Introduction

- Getting started with software engineering

Objectives

- To introduce software engineering and to explain its importance
- To set out the answers to key questions about software engineering
- To introduce ethical and professional issues and to explain why they are of concern to software engineers

Topics covered

- FAQs about software engineering
- Professional and ethical responsibility

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
- Software engineering expenditure represents a significant fraction of GNP in all developed countries

Software costs

- Software costs often dominate 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?
- What is the difference between software engineering and computer science?
- What is the difference between software engineering and 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
- 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
  - Bespoke (custom) - developed for a single customer according to their specification

What is software engineering?

- Software engineering is an engineering discipline which 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

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 currently insufficient to act as a complete underpinning for software engineering

What is the difference between software engineering and system engineering?

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

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
    - Evolutionary development
    - Formal transformation
    - Integration from reusable components

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

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 which 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 usable
- Maintainability
  - Software must evolve to meet changing needs
- Dependability
  - Software must be trustworthy
- Efficiency
  - Software should not make wasteful use of system resources
- Usability
  - Software must be usable by the users for which it was designed

What are the key challenges facing software engineering?

- Coping with legacy systems, coping with increasing diversity and coping with demands for reduced delivery times
- Legacy systems
  - Old, valuable systems must be maintained and updated
- Heterogeneity
  - Systems are distributed and include a mix of hardware and software
- Delivery
  - There is increasing pressure for faster delivery of software

Professional and ethical responsibility

- Software engineering involves wider responsibilities than simply the application of technical skills
- Software engineers must behave in an honest and ethically responsible way if they are to be respected as professionals
- Ethical behaviour is more than simply upholding the law.

Issues of professional responsibility

- *Confidentiality*
  - Engineers should normally respect the confidentiality of their employers or clients irrespective of whether or not a formal confidentiality agreement has been signed.
- *Competence*
  - Engineers should not misrepresent their level of competence. They should not knowingly accept work which is outwith their competence.

Issues of professional responsibility

- *Intellectual property rights*
    - Engineers should be aware of local laws governing the use of intellectual property such as patents, copyright, etc. They should be careful to ensure that the intellectual property of employers and clients is protected.
- *Computer misuse*
    - Software engineers should not use their technical skills to misuse other people's computers. Computer misuse ranges from relatively trivial (game playing on an employer's machine, say) to extremely serious (dissemination of viruses).

ACM/IEEE Code of Ethics

- The professional societies in the US have cooperated to produce a code of ethical practice.
- Members of these organisations sign up to the code of practice when they join.
- The Code contains eight Principles related to the behaviour of and decisions made by professional software engineers, including practitioners, educators, managers, supervisors and policy makers, as well as trainees and students of the profession.

Code of ethics - preamble

- **Preamble**
  - The short version of the code summarizes aspirations at a high level of the abstraction; the clauses that are included in the full version give examples and details of how these aspirations change the way we act as software engineering professionals. Without the aspirations, the details can become legalistic and tedious; without the details, the aspirations can become high sounding but empty; together, the aspirations and the details form a cohesive code.
  - Software engineers shall commit themselves to making the analysis, specification, design, development, testing and maintenance of software a beneficial and respected profession. In accordance with their commitment to the health, safety and welfare of the public, software engineers shall adhere to the following Eight Principles:

Code of ethics - principles

- 1. PUBLIC
  - Software engineers shall act consistently with the public interest.
- 2. CLIENT AND EMPLOYER
  - Software engineers shall act in a manner that is in the best interests of their client and employer consistent with the public interest.
- 3. PRODUCT
  - Software engineers shall ensure that their products and related modifications meet the highest professional standards possible.

Code of ethics - principles

- JUDGMENT
  - Software engineers shall maintain integrity and independence in their professional judgment.
- 5. MANAGEMENT
  - Software engineering managers and leaders shall subscribe to and promote an ethical approach to the management of software development and maintenance.
- 6. PROFESSION
  - Software engineers shall advance the integrity and reputation of the profession consistent with the public interest.

Code of ethics - principles

- 7. COLLEAGUES
  - Software engineers shall be fair to and supportive of their colleagues.
- 8. SELF
  - Software engineers shall participate in lifelong learning regarding the practice of their profession and shall promote an ethical approach to the practice of the profession.

Ethical dilemmas

- Disagreement in principle with the policies of senior management
- Your employer acts in an unethical way and releases a safety-critical system without finishing the testing of the system
- Participation in the development of military weapons systems or nuclear systems

Key points

- Software engineering is an engineering discipline which 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 which 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.

Key points

- CASE tools are software systems which are designed to support routine activities in the software process such as editing design diagrams, checking diagram consistency and keeping track of program tests which have been run.
- Software engineers have responsibilities to the engineering profession and society. They should not simply be concerned with technical issues.
- Professional societies publish codes of conduct which set out the standards of behaviour expected of their members.

Systems Engineering

- Designing, implementing, deploying and operating systems which include hardware, software and people

Objectives

- To explain why system software is affected by broader system engineering issues
- To introduce the concept of emergent system properties such as reliability and security
- To explain why the systems environment must be considered in the system design process
- To explain system engineering and system procurement processes

Topics covered

- Emergent system properties
- Systems and their environment
- System modelling
- The system engineering process
- System procurement

What is a system?

- A purposeful collection of inter-related components working together towards some common objective.
- A system may include software, mechanical, electrical and electronic hardware and be operated by people.
- System components are dependent on other system components
- The properties and behaviour of system components are inextricably inter-mingled

Problems of systems engineering

- Large systems are usually designed to solve 'wicked' problems
- Systems engineering requires a great deal of co-ordination across disciplines
  - Almost infinite possibilities for design trade-offs across components
  - Mutual distrust and lack of understanding across engineering disciplines
- Systems must be designed to last many years in a changing environment

Software and systems engineering

- The proportion of software in systems is increasing. Software-driven general purpose electronics is replacing special-purpose systems
- Problems of systems engineering are similar to problems of software engineering
- Software is (unfortunately) seen as a problem in systems engineering. Many large system projects have been delayed because of software problems

Emergent properties

- Properties of the system as a whole rather than properties that can be derived from the properties of components of a system
- Emergent properties are a consequence of the relationships between system components
- They can therefore only be assessed and measured once the components have been integrated into a system

Examples of emergent properties

- *The overall weight of the system*
  - This is an example of an emergent property that can be computed from individual component properties.
- *The reliability of the system*
  - This depends on the reliability of system components and the relationships between the components.
- *The usability of a system*
  - This is a complex property which is not simply dependent on the system hardware and software but also depends on the system operators and the environment where it is used.

Types of emergent property

- Functional properties
  - These appear when all the parts of a system work together to achieve some objective. For example, a bicycle has the functional property of being a transportation device once it has been assembled from its components.
- Non-functional emergent properties
  - Examples are reliability, performance, safety, and security. These relate to the behaviour of the system in its operational environment. They are often critical for computer-based systems as failure to achieve some minimal defined level in these properties may make the system unusable.

System reliability engineering

- Because of component inter-dependencies, faults can be propagated through the system
- System failures often occur because of unforeseen inter-relationships between components
- It is probably impossible to anticipate all possible component relationships
- Software reliability measures may give a false picture of the system reliability

Influences on reliability

- *Hardware reliability*
  - What is the probability of a hardware component failing and how long does it take to repair that component?
- *Software reliability*
  - How likely is it that a software component will produce an incorrect output. Software failure is usually distinct from hardware failure in that software does not wear out.
- *Operator reliability*
  - How likely is it that the operator of a system will make an error?

Reliability relationships

- Hardware failure can generate spurious signals that are outside the range of inputs expected by the software
- Software errors can cause alarms to be activated which cause operator stress and lead to operator errors
- The environment in which a system is installed can affect its reliability

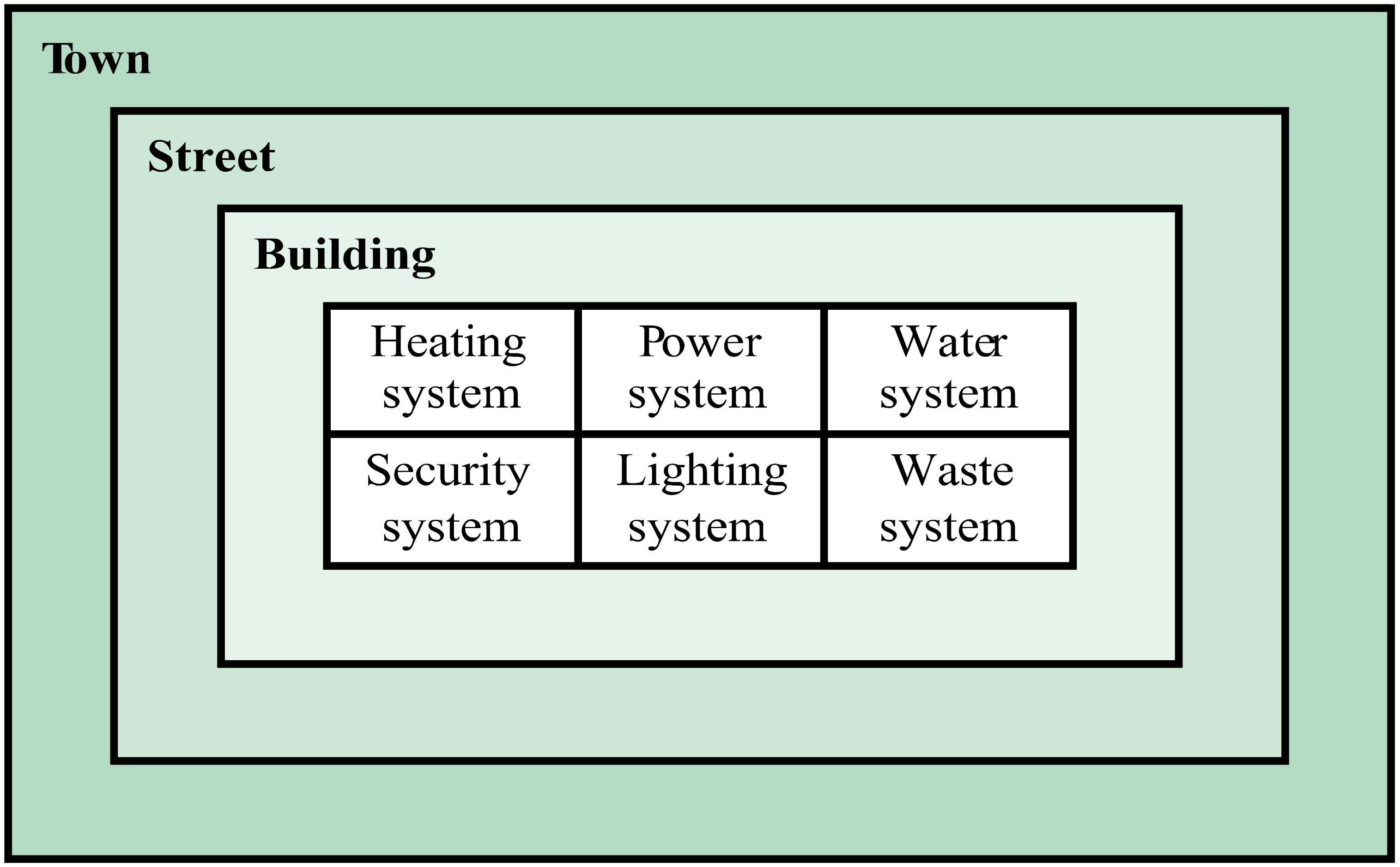
The ‘shall-not’ properties

- Properties such as performance and reliability can be measured
- However, some properties are properties that the system should not exhibit
  - Safety - the system should not behave in an unsafe way
  - Security - the system should not permit unauthorised use
- Measuring or assessing these properties is very hard

Systems and their environment

- Systems are not independent but exist in an environment
- System's function may be to change its environment
- Environment affects the functioning of the system e.g. system may require electrical supply from its environment
- The organizational as well as the physical environment may be important

System hierarchies



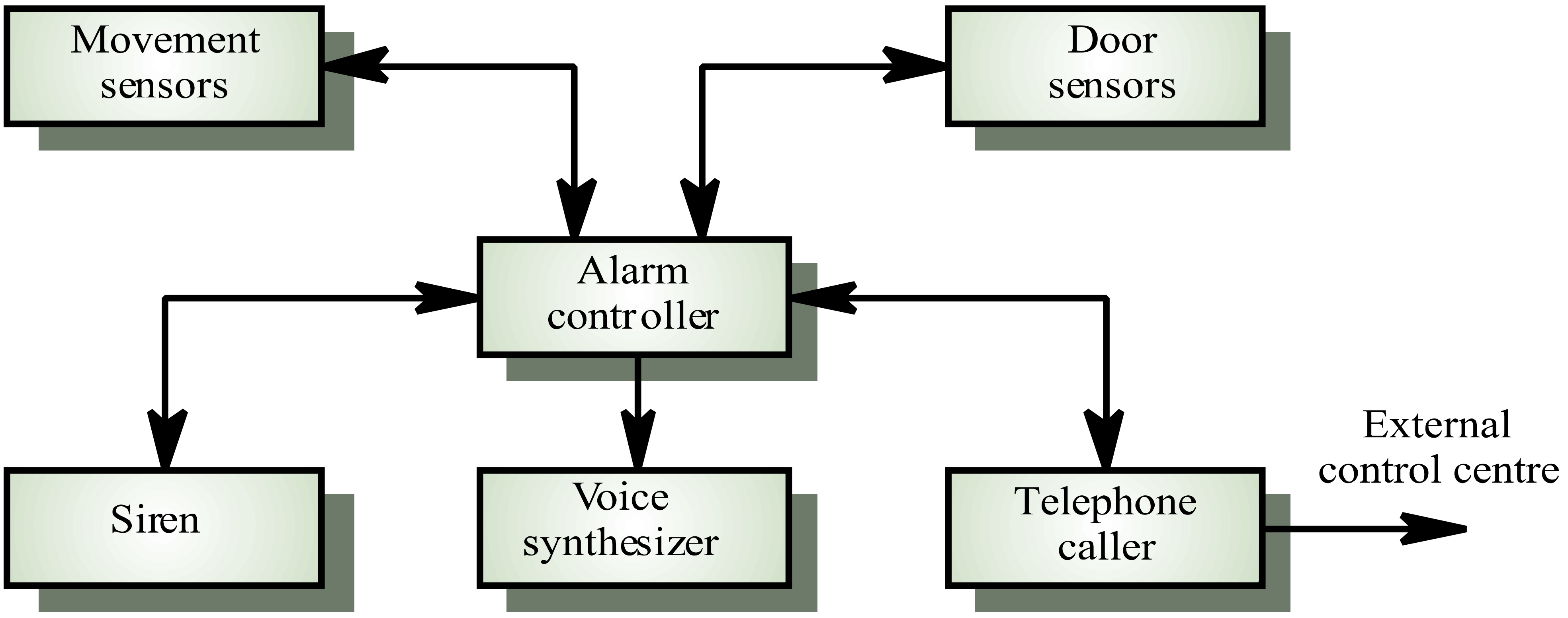
Human and organisational factors

- *Process changes*
  - Does the system require changes to the work processes in the environment?
- *Job changes*
  - Does the system de-skill the users in an environment or cause them to change the way they work?
- *Organisational changes*
  - Does the system change the political power structure in an organisation?

System architecture modelling

- An architectural model presents an abstract view of the sub-systems making up a system
- May include major information flows between sub-systems
- Usually presented as a block diagram
- May identify different types of functional component in the model

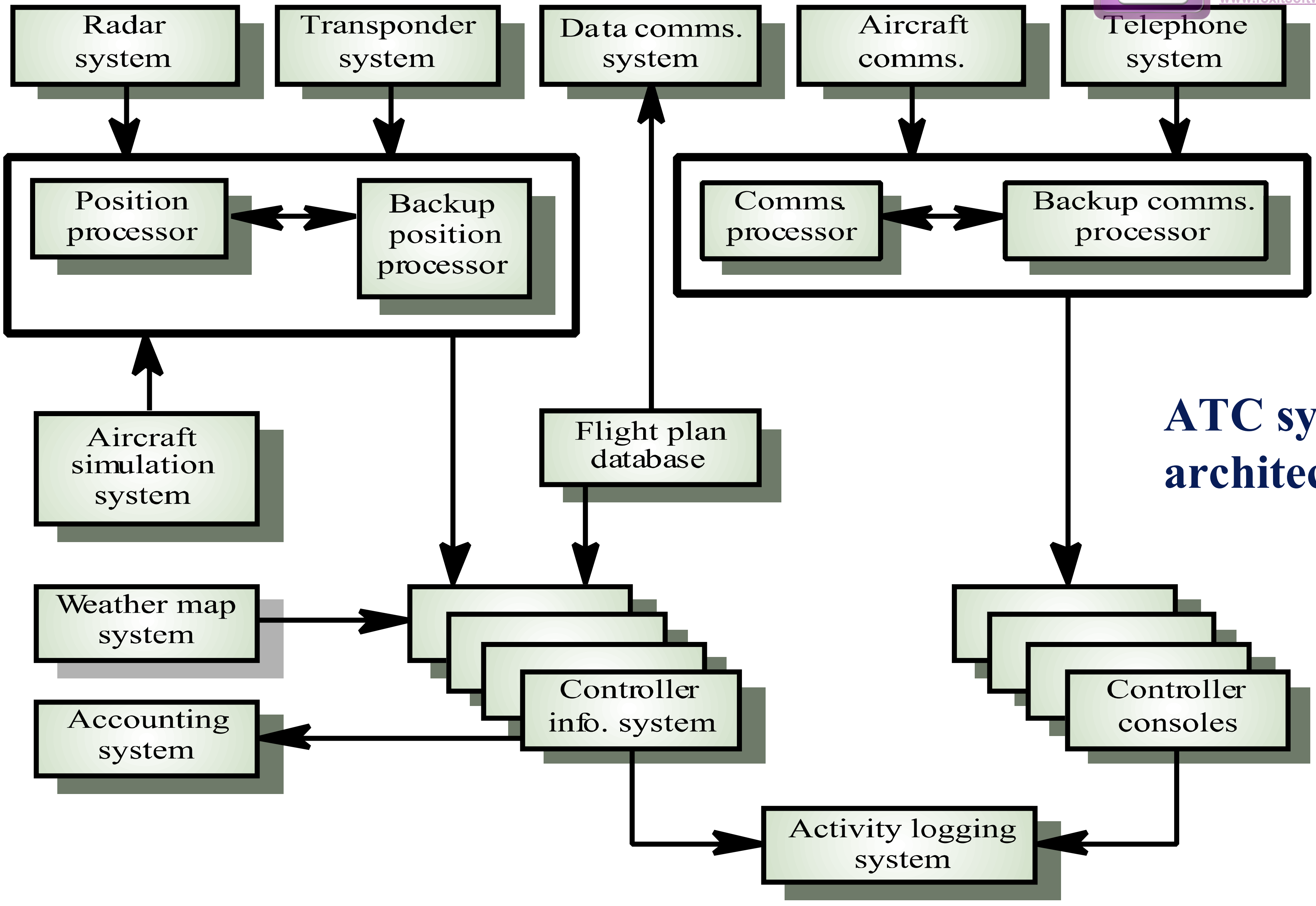
Intruder alarm system



Component types in alarm system

- Sensor
  - Movement sensor, door sensor
- Actuator
  - Siren
- Communication
  - Telephone caller
- Co-ordination
  - Alarm controller
- Interface
  - Voice synthesizer

ATC system architecture



Functional system components

- Sensor components
- Actuator components
- Computation components
- Communication components
- Co-ordination components
- Interface components

System components

- Sensor components
  - Collect information from the system's environment e.g. radars in an air traffic control system
- Actuator components
  - Cause some change in the system's environment e.g. valves in a process control system which increase or decrease material flow in a pipe
- Computation components
  - Carry out some computations on an input to produce an output e.g. a floating point processor in a computer system

System components

- Communication components
  - Allow system components to communicate with each other e.g. network linking distributed computers
- Co-ordination components
  - Co-ordinate the interactions of other system components e.g. scheduler in a real-time system
- Interface components
  - Facilitate the interactions of other system components e.g. operator interface
- All components are now usually software controlled

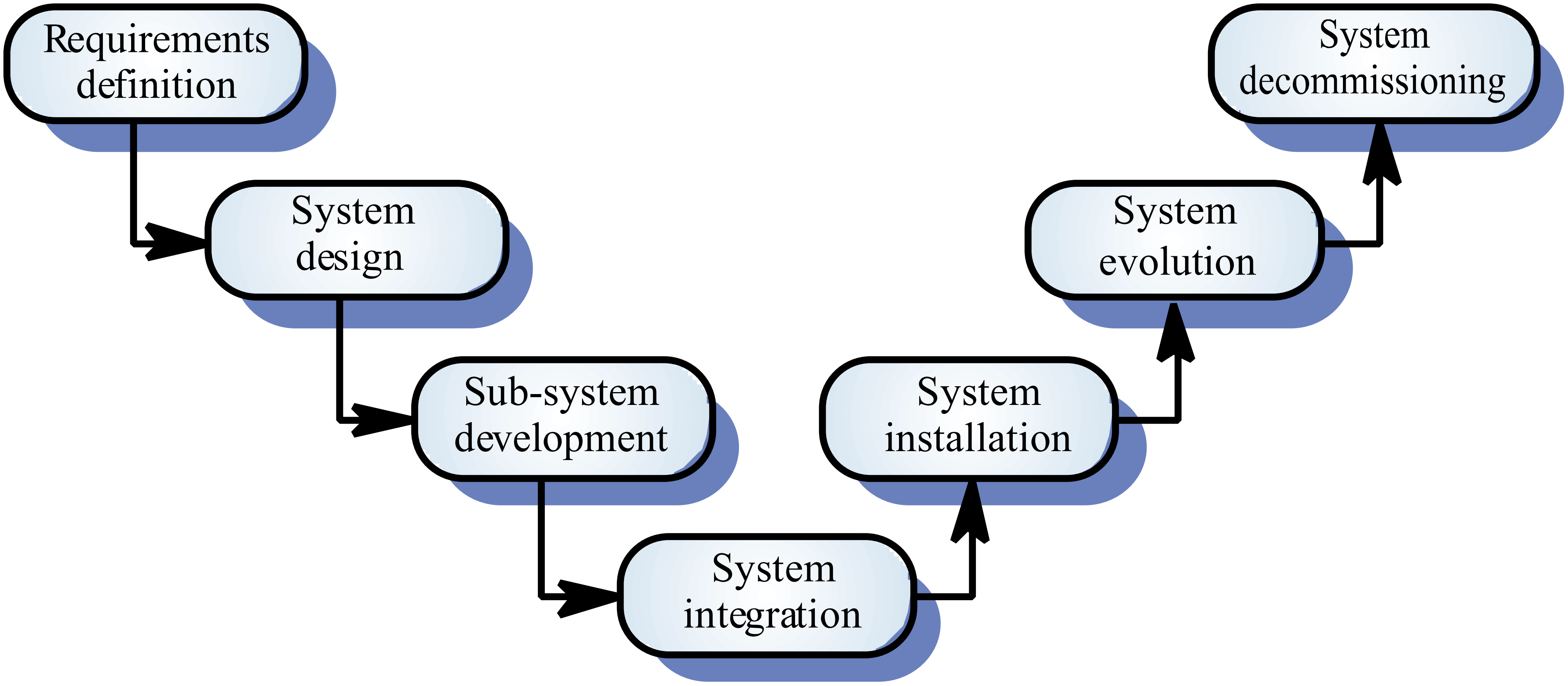
Component types in alarm system

- Sensor
  - Movement sensor, Door sensor
- Actuator
  - Siren
- Communication
  - Telephone caller
- Coordination
  - Alarm controller
- Interface
  - Voice synthesizer

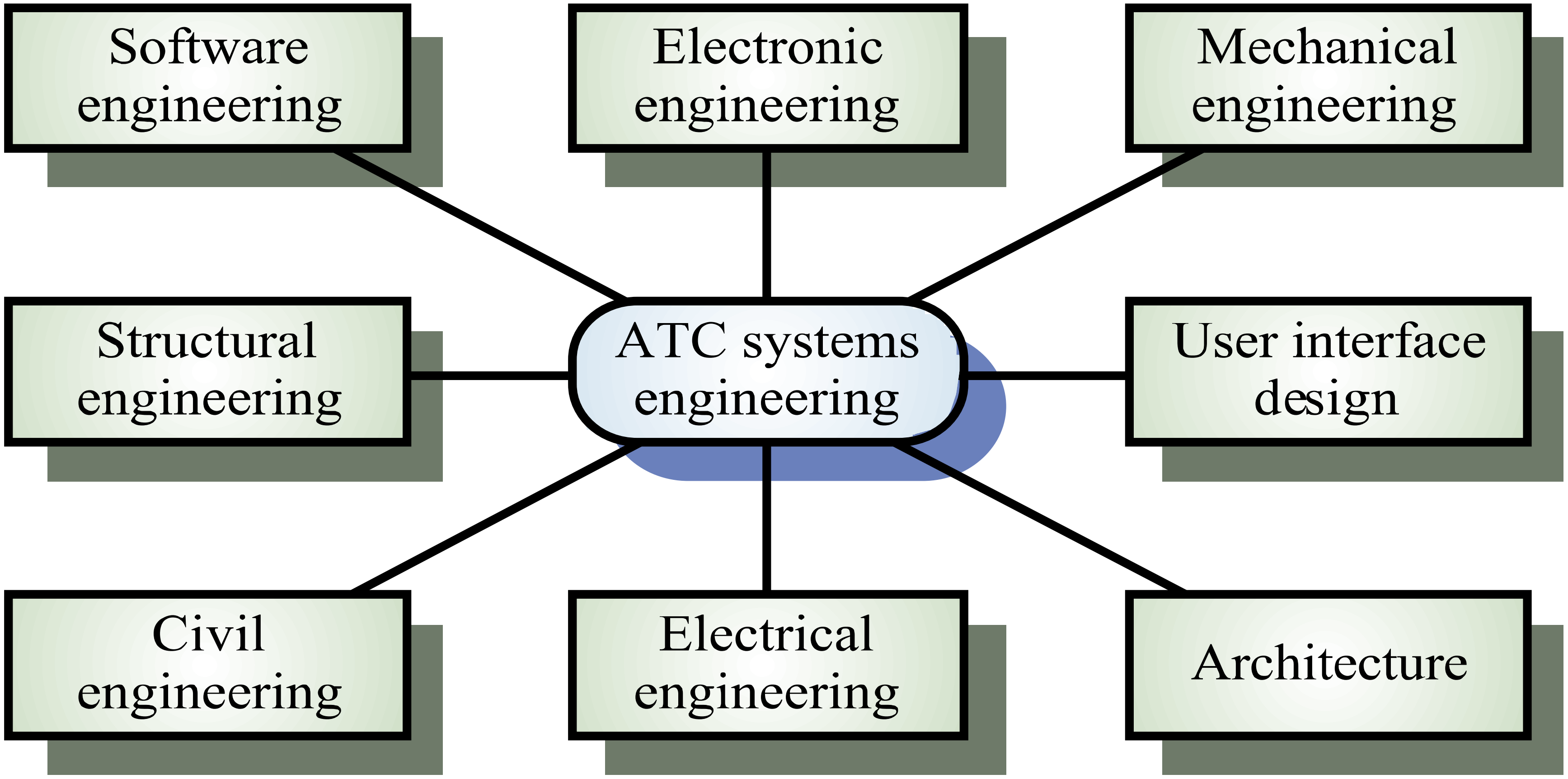
The system engineering process

- Usually follows a ‘waterfall’ model because of the need for parallel development of different parts of the system
    - Little scope for iteration between phases because hardware changes are very expensive. Software may have to compensate for hardware problems
- Inevitably involves engineers from different disciplines who must work together
    - Much scope for misunderstanding here. Different disciplines use a different vocabulary and much negotiation is required. Engineers may have personal agendas to fulfil

The system engineering process



Inter-disciplinary involvement



System requirements definition

- Three types of requirement defined at this stage
  - Abstract functional requirements. System functions are defined in an abstract way
  - System properties. Non-functional requirements for the system in general are defined
  - Undesirable characteristics. Unacceptable system behaviour is specified
- Should also define overall organisational objectives for the system

System objectives

- Functional objectives
  - To provide a fire and intruder alarm system for the building which will provide internal and external warning of fire or unauthorized intrusion
- Organisational objectives
  - To ensure that the normal functioning of work carried out in the building is not seriously disrupted by events such as fire and unauthorized intrusion

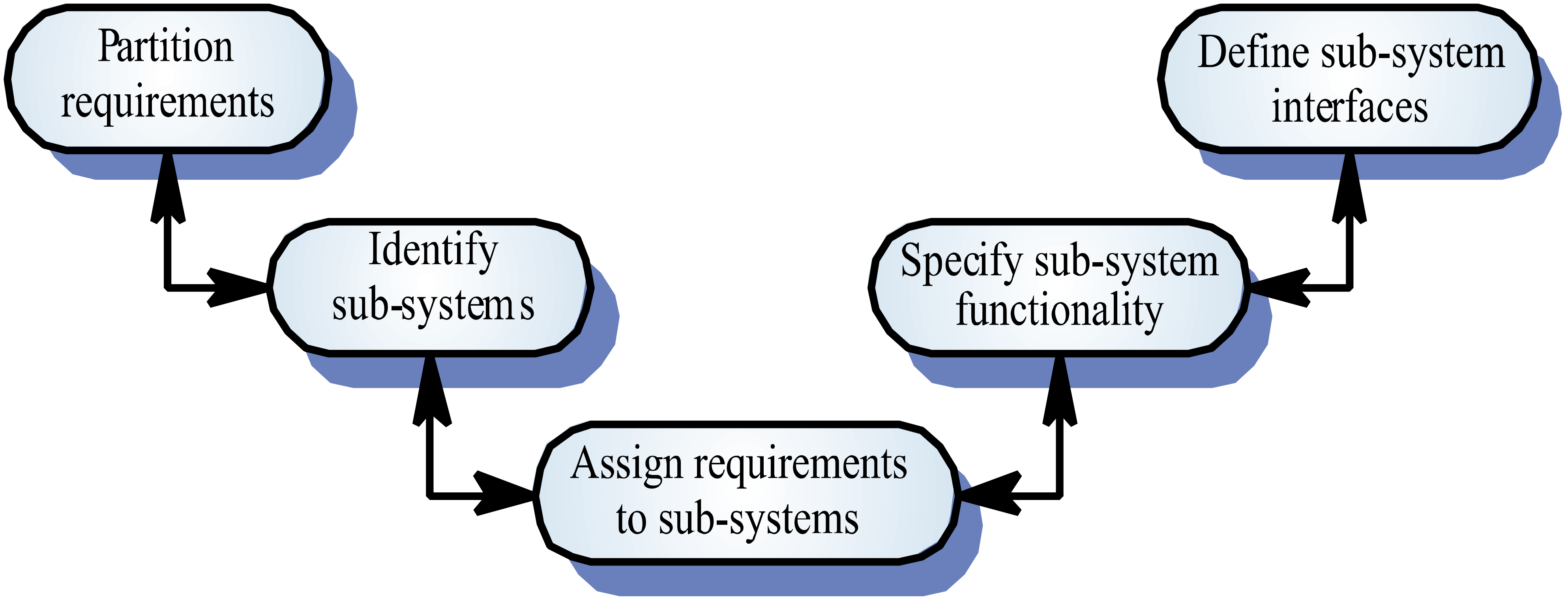
System requirements problems

- Changing as the system is being specified
- Must anticipate hardware/communications developments over the lifetime of the system
- Hard to define non-functional requirements (particularly) without an impression of component structure of the system.

The system design process

- Partition requirements
  - Organise requirements into related groups
- Identify sub-systems
  - Identify a set of sub-systems which collectively can meet the system requirements
- Assign requirements to sub-systems
  - Causes particular problems when COTS are integrated
- Specify sub-system functionality
- Define sub-system interfaces
  - Critical activity for parallel sub-system development

The system design process


Partition requirements
Identify sub-systems
Assign requirements to sub-systems
Specify sub-system functionality
Define sub-system interfaces

System design problems

- Requirements partitioning to hardware, software and human components may involve a lot of negotiation
- Difficult design problems are often assumed to be readily solved using software
- Hardware platforms may be inappropriate for software requirements so software must compensate for this

Sub-system development

- Typically parallel projects developing the hardware, software and communications
- May involve some COTS (Commercial Off-the-Shelf) systems procurement
- Lack of communication across implementation teams
- Bureaucratic and slow mechanism for proposing system changes means that the development schedule may be extended because of the need for rework

System integration

- The process of putting hardware, software and people together to make a system
- Should be tackled incrementally so that sub-systems are integrated one at a time
- Interface problems between sub-systems are usually found at this stage
- May be problems with uncoordinated deliveries of system components

System installation

- Environmental assumptions may be incorrect
- May be human resistance to the introduction of a new system
- System may have to coexist with alternative systems for some time
- May be physical installation problems (e.g. cabling problems)
- Operator training has to be identified

System operation

- Will bring unforeseen requirements to light
- Users may use the system in a way which is not anticipated by system designers
- May reveal problems in the interaction with other systems
    - Physical problems of incompatibility
    - Data conversion problems
    - Increased operator error rate because of inconsistent interfaces

System evolution

- Large systems have a long lifetime. They must evolve to meet changing requirements
- Evolution is inherently costly
  - Changes must be analysed from a technical and business perspective
  - Sub-systems interact so unanticipated problems can arise
  - There is rarely a rationale for original design decisions
  - System structure is corrupted as changes are made to it
- Existing systems which must be maintained are sometimes called legacy systems

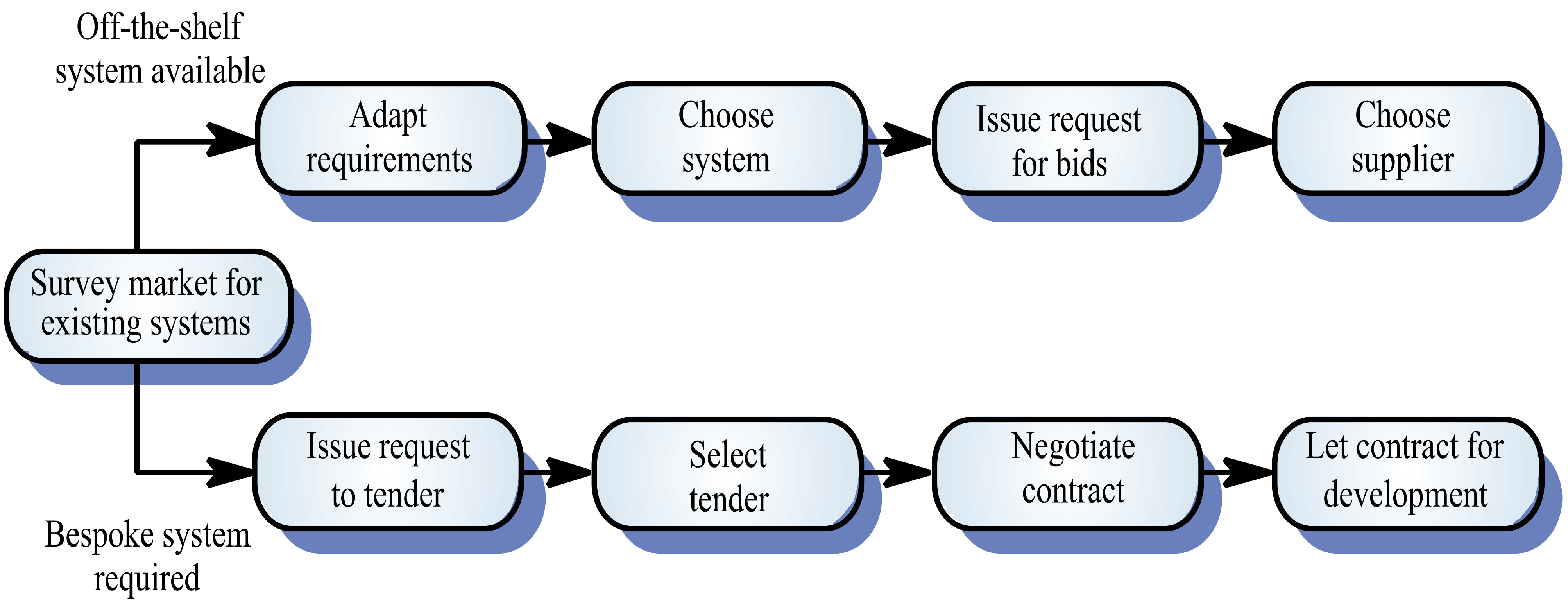
System decommissioning

- Taking the system out of service after its useful lifetime
- May require removal of materials (e.g. dangerous chemicals) which pollute the environment
  - Should be planned for in the system design by encapsulation
- May require data to be restructured and converted to be used in some other system

System procurement

- Acquiring a system for an organization to meet some need
- Some system specification and architectural design is usually necessary before procurement
  - You need a specification to let a contract for system development
  - The specification may allow you to buy a commercial off-the-shelf (COTS) system. Almost always cheaper than developing a system from scratch

The system procurement process



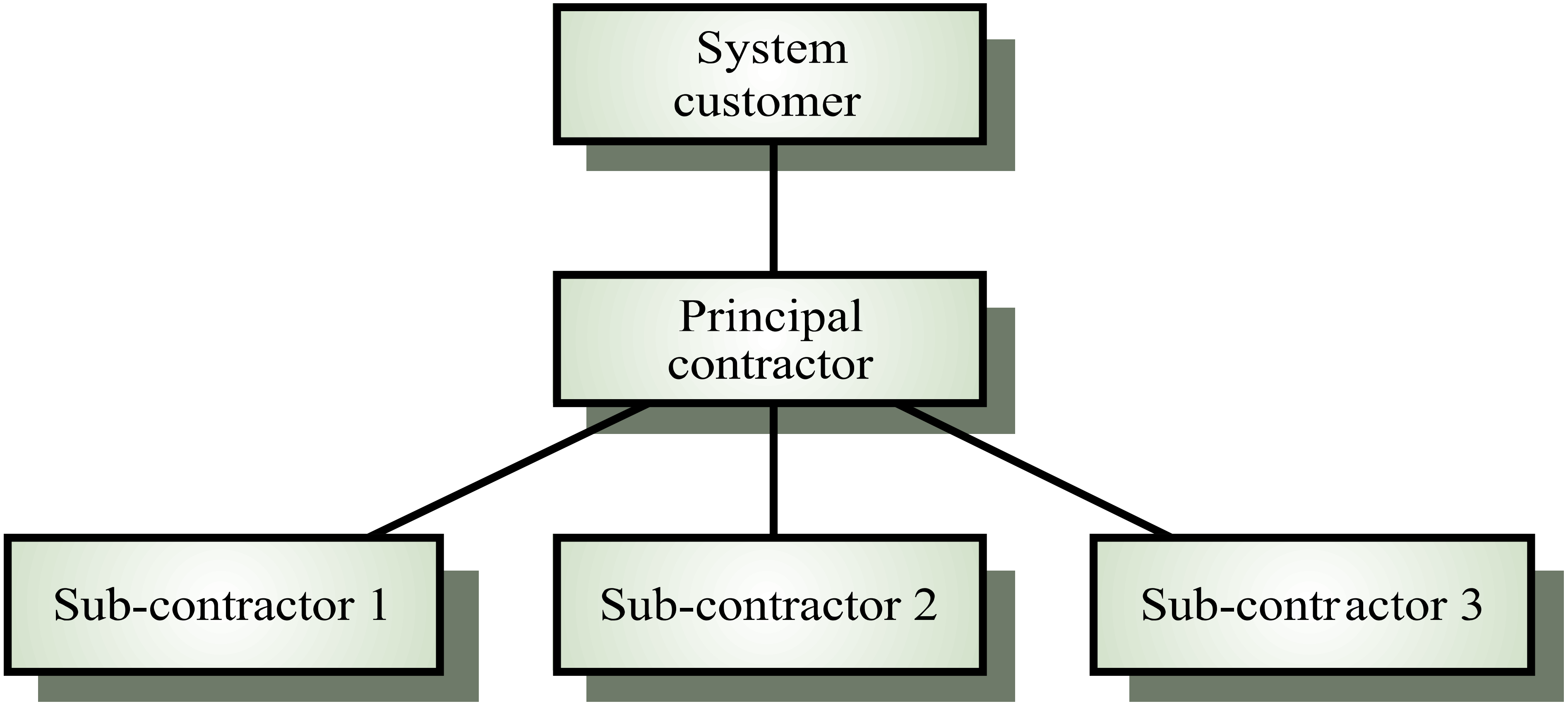
Procurement issues

- Requirements may have to be modified to match the capabilities of off-the-shelf components
- The requirements specification may be part of the contract for the development of the system
- There is usually a contract negotiation period to agree changes after the contractor to build a system has been selected

Contractors and sub-contractors

- The procurement of large hardware/software systems is usually based around some principal contractor
- Sub-contracts are issued to other suppliers to supply parts of the system
- Customer liases with the principal contractor and does not deal directly with sub-contractors

Contractor/Sub-contractor model



Key points

- System engineering involves input from a range of disciplines
- Emergent properties are properties that are characteristic of the system as a whole and not its component parts
- System architectural models show major sub-systems and inter-connections. They are usually described using block diagrams

Key points

- System component types are sensor, actuator, computation, co-ordination, communication and interface
- The systems engineering process is usually a waterfall model and includes specification, design, development and integration.
- System procurement is concerned with deciding which system to buy and who to buy it from

Conclusion

- Systems engineering is hard! There will never be an easy answer to the problems of complex system development
- Software engineers do not have all the answers but may be better at taking a systems viewpoint
- Disciplines need to recognise each others strengths and actively rather than reluctantly cooperate in the systems engineering process

Software Processes

- Coherent sets of activities for specifying, designing, implementing and testing software systems

Objectives

- To introduce software process models
- To describe a number of different process models and when they may be used
- To describe outline process models for requirements engineering, software development, testing and evolution
- To introduce CASE technology to support software process activities

Topics covered

- Software process models
- Process iteration
- Software specification
- Software design and implementation
- Software validation
- Software evolution
- Automated process support

The software process

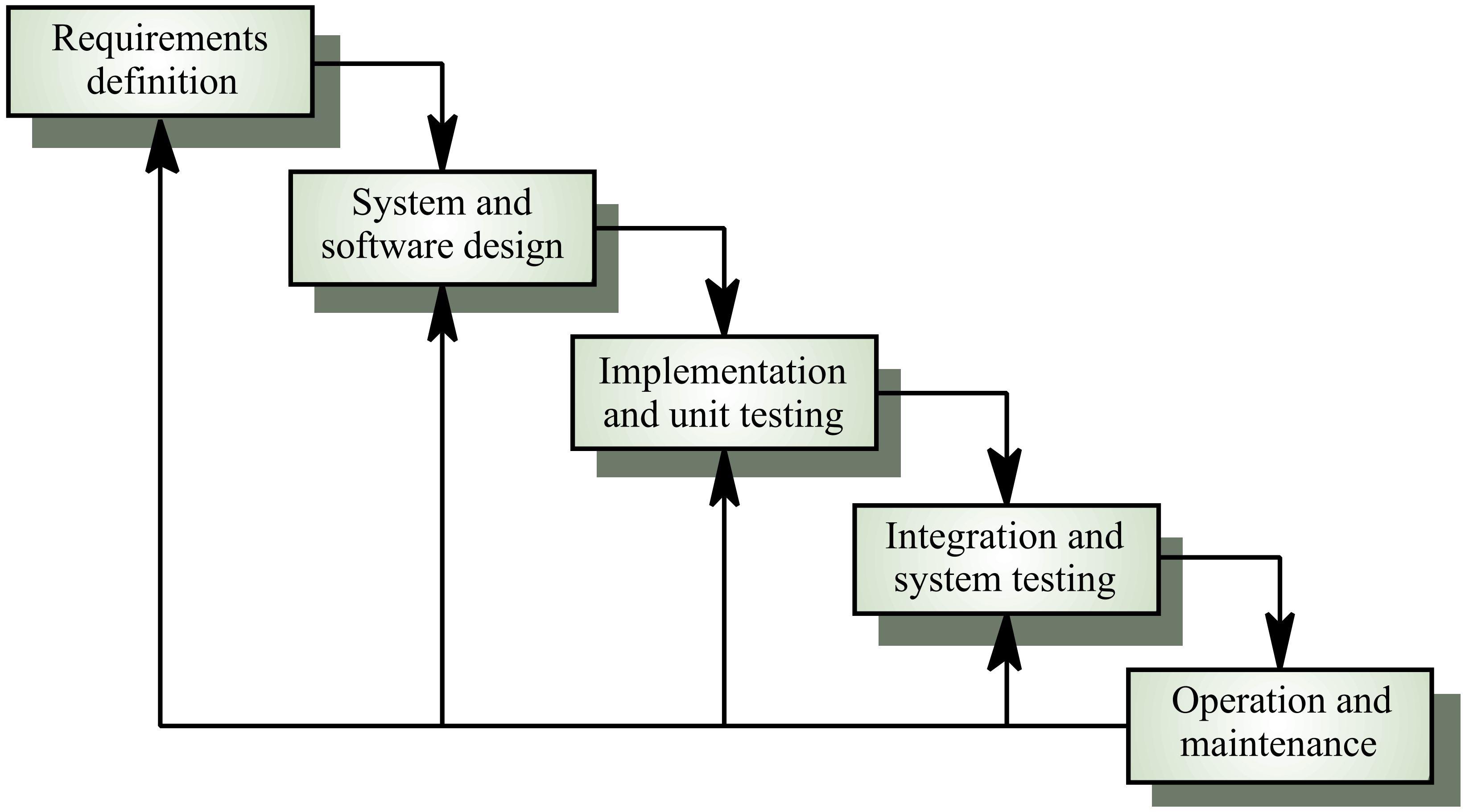
- A structured set of activities required to develop a software system
  - Specification
  - Design
  - Validation
  - Evolution
- A software process model is an abstract representation of a process. It presents a description of a process from some particular perspective

Software process models

Generic software process models

- The waterfall model
  - Separate and distinct phases of specification and development
- Evolutionary development
  - Specification and development are interleaved
- Formal systems development
  - A mathematical system model is formally transformed to an implementation
- Reuse-based development
  - The system is assembled from existing components

Waterfall model


Requirements definition
System and software design
Implementation and unit testing
Integration and system testing
Operation and maintenance

Waterfall model phases

- Requirements analysis and definition
- System and software design
- Implementation and unit testing
- Integration and system testing
- Operation and maintenance
- The drawback of the waterfall model is the difficulty of accommodating change after the process is underway

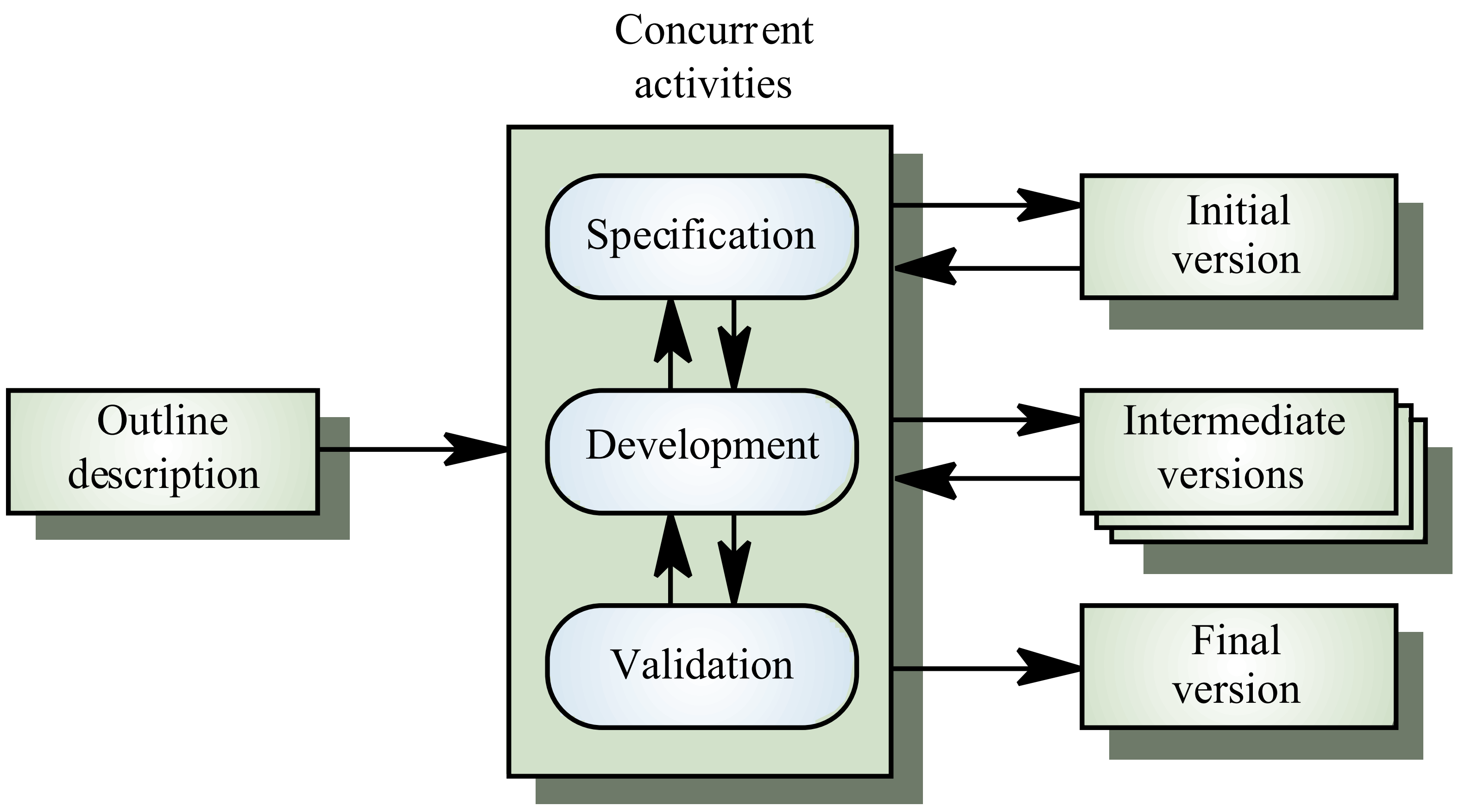
Waterfall model problems

- Inflexible partitioning of the project into distinct stages
- This makes it difficult to respond to changing customer requirements
- Therefore, this model is only appropriate when the requirements are well-understood

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
- Throw-away prototyping
  - Objective is to understand the system requirements. Should start with poorly understood requirements

Evolutionary development



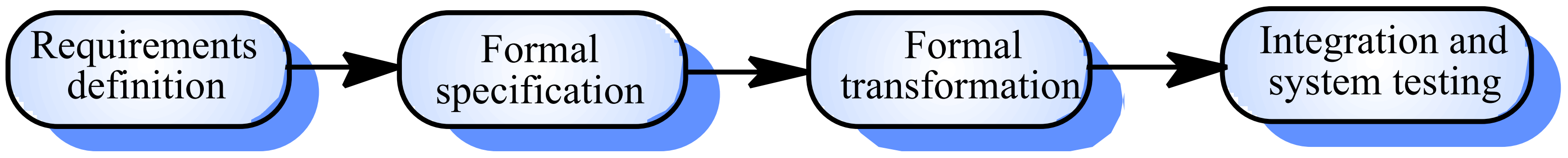
Evolutionary development

- 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

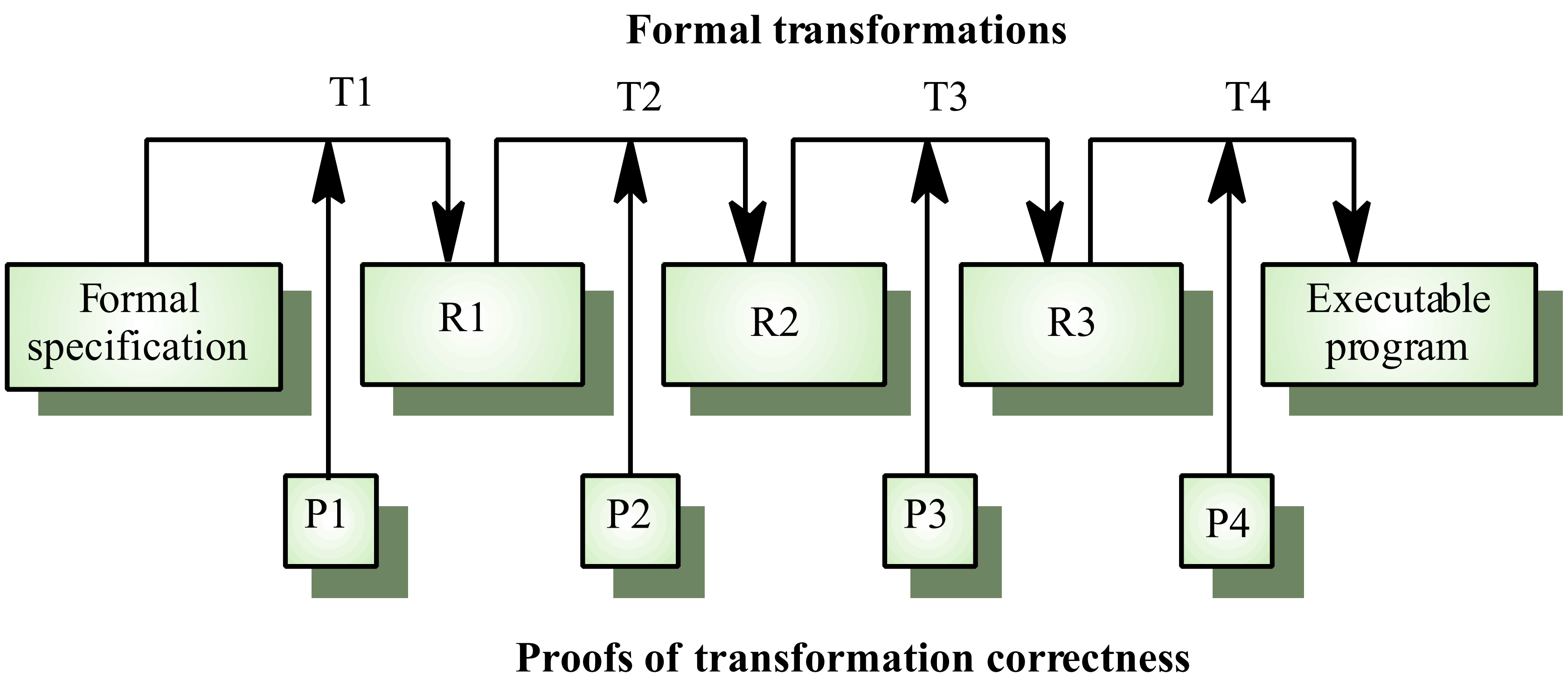
Formal systems development

- Based on the transformation of a mathematical specification through different representations to an executable program
- Transformations are 'correctness-preserving' so it is straightforward to show that the program conforms to its specification
- Embodied in the 'Cleanroom' approach to software development

Formal systems development



Formal transformations



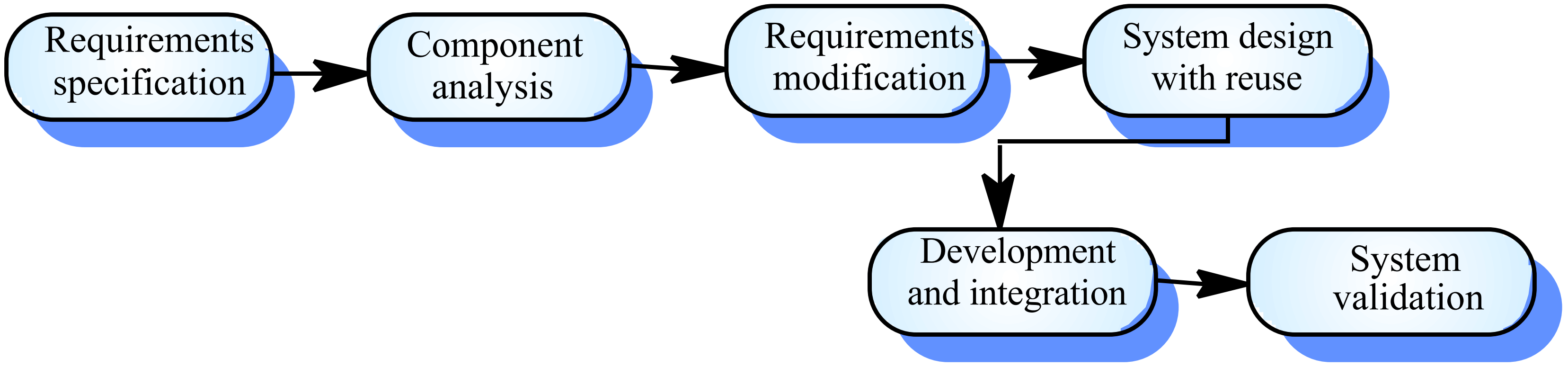
Formal systems development

- Problems
  - Need for specialised skills and training to apply the technique
  - Difficult to formally specify some aspects of the system such as the user interface
- Applicability
  - Critical systems especially those where a safety or security case must be made before the system is put into operation

Reuse-oriented development

- 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 more important but still limited experience with it

Reuse-oriented development


Requirements specification
Component analysis
Requirements modification
System design with reuse
Development and integration
System validation

Process iteration

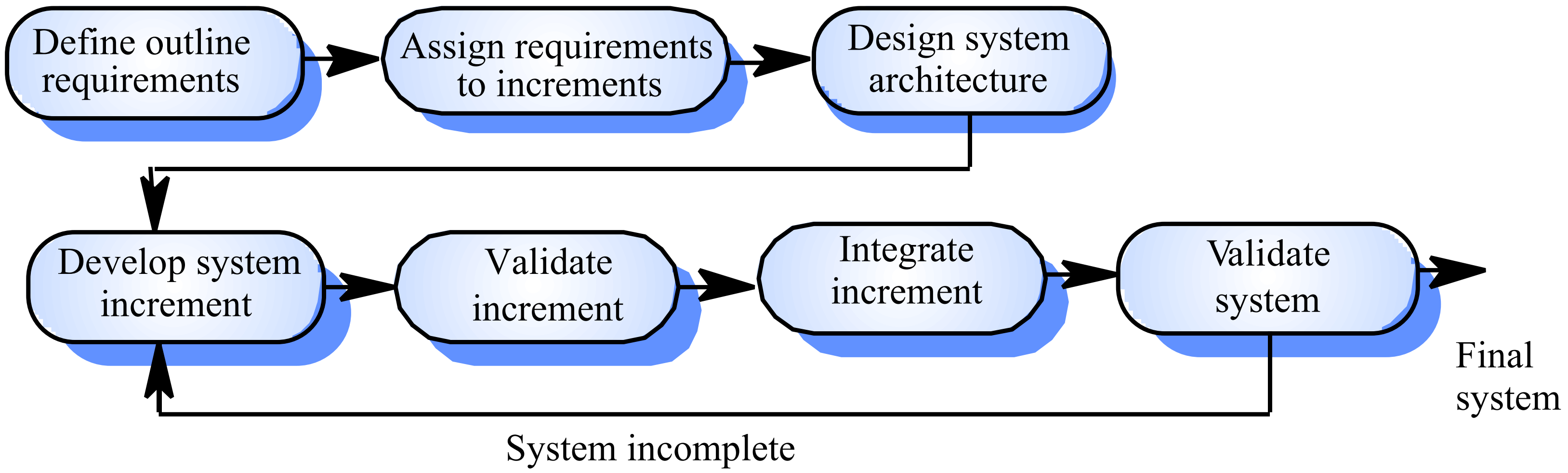
Process iteration

- 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 development
    - Spiral development

Incremental development

- 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

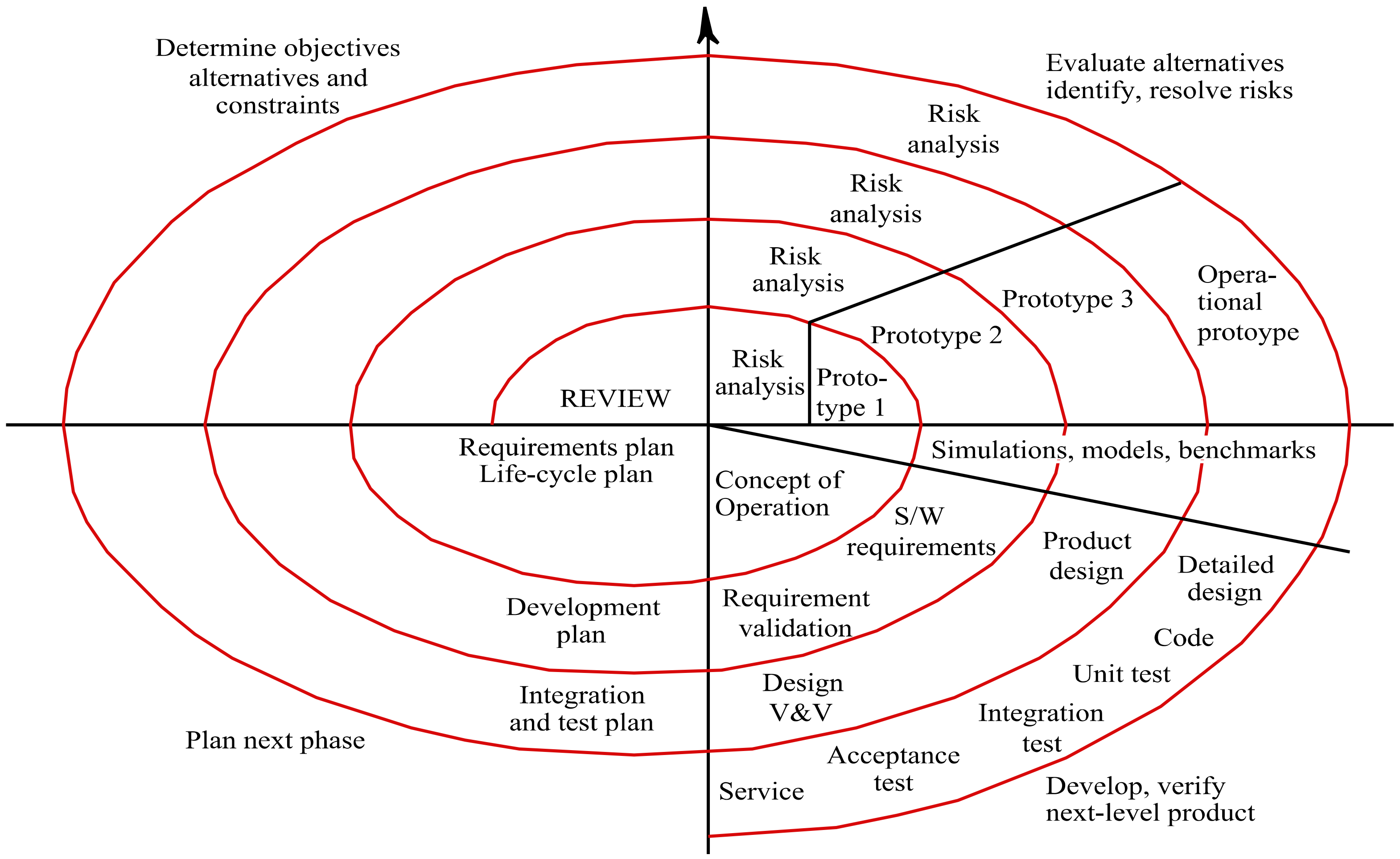
Extreme programming

- New 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

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



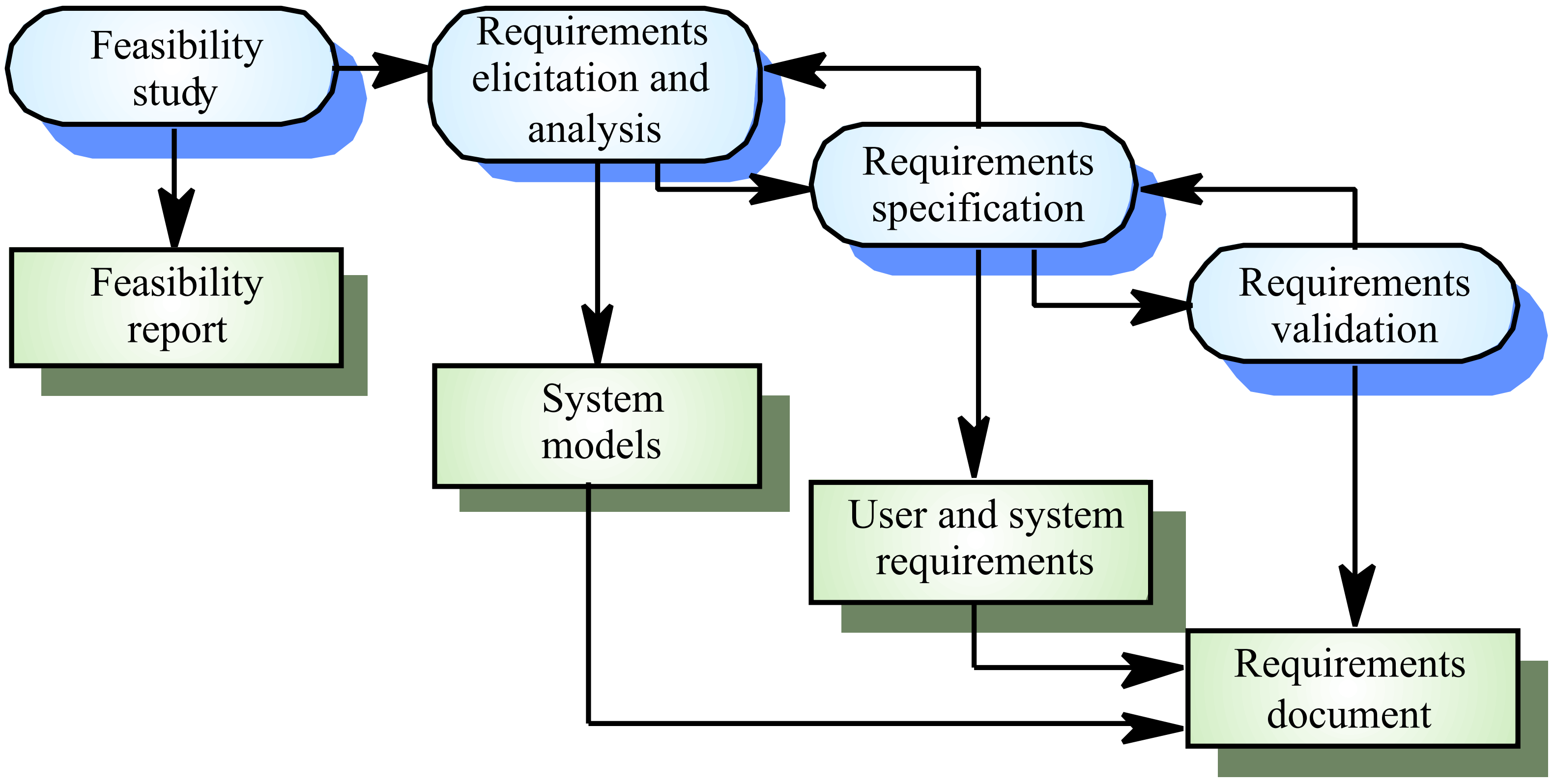
Spiral model sectors

- 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

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



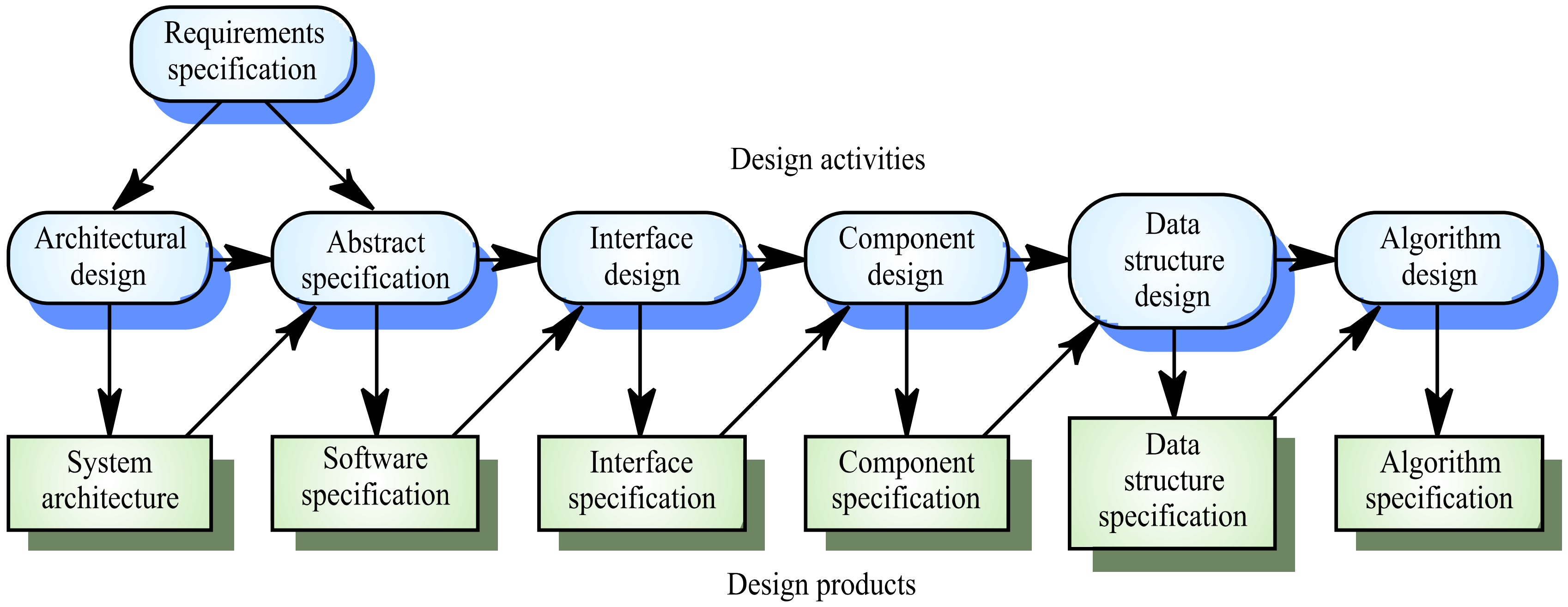
Software design and implementation

- 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



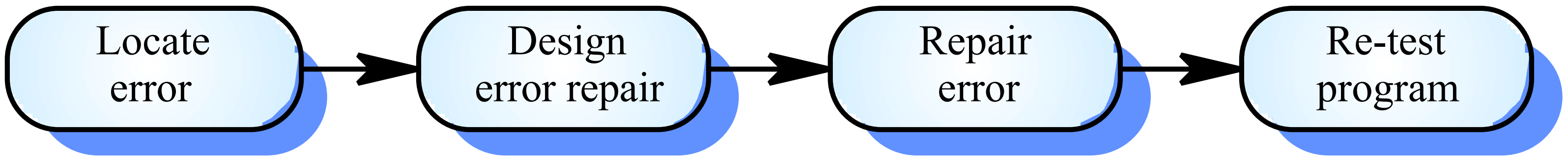
Design methods

- Systematic approaches to developing a software design
- The design is usually documented as a set of graphical models
- Possible models
    - Data-flow model
    - Entity-relation-attribute model
    - Structural model
    - Object models

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

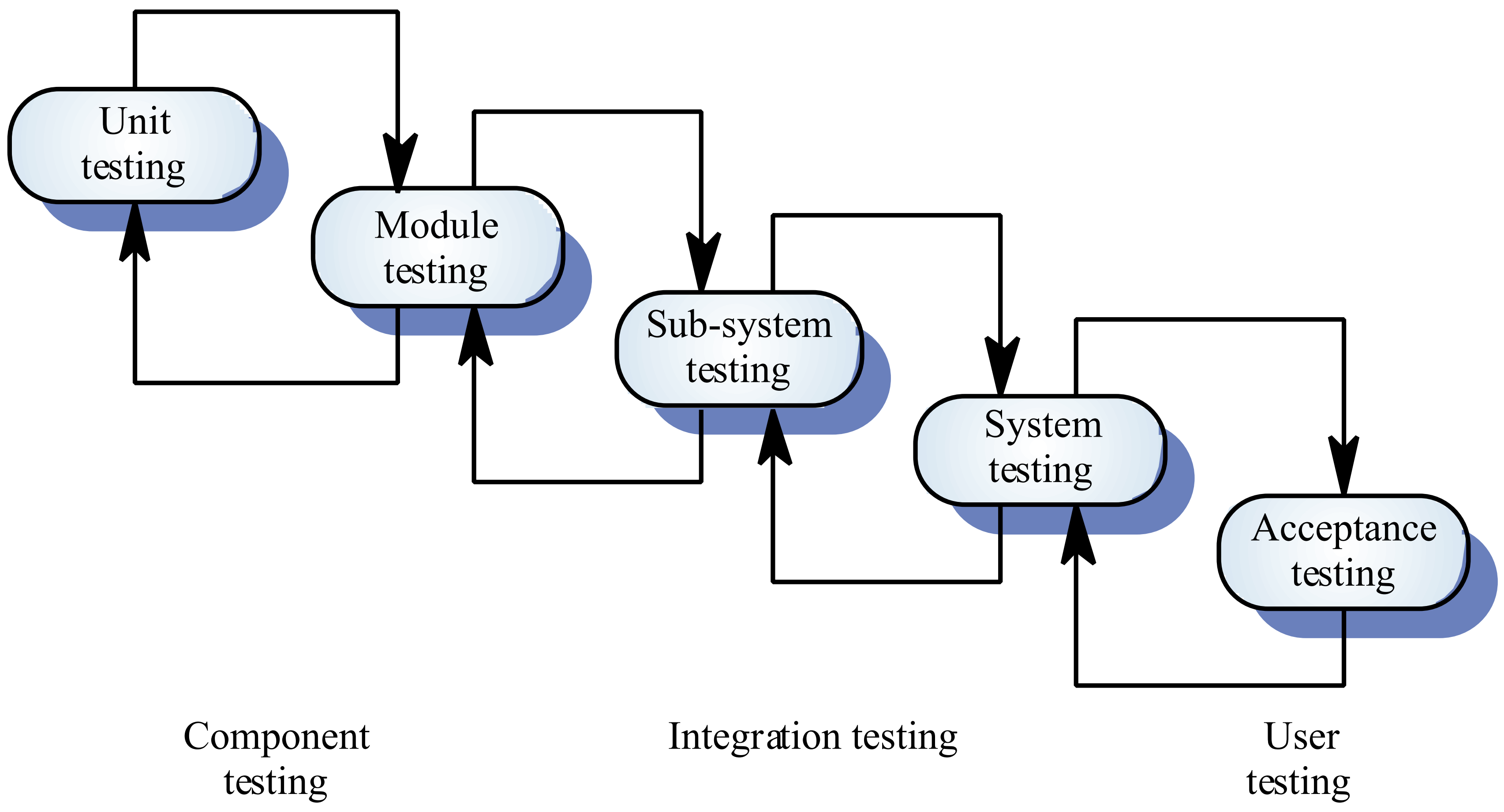
The debugging process



Software validation

- Verification and validation 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

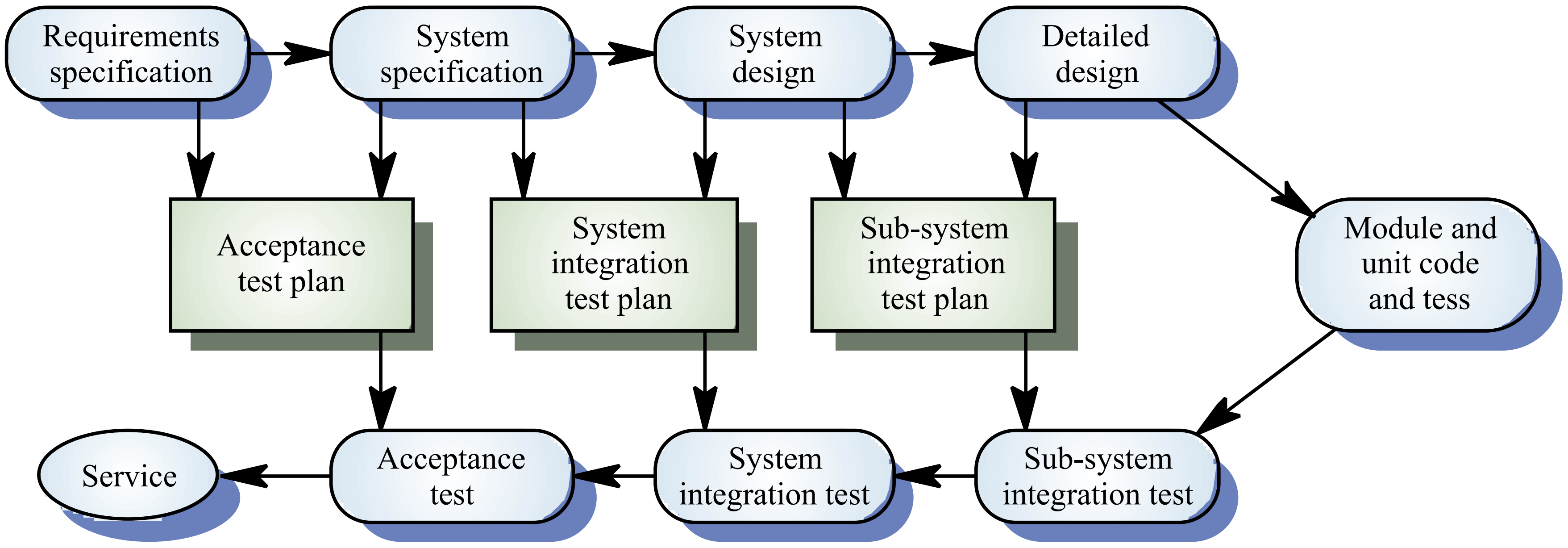
The testing process



Testing stages

- Unit testing
  - Individual components are tested
- Module testing
  - Related collections of dependent components are tested
- Sub-system testing
  - Modules are integrated into sub-systems and tested. The focus here should be on interface testing
- System testing
  - Testing of the system as a whole. Testing of emergent properties
- Acceptance testing
  - Testing with customer data to check that it is acceptable

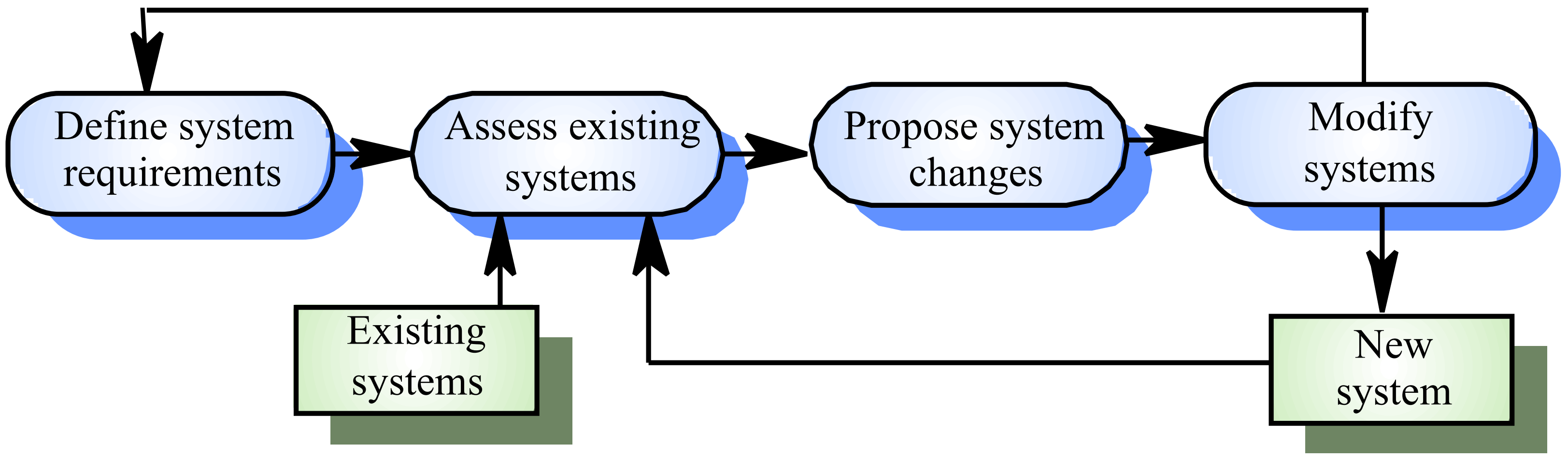
Testing phases


Requirements specification
System specification
System design
Detailed design
Acceptance test plan
System integration test plan
Sub-system integration test plan
Module and unit code and tess
Service
Acceptance test
System integration test
Sub-system integration test

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



Automated process support

CASE

- 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 though not the order of magnitude improvements that were once predicted
    - Software engineering requires creative thought - this is not readily automatable
    - 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

Functional tool classification

Tool type	**Examples**
Planning tools	PERT tools, estimation tools, spreadsheets
Editing tools	Text editors, diagram editors, word processors
Change management tools	Requirements traceability tools, change control systems
Configuration management tools	Version management systems, system building tools
Prototyping tools	Very high-level languages, user interface generators
Method-support tools	Design editors, data dictionaries, code generators
Language-processing tools	Compilers, interpreters
Program analysis tools	Cross reference generators, static analysers, dynamic analysers
Testing tools	Test data generators, file comparators
Debugging tools	Interactive debugging systems
Documentation tools	Page layout programs, image editors
Re-engineering tools	Cross-reference systems, program re-structuring systems

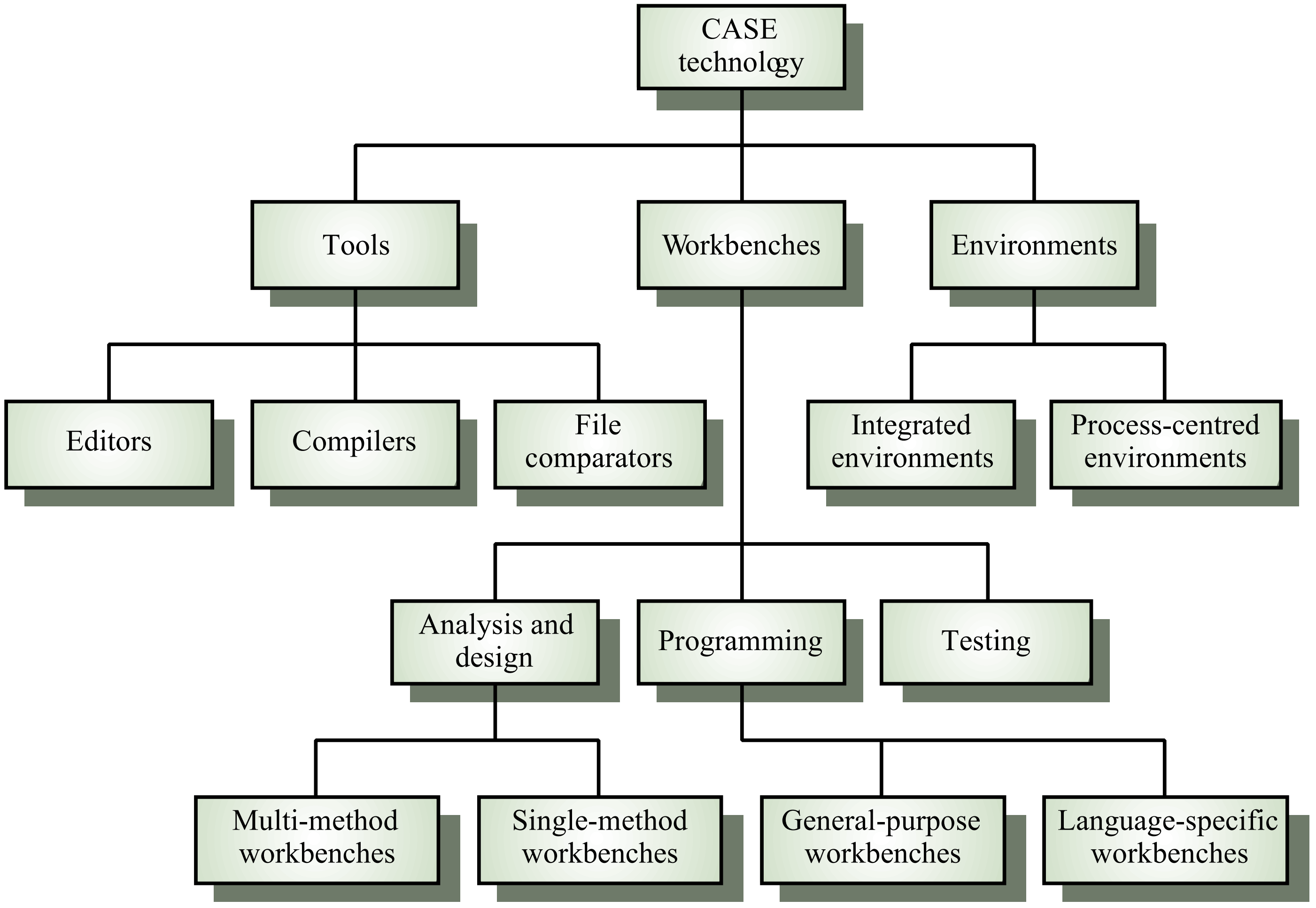
	Specification	Design	Implementation	Verification and Validation
Reengineering tools			●	
Testing tools			●	●
Debugging tools			●	●
Program analysis tools			●	●
Language-processing tools		●	●	
Method support tools	●	●		
Prototyping tools	●			●
Configuration management tools		●	●	
Change management tools	●	●	●	●
Documentation tools	●	●	●	●
Editing tools	●	●	●	●
Planning tools	●	●	●	●

Activity-based classification

CASE integration

- Tools
  - Support individual process tasks such as design consistency checking, text editing, etc.
- Workbenches
  - Support a process phase such as specification or design, Normally include a number of integrated tools
- Environments
  - Support all or a substantial part of an entire software process. Normally include several integrated workbenches

Tools, workbenches, environments



Key points

- Software processes are the activities involved in producing and evolving a software system. They are represented in a software process model
- General activities are specification, design and implementation, validation and evolution
- Generic process models describe the organisation of software processes
- Iterative process models describe the software process as a cycle of activities

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
- CASE technology supports software process activities

Project management

- Organising, planning and scheduling software projects

Objectives

- 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
- To discuss the notion of risks and the risk management process

Topics covered

- Management activities
- Project planning
- Project scheduling
- Risk 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

Management activities

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

Management commonalities

- These activities are not peculiar to software management
- Many techniques of engineering project management are equally applicable to software project management
- Technically complex engineering systems tend to suffer from the same problems as software systems

Project staffing

- May not be possible to appoint the ideal people to work on a project
  - Project budget may not allow for the use of highly-paid staff
  - Staff with the appropriate experience may not be available
  - An organisation may wish to develop employee skills on a software project
- Managers have to work within these constraints especially when (as is currently the case) there is an international shortage of skilled IT staff

Project planning

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

Project planning process

```
Establish the project constraints
Make initial assessments of the project parameters
Define project milestones and deliverables
while  project has not been completed or cancelled loop
        Draw up project schedule
        Initiate activities according to schedule
        Wait ( for a while )
        Review project progress
        Revise estimates of project parameters
        Update the project schedule
        Re-negotiate project constraints and deliverables
        if  ( problems arise )then
              Initiate technical review and possible revision
        end if
end loop
```

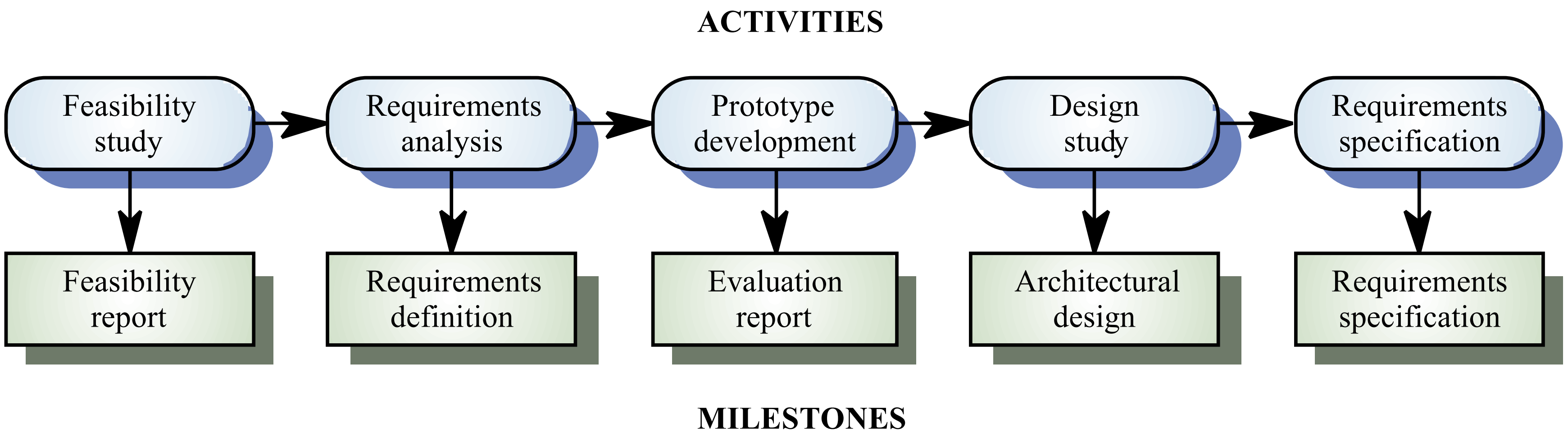
Project plan structure

- 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

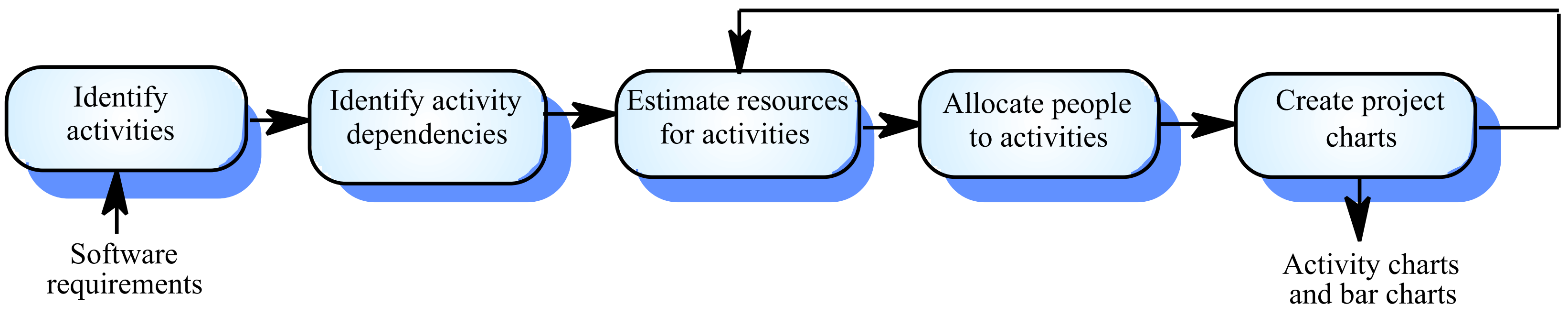


Project scheduling

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


Identify activities
Identify activity dependencies
Estimate resources for activities
Allocate people to activities
Create project charts
Software requirements
Activity charts and bar charts

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

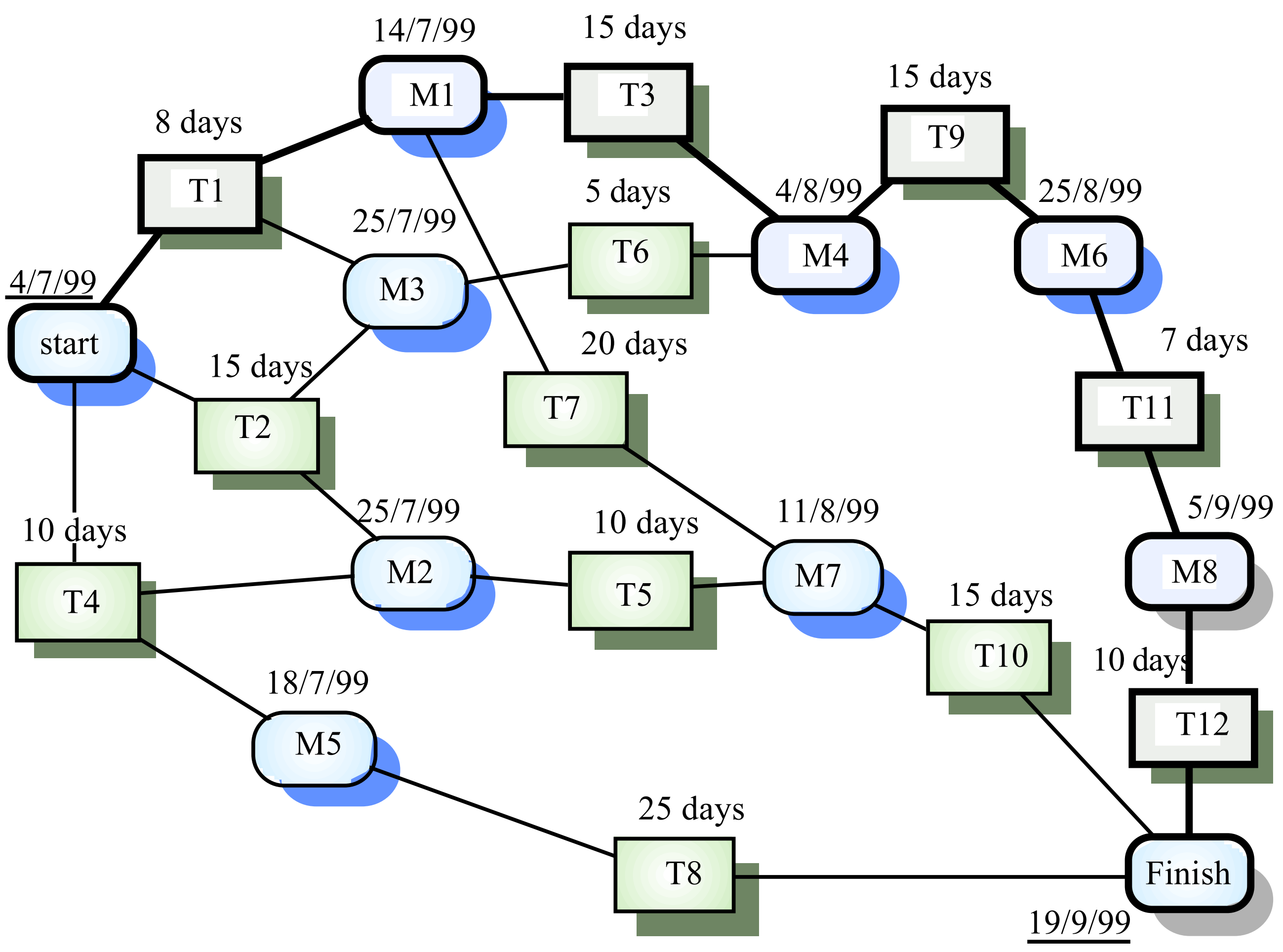
Bar charts and activity networks

- 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

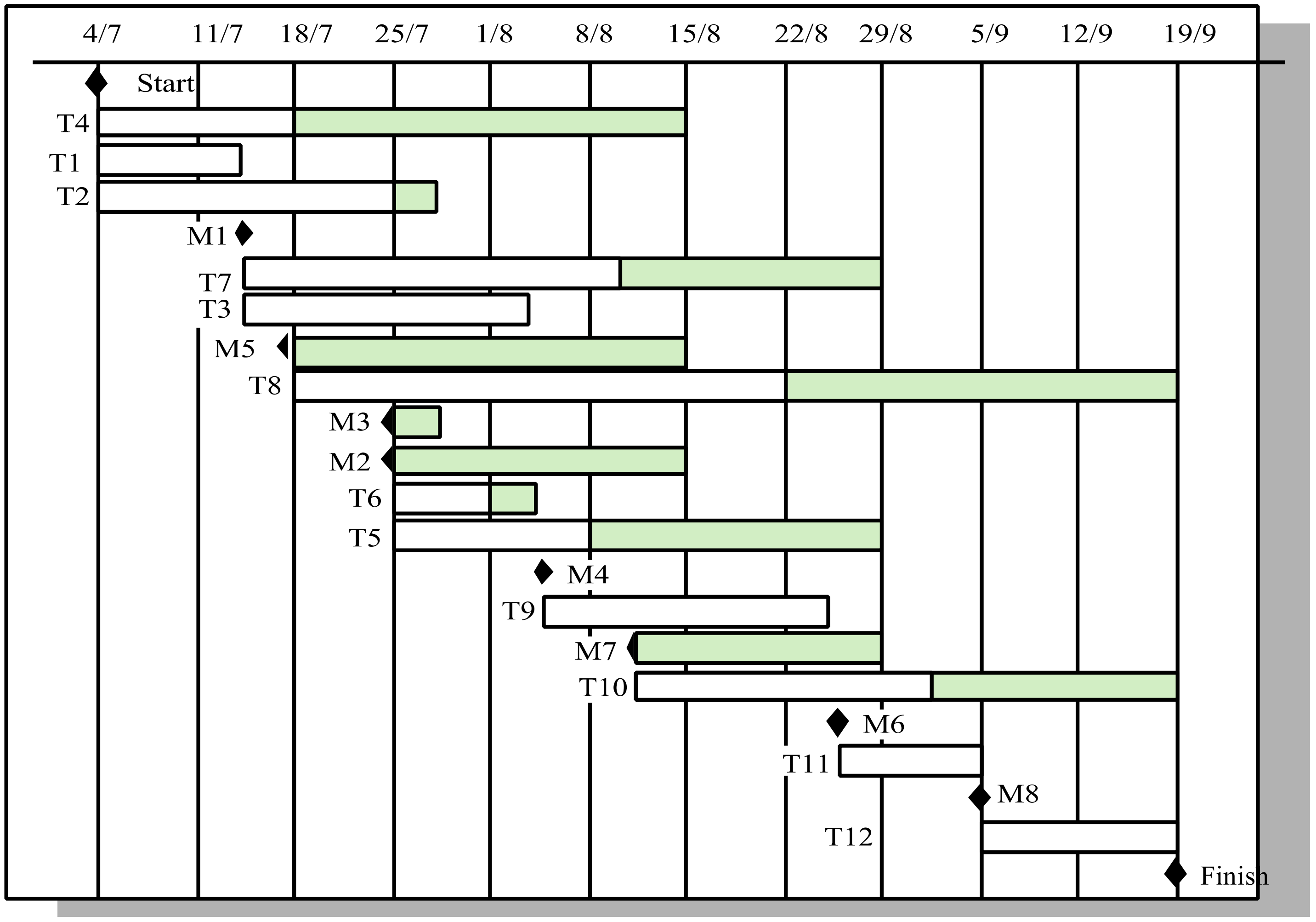
Task durations and dependencies

Task	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)

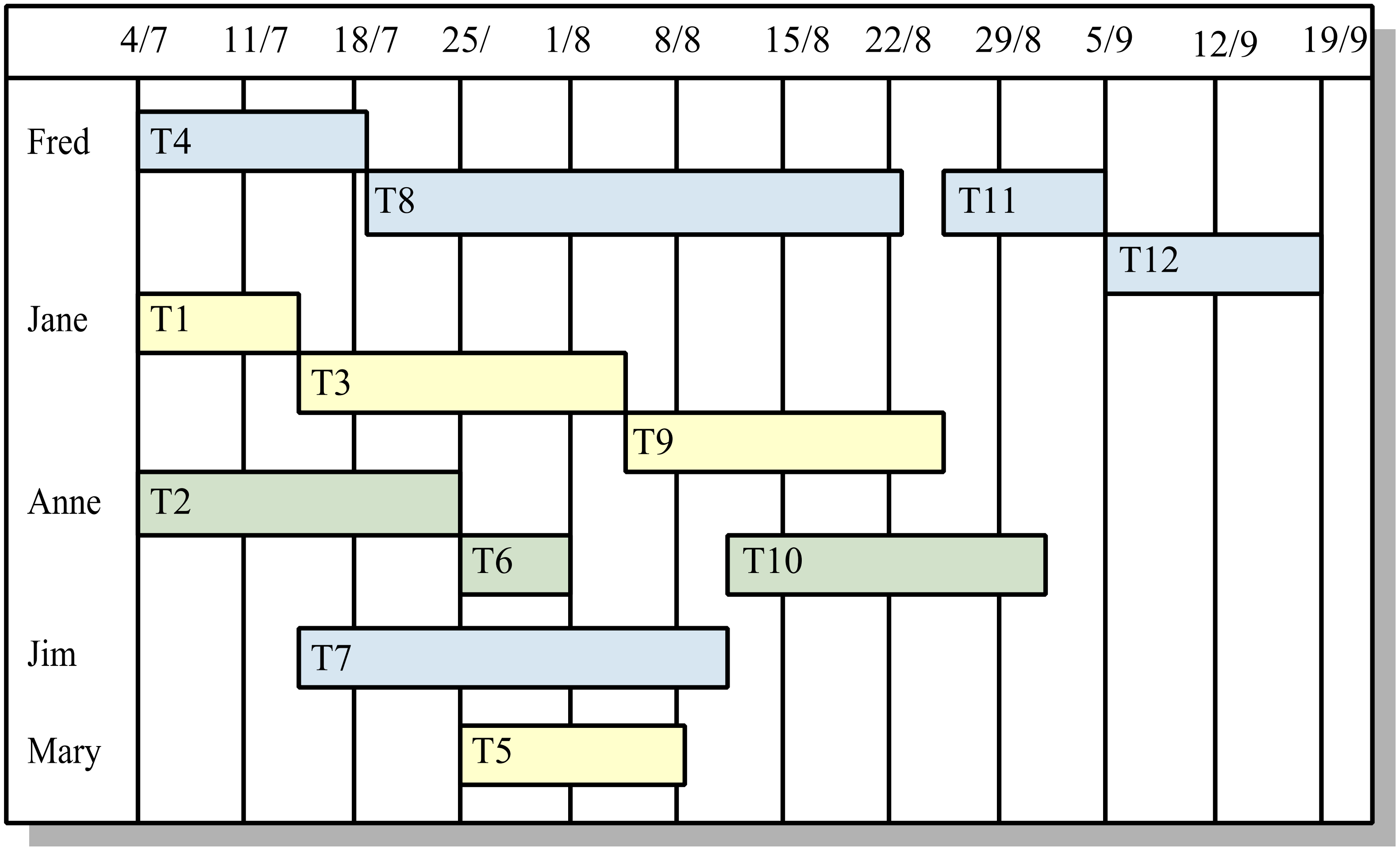
Activity network



Activity timeline



Staff allocation



Risk management

Risk management

- 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

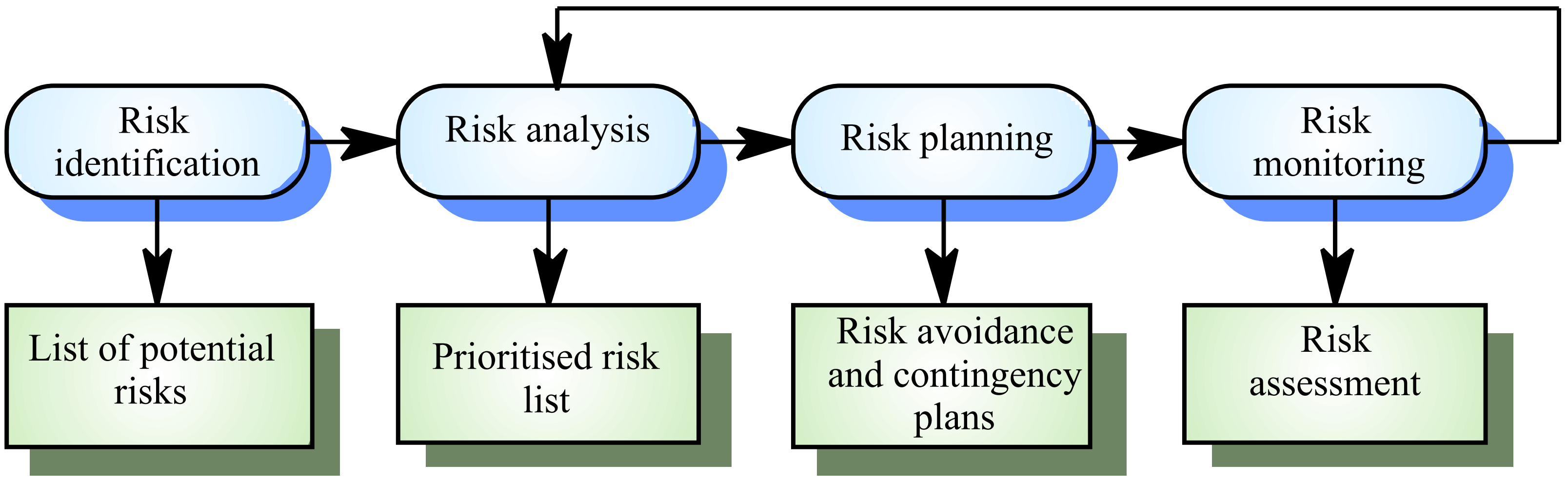
Software risks

Risk	Risk type	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 which 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 identification
  - Identify project, product and business risks
- Risk analysis
  - Assess the likelihood and consequences of these risks
- Risk planning
  - Draw up plans to avoid or minimise the effects of the risk
- Risk monitoring
  - Monitor the risks throughout the project

The risk management process



Risk identification

- Technology risks
- People risks
- Organisational risks
- Requirements risks
- Estimation risks

Risks and risk types

Risk type	**Possible risks**
Technology	The database used in the system cannot process as many transactions per second as expected. Software components which should be reused contain defects which limit their functionality.
People	It is impossible to recruit staff with the skills required. Key staff are ill and unavailable at critical times. Required training for staff is not available.
Organisational	The organisation is restructured so that different management are responsible for the project. Organisational financial problems force reductions in the project budget.
Tools	The code generated by CASE tools is inefficient. CASE tools cannot be integrated.
Requirements	Changes to requirements which require major design rework are proposed. Customers fail to understand the impact of requirements changes.
Estimation	The time required to develop the software is underestimated. The rate of defect repair is underestimated. The size of the software is underestimated.

Risk analysis

- Assess probability and seriousness of each risk
- Probability may be very low, low, moderate, high or very high
- Risk effects might be catastrophic, serious, tolerable or insignificant

Risk analysis

Risk	**Probability**	**Effects**
Organisational financial problems force reductions in the project budget.	Low	Catastrophic
It is impossible to recruit staff with the skills required for the project.	High	Catastrophic
Key staff are ill at critical times in the project.	Moderate	Serious
Software components which should be reused contain defects which limit their functionality.	Moderate	Serious
Changes to requirements which require major design rework are proposed.	Moderate	Serious
The organisation is restructured so that different management are responsible for the project.	High	Serious
The database used in the system cannot process as many transactions per second as expected.	Moderate	Serious
The time required to develop the software is underestimated.	High	Serious
CASE tools cannot be integrated.	High	Tolerable
Customers fail to understand the impact of requirements changes.	Moderate	Tolerable
Required training for staff is not available.	Moderate	Tolerable
The rate of defect repair is underestimated.	Moderate	Tolerable
The size of the software is underestimated.	High	Tolerable
The code generated by CASE tools is inefficient.	Moderate	Insignificant

Risk planning

- Consider each risk and develop a strategy to manage that risk
- Avoidance strategies
  - The probability that the risk will arise is reduced
- Minimisation strategies
  - The impact of the risk on the project or product will be reduced
- Contingency plans
  - If the risk arises, contingency plans are plans to deal with that risk

Risk management strategies

Risk	**Strategy**
Organisational financial problems	Prepare a briefing document for senior management showing how the project is making a very important contribution to the goals of the business.
Recruitment problems	Alert customer of potential difficulties and the possibility of delays, investigate buying-in components.
Staff illness	Reorganise team so that there is more overlap of work and people therefore understand each other’s jobs.
Defective components	Replace potentially defective components with bought-in components of known reliability.
Requirements changes	Derive traceability information to assess requirements change impact, maximise information hiding in the design.
Organisational restructuring	Prepare a briefing document for senior management showing how the project is making a very important contribution to the goals of the business.
Database performance	Investigate the possibility of buying a higher-performance database.
Underestimated development time	Investigate buying in components, investigate use of a program generator.

Risk monitoring

- Assess each identified risks regularly to decide whether or not it is becoming less or more probable
- Also assess whether the effects of the risk have changed
- Each key risk should be discussed at management progress meetings

Risk factors

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 some formal report of progress is presented to management.
- Risks may be project risks, product risks or business risks
- 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 Requirements

- Descriptions and specifications of a system

Objectives

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

Topics covered

- Functional and non-functional requirements
- User requirements
- System requirements
- The software 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 services. Written as a contract between client and contractor
- Software specification
    - A detailed software description which can serve as a basis for a design or implementation. Written for developers

Definitions and specifications

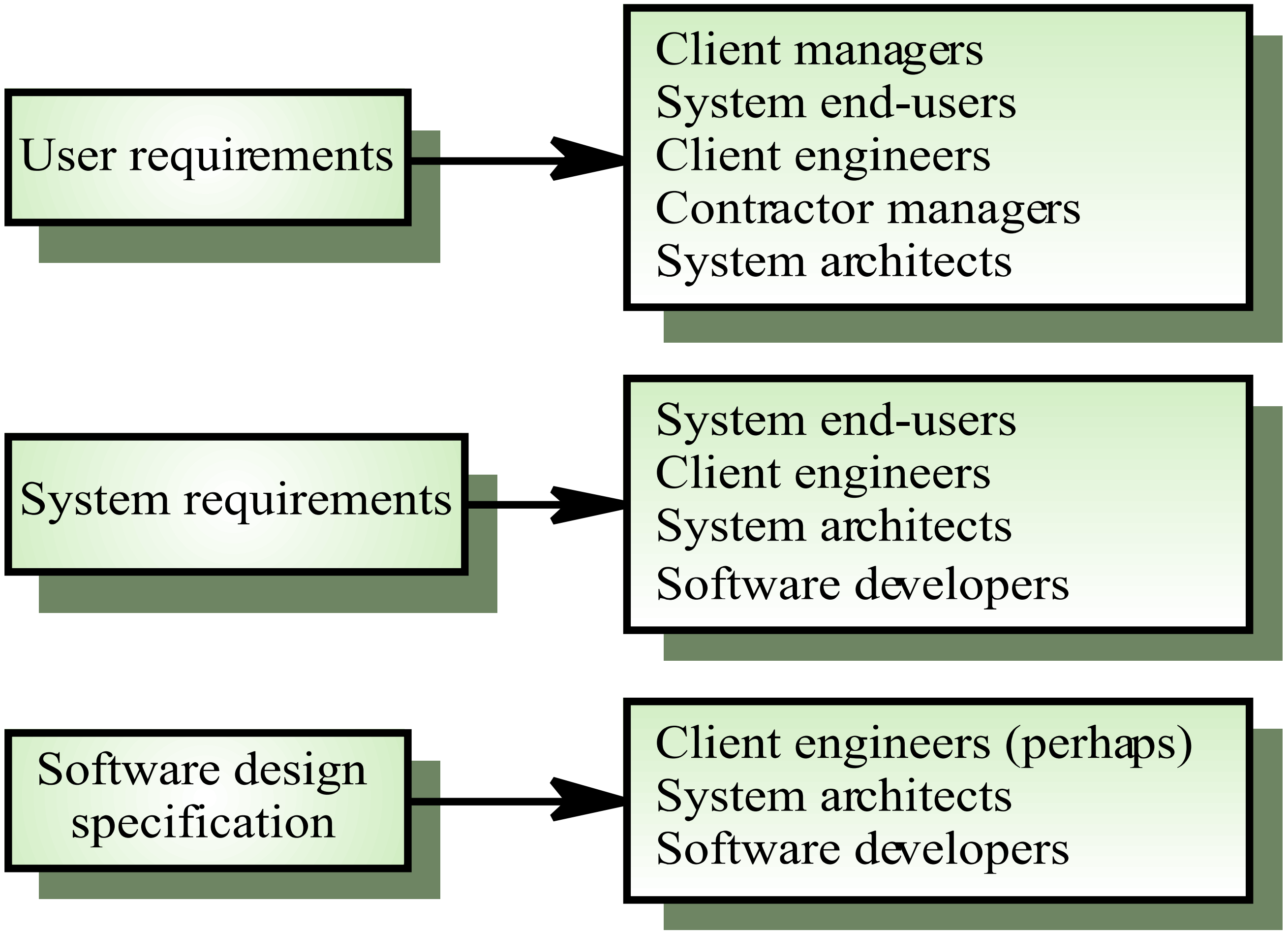
Requirements definition

1. The software must provide a means of representing and accessing external files created by other tools.

Requirements specification

1.1 The user should be provided with facilities to define the type of external files.
1.2 Each external file type may have an associated tool which may be applied to the file.
1.3 Each external file type may be represented as a specific icon on the user’s display.
1.4 Facilities should be provided for the icon representing an external file type to be defined by the user.
1.5 When a user selects an icon representing an external file, the effect of that selection is to apply the tool associated with the type of the external file to the file represented by the selected icon.

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

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

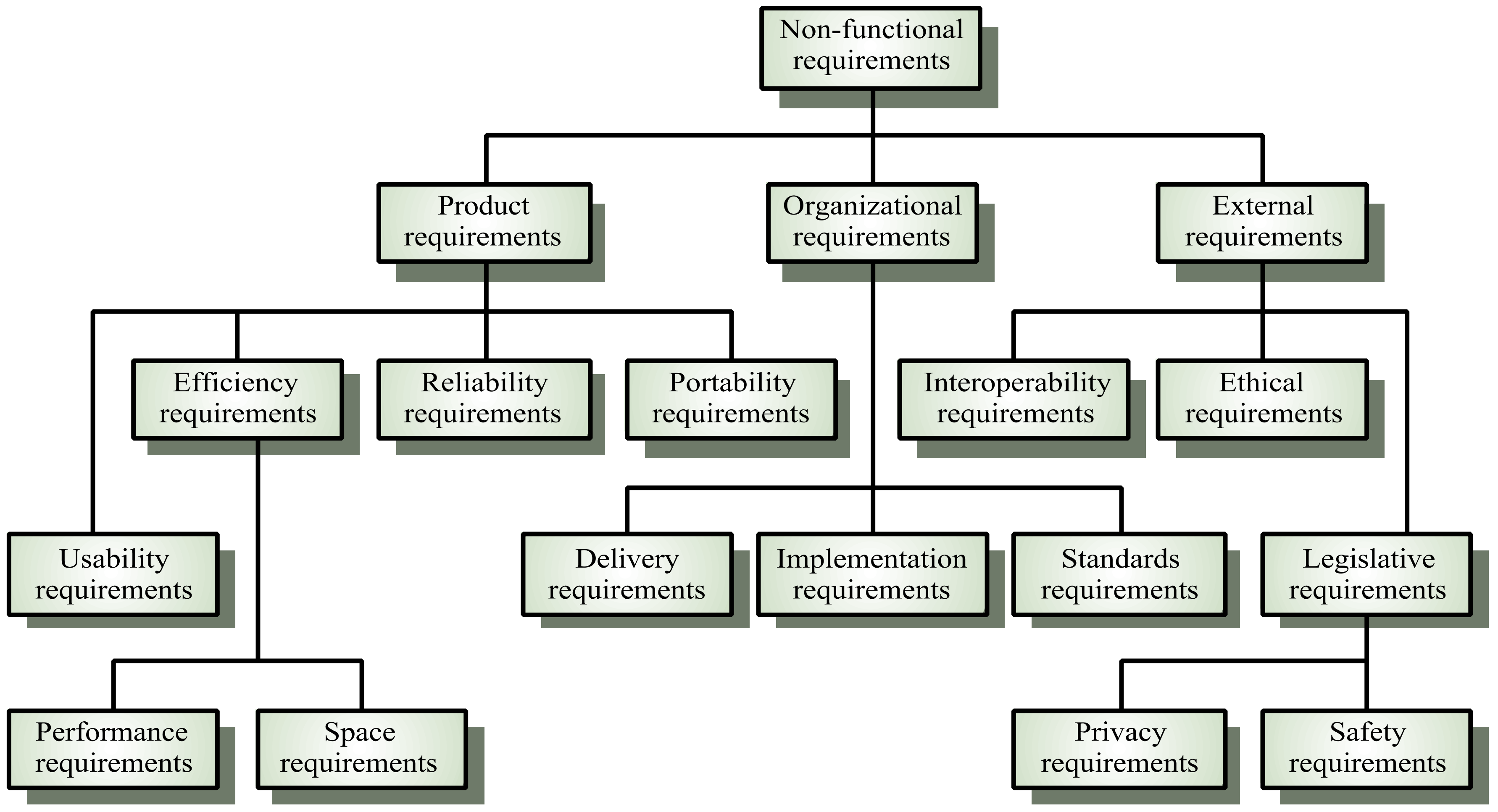
Non-functional requirements

- 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
  - 4.C.8 It shall be possible for all necessary communication between the APSE and the user to be expressed in the standard Ada character set
- 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	K Bytes Number of RAM 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?

Domain requirements

- Derived from the application domain and describe system characterisics and features that reflect the domain
- May be new functional requirements, constraints on existing requirements or define specific computations
- If domain requirements are not satisfied, the system may be unworkable

Library system domain requirements

- There shall be a standard user interface to all databases which shall be based on the Z39.50 standard.
- Because of copyright restrictions, some documents must be deleted immediately on arrival. Depending on the user's requirements, these documents will either be printed locally on the system server for manually forwarding to the user or routed to a network printer.

Train protection system

- The deceleration of the train shall be computed as:
  - $D_{train} = D_{control} + D_{gradient}$

  where $D_{gradient}$ is $9.81ms^2$ * compensated gradient/alpha and where the values of $9.81ms^2$ /alpha are known for different types of train.

Domain requirements problems

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

User requirements

- Should describe functional and non-functional requirements so that they are understandable by system users who don’t have detailed technical knowledge
- User requirements are defined using natural language, tables and diagrams

Problems with natural language

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

Database requirement

4.A.5 The database shall support the generation and control of configuration objects; that is, objects which are themselves groupings of other objects in the database. The configuration control facilities shall allow access to the objects in a version group by the use of an incomplete name.

Editor grid requirement

2.6 Grid facilities To assist in the positioning of entities on a diagram, the user may turn on a grid in either centimetres or inches, via an option on the control panel. Initially, the grid is off. The grid may be turned on and off at any time during an editing session and can be toggled between inches and centimetres at any time. A grid option will be provided on the reduce-to-fit view but the number of grid lines shown will be reduced to avoid filling the smaller diagram with grid lines.

Requirement problems

- Database requirements includes both conceptual and detailed information
  - Describes the concept of configuration control facilities
  - Includes the detail that objects may be accessed using an incomplete name
- Grid requirement mixes three different kinds of requirement
  - Conceptual functional requirement (the need for a grid)
  - Non-functional requirement (grid units)
  - Non-functional UI requirement (grid switching)

Structured presentation

2.6 Grid facilities

2.6.1 **The editor shall provide a grid facility where a matrix of horizontal and vertical lines provide a background to the editor window.** This grid shall be a passive grid where the alignment of entities is the user's responsibility.

Rationale: A grid helps the user to create a tidy diagram with well-spaced entities. Although an active grid, where entities 'snap-to' grid lines can be useful, the positioning is imprecise. The user is the best person to decide where entities should be positioned.

Specification: ECLIPSE/WS/Tools/DE/FS Section 5.6

Detailed user requirement

3.5.1 Adding nodes to a design

3.5.1.1 **The editor shall provide a facility for users to add nodes of a specified type to their design.**

3.5.1.2 The sequence of actions to add a node should be as follows:

1. The user should select the type of node to be added.
2. The user should move the cursor to the approximate node position in the diagram and indicate that the node symbol should be added at that point.
3. The user should then drag the node symbol to its final position.

Rationale: The user is the best person to decide where to position a node on the diagram. This approach gives the user direct control over node type selection and positioning.

Specification: ECLIPSE/WS/Tools/DE/FS. Section 3.5.1

Guidelines for writing requirements

- Invent a standard format and use it for all requirements
- Use language in a consistent way. Use shall for mandatory requirements, should for desirable requirements
- Use text highlighting to identify key parts of the requirement
- Avoid the use of computer jargon

System requirements

- More detailed specifications of user requirements
- Serve as a basis for designing the system
- May be used as part of the system contract
- System requirements may be expressed using system models discussed in Chapter 7

Requirements and design

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

Problems with NL specification

- Ambiguity
  - The readers and writers of the requirement must interpret the same words in the same way. NL is naturally ambiguous so this is very difficult
- Over-flexibility
  - The same thing may be said in a number of different ways in the specification
- Lack of modularisation
  - NL structures are inadequate to structure system requirements

Alternatives to NL specification

Notation	Description
Structured natural language	This approach depends on defining standard forms or templates to express the requirements specification.
Design description languages	This approach uses a language like a programming language but with more abstract features to specify the requirements by defining an operational model of the system.
Graphical notations	A graphical language, supplemented by text annotations is used to define the functional requirements for the system. An early example of such a graphical language was SADT (Ross, 1977; Schoman and Ross, 1977). More recently, use-case descriptions (Jacobsen, Christerson et al., 1993) have been used. I discuss these in the following chapter.
Mathematical specifications	These are notations based on mathematical concepts such as finite-state machines or sets. These unambiguous specifications reduce the arguments between customer and contractor about system functionality. However, most customers don't understand formal specifications and are reluctant to accept it as a system contract. I discuss formal specification in Chapter 9.

Structured language specifications

- A limited form of natural language may be used to express requirements
- This removes some of the problems resulting from ambiguity and flexibility and imposes a degree of uniformity on a specification
- Often bast supported using a forms-based approach

Form-based specifications

- Definition of the function or entity
- Description of inputs and where they come from
- Description of outputs and where they go to
- Indication of other entities required
- Pre and post conditions (if appropriate)
- The side effects (if any)

Form-based node specification

ECLIPSE/Workstation/Tools/DE/FS/3.5.1

Function Add node

Description Adds a node to an existing design. The user selects the type of node, and its position. When added to the design, the node becomes the current selection. The user chooses the node position by moving the cursor to the area where the node is added.

Inputs Node type, Node position, Design identifier.

Source Node type and Node position are input by the user, Design identifier from the database.

Outputs Design identifier.

Destination The design database. The design is committed to the database on completion of the operation.

Requires Design graph rooted at input design identifier.

Pre-condition The design is open and displayed on the user's screen.

Post-condition The design is unchanged apart from the addition of a node of the specified type at the given position.

Side-effects None

Definition: ECLIPSE/Workstation/Tools/DE/RD/3.5.1

PDL-based requirements definition

- Requirements may be defined operationally using a language like a programming language but with more flexibility of expression
- Most appropriate in two situations
  - Where an operation is specified as a sequence of actions and the order is important
  - When hardware and software interfaces have to be specified
- Disadvantages are
  - The PDL may not be sufficiently expressive to define domain concepts
  - The specification will be taken as a design rather than a specification

Part of an ATM specification

```
class ATM {
        // declarations here
        public static void main (String args[]) throws InvalidCard {
                try {
                        thisCard.read () ;  // may throw InvalidCard exception
                        pin = KeyPad.readPin () ; attempts = 1 ;
                        while ( !thisCard.pin.equals (pin) & attempts < 4 )
                                {       pin = KeyPad.readPin () ;  attempts = attempts + 1 ;
                                }
                                if (!thisCard.pin.equals (pin))
                                        throw new InvalidCard ("Bad PIN");
                        thisBalance = thisCard.getBalance () ;
                        do {  Screen.prompt (" Please select a service ") ;
                                service = Screen.touchKey () ;
                                switch (service) {
                                        case Services.withdrawalWithReceipt:
                                                        receiptRequired = true ;
```

PDL disadvantages

- PDL may not be sufficiently expressive to express the system functionality in an understandable way
- Notation is only understandable to people with programming language knowledge
- The requirement may be taken as a design specification rather than a model to help understand the system

Interface specification

- Most systems must operate with other systems and the operating interfaces must be specified as part of the requirements
- Three types of interface may have to be defined
  - Procedural interfaces
  - Data structures that are exchanged
  - Data representations
- Formal notations are an effective technique for interface specification

PDL interface description

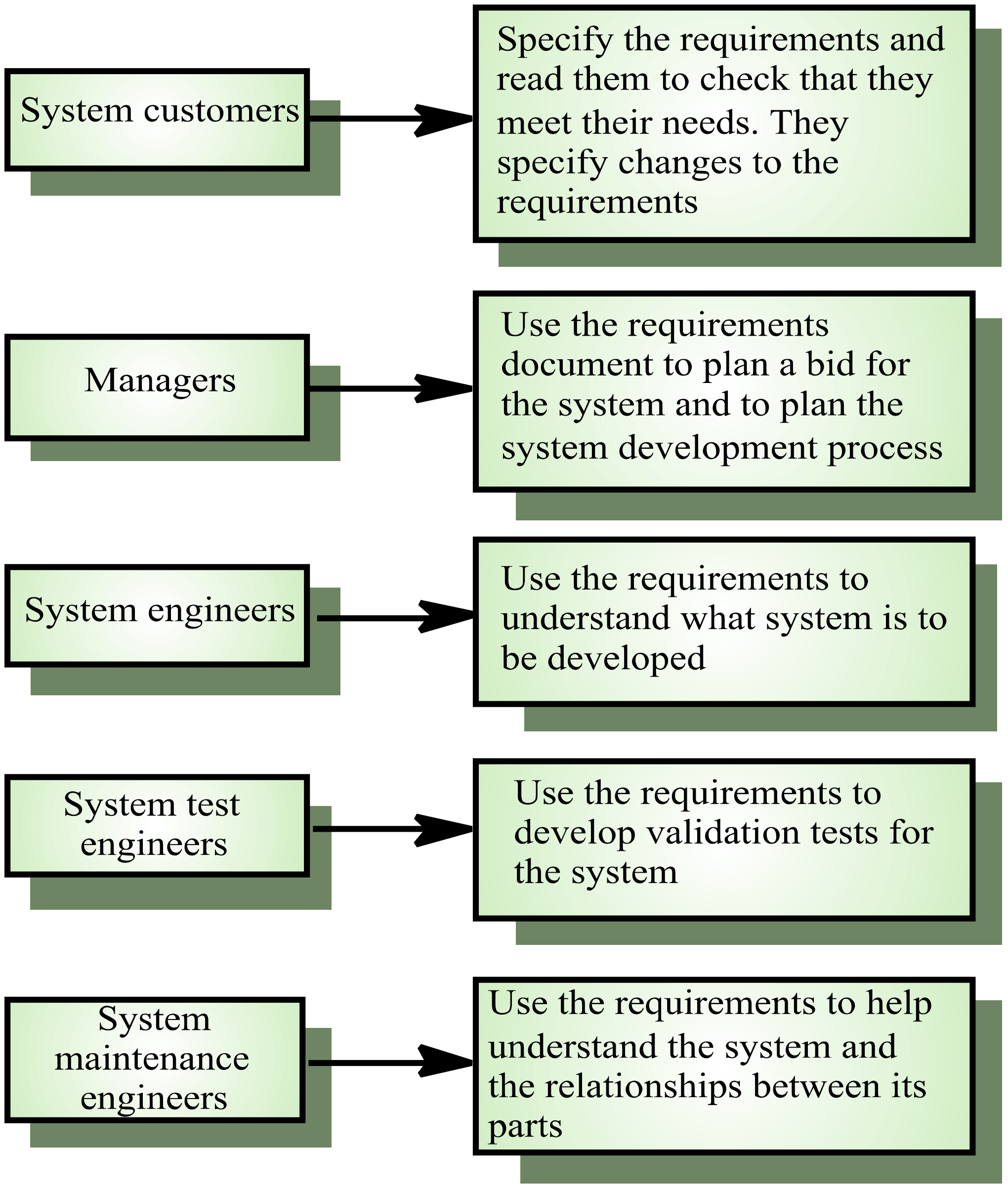
```
interface PrintServer {

// defines an abstract printer server
// requires:           interface Printer, interface PrintDoc
// provides: initialize, print, displayPrintQueue, cancelPrintJob, switchPrinter

          void initialize ( Printer p ) ;
          void print ( Printer p, PrintDoc d ) ;
          void displayPrintQueue ( Printer p ) ;
          void cancelPrintJob (Printer p, PrintDoc d) ;
          void switchPrinter (Printer p1, Printer p2, PrintDoc d) ;
} //PrintServer
```

The requirements document

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


System customers
Specify the requirements and read them to check that they meet their needs. They specify changes to the requirements
Managers
Use the requirements document to plan a bid for the system and to plan the system development process
System engineers
Use the requirements to understand what system is to be developed
System test engineers
Use the requirements to develop validation tests for the system
System maintenance engineers
Use the requirements to help understand the system and the relationships between its parts

Users of a requirements document

Requirements document requirements

- Specify external system behaviour
- Specify implementation constraints
- Easy to change
- Serve as reference tool for maintenance
- Record forethought about the life cycle of the system i.e. predict changes
- Characterise responses to unexpected events

IEEE requirements standard

- Introduction
- General description
- Specific requirements
- Appendices
- Index
- This is a generic structure that must be instantiated for specific systems

Requirements document structure

- Introduction
- Glossary
- User requirements definition
- System architecture
- System requirements specification
- System models
- System evolution
- Appendices
- Index

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

Key points

- User requirements should be written in natural language, tables and diagrams
- System requirements are intended to communicate the functions that the system should provide
- System requirements may be written in structured natural language, a PDL or in a formal language
- A software requirements document is an agreed statement of the system requirements