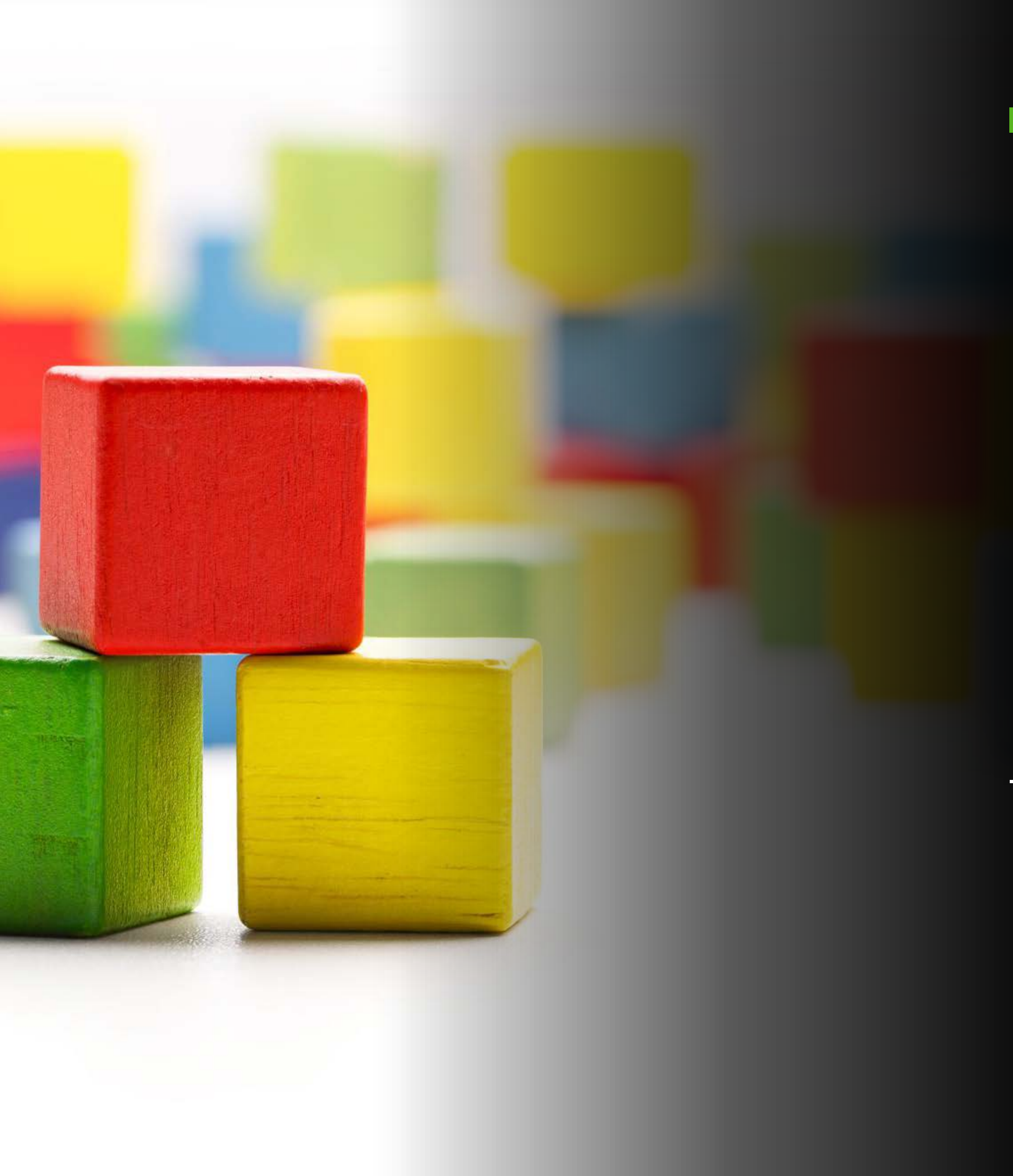

Software Engineering

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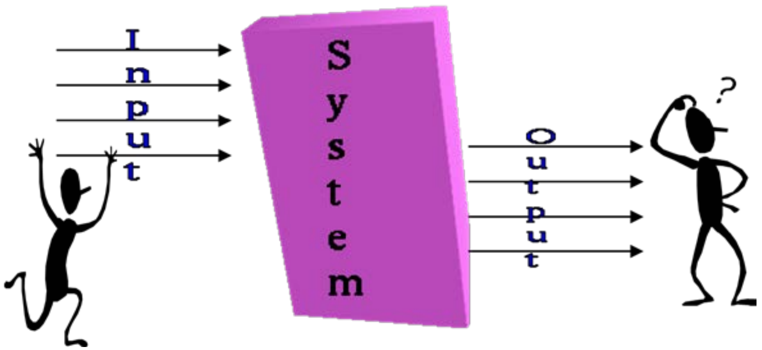
Contents of the slides are prepared based on the materials from web and textbooks. It is stated that this material will be used to make the students aware of the topics and practiced for non-profit purposes.

(slide can be found in this secure domain)

Testing and Debugging

How Do You Test 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.
  - ✓ 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.

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 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

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 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.
- 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 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.

There are essentially two main approaches to design black box test cases:

- Equivalence class partitioning
- Boundary value analysis

White-box Testing

- Designing white-box test cases:
  - ✓ Requires knowledge about the internal structure of software.
  - ✓ White-box testing is also called structural testing.
  - ✓ In this unit we will not study white-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.

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.

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

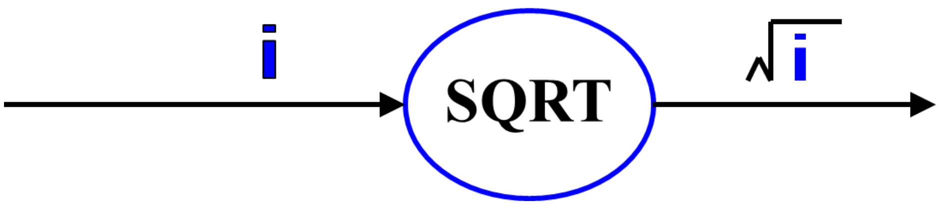
- If the input data to the program is specified by a range of values:
  - ✓ e.g. numbers between 1 to 5000.
  - ✓ One valid and two invalid equivalence classes are defined.

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 & 5000:
- Computes the square root of the input number



Example

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

- 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.

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.

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 like back tracking.

However, the search space is reduced by defining slices.

A slice is defined for a 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.
- 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.

Some program analysis tools:

- Produce reports regarding the adequacy of the test cases.

essentially two categories of program analysis

- Static analysis tools
- Dynamic analysis tools

Static Analysis Tools

- Assess properties of a program without executing it.
- Analyse the source code
    - ❑ Provide analytical conclusions.
- Whether coding standards have been adhered to?
    - ✓ Commenting is adequate?

Static Analysis Tools

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 behaviour recorded.
  - ✓ Produce reports such as adequacy of test cases.

Testing

testing is to identify all defects in a software

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 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 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 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 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.

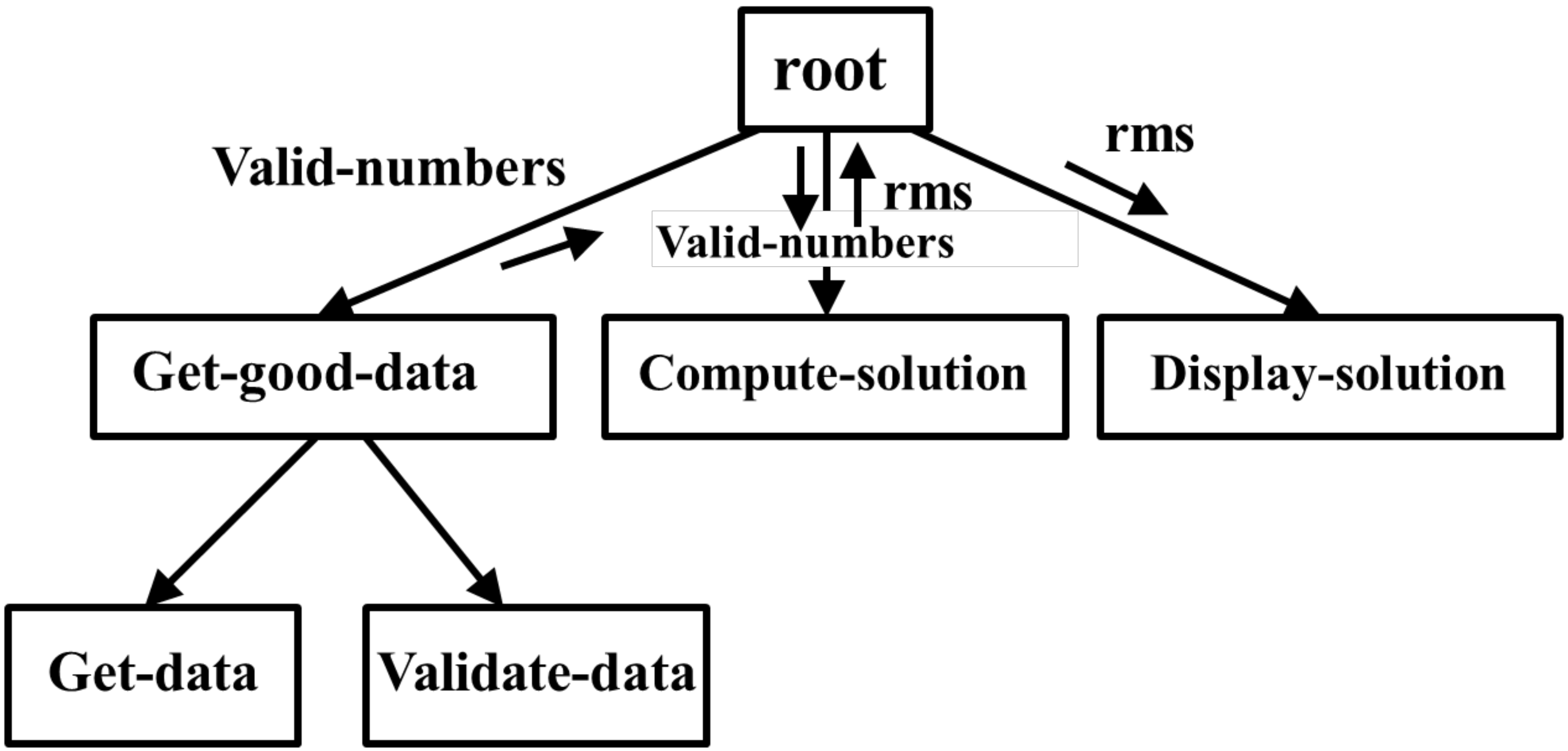
System Testing

- 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.

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: 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

- a software testing activity that determines the robustness of software by testing beyond the limits of normal operation

- 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?

- **Error Seeding** is the process of deliberately introducing errors within a program to check whether the test cases are able to capture the **seeded** errors.

- Alternately, 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.
- Therefore,
  - ✓ $n/N = s/S$
  - ✓ $N = S \quad n/s$
  - ✓ remaining defects:

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

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

aims to detect errors in order to find out the ratio between the actual and artificial errors.

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 analysing historical data from similar projects.

Summary

- Exhaustive testing of almost any non-trivial system is impractical.
  - ✓ we need to design an optimal test suite that would expose as many errors as possible.
- 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.
- We discussed black-box test case design strategies:
  - ✓ Equivalence partitioning
  - ✓ Boundary value analysis
- We discussed some important issues in integration and system testing.