# Course Review

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# Software Faults, Errors & Failures

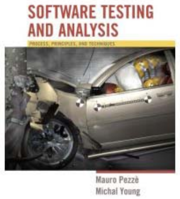
- Software Fault : A static defect in the software
- Software Failure : External, incorrect behavior with respect to the requirements or other description of the expected behavior
- Software Error : An incorrect internal state that is the manifestation of some fault

# Summary: Why Do We Test Software ?

**A tester's goal is to eliminate faults as early as possible**

- **Improve quality**
- **Reduce cost**
- **Preserve customer satisfaction**

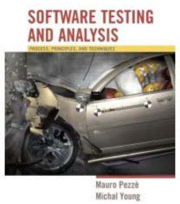
# Functional testing



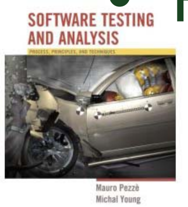
# Functional testing

- Functional testing: Deriving test cases from program specifications
    - *Functional* refers to the source of information used in test case design, not to what is tested
- *Also known as*:
    - specification-based testing (from specifications)
    - black-box testing (no view of the code)
- Functional specification = description of intended program behavior
    - either formal or informal



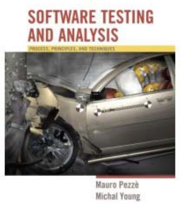
# Systematic vs Random Testing

- Random (uniform):
  - Pick possible inputs uniformly
  - Avoids designer bias
    - A real problem: The test designer can make the same logical mistakes and bad assumptions as the program designer (especially if they are the same person)
  - But treats all inputs as equally valuable
- Systematic (non-uniform):
  - Try to select inputs that are especially valuable
  - Usually by choosing representatives of classes that are apt to fail *often* or *not at all*
- Functional testing is systematic testing



# Functional testing: exploiting the specification

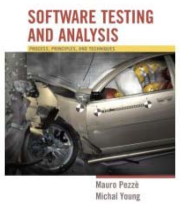
- Functional testing uses the specification (formal or informal) to partition the input space
  - E.g., specification of “roots” program suggests division between cases with zero, one, and two real roots
- Test each category, and boundaries between categories
  - No guarantees, but experience suggests failures often lie at the boundaries (as in the “roots” program)



# Combinatorial testing

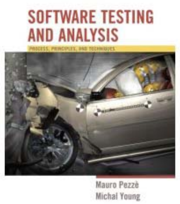
# Combinatorial testing: Basic idea

- Identify distinct attributes that can be varied
  - In the data, environment, or configuration
  - Example: browser could be “IE” or “Firefox”, operating system could be “Vista”, “XP”, or “OSX”
- Systematically generate combinations to be tested
  - Example: IE on Vista, IE on XP, Firefox on Vista, Firefox on OSX, ...
- Rationale: Test cases should be varied and include possible “corner cases”



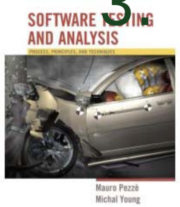
# Key ideas in combinatorial approaches

- Category-partition testing
  - separate (manual) identification of values that characterize the input space from (automatic) generation of combinations for test cases
- Pairwise testing
  - systematically test interactions among attributes of the program input space with a relatively small number of test cases
- Catalog-based testing
  - aggregate and synthesize the experience of test designers in a particular organization or application domain, to aid in identifying attribute values



# Category partition (manual steps)

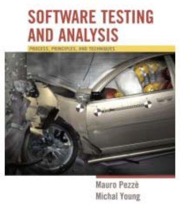
1. Decompose the specification into independently testable features
   - for each feature identify
     - parameters
     - environment elements
   - for each parameter and environment element identify elementary characteristics (categories)
2. Identify relevant values
   - for each characteristic (category) identify (classes of) values
     - normal values
     - boundary values
     - special values
     - error values
3. Introduce constraints



# Example: Display Control

No constraints reduce the total number of combinations
□□□432 (3x4x3x4x3) test cases
if we consider all combinations

| Display Mode | Language | Fonts | Color | Screen size |
|---|---|---|---|---|
| full-graphics | English | Minimal | Monochrome | Hand-held |
| text-only | French | Standard | Color-map | Laptop |
| limited-bandwidth | Spanish | Document-loaded | 16-bit | Full-size |
| | Portuguese | | True-color | |



# Pairwise combinations: 17 test cases

| Language | Color | Display Mode | Fonts | Screen Size |
|---|---|---|---|---|
| English | Monochrome | Full-graphics | Minimal | Hand-held |
| English | Color-map | Text-only | Standard | Full-size |
| English | 16-bit | Limited-bandwidth | - | Full-size |
| English | True-color | Text-only | Document-loaded | Laptop |
| French | Monochrome | Limited-bandwidth | Standard | Laptop |
| French | Color-map | Full-graphics | Document-loaded | Full-size |
| French | 16-bit | Text-only | Minimal | - |
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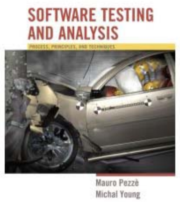
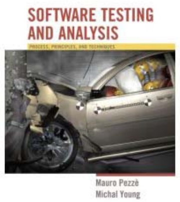
# Next ...

- Category-partition approach gives us …
  - Separation between (manual) identification of parameter characteristics and values and (automatic) generation of test cases that combine them
  - Constraints to reduce the number of combinations
- Pairwise (or n-way) testing gives us …
  - Much smaller test suites, even without constraints
    - (but we can still use constraints)
- We still need …
  - Help to make the manual step more systematic



# Catalog based testing

- Deriving value classes requires human judgment
- Gathering experience in a systematic collection can:
  - speed up the test design process
  - routinize many decisions, better focusing human effort
  - accelerate training and reduce human error
- Catalogs capture the experience of test designers by listing important cases for each possible type of variable
  - *Example: if the computation uses an integer variable a catalog might indicate the following relevant cases*
    - *The element immediately preceding the lower bound*
    - *The lower bound of the interval*
    - *A non-boundary element within the interval*
    - *The upper bound of the interval*
    - *The element immediately following the upper bound*



# Catalog based testing process

**Step1:**

Analyze the initial specification to identify simple elements:

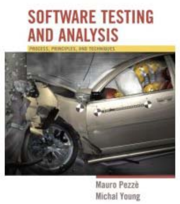
- Pre-conditions
- Post-conditions
- Definitions
- Variables
- Operations

**Step 2:**

Derive a first set of test case specifications from pre-conditions, post-conditions and definitions

**Step 3:**

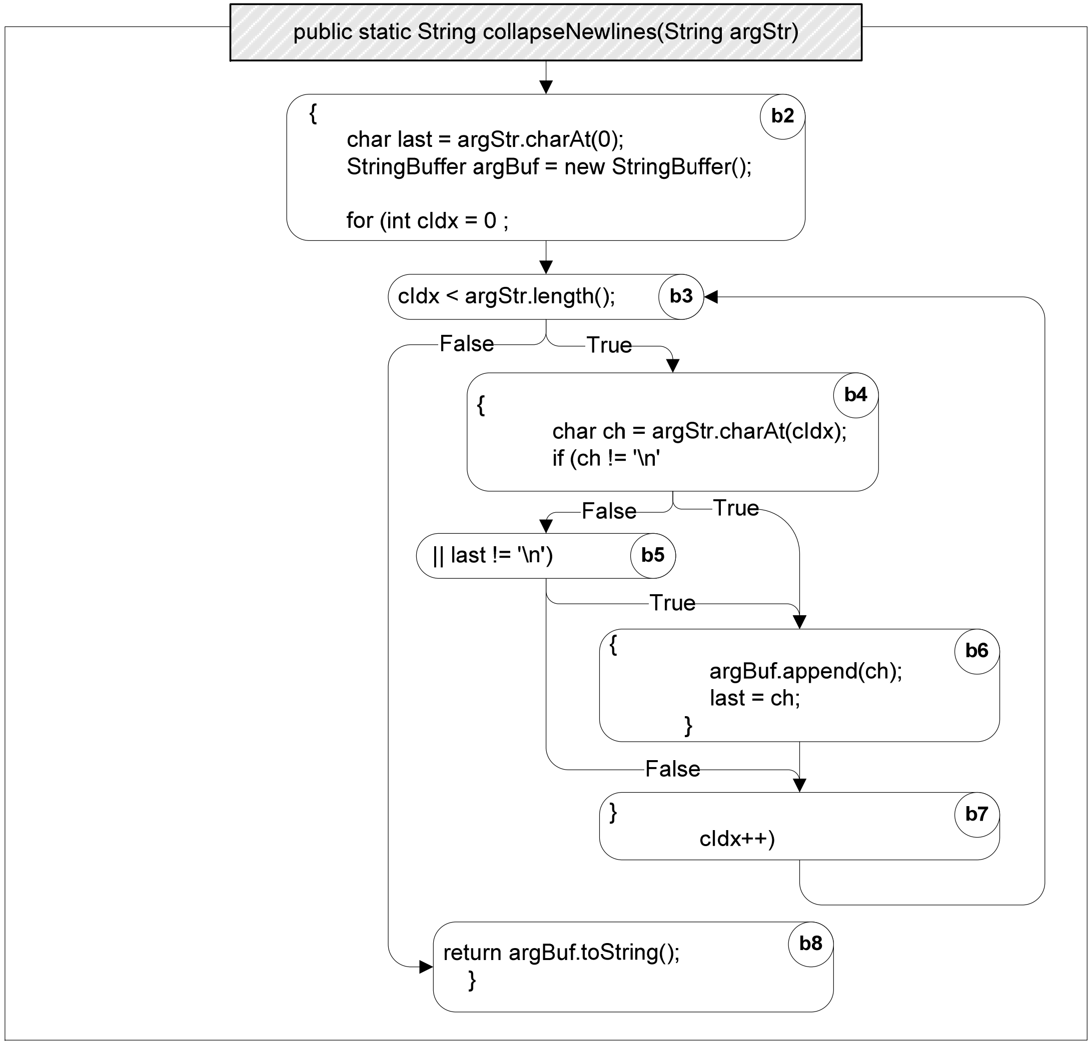
Complete the set of test case specifications using test catalogs

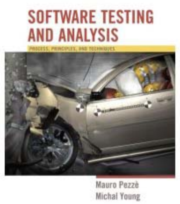


# Finite Models

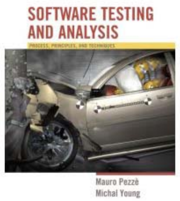
# Example of Control Flow Graph

```
public static String collapseNewlines(String argStr)
  {
     char last = argStr.charAt(0);
     StringBuffer argBuf = new StringBuffer();

     for (int cIdx = 0 ; cIdx < argStr.length(); cIdx++)
     {
        char ch = argStr.charAt(cIdx);
        if (ch != '\n' || last != '\n')
        {
           argBuf.append(ch);
           last = ch;
        }
     }

     return argBuf.toString();
  }
```



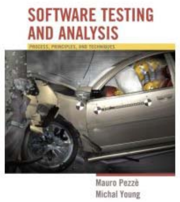



# Structural Testing



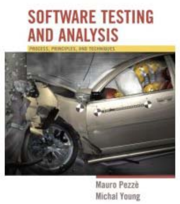
# "Structural" testing

- Judging test suite thoroughness based on the *structure* of the program itself
  - Also known as "white-box", "glass-box", or "code-based" testing
  - To distinguish from functional (requirements-based, "black-box" testing)
    - "Structural" testing is still testing product functionality against its specification. Only the measure of thoroughness has changed.

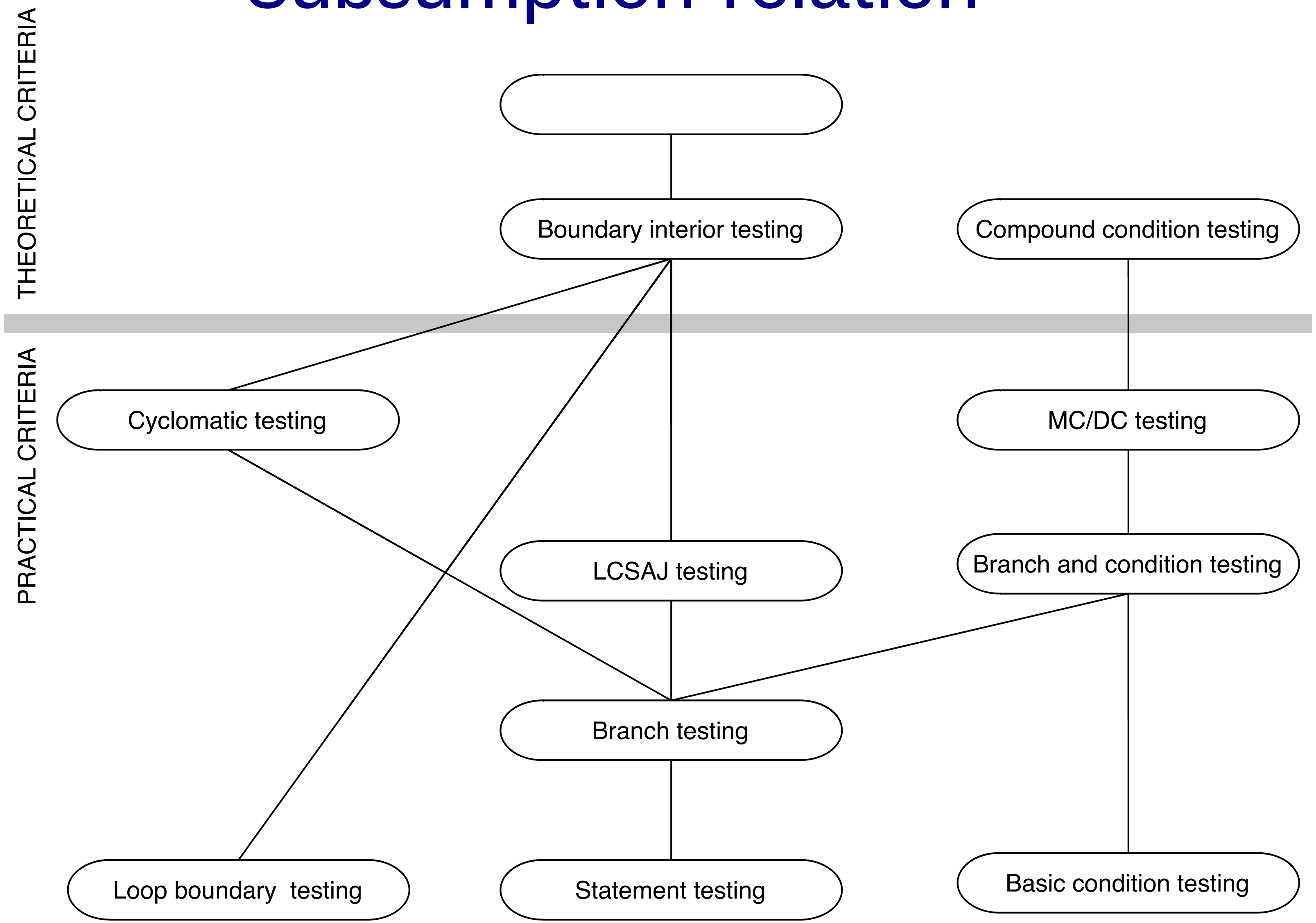


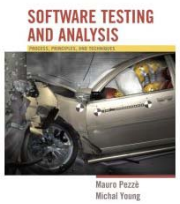
# Structural testing *complements* functional testing

- Control flow testing includes cases that may not be identified from specifications alone
  - Typical case: implementation of a single item of the specification by multiple parts of the program
  - Example: hash table collision  (invisible in interface spec)
- Test suites that satisfy control flow adequacy criteria could fail in revealing faults that can be caught with functional criteria
  - Typical case: missing path faults



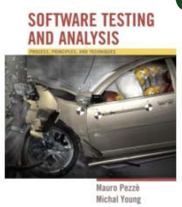
# Subsumption relation



# Summary

- We defined a number of adequacy criteria
  - NOT test design techniques!
- Different criteria address different classes of errors
- Full coverage is usually unattainable
  - Remember that attainability is an undecidable problem!
- ...and when attainable, "inversion" is usually hard
  - How do I find program inputs allowing to cover something buried deeply in the CFG?
  - Automated support (e.g., symbolic execution) may be necessary
- Therefore, rather than requiring full adequacy, the "degree of adequacy" of a test suite is estimated by coverage measures
  - May drive test improvement



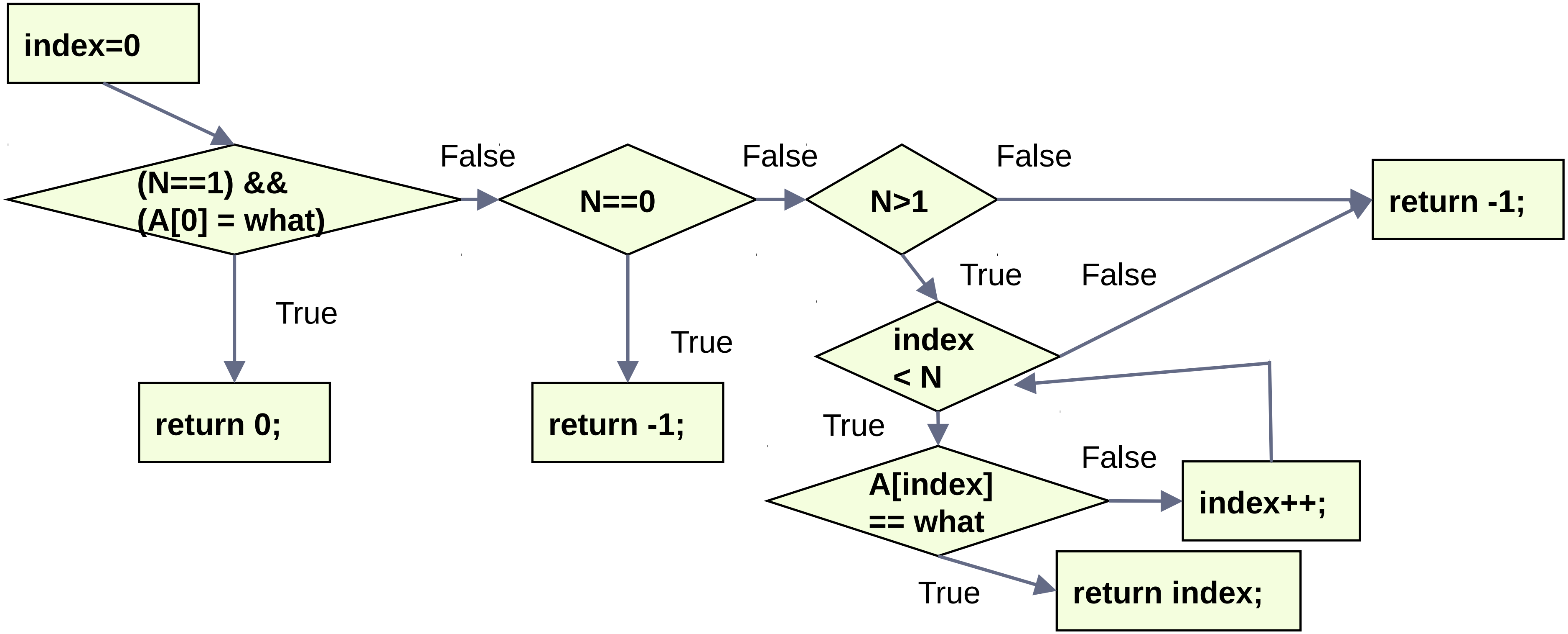
# Activity

- Write tests that provide statement, branch, and basic condition coverage over the following code:

```
int search(string A[], int N, string what){
    int index = 0;
    if ((N == 1) && (A[0] == what)){
         return 0;
             } else if (N == 0){
                 return -1;
             } else if (N > 1){
             while(index < N){
                     if (A[index] == what)
                    return index;
                     else
                         index++;
                 }
             }
        return -1;
    }
```

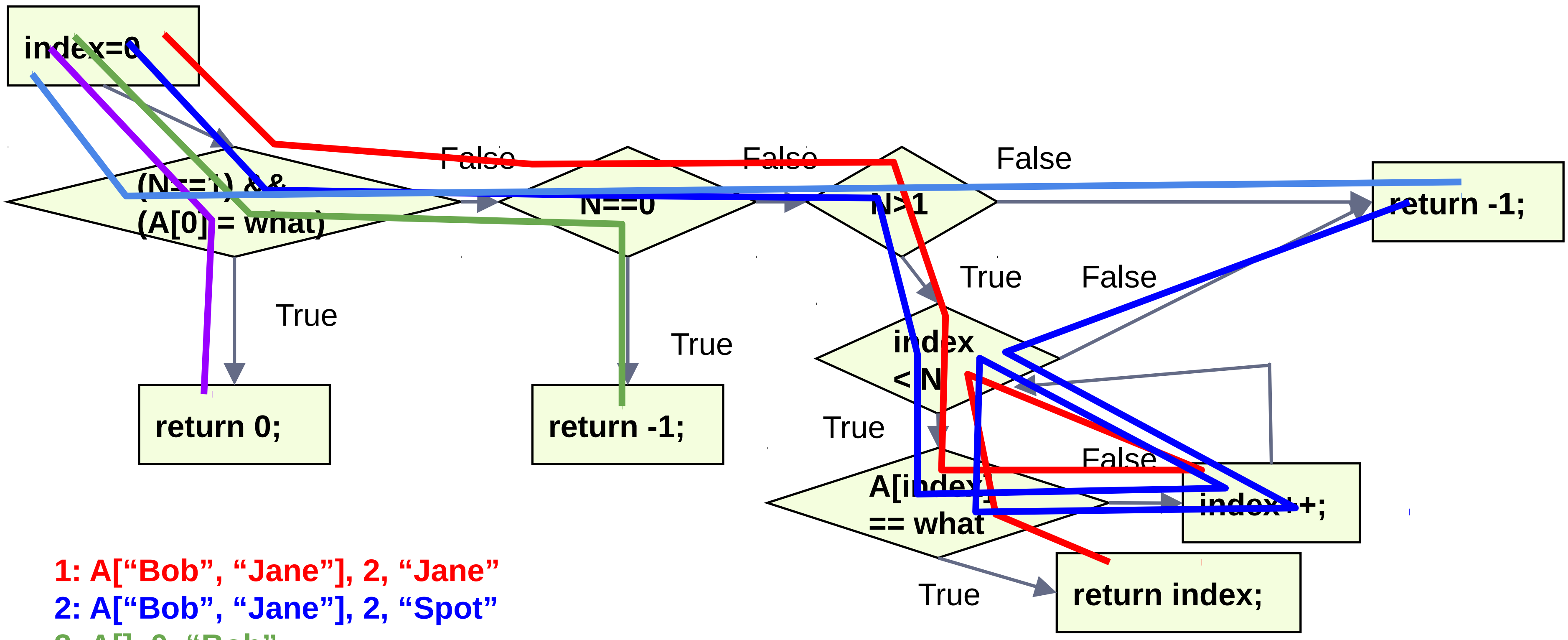
# Activity - Possible Solution

- Write tests that provide statement, branch, and basic condition coverage over the following code:



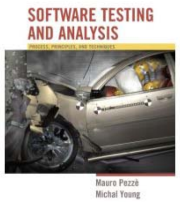
# Activity - Possible Solution

- Write tests that provide statement, branch, and basic condition coverage over the following code:



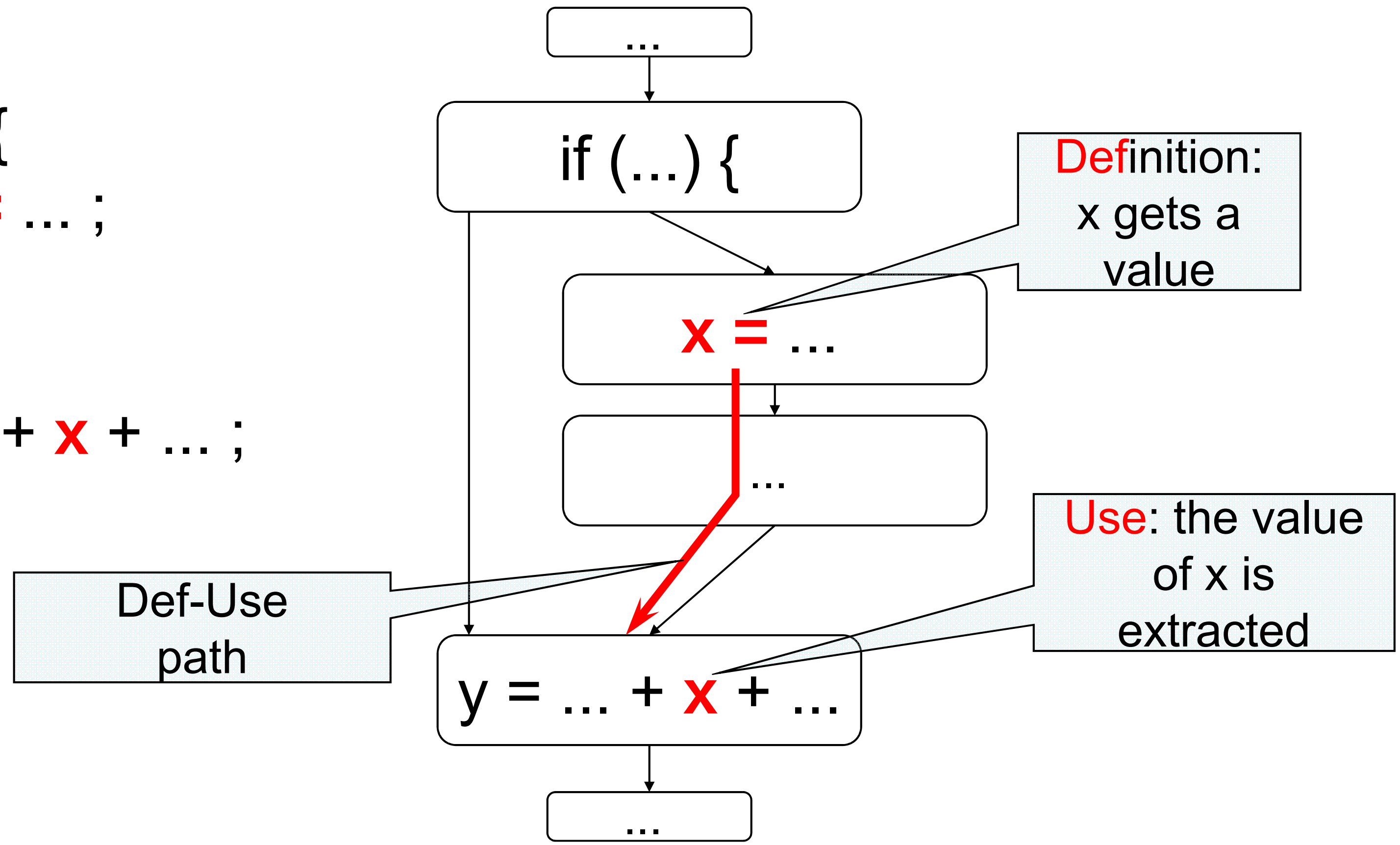

**1: A[“Bob”, “Jane”], 2, “Jane”**
**2: A[“Bob”, “Jane”], 2, “Spot”**
**3: A[], 0, “Bob”**
**4. A[“Bob”], 1, “Bob”**
**5. A[“Bob”], 1, “Spot”**

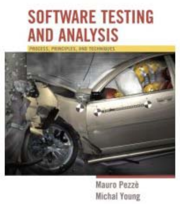
# Dependence and Data Flow Models



# Def-Use Pairs

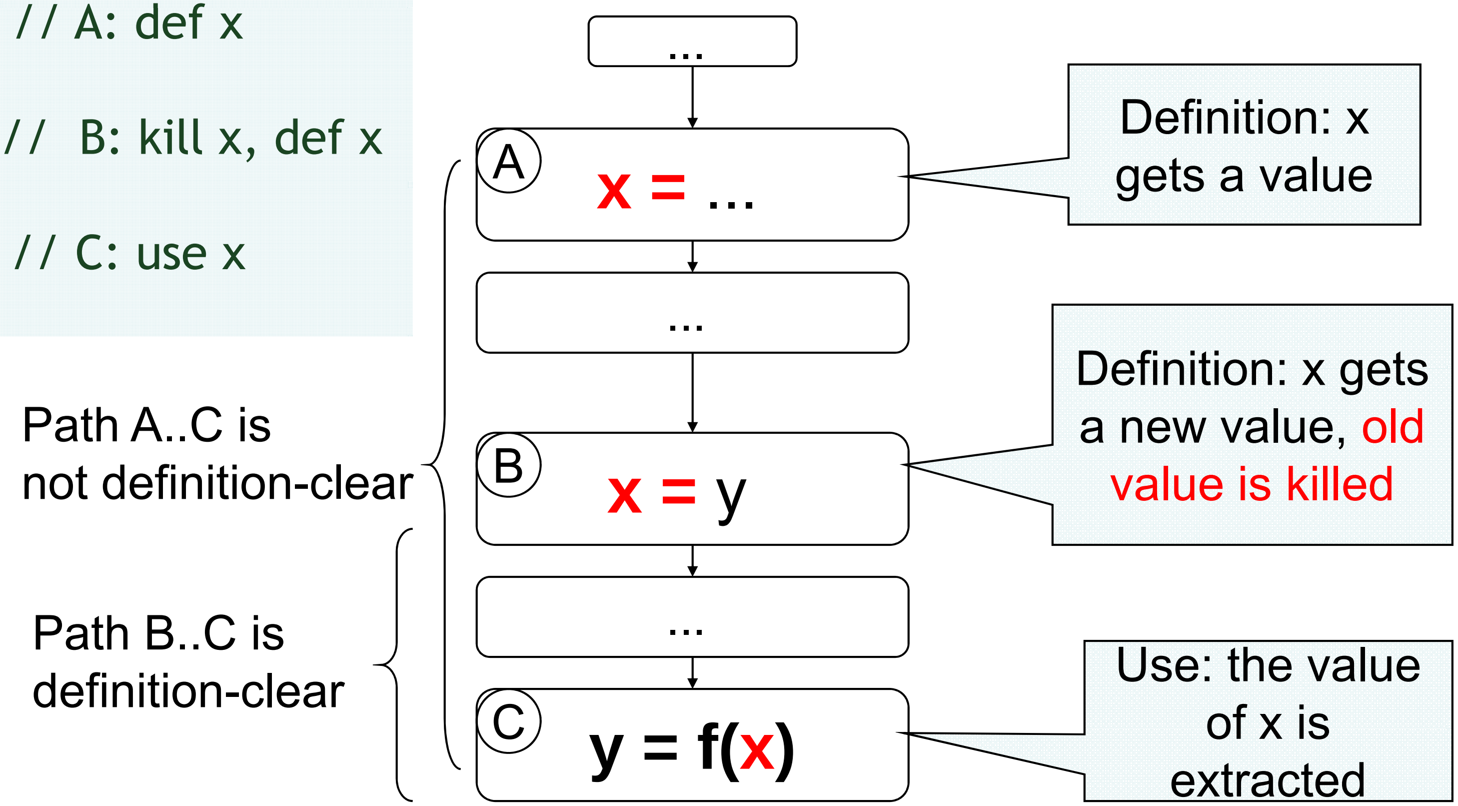
```
...
if (...) {
    x = ... ;
...
}
y = ... + x + ... ;
```

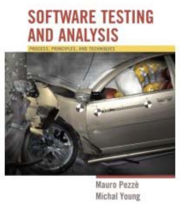


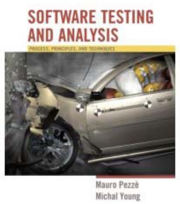
# Definition-Clear or Killing

```
x = ...      // A: def x
q = ...
x = y;      //  B: kill x, def x
z = ...
y = f(x);  // C: use x
```



# Data flow testing

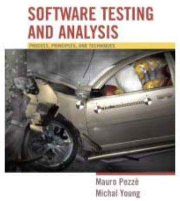


# Terms

- DU pair: a pair of *definition* and *use* for some variable, such that at least one DU path exists from the definition to the use

  x = … is a *definition* of x

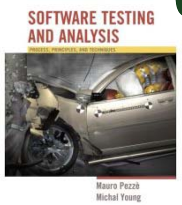
  = … x … is a *use* of x
- DU path: a definition-clear path on the CFG starting from a definition to a use of a same variable
  - Definition clear: Value is not replaced on path
  - Note – loops could create infinite DU paths between a def and a use



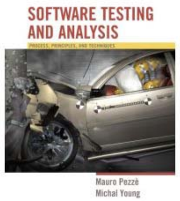
# Adequacy criteria

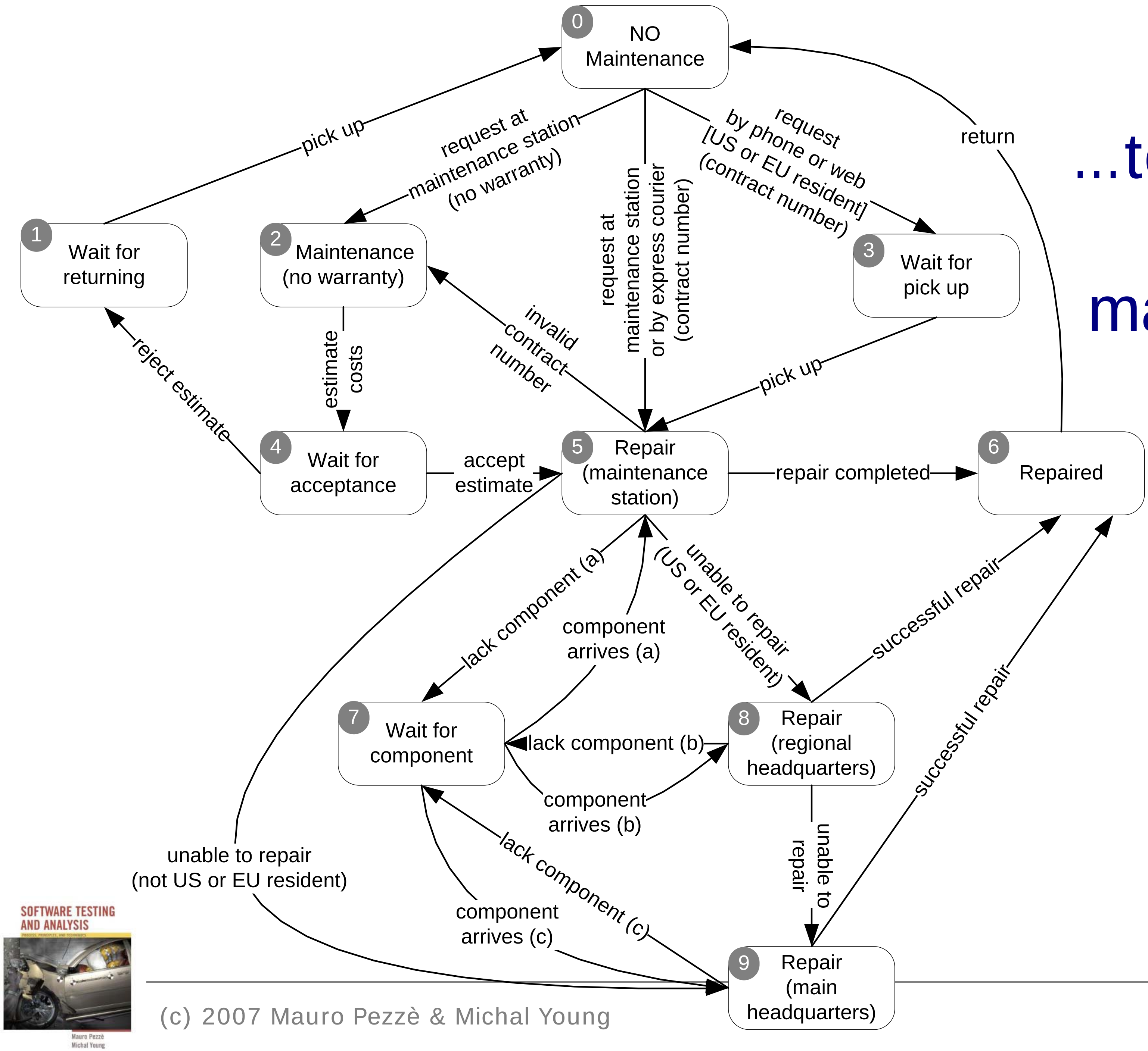
- All DU pairs: Each DU pair is exercised by at least one test case
- All DU paths: Each *simple* (non looping) DU path is exercised by at least one test case
- All definitions: For each definition, there is at least one test case which exercises a DU pair containing it
  - (Every computed value is used somewhere)

Corresponding coverage fractions can also be defined



# Model based testing

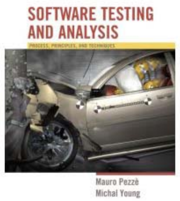





# ...to a finite state machine...

# Testing Object Oriented Software

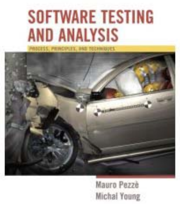
Chapter 15



# Characteristics of OO Software

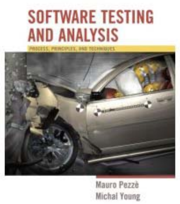
Typical OO software characteristics that impact testing

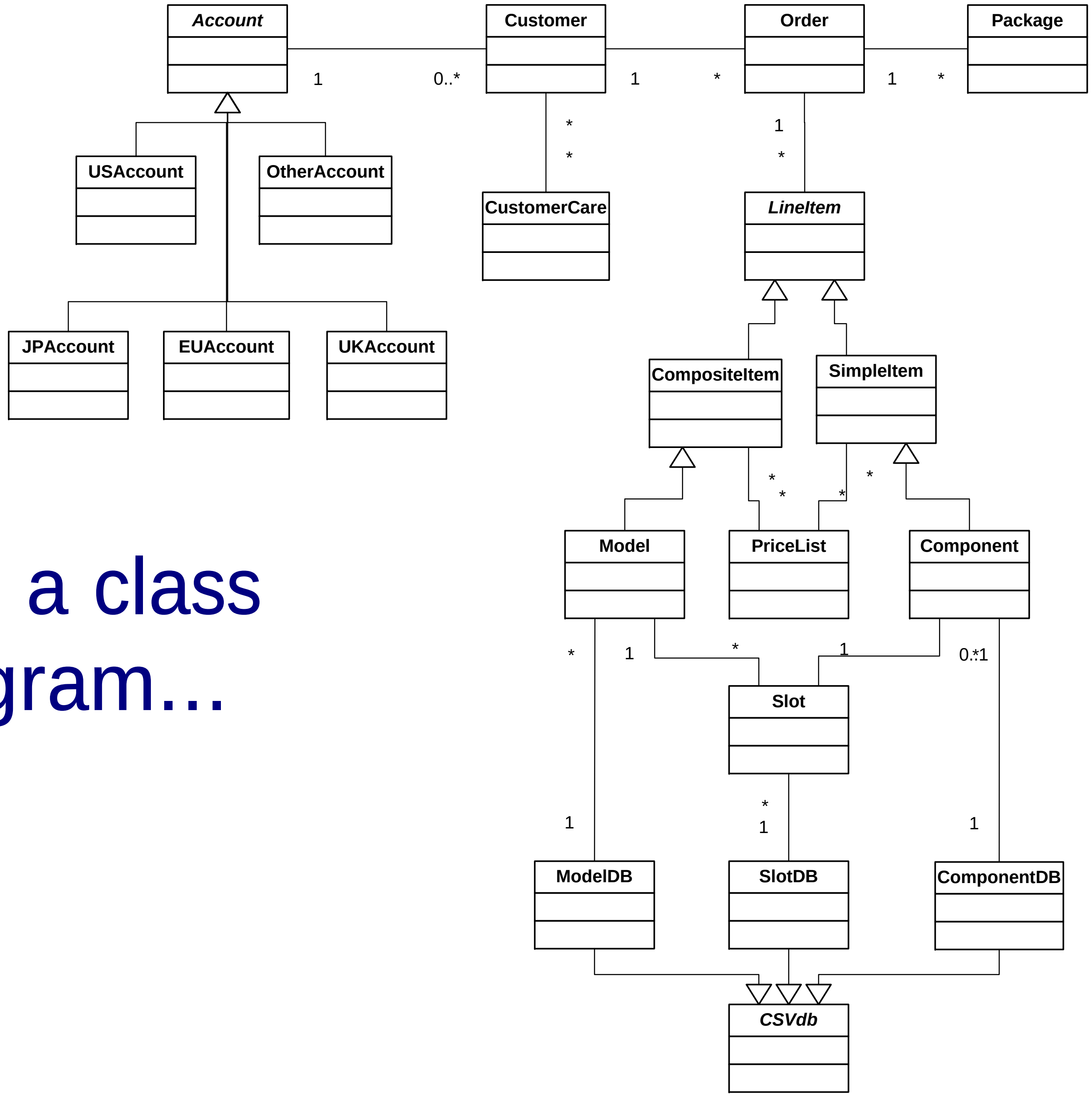
- State dependent behavior
- Encapsulation
- Inheritance
- Polymorphism and dynamic binding
- Abstract and generic classes
- Exception handling



# Interclass Testing

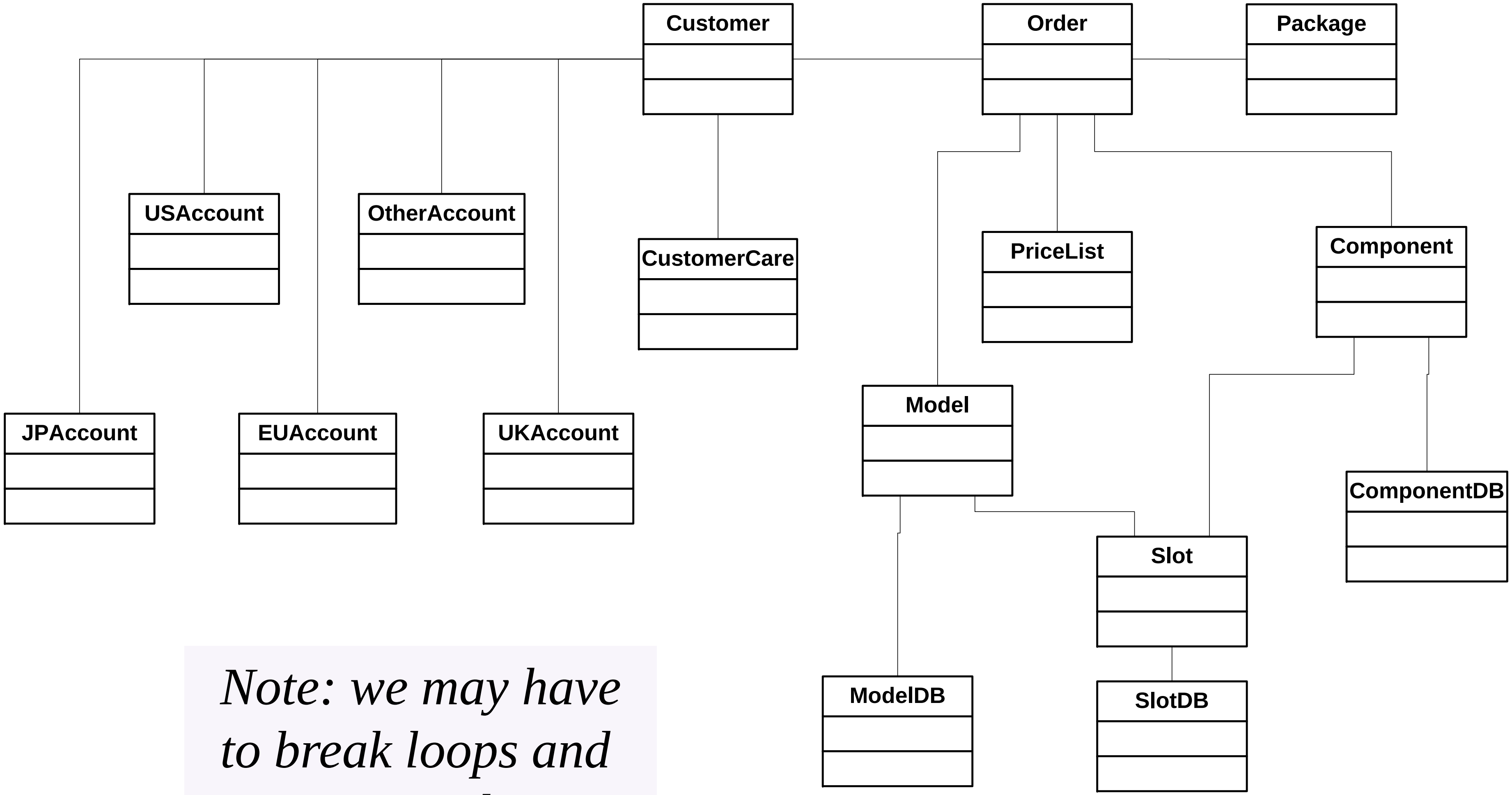
- The first level of *integration testing* for object-oriented software
  - Focus on interactions between classes
- Bottom-up integration according to "depends" relation
  - A depends on B:  Build and test B, then A
- Start from use/include hierarchy
  - Implementation-level parallel to logical "depends" relation
  - Class A makes method calls on class B
  - Class A objects include references to class B methods
    - but only if reference means "is part of"



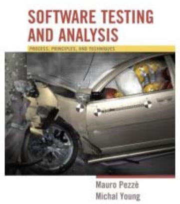



from a class diagram...

# ....to a hierarchy




*Note: we may have to break loops and generate stubs*



# Intraclass data flow testing

- Exercise sequences of methods
  - From setting or modifying a field value
  - To using that field value

- We need a control flow graph that encompasses more than a single method ...

# The intraclass control flow graph

Control flow for each method

\+

node for class

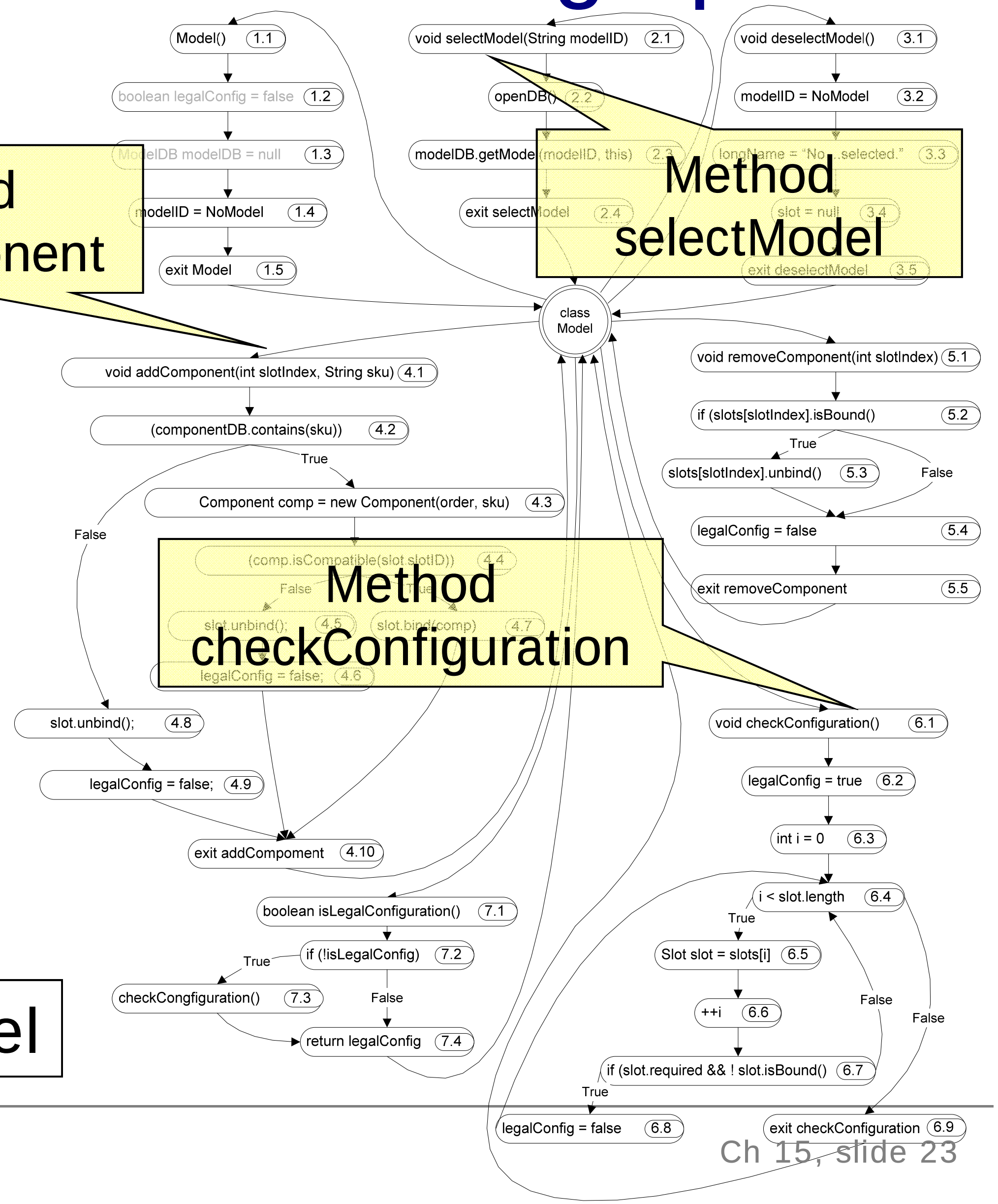
\+

edges

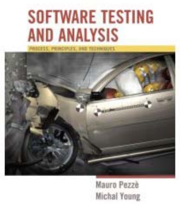
- from node *class* to the start nodes of the methods
- from the end nodes of the methods to node *class*

=> control flow through *sequences* of method calls

Method addComponent




class Model



# Mutation Testing

# Example of Mutation Operators I

- Constant replacement
- Scalar variable replacement
- Scalar variable for constant replacement
- Constant for scalar variable replacement
- Array reference for constant replacement
- Array reference for scalar variable replacement
- Constant for array reference replacement
- Scalar variable for array reference replacement
- Array reference for array reference replacement
- Source constant replacement
- Data statement alteration
- Comparable array name replacement
- Arithmetic operator replacement
- Relational operator replacement
- Logical connector replacement
- Absolute value insertion
- Unary operator insertion
- Statement deletion
- Return statement replacement

# Regression Testing

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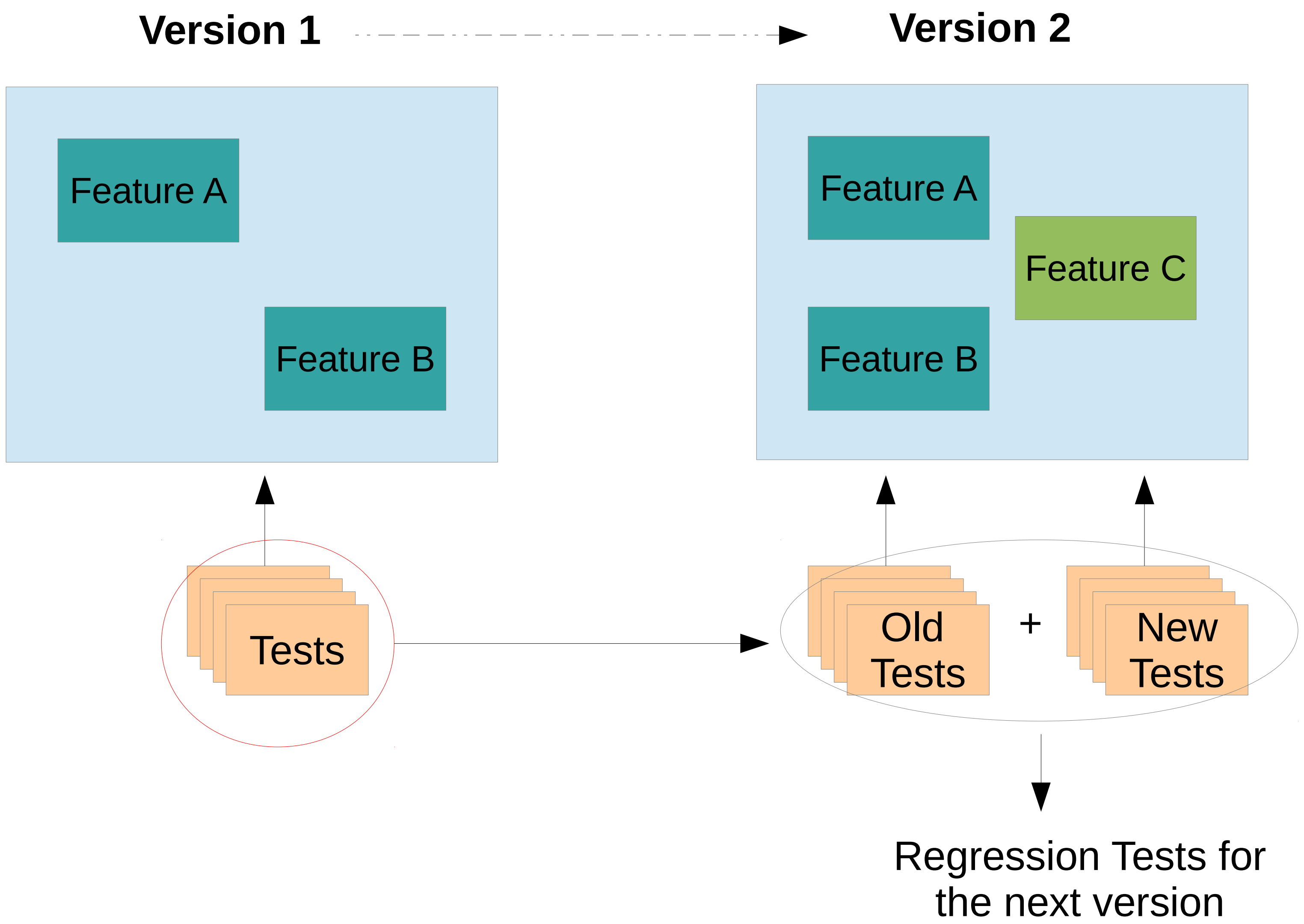
# Example

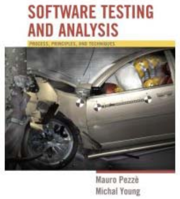


Version 1
Version 2
Feature A
Feature B
Feature A
Feature C
Feature B
Tests
Old Tests
+
New Tests
Regression Tests for the next version

# Regression Test Optimization

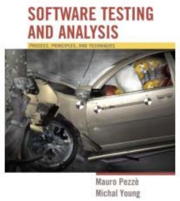
- Re-test All
- Regression Test Selection
- Regression Test Set Minimisation
- Regression Test Set Prioritisation

# Integration and Component-based Software Testing

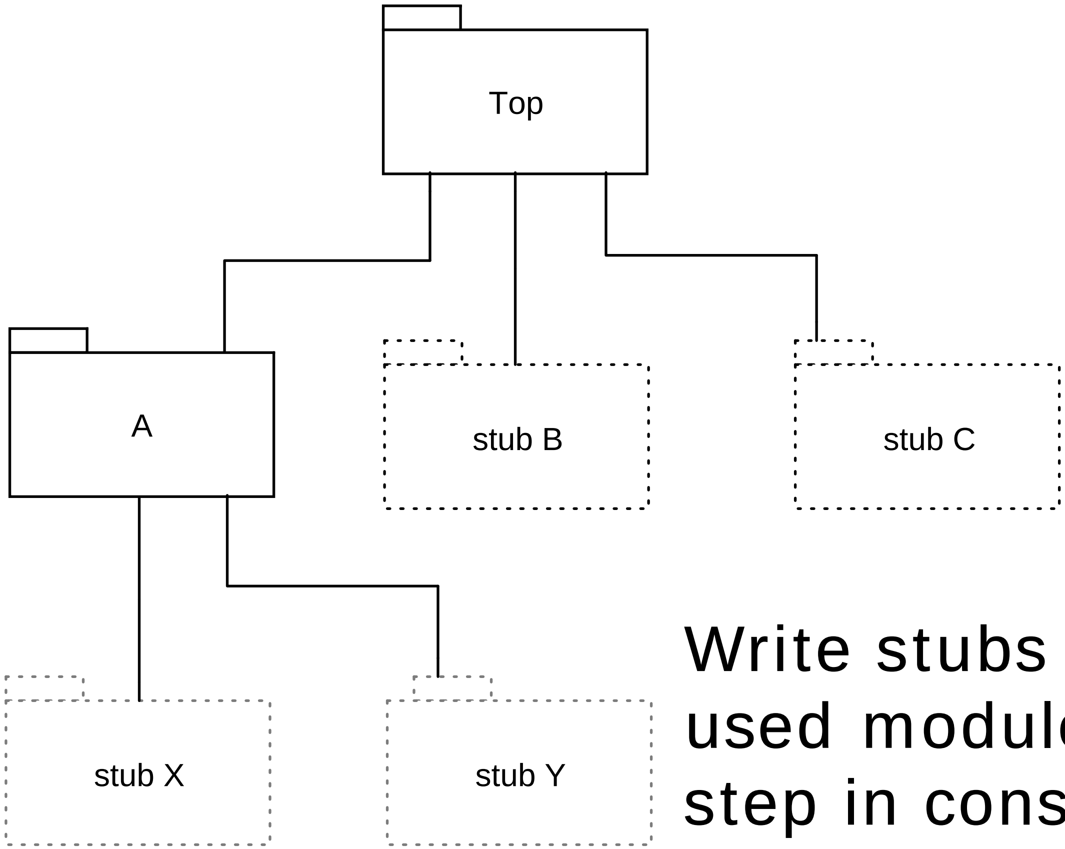


# What is integration testing?

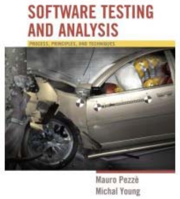
| | Module test | Integration test | System test |
|---|---|---|---|
| **Specification:** | Module interface | **Interface specs, module breakdown** | Requirements specification |
| **Visible structure:** | Coding details | **Modular structure (software architecture)** | — none — |
| **Scaffolding required:** | Some | **Often extensive** | Some |
| **Looking for faults in:** | Modules | **Interactions, compatibility** | System functionality |



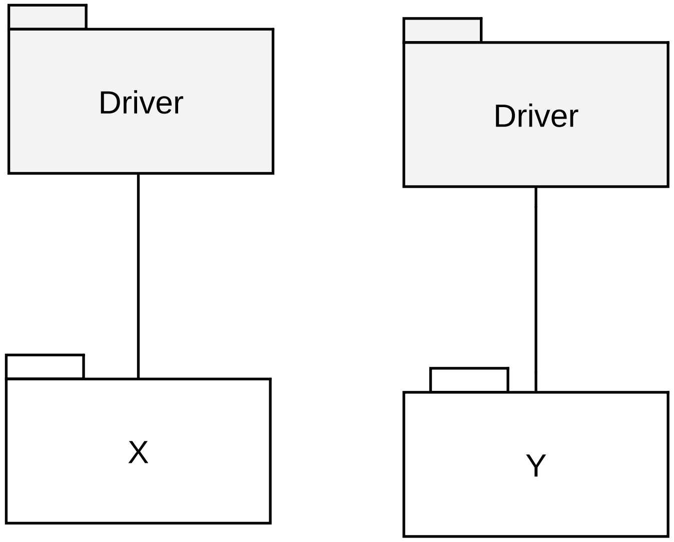
# Top down ..




Write stubs of called or used modules at each step in construction

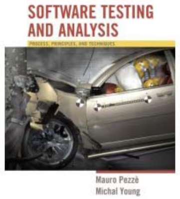


# Bottom Up ..




... but we must construct drivers for each module (as in unit testing) ...

# System, Acceptance, and Regression Testing

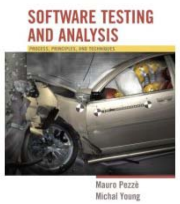


# System Testing

- Key characteristics:
  - Comprehensive (the whole system, the whole spec)
  - Based on specification of observable behavior

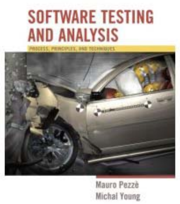
    Verification against a requirements specification, not validation, and not opinions
  - Independent of design and implementation

*Independence*: Avoid repeating software design errors in system test design



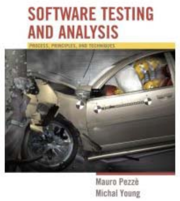
# Global Properties

- Some system properties are inherently global
  - Performance, latency, reliability, ...
  - Early and incremental testing is still necessary, but provide only estimates
- A major focus of system testing
  - The only opportunity to verify global properties against actual system specifications
  - Especially to find unanticipated effects, e.g., an unexpected performance bottleneck



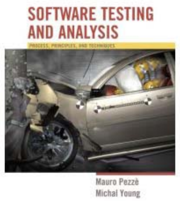
# Context-Dependent Properties

- Beyond system-global: Some properties depend on the system context and use
  - Example:  Performance properties depend on environment and configuration
  - Example: Privacy depends both on system and how it is used
    - Medical records system must protect against unauthorized use, and authorization must be provided only as needed
  - Example: Security depends on threat profiles
    - And threats change!
- Testing is just one part of the approach



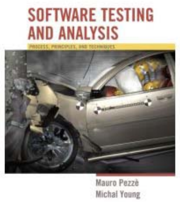
22.3

# Acceptance testing



# Estimating Dependability

- Measuring quality, not searching for faults
  - Fundamentally different goal than systematic testing
- Quantitative dependability goals are statistical
  - Reliability
  - Availability
  - Mean time to failure
  - …
- Requires valid statistical samples from *operational profile*
  - Fundamentally different from systematic testing



# Feedback

Please fill in the feedback questionnaire:

http://www.inf.ed.ac.uk/cgi-bin/ito/course_questionnaire.pl