Test-Driven Development (TDD)

CS 3250
Software Testing

[Lasse Koskela, "Test Driven", Chapters 1-3]
[Harry J.W. Percival, "Test-Driven Development with Python", Chapter 7]

Intro to TDD

What is TDD?

- Software development process that relies on the repetition of a very short development cycle
- Not a software testing technique; make use of software testing technique in software development process

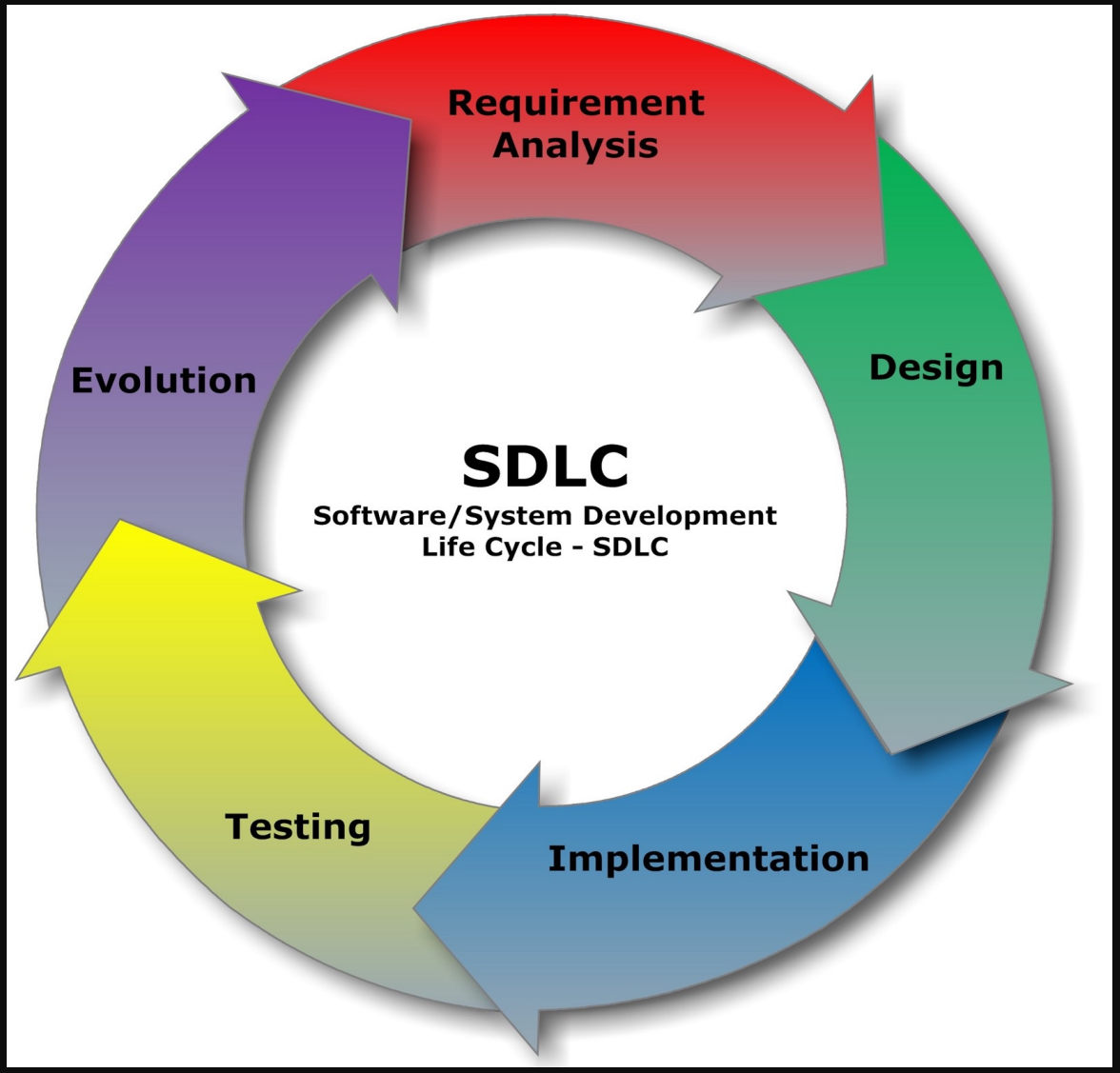
Why TDD?

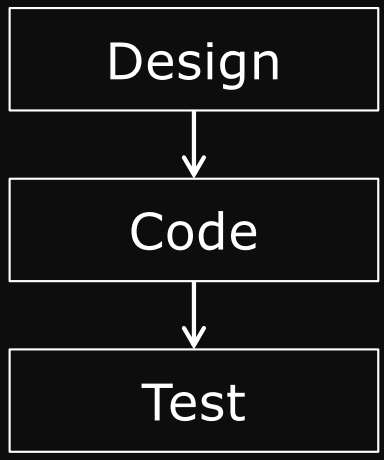
- Prerequisite for many other practices (e.g., continuous delivery)
- Support better design, well-written code, faster time-to-market, up-to-date documentation, solid test coverage

Drawback

- Require time and a lot of practice

Traditional Development Cycle



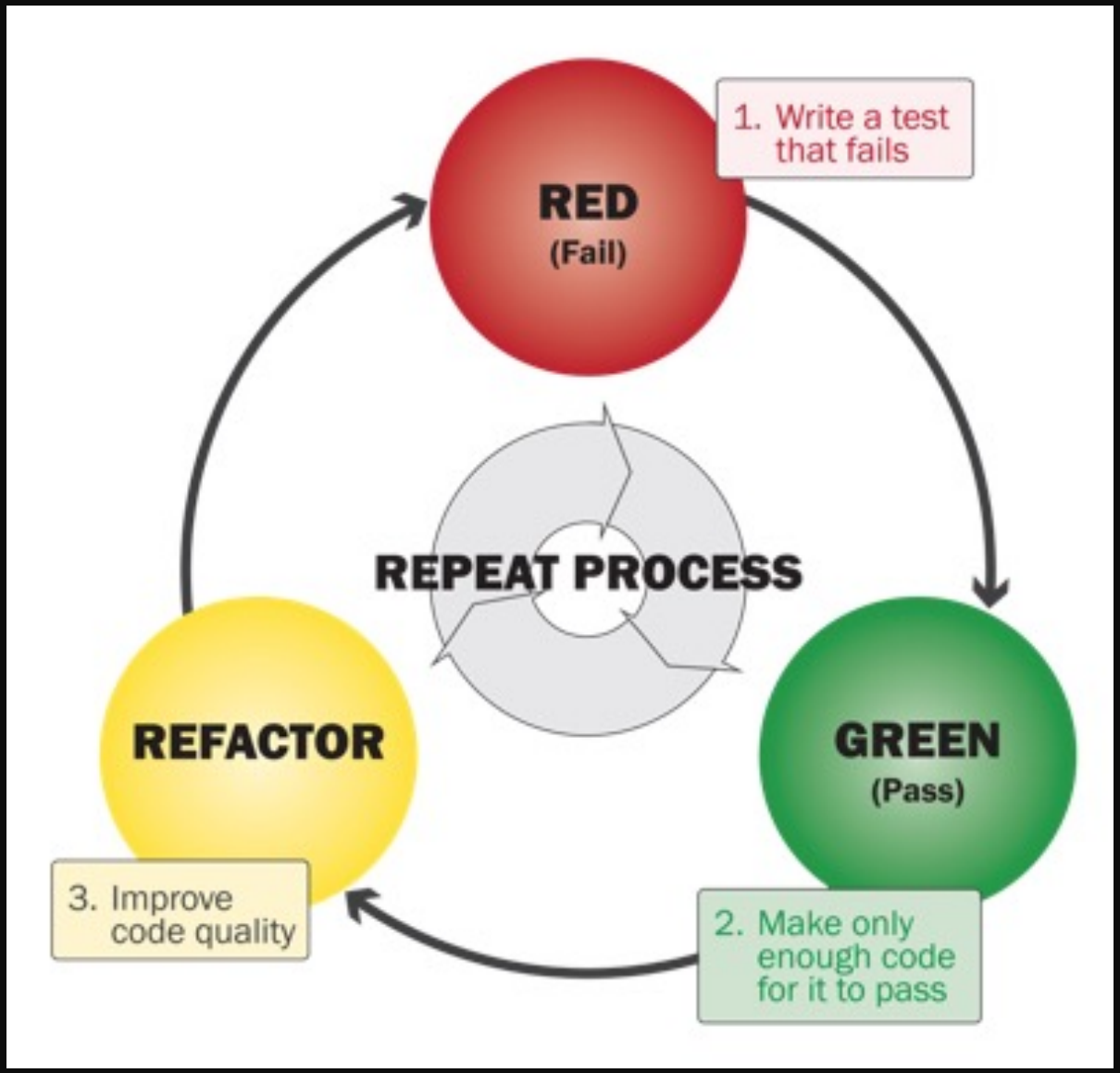


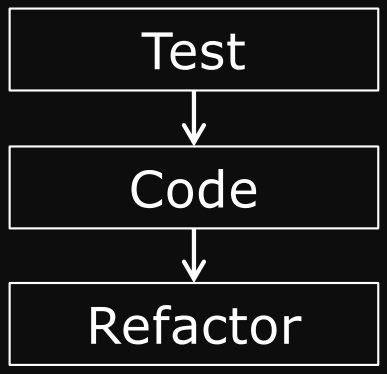
Big design up front

Design – not evolve

[image by Cliffydcw - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=19054763]

TDD: Red-Green-Refactor Process





Write tests before the actual implementation

Only write "just enough" code to fix a failing test

Deliver "for now" items

"YAGNI"

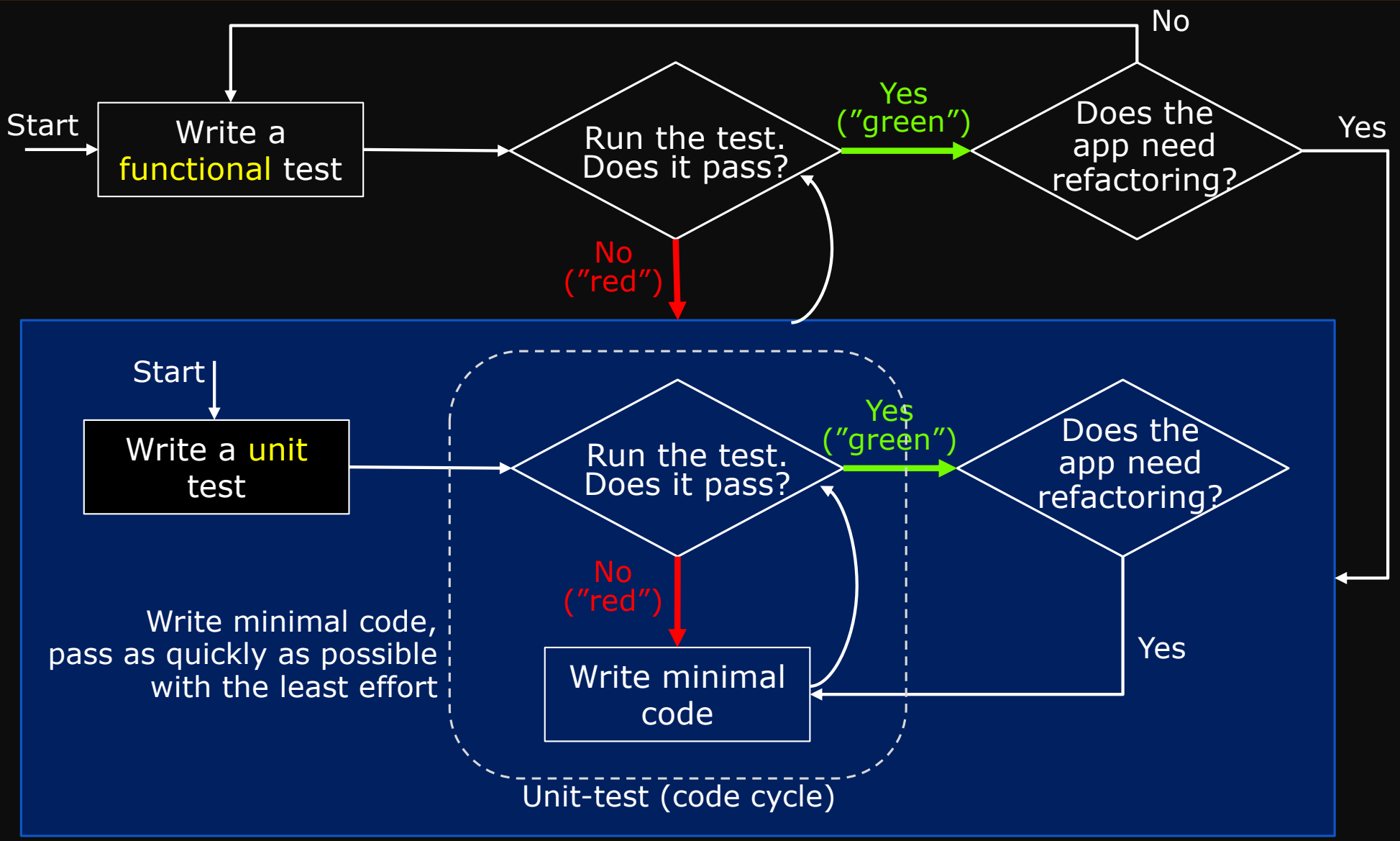
Speed is key

Not big design up front

Design – evolve based on feedback from real usage

[image from https://realpython.com/django-1-6-test-driven-development/]

TDD with Functional and Unit Tests



[Based on Percival, "Test-Driven Development with Python", Figure 7-1]

Overview of Process

1. From user story to requirements to tests
2. Choosing the first test
3. Breadth-first, depth-first
4. Let's not forget to refactor
5. Adding a bit of error handling
6. Loose ends on the test list
7. Repeat

Test first – make it run – make it better

Example: Requirements

- Imagine we are implementing a subsystem for the corporate email application.
- This subsystem is responsible for providing mail-template functionality so that the CEO's assistant can send all sorts of important, personalized emails to all personnel with a couple of mouse-clicks.
- How would tests drive the development of this subsystem?

1. From User Story to Requirements to Tests

The first step in TDD is writing a failing test,
we need to figure out what desired behavior we'd like to test for

- Decomposing requirements
  - Template system as tasks – "things we need to do"
    - When completed, lead to satisfying the original requirements
  - Template system as tests – "things we need to verify"
    - When passing, lead to the requirements being satisfied

Example: Tasks vs. Tests

Imagine you are implementing a subsystem for an email application

Template system as tasks	Template system as tests
• Write a regular expression for identifying variables from the template • Implement a template parser that uses the regular expression • Implement a template engine that provides a public API and uses the template parser internally • …	• Template without any variables renders as is • Template with one variable is rendered with the variable replaced with its value • Template with multiple variables is rendered with the appropriate placeholders replaced by the associated values • …
Idea of what we should do, easy to lose sight of the ultimate goal – not represent progress of the produced software	Idea of what should be done – connect to capabilities of the produced software

[Koskela, p. 46]

What Are Good Tests Made Of?

- Tests are generally better than tasks for guiding our work, but does it matter what kind of tests we write?
  - Sure it does!

- Two properties of a good test
  - A good test is atomic
    - Keeps things small and focused
  - A good test is isolated
    - Doesn't depend on other tests

Programming by Intention

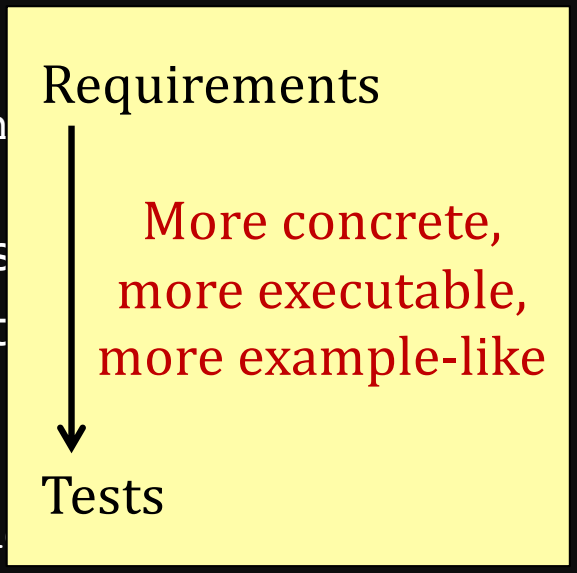
- Given an initial set of tests, pick one that is potentially lead to most progress with least effort
- Write test code
  - How to test something that doesn't exist without breaking our test?
    - Imagine code exists
- Benefit of programming by intention
  - Focus on what we could have instead of what we do have

2. Choosing the First Test

Restrict focus, do not worry about the whole system

- Before coming up with an initial list of tests, define a set of requirements for the subsystem under test

- Example requirements:
  - System replaces variable placeholders like `${firstn` with values provided at runtime
  - Attempt to send a template with undefined variables
  - System ignores variables that are not in the templat



- Example corresponding tests:
  - Evaluating template "`Hello, ${name}`" with value "`R` "`Hello, Reader`"
  - Evaluating "`${greeting}, ${name}`" with "`Hi`" and "`Reader`" result in "`Hi, Reader`"
  - Evaluating "`Hello, ${name}`" with "`name`" undefined raises `MissingValueError`

Writing The First Failing Test

- We got a list of tests that tell us exactly when the requirements have been fulfilled. Now, we start working through the list, making them pass one by one

- Consider the following test
  - Evaluating template "`Hello, ${name}`" with value "`Reader`" results in "`Hello, Reader`"

- Now, let's create a JUnit test

Example

Step 1: Creating a skeleton for our tests

```
import static org.junit.jupiter.api.Assertions.*;
import org.junit.jupiter.api.AfterAll;
import org.junit.jupiter.api.AfterEach;
import org.junit.jupiter.api.BeforeAll;
import org.junit.jupiter.api.BeforeEach;
import org.junit.jupiter.api.Test;

public class mail_TestTemplate
{

}
```

Note: this example uses Junit 5

Example

Step 2: Adding a test method

```
import static org.junit.jupiter.api.Assertions.*;
import org.junit.jupiter.api.AfterAll;
import org.junit.jupiter.api.AfterEach;
import org.junit.jupiter.api.BeforeAll;
import org.junit.jupiter.api.BeforeEach;
import org.junit.jupiter.api.Test;

public class mail_TestTemplate
{
    @Test
    public void oneVarible()
    {

    }
}
```

Example

Step 3: Writing the actual test

```
import static org.junit.jupiter.api.Assertions.*;
import org.junit.jupiter.api.AfterAll;
import org.junit.jupiter.api.AfterEach;
import org.junit.jupiter.api.BeforeAll;
import org.junit.jupiter.api.BeforeEach;
import org.junit.jupiter.api.Test;

public class mail_TestTemplate
{
   @Test
   public void oneVarible()
   {
      mailTemplate template = new mailTemplate("Hello, ${name}");
      template.set("name", "Reader");
      assertEquals("Hello, Reader", template.evaluate());
   }
}
```

assuming that the implementation is there (even though it isn't)

Example

Now, the compiler points out that there is no such constructor for `mailTemplate` that takes a `String` as a parameter

Step 4: Satisfying the compiler by adding empty methods and constructors

```
public class mailTemplate
{
   public mailTemplate(String templateText)
   {
   }

   public void set(String variable, String value)
   {
   }

   public String evaluate()
   {
      return null;
   }
}
```

Example

Step 5: Running test

- Yes, the test fails – not surprisingly, because we haven't implemented the methods yet
- Benefit: to check that the test is executed, not the test result

The red phase of the TDD cycle

What we have now tell us when we are done with this particular task

"when the test passes, the code does what we expect it to do"

Example

Step 6: Making the first test pass

- Passing as quickly as possible and with minimal effort – it's fine to use a hard-coded return statement at this point

```
public class mailTemplate
{
    public mailTemplate(String templateText)
    {
    }

    public void set(String variable, String value)
    {
    }

    public String evaluate()
    {
        return "Hello, Reader";
    }
}
```

The green phase of the TDD cycle

2 dimensions to move forward:

- Variable
- Template text

Example

Step 7: Writing another test

How to make the test pass

```
public class mail_TestTemplate
{
    @Test
    public void oneVarible()
    {
        mailTemplate template = new mailTemplate("Hello, ${name}");
        template.set("name", "Reader");
        assertEquals("Hello, Reader", template.evaluate());
    }

  @Test
   public void differentValue()
   {
        mailTemplate template = new mailTemplate("Hi, ${name}");
        template.set("name", "someone else");
        assertEquals("Hi, someone else", template.evaluate());
   }
}
```

Forcing out the hard-coded return statement with another test

The hard-coded evaluate method in the `mailTemplate` class will no longer pass this test

Example

Step 8: Revising code (to make the second test pass by storing and returning the set value)

```
public class mailTemplate
{
    private String variableValue;
    public mailTemplate(String templateText)
    {

    }

    public void set(String variable, String value)
    {
        this.variableValue = value;

    }

    public String evaluate()
    {
        return "Hello, " + variableValue;
    }
}
```

Our test passes again with minimal effort

Our test isn't good enough yet because of the hard-coded part

To improve the test's quality, follow three dimensions to push our code: variable, value, template

Example

Step 9: Revising test

```
public class mail_TestTemplate
{
    @Test
    public void oneVarible()
    {
        mailTemplate template = new mailTemplate("Hello, ${name}");
        template.set("name", "Reader");
        assertEquals("Hello, Reader", template.evaluate());
    }

  @Test
   public void differentTemplate() throw Exception
   {
       mailTemplate template = new mailTemplate("Hi, ${name}");
       template.set("name", "someone else");
       assertEquals("Hi, someone else", template.evaluate());
   }
}
```

Rename test to match what we're doing

Squeeze out more hard coding

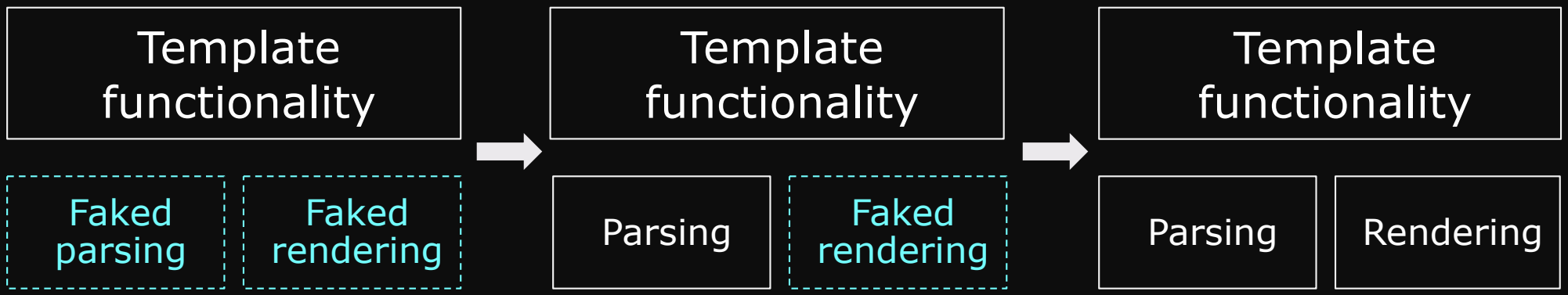
Hard-coded return from the production code won't work anymore

3. Breadth-First, Depth-First

- What to do with a "hard" red phase?
  - Issue is "What to fake" vs. "What to build"
- "Faking" is an accepted part of TDD
  - That is, "deferring a design decision"

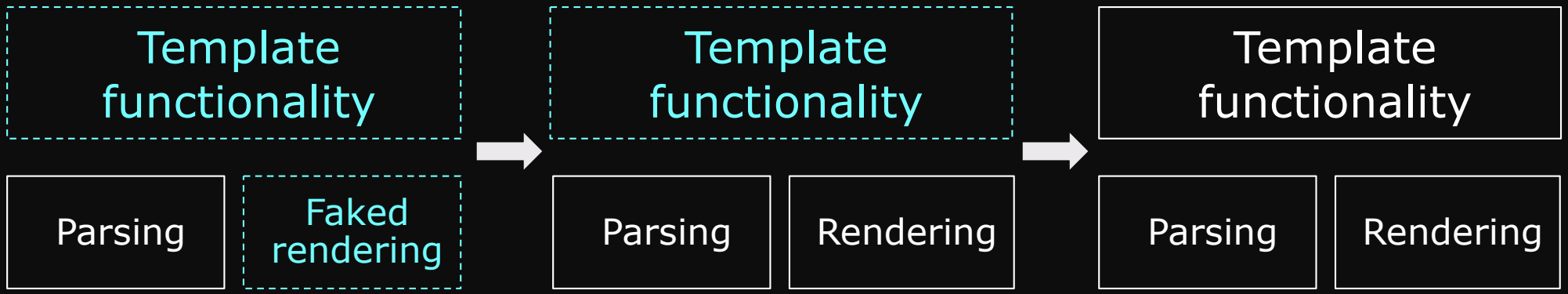
Breadth-First

- Implement the higher-level functionality first by faking the required lower-level functionality



Depth-First

- Implement the lower-level functionality first and only compose the higher-level functionality once all the ingredients are present



Back to Our Example

- Assume we are dealing with "`Hello, ${name}`"
- We can fake the lower-level functionality
- Do breath-first

Faking Details a Little Longer

Handling variables as variables

```
public class mailTemplate
{
   private String variableValue;
   private String templateText;

   public mailTemplate(String templateText)
   {
      this.templateText = templateText;
   }

   public void set(String variable, String value)
   {
      this.variableValue = value;

   }

   public String evaluate()
   {
      return templateText.replaceAll("\\$\\{name\\}", variableValue);
   }
}
```

Store the variable value and the template text somewhere

Make `evaluate()` replace the placeholder with the value

Proceed with the TDD Cycle

- Run the tests
- All tests are passing
- Now, add more test to squeeze out the fake stuff

The green phase of the TDD cycle

Squeezing Out The Fake Stuff

Writing test for multiple variables on a template

```
@Test
public void multipleVariables() throws Exception
{
    mailTemplate template = new mailTemplate("${one}, ${two}, ${three}");
    template.set("one", "1");
    template.set("two", "2");
    template.set("three", "3");
    assertEquals("1, 2, 3", template.evaluate());
}
```

The red phase

This test fails

To get the test passing as quickly as possible, do the search-and-replace implementation

Solution to Multiple Variables

```
import java.util.Map;
import java.util.HashMap;
import java.util.Map.Entry;

public class mailTemplate
{
   private Map<String, String>  variables;
   private String templateText;

   public mailTemplate(String templateText)
   {
      this.variables = new HashMap<String, String>();
      this.templateText = templateText;
   }

   public void set(String name, String value)
   {
      this.variables.put(name, value);
   }

   public String evaluate()
   {
      String result = templateText;
      for (Entry<String, String> entry : variables.entrySet())
      {
         String regex = "\\$\\{" + entry.getKey() + "\\}";
         result = result.replaceAll(regex, entry.getValue());
      }
      return result;
   }
}
```

Store variable values in HashMap

Loop through variables

Replacing each variable with its value

Run tests again, Nothing's broken!

Special Test Case

Evaluating template "`Hello, ${name}`" with values "`Hi`" and "`Reader`" for variables "`doesnotexist`" and "`name`", results in the string "`Hello, Reader`"

```
@Test
public void unknownVariablesAreIgnored() throws Exception
{
   mailTemplate template = new mailTemplate("Hello, ${name}");
   template.set("doesnotexist", "whatever");
   template.set("name", "Reader");
   assertEquals("Hello, Reader", template.evaluate());
}
```

If we set variables that don't exist in the template text, the variables are ignored by the `mailTemplate` class

This test passes without any changes to the `mailTemplate` class

Why Red Then Green

- We intentionally fail the test at first just to see that
  - Our test execution catches the failure
  - We are really executing the newly added test
    - Then proceed to implement the test and see the bar turn green again

4. Let's Not Forget To Refactor

- Refactor: changing internal structure (of the current code) without changing its external behavior
- At this point, it might seem that we didn't add any code and there is nothing to refactor

> Refactoring applies to code and test code

- Though we didn't add any production code, we added test code, and that is code – just like any other
  - We don't want to let our test code rot and get us into serious trouble later
- What could we do about our test code?
  - Identify any potential refactoring
  - Decide which of them we'll carry out

Example: Test Class (So Far)

```
public class mail_TestTemplate
{
   @Test
   public void oneVarible()
   {
      mailTemplate template = new mailTemplate("Hello, ${name}");
      template.set("name", "Reader");
      assertEquals("Hello, Reader", template.evaluate());
   }

   @Test
   public void differentTemplate() throw Exception
   {
      mailTemplate template = new mailTemplate("Hi, ${name}");
      template.set("name", "someone else");
      assertEquals("Hi, someone else", template.evaluate());
   }

   @Test
   public void multipleVariables() throws Exception
   {
      mailTemplate template = new mailTemplate("${one},${two},${three}");
      template.set("one", "1");
      template.set("two", "2");
      template.set("three", "3");
      assertEquals("1, 2, 3", template.evaluate());
   }

   @Test
   public void unknownVariablesAreIgnored() throws Exception
   {
      mailTemplate template = new mailTemplate("Hello, ${name}");
      template.set("doesnotexist", "whatever");
      template.set("name", "Reader");
      assertEquals("Hello, Reader", template.evaluate());
   }
}
```

Can you spot anything to refactor?

Potential Refactoring in Test Code

- All tests are using a `mailTemplate` object
  - Solution: extract it into an instance variable rather than declare it over and over again, use fixtures
- The `evaluate()` method is called several times as an argument to `assertEquals`
  - Solution: write a method that calls the `evaluate()` method
- The `mailTemplate` class is instantiated with the same template text in two places
  - Solution: remove the duplicate by using fixtures (with some unified values)

Remove redundant tests

Revisit Current Test Class

```
public class mail_TestTemplate
{
   @Test
   public void oneVarible()
   {
      mailTemplate template = new mailTemplate("Hello, ${name}");
      template.set("name", "Reader");
      assertEquals("Hello, Reader", template.evaluate());
   }

   @Test
   public void differentTemplate() throw Exception
   {
      mailTemplate template = new mailTemplate("Hi, ${na
      template.set("name", "someone else");
      assertEquals("Hi, someone else", template.evaluate
   }

   @Test
   public void multipleVariables() throws Exception
   {
      mailTemplate template = new mailTemplate("${one},${two},${three}");
      template.set("one", "1");
      template.set("two", "2");
      template.set("three", "3");
      assertEquals("1, 2, 3", template.evaluate());
   }

   @Test
   public void unknownVariablesAreIgnored() throws Exception
   {
      mailTemplate template = new mailTemplate("Hello, ${name}");
      template.set("doesnotexist", "whatever");
      template.set("name", "Reader");
      assertEquals("Hello, Reader", template.evaluate());
   }
}
```

Let's consider duplication between these tests

`multipleVariables()` covers `oneVariable()` and `differentTemplate()` -- thus, get rid of them

`unknownVariablesAreIgnored()` can use the same template text as `multipleVariables()`

Refactored Test Code

```
public class mail_TestTemplate
{
   private mailTemplate template;

   @BeforeEach
   public void setUp() throws Exception
   {
      template = new mailTemplate("${one}, ${two}, ${three}");
      template.set("one", "1");
      template.set("two", "2");
      template.set("three", "3");
   }

   @Test
   public void multipleVariables() throws Exception
   {
      assertTemplateEvaluatesTo("1, 2, 3");
   }

   @Test
   public void unknownVariablesAreIgnored() throws Exception
   {
      template.set("doesnotexist", "whatever");
      assertTemplateEvaluatesTo("1, 2, 3");
   }

   private void assertTemplateEvaluatesTo(String expected)
   {
      assertEquals(expected, template.evaluate());
   }
}
```

Common fixture for all tests

Simple, focused test

Helper method

Now, let's add more functionality ... add more tests

5. Adding a Bit of Error Handling

Add exception test, using try/catch block with `fail()`

```
@Test
public void missingValueRaisesException() throws Exception
{
   try {
      new mailTemplate("${foo}").evaluate();
      fail("evaluate() should throw an exception if " +
              "a variable was left without a value!");
   } catch (MissingValueException expected) { }
}
```

```
// in mailTemplate class
public class MissingValueException extends RuntimeException
{
   // this is all we need for now
}
```

Adding a Bit of Error Handling (2)

Add exception test, using `Assertions.assertThrows()`

```
@Test
public void missingValueRaisesException() throws Exception
{
   Assertions.assertThrows(RuntimeException.class, () -> {
      new mailTemplate("${foo}").evaluate();
   });
}
```

```
// in mailTemplate class
public class MissingValueException extends RuntimeException
{
   // this is all we need for now
}
```

Except test – either try/catch with `fail()` or `Assertions.assertThrows()` fails.
That means, we have to somehow check the missing variables.

Let's make the test pass
How to get to the green phase as quickly as possible?

Writing Code To Make The Test Pass

- How do we know inside evaluate, whether some of the variables specified in the template text are without a value?
- Checking for remaining variables after the search-and-replace

```
public String evaluate()
{
   String result = templateText;
   for (Entry<String, String> entry : variables.entrySet())
   {
      String regex = "\\$\\{" + entry.getKey() + "\\}";
      result = result.replaceAll(regex, entry.getValue());
   }

   if (result.matches(".*\\$\\{.+\\}.*"))
      throw new MissingValueException();

   return result;
}
```

Does it look like we left a variable in there?

Refactoring Toward Small Methods

- `evaluate()` is doing too many different things
  - Replacing variables with values, checking for missing values
- Extracting the check for missing variables into its own method

```
public String evaluate()
{
   String result = templateText;
   for (Entry<String, String> entry : variables.entrySet())
   {
      String regex = "\\$\\{" + entry.getKey() + "\\}";
      result = result.replaceAll(regex, entry.getValue());
   }
   checkForMissingValues(result);
   return result;
}

private void checkForMissingValues(String result)
{
   if (result.matches(".*\\$\\{.+\\}.*"))
      throw new MissingValueException();
}
```

Get rid of a whole if-block from `evaluate()`

Much better.
Is there still more to do?

More Refactoring

- `evaluate()` is still doing two things:
  - Replacing variables with values
  - Checking for missing values
- Extracting method refactoring
  - To create simple, single, clear purpose methods

Run tests again, Nothing's broken!

```
public String evaluate()
{
   String result = replaceVariables();
   checkForMissingValues(result);
   return result;
}

private String replaceVariables()
{
   String result = templateText;
   for (Entry<String, String> entry : variables.entrySet())
   {
      String regex = "\\$\\{" + entry.getKey() + "\\}";
      result = result.replaceAll(regex, entry.getValue());
   }
   return result;
}

Private void checkForMissingValues(String result)
{
   if (result.matches(".*\\$\\{.+\\}.*"))
      throw new MissingValueException();
}
```

Adding Diagnostics to Exceptions

```
@Test
public void missingValueRaisesException() throws Exception
{
   try {
      new mailTemplate("${foo}").evaluate();
      fail("evaluate() should throw an exception if " +
              "a variable was left without a value!");
   } catch (MissingValueException expected) {
      assertEquals("No value for ${foo}", expected.getMessage());
   }
}
```

```
// in mailTemplate class
import java.util.regex.Pattern;
import java.util.regex.Matcher;
...
private void checkForMissingValues(String result)
{
   Matcher m = Pattern.compile(".*\\$\\{.+\\}.*").matcher(result);
   if (m.find())
      throw new MissingValueException("No value for " + m.group());
}
public class MissingValueException extends RuntimeException
{
   public MissingValueException(String msg)
   {
      super(msg);
   }
}
```

6. Loose Ends On The Test List

Testing for performance

```
public class mail_TestTemplate
{
   // Omitted the setUp() for creating a 100-word template with 20 variables
   // and populating it with approximately 15-character values

   @Test
   public void templateWith100WordsAnd20Variables() throws Exception
   {
      long expected = 200L;
      long time = System.currentTimeMillis();
      template.evaluate();
      time = System.currentTimeMillis() - time;
      assertTrue(time <= expected,
                 "Rendering the template took " + time + " ms " +
                 "while the target was " + expected + " ms" );
   }
}
```

Test That Dooms Current Implementation

Write test that verifies whether the code's current behavior are correct

```
@Test
public void variablesGetProcessedJustOnce() throws Exception
   {
      template.set("one", "${one}");
      template.set("two", "${three}");
      template.set("three", "${two}");
      assertTemplateEvaluatesTo("${one}, ${three}, ${two}");
}
```

Note:

- Most TDD tests focus on "happy paths" and often miss
  - Confused-user paths
  - Creative-user paths
  - Malicious-user paths

Summary

- TDD
  - Test: write a test
  - Code: write code to make the test pass
  - Refactor: find the best possible design for what we have, relying on the existing tests to keep us from breaking things while we're at it
- Encourages good design, produces testable code, and keeps us away from over-engineering our system because of flawed assumptions
- When applying TDD, remember to consider both "happy paths" and "non-happy paths"