Software Engineering Lectures

1- Introduction

1.1 definitions

- **Engineering** is the use of scientific principles to design and build machines, structures, and other items, including bridges, tunnels, roads, vehicles, and buildings.

- Definition of software given by the IEEE:

Software is the collection of computer programs, procedure rules and associated documentation and data.

Software includes:
(i) Instructions (computer programs) that when executed provide desired functions and performance.

(ii) Data structures that enable the programs to adequately manipulate information.

(iii) Documents that describe the operation and use of the programs.

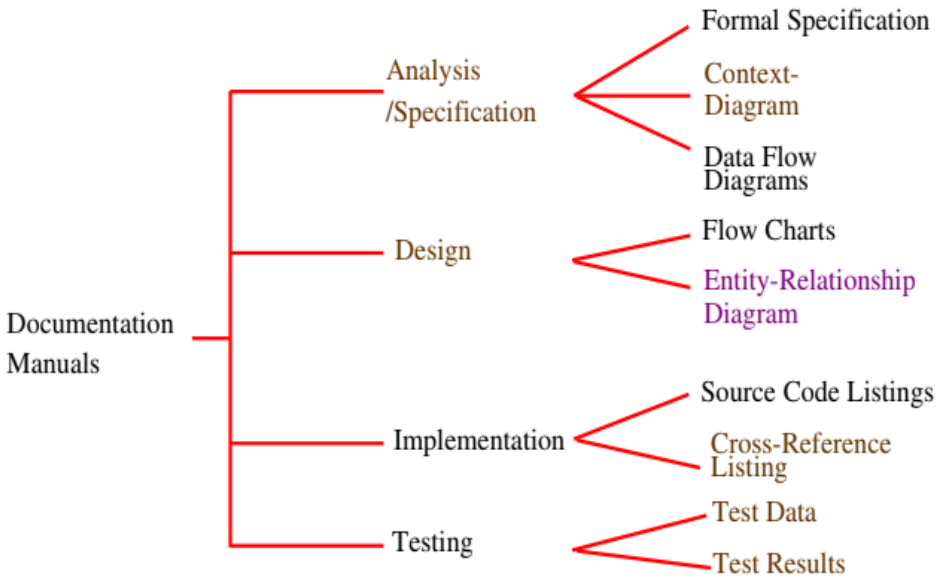


Figure 1.1 List of documentation manuals

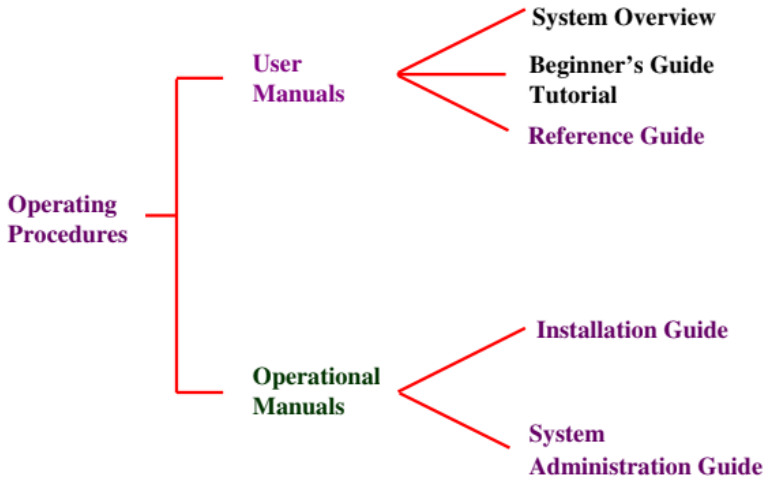


Figure 1.2 List of operating procedure manuals.

1.2 Importance of Software

Computer software has become a driving force.

- It is the engine that drives business decision making.
- It serves as the basis for modern scientific investigation and engineering problem-solving.
- It is embedded in all kinds of systems, such as transportation, medical, telecommunications, military, industrial processes, entertainment, office products, etc.

1.3 Types of software

Computer software is often divided into two categories:

1. System software. This software includes the operating system and all utilities that enable the computer to function.

2. Application software. These consist of programs that do real work for users. For example, word processors, spreadsheets, and database management systems fall under the category of applications software. Figure 1.3 gives an overview of software classification and its types.

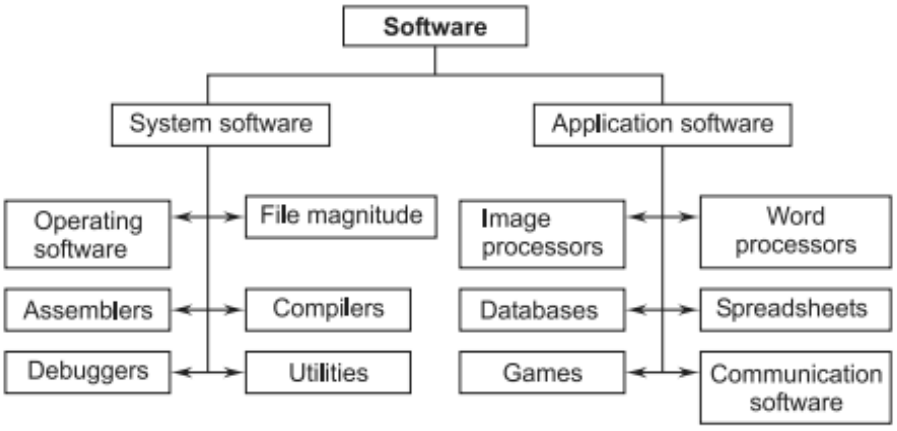


Figure 1.3 Types of software

1.4 CLASSES OF SOFTWARE

Software is classified into the following two classes:

1. Generic Software. Generic software is designed for a broad customer market whose requirements are very common, fairly stable, and well-understood by the software engineer.

2. Customized Software. Customized products are those that are developed for a customer where domain, environment, and requirements are unique to that customer and cannot be satisfied by generic products.

1.5 INTRODUCTION TO SOFTWARE ENGINEERING

IEEE Comprehensive Definition. Software Engineering is the application of a systematic, disciplined, quantifiable approach to the development, operation and maintenance of software, i.e., the application of engineering to software.

or

Software Engineering is the application of methods and scientific knowledge to create practical cost-effective solutions for the design, construction, operation and maintenance of software.

1.6 SOFTWARE CHARACTERISTICS

1. Most software is custom-built, rather than assembled from existing components.

2.Software is developed or engineered; it is not manufactured in the classical sense.

3. Software is flexible. We all feel that software is flexible. A program can be developed to do almost anything.

4. Software doesn't wear out. There is a well-known "bath-tub curve" in reliability studies for hardware products. Figure 1.4 depicts the failure rate as a function of time for hardware.

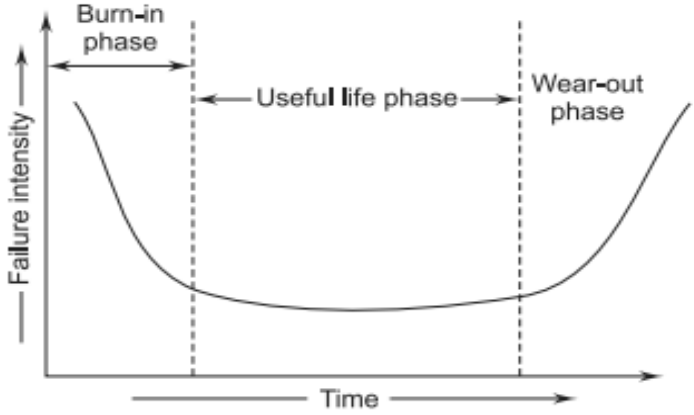


Figure 1.4 Bath-tub Curve

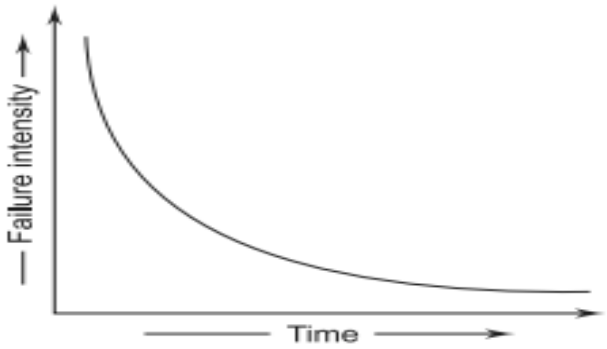


Figure 1.5 Software Curve

Then why not have entirely hardware systems?

•A virtue of software:
–Relatively easy and faster to develop and to change
–Consumes no space, weight, or power…
–Otherwise all might as well be hardware.
•The more is the complexity of software, the harder it is to change--why?
–Further, the more the changes made to a program, the greater becomes its complexity.

1.7 SOFTWARE CRISIS

According to Standish only 16.2% of projects were deemed successful by being completed on time and budget, with all the promised functionality. A majority of projects, or 52.7%, were over cost, over time, and/or lacking promised functionality. That leaves 31.1% to be classified as failed, which means they were abandoned or cancelled.
Links: https://www.standishgroup.com/sample_research_files/chaos_report_1994.pdf

It is often the case that software products:

- Fail to meet user requirements.
- Expensive.
- Difficult to alter, debug, and enhance.
- Often delivered late.
- Use resources non-optimally.

1.7.1 Causes

- The quality of the software is not good because most developers use historical data to develop the software.
- If there is delay in any process or stage (i.e., analysis, design, coding & testing) then scheduling does not match with actual timing.
- Communication between managers and customers, software developers, support staff, etc., can break down because the special characteristics of software and the problems associated with its development are misunderstood.
- The software people responsible for tapping the potential often change when it is discussed and resist change when it is introduced.

1.7.2 Factors are Contributing to the Software Crisis

- Larger problems,
- Poor project management
- Lack of adequate training in software engineering,
- Increasing skill shortage,
- Low productivity improvements.

Figure 1.6 Relative changes of hardware and software costs over time.

Software Crisis from the Programmer's Point-of-View

- ❖ Problem of compatibility.
- ❖ Problem of portability.
- ❖ Problem in documentation.
- ❖ Problem of piracy of software.
- ❖ Problem in coordination of work of different people.
- ❖ Problem of proper maintenance.

Software Crisis form the User's Point-of-View

- Software cost is very high.
- Hardware goes down.
- Lack of specialization in development.
- Problem of different versions of software.
- Problem of views.
- Problem of bugs.

1.7.3 Examples

1- Y2K problem:

It was simply the ignorance about the adequacy or otherwise of using only last two digits of the year.

The 4-digit date format, like 1964, was shortened to 2-digit format, like 64.

Links: https://www.nationalgeographic.org/encyclopedia/Y2K-bug/#:~:text=Powered%20by-,The%20Y2K%20bug%20was%20a%20computer%20flaw%2C%20or%20bug%2C%20that,dates%20beyond%20December%2031%2C%201999.&text=When%20complicated%20computer%20programs%20were,%2219%22%20was%20left%20out.

2- Ariane 5

It took the European Space Agency 10 years and $7 billion to produce Ariane 5, a giant rocket capable of hurling a pair of three-ton satellites into orbit with each launch and intended to give Europe overwhelming supremacy in the commercial space business.

The rocket was destroyed after 39 seconds of its launch, at an altitude of two and a half miles along with its payload of four expensive and uninsured scientific satellites.

3- Windows XP

o Microsoft released Windows XP on October 25, 2001.
o On the same day company posted 18 MB of compatibility patches on the website for bug fixes, compatibility updates, and enhancements.
o Two patches fixed important security holes.

This is Software Engineering.

1.8 Why study software engineering

1- To acquire skills to develop large programs

- Handling exponential growth in complexity with size
- Systematic techniques based on abstraction (modelling) and decomposition.

2- Learn systematic techniques of:

- specification, design, user interface development, testing, project management, maintenance, etc.
- appreciate issues that arise in team development

3- To acquire skills to be a better programmer

- Higher productivity
- Better quality programs

1.9 SOFTWARE-ENGINEERING PROCESSES

1.9.1 Process

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

Any process has the following characteristics:

- The process prescribes all of the major process activities.
- The process uses resources, subject to a set of constraints (such as a schedule), and produces intermediate and final products.
- The process may be composed of sub-processes that are linked in some way. The process may be defined as a hierarchy of processes, organized so that each sub-process has its own process model.
- Each process activity has entry and exit criteria, so that we know when the activity begins and ends.
- The activities are organized in a sequence, so that it is clear when one activity is performed relative to the other activities.
- Every process has a set of guiding principles that explain the goals of each activity.
- Constraints or controls may apply to an activity, resource, or product. For example, the budget or schedule may constrain the length of time an activity may take or a tool may limit the way in which a resource may be used.

1.9.2 What is a Software Process?

A software process is the related set of activities and processes that are involved in developing and evolving a software system.

OR

A set of activities whose goal is the development or evolution of software.

These activities are mostly carried out by software engineers. There are four fundamental process activities, which are common to all software processes. These activities are:
1. Software specifications: The functionality of the software and constraints on its operation must be defined.
2. Software development: Software that meets the specifications must be produced.
3. Software validation: The software must be validated to ensure that it does what the customer wants.
4. Software evolution: The software must evolve to meet changing customer needs.

1.10 Some Terminologies

- Deliverables and Milestones

Different deliverables are generated during software development. The examples are source code, user manuals, operating procedure manuals etc.

The milestones are the events that are used to ascertain the status of the project. Finalization of specification is a milestone. Completion of design documentation is another milestone. The milestones are essential for project planning and management.

- Product and Process

Product: What is delivered to the customer, is called a product. It may include source code, specification document, manuals, documentation etc. Basically, it is nothing but a set of deliverables only.

Process: Process is the way in which we produce software. It is the collection of activities that leads to (a part of) a product. An efficient process is required to produce good quality products.

If the process is weak, the end product will undoubtedly suffer, but an obsessive over reliance on process is also dangerous.

- Productivity and Effort

Productivity is defined as the rate of output, or production per unit of effort, i.e. the output achieved with regard to the time taken but irrespective of the cost incurred.

Hence most appropriate unit of effort is Person Months (PMs), meaning thereby number of persons involved for specified months. So, productivity may be measured as LOC/PM (lines of code produced/person month).

Sr. No	Constructing a bridge	Writing a program
1.	The problem is well understood	Only some parts of the problem are understood, others are not
2.	There are many existing bridges	Every program is different and designed for special applications.
3.	The requirement for a bridge typically do not change much during construction	Requirements typically change during all phases of development.
4.	The strength and stability of a bridge can be calculated with reasonable precision	Not possible to calculate correctness of a program with existing methods.
5.	When a bridge collapses, there is a detailed investigation and report	When a program fails, the reasons are often unavailable or even deliberately concealed.
6.	Engineers have been constructing bridges for thousands of years	Developers have been writing programs for 50 years or so.
7.	Materials (wood, stone,iron, steel) and techniques (making joints in wood, carving stone, casting iron) change slowly.	Hardware and software changes rapidly.

TABLE 1.1

Issue	Software Engineering	Computer Science
Ideal	Constructing software applications for real-world use for today	Finding eternal truths about problems and algorithms for posterity
Results	Working applications (such as office suites and video games) that deliver value to users	Computational complexity and correctness of algorithms (such as Shell sort) and analysis of problems (such as the traveling salesman problem)
Budgets and Schedules	Projects (such as upgrading an office suite) have fixed budgets and schedules	Projects (such as solving P = NP?) have open-ended budgets and schedules
Change	Applications evolve as user needs and expectations evolve, and as SE technologies and practices evolve	When computer science problems are solved, the solution will never change
Additional Skills	Domain knowledge	Mathematics

2- SOFTWARE-DEVELOPMENT LIFE-CYCLE MODELS

The software-development life-cycle is used to facilitate the development of a large software product in a systematic, well-defined, and cost-effective way.

The software development life-cycle can be divided into 5-9 phases, i.e., it must have a minimum of five phases and a maximum of nine phases. On average it has seven or eight phases. These are:

2.1 1- Build & Fix Model

- Product is constructed without specifications or any attempt at design
- Adhoc approach and not well defined Simple two-phase model

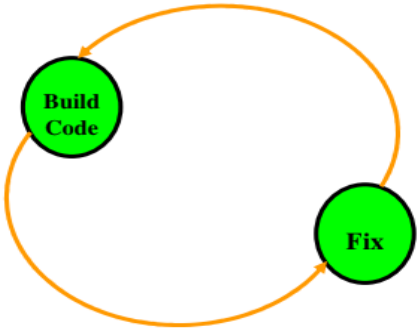


Figure 2.1 Build and Fix model

- ❖ Suitable for small programming exercises of 100 or 200 lines
- ❖ Unsatisfactory for software for any reasonable size
- ❖ Code soon becomes unfixable & enhanceable
- ❖ No room for structured design
- ❖ Maintenance is practically not possible

2.2 WATERFALL MODEL

The waterfall model is a very common software development process model. The waterfall model was popularized in the 1970s and permeates most current software-engineering textbooks and standard industrial practices.

The waterfall model is illustrated in Figure 2.2. Because of the cascade from one phase to another, this model is known as the waterfall model or software lifecycle, where the output of one phase constitutes the input to the next one. The phases shown in the figure are the following:

- Feasibility study

- Requirements analysis and specification
- Design and specification
- Coding and module testing
- Integration and system testing
- Delivery
- Maintenance

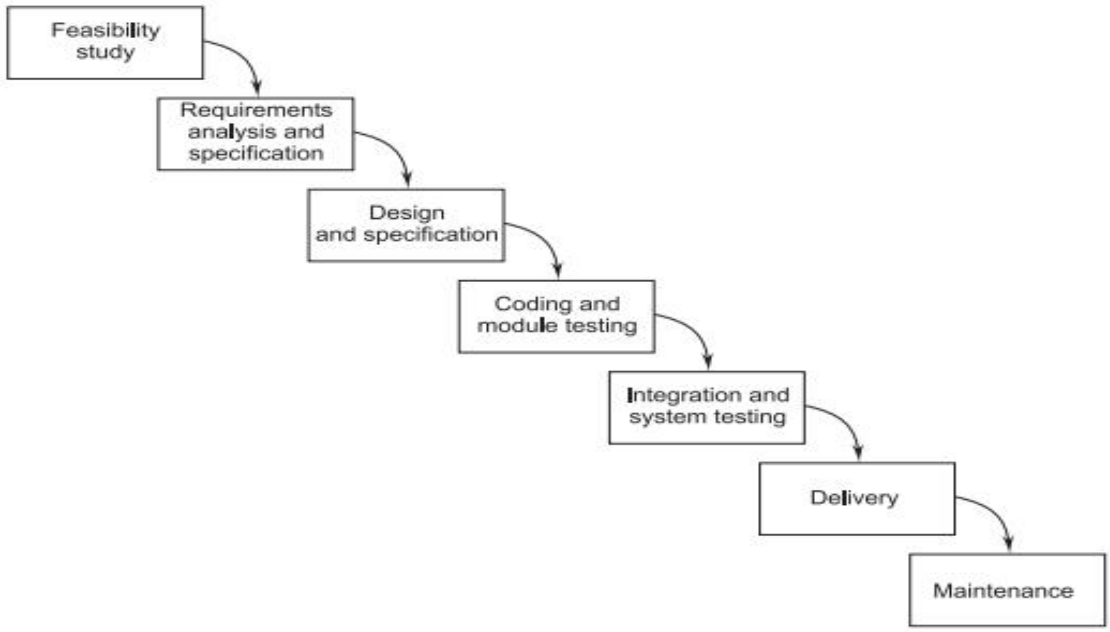


Figure 2.2 Waterfall Model

1. Feasibility Study. The purpose of this phase is to produce a feasibility study document that evaluates the costs and benefits of the proposed application. To do so, it is first necessary to analyze the problem, at least at a global level. Obviously, the more we understand the problem, the better we can identify alternative solutions, their costs, and their potential benefits to the user.

In sum, the feasibility study tries to anticipate future scenarios of software development. Its result is a document that should contain at least the following items:

- A definition of the problem.
- Determination of technical and economic viability.
- Alternative solutions and their expected benefits.
- Required resources, costs, and delivery dates in each proposed alternative solution.

2. Requirement Analysis and Specification. This phase exactly tells the requirements and needs of the project. This is a very important and critical phase in the waterfall model.
The purpose of a requirements analysis is to identify the qualities required of the application, in terms of functionality, performance, ease of use, portability, and so on.

The requirements describe the "what" of a system, not the "how." This phase produces a large document and contains a description of what the system will do without describing how it will be done. The resultant document is known as the software requirement specification (SRS) document.
An SRS document must contain the following:

- Detailed statement of problem.
- Possible alternative solution to problem.
- Functional requirements of the software system.
- Constraints on the software system.

3. Design and Specification. 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.
4. Coding and Module Testing. Coding and module testing is the phase in which we actually write programs using a programming language. It was the only recognized development phase in early development processes, but it is just one of several phases in a waterfall process. The output of this phase is an implemented and tested collection of modules.

Coding can be subject to company-wide standards, which may define the entire layout of programs, such as the headers for comments in every unit, naming conventions for variables and sub-programs, the maximum number of lines in each component, and other aspects that the company deems worthy of standardization.

Module testing is also often subject to company standards, including a precise definition of a test plan, the definition of testing criteria to be followed (e.g., black-box versus white-box, or a mixture of the two), the definition of completion criteria (when to stop testing), and the management of test cases. Debugging is a related activity performed in this phase.

5. Integration and System Testing. During the integration and system testing phase, the modules are integrated in a planned manner. 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 objective of system testing is to determine whether the software system performs per the requirements mentioned in the SRS document. This testing is known as system testing.

6. Delivery and Maintenance. The delivery of software is often done in two stages. In the first stage, the application is distributed among a selected group of customers prior to its official release. The purpose of this procedure is to perform a kind of controlled experiment to determine, on the basis of feedback from users, whether any changes are necessary prior to the official release. In the second stage, the product is distributed to the customers.
We define maintenance as the set of activities that are performed after the system is delivered to the customer. Basically, maintenance consists of correcting any remaining errors in the system (corrective

maintenance), adapting the application to changes in the environment (adaptive maintenance), and improving, changing, or adding features and qualities to the application (perfective maintenance).

Iterative Waterfall Model

We had pointed out in the previous section that in a practical software development project, the classical waterfall model is hard to use. We had branded the classical waterfall model as an idealistic model.

The main change brought about by the iterative waterfall model to the classical waterfall model is in the form of providing feedback paths from every phase to its preceding phases. The feedback paths introduced by the iterative waterfall model are shown in Figure 2.3.

- There is no feedback path to the feasibility stage. This is because once a team having accepted to take up a project, does not give up the project easily due to legal and moral reasons.

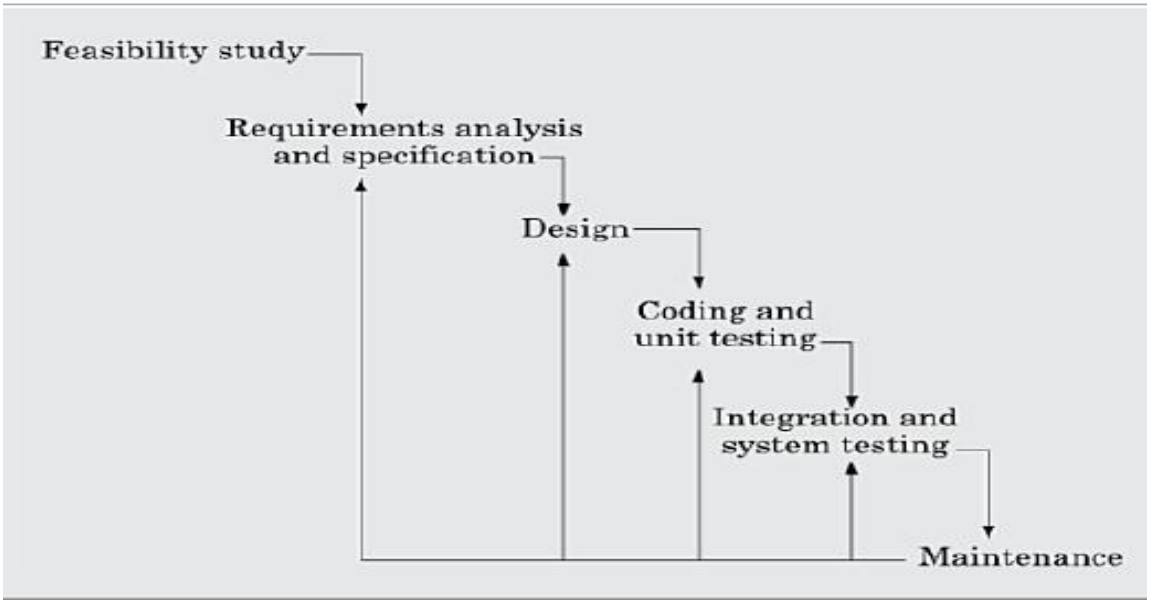


Figure 2.3 Iterative waterfall model

Advantages of Waterfall Model

The various advantages of the waterfall model include:

- ❖ It is a segmental model.
- ❖ It is systematic and sequential.
- ❖ It is a simple one.
- ❖ It has proper documentation.

Problems of waterfall model

i. It is difficult to define all requirements at the beginning of a project
ii. This model is not suitable for accommodating any change
iii. A working version of the system is not seen until late in the project's life

- Incremental delivery not supported

- Phase overlap not supported: For most real life projects, it becomes difficult to follow the rigid phase sequence prescribed by the waterfall model.
- Error correction unduly expensive: In waterfall model, validation is delayed till the complete development of the software.
- Limited customer interactions: This model supports very limited customer interactions.
- No support for risk handling and code reuse: It becomes difficult to use the waterfall model in projects that are susceptible to various types of risks, or those involving significant reuse of existing development artifacts.

Note:
If strict phase transitions are maintained, then the team members who complete their work early would idle waiting for the phase to be complete, and are said to be in a blocking state. Thus the developers who complete early would idle while waiting for their team mates to complete their assigned work. Clearly this is a cause for wastage of resources and a source of cost escalation and inefficiency.
As a result, in real projects, the phases are allowed to overlap.

2.3 V-Model

A popular development process model, V-model is a variant of the waterfall model.
In this model verification and validation activities are carried out throughout the development life cycle, and therefore the chances bugs in the work products considerably reduce. This model is therefore generally considered to be suitable for use in projects concerned with development of safety-critical software that are required to have high reliability.

As shown in Figure 2.4, there are two main phases—development and validation phases. The left half of the model comprises the development phases and the right half comprises the validation phases.

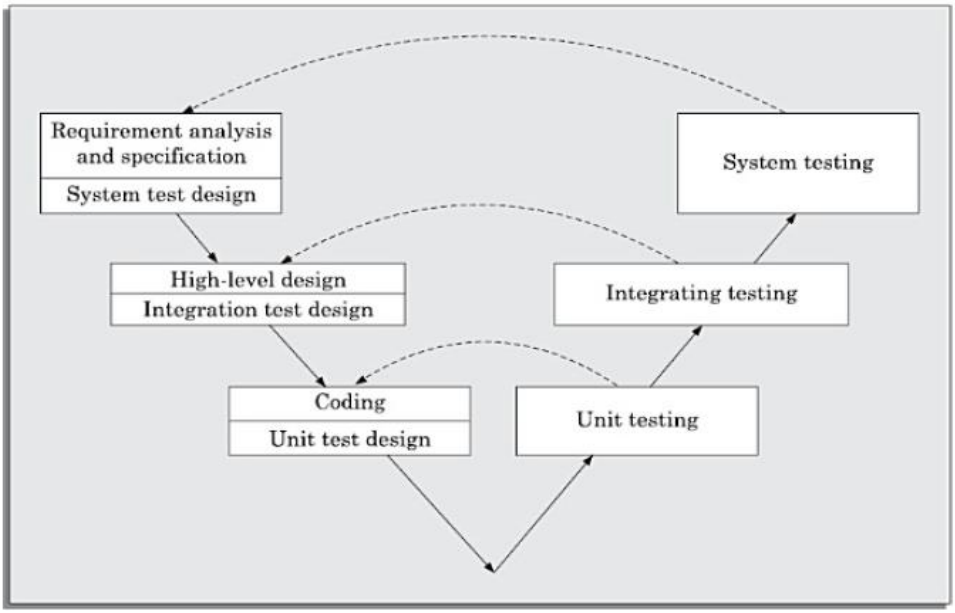


Figure 2.4 V-model

Note:
In contrast to the iterative waterfall model where testing activities are confined to the testing phase only, in the V-model testing activities are spread over the entire life cycle.

Advantages of V-model

- In the V-model, much of the testing activities (test case design, test planning, etc.) are carried out in parallel with the development activities. Therefore, before the testing phase starts, a significant part of the testing activities, including test case design and test planning, is already complete.

- The test team is reasonably kept occupied throughout the development cycle in contrast to the waterfall model where the testers are active only during the testing phase.
- In the V-model, the test team is associated with the project from the beginning. Therefore they build up a good understanding of the development artifacts, and this in turn, helps them to carry out effective testing of the software.

When to use V Model

- Natural choice for systems requiring high reliability:
  –Embedded control applications, safety-critical software
- All requirements are known up-front
- Solution and technology are known

Disadvantages of V-model

- Does not support overlapping of phases
- Does not handle iterations or phases
- Does not easily accommodate later changes to requirements
- Does not provide support for effective risk handling

Validation is the process of checking whether the specification captures the customer's needs, while **verification** is the process of checking that the **software** meets the specification:

- Verification: Are we building the product right?
- Validation: Are we building the right product?

2.4 PROTOTYPING MODEL

This model suggests building a working *prototype* of the system, before development of the actual software. A prototype is a toy and crude implementation of a system. It has limited functional capabilities, low reliability, or inefficient performance as compared to the actual software.

Necessity of the prototyping model

- It is advantageous to use the prototyping model for development of the *graphical user interface* (GUI) part of an application.

- The prototyping model is especially useful when the exact technical solutions are unclear to the development team.

Life cycle activities of prototyping model

As shown in Figure 2.5, software is developed through two major activities—prototype construction and iterative waterfall-based software development.

The code for the prototype is usually thrown away. However, the experience gathered from developing the prototype helps a great deal in developing the actual system.

Strengths of the prototyping model

This model is the most appropriate for projects that suffer from technical and requirements risks. A constructed prototype helps overcome these risks.

Weaknesses of the prototyping model

The prototype model can increase the cost of development for projects that are routine development work and do not suffer from any significant risks. Even when a project is susceptible to risks, the prototyping model is effective only for those projects for which the risks can be identified upfront before the development starts.

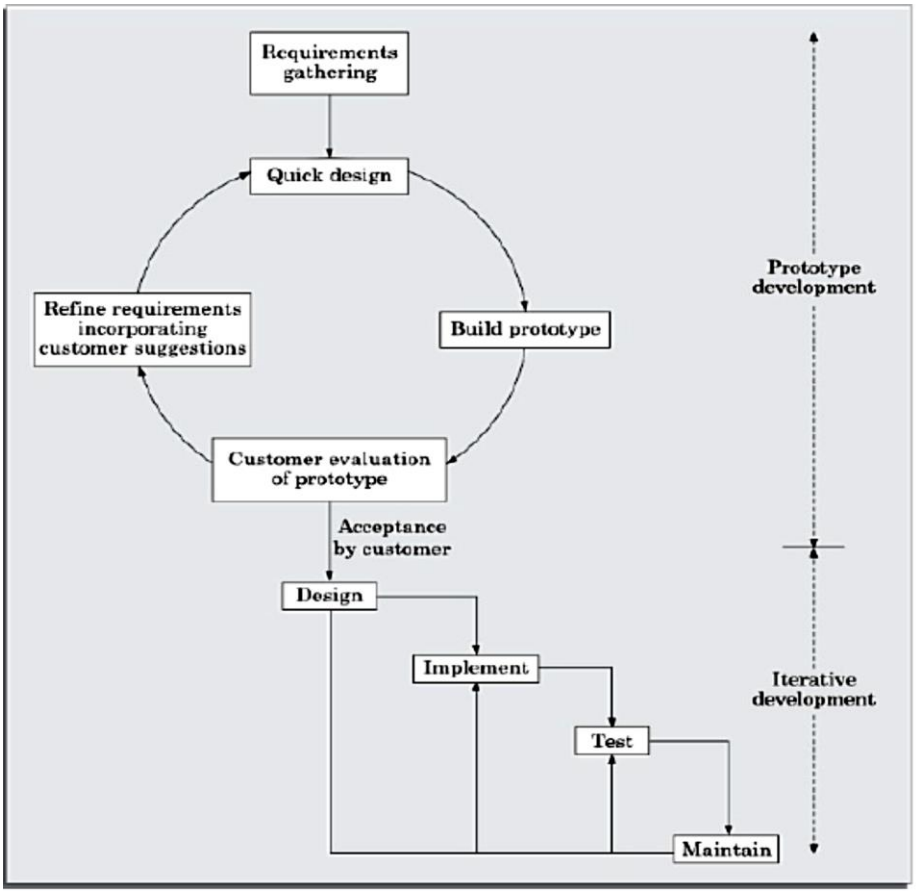


Figure 2.5 prototyping model of software development

2.5 Incremental Development Model

This life cycle model is sometimes referred to as the *successive versions* model and sometimes as the incremental model. In this life cycle model, first a simple working system implementing only a few basic features is built and delivered to the customer. Over many successive iterations successive versions are implemented and delivered to the customer until the desired system is realised.

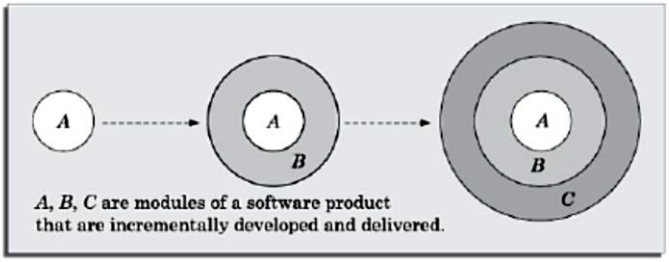


Figure 2.6 incremental software development

In the incremental life cycle model, the requirements of the software are first broken down into several modules or features that can be incrementally constructed and delivered.
The incremental model is schematically shown in Figure 2.7. As each successive version of the software is constructed and delivered to the customer, the customer feedback is obtained on the delivered version and these feedbacks are incorporated in the next version.

- Waterfall: single release
- Iterative: many releases (increments)
  - –First increment: core functionality
  - –Successive increments: add/fix functionality
  - –Final increment: the complete product
- Each iteration: a short mini-project with a separate lifecycle
  - –e.g., waterfall

Advantages

The incremental development model offers several advantages. Two important ones are the following:
Error reduction: The core modules are used by the customer from the beginning and therefore these get tested thoroughly. This reduces chances of errors in the core modules of the final product, leading to greater reliability of the software.
Incremental resource deployment: This model obviates the need for the customer to commit large resources at one go for development of the system. It also saves the developing organisation from deploying large resources and manpower for a project in one go.

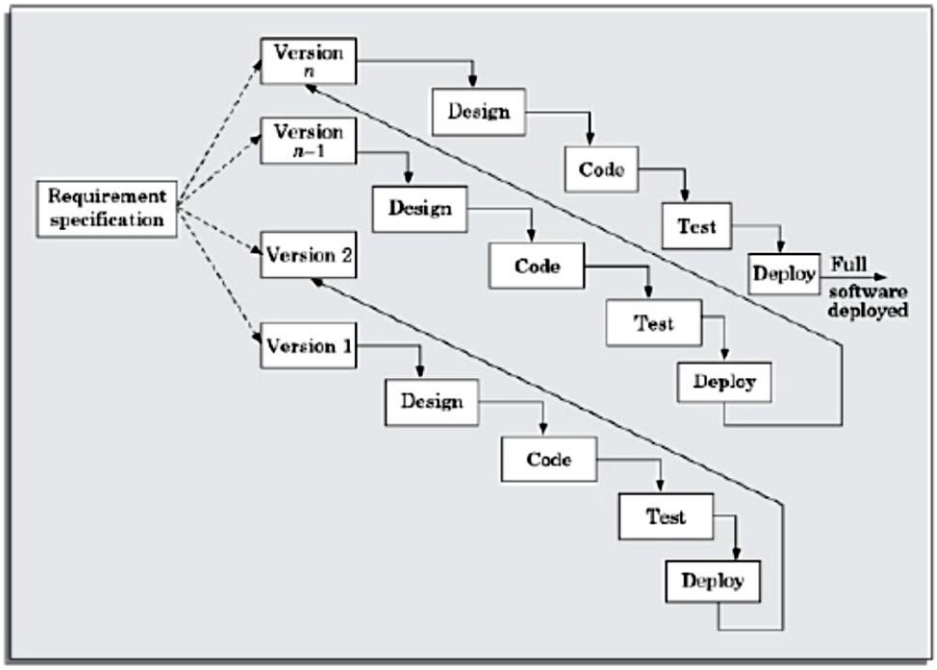


Figure 2.7 Incremental model of software development

2.6 Evolutionary Model

This model has many of the features of the incremental model. As in case of the incremental model, the software is developed over a number of increments.

In the incremental development model, complete requirements are first developed and the SRS document prepared. In contrast, in the evolutionary model, the requirements, plan, estimates, and solution evolve over the iterations, rather than fully defined and frozen in a major up-front specification effort before the development iterations begin. Such evolution is consistent with the pattern of unpredictable feature discovery and feature changes that take place in new product development.

The evolutionary software development process is sometimes referred to as *design a little, build a little, test a little, deploy a little* model. This means that after the requirements have been specified, the design, build, test, and deployment activities are iterated. A schematic representation of the evolutionary model of development has been shown in Figure 2.8.

Advantages

- Effective elicitation of actual customer requirements
- Easy handling changes requests

Disadvantages

- **Feature division into incremental parts can be non-trivial:** For many development projects, especially for small-sized projects, it is difficult to divide the required features into several parts that can be incrementally implemented and delivered.
- ***Ad hoc* design:** Since at a time design for only the current increment is done, the design can become ad hoc without specific attention being paid to maintainability and optimality. Obviously, for moderate sized problems and for those for which the customer requirements are clear, the iterative waterfall model can yield a better solution.

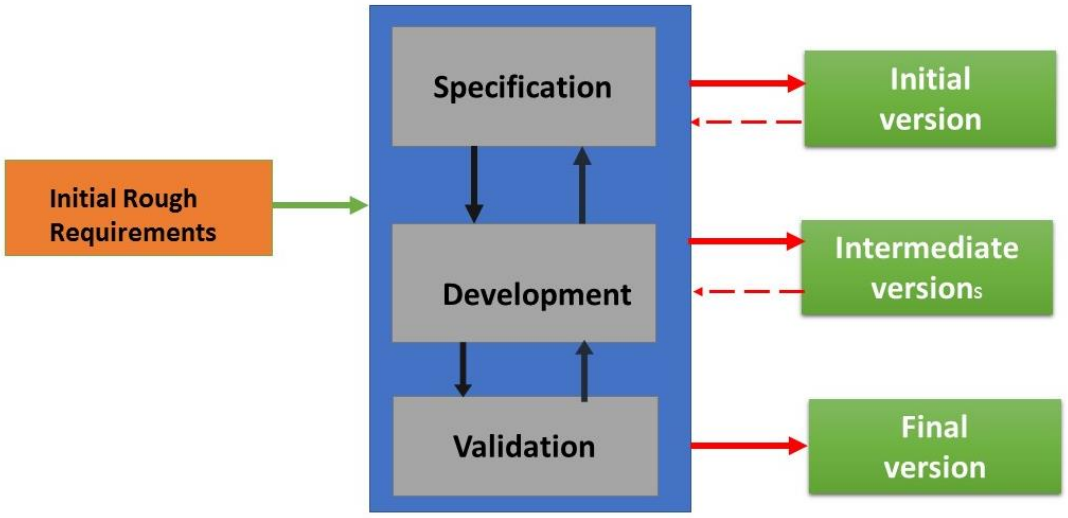


Figure 2.8 evolutionary model

2.7 RAPID APPLICATION DEVELOPMENT (RAD)

The *rapid application development* (RAD) model was proposed in the early nineties in an attempt to overcome the rigidity of the waterfall model (and its derivatives) that makes it difficult to accommodate any change requests from the customer. It proposed a few radical extensions to the waterfall model. This model has the features of both prototyping and evolutionary models. It deploys an evolutionary delivery model to obtain and incorporate the customer feedbacks on incrementally delivered versions.

In this model prototypes are constructed, and incrementally the features are developed and delivered to the customer. But unlike the prototyping model, the prototypes are not thrown away but are enhanced and used in the software construction

The major goals of the RAD model are as follows:

- To decrease the time taken and the cost incurred to develop software systems.
- To limit the costs of accommodating change requests.
- To reduce the communication gap between the customer and the developers.

often clients do not know what they exactly wanted until they saw a working system. It has now become well accepted among the practitioners that only through the process commenting on an installed application that the exact requirements can be brought out.

The customers usually suggest changes to a specific feature only after they have used it. Since the features are delivered in small increments, the customers are able to give their change requests pertaining to a feature already delivered.

Further, RAD advocates use of specialised tools to facilitate fast creation of working prototypes. These specialised tools usually support the following features:

- Visual style of development.
- Use of reusable components.

Applicability of RAD Model

The following are some of the characteristics of an application that indicate its suitability to RAD style of development:

Customised software: As already pointed out a customised software is developed for one or two customers only by adapting an existing software. In customised software development projects, substantial reuse is usually made of code from pre-existing software.

Non-critical software: the developed product is usually far from being optimal in performance and reliability. In this regard, for well understood development projects and where the scope of reuse is rather restricted, the iterative waterfall model may provide a better solution.

Large software: Only for software supporting many features (large software) can incremental development and delivery be meaningfully carried out.

Application characteristics that render RAD unsuitable

Generic products (wide distribution): software products are generic in nature and usually have wide distribution. For such systems, optimal performance and reliability are imperative in a competitive market. As it has already been discussed, the RAD model of development may not yield systems having optimal performance and reliability.

Requirement of optimal performance and/or reliability: For certain categories of products, optimal performance or reliability is required. Examples of such systems include an operating system (high reliability required) and a flight simulator software (high performance required). If such systems are to be developed using the RAD model, the desired product performance and reliability may not be realised.

Lack of similar products: If a company has not developed similar software, then it would hardly be able to reuse much of the existing artifacts. In the absence of sufficient plug-in components, it becomes difficult to develop rapid prototypes through reuse, and use of RAD model becomes meaningless.

Monolithic entity: For certain software, especially small-sized software, it may be hard to divide the required features into parts that can be incrementally developed and delivered. In this case, it becomes difficult to develop a software incrementally.

RAD *versus* prototyping model

In the prototyping model, the developed prototype is primarily used by the development team to gain insights into the problem, choose between alternatives, and elicit customer feedback.

RAD *versus* iterative waterfall model

In the iterative waterfall model, all the functionalities of a software are developed together. On the other hand, in the RAD model the product functionalities are developed incrementally through heavy code and design reuse.

RAD *versus* evolutionary model

Incremental development is the hallmark of both evolutionary and RAD models. However, in RAD each increment results in essentially a quick and dirty prototype, whereas in the evolutionary model each increment is systematically developed using the iterative waterfall model. Also in the RAD model, software is developed in much shorter increments compared the evolutionary model.

2.8 SPIRAL MODEL

The spiral model, originally proposed by Boehm, is an evolutionary software model that couples the iterative nature of prototyping with the controlled and systematic aspects of the linear segmental model.
The goal of the spiral model of the software production process is to provide a framework for designing such processes, guided by the risk levels in the projects at hand.
Let us present a few definitions. Risks are potentially adverse circumstances that may impair the development process and the quality of products. Boehm [1989] defines risk management as a discipline whose objectives are to identify, address, and eliminate software risk items before they become either threats to successful software operation or a major source of expensive software rework. The spiral model focuses on identifying and eliminating high-risk problems by careful process design, rather than treating both trivial and severe problems uniformly.

The spiral model is recommended where the requirements and solutions call for developing full-fledged, large, complex systems with many features and facilities from scratch. It is used when experimenting on technology, trying out new skills, and when the user is not able to offer requirements in clear terms. It is also useful when the requirements are not clear and when the solution intended has multi-users, multi-functions, multi-features, multi-location applications to be used on multiple platforms, where seamless integration, interfacing, data migration, and replication are the issues. The radial dimension of a cycle represents the cumulative costs, and the angular dimension represents the progress made in completing each cycle of the spiral.

Each loop of the spiral represents a phase of the software process:

- the innermost loop might be concerned with system feasibility,
- the next loop with system requirements definition,
- the next one with system design, and so on.

There are no fixed phases in this model, the phases shown in the figure 2.9 are just examples.
•The team must decide:
  –how to structure the project into phases.
•Start work using some generic model:
  –add extra phases
    •for specific projects or when problems are identified during a project.
•Each loop in the spiral is split into four sectors (quadrants).

Objective Setting (First Quadrant)

- ✓ Identify objectives of the phase,
- ✓ Find alternate solutions possible.

Risk Assessment and Reduction (Second Quadrant)

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

Development and Validation (Third quadrant)

- ✓ develop and validate the next level of the product.

Review and Planning (Fourth quadrant):

- ✓ review the results achieved so far with the customer and plan the next iteration around the spiral.

With each iteration around the spiral:

- ✓ progressively more complete version of the software gets built.

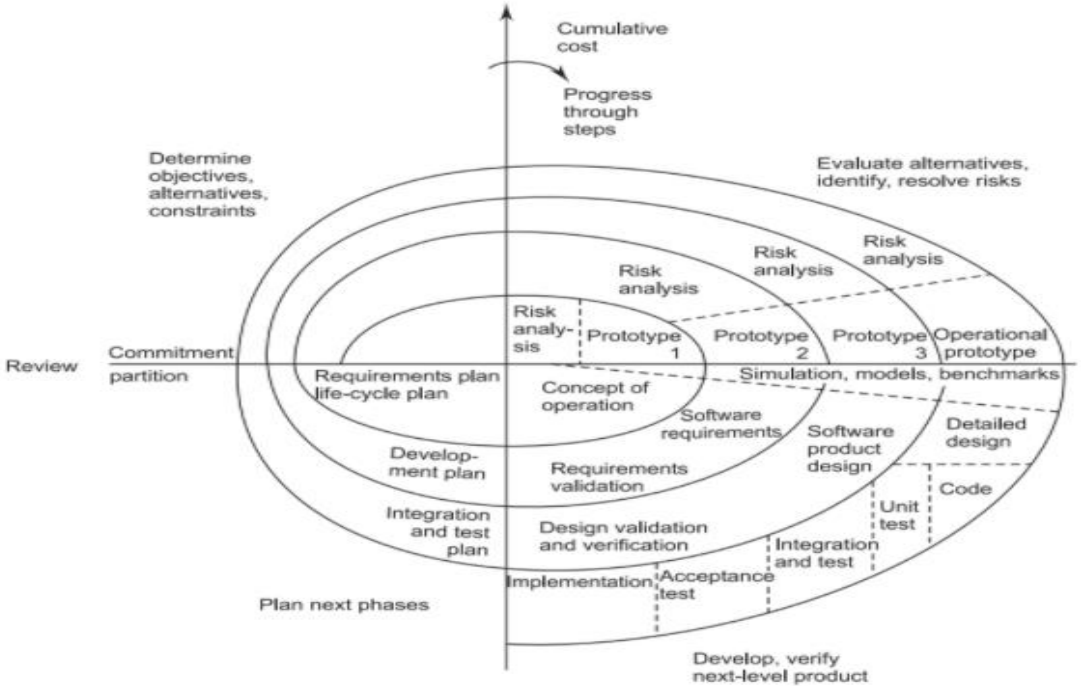


Figure 2.9 The Spiral Model

2.9 Agile Model

The meaning of Agile is swift or versatile. **"Agile process model**" refers to a software development approach based on iterative development. Agile methods break tasks into smaller iterations, or parts do not directly involve long term planning. The project scope and requirements are laid down at the beginning of the development process. Plans regarding the number of iterations, the duration and the scope of each iteration are clearly defined in advance.

•To overcome the shortcomings of the waterfall model of development.
–Proposed in mid-1990s
•The agile model was primarily designed:
–To help projects to adapt to change requests
•In the agile model:
–The requirements are decomposed into many small incremental parts that can be developed over one to four weeks each.

In 2001, these seventeen software developers met at a resort in Snowbird, Utah to discuss these lightweight development methods: Kent Beck, Ward Cunningham, Dave Thomas, Jeff Sutherland, Ken Schwaber, Jim Highsmith, Alistair Cockburn, Robert C. Martin, Mike Beedle, Arie van Bennekum, Martin Fowler, James Grenning, Andrew Hunt, Ron Jeffries, Jon Kern, Brian Marick, and Steve Mellor. Together they published the ***Manifesto for Agile Software Development***.

Ideology: Agile Manifesto
•Individuals and interactions ***over*** process and tools
•Working Software ***over*** comprehensive documentation
•Customer collaboration ***over*** contract negotiation
•Responding to change ***over*** following a plan

Agile software development principles

The *Manifesto for Agile Software Development* is based on twelve principles:

1. Customer satisfaction by early and continuous delivery of valuable software.
2. Welcome changing requirements, even in late development.
3. Deliver working software frequently (weeks rather than months)
4. Close, daily cooperation between business people and developers
5. Projects are built around motivated individuals, who should be trusted
6. Face-to-face conversation is the best form of communication (co-location)

Face-to-face communication favoured over written documents.

•To facilitate face-to-face communication,
–Development team to share a single office space.

–Team size is deliberately kept small (5-9 people)

–This makes the agile model most suited to the development of small projects.

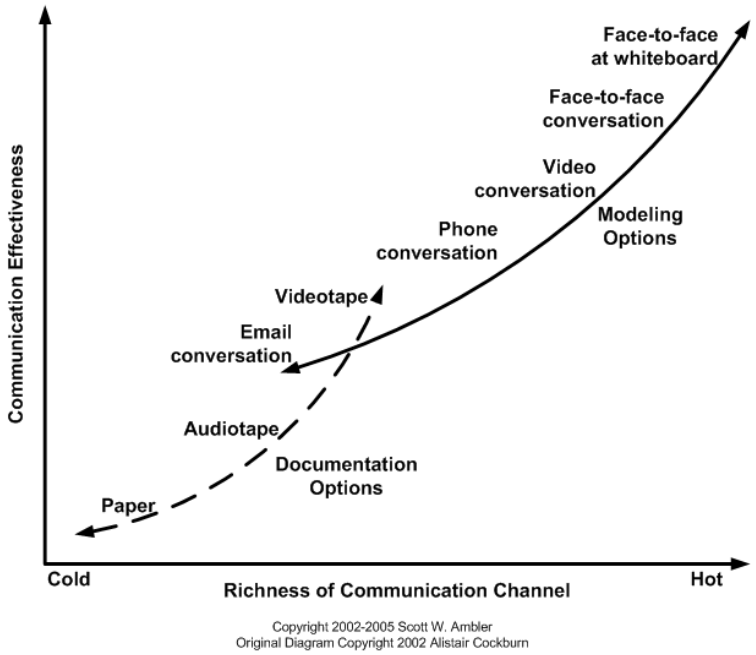


Figure 2.10 model of communication

7. Working software is the primary measure of progress
8. Sustainable development, able to maintain a constant pace
9. Continuous attention to technical excellence and good design
10. Simplicity—the art of maximizing the amount of work not done—is essential
11. Best architectures, requirements, and designs emerge from self-organizing teams
12. Regularly, the team reflects on how to become more effective, and adjusts accordingly

- The most popular Agile methods include Rational Unified Process (1994), Scrum (1995), Crystal Clear, Extreme Programming (1996), Adaptive Software Development, Feature Driven Development, and Dynamic Systems Development Method (DSDM) (1995). These are now collectively referred to as **Agile Methodologies**, after the Agile Manifesto was published in 2001.

2.9.1 Scrum

Scrum is based on the idea of adding value to a software product in an iterative manner. The software development process is repeated—iterated—multiple times until the software product is considered complete or the process is otherwise stopped. These iterations are called *sprints*, and they culminate in software that is *potentially* releasable. All work is prioritized on the *product backlog* and, at the start of each sprint, the development team commits to the work that they will complete during the new iteration by placing it on the *sprint backlog*. The unit of work within Scrum is the *story*. The product backlog is a

prioritized queue of pending stories, and each sprint is defined by the stories that will be developed during an iteration.

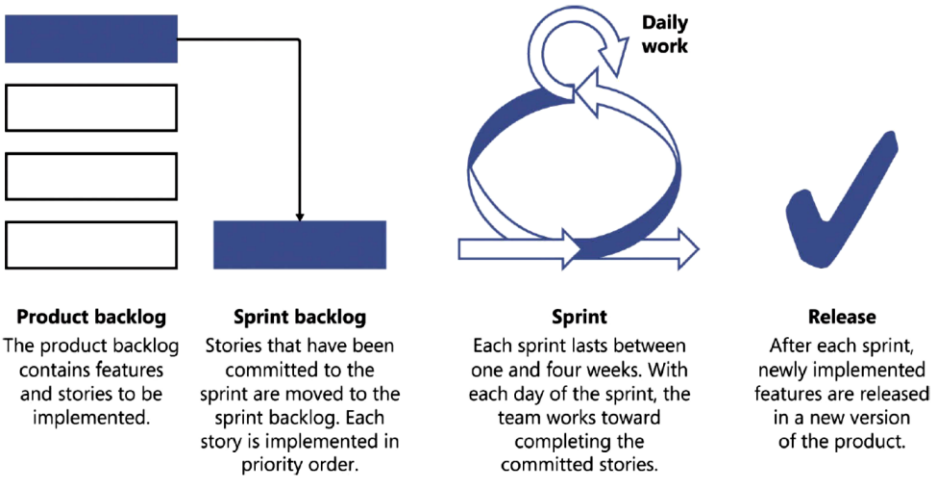


Figure 2.11 Scrum works like a production line for small features of a software product.

•Self-organizing teams
•Product progresses in a series of month-long **sprints**
•Requirements are captured as items in a list of **product backlog**
•**Software increment is designed, coded, and tested during the sprint**
•**No changes entertained during a sprint**

- The time to complete an iteration is called a *time box*

2.9.1.1 Scrum Framework
•Roles : Product Owner, ScrumMaster, Team

•Product Owner
–Acts on behalf of customer to represent their interests.

- Defines the features of the product
- Decide on release date and content
- Prioritize features according to market value
- Adjust features and priority every iteration, as needed
- Accept or reject work results.

- Scrum Master (aka Project Manager)

•Represents management to the project
•Removes impediments
•Ensure that the team is fully functional and productive
•Enable close cooperation across all roles and functions
•Shield the team from external interferences

–Facilitates scrum process and resolves impediments at the team and organization level by acting as a buffer between the team and outside interference.

•Development Team

•Typically 5-10 people
•Cross-functional
–QA, Programmers, UI Designers, etc.
•Teams are self-organizing
•Membership can change only between sprints.

2.9.1.2 Scrum Events

Prescribed events are used in Scrum to create regularity and to minimize the need for meetings not defined in Scrum. Scrum uses time-boxed events, such that every event has a maximum duration. This ensures an appropriate amount of time is spent planning without allowing waste in the planning process.
Scrum Events consist of the following:

- **The Sprint:**
  The heart of Scrum is Sprint, a time-box of one month or less during which a "Done", usable and potentially releasable product increment is developed. Sprint have consistent duration, a new Sprint starts immediately after the conclusion of the previous Sprint.

  Sprints consist of the Sprint Planning Meeting, Daily Scrum, the development work, the Sprint Review and the Sprint Retrospective.

  During the Sprint no changes are made that would affect the Sprint Goal. Quality goals do not decrease and scope may be clarified. Sprints are limited to one calendar month.

- **Canceling The Sprint:**

  A Sprint can be canceled before the Sprint time-box is over. Only the product owner has the authority to cancel the Sprint. A Sprint would be canceled if the Sprint goal becomes obsolete.

- **Sprint Planning Meeting:**

  The work to be done in Sprint is planned during the Sprint Planning Meeting. The plan is developed by the work of the entire Scrum team. Sprint planning is time-boxed for eight hours for a one-month Sprint. Sprint Planning meeting consist of two parts.

  Part 1: What will be done this Sprint?
  In this phase team works to forecast functionality that will be developed during the Sprint.
  Part 2 : How will the chosen work get done?
  Once the work is selected, the team decides how it will build the functionality into a "Done" product.

- **Sprint Goal:**

  As the development team works it keeps this goal in mind. In order to satisfy this goal, it implements the functionality and technology.

- **Daily Scrum:**

  The daily scrum is a 15-minute time-boxed event for the team to synchronize activities for the next 24 hours. The Daily Scrum is held at the same time and place each day to reduce complexity. During the meeting, each Development Team member explains:
  - What has been accomplished since the last meeting?
  - What will be done before the next meeting?
  - What obstacles are in the way?

The Daily Scrum improves communications, eliminates other meetings and highlights and promotes quick decision making.

- **Sprint Review:**

  A sprint review is held at the end of the Sprint to inspect increment and adapt the product Backlog if needed. The result of the Sprint Review is a revised Product Backlog that defines the probable Product Backlog items for the next Sprint. The Product Backlog may also be adjusted to meet new opportunities.

- **Sprint Retrospective:**

  The Sprint Retrospective is an opportunity for the Scrum Team to inspect itself and create a plan for improvements to be enacted during the next Sprint.

  By end of the Retrospective, the Scrum Team should have identified improvements that it will implement in the next Sprint.

2.9.1.3 Scrum Artifacts

- **Product Backlog:**

  The Product Backlog lists all features, functions, requirements, enhancements, and fixes that constitute the changes to be made to the product in the future releases. Requirements never stop changing. Changes in business requirements, market conditions, or technology may cause changes in the Product Backlog.

- **Sprint Backlog:**

  The Sprint Backlog is the set of Product Backlog items selected for the Sprint plus a plan for delivering the product Increment and realizing the Sprint Goal. The Sprint Backlog is a forecast by the Development Team about what functionality will be in the next Increment and the work needed to deliver that functionality.

- **Monitoring Sprint Progress:**
  Development team tracks total work remaining at least for every Daily Scrum. Development team tracks these sums daily and projects likelihood of achieving the Sprint Goals.

- **Increment:**
  The Increment is the sum of all the Product Backlog items completed during a Sprint and all previous Sprints.

2.9.2 XP

Extreme Programming (XP) was created in response to problem domains whose requirements change. Your customers may not have a firm idea of what the system should do.

When Applicable

The general characteristics where XP is appropriate were described by Don Wells on www.extremeprogramming.org:

- Dynamically changing software requirements
- Risks caused by fixed time projects using new technology
- Small, co-located extended development team
- The technology you are using allows for automated unit and functional tests

Extreme Programming emphasizes teamwork. Managers, customers, and developers are all equal partners in a collaborative team. Extreme Programming implements a simple, yet effective environment enabling teams to become highly productive. The team self-organizes around the problem to solve it as efficiently as possible.

Extreme Programming improves a software project in five essential ways; communication, simplicity, feedback, respect, and courage. Extreme Programmers constantly communicate with their customers and fellow programmers. They keep their design simple and clean. They get feedback by testing their software starting on day one. They deliver the system to the customers as early as possible and implement changes as suggested. Every small success deepens their respect for the unique contributions of each and every team member. With this foundation Extreme Programmers are able to courageously respond to changing requirements and technology.

Extreme Programming Activities

•XP Planning

- •Begins with the creation of "user stories"
- •Agile team assesses each story and assigns a cost
- •Stories are grouped to for a deliverable increment
- •A commitment is made on delivery date

•XP Design

- •Follows the ***keep it simple and straightforward*** principle
- •Encourage the use of CRC (**Class-responsibility-collaboration** (**CRC**) **cards)**
- •For difficult design problems, suggests the creation of "spike solutions"—a design prototype
- •Encourages "refactoring"—an iterative refinement of the internal program design

•XP Coding

- •Recommends the construction of unit test cases *before* coding commences (test-driven development)
- •Encourages "pair programming"

•**XP Testing**

•All unit tests are executed daily

•"Acceptance tests" are defined by the customer and executed to assess customer visible functionalities

These four basic activities need to be structured in the light of the Extreme Programming principles. To accomplish this, the Extreme Programming practices are defined.

Kent Beck, the author of 'Extreme Programming Explained' defined 12 Extreme Programming practices as follows −

1.Planning/Planning game–determine scope of the next release by combining business priorities and technical estimates

2.Small releases–put a simple system into production, then release new versions in very short cycles

3.Metaphor–all development is guided by a simple shared story of how the whole system works

4.Simple design–system is to be designed as simple as possible

5.Testing–programmers continuously write and execute unit tests

6.Refactoring–programmers continuously restructure the system without changing its behavior to remove duplication and simplify.

7.Pair-programming--all production code is written with two programmers at one machine

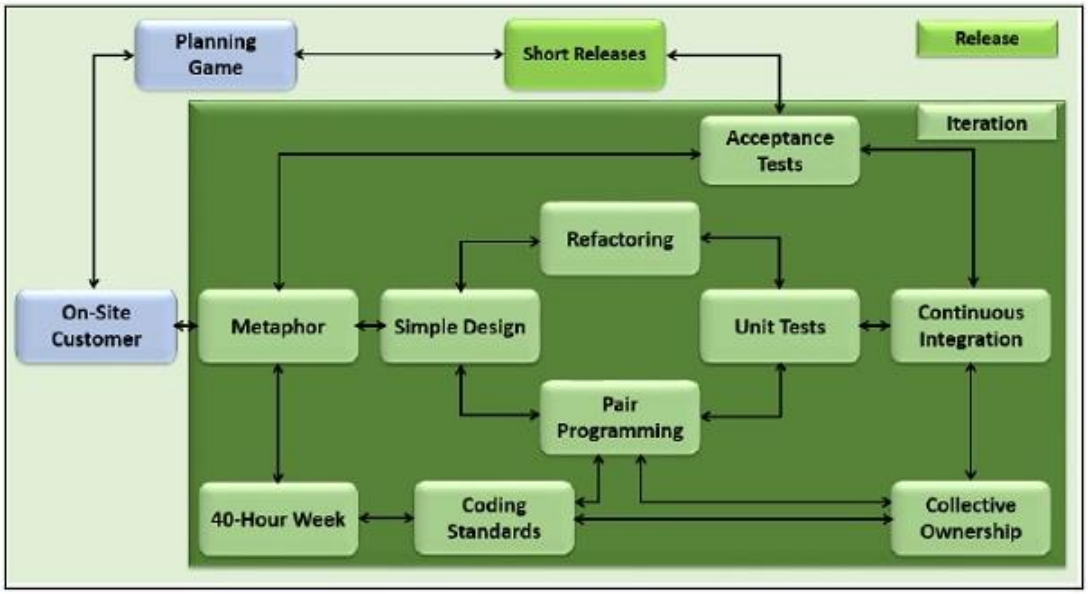
8.Collective ownership–anyone can change any code anywhere in the system at any time.

9.Continuous integration–integrate and build the system many times a day –every time a task is completed.

10.40-hour week–work no more than 40 hours a week as a rule

11.On-site customer–a user is a part of the team and available full-time to answer questions

12.Coding standards–programmers write all code in accordance with rules emphasizing communication through the code.



- ✓ A user story is a well-formed, short and simple description of a software requirement from the perspective of an end-user, written in an informal and natural language. It is the main artifact used in the agile software development process to capture user requirements.

- ✓ After user stories have been written you can use a release planning meeting to create a release plan. The release plan specifies which user stories are going to be implemented for each system release and dates for those releases.
- ✓ A spike solution is a very simple program to explore potential solutions. Build the spike to only addresses the problem under examination and ignore all other concerns.

3. SOFTWARE PROJECT MANAGEMENT

The main goal of software project management is to enable a group of developers to work effectively towards the successful completion of a project.

3.1 SOFTWARE PROJECT MANAGEMENT COMPLEXITIES

The main factors contributing to the complexity of managing a software project:

Invisibility: Invisibility of software makes it difficult to assess the progress of a project and is a major cause for the complexity of managing a software project.

Changeability: Because the software part of any system is easier to change as compared to the hardware part, the software part is the one that gets most frequently changed.
Complexity: Even a moderate sized software has millions of parts (functions) that interact with each other in many ways—data coupling, serial and concurrent runs, state transitions, control dependency, file sharing, etc.
Uniqueness: Every software project is usually associated with many unique features or situations. This makes every project much different from the others. This is unlike projects in other domains, such as car manufacturing.
Exactness of the solution: Mechanical components such as nuts and bolts typically work satisfactorily as long as they are within a tolerance of 1 per cent or so of their specified sizes. However, the parameters of a function call in a program are required to be in complete conformity with the function definition. This requirement not only makes it difficult to get a software product up and working, but also makes reusing parts of one software product in another difficult.
Team-oriented and intellect-intensive work: Software development projects are akin to research projects in the sense that they both involve team-oriented, intellect-intensive work. In contrast, projects in many domains are labour-intensive and each member works in a high degree of autonomy.

3.2 RESPONSIBILITIES OF A SOFTWARE PROJECT MANAGER

We can broadly classify a project manager's varied responsibilities into the following two major categories:
• **Project planning** is undertaken immediately after the feasibility study phase and before the starting of the requirements analysis and specification phase.
Project planning involves estimating several characteristics of a project and then planning the project activities based on these estimates made.
The initial project plans are revised from time to time as the project progresses and more project data become available.
• **Project monitoring and control** are undertaken once the development activities start. The focus of project monitoring and control activities is to ensure that the software development proceeds as per plan.

Skills Necessary for Managing Software Projects
Three skills that are most critical to successful project management are the following:
• Knowledge of project management techniques.
• Decision taking capabilities.
• Previous experience in managing similar projects.

3.2.1 Project planning

- Requires utmost care and attention --- commitments to unrealistic time and resource estimates result in:
  - irritating delays.
  - customer dissatisfaction
  - adverse affect on team morale
    - poor quality work
  - project failure.

During project planning, the project manager performs the following Activities:

Estimation*:* The following project attributes are estimated.

- **Cost:** How much is it going to cost to develop the software product?
- **Duration:** How long is it going to take to develop the product?
- **Effort:** How much effort would be necessary to develop the product?

✓ The effectiveness of all later planning activities such as scheduling and staffing are dependent on the accuracy with which these three estimations have been made.

Scheduling: the schedules for manpower and other resources are developed.
Staffing: Staff organisation and staffing plans are made.

Risk management: This includes risk identification, analysis, and abatement planning.
Miscellaneous plans: This includes making several other plans such as quality assurance plan, and configuration management plan, etc.

Figure 3.1 shows the order in which the planning activities are undertaken.

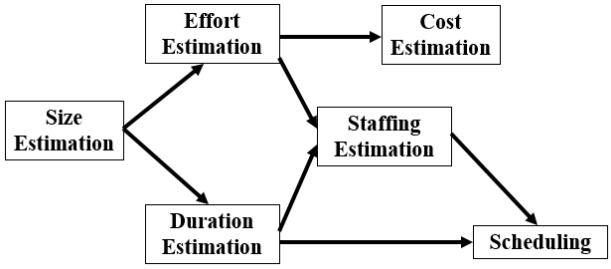


Figure 3.1: Precedence ordering among planning activities.

Based on the effort estimation, the cost of the project is computed. The estimated cost forms the basis on which price negotiations with the customer is carried out.

3.2.1.1 Sliding Window Planning

It is usually very difficult to make accurate plans for large projects at project initiation. A part of the difficulty arises from the fact that large projects may take several years to complete. As a result, during the span of the project, the project parameters, scope of the project, project staff, etc., often change drastically resulting in the initial plans going haywire.

- In order to overcome this problem, sometimes project managers undertake project planning over several stages:
  - protects managers from making big commitments too early.

- More information becomes available as project progresses.
  - Facilitates accurate planning.

3.2.1.2 The SPMP Document of Project Planning

Once project planning is complete, project managers document their plans in a software project management plan (SPMP) document. Listed below are the different items that the SPMP document should discuss.

Organisation of the software project management plan (SPMP) document

1. **Introduction**
(a) Objectives
(b) Major Functions
(c) Performance Issues
(d) Management and Technical Constraints
2. **Project estimates**
(a) Historical Data Used
(b) Estimation Techniques Used
(c) Effort, Resource, Cost, and Project Duration Estimates
3. **Schedule**
(a) Work Breakdown Structure
(b) Task Network Representation
(c) Gantt Chart Representation
(d) PERT Chart Representation
4. **Project resources**
(a) People
(b) Hardware and Software
(c) Special Resources
5. **Staff organisation**
(a) Team Structure
(b) Management Reporting
6. **Risk management plan**
(a) Risk Analysis
(b) Risk Identification
(c) Risk Estimation
(d) Risk Abatement Procedures
7. **Project tracking and control plan**
(a) Metrics to be tracked
(b) Tracking plan
(c) Control plan
8. **Miscellaneous plans**
(a) Process Tailoring
(b) Quality Assurance Plan
(c) Configuration Management Plan
(d) Validation and Verification
(e) System Testing Plan
(f) Delivery, Installation, and Maintenance Plan

3.3 METRICS FOR PROJECT SIZE ESTIMATION

The project size is a measure of the problem complexity in terms of the effort and time required to develop the product.

3.3.1 Lines of Code (LOC)

- Simplest and most widely used metric.
- Comments and blank lines should not be counted.

However, accurate estimation of LOC count at the beginning of a project is a very difficult task. One can possibly estimate the LOC count at the starting of a project, only by using some form of systematic guess work. Systematic guessing typically involves the following.

- The project manager divides the problem into modules, and each module into sub-modules and so on, until the LOC of the leaf-level modules are small enough to be predicted.
- To be able to predict the LOC count for the various leaf-level modules sufficiently accurately, past experience in developing similar modules is very helpful.

Disadvantages of LOC

- **LOC is a measure of coding activity alone.** A good problem size measure should consider the total effort needed to carry out various life cycle activities (i.e. specification, design, code, test, etc.) and not just the coding effort.
- **LOC count depends on the choice of specific instructions:** LOC gives a numerical value of problem size that can vary widely with coding styles of individual programmers.
- **LOC measure correlates poorly with the quality and efficiency of the code:** Larger code size does not necessarily imply better quality of code or higher efficiency.
- **LOC metric penalises use of higher-level programming languages and code reuse:** A paradox is that if a programmer consciously uses several library routines, then the LOC count will be lower.
- **LOC metric measures the lexical complexity of a program and does not address the more important issues of logical and structural complexities:** Between two programs with equal LOC counts, a program incorporating complex logic would require much more effort to develop than a program with very simple logic.
- **It is very difficult to accurately estimate LOC of the final program from problem specification.**

3.3.2 Function Point (FP) Metric

Function point metric was proposed by Albrecht in 1983. This metric overcomes many of the shortcomings of the LOC metric. Function point metric has several advantages over LOC metric. One of the important advantages of the function point metric over the LOC metric is that it can easily be computed from the problem specification itself.

Conceptually, the function point metric is based on the idea that a software product supporting many features would certainly be of larger size than a product with less number of features.

Albrecht postulated that in addition to the number of basic functions that a software performs, size also depends on the number of files and the number of interfaces that are associated with the software.

- Input: A set of related inputs is counted as one input.
- Output: A set of related outputs is counted as one output.
- Inquiries: Each user query type is counted (without any data input).
- Files: Files are logically related data and thus can be data structures or physical files.
- Interface: Data transfer to other systems.

The five functional units are divided in two categories:
(i) Data function types

- Internal Logical Files (ILF): A user identifiable group of logical related data or control information maintained within the system.

- External Interface files (EIF): A user identifiable group of logically related data or control information referenced by the system, but maintained within another system. This means that EIF counted for one system, may be an ILF in another system.

(ii) Transactional function types

- External Input (EI): An EI processes data or control information that comes from outside the system. The EI is an elementary process, which is the smallest unit of activity that is meaningful to the end user in the business.
- External Output (EO): An EO is an elementary process that generate data or control information to be sent outside the system.
- External Inquiry (EQ): An EQ is an elementary process that is made up to an input-output combination that results in data retrieval
- Function points are directly linked to the statement of requirements; any change of requirements can easily be followed by a re-estimate.
- Function points are based on the system user's external view of the system, non-technical users of the software system have a better understanding of what function points are measuring.

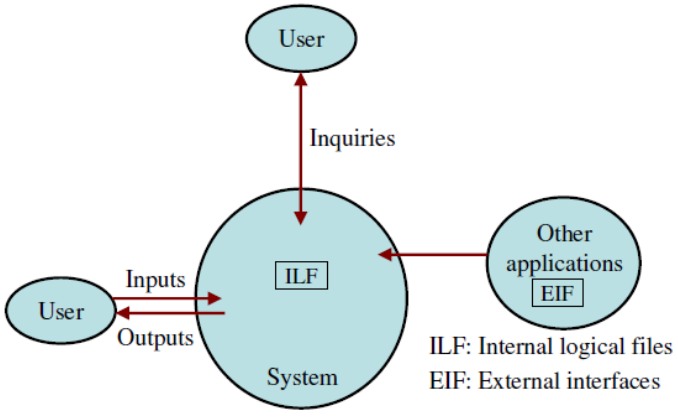


Figure 3.2: FPAs functional unit System

Special features

- Function point approach is independent of the language, tools, or methodologies used for implementation; i.e. they do not take into consideration programming languages, data base management systems, processing hardware or any other data base technology.

- Function points can be estimated from requirement specification or design specification, thus making it possible to estimate development efforts in early phases of development.

Counting function points

Functional Units	Weighting factors		
	Low	Average	High
External Inputs (EI)	3	4	6
External Output (EO)	4	5	7
External Inquiries (EQ)	3	4	6
External logical files (ILF)	7	10	15
External Interface files (EIF)	5	7	10

Table 1 : Functional units with weighting factors

Table 2: UFP calculation table

Functional Units	Count Complexity		Complexity Totals	Functional Unit Totals
External Inputs (EIs)		Low x 3 =		
		Average x 4 =		
		High x 6 =		
External Outputs (EOs)		Low x 4 =		
		Average x 5 =		
		High x 7 =		
External Inquiries (EQs)		Low x 3 =		
		Average x 4 =		
		High x 6 =		
External logical Files (ILFs)		Low x 7 =		
		Average x 10 =		
		High x 15 =		
External Interface Files (EIFs)		Low x 5 =		
		Average x 7 =		
		High x 10 =		
Total Unadjusted Function Point Count				

The weighting factors are identified for all functional units and multiplied with the functional units accordingly. The procedure for the calculation of *Unadjusted Function Point (UFP)* is given in table shown above.

The procedure for the calculation of UFP in mathematical form is given below:

$$UFP = \sum_{i=1}^{5} \sum_{J=1}^{3} Z_{ij} w_{ij}$$

Where i indicate the row and j indicates the column of Table 2
W_{ij} : It is the entry of the ith row and jth column of the table 3
Z_{ij} : It is the count of the number of functional units of Type *i* that have been classified as having the complexity corresponding to column *j*.

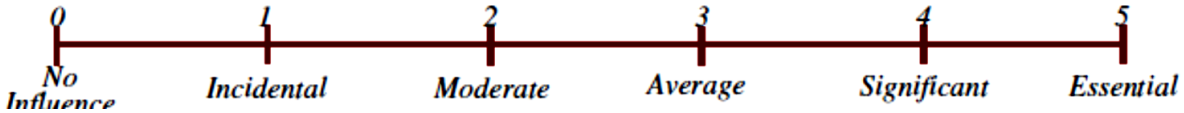
Organizations that use function point methods develop a criterion for determining whether a particular entry is Low, Average or High. Nonetheless, the determination of complexity is somewhat subjective.

$$FP = UFP * CAF$$

Where CAF is complexity adjustment factor and is equal to [0.65 + 0.01 x ∑Fi]. The Fi (*i*=1 to 14) are the degree of influence and are based on responses to questions noted in table 3.

Table 3 : Computing function points.

Rate each factor on a scale of 0 to 5.



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

Functions points may compute the following important metrics:
Productivity = FP / persons-months
Quality = Defects / FP
Cost = Dollar / FP
Documentation = Pages of documentation per FP

These metrics are controversial and are not universally acceptable.
There are standards issued by the International Functions Point User Group (IFPUG, covering the Albrecht method) and the United Kingdom Function Point User Group (UFPGU, covering the MK11 method). An ISO standard for function point method is also being developed.

Example: 3.1

Consider a project with the following functional units:
Number of user inputs = 50
Number of user outputs = 40
Number of user enquiries = 35
Number of user files = 06
Number of external interfaces = 04
Assume all complexity adjustment factors and weighting factors are average. Compute the function points for the project.

Solution

UFP = 50 x 4 + 40 x 5 + 35 x 4 + 6 x 10 + 4 x 7
= 200 + 200 + 140 + 60 + 28 = 628
CAF = (0.65 + 0.01 ∑Fi)
= (0.65 + 0.01 (14 x 3)) = 0.65 + 0.42 = 1.07
FP = UFP x CAF
= 628 x 1.07 = 672

Example:3.2

An application has the following:
10 low external inputs, 12 high external outputs, 20 low internal logical files, 15 high external interface files, 12 average external inquiries, and a value of complexity adjustment factor of 1.10.
What are the unadjusted and adjusted function point counts ?

Solution

Unadjusted function point counts may be calculated using as:

$$UFP = \sum_{i=1}^{5} \sum_{J=1}^{3} Z_{ij} w_{ij}$$

= 10 x 3 + 12 x 7 + 20 x 7 + 15 + 10 + 12 x 4
= 30 + 84 +140 + 150 + 48
= 452
FP = UFP x CAF
= 452 x 1.10 = 497.2.

Example: 3.3

Consider a project with the following parameters.
(*i*) External Inputs:
(a)10 with low complexity
(b)15 with average complexity
(c)17 with high complexity
(*ii*) External Outputs:
(a)6 with low complexity

(b)13 with high complexity

(*iii*) External Inquiries:

(a) 3 with low complexity

(b) 4 with average complexity

(c) 2 high complexity

(*iv*) Internal logical files:

(a)2 with average complexity

(b)1 with high complexity

(v) External Interface files:

(a)9 with low complexity

In addition to above, system requires

i. Significant data communication

ii. Performance is very critical

iii. Designed code may be moderately reusable

iv. System is not designed for multiple installation in different organizations.

Other complexity adjustment factors are treated as average. Compute the function points for the project.

$\sum_{i=1}^{14} Fi = 3+4+3+5+3+3+3+3+3+3+2+3+0+3=41$

CAF = (0.65 + 0.01 x ∑Fi)

= (0.65 + 0.01 x 41)

= 1.06

FP = UFP x CAF

= 424 x 1.06

= 449.44

Hence FP = 449

Function Point is subjective --- Different people can come up with different estimates for the same problem

3.4 PROJECT ESTIMATION TECHNIQUES

The different parameters of a project that need to be estimated include—project size, effort required to complete the project, project duration, and cost. Accurate estimation of these parameters is important, since these not only help in quoting an appropriate project cost to the customer, but also form the basis for resource planning and scheduling. These can broadly be classified into three main categories:

• Empirical estimation techniques

• Heuristic techniques

• Analytical estimation techniques

3.4.1 Empirical Estimation Techniques

Empirical estimation techniques are essentially based on making an educated guess of the project parameters. While using this technique, prior experience with development of similar products is helpful.

1- Expert Judgement:

- Experts divide a software product into component units: e.g. GUI, database module, data communication module, billing module, etc.
- Add up the guesses for each of the components.
- Suffers from individual bias.

2- Delphi Estimation:

- overcomes some of the problems of expert judgement.
- Team of Experts and a coordinator.
- Experts carry out estimation independently:
  - mention the rationale behind their estimation.
- coordinator notes down any extraordinary rationale:
  - circulates among experts.
- Experts re-estimate.
- Experts never meet each other to discuss their viewpoints.

3.4.2 Heuristic Techniques

Heuristic techniques assume that the relationships that exist among the different project parameters can be satisfactorily modelled using suitable mathematical expressions. Different heuristic estimation models can be divided into the following two broad categories—single variable and multivariable models.

3.4.2.1 COCOMO

COnstructive COst estimation MOdel (COCOMO) was proposed by Boehm [1981]. COCOMO prescribes a three stage process for project estimation. In the first stage, an initial estimate is arrived at. Over the next two stages, the initial estimate is refined to arrive at a more accurate estimate. COCOMO uses both single and multivariable estimation models at different stages of estimation.

The three stages of COCOMO estimation technique are—basic COCOMO, intermediate COCOMO, and complete COCOMO

A- Basic COCOMO Model

Boehm postulated that any software development project can be classified into one of the following three categories based on the development complexity—organic, semidetached, and embedded. Based on the category of a software development project, he gave different sets of formulas to estimate the effort and duration from the size estimate.

- In order to classify a project into the identified categories, Boehm requires us to consider not only the characteristics of the product but also those of the development team and development environment.

Mode	Project size	Nature of Project	Innovation	Deadline of the project	Development Environment
Organic	Typically 2-50 KLOC	Small size project, experienced developers in the familiar environment. For example, pay roll, inventory projects etc.	Little	Not tight	Familiar & In house
Semi detached	Typically 50-300 KLOC	Medium size project, Medium size team, Average previous experience on similar project. For example: Utility systems like compilers, database systems, editors etc.	Medium	Medium	Medium
Embedded	Typically over 300 KLOC	Large project, Real time systems, Complex interfaces, Very little previous experience. For example: ATMs, Air Traffic Control etc.	Significant	Tight	Complex Hardware/ customer Interfaces required

Table 4: The comparison of three COCOMO modes

$$E = a_b (KLOC)^{b_b}$$

$$D = c_b (E)^{d_b}$$

where E is effort applied in Person-Months, and D is the development time in months. The coefficients ab, bb, cb and db are given in table 5.

Software Project	a_b	b_b	c_b	d_b
Organic	2.4	1.05	2.5	0.38
Semidetached	3.0	1.12	2.5	0.35
Embedded	3.6	1.20	2.5	0.32

Table 5: Basic COCOMO coefficients

When effort and development time are known, the average staff size to complete the project may be calculated as:

$$\text{Average staff size } (SS) = \frac{E}{D} Persons$$

When project size is known, the productivity level may be calculated as:

$$\text{Productivity } (P) = \frac{KLOC}{E} KLOC / PM$$

Example: 3.4
Suppose that a project was estimated to be 400 KLOC. Calculate the effort and development time for each of the three modes i.e., organic, semidetached and embedded.
Solution
The basic COCOMO equation take the form:

$$E = a_b (KLOC)^{b_b}$$

$$D = c_b (KLOC)^{d_b}$$

Estimated size of the project = 400 KLOC
(i) Organic mode
$E = 2.4(400)^{1.05} = 1295.31$ PM
$D = 2.5(1295.31)^{0.38} = 38.07$ PM
(ii) Semidetached mode
$E = 3.0(400)^{1.12} = 2462.79$ PM
$D = 2.5(2462.79)^{0.35} = 38.45$ PM
(iii) Embedded mode
$E = 3.6(400)^{1.20} = 4772.81$ PM
$D = 2.5(4772.8)^{0.32} = 38$ PM

Example: 3.5
A project size of 200 KLOC is to be developed. Software development team has average experience on similar type of projects. The project schedule is not very tight. Calculate the effort, development time, average staff size and productivity of the project.

Solution
The semi-detached mode is the most appropriate mode; keeping in view the size, schedule and experience of the development team.

$E = 3.0(200)^{1.12} = 1133.12$ PM
$D = 2.5(1133.12)^{0.35} = 29.3$ PM

$$\text{Average staff size } (SS) = \frac{E}{D} Persons$$

$$= \frac{1133.12}{29.3} = 38.67 Persons$$

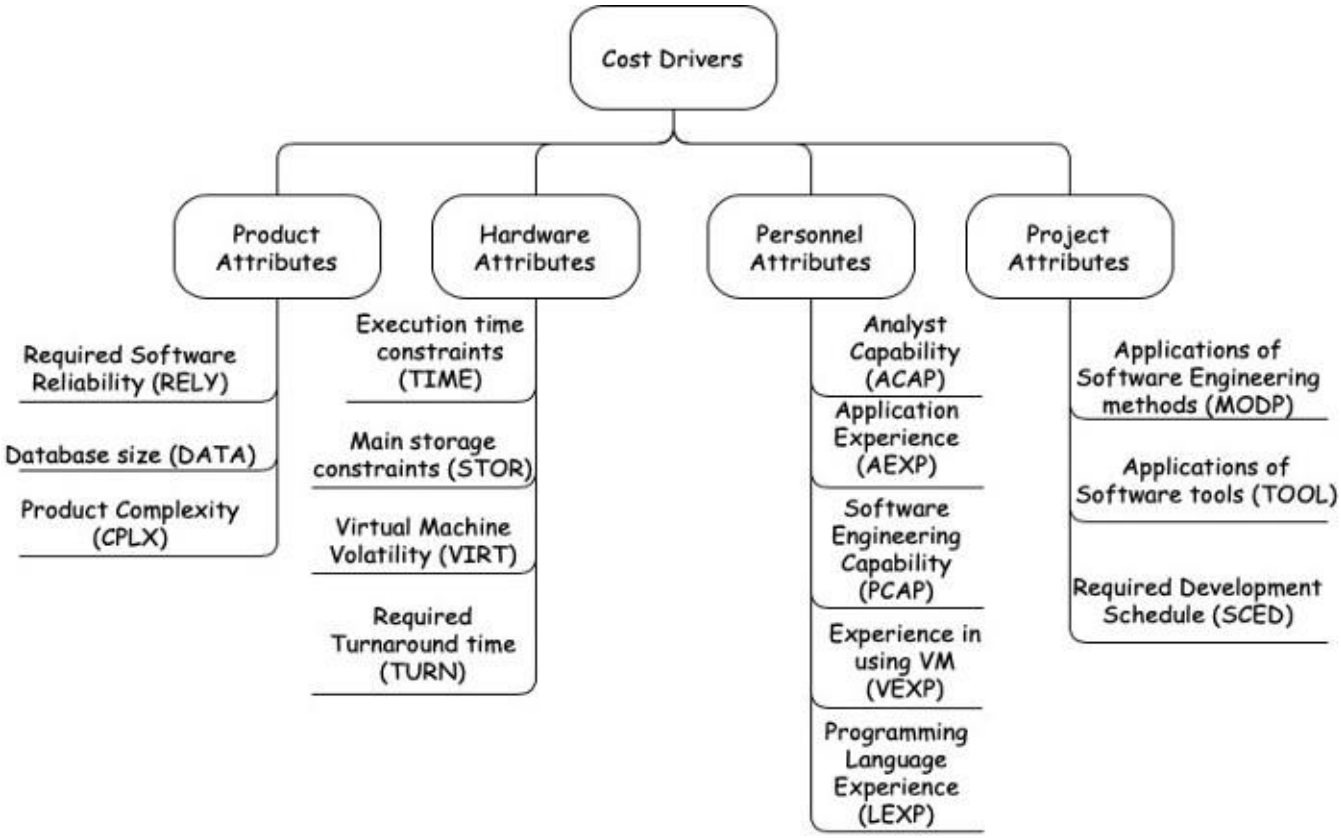
$$\text{Productivity} = \frac{KLOC}{E} = \frac{200}{1133.12} = 0.1765\, KLOC / PM$$

$$P = 176\, LOC / PM$$

B- Intermediate COCOMO

- Basic COCOMO model assumes
  - effort and development time depend on product size alone.
- However, several parameters affect effort and development time:
  - Reliability requirements
  - Availability of CASE tools and modern facilities to the developers
  - Size of data to be handled
- For accurate estimation,
  - the effect of all relevant parameters must be considered:
  - Intermediate COCOMO model recognizes this fact:
    - refines the initial estimate obtained by the basic COCOMO by using a set of 15 cost drivers (multipliers) (Effort Adjustment Factor).

Cost drivers



$$E = a_i (KLOC)^{b_i} * EAF$$
$$D = c_i (E)^{d_i}$$

Project	a_i	b_i	c_i	d_i
Organic	3.2	1.05	2.5	0.38
Semidetached	3.0	1.12	2.5	0.35
Embedded	2.8	1.20	2.5	0.32

Table 6: Coefficients for intermediate COCOMO

Shortcoming of basic and intermediate COCOMO models

- Both models:
  - consider a software product as a single homogeneous entity:
  - However, most large systems are made up of several smaller sub-systems.
    - Some sub-systems may be considered as organic type, some may be considered embedded, etc.
    - for some the reliability requirements may be high, and so on.

C- Complete COCOMO

- Cost of each sub-system is estimated separately.
- Costs of the sub-systems are added to obtain total cost.
- Reduces the margin of error in the final estimate.

Complete COCOMO Example

- A Management Information System (MIS) for an organization having offices at several places across the country:
  - Database part (semi-detached)
  - Graphical User Interface (GUI) part (organic)
  - Communication part (embedded)
- Costs of the components are estimated separately:
  - summed up to give the overall cost of the system.

3.4.2.2 COCOMO-II

- The present-day software projects are much larger in size and reuse of existing software to develop new products has become pervasive.

- New life cycle models and development paradigms are being deployed for web-based and component-based software. During the 1980s rarely any program was interactive, and graphical user interfaces were almost non-existent. On the other hand, the present-day software products are highly interactive and support elaborate graphical user interface. Effort spent on developing the GUI part is often as much as the effort spent on developing the actual functionality of the software. To make COCOMO suitable in the changed scenario, Boehm proposed COCOMO 2 in 1995.

- It is the model that allows one to estimate the cost, effort and schedule when planning a new software development activity.

- COCOMO 2 provides three models to arrive at increasingly accurate cost estimations. These can be used to estimate project costs at different phases of the software product. As the project progresses, these models can be applied at the different stages of the same project.

1- Application composition model

The application composition model is based on counting the number of screens, reports, and modules (components). Each of these components is considered to be an object. These are used to compute the object points of the application.
Effort is estimated in the application composition model as follows:
1. Estimate the number of screens, reports, and modules (components) from an analysis of the SRS document.
2. Determine the complexity level of each screen and report, and rate
these as either simple, medium, or difficult. The complexity of a screen or a report is determined by the number of tables and views it contains.

Number of views contained	*# and sources of data tables*		
	Total < 4 (< 2 server < 3 client)	*Total < 8 (2 – 3 server 3 – 5 client)*	*Total 8 + (> 3 server, > 5 client)*
< 3	Simple	Simple	Medium
3 – 7	Simple	Medium	Difficult
> 8	Medium	Difficult	Difficult

Table 7 (a): for screens

Number of sections contained	*# and sources of data tables*		
	Total < 4 (< 2 server < 3 client)	*Total < 8 (2 – 3 server 3 – 5 client)*	*Total 8 + (> 3 server, > 5 client)*
0 or 1	Simple	Simple	Medium
2 or 3	Simple	Medium	Difficult
4 +	Medium	Difficult	Difficult

Table 7 (b): for reports

3- Assign complexity weight to each object : The weights are used for three object types i.e., screen, report and 3GL components using the Table 8.

Object Type	*Complexity Weight*		
	Simple	*Medium*	*Difficult*
Screen	1	2	3
Report	2	5	8
3GL Component	—	—	10

Table 8: Complexity weights for each level

4. Determine object points: Add all the weighted object instances to get one number and this known as object-point count.
5. Compute new object points: We have to estimate the percentage of reuse to be achieved in a project. Depending on the percentage reuse, the new object points (NOP) are computed

$$NOP = \frac{(\text{object points}) * (100 - \%\text{reuse})}{100}$$

6. Calculation of productivity rate: The productivity rate can be calculated as:

$$\text{Productivity rate (PROD)} = \text{NOP/Person month}$$

Developer's experience & capability; ICASE maturity & capability	*PROD (NOP/PM)*
Very low	4
Low	7
Nominal	13
High	25
Very high	50

Table 9: Productivity value

7. Compute the effort in Persons-Months: When PROD is known, we may estimate effort in Person-Months as:

$$\text{Effort in PM} = \frac{\text{NOP}}{\text{PROD}}$$

Example: 3.9

Consider a database application project with the following characteristics:
I. The application has 4 screens with 4 views each and 7 data tables for 3 servers and 4 clients.
II. The application may generate two report of 6 sections each from 07 data tables for two server and 3 clients.
There is 10% reuse of object points.
The developer's experience and capability in the similar environment is low. The maturity of organization in terms of capability is also low. Calculate the object point count, New object points and effort to develop such a project.

Solution
This project comes under the category of application composition estimation model.
Number of screens = 4 with 4 views each
Number of reports = 2 with 6 sections each

From Table 7 we know that each screen will be of medium complexity and each report will be difficult complexity.

Using Table 8 of complexity weights, we may calculate object point count.
= 4 x 2 + 2 x 8 = 24

$$\text{NOP} = \frac{24 * (100 - 10)}{100} = 21.6$$

Table 9 gives the low value of productivity (PROD) i.e. 7.

$$\text{Efforts in PM} = \frac{\text{NOP}}{\text{PROD}}$$

$$\text{Efforts} = \frac{21.6}{7} = 3.086 \text{ PM}$$

2- The Early Design Model

$$PM_{nominal} = A * (size)^B$$

where
$PM_{nominal}$ = Effort of the project in person months
A = Constant representing the nominal productivity, provisionally set to 2.5
B = Scale factor
Size = Software size

The **early design model** uses Unadjusted Function Points (UFP) as measure of size. This model is used at the early stages of software project when there is not enough information available about size of product which has t be developed, nature of target platform and nature of employees to be involved in development of projector detailed specifications of process to be used.

The unadjusted function points (UFP) are counted and converted to source lines of code (SLOP). In a typical programming environment, each UFP would correspond to about 128 lines of C, 29 lines of C++, or 320 lines of assembly code. Of course, the conversion from UFP to LOC is environment specific, and depends on factors such as extent of reusable libraries supported. Seven cost drivers that characterise the post-architecture model are used. These are rated on a seven points scale.

If B = 1.0, there is linear relationship between effort and size of product. If the value of B is not equal to 1, there will be non-linear relationship between size of product and effort. If B < 1.0, rate of increase of effort decreases as the size of product increases. If B > 1.0, rate of increase of effort increase as the size of product is increase.

Scale factor	*Explanation*	*Remarks*
Precedentness	Reflects the previous experience on similar projects. This is applicable to individuals & organization both in terms of expertise & experience	Very low means no previous experiences, Extra high means that organization is completely familiar with this application domain.
Development flexibility	Reflect the degree of flexibility in the development process.	Very low means a well defined process is used. Extra high means that the client gives only general goals.
Architecture/ Risk resolution	Reflect the degree of risk analysis carried out.	Very low means very little analysis and Extra high means complete and through risk analysis.

Scale factor	Explanation	Remarks
Team cohesion	Reflects the team management skills.	Very low means no previous experiences, Extra high means that organization is completely familiar with this application domain.
Process maturity	Reflects the process maturity of the organization. Thus it is dependent on SEI-CMM level of the organization.	Very low means organization has no level at all and extra high means organization is related as highest level of SEI-CMM.

Scaling factors	Very low	Low	Nominal	High	Very high	Extra high
Precedent ness	6.20	4.96	3.72	2.48	1.24	0.00
Development flexibility	5.07	4.05	3.04	2.03	1.01	0.00
Architecture/ Risk resolution	7.07	5.65	4.24	2.83	1.41	0.00
Team cohesion	5.48	4.38	3.29	2.19	1.10	0.00
Process maturity	7.80	6.24	4.68	3.12	1.56	0.00

Table 10: Data for the computation of B

The value of B can be calculated as:
B=0.91 + 0.01 * (Sum of rating on scaling factors for the project)

Example:
A software project of application generator category with estimated 50 KLOC has to be developed. The scale factor (B) has low precedentness, high development flexibility and low team cohesion. Other factors are nominal.

Solution
Here B = 0.91 + 0.01 * (Sum of rating on scaling factors for the project)
= 0.91 + 0.01 * (4.96 + 2.03 + 4.24 + 4.38 + 4.68)
= 0.91 + 0.01(20.29)=1.1129

$$PM_{nominal} = A^*(size)^B$$
$$= 2.5 * (50)^{1.1129} = 194.41 \text{ Person months}$$

3- Post Architecture Model

The post architecture model is the most detailed estimation model and is intended to be used when a software life cycle architecture has been completed. This model is used in the development and maintenance of software products in the application generators, system integration or infrastructure sectors.

$$PM_{adjusted} = PM_{\text{nominal}} \times \left[\prod_{i=7}^{17} EM_i \right]$$

EM : Effort multiplier which is the product of 17 cost drivers.

3.5 STAFFING LEVEL ESTIMATION

Once the effort required to complete a software project has been estimated, the staffing requirement for the project can be determined. Putnam was the first to study the problem of determining a proper staffing pattern for software projects. He extended the classical work of Norden who had earlier investigated the staffing pattern of general research and development (R&D) type of projects.

3.5.1 Norden's Work

Norden concluded that the staffing pattern for any R&D project starting from a low level, increases until it reaches a peak value. It then starts to diminish. This pattern can be approximated by the Rayleigh distribution curve (see Figure 3.3).

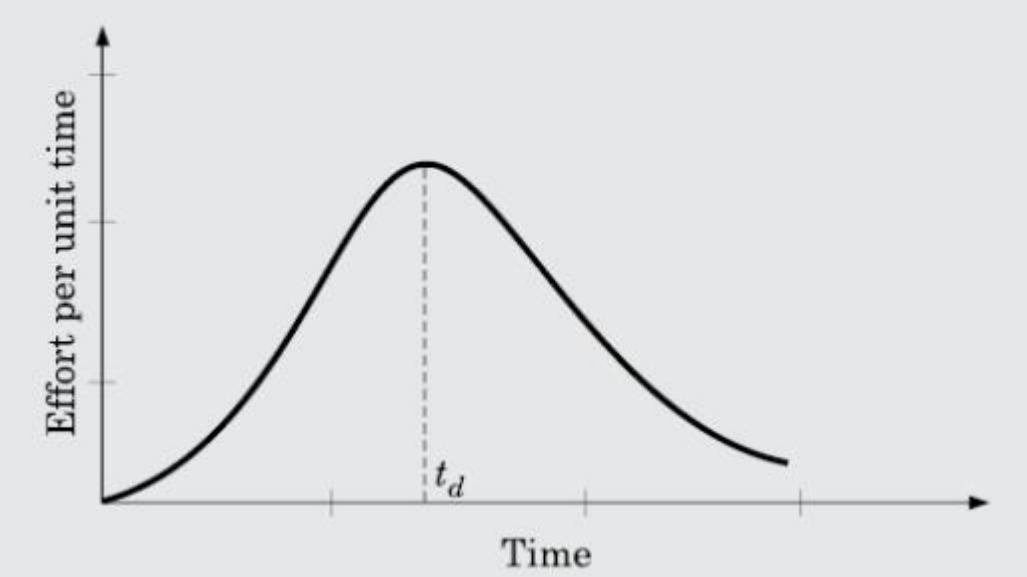


Figure 3.3: Rayleigh curve.

Norden represented the Rayleigh curve by the following equation:

$$E = \frac{K}{{t_d}^2} * t * e^{\frac{-t^2}{2{t_d}^2}}$$

where, E is the effort required at time t. E is an indication of the number of developers (or the staffing level) at any particular time during the duration of the project, K is the area under the curve, and td is the time at which the curve attains its maximum value. It must be remembered that the results of Norden are applicable to general R&D projects and were not meant to model the staffing pattern of software development projects.

3.9.2 Putnam's Work

Putnam found that the Rayleigh-Norden curve can be adapted to relate the number of delivered lines of code to the effort and the time required to develop the product. By analysing a large number of defence projects, Putnam derived the following expression:

$$L = C_k K^{1/3} t_d^{4/3}$$

where the different terms are as follows:

- K is the total effort expended (in PM) in the product development and L is the product size in KLOC.
- td corresponds to the time of system and integration and testing. Therefore, t d can be approximately considered as the time required to develop the software.
- Ck is the state of technology constant reflects factors that affect programmer productivity
  - Ck=2 for poor development environment
    - no methodology, poor documentation, and review, etc.
  - Ck=8 for good software development environment
    - software engineering principles used
  - Ck=11 for an excellent environment

- Putnam observed that:
  - the time at which the Rayleigh curve reaches its maximum value
    - corresponds to system testing and product release.
  - After system testing,
    - the number of project staff falls till product installation and delivery
  - From the Rayleigh curve observe that:
    - approximately 40% of the area under the Rayleigh curve is to the left of td
    - and 60% to the right.

Effect of Schedule Change on Cost

Putnam's method can be used to study the effect of changing the duration of a project. By using the Putnam's expression

$$K = \frac{L^3}{(C_k^3 t_d^4)}$$

$$K = \frac{C}{t_d^4}$$

- For the product same size

$$\frac{K_1}{K_2} = \frac{t_{d_2}^4}{t_{d_1}^4}$$

Example The nominal effort and duration of a project have been estimated to be 1000PM and 15 months. The project cost has been negotiated to be Rs. 200,000,000. The needs the product to be developed and delivered in 12 month time. What should be the new cost to be negotiated?
Answer: The project can be classified as a large project. Therefore, the new cost to be negotiated can be given by the Putnam's formula: new cost = Rs. 200, 000, 000 × (15/12)4 = Rs. 488,281,250.

3.10 Project scheduling

Project-task scheduling is an important project planning activity. It involves deciding which tasks would be taken up when. In order to schedule the project activities, a software project manager needs to do the following:

1. Identify all the tasks needed to complete the project.
2. Break down large tasks into small activities.
3. Determine the dependency among different activities.
4. Establish the most likely estimates for the time durations necessary to complete the activities.
5. Allocate resources to activities.
6. Plan the starting and ending dates for various activities.
7. Determine the critical path. A critical path is the chain of activities that determines the duration of the project.

A- Work breakdown structure

Work Breakdown Structure (WBS) is used to decompose a given task set recursively into small activities. WBS provides a notation for representing the major tasks need to be carried out in order to solve a problem. Figure 3.4 represents the WBS of an MIS (Management Information System) software.

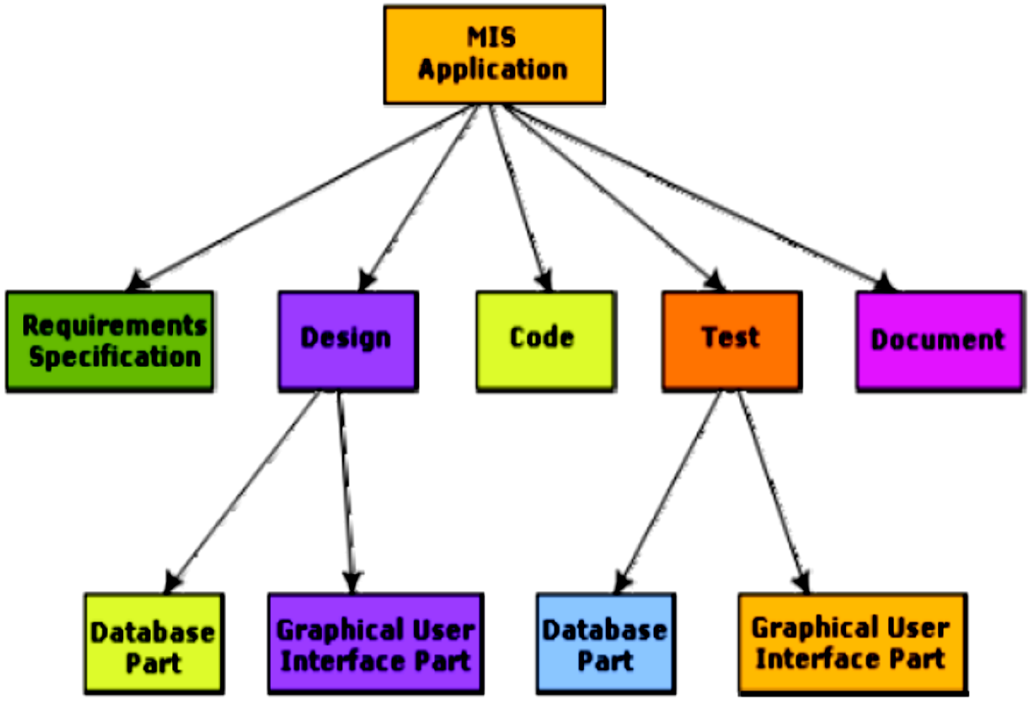


Figure 3.4 Work breakdown structure of an MIS problem

B- Activity networks and critical path method

WBS representation of a project is transformed into an activity network by representing activities identified in WBS along with their interdependencies. An activity network shows the different activities making up a project, their estimated durations, and interdependencies (as shown in figure 3.5). Each activity is represented by a rectangular node and the duration of the activity is shown alongside each task.

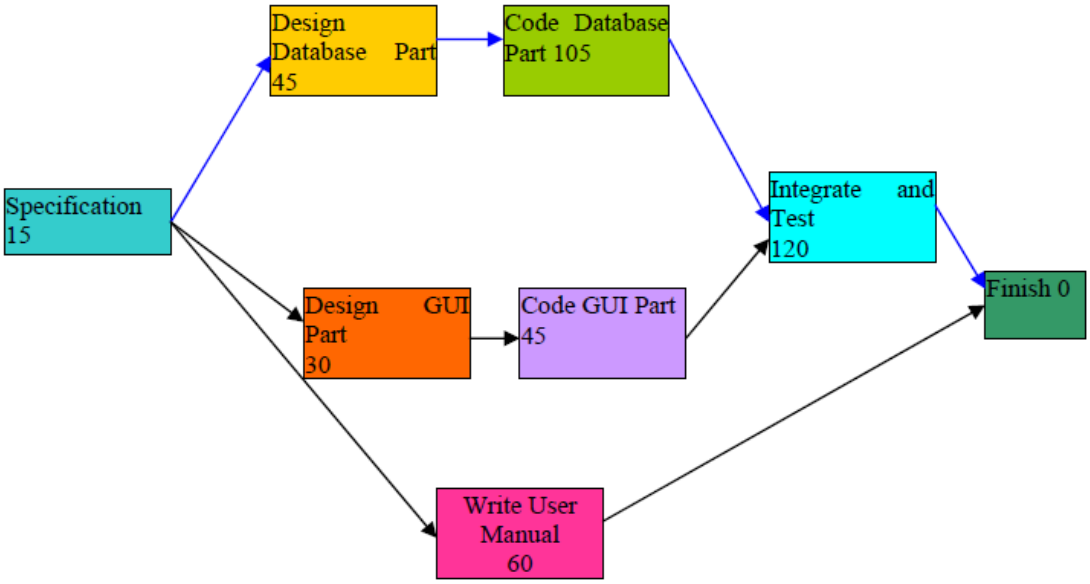


Figure 3.5 Activity network representation of the MIS problem.

C- Critical Path Method (CPM)

From the activity network representation following analysis can be made.

- The minimum time (MT) to complete the project is the maximum of all paths from start to finish.
- The earliest start (ES) time of a task is the maximum of all paths from the start to the task.
- The latest start time is the difference between MT and the maximum of all paths from this task to the finish.
- The earliest finish time (EF) of a task is the sum of the earliest start time of the task and the duration of the task.
- The latest finish (LF) time of a task can be obtained by subtracting maximum of all paths from this task to finish from MT.
- The slack time (ST) is LS – EF and equivalently can be written as LF – EF. The slack time (or float time) is the total time that a task may be delayed before it will affect the end time of the project. The slack time indicates the "flexibility" in starting and completion of tasks.
- A critical task is one with a zero slack time. A path from the start node to the finish node containing only critical tasks is called a critical path. These parameters for different tasks for the MIS problem are shown in the following table.

Task	ES	EF	LS	LF	ST
Specification	0	15	0	15	0
Design database	15	60	15	60	0
Design GUI part	15	45	90	120	75
Code database	60	165	60	165	0
Code GUI part	45	90	120	165	75

D- Gantt chart

Gantt charts are mainly used to allocate resources to activities. The resources allocated to activities include staff, hardware, and software. Gantt charts (named after its developer Henry Gantt) are useful for resource planning.

- A Gantt chart is a special type of bar chart where each bar represents an activity.

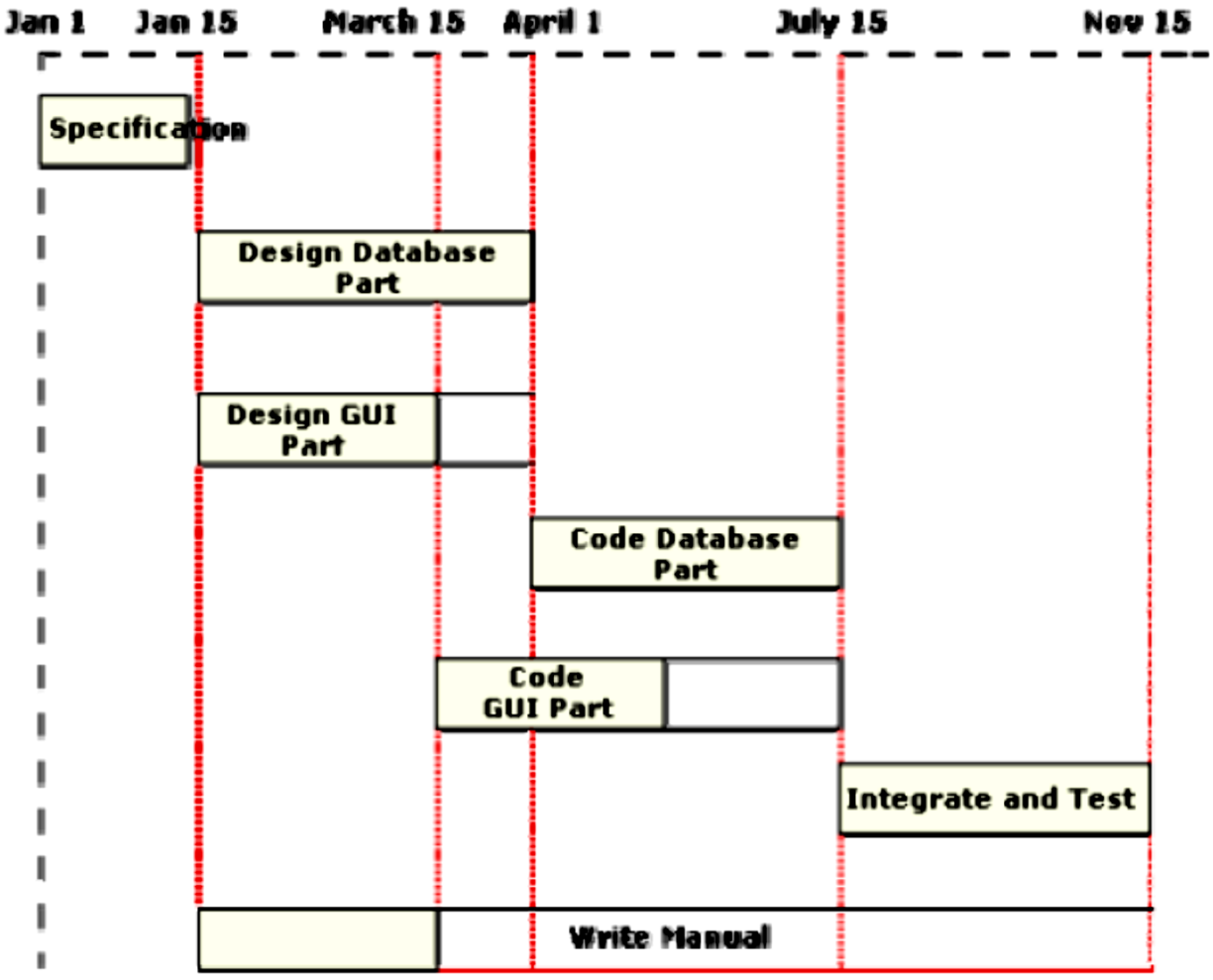


Figure 3.6 Gantt chart representation of the MIS problem

E- PERT chart

PERT (Project Evaluation and Review Technique) charts consist of a network of boxes and arrows. The boxes represent activities and the arrows represent task dependencies. PERT chart represents the statistical variations in the project estimates assuming a normal distribution. Thus, in a PERT chart instead of making a single estimate for each task, pessimistic, likely, and optimistic estimates are made.

Gantt chart representation of a project schedule is helpful in planning the utilization of resources, while PERT chart is useful for monitoring the timely progress of activities. Also, it is easier to identify parallel activities in a project using a PERT chart. Project managers need to identify the parallel activities in a project for assignment to different engineers.

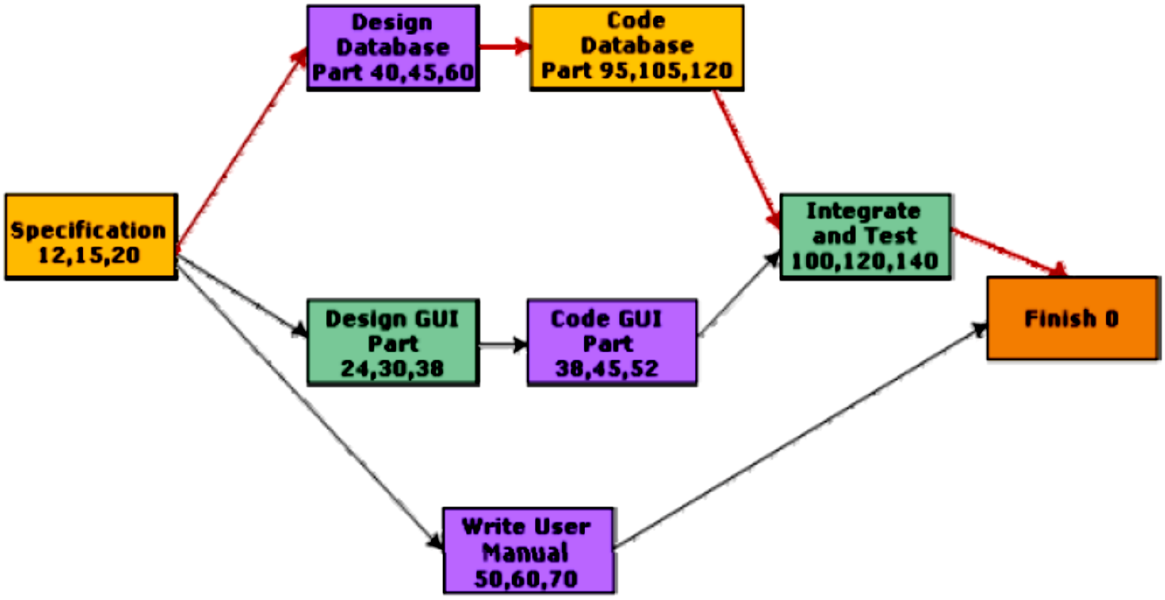


Figure 3.7 PERT chart representation of the MIS problem

3.11 SOFTWARE-RISK ANALYSIS AND MANAGEMENT

Risk analysis and management are a series of steps that help a software team to understand and manage uncertainty.

A risk is a potential problem—it might happen, it might not. But, regardless of the outcome, it's a really good idea to identify it, assess its probability of occurrence, estimate its impact, and establish a contingency plan should the problem actually occur.

Risk Management

Risk management is the area that tries to ensure that the impact of risks on cost, quality, and schedule is minimal.

- Dealing with concern before it becomes a crisis.
- Quantify probability of failure & consequences of failure.

3.11.1 Typical Software Risk

Capers Jones has identified the top five risk factors that threaten projects in different applications.

1. Dependencies on outside agencies or factors.

• Availability of trained, experienced persons
• Inter group dependencies
• Customer-Furnished items or information
• Internal & external subcontractor relationships

2. Requirement issues
Uncertain requirements → Wrong product Or Right product badly
- Lack of clear product vision
- Unprioritized requirements
- Lack of agreement on product requirements
- New market with uncertain needs
- Rapidly changing requirements
- Inadequate Impact analysis of requirements changes

3. Management Issues
Project managers usually write the risk management plans, and most people do not wish to air their weaknesses in public.
- Inadequate planning
- Inadequate visibility into actual project status
- Unclear project ownership and decision making
- Staff personality conflicts
- Unrealistic expectation
- Poor communication

4. Lack of knowledge
- Inadequate training
- Poor understanding of methods, tools, and techniques
- Inadequate application domain experience
- New Technologies
- Ineffective, poorly documented or neglected Processes

5. Other risk categories
- Unavailability of adequate testing facilities
- Turnover of essential personnel
- Unachievable performance requirements
- Technical approaches that may not work

3.11.2 Risk Management Activities

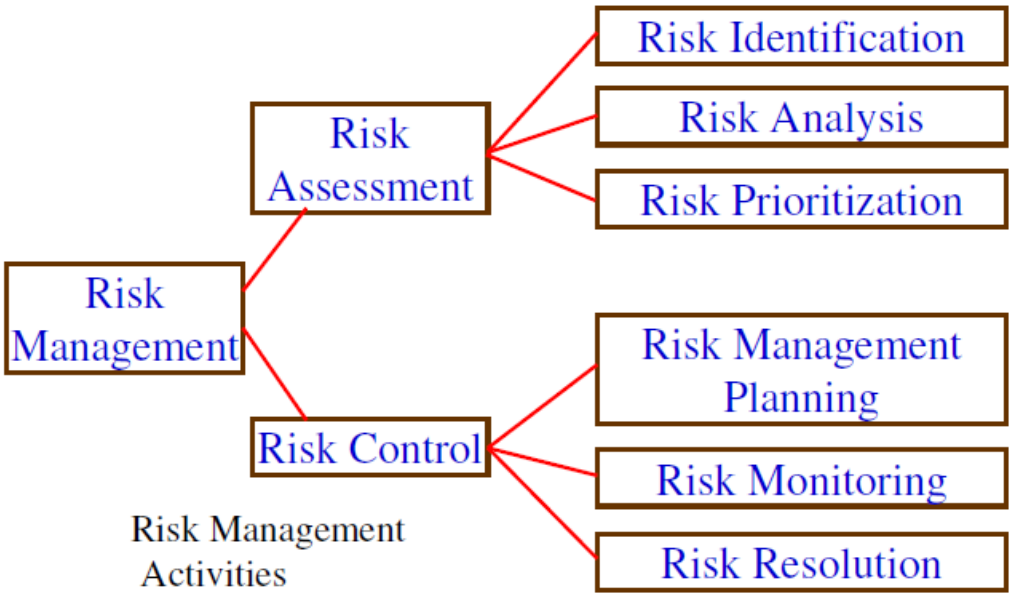
Risk Assessment

Identification of risks

Risk analysis involves examining how project outcomes might change with modification of risk input variables.

Risk prioritization focus for severe risks.

Risk exposure: It is the product of the probability of incurring a loss due to the risk and the potential magnitude of that loss.



Risk Control
Risk Management Planning produces a plan for dealing with each significant risks.
_ Record decision in the plan.
Risk resolution is the execution of the plans of dealing with each risk.

Exercises

Q\ Describe the basic COCOMO model in detail.
Q\ Why does cost estimation play an important role in the software-development process?
Q\What is risk? Is it economical to do risk management? What is the effect of this activity on the overall cost of the project?
Q\ What are the various reasons for poor/inacurate estimation?

4. REQUIREMENTS ANALYSIS AND SPECIFICATION

Experienced developers take considerable time to understand the exact requirements of the customer and to meticulously document those. They know that without a clear understanding of the problem and proper documentation of the same, it is impossible to develop a satisfactory solution.

The goal of the requirements analysis and specification phase is to clearly understand the customer requirements and to systematically organise the requirements into a document called the Software Requirements Specification (SRS) document.

Requirements describe
What not How
Produces one large document written in natural language contains a description of what the system will do without describing how it will do it.

Who carries out requirements analysis and specification?
Requirements analysis and specification activity is usually carried out by a few experienced members of the development team and it normally requires them to spend some time at the customer site. The engineers who gather and analyse customer requirements and then write the requirements specification document are known as *system analysts* in the software industry parlance.

What are the main activities carried out during requirements analysis and specification phase?

4.1 Requirements gathering

It is also popularly known as *requirements elicitation*. The primary objective of the requirements gathering task is to collect the requirements from the *stakeholders*.

- A stakeholder is a source of the requirements and is usually a person, or a group of persons who either directly or indirectly are concerned with the software.

The important ways in which an experienced analyst gathers requirements:

1. **Studying existing documentation:** The analyst usually studies all the available documents regarding the system to be developed before visiting the customer site. Customers usually provide statement of purpose (SoP) document to the developers. Typically these documents might discuss issues such as the context in which the software is required, the basic purpose, the stakeholders, features of any similar software developed elsewhere, etc.

2. **Interview:** Typically, there are many different categories of users of a software. Each category of users typically requires a different set of features from the software. Therefore,

it is important for the analyst to first identify the different categories of users and then determine the requirements of each.

For *example*, the different categories of users of a library automation software could be the library members, the librarians, and the accountants.

3. Task analysis: The users usually have a black-box view of a software and consider the software as something that provides a set of services (functionalities). A service supported by a software is also called a *task*. We can therefore say that the software performs various tasks of the users. In this context, the analyst tries to identify and understand the different tasks to be performed by the software.

4. Scenario analysis: A task can have many scenarios of operation. The different scenarios of a task may take place when the task is invoked under different situations. For different types of scenarios of a task, the behaviour of the software can be different.

For example, the possible scenarios for the book issue task of a library automation software may be:
Book is issued successfully to the member and the book issue slip is printed.
The book is reserved, and hence cannot be issued to the member.
The maximum number of books that can be issued to the member is already reached, and no more books can be issued to the member.

Some desirable attributes of a good requirements analyst:
–Good interaction skills,
–Imagination and creativity,
–Experience…

4.2 Requirements Analysis

The main purpose of the requirements analysis activity is to analyse the gathered requirements to remove all ambiguities, incompleteness, and inconsistencies from the gathered customer requirements and to obtain a clear understanding of the software to be developed.

The following basic questions pertaining to the project should be clearly understood by the analyst before carrying out analysis:

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

During requirements analysis, the analyst needs to identify and resolve three main types of problems in the requirements:

Anomaly: It is an anomaly is an ambiguity in a requirement. When a requirement is anomalous, several interpretations of that requirement are possible.

Example suppose one office clerk described the following requirement: during the final grade computation, if any student scores a sufficiently low grade in a semester, then his parents would need to be

informed. This is clearly an ambiguous requirement as it lacks any well defined criterion as to what can be considered as a "sufficiently low grade".

Inconsistency: Two requirements are said to be inconsistent, if one of the requirements contradicts the other. The following are two examples of inconsistent requirements.

Example: suppose one of the clerks gave the following requirement— a student securing fail grades in three or more subjects must repeat the courses over an entire semester, and he cannot credit any other courses while repeating the courses. Suppose another clerk expressed the following requirement—there is no provision for any student to repeat a semester; the student should clear the subject by taking it as an extra subject in any later semester. There is a clear inconsistency between the requirements given by the two stakeholders.

Incompleteness: An incomplete set of requirements is one in which some requirements have been overlooked. The lack of these features would be felt by the customer much later, possibly while using the software. Often, incompleteness is caused by the inability of the customer to visualise the system that is to be developed and to anticipate all the features that would be required.

Example: one of the clerks expressed the following—If a student secures a *grade point average* (GPA) of less than 6, then the parents of the student must be intimated about the regrettable performance through a (postal) letter as well as through e-mail. However, on an examination of all requirements, it was found that there is no provision by which either the postal or e-mail address of the parents of the students can be entered into the system. The feature that would allow entering the e-mail ids and postal addresses of the parents of the students was missing, thereby making the requirements incomplete.

4.3 Software Requirements Specification

•Main aim:
–Systematically organize the requirements arrived during requirements analysis.
–Document requirements properly.
- The SRS document usually contains all the user requirements in a structured though an informal form.

Users of SRS Document

Users, customers, and marketing personnel: These stakeholders need to refer to the SRS document to ensure that the system as described in the document will meet their needs.
Software developers: The software developers refer to the SRS document to make sure that they are developing exactly what is required by the customer.
Test engineers: The test engineers use the SRS document to understand the functionalities, and based on this write the test cases to validate its working.
User documentation writers: The user documentation writers need to read the SRS document to ensure that they understand the features of the product well enough to be able to write the users' manuals.
Project managers: The project managers refer to the SRS document to ensure that they can estimate the cost of the project easily by referring to the SRS document and that it contains all the information required to plan the project.
Maintenance engineers: The SRS document helps the maintenance engineers to under- stand the functionalities supported by the system.

Properties of a Good SRS Document

•**It should be concise**
–and at the same time should not be ambiguous.
•**It should specify what the system must do**
–and not say how to do it.

The SRS document should describe the system to be developed as a black box, and should specify only the externally visible behaviour of the system. For this reason, the SRS document is also called the black-box specification of the software being developed.

•**Easy to change.,**
–i.e. it should be well-structured.
•**It should be consistent.**
•**It should be complete.**
•**It should be traceable**
–You should be able to trace which part of the specification corresponds to which part of the design, code, etc and vice versa.
•**It should be verifiable**
This means that it should be possible to design test cases based on the description of the functionality as to whether or not requirements have been met in an implementation
–e.g. "system should be user friendly" is not verifiable
-On the other hand, the requirement—"When the name of a book is entered, the software should display whether the book is available for issue or it has been loaned out" is verifiable.

SRS should not include...

•**Project development plans**
–E.g. cost, staffing, schedules, methods, tools, etc
•**Product assurance plans**
–Configuration Management, Verification & Validation, test plans, Quality Assurance, etc
•**Different audiences**
•**Different lifetimes**
•**Designs**
–Requirements and designs have different audiences
–Analysis and design are different areas of expertise

Important Categories of Customer Requirements
A good SRS document, should properly categorize and organise the requirements into different sections [IEEE830]. As per the IEEE 830 guidelines, the important categories of user requirements are the following.

Four important parts:
–**Functional requirements,**
–**External Interfaces**
–**Non-functional requirements,**
–**Constraints**

A- Functional Requirements

•Specifies all the functionality that the system should support
–**Heart of the SRS document:**
–**Forms the bulk of the Document**
•Outputs for the given inputs and the relationship between them
•Must specify behaviour for invalid inputs too!

Functional Requirement Documentation
•**Overview**
–describe purpose of the function and the approaches and techniques employed
•**Inputs and Outputs**
–sources of inputs and destination of outputs
–quantities, units of measure, ranges of valid inputs and outputs
–timing
•**Processing**
–validation of input data
–exact sequence of operations
–responses to abnormal situations
–any methods (eg. equations, algorithms) to be used to transform inputs to outputs

B- Non-functional Requirements

•Characteristics of the system which can not be expressed as functions:
•**Maintainability,**
•**Portability,**
•**Usability,**
•**Security,**
•**Safety, etc.**
•Reliability issues
•Performance issues:

–**Example:** How fast can the system produce results?
•At a rate that does not overload another system to which it supplies data, etc.
•Response time should be less than 1sec 90% of the time
•Needs to be measurable (verifiability)

C- Constraints

•Hardware to be used,
•Operating system
–or DBMS to be used
•Capabilities of I/O devices
•Standards compliance
•Data representations by the interfaced system

D- External Interface Requirements

•User interfaces
•Hardware interfaces
•Software interfaces
•Communications interfaces with other systems
•File export formats

4.4 IEEE 830-1998 Standard

Title
Table of Contents
1. Introduction
   - **–1.1 Purpose**
   - **–1.2 Scope**
   - **–1.3 Definitions. Acronyms, and Abbreviations**
   - **–1.4 References**
   - **–1.5 Overview**

2. **Overall Description**
   - **–2.1 Product Perspective**
   - **–2.2 Product Functions**
   - **–2.3 User Characteristics**
   - **–2.4 Constraints**
   - **–2.5 Assumptions and Dependencies**

3. Specific Requirements
   - **–3.1 External Interfaces**
   - **–3.2 Functions**
   - **–3.3 Performance Requirements**
   - **–3.4 Logical Database Requirements**
   - **–3.5 Design Constraints**
   - **–3.6 Software System Quality Attributes**
   - **–3.7 Object Oriented Models**

4. Appendices
5. Index

. Identify the software product
•Enumerate what the system will and will not do
•Describe user classes and benefits for each

Summarize the major functional capabilities
•Include the Use Case Diagram and supporting narrative (identify actors and use cases)

--Describe technical skills of each user class

•Present the business case and operational concept of the system
•Describe how the proposed system fits into the business context
•Describe external interfaces: system, user, hardware, software,

•Detail all inputs and outputs(complement, not duplicate, information presented in section 2)
•Examples: GUI screens, file formats

Example Section 3 of SRS of Academic Administration Software

3.1 Functional Requirements 3.1.1 Subject Registration

–The subject registration requirements are concerned with functions regarding subject registration which includes students selecting, adding, dropping, and changing a subject.

- **F-001:**

–The system shall allow a student to register a subject.

- **F-002:**

–It shall allow a student to drop a course.

- **F-003:**

–It shall support checking how many students have already registered for a course.

•3.2 Design Constraints

- **C-001:**

–AAS shall provide user interface through standard web browsers.

- **C-002**:

–AAS shall use an open source RDBMS such as Postgres SQL.

- **C-003**:

–AAS shall be developed using the JAVA programming language

3.3 Non-Functional Requirements

- **N-001:**

–AAS shall respond to query in less than 5 seconds.

- **N-002**:

–AAS shall operate with zero down time.

- **N-003**:

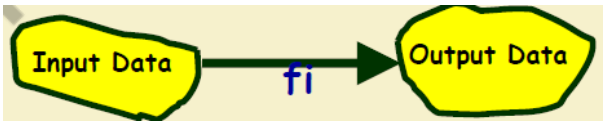
–AAS shall allow upto100users to remotely connect to the system.

- **N-004**:

–The system will be accompanied by a well-written user manual.

Functional Requirements

•It is desirable to consider every system as:
–Performing a set of functions {fi}.
•Each function fi considered as:
–Transforming a set of input data to corresponding output data.



Example: Functional Requirement
•F1: Search Book
–Input:
•an author's name:
–Output:
•details of the author's books and the locations of these books in the library.

•Functional requirements describe:
–A set of high-level requirements
–Each high-level requirement:
•takes in some data from the user
•outputs some data to the user
–Each high-level requirement:
•might consist of a set of identifiable sub-functions

•For each high-level requirement:
–A function is described in terms of:
•Input data set
•Output data set
•Processing required to obtain the output data set from the input data set.

4.4.1 USE CASE

Use cases specify the functionality of a system by specifying the behaviour of the system captured as interactions of the users with the system.

•A use case is a term in UML:
–Represents a high level functional requirement.
•Use case representation is more well-defined and has agreed documentation

–Therefore many organizations document the functional requirements in terms of use cases

- A use case is initiated by a user with a particular goal in mind, and completes successfully when that goal is satisfied.

* It describes the sequence of interactions between actors and the system necessary to deliver the services that satisfies the goal.

Thus

Use Case captures who (actor) does what (interaction) with the system, for what purpose (goal), without dealing with system internals.

Jacobson & others proposed a template for writing Use cases as shown below:

1. Introduction

Describe a quick background of the use case.

2.Actors

List the actors that interact and participate in the use cases.

3.Pre Conditions

Pre conditions that need to be satisfied for the use case to perform.

4. Post Conditions

Define the different states in which we expect the system to be in, after the use case executes.

5. Flow of events
5.1 Basic Flow
List the primary events that will occur when this use case is executed.
5.2 Alternative Flows
Any Subsidiary events that can occur in the use case should be separately listed. List each such event as an alternative flow. A use case can have many alternative flows as required.

6.Special Requirements
Business rules should be listed for basic & information flows as special requirements in the use case narration. These rules will also be used for writing test cases. Both success and failures scenarios should be described.

7.Use Case relationships
For Complex systems it is recommended to document the relationships between use cases. Listing the relationships between use cases also provides a mechanism for traceability

Use Case Guidelines

1. Identify all users
2. Create a user profile for each category of users including all roles of the users play that are relevant to the system.
3. Create a use case for each goal, following the use case template maintain the same level of abstraction throughout the use case. Steps in higher level use cases may be treated as goals for lower level (i.e. more detailed), subuse cases.
4. Structure the use case
5. Review and validate with users.

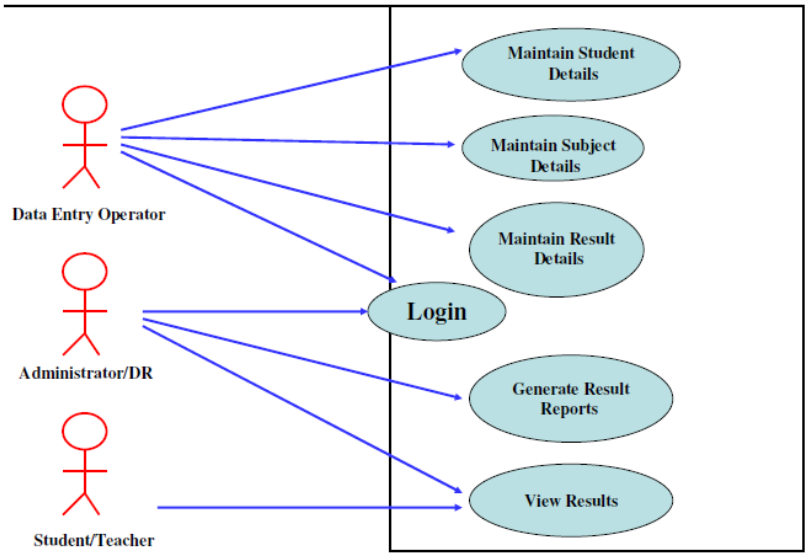
4.4.2 Use case Diagrams

-- represents what happens when actor interacts with a system.
-- captures functional aspect of the system.

-- Actors appear outside the rectangle.
--Use cases within rectangle providing functionality.
--Relationship association is a solid line between actor & use cases.

*Use cases should not be used to capture all the details of the system.

Example: Use case diagram for Result Management System



1. Maintain student Details
Add/Modify/update students details like name, address.
2.Maintain subject Details
Add/Modify/Update Subject information semester wise
3.Maintain Result Details
Include entry of marks and assignment of credit points for each paper.
4. Login
Use to Provide way to enter through user id & password.
5. Generate Result Report
Use to print various reports
6. View Result
(i) According to course code
(ii) According to Enrollment number/roll number

Login

1.1 Introduction : This use case describes how a user logs into the Result Management System.
1.2 Actors : (i) Data Entry Operator
(ii) Administrator/Deputy Registrar
1.3 Pre Conditions : None
1.4 Post Conditions : If the use case is successful, the actor is logged into the system. If not, the system state is unchanged.
1.5 Basic Flow : This use case starts when the actor wishes to login to the Result Management system.
(i) System requests that the actor enter his/her name and password.
(ii) The actor enters his/her name & password.
(iii) System validates name & password, and if finds correct allow the actor to logs into the system.
1.6 Alternate Flows
1.6.1 Invalid name & password
If in the basic flow, the actor enters an invalid name and/or password, the system displays an error message. The actor can choose to either return to the beginning of the basic flow or cancel the login, at that point, the use case ends.
1.7 Special Requirements:
None
1.8 Use case Relationships:
None

2.Maintain student details

2.1 Introduction : Allow DEO to maintain student details. This includes adding, changing and deleting student information
2.2 Actors : DEO
2.3 Pre-Conditions: DEO must be logged onto the system before this use case begins.
2.4 Post-conditions : If use case is successful, student information is added/updated/deleted from the system. Otherwise, the system state is unchanged.

2.5 Basic Flow : Starts when DEO wishes to add/modify/update/delete Student information.
(i) The system requests the DEO to specify the function, he/she would like to perform (Add/update/delete)
(ii) One of the sub flow will execute after getting the information.

2.4 Post-conditions : If use case is successful, student information is added/updated/deleted from the system. Otherwise, the system state is unchanged.

2.5 Basic Flow : Starts when DEO wishes to add/modify/update/delete Student information.
(i) The system requests the DEO to specify the function, he/she would like to perform (Add/update/delete)
(ii) One of the sub flow will execute after getting the information.
2.5.2 Update a student
(i) System requires the DEO to enter student-id.
(ii) DEO enters the student_id. The system retrieves and display the student information.
(iii) DEO makes the desired changes to the student information.
(iv) After changes, the system updates the student record with changed information.
2.5.3 Delete a student
(i) The system requests the DEO to specify the student-id.
(ii) DEO enters the student-id. The system retrieves and displays the student information.
(iii) The system prompts the DEO to confirm the deletion of the student.
(iv) The DEO confirms the deletion.
(v) The system marks the student record for deletion

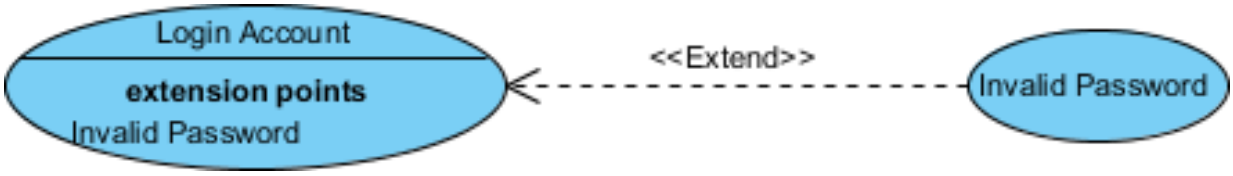
2.6 Alternative flows
2.6.1 Student not found
If in the update a student or delete a student sub flows, a student with specified_id does not exist, the system displays an error message. The DEO may enter a different id or cancel the operation. At this point ,Use case ends.
2.6.2 Update Cancelled
If in the update a student sub-flow, the data entry operator decides not to update the student information, the update is cancelled and the basic flow is restarted at the begin.
2.6.3 Delete cancelled
If in the delete a student sub flows, DEO decides not to delete student record ,the delete is cancelled and the basic flow is re-started at the beginning.
2.7 Special requirements
None
2.8 Use case relationships
None

4.2.2.1 Structuring Use Case Diagram with Relationships

Use cases share different kinds of relationships. Defining the relationship between two use cases is the decision of the software analysts of the use case diagram. A relationship between two use cases is basically modeling the dependency between the two use cases.

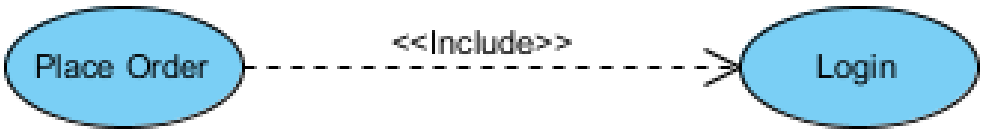
A- Extends

- Depict with a directed arrow having a dotted line. The tip of arrowhead points to the base use case and the child use case is connected at the base of the arrow.
- The stereotype "<<extends>>" identifies as an extend relationship



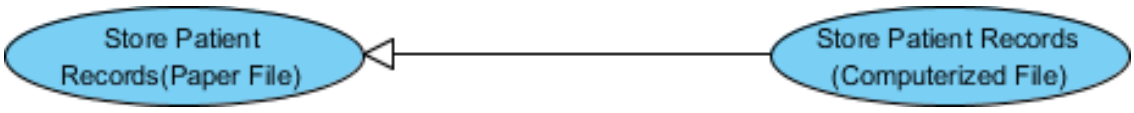
B- Include

- When a use case is depicted as using the functionality of another use case, the relationship between the use cases is named as include or uses relationship.
- A use case includes the functionality described in another use case as a part of its business process flow.



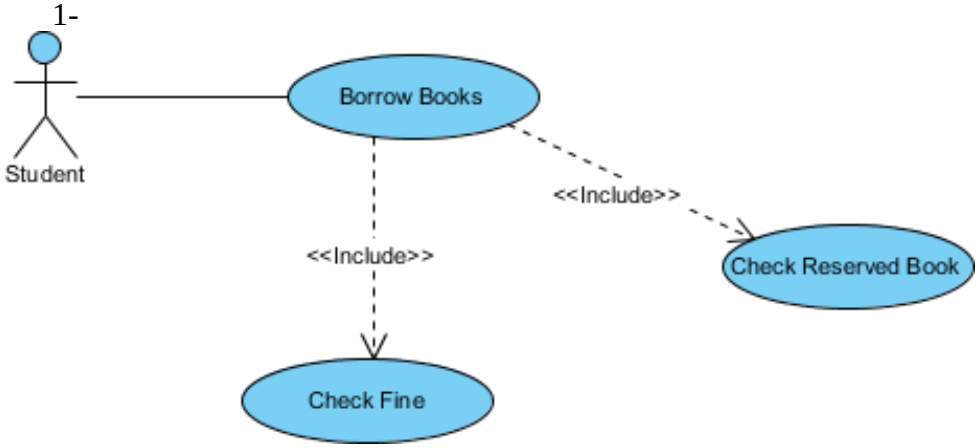
C- Generalization

- A generalization relationship is a parent-child relationship between use cases.

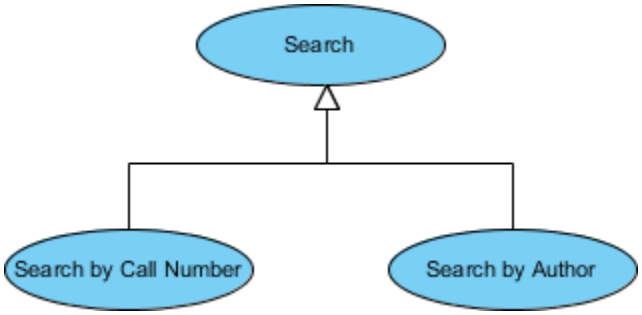


Example:

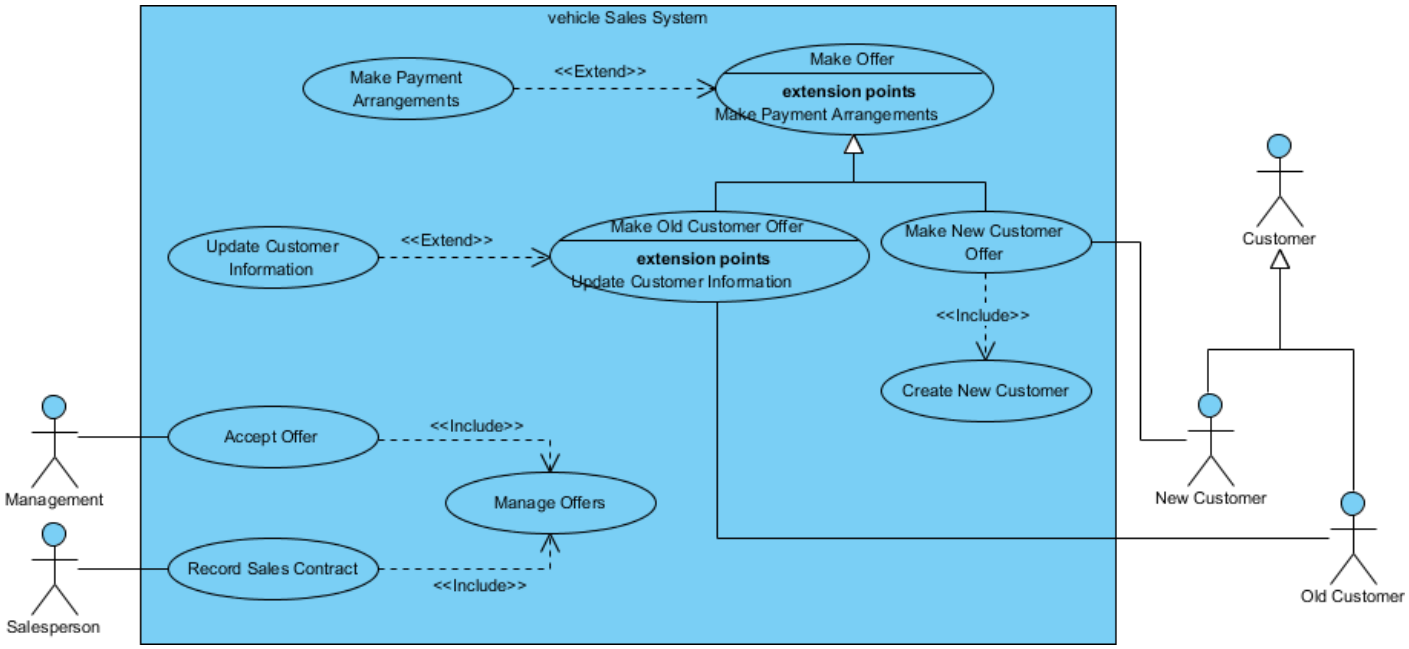
1-

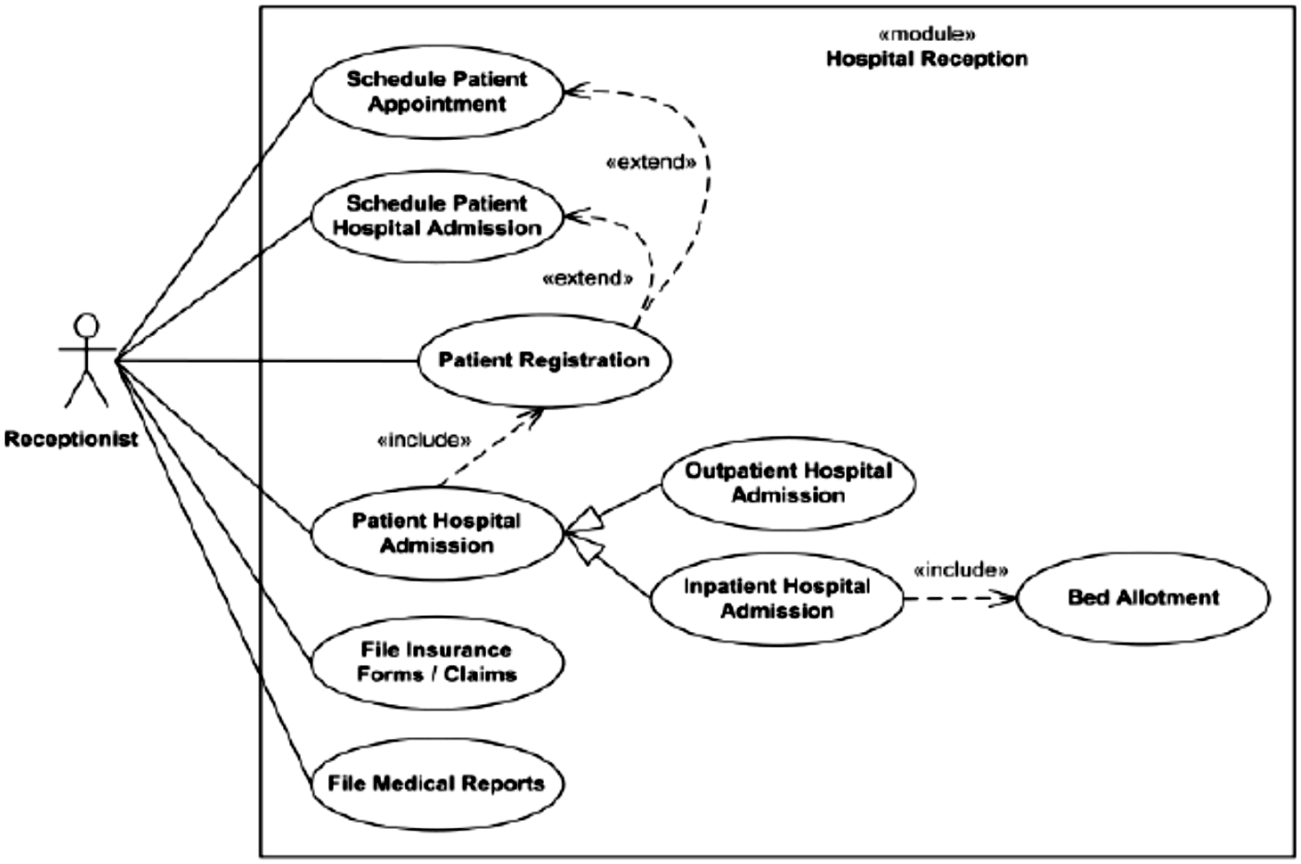

Student
Borrow Books
<<Include>>
Check Reserved Book
<<Include>>
Check Fine

2-


Search
Search by Call Number
Search by Author

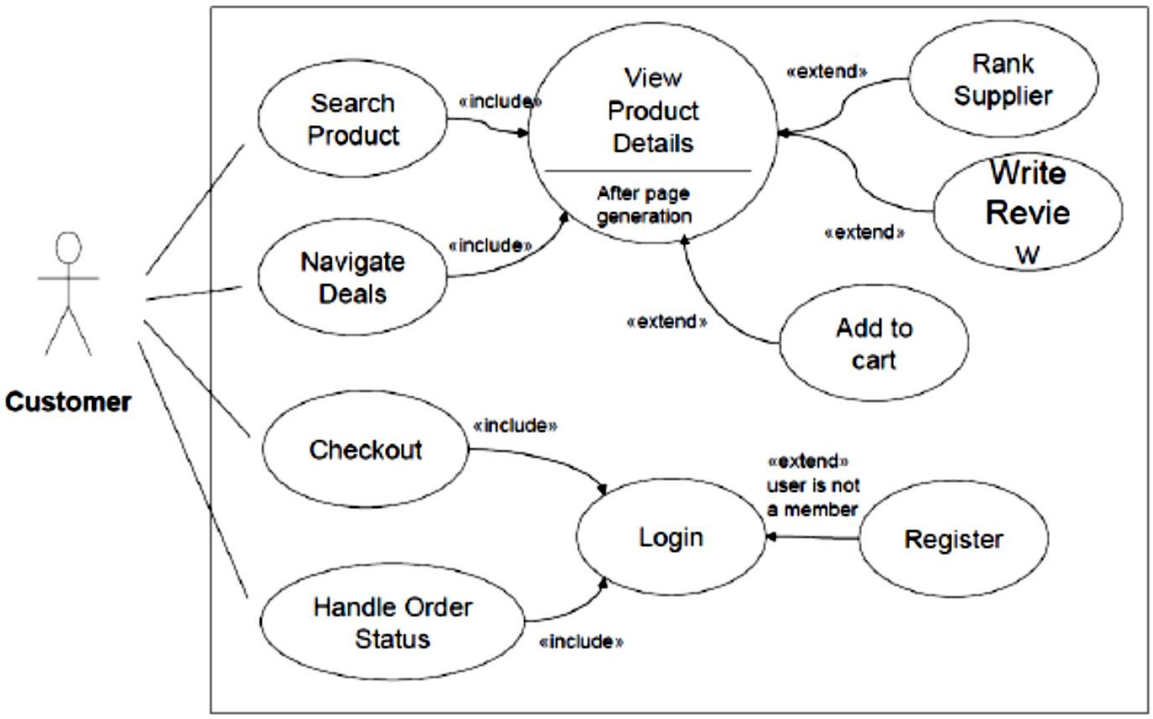
3-

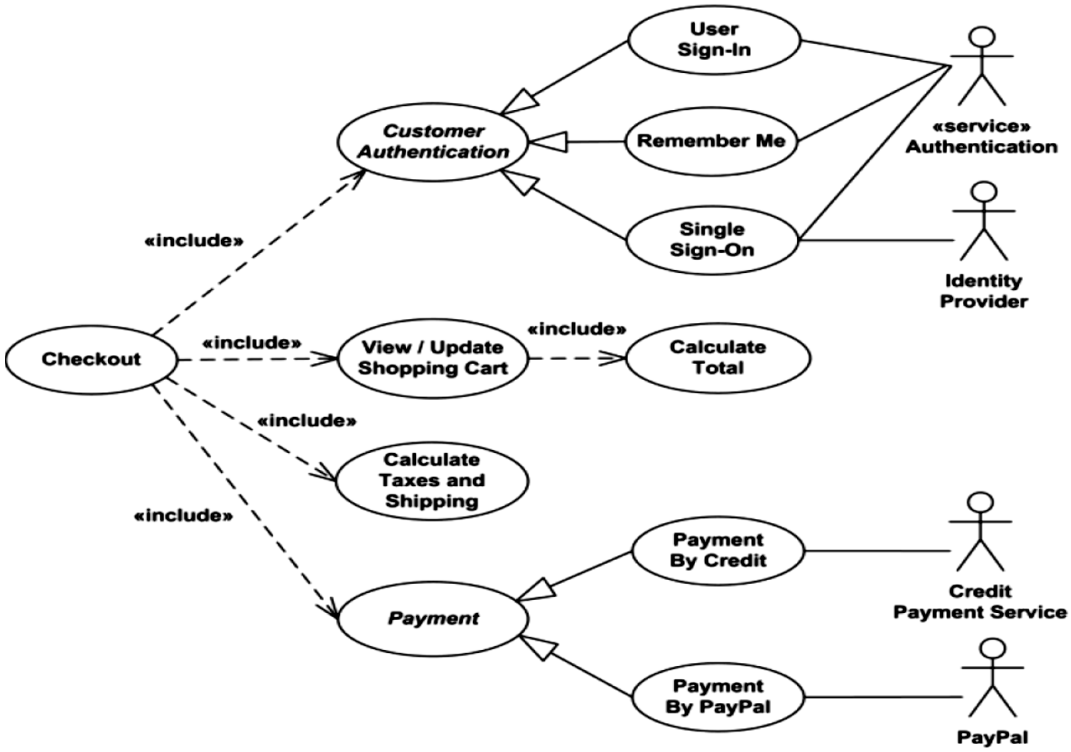

vehicle Sales System
Make Payment Arrangements
<<Extend>>
Make Offer
extension points
Make Payment Arrangements
Update Customer Information
<<Extend>>
Make Old Customer Offer
extension points
Update Customer Information
Make New Customer Offer
<<Include>>
Create New Customer
Customer
Accept Offer
<<Include>>
Manage Offers
Record Sales Contract
<<Include>>
Management
Salesperson
New Customer
Old Customer


«module»
Hospital Reception
Schedule Patient Appointment
«extend»
Schedule Patient Hospital Admission
«extend»
Patient Registration
Receptionist
«include»
Outpatient Hospital Admission
Patient Hospital Admission
Inpatient Hospital Admission
«include»
Bed Allotment
File Insurance Forms / Claims
File Medical Reports

Example:


Product Page
Shopping Cart
Review Writing


Customer
Search Product
Navigate Deals
Checkout
Handle Order Status
View Product Details
After page generation
Rank Supplier
Write Revie w
Add to cart
Login
Register
«include»
«include»
«include»
«include»
«extend»
«extend»
«extend»
«extend»
user is not a member


User Sign-In
Customer Authentication
Remember Me
Single Sign-On
«service» Authentication
Identity Provider
Checkout
View / Update Shopping Cart
Calculate Total
Calculate Taxes and Shipping
Payment
Payment By Credit
Payment By PayPal
Credit Payment Service
PayPal
«include»
«include»
«include»
«include»
«include»

4.5 Representation of complex processing logic

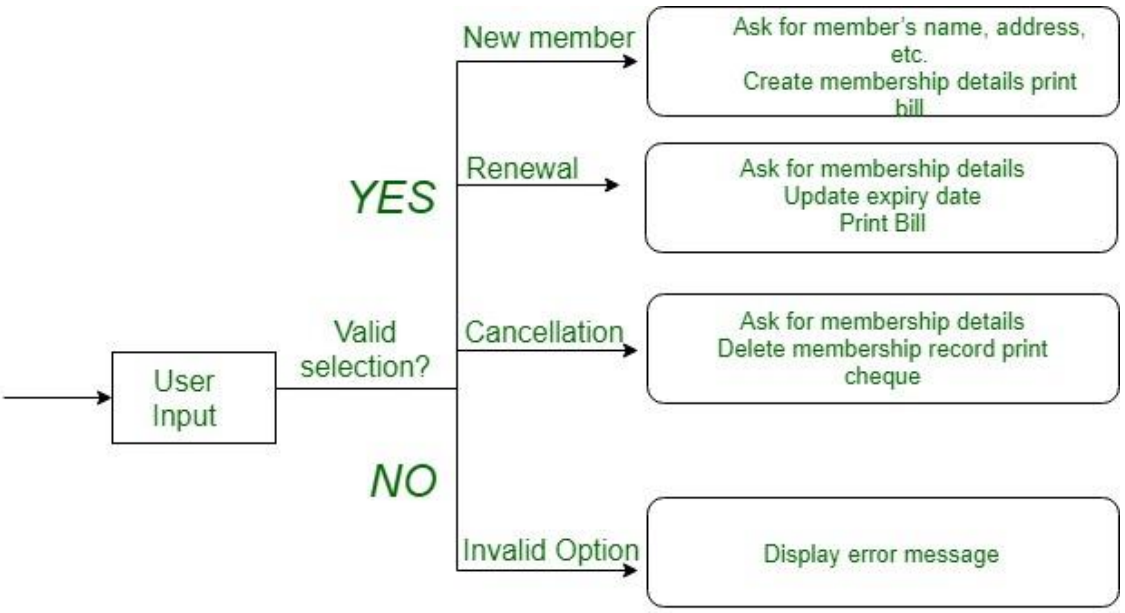
•Decision trees

•Decision tables

A- **Decision Tree** offers a graphic read of the processing logic concerned in a higher cognitive process and therefore the corresponding actions are taken.

–Edges of a decision tree represent conditions

–Leaf nodes represent actions to be performed.



Decision tree for LMS

B- **Decision Table**

•Decision tables specify:

–Which variables are to be tested

–What actions are to be taken if the conditions are true,

–The order in which decision making is performed.

•Upper rows of the table specify:

–The variables or conditions to be evaluated

•Lower rows specify:

–The actions to be taken when the corresponding conditions are satisfied.

Example:

Conditions	Rule 1	Rule 2	Rule 3	Rule 4
Username	F	T	F	T
Password	F	F	T	T
Output	E	E	E	H

In the above example,

- **T** – Correct username/password
- **F** – Wrong username/password
- **E** – Error message is displayed
- **H** – Home screen is displayed

Example:

Condition	Requirement Number				
	1	2	3	4	5
Requester is authorized	F	T	T	T	T
Chemical is available	—	F	T	T	T
Chemical is hazardous	—	—	F	T	T
Requester is trained	—	—	—	F	T
Action					
Accept request			X		X
Reject request	X	X		X	

Chapter 5
SOFTWARE DESIGN

The activities carried out during the design phase (called as design process) transform the SRS document into the design document.

Figure 5.1: The design process.

5.1 OVERVIEW OF THE DESIGN PROCESS

5.1.1 Outcome of the Design Process

The following items are designed and documented during the design phase.

Different modules required: The different modules in the solution should be clearly identified. Each module is a collection of functions and the data shared by the functions of the module. Each module should accomplish some well-defined task out of the overall responsibility of the software. Each module should be named according to the task it performs.

Control relationships among modules: A control relationship between two modules essentially arises due to function calls across the two modules.

Interfaces among different modules: The interfaces between two modules identifies the exact data items that are exchanged between the two modules when one module invokes a function of the other module.

Data structures of the individual modules: Each module normally stores some data that the functions of the module need to share to accomplish the overall responsibility of the module. Suitable data structures for storing and managing the data of a module need to be properly designed and documented.

Algorithms required to implement the individual modules: Each function in a module usually performs some processing activity. The algorithms required to accomplish the processing activities of various modules need to be carefully designed and documented with due considerations given to the accuracy of the results, space and time complexities.

5.1.2 Classification of Design Activities

A good software design is seldom realised by using a single step procedure, rather it requires iterating over a series of steps called the design activities. We can broadly classify them into two important stages.

• Preliminary (or high-level) design

Identify:

–modules
–control relationships among modules
–interfaces among modules.

The outcome of high-level design:

–program structure, also called software architecture.

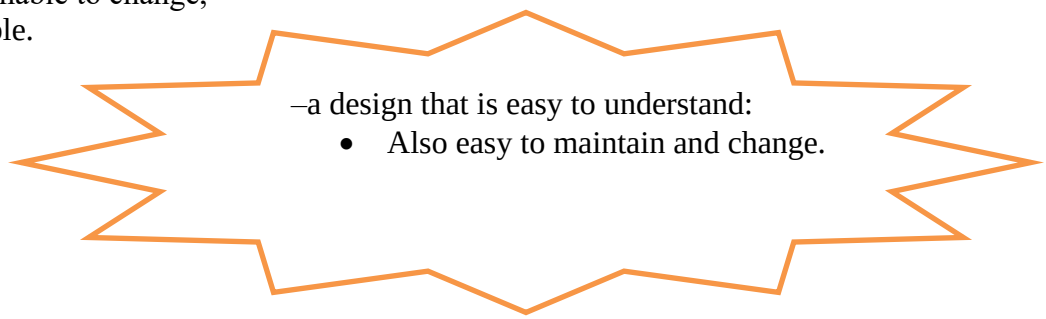
• Detailed design

For each module, design for it:
–data structure
–algorithms
•Outcome of detailed design:
–module specification.

5.2 What Is a Good Software Design?

•There is no unique way to design a software.
•Even while using the same design methodology:
–different engineers can arrive at very different designs.
•Need to determine which is a better design.

But:
•Should implement all functionalities of the system correctly.
•**Should be easily understandable.**
•Should be efficient.
•Should be easily amenable to change,
–i.e. easily maintainable.



How to Improve Understandability?

•Use consistent and meaningful names
–for various design components,
•Design solution should consist of:
–A set of well decomposed modules(**modularity**),
•Different modules should be neatly arranged in a hierarchy:
–A tree-like diagram.
–Called Layering

5.2.1 Modularity

•Modularity is a fundamental attributes of any good design.
–Decomposition of a problem into a clean set of modules:
–Modules are almost independent of each other
–Based on **divide and conquer principle.**

If modules are independent:

–Each module can be understood separately,
•reduces complexity greatly.
–To understand why this is so,
•remember that it is very difficult to break a bunch of sticks but very easy to break the sticks individually.

Q\ how can we compare the modularity of two alternate design solutions?

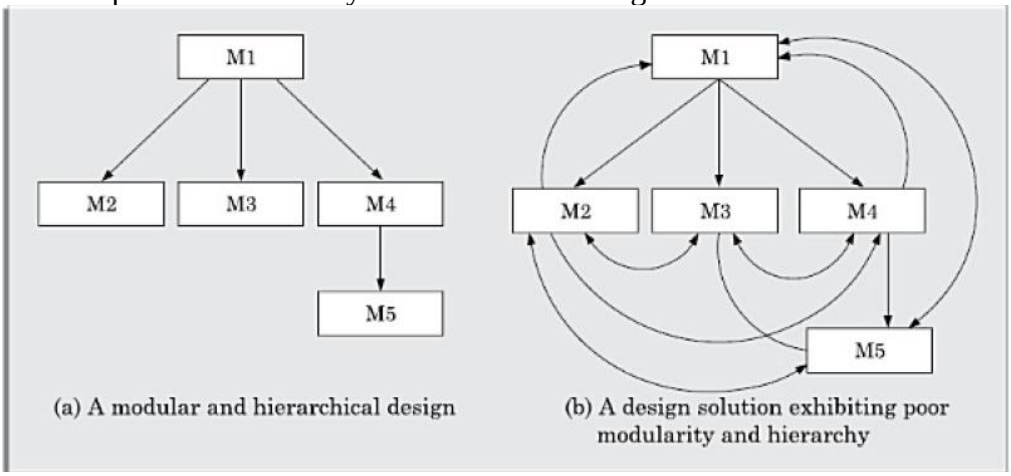


Figure 5.2 Two design solutions to the same problem

A design solution is said to be highly modular, if the different modules in the solution have high cohesion and their inter-module couplings are low.

5.3 COHESION AND COUPLING

Cohesion is a measure of the functional strength of a module, whereas the coupling between two modules is a measure of the degree of interaction (or interdependence) between the two modules.

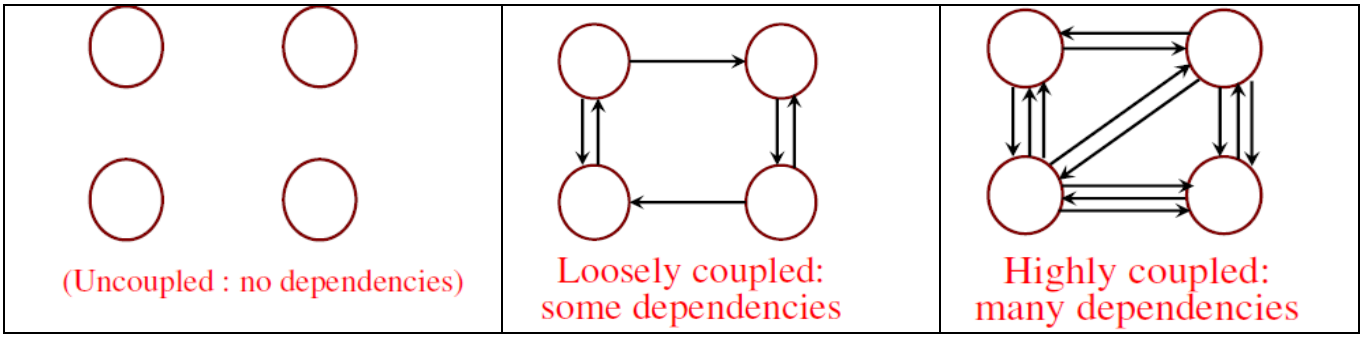


Figure 5.3: Module coupling

High coupling makes modifying parts of the system difficult, e.g., modifying a component affects all the components to which the component is connected.

A module having **high cohesion and low coupling**:
–**Called functionally independent** of other modules:
•A functionally independent module needs very little help from other modules and therefore has minimal interaction with other modules.

5.3.1 Why Functional Independence is Advantageous?

•Functional independence **reduces error propagation**.
–degree of interaction between modules is low.

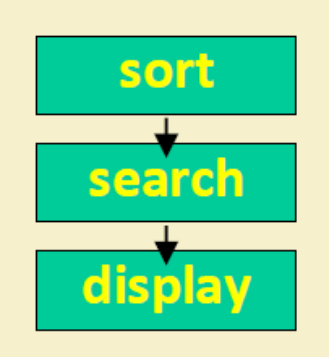
–an error existing in one module does not directly affect other modules.
•**Also: Reuse of modules is possible.**

–can be easily taken out and reused in a different program.
•each module does some well-defined and precise function

•the interfaces of a module with other modules is simple and minimal.

5.3.2 Measuring Functional Independence

•Unfortunately, there are no ways:
–to quantitatively measure the degree of cohesion and coupling:



–At least classification of different kinds of cohesion and coupling:
•will give us some idea regarding the degree of cohesiveness of a module.

5.3.3 Classification of Cohesiveness

•Classification can have scope for ambiguity:
–yet gives us some idea about cohesiveness of a module.
•By examining the type of cohesion exhibited by a module:
–we can roughly tell whether it displays high cohesion or low cohesion.

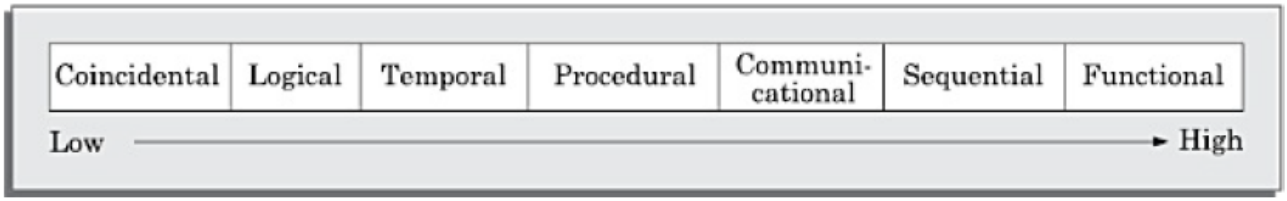


Figure 5.4 classification of cohesion

Functional Cohesion

_ A and B are part of a single functional task. This is very good reason for them to be contained in the same procedure.

Sequential Cohesion

_ Module A outputs some data which forms the input to B. This is the reason for them to be contained in the same procedure.

Communicational cohesion

•All functions of the module:
–Reference or update the same data structure,
•**Example:**
–The set of functions defined on an array or a stack.

```
handle-Student-Data() {
Static StructStudent-data[10000];
Store-student-data();
Search-Student-data();
Print-all-students();
};
```

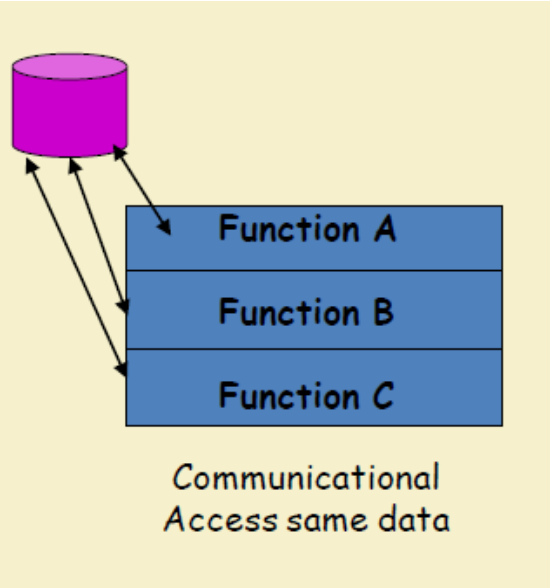
Procedural Cohesion

Procedural Cohesion occurs in modules whose instructions although accomplish different tasks yet have been combined because there is a specific order in which the tasks are to be completed.

–certain sequence of steps have to be carried out in a certain order for achieving an objective,
•e.g. the algorithm for decoding a message.

Temporal Cohesion

_Module exhibits temporal cohesion when it contains tasks that are related by the fact that all tasks must be executed in the same time-span.



•Example:
–The set of functions responsible for
•initialization,
•start-up, shut-down of some process, etc.

```
init() {
   Check-memory();
   Check-Hard-disk();
   Initialize-Ports();
   Display-Login-Screen();
 }
```

Logical Cohesion

•All elements of the module perform similar operations:
–e.g. error handling, data input, data output, etc.
•An example of logical cohesion:
–a set of print functions to generate an output report arranged into a single module.

```
module print{
   void print-grades(student-file){ …}
   void print-certificates(student-file){…}
   void print-salary(teacher-file){…}
}
```

Coincidental Cohesion
Coincidental cohesion exists in modules that contain instructions that have little or no relationship to one another.

```
Module AAA{
  Print-inventory();
  Register-Student();
  Issue-Book();
};
```

5.3.4 Classification of Coupling

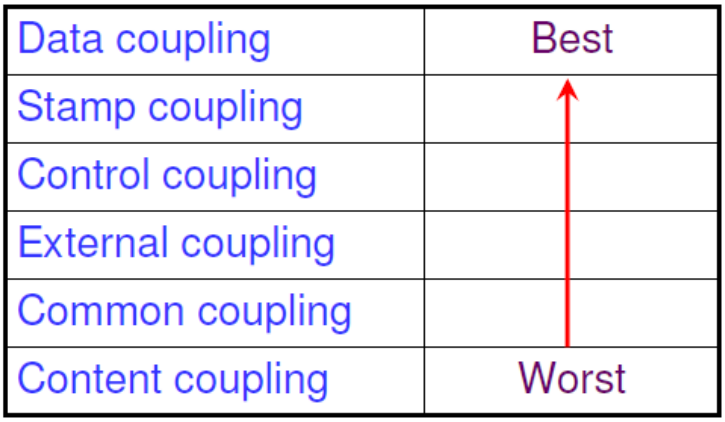


Figure 5.5 The types pf module coupling

Given two procedures A & B, we can identify number of ways in which they can be coupled.
Data coupling
The dependency between module A and B is said to be data coupled if their dependency is based on the fact they communicate by only passing of data. Other than communicating through data, the two modules are independent.

Stamp coupling
Stamp coupling occurs between module A and B when complete data structure is passed from one module to another.
Control coupling
Module A and B are said to be control coupled if they communicate by passing of control information. This is usually accomplished by means of flags that are set by one module and reacted upon by the dependent module.

Common coupling
With common coupling, module A and module B have shared data. Global data areas are commonly found in programming languages. Making a change to the common data means tracing back to all the modules which access that data to evaluate the effect of changes.

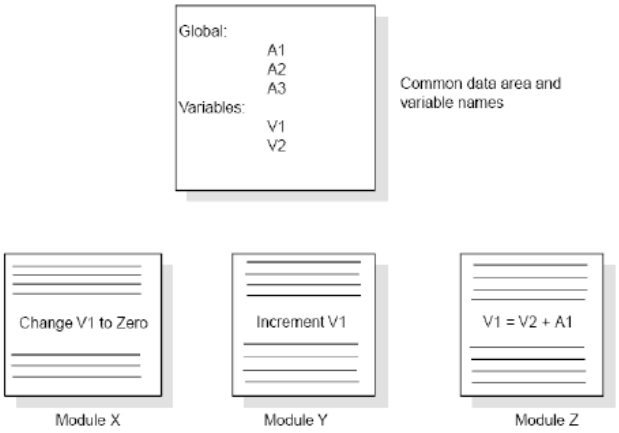


Figure 5.6 Example of common coupling

Content coupling

Content coupling occurs when module A changes data of module B or when control is passed from one module to the middle of another. In Figure 5.7, module B branches into D, even though D is supposed to be under the control of C.

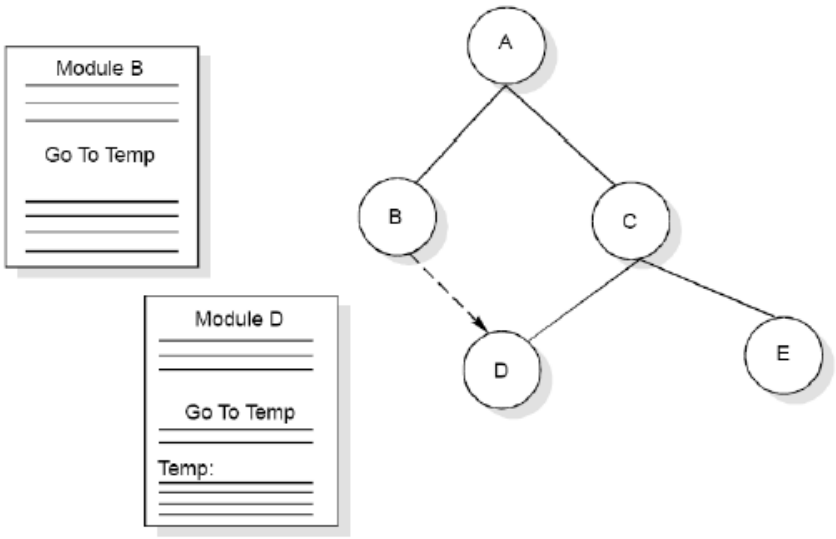


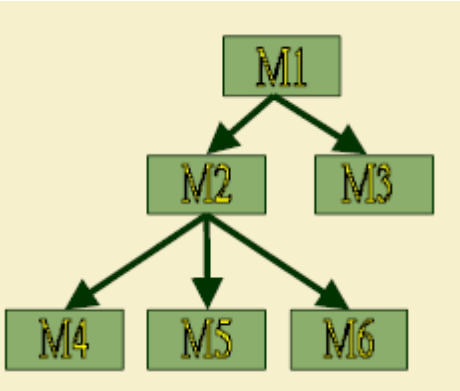
Figure 5.7 Example of content coupling

5.4 Hierarchical Design

•Control hierarchy represents:
–organization of modules.
–control hierarchy is also called program structure.
•Most common notation:
–a tree-like diagram called structure chart.

Good Hierarchical Arrangement of modules
•Essentially means:
–**low fan-out**
–**abstraction**

Characteristics of Module Structure
•**Depth**:
–number of levels of control
•**Width**:
–overall span of control.
•**Fan-out:**
–a measure of the number of modules directly controlled by given module.
•**Fan-in:**
–indicates how many modules directly invoke a given module.
–High fan-in represents code reuse and is in general encouraged.



- **Visibility:** A module B is said to be visible to another module A, if A directly calls B. Thus, only the immediately lower layer modules are said to be visible to a module.

- **Control abstraction:** In a layered design, a module should only invoke the functions of the modules that are in the layer immediately below it. In other words, the modules at the higher layers, should not be visible.

Goodness of Design
•A design having modules:
–with high fan-out numbers is not a good design.
–a module having high fan-out lacks cohesion.
•A module that controls another module:
–said to be superordinate to the later module.
•Conversely, a module controlled by another module:
–said to be subordinate to the later module.

5.5 Classification of Design Methodologies

The design activities vary considerably based on the specific design methodology being used. A large number of software design methodologies are available. We can roughly classify these methodologies into **procedural and object-oriented approaches**.

5.5.1 Function-oriented Design

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

Top-down decomposition: A system, to start with, is viewed as a black box that provides certain services (also known as high-level functions) to the users of the system.

For example, consider a function create-new-library member.
This high-level function may be refined into the following subfunctions:
• assign-membership-number
• create-member-record
• print-bill

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

Centralised system state: The system state can be defined as the values of certain data items that determine the response of the system to a user action or external event.

For example, in the library management system, several functions such as the following share data such as member-records for reference and updation:
• create-new-member
• delete-member
• update-member-record

Design Notations

Design notations are largely meant to be used during the process of design and are used to represent design or design decisions.
For a function-oriented design, the design can be represented graphically or mathematically by the following:

- ❖ Data flow diagrams
- ❖ Data Dictionaries
- ❖ Structure Charts
- ❖ Pseudocode

5.5.2 Object-oriented Design

In the object-oriented design (OOD) approach, a system is viewed as being made up of a collection of objects (i.e. entities).

- Each object is associated with a set of functions that are called its methods.
- Each object contains its own data and is responsible for managing it.

- The data internal to an object cannot be accessed directly by other objects and only through invocation of the methods of the object.
- The system state is decentralised since there is no globally shared data in the system and data is stored in each object.

For example, in a library automation software, each library member may be a separate object with its own data and functions to operate on the stored data.

→ Bottom-up approach

→ Carried out using UML

5.5.3 Object-Oriented versus Function-Oriented Design

Grady Boochsums up this fundamental difference saying:
–**"Identify verbs if you are after procedural design and nouns if you are after object-oriented design."**

•In OOD:
–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 shared in a centralized data.
–but is distributed among the objects of the system.

Example
•In an employee pay-roll system, the following can be global data:
–names of the employees,
–their code numbers,
–basic salaries, etc.

•In contrast, in object oriented systems:
–data is distributed among different employee objects of the system.

•Objects communicate by message passing.
–one object may discover the state information of another object by interrogating it.

5.6 Unified Modeling Language (UML)

The **Unified Modeling Language** (**UML**) is a general-purpose, developmental, modeling language in the field of software engineering that is intended to provide a standard way to visualize the design of a system.

- UML is a modelling language

  Not a system design or development methodology

-
- Used to document object-oriented analysis and design results.
- Independent of any specific design methodology.

- Adopted by Object Management Group (OMG) in 1997.

  ➔ OMG is an association of industries

- In 2005, UML was also published by the International Organization for Standardization (ISO) as an approved ISO standard.

Why are UML Models Required?

- Modelling is an abstraction mechanism:
  - Capture only important aspects and ignores the rest.
  - Different models obtained when different aspects are ignored.
- An effective mechanism to handle complexity.
- UML is a graphical modelling technique.
- Easy to understand and construct.

5.6.1 UML Diagrams

Nine diagrams in UML1.x :

✓ Used to capture 5 different views of a system:
User's view (**Use Case Diagram)**
Structural view (**Class Diagram, Object Diagram)**
Behavioral view (**Sequence Diagram**, **Collaboration Diagram**, **State-chart Diagram**, **Activity Diagram)**
Implementation view (**Component Diagram)**
Environmental view (**Deployment Diagram)**

✓ Views: Provide different perspectives of a software system.

✓ Diagrams can be refined to get the actual implementation of a system.

5.5.1.1 Class Diagram

Class

In any system, there shall be number of objects. Some of the objects may have common characteristics and we can group the objects according to these characteristics. This type of grouping is known as a class. Hence, a class is a set of objects that share a common structure and a common behavior.

A class represents a set of objects having similar attributes, operations, relationships and behavior

.

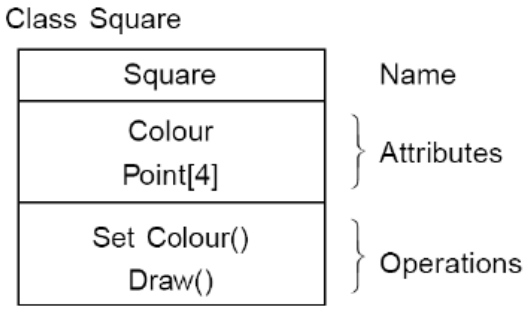
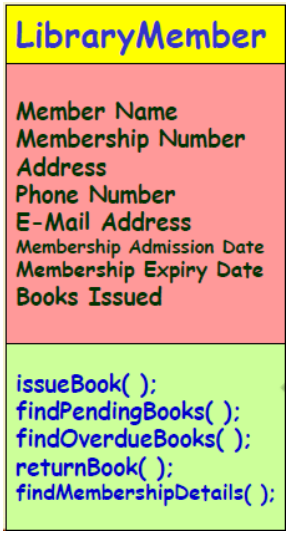


Figure 5.8 The squire class

Example:



What are the Different Types of Relationships Among Classes?

Four types of relationships:

Inheritance
Association
Aggregation/Composition
Dependency

B- Inheritance

Imagine that, as well as squares, we have triangle class. Figure 5.9 shows the class for a triangle.

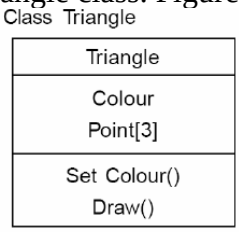


Figure 5.9 The triangle class

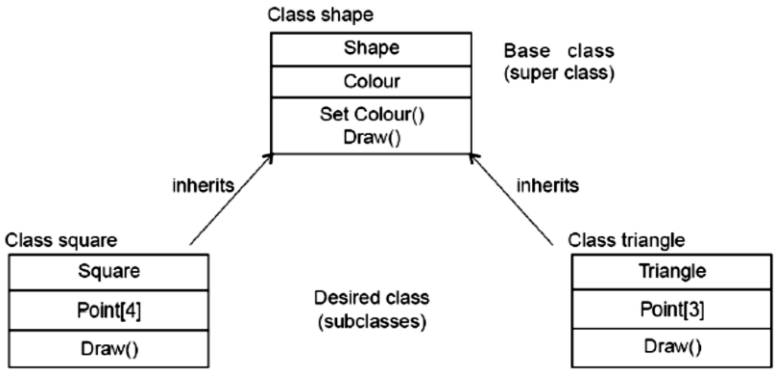


Figure 5.10 Abstraction common features in a new class

This sort of abstraction is called inheritance. The low level classes (known as subclasses or derived classes) inherit state and behaviour from this high level class (known as a super class or base class).

Polymorphism

When we abstract just the interface of an operation and leave the implementation to subclasses it is called a polymorphic operation and process is called polymorphism.

Encapsulation (Information Hiding)

Encapsulation is also commonly referred to as "Information Hiding". It consists of the separation of the external aspects of an object from the internal implementation details of the object.

Hierarchy

Hierarchy involves organizing something according to some particular order or rank. It is another mechanism for reducing the complexity of software by being able to treat and express sub-types in a generic way.

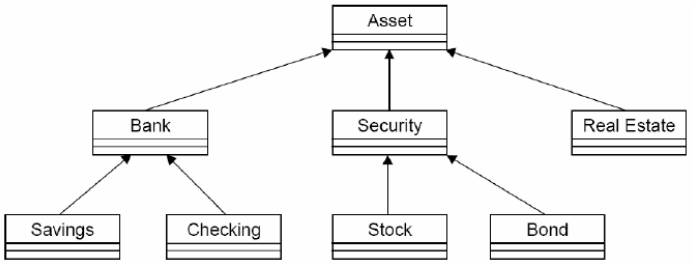
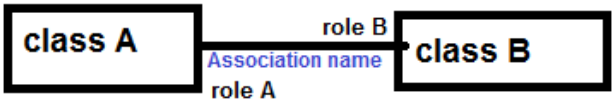


Figure 5.11 Hierarchy

C- Association Relationship

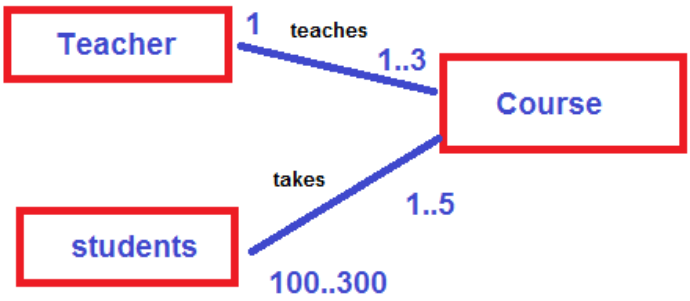
Enables objects to communicate with each other:

One object must "know" the ID of the corresponding object in the association.

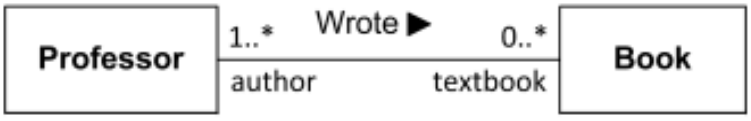


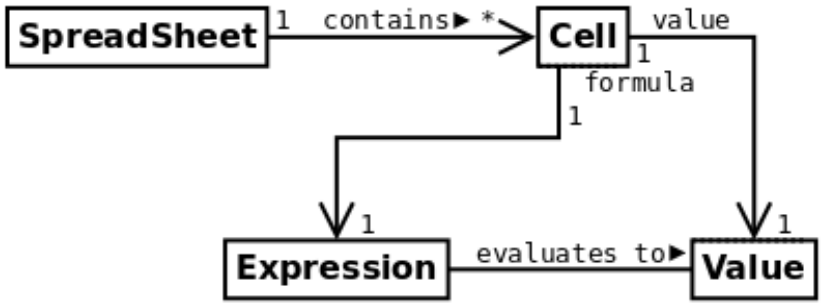
Example

- A teacher teaches 1 to 3 courses (subjects)
- Each course is taught by only one teacher.
- A student can take between 1 to 5 courses.
- A course can have 100 to 300 students



Multiplicity: The number of objects from one class that relate with a single object in an associated class.





Association and Link

- **A link:** An instance of an association
- Exists between two or more objects
- **Dynamically created and destroyed as the run of a system proceeds**
- For example: An employee joins an organization.
- Leaves that organization and joins a new organization.

D- **Aggregation Relationship**

Represents whole-part relationship

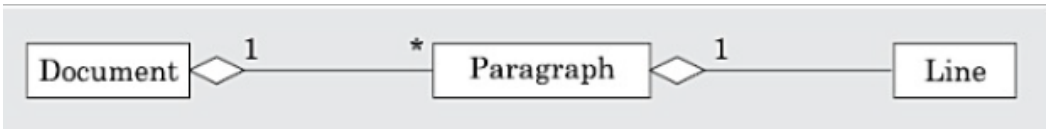
Represented by a diamondsymbol at the composite end.

Usually creates the components:

Also**, aggregate usually invokes the same operations of all its components.**

This is in contras to plain association

Aggregation



Observe that the number 1 is annotated at the diamond end, and a * is annotated at the other end. This means that one document can have many paragraphs. On the other hand, if we wanted o indicate that a document consists of exactly 10 paragraphs, then we would have written number 10 in place of the (*).

Aggregation vs. Inheritance

Inheritance: Different object types with similar features.

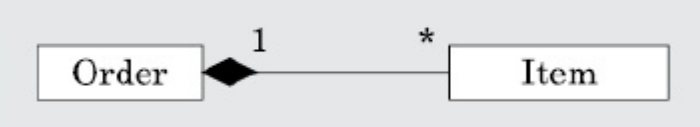
Necessary semantics for similarity of behavioris in place.

Aggregation: Containment allows construction of complex objects.

E- **Composition**

- A stronger form of aggregation
- The whole is the sole owner of its part.
- A component can belong to only one whole
-
- The life time of the part is dependent upon the whole.

- **The composite must manage the creation and destruction of its parts.**



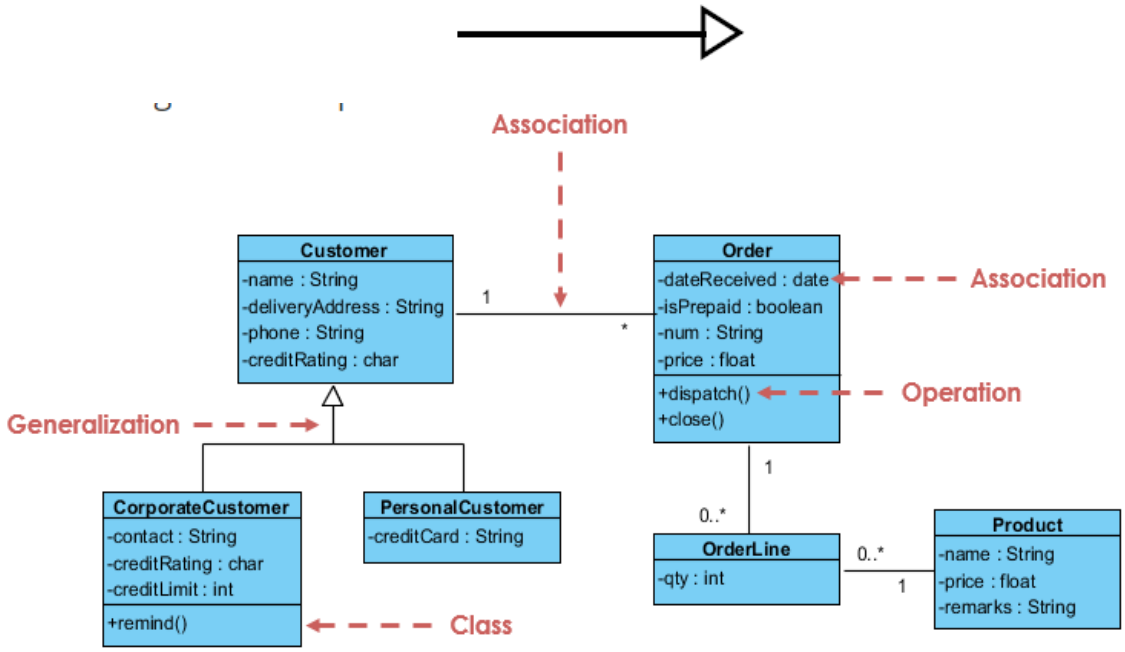
If any changes to any of the order items are required after the order has been placed, then the entire order has to be cancelled and a new order has to be placed with the changed item.

Aggregation versus Composition: Both aggregation and composition represent part/whole relationships. When the components can dynamically be added and removed from the aggregate, then the relationship is aggregation. If the components cannot be dynamically added/delete then the components are have the same life time as the composite.

```
public class Car{
        private Wheel wheels[4];
        public Car (){
                    wheels[0] = new Wheel();
                    wheels[1] = new Wheel();
                    wheels[2] = new Wheel();
                    wheels[3] = new Wheel();
        }

}
```

F- **Generalizations** are used to show an inheritance relationship between two classes.



G- Dependency

A dependency relation between two classes shows that any change made to the independent class would require the corresponding change to be made to the dependent class.

A dependency relationship is shown as a dotted arrow that is drawn from the dependent class to the independent class.

Two important reasons for dependency to exist between two classes are the following:

- A method of a class takes an object of another class as an argument.
- A class implements an interface class. In this case, dependency arises due to the following reason. If some properties of the interface class are changed, then a change becomes necessary to the class implementing the interface class as well.

Abstract class

Abstract classes cannot be instantiated, but they can be subclassed.

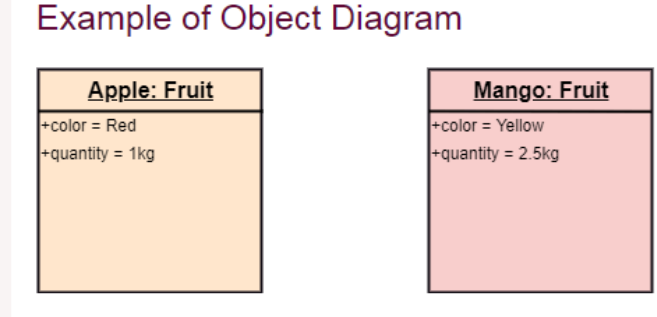
An *abstract method* is a method that is declared without an implementation.

Example:

```
abstract class Shape{
abstract void draw();
}
class Rectangle extends Shape{
void draw(){System.out.println("drawing rectangle");}
}
class Circle1 extends Shape{
void draw(){System.out.println("drawing circle");}
}
//In real scenario, method is called by programmer or user
class TestAbstraction1{
public static void main(String args[]){
Shape s=new Circle1();//In a real scenario, object is provided through method, e.g., getShape() m
ethod
s.draw();
}
}
```

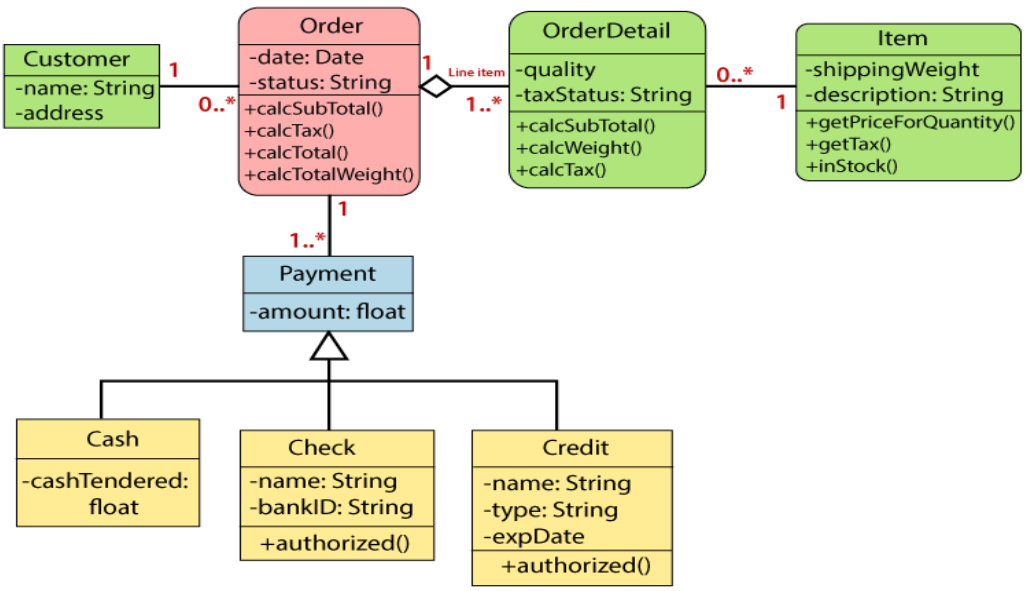
5.5.1.2 UML Object Diagram

Object diagrams are dependent on the class diagram as they are derived from the class diagram. It represents an instance of a class diagram.



Class vs. Object diagram

Serial No.	Class Diagram	Object Diagram
1.	It depicts the static view of a system.	It portrays the real-time behavior of a system.
2.	Dynamic changes are not included in the class diagram.	Dynamic changes are captured in the object diagram.
3.	The data values and attributes of an instance are not involved here.	It incorporates data values and attributes of an entity.
4.	The object behavior is manipulated in the class diagram.	Objects are the instances of a class.



- **aggregation: is part of"**
- **composition: is made of**
- **dependency: Depends on**

Composition B is a permanent part of A
- A contains B
- A is a permanent collection of Bs

Subclass / Superclass A is a kind of B
- A is a specialization of B
- A behaves like B

Association(Collaboration) A delegates to B
- A needs help from B
- A and B are

Identify Class Relations

- Faculty & student
- Hospital & doctor
- Door & Car
- Member & Organization
- People & student
- Department & Faculty
- Employee & Faculty
- Computer Peripheral & Printer
- Account & Savings account

- A square is a polygon
- Ahamed is a student
- Every student has a name
- 100 paisa is one dollar
- Students live in hostels
- Every student is a member of the library
- A student can renew his borrowed books
- The Department has many students

Example:

```
1 // An actor with "name" and "stage name" attributes
2 public class Actor {
3
4 // Fields
5       private String name, stageName;
6
7 // Create a new actor with the given stage name
8      public Actor(String sn) {
9          name = "<None>";
10         stageName = sn;
11   }
12
13 // Get the name
14 public String getName() {
15    return name;
16   }
17
18 // Set the name
19    public void setName(String n) {
20     name = n;
21   }
22
23 // Get the stage name
24   public String getStageName() {
25        return stageName;
26    }
27
28 // Set the stage name
29    public void setStageName(String sn) {
30         stageName = sn;
31    }
32
33 // Reply a summary of this actor's attributes, as a string
34      public String toString() {
35          return "I am known as " + getStageName() + ", but my real name is " + getName();
37     }
38   }
```

Element	Purpose	Example in Figure 2.20
Class name	Referring to the class elsewhere in our code.	Actor, line 2
Fields	Describing the information stored by this kind of object.	name and stageName, line 5
Constructors	Controlling initialization of the objects.	Actor(), line 8
Messages	Providing other objects with a way to use the objects.	getName(), line 14; setName(), line 19; getStageName(), line 24; setStageName(), line 29; and toString(), line 34
Operations	Telling the objects how to behave.	lines 15, 20, 25, 30, 35 and 36
Comments	Telling programmers how to use or maintain the class (ignored by the compiler).	lines starting //, e.g. lines 1 and 4

5.5.1.3 Interaction Diagram

- **Can model the way a group of objects interact to realize some behaviour.**
  - How many interaction diagrams to draw?
    - Typically each interaction diagram realizes behaviour of a single use case
  - **Draw one sequence diagram for each use case.**

A- Sequence Diagram

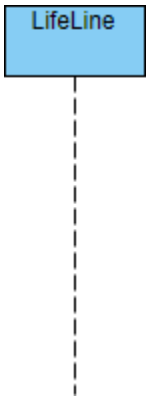
Captures how objects interact with each other: To realize some behaviour (use case execution).

•Emphasizes time ordering of messages.
•Can model: Simple sequential flow, branching, iteration, recursion, and concurrency

Sequence Diagram Notations

1- Lifeline

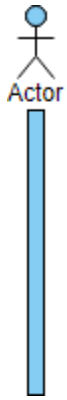
A lifeline represents an individual participant in the Interaction.



2- Actor

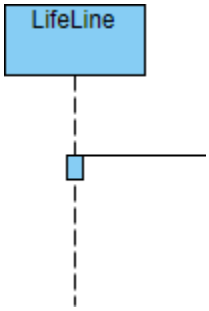
An Actor a type of role played by an entity that interacts with the subject (e.g., by exchanging signals and data). An actor can also be an external to the subject (i.e., in the sense that an instance of an actor is not a part of the instance of its corresponding subject). They typically represent roles played by human users, external hardware, or other subjects.
Note That:

1. An actor does not necessarily represent a specific physical entity but merely a particular role of some entity
2. A person may play the role of several different actors and, conversely, a given actor may be played by multiple different person.



3- Activation

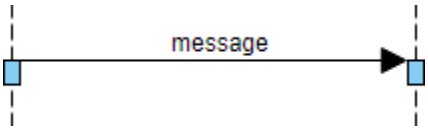
An activation is represented by a thin rectangle on a lifeline) represents the period during which an element is performing an operation. The top and the bottom of the of the rectangle are aligned with the initiation and the completion time respectively.



4- Messages

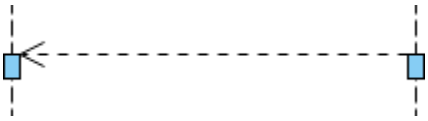
A- Call Message

A call message defines a particular communication between lifelines of an interaction, which represents an invocation of operation of target lifeline.



B- Return Message

A return message defines a particular communication between lifelines of an interaction, which represents the pass of information back to the caller of a corresponded former message.



c- Self Message

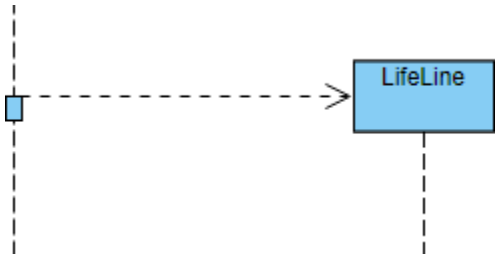
A self message defines a particular communication between lifelines of an interaction, which represents the invocation of message of the same lifeline.

d- Recursive Message

A recursive message defines a particular communication between lifelines of an interaction, which represents the invocation of message of the same lifeline. It's target points to an activation on top of the activation where the message was invoked from.

e- Create Message

A create message defines a particular communication between lifelines of an interaction, which represents the instantiation of (target) lifeline.

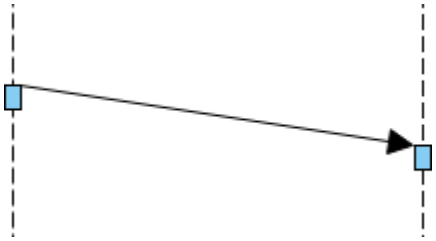


f- Destroy Message

A destroy message defines a particular communication between lifelines of an interaction, which represents the request of destroying the lifecycle of target lifeline.

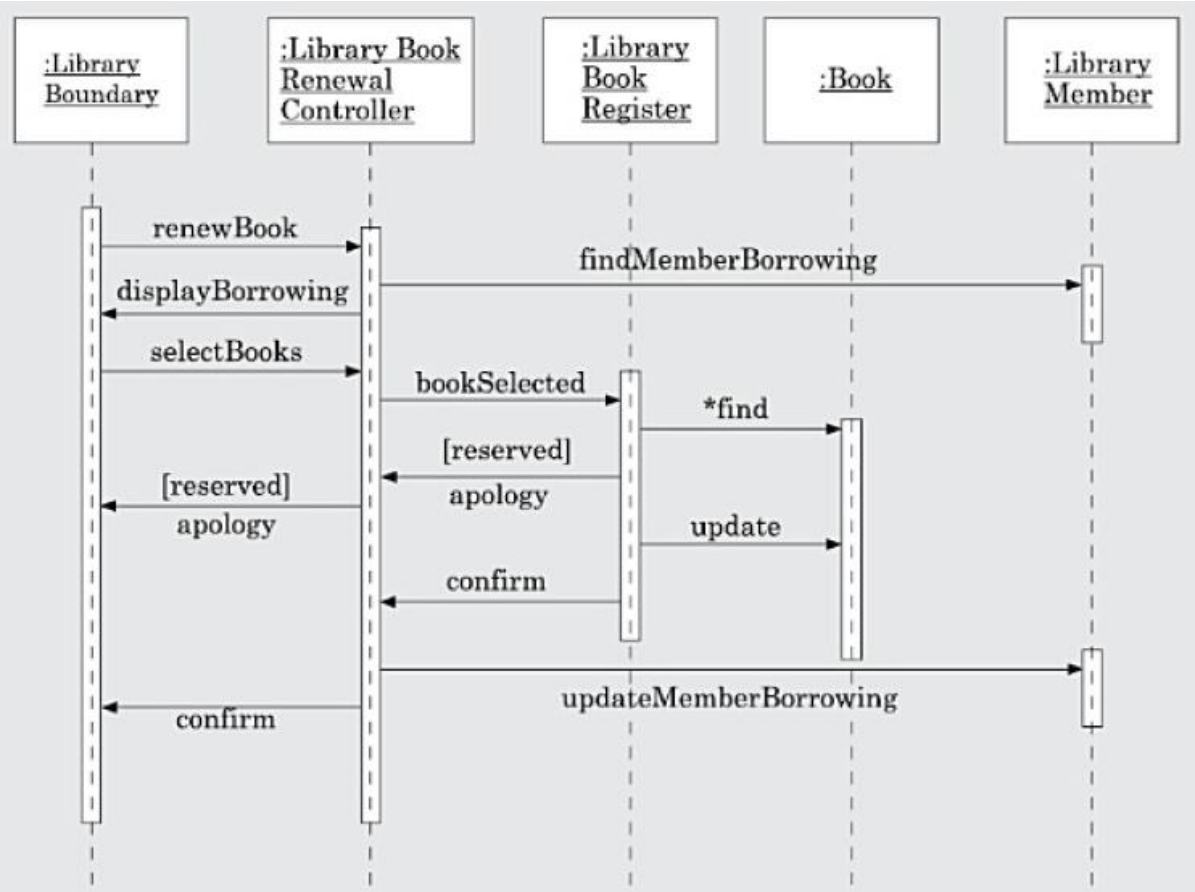
g- Duration Message

A duration message defines a particular communication between lifelines of an interaction, which shows the distance between two time instants for a message invocation.



Each message is labelled with the message name. Some control information can also be included. Two important types of control information are:

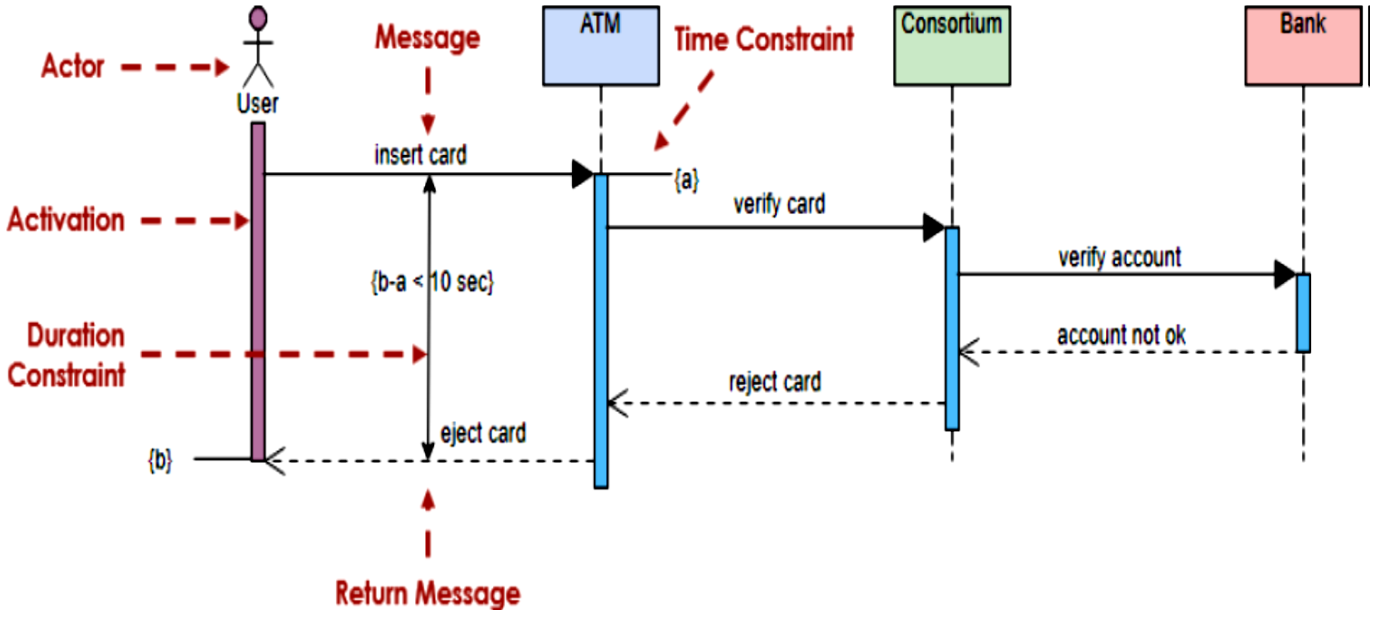
- A condition (e.g., [invalid]) indicates that a message is sent, only if the condition is true.
- An iteration marker shows that the message is sent many times to multiple receiver objects as would happen when you are iterating over a collection or the elements of an array.



Sequence diagram for the renew book use case

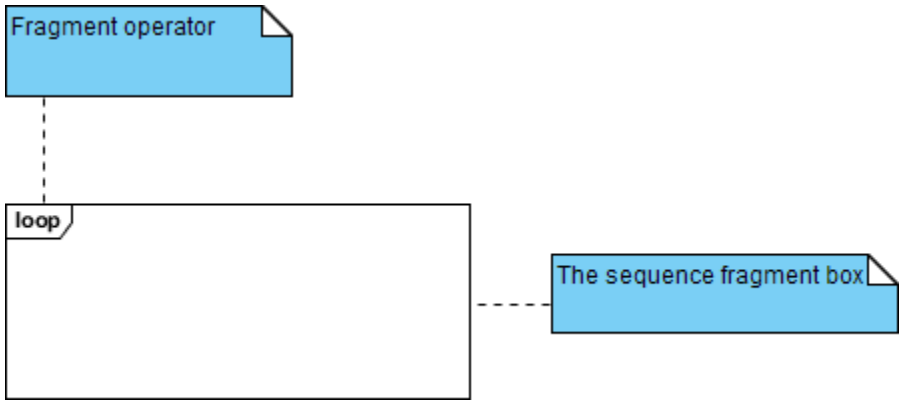
- Return Values

Optionally indicated using a dashed arrow: Label indicates the return value. Don't need when it is obvious what is being returned,

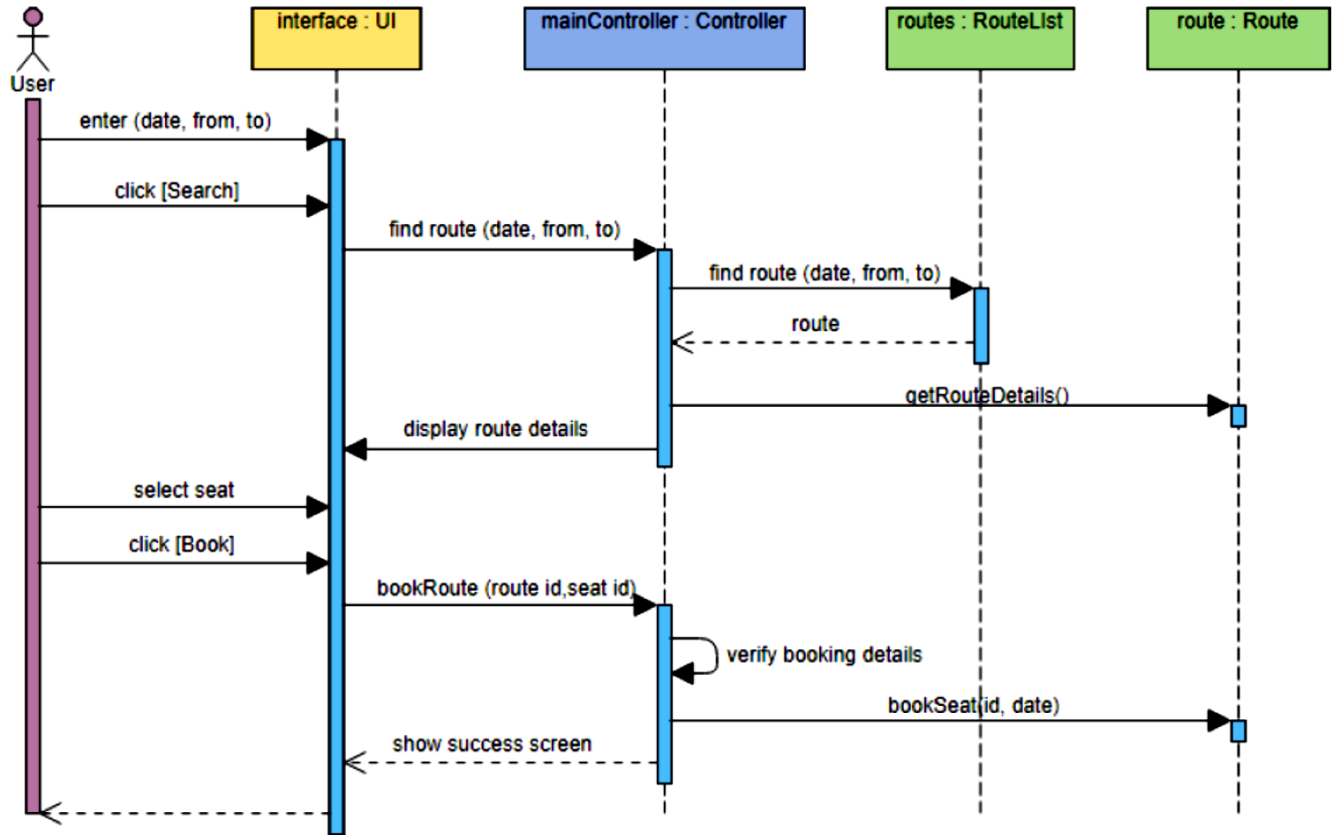


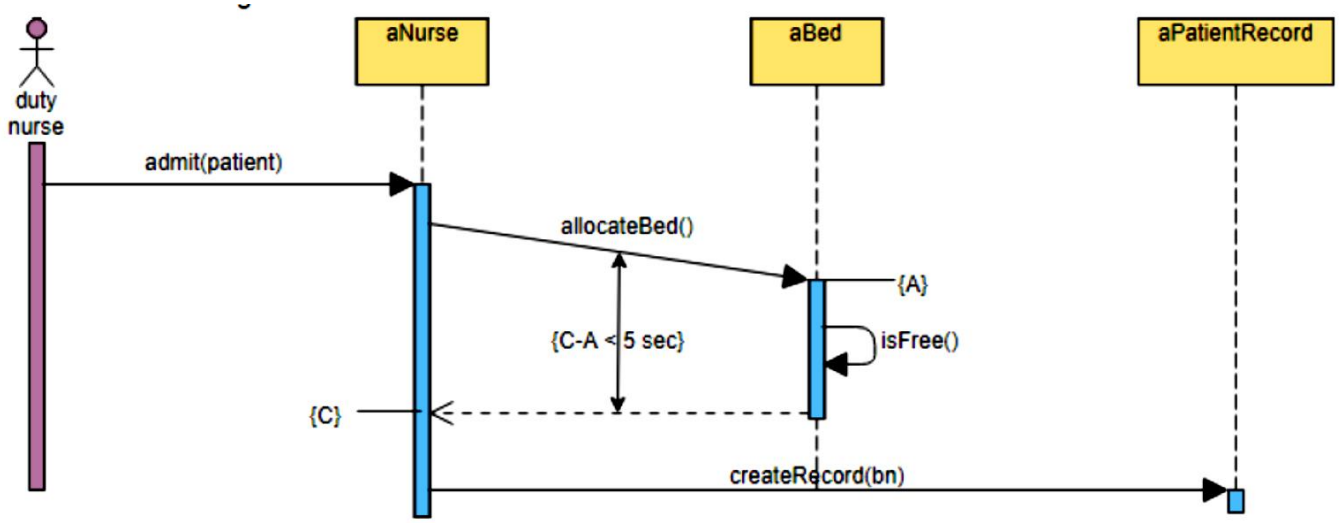
5- Sequence Fragments

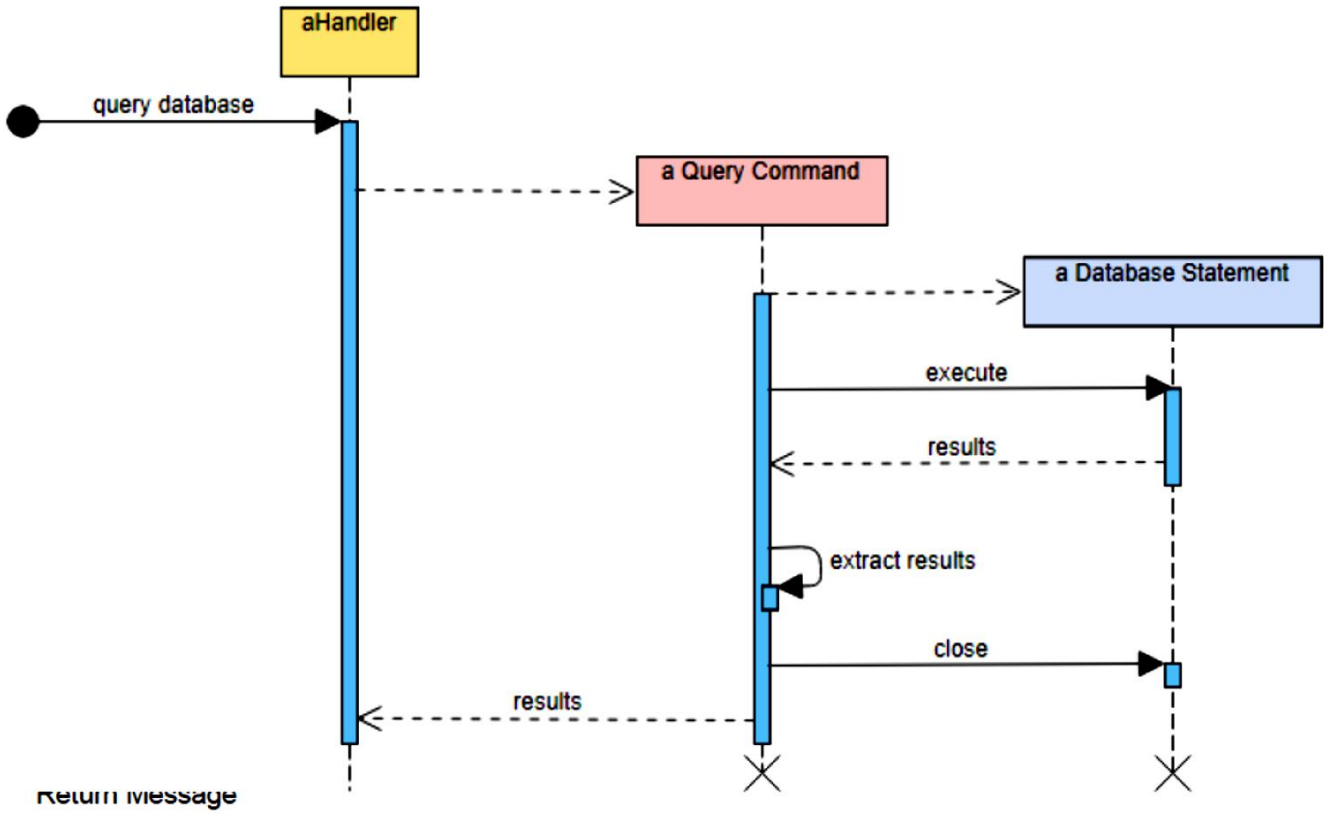
- UML 2.0 introduces sequence (or interaction) fragments. Sequence fragments make it easier to create and maintain accurate sequence diagrams
- A sequence fragment is represented as a box, called a combined fragment, which encloses a portion of the interactions within a sequence diagram
- The fragment operator (in the top left cornet) indicates the type of fragment
- Fragment types: ref, assert, loop, break, alt, opt, neg

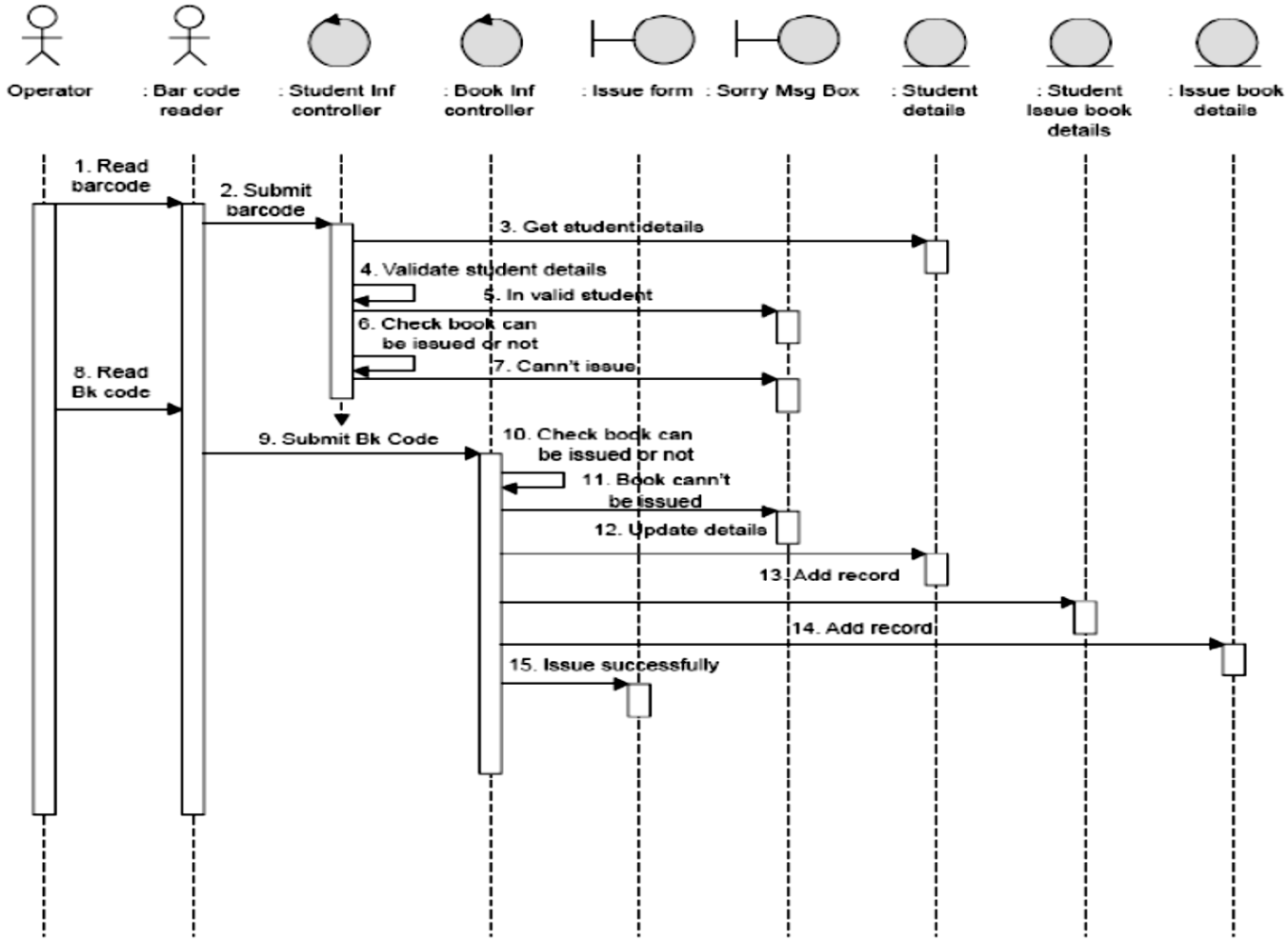


Operator	Fragment Type
alt	Alternative multiple fragments: only the one whose condition is true will execute.
opt	Optional: the fragment executes only if the supplied condition is true. Equivalent to an alt only with one trace.
par	Parallel: each fragment is run in parallel.
loop	Loop: the fragment may execute multiple times, and the guard indicates the basis of iteration.
region	Critical region: the fragment can have only one thread executing it at once.
neg	Negative: the fragment shows an invalid interaction.
ref	Reference: refers to an interaction defined on another diagram. The frame is drawn to cover the lifelines involved in the interaction. You can define parameters and a return value.
sd	Sequence diagram: used to surround an entire sequence diagram.

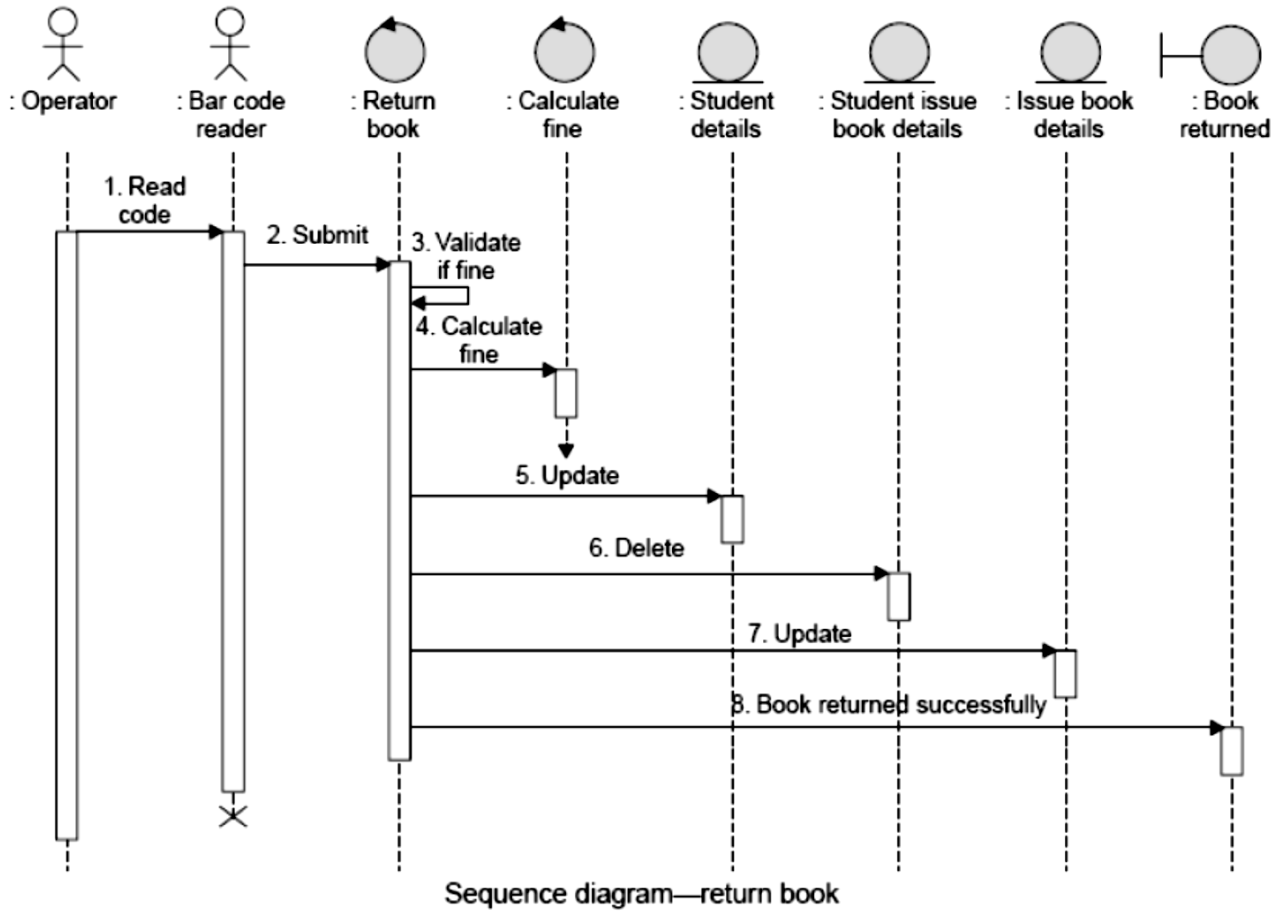



duty nurse
aNurse
aBed
aPatientRecord
admit(patient)
allocateBed()
{A}
{C-A < 5 sec}
isFree()
{C}
createRecord(bn)


aHandler
query database
a Query Command
a Database Statement
execute
results
extract results
close
results
Return Message



Sequence diagram—issue book

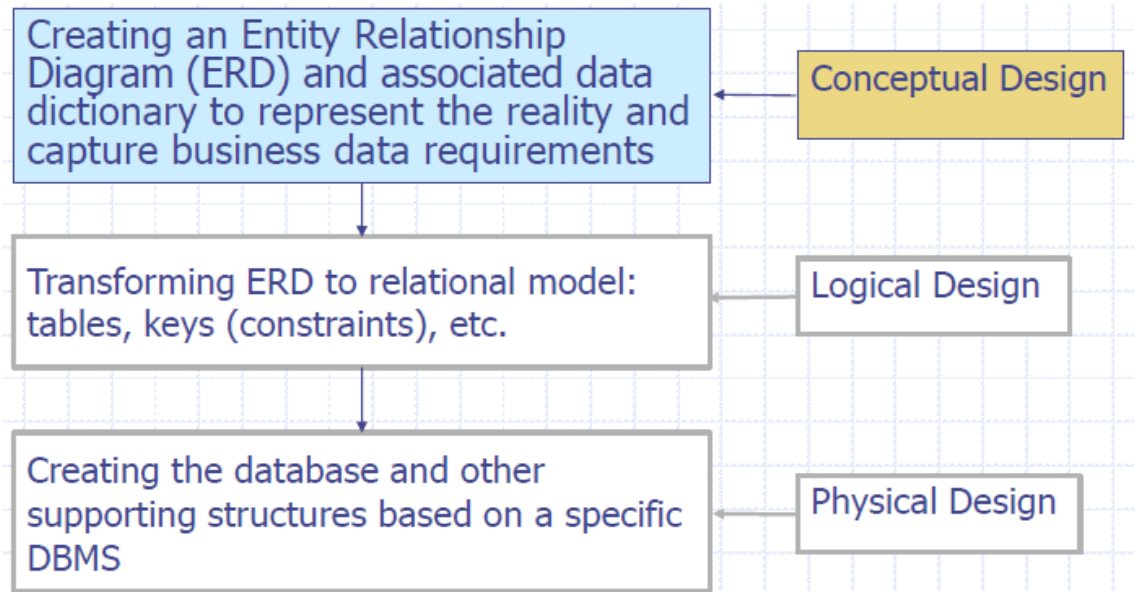


Sequence diagram—return book

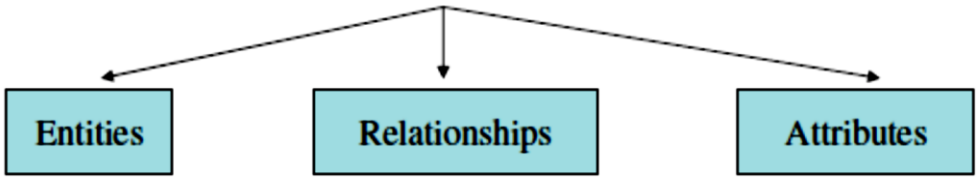
This is a tutorial link explain of the ATM sequence diagram: https://www.youtube.com/watch?v=pCK6prSq8aw

Database Design

- Overview: 3 Level Database Design



Entity-Relationship Diagrams
It is a detailed logical representation of data for an organization and uses three main constructs.



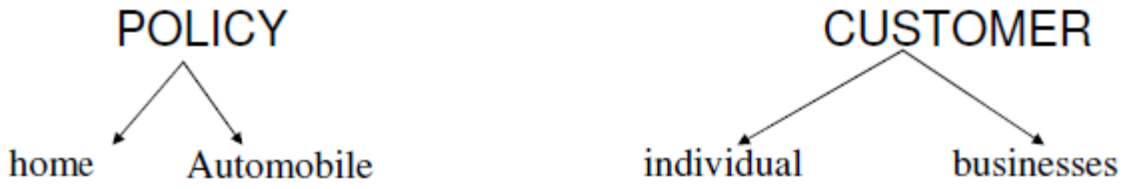
Entity
• Thing in the real world
Attribute
• Property of an entity
• Most of what we store in the database
Relationship
• Association between sets of entities
• Possibly with attribute(s)

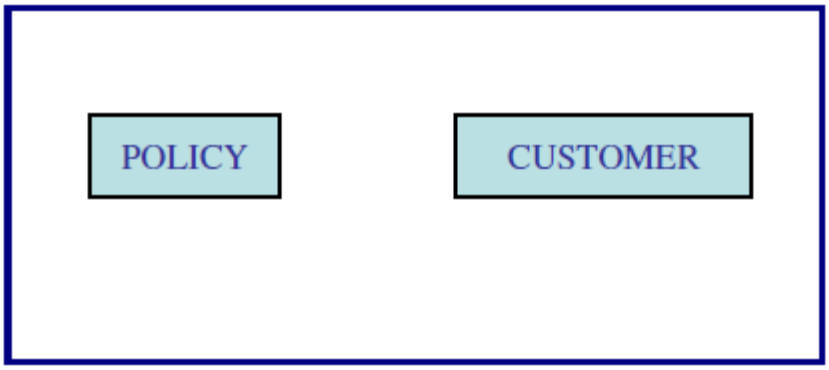
A- Entity

- Entities can be classified into different types.
- Each entity type contains a set of entities each satisfying a set of predefined common properties.

E.g. Employee, Student, Car, House, Bank Account

Consider an insurance company that offers both home and automobile insurance policies .These policies are offered to individuals and businesses.

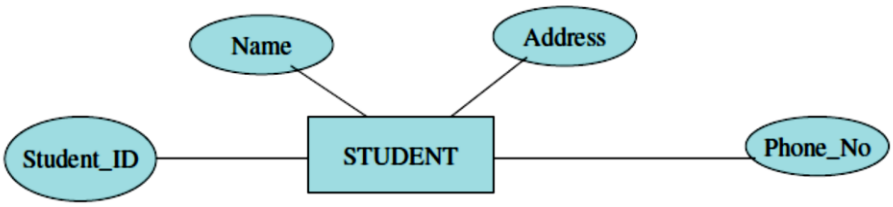




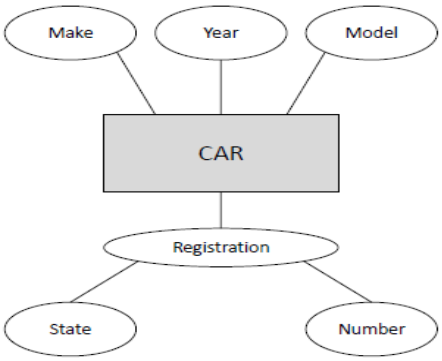
B- Attributes

- Each entity type has a set of attributes associated with it.
- An attribute is a property or characteristic of an entity that is of interest to organization.

A candidate key is an attribute or combination of attributes that uniquely identifies each instance of an entity type.
Student_ID → Candidate Key

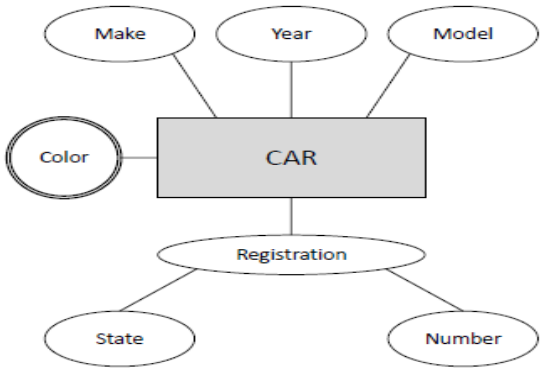


Composite Attributes
Can be subdivided into smaller subparts All cars have a year, make, model, and registration.

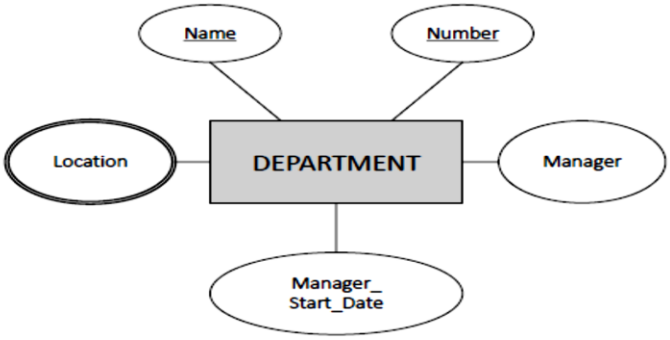


Multivalued Attributes
Can take a [possibly specified] number of values.

Ex: All cars have a year, make, model, registration, and some number of colors



Example: Draw an ERD for the following description: Each department has a unique name, a unique number, and a particular employee who manages the department. We keep track of the start date when that employee began managing the department. A department may have several locations.



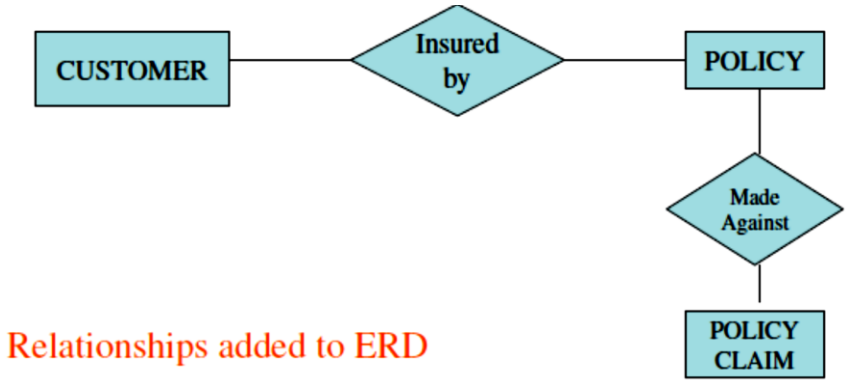
C- Relationships

A relationship is a reason for associating two entity types.

Binary relationships ⟶ involve two entity types

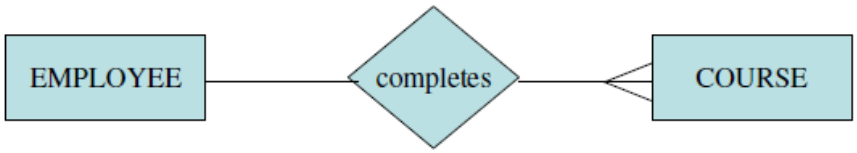
A CUSTOMER is insured by a POLICY. A POLICY CLAIM is made against a POLICY.

- Relationships are represented by diamond notation in a ER diagram.



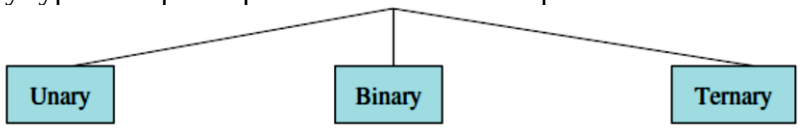
Relationships added to ERD

- A training department is interested in tracking which training courses each of its employee has completed.
- Each employee may complete more than one course, and each course may be completed by more than one employee.

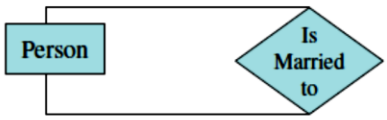


Degree of relationship

It is the number of entity types that participates in that relationship.

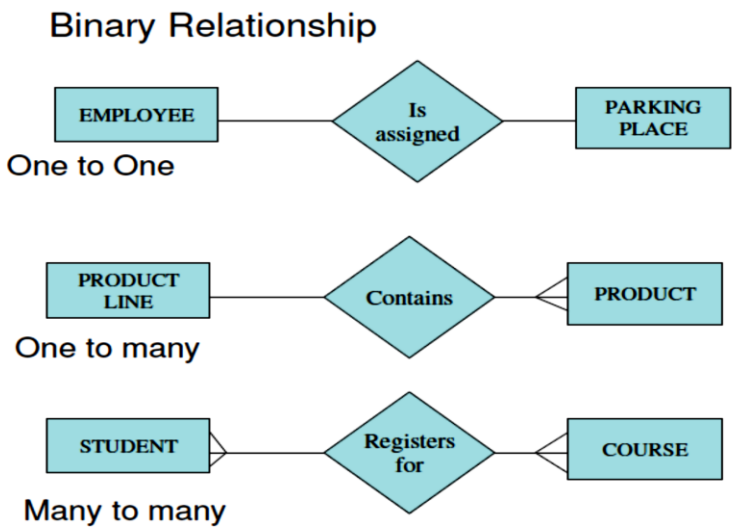


Unary relationship



One to One

One to many

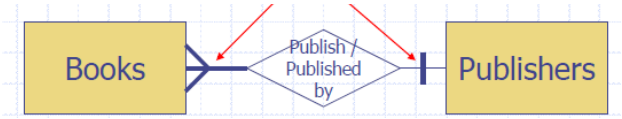


Relationship

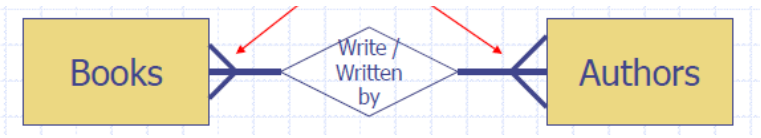
One-to-Many (1:N)

A single entity instance in one entity class (parent) is related to multiple entity instances in another entity class (child)

A book is published by (only) one publisher; a publisher can publish many (multiple) books



- A book can be written by many (multiple) authors; an author can write many (multiple) books



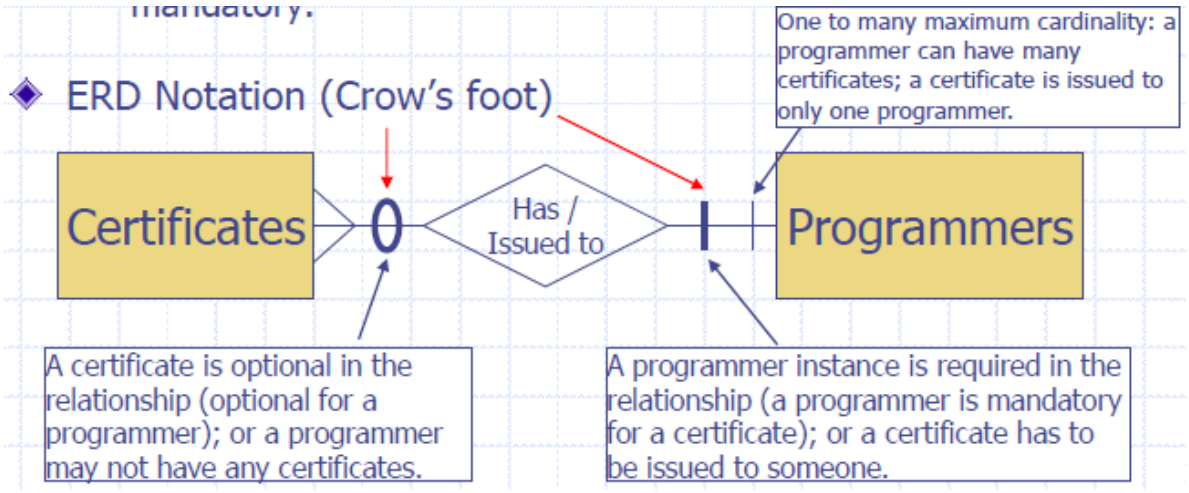
Minimum Cardinality

Minimum cardinality describes the minimum number of instances that must participate in a relationship for any one instance

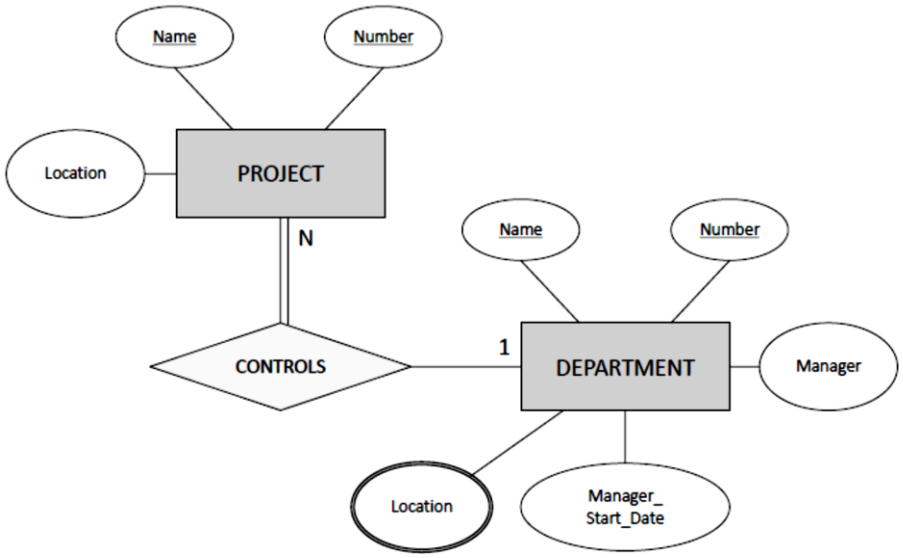
Minimums are generally stated as either zero or one:

0 (optional): participation in the relationship by the entity is optional.

1 (mandatory): participation in the relationship by the entity is mandatory.



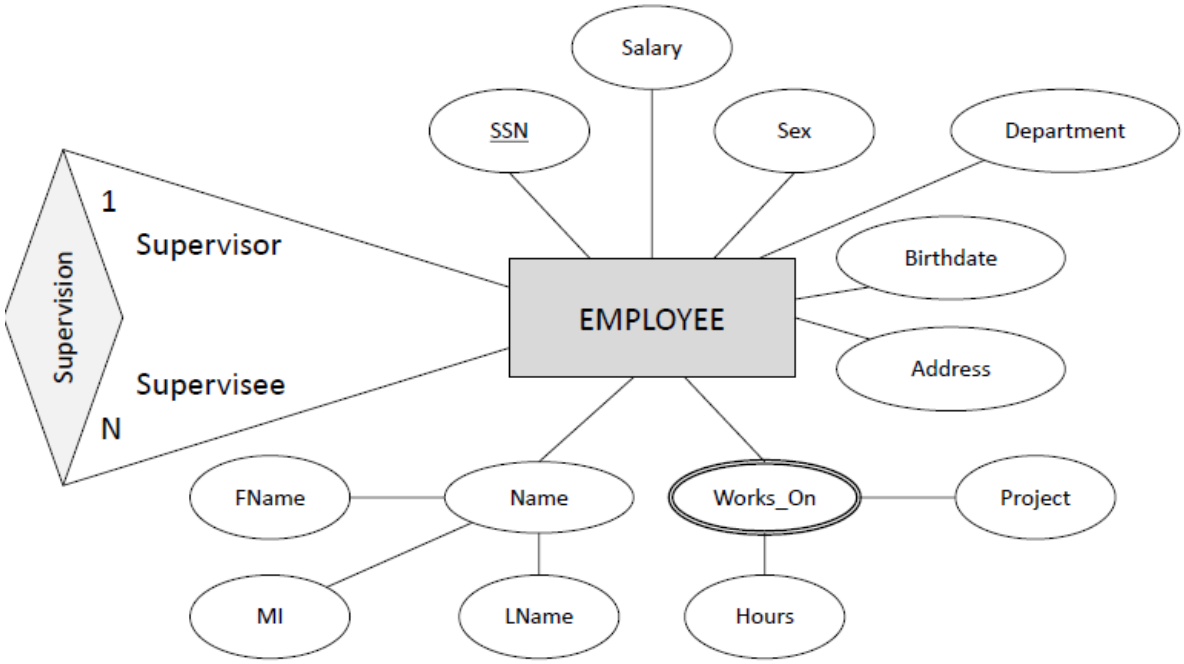
Example: A department controls a number of projects, each of which has a unique name, a unique number, and a single location.



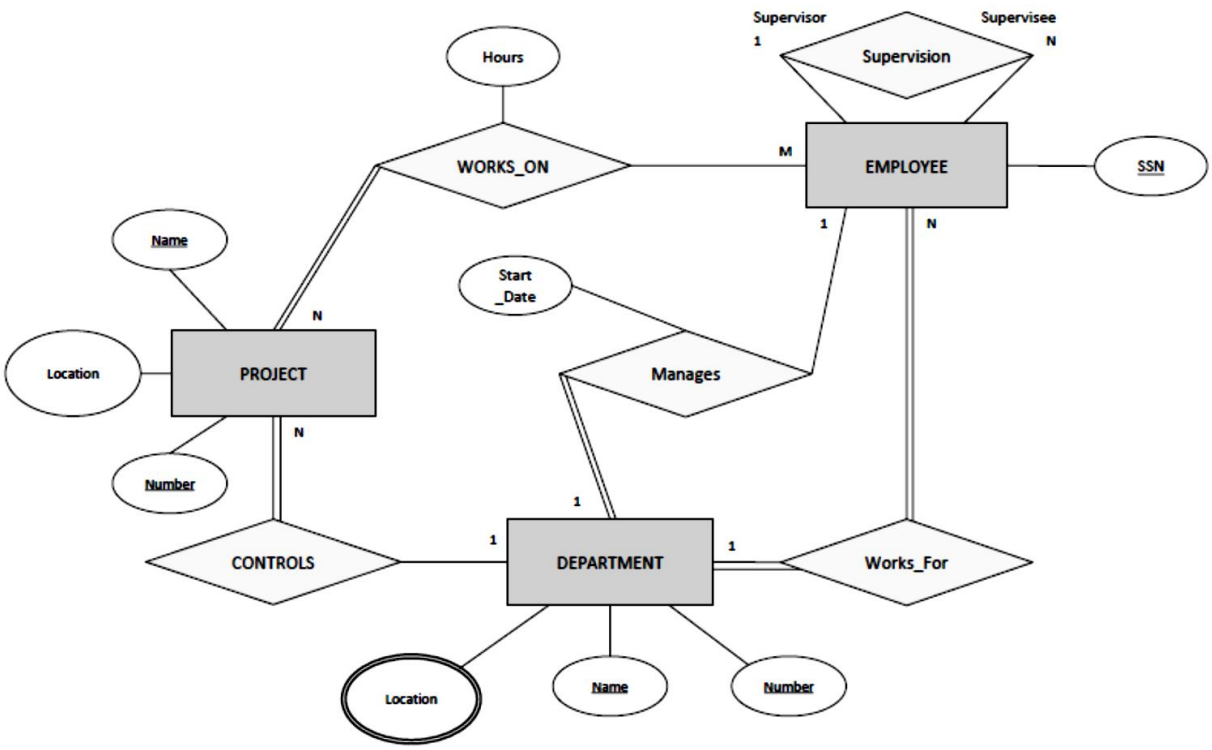
Exercise

Draw an ERD for the following description:

We store each employee's name (first, last, MI), Social Security number (SSN), street address, salary, sex (gender), and birth date. An employee is assigned to one department, but may work on several projects, which are not necessarily controlled by the same department. We keep track of the current number of hours per week that an employee works on each project. We also keep track of the direct supervisor of each employee (who is another employee).



H.W describe the following E-R Diagram

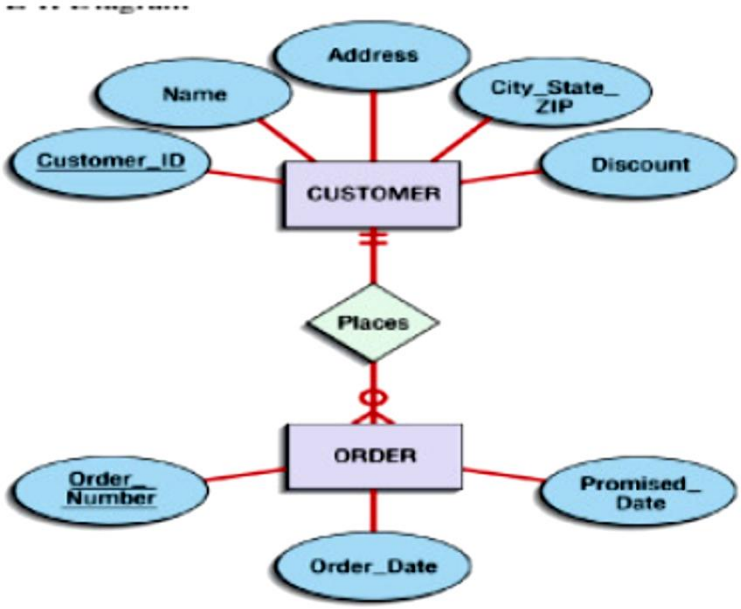


Transforming E-R Diagrams into Relations

– Binary 1:N Relationships

• Add the Primary key attribute (or attributes) of the entity on the one side of the relationship as a Foreign key in the relation on the other (N) side

• The one side migrates to the many side



CUSTOMER

Customer_ID	Name	Address	City_State_ZIP	Discount
1273	Contemporary Designs	123 Oak St.	Austin, TX 28384	5%
6390	Casual Corner	18 Hoosier Dr.	Bloomington, IN 45821	3%

ORDER

Order_Number	Order_Date	Promised_Date	Customer_ID
57194	3/15/0X	3/28/0X	6390
63725	3/17/0X	4/01/0X	1273
80149	3/14/0X	3/24/0X	6390

• Relationship:
CUSTOMER Places ORDER(s)

• ORDER Table BEFORE Relationship:
(Order_Number, Order_Date, Promised_Date)

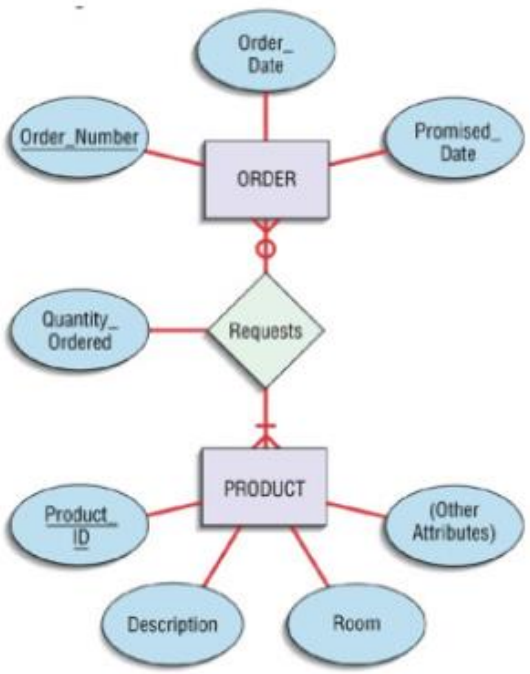
• ORDER Table AFTER Relationship:
(Order_Number, Order_Date, Promised_Date, Customer_ID)

```
CREATE TABLE ORDER(
Order_Number CHAR(1),
Order_Date DATE,
Promised_Date DATE,
Customer_ID CHAR(1),
PRIMARY KEY (Order_Number),
FOREIGN KEY (Customer_ID)
REFERENCES
CUSTOMER);
```

Represent Relationships

– Binary and higher M:N relationships

• Create another relation and include primary keys of all relations as primary key of new relation



ORDER

Order_Number	Order_Date	Promised_Date
61384	2/17/2002	3/01/2002
62009	2/13/2002	2/27/2002
62807	2/15/2002	3/01/2002

ORDER LINE

Order_Number	Product_ID	Quantity_ Ordered
61384	M128	2
61384	A261	1

PRODUCT

Product_ID	Description	(Other Attributes)
M128	Bookcase	—
A261	Wall unit	—
R149	Cabinet	—

CREATE TABLE Manages(
ssn CHAR(11),
did INTEGER,
since DATE,
PRIMARY KEY (did),
FOREIGN KEY (ssn) REFERENCES Employees,
FOREIGN KEY (did) REFERENCES Departments)

6. CODING AND TESTING

- Coding is undertaken once the design phase is complete and the design documents have been successfully reviewed.

In the coding phase, every module specified in the design document is coded and unit tested. During unit testing, each module is tested in isolation from other modules. That is, a module is tested independently as and when its coding is complete.

- After all the modules of a system have been coded and unit tested, the integration and system testing phase is undertaken.

Integration and testing of modules is carried out according to an integration plan.

6.1 CODING

- The objective of the coding phase is to transform the design of a system into code in a high-level language, and then to unit test this code.

Normally, good software development organisations require their programmers to adhere to some well-defined and standard style of coding which is called their coding standard.
The main advantages of adhering to a standard style of coding are the following:

- A coding standard gives a uniform appearance to the codes written by different engineers.
- It facilitates code understanding and code reuse.
- It promotes good programming practices.

6.1.1 Coding Standards and Guidelines

Good software development organisations usually develop their own coding standards and guidelines depending on what suits their organisation best and based on the specific types of software they develop.

Representative coding standards

A. **Rules for limiting the use of globals:** These rules list what types of data can be declared global and what cannot, with a view to limit the data that needs to be defined with global scope.
B. **Standard headers for different modules:** The following is an example of header format that is being used in some companies:

- Name of the module.
- Date on which the module was created.
- Author's name.
- Modification history.
- Synopsis of the module. This is a small writeup about what the module does.
- Different functions supported in the module, along with their
- input/output parameters.
- Global variables accessed/modified by the module.

C. **Naming conventions for global variables, local variables, and constant identifiers:** A popular naming convention is that variables are named using mixed case lettering. Global variable names would always start with a capital letter (e.g., GlobalData) and local variable names start with small

letters (e.g., localData). Constant names should be formed using capital letters only (e.g., CONSTDATA).

D. **Conventions regarding error return values and exception handling mechanisms:** The way error conditions are reported by different functions in a program should be standard within an organisation.

E. **Representative coding guidelines:** The following are some representative coding guidelines that are recommended by many software development organisations.

- **Do not use a coding style that is too clever or too difficult to understand** Clever coding can obscure meaning of the code and reduce code understandability; thereby making maintenance and debugging difficult and expensive.
- **Avoid obscure side effects:** The side effects of a function call include modifications to the parameters passed by reference, modification of global variables, and I/O operations. An obscure side effect is one that is not obvious from a casual examination of the code.
- **Do not use an identifier for multiple purposes:** Use of variables for multiple purposes usually makes future enhancements more difficult
- **Length of any function should not exceed 10 source lines:**
- **Do not use GO TO statements**

6.1.2 CODE REVIEW

Code review for a module is undertaken after the module successfully compiles. Obviously, code review does not target to design syntax errors in a program, but is designed to detect logical, algorithmic, and programming errors.

Normally, the following two types of reviews are carried out on the code of a module:

- Code inspection.
- Code walkthrough

6.1.2.1 Code Walkthrough

The main objective of code walkthrough is to discover the algorithmic and logical errors in the code. A few members of the development team are given the code a couple of days before the walkthrough meeting. Each member selects some test cases and simulates execution of the code by hand.
The members note down their findings of their walkthrough and discuss those in a walkthrough meeting where the coder of the module is present.

6.1.2.2 Code Inspection

During code inspection, the code is examined for the presence of some common programming errors. This is in contrast to the hand simulation of code execution carried out during code walkthroughs.
Following is a list of some classical programming errors which can be checked during code inspection:

- Use of uninitialized variables.
- Jumps into loops.
- Non-terminating loops.
- Incompatible assignments.

- Array indices out of bounds.
- Improper storage allocation and deallocation.
- Mismatch 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 equality of floating point values.
- Dangling reference caused when the referenced memory has not been allocated.

6.1.2.3 Clean Room Testing

Clean room testing was pioneered at IBM. This type of testing relies heavily on walkthroughs, inspection, and formal verification

6.2 SOFTWARE DOCUMENTATION

When a software is developed, in addition to the executable files and the source code, several kinds of documents such as users' manual, software requirements specification (SRS) document, design document, test document, installation manual, etc., are developed as part of the software engineering process.
Different types of software documents can broadly be classified into the following:
Internal documentation: These are provided in the source code itself.
External documentation: These are the supporting documents such as SRS document, installation document, user manual, design document, and test document.

6.3 Mapping object model to code

- During object design we would like to implement a system that realizes the use cases specified during requirements elicitation and system design.

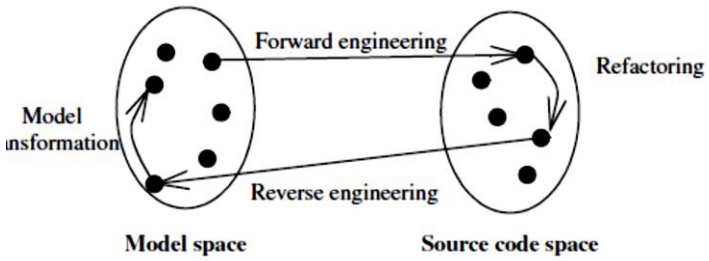
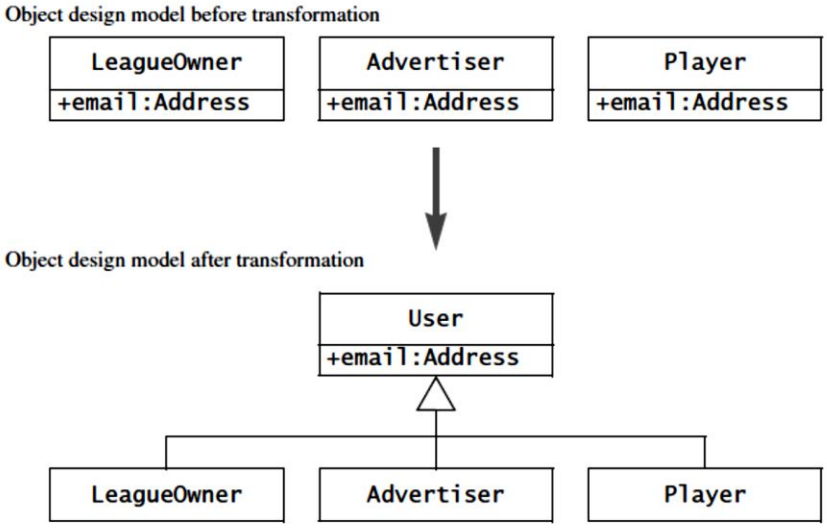


Figure 6-1 The four types of transformations: model transformations, refactorings, forward engineering, and reverse engineering

6.3.1 Model Transformation

A **model transformation** is applied to an object model and results in another object model. The purpose of object model transformation is to simplify or optimize the original model, bringing it into closer compliance with all requirements in the specification. A transformation may add, remove, or rename classes, operations, associations, or attributes.



A **refactoring** is a transformation of the source code that improves its readability or modifiability without changing the behavior of the system.

Before refactoring

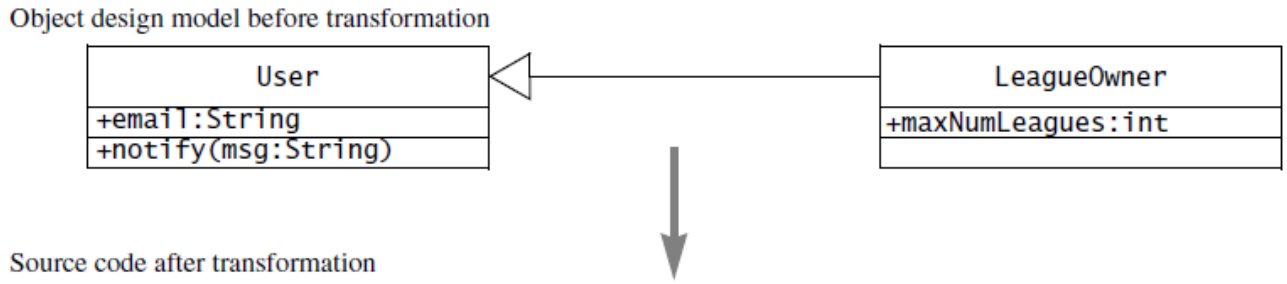
```
public class User {
    private String email;
}


public class Player extends User {
    public Player(String email) {
        this.email = email;
        //...
    }
}
public class LeagueOwner extends User
{
    public LeagueOwner(String email) {
        this.email = email;
        //...
    }
}
public class Advertiser extends User {
    public Advertiser(String email) {
        this.email = email;
    //...
    }
}
```

After refactoring

```
public class User {
    public User(String email) {
        this.email = email;
    }
}
public class Player extends User {
    public Player(String email) {
        super(email);
    //...
    }
}
public class LeagueOwner extends User
{
    public LeagueOwner(String email) {
        super(email);
    //...
    }
}
public class Advertiser extends User
    public Advertiser(String email) {
        super(email);
    //...
    }
}
```

Forward engineering is applied to a set of model elements and results in a set of corresponding source code statements, such as a class declaration, a Java expression, or a database schema. The purpose of forward engineering is to maintain a strong correspondence between the object design model and the code, and to reduce the number of errors introduced during implementation, thereby decreasing implementation effort.



Source code after transformation

```
public class User {
    private String email;
    public String getEmail() {
        return email;
    }
    public void setEmail(String
value){
        email = value;
    }
    public void notify(String msg) {
        // ....
    }
    /* Other methods omitted */
}
```

```
public class LeagueOwner extends User
{
    private int maxNumLeagues;
    public int getMaxNumLeagues() {
        return maxNumLeagues;
    }
    public void setMaxNumLeagues
                        (int value) {
        maxNumLeagues = value;
    }
    /* Other methods omitted */
}
```

Figure 6.2 Realization of the User and LeagueOwner classes (UML class diagram and Java excerpts.

Reverse engineering is applied to a set of source code elements and results in a set of model elements. The purpose of this type of transformation is to recreate the model for an existing system, either because the model was lost or never created, or because it became out of sync with the source code.

However, by trying to improve one aspect of the system, the developer runs the risk of introducing errors that will be difficult to detect and repair. To avoid introducing new errors, all transformations should follow these principles:

• Each transformation must address a single criteria. A transformation should improve the system with respect to only one design goal.

- *Each transformation must be local*. A transformation should change only a few methods or a few classes at once.
- *Each transformation must be applied in isolation to other changes*. To further localize changes, transformations should be applied one at the time.

• *Each transformation must be followed by a validation step*.

6.3.2 Mapping Activities

6.3.2.1 - Optimizing the Object Design Model

Direct translation of analysis models to code is often inefficient. This section describes four common optimizations to improve performance or meet other design goals.

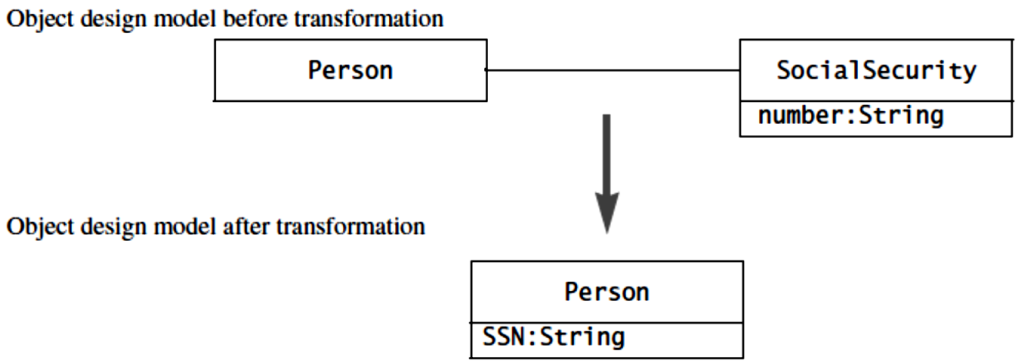
A- ***Optimizing access paths.***

Repeated association traversals. Operations that are performed frequently can suffer from poor performance if a large number of associations must be traversed. Performance can be enhanced by adding a direct link. Examine sequence diagrams of frequently performed operations to identify long association paths.

"Many" associations. If a lot of time is being spent working down a list of associations in a one-to-many or many-to-many situation, see if the to-many can be reduced to a to-one, possibly through qualified associations.

Misplaced attributes. Some classes may turn out to have very little if any interesting behavior. If an attribute is involved only in setter and getter operations, consider moving the attribute to the class that calls it. If enough of the attributes can be moved out of the class, it can sometimes be eliminated all together.

B- ***Collapsing objects: Turning objects into attributes.*** A class that has few attributes and behaviors, and is associated only with one other class, can be collapsed into that class, reducing the overall complexity of the system.



C- **Delaying expensive computations.** Put off performing expensive calculations until they are really needed.

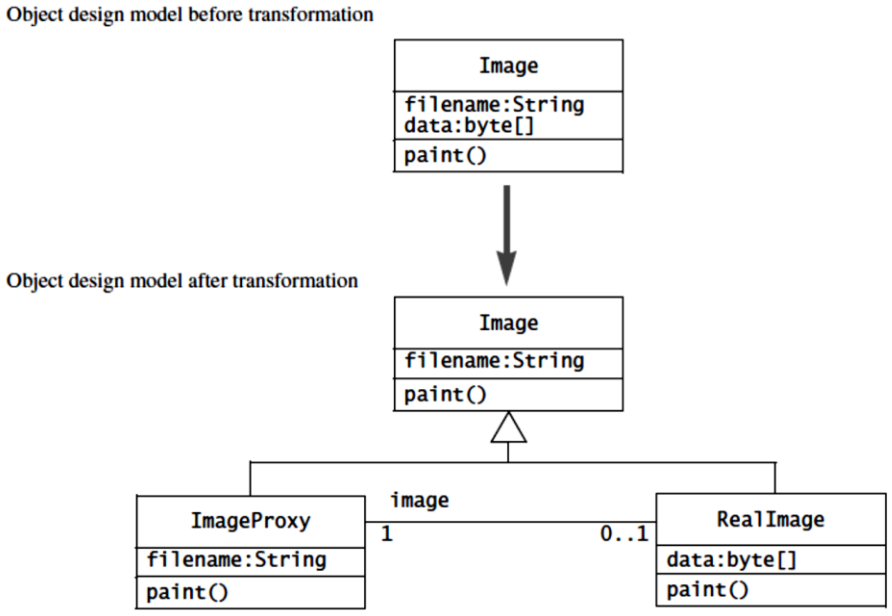


Figure 6.3 delaying expensive computations to transform the object design model using proxy design pattern (UML diagram)

Example

Caching the result of expensive computations. Sometimes it is more efficient to save the result of expensive calculations, rather than re-doing the calculations every time the result is needed. The tradeoff is the additional variable(s) that must be stored and maintained.

6.3.2.2 Mapping Associations to Collections

Associations are UML concepts that denote collections of bidirectional links between two or more objects. Object-oriented programming languages, however, do not provide the concept of association.

Unidirectional one-to-one associations
Bidirectional one-to-one associations.

Source code after transformation

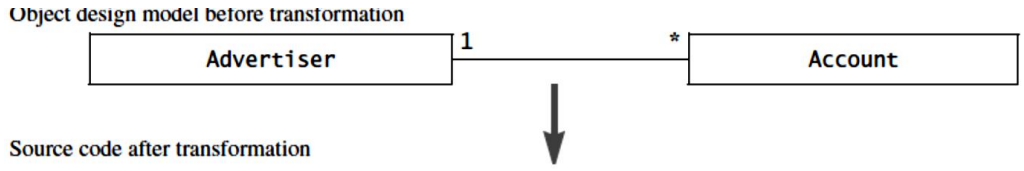
```
public class Advertiser {
    /* The account field is initialized
     * in the constructor and never
     * modified. */
    private Account account;

    public Advertiser() {
        account = new Account(this);
    }
    public Account getAccount() {
        return account;
    }
}
```

```
public class Account {
    /* The owner field is initialized
     * during the constructor and
     * never modified. */
    private Advertiser owner;

    public Account(Advertiser owner) {
        this.owner = owner;
    }
    public Advertiser getOwner() {
        return owner;
    }
}
```

One-to-many associations



Source code after transformation

```
public class Advertiser {
    private Set accounts;
    public Advertiser() {
        accounts = new HashSet();
    }
    public void addAccount(Account a) {
        accounts.add(a);
        a.setOwner(this);
    }
    public void removeAccount
            (Account a) {
        accounts.remove(a);
        a.setOwner(null);
    }
}
```

```
public class Account {
    private Advertiser owner;
    public void setOwner
            (Advertiser newOwner) {
        if (owner != newOwner) {
            Advertiser old = owner;
            owner = newOwner;
            if (newOwner != null)
              newOwner.addAccount(this);
            if (old != null)
              old.removeAccount(this);
        }
    }
}
```

Many-to-many associations.

6.3.2.3 - Mapping Contracts to Exceptions

Check pre-conditions at the beginning of methods, and check post-conditions and invariants at the end of methods.

Encapsulate checking code into methods that will be inherited properly by sub-classes (which inherit the contracts.)

```
public class TournamentControl {
   private Tournament tournament;
   public void addPlayer(Player p) throws KnownPlayerException {
         if (tournament.isPlayerAccepted(p)) {
               throw new KnownPlayerException(p);
         }
         //... Normal addPlayer behavior
   }
}
public class TournamentForm {
   private TournamentControl control;
   private ArrayList players;
   public void processPlayerApplications() { // Go through all the players
               for (Iteration i = players.iterator(); i.hasNext();) {
               try {       // Delegate to the control object.
                           control.acceptPlayer((Player)i.next());
               } catch (KnownPlayerException e) {
                           // If an exception was caught, log it to the console
                           ErrorConsole.log(e.getMessage());
               }
         }
   }
}
```

6.4 Testing

"*Testing is the process of executing a program with the intent of finding errors*."

- During unit testing, functions (or modules) are tested in isolation: What if all modules were to be tested together (i.e. system testing)?

- **Integration test evaluates a group of functions or classes:** Identifies interface compatibility, unexpected parameter values or state interactions, and run-time exceptions

- **System test tests working of the entire system**

• Why should We Test ?
Although software testing is itself an expensive activity, yet launching of software without testing may lead to cost potentially much higher than that of testing, specially in systems where human safety is involved.

• Who should Do the Testing ?
o Testing requires the developers to find errors from their software.
o It is difficult for software developer to point out errors from own creations.
o Many organisations have made a distinction between development and testing phase by making different people responsible for each phase.

What should We Test ?
We should test the program's responses to every possible input. It means, we should test for all valid and invalid inputs. Suppose a program requires two 8 bit integers as inputs. Total possible combinations are $2^8 x 2^8$. If only one second it required to execute one set of inputs, it may take 18 hours to test all combinations. Practically, inputs are more than two and size is also more than 8 bits. We have also not considered invalid inputs where so many combinations are possible. Hence, complete testing is just not possible, although, we may wish to do so.

6.4.1 Some Terminologies

A **mistake** is essentially any programmer action that later shows up as an incorrect result during program execution.
An **error** is the result of a mistake committed by a developer in any of the development activities.

- The terms error, fault, bug, and defect are considered to be synonyms in the area of program testing.

A **failure** of a program essentially denotes an incorrect behaviour exhibited by the program during its execution.
Test and **Test case** terms are used interchangeably. In practice, both are same and are treated as synonyms. Test case describes an input description and an expected output description.

- The set of test cases is called a **test suite**. Hence any combination of test cases may generate a test suite.

Test Case ID	
Section-I (Before Execution)	Section-II (After Execution)
Purpose :	Execution History:
Pre condition: (If any)	Result:
Inputs:	If fails, any possible reason (Optional);
Expected Outputs:	Any other observation:
Post conditions:	Any suggestion:
Written by:	Run by:
Date:	Date:

- The term **Acceptance Testing** is used when the software is developed for a specific customer. A series of tests are conducted to enable the customer to validate all requirements. These tests are conducted by the end user / customer and may range from adhoc tests to well planned systematic series of tests.

The terms alpha and beta testing are used when the software is developed as a product for anonymous customers.

- **Alpha Tests** are conducted at the developer's site by some potential customers. These tests are conducted in a controlled environment. Alpha testing may be started when formal testing process is near completion.
- **Beta Tests** are conducted by the customers / end users at their sites. Unlike alpha testing, developer is not present here. Beta testing is conducted in a real environment that cannot be controlled by the developer.

Verification is the process of evaluating a system or component to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase.

Validation is the process of evaluating a system or component during or at the end of development process to determine whether it satisfies the specified requirements.

Testing= Verification + Validation

Verification	Validation
Are you building it right?	Have you built the right thing?
Checks whether an artifact conforms to its previous artifact.	Checks the final product against the specification.
Done by developers.	Done by Testers.
Static and dynamic activities: reviews, unit testing.	Dynamic activities: Execute software and check against requirements.

- Verification does not require execution of the software, whereas validation requires execution of the software.
- Verification is carried out during the development process to check if the development activities are proceeding alright, whereas validation is carried out to check if the right as required by the customer has been developed.

6.4.2 Testing Activities

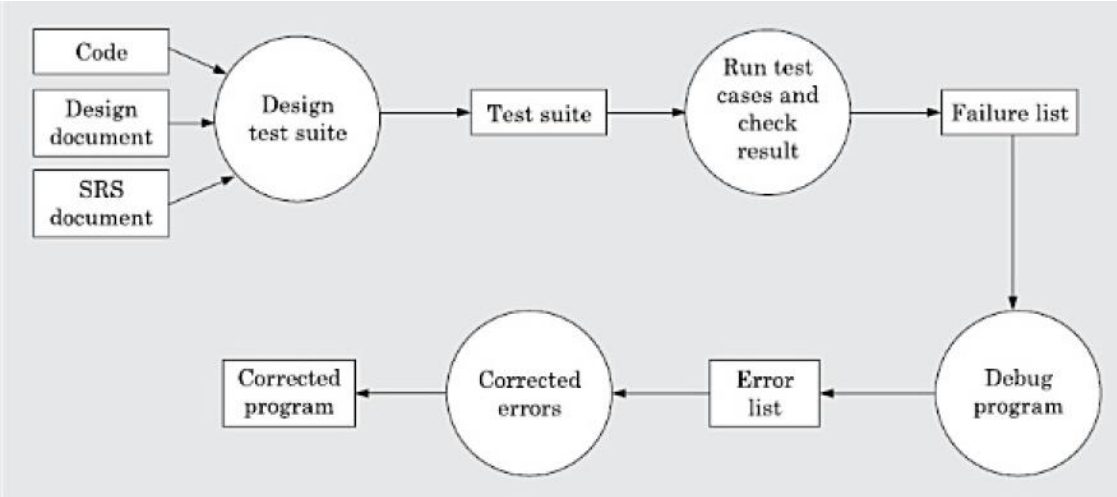


Figure 6.3: Testing process

Running test cases and checking the results to detect failures: Each test case is run and the results are compared with the expected results. A mismatch between the actual result and expected results indicates a failure. The test cases for which the system fails are noted down for later debugging.

Locate error: In this activity, the failure symptoms are analysed to locate the errors. For each failure observed during the previous activity, the statements that are in error are identified.
Error correction: After the error is located during debugging, the code is appropriately changed to correct the error

When test cases are designed based on random input data, many of the test cases do not contribute to the significance of the test suite, That is, they do not help detect any additional defects not already being detected by other test cases in the suite.

- A minimal test suite is a carefully designed set of test cases such that each test case helps detect different errors. This is in contrast to testing using some random input values.

- Test Suite Design
- Run test cases
- Check results to detect failures.
- Prepare failure list

} Tester

- Debug to locate errors
- Correct errors.

} Developer

6.4.3 Unit Testing

- Unit testing carried out: After coding of a unit is complete and it compiles successfully.
- Unit testing reduces debugging effort substantially.
- Without unit test:
  - Errors become difficult to track down.
  - Debugging cost increases substantially

Before carrying out unit testing, the unit test cases have to be designed and the test environment for the unit under test has to be developed. The following are needed to test the module:

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

stubs and drivers are designed to provide the complete environment for a module so that testing can be carried out.

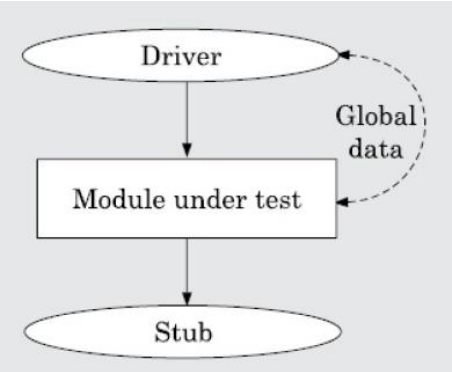


Figure 6.4: Unit testing with the help of driver and stub modules.

- A stub procedure is a dummy procedure that has the same I/O parameters as the function called by the unit under test but has a highly simplified behaviour. For example, a stub procedure may produce the expected behaviour using a simple table look up mechanism.
- A driver module should contain the non-local data structures accessed by the module under test. Additionally, it should also have the code to call the different functions of the unit under test with appropriate parameter values for testing.

There are essentially two main approaches to systematically design test cases:

- Black-box approach
- White-box (or glass-box) approach

A- BLACK-BOX TESTING

In 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 available to design black box test cases:

- ❖ Equivalence class partitioning
- ❖ Boundary value analysis

I. Equivalence Class Partitioning

In the equivalence class partitioning approach, the domain of input values to the program under test is partitioned into a set of equivalence classes.

The partitioning is done such that for every input data belonging to the same equivalence class, the program behaves similar.

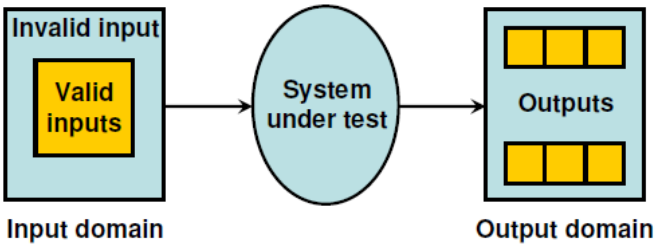
How do you identify equivalence classes?

- ✓ **Identify scenarios**
- ✓ **Examine the input data.**
- ✓ **Examine output**

The following are two general guidelines for designing the equivalence classes:

1. The equivalence classes are identified by taking each input condition and partitioning it into valid and invalid classes. For example, if an input condition specifies a range of values from 1 to 999, we identify one valid equivalence class [1<item<999]; and two invalid equivalence classes [item<1] and [item>999].

2. Generate the test cases using the equivalence classes identified in the previous step. This is performed by writing test cases covering all the valid equivalence classes. Then a test case is written for each invalid equivalence class so that no test contains more than one invalid class. This is to ensure that no two invalid classes mask each other.



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.

II. Boundary Value Analysis

Boundary value analysis-based test suite design involves designing test cases using the values at the boundaries of different equivalence classes.

Example: For a function that computes the square root of the integer values in the range of 0 and 5000, determine the boundary value test suite.
Answer: There are three equivalence classes—The set of negative integers, the set of integers in the range of 0 and 5000, and the set of integers larger than 5000. The boundary value-based test suite is: {0,-1,5000,5001}.

Example:
The boundary value analysis test cases for our program with two inputs variables (x and y) that may have any value from 100 to 300 are: (200,100), (200,101), (200,200), (200,299), (200,300), (100,200), (101,200), (299,200) and (300,200). This input domain is shown in Figure 6.5. Each dot represent a test case and inner rectangle is the domain of legitimate inputs.

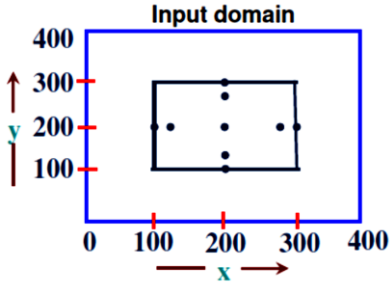


Figure 6.5 Input domain of two variables x and y with boundaries [100,300] each

Example
Consider a program for the determination of the nature of roots of a quadratic equation. Its input is a triple of positive integers (say a,b,c) and values may be from interval [0,100]. The program output may have one of the following words.
[Not a quadratic equation; Real roots; Imaginary roots; Equal roots]
Design the boundary value test cases.
Solution

Quadratic equation will be of type: $x^2+bx+c=0$

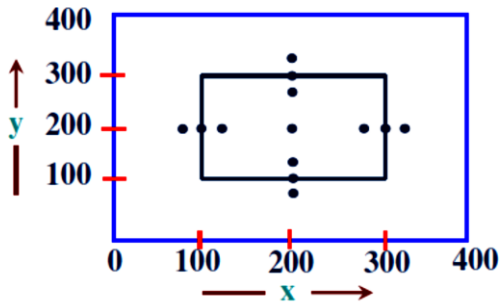
$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Roots are real if $(b^2-4ac)>0$
Roots are imaginary if $(b^2-4ac)<0$
Roots are equal if $(b^2-4ac)=0$
Equation is not quadratic if a=0

Test Case	a	b	c	Expected output
1	0	50	50	Not Quadratic
2	1	50	50	Real Roots
3	50	50	50	Imaginary Roots
4	99	50	50	Imaginary Roots
5	100	50	50	Imaginary Roots
6	50	0	50	Imaginary Roots
7	50	1	50	Imaginary Roots
8	50	99	50	Imaginary Roots
9	50	100	50	Equal Roots
10	50	50	0	Real Roots
11	50	50	1	Real Roots
12	50	50	99	Imaginary Roots
13	50	50	100	Imaginary Roots

Robustness testing

It is nothing but the extension of boundary value analysis. Here, we would like to see, what happens when the extreme values are exceeded with a value slightly greater than the maximum, and a value slightly less than minimum. It means, we want to go outside the legitimate boundary of input domain. This extended form of boundary value analysis is called robustness testing and shown in Figure below:



Decision Table Based Testing

Condition Stub		Entry						
C_1		True				False		
C_2		True		False		True		False
C_3		True	False	True	False	True	False	---
Action Stub	a_1	X	X			X		
	a_2	X		X			X	
	a_3		X			X		
	a_4				X		X	X

C_1:x,y,z are sides of a triangle?	N	Y							
C_2:x = y?	--	Y				N			
C_3:x = z?	--	Y		N		Y		N	
C_4:y = z?	--	Y	N	Y	N	Y	N	Y	N
a_1: Not a triangle	X								
a_2: Scalene									X
a_3: Isosceles					X		X	X	
a_4: Equilateral		X							
a_5: Impossible			X	X		X			

B- WHITE-BOX TESTING

White-box testing is an important type of unit testing. A large number of white-box testing strategies exist.

Basic Concepts

A white-box testing strategy can either be coverage-based or fault based.

i. Fault-based testing

A fault-based testing strategy targets to detect certain types of faults. These faults that a test strategy focuses on constitutes the fault model of the strategy.

ii. Coverage-based testing

A coverage-based testing strategy attempts to execute (or cover) certain elements of a program. Popular examples of coverage-based testing strategies are statement coverage.

- ✓ The set of specific program elements that a testing strategy targets to execute is called the testing criterion of the strategy.

- ✓ A white-box testing strategy is said to be stronger than another strategy, if the stronger testing strategy covers all program elements covered by the weaker testing strategy, and the stronger strategy additionally covers at least one program element that is not covered by the weaker strategy.

1- Statement Coverage

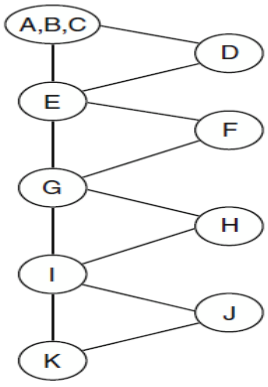
The principal idea governing the statement coverage strategy is that unless a statement is executed, there is no way to determine whether an error exists in that statement.

Node	Source Line	3,4,5	3,5,3	0,1,0	4,4,4
A	read a,b,c	*	*	*	*
B	type=''scalene''	*	*	*	*
C	if(a==b||b==c||a==c)	*	*	*	*
D	type=''isosceles''		*	*	*
E	if(a==b&&b==c)	*	*	*	*
F	type=''equilateral''				*
G	if(a>=b+c||b>=a+c||c>=a+b)	*	*	*	*
H	type=''not a triangle''			*	
I	if(a<=0||b<=0||c<=0)	*	*	*	*
J	type=''bad inputs''			*	
K	print type	*	*	*	*

2- Branch Coverage

A test suite satisfies branch coverage, if it makes each branch condition in the program to assume true and false values in turn.

Example:



Arcs	3,4,5	3,5,3	0,1,0	4,4,4
ABC–D		*	*	*
ABC–E	*			
D–E		*	*	*
E–F				*
E–G	*	*	*	
F–G				*
G–H			*	
G–I	*	*		*
H–I			*	
I–J			*	
I–K	*	*		*
J–K			*	

3- Multiple Condition Coverage

In the multiple condition (MC) coverage-based testing, test cases are designed to make each component of a composite conditional expression to assume both true and false values.

```
if(a==b||b==c||a==c)
```

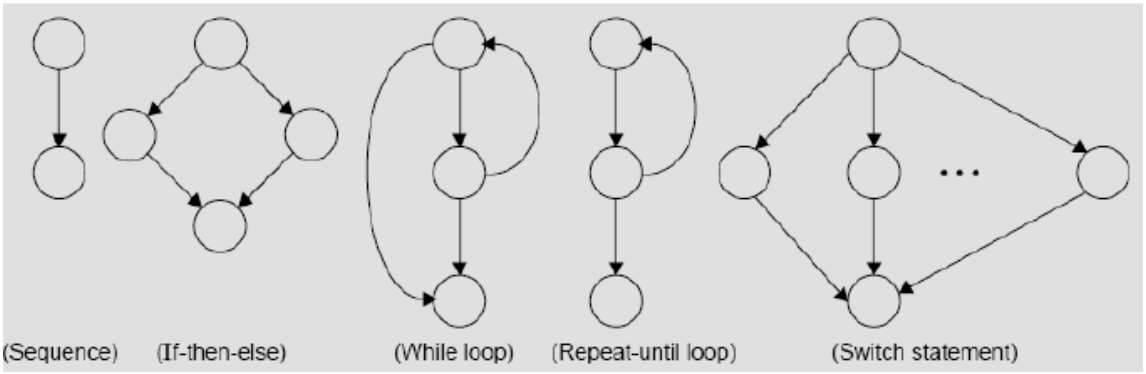
Combination	Possible Test Case	Branch
TXX	3,3,4	ABC-D
FTX	4,3,3	ABC-D
FFT	3,4,3	ABC-D
FFF	3,4,5	ABC-E

4- Path Coverage

A test suite achieves path coverage if it executes each linearly independent paths (or basis paths) 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)

The flow graph is a directed graph in which nodes are either entire statements or fragments of a statement, and edges represents flow of control.

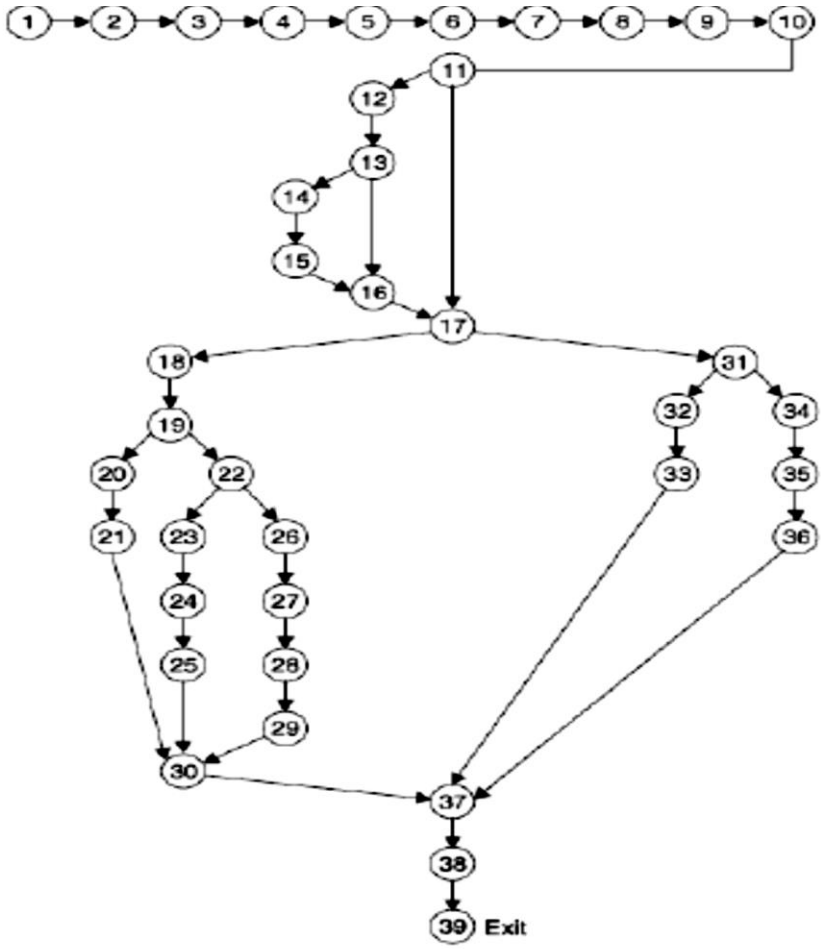


Example

Consider the problem for the determination of the nature of roots of a quadratic equation. Its input a triple of positive integers (say a,b,c) and value may be from interval [0,100].
The program is given in figure below. The output may have one of the following words:
[Not a quadratic equation; real roots; Imaginary roots; Equal roots]
Draw the flow graph.

```
#include <conio.h>
#include <math.h>
1       int main()
2     {
3       int a,b,c,validInput=0,d;
4       double D;
5       printf("Enter the 'a' value: ");
6       scanf("%d",&a);
7       printf("Enter the 'b' value: ");
8       scanf("%d",&b);
9       printf("Enter the 'c' value: ");
10      scanf("%d",&c);
11      if ((a >= 0) && (a <= 100) && (b >= 0) && (b <= 100) && (c >= 0)
          && (c <= 100)) {
12        validInput = 1;
13        if (a == 0) {
14          validInput = -1;
15        }
16      }
17      if (validInput==1) {
18        d = b*b - 4*a*c;
19        if (d == 0) {
20          printf("The roots are equal and are r1 = r2 = %f\n",
                    -b/(2*(float) a));

21        }
22        else if ( d > 0 ) {
23          D=sqrt(d);
24          printf("The roots are real and are r1 = %f and r2 = %f\n",
                    (-b-D)/(2* a), (-b+D)/(2* a));
25        }
26        else {
27          D=sqrt(-d)/(2*a);
28          printf("The roots are imaginary and are r1 = (%f,%f) and
                    r2 = (%f,%f)\n", -b/(2.0*a),D,-b/(2.0*a),-D);
29        }
30      }
31      else if (validInput == -1) {
32        printf("The vlaues do not constitute a Quadratic equation.");
33      }
34      else {
35        printf("The inputs belong to invalid range.");
36      }
37      getche();
38      return 1;
```



Example:

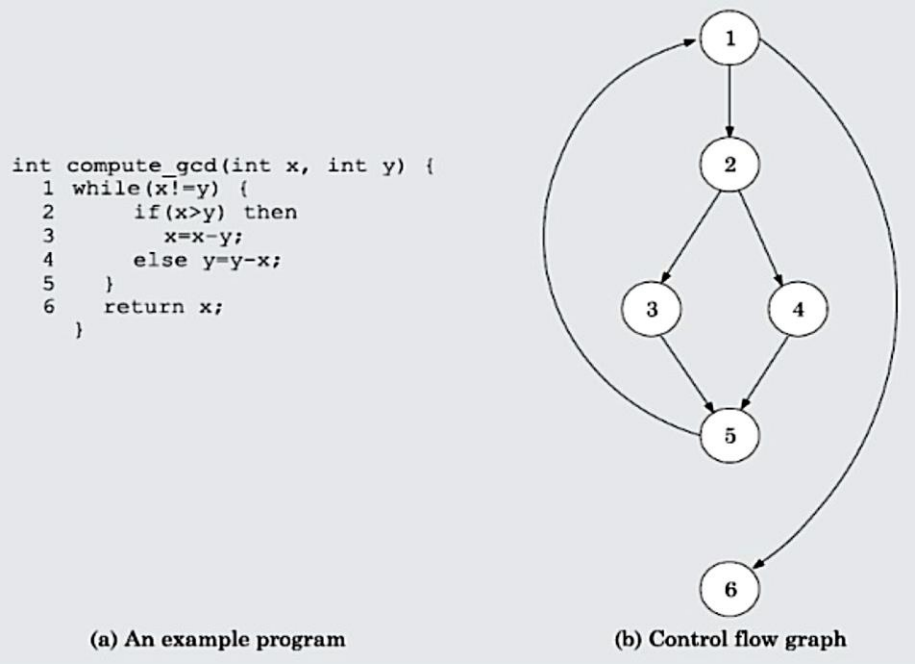
Path	T/F	Test Case	Output
ABCEGIK	FFFF	3,4,5	Scalene
ABCEGHIK	FFTF	3,4,8	Not a triangle
ABCEGHIJK	FFTT	0,5,6	Bad inputs
ABCDEGIK	TFFF	5,8,5	Isosceles
ABCDEGHIK	TFTF	3,8,3	Not a triangle
ABCDEGHIJK	TFTT	0,4,0	Bad inputs
ABCDEFGIK	TTFF	3,3,3	Equilateral
ABCDEFGHIJK	TTTT	0,0,0	Bad inputs

Linearly independent set of paths (or basis path set)
A set of paths for a given program is called linearly independent set of paths (or the set of basis paths or simply the basis set), if each path in the set introduces at least one new edge that is not included in any other path in the set.

- Possibly, the name basis set comes from the observation that the paths in the basis set form the "basis" for all the paths of a program.
- McCabe's cyclomatic complexity metric is an important result that lets us compute the number of linearly independent paths for any arbitrary program.

McCabe's Cyclomatic Complexity Metric
McCabe obtained his results by applying graph-theoretic techniques to the control flow graph of a program. McCabe's cyclomatic complexity defines an upper bound on the number of independent paths in a program.

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.
Example: Figure below, E = 7 and N = 6. Therefore, the value of the Cyclomatic complexity = 7 – 6 + 2 = 3.



Method 2: In this method, the cyclomatic complexity V (G) for a graph G is given by the following expression:
V(G) = Total number of non-overlapping bounded areas + 1
In the program's control flow graph G, any region enclosed by nodes and edges can be called as a bounded area.

Method 3: The cyclomatic complexity of a program can also be easily computed by computing the number of decision and loop statements of the program. If N is the number of decision and loop statements of a program, then the McCabe's metric is equal to N + 1.

Steps to carry out path coverage-based testing

The following is the sequence of steps that need to be undertaken for deriving the path coverage-based test cases for a program:

1. Draw control flow graph for the program.
2. Determine the McCabe's metric V(G).
3. Determine the cyclomatic complexity. This gives the minimum number of test cases required to achieve path coverage.

Uses of McCabe's cyclomatic complexity metric

Beside its use in path testing, cyclomatic complexity of programs has many other interesting applications such as the following:

- Estimation of structural complexity of code

From the maintenance perspective, it makes good sense to limit the cyclomatic complexity of the different functions to some reasonable value. Good software development organisations usually restrict the cyclomatic complexity of different functions to a maximum value of ten or so.

- Estimation of testing effort
- Estimation of program reliability

This relationship exists possibly due to the correlation of cyclomatic complexity with the structural complexity of code. Usually the larger is the structural complexity, the more difficult it is to test and debug the code.

6.5 DEBUGGING

After a failure has been detected, it is necessary to first identify the program statement(s) that are in error and are responsible for the failure, the error can then be fixed.

Debugging Approaches

The following are some of the approaches that are popularly adopted by the programmers for debugging:

- **Brute force method**

This is the most common method of debugging but is the least efficient method. In this approach, print statements are inserted throughout the program to print the intermediate values with the hope that some of the printed values will help to identify the statement in error.

- **Backtracking**

In this approach, starting from the statement at which an error symptom has been observed, the source code is traced backwards until the error is discovered.

- **Program slicing**

This technique is similar to back tracking. In the backtracking approach, one often has to examine a large number of statements. However, the search space is reduced by defining slices.

6.6 INTEGRATION TESTING

The objective of integration testing is to check whether the different modules of a program interface with each other properly.

The approaches of integration testing are:

- Big-bang approach to integration testing: it is the most obvious approach to integration testing. In this approach, all the modules making up a system are integrated in a single step.
- Top-down approach to integration testing
- Bottom-up approach to integration testing
- Mixed (also called sandwiched) approach to integration testing

Exercises

1- Draw the control flow graph and determine the minimum required test cases set

```
void Search(int values , int key,
         int *found,  int *index)
{

  int i=0;
  *found=0;
  while (i < N)
  {
    if values[i]== key

    {
      printf (found positive);

      *found= 1;
    }
    else

    {
      printf (non-positive);
      if (values[i]== -key)
      {
        printf (found negative);

        *found 1;
      }
    }

    if (*found)

    {
  printf(found at index  %i,  i);

      *index=i;

      return;
    }

    i;
  }
}
```