Syllabus:
System modeling:
Context models, Interaction models, Structural models, Behavioral models, Model-driven engineering.
Architectural design:
Architectural design decisions, Architectural views, Architectural patterns, Application architectures.

(Reference: Sommerville, Software Engineering, 10 ed., Chapter 5)

System modelling is the process of developing abstract models of a system, with each model presenting a different view or perspective of that system. It is about representing a system using some kind of graphical notation, which is now almost always based on notations in the **Unified Modelling Language** (**UML**).

Models help the analyst to understand the functionality of the system; they are used to communicate with customers.

Models can explain the system from different perspectives:

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

Five types of UML diagrams that are the most useful for system modeling:

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

Models of both new and existing system are used during requirements engineering. Models of the existing systems help clarify what the existing system does and can be used as a basis for discussing its strengths and weaknesses. These then lead to requirements for the new system. Models of the new system are used during requirements engineering to help explain the proposed requirements to other system stakeholders. Engineers use these models to discuss design proposals and to document the system for implementation.

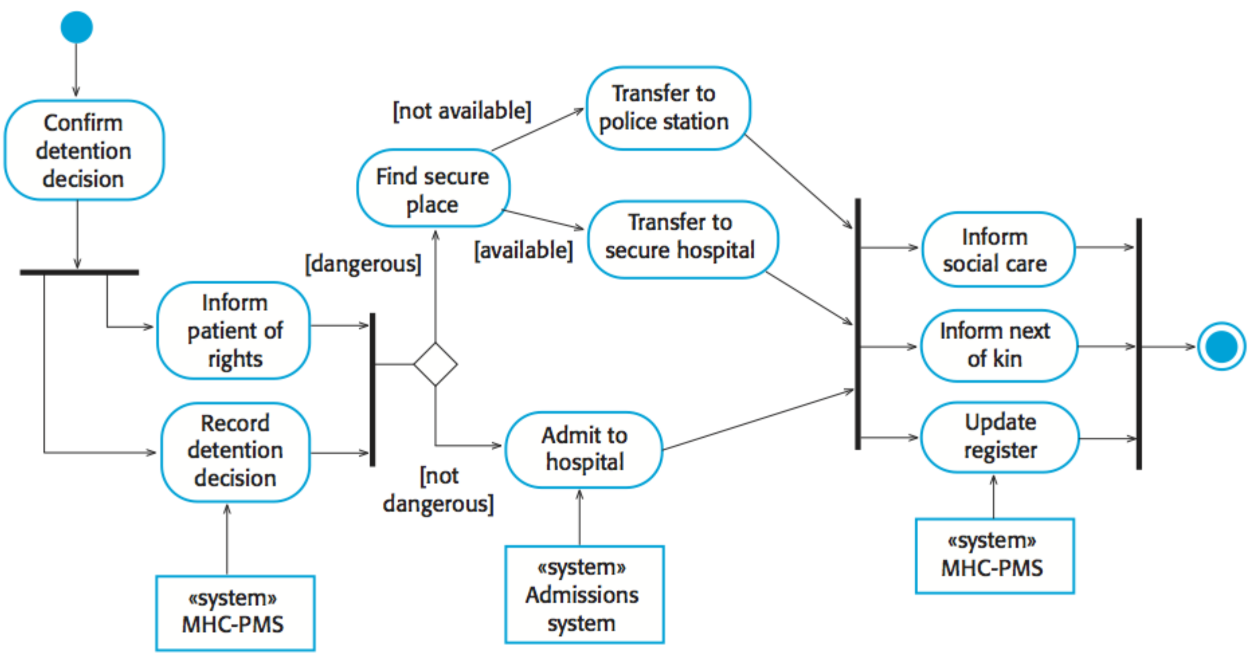
Context and process models

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

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

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

The example below shows a UML activity diagram describing the process of involuntary detention and the role of MHC-PMS (mental healthcare patient management system) in it.



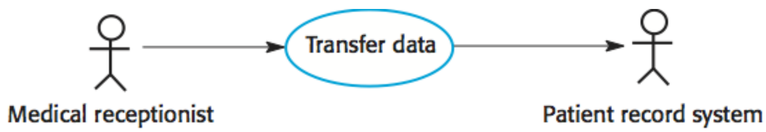
Interaction models

Types of interactions that can be represented in a model:

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

Use cases were developed originally to support requirements elicitation and now incorporated into the UML. Each use case represents a discrete task that involves external interaction with a system. Actors in a use case may be people or other systems. Use cases can be represented using a UML use case diagram and in a more detailed textual/tabular format.

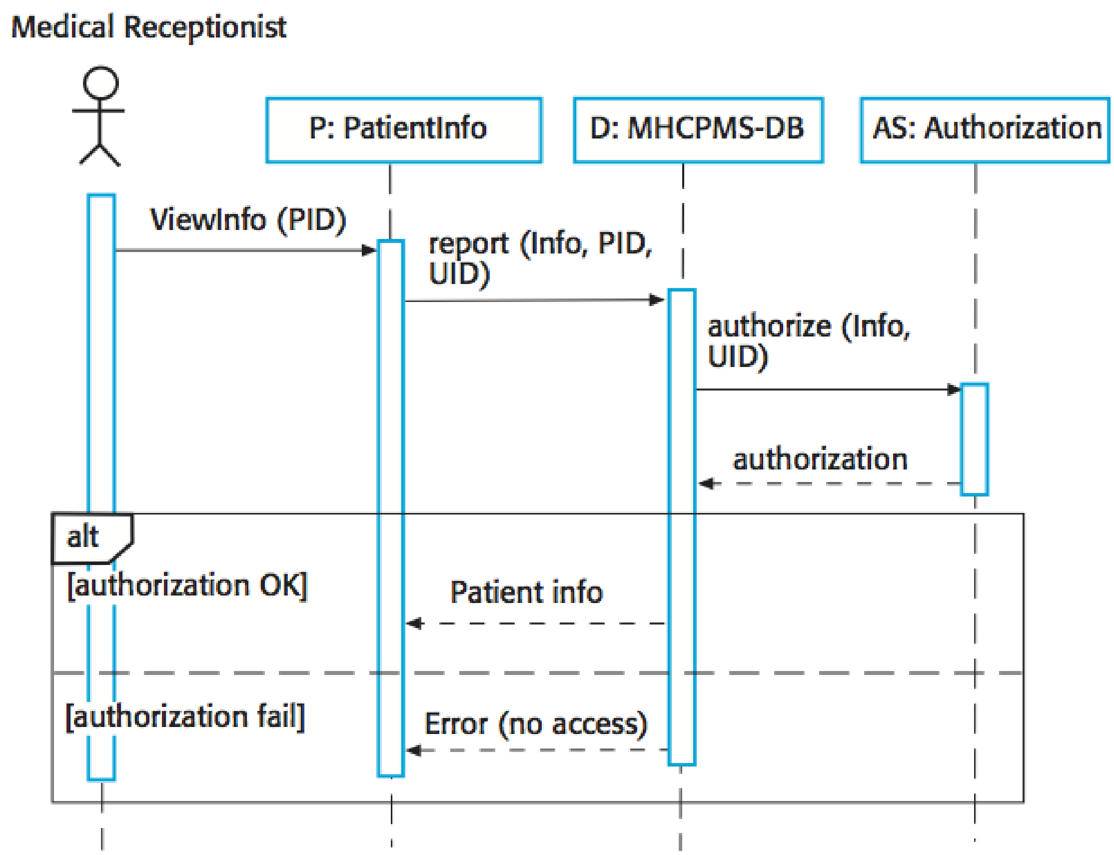
Simple use case diagram:



Use case description in a tabular format:

Use case title	Transfer data
Description	A receptionist may transfer data from the MHC-PMS to a general patient record database that is maintained by a health authority. The information transferred may either be updated personal information (address, phone number, etc.) or a summary of the patient's diagnosis and treatment.
Actor(s)	Medical receptionist, patient records system (PRS)
Preconditions	Patient data has been collected (personal information, treatment summary); The receptionist must have appropriate security permissions to access the patient information and the PRS.
Postconditions	PRS has been updated
Main success scenario	1. Receptionist selects the "Transfer data" option from the menu. 2. PRS verifies the security credentials of the receptionist. 3. Data is transferred. 4. PRS has been updated.
Extensions	2a. The receptionist does not have the necessary security credentials. 2a.1. An error message is displayed. 2a.2. The receptionist backs out of the use case.

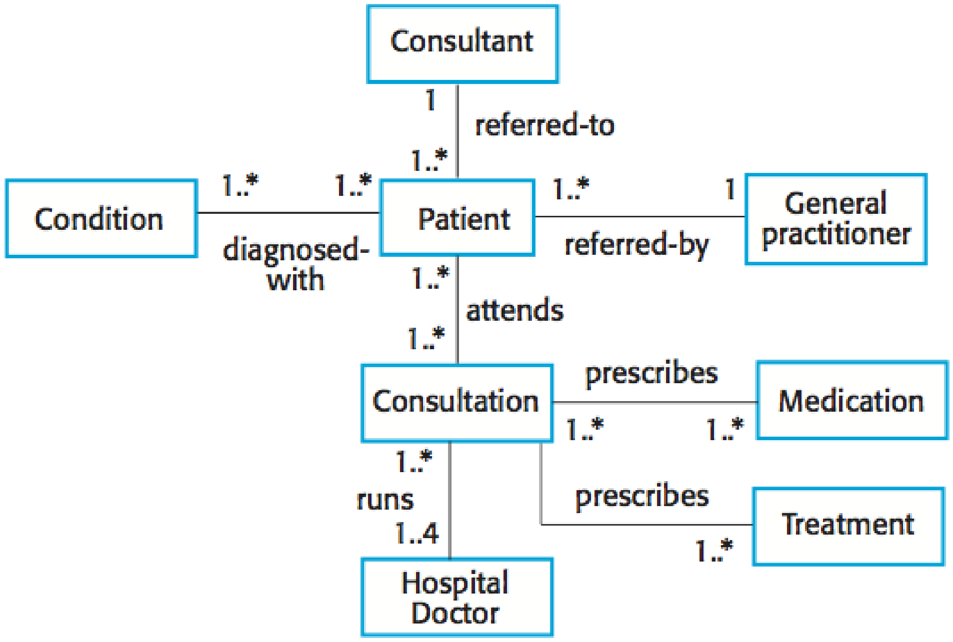
UML sequence diagrams are used to model the interactions between the actors and the objects within a system. A sequence diagram shows the sequence of interactions that take place during a particular use case or use case instance. The objects and actors involved are listed along the top of the diagram,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

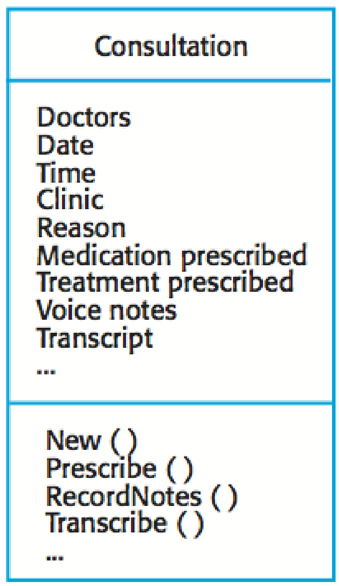


Structural models

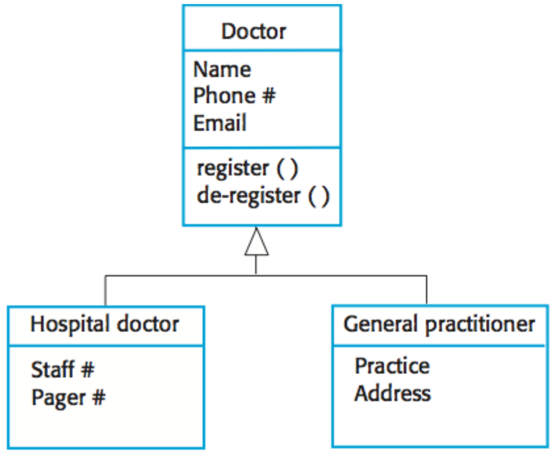
Structural models of software display the organization of a system in terms of the components that make up that system and their relationships. Structural models may be static models, which show the structure of the system design, or dynamic models, which show the organization of the system when it is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

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

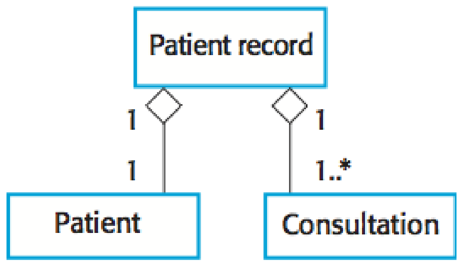




Generalization is an everyday technique that we use to manage complexity. In modeling systems, it is often useful to examine the classes in a system to see if there is scope for generalization. In object-oriented languages, such as Java, generalization is implemented using the class inheritance mechanisms built into the language. In a generalization, the attributes and operations associated with higher-level classes are also associated with the lower-level classes. The lower-level classes are subclasses inherit the attributes and operations from their superclasses. These lower-level classes then add more specific attributes and operations.



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

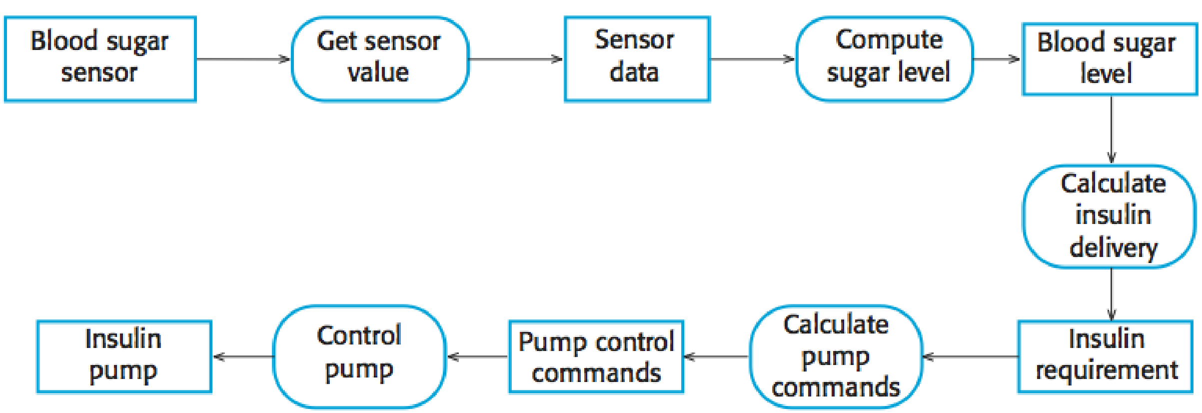


Behavioral models

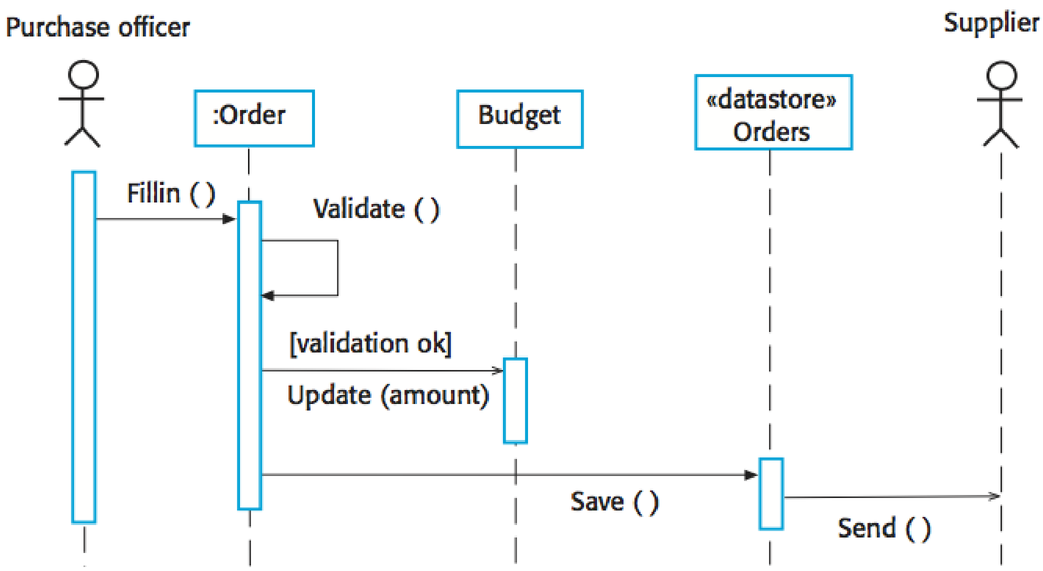
Behavioral models are models of the dynamic behavior of a system as it is executing. They show what happens or what is supposed to happen when a system responds to a stimulus from its environment. Two types of stimuli:

- Some data arrives that has to be processed by the system.
- Some event happens that triggers system processing. Events may have associated data, although this is not always the case.

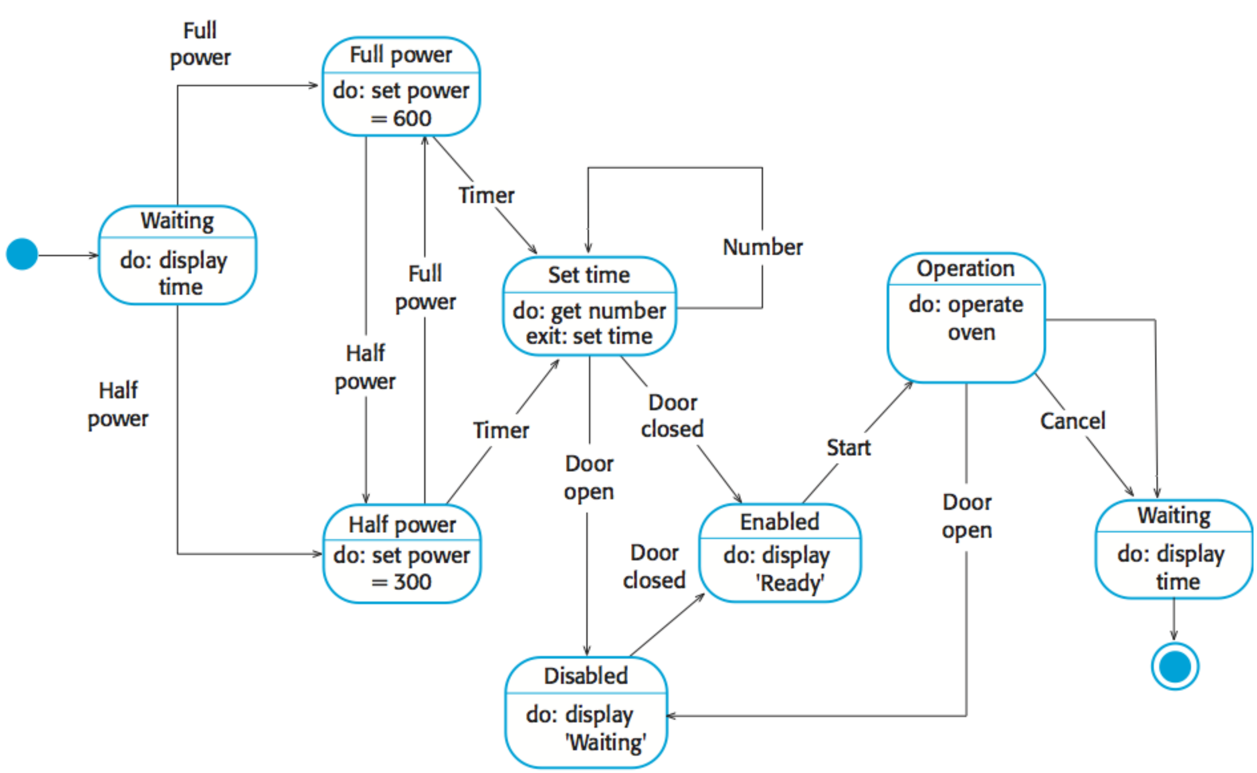
Many business systems are data-processing systems that are primarily driven by data. They are controlled by the data input to the system, with relatively little external event processing. Data-driven models show the sequence of actions involved in processing input data and generating an associated output.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



Data-driven models can also be created using UML sequence diagrams:



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



Model-Driven Software Engineering

Model-driven software engineering (MDE) is the practice of raising models to first-class artefacts of the software engineering process, using such models to do analysis, simulate and reason about properties of the system under development, and eventually often auto-generate a part of its implementation.

MDE brings and adapts well-understood and long-established principles and practices of trustworthy systems engineering to software engineering and is used extensively in organizations that produce business- or safety-critical software where defects can have catastrophic effects or can be very expensive to remedy. MDE is also increasingly used for non-critical systems due to the productivity and consistency benefits it delivers.

Architectural Design

Architectural design is a process for identifying the sub-systems making up a system and the framework for sub-system control and communication. The output of this design process is a description of the software architecture. Architectural design is an early stage of the system design process. It represents the link between specification and design processes and is often carried out in parallel with some specification activities. It involves identifying major system components and their communications.

Software architectures can be designed at **two levels of abstraction**:
- Architecture in the small is concerned with the architecture of individual programs. At this level, we are concerned with the way that an individual program is decomposed into components.
- Architecture in the large is concerned with the architecture of complex enterprise systems that include other systems, programs, and program components. These enterprise systems are distributed over different computers, which may be owned and managed by different companies.

Three advantages of explicitly designing and documenting software architecture:
- Stakeholder communication: Architecture may be used as a focus of discussion by system stakeholders.
- System analysis: Well-documented architecture enables the analysis of whether the system can meet its non-functional requirements.
- Large-scale reuse: The architecture may be reusable across a range of systems or entire lines of products.

Software architecture is most often represented using simple, informal block diagrams showing entities and relationships.
- Pros: simple, useful for communication with stakeholders, great for project planning.
- Cons: lack of semantics, types of relationships between entities, visible properties of entities in the architecture.

Uses of architectural models:

- As a way of facilitating discussion about the system design
  A high-level architectural view of a system is useful for communication with system stakeholders and project planning because it is not cluttered with detail. Stakeholders can relate to it and understand an abstract view of the system. They can then discuss the system as a whole without being confused by detail.
- As a way of documenting an architecture that has been designed
  The aim here is to produce a complete system model that shows the different components in a system, their interfaces and their connections.

Architectural design decisions

Architectural design is a creative process so the process differs depending on the type of system being developed. However, a number of common decisions span all design processes and these decisions affect the non-functional characteristics of the system:

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

Systems in the same domain often have similar architectures that reflect domain concepts. Application product lines are built around a core architecture with variants that satisfy particular customer requirements. The architecture of a system may be designed around one of more architectural patterns/styles, which capture the essence of an architecture and can be instantiated in different ways.

The particular architectural style should depend on the **non-functional system requirements**:

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

Architectural views

Each architectural model only shows one view or perspective of the system. It might show how a system is decomposed into modules, how the run-time processes interact or the different ways in which system components are distributed across a network. For both design and documentation, you usually need to present multiple views of the software architecture.

4+1 view model of software architecture:

- A logical view, which shows the key abstractions in the system as objects or object classes.
- A process view, which shows how, at run-time, the system is composed of interacting processes.

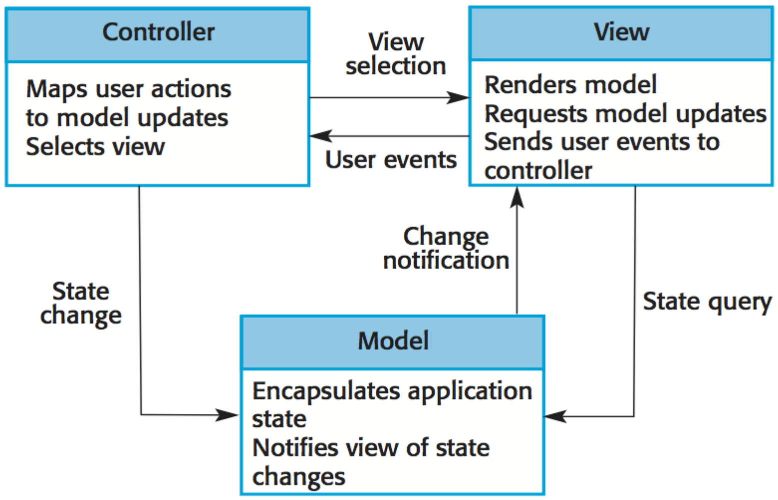
- A development view, which shows how the software is decomposed for development.
- A physical view, which shows the system hardware and how software components are distributed across the processors in the system.
- Related using use cases or scenarios (+1).

Architectural patterns

Patterns are a means of representing, sharing and reusing knowledge. An architectural pattern is a stylized description of a good design practice, which has been tried and tested in different environments. Patterns should include information about when they are and when they are not useful. Patterns may be represented using tabular and graphical descriptions.

Model-View-Controller

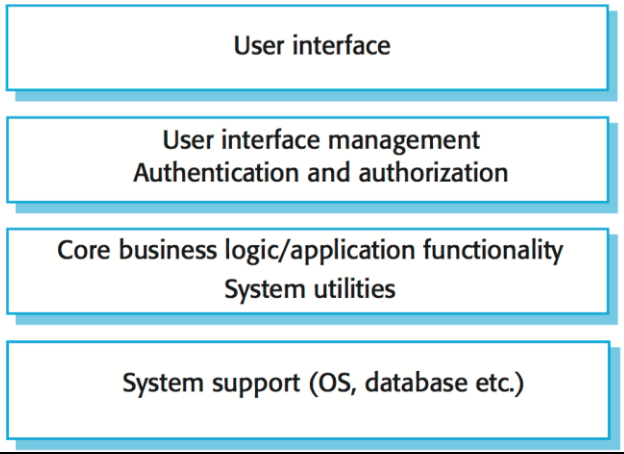
- Serves as a basis of interaction management in many web-based systems.
- Decouples three major interconnected components:
    - The model is the central component of the pattern that directly manages the data, logic and rules of the application. It is the application's dynamic data structure, independent of the user interface.
    - A view can be any output representation of information, such as a chart or a diagram. Multiple views of the same information are possible.
    - The controller accepts input and converts it to commands for the model or view.
- Supported by most language frameworks.



Pattern name	Model-View-Controller (MVC)
Description	Separates presentation and interaction from the system data. The system is structured into three logical components that interact with each other. The Model component manages the system data and associated operations on that data. The View component defines and manages how the data is presented to the user. The Controller component manages user interaction (e.g., key presses, mouse clicks, etc.) and passes these interactions to the View and the Model.
Problem description	The display presented to the user frequently changes over time in response to input or computation. Different users have different needs for how they want to view the program.s information. The system needs to reflect data changes to all users in the way that they want to view them, while making it easy to make changes to the user interface.
Solution description	This involves separating the data being manipulated from the manipulation logic and the details of display using three components: Model (a problem-domain component with data and operations, independent of the user interface), View (a data display component), and Controller (a component that receives and acts on user input).
Consequences	Advantages: views and controllers can be easily be added, removed, or changed; views can be added or changed during execution; user interface components can be changed, even at runtime. Disadvantages: views and controller are often hard to separate; frequent updates may slow data display and degrade user interface performance; the MVC style makes user interface components (views, controllers) highly dependent on model components.

Layered architecture

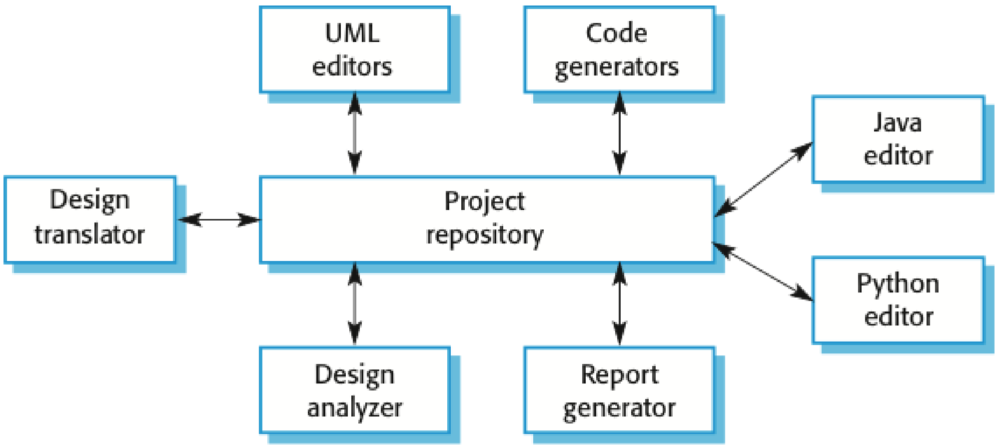
- Used to model the interfacing of sub-systems.
- Organizes the system into a set of layers (or abstract machines) each of which provide a set of services.
- Supports the incremental development of sub-systems in different layers. When a layer interface changes, only the adjacent layer is affected.
-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



Name	**Layered architecture**
Description	Organizes the system into layers with related functionality associated with each layer. A layer provides services to the layer above it so the lowest-level layers represent core services that are likely to be used throughout the system.
When used	Used when building new facilities on top of existing systems; when the development is spread across several teams with each team responsibility for a layer of functionality; when there is a requirement for multi-level security.
Advantages	Allows replacement of entire layers so long as the interface is maintained. Redundant facilities (e.g., authentication) can be provided in each layer to increase the dependability of the system.
Disadvantages	In practice, providing a clean separation between layers is often difficult and a high-level layer may have to interact directly with lower-level layers rather than through the layer immediately below it. Performance can be a problem because of multiple levels of interpretation of a service request as it is processed at each layer.

Repository architecture

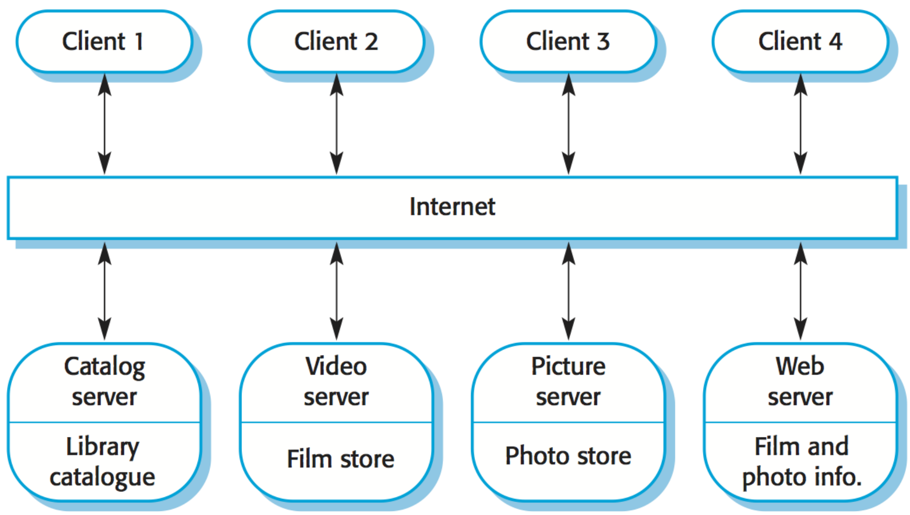
- Sub-systems must exchange data. This may be done in two ways:
  - Shared data is held in a central database or repository and may be accessed by all sub-systems;
  - Each sub-system maintains its own database and passes data explicitly to other sub-systems.
- When large amounts of data are to be shared,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



Name	Repository
Description	All data in a system is managed in a central repository that is accessible to all system components. Components do not interact directly, only through the repository.
When used	You should use this pattern when you have a system in which large volumes of information are generated that has to be stored for a long time. You may also use it in data-driven systems where the inclusion of data in the repository triggers an action or tool.
Advantages	Components can be independent--they do not need to know of the existence of other components. Changes made by one component can be propagated to all components. All data can be managed consistently (e.g., backups done at the same time) as it is all in one place.
Disadvantages	The repository is a single point of failure so problems in the repository affect the whole system. May be inefficiencies in organizing all communication through the repository. Distributing the repository across several computers may be difficult.

Client-server architecture

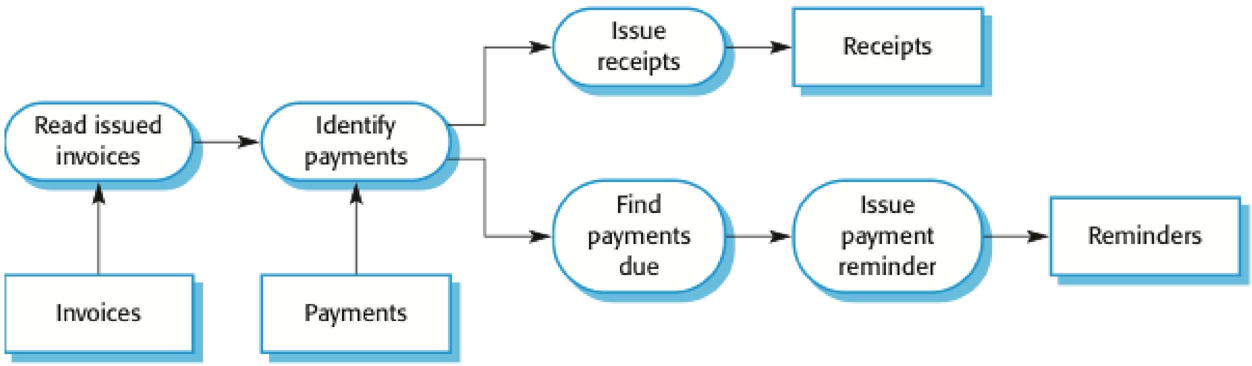
- Distributed system model which shows how data and processing is distributed across a range of components, but can also be implemented on a single computer.
- Set of stand-alone servers which provide specific services such as printing, data management, etc.
- Set of clients which call on these services.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



Name	**Client-server**
Description	In a client-server architecture, the functionality of the system is organized into services, with each service delivered from a separate server. Clients are users of these services and access servers to make use of them.
When used	Used when data in a shared database has to be accessed from a range of locations. Because servers can be replicated, may also be used when the load on a system is variable.
Advantages	The principal advantage of this model is that servers can be distributed across a network. General functionality (e.g., a printing service) can be available to all clients and does not need to be implemented by all services.
Disadvantages	Each service is a single point of failure so susceptible to denial of service attacks or server failure. Performance may be unpredictable because it depends on the network as well as the system. May be management problems if servers are owned by different organizations.

Pipe and filter architecture

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



Name	**Pipe and filter**
Description	The processing of the data in a system is organized so that each processing component (filter) is discrete and carries out one type of data transformation. The data flows (as in a pipe) from one component to another for processing.
When used	Commonly used in data processing applications (both batch- and transaction-based) where inputs are processed in separate stages to generate related outputs.
Advantages	Easy to understand and supports transformation reuse. Workflow style matches the structure of many business processes. Evolution by adding transformations is straightforward. Can be implemented as either a sequential or concurrent system.
Disadvantages	The format for data transfer has to be agreed upon between communicating transformations. Each transformation must parse its input and un-parse its output to the agreed form. This increases system overhead and may mean that it is impossible to reuse functional transformations that use incompatible data structures.

Application architectures

Application systems are designed to meet an organizational need. As businesses have much in common, their application systems also tend to have a common architecture that reflects the application requirements.

A generic application architecture is an architecture for a type of software system that may be configured and adapted to create a system that meets specific requirements. application architectures can be used as a:

- Starting point for architectural design.
- Design checklist.
- Way of organizing the work of the development team.
- Means of assessing components for reuse.
- Vocabulary for talking about application types.

Examples of application types:

- Data processing applications
  Data driven applications that process data in batches without explicit user intervention during the processing.
- Transaction processing applications
  Data-centered applications that process user requests and update information in a system database.
- Event processing systems
  Applications where system actions depend on interpreting events from the system's environment.
- Language processing systems
  Applications where the users' intentions are specified in a formal language that is processed and interpreted by the system.