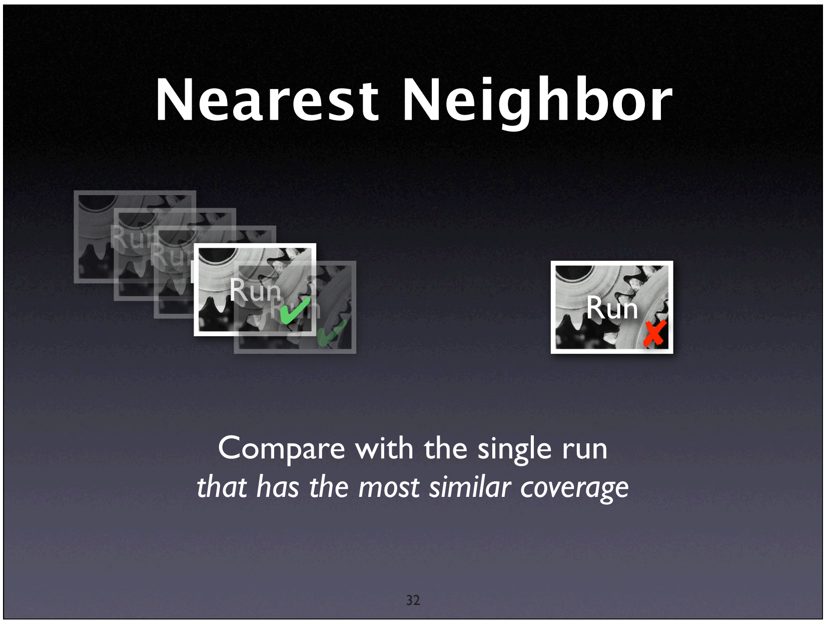
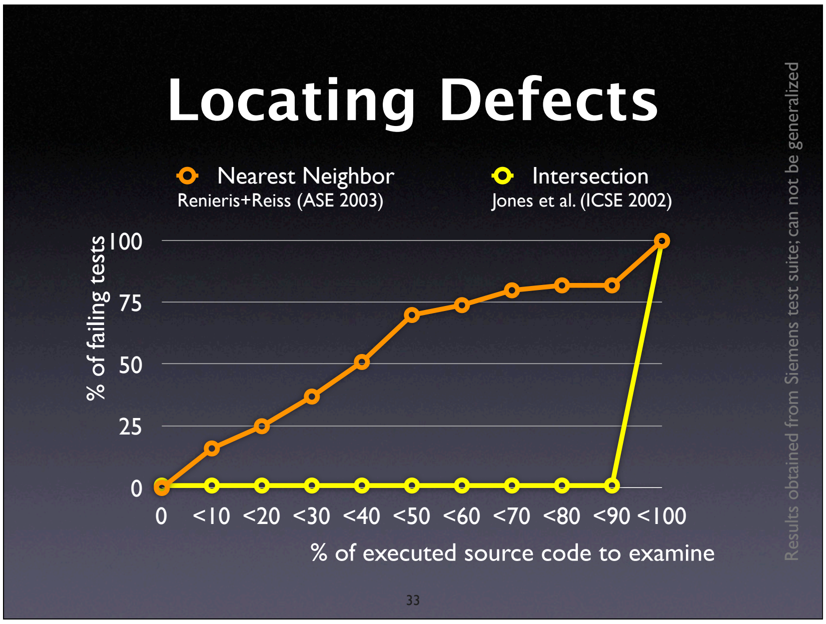


Nearest Neighbor
Run
Run
Compare with the single run
that has the most similar coverage
32

32



Locating Defects
Nearest Neighbor
Renieris+Reiss (ASE 2003)
Intersection
Jones et al. (ICSE 2002)
% of failing tests
100
75
50
25
0
0 <10 <20 <30 <40 <50 <60 <70 <80 <90 <100
% of executed source code to examine
Results obtained from Siemens test suite; can not be generalized
33

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Concepts

- ★ Comparing coverage (or other features) shows anomalies correlated with failure
- ★ Nearest neighbor or sequences locate errors more precisely than just coverage
- ★ Models add extra program understanding
- ★ Low overhead + simple to realize