CS20006: Software Engineering
Module 05: Software Testing & Maintenance

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Based on **Program Testing** *presentation by Prof. Rajib Mall, IIT Kharagpur*

March 24, 25, 26, 31. April 01, 07: 2021

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Why Test?

- **Ariane 5 Flight 501**



  - Un-manned satellite-launching rocket in 1996
  - Self-destructed 37 seconds after launch
  - Conversion from 64-bit floating point to 16-bit signed integer value had caused an exception (re-used from Ariane 4)
    - The floating point number was larger than 32767
    - Efficiency considerations had led to the disabling of the exception handler

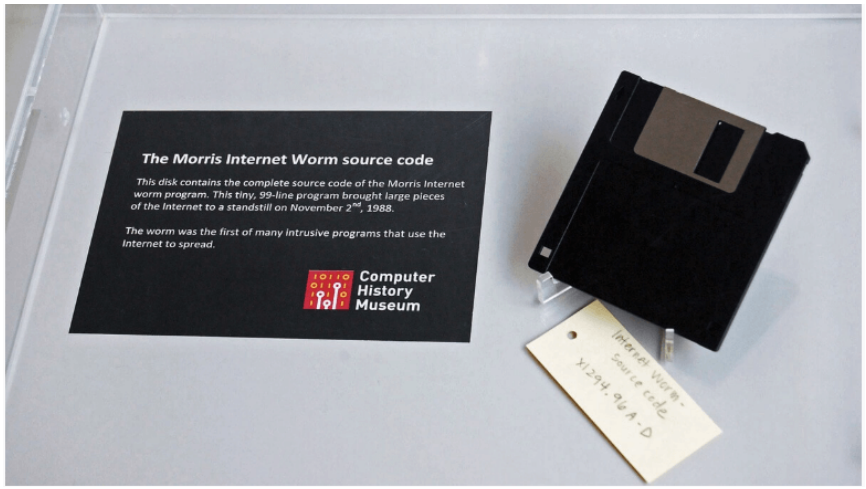
Source: 11 of the most costly software errors in history

Why Test?

- **NASA's Mars Climate Orbiter**
  - Mission to Mars in 1998, $125 Million
  - Lost in space
  - Simple conversion from English units to metric failed
- **EDS Child Support System in 2004**
  - Overpay 1.9 million people
  - Underpay another 700,000
  - US $7 billion in uncollected child support payments
  - Backlog of 239,000 cases
  - 36,000 new cases "stuck" in the system
  - Cost the UK taxpayers over US $1 billion
  - Incompatible software integration
- **Heathrow Terminal 5 Opening**
  - Baggage handling tested for 12,000 test pieces of luggage
  - Missed to test for *removal of baggage*
  - In 10 days some 42,000 bags failed to travel with their owners, and over 500 flights were cancelled

Why Test?

- **The Morris Worm**
  - Developed by a Cornell University student for a harmless experiment
  - Spread wildly and crashing thousands of computers in 1988 because of a coding error
  - It was the first widespread worm attack on the fledgling Internet
  - The graduate student, Robert Tappan Morris, was convicted of a criminal hacking offense and fined $10,000
  - Costs for cleaning up the mess may have gone as high as $100 Million
  - Morris, who co-founded the startup incubator Y Combinator, is now a professor at the Massachusetts Institute of Technology
  - A disk with the worm's source code is now housed at the University of Boston



Why Test?

- **Boeing Crash**
  - On March 10, 2019, Ethiopian Airlines Flight 302 crashed just minutes after takeoff. All 157 people on board the flight died
  - On October of 2018, Lion Air Flight 610 also crashed minutes after taking off
  - Both flights involved Boeing's 737 MAX jet
  - The software overpowered all other flight functions trying to mediate the nose lift
  - Many pilots did not know this system existed - they were not re-trained on 737 MAX Jet

  Source: Boeing Software Scandal Highlights Need for Full Lifecycle Testing
- **Airbus Crash**
  - On May 9, 2015, the Airbus A400M crashed near Seville after a failed emergency landing during its first flight
  - Electronic Control Units (ECU) on board malfunctioned

  Source: Airbus A400M plane crash linked to software fault

Testing a Program

- Input test data to the program
- Observe the output
- Check if the program behaved as expected
- If the program does not behave as expected:
  - Note the conditions under which it failed
  - Debug and correct

What's So Hard About Testing?

- Consider `int proc1(int x, int y)`
- Assuming a 64 bit computer
  - Input space $= 2^{128}$
- Assuming it takes 10secs to key-in an integer pair
  - It would take about a billion years to enter all possible values!
  - Automatic testing has its own problems!

Testing Facts

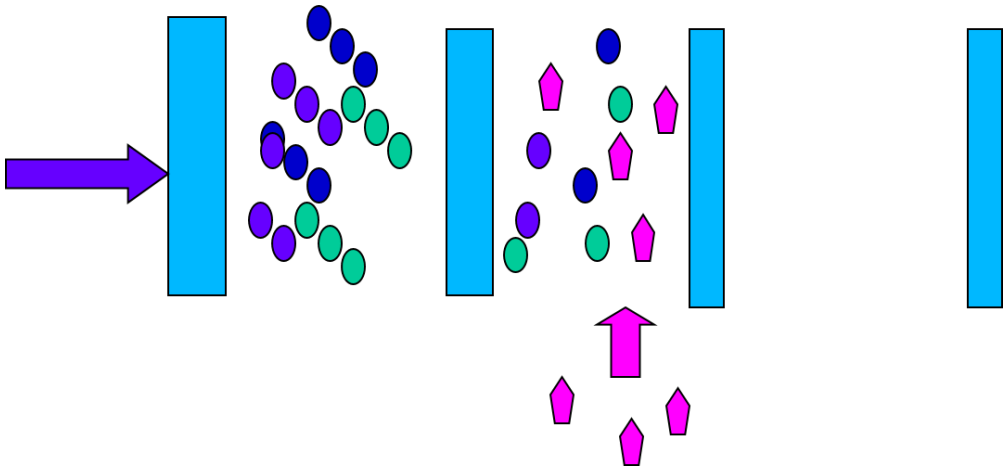
- Consumes largest effort among all phases
  - Largest manpower among all other development roles
  - Implies more job opportunities
- About 50% development effort
  - But 10% of development time?
  - How?
- Testing is getting more complex and sophisticated every year
  - Larger and more complex programs
  - Newer programming paradigms

Overview of Testing

- Testing Activities
  - Test Suite Design
  - Run test cases and observe results to detect failures.
  - Debug to locate errors
  - Correct errors
- Error, Faults, and Failures
  - A failure is a manifestation of an error (also defect or bug)
  - Mere presence of an error may not lead to a failure

Pesticide Effect

- Errors that escape a fault detection technique:
  - Can not be detected by further applications of that technique



- Assume we use 4 fault detection techniques and 1000 bugs:
  - Each detects only 70% bugs
  - How many bugs would remain?
  - $1000 * (0.3)^4 = 81$ bugs

Fault Model

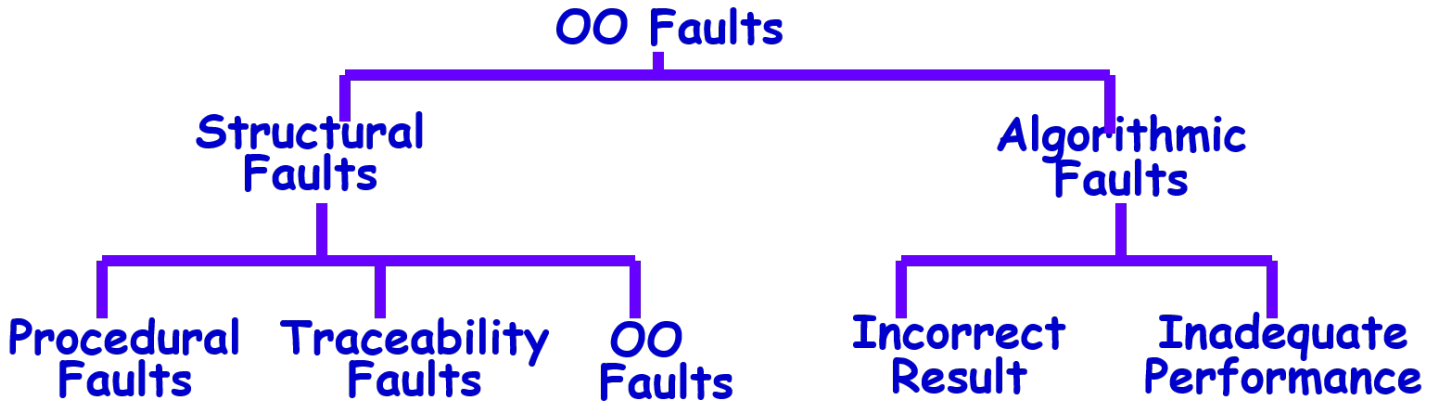
- Types of faults possible in a program
- Some types can be ruled out
  - Concurrency related-problems in a sequential program
  - Consider a singleton in multi-thread

```
#include <iostream>
using namespace std;
class Printer { /* THIS IS A SINGLETON PRINTER -- ONLY ONE INSTANCE */
    bool blackAndWhite_, bothSided_;
    Printer(bool bw = false, bool bs = false) : blackAndWhite_(bw), bothSided_(bs)
    { cout << "Printer constructed" << endl; }
    static Printer *myPrinter_; // Pointer to the Singleton Printer
public:
    ~Printer() { cout << "Printer destructed" << endl; }
    static const Printer& printer(bool bw = false, bool bs = false) {
        if (!myPrinter_) // What happens on multi-thread?
            myPrinter_ = new Printer(bw, bs);
        return *myPrinter_;
    }
    void print(int nP) const { cout << "Printing " << nP << " pages" << endl; }
};
Printer *Printer::myPrinter_ = 0;

int main() {
    Printer::printer().print(10);
    Printer::printer().print(20);
    delete &Printer::printer();
    return 0;
}
```

Fault Model

- Fault Model of an OO Program



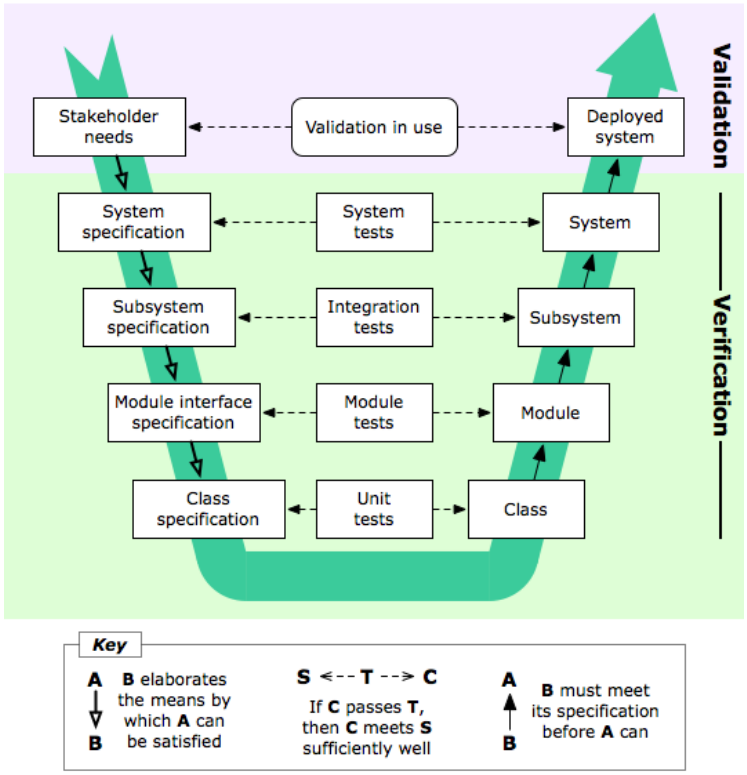
- Hardware Fault-Model
  - Simple:
    - Stuck-at 0
    - Stuck-at 1
    - Open circuit
    - Short circuit
  - Simple ways to test the presence of each
  - Hardware testing is fault-based testing

Test Cases and Test Suites

- Each test case typically tries to establish correct working of some functionality:
  - Executes (covers) some program elements
  - For restricted types of faults, fault-based testing exists
- Test a software using a set of carefully designed test cases:
  - The set of all test cases is called the test suite
- A test case is a triplet [I,S,O]
  - I is the data to be input to the system
  - S is the state of the system at which the data will be input
  - O is the expected output of the system (called *Golden*)

Verification versus Validation

- **Verification** is the process of determining
  - Whether output of one phase conforms to its previous phase
  - If we are building the system correctly
  - *Verification is concerned with phase containment of errors*
- **Validation** is the process of determining
  - Whether a fully developed system conforms to its SRS document
  - If we are building the correct system
  - *Whereas the aim of validation is that the final product be error free*



Source: Software Testing

Design of Test Cases

- Exhaustive testing of any non-trivial system is impractical
  - Input data domain is extremely large
- Design an optimal test suite
  - Of reasonable size and
  - Uncovers as many errors as possible
- If test cases are selected randomly
  - Many test cases would not contribute to the significance of the test suite
  - Would not detect errors not already being detected by other test cases in the suite
- Number of test cases in a randomly selected test suite
  - Not an indication of effectiveness of testing
- Testing a system using a large number of randomly selected test cases
  - Does not mean that many errors in the system will be uncovered

Design of Test Cases

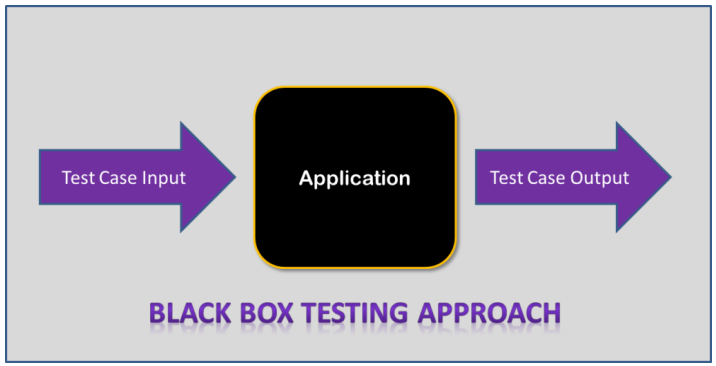
- Consider following example
  - Find the maximum of two integers x and y
- The code has a simple programming error

```
if (x>y)
    max = x;
else
    max = x;
```

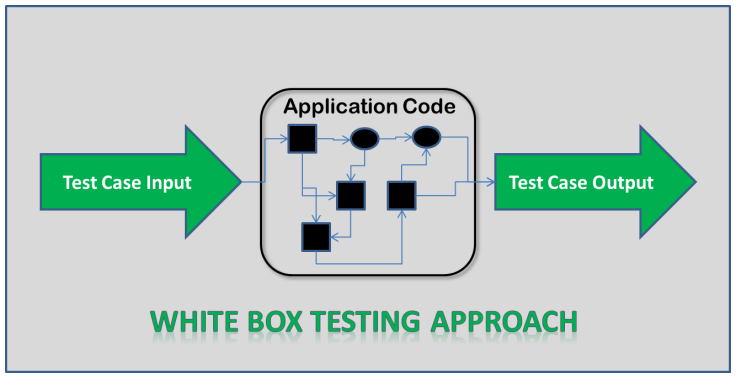
- Test suite {(x=3,y=2); (x=2,y=3)} can detect the error
- A larger test suite {(x=3,y=2); (x=4,y=3); (x=5,y=1)} does not detect the error

Design of Test Cases

- Systematic approaches are required to design an optimal test suite
  - Each test case in the suite should detect different errors
- There are essentially three main approaches to design test cases
  - **Black-box testing** (*Zero Knowledge*)



  - **White-box testing** (*Full Knowledge*)



  - **Grey-box testing** (*Some Knowledge*)

Why Both BB and WB Testing?

Black Box Testing

- Impossible to write a test case for every possible set of inputs and outputs
- Some code parts may not be reachable
- Does not tell if extra functionality has been implemented.

White Box Testing

- Does not address the question of whether or not a program matches the specification
- Does not tell you if all of the functionality has been implemented
- Does not discover missing program logic

Black-Box Testing

- Black-box testing is a method of software testing that examines the functionality of an application without peering into its internal structures or workings
- This method of test can be applied virtually to every level of software testing
  - unit
  - integration
  - system and
  - acceptance
- Test cases are designed using only *functional specification* of the software
  - Without any knowledge of the internal structure of the software
- For this reason, black-box testing is also known as *functional testing* or *specification-based testing*

White-Box Testing

- White-box testing is a method of software testing that tests internal structures or workings of an application, as opposed to its functionality
- In white-box testing an internal perspective of the system, as well as programming skills, are used to design test cases
- Designing white-box test cases
  - Requires knowledge about the *internal structure* of software
- White-box testing is also called *structural testing*

Grey-Box Testing

- Grey-box testing is a combination of white-box testing and black-box testing
- The aim of this testing is to search for the defects if any due to improper structure or improper usage of applications

Black-Box Testing Strategies

There are several significant approaches to design black box test cases including

- Equivalence class partitioning
- Boundary value analysis
- State Transition Testing
- Decision Table Testing
- Graph-Based Testing
- Error Guessing Technique

Other approaches include:

- Fuzzing Technique
- All Pair Testing
- Orthogonal Array Testing
- and so on

Source: Black Box Testing Techniques with Examples

Black-Box Testing: Equivalence Class Partitioning

- Input values to a program are partitioned into equivalence classes
- Partitioning is done such that
  - Program behaves in similar ways to every input value belonging to an equivalence class
  - Test the code with just one representative value from each equivalence class – As good as testing using any other values from the equivalence classes

Black-Box Testing: Equivalence Class Partitioning

How do you determine the equivalence classes?

- Examine the input data – Few general guidelines for determining the equivalence classes can be given
  - If the input data is specified by a range of values
    - For example, numbers between 1 to 5000
    - One valid and two invalid equivalence classes are defined
  - If input is an enumerated set of values
    - For example, { a, b, c }
    - One equivalence class for valid input values
    - Another equivalence class for invalid input values should be defined
  - A program reads an input value in the range of 1 and 5000
    - Computes the square root of the input number
    - One valid and two invalid equivalence classes are defined – The set of negative integers, Set of integers in the range of 1 and 5000, and Integers larger than 5000
    - A possible test suite can be: { -5, 500, 6000 }

Black-Box Testing: Equivalence Class Partitioning

- Max program reads two non-negative integers and spits the larger one

Equivalence Class	Condition	Test Case
EC 1 (Greater)	$x > y$	(5, 2)
EC 2 (Smaller)	$x < y$	(3, 7)
EC 3 (Equal)	$x = y$	(4, 4)

- QES program reads (a, b, c) and solves: $ax^2 + bx + c = 0$

Equivalence Class	Condition	Test Case
Infinite roots	$a = b = c = 0$	(0,0,0)
No root	$a = b = 0; c \neq 0$	(0,0,2)
Single root	$a = 0, b \neq 0$	(0,2,-4)
Repeated roots	$a \neq 0; b * b - 4 * a * c = 0$	(4,4,1)
Distinct roots	$a \neq 0; b * b - 4 * a * c > 0$	(1,-5,6)
Complex roots	$a \neq 0; b * b - 4 * a * c < 0$	(2,3,4)

Black-Box Testing: Boundary Value Analysis (BVA)

- Some typical programming errors occur
  - At boundaries of equivalence classes
  - Might be purely due to psychological factors
- Programmers often fail to see
  - Special processing required at the boundaries of equivalence classes

Black-Box Testing: Boundary Value Analysis (BVA)

- Some typical programming errors occur
  - At boundaries of equivalence classes
  - Might be purely due to psychological factors
- Programmers often fail to see
  - Special processing required at the boundaries of equivalence classes
- Programmers may improperly use $<$ instead of $\leq$
- Boundary value analysis
  - Select test cases at the boundaries of equivalence classes
- For a function that computes the square root of an integer in the range of 1 and 5000
  - Test cases must include the values: { 0, 1, 5000, 5001 }
- QES program reads (a, b, c) and solves: $ax^2 + bx + c = 0$
  - $a = 0$ is a boundary. Check if this test works well
  - $b * b - 4 * a * c = 0$ is a boundary. Check for the test

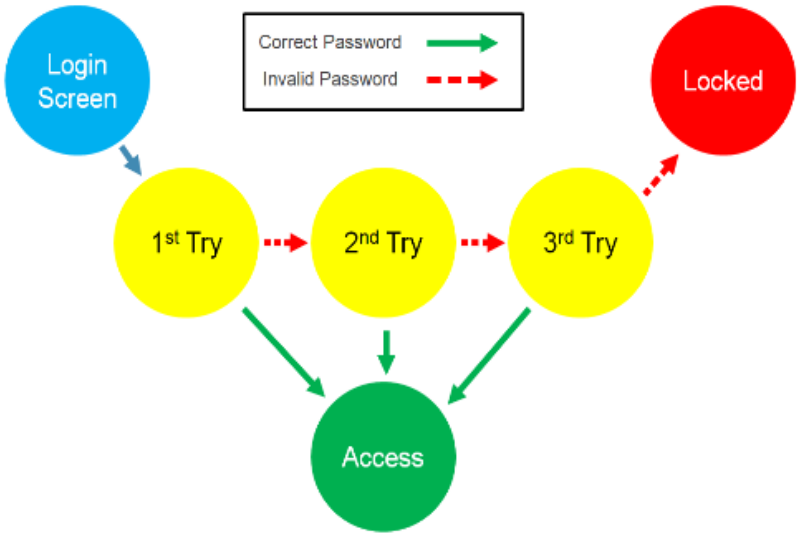
Black-Box Testing: State Transition Testing

- This technique usually considers the state, outputs, and inputs of a system during a specific period
- Based on the type of software that is tested, it checks for the behavioral changes of a system in a particular state or another state while maintaining the same inputs
- The test cases for this technique are created by checking the sequence of transitions and state or events among the inputs
- The whole set of test cases will have the traversal of the expected output values and all states

Source: Black Box Testing Techniques with Examples

Black-Box Testing: State Transition Testing

- **Example**: We need to perform black box testing for a login screen which allows a maximum of three attempts before the login is locked. Assuming that the user-id is correct, design the test suite.



Testcase #	Password for Trial			State
	Trial 1	Trial 2	Trial 3	*Golden*
(1)	Correct	X	X	Access
(2)	Wrong	Correct	X	Access
(3)	Wrong	Wrong	Correct	Access
(4)	Wrong	Wrong	Wrong	Locked

Source: Black Box Testing Techniques with Examples

Black-Box Testing: Decision Table Testing

- In some instances, the inputs combinations can become very complicated for tracking several possibilities
- Such complex situations rely on decision tables, as it offers the testers an organized view about the inputs combination and the expected output
- This technique is identical to the graph-based testing technique; the major difference is using tables instead of diagrams or graphs
- **Example 1**:

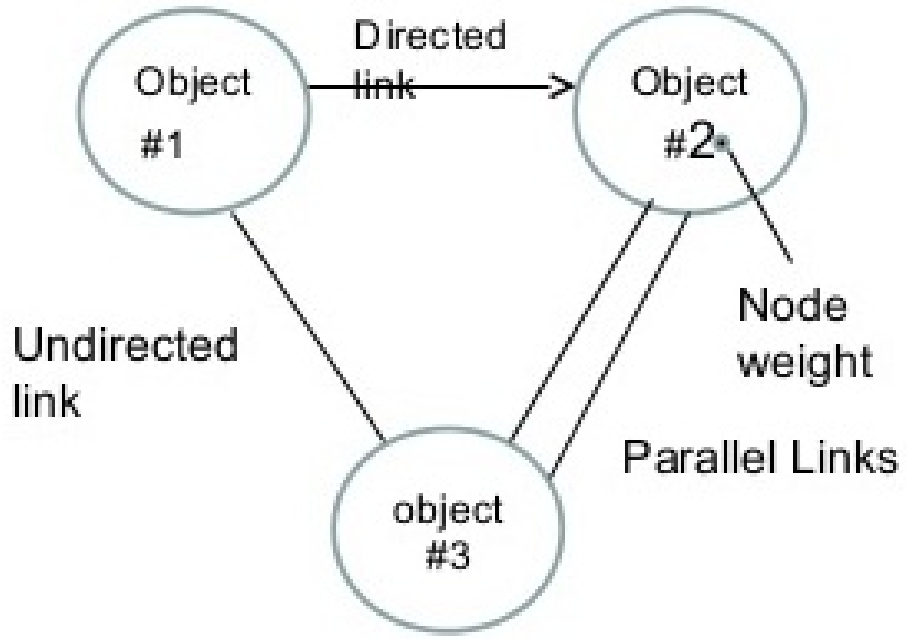
	Rule 1	Rule 2	Rule 3	Rule 4
Condition				
End of month	No	Yes	Yes	Yes
Salary Transferred	N/A	No	Yes	Yes
Provident fund	N/A	N/A	No	Yes
Action				
Income tax	No	No	Yes	Yes
Provident fund	No	No	No	Yes

- **Example 2**: States of various leaves in LMS Testplan 1

Source: Black Box Testing Techniques with Examples

Black-Box Testing: Graph-Based Testing

- This technique of Black box testing involves a graph drawing that depicts the link between the causes (inputs) and the effects (output), which trigger the effects
- This testing utilizes different combinations of output and inputs. It is a helpful technique to understand the software's functional performance, as it visualizes the flow of inputs and outputs in a lively fashion
- **Example**:



Source: Black Box Testing Techniques with Examples

Black-Box Testing: Error Guessing Technique

- This testing technique is capable of guessing the erroneous output and inputs to help the tester fix it easily
- It is solely based on judgment and perception of the earlier end user experience.

Source: Black Box Testing Techniques with Examples

Types of Black-Box Testing

- **Functional Testing**:
  This type of testing is useful for the testers in identifying the functional requirements of a software or system
- **Regression Testing**:
  This testing type is performed after the system maintenance procedure, upgrades or code fixes to know the impact of the new code over the earlier code
- **Non-Functional Testing**:
  This testing type is not connected with testing for any specific functionality but relates to non-functional parameters like usability, scalability, and performance

White-Box Testing Strategies

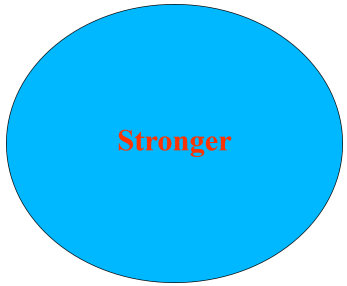
- Coverage-based
  - Design test cases to cover certain program elements
- Fault-based
  - Design test cases to expose some category of faults
- There exist several popular white-box testing methodologies
  - Coverage Based
    - Statement / Line Coverage
    - Function / Call Coverage
    - Branch Coverage
    - Condition Coverage
    - Path Coverage
    - MC/DC Coverage
  - Fault Based
    - Mutation Testing
    - Data Flow Testing

White Box Testing: Coverage-Based Testing vs Fault-Based Testing

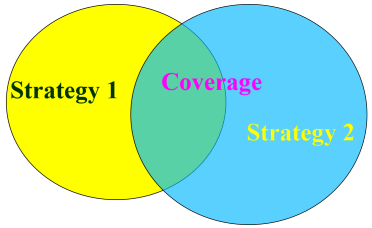
- Idea behind coverage-based testing
  - Design test cases so that certain program elements are executed (or covered)
  - Example: statement coverage, path coverage, etc.
- Idea behind fault-based testing
  - Design test cases that focus on discovering certain types of faults
  - Example: Mutation testing

Stronger, Weaker, and Complementary Testing

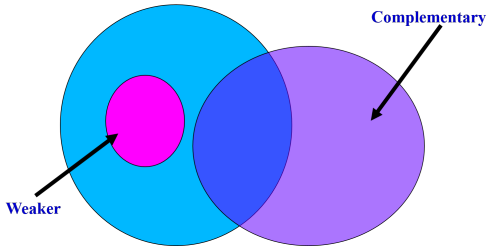
- Stronger and Weaker Testing: Test cases are a super-set of a weaker testing
  - A stronger testing covers at least all the elements of the elements covered by a weaker testing



- Complimentary Testing



- Stronger, Weaker & Complimentary Testing



White Box Testing: Statement / Line Coverage

- Statement coverage methodology
  - Design test cases so that every statement in the program is executed at least once
- The principal idea
  - Unless a statement is executed
  - We do not know if an error exists in that statement
- Observe that a statement behaves properly for one i/p
  - No guarantee that it will behave correctly for all i/p values
- **Line Coverage**
  - Most tools (like `gcov`, `lcov`) actually compute the coverage for the source lines
  - So it multiple statements are written in a single line, the coverage data may be inaccurate. For example, there are two statements in the following line that will be counted as one only

    ```
    x = 5; y = 6;
    ```

  - While the above may be okay, conditional statements should be placed in separate lines for proper statement coverage. For example, for

    ```
    if (x > y) max = x;
    max = y;
    ```

    we would never now if the statement `max = x;` has actually been executed or not
  - Single statement in every source line is a common coding guideline

White Box Testing: Statement / Line Coverage

- Coverage measurement
  - $\textit{Statement Coverage} = \frac{\#\textit{executed statements}}{\#\textit{statements}} * 100\%$
  - $\textit{Line Coverage} = \frac{\#\textit{executed lines}}{\#\textit{lines}} * 100\%$
  - Rationale: a fault in a statement can only be revealed by executing the faulty statement.

    Consider Euclid's GCD algorithm:

```
int f1(int x, int y) {
    while (x != y) {
        if (x>y)
            x = x - y;
        else y = y - x;
    }
    return x;
}
```

- By choosing the test set { `(x=3,y=3)`, `(x=4,y=3)`, `(x=3,y=4)` }, all statements are executed at least once
- Note that { `(x=4,y=3)` } or { `(x=3,y=4)` } itself will cover all lines due the the iterations of the `while` loop. However, it is customary to keep the analysis simple (mostly through a single flow) and include all of them in the test suite

White Box Testing: Function / Call Coverage

- Function Coverage methodology
  - Design test cases so that every function in the program is called at least once
  - This metric reports the call count of a function; it does not pay mind to the execution of the body of the function
  - It is thus generally useful as an initial assessment of a project's coverage, but higher-order metrics are generally required for more in-depth analysis
- Call Coverage methodology
  - Design test cases so that every function call in the program is executed at least once
  - In contrast to Function Coverage (which is about execution of the function itself), Call Coverage mandates that each call found in the code is executed at least once
  - 100% Function Coverage therefore does not imply 100% Call Coverage
  - The reverse is also not necessarily true either - there may be functions that are not called anywhere in the code (unused functions)
- Coverage measurement
  - $\textit{Function Coverage} = \frac{\#\textit{function called at least once}}{\#\textit{total functions}} * 100\%$
  - $\textit{Call Coverage} = \frac{\#\textit{call sites for functions called}}{\#\textit{total call sites of functions}} * 100\%$

White Box Testing: Branch Coverage

- Test cases are designed such that
  - Different branch conditions – are given true and false values in turn
- Branch testing guarantees statement coverage
  - A stronger testing compared to the statement coverage-based testing
  - Why?

```
1: cin >> x;
2: if (0 == x)
3:     x = x + 1;
4: y = 5;
```

Note that, {(x = 0)} covers lines {1, 2, 3, 4} while {(x = 1)} covers only lines {1, 2, 4}. So with {(x = 0)}, we get 100% statement coverage. But then, did we check for the jump from line 2 to 4 for the false condition? This condition did not get tested. So we need {(x = 0), (x = 1)} for 100% branch coverage and it obviously leads to 100% statement coverage.

How do we get 100% branch coverage for:

```
1: if (true)
2:     x = x + 1;
3: y = 5;
```

White Box Testing: Branch Coverage

- Example:

```
0: int f1(int x, int y) {
1:     while (x != y) {
2:         if (x > y)
3:             x = x - y;
4:         else y = y - x;
5:     }
6:     return x;
7: }
```

Branches: {1-2, 1-6, 2-3, 2-4, 3-5, 4-5, 5-1}

- Test cases for branch coverage can be
  - (x=3,y=3): {1-6}: {1, 6}
  - (x=4,y=3): {1-2, 2-3, 3-5, 5-1}: {1, 2, 3, 5}
  - (x=3,y=4): {1-2, 2-4, 4-5, 5-1}: {1, 2, 4, 5}
- *Adequacy criterion*: Each branch (in CFG) must be executed at least once
  - $\textit{Branch Coverage} = \frac{\#\textit{executed branches}}{\#\textit{branches}} * 100\%$
- Traversing all edges of a graph causes all nodes to be visited
  - So test suites that satisfy the branch adequacy criterion for a program also satisfy the statement adequacy criterion for the same program
- The converse is not true
  - A statement-adequate (or node-adequate) test suite may not be branch-adequate (edge-adequate)

White Box Testing: Condition Coverage

All Branches can still miss conditions

- Sample fault: missing operator (negation)

```
digit_high == 1 || digit_low == -1
```

- Branch adequacy criterion can be satisfied by varying only `digit_low`
  - The faulty sub-expression might not be tested
  - Even though we test both outcomes of the branch

White Box Testing: Condition Coverage

- Test cases are designed such that
  - Each component of a composite conditional expression
    - Given both true and false values
  - Consider the conditional expression
    - `((c1.and.c2).or.c3)`
  - Each of `c1`, `c2`, and `c3` are exercised at least once
    - That is, given true and false values
- Basic condition testing
  - Adequacy criterion: each basic condition must be executed at least once
- Coverage
  - $\textit{Condition Coverage} = \frac{\#\textit{truth values taken by all basic conditions}}{2*\#\textit{basic conditions}} * 100\%$

White Box Testing: Branch Testing

- Branch testing is the simplest condition testing strategy
  - Compound conditions appearing in different branch statements
    - Are given true and false values
  - Condition testing
    - Stronger testing than branch testing
  - Branch testing
    - Stronger than statement coverage testing

White Box Testing: Condition Coverage

- Consider a boolean expression having n components
  - For condition coverage we require 2^n test cases
- Condition coverage-based testing technique
  - Practical only if n (the number of component conditions) is small
- Commonly known as **Multiple Condition Coverage** (MCC), **Multicondition Coverage** and **Condition Combination Coverage**

White Box Testing: Modified Condition / Decision (MC/DC)

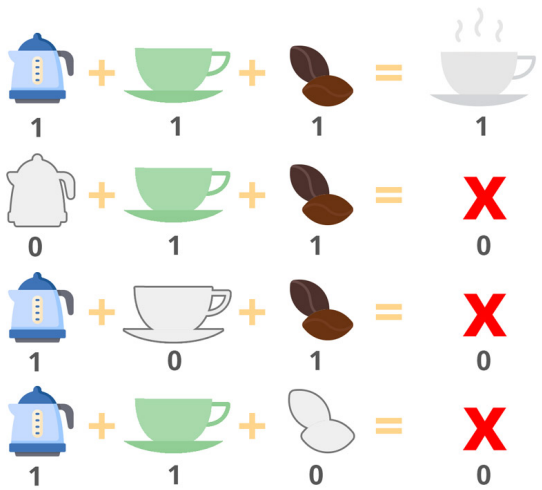
- **Motivation**
  - Effectively test important combinations of conditions, without exponential blowup in test suite size
  - *Important* combinations means: Each basic condition shown to independently affect the outcome of each decision
- **Requires**
  - For each basic condition C, two test cases obtained
  - Values of all evaluated conditions except C are the same
  - Compound condition as a whole evaluates to true for one and false for the other
- **MC/DC** stands for Modified Condition / Decision Coverage
- A kind of **Predicate Coverage** technique
  - Condition: Leaf level Boolean expression.
  - Decision: Controls the program flow
- **Main Idea**
  - Each condition must be shown to independently affect the outcome of a decision, that is, the outcome of a decision changes as a result of changing a single condition

White Box Testing: MC/DC in action: The Cup of Coffee Example

To make a cup of coffee, we would need ALL of the following: a kettle, a cup and coffee. If any of the components were missing, we would not be able to make our coffee. Or, to express this another way:

```
if (kettle && cup && coffee)
    return cup_of_coffee;
else
    return false;
```

Or to illustrate it visually:



	Inputs			Outputs
Test	Kettle	Mug	Coffee	Result
1	0	0	0	0
2	0	0	1	0
3	0	1	0	0
4	0	1	1	0
5	1	0	0	0
6	1	0	1	0
7	1	1	0	0
8	1	1	1	1

- **Tests 4 & 8 demonstrate that 'kettle' can independently affect the outcome**
- **Tests 6 & 8 demonstrate that 'mug' can independently affect the outcome**
- **Tests 7 & 8 demonstrate that 'coffee' can independently affect the outcome**

Source: What is MC/DC?

White Box Testing: MC/DC in action: Flow Check

A sample C/C++ function with a decision composed of OR and AND expressions illustrates the difference between Modified Condition/Decision Coverage and a coverage of all possible combinations as required by MCC:

```
bool isSilent(int *line1, int *line2)
{
    if ((!line1 || *line1 <= 0) && (!line2 || *line2 <= 0))
        return true;
    else
        return false;
}
```

Or to illustrate it visually:

Source: Modified Condition/Decision Coverage (MC/DC)

White Box Testing: Modified Condition / Decision (MC/DC)

Cond = `(((a || b) && c) || d) && e`

Condition Coverage Test Cases

Every condition in the decision has taken all possible outcomes at least once

#	a	b	c	d	e	Cond
0:	F	F	F	F	F	F
1:	F	F	F	F	T	F
2:	F	F	F	T	F	F
3:	F	F	F	T	T	T
4:	F	F	T	F	F	F
5:	F	F	T	F	T	F
6:	F	F	T	T	F	F
7:	F	F	T	T	T	T
8:	F	T	F	F	F	F
9:	F	T	F	F	T	F
10:	F	T	F	T	F	F
11:	F	T	F	T	T	T
12:	F	T	T	F	F	F
13:	F	T	T	F	T	T
14:	F	T	T	T	F	F
15:	F	T	T	T	T	T

#	a	b	c	d	e	Cond
16:	T	F	F	F	F	F
17:	T	F	F	F	T	F
18:	T	F	F	T	F	F
19:	T	F	F	T	T	T
20:	T	F	T	F	F	F
21:	T	F	T	F	T	T
22:	T	F	T	T	F	F
23:	T	F	T	T	T	T
24:	T	T	F	F	F	F
25:	T	T	F	F	T	F
26:	T	T	F	T	F	F
27:	T	T	F	T	T	T
28:	T	T	T	F	F	F
29:	T	T	T	F	T	T
30:	T	T	T	T	F	F
31:	T	T	T	T	T	T

MC/DC Coverage Test Cases

Every condition in the decision independently affects the decision's outcome

#	a	b	c	d	e	Cond	Cases
1:	T	X	T	X	T	T	21, 23, 29, 31
2:	F	T	T	X	T	T	13, 15
3:	T	X	F	T	T	T	19, 27
4:	T	X	T	X	F	F	20, 22, 28, 30
5:	T	X	F	F	X	F	16, 17, 24, 25
6:	F	F	X	F	X	F	0, 1, 4, 5

White Box Testing: Modified Condition / Decision (MC/DC)

- **MC/DC is**
  - basic condition coverage (C)
  - branch coverage (DC)
  - plus one additional condition (M): every condition must independently affect the decision's output
- It is subsumed by compound conditions and subsumes all other criteria discussed so far
  - stronger than statement and branch coverage
- A good balance of thoroughness and test size (and therefore widely used)
- MC/DC code coverage criterion is commonly used software testing. For example, DO-178C software development guidance in the aerospace industry requires MC/DC for the most critical software level (DAL A).
- **MC/DC vs. MCC**
  - MCC testing is characterized as number of tests $= 2^C$. In coffee example we have 3 conditions (kettle, cup and coffee) therefore tests $= 2^3 = 8$
  - MC/DC requires significantly fewer tests (C + 1). In coffee example we have 3 conditions, therefore $3 + 1 = 4$
  - In a real-world setting, most aerospace projects would include some decisions with 16 conditions or more. So the reduction would be from $2^16 = 65{,}536$ to $16 + 1 = 17$. That is, $65{,}519/65{,}536 = 99.97\%$

Source: What is MC/DC?

White Box Testing: Different Types of Code Coverage

Coverage Criteria	SC	DC	MC/DC	MCC
Every statement in the program has been invoked at least once	X			
Every point of entry and exit in the program has been invoked at least once		X	X	X
Every control statement (that is, branch-point) in the program has taken all possible outcomes (that is, branches) at least once		X	X	X
Every non-constant Boolean expression in the program has evaluated to both a True and False result		X	X	X
Every non-constant condition in a Boolean expression in the program has evaluated to both a True and False result			X	X
Every non-constant condition in a Boolean expression in the program has been shown to independently affect that expression's outcome			X	X
Every combination of condition outcomes within a decision has been invoked at least once				X

- **SC**: Statement Coverage
- **DC**: Decision Coverage
- **MC/DC**: Modified Condition / Decision Coverage
- **MCC**: Multiple Condition Coverage

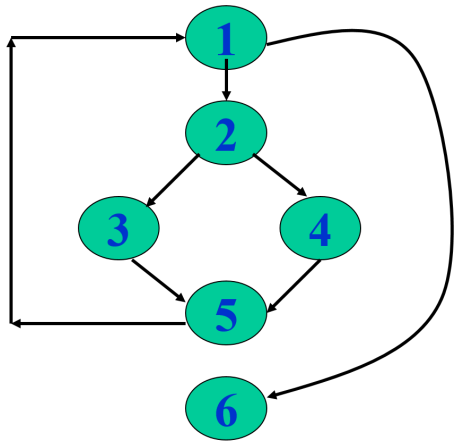
Source: What is MC/DC?

White Box Testing: Path Coverage

- Design test cases such that
  - All linearly independent paths in the program are executed at least once
- Defined in terms of
  - Control flow graph (CFG) of a program
- To understand the path coverage-based testing
  - we need to learn how to draw control flow graph of a program
- A control flow graph (CFG) describes
  - The sequence in which different instructions of a program get executed
  - The way control flows through the program
- Number all statements of a program
- Numbered statements
  - Represent nodes of control flow graph
- An edge from one node to another node exists
  - If execution of the statement representing the first node – Can result in transfer of control to the other node

White Box Testing: Path Coverage: CFG

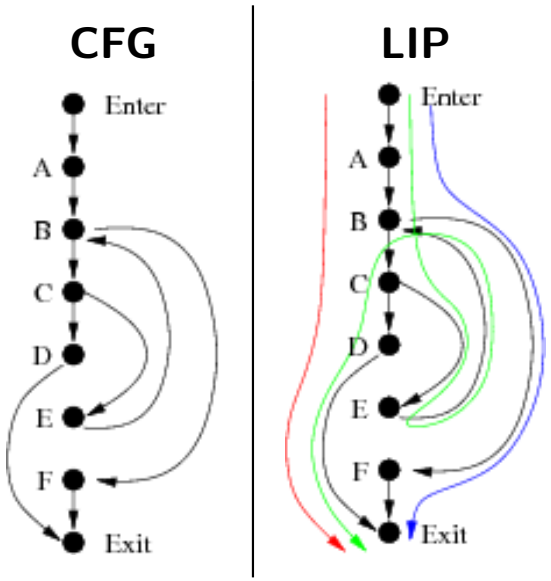

```
int f1(int x,int y) {
1 while (x != y){
2    if (x>y) then
3         x=x-y;
4    else y=y-x;
5 }
6 return x;        }
```



- A path through a program:
  - A node and edge sequence from the starting node to a terminal node of the control flow graph
  - There may be several terminal nodes for program
- Any path through the program that introduces at least one new edge (not included in any other independent path) is a *Linearly Independent Path* (LIP).
- A set of paths are linearly independent if none of them can be created by combining the others in some way.
  - It is straight forward to identify linearly independent paths of simple programs; but not so for complicated programs
- LIP in the above example:
  - 1,6
  - 1,2,3,5,1,6
  - 1,2,4,5,1,6

White Box Testing: Path Coverage: LIP

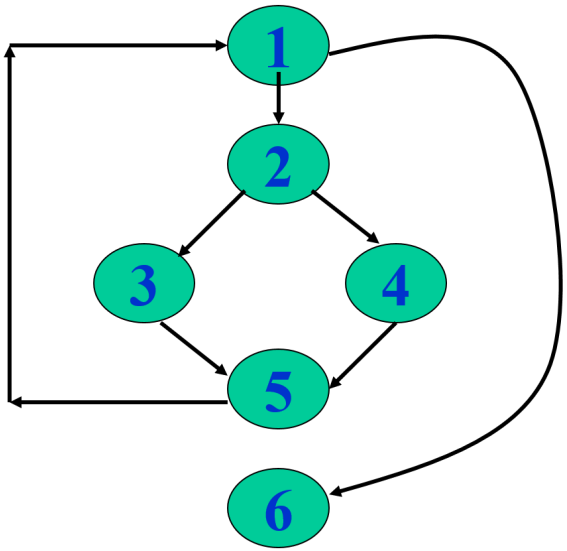

```
    public static boolean isPrime(int n) {
A       int i = 2;
B       while (i < n) {
C           if (n % i == 0) {
D               return false
            }
E           i++;
        }
F       return true;
    }
```



Source: The 'Linearly Independent Paths' Metric for Java

White Box Testing: Path Coverage: McCabe's Cyclomatic Metric

- An upper bound for the number of linearly independent paths of a program – a practical way of determining the maximum number of LIP
- Given a control flow graph G, cyclomatic complexity $V(G)$:
  - $V(G) = E - N + 2$
  - N is the number of nodes in G
  - E is the number of edges in G
- Alternately, inspect control flow graph to determine number of bounded areas (any region enclosed by a nodes and edge sequence) in the graph $V(G)$ = Total number of bounded areas + 1
- Example: Cyclomatic complexity $= 7 - 6 + 2 = 3 = 2 + 1$



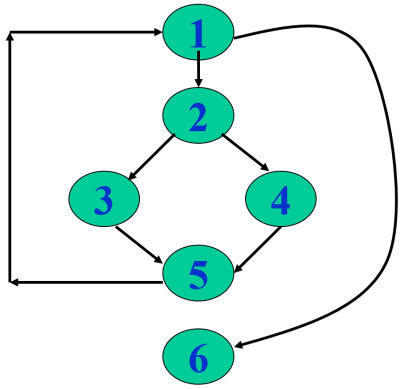
White Box Testing: Path Coverage: McCabe's Cyclomatic Metric

- McCabe's metric provides a quantitative measure of testing difficulty and the ultimate reliability
- Intuitively, number of bounded areas increases with the number of decision nodes and loops
- The first method of computing $V(G)$ is amenable to automation:
  - You can write a program which determines the number of nodes and edges of a graph
  - Applies the formula to find $V(G)$
- The cyclomatic complexity of a program provides:
  - A lower bound on the number of test cases to be designed
  - To guarantee coverage of all linearly independent paths
- A measure of the number of independent paths in a program
- Provides a lower bound
  - for the number of test cases for path coverage
- Knowing the number of test cases required
  - Does not make it any easier to derive the test cases
  - Only gives an indication of the minimum number of test cases required

White Box Testing: Path Coverage: Practical Path Testing

- Tester proposes initial set of test data using her experience & judgement
- A dynamic program analyzer is used to measures which parts of the program have been tested
- Result used to determine when to stop testing
- Derivation of Test Cases
  - Draw control flow graph.
  - Determine V(G).
  - Determine the set of linearly independent paths.
  - Prepare test cases to force execution along each path
- Example: Number of independent paths: 3

```
int f1(int x,int y) {
1 while (x != y){
2    if (x>y) then
3         x=x-y;
4    else y=y-x;
5 }
6 return x;        }
```

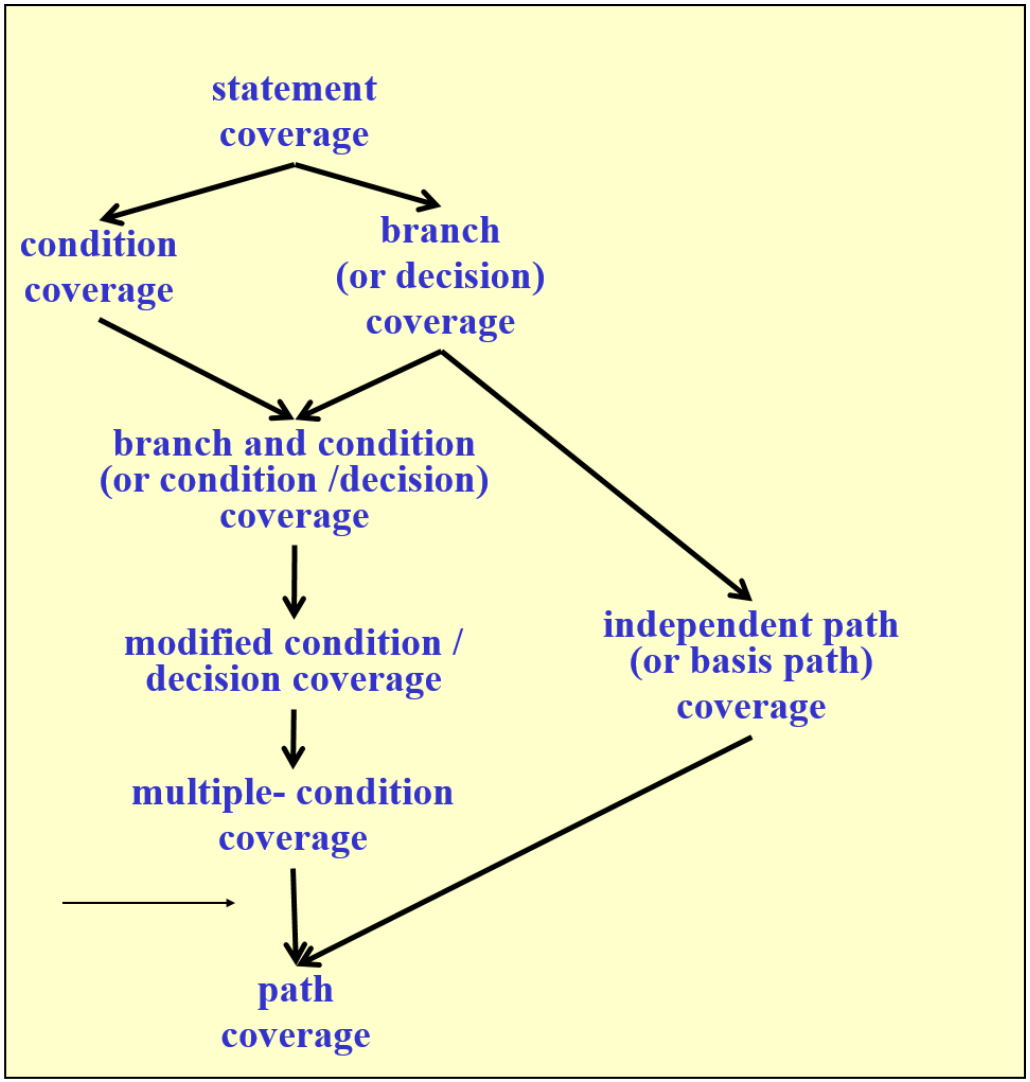


  - 1,6: test case (x=1, y=1)
  - 1,2,3,5,1,6: test case (x=1, y=2)
  - 1,2,4,5,1,6: test case (x=2, y=1)

White Box Testing: An Application of Cyclomatic Complexity

- Relationship exists between:
  - McCabe's metric
  - The number of errors existing in the code,
  - The time required to find and correct the errors.
- Cyclomatic complexity of a program:
  - Also indicates the psychological complexity of a program
  - Difficulty level of understanding the program
- From maintenance perspective,
  - Limit cyclomatic complexity of modules To some reasonable value.
- Good software development organizations:
  - Restrict cyclomatic complexity of functions to a maximum of ten or so

White-Box Testing: Coverage Testing Summary



White Box Testing: Mutation Testing

- The software is first tested:
  - Using an initial testing method based on white-box strategies we already discussed
- After the initial testing is complete
  - mutation testing is taken up
- The idea behind mutation testing
  - Make a few arbitrary small changes to a program at a time
- Good software development organizations:
  - Restrict cyclomatic complexity of functions to a maximum of ten or so
- Insert faults into a program:
  - Check whether the tests pick them up
  - Either validate or invalidate the tests
  - Example:

```
1: cin >> x;
2: if (0 == x)
3:     x = x + 1;
4: y = 5;
```

Note that, {(x = 0)} covers lines {1, 2, 3, 4} while {(x = 1)} covers only lines {1, 2, 4}. So with {(x = 0)}, we get 100% statement coverage. But then, did we check for the jump from line 2 to 4 for the false condition? This condition did not get tested. So we need {(x = 0), (x = 1)} for 100% branch coverage and it obviously leads to 100% statement coverage.

How do we get 100% branch coverage for:

```
1: if (true)
2:     x = x + 1;
3: y = 5;
```

White Box Testing: Mutation Testing

- Insert faults into a program:
  - Check whether the tests pick them up
  - Either validate or invalidate the tests
- Each time the program is changed
  - it is called a **mutated program**
  - the change is called a **mutant**
- A mutated program:
  - Tested against the full test suite of the program
- If there exists at least one test case in the test suite for which:
  - A mutant gives an incorrect result, then the mutant is said to be **dead**
- If a mutant remains **alive**:
  - even after all test cases have been exhausted, the test suite is enhanced to kill the mutant
- The process of generation and killing of mutants
  - can be automated by pre-defining a set of primitive changes that can be applied to the program
- The primitive changes can be
  - Deleting a statement
  - Altering an arithmetic operator
  - Changing the value of a constant
  - Changing a data type, etc.

White Box Testing: Mutation Testing: Error Seeding

- How Many Errors are Still Remaining?
- Seed the code with some known errors:
  - Artificial errors are introduced into the program
  - Check how many of the seeded errors are detected during testing
- Let
  - N be the total number of errors in the system and n of these errors be found by testing
  - S be the total number of seeded errors and s of the seeded errors be found during testing
  - $\frac{n}{N} = \frac{s}{S}$
  - $N = S * \frac{n}{s}$
  - Remaining defects:
$$N - n = n * \frac{S - s}{s}$$
- Example:
  - 100 errors were introduced
  - 90 of these errors were found during testing
  - 50 other errors were also found
  - Remaining errors:
$$50 * \frac{100 - 90}{90} = 6$$
- The kind of seeded errors should match closely with existing errors
  - However, it is difficult to predict the types of errors that exist
- Categories of remaining errors
  - even after all test cases have been exhausted, the test suite is enhanced to kill the mutant

White Box Testing: Data Flow Testing

Data Flow Testing is a type of structural testing. It is a method that is used to find the test paths of a program according to the locations of definitions and uses of variables in the program

- It is concerned with:
  - Statements where variables receive values
  - Statements where these values are used or referenced
- To illustrate the approach of data flow testing, assume that each statement in the program assigned a unique statement number. For a statement number S:
  - DEF(S) = {X | statement S contains a definition of X}
  - USE(S)= {X | statement S contains a use of X}
  - Example: 1: a = b; DEF(1) = {a}, USE(1) = {b}
  - Example: 2: a = a + b; DEF(2) = {a}, USE(2) = {a,b}
- If a statement is a loop or if condition then its DEF set is empty and USE set is based on the condition of statement s.
- Data Flow Testing uses the control flow graph to find the situations that can interrupt the flow of the program.
- Reference or define anomalies in the flow of the data are detected at the time of associations between values and variables. These anomalies are:
  - A variable is defined but not used or referenced
  - A variable is used but never defined
  - A variable is defined twice before it is used

White Box Testing: Data Flow Testing

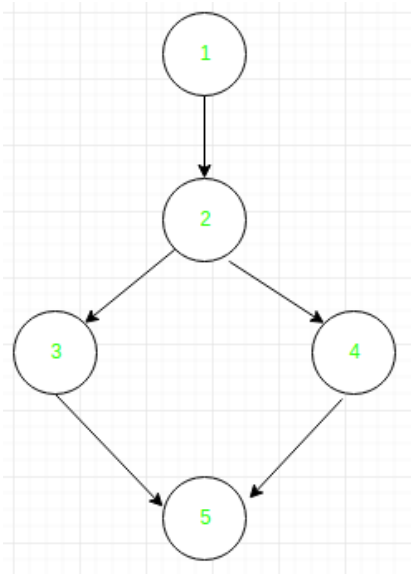
- **Advantages** of Data Flow Testing
  - To find a variable that is used but never defined
  - To find a variable that is defined but never used
  - To find a variable that is defined multiple times before it is use
  - Deallocating a variable before it is used
- **Disadvantages** of Data Flow Testing
  - Time consuming and costly process
  - Requires knowledge of programming languages

White Box Testing: Data Flow Testing

- Example:

```
1. read x, y;
2. if (x > y)
3. a = x + 1
   else
4. a = y - 1
5. print a;
```

- CFG



- Define/use of variables

Variable	Defined at node	Used at node
x	1	2, 3
y	1	2, 4
a	3, 4	5

Source: Data Flow Testing

Data Object Categories

- (d) Defined, Created, Initialized. An object (like variable) is defined when it:
  - appears in a data declaration
  - is assigned a new value
  - is a file that has been opened
  - is dynamically allocated
  - ...
- (k) Killed, Undefined, Released
- (u) Used:
  - (c) Used in a calculation
  - (p) Used in a predicate
  - An object is used when it is part of a computation or a predicate
    - A variable is used for a computation (c) when it appears on the RHS (sometimes even the LHS in case of array indices) of an assignment statement
    - A variable is used in a predicate (p) when it appears directly in that predicate

Source: Topics in Software Dynamic White-box Testing: Part 2: Data-flow Testing

White Box Testing: Data Flow-Based Testing: Definition and Use


```
1.  read (x, y);
2.  z = x + 2;
3.  if (z < y)
4.      w = x + 1;
    else
5.      y = y + 1;
6.  print (x, y, w, z);
```

Def	C-use	P-use
x, y		
z	x	
		z, y
w	x	
y	y	
	x, y, w, z	

- To find a variable that is used but never defined
- To find a variable that is defined but never used
- To find a variable that is defined multiple times before it is use
- Deallocating a variable before it is used

Processes for Development

Development involves a number of processes:

- Design & Coding (discussed in Modules 2 & 4)
- Debugging
- Issue / Bug Tracking
- Testing
- Documentation
- Release (discussed as a part of Maintenance)
- Version Control (discussed as a part of Maintenance)

Debugging Processes: Basic Methods

- **Brute-Force Method**
  - Least efficient method
  - Program is loaded with print statements to know intermediate values
  - Hope that some of printed values will help identify the error
- **Symbolic Debugger** (Common with IDEs)
  - Break point (control & data)
  - Single step, step-in, step-over etc. to control instruction
  - Watch points
  - Edit & Debug
- **Backtracking**
  - Trace back on source from the bug point until the error is found
  - As the number of source lines to be traced back increases, the number of potential backward paths increases
  - Becomes unmanageably large for complex programs
- **Cause-Elimination Method**
  - Make a list of possible causes for the error symptom
  - Conduct test to eliminate each
  - Software Fault Tree analysis

Debugging Processes: Program Slicing

- **Program Slicing**: *Refinement of Backtracking*
  - Program Slicing takes a group of statements testing particular test conditions or cases and that may affect a value at a particular point
  - *Static Slicing*
    - A static slice of a program contains all statements that may affect the value of a variable at any point for any arbitrary execution of the program
    - Static slices are generally larger
    - It considers every possible execution of the program
  - *Dynamic Slicing*
    - A dynamic slice of a program contains all the statements that actually affect the value of a variable at any point for a particular execution of the program
    - Dynamic slices are generally smaller
    - Considers only a particular execution of the program

Code	**Static Slice** `sum`	**Dynamic Slice** `sum, n = 22`

`int z = 10;`
`int n;`
`cin >> n;`
`int sum = 0;`
`if (n > 10)`
`  sum = sum + n;`
`else`
`  sum = sum - n;`
`cout << "Hey";`
	`int n;`
	`cin >> n;`
	`int sum = 0;`
	`if (n > 10)`
	`  sum = sum + n;`
	`else`
	`  sum = sum - n;`
		`int n;`
		`cin >> n;`
		`int sum = 0;`
		`if (n > 10)`
		`  sum = sum + n;`

Debugging Processes: Debugging with AOP

- **Debugging with AOP**
  - Aspect-Oriented Programming (AOP) is a programming paradigm which complements Object-Oriented Programming (OOP) by separating concerns of a software application to improve modularization
  - The *Separation of Concerns* (SoC) aims for making a software easier to maintain by grouping features and behavior into manageable parts which all have a specific purpose and business to take care of
  - Using aspects, therefore, we can separate the *Debugging Concerns* from the core program logic and manage them in separate classes
  - Such approach removes a lot of clutter of debug-specific codes under `_DEBUG` flag
  - Support for aspects is available for most common languages like
    - AspectJ for Java
    - AspectC++ for C++
    - AspectC for C
    - python-aspectlib for Python
  - Logging is a common use of aspects in every language which can greatly help debugging. We have an example:

Debugging Processes: Debugging with AOP

Logging without AOP:

```
namespace Examples\Forum\Domain\Model;
use Examples\Forum\Logger\ApplicationLoggerInterface;

class Forum {
    /**
     * @Flow\Inject
     * @var ApplicationLoggerInterface
     */
    protected $applicationLogger;
    /**
     * Delete a forum post and log operation
     */
    public function deletePost(Post $post): void {
            $this->applicationLogger->log('Removing post ' . $post->getTitle(), LOG_INFO);
            $this->posts->remove($post);
    }
}
```

- If you have to do this in a lot of places, the logging would become a part of you domain model logic
- You would have to inject all the logging dependencies in your models
- Since logging is nothing that a domain model should care about, this is an example of a non-functional requirement and a so-called *cross-cutting concern*
- With AOP, the code inside your model would know nothing about logging
- It will just concentrate on the business logic

Debugging Processes: Debugging with AOP

Logging with AOP (your class):

```
namespace Examples\Forum\Domain\Model;
class Forum {
    /** Delete a forum post
     */
    public function deletePost(Post $post): void {
            $this->posts->remove($post);
    }
}
```

Logging with AOP (aspect):

```
namespace Examples\Forum\Logging;
use Examples\Forum\Logger\ApplicationLoggerInterface;
use Neos\Flow\AOP\JoinPointInterface;
/**
 * @Flow\Aspect
 */
class LoggingAspect {
    /**
     * @Flow\Inject
     * @var ApplicationLoggerInterface
     */
    protected $applicationLogger;
    /** Log a message if a post is deleted
     * @Flow\Before("method(Examples\Forum\Domain\Model\Forum->deletePost())")
     */
    public function logDeletePost(JoinPointInterface $joinPoint): void {
            $post = $joinPoint->getMethodArgument('post');
            $this->applicationLogger->log('Removing post ' . $post->getTitle(), LOG_INFO);
    }
}
```

Debugging Processes: Debugging with AOP

- The logging is now done from an AOP aspect
- It is just a class tagged with `@aspect` and a method that implements the specific action, an before advice
- The expression after the `@before` tag tells the AOP framework to which method calls this action should be applied
- It is called *pointcut* expression and has many possibilities, even for complex scenarios
- As you can see the advice has full access to the actual method call, the *join point*, with information about the class, the method and method arguments

Debugging Processes: Debugging Guidelines

- **Debugging Guidelines**
  - Debugging requires a thorough understanding of program design
  - Debugging may sometimes require full redesign of the system
  - A common mistake novice programmers often make:
    - Not fixing the error but the error symptoms
  - Be aware of the possibility:
    - An error correction may introduce new errors
  - After every round of error-fixing:
    - Regression testing must be carried out

- **Debugging and AI**
  - *AI in Debugging*
    - Can AI Find Bugs in Your Code?, Feb-2020
    - AI-powered bug spray: Facebook's new tool SapFix debugs code with AI, Sep-2018
    - A Proposal for an Intelligent Debugging Assistant, Jan-1998
  - *Debugging in AI*
    - Microsoft makes AI debugging and visualization tool TensorWatch open source, Jun-2019
    - Google AI expert explains the challenge of debugging machine-learning systems, 2016

Debugging Life Cycle

1. [*Reporting*] Customer / QA reports a bug on the issue tracker
2. [*Reproduction*] Reproduce the bug from the issue report
   - The bug may be reported just as a symptom. In addition, it may have test case/s (better)
   - If the bug cannot be reproduced contact the creator of the issue
3. [*Localization*] Isolate the source of the bug
   - Find the files / functions / lines / statements etc. that is responsible for the bug
4. [*RCA : Root Cause Analysis*] Identify the cause of the bug, like:
   - *Implementation Errors*: Coding, Logic, Algorithm, Resource, Concurrency etc.
   - *Design Errors*: Functionality was wrongly understood, incompletely specified etc.
   - *Test Plan Errors*: What was missed out in the test plan / suite?
   - *Documentation / Other Errors*: Is the user using the software correctly? Say, API errors
   - [*RCA*] Is it a repeat bug? What was incomplete in the last fix?
   - [*RCA*] Why was the bug not caught in the in-house QA?
   - [*RCA*] How to guarantee similar issues will not repeat?
5. [*Fix Plan*] Determine a fix for the bug
   - Prepare design and test plan
6. [*Fix & Test*] Apply the fix and test it
   - Code and test: Dev Test clean & Regression clean
   - Code Review
7. [*Track & Version*] Update Bug Tracker and tag Code / Test Suite Versions
   - Check-in code with proper version
   - Update bug tracker with fix and release information
8. [*Release*] Release the bug-fixed code to customer / QA

Issue (Bug) Tracking

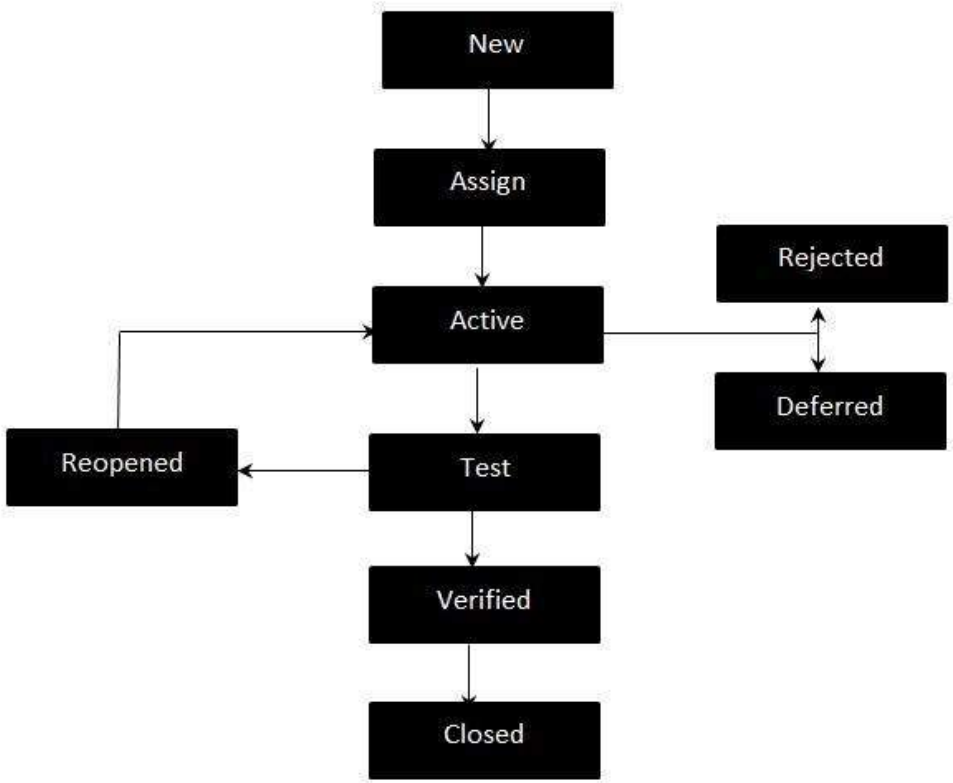
- An Issue Tracking System (aka *ITS*, *Trouble Ticket System*, *Support Ticket*, *Request Management*, or *Incident Ticket System*) is a tool that manages and maintains lists of issues
  - Bugzilla: A robust, featureful and mature Bug Tracking System: Open and free
  - Jira Software: Bug Tracking System from Atlassian: Commercial, advanced and SDLC linked
- Issue tracking systems
  - are generally used in collaborative settings, especially in large or distributed collaborations, or
  - employed by individuals as part of a time management or personal productivity regime
- These tools encompass:
  - implementing a centralized issue registry
  - resource allocation
  - time accounting
  - priority management
  - workflow
- These tools help find, record, and track bugs in software
  - It is critical that all team members are able to find and record bugs, and , assign them to the right members at the right time
  - An issue tracking tool gives a single view of all items in the backlog, regardless of whether the work item is a bug or a task related to new feature development
  - Having a single source of truth of all issue types helps teams prioritize against their big picture goals, while continually delivering value to their customers
- **Issue tracking is a life-cycle phenomenon closely tied with the Workflow of an organization**
- **Modern Issue Trackers integrates closely with SDLC**

Defect Life Cycle: Workflow Automation

Defect States [*Debug State*]

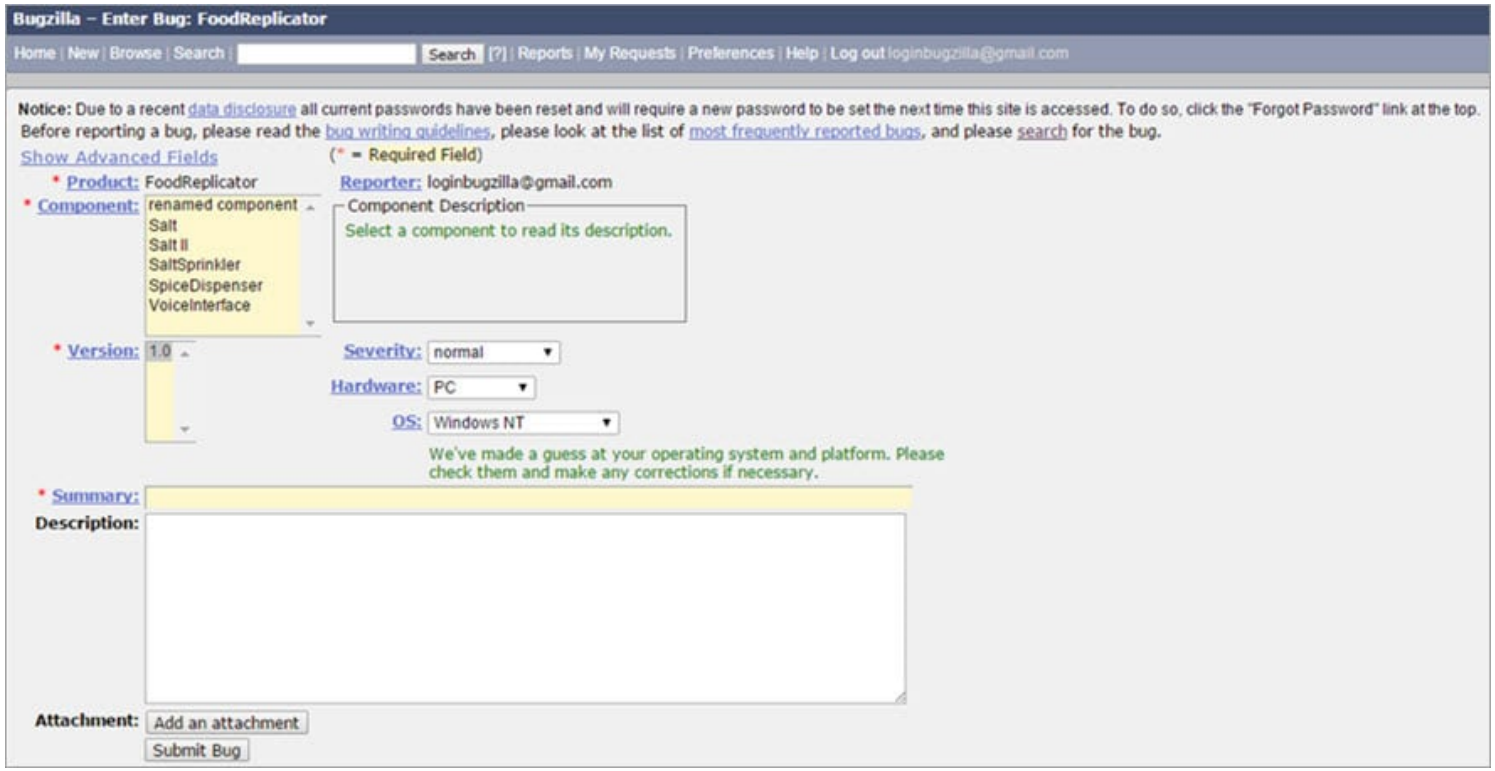
1. [*New*] A new defect is raised
2. [*Assign*] Assigned to a developer. [*Reporting*]
3. [*Active*] Defect is being addressed by the developer and investigation is under progress. May go to: [*Deferred*] or [*Rejected*]. [*Reproduction*], [*Localization*], [*RCA*], [*Fix Plan*] & [*Fix & Test*]
4. [*Test*] Defect is fixed and ready for testing [*Fix & Test*] & [*Track & Version*]
5. [*Verified*] The Defect that is retested and the test has been verified by QA [*Fix & Test*] & [*Release*]
6. [*Closed*] Defect closed after the QA retesting. May be closed if [*Duplicate*] or [*NOT a defect*] [*Release*]
7. [*Reopened*] When the defect is NOT fixed, QA reopens/reactivates the defect. [*Reporting*]
8. [*Deferred*] When a defect cannot be addressed in that particular cycle it is deferred to future release
9. [*Rejected*] A defect may be rejected if [*Duplicate*], [*NOT a defect*], or [*Non Reproducible*]

Defect State Transitions



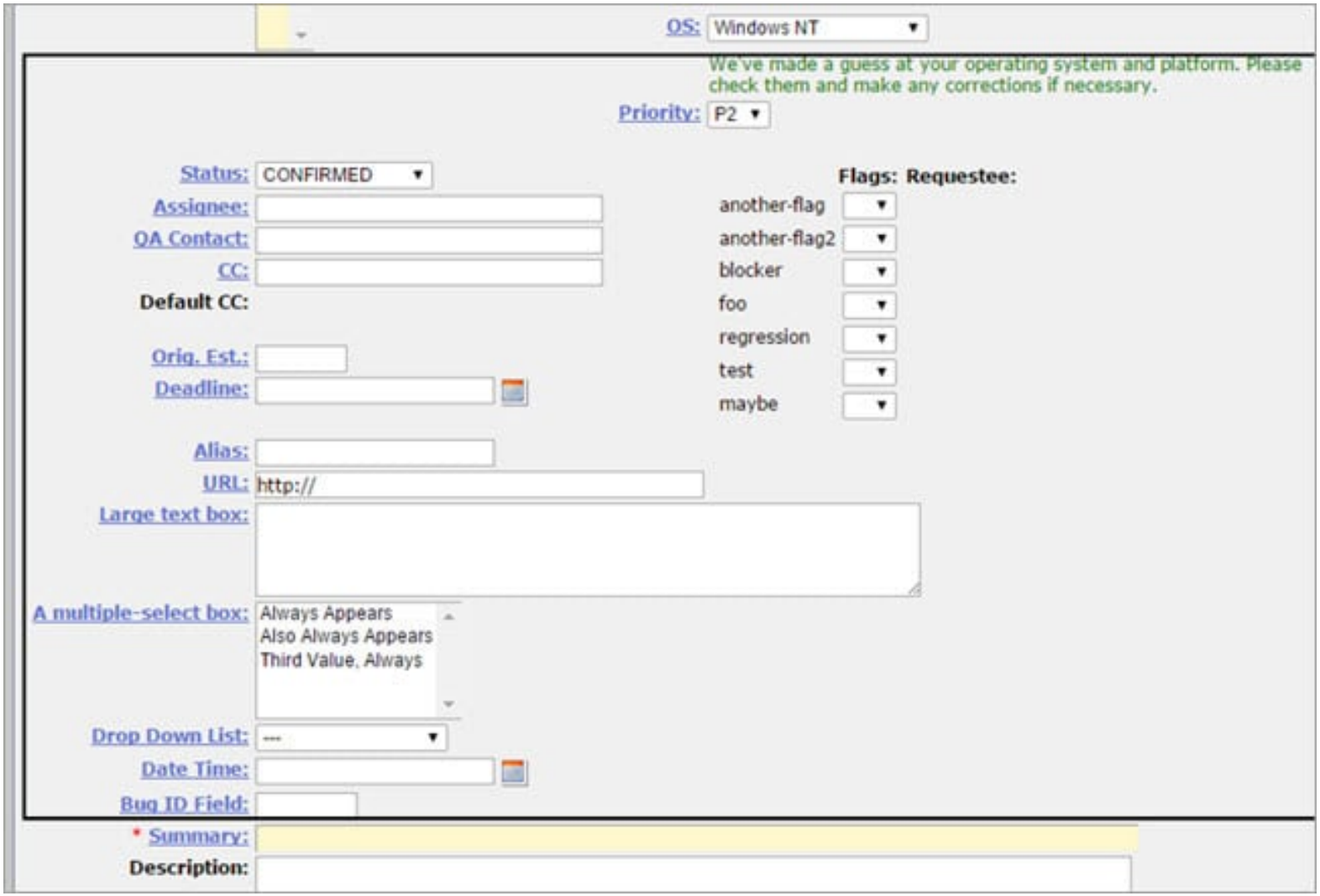
Bug Tracking: Bugzilla

- Enter Bug for FoodReplicator screen
  - Product – Which we selected on the previous page
  - Component – One or more product components based on the use or functionality etc.
  - Version – Version of the product in which the bug was detected
  - Reporter – Email id of the person logging the bug
  - Severity – Severity of the bug
  - Hardware and OS – Machine details from which bug is logged
  - Summary – To provide a summary for the bug
  - Description – A complete description of the bug
  - Add an Attachment, Submit a Bug – To submit the bug and create a Bug ID



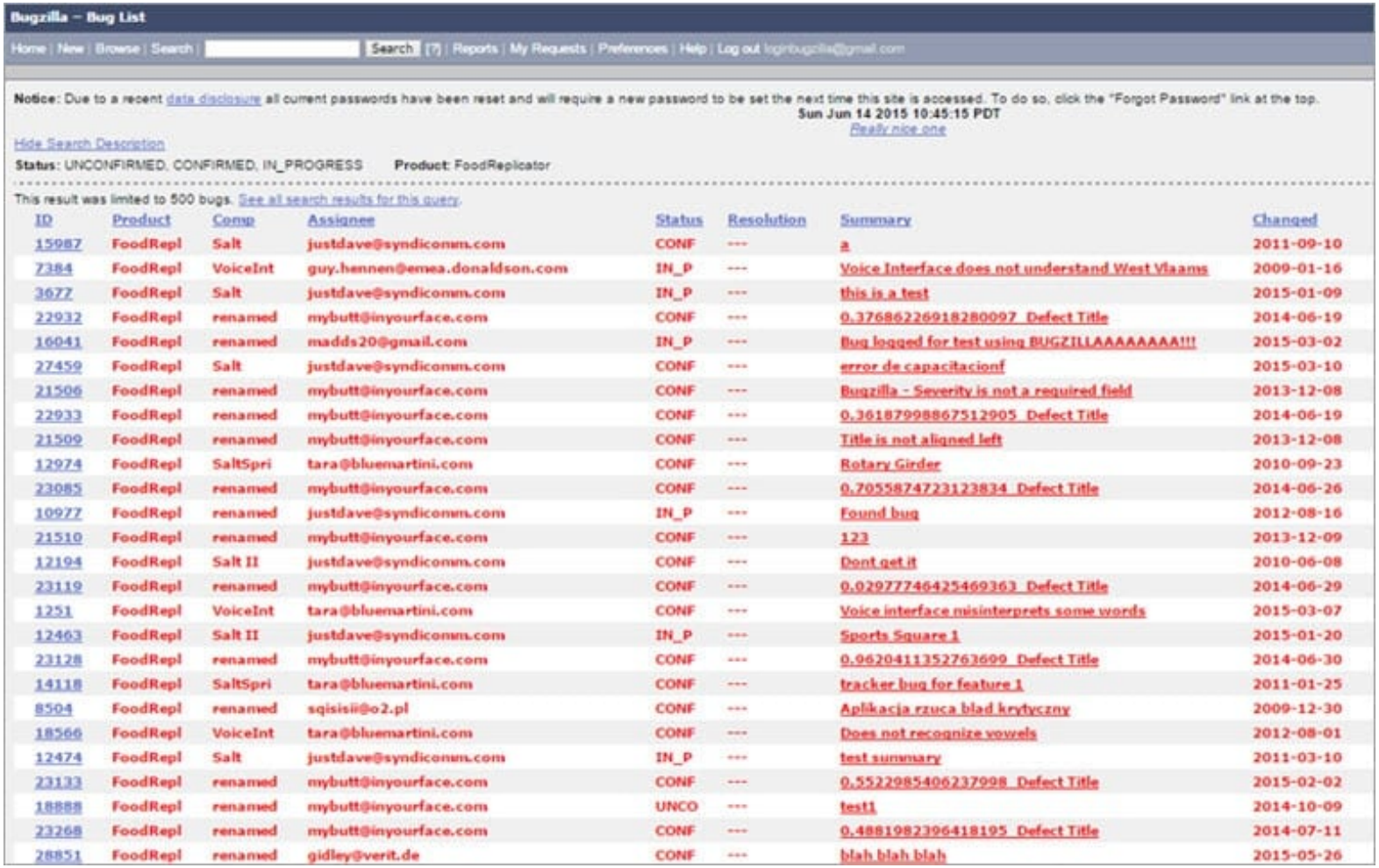
Bug Tracking: Bugzilla

- More fields



Bug Tracking: Bugzilla

- Searching an Issue



Bugzilla – Bug List

Home | New | Browse | Search | Search [?] | Reports | My Requests | Preferences | Help | Log out

Notice: Due to a recent data disclosure all current passwords have been reset and will require a new password to be set the next time this site is accessed. To do so, click the "Forgot Password" link at the top.

Sun Jun 14 2015 10:45:15 PDT

Really nice one

Hide Search Description

Status: UNCONFIRMED, CONFIRMED, IN_PROGRESS Product: FoodReplicator

This result was limited to 500 bugs. See all search results for this query.

ID	Product	Comp	Assignee	Status	Resolution	Summary	Changed
15987	FoodRepl	Salt	justdave@syndicomm.com	CONF	---	a	2011-09-10
7384	FoodRepl	VoiceInt	guy.hennen@emea.donaldson.com	IN_P	---	Voice Interface does not understand West Vlaams	2009-01-16
3677	FoodRepl	Salt	justdave@syndicomm.com	IN_P	---	this is a test	2015-01-09
22932	FoodRepl	renamed	mybutt@inyourface.com	CONF	---	0.37686226918280097 Defect Title	2014-06-19
16041	FoodRepl	renamed	madds20@gmail.com	IN_P	---	Bug logged for test using BUGZILLAAAAAAAA!!!	2015-03-02
27459	FoodRepl	Salt	justdave@syndicomm.com	CONF	---	error de capacitaciонf	2015-03-10
21506	FoodRepl	renamed	mybutt@inyourface.com	CONF	---	Bugzilla - Severity is not a required field	2013-12-08
22933	FoodRepl	renamed	mybutt@inyourface.com	CONF	---	0.36187998867512905 Defect Title	2014-06-19
21509	FoodRepl	renamed	mybutt@inyourface.com	CONF	---	Title is not aligned left	2013-12-08
12974	FoodRepl	SaltSpri	tara@bluemartini.com	CONF	---	Rotary Girder	2010-09-23
23085	FoodRepl	renamed	mybutt@inyourface.com	CONF	---	0.7055874723123834 Defect Title	2014-06-26
10977	FoodRepl	renamed	justdave@syndicomm.com	IN_P	---	Found bug	2012-08-16
21510	FoodRepl	renamed	mybutt@inyourface.com	CONF	---	123	2013-12-09
12194	FoodRepl	Salt II	justdave@syndicomm.com	CONF	---	Dont get it	2010-06-08
23119	FoodRepl	renamed	mybutt@inyourface.com	CONF	---	0.02977746425469363 Defect Title	2014-06-29
1251	FoodRepl	VoiceInt	tara@bluemartini.com	CONF	---	Voice interface misinterprets some words	2015-03-07
12463	FoodRepl	Salt II	justdave@syndicomm.com	IN_P	---	Sports Square 1	2015-01-20
23128	FoodRepl	renamed	mybutt@inyourface.com	CONF	---	0.9620411352763699 Defect Title	2014-06-30
14118	FoodRepl	SaltSpri	tara@bluemartini.com	CONF	---	tracker bug for feature 1	2011-01-25
8504	FoodRepl	renamed	sqisisi@o2.pl	CONF	---	Aplikacja rzuca blad krytyczny	2009-12-30
18566	FoodRepl	VoiceInt	tara@bluemartini.com	CONF	---	Does not recognize vowels	2012-08-01
12474	FoodRepl	Salt	justdave@syndicomm.com	IN_P	---	test summary	2011-03-10
23133	FoodRepl	renamed	mybutt@inyourface.com	CONF	---	0.5522985406237998 Defect Title	2015-02-02
18888	FoodRepl	renamed	mybutt@inyourface.com	UNCO	---	test1	2014-10-09
23268	FoodRepl	renamed	mybutt@inyourface.com	CONF	---	0.4881982396418195 Defect Title	2014-07-11
28851	FoodRepl	renamed	gidley@verit.de	CONF	---	blah blah blah	2015-05-26

Source: Bugzilla Tutorial: Defect Management Tool Hands-On Tutorial

Testing Processes

- The aim of testing is to identify all defects in a software product
- However, in practice even after thorough testing, one cannot guarantee that the software is error-free
- The input data domain of most software products is very large
  - It is not practical to test the software exhaustively with each input
- Testing however exposes many errors
  - Testing provides a practical way of reducing defects in a system
  - Increases the users' confidence in the system
- Testing
  - Is a continual process
  - Needs significant automation (especially to repeats tests already done when new stuff is added). Usually achieved through
    - **Regression Testing**
  - Has to happen at all phases and all levels of abstraction – both for development and for maintenance
- Software products are tested at three levels
  - **Unit testing**
  - **Integration testing**
  - **System testing**

Regression Testing

- **Regression**[1] **testing** is re-running functional and non-functional tests to ensure that previously developed and tested software still performs after a change
  - If not, that would be called a regression
  - The software *Regresses*
- Regression testing
  - Is usually done through auotmated processes after each change to the system after each bug fix
  - Ensures that no new bug has been introduced due to the change or the bug fix – the new system's performance is at least as good as the old system
  - Is always used during incremental system development
- Regression test is:
  - Required before every code check-in (no regression, that is)
  - Used at every level for every kind of test
  - Most powerful tool for quality control for software development and maintenance

[1] a return to a former or less developed state

Regression Testing: Positive & Negative Test Cases

	Execution Outcome	
Type of Test	**Successful**	**Unsuccessful**
Positive Case (Success)	PASS	FAIL
Negative Case (Failure)	FAIL	PASS

Regression outcome is typically shown by:

$$\frac{\#\ of\ PASS\ cases}{\#\ of\ PASS + FAIL\ (total)\ cases} * 100\%$$

How to do Regression Testing? Approach

- We need to first debug the code to identify the bugs
- Once the bugs are identified and fixed, then the regression testing is done by selecting relevant test cases from the test suite that covers both modified and affected parts of the code
- Regression Testing can be carried out using the following strategies:
  - Retest All
    - Needed for all version major / minor releases
  - Regression Test Selection
    - Test cases which have frequent defects
    - Functionalities which are more visible to the users
    - Test cases which verify core features of the product
    - Test cases of Functionalities which has undergone more and recent changes
    - All Integration Test Cases & all Complex Test Cases
    - Boundary value test cases
    - Samples of Successful test cases & Failure test cases
  - Prioritization of Test Cases
    - Depending on business impact, critical & frequently used functionalities
    - *General prioritization*: Beneficial on subsequent versions
    - *Version-specific prioritization*: Beneficial for a particular version of the software
  - Hybrid
    - This technique is a hybrid of regression test selection and test case prioritization

Source: What is Regression Testing? Definition, Test Cases (Example)

How to do Regression Testing? Automation

Regression Testing relies on intense automation to reduce menial manual testing efforts and costs

- Scripting for Regression Testing
  - Scripting is the biggest handle for Regression Automation
  - Unix: Shell, Bash, sed, awk etc.
  - Windows: VBScript
  - Perl
  - Python
- Regression Testing Tools
  - Selenium: Open Source portable framework for automating web applications (browser-based regression). It provides a playback tool for authoring functional tests without the need to learn a test scripting language (Selenium IDE)
  - Micro Focus Unified Functional Testing (UFT One) (formerly known as QuickTest Professional (QTP)): An tool to automate functional and regression test cases. UFT One Intelligent test automation with embedded AI-based capabilities that accelerates testing across desktop, web, mobile, mainframe, composite and packaged enterprise-grade apps.
  - IBM Rational Functional Tester (RFT): An automated functional testing and regression testing tool. This software provides automated testing capabilities for functional, regression, GUI and data-driven testing. It supports a range of applications, such as web-based, .Net, Java, Siebel, SAP, terminal emulator-based applications, PowerBuilder, Ajax, Adobe Flex, Dojo Toolkit, GEF, Adobe PDF documents, zSeries, iSeries and pSeries.

Source: What is Regression Testing? Definition, Test Cases (Example)

Retesting and Regression Testing

- **Retesting** means testing the functionality or bug again to ensure the code is fixed
  - If it is not fixed, defect needs to be re-opened
  - If fixed, defect is closed
- **Regression testing** means testing your software application when it undergoes a code change to ensure that the new code has not affected other parts of the software.

Regression Testing	Retesting
Confirms that a recent program or *code change has not adversely affected existing features*	Confirms that the *test cases that failed in the final execution are passing after the defects are fixed*
Ensures that new *code changes do not have any side effects* to existing functionalities	Is done *on the basis of the Defect fixes*
Defect verification **is not** in scope	*Defect verification* **is** in scope
May be carried out *parallel with Re-testing*	Must be carried out *before regression testing*
May be automated *Manual Testing is expensive*	*Cannot automate the test cases for Retesting*
Generic testing	*Planned testing*
Checks for *unexpected side-effects*	Makes sure that *the original fault has been corrected*
Done for any *mandatory modification or changes in an existing project*	Executes a defect with *the same data and the same environment with different inputs with a new build*
Test cases for **can be** *obtained* from the *functional specification, user tutorials and manuals, and defect reports in regards to corrected problems*	Test cases for retesting **cannot be** *obtained before start testing*

Source: Difference Between Retesting and Regression Testing

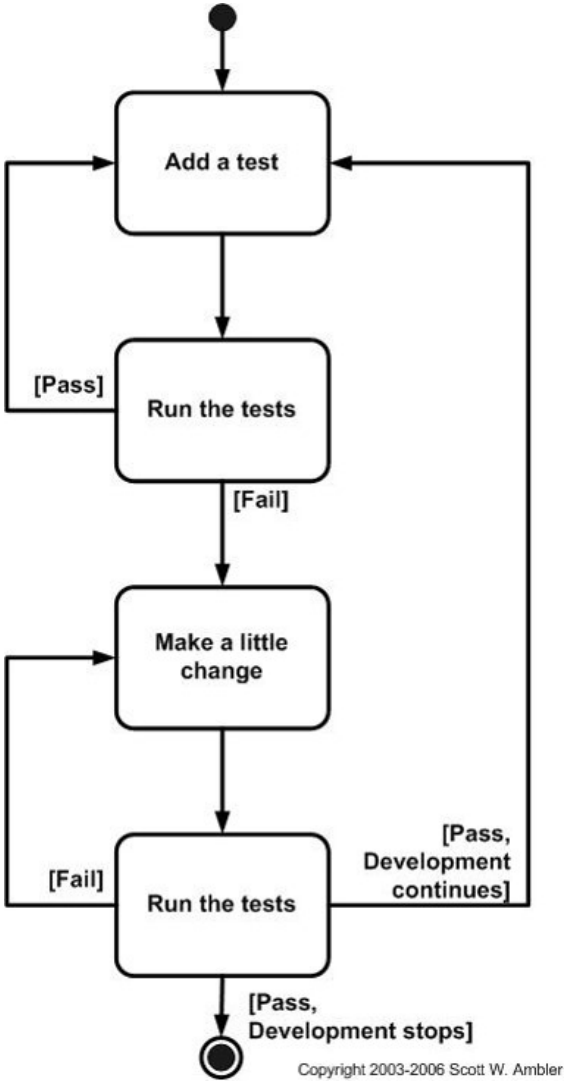
Regression Test Suite

- To repeat old tests and runs
- Test Case with Golden
  - Unit Tests
  - API / Application Tests
  - Directed Tests, Corner Cases, Customer Tests
  - Random & Huge Tests
  - Performance Tests
    - Time
    - Resources: Low Memory Tests
  - Coverage Tests
  - ...
- Folder Structure
  - Uniformity names of test case files: Critical for automation scripts
- Run script

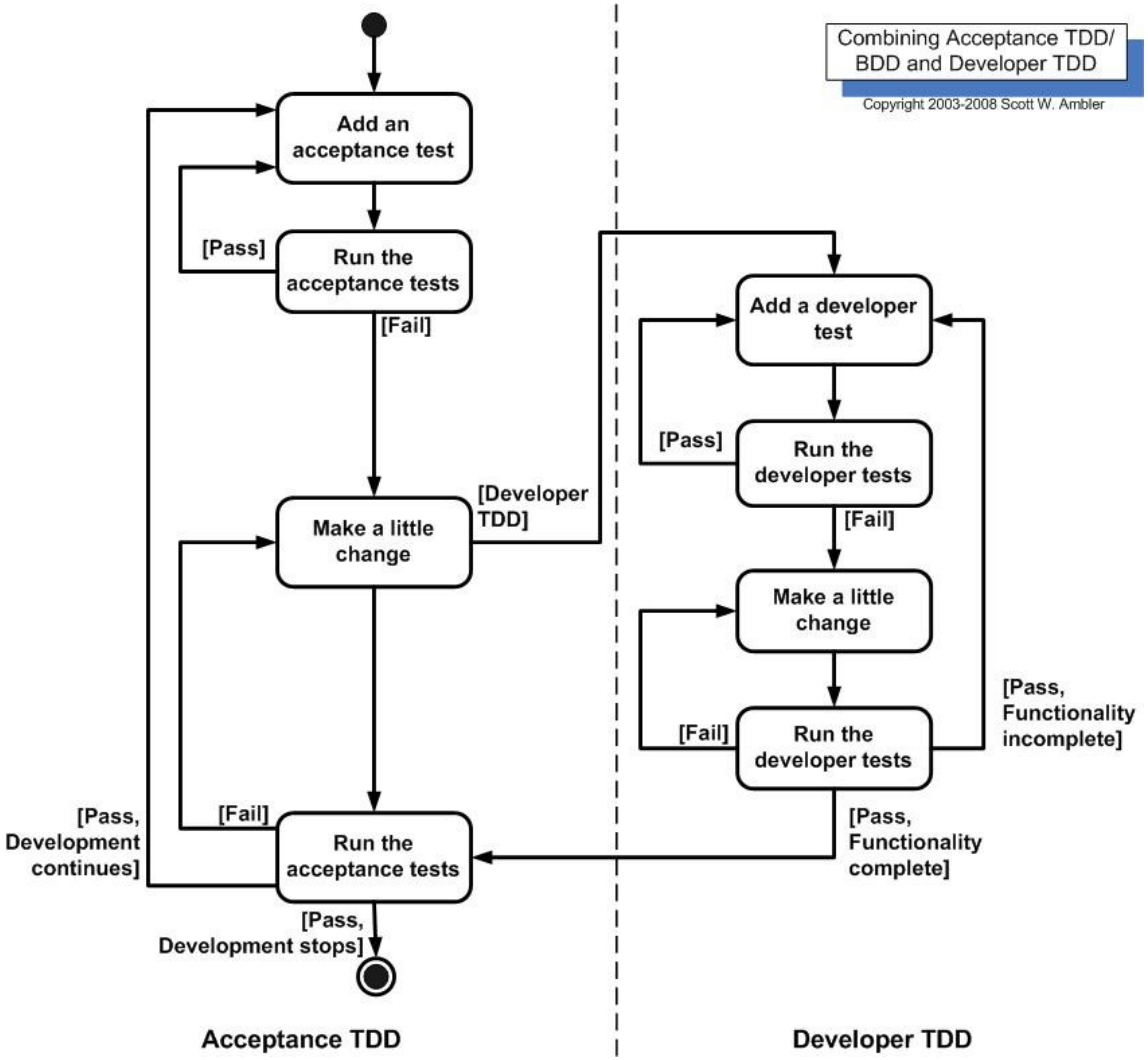
Unit Testing

- During unit testing, modules are tested in isolation
  - If all modules were to be tested together, it may not be easy to determine which module has the error
- Unit testing reduces debugging effort several folds
  - Programmers carry out unit testing immediately after they complete the coding of a module
- Unit testing drives development in Test-Driven Development (TDD)

TDD



TDD



Unit Testing

- For a class attach a (test) unit (typically JUnit in Java or CPPUnit in C++)) that tests the class
- D Language provides specific support for unit testing
- Unit testing is a main feature of D
- Unit testing in D
  - Unit tests can be added to a class - they are run upon program start-up
  - Aids in verifying that class implementations weren't inadvertently broken
  - Unit tests is a part of the code for a class
  - Creating tests is a part of the development process

Integration Testing

- After different modules of a system have been coded and unit tested:
  - Modules are integrated in steps according to an integration plan
  - Partially integrated system is tested at each integration step
- System Testing
  - Validate a fully developed system against its requirements
- Develop the integration plan by examining the structure chart:
  - **Big bang approach**
  - **Top-down approach**
  - **Bottom-up approach**
  - **Mixed approach**

Integration Testing

- **Big Bang** is the simplest integration testing approach
  - All the modules are simply put together and tested
  - This technique is used only for very small systems
  - If an error is found:
    - It is very difficult to localize the error
    - The error may potentially belong to any of the modules being integrated
  - Debugging errors found during big bang integration testing are very expensive to fix
- **Bottom-up** Integration Testing Integrate and test the bottom level modules first. A disadvantage of bottom-up testing:
  - when the system is made up of a large number of small subsystems
  - This extreme case corresponds to the big bang approach.
- **Top-down** Integration Testing Top-down integration testing starts with the main routine
  - and one or two subordinate routines in the system
  - After the top-level 'skeleton' has been tested
    - immediate subordinate modules of the 'skeleton' are combined with it and tested
- **Mixed** Integration Testing Mixed (or sandwiched) integration testing
  - Uses both top-down and bottom-up testing approaches
  - Most common approach

Integration Testing

- In top-down approach
  - testing waits till all top-level modules are coded and unit tested
- In bottom-up approach
  - testing can start only after bottom level modules are ready

System Testing

System tests are designed to validate a fully developed system

- To assure that it meets its requirements
- Functional requirements are validated through functional tests
- Non-functional requirements validated through performance tests

Testing	Release	Features
Alpha	Alpha	• All functionality has been implemented • Reasonable testing has been done – *Regression passes with known exceptions* • *Testing is carried out by the test team within the company* • No preview expected from *real* users yet
Beta	Beta	• All functionality has been thoroughly tested • Extensive testing has been done – *Regression passes with some (documented) exceptions* • Releases made to friendly customers (or non-developer internal groups). Or beta programs launched • *Testing performed by a select group of friendly customers* • Must include *real* users of a system
Acceptance	FCS	• FCS: **First Customer Shipment** • Company has gained fair confidence on the quality – *Regression is clean with rare (documented) exceptions* • Customer will use this release now till (Minor) bug fix releases are done or new (Major) version is produced • *Testing performed by the customer to determine whether the system should be accepted or rejected*

Test Summary Report

- Generated towards the end of testing phase
- Covers each subsystem
  - A summary of tests which have been applied to the subsystem
- Specifies
  - how many tests have been applied to a subsystem
  - how many tests have been successful
  - how many have been unsuccessful, and the degree to which they have been unsuccessful
    - whether a test was an outright failure
    - whether some expected results of the test were actually observed

System Testing: Selective Tests

- Performance Testing
  - Time, Peak Memory, Average Memory, Response Time etc.
- Stress / Endurance Testing
  - Impose a range of abnormal and even illegal input conditions
- Volume Testing
  - Large data sets, data structure etc.
- Configuration Testing
  - Scale-able configurations, Varied requirements
- Compatibility Testing
  - H/w & S/w compatibility: 32-bit on 64-bit, little / big endian-ness, etc.
- Recovery Testing
  - How does the system recover after an error (exceptions)? Failed Power, N/w connection
- Maintenance Testing
  - Regular tests over life cycle, testing versions, sources of problems
- Documentation Testing
  - Required documents exist & consistent: User / Maintenance Guides, Technical Documents
- Usability Testing
  - UI tests: Display screens, messages, report formats, navigation & selection problems
- Environmental Testing
  - Tolerance for: Heat, Humidity, Chemicals, Electric / Magnetic fields, Power quality, etc.

Performance Testing

- Addresses non-functional requirements
  - May sometimes involve testing hardware and software together
  - There are several categories of performance testing
- Typical performances are:
  - Time
  - Peak Memory
  - Average Memory
  - Response Time

Stress / Endurance Testing

- Evaluates system performance when stressed for short periods of time
- Stress tests are black box tests
  - Designed to impose a range of abnormal and illegal i/p conditions
  - So as to stress the capabilities of the software
  - Often stress tests test for the endurance of the internal data structures (like size of a stack)
- If the requirements is to handle a specified number of users, or devices
  - Stress testing evaluates system performance when all users or devices are busy simultaneously
- If an operating system is supposed to support 15 multi-programmed jobs
  - The system is stressed by attempting to run 15 or more jobs simultaneously
- A real-time system might be tested
  - To determine the effect of simultaneous arrival of several high-priority interrupts
- Stress testing usually involves an element of time or size
  - Such as the number of records transferred per unit time
  - The maximum number of users active at any time, input data size, etc

Volume Testing

- Addresses handling large amounts of data in the system
  - Whether data structures (e.g. queues, stacks, arrays, etc.) are large enough to handle all possible situations
  - Fields, records, and files are stressed to check if their size can accommodate all possible data volumes

Configuration Testing

- Analyze system behavior
  - in various hardware and software configurations specified in the requirements
  - sometimes systems are built in various configurations for different users
  - for instance, a minimal system may serve a single user, other configurations for additional users

Compatibility Testing

- These tests are needed when the system interfaces with other systems
  - Check whether the interface functions as required
  - For example, if a 32-bit release works on a 64-bit platform
- For example, if a system is to communicate with a large database system to retrieve information:
  - A compatibility test examines speed and accuracy of retrieval

Recovery Testing

- These tests check response to
  - Presence of faults or to the loss of data, power, devices, or services
  - Subject system to loss of resources
    - Check if the system recovers properly
    - For example, a net payment fails after the payer has been debited and before the payee has been credited

Maintenance Testing

- Diagnostic tools and procedures
  - help find source of problems.
  - It may be required to supply
    - memory maps
    - diagnostic programs
    - traces of transactions,
    - circuit diagrams, etc
- Verify that
  - all required artefacts for maintenance exist
  - they function properly
- For example, if MS Office crashes it asks for sending some system information to MS. These are meant for remote debugging and fix

Documentation Testing

- Check that required documents exist and are consistent
  - user guides
  - maintenance guides,
  - technical documents
- Sometimes requirements specify
  - Format and audience of specific documents
  - Documents are evaluated for compliance
- Keeping documents in sync with the code changes is a major challenge
- Documentation Tests must ascertain such gaps
- It is advised to use in-code documentation to generate help on the fly using
  - Doxygen
  - Javadoc

Usability Tests

- All aspects of user interfaces are tested
  - Display screens
  - messages
  - report formats
  - navigation and selection problems

Environmental Tests

- These tests check the system's ability to perform at the installation site
- Requirements might include tolerance for
  - heat
  - humidity
  - chemical presence
  - portability
  - electrical or magnetic fields
  - disruption of power, etc

Documentation Processes

All software documentation can be divided into two main categories:

- **Product Documentation**
- **Process Documentation**

The main difference between process and product documentation is that the first one records the process of development and the second one describes the product that is being developed.

- **Product Documentation** describes the product that is being developed and provides instructions on how to perform various tasks with it. There are two main types of product documentation:
  - *System documentation* represents documents that describe the system itself and its parts. It includes requirements documents, design decisions, architecture descriptions, test plan, program source code, and FAQs
    - Tools like `Doxygen` may be used for program source code documentation from program annotated with Javadoc commenting styleand tags like (@param)
    - On-line documentation browser (HTML) and/or an off-line reference manual (LaTeX)
    - Extracted directly from the sources – keeps the documentation consistent
    - Extract the code structure from undocumented source files.
    - Extracts dependency graphs, inheritance diagrams, and collaboration diagram
    - Creates nice HTML documentation
  - *User documentation* covers manuals that are mainly prepared for end-users of the product and system administrators. User documentation includes tutorials, user guides, troubleshooting manuals, installation, and reference manuals

Source: Technical Documentation in Software Development: Types, Best Practices, and Tools

Documentation Processes

- **Process Documentation** represents all documents produced during development and maintenance that describe the process. The common examples of
  - *Process-related documents* are standards, project documentation, such as project plans, test schedules, reports, meeting notes, or even business correspondence

Source: Technical Documentation in Software Development: Types, Best Practices, and Tools

Processes for Maintenance

Maintenance involves a number of processes:

- Debugging (discussed as a part of Development)
- Issue Tracking (discussed as a part of Development)
- Testing (discussed as a part of Development)
- Documentation (discussed as a part of Development)
- Release
- Version Control

Release Process

- A software may have varied forms of releases:
  - Major Release
    - Major new features, architecture changes, product components
    - Full, standalone product build
  - Minor Release
    - May include significant new features beyond previous minor / major version
    - Full, standalone product build
  - Patch Release
    - In response to a specific Software Failure
    - May only be a set of files, not a full, standalone product build
    - Released ad-hoc, as soon as available
    - Recommended to all customers to prevent a critical failure
    - Should be merged in the next major / minor version
  - Hot-Bug Fix Release
    - In response to a specific customer-reported Software Failure
    - May only be a set of files, not a full, standalone product build
    - Released ad-hoc, as soon as available, via Tech Support only
    - Typically created for show-stopper issues
    - Should be merged in the next major / minor version
  - Other Releases: Like new platfom
- Companies typically follow
  - A Release Numbering scheme
  - A Release Guidelines
  - A relation to Level of Support for various release

Release Process

- Numbering conventions are followed for releases:
  - Typically it is three part

    4.2.1

    MAJOR *Minor* patch

  - Examples:
    - major.minor[.build[.revision]] (example: 1.2.12.102)
    - major.minor[.patch[.build]] (example: 1.4.3.5249)
  - Release numbering is sequential; companies may skip numbers too
    - Internet Explorer 5 from 5.1 to 5.5
    - Adobe Photoshop 5 to 5.5
  - There is no standard in numbering – companies choose and document their schemes
    - A different approach is to use the major and minor numbers, along with an alphanumeric string denoting the release type, for example, *alpha* (a), *beta* (b), or *release candidate* (rc).
    - A software release train using this approach might look like 0.5, 0.6, 0.7, 0.8, 0.9 → 1.0b1, 1.0b2 (with some fixes), 1.0b3 (with more fixes) → 1.0rc1 (which, if it is stable enough), 1.0rc2 (if more bugs are found) → 1.0
    - It is a common practice in this scheme to lock-out new features and breaking changes during the release candidate phases and for some teams, even betas are lock-down to bug fixes only, in order to ensure convergence on the target release

Source: Software Versioning

Version Control Process

- **Version Control** (a part of **Software Configuration Management (SCM)**) is a class of systems responsible for managing changes to computer programs, documents, large web sites, or other collections of information
  - Changes are usually identified by a number or letter code, termed the *revision number*, *revision level*, or simply *revision*
  - For example, an initial set of files is *revision 1*
  - When the first change is made, the resulting set is *revision 2*, and so on.
  - Each revision is associated with a timestamp and the person making the change
  - Revisions can be compared, restored, and with some types of files, merged
- Version Control Tools: Git, CVS, SVN
- Branching is the way to manage versions

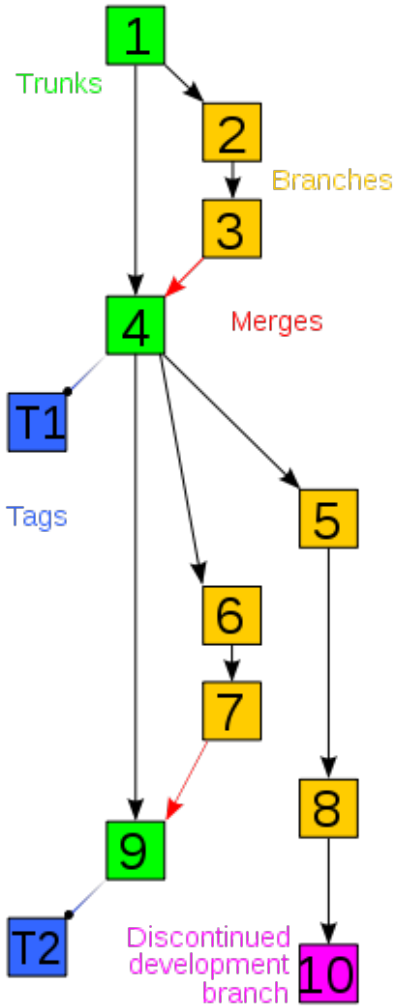
Source: Version Control

Version Control Process

- **Branching**, in version control and SCM, is the duplication of an object under version control (such as a source code file or a directory tree)
- Each object can thereafter be modified separately and in parallel so that the objects become different.
- In this context the objects are called branches.
- The users of the version control system can branch any branch
- The originating branch is the *Parent Branch*
- *Child Branches* are branches that have a parent; a branch without a parent is referred to as the *Trunk* or the *Mainline*
- Branching also generally implies the ability to later *merge or integrate changes back onto the parent branch*
- Often the changes are merged back to the trunk, even if this is not the parent branch
- A branch not intended to be merged is usually called a *fork*
- A *Revision Tag* is a textual label that can be associated with a specific revision of a project maintained by a version control system

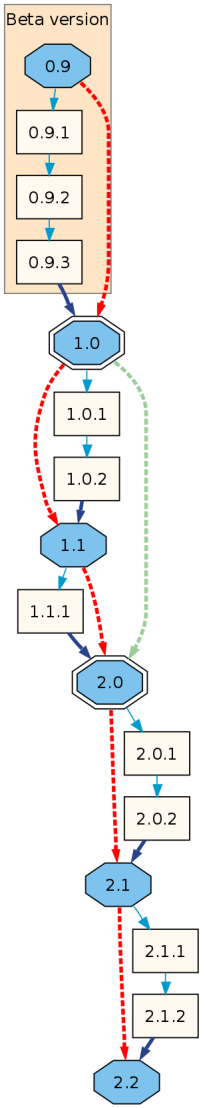
Source: Version Control

Branching Example



Source: Version Control

Branching Example



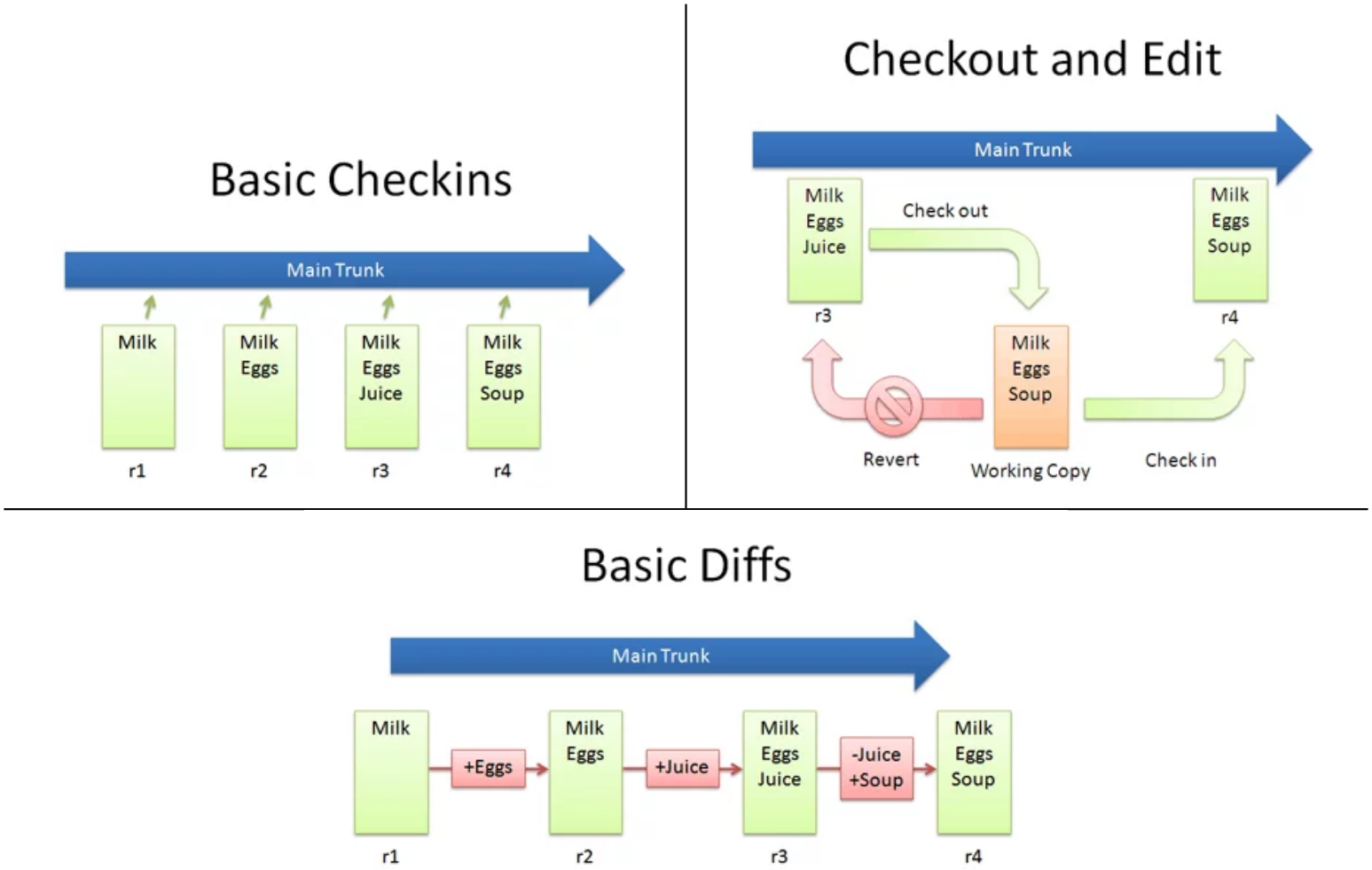
Source: Software Versioning

Working with Version Control

- **Basic Setup**
  - **Repository (repo)**: The database storing the files
  - **Server**: The computer storing the repo
  - **Client**: The computer connecting to the repo
  - **Working Set/Working Copy**: Your local directory of files, where you make changes
  - **Trunk/Main**: The primary location for code in the repo
- **Basic Actions**
  - **Add**: Put a file into the repo for the first time, that is, begin tracking it with VSC
  - **Revision**: What version a file is on (v1, v2, v3, etc.)
  - **Head**: The latest revision in the repo
  - **Check out**: Download a file from the repo
  - **Check in**: Upload a file to the repository (if it has changed). The file gets a new revision number, and people can *check out* the latest one
  - **Checkin Message**: A short message describing what was changed
  - **Changelog/History**: A list of changes made to a file since it was created
  - **Update/Sync**: Synchronize your files with the latest from the repository
  - **Revert**: Throw away your local changes and reload the latest version from the repository
- **Advanced Actions**
  - **Branch**: Create a separate copy of a file/folder for private use (bug fixing, testing, etc)
  - **Diff/Change/Delta**: Finding the differences between two files
  - **Merge (or patch)**: Apply the changes from one file to another, to bring it up-to-date. For example, you can merge features from one branch into another
  - **Conflict**: When pending changes to a file contradict each other (both cannot be applied)
  - **Resolve**: Fixing the changes that contradict each other and checking in the correct version
  - **Locking**: Taking control of a file so nobody else can edit it until you unlock it
  - **Breaking the lock**: Forcibly unlocking a file so you can edit it
  - **Check out for edit**: Checking out an *editable* version of a file

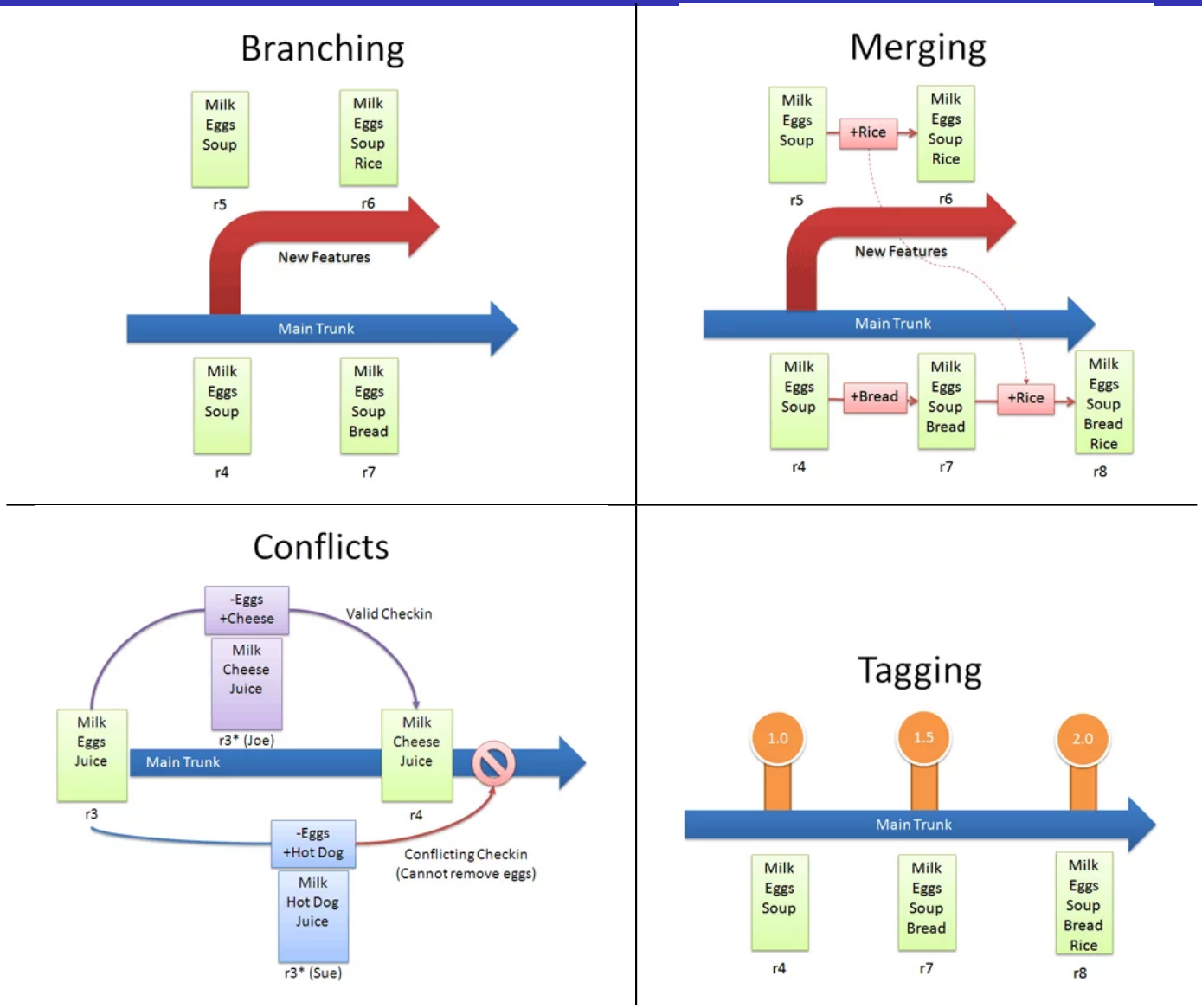
Source: A Visual Guide to Version Control

Working with Version Control



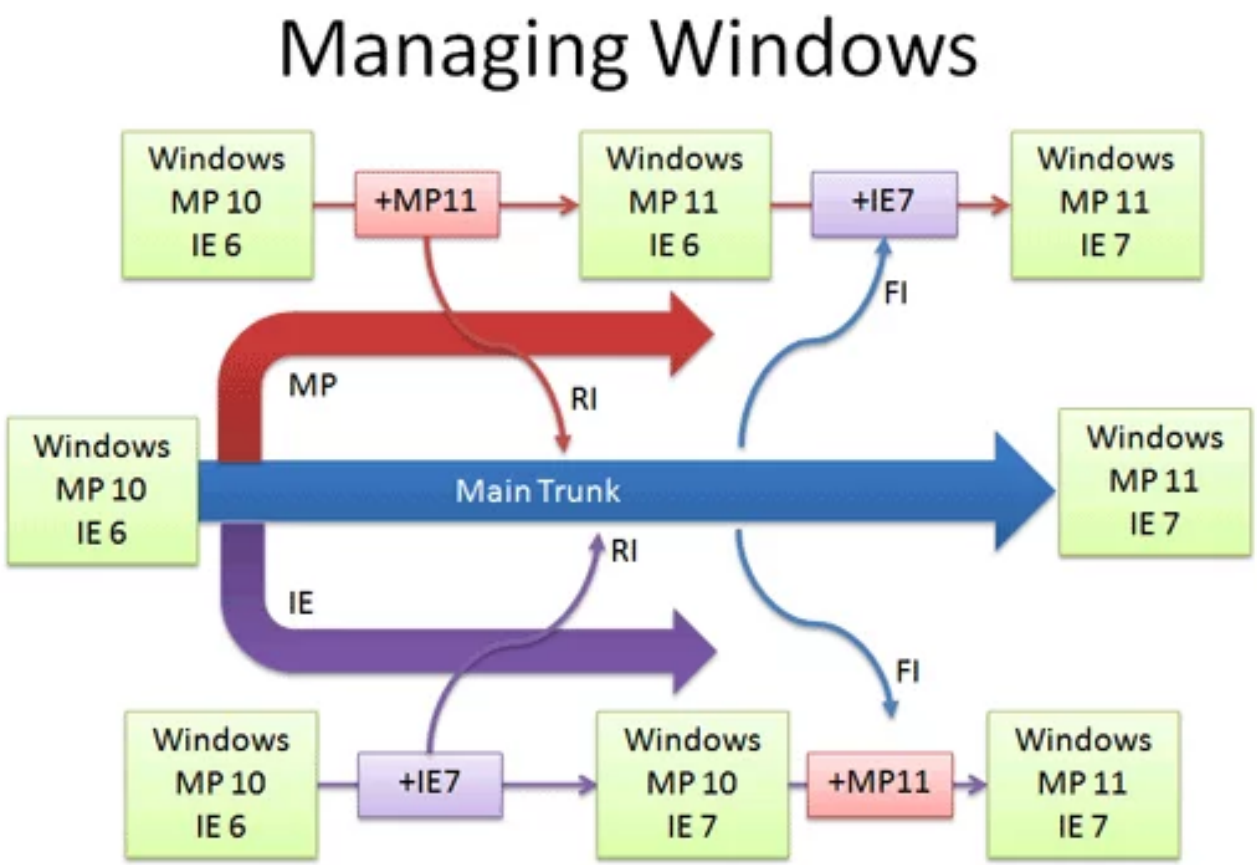
Source: A Visual Guide to Version Control

Working with Version Control



Source: A Visual Guide to Version Control

Working with Version Control



Source: A Visual Guide to Version Control

Program Analysis Tools

- An automated tool:
  - Takes program source code as input
  - Produces reports regarding several important characteristics of the program,
  - Such as size, complexity, adequacy of commenting, adherence to programming standards, etc.
- Some program analysis tools
  - Produce reports regarding the adequacy of the test cases
- There are essentially two categories of program analysis tools
  - **Static analysis tools**
  - **Dynamic analysis tools**

Static Analysis Tools

- Static analysis tools:
  - Assess properties of a program without executing it
  - Analyze the source code to provide analytical conclusions
- Whether coding standards have been adhered to?
  - Commenting is adequate?
- Programming errors such as
  - Uninitialized variables
  - Mismatch between actual and formal parameters
  - Variables declared but never used, etc.
- Code walk through and inspection can also be considered as static analysis methods:
  - However, the term *static program analysis* is generally used for automated analysis tools

Dynamic Analysis Tools

- Dynamic program analysis tools require the program to be executed:
  - its behavior recorded
  - Produce reports such as adequacy of test cases

Software Engineering Tools

Tool	Open Source (OS) / Source	Type	Instrumentation
Development and Process Management Tools			
CodeBlocks / Eclipse / MS-VS	OS / Microsoft	IDE	
BOUML / Visual Paradigm / Vision	OS / VP / MS	UML Modeling	
Git / CVS / SVN	OS	Version Control	
Bugzilla / GNATS / Jira	OS / GNU / Atlassian	Bug Tracking	
Doxygen / Javadoc	OS	Documentation	
Memory Checking Tools			
PurifyPLUS / Insure++	IBM / Parasoft	Dynamic	Source
BoundsChecker	Micro Focus	Dynamic	Source
Valgrind / Callgrind / Cachegrind	OS	Dynamic	Binary
Coverage Tools			
Purecov / Code Coverage Unit	IBM / Parasoft	Dynamic	Source
TrueCoverage	Micro Focus	Dynamic	Source
gcov / lcov	OS (GNU)	Dynamic	Source
Performance / Profiling Tools			
Quantify	IBM	Dynamic	Source
TrueTime	Micro Focus	Dynamic	Source
gprof	OS (GNU)	Dynamic	Binary
Code Analysis Tools			
GCC	OS (GNU)	Static	Source
C/C++ Test	Parasoft	Static, Dynamic	Source
GUI Test Tools			
Selenium	OS [ThoughtWorks]	Record	Playback
WinRunner	RPM Solutions	Record	Playback
Tool Building Tools			
PIN	Freeware (Intel)	Dynamic	Binary
LLVM	OS	Static	Source

Test Plans: LMS

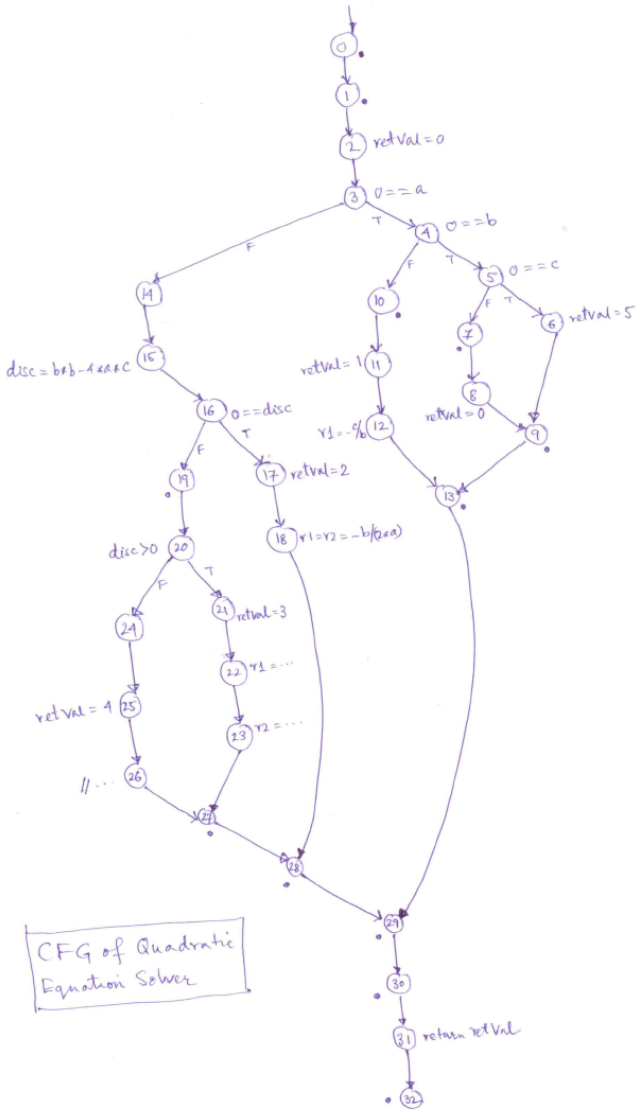
Leave Quota								
Test	CL	EL	DL	SL	ML	PL	LWP	Remarks
Credit			X					Checks if leave is rightly credited
Carry Forward			X					Checks if leave is rightly carried forward to next period
Brought Over			X					Checks if leave is rightly brought over from previous period
Encashment	X		X	X	X	X	X	Checks if leave is rightly transferred for encashment
Leave Period								
Test	CL	EL	DL	SL	ML	PL	LWP	Remarks
Duration								Checks if the leave is within permissible number of days
Holiday Mix								Checks if the leave mixes right with holidays - before, after, during, etc
Leave-Leave Mix								Checks if the leave mixes right with other leaves
Leave Financial								
Test	CL	EL	DL	SL	ML	PL	LWP	Remarks
Encashment Credit	X		X	X	X	X	X	Checks if leave is rightly encashed to salary
Salary Deduction	X	X	X	X	X	X		Checks if salary is rightly deducted / held back for exceeding leave quota
Leave Conditions								
Test	CL	EL	DL	SL	ML	PL	LWP	Remarks
Pre-Approval								Checks if a leave is usually pre-approved
Post-Approval		X			X	X	X	Checks if a leave is post-approved under special circumstances
Medical	X	X	X			X		Checks the medical conditions and certificates for leave
Maternity	X	X	X	X				Checks the maternity conditions and certificates for leave
Parental	X	X	X	X			X	Checks the parental conditions and certificates for leave
Exigency	X	X	X	X	X	X		Checks the exigency conditions and documents for leave

Test Plans: QES: Code

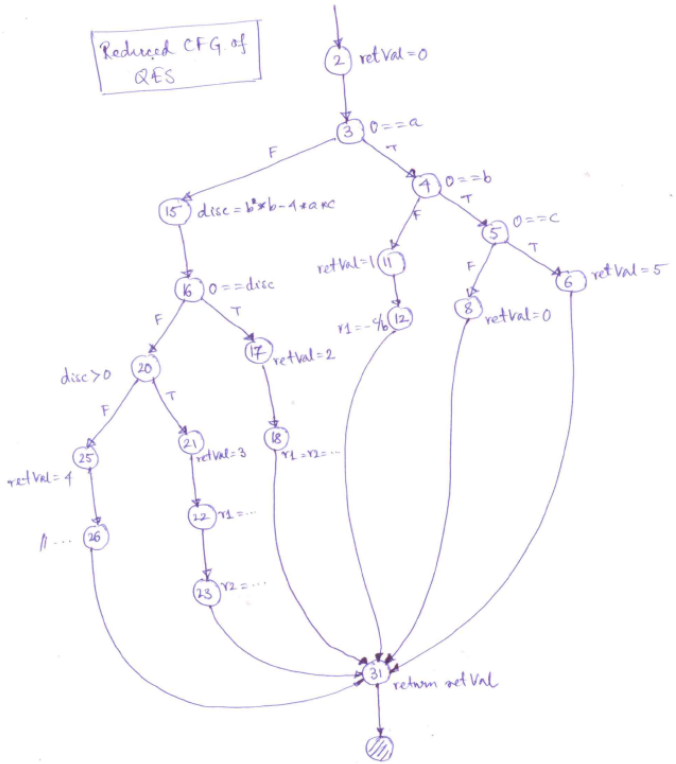

```
00: unsigned int Solve(double a, double b, double c, double& r1, double& r2)
01: {
02:     unsigned int retVal = 0;
03:     if (0 == a) {
04:         if (0 == b) {
05:             if (0 == c) { // Infinite solutions
06:                 retVal = 5;
07:             } else { // Inconsistent equation
08:                 retVal = 0;
09:             }
10:         } else { // Linear equation
11:             retVal = 1;
12:             r1 = -c/b;
13:         }
14:     } else {
15:         double disc = b*b - 4*a*c;
16:         if (0 == disc) { // Repeated roots
17:             retVal = 2;
18:             r1 = r2 = -b/(2*a);
19:         } else {
20:             if (disc > 0) { // Real distinct roots
21:                 retVal = 3;
22:                 r1 = (-b + sqrt(disc))/(2*a);
23:                 r2 = (-b - sqrt(disc))/(2*a);
24:             } else { // Complex conjugate roots
25:                 retVal = 4;
26:                 r1 = (-b)/(2*a); r2 = (sqrt(-disc))/(2*a);
27:             }
28:         }
29:     }
30:
31:     return retVal;
32: }
```

Test Plans: QES: CFG

CFG of QES



Reduced CFG of QES



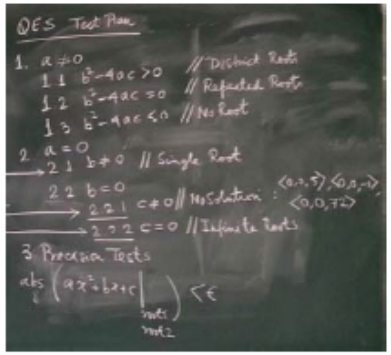
Test Plans: QES


```
#include <iostream>
using namespace std;

00 unsigned int Solve(double a, double b, double c, double& r1, double& r2)
01 {
02         unsigned int retVal = 0;
03         if (0 == a) {
04                 if (0 == b) {
05                         if (0 == c) { // Infinite solutions
06                                 retVal = 5;
07                         } else { // Inconsistent equation
08                                 retVal = 0;
09                         }
10                 } else { // Linear equation
11                         retVal = 1;
12                         r1 = -c/b;
13                 }
14         } else {
15                 double disc = b*b - 4*a*c;
16                 if (0 == disc) { // Repeated roots
17                         retVal = 2;
18                         r1 = r2 = -b/(2*a);
19                 } else {
20                         if (disc > 0) { // Real distinct roots
21                                 retVal = 3;
22                                 r1 = (-b + sqrt(disc))/(2*a);
23                                 r2 = (-b - sqrt(disc))/(2*a);
24                         } else { // Complex conjugate roots
25                                 retVal = 4;
26                                 // ...
27                         }
28                 }
29         }
30
31         return retVal;
32 }
```

Equivalence Classes of Test Cases:

a	b	c	Case
0	0	0	Infinite roots
0	0	2	No root
0	2	-4	Single root
4	4	1	Repeated roots
1	-5	6	Distinct roots
2	3	4	Complex roots



a	b	c	Equivalence Class	Statements Covered	Branches Covered	Paths Covered
0	0	0	Infinite roots	2,3,4,5,6,31	2-3,3-4,4-5,5-6,6-31	2-3-4-5-6-31
0	0	2	No root	2,3,4,5,8,31	2-3,3-4,4-5,5-8,8-31	2-3-4-5-8-31
0	2	-4	Single root	2,3,4,11,12,31	2-3,3-4,4-11,11-12,12-31	2-3-4-11-12-31
4	4	1	Repeated roots	2,3,15,16,17,18,31	2-3,3-15,15-16,16-17,17-18,18-31	2-3-15-16-17-18-31
1	-5	6	Distinct roots	2,3,15,16,20,21,22,23,31	2-3,3-15,15-16,16-20,20-21,21-22,22-23,23-31	2-3-15-16-20-21-22-23-31
2	3	4	Complex roots	2,3,15,16,20,25,26,31	2-3,3-15,15-16,16-20,20-25,25-26,26-31	2-3-15-16-20-25-26-31

Test Plans: QES


```
int main()
{
        double a, b, c;
        double r1, r2;
        unsigned int retVal = 0;
        unsigned int moreInputs = 0;

        do {
                cout << "Input coefficients: a, b and c" << endl;
                cin >> a >> b >> c;
                cout << endl;

                switch (retVal = Solve(a, b, c, r1, r2)) {
                        case 0: cout << "No root" << endl; break;
                        case 1: cout << "Linear Eqn: r1 = " << r1 << endl;  break;
                        case 2: cout << "Repeated real roots: r1 = " << r1 << " r2 = " << r2 << endl;  break;
                        case 3: cout << "Distinct real roots: r1 = " << r1 << " r2 = " << r2 << endl;  break;
                        case 4: cout << "Complex conjugate roots" << endl;  break;
                        case 5: cout << "Infinite roots" << endl;  break;
                        default: cout << "Something wrong" << endl;  break;
                }

                cout << "Continue Solving? Input 1" << endl;
                cin >> moreInputs;

        } while (1 == moreInputs);

        return 0;
}
```

Test Plans: Red Black Tree: Objective

- This document presents a test plan for a Red-Black BST data type
- It also refers to the corresponding test cases for the test plan items
- Finally, it discusses a regression setup and identifies the various user applications in the regression

Test Plans: Red Black Tree: Regression Setup

The regression setup will comprise[2] the following:

1. **Regression Applications**: These are either test by themselves or they will be used to drive the tests through the scenarios.
   In the simpler scenarios, the data & instruction may be embedded in the application itself. So every application then will represent a test case. In Big and Random scenarios, however, generic applications need to be written that'll use 'generated' input data / instruction to drive the test.
   In every application the Scenario will be maintained within the banner the 'Purpose' of the test.
2. **Regression Tests**: These are various inputs sets comprising
   1. Data Sequences (as Key and Info pairs) and / or
   2. Instruction Sequences – Insert or Find
3. **Regression Goldens**: These are expected outputs in every case as created from messages and / or Tree Prints. Possible messages include
   1. Created Tree
   2. Find Pass: <Key, Info>
   3. Find Fail: <Key, Info>
   4. Insert Pass: <Key, Info>
   5. Insert Fail (Duplicate): <Key, Info>
   6. Valid Tree
   7. Released Tree

[2] Normally, regression setup also comprises an automation script that can be invoked from a single command for all tests to run through the respective applications, generate the output and regress against the Goldens. We have now kept such activities out of the scope of DS if you are not familiar with scripting.

Test Plans: Red Black Tree: Regression Setup

The Regression setup will have a folder structure following the scenario classification. Multiple tests within the same classification will be number serially from 1 as 'Test 1', 'Test 2', 'Test 3' etc. Every folder will contain the following:

1. Application
2. Input File (.txt file)
3. Output File (.txt file)
4. Performance File (.txt file), if any, will include the memory time performance information.

All files in a folder will bear the same name.

Test Plans: Red Black Tree: Scenarios

Various scenarios have been enumerated here:

- **Functional Tests**: Test for the primary functionality of the data type
  1. Create / Destroy Tests – these are for testing various constructors & the destructor
     1. Automatic Tree
     2. Dynamic Tree
  2. Insertion Tests
     1. Normal (Common) Cases – without duplicates: Tree arising from Arbitrary Sequence of 5 / 10 / 15 Insertions
     2. Duplicate Insertion (3 cases)
  3. Find Tests
     1. Existing Keys (5 cases)
     2. Missing Keys (5 cases)
  4. Deletion Tests
     1. Existing Unique Keys (5 cases)
     2. Existing Duplicate Keys (5 cases)
     3. Missing Keys (5 cases)
  5. Print Tests
  6. Traversal Tests / Sorting Order
  7. Visitor Tests

Test Plans: Red Black Tree: Scenarios

- **API Tests**: Tests all APIs for the data type (library). All variants for an API (depending on default parameters) need to be tested
  1. Create – wraps the constructor
  2. Insert
  3. Find
  4. Validate
  5. Print
  6. Release – wraps the destructor
  7. Visitor
- **Directed Tests, Corner Cases and Tests from Implementation**:
  1. Empty Tree
  2. Tree with a Single Node
  3. Creating all scenarios for Tree rotation, color shifts and root splits – enumerate & elaborate from the Red-Black Tree algorithms
  4. Multiple Trees within the same scope
     1. Disjoint Lifetime
     2. Overlapped Lifetime
  5. Negative Tests
     1. No-Copy Test – the Tree cannot be copied
     2. No-Assignment Test – the Tree cannot be assigned
  6. Big Tests
     1. Tree from long (500) monotonic sequence of insertions • Increasing Decreasing
     2. Tree arising from long alternating sequences of insertions

Test Plans: Red Black Tree: Scenarios

- **Use-Model / Extension Tests**: If the Tree is specialized by the user. For example,
  1. Add a 'name' to a Tree.
  2. Change the type of Key in the Data nodes
  3. Change the type of Info in the Data nodes
  4. Allow for multiple Keys by accommodating a resolution on secondary Keys
- **Random & Huge Tests**[3]:
  1. Pseudo-Random Tests – the data for such tests should be generated beforehand using the random generator and stored. The size of every test should be between 10,000 and 1,000,000. Each category should have at least 5 tests
     1. No-Duplicate Inserts & Exists-only Finds
     2. Free Inserts & Exists-only Finds
     3. No-Duplicate Inserts & Free Finds
     4. Free Inserts & Free Finds
  2. Random Test – these tests will generate random test data every time the test is run. The random runs should be of the order of 100,000
- **Low Memory Tests**

[3] Write a generator for the random data in every case. This will generate the Key-Info pairs and the Insert-Find sequences. The generation process needs to confirm the constraints on the randomness (like Free Inserts and Exists-only Find)

Test Plans: Red Black Tree: Quality and Performance

- **Quality Parameters**: The following quality parameters need to be achieved by every positive Golden
  1. Zero Memory Leak
  2. Zero Memory Access Error
- **Performance Parameters**: The following performance parameters need to be measured for Big and Random Tests
  1. Peak Memory
  2. Memory / Key-Info pair
  3. Time / Insert
  4. Time / Find