Topics for this Lecture

- Test Case Minimization
- Delta Debugging
- What is fault localization?

Debugging

- Often when debugging, we find ourselves with the problem of having an input that crashes a program but not knowing what aspect of the input is causing the program's failure. For example, a random sequence of method/constructor calls crashes a Java class.
- Isolating the cause of the failure would be enormously helpful in finding what change needs to be made to the program's code.

- There are **two** common problems:
  1. Figuring out the error which causes this failure
  2. Reducing a test case to a minimal example

- How do people solve these problems?

Delta Debugging

- One automated technique for reducing down large failing inputs is **delta debugging**.
- Based on Zeller's delta-debugging tools
- **Delta debugging** is based on the scientific method: **hypothesize**, **experiment**, and **refine**.
- **Delta debugging** automatically removes irrelevant information from a failing test case in order to attain a "minimal" bug-inducing input.

- **REMEMBER DELTA DEBUGGING: IT CAN SAVE YOU ENDLESS HOURS OF EFFORT**

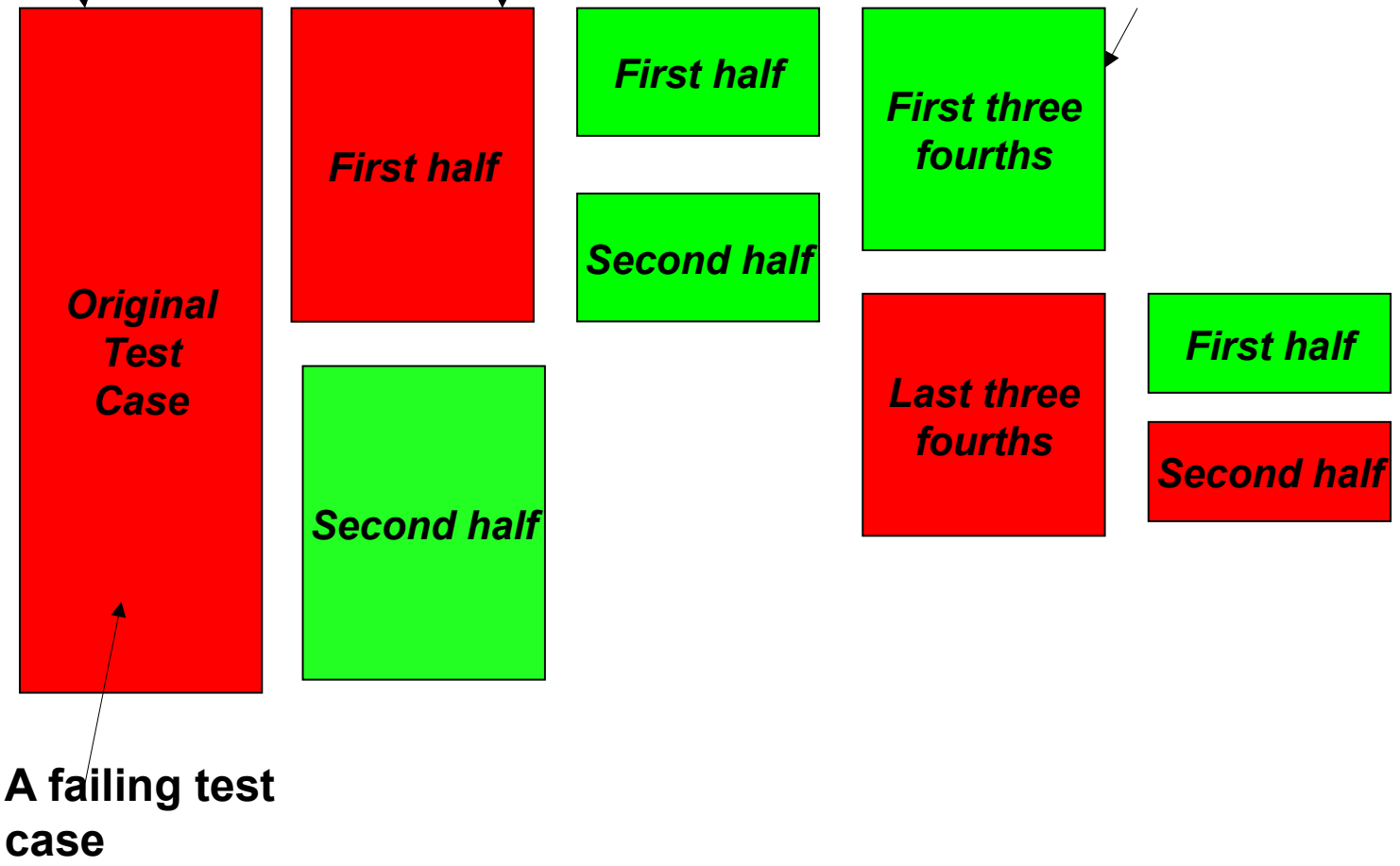
Delta Debugging

- Based on a clever modification of a "binary search" strategy

1) Split input into n subsets (initially n=2)

2) If removing any of these subsets fails, proceed with this subset.

3) Otherwise, increase granularity.



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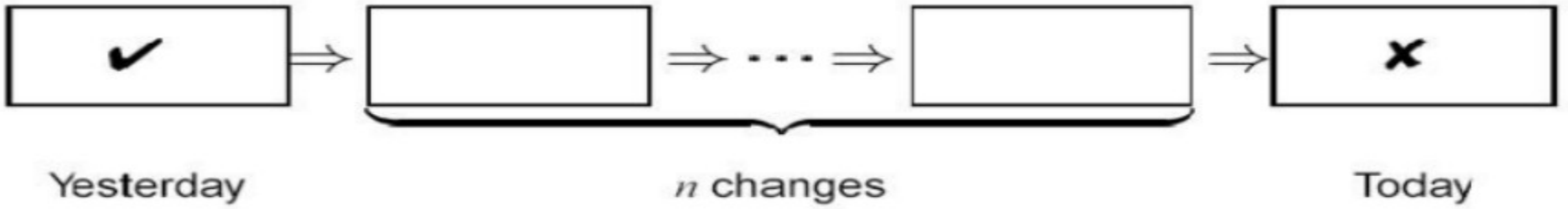
Example - My Program Worked Yesterday, Not Today



Step	c_i	Configuration								*test*	
1	c_1	1	2	3	4	.	.	.	.	✔	
2	c_2	.	.	.	.	5	6	7	8	✘	
3	c_1	.	.	.	.	5	6	.	.	✔	
4	c_2	.	.	.	.	.	.	7	8	✘	
5	c_1	.	.	.	.	.	.	7	.	✘	7 is found
Result		.	.	.	.	.	.	7	.		

Searching a single failure (7)

Step	c_i	Configuration								*test*	
1	c_1	1	2	3	4	.	.	.	.	✔	
2	c_2	.	.	.	.	5	6	7	8	✔	
3	c_1	1	2	.	.	5	6	7	8	✔	
4	c_2	.	.	3	4	5	6	7	8	✘	
5	c_1	.	.	3	.	5	6	7	8	✘	3 is found
6	c_1	1	2	3	4	5	6	.	.	✘	
7	c_1	1	2	3	4	5	.	.	.	✔	6 is found
Result		.	.	3	.	.	6	.	.		

Searching two failure (3 and 6)

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Example - A Very Bad Test Case

- Printing the following file causes **Mozilla** to crash:

```
<td align=left valign=top>
<SELECT NAME="op sys" MULTIPLE SIZE=7>
<OPTION VALUE="All">All<OPTION VALUE="Windows 3.1">Windows
3.1<OPTION VALUE="Windows 95">Windows 95<OPTION VALUE="Windows
98">Windows 98<OPTION VALUE="Windows ME">Windows ME<OPTION
VALUE="Windows 2000">Windows 2000<OPTION VALUE="Windows
NT">Windows NT<OPTION VALUE="Mac System 7">Mac System 7<OPTION
VALUE="Mac System 7.5">Mac System 7.5<OPTION VALUE="Mac
System 7.6.1">Mac System 7.6.1<OPTION VALUE="Mac System 8.0">Mac
System 8.0<OPTION VALUE="Mac System 8.5">Mac System
8.5<OPTION VALUE="Mac System 8.6">Mac System 8.6<OPTION VALUE="Mac
System 9.x">Mac System 9.x<OPTION VALUE="MacOS X">MacOS
X<OPTION VALUE="Linux">Linux<OPTION VALUE="BSDI">BSDI<OPTION
VALUE="FreeBSD">FreeBSD<OPTION VALUE="NetBSD">NetBSD<OPTION
VALUE="OpenBSD">OpenBSD<OPTION VALUE="AIX">AIX<OPTION
```

Example - A Very Bad Test Case

```
VALUE="BeOS">BeOS<OPTION VALUE="HP-UX">HP-UX<OPTION
VALUE="IRIX">IRIX<OPTION VALUE="Neutrino">Neutrino<OPTION
VALUE="OpenVMS">OpenVMS<OPTION VALUE="OS/2">OS/2<OPTION
VALUE="OSF/1">OSF/1<OPTION VALUE="Solaris">Solaris<OPTION
VALUE="SunOS">SunOS<OPTION VALUE="other">other</SELECT></td>
<td align=left valign=top>
<SELECT NAME="priority" MULTIPLE SIZE=7>
<OPTION VALUE="--">--<OPTION VALUE="P1">P1<OPTION
VALUE="P2">P2<OPTION VALUE="P3">P3<OPTION VALUE="P4">P4<OPTION
VALUE="P5">P5</SELECT>
</td>
<td align=left valign=top>
<SELECT NAME="bug severity" MULTIPLE SIZE=7>
<OPTION VALUE="blocker">blocker<OPTION
VALUE="critical">critical<OPTION VALUE="major">major<OPTION
VALUE="normal">normal<OPTION VALUE="minor">minor<OPTION
VALUE="trivial">trivial<OPTION
VALUE="enhancement">enhancement</SELECT>
</tr>
</table>
```

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Example - A Very Bad Test Case

- Now looking at that file it is hard to figure out what the real cause of the failure is
- It would be very helpful in finding the error if we can simplify the input file and still generate the same failure
- Assume that we know that when Mozilla tries to print the following HTML input it crashes:
  <SELECT NAME="priority" MULTIPLE SIZE=7>
- How can we go about simplifying this input?
  Remove parts of the input and see if it still causes the program to crash

Example - A Very Bad Test Case

Bold parts remain in the input, the rest is removed

1	**<SELECT NAME="priority" MULTIPLE SIZE=7>**	F	N=40 characters
2	<SELECT NAME="priori**ty" MULTIPLE SIZE=7>**	P	N=20 characters
3	**<SELECT NAME="priori**ty" MULTIPLE SIZE=7>	P	N=20 characters
4	<SELECT NA**ME="priority" MULTIPLE SIZE=7>**	P	N=30 characters
5	**<SELECT NA**ME="priori**ty" MULTIPLE SIZE=7>**	F	N=30 characters
6	**<SELECT NA**ME="priority" MULTIP**LE SIZE=7>**	F	N=20 characters
7	**<SELECT NA**ME="priority" MULTIPLE SIZE=7>	P	N=10 characters
8	<SELE**CT NA**ME="priority" MULTIP**LE SIZE=7>**	P	N=10 characters
9	**<SELE**CT NAME="priority" MULTIP**LE SIZE=7>**	P	N=15 characters
10	**<SELECT NA**ME="priority" MULTIPLE SI**ZE=7>**	F	N=15 characters
11	**<SELECT NA**ME="priority" MULTIPLE SIZE=7>	P	N=10 characters
12	<S**ELECT NA**ME="priority" MULTIPLE SI**ZE=7>**	P	N=13 characters
13	**<S**ELECT **NA**ME="priority" MULTIPLE SI**ZE=7>**	P	N=13 characters

Example - A Very Bad Test Case

Bold parts remain in the input, the rest is removed

14	**<SELECT NAME="priority" MULTIPLE SIZE=7>**	P	N=13 characters
15	**<SELECT NAME="priority" MULTIPLE SIZE=7>**	P	N=13 characters
16	**<SELECT** NAME="priority" MULTIPLE **SIZE=7>**	F	N=12 characters
17	**<SELECT** NAME="priority" MULTIPLE **SIZE=7>**	F	N=11 characters
18	**<SELECT** NAME="priority" MULTIPLE SIZE=7>	F	N=10 characters
19	<**SELECT** NAME="priority" MULTIPLE SIZE=7>	P	N=9 characters
20	<S**ELECT** NAME="priority" MULTIPLE SIZE=7>	P	N=9 characters
21	<SE**LECT** NAME="priority" MULTIPLE SIZE=7>	P	N=9 characters
22	<SEL**ECT** NAME="priority" MULTIPLE SIZE=7>	P	N=9 characters
23	<SEL**ECT** NAME="priority" MULTIPLE SIZE=7>	P	N=9 characters
24	<SELE**CT** NAME="priority" MULTIPLE SIZE=7>	P	N=9 characters
25	<SELEC**T** NAME="priority" MULTIPLE SIZE=7>	P	N=9 characters
26	**<SELECT** NAME="priority" MULTIPLE SIZE=7>	F	N=10 characters

Example - A Very Bad Test Case

- After 26 tries we found that printing an HTML file which consists of:
  <SELECT> causes Mozilla to crash

- Delta debugging technique automates this approach of repeated trials for reducing the input

Causality

- When a test case fails we start debugging
- We assume that the fault (what we're really after) causes the failure
- What do we mean when we say that "A causes B"?
- We don't know
- Though it is central to everyday life – and to the aims of science
  - A real understanding of causality eludes us to this day
  - Still no non-controversial way to answer the question "does A cause B"?

What does this have to do with automated debugging??

- A **fault** is an incorrect part of a program
- In a failing test case, some fault is reached and executes
  - Causing the state of the program to be corrupted (**error**)
  - This incorrect state is propagated through the program (propagation is a series of "A causes B"s)
  - Finally, bad state is observable as a **failure** – caused by the **fault**

Fault Localization

- **Fault localization**, then, is:
  - An effort to automatically find (one of the) causes of an observable failure
  - It is inherently difficult because there are many causes of the failure that are not the fault
  - For example: if we have a program that fails/crashes but there is an option input to terminate the execution immediately, like we hit the input X.
  - One causes of the failure is we did immediately hit X. The fault localization should roll out such a cause, which is not very interested to us.

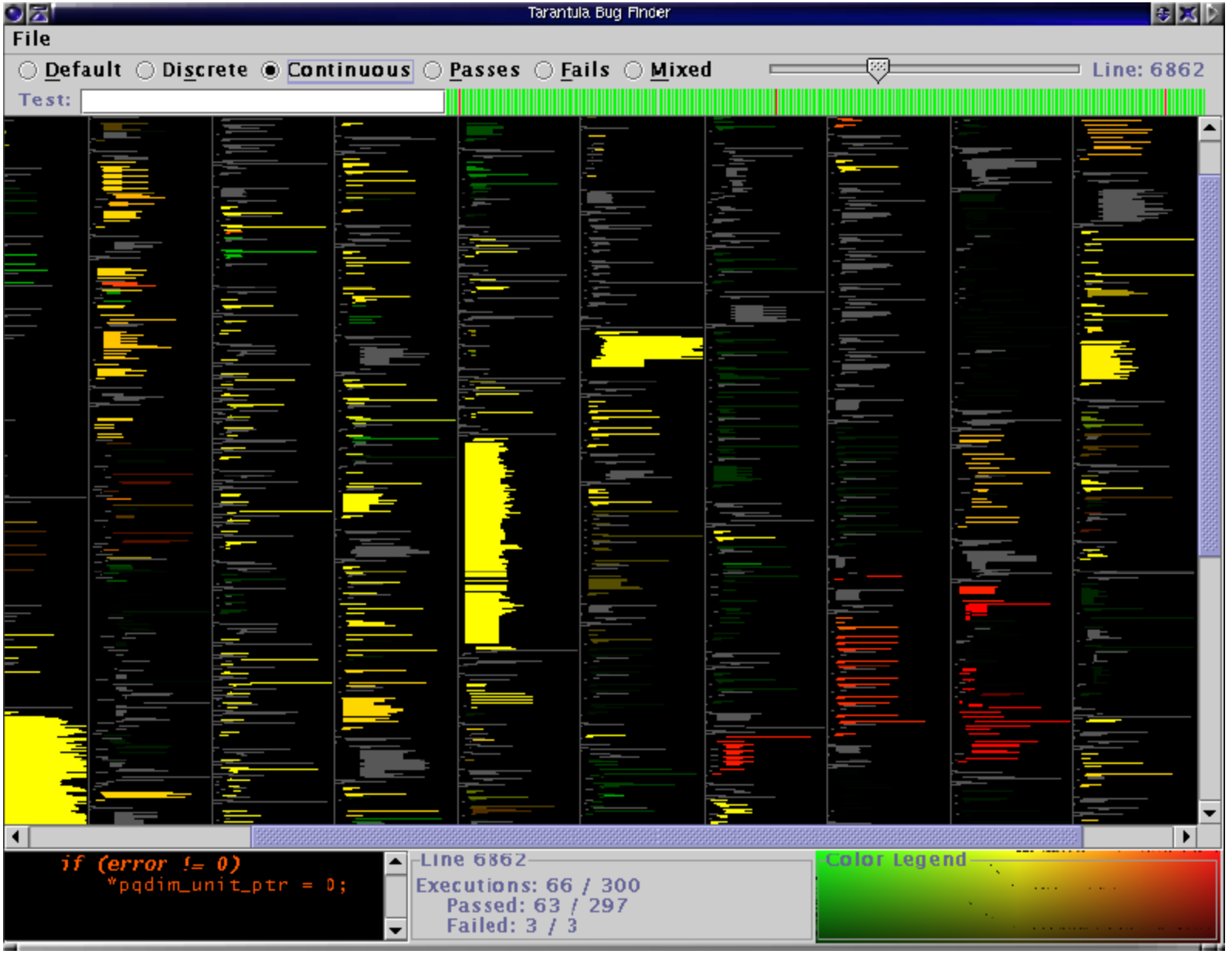
The Tarantula Approach

- Jones, Harrold (and Stasko): Tarantula

- Originally conceived of as a visualization approach: produces a picture of all source in program, colored according to how "suspicious" it is

  - Green: not likely to be faulty
  - Yellow: hrm, a little suspicious
  - Red: very suspicious, likely fault

The Tarantula Approach



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The Tarantula Approach

- How do we score a statement in this approach? (where do all those colors come from?)
- Again, assume we have a large set of tests, some passing, some failing
- "Coverage entity" e (e.g., statement)
  - failed(e) = # tests covering e that fail
  - passed(e) = # tests covering e that pass
  - totalfailed, totalpassed = total number of failed and passed test cases

The Tarantula Approach

- How do we score a statement in this approach? (where do all those colors come from?) . The suspiciousness of a statement (***e***) is computed by the following equation:

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

- ***passed***(***e***) is the number of passed test cases that executed statement ***e*** one or more times.
- ***failed***(***e***) is the number of failed test cases that executed statement ***e*** one or more times.
- ***totalpassed*** and ***totalfailed*** are the total numbers of test cases that pass and fail, respectively, in the entire test suite.

The Tarantula Approach

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

- Not very suspicious =0: appears in almost every passing test and almost every failing test
- Highly suspicious = 1: appears much more frequently in failing than passing tests

The Tarantula Approach

```
mid()
    int x, y, z, m;
1   read (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;
8   else
9     if (x > y)
10      m = y;
11    else if (x > z)
12      m = x;

13    print (m);
```

Program **mid()** takes three integers (x,y, and z) as input and outputs the **median** value.

The program contains a fault on **line 7**—this line should read "**m = x**;".

The Tarantula Approach

Run some tests. . .

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

(3,3,5) (1,2,3) (3,2,1) (5,5,5) (5,3,4) (2,1,3)

```
mid()
    int x, y, z, m;
1   read (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;
8   else
9     if (x > y)
10      m = y;
11    else if (x > z)
12      m = x;
13    print (m);
```

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The Tarantula Approach

Run some tests. . .

Look at whether they pass or fail

$$suspicious\,ness(e) = \frac{\frac{failed(e)}{totalfaile\,d}}{\frac{passed(e)}{totalpasse\,d} + \frac{failed(e)}{totalfaile\,d}}$$

(3,3,5) (1,2,3) (3,2,1) (5,5,5) (5,3,4) (2,1,3)

```
mid()
    int x, y, z, m;
1   read (x, y, z)
2   m = z;
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8   else
9     if (x > y)
10      m = y;
11    else if (x > z)
12      m = x;
13    print (m);
```

The Tarantula Approach

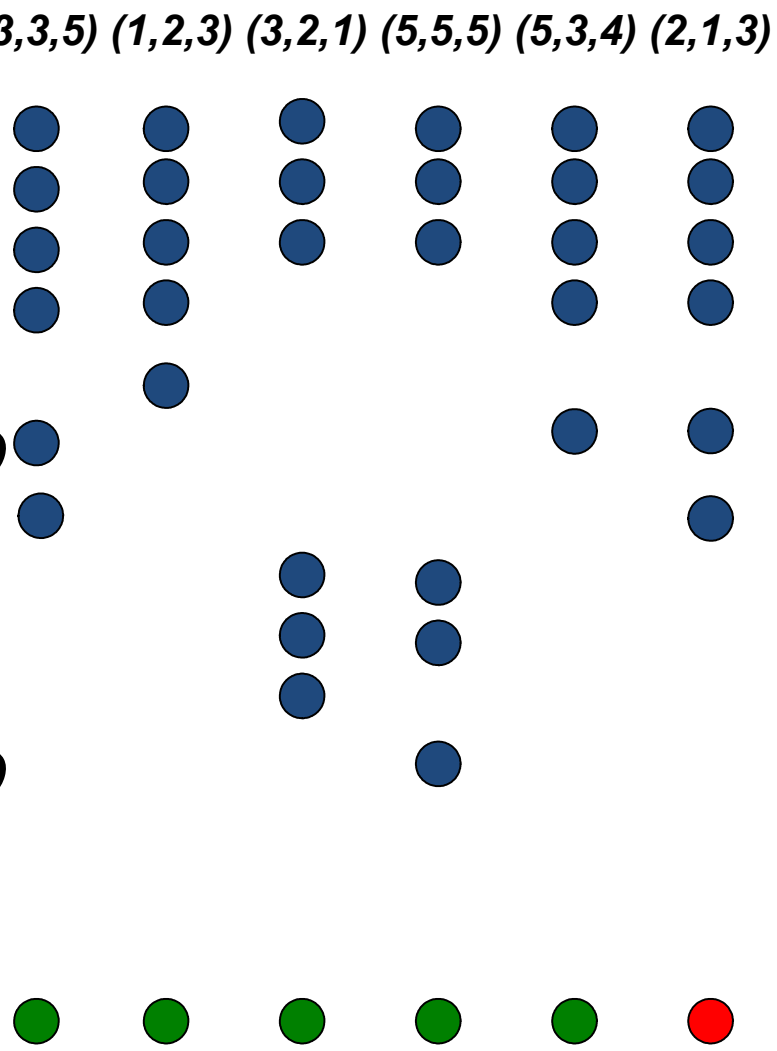
Run some tests. . .

Look at whether they pass or fail

Look at coverage of entities

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

```
mid()
    int x, y, z, m;
1   read (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;
8   else
9     if (x > y)
10      m = y;
11    else if (x > z)
12      m = x;
13    print (m);
```



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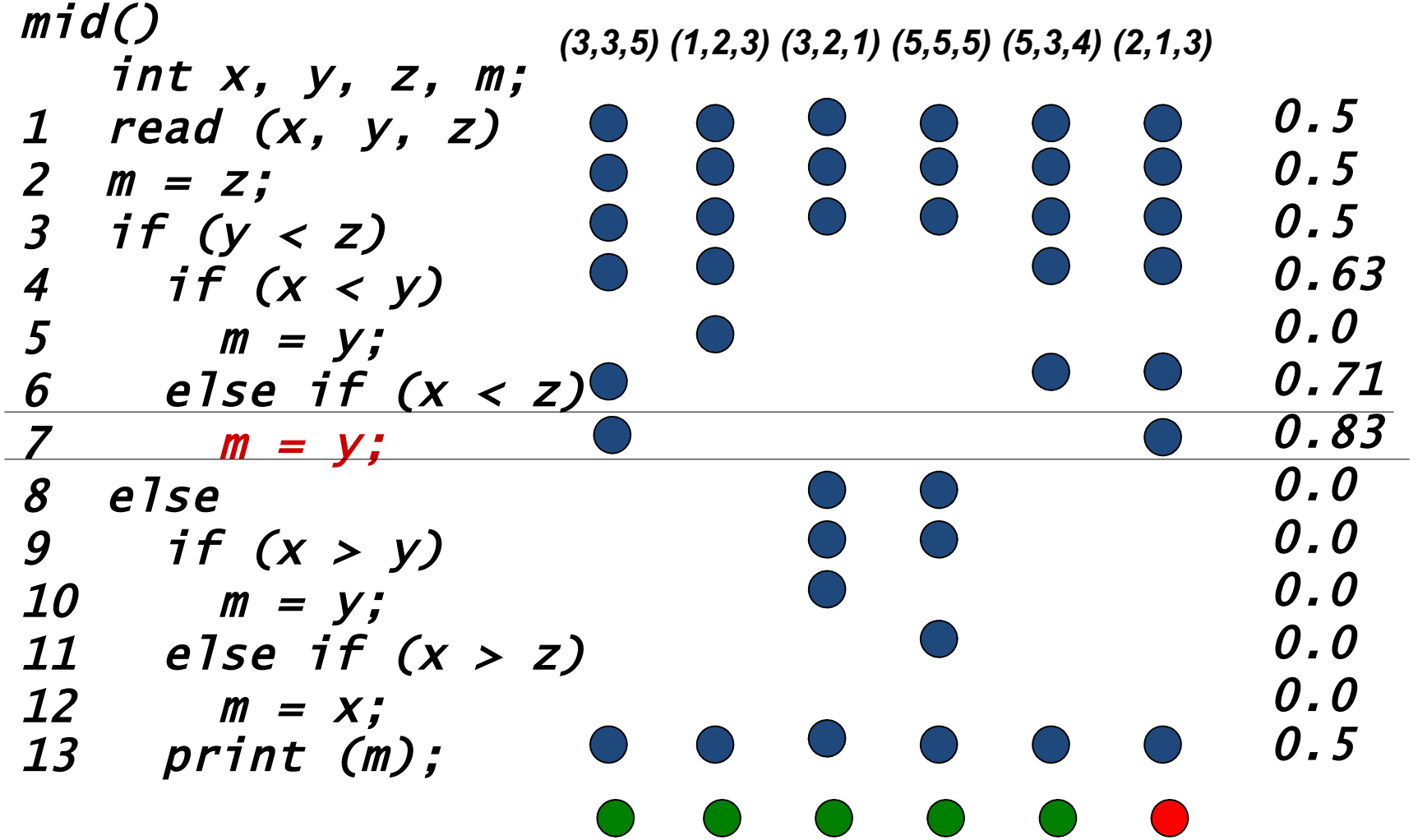
The Tarantula Approach

Run some tests. . .

Look at whether they pass or fail

Look at coverage of entities

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



Compute suspiciousness using the formula

Fault is indeed most suspicious!

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The Tarantula Approach

- Obvious benefits:
  - Provides a ranking of every statement, instead of just a set of nodes – directions on where to look next
    - Numerical, even – how much more suspicious is X than Y?
  - The pretty visualization may be quite helpful in seeing relationships between suspicious statements

References:

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