Architectural Design

Architectural design is concerned with understanding how a system should be organized and designing the overall structure of that system.

Architectural design is the first stage in the software design process. It is the critical link between design and requirements engineering, as it identifies the main structural components in a system and the relationships between them. The output of the architectural design process is an architectural model that describes how the system is organized as a set of communicating components.

Software architecture is important because it affects the performance, robustness, distributability, and maintainability of a system.

Architectural design decisions

Architectural design is a creative process where you design a system organization that will satisfy the functional and non-functional requirements of a system. During the architectural design process, system architects have to make a number of structural decisions that profoundly affect the system and its development process.

1. Performance If performance is a critical requirement, the architecture should be designed to localize critical operations within a small number of components, with these components all deployed on the same computer rather than distributed across the network. This may mean using a few relatively large components rather than small, fine-grain components, which reduces the number of component communications. You may also consider run-time system organizations that allow the system to be replicated and executed on different processors.

2. Security If security is a critical requirement, a layered structure for the architecture should be used, with the most critical assets protected in the innermost layers, with a high level of security validation applied to these layers.

3. Safety If safety is a critical requirement, the architecture should be designed so that safety-related operations are all located in either a single component or in a small number of components. This reduces the costs and problems of safety validation and makes it possible to provide related protection systems that can safely shut down the system in the event of failure.

4. Availability If availability is a critical requirement, the architecture should be designed to include redundant components so that it is possible to replace and update components without stopping the system.

5. Maintainability If maintainability is a critical requirement, the system architecture should be designed using fine-grain, self-contained components that may readily be changed. Producers of data should be separated from consumers and shared data structures should be avoided.

Architectural views

- **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, that is, it shows the breakdown of the software into components that are implemented by a single developer or development team.
- **A physical view,** which shows the system hardware and how software components are distributed across the processors in the system. This view is useful for systems engineers planning a system deployment

Architectural patterns

The idea of patterns as a way of presenting, sharing, and reusing knowledge about software systems is now widely used.

You can think of an architectural pattern as a stylized, abstract description of good practice, which has been tried and tested in different systems and environments. So, an architectural pattern should describe a system organization that has been successful in previous systems. It should include information of when it is and is not appropriate to use that pattern, and the pattern's strengths and weaknesses.

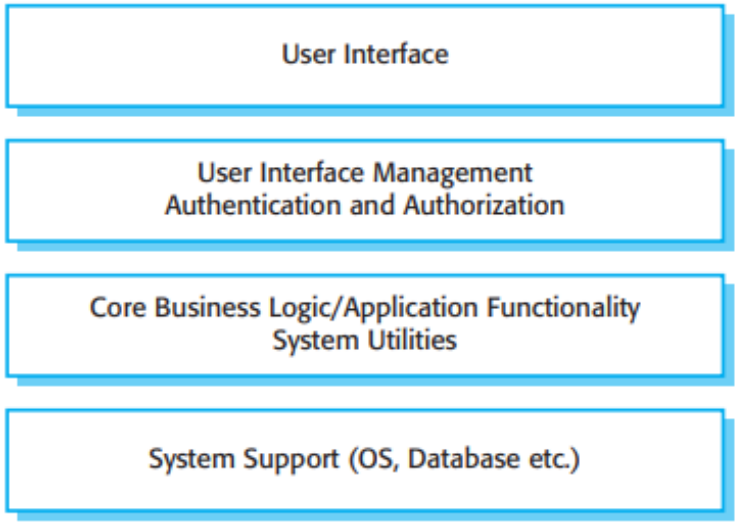
1. Layered architecture

The layered architecture pattern is another way of achieving separation and independence. This pattern is shown in Figure . Here, the system functionality is organized into separate layers, and each layer only relies on the facilities and services offered by the layer immediately beneath it.

- This layered approach supports the incremental development of systems. As a layer is developed, some of the services provided by that layer may be made available to users.
- The architecture is also changeable and portable. So long as its interface is unchanged, a layer can be replaced by another, equivalent layer. Furthermore, when layer interfaces change or new facilities are added to a layer, only the adjacent layer is affected.
- As layered systems localize machine dependencies in inner layers, this makes it easier to provide multi-platform implementations of an application system. Only

the inner, machine-dependent layers need be re-implemented to take account of the facilities of a different operating system or database.

- 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.

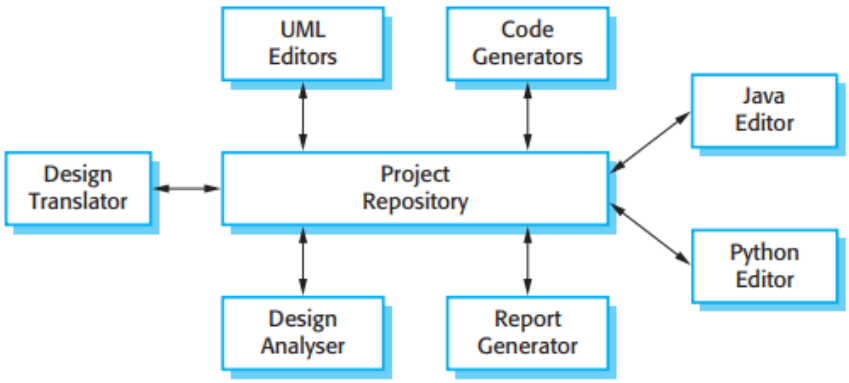
2. Repository architecture

Repository pattern describes how a set of interacting components can share data. The majority of systems that use large amounts of data are organized around a shared database or repository. This model is therefore suited to applications in which data is generated by one component and used by another. Examples of this type of system include command and control systems, management information systems, CAD systems, and interactive development environments for software.

- 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.
- 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.

Organizing tools around a repository is an efficient way to share large amounts of data. There is no need to transmit data explicitly from one component to another. However, components must operate around an agreed repository data model.



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.

Components need to compromise between the specific needs of each tool and it may be difficult or impossible to integrate new components if their data models do not fit the agreed schema.

3. Client–server architecture

A system that follows the client–server pattern is organized as a set of services and associated servers, and clients that access and use the services. The major components of this model are:

1. **A set of servers** that offer services to other components. Examples of servers include print servers that offer printing services, file servers that offer file management services, and a compile server, which offers programming language compilation services.
2. **A set of clients** that call on the services offered by servers. There will normally be several instances of a client program executing concurrently on different computers.
3. **A network** that allows the clients to access these services. Most client–server systems are implemented as distributed systems, connected using Internet protocols.

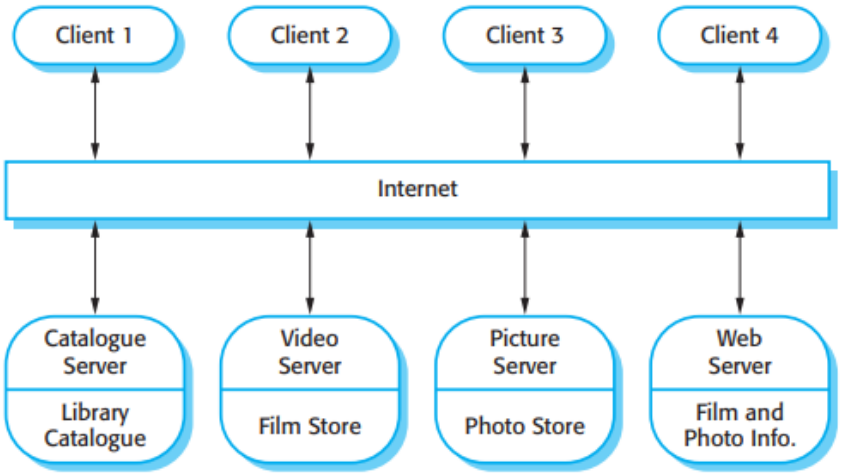
Client–server architectures are usually thought of as distributed systems architectures but the logical model of independent services running on separate servers can be implemented on a single computer. Again, an important benefit is separation and independence. Services and servers can be changed without affecting other parts of the system. Clients may have to know

the names of the available servers and the services that they provide. However, servers do not need to know the identity of clients or how many clients are accessing their services. Clients access the services provided by a server through remote procedure calls using a request-reply protocol such as the http protocol used in the WWW. Essentially, a client makes a request to a server and waits until it receives a reply.

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.

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.

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.

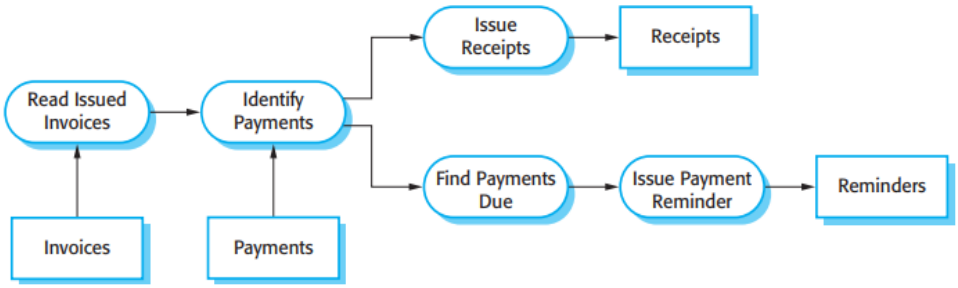


4. Pipe and filter architecture

This is a model of the run-time organization of a system where functional transformations process their inputs and produce outputs. Data flows from one to another and is transformed as it moves through the sequence. Each processing step is implemented as a transform. Input data flows through these transforms until converted to output. The transformations may execute sequentially or in parallel. The data can be processed by each transform item by item or in a single batch. 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 transformations are sequential with data processed in batches, this pipe and filter architectural model becomes a batch sequential model, a common architecture for data

processing systems (e.g., a billing system). The architecture of an embedded system may also be organized as a process pipeline, with each process executing concurrently.



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 unparse 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.

DESIGN AND IMPLEMENTATION

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

Object-oriented design using the UML

Object-oriented design processes involve designing object classes and the relationships between these classes. These classes define the objects in the system and their interactions. When the design is realized as an executing program, the objects are created dynamically from these class definitions.

Object-oriented design, there are several things that you need to do:

1. Understand and define the context and the external interactions with the system.

2. Design the system architecture.

3. Identify the principal objects in the system.

4. Develop design models.

5. Specify interfaces.

1. System context and interactions

The first stage in any software design process is to develop an understanding of the relationships between the software that is being designed and its external environment. This is essential for deciding how to provide the required system functionality and how to structure the system to communicate with its environment.

System context models and interaction models present complementary views of the relationships between a system and its environment:

1. A system context model is a structural model that demonstrates the other systems in the environment of the system being developed.

2. An interaction model is a dynamic model that shows how the system interacts with its environment as it is used

2. Architectural design

Once the interactions between the software system and the system's environment have been defined, you use this information as a basis for designing the system architecture.

You identify the major components that make up the system and their interactions, and then may organize the components using an architectural pattern such as a layered or client–server model.

3. Object class identification

By this stage in the design process, you should have some ideas about the essential objects in the system that you are designing. As your understanding of the design develops, you refine these ideas about the system objects.

There have been various proposals made about how to identify object classes in object-oriented systems:

1. Use a grammatical analysis of a natural language description of the system to be constructed. Objects and attributes are nouns; operations or services are verbs.
2. Use tangible entities (things) in the application domain such as aircraft, roles such as manager or doctor, events such as requests, interactions such as meetings, locations such as offices, organizational units such as companies, and so on.
3. Use a scenario-based analysis where various scenarios of system use are identified and analyzed in turn. As each scenario is analyzed, the team responsible for the analysis must identify the required objects, attributes, and operations.

4. Design models

These models are the bridge between the system requirements and the implementation of a system. you will normally develop two kinds of design model:

1. **Structural models,** which describe the static structure of the system using object classes and their relationships. Important relationships that may be documented at this stage are generalization (inheritance) relationships, uses/used-by relationships, and composition relationships.
2. **Dynamic models,** which describe the dynamic structure of the system and show the interactions between the system objects. Interactions that may be documented include the sequence of service requests made by objects and the state changes that are triggered by these object interactions.
3. **Subsystem models,** which that show logical groupings of objects into coherent subsystems. These are represented using a form of class diagram with each subsystem shown as a package with enclosed objects. Subsystem models are static (structural) models.
4. **Sequence models,** which show the sequence of object interactions. These are represented using a UML sequence or a collaboration diagram. Sequence models are dynamic models.

5. **State machine model**, which show how individual objects change their state in response to events. These are represented in the UML using state diagrams. State machine models are dynamic models.

5. Interface specification

Interface design is concerned with specifying the detail of the interface to an object or to a group of objects. This means defining the signatures and semantics of the services that are provided by the object or by a group of objects.

Design patterns

The pattern is a description of the problem and the essence of its solution, so that the solution may be reused in different settings. The pattern is not a detailed specification. Rather, you can think of it as a description of accumulated wisdom and experience, a well-tried solution to a common problem.

The four essential elements of design patterns were defined by the 'Gang of Four'

1. A name that is a meaningful reference to the pattern.
2. A description of the problem area that explains when the pattern may be applied.
3. A solution description of the parts of the design solution, their relationships, and their responsibilities. This is not a concrete design description. It is a template for a design solution that can be instantiated in different ways. This is often expressed graphically and shows the relationships between the objects and object classes in the solution.
4. A statement of the consequences—the results and trade-offs—of applying the pattern. This can help designers understand whether or not a pattern can be used in a particular situation.

Implementation issues

Software engineering includes all of the activities involved in software development from the initial requirements of the system through to maintenance and management of the deployed system. A critical stage of this process is, of course, system implementation, where you create an executable version of the software. Implementation may involve developing programs in high- or low-level programming languages or tailoring and adapting generic, off-the-shelf systems to meet the specific requirements of an organization.

1. *Reuse* Most modern software is constructed by reusing existing components or systems. When you are developing software, you should make as much use as possible of existing code.

2. *Configuration management* During the development process, many different versions of each software component are created. If you don't keep track of these versions in a configuration management system, you are liable to include the wrong versions of these components in your system.

3. *Host-target development* Production software does not usually execute on the same computer as the software development environment. Rather, you develop it on one computer (the host system) and execute it on a separate computer (the target system). The host and target systems are sometimes of the same type but, often they are completely different.