

# Engenharia de Software (14341, 16230, 15386)

## Requirements Engineering – Functional and Non-functional Requirements and Specifications

(adapted from *Software Engineering: International Version (10th Edition)*, Ian Sommerville, Pearson, 2015)

## Topics covered

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- ✧ Functional and non-functional requirements
- ✧ Requirements engineering processes
- ✧ Requirements elicitation
- ✧ Requirements specification
- ✧ Requirements validation
- ✧ Requirements change

# Requirements engineering

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

# What is a requirement?

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- ✧ 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.

# Types of requirement

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## ✧ User requirements

- Statements in natural language plus diagrams of the services the system provides and its operational constraints. Written for customers.

## ✧ System requirements

- A structured document setting out detailed descriptions of the system's functions, services and operational constraints. Defines what should be implemented so may be part of a contract between client and contractor.

# User and system requirements

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## User requirements definition

- 1.** The Mentcare system 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 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, 20mg, etc) separate reports shall be created for each dose unit.
- 1.5** Access to drug cost reports shall be restricted to authorized users as listed on a management access control list.

# System stakeholders

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- ✧ Any person or organization who is affected by the system in some way and so who has a legitimate interest
- ✧ Stakeholder types
  - End users
  - System managers
  - System owners
  - External stakeholders

# Stakeholders in the Mentcare system

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



# Stakeholders in the Mentcare system

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

# Agile methods and requirements

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- ✧ Many agile methods argue that producing detailed system requirements is a waste of time as requirements change so quickly.
- ✧ The requirements document is therefore always out of date.
- ✧ Agile methods usually use incremental requirements engineering and may express requirements as ‘user stories’.
- ✧ This is practical for business systems but problematic for systems that require pre-delivery analysis (e.g. critical systems) or systems developed by several teams.

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# Functional and non-functional requirements

# Functional and non-functional requirements

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## ✧ Functional requirements

- Statements of services the system should provide, how the system should react to particular inputs and how the system should behave in particular situations.
- May state what the system should not do.

## ✧ Non-functional requirements

- Constraints on the services or functions offered by the system such as timing constraints, constraints on the development process, standards, etc.
- Often apply to the system as a whole rather than individual features or services.

## ✧ Domain requirements

- Constraints on the system from the domain of operation

# Domain requirements

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✧ **Example**: Train protection system

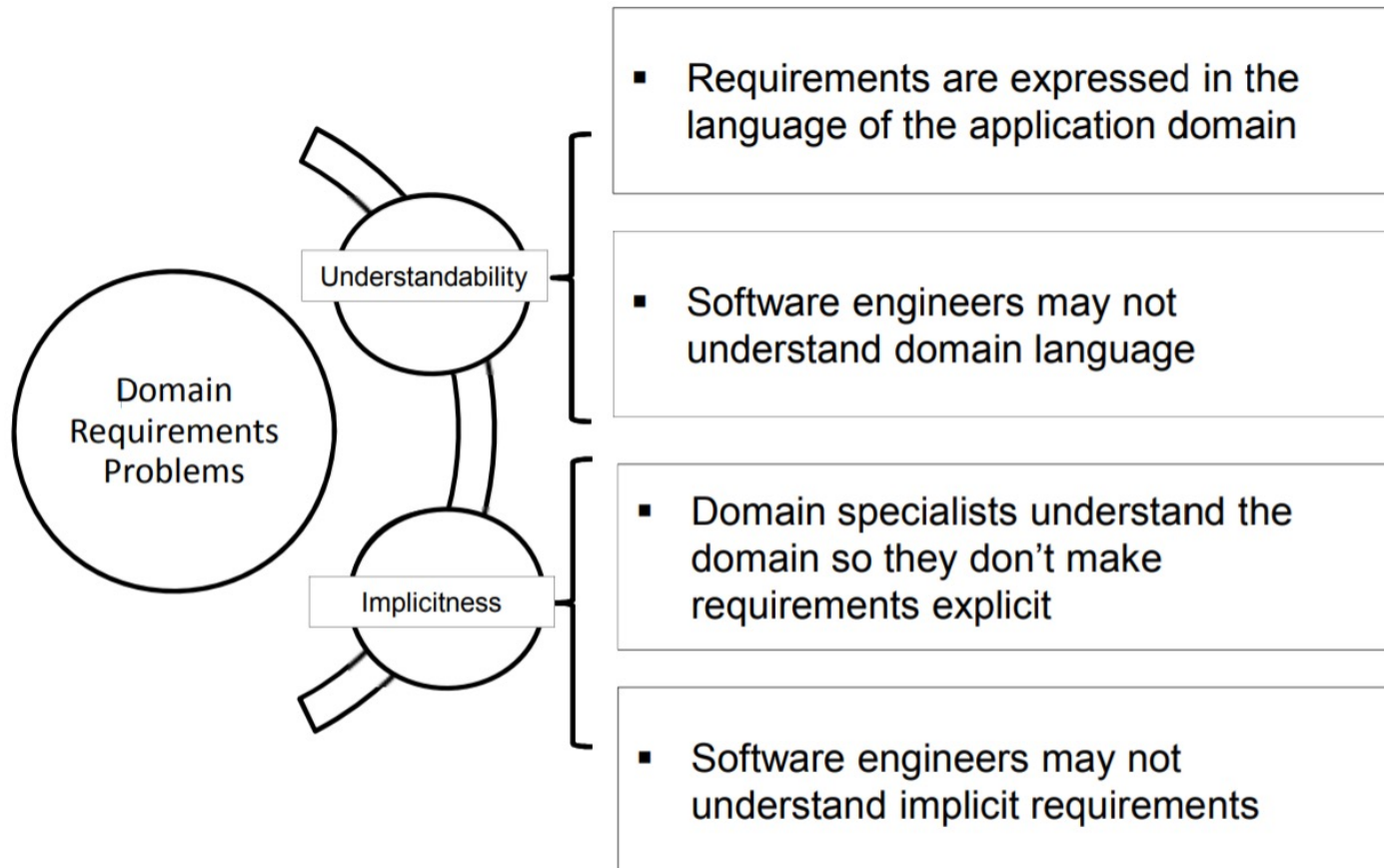
Train deceleration shall be computed as:

$$D_{train} = D_{control} + D_{gradient}$$

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

# Domain requirements

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# Functional requirements

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

## Mentcare system: functional requirements

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



# Requirements imprecision

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- ✧ Problems arise when functional requirements are not precisely stated.
- ✧ Ambiguous requirements may be interpreted in different ways by developers and users.
- ✧ Consider the term ‘search’ in requirement
  - “A user shall be able to **search** the appointments lists for all clinics.”
    - User intention – search for a patient name across all appointments in all clinics;
    - Developer interpretation – search for a patient name in an individual clinic. User chooses clinic then search.

# Requirements completeness and consistency

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- ✧ 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, because of system and environmental complexity, it is impossible to produce a complete and consistent requirements document.

## Example Requirement#1

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The product shall provide status messages regarding background processing at regular intervals not less than every 60 seconds.

### Problems:

- ✧ Regular intervals? “not less” than 60 seconds? What is the upper limit?
- ✧ What events need to trigger status messages?
- ✧ What are the status messages?

## Example#1 Rewritten

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1. The product shall provide status messages regarding background processing at intervals of 60, plus or minus 10, seconds.
  - i. If background processing is progressing normally, the percentage of the background task processing that has been completed shall be displayed.
  - ii. A message shall be displayed when the background task is complete.
  - iii. An error message shall be displayed if the background task has not progressed for 10 seconds or failed.
  - iv. Status messages are logged to the log file maintained on the local file system.

## Example Requirement#2

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The product shall switch between displaying and hiding non-printing characters instantaneously.

### Problems:

- ✧ Instantaneously is not testable - subjective.
- ✧ When is it switching? What causes this switch? Is it random?

## Example#2 Rewritten

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The text entry box shall switch between displaying and hiding non-printing characters within 200ms of mouse release of the display button in the quick function bar.

## Example Requirement#3

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Charge numbers should be validated online against the master corporate charge number list, if possible. The system shall validate the charge number entered against the online master corporate charge number list. If the charge number is not found on the list, an error message shall be displayed and the order shall not be accepted.

## Example#3 Rewritten

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1. The system shall validate the charge card number entered against the online master corporate charge card number list.
  - i. If the charge card number is not found on the list, an error message shall be displayed and the order shall not be accepted.
  - ii. If the charge card number is found on the list, a success message shall be displayed and the order shall be accepted.
  - iii. If the online master corporate charge number list is not available, an error message shall be displayed and the order shall not be accepted.



## Example Requirement#4

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The system shall respond to all user requests within 2 seconds.

### Problems:

- ✧ Too overarching - need to address different user requests one at a time, each might have different needs.
- ✧ Very likely to lead to inconsistent requirements.

## Practice: functional requirements

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- ✧ Determine multiple functional requirements for the iLearn system.



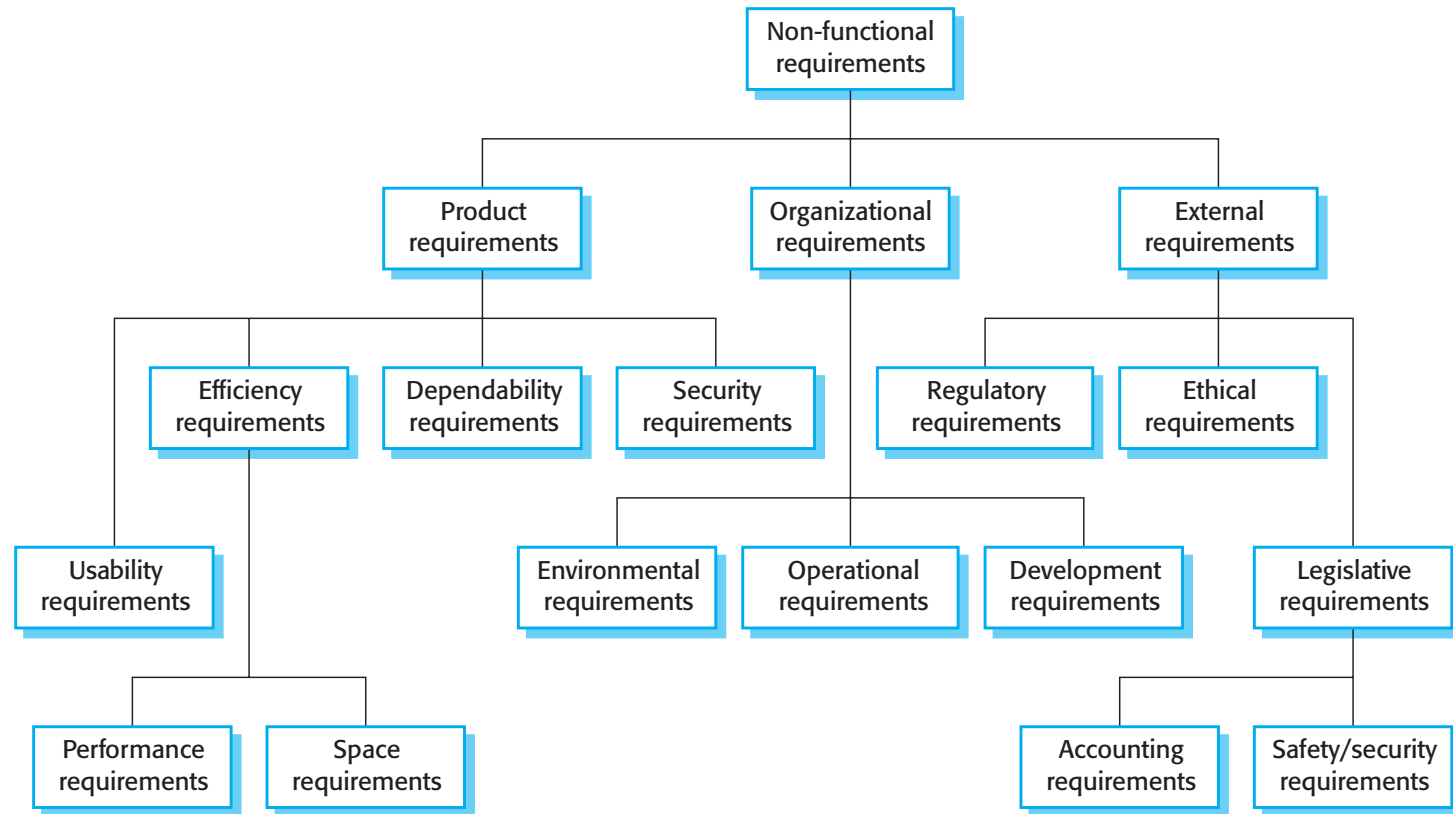
# Non-functional requirements

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

# Types of nonfunctional requirement

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# Non-functional requirements implementation

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

# Non-functional classifications

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## ✧ 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.

# Examples of nonfunctional requirements in the Mentcare system

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## **Product requirement**

The Mentcare system shall be available to all clinics during normal working hours (Mon–Fri, 08:30–17:30). Downtime within normal working hours shall not exceed five seconds in any one day.

## **Organizational requirement**

Users of the Mentcare system shall authenticate themselves using their health authority identity card.

## **External requirement**

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

# Goals and requirements

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



# Usability requirements

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

# Metrics for specifying nonfunctional requirements

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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

## Practice: non-functional requirements

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- ✧ Determine multiple non-functional requirements for the iLearn system.



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# Requirements engineering processes

# Requirements engineering processes

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

# Requirements elicitation and analysis

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

# Requirements elicitation

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

# Problems of requirements elicitation

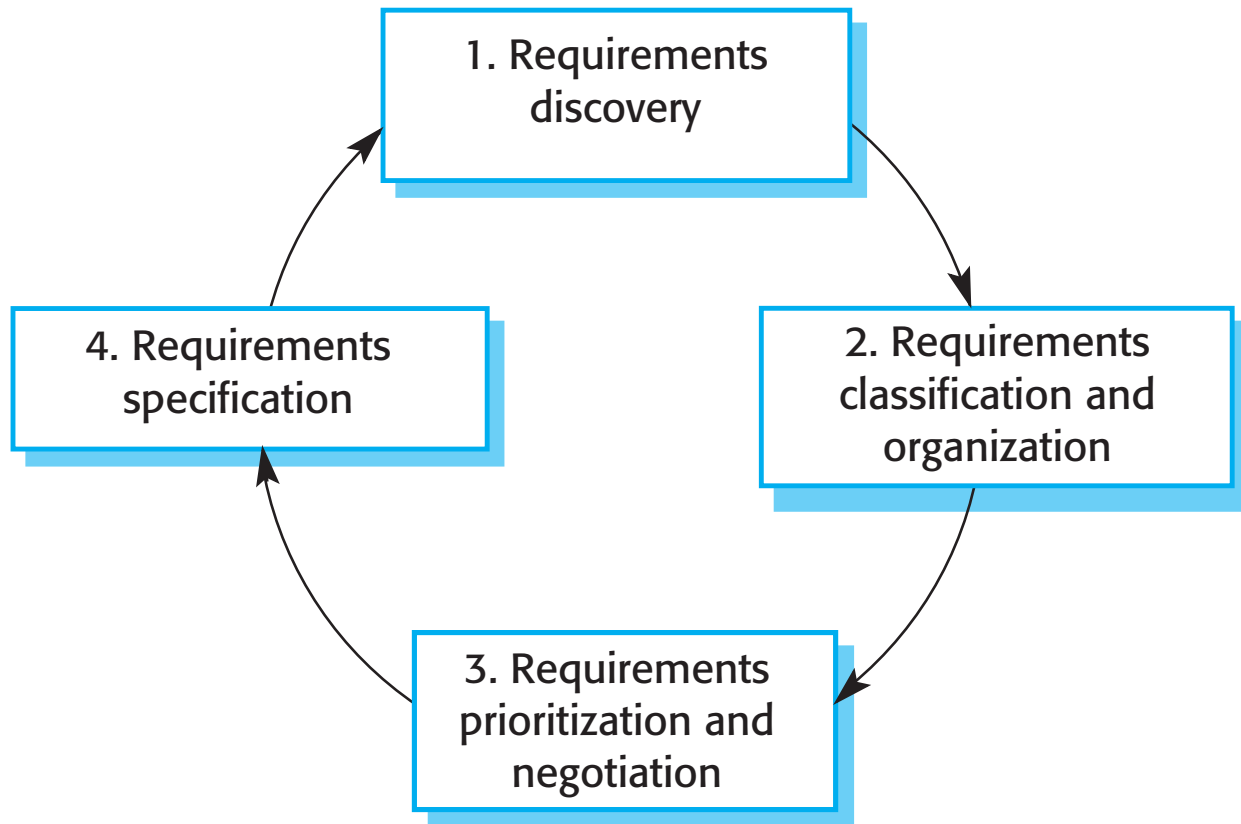
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- ✧ Stakeholders don't know what they really want.
- ✧ Stakeholders express requirements in their own terms.
- ✧ Different stakeholders may have conflicting requirements.
- ✧ Organisational and political factors may influence the system requirements.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



# The requirements elicitation and analysis process

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# Process activities

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## ✧ Requirements discovery

- Interacting with stakeholders to discover their requirements. Domain requirements are also discovered at this stage.

## ✧ Requirements classification and organisation

- Groups related requirements and organises them into coherent clusters.

## ✧ Prioritisation and negotiation

- Prioritising requirements and resolving requirements conflicts.

## ✧ Requirements specification

- Requirements are documented and input into the next round of the spiral.

# Requirements discovery

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

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# Requirements specification

# Requirements specification

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

# Ways of writing a system requirements specification

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

# Requirements and design

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

# Natural language specification

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



# Guidelines for writing requirements

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

# Problems with natural language

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## ✧ 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.

# Structured specifications

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- ✧ An approach to writing requirements where the freedom of the requirements writer is limited and requirements are written in a standard way.

# A structured specification of a requirement for an insulin pump

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## Insulin Pump/Control Software/SRS/3.3.2

**Function** Compute insulin dose: safe sugar level.

### **Description**

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

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

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

**Outputs** CompDose—the dose in insulin to be delivered.

**Destination** Main control loop.

# A structured specification of a requirement for an insulin pump

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## Action

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

## Requirements

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

## Pre-condition

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

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

**Side effects**      None.

## Form-based specifications

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

# Tabular specification

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

# Tabular specification of computation for an insulin pump

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



## Practice: structured specification

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- ✧ Determine a structured specification of the login process in the iLearn system.



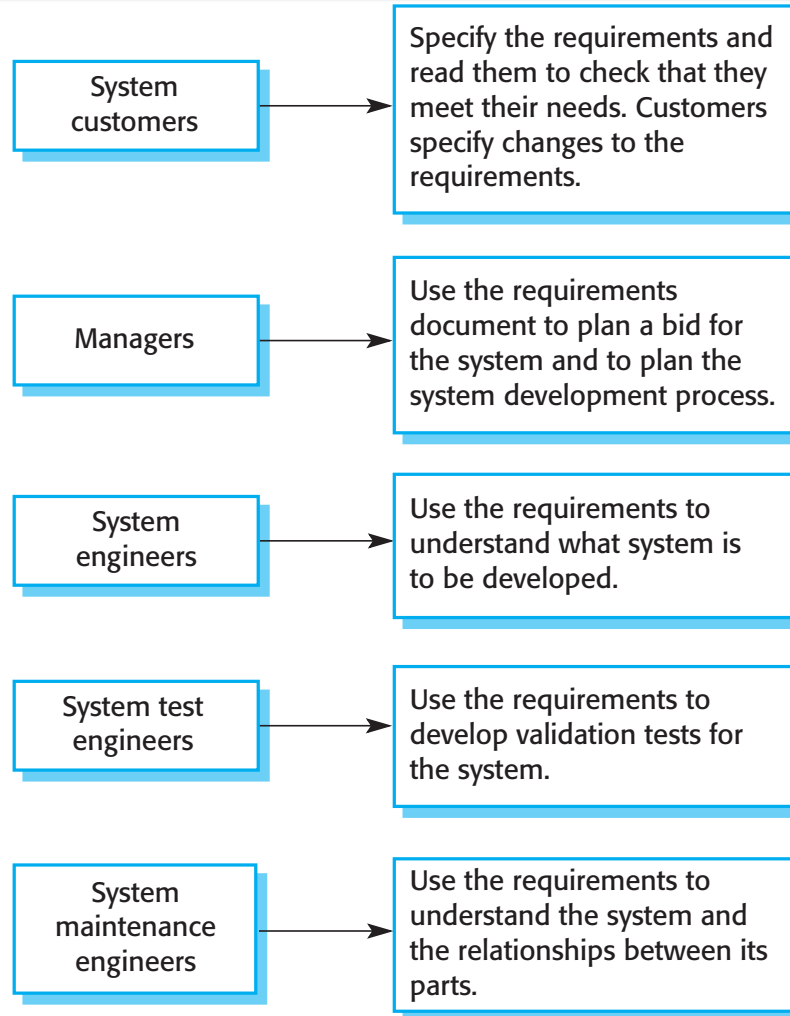
# The software requirements document

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

# Users of a requirements document

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# The structure of a requirements document

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

# The structure of a requirements document

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

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# Requirements validation

# Requirements validation

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

# Requirements checking

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



# Requirements validation techniques

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## ✧ Requirements reviews

- Systematic manual analysis of the requirements.

## ✧ Prototyping

- Using an executable model of the system to check requirements.

## ✧ Test-case generation

- Developing tests for requirements to check testability.

# Requirements reviews

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

# Review checks

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## ✧ Verifiability

- Is the requirement realistically testable?

## ✧ Comprehensibility

- Is the requirement properly understood?

## ✧ Traceability

- Is the origin of the requirement clearly stated?

## ✧ Adaptability

- Can the requirement be changed without a large impact on other requirements?

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# Requirements change

# Changing requirements

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

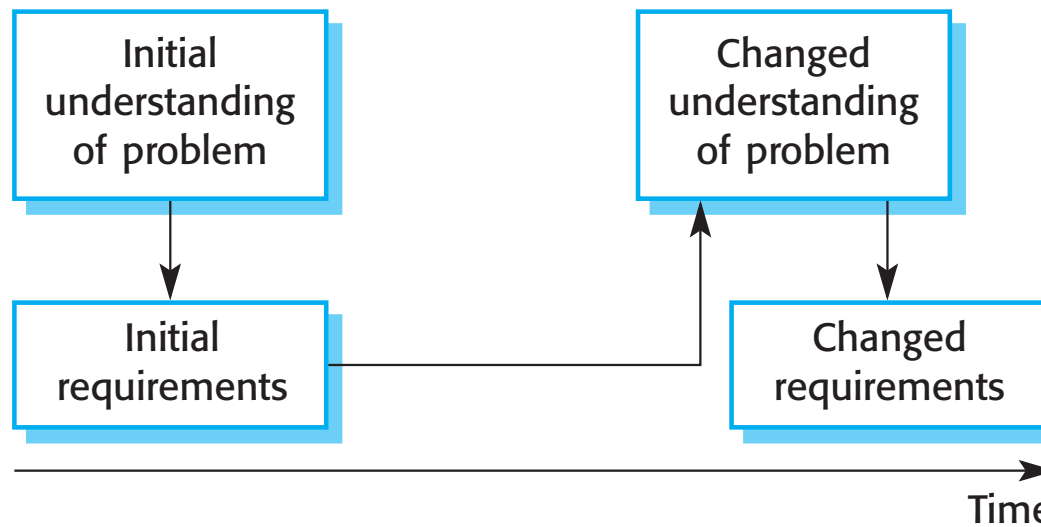
# Changing requirements

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

# Requirements evolution

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# Requirements management

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



# Requirements management planning

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

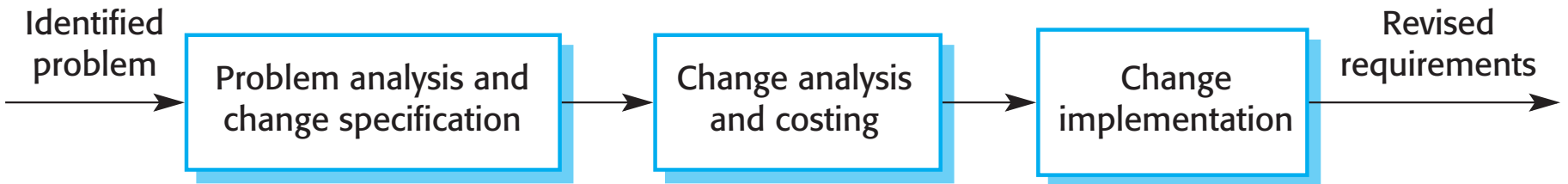
# Requirements change management

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

# Requirements change management

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## Key points

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- ✧ The requirements engineering process is an iterative process that includes requirements elicitation, specification and validation.
- ✧ Requirements elicitation is an iterative process that can be represented as a spiral of activities – requirements discovery, requirements classification and organization, requirements negotiation and requirements documentation.
- ✧ You can use a range of techniques for requirements elicitation including interviews and ethnography. User stories and scenarios may be used to facilitate discussions.

## Key points

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- ✧ Requirements for a software system set out what the system should do and define constraints on its operation and implementation.
- ✧ Functional requirements are statements of the services that the system must provide or are descriptions of how some computations must be carried out.
- ✧ Non-functional requirements often constrain the system being developed and the development process being used.
- ✧ They often relate to the emergent properties of the system and therefore apply to the system as a whole.

## Key points

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- ✧ Requirements specification is the process of formally documenting the user and system requirements and creating a software requirements document.
- ✧ The software requirements document is an agreed statement of the system requirements. It should be organized so that both system customers and software developers can use it.

## Key points

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- ✧ Requirements validation is the process of checking the requirements for validity, consistency, completeness, realism and verifiability.
- ✧ Business, organizational and technical changes inevitably lead to changes to the requirements for a software system. Requirements management is the process of managing and controlling these changes.

