

'Software Engineering' its need and characteristics, Abstraction and Decomposition for reducing complexity of Software during its development:

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

SDLC Model, different phases of SDLC Model, Waterfall Model, Iterative waterfall, Evolutionary Model, Spiral Model and Prototype Model and their comparison:

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

I. 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:

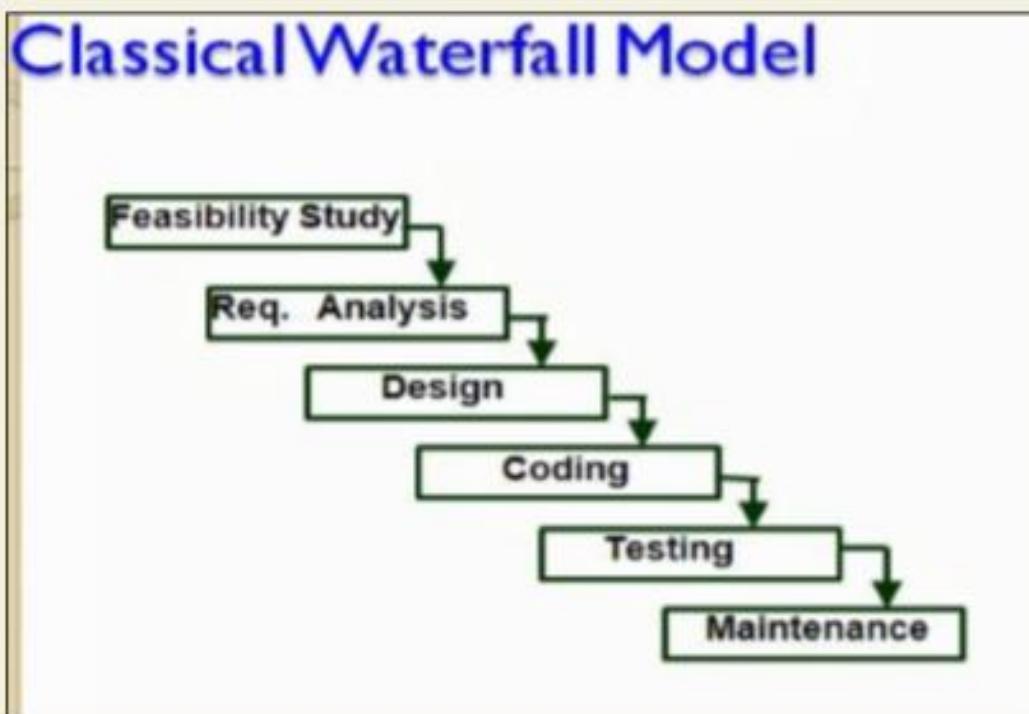


Fig 2.1: Classical Waterfall Model

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 nonfunctional 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.

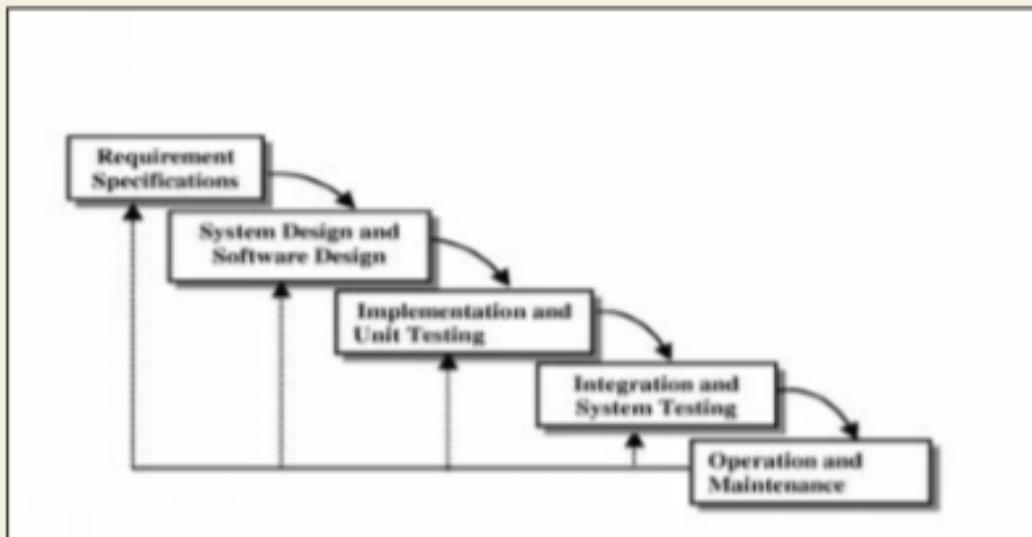


Fig 3.1 : Iterative Waterfall Model

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. PRTOTYPING 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.

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

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

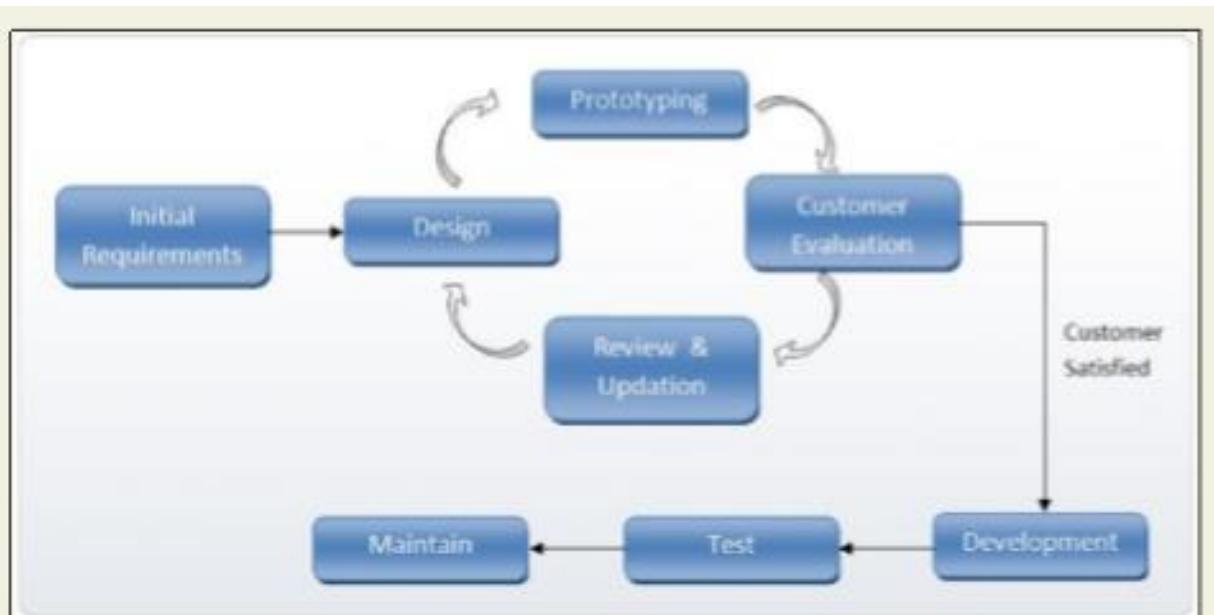


Fig 3.2: Prototype Model

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 & delivered.

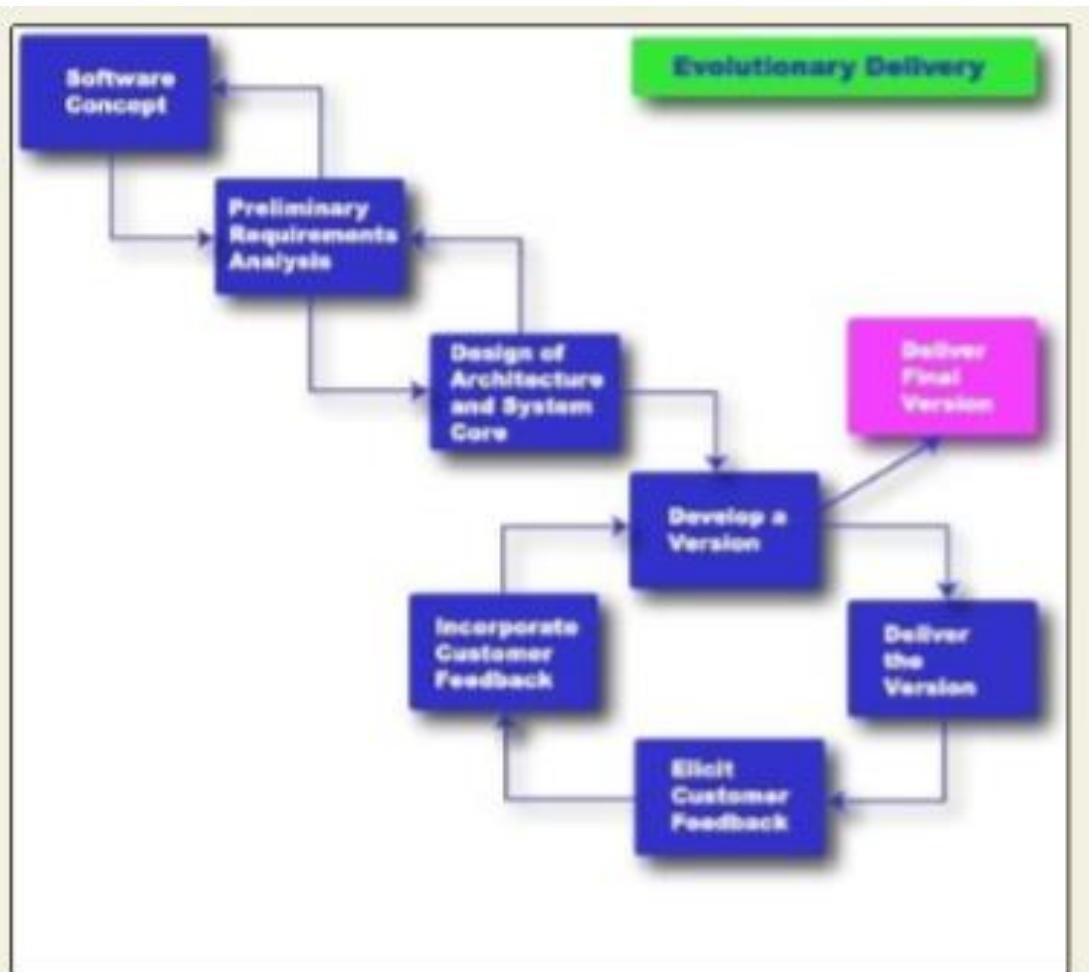


Fig 3.3: Evolutionary Model

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.

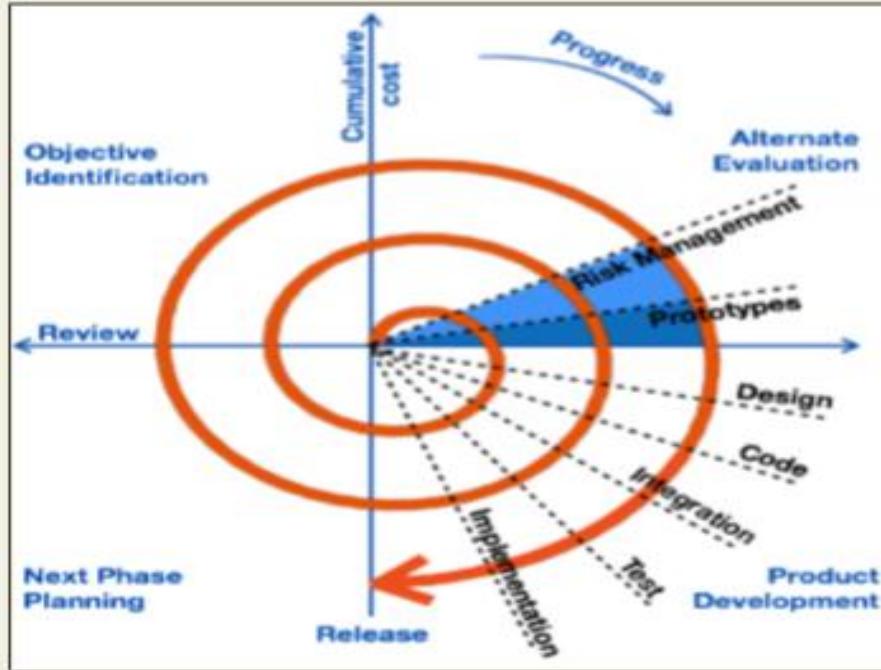


Fig 4.1: Spiral Model

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.

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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.

In continuation to Page-6 and Page-7 (of this document)

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_1, i_2, \dots, i_n) to the corresponding set of output data (o_1, o_2, \dots, o_n). The user can get some meaningful piece of work done using a high-level function.

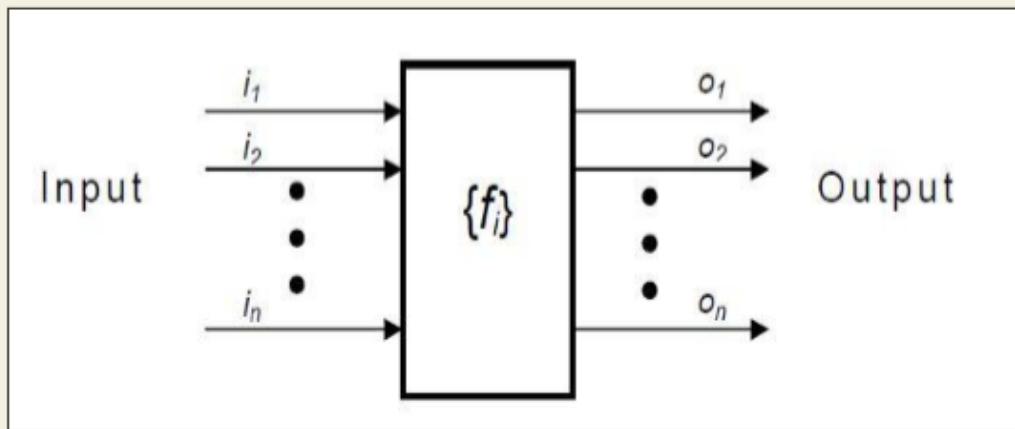


Fig. 5.1: View of a system performing a set of functions

Nonfunctional requirements:-

Nonfunctional 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.

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.

Traditional design approach and object oriented design approach for designing software:

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.

Structured design and function oriented design:

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 emphasizes 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.

Top down designing approach and bottom designing approach for software designing and development:

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 own 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.

Decision tree and decision table with respect to software designing with appropriate example:

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-

Decision: When the 'new member' option is selected, the software asks details about the member like the member's name, address, phone number etc.

Action: If proper information is entered then a membership record for the member is created and a bill is printed for the annual membership charge plus the security deposit payable.

Renewal option-

Decision: If the 'renewal' option is chosen, the LMS asks for the member's name and his membership number to check whether he is a valid member or not.

Action: If the membership is valid then membership expiry date is updated and the annual membership bill is printed, otherwise an error message is displayed.

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.

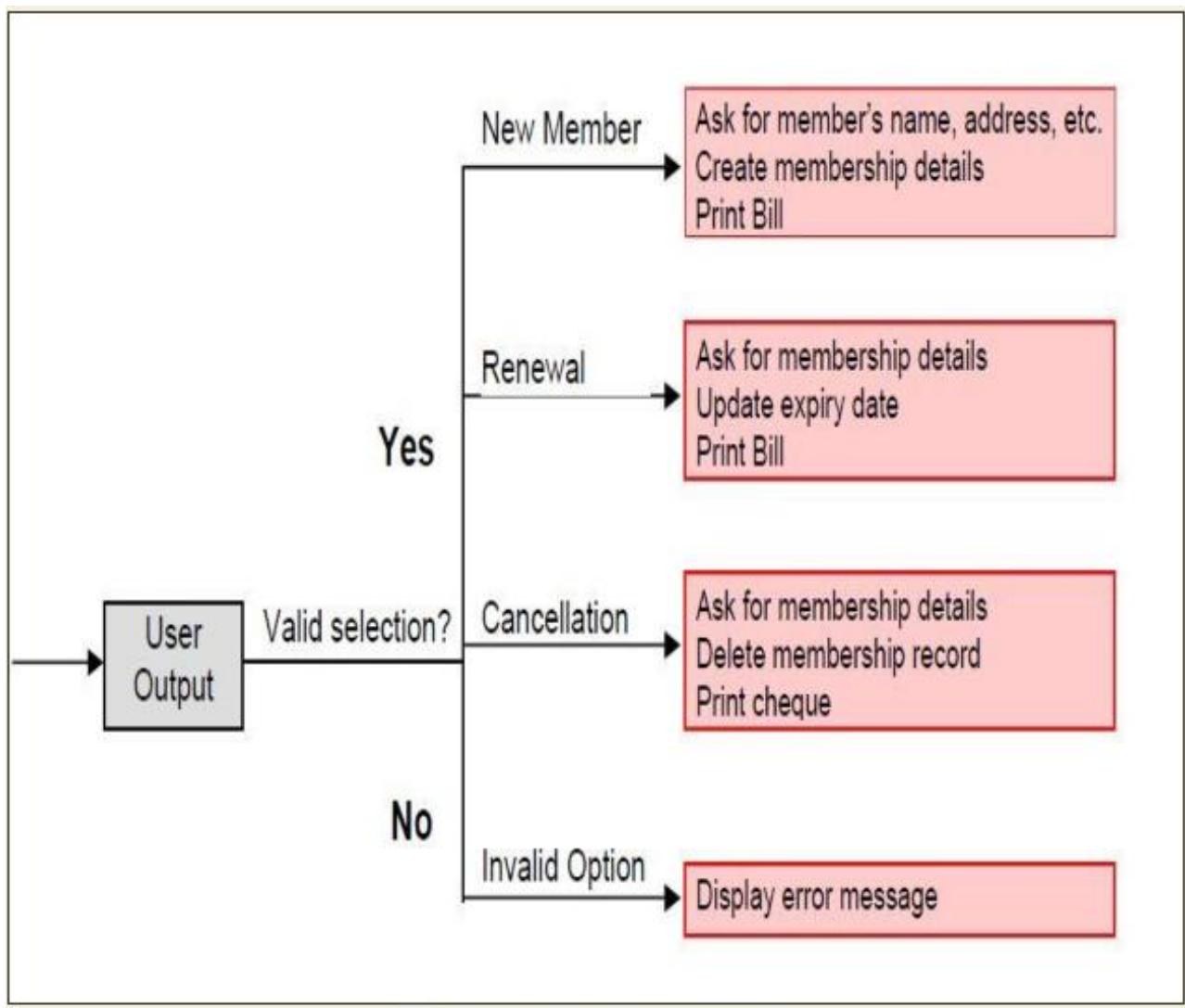


Fig.: Decision Tree of LMS

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		No	Yes	Yes	Yes
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.: 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.

Data flow diagram (DFD) and different DFD components with appropriate figure:

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 -

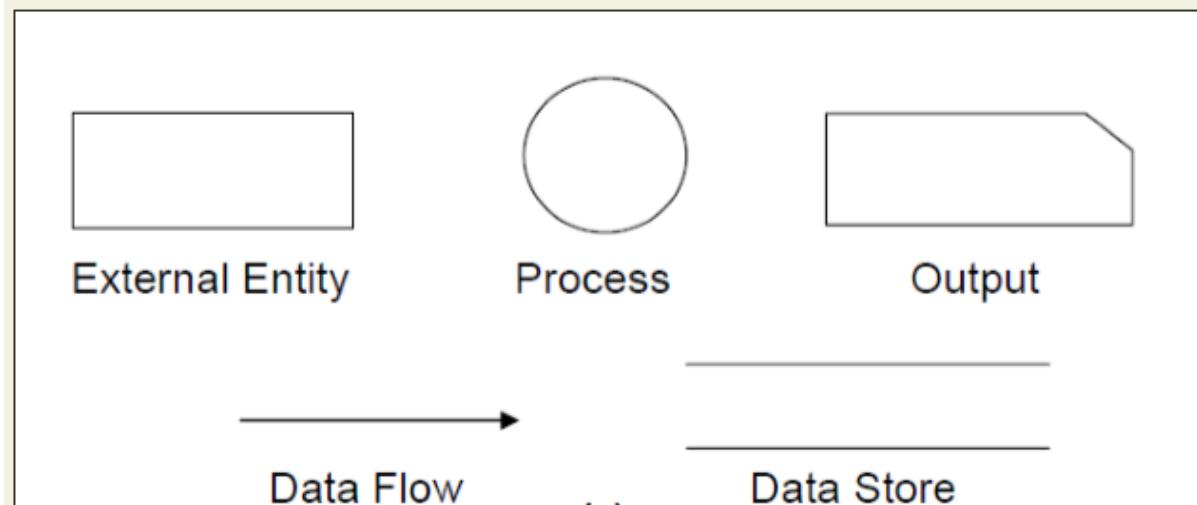


Fig 10.1: DFD Components

- **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.

Designing and develop a hostel/library management system, mentioning functional and non functional requirement, Use Case diagram, Class diagram, Sequence diagram, State Chart diagram and Collaborative diagram:

Refer – Lab Practice Note.

Modularization, Cohesion & Coupling in software modularization, different types of cohesion & different level of coupling:

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

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.

Characteristics of a Programming Language

For implementing our design into a code, one requires a good high level language. A programming language should have the following features:

Characteristics of a Programming Language

Readability: A good high-level language will allow programs to be written in some ways that resemble a quite-English description of the underlying algorithms. If care is taken, the coding may be done in a way that is essentially self-documenting.

Portability: High-level languages, being essentially machine independent, should be able to develop portable software.

Generality: Most high-level languages allow the writing of a wide variety of programs, thus relieving the programmer of the need to become expert in many diverse languages.

Brevity: Language should have the ability to implement the algorithm with less amount of code. Programs expressed in high-level languages are often considerably shorter than their low-level equivalents.

Error checking: Being human, a programmer is likely to make many mistakes in the development of a computer program. Many high-level languages enforce a great deal of error checking both at compile-time and at run-time.

Cost: The ultimate cost of a programming language is a function of many of its characteristics.

Familiar notation: A language should have familiar notation, so it can be understood by most of the programmers.

Quick translation: It should admit quick translation.

Efficiency: It should permit the generation of efficient object code.

Modularity: It is desirable that programs can be developed in the language as a collection of separately compiled modules, with appropriate mechanisms for ensuring self-consistency between these modules.

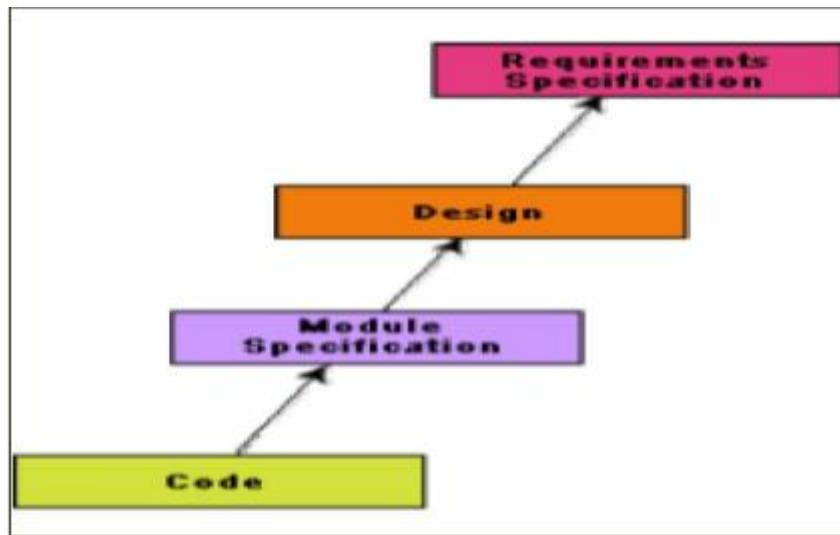
Widely available: Language should be widely available and it should be possible to provide translators for all the major machines and for all the major operating systems.

Software Reverse Engineering, Software Re-engineering process in software maintenance:

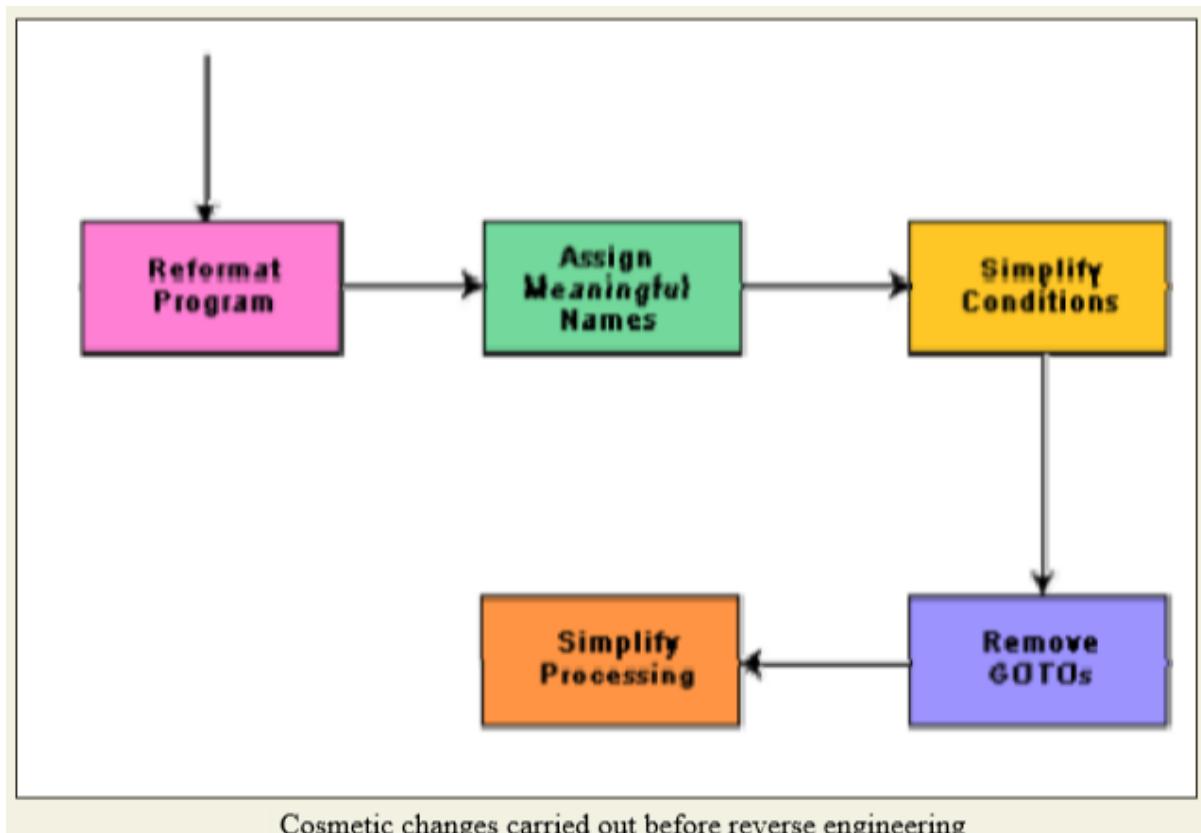
Software Reverse Engineering

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 following fig. 24.1. A program can be reformatted using any of the several available pretty printer 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 following fig. 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.



Cosmetic changes carried out before reverse engineering

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.

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 time, 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.

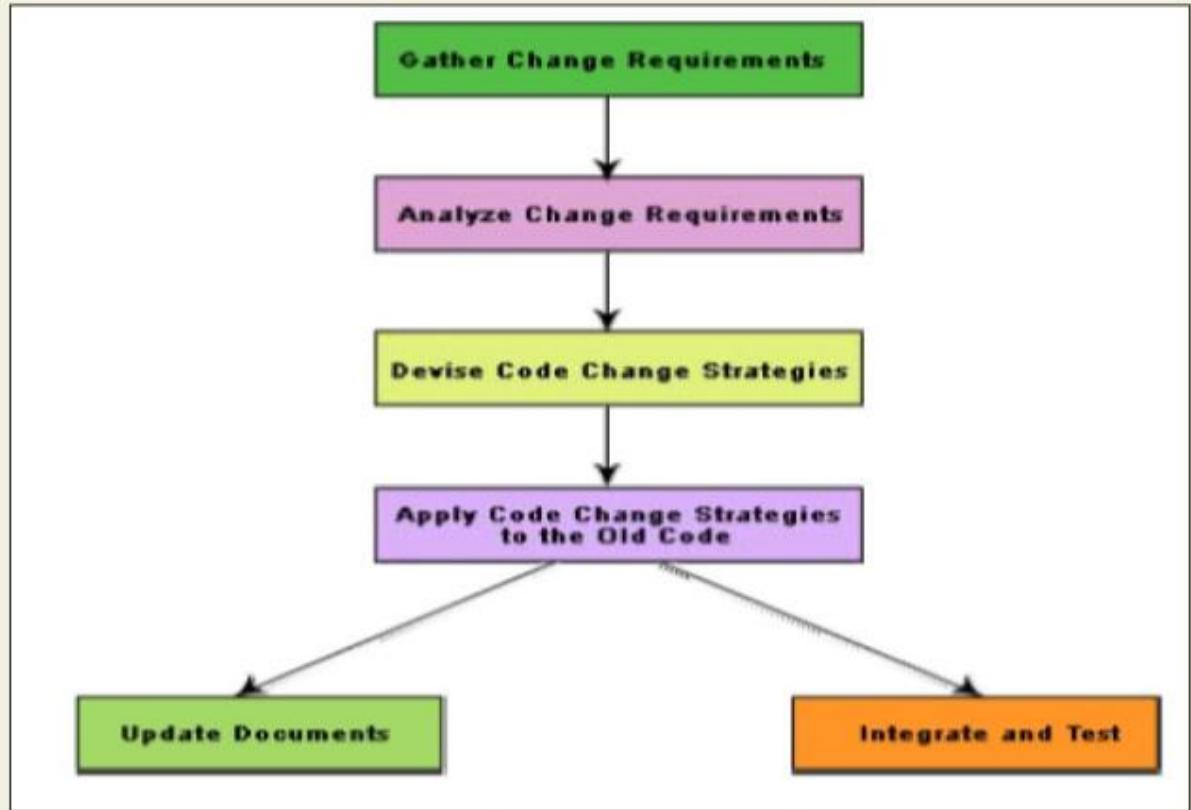


Fig. : Maintenance process model 1

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. 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.

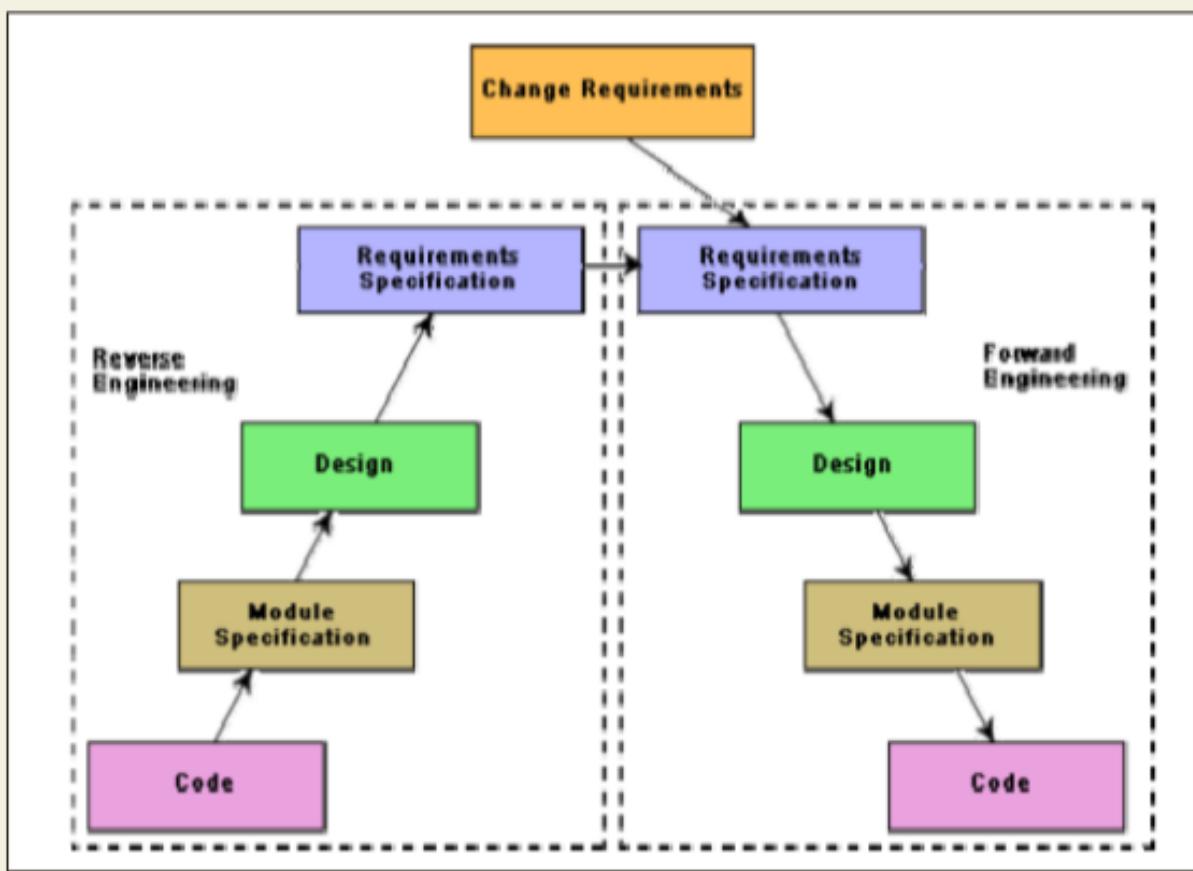


Fig.: Maintenance process model 2

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.

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.

Code review, code walk through, code inspection & clean room testing:

Code Review

Code review for a model is carried out after the module is successfully compiled and all the syntax errors have been eliminated. Code reviews are extremely cost-effective strategies for reduction in coding errors and to produce high quality code. Normally, two types of reviews are carried out on the code of a module. These two types code review techniques are code inspection and code walk through.

Code Walk Throughs

Code walk through is an informal code analysis technique. In this technique, after a module has been coded, successfully compiled and all syntax errors eliminated. A few members of the development team are given the code few days before the walk through meeting to read and understand code. Each member selects some test cases and simulates execution of the code by hand (i.e. trace execution through each statement and function execution). The main objectives of the walk through are to discover the algorithmic and logical errors in the code. The members note down their findings to discuss these in a walk through meeting where the coder of the module is present. Even though a code walk through is an informal analysis technique, several guidelines have evolved over the years for making this naïve but useful analysis technique more effective. Of course, these guidelines are based on personal experience, common sense, and several subjective factors. Therefore, these guidelines should be considered as examples rather than accepted as rules to be applied dogmatically. Some of these guidelines are the following:

- The team performing code walk through should not be either too big or too small. Ideally, it should consist of between three to seven members.
- Discussion should focus on discovery of errors and not on how to fix the discovered errors.

- In order to foster cooperation and to avoid the feeling among engineers that they are being evaluated in the code walk through meeting, managers should not attend the walk through meetings.

Code Inspection

In contrast to code walk through, the aim of code inspection is to discover some common types of errors caused due to oversight and improper programming. In other words, during code inspection the code is examined for the presence of certain kinds of errors, in contrast to the hand simulation of code execution done in code walk throughs. For instance, consider the classical error of writing a procedure that modifies a formal parameter while the calling routine calls that procedure with a constant actual parameter. It is more likely that such an error will be discovered by looking for these kinds of mistakes in the code, rather than by simply hand simulating execution of the procedure. In addition to the commonly made errors, adherence to coding standards is also checked during code inspection. Good software development companies collect statistics regarding different types of errors commonly committed by their engineers and identify the type of errors most frequently committed. Such a list of commonly committed errors can be used during code inspection to look out for possible errors.

Following is a list of some classical programming errors which can be checked during code inspection:

- Use of uninitialized variables.
- Jumps into loops.
- Nonterminating loops.
- Incompatible assignments.
- Array indices out of bounds.
- Improper storage allocation and deallocation.
- Mismatches between actual and formal parameter in procedure calls.
- Use of incorrect logical operators or incorrect precedence among operators.
- Improper modification of loop variables.
- Comparison of equally of floating point variables, etc.

Clean Room Testing

Clean room testing was pioneered by IBM. This type of testing relies heavily on walk throughs, inspection, and formal verification. The programmers are not allowed to test any of their code by executing the code other than doing some syntax testing using a compiler. The software development philosophy is based on avoiding software defects by using a rigorous inspection process. The objective of this software is zero-defect software. The name ‘clean room’ was derived from the analogy with semi-conductor fabrication units. In these units (clean rooms), defects are avoided by manufacturing in ultra-clean atmosphere. In this kind of development, inspections to check the consistency of the components with their specifications has replaced unit-testing.

This technique reportedly produces documentation and code that is more reliable and maintainable than other development methods relying heavily on code execution-based testing. The clean room approach to software development is based on five characteristics:

- **Formal specification:** The software to be developed is formally specified. A state-transition model which shows system responses to stimuli is used to express the specification.
- **Incremental development:** The software is partitioned into increments which are developed and validated separately using the clean room process. These increments are specified, with customer input, at an early stage in the process.
- **Structured programming:** Only a limited number of control and data abstraction constructs are used. The program development process is process of stepwise refinement of the specification.
- **Static verification:** The developed software is statically verified using rigorous software inspections. There is no unit or module testing process for code components
- **Statistical testing of the system:** The integrated software increment is tested statistically to determine its reliability. These statistical tests are based on the operational profile which is developed in parallel with the system specification. The main problem with this approach is that testing effort is increased as walk throughs, inspection, and verification are time-consuming.

Verification Vs Validation

Verification is the process of determining whether the output of one phase of software development conforms to that of its previous phase, whereas validation is the process of determining whether a fully developed system conforms to its requirements specification. Thus while verification is concerned with phase containment of errors, the aim of validation is that the final product be error free.

Functional Testing Vs. Structural Testing

In the black-box testing approach, test cases are designed using only the functional specification of the software, i.e. without any knowledge of the internal structure of the software. For this reason, black-box testing is known as functional testing. On the other hand, in the white-box testing approach, designing test cases requires thorough knowledge about the internal structure of software, and therefore the white-box testing is called structural testing.

Unit Testing

Unit testing is undertaken after a module has been coded and successfully reviewed. Unit testing (or **module testing**) is the testing of different units (or modules) of a system in isolation. In order to test a single module, a complete environment is needed to provide all

that is necessary for execution of the module. That is, besides the module under test itself, the following steps are needed in order to be able to test the module:

- The procedures belonging to other modules that the module under test calls.
- Nonlocal data structures that the module accesses.
- A procedure to call the functions of the module under test with appropriate parameters.

Black Box Testing

In the black-box testing, test cases are designed from an examination of the input/output values only and no knowledge of design or code is required. The following are the two main approaches to designing black box test cases.

- Equivalence class portioning
- Boundary value analysis

Equivalence Class Partitioning

In this approach, the domain of input values to a program is partitioned into a set of equivalence classes. This partitioning is done such that the behavior of the program is similar for every input data belonging to the same equivalence class. The main idea behind defining the equivalence classes is that testing the code with any one value belonging to an equivalence class is as good as testing the software with any other value belonging to that equivalence class. Equivalence classes for software can be designed by examining the input data and output data.

Boundary Value Analysis

A type of programming error frequently occurs at the boundaries of different equivalence classes of inputs. The reason behind such errors might purely be due to psychological factors. Programmers often fail to see the special processing required by the input values that lie at the boundary of the different equivalence classes. For example, programmers may improperly use `<` instead of `<=`, or conversely `<=` for `<`. Boundary value analysis leads to selection of test cases at the boundaries of the different equivalence classes.

Control Flow Graph (CFG)

A control flow graph describes the sequence in which the different instructions of a program get executed. In other words, a control flow graph describes how the control flows through

the program. In order to draw the control flow graph of a program, all the statements of a program must be numbered first. The different numbered statements serve as nodes of the control flow graph (as shown in following fig.). An edge from one node to another node exists if the execution of the statement representing the first node can result in the transfer of control to the other node.

The CFG for any program can be easily drawn by knowing how to represent the sequence, selection, and iteration type of statements in the CFG. After all, a program is made up from these types of statements. The Fig. summarizes how the CFG for these three types of statements can be drawn. It is important to note that for the iteration type of constructs such as the while construct, the loop condition is tested only at the beginning of the loop and therefore the control flow from the last statement of the loop is always to the top of the loop. Using these basic ideas, the CFG of Euclid's GCD computation algorithm can be drawn as shown in next fig.

Sequence:

a=5;

b = a*2-1;

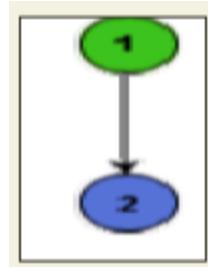


Fig. CFG for sequence constructs

Selection:

if (a>b)

c = 3;

else

c =5;

c=c*c;

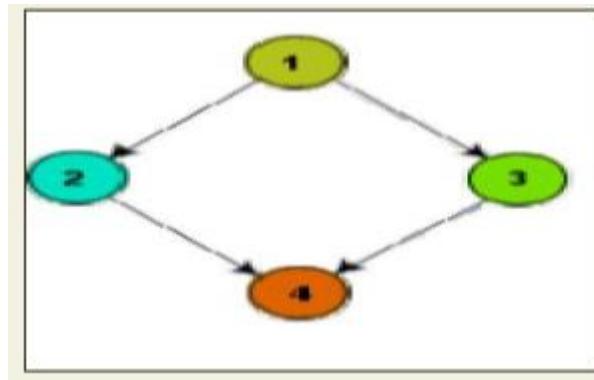


Fig.: CFG for selection constructs

Iteration :

while (a>b)

{

b=b -1;

b=b*a;

}

c = a+b;

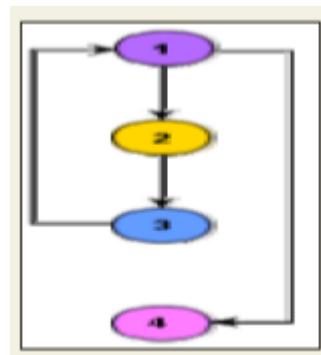
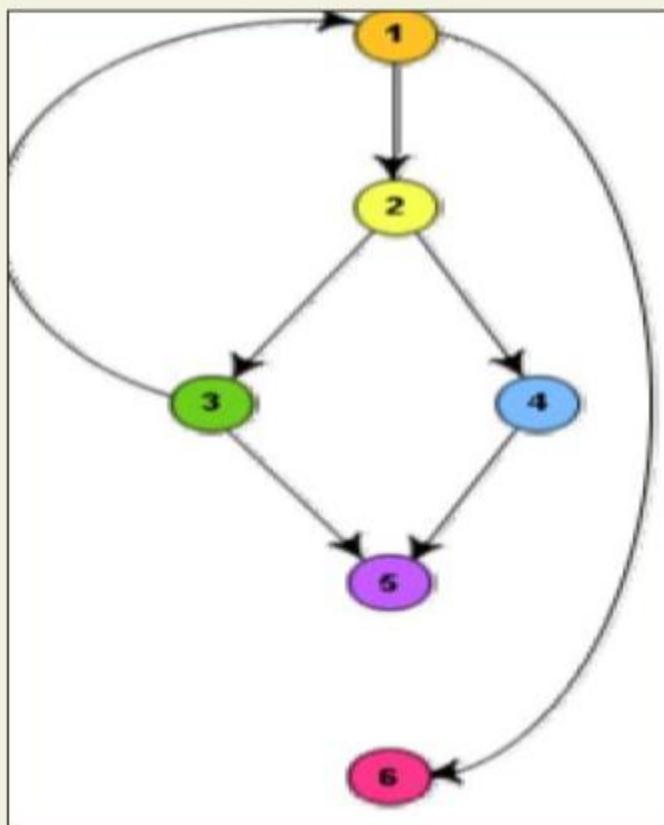


Fig.: CFG for and iteration type of constructs

EUCLID'S GCD Computation Algorithm

```
int compute_gcd(int x, int y){  
1 while(x!=y){  
2     if(x>y) then  
3         x=x-y;  
4     else y=y-x;  
5 }  
6 return x;  
}
```



Control flow diagram

Path

A path through a program is a node and edge sequence from the starting node to a terminal node of the control flow graph of a program. There can be more than one terminal node in a program. Writing test cases to cover all the paths of a typical program is impractical. For this reason, the path-coverage testing does not require coverage of all paths but only coverage of linearly independent paths.

Linearly independent path

A linearly independent path is any path through the program that introduces at least one new edge that is not included in any other linearly independent paths. If a path has one new node compared to all other linearly independent paths, then the path is also linearly independent. This is because; any path having a new node automatically implies that it has a new edge. Thus, a path that is sub-path of another path is not considered to be a linearly independent path.

Control Flow Graph

In order to understand the path coverage-based testing strategy, it is very much necessary to understand the control flow graph (CFG) of a program. Control flow graph (CFG) of a program has been discussed earlier.

Linearly Independent Path

The path-coverage testing does not require coverage of all paths but only coverage of linearly independent paths. Linearly independent paths have been discussed earlier.

Cyclomatic Complexity

For more complicated programs it is not easy to determine the number of independent paths of the program. McCabe's cyclomatic complexity defines an upper bound for the number of linearly independent paths through a program. Also, the McCabe's cyclomatic complexity is very simple to compute. Thus, the McCabe's cyclomatic complexity metric provides a practical way of determining the maximum number of linearly independent paths in a program. Though the McCabe's metric does not directly identify the linearly independent paths, but it informs approximately how many paths to look for.

There are three different ways to compute the cyclomatic complexity. The answers computed by the three methods are guaranteed to agree.

Method 1:

Given a control flow graph G of a program, the cyclomatic complexity $V(G)$ can be computed as: $V(G) = E - N + 2$ where N is the number of nodes of the control flow graph and E is the number of edges in the control flow graph. For the CFG of example shown in fig. 20.3, $E=7$ and $N=6$. Therefore, the cyclomatic complexity = $7-6+2 = 3$.

Method 2:

An alternative way of computing the cyclomatic complexity of a program from an inspection of its control flow graph is as follows: $V(G) = \text{Total number of bounded areas} + 1$ In the program's control flow graph G, any region enclosed by nodes and edges can be called as a bounded area. This is an easy way to determine the McCabe's cyclomatic complexity.

But, what if the graph G is not planar, i.e. however you draw the graph, two or more edges intersect? Actually, it can be shown that structured programs always yield planar graphs. But, presence of GOTO's can easily add intersecting edges. Therefore, for non-structured programs, this way of computing the McCabe's cyclomatic complexity cannot be used. The number of bounded areas increases with the number of decision paths and loops. Therefore, the McCabe's metric provides a quantitative measure of testing difficulty and the ultimate reliability. For the CFG example shown in fig. 20.3, from a visual examination of the CFG the number of bounded areas is 2. Therefore the cyclomatic complexity, computing with this method is also $2+1 = 3$. This method provides a very easy way of computing the cyclomatic complexity of CFGs, just from a visual examination of the CFG. On the other hand, the other method of computing CFGs is more amenable to automation, i.e. it can be easily coded into a program which can be used to determine the cyclomatic complexities of arbitrary CFGs.

Method 3:

The cyclomatic complexity of a program can also be easily computed by computing the number of decision statements of the program. If N is the number of decision statement of a program, then the McCabe's metric is equal to $N+1$.

Mutation Testing

In mutation testing, the software is first tested by using an initial test suite built up from the different white box testing strategies. After the initial testing is complete, mutation testing is taken up. The idea behind mutation testing is to make few arbitrary changes to a program at a time. Each time the program is changed, it is called as a mutated program and the change effected is called as a mutant. A mutated program is tested against the full test suite of the program. If there exists at least one test case in the test suite for which a mutant gives an incorrect result, then the mutant is said to be dead. If a mutant remains alive even after all the test cases have been exhausted, the test data is enhanced to kill the mutant. The process of generation and killing of mutants can be automated by predefining a set of primitive changes that can be applied to the program. These primitive changes can be alterations such as changing an arithmetic operator, changing the value of a constant, changing a data type, etc. A major disadvantage of the mutation-based testing approach is that it is computationally very expensive, since a large number of possible mutants can be generated.

Since mutation testing generates a large number of mutants and requires us to check each mutant with the full test suite, it is not suitable for manual testing. Mutation testing should be used in conjunction of some testing tool which would run all the test cases automatically

Alpha testing, beta testing and acceptance testing:

System tests are designed to validate a fully developed system to assure that it meets its requirements. There are essentially three main kinds of system testing:

Alpha Testing

Alpha testing refers to the system testing carried out by the test team within the developing organization.

Beta testing

Beta testing is the system testing performed by a select group of friendly customers.

Acceptance Testing

Acceptance testing is the system testing performed by the customer to determine whether he should accept the delivery of the system.

Project Estimation Techniques and its three types

Project Estimation Techniques

Estimation of various project parameters is a basic project planning activity. The important project parameters that are estimated include: project size, effort required to develop the software, project duration, and cost. These estimates not only help in quoting the project cost to the customer, but are also useful in resource planning and scheduling. There are three broad categories of estimation techniques:

- Empirical estimation techniques
- Heuristic techniques
- Analytical estimation techniques

Empirical Estimation Techniques

Empirical estimation techniques are based on making an educated guess of the project parameters. While using this technique, prior experience with development of similar products is helpful. Although empirical estimation techniques are based on common sense, different activities involved in estimation have been formalized over the years. Two popular empirical estimation techniques are: Expert judgment technique and Delphi cost estimation.

Expert Judgment Technique

Expert judgment is one of the most widely used estimation techniques. In this approach, an expert makes an educated guess of the problem size after analyzing the problem thoroughly. Usually, the expert estimates the cost of the different components (i.e. modules or subsystems) of the system and then combines them to arrive at the overall estimate. However, this technique is subject to human errors and individual bias. Also, it is possible that the expert may overlook some factors inadvertently. Further, an expert making an estimate may not have experience and knowledge of all aspects of a project. For example, he may be conversant with the database and user interface parts but may not be very knowledgeable about the computer communication part. A more refined form of expert judgment is the estimation made by group of experts. Estimation by a group of experts minimizes factors such as individual oversight, lack of familiarity with a particular aspect of a project, personal bias, and the desire to win contract through overly optimistic estimates. However, the estimate made by a group of experts may still exhibit bias on issues where the entire group of experts may be biased due to reasons such as political considerations. Also, the decision made by the group may be dominated by overly assertive members.

Delphi Cost Estimation

Delphi cost estimation approach tries to overcome some of the shortcomings of the expert judgment approach. Delphi estimation is carried out by a team comprising of a group of

experts and a coordinator. In this approach, the coordinator provides each estimator with a copy of the software requirements specification (SRS) document and a form for recording his cost estimate. Estimators complete their individual estimates anonymously and submit to the coordinator. In their estimates, the estimators mention any unusual characteristic of the product which has influenced his estimation. The coordinator prepares and distributes the summary of the responses of all the estimators, and includes any unusual rationale noted by any of the estimators. Based on this summary, the estimators re-estimate. This process is iterated for several rounds. However, no discussion among the estimators is allowed during the entire estimation process. The idea behind this is that if any discussion is allowed among the estimators, then many estimators may easily get influenced by the rationale of an estimator who may be more experienced or senior. After the completion of several iterations of estimations, the coordinator takes the responsibility of compiling the results and preparing the final estimate.

Heuristic techniques

Heuristic techniques assume that the relationships among the different project parameters can be modeled using suitable mathematical expressions. Once the basic (independent) parameters are known, the other (dependent) parameters can be easily determined by substituting the value of the basic parameters in the mathematical expression. Different heuristic estimation models can be divided into the following two classes: single variable model and the multi variable model. Single variable estimation models provide a means to estimate the desired characteristics of a problem, using some previously estimated basic (independent) characteristic of the software product such as its size.

Analytical Estimation Techniques

Analytical estimation techniques derive the required results starting with basic assumptions regarding the project. Thus, unlike empirical and heuristic techniques, analytical techniques do have scientific basis. Halstead's software science is an example of an analytical technique. Halstead's software science can be used to derive some interesting results starting with a few simple assumptions. Halstead's software science is especially useful for estimating software maintenance efforts. In fact, it outperforms both empirical and heuristic techniques when used for predicting software maintenance efforts.

Halstead's Software Science – An Analytical Technique Halstead's software science is an analytical technique to measure size, development effort, and development cost of software products. Halstead used a few primitive program parameters to develop the expressions for overall program length, potential minimum value, actual volume, effort, and development time.

Software Maintenance and its need:

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.

Three different categories of software according to Boehm, COCOMO model:

Organic, Semidetached and Embedded software projects

Boehm postulated that any software development project can be classified into one of the following three categories based on the development complexity: organic, semidetached, and embedded. In order to classify a product into the identified categories, Boehm not only considered the characteristics of the product but also those of the development team and development environment. Roughly speaking, these three product classes correspond to application, utility and system programs, respectively. Normally, data processing programs are considered to be application programs. Compilers, linkers, etc., are utility programs. Operating systems and real-time system programs, etc. are system programs. System programs interact directly with the hardware and typically involve meeting timing constraints and concurrent processing.

Boehm's [1981] definition of organic, semidetached, and embedded systems are elaborated below.

Organic: A development project can be considered of organic type, if the project deals with developing a well understood application program, the size of the development team is reasonably small, and the team members are experienced in developing similar types of projects.

Semidetached: A development project can be considered of semidetached type, if the development consists of a mixture of experienced and inexperienced staff. Team members may have limited experience on related systems but may be unfamiliar with some aspects of the system being developed.

Embedded: A development project is considered to be of embedded type, if the software being developed is strongly coupled to complex hardware, or if the stringent regulations on the operational procedures exist.

COCOMO

COCOMO (Constructive Cost Estimation Model) was proposed by Boehm [1981]. According to Boehm, software cost estimation should be done through three stages: Basic COCOMO, Intermediate COCOMO, and Complete COCOMO.

Basic COCOMO Model

The basic COCOMO model gives an approximate estimate of the project parameters. The basic COCOMO estimation model is given by the following expressions:

$$\text{Effort} = a_1 \times (\text{KLOC})^{\frac{a}{2}} \text{ PM}$$

$$T_{\text{dev}} = b_1 \times (\text{Effort})^{\frac{b}{2}} \text{ Months}$$

Where

- KLOC is the estimated size of the software product expressed in Kilo Lines of Code,
- a_1, a_2, b_1, b_2 are constants for each category of software products,
- T_{dev} is the estimated time to develop the software, expressed in months,
- Effort is the total effort required to develop the software product, expressed in person months (PMs).

According to Boehm, every line of source text should be calculated as one LOC irrespective of the actual number of instructions on that line. Thus, if a single instruction spans several lines (say n lines), it is considered to be nLOC. The values of a_1, a_2, b_1, b_2 for different categories of products (i.e. organic, semidetached, and embedded) as given by Boehm [1981] are summarized below. He derived the above expressions by examining historical data collected from a large number of actual projects.

Estimation of development effort

For the three classes of software products, the formulas for estimating the effort based on the code size are shown below:

$$\text{Organic : Effort} = 2.4(\text{KLOC})^{1.05} \text{ PM}$$

$$\text{Semi-detached : Effort} = 3.0(\text{KLOC})^{1.12} \text{ PM}$$

$$\text{Embedded : Effort} = 3.6(\text{KLOC})^{1.20} \text{ PM}$$

Estimation of development time

For the three classes of software products, the formulas for estimating the development time based on the effort are given below:

$$\text{Organic : } T_{\text{dev}} = 2.5(\text{Effort})^{0.38} \text{ Months}$$

$$\text{Semi-detached : } T_{\text{dev}} = 2.5(\text{Effort})^{0.35} \text{ Months}$$

$$\text{Embedded : } T_{\text{dev}} = 2.5(\text{Effort})^{0.32} \text{ Months}$$

From the effort estimation, the project cost can be obtained by multiplying the required effort by the manpower cost per month. But, implicit in this project cost computation is the assumption that the entire project cost is incurred on account of the manpower cost alone. In addition to manpower cost, a project would incur costs due to hardware and software required for the project and the company overheads for administration, office space, etc.

It is important to note that the effort and the duration estimations obtained using the COCOMO model are called as nominal effort estimate and nominal duration estimate. The term nominal implies that if anyone tries to complete the project in a time shorter than the estimated duration, then the cost will increase drastically. But, if anyone completes the project over a longer period of time than the estimated, then there is almost no decrease in the estimated cost value.

Example:

Assume that the size of an org organic type software product has been estimated to be 32,000 lines of source code. Assume that the average salary of software engineers be Rs. 15,000/- per month. Determine the effort required to develop the software product and the nominal development time.

From the basic COCOMO estimation formula for organic software:

$$\text{Effort} = 2.4 \times (32)^{1.05} = 91 \text{ PM}$$
$$\text{Nominal development time} = 2.5 \times (91)^{0.38} = 14 \text{ months}$$

$$\begin{aligned}\text{Cost required to develop the product} &= 14 \times 15,000 \\ &= \text{Rs. } 210,000/-\end{aligned}$$

Intermediate COCOMO model and complete COCOMO model:

The basic COCOMO model assumes that effort and development time are functions of the product size alone. However, a host of other project parameters besides the product size affect the effort required to develop the product as well as the development time. Therefore, in order to obtain an accurate estimation of the effort and project duration, the effect of all relevant parameters must be taken into account. The intermediate COCOMO model recognizes this fact and refines the initial estimate obtained using the basic COCOMO expressions by using a set of 15 cost drivers (multipliers) based on various attributes of software development. For example, if modern programming practices are used, the initial estimates are scaled downward by multiplication with a cost driver having a value less than 1. If there are stringent reliability requirements on the software product, this initial estimate is scaled upward. Boehm requires the project manager to rate these 15 different parameters for a particular project on a scale of one to three. Then, depending on these ratings, he suggests appropriate cost driver values which should be multiplied with the initial estimate obtained using the basic COCOMO. In general, the cost drivers can be classified as being attributes of the following items:

Product: The characteristics of the product that are considered include the inherent complexity of the product, reliability requirements of the product, etc.

Computer: Characteristics of the computer that are considered include the execution speed required, storage space required etc.

Personnel: The attributes of development personnel that are considered include the experience level of personnel, programming capability, analysis capability, etc.

Development Environment: Development environment attributes capture the development facilities available to the developers. An important parameter that is considered is the sophistication of the automation (CASE) tools used for software development.

Complete COCOMO model

A major shortcoming of both the basic and intermediate COCOMO models is that they consider a software product as a single homogeneous entity. However, most large systems are made up several smaller sub-systems. These sub-systems may have widely different characteristics. For example, some sub-systems may be considered as organic type, some semidetached, and some embedded. Not only that the inherent development complexity of the subsystems may be different, but also for some subsystems the reliability requirements may be high, for some the development team might have no previous experience of similar development, and so on. The complete COCOMO model considers these differences in characteristics of the subsystems and estimates the effort and development time as the sum of the estimates for the individual subsystems. The cost of each subsystem is estimated separately. This approach reduces the margin of error in the final estimate.

The following development project can be considered as an example application of the complete COCOMO model. A distributed Management Information System (MIS) product for an organization having offices at several places across the country can have the following sub-components:

- Database part
- Graphical User Interface (GUI) part
- Communication part

Of these, the communication part can be considered as embedded software. The database part could be semi-detached software, and the GUI part organic software. The costs for these three components can be estimated separately, and summed up to give the overall cost of the system.

CASE, CASE tools, benefits of using such tools, architecture of modern CASE environment:

CASE tool and its scope

A CASE (Computer Aided Software Engineering) tool is a generic term used to denote any form of automated support for software engineering. In a more restrictive sense, a CASE tool means any tool used to automate some activity associated with software development. Many CASE tools are available. Some of these CASE tools assist in phase related tasks such as specification, structured analysis, design, coding, testing, etc.; and others to non-phase activities such as project management and configuration management.

Reasons for using CASE tools

The primary reasons for using a CASE tool are:

- To increase productivity
- To help produce better quality software at lower cost

CASE environment

Although individual CASE tools are useful, the true power of a tool set can be realized only when these set of tools are integrated into a common framework or environment. CASE tools are characterized by the stage or stages of software development life cycle on which they focus. Since different tools covering different stages share common information, it is required that they integrate through some central repository to have a consistent view of information associated with the software development artifacts. This central repository is usually a data dictionary containing the definition of all composite and elementary data items. Through the central repository all the CASE tools in a CASE environment share common information among themselves. Thus a CASE environment facilitates the automation of the step-by-step methodologies for software development. A schematic representation of a CASE environment is shown in fig.

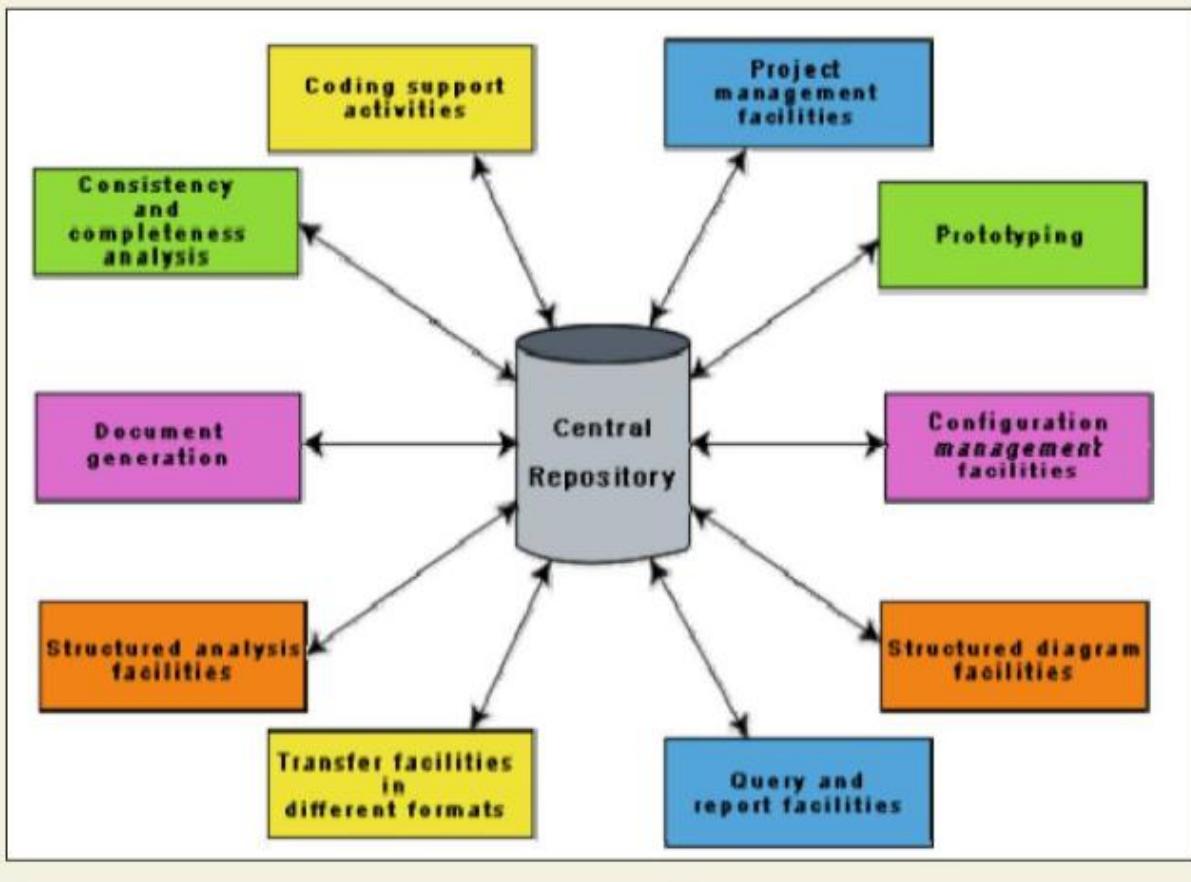


Fig. : A CASE Environment

CASE environment vs programming environment

A CASE environment facilitates the automation of the step-by-step methodologies for software development. In contrast to a CASE environment, a programming environment is an integrated collection of tools to support only the coding phase of software development.

Benefits of CASE

Several benefits accrue from the use of a CASE environment or even isolated CASE tools. Some of those benefits are:

- A key benefit arising out of the use of a CASE environment is cost saving through all development phases. Different studies carry out to measure the impact of CASE put the effort reduction between 30% to 40%.
- Use of CASE tools leads to considerable improvements to quality. This is mainly due to the facts that one can effortlessly iterate through the different phases of software development and the chances of human error are considerably reduced.

- CASE tools help produce high quality and consistent documents. Since the important data relating to a software product are maintained in a central repository, redundancy in the stored data is reduced and therefore chances of inconsistent documentation is reduced to a great extent.
- CASE tools take out most of the drudgery in a software engineer's work. For example, they need not check meticulously the balancing of the DFDs but can do it effortlessly through the press of a button.
- CASE tools have led to revolutionary cost saving in software maintenance efforts. This arises not only due to the tremendous value of a CASE environment in traceability and consistency checks, but also due to the systematic information capture during the various phases of software development as a result of adhering to a CASE environment.
- Introduction of a CASE environment has an impact on the style of working of a company, and makes it oriented towards the structured and orderly approach.

Architecture of a CASE environment

The architecture of a typical modern CASE environment is shown diagrammatically in fig. The important components of a modern CASE environment are user interface, tool set, object management system (OMS), and a repository. Characteristics of a tool set have been discussed earlier.

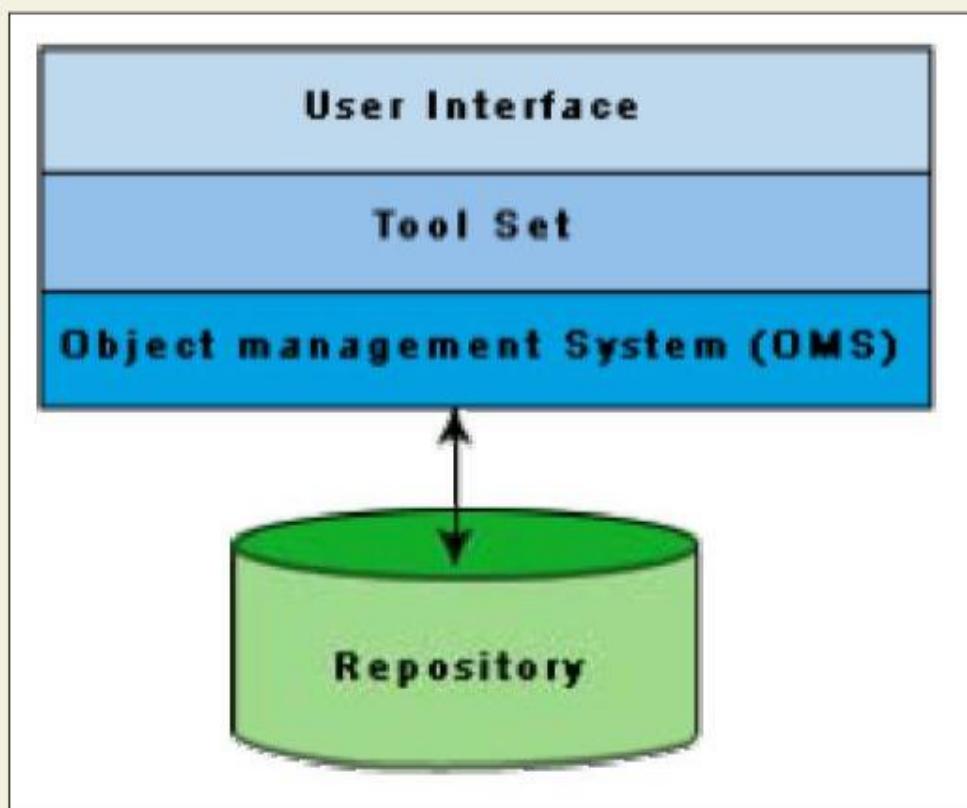


Fig.: Architecture of a Modern CASE Environment

User Interface

The user interface provides a consistent framework for accessing the different tools thus making it easier for the users to interact with the different tools and reducing the overhead of learning how the different tools are used.

Object Management System (OMS) and Repository

Different case tools represent the software product as a set of entities such as specification, design, text data, project plan, etc. The object management system maps these logical entities such into the underlying storage management system (repository). The commercial relational database management systems are geared towards supporting large volumes of information structured as simple relatively short records. There are a few types of entities but large number of instances. By contrast, CASE tools create a large number of entity and relation types with

perhaps a few instances of each. Thus the object management system takes care of appropriately mapping into the underlying storage management system.

Software reuse, basic issues starting any reuse program during software reuse:

Advantages of software reuse

Software products are expensive. Software project managers are worried about the high cost of software development and are desperately look for ways to cut development cost. A possible way to reduce development cost is to reuse parts from previously developed software. In addition to reduced development cost and time, reuse also leads to higher quality of the developed products since the reusable components are ensured to have high quality.

Artifacts that can be reused

It is important to know about the kinds of the artifacts associated with software development that can be reused. Almost all artifacts associated with software development, including project plan and test plan can be reused. However, the prominent items that can be effectively reused are:

- Requirements specification
- Design
- Code
- Test cases
- Knowledge

Pros and cons of knowledge reuse

Knowledge is the most abstract development artifact that can be reused. Out of all the reuse artifacts i.e. requirements specification, design, code, test cases, reuse of knowledge occurs automatically without any conscious effort in this direction. However, two major difficulties with unplanned reuse of knowledge are that a developer experienced in one type of software product might be included in a team developing a different type of software. Also, it is difficult to remember the details of the potentially reusable development knowledge. A planned reuse of knowledge can increase the effectiveness of reuse. For this, the reusable knowledge should be systematically extracted and documented. But, it is usually very difficult to extract and document reusable knowledge.

Easiness of reuse of mathematical functions

The routines of mathematical libraries are being reused very successfully by almost every programmer. No one in his right mind would think of writing a routine to compute sine or cosine. Reuse of commonly used mathematical functions is easy. Several interesting aspects emerge. Cosine means the same to all. Everyone has clear ideas about what kind of argument should cosine take, the type of processing to be carried out and the results returned. Secondly,

mathematical libraries have a small interface. For example, cosine requires only one parameter. Also, the data formats of the parameters are standardized.

Basic issues in any reuse program

The following are some of the basic issues that must be clearly understood for starting any reuse program.

- Component creation
- Component indexing and storing
- Component search
- Component understanding
- Component adaptation
- Repository maintenance

Component creation- For component creation, the reusable components have to be first identified. Selection of the right kind of components having potential for reuse is important. Domain analysis is a promising technique which can be used to create reusable components.

Component indexing and storing- Indexing requires classification of the reusable components so that they can be easily searched when looking for a component for reuse. The components need to be stored in a Relational Database Management System (RDBMS) or an Object-Oriented Database System (ODBMS) for efficient access when the number of components becomes large.

Component searching- The programmers need to search for right components matching their requirements in a database of components. To be able to search components efficiently, the programmers require a proper method to describe the components that they are looking for.

Component understanding- The programmers need a precise and sufficiently complete understanding of what the component does to be able to decide whether they can reuse the component. To facilitate understanding, the components should be well documented and should do something simple.

Component adaptation- Often, the components may need adaptation before they can be reused, since a selected component may not exactly fit the problem at hand. However, tinkering with the code is also not a satisfactory solution because this is very likely to be a source of bugs.

Repository maintenance- A component repository once is created requires continuous maintenance. New components, as and when created have to be entered into the repository. The faulty components have to be tracked. Further, when new applications emerge, the older applications become obsolete. In this case, the obsolete components might have to be removed from the repository.

Domain Analysis

The aim of domain analysis is to identify the reusable components for a problem domain.

Reuse domain- A reuse domain is a technically related set of application areas. A body of information is considered to be a problem domain for reuse, if a deep and comprehensive relationship exists among the information items as categorized by patterns of similarity among the development components of the software product. A reuse domain is shared understanding of some community, characterized by concepts, techniques, and terminologies that show some coherence. Examples of domains are accounting software domain, banking software domain, business software domain, manufacturing automation software domain, telecommunication software domain, etc.

Just to become familiar with the vocabulary of a domain requires months of interaction with the experts. Often, one needs to be familiar with a network of related domains for successfully carrying out domain analysis. Domain analysis identifies the objects, operations, and the relationships among them. For example, consider the airline reservation system, the reusable objects can be seats, flights, airports, crew, meal orders, etc. The reusable operations can be scheduling a flight, reserving a seat, assigning crew to flights, etc. The domain analysis generalizes the application domain. A domain model transcends specific applications. The common characteristics or the similarities between systems are generalized.

During domain analysis, a specific community of software developers gets together to discuss community-wide-solutions. Analysis of the application domain is required to identify the reusable components. The actual construction of reusable components for a domain is called domain engineering.

Evolution of a reuse domain- The ultimate result of domain analysis is development of problem-oriented languages. The problem-oriented languages are also known as application generators. These application generators, once developed form application development standards. The domains slowly develop. As a domain develops, it is distinguishable the various stages it undergoes:

Stage 1: There is no clear and consistent set of notations. Obviously, no reusable components are available. All software is written from scratch.

Stage 2: Here, only experience from similar projects is used in a development effort. This means that there is only knowledge reuse.

Stage 3: At this stage, the domain is ripe for reuse. The set of concepts are stabilized and the notations standardized. Standard solutions to standard problems are available. There is both knowledge and component reuse.

Stage 4: The domain has been fully explored. The software development for the domain can be largely automated. Programs are not written in the traditional sense any more. Programs are written using a domain specific language, which is also known as an application generator.