Software Engineering: *Software engineering* is defined as the systematic approach to the development, operation, maintenance, and retirement of software. Software engineering is the discipline that aims to provide methods and procedures for systematically developing industrial strength software. The main driving forces for software engineering are the problem of scale, quality and productivity (Q&P), consistency, and change. Achieving high Q&P consistently for problems whose scale may be large and where changes may happen continuously is the main challenge of software engineering.

Necessity of Software Engineering: Software engineering is an engineering approach for software development. 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 indispensable 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 as shown in fig. 1.3. For example, a program of size 1,000 Lines Of Code (LO C) has some complexity. But a program with 10,000 LOC is not just 10 times more difficult to develop, but may as well turn out to be 100 times more difficult unless software engineering principles are used. In such situations software engineering techniques come to rescue. Software engineering helps to reduce the programming complexity. Software engineering principles use two important techniques to reduce problem complexity: abstraction and decomposition.

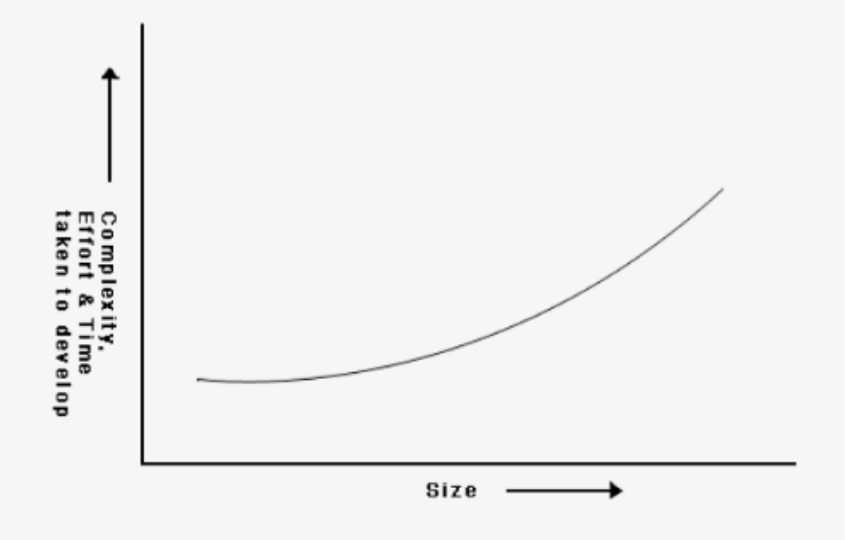


Fig. 1.3: Increase in development time and effort with problem size

Causes and solutions for software crisis: To explain the present software crisis in simple words, consider the following.

The expenses that organizations all around the world are incurring on software purchases compared to those on hardware purchases have been showing a worrying trend over the years (as shown in fig. 1.6).

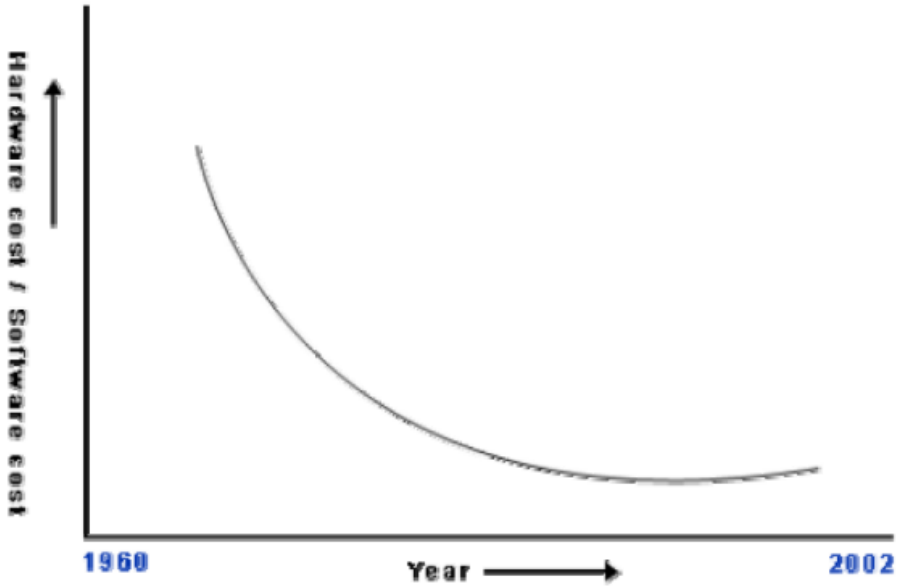


Fig. 1.6: Change in the relative cost of hardware and software over time

Organizations are spending larger and larger portions of their budget on software. Not only are the software products turning out to be more expensive than hardware, but they also present a host of other problems to the customers: software products are difficult to alter, debug, and enhance; use resources nonoptimally; often fail to meet the user requirements; are far from being reliable; frequently crash; and are often delivered late. Among these, the trend of increasing software costs is probably the most important symptom of the present software crisis.

There are many factors that have contributed to the making of the present software crisis. Factors are larger problem sizes, lack of adequate training in software engineering, increasing skill shortage, and low productivity improvements.

It is believed that the only satisfactory solution to the present software crisis can possibly come from a spread of software engineering practices among the engineers, coupled with further advancements to the software engineering discipline itself.

Differences between Program & software product: Programs are developed by individuals for their personal use. They are therefore, small in size and have limited functionality but software products are extremely large. In case of a program, the programmer himself is the sole user but on the other hand, in case of a software product, most users are not involved with the development. In case of a program, a single developer is involved but in case of a software product, a large number of developers are involved. For a program, the user interface may not be very important, because the programmer is the sole user. On the other hand, for a software product, user interface must be carefully designed and implemented because developers of that product and users of that product are totally different. In case of a program, very little documentation is expected, but a software product must be well documented. A program can be developed according to the programmer's individual style of development, but a software product must be developed using the accepted software engineering principles.

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.

Need of 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 it becomes difficult for software project managers to monitor the progress of the project.

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:

- Feasibility Study
- Requirements Analysis and Specification
- Design
- Coding and Unit Testing
- Integration and System Testing
- Maintenance

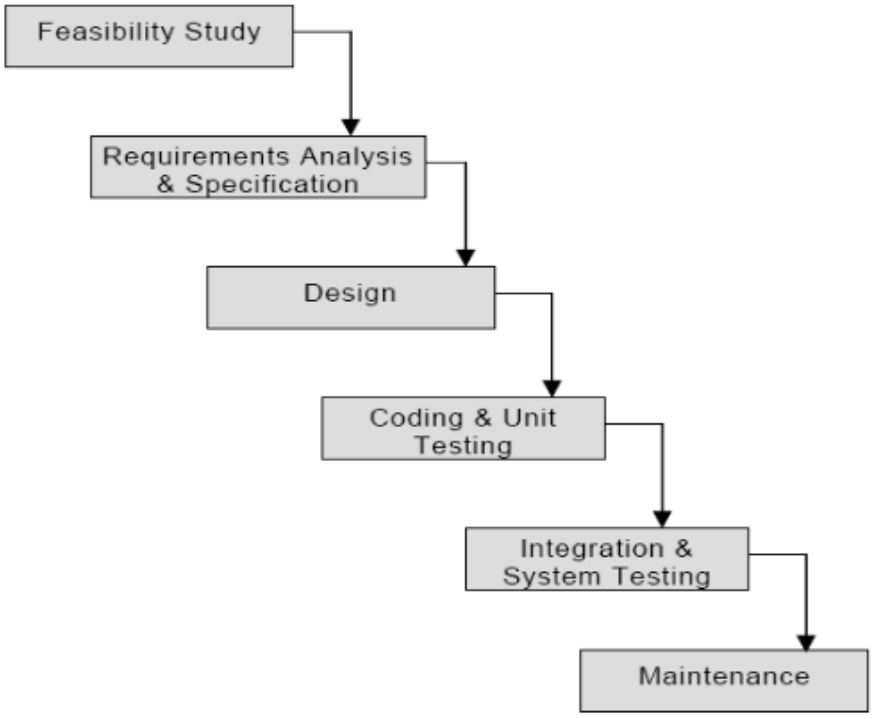


Fig 2.1: Classical Waterfall Model

1. **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.

2. **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, and
   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. 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 Requirements specification, 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.

3. **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.

4. **Coding and Unit Testing:** The purpose of the coding and unit testing 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.

5. **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.

6. **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 ratio. 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.

Limitations of Water fall Model: The waterfall model, although widely used, has some strong limitations. Some of the key limitations are:

1. It assumes that the requirements of a system can be frozen before the design begins. This is possible for systems designed to automate an existing manual system. But for new systems, determining the requirements is difficult as the user does not even know the requirements. Hence, having unchanging requirements is unrealistic for such projects.
2. Freezing the requirements usually requires choosing the hardware (because it forms a part of the requirements specification). A large project might take a few years to complete. If the hardware is selected early, then due to the speed at which hardware technology is changing, it is likely that the final software will use a hardware technology that becomes obsolete. This is clearly not desirable for such expensive software systems.
3. It follows the "big bang" approach—the entire software is delivered in one shot at the end. This entails heavy risks, as the user does not know until the very end what they are getting. Furthermore, if the project runs out of money in the middle, then there will be no software. That is, it has the "all or nothing" value proposition.
4. It is a document-driven process that requires formal documents at the end of each phase.

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.

Need for a Prototype: 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.

Prototyping Model: The goal of a prototyping-based development process is to counter the limitations of the waterfall model. The basic idea here is that instead of freezing the requirements before any design or coding can proceed, a throwaway prototype is built to help understand the requirements. This prototype is developed based on the currently known requirements. Development of the prototype obviously undergoes design, coding, and testing, but each of these phases is not done very formally or thoroughly. By using this prototype, the client can get an actual feel of the system; because the interactions with the prototype can enable the client to, better understand the requirements of the desired system. This results in more stable requirements that change less frequently.

Prototyping is an attractive idea for complicated and large systems for which there is no manual process or existing system to help determine the requirements. In such situations, letting the client "play" with the prototype provides invaluable and intangible inputs that help determine the requirements for the system. It is also an effective method of demonstrating the feasibility of a certain approach. The process model of the prototyping approach is shown in Figure 2.6.

A development process using throwaway prototyping typically proceeds as follows. The development of the prototype typically starts when the preliminary version of the requirements specification document has been developed. At this stage, there is a reasonable understanding of the system and its needs and which needs are unclear or likely to change. After the prototype has been developed, the end users and clients are given an opportunity to use the prototype and play with it. Based on their experience, they provide feedback to the developers regarding the prototype: what is correct, what needs to be modified, what is missing, what is not needed, etc. Based on the feedback, the prototype is modified to incorporate the suggested changes and then the users and the clients are again allowed to use the system.

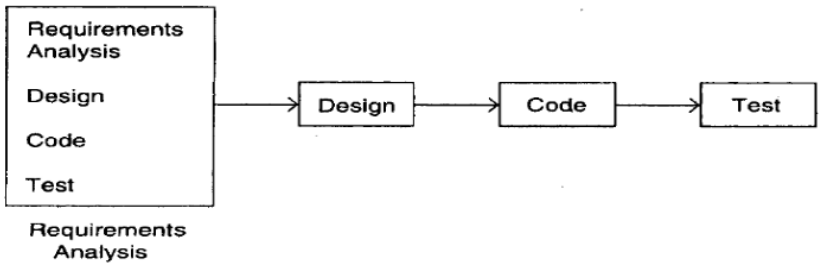


Figure 2.6: The prototyping model.

Prototyping is often not used, as it is feared that development costs may become large. However, in some situations, the cost of software development without prototyping may be more than with prototyping. There are two major reasons for this. First, the experience of developing the prototype might reduce the cost of the later phases when the actual software development is done. Secondly, in many projects the requirements are constantly changing, particularly when development takes a long time. In addition, because the client and users get experience with the system, it is more likely that the requirements specified after the prototype will be closer to the actual requirements. This again will lead to fewer changes in the requirements at a later time. Hence, the costs incurred due to changes in the requirements may be substantially reduced by prototyping. Hence, the cost of the development after the prototype can be substantially less than the cost without prototyping.

Prototyping is well suited for projects where requirements are hard to determine and the confidence in the stated requirements is low. In such projects, a waterfall model will have to freeze the requirements in order for the development to continue, even when the requirements are not stable.

Spiral Model: The spiral model is one type of iterative model. As the name suggests, the activities in this model can be organized like a spiral that has many cycles as shown in Figure 2.8. Each cycle in the spiral begins with the identification of objectives for that cycle, the different alternatives that are possible for achieving the objectives, and the constraints that exist. The next step in the cycle is to evaluate these different alternatives based on the objectives and constraints. The focus of evaluation in this step is based on the risk perception for the project. The next step is to develop strategies that resolve the uncertainties and risks. This step may involve activities such as benchmarking, simulation, and prototyping. Next, the software is developed, keeping in mind the risks. Finally the next stage is planned.

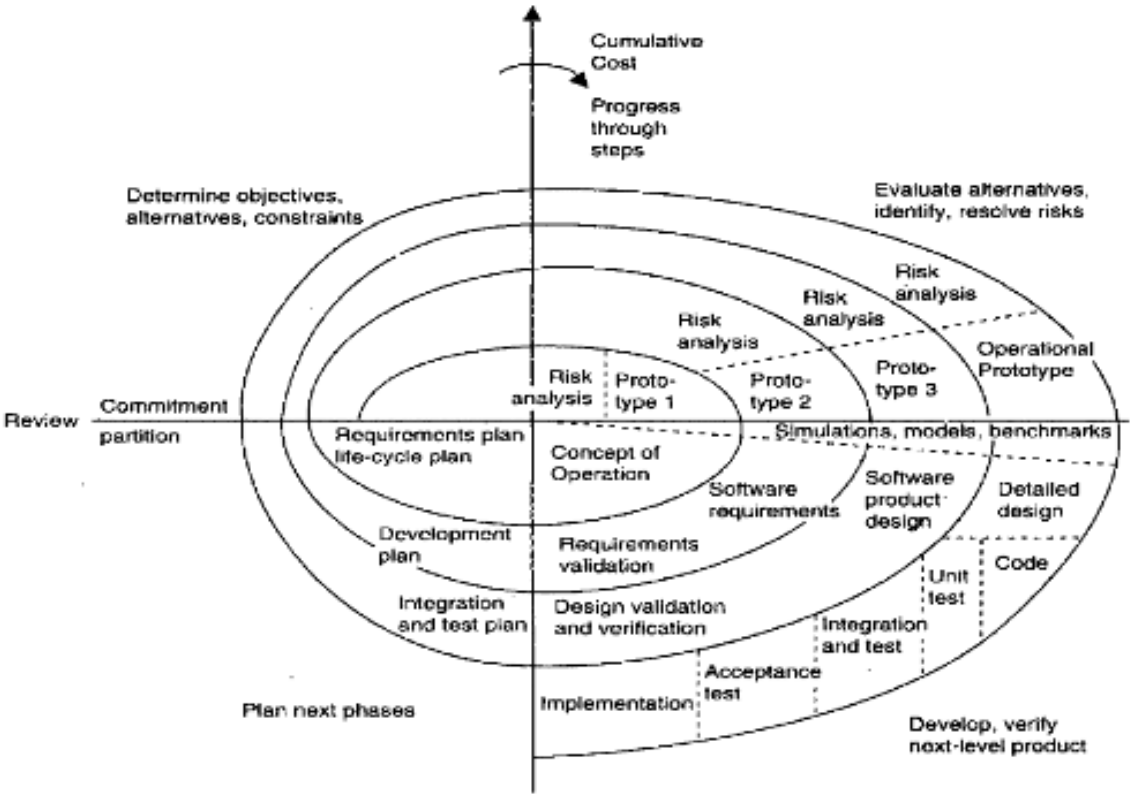


Figure 2.8: The spiral model.

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.

Advantages: 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.

Disadvantages: However, this model is much more complex than the other models – this is probably a factor deterring its use in ordinary projects.

V model: The software development process model shown in Figure 2.9 is sometimes called the V-model. It is an instantiation of the generic waterfall model and shows that test plans should be derived from the system specification and design. This model also breaks down Verification & Validation (V & V) system into a number of stages. Each stage is driven by tests that have been defined to check the conformance of the program with its design and specification. As part of the V & V planning process, one should decide on the balance between static and dynamic approaches to verification and validation, draw up standards and procedures for software inspections and testing, establish checklists to drive program inspections and define the software test plan. The relative effort devoted to inspections and testing depends on the type of system being developed and the organizational expertise with program inspection.

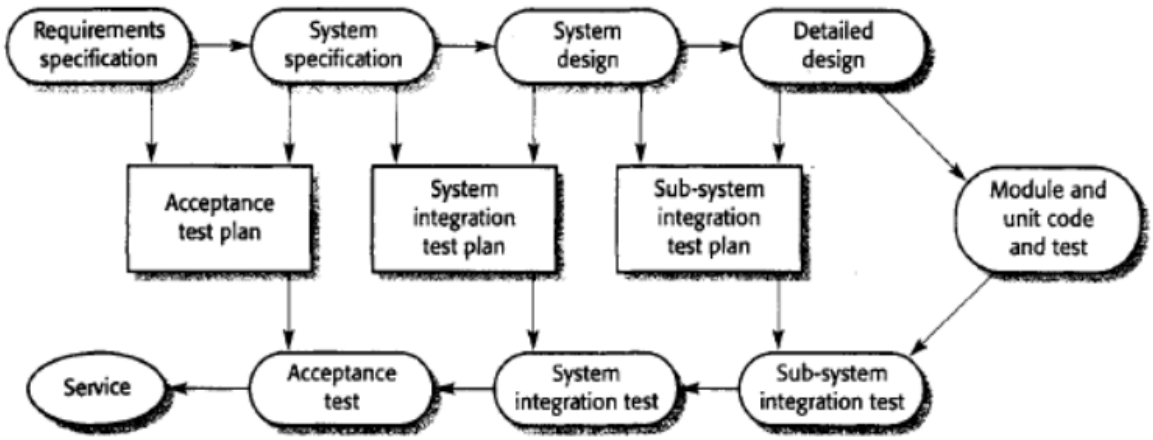


Figure 2.9: V model

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

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

The prototyping model is suitable for projects for which either the user requirements or the underlying technical aspects are not well understood. This model is especially popular for development of the user-interface part of the projects.

The evolutionary approach is suitable for large problems which can be decomposed into a set of modules for incremental development and delivery. This model is also widely used for object-oriented

development projects. Of course, this model can only be used if the incremental delivery of the system is acceptable to the customer.

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

Software Requirement: A condition of capability needed by a user to solve a problem or achieve an objective; or a condition or a capability that must be met or possessed by a system to satisfy a contract, standard, specification, or other formally imposed document. Note that in software requirements we are dealing with the requirements of the proposed system, that is, the capabilities that the system, which is yet to be developed, should have. It is because we are dealing with specifying a system that does not exist that the problem of requirements becomes complicated. The goal of the requirements activity is to produce the Software Requirements Specification (SRS) that describes *what* the proposed software should do without describing *how* the software will do it.

Need for SRS: The origin of most software systems is in the needs of some clients. The software system itself is created by some developers. Finally, the completed system will be used by the end users. Thus, there are three major parties interested in a new system: the client, the developer, and the users. Somehow the requirements for the system that will satisfy the needs of the clients and the concerns of the users have to be communicated to the developer.

The problem is that the client usually does not understand software or the software development process, and the developer often does not understand the client's problem and application area. This causes a communication gap between the parties involved in the development project. A basic purpose of software requirements specification is to bridge this communication gap. SRS is the medium through which the client and user needs are accurately specified to the developer. Hence one of the main advantages is:

- An SRS establishes the basis for agreement between the client and the supplier on what the software product will do. This basis for agreement is frequently formalized into a legal contract between the client (or the customer) and the developer (the supplier). So, through SRS, the client clearly describes what it expects from the supplier, and the developer clearly understands what capabilities to build in the software.

Another need of SRS is:

- A high-quality SRS is a prerequisite to high-quality software. It is clear that many errors are made during the requirements phase. And an error in the SRS will most likely manifest itself as an error in the final system implementing the SRS; after all, if the SRS document specifies a wrong system (i.e., one that will not satisfy the client's objectives), then even a correct implementation of the SRS will lead to a system that will not satisfy the client. Clearly, if we want a high-quality end product that has few errors, we must begin with a high-quality SRS.

Characteristics of an SRS: To properly satisfy the basic goals, an SRS should have certain properties and should contain different types of requirements. A good SRS is

1. Correct: An SRS is *correct* if every requirement included in the SRS represents something required in the final system.

2. Complete: An SRS is *complete* if everything the software is supposed to do and the responses of the software to all classes of input data are specified in the SRS

3. Unambiguous: An SRS is *unambiguous* if and only if every requirement stated has one and only one interpretation.

4. Verifiable: An SRS is *verifiable* if and only if every stated requirement is verifiable. A requirement is verifiable if there exists some cost-effective process that can check whether the final software meets that requirement

5. Consistent: An SRS is *consistent* if there is no requirement that conflicts with another. For example, suppose a requirement states that an event *e* is to occur before another event *f* . But then another set of requirements states (directly or indirectly by transitivity) that event *f* should occur before event *e*.

6. Ranked for importance and/or stability: Generally, all the requirements for software are not of equal importance. Some are critical, others are important but not critical, and there are some which are

desirable but not very important. An SRS is ranked for importance and/or stability if for each requirement the importance and the stability of the requirement are indicated.

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

8. Traceable: An SRS is traceable if the origin of each of its requirements is clear and if it facilitates the referencing of each requirement in future development

Components of an SRS: 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 highlevel functions {*fi*}. The functional view of the system is shown in fig. 3.1. Each function fi of the system can be considered as a transformation of a set of input data (i_i) to the corresponding set of output data (*oi*). The user can get some meaningful piece of work done using a high-level function.

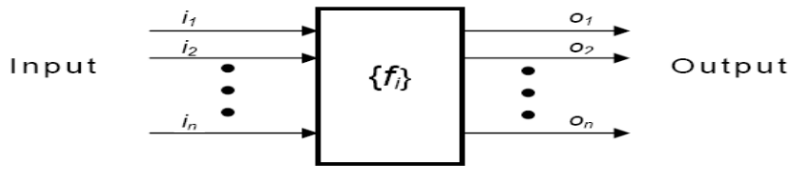


Fig. 3.1: View of a system performing a set of functions

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. Nonfunctional requirements may include:

- ✔ reliability issues,
- ✔ accuracy of results,
- ✔ human - computer interface issues,
- ✔ Constraints on the system implementation, 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.

Software Design: Software design deals with transforming the customer requirements, as described in the SRS document, into a form (a set of documents) that is suitable for implementation in a programming language. A good software design is seldom arrived by using a single step procedure but rather through several iterations through a series of steps. Design activities can be broadly classified into two important parts:

• *Preliminary (or high-level) design*: High-level design means identification of different modules and the control relationships among them and the definition of the interfaces among these modules. The outcome of high-level design is called the program structure or software architecture. Many different types of notations have been used to represent a high-level design. A popular way is to use a tree-like diagram called the structure chart to represent the control hierarchy in a high-level design.

• *Detailed design*: During detailed design, the data structure and the algorithms of the different modules are designed. The outcome of the detailed design stage is usually known as the module-specification document.

Characteristics of good Software Design: The definition of "a good software design" can vary depending on the application being designed. For example, the memory size used by a program may be an important issue to characterize a good solution for embedded software development – since embedded applications are

often required to be implemented using memory of limited size due to cost, space, or power consumption considerations. Therefore, the criteria used to judge how good a given design solution is can vary widely depending upon the application. Not only is the goodness of design dependent on the targeted application, but also the notion of goodness of a design itself varies widely across software engineers and academicians. However, most researchers and software engineers agree on a few desirable characteristics that every good software design for general application must possess. The characteristics are listed below:

*Correctness***:** A good design should correctly implement all the functionalities identified in the SRS document.

*Understandability***:** A good design is easily understandable.

*Efficiency***:** It should be efficient.

*Maintainability***:** It should be easily amenable to change.

Possibly the most important goodness criterion is design correctness. A design has to be correct to be acceptable. Given that a design solution is correct, understandability of a design is possibly the most important issue to be considered while judging the goodness of a design. A design that is easy to understand is also easy to develop, maintain and change. Thus, unless a design is easily understandable, it would require tremendous effort to implement and maintain it.

Cohesion: Most researchers and engineers agree that a good software design implies clean decomposition of the problem into modules, and the neat arrangement of these modules in a hierarchy. The primary characteristics of neat module decomposition are high cohesion and low coupling. Cohesion is a measure of functional strength of a module. A module having high cohesion and low coupling is said to be functionally independent of other modules. By the term functional independence, we mean that a cohesive module performs a single task or function. A functionally independent module has minimal interaction with other modules.

Classification of cohesion: The different classes of cohesion that a module may possess are depicted in fig. 4.1.

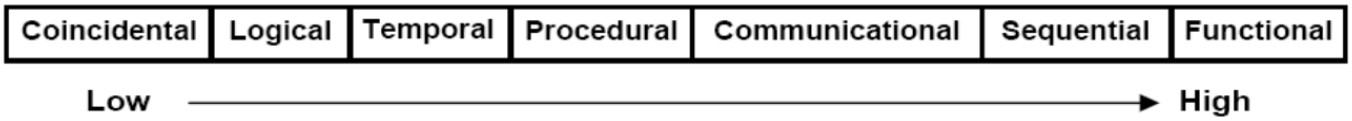


Fig. 4.1: Classification of cohesion

Coincidental cohesion: A module is said to have coincidental cohesion, if it performs a set of tasks that relate to each other very loosely, if at all. In this case, the module contains a random collection of functions. For example, in a transaction processing system (TPS), the get-input, print-error, and summarize-members functions are grouped into one module. The grouping does not have any relevance to the structure of the problem.

*Logical cohesion***:** A module is said to be logically cohesive, if all elements of the module perform similar operations, e.g. error handling, data input, data output, etc. An example of logical cohesion is the case where a set of print functions generating different output reports are arranged into a single module.

*Temporal cohesion***:** When a module contains functions that are related by the fact that all the functions must be executed in the same time span, the module is said to exhibit temporal cohesion. The set of functions responsible for initialization, start-up, shutdown of some process, exhibit temporal cohesion.

Procedural cohesion: A module is said to possess procedural cohesion, if the set of functions of the module are all part of a procedure (algorithm) in which certain sequence of steps have to be carried out for achieving an objective, e.g. the algorithm for decoding a message.

*Communicational cohesion***:** A module is said to have communicational cohesion, if all functions of the module refer to or update the same data structure, e.g. the set of functions defined on an array or a stack.

*Sequential cohesion***:** A module is said to possess sequential cohesion, if the elements of a module form the parts of sequence, where the output from one element of the sequence is input to the next. For example, in a TPS, the get-input, validate-input, sort-input functions are grouped into one module.

*Functional cohesion***:** Functional cohesion is said to exist, if different elements of a module cooperate to achieve a single function. For example, a module containing all the functions required to manage employees' pay-roll exhibits functional cohesion.

Coupling: Coupling between two modules is a measure of the degree of interdependence or interaction between the two modules. A module having high cohesion and low coupling is said to be functionally independent of other modules. If two modules interchange large amounts of data, then they are highly interdependent. The degree of coupling between two modules depends on their interface complexity. The interface complexity is basically determined by the number of types of parameters that are interchanged while invoking the functions of the module.

Classification of Coupling: Even if there are no techniques to precisely and quantitatively estimate the coupling between two modules, classification of the different types of coupling will help to quantitatively estimate the degree of coupling between two modules. Five types of coupling can occur between any two modules. This is shown in fig. 4.2

Fig. 4.2: Classification of coupling

*Data coupling***:** Two modules are data coupled, if they communicate through a parameter. An example is an elementary data item passed as a parameter between two modules, e.g. an integer, a float, a character, etc. This data item should be problem related and not used for the control purpose.
*Stamp coupling***:** Two modules are stamp coupled, if they communicate using a composite data item such as a record in PASCAL or a structure in C.
*Control coupling***:** Control coupling exists between two modules, if data from one module is used to direct the order of instructions execution in another. An example of control coupling is a flag set in one module and tested in another module.
*Common coupling***:** Two modules are common coupled, if they share data through some global data items.
*Content coupling***:** Content coupling exists between two modules, if they share code, e.g. a branch from one module into another module.

Functional independence: A module having high cohesion and low coupling is said to be functionally independent of other modules. By the term functional independence, we mean that a cohesive module performs a single task or function. A functionally independent module has minimal interaction with other modules.

Need for functional independence: Functional independence is a key to any good design due to the following reasons:
• *Error isolation***:** Functional independence reduces error propagation. The reason behind this is that if a module is functionally independent, its degree of interaction with the other modules is less. Therefore, any error existing in a module would not directly affect the other modules.
• *Scope of reuse:* Reuse of a module becomes possible. Because each module does some well-defined and precise function, and the interaction of the module with the other modules is simple and minimal. Therefore, a cohesive module can be easily taken out and reused in a different program.
• *Understandability***:** Complexity of the design is reduced, because different modules can be understood in isolation as modules are more or less independent of each other.

Function-oriented design: The following are the salient features of a typical function-oriented design approach:

1. A system is viewed as something that performs a set of functions. Starting at this high-level view of the system, each function is successively refined into more detailed functions. For example, consider a function create-newlibrary-member which essentially creates the record for a new member, assigns a unique membership number to him, and prints a bill towards his membership charge. This function may consist of the following subfunctions:

• assign-membership-number

• create-member-record
• print-bill

Each of these sub-functions may be split into more detailed subfunctions and so on.

2. The system state is centralized and shared among different functions, e.g. data such as member-records is available for reference and updation to several functions such as:

• create-new-member
• delete-member
• update-member-record

Object-oriented design: In the object-oriented design approach, the system is viewed as collection of objects (i.e. entities). The state is decentralized among the objects and each object manages its own state information. For example, in a Library Automation Software, each library member may be a separate object with its own data and functions to operate on these data. In fact, the functions defined for one object cannot refer or change data of other objects. Objects have their own internal data which define their state. Similar objects constitute a class. In other words, each object is a member of some class. Classes may inherit features from super class. Conceptually, objects communicate by message passing.

Function-oriented vs. Object-oriented design approach: The following are some of the important differences between function-oriented and object-oriented design.

• Unlike function-oriented design methods, in OOD, the basic abstraction are not real-world functions such as sort, display, track, etc, but real-world entities such as employee, picture, machine, radar system, etc. For example in OOD, an employee pay-roll software is not developed by designing functions such as update-employee-record, get-employee-address, etc. but by designing objects such as employees, departments, etc.

• In OOD, state information is not represented in a centralized shared memory but is distributed among the objects of the system. For example, while developing an employee pay-roll system, the employee data such as the names of the employees, their code numbers, basic salaries, etc. are usually implemented as global data in a traditional programming system; whereas in an object-oriented system these data are distributed among different employee objects of the system. Objects communicate by message passing. Therefore, one object may discover the state information of another object by interrogating it.

• Function-oriented techniques group functions together if, as a group, they constitute a higher-level function. On the other hand, object-oriented techniques group functions together on the basis of the data they operate on.

Data Flow Diagram (DFD): The DFD (also known as a bubble chart) is a hierarchical graphical model of a system that shows the different processing activities or functions that the system performs and the data interchange among these functions. Each function is considered as a processing station (or process) that consumes some input data and produces some output data. The system is represented in terms of the input data to the system, various processing carried out on these data, and the output data generated by the system. A DFD model uses a very limited number of primitive symbols [as shown in fig. 5.1(a)] to represent the functions performed by a system and the data flow among these functions.

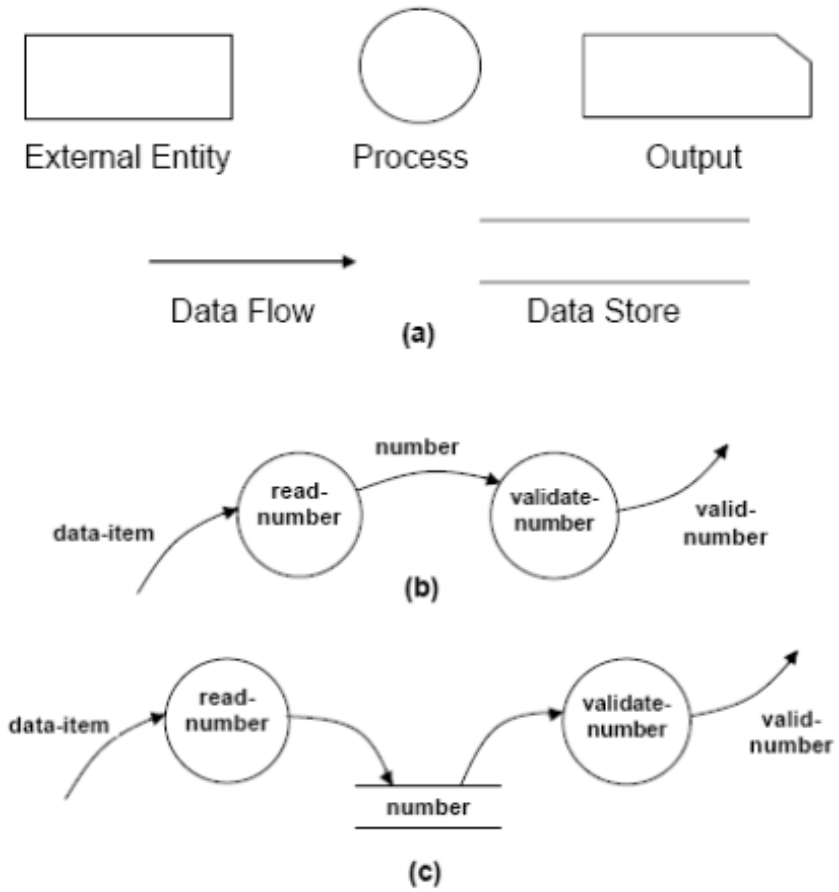


Fig. 5.1 (a) Symbols used for designing DFDs
(b), (c) Synchronous and asynchronous data flow

Here, two examples of data flow that describe input and validation of data are considered. In Fig. 5.1(b), the two processes are directly connected by a data flow. This means that the 'validate-number' process can start only after the 'readnumber' process had supplied data to it. However in Fig 5.1(c), the two processes are connected through a data store. Hence, the operations of the two bubbles are independent. The first one is termed 'synchronous' and the second one 'asynchronous'.

Advantages of DFD: 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.

Disadvantages of DFD: DFD models suffer from several shortcomings. The important shortcomings of the DFD models are the following:

- DFDs leave ample scope to be imprecise. In the DFD model, the function performed by a bubble is judged from its label. However, a short label may not capture the entire functionality of a bubble. For example, a bubble named find-book-position has only intuitive meaning and does not specify several things, e.g. what happens when some input information are missing or are incorrect. Further, the find-bookposition bubble may not convey anything regarding what happens when the required book is missing.
- Control aspects are not defined by a DFD. For instance, the order in which inputs are consumed and outputs are produced by a bubble is not specified. A DFD model does not specify the order in which

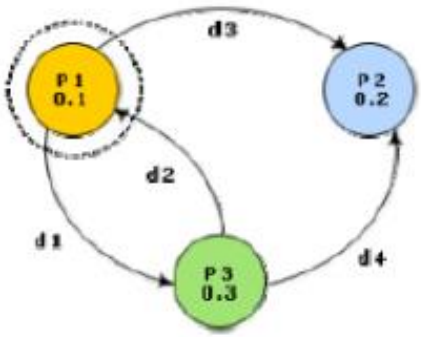
the different bubbles are executed. Representation of such aspects is very important for modeling real-time systems.

• The method of carrying out decomposition to arrive at the successive levels and the ultimate level to which decomposition is carried out are highly subjective and depend on the choice and judgment of the analyst. Due to this reason, even for the same problem, several alternative DFD representations are possible. Further, many times it is not possible to say which DFD representation is superior or preferable to another one.

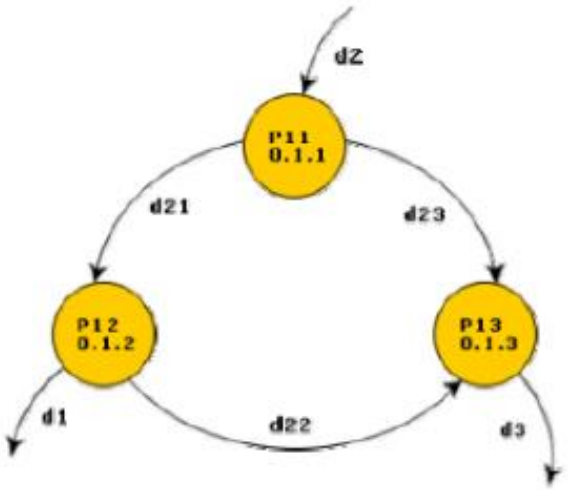
• The data flow diagramming technique does not provide any specific guidance as to how exactly to decompose a given function into its subfunctions and we have to use subjective judgment to carry out decomposition.

DFD Vs. Flow Chart: A DFD represents the flow of data, while a flowchart shows the flow of control. A DFD does not represent procedural information. So, while drawing a DFD, one *must not* get involved in procedural details, and procedural thinking must be consciously avoided. For example, considerations of loops and decisions must be ignored. In drawing the DFD, the designer has to specify the major transforms in the path of the data flowing from the input to output. *How* those transforms are performed is *not* an issue while drawing the data flow graph.

Balancing a DFD: The data that flow into or out of a bubble must match the data flow at the next level of DFD. This is known as balancing a DFD. The concept of balancing a DFD has been illustrated in fig. 5.3. In the level 1 of the DFD, data items d1 and d3 flow out of the bubble 0.1 and the data item d2 flows into the bubble 0.1. In the next level, bubble 0.1 is decomposed. The decomposition is balanced, as d1 and d3 flow out of the level 2 diagram and d2 flows in.



(a) Level 1 DFD



(b) Level 2 DFD

Fig. 5.3: An example showing balanced decomposition

Data dictionary: A data dictionary lists all data items appearing in the DFD model of a system. The data items listed include all data flows and the contents of all data stores appearing on the DFDs in the DFD model of a system. A data dictionary lists the purpose of all data items and the definition of all composite data items in terms of their component data items. For example, a data dictionary entry may represent that the data **grossPay** consists of the components regularPay and overtimePay.

grossPay = regularPay + overtimePay

For the smallest units of data items, the data dictionary lists their name and their type. Composite data items can be defined in terms of primitive data items using the following data definition operators:

+: denotes composition of two data items, e.g. **a+b** represents data a and **b**.
[, ,]: represents selection, i.e. any one of the data items listed in the brackets can occur. For example, **[a,b]** represents either **a** occurs or **b** occurs.
( ): the contents inside the bracket represent optional data which may or may not appear. e.g. **a+(b)** represents either **a** occurs or **a+b** occurs.
{ }: represents iterative data definition, e.g. **{name}**^{5} represents five **name** data. **{name}*** represents zero or more instances of **name** data.
=: represents equivalence, e.g. **a=b+c** means that **a** represents **b** and **c**.
/* */: Anything appearing within **/*** and ***/** is considered as a comment.

Importance of data dictionary: A data dictionary plays a very important role in any software development process because of the following reasons:

• A data dictionary provides a standard terminology for all relevant data for use by the engineers working in a project. A consistent vocabulary for data items is very important, since in large projects different engineers of the project have a tendency to use different terms to refer to the same data, which unnecessary causes confusion.
• The data dictionary provides the analyst with a means to determine the definition of different data structures in terms of their component elements.

How to Develop DFD model of a system: A DFD model of a system graphically depicts the transformation of the data input to the system to the final result through a hierarchy of levels. A DFD starts with the most abstract definition of the system (lowest level) and at each higher level DFD, more details are successively introduced. To develop a higher-level DFD model, processes are decomposed into their sub-processes and the data flow among these sub-processes is identified.

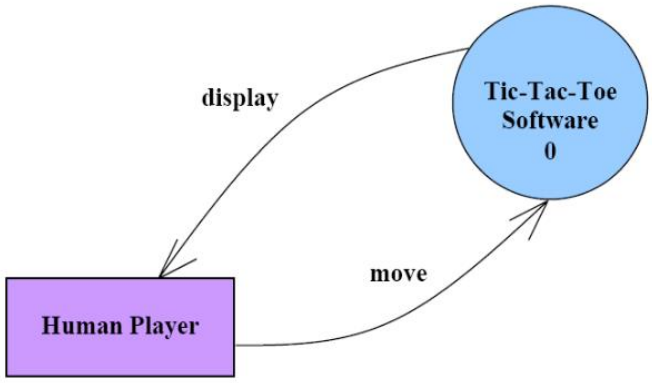
To develop the data flow model of a system, first the most abstract representation of the problem is to be worked out. The most abstract representation of the problem is also called the context diagram. After, developing the context diagram, the higher-level DFDs have to be developed.

Context Diagram: The context diagram is the most abstract data flow representation of a system. It represents the entire system as a single bubble. This bubble is labeled according to the main function of the system. The various external entities with which the system interacts and the data flow occurring between the system and the external entities are also represented. The data input to the system and the data output from the system are represented as incoming and outgoing arrows. These data flow arrows should be annotated with the corresponding data names. The name 'context diagram' is well justified because it represents the context in which the system is to exist, i.e. the external entities who would interact with the system and the specific data items they would be supplying the system and the data items they would be receiving from the system. The context diagram is also called as the level 0 DFD.

To develop the context diagram of the system, it is required to analyze the SRS document to identify the different types of users who would be using the system and the kinds of data they would be inputting to the system and the data they would be receiving the system.

The bubble in the context diagram is annotated with the name of the software system being developed (usually a noun). This is in contrast with the bubbles in all other levels which are annotated with verbs. This is expected since the purpose of the context diagram is to capture the context of the system rather than its functionality.

*Example***:** Tic-Tac-Toe Computer Game
Tic-tac-toe is a computer game in which a human player and the computer make alternative moves on a 3×3 square. A move consists of marking previously unmarked square. The player who first places three consecutive marks along a straight line on the square (i.e. along a row, column, or diagonal) wins the game. As soon as either the human player or the computer wins, a message congratulating the winner should be displayed. If neither player manages to get three consecutive marks along a straight line, but all the squares on the board are filled up, then the game is drawn. The computer always tries to win a game.



Context diagram of Tic-Tac-Toe

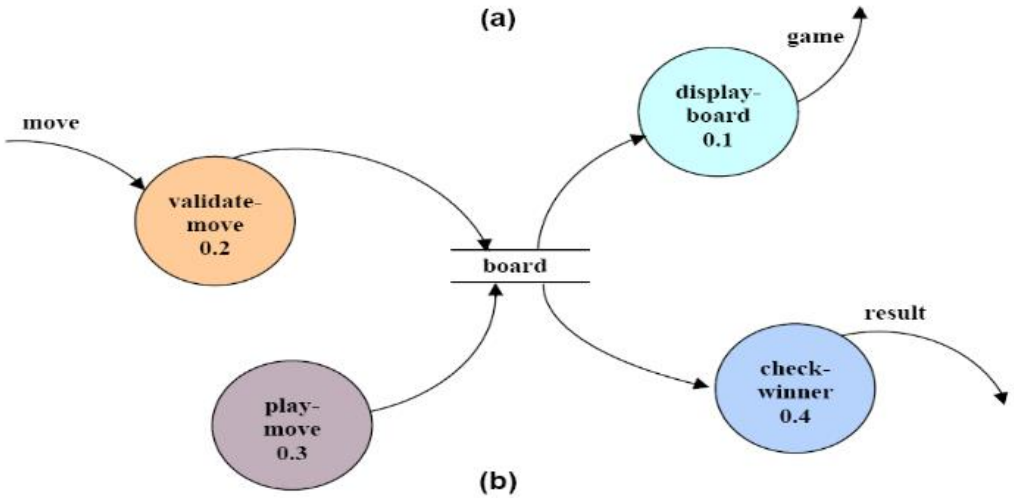
Level 1 DFD: To develop the level 1 DFD, examine the high-level functional requirements. If there are between 3 to 7 high-level functional requirements, then these can be directly represented as bubbles

in the level 1 DFD. We can then examine the input data to these functions and the data output by these functions and represent them appropriately in the diagram.

If a system has more than 7 high-level functional requirements, then some of the related requirements have to be combined and represented in the form of a bubble in the level 1 DFD. Such a bubble can be split in the lower DFD levels. If a system has less than three high-level functional requirements, then some of them need to be split into their sub-functions so that we have roughly about 5 to 7 bubbles on the diagram.

Decomposition: Each bubble in the DFD represents a function performed by the system. The bubbles are decomposed into sub-functions at the successive levels of the DFD. Decomposition of a bubble is also known as factoring or exploding a bubble. Each bubble at any level of DFD is usually decomposed to anything between 3 to 7 bubbles. Too few bubbles at any level make that level superfluous. For example, if a bubble is decomposed to just one bubble or two bubbles, then this decomposition becomes redundant. Also, too many bubbles, i.e. more than 7 bubbles at any level of a DFD makes the DFD model hard to understand. Decomposition of a bubble should be carried on until a level is reached at which the function of the bubble can be described using a simple algorithm.

Numbering of Bubbles: It is necessary to number the different bubbles occurring in the DFD. These numbers help in uniquely identifying any bubble in the DFD by its bubble number. The bubble at the context level is usually assigned the number 0 to indicate that it is the 0 level DFD. Bubbles at level 1 are numbered, 0.1, 0.2, 0.3, etc, etc. When a bubble numbered x is decomposed, its children bubble are numbered x.1, x.2, x.3, etc. In this numbering scheme, by looking at the number of a bubble we can unambiguously determine its level, its ancestors, and its successors.



Level 1 DFD of Tic-Tac-Toe

Data dictionary for a DFD: Every DFD model of a system must be accompanied by a data dictionary. A data dictionary lists all data items appearing in the DFD model of a system. The data items listed include all data flows and the contents of all data stores appearing on the DFDs in the DFD model of a system. We can understand the creation of a data dictionary better by considering an example.

Data dictionary for the DFD of Tic-Tac-Toe
move: integer /*number between 1 and 9 */
display: game+result
game: board
board: {integer}9
result: [“computer won”, “human won” “draw”]

Example: A supermarket needs to develop the following software to encourage regular customers. For this, the customer needs to supply his/her residence address, telephone number, and the driving license number. Each customer who registers for this scheme is assigned a unique customer number (CN) by the computer. A customer can present his CN to the check out staff when he makes any purchase. In this case, the value of his

purchase is credited against his CN. At the end of each year, the supermarket intends to award surprise gifts to 10 customers who make the highest total purchase over the year. Also, it intends to award a 22 caret gold coin to every customer whose purchase exceeded Rs.10,000. The entries against the CN are the reset on the day of every year after the prize winners' lists are generated.

The context diagram for this problem is shown in fig. 5.5, the level 1 DFD in fig. 5.6, and the level 2 DFD in fig. 5.7.

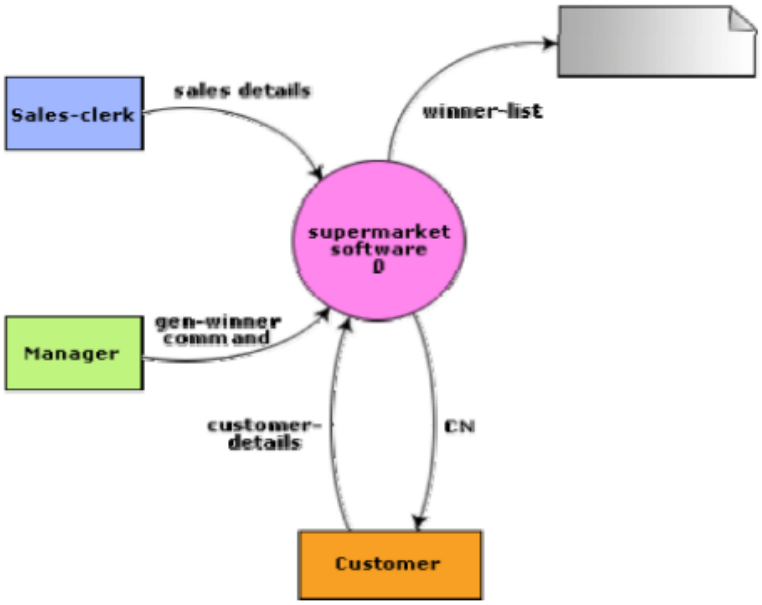


Fig. 5.5: Context diagram for supermarket problem

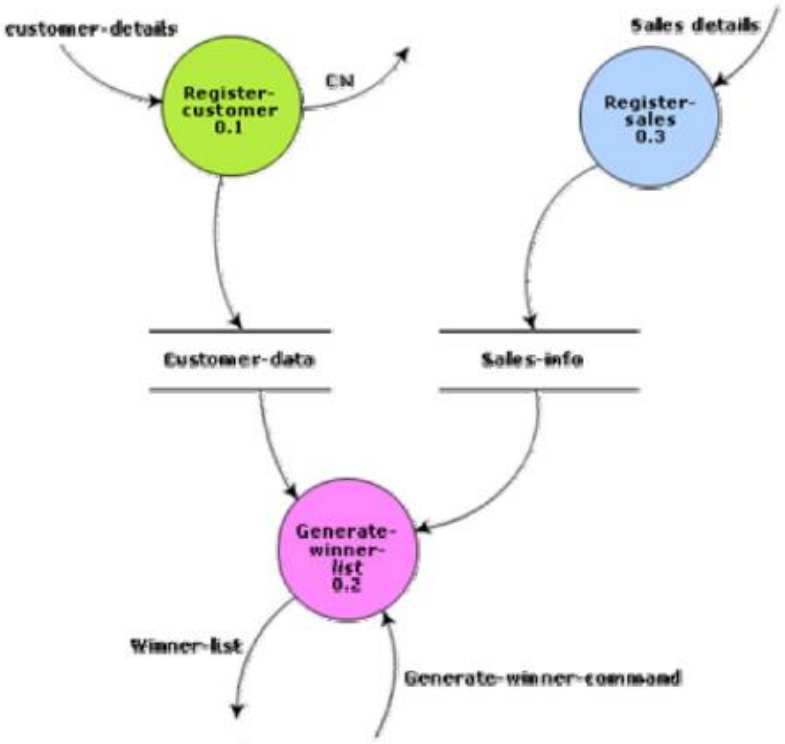


Fig. 5.6: Level 1 diagram for supermarket problem

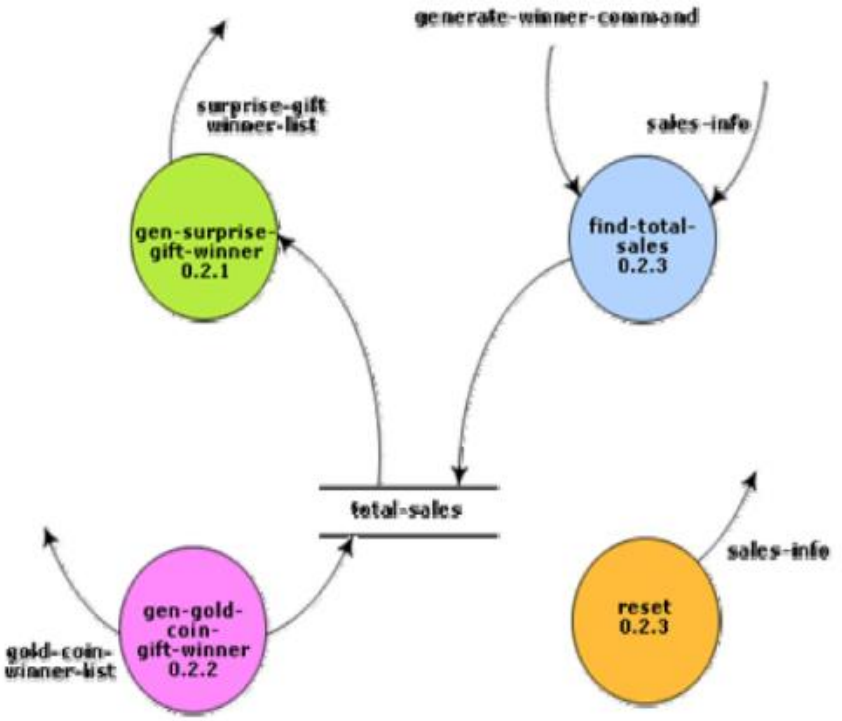


Fig. 5.7: Level 2 diagram for supermarket problem

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

- Transform analysis
- Transaction analysis

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

Structure Charts: For a function-oriented design, the design can be represented graphically by structure charts. The structure of a program is made up of the modules of that program together with the interconnections between modules. Every computer program has a structure, and given a program its structure can be determined. The structure chart of a program is a graphic representation of its structure. In a structure chart a module is represented by a box with the module name written in the box. An arrow from module A to module B represents that module A invokes module B. B is called the *subordinate* of A, and A is called the *superordinate* of B. The arrow is labeled by the parameters received by B as input and the parameters returned by B as output, with the direction of flow of the input and output parameters represented by small arrows. As an example consider the structure of the following program, whose structure is shown in Figure 6.1.

```
main ()
{
        int sum, n, N, a[MAX];
        readnumsCa, &N);
        sort ( a , N);
        scanf(&n);
        sum = addn(a, n) ;
        printf ( s u m );
}
readnums ( a , N)
int a [ ] , *N ;
{
        :
        :
```

```
}
sort ( a , N)
int a[ ] , N;
{
        :
        if ( a [ i ] > a [ t ] ) s w i t c h ( a [ i ] , a [ t ] );
        :
}
/* Add the first n numbers of a */
addn(a, n)
int a [ ] , n ;
{
        :
        :
}
```

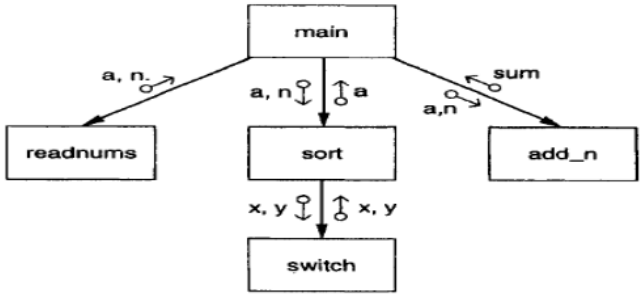


Figure 6.1: The structure chart of the sort program.

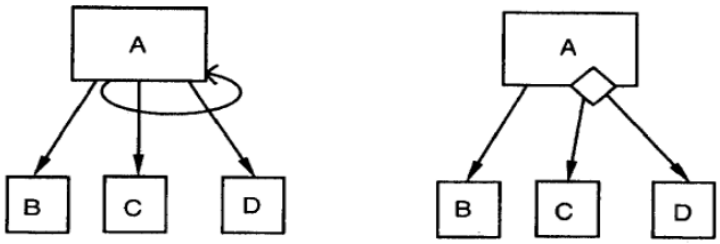


Figure 6.2: Iteration and decision representation.

Let us consider a situation where module A has subordinates B, C, and D, and A repeatedly calls the modules C and D. This can be represented by a looping arrow around the arrows joining the subordinates C and D to A, as shown in Figure 6.2. All the subordinate modules activated within a common loop are enclosed in the same looping arrow.

Major decisions can be represented similarly. For example, if the invocation of modules C and D in module A depends on the outcome of some decision, that is represented by a small diamond in the box for A, with the arrows joining C and D coming out of this diamond, as shown in Figure 6.2.

Modules in a system can be categorized into few classes. There are some modules that obtain information from their subordinates and then pass it to their superordinate. This kind of module is an *input module.* Similarly, there are *output modules,* that take information from their superordinate and pass it on to its subordinates. Then there are modules that exist solely for the sake of transforming data into some other form. Such a module is called a *transform module.* Finally, there are modules whose primary concern is managing the flow of data to and from different subordinates. Such modules are called *coordinate modules.* The structure chart representation of the different types of modules is shown in Figure 6.3.A module can perform functions

of more than one type of module. For example, the composite module in Figure 6.3 is an input module from the point of view of its superordinate, as it feeds the data Y to the superordinate. A is a coordinate module and views its job as getting data X from one subordinate and passing it to another subordinate, which converts it to Y.

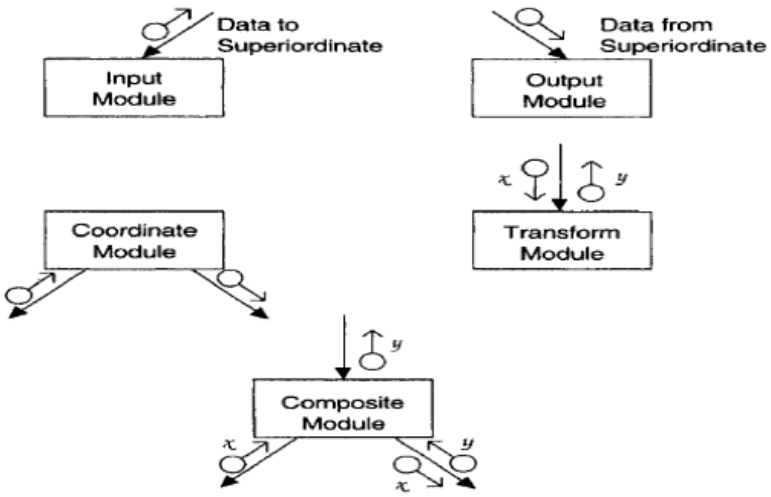


Figure 6.3: Different types of modules.

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

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

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

- Input
- Logical processing
- Output

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

The output portion of a DFD transforms output data from logical to physical form. Each output portion is called an efferent branch. The remaining portion of a DFD is called the central transform.

In the next step of transform analysis, the structure chart is derived by drawing one functional component for the central transform, and the afferent and efferent branches. These are drawn below a root module, which would invoke these modules.

The first level structure chart is produced by representing each input and output unit as boxes and each central transform as a single box.

In the third step of transform analysis, the structure chart is refined by adding sub-functions required by each of the high-level functional components. Many levels of functional components may be added. This process of breaking functional components into subcomponents is called factoring. Factoring includes adding read and write modules, error-handling modules, initialization and termination process, identifying customer modules, etc. The factoring process is continued until all bubbles in the DFD are represented in the structure chart.

Transaction Analysis: A transaction allows the user to perform some meaningful piece of work. Transaction analysis is useful while designing transaction processing programs. In a transaction-driven system, one of several possible paths through the DFD is traversed depending upon the input data item. This is in contrast to

a transform centered system which is characterized by similar processing steps for each data item. Each different way in which input data is handled is a transaction. A simple way to identify a transaction is to check the input data. The number of bubbles on which the input data to the DFD are incident defines the number of transactions. However, some transaction may not require any input data. These transactions can be identified from the experience of solving a large number of examples. For each identified transaction, trace the input data to the output. All the traversed bubbles belong to the transaction. These bubbles should be mapped to the same module on the structure chart. In the structure chart, draw a root module and below this module draw each identified transaction a module. Every transaction carries a tag, which identifies its type. Transaction analysis uses this tag to divide the system into transaction modules and a transaction-center module.

Coding: Good software development organizations normally require their programmers to adhere to some well-defined and standard style of coding called coding standards. Most software development organizations formulate their own coding standards that suit them most, and require their engineers to follow these standards rigorously. The purpose of requiring all engineers of an organization to adhere to a standard style of coding is the following:

- A coding standard gives a uniform appearance to the codes written by different engineers.
- It enhances code understanding.
- It encourages good programming practices.

A coding standard lists several rules to be followed during coding, such as the way variables are to be named, the way the code is to be laid out, error return conventions, etc.

Coding standards and guidelines: Good software development organizations usually develop their own coding standards and guidelines depending on what best suits their organization and the type of products they develop.

The following are some representative coding standards.

Rules for limiting the use of global: These rules list what types of data can be declared global and what cannot.

Contents of the headers preceding codes for different modules: The information contained in the headers of different modules should be standard for an organization. The exact format in which the header information is organized in the header can also be specified. The following are some standard header data:

- Name of the module.
- Date on which the module was created.
- Author's name.
- Modification history.
- Synopsis of the module.
- Different functions supported, along with their input/output parameters.
- Global variables accessed/modified by the module.

Naming conventions for global variables, local variables, and constant identifiers: A possible naming convention can be that global variable names always start with a capital letter, local variable names are made of small letters, and constant names are always capital letters.

Error return conventions and exception handling mechanisms: The way error conditions are reported by different functions in a program are handled should be standard within an organization. For example, different functions while encountering an error condition should either return a 0 or 1 consistently.

Code Review: Code review for a model is carried out after the module is successfully compiled and the 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.

Some of the guidelines for code walk through 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. 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.

Difference between Verification and Validation (V & V): 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.

Testing in the large vs. testing in the small: Software products are normally tested first at the individual component (or unit) level. This is referred to as testing in the small. After testing all the components individually, the components are slowly integrated and tested at each level of integration (integration testing). Finally, the fully integrated system is tested (called system testing). Integration and system testing are known as testing in the large.

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.

Modules required to provide the necessary environment (which either call or are called by the module under test) is usually not available until they too have been unit tested, stubs and drivers are designed to provide the complete environment for a module. The role of stub and driver modules is pictorially shown in fig. 10.1. A stub procedure is a dummy procedure that has the same I/O parameters as the given procedure but has a highly simplified behavior. For example, a stub procedure may produce the expected behavior using a simple table lookup mechanism. A driver module contains the nonlocal data structures accessed by the module under test, and would also have the code to call the different functions of the module with appropriate parameter values.

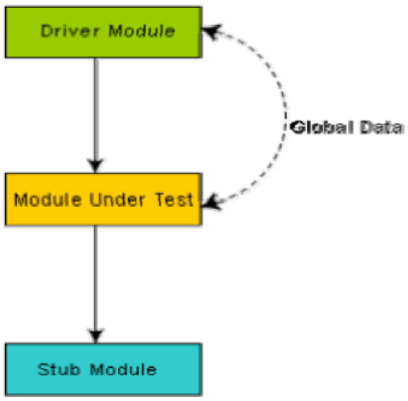


Fig. 10.1: Unit testing with the help of driver and stub modules

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. The following are some general guidelines for designing the equivalence classes:

1. If the input data values to a system can be specified by a range of values, then one valid and two invalid equivalence classes should be defined.

2. If the input data assumes values from a set of discrete members of some domain, then one equivalence class for valid input values and another equivalence class for invalid input values should be defined.

Example#1: For a software that computes the square root of an input integer which can assume values in the range of 0 to 5000, there are three equivalence classes: The set of negative integers, the set of integers in the range of 0 and 5000, and the integers larger than 5000. Therefore, the test cases must include representatives for each of the three equivalence classes and a possible test set can be: {-5, 500, 6000}.

Example#2: Design the black-box test suite for the following program. The program computes the intersection point of two straight lines and displays the result. It reads two integer pairs (m1, c1) and (m2, c2) defining the two straight lines of the form y=mx + c.

The equivalence classes are the following:

- Parallel lines (m1=m2, c1≠c2)
- Intersecting lines (m1≠m2)
- Coincident lines (m1=m2, c1=c2)

Now, selecting one representative value from each equivalence class, the test suit (2, 2) (2, 5), (5, 5) (7, 7), (10, 10) (10, 10) are obtained.

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.

Example: For a function that computes the square root of integer values in the range of 0 and 5000, the test cases must include the following values: {0, -1, 5000, 5001}.

White Box Testing: White-box testing (also known as clear box testing, glass box testing, transparent box testing, and structural testing) is a method of testing software that tests internal structures or workings of an application, as opposed to its functionality (i.e. black-box testing). In white-box testing an internal perspective of the system, as well as programming skills, are used to design test cases. The tester chooses inputs to exercise paths through the code and determine the appropriate outputs.

Statement coverage: The statement coverage strategy aims to design test cases so that every statement in a program is executed at least once. The principal idea governing the statement coverage strategy is that unless a statement is executed, it is very hard to determine if an error exists in that statement. Unless a statement is executed, it is very difficult to observe whether it causes failure due to some illegal memory access, wrong result computation, etc. However, executing some statement once and observing that it behaves properly for that input value is no guarantee that it will behave correctly for all input values. In the following, designing of test cases using the statement coverage strategy have been shown.

Example: Consider the Euclid's GCD computation algorithm:

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

By choosing the test set {(x=3, y=3), (x=4, y=3), (x=3, y=4)}, we can exercise the program such that all statements are executed at least once.

Branch coverage: In the branch coverage-based testing strategy, test cases are designed to make each branch condition to assume true and false values in turn. Branch testing is also known as edge testing as in this testing scheme, each edge of a program's control flow graph is traversed at least once. It is obvious that branch testing guarantees statement coverage and thus is a stronger testing strategy compared to the statement coverage-based testing.
For Euclid's GCD computation algorithm, the test cases for branch coverage can be {(x=3, y=3), (x=3, y=2), (x=4, y=3), (x=3, y=4)}.

Condition coverage: In this structural testing, test cases are designed to make each component of a composite conditional expression to assume both true and false values. For example, in the conditional expression ((c1.and.c2).or.c3), the components c1, c2 and c3 are each made to assume both true and false values. Branch testing is probably the simplest condition testing strategy where only the compound conditions appearing in the different branch statements are made to assume the true and false values. Thus, condition testing is a stronger testing strategy than branch testing and branch testing is stronger testing strategy than the statement coverage-based testing. For a composite conditional expression of n components, for condition coverage, 2^n test cases are required. Thus, for condition coverage, the number of test cases increases exponentially with the number of component conditions. Therefore, a condition coverage-based testing technique is practical only if n (the number of conditions) is small.

Path coverage: The path coverage-based testing strategy requires us to design test cases such that all linearly independent paths in the program are executed at least once. A linearly independent path can be defined in terms of the control flow graph (CFG) of a program.

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 fig. 10.3). 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. Fig. 10.3 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 fig. 10.4.

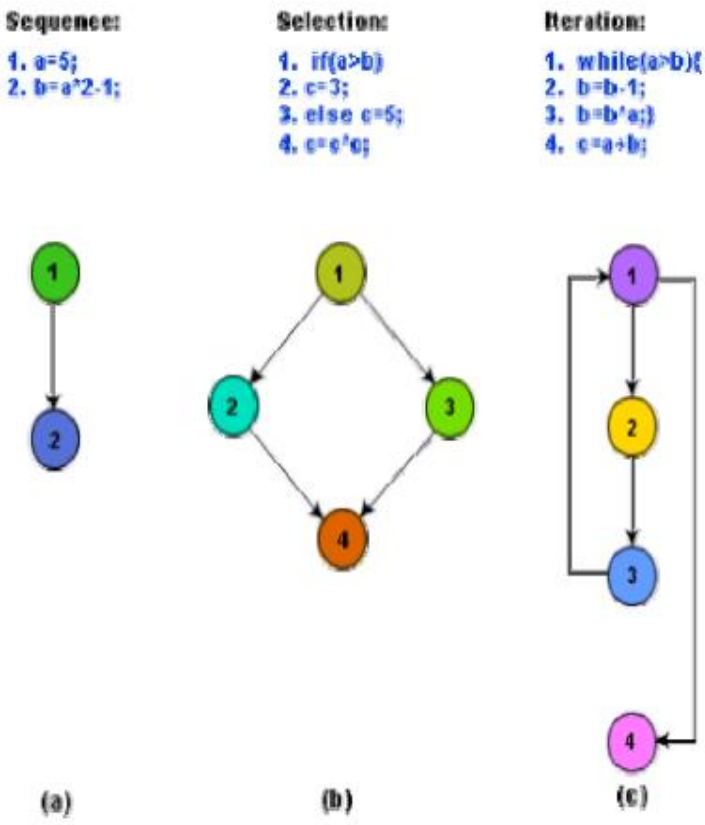


Fig. 10.3: CFG for (a) sequence, (b) selection, and (c) iteration type of constructs

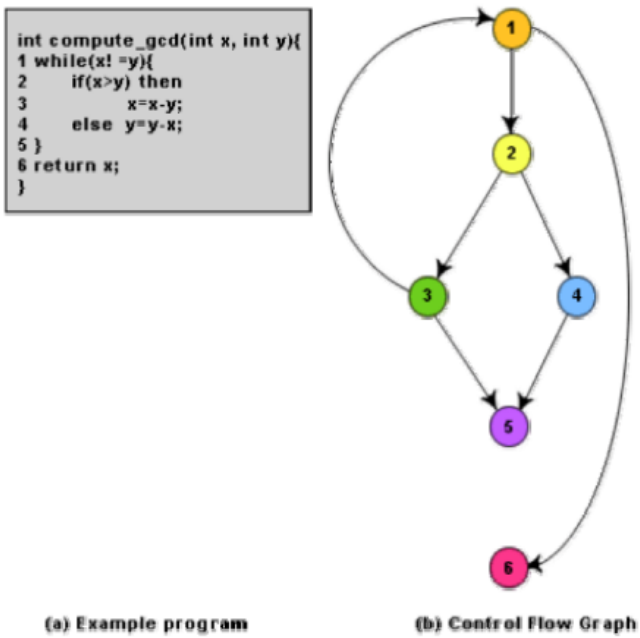


Fig. 10.4: Control flow diagram

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. 10.4, 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) = Total number of bounded areas + 1

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. 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.

Integration testing: The primary objective of integration testing is to test the module interfaces, i.e. there are no errors in the parameter passing, when one module invokes another module. During integration testing, different modules of a system are integrated in a planned manner using an integration plan. The integration plan specifies the steps and the order in which modules are combined to realize the full system.

After each integration step, the partially integrated system is tested. An important factor that guides the integration plan is the module dependency graph. The structure chart (or module dependency graph) denotes the order in which different modules call each other. By examining the structure chart the integration plan can be developed.

There are four types of integration testing approaches. Any one (or a mixture) of the following approaches can be used to develop the integration test plan. Those approaches are the following:

- Big bang approach
- Top-down approach
- Bottom-up approach
- Mixed-approach

Big-Bang Integration Testing: It is the simplest integration testing approach, where all the modules making up a system are integrated in a single step. In simple words, all the modules of the system are simply put together and tested. However, this technique is practicable only for very small systems. The main problem with this approach is that once an error is found during the integration testing, it is very difficult to localize the error as the error may potentially belong to any of the modules being integrated. Therefore, debugging errors reported during big bang integration testing are very expensive to fix.

Bottom-Up Integration Testing: In bottom-up testing, each subsystem is tested separately and then the full system is tested. A subsystem might consist of many modules which communicate among each other through well-defined interfaces. The primary purpose of testing each subsystem is to test the interfaces among various modules making up the subsystem. Both control and data interfaces are tested. The test cases must be carefully chosen to exercise the interfaces in all possible manners.

Large software systems normally require several levels of subsystem testing; lower-level subsystems are successively combined to form higher-level subsystems. A principal advantage of bottom-up integration testing is that several disjoint subsystems can be tested simultaneously. In a pure bottom-up testing no stubs are required, only test-drivers are required. A disadvantage of bottom-up testing is the complexity that occurs when the system is made up of a large number of small subsystems. The extreme case corresponds to the big-bang approach.

Top-Down Integration Testing: Top-down integration testing starts with the main routine and one or two subordinate routines in the system. After the top-level 'skeleton' has been tested, the immediately subroutines of the 'skeleton' are combined with it and tested. Top-down integration testing approach requires the use of program stubs to simulate the effect of lower-level routines that are called by the routines under test. Pure top-down integration does not require any driver routines. A disadvantage of the top-down integration testing approach is that in the absence of lower-level routines, many times it may become difficult to exercise the top level routines in the desired manner since the lower-level routines perform several low-level functions such as I/O.

Mixed Integration Testing: A mixed (also called sandwiched) integration testing follows a combination of topdown and bottom-up testing approaches. In top-down approach, testing can start only after the top-level modules have been coded and unit tested. Similarly, bottom-up testing can start only after the bottom level modules are ready. The mixed approach overcomes this shortcoming of the top-down and bottom-up approaches. In the mixed testing approaches, testing can start as and when modules become available. Therefore, this is one of the most commonly used integration testing approaches.

System 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.

Performance testing: Performance testing is carried out to check whether the system needs the nonfunctional requirements identified in the SRS document. There are several types of performance testing. Among of them nine types are discussed below. The types of performance testing to be carried out on a system depend on the different non-functional requirements of the system documented in the SRS document. All performance tests can be considered as black-box tests.

- Stress testing
- Volume testing
- Configuration testing
- Compatibility testing
- Regression testing
- Recovery testing
- Maintenance testing
- Documentation testing
- Usability testing

Stress Testing: Stress testing is also known as endurance testing. Stress testing evaluates system performance when it is stressed for short periods of time. Stress tests are black box tests which are designed to impose a range of abnormal and even illegal input conditions so as to stress the capabilities of the software. Input data

volume, input data rate, processing time, utilization of memory, etc. are tested beyond the designed capacity. For example, suppose an operating system is supposed to support 15 multi-programmed jobs, the system is stressed by attempting to run 15 or more jobs simultaneously. A real-time system might be tested to determine the effect of simultaneous arrival of several high-priority interrupts.

Volume Testing: It is especially important to check whether the data structures (arrays, queues, stacks, etc.) have been designed to successfully extraordinary situations. For example, a compiler might be tested to check whether the symbol table overflows when a very large program is compiled.

Configuration Testing: This is used to analyze system behavior in various hardware and software configurations specified in the requirements. Sometimes systems are built in variable configurations for different users. For instance, we might define a minimal system to serve a single user, and other extension configurations to serve additional users. The system is configured in each of the required configurations and it is checked if the system behaves correctly in all required configurations.

Compatibility Testing: This type of testing is required when the system interfaces with other types of systems. Compatibility aims to check whether the interface functions perform as required. For instance, if the system needs to communicate with a large database system to retrieve information, compatibility testing is required to test the speed and accuracy of data retrieval.

Regression Testing: This type of testing is required when the system being tested is an upgradation of an already existing system to fix some bugs or enhance functionality, performance, etc. Regression testing is the practice of running an old test suite after each change to the system or after each bug fix to ensure that no new bug has been introduced due to the change or the bug fix. However, if only a few statements are changed, then the entire test suite need not be run - only those test cases that test the functions that are likely to be affected by the change need to be run.

Recovery Testing: Recovery testing tests the response of the system to the presence of faults, or loss of power, devices, services, data, etc. The system is subjected to the loss of the mentioned resources (as applicable and discussed in the SRS document) and it is checked if the system recovers satisfactorily. For example, the printer can be disconnected to check if the system hangs. Or, the power may be shut down to check the extent of data loss and corruption.

Maintenance Testing: This testing addresses the diagnostic programs, and other procedures that are required to be developed to help maintenance of the system. It is verified that the artifacts exist and they perform properly.

Documentation Testing: It is checked that the required user manual, maintenance manuals, and technical manuals exist and are consistent. If the requirements specify the types of audience for which a specific manual should be designed, then the manual is checked for compliance.

Usability Testing: Usability testing concerns checking the user interface to see if it meets all user requirements concerning the user interface. During usability testing, the display screens, report formats, and other aspects relating to the user interface requirements are tested.

Software Reliability: Reliability of a software product essentially denotes its trustworthiness or dependability. Alternatively, reliability of a software product can also be defined as the probability of the product working “correctly” over a given period of time. It is obvious that a software product having a large number of defects is unreliable. It is also clear that the reliability of a system improves, if the number of defects in it is reduced. However, there is no simple relationship between the observed system reliability and the number of latent defects in the system. For example, removing errors from parts of a software which are rarely executed makes little difference to the perceived reliability of the product. It has been experimentally observed by analyzing the behavior of a large number of programs that 90% of the execution time of a typical program is spent in executing only 10% of the instructions in the program. These most used 10% instructions are often called the core of the program. The rest 90% of the program statements are called non-core and are executed

only for 10% of the total execution time. It therefore may not be very surprising to note that removing 60% product defects from the least used parts of a system would typically lead to only 3% improvement to the product reliability

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

Hardware Reliability vs. Software Reliability: Reliability behavior for hardware and software are very different. For example, hardware failures are inherently different from software failures. Most hardware failures are due to component wear and tear. A logic gate may be stuck at 1 or 0, or a resistor might short circuit. To fix hardware faults, one has to either replace or repair the failed part. On the other hand, a software product would continue to fail until the error is tracked down and either the design or the code is changed.

For this reason, when a hardware is repaired its reliability is maintained at the level that existed before the failure occurred; whereas when a software failure is repaired, the reliability may either increase or decrease (reliability may decrease if a bug introduces new errors). To put this fact in a different perspective, hardware reliability study is concerned with stability (for example, inter-failure times remain constant). On the other hand, software reliability study aims at reliability growth (i.e. inter-failure times increase). The change of failure rate over the product lifetime for a typical hardware and a software product are sketched in fig. 13.1. For hardware products, it can be observed that failure rate is high initially but decreases as the faulty components are identified and removed. The system then enters its useful life. After some time (called product life time) the components wear out, and the failure rate increases. This gives the plot of hardware reliability over time its characteristics "bath tub" shape. On the other hand, for software the failure rate is at it's highest during integration and test. As the system is tested, more and more errors are identified and removed resulting in reduced failure rate. This error removal continues at a slower pace during the useful life of the product. As the software becomes obsolete no error corrections occurs and the failure rate remains unchanged.

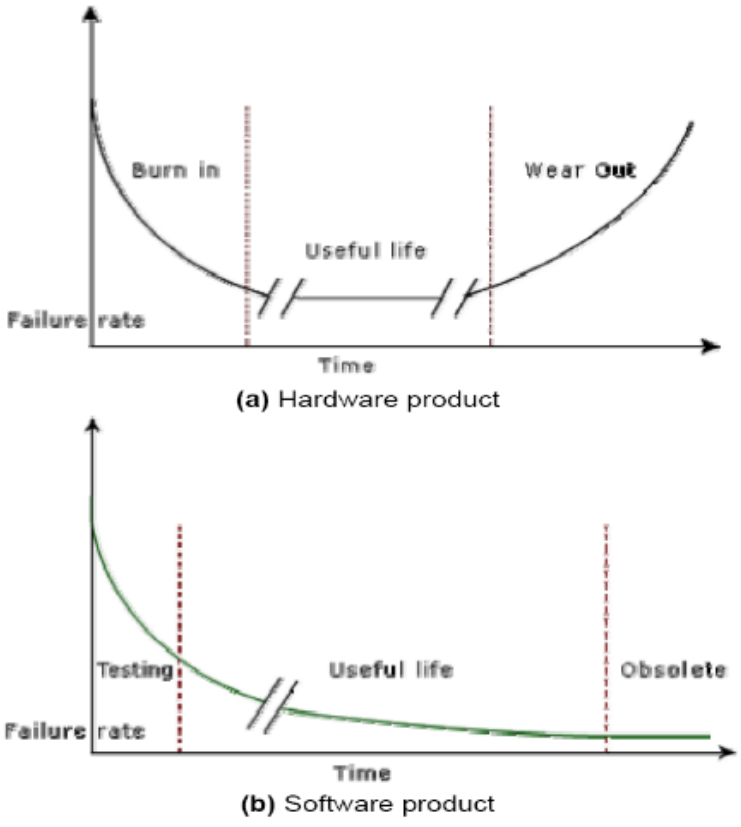


Fig. 13.1: Change in failure rate of a product

Software Quality: Traditionally, a quality product is defined in terms of its fitness of purpose. That is, a quality product does exactly what the users want it to do. For software products, fitness of purpose is usually interpreted in terms of satisfaction of the requirements laid down in the SRS document. To give an example, consider a software product that is functionally correct. That is, it performs all functions as specified in the SRS document. But, has an almost unusable user interface. Even though it may be functionally correct, we cannot consider it to be a quality product. Another example may be that of a product which does everything that the users want but has an almost incomprehensible and unmaintainable code. Therefore, the traditional concept of quality as "fitness of purpose" for software products is not wholly satisfactory.

The modern view of a quality associates with a software product several quality factors such as the following:

- *Portability:* A software product is said to be portable, if it can be easily made to work in different operating system environments, in different machines, with other software products, etc.
- *Usability:* A software product has good usability, if different categories of users (i.e. both expert and novice users) can easily invoke the functions of the product.
- *Reusability:* A software product has good reusability, if different modules of the product can easily be reused to develop new products.
- *Correctness:* A software product is correct, if different requirements as specified in the SRS document have been correctly implemented.
- *Maintainability***:** A software product is maintainable, if errors can be easily corrected as and when they show up, new functions can be easily added to the product, and the functionalities of the product can be easily modified, etc.

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.

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

The first stage of reverse engineering usually focuses on carrying out cosmetic changes to the code to improve its readability, structure, and understandability, without changing of its functionalities. A process model for reverse engineering has been shown in fig. 14.1. A program can be reformatted using any of the several available prettyprinter programs which layout the program neatly. Many legacy software products with complex control structure and unthoughtful variable names are difficult to comprehend. Assigning meaningful

variable names is important because meaningful variable names are the most helpful thing in code documentation. All variables, data structures, and functions should be assigned meaningful names wherever possible. Complex nested conditionals in the program can be replaced by simpler conditional statements or whenever appropriate by case statements.

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

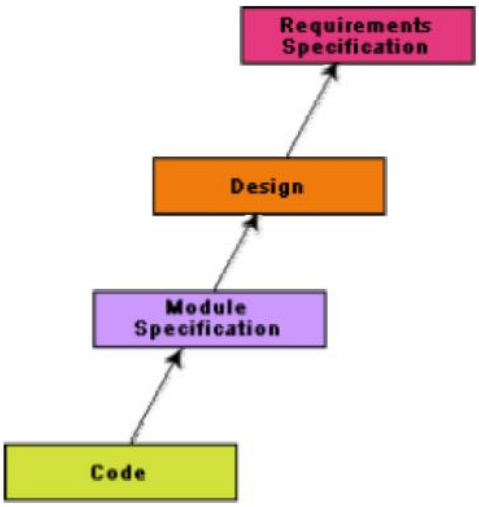


Fig. 14.1: A process model for reverse engineering