Software Testing and Quality Assurance

Theory and Practice

Chapter 3

Unit Testing

Outline of the Chapter

- Concept of Unit Testing
- Static Unit Testing
- Defect Prevention
- Dynamic Unit Testing
- Mutation Testing
- Debugging
- Unit Testing in eXtreme Programming
- Tools For Unit Testing

Concept of Unit Testing

- Static Unit Testing
  - Code is examined over all possible behaviors that might arise during run time
  - Code of each unit is validated against requirements of the unit by reviewing the code
- Dynamic Unit Testing
  - A program unit is actually executed and its outcomes are observed
  - One observe some representative program behavior, and reach conclusion about the quality of the system
- Static unit testing is not an alternative to dynamic unit testing
- Static and Dynamic analysis are complementary in nature
- In practice, partial dynamic unit testing is performed concurrently with static unit testing
- It is recommended that static unit testing be performed prior to the dynamic unit testing

Static Unit Testing

- In static unit testing code is reviewed by applying techniques:
  - **Inspection:** It is a step by step peer group review of a work product, with each step checked against pre-determined criteria
  - **Walkthrough:** It is review where the author leads the team through a manual or simulated executed of the product using pre-defined scenarios
- The idea here is to examine source code in detail in a systematic manner
- The objective of code review is to *review* the code, and *not* to evaluate the author of the code
- Code review must be planned and managed in a professional manner
- The key to the success of code is to divide and conquer
  - An examiner inspect small parts of the unit in isolation
    - nothing is overlooked
    - the correctness of all examined parts of the module implies the correctness of the whole module

Static Unit Testing (Code Review)

- Step 1: **Readiness**
  - **Criteria**
    - **Completeness**
    - **Minimal functionality**
    - **Readability**
    - **Complexity**
    - **Requirements and design documents**
  - **Roles**
    - **Moderator**
    - **Author**
    - **Presenter**
    - **Record keeper**
    - **Reviewers**
    - **Observer**
- Step 2: **Preparation**
  - **List of questions**
  - **Potential Change Request (CR)**
  - **Suggested improvement opportunities**

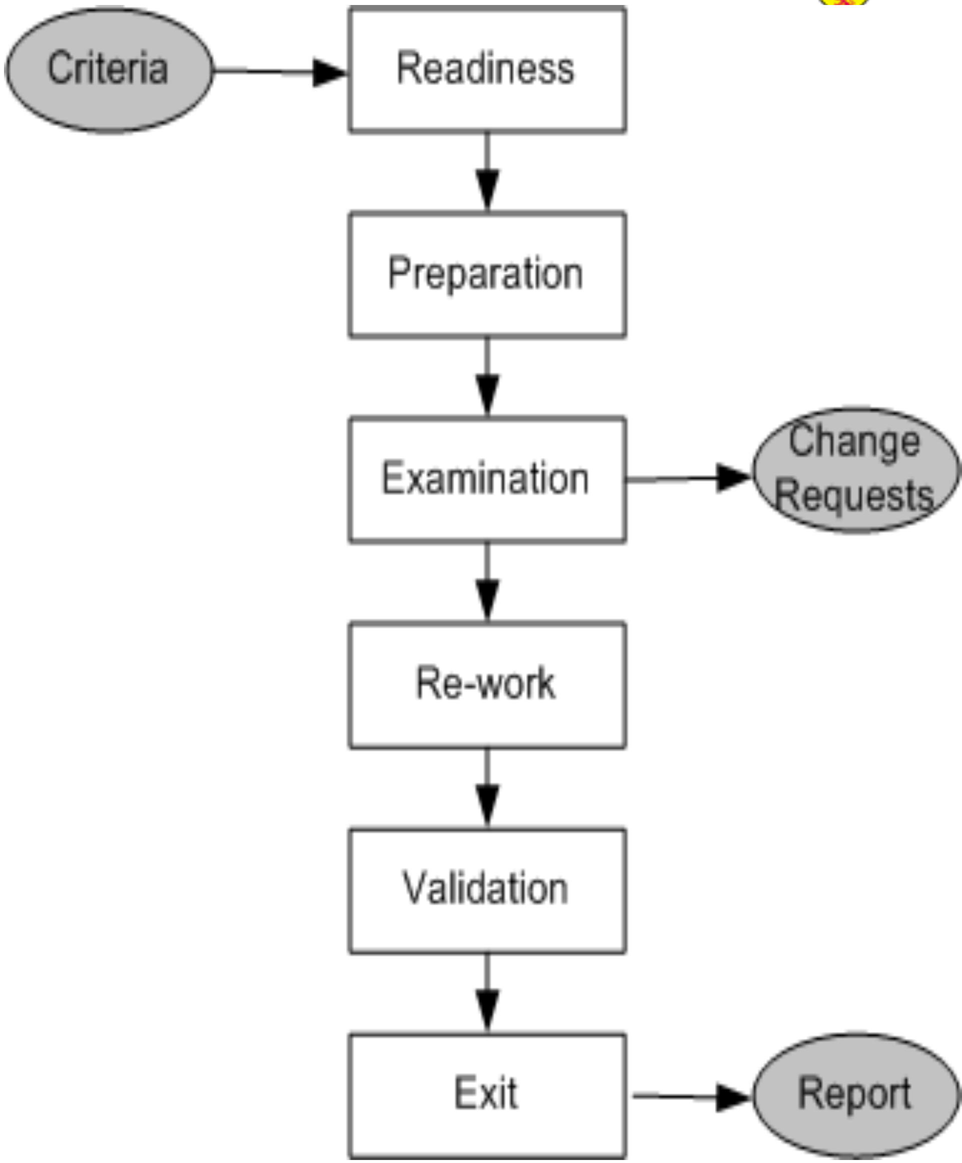


Figure 3.1: Steps in the code review process

Static Unit Testing (Code Review)

- Step 3: **Examination**
  - The author makes a presentation
  - The presenter reads the code
  - The record keeper documents the CR
  - Moderator ensures the review is on track
- Step 4: **Re-work**
  - Make the list of all the CRs
  - Make a list of improvements
  - Record the minutes meeting
  - Author works on the CRs to fix the issue
- Step 5: **Validation**
  - CRs are independently validated
- Step 6: **Exit**
  - A summary report of the meeting minutes is distributes

A **Change Request (CR)** includes the following details:

- Give a brief description of the issue
- Assign a priority level (major or minor) to a **CR**
- Assign a person to follow it up
- Set a deadline for addressing a **CR**

Static Unit Testing (Code Review)

The following metrics can be collected from a code review:

- The number of lines of code (LOC) reviewed per hour
- The number of CRs generated per thousand lines of code (KLOC)
- The number of CRs generated per hour
- The total number of hours spend on code review process

Static Unit Testing (Code Review)

- The code review methodology can be applicable to review other documents
- Five different types of system documents are generated by engineering department
  - Requirement
  - Functional Specification
  - High-level Design
  - Low-level Design
  - code
- In addition installation, user, and trouble shooting guides are developed by technical documentation group

Hierarchy of System Documents
Requirement: High-level marketing or product proposal.
Functional Specification: Software Engineering response to the marketing proposal.
High-Level Design: Overall system architecture.
Low-Level Design: Detailed specification of the modules within the architecture.
Programming: Coding of the modules.

Table 3.1: System documents

Example

Requirement 14. *Only basic food staples shall be carried by game characters.*

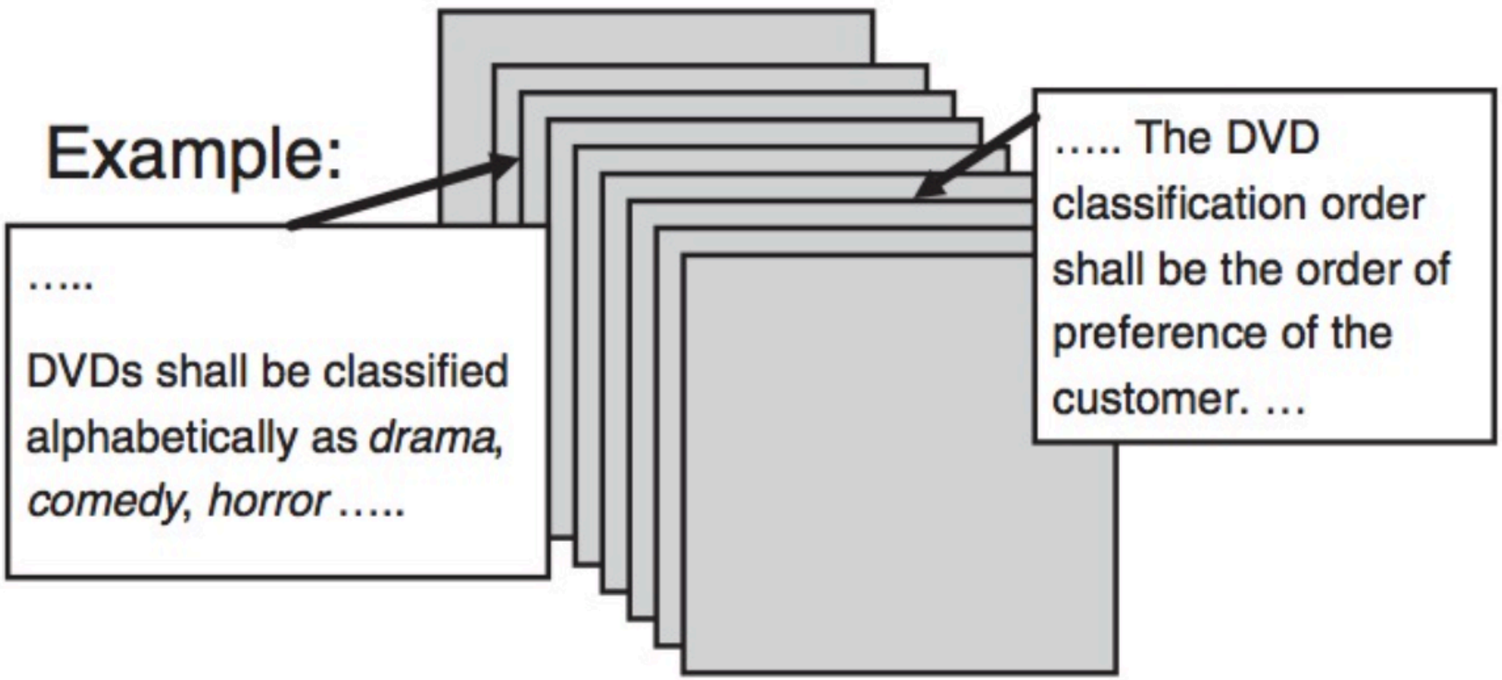
. . . . . .

Requirement 223. *Every game character shall carry water.*

. . . . . .

Requirement 497. *Flour, butter, milk, and salt shall be considered the only basic food staples.*

Example


Example:
.....
DVDs shall be classified alphabetically as *drama*, *comedy*, *horror* .....
..... The DVD classification order shall be the order of preference of the customer. ...

Example

```
#include "lshie.h"
int main(void) {
    char c ;
    while ((c = getchar()) != EOF) {
        if (c == ' ') {
            putchar(c) ;
            while ((c = getchar()) == ' ') ;
        }
        putchar(c) ;
    }
    printf("\n") ;
}
```

Defect Prevention

- Build instrumentation code into the code
- Use standard control to detect possible occurrences of error conditions
- Ensure that code exists for all return values
- Ensure that counter data fields and buffer overflow/underflow are appropriately handled
- Provide error messages and help texts from a common source
- Validate input data
- Use assertions to detect impossible conditions
- Leave assertions in the code.
- Fully document the assertions that appears to be unclear
- After every major computation reverse-compute the input(s) from the results in the code itself
- Include a loop counter within each loop

Dynamic Unit Testing

- The environment of a unit is emulated and tested in isolation
- The caller unit is known as *test driver*
  - A *test driver* is a program that invokes the unit under test (UUT)
  - It provides input data to unit under test and report the test result
- The emulation of the units called by the UUT are called *stubs*
  - It is a dummy program
- The *test driver* and the *stubs* are together called *scaffolding*
- The low-level design document provides guidance for selection of input test data

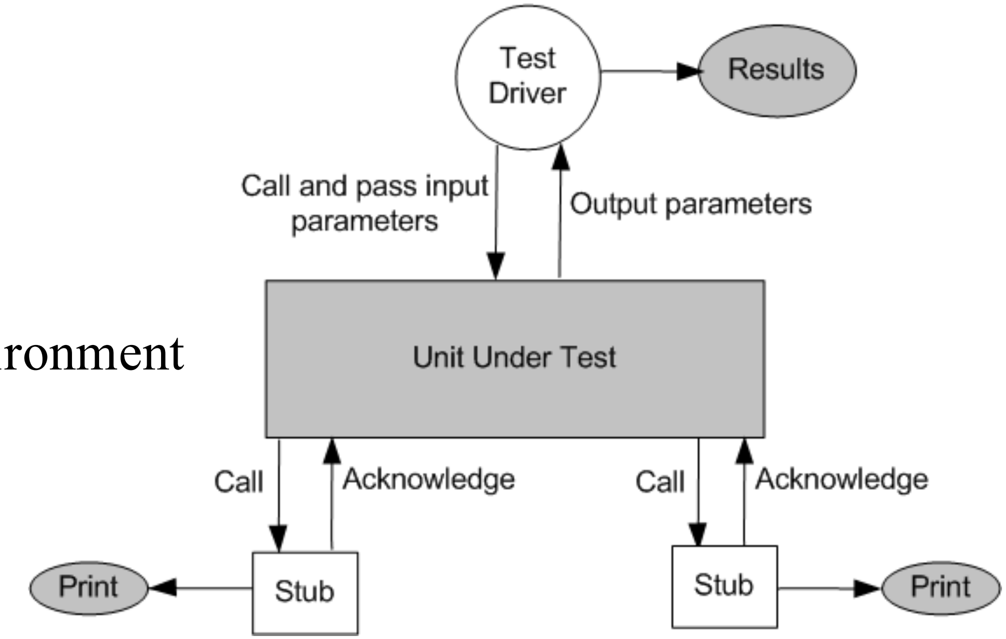


Figure 3.2: Dynamic unit test environment

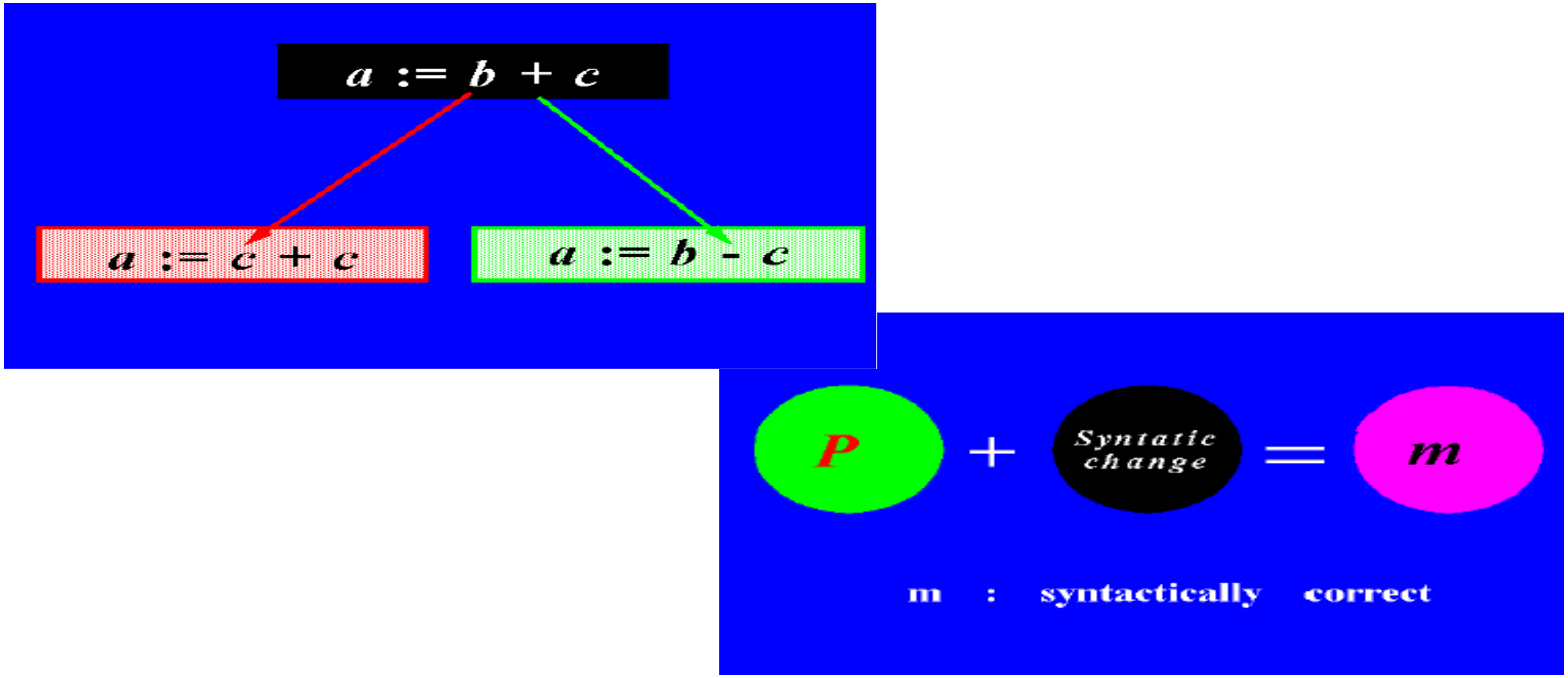
Dynamic Unit Testing

Selection of test data is broadly based on the following techniques:

- Control flow testing
  - Draw a control flow graph (CFG) from a program unit
  - Select a few control flow testing criteria
  - Identify a path in the CFG to satisfy the selection criteria
  - Derive the path predicate expression from the selection paths
  - By solving the path predicate expression for a path, one can generate the data
- Data flow testing
  - Draw a data flow graph (DFG) from a program unit and then follow the procedure described in control flow testing.
- Domain testing
  - Domain errors are defined and then test data are selected to catch those faults
- Functional program testing
  - Input/output domains are defined to compute the input values that will cause the unit to produce expected output values

Mutation Testing

- Basic Idea
  - *Consider a program under test*
  - *With a test suite that have all passed*
  - *Now introduce a small set of faults*
  - *Run the same suite of tests and observe*



Mutation Testing

Original program

```
int index=0;
while (...)
{
      . . .;
      index++;
      if (index==10)
          break;
}
```

A mutant

```
int index=0;
while (...)
{
      . . .;
      index++;
      if (index>=10)
          break;
}
```

Mutation Testing

- *Mutant*
  - *Program with a fault introduced into it*
- *Mutant Killed*
  - *If test fails with mutant*
  - *In other words, test discovers the fault*
- *Equivalent*
  - *Mutant passes test suite*
  - *Mutant is non-killable (need new test cases to discover faults)*
  - *In other words, mutation has no effect*

Mutation Testing

- *Adequacy of testing*
  - *If a test suite detects all induced faults*
  - *i.e., all mutants killed by a test suite*
  - *Such a test suite is termed mutation – adequate (Mutation score = 1 or 100%)*
  - *Can be used as a test stopping criterion*
  - *Remember we are talking about Unit Testing*
  - *Can we apply this to Integration or System Testing*
    - *Why?*
    - *Why not?*
- *Mutation Score*

$$M_s = \frac{\text{\# of Mutations Discovered}}{\text{Total \# of Mutations}}$$

Mutation Testing

Types of Mutations
(Also known as Mutation Operators)

- 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

Mutation Testing

Types of Mutations

- 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

Mutation Testing

Types of Mutations (OOP?)

- Replacing a type with a compatible subtype (inheritance)
- Changing the access modifier of an attribute, a method
- Changing the instance creation expression (inheritance)
- Changing the order of parameters in the definition of a method
- Changing the order of parameters in a call
- Removing an overloading method
- Reducing the number of parameters
- Removing an overriding method
- Removing a hiding Field
- Adding a hiding field
-

Mutation Testing


```
…
found := FALSE;
i := 1;
while(not(found)) and (i <= x) do begin // x is the length
   if a[i] = c then
     found := TRUE
   else
     i := i + 1
end
if (found)
   print("Character %c appears at position %i");
else
   print("Character is not present in the string");
end
…
```

Mutation Testing

Input				Expected Output (oracle)
x	a[ ]	c	Response	
25				The input integer should be between 1 and 20
1	x	x	found	Character x appears at position 1
1	x	a	not found	Character is not present in the string

Mutation Testing

- Replace `Found := FALSE;` with `Found := TRUE;`
- Re-run original test data set
- Note: It is better in Mutation Testing to make only one small change at a time to avoid the danger of introduced faults with interfering effects (masking)
- Failure: "character *a* appears at position 1" instead of saying "character is not present in the string"
- Mutant 1 is killed (since Output <> Oracle)

Last few slides borrowed from Lionel Briand

Mutation testing

Consider the following program P

```
1. main(argc,argv)
2. int argc, r, i;
3. char *argv[];
4. { r = 1;
5. for i = 2 to 3 do
6. if (atoi(argv[i]) > atoi(argv[r])) r = i;
7. printf("Value of the rank is %d \n", r);
8. exit(0); }
```

- Test Case 1:
  input: 1 2 3
  output: Value of the rank is 3
- Test Case 2:
  input: 1 2 1
  output: Values of the rank is 2
- Test Case 3:
  input: 3 1 2
  output: Value of the rank is 1

Mutant 1: Change line 5 to for i = 1 to 3 do
Mutant 2: Change line 6 to if (i > atoi(argv[r])) r = i;
Mutant 3: Change line 6 to if (atoi(argv[i]) >= atoi(argv[r])) r = i;
Mutant 4: Change line 6 to if (atoi(argv[r]) > atoi(argv[r])) r = i;
Execute modified programs against the test suite, you will get the results:
Mutants 1 & 3: Programs will pass the test suite, i.e., mutants 1 & 3 are not *killable*
Mutant 2: Program will fail test cases 2
Mutant 4: Program will fail test case 1 and test cases 2
Mutation score is 50%, assuming mutants 1 & 3 non-equivalent

Mutation testing

- The score is found to be low because we assumed mutants 1 & 3 are nonequivalent
- We need to show that mutants 1 and 3 are equivalent mutants or those are killable
- To show that those are killable, we need to add new test cases to kill these two mutants
- First, let us analyze mutant 1 in order to derive a "killer" test. The difference between P and mutant 1 is the starting point
- Mutant 1 starts with i = 1, whereas P starts with i = 2. There is no impact on the result r. Therefore, we conclude that mutant 1 is an equivalent mutant
- Second, if we add a fourth test case as follows:

Test Case 4:

input: 2 2 1

- Program P will produce the output "Value of the rank is 1" and mutant 3 will produce the output "Value of the rank is 2"
- Thus, this test data kills mutant 3, which give us a mutation score 100%

Mutation Testing

Mutation testing makes two major assumptions:

- Competent Programmer hypothesis
  - Programmers are generally competent and they do not create *random* programs
- Coupling effects
  - Complex faults are coupled to simple faults in such a way that a test suite detecting simple faults in a program will detect most of the complex faults

Debugging

- The process of determining the cause of a failure is known as *debugging*
- It is a time consuming and error-prone process
- Debugging involves a combination of systematic evaluation, intuition and a little bit of luck
- The purpose is to isolate and determine its specific cause, given a symptom of a problem
- There are three approaches to *debugging*
  - Brute force
  - Cause elimination
    - Induction
    - Deduction
  - Backtracking

Tools For Unit Testing

- Code auditor
  - This tool is used to check the quality of the software to ensure that it meets some minimum coding standard
- Bound checker
  - This tool can check for accidental writes into the instruction areas of memory, or to other memory location outside the data storage area of the application
- Documenters
  - These tools read the source code and automatically generate descriptions and caller/callee tree diagram or data model from the source code
- Interactive debuggers
  - These tools assist software developers in implementing different debugging techniques

    Examples: Breakpoint and Omniscient debuggers
- In-circuit emulators
  - It provides a high-speed Ethernet connection between a host debugger and a target microprocessor, enabling developers to perform source-level debugging

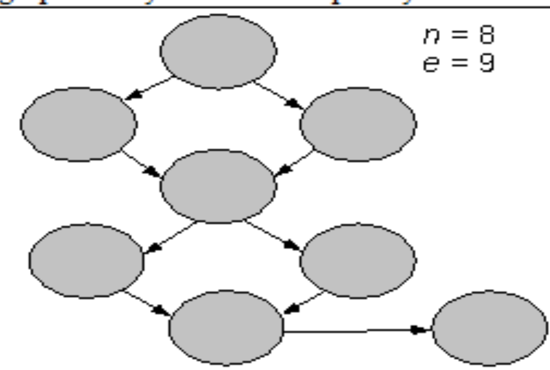
Tools for Unit Testing

- Memory leak detectors
  - These tools test the allocation of memory to an application which request for memory and fail to de-allocate memory
- Static code (path) analyzer
  - These tool identify paths to test based on the structure of code such as McCabe's cyclomatic complexity measure

Table 3.3: McCabe complexity measure

Cyclomatic complexity

McCabe's complexity measure is based on the cyclomatic complexity of a program graph for a module. The metric can be computed by using the formula: $v = e - n + 2$,
where:
v = cyclomatic complexity of the graph,
e = number of edges (program flow between nodes),
n = number of nodes (sequential group of program statements).
If a strongly connected graph is constructed (one in which there is an edge between the exit node and the entry node) the calculation is $v = e - n + 1$.
Example: A program graph, illustrated below is used to depict control flow. Each circled node represents a sequence of program statements, and the flow of control is represented by directed edges. For this graph the cyclomatic complexity is $v = 9 - 8 + 2 = 3$.



Tools for Unit Testing

- Software inspection support
  - Tools can help schedule group inspection
- Test coverage analyzer
  - These tools measure internal test coverage, often expressed in terms of control structure of the test object, and report the coverage metric
- Test data generator
  - These tools assist programmers in selecting test data that cause program to behave in a desired manner
- Test harness
  - This class of tools support the execution of dynamic unit tests
- Performance monitors
  - The timing characteristics of the software components be monitored and evaluate by these tools
- Network analyzers
  - These tools have the ability to analyze the traffic and identify problem areas

Tools for Unit Testing

- Simulators and emulators
  - These tools are used to replace the real software and hardware that are not currently available. Both the kinds of tools are used for training, safety, and economy purpose
- Traffic generators
  - These produces streams of transactions or data packets.
- Version control
  - A version control system provides functionalities to store a sequence of revisions of the software and associated information files under development