INTRODUCTION TO SOFTWARE TESTING FOR THE SCIENTIFIC COMMUNITY

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IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

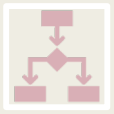
Laboratory for Variability-Aware Assurance and
Testing of Organic Programs

LaVA-OPs

Module I: Overview

Motivation

What to test



Types of Testing

Models

Coverage

Oracles

Why Test Software?

```
Error: NCBI C++ Exception:
T0 "/tmp/BLAST/2.11.0/gompi-2020b/ncbi-blast-2.11.0+-src/c++/src/serial/objistrasnb.cpp
T0 "/tmp/BLAST/2.11.0/gompi-2020b/ncbi-blast-2.11.0+-src/c++/src/serial/member.cpp", l
```

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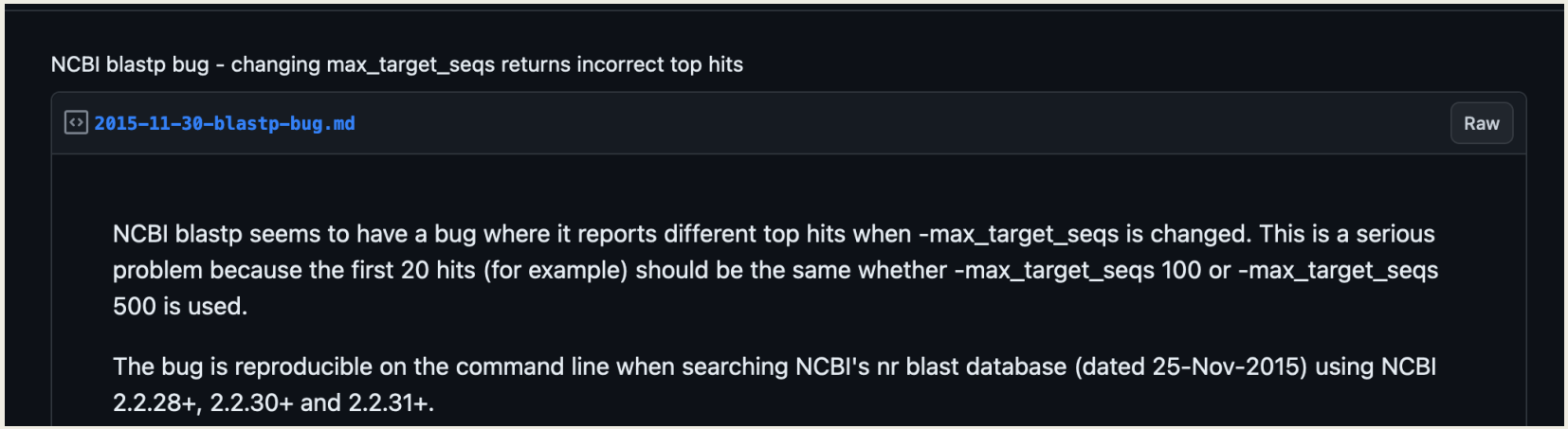
T0 "/tmp/BLAST/2.11.0/gompi-2020b/ncbi-blast-2.11.0+-src/c++/src/serial/member.cpp", l
```

```
ial/objistrasnb.cpp", line 499: Error: (CSerialException::eOverflow) byte 132: overf
ial/member.cpp", line 767: Error: (CSerialException::eOverflow) ncbi::CMemberInfoFur
```

Why Test Software?



Why Test Software?

NCBI blastp bug - changing max_target_seqs returns incorrect top hits

2015-11-30-blastp-bug.md Raw

NCBI blas serious
problem l et_seqs
500 is us

The bug g NCBI
2.2.28+,

Bioinformatics, 35(9), 2019, 1613–1614
doi: 10.1093/bioinformatics/bty833
Advance Access Publication Date: 24 September 2018
Letter to the Editor

OXFORD

Sequence analysis

Misunderstood parameter of NCBI BLAST impacts the correctness of bioinformatics workflows

Nidhi Shah[1], Michael G. Nute[2], Tandy Warnow [3] and Mihai Pop [1,*]

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Associate Editor: John Hancock
Contact: mpop@umd.edu
Received and revised on August 13, 2018; editorial decision on September 19, 2018; accepted on September 21, 2018

Why Test Software?

Bioinformatics, 35(15), 2019, 2699–2700
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Sequence analysis

Reply to the paper: Misunderstood parameters of NCBI BLAST impacts the correctness of bioinformatics workflows

Thomas L. Madden*, Ben Busby and Jian Ye

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Associate Editor: John Hancock

Contact: madden@ncbi.nlm.nih.gov

Received and revised on November 30, 2018; editorial decision on December 10, 2018; accepted on December 19, 2018

Why Test Software?

Dear Editor,

A recent letter by Shah *et al.* (2018) addressed the use of a command-line parameter in BLAST (Altschul *et al.*, 1997; Camacho *et al.*, 2009). BLAST is a very popular tool, so it is not surprising that this topic has provoked a great deal of interest. The authors have, however, conflated three different issues. One is a bug that will be fixed in the BLAST+ 2.8.1 release due out in December 2018, another is simply how BLAST works and the third might be viewed as a shortcoming of our implementation of composition-based statistics (CBS). Here, we address these issues and describe some new documentation about the BLAST process.

Shah et al. (2018) did not provide their own example in the letter, but later provided one at https://github.com/shahnidhi/BLAST_maxtargetseq_analysis. At the NCBI, we examined the new example and it became clear that the demonstrated behavior was a bug, resulting from an overly aggressive optimization, introduced in 2012 for BLASTN and MegaBLAST (DNA–DNA alignments). This bug has been fixed in the BLAST+ 2.8.1 release, due out in December 2018. The aberrant behavior seems to occur only in alignments with an extremely large number of gaps, which is the case in the example provided by Shah and collaborators.

Why Test Software?

contributed articles

DOI:10.1145/3382037

An approach to reproducibility problems related to porting software across machines and compilers.

BY DONG H. AHN, ALLISON H. BAKER, MICHAEL BENTLEY, IAN BRIGGS, GANESH GOPALAKRISHNAN, DORIT M. HAMMERLING, IGNACIO LAGUNA, GREGORY L. LEE, DANIEL J. MILROY, AND MARIANA VERTENSTEIN

Keeping Science on Keel When Software Moves

the machine instructions that actually get executed. Unfortunately, such changes do affect the computed results to a significant (and often worrisome) extent. In a majority of cases, there are not easily definable a priori answers one can check against. A programmer ends up comparing the new answer against a trusted baseline previously established or checks for indirect confirmations such as whether physical properties such as energy are conserved. However, such non-systematic efforts might miss underlying issues, and the code may keep misbehaving until these are fixed.

In this article, we present real-world evidence to show that ignoring numerical result changes can lead to misleading scientific conclusions. We present techniques and tools that can help computational scientists understand and analyze compiler effects on their scientific code. These techniques are applicable across a wide range of examples to narrow down the root-causes to single files, functions within files, and even computational expressions that affect specific variables. The developer may then rewrite the code selectively and/or suppress the application of certain optimizations to regain more predictable behavior.

Going forward, the frequency of required ports of computational software will increase, given that performance gains can no longer be obtained by mere-

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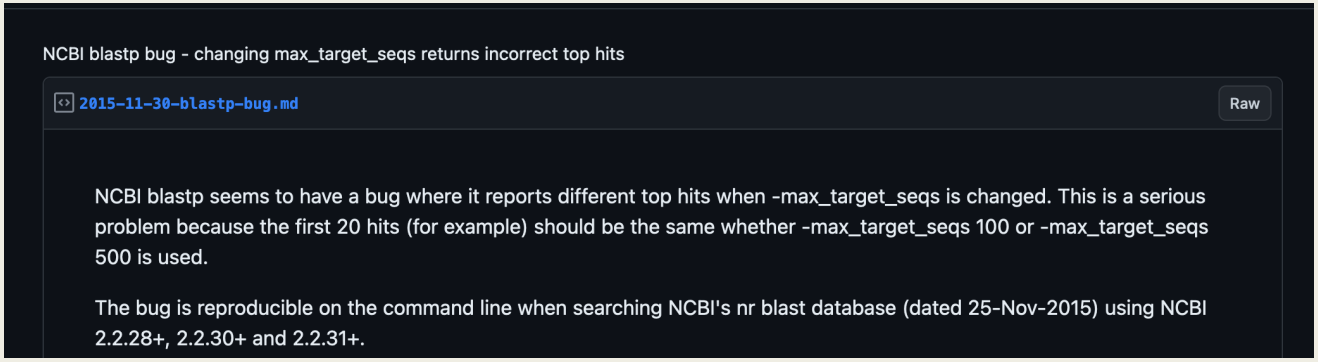

NCBI blastp bug - changing max_target_seqs returns incorrect top hits

2015-11-30-blastp-bug.md Raw

NCBI blastp seems to have a bug where it reports different top hits when -max_target_seqs is changed. This is a serious problem because the first 20 hits (for example) should be the same whether -max_target_seqs 100 or -max_target_seqs 500 is used.

The bug is reproducible on the command line when searching NCBI's nr blast database (dated 25-Nov-2015) using NCBI 2.2.28+, 2.2.30+ and 2.2.31+.

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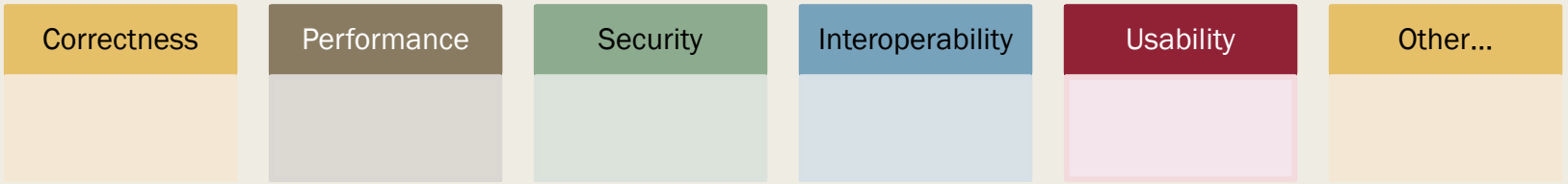
Why Test Software?

Merali, Zeeya. “Computational Science: ...Error.” *Nature* 467, no. 7317 (Oct, 2010): 775–77

What Should We Test?



What Should We Test?

Correctness	Performance	Security	Interoperability	Usability	Other…
					• *Extensibility* • *Modularity*

What Should We Test?

Correctness	Performance	Security	Interoperability	Usability	Other…
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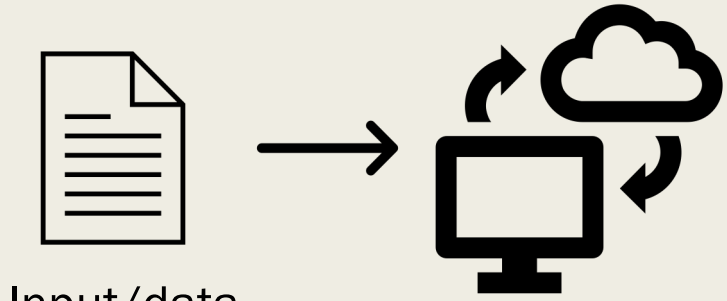
Our focus will be on correctness and interoperability

What is Testing

Input/data

What is Testing



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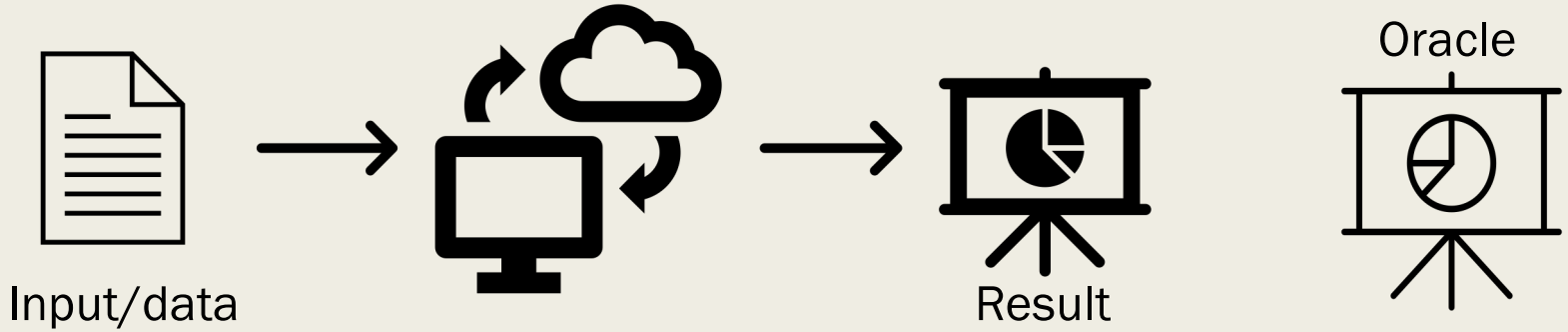

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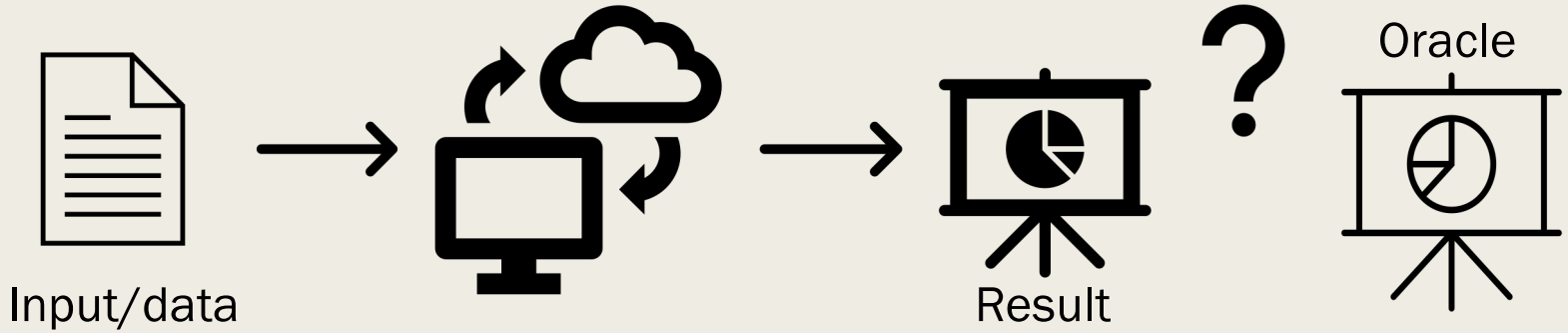
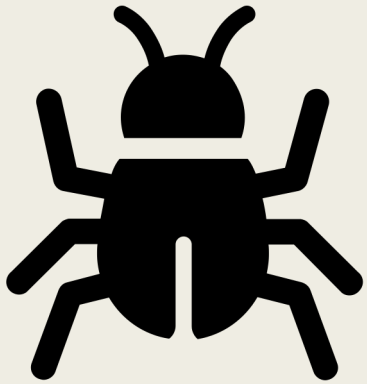


Limitations

Testing can only show the presence of faults.
It cannot determine their absence.

Edsger W. Dijkstra



Challenge

- To detect a program FAILURE we need to:
  - Reach a FAULT in the code
  - Infect the code (change to incorrect state) - ERROR
  - Propagate the error out of program
  - Reveal (detect) the error – (ORACLE)

RIPR model *Ammann, Offutt (Introduction to Software Testing, 2016)*

Tests Can Miss Faults

```python
def classify_triangle(a, b, c):
    # Sort the sides so that a <= b <= c
    if a > b:
        tmp = a
        a = tmp   #fault should be a=b
        b = tmp

    if a > c:
        tmp = a
        a = c
        c = tmp

    if b > c:
        tmp = b
        b = c
        c = tmp

    if a + b <= c:
        return TriangleType.INVALID
    elif a == b and b == c:
        return TriangleType.EQUILATERAL
    elif a == b or b == c:
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    else:
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1. Test Case 3, 4, 5 (scalene)
   - doesn't reach fault

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    5,5,1

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1. Test Case 3, 4, 5 (scalene)
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2. Test Case 5, 1, 1 (invalid)
   - reaches fault and infects
   - reveals (returns isosceles)

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```

2,2,-1

1. Test Case 3, 4, 5 (scalene)
   - doesn't reach fault

2. Test Case 5, 1, 1 (invalid)
   - reaches fault and infects
   - reveals (returns isosceles)

3. Test Case 2, 1, -1 (invalid)
   - reaches fault and infects
   - Doesn't propagate (2, 2,-1) is still INVALID

Software vs. Data

Scientific software is often data (or model driven)

Both software and data can lead to faults

We start by focusing on software

But I Have Unit Tests…

These are an essential part of testing

Focus is on individual modules

Can be re-used each time system changes (regression testing)

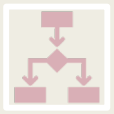
Can be packaged with software when released

Other testing focuses on the system specifications and overall program behavior

Module I: Overview


Motivation


What to test


Types of Testing


Models


Coverage


Oracles

This work was supported by the Better Scientific Software Fellowship Program, funded by the Exascale Computing Project (17-SC-20-SC), a collaborative effort of the U.S. Department of Energy (DOE) Office of Science and the National Nuclear Security Administration; and by the National Science Foundation (NSF) under Grant No. 2154495.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the DOE or NSF.

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Module I: Overview (cont.)

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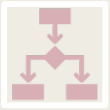
What to test



Types of Testing

Models

Coverage

Oracles

Types of Testing

Unit Testing

Integration Testing

System Testing

Configuration Testing

User Interface Testing

Regression Testing

Models

Provide an abstraction of the software we are testing

Can be for different dimensions of the software (specifications, interface, code)

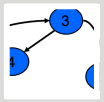
Allow us to reason about how much we have tested

The foundation for automated test generation

Example Models

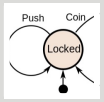
- Graphs
- Tabular
- Relational
- Grammar based
- Logic based

Graph Models

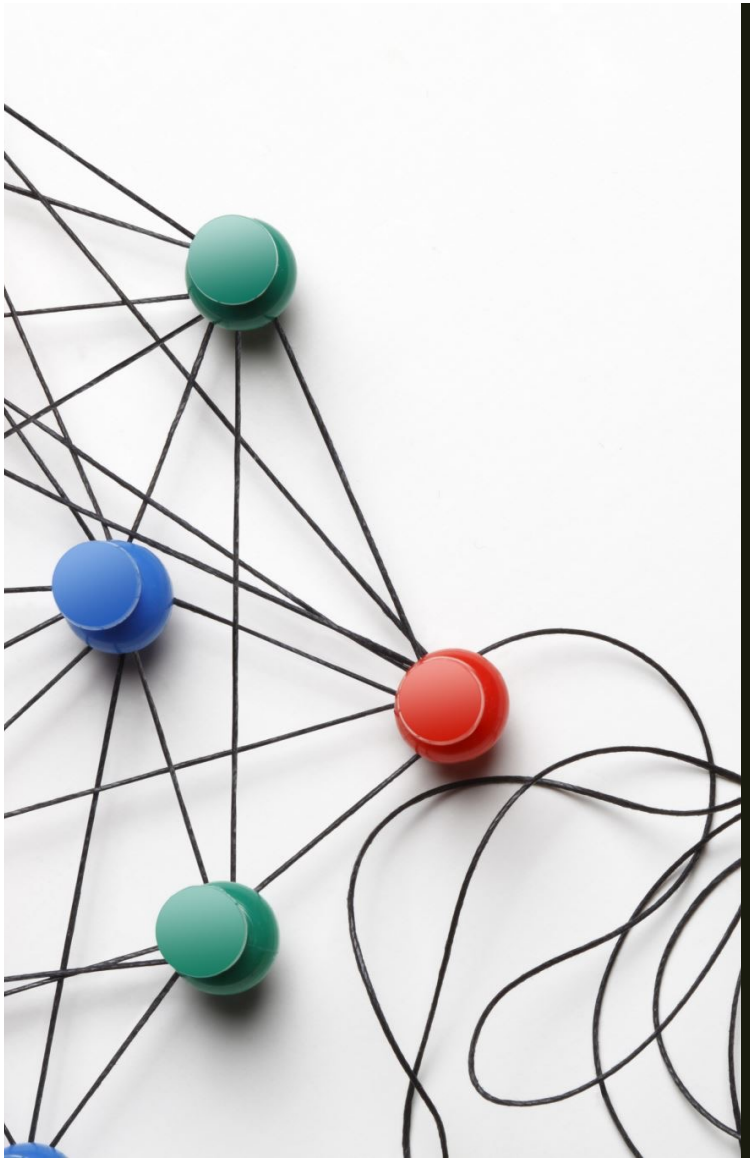


Program control flow graph

User interface



Program state machine

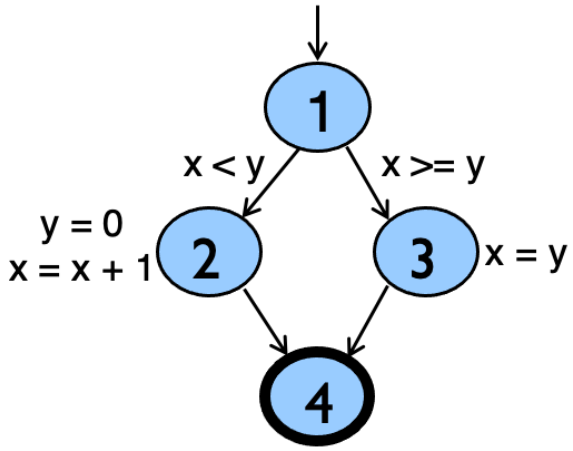


Types of Graph Coverage

- All nodes
- All edges (pairs of nodes)
- All length N paths
- M random length N paths

Program Code Coverage

```
if (x < y)
{
   y = 0;
   x = x + 1;
}
else
{
   x = y;
}
```



Control flow graph

Program Code Coverage

Cog coverage: 38.75%

coverage.py v7.2.7, created at 2023-05-29 15:26 -0400

Module	*statements*	*missing*	*excluded*	*branches*	*partial*	*coverage*
cogapp/__init__.py	1	0	0	0	0	100.00%
cogapp/__main__.py	3	3	0	0	0	0.00%
cogapp/cogapp.py	500	224	1	210	30	49.01%
cogapp/makefiles.py	22	18	0	14	0	11.11%
cogapp/test_cogapp.py	845	591	2	24	1	29.57%
cogapp/test_makefiles.py	70	53	0	6	0	22.37%
cogapp/test_whiteutils.py	68	50	0	0	0	26.47%
cogapp/whiteutils.py	43	5	0	34	4	88.31%
Total	**1552**	**944**	**3**	**288**	**35**	**38.75%**

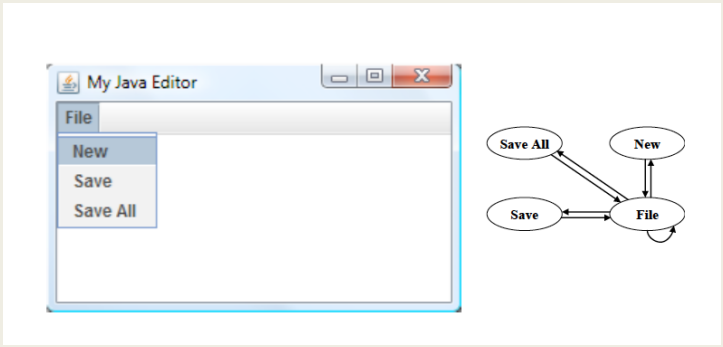
coverage.py v7.2.7, created at 2023-05-29 15:26 -0400

Triangle.java

```
1.  public class Triangle {
2.
3.      public enum TriangleType {
4.          INVALID, SCALENE, EQUILATERAL, ISOSCELES
5.      }
6.
7.      public static TriangleType classifyTriangle(int a, int b, int c) {
8.          if (a > b) {
9.              int tmp = a;
10.             a = b;
11.             b = tmp;
12.         }
13.
14.         if (a > c) {
15.         int tmp = c; // original: int tmp = a;
16.             a = c;
17.             c = tmp;
18.         }
19.
20.         if (b > c) {
21.             int tmp = b;
22.             b = c;
23.             c = tmp;
24.         }
25.
26.         if (a + b <= c) {
27.             return TriangleType.INVALID;
28.         } else if (a == b && b == c) {
29.             return TriangleType.EQUILATERAL;
30.         } else if (a == b || b == c) {
31.             return TriangleType.ISOSCELES;
32.         } else {
33.             return TriangleType.SCALENE;
34.         }
35.
36.     }
37. }
```

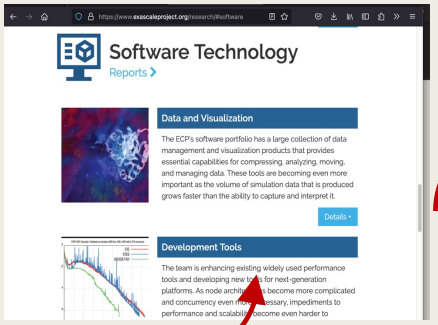
Example tools: jacoco, coverage.py, gcov

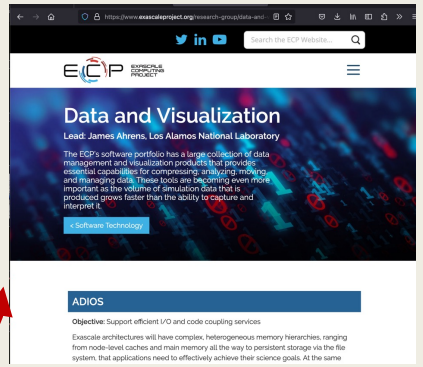
Interface (graph) Coverage

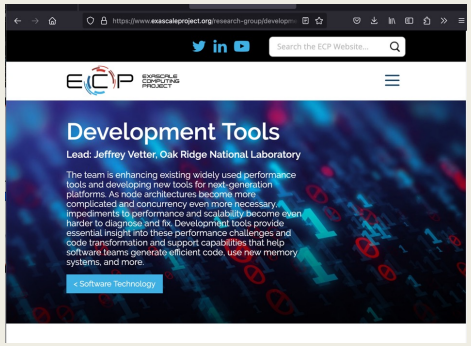


GUI

Web







Other Coverage

Specification coverage

- Cover the system requirements

Interaction coverage

- Measure interactions between components
  - Pairs, n-way coverage

Module I: Overview

Motivation

What to test

Types of Testing

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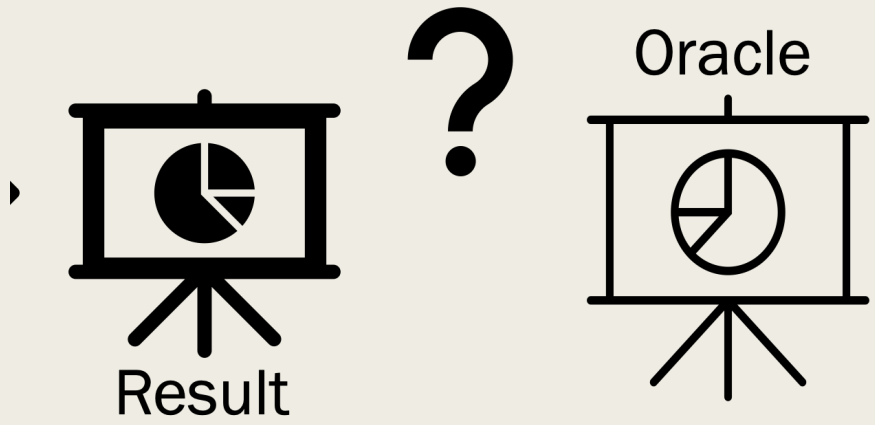
What is the Correct Answer?



Trivial Oracles

Program crashes
Core dump
Segmentation error
Overflow
Program hangs

Trivial Oracles

- Good when we don’t have a known result
- Weakest oracle since it only shows that the program fails/not that the result is incorrect
- Exact oracles are easy to compute in some programs

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def classify_triangle(a, b, c):
    # Sort the sides so that a <= b <= c
    if a > b:
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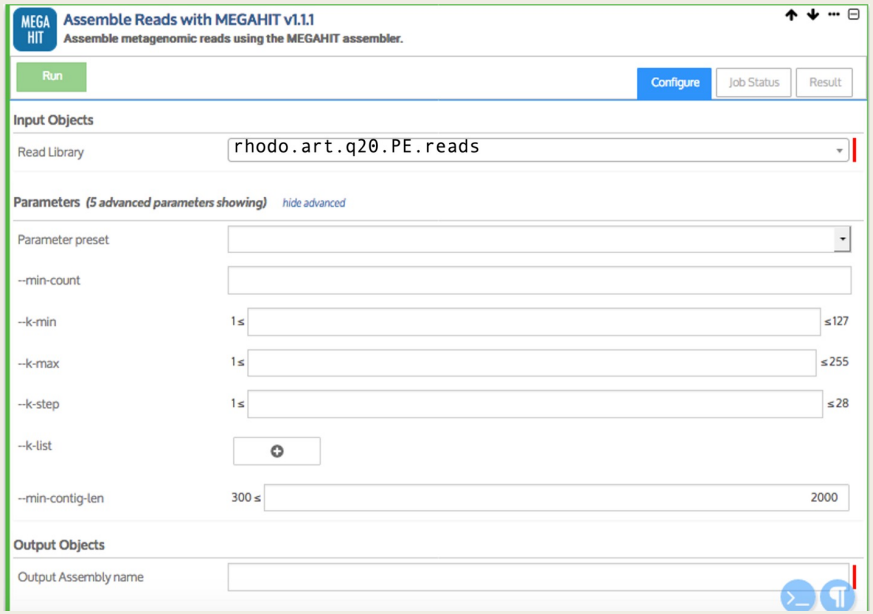
    elif a == b and b == c:
        return TriangleType.EQUILATERAL
    elif a == b or b == c:
        return TriangleType.ISOSCELES
    else:
        return TriangleType.SCALENE
```

Harder Oracles



Making Oracles Hard

- Results may differ by small epsilons (due to rounding)
- Expected result may not be computable without program
- May have time series results
- Takes a long time to manually compute each oracle (even when we can)
- Programs may be stochastic (or flaky)

Examples

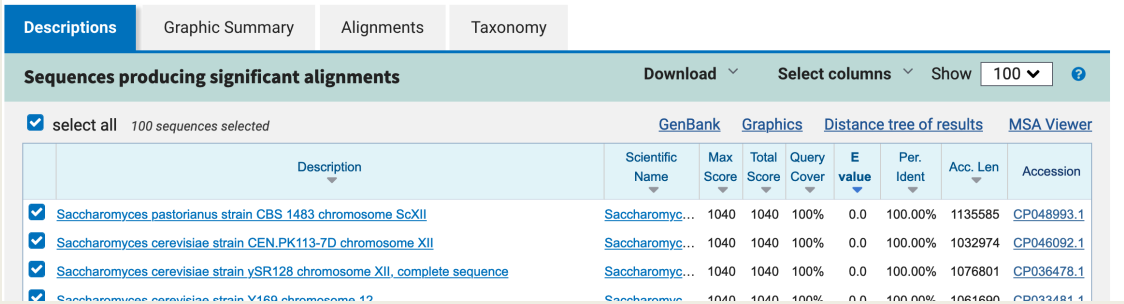
Python docs

Note: The behavior of `round()` for floats can be surprising: for example, `round(2.675, 2)` gives `2.67` instead of the expected `2.68`. This is not a bug: it's a result of the fact that most decimal fractions can't be represented exactly as a float. See Floating Point Arithmetic: Issues and Limitations for more information.

Same growth values?

Expected:	0.3569512**4**
Observed:	0.3569512**2**

Correct hits?



Some Techniques

Differential testing

Metamorphic testing

Some Techniques

Differential testing

Run same tests using different programs that have the same functionality

Some Techniques

Metamorphic testing

Define relations on sets of tests:

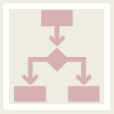
e.g. (subtraction)

A-B = C
Create A' (greater than A)
Then
A' -B = C' means C' is greater than C

Summary of Module I: Overview

Motivation

What to test



Types of Testing

Models

Coverage

Oracles

Future Modules

- Unit Testing and integrating with continuous integration
- Testing configurations and combinatorial testing
- Using differential and metamorphic testing
- Regression testing - prioritization and test selection

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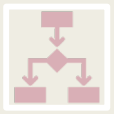
Module I: Overview


Motivation


What to test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