Coding and Unit Testing

UNIT -5

Coding

- Goal is to implement the design in best possible manner
- Coding affects testing and maintenance
- As testing and maintenance costs are high, aim of coding activity should be to write code that reduces them
- Hence, goal should not be to reduce coding cost, but testing and maint cost, i.e. make the job of tester and maintainer easier

Coding…

- Code is read a lot more
  - Coders themselves read the code many times for debugging, extending etc
  - Maintainers spend a lot of effort reading and understanding code
  - Other developers read code when they add to existing code
- Hence, code should be written so it is easy to understand and read, not easy to write!

Coding…

- Having clear goal for coding will help achieve them
- Weinberg experiment showed that coders achieve the goal they set
  - Diff coders were given the same problem
  - But different objectives were given to diff programmers – minimize effort, min size, min memory, maximize clarity, max output clarity
  - Final programs for diff programmers generally satisfied the criteria given to them

Weinberg experiment..

	Resulting Rank (1=best)				
	O1	o2	o3	o4	o5
Minimize Effort (o1)	1	4	4	5	3
Minimize prog size (o2)	2-3	1	2	3	5
Minimize memory (o3)	5	2	1	4	4
Maximize code clarity (o4)	4	3	3	2	2
Maximize output clarity (o5)	2-3	5	5	1	1

Programming Principles

- The main goal of the programmer is write simple and easy to read programs with few bugs in it
- Of course, the programmer has to develop it quickly to keep productivity high
- There are various programming principles that can help write code that is easier to understand (and test…)

Structured Programming

- Structured programming started in the 70s, primarily against indiscriminate use of control constructs like gotos
- Goal was to simplify program structure so it is easier to argue about programs
- Is now well established and followed

Structured Programming…

- A program has a static structure which is the ordering of stmts in the code – and this is a linear ordering
- A program also has dynamic structure –order in which stmts are executed
- Both dynamic and static structures are ordering of statements
- Correctness of a program must talk about the dynamic structure

Structured Programming…

- To show a program as correct, we must show that its dynamic behavior is as expected
- But we must argue about this from the code of the program, i.e. the static structure
- I.e program behavior arguments are made on the static code
- This will become easier if the dynamic and static structures are similar
- Closer correspondence will make it easier to understand dynamic behavior from static structure
- This is the idea behind structured programming

Structured Programming…

- Goal of structured programming is to write programs whose dynamic structure is same as static
- I.e. stmts are executed in the same order in which they are present in code
- As stmts organized linearly, the objective is to develop programs whose control flow is linear

Structured Programming…

- Meaningful programs cannot be written as seq of simple stmts
- To achieve the objectives, structured constructs are to be used
- These are single-entry-single-exit constructs
- With these, execution of the stmts can be in the order they appear in code
- The dynamic and static order becomes same

Structured Programming

- Main goal was to ease formal verification of programs
- For verification, the basic theorem to be shown for a program S is of the form

  $P \{S\} Q$
- P – precondition that holds before S executes
- Q – postcondition that holds after S has executed and terminated

Structured Prog – composing proofs

- If a program is a sequence of the type S1; S2 then it is easier to prove from proofs of S1 and S2
- Suppose we have shown P1 {S1} Q1 and R2 {S2} Q2
- Then, if we can show Q1 => R2, then we can conclude P1 {S1; S2} Q2
- So Structured Prog allows composing proofs of larger programs from proofs of its parts

Structured Programming…

- Each structured construct should also have a clear behavior
- Then we can compose behavior of stmts to understand behavior of programs
- Hence, arbitrary single-entry-single-exit constructs will not help
- It can be shown that a few constructs like while, if, and sequencing suffice for writing any type of program

Structured Programming…

- SP was promulgated to help formal verification of programs
- Without linear flow, composition is hard and verification difficult
- But, SP also helps simplify the control flow of programs, making them easier to understand and argue about
- SP is an accepted and standard practice today – modern languages support it well

Information Hiding

- Software solutions always contain data structures that hold information
- Programs work on these DS to perform the functions they want
- In general only some operations are performed on the information, i.e. the data is manipulated in a few ways only
- E.g. on a bank's ledger, only debit, credit, check cur balance etc are done

Information Hiding…

- Information hiding – the information should be hidden; only operations on it should be exposed
- I.e. data structures are hidden behind the access functions, which can be used by programs
- Info hiding reduces coupling
- This practice is a key foundation of OO and components, and is also widely used today

Some Programming Practices

- Control constructs: Use only a few structured constructs (rather than using a large no of constructs)
- Goto: Use them sparingly, and only when the alternatives are worse
- Info hiding: Use info hiding
- Use-defined types: use these to make the programs easier to read

Some Programming Practices..

- Nesting: Avoid heavy nesting of if-then-else; if disjoint nesting can be avoided
- Module size: Should not be too large – generally means low cohesion
- Module interface: make it simple
- Robustness: Handle exceptional situations
- Side effects: Avoid them, document

Some Programming Practices..

- Empty catch block: always have some default action rather than empty
- Empty if, while: bad practice
- Read return: should be checked for robustness
- Return from finally: should not return from finally
- Correlated parameters: Should check for compatibility

Coding Standards

- Programmers spend more time reading code than writing code
- They read their own code as well as other programmers code
- Readability is enhanced if some coding conventions are followed by all
- Coding standards provide these guidelines for programmers
- Generally are regarding naming, file organization, statements/declarations, …
- Some Java conventions discussed here

Coding Standards…

- Naming conventions
  - Package name should be in lower case (mypackage, edu.iitk.maths)
  - Type names should be nouns and start with uppercase (Day, DateOfBirth,…)
  - Var names should be nouns in lowercase; vars with large scope should have long names; loop iterators should be i, j, k…
  - Const names should be all caps
  - Method names should be verbs starting with lower case (eg getValue())
  - Prefix *is* should be used for boolean methods

Coding Standards…

- Files
  - Source files should have .java extension
  - Each file should contain one outer class and the name should be same as file
  - Line length should be less than 80; if longer continue on another line…

Coding Standards…

- Statements
  - Vars should be initialized where declared in the smallest possible scope
  - Declare related vars together; unrelated vars should be declared separately
  - Class vars should never be declared public
  - Loop vars should be initialized just before the loop
  - Avoid using break and continue in loops
  - Avoid executable stmts in conditionals
  - Avoid using the do… while construct

Coding Standards…

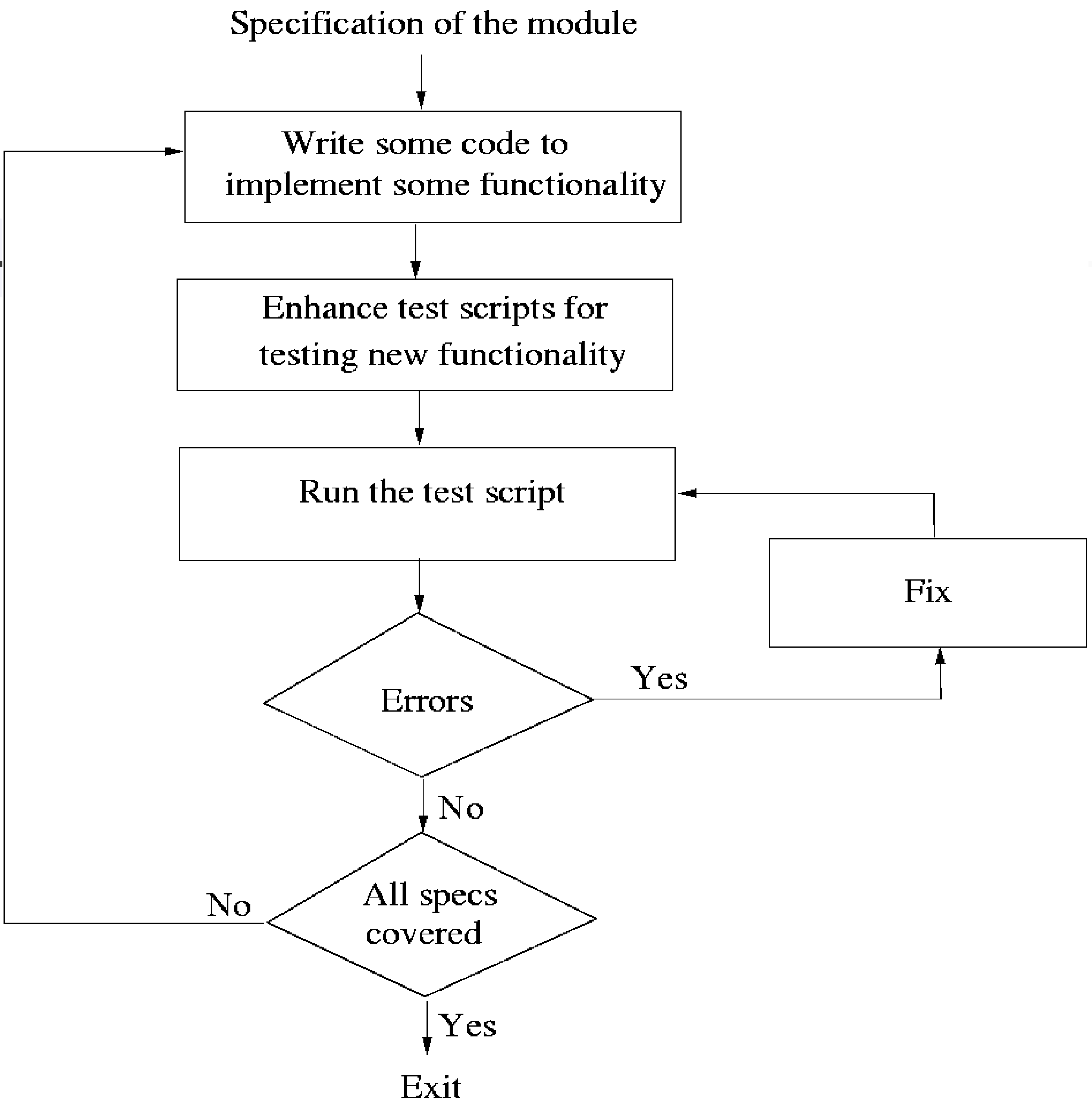
- Commenting and layout
  - Single line comments for a block should be aligned with the code block
  - There should be comments for all major vars explaining what they represent
  - A comment block should start with a line with just /* and end with a line with */
  - Trailing comments after stmts should be short and on the same line

Incrementally Developing Code

- Coding starts when specs for modules from design is available
- Usually modules are assigned to programmers for coding
- In top-down development, top level modules are developed first; in bottom-up lower levels modules
- For coding, developers use different processes; we discuss some here

An Incremental Coding Process

- Basic process: Write code for the module, unit test it, fix the bugs
- It is better to do this incrementally – write code for part of functionality, then test it and fix it, then proceed
- I.e. code is built code for a module incrementally



Specification of the module
Write some code to implement some functionality
Enhance test scripts for testing new functionality
Run the test script
Fix
Errors
Yes
No
All specs covered
No
Yes
Exit

Test Driven Development

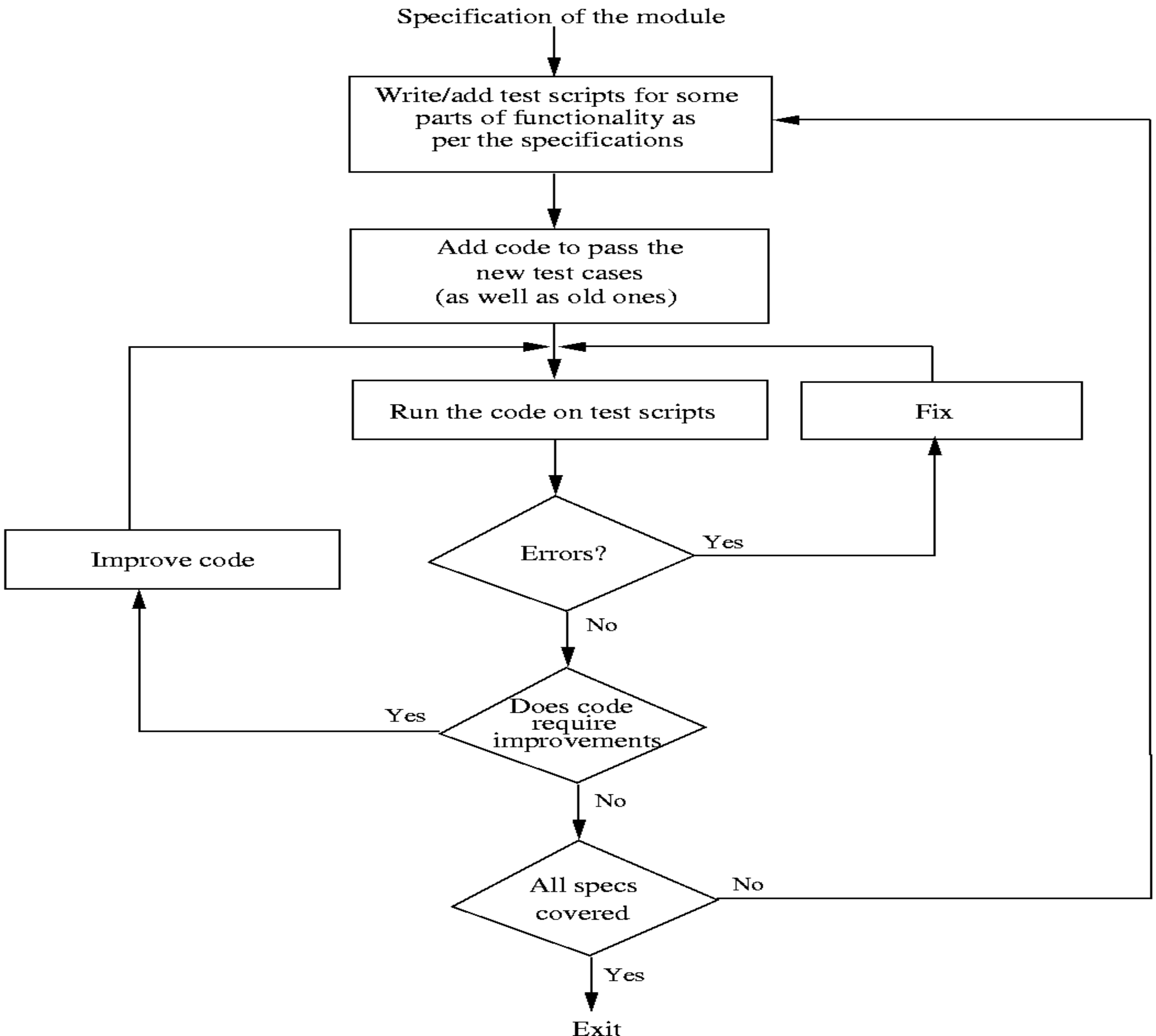
- This coding process changes the order of activities in coding
- In TDD, programmer first writes the test scripts and then writes the code to pass the test cases in the script
- This is done incrementally
- Is a relatively new approach, and is a part of the extreme programming (XP)

TDD…

- In TDD, you write just enough code to pass the test
- I.e. code is always in sync with the tests and gets tested by the test cases
  - Not true in code first approach, as test cases may only test part of functionality
- Responsibility to ensure that all functionality is there is on test case design, not coding
- Help ensure that all code is testable

TDD…

- Focus shifts to how code will be used as test cases are written first
  - Helps validate user interfaces specified in the design
  - Focuses on usage of code
- Functionality prioritization happens naturally
- Has possibility that special cases for which test cases are not possible get left out
- Code improvement through refactoring will be needed to avoid getting a messy code


Specification of the module
Write/add test scripts for some parts of functionality as per the specifications
Add code to pass the new test cases (as well as old ones)
Run the code on test scripts
Fix
Errors?
Yes
No
Improve code
Yes
Does code require improvements
No
All specs covered
No
Yes
Exit

Pair Programming

- Also a coding process that has been proposed as key practice in XP
- Code is written by pair of programmers rather than individuals
  - The pair together design algorithms, data structures, strategies, etc.
  - One person types the code, the other actively reviews what is being typed
  - Errors are pointed out and together solutions are formulated
  - Roles are reversed periodically

Pair Programming…

- PP has continuous code review, and reviews are known to be effective
- Better designs of algos/DS/logic/…
- Special conditions are likely to be dealt with better and not forgotten
- It may, however, result in loss of productivity
- Ownership and accountability issues are also there
- Effectiveness is not yet fully known

Managing Evolving Code

- During coding process, code written by a programmer evolves
- Code by different programmers have to be put together to form the system
- Besides normal code changes, requirement changes also cause chg.
- Evolving code has to be managed

Source Code Control and Built

- Source code control is an essential step programmers have to do
- Generally tools like CVS, VSS are used
- A tool consists of repository, which is a controlled directory structure
- The repository is the official source for all the code files
- System build is done from the files in the repository only
- Tool typically provides many commands to programmers

Source code control…

- Checkout a file: by this a programmer gets a local copy that can be modified
- Check in a file: changed files are uploaded in the repository and change is then available to all
- Tools maintain complete change history and all older versions can be recovered
- Source code control is an essential tool for developing large projects and for coordination

Refactoring

- As code evolves, the design becomes more complex
- Refactoring is a technique to improve existing code by improving its design (i.e. the internal structure)
- In TDD, refactoring is a key step
- Refactoring is done generally to reuce coupling or increase cohesion

Refactoring…

- Involves changing code to improve some design property
- No new functionality is added
- To mitigate risks associated with refactoring two golden rules
  - Refactor in small steps
  - Have test scripts available to test that the functionality is preserved

Refactoring…

- With refactoring code is continually improving; refactoring cost is paid by reduced maint effort later
- There are various refactoring patterns that have been proposed
- A catalog of refactorings and how to do them is available online

Refactoring…

- “Bad smells” that suggest that refactoring may be desired
  - Duplicate code
  - Long method
  - Long class
  - Long parameter list
  - Swith statement
  - Speculative generality
  - Too much communication between objects
  - …

Unit Testing

UT and Verification

- Code has to be verified before it can be used by others
- Here we discuss only verification of code written by a programmer (system verification is discussed in testing)
- There are many different techniques – two most commonly used are unit testing and inspection
- We will discuss these here

Unit Testing

- Is testing, except the focus is the module a programmer has written
- Most often UT is done by the programmer himself
- UT will require test cases for the module – will discuss in testing
- UT also requires drivers to be written to actually execute the module with test cases
- Besides the driver and test cases, tester needs to know the correct outcome as well

Unit Testing…

- If incremental coding is being done, then complete UT needs to be automated
- Otherwise, repeatedly doing UT will not be possible
- There are tools available to help
  - They provide the drivers
  - Test cases are programmed, with outcomes being checked in them
  - I.e. UT is a script that returns pass/fail

Unit Testing…

- Testing a module f() has following steps
  - Set the system state as needed
  - Set value of parameters suitably
  - Invoke the function f() with parms
  - Compare result of f() with expected results
  - Declare whether the test case succeeded or failed
- Test frameworks automate all this

Unit testing of Classes

- Is same as before, except the system state is generally the state of the object
- Many frameworks exist for OO – Junit is the most popular; others for other languages also exist
- Each testcase is a method, in which the desired sequence of methods is executed; assertions used to check the outcome
- The script will declare if all tests succeeded, and if not which ones have failed

Unit Testing…

- There are frameworks like Junit that can be used for testing Java classes
- Each test case is a method which ends with some assertions
- If assertions hold, the test case pass, otherwise it fails
- Complete execution and evaluation of the test cases is automated
- For enhancing the test script, additional test cases can be added easily

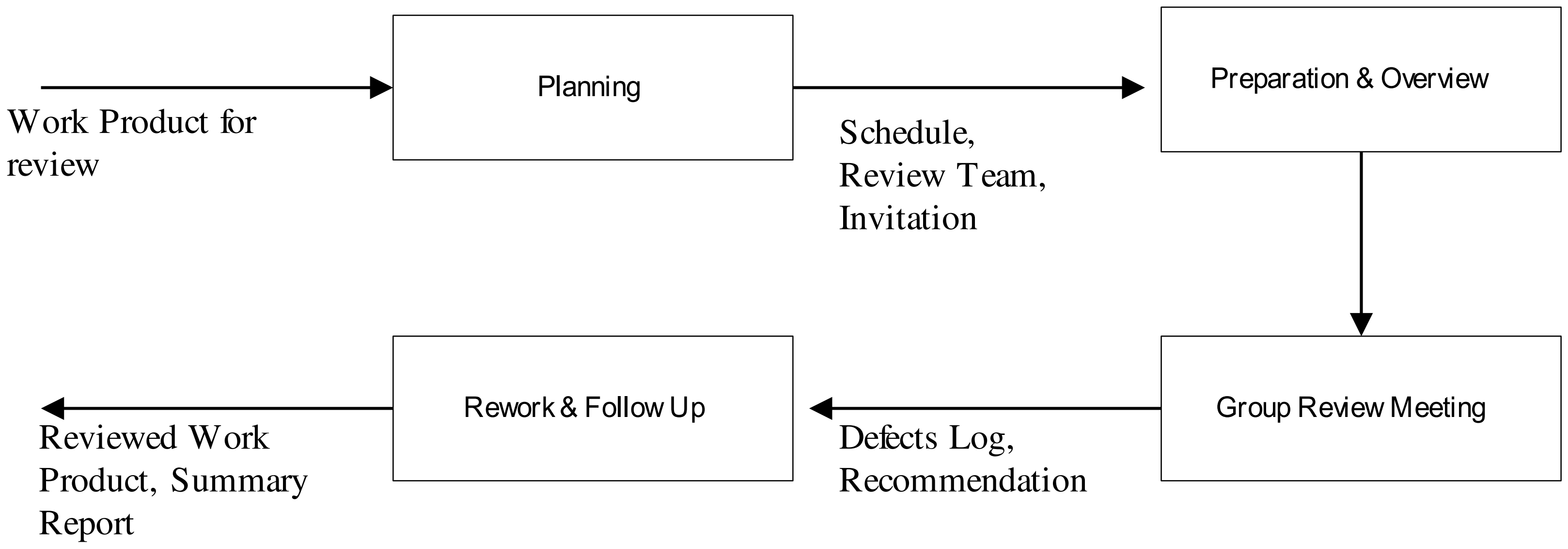
Code Inspections

- Code inspection is another technique that is often used effectively at the unit level
- Main goal of inspection process is to detect defects in work products
- First proposed by Fagan in 70s
- Earlier used for code, now used for all types of work products
- Is recognized as an industry best practice

Code review…

- Conducted by group of programmers for programmers (i.e. review done by peers)
- Is a structured process with defined roles for the participants
- The focus is on identifying problems, not resolving them
- Review data is recorded and used for monitoring the effectiveness

A Review Process


Work Product for review
Planning
Schedule, Review Team, Invitation
Preparation & Overview
Group Review Meeting
Defects Log, Recommendation
Rework & Follow Up
Reviewed Work Product, Summary Report

Planning

- Select the group review team – three to five people group is best
- Identify the moderator – has the main responsibility for the inspection
- Prepare package for distribution – work product for review plus supporting docs
- Package should be complete for review

Overview and Self-Review

- A brief meeting – deliver package, explain purpose of the review, intro,…
- All team members then individually review the work product
  - Lists the issues/problems they find in the self-preparation log
  - Checklists, guidelines are used
- Ideally, should be done in one sitting and issues recorded in a log

Self-Review Log

Project name:

Work product name and ID:

Reviewer Name

Effort spent (hours)

Defect list

No	Location	Description	Criticality

Group Review Meeting

- Purpose – define the final defect list
- Entry criteria – each member has done a proper self-review (logs are reviewed)
- Group review meeting
  - A reviewer goes over the product line by line
  - At any line, all issues are raised
  - Discussion follows to identify if a defect
  - Decision recorded (by the scribe)

Group Review Meeting…

- At the end of the meeting
  - Scribe presents the list of defects/issues
  - If few defects, the work product is accepted; else it might be asked for another review
  - Group does not propose solutions – though some suggestions may be recorded
  - A summary of the inspections is prepared – useful for evaluating effectiveness

Group Review Meeting…

- Moderator is in-charge of the meeting and plays a central role
  - Ensures that focus is on defect detection and solutions are not discussed/proposed
  - Work product is reviewed, not the author of the work product
  - Amicable/orderly execution of the meeting
  - Uses summary report to analyze the overall effectiveness of the review

Summary Report Example

Project	XXXX
Work Product Type	Class AuctionItem
Size of work product	250 LOC of Java
Review team	P1, P2, P3
Effort (person hours)	
Preparation	3 person-hrs (total)
Group meeting	4.5 person-hrs
Total	7.5

Summary Report…

Defects	
No of major defects	3
No of minor defects	8
Total	11
Review status	Accepted
Reco for next phase	Nil
Comments	Code can be improved

Summary Report…

- Defect density found – 3/0.25 = 12 major defects/KLOC
  - Seems OK from experience
  - Similarly for total and minor density
- Preparation rate – about 250/1 = 250 LOC / hr : Seems OK
- Group review rate: 250/1.5 = 180 LOC/hr; seems OK

Rework and Follow Up

- Defects in the defects list are fixed later by the author
- Once fixed, author gets it OKed by the moderator, or goes for another review
- Once all defects/issues are satisfactorily addressed, review is completed and collected data is submitted

Metrics

Metrics for Size

- LOC or KLOC
  - non-commented, non blank lines is a standard definition
  - Generally only new or modified lines are counted
  - Used heavily, though has shortcomings

Metrics for Size…

- Halstead’s Volume
  - n1: no of distinct operators
  - n2: no of distinct operands
  - N1: total occurrences of operators
  - N2: Total occurrences of operands
  - Vocabulary, $n = n1 + n2$
  - Length, $N = N1 + N2$
  - Volume, $V = N \log_2(n)$

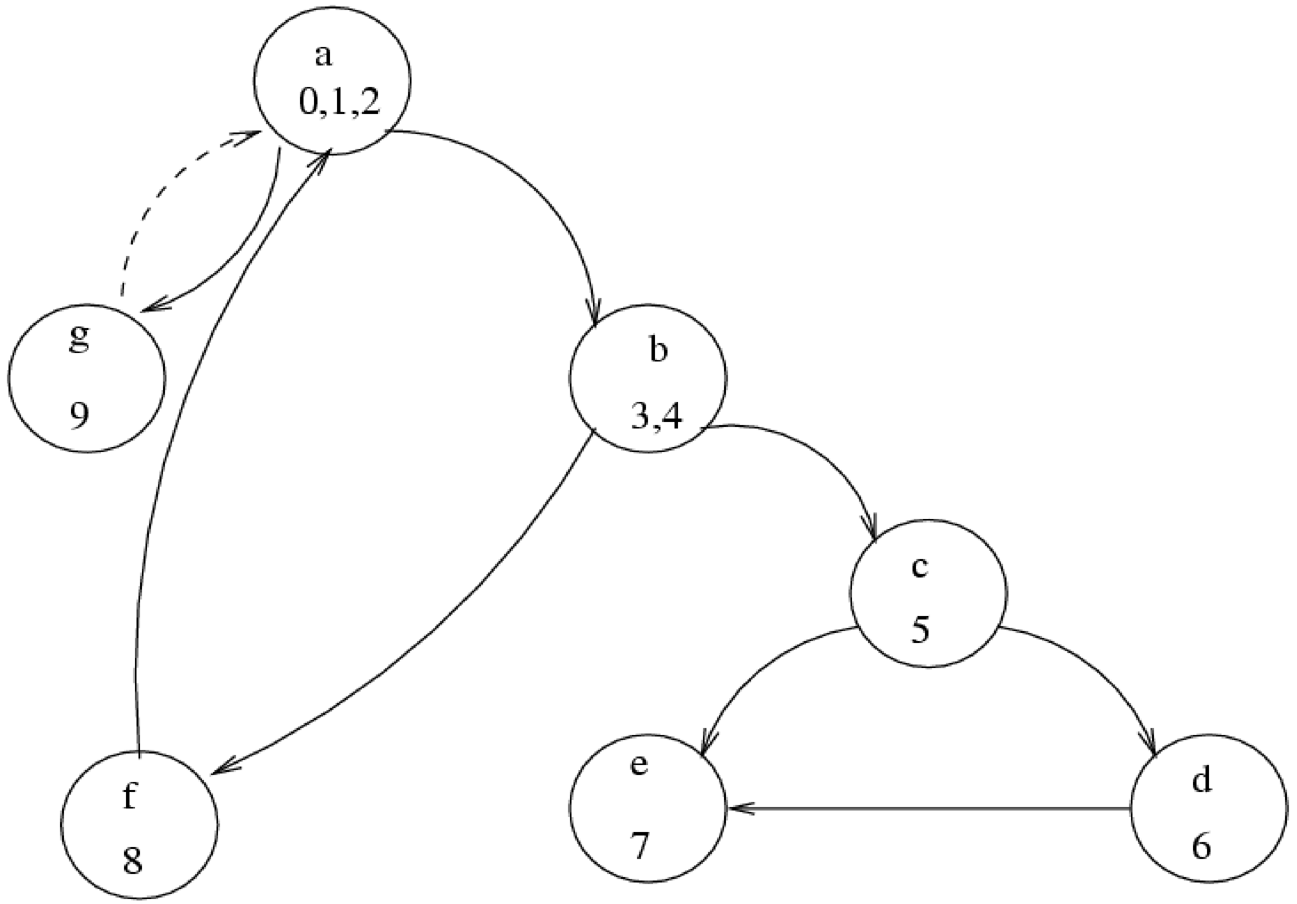
Metrics for Complexity

- Cyclomatic Complexity is perhaps the most widely used measure
- Represents the program by its control flow graph with e edges, n nodes, and p parts
- Cyclomatic complexity is defined as V(G) = e-n+p
- This is same as the number of linearly independent cycles in the graph
- And is same as the number of decisions (conditionals) in the program plus one

Cyclomatic complexity example…

```
{
    i=1;
    while (i<=n) {
       J=1;
       while(j <= i) {
           If (A[i]<A[j])
               Swap(A[i], A[j]);
           J=j+1;}
   i = i+1;}
}
```

Example…



Example…

- V(G) = 10-7+1 = 4
- Independent circuits
  1. b c e b
  2. b c d e b
  3. a b f a
  4. a g a
- No of decisions is 3 (while, while, if); complexity is 3+1 = 4

Complexity metrics…

- Halsteads
  - N2/n2 is avg times an operand is used
  - If vars are changed frequently, this is larger
  - Ease of reading or writing is defined as

$$D = (n1*N2)/(2*n2)$$

- There are others, e.g. live variables, knot count..

Complexity metrics…

- The basic use of these is to reduce the complexity of modules
- One suggestion is that cyclomatic complexity should be less than 10
- Another use is to identify high complexity modules and then see if their logic can be simplified

Summary

- Goal of coding is to convert a design into easy to read code with few bugs
- Good programming practices like structured programming, information hiding, etc can help
- There are many methods to verify the code of a module – unit testing and inspections are most commonly used
- Size and complexity measures are defined and often used; common ones are LOC and cyclomatic complexity

Software Testing

Testing Concepts

Background

- Main objectives of a project: High Quality & High Productivity (Q&P)
- Quality has many dimensions
  - reliability, maintainability, interoperability etc.
- Reliability is perhaps the most important
- Reliability: The chances of software failing
- More defects => more chances of failure => lesser reliability
- Hence Q goal: Have as few defects as possible in the delivered software

Faults & Failure

- Failure: A software failure occurs if the behavior of the s/w is different from expected/specified.
- Fault: cause of software failure
- Fault = bug = defect
- Failure implies presence of defects
- A defect has the potential to cause failure.
- Definition of a defect is environment, project specific

Role of Testing

- Reviews are human processes - can not catch all defects
- Hence there will be requirement defects, design defects and coding defects in code
- These defects have to be identified by testing
- Therefore testing plays a critical role in ensuring quality.
- All defects remaining from before as well as new ones introduced have to be identified by testing.

Detecting defects in Testing

- During testing, software under test (SUT) executed with set of test cases
- Failure during testing => defects are present
- No failure => confidence grows, but can not say "defects are absent"
- To detect defects, must cause failures during testing

Test Oracle

- To check if a failure has occurred when executed with a test case, we need to know the correct behavior
- I.e. need a test oracle, which is often a human
- Human oracle makes each test case expensive as someone has to check the correctness of its output

Test case and test suite

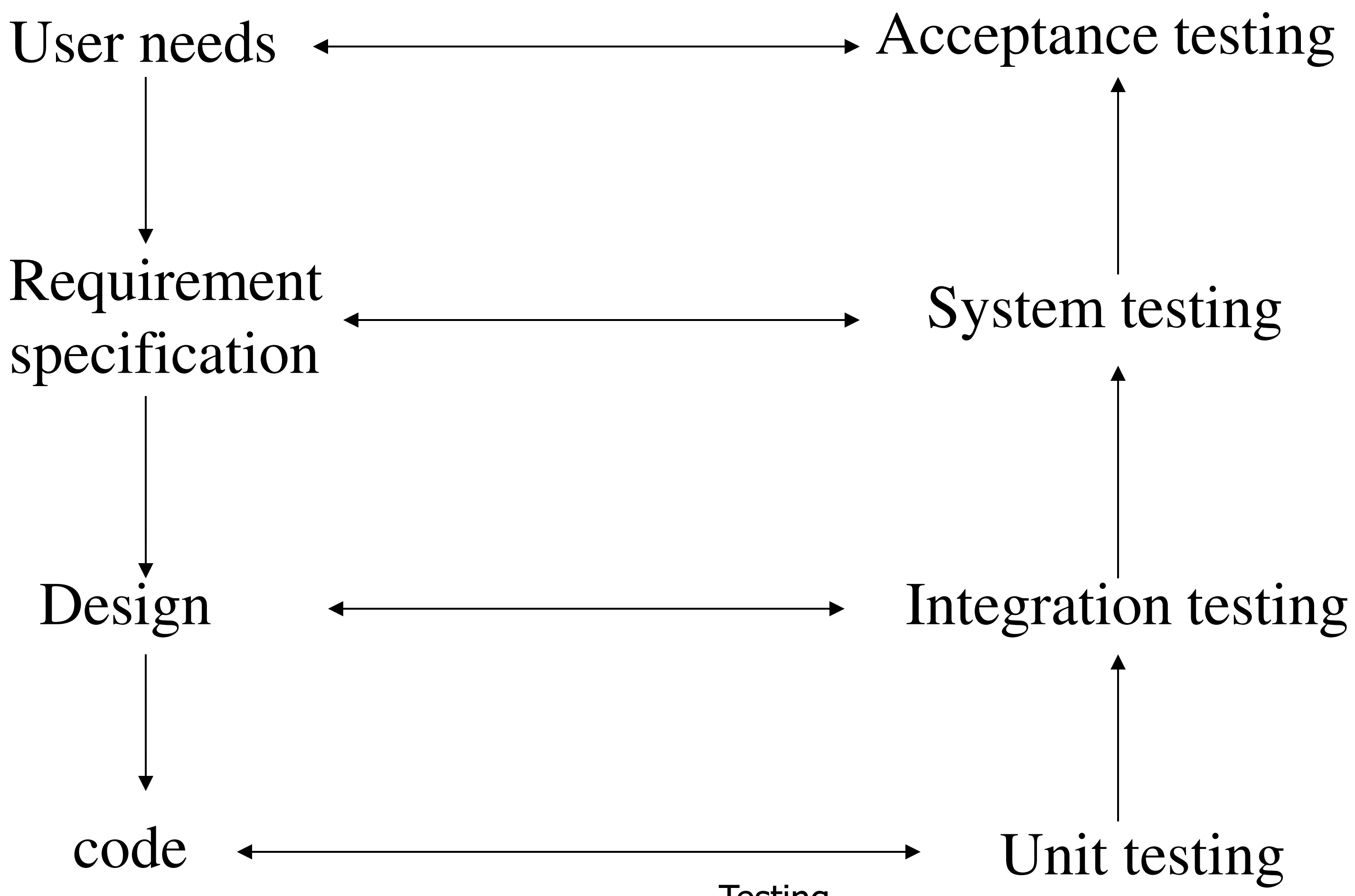
- Test case – a set of test inputs and execution conditions designed to exercise SUT in a particular manner
  - Test case should also specify the expected output – oracle uses this to detect failure
- Test suite - group of related test cases generally executed together

Test harness

- During testing, for each test case in a test suite, conditions have to be set, SUT called with inputs, output checked against expected to declare fail/pass
- Many test frameworks (or test harness) exist that automate the testing process
  - Each test case is often a function/method
  - A test case sets up the conditions, calls the SUT with the required inputs
  - Tests the results through assert statements
  - If any assert fails – declares failure

Levels of Testing

- The code contains requirement defects, design defects, and coding defects
- Nature of defects is different for different injection stages
- One type of testing will be unable to detect the different types of defects
- Different levels of testing are used to uncover these defects


User needs
Acceptance testing
Requirement specification
System testing
Design
Integration testing
code
Unit testing

Unit Testing

- Different modules tested separately
- Focus: defects injected during coding
- Essentially a code verification technique, covered in previous chapter
- UT is closely associated with coding
- Frequently the programmer does UT; coding phase sometimes called "coding and unit testing"

Integration Testing

- Focuses on interaction of modules in a subsystem
- Unit tested modules combined to form subsystems
- Test cases to “exercise” the interaction of modules in different ways
- May be skipped if the system is not too large

System Testing

- Entire software system is tested
- Focus: does the software implement the requirements?
- Validation exercise for the system with respect to the requirements
- Generally the final testing stage before the software is delivered
- May be done by independent people
- Defects removed by developers
- Most time consuming test phase

Acceptance Testing

- Focus: Does the software satisfy user needs?
- Generally done by end users/customer in customer environment, with real data
- Only after successful AT software is deployed
- Any defects found,are removed by developers
- Acceptance test plan is based on the acceptance test criteria in the SRS

Other forms of testing

- Performance testing
  - tools needed to “measure” performance
- Stress testing
  - load the system to peak, load generation tools needed
- Regression testing
  - test that previous functionality works alright
  - important when changes are made
  - Previous test records are needed for comparisons
  - Prioritization of testcases needed when complete test suite cannot be executed for a change

Testing Process

Testing

- Testing only reveals the presence of defects
- Does not identify nature and location of defects
- Identifying & removing the defect => role of debugging and rework
- Preparing test cases, performing testing, defects identification & removal all consume effort
- Overall testing becomes very expensive : 30-50% development cost

Testing…

- Multiple levels of testing are done in a project
- At each level, for each SUT, test cases have to be designed and then executed
- Overall, testing is very complex in a project and has to be done well
- Testing process at a high level has: test planning, test case design, and test execution

Test Plan

- Testing usually starts with test plan and ends with acceptance testing
- Test plan is a general document that defines the scope and approach for testing for the whole project
- Inputs are SRS, project plan, design
- Test plan identifies what levels of testing will be done, what units will be tested, etc in the project

Test Plan…

- Test plan usually contains
  - Test unit specs: what units need to be tested separately
  - Features to be tested: these may include functionality, performance, usability,…
  - Approach: criteria to be used, when to stop, how to evaluate, etc
  - Test deliverables
  - Schedule and task allocation

Test case Design

- Test plan focuses on testing a project; does not focus on details of testing a SUT
- Test case design has to be done separately for each SUT
- Based on the plan (approach, features,..) test cases are determined for a unit
- Expected outcome also needs to be specified for each test case

Test case design…

- Together the set of test cases should detect most of the defects
- Would like the set of test cases to detect any defects, if it exists
- Would also like set of test cases to be small - each test case consumes effort
- Determining a reasonable set of test case is the most challenging task of testing

Test case design

- The effectiveness and cost of testing depends on the set of test cases
- Q: How to determine if a set of test cases is good? I.e. the set will detect most of the defects, and a smaller set cannot catch these defects
- No easy way to determine goodness; usually the set of test cases is reviewed by experts
- This requires test cases be specified before testing – a key reason for having test case specs
- Test case specs are essentially a table

Test case specifications

Seq.No	Condition to be tested	Test Data	Expected result	successful

Test case specifications…

- So for each testing, test case specs are developed, reviewed, and executed
- Preparing test case specifications is challenging and time consuming
  - Test case criteria can be used
  - Special cases and scenarios may be used
- Once specified, the execution and checking of outputs may be automated through scripts
  - Desired if repeated testing is needed
  - Regularly done in large projects

Test case execution

- Executing test cases may require drivers or stubs to be written; some tests can be auto, others manual
  - A separate test procedure document may be prepared
- Test summary report is often an output – gives a summary of test cases executed, effort, defects found, etc
- Monitoring of testing effort is important to ensure that sufficient time is spent
- Computer time also is an indicator of how testing is proceeding

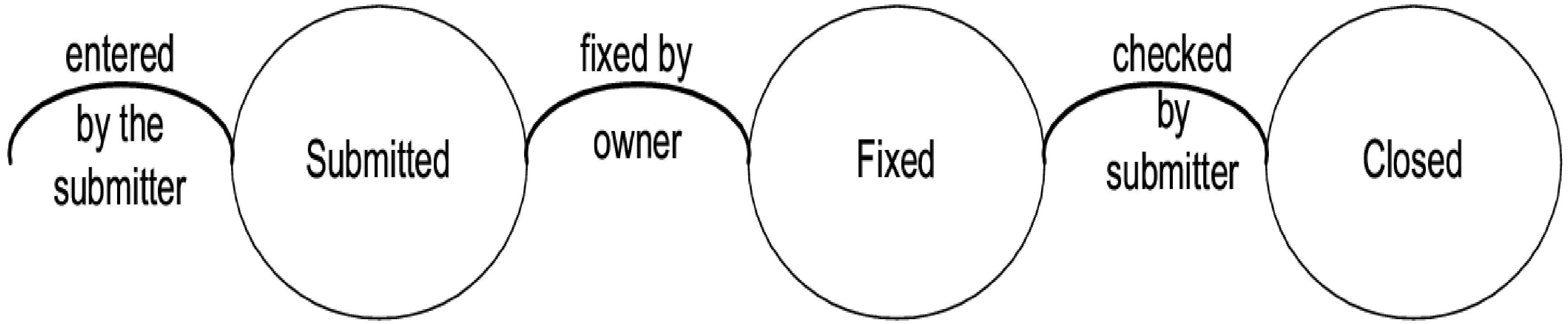
Defect logging and tracking

- A large software may have thousands of defects, found by many different people
- Often person who fixes (usually the coder) is different from who finds
- Due to large scope, reporting and fixing of defects cannot be done informally
- Defects found are usually logged in a defect tracking system and then tracked to closure
- Defect logging and tracking is one of the best practices in industry

Defect logging…

- A defect in a software project has a life cycle of its own, like
  - Found by someone, sometime and logged along with info about it (submitted)
  - Job of fixing is assigned; person debugs and then fixes (fixed)
  - The manager or the submitter verifies that the defect is indeed fixed (closed)
- More elaborate life cycles possible

Defect logging…



Defect logging…

- During the life cycle, info about defect is logged at diff stages to help debug as well as analysis
- Defects generally categorized into a few types, and type of defects is recorded
  - ODC is one classification
  - Some std categories: Logic, standards, UI, interface, performance, documentation,..

Defect logging…

- Severity of defects in terms of its impact on sw is also recorded
- Severity useful for prioritization of fixing
- One categorization
  - Critical: Show stopper
  - Major: Has a large impact
  - Minor: An isolated defect
  - Cosmetic: No impact on functionality

Defect logging…

- Ideally, all defects should be closed
- Sometimes, organizations release software with known defects (hopefully of lower severity only)
- Organizations have standards for when a product may be released
- Defect log may be used to track the trend of how defect arrival and fixing is happening

Black Box Testing

Role of Test cases

- Ideally would like the following for test cases
  - No failure implies “no defects” or “high quality”
  - If defects present, then some test case causes a failure
- Role of test cases is clearly very critical
- Only if test cases are “good”, the confidence increases after testing

Test case design

- During test planning, have to design a set of test cases that will detect defects present
- Some criteria needed to guide test case selection
- Two approaches to design test cases
  - functional or black box
  - structural or white box
- Both are complimentary; we discuss a few approaches/criteria for both

Black Box testing

- Software tested to be treated as a block box
- Specification for the black box is given
- The expected behavior of the system is used to design test cases
- i.e test cases are determined solely from specification.
- Internal structure of code not used for test case design

Black box Testing…

- Premise: Expected behavior is specified.
- Hence just test for specified expected behavior
- How it is implemented is not an issue.
- For modules,specification produced in design specify expected behavior
- For system testing, SRS specifies expected behavior

Black Box Testing…

- Most thorough functional testing - exhaustive testing
  - Software is designed to work for an input space
  - Test the software with all elements in the input space
- Infeasible - too high a cost
- Need better method for selecting test cases
- Different approaches have been proposed

Equivalence Class partitioning

- Divide the input space into equivalent classes
- If the software works for a test case from a class the it is likely to work for all
- Can reduce the set of test cases if such equivalent classes can be identified
- Getting ideal equivalent classes is impossible
- Approximate it by identifying classes for which different behavior is specified

Equivalence class partitioning…

- Rationale: specification requires same behavior for elements in a class
- Software likely to be constructed such that it either fails for all or for none.
- E.g. if a function was not designed for negative numbers then it will fail for all the negative numbers
- For robustness, should form equivalent classes for invalid inputs also

Equivalent class partitioning..

- Every condition specified as input is an equivalent class
- Define invalid equivalent classes also
- E.g. range 0< value<Max specified
  - one range is the valid class
  - input < 0 is an invalid class
  - input > max is an invalid class
- Whenever that entire range may not be treated uniformly - split into classes

Equivalent class partitioning..

- Should consider eq. classes in outputs also and then give test cases for different classes
- E.g.: Compute rate of interest given loan amount, monthly installment, and number of months
  - Equivalent classes in output: + rate, rate = 0 ,-ve rate
  - Have test cases to get these outputs

Equivalence class…

- Once eq classes selected for each of the inputs, test cases have to be selected
  - Select each test case covering as many valid eq classes as possible
  - Or, have a test case that covers at most one valid class for each input
  - Plus a separate test case for each invalid class

Example

- Consider a program that takes 2 inputs – a string s and an integer n
- Program determines n most frequent characters
- Tester believes that programmer may deal with diff types of chars separately
- A set of valid and invalid equivalence classes is given

Example..

Input	Valid Eq Class	Invalid Eq class
S	1: Contains numbers 2: Lower case letters 3: upper case letters 4: special chars 5: str len between 0-N(max)	1: non-ascii char 2: str len > N
N	6: Int in valid range	3: Int out of range

Example…

- Test cases (i.e. s , n) with first method
  - s : str of len < N with lower case, upper case, numbers, and special chars, and n=5
  - Plus test cases for each of the invalid eq classes
  - Total test cases: 1+3= 4
- With the second approach
  - A separate str for each type of char (i.e. a str of numbers, one of lower case, …) + invalid cases
  - Total test cases will be 5 + 2 = 7

Boundary value analysis

- Programs often fail on special values
- These values often lie on boundary of equivalence classes
- Test cases that have boundary values have *high yield*
- These are also called *extreme cases*
- A BV test case is a set of input data that lies on the edge of a eq class of input/output

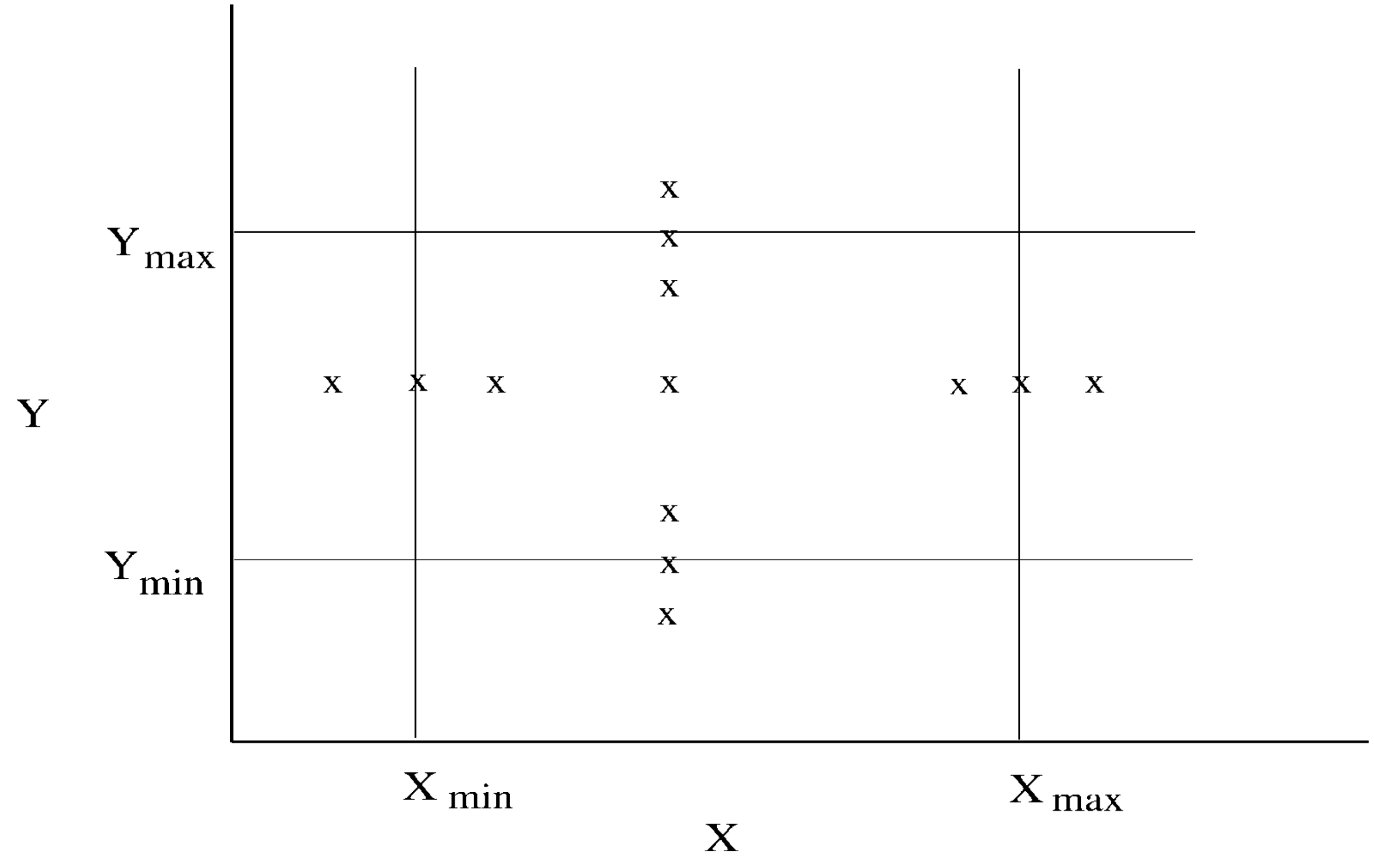
BVA…

- For each equivalence class
  - choose values on the edges of the class
  - choose values just outside the edges
- E.g. if 0 <= x <= 1.0
  - 0.0 , 1.0 are edges inside
  - -0.1,1.1 are just outside
- E.g. a bounded list - have a null list , a maximum value list
- Consider outputs also and have test cases generate outputs on the boundary

BVA…

- In BVA we determine the value of vars that should be used
- If input is a defined range, then there are 6 boundary values plus 1 normal value (tot: 7)
- If multiple inputs, how to combine them into test cases; two strategies possible
  - Try all possible combination of BV of diff variables, with n vars this will have 7^n test cases!
  - Select BV for one var; have other vars at normal values + 1 of all normal values

BVA.. (test cases for two vars – x and y)



Pair-wise testing

- Often many parmeters determine the behavior of a software system
- The parameters may be inputs or settings, and take diff values (or diff value ranges)
- Many defects involve one condition (single-mode fault), eg. sw not being able to print on some type of printer
  - Single mode faults can be detected by testing for different values of diff parms
  - If n parms and each can take m values, we can test for one diff value for each parm in each test case
  - Total test cases: m

Pair-wise testing…

- All faults are not single-mode and sw may fail at some combinations
  - Eg tel billing sw does not compute correct bill for night time calling (one parm) to a particular country (another parm)
  - Eg ticketing system fails to book a biz class ticket (a parm) for a child (a parm)
- Multi-modal faults can be revealed by testing diff combination of parm values
- This is called combinatorial testing

Pair-wise testing…

- Full combinatorial testing not feasible
  - For n parms each with m values, total combinations are n^m
  - For 5 parms, 5 values each (tot: 3125), if one test is 5 mts, tot time > 1 month!
- Research suggests that most such faults are revealed by interaction of a pair of values
- I.e. most faults tend to be double-mode
- For double mode, we need to exercise each pair – called pair-wise testing

Pair-wise testing…

- In pair-wise, all pairs of values have to be exercised in testing
- If n parms with m values each, between any 2 parms we have m*m pairs
  - 1st parm will have m*m with n-1 others
  - 2nd parm will have m*m pairs with n-2
  - 3rd parm will have m*m pairs with n-3, etc.
  - Total no of pairs are m*m*n*(n-1)/2

Pair-wise testing…

- A test case consists of some setting of the n parameters
- Smallest set of test cases when each pair is covered once only
- A test case can cover a maximum of $(n-1)+(n-2)+\ldots=n(n-1)/2$ pairs
- In the best case when each pair is covered exactly once, we will have m^2 different test cases providing the full pair-wise coverage

Pair-wise testing…

- Generating the smallest set of test cases that will provide pair-wise coverage is non-trivial
- Efficient algos exist; efficiently generating these test cases can reduce testing effort considerably
  - In an example with 13 parms each with 3 values pair-wise coverage can be done with 15 testcases
- Pair-wise testing is a practical approach that is widely used in industry

Pair-wise testing, Example

- A sw product for multiple platforms and uses browser as the interface, and is to work with diff OSs
- We have these parms and values
  - OS (parm A): Windows, Solaris, Linux
  - Mem size (B): 128M, 256M, 512M
  - Browser (C): IE, Netscape, Mozilla
- Total no of pair wise combinations: 27
- No of cases can be less

Pair-wise testing…

Test case	Pairs covered
a1, b1, c1	(a1,b1) (a1, c1) (b1,c1)
a1, b2, c2	(a1,b2) (a1,c2) (b2,c2)
a1, b3, c3	(a1,b3) (a1,c3) (b3,c3)
a2, b1, c2	(a2,b1) (a2,c2) (b1,c2)
a2, b2, c3	(a2,b2) (a2,c3) (b2,c3)
a2, b3, c1	(a2,b3) (a2,c1) (b3,c1)
a3, b1, c3	(a3,b1) (a3,c3) (b1,c3)
a3, b2, c1	(a3,b2) (a3,c1) (b2,c1)
a3, b3, c2	(a3,b3) (a3,c2) (b3,c2)

Special cases

- Programs often fail on special cases
- These depend on nature of inputs, types of data structures,etc.
- No good rules to identify them
- One way is to guess when the software might fail and create those test cases
- Also called error guessing
- Play the sadist & hit where it might hurt

Error Guessing

- Use experience and judgement to guess situations where a programmer might make mistakes
- Special cases can arise due to assumptions about inputs, user, operating environment, business, etc.
- E.g. A program to count frequency of words
  - file empty, file non existent, file only has blanks, contains only one word, all words are same, multiple consecutive blank lines, multiple blanks between words, blanks at the start, words in sorted order, blanks at end of file, etc.
- Perhaps the most widely used in practice

State-based Testing

- Some systems are state-less: for same inputs, same behavior is exhibited
- Many systems' behavior depends on the state of the system i.e. for the same input the behavior could be different
- I.e. behavior and output depend on the input as well as the system state
- System state – represents the cumulative impact of all past inputs
- State-based testing is for such systems

State-based Testing…

- A system can be modeled as a state machine
- The state space may be too large (is a cross product of all domains of vars)
- The state space can be partitioned in a few states, each representing a logical state of interest of the system
- State model is generally built from such states

State-based Testing…

- A state model has four components
  - States: Logical states representing cumulative impact of past inputs to system
  - Transitions: How state changes in response to some events
  - Events: Inputs to the system
  - Actions: The outputs for the events

State-based Testing…

- State model shows what transitions occur and what actions are performed
- Often state model is built from the specifications or requirements
- The key challenge is to identify states from the specs/requirements which capture the key properties but is small enough for modeling

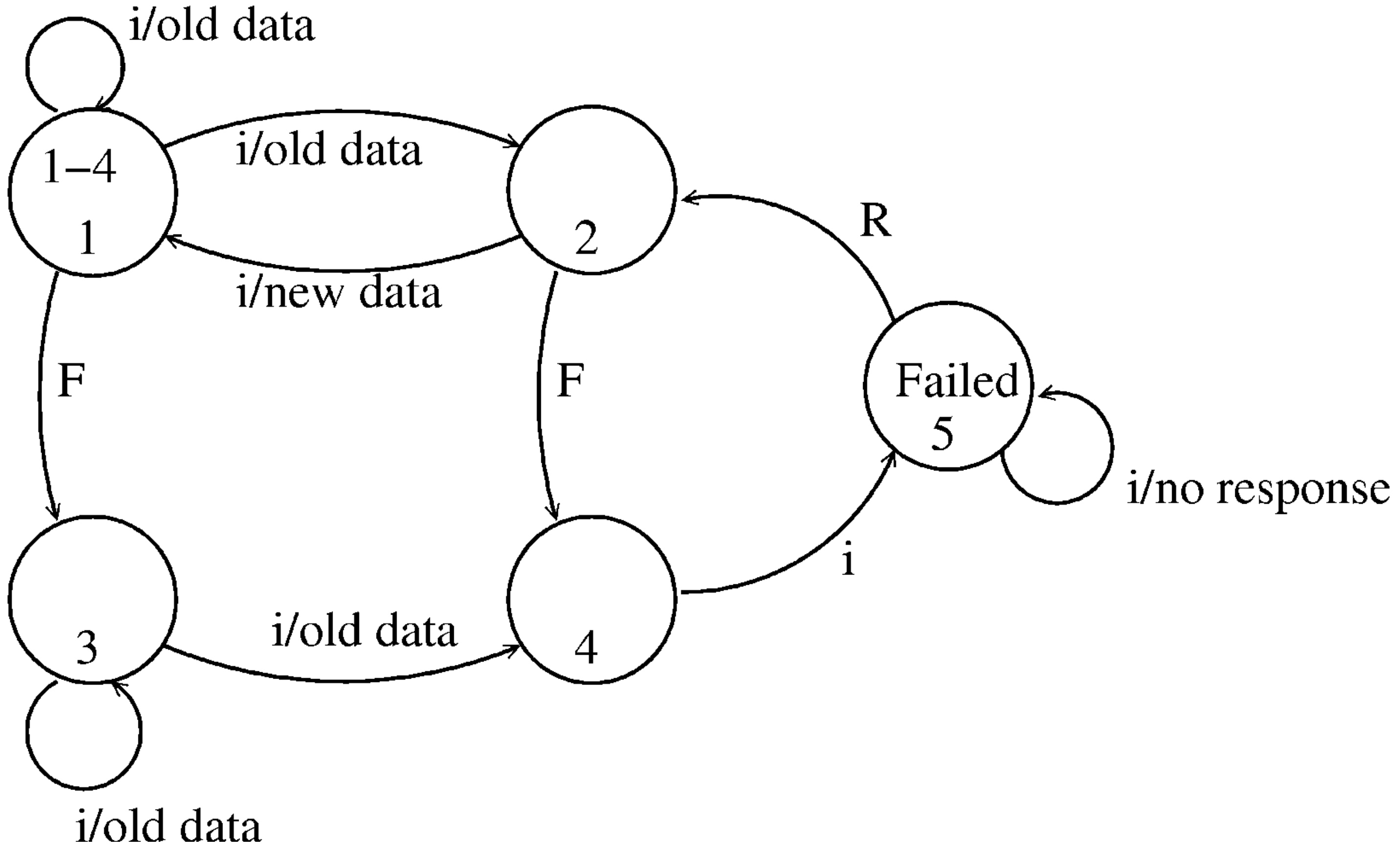
State-based Testing, example…

- Consider the student survey example (discussed in Chap 4)
    - A system to take survey of students
    - Student submits survey and is returned results of the survey so far
    - The result may be from the cache (if the database is down) and can be up to 5 surveys old

State-based Testing, example…

- In a series of requests, first 5 may be treated differently
- Hence, we have two states: one for req no 1-4 (state 1), and other for 5 (2)
- The db can be up or down, and it can go down in any of the two states (3-4)
- Once db is down, the system may get into failed state (5), from where it may recover

State-based Testing, example…



State-based Testing…

- State model can be created from the specs or the design
- For objects, state models are often built during the design process
- Test cases can be selected from the state model and later used to test an implementation
- Many criteria possible for test cases

State-based Testing criteria

- All transaction coverage (AT): test case set T must ensure that every transition is exercised
- All transitions pair coverage (ATP). T must execute all pairs of adjacent transitions (incoming and outgoing transition in a state)
- Transition tree coverage (TT). T must execute all simple paths (i.e. a path from start to end or a state it has visited)

Example, test cases for AT criteria

SNo	Transition	Test case
1	1 -> 2	Req()
2	1 -> 2	Req(); req(); req(); req();req(); req()
3	2 -> 1	Seq for 2; req()
4	1 -> 3	Req(); fail()
5	3 -> 3	Req(); fail(); req()
6	3 -> 4	Req(); fail(); req(); req(); req();req(); req()
7	4 -> 5	Seq for 6; req()
8	5 -> 2	Seq for 6; req(); recover()

State-based testing…

- SB testing focuses on testing the states and transitions to/from them
- Different system scenarios get tested; some easy to overlook otherwise
- State model is often done after design information is available
- Hence it is sometimes called *grey box testing* (as it not pure black box)

White Box Testing

White box testing

- Black box testing focuses only on functionality
  - What the program does; not how it is implemented
- White box testing focuses on implementation
  - Aim is to exercise different program structures with the intent of uncovering errors
- Is also called *structural testing*
- Various criteria exist for test case design
- Test cases have to be selected to satisfy coverage criteria

Types of structural testing

- Control flow based criteria
  - looks at the coverage of the control flow graph
- Data flow based testing
  - looks at the coverage in the definition-use graph
- Mutation testing
  - looks at various mutants of the program
- We will discuss only control flow based criteria – these are most commonly used

Control flow based criteria

- Considers the program as control flow graph
  - Nodes represent code blocks – i.e. set of statements always executed together
  - An edge (i,j) represents a possible transfer of control from i to j
- Assume a start node and an end node
- A path is a sequence of nodes from start to end

Statement Coverage Criterion

- Criterion: Each statement is executed at least once during testing
- I.e. set of paths executed during testing should include all nodes
- Limitation: does not require a decision to evaluate to false if no else clause
- E.g. : abs (x) : if (x>=0) x = -x; return(x)
  - The set of test cases {x = 0} achieves 100% statement coverage, but error not detected
- Guaranteeing 100% coverage not always possible due to possibility of unreachable nodes

Branch coverage

- Criterion: Each edge should be traversed at least once during testing
- i.e. each decision must evaluate to both true and false during testing
- Branch coverage implies stmt coverage
- If multiple conditions in a decision, then all conditions need not be evaluated to T and F

Control flow based…

- There are other criteria too - path coverage, predicate coverage, cyclomatic complexity based, ...
- None is sufficient to detect all types of defects (e.g. a program missing some paths cannot be detected)
- They provide some quantitative handle on the breadth of testing
- More used to evaluate the level of testing rather than selecting test cases

Tool support and test case selection

- Two major issues for using these criteria
  - How to determine the coverage
  - How to select test cases to ensure coverage
- For determining coverage - tools are essential
- Tools also tell which branches and statements are not executed
- Test case selection is mostly manual - test plan is to be augmented based on coverage data

In a Project

- Both functional and structural should be used
- Test plans are usually determined using functional methods; during testing, for further rounds, based on the coverage, more test cases can be added
- Structural testing is useful at lower levels only; at higher levels ensuring coverage is difficult
- Hence, a combination of functional and structural at unit testing
- Functional testing (but monitoring of coverage) at higher levels

Comparison

	Code Review	Structural Testing	Functional Testing
Computational	M	H	M
Logic	M	H	M
I/O	H	M	H
Data handling	H	L	H
Interface	H	H	M
Data defn.	M	L	M
Database	H	M	M

Metrics

Data

- Defects found are generally logged
- The log forms the basic data source for metrics and analysis during testing
- Main questions of interest for which metrics can be used
  - How good is the testing that has been done so far?
  - What is the quality or reliability of software after testing is completed?

Coverage Analysis

- Coverage is very commonly used to evaluate the thoroughness of testing
- This is not white box testing, but evaluating the overall testing through coverage
- Organization sometimes have guidelines for coverage, particularly at unit level (say 90% before checking code in)
- Coverage of requirements also checked – often by evaluating the test suites against requirements

Reliability Estimation

- High reliability is an important goal to be achieved by testing
- Reliability is usually quantified as a probability or a failure rate or mean time to failure
  - $R(t) = P(X > t)$
  - MTTF = mean time to failure
  - Failure rate
- For a system reliability can be measured by counting failures over a period of time
- Measurement often not possible for software as due to fixes reliability changes, and with one-off, not possible to measure

Reliability Estimation…

- Sw reliability estimation models are used to model the failure followed by fix model of software
- Data about failures and their times during the last stages of testing is used by these model
- These models then use this data and some statistical techniques to predict the reliability of the software
- Software reliability growth models are quite complex and sophisticated

Reliability Estimation

- Simple method of measuring reliability achieved during testing
  - Failure rate, measured by no of failures in some duration
- For using this for prediction, assumed that during this testing software is used as it will be by users
- Execution time is often used for failure rate, it can be converted to calendar time

Defect removal efficiency

- Basic objective of testing is to identify defects present in the programs
- Testing is good only if it succeeds in this goal
- Defect removal efficiency of a QC activity = % of present defects detected by that QC activity
- High DRE of a quality control activity means most defects present at the time will be removed

Defect removal efficiency …

- DRE for a project can be evaluated only when all defects are know, including delivered defects
- Delivered defects are approximated as the number of defects found in some duration after delivery
- The *injection stage* of a defect is the stage in which it was introduced in the software, and *detection stage* is when it was detected
  - These stages are typically logged for defects
- With injection and detection stages of all defects, DRE for a QC activity can be computed

Defect Removal Efficiency …

- DREs of different QC activities are a process property - determined from past data
- Past DRE can be used as expected value for this project
- Process followed by the project must be improved for better DRE

Summary

- Testing plays a critical role in removing defects, and in generating confidence
- Testing should be such that it catches most defects present, i.e. a high DRE
- Multiple levels of testing needed for this
- Incremental testing also helps
- At each testing, test cases should be specified, reviewed, and then executed

Summary …

- Deciding test cases during planning is the most important aspect of testing
- Two approaches – black box and white box
- Black box testing - test cases derived from specifications.
  - Equivalence class partitioning, boundary value, cause effect graphing, error guessing
- White box - aim is to cover code structures
  - statement coverage, branch coverage

Summary…

- In a project both used at lower levels
  - Test cases initially driven by functional
  - Coverage measured, test cases enhanced using coverage data
- At higher levels, mostly functional testing done; coverage monitored to evaluate the quality of testing
- Defect data is logged, and defects are tracked to closure
- The defect data can be used to estimate reliability, DRE