INTRODUCTION TO SOFTWARE ENGINEERING

The term ***software engineering*** is composed of two words, software and engineering.
Software is more than just a program code. A program is an executable code, which serves some computational purpose. Software is considered to be a collection of executable programming code, associated libraries and documentations. Software, when made for a specific requirement is called **software product.**

Engineering on the other hand, is all about developing products, using well-defined, scientific principles and methods. So, we can define ***software engineering*** as an engineering branch associated with the development of software product using well-defined scientific principles, methods and procedures. The outcome of software engineering is an efficient and reliable software product. IEEE defines software engineering as:
The application of a systematic, disciplined, quantifiable approach to the development, operation and maintenance of software.

We can alternatively view it as a systematic collection of past experience. The experience is arranged in the form of methodologies and guidelines. A small program can be written without using software engineering principles. But if one wants to develop a large software product, then software engineering principles are absolutely necessary to achieve a good quality software cost effectively.

Without using software engineering principles, it would be difficult to develop large programs. In industry it is usually needed to develop large programs to accommodate multiple functions. A problem with developing such large commercial programs is that the complexity and difficulty levels of the programs increase exponentially with their sizes. Software engineering helps to reduce this programming complexity. Software engineering principles use two important techniques to reduce problem complexity: ***abstraction*** and ***decomposition*.** The principle of abstraction implies that a problem can be simplified by omitting irrelevant details. In other words, the main purpose of abstraction is to consider only those aspects of the problem that are relevant for certain purpose and suppress other aspects that are not relevant for the given purpose. Once the simpler problem is solved, then the omitted details can be taken into consideration to solve the next lower level abstraction, and so on. Abstraction is a powerful way of reducing the complexity of the problem. The other approach to tackle problem complexity is decomposition. In this technique, a complex problem is divided into several smaller problems and then the smaller problems are solved one by one. However, in this technique any random decomposition of a problem into smaller parts will not help. The problem has to be decomposed such that each component of the decomposed problem can be solved independently and then the solution of the different components can be combined to get the full solution. A good decomposition of a problem should minimize interactions among various components. If the different subcomponents are interrelated, then the different components cannot be solved separately and the desired reduction in complexity will not be realized.

NEED OF SOFTWARE ENGINEERING

The need of software engineering arises because of higher rate of change in user requirements and environment on which the software is working.

- **Large software -** It is easier to build a wall than to a house or building, likewise, as the size of software become large engineering has to step to give it a scientific process.
- **Scalability-** If the software process were not based on scientific and engineering concepts, it would be easier to re-create new software than to scale an existing one.
- **Cost-** As hardware industry has shown its skills and huge manufacturing has lower down the price of computer and electronic hardware. But the cost of software remains high if proper process is not adapted.
- **Dynamic Nature-** The always growing and adapting nature of software hugely depends upon the environment in which the user works. If the nature of software is always changing, new enhancements need to be done in the existing one. This is where software engineering plays a good role.
- **Quality Management-** Better process of software development provides better and quality software product.

CHARACTERISTICS OF GOOD SOFTWARE

A software product can be judged by what it offers and how well it can be used. This software must satisfy on the following grounds:

- Operational
- Transitional
- Maintenance

Well-engineered and crafted software is expected to have the following characteristics:

Operational

This tells us how well software works in operations. It can be measured on:

- Budget
- Usability
- Efficiency
- Correctness
- Functionality
- Dependability
- Security
- Safety

Transitional

This aspect is important when the software is moved from one platform to another:

- Portability

- Interoperability
- Reusability
- Adaptability

Maintenance

This aspect briefs about how well a software has the capabilities to maintain itself in the ever-changing environment:

- Modularity
- Maintainability
- Flexibility
- Scalability

In short, Software engineering is a branch of computer science, which uses well-defined engineering concepts required to produce efficient, durable, scalable, in-budget and on-time software products

SOFTWARE DEVELOPMENT LIFE CYCLE

LIFE CYCLE MODEL

A software life cycle model (also called process model) is a descriptive and diagrammatic representation of the software life cycle. A life cycle model represents all the activities required to make a software product transit through its life cycle phases. It also captures the order in which these activities are to be undertaken. In other words, a life cycle model maps the different activities performed on a software product from its inception to retirement. Different life cycle models may map the basic development activities to phases in different ways. Thus, no matter which life cycle model is followed, the basic activities are included in all life cycle models though the activities may be carried out in different orders in different life cycle models. During any life cycle phase, more than one activity may also be carried out.

THE NEED FOR A SOFTWARE LIFE CYCLE MODEL

The development team must identify a suitable life cycle model for the particular project and then adhere to it. Without using of a particular life cycle model the development of a software product would not be in a systematic and disciplined manner. When a software product is being developed by a team there must be a clear understanding among team members about when and what to do. Otherwise it would lead to chaos and project failure. This problem can be illustrated by using an example. Suppose a software development problem is divided into several parts and the parts are assigned to the team members. From then on, suppose the team members are allowed the freedom to develop the parts assigned to them in whatever way they like. It is possible that one member might start writing the code for his part, another might decide to prepare the test documents first, and some other engineer might begin with the design phase of the parts assigned to him. This would be one of the perfect recipes for project failure. A software life cycle model defines entry and exit criteria for every phase. A phase can start only if its phase-entry criteria have been satisfied. So without software life cycle model the entry and exit criteria for a phase cannot be recognized. Without software life cycle models it becomes difficult for software project managers to monitor the progress of the project.

Different software life cycle models

Many life cycle models have been proposed so far. Each of them has some advantages as well as some disadvantages. A few important and commonly used life cycle models are as follows:

- Classical Waterfall Model
- Iterative Waterfall Model
- Prototyping Model
- Evolutionary Model
- Spiral Model

1. CLASSICAL WATERFALL MODEL

The classical waterfall model is intuitively the most obvious way to develop software. Though the classical waterfall model is elegant and intuitively obvious, it is not a practical model in the sense that it cannot be used in actual software development projects. Thus, this model can be considered to be a *theoretical way of developing software*. But all other life cycle models are essentially derived from the classical waterfall model. So, in order to be able to appreciate other life cycle models it is necessary to learn the classical waterfall model. Classical waterfall model divides the life cycle into the following phases as shown in fig.2.1:

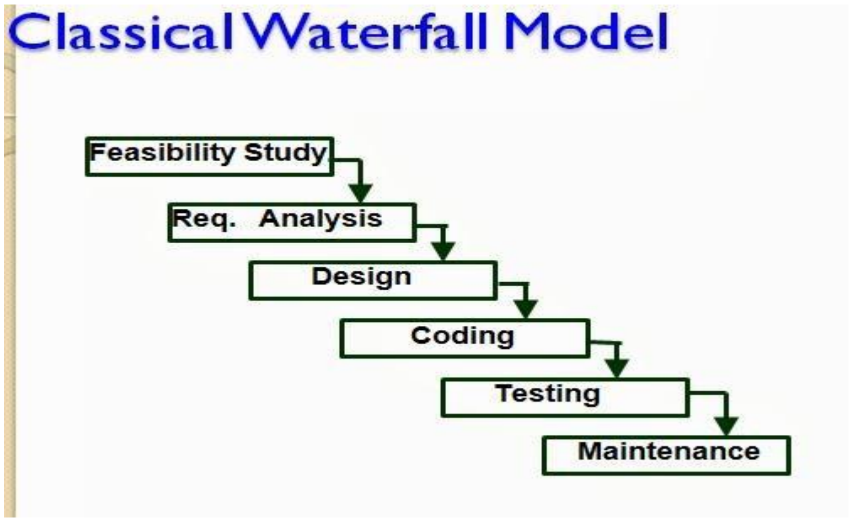


Fig 2.1: Classical Waterfall Model

Feasibility study - The main aim of feasibility study is to determine whether it would be financially and technically feasible to develop the product.

- At first project managers or team leaders try to have a rough understanding of what is required to be done by visiting the client side. They study different input data to the system and output data to be produced by the system. They study what kind of processing is needed to be done on these data and they look at the various constraints on the behavior of the system.
- After they have an overall understanding of the problem they investigate the different

solutions that are possible. Then they examine each of the solutions in terms of what kind of resources required, what would be the cost of development and what would be the development time for each solution.

- Based on this analysis they pick the best solution and determine whether the solution is feasible financially and technically. They check whether the customer budget would meet the cost of the product and whether they have sufficient technical expertise in the area of development.

Requirements analysis and specification: The aim of the requirements analysis and specification phase is to understand the exact requirements of the customer and to document them properly. This phase consists of two distinct activities, namely

- Requirements gathering and analysis
- Requirements specification

The goal of the requirements gathering activity is to collect all relevant information from the customer regarding the product to be developed. This is done to clearly understand the customer requirements so that incompleteness and inconsistencies are removed.

The requirements analysis activity is begun by collecting all relevant data regarding the product to be developed from the users of the product and from the customer through interviews and discussions. For example, to perform the requirements analysis of a business accounting software required by an organization, the analyst might interview all the accountants of the organization to ascertain their requirements. The data collected from such a group of users usually contain several contradictions and ambiguities, since each user typically has only a partial and incomplete view of the system. Therefore it is necessary to identify all ambiguities and contradictions in the requirements and resolve them through further discussions with the customer. After all ambiguities, inconsistencies, and incompleteness have been resolved and all the requirements properly understood, the requirements specification activity can start. During this activity, the user requirements are systematically organized into a Software Requirements Specification (SRS) document. The customer requirements identified during the requirements gathering and analysis activity are organized into a SRS document. The important components of this document are functional requirements, the non-functional requirements, and the goals of implementation.

Design: The goal of the design phase is to transform the requirements specified in the SRS document into a structure that is suitable for implementation in some programming language. In technical terms, during the design phase the software architecture is derived from the SRS document. Two distinctly different approaches are available: the traditional design approach and the object-oriented design approach.

- **Traditional design approach -**Traditional design consists of two different activities; first a structured analysis of the requirements specification is carried out where the detailed structure of the problem is examined. This is followed by a structured design activity. During structured design, the results of structured analysis are transformed into the software design.

- **Object-oriented design approach** -In this technique, various objects that occur in the problem domain and the solution domain are first identified, and the different relationships that exist among these objects are identified. The object structure is further refined to obtain the detailed design.

Coding and unit testing:-The purpose of the coding phase (sometimes called the implementation phase) of software development is to translate the software design into source code. Each component of the design is implemented as a program module. The end-product of this phase is a set of program modules that have been individually tested. During this phase, each module is unit tested to determine the correct working of all the individual modules. It involves testing each module in isolation as this is the most efficient way to debug the errors identified at this stage.

Integration and system testing: -Integration of different modules is undertaken once they have been coded and unit tested. During the integration and system testing phase, the modules are integrated in a planned manner. The different modules making up a software product are almost never integrated in one shot. Integration is normally carried out incrementally over a number of steps. During each integration step, the partially integrated system is tested and a set of previously planned modules are added to it. Finally, when all the modules have been successfully integrated and tested, system testing is carried out. The goal of system testing is to ensure that the developed system conforms to its requirements laid out in the SRS document. System testing usually consists of three different kinds of testing activities:

- α - testing: It is the system testing performed by the development team.
- β -testing: It is the system testing performed by a friendly set of customers.
- Acceptance testing: It is the system testing performed by the customer himself after the product delivery to determine whether to accept or reject the delivered product.

System testing is normally carried out in a planned manner according to the system test plan document. The system test plan identifies all testing-related activities that must be performed, specifies the schedule of testing, and allocates resources. It also lists all the test cases and the expected outputs for each test case.

Maintenance: Maintenance of a typical software product requires much more than the effort necessary to develop the product itself. Many studies carried out in the past confirm this and indicate that the relative effort of development of a typical software product to its maintenance effort is roughly in the 40:60 ratios. Maintenance involves performing any one or more of the following three kinds of activities:

- Correcting errors that were not discovered during the product development phase. This is called corrective maintenance.
- Improving the implementation of the system, and enhancing the functionalities of the system according to the customer's requirements. This is called perfective maintenance.
- Porting the software to work in a new environment. For example, porting may be required to get the software to work on a new computer platform or with a new operating system. This is

called adaptive maintenance.

Shortcomings of the classical waterfall model

The classical waterfall model is an idealistic one since it assumes that no development error is ever committed by the engineers during any of the life cycle phases. However, in practical development environments, the engineers do commit a large number of errors in almost every phase of the life cycle. The source of the defects can be many: oversight, wrong assumptions, use of inappropriate technology, communication gap among the project engineers, etc. These defects usually get detected much later in the life cycle. For example, a design defect might go unnoticed till we reach the coding or testing phase. Once a defect is detected, the engineers need to go back to the phase where the defect had occurred and redo some of the work done during that phase and the subsequent phases to correct the defect and its effect on the later phases. Therefore, in any practical software development work, it is not possible to strictly follow the classical waterfall model.

2. ITERATIVE WATERFALL MODEL

To overcome the major shortcomings of the classical waterfall model, we come up with the iterative waterfall model.

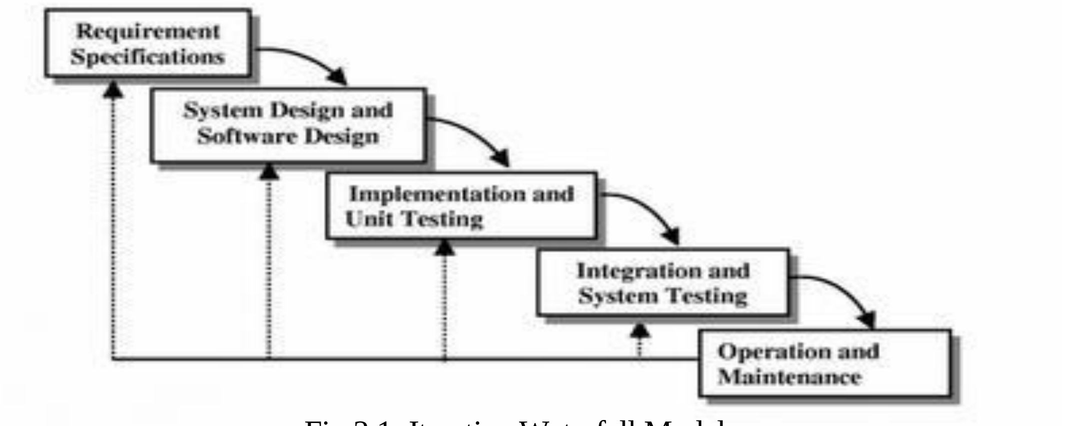

Requirement Specifications
System Design and Software Design
Implementation and Unit Testing
Integration and System Testing
Operation and Maintenance

Fig 2.1: Iterative Waterfall Model

Here, we provide feedback paths for error correction as & when detected later in a phase. Though errors are inevitable, but it is desirable to detect them in the same phase in which they occur. If so, this can reduce the effort to correct the bug.

The advantage of this model is that there is a working model of the system at a very early stage of development which makes it easier to find functional or design flaws. Finding issues at an early stage of development enables to take corrective measures in a limited budget.

The disadvantage with this SDLC model is that it is applicable only to large and bulky software development projects. This is because it is hard to break a small software system into further small serviceable increments/modules.

3. PROTOTYPING MODEL

Prototype

A prototype is a toy implementation of the system. A prototype usually exhibits limited functional capabilities, low reliability, and inefficient performance compared to the actual software. A prototype is usually built using several shortcuts. The shortcuts might involve using inefficient, inaccurate, or dummy functions. The shortcut implementation of a function, for example, may produce the desired results by using a table look-up instead of performing the actual computations. A prototype usually turns out to be a very crude version of the actual system.

Need for a prototype in software development

There are several uses of a prototype. An important purpose is to illustrate the input data formats, messages, reports, and the interactive dialogues to the customer. This is a valuable mechanism for gaining better understanding of the customer's needs:

- how the screens might look like
- how the user interface would behave
- how the system would produce outputs

Another reason for developing a prototype is that it is impossible to get the perfect product in the first attempt. Many researchers and engineers advocate that if you want to develop a good product you must plan to throw away the first version. The experience gained in developing the prototype can be used to develop the final product.

A prototyping model can be used when technical solutions are unclear to the development team. A developed prototype can help engineers to critically examine the technical issues associated with the product development. Often, major design decisions depend on issues like the response time of a hardware controller, or the efficiency of a sorting algorithm, etc. In such circumstances, a prototype may be the best or the only way to resolve the technical issues.

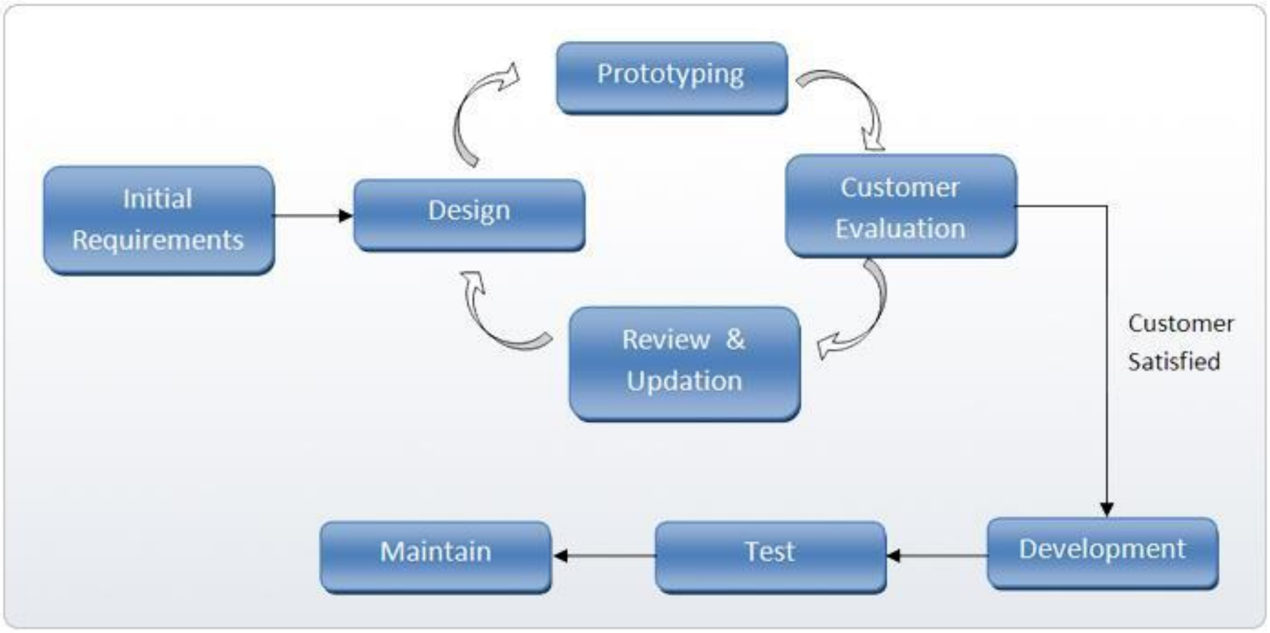


Fig 3.2: Prototype Model

A prototype of the actual product is preferred in situations such as:

- User requirements are not complete
- Technical issues are not clear

4. EVOLUTIONARY MODEL

It is also called *successive versions model* or *incremental model*. At first, a simple working model is built. Subsequently it undergoes functional improvements & we keep on adding new functions till the desired system is built.

Applications:

- Large projects where you can easily find modules for incremental implementation. Often used when the customer wants to start using the core features rather than waiting for the full software.
- Also used in object oriented software development because the system can be easily portioned into units in terms of objects.

Advantages:

- User gets a chance to experiment partially developed system
- Reduce the error because the core modules get tested thoroughly.

Disadvantages:

- It is difficult to divide the problem into several versions that would be acceptable to the customer which can be incrementally implemented and delivered.

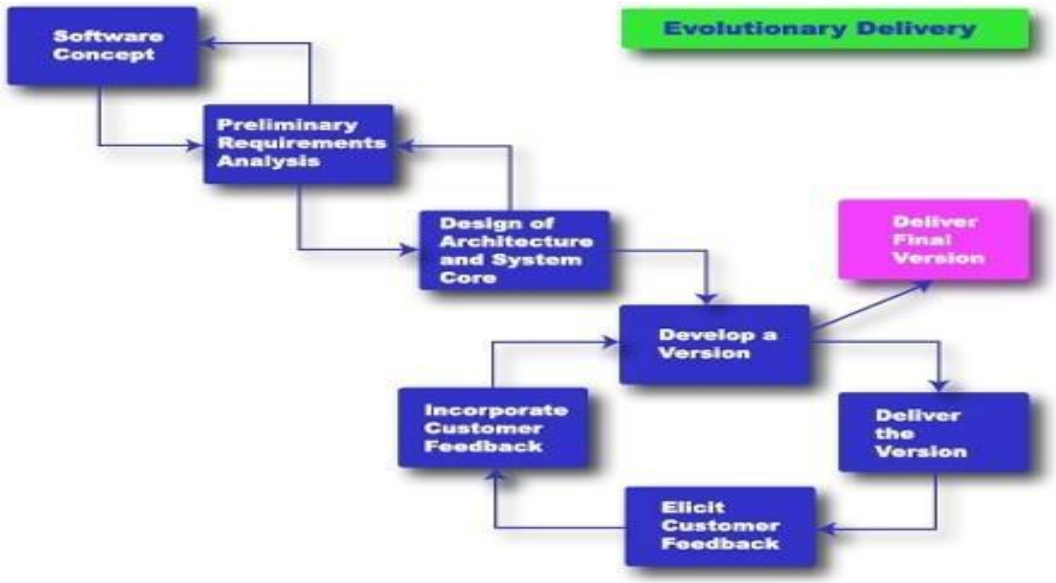


Fig 3.3: Evolutionary Model

5. SPIRAL MODEL

The Spiral model of software development is shown in fig. 4.1. The diagrammatic representation of this model appears like a spiral with many loops. The exact number of loops in the spiral is not fixed. Each loop of the spiral represents a phase of the software process. For example, the innermost loop might be concerned with feasibility study, the next loop with requirements specification, the next one with design, and so on. Each phase in this model is split into four sectors (or quadrants) as shown in fig. 4.1. The following activities are carried out during each phase of a spiral model.

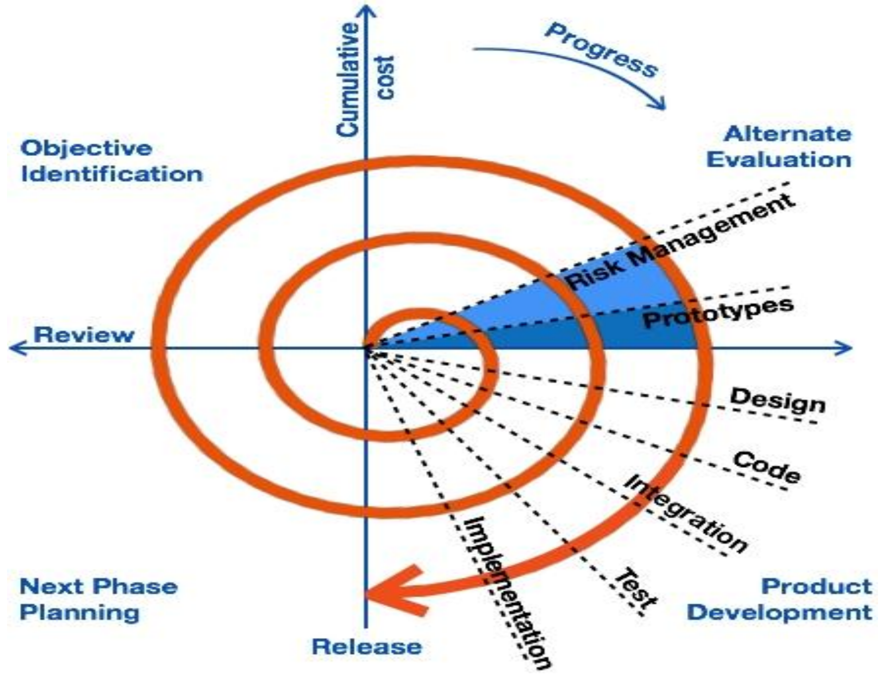


Fig 4.1: Spiral Model

First quadrant (Objective Setting)

- During the first quadrant, it is needed to identify the objectives of the phase.
- Examine the risks associated with these objectives.

Second Quadrant (Risk Assessment and Reduction)

- A detailed analysis is carried out for each identified project risk.
- Steps are taken to reduce the risks. For example, if there is a risk that the requirements are inappropriate, a prototype system may be developed.

Third Quadrant (Development and Validation)

- Develop and validate the next level of the product after resolving the identified risks.

Fourth Quadrant (Review and Planning)

- Review the results achieved so far with the customer and plan the next iteration around the spiral.
- Progressively more complete version of the software gets built with each iteration around the spiral.

Circumstances to use spiral model

The spiral model is called a meta model since it encompasses all other life cycle models. Risk handling is inherently built into this model. The spiral model is suitable for development of technically challenging software products that are prone to several kinds of risks. However, this model is much more complex than the other models - this is probably a factor deterring its use in ordinary projects.

Comparison of different life-cycle models

The classical waterfall model can be considered as the basic model and all other life cycle models as embellishments of this model. However, the classical waterfall model cannot be used in practical development projects, since this model supports no mechanism to handle the errors committed during any of the phases.

This problem is overcome in the iterative waterfall model. The iterative waterfall model is probably the most widely used software development model evolved so far. This model is simple to understand and use. However this model is suitable only for well-understood problems; it is not suitable for very large projects and for projects that are subject to many risks.

The prototyping model is suitable for projects for which either the user requirements or the underlying technical aspects are not well understood. This model is especially popular for development of the user-interface part of the projects. The evolutionary approach is suitable for large problems which can be decomposed into a set of modules for incremental development and delivery. This model is also widely used for object-oriented development projects. Of course, this model can only be used if the incremental delivery of the system is acceptable to the customer.

The spiral model is called a *meta-model* since it encompasses all other life cycle models. Risk handling is inherently built into this model. The spiral model is suitable for development of technically challenging software products that are prone to several kinds of risks. However, this model is much more complex than the other models - this is probably a factor deterring its use in ordinary projects.

The different software life cycle models can be compared from the viewpoint of the customer. Initially, customer confidence in the development team is usually high irrespective of the development model followed. During the lengthy development process, customer confidence normally drops off, as no working product is immediately visible. Developers answer customer queries using technical slang, and delays are announced. This gives rise to customer resentment. On the other hand, an evolutionary approach lets the customer experiment with a working product much earlier than the monolithic approaches. Another important advantage of the incremental model is that it reduces the customer's trauma of getting used to an entirely new system. The gradual introduction of the product via incremental phases provides time to the customer to adjust to the new product. Also, from the customer's financial viewpoint, incremental development does not require a large upfront capital outlay. The customer can order the incremental versions as and when he can afford them.

REQUIREMENTS ANALYSIS AND SPECIFICATION

Before we start to develop our software, it becomes quite essential for us to understand and document the exact requirement of the customer. Experienced members of the development team carry out this job. They are called as ***system analysts***.

The analyst starts *requirements gathering and analysis* activity by collecting all information from the customer which could be used to develop the requirements of the system. He then analyzes the collected information to obtain a clear and thorough understanding of the product to be developed, with a view to remove all ambiguities and inconsistencies from the initial customer perception of the problem. The following basic questions pertaining to the project should be clearly understood by the analyst in order to obtain a good grasp of the problem:

- What is the problem?
- Why is it important to solve the problem?
- What are the possible solutions to the problem?
- What exactly are the data input to the system and what exactly are the data output by the system?
- What are the likely complexities that might arise while solving the problem?
- If there are external software or hardware with which the developed software has to interface, then what exactly would the data interchange formats with the external system be?

After the analyst has understood the exact customer requirements, he proceeds to identify and resolve the various requirements problems. The most important requirements problems that the analyst has to identify and eliminate are the problems of anomalies, inconsistencies, and incompleteness. When the analyst detects any inconsistencies, anomalies or incompleteness in the gathered requirements, he resolves them by carrying out further discussions with the end-users and the customers.

Parts of a SRS document

- The important parts of SRS document are:
    - Functional requirements of the system
    - Non-functional requirements of the system, and
    - Goals of implementation

Functional requirements:-

The functional requirements part discusses the functionalities required from the system. The system is considered to perform a set of high-level functions $\{f_i\}$. The functional view of the system is shown in fig. 5.1. Each function f_i of the system can be considered as a transformation of a set of input data (i_i) to the corresponding set of output data (o_i). The user can get some meaningful piece of work done using a high-level function.

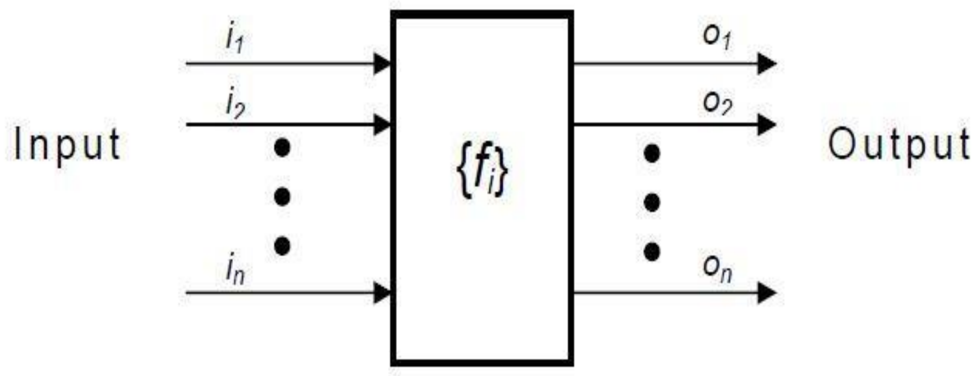


Fig. 5.1: View of a system performing a set of functions

Non-functional requirements:-

Non-functional requirements deal with the characteristics of the system which cannot be expressed as functions - such as the maintainability of the system, portability of the system, usability of the system, etc.

Goals of implementation:

The goals of implementation part documents some general suggestions regarding development. These suggestions guide trade-off among design goals. The goals of implementation section might document issues such as revisions to the system functionalities that may be required in the future, new devices to be supported in the future, reusability issues, etc. These are the items which the developers might keep in their mind during development so that the developed system may meet some aspects that are not required immediately.

Identifying functional requirements from a problem description

The high-level functional requirements often need to be identified either from an informal problem description document or from a conceptual understanding of the problem. Each high-level requirement characterizes a way of system usage by some user to perform some meaningful piece of work. There can be many types of users of a system and their requirements from the system may be very different. So, it is often useful to identify the different types of users who might use the system and then try to identify the requirements from each user's perspective.

Example: - Consider the case of the library system, where **-**

F1: Search Book function

Input: an author's name

Output: details of the author's books and the location of these books in the library

So the function Search Book (F1) takes the author's name and transforms it into book details.

Functional requirements actually describe a set of high-level requirements, where each high-level requirement takes some data from the user and provides some data to the user as an output. Also each high-level requirement might consist of several other functions.

Documenting functional requirements

For documenting the functional requirements, we need to specify the set of functionalities supported by the system. A function can be specified by identifying the state at which the data is to be input to the system, its input data domain, the output data domain, and the type of processing to be carried on the input data to obtain the output data. Let us first try to document the withdraw-cash function of an ATM (Automated Teller Machine) system. The withdraw-cash is a high-level requirement. It has several sub-requirements corresponding to the different user interactions. These different interaction sequences capture the different scenarios.

Example: - Withdraw Cash from ATM

R1: withdraw cash

Description: The withdraw cash function first determines the type of account that the user has and the account number from which the user wishes to withdraw cash. It checks the balance to determine whether the requested amount is available in the account. If enough balance is available, it outputs the required cash; otherwise it generates an error message.

R1.1 select withdraw amount option

Input: "withdraw amount" option

Output: user prompted to enter the account type

R1.2: select account type

Input: user option

Output: prompt to enter amount

R1.3: get required amount

Input: amount to be withdrawn in integer values greater than 100 and less than 10,000 in multiples of 100.

Output: The requested cash and printed transaction statement.

Processing: the amount is debited from the user's account if sufficient balance is available, otherwise an error message displayed

Properties of a good SRS document

The important properties of a good SRS document are the following:

- **Concise.** The SRS document should be concise and at the same time unambiguous, consistent, and complete. Verbose and irrelevant descriptions reduce readability and also increase error possibilities.

- **Structured.** It should be well-structured. A well-structured document is easy to understand and modify. In practice, the SRS document undergoes several revisions to cope up with the customer requirements. Often, the customer requirements evolve over a period of time. Therefore, in order to make the modifications to the SRS document easy, it is important to make the document well-structured.
- **Black-box view.** It should only specify what the system should do and refrain from stating how to do these. This means that the SRS document should specify the external behavior of the system and not discuss the implementation issues. The SRS document should view the system to be developed as black box, and should specify the externally visible behavior of the system. For this reason, the SRS document is also called the black-box specification of a system.
- **Conceptual integrity.** It should show conceptual integrity so that the reader can easily understand it.
- **Response to undesired events.** It should characterize acceptable responses to undesired events. These are called system response to exceptional conditions.
- **Verifiable.** All requirements of the system as documented in the SRS document should be verifiable. This means that it should be possible to determine whether or not requirements have been met in an implementation.

Problems without a SRS document

The important problems that an organization would face if it does not develop a SRS document are as follows:

- Without developing the SRS document, the system would not be implemented according to customer needs.
- Software developers would not know whether what they are developing is what exactly required by the customer.
- Without SRS document, it will be very much difficult for the maintenance engineers to understand the functionality of the system.
- It will be very much difficult for user document writers to write the users' manuals properly without understanding the SRS document.

Problems with an unstructured specification

- It would be very much difficult to understand that document.
- It would be very much difficult to modify that document.
- Conceptual integrity in that document would not be shown.
- The SRS document might be unambiguous and inconsistent.

DECISION TREE

A decision tree gives a graphic view of the processing logic involved in decision making and the corresponding actions taken. The edges of a decision tree represent conditions and the leaf nodes represent the actions to be performed depending on the outcome of testing the condition.

Example:

Consider Library Membership Automation Software (LMS) where it should support the following three options**:**

- **New member**
- **Renewal**
- **Cancel membership**

New member option

Cancel membership option-

Decision: If the 'cancel membership' option is selected, then the software asks for member's name and his membership number.

Action: The membership is cancelled, a cheque for the balance amount due to the member is printed and finally the membership record is deleted from the database.

The following tree (fig. 6.1) shows the graphical representation of the above example.

Cancel membership option-

Decision: If the 'cancel membership' option is selected, then the software asks for member's name and his membership number.

Action: The membership is cancelled, a cheque for the balance amount due to the member is printed and finally the membership record is deleted from the database.

The following tree (fig. 6.1) shows the graphical representation of the above example.

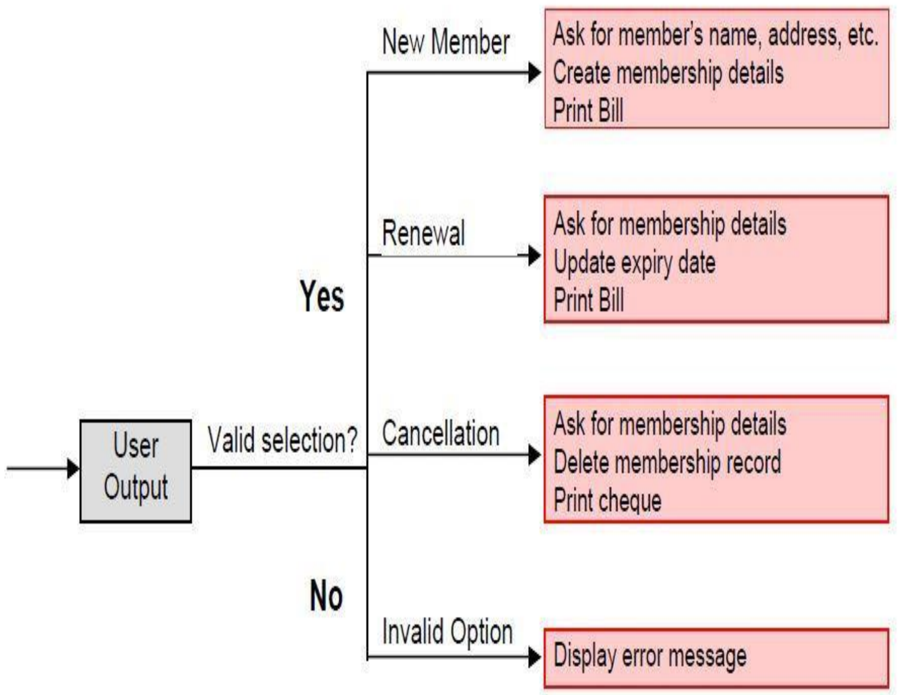
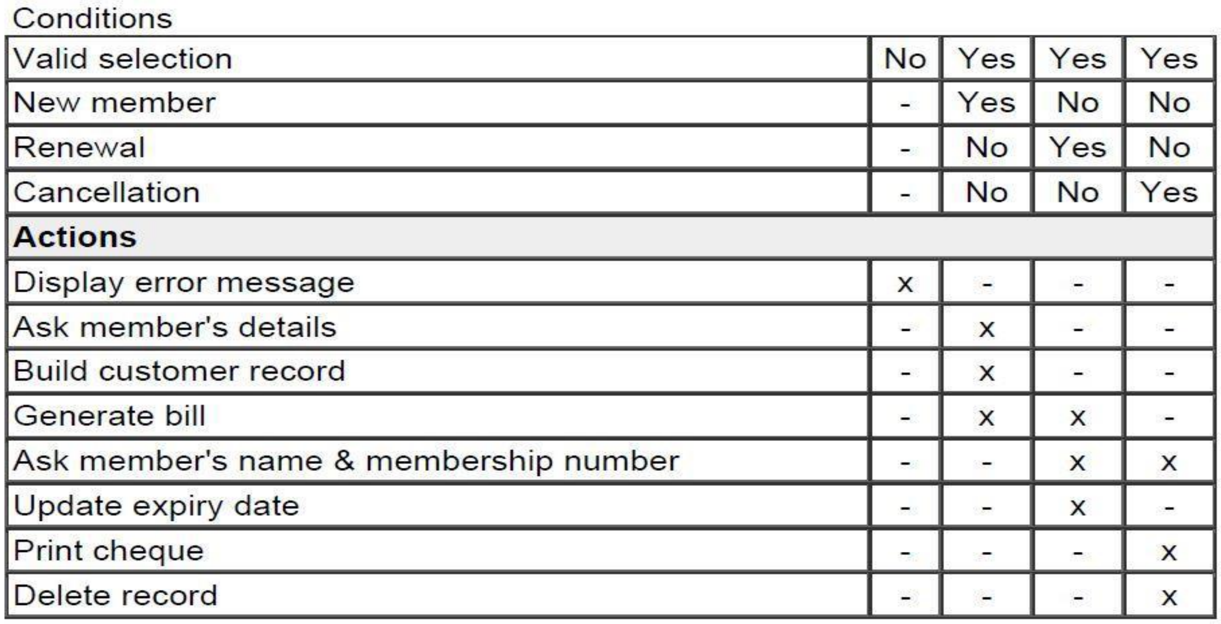


Fig 6.1: Decision Tree of LMS

DECISION TABLE
A decision table is used to represent the complex processing logic in a tabular or a matrix form. The upper rows of the table specify the variables or conditions to be evaluated. The lower rows of the table specify the actions to be taken when the corresponding conditions are satisfied. A column in a table is called a *rule*. A rule implies that if a condition is true, then the corresponding action is to be executed.

Example:

Consider the previously discussed LMS example. The following decision table (fig. 6.2) shows how to represent the LMS problem in a tabular form. Here the table is divided into two parts, the upper part shows the conditions and the lower part shows what actions are taken. Each column of the table is a rule.



Conditions				
Valid selection	No	Yes	Yes	Yes
New member	-	Yes	No	No
Renewal	-	No	Yes	No
Cancellation	-	No	No	Yes
Actions				
Display error message	x	-	-	-
Ask member's details	-	x	-	-
Build customer record	-	x	-	-
Generate bill	-	x	x	-
Ask member's name & membership number	-	-	x	x
Update expiry date	-	-	x	-
Print cheque	-	-	-	x
Delete record	-	-	-	x

Fig. 6.2: Decision table for LMS

From the above table you can easily understand that, if the valid selection condition is false then the action taken for this condition is 'display error message'. Similarly, the actions taken for other conditions can be inferred from the table.

FORMAL SYSTEM SPECIFICATION

Formal Technique
A formal technique is a mathematical method to specify a hardware and/or software system, verify whether a specification is realizable, verify that an implementation satisfies its specification, prove properties of a system without necessarily running the system, etc. The mathematical basis of a formal method is provided by the specification language.

Formal Specification Language

A formal specification language consists of two sets syn and sem, and a relation sat between them. The set syn is called the syntactic domain, the set sem is called the semantic domain, and the relation sat is called the satisfaction relation. For a given specification syn, and model of the system sem, if sat (syn, sem), then syn is said to be the specification of sem, and sem is said to be the specific and of syn.

Syntactic Domains

The syntactic domain of a formal specification language consists of an alphabet of symbols and set of formation rules to construct well-formed formulas from the alphabet. The well-formed formulas are used to specify a system.

Semantic Domains

Formal techniques can have considerably different semantic domains. Abstract data type specification languages are used to specify algebras, theories, and programs. Programming languages are used to specify functions from input to output values. Concurrent and distributed system specification languages are used to specify state sequences, event sequences, state transition sequences, synchronization trees, partial orders, state machines, etc.

Satisfaction Relation

Given the model of a system, it is important to determine whether an element of the semantic domain satisfies the specifications. This satisfaction is determined by using a homomorphism known as semantic abstraction function. The semantic abstraction function maps the elements of the semantic domain into equivalent classes. There can be different specifications describing different aspects of a system model, possibly using different specification languages. Some of these specifications describe the system's behavior and the others describe the system's structure. Consequently, two broad classes of semantic abstraction functions are defined: those that preserve a system's behavior and those that preserve a system's structure.

Model-oriented vs. property-oriented approaches

Formal methods are usually classified into two broad categories - model - oriented and property - oriented approaches. In a model-oriented style, one defines a system's behavior directly by constructing a model of the system in terms of mathematical structures such as tuples, relations, functions, sets, sequences, etc.

In the property-oriented style, the system's behavior is defined indirectly by stating its properties, usually in the form of a set of axioms that the system must satisfy.

Example:

Let us consider a simple producer/consumer example. In a property-oriented style, it is probably started by listing the properties of the system like: the consumer can start consuming only after the producer has produced an item; the producer starts to produce an item only after the consumer has consumed the last item, etc. A good example of a producer-consumer problem is CPU-Printer coordination. After processing of data, CPU outputs characters to the buffer for printing. Printer, on the other hand, reads characters from the buffer and prints them. The CPU is constrained by the capacity of the buffer, whereas the printer is constrained by an empty buffer. Examples of property-oriented specification styles are axiomatic specification and algebraic specification.

In a model-oriented approach, we start by defining the basic operations, p (produce) and c (consume). Then we can state that $S1 + p \rightarrow S$, $S + c \rightarrow S1$. Thus the model-oriented approaches essentially specify a program by writing another, presumably simpler program. Examples of popular model-oriented specification techniques are Z, CSP, CCS, etc.

Model-oriented approaches are more suited to use in later phases of life cycle because here even minor changes to a specification may lead to drastic changes to the entire specification. They do not support logical conjunctions (AND) and disjunctions (OR).

Property-oriented approaches are suitable for requirements specification because they can be easily changed. They specify a system as a conjunction of axioms and you can easily replace one axiom with another one.

Operational Semantics

Informally, the operational semantics of a formal method is the way computations are represented. There are different types of operational semantics according to what is meant by a single run of the system and how the runs are grouped together to describe the behavior of the system. Some commonly used operational semantics are as follows:

Linear Semantics:-

In this approach, a run of a system is described by a sequence (possibly infinite) of events or states. The concurrent activities of the system are represented by non-deterministic interleavings of the automatic actions. For example, a concurrent activity $a \| b$ is represented by the set of sequential activities a;b and b;a. This is simple but rather unnatural representation of concurrency. The behavior of a system in this model consists of the set of all its runs. To make this model realistic, usually justice and fairness restrictions are imposed on computations to exclude the unwanted interleavings.

Branching Semantics:-

In this approach, the behavior of a system is represented by a directed graph. The nodes of the graph represent the possible states in the evolution of a system. The descendants of each node of the graph represent the states which can be generated by any of the atomic actions enabled at that state. Although this semantic model distinguishes the branching points in a computation, still it represents concurrency by interleaving.

Maximally parallel semantics:-

In this approach, all the concurrent actions enabled at any state are assumed to be taken together. This is again not a natural model of concurrency since it implicitly assumes the availability of all the required computational resources.

Partial order semantics:-

Under this view, the semantics ascribed to a system is a structure of states satisfying a partial order relation among the states (events). The partial order represents a precedence ordering among events, and constraints some events to occur only after some other events have occurred; while the occurrence of other events (called concurrent events) is considered to be incomparable. This fact identifies concurrency as a phenomenon not translatable to any interleaved representation.

Formal methods possess several ***positive*** features, some of which are discussed below.

- Formal specifications encourage rigor. Often, the very process of construction of a rigorous specification is more important than the formal specification itself. The construction of a rigorous specification clarifies several aspects of system behavior that are not obvious in an informal specification.
- Formal methods usually have a well-founded mathematical basis. Thus, formal specifications are not only more precise, but also mathematically sound and can be used to reason about the properties of a specification and to rigorously prove that an implementation satisfies its specifications.
- Formal methods have well-defined semantics. Therefore, ambiguity in specifications is automatically avoided when one formally specifies a system.
- The mathematical basis of the formal methods facilitates automating the analysis of specifications. For example, a tableau-based technique has been used to automatically check the consistency of specifications. Also, automatic theorem proving techniques can be used to verify that an implementation satisfies its specifications. The possibility of automatic verification is one of the most important advantages of formal methods.

- Formal specifications can be executed to obtain immediate feedback on the features of the specified system. This concept of executable specifications is related to rapid prototyping. Informally, a prototype is a "toy" working model of a system that can provide immediate feedback on the behavior of the specified system, and is especially useful in checking the completeness of specifications.

Limitations of formal requirements specification

It is clear that formal methods provide mathematically sound frameworks within large, complex systems can be specified, developed and verified in a systematic rather than in an ad hoc manner. However, formal methods suffer from several shortcomings, some of which are the following:

- Formal methods are difficult to learn and use.
- The basic incompleteness results of first-order logic suggest that it is impossible to check absolute correctness of systems using theorem proving techniques.
- Formal techniques are not able to handle complex problems. This shortcoming results from the fact that, even moderately complicated problems blow up the complexity of formal specification and their analysis. Also, a large unstructured set of mathematical formulas is difficult to comprehend.

Axiomatic Specification

In axiomatic specification of a system, first-order logic is used to write the pre and post-conditions to specify the operations of the system in the form of axioms. The pre-conditions basically capture the conditions that must be satisfied before an operation can successfully be invoked. In essence, the pre-conditions capture the requirements on the input parameters of a function. The post-conditions are the conditions that must be satisfied when a function completes execution for the function to be considered to have executed successfully. Thus, the post-conditions are essentially constraints on the results produced for the function execution to be considered successful.

The following are the sequence of steps that can be followed to systematically develop the axiomatic specifications of a function:

- Establish the range of input values over which the function should behave correctly. Also find out other constraints on the input parameters and write it in the form of a predicate.
- Specify a predicate defining the conditions which must hold on the output of the function if it behaved properly.
- Establish the changes made to the function’s input parameters after execution of the function. Pure mathematical functions do not change their input and therefore this type of assertion is not necessary for pure functions.
- Combine all of the above into pre and post conditions of the function.

Example1:

Specify the pre- and post-conditions of a function that takes a real number as argument and returns half the input value if the input is less than or equal to 100, or else returns double the value.

f (x : real) : real

pre : $x \in R$

post : $\{(x \leq 100) \wedge (f(x) = x/2)\} \vee \{(x > 100) \wedge (f(x) = 2*x)\}$

Example2:

Axiomatically specify a function named search which takes an integer array and an integer key value as its arguments and returns the index in the array where the key value is present.

search(X : IntArray, key : Integer) : Integer

pre : $\exists\ i \in [Xfirst \ldots. Xlast], X[i] = key$

post : $\{(X'[search(X, key)] = key) \wedge (X = X')\}$

Here the convention followed is: If a function changes any of its input parameters and if that parameter is named X, and then it is referred to as X′ after the function completes execution faster.

SOFTWARE DESIGN

Software design is a process to transform user requirements into some suitable form, which helps the programmer in software coding and implementation. For assessing user requirements, an SRS (Software Requirement Specification) document is created whereas for coding and implementation, there is a need of more specific and detailed requirements in software terms. The output of this process can directly be used into implementation in programming languages.

Software design is the first step in SDLC (Software Design Life Cycle), which moves the concentration from problem domain to solution domain. It tries to specify how to fulfill the requirements mentioned in SRS.

Software Design Levels

Software design yields three levels of results:

- **Architectural Design -** The architectural design is the highest abstract version of the system. It identifies the software as a system with many components interacting with each other. At this level, the designers get the idea of proposed solution domain.
- **High-level Design-** The high-level design breaks the 'single entity-multiple component' concept of architectural design into less-abstracted view of sub-systems and modules and depicts their interaction with each other. High-level design focuses on how the system along with all of its components can be implemented in forms of modules. It recognizes modular structure of each sub-system and their relation and interaction among each other.
- **Detailed Design-** Detailed design deals with the implementation part of what is seen as a system and its sub-systems in the previous two designs. It is more detailed towards modules and their implementations. It defines logical structure of each module and their interfaces to communicate with other modules.

Modularization

Modularization is a technique to divide a software system into multiple discrete and independent modules, which are expected to be capable of carrying out task(s) independently. These modules may work as basic constructs for the entire software. Designers tend to design modules such that they can be executed and/or compiled separately and independently. Modular design unintentionally follows the rules of 'divide and conquer' problem-solving strategy this is because there are many other benefits attached with the modular design of a software.

Advantage of modularization:

- Smaller components are easier to maintain
- Program can be divided based on functional aspects
- Desired level of abstraction can be brought in the program
- Components with high cohesion can be re-used again.

- Concurrent execution can be made possible
- Desired from security aspect

Concurrency

Back in time, all software are meant to be executed sequentially. By sequential execution we mean that the coded instruction will be executed one after another implying only one portion of program being activated at any given time. Say, a software has multiple modules, then only one of all the modules can be found active at any time of execution. In software design, concurrency is implemented by splitting the software into multiple independent units of execution, like modules and executing them in parallel. In other words, concurrency provides capability to the software to execute more than one part of code in parallel to each other.

It is necessary for the programmers and designers to recognize those modules, which can be made parallel execution.

Example

The spell check feature in word processor is a module of software, which runs alongside the word processor itself.

Coupling and Cohesion

When a software program is modularized, its tasks are divided into several modules based on some characteristics. As we know, modules are set of instructions put together in order to achieve some tasks. They are though, considered as single entity but may refer to each other to work together. There are measures by which the quality of a design of modules and their interaction among them can be measured. These measures are called coupling and cohesion.

Cohesion

Cohesion is a measure that defines the degree of intra-dependability within elements of a module. The greater the cohesion, the better is the program design.

There are seven types of cohesion, namely -

- **Co-incidental cohesion -** It is unplanned and random cohesion, which might be the result of breaking the program into smaller modules for the sake of modularization. Because it is unplanned, it may serve confusion to the programmers and is generally not-accepted.
- **Logical cohesion -** When logically categorized elements are put together into a module, it is called logical cohesion.
- **Temporal Cohesion -** When elements of module are organized such that they are processed at a similar point in time, it is called temporal cohesion.
- **Procedural cohesion -** When elements of module are grouped together, which are executed sequentially in order to perform a task, it is called procedural cohesion.

- **Communicational cohesion -** When elements of module are grouped together, which are executed sequentially and work on same data (information), it is called communicational cohesion.
- **Sequential cohesion -** When elements of module are grouped because the output of one element serves as input to another and so on, it is called sequential cohesion.
- **Functional cohesion -** It is considered to be the highest degree of cohesion, and it is highly expected. Elements of module in functional cohesion are grouped because they all contribute to a single well-defined function. It can also be reused.

Coupling

Coupling is a measure that defines the level of inter-dependability among modules of a program. It tells at what level the modules interfere and interact with each other. The lower the coupling, the better the program.

There are five levels of coupling, namely -

- **Content coupling -** When a module can directly access or modify or refer to the content of another module, it is called content level coupling.
- **Common coupling-** When multiple modules have read and write access to some global data, it is called common or global coupling.
- **Control coupling-** Two modules are called control-coupled if one of them decides the function of the other module or changes its flow of execution.
- **Stamp coupling-** When multiple modules share common data structure and work on different part of it, it is called stamp coupling.
- **Data coupling-** Data coupling is when two modules interact with each other by means of passing data (as parameter). If a module passes data structure as parameter, then the receiving module should use all its components.

Ideally, no coupling is considered to be the best.

Design Verification

The output of software design process is design documentation, pseudo codes, detailed logic diagrams, process diagrams, and detailed description of all functional or non-functional requirements. The next phase, which is the implementation of software, depends on all outputs mentioned
above.

It is then becomes necessary to verify the output before proceeding to the next phase. The early any mistake is detected, the better it is or it might not be detected until testing of the product. If the outputs of design phase are in formal notation form, then their associated tools for verification should be used otherwise a thorough design review can be used for verification and validation.

By structured verification approach, reviewers can detect defects that might be caused by overlooking some conditions. A good design review is important for good software design, accuracy and quality.

SOFTWARE DESIGN STRATEGIES

Software design is a process to conceptualize the software requirements into software implementation. Software design takes the user requirements as challenges and tries to find optimum solution. While the software is being conceptualized, a plan is chalked out to find the best possible design for implementing the intended solution.

There are multiple variants of software design. Let us study them briefly:

Software design is a process to conceptualize the software requirements into software implementation. Software design takes the user requirements as challenges and tries to find optimum solution. While the software is being conceptualized, a plan is chalked out to find the best possible design for implementing the intended solution.

There are multiple variants of software design. Let us study them briefly:

Structured Design

Structured design is a conceptualization of problem into several well-organized elements of solution. It is basically concerned with the solution design. Benefit of structured design is, it gives better understanding of how the problem is being solved. Structured design also makes it simpler for designer to concentrate on the problem more accurately.

Structured design is mostly based on 'divide and conquer' strategy where a problem is broken into several small problems and each small problem is individually solved until the whole problem is solved.

The small pieces of problem are solved by means of solution modules. Structured design emphasis that these modules be well organized in order to achieve precise solution.

These modules are arranged in hierarchy. They communicate with each other. A good structured design always follows some rules for communication among multiple modules, namely -

Cohesion - grouping of all functionally related elements.

Coupling - communication between different modules.

A good structured design has ***high*** cohesion and ***low*** coupling arrangements.

Function Oriented Design

In function-oriented design, the system is comprised of many smaller sub-systems known as functions. These functions are capable of performing significant task in the system. The system is considered as top view of all functions.

Function oriented design inherits some properties of structured design where divide and conquer methodology is used.

This design mechanism divides the whole system into smaller functions, which provides means of abstraction by concealing the information and their operation. These functional modules can share information among themselves by means of information passing and using information available globally.

Another characteristic of functions is that when a program calls a function, the function changes the state of the program, which sometimes is not acceptable by other modules. Function oriented design works well where the system state does not matter and program/functions work on input rather than on a state.

Design Process

- The whole system is seen as how data flows in the system by means of data flow diagram.
- DFD depicts how functions change the data and state of entire system.
- The entire system is logically broken down into smaller units known as functions on the basis of their operation in the system.
- Each function is then described at large.

Object Oriented Design

Object oriented design works around the entities and their characteristics instead of functions involved in the software system. This design strategy focuses on entities and its characteristics. The whole concept of software solution revolves around the engaged entities.

Let us see the important concepts of Object Oriented Design:

- **Objects -** All entities involved in the solution design are known as objects. For example, person, banks, company and customers are treated as objects. Every entity has some attributes associated to it and has some methods to perform on the attributes.
- **Classes -** A class is a generalized description of an object. An object is an instance of a class. Class defines all the attributes, which an object can have and methods, which defines the functionality of the object.
  In the solution design, attributes are stored as variables and functionalities are defined by means of methods or procedures.
- **Encapsulation -** In OOD, the attributes (data variables) and methods (operation on the data) are bundled together is called encapsulation. Encapsulation not only bundles important information of an object together, but also restricts access of the data and methods from the outside world. This is called information hiding.
- **Inheritance -** OOD allows similar classes to stack up in hierarchical manner where the

lower or sub-classes can import, implement and re-use allowed variables and methods from their immediate super classes. This property of OOD is known as inheritance. This makes it easier to define specific class and to create generalized classes from specific ones.

- **Polymorphism -** OOD languages provide a mechanism where methods performing similar tasks but vary in arguments, can be assigned same name. This is called polymorphism, which allows a single interface performing tasks for different types. Depending upon how the function is invoked, respective portion of the code gets executed.

Design Process

Software design process can be perceived as series of well-defined steps. Though it varies according to design approach (function oriented or object oriented, yet It may have the following steps involved:

- A solution design is created from requirement or previous used system and/or system sequence diagram.
- Objects are identified and grouped into classes on behalf of similarity in attribute characteristics.
- Class hierarchy and relation among them are defined.
- Application framework is defined.

Software Design Approaches

There are two generic approaches for software designing:

Top down Design

We know that a system is composed of more than one sub-systems and it contains a number of components. Further, these sub-systems and components may have their one set of sub-system and components and creates hierarchical structure in the system.

Top-down design takes the whole software system as one entity and then decomposes it to achieve more than one sub-system or component based on some characteristics. Each sub-system or component is then treated as a system and decomposed further. This process keeps on running until the lowest level of system in the top-down hierarchy is achieved.

Top-down design starts with a generalized model of system and keeps on defining the more specific part of it. When all components are composed the whole system comes into existence.

Top-down design is more suitable when the software solution needs to be designed from scratch and specific details are unknown.

Bottom-up Design

The bottom up design model starts with most specific and basic components. It proceeds with composing higher level of components by using basic or lower level components. It keeps creating higher level components until the desired system is not evolved as one single component. With each higher level, the amount of abstraction is increased.

Bottom-up strategy is more suitable when a system needs to be created from some existing system, where the basic primitives can be used in the newer system. Both, top-down and bottom-up approaches are not practical individually. Instead, a good combination of both is used.

SOFTWARE ANALYSIS & DESIGN TOOLS

Software analysis and design includes all activities, which help the transformation of requirement specification into implementation. Requirement specifications specify all functional and non-functional expectations from the software. These requirement specifications come in the shape of human readable and understandable documents, to which a computer has nothing to do. Software analysis and design is the intermediate stage, which helps human-readable requirements to be transformed into actual code.

Let us see few analysis and design tools used by software designers:

Data Flow Diagram

Data flow diagram is a graphical representation of data flow in an information system. It is capable of depicting incoming data flow, outgoing data flow and stored data. The DFD does not mention anything about how data flows through the system.

There is a prominent difference between DFD and Flowchart. The flowchart depicts flow of control in program modules. DFDs depict flow of data in the system at various levels. DFD does not contain any control or branch elements.

Types of DFD

Data Flow Diagrams are either Logical or Physical.

- **Logical DFD** - This type of DFD concentrates on the system process and flow of data in the system. For example in a Banking software system, how data is moved between different entities.
- **Physical DFD** - This type of DFD shows how the data flow is actually implemented in the system. It is more specific and close to the implementation.

DFD Components

DFD can represent Source, destination, storage and flow of data using the following set of components -

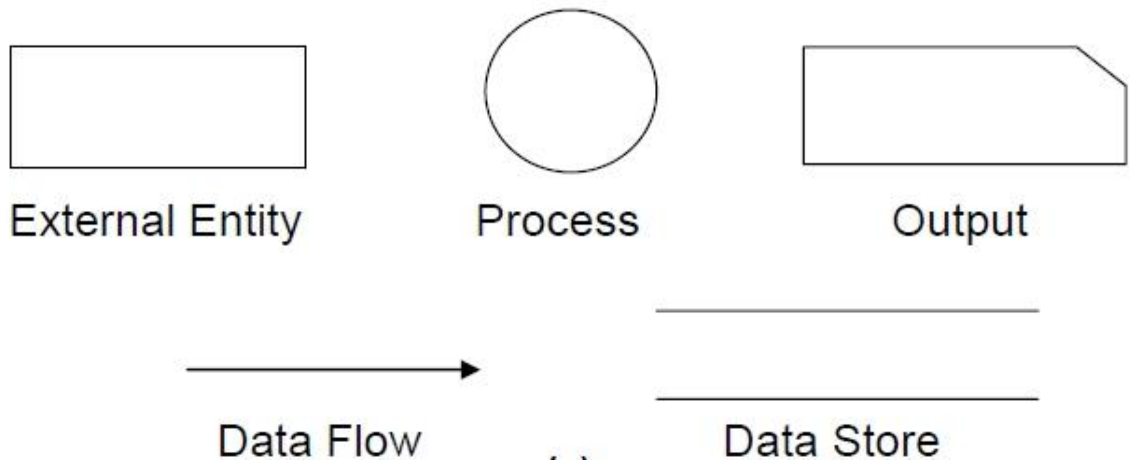


Fig 10.1: DFD Components

- **Entities** - Entities are source and destination of information data. Entities are represented by rectangles with their respective names.
- **Process** - Activities and action taken on the data are represented by Circle or Round-edged rectangles.
- **Data Storage** - There are two variants of data storage - it can either be represented as a rectangle with absence of both smaller sides or as an open-sided rectangle with only one side missing.
- **Data Flow** - Movement of data is shown by pointed arrows. Data movement is shown from the base of arrow as its source towards head of the arrow as destination.

Importance of DFDs in a good software design

The main reason why the DFD technique is so popular is probably because of the fact that DFD is a very simple formalism - it is simple to understand and use. Starting with a set of high-level functions that a system performs, a DFD model hierarchically represents various sub-functions. In fact, any hierarchical model is simple to understand. Human mind is such that it can easily understand any hierarchical model of a system - because in a hierarchical model, starting with a very simple and abstract model of a system, different details of the system are slowly introduced through different hierarchies. The data flow diagramming technique also follows a very simple set of intuitive concepts and rules. DFD is an elegant modeling technique that turns out to be useful not only to represent the results of structured analysis of a software problem, but also for several other applications such as showing the flow of documents or items in an organization.

STRUCTURED DESIGN

The aim of structured design is to transform the results of the structured analysis (i.e. a DFD representation) into a structure chart. Structured design provides two strategies to guide transformation of a DFD into a structure chart.

- • Transform analysis
- • Transaction analysis

Normally, one starts with the level 1 DFD, transforms it into module representation using either the transform or the transaction analysis and then proceeds towards the lower-level DFDs. At each level of transformation, it is important to first determine whether the transform or the transaction analysis is applicable to a particular DFD. These are discussed in the subsequent sub-sections.

Structure Chart

A structure chart represents the software architecture, i.e. the various modules making up the system, the dependency (which module calls which other modules), and the parameters that are passed among the different modules. Hence, the structure chart representation can be easily implemented using some programming language. Since the main focus in a structure chart representation is on the module structure of the software and the interactions among different modules, the procedural aspects (e.g. how a particular functionality is achieved) are not represented.

The basic building blocks which are used to design structure charts are the following:

- **Rectangular boxes:** Represents a module.
- **Module invocation arrows:** Control is passed from on one module to another module in the direction of the connecting arrow.
- **Data flow arrows:** Arrows are annotated with data name; named data passes from one module to another module in the direction of the arrow.
- **Library modules:** Represented by a rectangle with double edges.
- **Selection:** Represented by a diamond symbol.
- **Repetition:** Represented by a loop around the control flow arrow.

Structure Chart vs. Flow Chart

We are all familiar with the flow chart representation of a program. Flow chart is a convenient technique to represent the flow of control in a program. A structure chart differs from a flow chart in three principal ways:

- • It is usually difficult to identify the different modules of the software from its flow chart representation.
- • Data interchange among different modules is not represented in a flow chart.
- • Sequential ordering of tasks inherent in a flow chart is suppressed in a structure chart.

Transform Analysis

Transform analysis identifies the primary functional components (modules) and the high level inputs and outputs for these components. The first step in transform analysis is to divide the DFD into 3 types of parts:

- Input
- Logical processing
- Output

The input portion of the DFD includes processes that transform input data from physical (e.g. character from terminal) to logical forms (e.g. internal tables, lists, etc.). Each input portion is called an afferent branch.

The output portion of a DFD transforms output data from logical to physical form. Each output portion is called an efferent branch. The remaining portion of a DFD is called the central transform. In the next step of transform analysis, the structure chart is derived by drawing one functional component for the ***central transform***, and the ***afferent*** and ***efferent*** branches.

These are drawn below a root module, which would invoke these modules. Identifying the highest level input and output transforms requires experience and skill. One possible approach is to trace the inputs until a bubble is found whose output cannot be deduced from its inputs alone. Processes which validate input or add information to them are not central transforms. Processes which sort input or filter data from it are. The first level structure chart is produced by representing each input and output unit as boxes and each central transform as a single box. In the third step of transform analysis, the structure chart is refined by adding sub-functions required by each of the high-level functional components. Many levels of functional components may be added. This process of breaking functional components into subcomponents is called factoring. Factoring includes adding read and write modules, error-handling modules, initialization and termination process, identifying customer modules, etc. The factoring process is continued until all bubbles in the DFD are represented in the structure chart.

Example: Structure chart for the RMS software

For this example, the context diagram was drawn earlier.

To draw the level 1 DFD (fig.11.1), from a cursory analysis of the problem description, we can see that there are four basic functions that the system needs to perform - accept the input numbers from the user, validate the numbers, calculate the root mean square of the input numbers and, then display the result.

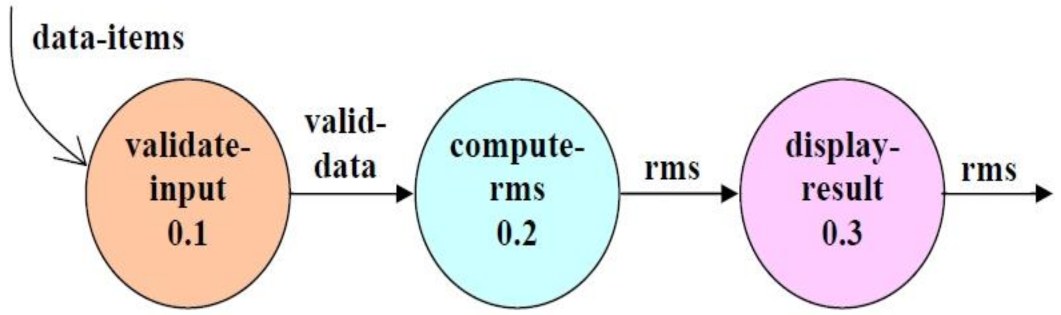


Fig. 11.1: Level 1 DFD

By observing the level 1 DFD, we identify the validate-input as the afferent branch and writeoutput as the efferent branch. The remaining portion (i.e. compute-rms) forms the central transform. By applying the step 2 and step 3 of transform analysis, we get the structure chart shown in fig.11.2.

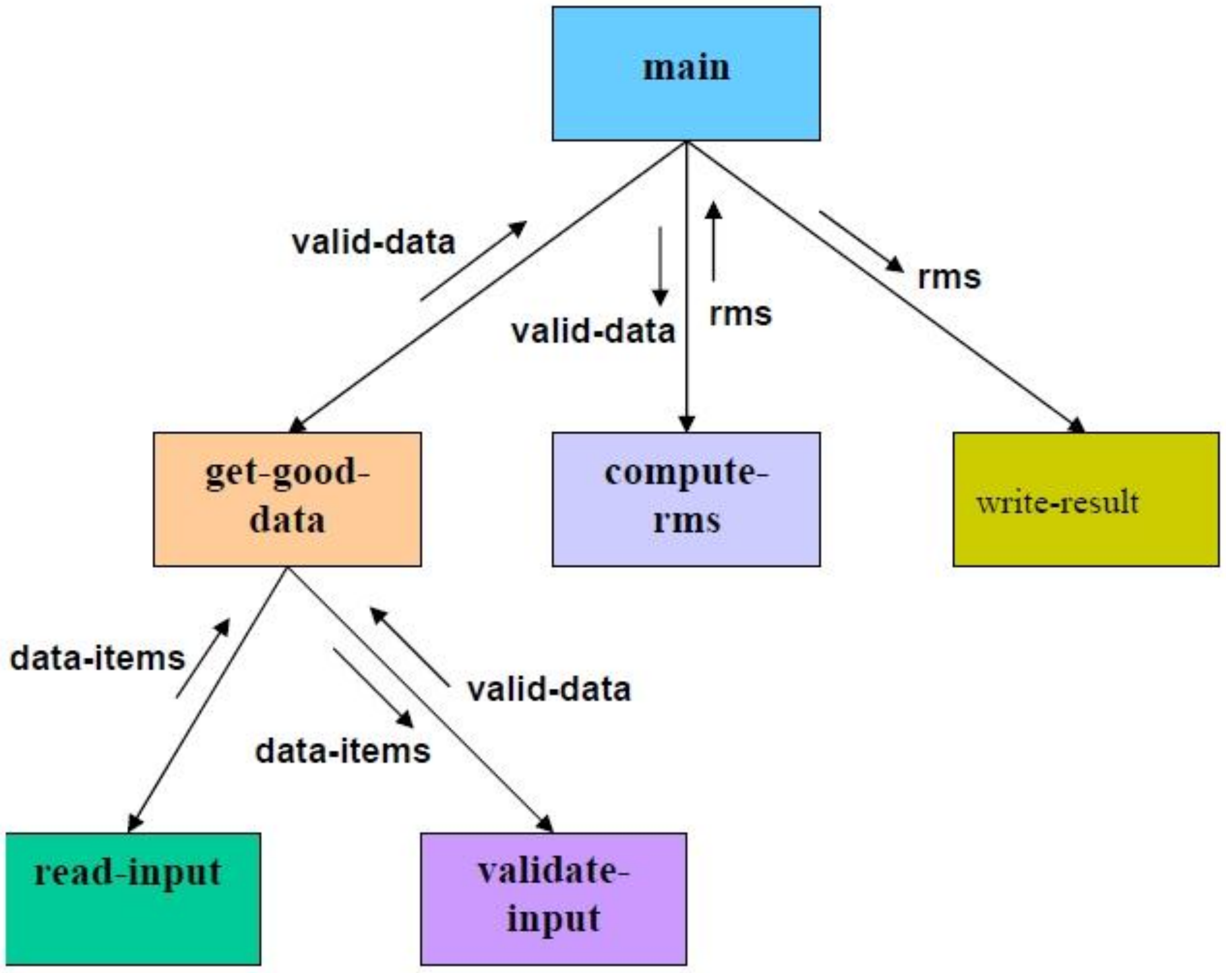


Fig. 11.2: Structure Chart

Transaction Analysis

A transaction allows the user to perform some meaningful piece of work. Transaction analysis is useful while designing transaction processing programs. In a transaction-driven system, one of several possible paths through the DFD is traversed depending upon the input data item. This is in contrast to a transform centered system which is characterized by similar processing steps for each data item. Each different way in which input data is handled is a transaction. A simple way to identify a transaction is to check the input data. The number of bubbles on which the input data to the DFD are incident defines the number of transactions. However, some transaction may not require any input data. These transactions can be identified from the experience of solving a large number of examples.

For each identified transaction, trace the input data to the output. All the traversed bubbles belong to the transaction. These bubbles should be mapped to the same module on the structure chart. In the structure chart, draw a root module and below this module draw each identified transaction a module. Every transaction carries a tag, which identifies its type. Transaction analysis uses this tag to divide the system into transaction modules and a transaction-center module.

The structure chart for the supermarket prize scheme software is shown in fig. 11.3.

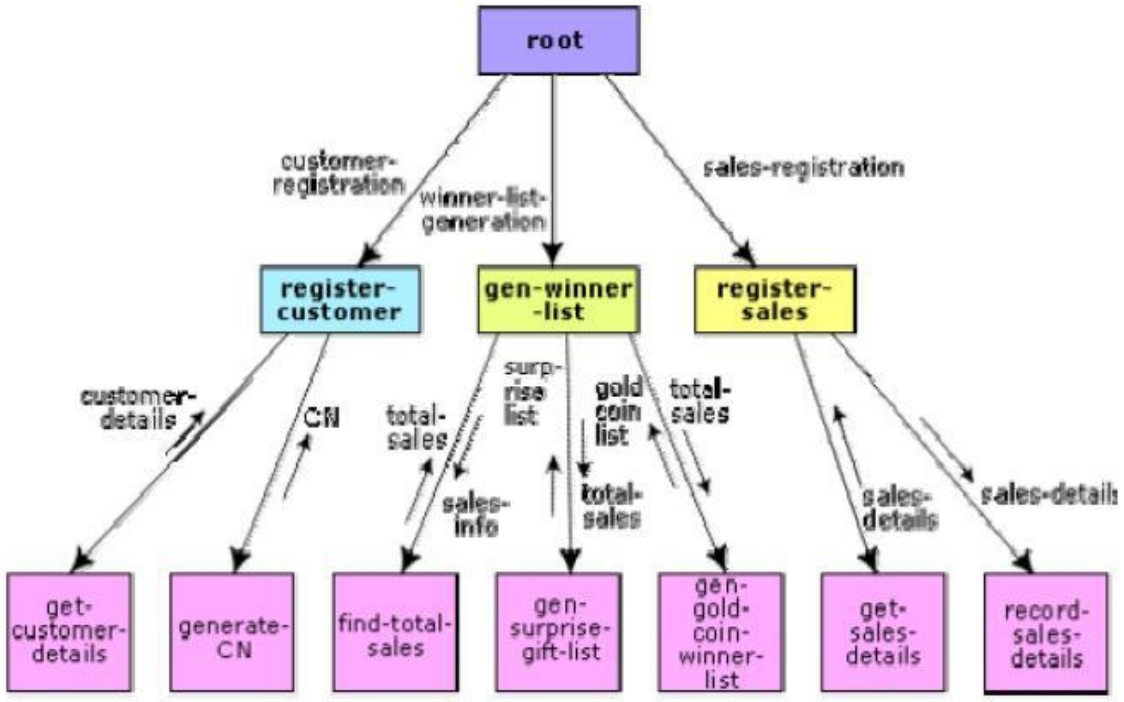


Fig. 11.3: Structure Chart for the supermarket prize scheme

OBJECT MODELLING USING UNIFIED MODELLING TOOL (UML)

Model

A model captures aspects important for some application while omitting (or abstracting) the rest. A model in the context of software development can be graphical, textual, mathematical, or program code-based. Models are very useful in documenting the design and analysis results. Models also facilitate the analysis and design procedures themselves. Graphical models are very popular because they are easy to understand and construct. UML is primarily a graphical modeling tool. However, it often requires text explanations to accompany the graphical models.

Need for a model

An important reason behind constructing a model is that it helps manage complexity. Once models of a system have been constructed, these can be used for a variety of purposes during software development, including the following**:**

- Analysis
- Specification
- Code generation
- Design
- Visualize and understand the problem and the working of a system
- Testing, etc.

In all these applications, the UML models can not only be used to document the results but also to arrive at the results themselves. Since a model can be used for a variety of purposes, it is reasonable to expect that the model would vary depending on the purpose for which it is being constructed. For example, a model developed for initial analysis and specification should be very different from the one used for design. A model that is being used for analysis and specification would not show any of the design decisions that would be made later on during the design stage. On the other hand, a model used for design purposes should capture all the design decisions. Therefore, it is a good idea to explicitly mention the purpose for which a model has been developed, along with the model.

Unified Modeling Language (UML)

UML, as the name implies, is a modeling language. It may be used to visualize, specify, construct, and document the artifacts of a software system. It provides a set of notations (e.g. rectangles, lines, ellipses, etc.) to create a visual model of the system. Like any other language, UML has its own syntax (symbols and sentence formation rules) and semantics (meanings of symbols and sentences). Also, we should clearly understand that UML is not a system design or development methodology, but can be used to document object-oriented and analysis results obtained using some methodology.

Origin of UML

In the late 1980s and early 1990s, there was a proliferation of object-oriented design techniques and notations. Different software development houses were using different notations to document their object-oriented designs. These diverse notations used to give rise to a lot of confusion.

UML was developed to standardize the large number of object-oriented modeling notations that existed and were used extensively in the early 1990s. The principles ones in use were:

- Object Management Technology [Rumbaugh 1991]
- Booch’s methodology [Booch 1991]
- Object-Oriented Software Engineering [Jacobson 1992]
- Odell’s methodology [Odell 1992]
- Shaler and Mellor methodology [Shaler 1992]

It is needless to say that UML has borrowed many concepts from these modeling techniques. Especially, concepts from the first three methodologies have been heavily drawn upon. UML was adopted by Object Management Group (OMG) as a *de facto* standard in 1997. OMG is an association of industries which tries to facilitate early formation of standards.

We shall see that UML contains an extensive set of notations and suggests construction of many types of diagrams. It has successfully been used to model both large and small problems. The elegance of UML, its adoption by OMG, and a strong industry backing have helped UML find widespread acceptance. UML is now being used in a large number of software development projects worldwide.

UML Diagrams

UML can be used to construct nine different types of diagrams to capture five different views of a system. Just as a building can be modeled from several views (or perspectives) such as ventilation perspective, electrical perspective, lighting perspective, heating perspective, etc.; the different UML diagrams provide different perspectives of the software system to be developed and facilitate a comprehensive understanding of the system. Such models can be refined to get the actual implementation of the system.

The UML diagrams can capture the following five views of a system**:**

- User's view
- Structural view
- Behavioral view
- Implementation view
- Environmental view

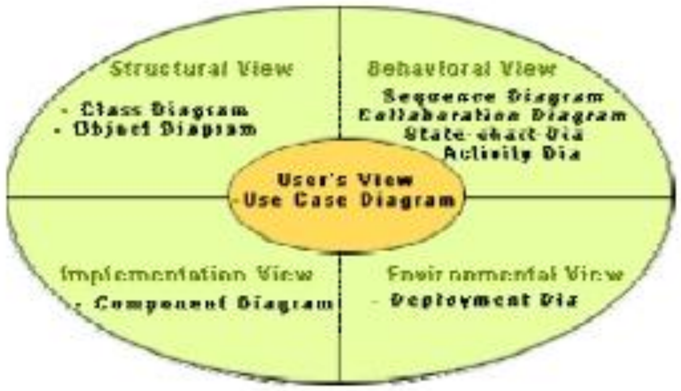


Fig. 12.1: Different types of diagrams and views supported in UML

User's view: This view defines the functionalities (facilities) made available by the system to its users. The users' view captures the external users' view of the system in terms of the functionalities offered by the system. The users' view is a black-box view of the system where the internal structure, the dynamic behavior of different system components, the implementation etc. are not visible. The users' view is very different from all other views in the sense that it is a functional model compared to the object model of all other views. The users' view can be considered as the central view and all other views are expected to conform to this view. This thinking is in fact the crux of any user centric development style.

Structural view: The structural view defines the kinds of objects (classes) important to the understanding of the working of a system and to its implementation. It also captures the relationships among the classes (objects). The structural model is also called the static model, since the structure of a system does not change with time.

Behavioral view: The behavioral view captures how objects interact with each other to realize the system behavior. The system behavior captures the time-dependent (dynamic) behavior of the system.

Implementation view: This view captures the important components of the system and their dependencies.

Environmental view: This view models how the different components are implemented on different pieces of hardware.

SOFTWARE MAINTENANCE

Necessity of Software Maintenance

Software maintenance is becoming an important activity of a large number of software organizations. This is no surprise, given the rate of hardware obsolescence, the immortality of a software product per se, and the demand of the user community to see the existing software products run on newer platforms, run in newer environments, and/or with enhanced features.

When the hardware platform is changed, and a software product performs some low-level functions, maintenance is necessary. Also, whenever the support environment of a software product changes, the software product requires rework to cope up with the newer interface. For instance, a software product may need to be maintained when the operating system changes. Thus, every software product continues to evolve after its development through maintenance efforts. Therefore it can be stated that software maintenance is needed to correct errors, enhance features, port the software to new platforms, etc.

Types of software maintenance

There are basically three types of software maintenance. These are:

- **Corrective:** Corrective maintenance of a software product is necessary to rectify the bugs observed while the system is in use.
- **Adaptive:** A software product might need maintenance when the customers need the product to run on new platforms, on new operating systems, or when they need the product to interface with new hardware or software.
- **Perfective:** A software product needs maintenance to support the new features that users want it to support, to change different functionalities of the system according to customer demands, or to enhance the performance of the system.

Problems associated with software maintenance

Software maintenance work typically is much more expensive than what it should be and takes more time than required. In software organizations, maintenance work is mostly carried out using ad hoc techniques. The primary reason being that software maintenance is one of the most neglected areas of software engineering. Even though software maintenance is fast becoming an important area of work for many companies as the software products of yester years age, still software maintenance is mostly being carried out as fire-fighting operations, rather than through systematic and planned activities.

Software maintenance has a very poor image in industry. Therefore, an organization often cannot employ bright engineers to carry out maintenance work. Even though maintenance suffers from a poor image, the work involved is often more challenging than development work. During maintenance it is necessary to thoroughly understand someone else's work and then carry out the required modifications and extensions. Another problem associated with maintenance work is that the majority of software products needing maintenance are legacy products.

Software Reverse Engineering

Software reverse engineering is the process of recovering the design and the requirements specification of a product from an analysis of its code. The purpose of reverse engineering is to facilitate maintenance work by improving the understandability of a system and to produce the necessary documents for a legacy system. Reverse engineering is becoming important, since legacy software products lack proper documentation, and are highly unstructured. Even well-designed products become legacy software as their structure degrades through a series of maintenance efforts.

The first stage of reverse engineering usually focuses on carrying out cosmetic changes to the code to improve its readability, structure, and understandability, without changing of its functionalities. A process model for reverse engineering has been shown in fig. 13.1. A program can be reformatted using any of the several available prettyprinter programs which layout the program neatly. Many legacy software products with complex control structure and unthoughtful variable names are difficult to comprehend. Assigning meaningful variable names is important because meaningful variable names are the most helpful thing in code documentation. All variables, data structures, and functions should be assigned meaningful names wherever possible. Complex nested conditionals in the program can be replaced by simpler conditional statements or whenever appropriate by case statements.

After the cosmetic changes have been carried out on a legacy software the process of extracting the code, design, and the requirements specification can begin. These activities are schematically shown in fig. 13.2. In order to extract the design, a full understanding of the code is needed. Some automatic tools can be used to derive the data flow and control flow diagram from the code. The structure chart (module invocation sequence and data interchange among modules) should also be extracted. The SRS document can be written once the full code has been thoroughly understood and the design extracted.

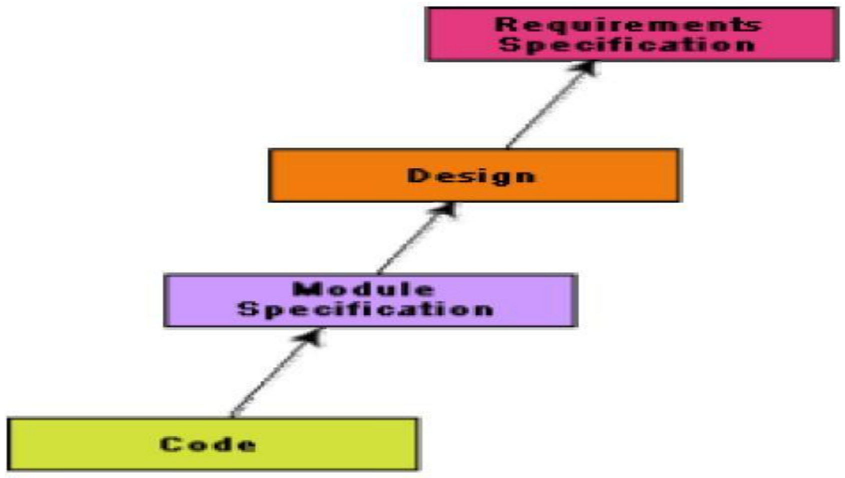


Fig. 13.1: A process model for reverse engineering

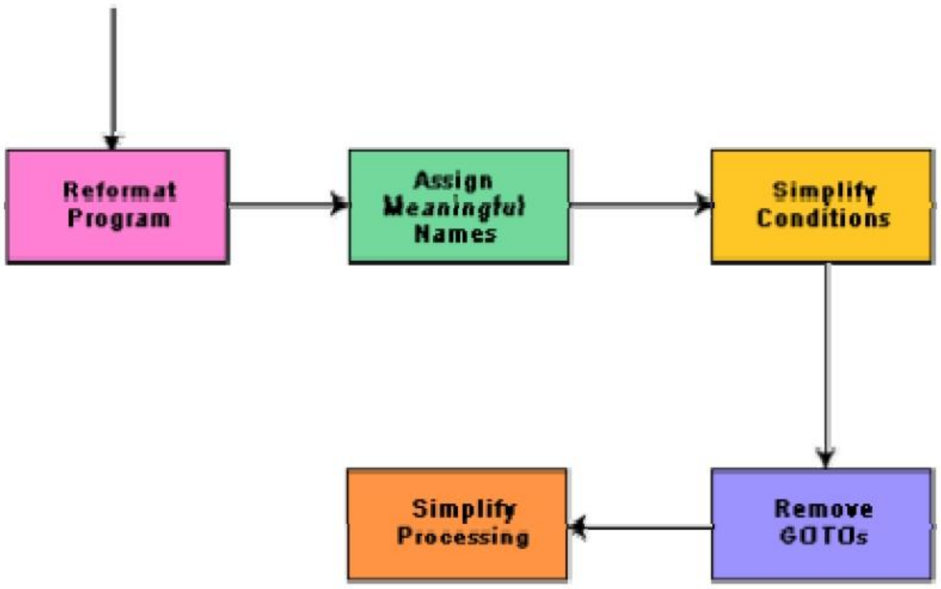


Fig. 13.2: Cosmetic changes carried out before reverse engineering

Legacy software products

It is prudent to define a legacy system as any software system that is hard to maintain. The typical problems associated with legacy systems are poor documentation, unstructured (spaghetti code with ugly control structure), and lack of personnel knowledgeable in the product. Many of the legacy systems were developed long time back. But, it is possible that a recently developed system having poor design and documentation can be considered to be a legacy system.

The activities involved in a software maintenance project are not unique and depend on several factors such as:

- the extent of modification to the product required
- the resources available to the maintenance team

the conditions of the existing product (e.g., how structured it is, how well documented it is, etc.)

• the expected project risks, etc.

When the changes needed to a software product are minor and straightforward, the code can be directly modified and the changes appropriately reflected in all the documents. But more elaborate activities are required when the required changes are not so trivial. Usually, for complex maintenance projects for legacy systems, the software process can be represented by a reverse engineering cycle followed by a forward engineering cycle with an emphasis on as much reuse as possible from the existing code and other documents.

SOFTWARE MAINTENANCE PROCESS MODELS

Two broad categories of process models for software maintenance can be proposed. The first model is preferred for projects involving small reworks where the code is changed directly and the changes are reflected in the relevant documents later. This maintenance process is graphically presented in fig. 14.1. In this approach, the project starts by gathering the requirements for changes. The requirements are next analyzed to formulate the strategies to be adopted for code change. At this stage, the association of at least a few members of the original development team goes a long way in reducing the cycle team, especially for projects involving unstructured and inadequately documented code. The availability of a working old system to the maintenance engineers at the maintenance site greatly facilitates the task of the maintenance team as they get a good insight into the working of the old system and also can compare the working of their modified system with the old system. Also, debugging of the reengineered system becomes easier as the program traces of both the systems can be compared to localize the bugs.

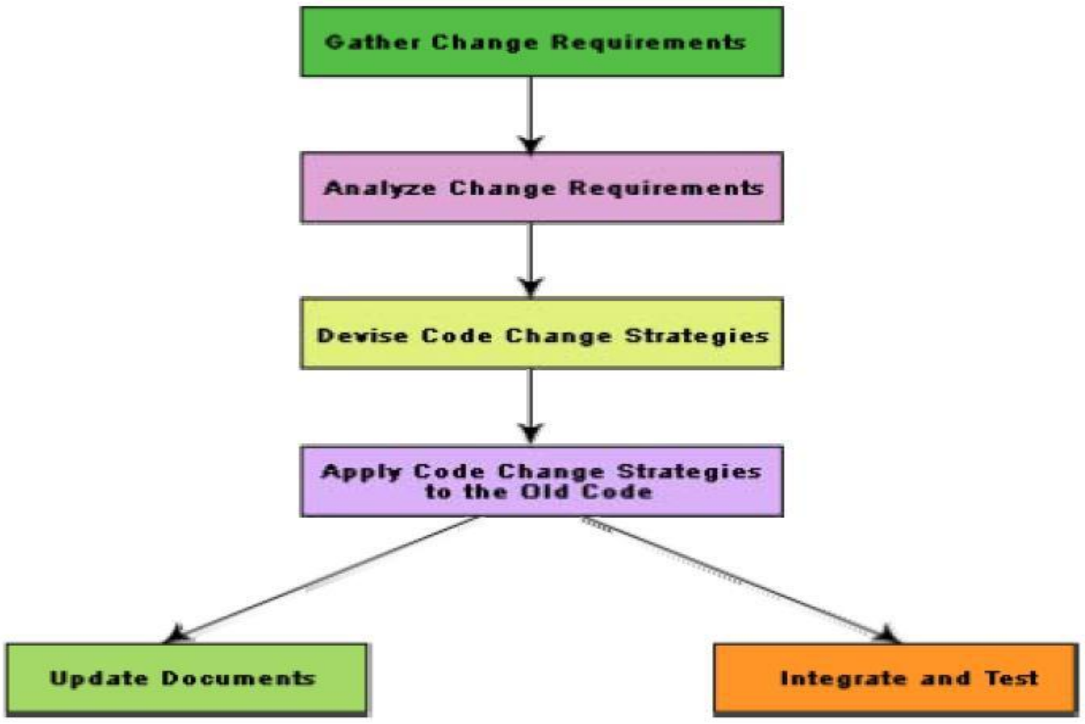

Gather Change Requirements
Analyze Change Requirements
Devise Code Change Strategies
Apply Code Change Strategies to the Old Code
Update Documents
Integrate and Test

Fig. 14.1: Maintenance process model 1

The second process model for software maintenance is preferred for projects where the amount of rework required is significant. This approach can be represented by a reverse engineering cycle followed by a forward engineering cycle. Such an approach is also known as software reengineering. This process model is depicted in fig. 25.2. The reverse engineering cycle is required for legacy products. During the reverse engineering, the old code is analyzed (abstracted) to extract the module specifications. The module specifications are then analyzed to produce the design. The design is analyzed (abstracted) to produce the original requirements specification. The change requests are then applied to this requirements specification to arrive at the new requirements specification. At the design, module specification, and coding a substantial reuse is made from the reverse engineered products. An important advantage of this approach is that it produces a more structured design compared to what the original product had, produces good documentation, and very often results in increased efficiency. The efficiency improvements are brought about by a more efficient design. However, this approach is more costly than the first approach. An empirical study indicates that process 1 is preferable when the amount of rework is no more than 15%. Besides the amount of rework, several other factors might affect the decision regarding using process model 1 over process model 2:

- Reengineering might be preferable for products which exhibit a high failure rate.
- Reengineering might also be preferable for legacy products having poor design and code structure.

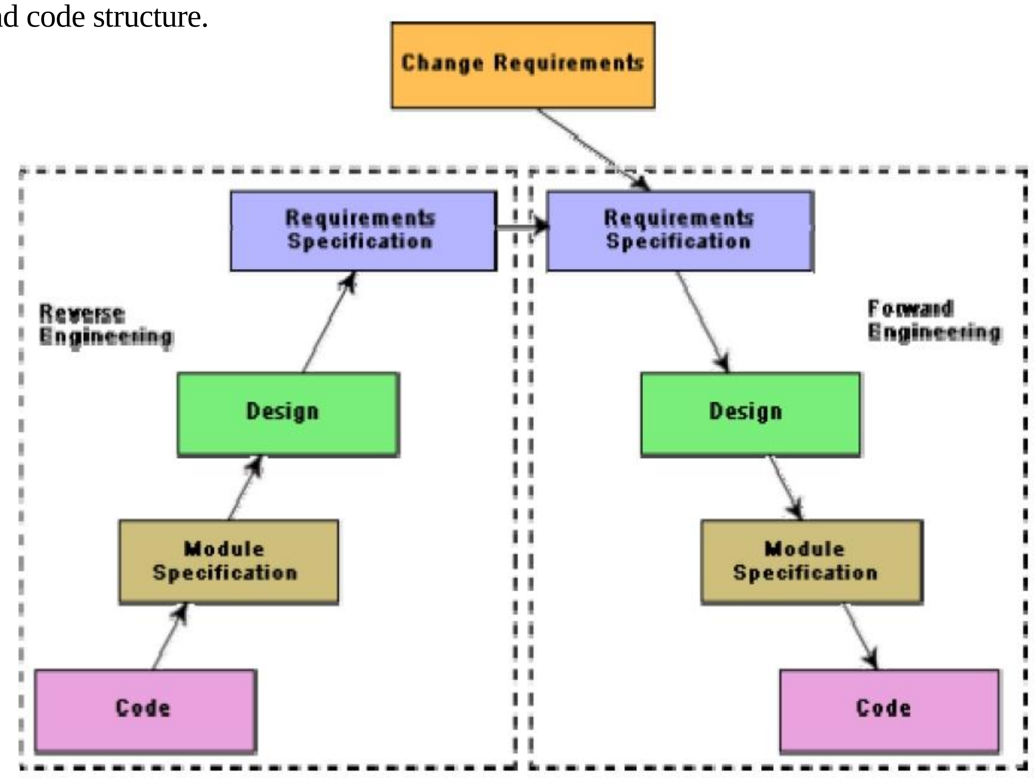


Fig. 14.2: Maintenance process model 2

Software Reengineering

Software reengineering is a combination of two consecutive processes i.e. software reverse engineering and software forward engineering as shown in the fig. 14.2.

Estimation of approximate maintenance cost

It is well known that maintenance efforts require about 60% of the total life cycle cost for a typical software product. However, maintenance costs vary widely from one application domain to another. For embedded systems, the maintenance cost can be as much as 2 to 4 times the development cost.

Boehm [1981] proposed a formula for estimating maintenance costs as part of his COCOMO cost estimation model. Boehm's maintenance cost estimation is made in terms of a quantity called the Annual Change Traffic (ACT). Boehm defined ACT as the fraction of a software product's source instructions which undergo change during a typical year either through addition or deletion.

$$ACT = \frac{KLOC_{added} + KLOC_{deleted}}{KLOC_{total}}$$

where, $KLOC_{added}$ is the total kilo lines of source code added during maintenance.

$KLOC_{deleted}$ is the total kilo lines of source code deleted during maintenance.

Thus, the code that is changed, should be counted in both the code added and the code deleted. The annual change traffic (ACT) is multiplied with the total development cost to arrive at the maintenance cost:

$$\text{maintenance cost} = ACT \times \text{development cost.}$$

Most maintenance cost estimation models, however, yield only approximate results because they do not take into account several factors such as experience level of the engineers, and familiarity of the engineers with the product, hardware requirements, software complexity, etc.

SOFTWARE RELIABILITY AND QUALITY MANAGEMENT

Repeatable vs. non-repeatable software development organization

A repeatable software development organization is one in which the software development process is person-independent. In a non-repeatable software development organization, a software development project becomes successful primarily due to the initiative, effort, brilliance, or enthusiasm displayed by certain individuals. Thus, in a non-repeatable software development organization, the chances of successful completion of a software project is to a great extent depends on the team members.

Software Reliability

Reliability of a software product essentially denotes its trustworthiness or dependability.

Alternatively, reliability of a software product can also be defined as the probability of the product working “correctly” over a given period of time.
It is obvious that a software product having a large number of defects is unreliable. It is also clear that the reliability of a system improves, if the number of defects in it is reduced. However, there is no simple relationship between the observed system reliability and the number of latent defects in the system. For example, removing errors from parts of a software which are rarely executed makes little difference to the perceived reliability of the product.

It has been experimentally observed by analyzing the behavior of a large number of programs that 90% of the execution time of a typical program is spent in executing only 10% of the instructions in the program. These most used 10% instructions are often called the core of the program. The rest 90% of the program statements are called non-core and are executed only for 10% of the total execution time. It therefore may not be very surprising to note that removing 60% product defects from the least used parts of a system would typically lead to only 3% improvement to the product reliability. It is clear that the quantity by which the overall reliability of a program improves due to the correction of a single error depends on how frequently the corresponding instruction is executed.

Thus, reliability of a product depends not only on the number of latent errors but also on the exact location of the errors. Apart from this, reliability also depends upon how the product is used, i.e. on its execution profile. If it is selected input data to the system such that only the “correctly” implemented functions are executed, none of the errors will be exposed and the perceived reliability of the product will be high. On the other hand, if the input data is selected such that only those functions which contain errors are invoked, the perceived reliability of the system will be very low.

Reasons for software reliability being difficult to measure

The reasons why software reliability is difficult to measure can be summarized as follows:

- The reliability improvement due to fixing a single bug depends on where the bug is located in the code.
- The perceived reliability of a software product is highly observer-dependent.
- The reliability of a product keeps changing as errors are detected and fixed.
- Hardware reliability vs. software reliability differs.

Reliability behavior for hardware and software are very different. For example, hardware failures are inherently different from software failures. Most hardware failures are due to component wear and tear. A logic gate may be stuck at 1 or 0, or a resistor might short circuit. To fix hardware faults, one has to either replace or repair the failed part. On the other hand, a software product would continue to fail until the error is tracked down and either the design or the code is changed. For this reason, when a hardware is repaired its reliability is maintained at the level that existed before the failure occurred; whereas when a software failure is repaired, the reliability may either increase or decrease (reliability may decrease if a bug introduces new errors). To put this fact in a different perspective, hardware reliability study is concerned with stability (for example, inter-failure times remain constant). On the other hand, software reliability study aims at reliability growth (i.e. inter-failure times increase). The change of failure rate over the product lifetime for a typical hardware and a software product are sketched in fig. 26.1. For hardware products, it can be observed that failure rate is high initially but decreases as the faulty components are identified and removed. The system then enters its useful life. After some time (called product life time) the components wear out, and the failure rate increases. This gives the plot of hardware reliability over time its characteristics "bath tub" shape. On the other hand, for software the failure rate is at its highest during integration and test. As the system is tested, more and more errors are identified and removed resulting in reduced failure rate. This error removal continues at a slower pace during the useful life of the product. As the software becomes obsolete no error corrections occurs and the failure rate remains unchanged.

Reliability Metrics

The reliability requirements for different categories of software products may be different. For this reason, it is necessary that the level of reliability required for a software product should be specified in the SRS (software requirements specification) document. In order to be able to do this, some metrics are needed to quantitatively express the reliability of a software product. A good reliability measure should be observer-dependent, so that different people can agree on the degree of reliability a system has. For example, there are precise techniques for measuring performance, which would result in obtaining the same performance value irrespective of who is carrying out the performance measurement.

However, in practice, it is very difficult to formulate a precise reliability measurement technique. The next base case is to have measures that correlate with reliability. There are six reliability metrics which can be used to quantify the reliability of software products.

- **Rate of occurrence of failure (ROCOF)-** ROCOF measures the frequency of occurrence of unexpected behavior (i.e. failures). ROCOF measure of a software product can be obtained by observing the behavior of a software product in operation over a specified time interval and then recording the total number of failures occurring during the interval.
- **Mean Time To Failure (MTTF) -** MTTF is the average time between two successive failures, observed over a large number of failures. To measure MTTF, we can record the failure data for n failures. Let the failures occur at the time instants t_1, $t_2, \ldots t_n$. Then, MTTF can be calculated as

$$\sum_{i=1}^{n} \frac{t_{i+1-}t_i}{(n-1)}$$

It is important to note that only run time is considered in the time measurements, i.e. the time for which the system is down to fix the error, the boot time, etc are not taken into account in the time measurements and the clock is stopped at these times.

 Mean Time To Repair (MTTR) - Once failure occurs, sometime is required to fix the error. MTTR measures the average time it takes to track the errors causing the failure and to fix them.

 Mean Time Between Failure (MTBR) - MTTF and MTTR can be combined to get the MTBR metric: MTBF = MTTF + MTTR. Thus, MTBF of 300 hours indicates that once a failure occurs, the next failure is expected after 300 hours. In this case, time measurements are real time and not the execution time as in MTTF.

o **Probability of Failure on Demand (POFOD) -** Unlike the other metrics discussed, this metric does not explicitly involve time measurements. POFOD measures the likelihood of the system failing when a service request is made. For example, a POFOD of 0.001 would mean that 1 out of every 1000 service requests would result in a failure.

o **Availability-** Availability of a system is a measure of how likely shall the system be available for use over a given period of time. This metric not only considers the number of failures occurring during a time interval, but also takes into account the repair time (down time) of a system when a failure occurs. This metric is important for systems such as telecommunication systems, and operating systems, which are supposed to be never down and where repair and restart time are significant and loss of service during that time is important.

Classification of software failures

A possible classification of failures of software products into five different types is as follows:

- **Transient-** Transient failures occur only for certain input values while invoking a function of the system.
- **Permanent-** Permanent failures occur for all input values while invoking a function of the system.
- **Recoverable-** When recoverable failures occur, the system recovers with or without operator intervention.
- **Unrecoverable-** In unrecoverable failures, the system may need to be restarted.
- **Cosmetic-** These classes of failures cause only minor irritations, and do not lead to incorrect results. An example of a cosmetic failure is the case where the mouse button has to be clicked twice instead of once to invoke a given function through the graphical user interface.