Principles of Software Engineering

DCAP305

LOVELY PROFESSIONAL UNIVERSITY

LOVELY
PROFESSIONAL
UNIVERSITY

PRINCIPLES OF SOFTWARE ENGINEERING

Produced & Printed by
EXCEL BOOKS PRIVATE LIMITED
A-45, Naraina, Phase-I,
New Delhi-110028
for
Lovely Professional University
Phagwara

CONTENTS

Unit 1:	Introduction to Software Engineering	1
Unit 2:	Software Processes and Models	19
Unit 3:	Software Requirements	35
Unit 4:	Introduction to Validation, Metrics and Software Architecture	55
Unit 5:	Software Project Planning	81
Unit 6:	Functional Design	109
Unit 7:	Introduction to Verification	132
Unit 8:	Detailed Design	141
Unit 9:	Metrics	150
Unit 10:	Coding	164
Unit 11:	Coding Process	181
Unit 12:	Refactoring	188
Unit 13:	Software Testing-I	201
Unit 14:	Software Testing-II	218

SYLLABUS

Principles of Software Engineering

Objectives:

- To enable the student to understand software development process.
- To enable the student to learn various software engineering approaches.
- To enable the student to implement various software testing techniques.
- To enable the student to prepare software requirement specification documents.
- To enable the student to learn various verification and validation techniques.
- To enable the Student to practice software engineering concepts using UML.

Sr. No.	Description
1.	***Introduction:*** Concept of Software Engineering. Software Engineering Challenges & Approach.
2.	***Software Processes and Models:*** Processes and Models, Characteristics of Software Model, Waterfall, Prototype, Iterative, Time Boxing. Comparison.
3.	***Software Requirements:*** Problem Analysis, DataFlow, Object Oriented Modelling, Prototyping. Software Requirement Specification Document: SRS, Characteristics, Components, Specification Language, Structure of Document.
4.	***Introduction to Validation, Metrics:*** Function Point & Quality Metrics. Software Architecture: Architecture Views, Architecture Styles: Client/Server, Shared Data.
5.	***Software Project Planning:*** Process Planning, Effort Estimation, COCOMO Model, Project Scheduling and Staffing. Intro to Software Configuration Management: Quality Plan, Risk Management, Project Monitoring.
6.	***Functional Design:*** Principles, Abstraction, Modularity, Top Down, Bottom Up Approach. Coupling, Cohesion. Structure Charts, Data Flow Diagrams, Design Heuristics.
7.	***Intro to Verification:*** Meaning, Metrics: Network, Stability, Information Flow.
8.	***Detailed Design:*** Process Design Language. Logic/Algorithm Design. Verification of Logic/Algorithm Design. Metrics: Cyclomatic Complexity, Data Bindings, Cohesion Metric.
9.	***Coding:*** Common Errors, Structured Programming, Programming Practices, Coding standards. Coding Process: Incremental, Test Driven, Pair Programming. Refactoring: Meaning and Example. Verification, Metrics: Size & Complexity.
10.	***Testing:*** Fundamentals, Error, Fault, Failure, Test Oracles, Test Cases & Criteria. Black Box: Equivalence Class Partitioning, Boundary Value Analysis. White Box: Control Flow Based, Data Flow Based Testing Process: Levels of Testing, Test Plan, Test Case Specifications, Execution and Analysis. Logging and Tracking. Metrics: Failure Data and Parameter Estimation.

Unit 1: Introduction to Software Engineering

CONTENTS

Objectives

Introduction

1.1 Concepts of Software Engineering

1.1.1 Evolving Role of Software

1.1.2 Software Characteristics

1.1.3 Program vs. Software

1.1.4 Software Engineering and its Relationship with other Disciplines

1.1.5 Software Myths

1.1.6 Software: A Crisis on the Horizon

1.1.7 Software Engineering Framework

1.1.8 Difference between Software Engineering and Computer Science

1.1.9 Difference between Software Engineering and System Engineering

1.2 Software Engineering Challenges and Approach

1.3 Summary

1.4 Keywords

1.5 Review Questions

1.6 Further Readings

Objectives

After studying this unit, you will be able to:

- Discuss various concepts of software engineering.
- Discuss software myths
- Describe software engineering framework.
- Explain the software engineering challenges and approach

Introduction

The complexity and nature of software have changed tremendously in the last four decades. In the 70s applications ran on a single processor, received single line inputs and produced alphanumeric results. However, the applications today are far more complex running on client-server technology and have a user friendly GUI. They run on multiple processors with different OS and even on different geographical machines. The software groups work hard as they can to keep abreast of the rapidly changing new technologies and cope with the developmental issues and backlogs. Even the Software Engineering Institute (SEI) advises to improve upon the developmental process. The “change” is an inevitable need of the hour. However, it often leads to conflicts between the groups of people who embrace change and those who strictly stick to the traditional ways of working. Thus, there is an urgent need to adopt software engineering concepts, practices, strategies to avoid conflicts and in order to improve the software development to deliver good quality software within budget and time.

1.1 Concepts of Software Engineering

The concepts of software engineering are discussed below:

1.1.1 Evolving Role of Software

The role of software has undergone drastic change in the last few decades. These improvements range through hardware, computing architecture, memory, storage capacity and a wide range of unusual input and output conditions. All these significant improvements have lead to the development of more complex and sophisticated computer-based systems. Sophistication leads to better results but can cause problems for those who build these systems.

Lone programmer has been replaced by a team of software experts. These experts focus on individual parts of technology in order to deliver a complex application. However, the experts still face the same questions as that by a lone programmer:

- Why does it take long to finish software?
- Why are the costs of development so high?
- Why aren't all the errors discovered before delivering the software to customers?
- Why is it difficult to measure the progress of developing software?

All these questions and many more have lead to the manifestation of the concern about software and the manner in which it is developed – a concern which lead to the evolution of the software engineering practices.

Today, software takes on a dual role. It is a product and, at the same time, the vehicle for delivering a product. As a product, it delivers the computing potential embodied by computer hardware or, more broadly, a network of computers that are accessible by local hardware. Whether it resides within a cellular phone or operates inside a mainframe computer, software is an information transformer-producing, managing, acquiring, modifying, displaying, or transmitting information that can be as simple as a single bit or as complex as a multimedia presentation. As the vehicle used to deliver the product, software acts as the basis for the control of the computer (operating systems), the communication of information (networks), and the creation and control of other programs (software tools and environments). Software delivers the most important product of our time-information.

Software transforms personal data (e.g., an individual's financial transactions) so that the data can be more useful in a local context; it manages business information to enhance competitiveness; it provides a gateway to worldwide information networks (e.g., Internet) and provides the means for acquiring information in all of its forms.

The role of computer software has undergone significant change over a time span of little more than 50 years. Dramatic improvements in hardware performance, profound changes in computing architectures, vast increases in memory and storage capacity, and a wide variety of exotic input and output options have all precipitated more sophisticated and complex computer-based systems.

The lone programmer of an earlier era has been replaced by a team of software specialists, each focusing on one part of the technology required to deliver a complex application.

The same questions asked of the lone programmer are being asked when modern computer-based systems are built. Give answers to questions:

1. Why does it take so long to get software finished?
2. Why are development costs so high?
3. Why can't we find all the errors before we give the software to customers?
4. Why do we continue to have difficulty in measuring progress as software is being developed?

1.1.2 Software Characteristics

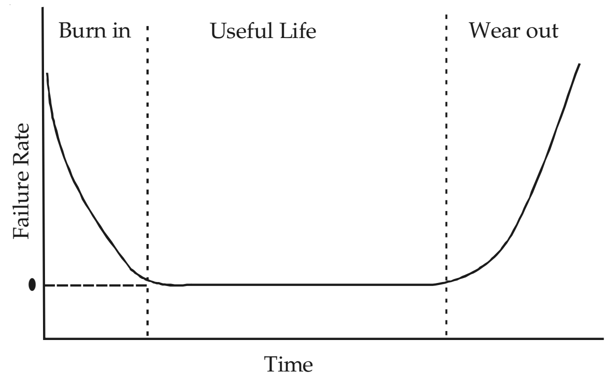
In the first NATO conference on software engineering in 1968, Fritz Bauer defined Software engineering as "The establishment and use of sound engineering principles in order to obtain economically software that is reliable and works efficiently on real machines". Stephen Schach defined the same as "A discipline whose aim is the production of quality software, software that is delivered on time, within budget and that satisfies its requirements".

Did u know? The software differs from hardware as it is more logical in nature and hence, the difference in characteristics.

Let us now explore the characteristics of software in detail:

- ***Software is Developed or Engineered and not Manufactured:*** Although there exists few similarities between the hardware manufacturing and software development, the two activities differ fundamentally. Both require a good design to attain high quality. But the manufacturing phase of hardware can induce quality related problems that are either non-existent for software or can be easily rectified. Although both activities depend on people but the relationship between people and work is totally different.
- ***Software does not Wear Out:*** Figure 1.1 shows the failure rate of hardware as a function of time. It is often called the "bathtub curve", indicating that a hardware shows high failure at its early stage (due to design and manufacturing defects); defects get resolved and the failure rate reduces to a steady-state level for some time. As time progresses, the failure rate shoots up again as the hardware wears out due to dust, temperature and other environmental factors.

Figure 1.1: Failure Curve for Hardware



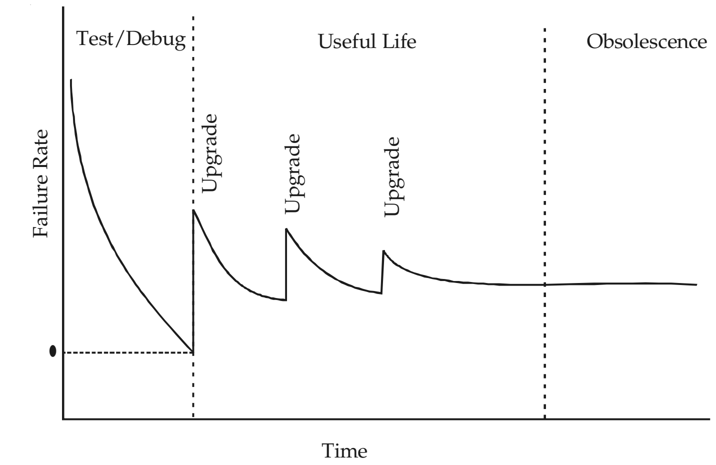
- Because the software does not undergo environmental degradation, its failure curve ideally should flatten out after the initial stage of its life. The initial failure rate is high because of

Notes

undiscovered defects. Once these defects are fixed, the curve flattens at a later stage. Thus, the software does not wear out but deteriorates.

- The actual curve as shown in Figure 1.2 can explain the contradiction stated above. Because software undergoes changes during its lifetime as a part of the maintenance activities, new defects creep in causing the failure rate to rise (spike). While the software enters its steady state further more changes are added which induce further more defects and hence, spikes in the failure rate.

Figure 1.2: Failure Curve for Software



The minimum failure rate rises and the software deteriorates due to induction of frequent changes.

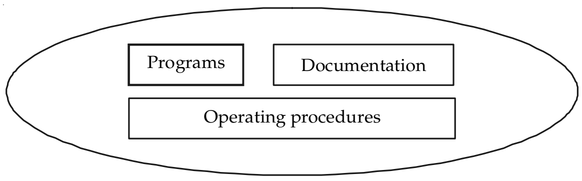
- ***Software is Custom Built and Not Designed Component Wise:*** Software is designed and built so that it can be reused in different programs. Few decades ago subroutine libraries were created that re-used well defined algorithms but had a limited domain. Today this view has been extended to ensure re-usability of not only algorithms but data structures as well.

Notes The data and the processes that operate on this data were combined together to be able to use later on.

1.1.3 Program vs. Software

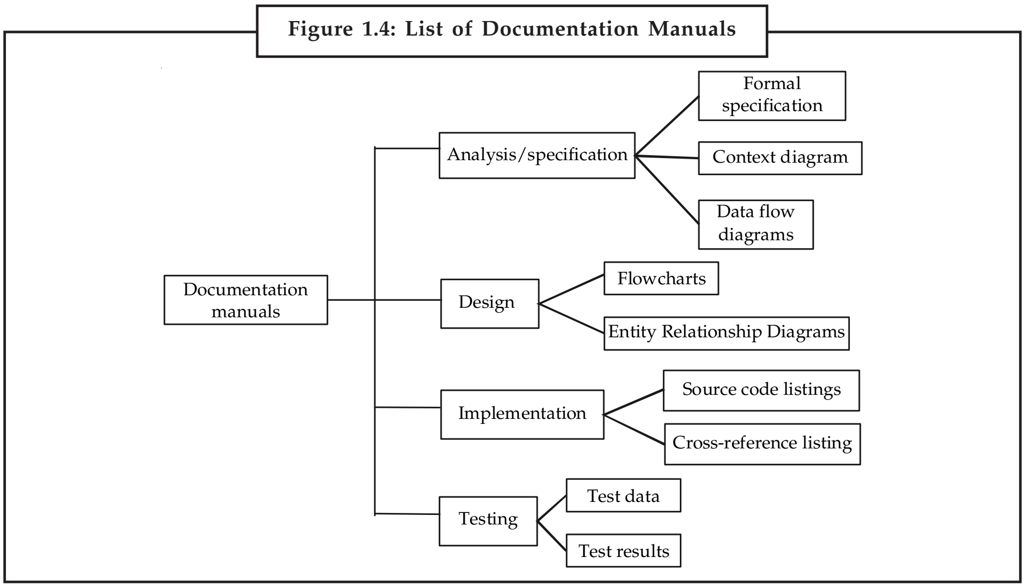
Software is more than programs. It comprises of programs, documentation to use these programs and the procedures that operate on the software systems.

Figure 1.3: Components of Software



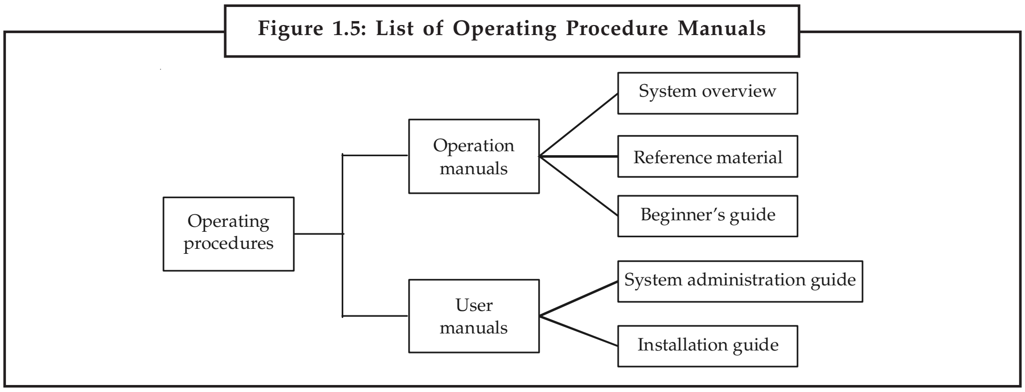
A program is a part of software and can be called software only if documentation and operating procedures are added to it. Program includes both source code and the object code.

Figure 1.4: List of Documentation Manuals



Operating procedures comprise of instructions required to setup and use the software and instructions on actions to be taken during failure. List of operating procedure manuals/documents is given in Figure 1.5.

Figure 1.5: List of Operating Procedure Manuals



1.1.4 Software Engineering and its Relationship with other Disciplines

Any area that involves a sequence of steps (i.e. an algorithm) to generate output can make use of software engineering. The nature of the software application depends upon two things:

1. the form of incoming and outgoing information. Some business applications generate more complex results then others and require more complex inputs.
2. The sequence and timing of the information being used.

A program that takes data in a predefined order, applies algorithms to it and generates results is called a determinate program. On the other hand, the application that accepts data from multiple users at varied timings, applies logic that can be interrupted by external conditions, and generates results that vary according to time and environment are called indeterminate. Although software application cannot be categorized, following areas show the potential application of software in various breadths:

- ***Real-time Software:*** It refers to the software that controls the events and when they occur. The data gatherer component of the software gathers the data and formats it into an acceptable form. The analyzer component that transforms information as required by the application. The output component that interacts with the external environment and the monitoring component that coordinates with all the components to generate timely results.
- ***Business Software:*** It is the single largest area of software application. These areas use one or more large databases for business information and reframe the information in such a manner that facilitates business operations and decision making.

Example: Library management, data inventory, HR management, etc.

- ***System Software:*** It is the software program that interacts with the hardware components so that other application software can run on it.

Example: Operating systems like Windows, Unix, DOS, etc., are examples of the system software.

Such type of software perform a wide range of operations like allocation and distribution of memory amongst various computer processes, process scheduling, resource scheduling, etc.

- ***Embedded Software:*** This software resides in the commodities for the consumer and industry markets in the form of read-only memory devices. They perform limited functions e.g. keypad of an automatic washing machine or significant functions as per requirement e.g. dashboard functions in an aircraft.
- ***Personal Computer Software:*** These software programs have grown rapidly over the past few decades. These include the like of database management, entertainment, computer graphics, multimedia, etc.
- ***Web-based Software:*** The web-pages displayed by a browser are programs that include executable instructions (e.g. CGI, Perl, Java), hypertext and audio-visual formats.
- ***Artificial Intelligence Software:*** AI software uses algorithms to solve problems that are not open to simple computing and analysis.

Example: Pattern matching (voice or image), game playing, robotics, expert systems, etc.

- ***Engineering Software:*** The software is characterized by number-crunching algorithms ranging from molecular biology, automated manufacturing to space shuttle orbit management, etc.

Task Make distinction between system software and embedded software.

1.1.5 Software Myths

- ***Myth 1:*** Computers are more reliable than the devices they have replaced.

Considering the reusability of the software, it can undoubtedly be said that the software does not fail. However, certain areas which have been mechanized have now become prone to software errors as they were prone to human errors while they were manually performed.

Example: Accounts in the business houses.

- ***Myth 2:*** Software is easy to change.

  Yes, changes are easy to make – but hard to make without introducing errors. With every change the entire system must be re-verified.

- ***Myth 3:*** If software development gets behind scheduled, adding more programmers will put the development back on track.

  Software development is not a mechanistic process like manufacturing. In the words of Brooks: "adding people to a late software project makes it later".

- ***Myth 4:*** Testing software removes all the errors.

  Testing ensures presence of errors and not absence. Our objective is to design test cases such that maximum number of errors is reported.

- ***Myth 5:*** Software with more features is better software.

  This is exactly the opposite of the truth. The best programs are those that do one kind of work.

- ***Myth 6:*** Aim has now shifted to develop working programs.

  The aim now is to deliver good quality and efficient programs rather than just delivering working programs. Programs delivered with high quality are maintainable.

The list is unending. These myths together with poor quality, increasing cost and delay in the software delivery have lead to the emergence of software engineering as a discipline.

Types of Myths

The different types of myths are:

- ***Software Myths:*** Software Myth beliefs about software and the process used to build it – can be traced to the earliest days of computing. Myths have a number of attributes that have made them insidious.

Example: For instance, myths appear to be reasonable statements of fact, they have an intuitive feel, and they are often promulgated by experienced practitioners who "know the score".

- ***Management Myths:*** Managers with software responsibility, like managers in most disciplines, are often under pressure to maintain budgets, keep schedules from slipping, and improve quality. Like a drowning person who grasps at a straw, a software manager often grasps at belief in a software myth, if the Belief will lessen the pressure.

  Myth: We already have a book that's full of standards and procedures for building software. Won't that provide my people with everything they need to know?

  Reality: The book of standards may very well exist, but is it used?

  - ❖ Are software practitioners aware of its existence?
  - ❖ Does it reflect modern software engineering practice?

  - ❖ Is it complete? Is it adaptable?
  - ❖ Is it streamlined to improve time to delivery while still maintaining a focus on Quality?

  In many cases, the answer to these entire questions is no:

  - ❖ *Myth:* If we get behind schedule, we can add more programmers and catch up (sometimes called the Mongolian horde concept).
  - ❖ *Reality:* Software development is not a mechanistic process like manufacturing. In the words of Brooks: "Adding people to a late software project makes it later." At first, this statement may seem counter-intuitive. However, as new people are added, people who were working must spend time educating the newcomers, thereby reducing the amount of time spent on productive development effort.
  - ❖ *Myth:* If we decide to outsource the software project to a third party, I can just relax and let that firm build it.
  - ❖ *Reality:* If an organization does not understand how to manage and control software project internally, it will invariably struggle when it out sources software project.

- ***Customer Myths:*** A customer who requests computer software may be a person at the next desk, a technical group down the hall, the marketing/sales department, or an outside company that has requested software under contract. In many cases, the customer believes myths about software because software managers and practitioners do little to correct misinformation.

Caution Myths led to false expectations and ultimately, dissatisfaction with the developers.

  - ❖ *Myth:* A general statement of objectives is sufficient to begin writing programs we can fill in details later.
  - ❖ *Reality:* Although a comprehensive and stable statement of requirements is not always possible, an ambiguous statement of objectives is a recipe for disaster. Unambiguous requirements are developed only through effective and continuous communication between customer and developer.
  - ❖ *Myth:* Project requirements continually change, but change can be easily accommodated because software is flexible.
  - ❖ *Reality:* It's true that software requirement change, but the impact of change varies with the time at which it is introduced. When requirement changes are requested early, cost impact is relatively small.

However, as time passes, cost impact grows rapidly – resources have been committed, a design framework has been established, and change can cause upheaval that requires additional resources and major design modification.

1.1.6 Software: A Crisis on the Horizon

It has been expected that, by 1990, the one half of work force will depend on computers and software to do its daily work. As computer hardware costs persist to decline, the demand for new applications software continues to boost at a rapid rate. The existing stock of software continues to grow, and the effort required for maintaining the stock continues to increase as well. At the same time, there is a major shortage of qualified software professionals. Combining these factors, one might project that at some point of time, every worker will have to be concerned for software development and maintenance. For now, the software development scene is often characterised by:

- ***Size:*** Software is becoming larger and more complex with the growing complexity and expectations out of software.

Example: The code in consumer products is doubling every couple of years.

- ***Quality:*** Many software products have poor quality i.e., the software produces defects after put into use due to ineffective testing techniques.

Example: Software testing typically finds 25 defects per 1000 lines of code.

- ***Cost:*** Software development is costly i.e., in terms of time taken to develop and the money involved.

Example: Development of the FAA's Advance Automation System cost over $700 per line of code.

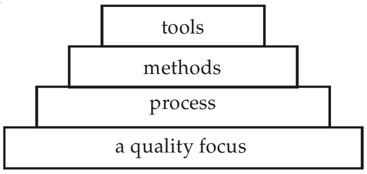
- ***Delayed Delivery:*** Serious schedule overruns are common. Very often the software takes longer than the estimated time to develop which in turn leads to cost shooting up.

Example: One in four large-scale development projects is never completed.

1.1.7 Software Engineering Framework

Software Engineering has a three layered framework. The foundation for software engineering is the process layer. Software engineering process holds the technology layers together and enables rational and timely development of computer software. Process defines a framework for a set of Key Process Areas (KPA) that must be established for effective delivery of software engineering technology.

Figure 1.6: Software Engineering Framework



Software engineering methods provide the technical know how for building software. Methods encompass a broad array of tasks that include requirements analysis, design, program construction, testing, and support.

Software engineering tools provide automated or semi-automated support for the process and the methods.

Notes When tools are integrated so that information created by one tool can be used by another, a system for the support of software development called Computer Aided Software Engineering (CASE) is established.

Notes

Software Process

A process is a series of steps involving activities, constraints and resources that produce an intended output of some kind.

In simpler words, when you build a product or system, it's important to go through a series of predictable steps – a road map that helps you create a timely, high quality result. The road map that you follow is called a software process.

In the last decade there has been a great deal of resources devoted to the definition, implementation, and improvement of software development processes.

- ISO 9000
- Software Process Improvement and Capability Determination (SPICE)
- SEI Processes
- Capability Maturity Model (CMM) for software
- Personal Software Process (PSP)
- Team Software Process (TSP)
- A set of activities whose goal is the development or evolution of software.

Generic activities in all software processes are:

- ***Specification:*** what the system should do and its development constraints
- ***Development:*** production of the software system
- ***Validation:*** checking that the software is what the customer wants
- ***Evolution:*** changing the software in response to changing demands.

Software Process Model

- A simplified representation of a software process, presented from a specific perspective.

  Example: Process perspectives are:
- Workflow perspective – sequence of activities
- Data-flow perspective – information flow
- Role/action perspective – who does what

Generic Process Models

- Waterfall
- Evolutionary development
- Formal transformation
- Integration from reusable components.

Software Engineering Methods

- Structured approaches to software development which include system models, notations, rules, design advice and process guidance
- Model descriptions – Descriptions of graphical models, which should be produced

Notes

- Rules Constraints applied to system models
- Recommendations – Advice on good design practice
- Process guidance – What activities to follow

CASE (Computer-Aided Software Engineering)

Software systems which are intended to provide automated support for software process activities. CASE systems are often used for method support:

- ***Upper-CASE:*** Tools to support the early process activities of requirements and design.
- ***Lower-CASE:*** Tools to support later activities such as programming, debugging and testing.

Attributes of Good Software

The software should deliver the required functionality and performance to the user and should be maintainable, dependable and usable.

- ***Maintainability:*** Software must evolve to meet changing needs.
- ***Dependability:*** Software must be trustworthy.
- ***Efficiency:*** Software should not make wasteful use of system resources.
- ***Usability:*** Software must be usable by the users for which it was designed.

Task Software engineering methods only became widely used when CASE technology became available to support them. Suggest five types of method support, which can be provided by CASE tools.

1.1.8 Difference between Software Engineering and Computer Science

Computer science covers the core concepts and technologies involved with how to make a computer do something while software engineering focuses on how to design and build software. The difference seems minimal but there is a major difference in the sense that in Software Engineering you will learn how to analyze, design, build and maintain software in teams. You will learn about working with people (communication, management, and working with non-technical customers), processes for developing software, and how to measure and analyze the software product and the software process.

Computer science is concerned with theory and fundamentals; software engineering is concerned with the practicalities of developing and delivering useful software.

Did u know? Computer science theories are currently insufficient to act as a complete underpinning for software engineering.

1.1.9 Difference between Software Engineering and System Engineering

As mentioned before software engineering deals with building and maintaining software systems. System engineering is an interdisciplinary field of engineering that focuses on the development and organization of complex artificial systems. System engineering integrates other disciplines and specialty groups into a team effort, forming a structured development process that proceeds from concept to production to operation and disposable.

System Engineering considers both the business and technical needs of all customers, with the goal of providing a quality product that meets the user needs.

Self Assessment

Fill in the blanks:

1. A ………………….. is a part of software and can be called software only if documentation and operating procedures are added to it.
2. A program that takes data in a predefined order, applies algorithms to it and generates results is called a ………………….. program.
3. ………………….. software refers to the software that controls the events and when they occur.
4. ………………….. is the software program that interacts with the hardware components so that other application software can run on it.
5. ………………….. software resides in the commodities for the consumer and industry markets in the form of read-only memory devices.
6. ………………….. software uses algorithms to solve problems that are not open to simple computing and analysis.
7. ………………….. software programs have grown rapidly over the past few decades.
8. Program includes both source code and the ………………….. code.
9. ………………….. beliefs about software and the process used to build it – can be traced to the earliest days of computing.
10. ………………….. tools support the early process activities of requirements and design.
11. The foundation for software engineering is the ………………….. layer.

1.2 Software Engineering Challenges and Approach

Over the years, the term software engineering has been attributed with a number of definitions. A common one that is used to characterize the discipline is a methodical, engineering approach to the design and development of software production, throughout its whole life cycle. It can also be considered analogous to an encompassing viewpoint which combines a number of potential sub-disciplines, including system analysis, system development and accompanying documentation as well as testing, amongst others.

The software engineering discipline has been faced with a number of challenges over the years, including those related to quality, management and under estimation. Although numerous approaches, including methods and frameworks have been introduced and adopted as industry standards and/or best practices that have mitigated many of these issues, the discipline is still faced with a number of challenges, and future challenges are also bound to appear.

Sommerville mentions three fundamental categories of such challenges, namely:

- ***Legacy Systems:*** Old, valuable systems must be maintained and updated
- ***Heterogeneity:*** Systems are distributed and include a mix of hardware and software

- ***Delivery:*** There is increasing pressure for faster delivery of software
- ***Trust:*** The ability to demonstrate to the end user the trustworthiness of the software

Although these are undoubtedly critical, perhaps one can also consider a number of others. Cost estimation and containment is potentially one of these issues and one which continues to be relatively difficult to control, and will potentially continue to be so in the near future, even though costing models such as COCOMO in its latest incarnation has become a versatile cost estimation method and used widely in the industry. Software costs tend to be an order of magnitude the cost the hardware they are executed on. This indicates that potentially better software development tools which potentially provide higher levels of abstractions are required, and which will hopefully lead to faster development times without reducing overall quality. Greater emphasis, with all its repercussions, on automated code generation will probably become more prevalent in the future in this respect.

Although metrics exist with respect to certain aspects for measuring the quality of software, in the future the emphasis on this will increase. This will put greater importance on software re-usability in general.

As more and more software seems to be shifting towards the adoption of a configuration based approach where the base product(s) offer a generalized view of the product capabilities and allow the end user to be able to provide specific business rules to enable tackling aspects of business in a particular fashion via configuration, or rather as it is usually referred to as construction-by-configuration, it becomes fundamental that the software engineering discipline also gears up to this new approach of delivering solutions as until recently, this aspect has been primarily neglected as identified in.

Another challenge for the software engineering discipline is the increasing concern with respect to the design and management of software projects whose complexity is increasing exponentially. This is amplified, as hinted earlier, with the greater level of inter-connectedness, with the accompanying dependencies imposed by most modern software, which will in turn place further emphasis on abstraction. This is an area where, potentially, agent-based intelligent adaptive systems become a more natural choice to minimize the increasing complexity of software systems in general.

Legacy systems will also continue to present a considerable challenge to software engineering because the need to ensure that the old technologies are capable to co-exist with the new and vice-versa will be much greater in the near future. This issue arises from the fact that while by and large it is an accepted fact that application and system topologies change very rapidly, throughout the metamorphosis cycles of predominant technologies, software systems evolve into mission critical tools for organizations. The repetitive enhancement and modification cycles performed on these systems inhibit the proper evolution process of such information systems, which almost inevitably leads to demotion of these systems to legacy status and outside the mainstream technology sphere.

⚠ *Caution* It is impossible to re-engineer these system with every technology cycle primarily due to cost.

From a human resources perspective, although the death of traditional application programmer role has been touted on a number of occasions, the current market still seems to require more than actually available, which is a big contradiction. However, as highlighted in, changing forces and development patterns, including the greater acceptance of off-the-shelf packages will probably have its affect on software engineering in general, especially if there is a shift towards a more declarative type of approach to programming, again as hinted in.

Notes

Although great strides have been and are continuously being made to bring software engineering to the same level of traditional engineering disciplines, admittedly, to date, there are still areas which are not yet up to scratch, perhaps stemming out primarily (not solely) from the fact that some artistic creativeness/flair is considered by many as a requirement in certain specific areas of software engineering. Greater consensus on best practices and patterns is required, especially between academia and the industry. Initiatives such as CHASE (Challenges and Achievements in Software Engineering) strive to "contrast an industrial perspective with an academic perspective, in order to identify the main achievements of the past, i.e., the state-of-the-art, and to identify the main challenges for the future." However, looking back at the improvements made by the discipline during the last couple of years, one can reckon that solutions will be identified accordingly, and as time goes by, the software engineering role will become more formal, with tools, approaches and models which resemble more closely the other, traditionally more formal, engineering disciplines.

Self Assessment

State whether the following statements are true or false:

12. There is increasing pressure for faster delivery of software.

13. Software costs tend to be an order of magnitude the cost the hardware they are executed on.

14. Although metrics exist with respect to certain aspects for measuring the quality of software, in the future the emphasis on this will decrease.

15. Process defines a framework for a set of Key Process Areas (KPA) that must be established for effective delivery of software engineering technology.

Case Study

Client Server

Introduction

ACME Financial is a fast growing company that owes part of its growth to several recent acquisitions. ACME Financial now wants to consolidate the companies' information technology resources to eliminate redundancy and share information among the new companies. The Chief Information Officer (CIO) has oversight responsibility for the project and has hired Client/Servers R Us to develop the architecture for the new corporate information system. Joe Consultant of C/S R Us presented 3 client/server designs to the CIO and is requesting the CIO to select one. The CIO is not sure which middleware design is best for the company's goals. The CIO has asked Chris Consultant to present the advantages and disadvantages for each of the alternatives.

Background

ACME Financial Incorporated (AF Inc.) is an investment banking company that provides an online service that allows their clients to access account and market information. ACME Financial Inc. recently acquired several small and medium sized companies throughout the country, each with their own financial and accounting systems. Almost all of the companies have developed their own application software for their analysts' use in their daily jobs, but only a few provided online account service. The analytical tools rely on near-real time market data and historical market data. The CIO wants to consolidate the financial and accounting information into a corporate information system that can support

Contd...

decision support applications for corporate management. Naturally, since the computer hardware is different for different companies, the CIO expects to upgrade the hardware to accommodate the new Information Technology (IT) system. The CIO will select the best analytical software as the standard software used by all company analysts. Each local site will be expected to provide an online service for their customers. Customers will be given the necessary application software to access their account information. Finally, ACME Financial has developed special data mining software that gives them a competitive advantage. AF Inc. offers their customers investment advice based on the information derived by the data mining software. Each account manager receives the information and then provides tailored recommendations to each customer based on their portfolio.

System Requirements

The following list of system requirements reflects the system's relative priorities:

1. ***Availability:*** The CIO's number one priority is high availability. AF Inc. markets their reliability and feels that most clients choose them for their dependability. The CIO wants to maximize the system's availability. To achieve high availability, if a regional office cannot provide support then a customer must always have access to the online service through a different office.

2. ***Data Integrity:*** The requirement for data integrity varies within the system. The most important data are customer's transactions. It is essential that a customer's transaction is never lost and the system must guarantee that each transaction is completed. In contrast, data lost from the high data rate inputs, such as Reuter's and the NYSE, are easily recovered in subsequent broadcasts so it is not critical if some data are lost during a broadcast.

3. ***Performance:*** Financial markets are highly volatile; time sensitivity of data is measured in minutes. Millions can be lost if information is delayed getting to the analysts. The system must be able to support information broadcast throughout the network.

4. ***Security:*** The CIO is concerned about the security of the data mining software and the information produced by the data mining software. The Chief Executive Officer thinks the data mining information software provides a competitive advantage for the company. If an unauthorized user had access to the information they could steal the data mining applications or steal the information produced by the data mining software. In either case, the perpetrator could make the same investment recommendations as AF Inc. account managers. Therefore, if competitors had access to the information the results could be financially devastating to the company. The CIO is concerned that a competitor could pose as a customer and hack into the highly sensitive information through his online service account.

5. ***Growth:*** The CIO envisions an incremental migration process to install the new system due to the magnitude of the change. Also, he expects that AF Inc. will continue to grow and acquire more companies. The CIO wants to be able to develop more application software as new customer services are added. The CIO also wants to add more near-real time information sources to the system.

6. ***Backup and Recovery:*** The CIO understands that the system will encounter problems from time to time. A key factor in determining the system's success is how quickly the system can recover from a failure. Backup and recovery must be smooth and non-disruptive. One way to ensure that the system can easily recover from a system crash is to make sure the data is duplicated elsewhere on the system. The corporate database is the primary back up for each of the regional offices.

Contd...

Each local office (Northeast, Northwest, Southeast, Southwest) has accesses a regional information hub. Local offices use client software to access the local application server. These application servers access the local databases for almost all of the information needed on a daily basis. For access to information needed less frequently the application software should access the central database at corporate headquarters. Each regional database has only the subset of information that is relevant for its area, whereas the corporate headquarters maintains all of the information from each region as well as data that is unique to corporate applications, such as additional accounting and company financial information.

The corporate office is also responsible for the data mining software and information. Each of the regional databases is connected with high capacity links to the corporate database. Finally, the corporate office receives information from Reuter's, NYSE, NASDAQ, and other financial markets. The information flow fluctuates daily from 30 40 KBps to 4 5 MBps. Twenty-five percent of the information is immediately broadcast to the regional offices to support the online account service. All the information is filtered and stored in the database.

Architectural Alternatives

Alternative I: The Database Management System This alternative takes advantage of the extended functionality provided by the popular relational database management companies, such as Oracle and Sybase. All information is delivered into the system where it is immediately stored into one of the databases. The relational database management software is responsible for the distribution of information throughout the system. Clients communicate with the databases through Standard Query Language (SQL). Corporate and regional databases are kept synchronized using features supplied by the RDBMS software. Transactions are guaranteed by using special Transaction Processing Software. The vendor-supplied RDBMS software is responsible for back-up and recovery of all the databases. Data security is handled at the row level within each database. This means that clients can only receive records for which their user has permission. Existing application software may have to be modified to use SQL.

Alternative II: Common Object Request Broker Architecture (CORBA) This solution depends on CORBA to tie together the clients and databases. CORBA is responsible for distributing data across the system. The RDBMS software is still responsible for the back-up and recovery, but the databases are kept synchronized using CORBA as the primary transport mechanism for the data. Clients, application servers, and databases communicate to each other through CORBAs transport mechanism. Existing application software would be wrapped in IDL to communicate with other applications. Special near-real time handling application software would send the information to each of the regional offices where it would be directed to clients that subscribe to the information.

Alternative III: Message and Queuing (M&Q) The message and queuing design uses commercial M & Q software combined with a transaction processing product to ensure customers transactions are completed. Dec Message Queue and MQ Series are some of the leading products for messaging and queuing software. Clients communicate to other entities using messages. Messages are deposited in queues and the message and queuing middleware is responsible for message distribution to the appropriate clients. The software applications will be modified to send and receive messages from queues.

Questions:

1. Describe in more detail the architecture of each alternative.
2. Evaluate each of the alternatives against the system requirements.

Source: http://www.cs.cmu.edu/afs/cs.cmu.edu/project/vit/ftp/pdf/client_server.pdf

1.3 Summary

- The software differs from hardware as it is more logical in nature and hence, the difference in characteristics.
- Software is more than programs. It comprises of programs, documentation to use these programs and the procedures that operate on the software systems.
- Any area that involves a sequence of steps (i.e. an algorithm) to generate output can make use of software engineering.
- The software myths together with poor quality, increasing cost and delay in the software delivery have lead to the emergence of software engineering as a discipline.
- Software engineering process holds the technology layers together and enables rational and timely development of computer software.
- The software engineering discipline has been faced with a number of challenges over the years, including those related to quality, management and under estimation.
- One of the challenge for the software engineering discipline is the increasing concern with respect to the design and management of software projects whose complexity is increasing exponentially.
- Legacy systems will also continue to present a considerable challenge to software engineering because the need to ensure that the old technologies are capable to co-exist with the new and vice-versa will be much greater in the near future

1.4 Keywords

Artificial Intelligence Software: AI software uses algorithms to solve problems that are not open to simple computing and analysis.

Determinate Program: A program that takes data in a predefined order, applies algorithms to it and generates results is called a determinate program.

Process: A process is a series of steps involving activities, constraints and resources that produce an intended output of some kind.

Program: A program is a part of software and can be called software only if documentation and operating procedures are added to it.

Real-time Software: It refers to the software that controls the events and when they occur.

Software: It is defined as a discipline whose aim is the production of quality software, software that is delivered on time, within budget and that satisfies its requirements.

System Engineering: System engineering is an interdisciplinary field of engineering that focuses on the development and organization of complex artificial systems.

System Software: It is the software program that interacts with the hardware components so that other application software can run on it.

1.5 Review Questions

1. Process defines a framework for a set of Key Process Areas (KPA) that must be established for effective delivery of software engineering technology. Analyze this statement.
2. "Software is designed and built so that it can be reused in different programs." Substantiate with suitable examples.

Notes

3. Suppose you are the software engineer of a modern and technically equipped company then explain how software delivers the most important product of our time-information.
4. Explain the different types of myths in software engineering.
5. Critically analyze the role of computer software. “Software has undergone significant change over a time span of little more than 50 years.” Comment.
6. “The software differs from hardware as it is more logical in nature and hence, the difference in characteristics.” Discuss.
7. Software is easy to change. It is myth. Explain why or why not? Explain with example.
8. Discuss the concept of software engineering framework.
9. Apart from the challenges of legacy systems, heterogeneity and rapid delivery, identify other problems and challenges that software engineering is likely to face in the 21st century.
10. Describe the relationship of software engineering with other relationships.

Answers: Self Assessment

1. program
2. Determinate
3. Real-time
4. System Software
5. Embedded
6. AI
7. Personal computer
8. Object
9. Software Myth
10. Upper-CASE
11. process
12. True
13. True
14. False
15. True

1.6 Further Readings

Books

Rajib Mall, *Fundamentals of Software Engineering*, 2nd Edition, PHI.

Richard Fairpy, *Software Engineering Concepts*, Tata McGraw Hill, 1997.

R.S. Pressman, *Software Engineering – A Practitioner’s Approach*, 5th Edition, Tata McGraw Hill Higher education.

Sommerville, *Software Engineering*, 6th Edition, Pearson Education

Online links

ftp://ftp.cordis.europa.eu/pub/ist/docs/directorate_d/st-ds/softeng.pdf

http://www0.cs.ucl.ac.uk/staff/A.Finkelstein/talks/10openchall.pdf

http://thepiratebay.sx/torrent/8192581/Software_Engineering__A_Practitioner_s_Approach__7th_Ed._[PDF]

http://www.etsf.eu/system/files/users/SottileF/XG_Basics_v2.pdf

Unit 2: Software Processes and Models

Notes

CONTENTS

Objectives

Introduction

2.1 Processes and Models

2.1.1 The Software Process Model

2.2 Characteristics of a Software Model

2.2.1 Operational Characteristics of a Software

2.2.2 Revision Characteristics of Software

2.2.3 Transition Characteristics of the Software

2.3 Water Fall Model

2.4 The Prototype Model

2.5 Iterative Model

2.6 Time Boxing Model

2.7 Comparison

2.8 Summary

2.9 Keywords

2.10 Review Questions

2.11 Further Readings

Objectives

After studying this unit, you will be able to:

- Discuss the concept of Processes and Models
- Explain the Software Process Model
- Discuss the characteristics of a Software Model
- Describe various process models
- Discuss the comparison between various models

Introduction

Software engineering approach pivots around the concept of process. A process means "a particular method of doing something, generally involving a number of steps or operations." In software engineering, the phrase software process refers to the method of developing software. A software process can be called a framework of tasks required to build high-quality software. Can we call the process as software engineering? The answer is "yes" and "no". Process means the techniques that are involved while software is being engineered. Also, the technical methods and tools that comprise in the software engineering form a part of the process. Software must be developed keeping in mind the demands of the end-user using a defined software process. In this unit, we will discuss the concept of software process models. We will also discuss different types of process models such as waterfall model, iterative model, etc.

2.1 Processes and Models

Software process specifies how one can manage and plan a software development project taking constraints and boundaries into consideration. A software process is a set of activities, together with ordering constraints among them, such that if the activities are performed properly and in accordance with the ordering constraints, the desired result is produced. The desired result is high-quality software at low cost. Clearly, if a process does not scale up and cannot handle large software projects or cannot produce good-quality software, it is not a suitable process.

Major software development organizations typically have many processes executing simultaneously. Many of these do not concern software engineering, though they do impact software development. These could be considered non-software engineering process models. Business process models, social process models, and training models, are all examples of processes that come under this. These processes also affect the software development activity but are beyond the purview of software engineering.

The process that deals with the technical and management issues of software development is called a software process. Clearly, many different types of activities need to be performed to develop software.

Caution A software development project must have at least development activities and project management activities. All these activities together comprise the software process.

As different type of activities are being performed, which are frequently done by different people, it is better to view the software process as consisting of many in component processes, each consisting of a certain type of activity. Each of these component processes typically has a different objective, though these processes obviously cooperate with each other to satisfy the overall software engineering objective.

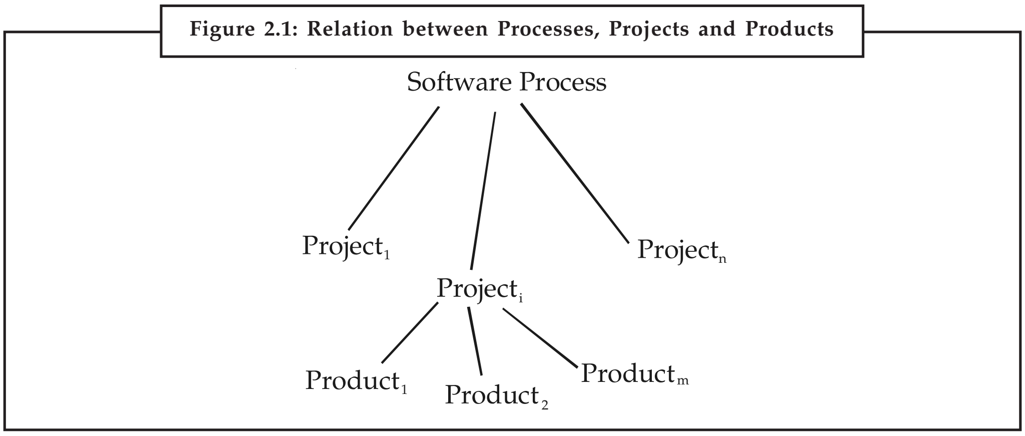
Software Process framework is a set of guidelines, concepts and best practices that describes high level processes in software engineering. It does not talk about how these processes are carried out and in what order.

A software process, as mentioned earlier, specifies a method of developing software. A software project, on the other hand, is a development project in which a software process is used. Software products are the outcomes of a software project. Each software development project starts with some needs and is expected to end with some software that satisfies those needs. A software process specifies the abstract set of activities that should be performed to go from user needs to the final product.

Notes The actual act of executing the activities for some specific user needs is a software project. All the outputs that are produced while the activities are being executed are the products.

One can view the software process as an abstract type, and each project is done using that process as an instance of this type. In other words, there can be many projects for a process and there can be many products produced in a project. This relationship is shown in Figure 2.1.

Figure 2.1: Relation between Processes, Projects and Products



The sequence of activities specified by the process is typically at an abstract level because they have to be usable for a wide range of projects. Hence, "implementing" them in a project is not straightforward.

Example: Let us take the example of book writing. A process for book writing on a subject will be something like this:

1. Set objectives of the book – audience, marketing etc.
2. Outline the contents.
3. Research the topics covered.
4. Do literature survey.
5. Write and/or compile the content.
6. Get the content evaluated by a team of experts.
7. Proof read the book.
8. Make corrections, if any.
9. Get the book typeset.
10. Print the book.
11. Bind the book.

Overall, the process specifies activities at an abstract level that are not project-specific.

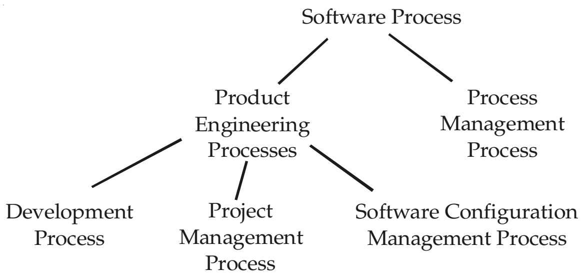
It is a generic set of activities that does not provide a detailed roadmap for a particular project. The detailed roadmap for a particular project is the project plan that specifies what specific activities to perform for this particular project, when, and how to ensure that the project progresses smoothly. In our book writing example, the project plan to write a book on Software Engineering will be the detailed marked map showing the activities, with other details like plans for getting illustrations, photographs, etc.

It should be clear that it is the process that drives a project. A process limits the degrees of freedom for a project, by specifying what types of activities must be done and in what order. Further, restriction on the degrees of freedom for a particular project are specified by the project plan, which, in itself, is within the boundaries established by the process. In other words, a project plan cannot include performing an activity that is not there in the process.

It is essentially the process that determines the expected outcomes of a project as each project is an instance of the process it follows. Due to this, the focus software engineering is heavily on the process.

Notes

Figure 2.2: Software Processes


Software Process
Product Engineering Processes
Process Management Process
Development Process
Project Management Process
Software Configuration Management Process

A software process is the set of activities and associated results that produce a software product. Software engineers mostly carry out these activities. There are four fundamental process activities, which are common to all software processes. These activities are:

1. ***Software Specification:*** The functionality of the software and constraints on its operation must be defined.
2. ***Software Development:*** The software to meet the specification must be produced.
3. ***Software Validation:*** The software must be validated to ensure that it does what the customer wants.
4. ***Software Evolution:*** The software must evolve to meet changing customer needs.

Different software processes organize these activities in different ways and are described at different levels of detail. The timing of the activities varies as does the results of each activity. Different organizations may use different processes to produce the same type of product. However, some processes are more suitable than others for some types of application. If an inappropriate process is used, this will probably reduce the quality or the usefulness of the software product to be developed.

2.1.1 The Software Process Model

A software process model is a simplified description of a software process, which is presented from a particular perspective. Models, by their very nature, are simplifications, so a software process model is an abstraction of the actual process, which is being described. Process models may include activities, which are part of the software process, software products and the roles of people involved in software engineering.

Example: Some examples of the types of software process model that may be produced are:

- ***A Workflow Model:*** This shows the sequence of activities in the process along with their inputs, outputs and dependencies. The activities in this model represent human actions.
- ***A Dataflow or Activity Model:*** This represents the process as a set of activities each of which carries out some data transformation. It shows how the input to the process such as a specification is transformed to an output such as a design. The activities here may be at a lower level than activities in a workflow model. They may represent transformations carried out by people or by computers.
- ***A Role/action Model:*** This represents the roles of the people involved in the software process and the activities for which they are responsible.

There are a number of different general models or paradigms of software development:

- ***The Waterfall Approach:*** This takes the above activities and represents them as separate process phases such as requirements specification, software design, implementation, testing and so on. After each stage is defined it is 'signed off' and development goes on to the following stage.

- ***Evolutionary Development:*** This approach interleaves the activities of specification, development and validation. An initial system is rapidly developed from very abstract specifications. This is then refined with customer input to produce a system which satisfies the customer's needs. The system may then be delivered. Alternatively, it may be re-implemented using a more structured approach to produce a more robust and maintainable system.

- ***Formal Transformation:*** This approach is based on producing a formal mathematical system specification and transforming this specification, using mathematical methods to a program. These transformations are 'correctness preserving'. This means that you can be sure that the developed program meets its specification.

- ***System Assembly from Reusable Components:*** This technique assumes that parts of the system already exist. The system development process focuses on integrating these parts rather than developing them from scratch.

Self Assessment

Fill in the blanks:

1. The process that deals with the technical and management issues of software development is called a ....

2. .... is a set of guidelines, concepts and best practices that describes high level processes in software engineering.

3. A .... shows the sequence of activities in the process along with their inputs, outputs and dependencies.

2.2 Characteristics of a Software Model

While developing any kind of software product, the first question in any developer's mind is, "What are the qualities that a good software should have ?" Well before going into technical characteristics, we would like to state the obvious expectations one has from any software. First and foremost, a software product must meet all the requirements of the customer or end-user. Also, the cost of developing and maintaining the software should be low. The development of software should be completed in the specified time-frame.

Well these were the obvious things which are expected from any project (and software development is a project in itself). Now lets take a look at Software Quality factors. These set of factors can be easily explained by Software Quality Triangle. The three characteristics of good application software are:

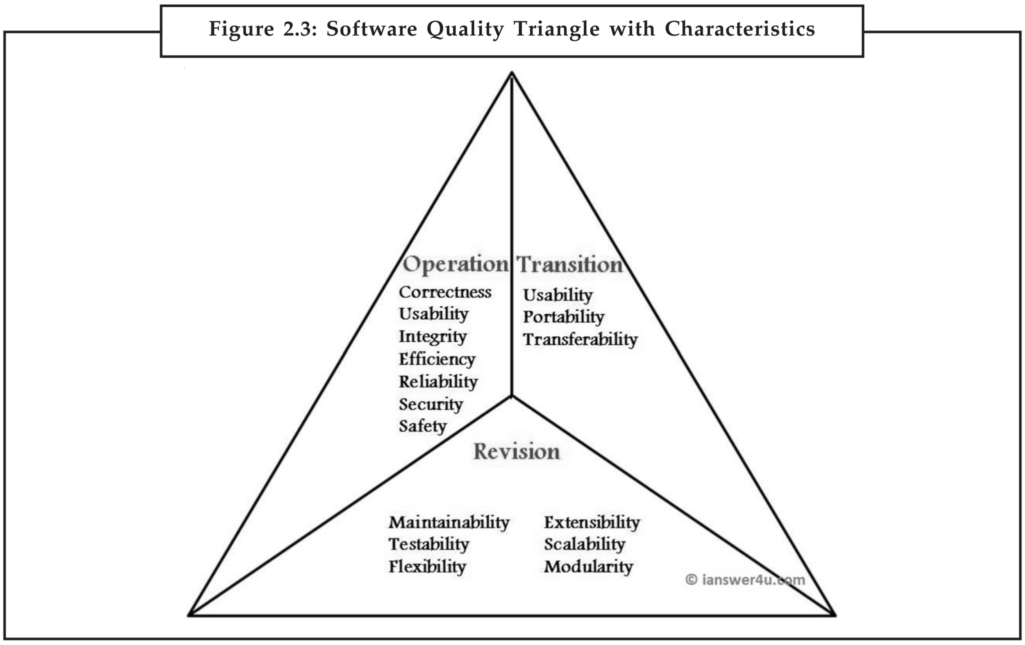
1. Operational Characteristics

2. Transition Characteristic

3. Revision Characteristics

Notes

Figure 2.3: Software Quality Triangle with Characteristics



Source: http://www.ianswer4u.com/2011/10/characteristics-of-good-software.html#axzz2cCUUuHIQ

2.2.1 Operational Characteristics of a Software

These are functionality based factors and related to 'exterior quality' of software. Various Operational Characteristics of software are:

- ***Correctness:*** The software which we are making should meet all the specifications stated by the customer.
- ***Usability/Learnability:*** The amount of efforts or time required to learn how to use the software should be less. This makes the software user-friendly even for IT-illiterate people.
- ***Integrity:*** Just like medicines have side-effects, in the same way a software may have a side-effect i.e. it may affect the working of another application. But a quality software should not have side effects.
- ***Reliability:*** The software product should not have any defects. Not only this, it shouldn't fail while execution.
- ***Efficiency:*** This characteristic relates to the way software uses the available resources. The software should make effective use of the storage space and execute command as per desired timing requirements.
- ***Security:*** With the increase in security threats nowadays, this factor is gaining importance. The software shouldn't have ill effects on data/hardware. Proper measures should be taken to keep data secure from external threats.
- ***Safety:*** The software should not be hazardous to the environment/life.

2.2.2 Revision Characteristics of Software

These engineering based factors of the relate to 'interior quality' of the software like efficiency, documentation and structure. These factors should be in-build in any good software. Various Revision Characteristics of software are:

- ***Maintainability:*** Maintenance of the software should be easy for any kind of user.

Notes

- ***Flexibility:*** Changes in the software should be easy to make.
- ***Extensibility:*** It should be easy to increase the functions performed by it.
- ***Scalability:*** It should be very easy to upgrade it for more work (or for more number of users).
- ***Testability:*** Testing the software should be easy.
- ***Modularity:*** Any software is said to made of units and modules which are independent of each other. These modules are then integrated to make the final software. If the software is divided into separate independent parts that can be modified, tested separately, it has high modularity.

2.2.3 Transition Characteristics of the Software

- ***Interoperability:*** Interoperability is the ability of software to exchange information with other applications and make use of information transparently.
- ***Reusability:*** If we are able to use the software code with some modifications for different purpose then we call software to be reusable.
- ***Portability:*** The ability of software to perform same functions across all environments and platforms, demonstrate its portability.

Importance of any of these factors varies from application-to-application.

Caution In systems where human life is at stake, integrity and reliability factors must be given prime importance.

In any business related application usability and maintainability are key factors to be considered. Always remember in Software Engineering, quality of software is everything, therefore try to deliver a product which has all these characteristics and qualities.

Self Assessment

Fill in the blanks:

4. Efficiency of a software relates to the way software uses the available …………………… .
5. …………………… is the ability of software to exchange information with other applications and make use of information transparently.

2.3 Water Fall Model

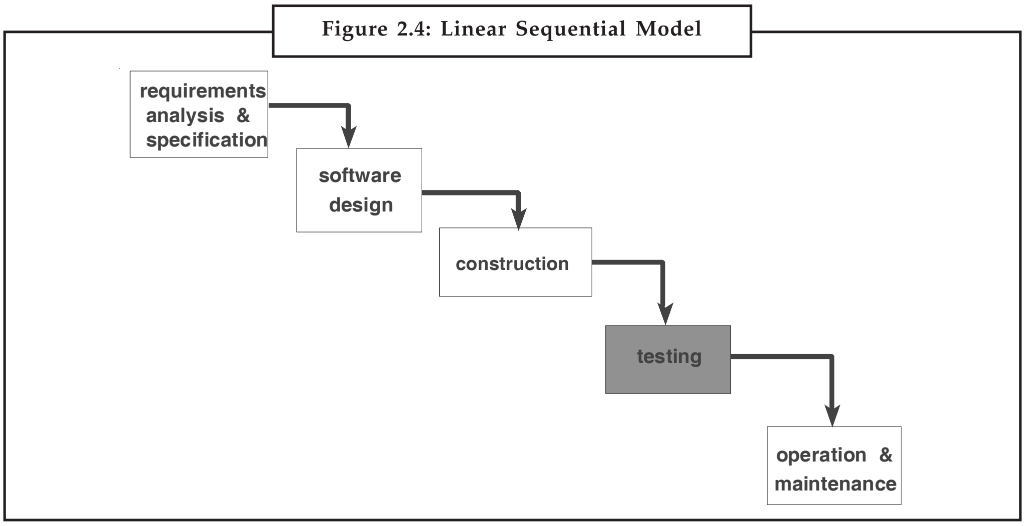
The waterfall model derives its name due to the cascading effect from one phase to the other as is illustrated in the figure below. In this model each phase is well defined, has a starting and ending point, with identifiable deliveries to the next phase.

According to the Figure 2.4 mentioned above you can broadly analyse the stages of a prototype model are:

1. ***Software Requirements Analysis:*** The requirements gathering process is intensified and focused specifically on software. In order to understand the nature of programs which are to be built, the system analyst or engineer must understand the software information domain in addition with the required behavior, function, performance and interface. These requirements for both the software and the system are documented and reviewed in discussion with clients or customers.

Notes

Figure 2.4: Linear Sequential Model



2. *Design:* Software design is actually a multi-step process that focuses on four distinct attributes of a program: data structure, software architecture, interface representations, and procedural (algorithmic) detail. The design process translates requirements into a representation of the software that can be assessed for quality before coding begins. Like requirements, the design is documented and becomes part of the software configuration.

3. *Code Generation:* The design must be translated into a machine-readable form. The code generation step performs this task. If design is performed in a detailed manner, code generation can be accomplished mechanistically.

4. *Testing:* Once code has been generated, program testing begins. The testing process focuses on the logical internals of the software, ensuring that all statements have been tested, and on the functional externals; that is, conducting tests to uncover errors and ensure that defined input will produce actual results that agree with required results.

5. *Support:* Software undergo a change after being delivered to customers as a result of the errors which are encountered as software changes as errors have been encountered, because the software must be adapted to accommodate changes in its external environment (e.g., a change required because of a new operating system or peripheral device), or because the customer requires functional or performance enhancements. Software support/maintenance reapplies each of the preceding phases to an existing program rather than a new one.

Task Analyse the process of code generation phase.

Self Assessment

Fill in the blanks:

6. In .... model each phase is well defined, has a starting and ending point, with identifiable deliveries to the next phase.

7. Software .... is actually a multi-step process that focuses on distinct attributes of a program.

2.4 The Prototype Model

A prototype model is beneficial when the customer requirements are dynamic and keep on changing with time and the developer is unsure about the software adaptability with the system and the operating system. Thus in a prototype model, a working prototype is built with the available set of requirements such that it has limited functionalities, low reliability and performance.

Figure 2.5: Prototype Model

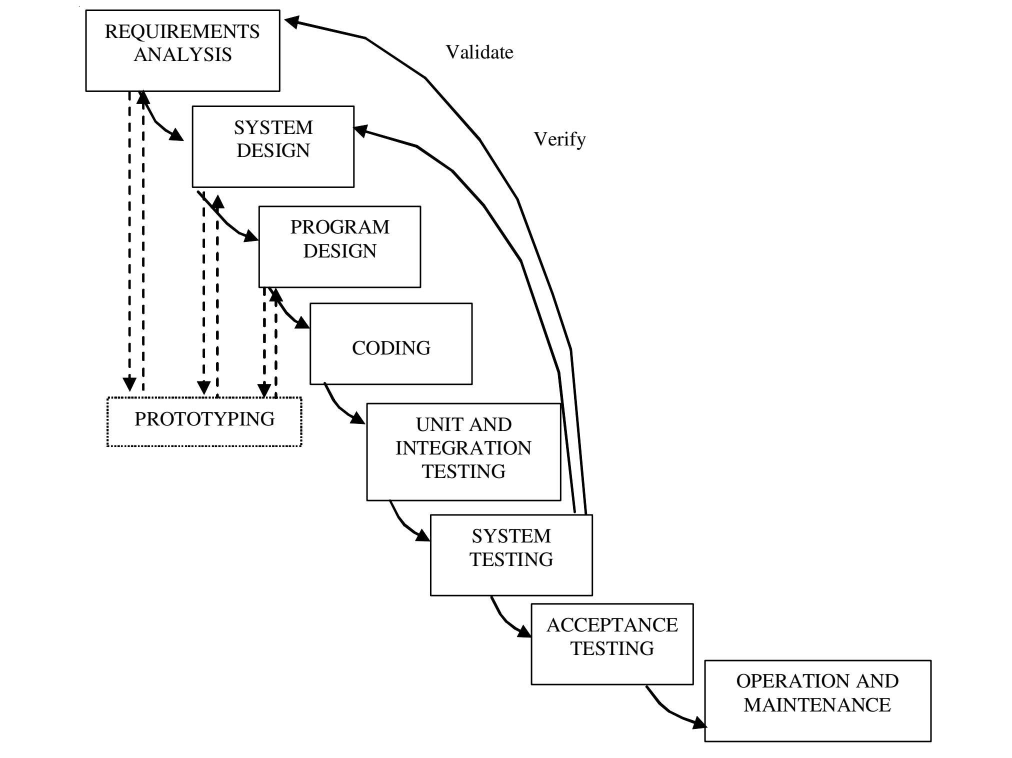
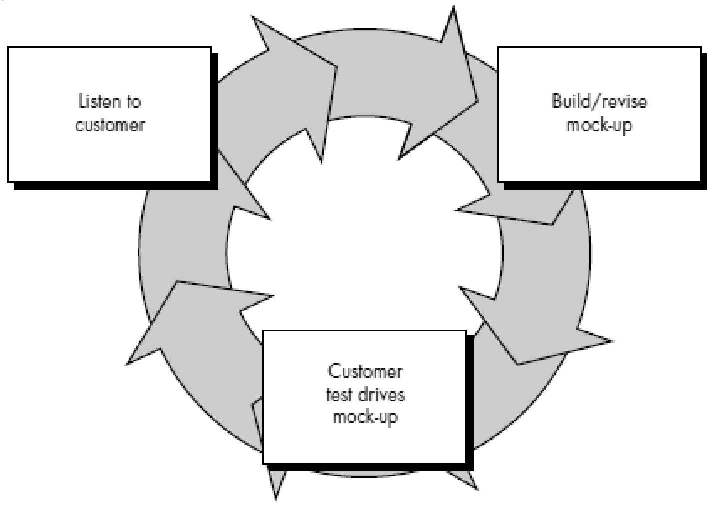


Figure 2.6 Prototyping Paradigm



This prototype is further enhanced by the developer with better understanding of the requirements and preparation of a final specification document. This working prototype is evaluated by the customer and the feedback received helps the developers to get rid of the uncertainties in the requirements and to start a re-iteration of requirements for further clarification. The prototype can be a usable program with limited functionality but cannot be used as a final product. This prototype is thrown away after preparing the final SRS; however the understanding obtained from developing the prototype helps in developing the actual system.

The development of prototype is an additional cost overhead but still the total cost is lower than that of the software developed using a waterfall model.

Did u know? The earlier the prototype is developed the speedier would be the software development process.

This model involves a lot of customer interaction which is not always possible.

Self Assessment

Fill in the blanks:

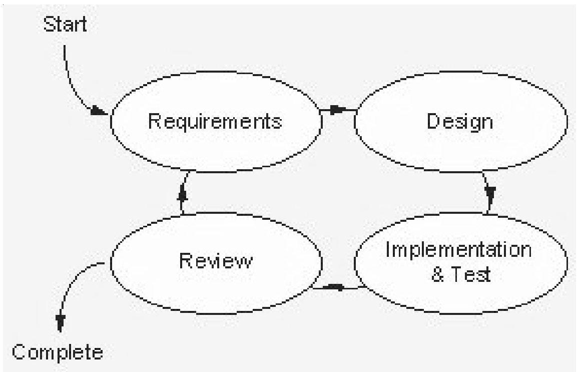
8. In a .... model, a working prototype is built with the available set of requirements such that it has limited functionalities, low reliability and performance.

9. The earlier the prototype is developed the speedier would be the software .... process.

2.5 Iterative Model

An iterative lifecycle model does not attempt to start with a full specification of requirements. Instead, development begins by specifying and implementing just part of the software, which can then be reviewed in order to identify further requirements. This process is then repeated, producing a new version of the software for each cycle of the model. Consider an iterative lifecycle model which consists of repeating the following four phases in sequence:

Figure 2.7: Iterative Model



Source: http://www.onestoptesting.com/sdlc-models/iterative-model.asp

A Requirements phase, in which the requirements for the software are gathered and analyzed. Iteration should eventually result in a requirements phase that produces a complete and final specification of requirements.

A Design phase, in which a software solution to meet the requirements is designed. This may be a new design, or an extension of an earlier design.

An Implementation and Test phase, when the software is coded, integrated and tested.

A Review phase, in which the software is evaluated, the current requirements are reviewed, and changes and additions to requirements proposed.

For each cycle of the model, a decision has to be made as to whether the software produced by the cycle will be discarded, or kept as a starting point for the next cycle (sometimes referred to as incremental prototyping). Eventually a point will be reached where the requirements are complete and the software can be delivered, or it becomes impossible to enhance the software as required, and a fresh start has to be made.

The iterative lifecycle model can be likened to producing software by successive approximation. Drawing an analogy with mathematical methods that use successive approximation to arrive at a final solution, the benefit of such methods depends on how rapidly they converge on a solution.

The key to successful use of an iterative software development lifecycle is rigorous validation of requirements, and verification (including testing) of each version of the software against those requirements within each cycle of the model. The first three phases of the example iterative model is in fact an abbreviated form of a sequential V or waterfall lifecycle model. Each cycle of the model produces software that requires testing at the unit level, for software integration, for system integration and for acceptance. As the software evolves through successive cycles, tests have to be repeated and extended to verify each version of the software.

Task Make distinction between test phase and review phase.

Self Assessment

Fill in the blanks:

10. An …………………… lifecycle model does not attempt to start with a full specification of requirements.

11. In …………………… phase, the software is evaluated, the current requirements are reviewed, and changes and additions to requirements proposed.

2.6 Time Boxing Model

To speed up development, parallelism between the different iterations can be employed. That is, a new iteration commences before the system produced by the current iteration is released, and hence development of a new release happens in parallel with the development of the current release. By starting an iteration before the previous iteration has completed, it is possible to reduce the average delivery time for iterations. However, to support parallel execution, each iteration has to be structured properly and teams have to be organized suitably. The timeboxing model proposes an approach for these.

In the timeboxing model, the basic unit of development is a time box, which is of fixed duration. Since the duration is fixed, a key factor in selecting the requirements or features to be built in a time box is what can be fit into the time box. This is in contrast to regular iterative approaches where the functionality is selected and then the time to deliver is determined.

Did u know? Timeboxing changes the perspective of development and makes the schedule a nonnegotiable and a high-priority commitment.

Each time box is divided into a sequence of stages, like in the waterfall model. Each stage performs some clearly defined task for the iteration and produces a clearly defined output. The model also requires that the duration of each stage, that is, the time it takes to complete the task of that stage, is approximately the same. Furthermore, the model requires that there be a dedicated team for each stage.

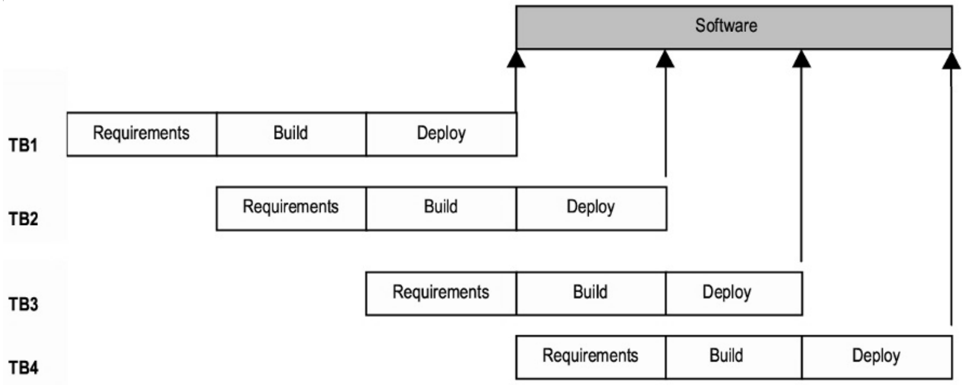
Notes The team for a stage performs only tasks of that stage—tasks for other stages are performed by their respective teams. This is quite different from other iterative models where the implicit assumption is that the same team performs all the different tasks of the project or the iteration.

Having time-boxed iterations with stages of equal duration and having dedicated teams renders itself to pipelining of different iterations. (Pipelining is a concept from hardware in which different instructions are executed in parallel, with the execution of a new instruction starting once the first stage of the previous instruction is finished.)

To illustrate the use of this model, consider a time box consisting of three stages: requirement specification, build, and deployment. The requirement stage is executed by its team of analysts and ends with a prioritized list of requirements to be built in this iteration along with a high-level design. The build team develops the code for implementing the requirements, and performs the testing. The tested code is then handed over to the deployment team, which performs pre-deployment tests, and then installs the system for production use. These three stages are such that they can be done in approximately equal time in an iteration.

With a time box of three stages, the project proceeds as follows. When the requirements team has finished requirements for timebox-1, the requirements are given to the build team for building the software. The requirements team then goes on and starts preparing the requirements for timebox-2. When the build for timebox-1 is completed, the code is handed over to the deployment team, and the build team moves on to build code for requirements for timebox-2, and the requirements team moves on to doing requirements for timebox-3. This pipelined execution of the timeboxing process is shown in Figure 2.8.

Figure 2.8: Executing the Timeboxing Process Model



Source: http://rpl-blog.blogspot.in/2010/02/235-timeboxing-model.html

Notes

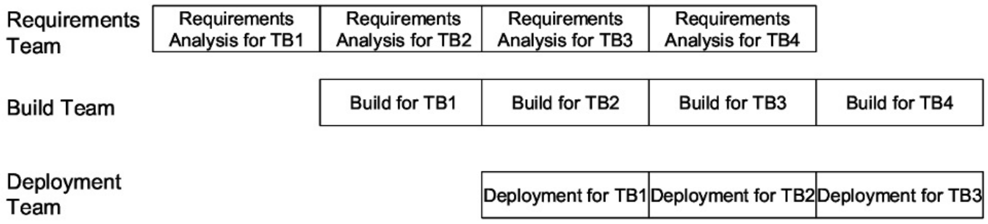
With a three-stage time box, at most three iterations can be concurrently in progress. If the time box is of size T days, then the first software delivery will occur after T days. The subsequent deliveries, however, will take place after every T/3 days.

Example: If the time box duration T is 9 weeks (and each stage duration is 3 weeks), the first delivery is made 9 weeks after the start of the project. The second delivery is made after 12 weeks, the third after 15 weeks, and so on. Contrast this with a linear execution of iterations, in which the first delivery will be made after 9 weeks, the second after 18 weeks, the third after 27 weeks, and so on.

There are three teams working on the project—the requirements team, the build team, and the deployment team. The team-wise activity for the 3-stage pipeline discussed above is shown in Figure 2.9.

It should be clear that the duration of each iteration has not been reduced.

Figure 2.9: Tasks of Different Teams



Source: http://rpl-blog.blogspot.in/2010/02/235-timeboxing-model.html

The total work done in a time box and the effort spent in it also remains the same—the same amount of software is delivered at the end of each iteration as the time box undergoes the same stages. If the effort and time spent in each iteration also remains the same, then what is the cost of reducing the delivery time? The real cost of this reduced time is in the resources used in this model. With timeboxing, there are dedicated teams for different stages and the total team size for the project is the sum of teams of different stages. This is the main difference from the situation where there is a single team which performs all the stages and the entire team works on the same iteration.

Hence, the timeboxing provides an approach for utilizing additional manpower to reduce the delivery time. It is well known that with standard methods of executing projects, we cannot compress the cycle time of a project substantially by adding more manpower. However, through the timeboxing model, we can use more manpower in a manner such that by parallel execution of different stages we are able to deliver software quicker. In other words, it provides a way of shortening delivery times through the use of additional manpower.

Timeboxing is well suited for projects that require a large number of features to be developed in a short time around a stable architecture using stable technologies. These features should be such that there is some flexibility in grouping them for building a meaningful system in an iteration that provides value to the users. The main cost of this model is the increased complexity of project management (and managing the products being developed) as multiple developments are concurrently active. Also, the impact of unusual situations in an iteration can be quite disruptive.

Self Assessment

Fill in the blanks:

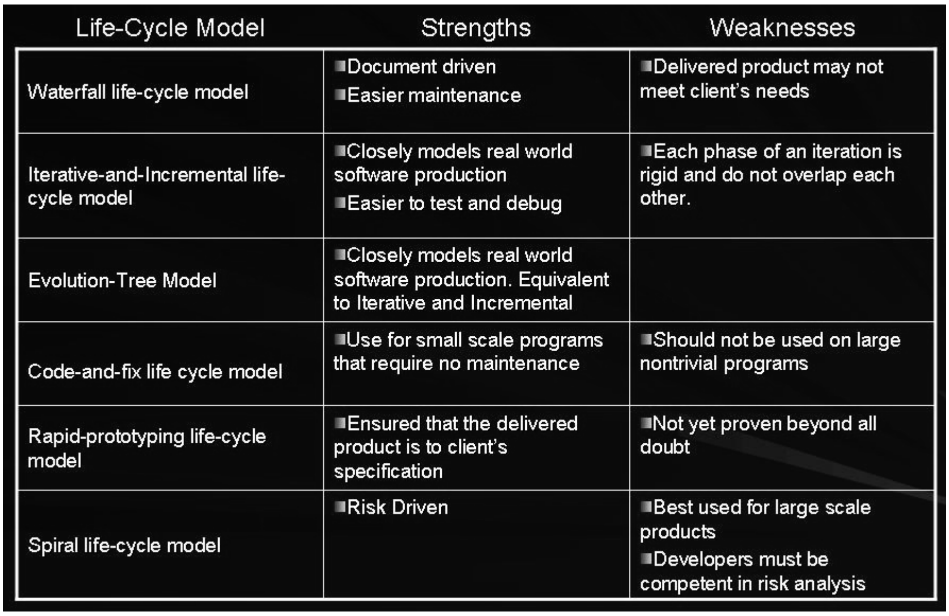
12. In the .... model, the basic unit of development is a time box, which is of fixed duration.

13. With a three-stage time box, at most three .... can be concurrently in progress.

2.7 Comparison

The comparison between various process models are shown in the table 2.1.

Table 2.1: Comparison of Different Models



Life-Cycle Model	Strengths	Weaknesses
Waterfall life-cycle model	■Document driven ■Easier maintenance	■Delivered product may not meet client's needs
Iterative-and-Incremental life-cycle model	■Closely models real world software production ■Easier to test and debug	■Each phase of an iteration is rigid and do not overlap each other.
Evolution-Tree Model	■Closely models real world software production. Equivalent to Iterative and Incremental	
Code-and-fix life cycle model	■Use for small scale programs that require no maintenance	■Should not be used on large nontrivial programs
Rapid-prototyping life-cycle model	■Ensured that the delivered product is to client's specification	■Not yet proven beyond all doubt
Spiral life-cycle model	■Risk Driven	■Best used for large scale products ■Developers must be competent in risk analysis

Self Assessment

State whether the following statements are true or false:

14. In case of waterfall model, delivered product may not meet client's requirement.

15. Iterative model is difficult to test and debug.

2.8 Summary

- A software process is a set of activities, together with ordering constraints among them, such that if the activities are performed properly and in accordance with the ordering constraints, the desired result is produced.
- Software Process framework is a set of guidelines, concepts and best practices that describes high level processes in software engineering.
- The sequence of activities specified by the process is typically at an abstract level because they have to be usable for a wide range of projects.

- A software process model is a simplified description of a software process, which is presented from a particular perspective.
- In waterfall model each phase is well defined, has a starting and ending point, with identifiable deliveries to the next phase.
- In a prototype model, a working prototype is built with the available set of requirements such that it has limited functionalities, low reliability and performance.
- An iterative lifecycle model does not attempt to start with a full specification of requirements.
- In the timeboxing model, the basic unit of development is a time box, which is of fixed duration.

2.9 Keywords

A Workflow Model: This shows the sequence of activities in the process along with their inputs, outputs and dependencies.

Dataflow or Activity Model: This represents the process as a set of activities each of which carries out some data transformation.

Design Phase: A Design phase is a phase in which a software solution to meet the requirements is designed.

Prototype Model: It is a model in which a working prototype is built with the available set of requirements such that it has limited functionalities, low reliability and performance.

Requirements Phase: A Requirements phase is a phase in which the requirements for the software are gathered and analyzed.

Software Processes: Software processes are the activities involved in producing and evolving a software system.

Software Process Framework: It is a set of guidelines, concepts and best practices that describes high level processes in software engineering.

Software Process Model: A software process model is a simplified description of a software process, which is presented from a particular perspective.

2.10 Review Questions

1. Explain the concept of software processes.
2. Describe the relation between Processes, Projects and Products.
3. Explain the concept of software process model with examples.
4. Discuss the number of different general models or paradigms of software development.
5. Discuss the characteristics of a Software Model.
6. Explain the working of waterfall model.
7. Describe the phases included in iterative model.
8. What is time boxing model? Illustrate the working of Time Boxing Model.
9. With a three-stage time box in time boxing model, at most three iterations can be concurrently in progress. Comment.
10. Compare and contrast waterfall model and iterative model.

Notes

Answers: Self Assessment

1. software process
2. Software Process framework
3. workflow model
4. Resources
5. Interoperability
6. Waterfall
7. design
8. Prototype
9. development
10. Iterative
11. Review
12. Timeboxing
13. iterations
14. True
15. False

2.11 Further Readings

Books

Rajib Mall, *Fundamentals of Software Engineering*, 2nd Edition, PHI.

Richard Fairpy, *Software Engineering Concepts*, Tata McGraw Hill, 1997.

R.S. Pressman, *Software Engineering – A Practitioner's Approach*, 5th Edition, Tata McGraw Hill Higher education.

Sommerville, *Software Engineering*, 6th Edition, Pearson Education.

Online links

http://www.ijcsi.org/papers/7-5-94-101.pdf

http://people.sju.edu/~jhodgson/se/models.html

http://www.ics.uci.edu/~wscacchi/Papers/SE-Encyc/Process-Models-SE-Encyc.pdf

Unit 3: Software Requirements

CONTENTS

Objectives

Introduction

3.1 Problem Analysis

3.1.1 Data Flow

3.2 Object Oriented Modelling

3.2.1 Functional Models

3.2.2 Behavioral Models

3.3 Prototyping

3.3.1 Prototyping Pitfalls

3.3.2 Prototyping Opportunities

3.3.3 Selecting the Prototyping Approach

3.3.4 Prototyping Methods and Tools

3.4 Software Requirements Specification Document

3.4.1 Characteristics of a Good SRS

3.4.2 Components of SRS

3.4.3 Specification Language

3.4.4 Structure of Document

3.5 Summary

3.6 Keywords

3.7 Review Questions

3.8 Further Readings

Objectives

After studying this unit, you will be able to:

- Discuss problem analysis
- Explain the concept of object oriented modelling and prototyping
- Describe the characteristics and components of SRS document.
- Explain software requirement specification language
- Discuss the structure of document

Introduction

The Software Requirements Specification is developed as a consequence of analysis. Requirements analysis is a software engineering task that bridges the gap between system level engineering and software design. Requirements analysis allow software engineer to refine the software allocation and build models of data, function and behavioral domain that will be used by the software. It provides the information to the designer to be transformed into data, architectural, interface and component-level design. Finally, it also provides the developer and the customer with the means to assess the quality of the software once it is built. Software requirements analysis can be divided into five areas of effort: Problem recognition, Evaluation and synthesis, Modeling, Specification, and Review. Initially, the analyst studies the system specification and the software project plan to understand the system as a whole in relation to the software and to review the scope of the software as per the planning estimates. After this the communication for analysis is established to ensure problem recognition.

3.1 Problem Analysis

The basic aim of problem analysis is to obtain a clear understanding of the needs of the clients and the users, what exactly is desired from the software, and what the constraints on the solution are. Frequently the client and the users do not understand or know all their needs, because the potential of the new system is often not fully appreciated. The analysts have to ensure that the real needs of the clients and the users are uncovered, even if they don't know them clearly. That is, the analysts are not just collecting and organizing information about the client's organization and its processes, but they also act as consultants who play an active role of helping the clients and users identify their needs.

The basic principle used in analysis is the same as in any complex task: divide and conquer. That is, partition the problem into subproblems and then try to understand each subproblem and its relationship to other subproblems in an effort to understand the total problem. The concepts of state and projection can sometimes also be used effectively in the partitioning process. A state of a system represents some conditions about the system. Frequently, when using state, a system is first viewed as operating in one of the several possible states, and then a detailed analysis is performed for each state.

Did u know? This approach is sometimes used in real-time software or process-control software.

In projection, a system is defined from multiple points of view. While using projection, different viewpoints of the system are defined and the system is then analyzed from these different perspectives. The different "projections" obtained are combined to form the analysis for the complete system. Analyzing the system from the different perspectives is often easier, as it limits and focuses the scope of the study.

Problem Analysis consists of the following approaches:

1. ***Informal Approach:*** An informal approach is one where no defined methodology is used to analyse. The information about the system is attained by interaction with the questionnaires, client, end users, study of existing documents, brainstorming, etc.

   The informal approach is used extensively to analysis and can be relatively suitable as conceptual modeling-based approaches repeatedly do not model all facets of the problem and are not always suitable for all the problems.

   As the Software Requirements Specification (SRS) is to be authorised and the feedback from the validation activity may necessitate for further analysis or requirement. Selecting an informal approach to analysis is not very uncertain—the errors that could be presented are not essentially heading for slip by the prerequisites phase. Therefore such approaches might be the utmost useful approach to analysis in some conditions.

Notes Several fact finding methods are used to collect comprehensive information about every aspect of an present system.

2. ***Shadowing:*** Shadowing provides an effective means to discover what is currently being done in a business. Shadowing is a good way to get an idea of what a person does on a day-to-day basis. However, you might not be able to observe all the tasks during shadowing because more than likely the person will not, during that session, perform all the tasks he or she is assigned. For example, accounting people might create reports at the end of the month, developers might create status reports on a weekly basis, and management might schedule status meetings only biweekly. In addition, you can also learn the purpose of performing a specific task. To gather as much information as possible, you need to encourage the user to explain the reasons for performing a task in as much detail as possible.

   Shadowing can be both passive and active. When performing passive shadowing, you observe the user and listen to any explanations that the user might provide. When performing active shadowing, you ask questions as the user explains events and activities. You might also be given the opportunity to perform some of the tasks, at the user's discretion.

3. ***Interviews:*** In interview is a one-on-one meeting between a member of the project team and a user. The quality of the information a team gathers depends on the skills of both the interviewer and the interviewee. An interviewer can learn a great deal about the difficulties and limitations of the current solution. Interviews provide the opportunity to ask a wide range of questions about topics that you cannot observe by means of shadowing. Shadowing is not the best option for gathering information about tasks such as management-level activities; long-term activities that span weeks, months, or years; or processes that require little or no human intervention. An example of a process that requires no human intervention is the automatic bill paying service provided by financial institutions. For gathering information about such activities and processes, you need to conduct interviews.

3.1.1 Data Flow

Data flow diagrams (also called data flow graphs) are commonly used during problem analysis. Data flow diagrams (DFDs) are quite general and are not limited to problem analysis for software requirements specification. They were in use long before the software engineering discipline began. DFDs are very useful in understanding a system and can be effectively used during analysis.

A DFD shows the flow of data through a system. It views a system as a function that transforms the inputs into desired outputs. Any complex system will not perform this transformation in a "single step," and data will typically undergo a series of transformations before it becomes the output. The DFD aims to capture the transformations that take place within a system to the input data so that eventually the output data is produced. The agent that performs the transformation of data from one state to another is called a process (or a bubble). Thus, a DFD shows the movement of data through the different transformations or processes in the system. The processes are shown by named circles and data flows are represented by named arrows entering or leaving the bubbles. A rectangle represents a source or sink and is a net originator or consumer of data. A source or a sink is typically outside the main system of study.

Data flow diagramming rules:

1. Processes cannot have only outputs, cannot have only inputs, and must have a verb phrase label.

2. Data can only move to a data store from a process, not from another data store or an outside source.
3. Similarly, data can only be moved to an outside sink or to another data store by a process.
4. Data to and from external sources and sinks can only be moved by processes.
5. Data flows move in one direction only.
6. Both branches of a forked or a joined data flow must represent the same type of data.
7. A data flow cannot return to the process from which it originated.

Self Assessment

Fill in the blanks:

1. A …………………… of a system represents some conditions about the system.
2. In ……………………, a system is defined from multiple points of view.
3. The different "projections" obtained are combined to form the …………………… for the complete system.
4. A …………………… shows the flow of data through a system.

3.2 Object Oriented Modelling

Object-Oriented Software Engineering (OOSE) is a software design technique that is used in software design in object-oriented programming. It includes a requirements, an analysis, a design, an implementation and a testing model. You create functional models to gain a better understanding of the actual entity to be built. When the entity is a physical thing (a building, a plane, a machine), we can build a model that is identical in form and shape but smaller in scale. However, when the entity to be built is software, our model must take a different form. It must be capable of representing the information that software transforms, the functions (and sub-functions) that enable the transformation to occur, and the behavior of the system as the transformation is taking place.

> *Notes* The second and third operational analysis principles require that we build models of function and behavior.

3.2.1 Functional Models

Software transforms information, and in order to accomplish this, it must perform at least three generic functions: input, processing, and output. When functional models of an application are created, the software engineer focuses on problem specific functions. The functional model begins with a single context level model (i.e., the name of the software to be built). Over a series of iterations, more and more functional detail is provided, until a thorough delineation of all system functionality is represented.

3.2.2 Behavioral Models

Most software responds to events from the outside world. This stimulus/response characteristic forms the basis of the behavioral model. A computer program always exists in some state an externally observable mode of behavior (e.g., waiting, computing, printing, and polling) that is changed only when some event occurs.

Example: Software will remain in the wait state until (1) an internal clock indicates that some time interval has passed, (2) an external event (e.g., a mouse movement) causes an interrupt, or (3) an external system signals the software to act in some manner.

A behavioral model creates a representation of the states of the software and the events that cause software to change state.

Models created during requirements analysis serve a number of important roles:

- The model aids the analyst in understanding the information, function, and behavior of a system, thereby making the requirements analysis task easier and more systematic.
- The model becomes the focal point for review and, therefore, the key to a determination of completeness, consistency, and accuracy of the specifications.
- The model becomes the foundation for design, providing the designer with an essential representation of software that can be “mapped” into an implementation context.

Self Assessment

Fill in the blanks:

5. ……………………. is a software design technique that is used in software design in object-oriented programming.
6. A ……………………. creates a representation of the states of the software and the events that cause software to change state.
7. When……………………. models of an application are created, the software engineer focuses on problem specific functions.
8. When the ……………………. is a physical thing, we can build a model that is identical in form and shape but smaller in scale.

3.3 Prototyping

Prototyping is the techniques of constructing a partial implementation of a system so that the users, customers and developers can have a better knowledge of the system. It is a partial implementation and that is the reason it is called a prototype.

Prototyping has evolved around two technologies: evolutionary and throw-away. In the throw-away approach, the prototype is discarded after extracting the desired knowledge about its problem or solution. In the evolutionary approach, the prototype is constructed to learn about its problem or solution in successive steps. Once the prototype has been used and the desired knowledge attained, the prototype is modified as per the new better-understood needs. Thus, the benefits of an early prototype are as under:

- Identifications of misunderstandings between the customer and the developers as the functions are specified.
- Missing user requirements can be detected.
- Difficult-to-use or confusing requirements may be identified and improved.
- A working system is available early to exhibit the capability and usefulness of the application to the management.
- It serves as the basis for writing specification of the system.

The differences between the throw-away and evolutionary prototyping have been illustrated in the Table 3.1.

Table 3.1: Differences between Throw-away and Evolutionary Prototyping

Sr. No.	Approach and Characteristics	Throw-away	Evolutionary
1	Development approach	Quick and dirty. No rigor.	No sloppiness. Rigorous
2	What to build	Build only difficult parts	Build understood parts first and build on solid foundations
3	Design drivers	Optimize development time	Optimize modifiability
4	Ultimate objective	Throw it away	Evolve it

3.3.1 Prototyping Pitfalls

A common problem with using prototyping technology is high expectations for productivity with insufficient effort. It can have execution inefficiencies with the associated tools and this may be considered as a negative aspect of prototyping.

The process of providing an early feedback to the user results in a problem related to the behavior of end-user and developers. An end-user with a poor past development experience can be biased with the developments in future.

3.3.2 Prototyping Opportunities

Software prototyping cannot be got rid of totally. The benefits of prototyping are obvious and established. The end user cannot expect the developer to come up with a full fledged system with incomplete software needs.

Prototyping must be used on critical portions of the existing software. The idea of completely re-engineering software is not a good idea. Total re-engineering must be planned and should not be used in reaction to a crisis situation.

Software prototyping must be implemented in an organization with the help of training, case-studies and library development. The end user involvement can be enhanced when the requirements are prototyped and communicated before starting with the development. Moreover, during the maintenance stage, the requirement change should lead to prototype being enhanced before the actual changes are confirmed.

3.3.3 Selecting the Prototyping Approach

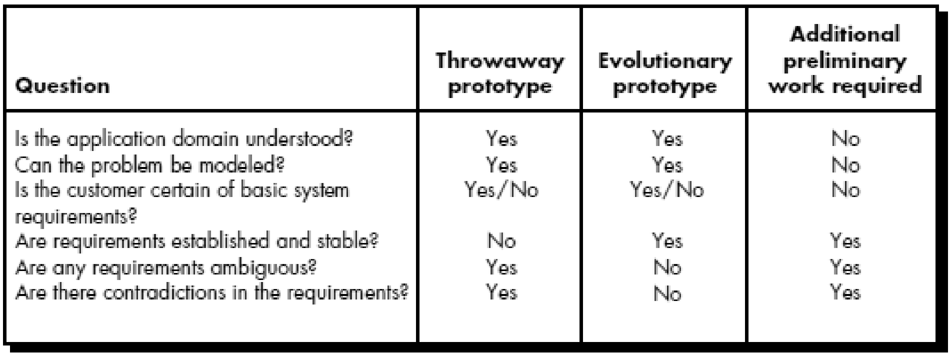
The prototyping paradigm can be either close-ended or open-ended. The close-ended approach is often called throwaway prototyping. Using this approach, a prototype serves solely as a rough demonstration of requirements. It is then discarded, and the software is engineered using a different paradigm. An open-ended approach, called evolutionary prototyping, uses the prototype as the first part of an analysis activity that will be continued into design and construction.

Did u know? The prototype of the software is the first evolution of the finished system.

Before a close-ended or open-ended approach can be chosen, it is necessary to determine whether the system to be built is amenable to prototyping. A number of prototyping candidacy factors can be defined: application area, application complexity, customer characteristics, and project characteristics.

In general, any application that creates dynamic visual displays, interacts heavily with a user, or demands algorithms or combinatorial processing that must be developed in an evolutionary fashion is a candidate for prototyping. However, these application areas must be weighed against application complexity. If a candidate application (one that has the characteristics noted) will require the development of tens of thousands of lines of code before any demonstrable function can be performed, it is likely to be too complex for prototyping. If, however, the complexity can be partitioned, it may still be possible to prototype portions of the software.

Table 3.2: Selecting appropriate Prototyping Approach



Question	Throwaway prototype	Evolutionary prototype	Additional preliminary work required
Is the application domain understood?	Yes	Yes	No
Can the problem be modeled?	Yes	Yes	No
Is the customer certain of basic system requirements?	Yes/No	Yes/No	No
Are requirements established and stable?	No	Yes	Yes
Are any requirements ambiguous?	Yes	No	Yes
Are there contradictions in the requirements?	Yes	No	Yes

Because the customer must interact with the prototype in later steps, it is essential that (1) customer resources be committed to the evaluation and refinement of the prototype and (2) the customer is capable of making requirements decisions in a timely fashion. Finally, the nature of the development project will have a strong bearing on the efficacy of prototyping. Is project management willing and able to work with the prototyping method? Are prototyping tools available? Do developers have experience with prototyping methods? Andriole suggests six questions and indicates typical sets of answers and the corresponding suggested prototyping approach.

3.3.4 Prototyping Methods and Tools

For software prototyping to be effective, a prototype must be developed rapidly so that the customer may assess results and recommend changes. To conduct rapid prototyping, three generic classes of methods and tools are available:

- *Fourth Generation Techniques:* Fourth generation techniques (4GT) encompass a broad array of database query and reporting languages, program and application generators, and other very high-level non-procedural languages. Because 4GT enable the software engineer to generate executable code quickly, they are ideal for rapid prototyping.
- *Reusable Software Components:* Another approach to rapid prototyping is to assemble, rather than build, the prototype by using a set of existing software components. Melding prototyping and program component reuse will work only if a library system is developed so that components that do exist can be cataloged and then retrieved.

Notes It should be noted that an existing software product can be used as a prototype for a "new, improved" competitive product. In a way, this is a form of reusability for software prototyping.

Notes

- ***Formal Specification and Prototyping Environments:*** Over the past two decades, a number of formal specification languages and tools have been developed as a replacement for natural language specification techniques. Today, developers of these formal languages are in the process of developing interactive environments that (1) enable an analyst to interactively create language-based specifications of a system or software, (2) invoke automated tools that translate the language-based specifications into executable code, and (3) enable the customer to use the prototype executable code to refine formal requirements.

Task Make distinction between Throw-away and Evolutionary Prototyping.

Self Assessment

Fill in the blanks:

9. .... is the techniques of constructing a partial implementation of a system.

10. In the .... approach, the prototype is discarded after extracting the desired knowledge about its problem or solution.

11. In the .... approach, the prototype is constructed to learn about its problem or solution in successive steps.

12. The .... approach is often called throwaway prototyping.

3.4 Software Requirements Specification Document

The SRS (Software Requirements Specification) contains specifications for a particular software product, program or a set of programs that perform a particular function in a specific environment. It serves a number of purposes depending upon its creator.

1. SRS could be written by the customer. It must address the needs and expectations of the users.

2. SRS could be written by the developer of the system. It serves a different purpose and mentions the contrast between the customer and the developer.

3.4.1 Characteristics of a Good SRS

An SRS should have the following characteristics:

- ***Correct:*** An SRS is said to be correct if it contains the requirements that the software should meet. The correctness cannot be measured through a tool or a procedure.
- ***Unambiguous:*** An SRS is unambiguous only if the requirements contained in it have only one interpretation. It must be unambiguous to both who create and who use it. However, the two groups may use different languages for description. But the language should be a natural language that can be easily understood by both the groups.
- ***Complete:*** An SRS is complete if it includes the following:
  - ❖ All significant requirements related to functionality, performance, design, attributes or external interfaces.
  - ❖ Definition of the software responses to all possible input classes in all possible situations.

  - Full references and labels to figures, tables, diagrams and the definition of all terms and units of measure.

- ***Consistent:*** An SRS is consistent if no subset of a requirement defines it in entirety. The conflicts can be of three types:
  - Characteristics of real-world objects.
  - Logical or temporal conflicts.
  - The same real world object defined in more than one places in different terminologies.
- ***Ranked for Importance and Stability:*** An SRS is ranked for importance and stability if each requirement contained in it has an identifier indicating its importance or stability of that requirement. Another way to implement the importance of requirements is to classify them as essential, conditional and optional.
- ***Verifiable:*** An SRS is verifiable if every requirement contained in it is verifiable i.e. there exists some defined method to judge if a software meets all the requirements. Non-verifiable requirements should be removed or revised.
  - *Modifiable:* An SRS is modifiable if its styles and structures can be retained easily, completely and consistently while changing a requirement.
  - *Traceable:* An SRS is traceable if each of its requirements is clear and can be referenced in future development or enhancement documentation. Two types of traceability are recommended:
  - *Backward Traceability:* This depends upon each requirement explicitly referencing its source in earlier documents.
  - *Forward Traceability:* This depends upon each requirement in SRS having a unique name or reference number.

3.4.2 Components of SRS

Completeness of specifications is difficult to achieve and even more difficult to verify. Having guidelines about what different things an SRS should specify will help in completely specifying the requirements. The basic issues an SRS must address are:

- Functionality
- Performance
- Design constraints imposed on an implementation
- External interfaces

Functional requirements specify the expected behavior of the system—which outputs should be produced from the given inputs. They describe the relationship between the input and output of the system.

Caution For each functional requirement, a detailed description of all the data inputs and their source, the units of measure, and the range of valid inputs must be specified.

All the operations to be performed on the input data to obtain the output should be specified. This includes specifying the validity checks on the input and output data, parameters affected by the operation, and equations or other logical operations that must be used to transform the inputs into corresponding outputs.

Example: If there is a formula for computing the output, it should be specified.

An important part of the specification is the system behavior in abnormal situations, like invalid input (which can occur in many ways) or error during computation. The functional requirement must clearly state what the system should do if such situations occur. Specifically, it should specify the behavior of the system for invalid inputs and invalid outputs. Furthermore, behavior for situations where the input is valid but the normal operation cannot be performed should also be specified.

Example: An example of this situation is a reservation system, where a reservation cannot be made even for a valid request if there is no availability.

In short, the system behavior for all foreseen inputs and all foreseen system states should be specified.

The performance requirements part of an SRS specifies the performance constraints on the software system. All the requirements relating to the performance characteristics of the system must be clearly specified. There are two types of performance requirements: static and dynamic. Static requirements are those that do not impose constraint on the execution characteristics of the system. These include requirements like the number of terminals to be supported, the number of simultaneous users to be supported, and the number of files that the system has to process and their sizes. These are also called capacity requirements of the system.

Dynamic requirements specify constraints on the execution behavior of the system. These typically include response time and throughput constraints on the system. Response time is the expected time for the completion of an operation under specified circumstances. Throughput is the expected number of operations that can be performed in a unit time.

Example: The SRS may specify the number of transactions that must be processed per unit time, or what the response time for a particular command should be. Acceptable ranges of the different performance parameters should be specified, as well as acceptable performance for both normal and peak workload conditions.

All of these requirements should be stated in measurable terms. Requirements such as "response time should be good" or the system must be able to "process all the transactions quickly" are not desirable because they are imprecise and not verifiable. Instead, statements like "the response time of command x should be less than one second 90% of the times" or "a transaction should be processed in less than one second 98% of the times" should be used to declare performance specifications.

There are a number of factors in the client's environment that may restrict the choices of a designer leading to design constraints. Such factors include standards that must be followed, resource limits, operating environment, reliability and security requirements, and policies that may have an impact on the design of the system. An SRS should identify and specify all such constraints.

Example: Some examples of these are:

- ***Standards Compliance:*** This specifies the requirements for the standards the system must follow. The standards may include the report format and accounting procedures. There may be audit requirements which may require logging of operations.

- ***Hardware Limitations:*** The software may have to operate on some existing or predetermined hardware, thus imposing restrictions on the design. Hardware limitations can include the type of machines to be used, operating system available on the system, languages supported, and limits on primary and secondary storage. Reliability and Fault Tolerance: Fault tolerance requirements can place a major constraint on how the system is to be designed, as they make the system more complex and expensive. Recovery requirements are often an integral part here, detailing what the system should do if some failure occurs to ensure certain properties.
- ***Security:*** Security requirements are becoming increasingly important. These requirements place restrictions on the use of certain commands, control access to data, provide different kinds of access requirements for different people, require the use of passwords and cryptography techniques, and maintain a log of activities in the system. They may also require proper assessment of security threats, proper programming techniques, and use of tools to detect flaws like buffer overflow.

In the external interface specification part, all the interactions of the software with people, hardware, and other software should be clearly specified. For the user interface, the characteristics of each user interface of the software product should be specified. User interface is becoming increasingly important and must be given proper attention. A preliminary user manual should be created with all user commands, screen formats, an explanation of how the system will appear to the user, and feedback and error messages. Like other specifications, these requirements should be precise and verifiable. So, a statement like "the system should be user friendly" should be avoided and statements like "commands should be no longer than six characters" or "command names should reflect the function they perform" used.

For hardware interface requirements, the SRS should specify the logical characteristics of each interface between the software product and the hardware components. If the software is to execute on existing hardware or on predetermined hardware, all the characteristics of the hardware, including memory restrictions, should be specified. In addition, the current use and load characteristics of the hardware should be given.

The interface requirement should specify the interface with other software the system will use or that will use the system. This includes the interface with the operating system and other applications.

⚠

Caution The message content and format of each interface should be specified.

3.4.3 Specification Language

Unlike formal language that allows developers and designers some latitude, the natural language of software requirements specifications must be exact, without ambiguity, and precise because the design specification, statement of work, and other project documents are what drive the development of the final product. That final product must be tested and validated against the design and original requirements. Specification language that allows for interpretation of key requirements will not yield a satisfactory final product and will likely lead to cost overruns, extended schedules, and missed deliverable deadlines.

Table 3.3 shows the fundamental characteristics of a quality SRS.

Notes

Table 3.3: The 10 Language Quality Characteristics of an SRS

SRS Quality Characteristic	What It Means
Complete	SRS defines precisely all the go-live situations that will be encountered and the system's capability to successfully address them.
Consistent	SRS capability functions and performance levels are compatible, and the required quality features (security, reliability, etc.) do not negate those capability functions. For example, the only electric hedge trimmer that is safe is one that is stored in a box and not connected to any electrical cords or outlets.
Accurate	SRS precisely defines the system's capability in a real-world environment, as well as how it interfaces and interacts with it. This aspect of requirements is a significant problem area for many SRSs.
Modifiable	The logical, hierarchical structure of the SRS should facilitate any necessary modifications (grouping related issues together and separating them from unrelated issues makes the SRS easier to modify).
Ranked	Individual requirements of an SRS are hierarchically arranged according to stability, security, perceived ease/difficulty of implementation, or other parameter that helps in the design of that and subsequent documents.
Testable	An SRS must be stated in such a manner that unambiguous assessment criteria (pass/fail or some quantitative measure) can be derived from the SRS itself.
Traceable	Each requirement in an SRS must be uniquely identified to a source (use case, government requirement, industry standard, etc.)
Unambiguous	SRS must contain requirements statements that can be interpreted in one way only. This is another area that creates significant problems for SRS development because of the use of natural language.
Valid	A valid SRS is one in which all parties and project participants can understand, analyze, accept, or approve it. This is one of the main reasons SRSs are written using natural language.
Verifiable	A verifiable SRS is consistent from one level of abstraction to another. Most attributes of a specification are subjective and a conclusive assessment of quality requires a technical review by domain experts. Using indicators of strength and weakness provide some evidence that preferred attributes are or are not present.

What makes an SRS "good?" A quality specification is one that fully addresses all the customer requirements for a particular product or system. That's part of the answer. While many quality attributes of an SRS are subjective, we do need indicators or measures that provide a sense of how strong or weak the language is in an SRS. A "strong" SRS is one in which the requirements are tightly, unambiguously, and precisely defined in such a way that leaves no other interpretation or meaning to any individual requirement.

There are dozens of NASA requirements specifications that revealed nine categories of SRS quality indicators. The individual components in each category are words, phrases, and sentence structures that are related to quality attributes. The nine categories fall into two classes: those related to individual specification statements, and those related to the total SRS document. Table 3.4 summarizes the classes, categories, and components of these quality indicators.

Table 3.4: Quality Measures Related to Individual SRS Statements

Imperatives: Words and phrases that command the presence of some feature, function, or deliverable. They are listed below in decreasing order of strength.	
Shall	Used to dictate the provision of a functional capability.
Must or must not	Most often used to establish performance requirement or constraints.

Contd...

Notes

Is required to	Used as an imperative in SRS statements when written in passive voice.
Are applicable	Used to include, by reference, standards, or other documentation as an addition to the requirement being specified.
Responsible for	Used as an imperative in SRSs that are written for systems with pre-defined architectures.
Will	Used to cite things that the operational or development environment is to provide to the capability being specified. For example, the vehicle's exhaust system will power the ABC widget.
Should	Not used often as an imperative in SRS statements; however, when used, the SRS statement always reads weak. Avoid using should in your SRSs.

Continuances: Phrases that follow an imperative and introduce the specification of requirements at a lower level. There is a correlation with the frequency of use of continuances and SRS organization and structure, up to a point. Excessive use of continuances often indicates a very complex, detailed SRS. The continuancesbelow are listed in decreasing order of use within NASA SRSs. Use continuancesin your SRSs, but balance the frequency with the appropriate level of detail called for in the SRS. 1. Below, 2. As follows, 3. Following, 4. Listed, 5. In particular, 6. Support.

Directives: Categories of words and phrases that indicate illustrative information within the SRS. A high ratio of total number of directives to total text line count appears to correlate with how precisely requirements are specified within the SRS. The directives below are listed in decreasing order of occurrence within NASA SRSs. Incorporate the use of directivesin your SRSs. 1. Figure, 2. Table, 3. For example, 4. Note.

Options: A category of words that provide latitude in satisfying the SRS statements that contain them. This category of words loosens the SRS, reduces the client's control over the final product, and allows for possible cost and schedule risks. You should avoid using them in your SRS. The optionsbelow are listed in the order they are found most often in NASA SRSs. 1. Can, 2. May, 3. Optionally.

Weak Phrases: A category of clauses that can create uncertainty and multiple/subjective interpretation. The total number of weak phrases found in an SRS indicates the relative ambiguity and incompleteness of an SRS. The weak phrases below are listed alphabetically.

adequate	be able to	easy	provide for
as a minimum	be capable of	effective	timely
as applicable	but not limited to	if possible	tbd
as appropriate	capability of	if practical	
at a minimum	capability to	normal	

Size: Used to indicate the sizeof the SRS document, and is the total number of the following: 1. Lines of text 2. Number of imperatives 3. Subjects of SRS statements 4. Paragraphs

Text Structure: Related to the number of statement identifiers found at each hierarchical level of the SRS and indicate the document's organization, consistency, and level of detail. The most detailed NASA SRSs were nine levels deep. High-level SRSs were rarely more than four levels deep. SRSs deemed well organized and a consistent level of detail had text structures resembling pyramids (few level 1 headings but each lower level having more numbered statements than the level above it). Hour-glass-shaped text structures (many level 1 headings, few a mid-levels, and many at lower levels) usually contain a greater amount of introductory and administrative information. Diamond-shaped text structures (pyramid shape followed by decreasing statement counts at levels below the pyramid) indicated that subjects introduced at higher levels were addressed at various levels of detail.

Specification Depth: The number of imperatives found at each of the SRS levels of text structure. These numbers include the count of lower level list items that are introduced at a higher level by an imperative and followed by a continuance. The numbers provide some insight into how much of the Requirements document was included in the SRS, and can indicate how concise the SRS is in specifying the requirements.

Readability Statistics: Measurements of how easily an adult can read and understand the requirements document. Four readability statistics are used (calculated by Microsoft Word). While readability statistics provide a relative quantitative measure, don't sacrifice sufficient technical depth in your SRS for a number. 1. Flesch, Reading Ease index, 2. Flesch-Kincaid Grade Level index, 3. Coleman-Liau Grade Level index, 4. Bormuth Grade Level index.

Notes

Task How do we know when we've written a "quality" specification?

3.4.4 Structure of Document

The Institute of Electrical and Electronics Engineers (IEEE) has published guidelines and standards to organize an SRS document. There is no single method that is suitable for all projects. So, different ways are proposed to structure the SRS. Although the first two sections are the same, the third section containing the "specific requirements" can differ.

The general organization of the SRS is given in Table 3.5.

Table 3.5: Organisation of an SRS

1 Introduction
    1.1 Purpose
    1.2 Scope
    1.3 Definitions, Acronyms and Abbreviations
    1.4 References
    1.5 Overview
2. Overall Description
    2.1 Product Perspective
    2.2 Product Functions
    2.3 User Characteristics
    2.4 Constraints
    2.5 Assumptions and Dependencies
3. Specific Requirements

Self Assessment

Fill in the blanks:

13. The .... contains specifications for a particular software product, program or a set of programs.

14. In the .... interface specification part, all the interactions of the software with people, hardware, and other software should be clearly specified.

15. For .... interface requirements, the SRS should specify the logical characteristics of each interface between the software product and the hardware components.

Case Study

Requirements Specification Document

Purpose

The purpose of this document is to describe the external requirements for a course scheduling system for an academic department in a University. It also describes the interfaces for the system.

Contd...

Scope

This document is the only one that describes the requirements of the system. It is meant for use by the developers and will be the basis for validating the final delivered system. Any changes made to the requirements in the future will have to go through a formal change approval process. The developer is responsible for asking for clarifications, where necessary, and will not make any alterations without the permission of the client.

Definitions, Acronyms, Abbreviations

Not applicable.

References

Not applicable.

Developer's Responsibilities

The developer is responsible for (a) developing the system, (b) installing the software on the client's hardware, (c) conducting any user training that might be needed for using the system, and (d) maintaining the system for a period of one year after installation

Product Functions Overview

In the computer science department there are a set of classrooms. Every semester the department offers courses, which are chosen from the set of department courses. A course has expected enrolment and could be for graduate students or undergraduate students. For each course, the instructor gives some time preferences for lectures.

The system is to produce a schedule for the department that species the time and room assignments for the different courses. Preference should be given to graduate courses, and no two graduate courses should be scheduled at the same time. If some courses cannot be scheduled, the system should produce a "conflict report" that lists the courses that cannot be scheduled and the reasons for the inability to schedule them.

User Characteristics

The main users of this system will be department secretaries, who are somewhat literate with computers and can use programs such as editors and text processors.

General Constraints

The system should run on Sun 3/50 workstations running UNIX 4.2 BSD.

General Assumptions and Dependencies

Not applicable.

Inputs and Outputs

The system has two file inputs and produces three types of outputs.

Input file 1: Contains the list of room numbers and their capacity; a list of all the courses in the department catalog; and the list of valid lecture times. The format of the file is:

```
rooms
room1: cap1
room2: cap2
:
;
courses
course1, course2, course3, ....;
```

Contd...

times
time1, time2, time3;

where room1 and room2 are room numbers with three digits, with a maximum of 20 rooms in the building; cap1 and cap2 are room capacities within the range [10, 300]; course1, course2 are course numbers, which are of the form "csddd," where d is a digit. There are no more than 30 courses. time1 and time2 are valid lecture times of the form "MWFd" or "MWFdd" or "TTd" or "TTd:dd" or "TTdd:dd". There are no more than 15 such valid lecture times. An example of this file is:

```
rooms
101: 25
115: 50
200: 250;
courses
cs101, cs102, cs110, cs120, cs220, cs412, cs430, cs612, cs630;
times
MWF9, MWF10, MWF11, MWF2, TT9, TT10:30, TT2, TT3:30;
```

Input file 2: Contains information about the courses being offered. For each course, it species the course number, expected enrolment, and a number of lecture time preferences.

A course number greater than 600 is a post-graduate course; the rest are undergraduate courses.

The format of this file is:

```
course enrollment preferences
c#1 cap1 pre1, pre2, pre3 ...
c#2 cap2 pre1, pre2, pre3 ...
:
:
```

where c#1 and c#2 are valid course numbers; cap1 and cap2 are integers in the range [3..250]; and pre1, pre2, and pre3 are time preferences of the instructor (a maximum of 5 preferences are allowed for a course). An example of this file is course enrollment preferences:

```
cs101 180 MWF9, MWF10, MWF11, TT9
cs412 80 MWF9, TT9, TT10:30
cs612 35
cs630 40
```

Output 1: The schedule specifying the class number and time of all the schedulable courses.

The schedule should be a table having the lecture times on the x-axis and classroom numbers on the y-axis. For each slot (i.e., lecture time, classroom) the course scheduled for it is given; if no course is scheduled the slot should be blank.

Output 2: List of courses that could not be scheduled and why. For each preference, the reason for inability to schedule should be stated. An example is:

cs612: Preference 1: Conflict with cs600.

Preference 2: No room with proper capacity

Output 3: Error messages. At the minimum, the following error messages are to be given:

e1. Input file does not exist.

Contd...

Notes

e2. Input-file-1 has error

e2.1. The course number has wrong format

e2.2. Some lecture time has wrong format.

e2.3. Classroom number has wrong format.

e2.4. Classroom capacity out of range.

e3. Input-file-2 has error

e3.1. No course of this number.

e3.2. No such lecture time.

e4. More than permissible courses in the file; later ones ignored.

e5. There are more than permissible preferences.

Later ones are ignored.

Functional Requirements

1. Determine the time and room number for the courses such that the following constraints are satisfied:

   (a) No more than one course should be scheduled at the same time in the same room.

   (b) The classroom capacity should be more than the expected enrollment of the course.

   (c) Preference is given to post-graduate courses over undergraduate courses for scheduling.

   (d) The post-graduate (undergraduate) courses should be scheduled in the order they appear in the input file, and the highest possible priority of an instructor should be given. If no priority is specified, any class and time can be assigned. If any priority is incorrect, it is to be discarded.

   (e) No two post-graduate courses should be scheduled at the same time.

   (f) If no preference is specified for a course, the course should be scheduled in any manner that does not violate these constraints.

   Inputs: Input file 1 and Input file 2.

   Outputs: Schedule.

2. Produce a list of all courses that could not be scheduled because some constraint(s) could not be satisfied and give reasons for unschedulability.

   Inputs: Input file 1, and Input file 2.

   Outputs: Output 2, i.e., list of unschedulable courses and preferences and why.

3. The data in input file 2 should be checked for validity against the data provided in input file 1. Where possible, the validity of the data in input file 1 should also be checked. Messages should be given for improper input data, and the invalid data item should be ignored.

   Inputs: Input file 1 and Input file 2.

   Outputs: Error messages.

Contd...

Notes

External Interface Requirements

User Interface: Only one user command is required. The file names can be specied in the command line itself or the system should prompt for the input file names.

Performance Constraints

For input file 2 containing 20 courses and up to 5 preferences for each course, the reports should be printed in less than 1 minute.

Design Constraints

Software Constraints

The system is to run under the UNIX operating system.

Hardware Constraints

The system will run on a Sun workstation with 256 MB RAM, running UNIX. It will be connected to an 8-page-per-minute printer.

Acceptance Criteria

Before accepting the system, the developer must demonstrate that the system works on the course data for the last 4 semesters. The developer will have to show through test cases that all conditions are satisfied.

Questions:

1. Discuss the functional requirements for this case.
2. Discuss various design constraints.

Source: http://www.iiitd.edu.in/~jalote/jalotesebook/JaloteSEbook/CaseStudies/CaseStudy1/SRS.pdf

3.5 Summary

- The basic aim of problem analysis is to obtain a clear understanding of the needs of the clients and the users, what exactly is desired from the software, and what the constraints on the solution are.
- Data flow diagrams (also called data flow graphs) are commonly used during problem analysis.
- Object-Oriented Software Engineering (OOSE) is a software design technique that is used in software design in object-oriented programming.
- Prototyping is the techniques of constructing a partial implementation of a system so that the users, customers and developers can have a better knowledge of the system.
- The prototyping paradigm can be either close-ended or open-ended. The close-ended approach is often called throwaway prototyping. An open-ended approach uses the prototype as the first part of an analysis activity that will be continued into design and construction.
- The SRS (Software Requirements Specification) contains specifications for a particular software product, program or a set of programs that perform a particular function in a specific environment.
- The performance requirements part of an SRS specifies the performance constraints on the software system.

Notes

- Unlike formal language that allows developers and designers some latitude, the natural language of software requirements specifications must be exact, without ambiguity, and precise.

3.6 Keywords

DFD: A DFD shows the flow of data through a system.

Evolutionary Prototyping: It uses the prototype as the first part of an analysis activity that will be continued into design and construction.

Object-Oriented Software Engineering (OOSE): It is a software design technique that is used in software design in object-oriented programming.

Problem Analysis: The basic aim of problem analysis is to obtain a clear understanding of the needs of the clients and the users, what exactly is desired from the software, and what the constraints on the solution are.

Prototyping: It is the technique of constructing a partial implementation of a system so that the users, customers and developers can have a better knowledge of the system.

Requirements Analysis: It is a software engineering task that bridges the gap between system level engineering and software design.

SRS: Software Requirements Specification contains specifications for a particular software product, program or a set of programs that perform a particular function in a specific environment.

Throwaway Prototyping: In this approach, a prototype serves solely as a rough demonstration of requirements. It is then discarded, and the software is engineered using a different paradigm.

3.7 Review Questions

1. What is the aim of problem analysis? Discuss.
2. Describe the different approaches used in problem analysis.
3. Explain the concept of data flow in software requirements.
4. Discuss the concept of object oriented modelling.
5. What is prototyping? Discuss the process of selecting a prototyping approach.
6. Describe the techniques used for conducting rapid prototyping.
7. Explain Software Requirements Specification (SRS). Also discuss the characteristics of SRS.
8. Discuss the different components of SRS.
9. Discuss the language quality characteristics of an SRS.
10. Discuss how to represent the Structure of SRS document?

Answers: Self Assessment

1. state
2. Projection
3. analysis
4. DFD
5. Object-Oriented Software Engineering (OOSE)
6. behavioral model
7. functional

Notes

8. Entity
9. Prototyping
10. throw-away
11. evolutionary
12. close-ended
13. SRS
14. External
15. hardware

3.8 Further Readings

Books

Rajib Mall, *Fundamentals of Software Engineering*, 2nd Edition, PHI.

Richard Fairpy, *Software Engineering Concepts*, Tata McGraw Hill, 1997.

R.S. Pressman, *Software Engineering – A Practitioner's Approach*, 5th Edition, Tata McGraw Hill Higher education.

Sommerville, *Software Engineering*, 6th Edition, Pearson Education

Online links

http://softwareengineeringhub.blogspot.in/2010/03/system-requirements-specification.html

http://computersciencesource.wordpress.com/2010/03/14/software-engineering-object-oriented-modelling/

http://www.software-requirements.tuffley.com/sample.pdf

Unit 4: Introduction to Validation, Metrics and Software Architecture

CONTENTS

Objectives

Introduction

4.1 Concept of Validation and Metrics

4.2 Function Point and Quality Metrics

4.2.1 Function Points

4.2.2 Quality Metrics

4.3 Software Architecture

4.3.1 Architecture Views

4.3.2 Architectural Styles

4.4 Summary

4.5 Keywords

4.6 Review Questions

4.7 Further Readings

Objectives

After studying this unit, you will be able to:

- Explain the concept of validation and metrics
- Discuss function point and quality metrics
- Describe software architecture
- Discuss architecture styles

Introduction

Validation demonstrates that a software or systems product is fit for purpose. That is, it satisfies all the customer's stated an implied needs. Validation can be performed progressively throughout the development life cycle. Metrics are units of measurement. The term "metrics" is also frequently used to mean a set of specific measurements taken on a particular item or process. Architectural design represents the structure of data and program components that are required to build a computer-based system. It considers the architectural style that the system will take, the structure and properties of the components that constitute the system, and the interrelationships that occur among all architectural components of a system.

4.1 Concept of Validation and Metrics

The development of software starts with a requirements document, which is also used to determine eventually whether or not the delivered software system is acceptable. It is therefore important that the requirements specification contains no errors and specifies the client's requirements correctly. Due to the nature of the requirement specification phase, there is a lot of room for misunderstanding and committing errors, and it is quite possible that the requirements specification does not accurately represent the client's needs.

The basic objective of the requirements validation activity is to ensure that the SRS reflects the actual requirements accurately and clearly. A related objective is to check that the SRS document is itself of "good quality".

The most common errors that occur can be classified in four types:

1. Omission is a common error in requirements. Some user requirement is simply not included in the SRS; the omitted requirement may be related to the behavior of the system, its performance, constraints, or any other factor.
2. Inconsistency can be due to contradictions within the requirements themselves or to incompatibility of the stated requirements with the actual requirements of the client or with the environment in which the system will operate.
3. Incorrect fact, Errors of this type occur when some fact recorded in the SRS is not correct.
4. Ambiguity, Errors of this type occur when there are some requirements that have multiple meanings, that is, their interpretation is not unique.

Checklists are frequently used in reviews to focus the review effort and ensure that no major source of errors is overlooked by the reviewers.

1. Are all hardware resources defined?
2. Have the response times of functions been specified?
3. Have all the hardware, external software, and data interfaces been defined?
4. Have all the functions required by the client been specified?
5. Is each requirement testable?
6. Is the initial state of the system defined?
7. Are the responses to exceptional conditions specified?
8. Does the requirement contain restrictions that can be controlled by the designer?
9. Are possible future modifications specified?

Software engineering metrics are units of measurement that are used to characterize:

- software engineering products, e.g., designs, source code, and test cases,
- software engineering processes, e.g., the activities of analysis, designing, and coding, and
- software engineering people, e.g., the efficiency of an individual tester, or the productivity of an individual designer.

If used properly, software engineering metrics can allow us to:

- quantitatively define success and failure, and/or the degree of success or failure, for a product, a process, or a person,
- identify and quantify improvement, lack of improvement, or degradation in our products, processes, and people,

- make meaningful and useful managerial and technical decisions,
- identify trends, and
- make quantified and meaningful estimates.

A software metric relates the individual measures in some way (e.g., the average number of errors found per review or the average number of errors found per person-hour expended on reviews). Measurements in the physical world can be categorized in two ways: direct measures and indirect measures. Direct measures of the product include lines of code (LOC) produced, execution speed, memory size, and defects reported over some set period of time. Indirect measures of the product include functionality, quality, complexity, efficiency, reliability, maintainability.

The basic purpose of metrics at any point during a development project is to provide quantitative information to the management process so that the information can be used to effectively control the development process. Unless the metric is useful in some form to monitor or control the cost, schedule, or quality of the project, it is of little use for a project.

There are very few metrics that have been defined for requirements.

A large number of software product metrics have been proposed in software engineering . Product metrics quantitatively characterize some aspect of the structure of a software product, such as a requirements specification, a design, or source code. They are also commonly collectively known as complexity metrics.

Notes While many of the metrics are based on good ideas about what is important to measure in software to capture its complexity, it is still necessary to systematically validate them.

The validation of software product metrics means convincingly demonstrating that:

1. The product metric measures what it purports to measure.

Example: That a coupling metric is really measuring coupling.

2. The product metric is associated with some important external metric (such as measures of maintainability or reliability).
3. The product metric is an improvement over existing product metrics.

Example: An improvement can mean that it is easier to collect the metric or that it is a better predictor of faults.

Self Assessment

Fill in the blanks:

1. The basic objective of the requirements …………………… activity is to ensure that the SRS reflects the actual requirements accurately and clearly.
2. The basic purpose of …………………… at any point during a development project is to provide quantitative information to the management process.
3. The …………………… metric measures what it purports to measure.

Notes

4. The product metric is associated with some important …………………… metric.

5. Product metrics are also commonly collectively known as …………………….

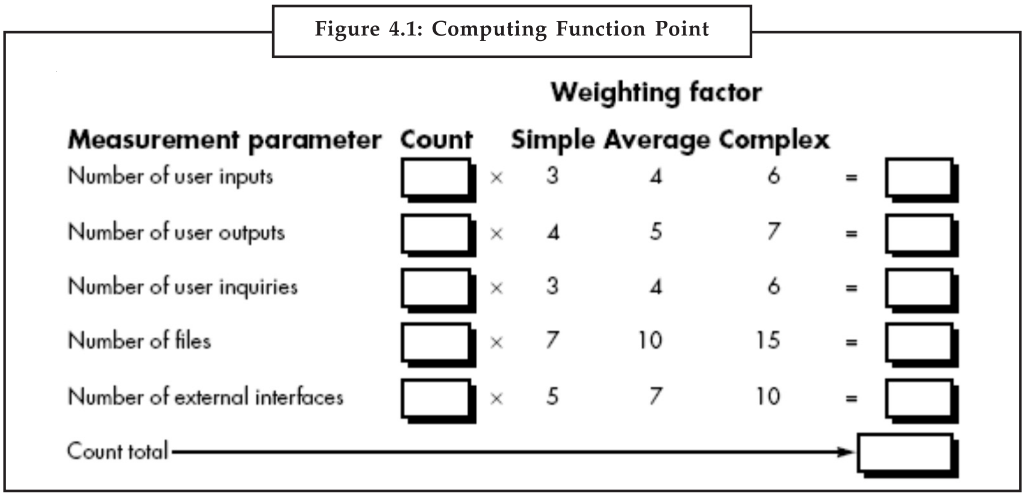
4.2 Function Point and Quality Metrics

In this section, we will discuss function point and quality metrics.

4.2.1 Function Points

Function-oriented software metrics use a measure of the functionality delivered by the application as a normalization value. Since 'functionality' cannot be measured directly, it must be derived indirectly using other direct measures. Function-oriented metrics were first proposed by Albrecht, who suggested a measure called the function point. Function points are derived using an empirical relationship based on countable (direct) measures of software's information domain and assessments of software complexity.

Figure 4.1: Computing Function Point



				Weighting factor			
Measurement parameter	**Count**		**Simple**	**Average**	**Complex**		
Number of user inputs	□	×	3	4	6	=	□
Number of user outputs	□	×	4	5	7	=	□
Number of user inquiries	□	×	3	4	6	=	□
Number of files	□	×	7	10	15	=	□
Number of external interfaces	□	×	5	7	10	=	□
Count total							□

Function points are computed by completing the table shown in Figure 4.1. Five information domain characteristics are determined and counts are provided in the appropriate table location. Information domain values are defined in the following manner:

- ***Number of User Inputs:*** Each user input that provides distinct application-oriented data to the software is counted. Inputs should be distinguished from inquiries, which are counted separately.
- ***Number of User Outputs:*** Each user output that provides application-oriented information to the user is counted. In this context output refers to reports, screens, error messages, etc. Individual data items within a report are not counted separately.
- ***Number of User Inquiries:*** An inquiry is defined as an online input that results in the generation of some immediate software response in the form of an online output. Each distinct inquiry is counted.
- ***Number of Files:*** Each logical master file (i.e., a logical grouping of data that may be one part of a large database or a separate file) is counted.
- ***Number of External Interfaces:*** All machine readable interfaces (e.g., data files on storage media) that are used to transmit information to another system are counted.

Once these data have been collected, a complexity value is associated with each count. Organizations that use function point methods develop criteria for determining whether a particular entry is simple, average, or complex. Nonetheless, the determination of complexity is somewhat subjective.

To compute function points (FP), the following relationship is used:

FP = Count total × [0.65 + 0.01 × “(Fi)] …(4.1)

where count total is the sum of all FP entries obtained from Figure 4.1.

The Fi (i = 1 to 14) are "complexity adjustment values" based on responses to the following questions:

1. Does the system require reliable backup and recovery?
2. Are data communications required?
3. Are there distributed processing functions?
4. Is performance critical?
5. Will the system run in an existing, heavily utilized operational environment?
6. Does the system require online data entry?
7. Does the online data entry require the input transaction to be built over multiple screens or operations?
8. Are the master files updated online?
9. Are the inputs, outputs, files, or inquiries complex?
10. Is the internal processing complex?
11. Is the code designed to be reusable?
12. Are conversion and installation included in the design?
13. Is the system designed for multiple installations in different organizations?
14. Is the application designed to facilitate change and ease of use by the user?

Each of these questions is answered using a scale that ranges from 0 (not important or applicable) to 5 (absolutely essential). The constant values in Equation (4.1) and the weighting factors that are applied to information domain counts are determined empirically.

Once function points have been calculated, they are used in a manner analogous to LOC as a way to normalize measures for software productivity, quality, and other attributes:

1. Errors per FP.
2. Defects per FP.
3. $ per FP.
4. Pages of documentation per FP.
5. FP per person-month.

Extended Function Point Metrics

The function point measure was originally designed to be applied to business information systems applications. To accommodate these applications, the data dimension (the information domain values discussed previously) was emphasized to the exclusion of the functional and behavioral (control) dimensions. For this reason, the function point measure was inadequate for many engineering and embedded systems (which emphasize function and control). A number of extensions to the basic function point measure have been proposed to remedy this situation.

A function point extension called feature points is a superset of the function point measure that can be applied to systems and engineering software applications.

The feature point measure accommodates applications in which algorithmic complexity is high.

Did u know? Real-time, process control and embedded software applications tend to have high algorithmic complexity and are therefore amenable to the feature point.

To compute the feature point, information domain values are again counted and weighted. In addition, the feature point metric counts new software characteristic algorithms. An algorithm is defined as "a bounded computational problem that is included within a specific computer program".

Example: Inverting a matrix, decoding a bit string, or handling an interrupt are all examples of algorithms.

Another function point extension for real-time systems and engineered products has been developed by Boeing. The Boeing approach integrates the data dimension of software with the functional and control dimensions to provide a function-oriented measure amenable to applications that emphasize function and control capabilities. Called the 3D function point, characteristics of all three software dimensions are "counted, quantified, and transformed" into a measure that provides an indication of the functionality delivered by the software.

Counts of retained data (the internal program data structure; e.g., files) and external data (inputs, outputs, inquiries, and external references) are used along with measures of complexity to derive a data dimension count. The functional dimension is measured by considering "the number of internal operations required to transform input to output data". For the purposes of 3D function point computation, a "transformation" is viewed as a series of processing steps that are constrained by a set of semantic statements. The control dimension is measured by counting the number of transitions between states.

A state represents some externally observable mode of behavior, and a transition occurs as a result of some event that causes the software or system to change its mode of behavior (i.e., to change state).

Example: A wireless phone contains software that supports auto dial functions.

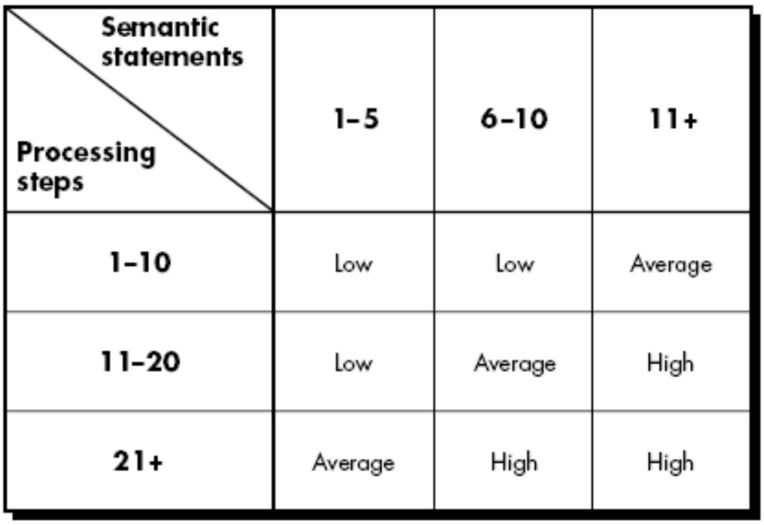
To enter the auto-dial state from a resting state, the user presses an Auto key on the keypad. This event causes an LCD display to prompt for a code that will indicate the party to be called. Upon entry of the code and hitting the Dial key (another event), the wireless phone software makes a transition to the dialing state. When computing 3D function points, transitions are not assigned a complexity value.

To compute 3D function points, the following relationship is used:

$$\text{Index} = I + O + Q + F + E + T + R \qquad \ldots(4.2)$$

Notes

Figure 4.2: Determining the Complexity of a Transformation for 3D Function Point



Processing steps \ Semantic statements	1–5	6–10	11+
1–10	Low	Low	Average
11–20	Low	Average	High
21+	Average	High	High

where I, O, Q, F, E, T, and R represent complexity weighted values for the elements discussed already: inputs, outputs, inquiries, internal data structures, external files, transformation, and transitions, respectively. Each complexity weighted value is computed using the following relationship:

Complexity weighted value $= NilWil + Ni_aWi_a + NihWih$ …(1)

where *Nil*, Ni_a, and *Nih* represent the number of occurrences of element *i* (e.g., outputs) for each level of complexity (low, medium, high); and *Wil*, Wi_a, and *Wih* are the corresponding weights. The overall complexity of a transformation for 3D function points is shown in Figure 4.2.

Notes It should be noted that function points, feature points, and 3D function points represent the same thing—"functionality" or "utility" delivered by software.

In fact, each of these measures results in the same value if only the data dimension of an application is considered. For more complex real-time systems, the feature point count is often between 20 and 35 percent higher than the count determined using function points alone.

The function point (and its extensions), like the LOC measure, is controversial. Proponents claim that FP is programming language independent, making it ideal for applications using conventional and non-procedural languages; that it is based on data that are more likely to be known early in the evolution of a project, making FP more attractive as an estimation approach. Opponents claim that the method requires some "sleight of hand" in that computation is based on subjective rather than objective data; that counts of the information domain (and other dimensions) can be difficult to collect after the fact; and that FP has no direct physical meaning—it's just a number.

Task Make distinction between function point and feature point.

Notes

4.2.2 Quality Metrics

Software metrics are numerical data related to software development. Metrics strongly support software project management activities. They relate to the four functions of management as follows:

1. ***Planning:*** Metrics serve as a basis of cost estimating, training planning, resource planning, scheduling, and budgeting.
2. ***Organizing:*** Size and schedule metrics influence a project's organization.
3. ***Controlling:*** Metrics are used to status and track software development activities for compliance to plans.
4. ***Improving:*** Metrics are used as a tool for process improvement and to identify where improvement efforts should be concentrated and measure the effects of process improvement efforts.

A metric quantifies a characteristic of a process or product. Metrics can be directly observable quantities or can be derived from one or more directly observable quantities.

Example: Raw metrics include the number of source lines of code, number of documentation pages, number of staff-hours, number of tests, number of requirements, etc.

Example: Derived metrics include source lines of code per staff-hour, defects per thousand lines of code, or a cost performance index.

The term indicator is used to denote a representation of metric data that provides insight into an ongoing software development project or process improvement activity. Indicators are metrics in a form suitable for assessing project behavior or process improvement.

Example: An indicator may be the behavior of a metric over time or the ratio of two metrics. Indicators may include the comparison of actual values versus the plan, project stability metrics, or quality metrics.

Example: Indicators used on a project include actual versus planned task completions, actual versus planned staffing, number of trouble reports written and resolved over time, and number of requirements changes over time.

Indicators are used in conjunction with one another to provide a more complete picture of project or organization behavior.

Example: A progress indicator is related to requirements and size indicators.

All three indicators should be used and interpreted together.

Task Analyse the use of indicators in quality metrics.

An Overview of Factors that Affect Quality

McCall and Cavano define a set of quality factors that were a first step toward the development of metrics for software quality. These factors assess software from three distinct points of view:

(1) product operation (using it), (2) product revision (changing it), and (3) product transition (modifying it to work in a different environment; i.e., "porting" it). In their work, the authors describe the relationship between these quality factors (what they call a framework) and other aspects of the software engineering process:

- First, the framework provides a mechanism for the project manager to identify what qualities are important. These qualities are attributes of the software in addition to its functional correctness and performance which have life cycle implications. Such factors as maintainability and portability have been shown in recent years to have significant life cycle cost impact . . .
- Secondly, the framework provides a means for quantitatively assessing how well the development is progressing relative to the quality goals established . . .
- Thirdly, the framework provides for more interaction of QA personnel throughout the development effort . . .
- Lastly, quality assurance personal can use indications of poor quality to help identify [better] standards to be enforced in the future.

Measuring Quality

Although there are many measures of software quality, correctness, maintainability, integrity, and usability provide useful indicators for the project team. Gilb suggests definitions and measures for each.

- ***Correctness:*** A program must operate correctly or it provides little value to its users. Correctness is the degree to which the software performs its required function. The most common measure for correctness is defects per KLOC, where a defect is defined as a verified lack of conformance to requirements. When considering the overall quality of a software product, defects are those problems reported by a user of the program after the program has been released for general use. For quality assessment purposes, defects are counted over a standard period of time, typically one year.
- ***Maintainability:*** Software maintenance accounts for more effort than any other software engineering activity. Maintainability is the ease with which a program can be corrected if an error is encountered, adapted if its environment changes, or enhanced if the customer desires a change in requirements. There is no way to measure maintainability directly; therefore, we must use indirect measures. A simple time-oriented metric is mean-time-to change (MTTC), the time it takes to analyze the change request, design an appropriate modification, implement the change, test it, and distribute the change to all users. On average, programs that are maintainable will have a lower MTTC (for equivalent types of changes) than programs that are not maintainable.
- ***Integrity:*** Software integrity has become increasingly important in the age of hackers and firewalls. This attribute measures a system's ability to withstand attacks (both accidental and intentional) to its security. Attacks can be made on all three components of software: programs, data, and documents.

  To measure integrity, two additional attributes must be defined: threat and security. Threat is the probability (which can be estimated or derived from empirical evidence) that an attack of a specific type will occur within a given time. Security is the probability (which can be estimated or derived from empirical evidence) that the attack of a specific type will be repelled. The integrity of a system can then be defined as:

  Integrity = Summation [(1 – Threat) × (1 – Security)]

  where threat and security are summed over each type of attack.

Notes

- ***Usability:*** The catch phrase "user-friendliness" has become ubiquitous in discussions of software products. If a program is not user-friendly, it is often doomed to failure, even if the functions that it performs are valuable. Usability is an attempt to quantify user-friendliness and can be measured in terms of four characteristics: (1) the physical and or intellectual skill required to learn the system, (2) the time required to become moderately efficient in the use of the system, (3) the net increase in productivity (over the approach that the system replaces) measured when the system is used by someone who is moderately efficient, and (4) a subjective assessment (sometimes obtained through a questionnaire) of users attitudes toward the system.

Defect Removal Efficiency

A quality metric that provides benefit at both the project and process level is Defect Removal Efficiency (DRE). In essence, DRE is a measure of the filtering ability of quality assurance and control activities as they are applied throughout all process framework activities.

When considered for a project as a whole, DRE is defined in the following manner:

$$DRE = E/(E + D) \qquad \ldots(4.4)$$

where E is the number of errors found before delivery of the software to the end-user and D is the number of defects found after delivery.

The ideal value for DRE is 1. That is, no defects are found in the software.

Did u know? Realistically, D will be greater than 0, but the value of DRE can still approach 1.

As E increases (for a given value of D), the overall value of DRE begins to approach 1. In fact, as E increases, it is likely that the final value of D will decrease (errors are filtered out before they become defects). If used as a metric that provides an indicator of the filtering ability of quality control and assurance activities, DRE encourages a software project team to institute techniques for finding as many errors as possible before delivery.

DRE can also be used within the project to assess a team's ability to find errors before they are passed to the next framework activity or software engineering task.

Example: The requirements analysis task produces an analysis model that can be reviewed to find and correct errors. Those errors that are not found during the review of the analysis model are passed on to the design task (where they may or may not be found). When used in this context, we redefine DRE as

$$DRE_i = E_i/(E_i + E_{i+1}) \qquad \ldots(4.5)$$

where E_i is the number of errors found during software engineering activity i and E_{i+1} is the number of errors found during software engineering activity i+1 that are traceable to errors that were not discovered in software engineering activity i.

A quality objective for a software team (or an individual software engineer) is to achieve DRE_i that approaches 1.

Caution Errors should be filtered out before they are passed on to the next activity.

Self Assessment

Fill in the blanks:

6. Function-oriented software metrics use a measure of the functionality delivered by the application as a …………………… value.
7. …………………… are derived using an empirical relationship based on countable (direct) measures of software's information domain and assessments of software complexity.
8. The …………………… measure accommodates applications in which algorithmic complexity is high.
9. …………………… are metrics in a form suitable for assessing project behavior or process improvement.
10. A quality metric that provides benefit at both the project and process level …………………….

4.3 Software Architecture

When you discuss about the architecture of a building, many different attributes come to mind. At the most simplistic level, we consider the overall shape of the physical structure. But in reality, architecture is much more. It is the manner in which the various components of the building are integrated to form a cohesive whole. It is the way in which the building fits into its environment and meshes with other buildings in its vicinity. It is the degree to which the building meets its stated purpose and satisfies the needs of its owner. It is the aesthetic feel of the structure—the visual impact of the building and the way textures, colors, and materials are combined to create the external facade and the internal "living environment." It is small details—the design of lighting fixtures, the type of flooring, the placement of wall hangings, list is almost endless. And finally, it is art.

The software architecture of a program or computing system is the structure or structures of the system, which comprise software components, the externally visible properties of those components, and the relationships among them.

The architecture is not the operational software. Rather, it is a representation that enables a software engineer to (1) analyze the effectiveness of the design in meeting its stated requirements, (2) consider architectural alternatives at a stage when making design changes is still relatively easy, and (3) reducing the risks associated with the construction of the software.

This definition emphasizes the role of "software components" in any architectural representation. In the context of architectural design, a software component can be something as simple as a program module, but it can also be extended to include databases and "middleware" that enable the configuration of a network of clients and servers. The properties of components are those characteristics that are necessary to an understanding of how the components interact with other components. At the architectural level, internal properties (e.g., details of an algorithm) are not specified. The relationships between components can be as simple as a procedure call from one module to another or as complex as a database access protocol.

The main reasons that software architecture is important:

- Representations of software architecture are an enabler for communication between all parties (stakeholders) interested in the development of a computer-based system.
- The architecture highlights early design decisions that will have a profound impact on all software engineering work that follows and, as important, on the ultimate success of the system as an operational entity.

Notes

- Architecture "constitutes a relatively small, intellectually graspable model of how the system is structured and how its components work together".

4.3.1 Architecture Views

There is a general view emerging that there is no unique architecture of a system. The definition that we have adopted (given above) also expresses this sentiment. Consequently, there is no one architecture drawing of the system. The situation is similar to that of civil construction, a discipline that is the original user of the concept of architecture and from where the concept of software architecture has been borrowed. For a building, if you want to see the floor plan, you are shown one set of drawings. If you are an electrical engineer and want to see how the electricity distribution has been planned, you will be shown another set of drawings. And if you are interested in safety and firefighting, another set of drawings is used. These drawings are not independent of each other—they are all about the same building. However, each drawing provides a different view of the building, a view that focuses on explaining one aspect of the building and tries to a good job at that, while not divulging much about the other aspects. And no one drawing can express all the different aspects—such a drawing will be too complex to be of any use.

Similar is the situation with software architecture. In software, the different drawings are called views. A view represents the system as composed of some types of elements and relationships between them. Which elements are used by a view, depends on what the view wants to highlight. Different views expose different properties and attributes, thereby allowing the stakeholders and analysts to properly evaluate those attributes for the system. By focusing only on some aspects of the system, a view reduces the complexity that a reader has to deal with at a time, thereby aiding system understanding and analysis.

A view describes a structure of the system. We will use these two concepts—views and structures—interchangeably. We will also use the term architectural view to refer to a view. Many types of views have been proposed. Most of the proposed views generally belong to one of these three types:

1. Module
2. Component and connector
3. Allocation

In a module view, the system is viewed as a collection of code units, each implementing some part of the system functionality. That is, the main elements in this view are modules. These views are code-based and do not explicitly represent any runtime structure of the system.

Example: Modules are packages, a class, a procedure, a method, a collection of functions, and a collection of classes.

The relationships between these modules are also code-based and depend on how code of a module interacts with another module.

Example: Relationships in this view are "is a part of" (i.e., module B is a part of module A), "uses or depends on" (a module A uses services of module B to perform its own functions and correctness of module A depends on correctness of module B), and "generalization or specialization" (a module B is a generalization of a module A).

In a component and connector (C&C) view, the system is viewed as a collection of runtime entities called components. That is, a component is a unit which has an identity in the executing system.

Example: Objects (not classes), a collection of objects, and a process are examples of components.

While executing, components need to interact with others to support the system services. Connectors provide means for this interaction.

Example: Connectors are pipes and sockets.

Shared data can also act as a connector. If the components use some middleware to communicate and coordinate, then the middleware is a connector. Hence, the primary elements of this view are components and connectors.

An allocation view focuses on how the different software units are allocated to resources like the hardware, file systems, and people. That is, an allocation view specifies the relationship between software elements and elements of the environments in which the software system is executed. They expose structural properties like which processes run on which processor, and how the system files are organized on a file system.

An architecture description consists of views of different types, with each view exposing some structure of the system. Module views show how the software is structured as a set of implementation units, C&C views show how the software is structured as interacting runtime elements, and allocation views show how software relates to non-software structures. These three types of view of the same system form the architecture of the system.

Note that the different views are not unrelated. They all represent the same system. Hence, there are relationships between elements in one view and elements in another view. These relationships may be simple or may be complex.

Example: The relationship between modules and components may be one to one in that one module implements one component. On the other hand, it may be quite complex with a module being used by multiple components, and a component using multiple modules.

While creating the different views, the designers have to be aware of this relationship.

The next question is what are the standard views that should be expressed for describing the architecture of a system? To answer this question, the analogy with buildings may again help. If one is building a simple small house, then perhaps there is no need to have a separate view describing the emergency and the fire system. Similarly, if there is no air conditioning in the building, there need not be any view for that. On the other hand, an office building will perhaps require both of these views, in addition to other views describing plumbing, space, wiring, etc.

However, despite the fact that there are multiple drawings showing different views of a building, there is one view that predominates in construction—that of physical structure. This view forms the basis of other views in that other views cannot really be completed unless this view can be done. Other views may or may not be needed for constructing a building, depending on the nature of the project. Hence, in a sense, the view giving the building structure may be considered as the primary view in that it is almost always used, and other views rely on this view substantially. The view also captures perhaps the most important property to be analyzed in the early stages, namely, that of space organization.

The situation with software architecture is also somewhat similar. As we have said, depending on what properties are of interest, different views of the software architecture are needed. However, of these views, the C&C view has become the de facto primary view, one which is almost always prepared when an architecture is designed (some definitions even view architecture only in terms of C&C views). As partitioning a system into smaller parts and composing the system from these parts is also a goal of design, a natural question is what is the difference between a design and architecture as both aim to achieve similar objectives and seem to fundamentally rely on the divide and conquer rule? First, it should be clear that architecture is a design in that it is in the solution domain and talks about the structure of the proposed system. Furthermore, an architecture view gives a high-level view of the system, relying on abstraction to convey the meaning—something which design also does. So, architecture is design. We can view architecture as a very high-level design, focusing only on main components, and the architecture activity as the first step in design. What we term as design is really about the modules that will eventually exist as code. That is, they are a more concrete representation of the implementation (though not yet an implementation). Consequently, during design lower-level issues like the data structures, files, and sources of data, have to be addressed, while such issues are not generally significant at the architecture level. We also take the view that design can be considered as providing the module view of the architecture of the system.

The boundaries between architecture and high-level design are not fully clear. The way the field has evolved, we can say that the line between architecture and design is really up to the designer or the architect. At the architecture level, one needs to show only those parts that are needed to perform the desired evaluation. The internal structure of these parts is not important. On the other hand, during design, designing the structure of the parts that can lead to constructing them is one of the key tasks. However, which parts of the structure should be examined and revealed during architecture and which parts during design is a matter of choice.

⚠

Caution Details that are not needed to perform the types of analysis we wish to do at the architecture time are unnecessary and should be left for design to uncover.

4.3.2 Architectural Styles

When a builder uses the phrase “center hall colonial” to describe a house, most people familiar with houses in the United States will be able to conjure a general image of what the house will look like and what the floor plan is likely to be. The builder has used an architectural style as a descriptive mechanism to differentiate the house from other styles (e.g., A-frame, raised ranch, Cape Cod). But more important, the architectural style is also a pattern for construction. Further details of the house must be defined, its final dimensions must be specified, customized features may be added, building materials are to be determined, but the pattern—a “center hall colonial” guides the builder in his work.

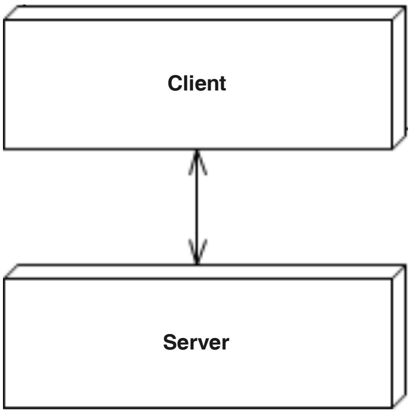
The software that is built for computer-based systems also exhibits one of many architectural styles. Each style describes a system category that encompasses (1) a set of components (e.g., a database, computational modules) that perform a function required by a system; (2) a set of connectors that enable “communication, coordination’s and cooperation” among components; (3) constraints that define how components can be integrated to form the system; and (4) semantic models that enable a designer to understand the overall properties of a system by analyzing the known properties of its constituent parts.

Although millions of computer-based systems have been created over the past 50 years, the vast majority can be categorized into one of a relatively small number of architectural styles:

Client Server Architecture Style

The client server architecture style become very well known when the explosion of internet brought it to common vocabulary. On the internet, a browser (client) responsible with user interaction connects to a web portal (server) responsible with data processing and HTML formatting. There are many examples of client-server architectures and initially it appeared as a result of the need to centralize processing and data to a common location and allow changes of the system to be implemented without modifying the whole system. In a system composed only of desktop clients any modification would presumably require redeployment of all clients, a operation that incurred high costs.

Figure 4.3: Client Server Architecture Style



It is not easy to balance the amount of functionality implemented on the server with the ones implemented on client because of the conflicting needs and requirements.

Example: You would want more processing on client when a fast user interface is desirable but you also want as much processing done on the server so that changes are more easily deployed.

The web browser clients, are traditionally thin clients where little or no processing is done except displaying server formatted pages and sending input. But, lately there is a grown tendency to add more processing on the clients, HTML5 being an example of this trend. Another aspect that is hard to balance is the amount of data exchanged between the client and the server. You would want very little data transmitted for performance reasons but however the users might demand a lot of additional information.

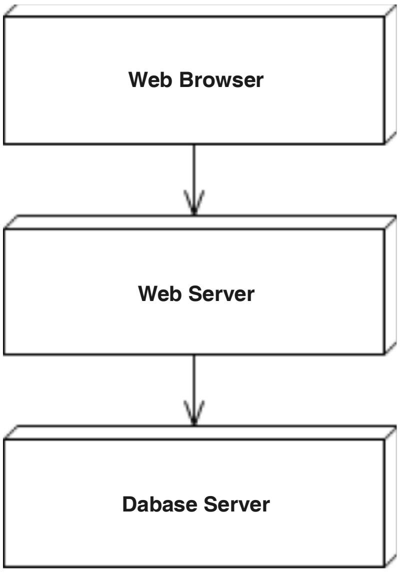
N-tier Architecture Style

N-tier architecture style can be seen as a generalization of the client-server architecture. The style appeared as a result of the need to place a system functionality onto more than one processing node. This style of architecture is supported naturally by the layered architecture and more often than not there is confusion between n-tier and n-layer architectures. As a rule of thumb tier refers to processing nodes while layers refers to the stratification of system functionality.

Notes

Example: Figure 4.4 is a classical example of a n-tier architecture:

Figure 4.4: N-tier Architecture Style Example



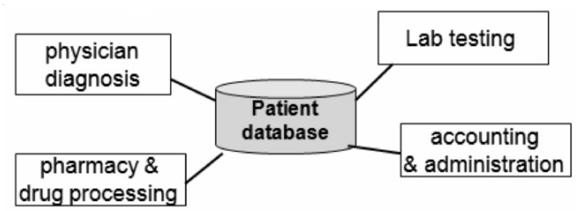
As with layered architecture you need to make a decision regarding the number of tiers balancing the performance, separation of concerns, deployment complexity, hardware, etc.

Shared Data Style

The high level design solution is based on a shared data-store which acts as the "central command" with 2 variations:

- ***Blackboard Style:*** the data-store alerts the participating parties whenever there is a data-store change (trigger)
- ***Repository Style:*** the participating parties check the data-store for changes

Figure 4.5: Example of Shared Data Style



Problems that fit this style such as patient processing, tax processing system, inventory control system; etc. have the following properties:

1. All the functionalities work off a single data-store.
2. Any change to the data-store may affect all or some of the functions
3. All the functionalities need the information from the data-store

In database management system we can set up a trigger which has 3 parts:

1. ***Event:*** change to the database that alerts or activates the trigger
2. ***Condition:*** a test that is true when the trigger is activated
3. ***Action:*** a procedure which is executed when the trigger is activated and the condition is true.

A trigger may be thought as a monitor of the database for changes to the database that matches the event specification (e.g. debit of bank customer accountant). Then the condition is checked to see if it is true (e.g. debited cust account results in negative bank accnt amount). If the debited account has a negative accnt amount, then kick off a procedure to send error message out and delay the execution of cust account debiting.

Advantages of shared data are:

- The independent functions are cohesive within itself and the coupling is restricted to the shared data
- Single data-store makes the maintenance of data in terms of back-up recovery and security easier to manage

Disadvantages of shared data are:

- (Common and control coupling through data) Any data format change in the shared data requires agreement and, potentially, changes in all or some the functional areas – this becomes a bigger problem as more functionalities are introduced that have dependency on the shared data (e.g. popular commercial product such as CRM or ERP)
- If the data-store fails, all parties are affected and possibly all functions have to stop (may need to have (1) redundant db for this architecture style; also, should have (2) good back up - and recovery procedures.)

Task Compare and contrast Blackboard style and repository style.

Call and Return Architectures

This architectural style enables a software designer (system architect) to achieve a program structure that is relatively easy to modify and scale. A number of substyles exist within this category:

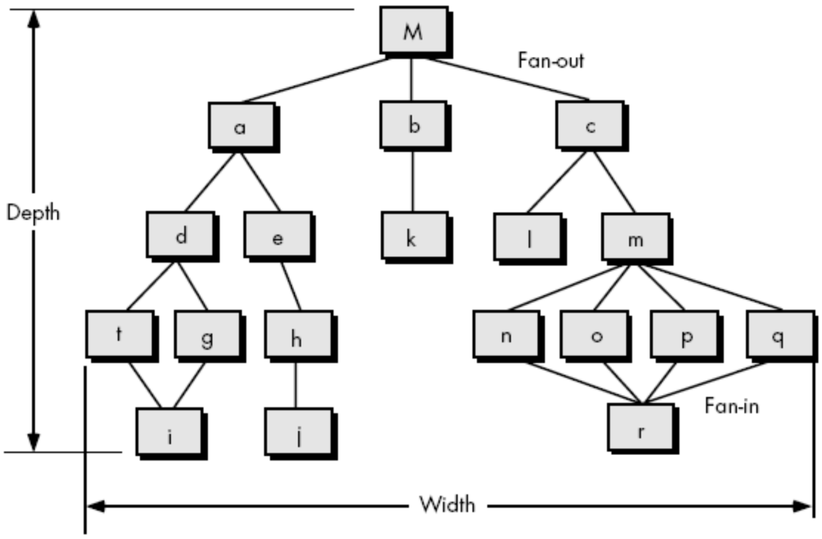
- ***Main Program/subprogram Architectures:*** This classic program structure decomposes function into a control hierarchy where a "main" program invokes a number of program components, which in turn may invoke still other components. Figure 4.6 illustrates architecture of this type.
- ***Remote Procedure Call Architectures:*** The components of a main program/subprogram architecture are distributed across multiple computers on a network.

Object-oriented Architectures

The components of a system encapsulate data and the operations that must be applied to manipulate the data. Communication and coordination between components is accomplished via message passing.

Notes

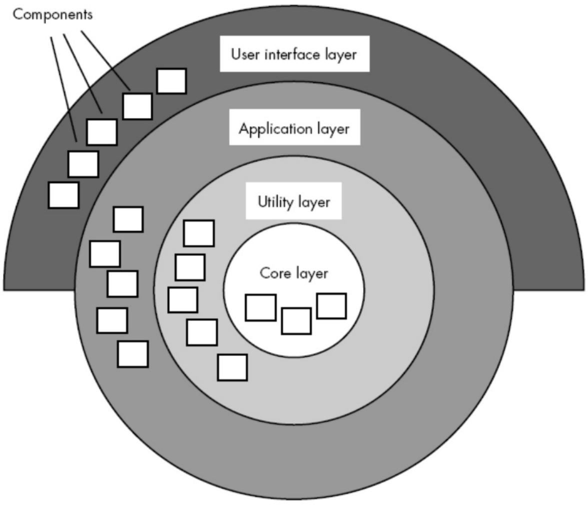
Figure 4.6: Structure Terminology for a Call and Return Architectural Style



Layered Architectures

The basic structure of a layered architecture is illustrated in Figure 4.7. A number of different layers are defined, each accomplishing operations that progressively become closer to the machine instruction set. At the outer layer, components service user interface operations. At the inner layer, components perform operating system interfacing. Intermediate layers provide utility services and application software functions.

Figure 4.7: Layered Architecture



Self Assessment

Fill in the blanks:

11. At the architectural level, …………………… properties are not specified.

12. A …………………… represents the system as composed of some types of elements and relationships between them.

13. In a …………………… view, the system is viewed as a collection of code units, each implementing some part of the system functionality.

14. A …………………… is a unit which has an identity in the executing system.

15. An …………………… view focuses on how the different software units are allocated to resources like the hardware, file systems, and people.

Case Study

Measuring Software Quality

The National Security Agency's mission is to provide support for the security of the United States. Over the years, the Agency has become extremely dependent on the software that makes up its information technology infrastructure. NSA has come to view software as a critical resource upon which much of the world's security, prosperity, and economic competitiveness increasingly rests. If anything, dependence on software and its corresponding effect on national security makes it imperative for NSA to accept and maintain only the highest quality software. Cost overruns, or software systems that are defective or of low quality, can impose a significant burden on national security and NSA's mission.

Software Engineering Applied Technology Center

The NSA organization responsible for addressing these needs is the Software Engineering Applied Technology Center. The SEATC's goal is to reduce maintenance costs while improving software development. In addition, NSA has formed partnerships with other government agencies and industry consortiums, the Software Engineering Institute, and vendors who supply automated tools and support technology for software development. Its aim is to discover the best current practices in government and industry and bring knowledge of them to NSA organizations.

A key initiative addresses software quality engineering. The benefits of structured testing and quality assurance activities throughout the entire software life cycle are often overlooked, but they are a key part of a complete software engineering process. Testing activities provide key software metrics and feedback mechanisms for defining and improving software products across a broad spectrum of software development activities at NSA. Process-level activities involve technical test management support and software quality assurance program implementation. After nearly three years of measurement and quality assurance activities, the SEATC has collected and analyzed the results on some 25 million lines of C, C++, Fortran, and Ada code. We have developed a streamlined set of code-level release criteria that we apply to code written at NSA organizations. This 25 million lines of code is the sample drawn from a population of more than one billion lines of code at NSA. The result is a highly correlated set of measures that promote high-quality processes where they matter most¾ at the code level.

The SEATC Software Quality Measures

We use two primary measurement activities to derive our code-level release criteria. The first is code metrics analysis: We measure development productivity indicators, predictability measures, maintainability indicators, essential quality attributes of the code, and "hot spots," and we identify overly complex modules that need additional work.

Contd...

Notes

Specific code metrics include Halstead's software science measures (purity ratio, volume, and effort), McCabe's cyclomatic complexity, and functional density analysis. The second measurement activity is coverage analysis, which centers on "inside-the-code" analysis (or decision-level metrics), testability indicators through executable path analysis, and predictive performance analysis based on the number of segments per path. These measures constitute what we call critical or essential measures. (See the "NSA SEATC critical measures" sidebar.) We have found them valid for measuring most high-order code produced in support of NSA and for determining code characteristics, such as:

Likelihood and frequency of errors, ·overly complex components that might require reengineering,

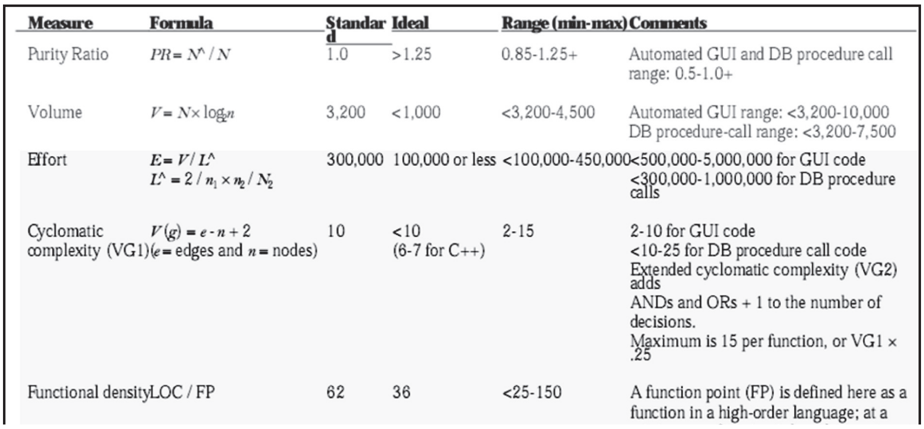
- allocation of resources for testing,
- difficulty of maintenance,
- predictive performance indicators, and
- optimization level.

The primary SEATC technique for determining software quality is to analyze the changes (deltas) to the code. We track this measure against changes in other measures over time via repeated milestone and turnover "snapshots." These snapshots provide a feedback loop that lets us improve not only the quality of the software, but that of the development process as well.

The SEATC's Code Quality Index

On the basis of the normalized use of simple standard deviation and frequency distribution curves, the SEATC has developed a code quality index to measure the relative stability, robustness, size, and predictive performance of a typical function in a high-order language. We used an integrated set of static quality indicators and correlated them to the results of dynamic testing of the same function running as a compiled executable in the real-world environment. The mean for each metric represents the "ideal" normalized value, and the quality index encompasses approximately three standard deviations on each side of the mean. Correlations between static and dynamic testing run between 85 and 95 percent. Acceptable ranges for each metric are detailed in Table 1, along with adjustments for graphical user interface code generators and for embedded database procedure calls. (The ranges in the table encompass approximately only one to one and a half sigmas.) In addition, these range values must be baselined for a particular application domain.

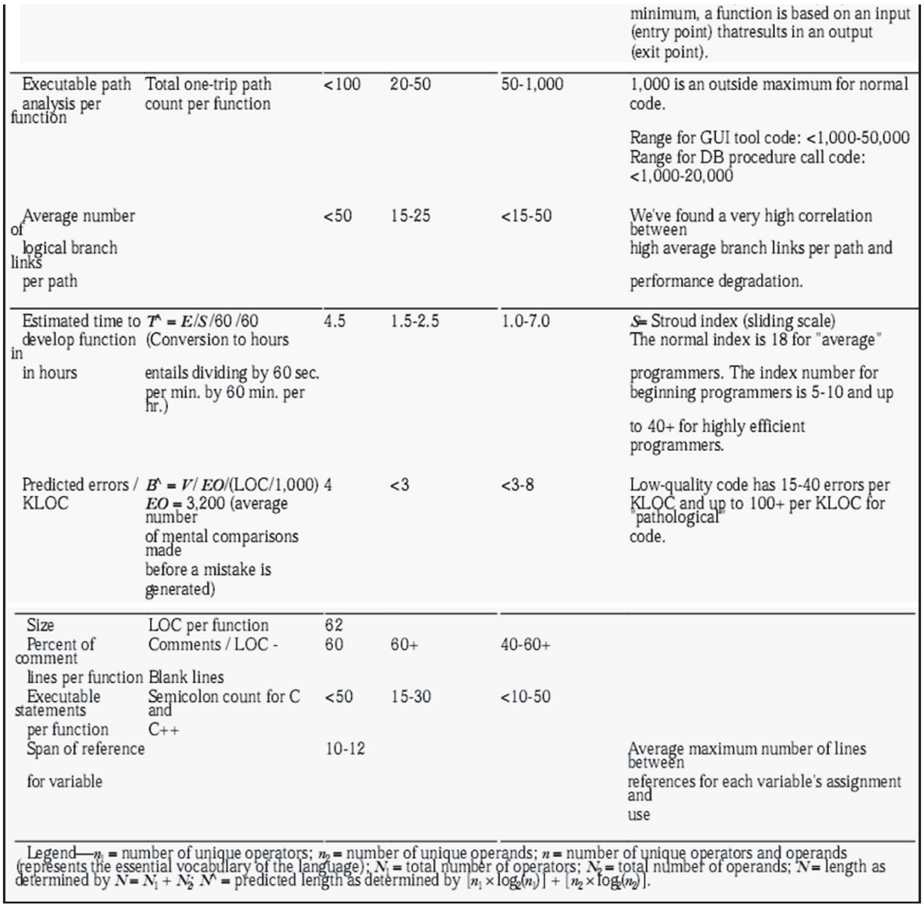
Table 1: The SEATC Critical Measures and Benchmarks



Measure	Formula	Standard	Ideal	Range (min-max)	Comments
Purity Ratio	$PR = N^{\wedge} / N$	1.0	>1.25	0.85-1.25+	Automated GUI and DB procedure call range: 0.5-1.0+
Volume	$V = N \times \log_2 n$	3,200	<1,000	<3,200-4,500	Automated GUI range: <3,200-10,000 DB procedure-call range: <3,200-7,500
Effort	$E = V / L^{\wedge}$ $L^{\wedge} = 2 / n_1 \times n_2 / N_2$	300,000	100,000 or less	<100,000-450,000	<500,000-5,000,000 for GUI code <300,000-1,000,000 for DB procedure calls
Cyclomatic complexity (VG1)	$V(g) = e - n + 2$ (e = edges and n = nodes)	10	<10 (6-7 for C++)	2-15	2-10 for GUI code <10-25 for DB procedure call code Extended cyclomatic complexity (VG2) adds ANDs and ORs + 1 to the number of decisions. Maximum is 15 per function, or VG1 × .25
Functional density	LOC / FP	62	36	<25-150	A function point (FP) is defined here as a function in a high-order language; at a

Contd...

Notes



					minimum, a function is based on an input (entry point) thatresults in an output (exit point).
Executable path analysis per function	Total one-trip path count per function	<100	20-50	50-1,000	1,000 is an outside maximum for normal code. Range for GUI tool code: <1,000-50,000 Range for DB procedure call code: <1,000-20,000
Average number of logical branch links per path		<50	15-25	<15-50	We've found a very high correlation between high average branch links per path and performance degradation.
Estimated time to develop function in in hours	$\hat{T} = E/S$/60 /60 (Conversion to hours entails dividing by 60 sec. per min. by 60 min. per hr.)	4.5	1.5-2.5	1.0-7.0	S= Stroud index (sliding scale) The normal index is 18 for "average" programmers. The index number for beginning programmers is 5-10 and up to 40+ for highly efficient programmers.
Predicted errors / KLOC	$\hat{B} = V/ EO$/(LOC/1,000) EO = 3,200 (average number of mental comparisons made before a mistake is generated)	4	<3	<3-8	Low-quality code has 15-40 errors per KLOC and up to 100+ per KLOC for "pathological" code.
Size	LOC per function	62			
Percent of comment lines per function	Comments / LOC - Blank lines	60	60+	40-60+	
Executable statements per function	Semicolon count for C and C++	<50	15-30	<10-50	
Span of reference for variable		10-12			Average maximum number of lines between references for each variable's assignment and use

Legend—n_1 = number of unique operators; n_2 = number of unique operands; n = number of unique operators and operands (represents the essential vocabulary of the language); N_1 = total number of operators; N_2 = total number of operands; N= length as determined by $N = N_1 + N_2$; $\hat{N}$ = predicted length as determined by $[n_1 \times \log_2(n_1)] + [n_2 \times \log_2(n_2)]$.

From this 25 million lines of code, I have drawn up a case study to dramatically illustrate the benefits of applied quality assurance and code-level measurement activities. About three and a half years ago, an NSA organization needed real-time network support. This software was designed to analyze the parameters of certain kinds of data streams and, on the basis of that analysis, send the data to a workstation on the same network. The software was to be developed, integrated, and delivered in six months. During these six months there were no code inspections, walkthroughs, separate testing activities, or process controls. When the code was installed for operational testing, it failed abysmally¾ not because it did not work, but because the critical function, the delivery of data, took four or five hours. The users deemed this unacceptable, even though technically the software worked.

The support organization assigned its senior developer to fix the code. She spent some two weeks trying to fix it before determining that it would have to be reengineered. Management (the root cause of much that afflicts software acquisition) was getting very antsy. The project was now way behind schedule. They insisted on keeping the old software on the system even though it caused analysts to wait hours for data.

This went on for some weeks until the senior developer simply decided to re-engineer the software anyway. After six weeks of effort, the new code was reintegrated. Data delivery that took four or five hours now took only seconds. The users were much happier, but management was still very upset because it took so much more effort to deliver the same functionality. The developers had no mechanism for demonstrating quantitatively what they already knew anecdotally about clear and obvious differences in performance between

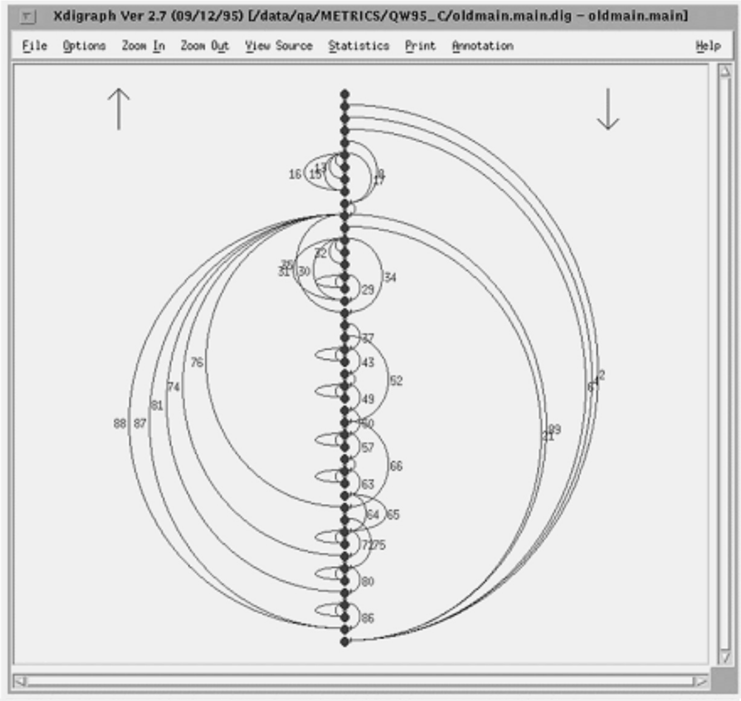
Contd...

the two functions. The senior developer in charge of the reengineering effort asked the SEATC to use its tools to analyze the code. Within two hours we were able to demonstrate very clearly why the new code was vastly superior in quality to the old code. We made this case by combining static metrics analysis with static coverage branch-level analysis at the individual function level, using two commercial, off-the-shelf tools. For the metrics analysis, we used the UX-Metric C language version 2.2 analyzer engine from SET Laboratories, supplied with the version 1.3 Metric tool from the Software Research Software TestWorks Advisor tool suite, which added Kiviat diagram graphing analysis. The metric engine assumed that the code was ANSI C compliant and/or Kernighan and Ritchie with the approved extensions. For the coverage analysis, we used the TCAT (Test Coverage Analysis Tool) version 8.2 code analyzer from the Software TestWorks Coverage tool suite, using version 2.7 of the Xdigraph directed graph (digraph) display technology. Both tools ran on a Sun Sparc platform under SunOS.

Coverage Analysis

The SEATC ran coverage analysis against the old and new code. It was this coverage analysis that predicted the performance, maintainability, and testability of both main functions. Figure 1 shows a directed graph (control flow graph) of the old main function. The entry point is the top node, and the exit point is the bottom node. Each node represents a statement in the code and is linked to other statements by segments, as represented by the linking arcs. The graph is read top to bottom, right to left. Note that nodes 2-4 are hardcoded and result in immediate exits. Note also the large number of grouped statements linked to another group of statements only by an isolated link. This represents an "island effect" and strongly indicates a lack of design: Get something to work, code some more and get it to work, and so on. The pattern generated by the digraph reflects a very complex, low-performance module.

Figure 1: A Directed Graph (Control Flow Graph) of the Old Main Function



Contd...

Each node represents a statement in the code and is linked to other statements by segments, as represented by the linking arcs. The pattern generated by the digraph reflects a very complex, low-performance module. This is by no means the total number. The original analysis on oldmain.c was executed on a Sparcstation 2 running 32 Mbytes of RAM and 32 Mbytes of swap space. After half an hour it ran out of memory after reporting at least 160,000 one-trip executable paths. When we put it on a Sparcstation 20 with 64 Mbytes of RAM and allocated 2.1 Gbytes of swap space from the network, it ran out of memory after almost 2.5 hours and reported more than eight million one-trip executable paths.

The normal maximum number of executable paths per function is 100. The extreme outside maximum is 1,000. The ideal number of paths is 20-50 on average per function. From a testability perspective, this particular function with its more than eight million paths cannot be tested. From a maintenance perspective, the program is essentially unmaintainable. Predicting a module’s performance is also important.

Software Risk Management

As a result of this kind of analysis, the SEATC is now promoting a series of measures related to defect rates, code/system scrap rates, workflow and process measures, and cost measures related to cost-per-unit of code based on level-of-effort calculations, maintenance resource analysis, and productivity measures. The whole intent of NSA’s software quality program is to reduce risk by managing it through the analysis of measurement data applied to both process and development tasks down to the functional code. NSA is investing in the long-term software process and programming environments to ensure the long-term stability and operational use of its software base. The national security stakes are just too great. The NSA SEATC created a comprehensive software process improvement effort through a series of strategic partnerships and pilot programs that allow the establishment, measurement, formalization, and improvement of the full life cycle software process.

The SEATC uses the SEI Capability Maturity Model as the basis for this initiative. In addition, we use the Experience Factory developed by NASA’s Software Engineering Laboratory as the mechanism for evaluating software improvement initiatives. The Experience Factory model allows NSA to gather objective measurements for software development organizations and analyze them to determine the effectiveness of development techniques and document their costs and associated level of effort. Reengineering, reuse, integrated software development environments, object-oriented technology, and training are additional SEATC initiatives to promote and sustain high-quality software.

Conclusion

Many people talk about market share and software content, but not in a tangible way. A project needs real measures from real data. If we don’t really understand software productivity factors, then we won’t know how to improve our development processes. None of the current or proposed software quality and process “standards” enforce the details of the software development process, so a real software process must be built from within. But change, even when done for the right reasons, will upset the status quo and will upset established norms and behavior patterns. More importantly, it will upset the minds and perceptions of people.

We must recognize the importance of the people in the process. Improved quality and higher productivity can be achieved by tapping their inherent strengths. The appropriate use of metrics and statistical techniques can help us measure progress and provide support to our software development teams, while at the same time mitigating risk, lowering

Contd...

cost, and improving quality. Proceed with deliberate intent and create meaningful goals based on the benchmarking of key development processes and milestones. Your code will be happier for it.

Questions:

1. Discuss the SEATC technique for determining software quality.
2. Explain coverage analysis in the above case.

Source: http://mridulasharma.com/wp-content/uploads/2013/01/Assignment-G-3.pdf

4.4 Summary

- The basic objective of the requirements validation activity is to ensure that the SRS reflects the actual requirements accurately and clearly.
- A software metric relates the individual measures in some way (e.g., the average number of errors found per review or the average number of errors found per person-hour expended on reviews).
- Product metrics quantitatively characterize some aspect of the structure of a software product, such as a requirements specification, a design, or source code. They are also commonly.
- Function-oriented software metrics use a measure of the functionality delivered by the application as a normalization value.
- A function point extension called feature points is a superset of the function point measure that can be applied to systems and engineering software applications.
- The Boeing approach integrates the data dimension of software with the functional and control dimensions to provide a function-oriented measure amenable to applications that emphasize function and control capabilities.
- Software metrics are numerical data related to software development.
- A quality metric that provides benefit at both the project and process level is Defect Removal Efficiency (DRE).
- A view represents the system as composed of some types of elements and relationships between them.
- The builder has used an architectural style as a descriptive mechanism to differentiate the house from other styles.
- A component is a unit which has an identity in the executing system.

4.5 Keywords

Boeing Approach: The Boeing approach integrates the data dimension of software with the functional and control dimensions to provide a function-oriented measure amenable to applications that emphasize function and control capabilities.

DRE: A quality metric that provides benefit at both the project and process level is Defect Removal Efficiency (DRE).

Function Points: Function points are derived using an empirical relationship based on countable (direct) measures of software's information domain and assessments of software complexity.

Indicator: The term indicator is used to denote a representation of metric data that provides insight into an ongoing software development project or process improvement activity.

Product Metrics: Product metrics quantitatively characterize some aspect of the structure of a software product, such as a requirements specification, a design, or source code.

Software Metrics: Software metrics are numerical data related to software development.

State: A state represents some externally observable mode of behavior, and a transition occurs as a result of some event.

View: A view represents the system as composed of some types of elements and relationships between them.

4.6 Review Questions

1. Discuss the concept of validation in software engineering.
2. What is the purpose of software metrics? Discuss.
3. Explain the concept of Function-oriented software metrics.
4. Discuss the process of computing function points.
5. Function points, feature points, and 3D function points represent the same thing. Comment.
6. Discuss the functions of management related to quality metrics.
7. Discuss the quality factors towards the development of metrics for software quality.
8. Explain the concept of Defect Removal Efficiency (DRE).
9. What are architectural views? Also discuss the different types of views.
10. Explain the concept of client/server architectural style and shared data architectural style.

Answers: Self Assessment

1. validation
2. Metrics
3. product
4. External
5. complexity metrics
6. Normalization
7. Function points
8. feature point
9. Indicators
10. is Defect Removal Efficiency (DRE)
11. internal
12. View
13. module
14. Component
15. allocation

4.7 Further Readings

Books

Rajib Mall, *Fundamentals of Software Engineering*, 2nd Edition, PHI.

Richard Fairpy, *Software Engineering Concepts*, Tata McGraw Hill, 1997.

R.S. Pressman, *Software Engineering – A Practitioner's Approach*, 5th Edition, Tata McGraw Hill Higher education.

Sommerville, *Software Engineering*, 6th Edition, Pearson Education

Online links

http://www.chambers.com.au/glossary/verification_validation.php

http://www.inf.ed.ac.uk/teaching/courses/cs2/LectureNotes/CS2Ah/SoftEng/se08.pdf

http://www.cs.colorado.edu/~kena/classes/5828/s12/presentation-materials/boughtonalexandra.pdf

http://web.itu.edu.tr/gokmen/SE-lecture-2.pdf

Unit 5: Software Project Planning

Notes

CONTENTS

Objectives

Introduction

5.1 Process Planning

5.2 Effort Estimation

5.2.1 Factors Contributing to Inaccurate Estimation

5.2.2 Impact of Under-estimating

5.2.3 The Estimation Process

5.3 The COCOMO Model

5.3.1 Brief Characteristics of the Model

5.3.2 Levels

5.3.3 Appraisal of the Model

5.3.4 Modes

5.4 Project Scheduling and Staffing

5.4.1 Comments on "Lateness"

5.4.2 Basic Principles

5.4.3 Project Staffing

5.5 Introduction to Software Configuration Management

5.5.1 Baselines

5.5.2 Software Configuration Items

5.5.3 The SCM Process

5.5.4 Identification of Objects in the Software Configuration

5.6 Quality Plan

5.7 Risk Management

5.7.1 Software Risk Management

5.7.2 Risk Classification

5.7.3 Strategies for Risk Management

5.8 Project Monitoring

5.8.1 Time Sheets

5.8.2 Reviews

5.8.3 Cost-Schedule-Milestone Graph

5.8.4 Earned Value Method

5.9 Summary

5.10 Keywords

5.11 Review Questions

5.12 Further Readings

Objectives

After studying this unit, you will be able to:

- Discuss the concept of process planning and effort estimation
- Explain the concept of COCOMO model
- Describe project scheduling and staffing
- Explain software configuration management
- Discuss risk management and project monitoring

Introduction

Project planning is a common thread that intertwines all the activities from conception to commissioning and handing over the clockwork to clients. Project planning encompasses the essential activities such as work breakdown structure, statement of work, and accurate time estimates and schedules which help further in anticipating snags in a project and overcome them. A plan is the first step in providing the means to satisfy the needs of a project sponsor and help in paving the way to reach desired goal. It is a beginning of the project manager's input to ensure that potential problems are identified timely and can easily be assessed on the basis of which further estimating and resource allocation may be comfortably done. That means, prevention is better than cure' philosophy is adhered to while drafting the project plans. Software Configuration Management (SCM) is one of the foundations of software engineering. It is used to track and manage the emerging product and its versions.

5.1 Process Planning

Project Planning is an aspect of Project Management that focuses a lot on Project Integration. The project plan reflects the current status of all project activities and is used to monitor and control the project. The Project Planning tasks ensure that various elements of the Project are coordinated and therefore guide the project execution.

Project Planning helps in:

- Facilitating communication
- Monitoring/measuring the project progress
- Provides overall documentation of assumptions/planning decisions

The Project Planning Phases can be broadly classified as follows:

- Development of the Project Plan
- Execution of the Project Plan
- Change Control and Corrective Actions

Project Planning is an ongoing effort throughout the Project Lifecycle.

Project planning is crucial to the success of the Project.

Caution Careful planning right from the beginning of the project can help to avoid costly mistakes.

It provides an assurance that the project execution will accomplish its goals on schedule and within budget.

Project Planning spans across the various aspects of the Project. Generally Project Planning is considered to be a process of estimating, scheduling and assigning the projects resources in order to deliver an end product of suitable quality. However it is much more as it can assume a very strategic role, which can determine the very success of the project. A Project Plan is one of the crucial steps in Project Planning in General!

Typically Project Planning can include the following types of project Planning:

1. Project Scope Definition and Scope Planning
2. Project Activity Definition and Activity Sequencing
3. Time, Effort and Resource Estimation
4. Risk Factors Identification
5. Cost Estimation and Budgeting
6. Organizational and Resource Planning
7. Schedule Development
8. Quality Planning
9. Risk Management Planning
10. Project Plan Development and Execution
11. Performance Reporting
12. Planning Change Management
13. Project Rollout Planning

We now briefly examine each of the above steps:

1. ***Project Scope Definition and Scope Planning:*** In this step we document the project work that would help us achieve the project goal. We document the assumptions, constraints, user expectations, Business Requirements, Technical requirements, project deliverables, project objectives and everything that defines the final product requirements. This is the foundation for a successful project completion.
2. ***Quality Planning:*** The relevant quality standards are determined for the project. This is an important aspect of Project Planning. Based on the inputs captured in the previous steps such as the Project Scope, Requirements, deliverables, etc. various factors influencing the quality of the final product are determined. The processes required to deliver the Product as promised and as per the standards are defined.
3. ***Project Activity Definition and Activity Sequencing:*** In this step we define all the specific activities that must be performed to deliver the product by producing the various product deliverables. The Project Activity sequencing identifies the interdependence of all the activities defined.
4. ***Time, Effort and Resource Estimation:*** Once the Scope, Activities and Activity interdependence is clearly defined and documented, the next crucial step is to determine the effort required to complete each of the activities. The Effort can be calculated using one of the many techniques available such as Function Points, Lines of Code, Complexity of Code, Benchmarks, etc.

Notes

This step clearly estimates and documents the time, effort and resource required for each activity.

5. ***Risk Factors Identification:*** "Expecting the unexpected and facing it".

   It is important to identify and document the risk factors associated with the project based on the assumptions, constraints, user expectations, specific circumstances, etc.

6. ***Schedule Development:*** The time schedule for the project can be arrived at based on the activities, interdependence and effort required for each of them. The schedule may influence the cost estimates, the cost benefit analysis and so on.

   Project Scheduling is one of the most important task of Project Planning and also the most difficult tasks. In very large projects it is possible that several teams work on developing the project. They may work on it in parallel. However their work may be interdependent.

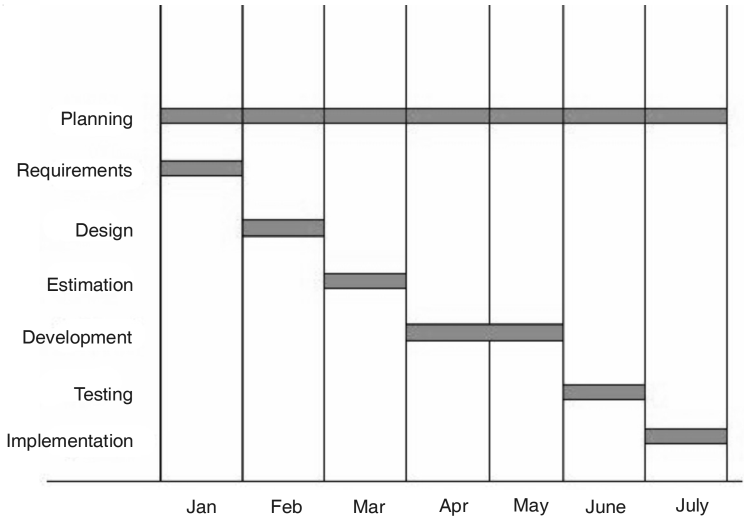
   Again various factors may impact in successfully scheduling a project

   ❖ Teams not directly under our control

   ❖ Resources with not enough experience

   Popular Tools can be used for creating and reporting the schedules such as Gantt Charts

Figure 5.1: Simple Gantt Chart



Source: http://www.exforsys.com/tutorials/testing/software-project-planning.html

7. ***Cost Estimation and Budgeting:*** Based on the information collected in all the previous steps it is possible to estimate the cost involved in executing and implementing the project. A Cost Benefit Analysis can be arrived at for the project. Based on the Cost Estimates Budget allocation is done for the project.

8. ***Organizational and Resource Planning:*** Based on the activities identified, schedule and budget allocation resource types and resources are identified. One of the primary goals of Resource planning is to ensure that the project is run efficiently. This can only be achieved by keeping all the project resources fully utilized as possible.

Did u know? The success depends on the accuracy in predicting the resource demands that will be placed on the project.

Resource planning is an iterative process and necessary to optimize the use of resources throughout the project life cycle thus making the project execution more efficient. There are various types of resources – Equipment, Personnel, Facilities, Money, etc.

9. ***Risk Management Planning:*** Risk Management is a process of identifying, analyzing and responding to a risk. Based on the Risk factors Identified a Risk resolution Plan is created. The plan analyses each of the risk factors and their impact on the project. The possible responses for each of them can be planned. Throughout the lifetime of the project these risk factors are monitored and acted upon as necessary.

10. ***Project Plan Development and Execution:*** Project Plan Development uses the inputs gathered from all the other planning processes such as Scope definition, Activity identification, Activity sequencing, Quality Management Planning, etc. A detailed Work Break down structure comprising of all the activities identified is used. The tasks are scheduled based on the inputs captured in the steps previously described. The Project Plan documents all the assumptions, activities, schedule, timelines and drives the project.

    Each of the Project tasks and activities are periodically monitored. The team and the stakeholders are informed of the progress. This serves as an excellent communication mechanism. Any delays are analyzed and the project plan may be adjusted accordingly

11. ***Performance Reporting:*** As described above the progress of each of the tasks/activities described in the Project plan is monitored. The progress is compared with the schedule and timelines documented in the Project Plan. Various techniques are used to measure and report the project performance such as EVM (Earned Value Management) A wide variety of tools can be used to report the performance of the project such as PERT Charts, GANTT charts, Logical Bar Charts, Histograms, Pie Charts, etc.

12. ***Planning Change Management:*** Analysis of project performance can necessitate that certain aspects of the project be changed. The Requests for Changes need to be analyzed carefully and its impact on the project should be studied. Considering all these aspects the Project Plan may be modified to accommodate this request for Change.

    Change Management is also necessary to accommodate the implementation of the project currently under development in the production environment. When the new product is implemented in the production environment it should not negatively impact the environment or the performance of other applications sharing the same hosting environment.

13. ***Project Rollout Planning:*** In Enterprise environments, the success of the Project depends a great deal on the success of its rollout and implementations. Whenever a Project is rolled out it may affect the technical systems, business systems and sometimes even the way business is run. For an application to be successfully implemented not only the technical environment should be ready but the users should accept it and use it effectively. For this to happen the users may need to be trained on the new system. All this requires planning.

Self Assessment

Fill in the blanks:

1. The …………………… tasks ensure that various elements of the Project are coordinated and therefore guide the project execution.

2. …………………… is an iterative process and necessary to optimize the use of resources throughout the project life cycle.

Notes

5.2 Effort Estimation

Software Cost Estimation is widely considered to be a weak link in software project management. It requires a significant amount of effort to perform it correctly. Errors in Software Cost Estimation can be attributed to a variety of factors. Various studies in the last decade indicated that 3 out of 4 Software projects are not finished on time or within budget or both.

The group of people responsible for creating a software cost estimate can vary with each organization. However the following is possible in most scenarios.

People who are directly involved with the implementation are involved in the estimate.

- Project Manager is responsible for producing realistic cost estimates.
- Project Managers may perform this task on their own or consult with programmers responsible.

Various studies indicate that if the programmers responsible for development are involved in the estimation it was more accurate. The programmers have more motivation to meet the targets if they were involved in the estimation process.

Following scenarios are also possible:

- An independent cost estimation team creates an Estimate.
- Independent Experts are given the Software specification and they create a Software Cost estimate. The Estimation team reviews this and group consensus arrives at a final figure.

5.2.1 Factors Contributing to Inaccurate Estimation

The factors contributing to inaccurate estimation are as follows:

- Scope Creeps, imprecise and drifting requirements.
- New software projects pose new challenges, which may be very different from the past projects.
- Many teams fail to document metrics and lessons learned from past projects.
- Many a times the estimates are forced to match the available time and resources by aggressive leaders.
- Unrealistic estimates may be created by various 'political under currents'.

5.2.2 Impact of Under-estimating

Under-estimating a project can be vary damaging:

- It leads to improper Project Planning
- It can also result in under-staffing and may result in an over worked and burnt out team
- Above all the quality of deliverables may be directly affected due insufficient testing and QA
- Missed Dead lines cause loss of Credibility and goodwill

5.2.3 The Estimation Process

Generally the Software Cost estimation process comprises of 4 main steps:

1. ***Estimate the size of the development product:*** This comprises of various sub-steps or sub tasks. These tasks may have been done already during Requirement Analysis phase. If not

then they should be done as a part of the estimation Process. Important thing is that they should be done to ensure the success of the Estimation Process and the Software Project as a whole.

- Create a detailed Work Break Down Structure. This directly impacts the accuracy of the estimate. This is one of the most important steps. The Work Break down structure should include any and all tasks that are within the scope of the Project, which is being estimated. The most serious handicap is the inability to clearly visualize the steps involved in the Project. Executing a Software Project is not just coding.
- The work Break down structure will include the size and complexity of each software module that can be expressed as number of Lines of Code, Function Points, or any other unit of measure.
- The Work Break down structure should include tasks other than coding such as Software Configuration Management, various levels and types of Testing, Documentation, Communication, User Interaction, Implementation, Knowledge Transition, Support tasks (if any) and so on.
- Clearly indicate or eliminate any gray areas (vague/unclear specifications etc.).
- Also take into account the various Risk Factors and down times. There are many different Risk Factors involved – Technical aspects such as availability of the Environment, Server/Machine uptime, 3rd party Software Hardware failures or Human aspects – Employee Attrition, Sick time, etc. Some of them may seem to be 'overkill' but real world experience shows that these factors affect the time lines of a project. If ignored they may adversely impact the Project timelines and estimates.

2. ***Estimate the effort in Person-hours:*** The Result of various tasks involved in step 1 is an effort estimate in person hours. The effort of various Project tasks expressed in person-hours is also influenced by various factors such as:
   - Experience/Capability of the Team members
   - Technical resources
   - Familiarity with the Development Tools and Technology Platform
3. ***Estimate the Schedule in Calendar Months:*** The Project Planners work closely with the Technical Leads, Project Manager and other stakeholders and create a Project schedule. Tight Schedules may impact the Cost needed to develop the Application.
4. ***Estimate the Project Cost in Dollars (or other Currency):*** Based on the above information the project effort is expressed in dollars or any other currency.

Self Assessment

Fill in the blanks:

3. Software .... Estimation requires a significant amount of effort to perform it correctly.
4. The .... structure should include any and all tasks that are within the scope of the Project, which is being estimated.

5.3 The COCOMO Model

Constructive Cost Model (COCOMO) is a method for assessing the cost of a software package. COCOMO, Constructive Cost Model is static single-variable model. Barry Boehm introduced COCOMO models. There are three levels of COCOMO model basic, immediate and detailed.

Notes

5.3.1 Brief Characteristics of the Model

- *CoCoMo (Constructive Cost Model)* is a combination of parametric estimation equation and weighting method. Based on the estimated instructions (Delivered Source Instructions DSI), the effort is calculated by taking into consideration both the attempted quality and the productivity factors.
- *CoCoMo* is based on the conventional top-down programming and concentrates on the number of instructions.

5.3.2 Levels

- *Basic CoCoMo:* Basic COCOMO model is static single-valued model that computes software development effort (and cost) as a function of program size expressed in estimated lines of code. By means of parametric estimation equations (differentiated according to the different system types) the development effort and the development duration are calculated on the basis of the estimated DSI. The breakdown to phases is realised in percentages. In this connection it is differentiated according to system types (organic-batch, semidetached-on-line, embedded-real-time) and project sizes (small, intermediate, medium, large, very large).
- *Intermediate CoCoMo:* Intermediate COCOMO model computes software development effort as a function of program size and a set of "cost drivers" that include subjective assessments of product, hardware, personnel, and project attributes. The estimation equations are now taking into consideration (apart from DSI) 15 influence factors; these are product attributes (like software reliability, size of the database, complexity), computer attributes (like computing time restriction, main memory restriction), personnel attributes (like programming and application experience, knowledge of the programming language), and project attributes (like software development environment, pressure of development time).

Did u know? The degree of influence can be classified as very low, low, normal, high, very high, extra high; the multipliers can be read from the available tables.

- *Detailed CoCoMo:* Advanced COCOMO model incorporates all characteristics of the intermediate version with an assessment of the cost driver's impact on each step, like analysis, design, etc. In this case the breakdown to phases is not realised in percentages but by means of influence factors allocated to the phases. At the same time, it is differentiated according to the three levels of the product hierarchy (module, subsystem, system); product-related influence factors are now taken into consideration in the corresponding estimation equations.

5.3.3 Appraisal of the Model

Applications of CoCoMo

- *Medium and Large Projects:* For small projects, the attempt for an estimation according to intermediate and detailed CoCoMo is too high; but the results from basic CoCoMo alone are not sufficiently exact.
- *Technical Application:* For software projects developing commercial applications, CoCoMo usually comes up with overstated effort estimation values therefore CoCoMo is only

applied for the development of technical software. This circumstance is due to the fact that the ratio DSI and man months implemented in the CoCoMo estimation equation fits the efficiency rate in a technical development; with regard to commercial software development a higher productivity rate DSI/man-month can be assumed.

Strong and Weak Points of the Model and Possible Remedial Measures

- ***Estimation Base "Delivered Source Instructions":*** By means of estimation base instructions (DSI) it was attempted to diminish the great uncertainties and problems in connection with the traditional estimation base LOC. However, some problems remain: the ambiguity of a DSI estimation and for the development effort the DSI are-based on modern software engineering methods-no longer of great importance since the effort increasingly occurs during the early activities and DSI will only be effective towards the end of the development process; DSI as well as LOC depends on the selected programming language (an Ada adoption to CoCoMo is already available, however). A remedy can be achieved by the weighting of instructions according to their various types compiler, data description, transformation, control, and I/O instruction, data description instructions (differentiated according to integration degree, message/data object, modification degree) and processing instructions (differentiated according to batch/online, modification degree, complexity, language).

- ***Macro and Micro Estimation:*** By means of the different levels of the model, CoCoMo makes it possible to realise both a macro estimation by means of Basic CoCoMo and a micro estimation by means of Intermediate CoCoMo and Detailed CoCoMo. The micro estimation allows the effort allocation to activities and functional units. However, method CoCoMo is not only based on a software life cycle deviating from the V-Model but also on another system structure. Therefore, in order to list individual efforts for sub-models, (sub-)activities, and (sub-)products, it is necessary to adjust these items of method CoCoMo to the V-Model concept.

- ***Influence Factors/Objectivity:*** In the effort estimation, CoCoMo takes into consideration the characteristics of the project, the product, and the personnel as well as of the technology. In order to achieve an objective evaluation of these influence factors, CoCoMo offers exact definitions. The quantification of influence factors represents a certain problem, though which has a strong impact on the quality of the estimation method and on the required DSI information.

- ***Range of Application:*** By differentiating the estimation equations according to project sizes and system types, the range of application for method CoCoMo is a wide one. It is also one of the few estimation methods offering-apart from the support for development projects-support for the effort estimation of SWMM tasks as well (also by parametric estimation equations) as for the estimation of the project duration.

- ***Tool Support:*** Computer-based support is required for Intermediate and Detailed CoCoMo, based on the quantity problem (differentiation of influence factors on phases and sub-products).

5.3.4 Modes

COCOMO can be applied to the following Software Project's Categories:

- ***Organic Mode:*** These projects are very easy and have small team size. The team has a good application experience work to a set of less than inflexible/rigid requirements.

Notes

Example: A thermal analysis program developed for a heat transfer group is an example of this.

- ***Semi-detached Mode:*** These are intermediate in size and complexity. Here the team has mixed experience to meet up a mix of rigid and less than rigid requirements.

Example: A transaction processing system with fixed requirements for terminal hardware and database software is an example of this.

- ***Embedded Mode:*** Software projects that must be developed within a set of tight hardware, software, and operational constraints.

Example: Flight control software for aircraft.

Task Compare and contrast organic mode and embedded mode.

Self Assessment

Fill in the blanks:

5. …………………… is a method for assessing the cost of a software package.

6. *CoCoMo* is based on the conventional …………………… programming and concentrates on the number of instructions.

5.4 Project Scheduling and Staffing

Following the definition of project activities, the activities are associated with time to create a project schedule. The project schedule provides a graphical representation of predicted tasks, milestones, dependencies, resource requirements, task duration, and deadlines. The project's master schedule interrelates all tasks on a common time scale. The project schedule should be detailed enough to show each WBS task to be performed, the name of the person responsible for completing the task, the start and end date of each task, and the expected duration of the task.

The basic concepts of project scheduling and tracking are given as under:

5.4.1 Comments on "Lateness"

Assume that a software development group has been asked to build a real-time controller for a medical diagnostic instrument that is to be introduced to the market in nine months. After careful estimation and risk analysis, the software project manager comes to the conclusion that the software, as requested, will require 14 calendar months to create with available staff. How does the project manager proceed?

It is unrealistic to march into the customer's office (in this case the likely customer is marketing/sales) and demand that the delivery date be changed. External market pressures have dictated the date, and the product must be released. It is equally foolhardy to refuse to undertake the work (from a career standpoint). So, what to do?

The following steps are recommended in this situation:

- Perform a detailed estimate using historical data from past projects. Determine the estimated effort and duration for the project.

- Using an incremental process model, develop a software engineering strategy that will deliver critical functionality by the imposed deadline, but delay other functionality until later. Document the plan.
- Meet with the customer and (using the detailed estimate) explain why the imposed deadline is unrealistic.

Notes Be certain to note that all estimates are based on performance on past projects. Also be certain to indicate the percent improvement that would be required to achieve the deadline as it currently exists.

- Offer the incremental development strategy as an alternative.
- You have a few options, and like you to make a decision based on them. First, we can increase the budget and bring on additional resources so that you have a shot at getting this job done in nine months. But understand that this will increase risk of poor quality due to the tight timeline. Second, you can remove a number of the software functions and capabilities that you're requesting. This will make the preliminary version of the product somewhat less functional, but we can announce all functionality and then deliver over the 14 month period. Third, we can dispense with reality and wish the project complete in nine months. You wind up with nothing that can be delivered to a customer.

5.4.2 Basic Principles

The reality of a technical project (whether it involves building a hydroelectric plant or developing an operating system) is that hundreds of small tasks must occur to accomplish a larger goal. Some of these tasks lie outside the mainstream and may be completed without worry about impact on project completion date. Other tasks lie on the "critical" path. If these "critical" tasks fall behind schedule, the completion date of the entire project is put into jeopardy.

The project manager's objective is to define all project tasks, build a network that depicts their interdependencies, identify the tasks that are critical within the network, and then track their progress to ensure that delay is recognized "one day at a time." To accomplish this, the manager must have a schedule that has been defined at a degree of resolution that enables the manager to monitor progress and control the project.

Software project scheduling is an activity that distributes estimated effort across the planned project duration by allocating the effort to specific software engineering tasks.

It is important to note, however, that the schedule evolves over time. During early stages of project planning, a macroscopic schedule is developed. This type of schedule identifies all major software engineering activities and the product functions to which they are applied. As the project gets under way, each entry on the macroscopic schedule is refined into a detailed schedule. Here, specific software tasks (required to accomplish an activity) are identified and scheduled.

Scheduling for software engineering projects can be viewed from two rather different perspectives. In the first, an end-date for release of a computer-based system has already (and irrevocably) been established. The software organization is constrained to distribute effort within the prescribed time frame. The second view of software scheduling assumes that rough chronological bounds have been discussed but that the end-date is set by the software engineering organization. Effort is distributed to make best use of resources and an end-date is defined after careful analysis of the software. Unfortunately, the first situation is encountered far more frequently than the second.

Notes

Like all other areas of software engineering, a number of basic principles guide software project scheduling:

- ***Compartmentalization:*** The project must be compartmentalized into a number of manageable activities and tasks. To accomplish compartmentalization, both the product and the process are decomposed.
- ***Interdependency:*** The interdependency of each compartmentalized activity or task must be determined. Some tasks must occur in sequence while others can occur in parallel. Some activities cannot commence until the work product produced by another is available. Other activities can occur independently.
- ***Time Allocation:*** Each task to be scheduled must be allocated some number of work units (e.g., person-days of effort). In addition, each task must be assigned a start date and a completion date that are a function of the interdependencies and whether work will be conducted on a full-time or part-time basis.
- ***Effort Validation:*** Every project has a defined number of staff members. As time allocation occurs, the project manager must ensure that no more than the allocated number of people being scheduled at any given time.

Example: Consider a project that has three assigned staff members (e.g., 3 person-days are available per day of assigned effort). On a given day, seven concurrent tasks must be accomplished. Each task requires 0.50 person days of effort. More effort has been allocated than there are people to do the work.

- ***Defined Responsibilities:*** Every task that is scheduled should be assigned to a specific team member.
- ***Defined Outcomes:*** Every task that is scheduled should have a defined outcome. For software projects, the outcome is normally a work product (e.g., the design of a module) or a part of a work product. Work products are often combined in deliverables.
- ***Defined Milestones:*** Every task or group of tasks should be associated with a project milestone. A milestone is accomplished when one or more work products has been reviewed for quality and has been approved.

Each of these principles is applied as the project schedule evolves.

5.4.3 Project Staffing

All the management activities that involve filling and keeping filled the positions that were established in the project organizational structure by well-qualified personnel.

Major Issues in Staffing

The major issues in staffing for a software engineering project are as follows:

- Project managers are frequently selected for their ability to program or perform engineering tasks rather than their ability to manage (few engineers make good managers).
- The productivity of programmers, analysts, and software engineers varies greatly from individual to individuals.
- There is a high turnover of staff on software projects especially those organized under a matrix organization.

- Universities are not producing a sufficient number of computer science graduates who understand the software engineering process or project management.
- Training plans for individual software developers are not developed or maintained.

Staffing Activities for Software Projects

Table 5.1 shows the Staffing Activities for Software Projects.

Table 5.1: Staffing Activities for Software Projects

Activity	Definition or Explanation
Fill organizational positions	Select, recruit, or promote qualified people for each project position.
Assimilate newly assigned personnel	Orient and familiarize new people with the organization, facilities, and tasks to be done on the project.
Educate or train personnel	Make up deficiencies in position qualifications through training and education.
Provide for general development	Improve knowledge, attitudes, and skills of project personnel.
Evaluate and appraise personnel	Record and analyze the quantity and quality of project work as the basis for personnel evaluations. Set performance goals and appraise personnel periodically.
Compensate	Provide wages, bonuses, benefits, or other financial remuneration commensurate with project responsibilities and performance.

Factors to Consider when Staffing

- *Education:* Does the candidate have the minimum level of education for the job? Does the candidate have the proper education for future growth in the company?
- *Experience:* Does the candidate have an acceptable level of experience? Is it the right type and variety of experience?
- *Training:* Is the candidate trained in the language, methodology, and equipment to be used, and the application area of the software system?
- *Motivation:* Is the candidate motivated to do the job, work for the project, work for the company, and take on the assignment?
- *Commitment:* Will the candidate demonstrate loyalty to the project, to the company, and to the decisions made?
- *Self-motivation:* Is the candidate a self-starter, willing to carry a task through to the end without excessive direction?
- *Group Affinity:* Does the candidate fit in with the current staff? Are there potential conflicts that need to be resolved?
- *Intelligence:* Does the candidate have the capability to learn, to take difficult assignments, and adapt to changing environments?

Sources of Qualified Project Individuals

- Transferring personnel from within the project itself, from task to another task.

Notes

- Transfers from other projects within the organization, when other project has ended or is being cancelled.
- New hires from other companies through such methods as job fairs, referrals, headhunters, want ads, and unsolicited resumes.
- New college graduates can be recruited either through interviews on campus or through referrals from recent graduates who are now company employees.
- If the project manager is unable to obtain qualified individuals to fill positions, one option is to hire unqualified but motivated individuals and train them for those vacancies.

Self Assessment

Fill in the blanks:

7. The project ……………………. provides a graphical representation of predicted tasks, milestones, dependencies, resource requirements, task duration, and deadlines.

8. The objective of ……………………. is to define all project tasks, build a network that depicts their interdependencies, etc.

5.5 Introduction to Software Configuration Management

Different people defined SCM differently. The following are the some software configuration management definitions:

- Software Configuration Management is the art of identifying, organizing, and controlling modifications to the software being built by a programming team. The goal of is to maximize productivity by minimizing mistakes.
- Software Configuration Management is the process of defining and implementing a standard configuration that results into the primary benefits such as easier step-up and maintenance, less down time, better integration with enterprise management, and more efficient and reliable backups.
- Software Configuration Management is the process concerned with the development of procedures and standards for managing an evolving software system product.
- Software Configuration Management is the ability to control and manage change in a software project.
- Software Configuration Management is a set of procedures meant to identify, control, provide and log the various work products of software project.
- In the simplest sense, Software Configuration Management is the process of controlling baseline software documents and code.

5.5.1 Baselines

In accordance of IEEE Standards 729, a baseline is “a specification or product that has been formally reviewed and agreed upon, that thereafter serves as the basis for further development, and that can be changed only through formal change control procedures.”

The baseline uses the shared project database. It is an SCM task to maintain the integrity of the set of artifacts. An approach to the integrity issue is to require approval for adding items to the baseline. A second part to maintaining integrity is dealing with modifications to items in the database.

Notes

The following are the some typical Software Configuration Items (SCIs) that are identified approved, made into baselines and then stored in the project database.

- Requirements
  - User defined requirements
  - System requirements
- Project Management Plan
  - Work packages
  - Schedule
  - Budget
  - Risk management plan
- User Manuals
  - User primer guide
  - Operations manual
  - User troubleshooting
- Design
  - Prototype design
  - Data structure design
  - Module design
  - Machine interface design
  - User interface design
  - Object design
- Source Code
  - File and data structure declarations
  - Subsystem 1 modules
  - Subsystem 2 modules
- Test Materials
  - Procedures
  - Cases
  - Data
  - Results
- Operational System
  - Subsystem 1 executable version
  - Subsystem 2 executable version
- Documents
  - Documents not previously listed.

Notes

5.5.2 Software Configuration Items

Software configuration items that comprise all information produced as part of the software engineering process are called a software configuration. Artifacts produced during the process are called Software Configuration Items (SCIs).

Example: Software configuration items are:

- Management plans (Project Plan, Test Plan, etc.)
- Specification (Requirements, Design, Test Case, etc.)
- Customer documentation (Implementation Manual, User Manuals, Operations Manuals, On-Line help files)
- Source code (PL/I Fortran, COBOL, Visual Basic, Visual C, etc.)
- Executable code (Machine readable object code, exe's, etc.)
- Libraries (Runtime Libraries, Procedures, API's DLL's, etc.)
- Database (Data being Processed, Data a program requires, test data, Regression test data, etc.)
- Production documentation.

5.5.3 The SCM Process

The procedures for software configuration management are laid down in the form of a SCM plan document. Sample structure of a configuration management plan is provided in Table 5.2.

Table 5.2: Software Configuration Management Plan

Introduction

- Purpose
- Scope
- Definitions and acronym
- References

Management

- Organizations
- Configuration Management Responsibilities
- Interface Control
- Implementation of Software Configuration Management Plan
- Applicable policies, Directives and Procedures

Configuration Management Activities

- Configuration Identification
- Configuration Control
- Configuration Status Accounting
- Audits and Reviews

Tools, Techniques and Methodologies

Supplier Control

Records Collection and Retention

5.5.4 Identification of Objects in the Software Configuration

Notes

The following are the major objectives of software configuration standards:

- Remote system administration
- Reduced user down-time
- Reliable data backups
- Easy workstation set-up
- Multi-user support
- Remote software installation

Remote System Administration

- The configuration standard should include necessary software and/or privileges for remote system administration tools.
- A remote administration client that is correctly and configured on the client side is the cornerstone of the remotely administered network.
- These remote tools can be used to check the version of virus protection, check machine configuration or offer remote help-desk functionality.

Reduced User Downtime

- A great advantage of using a standard configuration is that systems become completely interchangeable resulting in reduced user down time.
- If a given system experiences an unrecoverable error, an identical new system can be dropped into place.
- User data can be transferred if the non-functional machine is still accessible, or the most recent copy can be pulled off of the backup tape with the ultimate global being that the user experiences little change in the system interface.

Reliable Data Backups

- Using a standard directory for user data allows backup systems to selectively back up a small portion of a machine, greatly reducing the network traffic and tape usage for backup systems. Also, should a catastrophic failure occur the data directory could be restored to a new machine with little time and effort.
- A divided directory structure, between system and user data, is one of the main goals of the configuration standard.

Easy Workstation Set-up

- Any sort of standardized configuration streamlines the process of setting up the system and insures that vital components are available.
- If multiple machines are being set-up according to a standard set-up most of the set-up and configuration can be automated.

Multi-User Support

- Although it is not common for users to share a workstation, the system configuration is designed to allow multiple users the same workstation without interfacing with each other's work.
- Some software packages do not support completely independent settings for all users; however, users can have independent data areas.
- The directory structure implemented does not impose limits on the number of independent users a system can have.

Remote Software Installation

- Most modern software packages are installed in factory pre-defined directories. While software installed in this manner will function correctly for a single user, it will lead to non-uniform configuration among a collection of machines.
- A good configuration standard will have software installed in specified directory areas to logically divide software on the disk.
- This will lead to easier identification of installed components and the possibility of automating installation procedures through the use of universal scripts.
- With software installed into specific directories, maintenance and upgrading running software becomes less complex.

Self Assessment

Fill in the blanks:

9. …………………… is the process concerned with the development of procedures and standards for managing an evolving software system product.

10. Artifacts produced during the process are called …………………….

5.6 Quality Plan

According to Juran, there remains need for quality as it involves "fitness for use as seen by the user" (or, rather, something like "approximate fitness for use as seen by a big enough group of users"). Put at its most simple, we define service quality management as the processes and systems used to monitor and manage the service provided by a company. We see it as part of an operator's OSS (Operational Support System).

> *Notes* An OSS is net of computerised systems that support the business and operational processes peculiar to the online business industry.

The purpose of the Software Quality Plan is to define the techniques, procedures, and methodologies that will be used to assure timely delivery of the software and that the development system meets the specified requirements within project resources.

Software Quality Assurance is a process for evaluating and documenting the quality of the work products produced during each stage of the software development lifecycle. The primary objective of the SQA process is to ensure the production of high-quality work products according to stated requirements and established standards. The list of SQA process objectives could be expanded with formulating quality management approach, effective software engineering technology (its tools and methods), dealing with multi testing strategy, controlling of software documentation and its changes, as well as defining measurement and reporting mechanisms.

Quality plan discusses the procedures and software engineering processes which are covered by quality assurance controls such as:

- Monitoring quality assurance of the management team throughout the software
- engineering process
- Development and documentation of software development, evaluation and acceptance standards and conventions
- Verifying the test results
- Tracking problem solving and corrective actions needed as a result of testing

Self Assessment

Fill in the blanks:

11. The purpose of the Software .... is to define the techniques, procedures, and methodologies that will be used to assure timely delivery of the software.

12. .... is a process for evaluating and documenting the quality of the work products produced during each stage of the software development lifecycle.

5.7 Risk Management

In risk management, a prioritization process is followed whereby the risks with the greatest loss and the greatest probability of occurring are handled first, and risks with lower probability of occurrence and lower loss are handled in descending order. In practice the process can be very difficult, and balancing between risks with a high probability of occurrence but lower loss versus a risk with high loss but lower probability of occurrence can often be mishandled.

Intangible risk management identifies a new type of a risk that has a 100% probability of occurring but is ignored by the organization due to a lack of identification ability.

Example: When deficient knowledge is applied to a situation, a knowledge risk materialises.

Relationship risk appears when ineffective collaboration occurs. Process-engagement risk may be an issue when ineffective operational procedures are applied. These risks directly reduce the productivity of knowledge workers, decrease cost effectiveness, profitability, service, quality, reputation, brand value, and earnings quality. Intangible risk management allows risk management to create immediate value from the identification and reduction of risks that reduce productivity.

Risk management also faces difficulties allocating resources. This is the idea of opportunity cost. Resources spent on risk management could have been spent on more profitable activities. Again, ideal risk management minimizes spending while maximizing the reduction of the negative effects of risks.

The term risk is defined as the potential future harm that may arise due to some present actions. Risk management in software engineering is related to the various future harms that could be possible on the software due to some minor or non-noticeable mistakes in software development project or process. "Software projects have a high probability of failure so effective software development means dealing with risks adequately (www.thedacs.com)." Risk management is the most important issue involved in the software project development. This issue is generally managed by Software Project Management (SPM). During the life cycle of software projects, various risks are associated with them. These risks in the software project is identified and managed by software risk management which is a part of SPM. Some of the important aspects of risk management in software engineering are software risk management, risk classification and strategies for risk management.

5.7.1 Software Risk Management

Since there could be various risks associated with the software development projects, the key to identify and manage those risks is to know about the concepts of software risk management. Many concepts about software risk management could be identified but the most important are risk index, risk analysis, and risk assessment.

1. ***Risk Index:*** Generally risks are categorized into two factors namely impact of risk events and probability of occurrence. Risk index is the multiplication of impact and probability of occurrence. Risk index can be characterized as high, medium, or low depending upon the product of impact and occurrence. Risk index is very important and necessary for prioritization of risk.
2. ***Risk Analysis:*** There are quite different types of risk analysis that can be used. Basically, risk analysis is used to identify the high risk elements of a project in software engineering. Also, it provides ways of detailing the impact of risk mitigation strategies. Risk analysis has also been found to be most important in the software design phase to evaluate criticality of the system, where risks are analyzed and necessary counter measures are introduce. The main purpose of risk analysis is to understand risks in better ways and to verify and correct attributes. A successful risk analysis includes important elements like problem definition, problem formulation, data collection.
3. ***Risk Assessment:*** Risk assessment is another important case that integrates risk management and risk analysis. There are many risk assessment methodologies that focus on different types of risks. Risk assessment requires correct explanations of the target system and all security features. It is important that a risk referent levels like performance, cost, support and schedule must be defined properly for risk assessment to be useful.

Task Analyse the importance of risk analysis and risk assessment.

5.7.2 Risk Classification

The key purpose of classifying risk is to get a collective viewpoint on a group of factors. These are the types of factors which will help project managers to identify the group that contributes the maximum risk. A best and most scientific way of approaching risks is to classify them based on risk attributes. Risk classification is considered as an economical way of analyzing risks and their causes by grouping similar risks together into classes (Hoodat, H. & Rashidi, H.). Software risks could be classified as internal or external. Those risks that come from risk factors within the organization are called internal risks whereas the external risks come from out of the organization and are difficult to control. Internal risks are project risks, process risks, and product risks. External risks are generally business with the vendor, technical risks, customers' satisfaction, political stability and so on. In general, there are many risks in the software engineering which is very difficult or impossible to identify all of them. Some of most important risks in software engineering project are categorized as software requirement risks, software cost risks, software scheduling risk, software quality risks, and software business risks. These risks are explained in detail below:

5.7.3 Strategies for Risk Management

During the software development process various strategies for risk management could be identified and defined according to the amount of risk influence. Based upon the amount of risk influence in software development project, risk strategies could be divided into three classes namely careful, typical, and flexible. Generally, careful risk management strategy is projected for new and inexperienced organizations whose software development projects are connected with new and unproven technology; typical risk management strategy is well-defined as a support for mature organizations with experience in software development projects and used technologies, but whose projects carry a decent number of risks; and flexible risk management strategy is involved in experienced software development organizations whose software development projects are officially defined and based on proven technologies.

In this way, software risk management, risks classification, and strategies for risk management are clearly described in this paper. If risk management process is in place for each and every software development process then future problems could be minimized or completely eradicated. Hence, understanding various factors under risk management process and focusing on risk management strategies explained above could help in building risk free products in future.

Self Assessment

Fill in the blanks:

13. .... risk management identifies a new type of a risk that has a 100% probability of occurring but is ignored by the organization due to a lack of identification ability.

14. .... is the multiplication of impact and probability of occurrence.

5.8 Project Monitoring

Somebody says that person X is a very good planner but his/her execution policies are very poor then it will make her/his a bad manager. A good plan is useless unless it is properly executed. Consequently, the major management activity during the project is to ensure that the plan is properly executed, and when needed, to modify plans appropriately. Project assessment will be straightforward if everything went according to plan and no changes occurred in the requirements. However, on large projects, deviations from the original plan and changes to requirements are both to be expected. In these cases, the plan should be modified. Modifications are also needed as more information about the project becomes available or due to personnel turnover.

The project control phase of the management activity is the longest. For this kind of routine management activity, lasting for a long period of time, proper project monitoring can play a significant role in aiding project management. However, all the methods, that the management intends to use to monitor the project, should be planned before during the planning phase, so that management is prepared to handle the changes and deviations from the plan and can respond quickly. In this section, we will discuss some methods for monitoring a project.

Notes

5.8.1 Time Sheets

Once project development commences, the management has to track the progress of the project and the expenditure incurred on the project. Progress can be monitored by using the schedule and milestones laid down in the plan. The earned value method can also be used.

The most common method of keeping track of expenditures is by the use of a time sheet. The time sheet records how much time different project members are spending on the different identified activities in the project.

The time sheet is a common mechanism for collecting raw data. Time sheets can be filled daily or weekly. The data obtained from the time sheets can be used to obtain information regarding the overall expenditure and its breakup among different tasks and different phases at any given time.

Example: The effort distribution with phases in a particular organization can be obtained from the time sheets.

Caution By assigning codes to projects, tasks within a project, and the nature of the work being done, time sheet processing can easily be automated.

5.8.2 Reviews

We discussed reviews at some length in an earlier section. We will not go into details of reviews here; we'll just comment on a few points regarding the monitoring aspect of reviews. As mentioned earlier, one of the purposes of reviews is to provide information for project control. Reviews provide a definite and clearly defined milestone. It forces the author of a product to complete the product before the review. Having this goal gives some impetus and motivation to complete the product. For monitoring, as we have discussed, reviews can provide a wealth of information.

First, the review schedules can be used to determine how the project is progressing compared to its planned schedule. Then, the review reports indicate in which parts of the project the programmers/analysts are having difficulty. With this information, corrective action, such as replacing a junior person with a senior person, can be taken. In addition, review reports provide insight into the quality of the software being produced and the types of errors being detected.

5.8.3 Cost-Schedule-Milestone Graph

A cost-schedule-milestone graph represents the planned cost of different milestones. It also shows the actual cost of achieving the milestones gained so far. By having both the planned cost versus milestones and the actual cost versus milestones on the same graph, the progress of the project can be grasped easily.

The x-axis of this graph is time, where the months in the project schedule are marked. The y-axis represents the cost, in dollars or PMs. Two curves are drawn. One curve is the planned cost and planned schedule, in which each important milestone of the project is marked. This curve can be completed after the project plan is made. The second curve represents the actual cost and actual schedule, and the actual achievement of the milestones is marked. Thus, for each milestone, the point representing the time when the milestone is actually achieved and the actual cost of achieving it are marked.

Example: A cost-schedule-milestone graph for the example is shown in Figure 5.2.

Figure 5.2: A Cost-schedule Milestone Graph

The chart shown in Figure 5.2 is for a hypothetical project whose cost is estimated to be $100K. Different milestones have been identified and a curve is drawn with these milestones. The milestones in this project are PDR (preliminary design review), CDR (critical design review), Module 1 completion, Module 2 completion, integration testing, and acceptance testing. For each of these milestones some budget has been allocated based on the estimates. The planned budget is shown by a dotted line. The actual expenditure is shown with a bold line. This chart shows that only two milestones have been achieved, PDR and CDR, and though the project was within budget when PDR was complete, it is now slightly over budget.

5.8.4 Earned Value Method

The system design usually involves a small group of (senior) people. Having a large number of people at the system design stage is likely to result in a not-very-cohesive design. After the system design is complete, a large number of programmers whose job is to do the detailed design, coding, and testing may enter the project. During these activities, proper monitoring of people, progress of the different components, and progress of the overall project are important.

An effective method of monitoring the progress of a project (particularly, the phases after system design) is the earned value method. The earned value method uses a Summary Task Planning Sheet (STPS). The STPS is essentially a Gantt chart, with each task (relating to an independently assignable module) having an entry in the chart. Each task has the following milestones marked in STPS: detailed design, coding, testing, and integration.

Each milestone of a task is assigned an earned value, which is the value (in dollars or person-months) that will be “earned” on completion of this milestone. The sum of the assigned values for all the milestones for a task is equal to the total cost assigned to this task (or the total estimated effort required for this task).

At any given time, the total effort (or cost) spent on a particular task can be determined from the time sheets. The total value earned can be determined by adding the earned value of all the completed milestones of that task. By comparing the earned value with the total cost spent, the project manager can determine how far the project is deviating from the initial estimates and then take the necessary actions.

It should be pointed out that, in general, the earned value will be somewhat less than the actual effort spent on a task, because this method only attaches value to the completed milestones. The work in progress does not get adequately represented in the earned value.

The STPS usually has much more detail than is needed by project management. The earned value aspect can be summarized in an earned value summary report. This report summarizes the earned value for each task, the actual effort spent on that task, and how these compare for a given point in time. The summary report can be produced monthly or biweekly.

Self Assessment

Fill in the blanks:

15. The …………………… records how much time different project members are spending on the different identified activities in the project.

16. …………………… provide a definite and clearly defined milestone.

Case Study

An Industrial Case Study of Implementing Software Risk Management

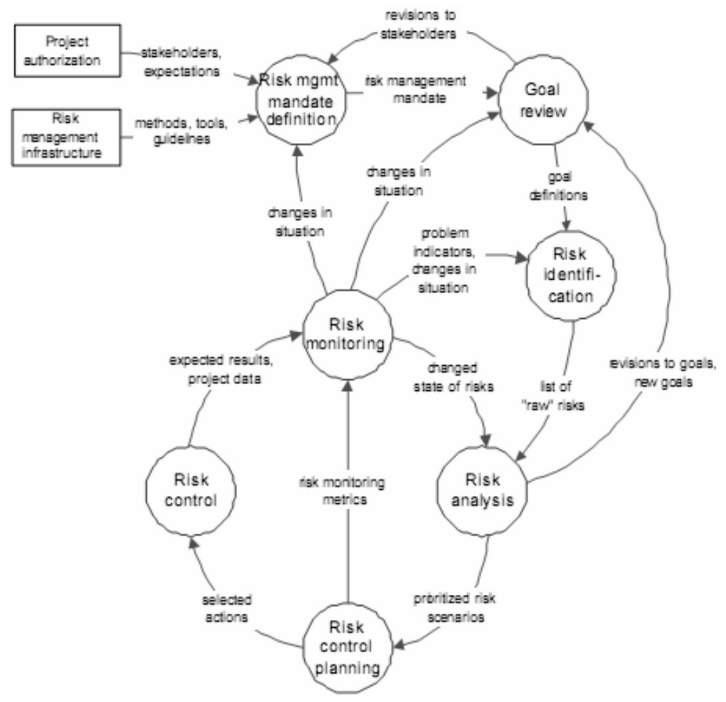
Explicit risk management is gaining ground in industrial software development projects. However, there are few empirical studies that investigate the transfer of explicit risk management into industry, the adequacy of the risk management approaches to the constraints of industrial contexts, or their cost-benefit.

The objective of the case study was (1) to analyze the usefulness and adequacy of the Riskit method and (2) to analyze the cost-benefit of the Riskit method in this industrial context.

The Risk Management Method

The risk management method transferred in this case study is called Riskit. Riskit is a comprehensive risk management method that is based on sound theoretical principles, yet it has been designed to have sufficiently low overhead and complexity so that it can be used in real, time-constrained projects.

Figure 1: Overview on Riskit Process

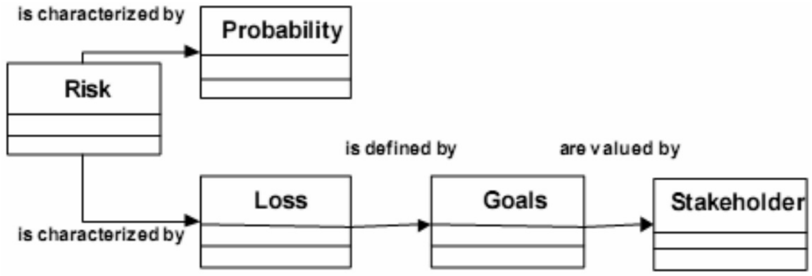


Contd...

Because of its more solid theoretical foundations, it avoids many of the limitations and problems that are common to many other risk management approaches in software engineering, such as use of biased ranking tables and expected value calculations. As Riskit has been extensively presented in other publications, we present here only the principles of the method and the features that distinguish it from other risk management approaches. Riskit contains a fully defined process, whose overview is presented in Figure 1 as a dataflow diagram. The full definition of the Riskit process is available as a separate report.

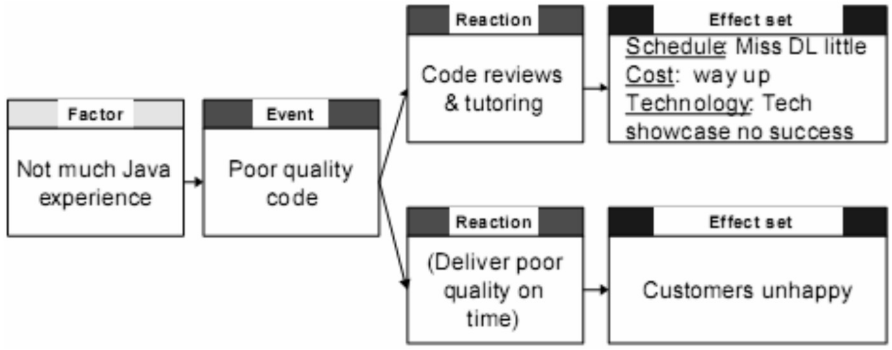
The Riskit process includes a specific step for analyzing stakeholder interests and how they link to risks. These links are visualized in Figure 2: when risks are defined, their impact on the project is described through the stated project goals. This allows full traceability between risks and goals and on to stakeholders: each risk can be described by its potential impact on the agreed project goals, and each stakeholder can use this information to rank risks from his perspective.

Figure 2: Definition of Risk within Riskit



In order to describe risks during Risk analysis, the Riskit method supports unambiguous definition of risks using the Riskit analysis graph (also called risk scenario) as a visual formalism. The Riskit analysis graph can be seen both as a conceptual template for defining risks as well as a well-defined graphical modeling formalism. An example Riskit analysis graph is presented in Figure 3. The Riskit analysis graph allows visual yet more formal documentation of risks, resulting in better communications and a comprehensive understanding of the risks' context.

Figure 3: Example of the Riskit Analysis Graph (Risk Scenarios)

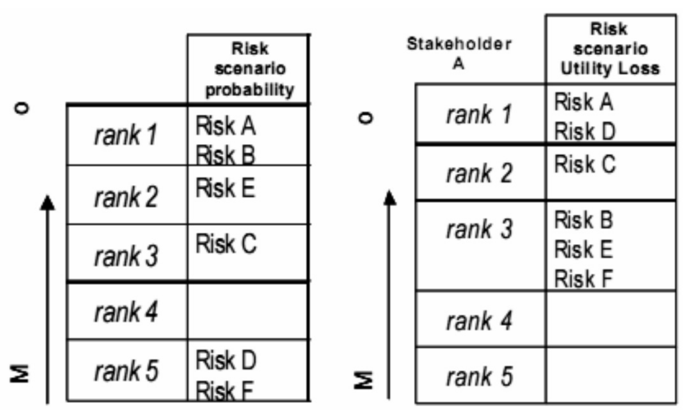


In order to prioritize risks during Risk analysis, the most important risks have to be selected based on their probability and loss. To perform this prioritization, most risk management approaches rely on risk estimation approaches that are either impractical or

Contd...

theoretically questionable. For example, the expected value calculations (i.e., risk = probability * loss) are often impractical because accurate estimates of probability and loss are seldom available and it is difficult to account for multiple goal effects and for a non-linear utility function. Riskit largely avoids these problems by using ranking techniques that are appropriate for the type of information available. When ratio or distance scale data are available for probability and loss, expected utility loss calculations are used. However, often only ordinal scale metrics are available for probability or utility loss. For example, the risk scenarios might be ranked in terms of probability and utility loss each as shown in Figure 4.

Figure 4: Ordinal Metrics for Probability and Loss

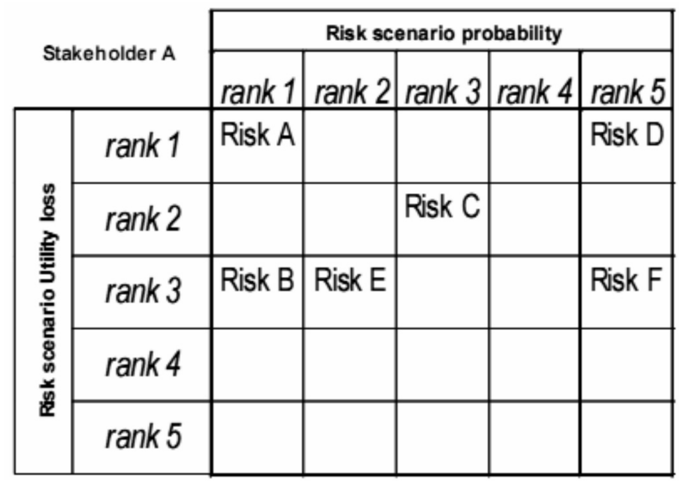


	Risk scenario probability
rank 1	Risk A Risk B
rank 2	Risk E
rank 3	Risk C
rank 4	
rank 5	Risk D Risk F

Stakeholder A	Risk scenario Utility Loss
rank 1	Risk A Risk D
rank 2	Risk C
rank 3	Risk B Risk E Risk F
rank 4	
rank 5	

To select in this case the most important risks based on the combination of probability and utility loss, a specific Riskit Pareto ranking technique is used. This technique uses a two-dimensional space to position risk scenarios by their relative probability and utility loss as shown in Figure 5. Using this technique, the evaluation of the risks is then based on utility theory. The value of this Riskit Pareto ranking technique is that it provides a reliable and consistent ranking approach that only ranks risks as far as the input data allows.

Figure 5: Example of Riskit Pareto Table



Stakeholder A		Risk scenario probability				
		rank 1	rank 2	rank 3	rank 4	rank 5
Risk scenario Utility loss	rank 1	Risk A				Risk D
	rank 2			Risk C		
	rank 3	Risk B	Risk E			Risk F
	rank 4					
	rank 5					

Source: http://mridulasharma.com/wp-content/uploads/2013/01/Assignment-1-Case-Study.pdf

5.9 Summary

- The project plan reflects the current status of all project activities and is used to monitor and control the project.
- Software Cost Estimation is widely considered to be a weak link in software project management. It requires a significant amount of effort to perform it correctly.
- Constructive Cost Model (COCOMO) is a method for assessing the cost of a software package.
- The project schedule provides a graphical representation of predicted tasks, milestones, dependencies, resource requirements, task duration, and deadlines.
- Software project scheduling is an activity that distributes estimated effort across the planned project duration by allocating the effort to specific software engineering tasks.
- Software Configuration Management is the art of identifying, organizing, and controlling modifications to the software being built by a programming team.
- Software configuration items that comprise all information produced as part of the software engineering process are called a software configuration.
- The purpose of the Software Quality Plan is to define the techniques, procedures, and methodologies that will be used to assure timely delivery of the software and that the development system meets the specified requirements within project resources.
- In risk management, a prioritization process is followed whereby the risks with the greatest loss and the greatest probability of occurring are handled first, and risks with lower probability of occurrence and lower loss are handled in descending order.

5.10 Keywords

COCOMO: Constructive Cost Model (COCOMO) is a method for assessing the cost of a software package.

Earned Value: Earned Value (EV) is a management tool for tracking and communicating a project's status.

Estimation: Estimation is the process of finding an estimate, or approximation, which is a value that is usable for some purpose even if input data may be incomplete, uncertain, or unstable.

Project Planning: Project planning is a common thread that intertwines all the activities from conception to commissioning and handing over the clockwork to clients.

Scheduling: Scheduling is the method by which threads, processes or data flows are given access to system resources (e.g. processor time, communications bandwidth). This is usually done to load balance a system effectively or achieve a target quality of service.

Software Configuration Management: Software Configuration Management is the ability to control and manage change in a software project.

Software Quality Plan: It defines the techniques, procedures, and methodologies that will be used to assure timely delivery of the software.

User: That person who actually performs his or her job functions with the assistance of the product.

Notes

5.11 Review Questions

1. "A plan is the first step in providing the means to satisfy the needs of a project sponsor and help in paving the way to reach desired goal." Discuss.
2. Discuss the factors that contribute to inaccurate estimation.
3. Discuss the steps included in Software Cost estimation process.
4. What is COCOMO Model? Discuss the different levels of COCOMO model.
5. Explain the concept of project scheduling.
6. Discuss the issues included in staffing.
7. Describe the concept of Software Configuration Management.
8. What are software configuration items? Discuss.
9. Explain how to identify objects in the Software Configuration.
10. Based upon the amount of risk influence in software development project, risk strategies could be divided into three classes. Comment.

Answers: Self Assessment

1. Project Planning
2. Resource planning
3. Cost
4. Work Break down
5. COCOMO
6. top-down
7. schedule
8. Project manager
9. Software Configuration Management
10. software configuration items
11. Quality Plan
12. Software Quality Assurance
13. Intangible
14. Risk index
15. time sheet
16. Reviews

5.12 Further Readings

Books

Rajib Mall, *Fundamentals of Software Engineering*, 2nd Edition, PHI.

Richard Fairpy, *Software Engineering Concepts*, Tata McGraw Hill, 1997.

R.S. Pressman, *Software Engineering – A Practitioner's Approach*, 5th Edition, Tata McGraw Hill Higher education.

Sommerville, *Software Engineering*, 6th Edition, Pearson Education

Online links

http://www.csbdu.in/econtent/Software%20Engineering/Unit_II.pdf

http://www.slideshare.net/PiyushGogia/chapter-4-software-project-planning

http://www.bth.se/fou/cuppsats.nsf/all/d4d4c4f99af27b2cc1256f5b004aa0c0/$file/The%20Relationship%20between%20Project%20Planning%20and%20Project%20Success.pdf

http://www.mhhe.com/engcs/compsci/pressman/graphics/Pressman5sepa/common/cs2/projplan.pdf

Unit 6: Functional Design

Notes

CONTENTS

Objectives

Introduction

6.1 Design Process

6.1.1 Features of a Good Design

6.2 Principles of Design

6.3 Design Concepts

6.3.1 Abstraction

6.3.2 Modularity

6.3.3 Top Down and Bottom Up Approach

6.4 Coupling

6.5 Cohesion

6.6 Structure Chart

6.7 Data Flow Diagrams

6.7.1 Components of Data Flow Diagrams

6.8 Design Heuristics

6.9 Summary

6.10 Keywords

6.11 Review Questions

6.12 Further Readings

Objectives

After studying this unit, you will be able to:

- Discuss the principles of design
- Discuss the concept of abstraction, modularity, top down and bottom up approach
- Explain coupling and cohesion.
- Discuss the concept of structure charts and data flow diagrams
- Explain design heuristics

Introduction

The systems objectives outlined during the feasibility study serve as the basis from which the work of system design is initiated. Much of the activities involved at this stage are of technical nature requiring a certain degree of experience in designing systems, sound knowledge of computer related technology and through understanding of computers available in the market and the various facilities provided by the vendors. Nevertheless, a system cannot be designed in isolation without the active involvement of the user. The user has a vital role to play at this stage too. As we know that data collected during feasibility study will be utilized systematically during the system design. It should, however, be kept in mind that detailed study of the existing system is not necessarily over with the completion of the feasibility study. Depending on the plan of feasibility study, the level of detailed study will vary and the system design stage will also vary in the amount of investigation that still needs to be done. Sometimes, but rarely, the investigation may form a separate stage between feasibility study and computer system design. Designing a new system is a creative process which calls for logical as well as lateral thinking. The logical approach involves systematic moves towards the end-product keeping in mind the capabilities of the personnel and the equipment. This is to ensure that no efforts are being made to fit previous solutions into new situations.

6.1 Design Process

Design transforms the information model created during analysis stage into data structures in order to implement the software. E-R diagrams and the data dictionaries are used as the basis for the design activities.

The architectural design defines the relationship between structural elements of the software, the design patterns and the constraints. The interface design model describes how the software communicates with itself, with the system and with the humans who use it. Thus an interface depicts a flow of information and behavior. The component-level design converts the structural elements of the software architecture into a procedural description of software components. This information can be obtained in the form of PSPEC, CSPEC and STD.

Thus, a design affects the effectiveness of the software that is being built. It fosters the quality of the software engineering.

6.1.1 Features of a Good Design

- It must implement all the explicit requirements contained in the analysis stage and all the implicit requirements mentioned by the customer.
- It must be readable and understandable for those who code, test and support.
- It must address the data, functional and behavioral aspects for the implementation of the software.
- It must exhibit an architectural structure.
- It must be modular i.e. the software must be partitioned into separate logical units to perform specific functions.
- It must contain distinct representation of data, architecture, interface and modules.

Self Assessment

Fill in the blanks:

1. The .... design defines the relationship between structural elements of the software, the design patterns and the constraints.
2. The .... design converts the structural elements of the software architecture into a procedural description of software components.

6.2 Principles of Design

Design is both a process and a model. Good design is a result of creative skills, past experience and a commitment to quality. Basic design principles allow a software engineer to ship through the design process. The principles listed below are suggested by Davis:

1. The design process must not suffer from "tunnel" vision. It must consider alternative approaches based on alternative requirements, resources available and the design concepts.
2. The design should be traceable to the analysis model. Because the design includes a lot of requirements, there must be a clear indication of the tracking of all these requirements in the design document.
3. The design must not reinvent the wheel. Because of time and resource constraint design must always try to implement new ideas using the already existing design patterns.
4. The design should minimize the distance between the software and the problem, i.e. design must mimic the structure of the problem domain.
5. The design must exhibit uniformity and integration. While creating the design standard styles and formats should be followed by the design team. The design components should be carefully integrated and the interfaces should be clearly defined.
6. The design should be structured to accommodate change.
7. The design should be structured to degrade eventually in the event of abnormal data, events and circumstances.
8. Design must be separated from coding in terms of data abstraction. Thus, the level of data hiding is higher in design than in coding. While coding every minute detail must be taken care of.
9. The design must be assessed for quality during creation.
10. The design must be reviews to minimize the semantic errors.

Self Assessment

State whether the following statements are true or false:

3. The design should be traceable to the analysis model.
4. The design should maximize the distance between the software and the problem.

6.3 Design Concepts

A number of design concepts exist which provide the software designer sophisticated design methods to be applied. These concepts answer a lot of questions like the following:

1. Which criteria should be used to decompose the software into multiple components?
2. How is the data or functional detail isolated from the conceptual representation of the software?
3. What uniform criteria must be applied to define the design quality?

6.3.1 Abstraction

Abstraction is the elimination of the irrelevant and amplification of the essentials. A number of levels of abstraction exist in a modular design. At the highest level, the solution is mentioned at a very broad level in terms of the problem. At the lower levels, a procedure oriented action is taken wherein problem oriented design is coupled with implementation level design. At the lowest level, the solution is mentioned in the form that can be directly used for coding.

The various levels of abstraction are as follows:

- ***Procedural Abstraction:*** It is a sequence of instructions that have limited functions in a specific area. For example, the word "prepare" for tea. Although it involves a lot of actions like going to the kitchen, boiling water in the kettle, adding tea leaves, sugar and milk, removing the kettle from the gas stove and finally putting the gas off.
- ***Data Abstraction:*** It is a named collection of data that describes the data object. For example, data abstraction for prepare tea will used kettle as a data object which in turn would contain a number of attributes like brand, weight, color, etc.
- ***Control Abstraction:*** It implies a program control mechanism without specifying its internal details.

Example: Synchronization semaphore in operating system which is used for coordination amongst various activities.

6.3.2 Modularity

Modularity refers to the division of software into separate modules which are differently named and addressed and are integrated later on in order to obtain the completely functional software. It is the only property that allows a program to be intellectually manageable. Single large programs are difficult to understand and read due to large number of reference variables, control paths, global variables, etc. The desirable properties of a modular system are:

- Each module is a well defined system that can be used with other applications.
- Each module has a single specific purpose.
- Modules can be separately compiled and stored in a library.
- Modules can use other modules.
- Modules should be easier to use than to build.
- Modules are simpler from outside than inside.

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

Notes It might seem to you that on dividing a problem into sub problems indefinitely, the effort required to develop it becomes negligibly small. However, the fact is that on dividing the program into numerous small modules, the effort associated with the integration of these modules grows. Thus, there is a number N of modules that result in the minimum development cost. However, there is no defined way to predict the value of this N.

In order to define a proper size of the modules, we need to define an effective design method to develop a modular system. Following are some of the criteria defined by Meyer for the same:

- ***Modular Decomposability:*** The overall complexity of the program will get reduced if the design provides a systematic mechanism to decompose the problem into sub-problems and will also lead to an efficient modular design.
- ***Modular Composability:*** If a design method involves using the existing design components while creating a new system it will lead to a solution that does not re-invent the wheel.
- ***Modular Understandability:*** If a module can be understood as a separate stand-alone unit without referring to other modules it will be easier to build and edit.
- ***Modular Continuity:*** If a change made in one module does not require changing all the modules involved in the system, the impact of change-induced side effects gets minimized.
- ***Modular Protection:*** If an unusual event occurs affecting a module and it does not affect other modules, the impact of error-induced side effects will be minimized.

6.3.3 Top Down and Bottom Up Approach

A system consists of components, which have components of their own; indeed a system is a hierarchy of components. The highest-level component correspond to the total system. To design such a hierarchy there are two possible approaches: top-down and bottom-up.

A top-down design approach starts by identifying the major components of the system, decomposing them into their lower-level components and iterating until the desired level of detail is achieved. Top-down design methods often result in some form of step-wise refinement.

Starting from an abstract design, in each step the design is refined to a more concrete level, until we reach a level where no more refinement is needed and the design can be implemented directly. Most design methodologies are based on the top-down approach.

A bottom-up design approach starts with designing the most basic or primitive components and proceeds to higher-level components that use these lower-level components.

Bottom-up methods work with layers of abstraction. Starting from the very bottom, operations that provide a layer of abstraction are implemented. The operations of this layer are then used to implement more powerful operations and a still higher layer of abstraction, until the stage is reached where the operations supported by the layer are those desired by the system.

A top-down approach is suitable only if the specifications of the system are clearly known and the system development is from scratch. If a system is to be built from an existing system, a bottom-up approach is more suitable, as it starts from some existing components.

Example: If an iterative enhancement type of process is being followed, in later iterations, the bottom-up approach could be more suitable (in the first iteration a top down approach can be used).

- Pure top-down or pure bottom-up approaches are often not practical.
- Combine approaches is also use full for layer of abstraction.
- This approach is frequently used for developing systems.

Notes

Self Assessment

Fill in the blanks:

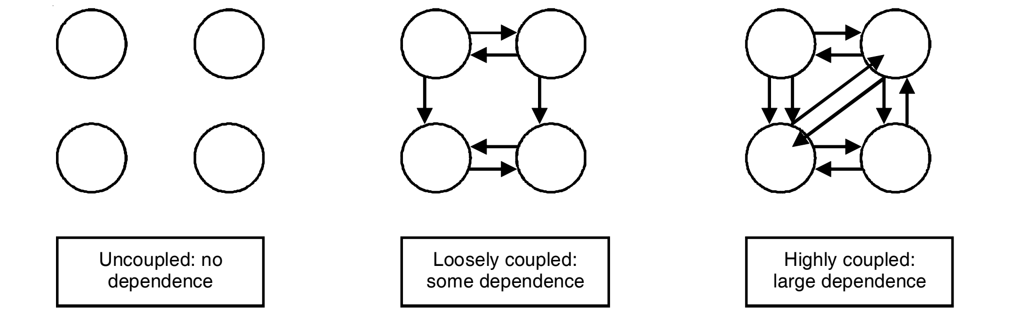
5. …………………… is the elimination of the irrelevant and amplification of the essentials.

6. …………………… methods work with layers of abstraction.

6.4 Coupling

Coupling is the measure of degree of interdependence amongst modules. Two modules that are tightly coupled are strongly dependent on each other. However, two modules that are loosely coupled are not dependent on each other. Uncoupled modules have no interdependence at all within them. The various types of coupling techniques are depicted in Figure 6.1.

Figure 6.1: Module Coupling

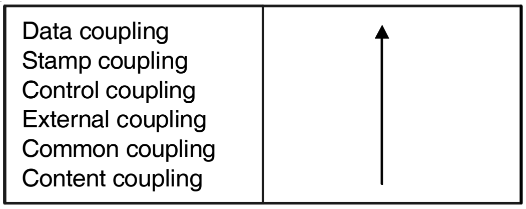

Uncoupled: no dependence
Loosely coupled: some dependence
Highly coupled: large dependence

A good design is the one that has low coupling. Coupling is measured by the number of interconnections between the modules. That the coupling increases as the number of calls between modules increase or the amount of shared data is large.

Did u know? A design with high coupling will have more errors.

Different types of coupling are content, common, external, control, stamp and data. The level of coupling in each of these types is given in Figure 6.2.

Figure 6.2: Types of Modules Coupling



The direction of the arrow in Figure 6.2 points from the lowest coupling to highest coupling. The strength of coupling is influenced by the complexity of the modules, the type of connection and the type of communication. Modifications done in the data of one block may require changes in other block of a different module which is coupled to the former module. However, if the communication takes place in the form of parameters then the internal details of the modules are no required to be modified while making changes in the related module.

Given two procedures X and Y, the type of coupling can be identified in them.

- ***Data Coupling:*** When X and Y communicates by passing parameters to one another and not unnecessary data. Thus, if a procedure needs a part of a data structure, it should be passed just that and not the complete thing.
- ***Stamp Coupling:*** Although X and Y make use of the same data type but perform different operations on them.
- ***Control Coupling (Activating):*** X transfers control to Y through procedure calls.
- ***Common Coupling:*** Both X and Y use some shared data e.g. global variables. This is the most undesirable, because if we wish to change the shared data, all the procedures accessing this shared data will need to be modified.
- ***Content Coupling:*** When X modifies Y either by branching in the middle of Y or by changing the local data values or instructions of Y.

Self Assessment

Fill in the blanks:

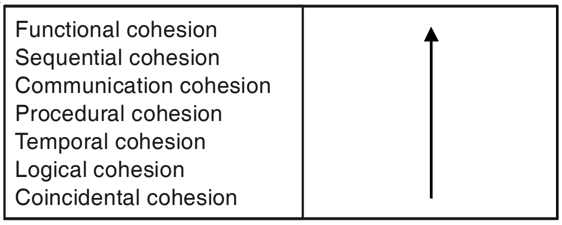
7. …………………… is the measure of degree of interdependence amongst modules.

8. Coupling is measured by the number of …………………… between the modules.

6.5 Cohesion

Cohesion is the measure of the degree of functional dependence of modules. A strongly cohesive module implements functionality that interacts little with the other modules. Thus, in order to achieve higher interaction amongst modules a higher cohesion is desired. Different types of cohesion are listed in Figure 6.3.

Figure 6.3: Types of Module Cohesion



The direction of the arrow in Figure 6.3 indicates the worst degree of cohesion to the best degree of cohesion. The worst degree of cohesion, coincidental, exists in the modules that are not related to each other in any way. So, all the functions, processes and data exist in the same module.

Logical is the next higher level where several logically related functions or data are placed in the same module.

At times a module initializes a system or a set of variables. Such a module performs several functions in sequence, but these functions are related only by the timing involved. Such cohesion is said to be temporal.

When the functions are grouped in a module to ensure that they are performed in a particular order, the module is said to be procedurally cohesive. Alternatively, some functions that use the same data set and produce the same output are combined in one module. This is known as communicational cohesion.

Notes

If the output of one part of a module acts as an input to the next part, the module is said to have sequential cohesion. Because the module is in the process of construction, it is possible that it does not contain all the processes of a function.

Notes The most ideal of all module cohesion techniques is functional cohesion. Here, every processing element is important to the function and all the important functions are contained in the same module. A functionally cohesive function performs only one kind of function and only that kind of function.

Given a procedure carrying out operations A and B, we can identify various forms of cohesion between A and B:

- ***Functional Cohesion:*** A and B are part of one function and hence, are contained in the same procedure.
- ***Sequential Cohesion:*** A produces an output that is used as input to B. Thus they can be a part of the same procedure.
- ***Communicational Cohesion:*** A and B take the same input or generate the same output. They can be parts of different procedures.
- ***Procedural Cohesion:*** A and B are structured in the similar manner. Thus, it is not advisable to put them both in the same procedure.
- ***Temporal Cohesion:*** Both A and B are performed at moreover the same time. Thus, they cannot necessarily be put in the same procedure because they may or may not be performed at once.
- ***Logical Cohesion:*** A and B perform logically similar operations.
- ***Coincidental Cohesion:*** A and B are not conceptually related but share the same code.

Task Compare and contrast coupling and cohesion.

Self Assessment

Fill in the blanks:

9. …………………… is the measure of the degree of functional dependence of modules.
10. If the output of one part of a module acts as an input to the next part, the module is said to have …………………… cohesion.

6.6 Structure Chart

There are many techniques for effectively communicating organizational ideas within the business environment. A structure chart is a graphical chart used for the purpose of describing and communicating a model or process within an organization. This chart typically consists of shapes with descriptions and connecting lines that show relationships to other shapes within the chart.

Project managers rely on structure charts for managing their daily activities. The most widely used structure chart for project management is the work breakdown structure chart. This is a graphical chart that consists of milestones and timelines. These timelines show the tasks that must be completed to successfully finish a project.

Functional modeling is a system engineering technique that requires the graphical design and presentation of complex business models. This visualization design approach provides an elegant method for describing information to a non-technical audience. The functional model decomposes the detail interfaces of a software application into clearly defined components.

Example: An organization chart is well known example of a structure chart that is used within most business operations. This chart is a graphical representation of the employees in an organization. It is typically displayed in a hierarchical manner with the senior executive represented at the top of the chart.

The study of organizational behavior is the art of describing how individuals and groups within an organization interact with other teams or departments. This collaboration and communication paradigm is typically referred to as group dynamics. A structure chart is used within organizational theory to describe individual groups and their interactions with other groups of an organization.

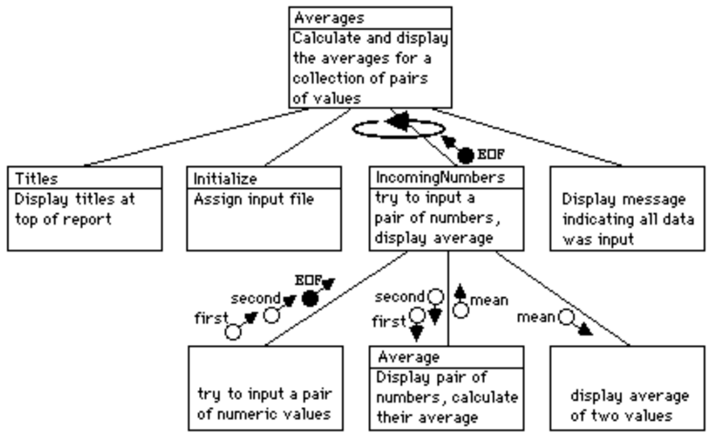
Structured analysis and design is an approach for managing the development process of applications within software engineering. This design pattern is based on a waterfall systems development method. The waterfall systems design approach includes specific structure charts for each phase of the development process including requirements, design, coding, and testing.

A data model is a structure chart used within structured analysis. This structure chart describes the relationships of data within a database. The data model defines the business rules and cardinality of data for an application. This chart describes how the user of a system will interact with the data.

The art of systems architecture requires effective communication at multiple technical levels within an organization. The system architect leverages visualization artifacts to describe events within an enterprise. This graphical representation of ideas creates a better overall understanding of how system components will interact with other interfaces throughout the enterprise.

Figure 6.4 shows the structure chart for calculating and displaying the averages for a collection of pairs of values.

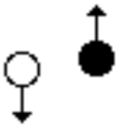
Figure 6.4: Structure Chart for Calculating and Displaying the Averages for a Collection of Pairs of Values


Averages
Calculate and display the averages for a collection of pairs of values
EOF
Titles
Display titles at top of report
Initialize
Assign input file
IncomingNumbers
try to input a pair of numbers, display average
Display message indicating all data was input
EOF
second
first
second
first
mean
mean
try to input a pair of numeric values
Average
Display pair of numbers, calculate their average
display average of two values

Source: http://www.ece.uc.edu/~mazlack/CS2.sp2008/CS2.sc.examples/sc.tutorial/SC.detailed.example.html

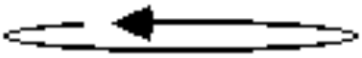
The following things should be noted about the structure chart.

- Boxes representing procedures are divided by a line. The name of the procedure is above the line. The description of what the procedure does is in the narrative section of the box. The narrative section of the box should approximately match the pseudo-code. Generally, the comment in the procedure describing what the procedure does should also approximately match the narrative description in the box.
- Boxes without dividing lines are not procedures.
- Boxes without dividing lines (non-procedures) generally should not be shown as controlling procedures. This is keeping with the idea of top-down design of top-most boxes being the most general.
- The data coupling represents data flows into and out of the activities represented by the boxes. In general, non-procedures should not be shown as controlling procedures.
- If possible, data coupling exiting an activity downward (in the structure chart) should be shown to the left of the line connecting the activities. data coupling exiting an activity upward should be shown to the right of the line.
- The data coupling names are those known in the top-most procedure. In the example, the procedure *IncomingNumbers* knows the data as first and second. The procedure *Average* is invoked by the procedure *IncomingNumbers*. *IncomingNumbers* knows the same data as leading and trailing. The structure chart shows first and second as the coupling between *IncomingNumbers* and *Average*. This is because *IncomingNumbers* is the controlling activity.
- Structure chart arrows indicate both the direction of information flow and what they do. Open circles are data and darkened circles are control information.



- In the example, the data coupling for EOF (end of file) is shown as a darkened circle because EOF is a control variable. EOF is used to decide if further activity in the iteration will happen.

  Iteration is shown by the iteration mark.



  It indicates the activities that are iterated. In the example, the activity *IncomingNumbers* is shown as an iterated activity. The activities within it are not shown as iterated. This has the effect on program implementation of this structure chart that iterative control must be in the activity above *IncomingNumbers*.

Self Assessment

Fill in the blanks:

11. A .... is a graphical chart used for the purpose of describing and communicating a model or process within an organization.

12. A .... is a structure chart used within structured analysis.

6.7 Data Flow Diagrams

The data flow diagrams should also have some associated documentation. This is necessary as the diagrams are meant as a visual representation of the way in which information is processed. There is limited space on the diagrams so that documentation to explain, refine and describe further details of what is shown need to be kept somewhere in the proposed system documentation. The data flow diagrams and the associated documentation together combine to form a data flow model. This is also commonly called a process model.

Before attempting to construct an initial DFD it is necessary to gather and digest information that helps us to understand how data is processed in the current system. Fact-finding techniques are used for this purpose and are discussed in another Unit. As the DFD is constructed a systems analyst will often come across areas of doubt where the precise way to model the system is unclear. This is a natural part of the development and should not be regarded with alarm. In fact, it is expected and it is a consequence of attempting to model the current situation that questions will be asked to clarify the exact processes which are taking place. Sometimes the analyst will make an assumption and then check this with the user at a subsequent meeting.

Results of interviews, documents, reports, questionnaires etc. will all play a part in helping the analyst to gain an insight into the current processes. Where a system is being developed from scratch the analyst will work with the user to develop the proposed DFDs.

When all the information about the current system is gather it should be possible to construct the DFDs to show:

- the information that enters and leaves the system
- the people/roles/other systems who generate and/or receive that information
- the processes that occur in the system to manipulate the information
- the information that is stored in the system
- the boundary of the system indicating what is (and what is not) included

As a starting point, it is sometimes useful to construct a document flow diagram. This diagram shows how 'documents' are passed around an organisation to fulfil the current requirements of the system under investigation. The term' documents' is interpreted very loosely and usually translates to information.

Sometimes before beginning to produce the set of data flow diagrams a document flow diagram is generated. This helps to establish the system boundary so we can decide which parts of the system we are modelling and which parts we are not. The document flow diagram shows the different documents (or information sources in the system and how they flow from a source to a recipient.

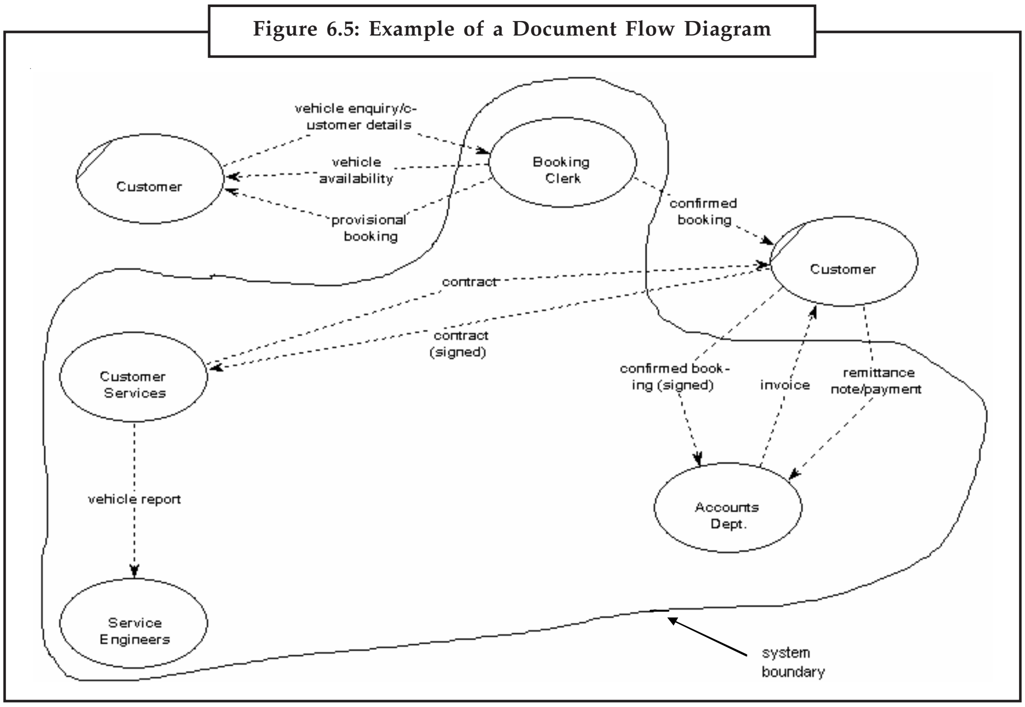
Example: Here is an example of a document flow diagram shown next page.

Here ellipses represent either the source or recipient of the 'documents' and named arrows show the direction of transfer and the nature of the information being exchanged. This kind of diagram is a first step in understanding what information is in the system and how it is used to perform the required functions.

Another useful feature of the construction of this type of diagram is that it enables a sensible discussion of where the system boundary should lie. In other words it is important to establish what is to be included in the proposed information system and what is not. To indicate this, a system boundary line is constructed on the document flow diagram.

Notes

Figure 6.5: Example of a Document Flow Diagram



The DFDs are used to:

- discuss with the user a diagrammatic interpretation of the processes in the system and clarify what is currently being performed
- determine what the new system should be able to do and what information is required for each different process that should be carried out
- check that the completed system conforms to its intended design

6.7.1 Components of Data Flow Diagrams

The components of a Data Flow Diagram are always the same but there are different diagrammatic notations used. The notation used here is one adopted by a methodology known as SSADM (Structured Systems Analysis and Design Methods). Luckily there are only four different symbols that are normally used on a DFD. The elements represented are:

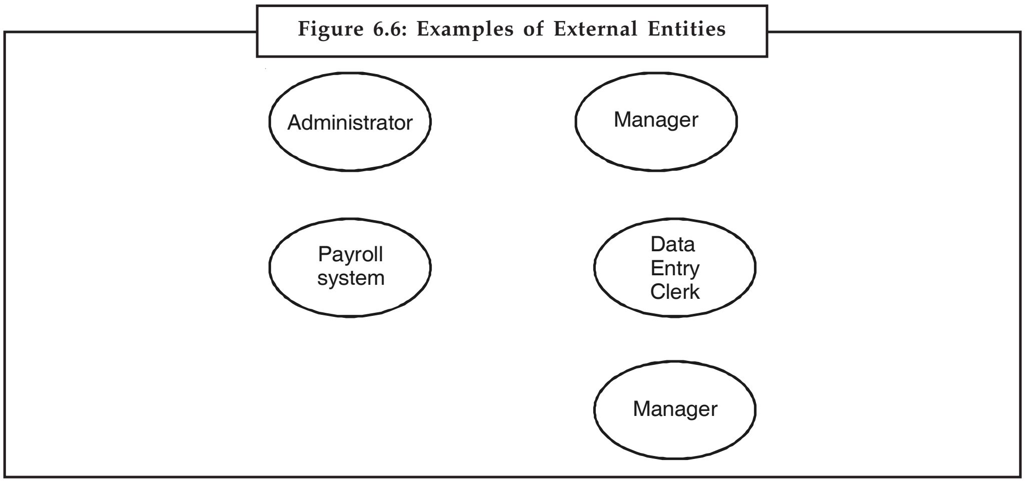
- External entities
- Processes
- Data stores
- Data flows

External Entities

External entities are those things that are identified as needing to interact with the system under consideration. The external entities either input information to the system, output information from the system or both. Typically they may represent job titles or other systems that interact with the system to be built.

Notes

Figure 6.6: Examples of External Entities



Example: Some examples are given below in Figure 6.6. Notice that the SSADM symbol is an ellipse. If the same external entity is shown more than once on a diagram (for clarity) a diagonal line indicates this.

Task Analyse the function of external entities.

Processes

Processes are actions that are carried out with the data that flows around the system. A process accepts input data needed for the process to be carried out and produces data that it passes on to another part of the DFD. The processes that are identified on a design DFD will be provided in the final artefact. They may be provided for using special screens for input and output or by the provision of specific buttons or menu items. Each identifiable process must have a well chosen process name that describes what the process will do with the information it uses and the output it will produce.

Caution Process names must be well chosen to give a precise meaning to the action to be taken.

It is good practice to always start with a strong verb and to follow with not more than four or five words.

Example: Good process names would be:

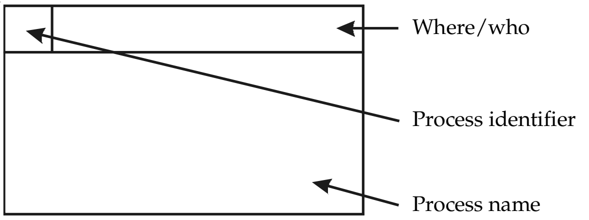
- Enter customer details
- Register new students
- Validate sales orders.

Try to avoid using the verb 'process', otherwise it is easy to use this for every process. We already know from the symbol it is a process so this does not help us to understand what kind of a process we are looking at.

Notes

The process symbol has three parts as shown in Figure 6.7.

Figure 6.7: Process Box

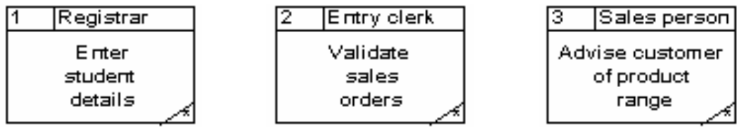


The process identifier is allocated so that each process may be referred to uniquely.

The sequence of the process identifiers is usually unimportant but they are frequently to be seen as 1, 2, 3, etc. The top right hand section of the box is used to describe where the process takes place or who is doing the process.

Example: Process boxes are given in Figure 6.8.

Figure 6.8: Examples of Process Boxes

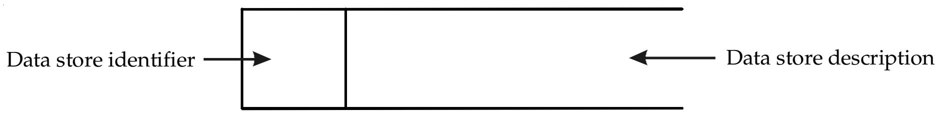


Data Stores

Data stores are places where data may be stored. This information may be stored either temporarily or permanently by the user. In any system you will probably need to make some assumptions about which relevant data stores to include. How many data stores you place on a DFD somewhat depends on the case study and how far you go in being specific about the information stored in them. It is important to remember that unless we store information coming into our system it will be lost.

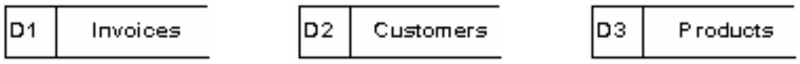
The symbol for a data store is shown in Figure 6.9 and examples are given in Figure 6.10.

Figure 6.9: Symbol for a Data Store



Example: A data store is given below:

Figure 6.10: Examples of Possible Data Stores



As data stores represent a person, place or thing they are named with a noun. Each data store is given a unique identifier D1, D2, D3, etc.

Data Flows

Notes

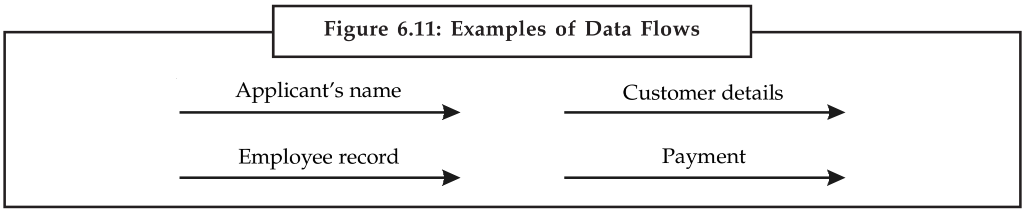
The previous three symbols may be interconnected with data flows. These represent the flow of data to or from a process. The symbol is an arrow and next to it a brief description of the data that is represented. There are some interconnections, though, that are not allowed. These are:

- Between a data store and another data store
  - ❖ This would imply that one data store could independently decide to send some of information to another data store. In practice this must involve a process.
- Between an external entity and a data store
  - ❖ This would mean that an external entity could read or write to the data stores having direct access. Again in practice this must involve a process.

Also, it is unusual to show interconnections between external entities. We are not normally concerned with information exchanges between two external entities as they are outside our system and therefore of less interest to us.

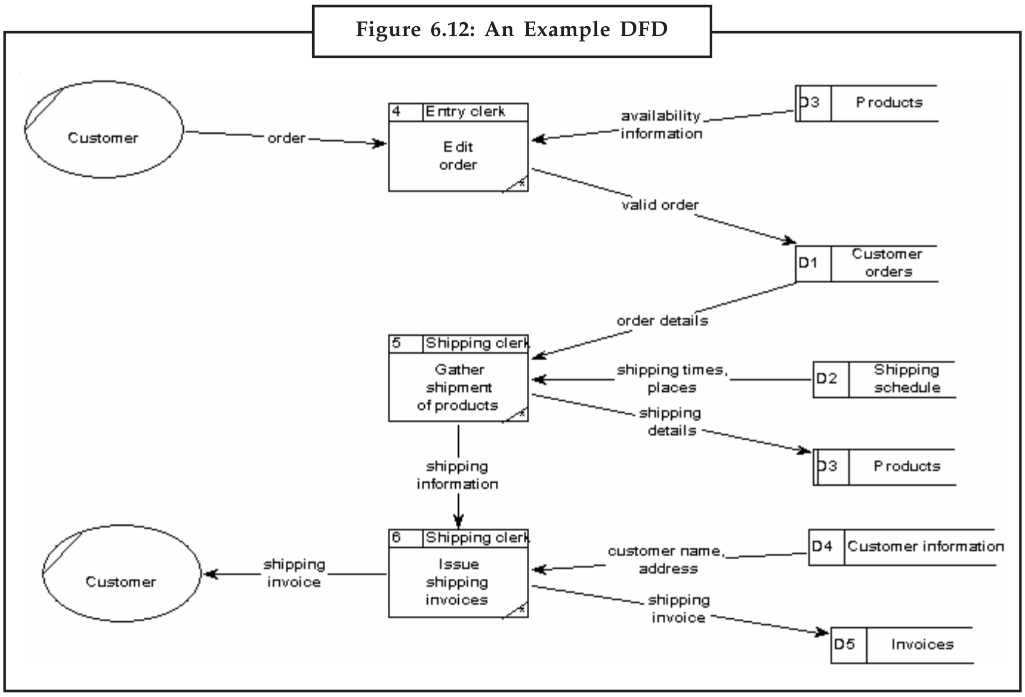
Example: Figure 6.11 shows some examples of data flows.

Figure 6.11: Examples of Data Flows



Example: Let's look at a DFD and see how the features that have just been described may be used. Figure 6.12 shows an example DFD.

Figure 6.12: An Example DFD



Here are some key points that apply to all DFDs.

- All the data flows are labelled and describe the information that is being carried.
- It tends to make the diagram easier to read if the processes are kept to the middle, the external entities to the left and the data stores appear on the right hand side of the diagram.
- The process names start with a strong verb.
- Each process has access to all the information it needs. In the example above, process 4 is required to check orders. Although the case study has not been given, it is reasonable to suppose that the process is looking at a customer's order and checking that any order items correspond to ones that the company sell. In order to do this the process is reading data from the product data store.
- Each process should have an output. If there is no output then there is no point in having that process. A corollary of this is that there must be at least one input to a process as it cannot produce data but can only convert it from one form to another.
- Data stores should have at least one data flow reading from them and one data flow writing to them. If the data is never accessed there is a question as to whether it should be stored. In addition, there must be some way of accumulating data in the data store in the first place so it is unlikely there will be no writing to the data store.
- Data may flow from
  - ❖ External entity to process and vice-versa
  - ❖ Process to process
  - ❖ Process to data store and vice-versa
- No logical order is implied by the choice of id for the process. In the example process id's start at 4. There is no significance to this.

Self Assessment

Fill in the blanks:

13. .... are actions that are carried out with the data that flows around the system.

14. .... are places where data may be stored.

6.8 Design Heuristics

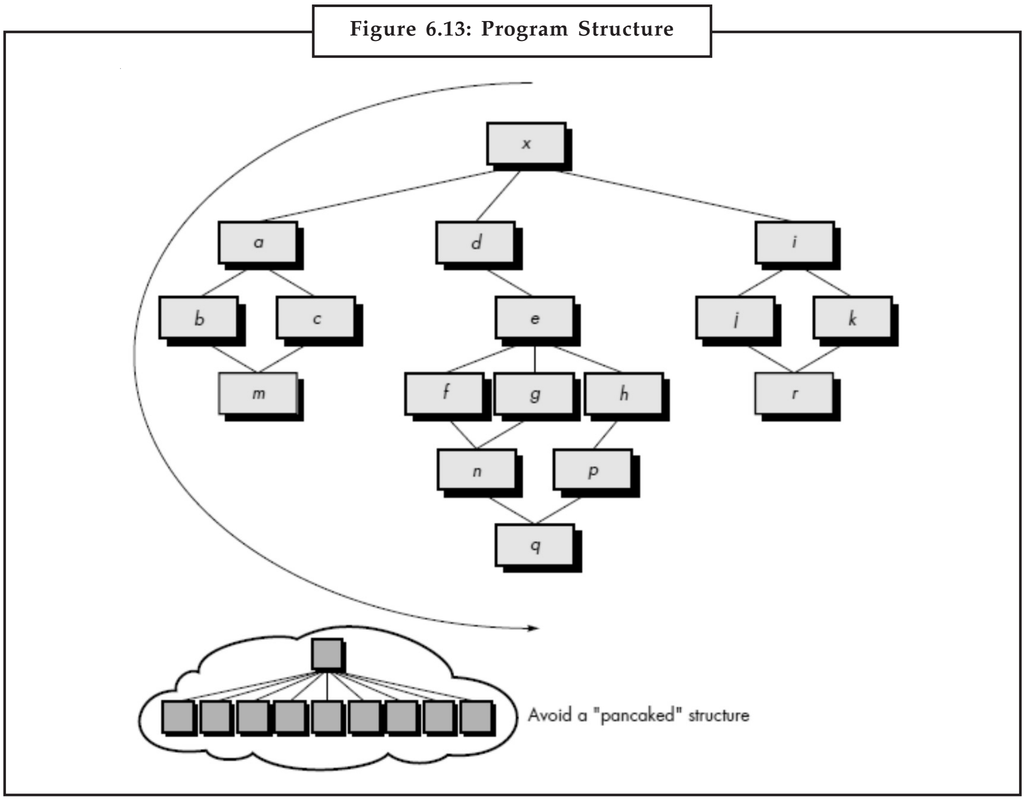
Once program structure has been developed, effective modularity can be achieved by applying the design concepts. The program structure can be manipulated according to the following set of heuristics:

- Evaluate the "first iteration" of the program structure to reduce coupling and improve cohesion. Once the program structure has been developed, modules may be exploded or imploded with an eye toward improving module independence. An exploded module becomes two or more modules in the final program structure. An imploded module is the result of combining the processing implied by two or more modules.

  An exploded module often results when common processing exists in two or more modules and can be redefined as a separate cohesive module. When high coupling is expected, modules can sometimes be imploded to reduce passage of control, reference to global data, and interface complexity.

Notes

Figure 6.13: Program Structure



- Attempt to minimize structures with high fan-out; strive for fan-in as depth increases. The structure shown inside the cloud in Figure 6.13 does not make effective use of factoring. All modules are "pancaked" below a single control module. In general, a more reasonable distribution of control is shown in the upper structure. The structure takes an oval shape, indicating a number of layers of control and highly utilitarian modules at lower levels.

- Keep the scope of effect of a module within the scope of control of that module. The scope of effect of module e is defined as all other modules that are affected by a decision made in module e. The scope of control of module is all modules that are subordinate and ultimately subordinate to module e. Referring to Figure 6.13, if module e makes a decision that affects module r, we have a violation of this heuristic, because module r lies outside the scope of control of module e.

- Evaluate module interfaces to reduce complexity and redundancy and improve consistency. Module interface complexity is a prime cause of software errors. Interfaces should be designed to pass information simply and should be consistent with the function of a module. Interface inconsistency (i.e., seemingly unrelated data passed via an argument list or other technique) is an indication of low cohesion. The module in question should be re-evaluated.

- Define modules whose function is predictable, but avoid modules that are overly restrictive. A module is predictable when it can be treated as a black box; that is, the same external data will be produced regardless of internal processing details.

⚠ *Caution* Modules that have internal "memory" can be unpredictable unless care is taken in their use.

Notes

A module, that restricts processing to a single sub function, exhibits high cohesion and is viewed with favor by a designer. However, a module that arbitrarily restricts the size of a local data structure, options within control flow, or modes of external interface will invariably require maintenance to remove such restrictions.

Strive for "controlled entry" modules by avoiding "pathological connections." This design heuristic warns against content coupling. Software is easier to understand and therefore easier to maintain when module interfaces are constrained and controlled.

Did u know? Pathological connection refers to branches or references into the middle of a module.

Self Assessment

State whether the following statements are true or false:

15. An exploded module becomes two or more modules in the final program structure.

16. A module is predictable when it can be treated as a white box.

Case Study

The Influence of Instruction Coverage on the Relationship Between Static and Run-time Coupling Metrics

When comparing static and run-time measures it is important to have a thorough understanding of the degree to which the analysed source code corresponds to the code that is actually executed. In this chapter this relationship is studied using instruction coverage measures with regard to the influence of coverage on the relationship between static and run-time metrics. It is proposed that coverage results have a significant influence on the relationship and thus should always be a measured, recorded factor in any such comparison.

An empirical investigation is conducted using a set of six run-time metrics on seventeen Java benchmark and real-world programs. First, the differences in the underlying dimensions of coupling captured by the static versus the run-time metrics are assessed using principal component analysis. Subsequently, multiple regression analysis is used to study the predictive ability of the static CBO and instruction coverage data to extrapolate the run-time measures.

Goals and Hypotheses

The Goal Question Metric/MEtric Definition Approach (GQM/MEDEA) framework proposed by Briand et al was used to set up the experiments for this study.

Experiment 1:

Goal: To investigate the relationship between static and run-time coupling metrics.

Perspective: We would expect some degree of correlation between the run-time measures for coupling and the static CBO metric. We use a number of statistical techniques, including principle component analysis to analyse the covariate structure of the metrics to determine if they are measuring the same class properties.

Contd...

Notes

Environment: We chose to evaluate a number of Java programs from well Defined publicly-available benchmark suites as well as a number of open source real-world programs.

Hypothesis

H0: Run-time measures for coupling are simply surrogate measures for the static CBO metric.

H1: Run-time measures for coupling are not simply surrogate measures for the static CBO metric.

Experiment 2:

Goal: To examine the relationship between static CBO and run-time coverage metrics, particularly in the context of the influence of instruction coverage.

Perspective: Intuitively, one would expect the better the coverage of the test cases used the greater the correlation between the static and run-time metrics. We use multiple regression analysis to determine if there is a significant correlation.

Environment: We chose to evaluate a number of Java programs from well defined publicly-available benchmark suites as well as a number of open source real-world programs.

Hypothesis:

H0: The coverage of the test cases used to evaluate a program has no influence on the relationship between static and run-time coupling metrics.

H1: The coverage of the test cases used to evaluate a program has an influence on the relationship between static and run-time coupling metrics.

Experimental Design

In order to conduct the practical experiments underlying this study, it was necessary to select a suite of Java programs and measure:

the static CBO metric

the instruction coverage percentages: IC

the run-time coupling metrics: IC CC, EC CC, IC CM, EC EM, IC CD, EC CD

The static metrics data collection tool StatMe was used to calculate CBO, while the InCov tool was used to determine the instruction coverage. The run-time metrics were evaluated using the ClMet tool.

The set of programs used in this study consist of the benchmark programs JOlden and SPECjvm98, as well as the real-world programs Velocity, Xalan and Ant. The SPECjvm98 suite was chosen as it is directly comparable to other studies that use Java software. The program mtrt was excluded from the investigation as it is multi-threaded and therefore is not suitable for this type of analysis. The more synthetic JOlden programs were included to ensure that it considers programs that create significantly large populations of objects. Three of the programs from the JOlden suite BiSort, TreeAdd and TSP were omitted from the analysis as they contained only two classes, therefore the results could not be further analysed. A selection of real programs were selected to ensure that the results were scalable to all types of programs.

Results

Experiment 1: To investigate the relationship between static and run-time coupling metrics

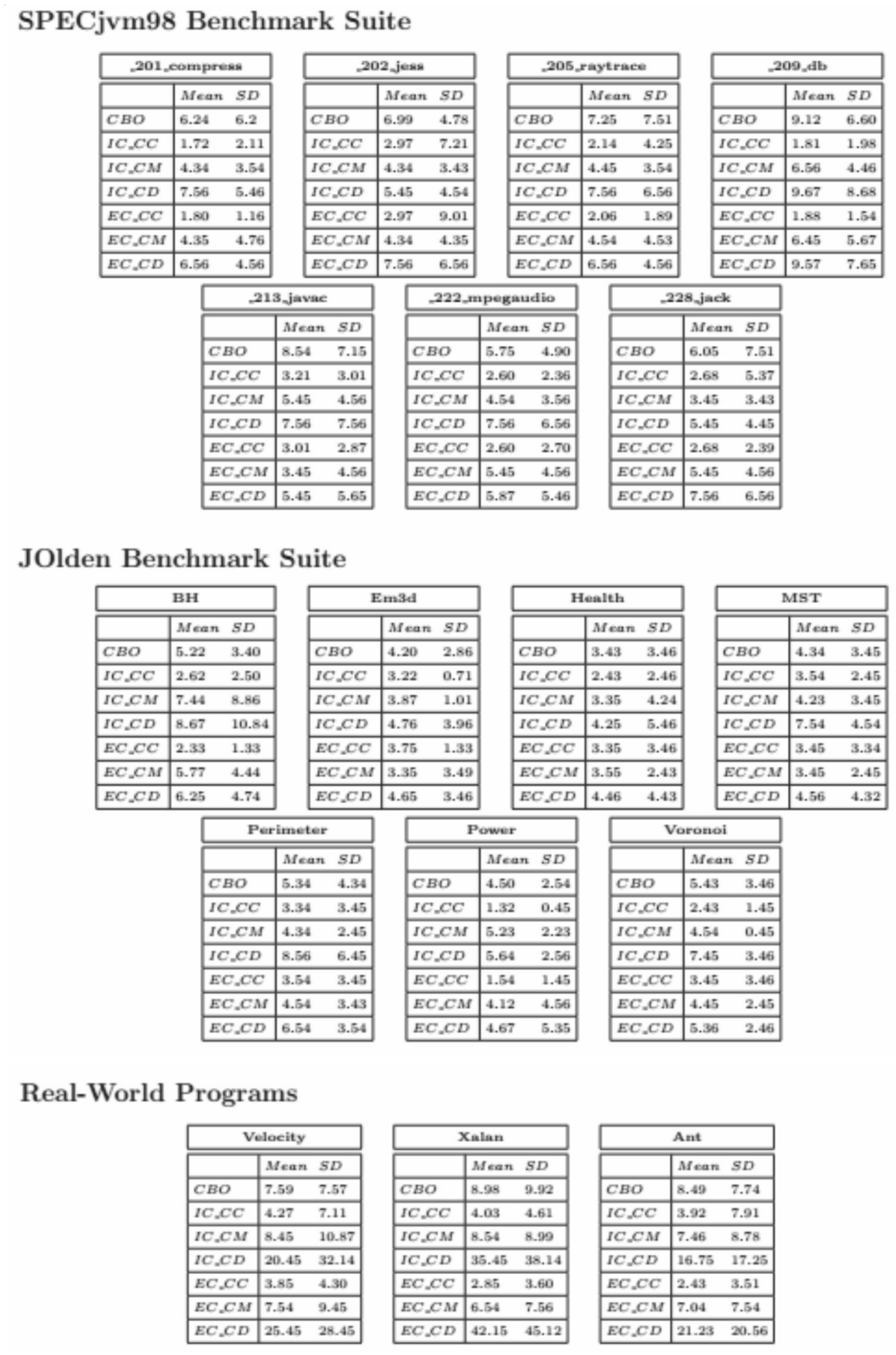
For each program the distribution (mean) and variance (standard deviation) of each measure across the class is calculated. These statistics are used to select metrics that exhibit enough

Contd...

Notes

variance to merit further analysis, as a low variance metric would not differentiate classes very well and therefore would not be a useful predictor of external quality. Descriptive statistics also aid in explaining the results of the subsequent analysis. The descriptive statistic results for each program are summarised in Table 1. The metric values exhibit large variances which makes them suitable candidates for further analysis.

Table 1: Descriptive Statistic Results for all Programs



SPECjvm98 Benchmark Suite

_201_compress

	Mean	SD
CBO	6.24	6.2
IC_CC	1.72	2.11
IC_CM	4.34	3.54
IC_CD	7.56	5.46
EC_CC	1.80	1.16
EC_CM	4.35	4.76
EC_CD	6.56	4.56

_202_jess

	Mean	SD
CBO	6.99	4.78
IC_CC	2.97	7.21
IC_CM	4.34	3.43
IC_CD	5.45	4.54
EC_CC	2.97	9.01
EC_CM	4.34	4.35
EC_CD	7.56	6.56

_205_raytrace

	Mean	SD
CBO	7.25	7.51
IC_CC	2.14	4.25
IC_CM	4.45	3.54
IC_CD	7.56	6.56
EC_CC	2.06	1.89
EC_CM	4.54	4.53
EC_CD	6.56	4.56

_209_db

	Mean	SD
CBO	9.12	6.60
IC_CC	1.81	1.98
IC_CM	6.56	4.46
IC_CD	9.67	8.68
EC_CC	1.88	1.54
EC_CM	6.45	5.67
EC_CD	9.57	7.65

_213_javac

	Mean	SD
CBO	8.54	7.15
IC_CC	3.21	3.01
IC_CM	5.45	4.56
IC_CD	7.56	7.56
EC_CC	3.01	2.87
EC_CM	3.45	4.56
EC_CD	5.45	5.65

_222_mpegaudio

	Mean	SD
CBO	5.75	4.90
IC_CC	2.60	2.36
IC_CM	4.54	3.56
IC_CD	7.56	6.56
EC_CC	2.60	2.70
EC_CM	5.45	4.56
EC_CD	5.87	5.46

_228_jack

	Mean	SD
CBO	6.05	7.51
IC_CC	2.68	5.37
IC_CM	3.45	3.43
IC_CD	5.45	4.45
EC_CC	2.68	2.39
EC_CM	5.45	4.56
EC_CD	7.56	6.56

JOlden Benchmark Suite

BH

	Mean	SD
CBO	5.22	3.40
IC_CC	2.62	2.50
IC_CM	7.44	8.86
IC_CD	8.67	10.84
EC_CC	2.33	1.33
EC_CM	5.77	4.44
EC_CD	6.25	4.74

Em3d

	Mean	SD
CBO	4.20	2.86
IC_CC	3.22	0.71
IC_CM	3.87	1.01
IC_CD	4.76	3.96
EC_CC	3.75	1.33
EC_CM	3.35	3.49
EC_CD	4.65	3.46

Health

	Mean	SD
CBO	3.43	3.46
IC_CC	2.43	2.46
IC_CM	3.35	4.24
IC_CD	4.25	5.46
EC_CC	3.35	3.46
EC_CM	3.55	2.43
EC_CD	4.46	4.43

MST

	Mean	SD
CBO	4.34	3.45
IC_CC	3.54	2.45
IC_CM	4.23	3.45
IC_CD	7.54	4.54
EC_CC	3.45	3.34
EC_CM	3.45	2.45
EC_CD	4.56	4.32

Perimeter

	Mean	SD
CBO	5.34	4.34
IC_CC	3.34	3.45
IC_CM	4.34	2.45
IC_CD	8.56	6.45
EC_CC	3.54	3.45
EC_CM	4.54	3.43
EC_CD	6.54	3.54

Power

	Mean	SD
CBO	4.50	2.54
IC_CC	1.32	0.45
IC_CM	5.23	2.23
IC_CD	5.64	2.56
EC_CC	1.54	1.45
EC_CM	4.12	4.56
EC_CD	4.67	5.35

Voronoi

	Mean	SD
CBO	5.43	3.46
IC_CC	2.43	1.45
IC_CM	4.54	0.45
IC_CD	7.45	3.46
EC_CC	3.45	3.46
EC_CM	4.45	2.45
EC_CD	5.36	2.46

Real-World Programs

Velocity

	Mean	SD
CBO	7.59	7.57
IC_CC	4.27	7.11
IC_CM	8.45	10.87
IC_CD	20.45	32.14
EC_CC	3.85	4.30
EC_CM	7.54	9.45
EC_CD	25.45	28.45

Xalan

	Mean	SD
CBO	8.98	9.92
IC_CC	4.03	4.61
IC_CM	8.54	8.99
IC_CD	35.45	38.14
EC_CC	2.85	3.60
EC_CM	6.54	7.56
EC_CD	42.15	45.12

Ant

	Mean	SD
CBO	8.49	7.74
IC_CC	3.92	7.91
IC_CM	7.46	8.78
IC_CD	16.75	17.25
EC_CC	2.43	3.51
EC_CM	7.04	7.54
EC_CD	21.23	20.56

Contd...

Principal Component Analysis

Principal Component Analysis (PCA) is used to investigate whether the run- time coupling metrics are not simply surrogate measures for static CBO. A similar study was carried out by Arisholm et al. using only the Velocity program. The work in this chapter extends their work to include fourteen benchmark programs as well as three real-world programs in order to demonstrate the robustness of these results over a larger range and variety of programs. Using the Kaiser criterion to select the number of factors to retain shows that the metrics mostly capture three orthogonal dimensions in the sample space formed by all measures. In other words, the coupling is divided along three dimensions for each of the programs analysed.

Experiment 2: The Influence of Instruction Coverage

Multiple Regression Analysis

Multiple regression analysis is used to test the hypothesis that instruction coverage of test cases used to evaluate a program has no influence on the relationship between static and run-time metrics. The two independent variables are thus the static CBO metric and the instruction coverage measure Ic; each of the six run-time coupling metrics in turn is then used as the dependent variable.

Results

First, all R values turned out to be positive for each of the programs used in this study. This means that there is a positive correlation between the dependent (run-time metric) and independent variables CBO and IC. Therefore as the values for CBO and IC increase or decrease so will the observed value for the run-time metric under consideration.

Questions:

1. Illustrate the function of Principal Component Analysis.
2. Discuss the relationship between Static and Run-time Coupling Metrics.

Source: http://www.cs.nuim.ie/research/pop/papers/AineMitchellPhD.pdf

6.9 Summary

- A design affects the effectiveness of the software that is being built. It fosters the quality of the software engineering.
- Abstraction is the elimination of the irrelevant and amplification of the essentials. A number of levels of abstraction exist in a modular design.
- Modularity refers to the division of software into separate modules which are differently named and addressed and are integrated later on in order to obtain the completely functional software.
- A top-down design approach starts by identifying the major components of the system, decomposing them into their lower-level components and iterating until the desired level of detail is achieved.
- A bottom-up design approach starts with designing the most basic or primitive components and proceeds to higher-level components that use these lower-level components.
- Coupling is the measure of degree of interdependence amongst modules.
- Cohesion is the measure of the degree of functional dependence of modules. A strongly cohesive module implements functionality that interacts little with the other modules.

- A structure chart is a graphical chart used for the purpose of describing and communicating a model or process within an organization.
- The data flow diagrams should also have some associated documentation. This is necessary as the diagrams are meant as a visual representation of the way in which information is processed.

6.10 Keywords

Abstraction: Abstraction is the elimination of the irrelevant and amplification of the essentials. A number of levels of abstraction exist in a modular design.

Architectural Design: The architectural design defines the relationship between structural elements of the software, the design patterns and the constraints.

Cohesion: It is the measure of the degree of functional dependence of modules.

Coupling: Coupling is the measure of degree of interdependence amongst modules.

Modularity: Modularity refers to the division of software into separate modules which are differently named and addressed and are integrated later on in order to obtain the completely functional software.

Software Design: Software design is a process of problem solving and planning for a software solution.

Software Design Principles: Software design principles represent a set of guidelines that helps us to avoid having a bad design.

Structure Chart: A structure chart is a graphical chart used for the purpose of describing and communicating a model or process within an organization.

6.11 Review Questions

1. Discuss the features of a good design. Also discuss the principles of design.
2. What is abstraction? Discuss the various levels of abstraction.
3. What is modularity? List the important properties of a modular system. Make distinction between top-down design and bottom-up design.
4. Explain the different types of coupling techniques.
5. Describe the concept of cohesion. Also discuss its various forms.
6. How do you communicate organizational ideas within the business environment? Discuss.
7. Illustrate the concept of structure chart with chart.
8. Describe the components of data flow diagram.
9. Explain the concept of data flow diagram with example.
10. A module, that restricts processing to a single sub function, exhibits high cohesion and is viewed with favor by a designer. Comment.

Answers: Self Assessment

1. architectural
2. component-level
3. True
4. False

5. Abstraction
6. Bottom-up
7. Coupling
8. interconnections
9. Cohesion
10. Sequential
11. structure chart
12. data model
13. Processes
14. Data stores
15. True
16. False

6.12 Further Readings

Books

Rajib Mall, *Fundamentals of Software Engineering*, 2nd Edition, PHI.

Richard Fairpy, *Software Engineering Concepts*, Tata McGraw Hill, 1997.

R.S. Pressman, *Software Engineering – A Practitioner's Approach*, 5th Edition, Tata McGraw Hill Higher education.

Sommerville, *Software Engineering*, 6th Edition, Pearson Education

Online links

http://selab.csuohio.edu/~nsridhar/teaching/fall07/eec521/slides/Lecture08.pdf

http://www.avatto.com/exam/software-engineering-coupling-65.html

http://www.math-cs.gordon.edu/courses/cps122/lectures-2013/Cohesion%20and%20Coupling.pdf

http://www.slideshare.net/arnoldindia/structure-chart

Notes

Unit 7: Introduction to Verification

CONTENTS

Objectives
Introduction
7.1 Meaning of Verification
7.1.1 Principles of Software Verification
7.2 Meaning of Metrics
7.2.1 Advantage of Software Metrics
7.2.2 Limitation of Software Metrics
7.2.3 Network Metrics
7.2.4 Stability Metrics
7.2.5 Information Flow Metrics
7.3 Summary
7.4 Keywords
7.5 Review Questions
7.6 Further Readings

Objectives

After studying this unit, you will be able to:

- Understand the meaning of verification
- Understand the meaning of metrics
- Explain network, stability, and information flow metrics

Introduction

Software verification provides objective evidence that the design outputs of a particular phase of the software development life cycle meet all of the specified requirements for that phase. Software verification looks for consistency, completeness, and correctness of the software and its supporting documentation, as it is being developed, and provides support for a subsequent conclusion that software is validated. Software testing is one of many verification activities intended to confirm that software development output meets its input requirements. Other verification activities include various static and dynamic analyses, code and document inspections, walkthroughs, and other techniques. Software metrics provide a quantitative way to assess the quality of internal product attributes, thereby enabling the software engineer to assess quality before the product is built.

7.1 Meaning of Verification

The terms Verification and Validation are commonly used in software engineering to mean two different types of analysis. The usual definitions are:

- ***Validation:*** Are we building the right system?
- ***Verification:*** Are we building the system right?

Verification includes all the activities associated with the producing high quality software: testing, inspection, design analysis, specification analysis, and so on. It is a relatively objective process, in that if the various products and documents are expressed precisely enough, no subjective judgements should be needed in order to verify software. Verification is to ensure that the software being developed implements a specific function. Verification is done against the design document. It verifies that the software being developed implements all the functionality specified in the design document.

In a traditional phased software lifecycle, verification is often taken to mean checking that the products of each phase satisfy the requirements of the previous phase. Validation is relegated to just the beginning and ending of the project: requirements analysis and acceptance testing. This view is common in many software engineering textbooks, and is misguided. It assumes that the customer's requirements can be captured completely at the start of a project, and that those requirements will not change while the software is being developed. In practice, the requirements change throughout a project, partly in reaction to the project itself: the development of new software makes new things possible. Therefore both validation and verification are needed throughout the lifecycle.

In contrast, validation is an extremely subjective process. It involves making subjective assessments of how well the (proposed) system addresses a real-world need. Validation includes activities such as requirements modelling, prototyping and user evaluation.

Finally, V&V (Verification and Validation) is now regarded as a coherent discipline: "Software V&V is a systems engineering discipline which evaluates the software in a systems context, relative to all system elements of hardware, users, and other software".

V&V is necessary because the designers and implementers of computer based systems are human; they will make errors. These errors will result in undetected faults in delivered systems. Faults can result in dangerous failures causing loss of life, financial loss or property damage. The mission of V&V is therefore to find and correct errors as early as possible in the development life cycle thus preventing the delivery of a faulty product to a customer.

> *Notes* The level of effort applied to V&V is a function of the criticality of the software or systems product. That is, the risks involved if the system fails.

At one end of the scale the software controlling the shutdown of a nuclear reactor will likely be thoroughly verified and validated by an independent organisation. At the other end of the scale, a website providing a company brochure will likely have no formal verification and validation applied.

Verification is achieved through:

- Static analysis of documentation (refer figure: Static Verification)
  - ❖ Evaluation of work products in the context of reviews
  - ❖ Traceability analysis
- Dynamic testing
  - ❖ Observing the behaviour software executing on a computer (refer figure: Dynamic Testing)

Notes

Figure 7.1: Static Verification

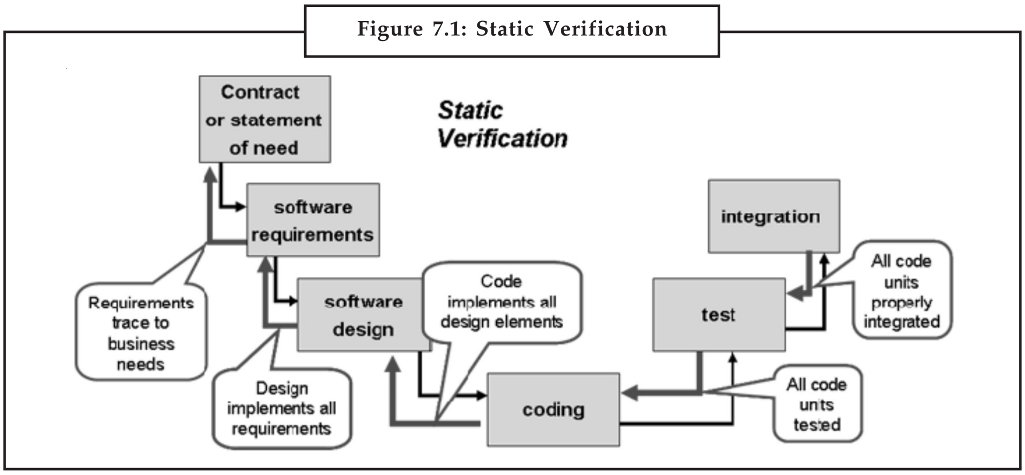
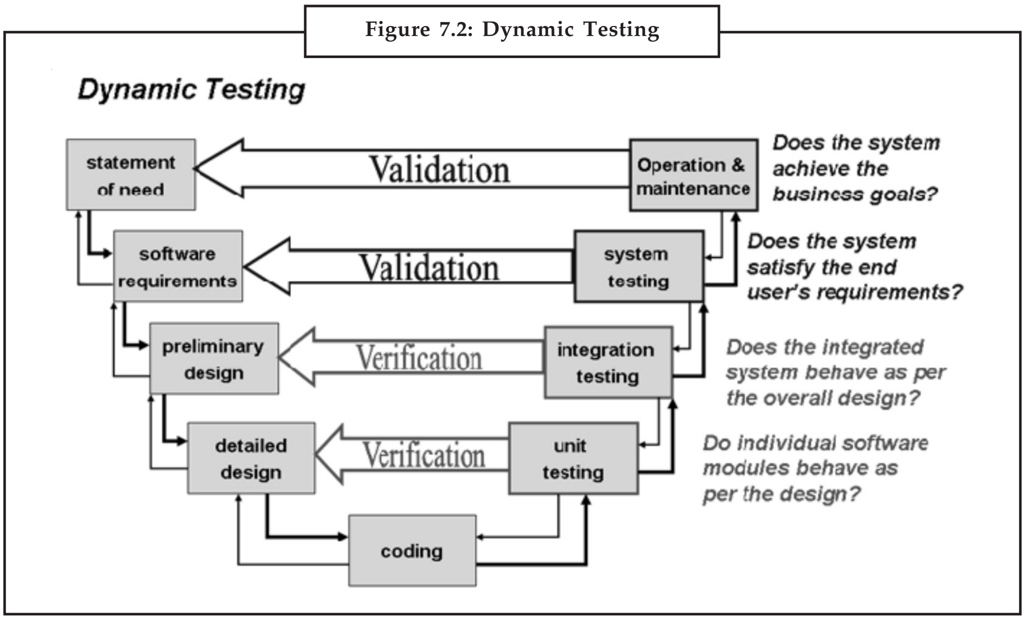

Static Verification
Contract or statement of need
software requirements
software design
coding
test
integration
Requirements trace to business needs
Design implements all requirements
Code implements all design elements
All code units tested
All code units properly integrated

Figure 7.2: Dynamic Testing


Dynamic Testing
statement of need
software requirements
preliminary design
detailed design
coding
unit testing
integration testing
system testing
Operation & maintenance
Validation
Validation
Verification
Verification
Does the system achieve the business goals?
Does the system satisfy the end user's requirements?
Does the integrated system behave as per the overall design?
Do individual software modules behave as per the design?

Source: http://www.chambers.com.au/glossary/verification_validation.php

7.1.1 Principles of Software Verification

Verification can mean the:

- act of reviewing, inspecting, testing, checking, auditing, or otherwise establishing and documenting whether items, processes, services or documents conform to specified requirements
- process of evaluating a system or component to determine whether the products of a given development phase satisfy the conditions imposed at the start of the phase
- formal proof of program correctness

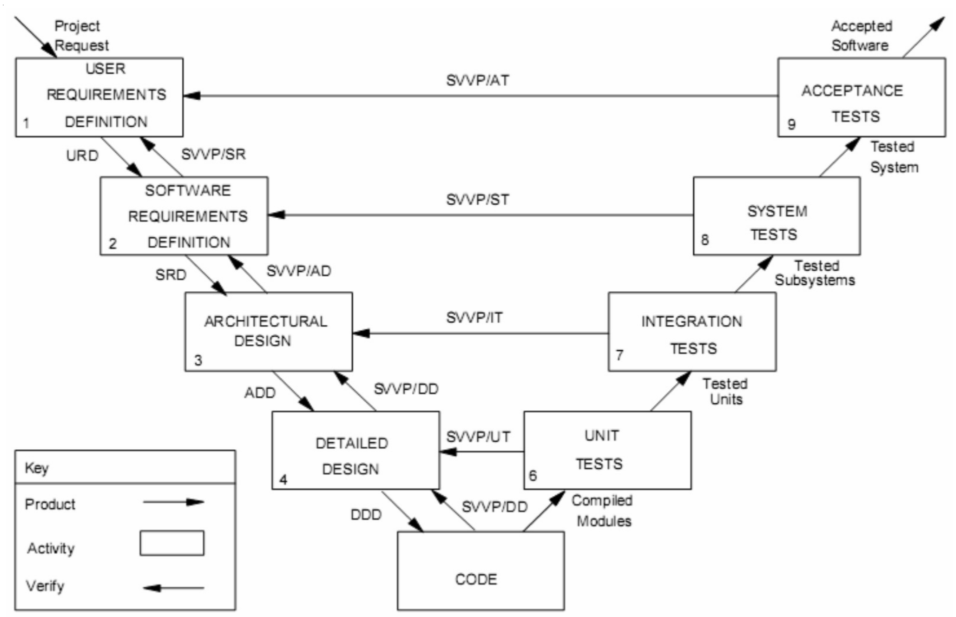
Verification activities include:

- technical reviews, walkthroughs and software inspections;
- checking that software requirements are traceable to user requirements;
- checking that design components are traceable to software

- requirements;
- unit testing;
- integration testing;
- system testing;
- acceptance testing;
- audit.

Figure 7.3 shows the life cycle verification approach.

Figure 7.3: Life Cycle Verification Approach



Source: http://cisas.unipd.it/didactics/STS_school/Software_development/Guide_to_the_SW_verification_and_validation-0510.pdf

Software development starts in the top left-hand corner, progresses down the left-hand 'specification' side to the bottom of the 'V' and then onwards up the right-hand 'production' side. The V-formation emphasises the need to verify each output specification against its input specification, and the need to verify the software at each stage of production against its corresponding specification.

Self Assessment

State whether the following statements are true or false:

1. Verification is to ensure that the software being developed implements a specific function.
2. Verification includes activities such as requirements modelling, prototyping and user evaluation.
3. Verification is achieved through dynamic analysis of documentation.
4. The V-formation emphasises the need to verify each output specification against its input specification.

Notes

7.2 Meaning of Metrics

The metric is a quantitative measure of the degree to which a system, component, or process possesses a given attribute.

Example: Number of errors

Metrics is defined as "a handle or guess about a given attribute."

Example: Number of errors found per person hours expended.

Metrics provide the insight necessary to create effective analysis and design models, solid code, and thorough tests. To be useful in a real world context, software metric must be simple and computable, persuasive, consistent, and objective.

Caution It should be programming language independent and provide effective feedback to the software engineer.

Software metrics can be defined as:

"The continuous application of measurement based techniques to the software development process and its products to supply meaningful and timely management information, together with the use of those techniques to improve that process and its products."

The most established area of software metrics is cost and size estimation techniques. The prediction of quality levels for software, often in terms of reliability, is another area where software metrics have an important role to play.

Did u know? The use of software metrics to provide quantitative checks on software design is also a well established area.

7.2.1 Advantage of Software Metrics

Software metrics is beneficial:

- In Comparative study of various design methodology of software systems.
- For analysis, comparison and critical study of various programming language with respect to their characteristics.
- In comparing and evaluating capabilities and productivity of people involved in software development.
- In the preparation of software quality specifications.
- In the verification of compliance of software systems requirements and specifications.
- In making inference about the effort to be put in the design and development of the software systems.
- In getting an idea about the complexity of the code.
- In taking decisions regarding further division of complex module is to be done or not.
- In providing guidance to resource manager for their proper utilization.

- In comparison and making design trade-offs between software development and maintenance cost.
- In providing feedback to software managers about the progress and quality during various phases of software development life cycle.
- In allocation of testing resources for testing the code.

7.2.2 Limitation of Software Metrics

- The application of software metrics is not always easy and in some cases it is difficult and costly.
- The verification and justification of software metrics is based on historical/empirical data
- whose validity is difficult to verify.
- These are useful for managing the software products but not for evaluating performance of the technical staff.
- The definition and derivation of Software metrics is generally based on assuming which are not standardized and may depend upon tools available and working environment.
- Most of the predictive models rely on estimates of certain variables which are often not known exactly.
- Most of the software development models are probabilistic and empirical.

Task Analyse the importance of software metrics.

7.2.3 Network Metrics

Network metrics focus on the structure chart of a system. They attempt to define how "good" the structure or network is in an effort to quantify the complexity of the call graph. The simplest structure occurs if the call graph is a tree. As a result, the graph impurity (deviation of the tree) is defined as nodes - edges – 1. In the case of a tree, this metric produces the result zero since there is always one more node in a tree than edges.

Notes This metric is designed to make you examine nodes that have high coupling and see if there are ways to reduce this coupling.

7.2.4 Stability Metrics

Stability of a design is a metric that tries to quantify the resistance of a design to the potential ripple effects that are caused by changes in modules. The creators of this metric argue that the higher the stability of a design, the easier it is to maintain the resulting system. This provides a stability value for each particular module.

Caution The lower the amount of coupling between modules, the higher the stability of the overall system.

Notes

7.2.5 Information Flow Metrics

Information flow metrics attempt to define the complexity of a system in terms of the total amount of information flowing through its modules. Information Flow metrics deal with complexity by observing the flow of information among system components or modules.

This metrics is based on the measurement of the information flow among system modules.

Did u know? It is sensitive to the complexity due to interconnection among system component.

This measure includes complexity of a software module is defined to be the sum of complexities of the procedures included in the module. A procedure contributes complexity due to the following two factors.

1. The complexity of the procedure code itself.
2. The complexity due to procedure's connections to its environment. The effect of the first factor has been included through LOC (Lin Of Code) measure. For the quantification of second factor, Henry and Kafura have defined two terms, namely FAN-IN and FAN-OUT.

FAN-IN of a procedure is the number of local flows into that procedure plus the number of data structures from which this procedure retrieve information. FAN – OUT is the number of local flows from that procedure plus the number of data structures which that procedure updates.

Procedure Complexity = Length * (FAN-IN * FAN-OUT)**2

Where the length is taken as LOC and the term FAN-IN

FAN-OUT represent the total number of input-output combinations for the procedure.

Task Make distinction between FAN-IN and FAN-OUT.

Self Assessment

Fill in the blanks:

5. The .... is a quantitative measure of the degree to which a system, component, or process possesses a given attribute.
6. .... metrics attempt to define how "good" the structure or network is in an effort to quantify the complexity of the call graph.
7. .... of a design is a metric that tries to quantify the resistance of a design to the potential ripple effects that are caused by changes in modules.
8. .... metrics attempt to define the complexity of a system in terms of the total amount of information flowing through its modules.
9. .... of a procedure is the number of local flows into that procedure plus the number of data structures from which this procedure retrieve information.
10. .... represent the total number of input-output combinations for the procedure.

7.3 Summary

- Verification includes all the activities associated with the producing high quality software: testing, inspection, design analysis, specification analysis, and so on.
- In a traditional phased software lifecycle, verification is often taken to mean checking that the products of each phase satisfy the requirements of the previous phase.
- Validation involves making subjective assessments of how well the (proposed) system addresses a real-world need.
- Software V&V is a systems engineering discipline which evaluates the software in a systems context, relative to all system elements of hardware, users, and other software.
- The metric is a quantitative measure of the degree to which a system, component, or process possesses a given attribute.
- Network metrics focus on the structure chart of a system. They attempt to define how "good" the structure or network is in an effort to quantify the complexity of the call graph.
- Stability of a design is a metric that tries to quantify the resistance of a design to the potential ripple effects that are caused by changes in modules.
- Information flow metrics attempt to define the complexity of a system in terms of the total amount of information flowing through its modules.

7.4 Keywords

FAN-IN: FAN-IN of a procedure is the number of local flows into that procedure plus the number of data structures from which this procedure retrieve information.

FAN-OUT: FAN-OUT is the number of local flows from that procedure plus the number of data structures which that procedure updates.

Information Flow Metrics: Information flow metrics attempt to define the complexity of a system in terms of the total amount of information flowing through its modules.

Metric: The metric is a quantitative measure of the degree to which a system, component, or process possesses a given attribute.

Network Metrics: Network metrics attempt to define how "good" the structure or network is in an effort to quantify the complexity of the call graph.

Stability Metric: Stability of a design is a metric that tries to quantify the resistance of a design to the potential ripple effects that are caused by changes in modules.

V&V: Software V&V is a systems engineering discipline which evaluates the software in a systems context, relative to all system elements of hardware, users, and other software.

Verification: Verification is an act of reviewing, inspecting, testing, checking, auditing, or otherwise establishing and documenting whether items, processes, services or documents conform to specified requirements.

7.5 Review Questions

1. What do you mean by verification? Illustrate with example.
2. Describe how can you achieve verification through Static Verification.

Notes

3. Discuss the principles of verification.
4. Explain the life cycle of verification approach.
5. Describe the concept of software metrics.
6. Discuss the advantages and disadvantages of software metrics.
7. Explain the functions of network metrics.
8. The higher the stability of a design, the easier it is to maintain the resulting system. Comment.
9. Discuss the concept of information flow metrics.
10. Compare and contrast network metrics and information flow metrics.

Answers: Self Assessment

1. True
2. False
3. False
4. True
5. metric
6. Network
7. Stability
8. Information flow
9. FAN-IN
10. FAN-OUT

7.6 Further Readings

Books

Rajib Mall, *Fundamentals of Software Engineering*, 2nd Edition, PHI.

Richard Fairpy, *Software Engineering Concepts*, Tata McGraw Hill, 1997.

R.S. Pressman, *Software Engineering – A Practitioner's Approach*, 5th Edition, Tata McGraw Hill Higher education.

Sommerville, *Software Engineering*, 6th Edition, Pearson Education

Online links

http://www.ijcem.org/papers12011/12011_14.pdf

http://www.slideshare.net/koolkampus/verification-and-validation-in-software-engineering-se19

http://ti.arc.nasa.gov/tech/rse/publications/vnv/

Unit 8: Detailed Design

CONTENTS

Objectives

Introduction

8.1 Concept of Detailed Design

8.1.1 Design Documentation

8.2 Process Design Language

8.3 Logic and Algorithm Design

8.3.1 Verification of Logic and Algorithm Design

8.4 Summary

8.5 Keywords

8.6 Review Questions

8.7 Further Readings

Objectives

After studying this unit, you will be able to:

- Discuss the concept of detailed design
- Explain process design language
- Describe the concept of logic/algorithm design
- Discuss verification of logic/algorithm design

Introduction

Detailed design of the system is the last design activity before implementation begins. The hardest design problems must be addressed by the detailed design or the design is not complete. The detailed design is still an abstraction as compared to source code, but should be detailed enough to ensure that translation to source is a precise mapping instead of a rough interpretation.

The detailed design should represent the system design in a variety of views where each view uses a different modeling technique. By using a variety of views, different parts of the system can be made clearer by different views. Some views are better at elaborating a systems states whereas other views are better at showing how data flows within the system. Other views are better at showing how different system entities relate to each through class taxonomies for systems that are designed using an object-oriented approach. A template for detailed design would not be of much use since each detailed design is likely to be unique and quite different from other designs.

8.1 Concept of Detailed Design

Once high-level design is done, you have:

- a graphical representation of the structure of your software system

Notes

- a document that defines high-level details of each module in your system, including
- a module's interface (including input and output data types)
- notes on possible algorithms or data structures the module can use to meet its responsibilities a list of any non-functional requirements that might impact the module.

After high-level design, a designer's focus shifts to low-level design

- Each module's responsibilities should be specified as precisely as possible
- Constraints on the use of its interface should be specified
- pre- and post-conditions can be identified
- module-wide invariants can be specified
- internal data structures and algorithms can be suggested.

A designer must exhibit caution, however, to not over specify a design

- as a result, we do not want to express a module's detailed design using a programming language
- you would naturally end up implementing the module perhaps unnecessarily constraining the approaches a developer would use to accomplish the same job
- nor do we (necessarily) want to use only natural language text to specify a module's detailed design
- natural language text slips too easily towards ambiguity

8.1.1 Design Documentation

The design specification contains various aspects of the design model and is completed as the designer improves his software representation. At first, the design specification derives its scope from System specification and the analysis model.

At the next level data design is specified. The data design includes database structure, external file structure, internal data structures and reference connecting data objects to files.

The design specification contains requirements cross reference represented as a simple matrix.

Did u know? The purpose of this matrix is:

(i) to ensure that the design includes all the requirements, and

(ii) to indicate the critical components for the implementation purpose.

The design document may also contain the first stage of test documentation. After the program structure and the interfaces have been established, guidelines to test individual and integrated modules are developed.

Design constraints such as limited physical memory or special external interface can cause special design techniques to evolve which in turn will lead to changes in software package.

The final section of the design specification contains supplementary data such as algorithm description, tabular data, excerpts from other documents, etc.

Self Assessment

Fill in the blanks:

1. The design .... contains various aspects of the design model and is completed as the designer improves his software representation.
2. The .... includes database structure, external file structure, internal data structures and reference connecting data objects to files.
3. The design specification contains requirements cross reference represented as a simple ....

8.2 Process Design Language

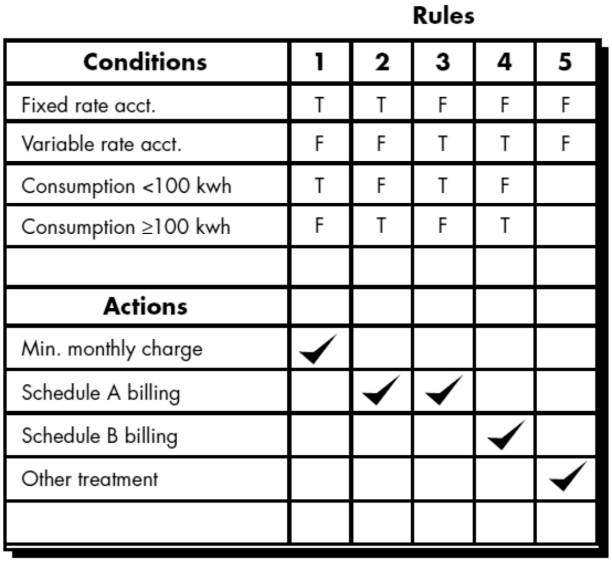
Process Design Language (PDL), also called structured English or pseudocode, is "a pidgin language in that it uses the vocabulary of one language (i.e., English) and the overall syntax of another (i.e., a structured programming language)".

At first glance PDL looks like a modern programming language. The difference between PDL and a real programming language lies in the use of narrative text (e.g., English) embedded directly within PDL statements.

Caution Given the use of narrative text embedded directly into a syntactical structure, PDL cannot be compiled (at least not yet).

However, PDL tools currently exist to translate PDL into a programming language "skeleton" and/or a graphical representation (e.g., a flowchart) of design. These tools also produce nesting maps, a design operation index, cross-reference tables, and a variety of other information.

Figure 8.1: Resultant Decision Table



	Rules				
Conditions	**1**	**2**	**3**	**4**	**5**
Fixed rate acct.	T	T	F	F	F
Variable rate acct.	F	F	T	T	F
Consumption <100 kwh	T	F	T	F	
Consumption ≥100 kwh	F	T	F	T	
Actions					
Min. monthly charge	✓				
Schedule A billing		✓	✓		
Schedule B billing				✓	
Other treatment					✓

A program design language may be a simple transposition of a language such as Ada or C. Alternatively, it may be a product purchased specifically for procedural design.

Notes

Regardless of origin, a design language should have the following characteristics:

- A fixed syntax of keywords that provide for all structured constructs, data declaration, and modularity characteristics.
- A free syntax of natural language that describes processing features.
- Data declaration facilities that should include both simple (scalar, array) and complex (linked list or tree) data structures.
- Subprogram definition and calling techniques that support various modes of interface description.

A basic PDL syntax should include constructs for subprogram definition, interface description, data declaration, techniques for block structuring, condition constructs, repetition constructs, and I/O constructs.

Notes It should be noted that PDL can be extended to include keywords for multi-tasking and/or concurrent processing, interrupt handling, inter-process synchronization, and many other features.

The application design for which PDL is to be used should dictate the final form for the design language.

Example: To illustrate the use of PDL, we present an example of a procedural design for the SafeHome security system software. The system monitors alarms for fire, smoke, burglar, water, and temperature (e.g., furnace breaks while homeowner is away during winter) and produces an alarm bell and calls a monitoring service, generating a voice-synthesized message. In the PDL that follows, we illustrate some of the important constructs noted in earlier sections.

Recall that PDL is not a programming language. The designer can adapt as required without worry of syntax errors. However, the design for the monitoring software would have to be reviewed (do you see any problems?) and further refined before code could be written. The following PDL defines an elaboration of the procedural design for the security monitor component.

PROCEDURE security.monitor;

INTERFACE RETURNS system.status;

TYPE signal IS STRUCTURE DEFINED

name IS STRING LENGTH VAR;

address IS HEX device location;

```
     bound.value IS upper bound SCALAR: message
   IS STRING LENGTH VAR: END signal TYPE:
 TYPE system.status IS BIT (4):
 TYPE alarm.type DEFINED
     smoke.alarm IS INSTANCE OF signal:
     fire.alarm IS INSTANCE OF signal:
     water.alarm IS INSTANCE OF signal:
     temp.alarm IS INSTANCE OF signal:
     burglar.alarm IS INSTANCE OF signal:
 TYPE phone.number IS area code + 7-digit
     number: o
                                   o
                                   o
```

```
initialize all system ports and reset all
hardware: CASE OF control.panel.switches
(cps):
     WHEN cps = "test" SELECT
        CALL alarm PROCEDURE WITH "on" for test.time in seconds:
     WHEN cps = "alarm-off" SELECT
        CALL alarm PROCEDURE WITH "off": WHEN cps =
     "new.bound.temp" SELECT CALL keypad.input
     PROCEDURE:
     WHEN cps = "burglar.alarm.off" SELECT deactivate signal
     [burglar.alarm]: o
     o
     o
     DEFAULT none: ENDCASE
REPEAT UNTIL activate.switch is turned off
     reset all signal.values and switches:
     DO FOR alarm.type = smoke, fire, water, temp, burglar:
        READ address [alarm.type] signal.value:
        IF signal.value > bound [alarm.type]
        THEN phone.message = message [alarm.type]:
               set alarm.bell to "on" for alarm.timeseconds:
               PARBEGIN
               CALL alarm PROCEDURE WITH "on", alarm.time in seconds:
               CALL phone PROCEDURE WITH message [alarm.type],
                  phone.number:
               ENDPAR
        ELSE skip ENDIF
     ENDFOR
ENDREP
END security.monitor
```

Note that the designer for the *security.monitor* component has used a new construct PARBEGIN . . . ENDPAR that specifies a parallel block. All tasks specified within the PARBEGIN block are executed in parallel. In this case, implementation details are not considered.

Task Make distinction between PDL and a real programming language.

Self Assessment

Fill in the blanks:

4. ………………….. is "a pidgin language in that it uses the vocabulary of one language and the overall syntax of another.

5. PDL ………………….. currently exist to translate PDL into a programming language "skeleton" and/or a graphical representation of design.

6. A basic PDL ………………….. should include constructs for subprogram definition, interface description, data declaration, etc.

8.3 Logic and Algorithm Design

Logic and Algorithms design covers Algorithmic and Computational Logic, and is the scientific foundation for constructing robust, efficient, and intelligent software applications based on mathematically sound solutions. Large data sets and basically hard problems are the two crucial aspects when designing efficient software. Usually, the naive algorithm or data structure can suffices for resolving minor problems. On a personal computer, a simple search engine can easily index the contents of a drive, but indexing the web is much more problematic. Likewise, an autonomous robot can design its actions optimally by an exhaustive state space search only if the number of possible actions and states is very inadequate. Consequently, more advanced methods are required to resolve these difficulties. Often some degree of intelligence is required in addition to efficiency in software applications for complex problems. Intelligence implies that the software is capable to collect and categorise knowledge, learn from experiences, do logical reasoning, and communicate and negotiate with other software applications.

Did u know? The scientific foundation for such applications comprises of logic-based AI and computational logic.

Algorithmic: An algorithm is a procedure to accomplish a specific task. An algorithm is the idea behind any reasonable computer program. Algorithmic is the systematic development of efficient algorithms and therefore has pivotal influence on the effective development of reliable and resource-conserving technology. An algorithmic problem is specied by describing the complete set of instances it must work on and of its output after running on one of these instances. This distinction, between a problem and an instance of a problem, is fundamental.

Computational Logic: Computational logic is the use of logic to perform or reason about computation. It bears a similar relationship to computer science and engineering as mathematical logic bears to mathematics and as philosophical logic bears to philosophy. It is synonymous with "logic in computer science". Computational Logic plays an important role in many areas of computer science, including verification of hardware and software, programming languages, databases and Artificial Intelligence.

In detailed design the basic aim is to identify the logic for the various modules that have been stated during system design. Stating the logic will necessitate developing an algorithm that will implement the given specifications. Now we contemplate certain principles for designing algorithms or logic that will apply the given conditions.

The term algorithm is relatively general and is applicable to wide-ranging areas. We can consider for software an algorithm to be an explicit procedure for solving a problem. A procedure is a finite sequence of well-defined steps or operations, each of which requires a memory time to complete and finite amount of. In this explanation we see that termination is a vital property of procedures. From now, we will use algorithms, logic, and procedures interchangeably.

Algorithm is a step-by-step finite sequence of instruction, to solve a well-defined computational problem. That is, in practice to solve any complex real life problems; first we have to define the problems. Second step is to design the algorithm to solve that problem. Writing and executing programs and then optimizing them may be effective for small programs. Optimization of a program is directly concerned with algorithm design. But for a large program, each part of the program must be well organized before writing the program. There are few steps of refinement involved when a problem is converted to program; this method is called step-wise refinement method. There are two approaches for algorithm design; they are top-down and bottom-up algorithm design.

Caution Once the algorithm is designed, its correctness should be verified.

We can write an informal algorithm, if we have an appropriate mathematical model for a problem. The initial version of the algorithm will contain general statements, i.e.,; informal instructions. Then we convert this informal algorithm to formal algorithm, that is, more definite instructions by applying any programming language syntax and semantics partially. Finally a program can be developed by converting the formal algorithm by a programming language manual. From the above discussion we have understood that there are several steps to reach a program from a mathematical model. In every step there is a refinement (or conversion). That is to convert an informal algorithm to a program, we must go through several stages of formalization until we arrive at a program—whose meaning is formally defined by a programming language manual—is called step-wise refinement techniques. There are three steps in refinement process:

1. In the first stage, modelling, we try to represent the problem using an appropriate mathematical model such as a graph, tree, etc. At this stage, the solution to the problem is an algorithm expressed very informally.
2. At the next stage, the algorithm is written in pseudo-language (or formal algorithm) that is, a mixture of any programming language constructs and less formal English statements. The operations to be performed on the various types of data become fixed.
3. In the final stage we choose an implementation for each abstract data type and write the procedures for the various operations on that type. The remaining informal statements in the pseudo-language algorithm are replaced by (or any programming language) C/C++ code.

Task Analyse various guidelines used for refinement technique.

8.3.1 Verification of Logic and Algorithm Design

The output of the system design phase should be verified specifically before continuing with the actions of the next phase. Unless the design is specified in a formal executable language, the design cannot be executed for verification. Other means for verification have to be used. The most common approach for verification is design reviews or inspections.

Example: Those modules used by another are defined, the interface of a module is consistent with the way others use it, data usage is consistent with declaration, etc.

Design cannot be processed through tools if it is not specified in a formal and executable language and other means for verification have to be used. The most common approach for verification is design review.

The aim of design reviews is to make sure that the design fulfils the necessities and is of good quality. If errors are made during the design process, they will reflect themselves in the end in the code and the final system. The system design review process is similar to the other reviews. In system design review a group of people get together to discuss the design with the aim of revealing design errors or undesirable properties. The review group must include a member of both the system design team and the detailed design team, the author of the requirements document, the author responsible for maintaining the design document and an independent software quality engineer. The review can be held in the same manner as the requirement review. The aim of meeting is to uncover design errors not to fix them; fixing is done later. The meeting ends with a list of action items, which are later acted on the design team. The number of ways in which errors can come in a design is limited only by the creativity of the designer.

Notes For design quality, modularity is the main criterion. However, since there is a need to validate whether performance requirements can be met by a design, efficiency is another key property for which a design is evaluated.

Self Assessment

Fill in the blanks:

7. ………………….. constitutes the scientific foundation for reasoning about resources used in computing such as time and space.

8. ………………….. is the study of logic and logical methods within computer science.

9. ………………….. is the study of valid inferences, and in computational logic it is studies how to automate such inferences on a computer.

10. The basic goal in ………………….. is to specify the logic for the different modules that have been specified during system design.

11. The step-wise ………………….. technique breaks the logic design problem into a series of steps, so that the development can be done gradually.

12. The purpose of design ………………….. is to ensure that the design satisfies the requirements and is of good quality.

8.4 Summary

- The design specification contains various aspects of the design model and is completed as the designer improves his software representation.
- The data design includes database structure, external file structure, internal data structures and reference connecting data objects to files.
- Process Design Language (PDL), also called structured English or pseudocode, is "a pidgin language in that it uses the vocabulary of one language (i.e., English) and the overall syntax of another (i.e., a structured programming language)".
- A basic PDL syntax should include constructs for subprogram definition, interface description, data declaration, techniques for block structuring, condition constructs, repetition constructs, and I/O constructs.
- The application design for which PDL is to be used should dictate the final form for the design language.
- A program design language may be a simple transposition of a language such as Ada or C.
- Computational logic is the study of logic and logical methods within computer science.
- The purpose of design reviews is to ensure that the design satisfies the requirements and is of good quality.

8.5 Keywords

Algorithmic: Algorithmic is the systematic development of efficient algorithms and therefore has pivotal influence on the effective development of reliable and resource-conserving technology.

Computational Logic: It is the study of logic and logical methods within computer science.

Logic: Logic is the study of valid inferences, and in computational logic it is studies how to automate such inferences on a computer.

PDL: Process Design Language (PDL), also called structured English or pseudocode, is "a pidgin language in that it uses the vocabulary of one language and the overall syntax of another.

8.6 Review Questions

1. Explain the concept of detailed design.
2. What is the purpose of the matrix included in design specification?
3. What is Process Design Language (PDL)? Discuss.
4. Illustrate the concept of Process Design Language (PDL) with example.
5. Discuss the characteristics of Process Design Language (PDL).
6. Discuss the format and semantics for some of these PDL constructs.
7. Explain the use of Algorithms and Logic design for constructing efficient, and intelligent software application.
8. Describe the goal of detailed design.
9. Discuss the verification of logic and algorithm design.
10. Given the use of narrative text embedded directly into a syntactical structure, PDL cannot be compiled. Comment.

Answers: Self Assessment

1. specification
2. data design
3. matrix
4. Process design language (PDL)
5. tools
6. Syntax
7. Algorithmic
8. Computational logic
9. Logic
10. detailed design
11. refinement
12. reviews

8.7 Further Readings

Books

Rajib Mall, *Fundamentals of Software Engineering*, 2nd Edition, PHI.

Richard Fairpy, *Software Engineering Concepts*, Tata McGraw Hill, 1997.

R.S. Pressman, *Software Engineering – A Practitioner's Approach*, 5th Edition, Tata McGraw Hill Higher education.

Sommerville, *Software Engineering*, 6th Edition, Pearson Education

Online links

http://www.cs.colorado.edu/~kena/classes/5828/s07/lectures/21/lecture21.pdf

http://wwwis.win.tue.nl/2R690/projects/spingrid/ddd.pdf

http://programmers.stackexchange.com/questions/19592/what-is-detailed-design-what-are-the-advantage-disadvantages-using-it

Notes

Unit 9: Metrics

CONTENTS

Objectives

Introduction

9.1 Cyclomatic Complexity

9.1.1 Variations: CC, CC2 and CC3

9.1.2 Values of Cyclomatic Complexity

9.1.3 Cyclomatic Complexity and Select Case

9.1.4 Total Cyclomatic Complexity (TCC)

9.1.5 DECDENS (Decision Density)

9.2 Data Binding Metrics

9.3 Cohesion Metrics

9.3.1 The idea of the cohesive class

9.3.2 Lack of Cohesion of Methods (LCOM)

9.3.3 Tight and Loose Class Cohesion (TCC and LCC)

9.3.4 Validity of Cohesion

9.4 Summary

9.5 Keywords

9.6 Review Questions

9.7 Further Readings

Objectives

After studying this unit, you will be able to:

- Discuss the concept of cyclomatic complexity
- Explain data binding metrics
- Discuss cohesion metrics

Introduction

Metrics are meaningful only if they have been examined for statistical validity. The control chart is a simple method for accomplishing this and at the same time examining the variation and location of metrics results. Measurement results in cultural change. Data collection, metrics computation, and metrics analysis are the three steps that must be implemented to begin a metrics program. In general, a goal-driven approach helps an organization focus on the right metrics for its business. By creating a metrics baseline a database containing process and product measurements software engineers and their managers can gain better insight into the work that they do and the product that they produce. An indicator is a metric or combination of metrics that provide insight into the software process, a software project, or the product itself. An

Notes

indicator provides insight that enables the project manager or software engineers to adjust the process, the project, or the process to make things better.

9.1 Cyclomatic Complexity

It is invented by Thomas McCabe (1974) to measure the complexity of a program's conditional logic. It counts the number of decisions in the program, under the assumption that decisions are difficult for people. It makes assumptions about decision-counting rules and linear dependence of the total count to complexity.

Cyclomatic complexity, also known as V(G) or the graph theoretic number, is probably the most widely used complexity metric in software engineering. Defined by Thomas McCabe, it's easy to understand and calculate, and it gives useful results. This metric considers the control logic in a procedure. It's a measure of structural complexity. Low complexity is desirable.

How to calculate cyclomatic complexity?

CC = Number of decisions + 1

The cyclomatic complexity of a procedure equals the number of decisions plus one. What are decisions? Decisions are caused by conditional statements. In Visual Basic they are If..ElseIf..Else, Case, For..Next, Until, While, Catch and When. In order to get CC, one simply counts the conditional statements. A multi-way decision, the Select Case block, typical counts as several conditional statements. The decisions counted for each statement or construct are listed below.

Table 9.1: Decisions Counted for each Statement

Construct	Decisions	Reasoning
If..Then	+1	An "If statement" is a single decision.
ElseIf..Then	+1	ElseIf adds a new decision.
Else	0	Else does not cause a new decision. The decision is at the If.
#If..#ElseIf..#Else	0	Conditional compilation adds no run-time decisions.
Select Case	0	Select Case initiates the following Case branches, but does not add a decision alone.
Case	+1	Each Case branch adds a new decision.
Case Else	0	Case Else does not cause a new decision. The decisions were made at the other Cases.
For [Each] .. Next	+1	There is a decision at the For statement.
Do While | Until	+1	There is a decision at the start of the Do..Loop.
Loop While | Until	+1	There is a decision at the end of the Do..Loop.
Do..Loop alone	0	There is no decision in an unconditional Do..Loop without While or Until.*
While	+1	There is a decision at the start of the While..Wend or While..End While loop.
Catch	+1	Each Catch branch adds a new conditional path of execution. Even though a Catch can be either conditional (catches specific exceptions) or unconditional (catches all exceptions), we treat all of them the same way.*
Catch..When	+2	The When condition adds a second decision.*

* Rules marked with an asterisk were added into Project Analyzer v8.0. Previous versions did not take these rules into account.

The minimum limit for cyclomatic complexity is 1. This happens with a procedure having no decisions at all. There is no maximum value since a procedure can have any number of decisions.

Notes

- A Case branch can cover several alternative values or ranges, such as Case 1, 2, 5 to 10. As they introduce no additional branches to decide on, they do not increase cyclomatic complexity either.
- Cyclomatic complexity does not consider if any decisions actually happen at run-time. A conditional statement can be unconditional in reality. This happens with constant decisions such as If True Then. This kind of an "unconditional condition" counts as a regular decision in cyclomatic complexity, even when there is only one path to take, really.
- Multiple exits do not increase complexity. A procedure with a single exit is as complex as one with multiple exits.
- Exit statements (Exit Do, Exit Sub, Return, End, and similar) do not increase cyclomatic complexity. They are not decisions, but jumps. Complexity-wise, exit statements are similar to GoTo statements, with the target being either end-of-structure or end-of-procedure.
- Yield statements do not increase cyclomatic complexity. Yield, new in VB2012, is like a procedure call, but backwards, back to the caller procedure. Execution potentially continues with the statement following Yield. If it doesn't, Yield is just a special exit, which doesn't increase cyclomatic complexity either.

9.1.1 Variations: CC, CC2 and CC3

Cyclomatic complexity comes in a couple of variations as to what exactly counts as a decision. Project Analyzer supports three alternative cyclomatic complexity metrics. CC is the basic version. CC2 and CC3 use slightly different rules.

CC does not count Boolean operators such as And and Or. Boolean operators add internal complexity to the decisions, but they are not counted in CC. CC and CC3 are similar what comes to Booleans, but CC2 is different.

CC2 Cyclomatic Complexity with Booleans ("Extended Cyclomatic Complexity")

CC2 = CC + Boolean operators

CC2 extends cyclomatic complexity by including Boolean operators in the decision count. Whenever a Boolean operator (And, Or, Xor, Eqv, AndAlso, OrElse) is found within a conditional statement, CC2 increases by one. The statements considered are: If, ElseIf, Select, Case, Until, While, When.

The reasoning behind CC2 is that a Boolean operator increases the internal complexity of a decision. CC2 counts the "real" number of decisions, regardless of whether they appear as a single conditional statement or split into several statements. Instead of using Boolean operators to combine decisions into one (x = 1 And y = 2), you could as well split the decisions into several sub-conditions (If x = 1 Then If y = 2 Then). CC2 is immune to this kind of restructuring, which might be well justified to make the code more readable. On the other hand, one can decrease CC simply by combining decisions with Boolean operators, which may not make sense.

Including Boolean operators in cyclomatic complexity was originally suggested by Thomas McCabe. In this sense, both CC and CC2 are "original" cyclomatic complexity measures.

Alternative names: CC2 is also known as ECC extended cyclomatic complexity or strict cyclomatic complexity.

Notes A Case branch can cover several alternative values or ranges, such as Case 1, 2, 5 to 10. These are not counted in CC2, even if they add internal complexity to the decision, quite the same way as the Or operator does in an If statement. A Case with several alternatives (Case 1, 2, 3) is usually simpler than the same decision as an If statement (If x = 1 Or x = 2 Or x = 3 Then). A Case like this will also yield a lower CC2 than the respective If. Splitting the If statement into successive If..ElseIf branches will keep CC2 unmodified, but rewriting it as a single Case will decrease CC2.

CC3 Cyclomatic Complexity without Cases ("Modified Cyclomatic Complexity")

CC3 = CC where each Select block counts as one

CC3 equals the regular CC metric, but each Select Case block is counted as one branch, not as multiple branches. In this variation, a Select Case is treated as if it were a single big decision. This leads to considerably lower complexity values for procedures with large Select Case statements. In many cases, Select Case blocks are simple enough to consider as one decision, which justifies the use of CC3.

Alternative Name: CC3 is sometimes called modified cyclomatic complexity.

Summary of cyclomatic complexity metrics is shown in the table.

Table 9.2: Summary of Cyclomatic Complexity Metrics

Metric	Name	Boolean operators	Select Case	Alternative name
CC	Cyclomatic complexity	Not counted	+1 for each Case branch	Regular cyclomatic complexity
CC2	Cyclomatic complexity with Booleans	+1 for each Boolean	+1 for each Case branch	Extended or strict cyclomatic complexity
CC3	Cyclomatic complexity without Cases	Not counted	+1 for an entire Select Case	Modified cyclomatic complexity

CC, CC2 or CC3—which one to use? This is your decision. Pick up the one that suits your use best. CC and CC2 are "original" metrics and probably more widely used than CC3. The numeric values are, in increasing order: CC3 (lowest), CC (middle) and CC2 (highest). In a sense, CC2 is the most pessimistic metric. All of them are heavily correlated, so you can achieve good results with any of them.

9.1.2 Values of Cyclomatic Complexity

A high cyclomatic complexity denotes a complex procedure that's hard to understand, test and maintain. There's a relationship between cyclomatic complexity and the "risk" in a procedure.

Notes

CC	Type of procedure	Risk
1-4	A simple procedure	Low
5-10	A well structured and stable procedure	Low
11-20	A more complex procedure	Moderate
21-50	A complex procedure, alarming	High
>50	An error-prone, extremely troublesome, untestable procedure	Very high

The original, usual limit for a maximum acceptable value for cyclomatic complexity is 10. Other values, such as 15 or 20, have also been suggested. Regardless of the exact limit, if cyclomatic complexity exceeds 20, you should consider it alarming. Procedures with a high cyclomatic complexity should be simplified or split into several smaller procedures.

Cyclomatic complexity equals the minimum number of test cases you must execute to cover every possible execution path through your procedure. This is important information for testing.

⚠ *Caution* Carefully test procedures with the highest cyclomatic complexity values.

Bad Fix Probability

There is a frequently quoted table of "bad fix probability" values by cyclomatic complexity. This is the probability of an error accidentally inserted into a program while trying to fix a previous error.

CC	Bad Fix Probability
1-10	5%
20-30	20%
>50	40%
approaching 100	60%

As the complexity reaches high values, changes in the program are likely to produce new errors.

9.1.3 Cyclomatic Complexity and Select Case

The use of multi-branch statements (Select Case) often leads to high cyclomatic complexity values. This is a potential source of confusion. Should a long multi-way selection be split into several procedures?

McCabe originally recommended exempting modules consisting of single multi-way decision statements from the complexity limit.

Although a procedure consisting of a single multi-way decision may require many tests, each test should be easy to construct and execute. Each decision branch can be understood and maintained in isolation, so the procedure is likely to be reliable and maintainable. Therefore, it is reasonable to exempt procedures consisting of a single multi-way decision statement from a complexity limit.

⚠ *Caution* If the branches of the decision statement contain complexity themselves, the rationale and thus the exemption does not automatically apply. However, if all the branches have very low complexity code in them, it may well apply.

Notes

Resolution: For each procedure, either limit cyclomatic complexity to 10 (or another sensible limit) or provide a written explanation of why the limit was exceeded.

9.1.4 Total Cyclomatic Complexity (TCC)

The total cyclomatic complexity for a project or a class is calculated as follows:

TCC = Sum(CC) - Count(CC) + 1

TCC equals the number of decisions + 1 in a project or a class. It's similar to CC but for several procedures.

Sum(CC) is simply the total sum of CC of all procedures. Count(CC) equals the number of procedures. It's deducted because we already added +1 in the formula of CC for each procedure.

TCC is immune to modularization, or the lack of modularization. TCC always equals the number of decisions + 1. It is not affected by how many procedures the decisions are distributed.

TCC can be decreased by reducing the complexity of individual procedures. An alternative is to eliminate duplicated or unused procedures.

9.1.5 DECDENS (Decision Density)

Cyclomatic complexity is usually higher in longer procedures. How much decision is there actually, compared to lines of code? This is where you need decision density, which also known as cyclomatic density.

DECDENS = Sum(CC)/LLOC

This metric shows the average cyclomatic density in your project. The numerator is sum of CC over all your procedures. The denominator is the logical lines of code metric. DECDENS ignores single-line procedure declarations since cyclomatic complexity isn't defined for them.

Did u know? DECDENS is relatively constant across projects.

A high or low DECDENS does not necessarily means anything is wrong. A low DECDENS might indicate lack of logic, such as in generated code, or code that primarily loads some data instead of performing actions.

Self Assessment

Fill in the blanks:

1. .... counts the number of decisions in the program, under the assumption that decisions are difficult for people.

2. Cyclomatic complexity is also known as ....

3. CC2 extends cyclomatic complexity by including .... operators in the decision count.

4. .... is also known as ECC extended cyclomatic complexity or strict cyclomatic complexity.

5. .... equals the regular CC metric, but each Select Case block is counted as one branch, not as multiple branches.

6. .... is simply the total sum of CC of all procedures.

Notes

9.2 Data Binding Metrics

It is a metric to capture the strength of coupling between modules in a software system. It is defined by triplet (p,x,q) where p and q are modules and X is variable within scope of both p and q.

Different types of data binding metrics are:

- ***Potential Data Binding:*** In case of potential data binding, X is declared in both, but does not check to see if accessed. It reflects possibility that p and q might communicate through the shared variable.
- ***Used Data Binding:*** It is a potential data binding where p and q use X. It is harder to compute than potential data binding and requires more information about internal logic of module.
- ***Actual Data Binding:*** It is used data binding where p assigns value to x and q references it. It is hardest to compute but indicates information flow from p to q.

The higher the value, the stronger the connection between p and q.

Task Compare and contrast potential data binding and used data binding.

Self Assessment

Fill in the blanks:

7. .... metric is a metric to capture the strength of coupling between modules in a software system.
8. In case of .... data binding, x is declared in both, but does not check to see if accessed.
9. .... data binding is a potential data binding where p and q use x.
10. .... data binding is used data binding where p assigns value to x and q references it.

9.3 Cohesion Metrics

Cohesion metrics measure how well the methods of a class are related to each other. A cohesive class performs one function. A non-cohesive class performs two or more unrelated functions. A non-cohesive class may need to be restructured into two or more smaller classes.

The assumption behind the following cohesion metrics is that methods are related if they work on the same class-level variables. Methods are unrelated if they work on different variables altogether. In a cohesive class, methods work with the same set of variables. In a non-cohesive class, there are some methods that work on different data.

9.3.1 The idea of the cohesive class

A cohesive class performs one function. Lack of cohesion means that a class performs more than one function. This is not desirable. If a class performs several unrelated functions, it should be split up.

- High cohesion is desirable since it promotes encapsulation. As a drawback, a highly cohesive class has high coupling between the methods of the class, which in turn indicates high testing effort for that class.
- Low cohesion indicates inappropriate design and high complexity. It has also been found to indicate a high likelihood of errors. The class should probably be split into two or more smaller classes.

Project Analyzer supports several ways to analyze cohesion:

- LCOM metrics Lack of Cohesion of Methods. This group of metrics aims to detect problem classes. A high LCOM value means low cohesion.
- TCC and LCC metrics: Tight and Loose Class Cohesion. This group of metrics aims to tell the difference of good and bad cohesion. With these metrics, large values are good and low values are bad.
- Cohesion diagrams visualize class cohesion.
- Non-cohesive classes report suggests which classes should be split and how.

9.3.2 Lack of Cohesion of Methods (LCOM)

There are several LCOM 'lack of cohesion of methods' metrics. Project Analyzer provides 4 variants: LCOM1, LCOM2, LCOM3 and LCOM4. We recommend the use of LCOM4 for Visual Basic systems. The other variants may be of scientific interest.

LCOM4 Recommended Metric

LCOM4 is the lack of cohesion metric we recommend for Visual Basic programs. LCOM4 measures the number of "connected components" in a class. A connected component is a set of related methods (and class-level variables). There should be only one such a component in each class. If there are 2 or more components, the class should be split into so many smaller classes.

Which methods are related? Methods a and b are related if:

- they both access the same class-level variable, or
- a calls b, or b calls a.

After determining the related methods, we draw a graph linking the related methods to each other. LCOM4 equals the number of connected groups of methods.

- LCOM4=1 indicates a cohesive class, which is the "good" class.
- LCOM4>=2 indicates a problem. The class should be split into so many smaller classes.
- LCOM4=0 happens when there are no methods in a class. This is also a "bad" class.

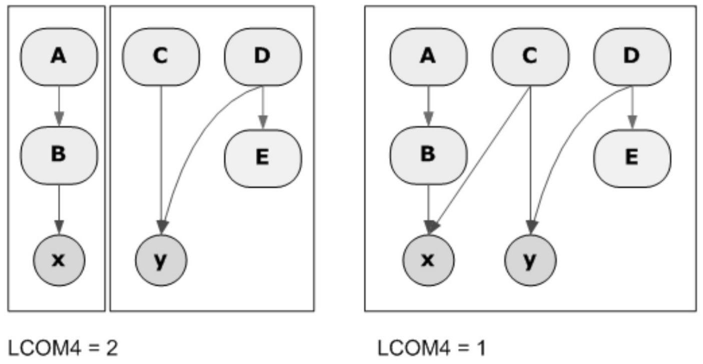
Example: The example on the left shows a class consisting of methods A through E and variables x and y. A calls B and B accesses x. Both C and D access y. D calls E, but E doesn't access any variables.

This class consists of 2 unrelated components (LCOM4=2). You could split it as {A, B, x} and {C, D, E, y}.

In the example on the right, we made C access x to increase cohesion.

Now the class consists of a single component (LCOM4=1). It is a cohesive class.

Figure 9.1: Example of LCOM4



It is to be noted that UserControls as well as VB.NET forms and web pages frequently report high LCOM4 values. Even if the value exceeds 1, it does not often make sense to split the control, form or web page as it would affect the user interface of your program. The explanation with UserControls is that they store information in the underlying UserControl object. The explanation with VB.NET is the form designer generated code that you cannot modify.

Implementation Details for LCOM4

We use the same definition for a method as with the WMC metric. This means that property accessors are considered regular methods, but inherited methods are not taken into account. Both Shared and non-Shared variables and methods are considered. We ignore empty procedures, though. Empty procedures tend to increase LCOM4 as they do not access any variables or other procedures. A cohesive class with empty procedures would have a high LCOM4. Sometimes empty procedures are required (for classic VB implements, for example). This is why we simply drop empty procedures from LCOM4. We also ignore constructors and destructors (Sub New, Finalize, Class_Initialize, Class_Terminate). Constructors and destructors frequently set and clear all variables in the class, making all methods connected through these variables, which increases cohesion artificially.

9.3.3 Tight and Loose Class Cohesion (TCC and LCC)

The metrics TCC (Tight Class Cohesion) and LCC (Loose Class Cohesion) provide another way to measure the cohesion of a class. The TCC and LCC metrics are closely related to the idea of LCOM4, even though are some differences.

Did u know? The higher TCC and LCC, the more cohesive and thus better the class.

For TCC and LCC we only consider visible methods (whereas the LCOMx metrics considered all methods). A method is visible unless it is Private. A method is visible also if it implements an interface or handles an event. In other respects, we use the same definition for a method as for LCOM4.

Which methods are related? Methods a and b are related if:

1. They both access the same class-level variable, or
2. The call trees starting at a and b access the same class-level variable. For the call trees we consider all procedures inside the class, including Private procedures. If a call goes outside the class, we stop following that call branch.

When 2 methods are related this way, we call them directly connected.

When 2 methods are not directly connected, but they are connected via other methods, we call them indirectly connected.

Example: A – B – C are direct connections. A is indirectly connected to C (via B).

TCC and LCC definitions

NP = maximum number of possible connections= N * (N-1)/2 where N is the number of methods. NDC = number of direct connections (number of edges in the connection graph)NID = number of indirect connections. Tight class cohesion TCC = NDC/NP Loose class cohesion LCC = (NDC+NIC)/NP

TCC is in the range 0..1.
LCC is in the range 0..1. TCC<=LCC.

The higher TCC and LCC, the more cohesive the class is.

What are good or bad values? According to the authors, TCC<0.5 and LCC<0.5 are considered non-cohesive classes. LCC=0.8 is considered "quite cohesive". TCC=LCC=1 is a maximally cohesive class: all methods are connected. As the authors Bieman & Kang stated: If a class is designed in ad hoc manner and unrelated components are included in the class, the class represents more than one concept and does not model an entity. A class designed so that it is a model of more than one entity will have more than one group of connections in the class. The cohesion value of such a class is likely to be less than 0.5.

LCC tells the overall connectedness. It depends on the number of methods and how they group together.

- When LCC=1, all the methods in the class are connected, either directly or indirectly. This is the cohesive case.
- When LCC<1, there are 2 or more unconnected method groups. The class is not cohesive. You may want to review these classes to see why it is so. Methods can be unconnected because they access no class-level variables or because they access totally different variables.
- When LCC=0, all methods are totally unconnected. This is the non-cohesive case.

TCC tells the "connection density", so to speak (while LCC is only affected by whether the methods are connected at all).

- TCC=LCC=1 is the maximally cohesive class where all methods are directly connected to each other.
- When TCC=LCC<1, all existing connections are direct (even though not all methods are connected).
- When TCC<LCC, the "connection density" is lower than what it could be in theory. Not all methods are directly connected with each other.

Example: A & B are connected through variable x and B & C through variable y. A and C do not share a variable, but they are indirectly connected via B.

- When TCC=0 (and LCC=0), the class is totally non-cohesive and all the methods are totally unconnected.

Notes

Example: The example on the left shows the same class as above. The connections considered are marked with thick violet lines.

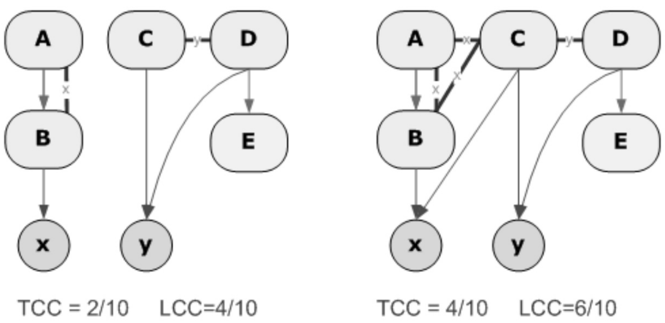
A and B are connected via variable x. C and D are connected via variable y. E is not connected because its call tree doesn't access any variables. There are 2 direct ("tight") connections. There are no additional indirect connections this time.

In the example on the right, we made C access x to increase cohesion.

Now {A, B, C} are directly connected via x. C and D are still connected via y and E stays unconnected. There are 4 direct connections, thus TCC=4/10.

The indirect connections are A–D and B–D. Thus, LCC=(4+2)/10=6/10.

Figure 9.2: Example of TCC



9.3.4 Validity of Cohesion

Is data cohesion the right kind of cohesion? Should the data and the methods in a class be related? If your answer is yes, these cohesion measures are the right choice for you. If, on the other hand, you don't care about that, you don't need these metrics.

There are several ways to design good classes with low cohesion.

Example: Here are some examples:

- A class groups related methods, not data. If you use classes as a way to group auxiliary procedures that don't work on class-level data, the cohesion is low. This is a viable, cohesive way to code, but not cohesive in the "connected via data" sense.
- A class groups related methods operating on different data. The methods perform related functionalities, but the cohesion is low as they are not connected via data.
- A class provides stateless methods in addition to methods operating on data. The stateless methods are not connected to the data methods and cohesion is low.
- A class provides no data storage. It is a stateless class with minimal cohesion. Such a class could well be written as a standard module, but if you prefer classes instead of modules, the low cohesion is not a problem, but a choice.
- A class provides storage only. If you use a class as a place to store and retrieve related data, but the class doesn't act on the data, its cohesion can be low. Consider a class that encapsulates 3 variables and provides 3 properties to access each of these 3 variables. Such a class displays low cohesion, even though it is well designed. The class could well be split into 3 small classes, yet this may not make any sense.

Task Make distinction between cohesive class and non-cohesive class.

Self Assessment

Fill in the blanks:

11. .... metrics measure how well the methods of a class are related to each other.
12. A .... class performs one function.
13. A .... class performs two or more unrelated functions.
14. .... measures the number of "connected components" in a class.
15. TCC=LCC=1 is the maximally cohesive class where all .... are directly connected to each other.

9.4 Summary

- Cyclomatic Complexity counts the number of decisions in the program, under the assumption that decisions are difficult for people.
- Cyclomatic complexity, also known as V(G) or the graph theoretic number, is probably the most widely used complexity metric in software engineering.
- Cyclomatic complexity comes in a couple of variations as to what exactly counts as a decision.
- Boolean operators add internal complexity to the decisions, but they are not counted in CC. CC and CC3 are similar what comes to Booleans, but CC2 is different.
- Cyclomatic complexity equals the minimum number of test cases you must execute to cover every possible execution path through your procedure.
- Data Binding Metrics is a metric to capture the strength of coupling between modules in a software system.
- Cohesion metrics measure how well the methods of a class are related to each other. A cohesive class performs one function.
- Lack of cohesion means that a class performs more than one function.

9.5 Keywords

CC2: CC2 extends cyclomatic complexity by including Boolean operators in the decision count.

CC3: CC3 equals the regular CC metric, but each Select Case block is counted as one branch, not as multiple branches.

Cohesion Metrics: It measures how well the methods of a class are related to each other. A cohesive class performs one function.

Cyclomatic Complexity: Cyclomatic Complexity counts the number of decisions in the program, under the assumption that decisions are difficult for people.

Notes

Data Binding Metrics: It is a metric to capture the strength of coupling between modules in a software system.

Indicator: An indicator is a metric or combination of metrics that provide insight into the software process, a software project, or the product itself.

LCOM4: It measures the number of "connected components" in a class.

TCC: TCC equals the number of decisions + 1 in a project or a class.

9.6 Review Questions

1. Explain the concept of Cyclomatic complexity.
2. Discuss the decisions counted for each statement or construct.
3. Discuss the different variations of Cyclomatic complexity.
4. Illustrate the CC3 Cyclomatic complexity without Cases.
5. Describe the relationship between cyclomatic complexity and the "risk" in a procedure.
6. Explain the concept of total cyclomatic complexity.
7. What is Data Binding Metrics? Discuss.
8. Explain the different types of Data Binding Metrics.
9. Describe the different types of LCOM 'lack of cohesion of methods' metrics.
10. Compare and contrast Tight and Loose Class Cohesion.

Answers: Self Assessment

1. Cyclomatic Complexity
2. V(G) or the graph theoretic number
3. Boolean
4. CC2
5. CC3
6. Sum(CC)
7. Data Binding
8. Potential
9. Used
10. Actual
11. Cohesion
12. Cohesive
13. non-cohesive
14. LCOM4
15. methods

9.7 Further Readings

Books

Rajib Mall, *Fundamentals of Software Engineering*, 2nd Edition, PHI.

Richard Fairpy, *Software Engineering Concepts*, Tata McGraw Hill, 1997.

R.S. Pressman, *Software Engineering – A Practitioner's Approach*, 5th Edition, Tata McGraw Hill Higher education.

Sommerville, *Software Engineering*, 6th Edition, Pearson Education

Online links

http://c2.com/cgi/wiki?CyclomaticComplexityMetric

http://www.guru99.com/cyclomatic-complexity.html

http://sunnyday.mit.edu/16.355/classnotes-metrics.pdf

http://beyondtesting.co.in/Magazine/index.php?option=com_content&view=article&id=88:basics-of-software-testing-metrics&catid=35:coverstory&Itemid=67

Notes

Unit 10: Coding

CONTENTS

Objectives

Introduction

10.1 Common Errors

10.2 Structured Programming

- 10.2.1 Building Blocks
- 10.2.2 More Iteration

10.3 Programming Practices

- 10.3.1 Line Length
- 10.3.2 Spacing
- 10.3.3 Wrapping Lines
- 10.3.4 Variable Declarations
- 10.3.5 Program Statements
- 10.3.6 Use of Parentheses
- 10.3.7 In-line Comments
- 10.3.8 Coding for Efficiency vs. Coding for Readability
- 10.3.9 Meaningful Error Messages
- 10.3.10 Reasonably Sized Functions and Methods
- 10.3.11 Number of Routines per File

10.4 Coding Standards

- 10.4.1 Indentation
- 10.4.2 In-line Comments
- 10.4.3 Structured Programming
- 10.4.4 Classes, Subroutines, Functions, and Methods
- 10.4.5 Source Files
- 10.4.6 Variable Names
- 10.4.7 Use of Braces
- 10.4.8 Compiler Warnings

10.5 Summary

10.6 Keywords

10.7 Review Questions

10.8 Further Readings

Objectives

After studying this unit, you will be able to:

- Discuss common coding errors
- Explain the concept of structured programming
- Discuss programming practices
- Discuss coding standards used by developer

Introduction

When designing, and implementing software or applications, certain guidelines must be followed to ensure that your software meets the required qualities in order to function as intended. These guidelines also ensure that the final product is acceptable to your clients. Coding is what makes it possible for us to create computer software, apps and websites. The coding phase is the longest phase in the software development life cycle. Coding usually begins after the documentation of the design is finalized. This phase will almost entirely involve the work of the developer. The coding phase of the software life-cycle is concerned with the development of code that will implement the design. This code is written is a formal language called a programming language. Programming languages have evolved over time from sequences of ones and zeros directly interpretable by a computer, through symbolic machine code, assembly languages, and finally to higher-level languages that are more understandable to humans.

10.1 Common Errors

One common definition of a software error is a mismatch between the program and its specification. In other words, we can say, a software error is present in a program when the program does not do what its end user expects. Errors can cause a wide variety of different problems depending on the kind of program and the particular kind of bug involved.

Example: Some errors may cause programs to freeze and stop working.

Others have the potential to cause errors in the performance of the program that result in the program behaving in unexpected ways. Sometimes a software error can even cause a program to shut down completely.

Following are the most common software errors. This helps you to identify errors systematically and increases the efficiency and productivity of software testing.

Example: We have discussed below different types of errors with examples:

- ***User Interface Errors:*** Missing/Wrong Functions, Doesn't do what the user expects, Missing information, Misleading, Confusing information, Wrong content in Help text, Inappropriate error messages. Performance issues - Poor responsiveness, Can't redirect output, inappropriate use of key board.
- ***Error Handling:*** Inadequate – protection against corrupted data, tests of user input, version control; Ignores – overflow, data comparison, Error recovery – aborting errors, recovery from hardware problems.
- ***Boundary Related Errors:*** Boundaries in loop, space, time, memory, mishandling of cases outside boundary.

- ***Calculation Errors:*** Bad Logic, Bad Arithmetic, Outdated constants, Calculation errors, Incorrect conversion from one data representation to another, Wrong formula, Incorrect approximation.
- ***Initial and Later States:*** Failure to – set data item to zero, to initialize a loop-control variable, or re-initialize a pointer, to clear a string or flag, Incorrect initialization.
- ***Control Flow Errors:*** Wrong returning state assumed, Exception handling based exits, Stack underflow/overflow, Failure to block or unblock interrupts, Comparison sometimes yields wrong result, Missing/wrong default, Data Type errors.
- ***Errors in Handling or Interpreting Data:*** Unterminated null strings, Overwriting a file after an error exit or user abort.
- ***Race Conditions:*** Assumption that one event or task finished before another begins, Resource races, Tasks starts before its prerequisites are met, Messages cross or don't arrive in the order sent.
- ***Load Conditions:*** Required resources are not available, No available large memory area, Low priority tasks not put off, Doesn't erase old files from mass storage, Doesn't return unused memory.
- ***Hardware:*** Wrong Device, Device unavailable, Underutilizing device intelligence, Misunderstood status or return code, Wrong operation or instruction codes.
- ***Source, Version and ID Control:*** No Title or version ID, Failure to update multiple copies of data or program files.
- ***Testing Errors:*** Failure to notice/report a problem, Failure to use the most promising test case, Corrupted data files, Misinterpreted specifications or documentation, Failure to make it clear how to reproduce the problem, Failure to check for unresolved problems just before release, Failure to verify fixes, Failure to provide summary report.

Self Assessment

State whether the following statements are true or false:

1. A software error is a mismatch between the program and its specification.
2. Sometimes a software error can cause a program to shut down completely.

10.2 Structured Programming

Structured Programming is a method of planning programs that avoids the branching category of control structures. Structured programming is a technique for organizing and coding computer programs in which a hierarchy of modules is used, each having a single entry and a single exit point, and in which control is passed downward through the structure without unconditional branches to higher levels of the structure. Three types of control flow are used: sequential, test or selection, and iteration. Software engineering is a discipline that is concerned with the construction of robust and reliable computer programs. Just as civil engineers will use tried and tested methods for the construction of buildings, software engineers will use accepted methods for analysing a problem to be solved, a blueprint or plan for the design of the solution and a construction method that minimises the risk of error. The discipline has evolved as the use of computers has spread. In particular, it has tackled issues that have arisen as a result of some catastrophic failures of software projects involving teams of programmers writing thousands of lines of program code. Just as civil engineers have learned from their failures so have software engineers.

The single most important idea of structured programming is that the code you write should represent a clear, simple and straightforward solution to the problem at hand.

One of the basic precepts of structured programming has been with us clear through our software engineering sojourn: a structured program consists of a hierarchical collection of individual modules, which appear more abstract at the top levels and more detailed at the lower levels. This fits with our overall strategy of hierarchical decomposition, which we've followed from structured system specification through structured design and now down to structured programming. The process of building a program in this fashion is called "top-down programming," or step-wise refinement.

Each of these modules (or processes, in design terms) communicates with others through well-defined data interfaces. These data interfaces typically are subroutine parameter lists or function argument lists. Each part of the program appears to other parts as a black box that simply performs its assigned function in some unknown way.

You've encountered this idea every time you called a built-in function in some programming language. Think about 8-bit Atari BASIC. Do you recall the STICK function? It told you something about the position of the joystick. Do you know how to communicate with the STICK function? Yes; all you had to do was pass it the number of the joystick you were interested in, like this: STICK(1), and it returned a numeric answer. Do you know how it worked? No; could be magic, for all you know. Do you care? No. This is the beauty of a "black box" approach to software development. There's no reason why the modules you write should be any different in this regard than the modules supplied by the guys who wrote the language you're using.

In practice, you apply the notion of step-wise refinement by writing your initial description of each fundamental process in a very high-level "language" that we called pseudocode. This is a first attempt at a picture of how each process will accomplish its assigned task. As you continue down the path from design toward code, you add detail to this description until eventually you reach something that conforms to the exact syntax of the language you're using: source code.

We suppose we could consider that one additional step takes place even after this, which is the compiling of your source code into something the computer can deal with: object code. Fortunately, we humans can halt our step-wise refinement at the source code stage and let the machine take over from there.

The first thing most people learn about structured programming is that you shouldn't use GOTO statements. We don't always have a choice.

Did u know? In older forms of BASIC, GOTO statements were needed everywhere, because there just wasn't the richness of commands that we need to avoid GOTO.

Caution The careless use of GOTO inevitably leads to the notorious "spaghetti code" that makes a program nearly impossible to comprehend and debug.

The worst case is a GOTO that branches back to a previous statement in the program listing.

Modern programming languages provide logic and control commands that allow us to almost completely avoid using GOTO statements (we'll discuss these shortly). However, there are still a few situations in which a GOTO actually can result in cleaner, more understandable code. Error-handling situations sometimes benefit from GOTOs. Premature exits from loops, or breaking out of deeply nested IF structures, may be more easily handled with a GOTO than by some other method. Nonetheless, the general guideline that GOTOs should not be used for routine transfer of control within a program is still valid, so try to break any lingering bad habits from your earlier experiences with BASIC interpreters.

The programming style you use can greatly influence the readability of your code. While not strictly part of structured programming, there are some matters of style to keep in mind. The following represent some of the highlights of programming style; some don't apply to all programming languages.

Use indentation to visually block logically related sections of your code, such as the sections of IF/ELSE IF/ELSE/END IF and SELECT/CASE constructs. Use blank lines in the source code to further delineate sections of the program. Use comments judiciously in the source code for clarification (we talked about this last time), and make sure the comments are accurate. Don't bother to document bad code—rewrite it, instead. Never put more than one statement on the same source line. We always did this in Atari BASIC because it saved six bytes per statement, but you don't need such tricks when you have a megabyte at your disposal.

Select meaningful variable and procedure names. Don't use different names to represent the same piece of information (refer to your data dictionary). Explicitly declare the type of each variable used, if your language permits this. Use parentheses to resolve any ambiguities in mathematical expressions, even if they aren't required for the operation to be executed correctly. Make sure conditional tests (IF some condition THEN do something) read clearly. Generally speaking, the first condition tested for should be the desired condition, with an error condition handled second.

Program defensively: Try to anticipate all possible errors in input data or mathematical operations, and write code to handle such situations. This includes validating input data before trying to use it and testing for such mathematical problems as division by 0 or taking the logarithm of a negative number. Make sure that input data does not exceed the bounds of what the routine can handle. Think of the user when designing your programs; make input easy to prepare correctly, and make output self-explanatory.

Initialize variables before using them. Who knows what was in those bytes before they were reserved for a variable's use? Avoid multiple entry points, and exits from loops and subroutines.

The first priority is to get the program running correctly. You can worry about optimization later. And when you do, make sure the program still runs correctly. Don't try to optimize every little step; the compiler will do a lot of this for you. Usually, a program spends most of its time in a small section of the code, so concentrate your optimization efforts here (if you can find it).

Use the best algorithms you can find for calculations, but remember that both the algorithm and the structure of your data will influence how the algorithm will be implemented in code. Insert "instrumentation" checkpoints in your programs to write out intermediate results someplace; so that you can verify accuracy, track down errors and assess efficiency. These outputs can be sent to a trace file on the disk, which you can then examine at your leisure.

10.2.1 Building Blocks

Another basic premise of structured programming states that any program logic, no matter how complex, can be expressed in terms of just three kinds of logical operations: sequence, selection and iteration. A program then is made up of a series of blocks of code to perform these operations. Let's define these three kinds of operations.

Sequence—a series of program statements are executed one after the other, in the order in which they appear in the source code. Obviously, this rules out statements like GOTO and IF, restricting us just to statements that perform some specific action. (A CALL or GOSUB to another procedure would qualify as an action in this sense.) Hence, a block of statements that are executed sequentially is called an "action block."

Selection—one set of statements, from a choice of two or more, is selected for sequential execution, based on some criterion. One way to accomplish this is to use an IF/THEN/ELSE construct. Some of the languages will also permit a SELECT/CASE/OTHERWISE/END - type structure, perhaps with different but analogous keywords. The set of statements that gets executed in each case is itself an action block. Sometimes selection constructs are called "branch blocks."

Iteration—a series of statements is executed repeatedly until some termination condition is met. These are also called "loop blocks." Virtually all languages contain simple FOR/NEXT or DO/END-type loops. More modern languages include variations such as DO UNTIL/END and DO WHILE/END.

These three kinds of "control blocks" have some features in common. First, the code in each is executed from top to bottom, which is the same way that it appears in the source file. This makes the program much easier to read and understand than does the convoluted branching you find in so many BASIC programs. Of course, in a selection block, not every statement is executed, and in a loop block they may be executed more than once, but they still are always executed from top to bottom.

In addition, each control block has just one logical entry point: the first statement. And if they're well structured, they have just one logical exit point: the last statement. A complete program is written by assembling and nesting blocks of these three kinds to perform the required processing.

Believe it or not, it's possible to write more or less structured programs in BASIC by following these rules. Some simulation of certain missing language features is required and some GOTOs inevitably creep in. But by keeping the notion of just three flavors of control blocks in mind, a surprisingly good job of structured programming can be done.

Task Compare and contrast loop blocks and control blocks.

10.2.2 More Iteration

Let us imagine we are pretty comfortable with the ideas behind action blocks and selection blocks, but let's take a close look at the iteration, or repetition, constructs. The simplest type of loop looks like this in BASIC:

```
FOR I = 1 TO 10
  calculate something
NEXT I
```

In other languages, such a loop is commonly called a DO loop and is terminated by an END or END DO statement:

```
DO I = 1 TO 10
  calculate something
END
```

In either case, some test is used to determine the number of times the loop is executed. In these simple examples, a variable called I (the index variable) is incremented after each iteration and compared to the value 10. If I is less than or equal to 10, the statements in the loop are executed again; otherwise, execution of the loop terminates. Here we're assuming that the value of I will go up by one on each iteration. Of course, you can set a different step interval with a statement like: DO I = 1 TO 10 BY 0.5.

Here's the key question: Is the comparison done before the loop is executed or after? There's a big difference. Suppose I has a value of 20 at the time this loop is encountered in the course of

Notes

executing the program. Will the loop be executed (since the value of the index variable is already greater than 10) or not?

In Atari BASIC, the comparison is done after the contents of the loop are executed, so the loop is always executed at least once. This is generally true of simple FOR/NEXT and DO/END loops. Many modern languages resolve any ambiguity by providing two explicit statement choices: DO WHILE and DO UNTIL. In a DO UNTIL loop, the termination condition is tested at the end of the loop, so the loop is always executed at least once. The simple FOR/NEXT loop in BASIC is thus a DO UNTIL type loop. In a DO WHILE construct, the termination condition is tested at the beginning of the loop. If the termination condition is already true, the contents of the loop aren't executed at all.

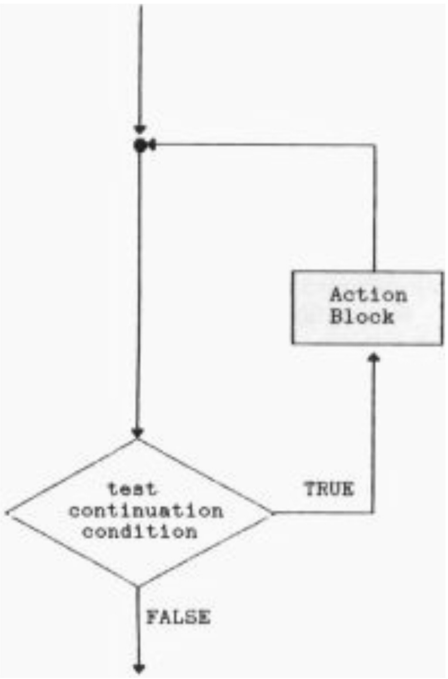
One important point is that DO WHILE and DO UNTIL loops need not rely on a changing index variable in the termination test. Any logical expression can be used, such as: DO UNTIL STATUS = 'DONE'. It also may be possible to have complex combinations of termination conditions, either of which could cause loop execution to cease.

Example: Consider this example, which will terminate either when I is greater than 100 or when J becomes less than or equal to 30:

```
D0 I = 1 To 100 BY 10 WHILE J > 30
   calculate something
END
```

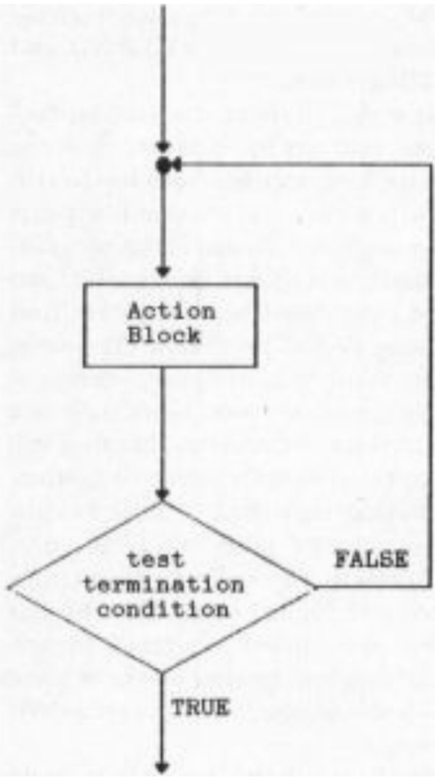
Maybe it will help to see a visual representation of these two looping structures. In flowcharts, the action statements are represented with rectangles and decisions with diamonds. Figure l0.1 uses a fragment of a flowchart to illustrate that, in a DO WHILE loop, the conditional test is done before the action statements are executed. In Figure 10.2, you see that the conditional test for a DO UNTIL is performed after the action statements are executed.

Figure 10.1: Conditional Test is done before the Action Statements are Executed



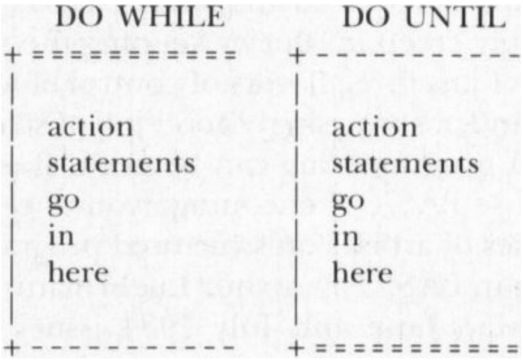
Source: http://www.atarimagazines.com/st-log/issue35/42_1_SOFTWARE_ENGINEERING.php

Figure 10.2: Conditional Test for a DO UNTIL



Source: http://www.atarimagazines.com/st-log/issue35/42_1_SOFTWARE_ENGINEERING.php

Figure 10.3: DO WHILE and DO UNTIL



```
DO WHILE          DO UNTIL
+===========      +-----------
|                 |
| action          | action
| statements      | statements
| go              | go
| in              | in
| here            | here
|                 |
+-----------      +===========
```

Source: http://www.atarimagazines.com/st-log/issue35/42_1_SOFTWARE_ENGINEERING.php

There are times when you want execution of a loop to end prematurely, for a variety of reasons. Bad input data may have been encountered, some error condition may have cropped up or whatever. Remember that we want to write our code so that each control block has only one logical exit point, so let’s resist the impulse to GOTO out of the loop. A DO WHILE is a good approach, because you can put the anticipated error or exit conditions into the WHILE clause:

```
DO I = 1 TO 10 WHILE EOF = ‘FALSE’ AND INPUT = ‘OK’
```

Notes

But things can get tricky if you don’t have a DO WHILE available; you may just have to violate the one-exit rule. Some languages provide a command like LEAVE for premature loop exits. In BASIC, you can set the index variable to its termination condition, so that the loop isn’t executed anymore; FORTRAN won’t let you do this. A more graceful solution is to use an IF block that tests for the abnormal termination condition right inside your DO block:

```
DO I = 1 TO 10
   IF EOF = ‘FALSE’ AND INPUT = ‘OK’ THEN
      DO
         calculate something
   END
   END IF
END
```

This is basically a way to simulate the DO WHILE command with your own explicit test.

Notes The innermost DO/END block without any loop criteria on the DO statement. This is really defining an action block to be executed within the selection block (IF/END IF), not a loop block. If you prefer, you can think of this as a loop block that gets executed exactly one time.

The structured programming concepts are all geared toward making the programs you write more understandable to human beings. The computer doesn’t care if your program makes sense, so long as it compiles properly. But anyone who must understand how your program works needs all the help he or she can get. You can provide that help not only by using good structured programming practices, but also by using common sense. Keeping your code clear and simple, rather than cute, condensed or clever, will go a long way toward writing programs that are easy to read, comprehend and alter.

Task Make distinction between DO WHILE and DO UNTIL.

Self Assessment

Fill in the blanks:

3. …………………… is a method of planning programs that avoids the branching category of control structures.

4. …………………… is a discipline that is concerned with the construction of robust and reliable computer programs.

5. Modern programming languages provide logic and control commands that allow us to almost completely avoid using …………………… statements.

6. …………………… is a series of program statements are executed one after the other, in the order in which they appear in the source code.

7. In case of ……………………, a series of statements is executed repeatedly until some termination condition is met.

8. Each …………………… block has just one logical entry point: the first statement.

10.3 Programming Practices

General coding guidelines provide the programmer with a set of best practices which can be used to make programs easier to read and maintain. Unlike the coding standards, the use of these guidelines is not mandatory. However, the programmer is encouraged to review them and attempt to incorporate them into his/her programming style where appropriate. Most of the examples use the C language syntax but the guidelines can be applied to all languages.

10.3.1 Line Length

It is considered good practice to keep the lengths of source code lines at or below 80 characters. Lines longer than this may not be displayed properly on some terminals and tools. Some printers will truncate lines longer than 80 columns. FORTRAN is an exception to this standard. Its line lengths cannot exceed 72 columns.

10.3.2 Spacing

The proper use of spaces within a line of code can enhance readability. Good rules of thumb are as follows:

A keyword followed by a parenthesis should be separated by a space.

- A blank space should appear after each comma in an argument list.
- All binary operators except "." should be separated from their operands by spaces.
- Blank spaces should never separate unary operators such as unary minus, increment ("++"), and decrement("—") from their operands.
- Casts should be made followed by a blank space.

Example: Bad:

```
cost=price+(price*sales_tax);
fprintf(stdout,"The total cost is %5.2f\n",cost);
```

Better:

```
cost = price + (price * sales_tax);
fprintf (stdout, "The total cost is %5.2f\n", cost);
```

10.3.3 Wrapping Lines

When an expression will not fit on a single line, break it according to these following principles:

- Break after a Comma

Example: `fprintf (stdout, "\nThere are %d reasons to use standards\n", num_reasons);`

- Break after an Operator

Example:
```
long int total_apples = num_my_apples + num_his_apples +
num_her_apples;
```

- Prefer Higher-level Breaks to Lower-level Breaks

Example: Bad:

```
longName1 = longName2 * (longName3 + LongName4 – longName5) + 4 * longName6;
```

Better:

```
longName1 = longName2 * (longName3 + LongName4 – LongName5) + 4 * longName6;
```

- Align the new line with the beginning of the expression at the same level on the previous line.

Example: total_windows = number_attic_windows + number_second_floor_windows + number_first_floor_windows;

10.3.4 Variable Declarations

Variable declarations that span multiple lines should always be preceded by a type.

Example: Acceptable:

```
int price, score;
```

Acceptable:

```
int price;
int score;
```

Not Acceptable:

```
int price,
score;
```

10.3.5 Program Statements

Program statements should be limited to one per line. Also, nested statements should be avoided when possible.

Example: Bad:

```
number_of_names = names.length; b = new JButton [ number_of_names ];
```

Better:

```
number_of_names = names.length;
b = new JButton [ number_of_names ];
```

10.3.6 Use of Parentheses

It is better to use parentheses liberally. Even in cases where operator precedence unambiguously dictates the order of evaluation of an expression, often it is beneficial from a readability point of view to include parentheses anyway.

Example: Acceptable:

```
total = 3 – 4 * 3;
```

Better:

```
total = 3 – (4 * 3);
```

Even better:
total = (-4 * 3) + 3;

10.3.7 In-line Comments

In-line comments promote program readability. They allow a person not familiar with the code to more quickly understand it. It also helps the programmer who wrote the code to remember details forgotten over time. This reduces the amount of time required to perform software maintenance tasks.

As the name suggests, in-line comments appear in the body of the source code itself. They explain the logic or parts of the algorithm which are not readily apparent from the code itself. In-line comments can also be used to describe the task being performed by a block of code.

In-line comments should be used to make the code clearer to a programmer trying to read and understand it. Writing a well structured program lends much to its readability even without in-line comments. The bottom line is to use in-line comments where they are needed to explain complicated program behavior or requirements. Use in-line comments to generalize what a block of code, conditional structure, or control structure is doing. Do not use overuse in-line comments to explain program details which are readily obvious to an intermediately skilled programmer.

Did u know? A rule of thumb is that in-line comments should make up 20% of the total lines of code in a program, excluding the header documentation blocks.

10.3.8 Coding for Efficiency vs. Coding for Readability

There are many aspects to programming. These include writing software that runs efficiently and writing software that is easy to maintain. These two goals often collide with each other. Creating code that runs as efficiently as possible often means writing code that uses tricky logic and complex algorithms, code that can be hard to follow and maintain even with ample in-line comments.

Caution The programmer needs to carefully weigh efficiency gains versus program complexity and readability.

If a more complicated algorithm offers only small gains in the speed of a program, the programmer should consider using a simpler algorithm. Although slower, the simpler algorithm will be easier for other programmers to understand.

Task Illustrate the different aspects of programming.

10.3.9 Meaningful Error Messages

Error handling is an important aspect of computer programming. This not only includes adding the necessary logic to test for and handle errors but also involves making error messages meaningful.

Error messages should be meaningful. When possible, they should indicate what the problem is, where the problem occurred, and when the problem occurred. A useful Java exception handling feature is the option to show a stack trace, which shows the sequence of method calls which led up to the exception.

Code which attempts to acquire system resources such as dynamic memory or files should always be tested for failure.

Error messages should be stored in way that makes them easy to review. For non interactive applications, such as a program which runs as part of a cron job, error messages should be logged into a log file. Interactive applications can either send error messages to a log file, standard output, or standard error. Interactive applications can also use popup windows to display error messages.

10.3.10 Reasonably Sized Functions and Methods

Software modules and methods should not contain an excessively large number of lines of code. They should be written to perform one specific task. If they become too long, then chances are the task being performed can be broken down into sub-tasks which can be handled by new routines or methods.

A reasonable number of lines of code for routine or a method is 200. This does not include documentation, either in the function/method header or in-line comments.

10.3.11 Number of Routines per File

It is much easier to sort through code you did not write and you have never seen before if there are a minimal number of routines per file. This is only applicable to procedural languages such as C and FORTRAN. It does not apply to C++ and Java where there tends to be one public class definition per file.

Self Assessment

State whether the following statements are true or false:

9. Variable declarations that span multiple lines should always be preceded by a type.
10. Program statements should be limited to two per line.
11. In-line comments does not promote program readability.
12. In-line comments appear in the body of the source code itself.
13. Error messages should be stored in way that makes them easy to review.

10.4 Coding Standards

General coding standards pertain to how the developer writes code.

10.4.1 Indentation

Proper and consistent indentation is important in producing easy to read and maintainable programs. Indentation should be used to:

- Emphasize the body of a control statement such as a loop or a select statement
- Emphasize the body of a conditional statement
- Emphasize a new scope block

A minimum of 3 spaces shall be used to indent. Generally, indenting by three or four spaces is considered to be adequate. Once the programmer chooses the number of spaces to indent by, then it is important that this indentation amount be consistently applied throughout the program. Tabs shall not be used for indentation purposes.

Example: The example given below shows the indentation used in a loop construct and in a conditional statement.

```
/* Indentation used in a loop construct. Four spaces are used for indentation. */
for (int i = 0; i < number_of_employees; ++i)
{
total_wages += employee [ i ] . wages;
}
//Indentation used in the body of a method.
package void get_vehicle_info ()
{
System.out.println (“VIN: “ + vin);
System.out.println (“Make: “ + make);
System.out.println (“Model: “ + model);
System.out.println (“Year: “ + year);
}
/* Indentation used in a conditional statement. */
IF (IOS .NE. 0)
WRITE (*, 10) IOS
ENDIF
10 FORMAT (“Error opening log file: “, I4)
```

10.4.2 In-line Comments

In-line comments explaining the functioning of the subroutine or key aspects of the algorithm shall be frequently used.

10.4.3 Structured Programming

Structured (or modular) programming techniques shall be used. GO TO statements shall not be used as they lead to “spaghetti” code, which is hard to read and maintain, except as outlined in the FORTRAN Standards and Guidelines.

10.4.4 Classes, Subroutines, Functions, and Methods

Keep subroutines, functions, and methods reasonably sized. This depends upon the language being used. A good rule of thumb for module length is to constrain each module to one function or action (i.e. each module should only do one “thing”). If a module grows too large, it is usually because the programmer is trying to accomplish too many actions at one time.

The names of the classes, subroutines, functions, and methods shall have verbs in them.

That is the names shall specify an action, e.g. “get_name”, “compute_temperature”.

10.4.5 Source Files

The name of the source file or script shall represent its function. All of the routines in a file shall have a common purpose.

Notes

10.4.6 Variable Names

Variable shall have mnemonic or meaningful names that convey to a casual observer, the intent of its use. Variables shall be initialized prior to its first use.

10.4.7 Use of Braces

In some languages, braces are used to delimit the bodies of conditional statements, control constructs, and blocks of scope. Programmers shall use either of the following bracing styles:

```
for (int j = 0; j < max_iterations; ++j)
{
/* Some work is done here. */
}
```

or the Kernighan and Ritchie style:

```
for (int j = 0; j < max_iterations; ++j) {
/* Some work is done here. */
}
```

It is felt that the former brace style is more readable and leads to neater-looking code than the latter style, but either use is acceptable.

> *Notes* Whichever style is used, be sure to be consistent throughout the code. When editing code written by another author, adopt the style of bracing used.

10.4.8 Compiler Warnings

Compilers often issue two types of messages: warnings and errors. Compiler warnings normally do not stop the compilation process. However, compiler errors do stop the compilation process, forcing the developer to fix the problem and recompile. Compiler and linker warnings shall be treated as errors and fixed. Even though the program will continue to compile in the presence of warnings, they often indicate problems which may affect the behavior, reliability and portability of the code. Some compilers have options to suppress or enhance compile-time warning messages. Developers shall study the documentation and/or man pages associated with a compiler and choose the options which fully enable the compiler's code-checking features.

Example: The Wall option fully enables the gcc code checking features and should always be used:

```
gcc -Wall
```

Self Assessment

State whether the following statements are true or false:

14. The name of the source file or script shall represent its function.

15. Compiler errors stop the compilation process.

10.5 Summary

- A software error is present in a program when the program does not do what its end user expects.
- Errors can cause a wide variety of different problems depending on the kind of program and the particular kind of bug involved.
- Structured Programming is a method of planning programs that avoids the branching category of control structures.
- The single most important idea of structured programming is that the code you write should represent a clear, simple and straightforward solution to the problem at hand.
- General coding guidelines provide the programmer with a set of best practices which can be used to make programs easier to read and maintain.
- In-line comments promote program readability. They allow a person not familiar with the code to more quickly understand it.
- If a more complicated algorithm offers only small gains in the speed of a program, the programmer should consider using a simpler algorithm.
- Compiler warnings normally do not stop the compilation process. However, compiler errors do stop the compilation process, forcing the developer to fix the problem and recompile.

10.6 Keywords

Compiler Errors: Compiler errors do stop the compilation process, forcing the developer to fix the problem and recompile.

Compiler Warnings: Compiler warnings is a message which normally do not stop the compilation process.

Error Handling: Error handling includes adding the necessary logic to test for and handle errors but also involves making error messages meaningful.

In-line Comments: In-line comments allow a person not familiar with the code to more quickly understand it.

Sequence: Sequence is a series of program statements are executed one after the other, in the order in which they appear in the source code.

Series: A series of statements is executed repeatedly until some termination condition is met.

Software Error: A software error is a mismatch between the program and its specification.

Structured Programming: Structured Programming is a method of planning programs that avoids the branching category of control structures.

10.7 Review Questions

1. Discuss different types of common errors with example.
2. Explain the technique used for organizing and coding computer programs.
3. Discuss the basic principles of structured programming.

Notes

4. Describe the building blocks of structured programming.
5. What are the different types of control blocks? Discuss.
6. Discuss the best programming practices which can be used to make programs easier to read and maintain.
7. Illustrate how the use of spaces within a line of code can enhance readability.
8. Illustrate the use of Parentheses with example.
9. What are in-line comments? Discuss the use of in-line comments.
10. Discuss the general coding standards used by the developer when writing code.

Answers: Self Assessment

1. True
2. True
3. Structured Programming
4. Software engineering
5. GOTO
6. Sequence
7. Iteration
8. Control
9. True
10. False
11. False
12. True
13. True
14. True
15. False

10.8 Further Readings

Books

Rajib Mall, *Fundamentals of Software Engineering*, 2nd Edition, PHI.

Richard Fairpy, *Software Engineering Concepts*, Tata McGraw Hill, 1997.

R.S. Pressman, *Software Engineering – A Practitioner's Approach*, 5th Edition, Tata McGraw Hill Higher education.

Sommerville, *Software Engineering*, 6th Edition, Pearson Education

Online links

http://software-engineering142.blogspot.in/2009/04/coding-phase.html

http://www.computer.org/portal/web/certification/resources/code_of_ethics

http://www.indeed.com/q-Software-Process-Engineer-Coding-Standard-Practice-jobs.html

http://www.win.tue.nl/~wstomv/edu/jpid/Coding_Standard_Motivation-4up.pdf

Unit 11: Coding Process

Notes

CONTENTS

Objectives

Introduction

11.1 Incremental Coding Process

11.2 Test Driven Programming

11.3 Pair Programming

11.3.1 Pair Programming, Rights and Responsibilities

11.3.2 Partnership Documentation

11.4 Summary

11.5 Keywords

11.6 Review Questions

11.7 Further Readings

Objectives

After studying this unit, you will be able to:

- Understand the Incremental Coding Process
- Discuss the Test driven Programming
- Explain the concept of Pair programming

Introduction

The coding activity starts when some form of design has been done and the specifications of the modules to be developed are available. The programming team must have a designated leader, a well-defined organization structure and a thorough understanding of the duties and responsibilities of each team member. The implementation team must be provided with a well-defined set of software requirements, an architectural design specification, and a detailed design description. Also, each team member must understand the objectives of implementation. A famous experiment by Weinberg showed that if programmers are specified a clear objective for the program, they usually satisfy it.

11.1 Incremental Coding Process

Many novice programmers start a program with a "big bang" approach, meaning they want to write the whole program in one step and then only they would try to compile and run. However as humans we make many mistakes when programming, especially given that we have to use a programming language to do the job and most programming languages differ drastically from natural languages. Because it is very likely that we would make mistakes, we have to ensure that we leave room so that we could easily identify the mistakes we have made.

The solution to this situation is to adopt an incremental approach in programming. The idea is to keep building your code using several small working pieces. The pieces of code would not do a complete job. Rather they will lay out the skeleton for the final complete program.

Notes

Did u know? Once you are convinced the correct skeleton is in place, you could go on and add muscle to the program.

A code is written for implementing only part of the functionality of the module. This code is compiled and tested with some quick tests to check and when it is passed, the developer proceeds to add further functionality. The advantage is easy identification of error in the code as small parts are tested. Test scripts can be prepared and run each time with new code to ensure the old functionality is still working.

In incremental programming, the program is incrementally built using several iterations. In each iteration of the program, it is compiled and run to ensure that whatever we have in a given increment is correct.

Caution It is very important to always have a working version of the program, no matter how much logic we have implemented so far.

Here is a simple algorithm depicting the incremental programming process:

```
Identify the main parts of the program
Write the initial stub to include all the parts
Compile and run to verify the correctness
Fix bugs if any
While whole program is not complete
Change the code to implement more logic
Compile and run to verify the correctness
Fix bugs if any
End while
Program complete
```

As you could notice in the above process, we always compile and run the program whenever we add some logic. The idea is to ensure that we write a clean program all the time. One would think that this is going to waste time as we compile and run the incomplete program many times. However this process going to save time rather than waste time in the long run. The rationale is that, when you write the whole program at once and try to compile, you would introduce many bugs at once to the program and it takes more time to debug.

Did u know? The incremental approach on the other hand cut down time to debug by eliminating bugs along the way.

Self Assessment

Fill in the blanks:

1. A .... is written for implementing only part of the functionality of the module.
2. In ...., the program is incrementally built using several iterations.
3. .... can be prepared and run each time with new code to ensure the old functionality is still working.
4. The incremental approach cut down time to .... by eliminating bugs along the way.

Notes

11.2 Test Driven Programming

Test Driven Development (TDD) is a technique for building software that guides software development by writing tests. It was developed by Kent Beck in the late 1990s as part of Extreme Programming. The programmer first writes the test scripts then writes the code to pass the tests. The whole process is done incrementally.

In essence you follow three simple steps repeatedly:

- Write a test for the next bit of functionality you want to add.
- Write the functional code until the test passes.
- Refactor both new and old code to make it well structured.

You continue cycling through these three steps, one test at a time, building up the functionality of the system. Writing the test first, what XPE2 calls Test-First Programming, provides two main benefits. Most obviously it's a way to get SelfTestingCode, since you can only write some functional code in response to making a test pass. The second benefit is that thinking about the test first forces you to think about the interface to the code first. This focus on interface and how you use a class helps you separate interface from implementation.

> *Notes* The most common way that we hear to screw up TDD is neglecting the third step.

Refactoring the code to keep it clean is a key part of the process; otherwise you just end up with a messy aggregation of code fragments. (At least these will have tests, so it's a less painful result than most failures of design.)

Self Assessment

State whether the following statements are true or false:

5. Test Driven Development (TDD) is a technique for building software that guides software development by writing tests.
6. Refactoring the code to keep it clean is a key part of the process.

11.3 Pair Programming

Pair programming is the Software Engineering term for when two people collaborate and interact to create a software solution. Both partners must take equal responsibility for reading the class notes, reading the assignment requirements, typing code, reviewing their partner's code, planning the direction of the project, etc. For the purposes of our course, pair programming requires that all of your work is done with your partner at the same computer at the same time. One person should be typing, one person should be directing; each person is responsible for all parts of the project. It is not allowable to have one person work on the first half and the other work on the second. Again, both partners must be actively working together at the same time for all aspects of the problem set.

Working in a Team can be more than twice as effective as working alone. You can feed off of each other's knowledge and excitement. You can help each other when things go wrong. You can learn from each other and study twice as much material. Sometimes you can finish assignments in less than half the time a single person would take!

Notes

We will refer to our partnerships as "Pair Programming". Pair programming is a technique where two programmers sit side by side helping each other to complete a project. By working together, syntax errors are more easily avoided, and more importantly logic errors can often be caught before running the program.

In Pair Programming, one programmer is the driver and the other is the navigator. While the driver is typing (i.e., coding) the navigator is making strategic plans and correcting tactical (logical) errors.

Each partner should actively communicate with the other, bouncing ideas off one another, searching for information in the notes or book to solve the current problem (together), reviewing each other's typing (in real time), etc. By being able to "multi-task", each partner bringing their own view and expertise, the partnership will enable both partners to learn more, and learn "better".

When pair up, you will gain certain rights and be held to certain responsibilities.

Task Find out the pros and cons of pair programming.

11.3.1 Pair Programming, Rights and Responsibilities

- You are allowed to (and required to) talk over all aspects of the program with your partner.
- You can meet with other groups/individuals away from the computer if you need to reason about and discuss the program on a high level. While you are actually programming, you should work exclusively with your partner.
- You should learn from your partner and help your partner to learn... if you find yourself in a one-sided partnership, you should choose a new partner for the next assignment.
- Written work or analysis (when specified by the assignment) is to be done separately! Thus if the assignment requires a written report, both partners should complete their own.
- You must choose your partner at least 4 days before the assignment is due or you will be required to work on your own until the next programming assignment. In other words, you are not allowed to join someone who has already completed (or mostly completed) the assignment without you.
- You and your partner must both be present when you are entering your solution into the computer. You are not allowed to divide the program into sections and each complete separate work. This defeats the goals of pair programming.
- You must strive to contribute an equal amount to your group.
- Again, you are not allowed to let one partner do "half" the work and you the other "half". You both must work together in all aspects of the design and coding of the program.
- You must take equal turns driving (typing at the computer) and navigating (from the chair next to the computer). In fact, you should endeavor to switch every 15 minutes or less.
- You are both required to keep a copy of the solution.
- One of you should turn in all the files. The other should only turn in the i_worked_with file and the partner evaluation file (and any written work that is required as an individual).

- Only two people may work as a partnership. No groups of 3, 4, etc...
- You must evaluate your partner.

11.3.2 Partnership Documentation

You and your partner should immediately create a text file in your working directories with the file name 'i_worked_with'. This file should simply contain your name and your partner's name, the name of the assignment, and the current date.

Example:

```
------- i_worked_with file -------
Homework X - Partner Declaration
My Name: Jim de St. Germain, germain@eng.utah.edu
Partner: Dav de St. Germain, dav@eng.utah.edu
Date: The current date
----------------------------------
```

Each of you should immediately submit this file to the current homework web page.

Once your programming project is complete, you should, separately from your partner, create another text file called "partner_evaluation". This file should contain your name. Your partners name. A ranking from 1-5 detailing how much your partner contributed. Here are the possible values:

- Partner did very little.
- Partner did less work than the other partner did.
- Partner did an equal value of work as the other partner did.
- Partner did more work than the other partner did.
- Partner did almost all the work.

Additionally, the file should contain a short paragraph describing the strengths and weaknesses of your team and how it worked/didn't work. This file should also contain the number hours you worked on the project, so please keep careful track of how much time you are working.

Notes Do not report the number of hours combined that you and your partner worked, just your hours.

```
----- partner evaluation file -----
Homework X - Partner Evaluation
My Name: Jim de St. Germain, germain
Partner: Dav de St. Germain, dav
Date: The current date

Hours Worked on Project: 8 hours

Partner Score: # - Partner did .....

Group Analysis:

Our group worked/didn't work because.....
----------------------------------
```

Notes

If you work with the same partner more than once, you should comment on how your partnership is “maturing” or growing, and what went better the 2nd time around, etc. Alternatively, it is to your advantage to work with several partners over the course of the semester to be able to learn from the strengths of other people. Don’t feel that you have to stay with the same partner every week.

Self Assessment

Fill in the blanks:

7. ………………….. is the Software Engineering term for when two people collaborate and interact to create a software solution.

8. Once your programming project is complete, you should, separately from your partner, create another text file called …………………….

9. In Pair Programming, one programmer is the ………………….. and the other is the …………………….

10. Pair programming is a technique where ………………….. sit side by side helping each other to complete a project.

11.4 Summary

- In incremental programming, the program is incrementally built using several iterations.
- In each iteration of the program, it is compiled and run to ensure that whatever we have in a given increment is correct.
- We always compile and run the program whenever we add some logic.
- Test Driven Development (TDD) is a technique for building software that guides software development by writing tests.
- The most common way that we hear to screw up TDD is neglecting the third step.
- Pair programming is the Software Engineering term for when two people collaborate and interact to create a software solution.
- Working in a Team can be more than twice as effective as working alone.
- In Pair Programming, one programmer is the driver and the other is the navigator.
- If you work with the same partner more than once, you should comment on how your partnership is “maturing” or growing, and what went better the 2nd time around, etc.

11.5 Keywords

Debugging: Debugging is a methodical process of finding and reducing the number of bugs, or defects, in a computer program or a piece of electronic hardware, thus making it behaves as expected.

Incrementing Programming: Incremental programming is a technique in which the program is incrementally built using several iterations.

Pair Programming: Pair programming is the Software Engineering term for when two people collaborate and interact to create a software solution.

TDD: Test Driven Development (TDD) is a technique for building software that guides software development by writing tests.

Notes

11.6 Review Questions

1. What are the different processes of coding? Discuss.
2. Explain the concept of Incremental Coding Process.
3. "In incremental programming, the program is incrementally built using several iterations". Comment.
4. Write a simple algorithm depicting the incremental programming process.
5. What is Test Driven Development (TDD)? Discuss.
6. Briefly explain the concept the pair programming.
7. Discuss about the pair programming, rights and responsibilities.
8. Explain the partnership documentation.

Answers: Self-Assessment

1. Code
2. Incremental programming
3. Test scripts
4. Debug
5. True
6. True
7. Pair programming
8. Partner_evaluation
9. Driver, navigator
10. Two programmers

11.7 Further Readings

Books

Rajib Mall, *Fundamentals of Software Engineering*, 2nd Edition, PHI.

Richard Fairpy, *Software Engineering Concepts*, Tata McGraw Hill, 1997.

R.S. Pressman, *Software Engineering – A Practitioner's Approach*, 5th Edition, Tata McGraw Hill Higher education.

Sommerville, *Software Engineering*, 6th Edition, Pearson Education

Online links

c2.com/cgi/wiki?PairProgramming

www.extremeprogramming.org/rules/testfirst.html

www.klab.caltech.edu/~xhou/papers/nips08icl.pdf

Notes

Unit 12: Refactoring

CONTENTS

Objectives

Introduction

12.1 Meaning of Refactoring

12.1.1 Benefits of Refactoring

12.1.2 Reasons to Refactor your Code

12.1.3 Leveraging Refactoring

12.1.4 Properties of Refactoring

12.1.5 Refactoring Examples

12.1.6 Pattern-based Refactoring

12.2 Verification

12.3 Software Metrics

12.3.1 Size of Metrics

12.4 Summary

12.5 Keywords

12.6 Review Questions

12.7 Further Readings

Objectives

After studying this unit, you will be able to:

- Know the meaning of Refactoring
- Discuss about Verification
- Explain the concept of Software Metrics

Introduction

Refactoring is a disciplined technique for restructuring an existing body of code, altering its internal structure without changing its external behavior. Its heart is a series of small behavior preserving transformations. Each transformation (called a 'refactoring') does little, but a sequence of transformations can produce a significant restructuring. Since each refactoring is small, it's less likely to go wrong. The system is also kept fully working after each small refactoring, reducing the chances that a system can get seriously broken during the restructuring. Code refactoring is the process of changing a computer program's source code without modifying its external functional behavior, in order to improve some of the non-functional attributes of the software.

12.1 Meaning of Refactoring

Refactoring is "the process of changing a software system in such a way that it does not alter the external behavior of the code yet improves its internal structure," according to Martin Fowler, the "father" of refactoring.

Did u know? While refactoring can be applied to any programming language, the majority of refactoring current tools has been developed for the Java language.

One approach to refactoring is to improve the structure of source code at one point and then extend the same changes systematically to all applicable references throughout the program. The result is to make the code more efficient, scalable, maintainable or reusable, without actually changing any functions of the program itself. In his book, Fowler describes a methodology for cleaning up code while minimizing the chance of introducing new bugs.

In Refactoring:

- The system works fine, but its design and code can be improved.
- New local requirements and functions cannot be addressed or integrated appropriately.

According to Martin Fowler it is:

- Refactoring is the process of changing a software system in such a way that it does not alter the external behavior of the code yet improves its internal structure.
- Refactoring is a disciplined way to clean up code that minimizes the chances of introducing bugs.

12.1.1 Benefits of Refactoring

Refactoring is usually motivated by noting a code's smell (A code smell is a surface indication that usually corresponds to a deeper problem in the system.).

Example: The method at hand may be very long, or it may be a near duplicate of another nearby method.

Once recognized, such problems can be addressed by refactoring the source code, or transforming it into a new form that behaves the same as before, but that no longer "smells". For a long routine, extract one or more smaller subroutines. Or, for duplicate routines, remove the duplication and utilize one shared function in their place. Failure to perform refactoring can result in accumulating technical debt.

There are two general categories of benefits to the activity of refactoring:

- ***Maintainability:*** It is easier to fix bugs because the source code is easy to read and the intent of its author is easy to grasp. This might be achieved by reducing large monolithic routines into a set of individually concise, well-named, single-purpose methods. It might be achieved by moving a method to a more appropriate class, or by removing misleading comments.
- ***Extensibility:*** It is easier to extend the capabilities of the application if it uses recognizable design patterns, and it provides some flexibility where none may have existed before.

Did u know? Refactoring is a huge aid in untangling production code without breaking it, and in improving its long-term maintainability.

Refactoring helps you achieve:

1. Self-documenting code, for better readability and maintainability, which is pretty much the only kind of code documentation that ever seems to stay current (Extract Method and Introduce Local allow you to create function and variable names that are descriptive enough to rarely need comments). Until you experience readable, self-describing code, you don't know what you're missing
2. Fine-grained encapsulation, for easier debugging and code reuse: Extract Method automatically determines the parameters needs in order to create a method from the current selection, and handles them correctly. You then know exactly what external information the selected block requires in order to operate. This can be a great aid in untangling complex code during code reviews or debugging.
3. The generalization of existing code, to make it easier to apply existing code to a broader range of problems – as you Extract Method, you can easily replace things like hard-coded constants (perhaps, a connection string, or a table name) with parameters, thus allowing the application of proven code to new contexts.

12.1.2 Reasons to Refactor your Code

Whenever reading your code, if you stumble upon one of the following cases, it is probably better to stop and refactor that piece of code.

- Duplicate Code – There is no reason to have duplicate code. Try to respect the DRY principle (Don't repeat yourself). As Parnas said best, "Copy and Paste is a design error". Also, coding will become absolutely boring.
- A routine is too long – In OOP, you rarely need a routine longer than one screen. Consider breaking it into multiple routines.
- A loop is too long or too deeply nested – Consider refactoring part of the code as routines, or changing the algorithm.

Caution Nested loops are one of the biggest performance penalties.

- A class has poor cohesion – If a class has unrelated responsibilities, consider changing it.
- A parameter list has too many parameters – If you need to pass too many parameters, consider merging them in a cohesive class or rethinking the problem.
- Changes in a class tend to be compartmentalized – This may be a sign that the class should be broken into smaller ones.
- Changes require parallel modifications in different classes – This is a sign that they are tied together. Try cut most of the dependencies. This kind of refactoring can be a real challenge, but it is worthy.
- Inheritance hierarchies need parallel changes – This is a special kind for the problem above.
- Case statements need parallel changes – Consider using inheritance with polymorphism instead of case.

- Related data items that are used together are not tied into classes – The first time you code/design, you may overlook some classes. Take your time and create them.
- A routine uses more features of another class than of its own – Probably it should be moved into the other class
- A primitive data type is overloaded.

Example: You may use int to represent both money and temperature. It is better to create a Money and a Temperature class. By doing so, you will be able to impose custom conditions on the types. Also the compiler will not allow you to mix money with temperatures.

- A class doesn't do much – Maybe it should be merge with another.
- A chain of routines passes tramp data – If a routine takes some data only to pass it to another, you should probably eliminate it.
- A middle man object does nothing – same as above.
- One class is very intimate to another – This works against one of your most powerful complexity management tools: encapsulation.
- A routine has a poor name – In the best case, you can rename it. In the worst, the problem is the design. The name is just a sign. Anyway, take your time to solve this one.
- Data members are public – This is plain wrong. Today, you can use properties in many programming languages, so hiding data behind them is very easy.
- A subclass uses a small percentage of the parent class – Usually, this denotes wrong inheritance design.
- Comments are used to explain difficult code – Comments are very good, but creating difficult-to-understand code and commenting it is plain wrong.
- Global variables are used – There are few cases when global variables are the only logical option.
- You need setup/cleanup code before/after calling a routine – Try to merge this code into the routine.
- A program contains code that might be needed someday – The only way to write code taking into account future releases is to write it as clear and obvious as possible, enabling quick understanding and modification.

12.1.3 Leveraging Refactoring

It is essential to set up a huge test suite

- Refactoring steps are small (design a little, code a little, change a little, test)
- Worst problem or risk areas first
- If test suite fails start again

12.1.4 Properties of Refactoring

A Refactoring reveals the following parts:

- Name, for example: Extract Method
- Summary (of Situation), for example: Code fragment that can be grouped together.

Notes

- Turn the fragment into a method whose name explains the purpose of the method
- Motivation.

Example: Use Extract Method when encountering long methods or replicated code

- Mechanics, for example:
  - ❖ Create a new method and name it after the intention of the method
  - ❖ Copy extracted code from source to new target method
  - ❖ Scan extracted method for local variables
  - ❖ If one mutated local variable, make method as a query that returns that local variable's value. If more than one you might need to apply additional refactoring first (e.g., Split Temporary Variable)
  - ❖ Read-only local variables will be passed as parameters to new target method
  - ❖ Compile
  - ❖ Replace in source-code extracted code with call to new target method
  - ❖ Compile and test
- Refactoring might be considered like patterns: forces, context, problem, solution
- Most refactoring are reversible

12.1.5 Refactoring Examples

We use three examples to explain some basic refactoring

- ***Extract Method:***
  - ❖ signalled by comments
  - ❖ single-entry, single-exit
  - ❖ increase the level of indirection
  - ❖ reduce the length of a method
  - ❖ increase the chance of reuse
- ***Move Method:***
  - ❖ Place method together with the object, Putting things together when changes are together
- ***Replace Conditions with Polymorphism:***
  - ❖ Switches are "hard code", polymorphism is better for extensibility in OO

Example 1: ***Extract Method***

```
void f() {
...
```

Notes

//Compute score
score = a * b + c;
score -= discount;
}
	d f() {
	...
	computeScore();
	}
	void computeScore() {
	score = a * b + c;
	score -= discount;
	}

Example 2: ***Move Method***

class Jar {
...
}
class RoboPacker {
private bool isFragile(Jar foo) {
switch(foo.material) {
case GLASS: return true;
case WOOD: return true;
case TIN: return false;
}
}
}
	class Jar {
	bool isFragile() {
	switch(material) {
	case GLASS: return true;
	case WOOD: return true;
	case TIN: return false;
	} } }
	class RoboPacker {
	private bool isFragile(Jar foo) {
	return foo.isFragile();
	}
	}

Example 3: ***Replace Conditionals with Polymorphism***

class Jar {
bool isFragile() {
switch(material) {
case GLASS:
//complex glass calculation
case WOOD:
//complex wood calculation
case TIN:
//complex tin calculation
} } }
	class Jar {
	bool isFragile() {
	return material.isFragile();
	} }
	interface Material { ... }
	class GlassMaterial:Material { ... }
	class WoodMaterial:Material { ... }
	class TinMaterial:Material { ... }

Task Compare and Contrast the extract method and move method.

12.1.6 Pattern-based Refactoring

Refactoring might be documented in kind of pattern form. Patterns might help to refactor on architectural level:

- Replace your proprietary solution with a pattern that solves the same problem

- Introduce symmetry and orthogonality by making sure the same problem is always solved using the same pattern/solution

Self Assessment

Fill in the blanks:

1. .... is the process of changing a computer program's source code without modifying its external functional behavior.
2. .... is the process of changing a software system in such a way that it does not alter the external behavior of the code yet improves its internal structure.
3. A .... is a surface indication that usually corresponds to a deeper problem in the system.
4. .... loops are one of the biggest performance penalties.
5. .... need parallel changes – consider using inheritance with polymorphism instead of case.
6. .... might help to refactor on architectural level.

12.2 Verification

Once we have decomposed a refactoring implementation both in terms of its functionality and in terms of the object language, we need to find a suitable verification method to prove correctness of the components. If the correctness properties are simple enough, an intriguing possibility would be to use model checking techniques for automatic verification. Such an approach is taken by Estler et al., who verify refactorings on the Z specification language. The scope of their approach, however, seems to be very limited, and it is probably not applicable to general purpose refactoring tools. Inspiration can be drawn from the success of Rhodium, a domain specific language for declaratively specifying dataflow analyses that are verified by an automatic theorem prover without any need for human intervention. However, analyses implemented in Rhodium work on a simplified intermediate representation of programs, and it seems likely that in order to verify source-level analyses interactive theorem proving is a more appropriate choice. The experience of the CompCert project shows that verification of a compiler for a simple but realistic, C-like language is indeed possible with a theorem prover.

Caution It is not clear that their techniques transfer to our setting, since many of the challenges in refactoring are due to the complexities of dealing with a rich source language.

Sultana and Thompson have succeeded in mechanically verifying refactorings using the theorem prover Isabelle/HOL. Their success is heartening, but they are again only dealing with a very simple object language and it is unclear how well their techniques would scale to larger languages, since they do not seem to put much emphasis on modularity.

The experiences of our own verification show that attribute grammars generally lend themselves well to interactive proofs: the evaluation schemata of synthesised and inherited attributes correspond (via Curry-Howard) to induction schemata, and in a prover with an extensible tactic language like Coq the use of domain specific tactics simplifies commonly occurring proof steps and provides some automation. Proofs involving circularly defined attributes are a bit more problematic, since explicit proofs of monotonicity have to be provided; additional automation would be helpful here.

The biggest challenge to verifying major refactorings, however, are extensible proofs. Since our encoding of CRAGs maps attributes to Coq functions, which have to be defined en bloc, there is no way to match JastAdd's mechanism for gradually extending attribute definitions to deal with new language constructs. The same is true of proof scripts, which likewise are monolithic entities impervious to extensions. Although our experiments show that extending the language requires little additional code and only modest changes to the proof scripts, all these changes still have to be performed in place and are hence not true extensions.

What we would like to see is a three-tiered extension mechanism, in which the object language, the refactoring implementations, and their proofs can all be extended modularly. In particular, the usual approach of introducing new language features in an extended language and then provide a semantics preserving translation back to a core calculus (as done, for example, for inner classes in) would not work here, since the analyses and transformations to be verified have to work on the extended language, not on the core calculus.

We are thus facing the well-known expression problem:

Our underlying datatype is the abstract syntax of the object language, on which we write functions (the refactorings and their correctness proofs). Coq as a functional language is, for our purposes, located at the wrong end of the spectrum, where it is easy to extend the functions, but hard to extend the datatype. It would certainly be interesting to survey the literature of solutions to the expression problem to see if they are applicable to our challenge.

Self Assessment

State whether the following statements are true or false:

7. Proofs involving circularly defined attributes are a bit more problematic.
8. The biggest challenge to verifying major refactoring are extensible proofs.
9. Data type is the abstract syntax of the object language, on which we write functions.

12.3 Software Metrics

We use software metrics to try to quantify particular characteristics of software systems, such as quality, maintainability, or reliability. In general, however, these characteristics cannot be measured directly. Instead, we directly measure particular attributes of software by using software metrics and then infer information about quality from those direct measurements.

Three commonly used software metrics are coupling, cohesion, and McCabe's Cyclomatic Complexity; all three have been extended from their original definitions for use with object oriented systems (OOS).

The first metric to consider is coupling, which measures the strength of the connections between the software modules that comprise a particular system to quantify the dependencies between the modules. The key idea is that the more interdependent the modules in the system are, the more difficult the system is to understand and the more likely it is that changes to one module will affect other modules in the system.

The second metric to consider is cohesion, which measures how strongly the elements of each module are related to each other. Coupling and cohesion are related, though not perfectly correlated. As we increase the cohesion of the modules in the system, we tend to reduce the coupling between those modules.

The final metric, which is probably the most commonly used metric of those discussed here, is McCabe's Cyclomatic Complexity. At the module level, this metric is the number of linearly independent paths through the module. Our goal is to use software metrics to provide guidance to those undertaking refactoring efforts.

> *Notes* It is important to note, of course, that we do not refactor code simply for the sake of better code; rather, we expect some return on the investment expended on any refactoring efforts.

We must therefore consider some of the important relationships between our software metrics and software quality, testing costs, and maintenance costs.

Intuitively, we expect software with high coupling and low cohesion to be of lower quality than software with low coupling and high cohesion. The additional programmer effort required for understanding highly interrelated modules and their effects on each other leads to a higher potential for mistakes. Similarly, a programmer working on a module with low cohesion needs to keep track of multiple functions being performed by the module rather than on a single function, which also increases the potential for programmer error. Our intuition turns out to be true in practice. Research on operational systems has shown that modules with high coupling/low cohesion contained seven times as many errors as modules with low coupling/high cohesion.

In addition, programmers spent almost 22 times as many hours correcting the errors in those modules with high coupling/low cohesion. Clearly, coupling and cohesion have a significant impact on both the quality of the software and the effort required to fix errors in the software.

We also expect all three metrics to have an impact on the amount of effort associated with software testing. Because coupling measures the dependencies between modules, higher coupling implies the need to expend more effort accomplishing integration testing of the modules. Modules with low cohesion implement more than one function; testing the functionality of that module (typically during unit testing) requires more test cases to cover all of that module's functionality. Cyclomatic complexity essentially measures the number of paths through a module, so modules with higher cyclomatic complexity will require more test cases to cover all the paths.

It is clear that refactoring software to improve coupling, cohesion, and cyclomatic complexity of the software yields improvements in overall software quality and reductions in testing and maintenance costs. Despite the clear benefits associated with refactoring, the amount of effort required to refactor large systems without tool support is generally prohibitive. Metrics and other methods have been proposed to help guide program refactoring. One problem with traditional metrics is that they are often not useful for making fine distinctions between routines and modules. Refactoring does not have this limitation.

12.3.1 Size of Metrics

Size of metrics is derived by normalizing quality and/or productivity measures by considering the size of the software produced:

- ***LOC:*** Lines Of Code
- ***KLOC:*** 1000 Lines Of Code
- ***SLOC:*** Statement Lines of Code (ignore whitespace)

Thousand lines of code (KLOC) are often chosen as the normalization value.

Metrics include:

- Errors per KLOC

Notes

  - ❖ Errors per person-month
- Defects per KLOC
  - ❖ KLOC per person-month
- Dollars per KLOC
  - ❖ Dollars per page of documentation
- Pages of documentation per KLOC

LOC Metrics are:

- Easy to use
- Easy to compute
- Language and programmer dependent

Size-oriented metrics are not universally accepted as the best way to measure the software process.

Complexity Metrics

LOC is a function of complexity. Opponents argue that KLOC measurements:

- are dependent on the programming language
- penalize well-designed but short programs
- cannot easily accommodate non-procedural languages
- require a level of detail that may be difficult to achieve

Example:

```
if (k < 2)
{
   if (k > 3)
       x = x*k;
}
```

- Distinct operators: if () { } > < = *;
- Distinct operands: k 2 3 x
- $n_1 = 10$
- $n_2 = 4$
- $N_1 = 13$
- $N_2 = 7$

Where,

n_1 - number of distinct operators

n_2 - number of distinct operands

N_1 - total number of operators

N_2 - total number of operands

Self Assessment

Fill in the blanks:

10. Three commonly used software metrics are coupling, cohesion, and …………………….
11. ……………………. measures the strength of the connections between the software modules that comprise a particular system to quantify the dependencies between the modules.
12. ……………………. measures how strongly the elements of each module are related to each other.
13. McCabe's Cyclomatic Complexity is the number of ……………………. through the module.
14. ……………………. and ……………………. have a significant impact on both the quality of the software and the effort required fixing errors in the software.
15. Modules with ……………………. cohesion implement more than one function.

12.4 Summary

- Refactoring is a disciplined technique for restructuring an existing body of code, altering its internal structure without changing its external behavior.
- Code refactoring is the process of changing a computer program's source code without modifying its external functional behavior, in order to improve some of the non-functional attributes of the software.
- One approach to refactoring is to improve the structure of source code at one point and then extend the same changes systematically to all applicable references throughout the program.
- Refactoring is usually motivated by noting a code's smell.
- Once we have decomposed a refactoring implementation both in terms of its functionality and in terms of the object language, we need to find a suitable verification method to prove correctness of the components.
- We use software metrics to try to quantify particular characteristics of software systems, such as quality, maintainability, or reliability.
- The final metric, which is probably the most commonly used metric of those discussed here, is McCabe's Cyclomatic Complexity.

12.5 Keywords

Code Refactoring: Code refactoring is a "disciplined technique for restructuring an existing body of code, altering its internal structure without changing its external behavior", undertaken in order to improve some of the nonfunctional attributes of the software.

Duplicate Code: Duplicate code is a computer programming term for a sequence of source code that occurs more than once, either within a program or across different programs owned or maintained by the same entity.

Extract Method: Extract Method is a refactoring operation that provides an easy way to create a new method from a code fragment in an existing member.

Move Method: A method is, or will be, using or used by more features of another class than the class on which it is defined.

Notes

Refactoring: Refactoring is a kind of reorganization. Technically, it comes from mathematics when you factor an expression into equivalence – the factors are cleaner ways of expressing the same statement.

12.6 Review Questions

1. What is refactoring? Discuss the approach to refactoring.
2. Write down the meaning and concept of code refactoring.
3. Discuss the benefits of refactoring.
4. Write down the two general categories of benefits to the activity of refactoring.
5. "Refactoring is a huge aid in untangling production code without breaking it". Elucidate.
6. Give reasons to refactor code.
7. Write short note on:
    - (a) Leveraging Refactoring
    - (b) Properties of Refactoring's
    - (c) Extract method
    - (d) Move method
8. Discuss the verification in refactoring.
9. Explain the three commonly used software metrics.
10. Discuss about the size of metrics.

Answers: Self Assessment

1. Code Refactoring
2. Refactoring
3. Code smell
4. Nested
5. Case statements
6. Patterns
7. True
8. True
9. True
10. McCabe's Cyclomatic Complexity
11. Coupling
12. Cohesion
13. Linearly independent paths
14. Coupling, cohesion
15. Low

12.7 Further Readings

Books

Rajib Mall, *Fundamentals of Software Engineering*, 2nd Edition, PHI.

Richard Fairpy, *Software Engineering Concepts*, Tata McGraw Hill, 1997.

R.S. Pressman, *Software Engineering – A Practitioner's Approach*, 5th Edition, Tata McGraw Hill Higher education.

Sommerville, *Software Engineering*, 6th Edition, Pearson Education

Notes

Online links

www.cs.tau.ac.il/~apartzin/systems/7_refactoring.pdf

jaoo.dk/jaoo1999/schedule/MartinFowlerRefractoring.pdf

martinfowler.com/books/refactoring.html

www.4shared.com/office/.../Refactoring_-_Improving_the_De.html

Unit 13: Software Testing-I

Notes

CONTENTS

Objectives

Introduction

13.1 Fundamentals of Testing

13.1.1 Benefits of Testing

13.1.2 Testing Principles

13.1.3 Testing Objectives

13.1.4 Testability

13.1.5 Error, Fault, Failure

13.2 Test Oracles

13.3 Test Cases and Criteria

13.4 Black Box Testing

13.4.1 Equivalence Partitioning

13.4.2 Boundary Value Analysis

13.5 White Box Testing

13.5.1 Basis Path Testing

13.5.2 Control Flow Based Testing

13.5.3 Data Flow Testing

13.5.4 Loop Testing

13.6 Summary

13.7 Keywords

13.8 Review Questions

13.9 Further Readings

Objectives

After studying this unit, you will be able to:

- Discuss the fundamentals of Testing
- Explain the test oracles
- Understand the test cases and criteria
- Discuss about black box testing
- Explain about the white box testing

Introduction

Software testing is a critical element of software quality assurance and resents the final review of specification, design, and code. The source-code once generated needs to be tested for bugs and defects to get rid of maximum errors before the software is sent to the customer. Test cases are designed with an aim to find errors. During initial stages of testing, a software engineer performs all the tests. However, at later stages a specialist may be involved. Tests must be conducted to find the highest possible number of errors, must be done systematically and in a disciplined way. Testing involves checking both the internal program logic and the software requirements.

13.1 Fundamentals of Testing

Testing software can be considered as the only destructive (psychologically) step in the entire life cycle of software production. Although all the initial activities aimed at building a product, the testing is done to find errors in software.

13.1.1 Benefits of Testing

The following are the benefits of testing:

- It reveals the errors in the software.
- It ensures that software is functioning as per specifications and it meets all the behavioral requirements as well.
- The data obtained during testing is indicative of software reliability and quality as a whole.
- It indicates presence of errors and not absence of errors.

13.1.2 Testing Principles

Before coming up with ways to design efficient test cases, one must understand the basic principles of testing:

- ***Test Cases must be Traceable to Requirements:*** Because software testing reveals errors, so, the severe defects will be those that prevent the program from acting as per the customer's expectations and requirements.
- ***Test Planning must be done before Beginning Testing:*** Test planning can begin soon after the requirements specification is complete and the detailed test cases can be developed after the design has been fixed.
- ***Pareto Principle Applies to Software Testing:*** Pareto principle states that 80 percent of the uncovered errors during testing will likely be traceable to 20 percent of all the program components. Thus, the main aim is to thoroughly test these 20 percent components after identifying them.
- ***Testing should begin with Small and End in Large:*** The initial tests planned and carried out are usually individual components and as testing progresses the aim shifts to find errors in integrated components of the system as whole rather than individual components.
- ***Exhaustive Testing is Impossible:*** For a normal sized program the number of permutations of execution paths is very huge. Thus, it is impossible to execute all the combinations possible. Thus, while designing a test case it should be kept in minds that it must cover the maximum logic and the component-level design.

- ***Efficient Testing can be Conducted only by a Third Party:*** The highest probability of finding errors exists when the testing is not carried by the party which develops the system.

13.1.3 Testing Objectives

Various testing objectives are:

- Executing a program in order to find errors.
- A good test case is the one that has a high probability of finding an undiscovered error.
- A successful test is the one that reports an as – yet undiscovered error.

13.1.4 Testability

A program developed should be testable i.e. it should be possible to test the program. The testability of a program can be measured in terms of few properties like: operability, observability, controllability, decomposability, simplicity, stability, understandability, etc.

Caution The test also, must also comply with the characteristics of a good test case.

These characteristics are mentioned here:

- The probability of finding error should be high. In order to achieve this, tester must understand the actual functionality of the software and think of a suitable condition that can lead to failure of the software.
- A test case must be non-redundant. Because the testing time and resources are limited, it will waste a lot of time to conduct the same test again and again. Every test must have a distinct purpose.
- A test case must be of the best quality. In a group of similar test cases, the one that covers the maximum scenarios to uncover maximum errors should only be used.
- A good test case should neither be too simple nor too complex. A complex test that includes several other tests can lead to masking of errors. Thus, each test case should be executed separately.

Did u know? Testing is an extremely important, although often neglected, activity in the software quality initiative.

13.1.5 Error, Fault, Failure

Many people associate quality of a software system with a suggestion that some software troubles are estimated to happen (or not). And in the case if such troubles do occur, the negative influence is estimated to be minimal. Clue to the correctness perspective of software quality is in the concept of failure, fault, and error.

Error

An error is a person act that generates an erroneous result. The term error is used in two different ways. It refers to the discrepancy between a computed, observed, or measured value and the true, specified, or theoretically correct value. That is error refers to the difference between the actual output of software and the correct output. The term error is a discrepancy between a computed, observed, or measured value or condition and the true, specified, or theoretically correct value or condition

Fault

Fault is a condition that causes a system to fail in performing its required function. It refers to an underlying condition within software that causes failure to happen. A fault is the basic reason for software malfunction and is synonymous with the commonly used term bug. It is an incorrect step, process, or data definition in a computer program which causes the program to perform in an unintended or unanticipated manner.

Failure

Failure is the inability of a system or component to perform a required function according to its specifications. It refers to a behavioral deviation from the user wants or the product specification. A software failure occurs if the behavior of the software is different from the specified behavior.

Task Make difference between Error, Fault, and Failure.

Self Assessment

Fill in the blanks:

1. …………………… can be considered as the only destructive (psychologically) step in the entire life cycle of software production.
2. …………………… refers to the discrepancy between a computed, observed, or measured value and the true, specified, or theoretically correct value.
3. …………………… refers to an underlying condition within software that causes failure to happen.
4. …………………… refers to a behavioral deviation from the user wants or the product specification.

13.2 Test Oracles

An oracle is a mechanism for determining whether the program has passed or failed a test. All software testing methods depend on the availability of an oracle, that is, some method for checking whether the system under test has behaved correctly on a particular execution.

Oracles are either based on a program specification, or are a (perhaps very incomplete) specification of intended behavior. Some oracles, particularly those expressed in assertion languages embedded in program text, describe acceptable behaviors entirely at an implementation level. Others are derived from or associated with external, usually more abstract specifications or models. In either case, a key problem for test oracles is bridging the gap between abstract specifications and efficiently checkable properties of concrete execution sequences. Common problems that have been addressed in different ways include evaluation of predicates involving quantification over large or infinite sets and predicates relating values at different points in execution history. The survey is not encyclopedic, but discusses representative examples of the main approaches and tactics for solving common problems.

A complete oracle would have three capabilities and would carry them out perfectly:

- A generator, to provide predicted or expected results for each test.
- A comparator, to compare predicted and obtained results.
- An evaluator, to determine whether the comparison results are sufficiently close to be a pass.

One of the key problems with oracles is that they can only address a small subset of the inputs and outputs actually associated with any test. The tester might intentionally set the values of some variables, but the entire program's other variables have values too. Configuration settings, amount of available memory, and program options can also affect the test results. As a result, our evaluation of the test results (that we look at) in terms of the test inputs (that we set intentionally) is based on incomplete data, and may be incorrect.

Any of the oracle capabilities may be automated.

Example: We might generate predictions for a test from previous test results on this program, from the behavior of a previous release of this program or a competitor's program, from a standard function or from a custom model.

We might generate these by hand, by a tool that feeds input to the reference program and captures output or by something that combines automated and manual testing. We might instead generate predictions from specifications, advertised claims, regulatory requirements or other sources of information that require a human to evaluate the information in order to generate the prediction.

Self Assessment

Fill in the blanks:

5. An .... is a mechanism for determining whether the program has passed or failed a test.
6. Oracles are either based on a program specification, or are a (perhaps very incomplete) specification of ....

13.3 Test Cases and Criteria

A test case is a set of conditions or variables under which a tester will determine whether a system under test satisfies requirements or works correctly. The process of developing test cases can also help find problems in the requirements or design of an application. Having test cases that are good at revealing the presence of faults is central to successful testing. Ideally, we would like to determine a set of test cases such that successful execution of all of them implies that there are no errors in the program. This ideal goal cannot usually be achieved due to practical and theoretical constraints.

As each test case costs money, effort is needed to generate the test case, machine time is needed to execute the program for that test case, and more effort is needed to evaluate the results.

Therefore, we would also like to minimize the number of test cases needed to detect errors. These are the two fundamental goals of a practical testing activity – maximize the number of errors detected and minimize the number of test cases. With selecting test cases the primary objectives is to ensure that if there is an error or fault in the program, it is exercised by one of the test cases.

Notes

An ideal test case set is one that succeeds (meaning that its execution reveals no errors) only if there are no errors in the program. For this test selection criterion can be used. There are two aspects of test case selection – specifying a criterion for evaluating a set of test cases, and generating a set of test cases that satisfy a given criterion.

There are two fundamental properties for a testing criterion: reliability and validity. A criterion is reliable if all the sets that satisfy the criterion detect the same errors. A criterion is valid if for any error in the program there is some set satisfying the criterion that will reveal the error. Some axioms capturing some of the desirable properties of test criteria have been proposed. The first axiom is the applicability axiom, which states that for every program there exists a test set T that satisfies the criterion.

This is clearly desirable for a general-purpose criterion: a criterion that can be satisfied only for some types of programs is of limited use in testing. The anti-extensionality axiom states that there are programs P and Q, both of which implement the same specifications, such that a test set T satisfies the criterion for P but does not satisfy the criterion for Q.

Notes This axiom ensures that the program structure has an important role to play in deciding the test cases.

The anti-decomposition axiom states that there exists a program P and its component Q such that a test case set T satisfies the criterion for P and T1 is the set of values that variables can assume on entering Q for some test case in T and T1 does not satisfy the criterion for Q. Essentially, the axiom says that just because the criterion is satisfied for the entire program, it does not mean that the criterion has been satisfied for its components.

The anti-composition axiom states that there exist program P and Q such that T satisfies the criterion for P and the outputs of P for T satisfy the criterion for Q, but T does not satisfy the criterion for the parts P and Q does not imply that the criterion has been satisfied by the program comprising P, Q. It is very difficult to get a criterion that satisfies even these axioms. This is largely due to the fact that a program may have paths that are infeasible, and one cannot determine these infeasible paths algorithmically as the problem is undesirable.

Self Assessment

State whether the following statements are true or false:

7. A test case is a set of conditions or variables under which a tester will determine whether a system under test satisfies requirements or works correctly.
8. An ideal test case set is one that succeeds (meaning that its execution reveals no errors) only if there are no errors in the program.
9. There are two fundamental properties for a testing criterion: reliability and validity.

13.4 Black Box Testing

Black-box testing, also called behavioral testing, focuses on the functional requirements of the software. That is, black-box testing enables the software engineer to derive sets of input conditions that will fully exercise all functional requirements for a program. Black-box testing is not an alternative to white-box techniques. Rather, it is a complementary approach that is likely to uncover a different class of errors than white-box methods.

Black-box testing attempts to find errors in the following categories:

1. Incorrect or missing functions
2. Interface errors
3. Errors in data structures or external data base access
4. Behavior or performance errors
5. Initialization and termination errors.

By applying black-box techniques, we derive a set of test cases that satisfy the following criteria:

1. Test cases that reduce, by a count that is greater than one, the number of additional test cases that must be designed to achieve reasonable testing.
2. Test cases that tell us something about the presence or absence of classes of errors, rather than an error associated only with the specific test at hand.

13.4.1 Equivalence Partitioning

Equivalence partitioning is a black-box testing method that divides the input domain of a program into classes of data from which test cases can be derived. An ideal test case single-handedly uncovers a class of errors that might otherwise require many cases to be executed before the general error is observed.

Equivalence partitioning strives to define a test case that uncovers classes of errors, thereby reducing the total number of test cases that must be developed.

Test case design for equivalence partitioning is based on an evaluation of equivalence classes for an input condition. Using concepts introduced in the preceding section, if a set of objects can be linked by relationships that are symmetric, transitive, and reflexive, an equivalence class is present.

An *equivalence class* represents a set of valid or invalid states for input conditions. Typically, an input condition is a specific numeric value, a range of values, a set of related values, or a Boolean condition. Equivalence classes may be defined according to the following guidelines:

1. If an input condition specifies a *range,* one valid and two invalid equivalence classes are defined.
2. If an input condition requires a specific *value,* one valid and two invalid equivalence classes are defined.
3. If an input condition specifies a member of a *set,* one valid and one invalid equivalence class are defined.
4. If an input condition is *Boolean,* one valid and one invalid class are defined.

13.4.2 Boundary Value Analysis

Boundary value analysis is a test case design technique that complements equivalence partitioning. Rather than selecting any element of an equivalence class, BVA leads to the selection of test cases at the "edges" of the class. Rather than focusing solely on input conditions, BVA derives test cases from the output domain as well

Guidelines for BVA are similar in many respects to those provided for equivalence partitioning:

1. If an input condition specifies a range bounded by values *a* and *b,* test cases should be designed with values *a* and *b* and just above and just below *a* and *b*.

Notes

2. If an input condition specifies a number of values, test cases should be developed that exercise the minimum and maximum numbers.

Caution Values just above and below minimum and maximum are also tested.

3. Apply guidelines 1 and 2 to output conditions.

Example: Assume that a temperature vs. pressure table is required as output from an engineering analysis program.

Test cases should be designed to create an output report that produces the maximum (and minimum) allowable number of table entries.

4. If internal program data structures have prescribed boundaries (e.g., an array has a defined limit of 100 entries), be certain to design a test case to exercise the data structure at its boundary.

Most software engineers intuitively perform BVA to some degree. By applying these guidelines, boundary testing will be more complete, thereby having a higher likelihood for error detection.

Self Assessment

Fill in the blanks:

10. Black-box testing, also called …………………….

11. Black-box testing is not an alternative to …………………… techniques.

12. …………………… is a black-box testing method that divides the input domain of a program into classes of data from which test cases can be derived.

13. An …………………… represents a set of valid or invalid states for input conditions.

14. …………………… analysis is a test case design technique that complements equivalence partitioning.

13.5 White Box Testing

White box-testing referred to as glass box test can be defined as a test case design method which employs control structure of procedural design in order to derive test cases. Such kind of testing, software engineer can be deriving test cases which:

1. Guarantee that all independent paths within a module have been exercised at least once,
2. Exercise all logical decisions on their true and false sides
3. Execute all loops at their boundaries and within their operational bounds
4. Exercise internal data structures to ensure their validity.

The arguments mentioned below provide us with the reason for conducting white-box tests.

- Logic errors and incorrect assumptions are inversely proportional to the probability that a program path will be executed
- We often believe that a logical path is not likely to be executed when, in fact, it may be executed on a regular basis
- Typographical errors are random

The different types of White Box testing are discussed below:

Notes

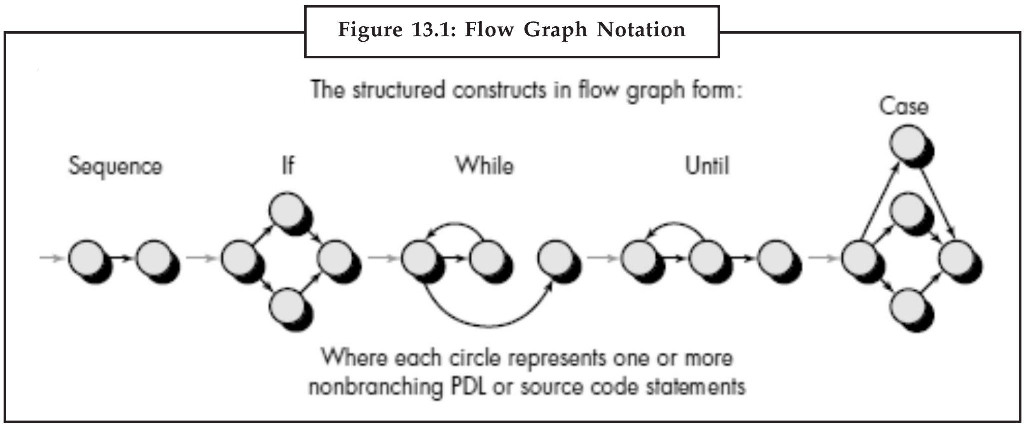
13.5.1 Basis Path Testing

Basis path testing is a white-box testing technique, proposed by Tom McCabe which enables the test case designer to derive a logical complexity measure of a procedural design and use this measure as a guide for defining a basis set of execution paths. Test cases derived to exercise the basis set are guaranteed to execute every statement in the program at least one time during testing.

Flow Graph Notation

Before the basis path method can be introduced, a simple notation for the representation of control flow, called a flow graph or program graph must be introduced. The flow graph depicts logical control flow using the notation illustrated in Figure 13.1. Each structured construct has a corresponding flow graph symbol.

Figure 13.1: Flow Graph Notation


The structured constructs in flow graph form:
Sequence
If
While
Until
Case
Where each circle represents one or more nonbranching PDL or source code statements

Cyclomatic Complexity

Cyclomatic complexity is software metric that provides a quantitative measure of the logical complexity of a program. When used in the context of the basis path testing method, the value computed for Cyclomatic complexity defines the number of independent paths in the basis set of a program and provides us with an upper bound for the number of tests that must be conducted to ensure that all statements have been executed at least once.

Driving Test Cases

The basis path testing method can be applied to a procedural design or to source code. The procedure averag*e,* depicted in PDL in Figure 13.2 can be used as an example to illustrate each step in the test case design method. The following steps can be applied to derive the basis set:

1. ***Using the Design or Code as a Foundation, Draw a Corresponding Flow Graph:*** A flow graph is created using the symbols and construction rules. Referring to the PDL for average in Figure 13.2, a flow graph is created by numbering those PDL statements that will be mapped into corresponding flow graph nodes. The corresponding flow graph is in Figure 13.1.

2. ***Determine the Cyclomatic Complexity of the Resultant Flow Graph:*** The cyclomatic complexity, $V(G)$, is determined by applying the algorithms.

Notes

> *Notes* It should be noted that *V*(*G*) can be determined without developing a flow graph by counting all conditional statements in the PDL and adding 1.

Referring to Figure 13.2,

V(*G*) = 6 regions

V(*G*) = 17 edges _ 13 nodes + 2 = 6

V(*G*) = 5 predicate nodes + 1 = 6

3. ***Determine a Basis Set of Linearly Independent Paths:*** The value of V(G) provides the number of linearly independent paths through the program control structure. In the case of procedure *average,* we expect to specify six

   paths:

   path 1: 1-2-10-11-13

   path 2: 1-2-10-12-13

   path 3: 1-2-3-10-11-13

   path 4: 1-2-3-4-5-8-9-2-. . .

   path 5: 1-2-3-4-5-6-8-9-2-. . .

   path 6: 1-2-3-4-5-6-7-8-9-2-. . .

   The ellipsis (. . .) following paths 4, 5, and 6 indicates that any path through the remainder of the control structure is acceptable. It is often worthwhile to identify predicate nodes as an aid in the derivation of test cases. In this case, nodes 2, 3, 5, 6, and 10 are predicate nodes.

4. ***Prepare Test Cases that will Force Execution of each Path in the Basis Set:*** Data should be chosen so that conditions at the predicate nodes are appropriately set as each path is tested. Test cases that satisfy the basis set just described are:

   Path 1 Test Case:

   value(*k*) = valid input, where *k* < *i* for 2 d" *i* d" 100

   value(*i*) = _999 where 2 d" *i* d" 100

   Expected Results: Correct average based on *k* values and proper totals.

> *Notes* Path 1 cannot be tested stand-alone but must be tested as part of path 4, 5, and 6 tests.

Path 2 Test Case:

value(1) = _999

Expected Results: Average = _999; other totals at initial values.

Path 3 Test Case:

Attempt to process 101 or more values.

First 100 values should be valid.

Expected Results: Same as test case 1.

Path 4 Test Case:

value(*i*) = valid input where i < 100

value(*k*) < minimum where *k* < *i*

Expected Results: Correct average based on *k* values and proper totals.

Path 5 Test Case:

value(*i*) = valid input where *i* < 100

value(*k*) > maximum where *k* <= *i*

Expected Results: Correct average based on *n* values and proper totals.

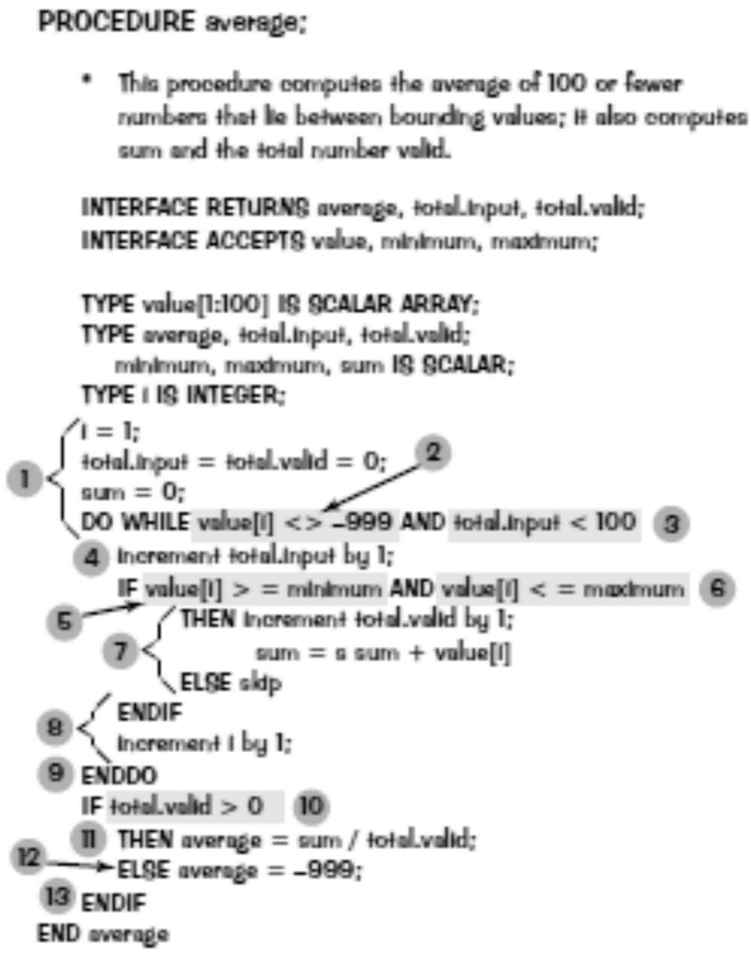
Path 6 Test Case:

value(*i*) = valid input where *i* < 100

Expected Results: Correct average based on *n* values and proper totals.

Each test case is executed and compared to expected results. Once all test cases have been completed, the tester can be sure that all statements in the program have been executed at least once.

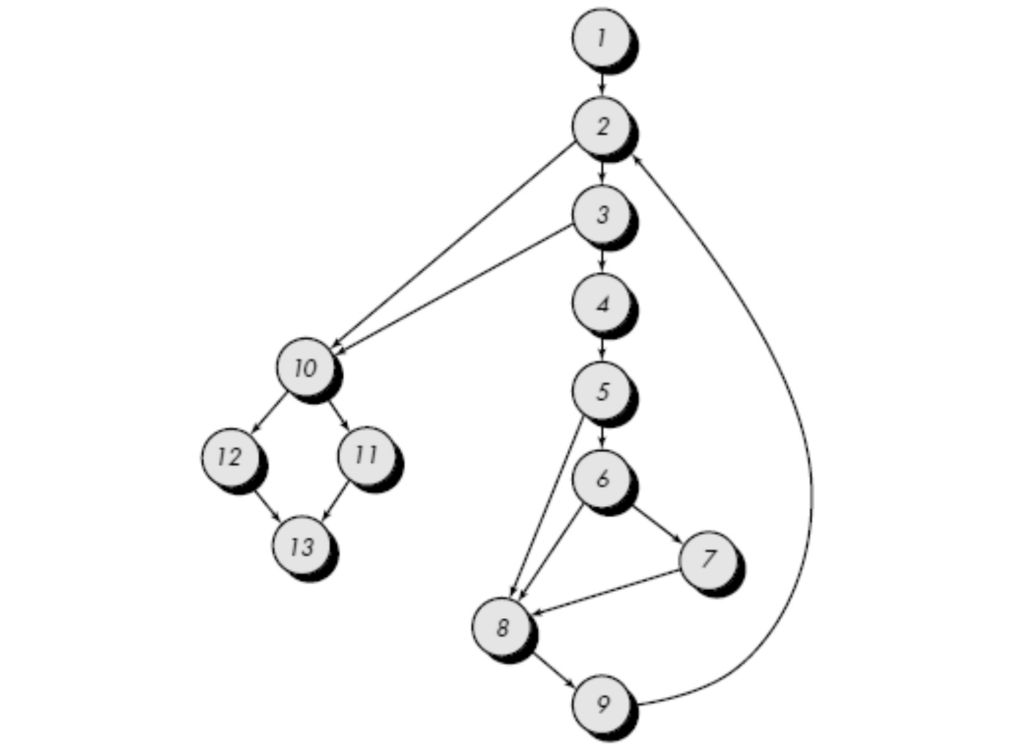
Figure 13.2: PDL for Test Case Design with Nodes Identified



```
PROCEDURE average;

   •  This procedure computes the average of 100 or fewer
      numbers that lie between bounding values; it also computes the
      sum and the total number valid.

   INTERFACE RETURNS average, total.input, total.valid;
   INTERFACE ACCEPTS value, minimum, maximum;

   TYPE value[1:100] IS SCALAR ARRAY;
   TYPE average, total.input, total.valid;
      minimum, maximum, sum IS SCALAR;
   TYPE i IS INTEGER;
   i = 1;
   total.input = total.valid = 0;
   sum = 0;
   DO WHILE value[i] <> -999 AND total.input < 100
      increment total.input by 1;
      IF value[i] > = minimum AND value[i] < = maximum
         THEN increment total.valid by 1;
                 sum = s sum + value[i]
         ELSE skip
      ENDIF
      increment i by 1;
   ENDDO
   IF total.valid > 0
      THEN average = sum / total.valid;
      ELSE average = -999;
   ENDIF
END average
```

Notes

Figure 13.3: Flow Graph for the Procedure Average



13.5.2 Control Flow Based Testing

It is a white box testing technique to find bug is control flow testing. Control flow testing applies to almost all software and is effective for most software. It is a structural testing strategy that uses the program's control flow as a model control flow testing favour more but simpler paths over complicated but fewer paths. Researches shows that control flow testing catches about 50% of all bugs during unit testing (unit testing is dominated by control flow testing). Control flow testing is more effective for unstructured code rather than structured code. Most bugs can result in control flow errors and therefore misbehaviour that could be caught by control flow testing. Control flow bugs are not as common as they used to be as they are minimize because of structured programming languages. Some of the limitations of control flow testing are:

1. Control flow testing cannot catch all initialization mistakes.
2. Specification mistake are not caught by control flow testing.
3. It's unlikely to find missing paths and features if the program and the model on which the tests are based are done by the same person.

The adequacy of the test cases measured with a metric called coverage (coverage is a measure of the completeness of the set of test cases). Now, we will define various coverage methods.

Statement Coverage

Statement coverage is a measure of the percentage of statements that have been executed by test cases. Anything less than 100% statement coverage means that not all lines of code have been executed. We can achieve statement coverage by identifying cyclomatic number an executing this minimum set of test cases. Measure benefit of statement coverage is that it is greatly able to isolate the portion of code, which could not be executed. Since it tends to become expensive, the developer chose a better testing technique called branch coverage or decision coverage.

Branch Coverage

A stronger logic coverage criterion is known as branch coverage or decision coverage. Branch coverage or decision coverage is a measure of the percentage of the decision point of the program have been evaluated as both true and false in test cases.

Example: Branch coverage-DO statements, IF statements and multi-way GOTO statements. Branch coverage is usually shown to satisfy statement coverage. By 100% branch coverage we mean that every control flow graph is traversed.

Condition Coverage

A criterion which is stronger than decision coverage is condition coverage. It is a measure of percentage of Boolean sub-expressions of the program that have been evaluated as both true and false outcome in test cases.

13.5.3 Data Flow Testing

The data flow testing method selects test paths of a program according to the locations of definitions and uses of variables in the program. A number of data flow testing strategies have been studied and compared.

To illustrate the data flow testing approach, assume that each statement in a program is 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* at statement *S* is said to be *live* at statement *S′* if there exists a path from statement *S* to statement *S′* that contains no other definition of *X.*

A *definition-use* (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 statement *S* is live at statement *S′*.

One simple data flow testing strategy is to require that every DU chain be covered at least once. We refer to this strategy as the *DU testing strategy.* It has been shown that DU testing does not guarantee the coverage of all branches of a program. However, a branch is not guaranteed to be covered by DU testing only in rare situations such as if-then-else constructs in which the *then part* has no definition of any variable and the *else part* does not exist. In this situation, the else branch of the *if* statement is not necessarily covered by DU testing.

Moreover the Data flow testing strategies are useful for selecting test paths of a program containing nested *if* and *loop* statements.

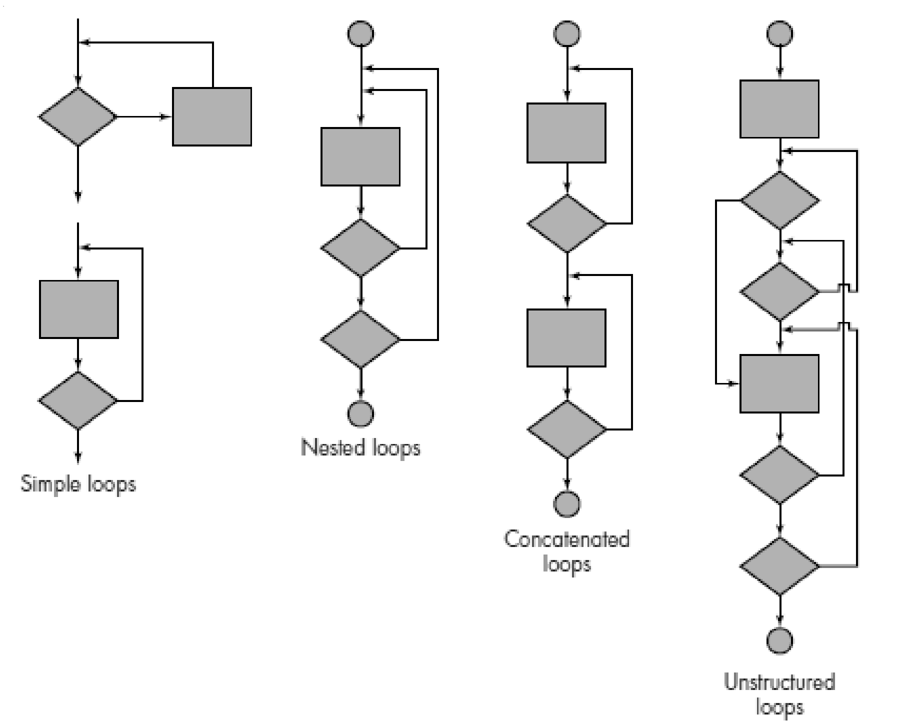
Notes

13.5.4 Loop Testing

Loop testing is a white-box testing technique that focuses exclusively on the validity of loop constructs. Four different classes of loops can be defined given in Figure 13.4:

- Simple loops
- Nested loops
- Concatenated loops
- Unstructured loops

Figure 13.4: Loops Classes



1. ***Simple Loops:*** The following set of tests can be applied to simple loops, where *n* is the maximum number of allowable passes through the loop:

   (a) Skip the loop entirely.

   (b) Only one pass through the loop.

   (c) Two passes through the loop.

   (d) *m* passes through the loop where *m* < *n*.

   (e) *n* _1, *n*, *n* + 1 passes through the loop.

2. ***Nested Loops:*** If you were to extend the test approach for simple loops to nested loops, the number of possible tests would grow geometrically as the level of nesting increases. This would result in an impractical number of tests. Beizer suggests an approach that will help to reduce the number of tests:

   (a) Start at the innermost loop. Set all other loops to minimum values.

(b) Conduct simple loop tests for the innermost loop while holding the outer loops at their minimum iteration parameter (e.g., loop counter) values. Add other tests for out-of-range or excluded values.

(c) Work outward, conducting tests for the next loop, but keeping all other outer loops at minimum values and other nested loops to "typical" values.

(d) Continue until all loops have been tested.

3. ***Concatenated Loops*: ** Concatenated loops can be tested using the approach defined for simple loops, if each of the loops is independent of the other. However, if two loops are concatenated and the loop counter for loop 1 is used as the initial value for loop 2, then the loops are not independent. When the loops are not independent, the approach applied to nested loops is recommended.

4. ***Unstructured Loops:*** Whenever possible, this class of loops should be redesigned to reflect the use of the structured programming constructs.

Self Assessment

Fill in the blanks:

15. .... referred to as glass box test can be defined as a test case design method which employs control structure of procedural design in order to derive test cases.

16. .... complexity is software metric that provides a quantitative measure of the logical complexity of a program.

13.6 Summary

- Tests must be conducted to find the highest possible number of errors, must be done systematically and in a disciplined way.
- Testing software can be considered as the only destructive (psychologically) step in the entire life cycle of software production.
- A program developed should be testable i.e. it should be possible to test the program.
- An oracle is a mechanism for determining whether the program has passed or failed a test.
- One of the key problems with oracles is that they can only address a small subset of the inputs and outputs actually associated with any test.
- A test case is a set of conditions or variables under which a tester will determine whether a system under test satisfies requirements or works correctly.
- There are two fundamental properties for a testing criterion: reliability and validity.
- Black-box testing, also called behavioral testing, focuses on the functional requirements of the software.
- Equivalence partitioning is a black-box testing method that divides the input domain of a program into classes of data from which test cases can be derived.
- White box-testing referred to as glass box test can be defined as a test case design method which employs control structure of procedural design in order to derive test cases.

Notes

13.7 Keywords

Basis Path Testing: It allows the design and definition of a basis set of execution paths.

Black-box Testing: It refers to tests that are conducted at the software interfaces; it mainly focuses on the functional requirements of the software.

Boundary Value Analysis: Boundary value analysis is a test case design technique that complements equivalence partitioning.

Data Flow Testing: The data flow testing method selects test paths of a program according to the locations of definitions and uses of variables in the program.

Equivalence Class: An equivalence class represents a set of valid or invalid states for input conditions.

Equivalence Partitioning: Equivalence partitioning is a black-box testing method that divides the input domain of a program into classes of data from which test cases can be derived.

Error: An error is a person act that generates an erroneous result.

Failure: Failure is the inability of a system or component to perform a required function according to its specifications.

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

Loop Testing: Loop testing is a white-box testing technique that focuses exclusively on the validity of loop constructs.

Oracle: An oracle is a mechanism for determining whether the program has passed or failed a test.

Software Testing: Software testing is an investigation conducted to provide stakeholders with information about the quality of the product or service under test.

Statement Coverage: Statement coverage is a measure of the percentage of statements that have been executed by test cases.

Structural Testing: It examine source code and analysis what is present in the code.

Test Case: A test case is a set of conditions or variables under which a tester will determine whether a system under test satisfies requirements or works correctly.

White-box Testing: It works on the principle of closely monitoring the procedural details of the software.

13.8 Review Questions

1. What are the fundamentals of software testing?
2. Explain the benefits and objectives of testing.
3. Enumerate the various principles of testing.
4. What are the various testing objectives?
5. Define testability.
6. What is oracle? What are the problems with oracles?
7. Define test case. Discuss about the test cases & its various criteria.
8. Briefly explain the Black-box testing. Discuss about equivalence partitioning.

9. Elaborate the boundary value analysis.
10. Describe about White box-testing.
11. What are the different types of White Box testing?
12. Discuss about control flow based testing.
13. Explain the data flow testing.
14. What are the four different classes of loops?
15. Write short notes on:
    (a) Base Path Testing
    (b) Control Structure Testing
    (c) Black-Box Testing
    (d) Equivalence Class Testing
    (e) White Box Testing

Answers: Self Assessment

1. Testing software
2. Error
3. Fault
4. Failure
5. Oracle
6. Intended behavior
7. True
8. True
9. True
10. Behavioral testing
11. White-box
12. Equivalence partitioning
13. Equivalence class
14. Boundary value
15. White box-testing
16. Cyclomatic

13.9 Further Readings

Books

Rajib Mall, *Fundamentals of Software Engineering*, 2nd Edition, PHI.

Richard Fairpy, *Software Engineering Concepts*, Tata McGraw Hill, 1997.

R.S. Pressman, *Software Engineering – A Practitioner's Approach*, 5th Edition, Tata McGraw Hill Higher education.

Sommerville, *Software Engineering*, 6th Edition, Pearson Education

Online links

www.guru99.com/software-testing.html

www.ece.cmu.edu/~koopman/des_s99/sw_testing/

www.softwarequalitymethods.com/Papers/OracleTax.pdf

se.fsksm.utm.my/.../IST-AutomatedFrameworkSoftTestOracle-FPage.pdf

Notes

Unit 14: Software Testing-II

CONTENTS

Objectives

Introduction

14.1 Levels of Testing

14.1.1 Unit Testing

14.1.2 Integration Testing

14.1.3 System Testing

14.1.4 Acceptance Testing

14.2 Test Plan

14.3 Test Case Specifications

14.4 Execution and Analysis

14.5 Logging and Tracking

14.5.1 Earned Value Analysis

14.6 Metrics

14.6.1 Failure Data Estimation

14.6.2 Parameter Estimation

14.7 Summary

14.8 Keywords

14.9 Review Questions

14.10 Further Readings

Objectives

After studying this unit, you will be able to:

- Discuss various levels of testing
- Discuss about test plan
- Explain the test case specifications
- Identify the execution and analysis
- Understand logging and tracking
- Discuss about metrics

Introduction

Software testing is an investigation conducted to provide stakeholders with information about the quality of the product or service under test. Software testing can also provide an objective, independent view of the software to allow the business to appreciate and understand the risks of software implementation. Test techniques include, but are not limited to, the process of executing a program or application with the intent of finding software bugs (errors or other defects). Testing is the process of evaluating a system or its component(s) with the intent to find that whether it satisfies the specified requirements or not. Testing is executing a system in order to identify any gaps, errors or missing requirements in contrary to the actual desire or requirements.

14.1 Levels of Testing

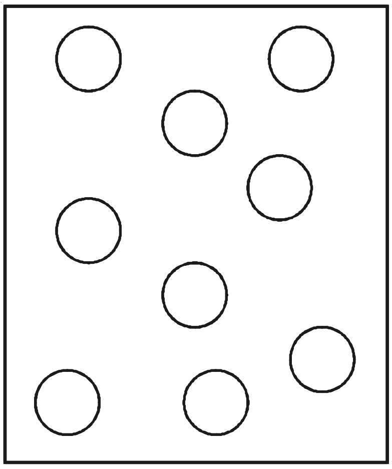
The levels of testing are discussed below:

14.1.1 Unit Testing

The first level of testing is called unit testing. Unit testing focuses on verification of individual units or modules of software. Using the design, important control paths are identified and tested to find errors within the module boundary.

Did u know? The unit testing is white-box oriented and can be conducted in parallel for multiple components.

Figure 14.1: Unit Testing



It involves running a module in isolation from the rest of the software by preparing test cases and comparing the actual results with the expected results as specified by the specifications and design. One of its purposes is to find and remove as many errors in the software as practical.

Advantages of Unit Testing

- The size of a module is small enough to locate errors comparatively easily.
- The module is small enough to be able to test it in an exhaustive fashion.
- Confusing interactions of multiple errors in different parts of the software are eliminated.

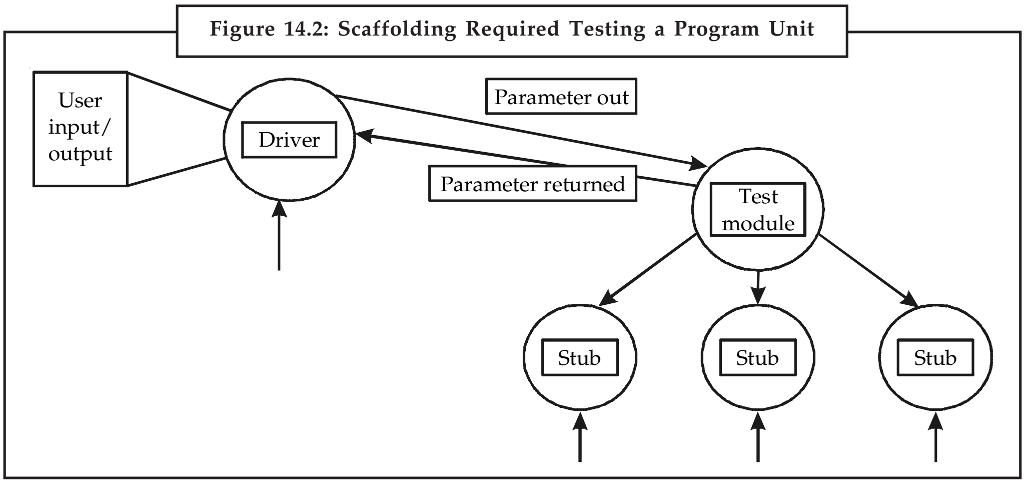
However, there are problems associated with running a program in isolation. The biggest problem is how to run a module in isolation, without anything to call it and without anything being called by it. One approach is to build an appropriate routine to call it and the stubs to be called by it or to simply insert output statements.

Notes

These additional costs of writing code, called scaffolding, although include effort important to testing but are not delivered in the actual product, as shown in Figure 14.2.

Selective Testing of Execution Paths: Test cases should be designed to detect maximum errors due to erroneous computations, incorrect comparisons or improper control flow. Basis path and loop testing are used to find a broad array of path errors.

Figure 14.2: Scaffolding Required Testing a Program Unit



Good design ensures that error conditions are anticipated and error-handling paths be set up to reroute or terminate processing when an error occurs.

Did u know? This approach is called anti-bugging.

The various errors that must be checked for while testing are as under:

1. Error description is unintelligible.
2. Error noted does not correspond to error encountered.
3. Error condition causes system intervention prior to error handling.
4. Exception-condition processing is incorrect.
5. Error description does not provide enough information to assist in the location of the cause of the error.

Boundary testing is the most important task of unit testing. Software often fails at boundaries.

14.1.2 Integration Testing

The next level of testing is often called integration testing. Integration testing is a systematic technique for constructing the program structure while at the same time conducting tests to uncover errors associated with interfacing.

The objective is to take unit tested components and build a program structure that has been dictated by design. There is often a tendency to attempt non-incremental integration; that is, to construct the program using a "big bang" approaches. All components are combined in advance. The entire program is tested as a whole. A set of errors is encountered. Correction is difficult because isolation of causes is complicated by the vast expanse of the entire program. Once these errors are corrected, new ones appear and the process continues in a seemingly endless loop.

Notes

Incremental integration is the antithesis of the big bang approach. The program is constructed and tested in small increments, where errors are easier to isolate and correct; interfaces are more likely to be tested completely; and a systematic test approach may be applied.

Top-down Integration

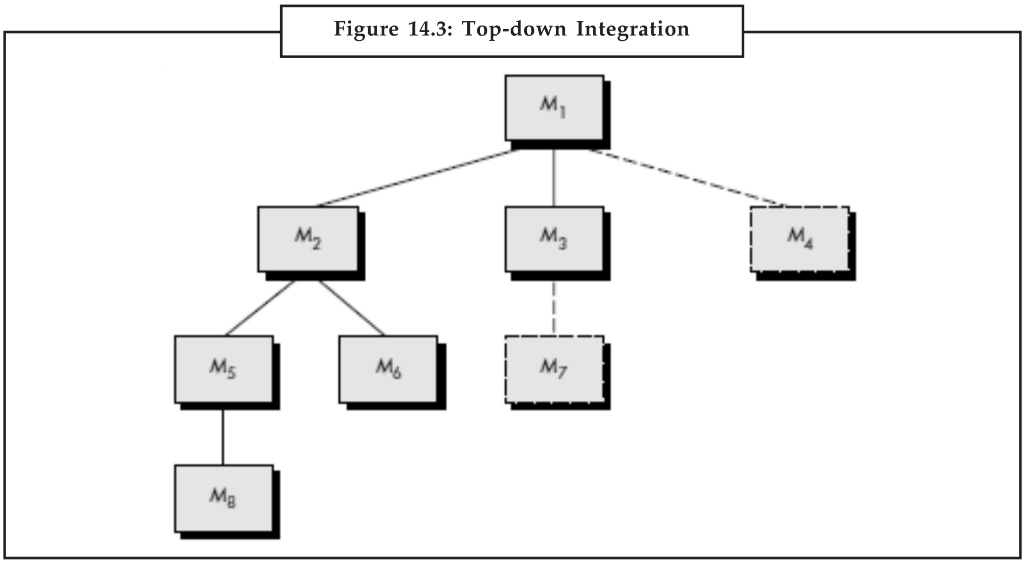
Top-down integration testing is an incremental approach to construction of program structure. Modules are integrated by moving downward through the control hierarchy, beginning with the main control module. Modules subordinate to the main control module are incorporated into the structure in either a depth-first or breadth-first manner.

Referring to Figure 14.3, depth-first integration would integrate all components on a major control path of the structure. Selection of a major path is somewhat arbitrary and depends on application-specific characteristics.

Example: Selecting the left-hand path, components M1, M2, M5 would be integrated first.

Next, M8 or if needed for proper functioning of M2) M6 would be integrated. Then, the central and right-hand control paths are built. *Breadth-first integration* incorporates all components directly subordinate at each level, moving across the structure horizontally. From the figure, components M2, M3, and M4 (a replacement for stub S4) would be integrated first. The next control level, M5, M6, and so on, follows.

Figure 14.3: Top-down Integration



The integration process is performed in a series of five steps:

1. The main control module is used as a test driver and stubs are substituted for all components directly subordinate to the main control module.
2. Depending on the integration approach selected (i.e., depth or breadth first), subordinate stubs are replaced one at a time with actual components.
3. Tests are conducted as each component is integrated.
4. On completion of each set of tests, another stub is replaced with the real component.
5. Regression testing may be conducted to ensure that new errors have not been introduced.

Notes

The process continues from step 2 until the entire program structure is built.

Bottom-Up Integration

Bottom-up integration testing, as its name implies, begins construction and testing with atomic modules i.e., components at the lowest levels in the program structure.

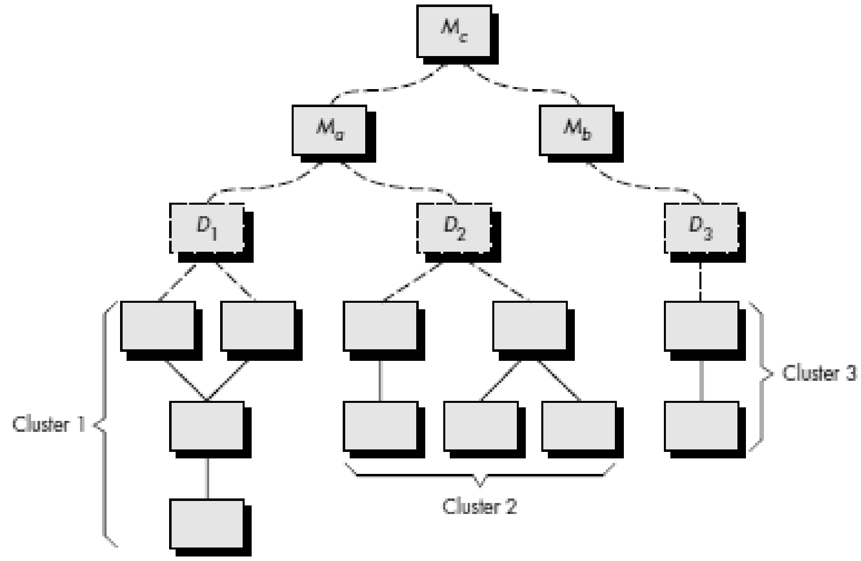
Because components are integrated from the bottom up, processing required for components subordinate to a given level is always available and the need for stubs is eliminated.

A bottom-up integration strategy may be implemented with the following steps:

1. Low-level components are combined into clusters (also referred as *builds*) that perform a specific software sub function.
2. A driver is written to coordinate test case input and output.
3. The cluster is tested.
4. Drivers are removed and clusters are combined moving upward in the program structure.

Integration follows the pattern illustrated in Figure 14.4. Components are combined to form clusters 1, 2, and 3. Each of the clusters is tested using a driver (shown as a dashed block). Components in clusters 1 and 2 are subordinate to Ma. Drivers D1 and D2 are removed and the clusters are interfaced directly to Ma. Similarly, driver D3 for cluster 3 is removed prior to integration with module Mb. Both Ma and Mb will ultimately be integrated with component Mc, and so forth.

Figure 14.4: Bottom-up Integration



Regression Testing

Regression testing is the re-execution of some subset of tests that have already been conducted to ensure that changes have not propagated unintended side effects. Regression testing may be conducted manually, by re-executing a subset of all test cases or using automated capture or playback tools. Capture or playback tools enable the software engineer to capture test cases and results for subsequent playback and comparison.

The regression test suite (the subset of tests to be executed) contains three different classes of test cases:

- A representative sample of tests that will exercise all software functions.
- Additional tests that focus on software functions that are likely to be affected by the change.
- Tests that focus on the software components that have been changed.

As integration testing proceeds, the number of regression tests can grow quite large. Therefore, the regression test suite should be designed to include only those tests that address one or more classes of errors in each of the major program functions. It is impractical and inefficient to re-execute every test for every program function once a change has occurred.

Smoke Testing

Smoke testing is an integration testing approach that is commonly used when "shrink-wrapped" software products are being developed. It is designed as a pacing mechanism for time-critical projects, allowing the software team to assess its project on a frequent basis. In essence, the smoke testing approach encompasses the following activities:

1. Software components that have been translated into code are integrated into a "build." A build includes all data files, libraries, reusable modules, and engineered components that are required to implement one or more product functions.
2. A series of tests is designed to expose errors that will keep the build from properly performing its function. The intent should be to uncover "show stopper" errors that have the highest likelihood of throwing the software project behind schedule.
3. The build is integrated with other builds and the entire product (in its current form) is smoke tested daily. The integration approach may be top down or bottom up.

The smoke test should exercise the entire system from end to end. It does not have to be exhaustive, but it should be capable of exposing major problems. The smoke test should be thorough enough that if the build passes, you can assume that it is stable enough to be tested more thoroughly.

Smoke testing provides a number of benefits when it is applied on complex, time critical software engineering projects like it minimises the Integration risk, improves the quality of the end-product, error diagnosis and correction become simple and progress becomes easier to assess etc.

Task Make a difference between top-down and bottom-up integration.

14.1.3 System Testing

System testing is testing conducted on a complete, integrated system to evaluate the system's compliance with its specified requirements. System testing falls within the scope of Black box testing, and as such, should require no knowledge of the inner design of the code.

System testing is actually done to the entire system against the Functional Requirement Specifications (FRS) and/or the System Requirement Specification (SRS). Moreover, the System testing is an investigatory testing phase, where the focus is to have almost a destructive attitude and test not only the design, but also the behavior and even the believed expectations of the customer. It is also intended to test up to and beyond the bounds defined in the software/ hardware requirements specifications. Remaining All Testing Models comes under System Testing.

Figure 14.5: System Testing

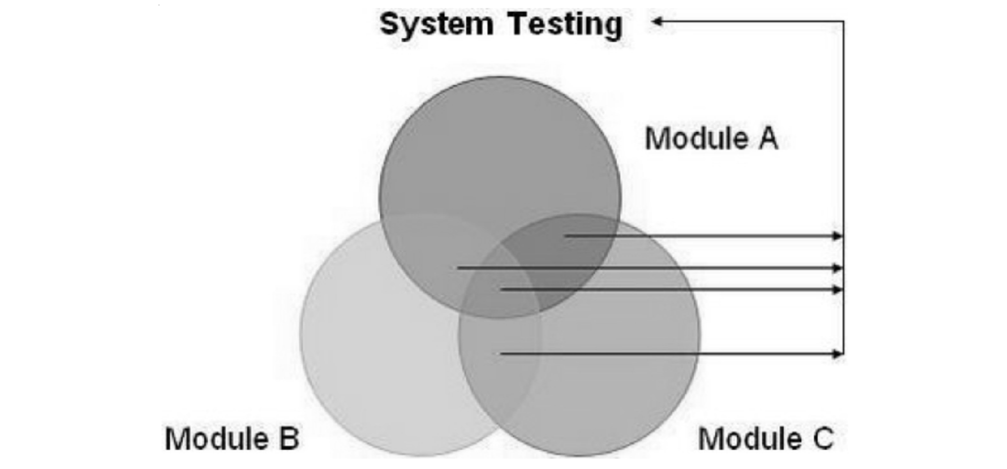
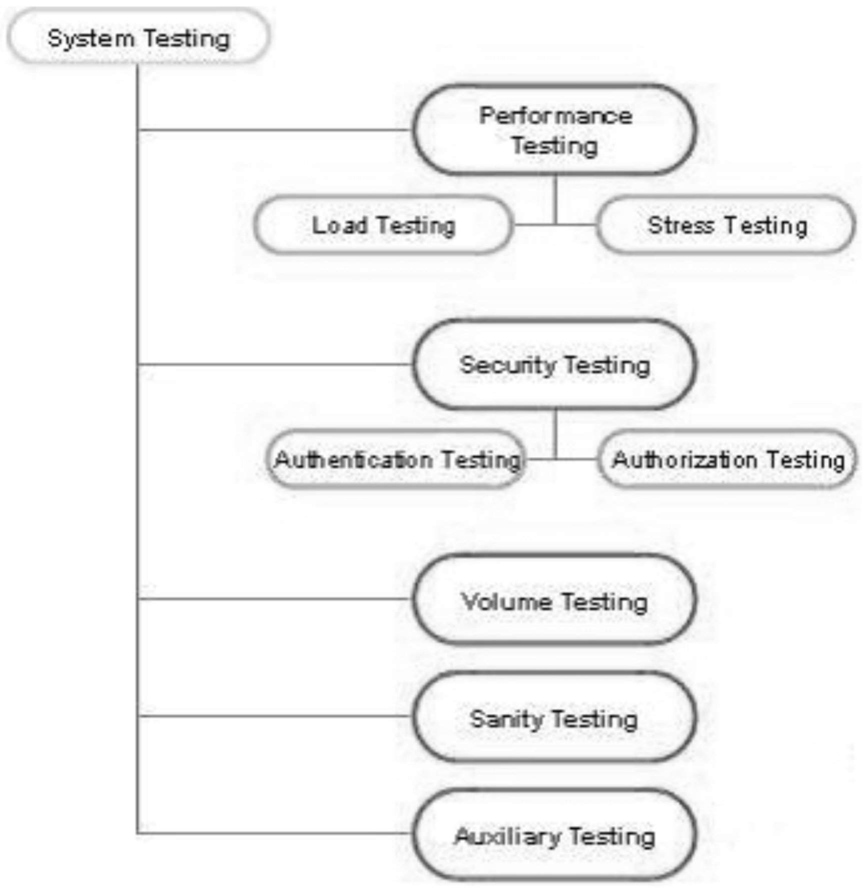


Figure 14.6: Remaining System Testing Models



14.1.4 Acceptance Testing

This is arguably the most importance type of testing as it is conducted by the Quality Assurance Team who will gauge whether the application meets the intended specifications and satisfies the client's requirements. The QA team will have a set of pre written scenarios and Test Cases that will be used to test the application.

More ideas will be shared about the application and more tests can be performed on it to gauge its accuracy and the reasons why the project was initiated. Acceptance tests are not only intended to point out simple spelling mistakes, cosmetic errors or Interface gaps, but also to point out any bugs in the application that will result in system crashers or major errors in the application.

By performing acceptance tests on an application the testing team will deduce how the application will perform in production. There are also legal and contractual requirements for acceptance of the system.

Self Assessment

Fill in the blanks:

1. …………………… focuses on verification of individual units or modules of software.
2. …………………… is a systematic technique for constructing the program structure while at the same time conducting tests to uncover errors associated with interfacing.
3. …………………… testing is an incremental approach to construction of program structure.
4. …………………… testing, as its name implies, begins construction and testing with atomic modules i.e., components at the lowest levels in the program structure.
5. …………………… is the re-execution of some subset of tests that have already been conducted to ensure that changes have not propagated unintended side effects.
6. …………………… is an integration testing approach that is commonly used when "shrink-wrapped" software products are being developed.
7. …………………… is testing conducted on a complete, integrated system to evaluate the system's compliance with its specified requirements.

14.2 Test Plan

In general, testing commences with a test plan and terminates with acceptance testing. A test plan is a general document for the entire project that defines the scope, approach to be taken, and the schedule of testing as well as identifies the test items for the entire testing process and the person responsible for the different activities of testing.

The test planning can be done well before the actual testing commences and can be done in parallel with the coding and design phases. The inputs for forming the test plan are: (1) project plan (2) requirements document and (3) system design document. The project plan is needed to make sure that the test plan is consistent with the overall plan for the project and the testing the test plan is consistent with the overall plan for the project and the testing schedule matches that of the project plan.

The requirements document and the design document are the basic documents used for selecting the test units and deciding the approaches to be used during testing. A test plan should contain the following:

Notes

- Test unit specification
- Features to be tested
- Approach for testing
- Test deliverable
- Schedule
- Personnel allocation.

One of the most important activities of the test plan is to identify the test units. A test unit is a set of one or more modules, together with associate data, that are from a single computer program and that are the objects of testing. A test unit can occur at any level and can contain from a single module to the entire system.

Thus, a test unit may be a module, a few modules, or a complete system. The levels are specified in the test plan by identifying the test units for the project. Different units are usually specified for unit integration, and system testing. The identification of test units may be a module, a few modules or a complete system. The levels are specified in the test plan by identifying the test units for the project.

The identification of test units establishes the different levels of testing that will be performed in the project. The basic idea behind forming test units is to make sure that testing is being performed incrementally, with each increment including only a few aspects that need to be tested.

Caution A unit should be such that it can be easily tested.

In other words, it should be possible to form meaningful test cases and execute the unit without much effort with these test cases. Features to be tested include all software features and combinations of features that should be tested. A software feature is a software characteristic specified or implied by the requirements or design documents. These may include functionality, performance, design constraints, and attributes.

The approach for testing specifies the overall approach to be followed in the current project. The technique that will be used to judge the testing effort should also be specified.

Did u know? This is sometimes called the testing criterion.

Testing deliverable should be specified in the test plan before the actual testing begins. Deliverables could be a list of test cases that were used, detailed result of testing, test summary report, test log, and data about the code coverage. In general, a test case specification report, test summary report, and a test log should always be specified as deliverables.

Self Assessment

Fill in the blanks:

8. Different units are usually specified for unit, ... and system testing.

9. A .... is a software characteristic specified or implied by the requirements or design documents.

14.3 Test Case Specifications

The test plan focuses on how the testing for the project will proceed, which units will be tested and what approaches (and tools) are to be used during the various stages of testing. However it does not deals with details of testing a unit nor does it specify which test case is to be used.

Test case specification has to be done separately for each unit. Based on the approach specified in the test plan first the feature to be tested for this unit must be determined. The overall approach stated in the plan is refined into specific test techniques that should be followed and into the criteria to be used for evaluation. Based on these the test cases are specified for testing unit.

The two basic reasons test cases are specified before they are used for testing. It is known that testing has severe limitations and the effectiveness of testing depends very heavily on the exact nature of the test case. Even for a given criterion the exact nature of the test cases affects the effectiveness of testing.

Constructing good test case that will reveal errors in programs is still a very creative activity that depends a great deal on the tester. Clearly it is important to ensure that the set of test cases used is of high quality. As with many other verification methods evaluation of quality of test case is done through "test case review" And for any review a formal document or work product is needed. This is the primary reason for having the test case specification in the form of a document.

14.4 Execution and Analysis

Test execution involves running test cases developed for the system and reporting test results. The first step in test execution is generally to validate the infrastructure needed for running tests in the first place. This infrastructure primarily encompasses the test environment and test automation, including stubs that might be needed to run individual components, synthetic data used for testing or populating databases that the software needs to run, and other applications that interact with the software. The issues being sought are those that will prevent the software under test from being executed or else cause it to fail for reasons not related to faults in the software itself. The members of the test team are responsible for test execution and reporting.

The test plan should be executed as designed according to the software objective. The test plan should be changed as per the progress, or notations made as to what aspects of the plan were not performed. The test plan should commence when the project commences (Business Idea Phase) and conclude when the software is no longer in operation.

Important Steps of Software Test Plan Execution are:

1. Building the Test Environment
2. Creating the Test Plan
3. Design and prepare the Test Cases document
4. Executing the Test Cases taking the Test Plan guidelines.

Test analysis and design is the activity where general testing objectives are transformed into tangible test conditions and test designs.

Test analysis and design has the following major tasks:

- Review and analyse the requirements, architecture, design, interfaces and etc.
- Identifying Test Scenarios, test conditions, test requirements and also required test data based on analysis of test items, the specification, behavior and structure

Notes

- Designing the test cases based on the Test Scenarios or Test Conditions
- Evaluating testability of the requirements and system
- Test environment setup and identifying any required infrastructure and tools

Self Assessment

State whether the following statements are true or false:

10. Test case specification has to be done separately for each unit.
11. For a given criterion the exact nature of the test cases affects the effectiveness of testing.
12. Test execution involves running test cases developed for the system and reporting test results.
13. The test plan should be executed as designed according to the software objective.

14.5 Logging and Tracking

Schedule Tracking conduct periodic project status meetings in which each team member reports progress and problems. It evaluates the results of all reviews conducted throughout engineering process. It determines whether formal project milestones have been accomplished by the scheduled date. It compare actual start – date to planned start date for each project date. It meets informally with practitioners to obtain their subjective assessment of progress to date and problems on the horizon. It use earned value analysis to assess progress quantitatively.

Error Tracking allows comparison of current work to past projects and provides a quantitative indication of the quality of the work being conducted. The more quantitative the approach to project tracking and control, the more likely problems can be anticipated and dealt with in a proactive manner.

14.5.1 Earned Value Analysis

Earned value (EV) is one of the most sophisticated and accurate methods for measuring and controlling project schedules and budgets. Earned value has been used extensively in large projects, especially in government projects. PMI is a strong supporter of the earned value approach because of its ability to accurately monitor the schedule and cost variances for complex projects.

Although it is sophisticated, earned value can be scaled to be appropriate for any size of project. The key is in the project planning.

There are three primary advantages to using earned value:

- Accuracy in reporting
- Ability to deal with the uneven rate of project expenditures and work
- The early warning it provides project managers, allowing them to take the necessary corrective action should the project be spending more money than it is physically accomplishing

Other less professional methods for measuring budget and schedules generally only monitor the percent of the time through the schedule and make the often mistaken assumption that this is also the percent that the project should be through the budget. But cost and project progress generally are not evenly expended through a project. The reason earned value stands above the alternatives are that it accurately deals with this reality.

It is one thing to meet a project deadline at any cost. It is another to do it for a reasonable cost. Project cost control is concerned with ensuring that projects stay within their budgets, while getting the work done on time and at the correct quality. One system for doing this, called earned value analysis, was developed in the 1960s to allow the government to decide whether a contractor should receive a progress payment for work done. The method is finally coming into its own outside government projects, and it is considered the correct way to monitor and control almost any project. The method is also called simply variance analysis.

> *Notes* Variance analysis allows the project manager to determine trouble spots in the project and to take corrective action.

The following definitions are useful in understanding the analysis:

- ***Cost Variance:*** Compares deviations and performed work.
- ***Schedule Variance:*** Compares planned and actual work completed.
- ***BCWS (Budgeted Cost of Work Scheduled):*** The budgeted cost of work scheduled to be done in a given time period, or the level of effort that is supposed to be performed in that period.
- ***BCWP (Budgeted Cost of Work Performed):*** The budgeted cost of work actually performed in a given period, or the budgeted level of effort actually expended. BCWP is also called earned value and is a measure of the dollar value of the work actually accomplished in the period being monitored.
- ***ACWP (Actual Cost of Work Performed):*** The amount of money (or effort) actually spent in completing work in a given period.

Variance thresholds can be established that define the level at which reports must be sent to various levels of management within an organization.

$$\text{Cost Variance} = \text{BCWP} - \text{ACWP}$$

$$\text{Schedule Variance} = \text{BCWP} - \text{BCWS}$$

Variance: Any deviation from plan by combining cost and schedule variances, an integrated cost/schedule reporting system can be developed.

Self Assessment

Fill in the blanks:

14. …………………… evaluates the results of all reviews conducted throughout engineering process.

15. …………………… allows comparison of current works to past projects and provides a quantitative indication of the quality of the work being conducted.

14.6 Metrics

Metric is a standard unit of measurement that quantifies results. Metric used for evaluating the software processes, products and services is termed as Software Metrics. Software Metrics is a Measurement Based Technique which is applied to processes, products and services to supply engineering and management information and working on the information supplied to improve processes, products and services, if required.

Increase in competition and leaps in technology have forced companies to adopt innovative approaches to assess themselves with respect to processes, products and services. This assessment helps them to improve their business so that they succeed and make more profits and acquire higher percentage of market. Metric is the cornerstone in assessment and also foundation for any business improvement.

Let us discuss the importance of metrics.

- Metrics is used to improve the quality and productivity of products and services thus achieving Customer Satisfaction.
- Easy for management to digest one number and drill down, if required.
- Different Metric(s) trend act as monitor when the process is going out of control.
- Metrics provides improvement for current process.

Limitations of metrics are:

- Many company avoid metrics because its time consuming and expensive.
- Metrics has to be prepared with full understanding about the concepts of metrics and details of projects. Metrics has direct impact on the project as it tells the user about the progress in project.
- It's very difficult to maintain and keep track of the metrics.

Good practices to follow:

- Metrics are essential to maintain the high quality of the project.
- Metrics tell the progress of the project, so it helps to maintain the standards.
- To maintain the metrics, it's very important to have a good communication between the teams to get the details about the project.
- Metrics helps the team to work in right path.
- Metrics helps to maintain the high quality of the project and also cost effective.
- Metrics gives a complete understanding about the project and also help to make right decision in every phase.

14.6.1 Failure Data Estimation

Software reliability refers to the probability of failure-free operation of a system. It is related to many aspects of software, including the testing process. Directly estimating software reliability by quantifying its related factors can be difficult. Testing is an effective sampling method to measure software reliability. Guided by the operational profile, software testing (usually black-box testing) can be used to obtain failure data, and an estimation model can be further used to analyze the data to estimate the present reliability and predict future reliability. Therefore, based on the estimation, the developers can decide whether to release the software, and the users can decide whether to adopt and use the software. Risk of using software can also be assessed based on reliability information.

Notes The primary goal of testing should be to measure the dependability of tested software.

14.6.2 Parameter Estimation

The regression line:

$$y = y = \beta_0 + \beta_1 x$$

is fitted to the data points by finding the line which is the "closest" to the data points in some sense.

Consider the vertical deviations between the line and the data points:

$$y_i - \left(\beta_0 + \beta_1 x_i\right), 1 \le i \le n$$

Minimizes the sum of the squares of these vertical deviations:

$$Q = \sum_{i=1}^{n}\left(y_i - \left(\beta_0 + \beta_1 x_i\right)\right)^2$$

and this is referred to as the *least squares* fit.

The parameter estimates are easily found by taking partial derivatives of Q with respect to and setting the resulting expressions equal to zero.

Since

$$\frac{\partial Q}{\partial \beta_0} = -\sum_{i=1}^{n} 2\left(y_i - \left(\beta_0 + \beta_1 x_i\right)\right)$$

and

$$\frac{\partial Q}{\partial \beta_1} = -\sum_{i=1}^{n} 2x_i\left(y_i - \left(\beta_0 + \beta_1 x_i\right)\right)$$

The parameter estimates are thus the solutions to the normal equations:

$$\sum_{i=1}^{n} y_i = n\beta_0 + \beta_1 \sum_{i=1}^{n} x_i$$

and

$$\sum_{i=1}^{n} x_i y_i = \beta_0 \sum_{i=1}^{n} x_i + \beta_1 \sum_{i=1}^{n} x_i^2.$$

The normal equations can be solved to give:

$$\hat{\beta}_1 = \frac{n\sum_{i=1}^{n} x_i y_i - \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2}$$

and

$$\hat{\beta}_0 = \frac{\sum_{i=1}^{n} y_i}{n} - \hat{\beta}_1 \frac{\sum_{i=1}^{n} x_i}{n} = \bar{y} - \hat{\beta}_1 \bar{x}.$$

Self Assessment

Fill in the blanks:

16. .... is a standard unit of measurement that quantifies results.

17. .... is a Measurement Based Technique which is applied to processes, products and services to supply engineering and management information and working on the information supplied to improve processes, products and services, if required.

18. .... refers to the probability of failure-free operation of a system.

Notes

14.7 Summary

- The first level of testing is called unit testing. Unit testing focuses on verification of individual units or modules of software.
- The next level of testing is often called integration testing. Integration testing is a systematic technique for constructing the program structure while at the same time conducting tests to uncover errors associated with interfacing.
- System testing is testing conducted on a complete, integrated system to evaluate the system's compliance with its specified requirements.
- The test planning can be done well before the actual testing commences and can be done in parallel with the coding and design phases.
- The test plan focuses on how the testing for the project will proceed, which units will be tested and what approaches (and tools) are to be used during the various stages of testing.
- Test execution involves running test cases developed for the system and reporting test results.
- Schedule Tracking conduct periodic project status meetings in which each team member reports progress and problems. It evaluates the results of all reviews conducted throughout engineering process.
- Metric is a standard unit of measurement that quantifies results. Metric used for evaluating the software processes, products and services is termed as Software Metrics.

14.8 Keywords

Bottom-up Integration: Bottom-up integration testing begins construction and testing with atomic modules i.e., components at the lowest levels in the program structure.

Earned Value (EV): Earned value (EV) is one of the most sophisticated and accurate methods for measuring and controlling project schedules and budgets.

Integration Testing: Integration testing is a systematic technique for constructing the program structure while at the same time conducting tests to uncover errors associated with interfacing.

Metric: Metric is a standard unit of measurement that quantifies results.

Regression Testing: Regression testing is the re-execution of some subset of tests that have already been conducted to ensure that changes have not propagated unintended side effects.

Smoke Testing: Smoke testing is an integration testing approach that is commonly used when "shrink-wrapped" software products are being developed.

Software Reliability: Software reliability refers to the probability of failure-free operation of a system.

System Testing: System testing is testing conducted on a complete, integrated system to evaluate the system's compliance with its specified requirements.

Top-down Integration: Top-down integration testing is an incremental approach to construction of program structure.

Unit Testing: Unit testing focuses on verification of individual units or modules of software.

Variance: Any deviation from plan by combining cost and schedule variances, an integrated cost/schedule reporting system can be developed.

14.9 Review Questions

1. What is unit testing? What are the advantages of unit testing?
2. Explain the scaffolding required testing a program unit.
3. Define integration testing. Explain top-down and bottom-up integration.
4. "Capture or playback tools enable the software engineer to capture test cases and results for subsequent playback and comparison". Elucidate.
5. Write down the three different classes of test cases of regression test suite.
6. What is smoke testing?
7. Discuss about system testing.
8. "Testing commences with a test plan and terminates with acceptance testing". Comment.
9. Briefly explain about test case specifications.
10. Provide insight into logging and tracking.
11. "Metric is a standard unit of measurement that quantifies results". Explain. Also discuss the failure data estimation.

Answers: Self Assessment

1. Unit testing
2. Integration testing
3. Top-down integration
4. Bottom-up integration
5. Regression testing
6. Smoke testing
7. System testing
8. Integration
9. Software feature
10. True
11. True
12. True
13. True
14. Schedule Tracking
15. Error Tracking
16. Metric
17. Software Metrics
18. Software reliability

14.10 Further Readings

Books

Rajib Mall, *Fundamentals of Software Engineering*, 2nd Edition, PHI.

Richard Fairpy, *Software Engineering Concepts*, Tata McGraw Hill, 1997.

R.S. Pressman, *Software Engineering – A Practitioner's Approach*, 5th Edition, Tata McGraw Hill Higher education.

Sommerville, *Software Engineering*, 6th Edition, Pearson Education.

Online links

rajeevprabhakaran.wordpress.com/2008/11/20/levels-of-testing/

Notes

http://www.tutorialspoint.com/software_testing/levels_of_testing.htm

www.cs.swan.ac.uk/.../20061202_Oladimeji_Levels_of_Testing.pdf

ecomputernotes.com/software.../discuss-the-different-levels-of-testing

LOVELY PROFESSIONAL UNIVERSITY
Jalandhar-Delhi G.T. Road (NH-1)
Phagwara, Punjab (India)-144411
For Enquiry: +91-1824-300360
Fax.: +91-1824-506111
Email: odl@lpu.co.in