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MSE | MASTER OF SCIENCE IN ENGINEERING

09 - XUnit Testing Patterns

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Learning goals

- **The student…**
  - appreciates the importance of automated builds and testing
  - applies automated tests at different levels (unit, functional, system)
  - knows four phases of an automated test and create test accordingly
  - understands how to improve test coverage by using test stubs and mock objects
  - can design software for greater testability
  - can detect "test smells" that imply refactoring tests for greater simplicity, robustness, and execution speed.

Is that Testing?

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- **“it compiles!”**
  - no syntax error detected by compiler
- **“it runs!”**
  - program can be started
- **“it doesn’t crash”**
  - … immediately with useful input
- **“it runs even with random input”**
  - the cat jumped on the keyboard
- **“it creates a correct result”**
  - a single use case is working with a single reasonable input

What is Testing?

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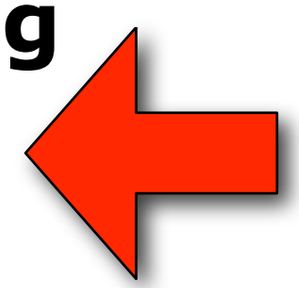
- **All on the previous slide, but much more!**
- **Manual Testing**
  - sometimes useful and needed
    - UI testing, usability testing, user testing with a plan
  - but automation is much better!
    - no ad-hoc testing!
- **Automated Testing**
  - unit tests
  - functional tests
  - integration, load and performance tests
  - code quality tests (lint, compiler, code checkers)



Today's topic

Unit Testing

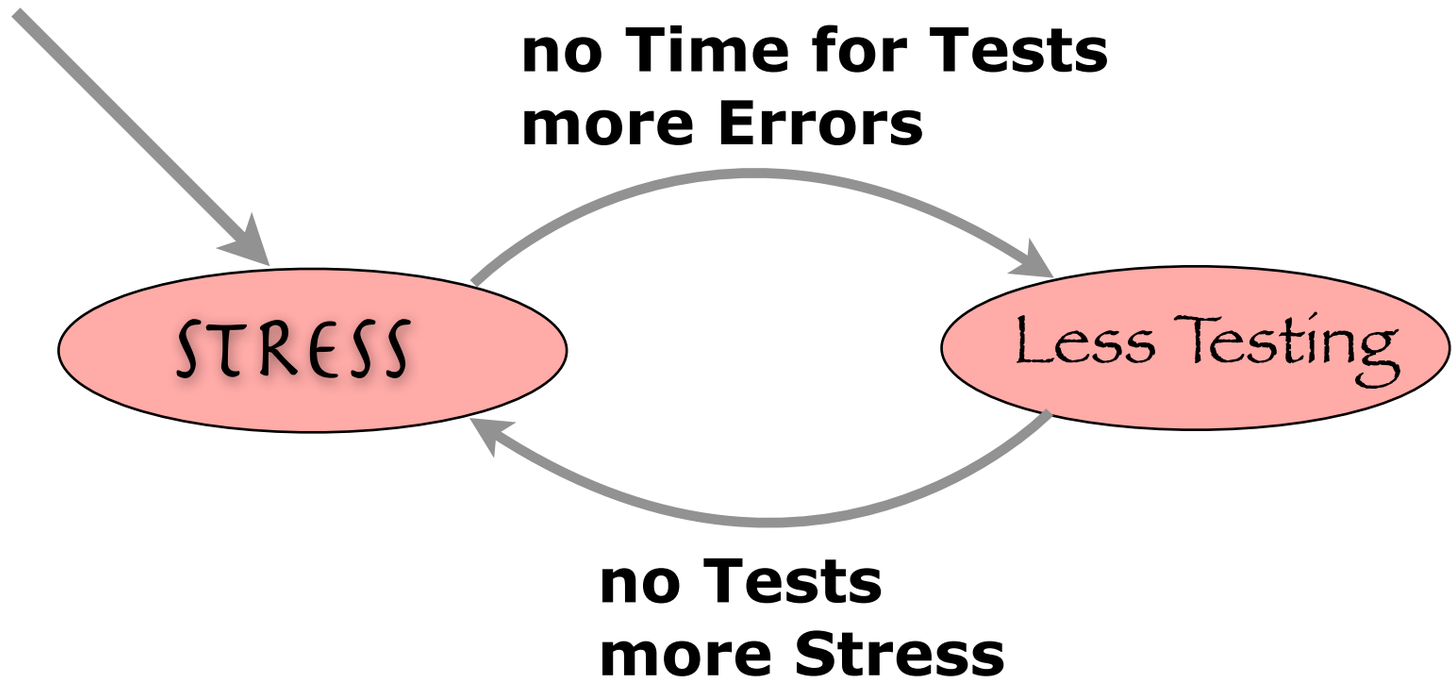
- **Is not "Testing" in the classic sense:**

> Program testing can be used to show the presence of bugs, but never to show their absence! - *E.W. Dijkstra*

But

- **Is Built-In Quality Assurance**
- **Allows Regression Testing**
- **Enables Refactoring**
- **Is Change Insurance**
- **Improves Built Automation**

Vicious Circle: Manual Testing - Stress



- **Automate tests and run them often!**

Test Automation

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- **Advantages**
  - repeatability - regression
    - insurance for change, portability, extension
    - no (or very low) cost for re-testing
  - well-defined specification given by executable tests
    - test-code is program code with well defined semantics
  - repeatability, repeatability, repeatability, ...
- **Drawbacks**
  - need to write and maintain also test code
    - tests also require refactoring
  - test code is program code
    - is the right thing tested? (instead of implemented?)

Why and When?

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- **Become "test-infected". Once you are used to unit testing your code, you get addicted.**
  - That's a fact I observed many times.
  - You'll regret every piece of code you want to change where you don't have tests for
- **Write your tests close to writing your code!**
  - Some say: Test-First or Test-Driven Design (TDD)
  - modern: Behavior-Driven Design (BDD)
  - Retrofitting existing code with tests will show you its design deficiencies
    - hard to write tests -> entangled design, too complex
    - easy to write tests -> orthogonal design, simpler
- **At least write tests before you change code!**

How do I write good Unit Tests (GUTs)?

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- **Ask yourself the following questions: (among others about your coding)**

- **If the code is correct, how would I know?**
- **How can I test this?**
- **What else could go wrong?**
- **Could a similar problem happen elsewhere?**

  - Code coverage tools help for seeing what code is really tested --> e.g. eclEMMA

Why even more on Test Automation?

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- **Writing good automated tests is hard.**
- **Beginners are often satisfied with "happy-path" tests**
  - error conditions and reactions aren't defined by the tests
    - coverage tools help here!
- **Code depending on external stuff (DB, IO, etc) is hard to test. How can you test it?**
- **Will good tests provide better class design?**
- **How can tests be designed well?**

Principle of Automated Tests Triple-A (AAA)

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1. **Arrange**
   - initialize object(s) under test
2. **Act**
   - call functionality that you want to test
3. **Assert**
   - assert that results are as you expect

Remember: "Triple-A: arrange, act, assert"

Terminology xunitpatterns.com

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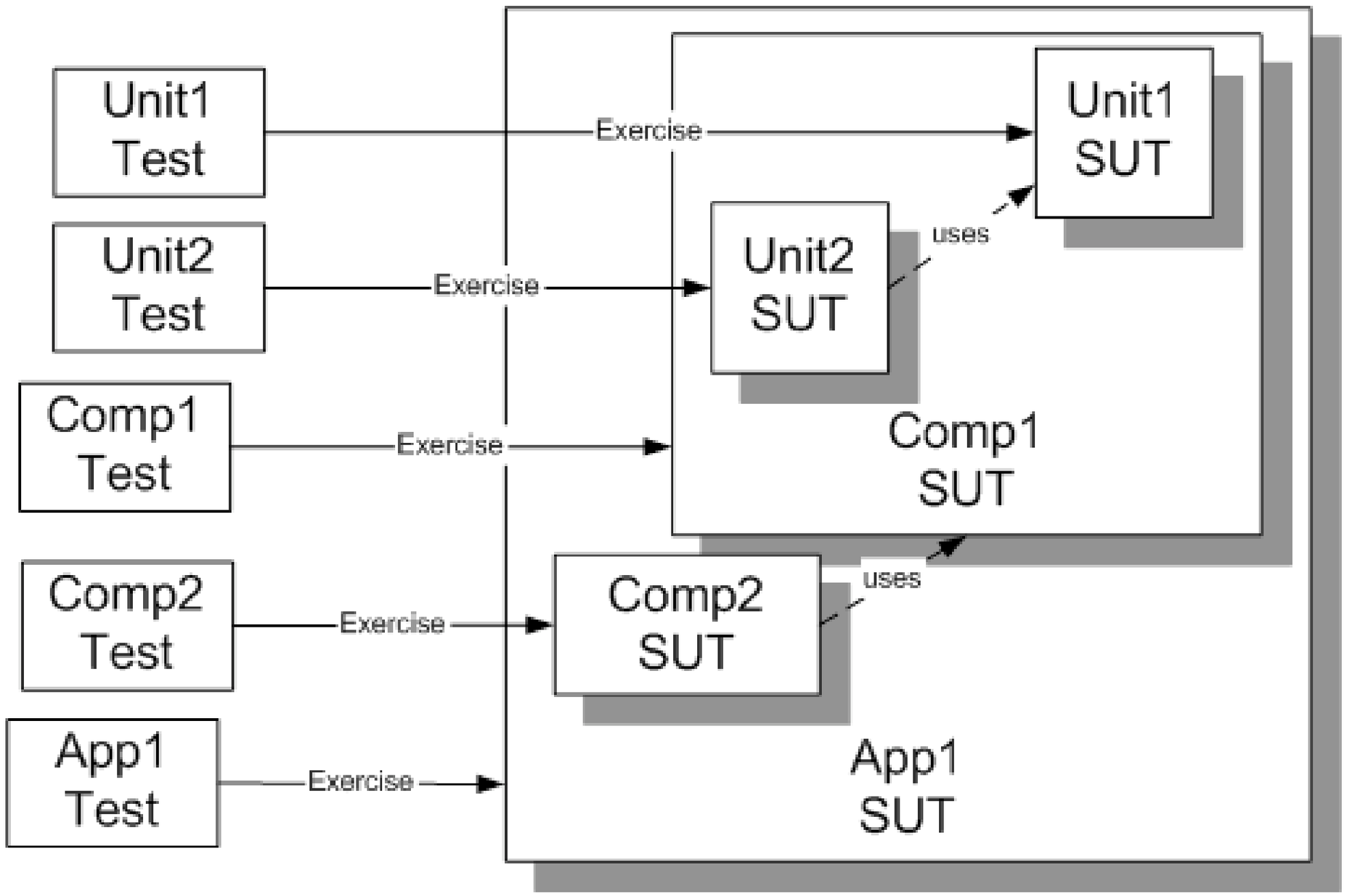
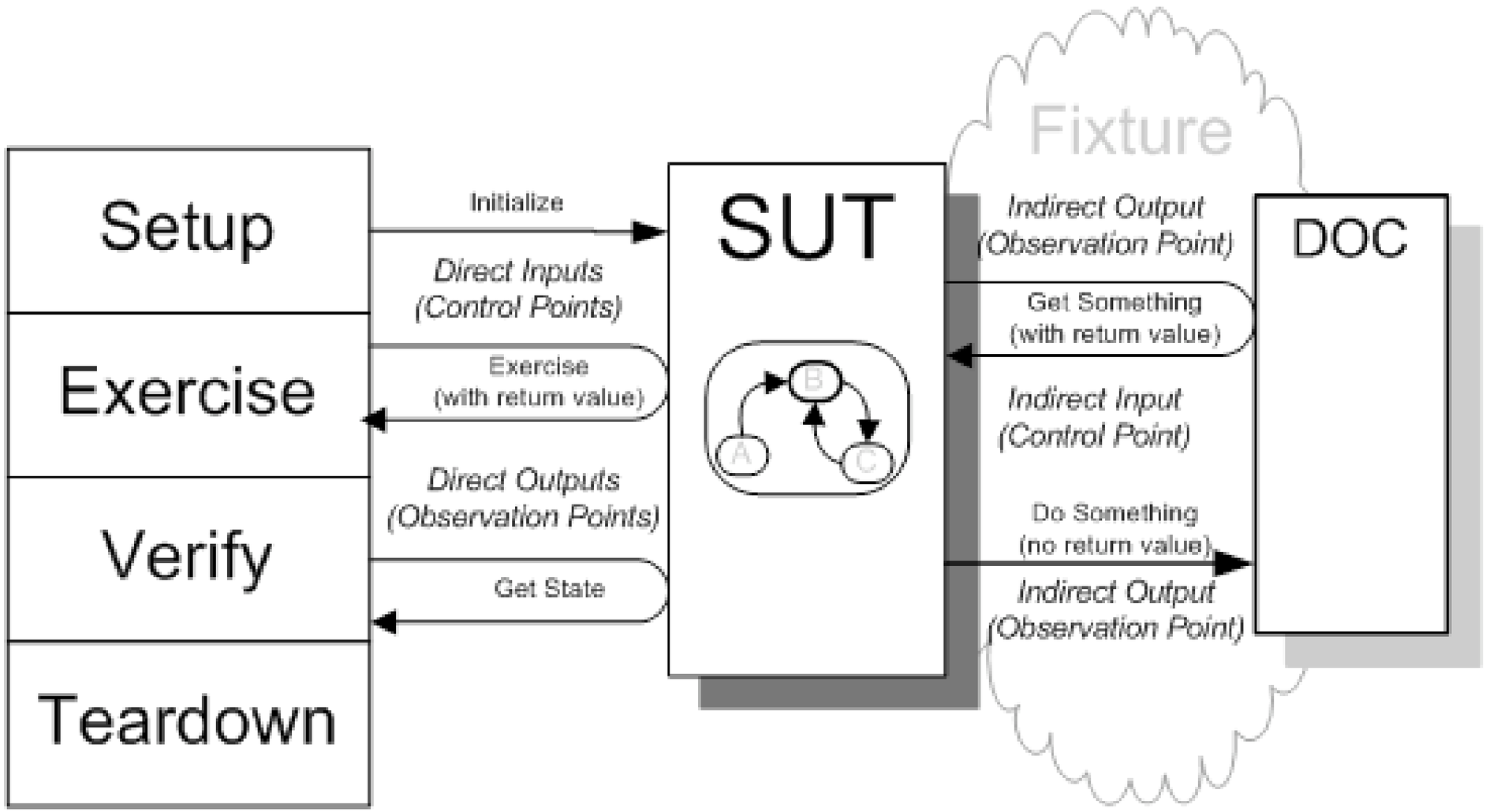
- **SUT system under test**



Test Case Structure: Four Phase Test



- compare that to AAA ---> another similarity
- Source: xunitpatterns.com

How many unit tests should I write?

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- **Test anything that might break**
  - don’t write tests for code that cannot break
- **Test everything that does break**
  - for every bug, write a test demonstrating it
- **New code is guilty until proven innocent**
- **At least as much test code as production code**
- **Run local tests with each compile**
  - don’t write new code when tests are failing
- **Run all tests before check-in to repository**
  - also run them after check-in on your build server

Use your Right-BICEP [PragProg]

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- **Are the results right?**
  - ASSERT_EQUAL(42,7*6)
- **Are all boundary conditions CORRECT?**
  - 0, 1, 0xffffffff
- **Can you check inverse relationships?**
  - sqrt(x)*sqrt(x) == x
- **Can you cross-check results using other means?**
- **Can you force error conditions to happen?**
  - y/x, x=0
- **Are performance characteristics within bounds?**

CORRECT
Boundary Conditions

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- **Conformance**
  - e.g., check email address: foo@bar.com
- **Ordering**
  - is sequence relevant? what if out of order?
- **Range**
  - is the domain range correct
- **Reference**
  - expectations on environment
- **Existence**
  - is some parameter/variable defined, null, existent
- **Cardinality**
  - off-by one errors, 0,1, many
- **Time**
  - sequencing of actions, concurrency

Test Fixtures

- **Often several test cases require identical arrangements of tested objects**
- **Reasons**
  - "expensive" setup of objects
  - no duplication of code (DRY principle)
- **Mechanisms**
  - JUnit 3 provides setup() and teardown() methods
  - JUnit 4 corresponding @Before @After annotations for these fixture methods
    - and @BeforeClass, @AfterClass for static methods before/ after all tests in the current class

Test-Driven Development

Exploiting Unit Tests...

Test-Driven Development [Beck-TDD]

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- **There are several books on test-driven design (or TDD)**
  - Kent Beck, Dave Astels, Gerard Meszaros
- **TDD is not a testing technique, but a coding and design technique**
  - nevertheless TDD patterns help you writing tests, regardless if you follow TDD or not
- **TDD relies heavily on Refactoring**
  - we at IFS try hard to provide you with such Refactoring automation for C++ as well as you might be used to with Java or Ruby. (plus Refactoring for Groovy, Python (PyDev), PHP, JavaScript)

TDD [Kevlin Henney]

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- **TDD has emerged from the many practices that form Extreme Programming's core**
  - Focused on code-centric practices in the micro process rather than driving the macro process
- **TDD can be used in other macro-process models**
  - TDD is not XP, and vice versa
  - TDD is not just unit testing
- **BDD (Behavior Driven Design)**
  - Follow-up to TDD
  - since TDD is not about Testing but specifying behavior

TDD Practices and Characteristics

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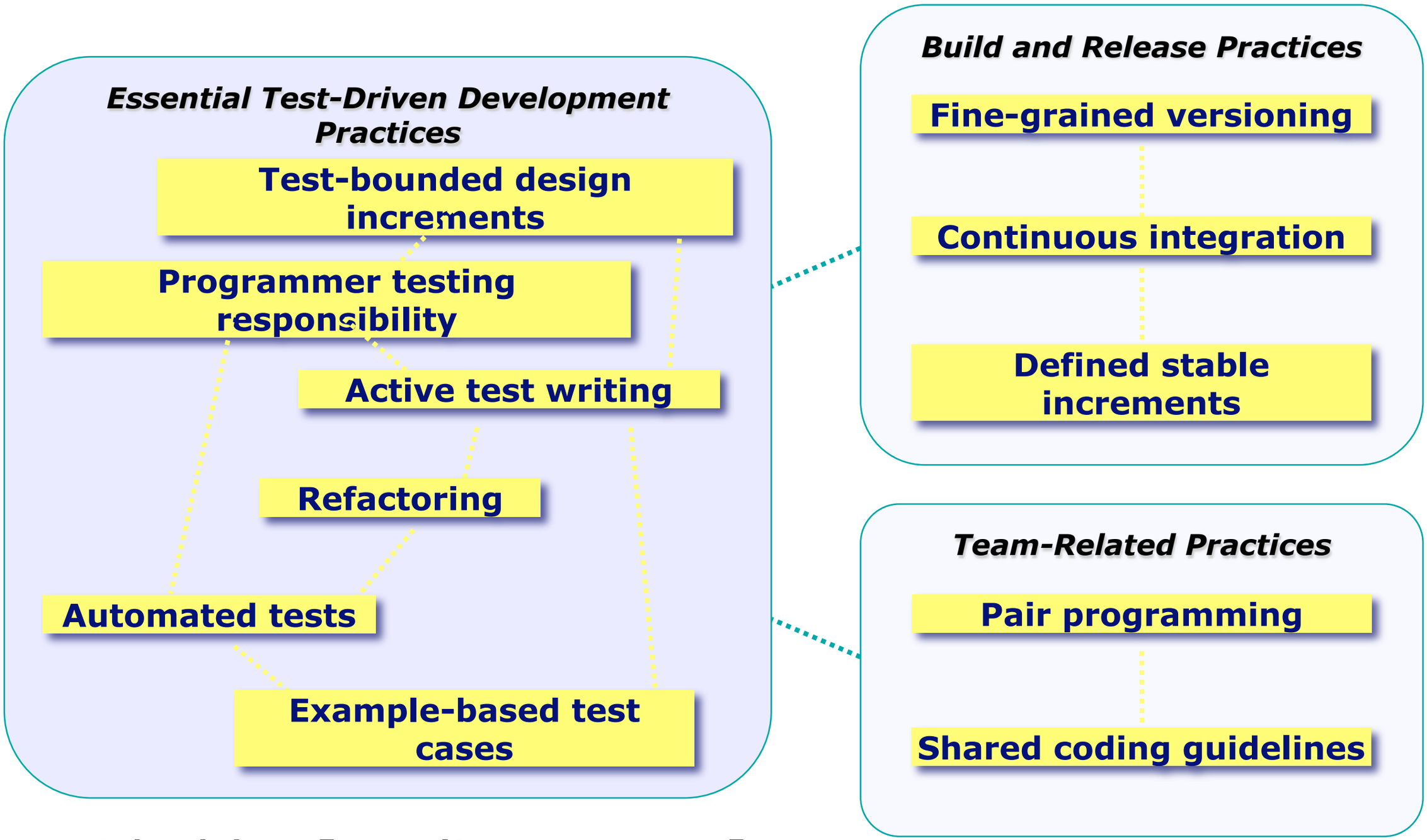


provided by [Kevlin Henney]

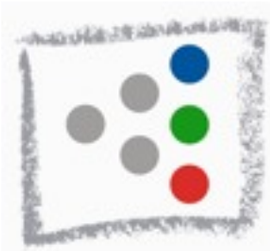
TDD Patterns
Writing Tests & Habits

- **Isolated Tests**
  - write tests that are independent of other tests
- **Test List**
  - use a list of to-be-written tests as a reminder
  - only implement one failing test at a time
- **Test First**
  - write your tests before your production code
- **Assert First**
  - start writing a test with the assertion
  - only add the acting and arrangement code when you know what you actually assert

"Red-bar" Patterns
Finding Tests to write

- **One Step Test**
  - solve a development task test-by-test
    - no backlog of test code, only on your test list
    - select the simplest/easiest problem next
- **Starter Test**
  - start small, e.g., test for an empty list
  - refactor while growing your code
- **Explanation Test**
  - discuss design through writing a test for it
- **Learning Test**
  - understand existing code/APIs through writing tests exercising it

“Green Bar” - Patterns
Make your Tests succeed



- **Fake It ('Til You Make It)**
  - It is OK to “hack” to make your test succeed.
  - Refactor towards the real solution ASAP
- **Triangulate**
  - How can you select a good abstraction?
  - try to code two examples, and then refactor to the “right” solution
- **Obvious Implementation**
  - Nevertheless, when it’s easy, just do it.
- **One to Many**
  - Implement functions with many elements first for one element (or none) correctly

"Red Bar" Patterns (2)

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- **Regression Test**
  - For every bug report write tests showing the bug
- **Break**
  - Enough breaks are essential. When you are tired you loose concentration and your judgement gets worse. This results in more errors, more work, and makes you more fatigue. (vicious circle!)
- **Do Over**
  - If you recognize your design and tests lead nowhere, DELETE your code! A fresh start earlier is often better.

Demo/Exercise TDD V1
Generate Roman Numbers

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- **generate roman numbers as strings from an integer representation**
  - start with the following list of tests
  - write test, implement function, refactor, repeat
  - make up new tests as you go and see need

THE LIST FOR ROMAN NUMBERS (V0)

1 → I

0 → EMPTY STRING

2 → II

...

Demo/Exercise TDD V2
(3+4)*6 → 42

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- **Expression Evaluator for simple Arithmetic**
- **Test-First Development with CUTE**
- **Incremental Requirements Discovery**

The List for Eval (V0)

"" → error

"0" → 0

"2" → 2

"1+1" → 2

TDD Patterns
Habits

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- **Child Test**
  - If a test case gets too large, “remove” it, redo the core, get “green-bar”, and then introduce the “full” case again, get “green-bar”
- **Broken Test**
  - If you have to stop programming or take a break, leave a broken test to remind you where you left.
    - but only do Clean Check-in!
- **Clean Check-in**
  - Do only (and may be always) check-in your code and tests when you have a green bar.

Test-Doubles

Testing the untestable ...

Test Double Pattern xunitpatterns.com

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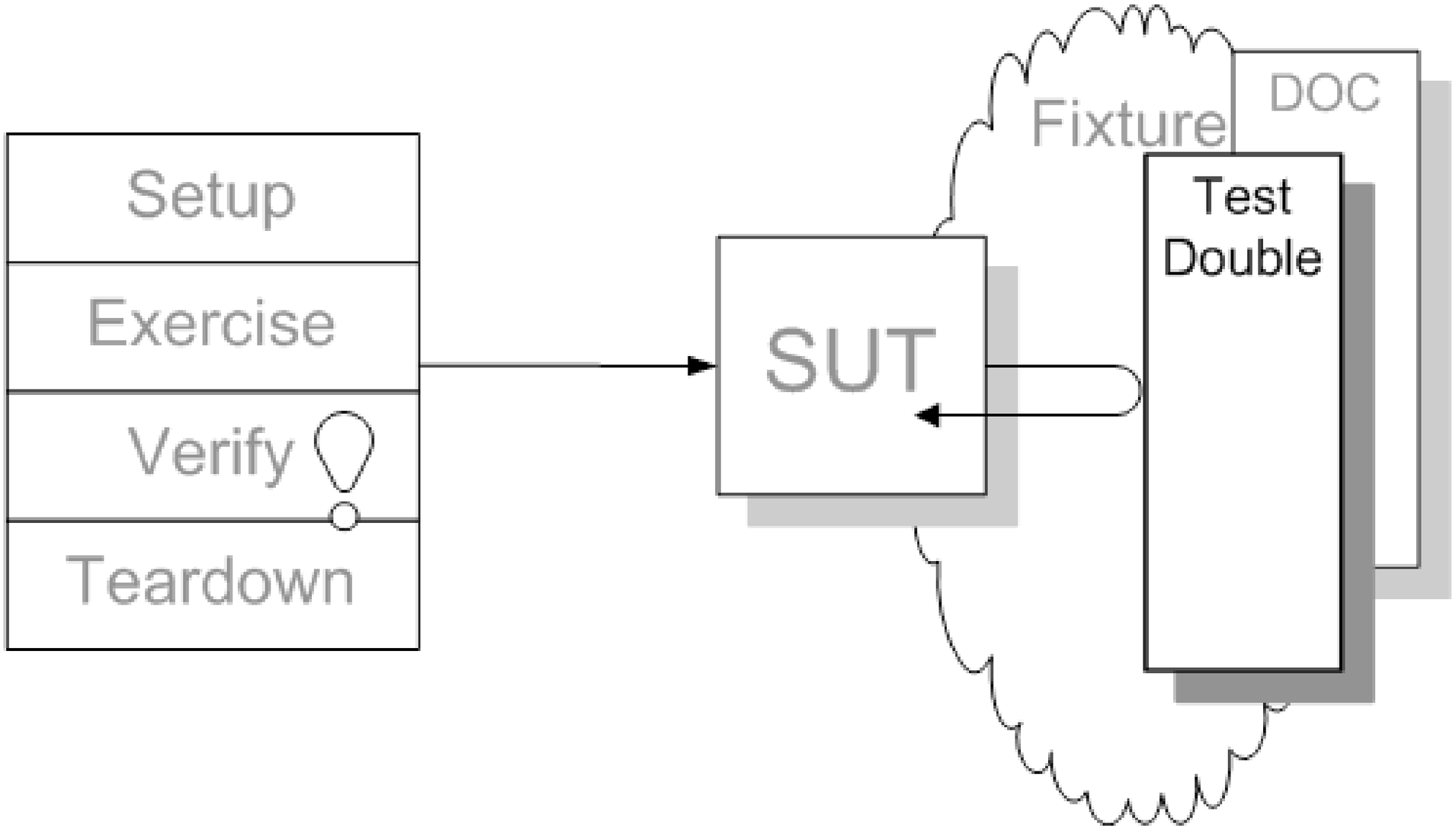
- How can we verify logic independently when code it depends on is unusable?
- How can we avoid Slow Tests?



Principle of Test Doubles

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- **A unit/system under test (SUT) depends on another component (DOC) that we want to separate out from our test.**
- **Reasons**
  - real DOC might not exist yet
  - real DOC contains uncontrollable behavior
  - want to test exceptional behavior by DOC that is hard to trigger
  - using the real DOC is too expensive or takes to long
  - need to locate problems within SUT not DOC
  - want to test usage of DOC by SUT is correct

Why the need for Test Doubles?

- **Simpler Tests and Design**
  - o especially for external dependencies
  - o promote interface-oriented design
- **Independent Testing of single Units**
  - o isolation of unit under testing
  - o or for not-yet-existing units
- **Speed of Tests**
  - o no external communication (e.g., DB, network)
- **Check usage of third component**
  - o is complex API used correctly
- **Test exceptional behaviour**
  - o especially when such behaviour is hard to trigger

Types of Mock Objects [Dave Astels]

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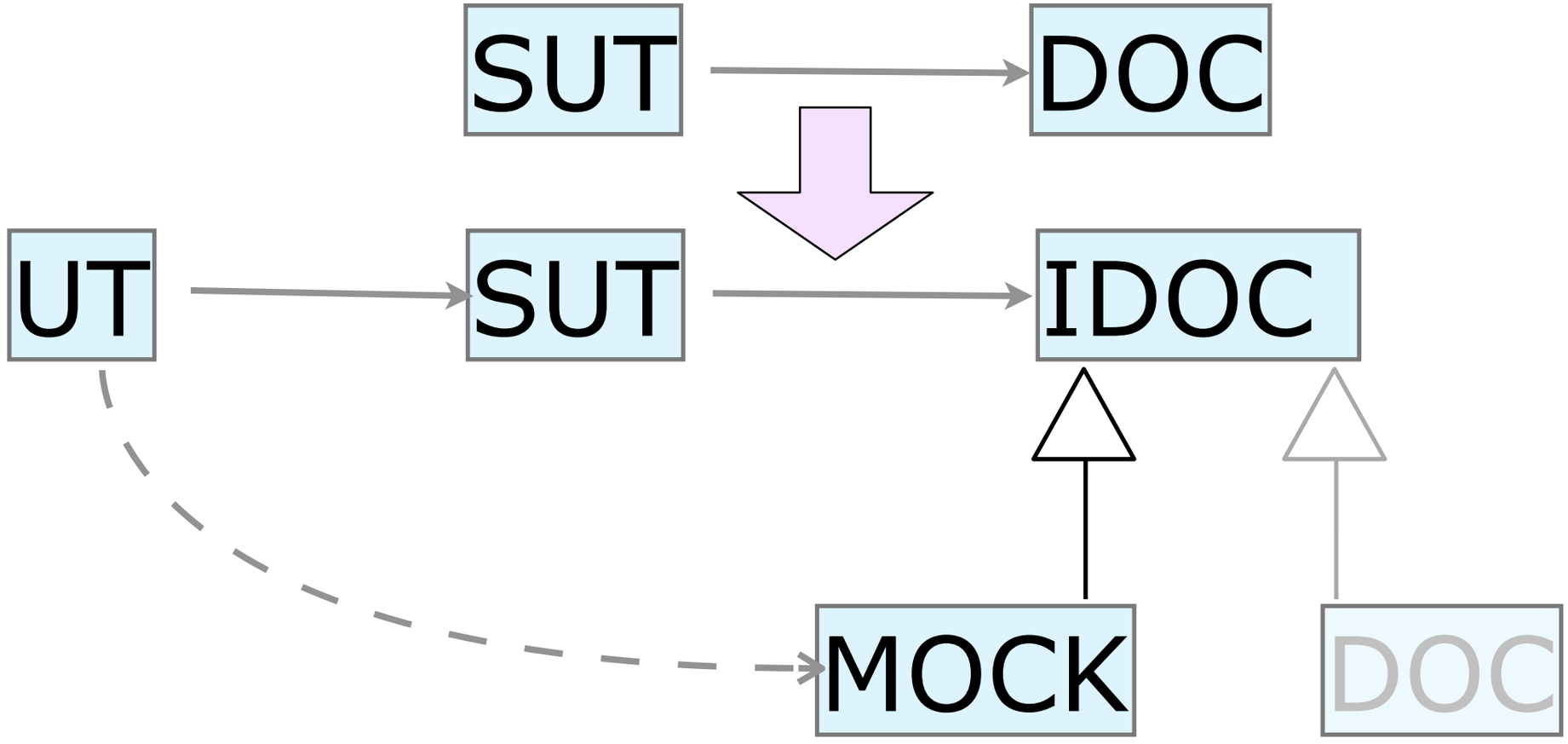
- **There exist different categories of Mock objects and different categorizers.**

- **Stubs**
  - substitutes for “expensive” or non-deterministic classes with fixed, hard-coded return values
- **Fakes**
  - substitutes for not yet implemented classes
- **Mocks**
  - substitutes with additional functionality to record function calls, and the potential to deliver different values for different calls

Interface-oriented Test Double introduction

- **classic inheritance based mocking**
  - o extract interface for DOC -> IDOC
  - o make SUT use IDOC
  - o create MOCK implementing IDOC and use it in UT



Test Double Patterns [Beck-TDD]

- **Mock Object**
  - Decouple a class under test from its environment
- **Self Shunt**
  - Use the test case class itself as a Mock Object
- **Log String**
  - test temporal dependencies of calls by concatenating call info in a string, e.g., using Self Shunt
- **Crash Test Dummy**
  - How do you tests exceptions that are hard to force, but might occur during production?
  - Use a dummy/Mock Object that throws an exception instead of the real object.

Example for a Crash Test Dummy

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- **like a Mock Object, but an inner class for it can be an elegant solution**

```
public void testFileSystmeError() {
  File f = new File("foo") {
      public boolean createNewFile() throws IOException {
        throw new IOException();
      }
    };
  try {
    saveAs(f);
    fail();
  } catch (IOException e){}
}
```

how to test Exceptions!

Mock Object xunitpatterns

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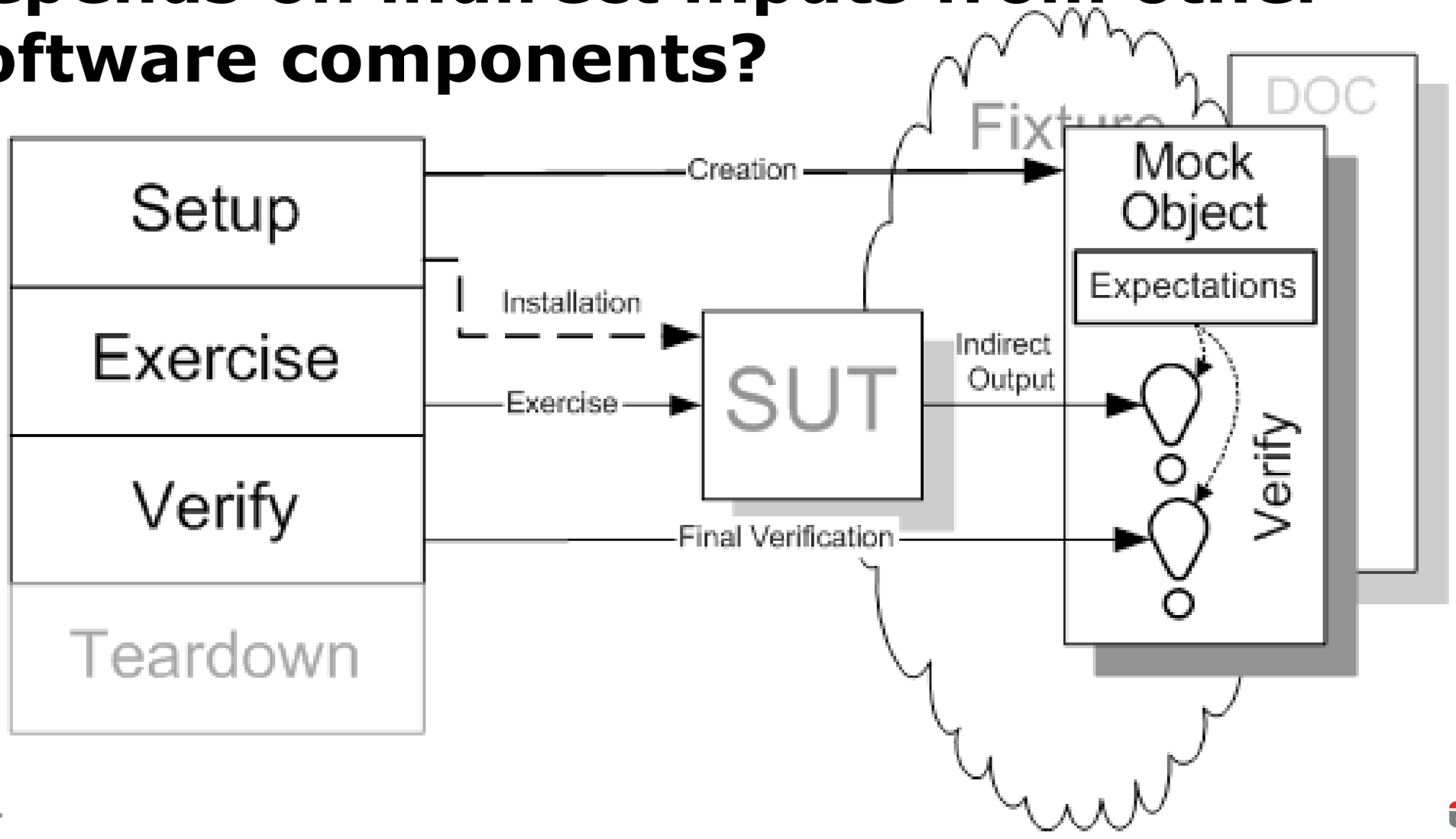
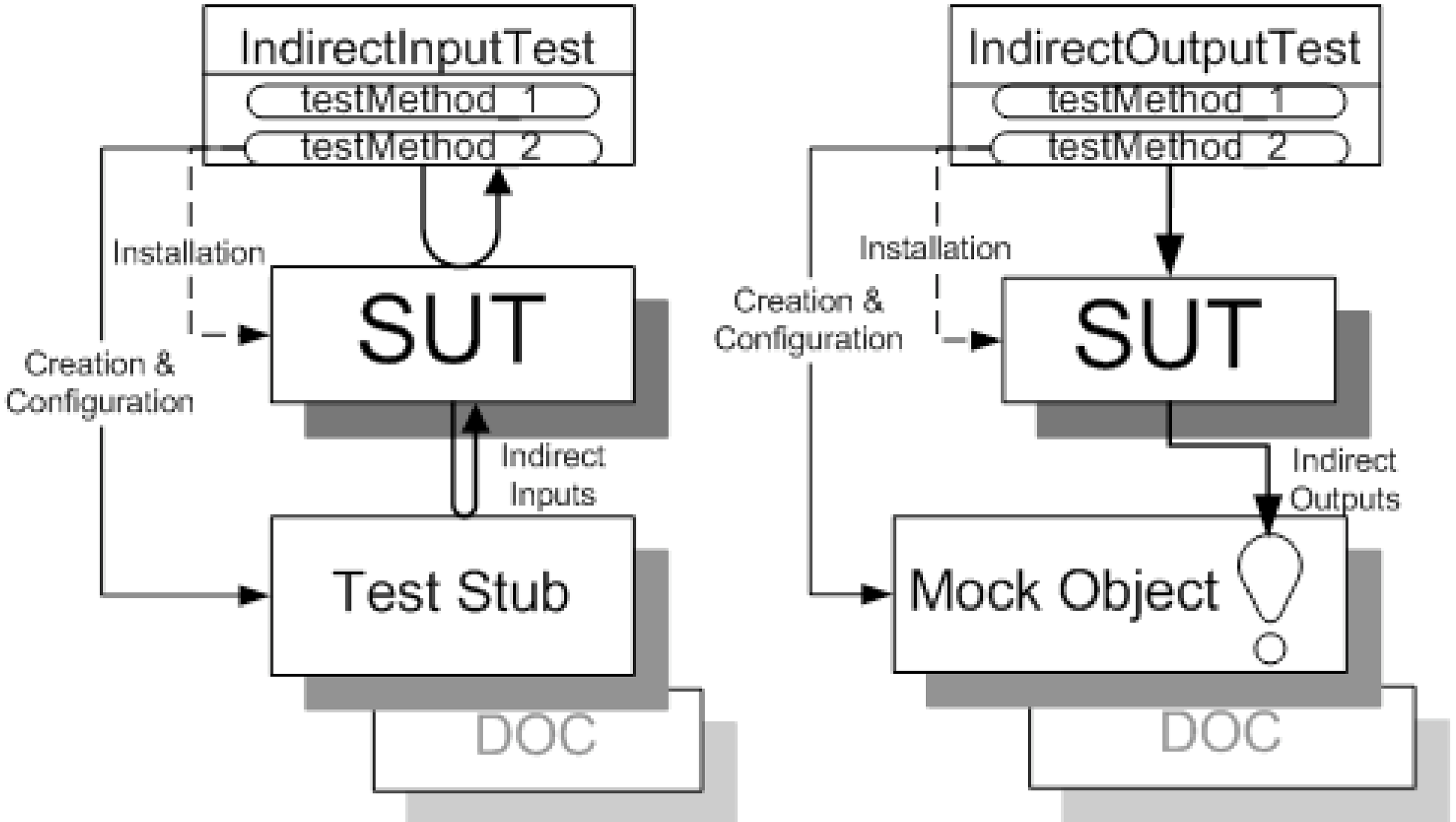
- How do we implement Behavior Verification for indirect outputs of the SUT?
- How can we verify logic independently when it depends on indirect inputs from other software components?



Difference Test-Stub and Mock-Object



- **xunitpatterns.com**

Why Test Doubles and Mock Objects? [PragUnit]

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- The real object has **nondeterministic behavior** (it produces unpredictable results, like a stock-market quote feed.)
- The real object is **difficult to set up**.
- The real object has **behavior that is hard to trigger** (for example, a network error).
- The real object is **slow**.
- The real object has (or is) a **user interface**.
- The test needs to **ask** the real object about **how it was used** (for example, a test might need to confirm that a callback function was actually called).
- The real object **does not yet exist** (a common problem when interfacing with other teams or new hardware systems).

Benefits of Test Doubles

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- **tests run faster and are simpler**
  - test really the component in isolation not its environment
- **software design is improved**
  - less tight coupling
  - programming against interfaces instead of concrete objects
  - Parameterize from Above
    - e.g., PrintStream parameter instead of System.out
    - output can be tested automatically
- **Refactoring can be necessary for getting these benefits**

Example Test Double
[PragUnit]

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```
import java.util.Calendar;
public class Checker {
  public Checker(Environmental anEnv) {
    env = anEnv;
  }
  /**
   * After 5 o'clock, remind people to go home
   * by playing a whistle
   */
  public void reminder() {
    Calendar cal = Calendar.getInstance();
    cal.setTimeInMillis(env.getTime());
    int hour = cal.get(Calendar.HOUR_OF_DAY);

    if (hour >= 17) { // 5:00PM
      env.playWavFile("quit_whistle.wav");
    }

  }
  // ...
  private Environmental env;
}
```

```
public interface Environmental {
  public long getTime();
  // Other methods omitted...
  public void playWavFile(String name);
}
```

```
public class SystemEnvironment
implements Environmental {
  public long getTime() {
    return System.currentTimeMillis();
  }
  // other methods ...
  public void playWavFile(String name) {
    // Left as an exercise
  }
```

```
public class MockSystemEnvironment
implements Environmental {
  public long getTime() {
    return current_time;
  }
  public void setTime(long aTime) {
    current_time = aTime;
  }
  private long current_time;
  public void playWavFile(String filename)
{
    playedWav = true;
  }
  public boolean wavWasPlayed() {
    return playedWav;
  }
  public void resetWav() {
    playedWav = false;
  }
  private boolean playedWav = false;
  // ...
}
```

Example Test Double(2)
[PragUnit]


```
import junit.framework.*;
import java.util.Calendar;

public class TestChecker extends TestCase
{

  public void testQuittingTime() {

    MockSystemEnvironment env =
      new MockSystemEnvironment();

    // Set up a target test time
    Calendar cal = Calendar.getInstance();
    cal.set(Calendar.YEAR, 2004);
    cal.set(Calendar.MONTH, 10);
    cal.set(Calendar.DAY_OF_MONTH, 1);
    cal.set(Calendar.HOUR_OF_DAY, 16);
    cal.set(Calendar.MINUTE, 55);
    long t1 = cal.getTimeInMillis();

    env.setTime(t1);

    Checker checker = new Checker(env);

    // Run the checker
    checker.reminder();

    // Nothing should have been played yet
    assertFalse(env.wavWasPlayed());

    // Advance the time by 5 minutes
    t1 += (5 * 60 * 1000);
    env.setTime(t1);

    // Now run the checker
    checker.reminder();

    // Should have played now
    assertTrue(env.wavWasPlayed());

    // Reset the flag so we can try again
    env.resetWav();

    // Advance the time by 2 hours and
check
    t1 += 2 * 60 * 60 * 1000;
    env.setTime(t1);

    checker.reminder();
    assertTrue(env.wavWasPlayed());
  }
}
```

Summary Test Doubles and Mock Objects

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- **Test Doubles/Mock Objects are important for isolating unit tests**
  - or speeding them up
- **They can lead to better, less-coupled design**
  - separation of concerns
    - danger with auto-generated mock objects
- **Overdoing mocking can be dangerous**
  - go for simplicity!
  - test against interfaces, do not over-specify a specific implementation

Questions?

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Outlook

- **Even though unit tests relieve the burden of interactive debugging you will learn a bit more about that later.**
- **Refactoring your code is relying on GUTs and is even more important to make your design better and simpler.**
- **Look forward to conscious debugging and bug tracking in the last week of the semester.**

References

- **[Gerard Meszaros] - xUnit Test Patterns**
  - http://xunitpatterns.com
  - very good overview of the problems of and with test automation and their solutions
- **[Beck-TDD]**
  - Kent Beck: Test-Driven Design
- **[PragUnit]**
  - Andy Hunt, Dave Thomas: Pragmatic Unit Testing
- **[Kevlin Henney]**
  - JUTLAND:
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  - http://dannorth.net/introducing-bdd/
  - http://behaviour-driven.org/