Software Testing

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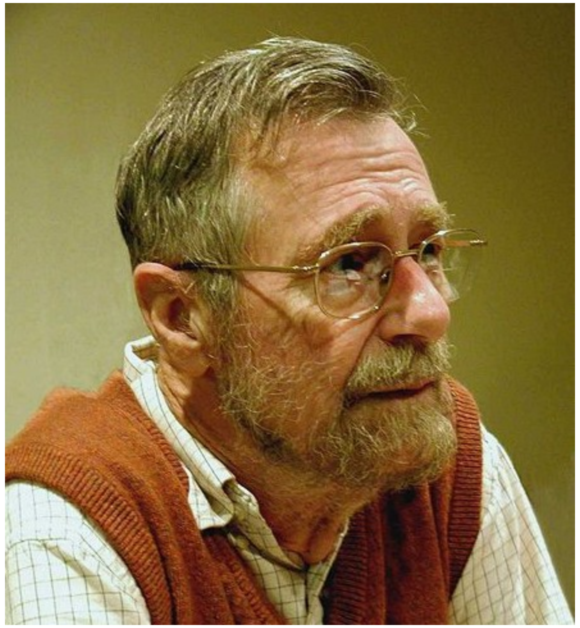
(Slide credits: George Candea, EPFL and Armando Fox, UCB)

Goals of Testing



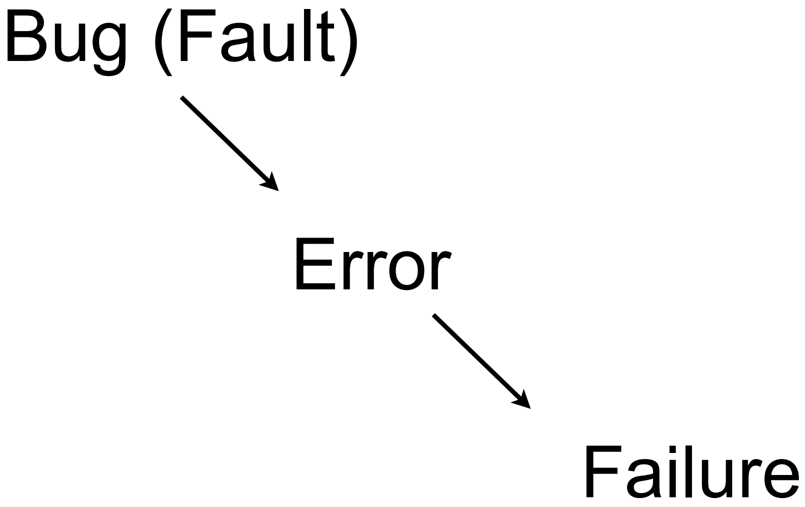
“Program testing can be used to show the presence of bugs, but never to show their absence.”

— Edsger Dijkstra

- Cannot prove correctness
  - *Testing = exec a program in order to find bugs*
  - *Ideally, the found bugs are easy to reproduce*
- *Risk management*
  - *Use testing to gain some level of confidence*
  - *Write tests to catch bugs as early as we can*

The Risk of Not Testing

- Industry-average bug density
  - 10-100 bugs / KLOC after coding
  - 0.5 – 5 bugs / KLOC not detected before delivery

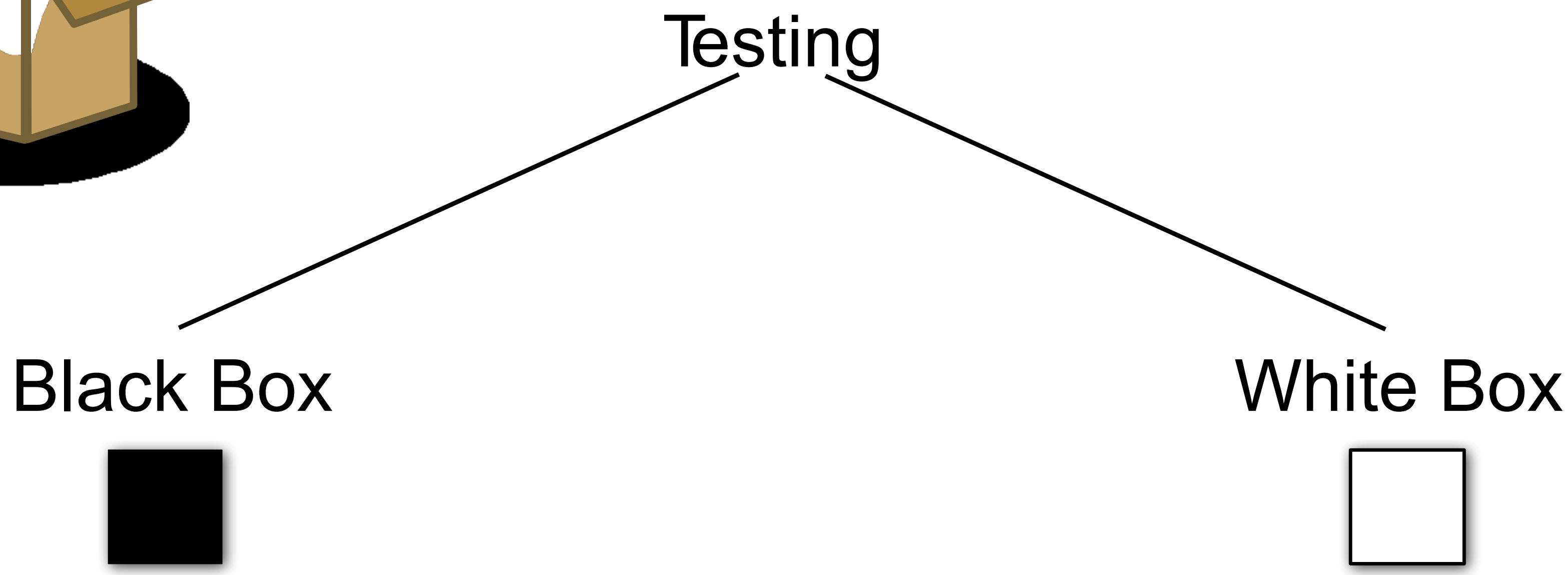


Bug (Fault)

Error

Failure

Types of Testing

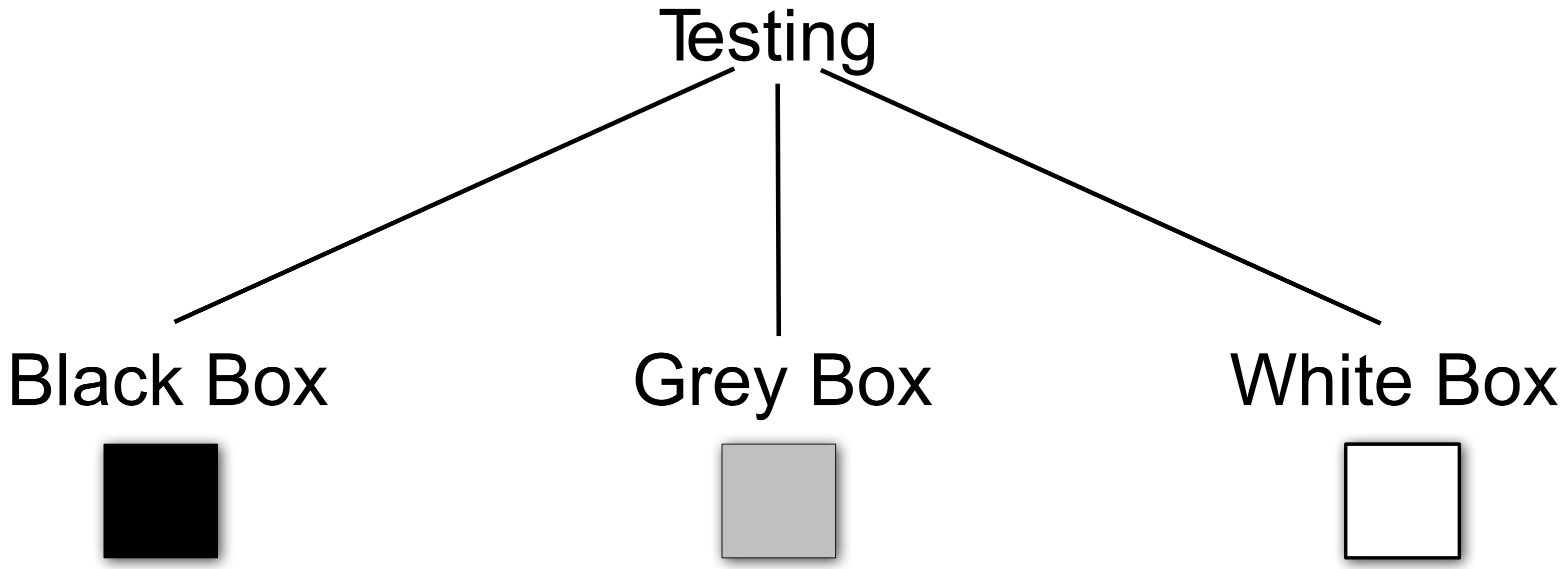


Testing

Black Box

White Box

Types of Testing



Testing

Black Box

Grey Box

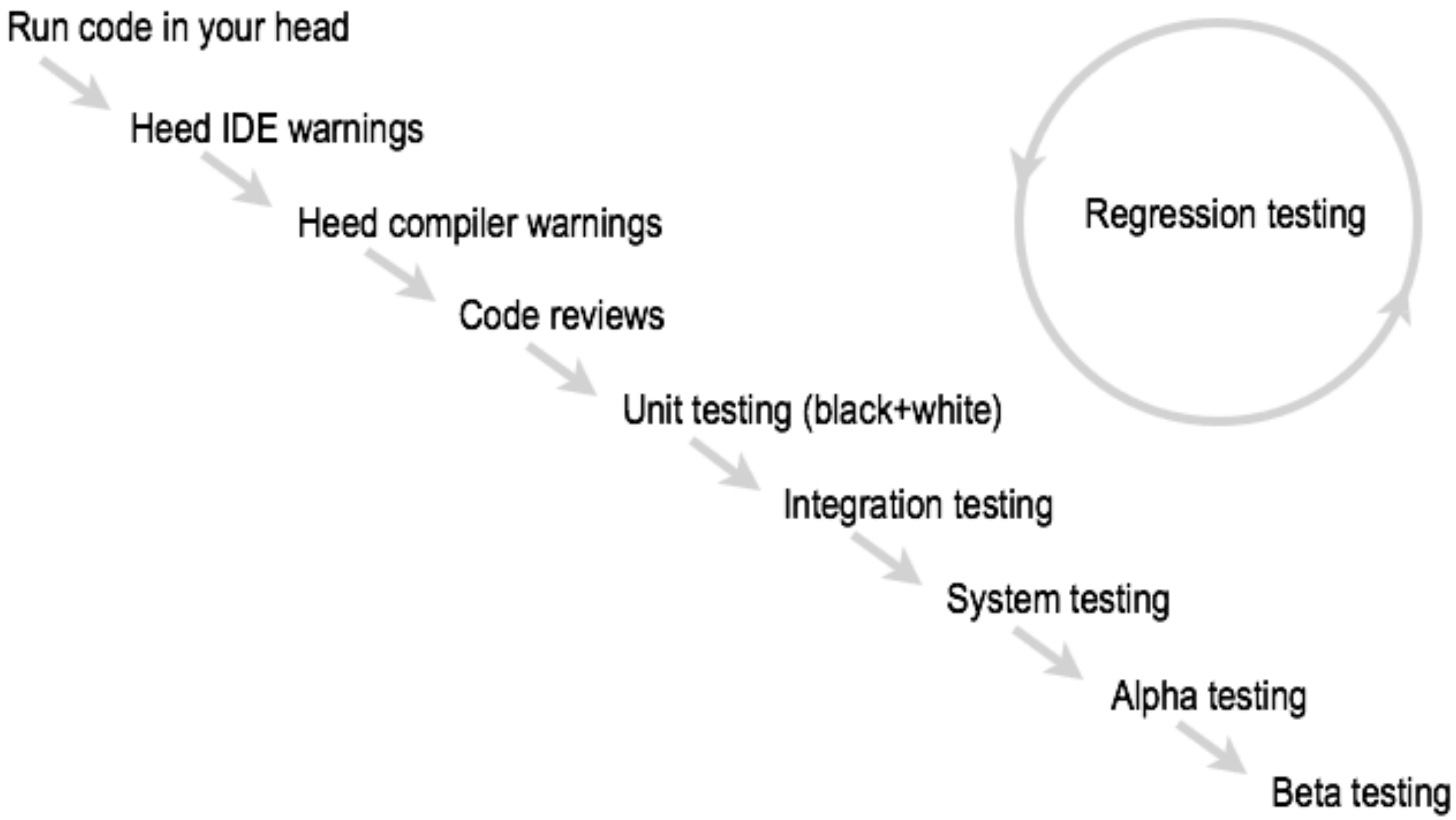
White Box

Boundaries & Equivalence Classes

- Equivalence classes
  - Once check -> two classes
    - E.g., “for input to be valid, it must be < 10”
    - Equivalence class #1: x < 10
    - Equivalence class #2: x >= 10
  - Two checks => three classes
    - E.g., valid x is in range (0, 100)
    - Equivalence class #1: 0 < x < 100
    - Equivalence class #2: x <= 0
    - Equivalence class #3: x >= 100
  - Test at least one value in each class

- Boundary testing
  - Most programs fail at input boundaries
  - If valid input in [min…max], test with
    - x = min and x = max
    - x < min and x > max
  - Same for boundaries of data structures (e.g., arrays)

Traditional Quality Assurance



Run code in your head

Heed IDE warnings

Heed compiler warnings

Code reviews

Unit testing (black+white)

Integration testing

System testing

Alpha testing

Beta testing

Regression testing

How much testing is enough?

- Bad: “Until time to ship”
- A bit better: (Lines of test) / (Lines of code)
  - 1.2–1.5 not unreasonable
  - often *much higher* for production systems
- Better question: “How thorough is my testing?”
  - Formal methods
  - Coverage measurement
  - We focus on the latter, though the former is gaining steady traction

Metrics

- X is covered if it is executed at least once by at least one test
- Coverage = % covered of total available

```
// ...
if (initialCapacity > MAXIMUM_CAPACITY) {
   initialCapacity = MAXIMUM_CAPACITY;
}
int capacity = 1;
while (capacity < initialCapacity) {
   capacity <<= 1;
}
// ...
```

- Tension between quality vs. cost
- Popular metric = coverage
  - X = methods -> method/function coverage
  - X = statements -> statement/line/basic-block coverage
  - X = branches -> branch coverage
  - X = paths -> path coverage

Using Coverage

```
static final int MAXIMUM_CAPACITY = 1 << 30;
static final float DEFAULT_LOAD_FACTOR = 0.75f;
// ...
public HashMap(int initialCapacity, float loadFactor)
{
  if (initialCapacity < 0)
    throw new IllegalArgumentException("Illegal initial capacity: " +
                                       initialCapacity);
  if (initialCapacity > MAXIMUM_CAPACITY)
    initialCapacity = MAXIMUM_CAPACITY;
  if (loadFactor <= 0 || Float.isNaN(loadFactor))
    throw new IllegalArgumentException("Illegal load factor: " +
                                       loadFactor);
  int capacity = 1;
  while (capacity < initialCapacity)
    capacity <<= 1;

  this.loadFactor = loadFactor;
  threshold = (int)(capacity * loadFactor);
  table = new Entry[capacity];
  init();
}
```

- x = new HashMap(64, 0.75);
  x = new HashMap(-1, 0.75);
  x = new HashMap(1+MAXIMUM_CAPACITY, -1);

- 100% statement coverage
  4.6% path coverage

Measuring Coverage—Basics

```
class MyClass
 def foo(x,y,z)
  if x
   if (y && z) then bar(0) end
  else
   bar(1)
  end
 end
 def bar(x) ; @w = x ; end
end
```

- S0: every method called
- S1: every method *from every call site*
- C0: every statement
- C1: every branch in both directions
- C1+decision coverage: every *subexpression* in conditional
- C2: every path (difficult, and disagreement on how valuable)

Identifying What’s Wrong

- How can you tell when code is less than beautiful, and how do you improve it?

- We can identify problems in two ways:
  - Quantitatively using software metrics
  - Qualitatively using code smells

Quantitative: Metrics

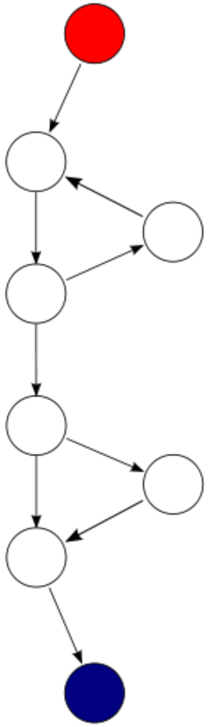
Metric	Target score
Code-to-test ratio	≤ 1:2
C0 (statement) coverage	90%+
Assignment-Branch-Condition score (ABC score)	< 20 per method
Cyclomatic complexity	< 10 per method (NIST)

- "Hotspots": places where *multiple metrics* raise red flags
- Take metrics with a grain of salt
  - – Like coverage, better for *identifying where improvement is needed* than for *signing off*

Cyclomatic complexity (McCabe, 1976)

- # of linearly-independent paths thru code = E– N+2P (edges, nodes, connected components)

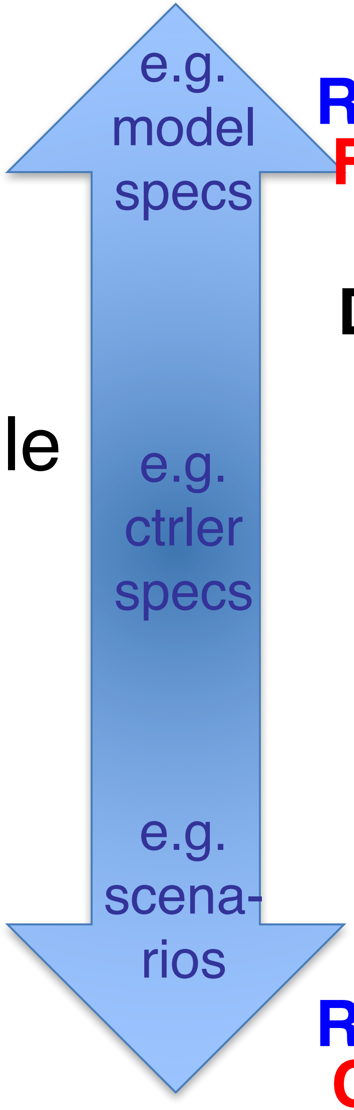
```
def mymeth
  while(...)
    ....
  end
  if (...)
    do_something
  end
end
```



- Here, E=9, N=8, P=1, so CC=3
- NIST (Natl. Inst. Stds. & Tech.): ≤10 /module

What kinds of tests?

- Unit (one method/class)
- Functional or module (a few methods/classes)
- Integration/system



e.g. model specs

e.g. ctrler specs

e.g. scenarios

Runs fast **High coverage**
Fine resolution

Many mocks;
Doesn’t test interfaces

Few mocks;
tests interfaces

Runs slow **Low coverage**
Coarse resolution

Going to extremes

- × "I kicked the tires, it works"
- × "Don't ship until 100% covered & green"
- ☑ use coverage to identify untested or undertested parts of code
- × "Focus on unit tests, they're more thorough"
- × "Focus on integration tests, they're more realistic"
- ☑ each finds bugs the other misses

Other Kinds of Testing

- Acceptance testing
  - Performed by user upon receiving product
- Smoke/sanity testing
  - Quick test to check for serious errors
  - E.g., does it compile? Does it do the basic stuff?
- Compatibility testing
  - Does app work with other hw/sw?
  - E.g., web app with smartphone
- Fault injection
  - Does app work in the presence of bad inputs, bad returns from libraries, etc.?
  - Can inject exceptions, simulate failures
- Performance testing
  - Goal is to check performance characteristics
  - Load/stress/scalability testing
- Usability testing
  - Can users accomplish their objectives with the software as designed?

Other testing terms you may hear

- Mutation testing: if introduce deliberate error in code, does some test break?
- Fuzz testing: 10,000 monkeys throw random input at your code
  - Find ~20% MS bugs, crash ~25% Unix utilities
  - *Tests app the way it wasn't meant to be used*
- DU-coverage: is every pair <define x/use x> executed?

QA in Agile

- Antiquated for SaaS apps: Quality assurance is the responsibility of a separate group rather than the result of a good process
- Developers bear far more responsibility for testing their own code and participating in reviews
- QA engineers have largely shifted to improving the testing tools infrastructure, helping developers make their code more testable, and verifying that customer-reported bugs reproducible

Testing Today

- Far more automated
- Tests are self-checking
  - The test code itself can determine if the code being tested works or not
- A high degree of automation is key to supporting the five principles for creating good tests

Unit tests should be FIRST

- **F**ast
- **I**ndependent
- **R**epeatable
- **S**elf-checking
- **T**imely

Unit tests should be FIRST

- **F**ast: run (subset of) tests quickly (since you'll be running them *all the time*)
- **I**ndependent: no tests depend on others, so can run *any subset* in *any order*
- **R**epeatable: run N times, get same result (to help isolate bugs and enable automation)
- **S**elf-checking: test can *automatically* detect if passed (*no human checking* of output)
- **T**imely: written about the same time as code under test (with TDD, written *first!*)

(Conventional) Unit Testing Tool
(Used for unit/functional testing)

- xUnit: a framework to write repeatable tests
  - JUnit
  - NUnit
  - CUnit
  - Ruby Test::Unit
  - Python unittest
  - …
- Creating tests: annotation, inheritance, DSL

xUnit

- Creating tests
  - Annotation: Java, C#, …
  - Inheritance: ruby, python, …

- Automatic checking using assertions
  - Tests that exercise happy paths
  - Tests that exercise sad paths

Example: JUnit

(Ref. https://github.com/junit-team/junit/wiki/Getting-started)

Calculator.java

```
public class Calculator {
  public int evaluate(String expression) {
    int sum = 0;
    for (String summand: expression.split("\\+"))
      sum += Integer.valueOf(summand);
    return sum;
  }
}
```

CalculatorTest.java

```
import static org.junit.Assert.assertEquals;
import org.junit.Test;

public class CalculatorTest {
  @Test
  public void evaluatesExpression() {
    Calculator calculator = new Calculator();
    int sum = calculator.evaluate("1+2+3");
    assertEquals(6, sum);
  }
}
```

Example: A Successful Test

```
java -cp .:junit-4.XX.jar:hamcrest-core-1.3.jar org.junit.runner.JUnitCore CalculatorTest
```

```
JUnit version 4.12
.
Time: 0,006

OK (1 test)
```

(you will use a software project management tool, which simplifies running tests.
E.g., make, maven, rake)

Example: A Failing Test

- Replace the line `sum += Integer.valueOf(summand);`

  with `sum -= Integer.valueOf(summand);`

```
java -cp .:junit-4.XX.jar:hamcrest-core-1.3.jar org.junit.runner.JUnitCore CalculatorTest
```

```
JUnit version 4.12
.E
Time: 0,007
There was 1 failure:
1) evaluatesExpression(CalculatorTest)
java.lang.AssertionError: expected:<6> but was:<-6>
  at org.junit.Assert.fail(Assert.java:88)
  ...

FAILURES!!!
Tests run: 1,  Failures: 1
```

← Which test failed

← What went wrong

Example. Python Unit Test

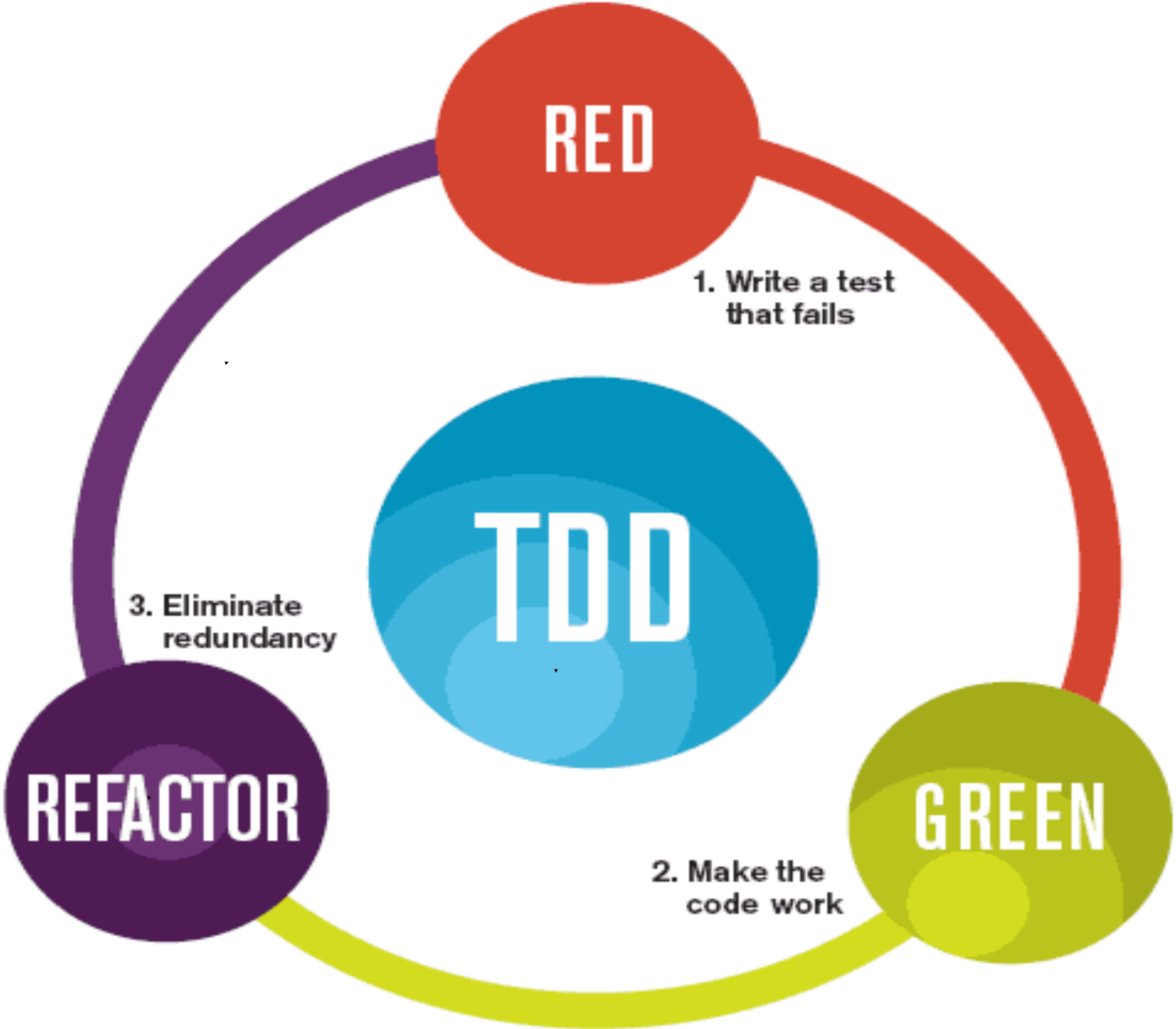
```python
import unittest

class TestStringMethods(unittest.TestCase):

    def test_upper(self):
        self.assertEqual('foo'.upper(), 'FOO')

    def test_isupper(self):
        self.assertTrue('FOO'.isupper())
        self.assertFalse('Foo'.isupper())

    def test_split(self):
        s = 'hello world'
        self.assertEqual(s.split(), ['hello', 'world'])
        # check that s.split fails when the separator is not a string
        with self.assertRaises(TypeError):
            s.split(2)

if __name__ == '__main__':
    unittest.main()
```

```
...
-------------------------------------
Ran 3 tests in 0.000s OK
```

TDD

How To Do TDD

TDD
ALL CODE IS GUILTY
UNTIL PROVEN INNOCENT


RED
1. Write a test that fails
TDD
GREEN
2. Make the code work
REFACTOR
3. Eliminate redundancy

TDD Principles

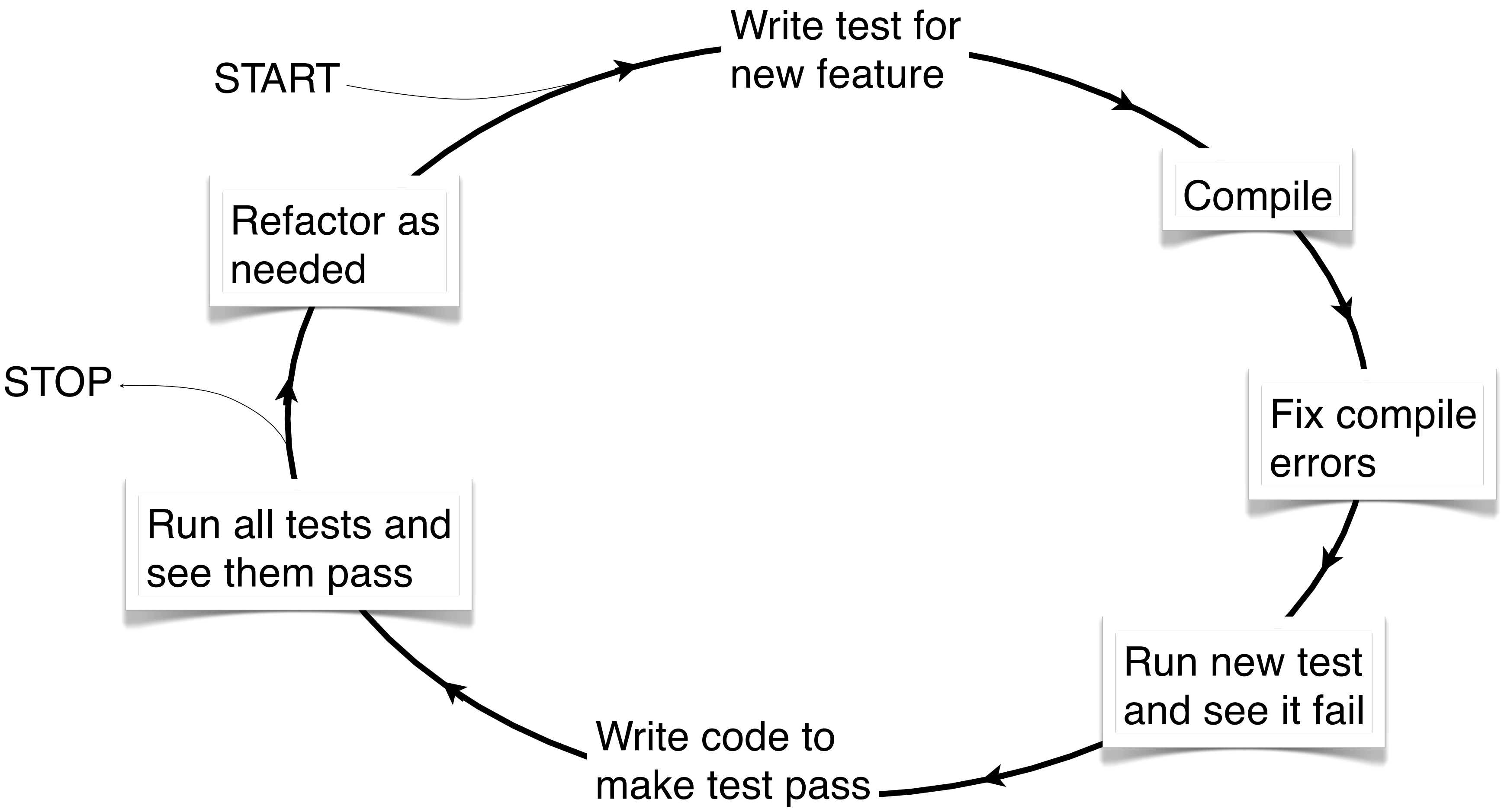
- You write code in order to make the tests pass
  - You don’t write tests in order to check code you wrote
  - Tests drive the design and implementation
- Invest time early in writing tests => save time later
- It’s not a silver bullet

TDD Reduces Bug Density

Metric description	IBM: Drivers	Microsoft: Windows	Microsoft: MSN	Microsoft: VS
Defect density of comparable team in organization but not using TDD	W	X	Y	Z
Defect density of team using TDD	0.61W	0.38X	0.24Y	0.09Z
Increase in time taken to code the feature because of TDD (%) [Management estimates]	15 – 20%	25-35%	15%	20-25%

Ref. Nagappan et al., "Realizing quality improvement through TDD: results and experiences of four industrial teams", Empirical Software Engineering, 13(3):289–302, Feb 2008, Software Engineering.

How To Do TDD



Write test for new feature

Compile

Fix compile errors

Run new test and see it fail

Write code to make test pass

Run all tests and see them pass

Refactor as needed

When To Use TDD?

- TDD is not a silver bullet
- Good candidates
  - User interface behavior (button enabling, button logic, models, etc.)
  - Business logic
  - Pretty much any Java class / method
- Bad candidates
  - User interface appearance (layout, colors, etc.)
  - Client/server interactions (will need to do mock testing)
  - Large code bases, legacy code

Tips and Tricks

- Code coverage > 90% (otherwise why doing TDD?)
- Start TDD from the beginning of the project
- Add a test for every problem found
- Discipline
- Continuous testing
- Efficient tests
- Track metrics