Lesson -4 Project Planning

4.0 Objectives

Project planning is an important issue in the successful completion of a software project. The objective of this lesson is to make the students familiar with the factors affecting the cost of the software, different versions of COCOMO and the problems and criteria to evaluate the models.

4.1 Introduction

Software cost estimation is the process of predicting the amount of effort required to build a software system. Software cost estimation is one of the most difficult and error prone task in software engineering. Cost estimates are needed throughout the software lifecycle. Preliminary estimates are required to determine the feasibility of a project. Detailed estimates are needed to assist with project planning. The actual effort for individual tasks is compared with estimated and planned values, enabling project managers to reallocate resources when necessary. Analysis of historical project data indicates that cost trends can be correlated with certain measurable parameters. This observation has resulted in a wide range of models that can be used to assess, predict, and control software costs on a real- time basis. Models provide one or more mathematical algorithms that compute cost as a function of a number of variables.

4.2 Cost factor

There are a number of factors affecting the cost of the software. The major one are listed below:

- **Programmer ability:** Results of the experiments conducted by Sackman show a significant difference in individual performance among the programmers. The difference between best and worst performance were factors of 6 to I in program size, 8 to 1 in execution time, 9 to 1 in development time, 18 to 1 in coding time, and 28 to 1 in debugging time.
- **Product Complexity:** There are generally three acknowledged category of the software: application programs, utility programs and system programs. According to Brook utility programs are three times as difficult to write as application programs, and that system programs are three times as difficult to write as utility programs. So it is a major factor influencing the cost of software.
- **Product Size:** It is obvious that a large software product will be more expensive than a smaller one.

➢ **Available time:** It is generally agreed that software projects require more total efforts if development time is compressed or expanded from the optimal time.

➢ **Required reliability:** Software reliability can be defined as the probability that a program will perform a required function under stated conditions for a stated period of time. Reliability can be improved in a software, but there is a cost associated with the increased level of analysis, design, implementation, verification and validation efforts that must be exerted to ensure high reliability.

➢ **Level of technology:** The level of technology is reflected by the

programming language, abstract machine, programming practices and software tools used. Using a high level language instead of assembly language will certainly improve the productivity of programmer thus resulting into a decrease in the cost of software.

4.3 COCOMO’81

Boehm's COCOMO model is one of the mostly used models commercially. The first version of the model delivered in 1981 and COCOMO II is available now. COCOMO 81 is a model designed by Barry Boehm to give an estimate of the number of man-months it will take to develop a software product. This "Constructive Cost Estimation Model" is based on a study of about sixty projects at TRW,

a Californian automotive and IT company, acquired by Northrop Grumman in late 2002. The programs examined ranged in size from 2000 to 100,000 lines of code, and programming languages used ranged from assembly to PL/I. COCOMO consists of a hierarchy of three increasingly detailed and accurate forms.

✓ Basic COCOMO - is a static, single-valued model that computes software development effort (and cost) as a function of program size expressed in estimated lines of code.

✓ Intermediate COCOMO - computes software development effort as function of program size and a set of "cost drivers" that include subjective assessment of product, hardware, personnel and project attributes.

✓ Detailed COCOMO - incorporates all characteristics of the intermediate version with an assessment of the cost driver's impact on each step (analysis, design, etc.) of the software engineering process.

4.3.1 Basic COCOMO 81

Basic COCOMO is a form of the COCOMO model. COCOMO may be applied

to three classes of software projects. These give a general impression of the software project.

- **Organic projects** – These are relatively small, simple software projects in

  which small teams with good application experience work to a set of less than rigid requirements.
- **Semi-detached projects** – These are intermediate (in size and complexity) software projects in which teams with mixed experience levels must meet a mix of rigid and less than rigid requirements.
- **Embedded projects** – These are software projects that must be developed within a set of tight hardware, software, and operational constraints.

	Size	Innovation	Deadline/constraints	Dev. Environment
Organic	Small	Little	Not tight	Stable
Semi-detached	Medium	Medium	Medium	Medium
Embedded	Large	Greater	Tight	Complex H/W /customer interfaces

Table 4.1 Three classes of S/W projects for COCOMO The basic COCOMO equations take the form

$$E=a\,(KLOC)^{b}$$

$$D=c\,(E)^{d}$$

$$P=E/D$$

where E is the effort applied in person-months, D is the development time in chronological months, KLOC is the estimated number of delivered lines of code for the project (expressed in thousands), and P is the number of people required. The coefficients a_b, b_b, c_b and d_b are given in the table 4.2.

Software project	a	b	c	D
Organic	2.4	1.05	2.5	0.38
Semi-detached	3.0	1.12	2.5	0.35
Embedded	3.6	1.20	2.5	0.32

Table 4.2 Coefficients for Basic COCOMO

Basic COCOMO is good for quick, early, rough order of magnitude estimates of software costs, but its accuracy is necessarily limited because of its lack of factors to account for differences in hardware constraints, personnel quality and experience, use of modern tools and techniques, and other project attributes known to have a significant influence on software costs.

4.3.2 Intermediate COCOMO 81

The Intermediate COCOMO is an extension of the Basic COCOMO model, and

is used to estimate the programmer time to develop a software product. This extension considers a set of "cost driver attributes" that can be grouped into four major categories, each with a number of subcategories:

™ Product attributes

- ➢ Required software reliability (RELY)
- ➢ Size of application database (DATA)
- ➢ Complexity of the product (CPLX)

™ Hardware attributes

- ➢ Execution-time constraints (TIME)

- Main Storage Constraints (STOR)

- Volatility of the virtual machine environment (VIRT)

➢ Required turnabout time (TURN)

™ Personnel attributes

➢ Analyst capability (ACAP)

➢ Programmer capability (PCAP)

➢ Applications experience (AEXP)

➢ Virtual machine experience (VEXP)

➢ Programming language experience (LEXP)

™ Project attributes

➢ Use of software tools (TOOL)

➢ Modern Programming Practices (MODP)

➢ Required development schedule (SCED)

Each of the 15 attributes is rated on a 6-point scale that ranges from "very low"

to "extra high" (in importance or value). Based on the rating, an effort multiplier is determined from the table below. The product of all effort multipliers results in an

'effort adjustment factor (EAF). Typical values for EAF range from 0.9 to 1.4 as shown in table 4.3.

Cost Drivers	Ratings					
	Very Low	Low	Nominal	High	Very High	Extra High
RELY	0.75	0.88	1.00	1.15	1.40	
DATA		0.94	1.00	1.08	1.16	
CPLX	0.70	0.85	1.00	1.15	1.30	1.65
TIME			1.00	1.11	1.30	1.66
STOR			1.00	1.06	1.21	1.56
VIRT		0.87	1.00	1.15	1.30	

TURN		0.87	1.00	1.07	1.15	
ACAP	1.46	1.19	1.00	0.86	0.71	
PCAP	1.29	1.13	1.00	0.91	0.82	
AEXP	1.42	1.17	1.00	0.86	0.70	
VEXP	1.21	1.10	1.00	0.90		
LEXP	1.14	1.07	1.00	0.95		
TOOL	1.24	1.10	1.00	0.91	0.82	

MODP	1.24	1.10	1.00	0.91	0.83	
SCED	1.23	1.08	1.00	1.04	1.10	

Table 4.3 Effort adjustment factor

The Intermediate COCOMO formula now takes the form...

$E=a\ (KLOC)^{(b)}.EAF$

Where E is the effort applied in person-months, KLOC is the estimated number

of thousands of delivered lines of code for the project and EAF is the factor calculated above. The coefficient a and the exponent b are given in the next table.

Software project	a	b
Organic	3.2	1.05
Semi-detached	3.0	1.12
Embedded	2.8	1.20

Table 4.4 Coefficients for intermediate COCOM

The Development time D is calculated from E in the same way as with Basic

COCOMO.

The steps in producing an estimate using the intermediate model COCOMO'81

are:

1. Identify the mode (organic, semi-detached, or embedded) of development for the new product.
2. Estimate the size of the project in KLOC to derive a nominal effort prediction.
3. Adjust 15 cost drivers to reflect your project.

4. Calculate the predicted project effort using first equation and the effort adjustment factor (EAF)
5. Calculate the project duration using second equation.

Example estimate using the intermediate COCOMO'81

Mode is organic

Size = 200KDSI

Cost drivers:

- Low reliability => .88
- High product complexity => 1.15
- Low application experience => 1.13
- High programming language experience => .95
- Other cost drivers assumed to be nominal => 1.00

C = .88 * 1.15 * 1.13 * .95 = 1.086

Effort = 3.2 * ($200^{1.05}$) * 1.086 = 906 MM

Development time = 2.5 * $906^{0.38}$

4.3.3 Detailed COCOMO

The Advanced COCOMO model computes effort as a function of program size and a set of cost drivers weighted according to each phase of the software lifecycle. The Advanced model applies the Intermediate model at the component level, and then a phase-based approach is used to consolidate the estimate.

The 4 phases used in the detailed COCOMO model are: requirements planning and product design (RPD), detailed design (DD), code and unit test (CUT), and integration and test (IT). Each cost driver is broken down by phase as in the example shown in Table 4.5.

Cost Driver	Rating	RPD	DD	CUT	IT
ACAP	Very Low	1.80	1.35	1.35	1.50
	Low	0.85	0.85	0.85	1.20
	Nominal	1.00	1.00	1.00	1.00
	High	0.75	0.90	0.90	0.85
	Very High	0.55	0.75	0.75	0.70

Table 4.5 Analyst capability effort multiplier for Detailed COCOMO Estimates made for each module are combined into subsystems and eventually

an overall project estimate. Using the detailed cost drivers, an estimate is determined for each phase of the lifecycle.

Advantages of COCOMO'81

- COCOMO is transparent; you can see how it works unlike other models such as SLIM.
- Drivers are particularly helpful to the estimator to understand the impact of different factors that affect project costs.

Drawbacks of COCOMO'81

- It is hard to accurately estimate KDSI early on in the project, when most effort estimates are required.
  - KDSI, actually, is not a size measure it is a length measure.
- Extremely vulnerable to mis-classification of the development mode
- Success depends largely on tuning the model to the needs of the organization, using historical data which is not always available

Lesson -5

Software Requirement Analysis &Specification

5.1 Introduction

The analysis phase of software development is concerned with project planning and software requirement definition. To identify the requirements of the user is a tedious job. The description of the services and constraints are the requirements for the system and the process of finding out, analyzing, documenting, and checking these services is called requirement engineering. The goal of requirement definition is to completely and consistently specify the requirements for the software product in a concise and unambiguous manner, using formal notations as appropriate. The software requirement specification is based on the system definition. The requirement specification will state the "what of" the software product without implying "how". Software design is concerned with specifying how the product will provide the required features.

5.2. Software system requirements

Software system requirements are classified as functional requirements and non-functional requirements.

5.2.1. Functional requirements

The functional requirements for a system describe the functionalities or services that the system is expected to provide. They provide how the system should react to particular inputs and how the system should behave in a particular situation.

5.2.2 Non-functional requirements these are constraints on the services or functionalities offered by the system.

They include timing constraints, constraints on the development process, standards etc. These requirements are not directly concerned with the specific function delivered by the system. They may relate to such system properties such as reliability, response time, and storage. They may define the constraints
on the system such as capabilities of I/O devices and the data representations used in system interfaces.

5.3 Software requirement specification

It is the official document of what is required of the system developers. It consists of user requirements and detailed specification of the system requirements. According to Henninger there are six requirements that an SRS should satisfy:

1. It should specify only external system behavior.

2. It should specify constraints on the implementation.

3. It should be easy to change.

4. It should serve as a reference tool for system maintainers.

5. It should record forethought about the life cycle of the system.

6. It should characterize acceptable response to undesired events. The IEEE standard suggests the following structure for SRS:

- **Introduction**

1.1 Purpose of the requirement document.

1.2 Scope of the product

1.3 Definitions, acronyms, and abbreviations

1.4 References

1.5 Overview of the remainder of the document 2.

General description

2.1 Product perspective

2.2 Product functions

2.3 User characteristics

2.4 General constraints

2.5 Assumption and dependencies

- ➢ Specific requirements covering functional, non-functional and interface requirements.
- ➢ Appendices
- ➢ Index

5.4 Characteristics of SRS

The desirable characteristics of an SRS are following:

- ➢ **Correct:** An SRS is correct if every requirement included in the SRS

  represents something required in the final system.

- ➢ **Complete:** An SRS is complete if everything software is supposed to do and the responses of the software to all classes of input data are specified in the SRS.
- ➢ **Unambiguous:** An SRS is unambiguous if and only if every requirement stated has one and only one interpretation.
- ➢ **Verifiable:** An SRS is verifiable if and only if every specified requirement is

  verifiable i.e. there exists a procedure to check that final software meets the requirement.
- ➢ **Consistent:** An SRS is consistent if there is no requirement that conflicts with another.
- ➢ **Traceable:** An SRS is traceable if each requirement in it must be uniquely identified to a source.

➢ **Modifiable:** An SRS is modifiable if its structure and style are such that any necessary change can be made easily while preserving completeness and consistency.

➢ **Ranked:** An SRS is ranked for importance and/or stability if for each requirement the importance and the stability of the requirements are indicated.

5.5 Components of an SRS

An SRS should have the following components:

(i) Functionality

(ii) Performance

(iii) Design constraints

(iv) External Interfaces

Functionality

Here functional requirements are to be specified. It should specify which outputs should be produced from the given input. For each functional requirement, a detailed description of all the inputs, their sources, range of valid inputs, the units
of measure are to be specified. All the operation to be performed on input should also be specified.

Performance requirements

In this component of SRS all the performance constraints on the system should be specified such as response time, throughput constraints, number of terminals

to be supported, number of simultaneous users to be supported etc.

Design constraints

Here design constraints such as standard compliance, hardware limitations, Reliability, and security should be specified. There may be a requirement that system will have to use some existing hardware, limited primary and/or secondary memory. So it is a constraint on the designer. There may be some standards of the organization that should be obeyed such as the format of reports. Security requirements may be particularly significant in defense systems. It imposes a restriction sometimes on the use of some commands, control access to data; require the use of passwords and cryptography techniques etc.

External Interface requirements

Software has to interact with people, hardware, and other software. All these interfaces should be specified. User interface has become a very important issue now a day. So the characteristics of user interface should be precisely specified and should be verifiable.

Lesson-6 Software Design

6.1 Introduction

Design is an iterative process of transforming the requirements specification into

a design specification. Consider an example where Mrs. & Mr. XYZ want a new house. Their requirements include,

- ➢ a room for two children to play and sleep
- ➢ a room for Mrs. & Mr. XYZ to sleep
- ➢ a room for cooking
- ➢ a room for dining
- ➢ a room for general activities

and so on. An architect takes these requirements and designs a house. The architectural design specifies a particular solution. In fact, the architect may produce several designs to meet this requirement. For example, one may maximize children's room, and other minimizes it to have large living room. In addition, the style of the proposed houses may differ: traditional, modern and two-storied. All of the proposed designs solve the problem, and there may not be a "best" design.

Software design can be viewed in the same way. We use requirements specification to define the problem and transform this to a solution that satisfies all the requirements in the specification. Design is the first step in the development phase for any engineered product. The designer goal is to produce a model of an entity that will later be built.

6.2 Definitions for Design

- ➢ "Devising artifacts to attain goals" [H.A. Simon, 1981].
- ➢ "The process of defining the architecture, component, interfaces and other

characteristics of a system or component" [IEEE 160.12].

- ➢ The process of applying various techniques and principles for the purpose of defining a device, a process or a system in sufficient detail to permit its physical realization.

Without Design, System will be

- ➢ Unmanageable since there is no concrete output until coding. Therefore it is difficult to monitor & control.
- ➢ Inflexible since planning for long term changes was not given due emphasis.
- ➢ Un maintainable since standards & guidelines for design & construction are not used. No reusability consideration. Poor design may result in tightly coupled modules with low cohesion. Data disintegrity may also result.
- ➢ Inefficient due to possible data redundancy and unturned code.
- ➢ Not portable to various hardware / software platforms.

Design is different from programming. Design brings out a representation for the program – not the program or any component of it. The difference is tabulated below.

6.3 Qualities of a Good Design

Functional: It is a very basic quality attribute. Any design solution should work, and should be construct able.

Efficiency: This can be measured through

- ➢ run time (time taken to undertake whole of processing task or transaction)
- ➢ response time (time taken to respond to a request for information)
- ➢ throughput (no. of transactions / unit time)
- ➢ memory usage, size of executable, size of source, etc

Flexibility: It is another basic and important attribute. The very purpose of doing design activities is to build systems that are modifiable in the event of any changes in the requirements.

Portability & Security: These are to be addressed during design - so that such needs are not “hard-coded” later.

Reliability: It tells the goodness of the design - how it work successfully (More important for real-time and mission critical and on-line systems).

Economy: This can be achieved by identifying re-usable components.

Usability: Usability is in terms of how the interfaces are designed (clarity, aesthetics, directness, forgiveness, user control, ergonomics, etc) and how much time it takes to master the system.

6.4 Modularity

There are many definitions of the term "module." They range from "a module is a FORTRAN subroutine" to "a module is an Ada package" to "a module is a work assignment for an individual programmer". All of these definitions are correct, in the sense that modular systems incorporate collections of abstractions in which

each functional abstraction, each data abstraction, and each control abstraction handles a local aspect of the problem being solved. Modular systems consist of well-defined, manageable units with well-defined interfaces among the units. Desirable properties of a modular system include:

- ➢ Each processing abstraction is a well-defined subsystem that is potentially useful in other applications.
- ➢ Each function in each abstraction has a single, well-defined purpose.
- ➢ Each function manipulates no more than one major data structure.
  - ➢ Functions share global data selectively. It is easy to identify all routines that share a major data structure.
  - ➢ Functions that manipulate instances of abstract data types are encapsulated with the data structure being manipulated.

Modularity enhances design clarity, which in turn eases implementation, debugging, testing, documenting, and maintenance of the software product.

Modularization criteria

Architectural design has the goal of producing well-structured, modular software systems. In this section of the text, we consider a software module to be a named entity having the following characteristics:

- ➢ Modules contain instructions, processing logic, and data structures.
- ➢ Modules can be separately compiled and stored in a library.
- ➢ Modules can be included in a program.
- ➢ Module segments can be used by invoking a name and some parameters.
- ➢ Modules can use other modules.

Examples of modules include procedures, subroutines, and functions; functional groups of related procedures, subroutines, and functions; data abstraction groups; utility groups; and concurrent processes. Modularization allows the designer to decompose a system into functional units, to impose hierarchical ordering on function usage,to implement dataabstraction, to develop independently useful subsystems. In addition, modularization can be used to isolate machine dependencies, to improve the performance of a software product, or to ease debugging, testing, integration, tuning, and modification of the system.

There are numerous criteria that can be used to guide the modularization of a system. Depending on the criteria used, different system structures may result. Modularization criteria include the conventional criterion, in which each module and its sub modules correspond to a processing step in the execution sequence; the information hiding criterion, in which each module hides a difficult or changeable design decision from the other modules; the data abstraction criterion, in which each module hides the representation details of a major data structure behind functions that access and modify the data structure; levels of abstraction, in which modules and collections of modules provide a hierarchical set of increasingly complex services; coupling-cohesion, in which a system is structured to maximize the cohesion of elements in each module and to minimize the coupling between modules; and problem modelling, in which the modular structure of the system matches the structure of the problem being solved. There are two versions of problem modeling: either the data structures match the problem structure and the visible functions manipulate the data structures, or the modules form a network of communicating processes where each process corresponds to a problem entity.

Coupling and cohesion

A fundamental goal of software design is to structure the software product so that the number and complexity of interconnection between modules is minimized. A good heuristic for achieving this goal involves the concepts of coupling and cohesion.

Coupling

Coupling is the measure of strength of association established by a connection from one module to another. Minimizing connections between modules also minimizes the paths along which changes and errors can propagate into other parts of the system ('ripple effect'). The use of global variables can result in an enormous number of connections between the modules of a program. The degree of coupling between two modules is a function of several factors: (1) How complicated the connection is, (2) Whether the connection refers to the module itself or something inside it, and (3) What is being sent or received. Coupling is usually contrasted with cohesion. Low coupling often correlates with high cohesion, and vice versa. Coupling can be "low" (also "loose" and "weak") or "high" (also "tight" and "strong"). Low coupling means that one module does not have to be concerned with the internal implementation of another module, and interacts with another module with a stable interface. With low coupling, a change in one module will not require a change in the implementation of another module. Low coupling is a sign of a well structured computer system.

However, in order to achieve maximum efficiency, a highly coupled system is sometimes needed. In modern computing systems, performance is often traded for lower coupling; the gains in the software development process are greater than the value of the running performance gain.

Low-coupling / high-cohesion is a general goal to achieve when structuring computer programs, so that they are easier to understand and maintain.

The concepts are usually related: low coupling implies high cohesion and vice versa. In the field of object-oriented programming, the connection between classes tends to get lower (low coupling), if we group related methods of a class together (high cohesion). The different types of coupling, in order of lowest to highest, are as follows:

- ✓ Data coupling
- ✓ Stamp coupling
- ✓ Control coupling
- ✓ External coupling
- ✓ Common coupling
- ✓ Content coupling

Where data coupling is most desirable and content coupling least.

Data Coupling

Two modules are data coupled if they communicate by parameters (each being

an elementary piece of data).E.g. sin (theta) returning sine value, calculate_interest (amount, interest rate, term) returning interest amt.

Stamp Coupling (Data-structured coupling)

Two modules are stamp coupled if one passes to other a composite piece of data

(a piece of data with meaningful internal structure). Stamp coupling is when modules share a composite data structure, each module not knowing which part of the data structure will be used by the other (e.g. passing a student record to a function which calculates the student's GPA)

Control Coupling

Two modules are control coupled if one passes to other a piece of information intended to control the internal logic of the other. In Control coupling, one module controls logic of another, by passing it information on what to do (e.g. passing a what-to-do flag).

External coupling

External coupling occurs when two modules share an externally imposed data format, communication protocol, or device interface.

Common coupling

Two modules are common coupled if they refer to the same global data area. Instead of communicating through parameters, two modules use a global data **Content coupling**

Two modules exhibit content coupled if one refers to the inside of the other in any way (if one module 'jumps' inside another module). E.g. Jumping inside a module violate all the design principles like abstraction, information hiding and modularity.

In object-oriented programming, subclass coupling describes a special type of coupling between a parent class and its child. The parent has no connection to the child class, so the connection is one way (i.e. the parent is a sensible class on its own). The coupling is hard to classify as low or high; it can depend on the

situation.

We aim for a 'loose' coupling. We may come across a (rare) case of module A calling module B, but no parameters passed between them (neither send, nor received). This is strictly should be positioned at zero point on the scale of coupling (lower than Normal Coupling itself). Two modules A &B are normally coupled if A calls B – B returns to A – (and) all information passed between them

is by means of parameters passed through the call mechanism. The other two types of coupling (Common and content) are abnormal coupling and not desired. Even in Normal Coupling we should take care of following issues:

- Data coupling can become complex if number of parameters communicated between is large.
- In Stamp coupling there is always a danger of over-exposing irrelevant data

  to called module. (Beware of the meaning of composite data. Name represented as an array of characters may not qualify as a composite data.
  The meaning of composite data is the way it is used in the application NOT

  as represented in a program)

- "What-to-do flags" are not desirable when it comes from a called module

  ('inversion of authority'): It is alright to have calling module (by virtue of the fact, is a boss in the hierarchical arrangement) know internals of called module and not the other way around.

In general, use of tramp data and hybrid coupling is not advisable. When data is passed up and down merely to send it to a desired module, the data will have no meaning at various levels. This will lead to tramp data. Hybrid coupling will result when different parts of flags are used (misused?) to mean different things in different places (Usually we may brand it as control coupling – but hybrid coupling complicate connections between modules). Two modules may be coupled in more than one way. In such cases, their coupling is defined by the worst coupling type they exhibit.
In object-oriented programming, coupling is a measure of how strongly one class

is connected to another.

Coupling is increased between two classes A and B if:

- ➢ A has an attribute that refers to (is of type) B.
- ➢ A calls on services of a B object.
- ➢ A has a method which references B (via return type or parameter).
- ➢ A is a subclass of (or implements) B.

Disadvantages of high coupling include:

- ➢ A change in one class forces a ripple of changes in other classes.
- ➢ Difficult to understand a class in isolation.
- ➢ Difficult to reuse or test a class because dependent class must also be included.

One measure to achieve low coupling is functional design: it limits the responsibilities of modules. Modules with single responsibilities usually need to communicate less with other modules, and this has the virtuous side-effect of reducing coupling and increasing cohesion in many cases.

Cohesion

Designers should aim for loosely coupled and highly cohesive modules. Coupling is reduced when the relationships among elements not in the same module are minimized. Cohesion on the other hand aims to maximize the relationships among elements in the same module. Cohesion is a good measure of the maintainability of a module. Modules with high cohesion tend to be preferable because high cohesion is associated with several desirable traits of software including robustness, reliability, reusability, and understand ability whereas low cohesion is associated with undesirable traits such as being difficult to maintain, difficult to test, difficult to reuse, and even difficult to understand.

The types of cohesion, in order of lowest to highest, are as follows:

1. Coincidental Cohesion (Worst)

2. Logical Cohesion
3. Temporal Cohesion
4. Procedural Cohesion
5. Communicational Cohesion
6. Sequential Cohesion
7. Functional Cohesion (Best)

Coincidental cohesion (worst)

Coincidental cohesion is when parts of a module are grouped arbitrarily; the parts have no significant relationship (e.g. a module of frequently used functions).

Logical cohesion

Logical cohesion is when parts of a module are grouped because of a slight relation (e.g. using control coupling to decide which part of a module to use, such as how to operate on a bank account).

Temporal cohesion

In a temporally bound (cohesion) module, the elements are related in time. Temporal cohesion is when parts of a module are grouped by when they are processed - the parts are processed at a particular time in program execution (e.g. a function which is called after catching an exception which closes open

files, creates an error log, and notifies the user).

Procedural cohesion

Procedural cohesion is when parts of a module are grouped because they always follow a certain sequence of execution (e.g. a function which checks file permissions and then opens the file).

Communicational cohesion

Communicational cohesion is when parts of a module are grouped because they

operate on the same data (e.g. a method updateStudentRecord which operates on a student record, but the actions which the method performs are not clear). **Sequential cohesion**
Sequential cohesion is when parts of a module are grouped because the output from one part is the input to another part (e.g. a function which reads data from a file and processes the data).
Functional cohesion (best)

Functional cohesion is when parts of a module are grouped because they all contribute to a single well-defined task of the module (a perfect module).
Since cohesion is a ranking type of scale, the ranks do not indicate a steady progression of improved cohesion. Studies by various people including Larry Constantine and Edward Yourdon as well as others indicate that the first two types of cohesion are much inferior to the others and that module with communicational cohesion or better tend to be much superior to lower types of cohesion. The seventh type, functional cohesion, is considered the best type. However, while functional cohesion is considered the most desirable type of cohesion for a software module, it may not actually be achievable. There are many cases where communicational cohesion is about the best that can be attained in the circumstances. However the emphasis of a software design should be to maintain module cohesion of communicational or better since these types of cohesion are associated with modules of lower lines of code per module with the source code focused on a particular functional objective with less extraneous or unnecessary functionality, and tend to be reusable under a greater variety of conditions.

Example: Let us create a module that calculates average of marks obtained by students in a class:

calc_stat(){read (x[]); a = average (x); print a}

average (m){sum=0; for i = 1 to N { sum = sum + x[i]; } return (sum/N);}

In average() above, all of the elements are related to the performance of a single function. Such a functional binding (cohesion) is the strongest type of binding. Suppose we need to calculate standard deviation also in the above problem, our pseudo code would look like:

calc_stat(){ read (x[]); a = average (x); s = sd (x, a); print a, s;}

average(m) // function to calculate average

{sum =0; for i = 1 to N { sum = sum + x[i]; } return (sum/N);}

sd (m, y) //function to calculate standard deviation

{ …}

Now, though average () and sd () are functionally cohesive, calc_stat() has a sequential binding (cohesion). Like a factory assembly line, functions are arranged in sequence and output from average () goes as an input to sd(). Suppose we make sd () to calculate average also, then calc_stat() has two functions related by a reference to the same set of input. This results in communication cohesion.

Let us make calc-stat() into a procedure as below:

calc_stat(){

sum = sumsq = count =

0 for i = 1 to N

read (x[i])

sum = sum + x[i]

sumsq = sumsq + x[i]*x[i]

…}

a = sum/N

s = … // formula to calculate

SD print a, s

}

Now, instead of binding functional units with data, calc-stat() is involved in binding activities through control flow. calc-stat() has made two statistical functions into a procedure. Obviously, this arrangement affects reuse of this module in a different context (for instance, when we need to calculate only average not std. dev.). Such cohesion is called procedural.

A good design for calc_stat () could be (Figure 6.1):

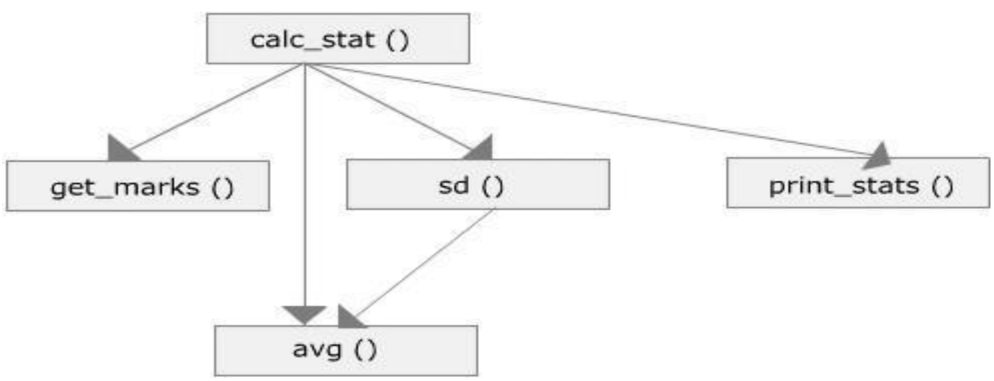


Figure 6.1

A logically cohesive module contains a number of activities of the same kind. To use the module, we may have to send a flag to indicate what we want (forcing various activities sharing the interface). Examples are a module that performs all input and output operations for a program. The activities in a logically cohesive module usually fall into same category (validate all input or edit all data) leading

to sharing of common lines of code (plate of spaghetti?). Suppose we have a module with possible statistical measures (average, standard deviation). If we want to calculate only average, the call to it would look like calc_all_stat (x[], flag). The flag is used to indicate out intent i.e. if flag=0 then function will return average, and if flag=1, it will return standard deviation.

```
calc_stat(){ read (x[]); a = average (x); s = sd (x, a); print a, s;}
calc_all_stat(m, flag)
{

If flag=0{sum=0; for i = 1 to N { sum = sum + x[i]; }return


(sum/N);} If flag=1{ …….; return sd;


}
```

7.1 Introduction

Design is a process in which representations of data structure, program structure, interface characteristics, and procedural details are synthesized from information requirements. During design a large system can be decomposed into sub-systems that provide some related set of services. The initial design process of identifying these sub-systems and establishing a framework for sub- system control and communication is called architectural design. In architectural design process the activities carried out are system structuring (system is decomposed into sub-systems and communications between them are identified), control modelling, modular decomposition. In a structured approach to design, the system is decomposed into a set of interacting functions.

7.2 Structured Programming

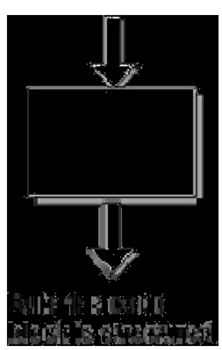
The goal of structured programming is to linearism control flow through a computer program so that the execution sequence follows the sequence in which the code is written. The dynamic structure of the program than resemble the static structure of the program. This enhances the readability, testability, and modifiability of the program. This linear flow of control can be achieved by restricting the set of allowed program construct to single entry, single exit formats. These issues are discussed in the following section:

Structure Rule One: Code Block

If the entry conditions are correct, but the exit conditions are wrong, the bug must be in the block. This is not true if execution is allowed to jump into a block. The bug might be anywhere in the program. Debugging under these conditions is much harder.

Rule 1 of Structured Programming: A code block is structured as shown in figure 7.1. In flow-charting terms, a box with a single entry point and single exit point is structured. This may look obvious, but that is the idea. Structured programming is a way of making it obvious that program is correct.

Figure 7.1



Structure Rule Two: Sequence

A sequence of blocks is correct if the exit conditions of each block match the entry conditions of the following block. Execution enters each block at the block's entry point, and leaves through the block's exit point. The whole sequence can be regarded as a single block, with an entry point and an exit point.

Rule 2 of Structured Programming: Two or more code blocks in sequence are structured as shown in figure 7.2.

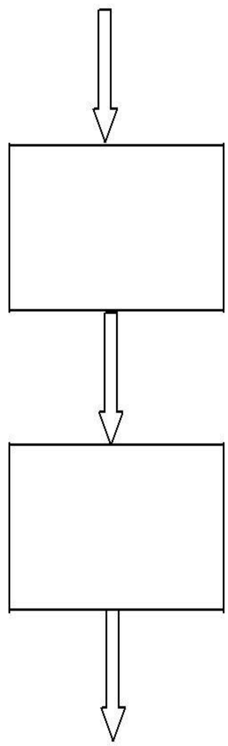


Figure 7.2 Rule 2: A sequence of code blocks is structured

Structure Rule Three: Alternation

If-then-else is sometimes called alternation (because there are alternative choices). In structured programming, each choice is a code block. If alternation is arranged as in the flowchart at right, then there is one entry point (at the top) and one exit point (at the bottom). The structure should be coded so that if the entry conditions are satisfied, then the exit conditions are fulfilled (just like a code block).

Rule 3 of Structured Programming: The alternation of two code blocks is structured as shown in figure 7.3.

An example of an entry condition for an alternation structure is: register $8 contains a signed integer. The exit condition might be: register $8 contains the absolute value of the signed integer. The branch structure is used to fulfill the exit condition.

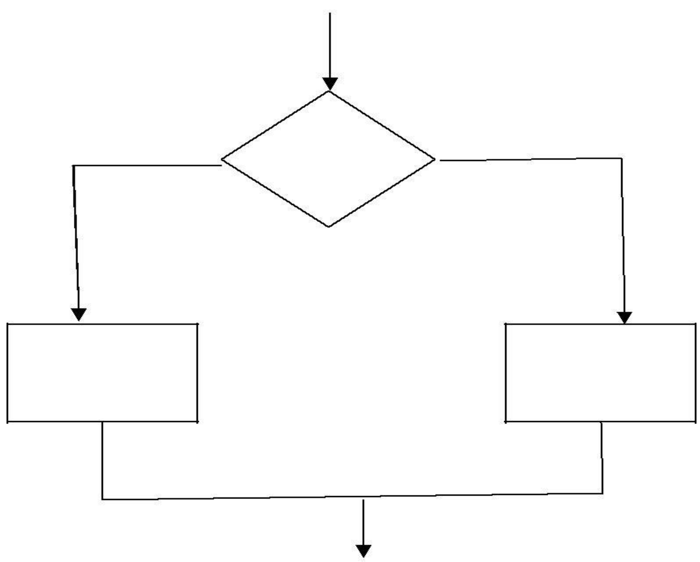
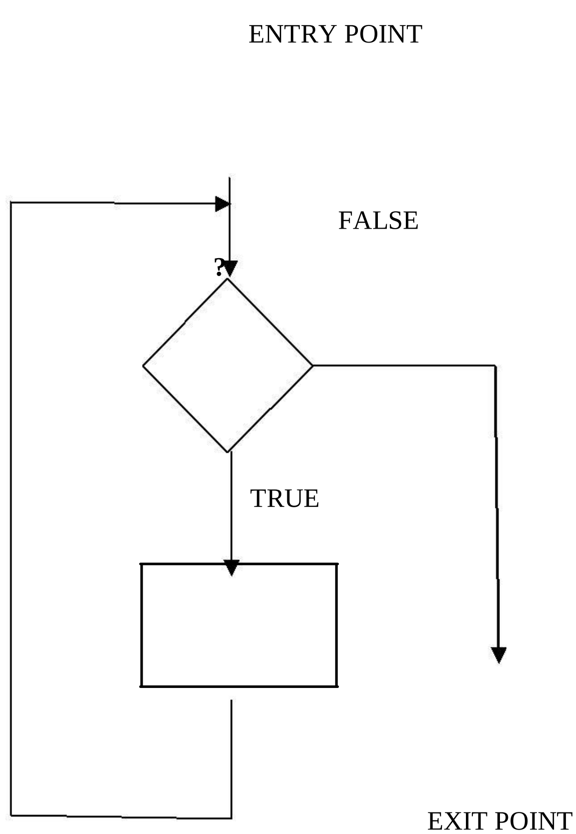


Figure 7.3 Rule 3: An alternation of code blocks is structured

Structure rule four - Iteration

Iteration (while-loop) is arranged as at right. It also has one entry point and one exit point. The entry point has conditions that must be satisfied and the exit point has conditions that will be fulfilled. There are no jumps into the structure from external points of the code.

Rule 4 of Structured Programming: The iteration of a code block is structured as shown in figure 7.4.



to

Figure 7.4 Rule 4: The iteration of code block is structured

Structure Rule Five: Nesting Structures

In flowcharting terms, any code block can be expanded into any of the structures. Or, going the other direction, if there is a portion of the flowchart that has a single entry point and a single exit point, it can be summarized as a single code block.

Rule 5 of Structured Programming: A structure (of any size) that has a single entry point and a single exit point is equivalent to a code block.

For example, say that you are designing a program to go through a list of signed

integers calculating the absolute value of each one. You might (1) first regard the program as one block, then (2) sketch in the iteration required, and finally

(3) put in the details of the loop body, as shown in figure 7.5.

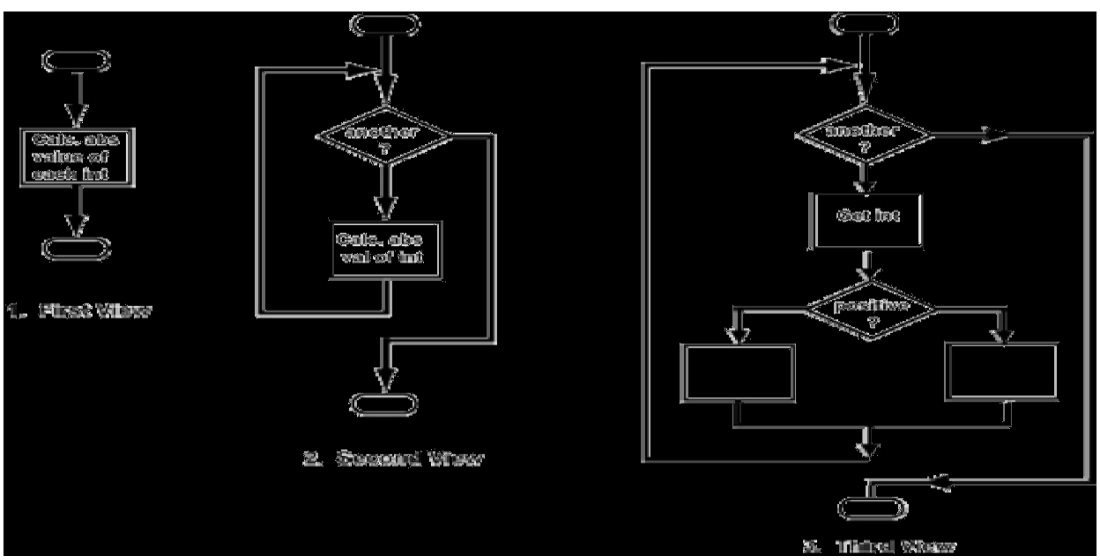


Figure 7.5

Or, you might go the other way. Once the absolute value code is working, you can regard it as a single code block to be used as a component of a larger program.

You might think that these rules are OK for ensuring stable code, but that they are too restrictive. Some power must be lost. But nothing is lost. Two researchers, Böhm and Jacopini, proved that any program could be written in a structured style. Restricting control flow to the forms of structured programming loses no computing power.

The other control structures you may know, such as case, do-until, do-while, and for are not needed. However, they are sometimes convenient, and are usually regarded as part of structured programming. In assembly language they add little convenience

Lesson-8 Coding

8.0 Objectives

The objective of this lesson is to make the students familiar

1. With the concept of coding.
2. Programming Style
3. Verification and validations techniques.

8.1 Introduction

The coding is concerned with translating design specifications into source code. The good programming should ensure the ease of debugging, testing and modification. This is achieved by making the source code as clear and straightforward as possible. An old saying is “Simple is great”. Simplicity, clarity and elegance are the hallmarks of good programs. Obscurity, cleverness, and complexity are indications of inadequate design. Source code clarity is enhanced
by structured coding techniques, by good coding style, by appropriate supporting documents, by good internal comments etc. Production of high quality software requires that the programming team should have a thorough understanding of duties and responsibilities and should be provided with a well defined set of requirements, an architectural design specification, and a detailed design description.

8.2 Programming style

Programming style refers to the style used in writing the source code for a computer program. Most programming styles are designed to help programmers quickly read and understands the program as well as avoid making errors. (Older programming styles also focused on conserving screen space.) A good coding style can overcome the many deficiencies of a primitive programming language, while poor style can defeat the intent of en excellent language. The goal of good programming style is to provide understandable, straightforward, elegant code.

The programming style used in a particular program may be derived from the coding standards or code conventions of a company or other computing organization, as well as the preferences of the actual programmer. Programming styles are often designed for a specific programming language (or language family) and are not used in whole for other languages. (Style considered good in

C source code may not be appropriate for BASIC source code, and so on.) Good style, being a subjective matter, is difficult to concretely categorize; however, there are several elements common to a large number of programming styles. Programming styles are often designed for a specific programming language and

are not used in whole for other languages. So there is no single set of rules that

can be applied in every situation; however there are general guidelines that are widely applicable. These are listed below:

Dos of good programming style

1. Use a few standards, agreed upon control constructs.

2. Use GOTO in a disciplined way.

3. Use user-defined data types to model entities in the problem domain.

4. Hide data structure behind access functions

5. Isolate machine dependencies in a few routines.

6. Use appropriate variable names

7. Use indentation, parentheses, blank spaces, and blank lines to enhance readability.

- **Use a few standard control constructs**

There is no standard set of constructs for structured coding. For example to implement loops, a number of constructs are available such as repeat-until.
While-do, for loop etc. If the implementation language does not provide structured coding constructs, a few stylistic patterns should be used by the

programmers. This will make coding style more uniform with the result that programs will be easier to read, easier to understand, and easier to modify.

- **Use GOTO in a disciplined way**

The best time to use GOTO statement is never. In all the modern programming languages, constructs are available which help you in avoiding the use of GOTO statement, so if you are a good programmer then you can avoid the use of
GOTO statement. But if it is warranted then the acceptable uses of GOTO

statements are almost always forward transfers of control within a local region of

code. Don't use GOTO to achieve backward transfer of control.

- **Use user-defined data types to model entities in the problem domain** Use of distinct data types makes it possible for humans to distinguish between entities from the problem domain. All the modern programming languages provide the facilities of enumerated data type. For example, if an identifier is to
be used to represent the month of a year, then instead of using integer data type

to represent it, a better option can be an enumerated data type as illustrated below:
enum month = (jan, feb, march, april, may, june, july, aug, sep, oct, nov, dec); month x;
Variables x is declared of month type. Using such types makes the program much understandable.
X = july;

is more meaningful than

x = 7;

- ➢ **Hide data structure behind access functions**

It is the manifestation of the principle of information hiding. It is the approach taken in data encapsulation, wherein data structures and its accessing routines are encapsulated in a single module. So a module makes visible only those features that are required by other modules.

- ➢ **Appropriate variable names**

Appropriate choices for variable names are seen as the keystone for good style. Poorly-named variables make code harder to read and understand. For example, consider the following pseudo code snippet:

```
get a b c

if a < 24 and b < 60 and c <

  60   return   true
else
  return false
```

Because of the choice of variable names, the function of the code is difficult to work out. However, if the variable names are made more descriptive:

```
get hours minutes seconds

if hours < 24 and minutes < 60 and seconds < 60

  return    true
else
  return false
```

the code's intent is easier to discern, namely, "Given a 24-hour time, true will be returned if it is a valid time and false otherwise."

A general guideline is “use the descriptive names suggesting the purpose of identifier”.

- **Use indentation, parentheses, blank spaces, and blank lines to enhance readability**

Programming styles commonly deal with the appearance of source code, with the goal of improving the readability of the program. However, with the advent of software that formats source code automatically, the focus on appearance will likely yield to a greater focus on naming, logic, and higher techniques. As a practical point, using a computer to format source code saves time, and it is possible to then enforce company-wide standards without religious debates.

- **Indenting**

Indent styles assist in identifying control flow and blocks of code. In programming languages that use indentation to delimit logical blocks of code, good indentation style directly affects the behavior of the resulting program. In other languages, such as those that use brackets to delimit code blocks, the indent style does not directly affect the product. Instead, using a logical and consistent indent style makes one's code more readable. Compare:

```
if (hours < 24 && minutes < 60 && seconds < 60){

   return true;

}  else  {  return
   false;
```

```
}
```

or

```
if (hours < 24 && minutes < 60 && seconds < 60)

{

   return true;

}

else

{

   return false;

}
```

with something like

```
if (hours < 24 && minutes < 60 && seconds < 60) {return true;}

else {return false;}
```

The first two examples are much easier to read because they are indented well, and logical blocks of code are grouped and displayed together more clearly.
This example is somewhat contrived, of course - all the above are more complex

(less stylish) than

```
return hours < 24 && minutes < 60 && seconds < 60;
```

- **Spacing**

Free-format languages often completely ignore white space. Making good use of spacing in one's layout is therefore considered good programming style.
Compare the following examples of C code. int count;

```
for(count=0;count<10;count++)

{

  printf("%d",count*count+count);

}
```

with

```
int count;

for( count = 0; count < 10; count++ )

{

  printf( "%d", count * count + count);

}
```

In the C-family languages, it is also recommended to avoid using tab characters

in the middle of a line as different text editors render their width differently.

Python uses indentation to indicate control structures, so correct indentation is required. By doing this, the need for bracketing with curly braces ({ and }) is eliminated, and readability is improved while not interfering with common coding styles. However, this frequently leads to problems where code is copied and pasted into a Python program, requiring tedious reformatting. Additionally, Python code is rendered unusable when posted on a forum or webpage that removes white space.

- **Boolean values in decision structures**

Some programmers think decision structures such as the above, where the result of the decision is merely computation of a Boolean value, are overly verbose and

even prone to error. They prefer to have the decision in the computation itself, like this:
return hours < 12 && minutes < 60 && seconds < 60;

The difference is often purely stylistic and syntactic, as modern compilers produce identical object code for both forms.

- **Looping and control structures**

The use of logical control structures for looping adds to good programming style

as well. It helps someone reading code to understand the program's sequence of execution (in imperative programming languages). For example, in pseudocode: count = 0

```
while count < 5 print
count * 2 count = count
+ 1 endwhile
```

The above snippet obeys the two aforementioned style guidelines, but the following use of the "for" construct makes the code much easier to read:

```
for count = 0, count < 5, count=count+1

  print count * 2
```

In many languages, the often used "for each element in a range" pattern can be shortened to:

```
for count = 0 to 5

  print count * 2
```

- **Examine routines having more than five formal parameters**

Parameters are used to exchange the information among the functions or routines. Use of more than five formal parameters gives a feeling that probably the function is complete. So it is to be carefully examined. The choice of number five is not arbitrary. It is well known that human beings can deal with approximately seven items at one time and ease of understanding a subprogram call or the body of subprogram is a function of the number of parameters.

8.3 Don’ts of good programming style

1. Don’t be too clever.
2. Avoid null Then statement
3. Avoid Then If statement
4. Don’t nest too deeply.
5. Don’t use an identifier for multiple purposes.
6. Examine routines having more than five formal parameters.

- **Don’t be too clever**

There is an old saying “Simple engineering is great engineering”. We should try

to keep our program simple. By making the use of tricks and showing cleverness, sometimes the complexity is increased. This can be illustrated using following example:

//Code to swap the values of two integer
variables. A=A+B;
B=A-B;
A=A-B;

You can observe the obscurity in the above code. The better approach can be:

T=A;

A=B;

B=T;

The second version to swap the values of two inegers is more clear and simple.

- **Avoid null then statement**

A null then statement is of the form

If B then ; else S; Which is equivalent to If (not B) the S;

- **Avoid then_If statement**

A then_if statement is of the form

```
If(A>B) then
        if(X>Y) then
                  A=X
         Else
                  B=Y
         Endif

Else    A=B

Endif
```

Then_if statement tend to obscure the conditions under which various actions are

performed. It can be rewritten in the following form: If(A<B) then

```
        A=B
Elseif (X>Y) then
        B=Y
Else
        A=X
Endif
```

- **Don’t nest too deeply**

Consider the following code While X
loop
  If Y then

```
While Y loop
  While Z loop If
  W then S
```

In the above code, it is difficult to identify the conditions under which statement S

will be executed. As a general guideline, nesting of program constructs to depths greater than three or four levels should be avoided.

- **Don’t use an identifier for multiple purposes**

Using an identifier for multiple purposes is a dangerous practice because it makes your program highly sensitive to future modification. Moreover the variable names should be descriptive suggesting their purposes to make the program understandable. This is not possible if the identifier is used for multiple purposes.

8.4 Software Verification and Validation Concepts and Definitions

Software Verification and Validation (V&V) is the process of ensuring that software being developed or changed will satisfy functional and other requirements (validation) and each step in the process of building the software yields the right products (verification). The differences between verification and validation (shown in table 8.1) are unimportant except to the theorist;

practitioners' use the term V&V to refer to all of the activities that are aimed at making sure the software will function as required.

V&V is intended to be a systematic and technical evaluation of software and associated products of the development and maintenance processes. Reviews and tests are done at the end of each phase of the development process to ensure software requirements are complete and testable and that design, code, documentation, and data satisfy those requirements.

Table 8.1 Difference between verification and validation

Validation	**Verification**
Am I building the right product?	Am I building the product right?
Determining if the system complies with the requirements and performs functions for which it is intended and meets the organization's goals and user needs. It is traditional and is	The review of interim work steps and interim deliverables during a project to ensure they are acceptable. To determine if the system is consistent, adheres to standards, uses reliable techniques and prudent practices, and performs the
Am I accessing the right data (in terms of the data required to satisfy the requirement)	Am I accessing the data right (in the right place; in the right way).
High level activity	Low level activity
Performed after a work product is produced against established	Performed during development on key artifacts, like walkthroughs, reviews and

criteria ensuring that the product integrates correctly into the environment	inspections, mentor feedback, training, checklists and standards
Determination of correctness of the final software product by a development project with respect to	Demonstration of consistency, completeness, and correctness of the software at each stage and between each

Activities

The two major V&V activities are reviews, including inspections and walkthroughs, and testing.

Reviews, Inspections, and Walkthroughs

Reviews are conducted during and at the end of each phase of the life cycle to determine whether established requirements, design concepts, and specifications have been met. Reviews consist of the presentation of material to a review board or panel. Reviews are most effective when conducted by personnel who have not been directly involved in the development of the software being reviewed.

Informal reviews are conducted on an as-needed basis. The developer chooses

a review panel and provides and/or presents the material to be reviewed. The material may be as informal as a computer listing or hand-written documentation. Formal reviews are conducted at the end of each life cycle phase. The acquirer of the software appoints the formal review panel or board, who may make or affect a go/no-go decision to proceed to the next step of the life cycle. Formal reviews include the Software Requirements Review, the Software Preliminary Design Review, the Software Critical Design Review, and the Software Test Readiness Review.

An inspection or walkthrough is a detailed examination of a product on a step-by-step or line-of-code by line-of-code basis. The purpose of conducting inspections and walkthroughs is to find errors. The group that does an inspection or walkthrough is composed of peers from development, test, and quality assurance.

Lesson-9 Software Testing

9.1 Introduction

Until 1956 it was the debugging oriented period, where testing was often associated to debugging: there was no clear difference between testing and debugging. From 1957-1978 there was the demonstration oriented period where debugging and testing was distinguished now - in this period it was shown, that software satisfies the requirements. The time between 1979-1982 is announced as the destruction oriented period, where the goal was to find errors. 1983-1987 is classified as the evaluation oriented period: intention here is that during the software lifecycle a product evaluation is provided and measuring quality. From 1988 on it was seen as prevention oriented

period where tests were to demonstrate that software satisfies its specification, to detect faults and to prevent faults.

Software testing is the process used to help identify the correctness, completeness, security, and quality of developed computer software. Testing is a process of technical investigation, performed on behalf of stakeholders, that is intended to reveal quality- related information about the product with respect to the context in which it is intended to operate. This includes the process of executing a program or application with the

intent of finding errors. Quality is not an absolute; it is value to some person. With that

in mind, testing can never completely establish the correctness of arbitrary computer software; testing furnishes a criticism or comparison that compares the state and behaviour of the product against a specification. An important point is that software testing should be distinguished from the separate discipline of software quality assurance, which encompasses all business process areas, not just testing.

There are many approaches to software testing, but effective testing of complex products is essentially a process of investigation, not merely a matter of creating and

following routine procedure. One definition of testing is "the process of questioning a product in order to evaluate it", where the "questions" are operations the tester attempts to execute with the product, and the product answers with its behavior in reaction to the probing of the tester. Although most of the intellectual processes of testing are nearly identical to that of review or inspection, the word testing is connoted
to mean the dynamic analysis of the product—putting the product through its paces.

The quality of the application can, and normally does, vary widely from system to system but some of the common quality attributes include capability, reliability, efficiency, portability, maintainability, compatibility and usability. A good test is sometimes described as one which reveals an error; however, more recent thinking suggests that a good test is one which reveals information of interest to someone who matters within the project community.

9.2.1 Error, fault and failure

In general, software engineers distinguish software faults from software failures.

In case of a failure, the software does not do what the user expects. A fault is a programming bug that may or may not actually manifest as a failure. A fault can also
be described as an error in the correctness of the semantic of a computer program. A

fault will become a failure if the exact computation conditions are met, one of them being that the faulty portion of computer software executes on the CPU. A fault can also turn into a failure when the software is ported to a different hardware platform or a different compiler, or when the software gets extended.

The term error is used to refer to the discrepancy between a computed, observed or measured value and the true, specified or theoretically correct value. Basically it refers
to the difference between the actual output of a program and the correct output.

Fault is a condition that causes a system to fail in performing its required functions.

Failure is the inability of a system to perform a required function according to its specification. In case of a failure the observed behavior of the system is different from the specified behavior. Whenever there is a failure, there is a fault in the system but vice-versa may not be true. That is, sometimes there is a fault in the software but failure is not observed. Fault is just like an infection in the body. Whenever there is fever there is an infection, but sometimes body has infection but fever is not observed,

9.2.2 Software Testing Fundamentals

Software testing may be viewed as a sub-field of software quality assurance but typically exists independently (and there may be no SQA areas in some companies). In SQA, software process specialists and auditors take a broader view on software and its development. They examine and change the software engineering process itself to reduce the amount of faults that end up in the code or deliver faster.

Regardless of the methods used or level of formality involved the desired result of testing is a level of confidence in the software so that the developers are confident that the software has an acceptable defect rate. What constitutes an acceptable defect rate depends on the nature of the software.

A problem with software testing is that the number of defects in a software product can

be very large, and the number of configurations of the product larger still. Bugs that occur infrequently are difficult to find in testing. A rule of thumb is that a system that is expected to function without faults for a certain length of time must have already been tested for at least that length of time. This has severe consequences for projects to write long-lived reliable software.

A common practice of software testing is that it is performed by an independent group of testers after the functionality is developed but before it is shipped to the customer. This practice often results in the testing phase being used as project buffer to compensate for project delays. Another practice is to start software testing at the same moment the project starts and it is a continuous process until the project finishes. Another common practice is for test suites to be developed during technical support escalation procedures. Such tests are then maintained in regression testing suites to ensure that future updates to the software don't repeat any of the known mistakes.

	Time Detected				
Time Introduced	Requirements	Architecture	Construction	System Test	Post-Release
Requirements	1	3	5-10	10	10-100
Architecture	-	1	10	15	25-100
Construction	-	-	1	10	10-25

It is commonly believed that the earlier a defect is found the cheaper it is to fix it.

In counterpoint, some emerging software disciplines such as extreme programming and the agile software development movement, adhere to a "test-driven software development" model. In this process unit tests are written first, by

the programmers. Of course these tests fail initially; as they are expected to.

Then as code is written it passes incrementally larger portions of the test suites.

The test suites are continuously updated as new failure conditions and corner cases are discovered, and they are integrated with any regression tests that are developed.

It tests are maintained along with the rest of the software source code and generally integrated into the build process (with inherently interactive tests being relegated to a partially manual build acceptance process).

The software, tools, samples of data input and output, and configurations are all referred to collectively as a test harness.

Testing is the process of finding the differences between the expected behavior specified by system models and the observed behavior of the system. Software testing consists of the dynamic verification of the behavior of a program on a finite set of test cases, suitably selected from the usually infinite executions domain, against the specified expected behavior.

9.2.3 A sample testing cycle

Although testing varies between organizations, there is a cycle to testing:

1. Requirements Analysis: Testing should begin in the requirements phase of the software development life cycle.
2. Design Analysis: During the design phase, testers work with developers in determining what aspects of a design are testable and under what parameter those tests work.
3. Test Planning: Test Strategy, Test Plan(s), Test Bed creation.
4. Test Development: Test Procedures, Test Scenarios, Test Cases, Test

   Scripts to use in testing software.
5. Test Execution: Testers execute the software based on the plans and tests and report any errors found to the development team.
6. Test Reporting: Once testing is completed, testers generate metrics and make final reports on their test effort and whether or not the software tested is ready for release.

7. Retesting the Defects

9.2.4 Testing Objectives

Glen Myres states a number of rules that can serves as testing objectives:

- ➢ Testing is a process of executing a program with the intent of finding an error.
- ➢ A good test case is one that has the high probability of finding an as-yet undiscovered error.
- ➢ A successful test is one that uncovers an as-yet undiscovered error.

9.2.5 Testing principles

Davis suggested the following testing principles:

- ✓ All tests should be traceable to customer requirements.
- ✓ Tests should be planned long before testing begins.
- ✓ The Pareto principle applies to software testing. According to this principle 80 percent of all errors uncovered during testing will likely to be traceable to 20 percent of all program modules. The problem is to isolate these 20 percent modules and test them thoroughly.
- ✓ Testing should begin “in the small” and progress toward testing “in the large”.
- ✓ Exhaustive testing is not possible.

- ✓ To be most effective, testing should be conducted by an independent third party.

9.2.6 Psychology of Testing

"Testing cannot show the absence of defects, it can only show that software errors are present". So devising a set of test cases that will guarantee that all errors will be detected is not feasible. Moreover, there are no formal or precise methods for selecting test cases. Even though, there are a number of heuristics and rules of thumb for deciding the test cases, selecting test cases is still a creative activity that relies on the ingenuity of the tester. Due to this reason, the psychology of the person performing the testing becomes important.

The aim of testing is often to demonstrate that a program works by showing that

it has no errors. This is the opposite of what testing should be viewed as. The basic purpose of the testing phase is to detect the errors that may be present in the program. Hence, one should not start testing with the intent of showing that a program works; but the intent should be to show that a program does not work. With this in mind, we define testing as follows: testing is the process of executing

a program with the intent of finding errors.

This emphasis on proper intent of testing is a trivial matter because test cases are designed by human beings, and human beings have a tendency to perform actions to achieve the goal they have in mind. So, if the goal is to demonstrate that a program works, we may consciously or subconsciously select test cases that will try to demonstrate that goal and that will beat the basic purpose of testing. On the other hand, if the intent is to show that the program does not work, we will challenge our intellect to find test cases towards that end, and we are likely to detect more errors. Testing is the one step in the software engineering process that could be viewed as destructive rather than constructive.

In it the engineer creates a set of test cases that are intended to demolish the software. With this in mind, a test case is "good" if it detects an as-yet- undetected error in the program, and our goal during designing test cases should be to design such "good" test cases.

Due to these reasons, it is said that the creator of a program (i.e. programmer) should not be its tester because psychologically you cannot be destructive to your own creation. Many organizations require a product to be tested by people not involved with developing the program before finally delivering it to the customer. Another reason for independent testing is that sometimes errors occur because the programmer did not understand the specifications clearly. Testing of a program by its programmer will not detect such errors, whereas independent testing may succeed in finding them.

9.2.7 Test Levels

- Unit testing: It tests the minimal software item that can be tested. Each component is tested independently.
- Module testing: A module is a collection of dependent components. So it is component integration testing and it exposes defects in the interfaces and interaction between integrated components.

- Sub-system testing: It involves testing collection of modules which have been integrated into sub-systems. The sub-system test should concentrate on the detection of interface errors.
- System testing: System testing tests an integrated system to verify that it meets its requirements. It is concerned with validating that the system meets its functional and non-functional requirements.

- Acceptance testing: Acceptance testing allows the end-user or customer to decide whether or not to accept the product.

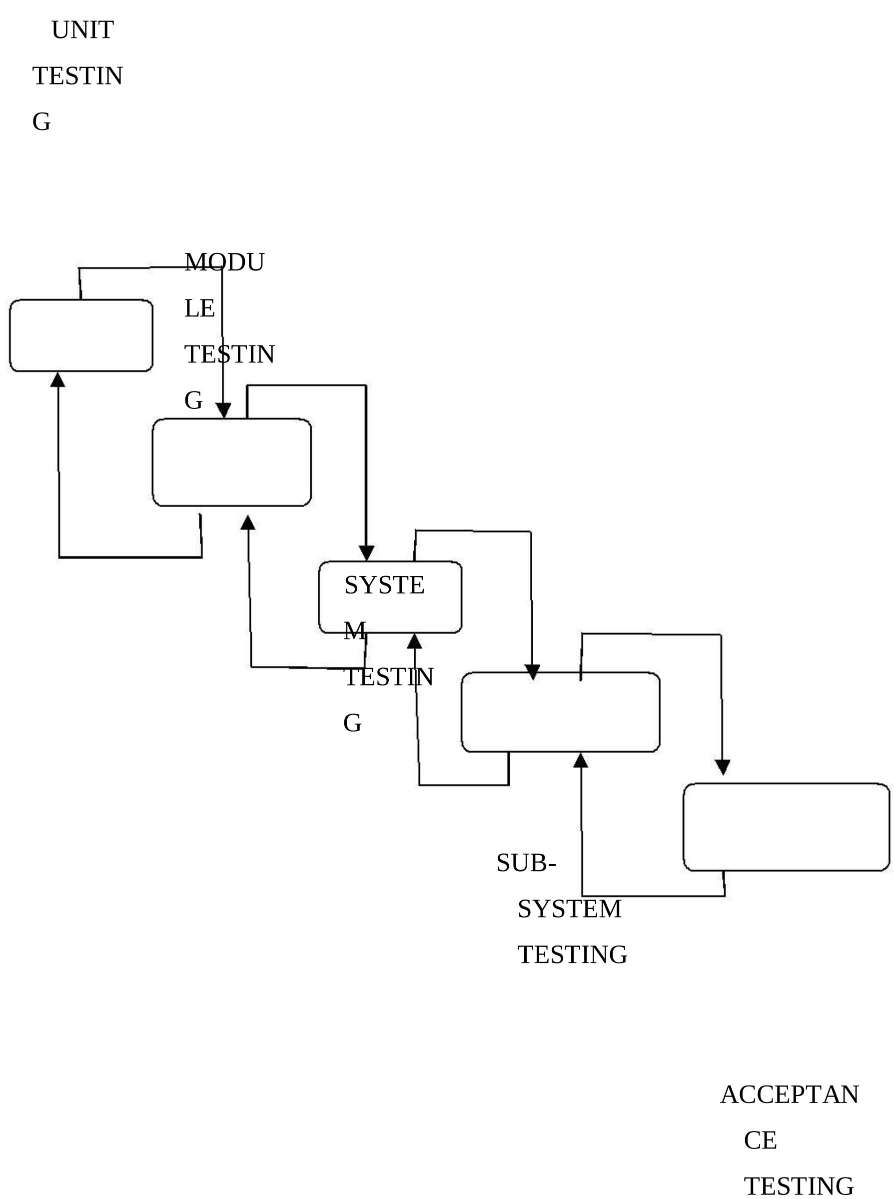


Figure 9.1 Test levels

9.2.8 SYSTEM TESTING

System testing involves two kinds of activities: integration testing and acceptance testing. Strategies for integrating software components into a functioning product include the bottom-up strategy, the top-down strategy, and the sandwich strategy. Careful planning and scheduling are required to ensure that modules will be available for integration into the evolving software product when needed.

The integration strategy dictates the order in which modules must be available, and thus exerts a strong influence on the order in which modules are written, debugged, and unit tested.

Acceptance testing involves planning and execution of functional tests, performance tests, and stress tests to verify that the implemented system satisfies its requirements. Acceptance tests are typically performed by the quality assurance and/or customer organizations. Depending on local circumstances, the development group may or may not be involved in acceptance testing. Integration testing and acceptance testing are discussed in the following sections.

9.2.8.1 Integration Testing

Three are two important variants of integration testing, (a) Bottom-up integration and top-down integration, which are discussed in the following sections:

9.2.8.1.1 Bottom-up integration

Bottom-up integration is the traditional strategy used to integrate the components

of a software system into a functioning whole. Bottom-up integration consists of unit testing, followed by subsystem testing, followed by testing of the entire system. Unit testing has the goal of discovering errors in the individual modules

of the system. Modules are tested in isolation from one another in an artificial environment known as a "test harness," which consists of the driver programs and data necessary to exercise the modules. Unit testing should be as exhaustive as possible to ensure that each representative case handled by each module has been tested. Unit testing is eased by a system structure that is composed of small, loosely coupled modules. A subsystem consists of several modules that communicate with each other through well-defined interfaces. Normally, a subsystem implements a major segment of the total system. The primary purpose of subsystem testing is to verify the operation of the interfaces between modules in the subsystem. Both control and data interfaces must be tested. Large software may require several levels of subsystem testing; lower- level subsystems are successively combined to form higher-level subsystems. In most software systems, exhaustive testing of subsystem capabilities is not feasible due to the combinational complexity of the module interfaces; therefore, test cases must be carefully chosen to exercise the interfaces in the desired manner.

System testing is concerned with subtleties in the interfaces, decision logic, control flow, recovery procedures, throughput; capacity, and timing characteristics of the entire system. Careful test planning is required to determine the extent and nature of system testing to be performed and to establish criteria by which the results will be evaluated.

Disadvantages of bottom-up testing include the necessity to write and debug test harnesses for the modules and subsystems, and the level of complexity that result from combining modules and subsystems into larger and larger units. The extreme case of complexity results when each module is unit tested in isolation and all modules are then linked and executed in one single integration run. This is the "big bang" approach to integration testing. The main problem with big-bang integration is the difficulty of isolating the sources of errors.

Test harnesses provide data environments and calling sequences for the routines and subsystems that are being tested in isolation. Test harness preparation can amount to 50 percent or more of the coding and debugging effort for a software product.

9.2.8.1.2 Top-down integration

Top-down integration starts with the main routine and one or two immediately subordinate routines in the system structure. After this top-level "skeleton" has been thoroughly tested, it becomes the test harness for its immediately subordinate routines. Top-down integration requires the use of program stubs to simulate the effect of lower-level routines that are called by those being tested.

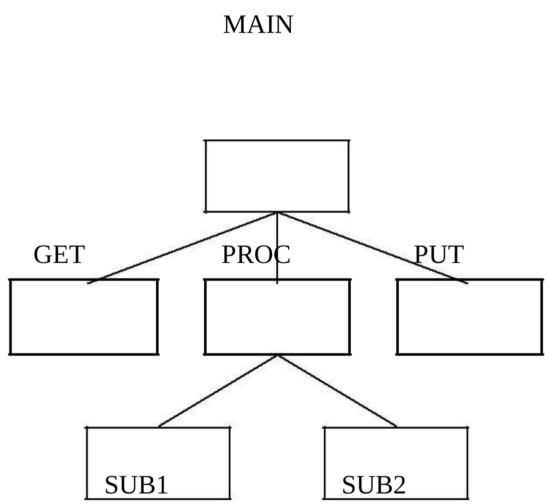


Figure 9.2

1. Test MAIN module, stubs for GET, PROC, and PUT are required.

2. Integrate GET module and now test MAIN and GET

3. Integrate PROC, stubs for SUBI, SUB2 are required.

4. Integrate PUT, Test MAIN, GET, PROC, PUT

5. Integrate SUB1 and test MAIN, GET, PROC, PUT, SUBI

6. Integrate SUB2 and test MAIN, GET, PROC, PUT, SUBI, SUB2

Above Figure 9.2 illustrates integrated top-down integration testing. Top-down integration offers several advantages:

1. System integration is distributed throughout the implementation phase. Modules are integrated as they are developed.
2. Top-level interfaces are tested first and most often.

3. The top-level routines provide a natural test harness for lower-Level routines.

4. Errors are localized to the new modules and interfaces that are being added. While it may appear that top-down integration is always preferable, there are many situations in which it is not possible to adhere to a strict top-down coding and integration strategy. For example, it may be difficult to find top-Level input data that will exercise a lower level module in a particular desired manner. Also, the evolving system may be very expensive to run as a test harness for new routines; it may not be cost effective to relink and re-execute a system of 50 or

100 routines each time a new routine is added. Significant amounts of machine time can often be saved by testing subsystems in isolation before inserting them into the evolving top-down structure. In some cases, it may not be possible to use program stubs to simulate modules below the current level (e.g. device drivers, interrupt handlers). It may be necessary to test certain critical low-level modules first.

The sandwich testing strategy may be preferred in these situations. Sandwich integration is predominately top-down, but bottom-up techniques are used on some modules and subsystems. This mix alleviates many of the problems encountered in pure top-down testing and retains the advantages of top-down integration at the subsystem and system level.

9.2.8.2 Regression testing

After modifying software, either for a change in functionality or to fix defects, a regression test re-runs previously passing tests on the modified software to ensure that the modifications haven't unintentionally caused a regression of previous functionality. Regression testing can be performed at any or all of the above test levels. These regression tests are often automated.

In integration testing also, each time a module is added, the software changes. New data flow paths are established, new I/O may occur, and new control logic is invoked. Hence, there is the need of regression testing.

Regression testing is any type of software testing which seeks to uncover regression bugs. Regression bugs occur whenever software functionality that previously worked as desired stops working or no longer works in the same way that was previously planned. Typically regression bugs occur as an unintended consequence of program changes.

Common methods of regression testing include re-running previously run tests and checking whether previously fixed faults have reemerged.

Experience has shown that as software is developed, this kind of reemergence of faults is quite common. Sometimes it occurs because a fix gets lost through poor revision control practices (or simple human error in revision control), but just as often a fix for a problem will be "fragile" - i.e. if some other change is made to the program, the fix no longer works. Finally, it has often been the case that when some feature is redesigned, the same mistakes will be made in the redesign that were made in the original implementation of the feature.

Therefore, in most software development situations it is considered good practice that when a bug is located and fixed, a test that exposes the bug is recorded and regularly retested after subsequent changes to the program. Although this may

be done through manual testing procedures using programming techniques, it is often done using automated testing tools. Such a 'test suite' contains software tools that allows the testing environment to execute all the regression test cases automatically; some projects even set up automated systems to automatically re- run all regression tests at specified intervals and report any regressions. Common strategies are to run such a system after every successful compile (for small projects), every night, or once a week.

Regression testing is an integral part of the extreme programming software development methodology. In this methodology, design documents are replaced

by extensive, repeatable, and automated testing of the entire software package

at every stage in the software development cycle.

Uses of regression testing

Regression testing can be used not only for testing the correctness of a program, but it is also often used to track the quality of its output. For instance in the design of a compiler, regression testing should track the code size, simulation time, and compilation time of the test suites.

System testing is a series of different tests and each test has a different purpose but all work to verify that all system elements have been properly integrated and perform allocated functions. In the following part a number of other system tests have been discussed.

9.2.8.3 Recovery testing

Many systems must recover from faults and resume processing within a specified time. Recovery testing is a system test that forces the software to fail in a variety of ways and verifies that recovery is properly performed.

9.2.8.4 Stress testing

Stress tests are designed to confront programs with abnormal situations. Stress testing executes a program in a manner that demands resources in abnormal quantity, frequency, or volume. For example, a test case that may cause thrashing in a virtual operating system.

9.2.8.5 Performance Testing

For real time and embedded systems, performance testing is essential. In these systems, the compromise on performance is unacceptable. Performance testing is designed to test run-time performance of software within the context of an integrated system.

9.2.9 Acceptance testing

Acceptance testing involves planning and execution of functional tests, performance tests, and stress tests in order to demonstrate that the implemented system satisfies its requirements. Stress tests are performed to test the limitations of the systems. For example, a compiler may be tested to determine the effect of symbol table overflow.

Acceptance test will incorporate test cases developed during unit testing and integration testing. Additional test cases are added to achieve the desired level of functional, performance and stress testing of the entire system.

9.2.9.1 Alpha testing

Alpha testing is simulated or actual operational testing by potential users/customers or an independent test team at the developers' site. Alpha testing is often employed for off-the-shelf software as a form of internal acceptance testing, before the software goes to beta testing.

9.2.9.2 Beta testing

Beta testing comes after alpha testing. Versions of the software, known as beta versions, are released to a limited audience outside of the company. The software is released to groups of people so that further testing can ensure the product has few faults or bugs. Sometimes, beta versions are made available to the open public to increase the feedback field to a maximal number of future users.

9.3 White-box and black-box testing

White box and black box testing are terms used to describe the point of view a test engineer takes when designing test cases. Black box is an external view of the test object and white box, an internal view.

In recent years the term grey box testing has come into common usage. The

typical grey box tester is permitted to set up or manipulate the testing environment, like seeding a database, and can view the state of the product after her actions, like performing a SQL query on the database to be certain of the values of columns. It is used almost exclusively of client-server testers or others

who use a database as a repository of information, but can also apply to a tester who has to manipulate XML files (DTD or an actual XML file) or configuration files directly. It can also be used of testers who know the internal workings or algorithm of the software under test and can write tests specifically for the anticipated results. For example, testing a data warehouse implementation involves loading the target database with information, and verifying the correctness of data population and loading of data into the correct tables.

White box testing

White box testing (also known as clear box testing, glass box testing or structural testing) uses an internal perspective of the system to design test cases based on internal structure. It requires programming skills to identify all paths through the software. The tester chooses test case inputs to exercise all paths and determines the appropriate outputs. In electrical hardware testing every node in a circuit may be probed and measured, an example is In circuit test (ICT).

Since the tests are based on the actual implementation, if the implementation changes, the tests probably will need to also. For example ICT needs updates if component values change, and needs modified/new fixture if the circuit changes. This adds financial resistance to the change process, thus buggy products may stay buggy. Automated optical inspection (AOI) offers similar component level correctness checking without the cost of ICT fixtures, however changes still require test updates.

While white box testing is applicable at the unit, integration and system levels, it's typically applied to the unit. So while it normally tests paths within a unit, it can also test paths between units during integration, and between subsystems during

a system level test. Though this method of test design can uncover an overwhelming number of test cases, it might not detect unimplemented parts of the specification or missing requirements. But you can be sure that all paths through the test object are executed.

Typical white box test design techniques include:

- Control flow testing

- Data flow testing

Code coverage

The most common structure based criteria are based on the control flow of the program. In this criterion, a control flow graph of the program is constructed and coverage of various aspects of the graph is specified as criteria. A control flow graph of program consists of nodes and edges. A node in the graph represents a block of statement that is always executed together. An edge frm node i to node j represents a possible transfer of control after executing the last statement in the block represented by node i to the first statement of the block represented by node j. Three common forms of code coverage used by testers are statement (or line) coverage, branch coverage, and path coverage. Line coverage reports on the execution footprint of testing in terms of which lines of code were executed to complete the test. According to this criterion each statement of the program to be tested should be executed at least once. Using branch coverage as the test criteria, the tester attempts to find a set of test cases that will execute each branching statement in each duirection at least once. A path coverage criterion acknowledges that the order in which the btanches are executed during a test

(the path traversed) is an important factor in determining the test outcome. So tester attempts to find a set of test cases that ensure the traversal of each logical path in the control flow graph.

A Control Flow Graph (CFG) is a diagrammatic representation of a program and

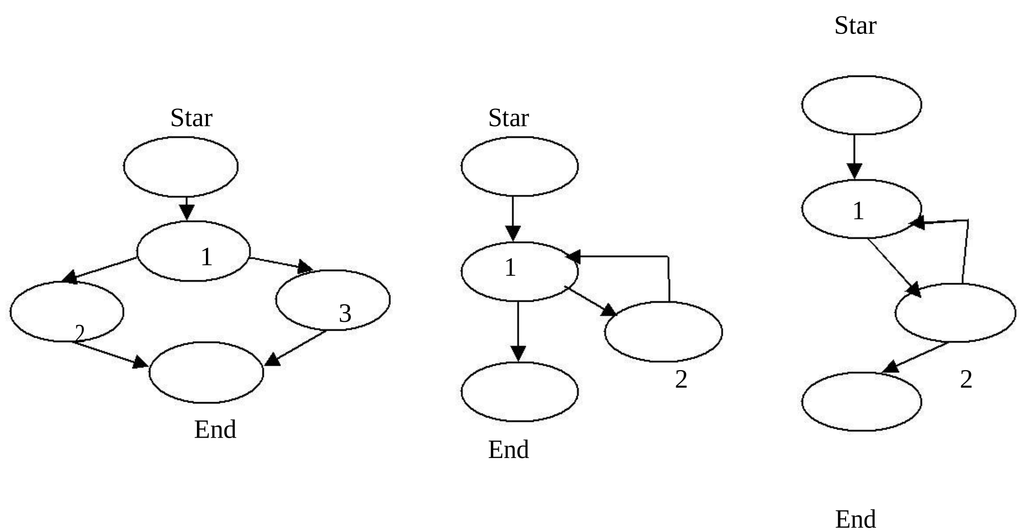
its execution. A CFG shows all the possible sequences of statements of a program. CFGs consist of all the typical building blocks of any flow diagrams.

There is always a start node, an end node, and flows (or arcs) between nodes.

Each node is labeled in order for it to be identified and associated correctly with its corresponding part in the program code.

CFGs allow for constructs to be nested in order to represent nested loops in the

actual code. Some examples are given below in figure 9.3.1:



If loop **While Loop** **Do While Loop**

Figure 9.3.1

In programs where while loops exist, there are potentially an infinite number of unique paths through the program. Every path through a program has a set of associated conditions. Finding out what these conditions are allows for test data

to be created. This enables the code to be tested to a suitable degree.

The conditions that exist for a path through a program are defined by the values

of variable, which change through the execution of the code. At any point in the program execution, the program state is described by these variables.
Statements in the code such as "x = x + 1" alter the state of the program by changing the value of a variable (in this case, x). Infeasible paths are those paths, which cannot be executed. Infeasible paths occur when no values will satisfy the path constraint.

Example:

//Program to find the largest of three
numbers: input a,b,c;
max=a;

if (b>max) max=b;
if(c=max) max=c;
output max;

The control flow graph of this program is given below in figure 9.3.2. In this flowgraph node 1 represents the statements [input a,b,c;max=a;if(b>max)], node
2 represents [max=b], node 3 represents [if(c>max)], node 4 represents [max=c]

and node 5 represents [output max].

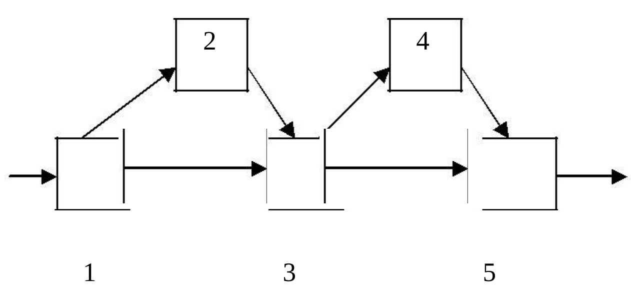


Figure 9.3.2

To ensure the Statement coverage [1, 2, 3, 4, 5] one test case a=5, b=10, and c=15 is sufficient.
To ensure Branch coverage [1, 3, 5] and [1, 2, 3, 4, 5], two test cases are required (i) a=5, b=10, c=15 and (ii) a=15, b=10, and c=5.
To ensure Path coverage ([1,2,3,4,5], [1,3,5], [1,2,3,5], and [1,3,4,5]), four test cases are required:

(i) a=5, b=10, c=15

(ii) a=15, b=10, and c=5.

(iii) a=5, b=10, and c=8

(iv) a=10, b=5, c=15

Path coverage criteria leads to a potentially infinite number of paths, some efforts have been made to limit the number of paths to be tested. One such approach is the cyclomatic complexity. The cyclomatic complexity of a path represents the logically independent path in a program as in the above case the cyclomatic complexity is three so three test cases are sufficient. As these are the independent paths, all other paths can be represented as a combination of these basic paths.

Data Flow testing

The data flow testing is based on the information about where the variables are defined and where the definitions are used. During testing the definitions of variables and their subsequent use is tested. Data flow testing looks at how data moves within a program. There are a number of associated test criteria and these should complement the control-flow criteria. Data flow occurs through

assigning a value to a variable in one place accessing that a value in another place.
To illustrate the data flow based testing; let us assume that each statement in the program has been assigned a unique statement number and that each function does not modify its parameters or global variables. For a statement with S as its statement number,
DEF(S) = { X| statement S contains a definition of X} USE(S) = {
X | statement S contains a use of X}
If statement S is an if or loop statement, its DEF set is empty and its USE set is based on the condition of statement S. The definition of variable X is said to be live at the statement S' if there exists a path from statement S to statement S' that does not contain any other definition of X. A Definition Use chain (DU chain)
of variable X is of the form [X, S, S'], where S and S' are statement numbers, X is

in DEF(S) and USE(S'), and the definition of X in the statement S is live at the statement S'.
One simple data flow testing strategy is to require that every DU chain be covered at least once. This strategy is known as DU testing strategy.

Loop testing

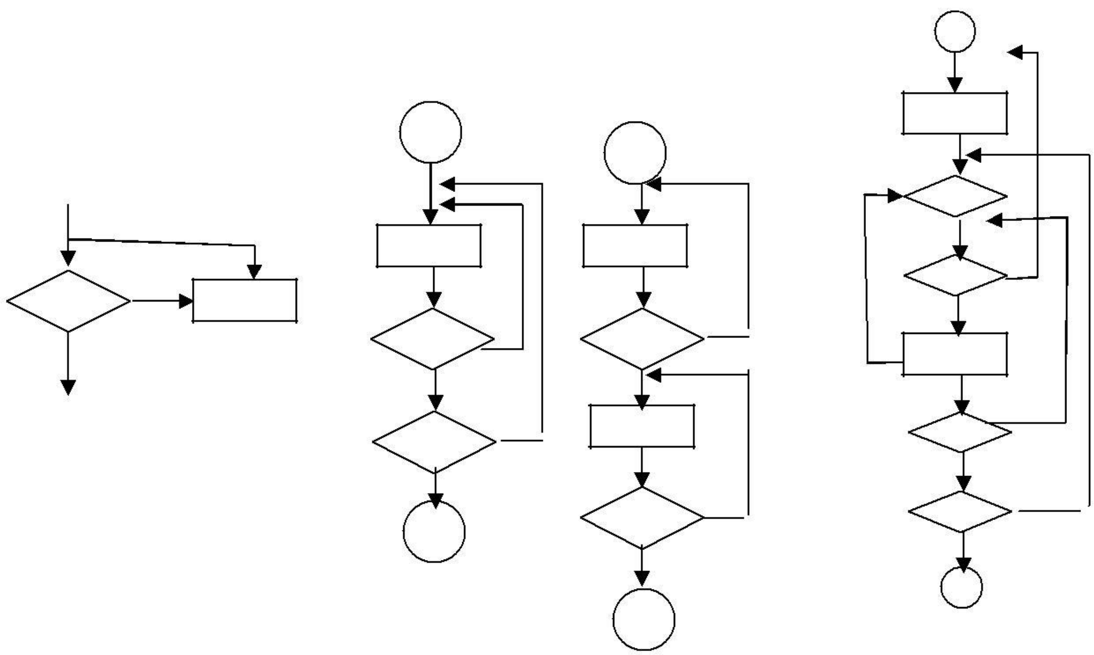
Loops are very important constructs for generally all the algorithms. Loop testing

is a white box testing technique. It focuses exclusively on the validity of loop constructs. Four different types of loops are: simple loop, concatenated loop, nested loop, and unstructured loop as shown in figure 9.3.3.

Simple loop: The following set of tests should be applied to simple loop where n

is the maximum number of allowable passes thru the loop:

- Skip the loop entirely.
- Only one pass thru the loop.
- Two passes thru the loop.
- M passes thru the loop where m < n.
- N-1, n, n+1 passes thru the loop.



Simple loop Nested loop Concatenated loop Unstructured loop

Figure 9.3.3

Nested loop: Beizer approach to the nested loop is:

- Start at the innermost loop. Set all other loops to minimum value.

- Conduct the simple loop test for the innermost loop while holding the outer loops at their minimum iteration parameter value.

- Work outward, conducting tests for next loop, but keeping all other outer loops at minimum values and other nested loops to typical values.
- Continue until all loops have been tested.

Concatenated loops: These can be tested using the approach of simple loops if each loop is independent of other. However, if the loop counter of loop 1 is used
as the initial value for loop 2 then approach of nested loop is to be used.

Unstructured loop: This class of loops should be redesigned to reflect the use

of the structured programming constructs.

9.4 Black Box testing

Black box testing takes an external perspective of the test object to derive test cases. These tests can be functional or non-functional, though usually functional. The test designer selects valid and invalid input and determines the correct output. There is no knowledge of the test object's internal structure.
This method of test design is applicable to all levels of development - unit, integration, system and acceptance. The higher the level, and hence the bigger and more complex the box, the more we are forced to use black box testing to simplify. While this method can uncover unimplemented parts of the specification, you can't be sure that all existent paths are tested. Some common approaches of black box testing are equivalence class partitioning, boundary value analysis etc.

Equivalence class partitioning

Equivalence partitioning is software testing related technique with the

goal: 1. To reduce the number of test cases to a necessary minimum.

2. To select the right test cases to cover all possible scenarios.

Although in rare cases equivalence partitioning is also applied to outputs of a software component, typically it is applied to the inputs of a tested component. The equivalence partitions are usually derived from the specification of the component's behaviour. An input has certain ranges which are valid and other ranges which are invalid. This may be best explained at the following example of
a function which has the pass parameter "month" of a date. The valid range for the month is 1 to 12, standing for January to December. This valid range is called
a partition. In this example there are two further partitions of invalid ranges. The first invalid partition would be <= 0 and the second invalid partition would be >=
13.

-2, -1, 0	1,2,……..12	13, 14, 15
Invalid partition 1	Valid partition	Invalid partition 2

The testing theory related to equivalence partitioning says that only one test case

of each partition is needed to evaluate the behaviour of the program for the related partition. In other words it is sufficient to select one test case out of each partition to check the behaviour of the program. To use more or even all test cases of a partition will not find new faults in the program. The values within one partition are considered to be "equivalent". Thus the number of test cases can be reduced considerably.
An additional effect by applying this technique is that you also find the so called

"dirty" test cases. An inexperienced tester may be tempted to use as test cases the input data 1 to 12 for the month and forget to select some out of the invalid partitions. This would lead to a huge number of unnecessary test cases on the one hand, and a lack of test cases for the dirty ranges on the other hand.

The tendency is to relate equivalence partitioning to the so called black box testing which is strictly checking a software component at its interface, without consideration of internal structures of the software. But having a closer look on the subject there are cases where it applies to the white box testing as well.

Imagine an interface to a component which has a valid range between 1 and 12 like in the example above. However internally the function may have a differentiation of values between 1 and 6 and the values between 7 and 12. Depending on the input value the software internally will run through different paths to perform slightly different actions. Regarding the input and output interfaces to the component this difference will not be noticed, however in your white-box testing you would like to make sure that both paths are examined. To achieve this it is necessary to introduce additional equivalence partitions which would not be needed for black-box testing. For this example this would be:

<table>
<tr><td>-2, -1, 0</td><td>1,…..6</td><td>7,……12</td><td>13, 14, 15</td></tr>
<tr><td rowspan="2">Invalid Partition 1</td><td>P1</td><td>P2</td><td rowspan="2">Invalid Partition 2</td></tr>
<tr><td colspan="2">Valid Partition</td></tr>
</table>

To check for the expected results you would need to evaluate some internal intermediate values rather than the output interface.

Equivalence partitioning is no stand alone method to determine test cases. It has

to be supplemented by boundary value analysis. Having determined the partitions of possible inputs the method of boundary value analysis has to be applied to select the most effective test cases out of these partitions.

Boundary value analysis

Boundary value analysis is software testing related technique to determine test cases covering known areas of frequent problems at the boundaries of software component input ranges. Testing experience has shown that especially the boundaries of input ranges to a software component are liable to defects. A programmer who has to implement e.g. the range 1 to 12 at an input, which e.g. stands for the month January to December in a date, has in his code a line checking for this range. This may look like:

```
if (month > 0 && month < 13)
```

But a common programming error may check a wrong range e.g. starting the range at 0 by writing:

```
if (month >= 0 && month < 13)
```

For more complex range checks in a program this may be a problem which is not so easily spotted as in the above simple example.

Applying boundary value analysis

To set up boundary value analysis test cases you first have to determine which boundaries you have at the interface of a software component. This has to be done by applying the equivalence partitioning technique. Boundary value analysis and equivalence partitioning are inevitably linked together. For the example of the month in a date you would have the following partitions:

-2, -1, 0	1,2,……..12	13, 14, 15

Invalid partition 1	Valid partition	Invalid partition 2

Applying boundary value analysis you have to select now a test case at each side of the boundary between two partitions. In the above example this would be

0 and 1 for the lower boundary as well as 12 and 13 for the upper boundary.

Each of these pairs consists of a "clean" and a "dirty" test case. A "clean" test case should give you a valid operation result of your program. A "dirty" test case should lead to a correct and specified input error treatment such as the limiting of values, the usage of a substitute value, or in case of a program with a user interface, it has to lead to warning and request to enter correct data. The boundary value analysis can have 6 textcases.n,n-1,n+1 for the upper limit and n,n-1,n+1 for the lower limit.

A further set of boundaries has to be considered when you set up your test cases. A solid testing strategy also has to consider the natural boundaries of the data types used in the program. If you are working with signed values this is especially the range around zero (-1, 0, +1). Similar to the typical range check faults programmers tend to have weaknesses in their programs in this range. E.g. this could be a division by zero problems when a zero value is possible to occur although the programmer always thought the range starting at 1. It could

be a sign problem when a value turns out to be negative in some rare cases, although the programmer always expected it to be positive. Even if this critical natural boundary is clearly within an equivalence partition it should lead to additional test cases checking the range around zero. A further natural boundary

is the natural lower und upper limit of the data type itself. E.g. an unsigned 8-bit value has the range of 0 to 255. A good test strategy would also check how the

program reacts at an input of -1 and 0 as well as 255 and 256.

The tendency is to relate boundary value analysis more to the so called black box testing which is strictly checking a software component at its interfaces, without consideration of internal structures of the software. But having a closer look on the subject there are cases where it applies also to white box testing.

After determining the necessary test cases with equivalence partitioning and the subsequent boundary value analysis it is necessary to define the combinations of the test cases in case of multiple inputs to a software component.

Cause-Effect Graphing

One weakness with the equivalence class partitioning and boundary value methods is that they consider each input separately. That is, both concentrate on the conditions and classes of one input. They do not consider combinations of input circumstances that may form interesting situations that should be tested. One way to exercise combinations of different input conditions is to consider all valid combinations of the equivalence classes of input conditions. This simple approach will result in an unusually large number of test cases, many of which will not be useful for revealing any new errors. For example, if there are n different input conditions, such that any combination of the input conditions is valid, we will have 2^n test cases.

Cause-effect graphing is a technique that aids in selecting combinations of input conditions in a systematic way, such that the number of test cases does not become unmanageably large. The technique starts with identifying causes and effects of the system under testing. A cause is a distinct input condition, and an effect is a distinct output condition. Each condition forms a node in the cause- effect graph. The conditions should be stated such that they can be set to either true or false. For example, an input condition can be "file is empty," which can be set to true by having an empty input file, and false by a nonempty file. After identifying the causes and effects, for each effect we identify the causes that can produce that effect and how the conditions have to be combined to make the effect true. Conditions are combined using the Boolean operators "and", "or", and

"not", which are represented in the graph by Λ, V and zigzag line respectively. Then, for each effect, all combinations of the causes that the effect depends on which will make the effect true, are generated (the causes that the effect does not depend on are essentially "don't care"). By doing this, we identify the combinations of conditions that make different effects true. A test case is then generated for each combination of conditions, which make some effect true.

Let us illustrate this technique with a small example. Suppose that for a bank database there are two commands allowed:

credit acct-number transaction_amount debit

acct-number transaction_amount

The requirements are that if the command is credit and the acct-number is valid, then the account is credited. If the command is debit, the acct-number is valid, and the transaction_amount is valid (less than the balance), then the account is debited. If the command is not valid, the account number is not valid, or the debit amount is not valid, a suitable message is generated. We can identify the following causes and effects from these requirements:

Cause:

c_1. Command is credit c_2.

Command is debit

c_3. Account number is valid

c_4. Transaction_amt. is valid

Effects:

e_I. Print "invalid command"

e_2. Print "invalid account-number" e_3. Print "Debit amount not valid" e_4. Debit account

e_5. Credit account

The cause effect of this is shown in following Figure 9.3.4. In the graph, the cause-effect relationship of this example is captured. For all effects, one can easily determine the causes each effect depends on and the exact nature of the dependency. For example, according to this graph, the effect E_5 depends on the causes c_2, c_3, and c_4 in a manner such that the effect E_5 is enabled when all c_2, c_3, and c_4 are true. Similarly, the effect E_2 is enabled if c_3 is false.

From this graph, a list of test cases can be generated. The basic strategy is to

set an effect to I and then set the causes that enable this condition. The condition

of causes forms the test case. A cause may be set to false, true, or don't care (in the case when the effect does not depend at all on the cause). To do this for all the effects, it is convenient to use a decision table (Table 9.3.1). This table lists the combinations of conditions to set different effects. Each combination of conditions in the table for an effect is a test case. Together, these condition combinations check for various effects the software should display. For example,

to test for the effect E_3, both c_2 and c_4 have to be set. That is, to test the effect

"Print debit amount not valid," the test case should be: Command is debit

(setting: c_2 to True), the account number is valid (setting c_3 to False), and the transaction money is not proper (setting c_4 to False).

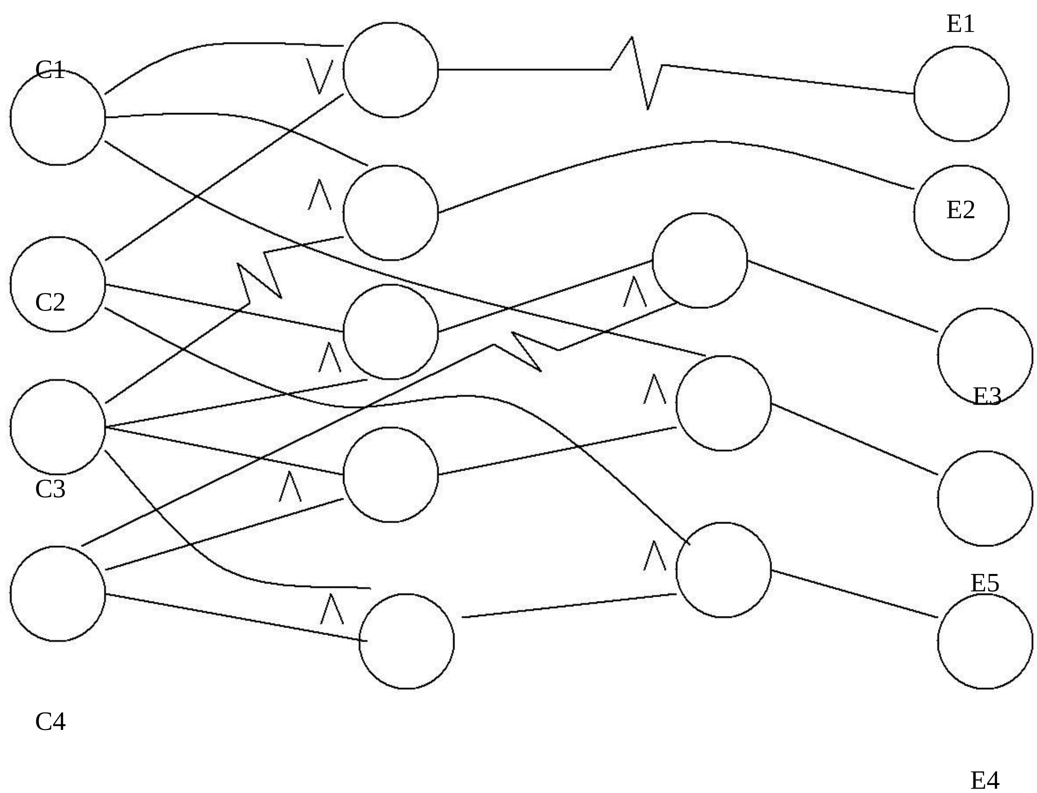


Figure 9.3.4 The Cause Effect Graph

SNo.	1	2	3	4	5
C_1	0	1	x	x	1
C_2	0	x	1	1	x

C_3	x	0	1	1	1

C_4	x	x	0	1	1
E_1	1				
E_2		1			
E_3			1		
E_4				1	
E_5					1

Table 9.3.1 Decision Table for the Cause-effect Graph

Cause-effect graphing, beyond generating high-yield test cases, also aids the understanding of the functionality of the system, because the tester must identify the distinct causes and effects. There are methods of reducing the number of test cases generated by proper traversing of the graph. Once the causes and effects are listed and their dependencies specified, much of the remaining work can also
be automated.

Black box and white box testing compared

White box testing is concerned only with testing the software product; it cannot guarantee that the complete specification has been implemented. Black box testing is concerned only with testing the specification; it cannot guarantee that
all parts of the implementation have been tested. Thus black box testing is testing against the specification and will discover faults of omission, indicating that part of the specification has not been fulfilled. White box testing is testing against the implementation and will discover faults of commission, indicating that part of the implementation is faulty. In order to fully test a software product both black and white box testing are required.
White box testing is much more expensive than black box testing. It requires the

source code to be produced before the tests can be planned and is much more laborious in the determination of suitable input data and the determination if the software is or is not correct. The advice given is to start test planning with a black box test approach as soon as the specification is available. White box planning should commence as soon as all black box tests have been successfully passed, with the production of flow graphs and determination of paths. The paths should then be checked against the black box test plan and any additional required test runs determined and applied.

The consequences of test failure at this stage may be very expensive. A failure of

a white box test may result in a change which requires all black box testing to be repeated and the re-determination of the white box paths. The cheaper option is

to regard the process of testing as one of quality assurance rather than quality control. The intention is that sufficient quality will be put into all previous design and production stages so that it can be expected that testing will confirm that there are very few faults present, quality assurance, rather than testing being relied upon to discover any faults in the software, quality control. A combination

of black box and white box test considerations is still not a completely adequate test rationale; additional considerations are to be introduced.