System Testing

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Outline

1. **Test Coverage**
   - Coverage Measures
   - C/C++ - gcov
   - Java
2. **Oracles**
   - expect
   - *Unit
   - GUI systems
   - Web systems
   - Selenium

Outline I

1. Test Coverage
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2. Oracles
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   - Web systems
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Black-Box Testing

Black-box (a.k.a. *specification-based*) testing chooses tests without consulting the implementation.

- Equivalence partitioning
- Boundary-value testing
- Special-values testing

Equivalence Partitioning

(a.k.a *functional testing*)

- Attempt to choose test data illustrating each distinct behavior or each distinct class of inputs and outputs at least once.
    - e.g., each kind of transaction, each kind of report
- Can be driven by function points.

Boundary-Values Testing

Choose data at the boundaries of a functional testing class or of the overall input domain.

- check amount $= 0$
- check amount $\geq \$1,000,000$
- transaction date $=$ day before bank was founded
- transaction date 100 years in future
- name string empty
- name string one less than full
- name string full
- name string overfull

Special-Values Testing

Choose data reflecting “special” or troublesome cases.

Examples include choosing for

- each numeric input
    - negative,
    - zero, and
    - positive values,
- each string input
    - empty
    - entirely blank strings,

etc.

White-Box Testing

White-Box (a.k.a. *Implementation-based* testing) uses information from the implementation to choose tests.

- Structural Testing (a.k.a., "path testing" (not per your text) Designate a set of paths through the program that must be exercised during testing.
  - Statement Coverage
  - Branch Coverage
  - Cyclomatic coverage ("independent path testing")
  - Data-flow Coverage
- Mutation testing

Statement Coverage

Require that every statement in the code be executed at least once during testing.

- Needs software tools to monitor this requirement for you.
  - e.g., **gcov** in Unix for C, C++

Statement Coverage Example

```
cin >> x >> y;
while (x > y)
  {
   if (x > 0)
       cout << x;
   x = f(x, y);
  }
cout << x;
```

What kinds of tests are required for statement coverage?

Branch Coverage

Requires that every "branch" in the flowchart be tested at least once

- Equivalent to saying that each conditional stmt must be tested as both true and false
- Branch coverage implies Statement Coverage, but not vice versa

```
if (X < 0)
    X = -X;
Y = sqrt(X);
```

Branch Coverage Example

```
cin >> x >> y;
while (x > y)
  {
    if (x > 0)
        cout << x;
    x = f(x, y);
  }
cout << x;
```

What kinds of tests are required for branch coverage?

Variations on Branch Coverage

- *Path coverage* seeks to cover each path from start to finish through the program.
  - Infeasible (why?)
- Loop coverage: various rules such as

> *A loop is covered if, in at least one test, the body was executed 0 times, and if in some test the body was executed exactly once, and if in some test the body was executed more than once.*

Multi-Condition Coverage

a.k.a., Condition coverage

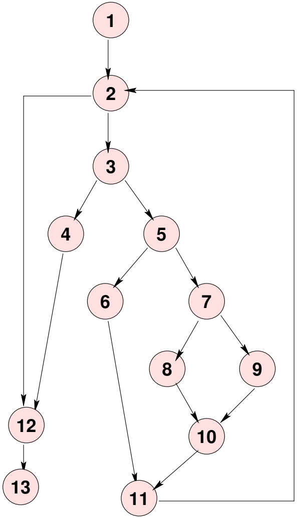
- Various approaches to coping with boolean expressions, particularly short-circuited ones.
- Goal: given a boolean expression $a \oplus b$, where $\oplus$ could be &, &&, $|$, etc., need at least one test where
  - a is true and, had it been false, the value of $a \oplus b$ would change
  - a is false and, had it been true, the value of $a \oplus b$ would change
  - b is true and, had it been false, the value of $a \oplus b$ would change
  - b is false and, had it been true, the value of $a \oplus b$ would change
- For example, for the expression $a\&b$, we would need th combinations

a	b
true	true
false	true
true	false

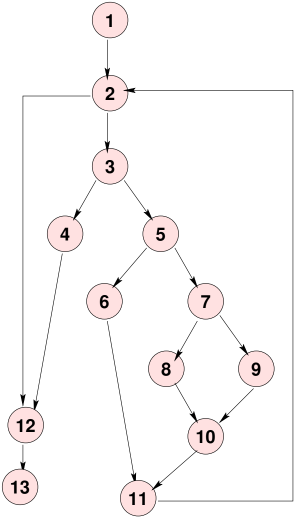
Cyclomatic Coverage

(a.k.a "independent path coverage", "path testing")

- The latter term (used in your text) should be discouraged as it is both vague and means something entirely different to most of the testing community
- Each independent path must be tested
  - An *independent path* is one that includes a branch not previously taken.

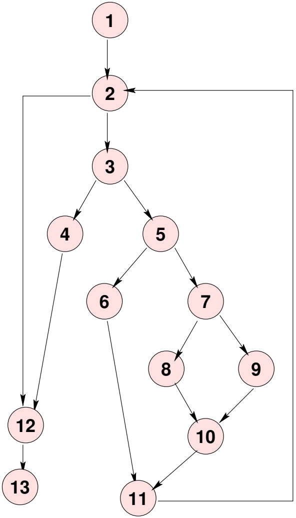


Cyclomatic Example



What are the independent paths?

Cyclomatic Example



What are the independent paths?
One set:

1, 2, 3, 4, 12, 13
1, 2, 3, 5, 6, 11, 2, 12, 13
1, 2, 3, 5, 7, 8, 10, 11, 2, 12, 13
1, 2, 3, 5, 7, 9, 10, 11, 2, 12, 13

Cyclomatic Complexity

The number of independent paths in a program can be discovered by computing the cyclomatic complexity (McCabe, 1976) ...

$$CC(G) = \text{Number}(\text{edges}) - \text{Number}(\text{nodes}) + 1$$

- This is a popular metric for module complexity.
- Actually pretty trivial: for structured programs with only binary decision constructs, equals number of conditional statements $+1$
- relation to testing is dubious
  - simply branch coverage hidden behind smoke and mirrors

Issues

- Sets of independent paths are not unique, nor is their size:

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1,2,3,5,6,11,
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10,11,2,3,
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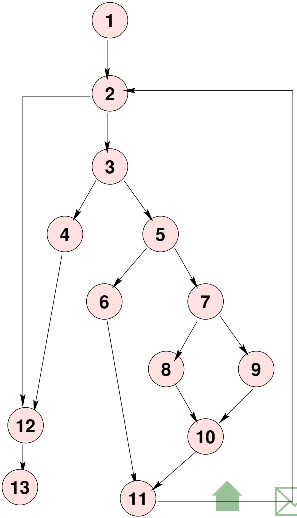
2,12,13

1,2,3,4,12,13



Data-Flow Coverage

Attempts to test significant combinations of branches.

- Any stmt `i` where a variable `X` may be assigned a new value is called a *definition* of `X` at `i`: *def(X,i)*
- Any stmt `i` where a variable `X` may be used/retrieved is called a *reference* or *use* of `X` at `i`: *ref(X,i)*

Def-Clear Paths

- A path from stmt `i` to stmt `j` is *def-clear with respect to X* if it contains no definitions of `X` except possibly at the beginning (`i`) and end (`j`)

all-defs

The *all-defs* criterion requires that each definition `def(X,i)` be tested some def-clear path to some reference `ref(X,j)`.

```
cin >> x >> y;        // d(x,1) d(y,1)
while (x > y)         // r(x,2), r(y,2)
  {
    if (x > 0)        // r(x,4)
         cout << x;   // r(x,5)
     x = f(x, y);     // r(x,6), r(y,6), d(x,6)
  }
cout << x;            // r(x,8)
```

What kinds of tests are required for all-defs coverage?

all-uses

The *all-uses* criterion requires that each pair (`def(X,i)`, `ref(X,j)`) be tested using some def-clear path from `i` to `j`.

```
1:  cin >> x >> y;         // d(x,1) d(y,1)
2:  while (x > y)          // r(x,2), r(y,2)
3:    {
4:      if (x > 0)         // r(x,4)
5:          cout << x;     // r(x,5)
6:      x = f(x, y);       // r(x,6), r(y,6), d(x,6)
7:    }
8:  cout << x;             // r(x,8)
```

What kinds of tests are required for all-uses coverage?

Mutation Testing

Given a program P,

- Form a set of *mutant* programs that differ from P by some single change
- These changes (called *mutation operators*) include:
  - exchanging one variable name by another
  - altering a numeric constant by some small amount
  - exchanging one arithmetic operator by another
  - exchanging one relational operator by another
  - deleting an entire statement
  - replacing an entire statement by an `abort()` call

Mutation Testing (cont.)

- Run P and each mutant P_i on a previously chosen set of tests
- Compare the output of each P_i to that of P
  - If the outputs differ on any test, P_i is *killed* and removed from the set of mutant programs
  - If the outputs are the same on all tests, P_i is still considered *alive*.

Mutation Testing (cont.)

A set of test data is considered *inadequate* if it cannot distinguish between the program as written (P) and programs that differ from it by only a simple change.

- So if any mutants are still alive after running a set of tests, we augment the tests until we can kill all the mutants.

Mutation Testing Problems

- Even simple programs yield tens of thousands of mutants. Executing these is time-consuming.
  - But most are killed on first few tests
  - And the process *is* automated
- Some mutants are actually *equivalent* to the original program:

```
X = Y;            X = Y;
if (X > 0)        if ( Y > 0)
  ⋮                 ⋮
```

  - Identifying these can be difficult (and cannot be automated)

Monitoring Statement Coverage with gcov

- coverage tool includes with the GNU compiler suite (**gcc**, **g++**, etc.)
  - As an example, look at testing the three search functions in **arrayUtils.h**
  - with test driver
    gcovDemo.cpp, which reads data from a text stream (e.g., standard in), uses that data to construct arrays, and invokes each function on those arrays, printing the results of each.

Compiling for gcov Statement Coverage

- To use **gcov**, we compile with special options
  - `-fprofile-arcs -ftest-coverage`
- When the code has been compiled, in addition to the usual files there will be several files with endings like `.gcno`
  - These hold data on where the statements and branches in our code are.

Running Tests with gcov

- Run your tests normally.
- As you test, a `*.gcda` file will accumulate

Viewing Your Report

- Run `gcov` *`mainProgram`*
  - The immediate output will be a report on the percentages of statements covered in each source code file.
  - Also creates a `*.gcov` detailed report for each source code file. e.g.,

Sample Statement Coverage Report

```
      -:   69:template <typename T>
      -:   70:int seqSearch(const T list[], int listLength
      -:   71:{
      1:   72:    int loc;
      -:   73:
      2:   74:    for (loc = 0; loc < listLength; loc++)
      2:   75:        if (list[loc] == searchItem)
      1:   76:            return loc;
      -:   77:
  #####:   78:    return -1;
      -:   79:}
```

- Report lists number of times each statement has been executed
  - Lists #### if a statement has never been executed

Monitoring Branch Coverage with gcov

gcov can report on branches taken.

- Just add options to the gcov command:
  - `gcov -b -c` *mainProgram*

Reading gcov Branch Info

- **gcov** reports
  - Number of times each function call successfully returned
  - # of times a branch was *executed* (i.e,, how many times the branch condition was evaluated)
  - and # times each branch was *taken*
    - For branch coverage, this is the relevant figure

But What is a “Branch”?

- A "branch" is anything that causes the code to not continue on in straight-line fashion
  - Branch listed right after an "if" is the "branch" that jumps around the "then" part to go to the "else" part.
  - && and || operators introduce their own branches
  - Other branches may be hidden
    - Contributed by calls to inline functions
    - Or just a branch generated by the compiler's code generator
- In practice, this can be very hard to intepret

Example: gcov Branch Coverage report I

```
        -:   84:template <typename T>
        -:   85:int seqOrderedSearch(const T list[], int
        -:   86:{
        1:   87:    int loc = 0;
        -:   88:
        1:   89:    while (loc < listLength && list[loc]
branch  0 taken 0
call    1 returns 1
branch  2 taken 0
branch  3 taken 1
        -:   90:      {
    #####:   91:       ++loc;
branch  0 never executed
        -:   92:      }
        1:   93:    if (loc < listLength && list[loc] ==
branch  0 taken 0
```

Example: gcov Branch Coverage report II

```
call     1 returns 1
branch   2 taken 0
         1:    94:          return loc;
branch   0 taken 1
         -:    95:      else
    #####:     96:          return -1;
         -:    97:}
```

- Report is organized by *basic blocks*, straight-line sequences of code terminated by a branch or a call
- Hard to map to specific source code constructs</para>
  - lowest-numbered branch is often the leftmost condition
  - Fact of life that compilers insert branches and calls that are often invisible to us

Java Coverage Tools

- Clover
- JaCoCo
  - Part of the EclEmma project (Eclipse plugin for Emma)
  - Emma, an older coverage tool, now replaced by JaCoCo

Clover

- Commercial product, currently free for open-source projects
  - integrates with Ant, Maven
  - lots of reporting features
- Works in "traditional" coverage tool fashion
  - Requires a "fork" of the build process to build a monitoring version
  - Injects monitors into compiled code
- Test optimization: can re-run only those tests that covered changed code

JaCoCo

- line and branch coverage
- Instrumentation is done on the fly
  - An "agent" monitors execution of normally compiled bytecode
    - No special build required
- Supports full Java 7
- Works with Maven & Ant
  - In Ant, wrap normal `<java>` and `<junit>` tasks inside a `<jacoco:coverage>` element

Example: JaCoCo in Ant

Working with our Code Annotation project, add a dependency on the JaCoCo library:

```
<ivy-module version="2.0">
  <info organisation="edu.odu.cs" module="codeAnnotation" re
  <publications>
    <artifact name="codeAnnotation" type="jar" ext="jar"/>
    <artifact name="codeAnnotation-src" type="source" ext="z
  </publications>
  <dependencies>
    <dependency org="de.jflex" name="jflex" rev="1.4.3"/>
    <dependency org="junit" name="junit" rev="4.10"/>
    <dependency org="org.jacoco" name="org.jacoco.ant"
        rev="latest.integration"/>
  </dependencies>
</ivy-module>
```

Example: JaCoCo in Ant (cont.) I

jacoco-build.xml.listing

❶ Once the dependencies are resolved, we can activate the JaCoCo tasks.

❷ Note that there is no change at all in compilation

❸ And minimal change to execution

- Test execution must have `fork="true"` because
  - agent needs to be attached to the running JVM
  - (which is already running **ant**)
- In practice, I might coverage data collection a separate target

❹ Preparation of reports starts here

❺ Must match destination given when running tests

❻ This describes the class and source code file locations

❼ Choose report format and location

Example: JaCoCo Report

- Report
  - Notice that even JFlex-generated code gets measured and included in report
    - Though the annotated listings are missing for some reason.

EclEmma

Eclipse plugin for coverage tools (JaCoCo)

- Adds a new launch mode, *Coverage mode*, for running programs similar to normal “run” and “debug” modes
- Reports include
  - Summary Coverage View
  - Can highlight coverage in Eclipse code editors as colored annotations

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2. Oracles
   - expect
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   - GUI systems
   - Web systems
   - Selenium

Oracles

A testing *oracle* is the process, person, and/or program that determines if test output is correct

expect

Covered previously, **expect** is a shell for testing interactive programs.

- an extension of **TCL** (a portable shell script).
- Largely confined to text streams as input/output

*Unit

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  - Such tests do not (should not) be at the expense of having done earlier "proper" unit testing.

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  - Particularly in Java, `MyClass.main(String[])` can be called just like any other function
    - And *System.in*/varnamecin and *System.out*/*cout* can be rerouted to/from files or internal strings
  - Major limitation is the accessibility of system inputs & outputs.
    - GUIs, data bases, etc.

GUI testing

- Scripting or record/playback: playing back input events for
  - convenience & efficiency
  - consistent reproducibility
- Capture of results
  - Can occur at different levels
    - event/message level
    - graphics level

Some Open Alternatives

- Marathon - free in limited version
- Jemmy

Marathon

For Java GUIs

- Recorder captures AWT/swing events as JRuby scripts
- Scripts can then be edited to alter inputs, add assertions, etc.

```
def test

  $java_recorded_version = "1.6.0_24"

  with_window("Simple Widgets") {
      select("First Name", "Jalian Systems")
      select("Password", "Secret")
      assert_p("First Name", "Text", "Jalian System
   }
end
```

Jemmy

Also for Java GUIs

- Tests scripted as Java
- Integrates with JUnit
    - Example

Web systems

- A subproblem of GUI testing
  - Simpler because input structure more contrained
  - Output detail level is fixed (http: events)

Some Open Alternatives

- Selenium
- antEater
- Watir

Selenium

- Browser automation (SeleniumIDE - Firefox add-on)
  - Record & playback
  - Or scripted (Selenium Webdriver)
    - Firefox, IE, Safari, Opera, Chrome

Selenium Scripting

- Actions do things to elements.
  E.g., click buttons, select options
- Accessors examine the application state
- Assertions validate the state
  Each assertion has 3 modes
  - assert: failure aborts the test
  - verify: test continues, but failure is logged
  - waitFor: conditions that may be true immediately or may become true within a specified time interval

Selenese

A typical scripting statement has the form

Syntax

command parameter1 [*parameter2*]

Parameters can be

- locators for finding a UI element within a page (xpath)
- text patterns
- variable names

A Sample Selenium Script

```
<table>
  <tr><td>open</td><td>http://mySite.com/downloads/</td>
  <tr><td>assertTitle</td><td></td><td>Downloads</td></t
  <tr><td>verifyText</td><td>//h2</td><td>Terms and Conc
  <tr><td>clickAndWait</td><td>//input[@value="I agree"]<
  <tr><td>assertTitle</td><td></td><td>Product Selection
</table>
```

That's right – it's an HTML table:

open	http://mySite.com/downloads/	
assertTitle		Downloads
verifyText	//h2	Terms and Conditions
clickAndWait	//input[@value="I agree"]	
assertTitle		Product Selection

A Selenium "test suite" is a web page with a table of links to web pages with test cases.

Selenium Webdriver

Provides APIs to a variety of languages allowing for very similar capabilities:

```
Select select = new Select(driver.findElement(
        By.tagName("select")));
select.deselectAll();
select.selectByVisibleText("Edam");
```

Waiting

```
WebDriver driver = new FirefoxDriver();
driver.get("http://somedomain/url_that_delays_loading");
WebElement myDynamicElement = (
  new WebDriverWait(driver, 10))
  .until(ExpectedConditions.presenceOfElementLocated(
                By.id("myDynamicElement")));
```

Waits up to 10 seconds for an expected element to load