System Testing

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April 9, 2013

Contents

1 Test Coverage

1.1 Coverage Measures

1.1.1 Black-Box Testing

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

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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.

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Boundary-Values Testing

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

- check amount = 0
- check amount ≥ $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

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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.

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1.1.2 White-Box Testing

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

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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++

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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?

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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?

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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.

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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

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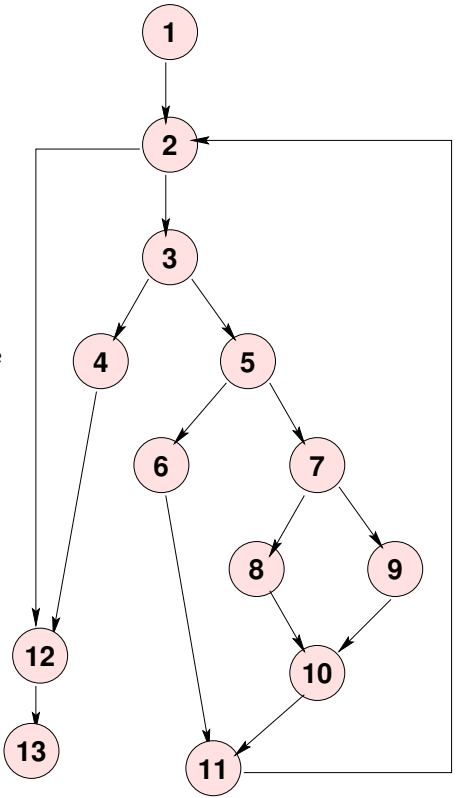
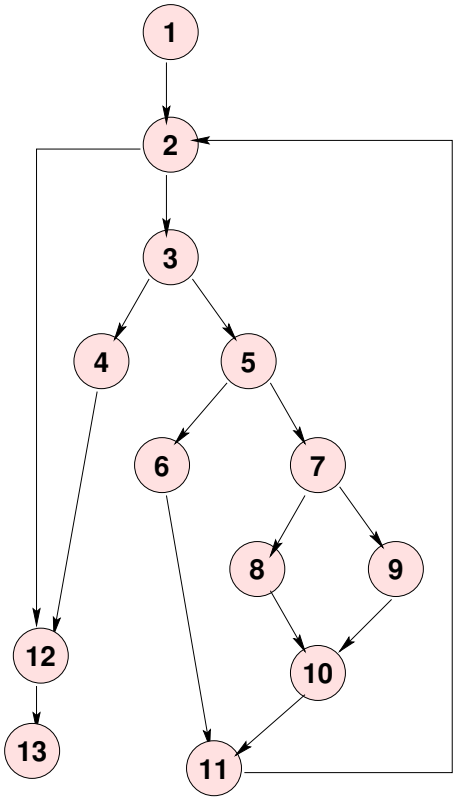
Cyclomatic Coverage

(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?
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

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Cyclomatic Complexity

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

$$CC(G) = Number(edges) - Number(nodes) + 1$$

- 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

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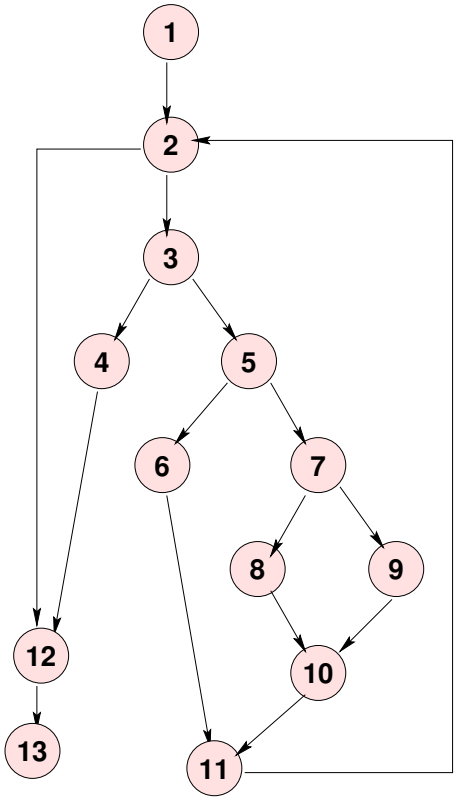
Issues

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

1,2,3,5,6,11,
2,3,5,7,8,
10,11,2,3,
5,7,9,10,11,
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)*

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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`)

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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)`.

```
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-defs coverage?

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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?

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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

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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*.

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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.

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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)

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1.2 C/C++ - gcov

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

```
#ifndef ARRAYUTILS_H
#define ARRAYUTILS_H



//  Add to the end
//  - Assumes that we have a separate integer (size) indicating how
//     many elements are in the array
//  - and that the "true" size of the array is at least one larger
//      than the current value of that counter
template <typename T>
void addToEnd (T* array, int& size, T value)
{
   array[size] = value;
   ++size;
}



// Add value into array[index], shifting all elements already in positions
//    index..size-1 up one, to make room.
//  - Assumes that we have a separate integer (size) indicating how
//     many elements are in the array
//  - and that the "true" size of the array is at least one larger
//      than the current value of that counter

template <typename T>
void addElement (T* array, int& size, int index, T value)
{
  // Make room for the insertion
  int toBeMoved = size - 1;
```


```
  while (toBeMoved >= index) {
    array[toBeMoved+1] = array[toBeMoved];
    --toBeMoved;
  }
  // Insert the new value
  array[index] = value;
  ++size;
}


// Assume the elements of the array are already in order
// Find the position where value could be added to keep
//    everything in order, and insert it there.
// Return the position where it was inserted
//  - Assumes that we have a separate integer (size) indicating how
//     many elements are in the array
//  - and that the "true" size of the array is at least one larger
//      than the current value of that counter

template <typename T>
int addInOrder (T* array, int& size, T value)
{
  // Make room for the insertion
  int toBeMoved = size - 1;
  while (toBeMoved >= 0 && value < array[toBeMoved]) {
    array[toBeMoved+1] = array[toBeMoved];
    --toBeMoved;
  }
  // Insert the new value
  array[toBeMoved+1] = value;
  ++size;
```


```
  return toBeMoved+1;
}


// Search an array for a given value, returning the index where
//    found or -1 if not found.
template <typename T>
int seqSearch(const T list[], int listLength, T searchItem)
{
    int loc;

    for (loc = 0; loc < listLength; loc++)
        if (list[loc] == searchItem)
            return loc;

    return -1;
}


// Search an ordered array for a given value, returning the index where
//    found or -1 if not found.
template <typename T>
int seqOrderedSearch(const T list[], int listLength, T searchItem)
{
    int loc = 0;

    while (loc < listLength && list[loc] < searchItem)
      {
       ++loc;
      }
    if (loc < listLength && list[loc] == searchItem)
```


```
      return loc;
   else
      return -1;
}


// Removes an element from the indicated position in the array, moving
// all elements in higher positions down one to fill in the gap.
template <typename T>
void removeElement (T* array, int& size, int index)
{
  int toBeMoved = index + 1;
  while (toBeMoved < size) {
    array[toBeMoved] = array[toBeMoved+1];
    ++toBeMoved;
  }
  --size;
}



// Search an ordered array for a given value, returning the index where
//    found or -1 if not found.
template <typename T>
int binarySearch(const T list[], int listLength, T searchItem)
{
    int first = 0;
    int last = listLength - 1;
    int mid;

    bool found = false;
```


```
    while (first <= last && !found)
    {
        mid = (first + last) / 2;

        if (list[mid] == searchItem)
            found = true;
        else
            if (searchItem < list[mid])
                last = mid - 1;
            else
                first = mid + 1;
    }

    if (found)
        return mid;
    else
        return -1;
}




#endif
```

– with test driver

```
#include <cassert>
#include <iostream>
#include <sstream>
#include <string>
```


```
#include "arrayUtils.h"

using namespace std;



// Unit test driver for array search functions




int main(int argc, char** argv)
{
  // Repeatedly reads tests from cin
  // Each test consists of a line containing one or more words.
  // The first word is one that we want to search for. The
  // remaining words are placed into an array and represent the collection
  // we will search through.

  string line;
  getline (cin, line);
  while (cin)
    {
      istringstream in (line);
      cout << line << endl;
      string toSearchFor;
      in >> toSearchFor;
      int nWords = 0;
      string words[100];
```


```
      while (in >> words[nWords])
    ++nWords;

      cout << seqSearch (words, nWords, toSearchFor)
       << " "
       << seqOrderedSearch (words, nWords, toSearchFor)
       << " "
       << binarySearch (words, nWords, toSearchFor)
       << endl;

      getline (cin, line);
    }

  return 0;
}
```

, 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.

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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.

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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, T searchItem)
    -:   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`

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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

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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

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Example: gcov Branch Coverage report

```
        -:   84:template <typename T>
        -:   85:int seqOrderedSearch(const T list[], int listLength, T searchItem)
        -:   86:{
        1:   87:    int loc = 0;
        -:   88:
        1:   89:    while (loc < listLength && list[loc] < searchItem)
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] == searchItem)
branch  0 taken 0
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

1.3 Java

Java Coverage Tools

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

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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

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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

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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" revision="1.0"/>
  <publications>
    <artifact name="codeAnnotation" type="jar" ext="jar"/>
    <artifact name="codeAnnotation-src" type="source" ext="zip"/>
  </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.)

```
<project name="codeAnnotation" basedir="." default="build"
     xmlns:ivy="antlib:org.apache.ivy.ant"
     xmlns:jacoco="antlib:org.jacoco.ant"
>

  <record name="ant.log" action="start" append="false" />

  <path id="testCompilationPath">
    <fileset dir="lib" includes="*.jar"/>
    <pathelement path="target/classes"/>
  </path>

  <path id="testExecutionPath">
    <fileset dir="lib" includes="*.jar"/>
    <pathelement path="target/classes"/>
    <pathelement path="target/test-classes"/>
  </path>


  <property name="ivy.install.version" value="2.3.0"/>
  <property name="jsch.install.version" value="0.1.49"/>
  <property name="ivy.jar.dir" value="${basedir}/ivy"/>
  <property name="ivy.jar.file" value="${ivy.jar.dir}/ivy.jar"/>
  <property name="jsch.jar.file" value="${ivy.jar.dir}/jsch.jar"/>
  <property name="build.dir" value="build"/>
  <property name="src.dir" value="src"/>

  <target name="download-ivy" unless="skip.download">
    <mkdir dir="${ivy.jar.dir}"/>
```


```
  <echo message="installing ivy..."/>
  <get src="http://repo1.maven.org/maven2/org/apache/ivy/ivy/${ivy.install.version}/ivy-${ivy.install.ve
   dest="${ivy.jar.file}" usetimestamp="true"/>
</target>

<target name="download-jsch" unless="skip.download">
  <mkdir dir="${ivy.jar.dir}"/>
  <echo message="installing jsch..."/>
  <get src="http://repo1.maven.org/maven2/com/jcraft/jsch/${jsch.install.version}/jsch-${jsch.install.ve
   dest="${jsch.jar.file}" usetimestamp="true"/>
</target>

<target name="install-jsch" depends="download-jsch">
</target>

<target name="install-ivy" depends="download-ivy"
    description="--> install ivy">
  <path id="ivy.lib.path">
    <fileset dir="${ivy.jar.dir}" includes="*.jar"/>
  </path>
  <taskdef resource="org/apache/ivy/ant/antlib.xml"
       uri="antlib:org.apache.ivy.ant" classpathref="ivy.lib.path"/>
</target>

<target name="resolve-ivy" depends="install-ivy,install-jsch" description="Resolve library dependencies"
  <ivy:retrieve/>
  <echo>ivy.default.ivy.user.dir is ${ivy.default.ivy.user.dir}</echo>
  <taskdef uri="antlib:org.jacoco.ant" resource="org/jacoco/ant/antlib.xml"> ❶
      <classpath refid="testExecutionPath"/>
  </taskdef>
  <taskdef classname="JFlex.anttask.JFlexTask" name="jflex">
```


```
      <classpath refid="testExecutionPath"/>
  </taskdef>
</target>

<target name="generateSource" depends="resolve-ivy">
  <mkdir dir="target/gen/java"/>
  <jflex file="src/main/jflex/code2html.flex"
     destdir="target/gen/java"/>
  <jflex file="src/main/jflex/code2tex.flex"
     destdir="target/gen/java"/>
  <jflex file="src/main/jflex/list2html.flex"
     destdir="target/gen/java"/>
  <jflex file="src/main/jflex/list2tex.flex"
     destdir="target/gen/java"/>
</target>


<target name="compile" depends="generateSource">   ❷
  <mkdir dir="target/classes"/>
  <javac srcdir="target/gen/java" destdir="target/classes" debug="true"
     source="1.6" includeantruntime="false"/>
  <javac srcdir="src/main/java" destdir="target/classes" debug="true"
     source="1.6" includeantruntime="false"/>
</target>

<target name="compile-tests" depends="compile">
  <mkdir dir="target/test-classes"/>
  <javac srcdir="src/test/java" destdir="target/test-classes" debug="true"
     source="1.6" includeantruntime="false">
    <classpath refid="testCompilationPath"/>
  </javac>
```


```
</target>

<target name="test" depends="compile-tests">
  <mkdir dir="target/test-results/details"/>
  <jacoco:coverage destfile="target/jacoco.exec">    ❸
    <junit printsummary="yes"
       haltonfailure="yes" fork="yes"
       >
  <classpath refid="testExecutionPath"/>
  <formatter type="xml"/>
  <batchtest todir="target/test-results/details">
    <fileset dir="target/test-classes">
      <include name="**/*Test*.class"/>
    </fileset>
  </batchtest>
    </junit>
  </jacoco:coverage>
  <junitreport todir="target/test-results">
    <fileset dir="target/test-results/details">
      <include name="TEST-*.xml"/>
    </fileset>
    <report format="frames" todir="target/test-results/html"/>
  </junitreport>
</target>

<target name="coverageReport" depends="test">
  <jacoco:report>               ❹
      <executiondata>
          <file file="target/jacoco.exec"/>  ❺
      </executiondata>
```


```
  <structure name="Code Annotation Project"> ❻
    <classfiles>
      <fileset dir="target/classes"/>
      <fileset dir="target/test-classes"/>
    </classfiles>
    <sourcefiles encoding="UTF-8">
      <fileset dir="src/main/java"/>
      <fileset dir="src/test/java"/>
      <fileset dir="target/gen/java"/>
    </sourcefiles>
      </structure>

      <html destdir="target/coverageReport"/>   ❼

  </jacoco:report>
</target>

<target name="build"  depends="coverageReport">
  <jar destfile="codeAnnotation.jar" basedir="target/classes">
      <manifest>
       <attribute name="Main-Class"
                  value="edu.odu.cs.code2html.Code2HTML"/>
   </manifest>
  </jar>
  <zip destfile="target/codeAnnotation-src.zip">
    <fileset dir=".">
      <include name="*.xml"/>
      <include name="test.cpp"/>
      <include name="*.css.cpp"/>
      <include name="src/**/*"/>
      <exclude name="**/*~"/>
```


```
        <exclude name="target/**/*"/>
      </fileset>
    </zip>
  </target>

  <target name="publish" depends="build">
    <ivy:retrieve/>
    <ivy:publish resolver="Forge350Publish"
      status="release"
      update="true"
      overwrite="true"
      publishivy="true">
      <artifacts pattern="[artifact].[ext]"/>
    </ivy:publish>
  </target>

  <target name="clean">
    <delete dir="target"/>
  </target>

  <target name="cleaner" depends="clean">
    <delete dir="lib"/>
  </target>

  <target name="cleanest" depends="cleaner">
    <delete dir="ivy"/>
  </target>

</project>
```

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

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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.

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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

Oracles

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

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2.1 expect

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

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2.2 *Unit

***Unit**

Can we use *Unit-style frameworks as oracles at the system test level?

- The very question is heresy to many *Unit advocates
  - Particularly runs counter to the goals of the various Mock Objects projects
- But, why not?

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

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2.3 GUI systems

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

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Some Open Alternatives

- Marathon - free in limited version
- Jemmy

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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 Systems")
    }
end
```

.....

Jemmy

Also for Java GUIs

- Tests scripted as Java
- Integrates with JUnit
  - Example

.....

2.4 Web systems

Web systems

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

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Some Open Alternatives

- Selenium
- antEater
- Watir

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2.5 Selenium

Selenium

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

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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

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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

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A Sample Selenium Script

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

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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