“Searching” for the Best Tests

An Introduction to Automated Software Testing with Search-Based Techniques

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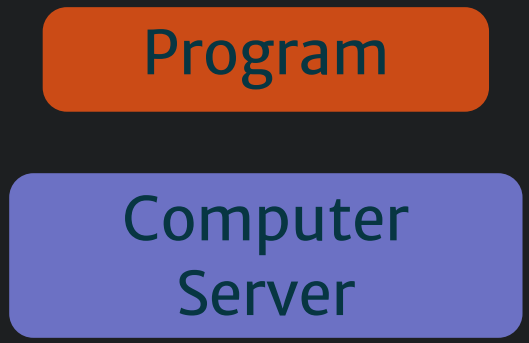
Allegheny College

March 31, 2015

Software is Everywhere

Software is pervasive — and so it must be thoroughly tested!



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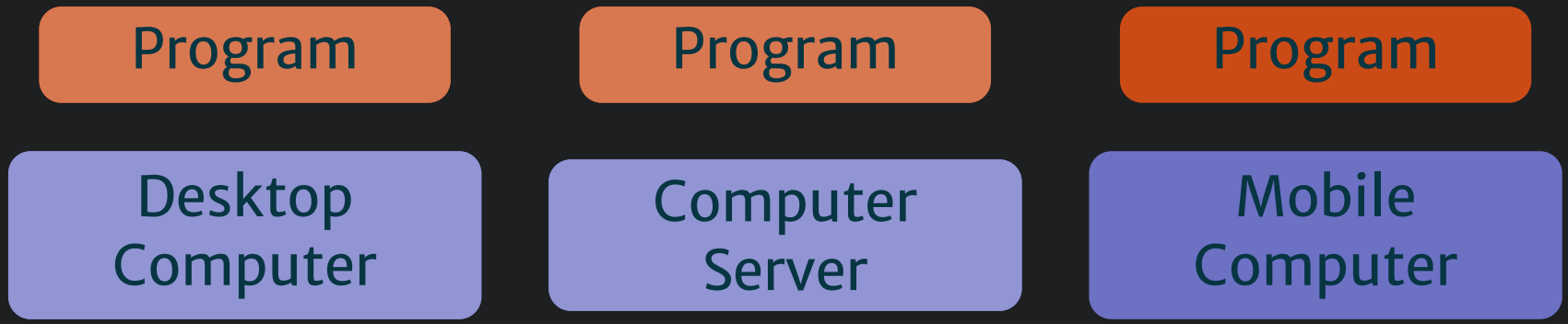

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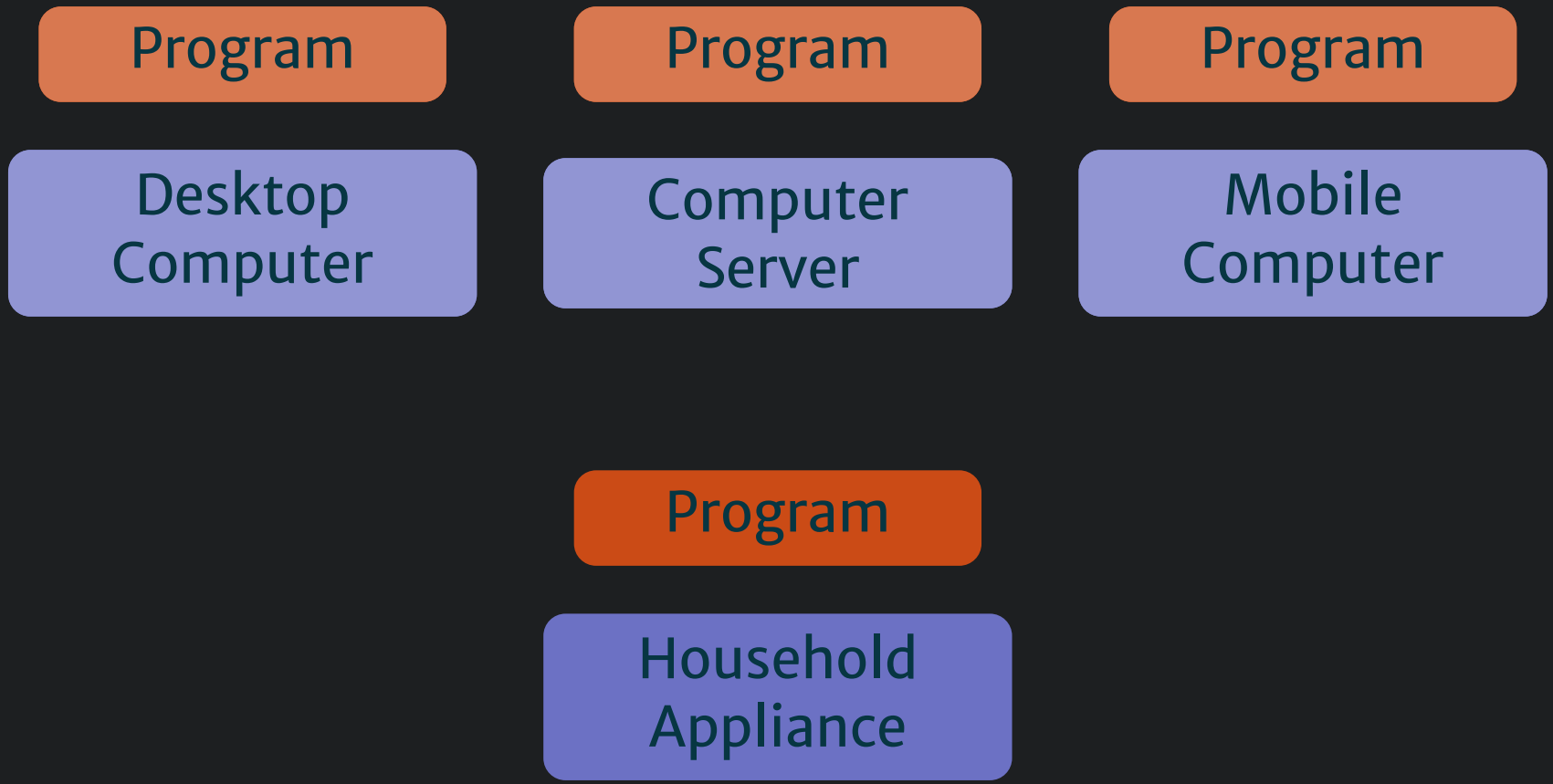

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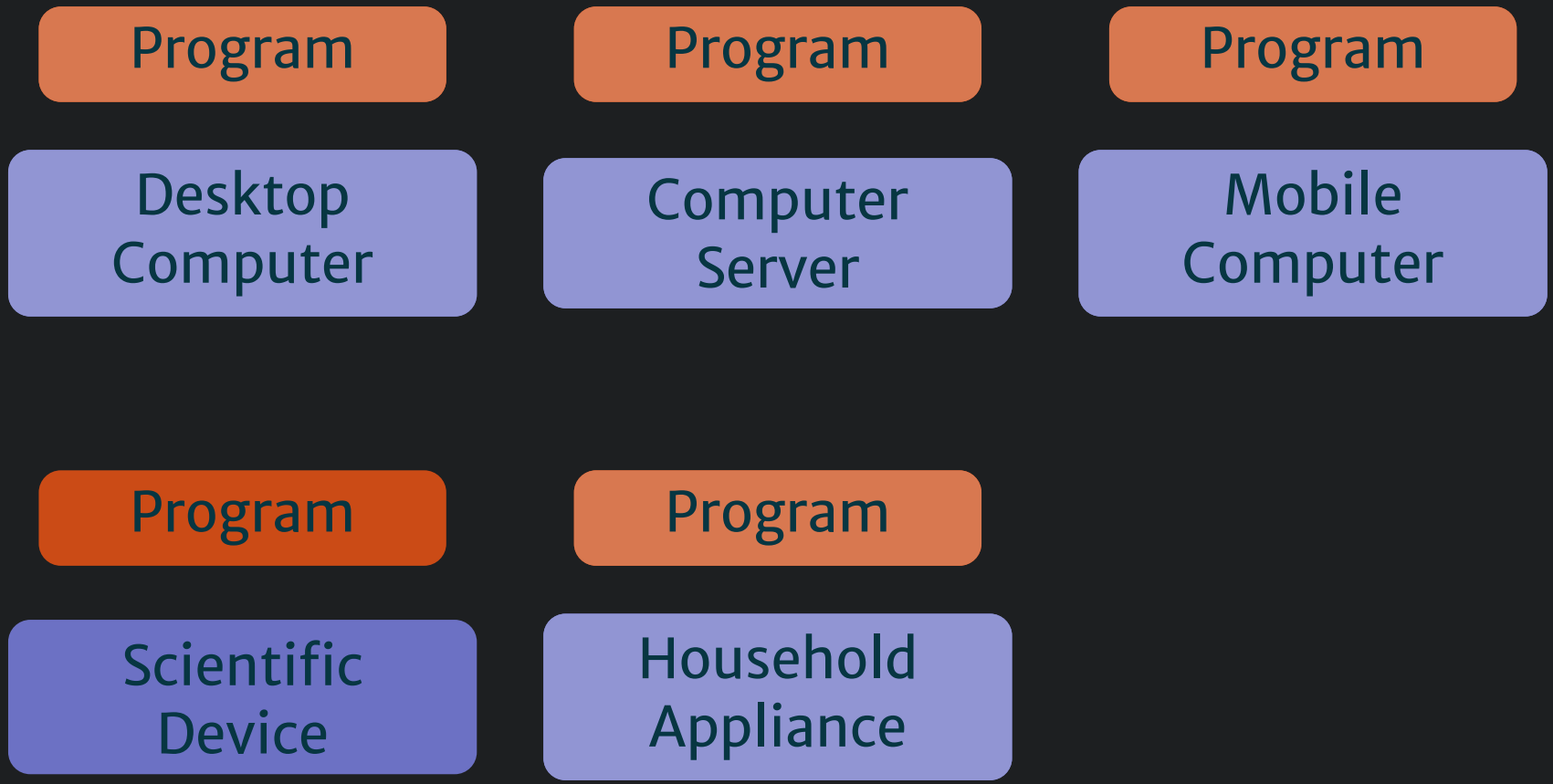

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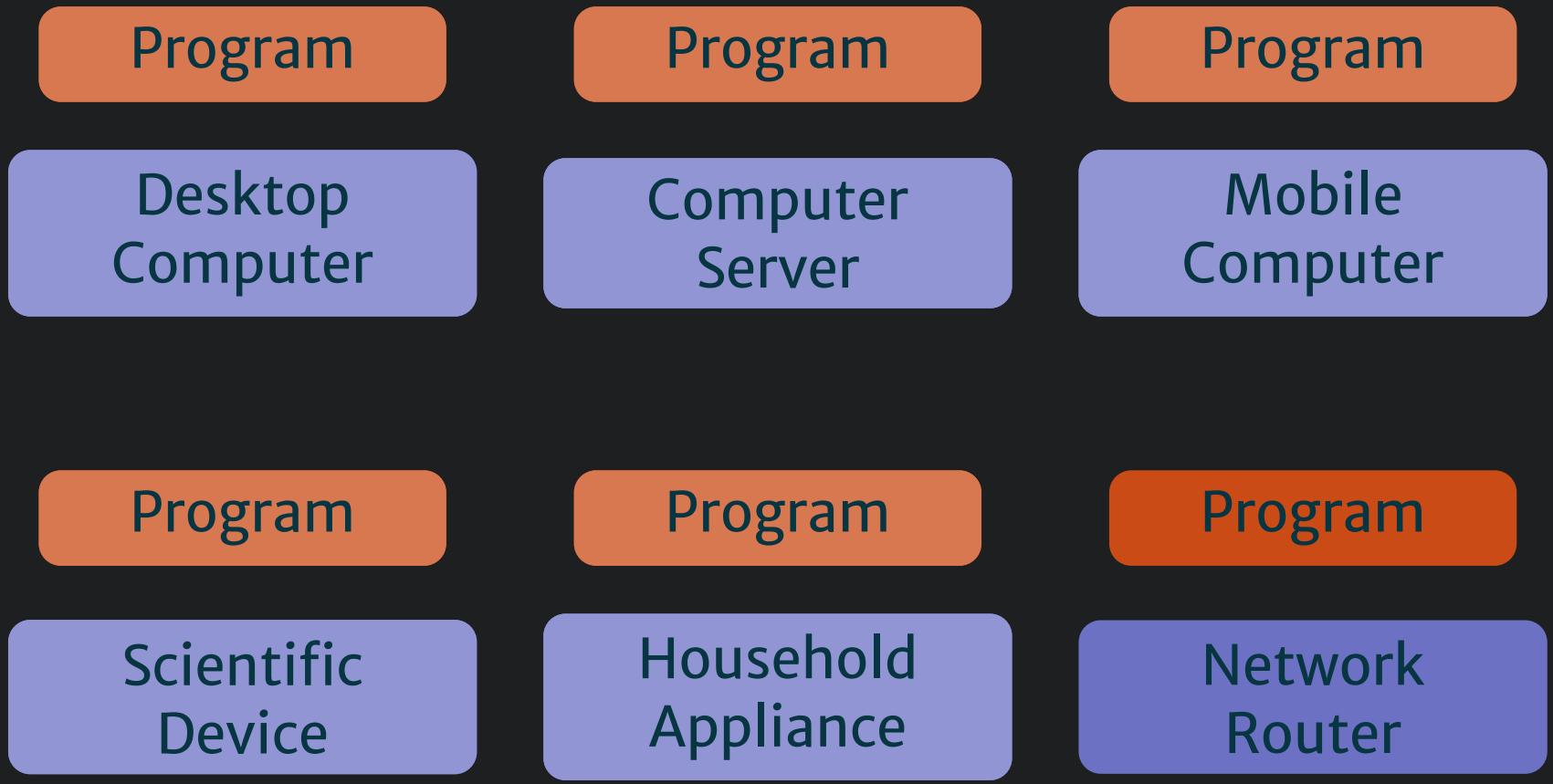

Software is Complex

Even simple programs are intricate — and difficult to test!

Computer Software

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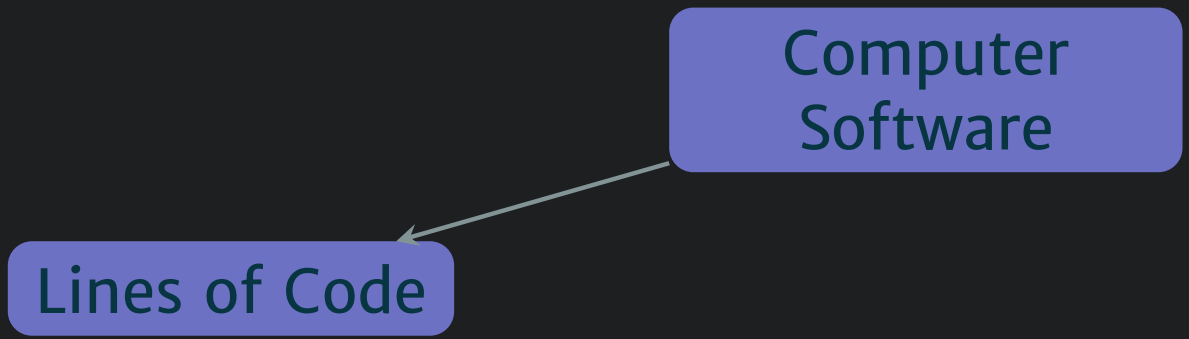

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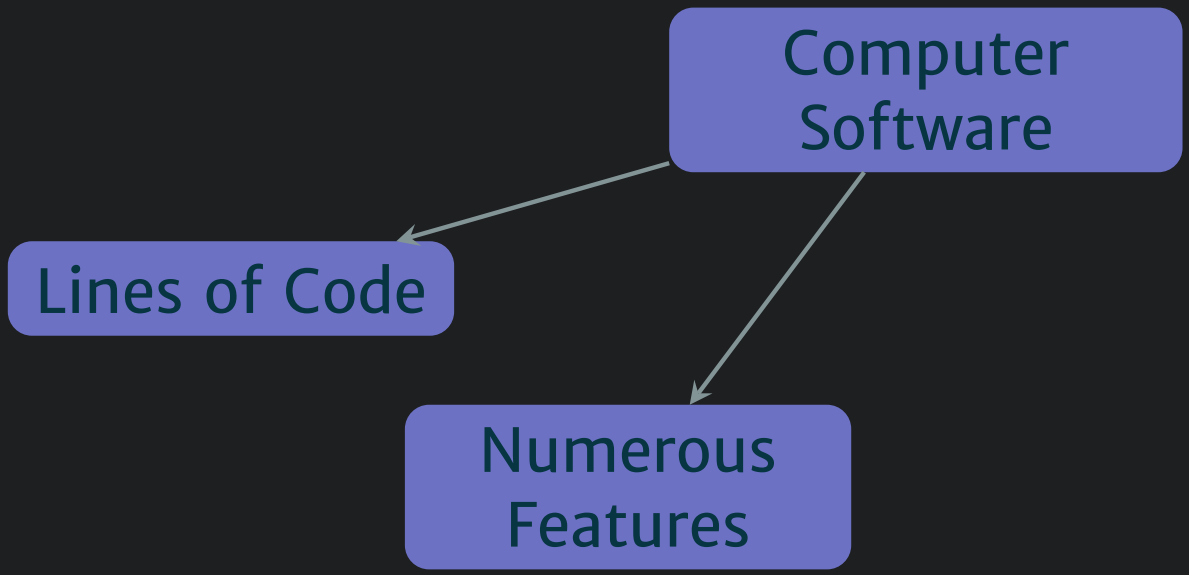

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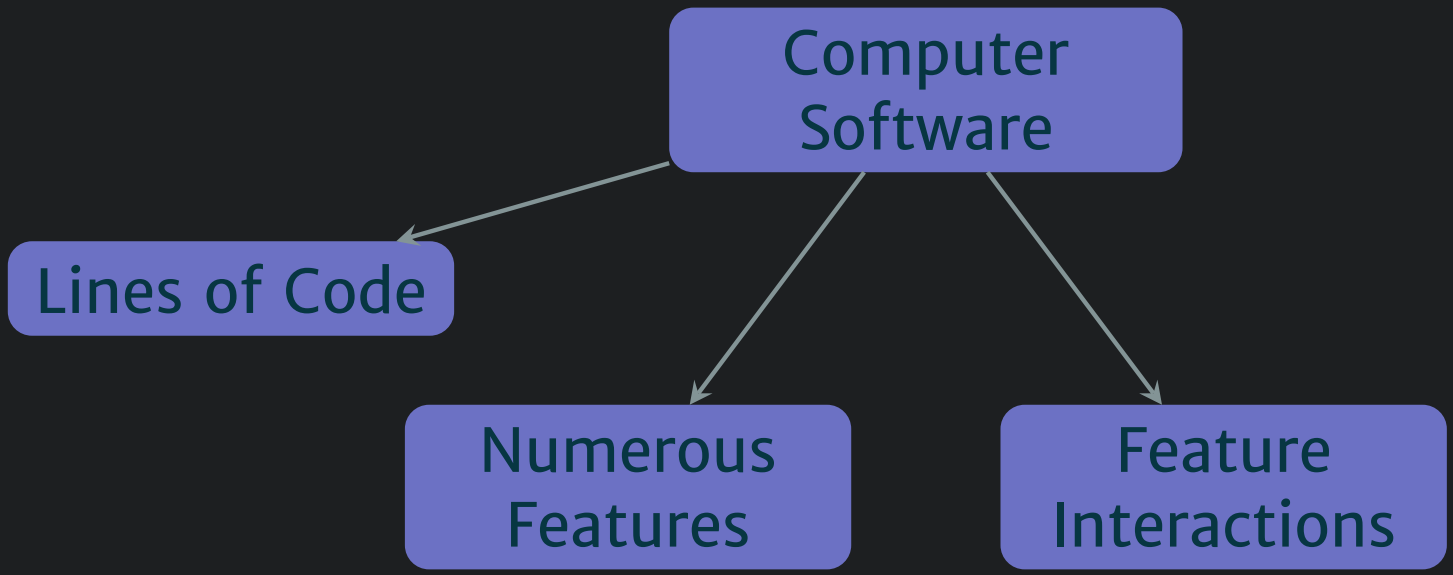

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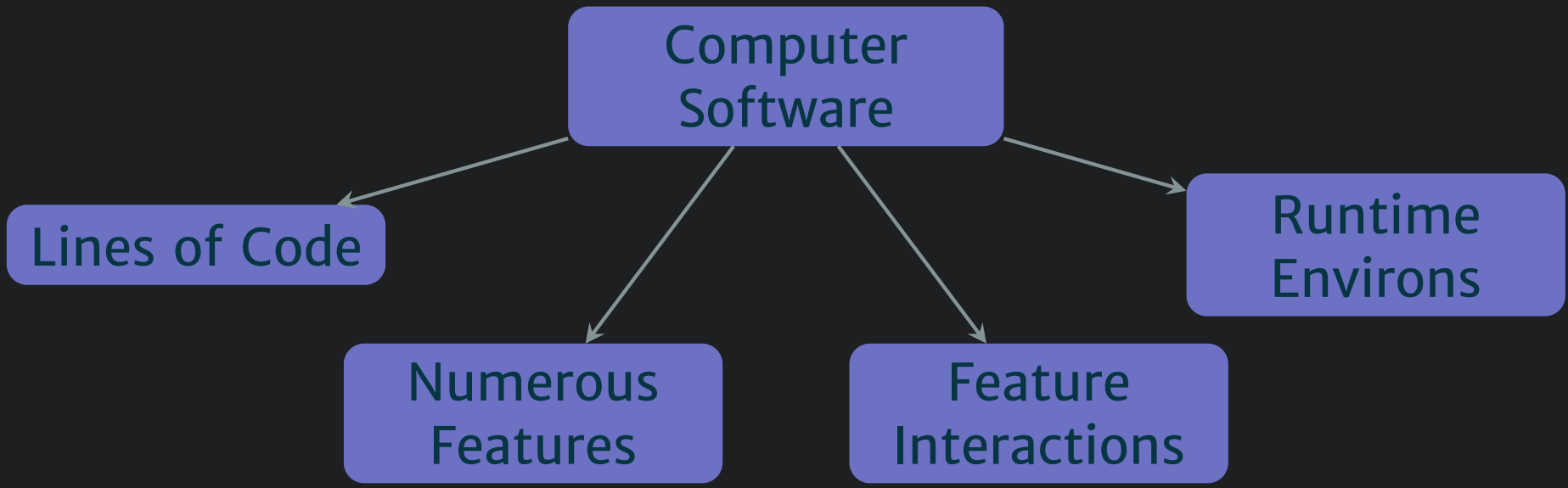
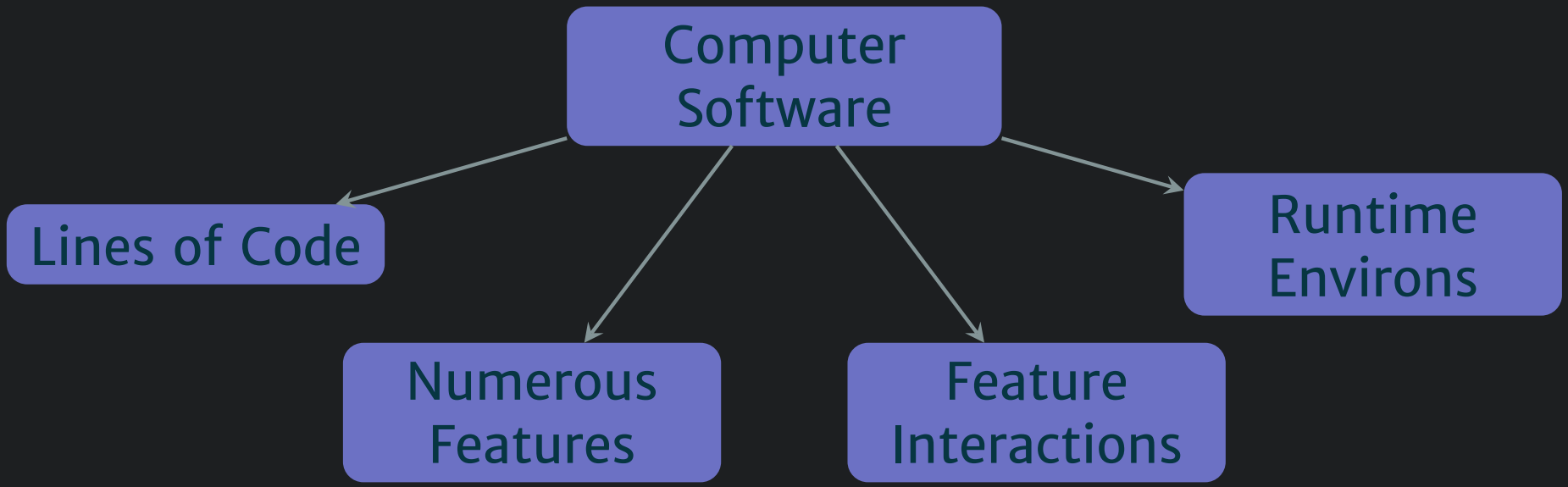


Software is Complex

Even simple programs are intricate — and difficult to test!

> "Software entities are more complex for their size than perhaps any other human construct" — Frederick P. Brooks, Jr.



Software is Evolving

Software is continuously updated — making testing critical!

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Program Changed because of the addition of a new feature or the correction of a defect

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Execution Environment Changed due to an upgrade in a kernel, device driver, or virtual machine

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Software is continuously updated — making testing critical!

Execution Environment Changed due to an upgrade in a kernel, device driver, or virtual machine

"Release early, release often" means that programs are regularly updated

Motivating Example

The computation of an object's velocity presents challenges!

$$K = \frac{1}{2} m \times v^2$$

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Computing Velocity

```
public static String computeVelocity(int kinetic, int mass) {
  int velocitySquared = 0;
  int velocity = 0;
  StringBuffer finalVelocity = new StringBuffer();
  if( mass != 0 ) {
    velocitySquared = 3 * (kinetic / mass);
    velocity = (int)Math.sqrt(velocitySquared);
    finalVelocity.append(velocity);
  }
  else {
    finalVelocity.append("Undefined");
  }
  return finalVelocity.toString();
}
```

Important Questions

Finding software defects is a challenging and rewarding task

Can you find the defect in this program?

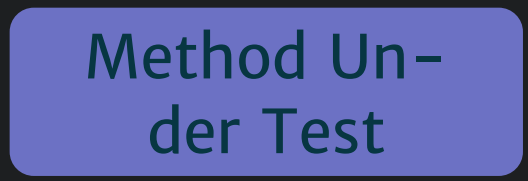
Important Questions

Finding software defects is a challenging and rewarding task

Are there general purpose strategies for defect isolation?

What is a Test Case?

A test case calls a method and checks its output with an oracle



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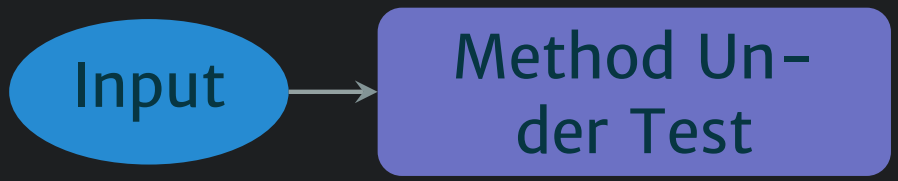

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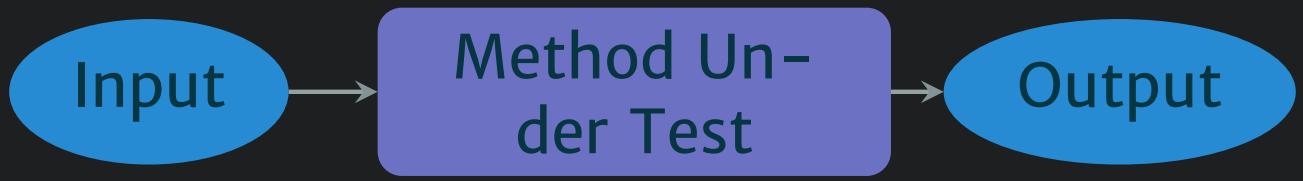

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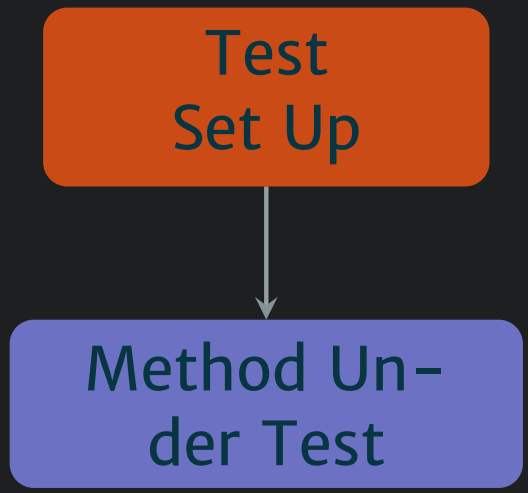

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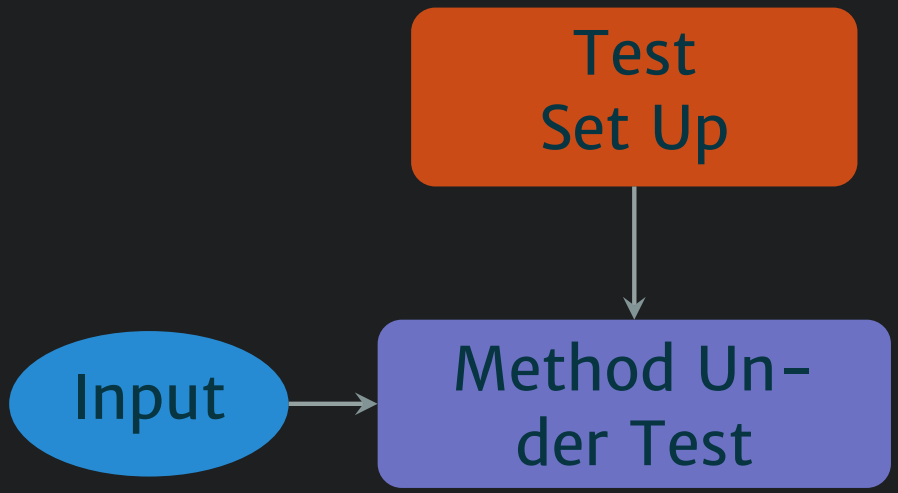

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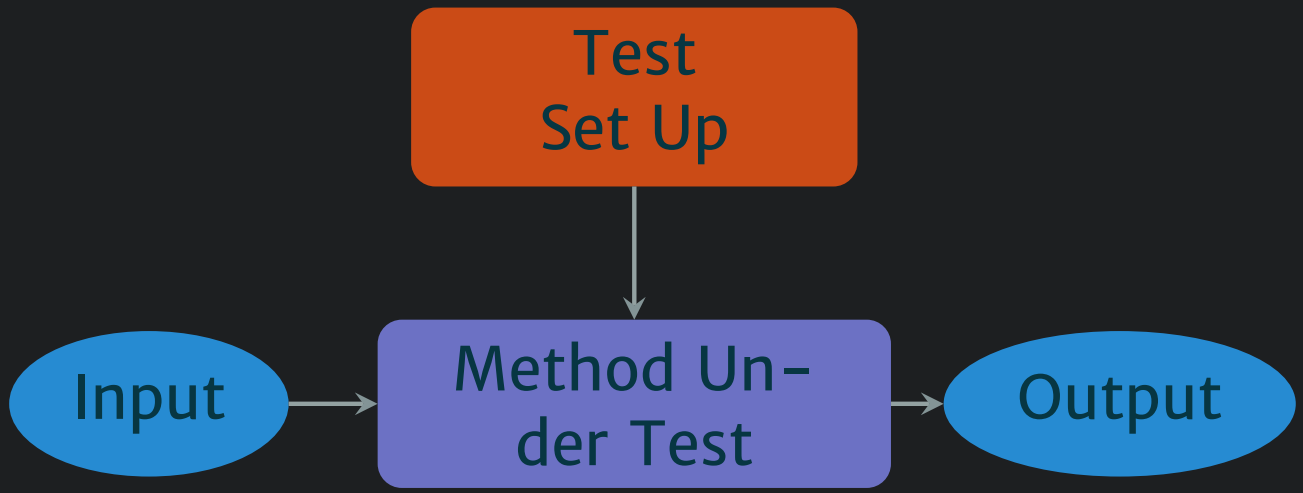

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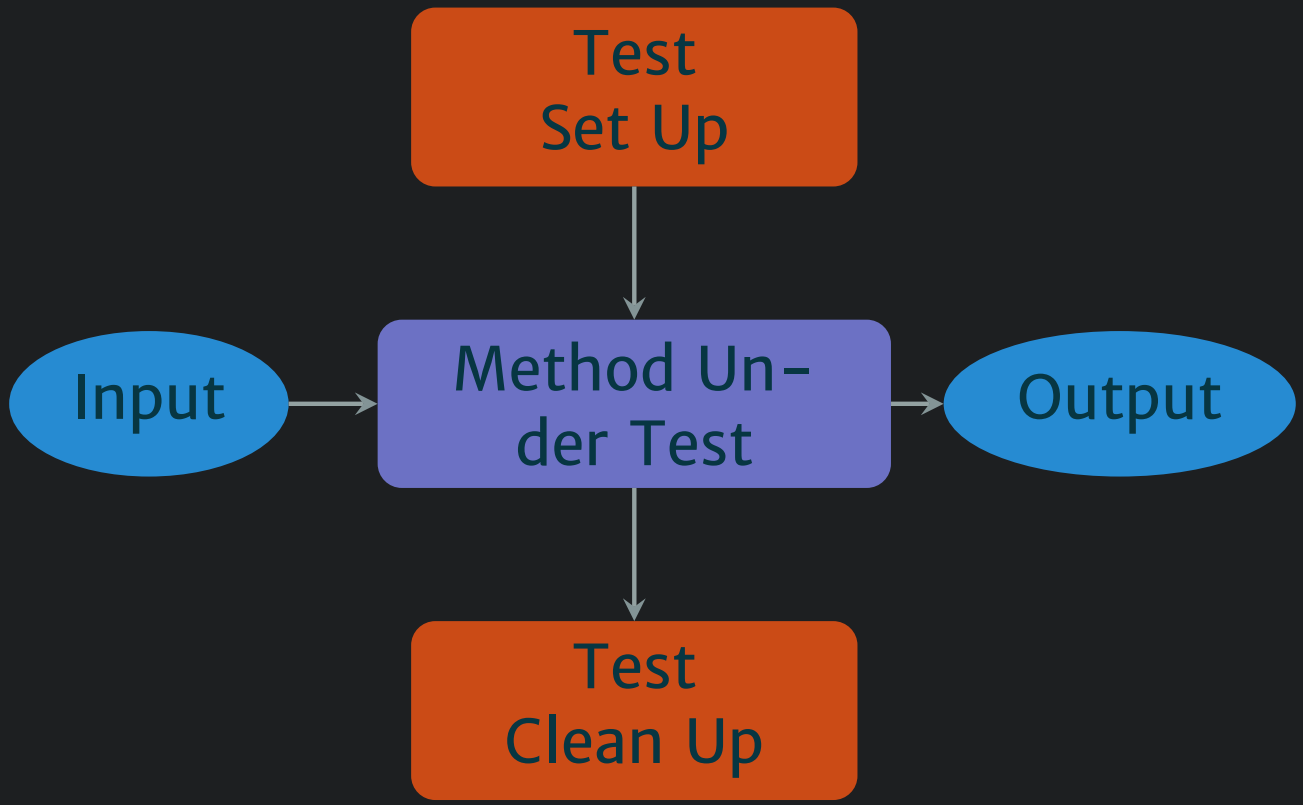

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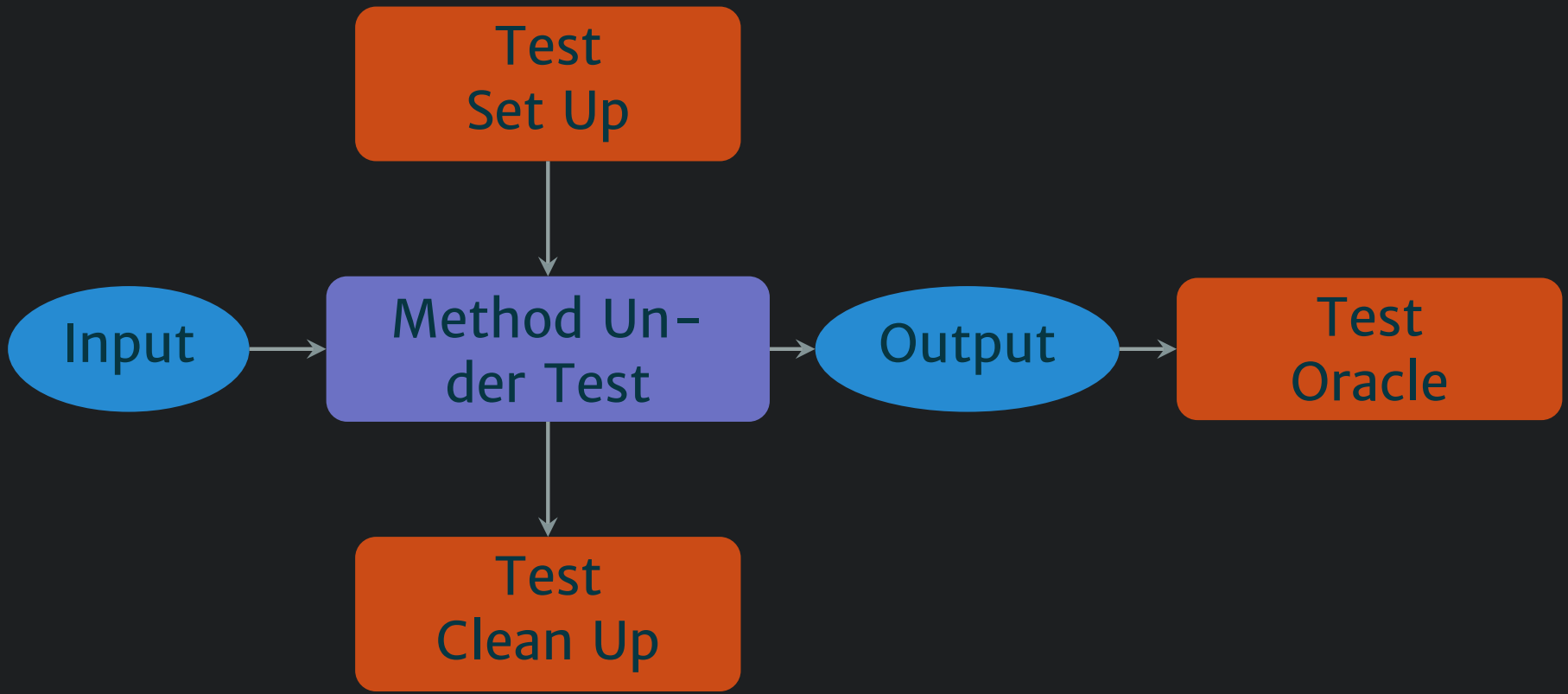

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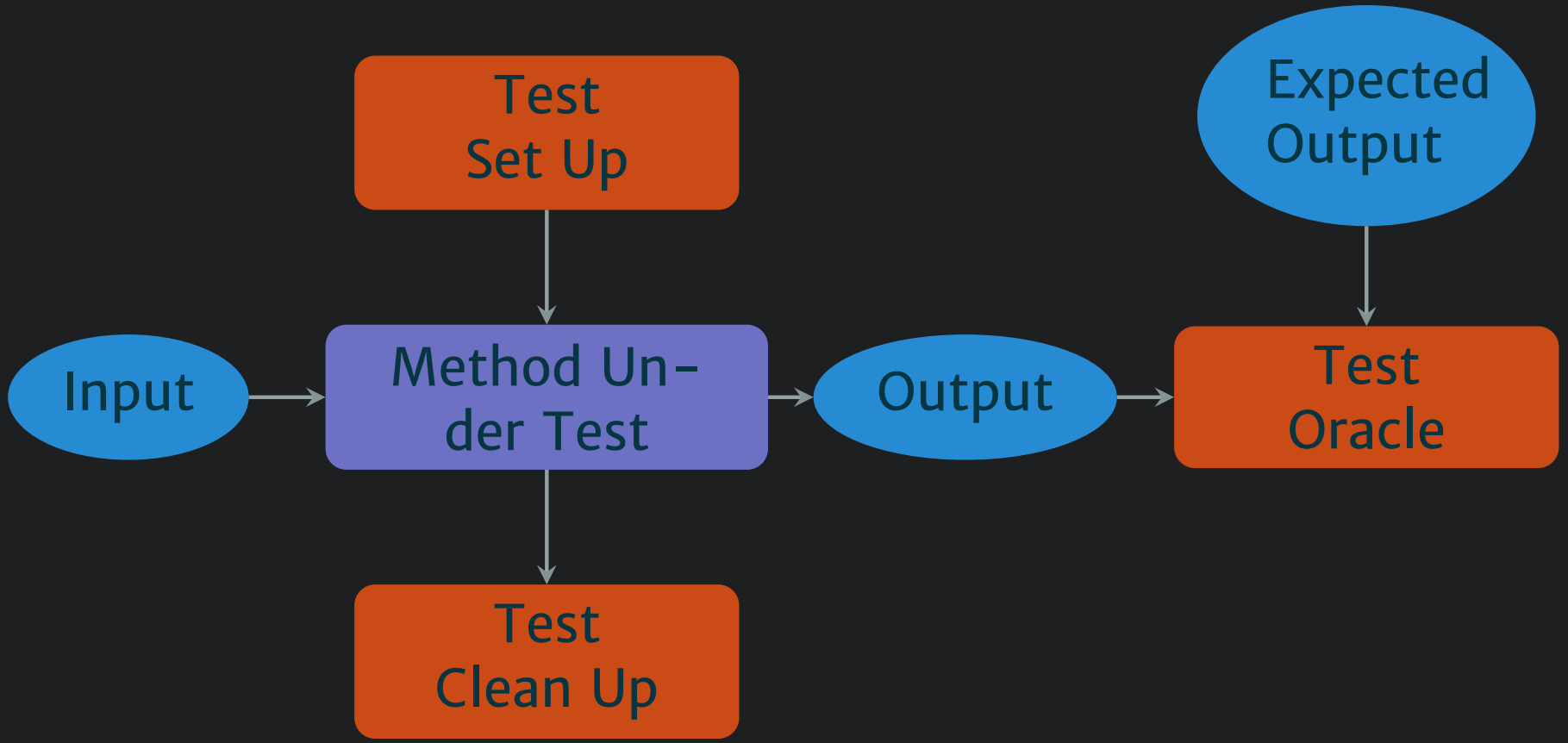

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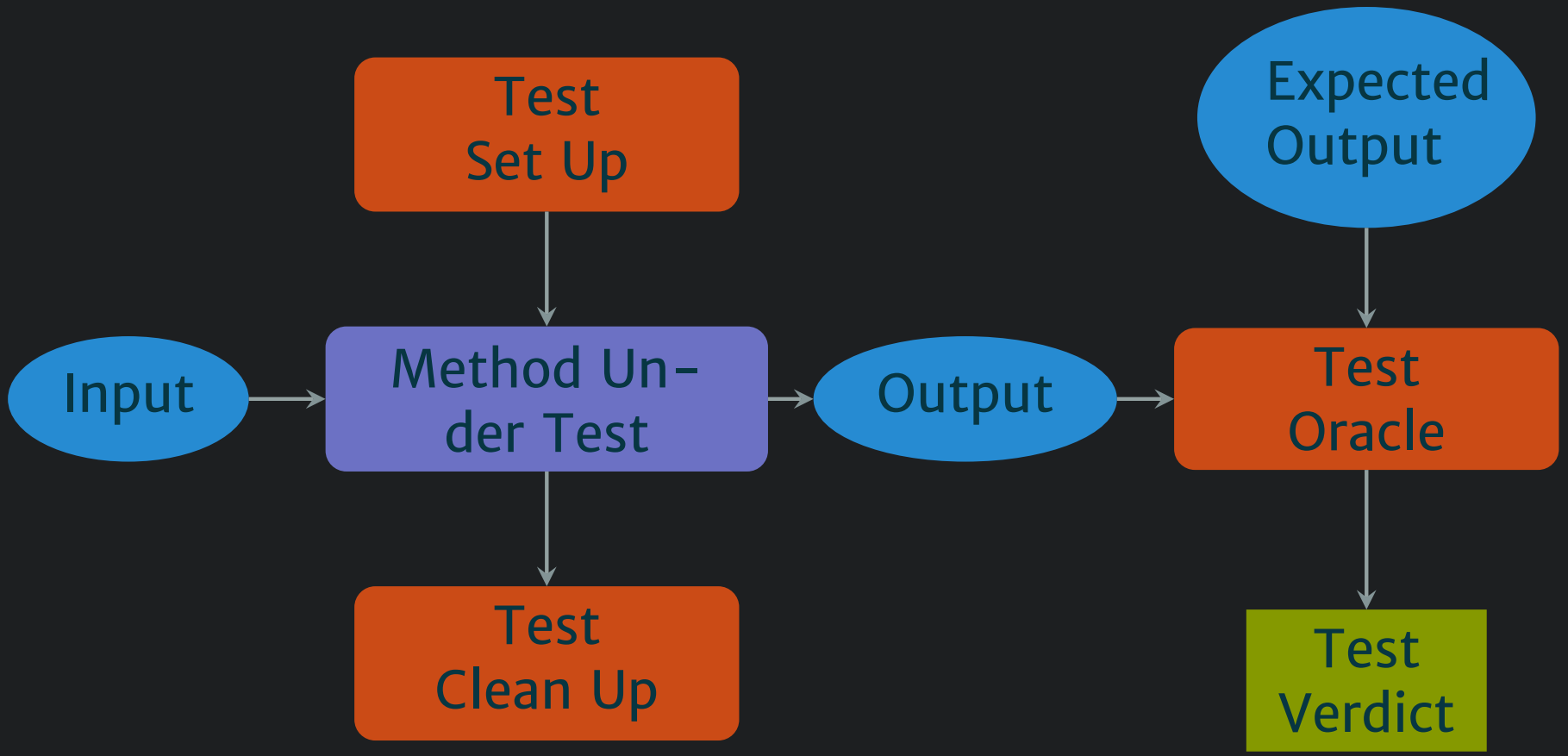

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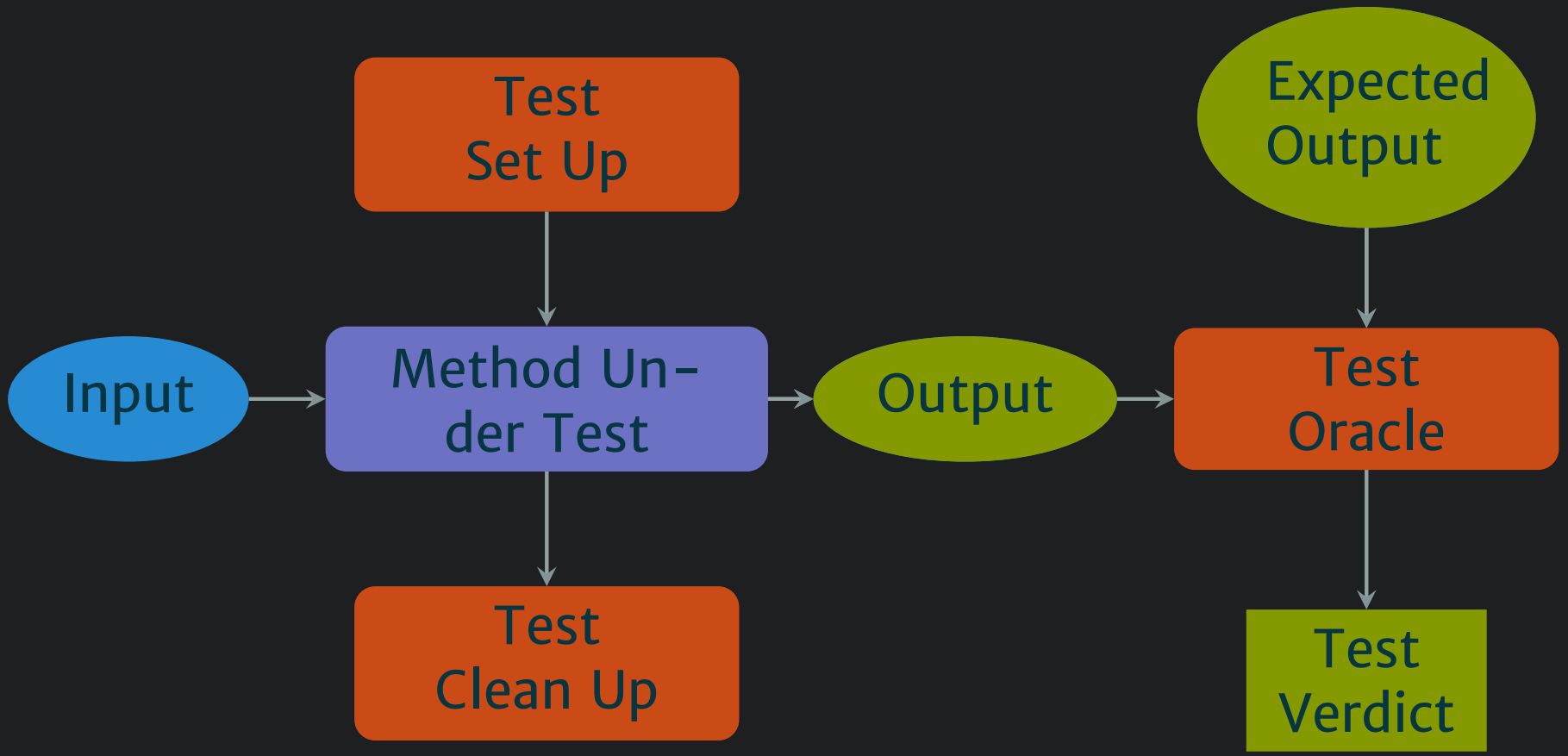

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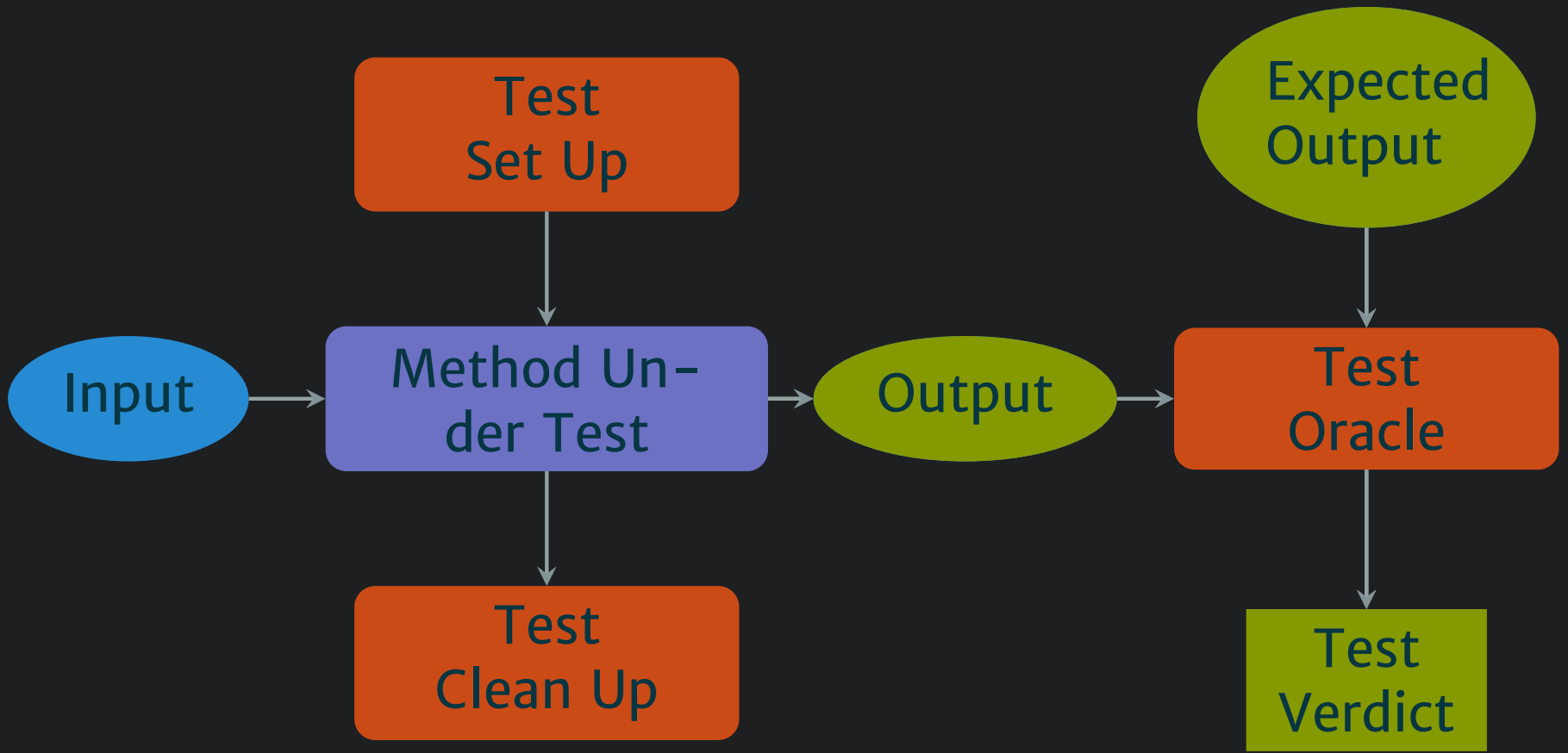

The test case passes and the code is correct!

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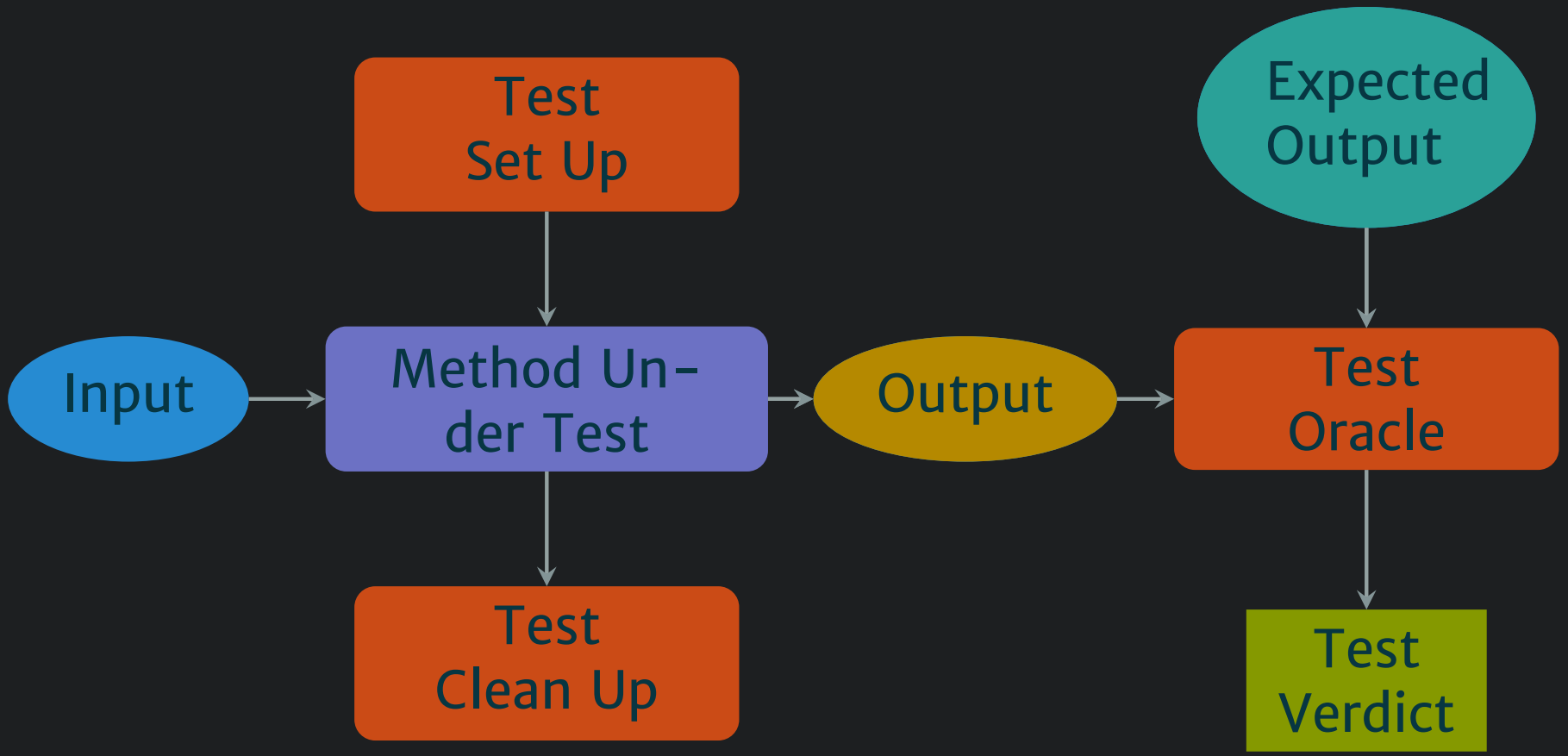

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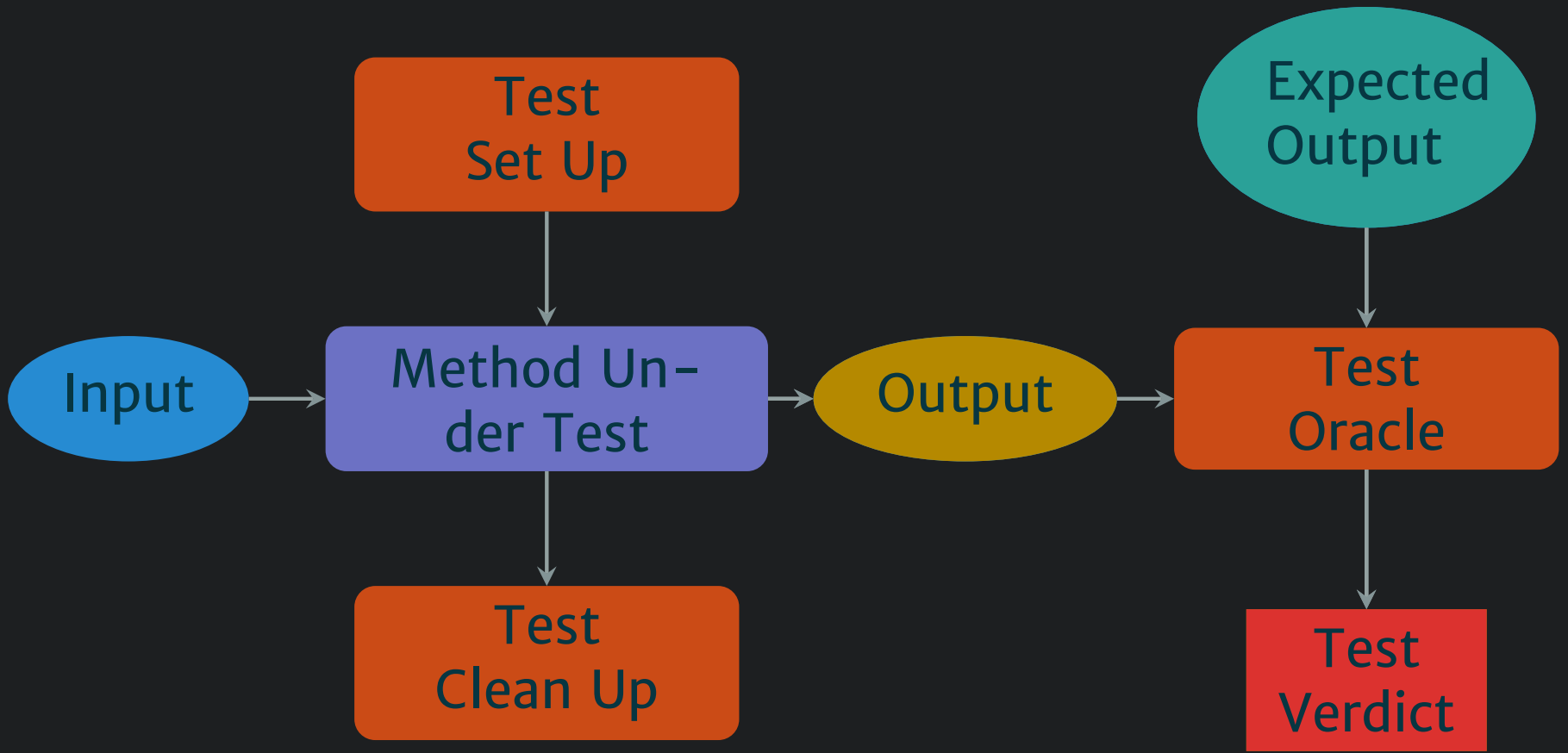
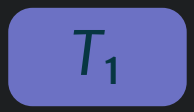


The test case fails and a defect is found!

What is a Test Suite?

A test suite is an organized collection of test cases



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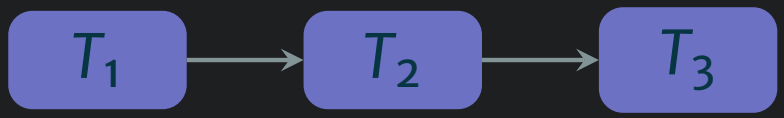

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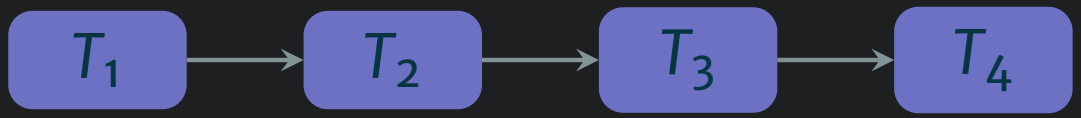

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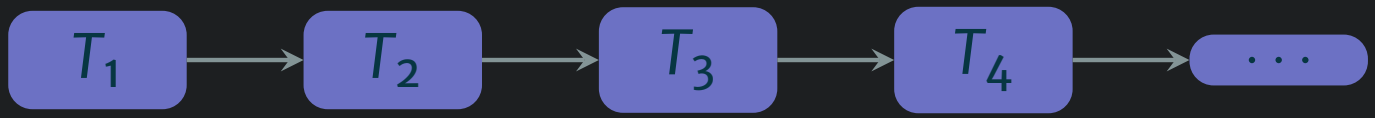

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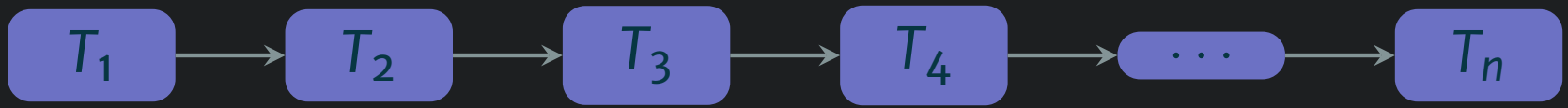

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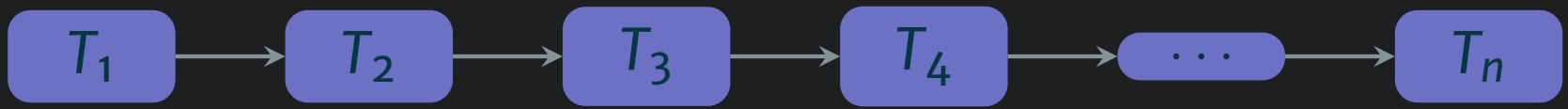
Organize the Test Cases into a Test Suite



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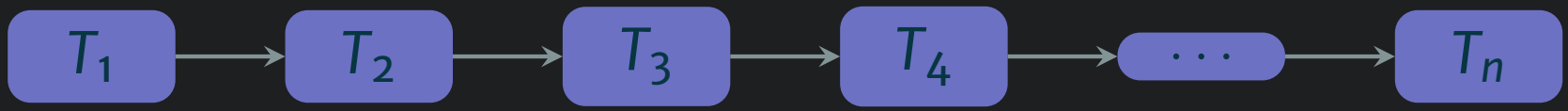

Tool Support for Software Testing?

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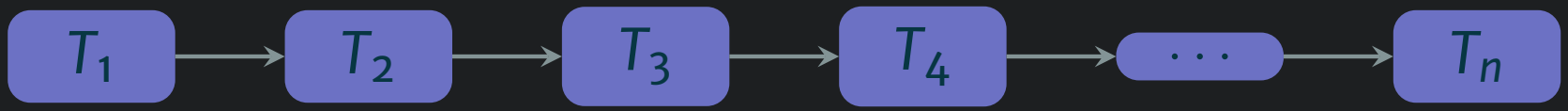

Tool Support for Software Testing?

JUnit

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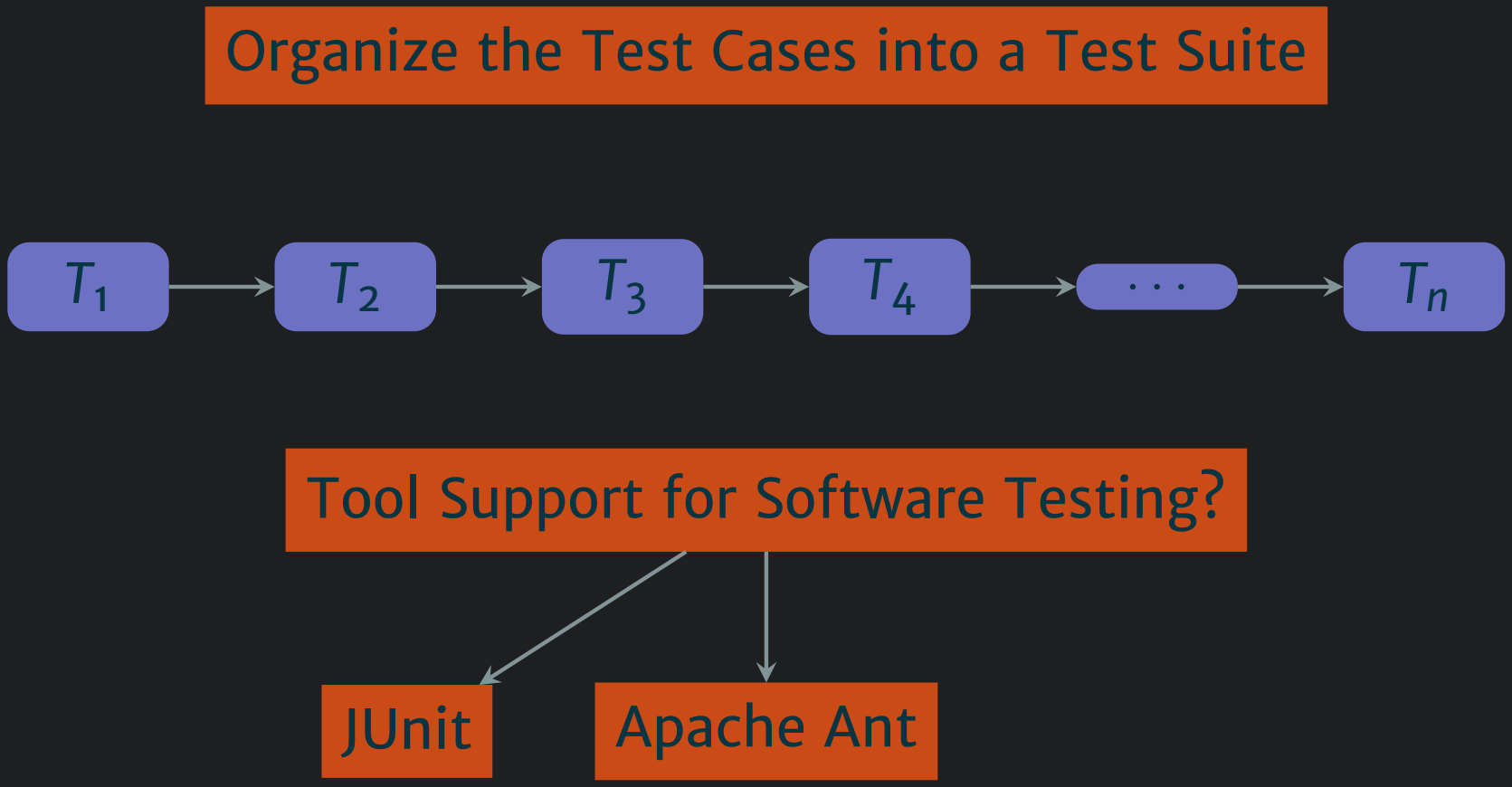

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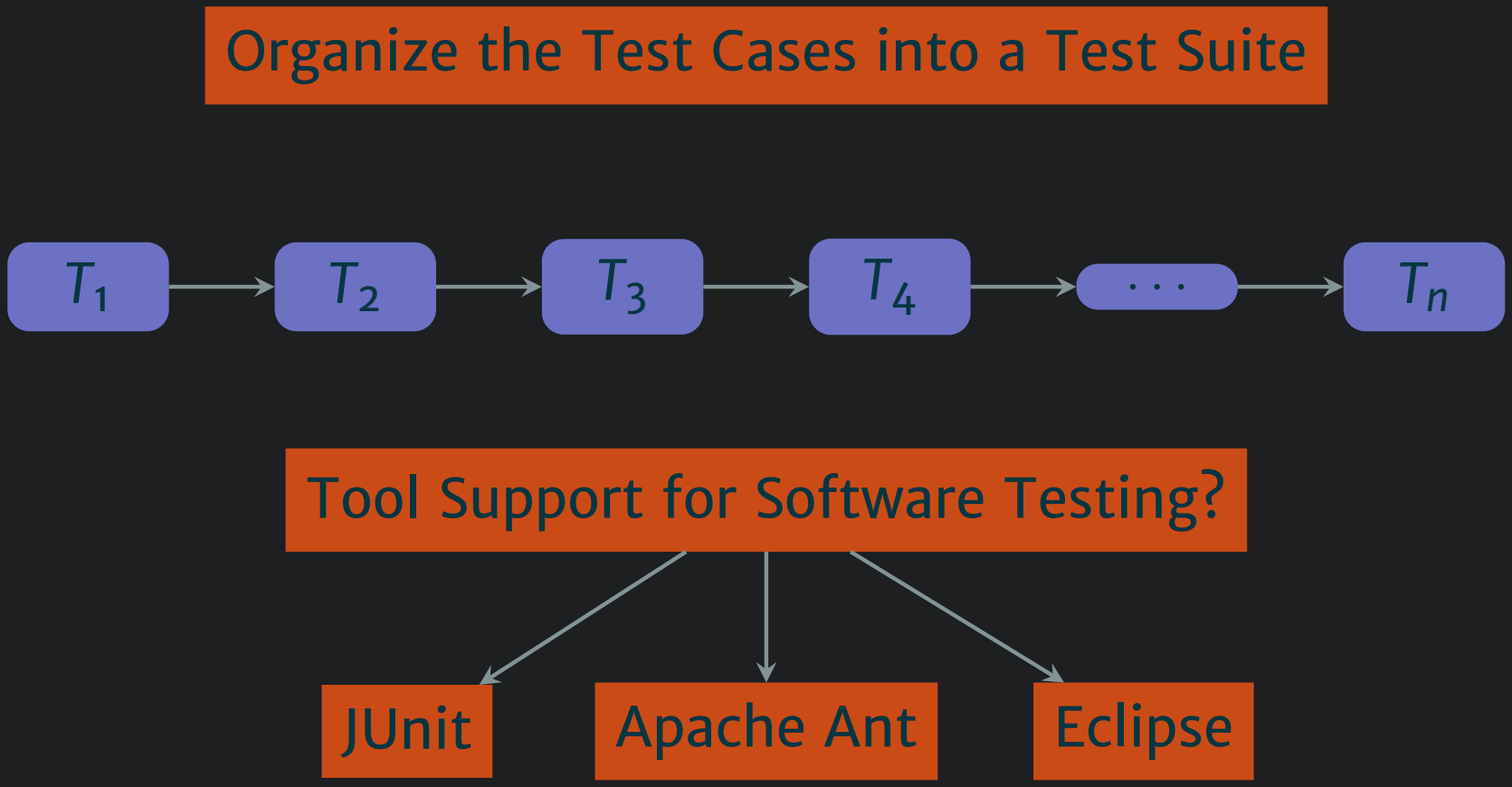

A JUnit Test Case

```
@Test
public void testOne() {
    String expected = new String("Undefined");
    String actual = Kinetic.
                        computeVelocity(5,0);
    assertEquals(expected, actual);
}
```

Another JUnit Test

```
@Test
public void testTwo() {
    String expected = new String("0");
    String actual = Kinetic.
                        computeVelocity(0,5);
    assertEquals(expected, actual);
}
```

Important Questions

Not all tests have the same fault detection effectiveness!

Will these test cases find the fault in the example program?

Important Questions

Not all tests have the same fault detection effectiveness!

T_1 assigns

$K = 5, m = 0$ —

Pass or fail?

Important Questions

Not all tests have the same fault detection effectiveness!

T_2 assigns

$K = 0, m = 5$ —

Pass or fail?

Important Questions

Not all tests have the same fault detection effectiveness!

How do we study the effectiveness of different test cases?

The PIE Model

There are necessary and sufficient conditions for fault detection

- Execute the faulty source code
- Infect the program's data state
- Propagate to the program's output

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All of these *must occur* before the fault manifests itself as a failure!

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There are necessary and sufficient conditions for fault detection

- Execute the faulty source code
- Infect the program's data state
- Propagate to the program's output

All of these *must occur* before the fault manifests itself as a failure!

Using the PIE model, will the test cases *find* the defect in the program?

A JUnit Test Case — T_1

```
@Test
public void testOne() {
    String expected = new String("Undefined");
    String actual = Kinetic.
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    assertEquals(expected, actual);
}
```

E I P

A JUnit Test Case — T_1

```
@Test
public void testOne() {
    String expected = new String("Undefined");
    String actual = Kinetic.
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    assertEquals(expected, actual);
}
```

E	I	P
✗	✗	✗

A JUnit Test Case — T_2

```
@Test
public void testTwo() {
    String expected = new String("0");
    String actual = Kinetic.
                        computeVelocity(0,5);
    assertEquals(expected, actual);
}
```

E I P

A JUnit Test Case — T_2

```
@Test
public void testTwo() {
    String expected = new String("0");
    String actual = Kinetic.
                        computeVelocity(0,5);
    assertEquals(expected, actual);
}
```

E	I	P
✓	✗	✗

A JUnit Test Case — T_3

```
@Test
public void testThree() {
    String expected = new String("4");
    String actual = Kinetic.
                        computeVelocity(8,1);
    assertEquals(expected, actual);
}
```

E I P

A JUnit Test Case — T_3

```
@Test
public void testThree() {
    String expected = new String("4");
    String actual = Kinetic.
                        computeVelocity(8,1);
    assertEquals(expected, actual);
}
```

E	I	P
✓	✓	✗

A JUnit Test Case — T_4

```
@Test
public void testFour() {
    String expected = new String("20");
    String actual = Kinetic.
                        computeVelocity(1000,5);
    assertEquals(expected, actual);
}
```

E I P

A JUnit Test Case — T_4

```
@Test
public void testFour() {
    String expected = new String("20");
    String actual = Kinetic.
                        computeVelocity(1000,5);
    assertEquals(expected, actual);
}
```

E I P

Test Suite Summary

A test case must create specific inputs in order to cause failure!

Test Case	Status
T_1	Pass
T_2	Pass
T_3	Pass
T_4	Fail

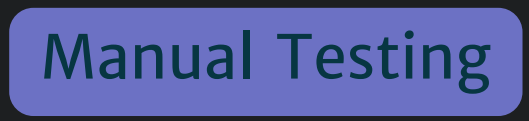
Important Insights

Software testing is fundamentally challenging — is there help?

> *I shall not deny that the construction of these testing programs has been a major intellectual effort: to convince oneself that one has not overlooked "a relevant state" and to convince oneself that the testing programs generate them all is no simple matter.*
>
> Edsger W. Dijkstra, *Communications of the ACM*, 1968

Manual Testing

While it has benefits, this industry standard may be limited!



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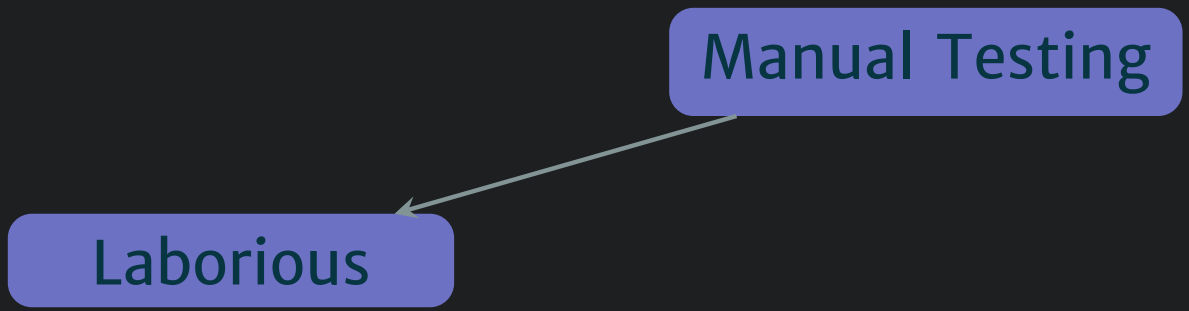

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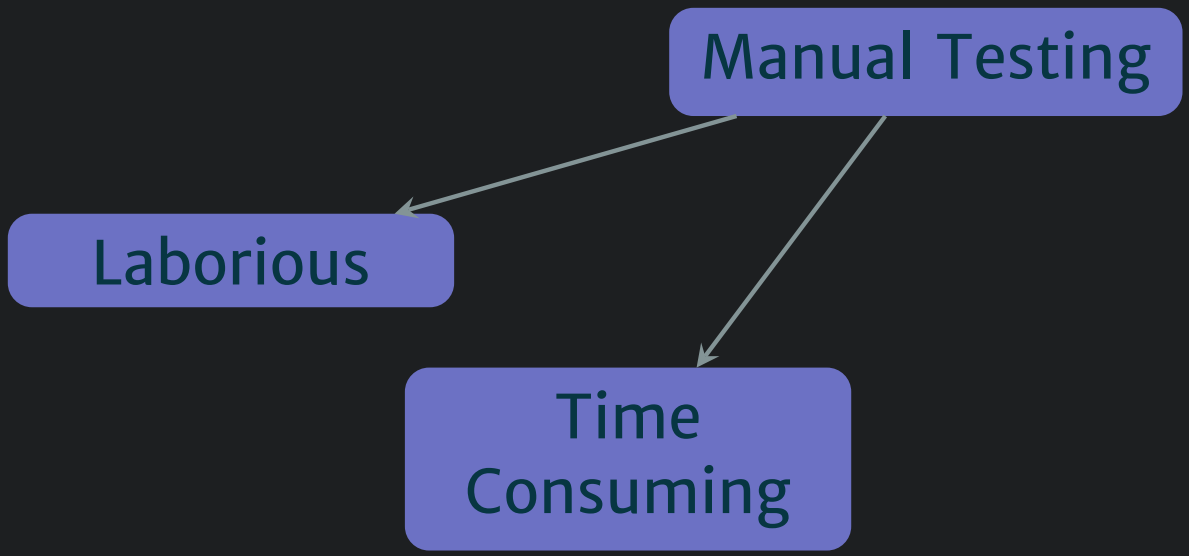

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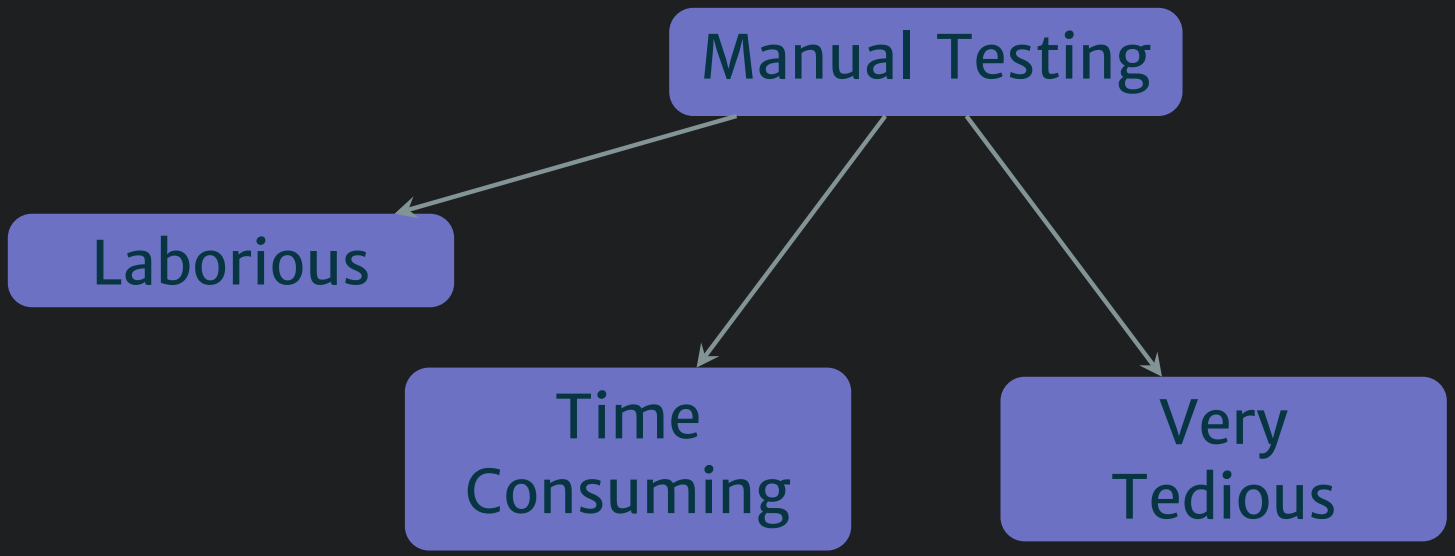

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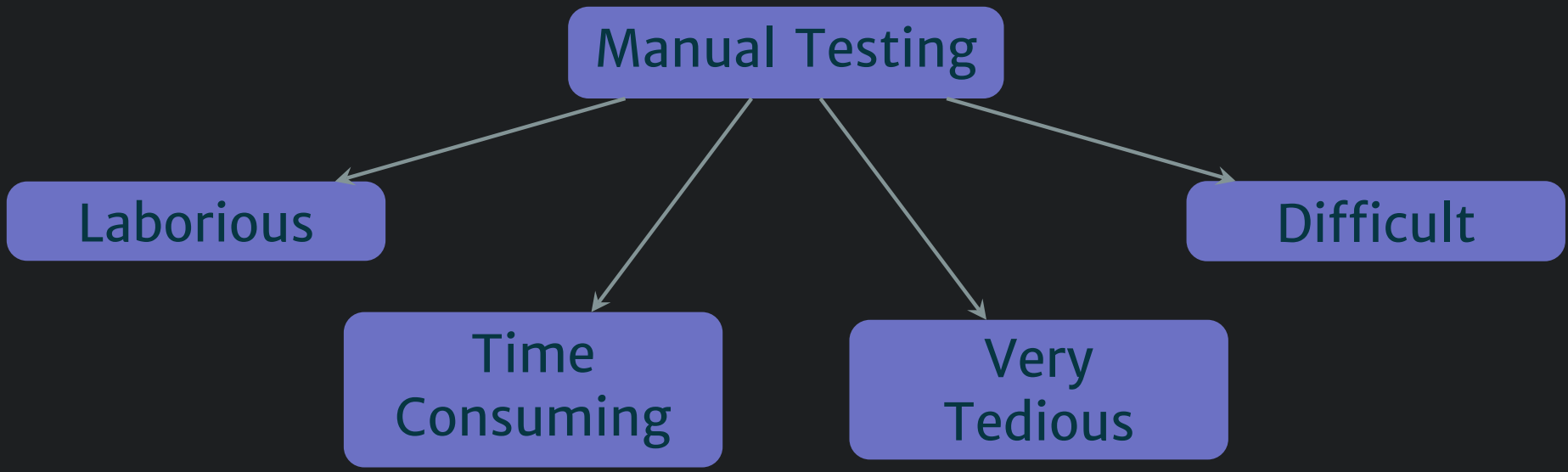
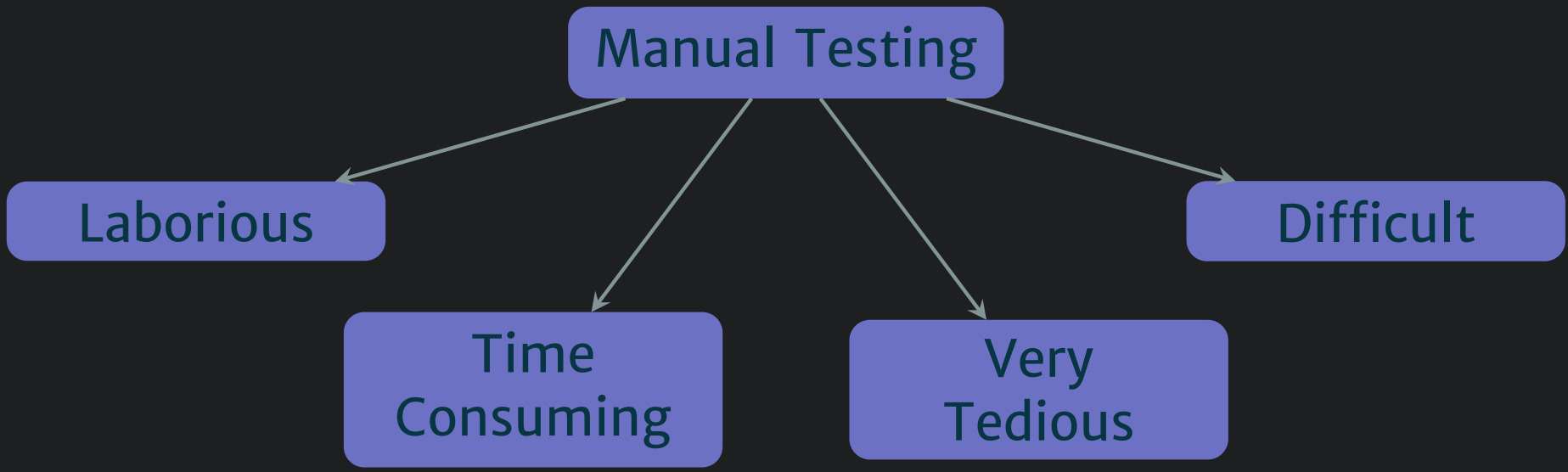


Manual Testing

While it has benefits, this industry standard may be limited!

Can we develop and employ methods that will automatically generate high-quality test cases for real-world software?



Automated Testing

Automatically generating tests is amazing — but does it work?

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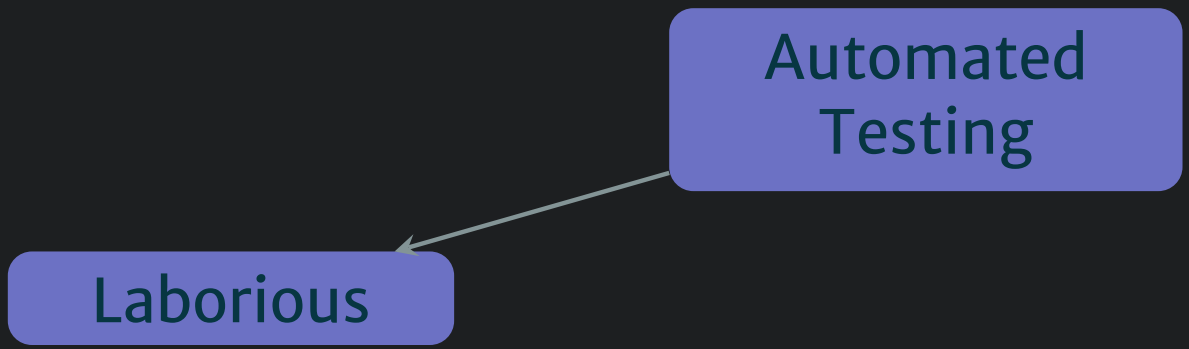

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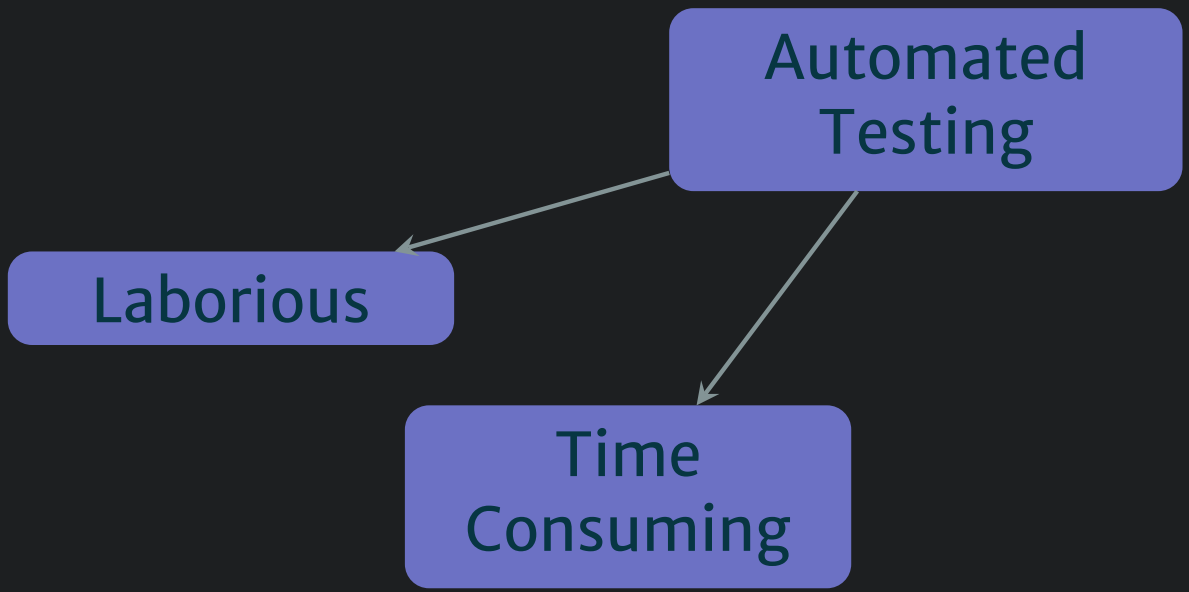

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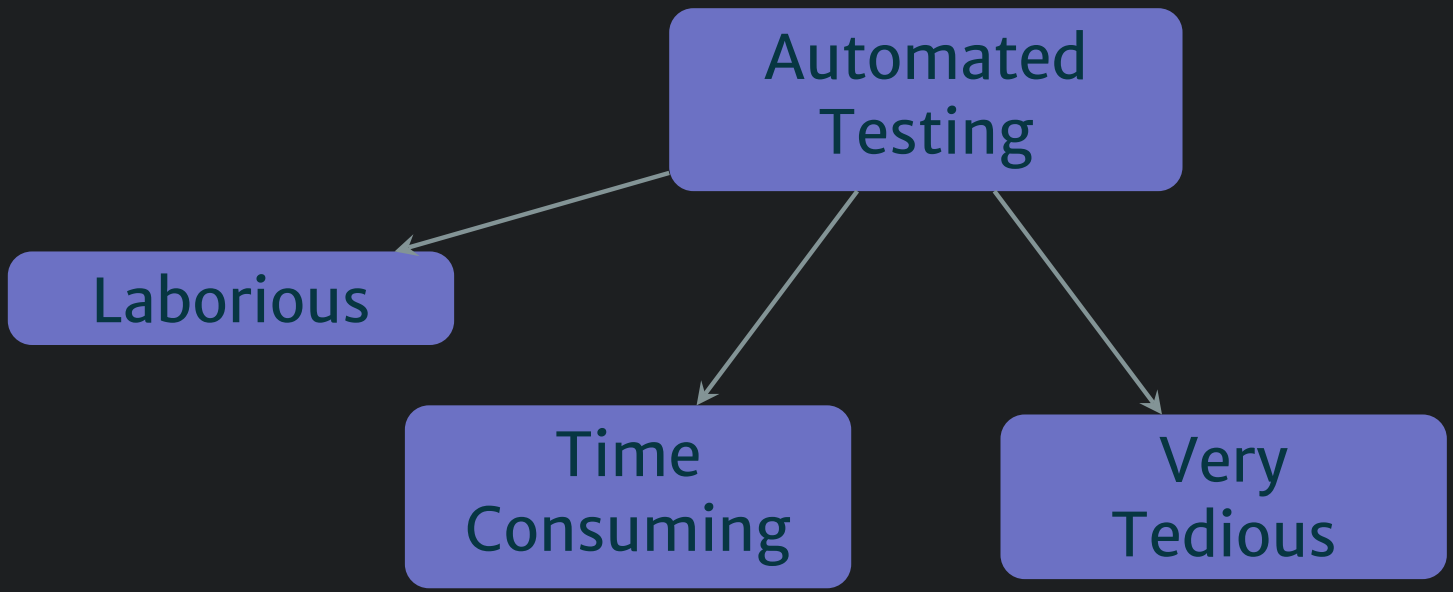

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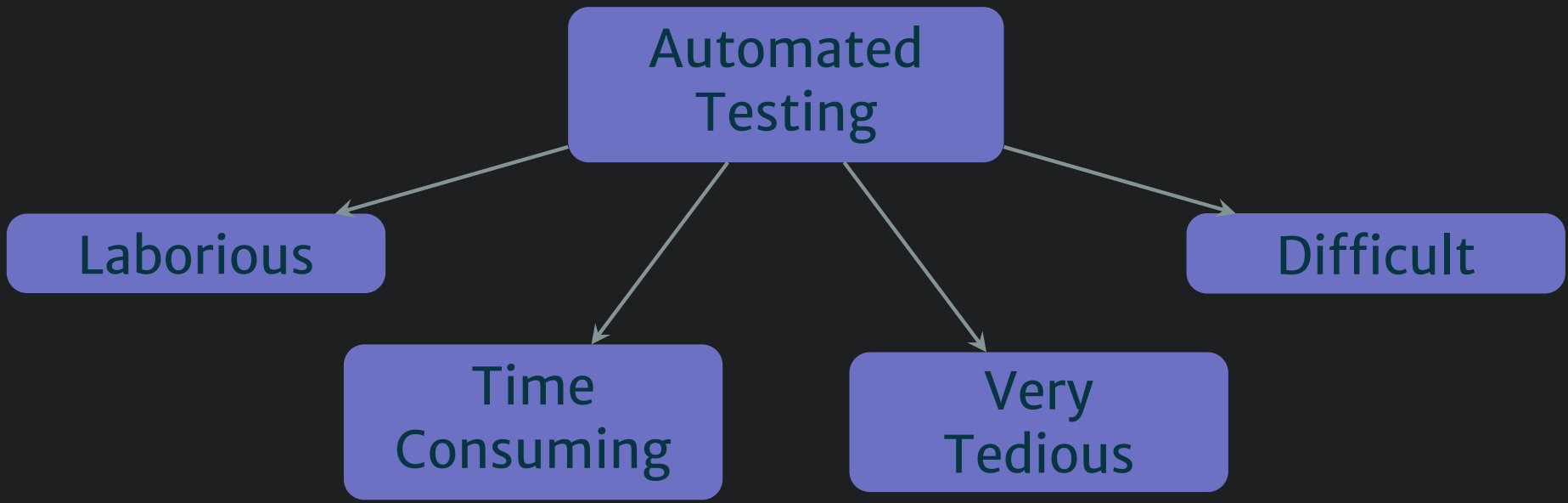

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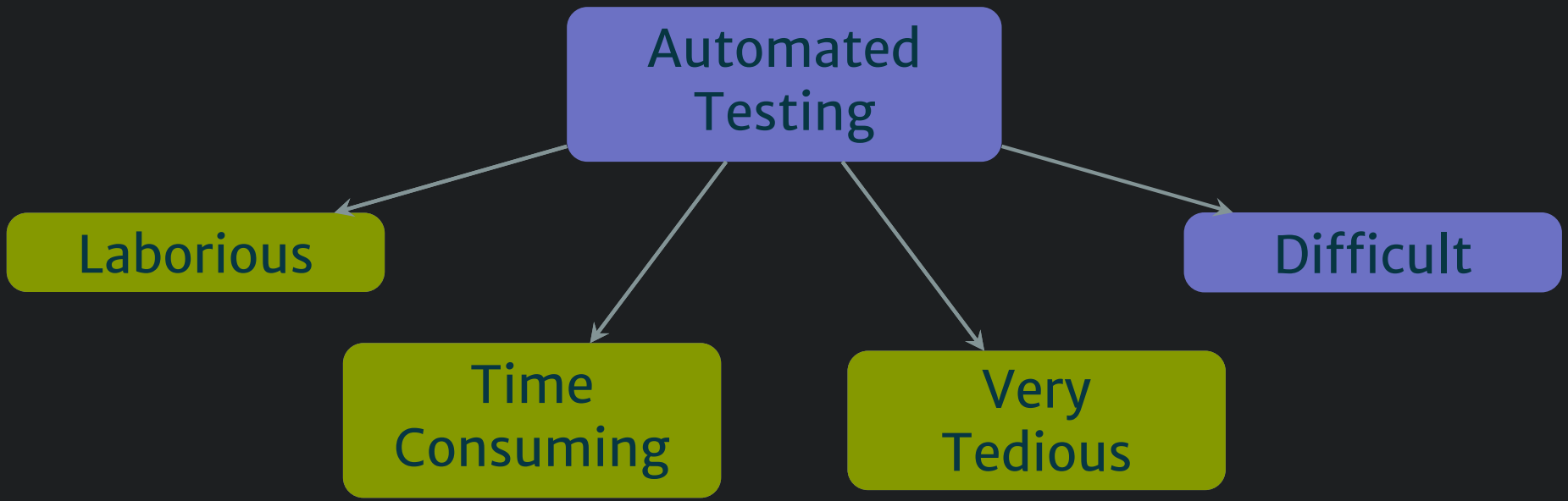
Testing is *less* laborious and tedious because an algorithm generates the tests. While computational time is needed, a human can be *less* involved!



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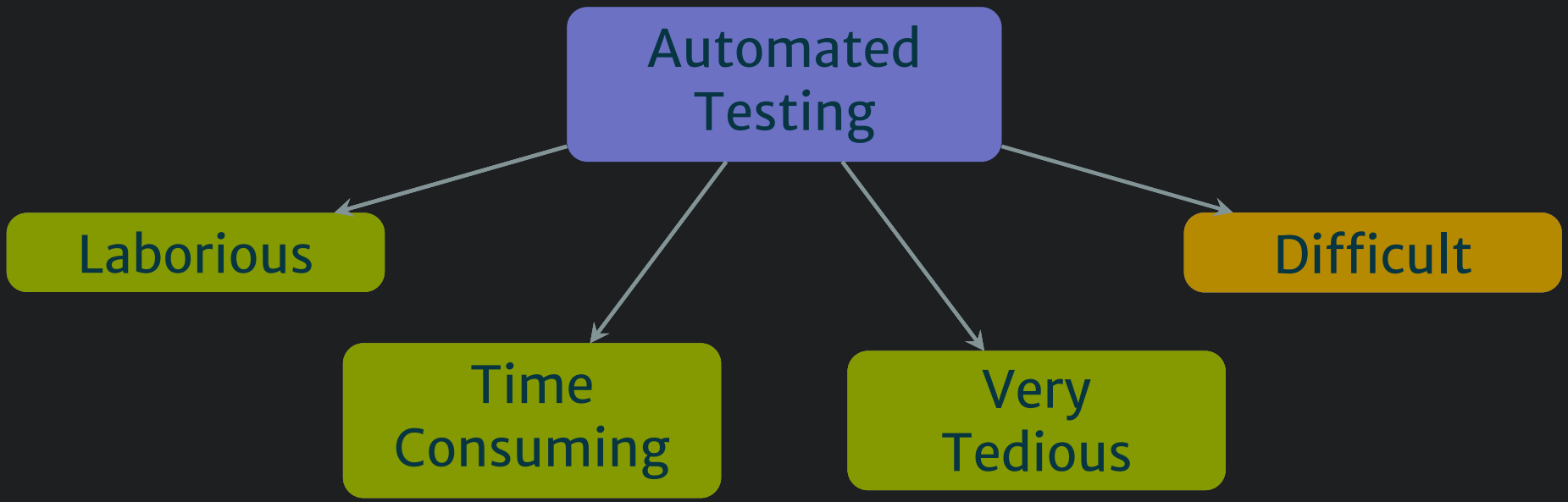
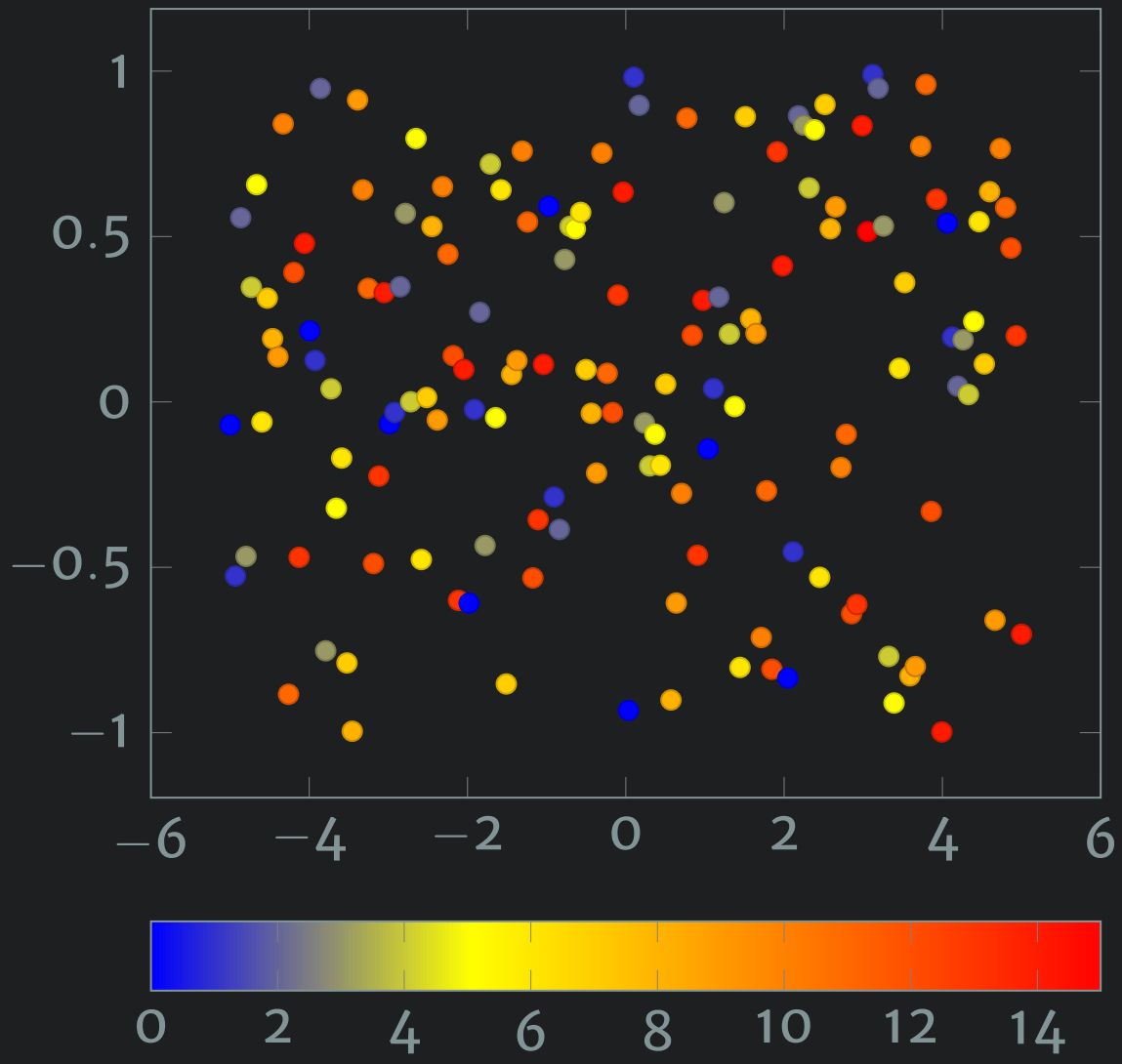
Automated testing is *less* difficult since a good fitness function can guide the algorithm to inputs that find the faults



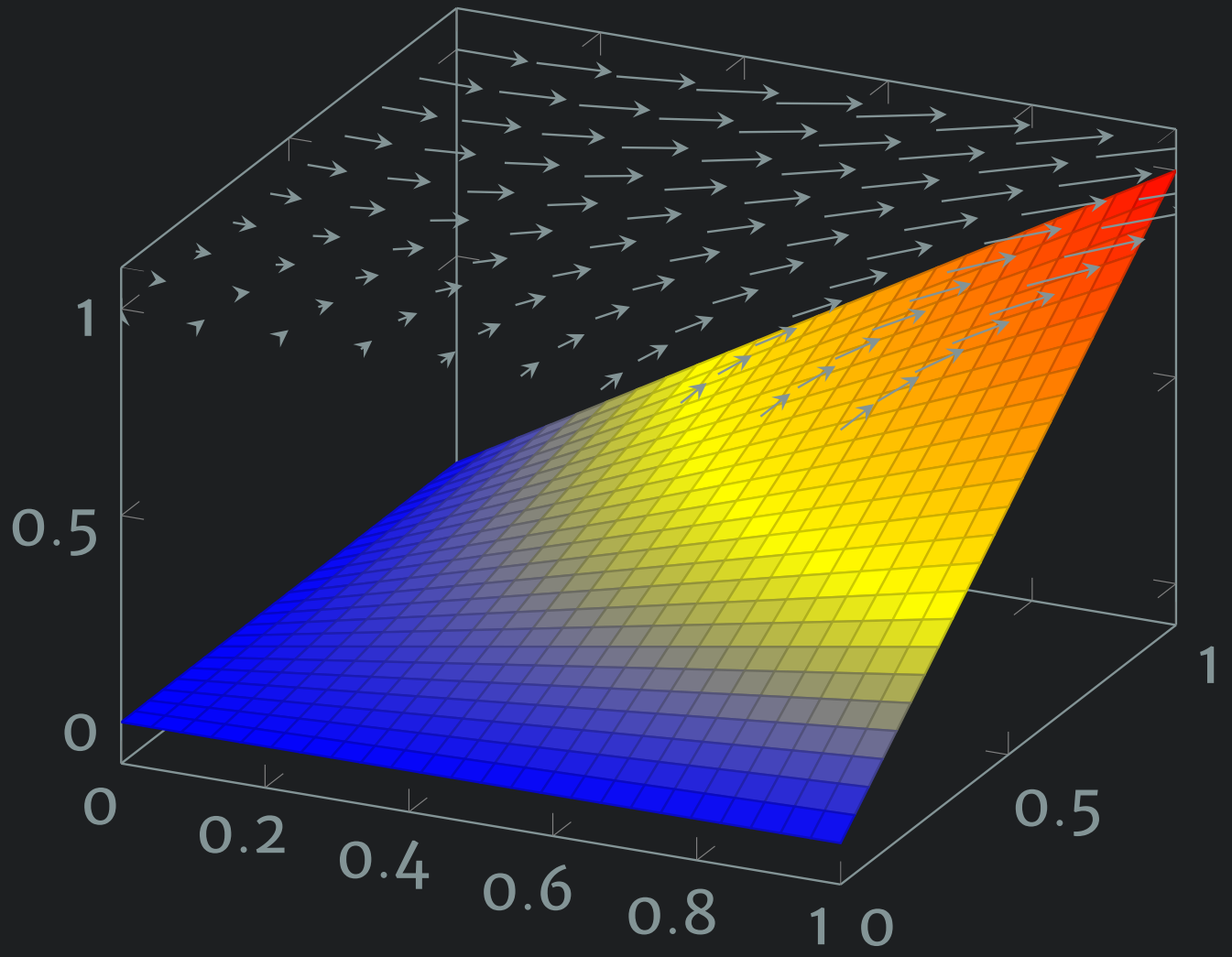
Random Testing

It is easy to randomly generate tests — but how good are they?



Search-Based Testing

Use a fitness function to guide the search to “good” values



Mutation Testing

Let's purposefully insert faults into the program under test!

T_1 T_2

Mutation Testing

Let's purposefully insert faults into the program under test!

T_1 T_2 T_3 T_4

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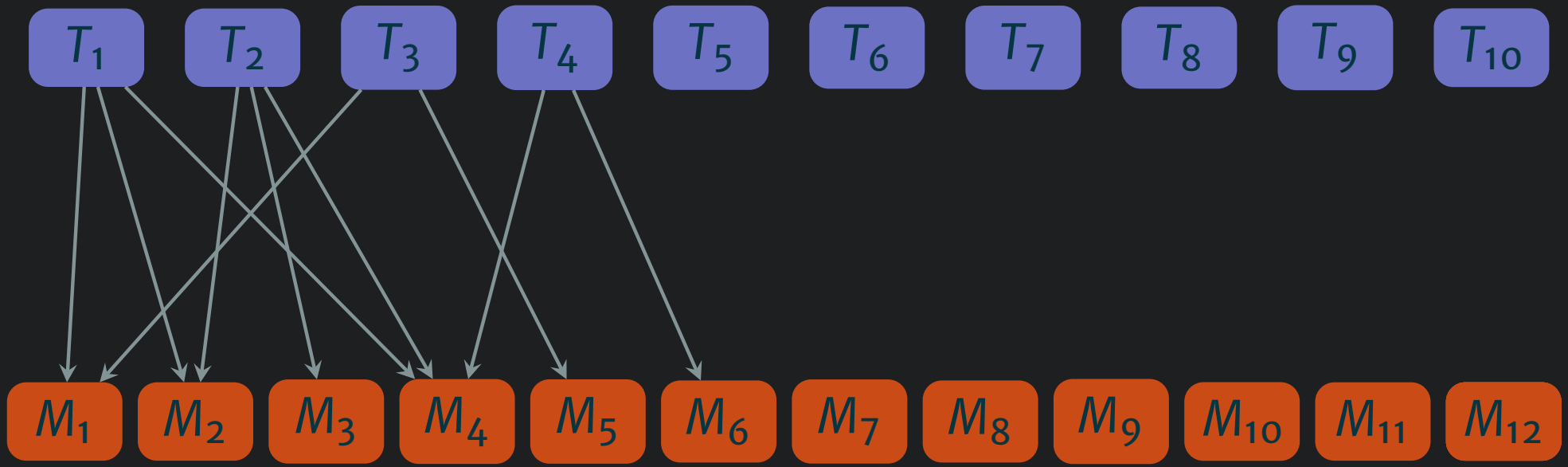

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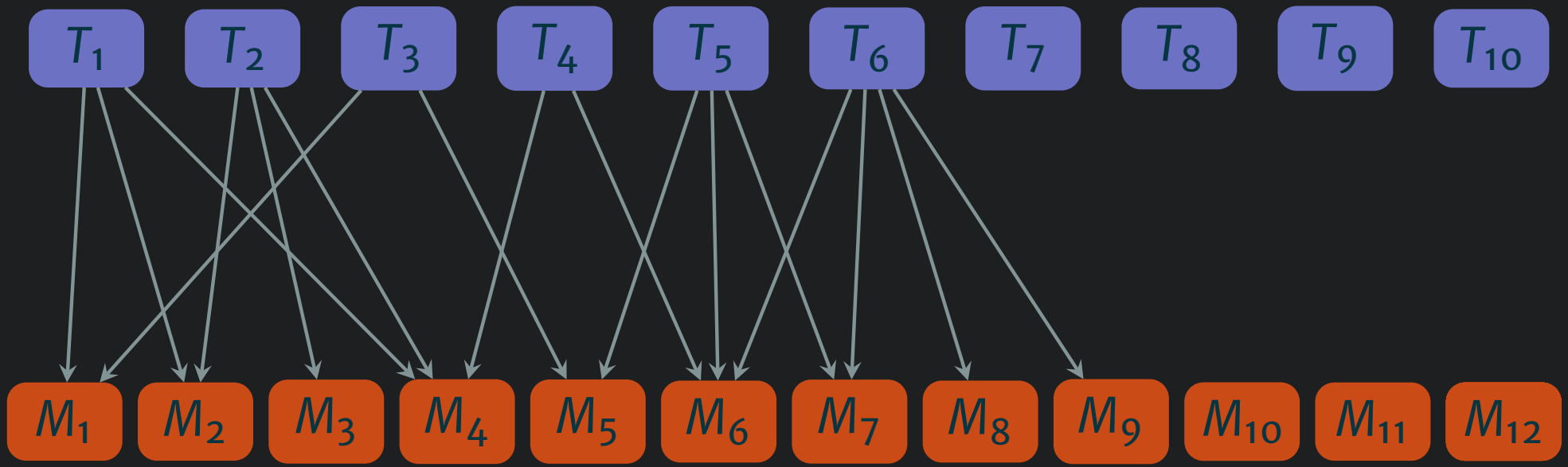

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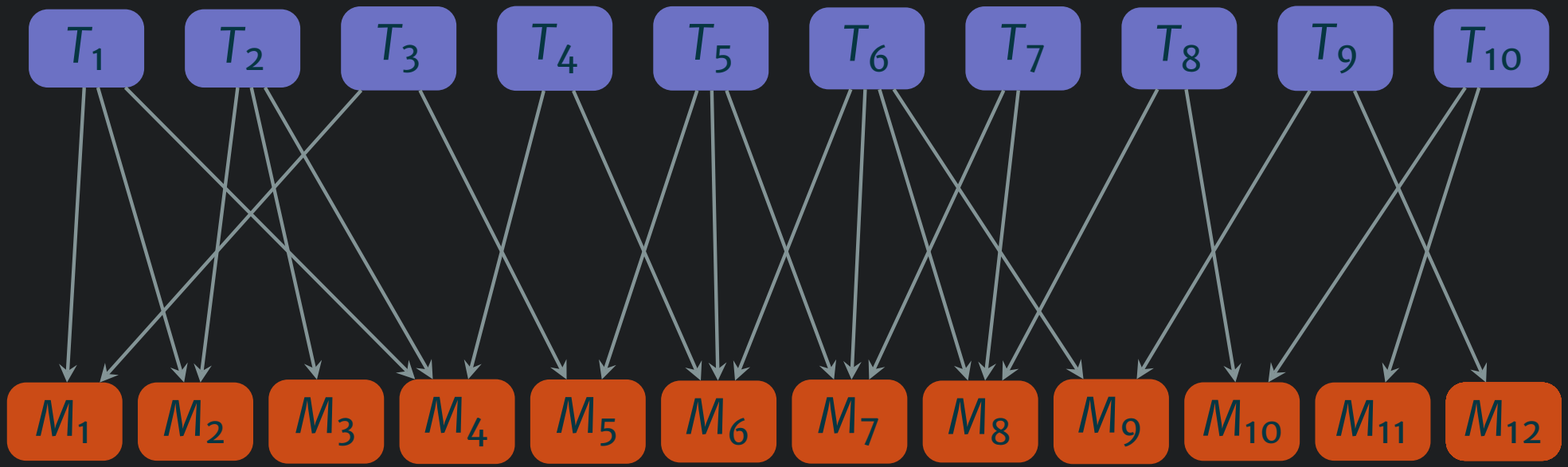

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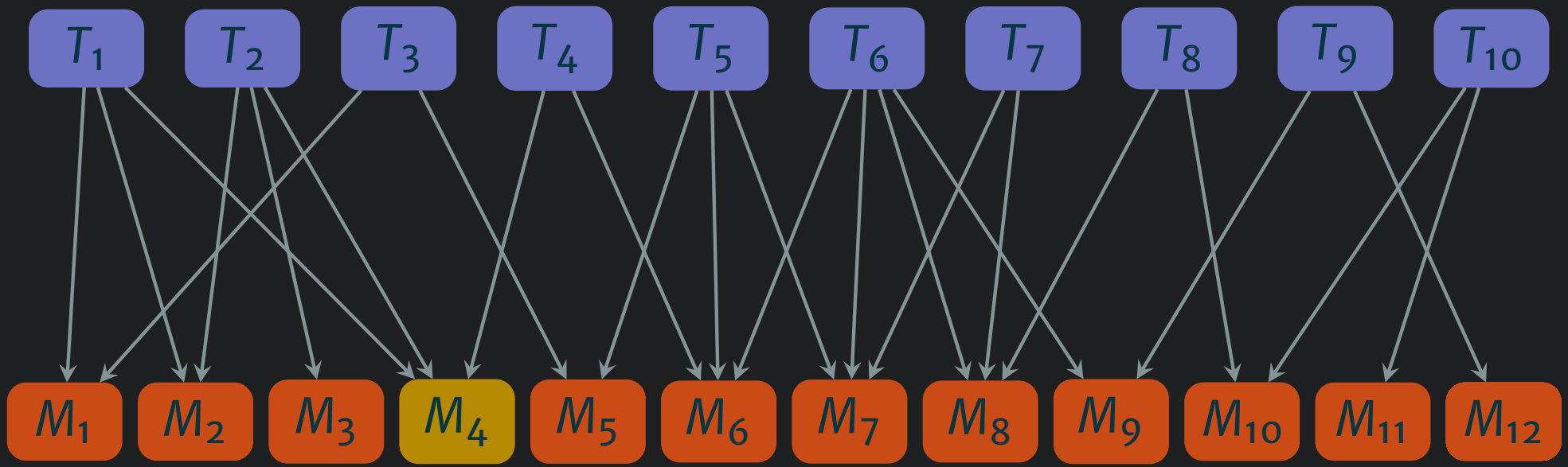

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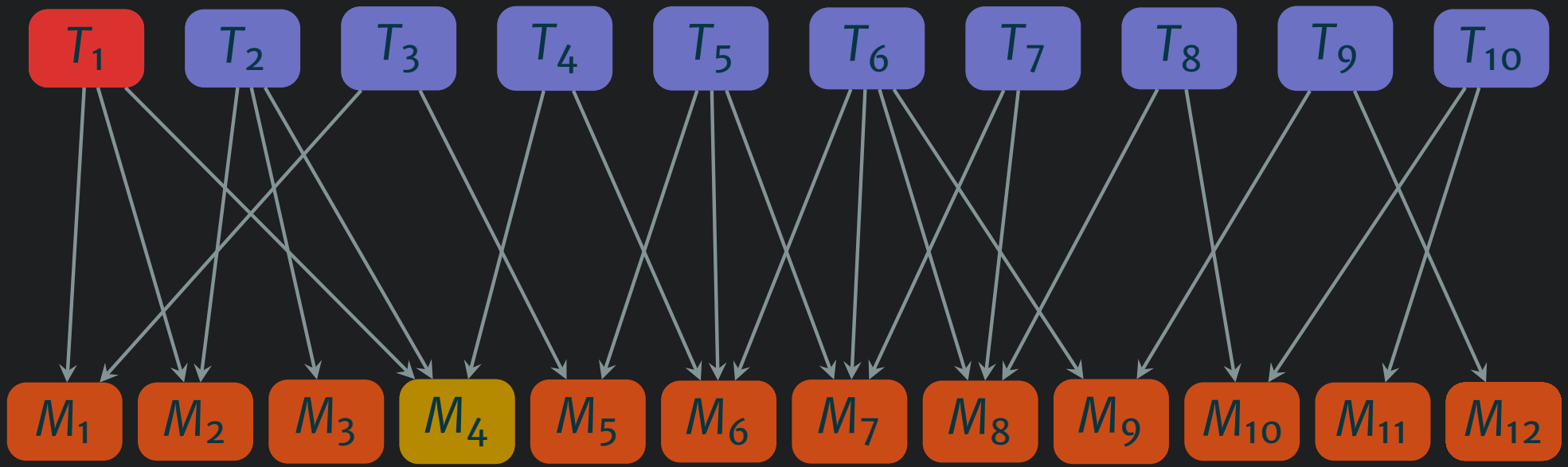

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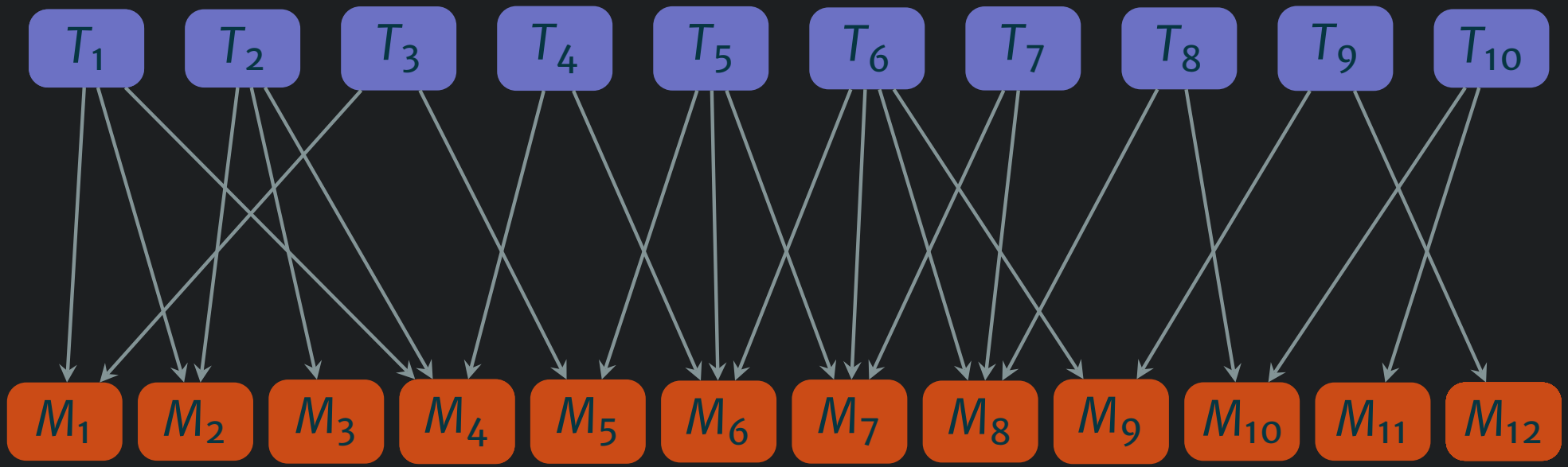

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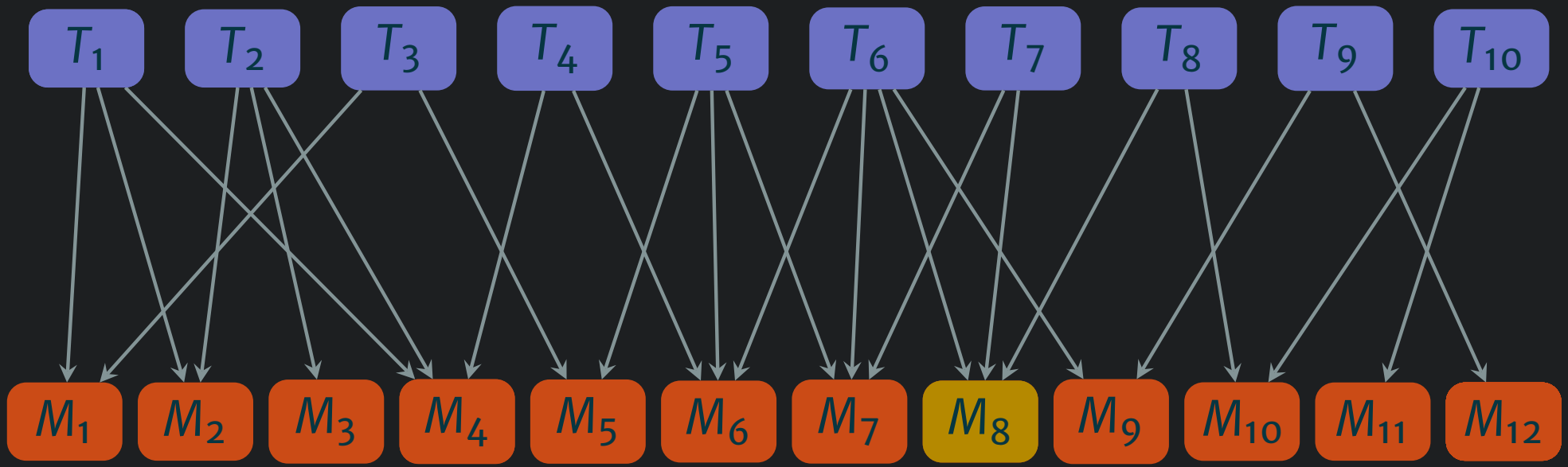

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Testing with EvoSuite

This prototype can automatically generate real JUnit test suites!

Evolutionary Testing

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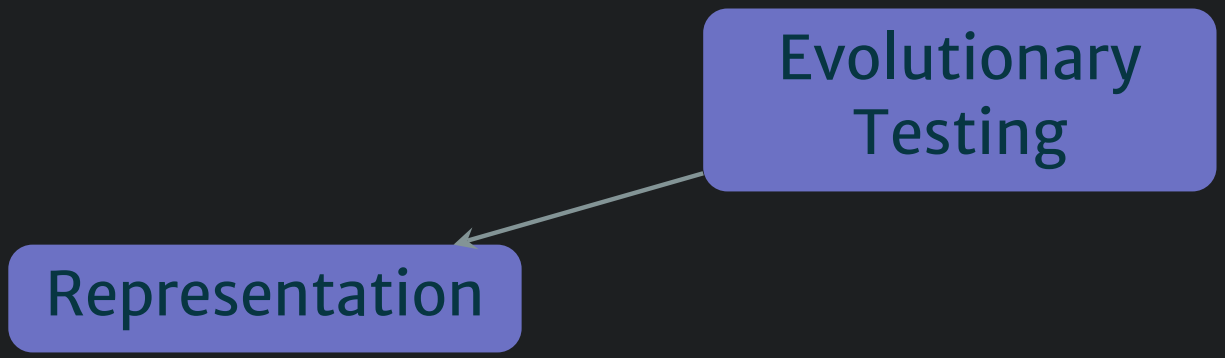

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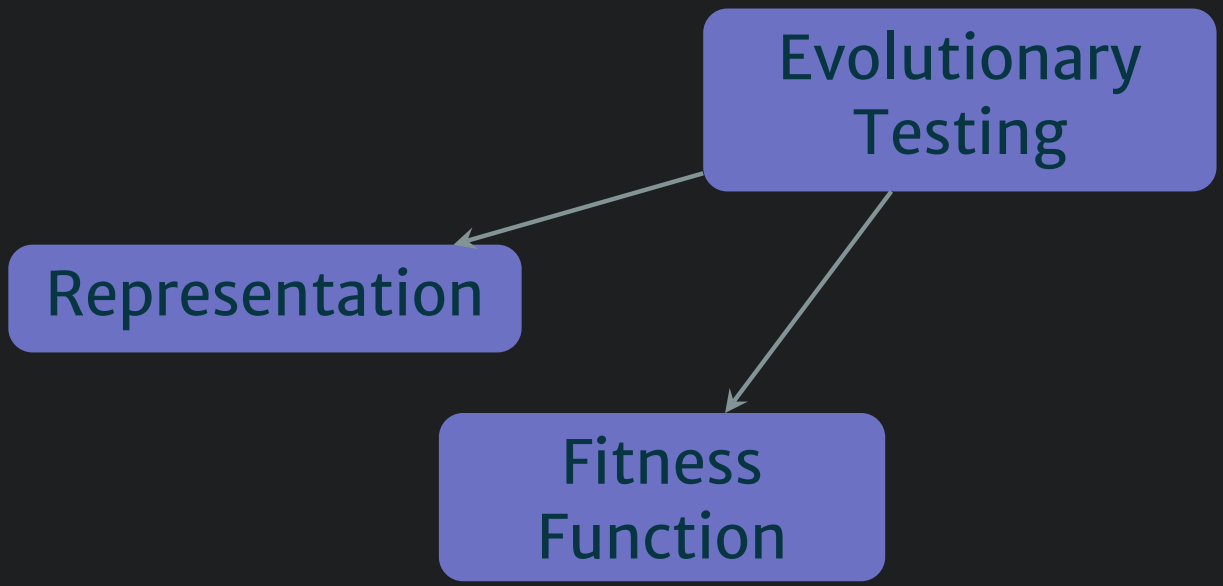

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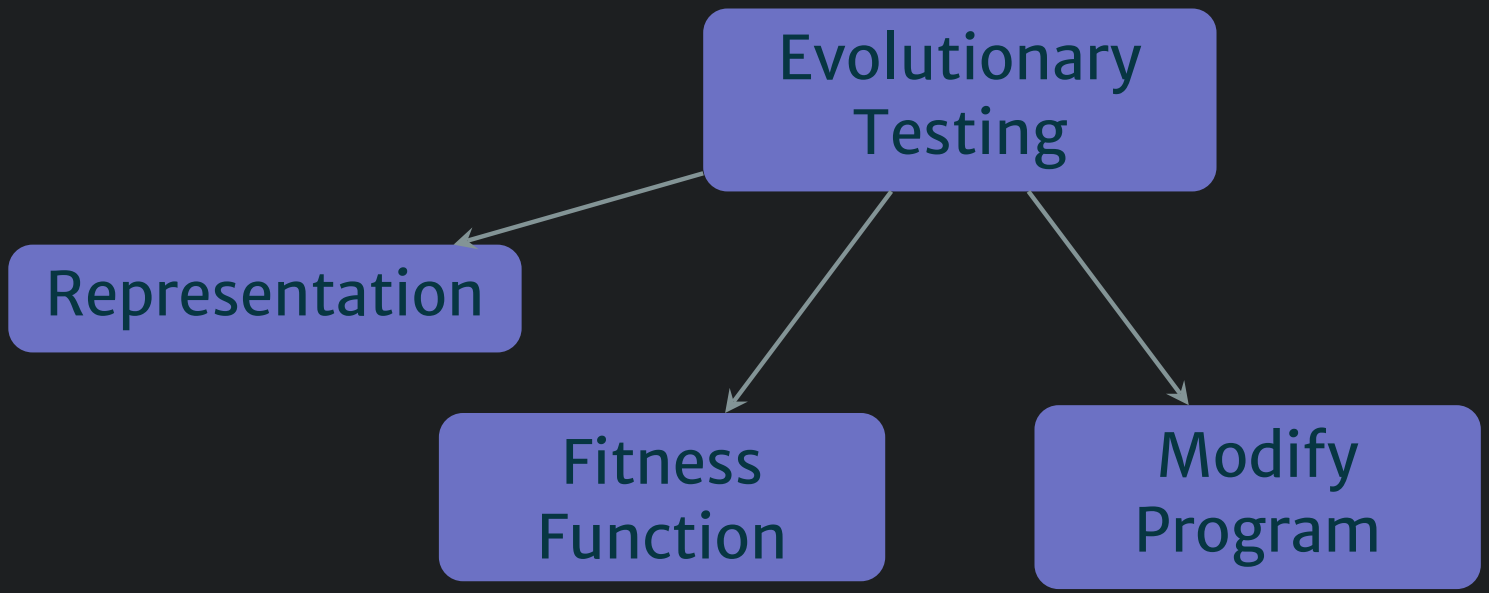

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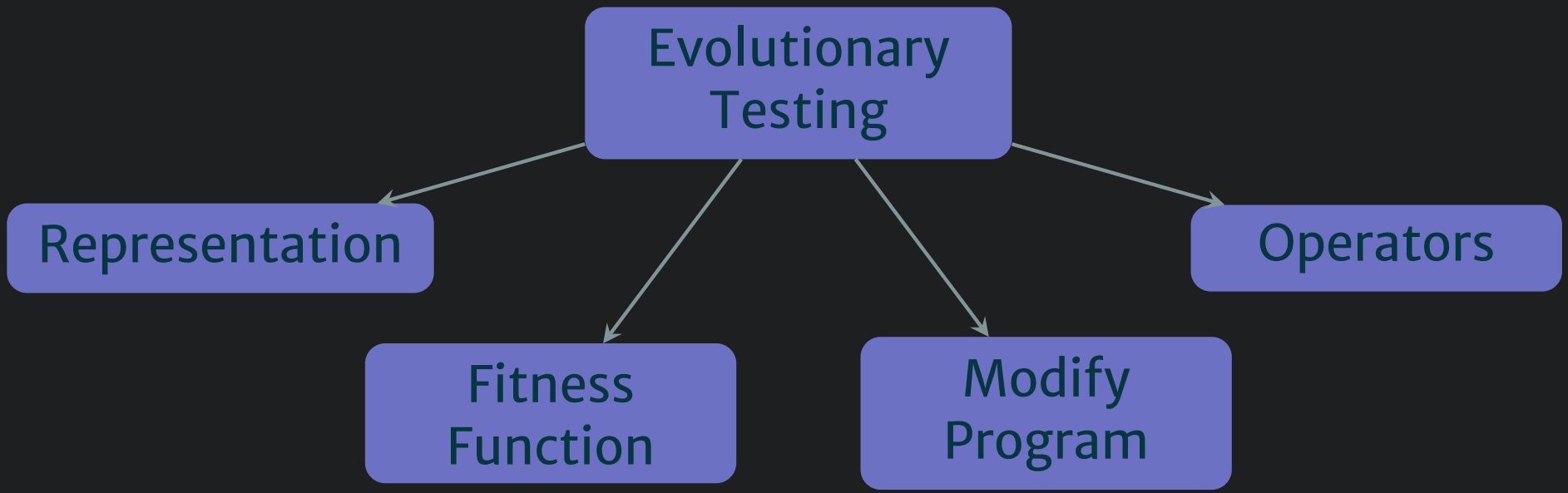

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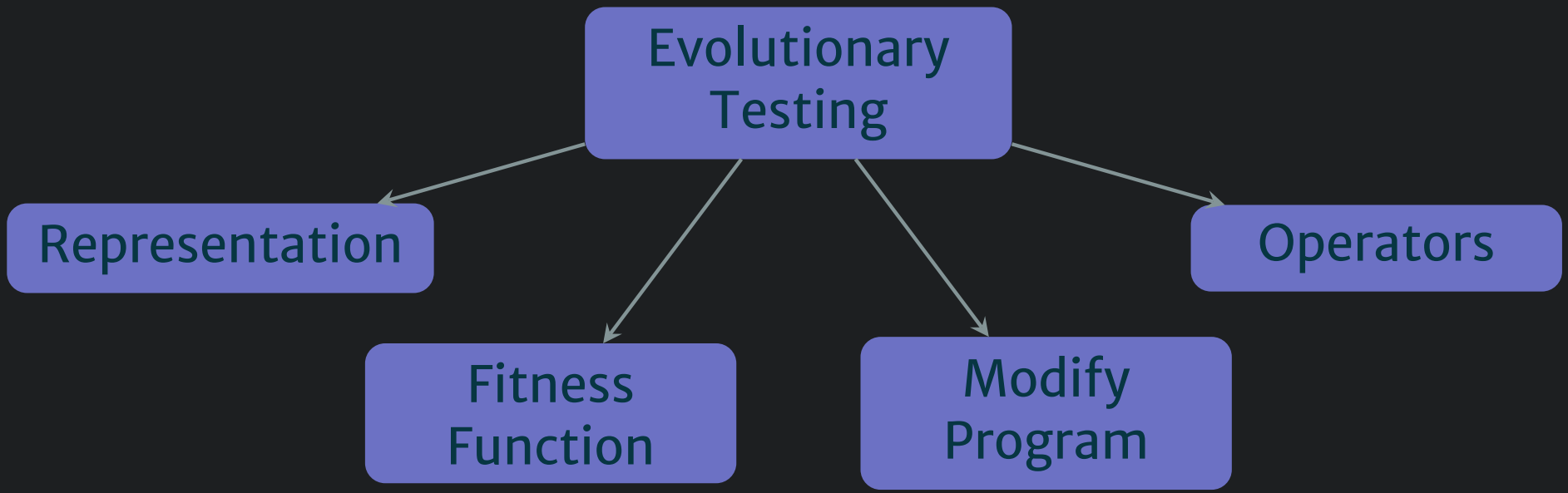
"1600 Faults in 100 Projects: Automatically Finding Faults While Achieving High Coverage with EvoSuite", *Empirical Software Engineering*



Configuring EvoSuite

This tool has many unique configurations — which are best?

EvoSuite's Configurations

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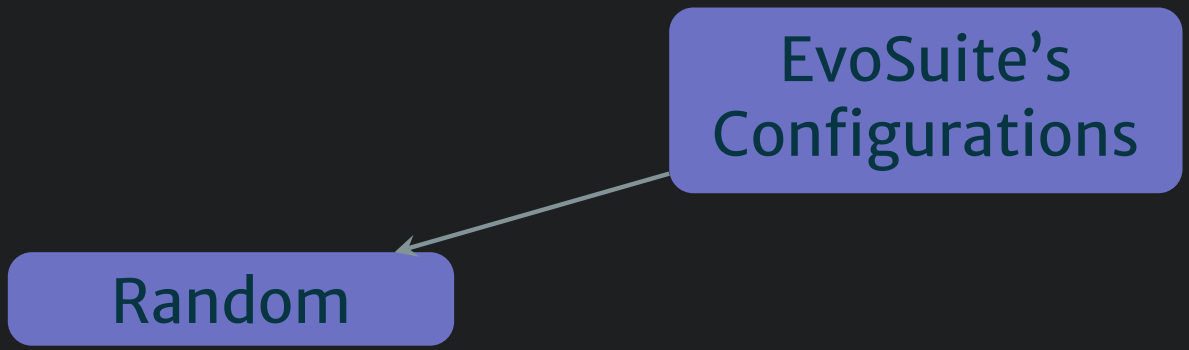

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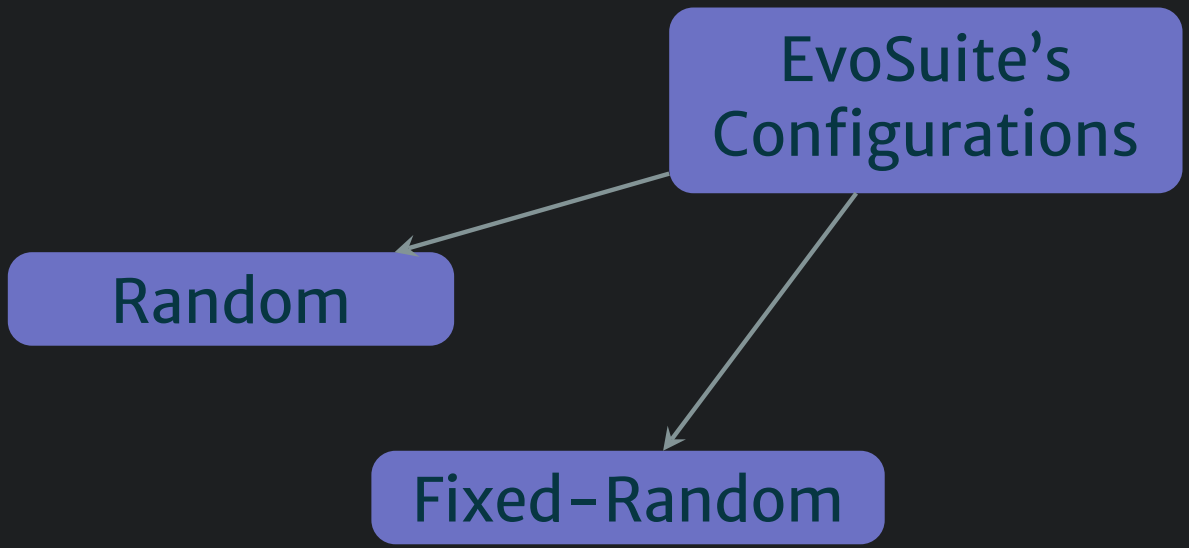

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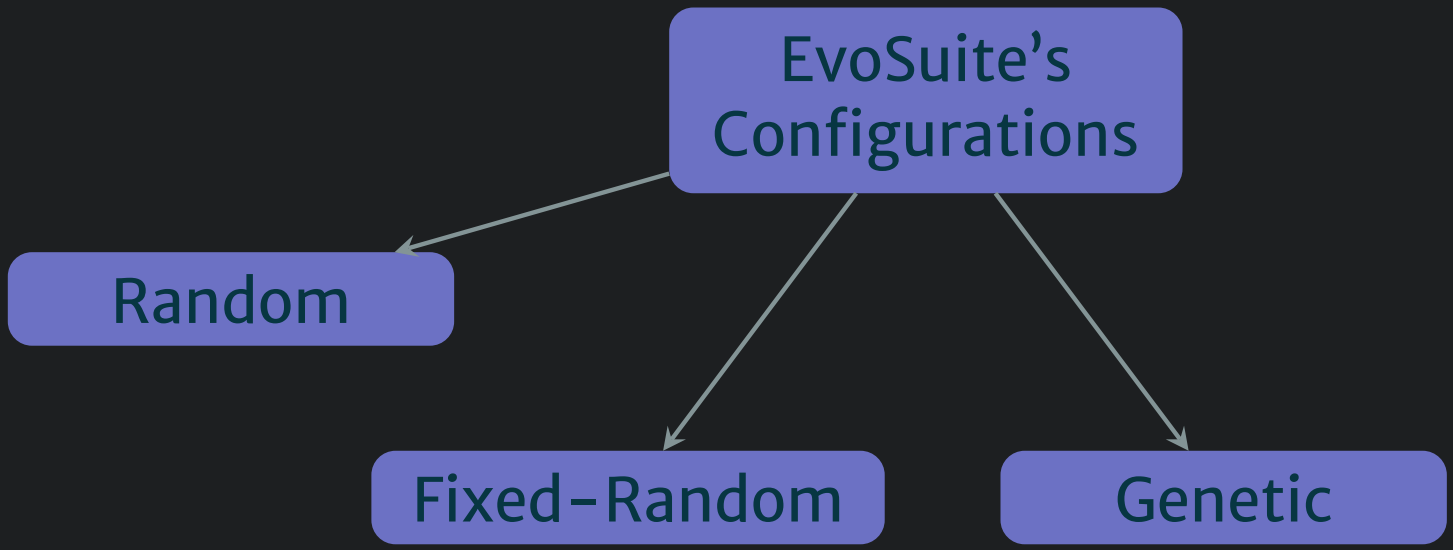

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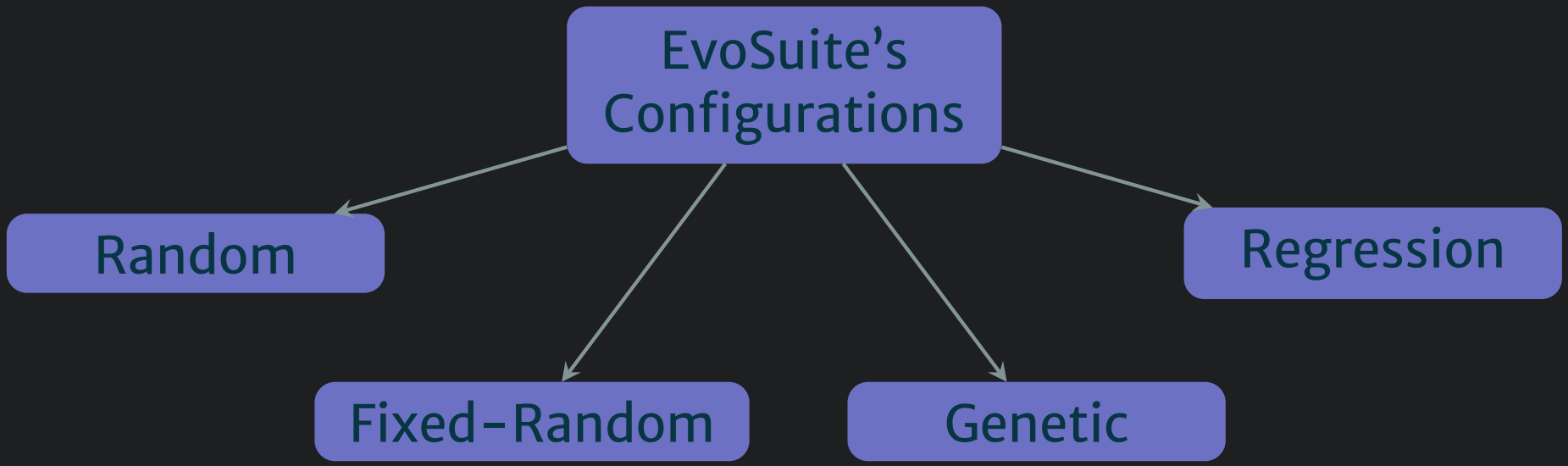
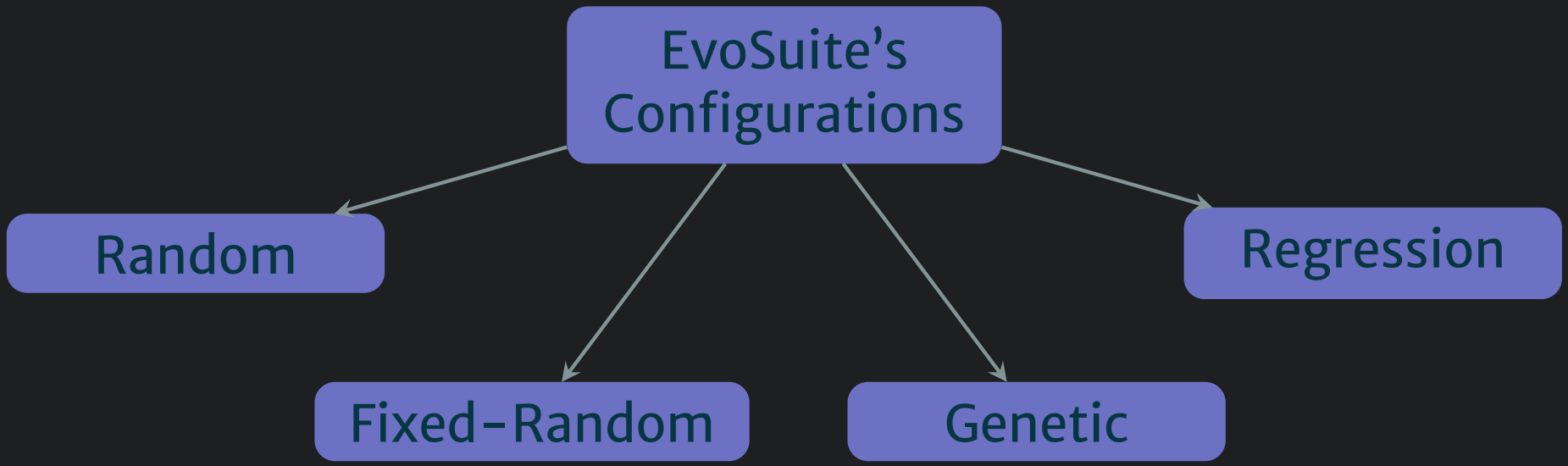


Configuring EvoSuite

This tool has many unique configurations — which are best?

The fitness function computes
branch coverage, *weak mutation score*,
or *strong mutation score* to guide
the search to the "best" test cases



A Test from EvoSuite

```
@Test
public void test001() throws Throwable {
  int int0 = 0;
  String string0 = Kinetic.computeVelocity(int0, int0);
  assertEquals("Undefined", string0);
  assertNotNull(string0);
  int int1 = 1262;
  String string1 = Kinetic.computeVelocity(int0, int0);
  int int2 = 5349;
  String string2 = Kinetic.computeVelocity(int1, int2);
  int int3 = 0;
  int int4 = 3;
  String string3 = Kinetic.computeVelocity(int3, int4);
  Kinetic kinetic0 = new Kinetic();
}
```

Important Questions

EvoSuite is an advanced, yet sometimes limited, testing tool

Will EvoSuite's test cases find the fault in the example program?

Important Questions

EvoSuite is an advanced, yet sometimes limited, testing tool

What is missing from the test cases that EvoSuite generates?

Important Questions

EvoSuite is an advanced, yet sometimes limited, testing tool

How does the *oracle problem* influence the effectiveness of EvoSuite?

Important Questions

EvoSuite is an advanced, yet sometimes limited, testing tool

What are the *fundamental* limitations of automated testing?

No Silver Bullet

Software tools are fundamentally limited — what is our hope?

> *There is no single development, in either technology or management technique, which by itself promises even one order-of-magnitude improvement within a decade in productivity, in reliability, in simplicity.*
>
> Frederick P. Brooks, Jr., *Proceedings of the IFIP Tenth World Computing Conference*, 1986

The Software Crisis

Solutions are available — but not always obvious or popular

What are the solutions to the software crisis?

The Software Crisis

Solutions are available — but not always obvious or popular

Great Designers

The Software Crisis

Solutions are available — but not always obvious or popular

Unremitting Care

The Software Crisis

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Incremental Advances

Final Admonishment

An epilogue called “Fifty Years of Wonder, Excitement, and Joy”

> *Too many interests, too many exciting opportunities for learning, research, and thought. What a marvelous predicament! Not only is the end not in sight, but the pace is not slackening. We have many future joys.*
>
> Frederick P. Brooks, Jr., *The Mythical Man-Month*, 1995