System and Software Engineering

Objectives

- To introduce software engineering and to explain its importance
- To set out the answers to key questions about software engineering

Software engineering

- The economies of ALL developed nations are dependent on software.
- More and more systems are software controlled
- Software engineering is concerned with theories, methods and tools for professional software development.
- Expenditure on software represents a significant fraction of GNP in all developed countries.

Software costs

- Software costs often dominate computer system costs. The costs of software on a PC are often greater than the hardware cost.
- Software costs more to maintain than it does to develop. For systems with a long life, maintenance costs may be several times development costs.
- Software engineering is concerned with cost-effective software development.

FAQs about software engineering

- What is software?
- What is software engineering?
- Why is software engineering important?
- What is the difference between software engineering and computer science?
- What is system engineering?
- What is a software process?
- What is a software process model?

FAQs about software engineering

- What are the costs of software engineering?
- What are software engineering methods?
- What is CASE (Computer-Aided Software Engineering)
- What are the attributes of good software?
- What are the key challenges facing software engineering?

What is software?

- Computer programs and associated documentation such as requirements, design models and user manuals.
- Software products may be developed for a particular customer or may be developed for a general market.
- Software products may be
  - Generic - developed to be sold to a range of different customers e.g. PC software such as Excel or Word.
  - Bespoke (custom) - developed for a single customer according to their specification.
- New software can be created by developing new programs, configuring generic software systems or reusing existing software.

What is software engineering?

- Software engineering is an engineering discipline that is concerned with all aspects of software production.
- Software engineers should adopt a systematic and organised approach to their work and use appropriate tools and techniques depending on the problem to be solved, the development constraints and the resources available.

Why is software engineering important?

- Software must be reliable, secure, usable and maintainable. Software engineering explicitly focuses on delivering software with these attributes and, unlike programming, is not just concerned with the functionality or features of a system.
- Software engineering is particularly important for systems which people and businesses depend on and which are used for many years.

What is the difference between software engineering and computer science?

- Computer science is concerned with theory and fundamentals; software engineering is concerned with the practicalities of developing and delivering useful software.
- Computer science theories are still insufficient to act as a complete underpinning for software engineering (unlike e.g. physics and electrical engineering).

What is system engineering?

- System engineering is concerned with all aspects of computer-based systems development including hardware, software and process engineering.
- System engineers are involved in system specification, architectural design, integration and deployment.
- Software engineering is part of this process concerned with developing the software infrastructure, control, applications and databases in the system.

What is a software process?

- A set of activities whose goal is the development or evolution of software.
- Generic activities in all software processes are:
  - Specification - what the system should do and its development constraints
  - Development - production of the software system
  - Validation - checking that the software is what the customer wants
  - Evolution - changing the software in response to changing demands.

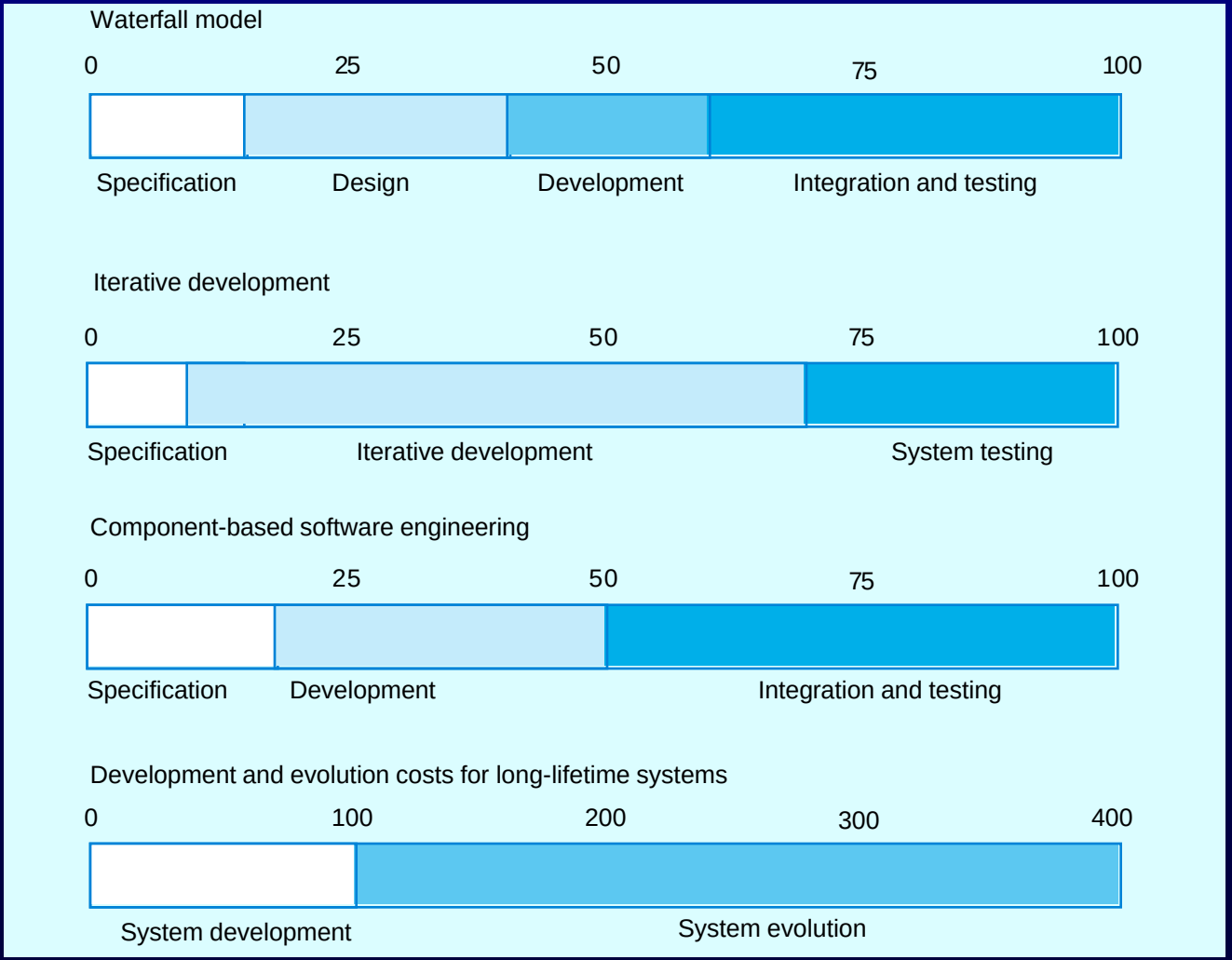
What is a software process model?

- A simplified representation of a software process, presented from a specific perspective.
- Examples of process perspectives are
  - Workflow perspective - sequence of activities;
  - Data-flow perspective - information flow;
  - Role/action perspective - who does what.
- Generic process models
  - Waterfall;
  - Iterative development;
  - Component-based software engineering.

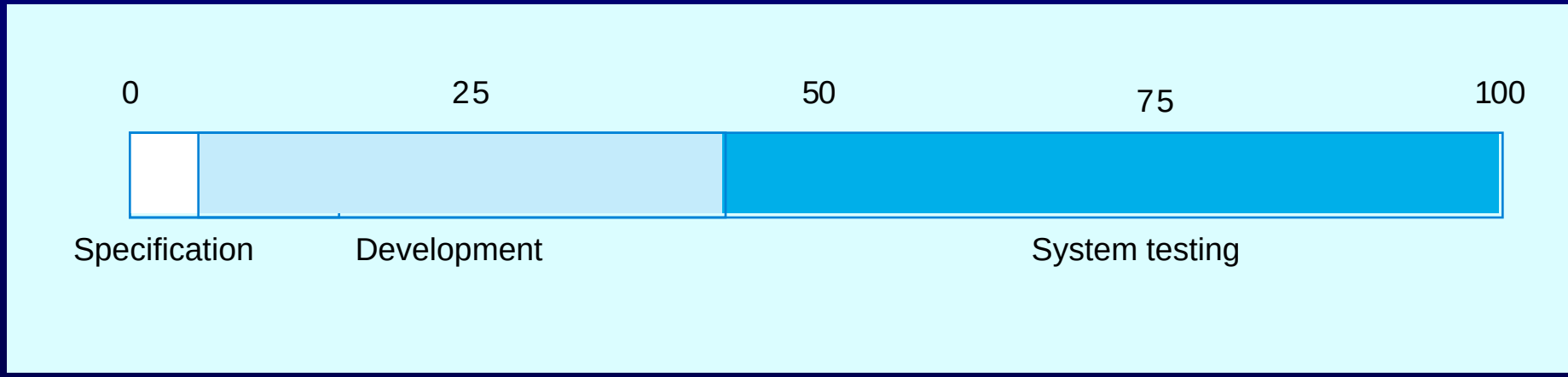
What are the costs of software engineering?

- Roughly 60% of costs are development costs, 40% are testing costs. For custom software, evolution costs often exceed development costs.
- Costs vary depending on the type of system being developed and the requirements of system attributes such as performance and system reliability.
- Distribution of costs depends on the development model that is used.

Activity cost distribution



Product development costs



What are software engineering methods?

- Structured approaches to software development which include system models, notations, rules, design advice and process guidance.
- Model descriptions
  - Descriptions of graphical models which should be produced;
- Rules
  - Constraints applied to system models;
- Recommendations
  - Advice on good design practice;
- Process guidance
  - What activities to follow.

What is CASE (Computer-Aided Software Engineering)

- Software systems that are intended to provide automated support for software process activities.
- CASE systems are often used for method support.
- Upper-CASE
  - Tools to support the early process activities of requirements and design;
- Lower-CASE
  - Tools to support later activities such as programming, debugging and testing.

What are the attributes of good software?

- The software should deliver the required functionality and performance to the user and should be maintainable, dependable and acceptable.
- Maintainability
  - Software must evolve to meet changing needs;
- Dependability
  - Software must be trustworthy;
- Efficiency
  - Software should not make wasteful use of system resources;
- Acceptability
  - Software must accepted by the users for which it was designed. This means it must be understandable, usable and compatible with other systems.

What are the key challenges facing software engineering?

- Heterogeneity, delivery and trust.
- Heterogeneity
  - Developing techniques for building software that can cope with heterogeneous platforms and execution environments;
- Delivery
  - Developing techniques that lead to faster delivery of software;
- Trust
  - Developing techniques that demonstrate that software can be trusted by its users.

Key points

- Software engineering is an engineering discipline that is concerned with all aspects of software production.
- Software products consist of developed programs and associated documentation. Essential product attributes are maintainability, dependability, efficiency and usability.
- The software process consists of activities that are involved in developing software products. Basic activities are software specification, development, validation and evolution.
- Methods are organised ways of producing software. They include suggestions for the process to be followed, the notations to be used, rules governing the system descriptions which are produced and design guidelines.

Critical Systems

Topics covered

- A simple safety-critical system
- System dependability
- Availability and reliability
- Safety
- Security

Critical Systems

- Safety-critical systems
  - Failure results in loss of life, injury or damage to the environment;
  - Chemical plant protection system;
- Mission-critical systems
  - Failure results in failure of some goal-directed activity;
  - Spacecraft navigation system;
- Business-critical systems
  - Failure results in high economic losses;
  - Customer accounting system in a bank;

System dependability

- For critical systems, it is usually the case that the most important system property is the dependability of the system.
- The dependability of a system reflects the user's degree of trust in that system. It reflects the extent of the user's confidence that it will operate as users expect and that it will not 'fail' in normal use.
- Usefulness and trustworthiness are not the same thing. A system does not have to be trusted to be useful.

Importance of dependability

- Systems that are not dependable and are unreliable, unsafe or insecure may be rejected by their users.
- The costs of system failure may be very high.
- Undependable systems may cause information loss with a high consequent recovery cost.

Development methods for critical systems

- The costs of critical system failure are so high that development methods may be used that are not cost-effective for other types of system.
- Examples of development methods
  - Formal methods of software development
  - Static analysis
  - External quality assurance

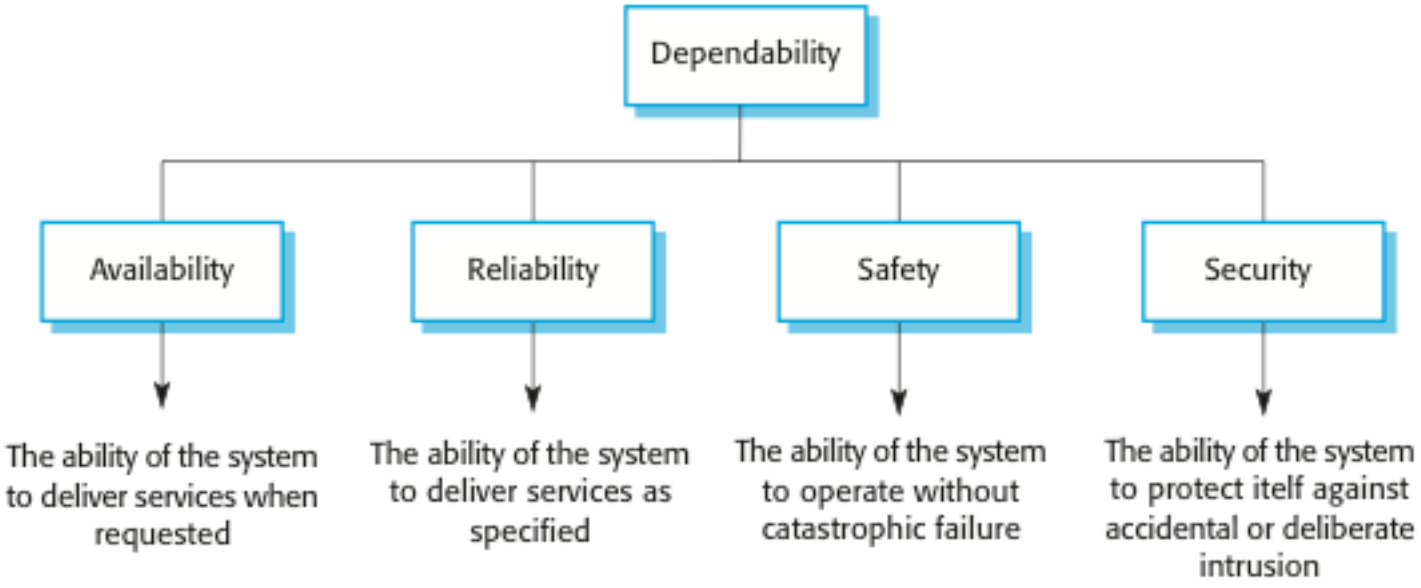
Socio-technical critical systems

- Hardware failure
  - Hardware fails because of design and manufacturing errors or because components have reached the end of their natural life.
- Software failure
  - Software fails due to errors in its specification, design or implementation.
- Operational failure
  - Human operators make mistakes. Now perhaps the largest single cause of system failures.

Dependability

- The dependability of a system equates to its trustworthiness.
- A dependable system is a system that is trusted by its users.
- Principal dimensions of dependability are:
  - Availability;
  - Reliability;
  - Safety;
  - Security

Dimensions of dependability



Other dependability properties

- Repairability
  - Reflects the extent to which the system can be repaired in the event of a failure
- Maintainability
  - Reflects the extent to which the system can be adapted to new requirements;
- Survivability
  - Reflects the extent to which the system can deliver services whilst under hostile attack;
- Error tolerance
  - Reflects the extent to which user input errors can be avoided and tolerated.

Maintainability

- A system attribute that is concerned with the ease of repairing the system after a failure has been discovered or changing the system to include new features
- Very important for critical systems as faults are often introduced into a system because of maintenance problems
- Maintainability is distinct from other dimensions of dependability because it is a static and not a dynamic system attribute.

Survivability

- The ability of a system to continue to deliver its services to users in the face of deliberate or accidental attack
- This is an increasingly important attribute for distributed systems whose security can be compromised
- Survivability subsumes the notion of resilience - the ability of a system to continue in operation in spite of component failures

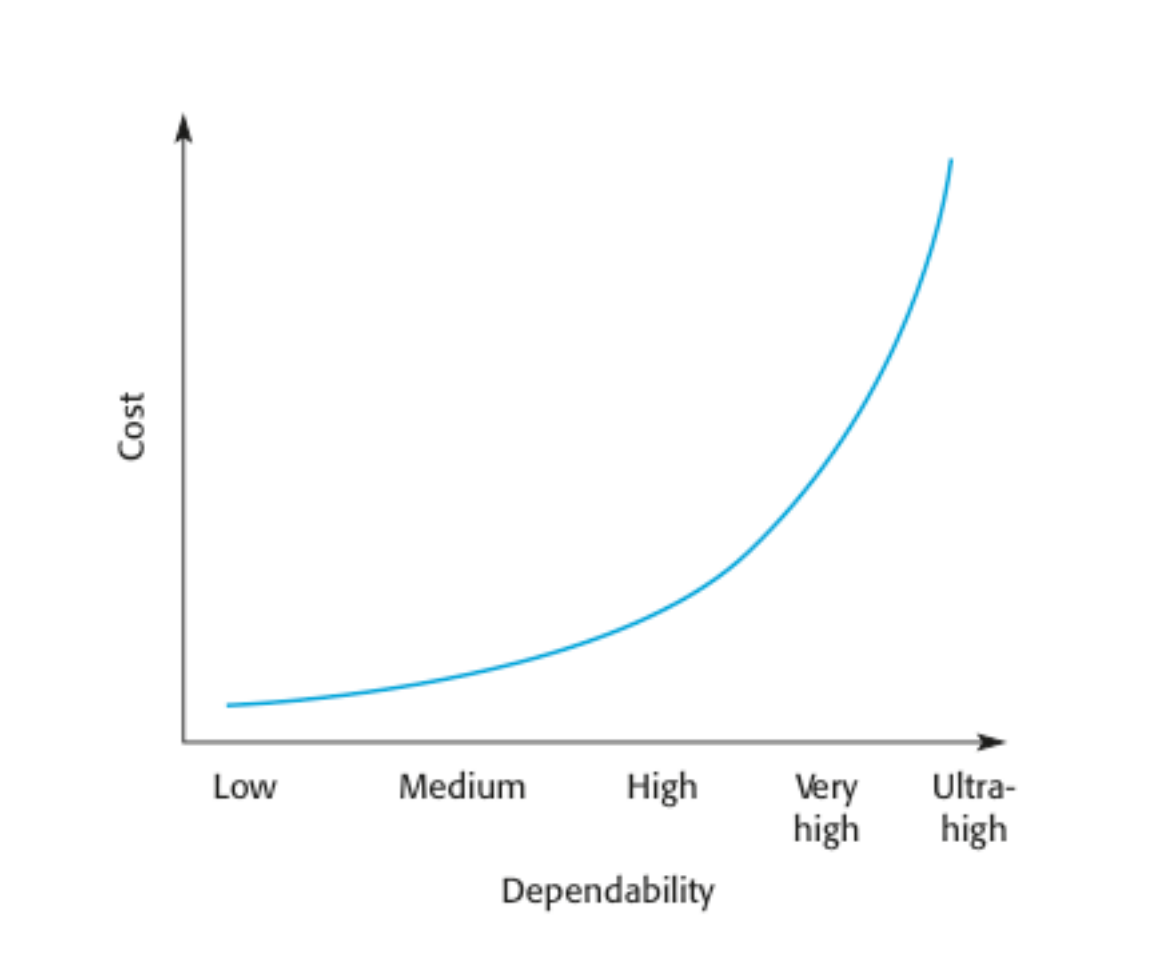
Dependability vs performance

- Untrustworthy systems may be rejected by their users
- System failure costs may be very high
- It is very difficult to tune systems to make them more dependable
- It may be possible to compensate for poor performance
- Untrustworthy systems may cause loss of valuable information

Dependability costs

- Dependability costs tend to increase exponentially as increasing levels of dependability are required
- There are two reasons for this
  - The use of more expensive development techniques and hardware that are required to achieve the higher levels of dependability
  - The increased testing and system validation that is required to convince the system client that the required levels of dependability have been achieved

Costs of increasing dependability



Availability and reliability

- Reliability
  - The probability of failure-free system operation over a specified time in a given environment for a given purpose
- Availability
  - The probability that a system, at a point in time, will be operational and able to deliver the requested services
- Both of these attributes can be expressed quantitatively

Availability and reliability

- It is sometimes possible to subsume system availability under system reliability
  - Obviously if a system is unavailable it is not delivering the specified system services
- However, it is possible to have systems with low reliability that must be available. So long as system failures can be repaired quickly and do not damage data, low reliability may not be a problem
- Availability takes repair time into account

Reliability terminology

Term	Description
System failure	An event that occurs at some point in time when the system does not deliver a service as expected by its users
System error	An erroneous system state that can lead to system behaviour that is unexpected by system users.
System fault	A characteristic of a software system that can lead to a system error. For example, failure to initialise a variable could lead to that variable having the wrong value when it is used.
Human error or mistake	Human behaviour that results in the introduction of faults into a system.

Reliability achievement

- Fault avoidance
  - Development technique are used that either minimise the possibility of mistakes or trap mistakes before they result in the introduction of system faults
- Fault detection and removal
  - Verification and validation techniques that increase the probability of detecting and correcting errors before the system goes into service are used
- Fault tolerance
  - Run-time techniques are used to ensure that system faults do not result in system errors and/or that system errors do not lead to system failures

Safety

- Safety is a property of a system that reflects the system's ability to operate, normally or abnormally, without danger of causing human injury or death and without damage to the system's environment
- It is increasingly important to consider software safety as more and more devices incorporate software-based control systems
- Safety requirements are exclusive requirements i.e. they exclude undesirable situations rather than specify required system services

Safety criticality

- Primary safety-critical systems
  - Embedded software systems whose failure can cause the associated hardware to fail and directly threaten people.
- Secondary safety-critical systems
  - Systems whose failure results in faults in other systems which can threaten people
- Discussion here focuses on primary safety-critical systems
  - Secondary safety-critical systems can only be considered on a one-off basis

Safety and reliability

- Safety and reliability are related but distinct
  - In general, reliability and availability are necessary but not sufficient conditions for system safety
- Reliability is concerned with conformance to a given specification and delivery of service
- Safety is concerned with ensuring system cannot cause damage irrespective of whether
  or not it conforms to its specification

Unsafe reliable systems

- Specification errors
  - If the system specification is incorrect then the system can behave as specified but still cause an accident
- Hardware failures generating spurious inputs
  - Hard to anticipate in the specification
- Context-sensitive commands i.e. issuing the right command at the wrong time
  - Often the result of operator error

Safety terminology

Term	Definition
Accident (or mishap)	An unplanned event or sequence of events which results in human death or injury, damage to property or to the environment. A computer-controlled machine injuring its operator is an example of an accident.
Hazard	A condition with the potential for causing or contributing to an accident. A failure of the sensor that detects an obstacle in front of a machine is an example of a hazard.
Damage	A measure of the loss resulting from a mishap. Damage can range from many people killed as a result of an accident to minor injury or property damage.
Hazard severity	An assessment of the worst possible damage that could result from a particular hazard. Hazard severity can range from catastrophic where many people are killed to minor where only minor damage results.
Hazard probability	The probability of the events occurring which create a hazard. Probability values tend to be arbitrary but range from *probable* (say 1/100 chance of a hazard occurring) to implausible (no conceivable situations are likely where the hazard could occur).
Risk	This is a measure of the probability that the system will cause an accident. The risk is assessed by considering the hazard probability, the hazard severity and the probability that a hazard will result in an accident.

Safety achievement

- Hazard avoidance
  - The system is designed so that some classes of hazard simply cannot arise.
- Hazard detection and removal
  - The system is designed so that hazards are detected and removed before they result in an accident
- Damage limitation
  - The system includes protection features that minimise the damage that may result from an accident

Security

- The security of a system is a system property that reflects the system's ability to protect itself from accidental or deliberate external attack
- Security is becoming increasingly important as systems are networked so that external access to the system through the Internet is possible
- Security is an essential pre-requisite for availability, reliability and safety

Fundamental security

- If a system is a networked system and is insecure then statements about its reliability and its safety are unreliable
- These statements depend on the executing system and the developed system being the same. However, intrusion can change the executing system and/or its data
- Therefore, the reliability and safety assurance is no longer valid

Security terminology

Term	Definition
Exposure	Possible loss or harm in a computing system. This can be loss or damage to data or can be a loss of time and effort if recovery is necessary after a security breach.
Vulnerability	A weakness in a computer-based system that may be exploited to cause loss or harm.
Attack	An exploitation of a system vulnerability. Generally, this is from outside the system and is a deliberate attempt to cause some damage.
Threats	Circumstances that have potential to cause loss or harm. You can think of these as a system vulnerability that is subjected to an attack.
Control	A protective measure that reduces a system vulnerability. Encryption would be an example of a control that reduced a vulnerability of a weak access control system.

Damage from insecurity

- Denial of service
  - The system is forced into a state where normal services are unavailable or where service provision is significantly degraded
- Corruption of programs or data
  - The programs or data in the system may be modified in an unauthorised way
- Disclosure of confidential information
  - Information that is managed by the system may be exposed to people who are not authorised to read or use that information

Security assurance

- Vulnerability avoidance
  - The system is designed so that vulnerabilities do not occur. For example, if there is no external network connection then external attack is impossible
- Attack detection and elimination
  - The system is designed so that attacks on vulnerabilities are detected and neutralised before they result in an exposure. For example, virus checkers find and remove viruses before they infect a system
- Exposure limitation
  - The system is designed so that the adverse consequences of a successful attack are minimised. For example, a backup policy allows damaged information to be restored

Key points

- A critical system is a system where failure can lead to high economic loss, physical damage or threats to life.
- The dependability in a system reflects the user's trust in that system
- The availability of a system is the probability that it will be available to deliver services when requested
- The reliability of a system is the probability that system services will be delivered as specified
- Reliability and availability are generally seen as necessary but not sufficient conditions for safety and security

Key points

- Reliability is related to the probability of an error occurring in operational use. A system with known faults may be reliable
- Safety is a system attribute that reflects the system's ability to operate without threatening people or the environment
- Security is a system attribute that reflects the system's ability to protect itself from external attack
- Dependability improvement requires a socio-technical approach to design where you consider the humans as well as the hardware and software

Software Processes

Objectives

- To introduce software process models
- To describe three generic process models and when they may be used
- To describe outline process models for requirements engineering, software development, testing and evolution
- To explain the Rational Unified Process model
- To introduce CASE technology to support software process activities

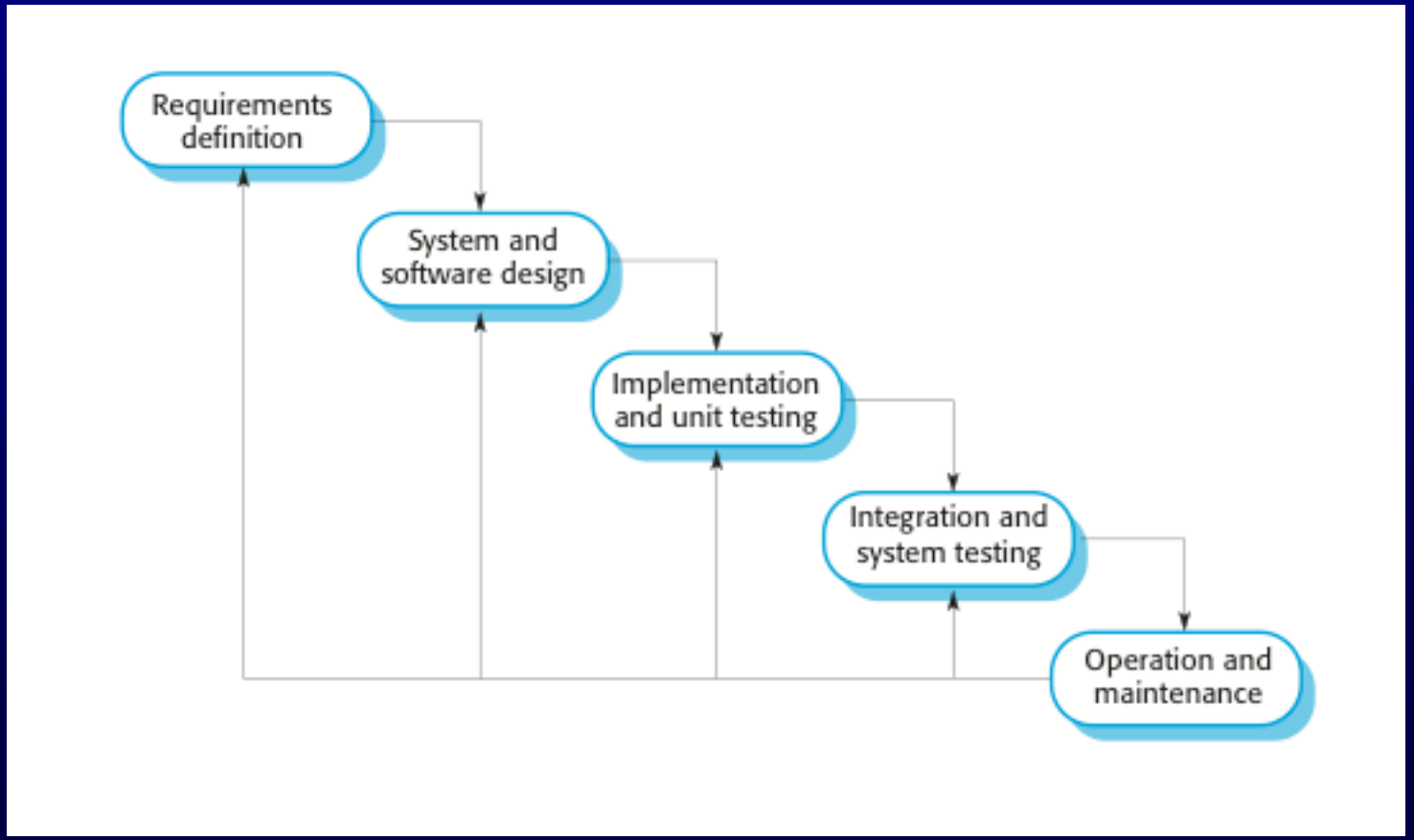
The software process

- A structured set of activities required to develop a software system
  - Specification;
  - Design;
  - Validation;
  - Evolution.
- A software process model is an abstract representation of a process. It presents a description of a process from some particular perspective.

Generic software process models

- The waterfall model
  - Separate and distinct phases of specification and development.
- Evolutionary development
  - Specification, development and validation are interleaved.
- Component-based software engineering
  - The system is assembled from existing components.
- There are many variants of these models e.g. formal development where a waterfall-like process is used but the specification is a formal specification that is refined through several stages to an implementable design.

Waterfall model



Waterfall model phases

- 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. One phase has to be complete before moving onto the next phase.

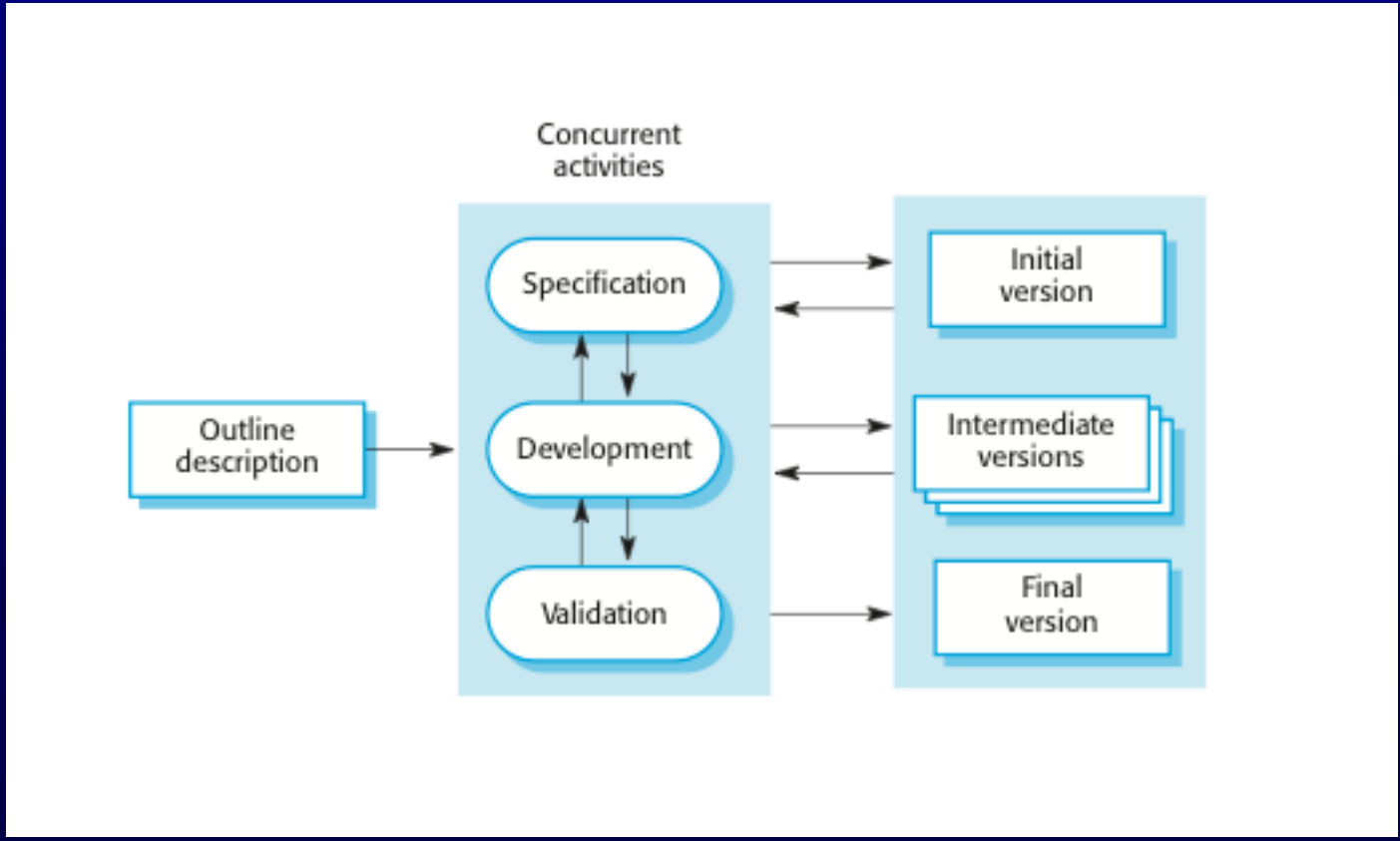
Waterfall model problems

- 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.

Evolutionary development

- Exploratory development
  - Objective is to work with customers and to evolve a final system from an initial outline specification. Should start with well-understood requirements and add new features as proposed by the customer.
- Throw-away prototyping
  - Objective is to understand the system requirements. Should start with poorly understood requirements to clarify what is really needed.

Evolutionary development



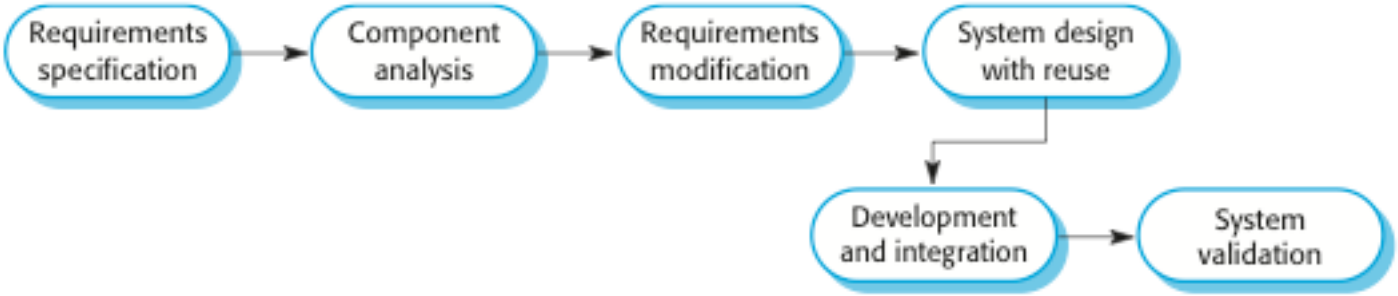
Evolutionary development

- Problems
  - Lack of process visibility;
  - Systems are often poorly structured;
  - Special skills (e.g. in languages for rapid prototyping) may be required.
- Applicability
  - For small or medium-size interactive systems;
  - For parts of large systems (e.g. the user interface);
  - For short-lifetime systems.

Component-based 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.
- This approach is becoming increasingly used as component standards have emerged.

Reuse-oriented development



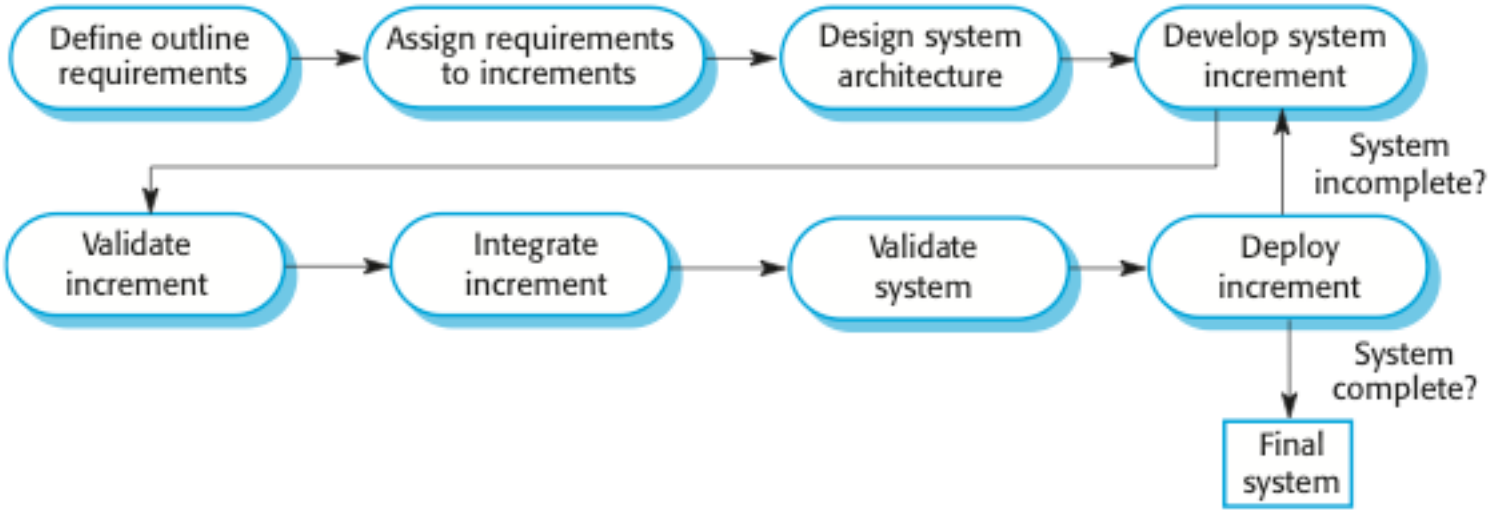
Process iteration

- System requirements ALWAYS evolve in the course of a project so process iteration where earlier stages are reworked is always part of the process for large systems.
- Iteration can be applied to any of the generic process models.
- Two (related) approaches
  - Incremental delivery;
  - Spiral development.

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



Incremental development 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.

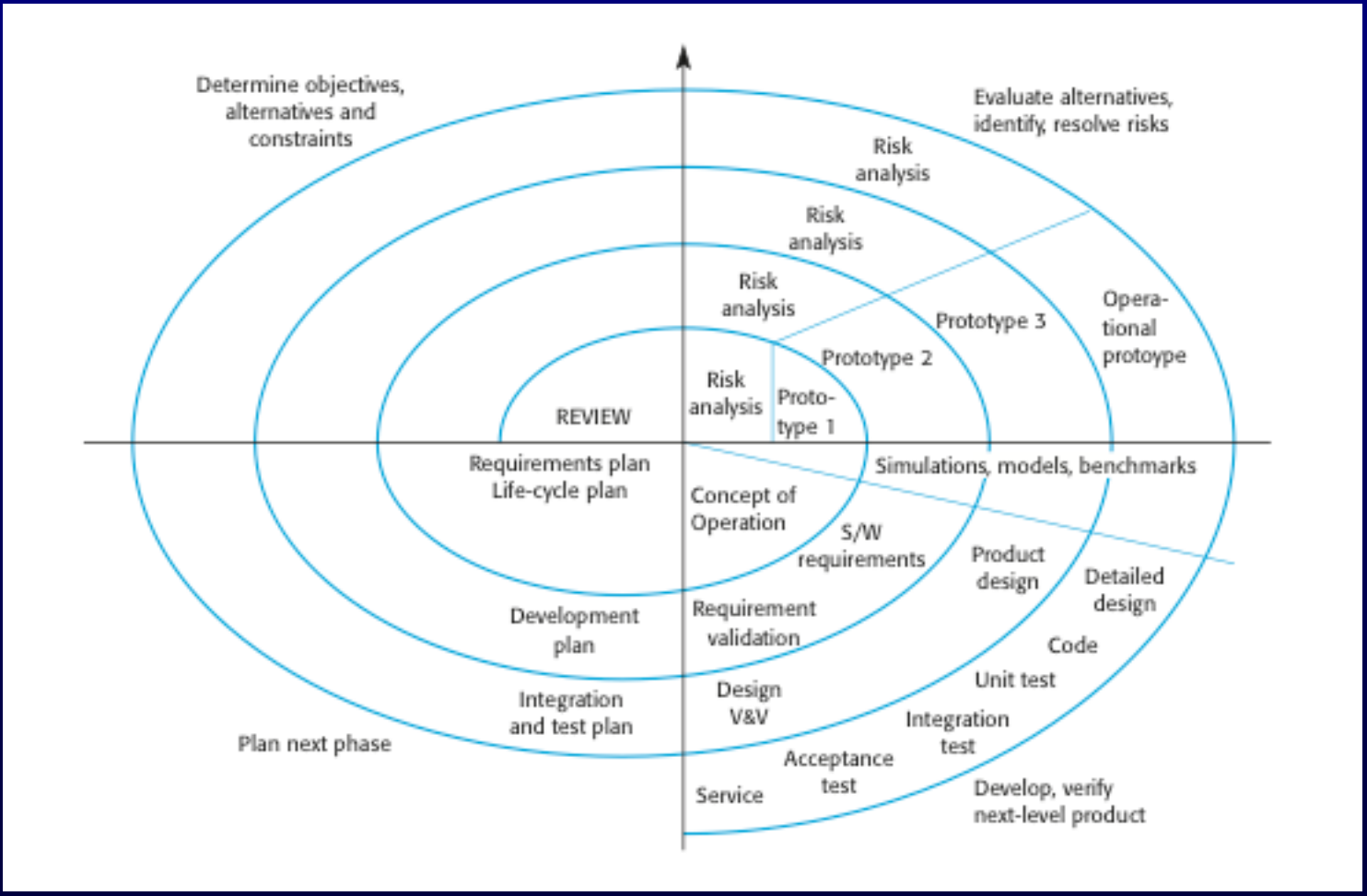
Extreme programming

- An approach to development based on the development and delivery of very small increments of functionality.
- Relies on constant code improvement, user involvement in the development team and pairwise programming.
- Covered in Chapter 17

Spiral development

- 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 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.

Key points

- Software processes are the activities involved in producing and evolving a software system.
- Software process models are abstract representations of these processes.
- General activities are specification, design and implementation, validation and evolution.
- Generic process models describe the organisation of software processes. Examples include the waterfall model, evolutionary development and component-based software engineering.
- Iterative process models describe the software process as a cycle of activities.

Software processes 2

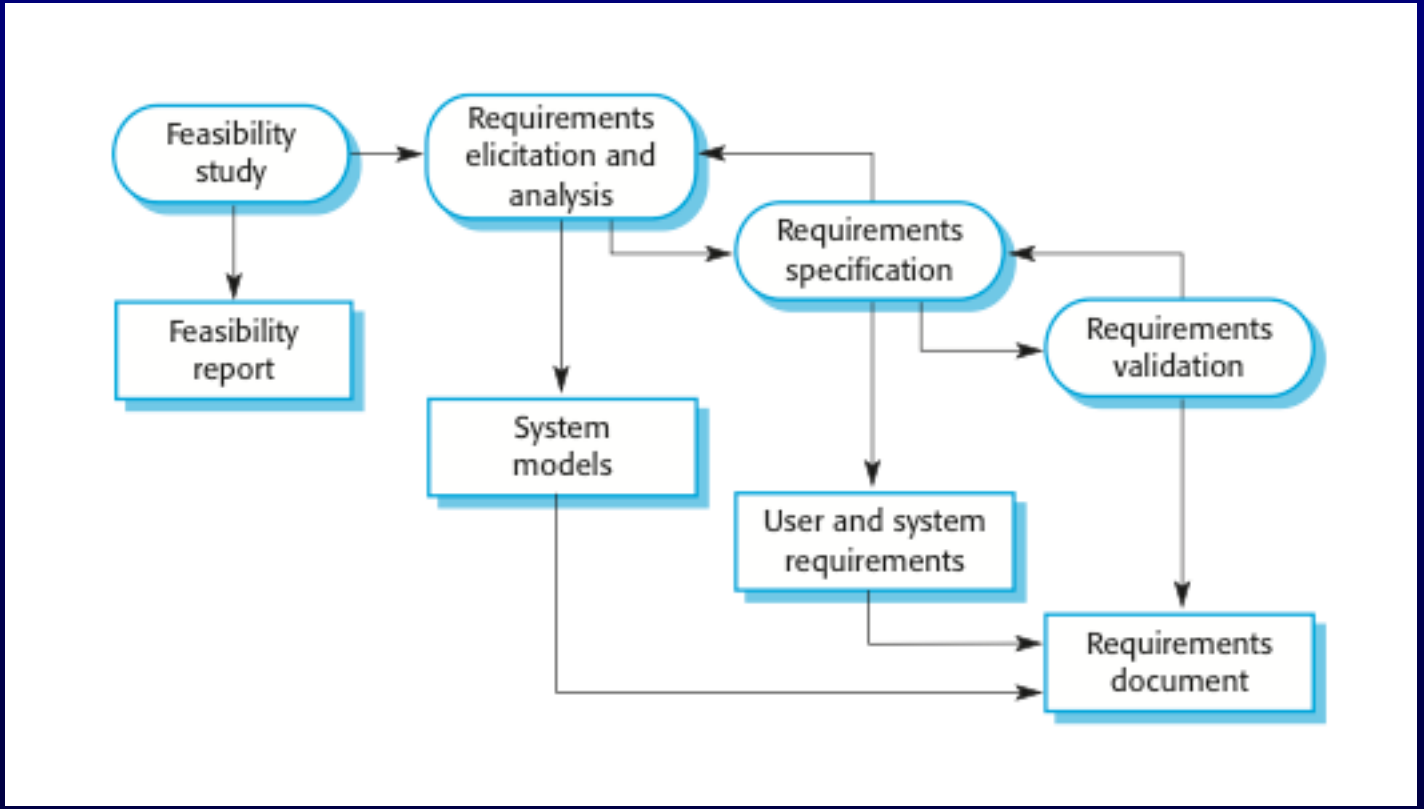
Process activities

- Software specification
- Software design and implementation
- Software validation
- Software evolution

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;
  - Requirements elicitation and analysis;
  - Requirements specification;
  - Requirements validation.

The requirements engineering process



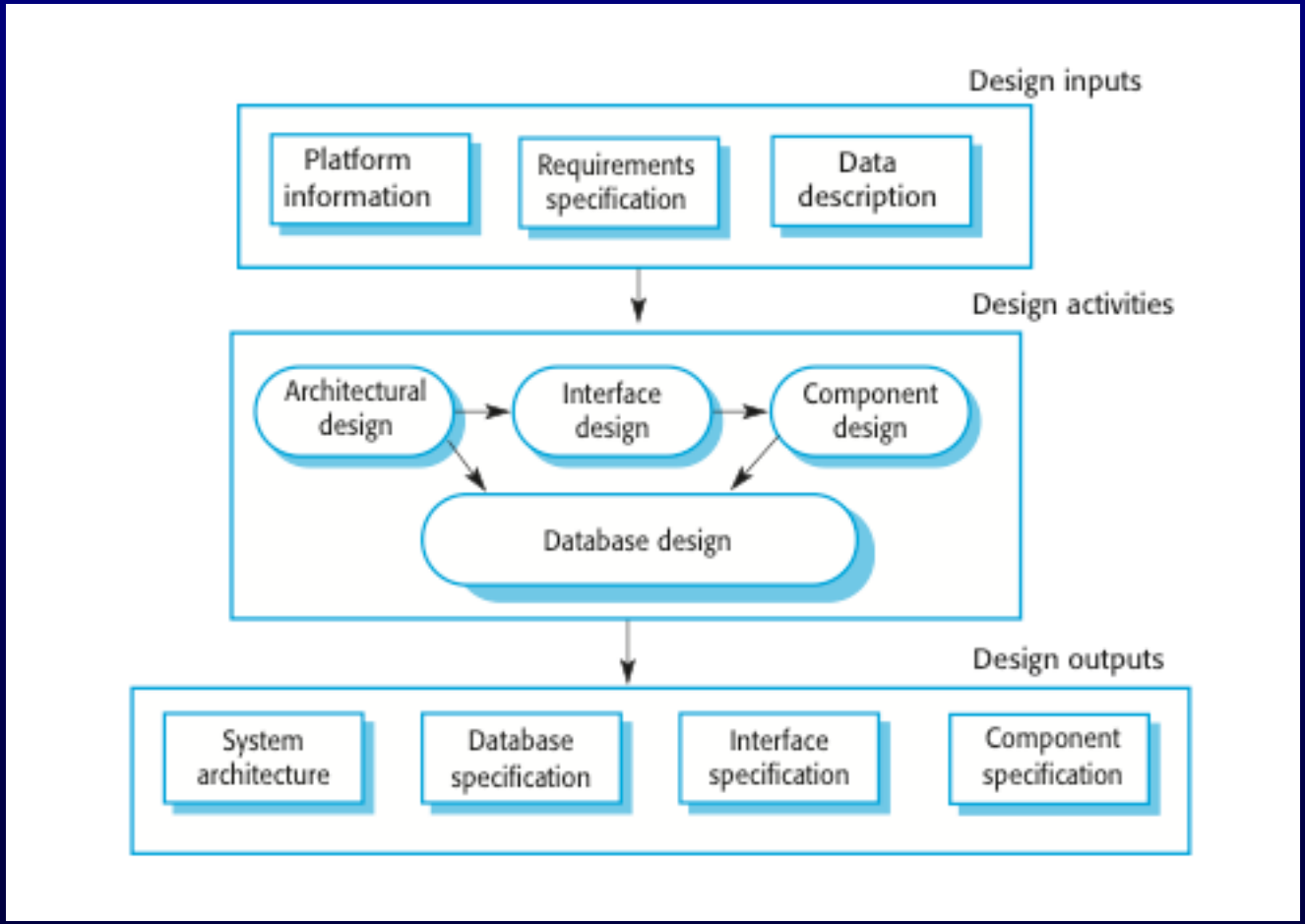
Software design and implementation

- 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.

Design process activities

- Architectural design
- Abstract specification
- Interface design
- Component design
- Data structure design
- Algorithm design

The software design process



Structured methods

- Systematic approaches to developing a software design.
- The design is usually documented as a set of graphical models.
- Possible models
  - Object model;
  - Sequence model;
  - State transition model;
  - Structural model;
  - Data-flow model.

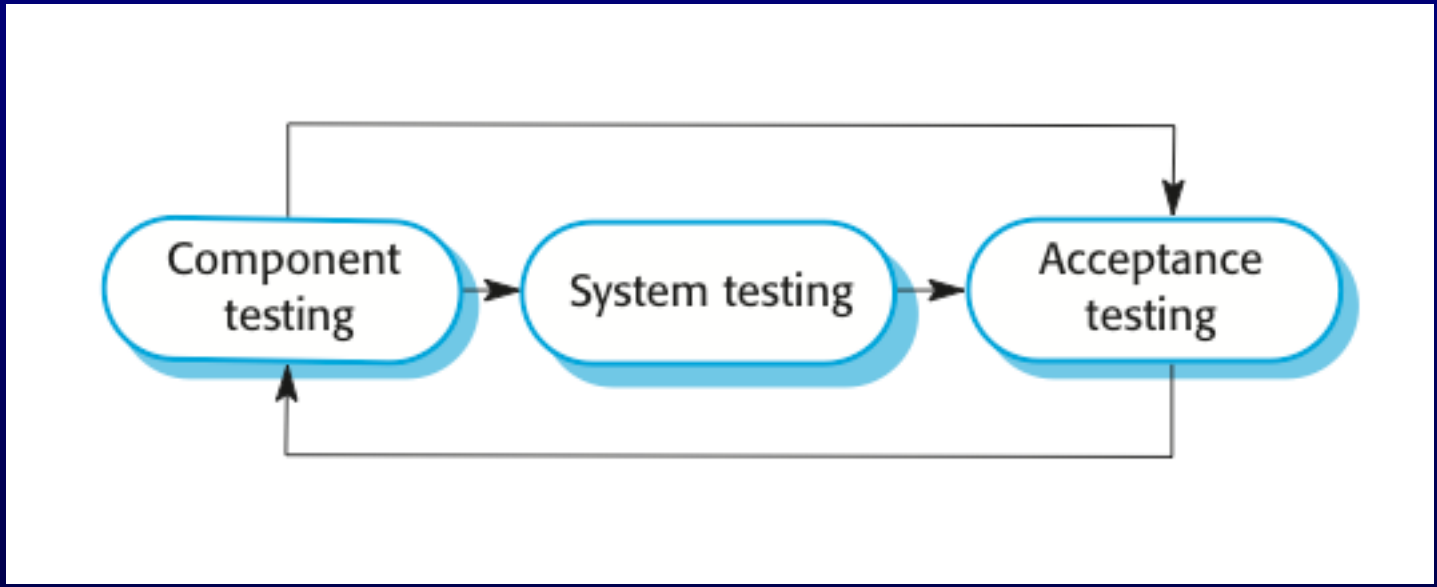
Programming and debugging

- Translating a design into a program and removing errors from that program.
- Programming is a personal activity - there is no generic programming process.
- Programmers carry out some program testing to discover faults in the program and remove these faults in the debugging process.

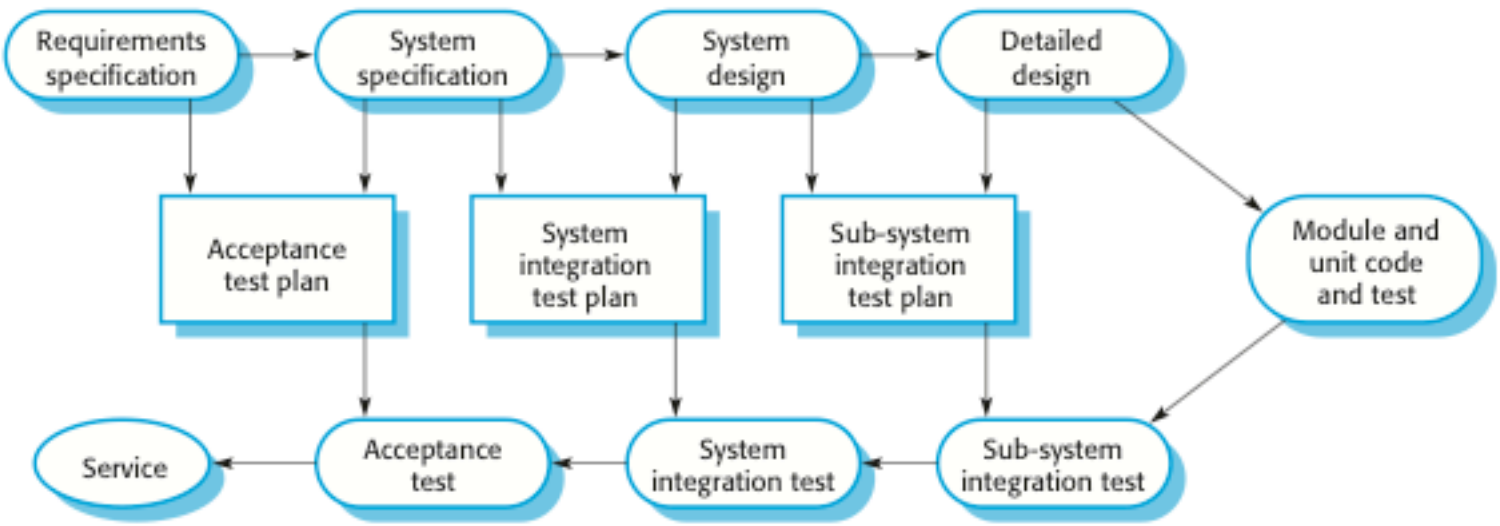
Software validation

- 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.

The testing process



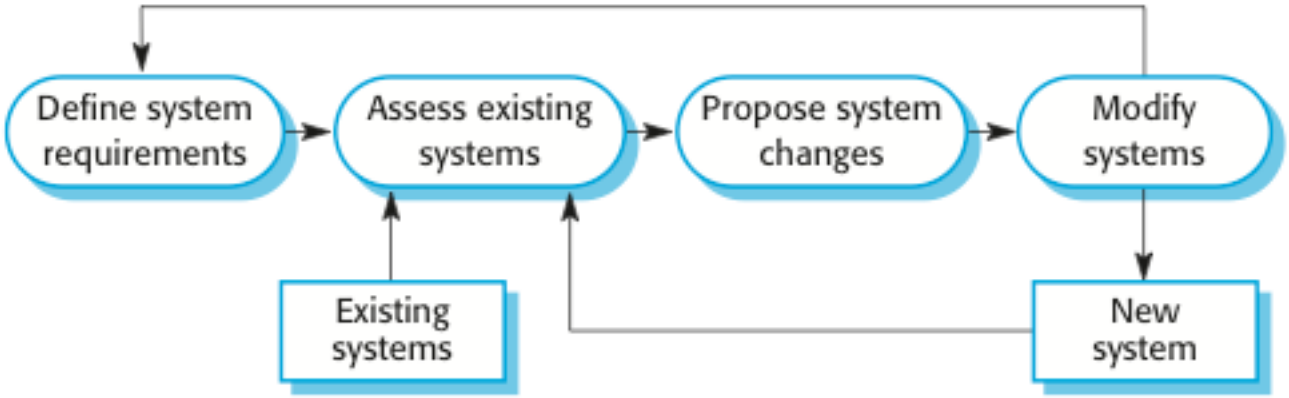
Testing phases



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.

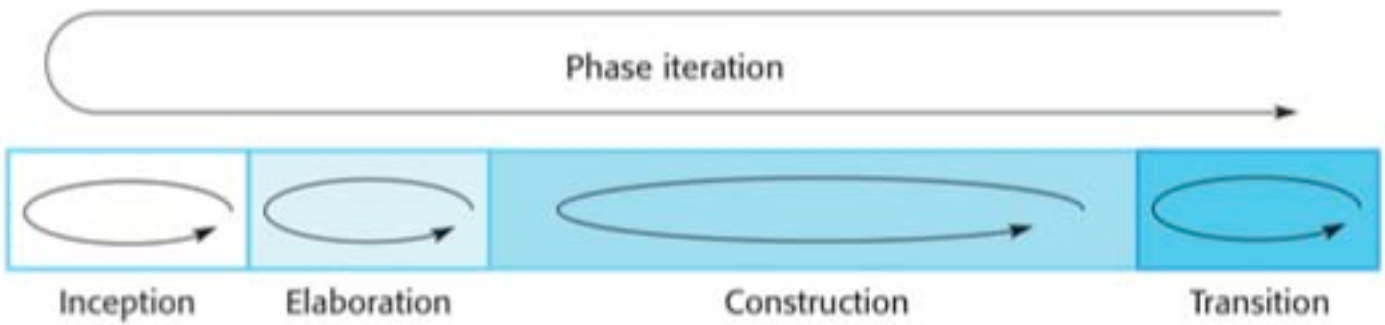
System evolution



The Rational Unified Process

- A modern process model derived from the work on the UML and associated process.
- Normally described from 3 perspectives
  - A dynamic perspective that shows phases over time;
  - A static perspective that shows process activities;
  - A practive perspective that suggests good practice.

RUP phase model



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 good practice

- Develop software iteratively
- Manage requirements
- Use component-based architectures
- Visually model software
- Verify software quality
- Control changes to software

Static workflows

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.
Test	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 29).
Project management	This supporting workflow manages the system development (see Chapter 5).
Environment	This workflow is concerned with making appropriate software tools available to the software development team.

Computer-aided software engineering

- Computer-aided software engineering (CASE) is software to support software development and evolution processes.
- Activity automation
  - Graphical editors for system model development;
  - Data dictionary to manage design entities;
  - Graphical UI builder for user interface construction;
  - Debuggers to support program fault finding;
  - Automated translators to generate new versions of a program.

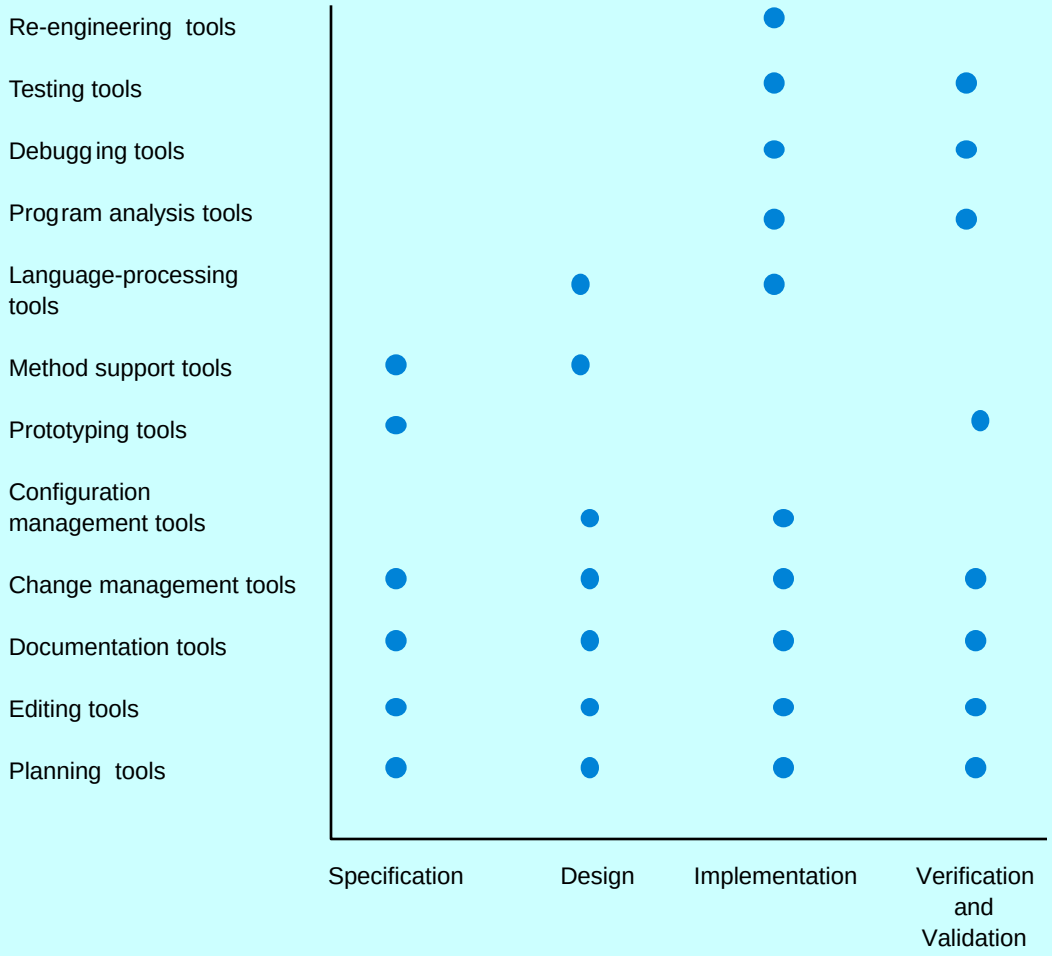
Case technology

- Case technology has led to significant improvements in the software process. However, these are not the order of magnitude improvements that were once predicted
  - Software engineering requires creative thought - this is not readily automated;
  - Software engineering is a team activity and, for large projects, much time is spent in team interactions. CASE technology does not really support these.

CASE classification

- Classification helps us understand the different types of CASE tools and their support for process activities.
- Functional perspective
  - Tools are classified according to their specific function.
- Process perspective
  - Tools are classified according to process activities that are supported.
- Integration perspective
  - Tools are classified according to their organisation into integrated units.

Activity-based tool classification



Key points

- Requirements engineering is the process of developing a software specification.
- Design and implementation processes transform the specification to an executable program.
- Validation involves checking that the system meets to its specification and user needs.
- Evolution is concerned with modifying the system after it is in use.
- The Rational Unified Process is a generic process model that separates activities from phases.
- CASE technology supports software process activities.

Project management

Objectives

- To explain the main tasks undertaken by project managers
- To introduce software project management and to describe its distinctive characteristics
- To discuss project planning and the planning process
- To show how graphical schedule representations are used by project management

Software project management

- Concerned with activities involved in ensuring that software is delivered on time and on schedule and in accordance with the requirements of the organisations developing and procuring the software.
- Project management is needed because software development is always subject to budget and schedule constraints that are set by the organisation developing the software.

Software management distinctions

- The product is intangible.
- The product is uniquely flexible.
- Software engineering is not recognized as an engineering discipline with the sane status as mechanical, electrical engineering, etc.
- The software development process is not standardised.
- Many software projects are 'one-off' projects.

Management activities

- Proposal writing.
- Project planning and scheduling.
- Project costing.
- Project monitoring and reviews.
- Personnel selection and evaluation.
- Report writing and presentations.

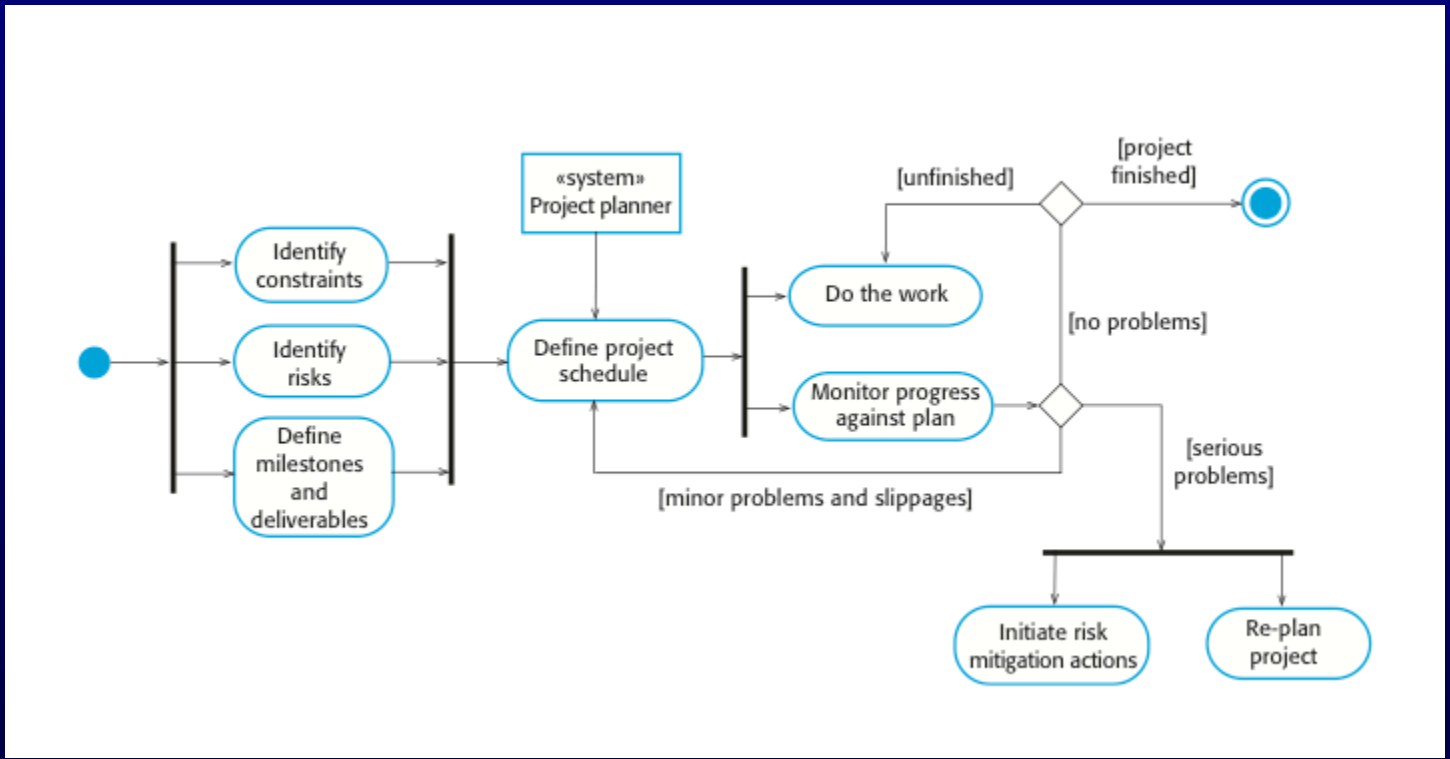
Project planning

- Probably the most time-consuming project management activity.
- Continuous activity from initial concept through to system delivery. Plans must be regularly revised as new information becomes available.
- Various different types of plan may be developed to support the main software project plan that is concerned with schedule and budget.

Types of project plan

Plan	Description
Quality plan	Describes the quality procedures and standards that will be used in a project. See Chapter 27.
Validation plan	Describes the approach, resources and schedule used for system validation. See Chapter 22.
Configuration management plan	Describes the configuration management procedures and structures to be used. See Chapter 29.
Maintenance plan	Predicts the maintenance requirements of the system, maintenance costs and effort required. See Chapter 21.
Staff development plan.	Describes how the skills and experience of the project team members will be developed. See Chapter 25.

Project planning process



The project plan

- The project plan sets out:
  - The resources available to the project;
  - The work breakdown;
  - A schedule for the work.

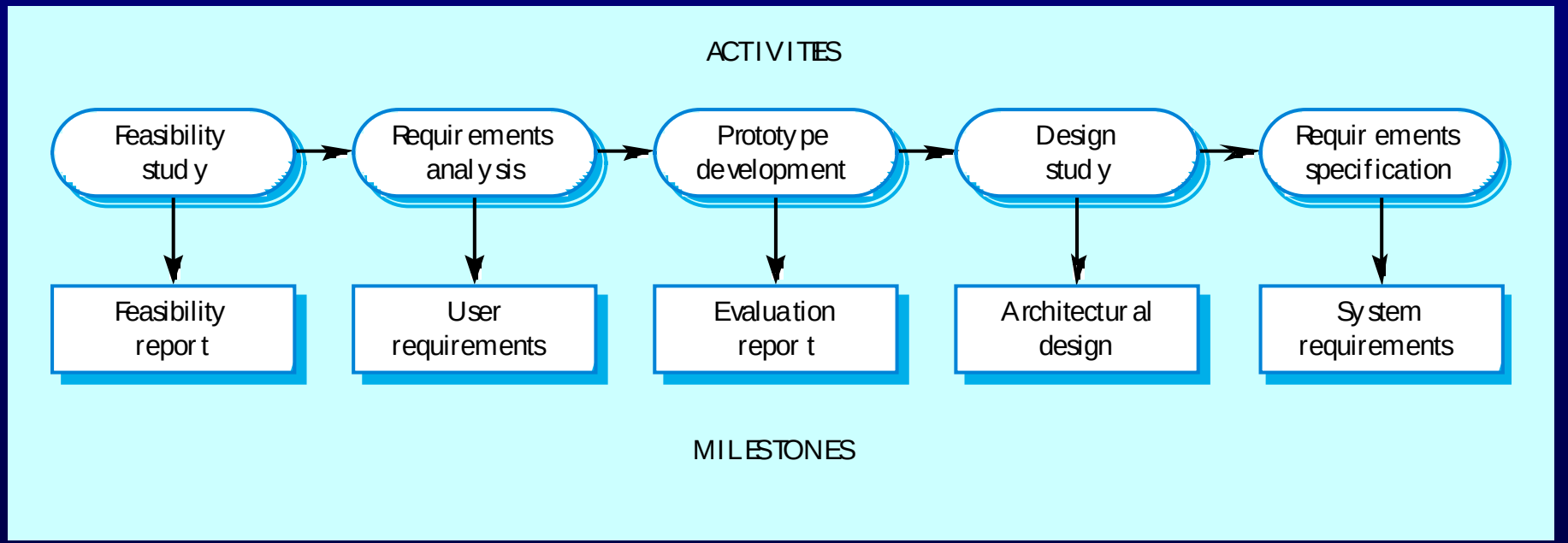
Project plan structure

- Introduction.
- Project organisation.
- Risk analysis.
- Hardware and software resource requirements.
- Work breakdown.
- Project schedule.
- Monitoring and reporting mechanisms.

Activity organization

- Activities in a project should be organised to produce tangible outputs for management to judge progress.
- *Milestones* are the end-point of a process activity.
- *Deliverables* are project results delivered to customers.
- The waterfall process allows for the straightforward definition of progress milestones.

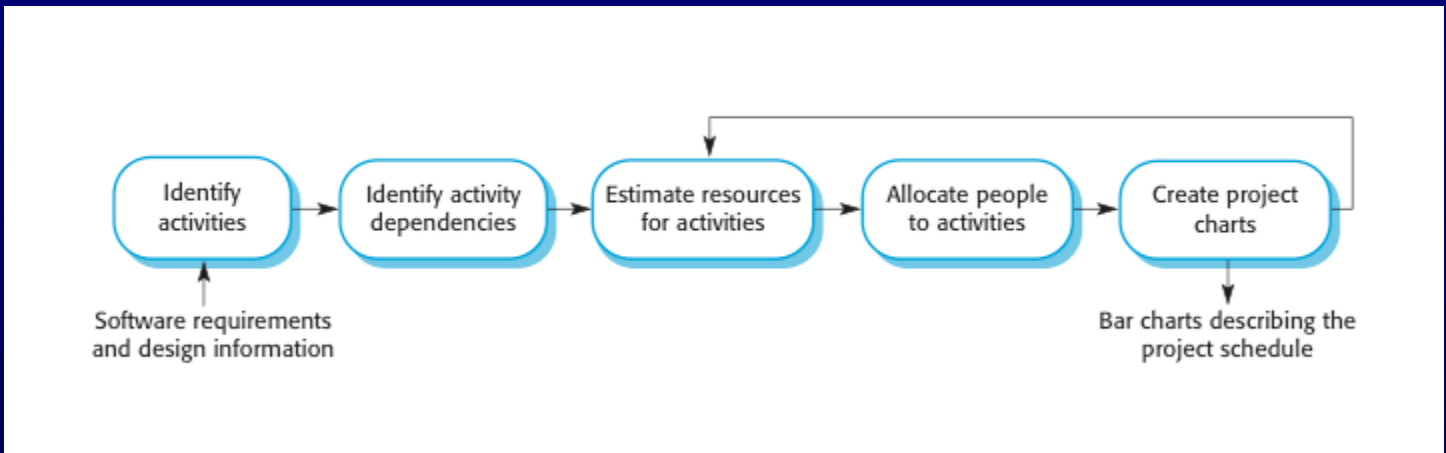
Milestones in the RE process



Project scheduling

- 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.

The project scheduling process



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.

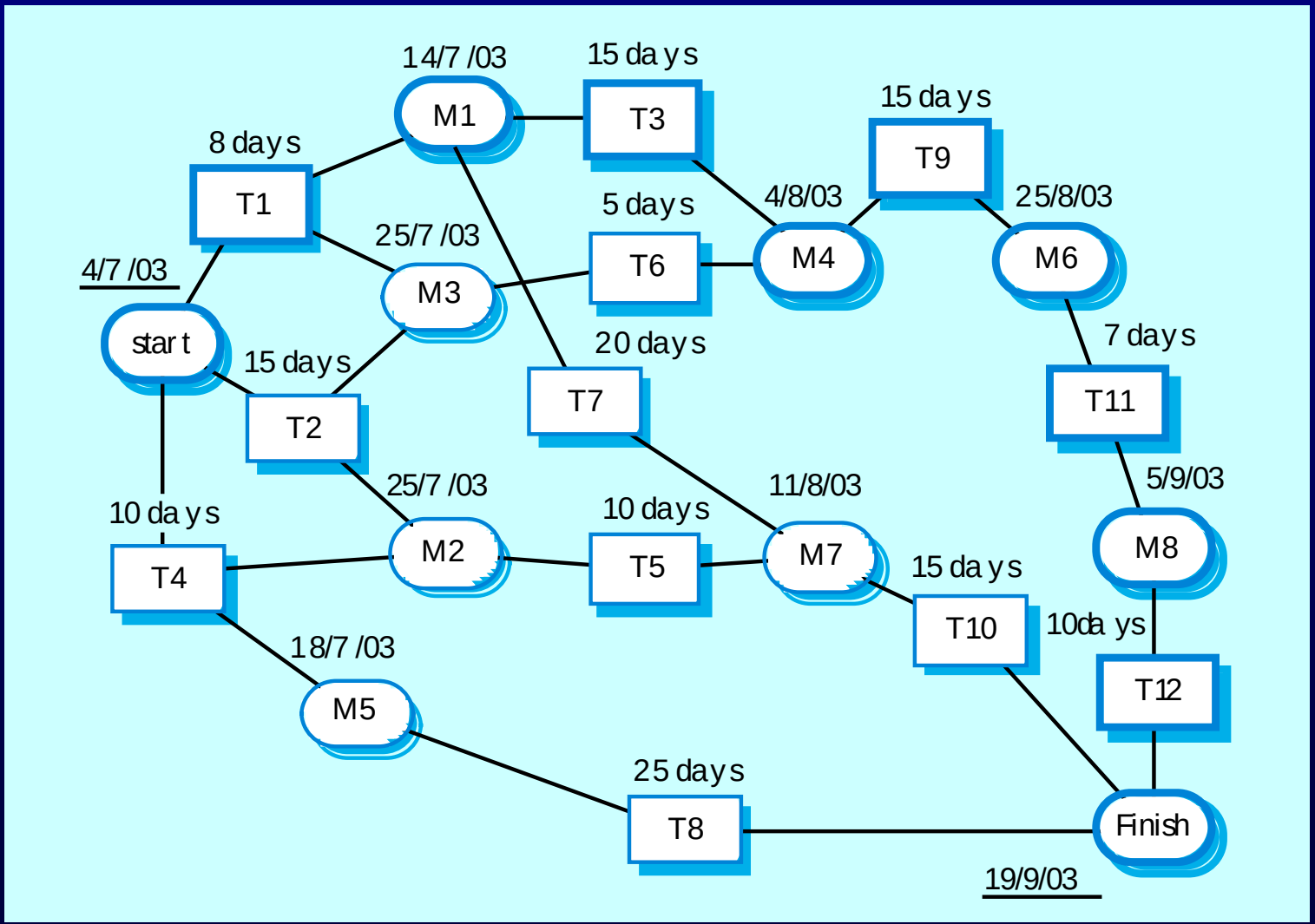
Bar charts and activity networks

- Graphical notations used to illustrate the project schedule.
- Show project breakdown into tasks. Tasks should not be too small. They should take about a week or two.
- Activity charts show task dependencies and the the critical path.
- Bar charts show schedule against calendar time.

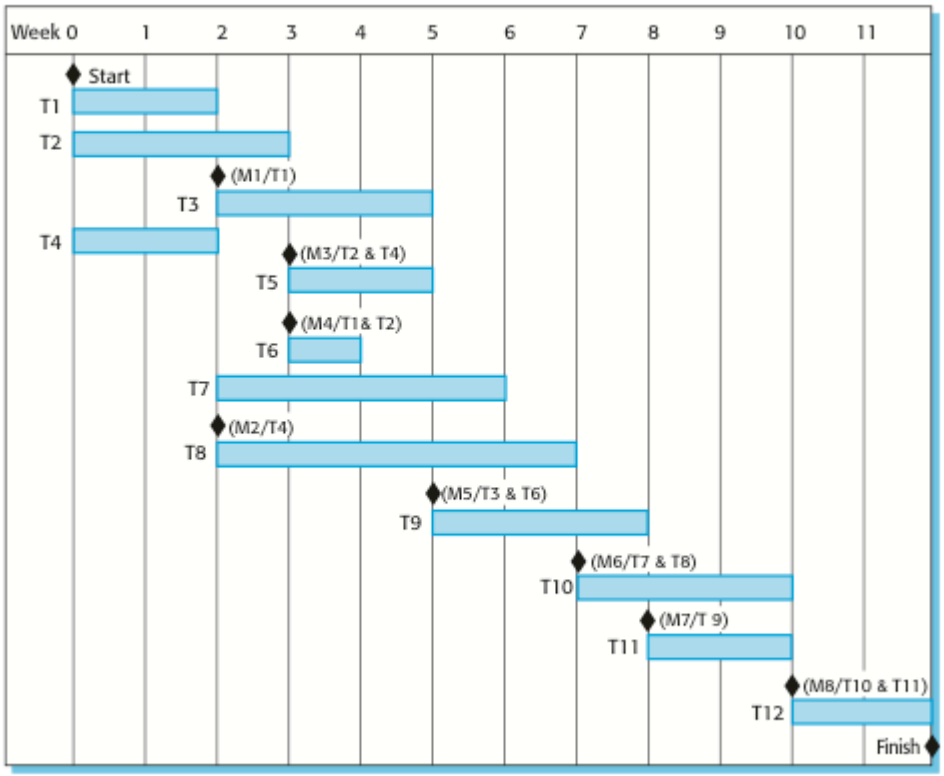
Task durations and dependencies

Activity	Duration (days)	Dependencies
T1	8	
T2	15	
T3	15	T1 (M1)
T4	10	
T5	10	T2, T4 (M2)
T6	5	T1, T2 (M3)
T7	20	T1 (M1)
T8	25	T4 (M5)
T9	15	T3, T6 (M4)
T10	15	T5, T7 (M7)
T11	7	T9 (M6)
T12	10	T11 (M8)

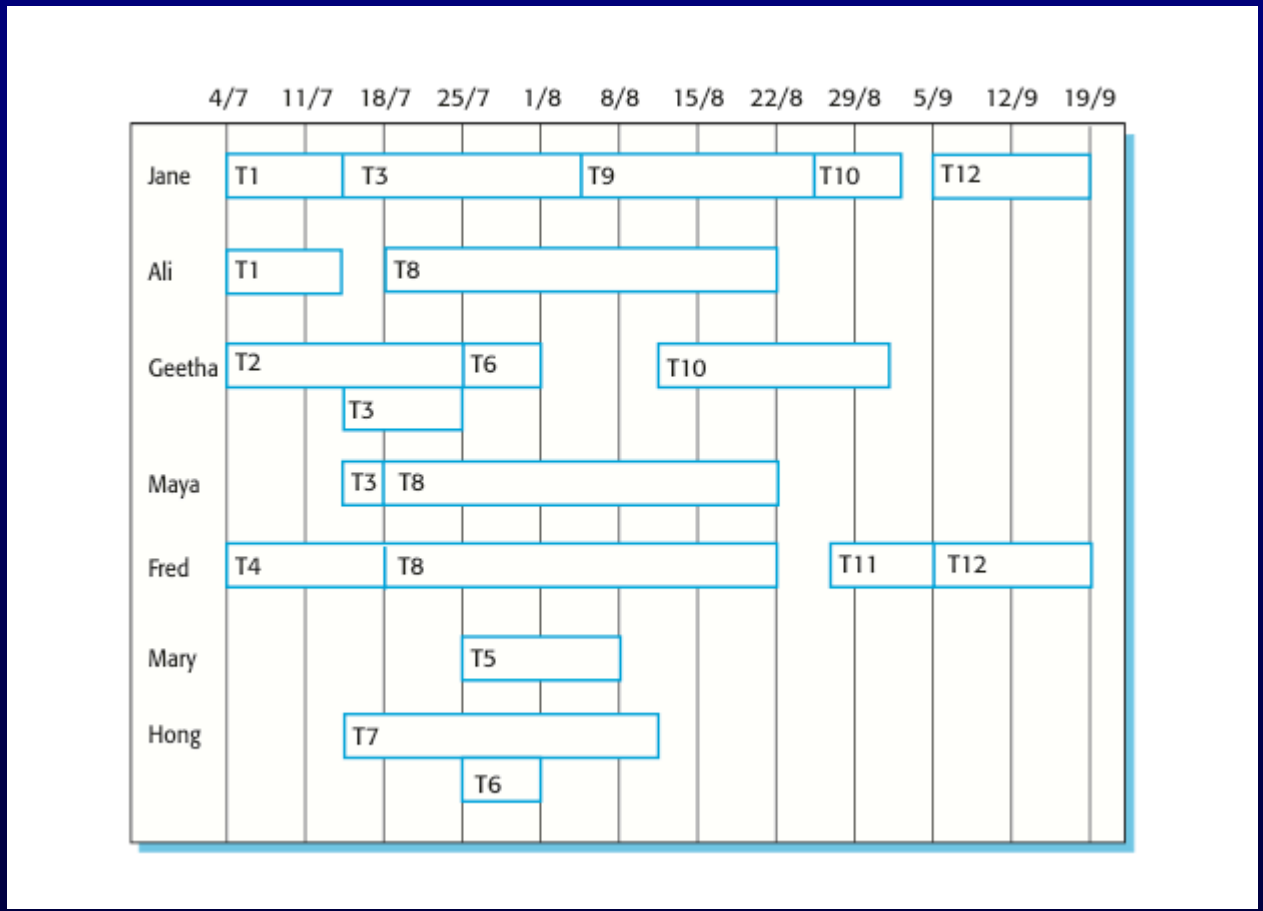
Activity network



Activity timeline



Staff allocation



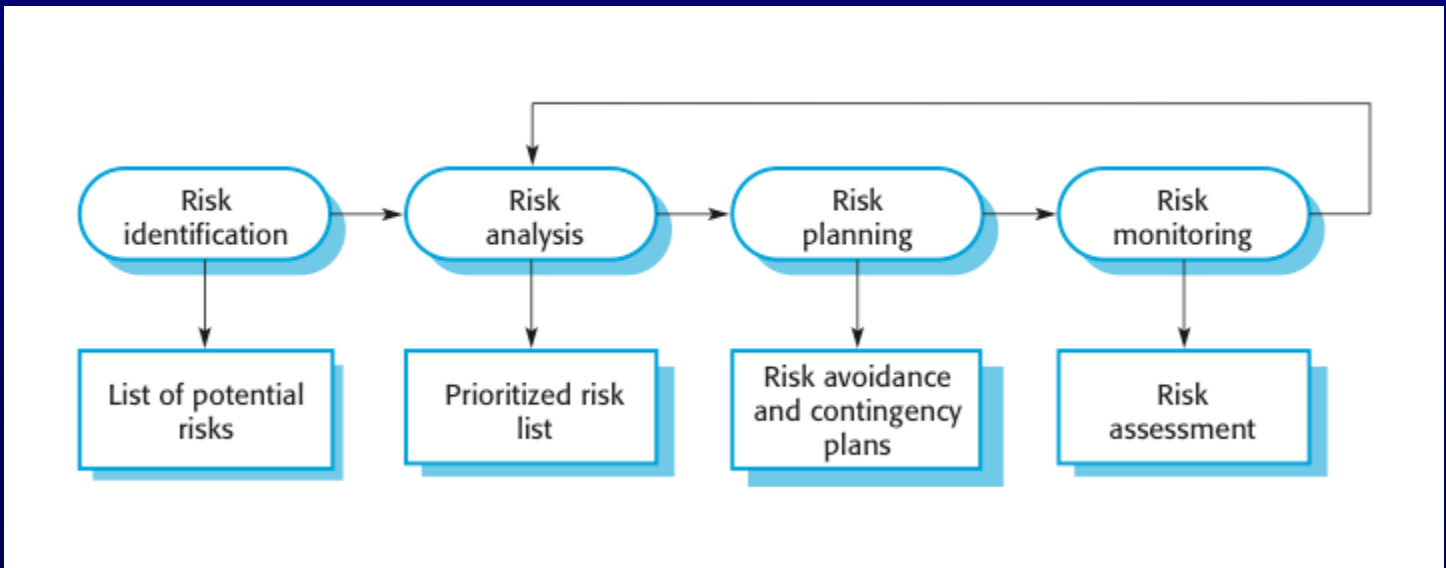
Risk management

- Risk management is concerned with identifying risks and drawing up plans to minimise their effect on a project.
- A risk is a probability that some adverse circumstance will occur
  - Project risks affect schedule or resources;
  - Product risks affect the quality or performance of the software being developed;
  - Business risks affect the organisation developing or procuring the software.

Software risks

Risk	Affects	Description
Staff turnover	Project	Experienced staff will leave the project before it is finished.
Management change	Project	There will be a change of organisational management with different priorities.
Hardware unavailability	Project	Hardware that is essential for the project will not be delivered on schedule.
Requirements change	Project and product	There will be a larger number of changes to the requirements than anticipated.
Specification delays	Project and product	Specifications of essential interfaces are not available on schedule
Size underestimate	Project and product	The size of the system has been underestimated.
CASE tool under-performance	Product	CASE tools which support the project do not perform as anticipated
Technology change	Business	The underlying technology on which the system is built is superseded by new technology.
Product competition	Business	A competitive product is marketed before the system is completed.

The risk management process



Risk indicators

Risk type	Potential indicators
Technology	Late delivery of hardware or support software, many reported technology problems
People	Poor staff morale, poor relationships amongst team member, job availability
Organisational	Organisational gossip, lack of action by senior management
Tools	Reluctance by team members to use tools, complaints about CASE tools, demands for higher-powered workstations
Requirements	Many requirements change requests, customer complaints
Estimation	Failure to meet agreed schedule, failure to clear reported defects

Key points

- Good project management is essential for project success.
- The intangible nature of software causes problems for management.
- Managers have diverse roles but their most significant activities are planning, estimating and scheduling.
- Planning and estimating are iterative processes which continue throughout the course of a project.

Key points

- A project milestone is a predictable state where a formal report of progress is presented to management.
- Project scheduling involves preparing various graphical representations showing project activities, their durations and staffing.
- Risk management is concerned with identifying risks which may affect the project and planning to ensure that these risks do not develop into major threats.

Software change management

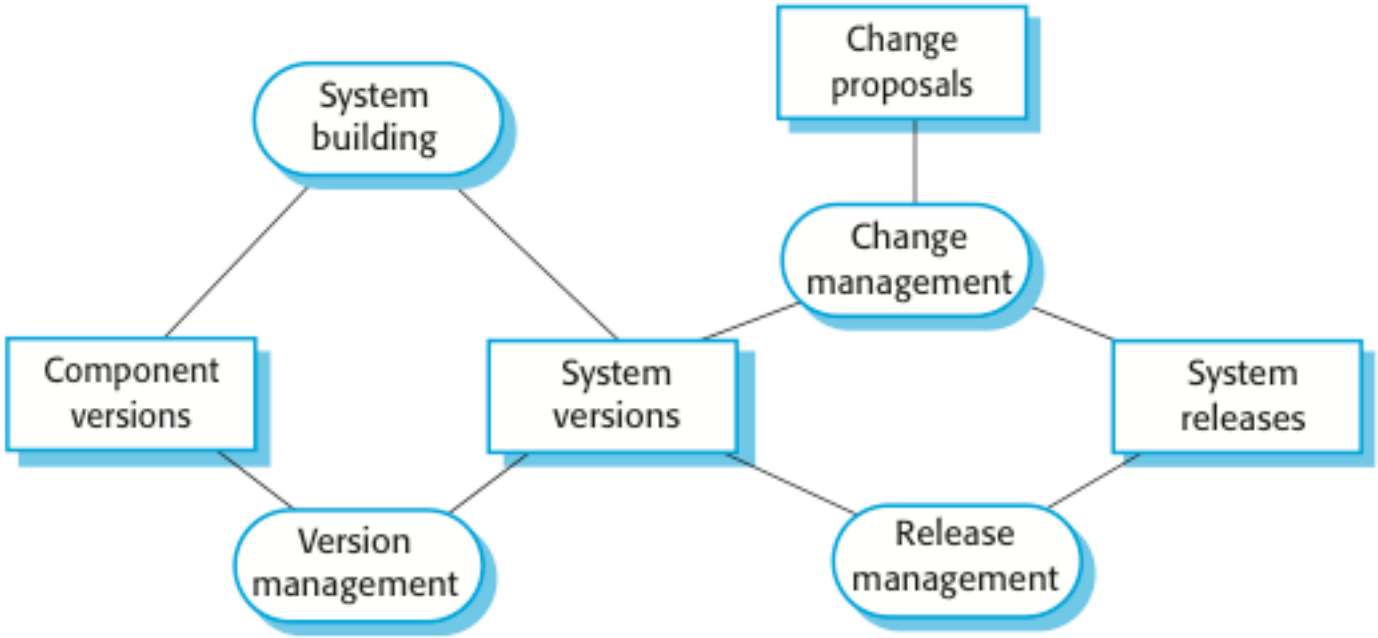
Objectives

- To explain the importance of software change management
- To describe key change management activities - planning, change management, version management and system building
- To discuss the use of CASE tools to support change management processes

Change management

- Software systems are subject to continual change requests:
  - From users;
  - From developers;
  - From market forces.
- Change management is concerned with keeping track of these changes and ensuring that they are implemented in the most cost-effective way.

Change management activities



Change management requirements

- Some means for users and developers to suggest required system changes
- A process to decide if changes should be included in a system
- Software to keep track of suggested changes and their status
- Software support for managing changing system configurations and building new systems

Change request form

- The definition of a change request form is part of the CM planning process.
- This form records the change proposed, requestor of change, the reason why change was suggested and the urgency of change(from requestor of the change).
- It also records change evaluation, impact analysis, change cost and recommendations (System maintenance staff).

Change request form

Change Request Form

Project: SICSA/AppProcessing **Number:** 23/02
Change requester: I. Sommerville **Date:** 20/01/09
Requested change: The status of applicants (rejected, accepted, etc.) should be shown visually in the displayed list of applicants.

Change analyzer: R. Looek **Analysis date:** 25/01/09
Components affected: ApplicantListDisplay, StatusUpdater

Associated components: StudentDatabase

Change assessment: Relatively simple to implement by changing the display color according to status. A table must be added to relate status to colors. No changes to associated components are required.

Change priority: Medium
Change implementation:
Estimated effort: 2 hours
Date to SGA app. team: 28/01/09 **CCB decision date:** 30/01/09
Decision: Accept change. Change to be implemented in Release 1.2
Change implementor: **Date of change:**
Date submitted to QA: **QA decision:**
Date submitted to CM:
Comments:

Change tracking tools

- A major problem in change management is tracking change status.
- Change tracking tools keep track the status of each change request and automatically ensure that change requests are sent to the right people at the right time.
- Integrated with E-mail systems allowing electronic change request distribution.

Change approval

- Changes should be reviewed by an external group who decide whether or not they are cost-effective from a strategic and organizational viewpoint rather than a technical viewpoint.
- Should be independent of project responsible for system. The group is sometimes called a change control board.
- The CCB may include representatives from client and contractor staff.

Derivation history

- This is a record of changes applied to a document or code component.
- It should record, in outline, the change made, the rationale for the change, who made the change and when it was implemented.
- It may be included as a comment in code. If a standard prologue style is used for the derivation history, tools can process this automatically.

Configuration management

- New versions of software systems are created as they change:
  - For different machines/OS;
  - Offering different functionality;
  - Tailored for particular user requirements.
- Configuration management is concerned with managing evolving software systems:
  - System change is a team activity;
  - CM aims to control the costs and effort involved in making changes to the software system and associated documentation.

Configuration management

- Involves the development and application of procedures and standards to manage an evolving software product.
- CM may be part of a more general quality management process.
- When released to CM, software systems are sometimes called *baselines* as they are a starting point for further development.

The configuration management plan

- Defines the types of documents to be managed and a document naming scheme.
- Defines who takes responsibility for the CM procedures and creation of baselines.
- Defines policies for change control and version management.
- Defines the CM records which must be maintained.

The configuration management plan

- Describes the tools which should be used to assist the CM process and any limitations on their use.
- Defines the process of tool use.
- Defines the CM database used to record configuration information.
- May include information such as the CM of external software, process auditing, etc.

Release management

- Releases must incorporate changes forced on the system by errors discovered by users and by hardware changes.
- They must also incorporate new system functionality.
- Release planning is concerned with when to issue a system version as a release.

System releases

- Not just a set of executable programs.
- May also include:
  - Configuration files defining how the release is configured for a particular installation;
  - Data files needed for system operation;
  - An installation program or shell script to install the system on target hardware;
  - Electronic and paper documentation;
  - Packaging and associated publicity.
- Systems are now normally released on optical disks (CD or DVD) or as downloadable installation files from the web.

System building

- The process of compiling and linking software components into an executable system.
- Different systems are built from different combinations of components.
- This process is now always supported by automated tools that are driven by ‘build scripts’.
- These may be separate tools (e.g. make) or part of the programming language environment (as in Java).

System building problems

- Do the build instructions include all required components?
  - When there are many hundreds of components making up a system, it is easy to miss one out. This should normally be detected by the linker.
- Is the appropriate component version specified?
  - A more significant problem. A system built with the wrong version may work initially but fail after delivery.
- Are all data files available?
  - The build should not rely on 'standard' data files. Standards vary from place to place.

System building problems

- Are data file references within components correct?
  - Embedding absolute names in code almost always causes problems as naming conventions differ from place to place.
- Is the system being built for the right platform
  - Sometimes you must build for a specific OS version or hardware configuration.
- Is the right version of the compiler and other software tools specified?
  - Different compiler versions may actually generate different code and the compiled component will exhibit different behaviour.

Change management tools

- CM processes are standardised and involve applying pre-defined procedures.
- Large amounts of data must be managed.
- Tool support for CM is therefore essential.
- Mature CASE tools to support configuration management are available ranging from stand-alone tools to integrated CM workbenches.

The configuration database

- All CM information should be maintained in a configuration database.
- This should allow queries about configurations to be answered:
  - Who has a particular system version?
  - What platform is required for a particular version?
  - What versions are affected by a change to component X?
  - How many reported faults in version T?
- The CM database should preferably be linked to the software being managed.

Change control tools

- Change control is a procedural process so it can be modelled and integrated with a version management system.
- Change control tools
  - Form editor to support processing the change request forms;
  - Workflow system to define who does what and to automate information transfer;
  - Change database that manages change proposals and is linked to a VM system;
  - Change reporting system that generates management reports on the status of change requests.

Version management tools

- Version and release identification
  - Systems assign identifiers automatically when a new version is submitted to the system.
- Storage management.
  - System stores the differences between versions rather than all the version code.
- Change history recording
  - Record reasons for version creation.
- Independent development
  - Only one version at a time may be checked out for change. Parallel working on different versions.
- Project support
  - Can manage groups of files associated with a project rather than just single files.

System building

- Building a large system is computationally expensive and may take several hours.
- Hundreds of files may be involved.
- System building tools may provide
  - A dependency specification language and interpreter;
  - Tool selection and instantiation support;
  - Distributed compilation;
  - Derived object management.

Key points

- Change management is concerned with all of the activities around proposing, evaluating and implementing changes to a software system.
- Change control involves assessing the technical and economic viability of change proposals.
- Configuration management is the process of managing the evolving software product.
- Change management tools may be stand-alone tools or may be integrated systems which integrate support for change control, version management, system building and change management.

Software Requirements

Objectives

- To introduce the concepts of user and system requirements
- To describe functional and non-functional requirements
- To explain how software requirements may be organised in a requirements document

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 organisation'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."

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.

Definitions and specifications

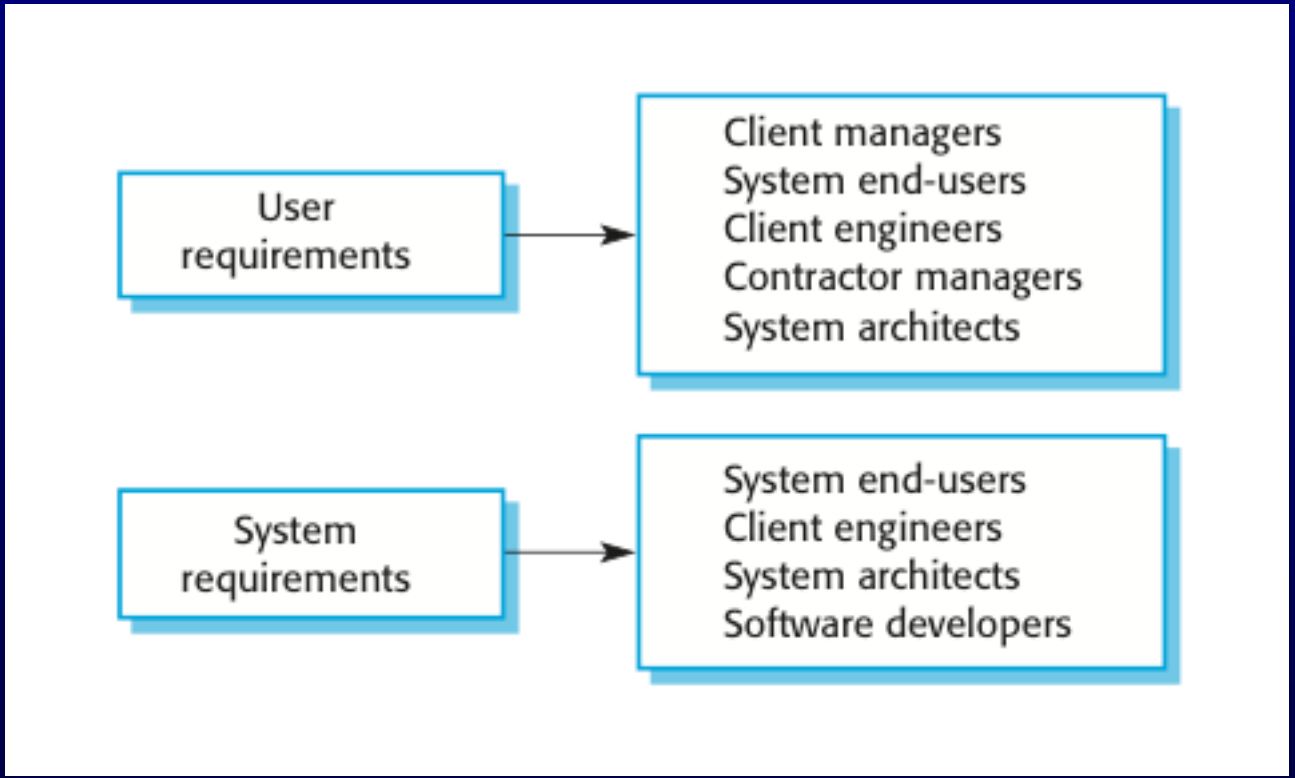
User requirement definition

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.

Requirements readers



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.
- Non-functional requirements
  - constraints on the services or functions offered by the system such as timing constraints, constraints on the development process, standards, etc.
- Domain requirements
  - Requirements that come from the application domain of the system and that reflect characteristics of that domain.

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 but functional system requirements should describe the system services in detail.

The LIBSYS system

- A library system that provides a single interface to a number of databases of articles in different libraries.
- Users can search for, download and print these articles for personal study.

Examples of functional requirements

- The user shall be able to search either all of the initial set of databases or select a subset from it.
- The system shall provide appropriate viewers for the user to read documents in the document store.
- Every order shall be allocated a unique identifier (ORDER_ID) which the user shall be able to copy to the account's permanent storage area.

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 ‘appropriate viewers’
  - User intention - special purpose viewer for each different document type;
  - Developer interpretation - Provide a text viewer that shows the contents of the document.

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.

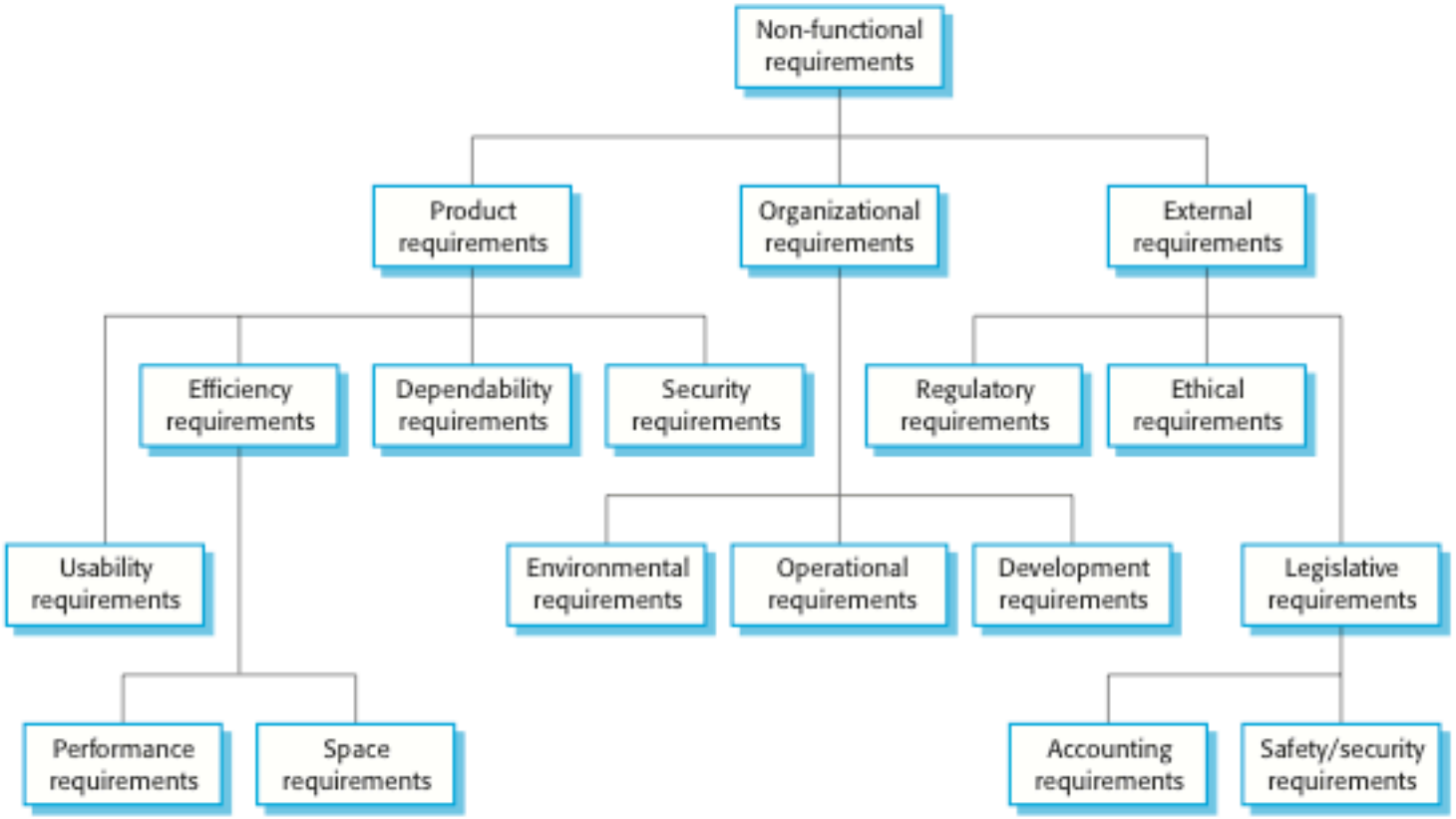
Non-functional requirements

- 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 CASE system, programming language or development method.
- Non-functional requirements may be more critical than functional requirements. If these are not met, the system is useless.

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.

Non-functional requirement types



Non-functional requirements examples

- Product requirement
  - 8.1 The user interface for LIBSYS shall be implemented as simple HTML without frames or Java applets.
- Organisational requirement
  - 9.3.2 The system development process and deliverable documents shall conform to the process and deliverables defined in XYZCo-SP-STAN-95.
- External requirement
  - 7.6.5 The system shall not disclose any personal information about customers apart from their name and reference number to the operators of the system.

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.

Examples

- **A system goal**
  - The system should be easy to use by experienced controllers and should be organised in such a way that user errors are minimised.
- **A verifiable non-functional requirement**
  - Experienced controllers shall be able to use all the system functions after a total of two hours training. After this training, the average number of errors made by experienced users shall not exceed two per day.

Requirements measures

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

Requirements interaction

- Conflicts between different non-functional requirements are common in complex systems.
- Spacecraft system
  - To minimise weight, the number of separate chips in the system should be minimised.
  - To minimise power consumption, lower power chips should be used.
  - However, using low power chips may mean that more chips have to be used. Which is the most critical requirement?

Key points

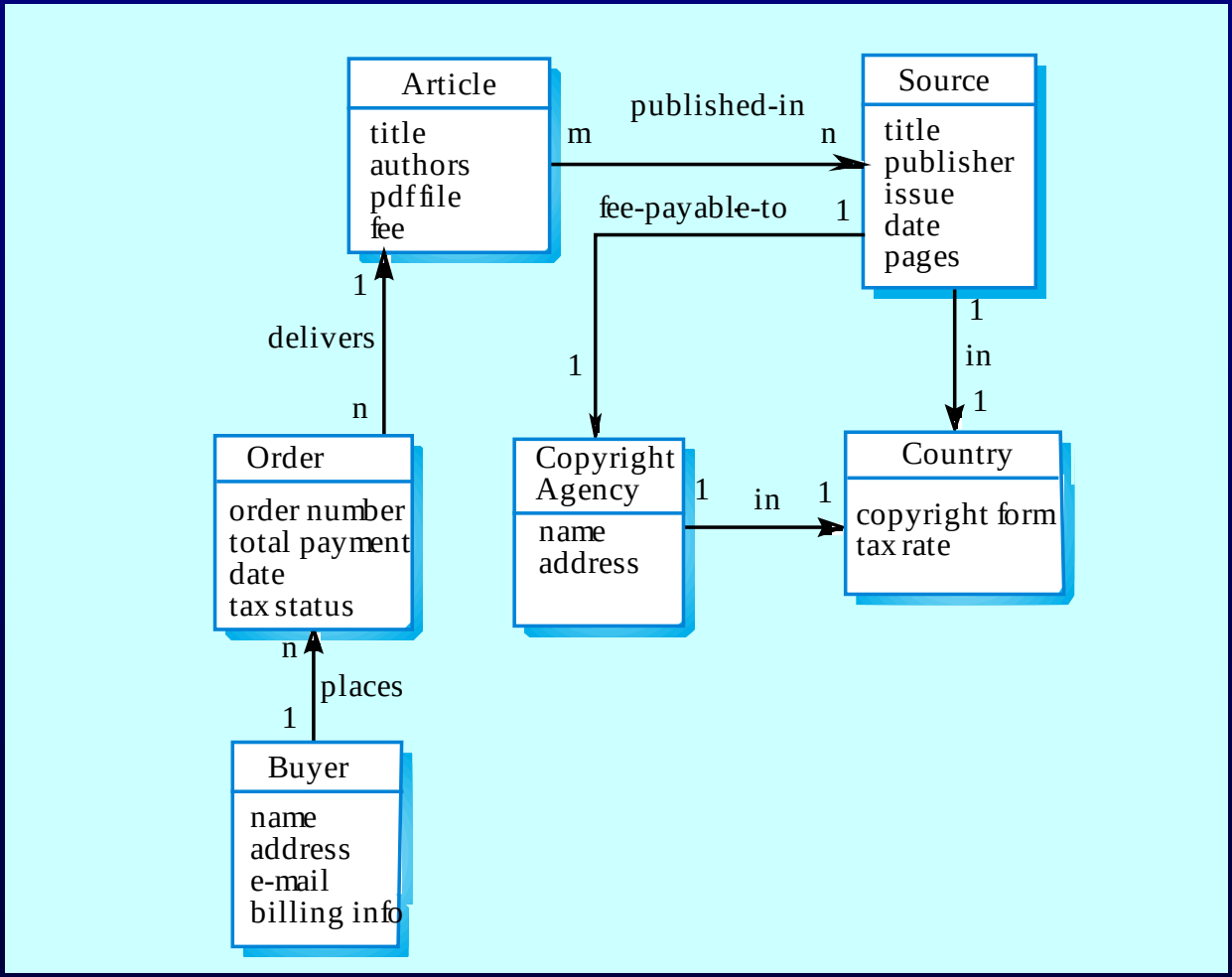
- Requirements set out what the system should do and define constraints on its operation and implementation.
- Functional requirements set out services the system should provide.
- Non-functional requirements constrain the system being developed or the development process.
- User requirements are high-level statements of what the system should do. User requirements should be written using natural language, tables and diagrams.

System modeling 2

Semantic data models

- Used to describe the logical structure of data processed by the system.
- An entity-relation-attribute model sets out the entities in the system, the relationships between these entities and the entity attributes
- Widely used in database design. Can readily be implemented using relational databases.
- In the UML, objects and associations may be used for semantic data modelling.

Library semantic model



Data dictionaries

- Data dictionaries are lists of all of the names used in the system models. Descriptions of the entities, relationships and attributes are also included.
- Advantages
  - Support name management and avoid duplication;
  - Store of organisational knowledge linking analysis, design and implementation;
- CASE tools can sometimes automatically generate data dictionaries from system models.

Data dictionary entries

Name	Description	Type	Date
Article	Details of the published article that may be ordered by people using LIBSYS.	Entity	30.12.2002
authors	The names of the authors of the article who may be due a share of the fee.	Attribute	30.12.2002
Buyer	The person or organisation that orders a copy of the article.	Entity	30.12.2002
fee-payable-to	A 1:1 relationship between Article and the Copyright Agency who should be paid the copyright fee.	Relation	29.12.2002
Address (Buyer)	The address of the buyer. This is used to any paper billing information that is required.	Attribute	31.12.2002

Object models

- Object models describe the system in terms of object classes and their associations.
- An object class is an abstraction over a set of objects with common attributes and the services (operations) provided by each object.
- Various object models may be produced
  - Inheritance models;
  - Aggregation models;
  - Interaction models.

Object models

- Natural ways of reflecting the real-world entities manipulated by the system
- More abstract entities are more difficult to model using this approach
- Object class identification is recognised as a difficult process requiring a deep understanding of the application domain
- Object classes reflecting domain entities are reusable across systems

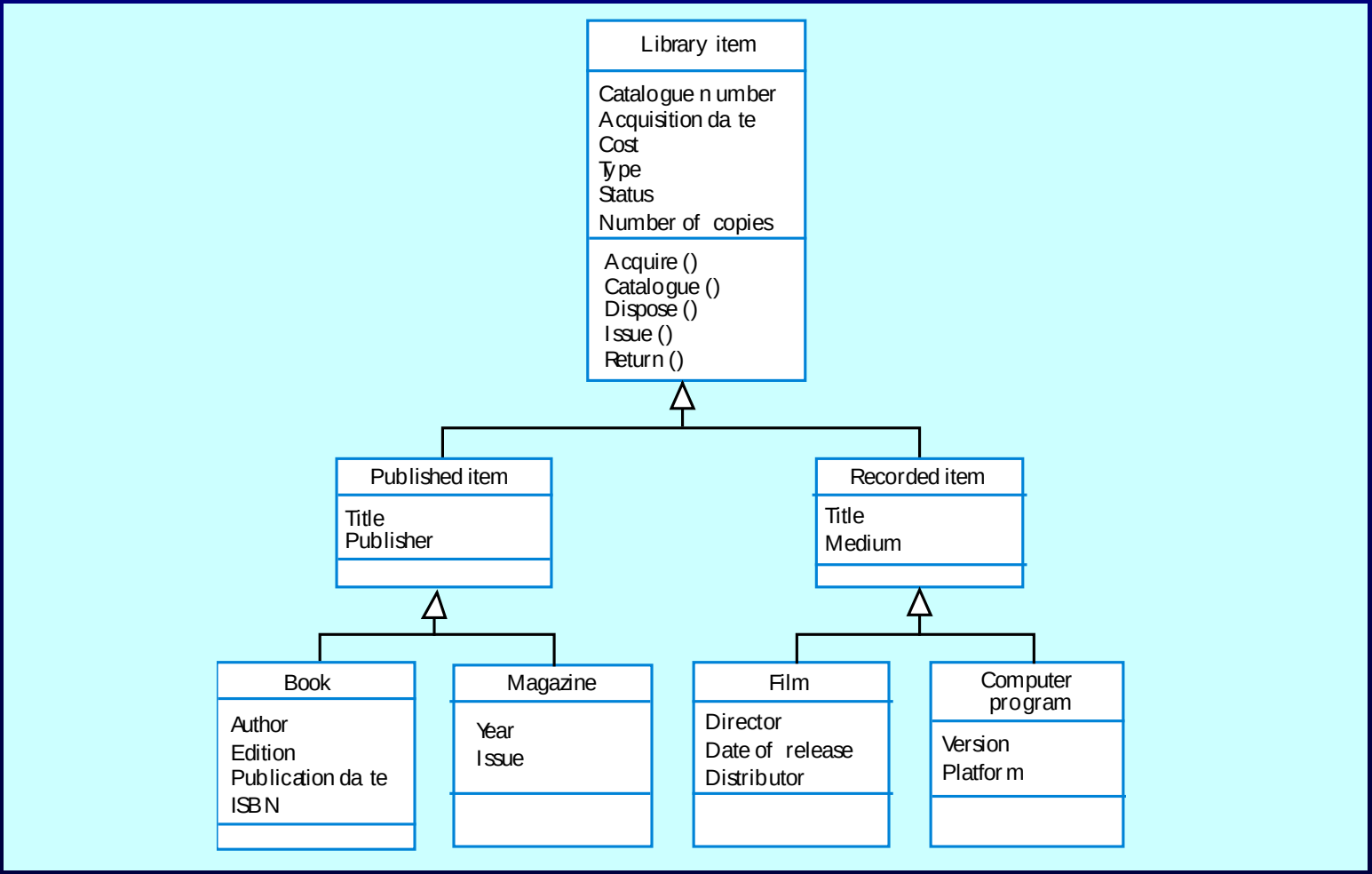
Inheritance models

- Organise the domain object classes into a hierarchy.
- Classes at the top of the hierarchy reflect the common features of all classes.
- Object classes inherit their attributes and services from one or more super-classes. these may then be specialised as necessary.
- Class hierarchy design can be a difficult process if duplication in different branches is to be avoided.

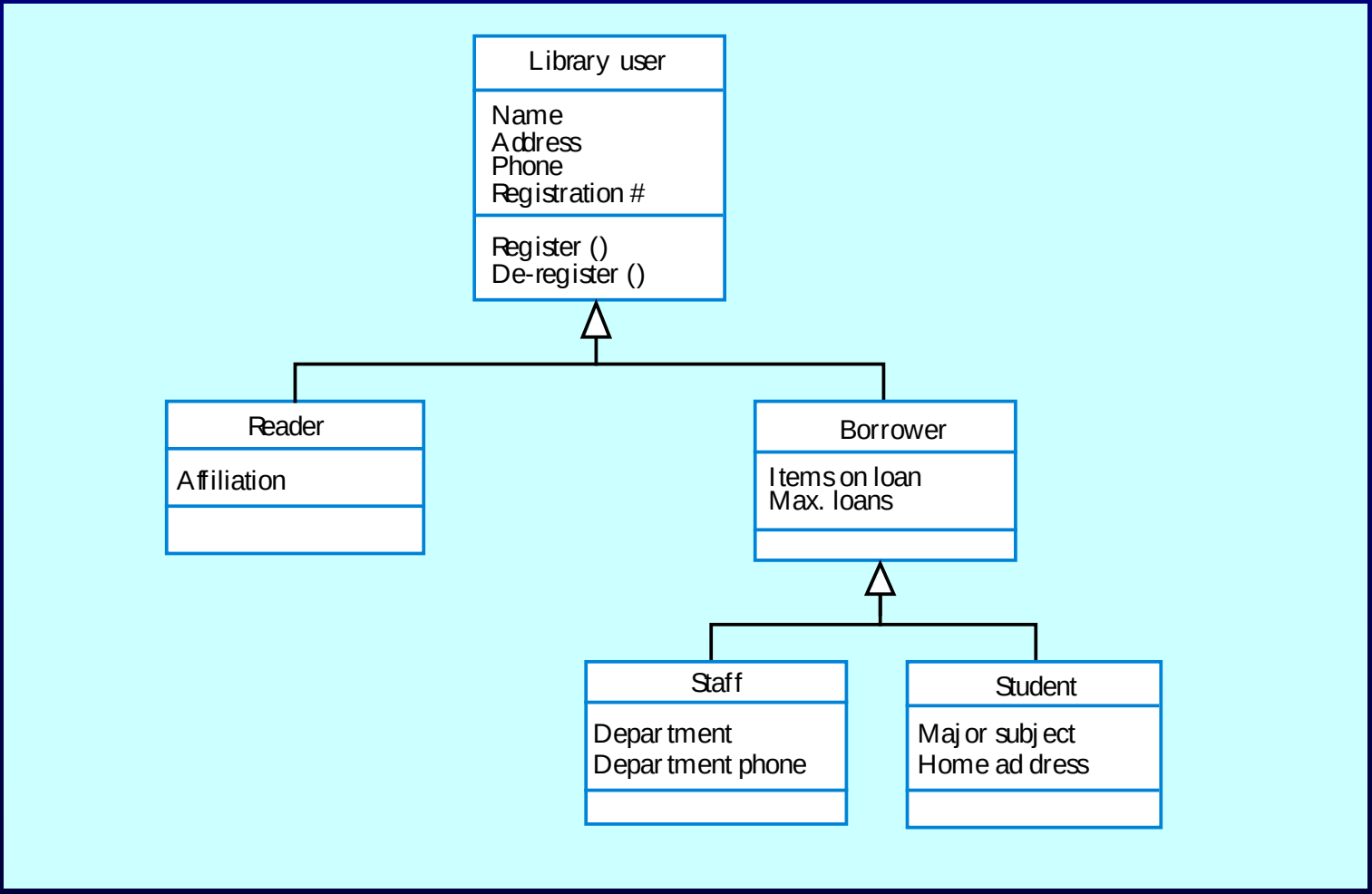
UML notation

- Object classes are rectangles with the name at the top, attributes in the middle section and operations in the bottom section.
- Relationships between object classes (known as associations) are shown as lines linking objects. Associations may be annotated with the type of association or special arrow symbols may be used to denote the association type (e.g. inheritance is a triangular white arrowhead)
- Inheritance is referred to as generalisation and is shown ‘upwards’ rather than ‘downwards’ in a hierarchy.

Library class hierarchy



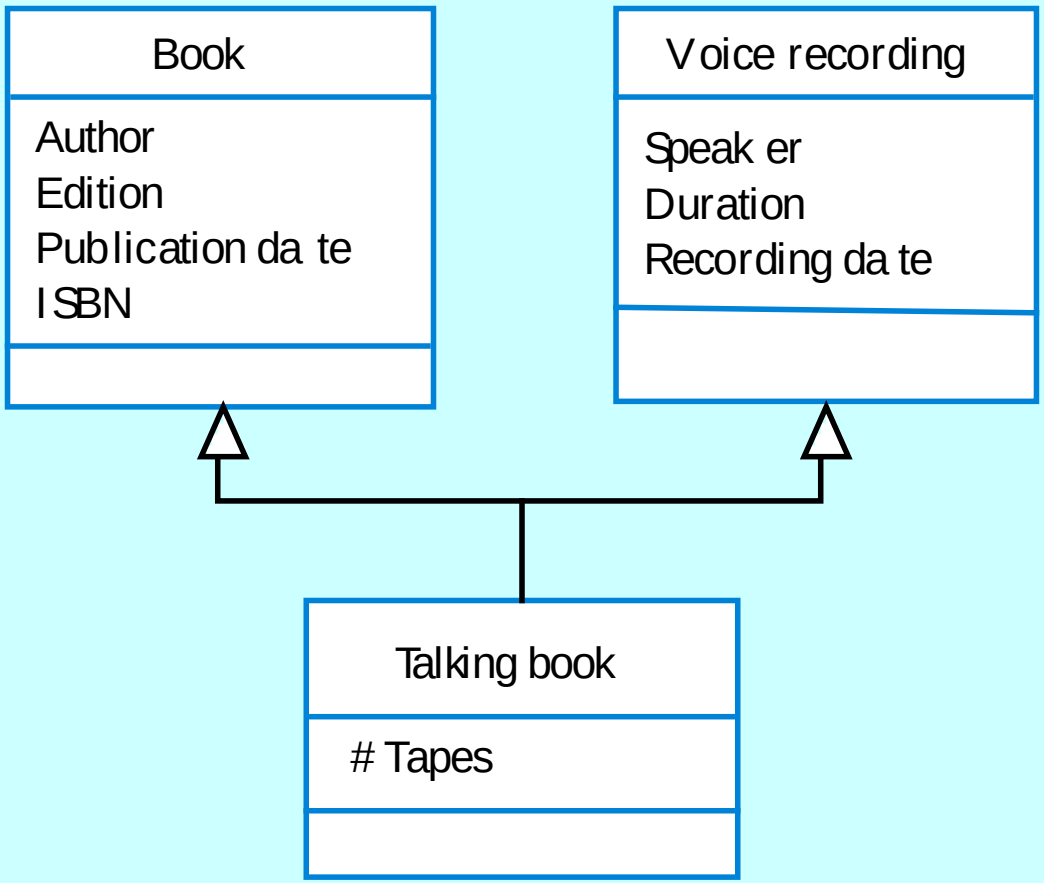
User class hierarchy



Multiple inheritance

- Rather than inheriting the attributes and services from a single parent class, a system which supports multiple inheritance allows object classes to inherit from several super-classes.
- This can lead to semantic conflicts where attributes/services with the same name in different super-classes have different semantics.
- Multiple inheritance makes class hierarchy reorganisation more complex.

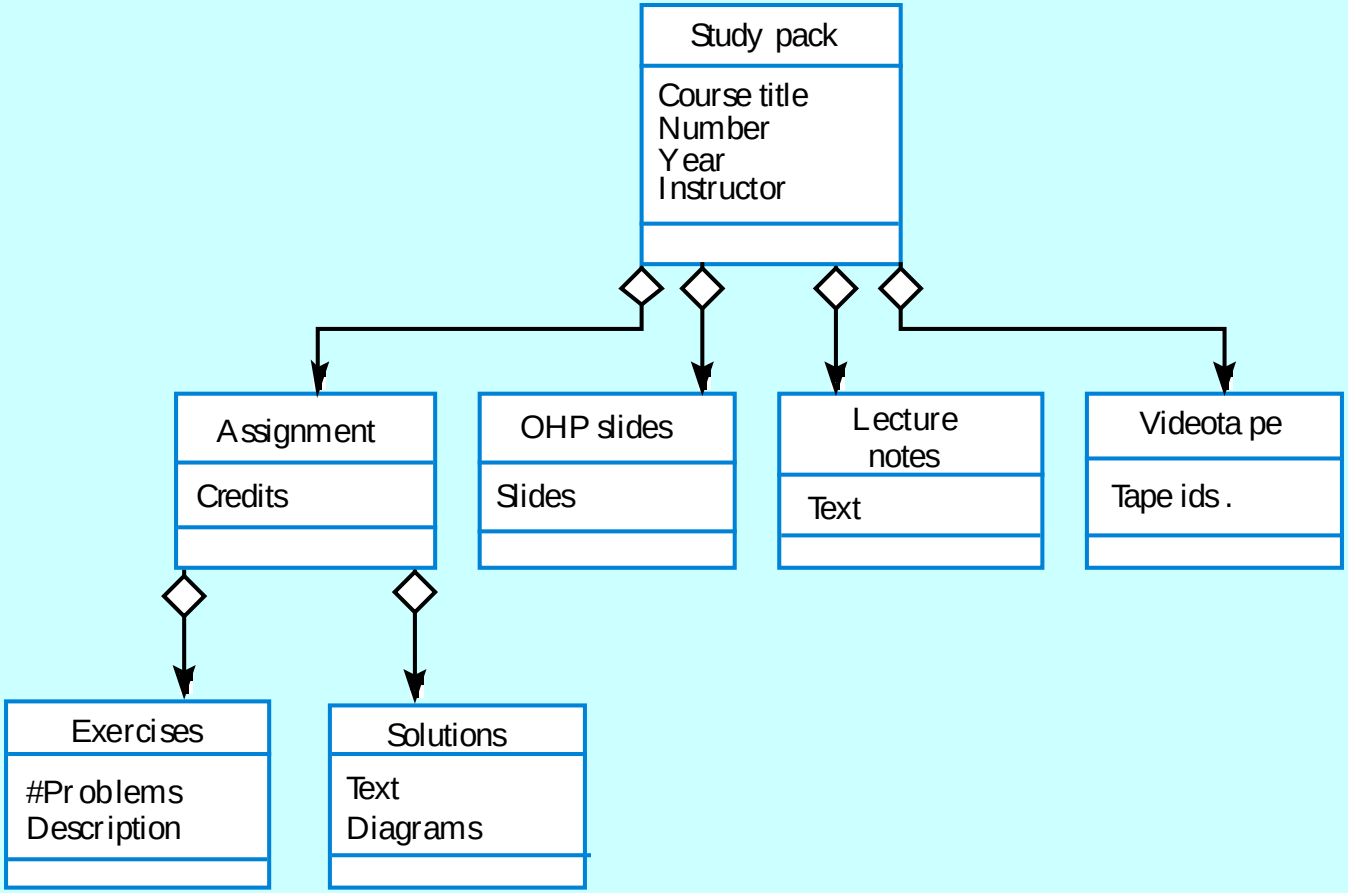
Multiple inheritance



Object aggregation

- 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.

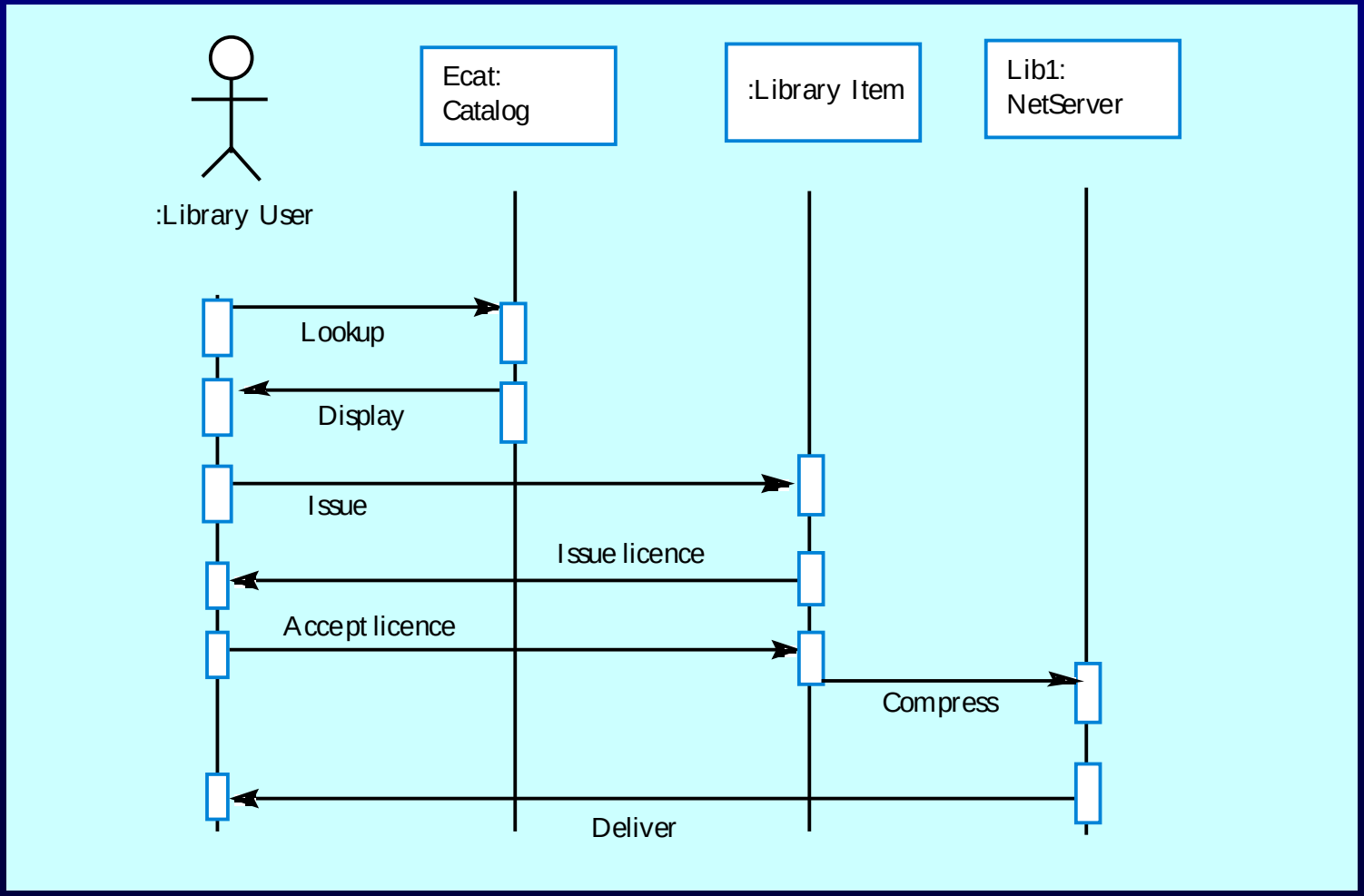
Object aggregation



Object behaviour modelling

- A behavioural model shows the interactions between objects to produce some particular system behaviour that is specified as a use-case.
- Sequence diagrams (or collaboration diagrams) in the UML are used to model interaction between objects.

Issue of electronic items



Structured analysis and design

- Structured analysis and design methods incorporate system modelling as an inherent part of the method.
- Methods define a set of models, a process for deriving these models and rules and guidelines that should apply to the models.
- CASE tools support system modelling as part of the structured method.

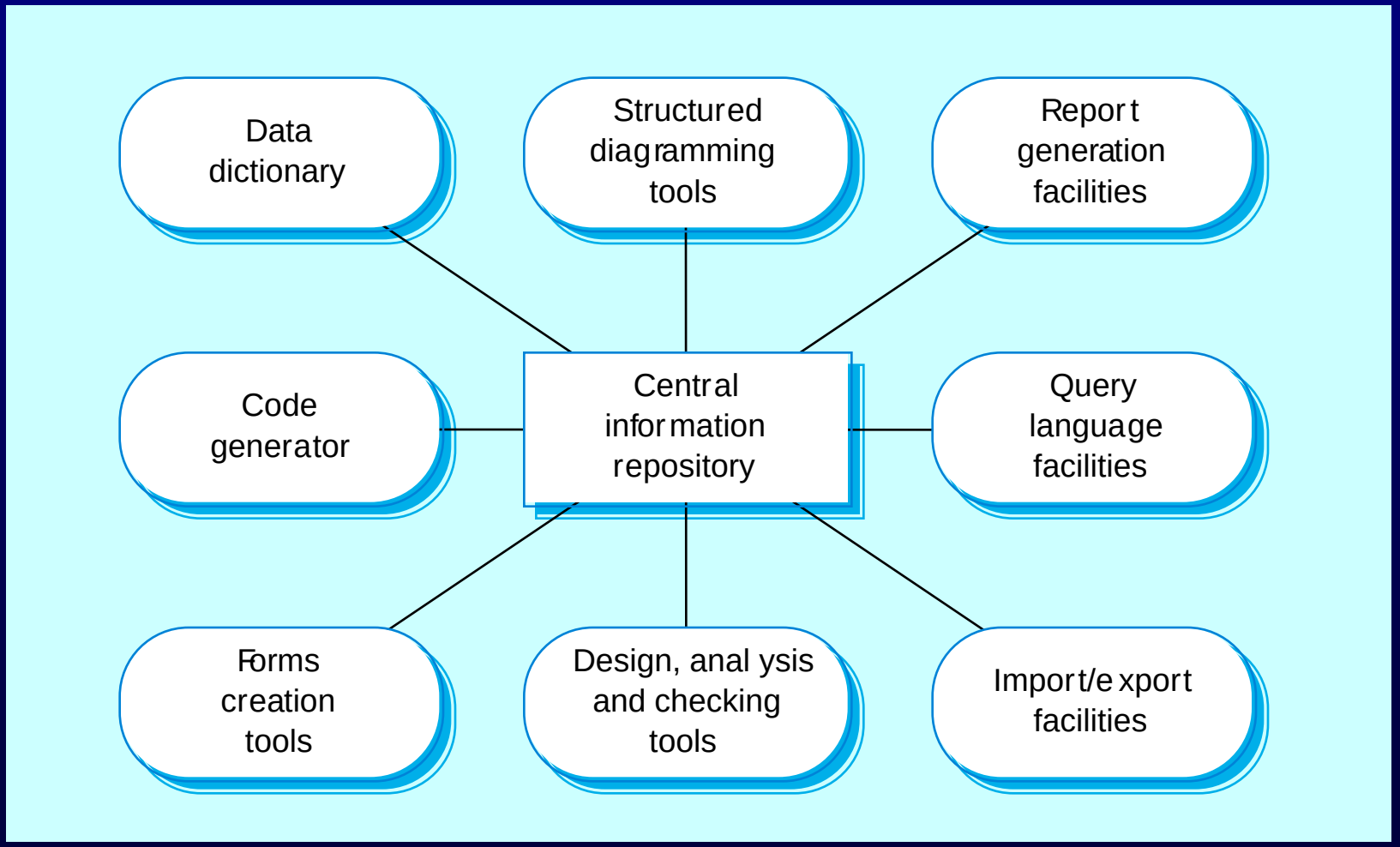
Method weaknesses

- They do not model non-functional system requirements.
- They do not usually include information about whether a method is appropriate for a given problem.
- The may produce too much documentation.
- The system models are sometimes too detailed and difficult for users to understand.

CASE workbenches

- A coherent set of tools that is designed to support related software process activities such as analysis, design or testing. May be incorporated in an IDE such as ECLIPSE.
- Support system modelling during both requirements engineering and system design.
- UML workbenches provide support for all UML diagrams and, usually, some automatic code generation. Java, C++ or C# may be generated.

An analysis and design workbench



Analysis workbench components

- Diagram editors
- Model analysis and checking tools
- Repository and associated query language
- Data dictionary
- Report definition and generation tools
- Forms definition tools
- Import/export translators
- Code generation tools

Key points

- Semantic data models describe the logical structure of data which is imported to or exported by the systems.
- Object models describe logical system entities, their classification and aggregation.
- Sequence models show the interactions between actors and the system objects that they use.
- Structured methods provide a framework for developing system models.

Architectural Design

Objectives

- To introduce architectural design and to discuss its importance
- To explain the architectural design decisions that have to be made
- To introduce three complementary architectural styles covering organisation, decomposition and control
- To discuss reference architectures are used to communicate and compare architectures

Software architecture

- The design process for identifying the sub-systems making up a system and the framework for sub-system control and communication is architectural design.
- The output of this design process is a description of the software architecture.

Architectural design

- An early stage of the system design process.
- Represents the link between specification and design processes.
- Often carried out in parallel with some specification activities.
- It involves identifying major system components and their communications.

Advantages of explicit architecture

- Stakeholder communication
  - Architecture may be used as a focus of discussion by system stakeholders.
- System analysis
  - Means that analysis of whether the system can meet its non-functional requirements is possible.
- Large-scale reuse
  - The architecture may be reusable across a range of systems.

Architecture and system characteristics

- Performance
  - Localise critical operations and minimise communications. Use large rather than fine-grain components.
- Security
  - Use a layered architecture with critical assets in the inner layers.
- Safety
  - Localise safety-critical features in a small number of sub-systems.
- Availability
  - Include redundant components and mechanisms for fault tolerance.
- Maintainability
  - Use fine-grain, replaceable components.

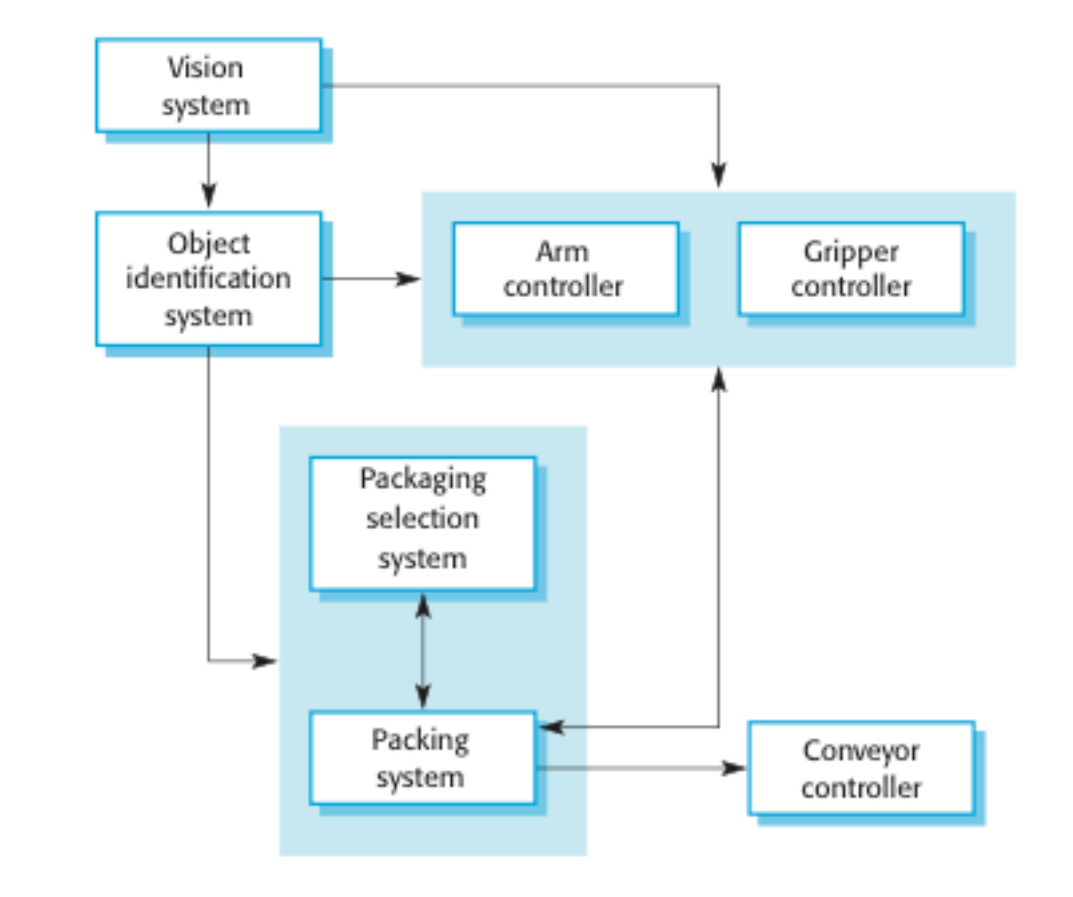
Architectural conflicts

- Using large-grain components improves performance but reduces maintainability.
- Introducing redundant data improves availability but makes security more difficult.
- Localising safety-related features usually means more communication so degraded performance.

System structuring

- Concerned with decomposing the system into interacting sub-systems.
- The architectural design is normally expressed as a block diagram presenting an overview of the system structure.
- More specific models showing how sub-systems share data, are distributed and interface with each other may also be developed.

Packing robot control system



Box and line diagrams

- Very abstract - they do not show the nature of component relationships nor the externally visible properties of the sub-systems.
- However, useful for communication with stakeholders and for project planning.

Architectural design decisions

- Architectural design is a creative process so the process differs depending on the type of system being developed.
- However, a number of common decisions span all design processes.

Architectural design decisions

- Is there a generic application architecture that can be used?
- How will the system be distributed?
- What architectural styles are appropriate?
- What approach will be used to structure the system?
- How will the system be decomposed into modules?
- What control strategy should be used?
- How will the architectural design be evaluated?
- How should the architecture be documented?

Architecture reuse

- Systems in the same domain often have similar architectures that reflect domain concepts.
- Application product lines are built around a core architecture with variants that satisfy particular customer requirements.
- Application architectures are covered in Chapter 13 and product lines in Chapter 18.

Architectural styles

- The architectural model of a system may conform to a generic architectural model or style.
- An awareness of these styles can simplify the problem of defining system architectures.
- However, most large systems are heterogeneous and do not follow a single architectural style.

Architectural models

- Used to document an architectural design.
- Static structural model that shows the major system components.
- Dynamic process model that shows the process structure of the system.
- Interface model that defines sub-system interfaces.
- Relationships model such as a data-flow model that shows sub-system relationships.
- Distribution model that shows how sub-systems are distributed across computers.

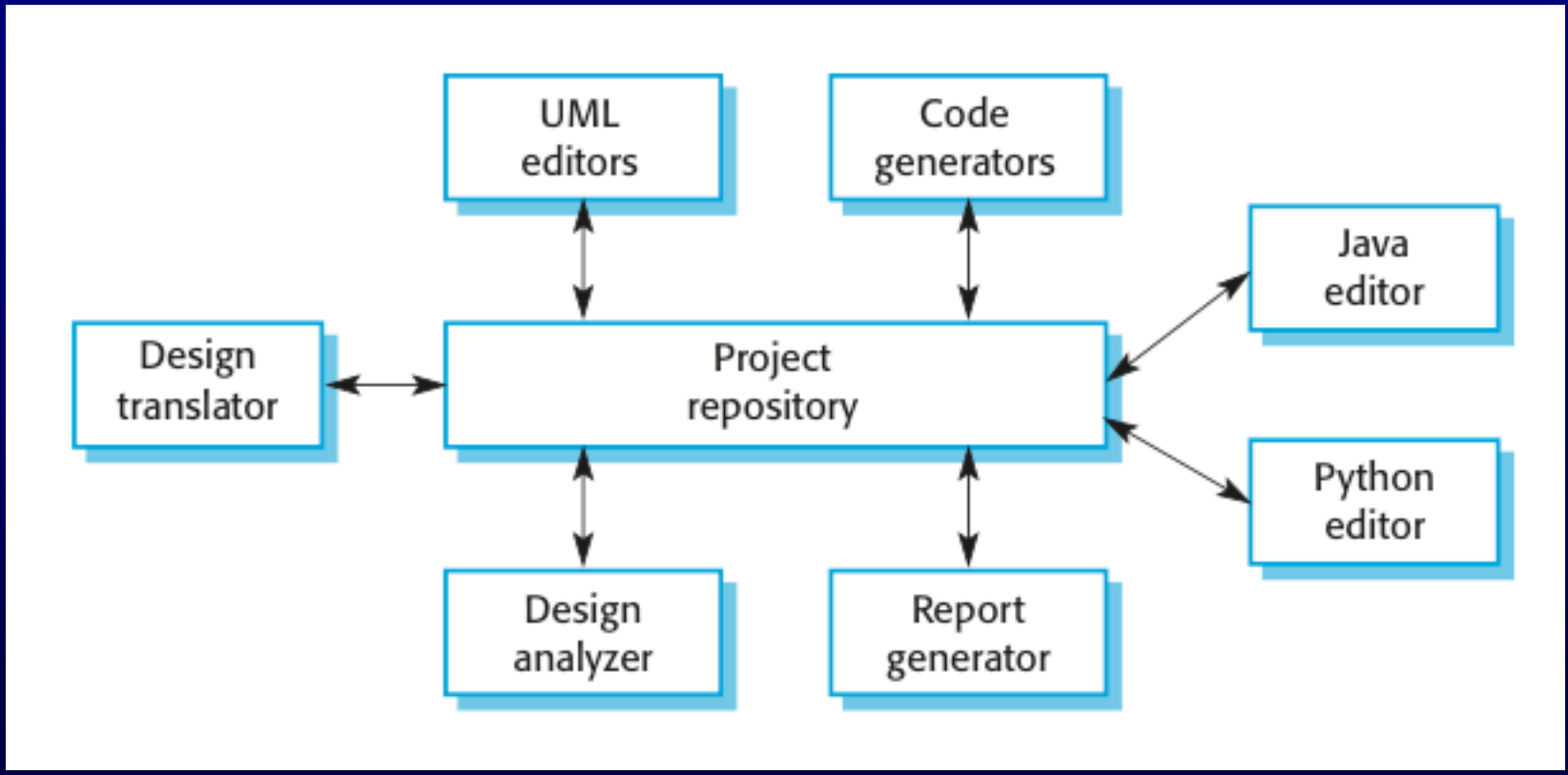
System organisation

- Reflects the basic strategy that is used to structure a system.
- Three organisational styles are widely used:
  - A shared data repository style;
  - A shared services and servers style;
  - An abstract machine or layered style.

The repository model

- Sub-systems must exchange data. This may be done in two ways:
  - Shared data is held in a central database or repository and may be accessed by all sub-systems;
  - Each sub-system maintains its own database and passes data explicitly to other sub-systems.
- When large amounts of data are to be shared, the repository model of sharing is most commonly used.

Repository architecture example



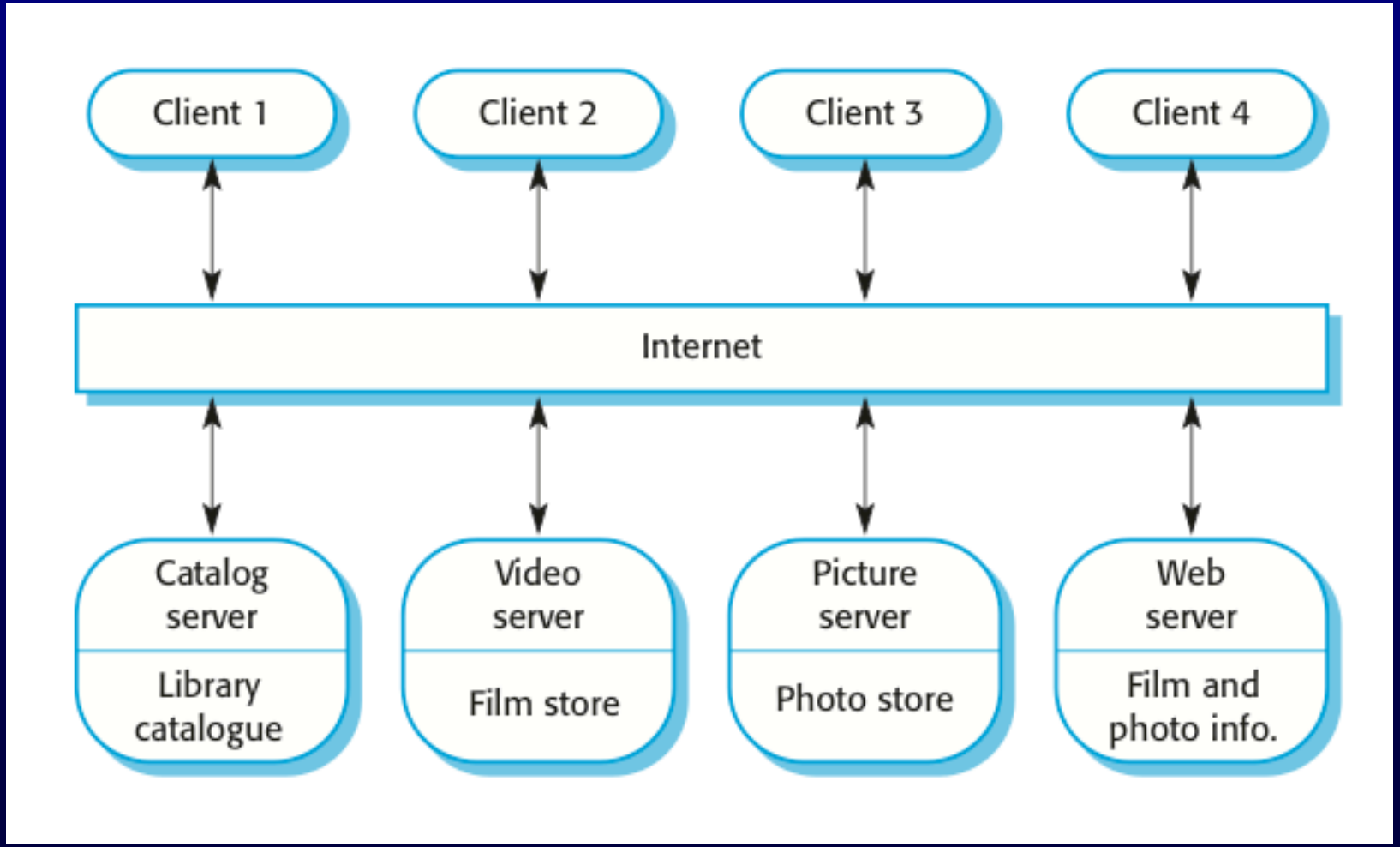
Repository model characteristics

- Advantages
  - Efficient way to share large amounts of data;
  - Sub-systems need not be concerned with how data is produced Centralised management e.g. backup, security, etc.
  - Sharing model is published as the repository schema.
- Disadvantages
  - Sub-systems must agree on a repository data model. Inevitably a compromise;
  - Data evolution is difficult and expensive;
  - No scope for specific management policies;
  - Difficult to distribute efficiently.

Client-server model

- Distributed system model which shows how data and processing is distributed across a range of components.
- Set of stand-alone servers which provide specific services such as printing, data management, etc.
- Set of clients which call on these services.
- Network which allows clients to access servers.

Film and picture library



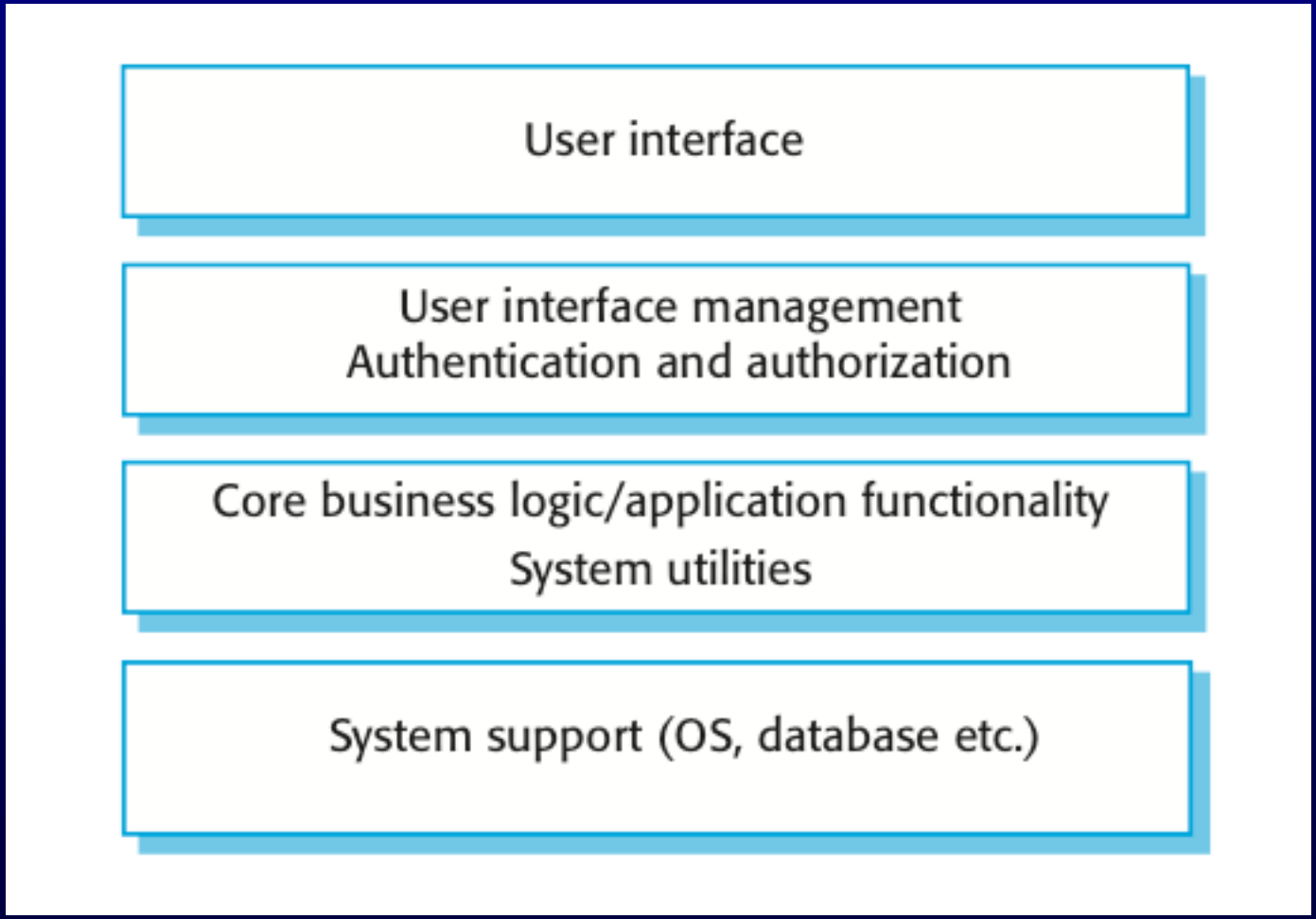
Client-server characteristics

- Advantages
  - Distribution of data is straightforward;
  - Makes effective use of networked systems. May require cheaper hardware;
  - Easy to add new servers or upgrade existing servers.
- Disadvantages
  - No shared data model so sub-systems use different data organisation. Data interchange may be inefficient;
  - Redundant management in each server;
  - No central register of names and services - it may be hard to find out what servers and services are available.

Abstract machine (layered) model

- Used to model the interfacing of sub-systems.
- Organises the system into a set of layers (or abstract machines) each of which provide a set of services.
- Supports the incremental development of sub-systems in different layers. When a layer interface changes, only the adjacent layer is affected.
- However, often artificial to structure systems in this way.

Version management system



Key points

- The software architecture is the fundamental framework for structuring the system.
- Architectural design decisions include decisions on the application architecture, the distribution and the architectural styles to be used.
- Different architectural models such as a structural model, a control model and a decomposition model may be developed.
- System organisational models include repository models, client-server models and abstract machine models.

Architectural Design 2

Modular decomposition styles

- Styles of decomposing sub-systems into modules.
- No rigid distinction between system organisation and modular decomposition.

Sub-systems and modules

- A sub-system is a system in its own right whose operation is independent of the services provided by other sub-systems.
- A module is a system component that provides services to other components but would not normally be considered as a separate system.

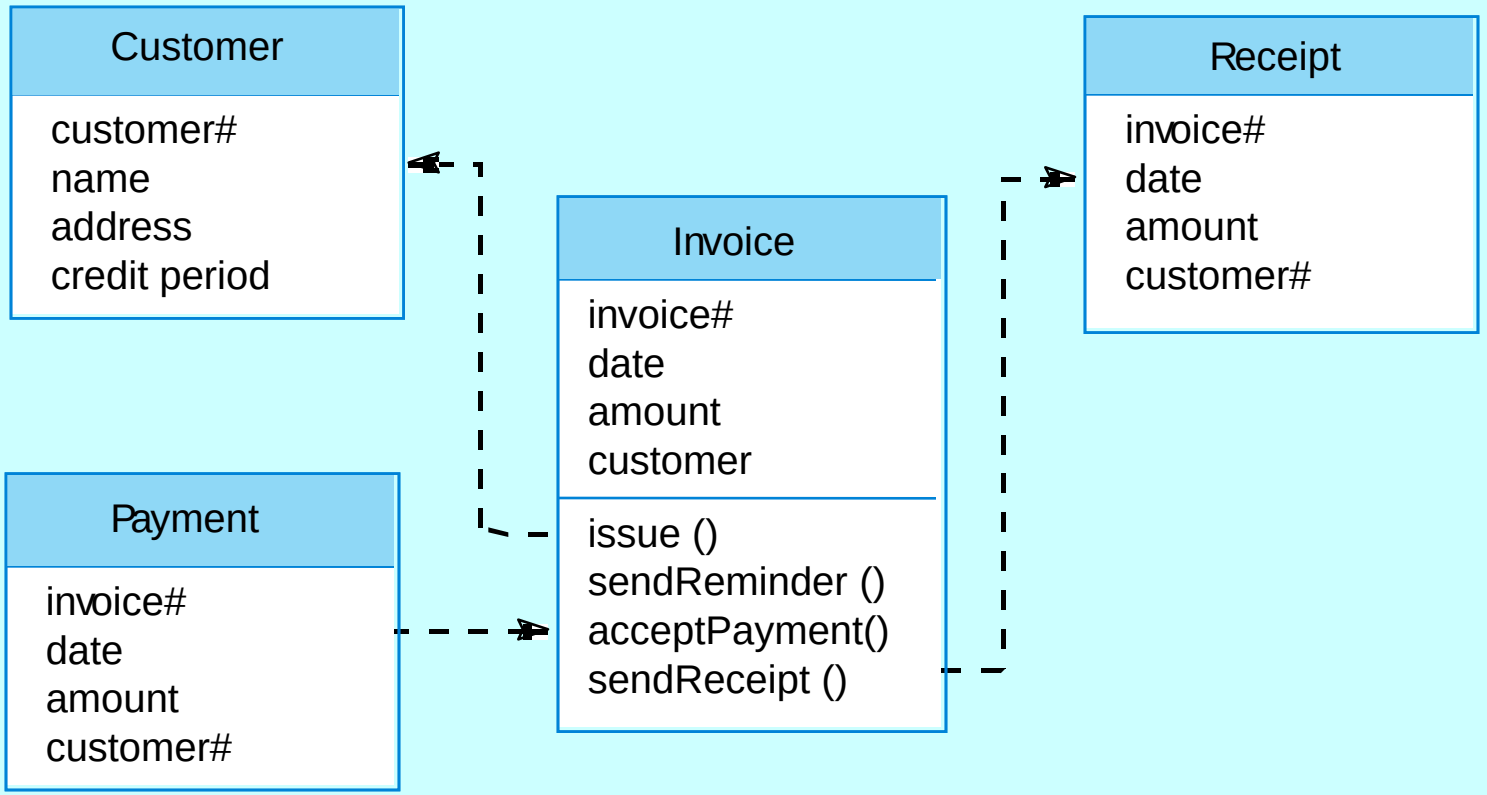
Modular decomposition

- Another structural level where sub-systems are decomposed into modules.
- Two modular decomposition models covered
  - An object model where the system is decomposed into interacting object;
  - A pipeline or data-flow model where the system is decomposed into functional modules which transform inputs to outputs.
- If possible, decisions about concurrency should be delayed until modules are implemented.

Object models

- Structure the system into a set of loosely coupled objects with well-defined interfaces.
- Object-oriented decomposition is concerned with identifying object classes, their attributes and operations.
- When implemented, objects are created from these classes and some control model used to coordinate object operations.

Invoice processing system



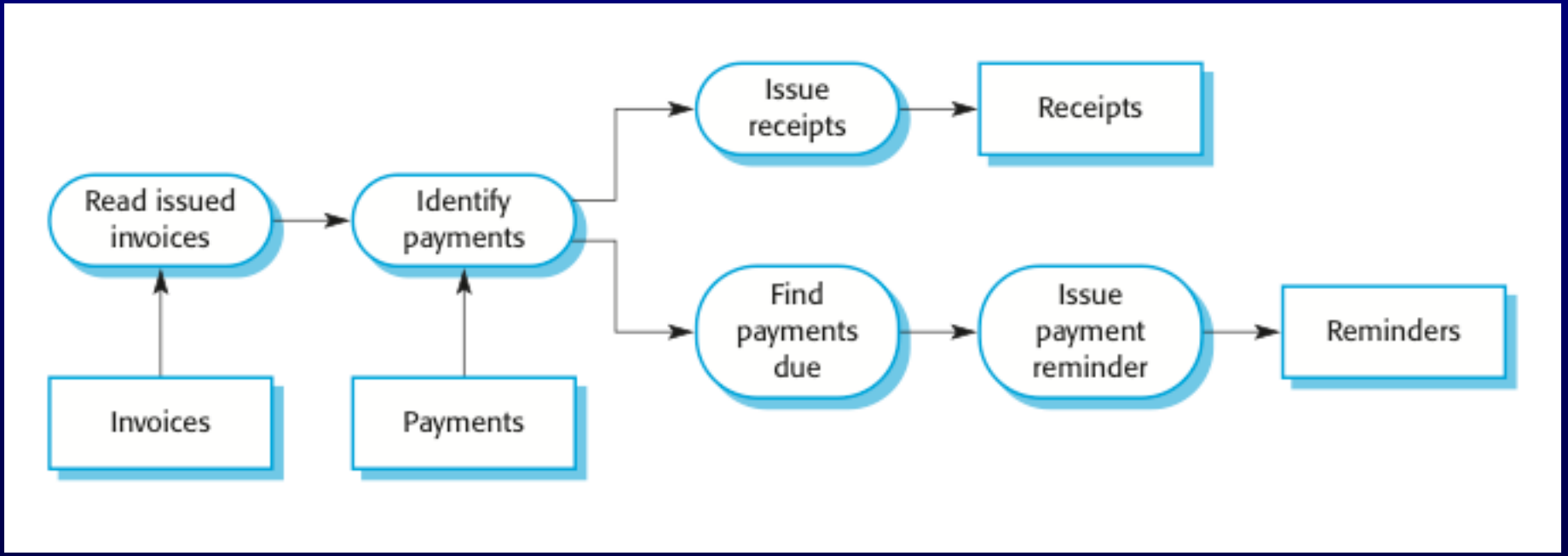
Object model advantages

- Objects are loosely coupled so their implementation can be modified without affecting other objects.
- The objects may reflect real-world entities.
- OO implementation languages are widely used.
- However, object interface changes may cause problems and complex entities may be hard to represent as objects.

Function-oriented pipelining

- Functional transformations process their inputs to produce outputs.
- May be referred to as a pipe and filter model (as in UNIX shell).
- Variants of this approach are very common. When transformations are sequential, this is a batch sequential model which is extensively used in data processing systems.
- Not really suitable for interactive systems.

Invoice processing system



Pipeline model advantages

- Supports transformation reuse.
- Intuitive organisation for stakeholder communication.
- Easy to add new transformations.
- Relatively simple to implement as either a concurrent or sequential system.
- However, requires a common format for data transfer along the pipeline and difficult to support event-based interaction.

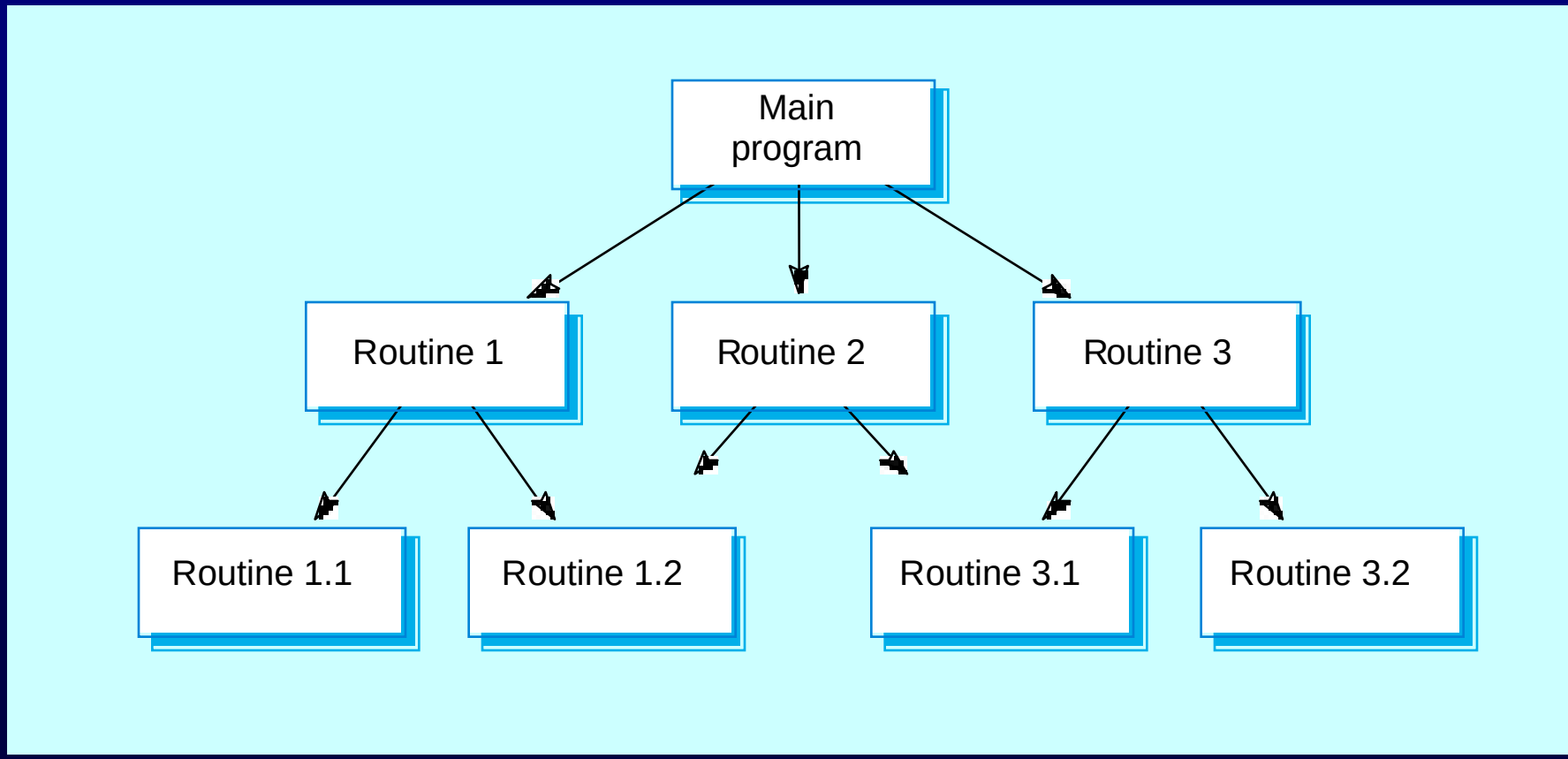
Control styles

- Are concerned with the control flow between sub-systems. Distinct from the system decomposition model.
- Centralised control
  - One sub-system has overall responsibility for control and starts and stops other sub-systems.
- Event-based control
  - Each sub-system can respond to externally generated events from other sub-systems or the system's environment.

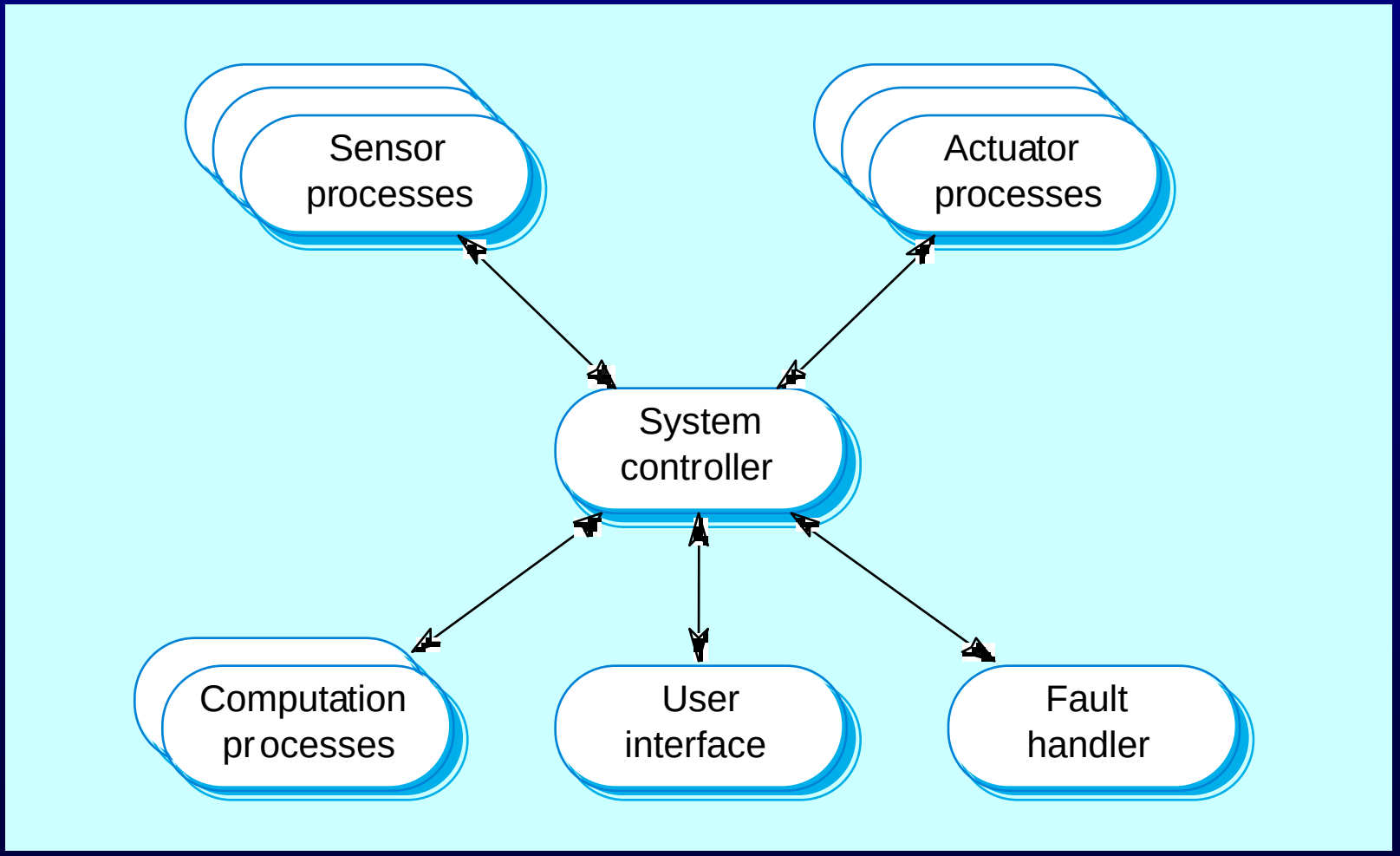
Centralised control

- A control sub-system takes responsibility for managing the execution of other sub-systems.
- Call-return model
  - Top-down subroutine model where control starts at the top of a subroutine hierarchy and moves downwards. Applicable to sequential systems.
- Manager model
  - Applicable to concurrent systems. One system component controls the stopping, starting and coordination of other system processes. Can be implemented in sequential systems as a case statement.

Call-return model



Real-time system control



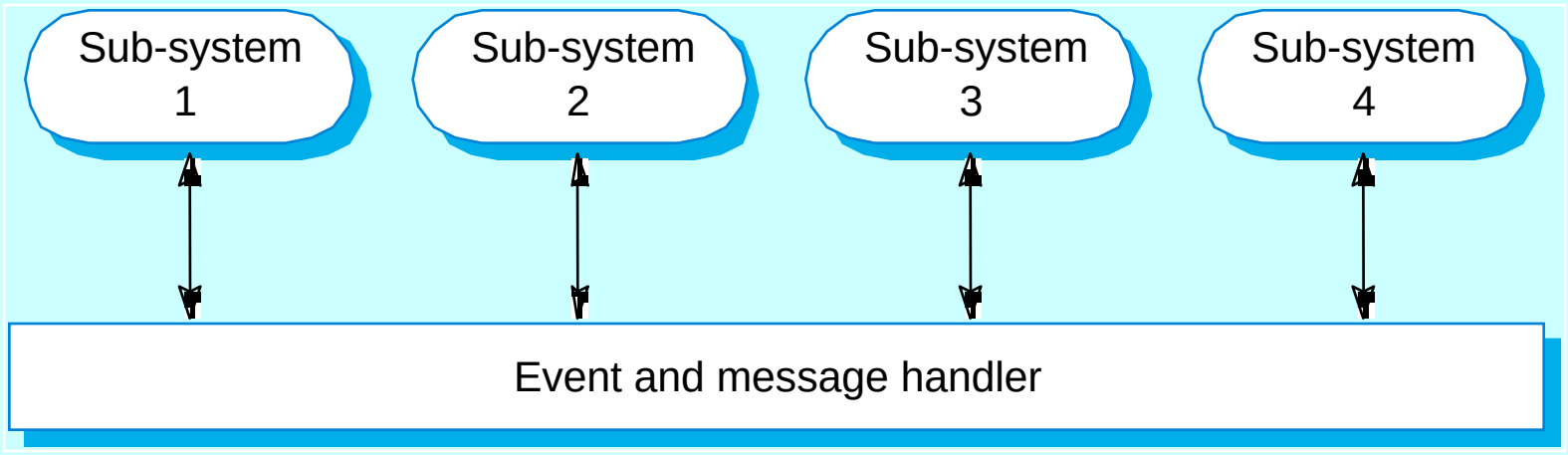
Event-driven systems

- Driven by externally generated events where the timing of the event is outwith the control of the sub-systems which process the event.
- Two principal event-driven models
  - Broadcast models. An event is broadcast to all sub-systems. Any sub-system which can handle the event may do so;
  - Interrupt-driven models. Used in real-time systems where interrupts are detected by an interrupt handler and passed to some other component for processing.
- Other event driven models include spreadsheets and production systems.

Broadcast model

- Effective in integrating sub-systems on different computers in a network.
- Sub-systems register an interest in specific events. When these occur, control is transferred to the sub-system which can handle the event.
- Control policy is not embedded in the event and message handler. Sub-systems decide on events of interest to them.
- However, sub-systems don’t know if or when an event will be handled.

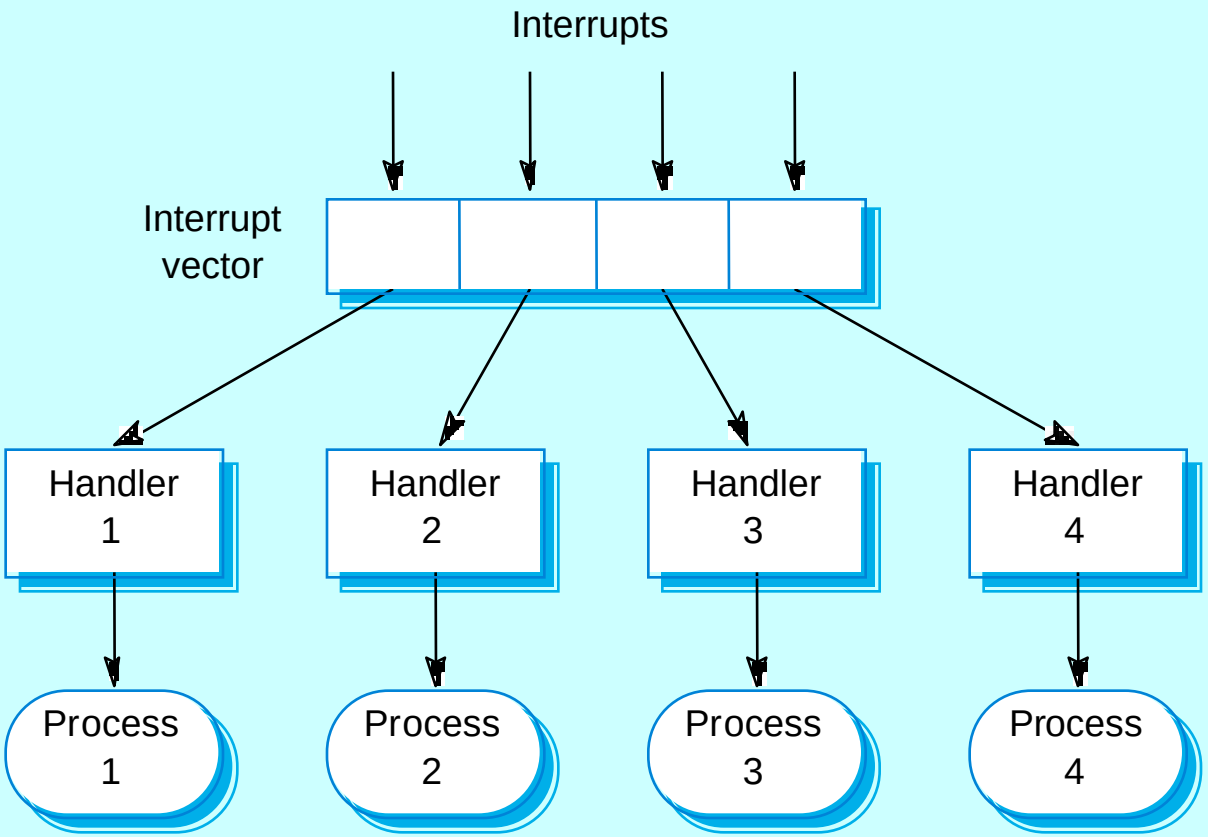
Selective broadcasting



Interrupt-driven systems

- Used in real-time systems where fast response to an event is essential.
- There are known interrupt types with a handler defined for each type.
- Each type is associated with a memory location and a hardware switch causes transfer to its handler.
- Allows fast response but complex to program and difficult to validate.

Interrupt-driven control



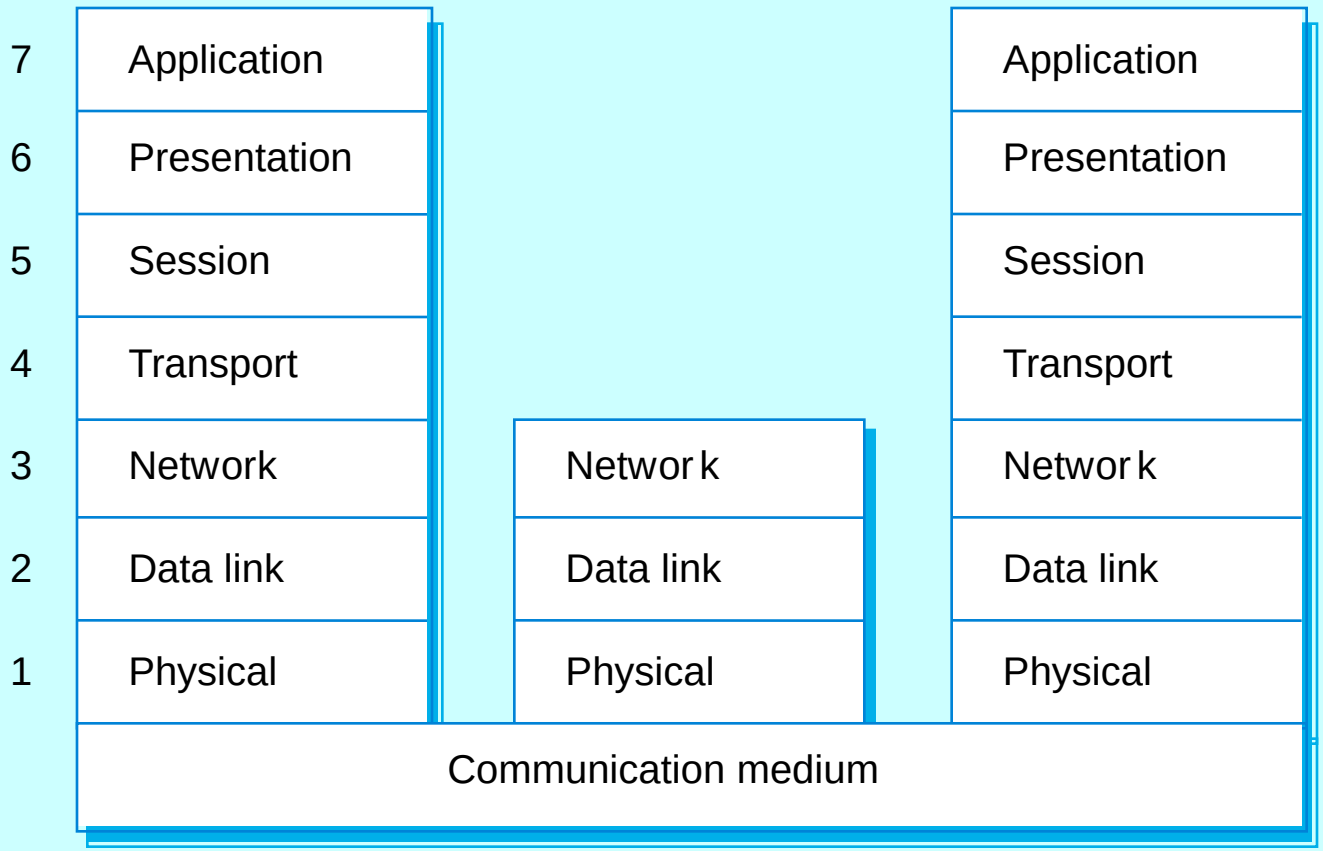
Reference architectures

- Architectural models may be specific to some application domain.
- Two types of domain-specific model
  - Generic models which are abstractions from a number of real systems and which encapsulate the principal characteristics of these systems. Covered in Chapter 13.
  - Reference models which are more abstract, idealised model. Provide a means of information about that class of system and of comparing different architectures.
- Generic models are usually bottom-up models; Reference models are top-down models.

Reference architectures

- Reference models are derived from a study of the application domain rather than from existing systems.
- May be used as a basis for system implementation or to compare different systems. It acts as a standard against which systems can be evaluated.
- OSI model is a layered model for communication systems.

OSI reference model



Key points

- Modular decomposition models include object models and pipelining models.
- Control models include centralised control and event-driven models.
- Reference architectures may be used to communicate domain-specific architectures and to assess and compare architectural designs.

Object-oriented Design 1

Objectives

- To introduce an object-oriented design process for developing OO software.
- To develop a case study (based on a weather monitoring system) that illustrates some of the models developed as part of an OO process.
- To illustrate how an OO approach can lead to systems that can evolve in response to new requirements.

Object-oriented development

- Object-oriented analysis, design and programming are related but distinct.
- OOA is concerned with developing an object model of the application domain.
- OOD is concerned with developing an object-oriented system model to implement requirements.
- OOP is concerned with realising an OOD using an OO programming language such as Java, C++ or C#.

Characteristics of OOD

- Objects are abstractions of real-world or system entities and manage themselves.
- Objects are independent and encapsulate state and representation information.
- System functionality is expressed in terms of object services.
- Shared data areas are eliminated. Objects communicate by message passing.
- Objects may be distributed and may execute sequentially or in parallel.

Object oriented modelling

- An inherent part of object-oriented development is to develop UML models to represent the system.
- Structural and behavioural UML models have already been introduced in previous lectures on system modelling.
- Diagram types used here are from UML 1 rather than UML 2 but differences are minimal.

An object-oriented design process

- Structured 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 essential communication mechanism.

Process stages

- The principal activities in any OO design process include:
  - Context: Define the context and modes of use of the system;
  - Architecture: Design the system architecture;
  - Objects: Identify the principal system objects;
  - Models: Develop design models;
  - Interfaces: Specify object interfaces.

Weather system description

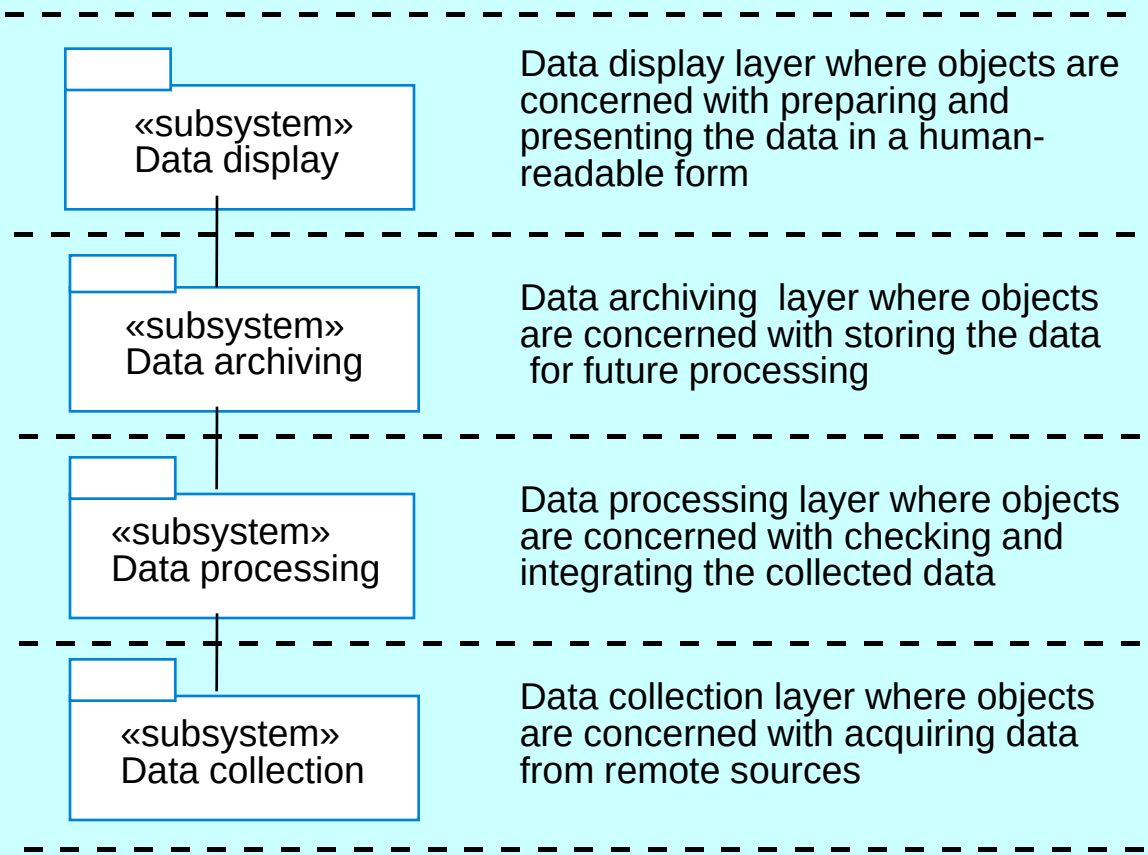
A weather mapping system is required to generate weather maps on a regular basis using data collected from remote, unattended weather stations and other data sources such as weather observers, balloons and satellites. Weather stations transmit their data to the area computer in response to a request from that machine.

The area computer system validates the collected data and integrates it with the data from different sources. The integrated data is archived and, using data from this archive and a digitised map database a set of local weather maps is created. Maps may be printed for distribution on a special-purpose map printer or may be displayed in a number of different formats.

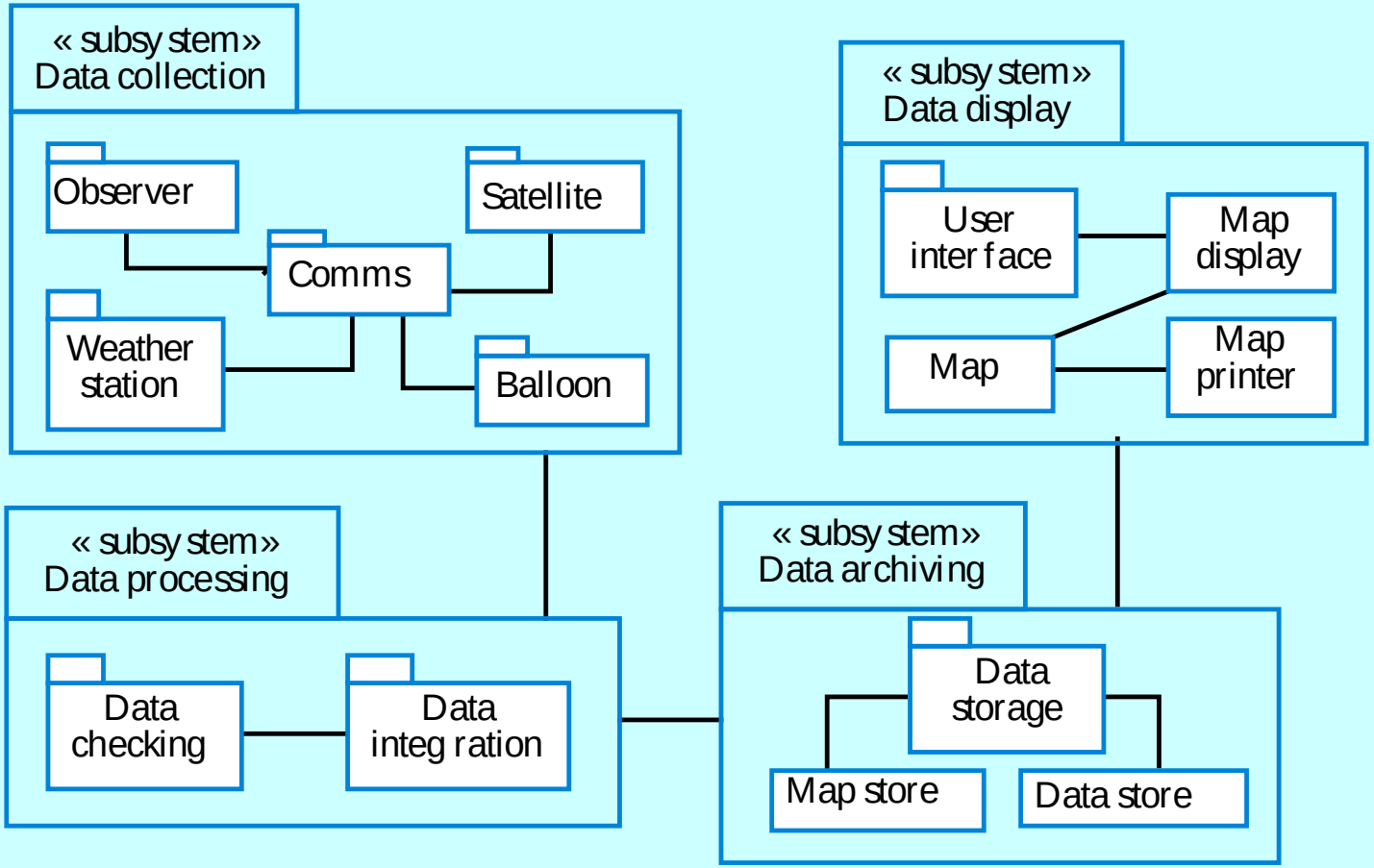
Context

- Develop an understanding of the relationships between the software being designed and its external environment
- System context
  - A static model that describes other systems in the environment. Use a subsystem model to show other systems. Following slide shows the systems around the weather station system.
- Model of system use
  - A dynamic model that describes how the system interacts with its environment. Use use-cases to show interactions

Layered architecture (1)



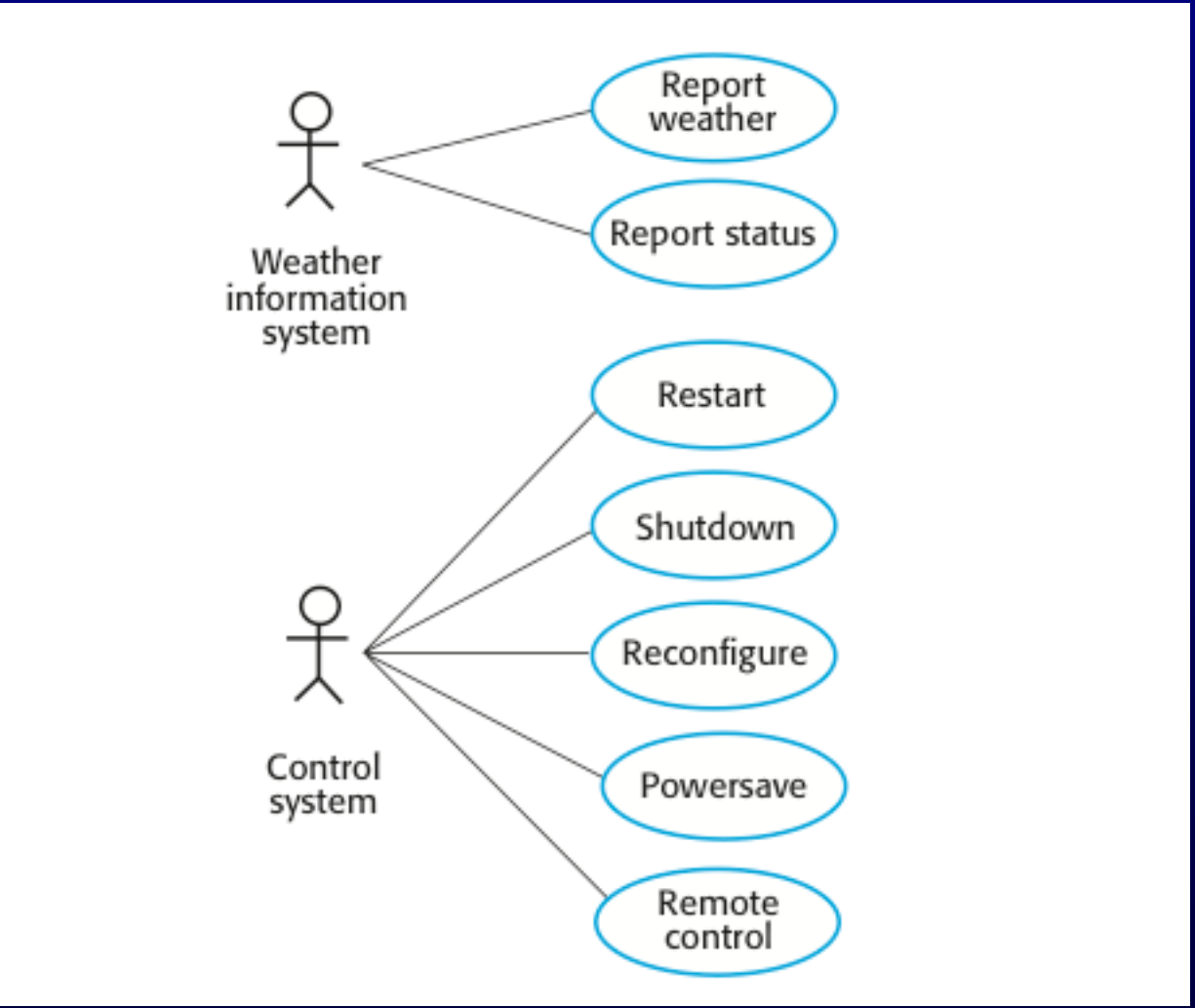
Subsystems in the weather mapping system



Use-case models

- Use-case models are used to represent each interaction with the system.
- A use-case model shows the system features as ellipses and the interacting entity as a stick figure.

Use-cases for the weather station



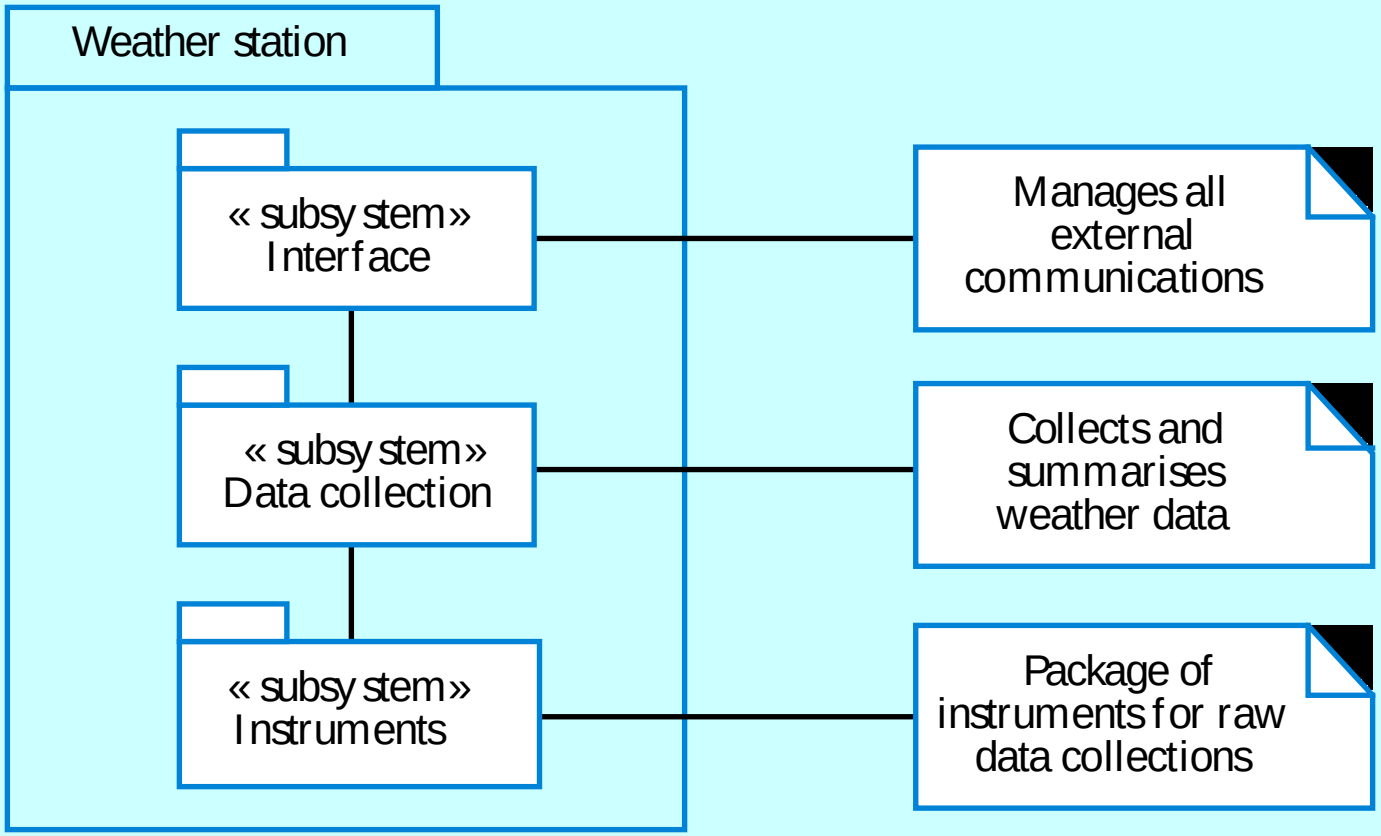
Use-case description

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.

Architecture

- Once interactions between the system and its environment have been understood, you use this information for designing the system architecture.
- A layered architecture as discussed in Chapter 11 is appropriate for the weather station
  - Interface layer for handling communications;
  - Data collection layer for managing instruments;
  - Instruments layer for collecting data.
- There should normally be no more than 7 entities in an architectural model.

Weather station architecture (2)



Objects

- Identifying objects (or object classes) is the most 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.

Weather station object classes

- 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 summarised data from the instruments.

Key points

- Object-oriented development involves adopting an OO approach at all stages from specification through to programming
- OO design involves designing the system using objects as the fundamental abstraction and representing the system as an associated set of models in the UML
- The OO design process involves several stages - discussed here were Context, Architecture and Objects.

Object-oriented design 2

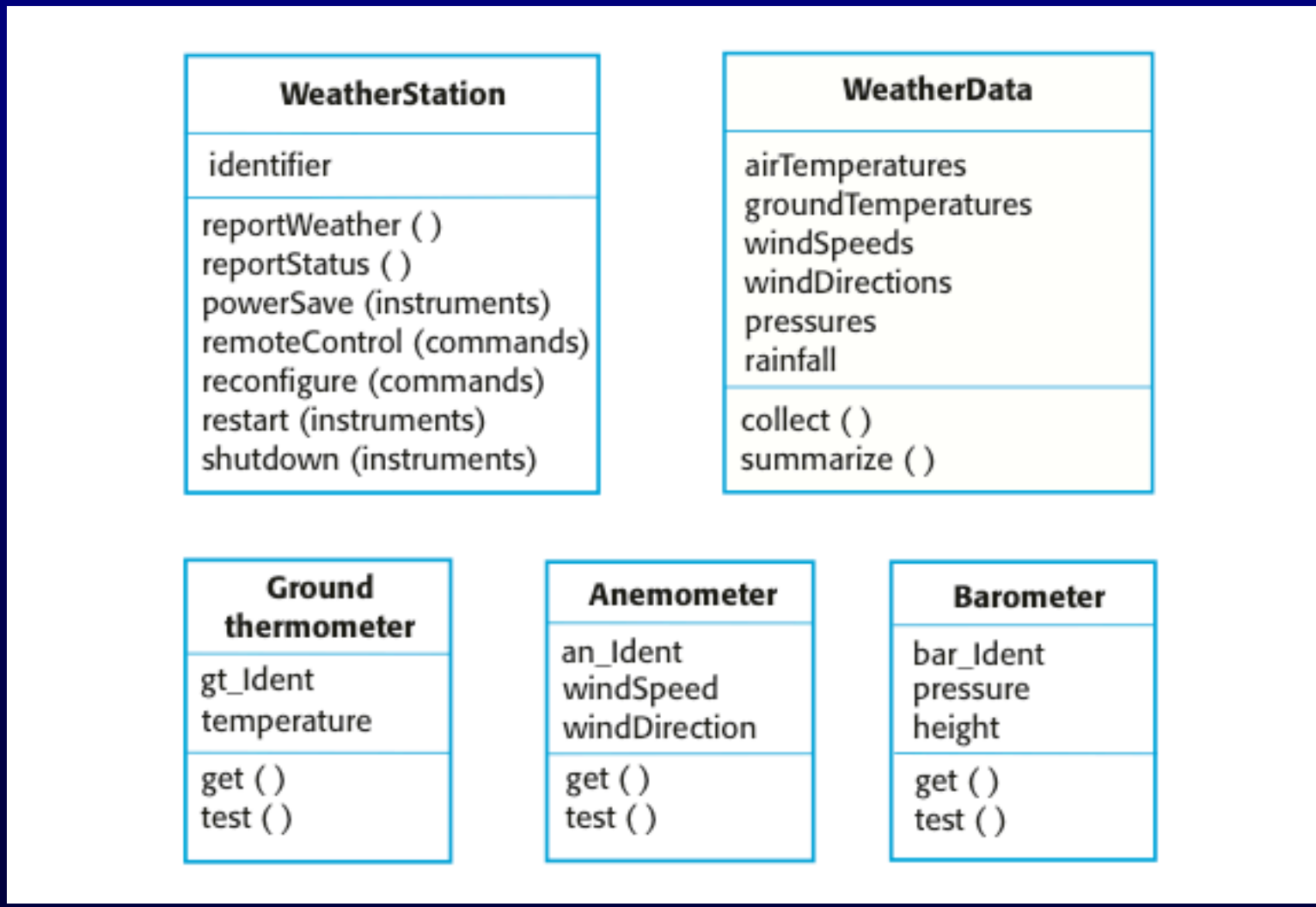
Recap

- The stages in the OO design process are:
  - Context: Define the context and modes of use of the system;
  - Architecture: Design the system architecture;
  - Objects: Identify the principal system objects;
  - Models: Develop design models;
  - Interfaces: Specify object interfaces.

Further objects and object refinement

- Use domain knowledge to identify more objects and operations
  - Weather stations should have a unique identifier;
  - Weather stations are remotely situated so instrument failures have to be reported automatically. Therefore attributes and operations for self-checking are required.
- Active or passive objects
  - In this case, objects are passive and collect data on request rather than autonomously. This introduces flexibility at the expense of controller processing time.

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

- Sub-system 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.

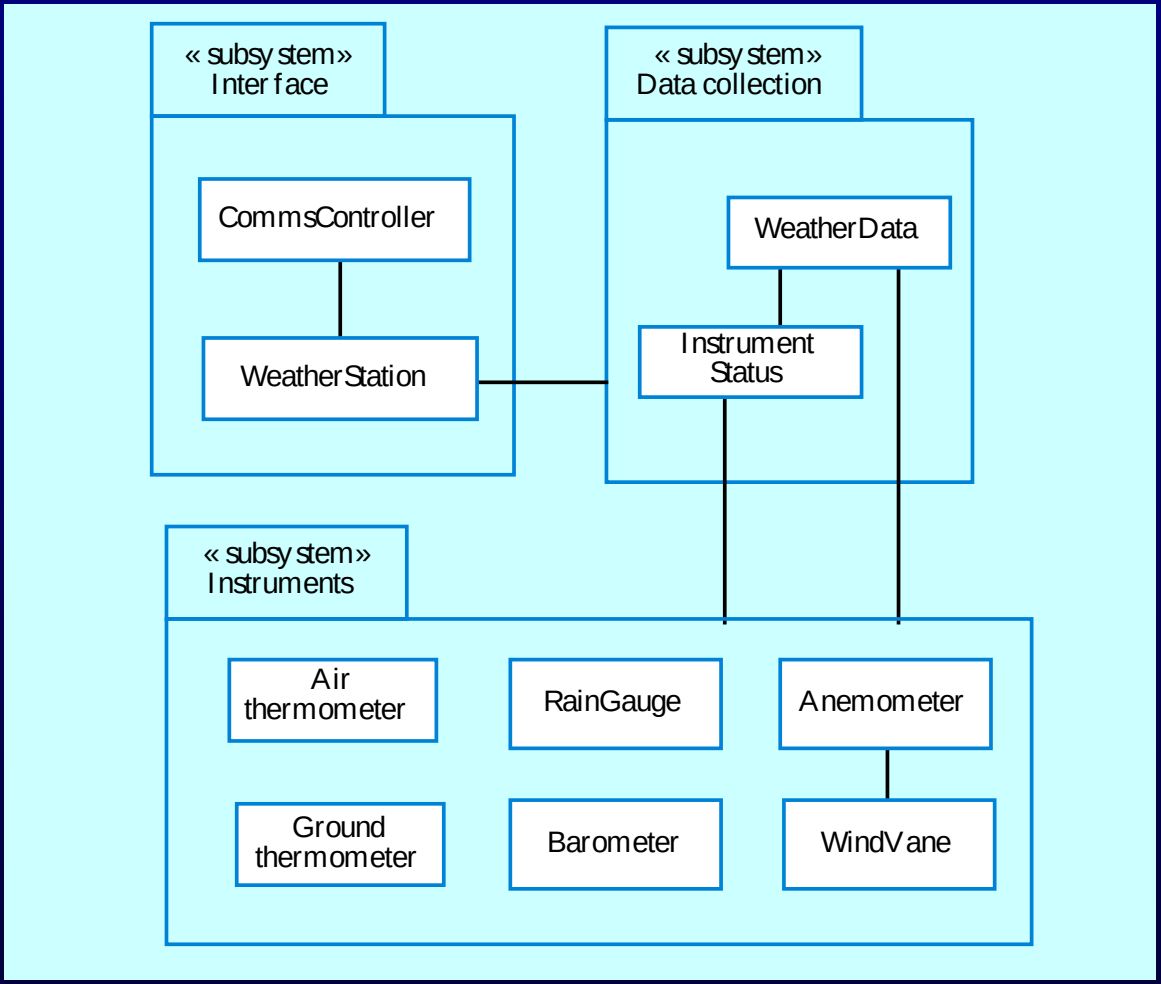
Subsystem models

- Shows how the design is organised into logically related groups of objects.
- In the UML, these are shown using packages - an encapsulation construct.
- The UML stereotype annotation is used to label packages as sub-systems.

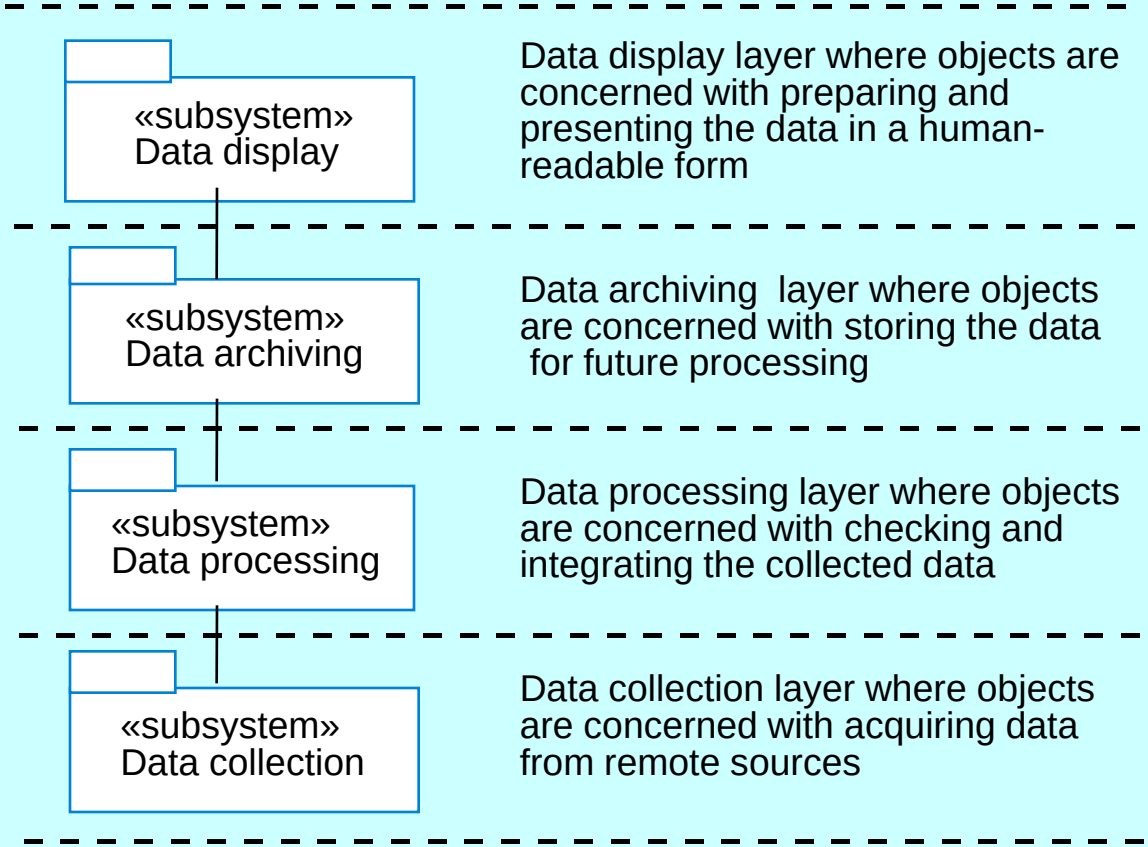
Subsystem decomposition (A)

- Interface subsystem
  - Includes the objects in the system that are concerned with interfacing the weather station to external systems
  - May include other objects from those shown here - e.g. a user interface for testing.
- Data collection subsystem
  - Includes objects that implement the strategies adoped for data collection
  - These are deliberately separated from the actual data collection to allow for changes to these strategies
- Instruments subsystem
  - Includes all objects that interface to the instrument hardware

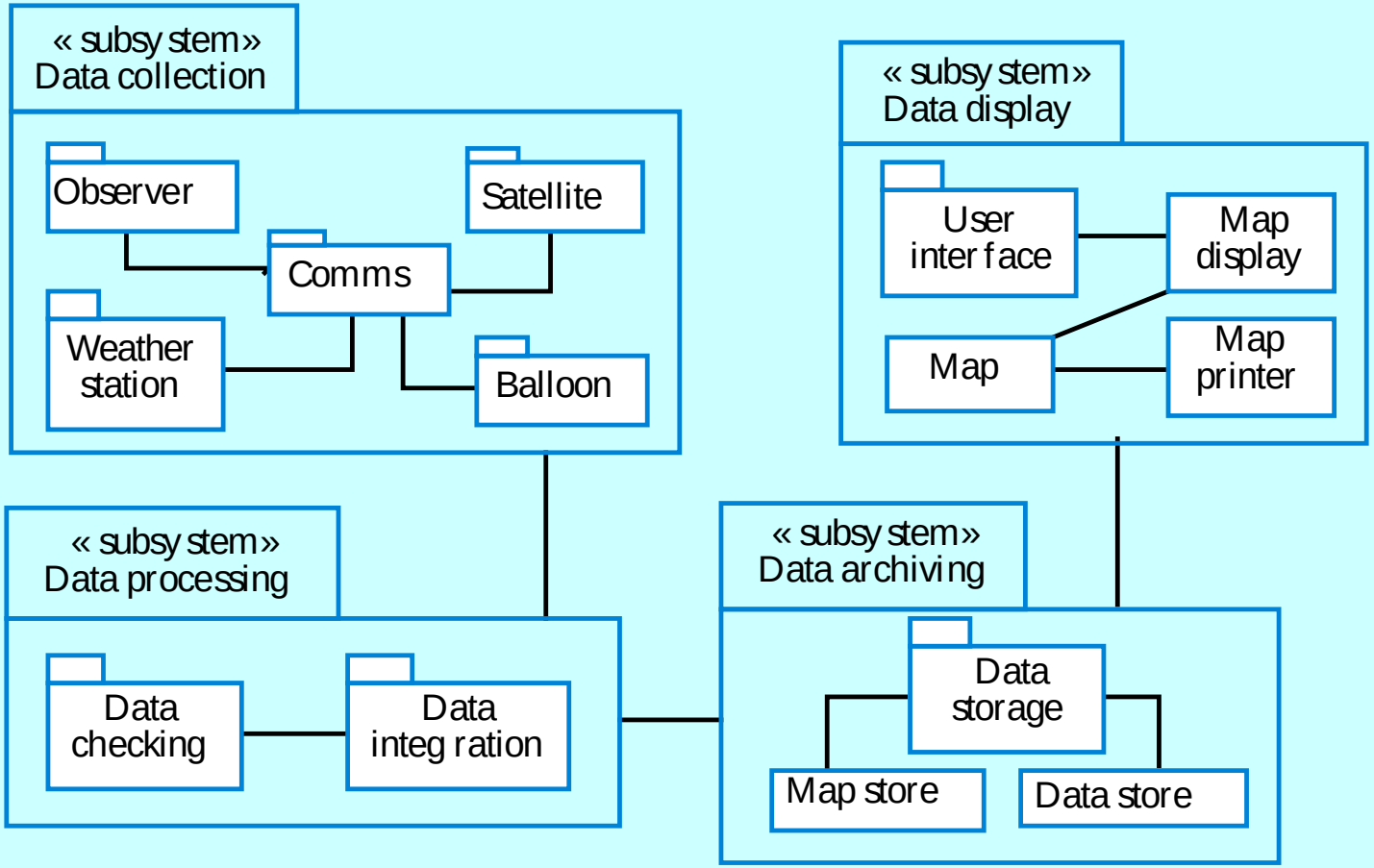
Weather station subsystems



Subsystem decomposition (B)



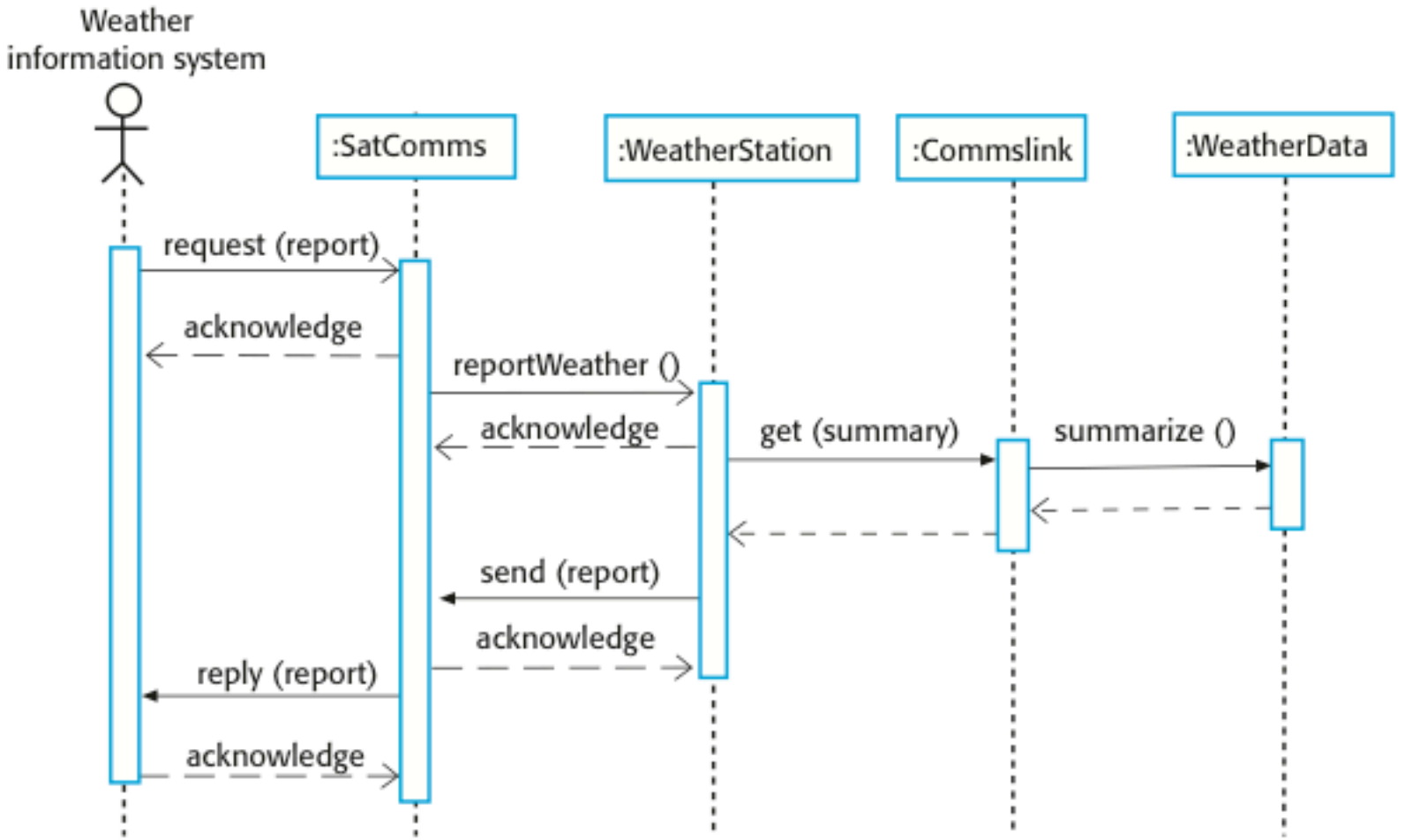
Subsystems in the weather mapping system



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.

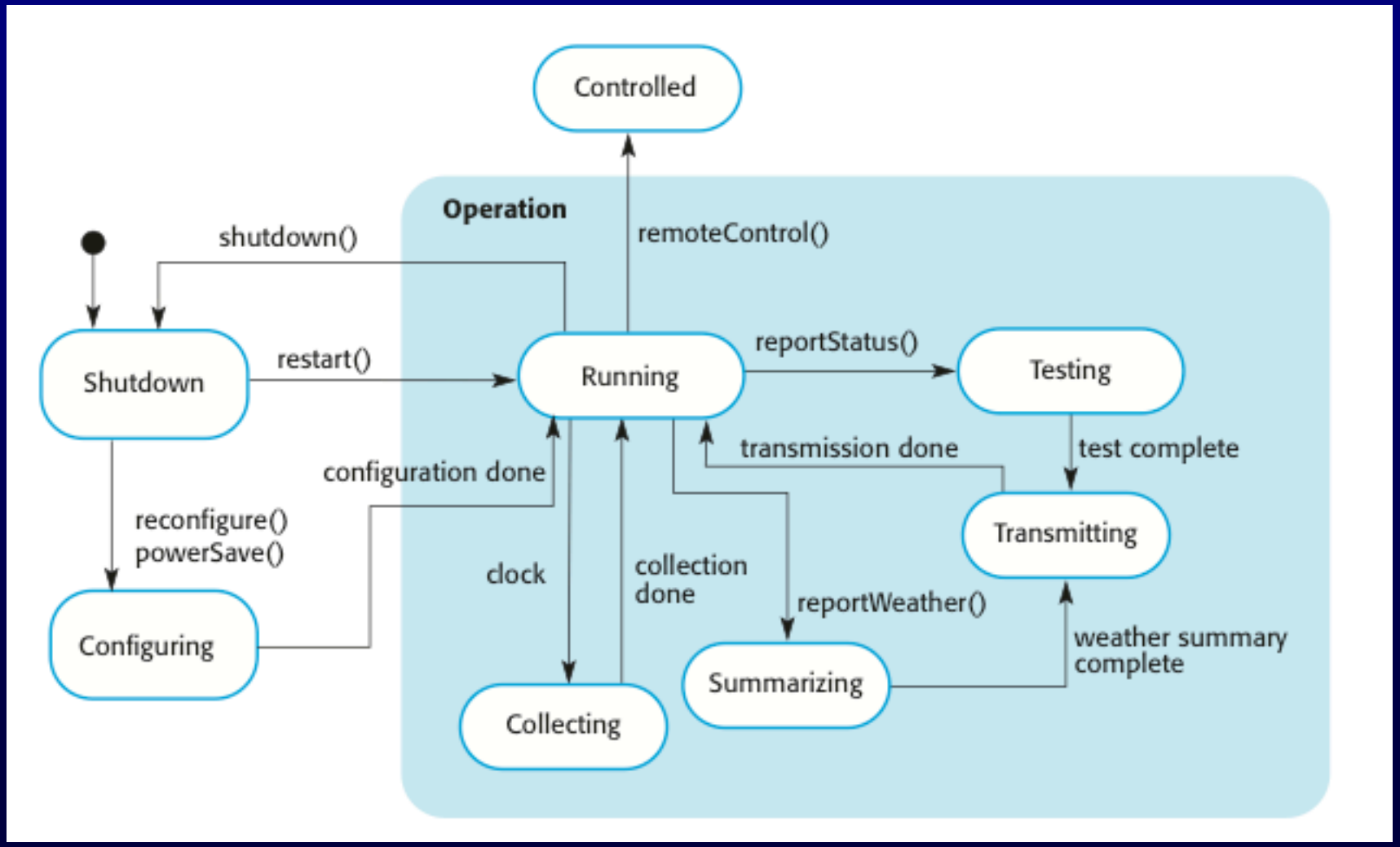
Data collection sequence



Statecharts

- Show how objects respond to different service requests and the state transitions triggered by these requests
- The states are represented as rounded rectangles
- State transitions are labelled links between these rectangles

Weather station state diagram



Weather station system states

- If object state is Shutdown then it responds to a reconfigure() message;
- If reportWeather () then system moves to Wummarising state;
- A Collecting state is entered when a clock signal is received.
- ...

Interfaces

- 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 interface

```
interface WeatherStation {

        public void WeatherStation () ;

        public void startup () ;
        public void startup (Instrument i) ;

        public void shutdown () ;
        public void shutdown (Instrument i) ;

        public void reportWeather ( ) ;

        public void test () ;
        public void test ( Instrument i ) ;

        public void calibrate ( Instrument i) ;

        public int getID () ;

} //WeatherStation
```

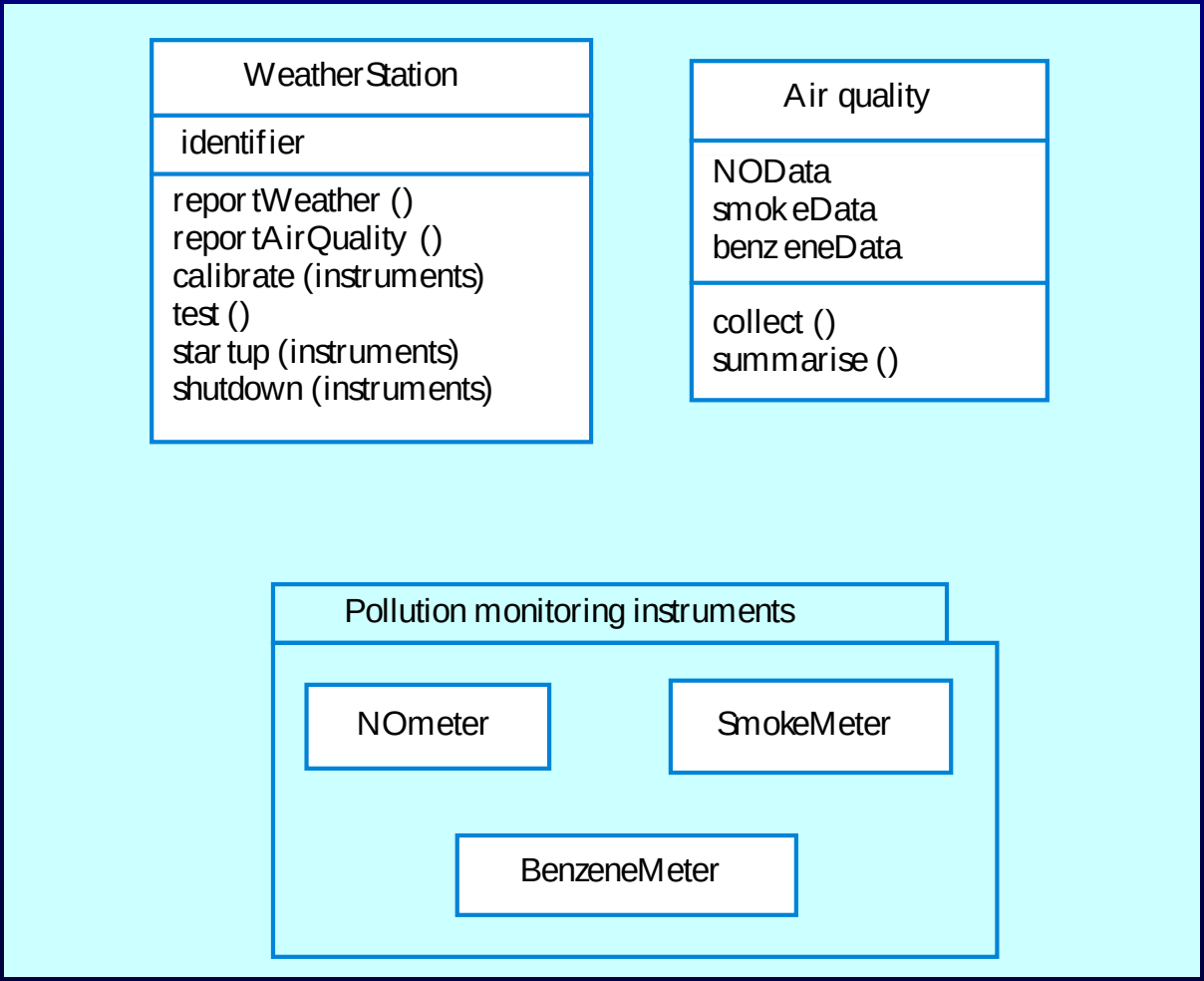
Design evolution

- Hiding information inside objects means that changes made to an object do not affect other objects in an unpredictable way.
- Assume pollution monitoring facilities are to be added to weather stations. These sample the air and compute the amount of different pollutants in the atmosphere.
- Pollution readings are transmitted with weather data.

Changes required

- Add an object class called Air quality as part of WeatherStation.
- Add an operation reportAirQuality to WeatherStation. Modify the control software to collect pollution readings.
- Add objects representing pollution monitoring instruments.

Pollution monitoring



Key points

- A range of different models may be produced during an object-oriented design process. These include static and dynamic system models.
- Object interfaces should be defined precisely using e.g. a programming language like Java.
- Object-oriented design potentially simplifies system evolution.