Test-Driven Development

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Credit where Credit is Due

- Some of the material for this lecture is taken from “Test-Driven Development” by Kent Beck
    - as such some of this material is copyright © Addison Wesley, 2003
- In addition, some material for this lecture is taken from “Agile Software Development: Principles, Patterns, and Practices” by Robert C. Martin
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- Finally, one of the examples is inspired by the Roman Numerals example that is featured in Dive into Python 3 <http://diveintopython3.org/> by Mark Pilgrim. The slides devoted to that example are thus distributed using the following license: <http://creativecommons.org/licenses/by-sa/3.0/>.

Goals for this lecture

- Introduce the concept of Test-Driven Development (TDD)
- Present several examples

Test-Driven Development

- The idea is simple
  - No **production** code is written except to make a failing test pass
- Implication
  - You have to write test cases before you write code
- Note: use of the word “production”
  - which refers to code that is going to be deployed to and used by real users
- It does not say: “No code is written except…”

Writing Test Cases First

- This means that when you first write a test case, you may be testing code that does not exist
    - And since that means the test case will not compile, obviously the test case “fails”
        - After you write the skeleton code for the objects referenced in the test case, it will now compile, but also may not pass
- So, then you write the simplest code that will make the test case pass

Example (I)

- Consider writing a program to score the game of bowling
- You might start with the following test

```
public class TestGame extends TestCase {
   public void testOneThrow() {
      Game g = new Game();
      g.addThrow(5);
      assertEquals(5, g.getScore());
   }
}
```

- When you compile this program, the test “fails” because the Game class does not yet exist. But:
  - You have defined two methods on the class that you want to use
  - You are designing this class from a client’s perspective

Example (II)

- You would now write the Game class

```
public class Game {
   public void addThrow(int pins) {
   }
   public int getScore() {
      return 0;
   }
}
```

- The code now compiles but the test will still fail: getScore() returns 0 not 5
  - In Test-Driven Design, Beck recommends taking small, simple steps
  - So, we get the test case to compile before we get it to pass

Example (III)

- Once we confirm that the test still fails, we would then write the simplest code to make the test case pass; that would be

```
public class Game {

   public void addThrow(int pins) {
   }

   public int getScore() {
      return 5;
   }
}
```

- The test case now passes!

Example (IV)

- But, this code is not very useful!
- Lets add a new test case to enable progress

```
public class TestGame extends TestCase {
     public void testOneThrow() {
        Game g = new Game();
        g.addThrow(5);
        assertEquals(5, g.getScore());
     }
     public void testTwoThrows() {
        Game g = new Game()
        g.addThrow(5)
        g.addThrow(4)
        assertEquals(9, g.getScore());
     }
}
```

- The first test passes, but the second case fails (since 9 ≠ 5)
  - This code is written using JUnit; it uses reflection to invoke tests automatically

Example (V)

- We have duplication of information between the first test and the Game class
  - In particular, the number 5 appears in both places
  - This duplication occurred because we were writing the simplest code to make the test pass
  - Now, in the presence of the second test case, this duplication does more harm than good
  - So, we must now refactor the code to remove this duplication

Example (VI)

```
public class Game {
   private int score = 0;
   public void addThrow(int pins) {
      score += pins;
   }
   public int getScore() {
      return score;
   }
}
```

Both tests now pass. Progress!

Example (VII)

- But now, to make additional progress, we add another test case to the TestGame class

  …

```
public void testSimpleSpare() {
    Game g = new Game()
    g.addThrow(3); g.addThrow(7); g.addThrow(3);
    assertEquals(13, g.scoreForFrame(1));
    assertEquals(16, g.getScore());
}
```

  …

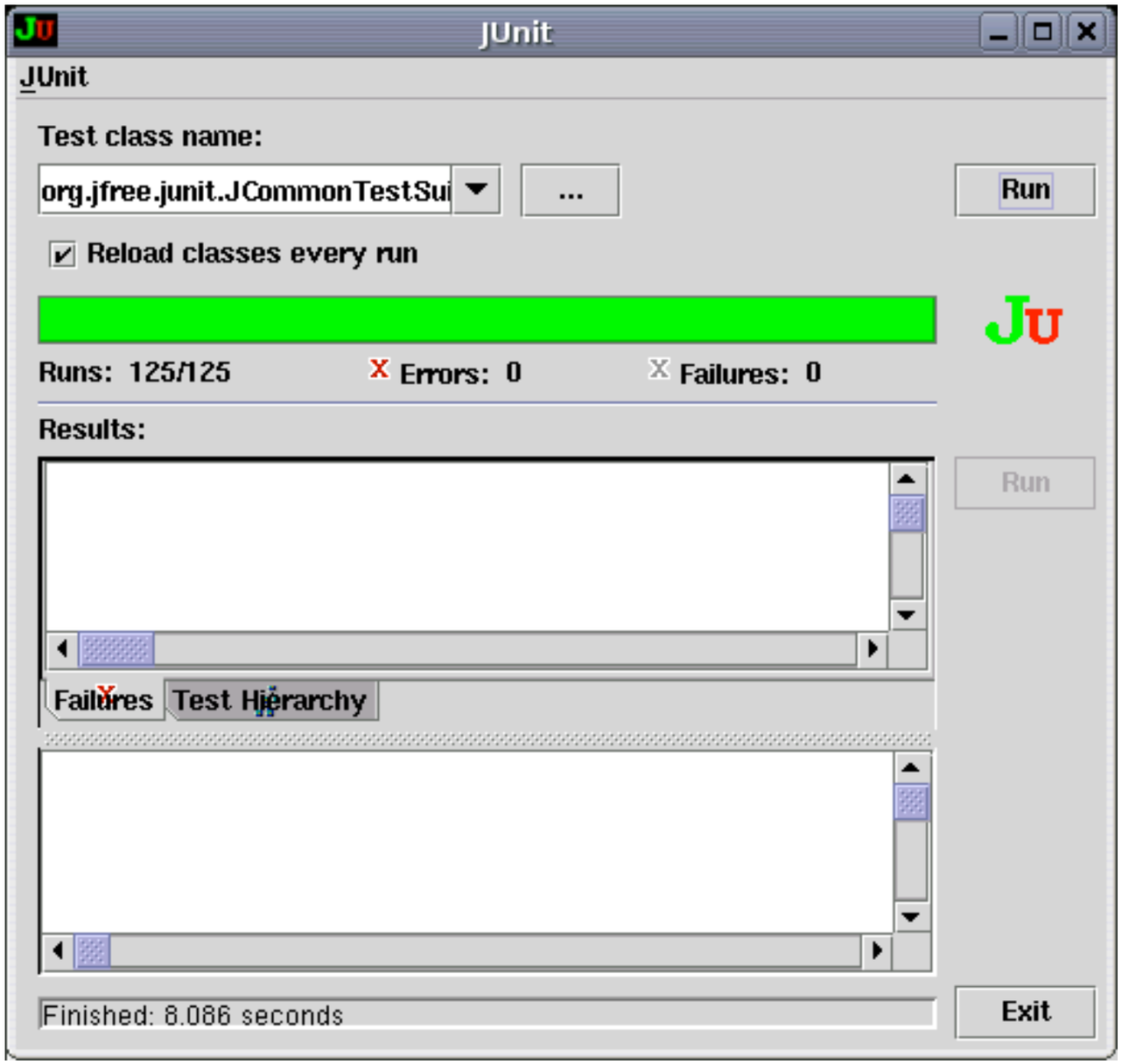
- We’re back to the code not compiling due to scoreForFrame()
  - We’ll need to add a method body for this method and give it the simplest implementation that will make all three of our tests cases pass

TDD Life Cycle

- The life cycle of test-driven development is
    - Quickly add a test
    - Run all tests and see the new one fail
    - Make a simple change
    - Run all tests and see them all pass
    - Refactor to remove duplication
- This cycle is followed until you have met your goal;
    - note that this cycle simply adds testing to the “add functionality; refactor” loop covered in the our two lectures on refactoring

TDD Life Cycle, continued

- Kent Beck likes to perform TDD using a testing framework, such as JUnit.
- Within such frameworks
  - failing tests are indicated with a "red bar"
  - passing tests are shown with a "green bar"
- As such, the TDD life cycle is sometimes described as
  - "red bar/green bar/refactor"



JUnit: Red Bar...

- When a test fails:
  - You see a red bar
  - Failures/Errors are listed
  - Clicking on a failure displays more detailed information about what went wrong

Example Background: Multi-Currency Money

- Lets design a system that will allow us to perform financial transactions with money that may be in different currencies
    - e.g. if we know that the exchange rate from Swiss Francs to U.S. Dollars is 2 to 1 then we can calculate expressions like
        - 5 USD + 10 CHF = 10 USD
    - or
        - 5 USD + 10 CHF = 20 CHF

Starting From Scratch

- Lets start developing such an example
- How do we start?
    - TDD recommends writing a list of things we want to test
    - This list can take any format, just keep it simple
- Example
    - $5 + 10 CHF = $10 if rate is 2:1
    - $5 * 2 = $10

First Test

- The first test case looks a bit complex, lets start with the second
  - 5 USD * 2 = 10 USD
- First, we write a test case

```
public void testMultiplication() {
   Dollar five = new Dollar(5);
   five.times(2);
   assertEquals(10, five.amount)
}
```

Discussion on Test Case

```
public void testMultiplication() {
   Dollar five = new Dollar(5);
   five.times(2);
   assertEquals(10, five.amount)
}
```

- What benefits does this provide?
  - target class plus some of its interface
    - we are designing the interface of the Dollar class by thinking about how we would want to use it
  - We have made a testable assertion about the state of that class after we perform a particular sequence of operations

What's Next?

- We need to update our test list
    - The test case revealed some things about Dollar that we will want to address
        - We are representing the amount as an integer, which will make it difficult to represent values like 1.5 USD; how will we handle rounding of factional amounts?
    - Dollar.amount is public; violates encapsulation
    - What about side effects?; we first declared our variable as "five" but after we performed the multiplication it now equals "ten"

Update Testing List

- The New List
  - 5 USD + 10 CHF = 10 USD
  - $5 * 2 = $10
  - make “amount” private
    - Dollar side-effects?
    - Money rounding?
- Now, we need to fix the compile errors
  - no class Dollar, no constructor, no method: times(), no field: amount

First version of Dollar Class

```
public class Dollar {

   public Dollar(int amount) {

   }

   public void times(int multiplier) {

   }

   public int amount;

}
```

- Now our test compiles and fails!

Too Slow?

- Note: we did the simplest thing to make the test compile;
- now, we are going to do the simplest thing to make the test pass
- Is this process too slow?
    - **YES**, as you get familiar with the TDD life cycle you will gain confidence and make bigger steps
- **NO**, taking small simple steps avoids mistakes;
    - beginning programmers try to code too much before invoking the compiler;
    - they then spend the rest of their time debugging!

How do we make the test pass?

- Here's one way

```
public void times(int multiplier) {

   amount = 5 * 2;

}
```

- The test now passes, we received a "green bar"!
- Now, we need to "refactor to remove duplication"
  - But where is the duplication?
  - Hint: its between the Dollar class and the test case

Refactoring

- To remove the duplication of the test data and the hard-wired code of the times method, we think the following
- “We are trying to get a 10 at the end of our test case and we’ve been given a 5 in the constructor and a 2 was passed as a parameter to the times method”
    - So, lets connect the dots…

First version of Dollar Class

```
public class Dollar {

   public Dollar(int amount) {

         this.amount = amount;

   }

   public void times(int multiplier) {

         amount = amount * multiplier;

   }

   public int amount;

}
```

- Now our test compiles and passes, and we didn’t have to cheat!

One loop complete!

- Before writing the next test case, we update our testing list
  - 5 USD + 10 CHF = 10 USD
  - ~~$5 * 2 = $10~~
  - make “amount” private
    - Dollar side-effects?
    - Money rounding?

One more example

- Lets address the “Dollar Side-Effects” item and then move on to another example
- Lets write the next test case
    - When we called the times operation our variable “five” was pointing at an object whose amount equaled “ten”; not good
    - the times operation had a side effect which was to change the value of a previously created “value object”
    - Think about it, as much as you might like to, you can’t change a 5 dollar bill into a 500 dollar bill; the 5 dollar bill remains the same throughout multiple financial transactions

Next test case

- The behavior we want is

```
public void testMultiplication() {
    Dollar five = new Dollar(5);
    Dollar product = five.times(2);
    assertEquals(10, product.amount);
    product = five.times(3);
    assertEquals(15, product.amount);
    assertEquals(5, five.amount);
}
```

Test fails

- The test fails because it won't compile;
- We need to change the signature of the times method; previously it returned void and now it needs to return Dollar

```
public Dollar times(int multiplier) {
    amount = amount * multiplier;
    return null;
}
```

- The test compiles but still fails; as Kent Beck likes to say "Progress!"

Test Passes

- To make the test pass, we need to return a new Dollar object whose amount equals the result of the multiplication

```
public Dollar times(int multiplier) {

   return new Dollar(amount * multiplier);
}
```

- Test Passes;
- Cross “Dollar Side Effects?” off the testing list; second loop complete!
- There was no need to refactor in this situation

Discussion of the Example

- There is still a long way to go
  - only scratched the surface
- But
  - we saw the life cycle performed twice
  - we saw the advantage of writing tests first
  - we saw the advantage of keeping things simple
  - we saw the advantage of keeping a testing list to keep track of our progress
- Plus, as we write new code, we will know if we are breaking things because our old test cases will fail if we do;
  - if the old tests stay green, we can proceed with confidence

Roman Numerals (I)

- Let’s develop a class that can manipulate roman numerals
    - Roman numerals can express integers from 1 to 3999
- They do this using the following set of symbols that map to the following values
    - I = 1, V = 5, X = 10, L = 50, C = 100, D = 500, M = 1000
- There are rules concerning how these characters can be combined
    - For instance, the 10s characters (X,C,M) can be repeated up to three times
    - The 5s characters (V, L, D) cannot be repeated
    - Character sequences can be additive (III = 3) or subtractive (IX = 9)
        - Can be complex 99 is written as XCIX (100-10 + 10-1)

Roman Numerals (II)

- We start by developing a testing list
    - able to convert legal roman numerals to integers
    - able to convert integers in the range 1 to 3999 into roman numerals
    - able to add two roman numerals, checking for boundary conditions
    - able to subtract two roman numerals, checking for boundary conditions
- We will not complete the example but we'll make progress on a few of these

Test Case: Create a Roman Numeral, Get Its Value

- Let's use Python's Unit Test framework
  - We write the test case as if all the code we need is available

```
1  import roman
2  import unittest
3
4  class TestRomanNumerals(unittest.TestCase):
5
6    def testCreateAndGetValue(self):
7      thousand = roman.RomanNumeral("M")
8      self.assertEqual(thousand.value(), 1000)
9
10 if __name__ == "__main__":
11   unittest.main()
12
```

Several Failures on the Path to Green

- module import fail: no file named roman.py ➟ create one
- no class called RomanNumeral ➟ create one
- wrong number of arguments for constructor ➟ add self and value arguments
- no method called value() ➟ create a “blank” one
- test now runs and reports failure!! ➟ write simplest code to make it work
- test passes but contains duplication ➟ add another test case to make it fail
  - end of step 2, onto step 3 directory
- original test passes, but new test fails ➟ write simplest code to make it work
  - note, because of the tests, this is no longer trivial code to write

Making Progress; But Long way to go

- We now have a class that can successfully handle Roman Numerals that consist only of “M” characters
    - And, we haven’t fully completed any of the items on our test list
    - We have lots of different directions we could go in
        - Add tests to check that we handle bad input
        - Add tests to add support for other roman numeral characters
        - Add tests to add basic support for addition or subtraction
        - etc.
- Let’s focus on bad input to see the test-code-refactor loop one more time

Test Case: Handle Bad Input

- Let’s add test cases that handle
  - wrong input types (being handed a number or array rather than a string)
  - wrong values (producing a value that is outside the legal set of values)
- Then, we’ll add a test case that can handle basic addition

Several Failures on the Path to Green (Again)

- add test case to handle non-string args to the constructor
  - Here we want to give it bad input and see if it raises an exception
    - All such tests will currently fail since the constructor just accepts whatever it is given
  - Start by passing a number, check to see if it raises an exception ➟ fail
    - Add code to check for int ➟ pass; now pass collection ➟ fail
      - Make it pass but then erase code written so far and now write code to raise exception whenever a non-string is passed
        - This is the refactor step, as we were adding duplication based on the types of the parameters passed in between code and test case
- End of step 4; now make sure that we test the contents of the string
  - accept “M”, “MM”, and “MMM” for now, all else should fail

Test Case: Handle Addition

- All we'll be able to do is handle 1000 + 1000 and 1000 + 2000
  - but this will ensure that we've got the basics in place
    - can handle correct additions
    - can flag additions that produce numbers outside the legal range
- Getting to Green
  - Add a sum method that follows the "value" pattern seen above
  - Generates ValueError if the value goes outside of the legal range
  - First a test case to handle an illegal addition
  - Then a test case to handle a legal addition
    - We'll encounter familiar steps
      - fails because there is no sum method
      - fails because it doesn't throw an exception
      - etc.

End of Example

- Still a long way to go, but you should now have the feel of what test-driven development is like
  - Start with a system that needs a new feature
  - Write a test that documents what the expected results of the feature are
  - Add simplest code to make test pass
  - Make test more complicated, or add new test to reveal duplication
  - Once duplication is found, refactor to produce general code
  - Loop until feature is implemented and all tests pass

Principles of TDD

- Testing List
  - keep a record of where you want to go;
    - Beck keeps two lists, one for his current coding session and one for “later”; You won’t necessarily finish everything in one go!
- Test First
  - Write tests before code, because you probably won’t do it after
  - Writing test cases gets you thinking about the design of your implementation;
    - does this code structure make sense?
    - what should the signature of this method be?

Principles of TDD, continued

- Assert First
  - How do you write a test case?
    - By writing its assertions first!
  - Suppose you are writing a client/server system and you want to test an interaction between the server and the client
    - Suppose that for each transaction
      - some string has to have been read from the server, and
      - the socket used to talk to the server should be closed after the transaction
- Lets write the test case

Assert First

```
public void testCompleteTransaction {

   …

   assertTrue(reader.isClosed());

   assertEquals(“abc”, reply.contents());

}
```

- Now write the code that will make these asserts possible

Assert First, continued

```
public void testCompleteTransaction {
   Server writer = Server(defaultPort(), “abc”)
   Socket reader = Socket(“localhost”, defaultPort());
   Buffer reply = reader.contents();
   assertTrue(reader.isClosed());
   assertEquals(“abc”, reply.contents());
}
```

- Now you have a test case that can drive development
  - if you don’t like the interface above for server and socket, then write a different test case
  - or refactor the test case, after you get the above test to pass

Principles of TDD, continued

- Evident Data
  - How do you represent the intent of your test data
  - Even in test cases, we'd like to avoid magic numbers; consider this rewrite of our second "times" test case

```
public void testMultiplication() {
    Dollar five = new Dollar(5);
    Dollar product = five.times(2);
    assertEquals(5 * 2, product.amount);
    product = five.times(3);
    assertEquals(5 * 3, product.amount);
}
```

- Replace the "magic numbers" with expressions

Summary

- Test-Driven Design is a “mini” software development life cycle that helps to organize coding sessions and make them more productive
    - Write a failing test case
    - Make the simplest change to make it pass
    - Refactor to remove duplication
    - Repeat!

Reflections

- Test-Driven Design builds on the practices of Agile Design Methods
    - If you decide to adopt it, not only do you “write code only to make failing tests pass” but you also get
        - an easy way to integrate refactoring into your daily coding practices
        - an easy way to introduce “integration testing/building your system every day” into your work environment
            - because you need to run all your tests to make sure that your new code didn’t break anything; this has the side effect of making refactoring safe
        - courage to try new things, such as unfamiliar design pattern, because now you have a safety net

Ken’s Corner: Testing Frameworks

- JUnit Tutorial: <http://clarkware.com/articles/JUnitPrimer.html>
- PyUnit: <http://wiki.python.org/moin/PyUnit>
- Unit testing in Objective-C and Xcode:
  - <http://developer.apple.com/mac/articles/tools/unittestingwithxcode3.html>
- Unit testing with C#: <http://www.csunit.org/tutorials/tutorial7/>
- Unit testing for Ruby:
  - <http://www.ruby-doc.org/stdlib/libdoc/test/unit/rdoc/classes/Test/Unit.html>
  -

Coming Up Next

- Lecture 30: Scala Traits, Ruby mix-ins and Semester Wrap Up