# Testing and Debugging
## (Lecture 11)

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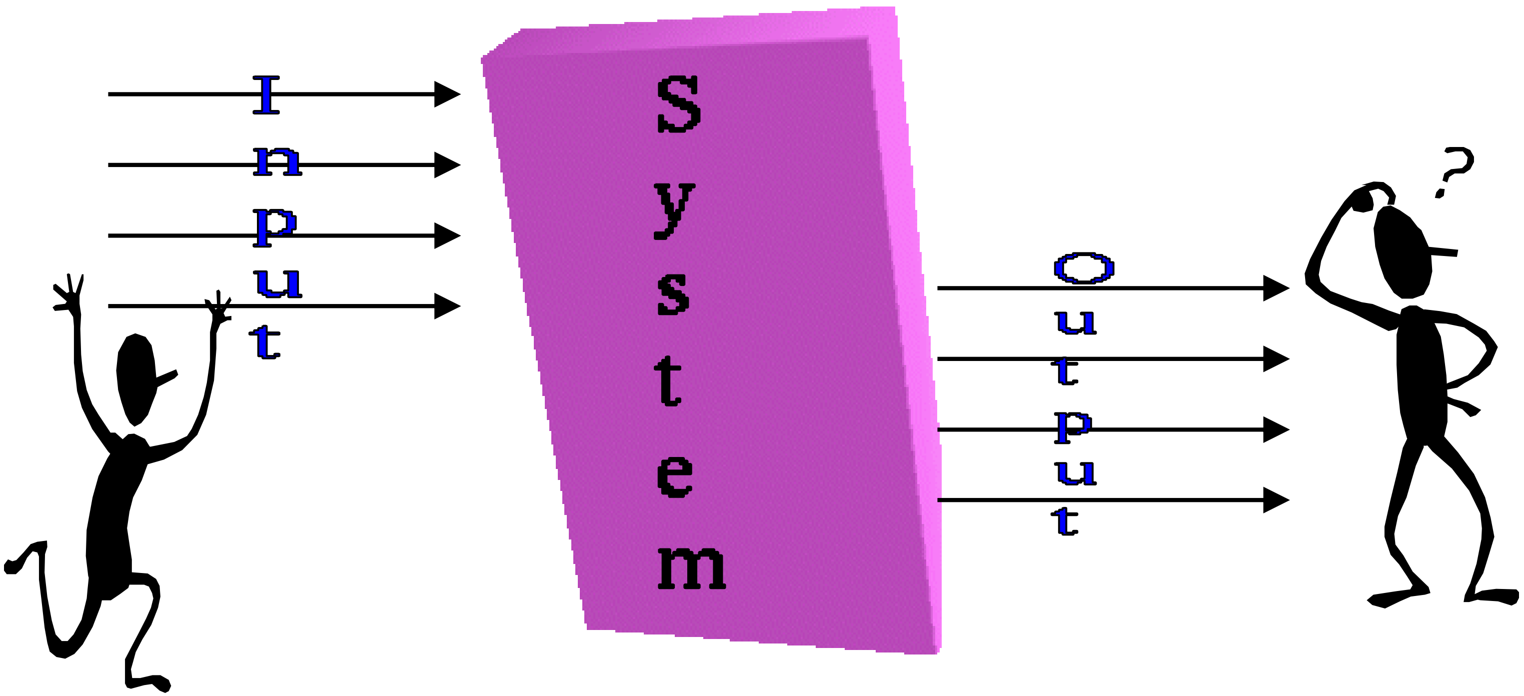
# How Do You Test a Program?

- Input test data to the program.
- Observe the output:
  - Check if the program behaved as expected.

# How Do You Test a Program?



# How Do You Test a Program?

- If the program does not behave as expected:
  - Note the conditions under which it failed.
  - Later debug and correct.

# Overview of 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 (aka defect or bug).
  - Mere presence of an error may not lead to a failure.

# Error, Faults, and Failures

- A fault is an incorrect state entered during program execution:
  - A variable value is different from what it should be.
  - A fault may or may not not lead to a failure.

# Test cases and Test suites

- Test a software using a set of carefully designed test cases:
  - The set of all test cases is called the test suite

# Test cases and Test suites

- 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.

# Verification versus Validation

- Verification is the process of determining:
  - Whether output of one phase of development conforms to its previous phase.

- Validation is the process of determining:
  - Whether a fully developed system conforms to its SRS document.

# Verification versus Validation

- Verification is concerned with phase containment of errors,
  - Whereas the aim of validation is that the final product be error free.

# 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.

# Design of Test Cases

- 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.

# Design of Test Cases

- Testing a system using a large number of randomly selected test cases:
  - Does not mean that many errors in the system will be uncovered.
- Consider following example:
  - Find the maximum of two integers x and y.

# Design of Test Cases

- 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.

# Design of Test Cases

- There are essentially two main approaches to design test cases:
  - Black-box approach
  - White-box (or glass-box) approach

# Black-Box Testing

- 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.

# White-box Testing

- Designing white-box test cases:
  - Requires knowledge about the internal structure of software.
  - White-box testing is also called <u>structural testing</u>.

# Black-Box Testing

- There are essentially two main approaches to design black box test cases:
  - Equivalence class partitioning
  - Boundary value analysis

# 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.

# Why Define Equivalence Classes?

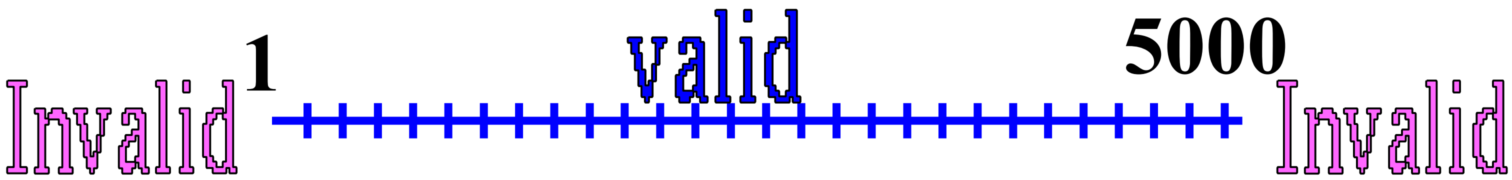
- Test the code with just one representative value from each equivalence class:
  - As good as testing using any other values from the equivalence classes.

# 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

# Equivalence Class Partitioning

- **If the input data to the program is specified by a range of values:**
  - e.g. numbers between 1 to 5000.
  - One valid and two invalid equivalence classes are defined.

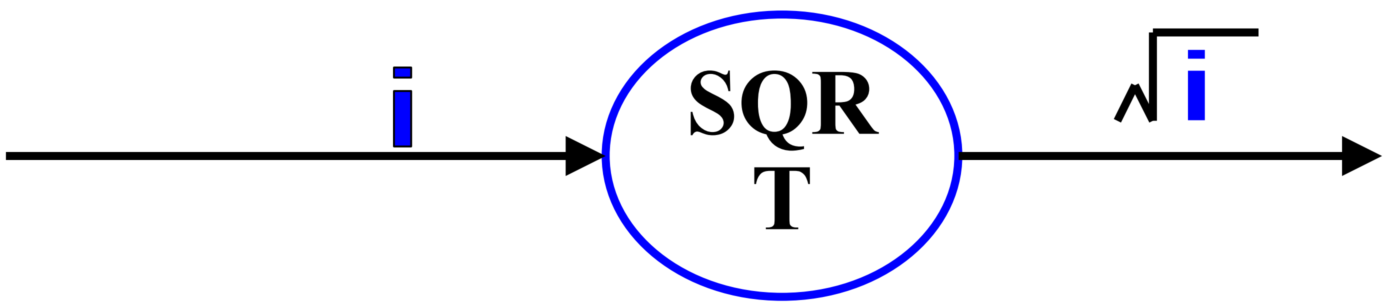


# Equivalence Class Partitioning

- If input is an enumerated set of values:
  - e.g. {a,b,c}
  - One equivalence class for valid input values.
  - Another equivalence class for invalid input values should be defined.

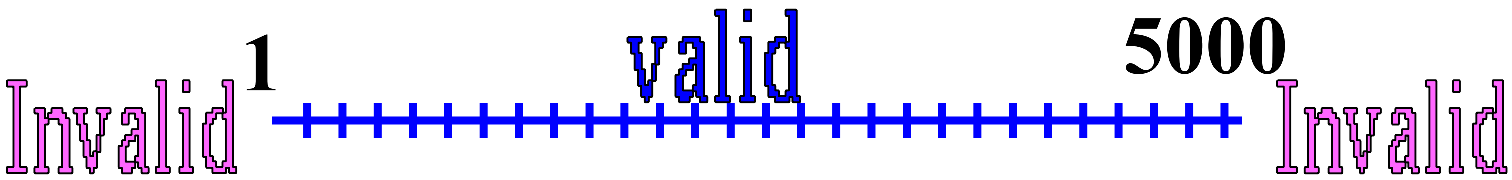
# Example

- A program reads an input value in the range of 1 and 5000:
  - Computes the square root of the input number



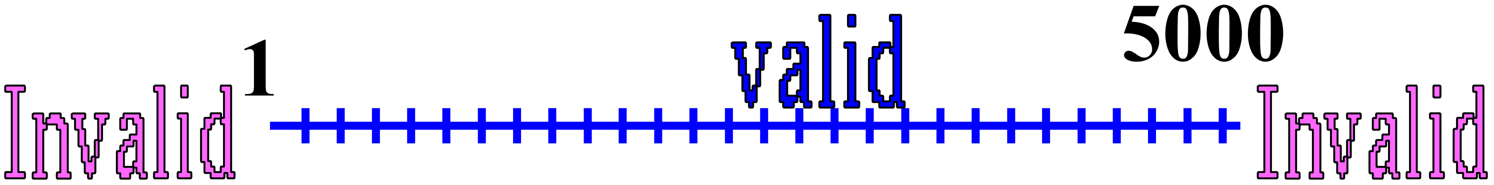
# Example (cont.)

- There are three equivalence classes:
  - The set of negative integers,
  - Set of integers in the range of 1 and 5000,
  - Integers larger than 5000.



# Example (cont.)

- The test suite must include:
  - Representatives from each of the three equivalence classes:
  - A possible test suite can be: {-5,500,6000}.



# Boundary Value Analysis

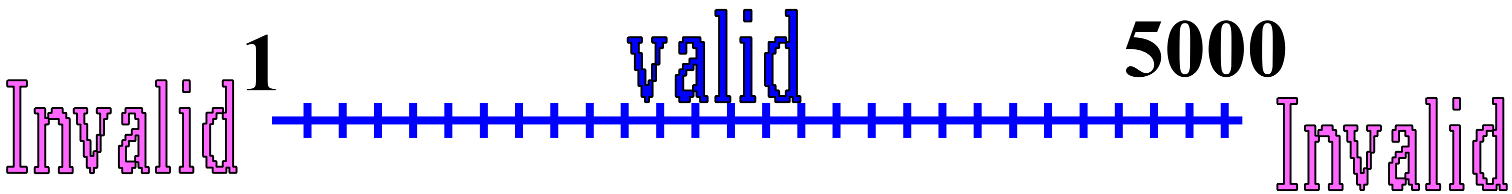
- Some typical programming errors occur:
  - At boundaries of equivalence classes
  - Might be purely due to psychological factors.
- Programmers often fail to see:
  - Special processing required at the boundaries of equivalence classes.

# Boundary Value Analysis

- Programmers may improperly use < instead of <=
- Boundary value analysis:
  - Select test cases at the boundaries of different equivalence classes.

# Example

- 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}.



# Debugging

- Once errors are identified:
  - It is necessary identify the precise location of the errors and to fix them.
- Each debugging approach has its own advantages and disadvantages:
  - Each is useful in appropriate circumstances.

# Brute-Force method

- This is the most common method of debugging:
  - Least efficient method.
  - Program is loaded with print statements
  - Print the intermediate values
  - Hope that some of printed values will help identify the error.

# Symbolic Debugger

- Brute force approach becomes more systematic:
  - With the use of a symbolic debugger,
  - Symbolic debuggers get their name for historical reasons
  - Early debuggers let you only see values from a program dump:
    - Determine which variable it corresponds to.

# Symbolic Debugger

- Using a symbolic debugger:
  - Values of different variables can be easily checked and modified
  - Single stepping to execute one instruction at a time
  - Break points and watch points can be set to test the values of variables.

# Backtracking

- This is a fairly common approach.
- Beginning at the statement where an error symptom has been observed:
  - Source code is traced backwards until the error is discovered.

# Example

```
int main(){
 int i,j,s;
 i=1;
 while(i<=10){
        s=s+i;
        i++; j=j++;}
printf("%d",s);
}
```

# Backtracking

- Unfortunately, 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

- Determine a list of causes:
  - which could possibly have contributed to the error symptom.
  - tests are conducted to eliminate each.
- A related technique of identifying error by examining error symptoms:
  - software fault tree analysis.

# Program Slicing

- This technique is similar to back tracking.
- However, the search space is reduced by defining slices.
- A slice is defined for a particular variable at a particular statement:
  - set of source lines preceding this statement which can influence the value of the variable.

# Example

```
int main(){
 int i,s;
 i=1; s=1;
 while(i<=10){
        s=s+i;
        i++;}
printf("%d",s);
printf("%d",i);
}
```

# Debugging Guidelines

- Debugging usually requires a thorough understanding of the 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.

# Debugging Guidelines

- Be aware of the possibility:
  - an error correction may introduce new errors.
- After every round of error-fixing:
  - regression testing must be carried out.

# 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.

# Program Analysis Tools

- 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
    - Provide analytical conclusions.

# Static Analysis Tools

- 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.

# Static Analysis Tools

- 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.

# Testing

- 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.

# Testing

- The input data domain of most software products is very large:
  - It is not practical to test the software exhaustively with each input data value.

# Testing

- Testing does however expose many errors:
  - Testing provides a practical way of reducing defects in a system
  - Increases the users' confidence in a developed system.

# Testing

- Testing is an important development phase:
  - requires the maximum effort among all development phases.
- In a typical development organization:
  - maximum number of software engineers can be found to be engaged in testing activities.

# Testing

- Many engineers have the wrong impression:
  - testing is a secondary activity
  - it is intellectually not as stimulating as the other development activities, etc.

# Testing

- Testing a software product is in fact:
  - as much challenging as initial development activities such as specification, design, and coding.
- Also, testing involves a lot of creative thinking.

# Testing

- Software products are tested at three levels:
  - Unit testing
  - Integration testing
  - System testing

# 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

- Unit testing reduces debugging effort several folds.
  - Programmers carry out unit testing immediately after they complete the coding of a module.

# 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.

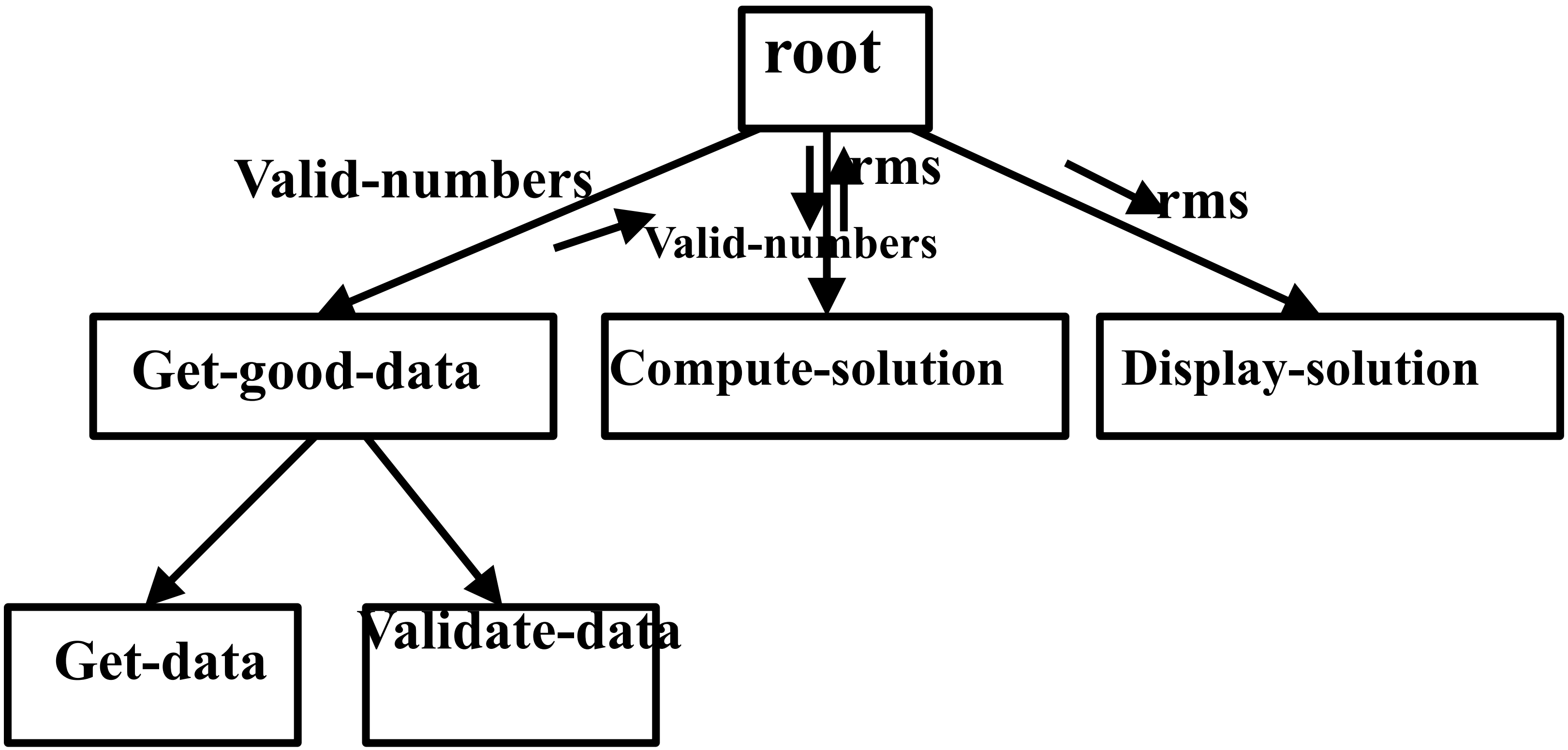
# System Testing

- System testing involves:
  - validating a fully developed system against its requirements.

# Integration Testing

- Develop the integration plan by examining the structure chart :
  - big bang approach
  - top-down approach
  - bottom-up approach
  - mixed approach

# Example Structured Design



# Big Bang Integration Testing

- Big bang approach is the simplest integration testing approach:
  - all the modules are simply put together and tested.
  - this technique is used only for very small systems.

# Big Bang Integration Testing

- Main problems with this approach:
  - 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

- There are three main kinds of system testing:
  - Alpha Testing
  - Beta Testing
  - Acceptance Testing

# Alpha Testing

- System testing is carried out by the test team within the developing organization.

# Beta Testing

- System testing performed by a select group of friendly customers.

# Acceptance Testing

- System testing performed by the customer himself:
  - to determine whether the system should be accepted or rejected.

# Stress Testing

- Stress testing (aka endurance testing):
  - impose abnormal input to stress the capabilities of the software.
  - Input data volume, input data rate, processing time, utilization of memory, etc. are tested beyond the designed capacity.

# 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.

# Error Seeding

- Let:
  - N be the total number of errors in the system
  - n of these errors be found by testing.
  - S be the total number of seeded errors,
  - s of the seeded errors be found during testing.

# Error Seeding

- $n/N = s/S$
- $N = S\ n/s$
- remaining defects:

  $N - n = n\ ((S - s)/\ s)$

# Example

- 100 errors were introduced.
- 90 of these errors were found during testing
- 50 other errors were also found.
- Remaining errors=
  50 (100-90)/90 = 6

# Error Seeding

- 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:
  - can be estimated by analyzing historical data from similar projects.

# Summary

- Exhaustive testing of almost any non-trivial system is impractical.
  - we need to design an <u>optimal test suite</u> that would expose as many errors as possible.

# Summary

- If we select test cases randomly:
  - many of the test cases may not add to the significance of the test suite.
- There are two approaches to testing:
  - black-box testing
  - white-box testing.

# Summary

- Black box testing is also known as functional testing.
- Designing black box test cases:
  – Requires understanding only SRS document
  – Does not require any knowledge about design and code.
- Designing white box testing requires knowledge about design and code.

# Summary

- We discussed black-box test case design strategies:
  - Equivalence partitioning
  - Boundary value analysis
- We discussed some important issues in integration and system testing.