Testing Object-Oriented Systems (Part 2)

CSCE 747 - Lecture 17 - 03/27/2018

Testing Object-Oriented Software

- Testing of OO systems is impacted by
  - State Dependent Behavior
  - Encapsulation
  - Inheritance
  - Polymorphism and Dynamic Binding
  - Abstract Classes
  - Exception Handling
  - Concurrency
- To test such systems, we must test both individual classes and groups of related classes.

Intraclass Testing

To test a class in isolation, we:

1. If the class is abstract, derive a set of instantiations to cover significant cases.
2. Design test cases to check correct invocation of inherited and overridden methods.
3. Design a set of test cases based on the states that the class can be put into.
    a. Build a state machine model based on the class.

Intraclass Testing

4. Derive structural information from the source code (control and data-flow) and cover the code structure of the class.
5. Design test cases for exception handling.
   a. Exercising exceptions that should be thrown by methods in the class and exceptions that should be caught and handled by them.
6. Design test cases for polymorphic calls.
   a. Calls to superclass or interface methods that can be bound to different subclass objects.

Interclass Testing

1. Identify a hierarchy of classes to be tested incrementally.
2. Design a set of interclass test cases for the cluster-under test.
3. Add test cases to cover data flow between method calls.
4. Integrate the intraclass exception-handling tests with interclass exception-handling tests.
5. Integrate polymorphism test suite with tests that check for interclass interactions.

Structural Testing for Classes

Classes are Stateful

- A class has state, and state is impacted by the class' methods.
  - The state of the class is the result of a sequence of methods called.
  - Functional testing of classes focused on identifying the sequence of method calls that would cover different states.
- Structural techniques must also extend control and data flow across sequences of method calls.

Direct and Indirect Coverage

- Expressions in a method can be covered either through a **direct** call from a test case or a call from one method to another.
  - The test calls Method A, then Method A calls Method B. Code in Method B is covered **indirectly**.
- How coverage is attained may impact the likelihood of fault detection.
  - Coverage is attained contextually. Direct and indirect method calls may cover the same elements, but use different input.

Direct and Indirect Coverage

- Branch Coverage of faultyAdd can be attained through direct method calls from a test case, or by calling add (which calls faultyAdd).
- Indirect coverage cannot reveal the fault.
- We must consider the context in which coverage is attained.

```
public int[] add(int[] values, int valueToAdd){
    for(int i = 0; i < values.size(); i++){
        if(valueToAdd >= 0){ values[i] =
            faultyAdd(values[i], valueToAdd);
         }
    }
    return values;
}

public int faultyAdd(int value, int valueToAdd){
    if (valueToAdd <= 0){
        // FAULT, should be ==
        return value;
    }
    return value + valueToAdd;
}
```

Structural Testing of Classes

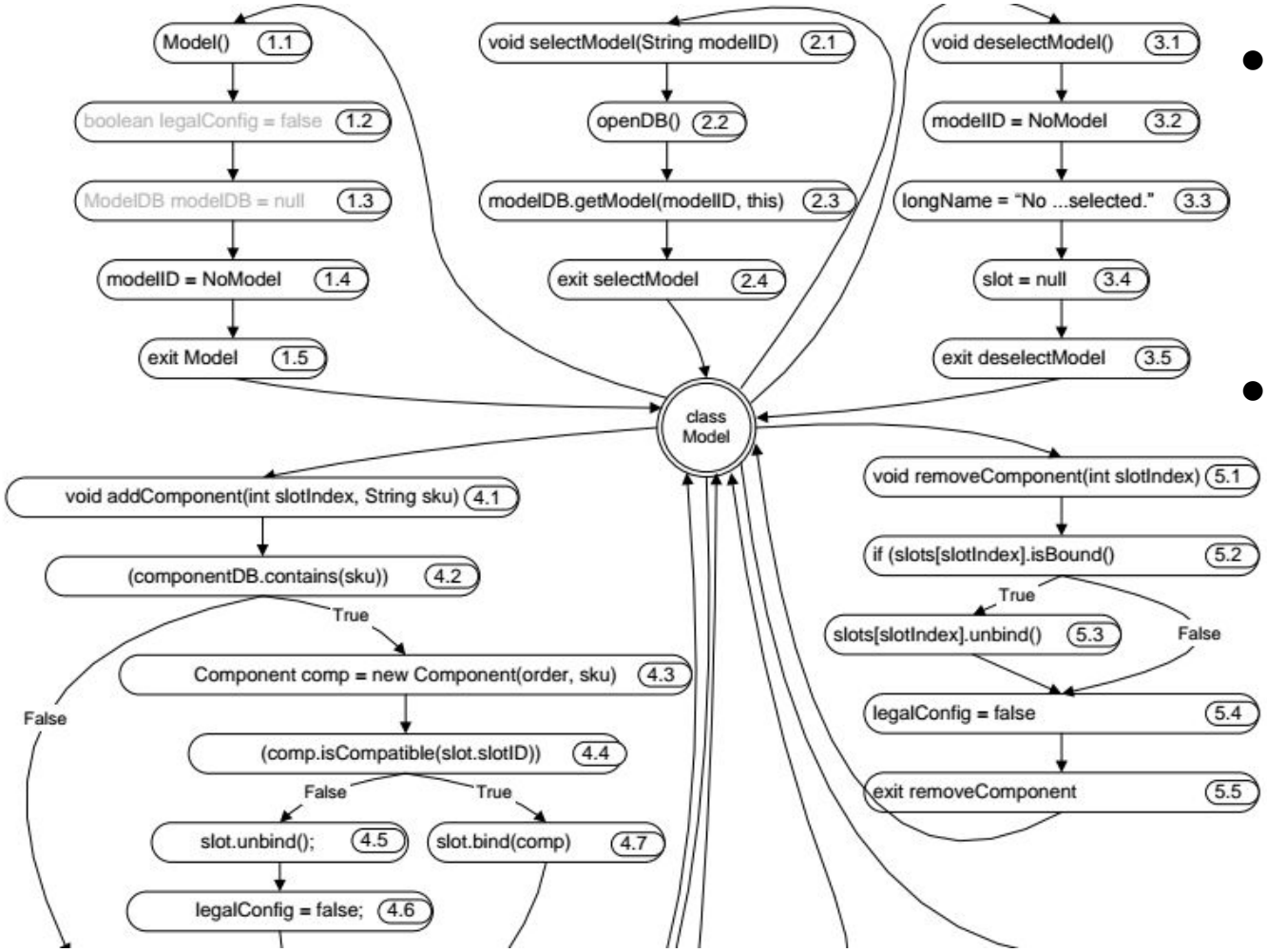
- Private methods can **only** be covered indirectly.
  - Coverage may be difficult or impossible to achieve.
- Context is important.
  - Structural techniques must extend control and data flow across sequences of method calls.

```
public class Model extends Orders.CompositeItem{
      public String modelID;
      private int baseWeight;
      private int heightCm, widthCM, depthCM;
      private Slot[] slots;
      private boolean legalConfig = false;
      private static final String NoModel = "NO
MODEL SELECTED";

      private void checkConfiguration(){
            ...
      }

      public boolean isLegalConfiguration(){
            if(!legalConfig){
                  this.checkConfiguration();
            }
            return legalConfig;
      }
}
```

Intraclass Structural Testing

- We need to track definitions and uses of the class variables across multiple methods instead of just one.
- Create control-flow graph across the class.
  - Create control-flow graphs for each method.
  - Add a central node representing the class itself.
    - Edges from node Class to the entry of each method
    - Edge from exit of each method to node Class.
  - Add global declarations to the constructor's CFG.

Intraclass CFG



- For now - treat calls to methods of **other classes** as simple statements.
- Need a strategy for arrays and objects, like with one-method data-flow.

Structural Testing of Classes

- A test case to exercise a DU pair is a sequence of method calls that starts with the constructor and includes a definition-clear path.
- Can use All DU Pair, All DU Path, All Definitions coverage metrics.
- Covers variables not mentioned in the specification (or modeled in state machine)

```
public class Model extends
Orders.CompositeItem{
      private boolean legalConfig = false;

      private void checkConfiguration() {}
      // 2 definitions

      public boolean isLegalConfiguration(){
            if(!legalConfig){
                  this.checkConfiguration();
            }
            return legalConfig;
      }
      public void addComponent(int slotIndex,
String sku){}    // 2 definitions

      public void removeComponent(int
slotIndex){}     // 1 definition
}
```

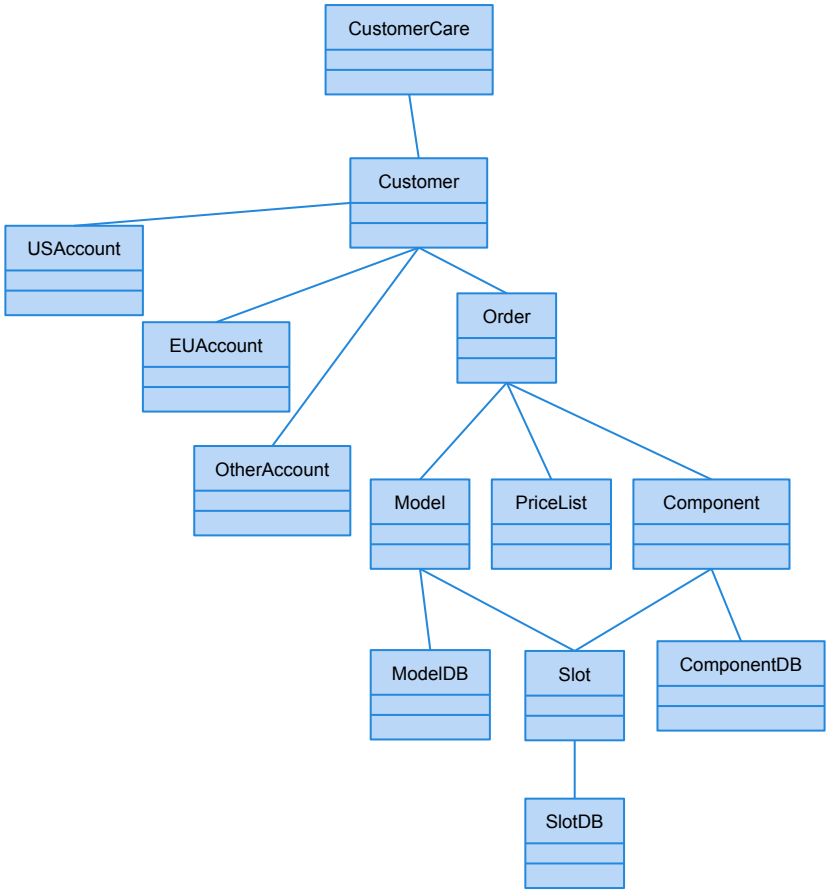
Structural Testing of Classes

```
@Test
public void legalConfigDUTest(){
    Model m = new Model();
    // Covers initialization
    Bool result = m.isLegalConfiguration();
    // Covers use of initial def
    assertFalse("init value is F", result);
    m.addComponent(1,"1234");
    //Covers one of two new definitions,
    check which are covered.
    Bool result = m.isLegalConfiguration();
    // Covers use of new definition
    assertTrue("Legal config", result);
}
```

```
public class Model extends
Orders.CompositeItem{
      private boolean legalConfig = false;

      private void checkConfiguration() {}
      // 2 definitions

      public boolean isLegalConfiguration(){
            if(!legalConfig){
                  this.checkConfiguration();
            }
            return legalConfig;
      }
      public void addComponent(int slotIndex,
String sku){}    // 2 definitions

      public void removeComponent(int
slotIndex){}     // 1 definition
}
```

Interclass Data-Flow Testing

- Too many potential DU pairs to consider all.
- Instead, follow the dependence relation.
- Examine how each class can define and use class variables from its leaves.
  - Classify inspectors, modifiers, inspector/modifier methods.
  - Not per variable, but overall.



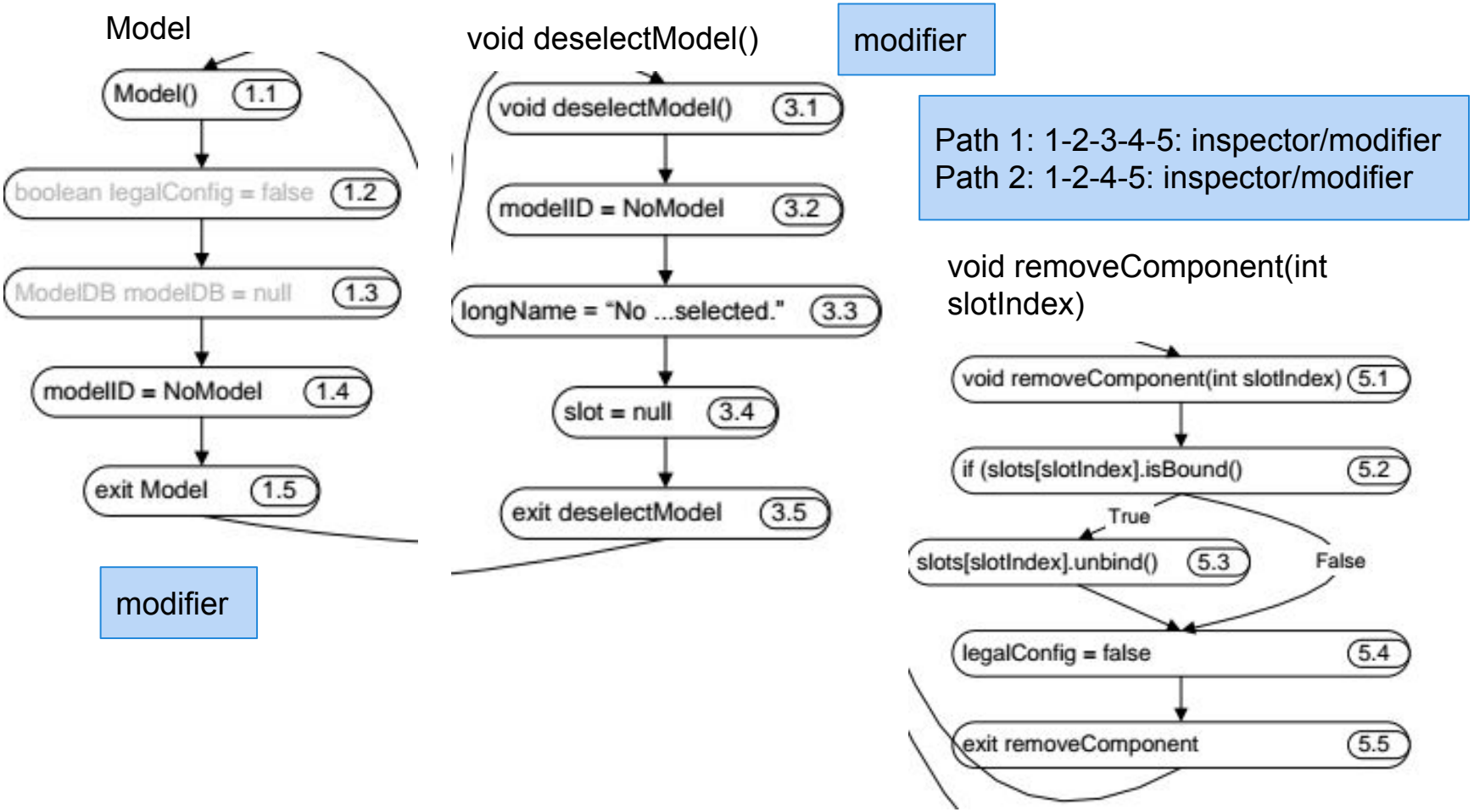
Interclass Data-Flow Testing

- Inspectors
  - Methods that access, but do not modify the state of a dependent class.
  - Uses, no definitions.
- Modifiers
  - Methods that modify, but do not access the state.
  - Definitions, no uses.
- Inspector/Modifiers
  - Methods that both define and use variables.
- Other methods do not need to be considered in interclass data-flow testing.

Interclass Structural Testing

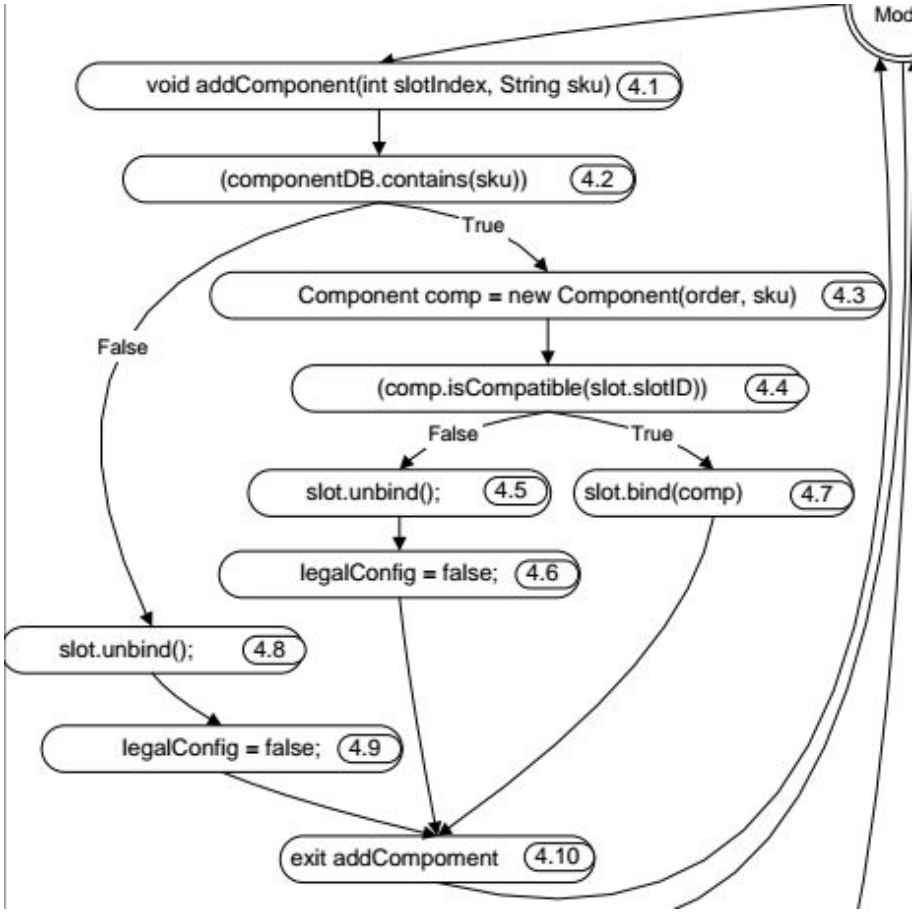
- Consider the whole object state when classifying.
  - Method is a inspector/modifier, even if it inspects one class variable and modifies another.
  - Important for improving scalability.
- If a method has multiple execution paths
  - Can classify whole method.
  - Or split into separate paths if they would have different classifications.

Example - Model



Example - Model

void addComponent(int slotIndex, String sku)

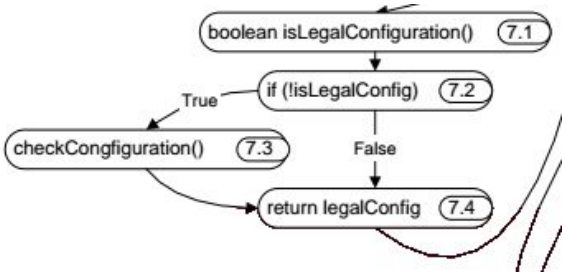


Paths:
1-2-3-4-7-10
1-2-3-4-5-6-10
1-2-8-9-10

Path 1:
inspector/modifier
Path 2:
inspector/modifier
Path 3:
inspector/modifier

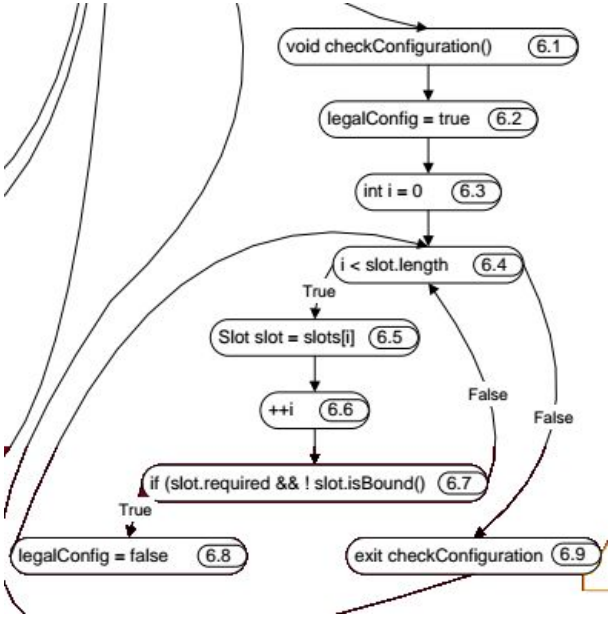
Example - Model

boolean isLegalConfiguration()



Paths:
1: 1-2-3-[1-2-3-4-5-6-7-8-4-9]-4
2: 1-2-3-[1-2-3-4-5-6-7-4-9]-4
3: 1-2-3-[1-2-3-4-9]-4
4: 1-2-4

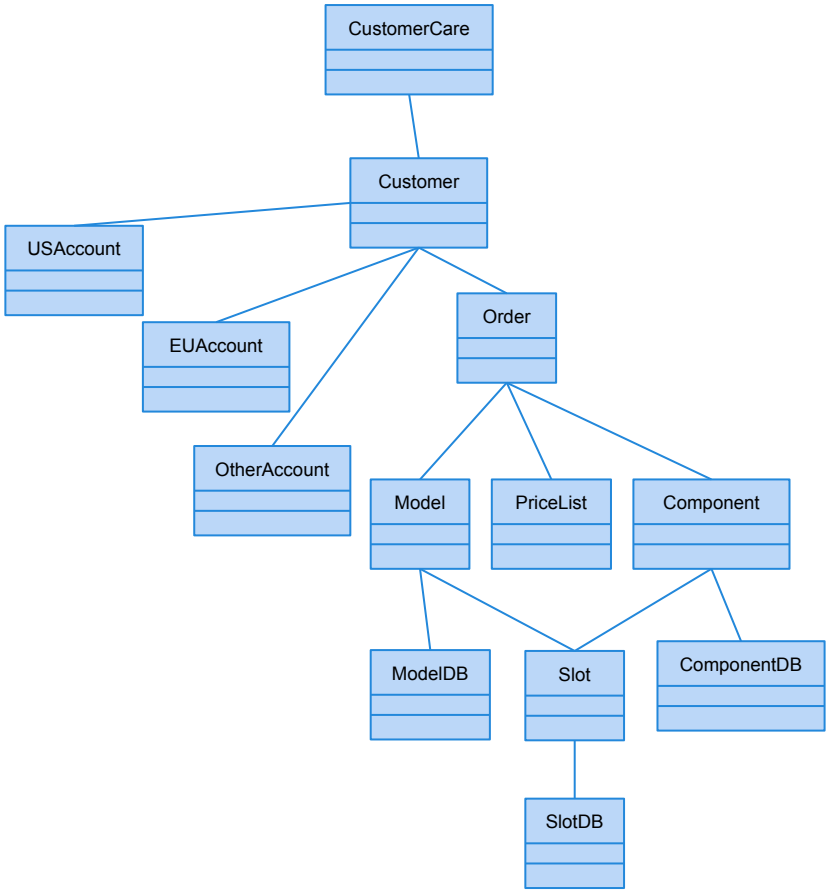
void checkConfiguration()



Path 1: inspector/modifier
Path 2: inspector/modifier
Path 3: inspector/modifier
Path 4: modifier

Interclass Structural Testing

- Test classes that use or contain leaf classes.
- Invocations of modifiers and inspector/modifiers are treated as definitions
- Invocations of inspectors and inspector/modifiers are treated as uses.
- Analyze classes that depend on classes already analyzed.



Addressing OO Testing Issues

Writing Oracles for Classes

- The correctness of a method is not just judged on the output of the method, but on the state of the object.
  - deselectModel() should clear the array slots on the object.
- Oracles must check the validity of both output and state.
- State may not be directly accessible.
  - Private variables.

Option 1: Modify the Code

- Break encapsulation by making variables public while testing.
  - Risk - different behavior between testing and production code.
  - C++ has friend classes
- Add “getter” methods.
- Add a method that produces a representation of the entire state of the object.
  - object.toString() in Java.

Option 2: Java Reflection

- Reflection allows Java code to inspect objects at runtime.
- Can be used to identify their class, fields, and methods, and use them to perform tasks.

```
Method[] methods = MyObject.class.getMethods();

for(Method method : methods){
    System.out.println("method = " + method.getName());
}
```

- This code gets the class and prints out the list of methods.

Option 2: Java Reflection

- Reflection can be used to access private fields and methods.
- Protects the real object from modification, but can be used to get information for testing.

```
public class PrivateObject {

  private String privateString = null;

  public PrivateObject(String privateString) {
    this.privateString = privateString;
  }
}

PrivateObject privateObject = new
PrivateObject("The Private Value");


Field privateStringField =
PrivateObject.class.getDeclaredField("privateStrin
g");
privateStringField.setAccessible(true);

String fieldValue = (String)
privateStringField.get(privateObject);
System.out.println("fieldValue = " + fieldValue);
```

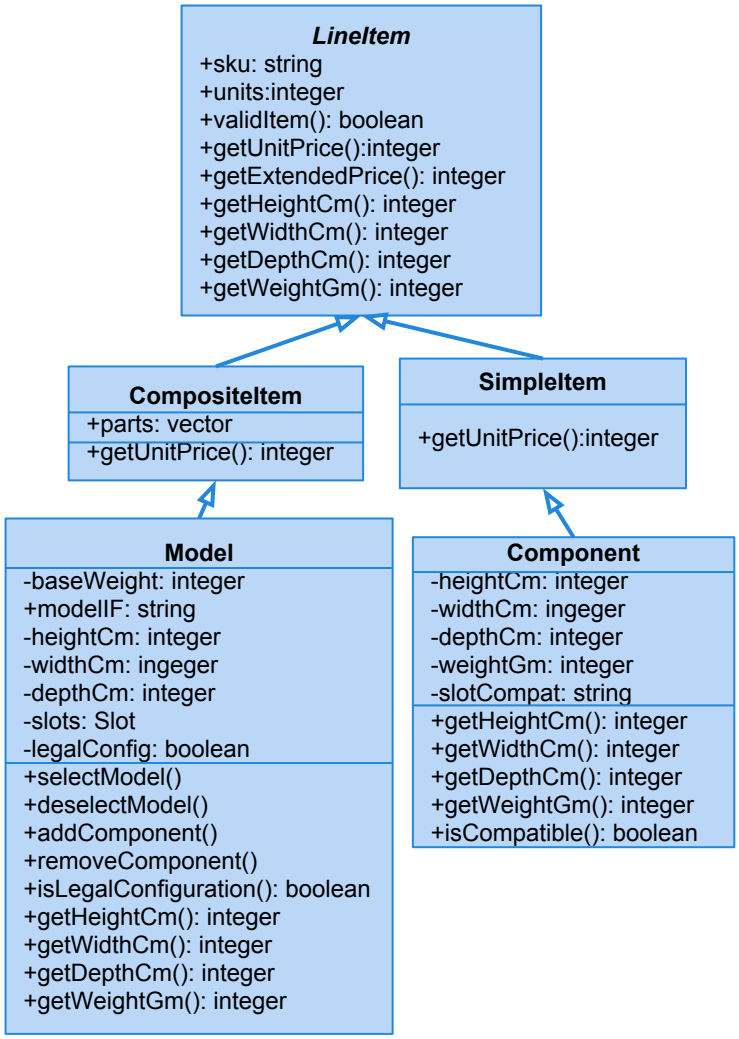
Option 3: Equivalent Scenarios

- Rather than exposing internal state, execute two *equivalent* scenarios and check whether the inspectable portions of the two produced objects match.
  - Then, run a third *non-equivalent* scenario and make sure it differs from the first two.

selectModel(M1) addComponent(S1,C1) addComponent(S2,C2) isLegalConfig() deselectModel() selectModel(M2) addComponent(S1,C1) isLegalConfig()	selectModel(M2) addComponent(S1,C1) isLegalConfig()	selectModel(M2) addComponent(S1,C1) addComponent(S2,C2) isLegalConfig()
	Equivalent	**Non-Equivalent**

Polymorphism and Dynamic Binding

- Behavior depends on the object assigned at runtime.
  - If LineItem.getUnitPrice() is called, it may actually be SimpleItem.getUnitPrice().
  - Wrong object might be bound to the variable.
  - May be difficult to tell which class has the fault.
  - Fault may be a result of a combination of bindings.
- Testing one possible binding is not enough - must try multiple bindings.



Polymorphism and Dynamic Binding

- Limited use of polymorphism: Unfold calls.
  - Try each possible binding.
- Challenge - layers of polymorphic calls.

```
public abstract class Credit{
     abstract boolean validateCredit(Account a, int amt, CreditCard c);
}

Credit c;
boolean canPurchase = c.validateCredit(a,amt,cc);
```

Credit can be one of: EduCredit, BusinessCredit, IndividualCredit

Account can be one of: USAccount, UKAccount,EUAccount, JPAccount, or OtherAccount

CreditCard can be one of: VISACard, AmexCard, MasterCard

Apply Combinatorial Testing

- This is the same problem faced in functional testing, with parameter combinations.
- Use combinatorial interaction testing to test all n-way combinations.

Account	Credit	creditCard
USAccount	EDUCredit	VISACard
USAccount	BusinessCredit	AmExCard
USAccount	IndividualCredit	MasterCard
UKAccount	EDUCredit	AmExCard
UKAccount	BusinessCredit	VISACard
UKAccount	IndividualCredit	MasterCard
EUAccount	EDUCredit	MasterCard
EUAccount	BusinessCredit	AmExCard
EUAccount	IndividualCredit	VISACard
JPAccount	EDUCredit	VISACard
JPAccount	BusinessCredit	MasterCard
JPAccount	IndividualCredit	AmExCard
OtherAccount	EDUCredit	MasterCard
OtherAccount	BusinessCredit	VISACard
OtherAccount	IndividualCredit	AmExCard

Polymorphism and Dynamic Binding

- Problem - bad polymorphic call infects a variable definition.

```
public abstract class Account{
      public int getYTDPurchased(){
            int totalPurchased = 0;

            for(Enumeration e = subsidiaries.elements(); e.hasMoreElements(); ){
                  Account subsidiary = (Account) e.nextElement();
                  totalPurchased += subsidiary.getYTDPurchased();
            }
            return totalPurchased;
      }
}
```

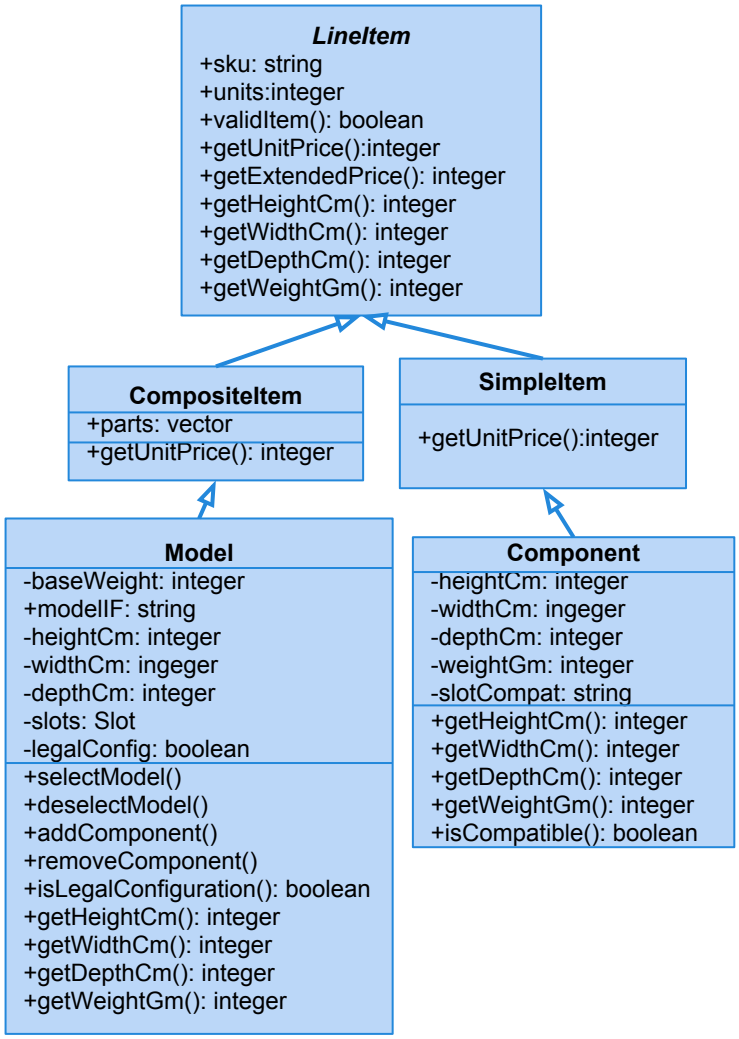
- Combine polymorphic variations with data-flow techniques.

Data-Flow x Polymorphic Calls

- Use data flow analysis to identify DU pairs.
  - At each definition and use bound to a polymorphic call, note the possible bindings.
- One DU pair becomes N x M pairs.
  - N ways the definition can be bound.
  - M ways the point of use can be bound.
- High number of tests, but only those polymorphic calls that can corrupt variables.
  - If too many, cover all N and M settings in any combination, rather than their product.

Inheritance

- We can define child classes that inherit attributes and operations.
- Most inheritance issues are really polymorphism issues.
- However, inheritance may allow us to **reduce** the number of test cases required.



Inheritance and Test Reuse

- Subclasses share methods with ancestors.
- We can categorize methods as:
  - **New:** If not inherited, we need to test them.
    - If the name is the same, but parameters have changed, it is new.
  - **Recursive:** Inherited from the ancestor without change. Code only appears in the ancestor.
  - **Redefined:** Overridden in the subclass.

Inheritance and Test Reuse

- We can categorize methods as:
  - **Abstract New:** New and abstract in the subclass.
  - **Abstract Recursive:** Inherited when *the ancestor's version was abstract*.
  - **Abstract Redefined:** Redefined when *the ancestor's version was abstract*.

Inheritance and Test Reuse

- In general, four sets of tests for a method:
  - Int*ra*class Functional, Intraclass Structural
  - Int*er*class Functional, Interclass Structural
- When we test a subclass, new methods need test cases.
- Recursive/Abstract Recursive methods do not need to be retested.
- Redefined/Abstract Redefined must be retested.

Genericity

- Generics
  - Generic class is instantiated with different types:
    - LinkedList<String>, LinkedList<Integer>
    - HashMap<String,Integer>, HashMap<ArrayList<Integer>,Boolean>
- Important for building reusable components and libraries.
- Challenging to test:
  - Can only test instantiations, not the generic class.
  - May not know all ways it can be instantiated.

Testing Generics

- Designed to behave consistently.
- First, testing requires showing that any instantiation is correct.
  - In general, this is straightforward if we have code of the generic class and the parameterized version.
- Second, do all possible parameterizations behave identically to the tested one?

Testing Generics

- Second, do all possible parameterizations behave identically to the tested one?
  - Potential challenge - does the generic class interact with the parameterized version?
    - i.e., the generic makes use of a service the parameterized version might also make use of.
    - `class PriorityQueue<Elem implements Comparable> {...}`
      - Behavior of PriorityQueue<E> depends on E.
    - Acceptable as long as E behaves correctly when fulfilling requirements of Comparable.
    - Interfaces are a type of specification.

Exceptions

- Exceptions separate error handling from the primary program logic.
  - Common fault in C - not checking for error indications returned by a function.
  - In Java, a thrown exception interrupts control.
- Introduces implicit control flow
  - The point where an exception is caught and handled may not match where it is thrown.
  - Associations of exceptions with handlers is dynamic.
    - Exception propagates up stack of calling methods until it reaches a matching handler.

Exceptions

- Cannot be treated as normal control flow.
  - Would have to add branches for every possible exception (array index references, memory allocations, casts, etc.) and match to any handler.
- Separate exceptions from normal, explicit control flow.
  - Dismiss any exceptions triggered by program errors signaled by the system.
    - Subscript errors, bad casts.
    - Exercising these does not help prevent or find errors.

Exceptions

- Unless we have explicitly written code to handle those kind of exceptions.
  - Fault-tolerant systems.
  - Must test the error recovery code.
    - Still do not need to couple recovery code to every point where there might be an error.
- Must handle exceptions that indicate abnormal cases.
  - If exception handler is local, must test the handler.
  - Do not need to test each point the exception might be raised.

Exceptions

- Must handle exceptions that indicate abnormal cases.
  - If the handler is not local…
  - The exception will be passed up the stack until it is handled. There could be many potential handlers.
  - It is very hard to determine *where* it will be handled.
  - We can’t test all possible chains.
  - Instead, enforce a design rule:
    - If a method can propagate an exception without catching it, that call should have no other effect.

We Have Learned

- Basic functional and structural testing techniques can be applied to OO systems, with a few adaptations.
  - When testing one class, build an intraclass CFG and cover control and data-flow.
  - When testing multiple classes, categorize methods as inspectors and modifiers and cover DU pairs between them.

We Have Learned

- Oracles can inspect hidden state through added code, code changes, or reflection.
- Polymorphic bindings can be covered through combinatorial testing and DU pairings.
- Inheritance can reduce testing effort.
- Exceptions require special handling.

Next Time

- Model-Based Testing
  - Reading: Chapter 14
  - Video Lecture - Watch from Home
    - Turn in activity next Tuesday

- Homework:
  - Assignment 3 - due 04/03