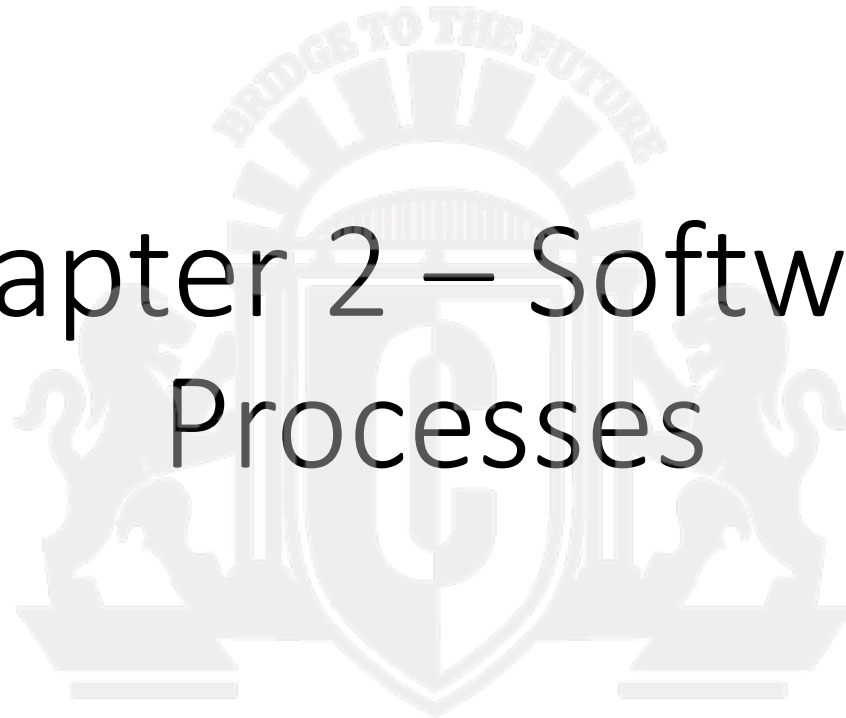


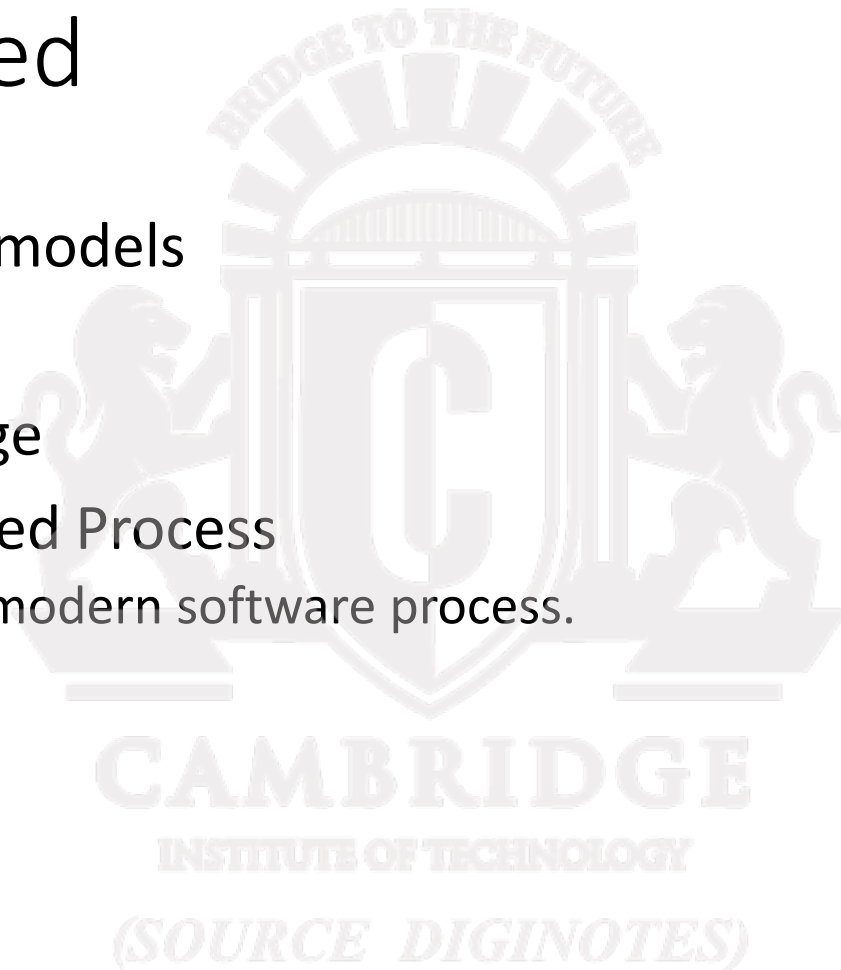
Chapter 2 – Software Processes



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Topics covered

- Software process models
- Process activities
- Coping with change
- The Rational Unified Process
 - An example of a modern software process.



The software process

- A structured set of activities required to develop a software system.
- Many different software processes but all involve:
 - Specification – defining what the system should do;
 - Design and implementation – defining the organization of the system and implementing the system;
 - Validation – checking that it does what the customer wants;
 - Evolution – changing the system in response to changing customer needs.
- A software process model is an abstract representation of a process. It presents a description of a process from some particular perspective.

(SOURCE DIGINOTES)

Software process descriptions

- When we describe and discuss processes, we usually talk about the activities in these processes such as specifying a data model, designing a user interface, etc. and the ordering of these activities.
- Process descriptions may also include:
 - Products, which are the outcomes of a process activity;
 - Roles, which reflect the responsibilities of the people involved in the process;
 - Pre- and post-conditions, which are statements that are true before and after a process activity has been enacted or a product produced.

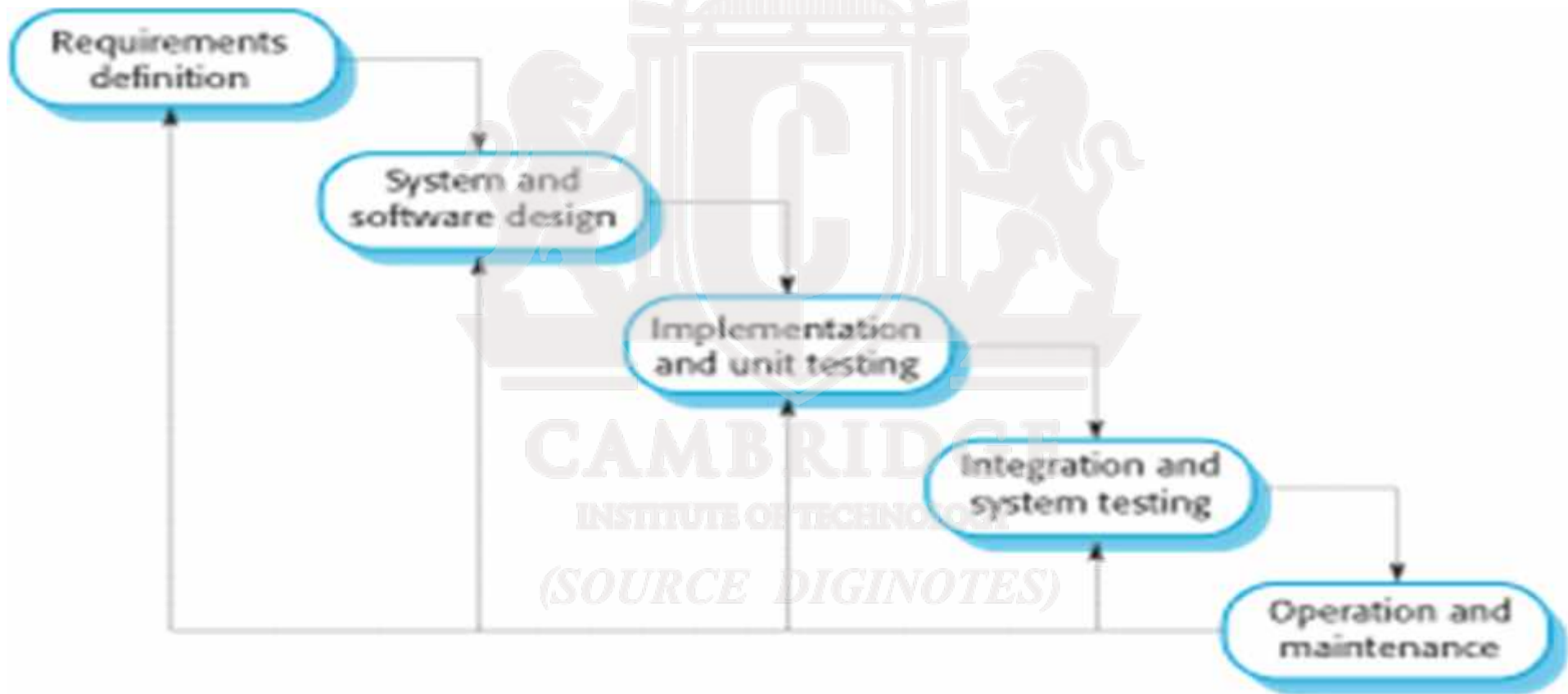
Plan-driven and agile processes

- Plan-driven processes are processes where all of the process activities are planned in advance and progress is measured against this plan.
- In agile processes, planning is incremental and it is easier to change the process to reflect changing customer requirements.
- In practice, most practical processes include elements of both plan-driven and agile approaches.
- There are no right or wrong software processes.

Software process models

- The waterfall model
 - Plan-driven model. Separate and distinct phases of specification and development.
- Incremental development
 - Specification, development and validation are interleaved. May be plan-driven or agile.
- Reuse-oriented software engineering
 - The system is assembled from existing components. May be plan-driven or agile.
- In practice, most large systems are developed using a process that incorporates elements from all of these models.

The waterfall model



Waterfall model phases

- There are separate identified phases in the waterfall model:
 - Requirements analysis and definition
 - System and software design
 - Implementation and unit testing
 - Integration and system testing
 - Operation and maintenance
- The main drawback of the waterfall model is the difficulty of accommodating change after the process is underway. In principle, a phase has to be complete before moving onto the next phase.

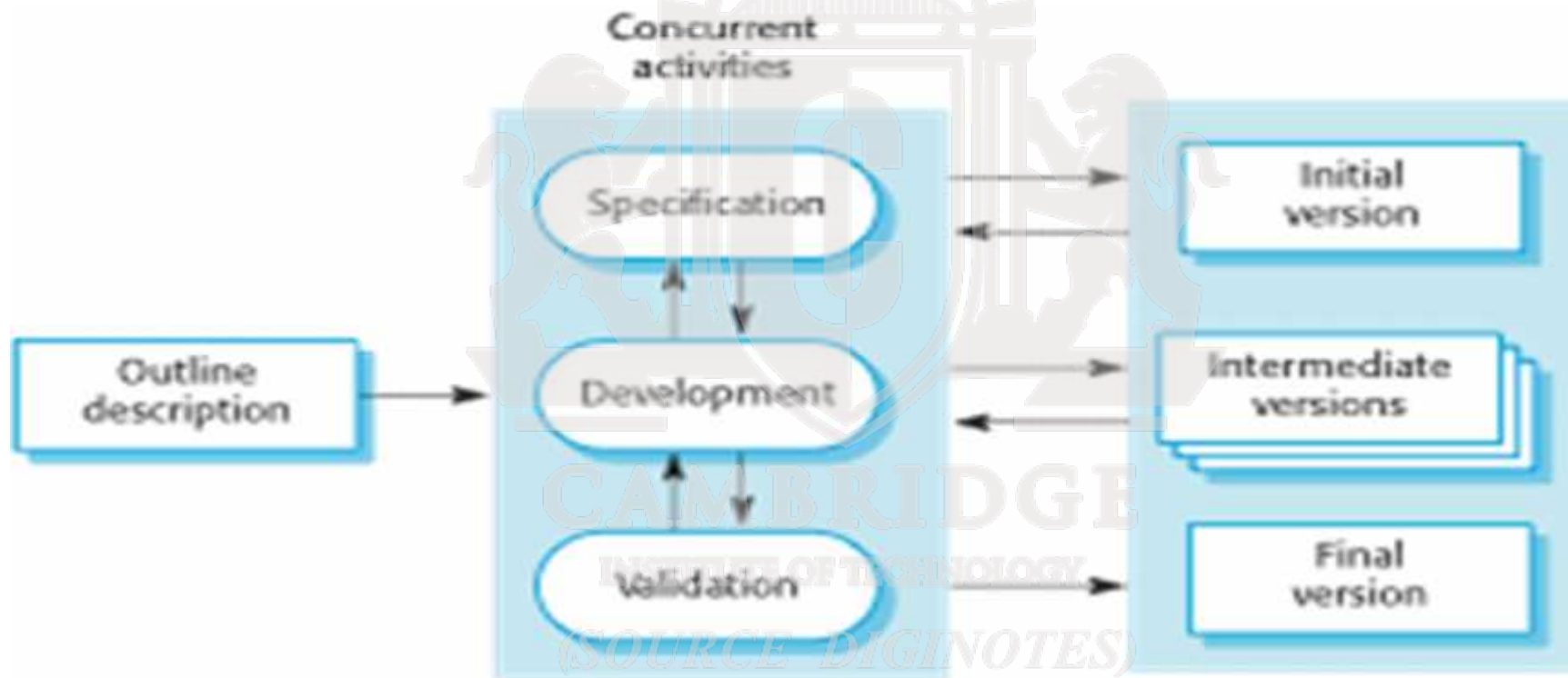
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Waterfall model problems

- Inflexible partitioning of the project into distinct stages makes it difficult to respond to changing customer requirements.
 - Therefore, this model is only appropriate when the requirements are well-understood and changes will be fairly limited during the design process.
 - Few business systems have stable requirements.
- The waterfall model is mostly used for large systems engineering projects where a system is developed at several sites.
 - In those circumstances, the plan-driven nature of the waterfall model helps coordinate the work.

(SOURCE DIGINOTES)

Incremental development



Incremental development benefits

- The cost of accommodating changing customer requirements is reduced.
 - The amount of analysis and documentation that has to be redone is much less than is required with the waterfall model.
- It is easier to get customer feedback on the development work that has been done.
 - Customers can comment on demonstrations of the software and see how much has been implemented.
- More rapid delivery and deployment of useful software to the customer is possible.
 - Customers are able to use and gain value from the software earlier than is possible with a waterfall process.

Incremental development problems

- The process is not visible.
 - Managers need regular deliverables to measure progress. If systems are developed quickly, it is not cost-effective to produce documents that reflect every version of the system.
- System structure tends to degrade as new increments are added.
 - Unless time and money is spent on refactoring to improve the software, regular change tends to corrupt its structure. Incorporating further software changes becomes increasingly difficult and costly.

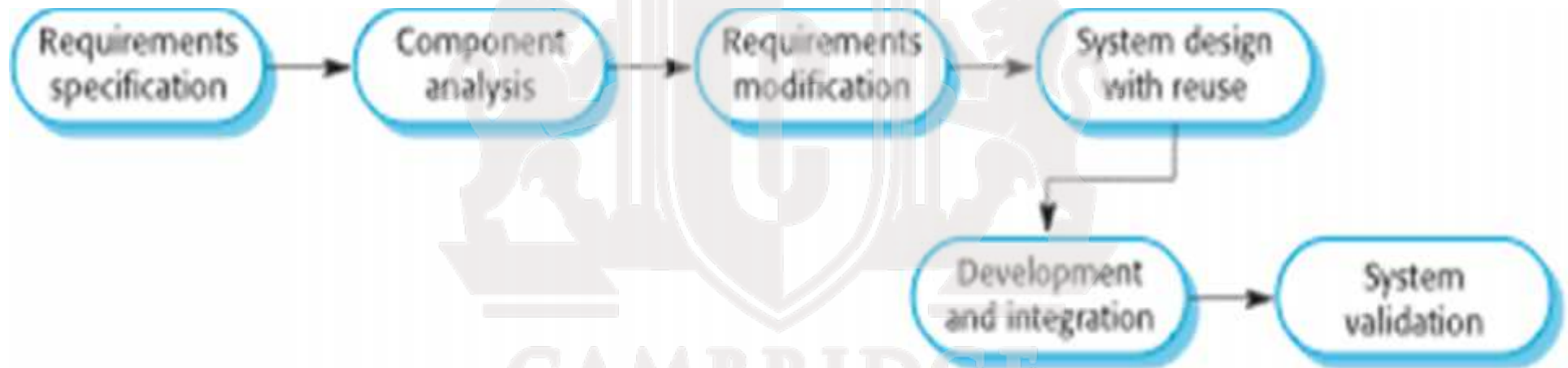
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Reuse-oriented software engineering

- Based on systematic reuse where systems are integrated from existing components or COTS (Commercial-off-the-shelf) systems.
- Process stages
 - Component analysis;
 - Requirements modification;
 - System design with reuse;
 - Development and integration.
- Reuse is now the standard approach for building many types of business system
 - Reuse covered in more depth in Chapter 16.

Reuse-oriented software engineering



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Types of software component

- Web services that are developed according to service standards and which are available for remote invocation.
- Collections of objects that are developed as a package to be integrated with a component framework such as .NET or J2EE.
- Stand-alone software systems (COTS) that are configured for use in a particular environment.

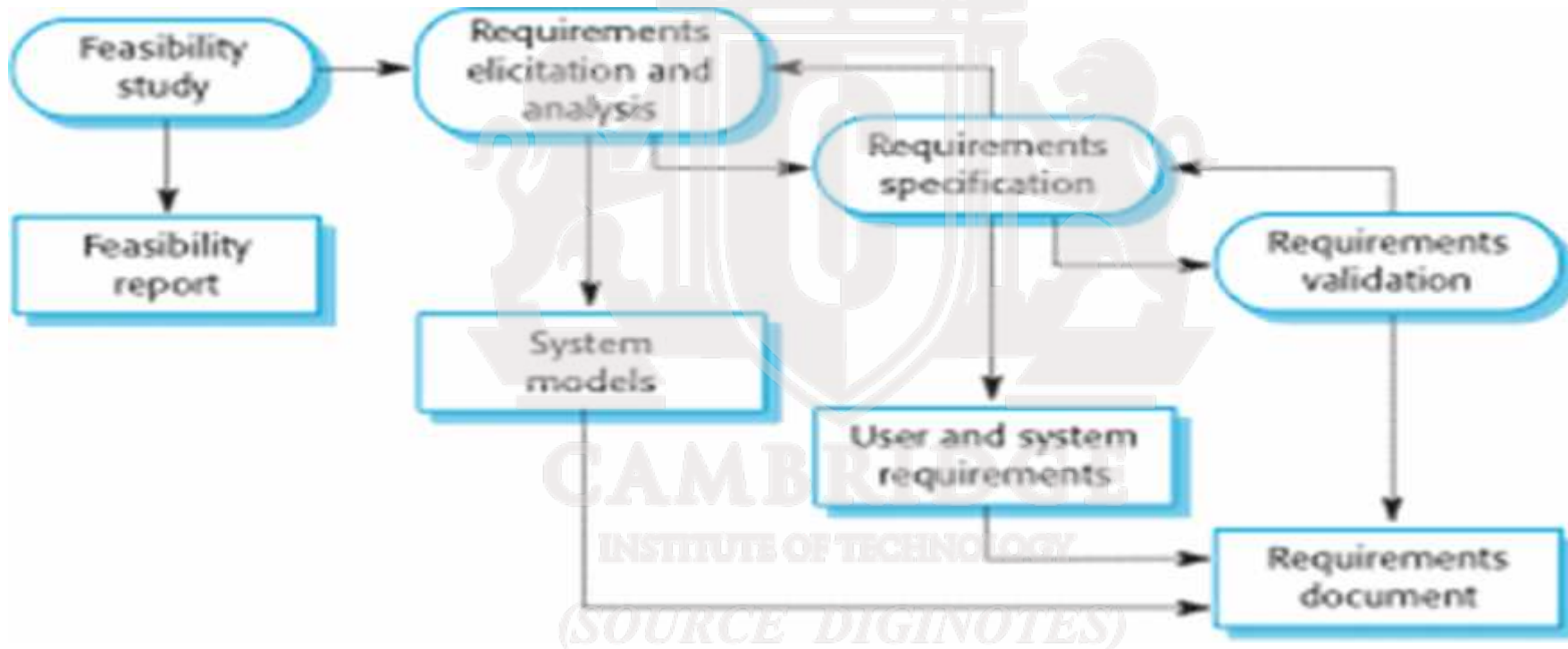
Process activities

- Real software processes are inter-leaved sequences of technical, collaborative and managerial activities with the overall goal of specifying, designing, implementing and testing a software system.
- The four basic process activities of specification, development, validation and evolution are organized differently in different development processes. In the waterfall model, they are organized in sequence, whereas in incremental development they are inter-leaved.

Software specification

- The process of establishing what services are required and the constraints on the system's operation and development.
- Requirements engineering process
 - Feasibility study
 - Is it technically and financially feasible to build the system?
 - Requirements elicitation and analysis
 - What do the system stakeholders require or expect from the system?
 - Requirements specification
 - Defining the requirements in detail
 - Requirements validation
 - Checking the validity of the requirements

The requirements engineering process

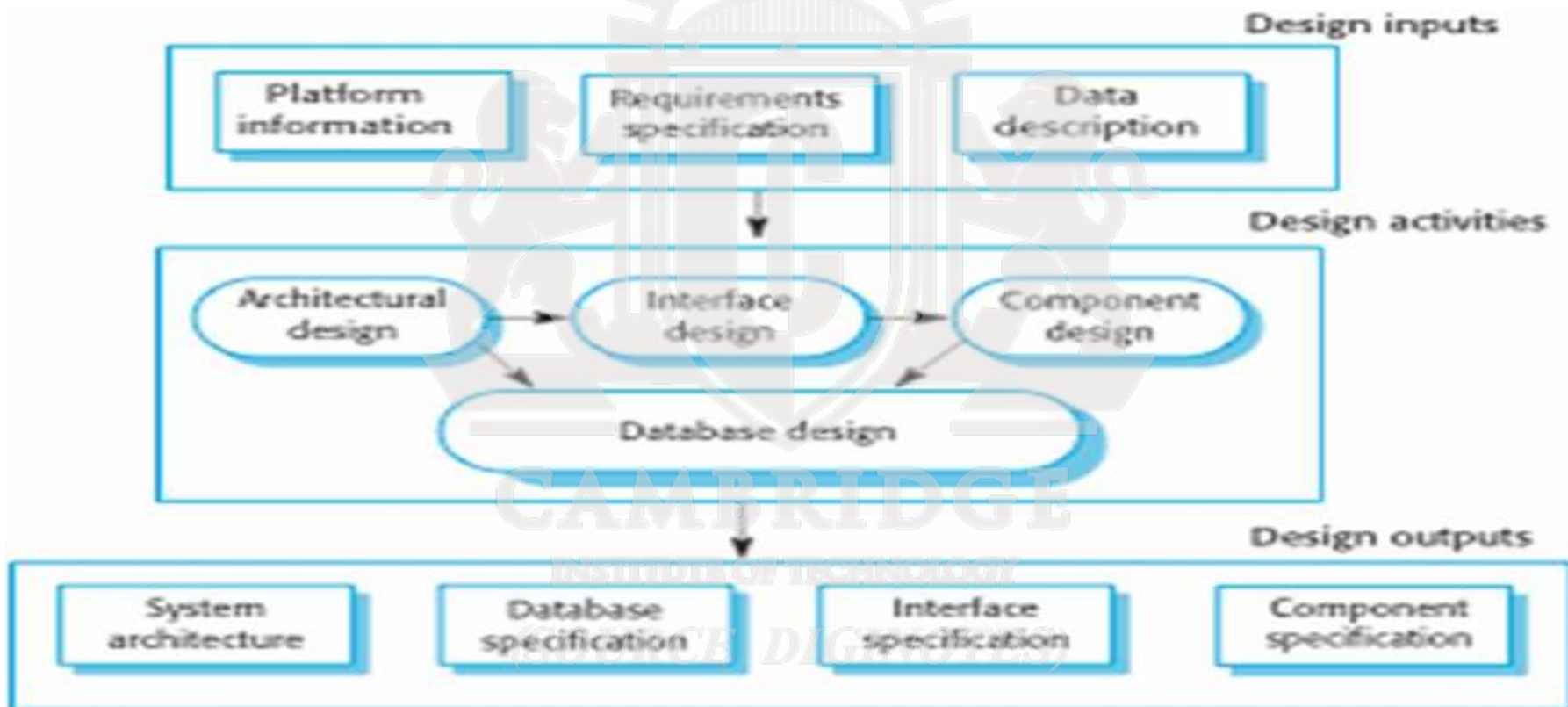


Software design and implementation

- The process of converting the system specification into an executable system.
- Software design
 - Design a software structure that realises the specification;
- Implementation
 - Translate this structure into an executable program;
- The activities of design and implementation are closely related and may be inter-leaved.

(SOURCE DIGINOTES)

A general model of the design process



Design activities

- *Architectural design*, where you identify the overall structure of the system, the principal components (sometimes called sub-systems or modules), their relationships and how they are distributed.
- *Interface design*, where you define the interfaces between system components.
- *Component design*, where you take each system component and design how it will operate.
- *Database design*, where you design the system data structures and how these are to be represented in a database.

(SOURCE DIGINOTES)

Software validation

- Verification and validation (V & V) is intended to show that a system conforms to its specification and meets the requirements of the system customer.
- Involves checking and review processes and system testing.
- System testing involves executing the system with test cases that are derived from the specification of the real data to be processed by the system.
- Testing is the most commonly used V & V activity.

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Stages of testing



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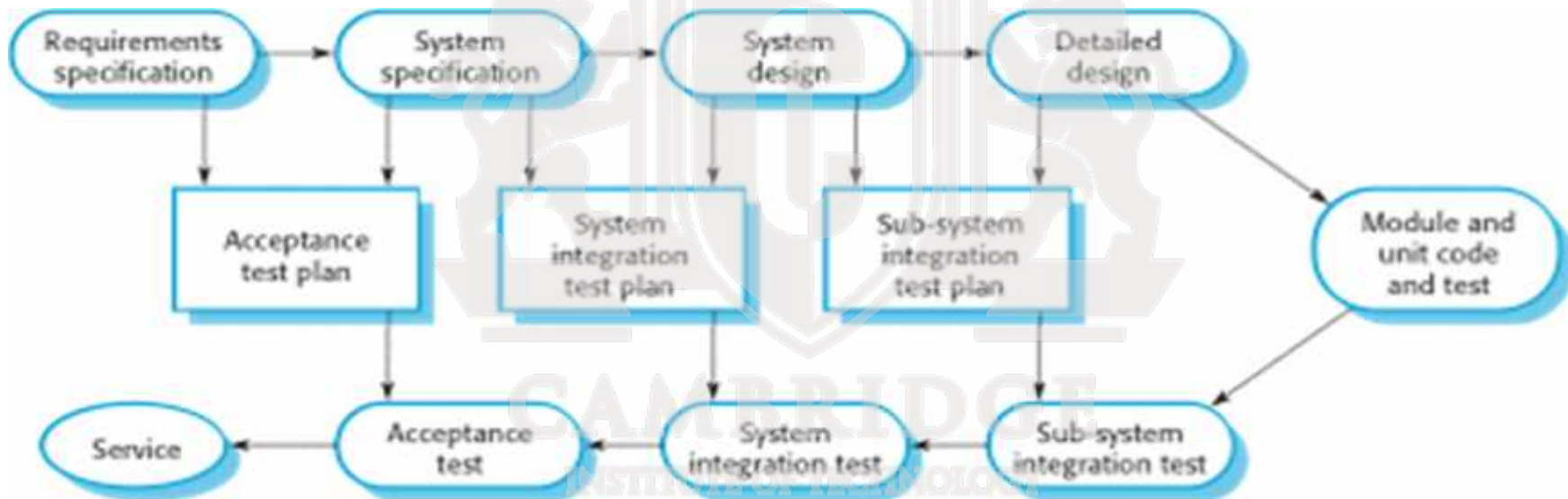
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Testing stages

- Development or component testing
 - Individual components are tested independently;
 - Components may be functions or objects or coherent groupings of these entities.
- System testing
 - Testing of the system as a whole. Testing of emergent properties is particularly important.
- Acceptance testing
 - Testing with customer data to check that the system meets the customer's needs.

(SOURCE DIGINOTES)

Testing phases in a plan-driven software process

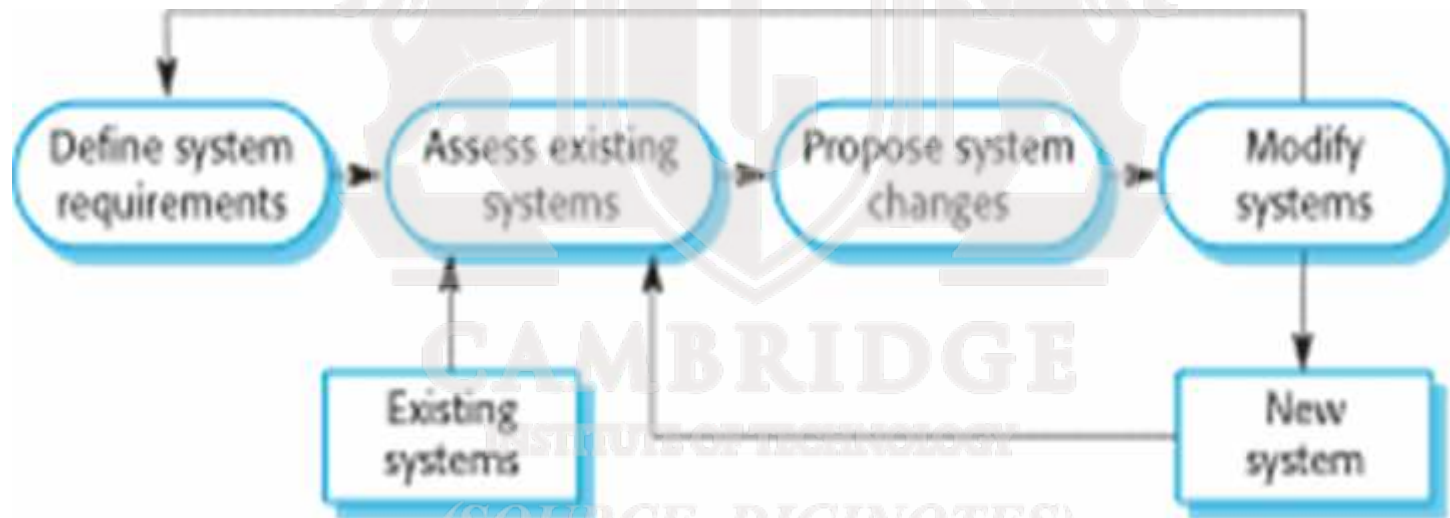


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Software evolution

- Software is inherently flexible and can change.
- As requirements change through changing business circumstances, the software that supports the business must also evolve and change.
- Although there has been a demarcation between development and evolution (maintenance) this is increasingly irrelevant as fewer and fewer systems are completely new.

System evolution



(SOURCE DIGINOTES)

Coping with change

- Change is inevitable in all large software projects.
 - Business changes lead to new and changed system requirements
 - New technologies open up new possibilities for improving implementations
 - Changing platforms require application changes
- Change leads to rework so the costs of change include both rework (e.g. re-analysing requirements) as well as the costs of implementing new functionality

Reducing the costs of rework

- Change avoidance, where the software process includes activities that can anticipate possible changes before significant rework is required.
 - For example, a prototype system may be developed to show some key features of the system to customers.
- Change tolerance, where the process is designed so that changes can be accommodated at relatively low cost.
 - This normally involves some form of incremental development. Proposed changes may be implemented in increments that have not yet been developed. If this is impossible, then only a single increment (a small part of the system) may have be altered to incorporate the change.

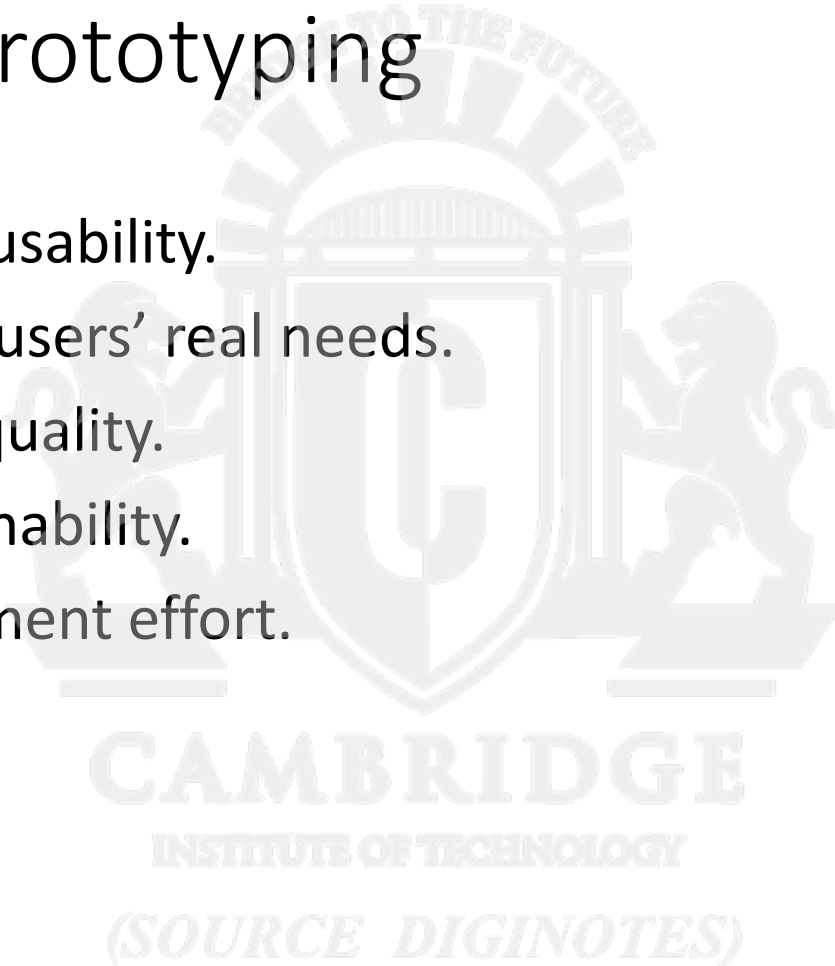
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Software prototyping

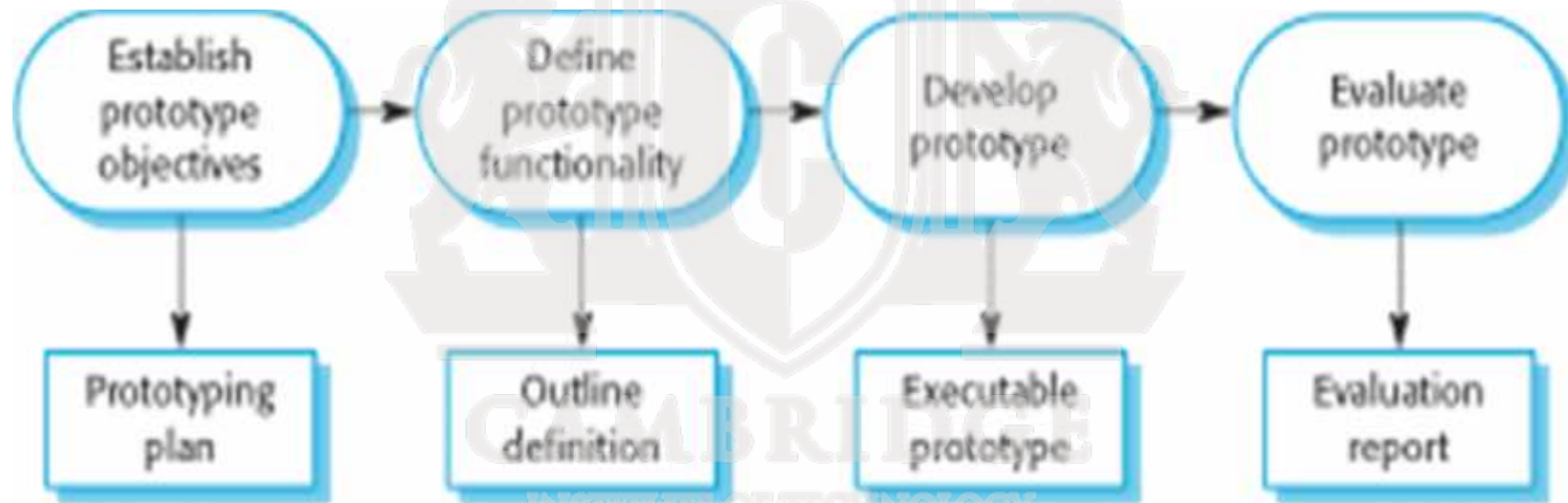
- A prototype is an initial version of a system used to demonstrate concepts and try out design options.
- A prototype can be used in:
 - The requirements engineering process to help with requirements elicitation and validation;
 - In design processes to explore options and develop a UI design;
 - In the testing process to run back-to-back tests.

Benefits of prototyping

- Improved system usability.
- A closer match to users' real needs.
- Improved design quality.
- Improved maintainability.
- Reduced development effort.



The process of prototype development



(SOURCE DIGINOTES)

Prototype development

- May be based on rapid prototyping languages or tools
- May involve leaving out functionality
 - Prototype should focus on areas of the product that are not well-understood;
 - Error checking and recovery may not be included in the prototype;
 - Focus on functional rather than non-functional requirements such as reliability and security

Throw-away prototypes

- Prototypes should be discarded after development as they are not a good basis for a production system:
 - It may be impossible to tune the system to meet non-functional requirements;
 - Prototypes are normally undocumented;
 - The prototype structure is usually degraded through rapid change;
 - The prototype probably will not meet normal organisational quality standards.

Incremental delivery

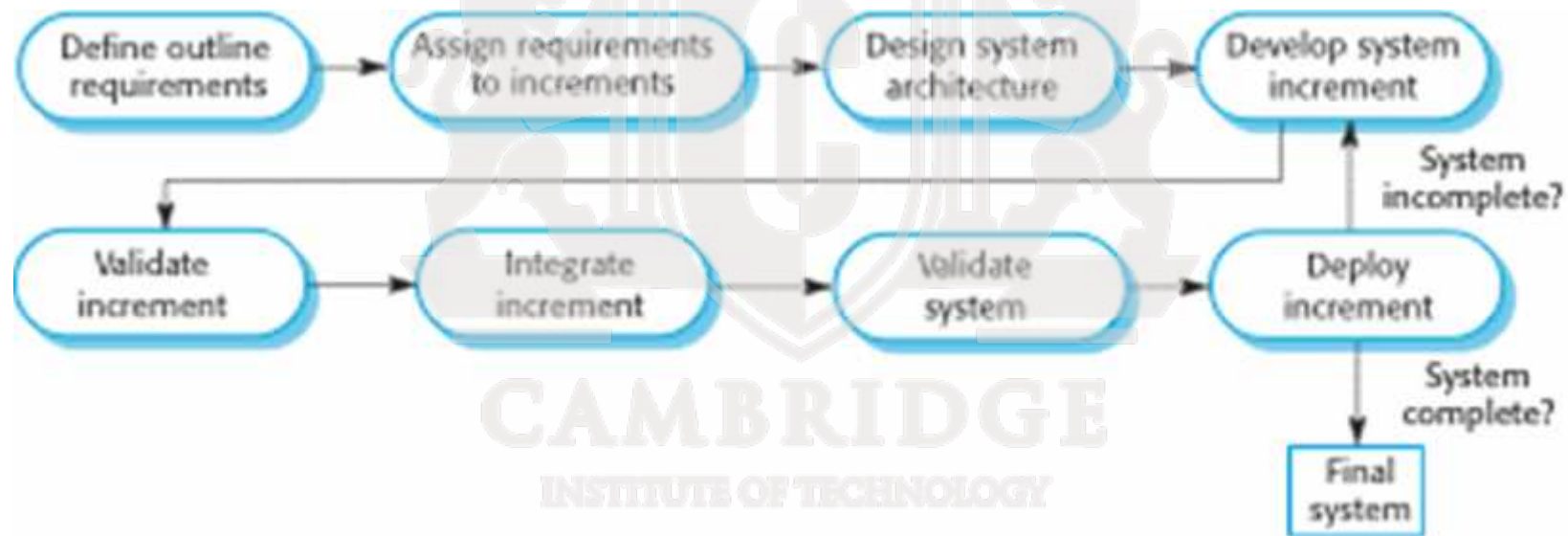
- Rather than deliver the system as a single delivery, the development and delivery is broken down into increments with each increment delivering part of the required functionality.
- User requirements are prioritised and the highest priority requirements are included in early increments.
- Once the development of an increment is started, the requirements are frozen though requirements for later increments can continue to evolve.

(SOURCE DIGINOTES)

Incremental development and delivery

- Incremental development
 - Develop the system in increments and evaluate each increment before proceeding to the development of the next increment;
 - Normal approach used in agile methods;
 - Evaluation done by user/customer proxy.
- Incremental delivery
 - Deploy an increment for use by end-users;
 - More realistic evaluation about practical use of software;
 - Difficult to implement for replacement systems as increments have less functionality than the system being replaced.

Incremental delivery



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Incremental delivery advantages

- Customer value can be delivered with each increment so system functionality is available earlier.
- Early increments act as a prototype to help elicit requirements for later increments.
- Lower risk of overall project failure.
- The highest priority system services tend to receive the most testing.

Incremental delivery problems

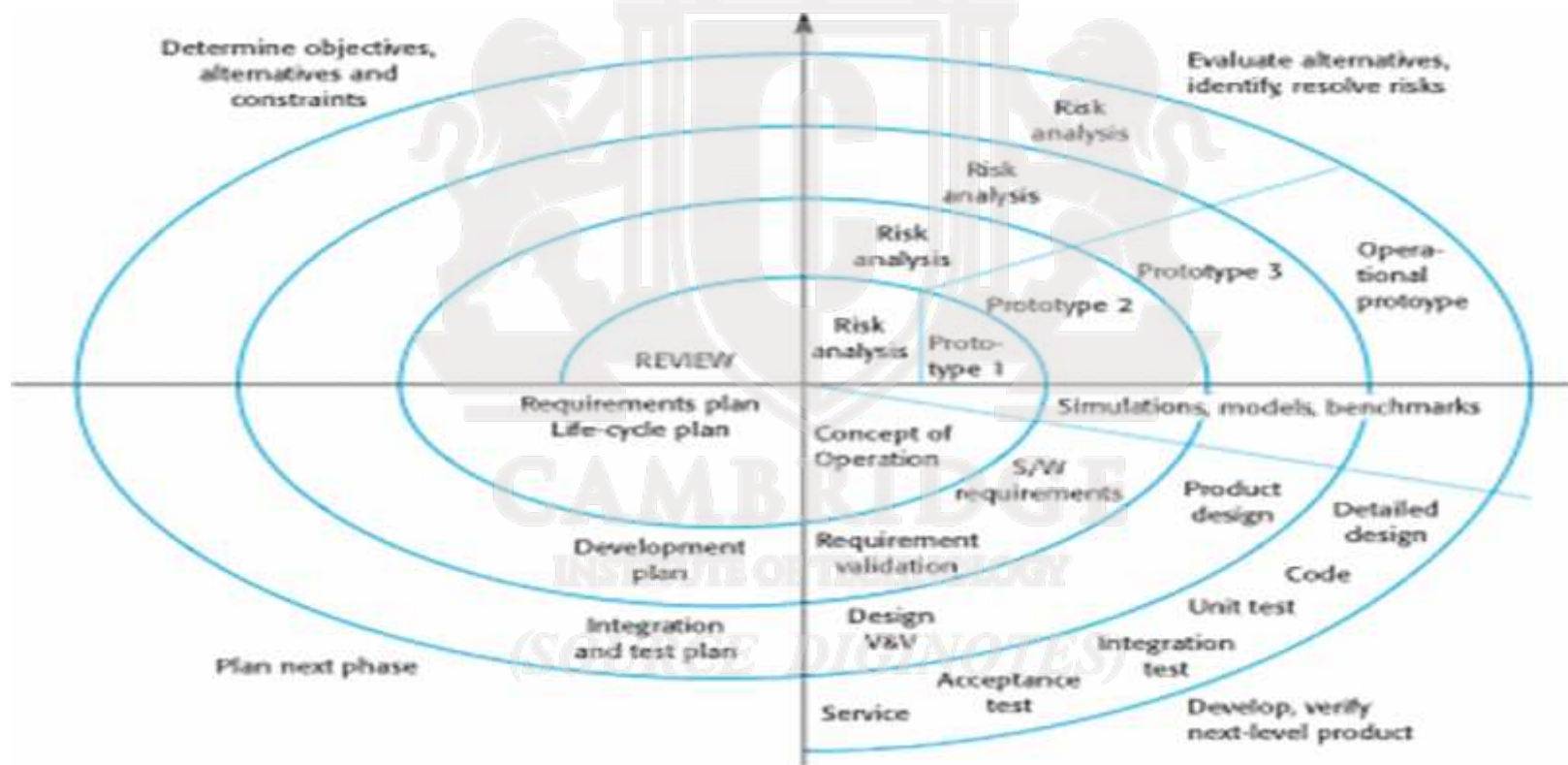
- Most systems require a set of basic facilities that are used by different parts of the system.
 - As requirements are not defined in detail until an increment is to be implemented, it can be hard to identify common facilities that are needed by all increments.
- The essence of iterative processes is that the specification is developed in conjunction with the software.
 - However, this conflicts with the procurement model of many organizations, where the complete system specification is part of the system development contract.

(SOURCE DIGINOTES)

Boehm's spiral model

- Process is represented as a spiral rather than as a sequence of activities with backtracking.
- Each loop in the spiral represents a phase in the process.
- No fixed phases such as specification or design - loops in the spiral are chosen depending on what is required.
- Risks are explicitly assessed and resolved throughout the process.

Boehm's spiral model of the software process

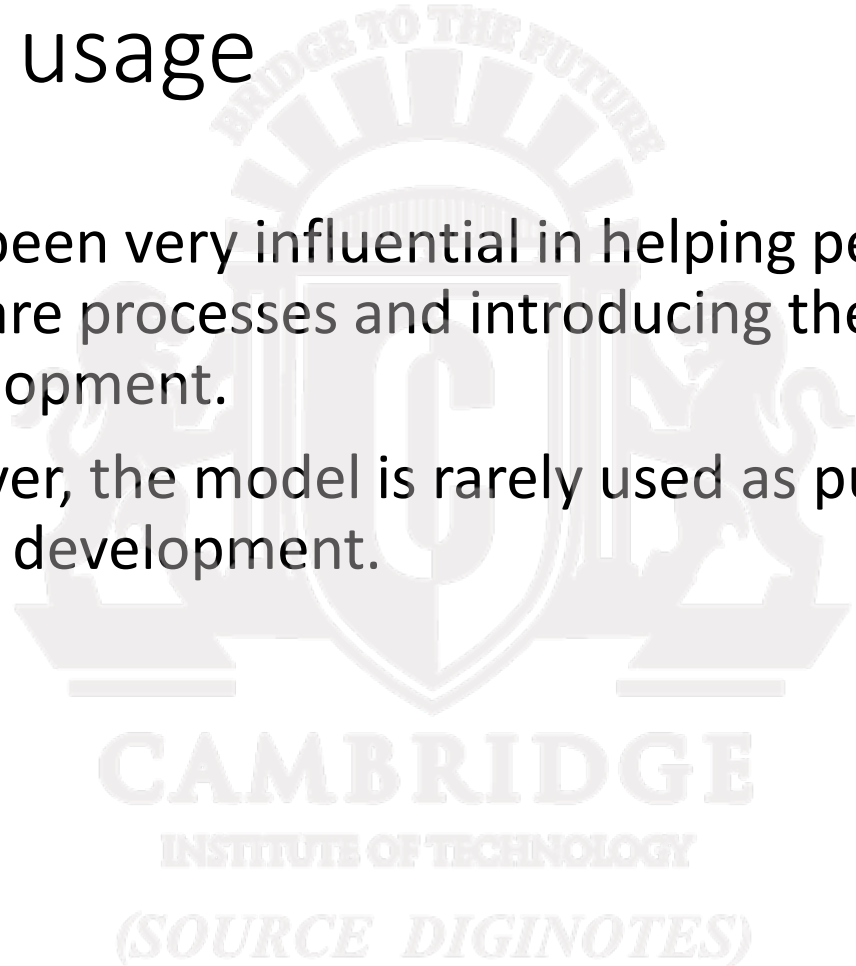


Spiral model sectors

- Objective setting
 - Specific objectives for the phase are identified.
- Risk assessment and reduction
 - Risks are assessed and activities put in place to reduce the key risks.
- Development and validation
 - A development model for the system is chosen which can be any of the generic models.
- Planning
 - The project is reviewed and the next phase of the spiral is planned.

Spiral model usage

- Spiral model has been very influential in helping people think about iteration in software processes and introducing the risk-driven approach to development.
- In practice, however, the model is rarely used as published for practical software development.

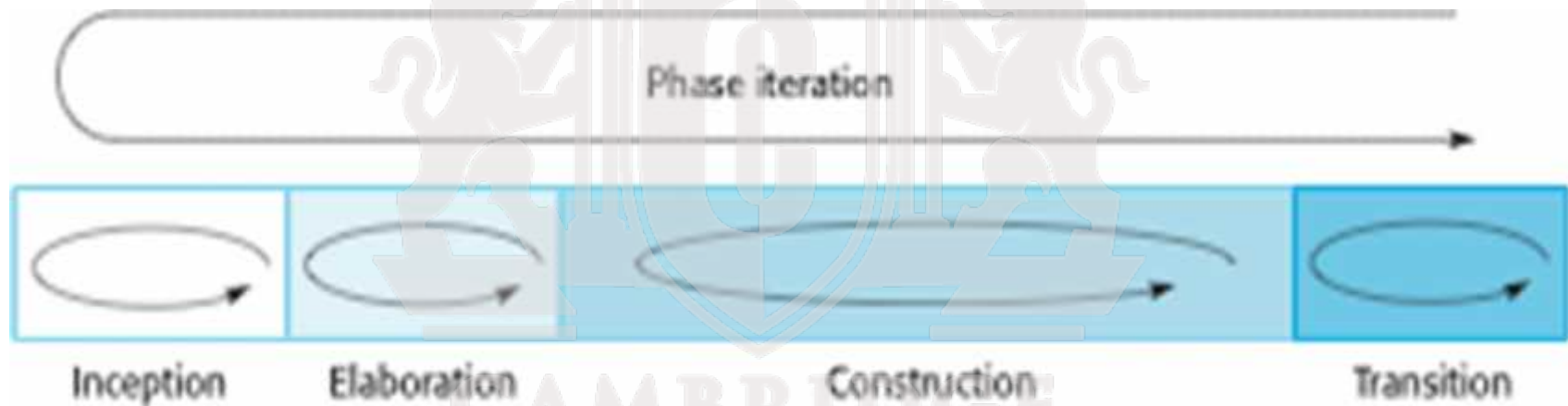


The Rational Unified Process

- A modern generic process derived from the work on the UML and associated process.
- Brings together aspects of the 3 generic process models discussed previously.
- Normally described from 3 perspectives
 - A dynamic perspective that shows phases over time;
 - A static perspective that shows process activities;
 - A practice perspective that suggests good practice.

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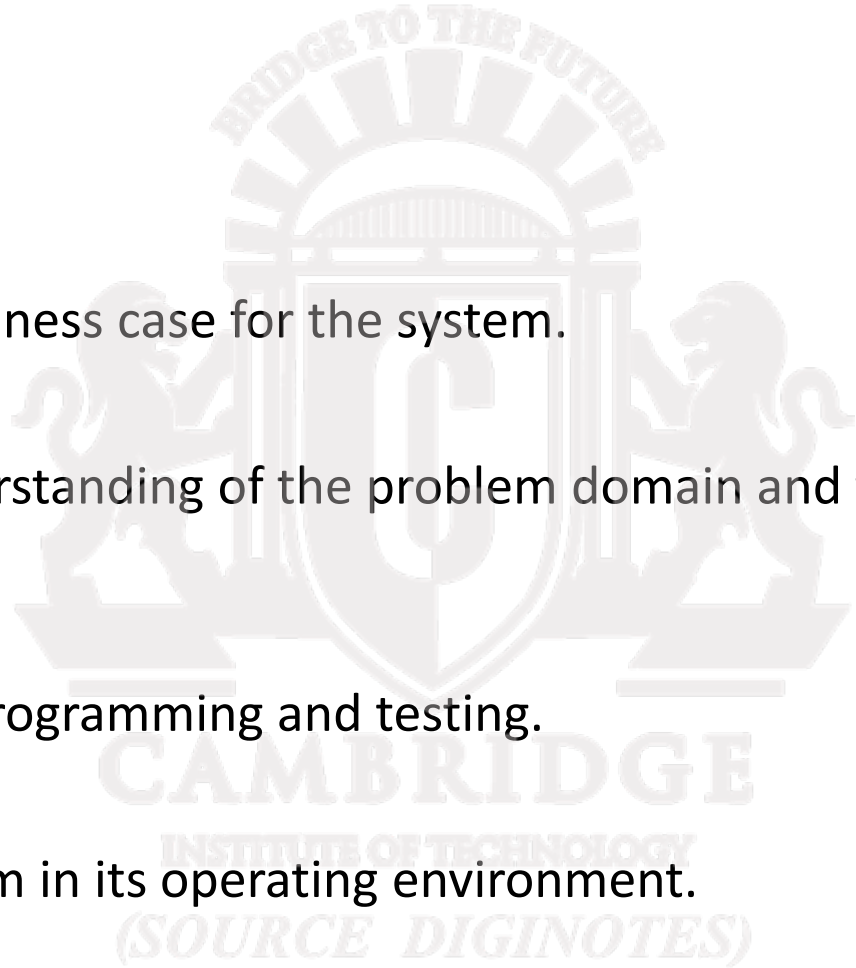
Phases in the Rational Unified Process



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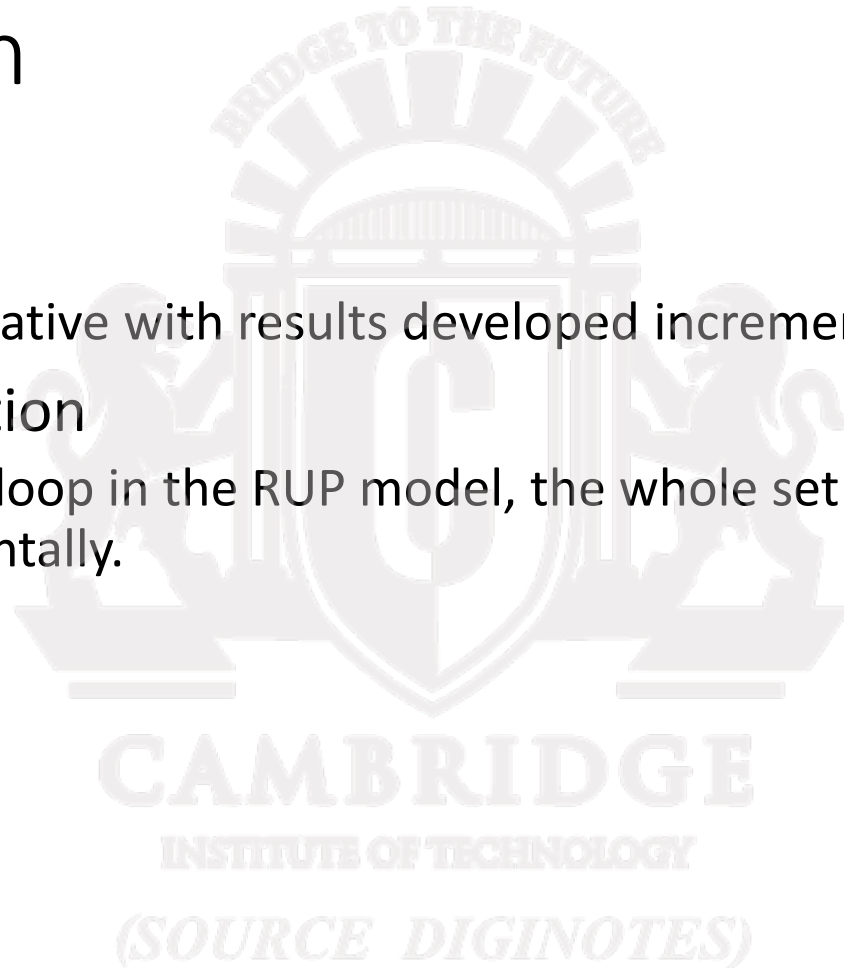
RUP phases

- Inception
 - Establish the business case for the system.
- Elaboration
 - Develop an understanding of the problem domain and the system architecture.
- Construction
 - System design, programming and testing.
- Transition
 - Deploy the system in its operating environment.



RUP iteration

- In-phase iteration
 - Each phase is iterative with results developed incrementally.
- Cross-phase iteration
 - As shown by the loop in the RUP model, the whole set of phases may be enacted incrementally.



Static workflows in the Rational Unified Process

Workflow	Description
Business modelling	The business processes are modelled using business use cases.
Requirements	Actors who interact with the system are identified and use cases are developed to model the system requirements.
Analysis and design	A design model is created and documented using architectural models, component models, object models and sequence models.
Implementation	The components in the system are implemented and structured into implementation sub-systems. Automatic code generation from design models helps accelerate this process.

(SOURCE DIGINOTES)

Static workflows in the Rational Unified Process

Workflow	Description
Testing	Testing is an iterative process that is carried out in conjunction with implementation. System testing follows the completion of the implementation.
Deployment	A product release is created, distributed to users and installed in their workplace.
Configuration and change management	This supporting workflow managed changes to the system (see Chapter 25).
Project management	This supporting workflow manages the system development (see Chapters 22 and 23).
Environment	This workflow is concerned with making appropriate software tools available to the software development team.

RUP good practice

- Develop software iteratively
 - Plan increments based on customer priorities and deliver highest priority increments first.
- Manage requirements
 - Explicitly document customer requirements and keep track of changes to these requirements.
- Use component-based architectures
 - Organize the system architecture as a set of reusable components.

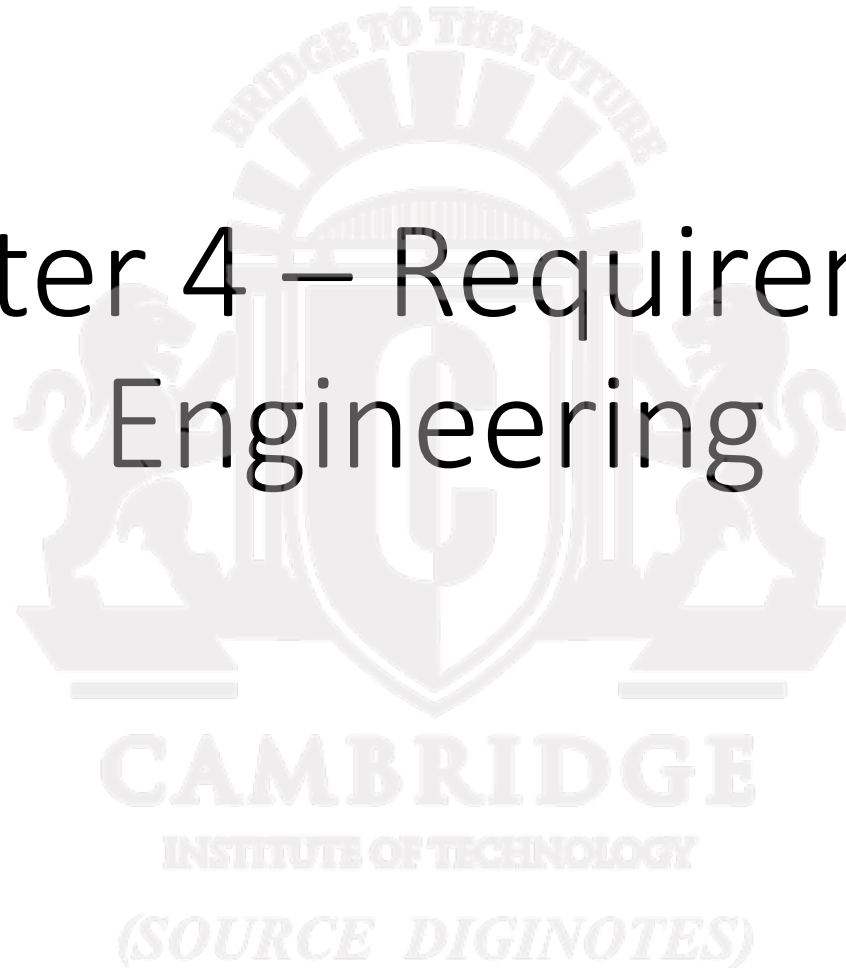
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RUP good practice

- Visually model software
 - Use graphical UML models to present static and dynamic views of the software.
- Verify software quality
 - Ensure that the software meet's organizational quality standards.
- Control changes to software
 - Manage software changes using a change management system and configuration management tools.

(SOURCE DIGINOTES)

Chapter 4 – Requirements Engineering



Topics covered

- Functional and non-functional requirements
- The software requirements document
- Requirements specification
- Requirements engineering processes
- Requirements elicitation and analysis
- Requirements validation
- Requirements management

(SOURCE DIGINOTES)

Requirements engineering

- The process of establishing the services that the customer requires from a system and the constraints under which it operates and is developed.
- The requirements themselves are the descriptions of the system services and constraints that are generated during the requirements engineering process.

What is a requirement?

- It may range from a high-level abstract statement of a service or of a system constraint to a detailed mathematical functional specification.
- This is inevitable as requirements may serve a dual function
 - May be the basis for a bid for a contract - therefore must be open to interpretation;
 - May be the basis for the contract itself - therefore must be defined in detail;
 - Both these statements may be called requirements.

Requirements abstraction (Davis)

- “If a company wishes to let a contract for a large software development project, it must define its needs in a sufficiently abstract way that a solution is not pre-defined. The requirements must be written so that several contractors can bid for the contract, offering, perhaps, different ways of meeting the client organization’s needs. Once a contract has been awarded, the contractor must write a system definition for the client in more detail so that the client understands and can validate what the software will do. Both of these documents may be called the requirements document for the system.”

(SOURCE DIGINOTES)

Types of requirement

- User requirements
 - Statements in natural language plus diagrams of the services the system provides and its operational constraints. Written for customers.
- System requirements
 - A structured document setting out detailed descriptions of the system's functions, services and operational constraints. Defines what should be implemented so may be part of a contract between client and contractor.

User and system requirements

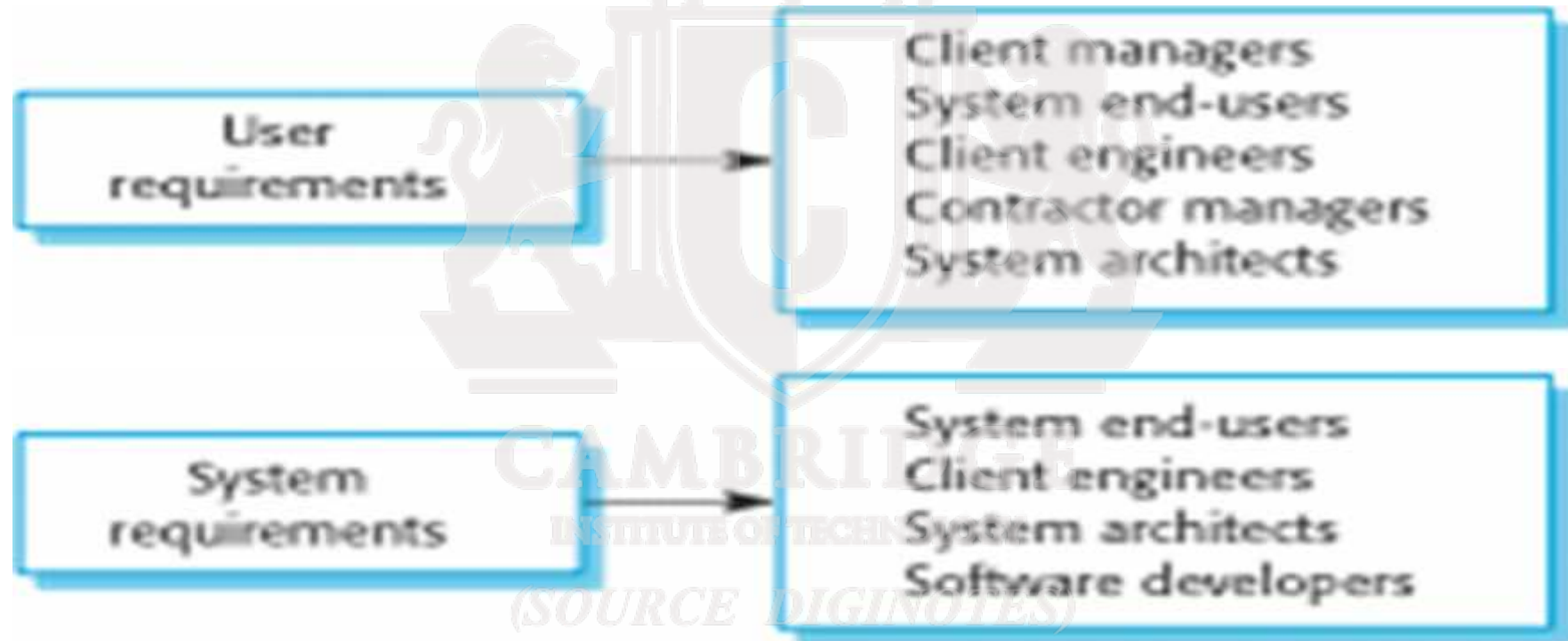
User requirement definition

1. The MHC-PMS shall generate monthly management reports showing the cost of drugs prescribed by each clinic during that month.

System requirements specification

- 1.1 On the last working day of each month, a summary of the drugs prescribed, their cost and the prescribing clinics shall be generated.
- 1.2 The system shall automatically generate the report for printing after 17.30 on the last working day of the month.
- 1.3 A report shall be created for each clinic and shall list the individual drug names, the total number of prescriptions, the number of doses prescribed and the total cost of the prescribed drugs.
- 1.4 If drugs are available in different dose units (e.g. 10mg, 20 mg, etc.) separate reports shall be created for each dose unit.
- 1.5 Access to all cost reports shall be restricted to authorized users listed on a management access control list.

Readers of different types of requirements specification



Functional and non-functional requirements

- Functional requirements
 - Statements of services the system should provide, how the system should react to particular inputs and how the system should behave in particular situations.
 - May state what the system should not do.
- Non-functional requirements
 - Constraints on the services or functions offered by the system such as timing constraints, constraints on the development process, standards, etc.
 - Often apply to the system as a whole rather than individual features or services.
- Domain requirements
 - Constraints on the system from the domain of operation

Functional requirements

- Describe functionality or system services.
- Depend on the type of software, expected users and the type of system where the software is used.
- Functional user requirements may be high-level statements of what the system should do.
- Functional system requirements should describe the system services in detail.

Functional requirements for the MHC-PMS

- A user shall be able to search the appointments lists for all clinics.
- The system shall generate each day, for each clinic, a list of patients who are expected to attend appointments that day.
- Each staff member using the system shall be uniquely identified by his or her 8-digit employee number.

Requirements imprecision

- Problems arise when requirements are not precisely stated.
- Ambiguous requirements may be interpreted in different ways by developers and users.
- Consider the term 'search' in requirement 1
 - User intention – search for a patient name across all appointments in all clinics;
 - Developer interpretation – search for a patient name in an individual clinic. User chooses clinic then search.

(SOURCE DIGINOTES)

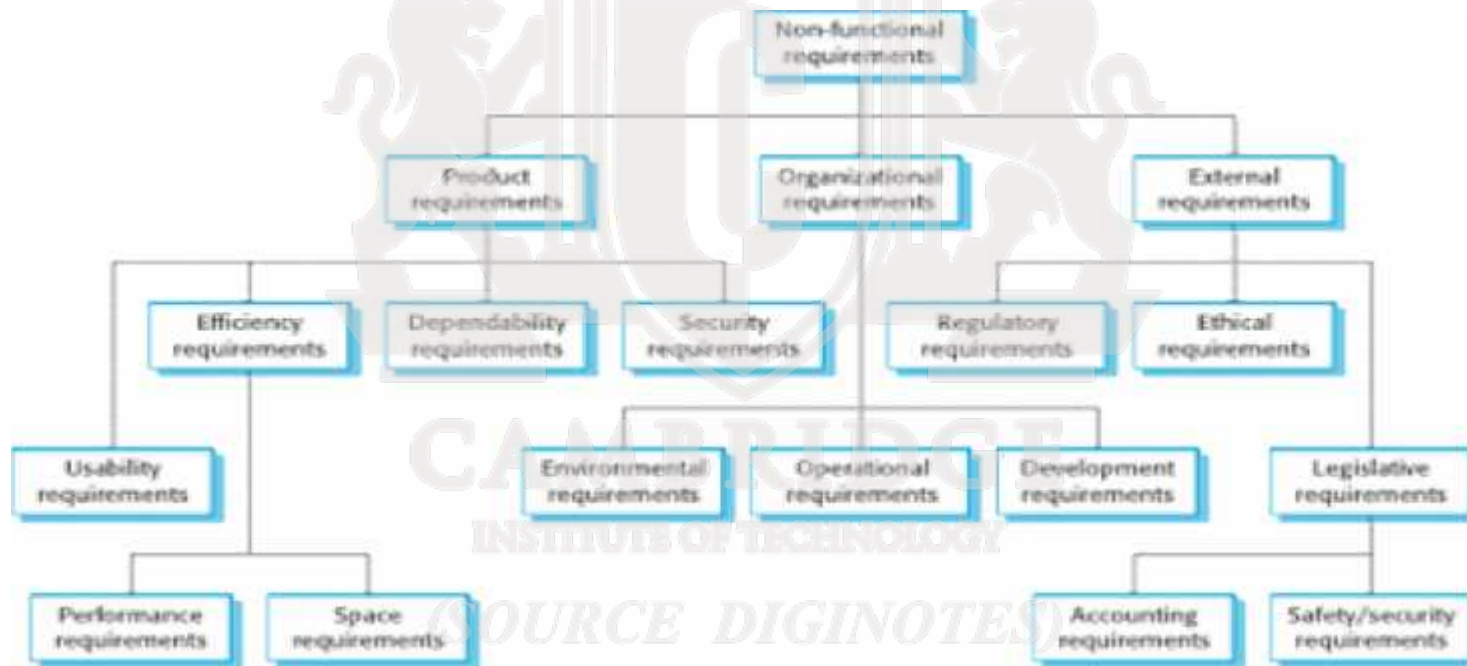
Requirements completeness and consistency

- In principle, requirements should be both complete and consistent.
- Complete
 - They should include descriptions of all facilities required.
- Consistent
 - There should be no conflicts or contradictions in the descriptions of the system facilities.
- In practice, it is impossible to produce a complete and consistent requirements document.

Non-functional requirements

- These define system properties and constraints e.g. reliability, response time and storage requirements. Constraints are I/O device capability, system representations, etc.
- Process requirements may also be specified mandating a particular IDE, programming language or development method.
- Non-functional requirements may be more critical than functional requirements. If these are not met, the system may be useless.

Types of nonfunctional requirement



Non-functional requirements implementation

- Non-functional requirements may affect the overall architecture of a system rather than the individual components.
 - For example, to ensure that performance requirements are met, you may have to organize the system to minimize communications between components.
- A single non-functional requirement, such as a security requirement, may generate a number of related functional requirements that define system services that are required.
 - It may also generate requirements that restrict existing requirements.

(SOURCE DIGINOTES)

Non-functional classifications

- Product requirements
 - Requirements which specify that the delivered product must behave in a particular way e.g. execution speed, reliability, etc.
- Organisational requirements
 - Requirements which are a consequence of organisational policies and procedures e.g. process standards used, implementation requirements, etc.
- External requirements
 - Requirements which arise from factors which are external to the system and its development process e.g. interoperability requirements, legislative requirements, etc.

(SOURCE DIGINOTES)

Examples of nonfunctional requirements in the MHC-PMS

Product requirement

The MHC-PMS shall be available to all clinics during normal working hours (Mon–Fri, 0830–17.30). Downtime within normal working hours shall not exceed five seconds in any one day.

Organizational requirement

Users of the MHC-PMS system shall authenticate themselves using their health authority identity card.

External requirement

The system shall implement patient privacy provisions as set out in HStan-03-2006-priv.

(SOURCE DIGINOTES)

Goals and requirements

- Non-functional requirements may be very difficult to state precisely and imprecise requirements may be difficult to verify.
- Goal
 - A general intention of the user such as ease of use.
- Verifiable non-functional requirement
 - A statement using some measure that can be objectively tested.
- Goals are helpful to developers as they convey the intentions of the system users.

Usability requirements

- The system should be easy to use by medical staff and should be organized in such a way that user errors are minimized. (Goal)
- Medical staff shall be able to use all the system functions after four hours of training. After this training, the average number of errors made by experienced users shall not exceed two per hour of system use. (Testable non-functional requirement)

Metrics for specifying nonfunctional requirements

Property	Measure
Speed	Processed transactions/second User/event response time Screen refresh time
Size	Mbytes Number of ROM chips
Ease of use	Training time Number of help frames
Reliability	Mean time to failure Probability of unavailability Rate of failure occurrence Availability
Robustness	Time to restart after failure Percentage of events causing failure Probability of data corruption on failure
Portability	Percentage of target dependent statements Number of target systems

Domain requirements

- The system's operational domain imposes requirements on the system.
 - For example, a train control system has to take into account the braking characteristics in different weather conditions.
- Domain requirements be new functional requirements, constraints on existing requirements or define specific computations.
- If domain requirements are not satisfied, the system may be unworkable.

(SOURCE DIGINOTES)

Train protection system

- This is a domain requirement for a train protection system:
- The deceleration of the train shall be computed as:
 - $D_{train} = D_{control} + D_{gradient}$
 - where $D_{gradient}$ is $9.81ms^2 * compensated\ gradient / \alpha$ and where the values of $9.81ms^2 / \alpha$ are known for different types of train.
- It is difficult for a non-specialist to understand the implications of this and how it interacts with other requirements.

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Domain requirements problems

- Understandability
 - Requirements are expressed in the language of the application domain;
 - This is often not understood by software engineers developing the system.
- Implicitness
 - Domain specialists understand the area so well that they do not think of making the domain requirements explicit.

The software requirements document

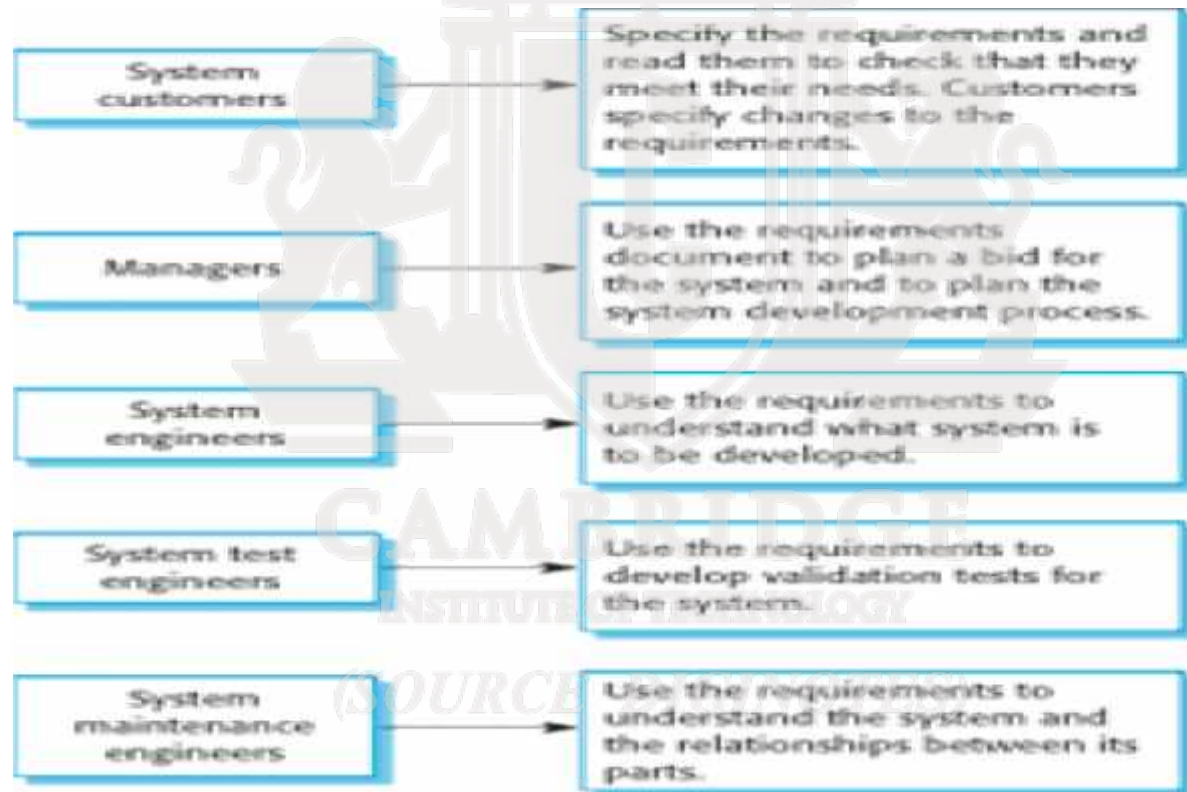
- The software requirements document is the official statement of what is required of the system developers.
- Should include both a definition of user requirements and a specification of the system requirements.
- It is NOT a design document. As far as possible, it should set of WHAT the system should do rather than HOW it should do it.

Agile methods and requirements

- Many agile methods argue that producing a requirements document is a waste of time as requirements change so quickly.
- The document is therefore always out of date.
- Methods such as XP use incremental requirements engineering and express requirements as 'user stories' (discussed in Chapter 3).
- This is practical for business systems but problematic for systems that require a lot of pre-delivery analysis (e.g. critical systems) or systems developed by several teams.

(SOURCE DIGINOTES)

Users of a requirements document



Requirements document variability

- Information in requirements document depends on type of system and the approach to development used.
- Systems developed incrementally will, typically, have less detail in the requirements document.
- Requirements documents standards have been designed e.g. IEEE standard. These are mostly applicable to the requirements for large systems engineering projects.

The structure of a requirements document

Chapter	Description
Preface	This should define the expected readership of the document and describe its version history, including a rationale for the creation of a new version and a summary of the changes made in each version.
Introduction	This should describe the need for the system. It should briefly describe the system's functions and explain how it will work with other systems. It should also describe how the system fits into the overall business or strategic objectives of the organization commissioning the software.
Glossary	This should define the technical terms used in the document. You should not make assumptions about the experience or expertise of the reader.
User requirements definition	Here, you describe the services provided for the user. The nonfunctional system requirements should also be described in this section. This description may use natural language, diagrams, or other notations that are understandable to customers. Product and process standards that must be followed should be specified.
System architecture	This chapter should present a high-level overview of the anticipated system architecture, showing the distribution of functions across system modules. Architectural components that are reused should be highlighted.

The structure of a requirements document

Chapter	Description
System requirements specification	This should describe the functional and nonfunctional requirements in more detail. If necessary, further detail may also be added to the nonfunctional requirements. Interfaces to other systems may be defined.
System models	This might include graphical system models showing the relationships between the system components and the system and its environment. Examples of possible models are object models, data-flow models, or semantic data models.
System evolution	This should describe the fundamental assumptions on which the system is based, and any anticipated changes due to hardware evolution, changing user needs, and so on. This section is useful for system designers as it may help them avoid design decisions that would constrain likely future changes to the system.
Appendices	These should provide detailed, specific information that is related to the application being developed; for example, hardware and database descriptions. Hardware requirements define the minimal and optimal configurations for the system. Database requirements define the logical organization of the data used by the system and the relationships between data.
Index	Several indexes to the document may be included. As well as a normal alphabetic index, there may be an index of diagrams, an index of functions, and so on.

Requirements specification

- The process of writing down the user and system requirements in a requirements document.
- User requirements have to be understandable by end-users and customers who do not have a technical background.
- System requirements are more detailed requirements and may include more technical information.
- The requirements may be part of a contract for the system development
 - It is therefore important that these are as complete as possible.

Ways of writing a system requirements specification

Notation	Description
Natural language	The requirements are written using numbered sentences in natural language. Each sentence should express one requirement.
Structured natural language	The requirements are written in natural language on a standard form or template. Each field provides information about an aspect of the requirement.
Design description languages	This approach uses a language like a programming language, but with more abstract features to specify the requirements by defining an operational model of the system. This approach is now rarely used although it can be useful for interface specifications.
Graphical notations	Graphical models, supplemented by text annotations, are used to define the functional requirements for the system; UML use case and sequence diagrams are commonly used.
Mathematical specifications	These notations are based on mathematical concepts such as finite-state machines or sets. Although these unambiguous specifications can reduce the ambiguity in a requirements document, most customers don't understand a formal specification. They cannot check that it represents what they want and are reluctant to accept it as a system contract

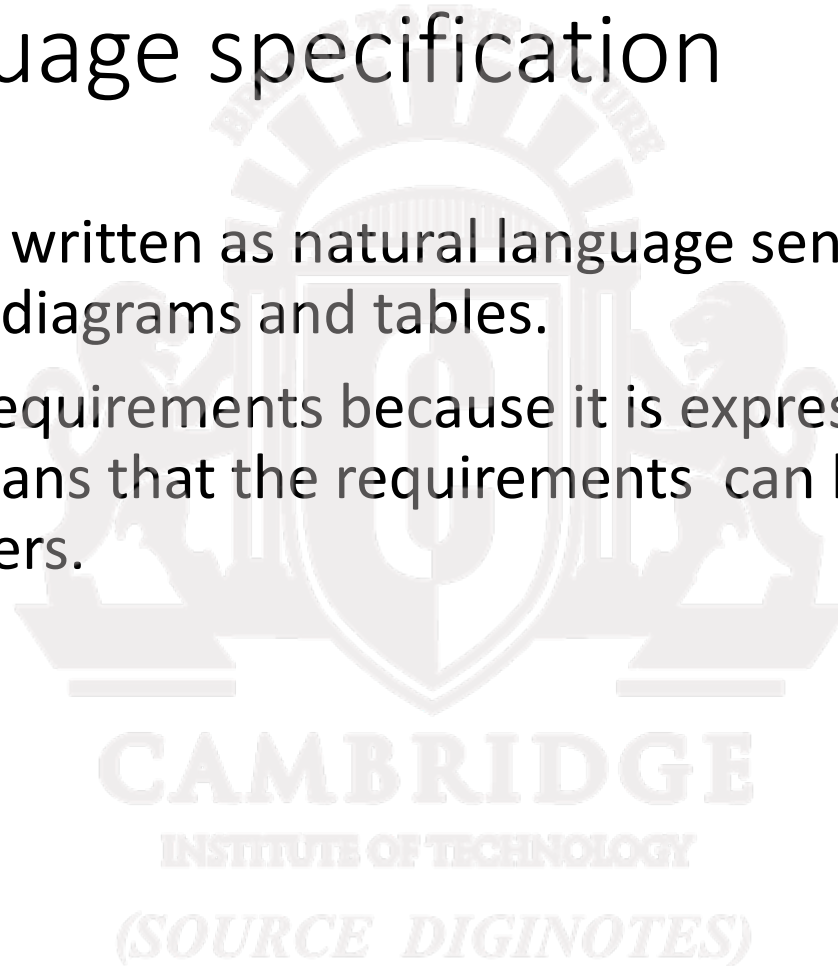
Requirements and design

- In principle, requirements should state what the system should do and the design should describe how it does this.
- In practice, requirements and design are inseparable
 - A system architecture may be designed to structure the requirements;
 - The system may inter-operate with other systems that generate design requirements;
 - The use of a specific architecture to satisfy non-functional requirements may be a domain requirement.
 - This may be the consequence of a regulatory requirement.

(SOURCE DIGINOTES)

Natural language specification

- Requirements are written as natural language sentences supplemented by diagrams and tables.
- Used for writing requirements because it is expressive, intuitive and universal. This means that the requirements can be understood by users and customers.



Guidelines for writing requirements

- Invent a standard format and use it for all requirements.
- Use language in a consistent way. Use shall for mandatory requirements, should for desirable requirements.
- Use text highlighting to identify key parts of the requirement.
- Avoid the use of computer jargon.
- Include an explanation (rationale) of why a requirement is necessary.

Problems with natural language

- Lack of clarity
 - Precision is difficult without making the document difficult to read.
- Requirements confusion
 - Functional and non-functional requirements tend to be mixed-up.
- Requirements amalgamation
 - Several different requirements may be expressed together.

Example requirements for the insulin pump software system

3.2 The system shall measure the blood sugar and deliver insulin, if required, every 10 minutes. *(Changes in blood sugar are relatively slow so more frequent measurement is unnecessary; less frequent measurement could lead to unnecessarily high sugar levels.)*

3.6 The system shall run a self-test routine every minute with the conditions to be tested and the associated actions defined in Table 1. *(A self-test routine can discover hardware and software problems and alert the user to the fact the normal operation may be impossible.)*

(SOURCE DIGINOTES)

Structured specifications

- An approach to writing requirements where the freedom of the requirements writer is limited and requirements are written in a standard way.
- This works well for some types of requirements e.g. requirements for embedded control system but is sometimes too rigid for writing business system requirements.

Form-based specifications

- Definition of the function or entity.
- Description of inputs and where they come from.
- Description of outputs and where they go to.
- Information about the information needed for the computation and other entities used.
- Description of the action to be taken.
- Pre and post conditions (if appropriate).
- The side effects (if any) of the function.

(SOURCE DIGINOTES)

A structured specification of a requirement for an insulin pump

Insulin Pump/Control Software/SRS/3.3.2

Function Compute insulin dose: safe sugar level.

Description

Computes the dose of insulin to be delivered when the current measured sugar level is in the safe zone between 3 and 7 units.

Inputs Current sugar reading (r2); the previous two readings (r0 and r1).

Source Current sugar reading from sensor. Other readings from memory.

Outputs CompDose—the dose in insulin to be delivered.

Destination Main control loop.

(SOURCE DIGINOTES)

A structured specification of a requirement for an insulin pump

Action

CompDose is zero if the sugar level is stable or falling or if the level is increasing but the rate of increase is decreasing. If the level is increasing and the rate of increase is increasing, then CompDose is computed by dividing the difference between the current sugar level and the previous level by 4 and rounding the result. If the result, is rounded to zero then CompDose is set to the minimum dose that can be delivered.

Requirements

Two previous readings so that the rate of change of sugar level can be computed.

Pre-condition

The insulin reservoir contains at least the maximum allowed single dose of insulin.

Post-condition r0 is replaced by r1 then r1 is replaced by r2.

Side effects None.

Tabular specification

- Used to supplement natural language.
- Particularly useful when you have to define a number of possible alternative courses of action.
- For example, the insulin pump systems bases its computations on the rate of change of blood sugar level and the tabular specification explains how to calculate the insulin requirement for different scenarios.

Tabular specification of computation for an insulin pump

Condition	Action
Sugar level falling ($r_2 < r_1$)	CompDose = 0
Sugar level stable ($r_2 = r_1$)	CompDose = 0
Sugar level increasing and rate of increase and rate of decrease ($(r_2 - r_1) < (r_1 - r_0)$)	CompDose = 0
Sugar level increasing and rate of increase stable or increasing ($(r_2 - r_1) \geq (r_1 - r_0)$)	CompDose = = round $((r_2 - r_1)/4)$ If rounded result = 0 then CompDose = = MinimumDose

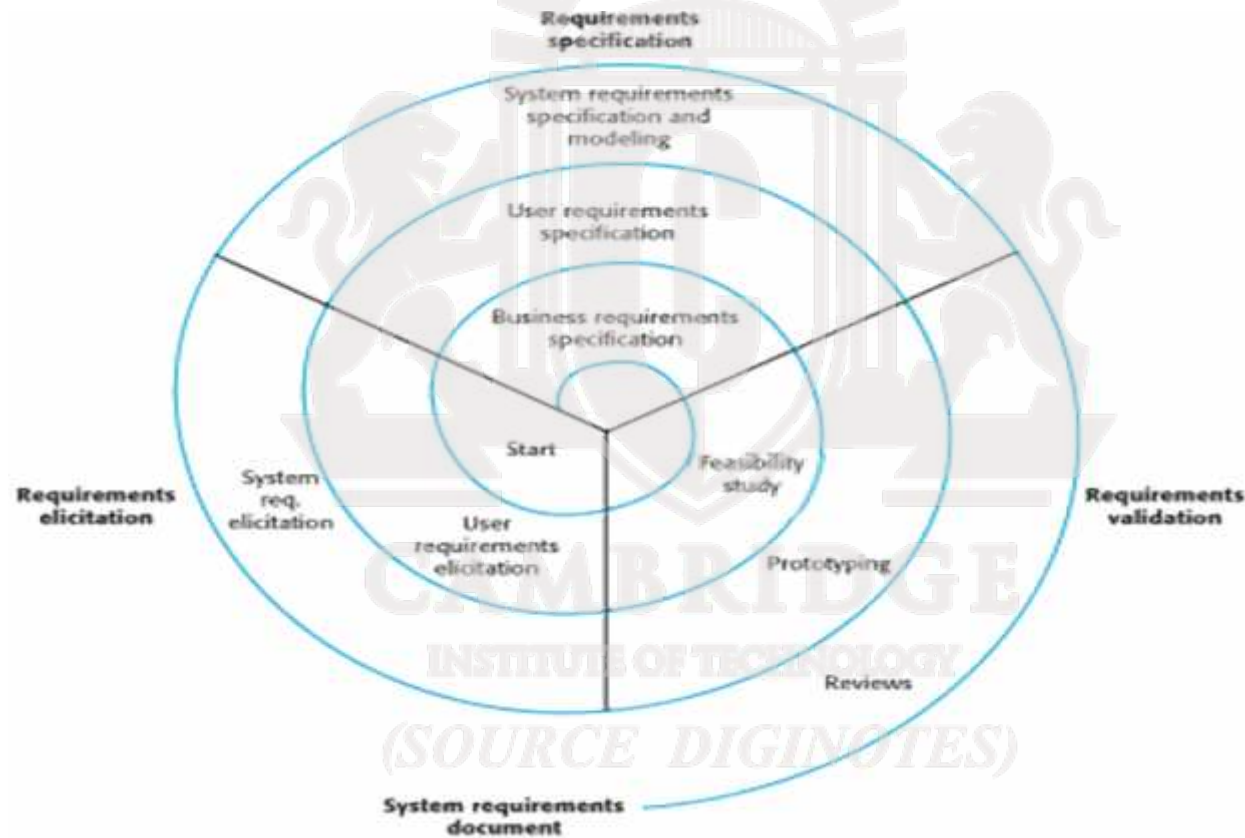
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Requirements engineering processes

- The processes used for RE vary widely depending on the application domain, the people involved and the organisation developing the requirements.
- However, there are a number of generic activities common to all processes
 - Requirements elicitation;
 - Requirements analysis;
 - Requirements validation;
 - Requirements management.
- In practice, RE is an iterative activity in which these processes are interleaved.

(SOURCE DIGINOTES)

A spiral view of the requirements engineering process



Requirements elicitation and analysis

- Sometimes called requirements elicitation or requirements discovery.
- Involves technical staff working with customers to find out about the application domain, the services that the system should provide and the system's operational constraints.
- May involve end-users, managers, engineers involved in maintenance, domain experts, trade unions, etc. These are called *stakeholders*.

Problems of requirements analysis

- Stakeholders don't know what they really want.
- Stakeholders express requirements in their own terms.
- Different stakeholders may have conflicting requirements.
- Organisational and political factors may influence the system requirements.
- The requirements change during the analysis process. New stakeholders may emerge and the business environment may change.

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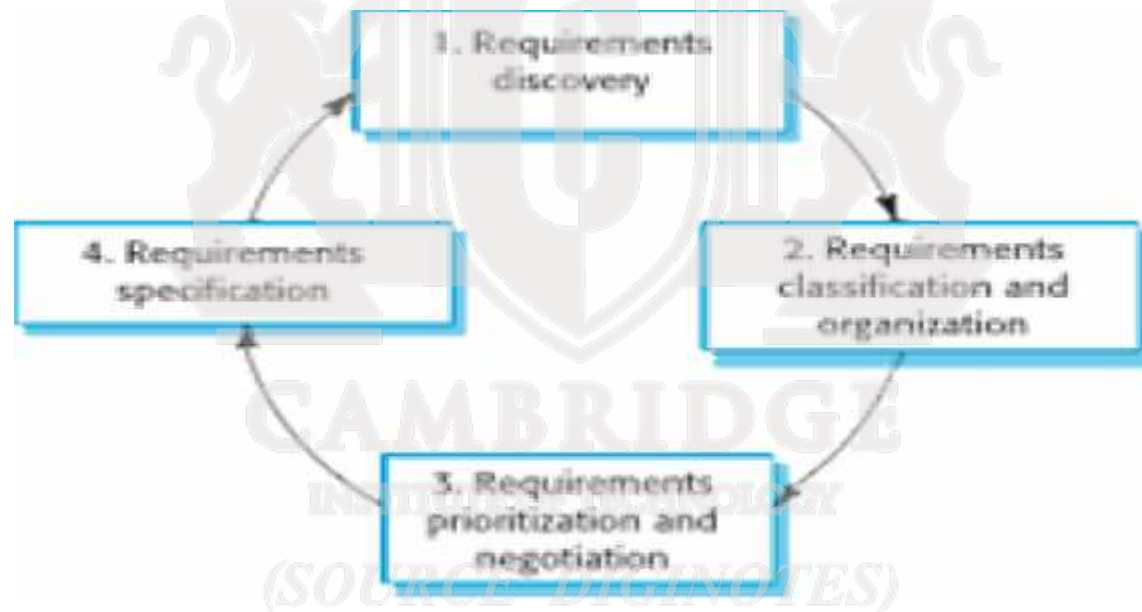
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Requirements elicitation and analysis

- Software engineers work with a range of system stakeholders to find out about the application domain, the services that the system should provide, the required system performance, hardware constraints, other systems, etc.
- Stages include:
 - Requirements discovery,
 - Requirements classification and organization,
 - Requirements prioritization and negotiation,
 - Requirements specification.

(SOURCE DIGINOTES)

The requirements elicitation and analysis process



Process activities

- Requirements discovery
 - Interacting with stakeholders to discover their requirements. Domain requirements are also discovered at this stage.
- Requirements classification and organisation
 - Groups related requirements and organises them into coherent clusters.
- Prioritisation and negotiation
 - Prioritising requirements and resolving requirements conflicts.
- Requirements specification
 - Requirements are documented and input into the next round of the spiral.

(SOURCE DIGINOTES)

Problems of requirements elicitation

- Stakeholders don't know what they really want.
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Requirements discovery

- The process of gathering information about the required and existing systems and distilling the user and system requirements from this information.
- Interaction is with system stakeholders from managers to external regulators.
- Systems normally have a range of stakeholders.

Stakeholders in the MHC-PMS

- Patients whose information is recorded in the system.
- Doctors who are responsible for assessing and treating patients.
- Nurses who coordinate the consultations with doctors and administer some treatments.
- Medical receptionists who manage patients' appointments.
- IT staff who are responsible for installing and maintaining the system.

Stakeholders in the MHC-PMS

- A medical ethics manager who must ensure that the system meets current ethical guidelines for patient care.
- Health care managers who obtain management information from the system.
- Medical records staff who are responsible for ensuring that system information can be maintained and preserved, and that record keeping procedures have been properly implemented.

(SOURCE DIGINOTES)

Interviewing

- Formal or informal interviews with stakeholders are part of most RE processes.
- Types of interview
 - Closed interviews based on pre-determined list of questions
 - Open interviews where various issues are explored with stakeholders.
- Effective interviewing
 - Be open-minded, avoid pre-conceived ideas about the requirements and are willing to listen to stakeholders.
 - Prompt the interviewee to get discussions going using a springboard question, a requirements proposal, or by working together on a prototype system.

Interviews in practice

- Normally a mix of closed and open-ended interviewing.
- Interviews are good for getting an overall understanding of what stakeholders do and how they might interact with the system.
- Interviews are not good for understanding domain requirements
 - Requirements engineers cannot understand specific domain terminology;
 - Some domain knowledge is so familiar that people find it hard to articulate or think that it isn't worth articulating.

Scenarios

- Scenarios are real-life examples of how a system can be used.
- They should include
 - A description of the starting situation;
 - A description of the normal flow of events;
 - A description of what can go wrong;
 - Information about other concurrent activities;
 - A description of the state when the scenario finishes.

Scenario for collecting medical history in MHC-PMS

- **Initial assumption:** The patient has seen a medical receptionist who has created a record in the system and collected the patient's personal information (name, address, age, etc.). A nurse is logged on to the system and is collecting medical history.
- **Normal:** The nurse searches for the patient by family name. If there is more than one patient with the same surname, the given name (first name in English) and date of birth are used to identify the patient.
- The nurse chooses the menu option to add medical history.
- The nurse then follows a series of prompts from the system to enter information about consultations elsewhere on mental health problems (free text input), existing medical conditions (nurse selects conditions from menu), medication currently taken (selected from menu), allergies (free text), and home life (form).

Scenario for collecting medical history in MHC-PMS

What can go wrong: The patient's record does not exist or cannot be found. The nurse should create a new record and record personal information.

Patient conditions or medication are not entered in the menu. The nurse should choose the 'other' option and enter free text describing the condition/medication.

Patient cannot/will not provide information on medical history. The nurse should enter free text recording the patient's inability/unwillingness to provide information. The system should print the standard exclusion form stating that the lack of information may mean that treatment will be limited or delayed. This should be signed and handed to the patient.

Other activities: Record may be consulted but not edited by other staff while information is being entered.

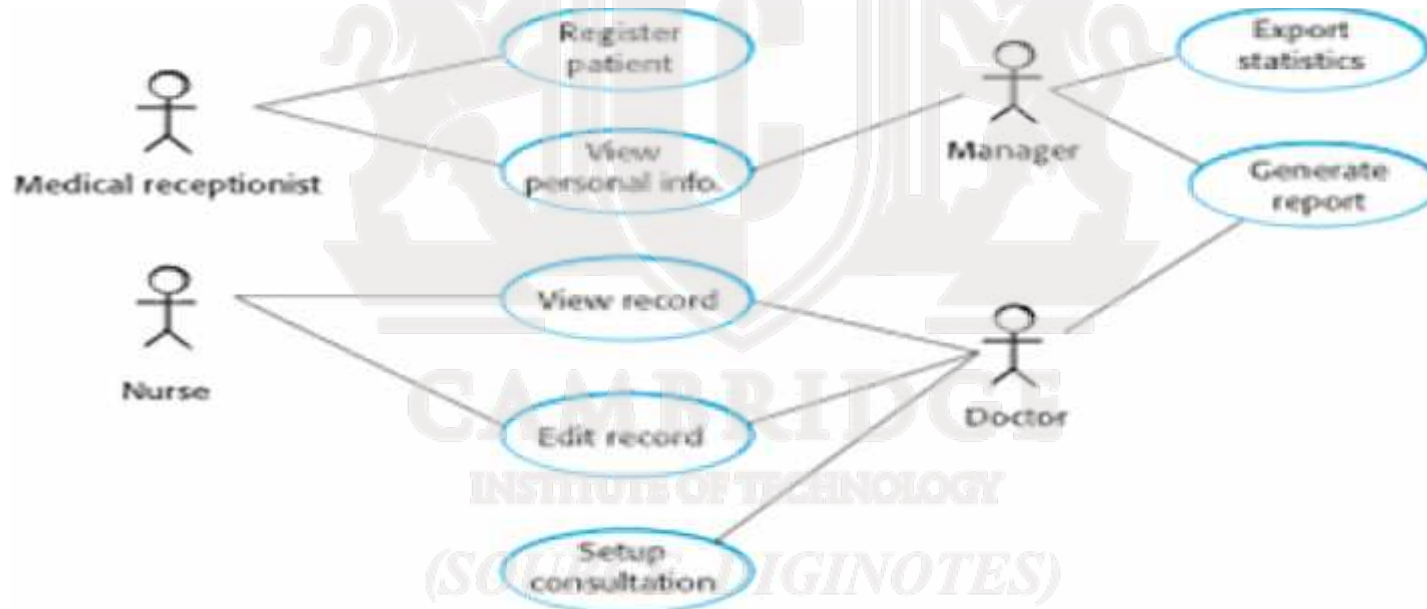
System state on completion: User is logged on. The patient record including medical history is entered in the database, a record is added to the system log showing the start and end time of the session and the nurse involved.

Use cases

- Use-cases are a scenario based technique in the UML which identify the actors in an interaction and which describe the interaction itself.
- A set of use cases should describe all possible interactions with the system.
- High-level graphical model supplemented by more detailed tabular description (see Chapter 5).
- Sequence diagrams may be used to add detail to use-cases by showing the sequence of event processing in the system.

(SOURCE DIGINOTES)

Use cases for the MHC-PMS



Ethnography

- A social scientist spends a considerable time observing and analysing how people actually work.
- People do not have to explain or articulate their work.
- Social and organisational factors of importance may be observed.
- Ethnographic studies have shown that work is usually richer and more complex than suggested by simple system models.

Scope of ethnography

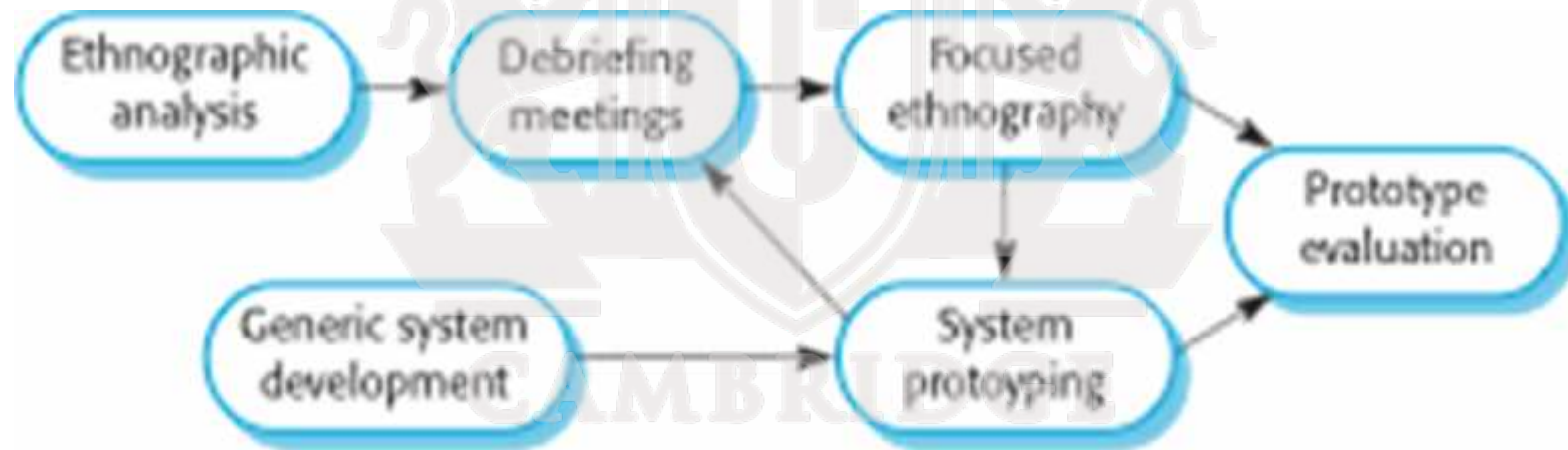
- Requirements that are derived from the way that people actually work rather than the way I which process definitions suggest that they ought to work.
- Requirements that are derived from cooperation and awareness of other people's activities.
 - Awareness of what other people are doing leads to changes in the ways in which we do things.
- Ethnography is effective for understanding existing processes but cannot identify new features that should be added to a system.

(SOURCE DIGINOTES)

Focused ethnography

- Developed in a project studying the air traffic control process
- Combines ethnography with prototyping
- Prototype development results in unanswered questions which focus the ethnographic analysis.
- The problem with ethnography is that it studies existing practices which may have some historical basis which is no longer relevant.

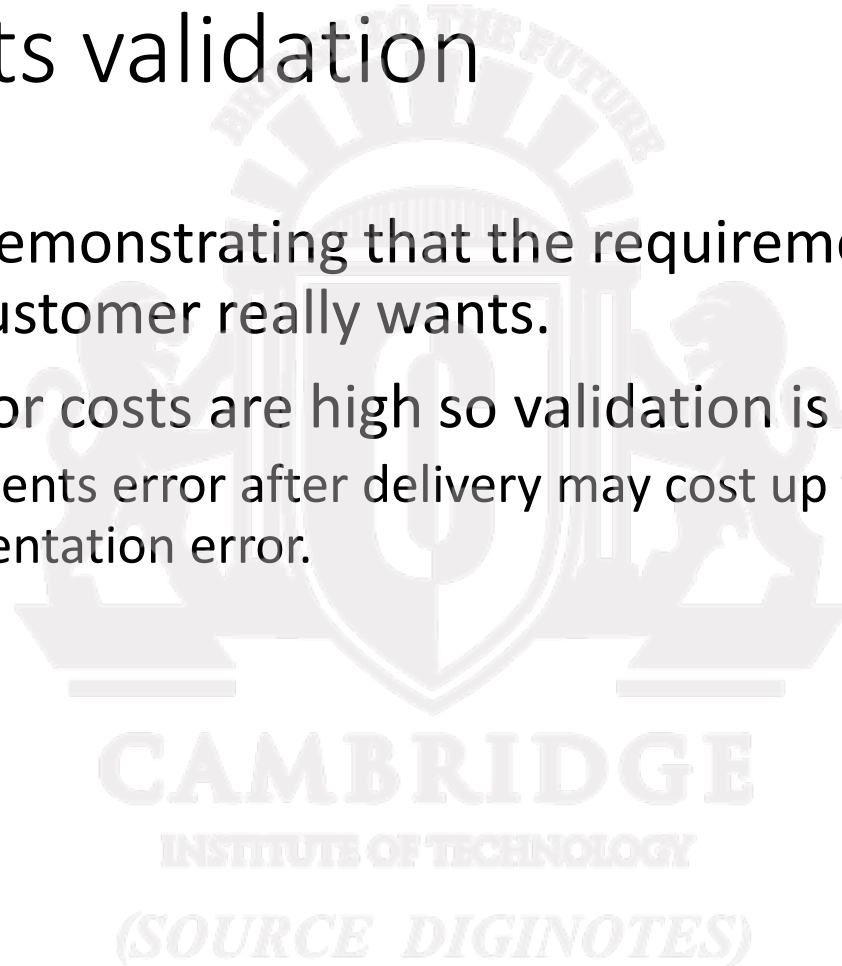
Ethnography and prototyping for requirements analysis



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Requirements validation

- Concerned with demonstrating that the requirements define the system that the customer really wants.
- Requirements error costs are high so validation is very important
 - Fixing a requirements error after delivery may cost up to 100 times the cost of fixing an implementation error.



Requirements checking

- **Validity.** Does the system provide the functions which best support the customer's needs?
- **Consistency.** Are there any requirements conflicts?
- **Completeness.** Are all functions required by the customer included?
- **Realism.** Can the requirements be implemented given available budget and technology
- **Verifiability.** Can the requirements be checked?

Requirements validation techniques

- Requirements reviews
 - Systematic manual analysis of the requirements.
- Prototyping
 - Using an executable model of the system to check requirements. Covered in Chapter 2.
- Test-case generation
 - Developing tests for requirements to check testability.

Requirements reviews

- Regular reviews should be held while the requirements definition is being formulated.
- Both client and contractor staff should be involved in reviews.
- Reviews may be formal (with completed documents) or informal. Good communications between developers, customers and users can resolve problems at an early stage.

Review checks

- **Verifiability**
 - Is the requirement realistically testable?
- **Comprehensibility**
 - Is the requirement properly understood?
- **Traceability**
 - Is the origin of the requirement clearly stated?
- **Adaptability**
 - Can the requirement be changed without a large impact on other requirements?

(SOURCE DIGINOTES)

Requirements management

- Requirements management is the process of managing changing requirements during the requirements engineering process and system development.
- New requirements emerge as a system is being developed and after it has gone into use.
- You need to keep track of individual requirements and maintain links between dependent requirements so that you can assess the impact of requirements changes. You need to establish a formal process for making change proposals and linking these to system requirements.

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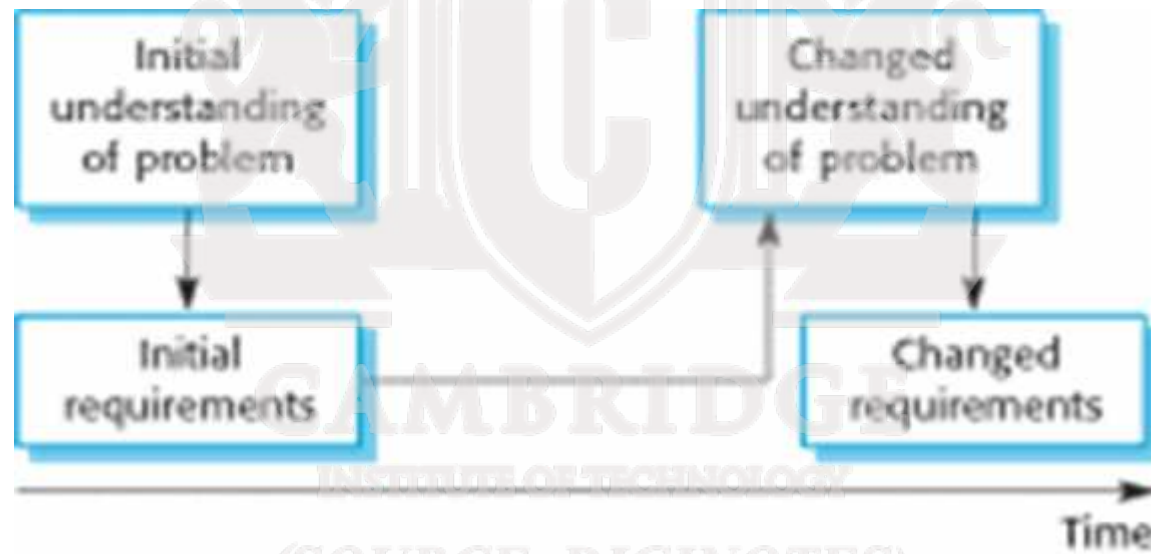
Changing requirements

- The business and technical environment of the system always changes after installation.
 - New hardware may be introduced, it may be necessary to interface the system with other systems, business priorities may change (with consequent changes in the system support required), and new legislation and regulations may be introduced that the system must necessarily abide by.
- The people who pay for a system and the users of that system are rarely the same people.
 - System customers impose requirements because of organizational and budgetary constraints. These may conflict with end-user requirements and, after delivery, new features may have to be added for user support if the system is to meet its goals.

Changing requirements

- Large systems usually have a diverse user community, with many users having different requirements and priorities that may be conflicting or contradictory.
 - The final system requirements are inevitably a compromise between them and, with experience, it is often discovered that the balance of support given to different users has to be changed.

Requirements evolution



(SOURCE DIGINOTES)

Requirements management planning

- Establishes the level of requirements management detail that is required.
- Requirements management decisions:
 - *Requirements identification* Each requirement must be uniquely identified so that it can be cross-referenced with other requirements.
 - *A change management process* This is the set of activities that assess the impact and cost of changes. I discuss this process in more detail in the following section.
 - *Traceability policies* These policies define the relationships between each requirement and between the requirements and the system design that should be recorded.
 - *Tool support* Tools that may be used range from specialist requirements management systems to spreadsheets and simple database systems.

(SOURCE DIGINOTES)

Requirements change management

- Deciding if a requirements change should be accepted
 - *Problem analysis and change specification*
 - During this stage, the problem or the change proposal is analyzed to check that it is valid. This analysis is fed back to the change requestor who may respond with a more specific requirements change proposal, or decide to withdraw the request.
 - *Change analysis and costing*
 - The effect of the proposed change is assessed using traceability information and general knowledge of the system requirements. Once this analysis is completed, a decision is made whether or not to proceed with the requirements change.
 - *Change implementation*
 - The requirements document and, where necessary, the system design and implementation, are modified. Ideally, the document should be organized so that changes can be easily implemented.

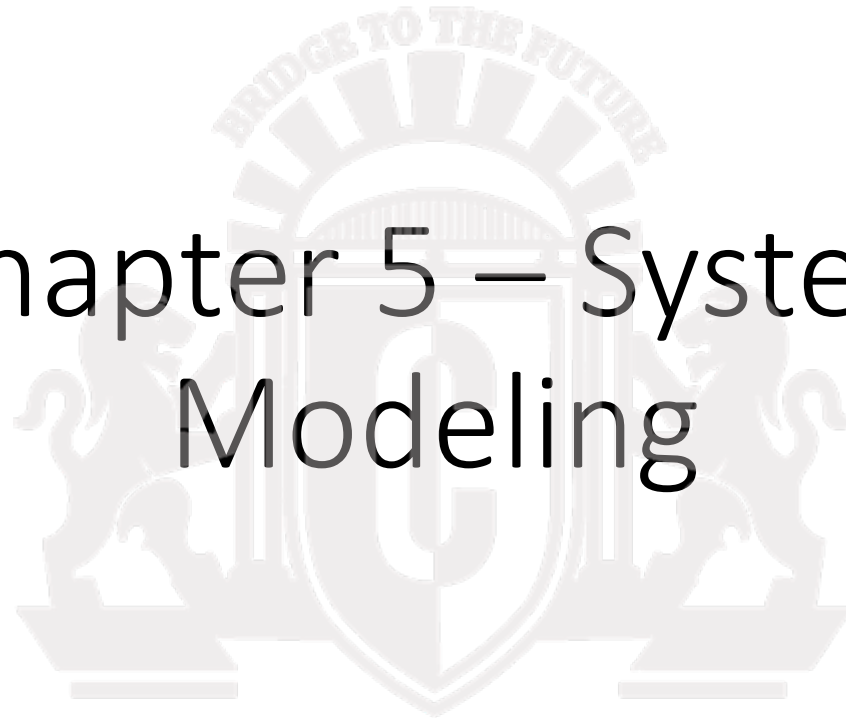
Requirements change management



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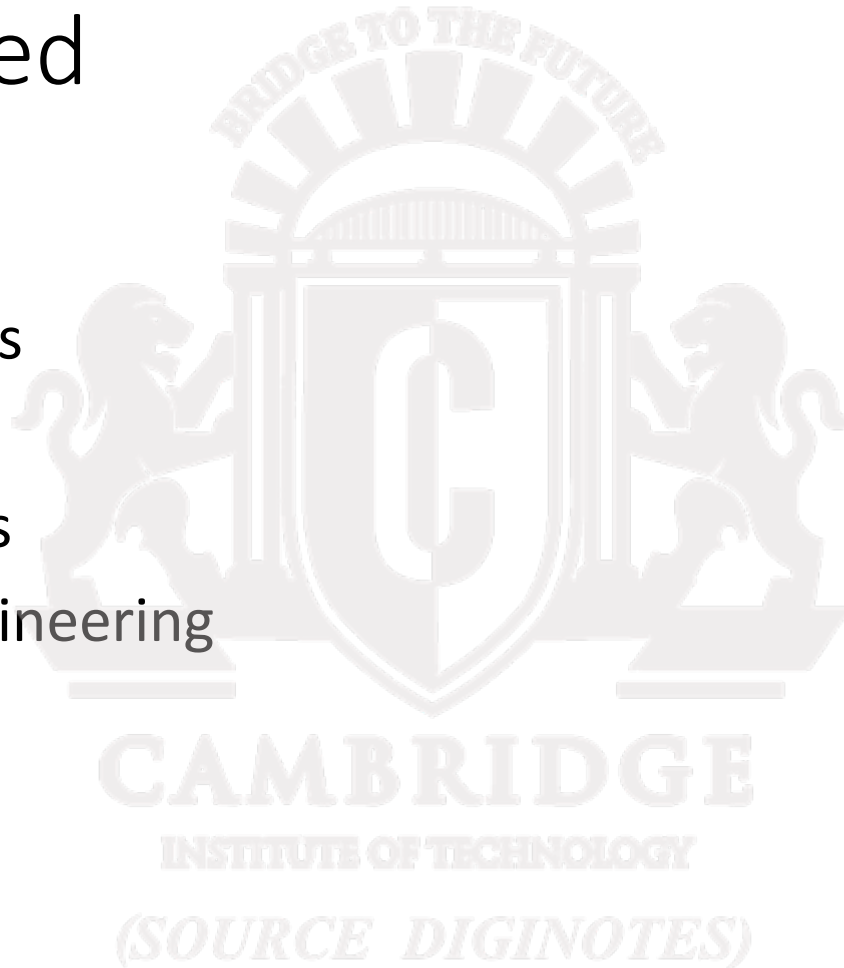
Chapter 5 – System Modeling



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Topics covered

- Context models
- Interaction models
- Structural models
- Behavioral models
- Model-driven engineering



System modeling

- System modeling is the process of developing abstract models of a system, with each model presenting a different view or perspective of that system.
- System modeling has now come to mean representing a system using some kind of graphical notation, which is now almost always based on notations in the Unified Modeling Language (UML).
- System modelling helps the analyst to understand the functionality of the system and models are used to communicate with customers.

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Existing and planned system models

- Models of the existing system are used during requirements engineering. They help clarify what the existing system does and can be used as a basis for discussing its strengths and weaknesses. These then lead to requirements for the new system.
- Models of the new system are used during requirements engineering to help explain the proposed requirements to other system stakeholders. Engineers use these models to discuss design proposals and to document the system for implementation.
- In a model-driven engineering process, it is possible to generate a complete or partial system implementation from the system model.

System perspectives

- An external perspective, where you model the context or environment of the system.
- An interaction perspective, where you model the interactions between a system and its environment, or between the components of a system.
- A structural perspective, where you model the organization of a system or the structure of the data that is processed by the system.
- A behavioral perspective, where you model the dynamic behavior of the system and how it responds to events.

(SOURCE DIGINOTES)

UML diagram types

- Activity diagrams, which show the activities involved in a process or in data processing .
- Use case diagrams, which show the interactions between a system and its environment.
- Sequence diagrams, which show interactions between actors and the system and between system components.
- Class diagrams, which show the object classes in the system and the associations between these classes.
- State diagrams, which show how the system reacts to internal and external events.

(SOURCE DIGINOTES)

Use of graphical models

- As a means of facilitating discussion about an existing or proposed system
 - Incomplete and incorrect models are OK as their role is to support discussion.
- As a way of documenting an existing system
 - Models should be an accurate representation of the system but need not be complete.
- As a detailed system description that can be used to generate a system implementation
 - Models have to be both correct and complete.

(SOURCE DIGINOTES)

Context models

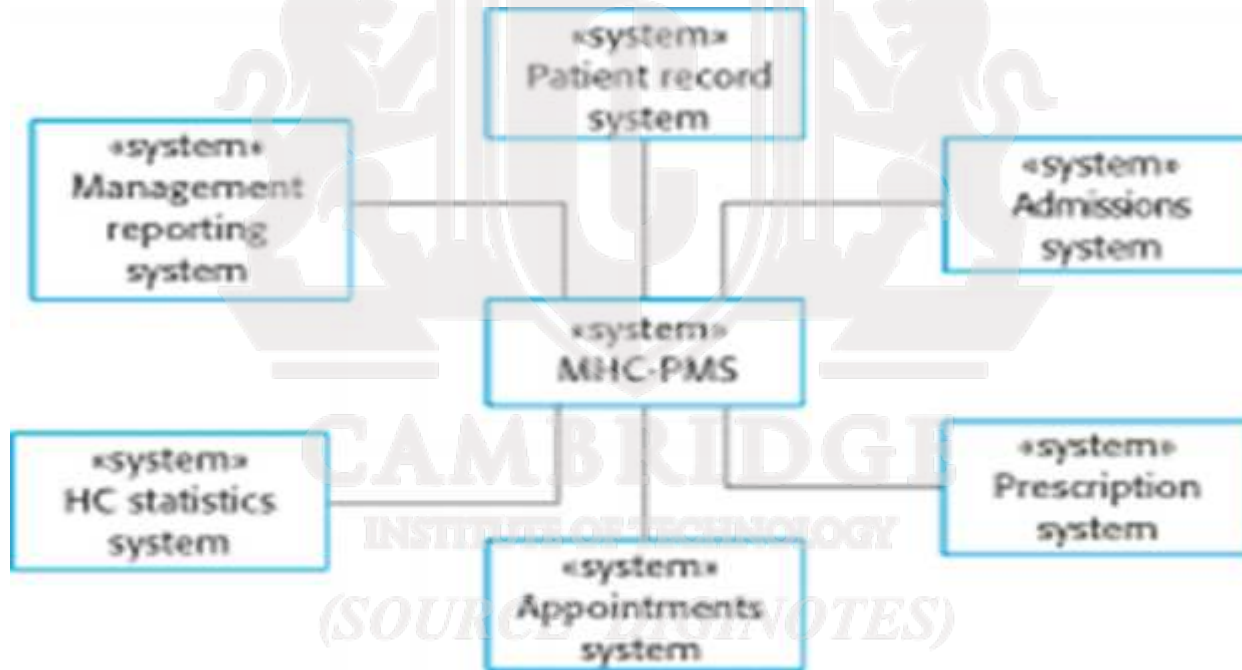
- Context models are used to illustrate the operational context of a system - they show what lies outside the system boundaries.
- Social and organisational concerns may affect the decision on where to position system boundaries.
- Architectural models show the system and its relationship with other systems.

System boundaries

- System boundaries are established to define what is inside and what is outside the system.
 - They show other systems that are used or depend on the system being developed.
- The position of the system boundary has a profound effect on the system requirements.
- Defining a system boundary is a political judgment
 - There may be pressures to develop system boundaries that increase / decrease the influence or workload of different parts of an organization.

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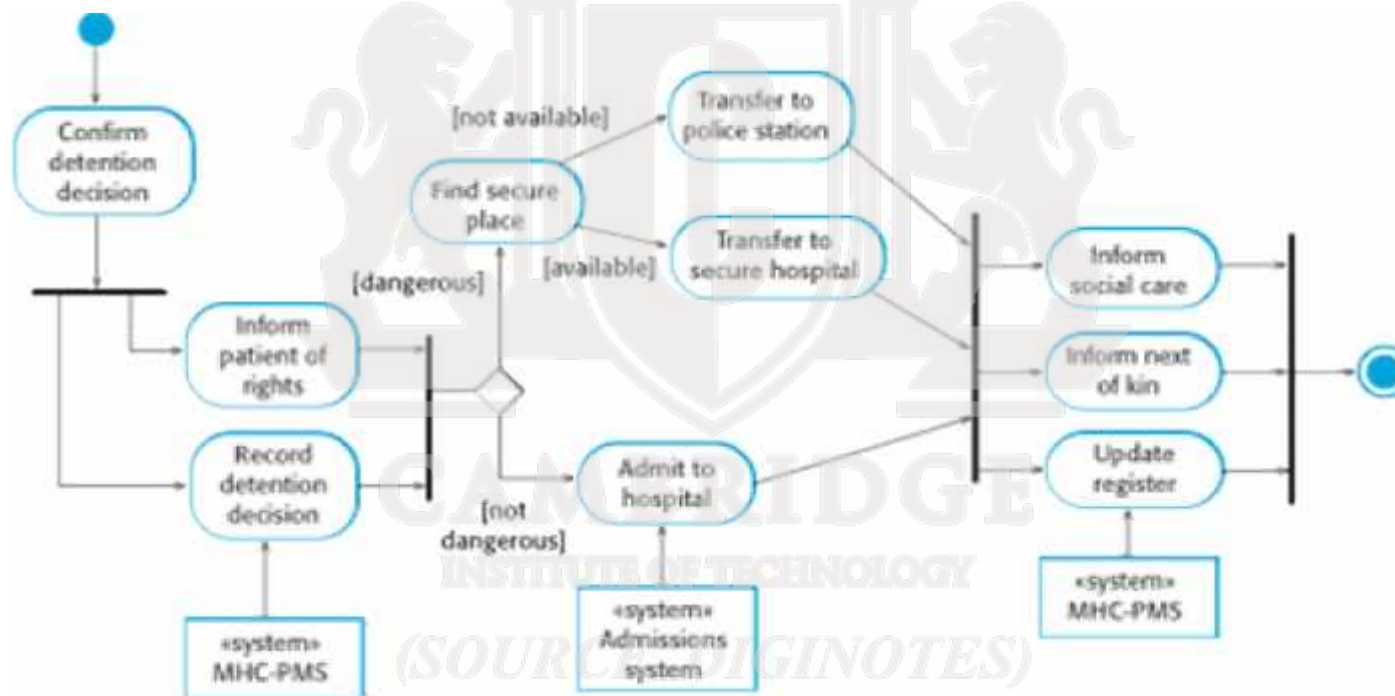
The context of the MHC-PMS



Process perspective

- Context models simply show the other systems in the environment, not how the system being developed is used in that environment.
- Process models reveal how the system being developed is used in broader business processes.
- UML activity diagrams may be used to define business process models.

Process model of involuntary detention



Interaction models

- Modeling user interaction is important as it helps to identify user requirements.
- Modeling system-to-system interaction highlights the communication problems that may arise.
- Modeling component interaction helps us understand if a proposed system structure is likely to deliver the required system performance and dependability.
- Use case diagrams and sequence diagrams may be used for interaction modeling.

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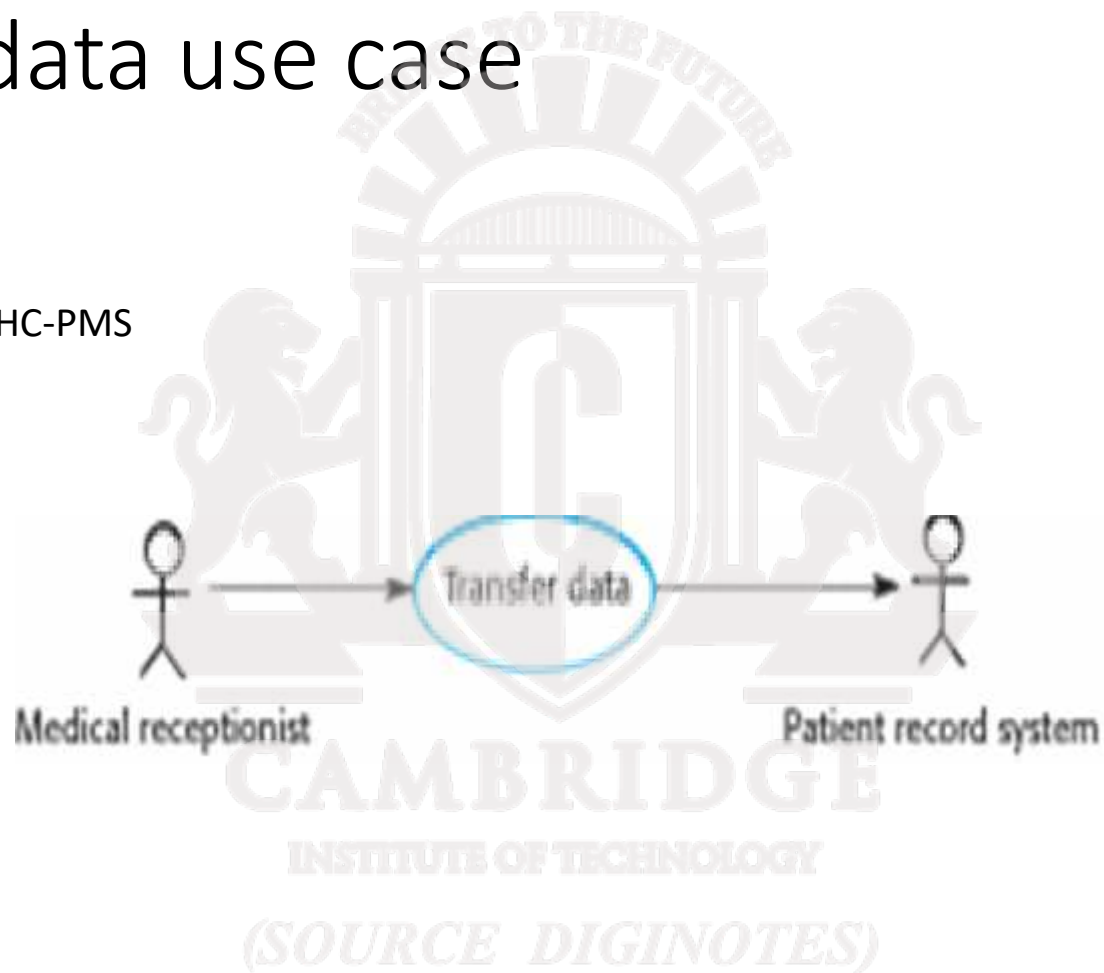
Use case modeling

- Use cases were developed originally to support requirements elicitation and now incorporated into the UML.
- Each use case represents a discrete task that involves external interaction with a system.
- Actors in a use case may be people or other systems.
- Represented diagrammatically to provide an overview of the use case and in a more detailed textual form.

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Transfer-data use case

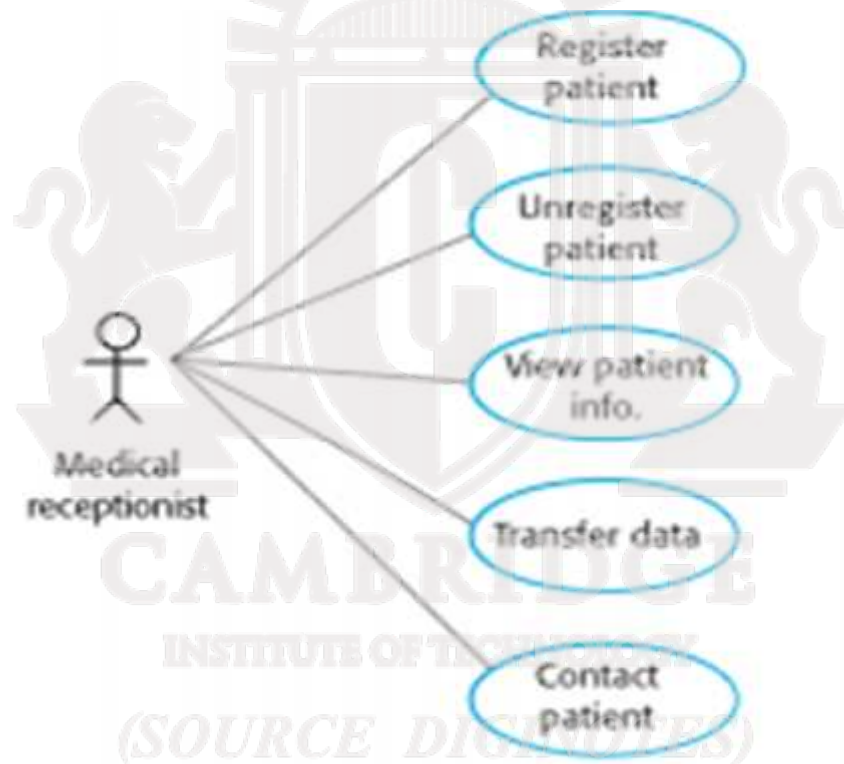
A use case in the MHC-PMS



Tabular description of the 'Transfer data' use-case

MHC-PMS: Transfer data	
Actors	Medical receptionist, patient records system (PRS)
Description	A receptionist may transfer data from the MHC-PMS to a general patient record database that is maintained by a health authority. The information transferred may either be updated personal information (address, phone number, etc.) or a summary of the patient's diagnosis and treatment.
Data	Patient's personal information, treatment summary
Stimulus	User command issued by medical receptionist
Response	Confirmation that PRS has been updated
Comments	The receptionist must have appropriate security permissions to access the patient information and the PRS.

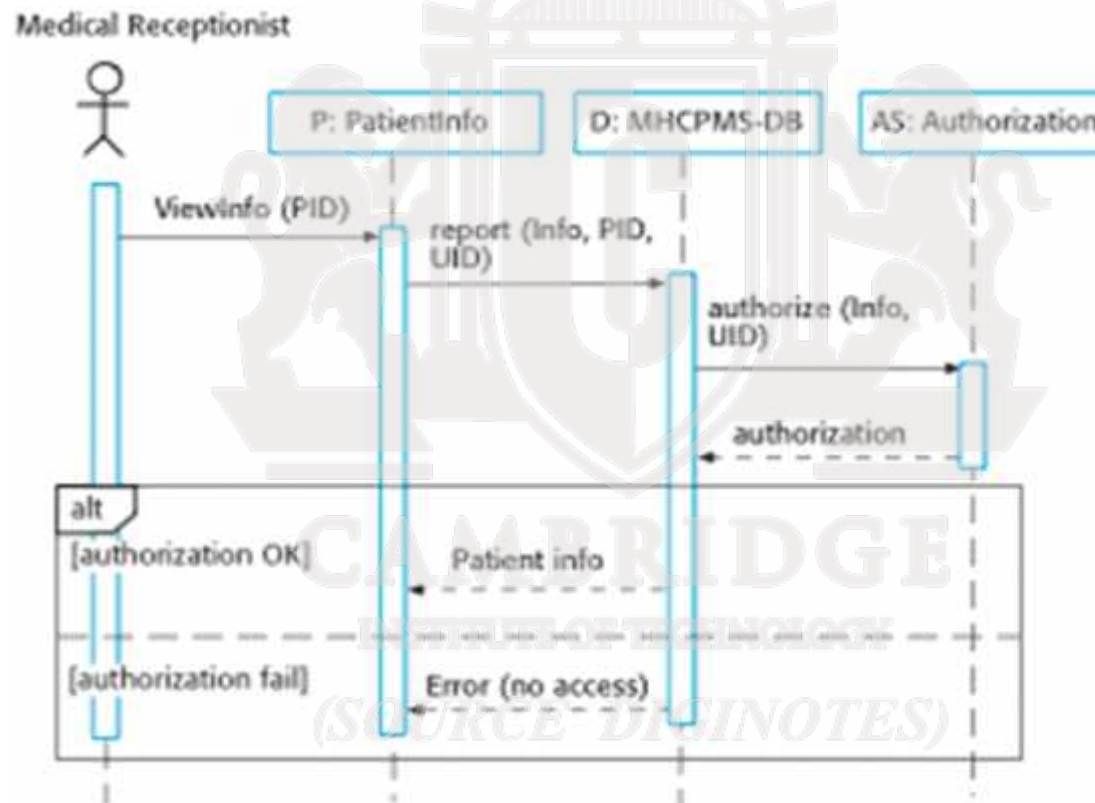
Use cases in the MHC-PMS involving the role 'Medical Receptionist'



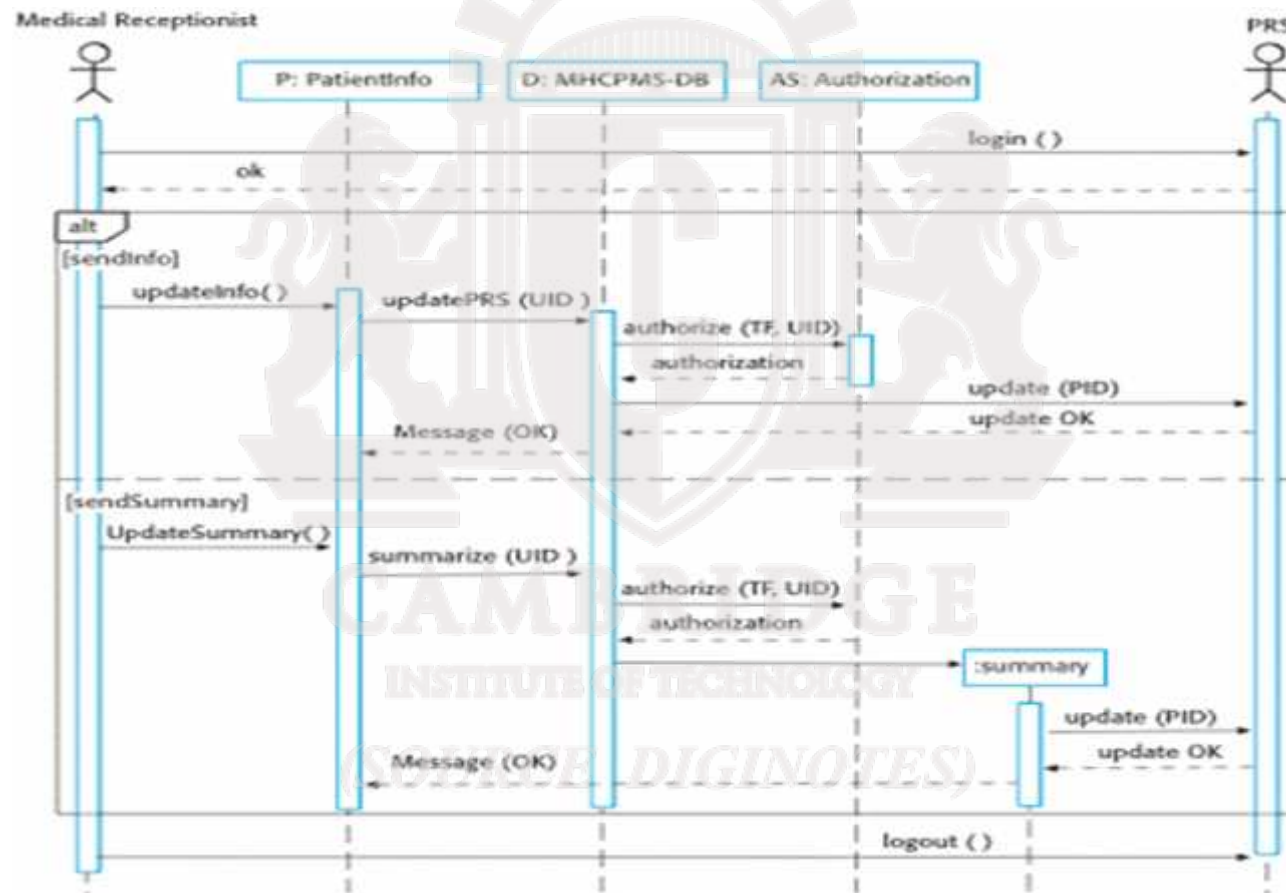
Sequence diagrams

- Sequence diagrams are part of the UML and are used to model the interactions between the actors and the objects within a system.
- A sequence diagram shows the sequence of interactions that take place during a particular use case or use case instance.
- The objects and actors involved are listed along the top of the diagram, with a dotted line drawn vertically from these.
- Interactions between objects are indicated by annotated arrows.

Sequence diagram for View patient information



Sequence diagram for Transfer Data



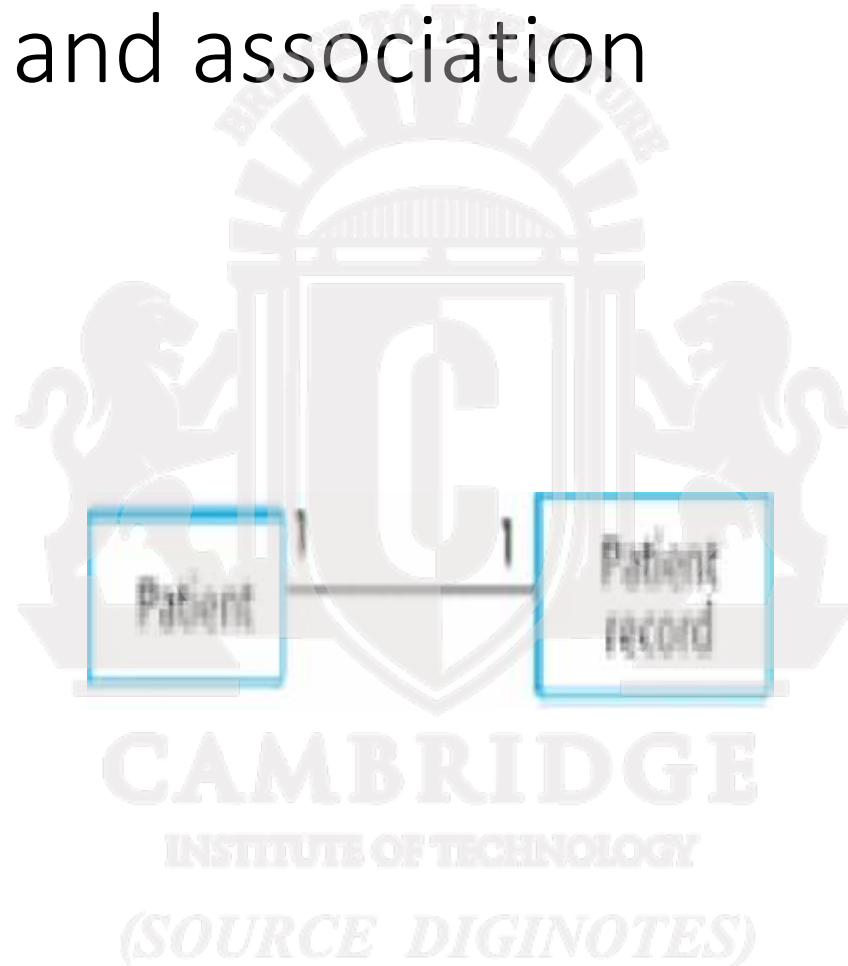
Structural models

- Structural models of software display the organization of a system in terms of the components that make up that system and their relationships.
- Structural models may be static models, which show the structure of the system design, or dynamic models, which show the organization of the system when it is executing.
- You create structural models of a system when you are discussing and designing the system architecture.

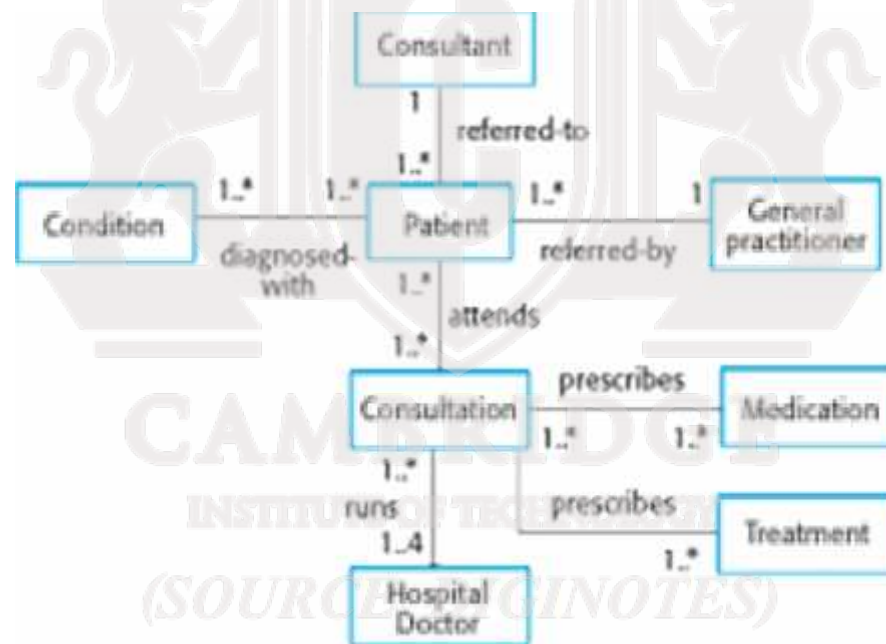
Class diagrams

- Class diagrams are used when developing an object-oriented system model to show the classes in a system and the associations between these classes.
- An object class can be thought of as a general definition of one kind of system object.
- An association is a link between classes that indicates that there is some relationship between these classes.
- When you are developing models during the early stages of the software engineering process, objects represent something in the real world, such as a patient, a prescription, doctor, etc.

UML classes and association



Classes and associations in the MHC-PMS



The Consultation class

Consultation
Doctors Date Time Clinic Reason Medication prescribed Treatment prescribed Voice notes Transcript
--- New () Prescribe () RecordNotes () Transcribe () ---

Generalization

- Generalization is an everyday technique that we use to manage complexity.
- Rather than learn the detailed characteristics of every entity that we experience, we place these entities in more general classes (animals, cars, houses, etc.) and learn the characteristics of these classes.
- This allows us to infer that different members of these classes have some common characteristics e.g. squirrels and rats are rodents.

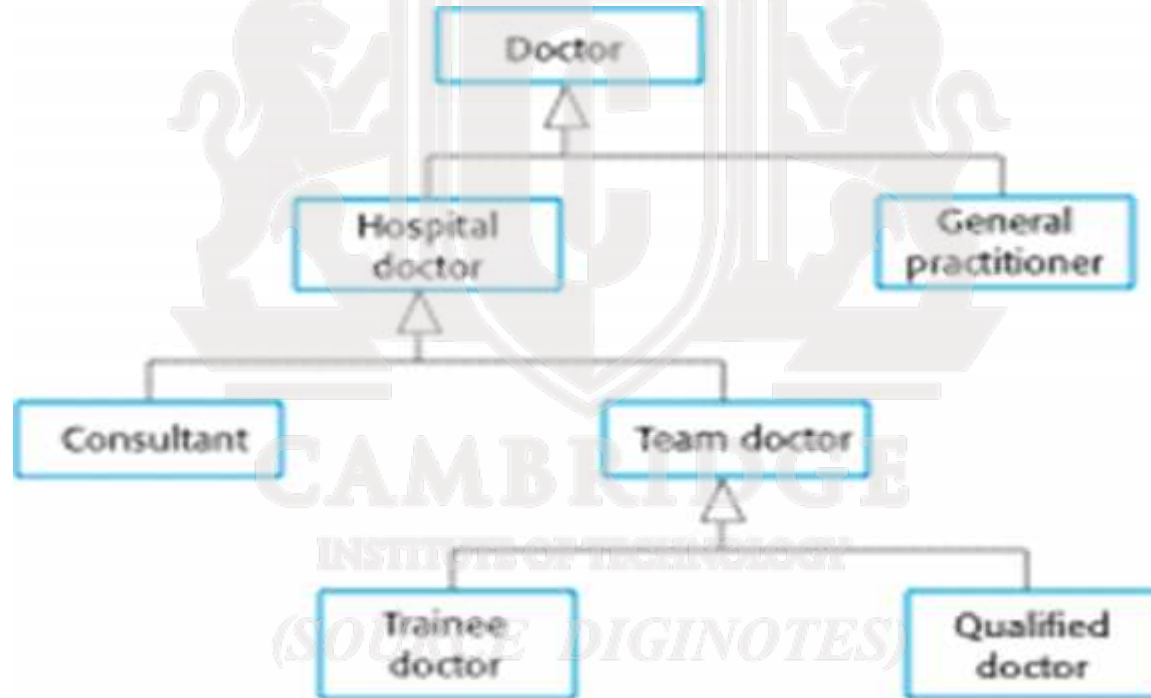
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Generalization

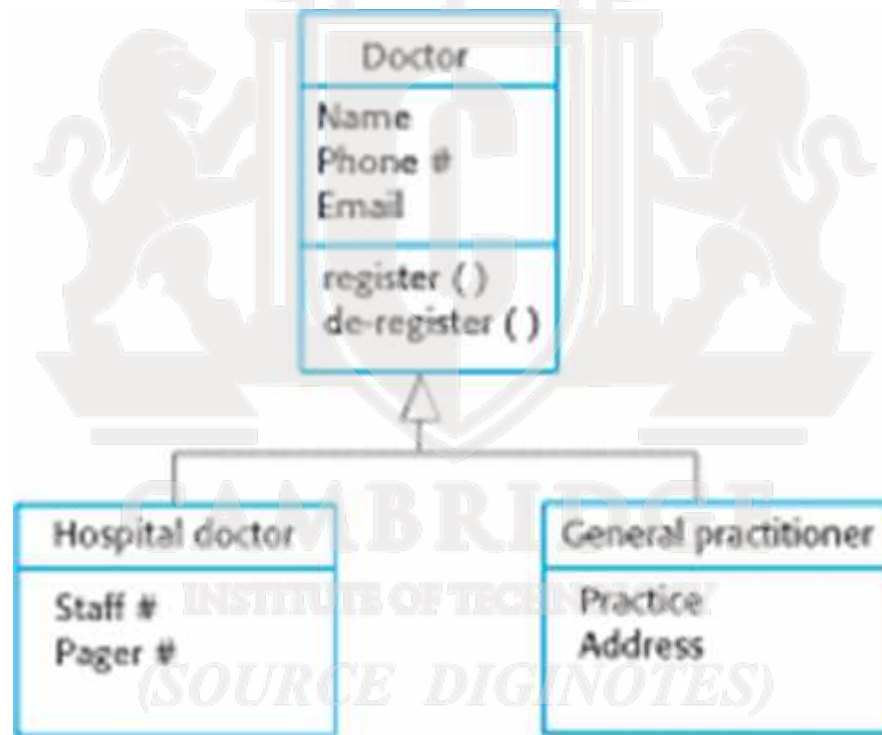
- In modeling systems, it is often useful to examine the classes in a system to see if there is scope for generalization. If changes are proposed, then you do not have to look at all classes in the system to see if they are affected by the change.
- In object-oriented languages, such as Java, generalization is implemented using the class inheritance mechanisms built into the language.
- In a generalization, the attributes and operations associated with higher-level classes are also associated with the lower-level classes.
- The lower-level classes are subclasses inherit the attributes and operations from their superclasses. These lower-level classes then add more specific attributes and operations.

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A generalization hierarchy

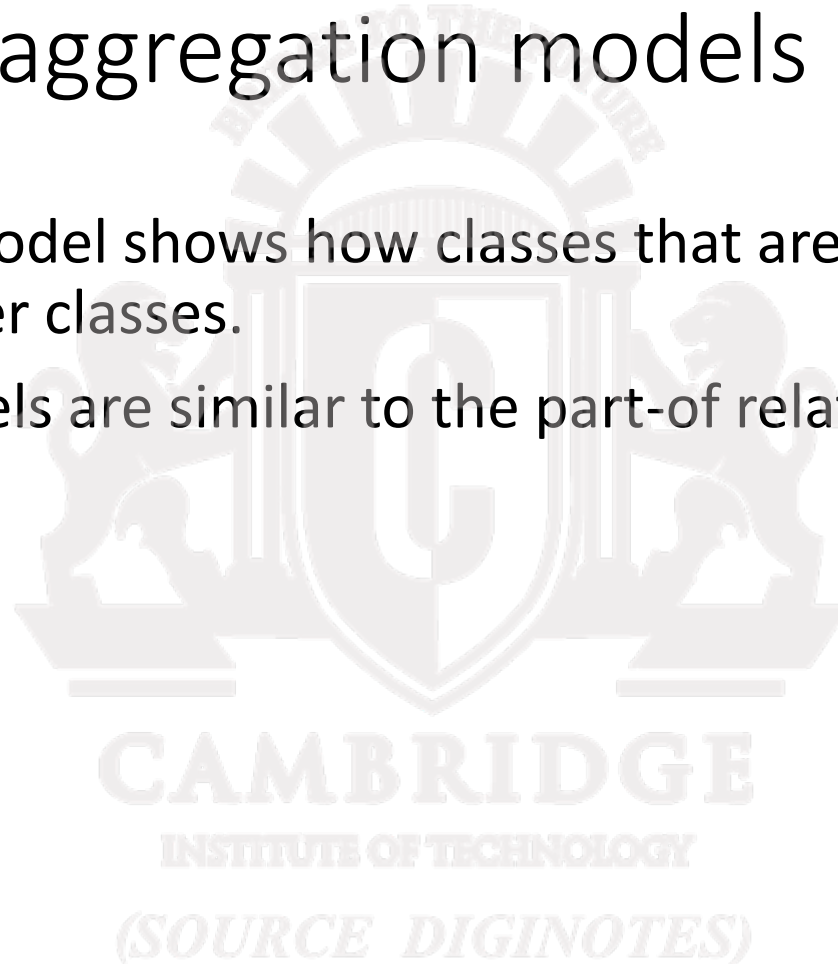


A generalization hierarchy with added detail

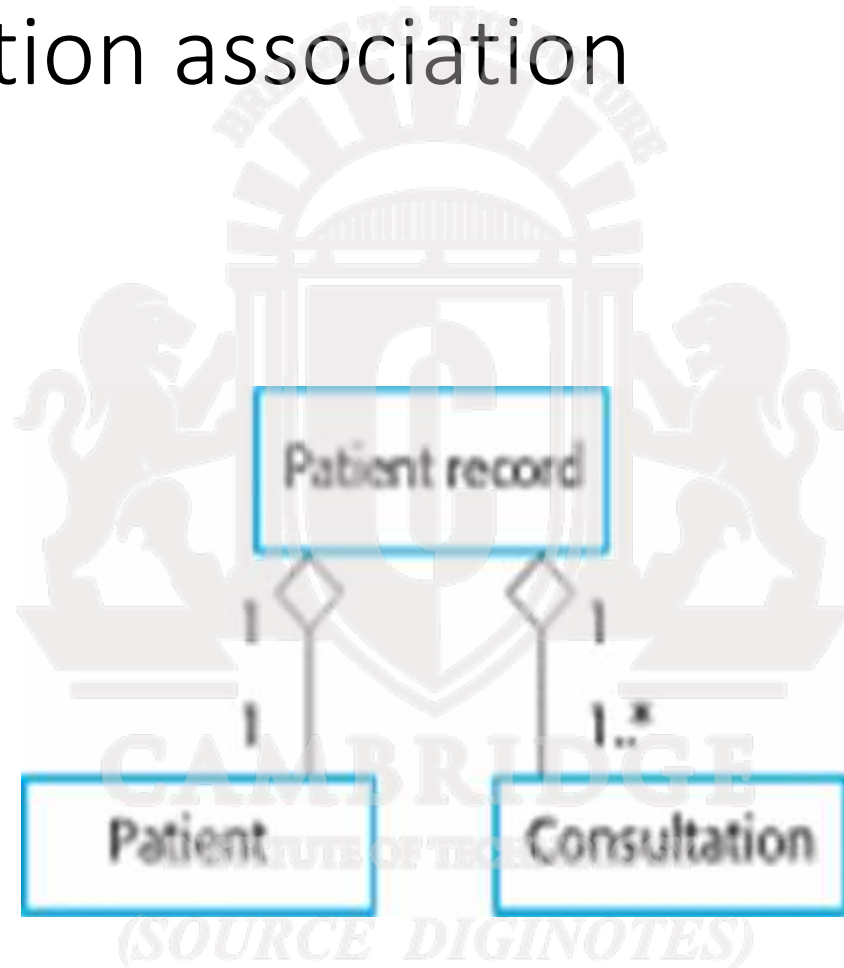


Object class aggregation models

- An aggregation model shows how classes that are collections are composed of other classes.
- Aggregation models are similar to the part-of relationship in semantic data models.



The aggregation association



Behavioral models

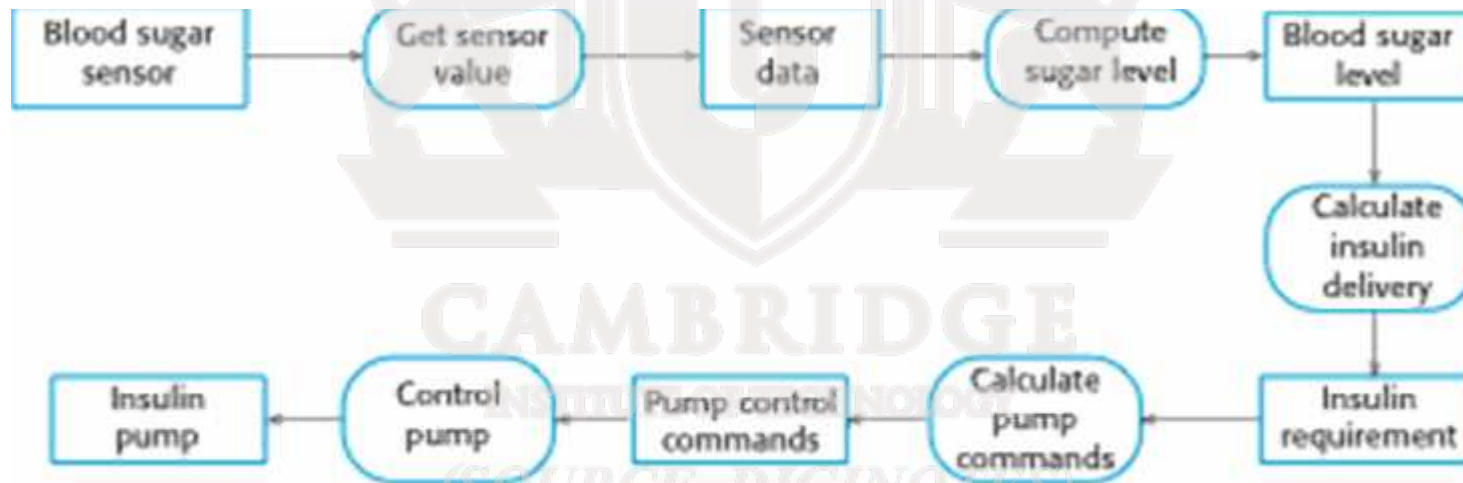
- Behavioral models are models of the dynamic behavior of a system as it is executing. They show what happens or what is supposed to happen when a system responds to a stimulus from its environment.
- You can think of these stimuli as being of two types:
 - **Data** Some data arrives that has to be processed by the system.
 - **Events** Some event happens that triggers system processing. Events may have associated data, although this is not always the case.

Data-driven modeling

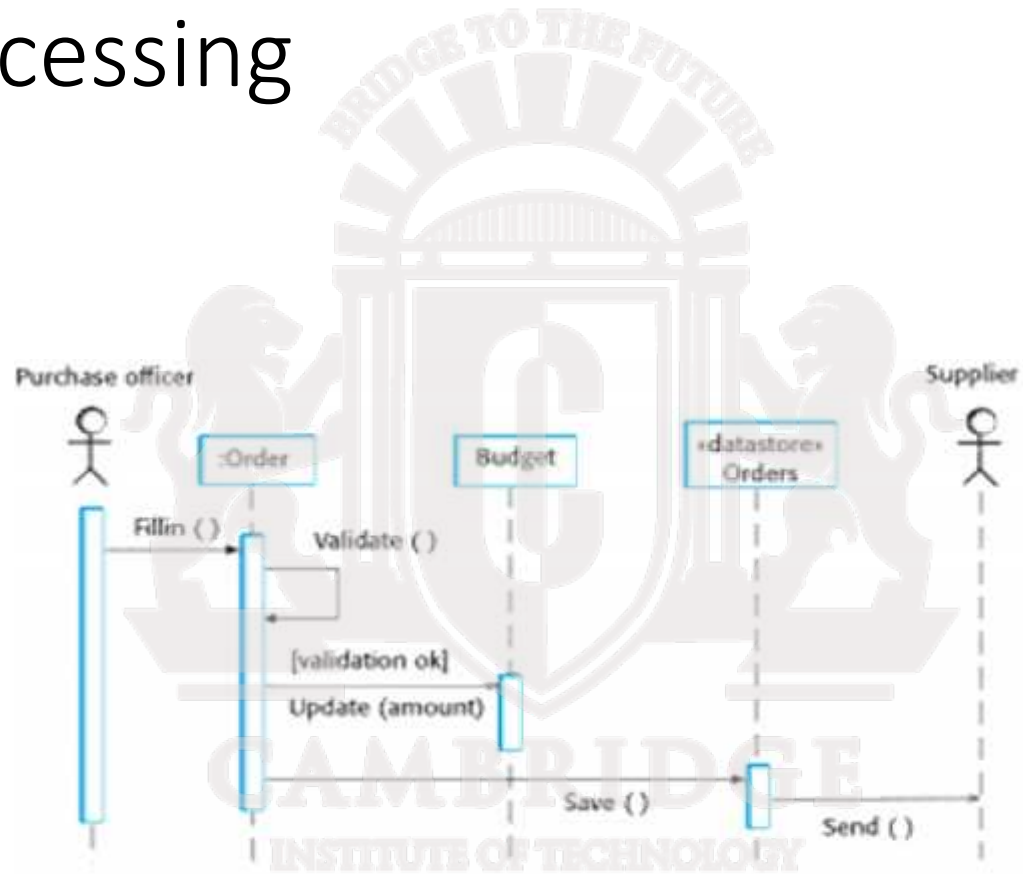
- Many business systems are data-processing systems that are primarily driven by data. They are controlled by the data input to the system, with relatively little external event processing.
- Data-driven models show the sequence of actions involved in processing input data and generating an associated output.
- They are particularly useful during the analysis of requirements as they can be used to show end-to-end processing in a system.

(SOURCE DIGINOTES)

An activity model of the insulin pump's operation



Order processing



(SOURCE DIGINOTES)

Event-driven modeling

- Real-time systems are often event-driven, with minimal data processing. For example, a landline phone switching system responds to events such as 'receiver off hook' by generating a dial tone.
- Event-driven modeling shows how a system responds to external and internal events.
- It is based on the assumption that a system has a finite number of states and that events (stimuli) may cause a transition from one state to another.

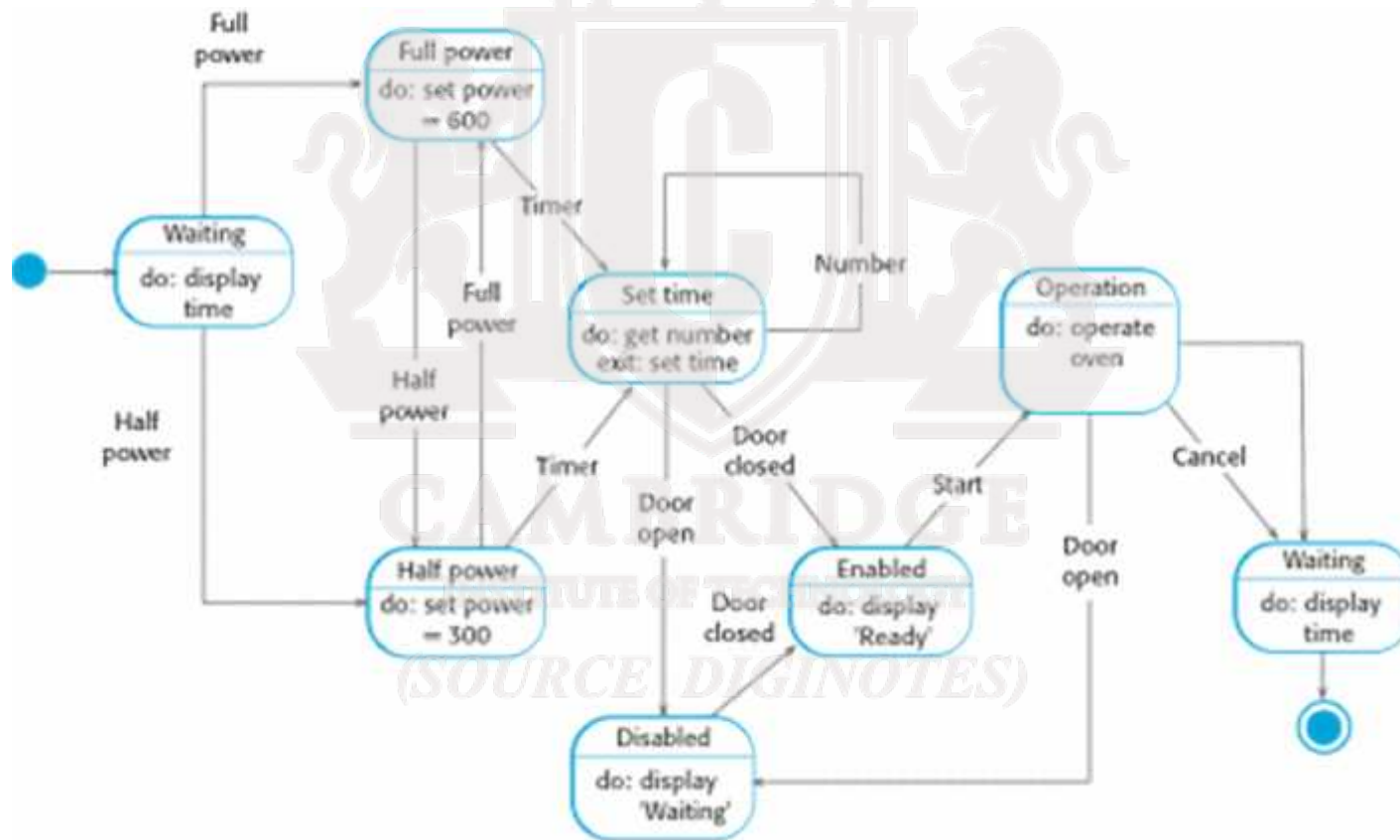
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State machine models

- These model the behaviour of the system in response to external and internal events.
- They show the system's responses to stimuli so are often used for modelling real-time systems.
- State machine models show system states as nodes and events as arcs between these nodes. When an event occurs, the system moves from one state to another.
- Statecharts are an integral part of the UML and are used to represent state machine models.

(SOURCE DIGINOTES)

State diagram of a microwave oven



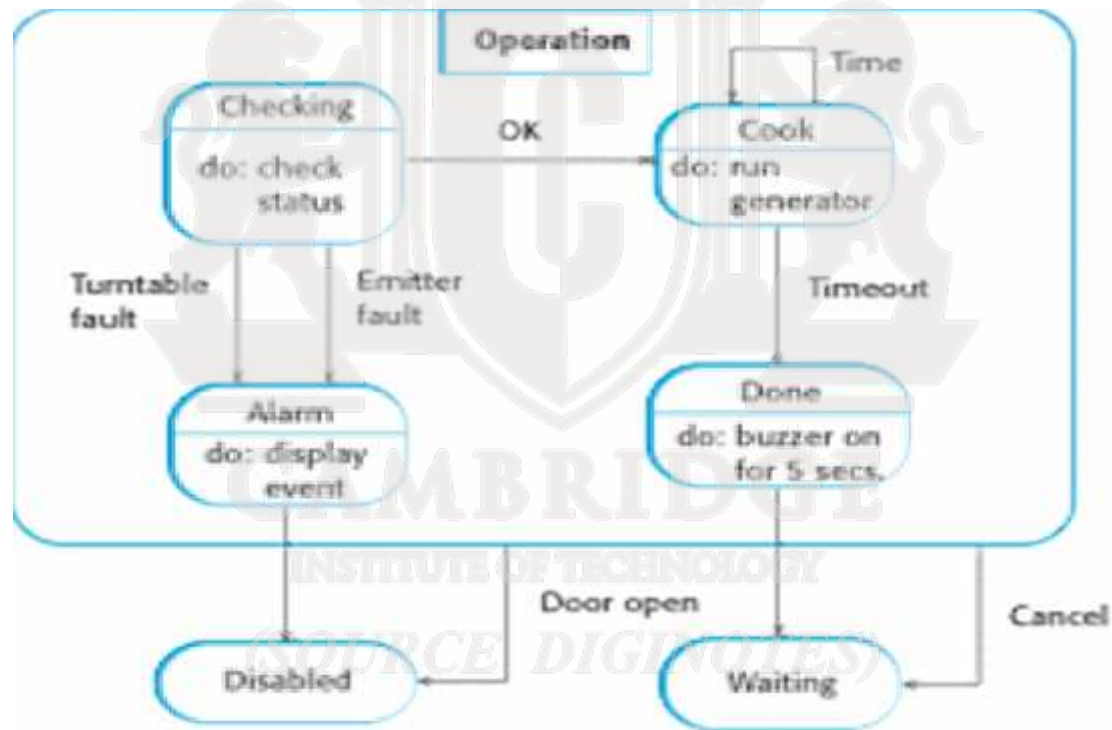
States and stimuli for the microwave oven (a)

State	Description
Waiting	The oven is waiting for input. The display shows the current time.
Half power	The oven power is set to 300 watts. The display shows 'Half power'.
Full power	The oven power is set to 600 watts. The display shows 'Full power'.
Set time	The cooking time is set to the user's input value. The display shows the cooking time selected and is updated as the time is set.
Disabled	Oven operation is disabled for safety. Interior oven light is on. Display shows 'Not ready'.
Enabled	Oven operation is enabled. Interior oven light is off. Display shows 'Ready to cook'.
Operation	Oven in operation. Interior oven light is on. Display shows the timer countdown. On completion of cooking, the buzzer is sounded for five seconds. Oven light is on. Display shows 'Cooking complete' while buzzer is sounding.

States and stimuli for the microwave oven (b)

Stimulus	Description
Half power	The user has pressed the half-power button.
Full power	The user has pressed the full-power button.
Timer	The user has pressed one of the timer buttons.
Number	The user has pressed a numeric key.
Door open	The oven door switch is not closed.
Door closed	The oven door switch is closed.
Start	The user has pressed the Start button.
Cancel	The user has pressed the Cancel button.

Microwave oven operation



Model-driven engineering

- Model-driven engineering (MDE) is an approach to software development where models rather than programs are the principal outputs of the development process.
- The programs that execute on a hardware/software platform are then generated automatically from the models.
- Proponents of MDE argue that this raises the level of abstraction in software engineering so that engineers no longer have to be concerned with programming language details or the specifics of execution platforms.

(SOURCE DIGINOTES)

Usage of model-driven engineering

- Model-driven engineering is still at an early stage of development, and it is unclear whether or not it will have a significant effect on software engineering practice.
- Pros
 - Allows systems to be considered at higher levels of abstraction
 - Generating code automatically means that it is cheaper to adapt systems to new platforms.
- Cons
 - Models for abstraction and not necessarily right for implementation.
 - Savings from generating code may be outweighed by the costs of developing translators for new platforms.

Model driven architecture

- Model-driven architecture (MDA) was the precursor of more general model-driven engineering
- MDA is a model-focused approach to software design and implementation that uses a subset of UML models to describe a system.
- Models at different levels of abstraction are created. From a high-level, platform independent model, it is possible, in principle, to generate a working program without manual intervention.

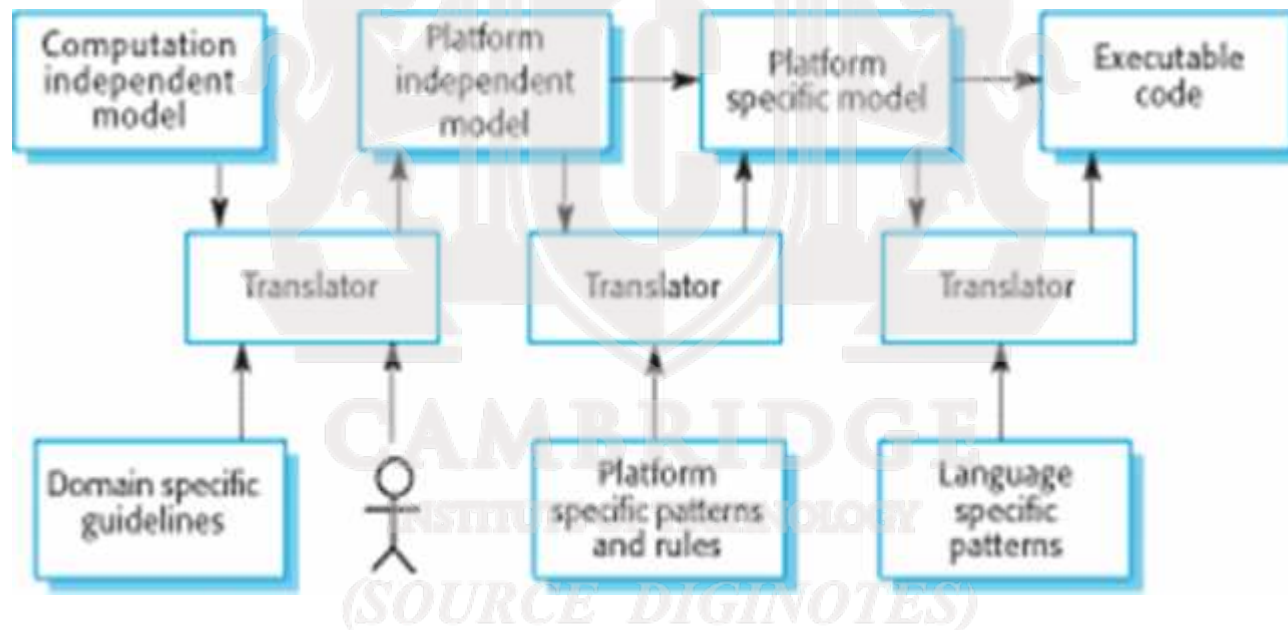
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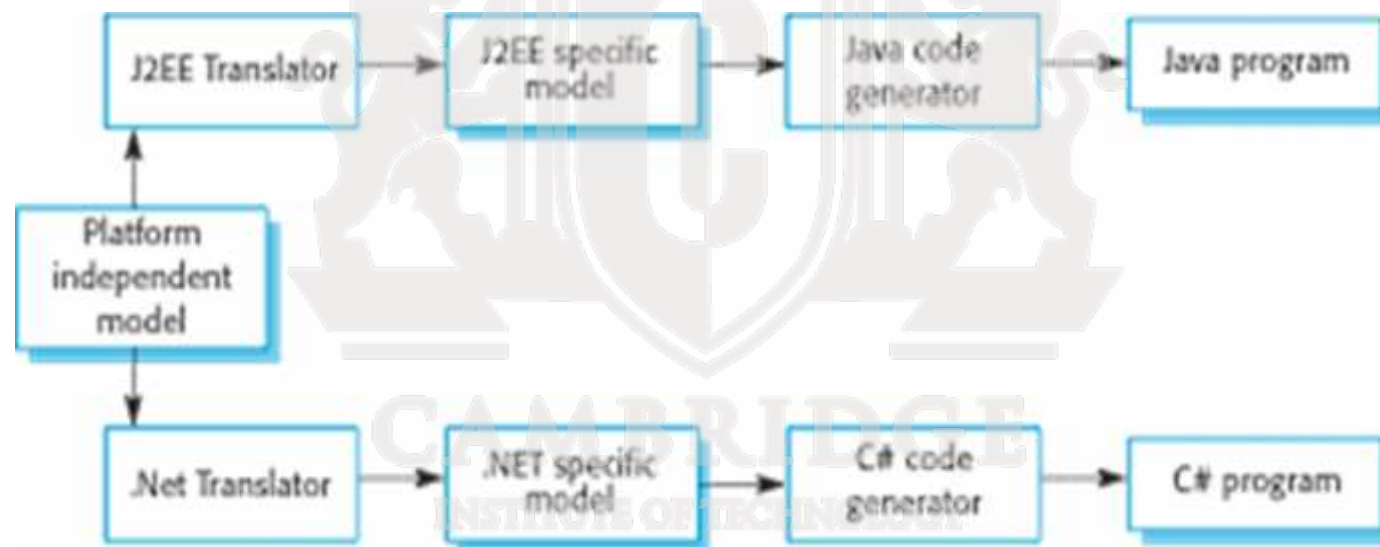
Types of model

- A computation independent model (CIM)
 - These model the important domain abstractions used in a system. CIMs are sometimes called domain models.
- A platform independent model (PIM)
 - These model the operation of the system without reference to its implementation. The PIM is usually described using UML models that show the static system structure and how it responds to external and internal events.
- *Platform specific models (PSM)*
 - These are transformations of the platform-independent model with a separate PSM for each application platform. In principle, there may be layers of PSM, with each layer adding some platform-specific detail.

MDA transformations



Multiple platform-specific models



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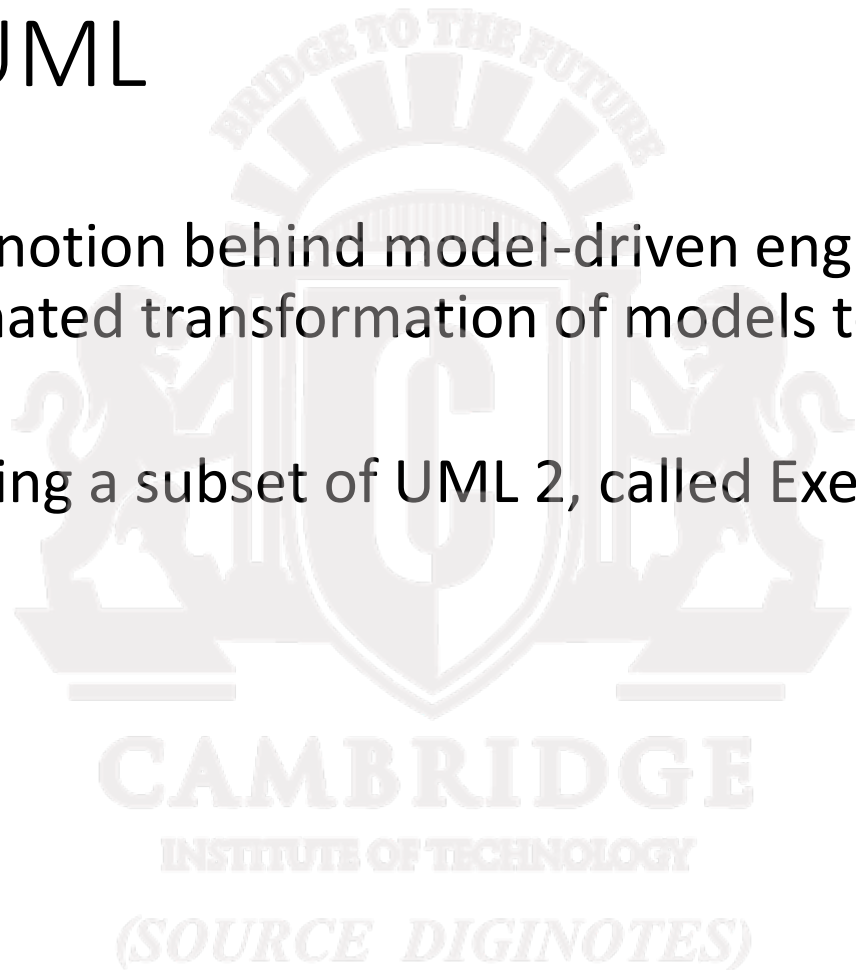
Agile methods and MDA

- The developers of MDA claim that it is intended to support an iterative approach to development and so can be used within agile methods.
- The notion of extensive up-front modeling contradicts the fundamental ideas in the agile manifesto and I suspect that few agile developers feel comfortable with model-driven engineering.
- If transformations can be completely automated and a complete program generated from a PIM, then, in principle, MDA could be used in an agile development process as no separate coding would be required.

(SOURCE DIGINOTES)

Executable UML

- The fundamental notion behind model-driven engineering is that completely automated transformation of models to code should be possible.
- This is possible using a subset of UML 2, called Executable UML or xUML.



Features of executable UML

- To create an executable subset of UML, the number of model types has therefore been dramatically reduced to these 3 key types:
 - Domain models that identify the principal concerns in a system. They are defined using UML class diagrams and include objects, attributes and associations.
 - Class models in which classes are defined, along with their attributes and operations.
 - State models in which a state diagram is associated with each class and is used to describe the life cycle of the class.
- The dynamic behavior of the system may be specified declaratively using the object constraint language (OCL), or may be expressed using UML's action language.

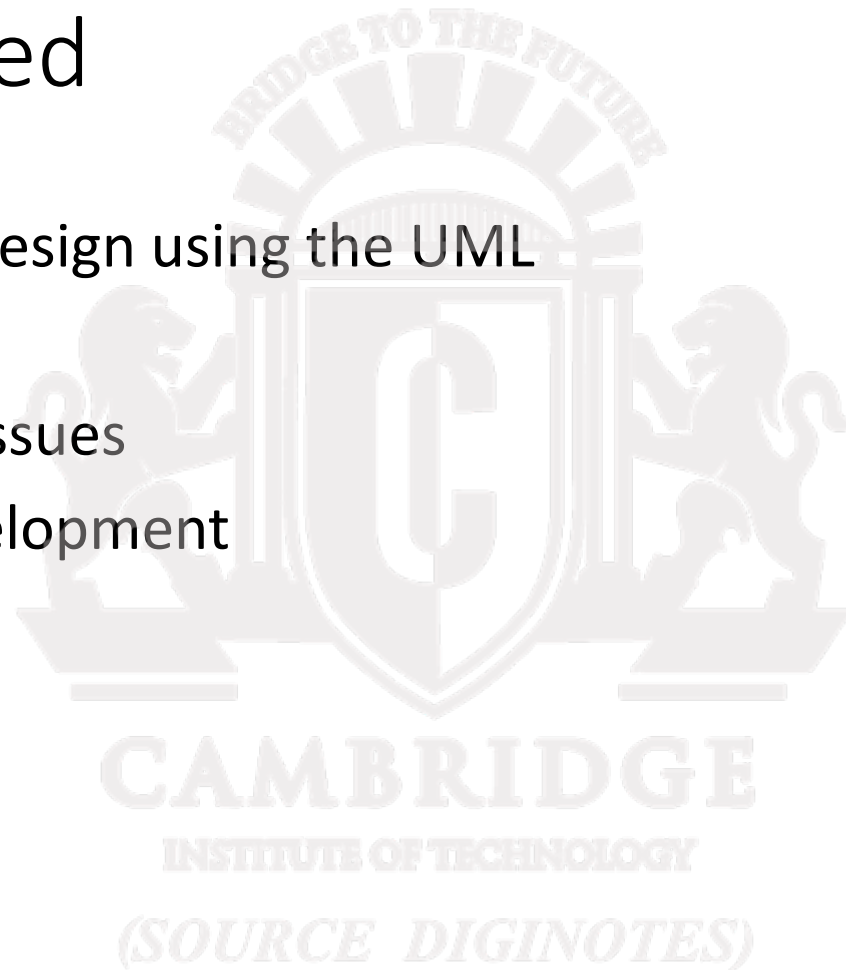
Chapter 7 – Design and Implementation



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Topics covered

- Object-oriented design using the UML
- Design patterns
- Implementation issues
- Open source development



Design and implementation

- Software design and implementation is the stage in the software engineering process at which an executable software system is developed.
- Software design and implementation activities are invariably interleaved.
 - Software design is a creative activity in which you identify software components and their relationships, based on a customer's requirements.
 - Implementation is the process of realizing the design as a program.

Build or buy

- In a wide range of domains, it is now possible to buy off-the-shelf systems (COTS) that can be adapted and tailored to the users' requirements.
 - For example, if you want to implement a medical records system, you can buy a package that is already used in hospitals. It can be cheaper and faster to use this approach rather than developing a system in a conventional programming language.
- When you develop an application in this way, the design process becomes concerned with how to use the configuration features of that system to deliver the system requirements.

(SOURCE DIGINOTES)

An object-oriented design process

- Structured object-oriented design processes involve developing a number of different system models.
- They require a lot of effort for development and maintenance of these models and, for small systems, this may not be cost-effective.
- However, for large systems developed by different groups design models are an important communication mechanism.

Process stages

- There are a variety of different object-oriented design processes that depend on the organization using the process.
- Common activities in these processes include:
 - Define the context and modes of use of the system;
 - Design the system architecture;
 - Identify the principal system objects;
 - Develop design models;
 - Specify object interfaces.
- Process illustrated here using a design for a wilderness weather station.

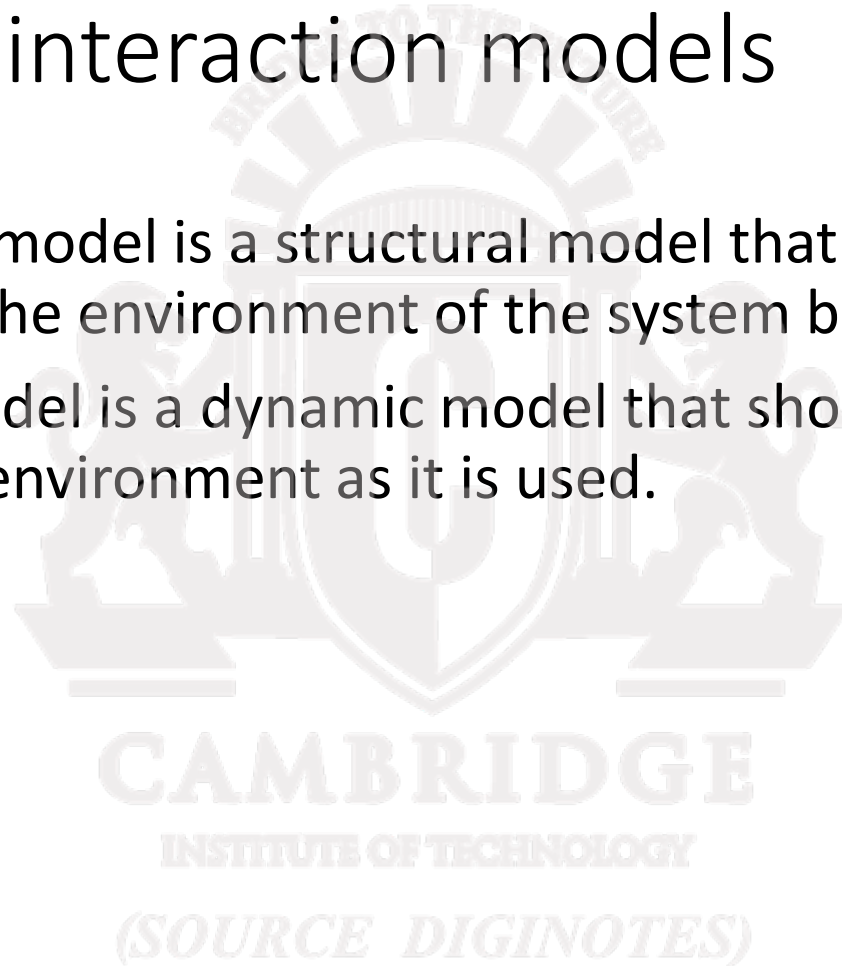
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System context and interactions

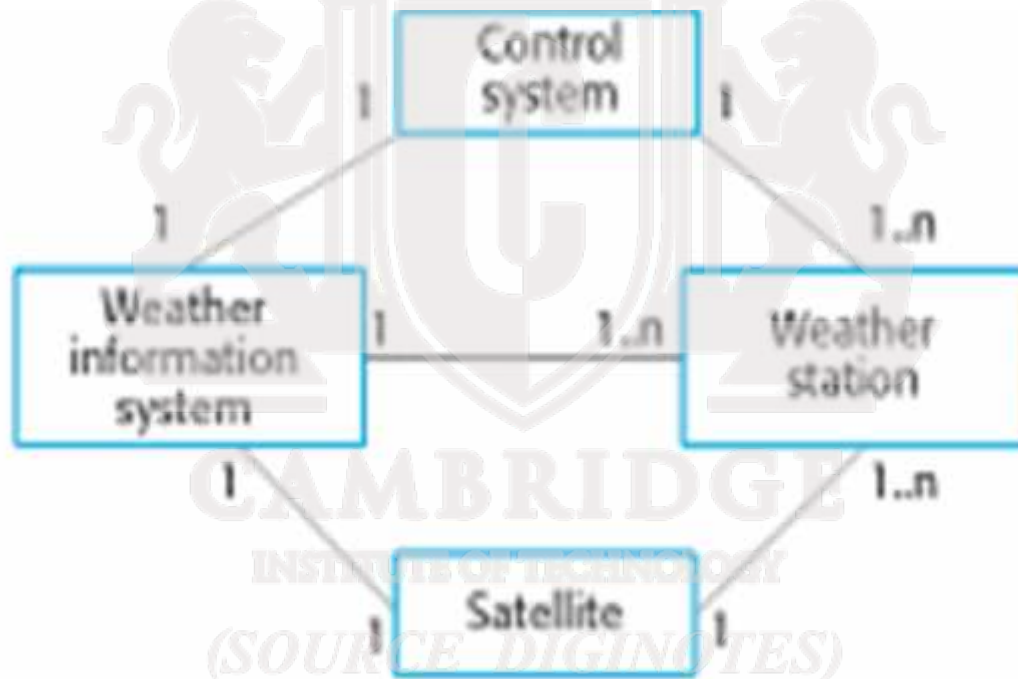
- Understanding the relationships between the software that is being designed and its external environment is essential for deciding how to provide the required system functionality and how to structure the system to communicate with its environment.
- Understanding of the context also lets you establish the boundaries of the system. Setting the system boundaries helps you decide what features are implemented in the system being designed and what features are in other associated systems.

Context and interaction models

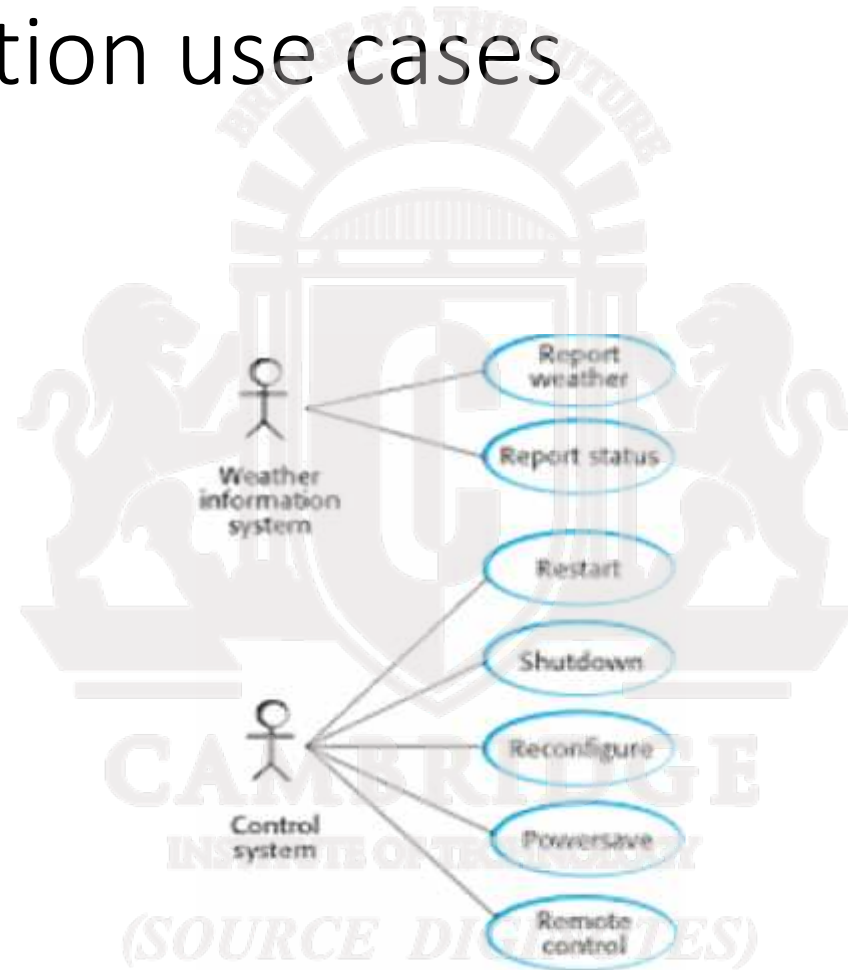
- A system context model is a structural model that demonstrates the other systems in the environment of the system being developed.
- An interaction model is a dynamic model that shows how the system interacts with its environment as it is used.



System context for the weather station



Weather station use cases



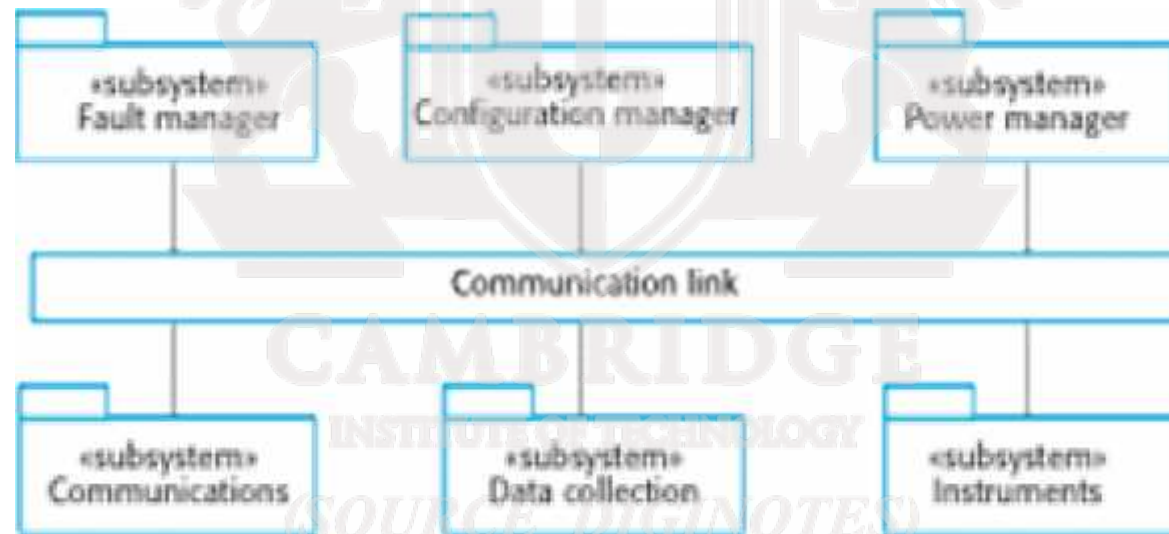
Use case description—Report weather

System	Weather station
Use case	Report weather
Actors	Weather information system, Weather station
Description	The weather station sends a summary of the weather data that has been collected from the instruments in the collection period to the weather information system. The data sent are the maximum, minimum, and average ground and air temperatures; the maximum, minimum, and average air pressures; the maximum, minimum, and average wind speeds; the total rainfall; and the wind direction as sampled at five-minute intervals.
Stimulus	The weather information system establishes a satellite communication link with the weather station and requests transmission of the data.
Response	The summarized data is sent to the weather information system.
Comments	Weather stations are usually asked to report once per hour but this frequency may differ from one station to another and may be modified in the future.

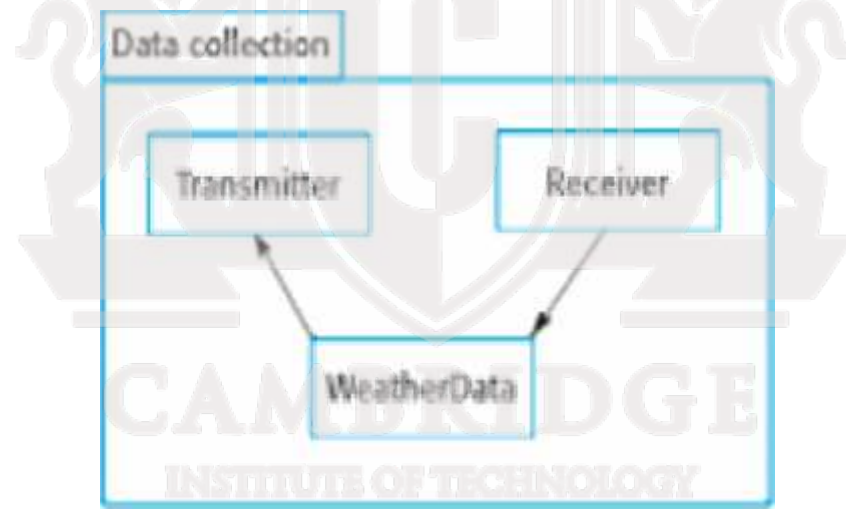
Architectural design

- Once interactions between the system and its environment have been understood, you use this information for designing the system architecture.
- You identify the major components that make up the system and their interactions, and then may organize the components using an architectural pattern such as a layered or client-server model.
- The weather station is composed of independent subsystems that communicate by broadcasting messages on a common infrastructure.

High-level architecture of the weather station



Architecture of data collection system



(SOURCE DIGINOTES)

Object class identification

- Identifying object classes is often a difficult part of object oriented design.
- There is no 'magic formula' for object identification. It relies on the skill, experience and domain knowledge of system designers.
- Object identification is an iterative process. You are unlikely to get it right first time.

Approaches to identification

- Use a grammatical approach based on a natural language description of the system (used in Hood OOD method).
- Base the identification on tangible things in the application domain.
- Use a behavioural approach and identify objects based on what participates in what behaviour.
- Use a scenario-based analysis. The objects, attributes and methods in each scenario are identified.

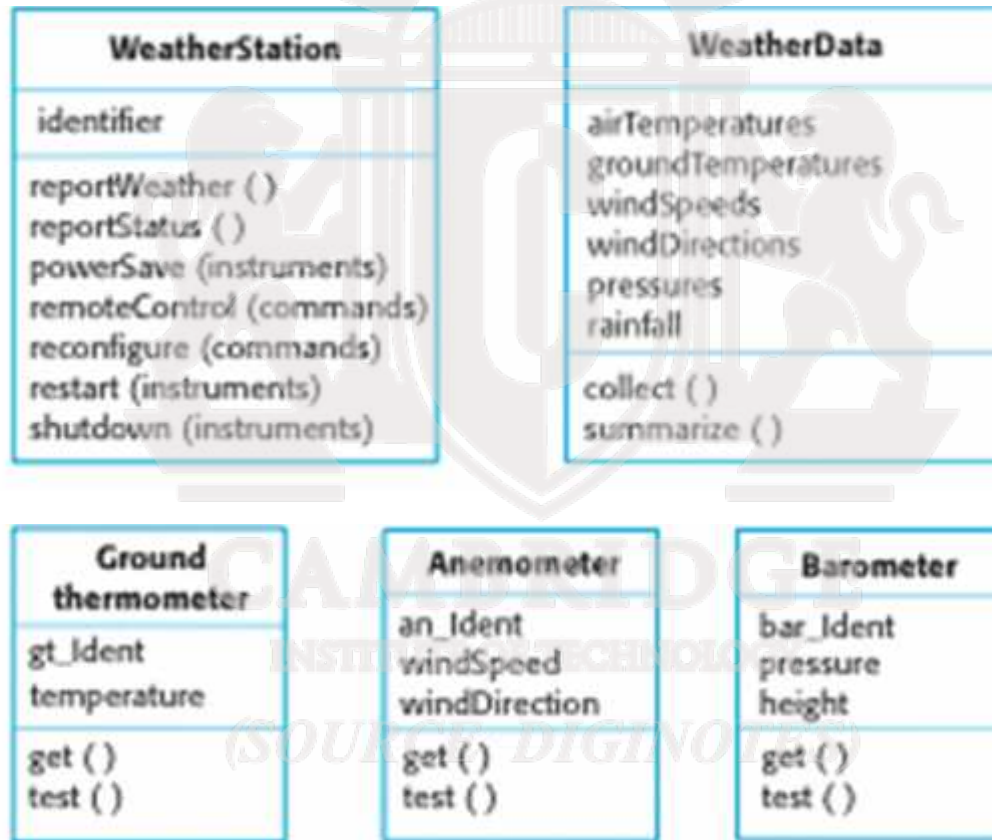
Weather station description

- A **weather station** is a package of software controlled instruments which collects data, performs some data processing and transmits this data for further processing. The instruments include air and ground thermometers, an anemometer, a wind vane, a barometer and a rain gauge. Data is collected periodically.
- When a command is issued to transmit the weather data, the weather station processes and summarises the collected data. The summarised data is transmitted to the mapping computer when a request is received. *(SOURCE DIGINOTES)*

Weather station object classes

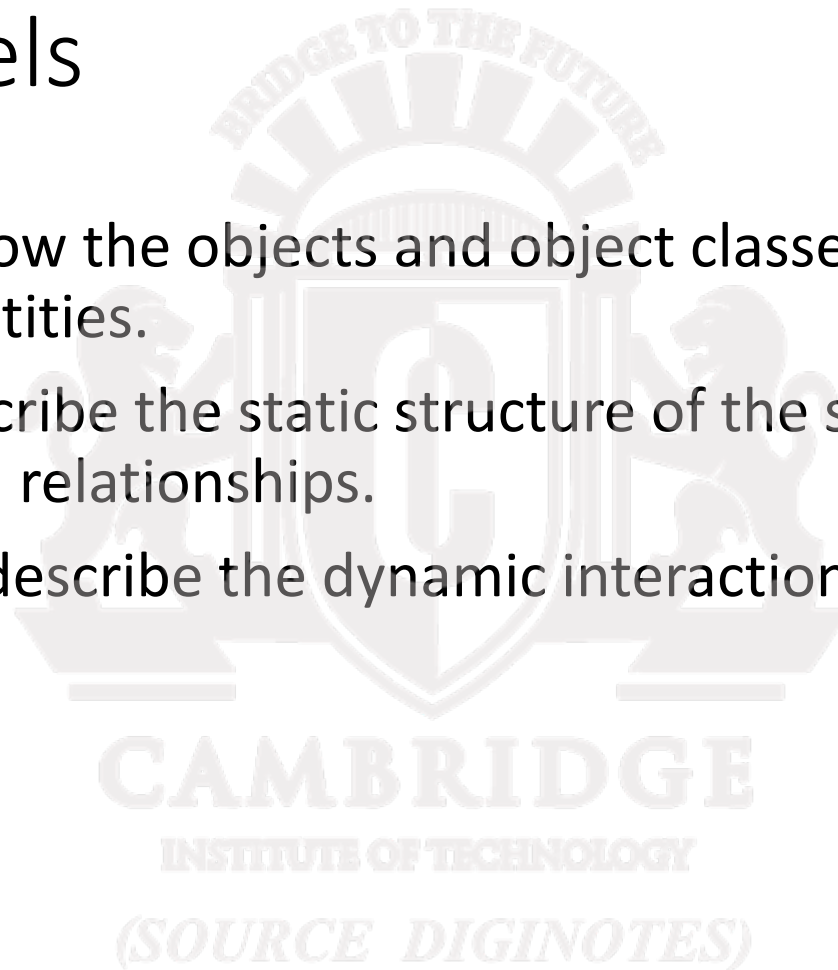
- Object class identification in the weather station system may be based on the tangible hardware and data in the system:
 - Ground thermometer, Anemometer, Barometer
 - Application domain objects that are 'hardware' objects related to the instruments in the system.
 - Weather station
 - The basic interface of the weather station to its environment. It therefore reflects the interactions identified in the use-case model.
 - Weather data
 - Encapsulates the summarized data from the instruments.

Weather station object classes



Design models

- Design models show the objects and object classes and relationships between these entities.
- Static models describe the static structure of the system in terms of object classes and relationships.
- Dynamic models describe the dynamic interactions between objects.

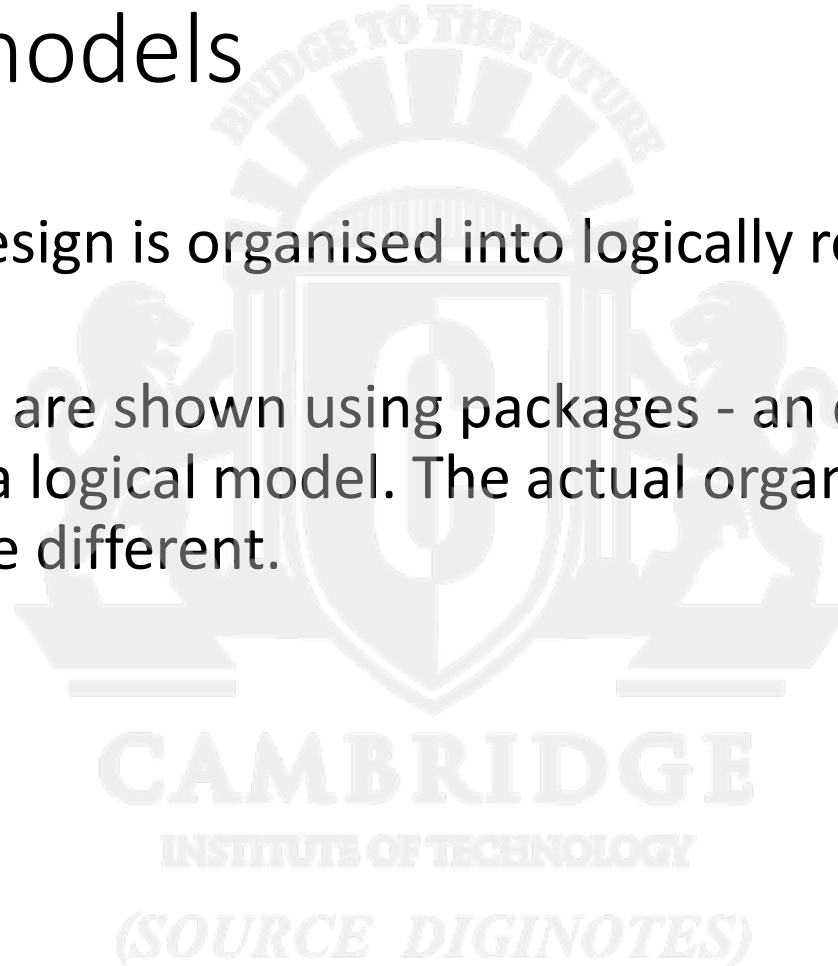


Examples of design models

- Subsystem models that show logical groupings of objects into coherent subsystems.
- Sequence models that show the sequence of object interactions.
- State machine models that show how individual objects change their state in response to events.
- Other models include use-case models, aggregation models, generalisation models, etc.

Subsystem models

- Shows how the design is organised into logically related groups of objects.
- In the UML, these are shown using packages - an encapsulation construct. This is a logical model. The actual organisation of objects in the system may be different.

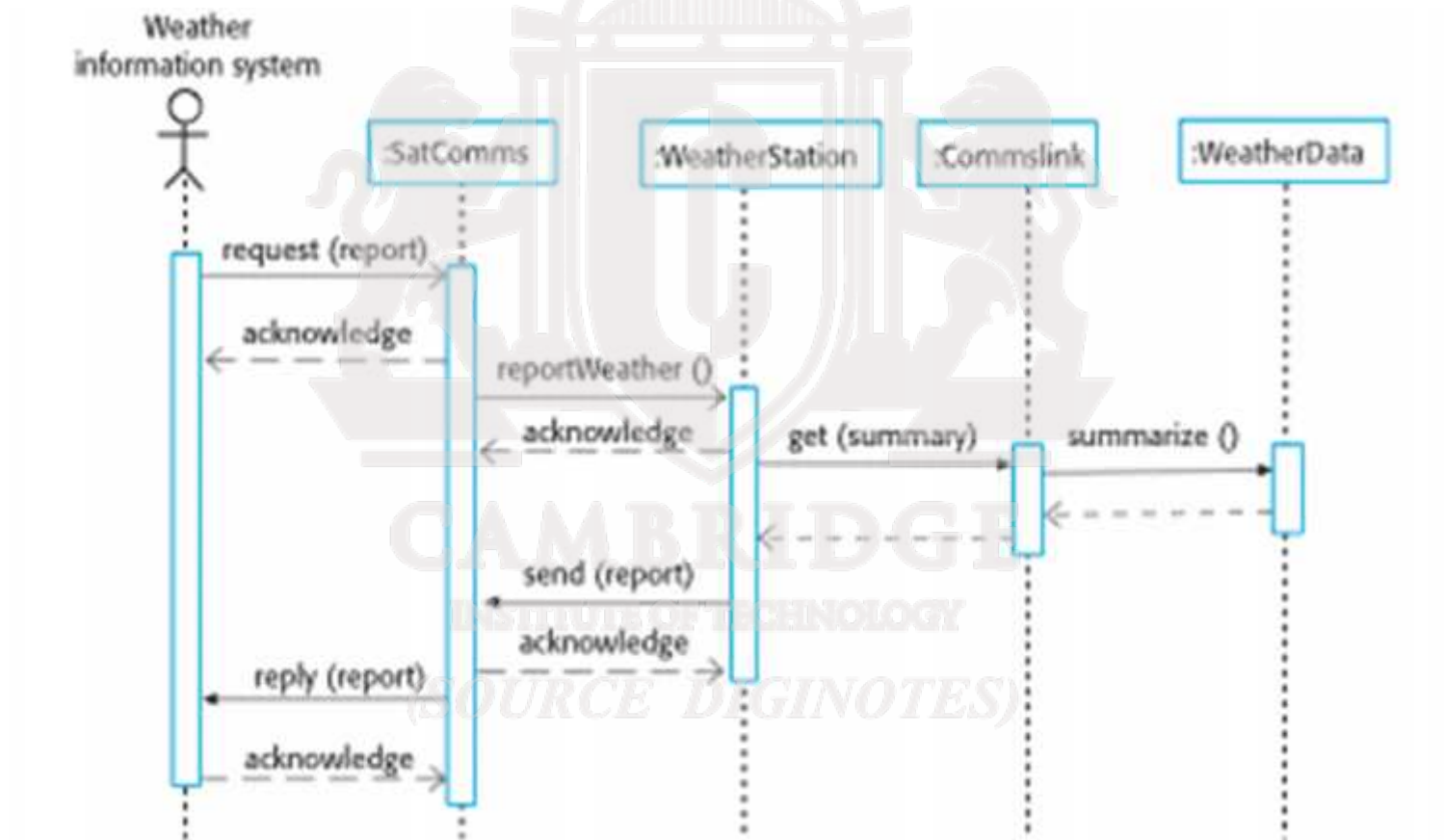


Sequence models

- Sequence models show the sequence of object interactions that take place
 - Objects are arranged horizontally across the top;
 - Time is represented vertically so models are read top to bottom;
 - Interactions are represented by labelled arrows, Different styles of arrow represent different types of interaction;
 - A thin rectangle in an object lifeline represents the time when the object is the controlling object in the system.

(SOURCE DIGINOTES)

Sequence diagram describing data collection

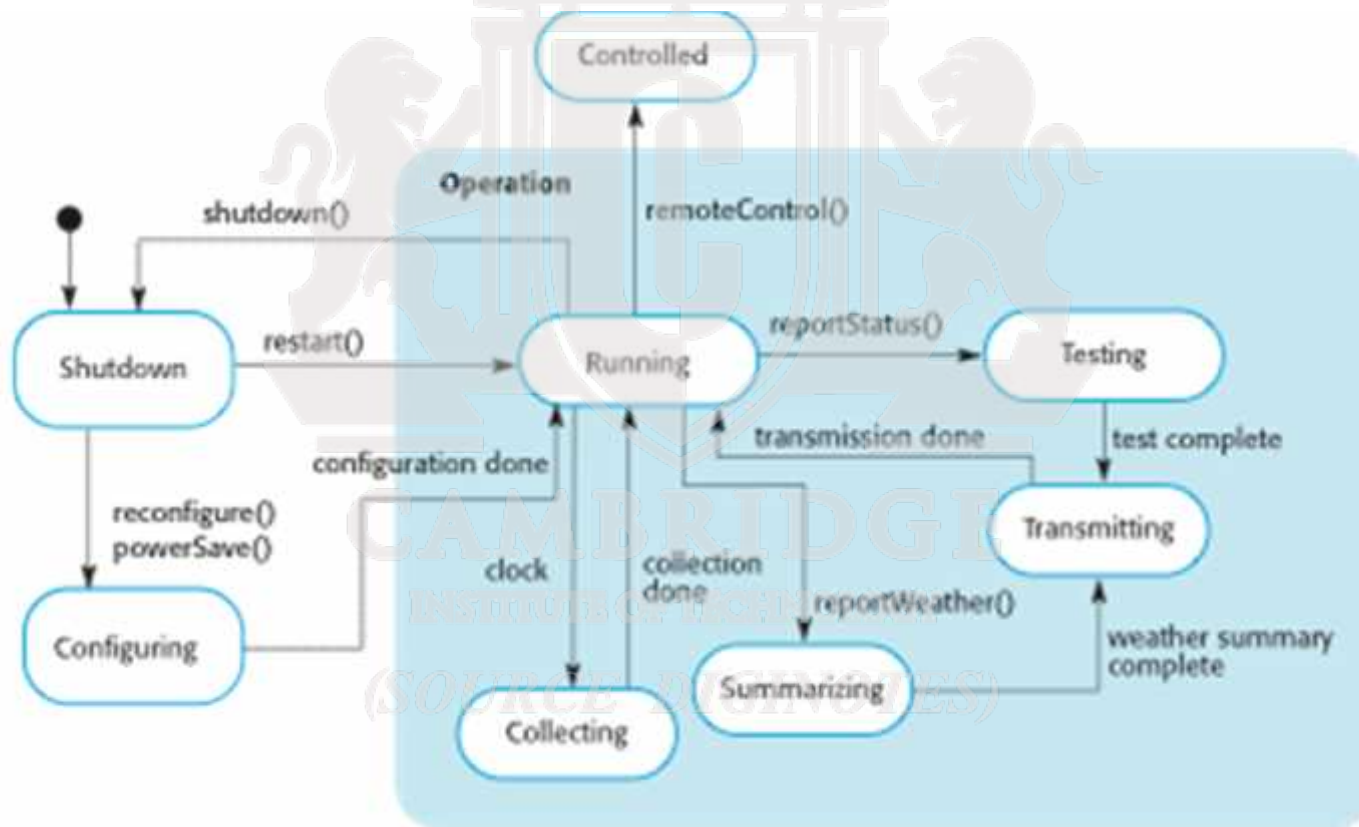


State diagrams

- State diagrams are used to show how objects respond to different service requests and the state transitions triggered by these requests.
- State diagrams are useful high-level models of a system or an object's run-time behavior.
- You don't usually need a state diagram for all of the objects in the system. Many of the objects in a system are relatively simple and a state model adds unnecessary detail to the design.

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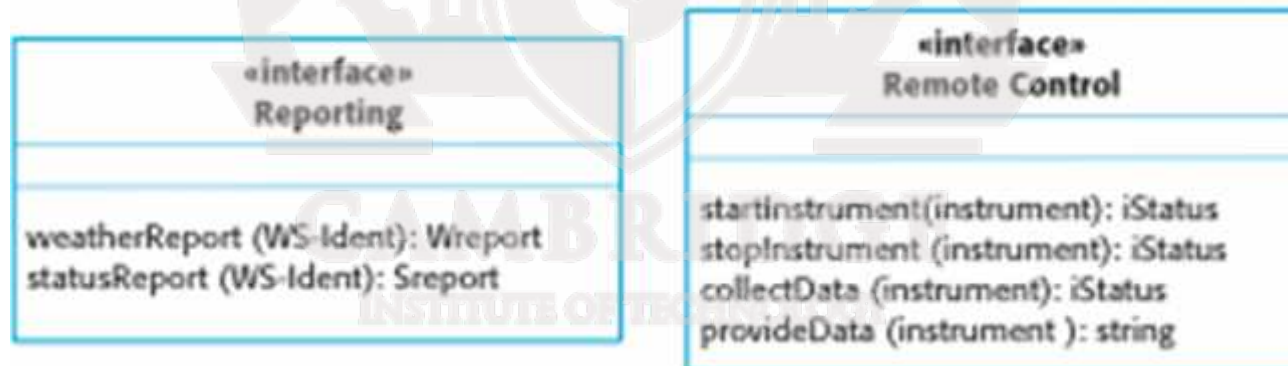
Weather station state diagram



Interface specification

- Object interfaces have to be specified so that the objects and other components can be designed in parallel.
- Designers should avoid designing the interface representation but should hide this in the object itself.
- Objects may have several interfaces which are viewpoints on the methods provided.
- The UML uses class diagrams for interface specification but Java may also be used.

Weather station interfaces



(SOURCE DIGINOTES)

Design patterns

- A design pattern is a way of reusing abstract knowledge about a problem and its solution.
- A pattern is a description of the problem and the essence of its solution.
- It should be sufficiently abstract to be reused in different settings.
- Pattern descriptions usually make use of object-oriented characteristics such as inheritance and polymorphism.

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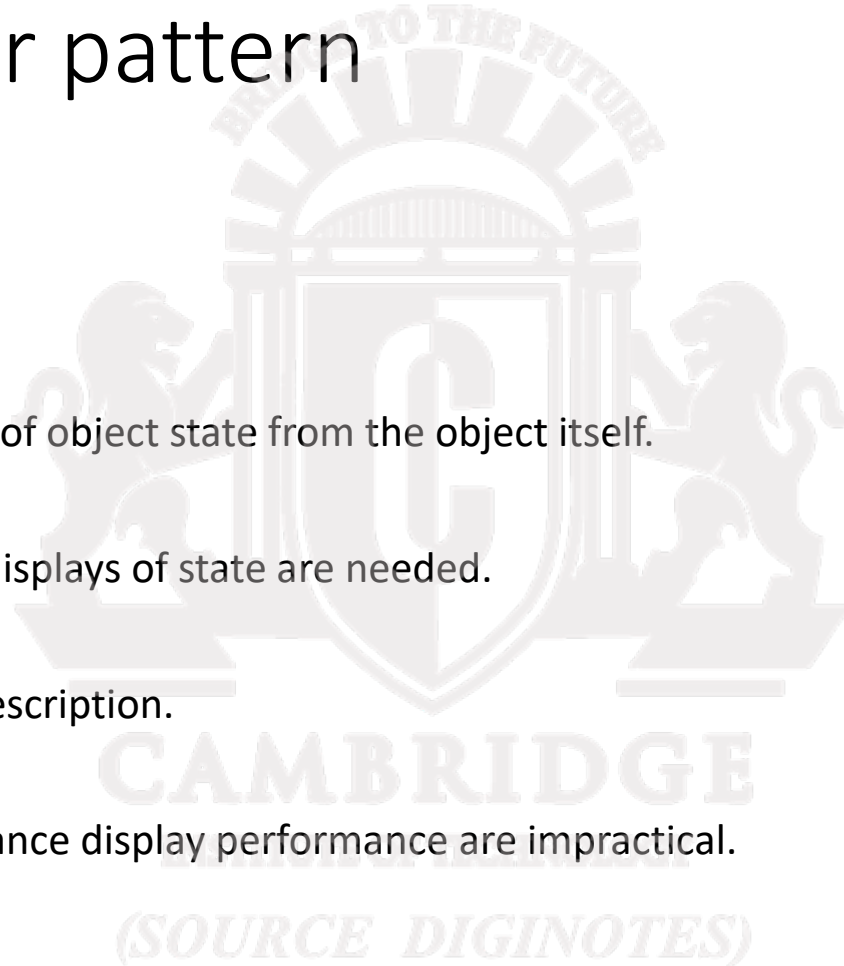
Pattern elements

- Name
 - A meaningful pattern identifier.
- Problem description.
- Solution description.
 - Not a concrete design but a template for a design solution that can be instantiated in different ways.
- Consequences
 - The results and trade-offs of applying the pattern.

(SOURCE DIGINOTES)

The Observer pattern

- Name
 - Observer.
- Description
 - Separates the display of object state from the object itself.
- Problem description
 - Used when multiple displays of state are needed.
- Solution description
 - See slide with UML description.
- Consequences
 - Optimisations to enhance display performance are impractical.



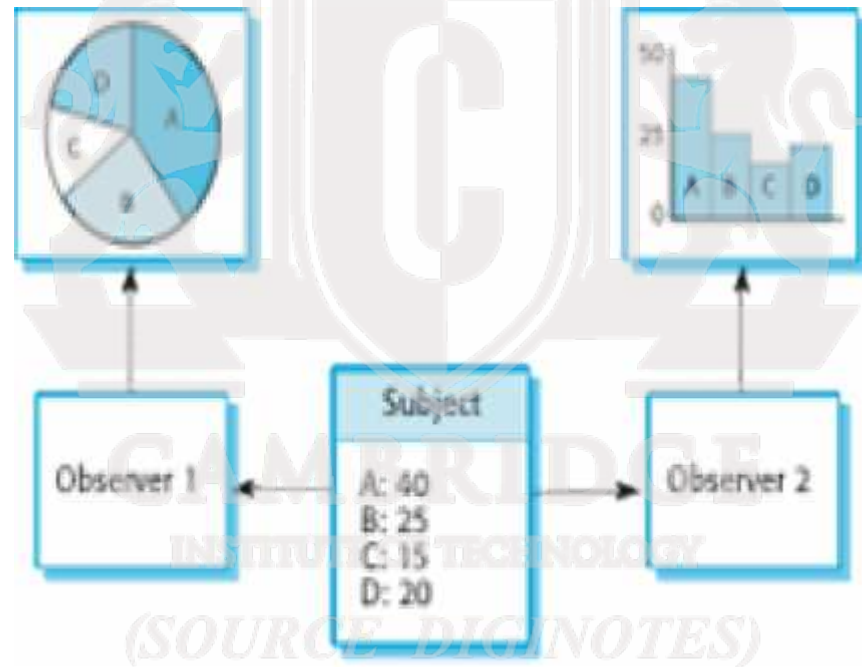
The Observer pattern (1)

Pattern name	Observer
Description	<p>Separates the display of the state of an object from the object itself and allows alternative displays to be provided. When the object state changes, all displays are automatically notified and updated to reflect the change.</p>
Problem description	<p>In many situations, you have to provide multiple displays of state information, such as a graphical display and a tabular display. Not all of these may be known when the information is specified. All alternative presentations should support interaction and, when the state is changed, all displays must be updated.</p> <p>This pattern may be used in all situations where more than one display format for state information is required and where it is not necessary for the object that maintains the state information to know about the specific display formats used.</p>

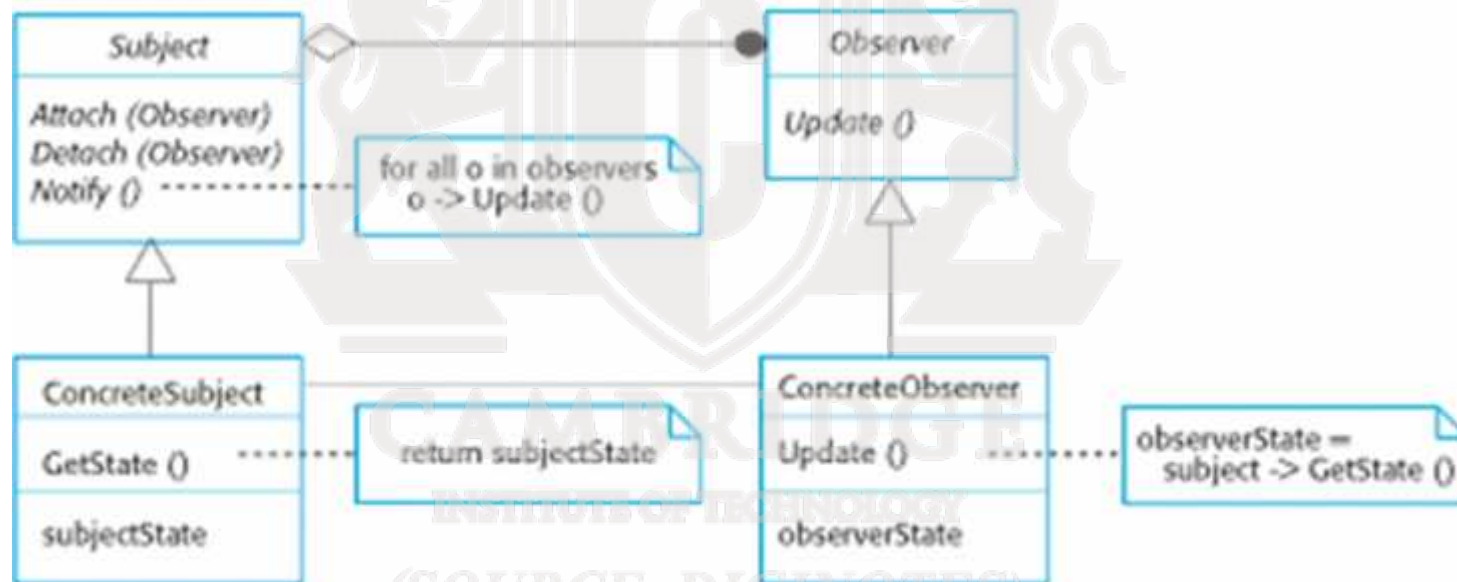
The Observer pattern (2)

Pattern name	Observer
Solution description	<p>This involves two abstract objects, Subject and Observer, and two concrete objects, ConcreteSubject and ConcreteObserver, which inherit the attributes of the related abstract objects. The abstract objects include general operations that are applicable in all situations. The state to be displayed is maintained in ConcreteSubject, which inherits operations from Subject allowing it to add and remove Observers (each observer corresponds to a display) and to issue a notification when the state has changed.</p> <p>The ConcreteObserver maintains a copy of the state of ConcreteSubject and implements the Update() interface of Observer that allows these copies to be kept in step. The ConcreteObserver automatically displays the state and reflects changes whenever the state is updated.</p>
Consequences	<p>The subject only knows the abstract Observer and does not know details of the concrete class. Therefore there is minimal coupling between these objects. Because of this lack of knowledge, optimizations that enhance display performance are impractical. Changes to the subject may cause a set of linked updates to observers to be generated, some of which may not be necessary.</p>

Multiple displays using the Observer pattern



A UML model of the Observer pattern



(SOURCE DIGINOTES)

Design problems

- To use patterns in your design, you need to recognize that any design problem you are facing may have an associated pattern that can be applied.
 - Tell several objects that the state of some other object has changed (Observer pattern).
 - Tidy up the interfaces to a number of related objects that have often been developed incrementally (Façade pattern).
 - Provide a standard way of accessing the elements in a collection, irrespective of how that collection is implemented (Iterator pattern).
 - Allow for the possibility of extending the functionality of an existing class at run-time (Decorator pattern).

Implementation issues

- Focus here is not on programming, although this is obviously important, but on other implementation issues that are often not covered in programming texts:
 - **Reuse** Most modern software is constructed by reusing existing components or systems. When you are developing software, you should make as much use as possible of existing code.
 - **Configuration management** During the development process, you have to keep track of the many different versions of each software component in a configuration management system.
 - **Host-target development** Production software does not usually execute on the same computer as the software development environment. Rather, you develop it on one computer (the host system) and execute it on a separate computer (the target system).

Reuse

- From the 1960s to the 1990s, most new software was developed from scratch, by writing all code in a high-level programming language.
 - The only significant reuse of software was the reuse of functions and objects in programming language libraries.
- Costs and schedule pressure mean that this approach became increasingly unviable, especially for commercial and Internet-based systems.
- An approach to development based around the reuse of existing software emerged and is now generally used for business and scientific software.

(SOURCE DIGINOTES)

Reuse levels

- The abstraction level
 - At this level, you don't reuse software directly but use knowledge of successful abstractions in the design of your software.
- The object level
 - At this level, you directly reuse objects from a library rather than writing the code yourself.
- The component level
 - Components are collections of objects and object classes that you reuse in application systems.
- The system level
 - At this level, you reuse entire application systems.

Reuse costs

- The costs of the time spent in looking for software to reuse and assessing whether or not it meets your needs.
- Where applicable, the costs of buying the reusable software. For large off-the-shelf systems, these costs can be very high.
- The costs of adapting and configuring the reusable software components or systems to reflect the requirements of the system that you are developing.
- The costs of integrating reusable software elements with each other (if you are using software from different sources) and with the new code that you have developed.

Configuration management

- Configuration management is the name given to the general process of managing a changing software system.
- The aim of configuration management is to support the system integration process so that all developers can access the project code and documents in a controlled way, find out what changes have been made, and compile and link components to create a system.
- See also Chapter 25.

Configuration management activities

- Version management, where support is provided to keep track of the different versions of software components. Version management systems include facilities to coordinate development by several programmers.
- System integration, where support is provided to help developers define what versions of components are used to create each version of a system. This description is then used to build a system automatically by compiling and linking the required components.
- Problem tracking, where support is provided to allow users to report bugs and other problems, and to allow all developers to see who is working on these problems and when they are fixed.

Host-target development

- Most software is developed on one computer (the host), but runs on a separate machine (the target).
- More generally, we can talk about a development platform and an execution platform.
 - A platform is more than just hardware.
 - It includes the installed operating system plus other supporting software such as a database management system or, for development platforms, an interactive development environment.
- Development platform usually has different installed software than execution platform; these platforms may have different architectures.

Development platform tools

- An integrated compiler and syntax-directed editing system that allows you to create, edit and compile code.
- A language debugging system.
- Graphical editing tools, such as tools to edit UML models.
- Testing tools, such as Junit that can automatically run a set of tests on a new version of a program.
- Project support tools that help you organize the code for different development projects.

(SOURCE DIGINOTES)

Integrated development environments (IDEs)

- Software development tools are often grouped to create an integrated development environment (IDE).
- An IDE is a set of software tools that supports different aspects of software development, within some common framework and user interface.
- IDEs are created to support development in a specific programming language such as Java. The language IDE may be developed specially, or may be an instantiation of a general-purpose IDE, with specific language-support tools.

(SOURCE DIGINOTES)

Component/system deployment factors

- If a component is designed for a specific hardware architecture, or relies on some other software system, it must obviously be deployed on a platform that provides the required hardware and software support.
- High availability systems may require components to be deployed on more than one platform. This means that, in the event of platform failure, an alternative implementation of the component is available.
- If there is a high level of communications traffic between components, it usually makes sense to deploy them on the same platform or on platforms that are physically close to one other. This reduces the delay between the time a message is sent by one component and received by another.

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Open source development

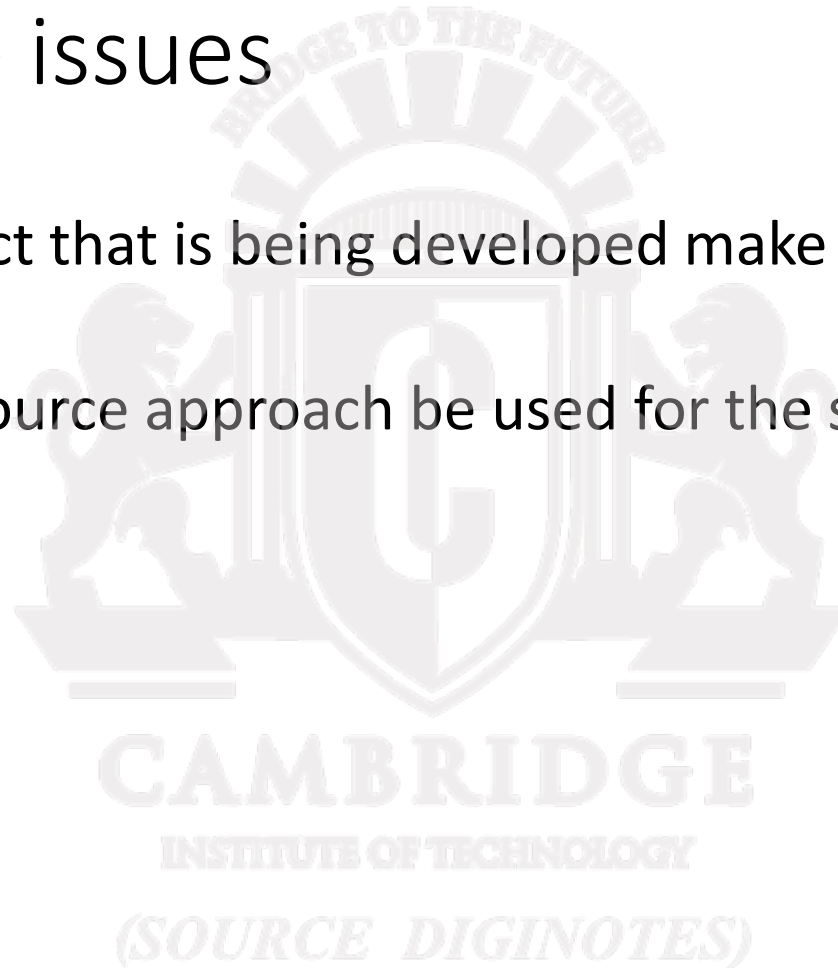
- Open source development is an approach to software development in which the source code of a software system is published and volunteers are invited to participate in the development process
- Its roots are in the Free Software Foundation (www.fsf.org), which advocates that source code should not be proprietary but rather should always be available for users to examine and modify as they wish.
- Open source software extended this idea by using the Internet to recruit a much larger population of volunteer developers. Many of them are also users of the code.

Open source systems

- The best-known open source product is, of course, the Linux operating system which is widely used as a server system and, increasingly, as a desktop environment.
- Other important open source products are Java, the Apache web server and the MySQL database management system.

Open source issues

- Should the product that is being developed make use of open source components?
- Should an open source approach be used for the software's development?



Open source business

- More and more product companies are using an open source approach to development.
- Their business model is not reliant on selling a software product but on selling support for that product.
- They believe that involving the open source community will allow software to be developed more cheaply, more quickly and will create a community of users for the software.

Open source licensing

- A fundamental principle of open-source development is that source code should be freely available, this does not mean that anyone can do as they wish with that code.
 - Legally, the developer of the code (either a company or an individual) still owns the code. They can place restrictions on how it is used by including legally binding conditions in an open source software license.
 - Some open source developers believe that if an open source component is used to develop a new system, then that system should also be open source.
 - Others are willing to allow their code to be used without this restriction. The developed systems may be proprietary and sold as closed source systems.

(SOURCE DIGINOTES)

License models

- The GNU General Public License (GPL). This is a so-called ‘reciprocal’ license that means that if you use open source software that is licensed under the GPL license, then you must make that software open source.
- The GNU Lesser General Public License (LGPL) is a variant of the GPL license where you can write components that link to open source code without having to publish the source of these components.
- The Berkley Standard Distribution (BSD) License. This is a non-reciprocal license, which means you are not obliged to re-publish any changes or modifications made to open source code. You can include the code in proprietary systems that are sold.

License management

- Establish a system for maintaining information about open-source components that are downloaded and used.
- Be aware of the different types of licenses and understand how a component is licensed before it is used.
- Be aware of evolution pathways for components.
- Educate people about open source.
- Have auditing systems in place.
- Participate in the open source community.

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Chapter 8 – Software Testing



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Topics covered

- Development testing
- Test-driven development
- Release testing
- User testing



Program testing

- Testing is intended to show that a program does what it is intended to do and to discover program defects before it is put into use.
- When you test software, you execute a program using artificial data.
- You check the results of the test run for errors, anomalies or information about the program's non-functional attributes.
- Can reveal the presence of errors NOT their absence.
- Testing is part of a more general verification and validation process, which also includes static validation techniques.

Program testing goals

- To demonstrate to the developer and the customer that the software meets its requirements.
 - For custom software, this means that there should be at least one test for every requirement in the requirements document. For generic software products, it means that there should be tests for all of the system features, plus combinations of these features, that will be incorporated in the product release.
- To discover situations in which the behavior of the software is incorrect, undesirable or does not conform to its specification.
 - Defect testing is concerned with rooting out undesirable system behavior such as system crashes, unwanted interactions with other systems, incorrect computations and data corruption.

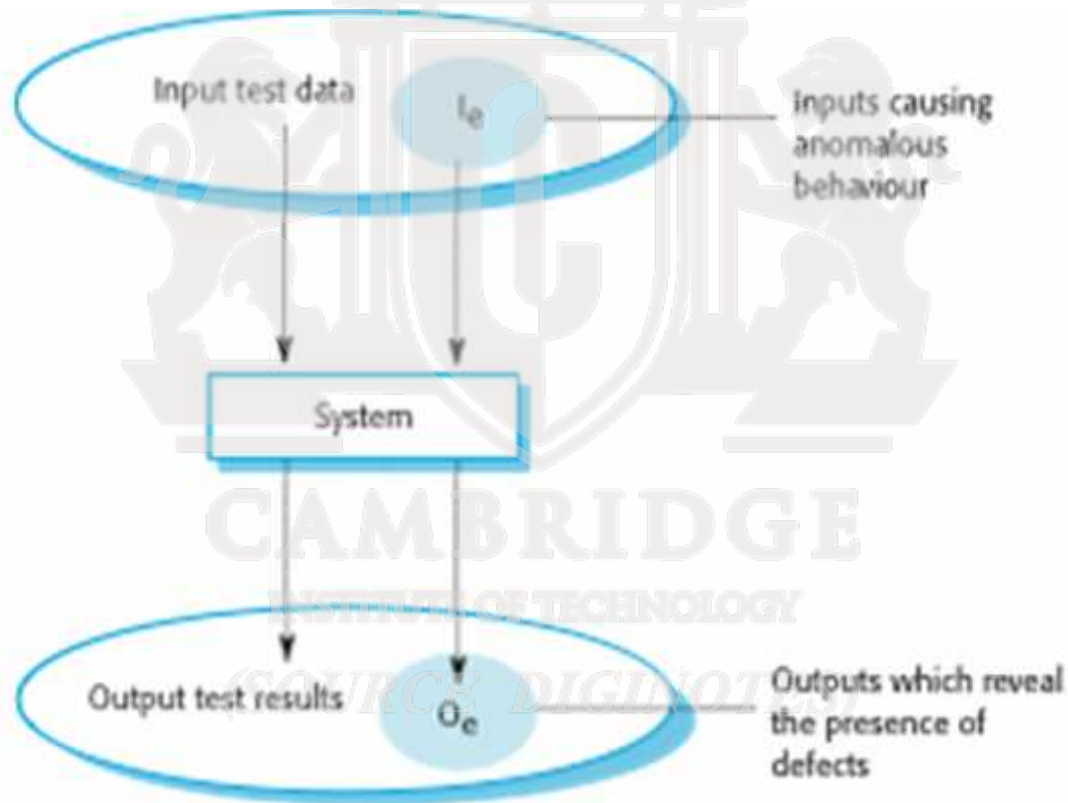
Validation and defect testing

- The first goal leads to **validation testing**
 - You expect the system to perform correctly using a given set of test cases that reflect the system's expected use.
- The second goal leads to **defect testing**
 - The test cases are designed to expose defects. The test cases in defect testing can be deliberately obscure and need not reflect how the system is normally used.

Testing process goals

- Validation testing
 - To demonstrate to the developer and the system customer that the software meets its requirements
 - A successful test shows that the system operates as intended.
- Defect testing
 - To discover faults or defects in the software where its behaviour is incorrect or not in conformance with its specification
 - A successful test is a test that makes the system perform incorrectly and so exposes a defect in the system.

An input-output model of program testing

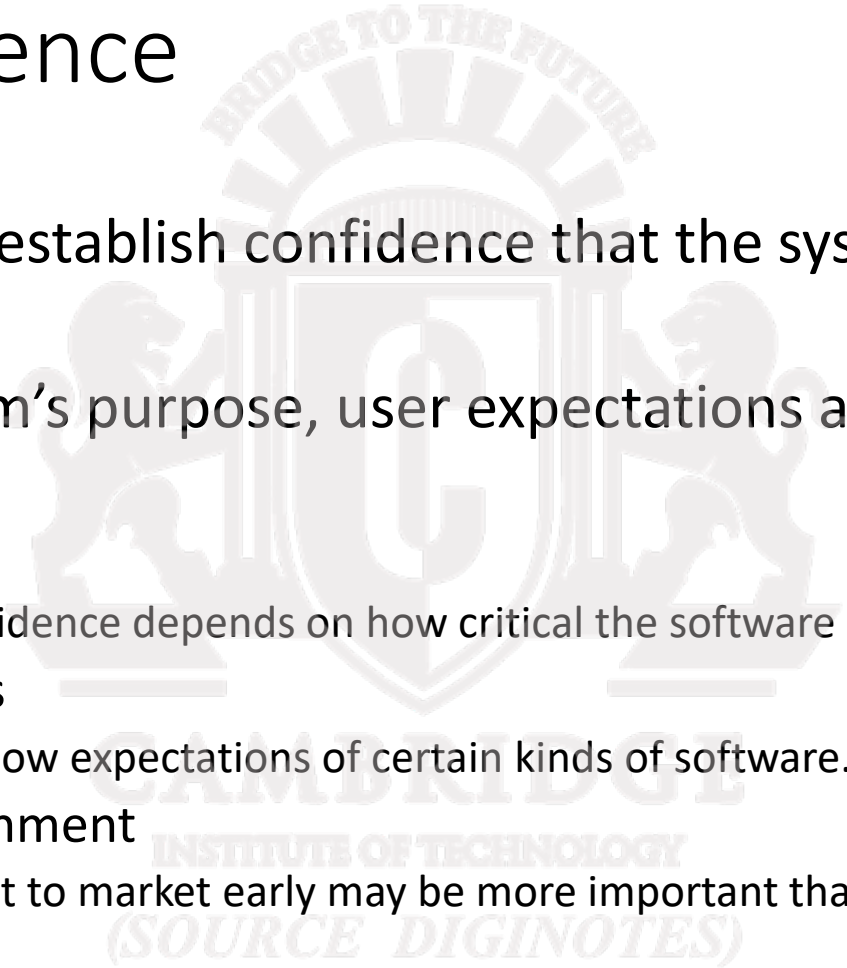


Verification vs validation

- Verification:
"Are we building the product right".
- The software should conform to its specification.
- Validation:
"Are we building the right product".
- The software should do what the user really requires.

V & V confidence

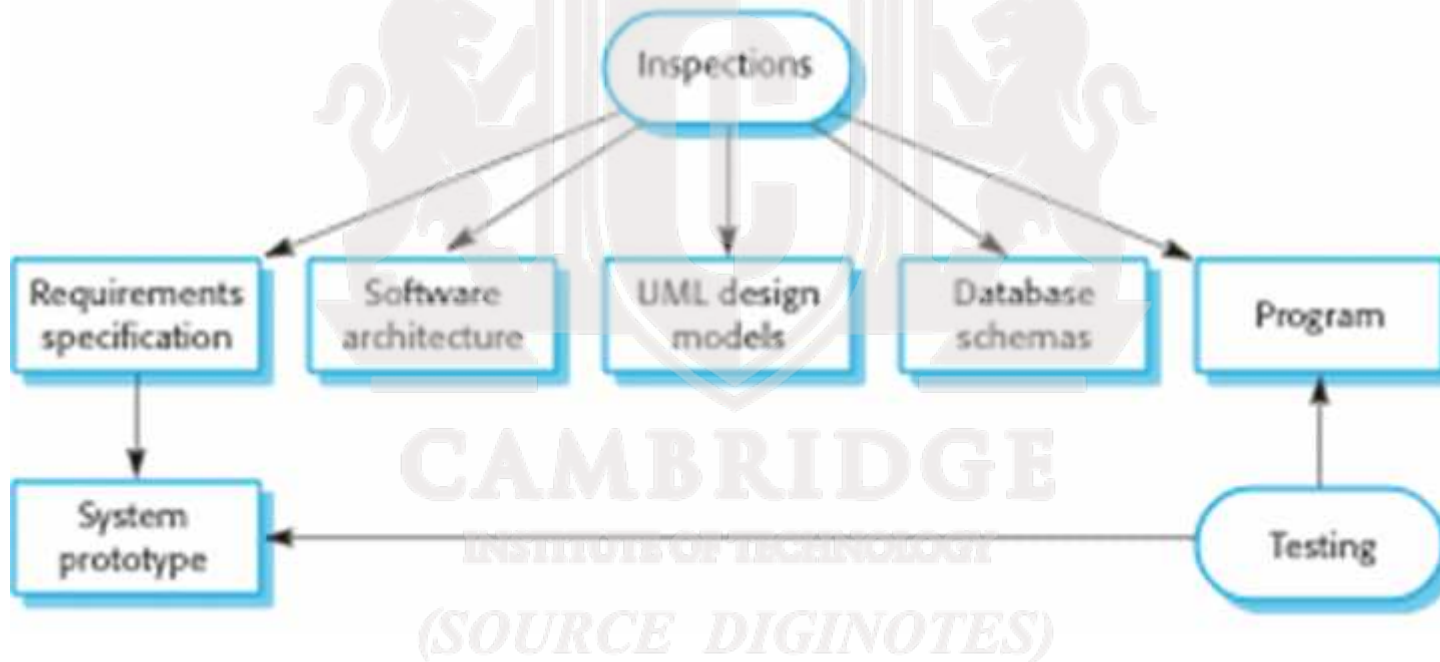
- Aim of V & V is to establish confidence that the system is 'fit for purpose'.
- Depends on system's purpose, user expectations and marketing environment
 - Software purpose
 - The level of confidence depends on how critical the software is to an organisation.
 - User expectations
 - Users may have low expectations of certain kinds of software.
 - Marketing environment
 - Getting a product to market early may be more important than finding defects in the program.



Inspections and testing

- **Software inspections** Concerned with analysis of the static system representation to discover problems (static verification)
 - May be supplement by tool-based document and code analysis.
 - Discussed in Chapter 15.
- **Software testing** Concerned with exercising and observing product behaviour (dynamic verification)
 - The system is executed with test data and its operational behaviour is observed.

Inspections and testing



Software inspections

- These involve people examining the source representation with the aim of discovering anomalies and defects.
- Inspections not require execution of a system so may be used before implementation.
- They may be applied to any representation of the system (requirements, design, configuration data, test data, etc.).
- They have been shown to be an effective technique for discovering program errors.

Advantages of inspections

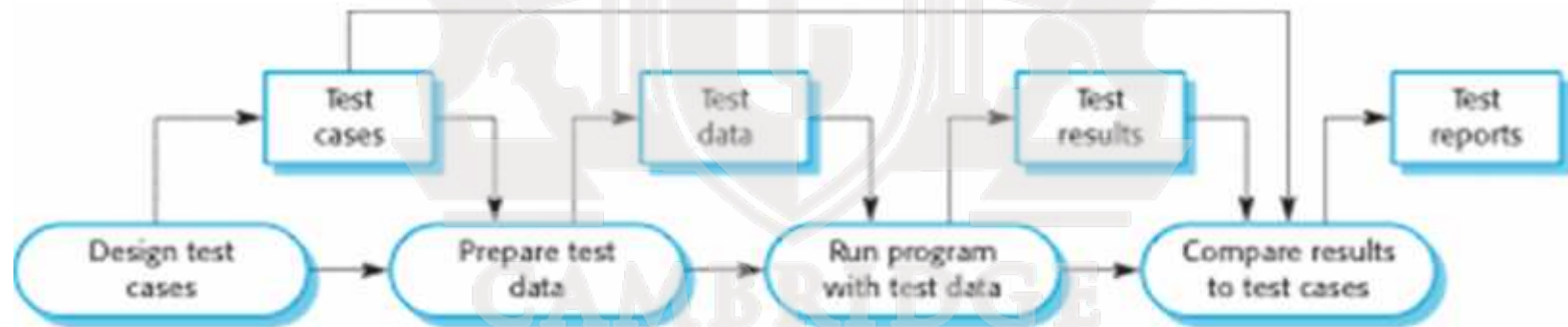
- During testing, errors can mask (hide) other errors. Because inspection is a static process, you don't have to be concerned with interactions between errors.
- Incomplete versions of a system can be inspected without additional costs. If a program is incomplete, then you need to develop specialized test harnesses to test the parts that are available.
- As well as searching for program defects, an inspection can also consider broader quality attributes of a program, such as compliance with standards, portability and maintainability.

(SOURCE DIGINOTES)

Inspections and testing

- Inspections and testing are complementary and not opposing verification techniques.
- Both should be used during the V & V process.
- Inspections can check conformance with a specification but not conformance with the customer's real requirements.
- Inspections cannot check non-functional characteristics such as performance, usability, etc.

A model of the software testing process



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Stages of testing

- Development testing, where the system is tested during development to discover bugs and defects.
- Release testing, where a separate testing team test a complete version of the system before it is released to users.
- User testing, where users or potential users of a system test the system in their own environment.

Development testing

- Development testing includes all testing activities that are carried out by the team developing the system.
 - Unit testing, where individual program units or object classes are tested. Unit testing should focus on testing the functionality of objects or methods.
 - Component testing, where several individual units are integrated to create composite components. Component testing should focus on testing component interfaces.
 - System testing, where some or all of the components in a system are integrated and the system is tested as a whole. System testing should focus on testing component interactions.

(SOURCE DIGINOTES)

Unit testing

- Unit testing is the process of testing individual components in isolation.
- It is a defect testing process.
- Units may be:
 - Individual functions or methods within an object
 - Object classes with several attributes and methods
 - Composite components with defined interfaces used to access their functionality.

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Object class testing

- Complete test coverage of a class involves
 - Testing all operations associated with an object
 - Setting and interrogating all object attributes
 - Exercising the object in all possible states.
- Inheritance makes it more difficult to design object class tests as the information to be tested is not localised.

The weather station object interface

WeatherStation
identifier
reportWeather ()
reportStatus ()
powerSave (instruments)
remoteControl (commands)
reconfigure (commands)
restart (instruments)
shutdown (instruments)

Weather station testing

- Need to define test cases for reportWeather, calibrate, test, startup and shutdown.
- Using a state model, identify sequences of state transitions to be tested and the event sequences to cause these transitions
- For example:
 - Shutdown -> Running-> Shutdown
 - Configuring-> Running-> Testing -> Transmitting -> Running
 - Running-> Collecting-> Running-> Summarizing -> Transmitting -> Running

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Automated testing

- Whenever possible, unit testing should be automated so that tests are run and checked without manual intervention.
- In automated unit testing, you make use of a test automation framework (such as JUnit) to write and run your program tests.
- Unit testing frameworks provide generic test classes that you extend to create specific test cases. They can then run all of the tests that you have implemented and report, often through some GUI, on the success or otherwise of the tests.

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Automated test components

- A setup part, where you initialize the system with the test case, namely the inputs and expected outputs.
- A call part, where you call the object or method to be tested.
- An assertion part where you compare the result of the call with the expected result. If the assertion evaluates to true, the test has been successful if false, then it has failed.

Unit test effectiveness

- The test cases should show that, when used as expected, the component that you are testing does what it is supposed to do.
- If there are defects in the component, these should be revealed by test cases.
- This leads to 2 types of unit test case:
 - The first of these should reflect normal operation of a program and should show that the component works as expected.
 - The other kind of test case should be based on testing experience of where common problems arise. It should use abnormal inputs to check that these are properly processed and do not crash the component.

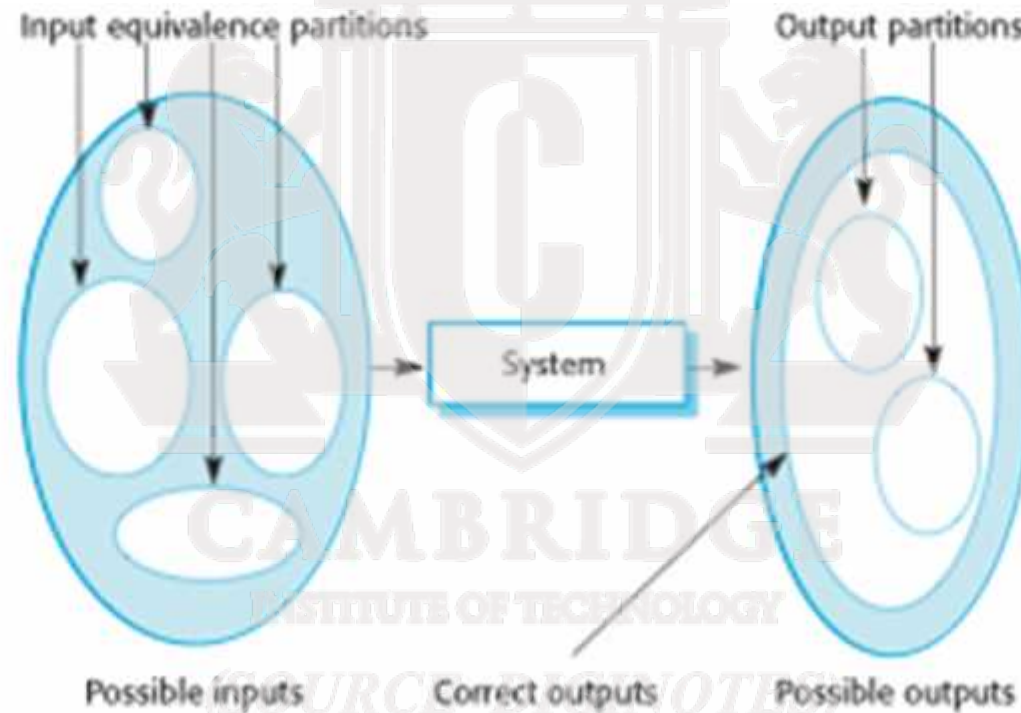
Testing strategies

- Partition testing, where you identify groups of inputs that have common characteristics and should be processed in the same way.
 - You should choose tests from within each of these groups.
- Guideline-based testing, where you use testing guidelines to choose test cases.
 - These guidelines reflect previous experience of the kinds of errors that programmers often make when developing components.

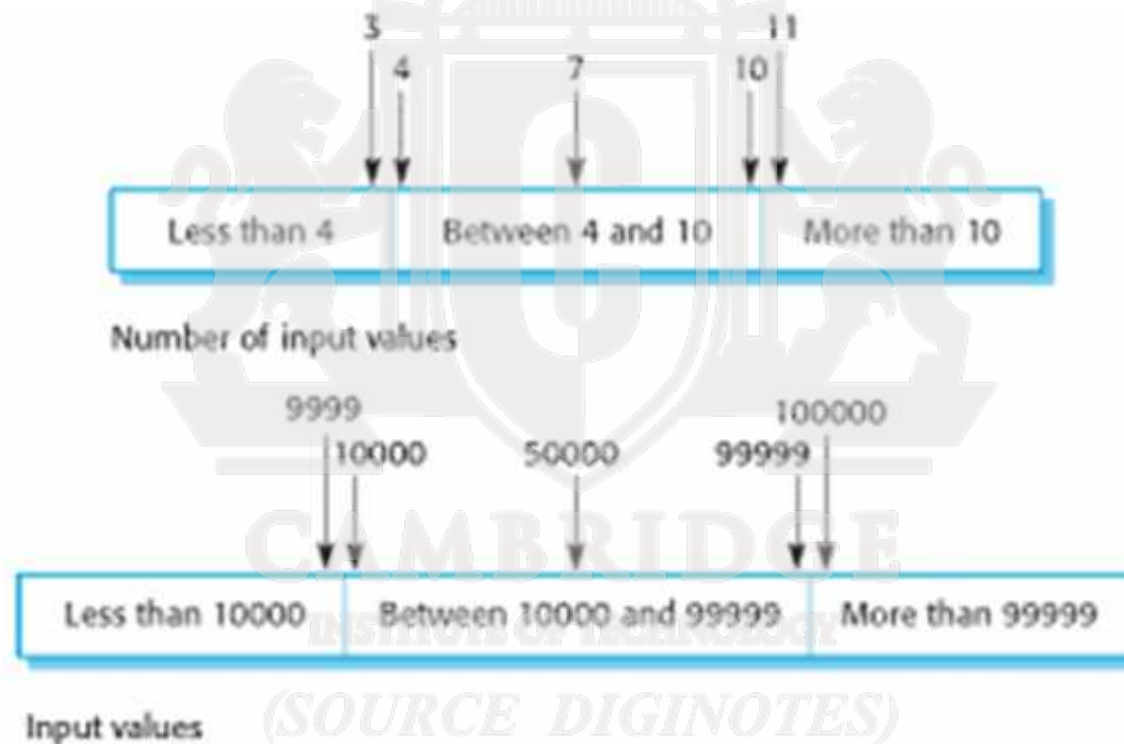
Partition testing

- Input data and output results often fall into different classes where all members of a class are related.
- Each of these classes is an **equivalence partition** or domain where the program behaves in an equivalent way for each class member.
- Test cases should be chosen from each partition.

Equivalence partitioning



Equivalence partitions



Testing guidelines (sequences)

- Test software with sequences which have only a single value.
- Use sequences of different sizes in different tests.
- Derive tests so that the first, middle and last elements of the sequence are accessed.
- Test with sequences of zero length.

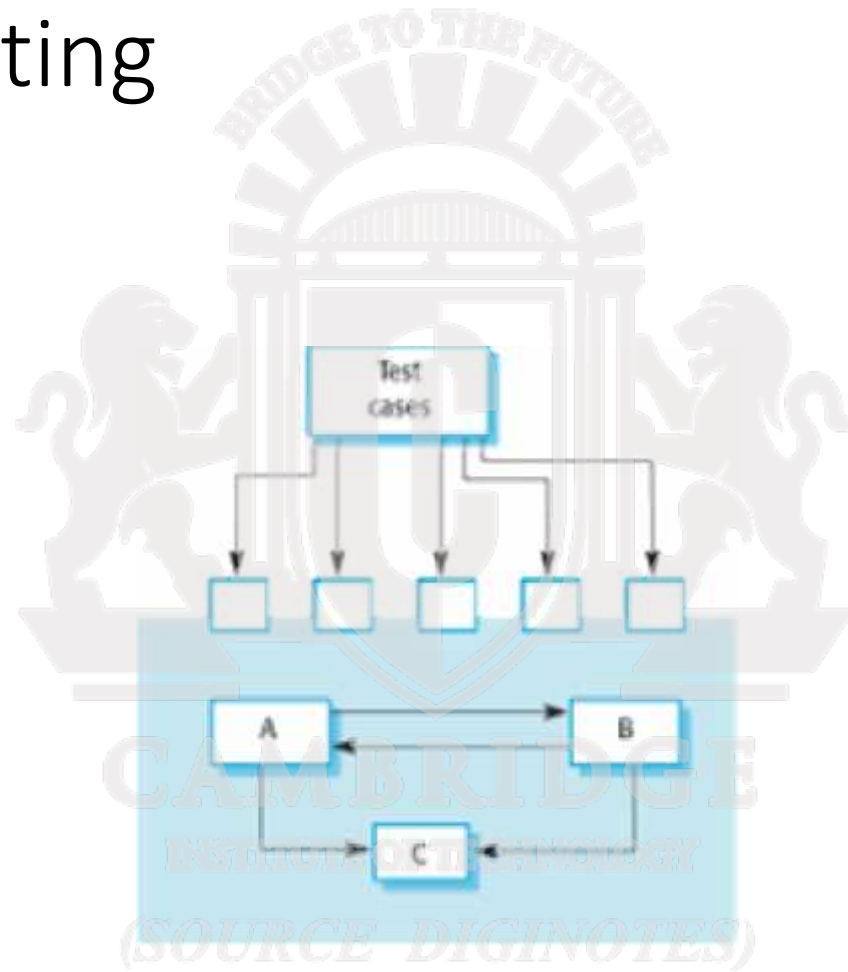
General testing guidelines

- Choose inputs that force the system to generate all error messages
- Design inputs that cause input buffers to overflow
- Repeat the same input or series of inputs numerous times
- Force invalid outputs to be generated
- Force computation results to be too large or too small.

Component testing

- Software components are often composite components that are made up of several interacting objects.
 - For example, in the weather station system, the reconfiguration component includes objects that deal with each aspect of the reconfiguration.
- You access the functionality of these objects through the defined component interface.
- Testing composite components should therefore focus on showing that the component interface behaves according to its specification.
 - You can assume that unit tests on the individual objects within the component have been completed.

Interface testing



Interface testing

- Objectives are to detect faults due to interface errors or invalid assumptions about interfaces.
- Interface types
 - **Parameter interfaces** Data passed from one method or procedure to another.
 - **Shared memory interfaces** Block of memory is shared between procedures or functions.
 - **Procedural interfaces** Sub-system encapsulates a set of procedures to be called by other sub-systems.
 - **Message passing interfaces** Sub-systems request services from other sub-systems

(SOURCE DIGINOTES)

Interface errors

- Interface misuse
 - A calling component calls another component and makes an error in its use of its interface e.g. parameters in the wrong order.
- Interface misunderstanding
 - A calling component embeds assumptions about the behaviour of the called component which are incorrect.
- Timing errors
 - The called and the calling component operate at different speeds and out-of-date information is accessed.

Interface testing guidelines

- Design tests so that parameters to a called procedure are at the extreme ends of their ranges.
- Always test pointer parameters with null pointers.
- Design tests which cause the component to fail.
- Use stress testing in message passing systems.
- In shared memory systems, vary the order in which components are activated.

System testing

- System testing during development involves integrating components to create a version of the system and then testing the integrated system.
- The focus in system testing is testing the interactions between components.
- System testing checks that components are compatible, interact correctly and transfer the right data at the right time across their interfaces.
- System testing tests the emergent behaviour of a system.

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System and component testing

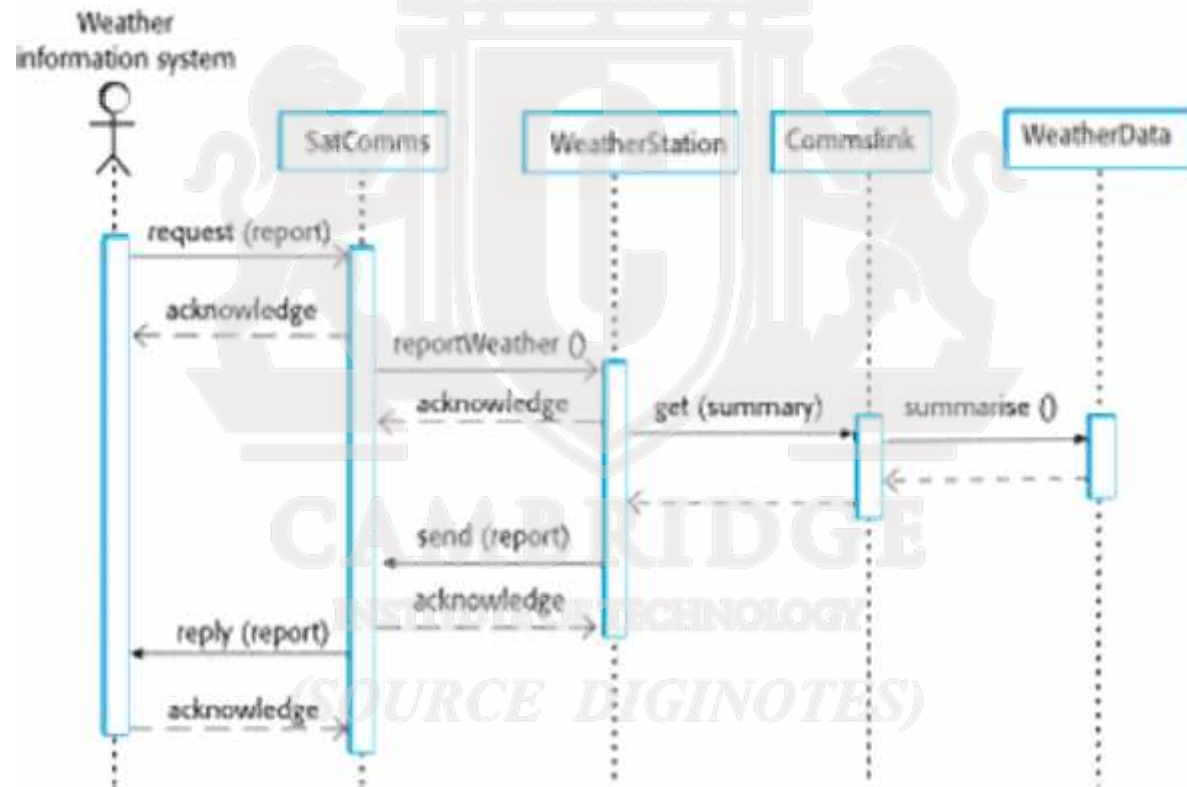
- During system testing, reusable components that have been separately developed and off-the-shelf systems may be integrated with newly developed components. The complete system is then tested.
- Components developed by different team members or sub-teams may be integrated at this stage. System testing is a collective rather than an individual process.
 - In some companies, system testing may involve a separate testing team with no involvement from designers and programmers.

(SOURCE DIGINOTES)

Use-case testing

- The use-cases developed to identify system interactions can be used as a basis for system testing.
- Each use case usually involves several system components so testing the use case forces these interactions to occur.
- The sequence diagrams associated with the use case documents the components and interactions that are being tested.

Collect weather data sequence chart



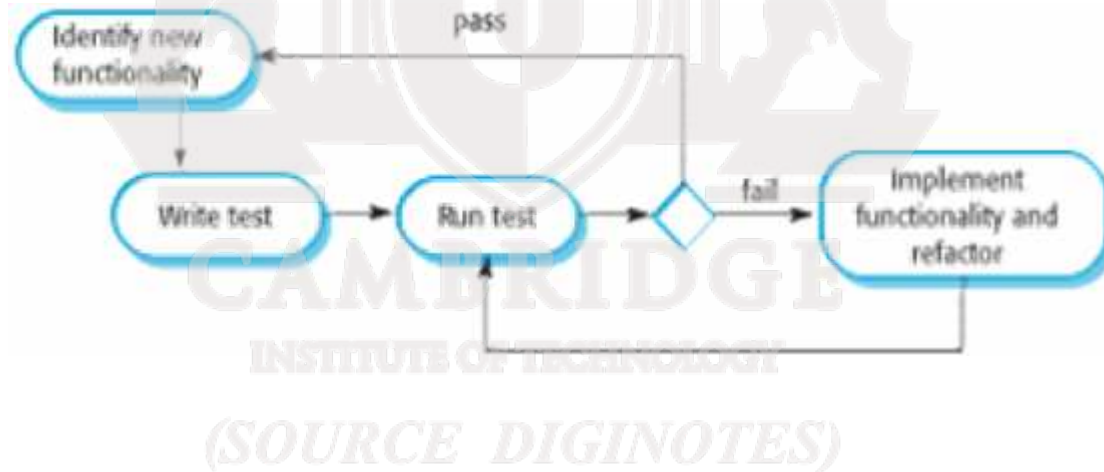
Testing policies

- Exhaustive system testing is impossible so testing policies which define the required system test coverage may be developed.
- Examples of testing policies:
 - All system functions that are accessed through menus should be tested.
 - Combinations of functions (e.g. text formatting) that are accessed through the same menu must be tested.
 - Where user input is provided, all functions must be tested with both correct and incorrect input.

Test-driven development

- Test-driven development (TDD) is an approach to program development in which you inter-leave testing and code development.
- Tests are written before code and 'passing' the tests is the critical driver of development.
- You develop code incrementally, along with a test for that increment. You don't move on to the next increment until the code that you have developed passes its test.
- TDD was introduced as part of agile methods such as Extreme Programming. However, it can also be used in plan-driven development processes.

Test-driven development



TDD process activities

- Start by identifying the increment of functionality that is required. This should normally be small and implementable in a few lines of code.
- Write a test for this functionality and implement this as an automated test.
- Run the test, along with all other tests that have been implemented. Initially, you have not implemented the functionality so the new test will fail.
- Implement the functionality and re-run the test.
- Once all tests run successfully, you move on to implementing the next chunk of functionality.

(SOURCE DIGINOTES)

Benefits of test-driven development

- Code coverage
 - Every code segment that you write has at least one associated test so all code written has at least one test.
- Regression testing
 - A regression test suite is developed incrementally as a program is developed.
- Simplified debugging
 - When a test fails, it should be obvious where the problem lies. The newly written code needs to be checked and modified.
- System documentation
 - The tests themselves are a form of documentation that describe what the code should be doing.

(SOURCE DIGINOTES)

Regression testing

- Regression testing is testing the system to check that changes have not 'broken' previously working code.
- In a manual testing process, regression testing is expensive but, with automated testing, it is simple and straightforward. All tests are rerun every time a change is made to the program.
- Tests must run 'successfully' before the change is committed.

Release testing

- Release testing is the process of testing a particular release of a system that is intended for use outside of the development team.
- The primary goal of the release testing process is to convince the supplier of the system that it is good enough for use.
 - Release testing, therefore, has to show that the system delivers its specified functionality, performance and dependability, and that it does not fail during normal use.
- Release testing is usually a black-box testing process where tests are only derived from the system specification.

(SOURCE DIGINOTES)

Release testing and system testing

- Release testing is a form of system testing.
- Important differences:
 - A separate team that has not been involved in the system development, should be responsible for release testing.
 - System testing by the development team should focus on discovering bugs in the system (defect testing). The objective of release testing is to check that the system meets its requirements and is good enough for external use (validation testing).

Requirements based testing

- Requirements-based testing involves examining each requirement and developing a test or tests for it.
- MHC-PMS requirements:
 - If a patient is known to be allergic to any particular medication, then prescription of that medication shall result in a warning message being issued to the system user.
 - If a prescriber chooses to ignore an allergy warning, they shall provide a reason why this has been ignored.

Requirements tests

- Set up a patient record with no known allergies. Prescribe medication for allergies that are known to exist. Check that a warning message is not issued by the system.
- Set up a patient record with a known allergy. Prescribe the medication to that the patient is allergic to, and check that the warning is issued by the system.
- Set up a patient record in which allergies to two or more drugs are recorded. Prescribe both of these drugs separately and check that the correct warning for each drug is issued.
- Prescribe two drugs that the patient is allergic to. Check that two warnings are correctly issued.
- Prescribe a drug that issues a warning and overrule that warning. Check that the system requires the user to provide information explaining why the warning was overruled.

(SOURCE DIGINOTES)

Features tested by scenario

- Authentication by logging on to the system.
- Downloading and uploading of specified patient records to a laptop.
- Home visit scheduling.
- Encryption and decryption of patient records on a mobile device.
- Record retrieval and modification.
- Links with the drugs database that maintains side-effect information.
- The system for call prompting.

(SOURCE DIGINOTES)

A usage scenario for the MHC-PMS

Kate is a nurse who specializes in mental health care. One of her responsibilities is to visit patients at home to check that their treatment is effective and that they are not suffering from medication side-effects.

On a day for home visits, Kate logs into the MHC-PMS and uses it to print her schedule of home visits for that day, along with summary information about the patients to be visited. She requests that the records for these patients be downloaded to her laptop. She is prompted for her key phrase to encrypt the records on the laptop.

One of the patients that she visits is Jim, who is being treated with medication for depression. Jim feels that the medication is helping him but believes that it has the side-effect of keeping him awake at night. Kate looks up Jim's record and is prompted for her key phrase to decrypt the record. She checks the drug prescribed and queries its side effects. Sleeplessness is a known side effect so she notes the problem in Jim's record and suggests that he visits the clinic to have his medication changed. He agrees so Kate enters a prompt to call him when she gets back to the clinic to make an appointment with a physician. She ends the consultation and the system re-encrypts Jim's record.

After finishing her consultations, Kate returns to the clinic and uploads the records of patients visited to the database. The system generates a call list for Kate of those patients who she has to contact for follow-up information and make clinic appointments.

Performance testing

- Part of release testing may involve testing the emergent properties of a system, such as performance and reliability.
- Tests should reflect the profile of use of the system.
- Performance tests usually involve planning a series of tests where the load is steadily increased until the system performance becomes unacceptable.
- Stress testing is a form of performance testing where the system is deliberately overloaded to test its failure behaviour.

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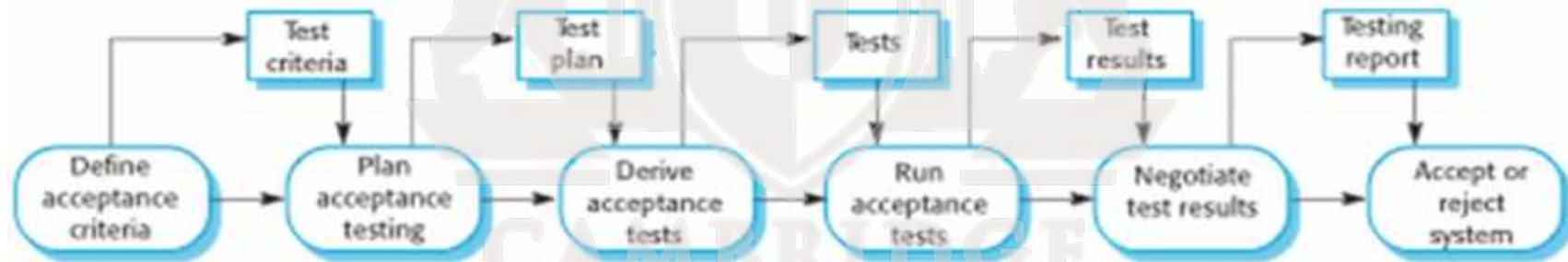
User testing

- User or customer testing is a stage in the testing process in which users or customers provide input and advice on system testing.
- User testing is essential, even when comprehensive system and release testing have been carried out.
 - The reason for this is that influences from the user's working environment have a major effect on the reliability, performance, usability and robustness of a system. These cannot be replicated in a testing environment.

Types of user testing

- Alpha testing
 - Users of the software work with the development team to test the software at the developer's site.
- Beta testing
 - A release of the software is made available to users to allow them to experiment and to raise problems that they discover with the system developers.
- Acceptance testing
 - Customers test a system to decide whether or not it is ready to be accepted from the system developers and deployed in the customer environment. Primarily for custom systems.

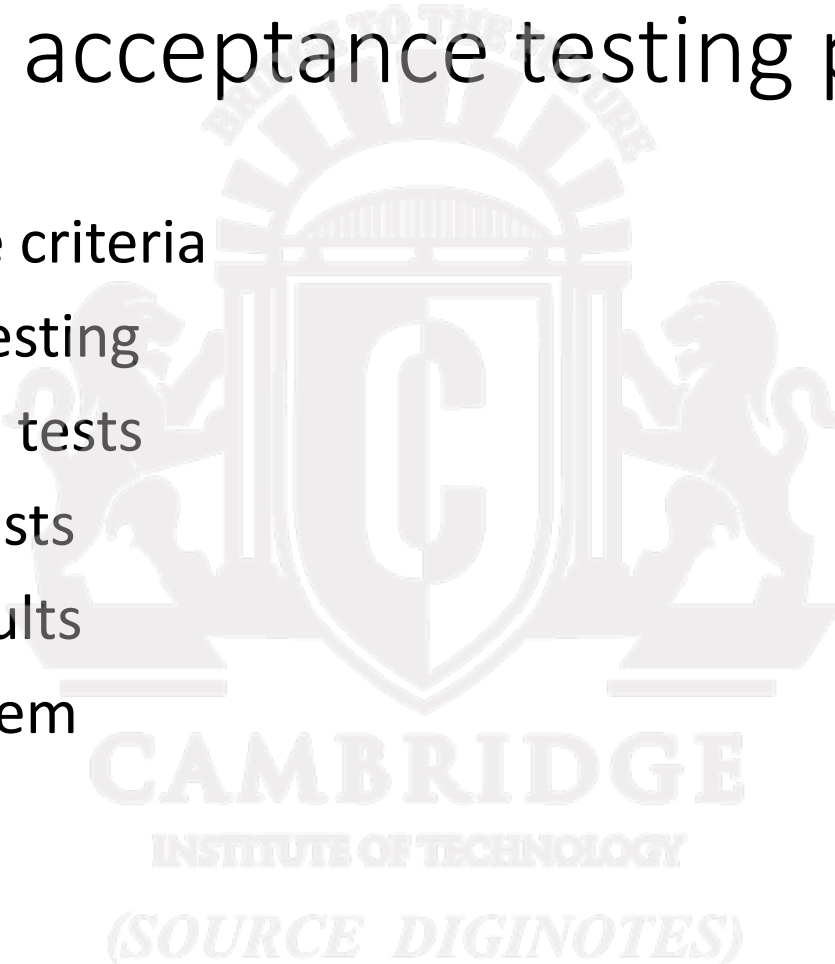
The acceptance testing process



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Stages in the acceptance testing process

- Define acceptance criteria
- Plan acceptance testing
- Derive acceptance tests
- Run acceptance tests
- Negotiate test results
- Reject/accept system



Agile methods and acceptance testing

- In agile methods, the user/customer is part of the development team and is responsible for making decisions on the acceptability of the system.
- Tests are defined by the user/customer and are integrated with other tests in that they are run automatically when changes are made.
- There is no separate acceptance testing process.
- Main problem here is whether or not the embedded user is 'typical' and can represent the interests of all system stakeholders.

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Chapter 9 – Software Evolution



Topics covered

- Evolution processes
 - Change processes for software systems
- Program evolution dynamics
 - Understanding software evolution
- Software maintenance
 - Making changes to operational software systems
- Legacy system management
 - Making decisions about software change

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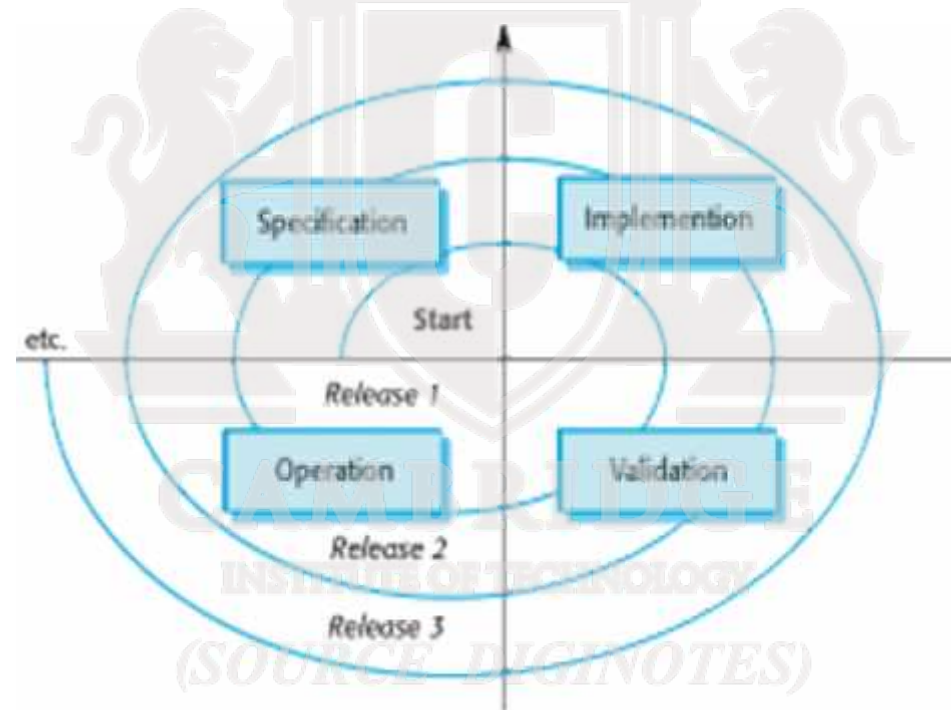
Software change

- Software change is inevitable
 - New requirements emerge when the software is used;
 - The business environment changes;
 - Errors must be repaired;
 - New computers and equipment is added to the system;
 - The performance or reliability of the system may have to be improved.
- A key problem for all organizations is implementing and managing change to their existing software systems.

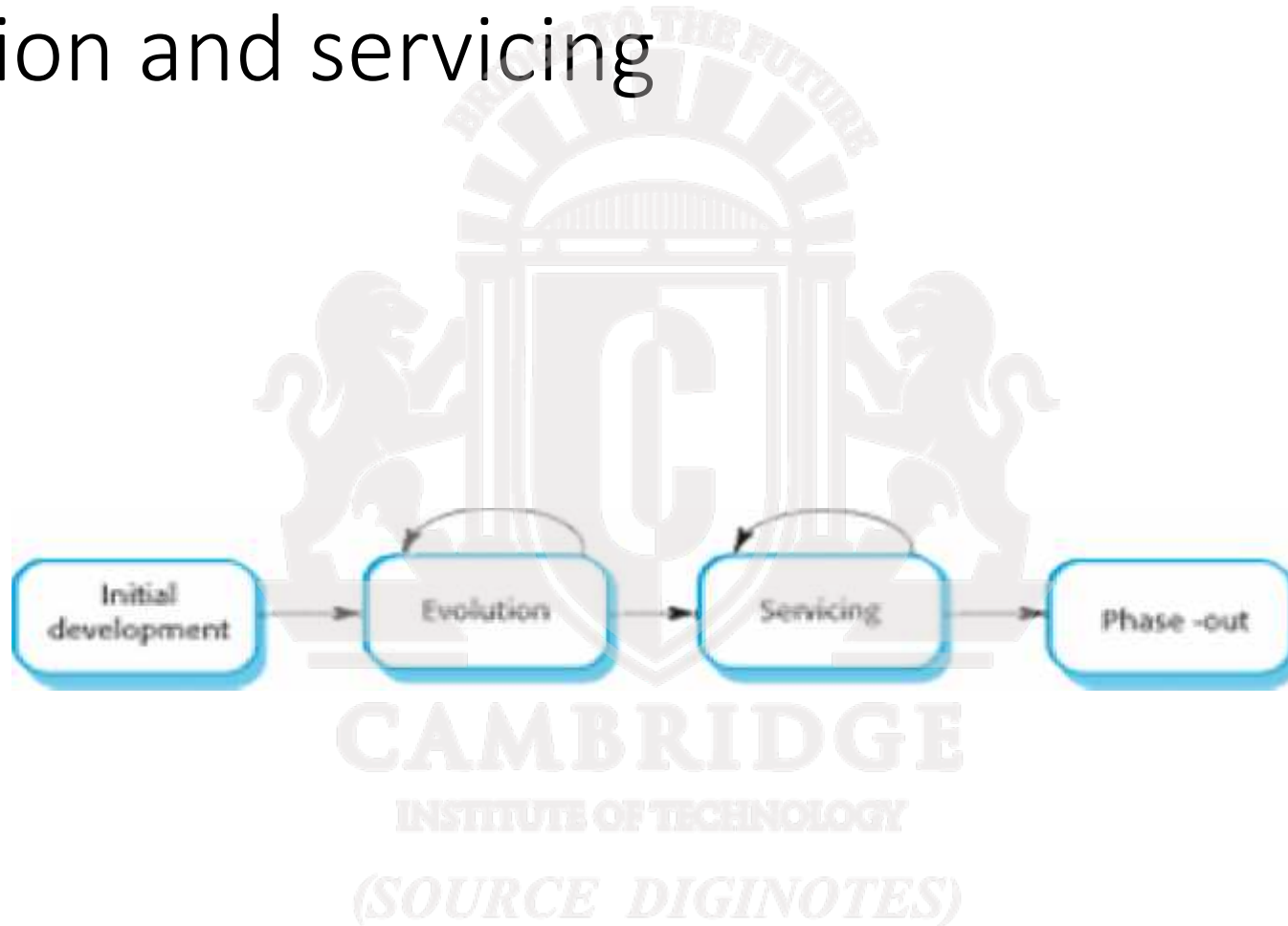
Importance of evolution

- Organisations have huge investments in their software systems - they are critical business assets.
- To maintain the value of these assets to the business, they must be changed and updated.
- The majority of the software budget in large companies is devoted to changing and evolving existing software rather than developing new software.

A spiral model of development and evolution



Evolution and servicing



Evolution and servicing

- Evolution

- The stage in a software system's life cycle where it is in operational use and is evolving as new requirements are proposed and implemented in the system.

- Servicing

- At this stage, the software remains useful but the only changes made are those required to keep it operational i.e. bug fixes and changes to reflect changes in the software's environment. No new functionality is added.

- Phase-out

- The software may still be used but no further changes are made to it.

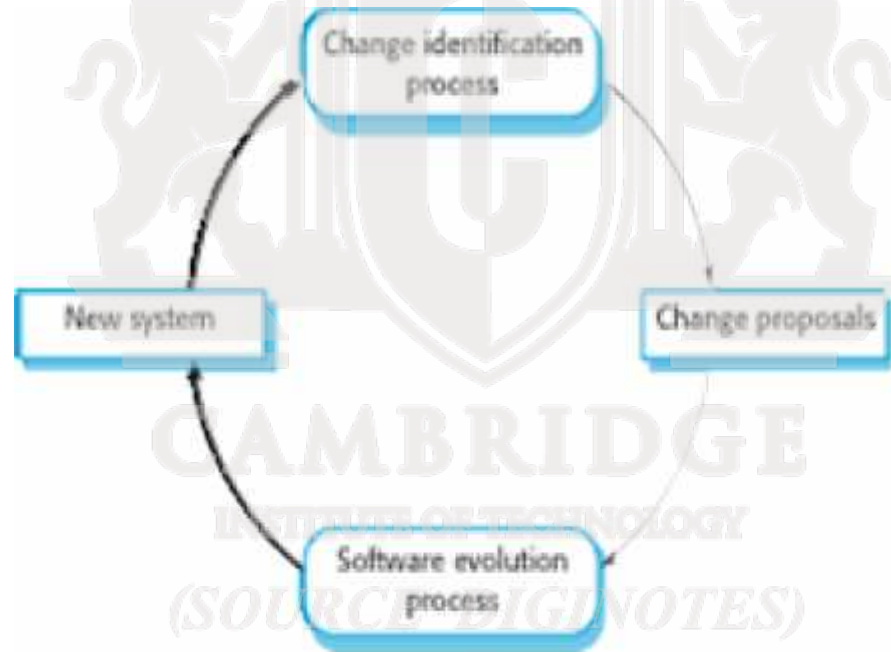
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Evolution processes

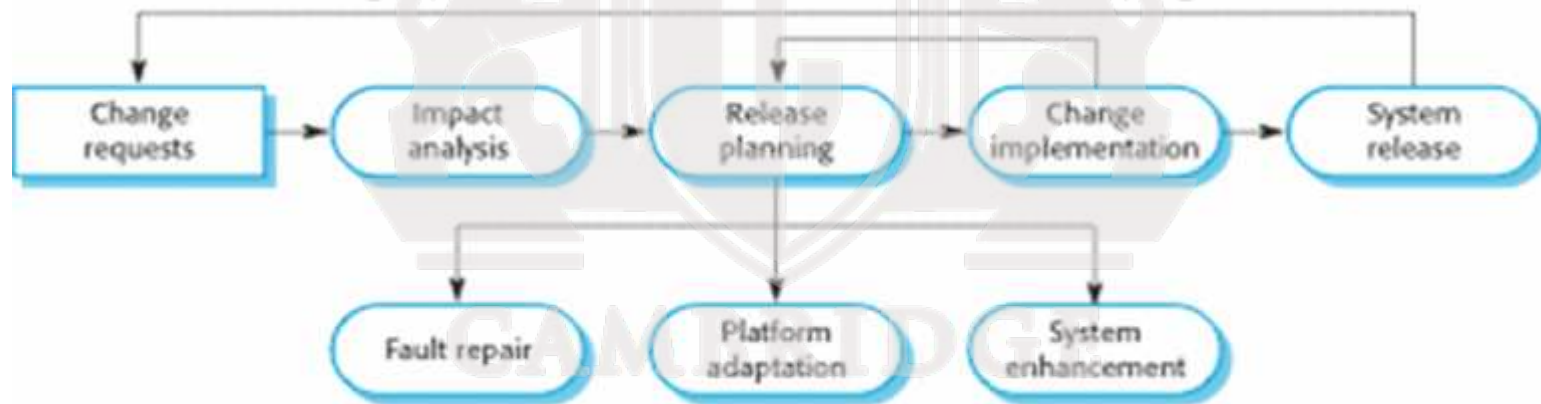
- Software evolution processes depend on
 - The type of software being maintained;
 - The development processes used;
 - The skills and experience of the people involved.
- Proposals for change are the driver for system evolution.
 - Should be linked with components that are affected by the change, thus allowing the cost and impact of the change to be estimated.
- Change identification and evolution continues throughout the system lifetime.

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Change identification and evolution processes



The software evolution process



(SOURCE DIGINOTES)

Change implementation



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Change implementation

- Iteration of the development process where the revisions to the system are designed, implemented and tested.
- A critical difference is that the first stage of change implementation may involve program understanding, especially if the original system developers are not responsible for the change implementation.
- During the program understanding phase, you have to understand how the program is structured, how it delivers functionality and how the proposed change might affect the program.

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Urgent change requests

- Urgent changes may have to be implemented without going through all stages of the software engineering process
 - If a serious system fault has to be repaired to allow normal operation to continue;
 - If changes to the system's environment (e.g. an OS upgrade) have unexpected effects;
 - If there are business changes that require a very rapid response (e.g. the release of a competing product).

The emergency repair process



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Agile methods and evolution

- Agile methods are based on incremental development so the transition from development to evolution is a seamless one.
 - Evolution is simply a continuation of the development process based on frequent system releases.
- Automated regression testing is particularly valuable when changes are made to a system.
- Changes may be expressed as additional user stories.

Handover problems

- Where the development team have used an agile approach but the evolution team is unfamiliar with agile methods and prefer a plan-based approach.
 - The evolution team may expect detailed documentation to support evolution and this is not produced in agile processes.
- Where a plan-based approach has been used for development but the evolution team prefer to use agile methods.
 - The evolution team may have to start from scratch developing automated tests and the code in the system may not have been refactored and simplified as is expected in agile development.

(SOURCE DIGINOTES)

Program evolution dynamics

- *Program evolution dynamics* is the study of the processes of system change.
- After several major empirical studies, Lehman and Belady proposed that there were a number of 'laws' which applied to all systems as they evolved.
- There are sensible observations rather than laws. They are applicable to large systems developed by large organisations.
 - It is not clear if these are applicable to other types of software system.

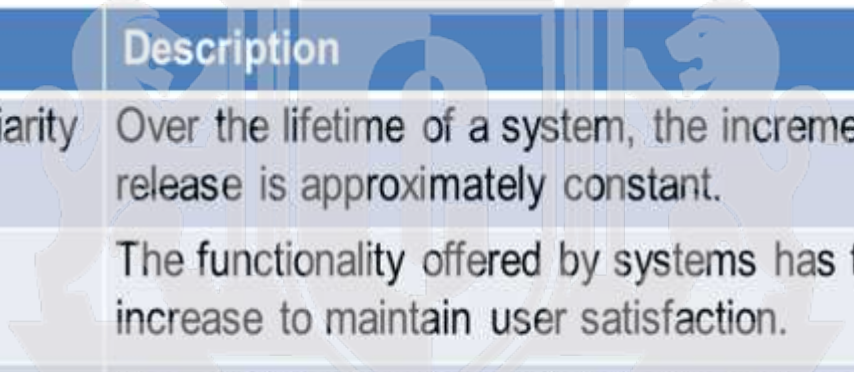
Change is inevitable

- The system requirements are likely to change while the system is being developed because the environment is changing. Therefore a delivered system won't meet its requirements!
- Systems are tightly coupled with their environment. When a system is installed in an environment it changes that environment and therefore changes the system requirements.
- Systems **MUST** be changed if they are to remain useful in an environment.

Lehman's laws

Law	Description
Continuing change	A program that is used in a real-world environment must necessarily change, or else become progressively less useful in that environment.
Increasing complexity	As an evolving program changes, its structure tends to become more complex. Extra resources must be devoted to preserving and simplifying the structure.
Large program evolution	Program evolution is a self-regulating process. System attributes such as size, time between releases, and the number of reported errors is approximately invariant for each system release.
Organizational stability	Over a program's lifetime, its rate of development is approximately constant and independent of the resources devoted to system development.

Lehman's laws



Law	Description
Conservation of familiarity	Over the lifetime of a system, the incremental change in each release is approximately constant.
Continuing growth	The functionality offered by systems has to continually increase to maintain user satisfaction.
Declining quality	The quality of systems will decline unless they are modified to reflect changes in their operational environment.
Feedback system	Evolution processes incorporate multiagent, multiloop feedback systems and you have to treat them as feedback systems to achieve significant product improvement.

Applicability of Lehman's laws

- Lehman's laws seem to be generally applicable to large, tailored systems developed by large organisations.
 - Confirmed in early 2000's by work by Lehman on the FEAST project.
- It is not clear how they should be modified for
 - Shrink-wrapped software products;
 - Systems that incorporate a significant number of COTS components;
 - Small organisations;
 - Medium sized systems.

Software maintenance

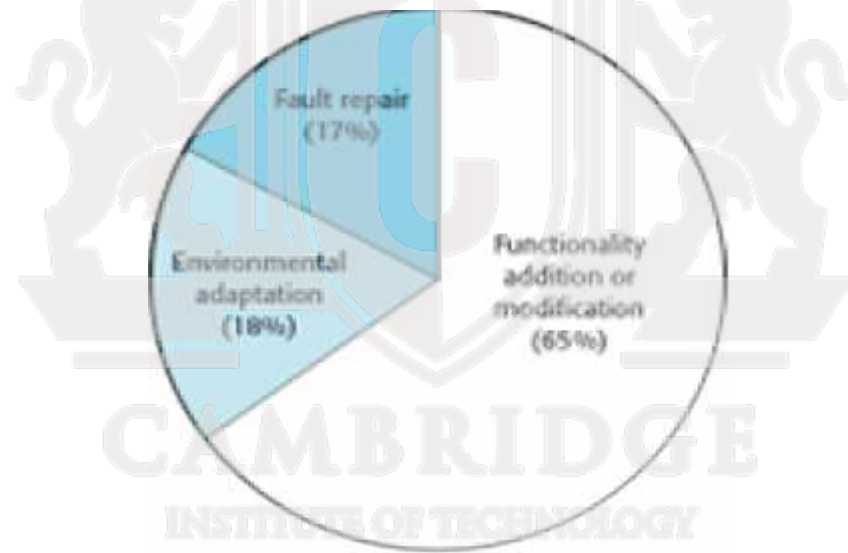
- Modifying a program after it has been put into use.
- The term is mostly used for changing custom software. Generic software products are said to evolve to create new versions.
- Maintenance does not normally involve major changes to the system's architecture.
- Changes are implemented by modifying existing components and adding new components to the system.

(SOURCE DIGINOTES)

Types of maintenance

- Maintenance to repair software faults
 - Changing a system to correct deficiencies in the way meets its requirements.
- Maintenance to adapt software to a different operating environment
 - Changing a system so that it operates in a different environment (computer, OS, etc.) from its initial implementation.
- Maintenance to add to or modify the system's functionality
 - Modifying the system to satisfy new requirements.

Figure 9.8 Maintenance effort distribution



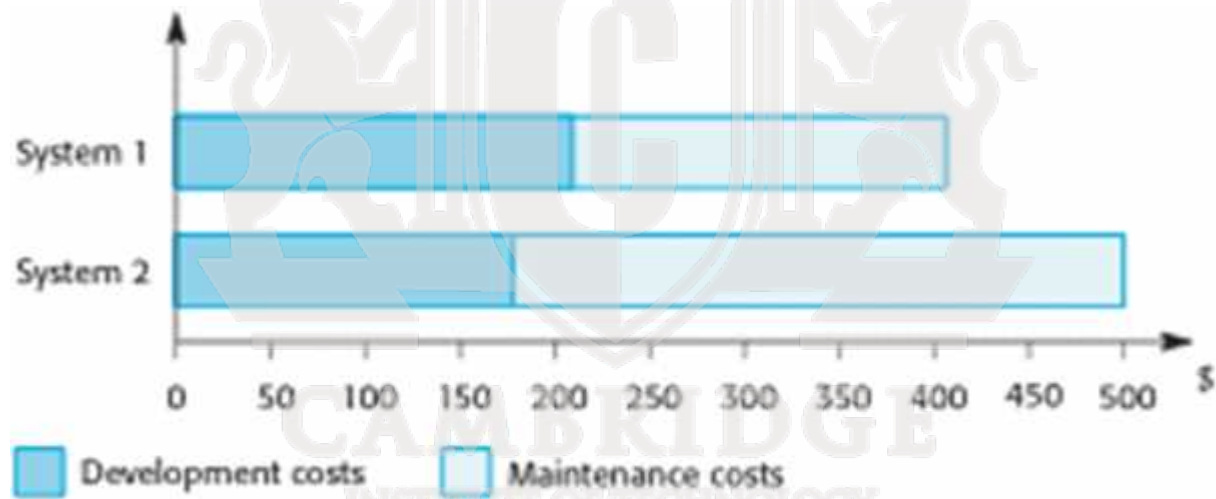
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Maintenance costs

- Usually greater than development costs (2^* to 100^* depending on the application).
- Affected by both technical and non-technical factors.
- Increases as software is maintained.
Maintenance corrupts the software structure so makes further maintenance more difficult.
- Ageing software can have high support costs (e.g. old languages, compilers etc.).

(SOURCE DIGINOTES)

Figure 9.9 Development and maintenance costs



(SOURCE DIGINOTES)

Maintenance cost factors

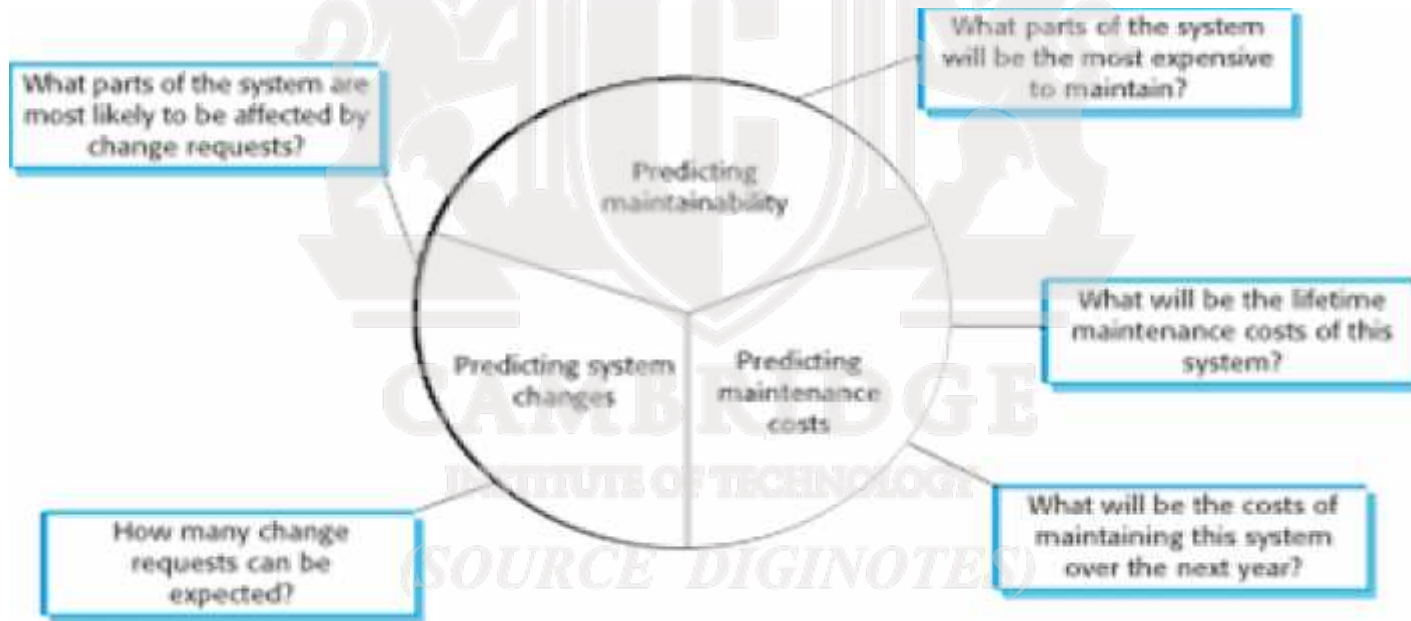
- Team stability
 - Maintenance costs are reduced if the same staff are involved with them for some time.
- Contractual responsibility
 - The developers of a system may have no contractual responsibility for maintenance so there is no incentive to design for future change.
- Staff skills
 - Maintenance staff are often inexperienced and have limited domain knowledge.
- Program age and structure
 - As programs age, their structure is degraded and they become harder to understand and change.

(SOURCE DIGINOTES)

Maintenance prediction

- Maintenance prediction is concerned with assessing which parts of the system may cause problems and have high maintenance costs
 - Change acceptance depends on the maintainability of the components affected by the change;
 - Implementing changes degrades the system and reduces its maintainability;
 - Maintenance costs depend on the number of changes and costs of change depend on maintainability.

Maintenance prediction



Change prediction

- Predicting the number of changes requires an understanding of the relationships between a system and its environment.
- Tightly coupled systems require changes whenever the environment is changed.
- Factors influencing this relationship are
 - Number and complexity of system interfaces;
 - Number of inherently volatile system requirements;
 - The business processes where the system is used.

Complexity metrics

- Predictions of maintainability can be made by assessing the complexity of system components.
- Studies have shown that most maintenance effort is spent on a relatively small number of system components.
- Complexity depends on
 - Complexity of control structures;
 - Complexity of data structures;
 - Object, method (procedure) and module size.

Process metrics

- Process metrics may be used to assess maintainability
 - Number of requests for corrective maintenance;
 - Average time required for impact analysis;
 - Average time taken to implement a change request;
 - Number of outstanding change requests.
- If any or all of these is increasing, this may indicate a decline in maintainability.

System re-engineering

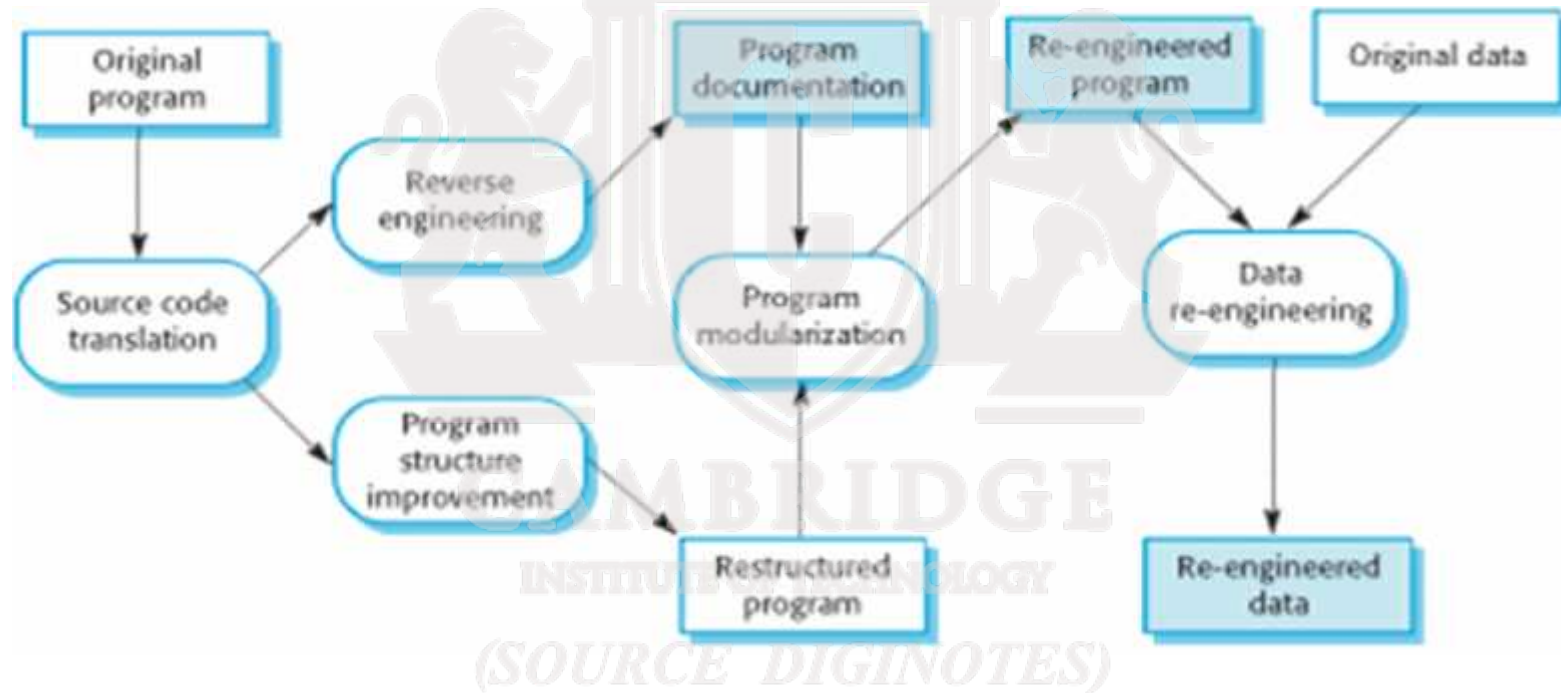
- Re-structuring or re-writing part or all of a legacy system without changing its functionality.
- Applicable where some but not all sub-systems of a larger system require frequent maintenance.
- Re-engineering involves adding effort to make them easier to maintain. The system may be re-structured and re-documented.

(SOURCE DIGINOTES)

Advantages of reengineering

- Reduced risk
 - There is a high risk in new software development. There may be development problems, staffing problems and specification problems.
- Reduced cost
 - The cost of re-engineering is often significantly less than the costs of developing new software.

The reengineering process



Reengineering process activities

- Source code translation
 - Convert code to a new language.
- Reverse engineering
 - Analyse the program to understand it;
- Program structure improvement
 - Restructure automatically for understandability;
- Program modularisation
 - Reorganise the program structure;
- Data reengineering
 - Clean-up and restructure system data.

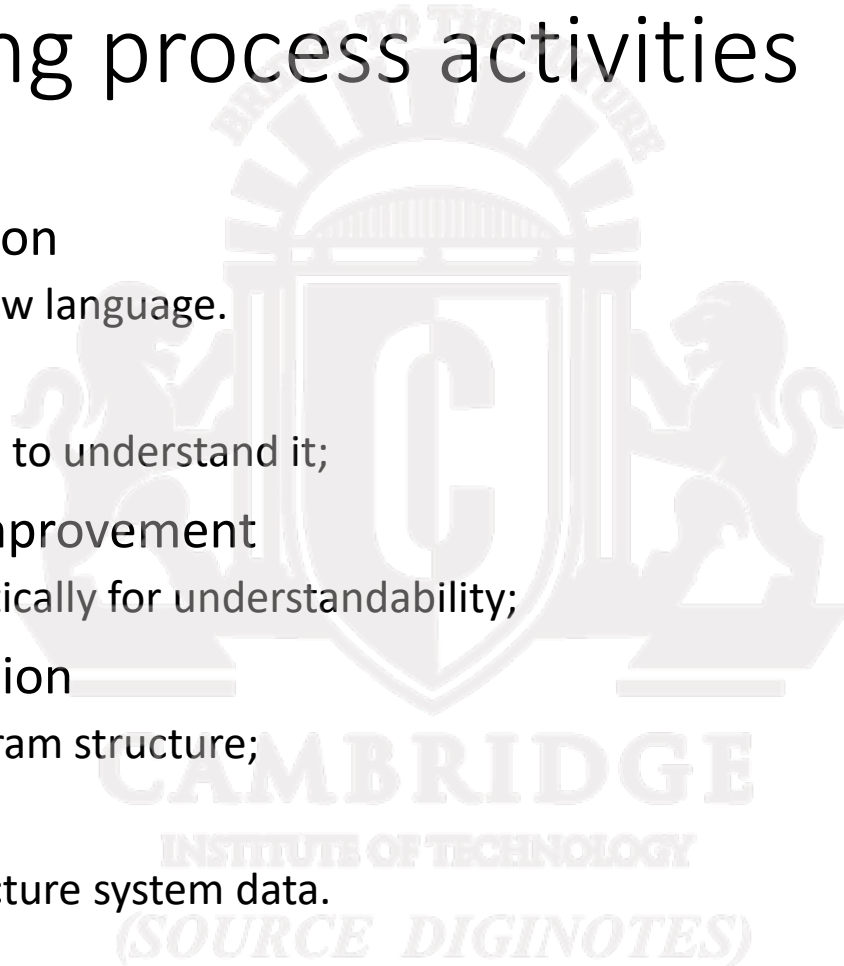
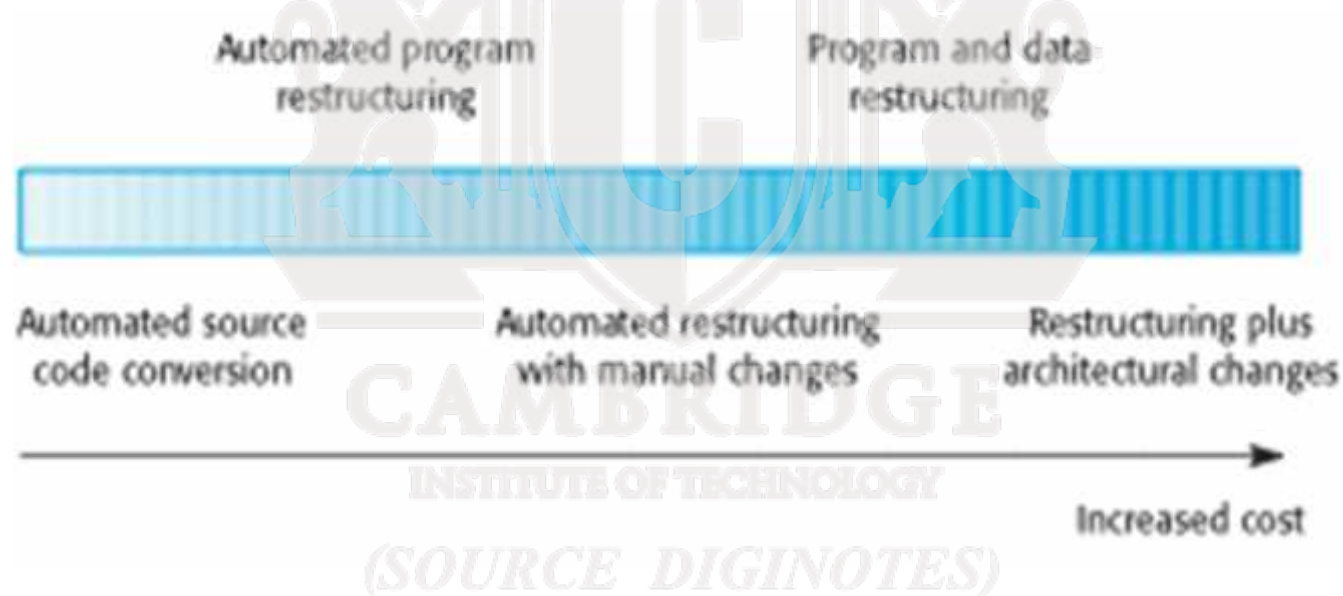


Figure 9.12 Reengineering approaches



Reengineering cost factors

- The quality of the software to be reengineered.
- The tool support available for reengineering.
- The extent of the data conversion which is required.
- The availability of expert staff for reengineering.
 - This can be a problem with old systems based on technology that is no longer widely used.

Preventative maintenance by refactoring

- Refactoring is the process of making improvements to a program to slow down degradation through change.
- You can think of refactoring as 'preventative maintenance' that reduces the problems of future change.
- Refactoring involves modifying a program to improve its structure, reduce its complexity or make it easier to understand.
- When you refactor a program, you should not add functionality but rather concentrate on program improvement.

(SOURCE DIGINOTES)

Refactoring and reengineering

- Re-engineering takes place after a system has been maintained for some time and maintenance costs are increasing. You use automated tools to process and re-engineer a legacy system to create a new system that is more maintainable.
- Refactoring is a continuous process of improvement throughout the development and evolution process. It is intended to avoid the structure and code degradation that increases the costs and difficulties of maintaining a system.

'Bad smells' in program code

- Duplicate code
 - The same or very similar code may be included at different places in a program. This can be removed and implemented as a single method or function that is called as required.
- Long methods
 - If a method is too long, it should be redesigned as a number of shorter methods.
- Switch (case) statements
 - These often involve duplication, where the switch depends on the type of a value. The switch statements may be scattered around a program. In object-oriented languages, you can often use polymorphism to achieve the same thing.

(SOURCE DIGINOTES)

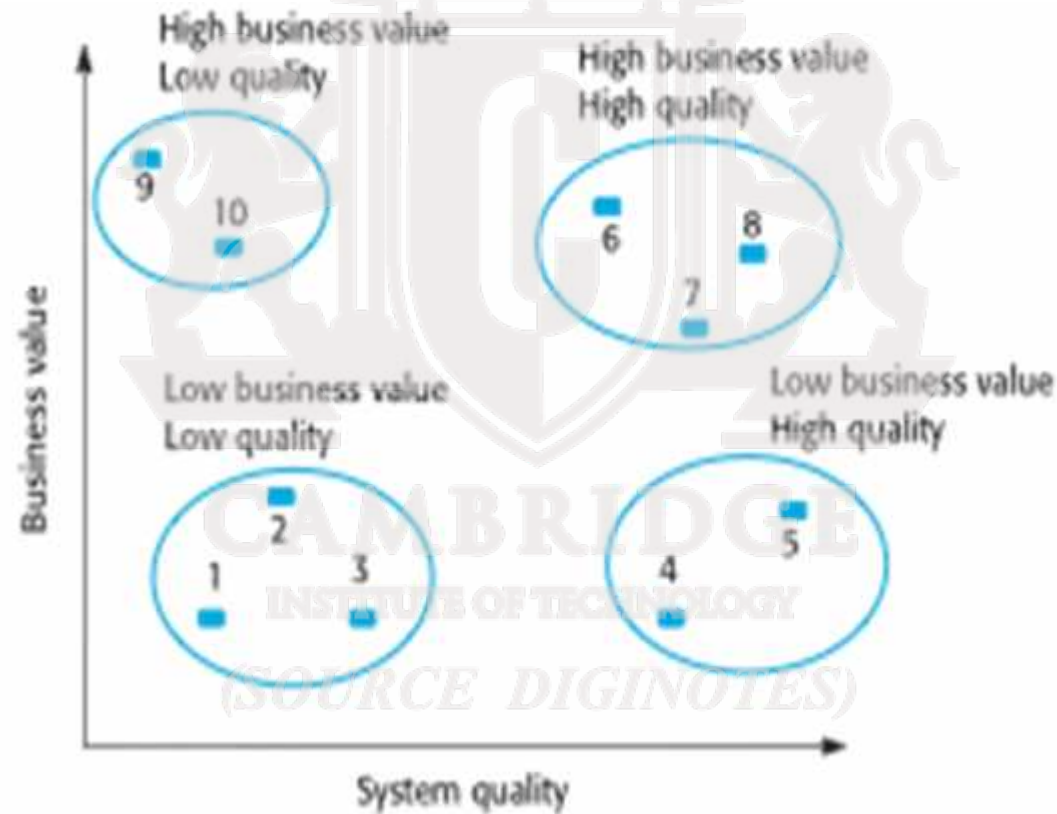
'Bad smells' in program code

- Data clumping
 - Data clumps occur when the same group of data items (fields in classes, parameters in methods) re-occur in several places in a program. These can often be replaced with an object that encapsulates all of the data.
- Speculative generality
 - This occurs when developers include generality in a program in case it is required in the future. This can often simply be removed.

Legacy system management

- Organisations that rely on legacy systems must choose a strategy for evolving these systems
 - Scrap the system completely and modify business processes so that it is no longer required;
 - Continue maintaining the system;
 - Transform the system by re-engineering to improve its maintainability;
 - Replace the system with a new system.
- The strategy chosen should depend on the system quality and its business value.

Figure 9.13 An example of a legacy system assessment



Legacy system categories

- Low quality, low business value
 - These systems should be scrapped.
- Low-quality, high-business value
 - These make an important business contribution but are expensive to maintain. Should be re-engineered or replaced if a suitable system is available.
- High-quality, low-business value
 - Replace with COTS, scrap completely or maintain.
- High-quality, high business value
 - Continue in operation using normal system maintenance.

(SOURCE DIGINOTES)

Business value assessment

- Assessment should take different viewpoints into account
 - System end-users;
 - Business customers;
 - Line managers;
 - IT managers;
 - Senior managers.
- Interview different stakeholders and collate results.

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Issues in business value assessment

- The use of the system
 - If systems are only used occasionally or by a small number of people, they may have a low business value.
- The business processes that are supported
 - A system may have a low business value if it forces the use of inefficient business processes.
- System dependability
 - If a system is not dependable and the problems directly affect business customers, the system has a low business value.
- The system outputs
 - If the business depends on system outputs, then the system has a high business value.

System quality assessment

- Business process assessment
 - How well does the business process support the current goals of the business?
- Environment assessment
 - How effective is the system's environment and how expensive is it to maintain?
- Application assessment
 - What is the quality of the application software system?

Business process assessment

- Use a viewpoint-oriented approach and seek answers from system stakeholders
 - Is there a defined process model and is it followed?
 - Do different parts of the organisation use different processes for the same function?
 - How has the process been adapted?
 - What are the relationships with other business processes and are these necessary?
 - Is the process effectively supported by the legacy application software?
- Example - a travel ordering system may have a low business value because of the widespread use of web-based ordering.

Factors used in environment assessment

Factor	Questions
Supplier stability	Is the supplier still in existence? Is the supplier financially stable and likely to continue in existence? If the supplier is no longer in business, does someone else maintain the systems?
Failure rate	Does the hardware have a high rate of reported failures? Does the support software crash and force system restarts?
Age	How old is the hardware and software? The older the hardware and support software, the more obsolete it will be. It may still function correctly but there could be significant economic and business benefits to moving to a more modern system.
Performance	Is the performance of the system adequate? Do performance problems have a significant effect on system users?

Factors used in environment assessment

Factor	Questions
Support requirements	What local support is required by the hardware and software? If there are high costs associated with this support, it may be worth considering system replacement.
Maintenance costs	What are the costs of hardware maintenance and support software licences? Older hardware may have higher maintenance costs than modern systems. Support software may have high annual licensing costs.
Interoperability	Are there problems interfacing the system to other systems? Can compilers, for example, be used with current versions of the operating system? Is hardware emulation required?

(SOURCE DIGINOTES)

Factors used in application assessment

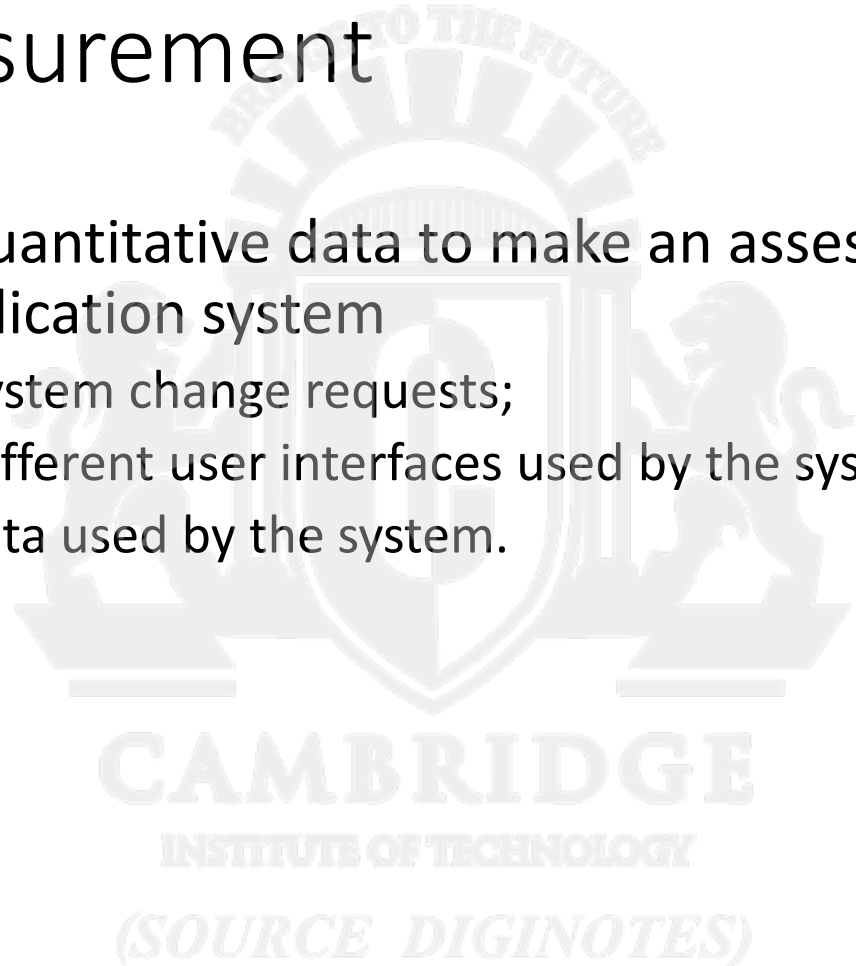
Factor	Questions
Understandability	How difficult is it to understand the source code of the current system? How complex are the control structures that are used? Do variables have meaningful names that reflect their function?
Documentation	What system documentation is available? Is the documentation complete, consistent, and current?
Data	Is there an explicit data model for the system? To what extent is data duplicated across files? Is the data used by the system up to date and consistent?
Performance	Is the performance of the application adequate? Do performance problems have a significant effect on system users?

Factors used in application assessment

Factor	Questions
Programming language	Are modern compilers available for the programming language used to develop the system? Is the programming language still used for new system development?
Configuration management	Are all versions of all parts of the system managed by a configuration management system? Is there an explicit description of the versions of components that are used in the current system?
Test data	Does test data for the system exist? Is there a record of regression tests carried out when new features have been added to the system?
Personnel skills	Are there people available who have the skills to maintain the application? Are there people available who have experience with the system?

System measurement

- You may collect quantitative data to make an assessment of the quality of the application system
 - The number of system change requests;
 - The number of different user interfaces used by the system;
 - The volume of data used by the system.



Module 4 – Project planning

Software pricing

- ✧ Plan-driven development
- ✧ Project scheduling
- ✧ Agile planning
- ✧ Estimation techniques

Project planning

- ✧ Project planning involves breaking down the work into parts and assign these to project team members, anticipate problems that might arise and prepare tentative solutions to those problems.
- ✧ The project plan, which is created at the start of a project, is used to communicate how the work will be done to the project team and customers, and to help assess progress on the project.

Planning stages

- ✧ At the proposal stage, when you are bidding for a contract to develop or provide a software system.
- ✧ During the project startup phase, when you have to plan who will work on the project, how the project will be broken down into increments, how resources will be allocated across your company, etc.
- ✧ Periodically throughout the project, when you modify your plan in the light of experience gained and information from monitoring the progress of the work.

Proposal planning

- ✧ Planning may be necessary with only outline software requirements.
- ✧ The aim of planning at this stage is to provide information that will be used in setting a price for the system to customers.

Software pricing

- ✧ Estimates are made to discover the cost, to the developer, of producing a software system.
 - You take into account, hardware, software, travel, training and effort costs.
- ✧ There is not a simple relationship between the development cost and the price charged to the customer.
- ✧ Broader organisational, economic, political and business considerations influence the price charged.

Factors affecting software pricing

Factor	Description
Market opportunity	A development organization may quote a low price because it wishes to move into a new segment of the software market. Accepting a low profit on one project may give the organization the opportunity to make a greater profit later. The experience gained may also help it develop new products.
Cost estimate uncertainty	If an organization is unsure of its cost estimate, it may increase its price by a contingency over and above its normal profit.
Contractual terms	A customer may be willing to allow the developer to retain ownership of the source code and reuse it in other projects. The price charged may then be less than if the software source code is handed over to the customer.

Plan-driven development

- ✧ Plan-driven or plan-based development is an approach to software engineering where the development process is planned in detail.
 - Plan-driven development is based on engineering project management techniques and is the 'traditional' way of managing large software development projects.
- ✧ A project plan is created that records the work to be done, who will do it, the development schedule and the work products.
- ✧ Managers use the plan to support project decision making and as a way of measuring progress.

Plan-driven development – pros and cons

- ✧ The arguments in favor of a plan-driven approach are that early planning allows organizational issues (availability of staff, other projects, etc.) to be closely taken into account, and that potential problems and dependencies are discovered before the project starts, rather than once the project is underway.
- ✧ The principal argument against plan-driven development is that many early decisions have to be revised because of changes to the environment in which the software is to be developed and used.

Project plans

- ✧ In a plan-driven development project, a project plan sets out the resources available to the project, the work breakdown and a schedule for carrying out the work.
- ✧ Plan sections
 - Introduction
 - Project organization
 - Risk analysis
 - Hardware and software resource requirements

- Work breakdown
- Project schedule
- Monitoring and reporting mechanisms

Project plan supplements

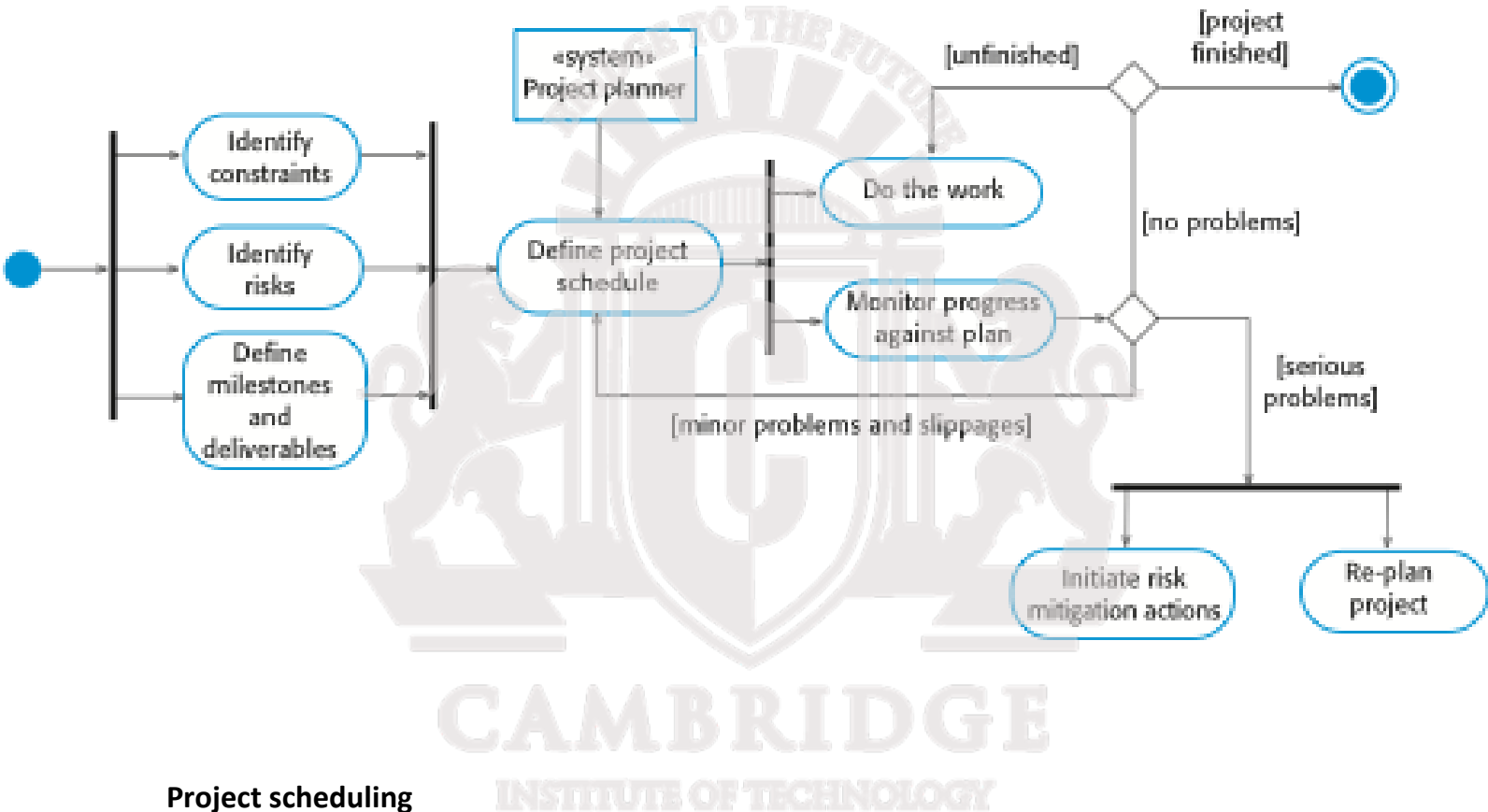
Plan	Description
Quality plan	Describes the quality procedures and standards that will be used in a project.
Validation plan	Describes the approach, resources, and schedule used for system validation.
Configuration management plan	Describes the configuration management procedures and structures to be used.
Maintenance plan	Predicts the maintenance requirements, costs, and effort.
Staff development plan	Describes how the skills and experience of the project team members will be developed.

The planning process

- ✧ **Project planning is an iterative process that starts when you create an initial project plan during the project startup phase.**
- ✧ **Plan changes are inevitable.**
 - **As more information about the system and the project team becomes available during the project, you should regularly revise the plan to reflect requirements, schedule and risk changes.**

- Changing business goals also leads to changes in project plans. As business goals change, this could affect all projects, which may then have to be re-planned.

The project planning process



Project scheduling

- ✧ Project scheduling is the process of deciding how the work in a project will be organized as separate tasks, and when and how these tasks will be executed.
- ✧ You estimate the calendar time needed to complete each task, the effort required and who will work on the tasks that have been identified.
- ✧ You also have to estimate the resources needed to complete each task, such as the disk space required on a server, the time required on specialized hardware, such as a simulator, and what the travel budget will be.

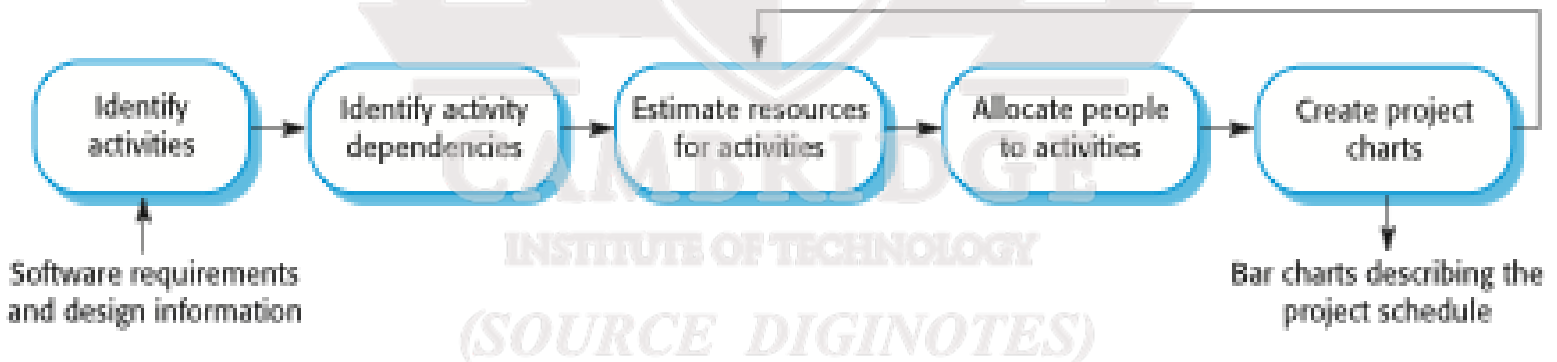
Project scheduling activities

- ✧ Split project into tasks and estimate time and resources required to complete each task.
- ✧ Organize tasks concurrently to make optimal use of workforce.
- ✧ Minimize task dependencies to avoid delays caused by one task waiting for another to complete.
- ✧ Dependent on project managers intuition and experience.

Milestones and deliverables

- ✧ Milestones are points in the schedule against which you can assess progress, for example, the handover of the system for testing.

Deliverables are work products that are delivered to the customer, e.g. a requirements document for the system



Scheduling problems

- ✧ Estimating the difficulty of problems and hence the cost of developing a solution is hard.
- ✧ Productivity is not proportional to the number of people working on a task.

- ✧ Adding people to a late project makes it later because of communication overheads.
- ✧ The unexpected always happens. Always allow contingency in planning.

Schedule representation

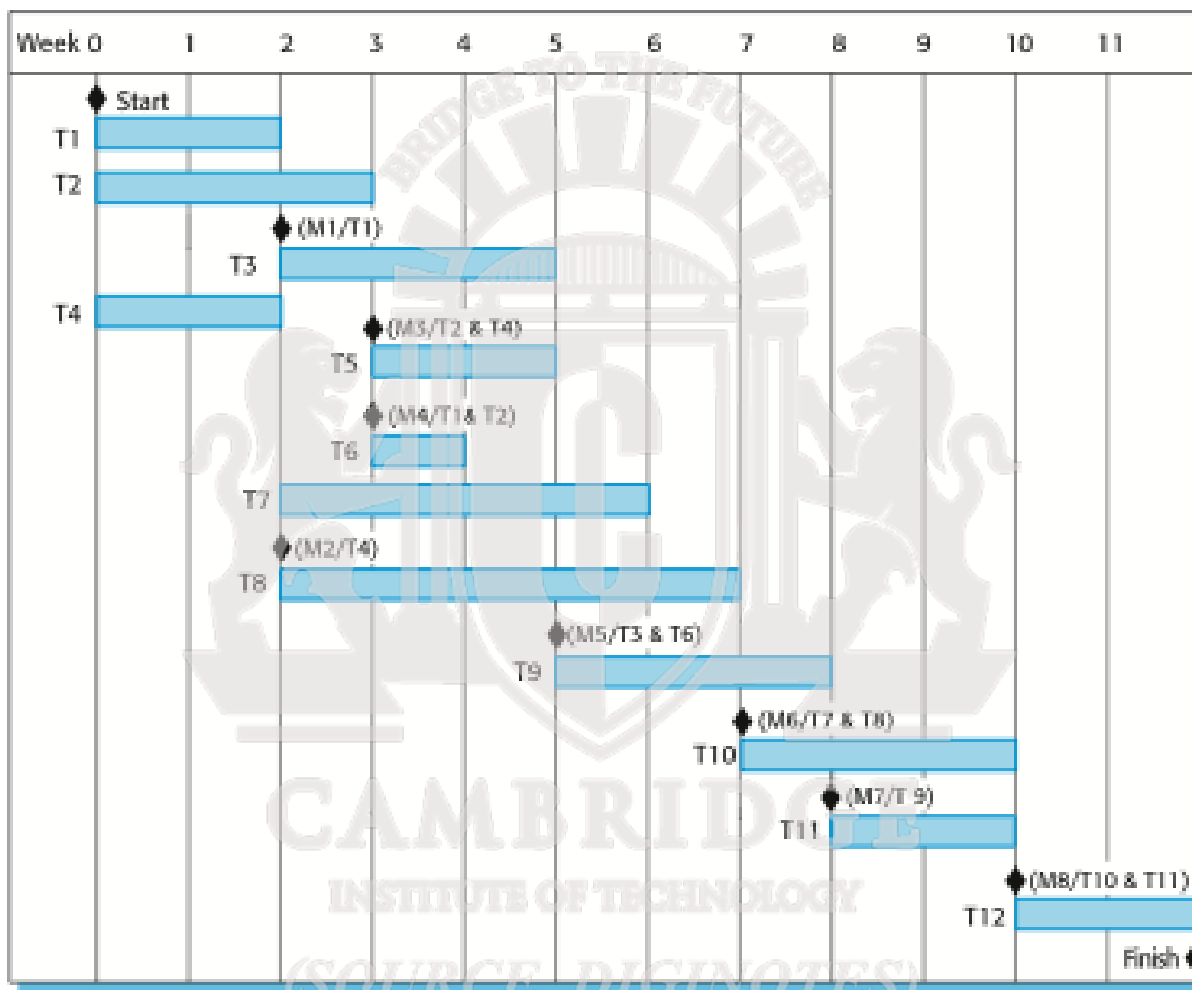
- ✧ Graphical notations are normally used to illustrate the project schedule.
- ✧ These show the project breakdown into tasks. Tasks should not be too small. They should take about a week or two.
- ✧ Bar charts are the most commonly used representation for project schedules. They show the schedule as activities or resources against time.

Tasks, durations, and dependencies

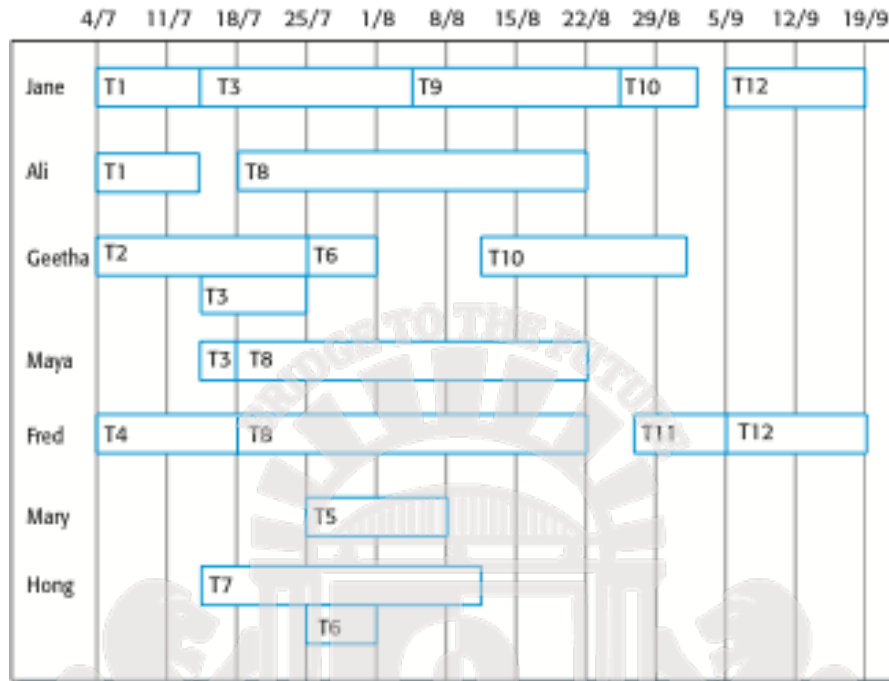
Task	Effort (person-days)	Duration (days)	Dependencies
T1	15	10	
T2	8	15	
T3	20	15	T1 (M1)
T4	5	10	
T5	5	10	T2, T4 (M3)
T6	10	5	T1, T2 (M4)
T7	25	20	T1 (M1)
T8	75	25	T4 (M2)
T9	10	15	T3, T6 (M5)
T10	20	15	T7, T8 (M6)

T11	10	10	T9 (M7)
T12	20	10	T10, T11 (M8)

Activity bar chart



Staff allocation chart



Estimation techniques

- ✧ Organizations need to make software effort and cost estimates. There are two types of technique that can be used to do this:
 - *Experience-based techniques* The estimate of future effort requirements is based on the manager's experience of past projects and the application domain. Essentially, the manager makes an informed judgment of what the effort requirements are likely to be.
 - *Algorithmic cost modeling* In this approach, a formulaic approach is used to compute the project effort based on estimates of product attributes, such as size, and process characteristics, such as experience of staff involved.

Experience-based approaches

- ✧ Experience-based techniques rely on judgments based on experience of past projects and the effort expended in these projects on software development activities.
- ✧ Typically, you identify the deliverables to be produced in a project and the different software components or systems that are to be developed.
- ✧ You document these in a spreadsheet, estimate them individually and compute the total effort required.
- ✧ It usually helps to get a group of people involved in the effort estimation and to ask each member of the group to explain their estimate.

Algorithmic cost modelling

- ✧ Cost is estimated as a mathematical function of product, project and process attributes whose values are estimated by project managers:
 - $\text{Effort} = A \cdot \text{Size}^B \cdot M$
 - A is an organisation-dependent constant, B reflects the disproportionate effort for large projects and M is a multiplier reflecting product, process and people attributes.
- ✧ The most commonly used product attribute for cost estimation is code size.
- ✧ Most models are similar but they use different values for A, B and M.

Estimation accuracy

- ✧ The size of a software system can only be known accurately when it is finished.
- ✧ Several factors influence the final size
 - Use of COTS and components;

- Programming language;
 - Distribution of system.
- ✧ As the development process progresses then the size estimate becomes more accurate.
- ✧ The estimates of the factors contributing to B and M are subjective and vary according to the judgment of the estimator.

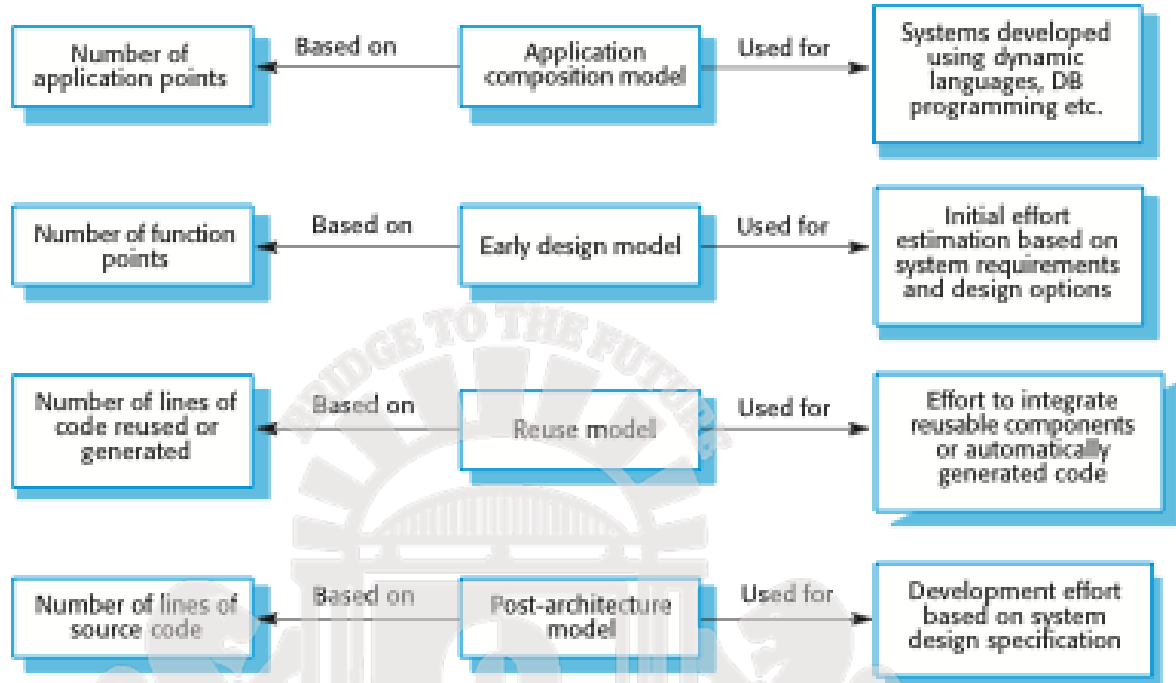
The COCOMO 2 model

- ✧ An empirical model based on project experience.
- ✧ Well-documented, 'independent' model which is not tied to a specific software vendor.
- ✧ Long history from initial version published in 1981 (COCOMO-81) through various instantiations to COCOMO 2.
- ✧ COCOMO 2 takes into account different approaches to software development, reuse, etc.

COCOMO 2 models

- ✧ COCOMO 2 incorporates a range of sub-models that produce increasingly detailed software estimates.
- ✧ The sub-models in COCOMO 2 are:
 - Application composition model. Used when software is composed from existing parts.
 - Early design model. Used when requirements are available but design has not yet started.
 - Reuse model. Used to compute the effort of integrating reusable components.
 - Post-architecture model. Used once the system architecture has been designed and more information about the system is available.

COCOMO estimation models



Application composition model

- ✧ Supports prototyping projects and projects where there is extensive reuse.
- ✧ Based on standard estimates of developer productivity in application (object) points/month.
- ✧ Takes CASE tool use into account.
- ✧ Formula is
 - $PM = (NAP \cdot (1 - \%reuse/100)) / PROD$
 - PM is the effort in person-months, NAP is the number of application points and PROD is the productivity.

Application-point productivity

Developer's experience and capability	Very low	Low	Nominal	High	Very high
ICASE maturity and capability	Very low	Low	Nominal	High	Very high
PROD (NAP/month)	4	7	13	25	50

Early design model

- ✧ Estimates can be made after the requirements have been agreed.
- ✧ Based on a standard formula for algorithmic models
 - $PM = A \cdot \text{Size}^B \cdot M$ where
 - $M = \text{PERS} \cdot \text{RCPX} \cdot \text{RUSE} \cdot \text{PDIF} \cdot \text{PREX} \cdot \text{FCIL} \cdot \text{SCED}$;

A = 2.94 in initial calibration, Size in KLOC, B varies from 1.1 to 1.24 depending on novelty of the project, development flexibility, risk management approaches and the process maturity

Multipliers

- ✧ Multipliers reflect the capability of the developers, the non-functional requirements, the familiarity with the development platform, etc.
 - RCPX - product reliability and complexity;
 - RUSE - the reuse required;
 - PDIF - platform difficulty;

- PREX - personnel experience;
- PERS - personnel capability;
- SCED - required schedule;
- FCIL - the team support facilities.

The reuse model

- ✧ Takes into account black-box code that is reused without change and code that has to be adapted to integrate it with new code.
- ✧ There are two versions:
 - Black-box reuse where code is not modified. An effort estimate (PM) is computed.
 - White-box reuse where code is modified. A size estimate equivalent to the number of lines of new source code is computed. This then adjusts the size estimate for new code.

Reuse model estimates 1

- ✧ For generated code:
 - $PM = (ASLOC * AT/100)/ATPROD$
 - ASLOC is the number of lines of generated code
 - AT is the percentage of code automatically generated.
 - ATPROD is the productivity of engineers in integrating this code.

Reuse model estimates 2

- ✧ When code has to be understood and integrated:
 - $ESLOC = ASLOC * (1-AT/100) * AAM$.
 - ASLOC and AT as before.

- AAM is the adaptation adjustment multiplier computed from the costs of changing the reused code, the costs of understanding how to integrate the code and the costs of reuse decision making.

Post-architecture level

- ✧ Uses the same formula as the early design model but with 17 rather than 7 associated multipliers.
- ✧ The code size is estimated as:
 - Number of lines of new code to be developed;
 - Estimate of equivalent number of lines of new code computed using the reuse model;
 - An estimate of the number of lines of code that have to be modified according to requirements changes.

The exponent term

- ✧ This depends on 5 scale factors (see next slide). Their sum/100 is added to 1.01
- ✧ A company takes on a project in a new domain. The client has not defined the process to be used and has not allowed time for risk analysis. The company has a CMM level 2 rating.
 - Precedentness - new project (4)
 - Development flexibility - no client involvement - Very high (1)
 - Architecture/risk resolution - No risk analysis - V. Low .(5)
 - Team cohesion - new team - nominal (3)
 - Process maturity - some control - nominal (3)
- ✧ Scale factor is therefore 1.17.

Scale factors used in the exponent computation in the post-architecture model

Scale factor	Explanation
Precedentedness	Reflects the previous experience of the organization with this type of project. Very low means no previous experience; extra-high means that the organization is completely familiar with this application domain.
Development flexibility	Reflects the degree of flexibility in the development process. Very low means a prescribed process is used; extra-high means that the client sets only general goals.
Architecture/risk resolution	Reflects the extent of risk analysis carried out. Very low means little analysis; extra-high means a complete and thorough risk analysis.
Team cohesion	Reflects how well the development team knows each other and work together. Very low means very difficult interactions; extra-high means an integrated and effective team with no communication problems.
Process maturity	Reflects the process maturity of the organization. The computation of this value depends on the CMM Maturity Questionnaire, but an estimate can be achieved by subtracting the CMM process maturity level from 5.

Multipliers

- ✧ Product attributes
 - Concerned with required characteristics of the software product being developed.
- ✧ Computer attributes

- Constraints imposed on the software by the hardware platform.
- ✧ Personnel attributes
 - Multipliers that take the experience and capabilities of the people working on the project into account.
- ✧ Project attributes
 - Concerned with the particular characteristics of the software development project.

The effect of cost drivers on effort estimates

Exponent value	1.17
System size (including factors for reuse and requirements volatility)	128,000 DSI
Initial COCOMO estimate without cost drivers	730 person-months
Reliability	Very high, multiplier = 1.39
Complexity	Very high, multiplier = 1.3
Memory constraint	High, multiplier = 1.21
Tool use	Low, multiplier = 1.12
Schedule	Accelerated, multiplier = 1.29
Adjusted COCOMO estimate	2,306 person-months

The effect of cost drivers on effort estimates

Exponent value

Exponent value	1.17
Reliability	Very low, multiplier = 0.75
Complexity	Very low, multiplier = 0.75
Memory constraint	None, multiplier = 1
Tool use	Very high, multiplier = 0.72
Schedule	Normal, multiplier = 1
Adjusted COCOMO estimate	295 person-months

Project duration and staffing

- ✧ As well as effort estimation, managers must estimate the calendar time required to complete a project and when staff will be required.
- ✧ Calendar time can be estimated using a COCOMO 2 formula
 - $TDEV = 3 \sqrt{(PM)^{(0.33+0.2*(B-1.01))}}$
 - PM is the effort computation and B is the exponent computed as discussed above (B is 1 for the early prototyping model). This computation predicts the nominal schedule for the project.
- ✧ The time required is independent of the number of people working on the project.

Staffing requirements

- ✧ Staff required can't be computed by dividing the development time by the required schedule.

- ✧ The number of people working on a project varies depending on the phase of the project.
- ✧ The more people who work on the project, the more total effort is usually required.
- ✧ A very rapid build-up of people often correlates with schedule slippage.

Key points

- ✧ Estimation techniques for software may be experience-based, where managers judge the effort required, or algorithmic, where the effort required is computed from other estimated project parameters.
- ✧ The COCOMO II costing model is an algorithmic cost model that uses project, product, hardware and personnel attributes as well as product size and complexity attributes to derive a cost estimate.

Chapter 24 - Quality Management

- ✧ Software quality
- ✧ Software standards
- ✧ Reviews and inspections
- ✧ Software measurement and metrics

Software quality management

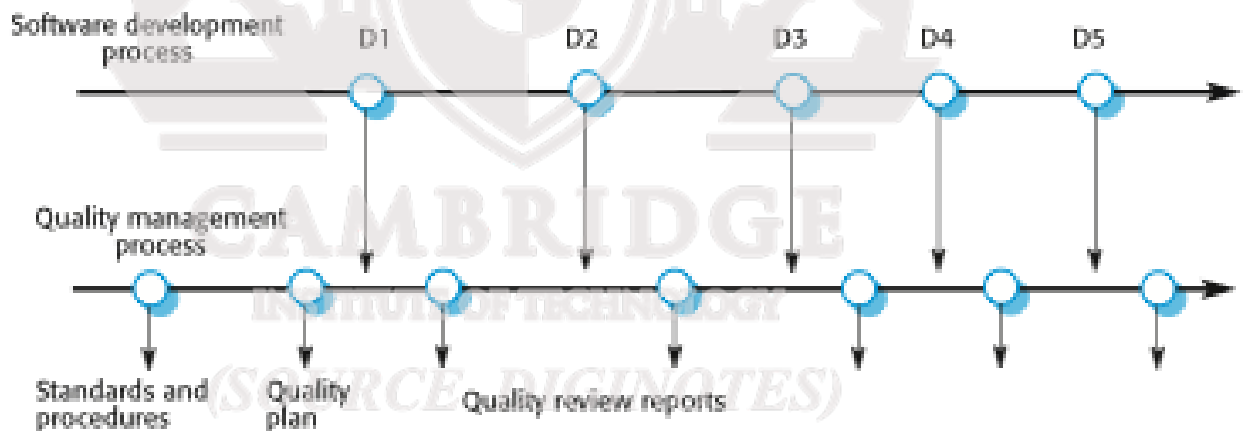
- ✧ Concerned with ensuring that the required level of quality is achieved in a software product.
- ✧ Three principal concerns:
 - At the organizational level, quality management is concerned with establishing a framework of organizational processes and standards that will lead to high-quality software.
 - At the project level, quality management involves the application of specific quality processes and checking that these planned processes have been followed.

- At the project level, quality management is also concerned with establishing a quality plan for a project. The quality plan should set out the quality goals for the project and define what processes and standards are to be used.

Quality management activities

- ✧ Quality management provides an independent check on the software development process.
- ✧ The quality management process checks the project deliverables to ensure that they are consistent with organizational standards and goals
- ✧ The quality team should be independent from the development team so that they can take an objective view of the software. This allows them to report on software quality without being influenced by software development issues.

Quality management and software development



Quality planning

- ✧ A quality plan sets out the desired product qualities and how these are assessed and defines the most significant quality attributes.

- ✧ The quality plan should define the quality assessment process.
- ✧ It should set out which organisational standards should be applied and, where necessary, define new standards to be used.

Quality plans

- ✧ Quality plan structure
 - Product introduction;
 - Product plans;
 - Process descriptions;
 - Quality goals;
 - Risks and risk management.
- ✧ Quality plans should be short, succinct documents
 - If they are too long, no-one will read them.

Scope of quality management

- ✧ Quality management is particularly important for large, complex systems. The quality documentation is a record of progress and supports continuity of development as the development team changes.
- ✧ For smaller systems, quality management needs less documentation and should focus on establishing a quality culture.

Software quality

- ✧ Quality, simplistically, means that a product should meet its specification.
- ✧ This is problematical for software systems
 - There is a tension between customer quality requirements (efficiency, reliability, etc.) and developer quality requirements (maintainability, reusability, etc.);
 - Some quality requirements are difficult to specify in an unambiguous way;

- Software specifications are usually incomplete and often inconsistent.
- ✧ The focus may be 'fitness for purpose' rather than specification conformance.

Software fitness for purpose

- ✧ Have programming and documentation standards been followed in the development process?
- ✧ Has the software been properly tested?
- ✧ Is the software sufficiently dependable to be put into use?
- ✧ Is the performance of the software acceptable for normal use?
- ✧ Is the software usable?
- ✧ Is the software well-structured and understandable?

Software quality attributes

Safety	Understandability	Portability
Security	Testability	Usability
Reliability	Adaptability	Reusability
Resilience	Modularity	Efficiency
Robustness	Complexity	Learnability

Quality conflicts

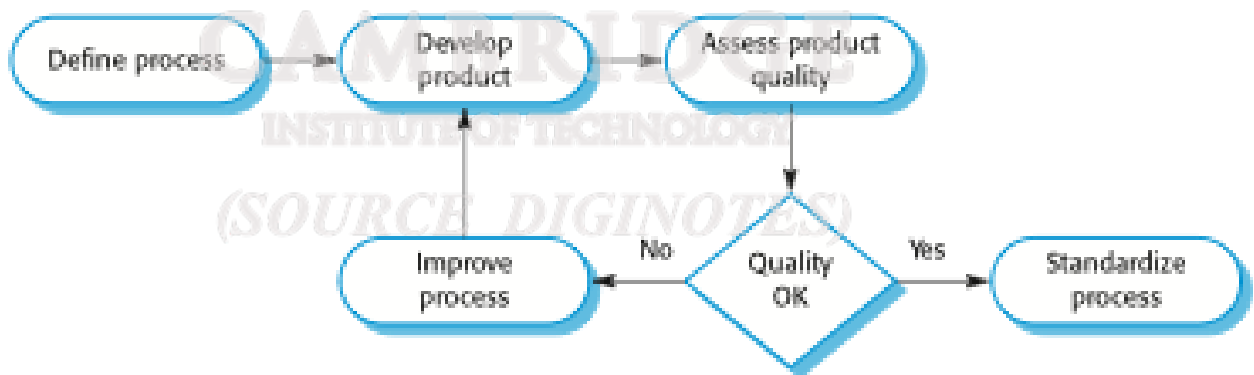
- ✧ It is not possible for any system to be optimized for all of these attributes – for example, improving robustness may lead to loss of performance.
- ✧ The quality plan should therefore define the most important quality attributes for the software that is being developed.

- ✧ The plan should also include a definition of the quality assessment process, an agreed way of assessing whether some quality, such as maintainability or robustness, is present in the product.

Process and product quality

- ✧ The quality of a developed product is influenced by the quality of the production process.
- ✧ This is important in software development as some product quality attributes are hard to assess.
- ✧ However, there is a very complex and poorly understood relationship between software processes and product quality.
 - The application of individual skills and experience is particularly important in software development;
 - External factors such as the novelty of an application or the need for an accelerated development schedule may impair product quality.

Process-based quality



Software standards

- ✧ Standards define the required attributes of a product or process. They play an important role in quality management.
- ✧ Standards may be international, national, organizational or project standards.
- ✧ Product standards define characteristics that all software components should exhibit e.g. a common programming style.
- ✧ Process standards define how the software process should be enacted.

Importance of standards

- ✧ Encapsulation of best practice- avoids repetition of past mistakes.
- ✧ They are a framework for defining what quality means in a particular setting i.e. that organization's view of quality.
- ✧ They provide continuity - new staff can understand the organisation by understanding the standards that are used.

Product and process standards

Product standards	Process standards
Design review form	Design review conduct
Requirements document structure	Submission of new code for system building
Method header format	Version release process
Java programming style	Project plan approval process
Project plan format	Change control process
Change request form	Test recording process

Problems with standards

- ✧ They may not be seen as relevant and up-to-date by software engineers.
- ✧ They often involve too much bureaucratic form filling.
- ✧ If they are unsupported by software tools, tedious form filling work is often involved to maintain the documentation associated with the standards.

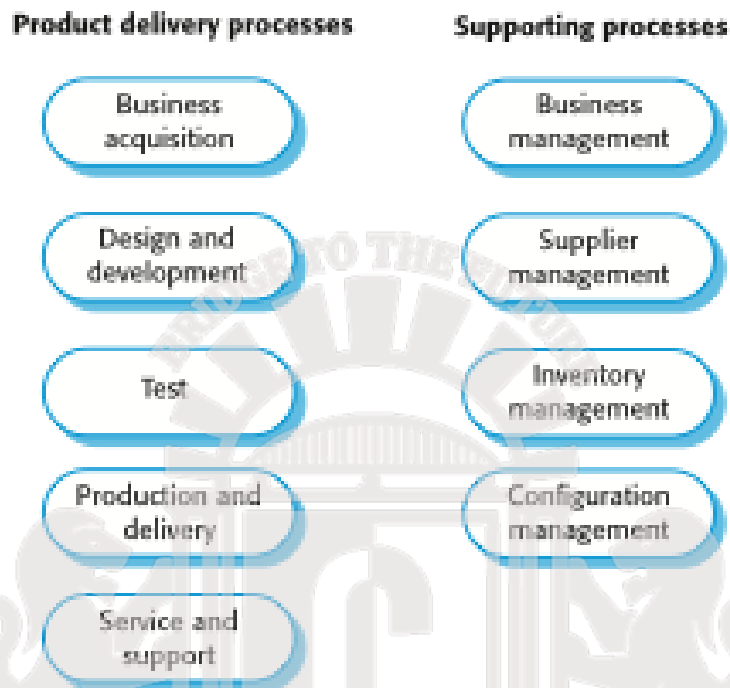
Standards development

- ✧ Involve practitioners in development. Engineers should understand the rationale underlying a standard.
- ✧ Review standards and their usage regularly. Standards can quickly become outdated and this reduces their credibility amongst practitioners.
- ✧ Detailed standards should have specialized tool support. Excessive clerical work is the most significant complaint against standards.
 - Web-based forms are not good enough.

ISO 9001 standards framework

- ✧ An international set of standards that can be used as a basis for developing quality management systems.
- ✧ ISO 9001, the most general of these standards, applies to organizations that design, develop and maintain products, including software.
- ✧ The ISO 9001 standard is a framework for developing software standards.
 - It sets out general quality principles, describes quality processes in general and lays out the organizational standards and procedures that should be defined. These should be documented in an organizational quality manual.

ISO 9001 core processes



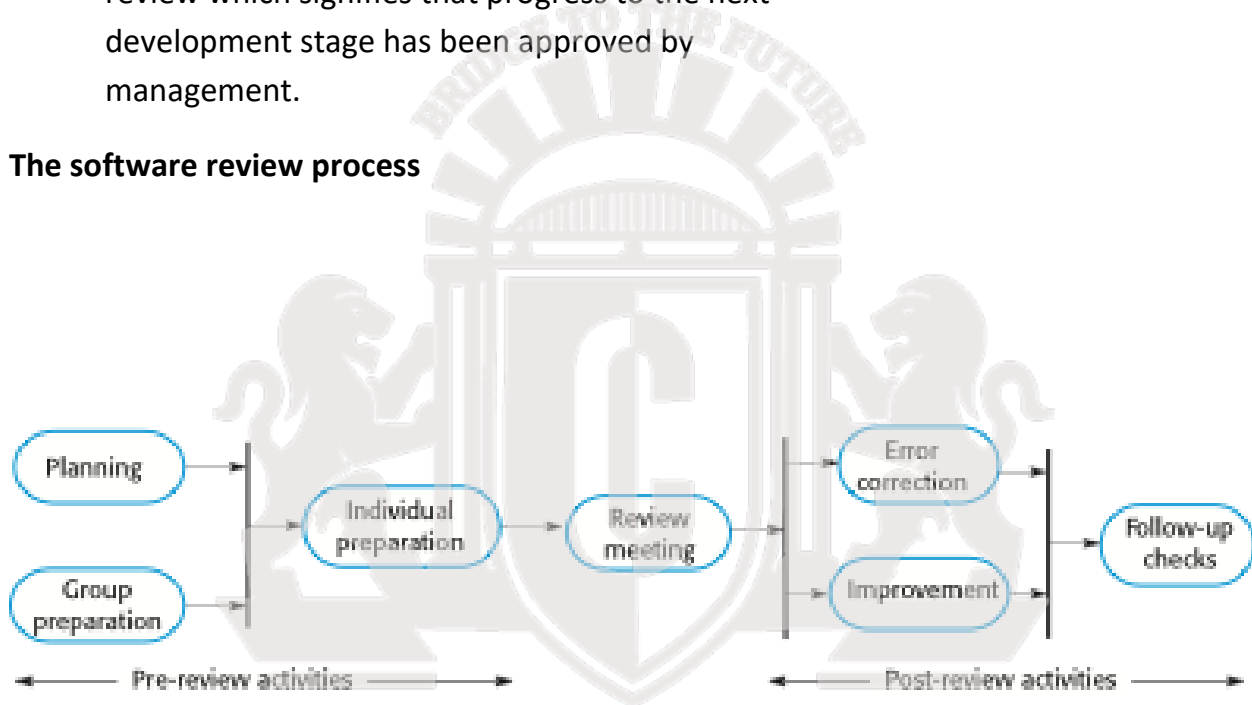
Reviews and inspections

- ✧ A group examines part or all of a process or system and its documentation to find potential problems.
- ✧ Software or documents may be 'signed off' at a review which signifies that progress to the next development stage has been approved by management.
- ✧ There are different types of review with different objectives
 - Inspections for defect removal (product);
 - Reviews for progress assessment (product and process);
 - Quality reviews (product and standards).

Quality reviews

- ✧ A group of people carefully examine part or all of a software system and its associated documentation.
- ✧ Code, designs, specifications, test plans, standards, etc. can all be reviewed.
- ✧ Software or documents may be 'signed off' at a review which signifies that progress to the next development stage has been approved by management.

The software review process



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Software measurement and metrics

- ✧ Software measurement is concerned with deriving a numeric value for an attribute of a software product or process.
- ✧ This allows for objective comparisons between techniques and processes.
- ✧ Although some companies have introduced measurement programmes, most organisations still don't make systematic use of software measurement.

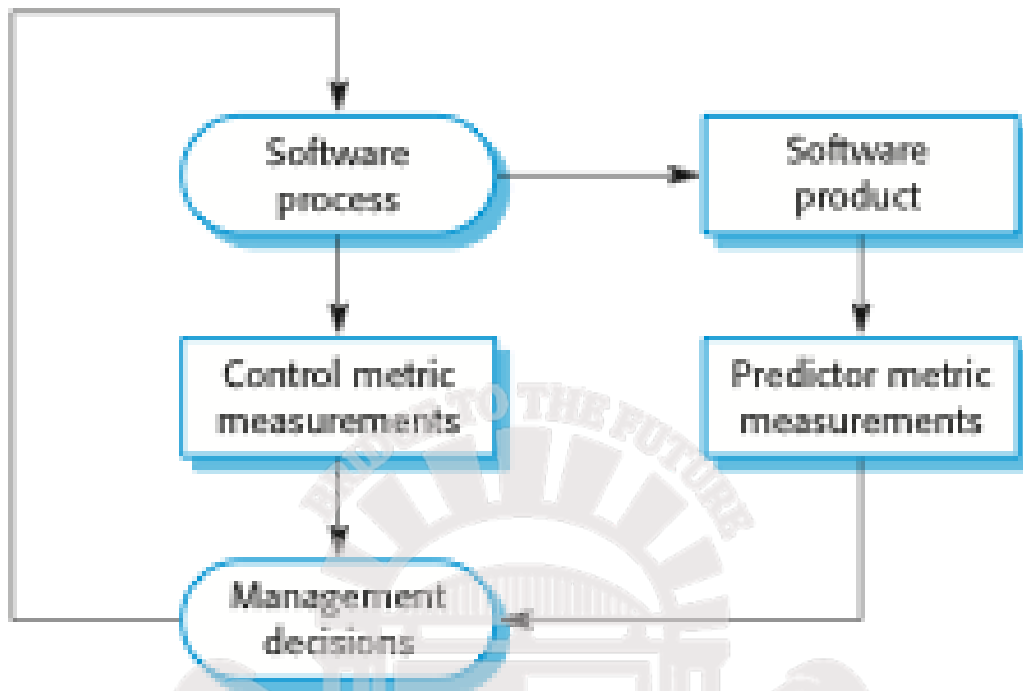
There are few established standards in this area

Software metric

- ✧ Any type of measurement which relates to a software system, process or related documentation
 - Lines of code in a program, the Fog index, number of person-days required to develop a component.
- ✧ Allow the software and the software process to be quantified.
- ✧ May be used to predict product attributes or to control the software process.
- ✧ Product metrics can be used for general predictions or to identify anomalous components.

Predictor and control measurements

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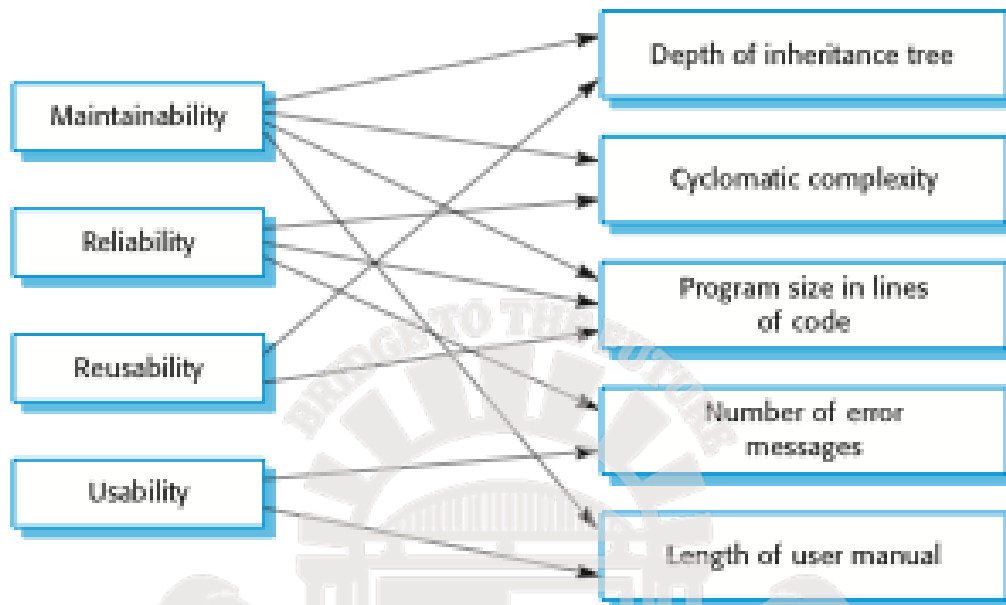
Use of measurements

- ✧ To assign a value to system quality attributes
 - By measuring the characteristics of system components, such as their cyclomatic complexity, and then aggregating these measurements, you can assess system quality attributes, such as maintainability.
- ✧ To identify the system components whose quality is sub-standard
 - Measurements can identify individual components with characteristics that deviate from the norm. For example, you can measure components to discover those with the highest complexity. These are most likely to contain bugs because the complexity makes them harder to understand.

Relationships between internal and external software

External quality attributes

Internal attributes



Problems with measurement in industry

- ✧ It is impossible to quantify the return on investment of introducing an organizational metrics program.
- ✧ There are no standards for software metrics or standardized processes for measurement and analysis.
- ✧ In many companies, software processes are not standardized and are poorly defined and controlled.
- ✧ Most work on software measurement has focused on code-based metrics and plan-driven development processes. However, more and more software is now developed by configuring ERP systems or COTS.
- ✧ Introducing measurement adds additional overhead to processes.

Product metrics

- ✧ A quality metric should be a predictor of product quality.
- ✧ Classes of product metric

- Dynamic metrics which are collected by measurements made of a program in execution;
- Static metrics which are collected by measurements made of the system representations;
- Dynamic metrics help assess efficiency and reliability
- Static metrics help assess complexity, understandability and maintainability.

Static software product metrics

Software metric	Description
Fan-in/Fan-out	Fan-in is a measure of the number of functions or methods that call another function or method (say X). Fan-out is the number of functions that are called by function X. A high value for fan-in means that X is tightly coupled to the rest of the design and changes to X will have extensive knock-on effects. A high value for fan-out suggests that the overall complexity of X may be high because of the complexity of the control logic needed to coordinate the called components.
Length of code	This is a measure of the size of a program. Generally, the larger the size of the code of a component, the more complex and error-prone that component is likely to be. Length of code has been shown to be one of the most reliable metrics for predicting error-proneness in components.

Static software product metrics

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Static software product metrics

Software metric	Description
Cyclomatic complexity	This is a measure of the control complexity of a program. This control complexity may be related to program understandability. I discuss cyclomatic complexity in Chapter 8.

Length of identifiers	This is a measure of the average length of identifiers (names for variables, classes, methods, etc.) in a program. The longer the identifiers, the more likely they are to be meaningful and hence the more understandable the program.
Depth of conditional nesting	This is a measure of the depth of nesting of if-statements in a program. Deeply nested if-statements are hard to understand and potentially error-prone.
Fog index	This is a measure of the average length of words and sentences in documents. The higher the value of a document's Fog index, the more difficult the document is to understand.

The CK object-oriented metrics suite

Object-oriented metric	Description
Weighted methods per class (WMC)	This is the number of methods in each class, weighted by the complexity of each method. Therefore, a simple method may have a complexity of 1, and a large and complex method a much higher value. The larger the value for this metric, the more complex the object class. Complex objects are more likely to be difficult to understand. They may not be logically cohesive, so cannot be reused effectively as superclasses in an inheritance tree.
Depth of inheritance tree (DIT)	This represents the number of discrete levels in the inheritance tree where subclasses inherit attributes and operations (methods) from superclasses. The deeper the inheritance tree, the more complex the design. Many object classes may have to be understood to understand the object classes at the leaves of the tree.
Number of	This is a measure of the number of immediate subclasses in a class. It measures the breadth of a class hierarchy, whereas DIT measures its depth.

children (NOC)

A high value for NOC may indicate greater reuse. It may mean that more effort should be made in validating base classes because of the number of subclasses that depend on them.



Module -5 – Agile Software Development

Topics covered

- ✧ Agile methods
- ✧ Plan-driven and agile development
- ✧ Extreme programming
- ✧ Agile project management
- ✧ Scaling agile methods

Reducing the costs of rework

- ✧ Change avoidance, where the software process includes activities that can anticipate possible changes before significant rework is required.
 - For example, a prototype system may be developed to show some key features of the system to customers.
- ✧ Change tolerance, where the process is designed so that changes can be accommodated at relatively low cost.
 - This normally involves some form of incremental development. Proposed changes may be implemented in increments that have not yet been developed. If this is impossible, then only a single increment (a small part of the system) may have be altered to incorporate the change.

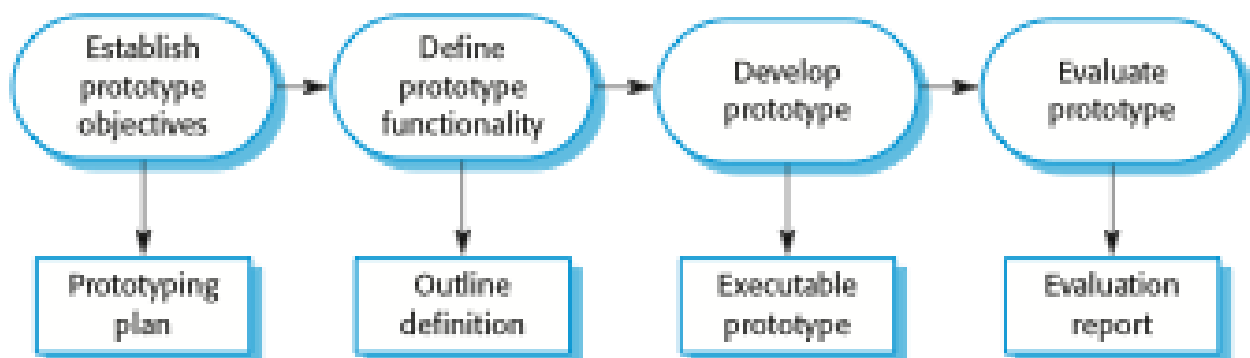
Software prototyping

- ✧ A prototype is an initial version of a system used to demonstrate concepts and try out design options.
- ✧ A prototype can be used in:
 - The requirements engineering process to help with requirements elicitation and validation;
 - In design processes to explore options and develop a UI design;
 - In the testing process to run back-to-back tests.

Benefits of prototyping

- ✧ Improved system usability.
- ✧ A closer match to users' real needs.
- ✧ Improved design quality.
- ✧ Improved maintainability.
- ✧ Reduced development effort.

The process of prototype development



Prototype development

- ✧ May be based on rapid prototyping languages or tools
- ✧ May involve leaving out functionality
 - Prototype should focus on areas of the product that are not well-understood;
 - Error checking and recovery may not be included in the prototype;
 - Focus on functional rather than non-functional requirements such as reliability and security

Throw-away prototypes

- ✧ Prototypes should be discarded after development as they are not a good basis for a production system:
 - It may be impossible to tune the system to meet non-functional requirements;
 - Prototypes are normally undocumented;
 - The prototype structure is usually degraded through rapid change;
 - The prototype probably will not meet normal organisational quality standards.

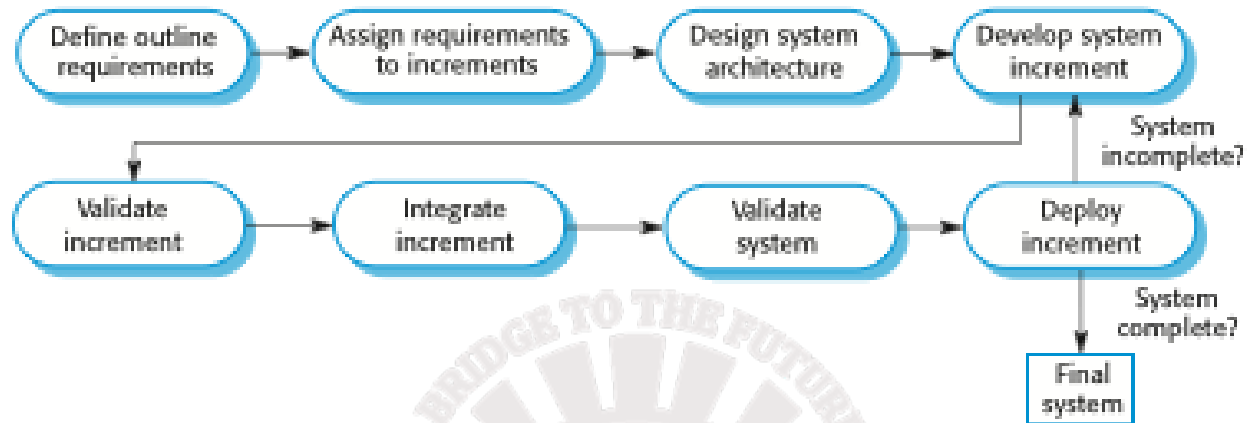
Incremental delivery

- ✧ Rather than deliver the system as a single delivery, the development and delivery is broken down into increments with each increment delivering part of the required functionality.
- ✧ User requirements are prioritised and the highest priority requirements are included in early increments.
- ✧ Once the development of an increment is started, the requirements are frozen though requirements for later increments can continue to evolve.

Incremental development and delivery

- ✧ Incremental development
 - Develop the system in increments and evaluate each increment before proceeding to the development of the next increment;
 - Normal approach used in agile methods;
 - Evaluation done by user/customer proxy.
- ✧ Incremental delivery
 - Deploy an increment for use by end-users;
 - More realistic evaluation about practical use of software;
 - Difficult to implement for replacement systems as increments have less functionality than the system being replaced.

Incremental delivery



Incremental delivery advantages

- ✧ Customer value can be delivered with each increment so system functionality is available earlier.
- ✧ Early increments act as a prototype to help elicit requirements for later increments.
- ✧ Lower risk of overall project failure.
- ✧ The highest priority system services tend to receive the most testing.

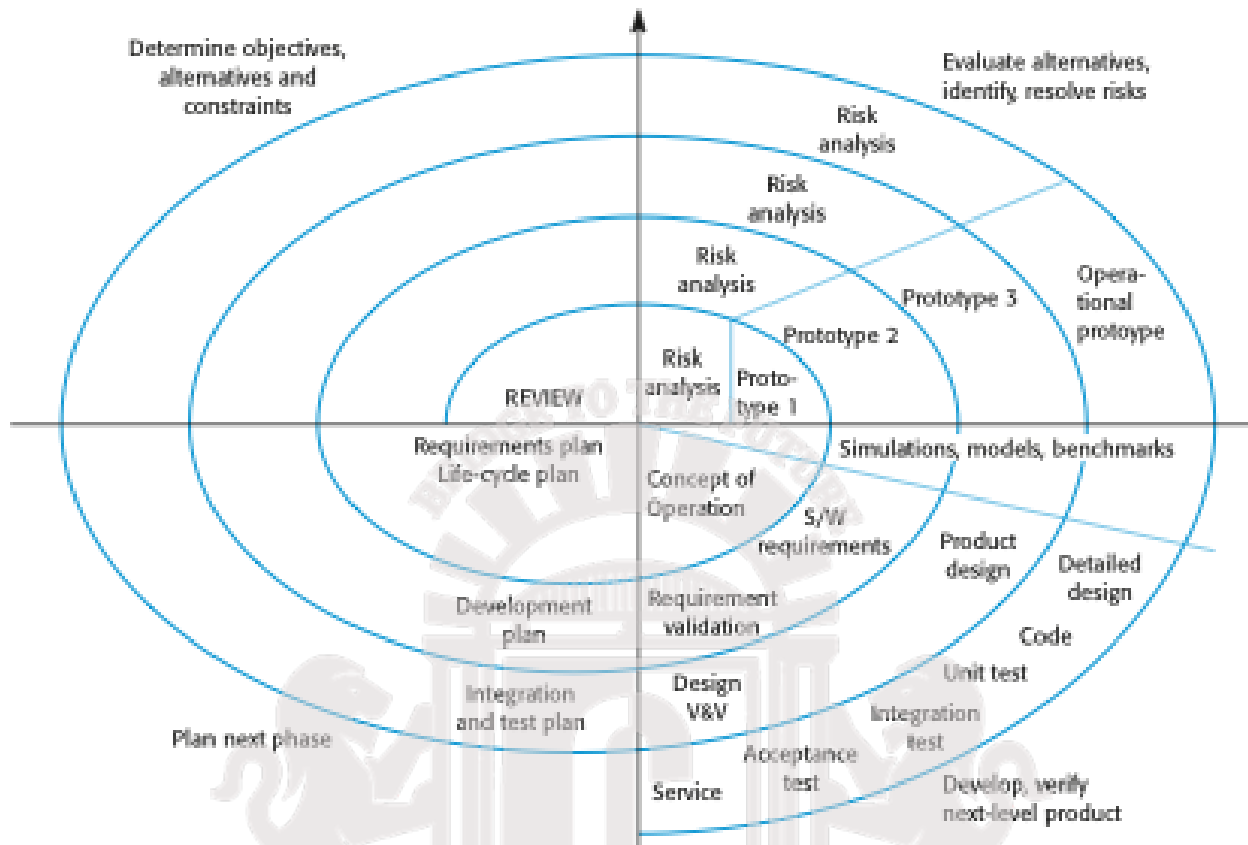
Incremental delivery problems

- ✧ Most systems require a set of basic facilities that are used by different parts of the system.
 - As requirements are not defined in detail until an increment is to be implemented, it can be hard to identify common facilities that are needed by all increments.

- ✧ The essence of iterative processes is that the specification is developed in conjunction with the software.
 - However, this conflicts with the procurement model of many organizations, where the complete system specification is part of the system development contract.

Boehm's spiral model

- ✧ Process is represented as a spiral rather than as a sequence of activities with backtracking.
- ✧ Each loop in the spiral represents a phase in the process.
- ✧ No fixed phases such as specification or design - loops in the spiral are chosen depending on what is required.
- ✧ Risks are explicitly assessed and resolved throughout the process.



Spiral model sectors

- ✧ Objective setting
 - Specific objectives for the phase are identified.
- ✧ Risk assessment and reduction
 - Risks are assessed and activities put in place to reduce the key risks.
- ✧ Development and validation
 - A development model for the system is chosen which can be any of the generic models.
- ✧ Planning

- The project is reviewed and the next phase of the spiral is planned.

Spiral model usage

- ✧ Spiral model has been very influential in helping people think about iteration in software processes and introducing the risk-driven approach to development.
- ✧ In practice, however, the model is rarely used as published for practical software development.

Rapid software development

- ✧ Rapid development and delivery is now often the most important requirement for software systems
 - Businesses operate in a fast –changing requirement and it is practically impossible to produce a set of stable software requirements
 - Software has to evolve quickly to reflect changing business needs.
- ✧ Rapid software development
 - Specification, design and implementation are inter-leaved
 - System is developed as a series of versions with stakeholders involved in version evaluation
 - User interfaces are often developed using an IDE and graphical toolset.

Agile methods

✧ Dissatisfaction with the overheads involved in software design methods of the 1980s and 1990s led to the creation of agile methods. These methods:

- Focus on the code rather than the design
- Are based on an iterative approach to software development
- Are intended to deliver working software quickly and evolve this quickly to meet changing requirements.

✧ The aim of agile methods is to reduce overheads in the software process (e.g. by limiting documentation) and to be able to respond quickly to changing requirements without excessive rework.

Agile manifesto

✧ *We are uncovering better ways of developing software by doing it and helping others do it. Through this work we have come to value:*

- *Individuals and interactions over processes and tools*
- *Working software over comprehensive documentation*
- *Customer collaboration over contract negotiation*
- *Responding to change over following a plan*

✧ *That is, while there is value in the items on the right, we value the items on the left more.*

The principles of agile methods

Principle	Description
Customer involvement	Customers should be closely involved throughout the development process. Their role is provide and prioritize new system requirements and to evaluate the iterations of the system.
Incremental delivery	The software is developed in increments with the customer specifying the requirements to be included in each increment.
People not process	The skills of the development team should be recognized and exploited. Team members should be left to develop their own ways of working without prescriptive processes.
Embrace change	Expect the system requirements to change and so design the system to accommodate these changes.
Maintain simplicity	Focus on simplicity in both the software being developed and in the development process. Wherever possible, actively work to eliminate complexity from the system.

Agile method applicability

- ✧ **Product development where a software company is developing a small or medium-sized product for sale.**
- ✧ **Custom system development within an organization, where there is a clear commitment from the customer to become involved in the development process and where there are not a lot of external rules and regulations that affect the software.**
- ✧ **Because of their focus on small, tightly-integrated teams, there are problems in scaling agile methods to large systems.**

Problems with agile methods

- ✧ It can be difficult to keep the interest of customers who are involved in the process.
- ✧ Team members may be unsuited to the intense involvement that characterises agile methods.
- ✧ Prioritising changes can be difficult where there are multiple stakeholders.
- ✧ Maintaining simplicity requires extra work.
- ✧ Contracts may be a problem as with other approaches to iterative development.

Agile methods and software maintenance

- ✧ Most organizations spend more on maintaining existing software than they do on new software development. So, if agile methods are to be successful, they have to support maintenance as well as original development.
- ✧ Two key issues:
 - Are systems that are developed using an agile approach maintainable, given the emphasis in the development process of minimizing formal documentation?
 - Can agile methods be used effectively for evolving a system in response to customer change requests?
- ✧ Problems may arise if original development team cannot be maintained.

Plan-driven and agile development

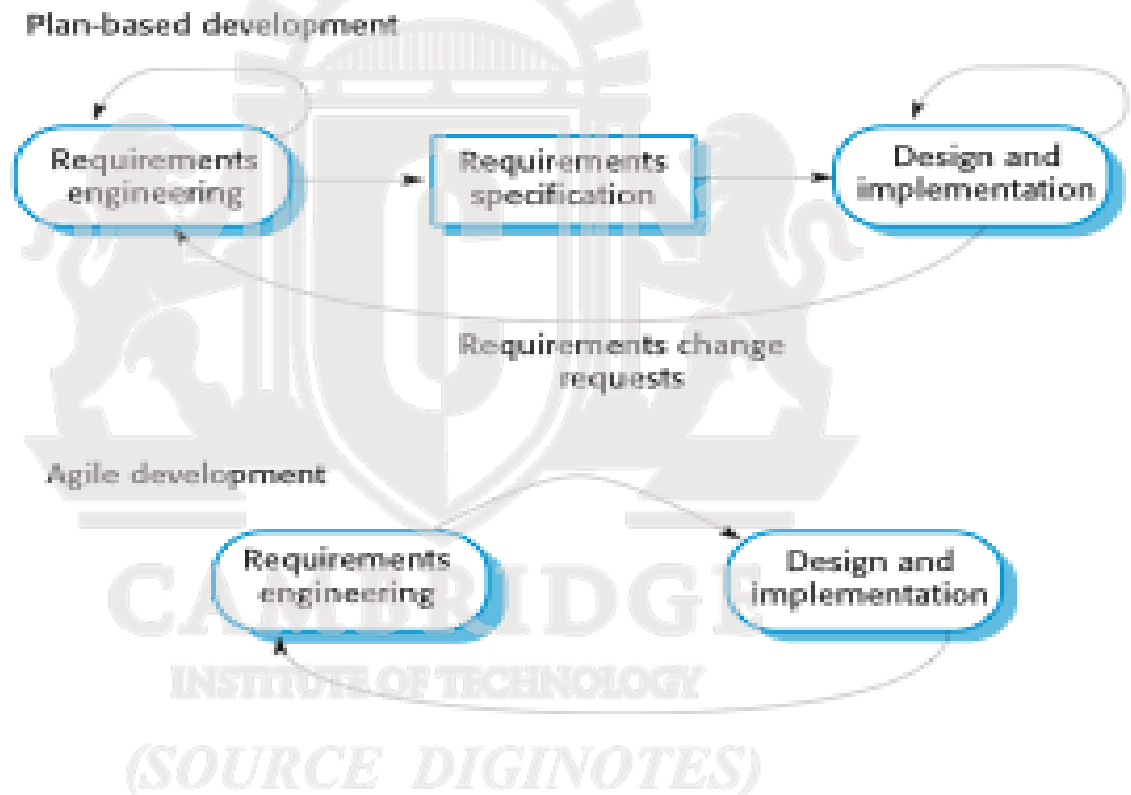
- ✧ Plan-driven development
 - A plan-driven approach to software engineering is based around separate development stages with the outputs to be produced at each of these stages planned in advance.

- Not necessarily waterfall model – plan-driven, incremental development is possible
- Iteration occurs within activities.

✧ Agile development

- Specification, design, implementation and testing are inter-leaved and the outputs from the development process are decided through a process of negotiation during the software development process.

Plan-driven and agile specification



Technical, human, organizational issues

- ✧ Most projects include elements of plan-driven and agile processes. Deciding on the balance depends on:

- Is it important to have a very detailed specification and design before moving to implementation? If so, you probably need to use a plan-driven approach.
- Is an incremental delivery strategy, where you deliver the software to customers and get rapid feedback from them, realistic? If so, consider using agile methods.
- How large is the system that is being developed? Agile methods are most effective when the system can be developed with a small co-located team who can communicate informally. This may not be possible for large systems that require larger development teams so a plan-driven approach may have to be used.
- What type of system is being developed?
 - ✧ Plan-driven approaches may be required for systems that require a lot of analysis before implementation (e.g. real-time system with complex timing requirements).
- What is the expected system lifetime?
 - ✧ Long-lifetime systems may require more design documentation to communicate the original intentions of the system developers to the support team.
- What technologies are available to support system development?
 - ✧ Agile methods rely on good tools to keep track of an evolving design
- How is the development team organized?
 - ✧ If the development team is distributed or if part of the development is being outsourced, then you may need to develop design documents to communicate across the development teams.

- Are there cultural or organizational issues that may affect the system development?
 - Traditional engineering organizations have a culture of plan-based development, as this is the norm in engineering.
- How good are the designers and programmers in the development team?
 - It is sometimes argued that agile methods require higher skill levels than plan-based approaches in which programmers simply translate a detailed design into code
- Is the system subject to external regulation?
 - If a system has to be approved by an external regulator (e.g. the FAA approve software that is critical to the operation of an aircraft) then you will probably be required to produce detailed documentation as part of the system safety case.

Extreme programming

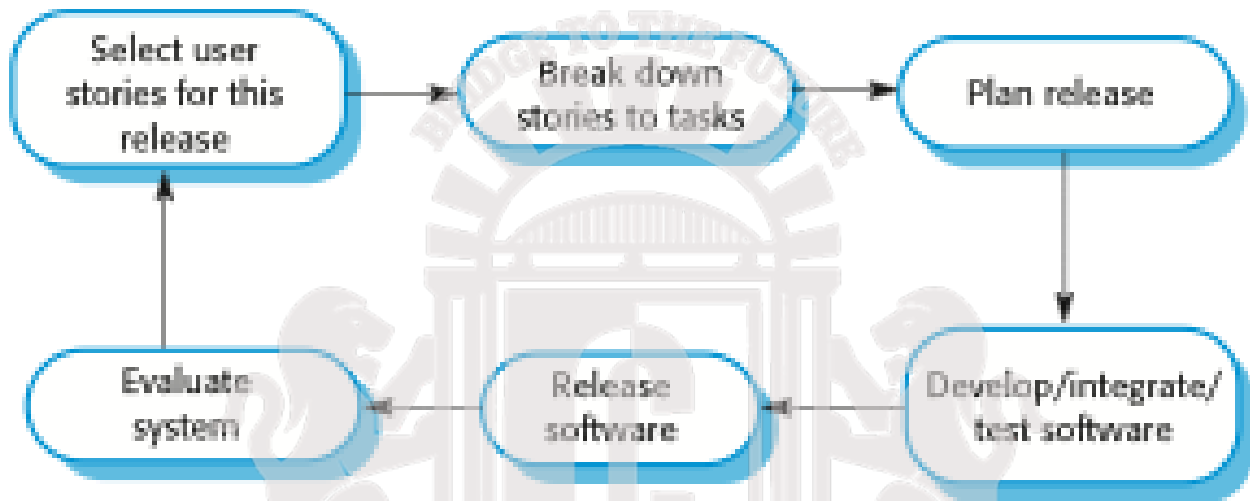
- ✧ Perhaps the best-known and most widely used agile method.
- ✧ Extreme Programming (XP) takes an 'extreme' approach to iterative development.
 - New versions may be built several times per day;
 - Increments are delivered to customers every 2 weeks;
 - All tests must be run for every build and the build is only accepted if tests run successfully.

XP and agile principles

- ✧ Incremental development is supported through small, frequent system releases.
- ✧ Customer involvement means full-time customer engagement with the team.

- ✧ People not process through pair programming, collective ownership and a process that avoids long working hours.
- ✧ Change supported through regular system releases.
- ✧ Maintaining simplicity through constant refactoring of code.

The extreme programming release cycle



Extreme programming practices (a)

Principle or practice	Description
Incremental planning	Requirements are recorded on story cards and the stories to be included in a release are determined by the time available and their relative priority. The developers break these stories into development 'Tasks'. See Figures 3.5 and 3.6.
Small releases	The minimal useful set of functionality that provides business value is developed first. Releases of the system are frequent and incrementally add functionality to the first release.
Simple design	Enough design is carried out to meet the current requirements and no more.
Test-first development	An automated unit test framework is used to write tests for a new piece of functionality before that functionality itself is implemented.
Refactoring	All developers are expected to refactor the code continuously as soon as possible code improvements are found. This keeps the code simple and maintainable.

Pair programming	Developers work in pairs, checking each other's work and providing the support to always do a good job.
Collective ownership	The pairs of developers work on all areas of the system, so that no islands of expertise develop and all the developers take responsibility for all of the code. Anyone can change anything.
Continuous integration	As soon as the work on a task is complete, it is integrated into the whole system. After any such integration, all the unit tests in the system must pass.
Sustainable pace	Large amounts of overtime are not considered acceptable as the net effect is often to reduce code quality and medium term productivity
On-site customer	A representative of the end-user of the system (the customer) should be available full time for the use of the XP team. In an extreme programming process, the customer is a member of the development team and is responsible for bringing system requirements to the team for implementation.

Requirements scenarios

- ✧ In XP, a customer or user is part of the XP team and is responsible for making decisions on requirements.
- ✧ User requirements are expressed as scenarios or user stories.
- ✧ These are written on cards and the development team break them down into implementation tasks. These tasks are the basis of schedule and cost estimates.
- ✧ The customer chooses the stories for inclusion in the next release based on their priorities and the schedule estimates.

A 'prescribing medication' story

Prescribing medication

The record of the patient must be open for input. Click on the medication field and select either 'current medication', 'new medication' or 'formulary'.

If you select 'current medication', you will be asked to check the dose; if you wish to change the dose, enter the new dose then confirm the prescription.

If you choose, 'new medication', the system assumes that you know which medication you wish to prescribe. Type the first few letters of the drug name. You will then see a list of possible drugs starting with these letters. Choose the required medication. You will then be asked to check that the medication you have selected is correct. Enter the dose then confirm the prescription.

If you choose 'formulary', you will be presented with a search box for the approved formulary. Search for the drug required then select it. You will then be asked to check that the medication you have selected is correct. Enter the dose then confirm the prescription.

In all cases, the system will check that the dose is within the approved range and will ask you to change it if it is outside the range of recommended doses.

After you have confirmed the prescription, it will be displayed for checking. Either click 'OK' or 'Change'. If you click 'OK', your prescription will be recorded on the audit database. If you click 'Change', you reenter the 'Prescribing medication' process.

Examples of task cards for prescribing medication

Task 1: Change dose of prescribed drug

Task 2: Formulary selection

Task 3: Dose checking

Dose checking is a safety precaution to check that the doctor has not prescribed a dangerously small or large dose.

Using the formulary id for the generic drug name, lookup the formulary and retrieve the recommended maximum and minimum dose.

Check the prescribed dose against the minimum and maximum. If outside the range, issue an error message saying that the dose is too high or too low. If within the range, enable the 'Confirm' button.

XP and change

- ✧ Conventional wisdom in software engineering is to design for change. It is worth spending time and effort anticipating changes as this reduces costs later in the life cycle.
- ✧ XP, however, maintains that this is not worthwhile as changes cannot be reliably anticipated.

Rather, it proposes constant code improvement (refactoring) to make changes easier when they have to be implemented.

Refactoring

- ✧ Programming team look for possible software improvements and make these improvements even where there is no immediate need for them.
- ✧ This improves the understandability of the software and so reduces the need for documentation.
- ✧ Changes are easier to make because the code is well-structured and clear.
- ✧ However, some changes requires architecture refactoring and this is much more expensive.

Examples of refactoring

- ✧ Re-organization of a class hierarchy to remove duplicate code.
- ✧ Tidying up and renaming attributes and methods to make them easier to understand.
- ✧ The replacement of inline code with calls to methods that have been included in a program library.

Key points

- ✧ Agile methods are incremental development methods that focus on rapid development, frequent releases of the software, reducing process overheads and producing high-quality code. They involve the customer directly in the development process.
- ✧ The decision on whether to use an agile or a plan-driven approach to development should depend on the type of software being developed, the capabilities of the development team and the culture of the company developing the system.
- ✧ Extreme programming is a well-known agile method that integrates a range of good programming practices such as frequent releases of the software, continuous software improvement and customer participation in the development team.

Agile Software Development

Testing in XP

- ✧ Testing is central to XP and XP has developed an approach where the program is tested after every change has been made.
- ✧ XP testing features:
 - Test-first development.
 - Incremental test development from scenarios.
 - User involvement in test development and validation.
 - Automated test harnesses are used to run all component tests each time that a new release is built.

Test-first development

- ✧ Writing tests before code clarifies the requirements to be implemented.
- ✧ Tests are written as programs rather than data so that they can be executed automatically. The test includes a check that it has executed correctly.
 - Usually relies on a testing framework such as Junit.
- ✧ All previous and new tests are run automatically when new functionality is added, thus checking that the new functionality has not introduced errors.

Customer involvement

- ✧ The role of the customer in the testing process is to help develop acceptance tests for the stories that are to be implemented in the next release of the system.
- ✧ The customer who is part of the team writes tests as development proceeds. All new code is therefore validated to ensure that it is what the customer needs.
- ✧ However, people adopting the customer role have limited time available and so cannot work full-time with the development team. They may feel that providing the requirements was enough of a contribution and so may be reluctant to get involved in the testing process.

Test case description for dose checking

Test 4: Dose checking

Input:

1. A number in mg representing a single dose of the drug.
2. A number representing the number of single doses per day.

Tests:

1. Test for inputs where the single dose is correct but the frequency is too high.
2. Test for inputs where the single dose is too high and too low.
3. Test for inputs where the single dose * frequency is too high and too low.
4. Test for inputs where single dose * frequency is in the permitted range.

Output:

OK or error message indicating that the dose is outside the safe range.

Test automation

- ✧ Test automation means that tests are written as executable components before the task is implemented
 - These testing components should be stand-alone, should simulate the submission of input to be tested and should check that the result meets the output specification. An automated test framework (e.g. Junit) is a system that makes it easy to write executable tests and submit a set of tests for execution.
- ✧ As testing is automated, there is always a set of tests that can be quickly and easily executed
 - Whenever any functionality is added to the system, the tests can be run and problems that the new code has introduced can be caught immediately.

XP testing difficulties

- ✧ Programmers prefer programming to testing and sometimes they take short cuts when writing tests. For example, they may write incomplete tests that do not check for all possible exceptions that may occur.
- ✧ Some tests can be very difficult to write incrementally. For example, in a complex user interface, it is often difficult to write unit tests for the code that implements the 'display logic' and workflow between screens.
- ✧ It difficult to judge the completeness of a set of tests. Although you may have a lot of system tests, your test set may not provide complete coverage.

Pair programming

- ✧ In XP, programmers work in pairs, sitting together to develop code.
- ✧ This helps develop common ownership of code and spreads knowledge across the team.
- ✧ It serves as an informal review process as each line of code is looked at by more than 1 person.
- ✧ It encourages refactoring as the whole team can benefit from this.

Measurements suggest that development productivity with pair programming is similar to that of two people working independently.

- ✧ In pair programming, programmers sit together at the same workstation to develop the software.
- ✧ Pairs are created dynamically so that all team members work with each other during the development process.
- ✧ The sharing of knowledge that happens during pair programming is very important as it reduces the overall risks to a project when team members leave.
- ✧ Pair programming is not necessarily inefficient and there is evidence that a pair working together is more efficient than 2 programmers working separately.

Advantages of pair programming

- ✧ It supports the idea of collective ownership and responsibility for the system.

- Individuals are not held responsible for problems with the code. Instead, the team has collective responsibility for resolving these problems.
- ✧ It acts as an informal review process because each line of code is looked at by at least two people.
- ✧ It helps support refactoring, which is a process of software improvement.
 - Where pair programming and collective ownership are used, others benefit immediately from the refactoring so they are likely to support the process.

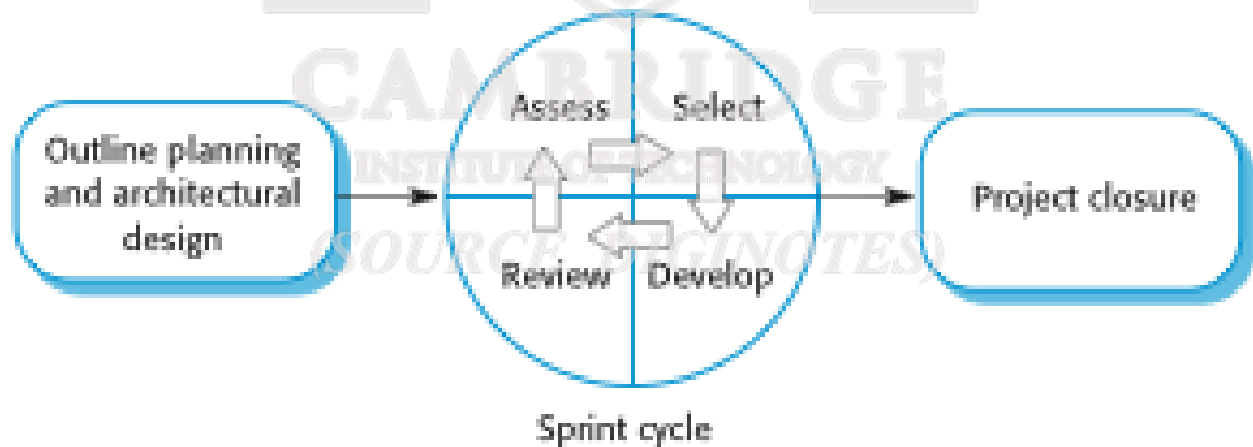
Agile project management

- ✧ The principal responsibility of software project managers is to manage the project so that the software is delivered on time and within the planned budget for the project.
- ✧ The standard approach to project management is plan-driven. Managers draw up a plan for the project showing what should be delivered, when it should be delivered and who will work on the development of the project deliverables.
- ✧ Agile project management requires a different approach, which is adapted to incremental development and the particular strengths of agile methods.

Scrum

- ✧ The Scrum approach is a general agile method but its focus is on managing iterative development rather than specific agile practices.
- ✧ There are three phases in Scrum.
 - The initial phase is an outline planning phase where you establish the general objectives for the project and design the software architecture.
 - This is followed by a series of sprint cycles, where each cycle develops an increment of the system.
 - The project closure phase wraps up the project, completes required documentation such as system help frames and user manuals and assesses the lessons learned from the project.

The Scrum process



The Sprint cycle

- ✧ Sprints are fixed length, normally 2–4 weeks. They correspond to the development of a release of the system in XP.
- ✧ The starting point for planning is the product backlog, which is the list of work to be done on the project.
- ✧ The selection phase involves all of the project team who work with the customer to select the features and functionality to be developed during the sprint.
- ✧ Once these are agreed, the team organize themselves to develop the software. During this stage the team is isolated from the customer and the organization, with all communications channelled through the so-called 'Scrum master'.
- ✧ The role of the Scrum master is to protect the development team from external distractions.
- ✧ At the end of the sprint, the work done is reviewed and presented to stakeholders. The next sprint cycle then begins.

Teamwork in Scrum

- ✧ The 'Scrum master' is a facilitator who arranges daily meetings, tracks the backlog of work to be done, records decisions, measures progress against the backlog and communicates with customers and management outside of the team.
- ✧ The whole team attends short daily meetings where all team members share information, describe their progress since the last meeting, problems that have arisen and what is planned for the following day.
 - This means that everyone on the team knows what is going on and, if problems arise, can re-plan short-term work to cope with them.

Scrum benefits

- ✧ The product is broken down into a set of manageable and understandable chunks.
- ✧ Unstable requirements do not hold up progress.
- ✧ The whole team have visibility of everything and consequently team communication is improved.
- ✧ Customers see on-time delivery of increments and gain feedback on how the product works.
- ✧ Trust between customers and developers is established and a positive culture is created in which everyone expects the project to succeed.

Scaling agile methods

- ✧ Agile methods have proved to be successful for small and medium sized projects that can be developed by a small co-located team.
- ✧ It is sometimes argued that the success of these methods comes because of improved communications which is possible when everyone is working together.
- ✧ Scaling up agile methods involves changing these to cope with larger, longer projects where there are multiple development teams, perhaps working in different locations.

Large systems development

- ✧ Large systems are usually collections of separate, communicating systems, where separate teams develop each system. Frequently, these teams are working in different places, sometimes in different time zones.
- ✧ Large systems are 'brownfield systems', that is they include and interact with a number of existing systems. Many of the system requirements are concerned with this interaction and so don't really lend themselves to flexibility and incremental development.
- ✧ Where several systems are integrated to create a system, a significant fraction of the development is concerned with system configuration rather than original code development.

Large system development

- ✧ Large systems and their development processes are often constrained by external rules and regulations limiting the way that they can be developed.
- ✧ Large systems have a long procurement and development time. It is difficult to maintain coherent teams who know about the system over that period as, inevitably, people move on to other jobs and projects.
- ✧ Large systems usually have a diverse set of stakeholders. It is practically impossible to involve all of these different stakeholders in the development process.

Scaling out and scaling up

- ✧ 'Scaling up' is concerned with using agile methods for developing large software systems that cannot be developed by a small team.
- ✧ 'Scaling out' is concerned with how agile methods can be introduced across a large organization with many years of software development experience.
- ✧ When scaling agile methods it is essential to maintain agile fundamentals
 - Flexible planning, frequent system releases, continuous integration, test-driven development and good team communications.

Scaling up to large systems

- ✧ For large systems development, it is not possible to focus only on the code of the system. You need to do more up-front design and system documentation
- ✧ Cross-team communication mechanisms have to be designed and used. This should involve regular phone and video conferences between team members and frequent, short electronic meetings where teams update each other on progress.
- ✧ Continuous integration, where the whole system is built every time any developer checks in a change, is practically impossible. However, it is essential to maintain frequent system builds and regular releases of the system.

Scaling out to large companies

- ✧ Project managers who do not have experience of agile methods may be reluctant to accept the risk of a new approach.
- ✧ Large organizations often have quality procedures and standards that all projects are expected to follow and, because of their bureaucratic nature, these are likely to be incompatible with agile methods.
- ✧ Agile methods seem to work best when team members have a relatively high skill level. However, within large organizations, there are likely to be a wide range of skills and abilities.
- ✧ There may be cultural resistance to agile methods, especially in those organizations that have a long history of using conventional systems engineering processes.

Key points

- ✧ A particular strength of extreme programming is the development of automated tests before a program feature is created. All tests must successfully execute when an increment is integrated into a system.
- ✧ The Scrum method is an agile method that provides a project management framework. It is centred round a set of sprints, which are fixed time periods when a system increment is developed.
- ✧ Scaling agile methods for large systems is difficult. Large systems need up-front design and some documentation.

