Why is Software Architecture Important?

Software architecture plays a critical role in the overall success and evolution of a software system. The architecture directly influences various qualities of the system, including performance, modifiability, security, scalability, and reusability. Below are the key reasons why software architecture is important:

1. **Enabling Quality Attributes**:
   Architecture decisions either enable or inhibit a system's ability to achieve desired quality attributes, such as performance, scalability, and security.
   - **Example**: Choosing a microservices architecture might enhance scalability but may impact performance due to the overhead of inter-service communication.
2. **Managing Change**:
   The architecture helps manage changes as the system evolves, ensuring that the system can accommodate new features or changes with minimal disruption.
   - **Example**: In an online retail system, designing the order processing module as a separate component allows for easier updates without affecting other parts of the system.
3. **Predicting System Qualities**:
   By analyzing the architecture, one can predict how well the system will perform based on its design decisions.
   - **Example**: If an architecture uses a single database for all user transactions, it may predict potential performance bottlenecks as the number of users increases.
4. **Enhancing Communication Among Stakeholders**:
   A documented architecture fosters communication among all stakeholders (e.g., developers, clients, users), allowing everyone to align their expectations and understand the system’s design.
   - **Example**: A project manager might use the architecture to explain to non-technical stakeholders how the system will scale under heavy traffic.
5. **Fundamental Design Decisions**:
   The architecture embodies the earliest, most fundamental decisions about the system. These decisions set the direction for the entire development process.
   - **Example**: Deciding on a layered architecture early on establishes a structure that dictates how different components will interact and how data will flow.
6. **Defining Constraints on Implementation**:
   The architecture defines constraints on how software elements interact, guiding the implementation team to meet specific performance or security requirements.
   - **Example**: A decision to encrypt all data transfers can constrain the implementers to use secure communication protocols.
7. **Influencing Organizational Structure**:
   The architecture also affects the organizational structure, as teams are often organized to align with architectural components.

    - **Example**: A large system divided into microservices might result in teams that work independently on different services.
8. **Supporting Evolutionary Prototyping**:
   The architecture can serve as the foundation for building early prototypes that help explore and validate design decisions early in the product life cycle.
    - **Example**: A skeletal prototype can be developed to test performance assumptions, with minimal functionality implemented initially.
9. **Guiding Cost and Schedule Estimates**:
   The architecture enables project managers and architects to make better estimates regarding the cost and schedule by understanding the complexity and resource requirements early on.
    - **Example**: An architect might use the system's modular design to break down development into smaller tasks, improving cost estimation accuracy.
10. **Transferable and Reusable Model**:
    Once defined, an architecture can serve as a reusable model for similar projects, reducing development time and leveraging past design decisions.
    - **Example**: A software product line based on a reusable architecture allows the development of similar applications with minimal changes.
11. **Focus on Component Assembly**:
    Architecture-based development emphasizes assembling components in a way that meets system requirements rather than just creating components in isolation.
    - **Example**: Instead of creating isolated, monolithic code, an architect would focus on how different components (like payment gateway, user authentication, etc.) interact within the system.
12. **Restricting Design Alternatives**:
    By limiting design options, architecture helps developers focus on creating effective solutions, reducing unnecessary complexity.
    - **Example**: By choosing a specific database model (e.g., relational vs. NoSQL), the architecture constrains developers to design accordingly, simplifying the decision-making process.
13. **Foundation for Training New Team Members**:
    The architecture can serve as the first step in training new team members, helping them understand the overall structure of the system and their role in it.
    - **Example**: A new developer can be trained on how the payment processing component integrates with the rest of the system based on the architecture.

Key Aspects of Software Architecture

1. **Performance**:
   Architecture plays a crucial role in managing time-based behaviors, shared resources, and inter-element communication. Good architectural decisions ensure that performance requirements are met throughout the system.

2. **Modifiability**:
   A well-designed architecture assigns responsibilities to elements in such a way that the majority of changes impact a small number of elements. This modular approach reduces the cost and effort required for modifications.
3. **Security**:
   The architecture defines how to protect system components and manage data access. Decisions like data encryption, access control, and authentication mechanisms are crucial to ensuring the system's security.
4. **Scalability**:
   The architecture enables the system to handle growth in user load and data volume by designing scalable components that can be expanded or replaced as needed.
5. **Incremental Subset Delivery**:
   The architecture should allow for incremental delivery of system components. This means that the system can be partially delivered and improved over time, rather than all at once.
6. **Reusability**:
   By designing components that are loosely coupled, the architecture ensures that they can be reused in other parts of the system or even in other systems, saving time and effort in future developments.

Case Study: E-Commerce System Architecture

Scenario:

An e-commerce platform is being developed to handle large amounts of traffic, secure user transactions, and offer scalability to accommodate growing product listings.

Architecture Design:

1. **Module Structure**: The system is divided into separate modules for **User Authentication**, **Order Management**, and **Payment Processing**. Each module has a specific responsibility and can be modified independently.
2. **Component-and-Connector Structure**: Components such as **Payment Gateway** and **Inventory Service** communicate with each other through APIs. Data is exchanged asynchronously to optimize performance.
3. **Allocation Structure**: The system is hosted on cloud infrastructure, with modules deployed across multiple servers to handle high traffic loads. A distributed database ensures data is accessible and consistent.

Benefits:

- **Scalability**: The modular design allows for easy scaling by adding more servers or updating components independently.

- **Security**: Sensitive user data, such as credit card information, is handled by secure components and encrypted during transmission.
- **Maintainability**: Each module can be updated or replaced without affecting the rest of the system, ensuring easier maintenance and adaptability.

Summary of Key Points

1. Software architecture enables or inhibits a system’s core quality attributes (e.g., performance, modifiability, security).
2. Architecture decisions help manage change and ensure that quality attributes are achieved.
3. Predicting system qualities early through architectural analysis allows for easier and cheaper fixes.
4. Architecture provides a shared language for all stakeholders to understand and communicate their concerns.
5. Early design decisions made in the architecture have long-lasting effects on the system's development and maintenance.
6. A well-designed architecture defines constraints that guide the implementation and the overall project structure.
7. Architecture enables evolutionary prototyping, helping identify risks and performance issues early.
8. Architecture-based development helps improve cost and schedule estimates and provides reusable models for future projects.

Software Architecture Overview

What Software Architecture Is and What It Isn't

Software Architecture Definition:
Software architecture refers to the set of structures required to reason about a system, which includes its software elements, the relationships among them, and the properties of both.

What It Isn't:

- It is not just about early decisions or major design decisions, but involves structures that evolve over time.
- Not all early decisions are architectural, and not all "major" decisions are considered architectural.

Key Point:

Architecture is about identifying the structures that are important for reasoning about the system and ensuring its correct behavior.

Architectural Structures and Views

Structures in Architecture: Software systems are composed of various structures, each providing a different perspective. There are three key categories of architectural structures:

1. **Module Structures**
    - **Modules** represent system components that are assigned specific computational responsibilities. They help partition a system into manageable parts.
2. **Example**:
   An e-commerce platform might have modules for user authentication, order management, and payment processing.
3. **Component-and-Connector Structures (C&C)**
    - **Components** are runtime entities (e.g., services or servers).
    - **Connectors** represent how components interact during execution (e.g., APIs, message queues).
4. **Example**:
   In an online payment system, the payment module might be a component that communicates with external payment processors via a connector.
5. **Allocation Structures**
    - These show how software elements are assigned to various external environments (e.g., hardware, teams, or network resources).

6. **Example**:
   In a distributed system, modules may be deployed across multiple servers, and allocation structures describe the physical deployment of these components.

What Makes a “Good” Architecture?

A good software architecture is:

1. **Conceptually Consistent**: Developed by a team with a unified vision to maintain coherence and consistency.
2. **Prioritized Based on Quality Attributes**: Focuses on critical attributes such as performance, scalability, security, and maintainability.
3. **Documented with Views**: Architecture should be documented using different views to represent various perspectives of the system, such as **module views**, **component views**, and **allocation views**.
4. **Evaluated for Quality Attributes**: Early evaluation of how well the architecture meets its requirements, with adjustments made during development.
5. **Flexible and Incremental**: Architecture should allow for easy modifications and be incrementally implemented, starting with a "skeletal" version that evolves over time.

Good Architecture Principles:

- **Information Hiding**: Details that may change over time should be encapsulated within modules.
- **Modularity**: Functions should be split into distinct modules to aid in maintenance and expansion.
- **Separation of Concerns**: Ensure that each module has a clear responsibility, focusing on one task at a time.
- **Maintainability**: The system should be easy to modify without affecting other parts of the system.

Architectural Patterns

Architectural patterns provide reusable solutions to common design problems by identifying key components and their interactions.

Common Architectural Patterns:

1. **Layered Pattern**
   - The system is divided into layers where each layer only interacts with the one directly below it.

2. **Example**:
   A typical web application architecture with three layers:
   - **Presentation Layer**
   - **Business Logic Layer**
   - **Data Access Layer**
3. **Diagram Placeholder**: *(Include a diagram showing the layers: Presentation Layer → Business Logic Layer → Data Access Layer)*
4. **Client-Server Pattern**
   - Divides the system into clients that request services and servers that provide those services.
5. **Example**:
   A web browser (client) interacts with a web server to fetch data.
6. **Microservices Architecture**
   - Composed of small, independent services that interact with each other via APIs.
7. **Example**:
   A shopping platform with separate services for payment, user management, and inventory.
8. **Shared-Data (Repository) Pattern**
   - Centralizes data storage, which is accessed by different components through predefined connectors.
9. **Example**:
   A banking system with a centralized database storing customer account information, accessed by various services like loan processing and user management.

Component vs Module

Module:

A module is an implementation unit that encapsulates a specific functionality, such as a class, function, or a set of related classes. It focuses on organizing the system into manageable parts for ease of development and maintenance.

Example:
In a banking application, the **Transaction Module** would handle the logic for processing transactions, while the **User Module** would handle user management tasks.

Diagram Placeholder:

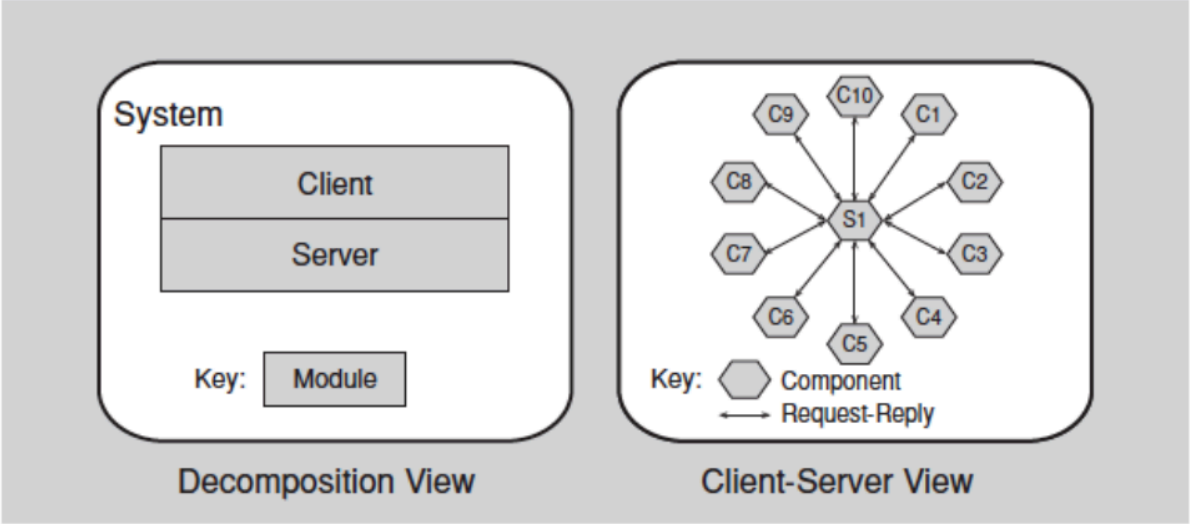

FIGURE 1.2 Two views of a client-server system

Component:

A component refers to a runtime entity in the system. It performs operations during execution and interacts with other components through connectors. Components focus on runtime behavior.

Example:
In an e-commerce application, the **Payment Component** would interact with a third-party payment gateway, while the **Inventory Component** would check product availability.

Relating Structures to Each Other

The various structures (module, component, allocation) are often interrelated, and a system may contain elements from all three.

Example:
A module in a **decomposition structure** (like an authentication module) may be represented by multiple components in the **component-and-connector structure**, where each component (e.g., user login, session management) interacts with the other components.

Case Study: E-Commerce System Architecture

Scenario:

An e-commerce platform needs to support high traffic, offer secure payment processing, and allow easy extensibility for future features.

Architecture:

1. **Module Structure**: Divide the system into modules like **User Authentication**, **Order Management**, and **Payment Processing**.
2. **Component-and-Connector Structure**: Each module communicates with other modules via APIs. For example, the **Payment Processing Component** interacts with third-party payment services.
3. **Allocation Structure**: The system is deployed across multiple servers to ensure scalability and high availability, with each server handling different parts of the system (e.g., one for user management, one for payment processing).

Benefits:

- **Scalability**: Distributed components allow the system to handle increased load by adding more servers.
- **Security**: Payment processing is isolated in a dedicated component to ensure secure handling of sensitive information.

Conclusion

Software architecture defines the high-level structures of a system and guides its design and implementation. It is critical for ensuring the system is maintainable, scalable, and secure. A well-designed architecture supports reasoning about key system properties and helps achieve system goals through structured design decisions.

Summary:

1. **Architectural Structures**: Three main types: Module, Component-and-Connector, and Allocation.
2. **Architectural Views**: Different views provide perspectives on the system's design.
3. **Architectural Patterns**: Reusable solutions to common design problems.
4. **Good Architecture**: Conceptually consistent, focused on quality attributes, and flexible for future changes.

Understanding Software Architecture in Different Contexts

Introduction

Software architecture is the fundamental structure of a software system, encompassing its components, their relationships, and the principles guiding its design and evolution. However, software architecture doesn't exist in isolation; it interacts with various contexts that influence its creation and implementation. This guide explores software architecture in four key contexts:

1. **Technical Context**
2. **Project Life-Cycle Context**
3. **Business Context**
4. **Professional Context**

We will also discuss how architecture is influenced, what architectures influence, and the role of stakeholders. Examples and scenarios are provided to illustrate these concepts.

---

1. Architecture in a Technical Context

Explanation

In the technical context, software architecture is concerned with the technical aspects of a system. It focuses on how the architecture helps achieve the system's quality attributes, such as performance, security, scalability, and modifiability. The architecture must align with current technical environments, standard industry practices, and prevalent software engineering techniques.

Key Points

- **Quality Attributes**: The architecture must support the desired qualities of the system.
- **Technical Environment**: Architecture should consider current technologies and anticipate future trends.

Examples

- **Web-Based Systems**: Modern architectures often need to support web technologies, mobile access, and cloud integration.

- **Legacy Systems**: An architecture might need to accommodate outdated technologies if integrating with legacy systems.

Scenario

A company developing a new online banking platform needs an architecture that ensures high security, scalability for growing user numbers, and compatibility with mobile devices. The architecture must incorporate encryption, scalable server infrastructure, and responsive design principles.

---

2. Architecture in a Project Life-Cycle Context

Explanation

In the project life-cycle context, software architecture relates to the phases of software development. Regardless of the development methodology (Waterfall, Iterative, Agile, Model-Driven Development), certain architectural activities are essential.

Key Architectural Activities

1. **Making a Business Case**: Justifying the system's development.
2. **Understanding Requirements**: Identifying architecturally significant requirements.
3. **Creating or Selecting the Architecture**: Designing the architecture or choosing an existing one.
4. **Documenting and Communicating**: Sharing the architecture with stakeholders.
5. **Analyzing or Evaluating**: Assessing the architecture's effectiveness.
6. **Implementing and Testing**: Building the system based on the architecture.
7. **Ensuring Conformance**: Verifying that the implementation aligns with the architecture.

Example

- **Agile Development**: In Agile methodologies, architecture evolves iteratively. Architects must adapt the architecture as new requirements emerge during sprints.

Case Study

A software company uses an iterative development process to build a healthcare application. The architects work closely with developers and stakeholders in each iteration to refine the architecture, ensuring it meets regulatory compliance and user needs.

---

3. Architecture in a Business Context

Explanation

Software architecture affects and is affected by the business goals of the organization. It must align with objectives such as profitability, market capture, customer satisfaction, and operational efficiency.

Key Points

- **Business Goals Influence Architecture**: Objectives like time-to-market, cost reduction, and differentiation guide architectural decisions.
- **Architecture Impacts Business**: A good architecture can provide a competitive advantage and open new business opportunities.

Examples

- **Product Differentiation**: An architecture that supports unique features can set a product apart in the market.
- **Cost Efficiency**: Reusing architectural components across products can reduce development costs.

Scenario

An e-commerce company wants to expand globally. The architecture must support multiple languages, currencies, and comply with international regulations. The architects design a modular system where regional customizations can be added without affecting the core functionality.

---

4. Architecture in a Professional Context

Explanation

In the professional context, the role of the software architect extends beyond technical duties. Architects interact with management, customers, and development teams, requiring strong communication, leadership, and negotiation skills.

Key Responsibilities of an Architect

- **Communication**: Explaining architectural decisions to stakeholders with varying technical backgrounds.

- **Leadership**: Guiding development teams and influencing project direction.
- **Negotiation**: Balancing conflicting requirements and priorities among stakeholders.
- **Continuous Learning**: Staying updated with the latest technologies and industry trends.

Example

An architect must convince management to invest in a more robust security framework, explaining how it mitigates risks and aligns with business goals, despite the higher initial cost.

Stakeholders

Explanation

Stakeholders are individuals or organizations with an interest in the system's success. They include customers, users, developers, managers, regulators, and others.

Importance

- **Diverse Concerns**: Each stakeholder has specific concerns (e.g., performance, usability, cost).
- **Influence on Architecture**: Stakeholder requirements shape architectural decisions.
- **Engagement**: Early and ongoing engagement with stakeholders ensures their needs are met.

Examples

- **Users**: Interested in usability and reliability.
- **Developers**: Concerned with maintainability and clear architectural guidelines.
- **Regulators**: Focus on compliance with laws and standards.

Scenario

In developing a medical records system, stakeholders include doctors (users), IT staff (developers), patients, and regulatory bodies. Architects must design a system that is user-friendly for doctors, secure to protect patient data, and compliant with healthcare regulations.

How Is Architecture Influenced?

Explanation

Architecture is influenced by various factors beyond the initial requirements. These include:

- **Technical Influences**: New technologies, best practices, and technical constraints.
- **Business Influences**: Market trends, competition, and business strategies.
- **Social Influences**: User expectations, cultural factors, and societal changes.

Examples

- **Emerging Technologies**: The rise of artificial intelligence might influence an architecture to include machine learning components.
- **Market Demand**: A surge in mobile device usage could lead to an architecture that prioritizes mobile accessibility.

Case Study

A ride-sharing app adjusts its architecture to integrate with wearable devices as consumer interest in smartwatches grows, enhancing user experience.

What Do Architectures Influence?

Explanation

Architectures, in turn, influence:

- **Technical Context**: They set precedents for future systems and can shape technical requirements.
- **Project Structure**: Influence team organization and development processes.
- **Business Goals**: Affect business strategies and opportunities.
- **Professional Growth**: Impact the architect's experience and future approaches.

Examples

- **Reuse in Future Projects**: A successful architecture might be reused as a template for new products.
- **Organizational Structure**: A microservices architecture may lead to smaller, cross-functional teams.

Scenario

After successfully implementing a microservices architecture, a company restructures its development teams into smaller units focused on individual services, leading to faster deployment cycles and innovation.

Summary

Software architecture plays a critical role in various contexts:

- **Technical Context**: It helps achieve quality attributes and adapts to technological environments.
- **Project Life-Cycle Context**: It guides development activities across methodologies.
- **Business Context**: It aligns with business goals and can drive strategic decisions.
- **Professional Context**: Architects must possess a blend of technical and soft skills to navigate complex projects.

Understanding the influences on architecture and its impact on different domains ensures that architects can design systems that meet technical requirements, fulfill business objectives, and satisfy stakeholder needs.

Understanding Quality Attributes in Software Architecture

Introduction

Software architecture plays a crucial role in ensuring that a software system meets its intended requirements and quality expectations. This guide covers the following key topics:

- Architecture and Requirements
- Functionality
- Quality Attribute Considerations
- Specifying Quality Attribute Requirements
- Achieving Quality Attributes through Tactics
- Guiding Quality Design Decisions

We will explore each topic with simple explanations, examples, and case studies where appropriate. Diagrams are described to aid understanding.

---

1. Architecture and Requirements

System Requirements Categories

System requirements are generally categorized into three types:

1. **Functional Requirements**: Describe what the system should do—the functionalities and services it must provide.
    - *Example*: "The system must allow users to register and log in."
2. **Quality Attribute Requirements**: Define how well the system performs its functions—non-functional aspects like performance, security, usability, etc.
    - *Example*: "The system should respond to user actions within 2 seconds."
3. **Constraints**: Design decisions that are already made and cannot be changed, limiting the options available to architects.
    - *Example*: "The application must be developed using Java."

Architectural Description

An architectural description encompasses the system's structures, components, their interactions, and the principles guiding its design and evolution.

---

2. Functionality

Functionality refers to the set of actions or services that the system is designed to perform—the primary purpose of the software.

- **Relation to Architecture**: Multiple architectures can fulfill the same functional requirements; functionality alone does not determine the architecture.
- **Orthogonality to Quality Attributes**: While functionality defines what the system does, quality attributes define how well it does it. They are independent but complementary.

Example:

- **Functional Requirement**: "The system must process customer orders."
- **Quality Attribute**: "Order processing must be completed within 3 seconds."

---

3. Quality Attribute Considerations

Quality attributes (non-functional requirements) specify criteria that judge the operation of a system, rather than specific behaviors.

Common Quality Attributes

- **Performance**: How fast the system responds.
- **Security**: Protection against unauthorized access.
- **Usability**: Ease of use for end-users.
- **Modifiability**: Ease of making changes.
- **Availability**: System uptime and reliability.

Challenges in Defining Quality Attributes

1. **Untestable Definitions**: Vague terms like "The system shall be user-friendly" are not measurable.
2. **Overlapping Concerns**: Issues may relate to multiple quality attributes (e.g., a security breach affects both security and availability).
3. **Different Vocabularies**: Different stakeholders may use different terms for the same concepts.

Solutions

- **Use Quality Attribute Scenarios**: Define attributes in specific, testable terms.

- **Standardize Vocabulary**: Establish common definitions among stakeholders.

---

4. Specifying Quality Attribute Requirements

Quality Attribute Scenarios

A quality attribute scenario is a structured description of a quality attribute requirement, consisting of six parts:

1. **Source of Stimulus**: The entity that generates the stimulus (e.g., user, system component).
2. **Stimulus**: The event that requires a response (e.g., a request, failure).
3. **Environment**: The conditions under which the stimulus occurs (e.g., normal operation, peak load).
4. **Artifact**: The part of the system that is stimulated (e.g., database, server).
5. **Response**: The activity the system must perform (e.g., process request, failover).
6. **Response Measure**: The metric that quantifies the response (e.g., response time, throughput).

General vs. Concrete Scenarios:

- **General Scenarios**: System-independent, can apply to any system.
- **Concrete Scenarios**: Specific to a particular system.

Example of a General Scenario for Availability:

- **Source of Stimulus**: Internal component.
- **Stimulus**: Failure occurs.
- **Environment**: Normal operation.
- **Artifact**: System.
- **Response**: System detects failure, recovers, and notifies support.
- **Response Measure**: Recovery occurs within 1 second.

Concrete Scenario Example:

- In an **online payment system**:
    - **Source of Stimulus**: Network failure.
    - **Stimulus**: Loss of connection to the payment gateway.
    - **Environment**: During transaction processing.
    - **Artifact**: Payment processing module.
    - **Response**: System retries the connection every 10 seconds.
    - **Response Measure**: Connection re-established within 1 minute without data loss.

---

5. Achieving Quality Attributes through Tactics

What Are Tactics?

Tactics are design decisions or techniques that influence the achievement of specific quality attribute responses. They are the building blocks for achieving desired qualities in a system.

Importance of Tactics

1. **Understanding Patterns**: They help in modifying design patterns to meet specific quality goals.
2. **Design from Scratch**: Enable architects to construct designs when no suitable patterns exist.
3. **Systematic Design**: Provide a structured approach to selecting design options based on trade-offs.

Examples of Tactics

- **Performance Tactics**:
  - *Resource Demand Management*: Caching, pooling resources.
  - *Resource Management*: Load balancing, concurrency control.
- **Security Tactics**:
  - *Detect Attacks*: Intrusion detection systems.
  - *Resist Attacks*: Authentication, authorization, encryption.

Case Study: Improving Performance in a Web Application

- **Problem**: Users experience slow page loads during peak hours.
- **Tactics Applied**:
  - **Implement Caching**: Store frequently accessed data in memory.
  - **Load Balancing**: Distribute requests across multiple servers.
  - **Optimize Database Queries**: Reduce response time from the database.

---

6. Guiding Quality Design Decisions

Architectural design involves making decisions that address various quality attributes. These decisions are categorized as follows:

1. Allocation of Responsibilities

Assigning functions and services to architectural elements (modules, components).

- **Example**: Separating the user interface, business logic, and data access into different layers in an application.

2. Coordination Model

Defining how components interact and communicate.

- **Considerations**:
  - *Synchronous vs. Asynchronous Communication*: Immediate response vs. delayed processing.
  - *Stateful vs. Stateless Interactions*: Maintaining session state vs. treating each request independently.
- **Example**: Using asynchronous messaging in a microservices architecture to improve scalability.

3. Data Model

Determining how data is structured, stored, and accessed.

- **Considerations**:
  - *Data Organization*: Relational databases, NoSQL, in-memory data stores.
  - *Data Access Patterns*: Read/write operations, transactions.
- **Example**: Choosing a NoSQL database for handling large volumes of unstructured data.

4. Management of Resources

Managing system resources like CPU, memory, network bandwidth.

- **Considerations**:
  - *Resource Limits*: Setting maximum usage levels.
  - *Resource Sharing and Contention*: Handling concurrent access.
- **Example**: Implementing thread pools to manage concurrent processing.

5. Mapping Among Architectural Elements

Defining how software components map to hardware or deployment environments.

- **Example**: Deploying a database on a separate server to reduce load on the application server.

6. Binding Time Decisions

Determining when certain decisions are made—compile-time, build-time, deployment-time, or run-time.

- **Example**: Allowing plug-ins to be added at runtime to extend functionality.

7. Choice of Technology

Selecting technologies that support the architectural decisions.

- **Considerations**:
  - *Tool Support*: Availability of development and testing tools.
  - *Team Expertise*: Familiarity with the technology.
  - *Compatibility*: With existing systems.
- **Example**: Choosing a web framework like React or Angular based on team skills and project requirements.

Diagrams (Descriptive)

Diagram 1: Quality Attribute Scenario Structure

css
Copy code

```
[Source of Stimulus] --> [Stimulus] --> [Environment] --> [Artifact]
--> [Response] --> [Response Measure]
```

- **Description**: This linear flow represents how a stimulus from a source under certain conditions affects a system component, leading to a response that can be measured.

Diagram 2: Categories of Design Decisions

css
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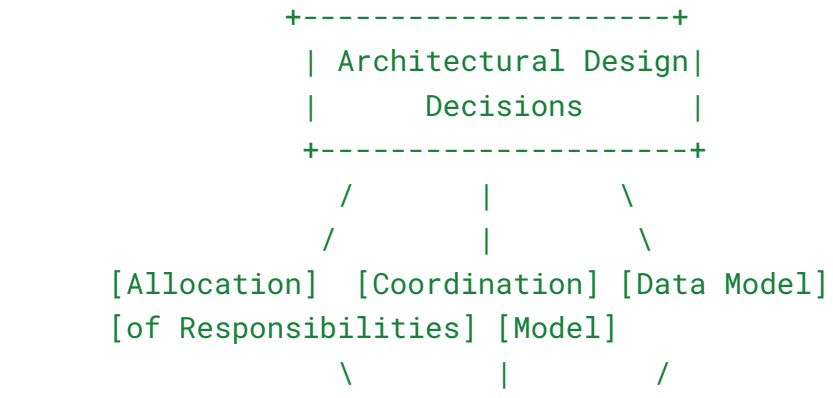
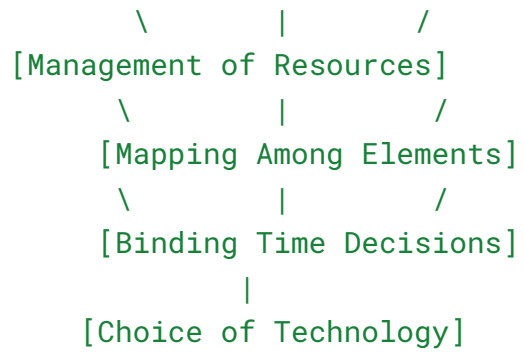




- **Description**: This diagram shows the interrelated categories of design decisions that architects make, emphasizing that these decisions collectively shape the architecture.

Summary

- **Requirements Classification**:
  - *Functional Requirements*: What the system should do.
  - *Quality Attribute Requirements*: How well the system performs.
  - *Constraints*: Predefined design decisions.
- **Quality Attributes Specification**:
  - Use quality attribute scenarios to make requirements measurable and testable.
  - Consider the six parts: source, stimulus, environment, artifact, response, and response measure.
- **Achieving Quality Attributes**:
  - Apply architectural tactics to address specific quality concerns.
  - Understand the trade-offs between different tactics.
- **Guiding Design Decisions**:
  - Make informed choices in allocation of responsibilities, coordination models, data models, resource management, mapping elements, binding times, and technology selection.

Additional Examples

Case Study: Online Retail Application

Requirements:

- **Functional**: Users can browse products, add to cart, and make purchases.

- **Quality Attributes**:
    - *Performance*: Pages should load within 2 seconds.
    - *Availability*: System uptime of 99.9%.
    - *Security*: Secure handling of payment information.

Design Decisions:

- **Allocation of Responsibilities**: Separate services for product catalog, shopping cart, and payment processing.
- **Coordination Model**: Use RESTful APIs for communication between services.
- **Data Model**: Utilize a relational database for transaction consistency.
- **Management of Resources**: Implement auto-scaling to handle traffic spikes.
- **Mapping Elements**: Deploy services in a cloud environment across multiple regions.
- **Binding Time**: Allow feature toggles for enabling/disabling features at runtime.
- **Choice of Technology**: Use established e-commerce platforms and secure payment gateways.

Conclusion

Understanding and specifying quality attributes is essential for designing robust software architectures. By using quality attribute scenarios and applying appropriate tactics, architects can ensure that systems meet both functional and non-functional requirements. Guiding design decisions across key categories allows for a systematic approach to architecture that addresses various stakeholder concerns and quality goals.

Understanding Availability in Software Architecture

Introduction

In software architecture, **availability** is a crucial quality attribute that ensures a system is operational and accessible when required. This guide provides an in-depth understanding of availability, including:

- What is Availability?
- Availability General Scenario
- Tactics for Achieving Availability
- A Design Checklist for Availability
- Summary

We will explore each topic with clear explanations, examples, scenarios, and diagrams where appropriate to enhance comprehension.

What is Availability?

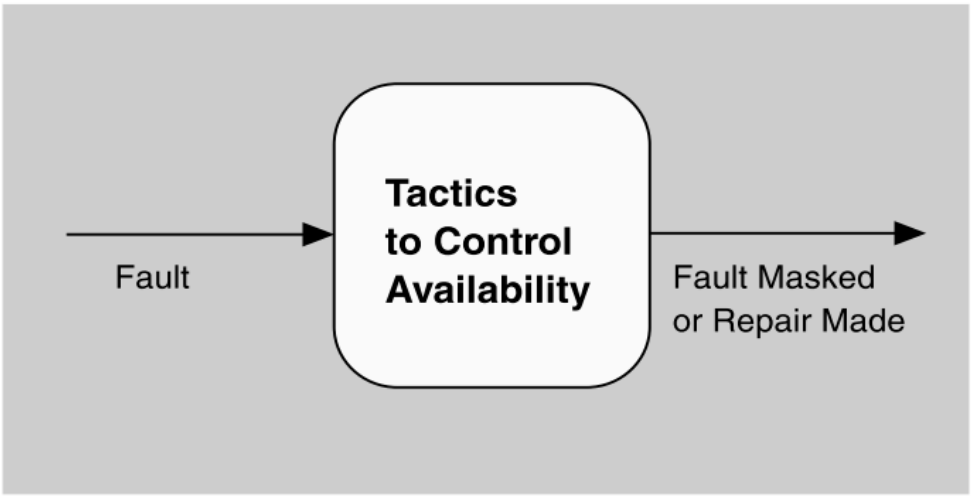
Availability refers to the ability of a system to be operational and accessible when needed. It encompasses not only the system's reliability but also its capacity to recover from faults and continue providing services with minimal downtime.

- **Reliability vs. Availability**: While reliability focuses on a system's ability to operate without failure, availability includes mechanisms for fault detection and recovery, ensuring the system can quickly resume normal operations after a failure.

Key Concepts

- **Fault**: An underlying issue in the system (e.g., software bug, hardware malfunction) that has the potential to cause a failure.
- **Failure**: When the system deviates from its expected behavior or specifications, often observed by users or external systems.
- **Recovery**: The process of restoring the system to normal operation after a fault or failure.

Goal of Availability: Minimize service outages by preventing faults from becoming failures or by mitigating their impact through quick detection and recovery.



Availability General Scenario

To effectively design for availability, architects use **general scenarios** that outline potential situations affecting availability. A general scenario includes:

1. **Source of Stimulus**: The entity that generates the stimulus (e.g., user, hardware component, external system).
2. **Stimulus**: The event that may cause a fault or failure (e.g., hardware failure, software exception).
3. **Environment**: The conditions under which the stimulus occurs (e.g., normal operation, peak load).
4. **Artifact**: The part of the system affected (e.g., server, network link).
5. **Response**: How the system should respond to the stimulus (e.g., detect fault, recover operation).
6. **Response Measure**: Metrics to evaluate the response (e.g., downtime duration, time to detect fault).

Example General Scenario

- **Source**: Internal hardware component.
- **Stimulus**: A fault occurs (e.g., server crash).
- **Environment**: During normal operation.
- **Artifact**: The primary database server.
- **Response**:
    - Detect the fault.
    - Switch operations to a backup server.
    - Notify system administrators.
- **Response Measure**:
    - Fault detected within 5 seconds.

    - Failover to backup server within 30 seconds.
    - No data loss during the transition.

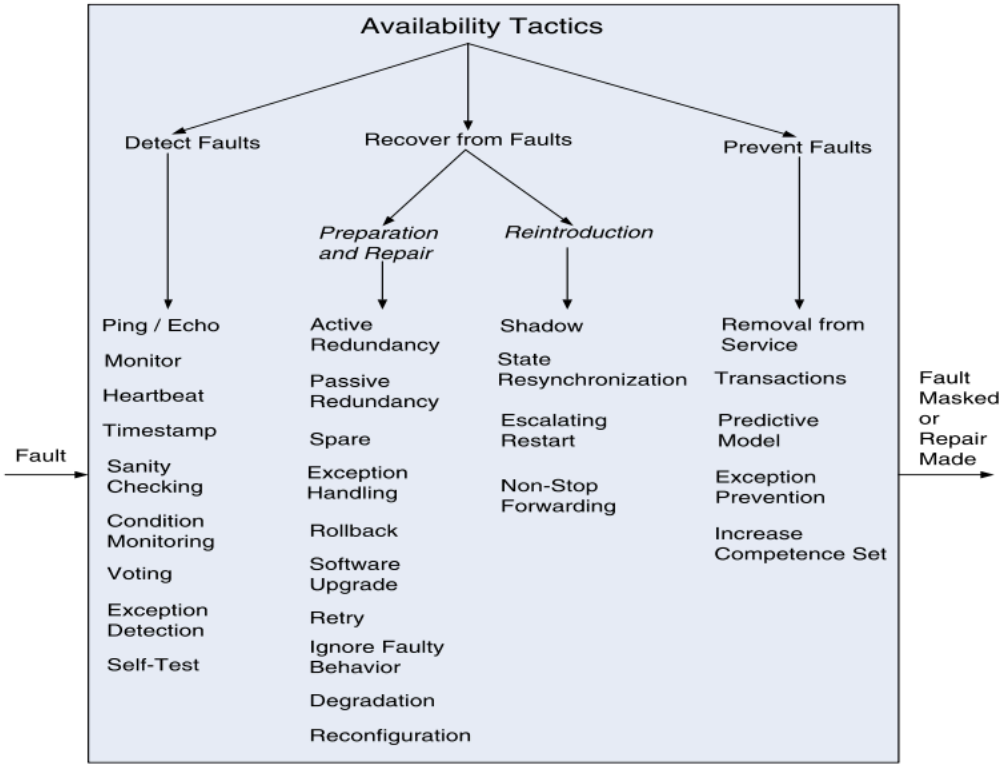
Sample Concrete Scenario

In an **e-commerce application**:

- **Source**: System monitoring tool.
- **Stimulus**: Detects that the payment processing service is non-responsive.
- **Environment**: Under normal operation during business hours.
- **Artifact**: Payment processing microservice.
- **Response**:
    - System logs the fault.
    - Routes payment requests to a redundant service instance.
    - Sends an alert to the support team.
- **Response Measure**:
    - Detection and failover occur within 10 seconds.
    - No transactions are lost or duplicated.

Tactics for Achieving Availability

Tactics are design decisions or patterns that architects employ to achieve desired quality attributes like availability. Availability tactics are grouped into three main categories:



1. **Fault Detection**

2. **Fault Recovery**
3. **Fault Prevention**

1. Fault Detection Tactics

Fault detection tactics help identify faults before they lead to system failures.

- **Ping/Echo**: An asynchronous request-response mechanism to check if a component is reachable.
    - *Example*: A monitoring service pings servers to verify they are operational.
- **Heartbeat**: Regular signals sent between components to indicate normal operation.
    - *Example*: A database cluster uses heartbeats to ensure nodes are active.
- **Exception Detection**: Identifying and handling unexpected conditions in software execution.
    - *Example*: Try-catch blocks in code to catch runtime exceptions.
- **Sanity Checking**: Validating data or outputs to ensure they are within expected parameters.
    - *Example*: Verifying that user input matches expected formats.
- **Voting**: Using redundant components and comparing their outputs to detect discrepancies.
    - *Example*: Triple Modular Redundancy (TMR) systems in avionics.

2. Fault Recovery Tactics

Fault recovery tactics enable the system to continue operating or restore operations after a fault is detected.

- **Active Redundancy (Hot Spare)**: All redundant components run simultaneously, providing instant failover.
    - *Example*: Web servers behind a load balancer, all actively handling requests.
- **Passive Redundancy (Warm Spare)**: Redundant components receive updates but are not active until needed.
    - *Example*: A standby database server that synchronizes data but only takes over if the primary fails.
- **Spare (Cold Spare)**: A redundant component that is powered on and initialized only after a failure.
    - *Example*: A backup server that is turned on when the primary server fails.
- **Rollback**: Reverting the system to a previous stable state.
    - *Example*: Rolling back a failed software update to a known good version.
- **Exception Handling**: Managing exceptions to prevent system crashes.
    - *Example*: Logging errors and gracefully degrading functionality instead of crashing.
- **Retry**: Attempting an operation again after a failure, useful for transient faults.
    - *Example*: Retrying a network request after a timeout.

3. Fault Prevention Tactics

Fault prevention tactics aim to prevent faults from occurring or limit their impact.

- **Removal from Service**: Temporarily taking components offline for maintenance

before they fail.
    - *Example*: Scheduling regular maintenance windows for system updates.
- **Transactions**: Ensuring operations are completed entirely or not at all to maintain system consistency.
    - *Example*: Database transactions that follow ACID properties.
- **Predictive Models**: Monitoring system parameters to predict and prevent failures.
    - *Example*: Using machine learning models to forecast hardware failures based on sensor data.
- **Exception Prevention**: Coding practices that prevent exceptions from occurring.
    - *Example*: Input validation to prevent invalid data from causing errors.
- **Increase Competence Set**: Designing components to handle a wider range of situations as normal operations.
    - *Example*: A parser that can handle variations in input formats without failing.

A Design Checklist for Availability

When designing for availability, architects should consider the following aspects:

1. Allocation of Responsibilities

- **Identify Critical Components**: Determine which system functionalities need high availability.
- **Assign Fault Detection Responsibilities**: Ensure components are responsible for detecting faults related to their operation.
- **Example**:
    - Allocating a monitoring service to oversee server health and trigger alerts.

2. Coordination Model

- **Communication Mechanisms**: Choose protocols that support reliable communication and fault detection.
- **Consider Degraded Communication**: Ensure coordination works even under partial failures.
- **Example**:
    - Implementing message queues that guarantee message delivery even if some services are down.

3. Data Model

- **Data Consistency and Recovery**: Plan for data replication and recovery mechanisms.
- **Handle Faulty Data Operations**: Ensure the system can cope with data read/write failures.
- **Example**:
    - Using distributed databases with automatic failover and data synchronization.

4. Mapping Among Architectural Elements

- **Flexible Deployment**: Allow components to be re-assigned or re-deployed in case of failures.
- **Redundancy Planning**: Map critical services to multiple physical nodes.
- **Example**:
    - Deploying microservices across multiple servers and cloud regions.

5. Resource Management

- **Identify Critical Resources**: CPU, memory, network bandwidth, etc., that need to be managed for availability.
- **Plan for Resource Saturation**: Ensure the system can handle overload conditions gracefully.
- **Example**:
    - Implementing rate limiting to prevent resource exhaustion during peak loads.

6. Binding Time

- **Late Binding for Flexibility**: Decide when components are bound together (compile-time, deploy-time, run-time).
- **Evaluate Impact on Availability**: Ensure late binding doesn't introduce vulnerabilities.
- **Example**:
    - Using service discovery mechanisms that allow services to find each other at runtime.

7. Choice of Technology

- **Select Reliable Technologies**: Choose technologies with built-in support for availability features.
- **Assess Technology Risks**: Understand potential faults introduced by the technology itself.
- **Example**:
    - Choosing a cloud provider that offers high availability SLAs and built-in redundancy.

Summary

- **Availability** is a critical quality attribute that ensures systems are operational and accessible when needed.
- **General Scenarios** help architects anticipate potential availability issues and plan appropriate responses.
- **Tactics for Availability** include detecting faults, recovering from faults, and preventing faults.
    - **Fault Detection**: Mechanisms like heartbeats and exception detection identify issues early.
    - **Fault Recovery**: Strategies like redundancy and rollback restore normal operations.
    - **Fault Prevention**: Practices like maintenance and exception prevention reduce

the likelihood of faults.
- **Design Checklist**: Architects should consider allocation of responsibilities, coordination models, data models, resource management, mapping of elements, binding time, and technology choices to enhance availability.
- **Implementing Availability** requires a holistic approach that integrates these tactics and considerations into the system's architecture from the outset.

Case Study: High Availability in an Online Banking System

Scenario:

A bank wants to ensure that its online banking platform is highly available to customers, even during unexpected failures.

Design Approach

1. **Allocation of Responsibilities**:
    - **Critical Components**: Transaction processing, account management, authentication services.
    - **Monitoring**: Implement health checks for all critical services.
2. **Coordination Model**:
    - **Asynchronous Communication**: Use message queues to decouple services and improve resilience.
    - **Fallback Mechanisms**: If the primary authentication service fails, switch to a backup.
3. **Data Model**:
    - **Data Replication**: Use a distributed database system with data replicated across multiple nodes.
    - **Consistency Models**: Employ eventual consistency for non-critical data to improve availability.
4. **Mapping Among Architectural Elements**:
    - **Redundant Deployment**: Deploy services across multiple data centers.
    - **Load Balancing**: Distribute traffic evenly and reroute as needed.
5. **Resource Management**:
    - **Auto-Scaling**: Automatically scale resources up or down based on load.
    - **Resource Isolation**: Use containerization to isolate services and prevent cascading failures.
6. **Binding Time**:
    - **Dynamic Service Discovery**: Services register themselves at runtime, allowing for flexible reconfiguration.
7. **Choice of Technology**:
    - **Cloud Infrastructure**: Utilize cloud services that offer high availability guarantees.
    - **Proven Technologies**: Select databases and middleware with strong community support and reliability track records.

Outcome

By applying these tactics and considerations, the bank's online platform achieves:

- **Reduced Downtime**: Failures are quickly detected and mitigated.
- **Continuous Operation**: Customers experience minimal service interruptions.
- **Scalability**: The system adapts to increasing user demands without compromising availability.

Conclusion

Designing for availability is essential for modern software systems where downtime can have significant negative impacts. By understanding and applying availability tactics, architects can build systems that are resilient to faults and continue to meet user needs even under adverse conditions.

Key Takeaways:

- **Proactive Design**: Incorporate availability considerations early in the design process.
- **Comprehensive Approach**: Combine multiple tactics to address different aspects of availability.
- **Continuous Monitoring**: Implement robust monitoring to detect and respond to issues promptly.
- **Regular Testing**: Conduct failure drills and simulations to ensure the system behaves as expected during faults.

Understanding Performance in Software Architecture

Introduction

In software architecture, **performance** is a critical quality attribute that determines how well a system responds to demands in terms of time and resource utilization. Performance affects user satisfaction, system scalability, and overall effectiveness. This guide provides an in-depth understanding of performance in software architecture, covering:

- What is Performance?
- Performance General Scenario
- Tactics for Achieving Performance
- A Design Checklist for Performance
- Summary

We will explore each topic with clear explanations, examples, scenarios, case studies where appropriate, and descriptions of diagrams to enhance comprehension.

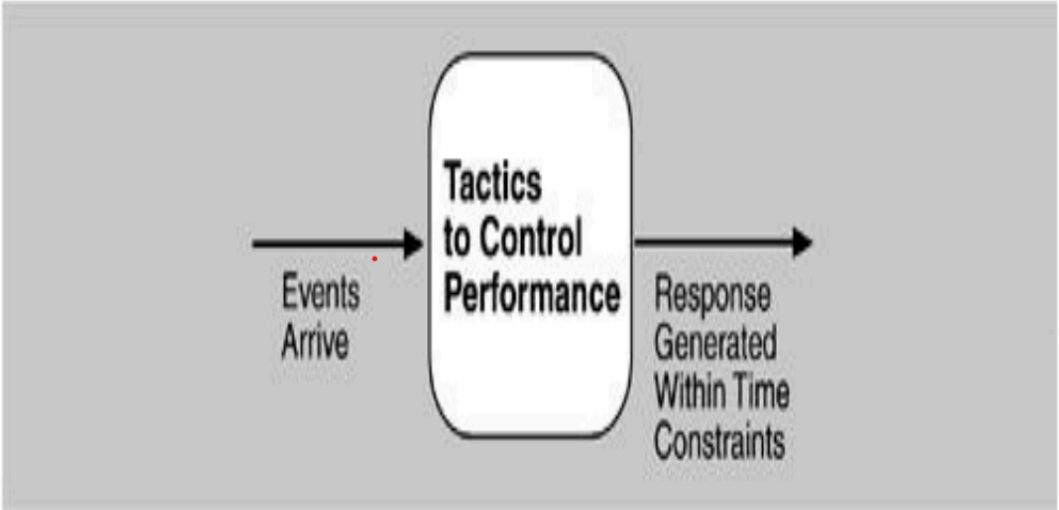
What is Performance?

Performance in software architecture refers to the system's ability to meet timing requirements and manage system resources efficiently under varying loads. It is about how quickly and efficiently a system can respond to events and process requests.

Key Aspects of Performance

- **Latency**: The time taken to respond to a specific event or request.
- **Throughput**: The amount of work or number of requests processed in a given time period.
- **Resource Utilization**: The amount of system resources (CPU, memory, network bandwidth) consumed while processing requests.
- **Scalability**: The system's ability to maintain performance levels when processing load increases.

Goal of Performance: Ensure that the system responds to events within acceptable time constraints while efficiently utilizing resources.



Performance General Scenario

To effectively design for performance, architects use **general scenarios** that describe potential situations affecting performance. A performance general scenario includes:

1. **Source of Stimulus**: The entity that generates events or requests (e.g., user, external system).
2. **Stimulus**: The event that requires processing (e.g., user action, data input, message arrival).
3. **Environment**: The conditions under which the stimulus occurs (e.g., normal operation, peak load).
4. **Artifact**: The part of the system that is stimulated (e.g., server, application component).
5. **Response**: The system's activity in response to the stimulus (e.g., processing the request).
6. **Response Measure**: Metrics to evaluate the response (e.g., latency, throughput).

Example General Scenario

- **Source of Stimulus**: External user.
- **Stimulus**: Sends a request to the system.
- **Environment**: During normal operation.
- **Artifact**: Web application server.
- **Response**:
    - The system processes the request.
    - Provides a response to the user.
- **Response Measure**:
    - Average latency of less than 2 seconds per request.
    - Ability to handle 1000 requests per second (throughput).

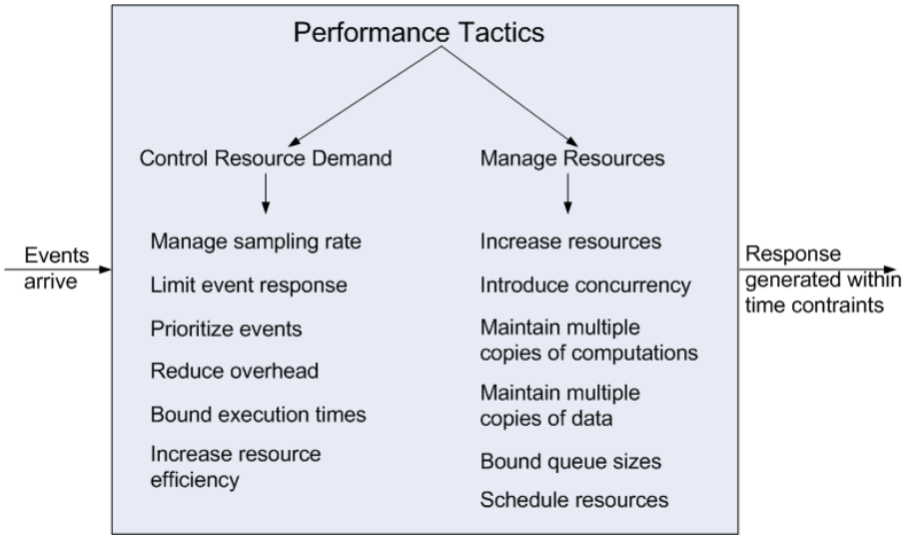
Sample Concrete Scenario

Scenario: In an **online shopping platform**, users initiate transactions during a sale event.

- **Source of Stimulus**: Multiple users.
- **Stimulus**: Initiate purchase transactions simultaneously.
- **Environment**: Peak load during a flash sale.
- **Artifact**: Transaction processing service.
- **Response**:
    - System processes transactions efficiently.
    - Confirms orders to users.
- **Response Measure**:
    - Average latency per transaction is under 3 seconds.
    - System handles up to 5000 transactions per minute.

Tactics for Achieving Performance

Tactics are architectural design decisions that influence the achievement of quality attributes like performance. Performance tactics help architects design systems that meet timing requirements and efficiently manage resources



Performance tactics are grouped into two main categories:

1. **Control Resource Demand**
2. **Manage Resources**

1. Control Resource Demand

These tactics aim to reduce the demand on system resources, thereby improving performance.

Common Tactics to Control Resource Demand

- **Manage Sampling Rate**: Reduce the frequency at which data is collected or processed.
    - *Example*: In a monitoring system, collect data every minute instead of every second to reduce load.
- **Limit Event Response**: Process events up to a maximum rate to prevent overload.
    - *Example*: Throttle API requests to a maximum of 1000 requests per minute per user.
- **Prioritize Events**: Assign priorities to events, processing critical ones first.
    - *Example*: In a real-time system, prioritize emergency alerts over routine data updates.
- **Reduce Overhead**: Remove unnecessary intermediaries or processing steps.
    - *Example*: Bypass middleware layers for performance-critical operations.
- **Bound Execution Times**: Set limits on how long operations can take.
    - *Example*: Implement timeouts for database queries that exceed 2 seconds.
- **Increase Resource Efficiency**: Optimize algorithms and data structures for better performance.
    - *Example*: Replace a quadratic time algorithm with a linear time algorithm.

2. Manage Resources

These tactics focus on optimizing the use of system resources to improve performance.

Common Tactics to Manage Resources

- **Increase Resources**: Add more or faster hardware resources.
    - *Example*: Upgrade servers to ones with faster CPUs and more RAM.
- **Increase Concurrency**: Process multiple requests in parallel.
    - *Example*: Use multithreading or deploy multiple instances of a service.
- **Maintain Multiple Copies of Computations**: Replicate processing components to reduce contention.
    - *Example*: Deploy multiple instances of a microservice behind a load balancer.
- **Maintain Multiple Copies of Data**: Use data replication or caching.
    - *Example*: Implement caching layers like Redis or Memcached for frequently accessed data.
- **Bound Queue Sizes**: Limit the size of queues to prevent resource exhaustion.
    - *Example*: Set a maximum queue length for incoming requests to 1000.
- **Schedule Resources**: Implement scheduling policies to manage resource access.
    - *Example*: Use priority-based scheduling for CPU resources.

A Design Checklist for Performance

When designing for performance, architects should consider the following aspects:

1. Allocation of Responsibilities

- **Identify Performance-Critical Responsibilities**: Determine which functionalities are time-sensitive or resource-intensive.
    - *Example*: In a video streaming service, streaming and encoding are performance-critical.
- **Analyze Processing Requirements**: Assess the processing demands of each responsibility.
    - *Example*: Determine CPU and memory usage for encoding high-definition videos.
- **Manage Threading and Concurrency**: Allocate responsibilities to threads or processes appropriately.
    - *Example*: Use separate threads for handling I/O operations and computation.

2. Coordination Model

- **Choose Appropriate Communication Mechanisms**: Select protocols and messaging systems that support performance goals.
    - *Example*: Use asynchronous messaging to decouple components and improve responsiveness.
- **Support Concurrency and Prioritization**: Ensure the coordination model handles concurrent operations and prioritizes critical tasks.
    - *Example*: Implement non-blocking I/O to prevent threads from waiting.

3. Data Model

- **Optimize Data Access and Storage**: Design data models for efficient read/write operations.
    - *Example*: Use denormalization in databases where read performance is critical.
- **Consider Data Partitioning and Replication**: Distribute data across multiple nodes or replicate for faster access.
    - *Example*: Shard a database by user ID to distribute load.
- **Use Caching Strategically**: Cache frequently accessed data to reduce database load.
    - *Example*: Cache user session data in memory.

4. Mapping Among Architectural Elements

- **Co-locate Components**: Place interdependent components close to each other to reduce communication latency.
    - *Example*: Deploy application servers and databases in the same data center.
- **Allocate Resources Based on Demand**: Assign resource-intensive components to powerful hardware.
    - *Example*: Run machine learning inference services on GPU-enabled servers.
- **Introduce Concurrency Where Beneficial**: Use parallel processing to handle heavy loads.
    - *Example*: Process batch jobs using a distributed computing framework like Apache Spark.

5. Resource Management

- **Identify Critical Resources**: Determine which resources (CPU, memory, network) impact performance.
- **Implement Monitoring and Management**: Use tools to monitor resource usage and manage allocation.
    - *Example*: Set up dashboards to track CPU and memory utilization.
- **Plan for Scalability**: Ensure the system can scale resources up or down based on load.
    - *Example*: Use auto-scaling groups in cloud environments.

6. Binding Time

- **Understand Binding Time Impact**: Late binding (runtime decisions) can introduce overhead.
- **Assess Performance Penalties**: Ensure that dynamic binding mechanisms do not adversely affect performance.
    - *Example*: Evaluate the overhead of using reflection in Java.

7. Choice of Technology

- **Select Technologies That Meet Performance Needs**: Choose frameworks and platforms known for high performance.
    - *Example*: Use high-performance web servers like Nginx.
- **Evaluate Technology Overhead**: Be aware of any performance costs associated with chosen technologies.
    - *Example*: Understand the garbage collection impact in JVM-based applications.

Case Study: Improving Performance in a Web Application

Scenario

A company operates an **e-commerce website** experiencing slow page load times, especially during peak shopping periods, leading to customer dissatisfaction and lost sales.

Design Approach

1. Analyze Performance Bottlenecks

- **Identify Slow Components**: Use profiling tools to find slow database queries and heavy server-side processing.

2. Control Resource Demand

- **Implement Caching**: Use caching for product data that doesn't change frequently.
    - *Example*: Cache product listings in memory to reduce database queries.
- **Optimize Images and Assets**: Reduce the size of images and combine assets to

decrease page load times.

3. Manage Resources

- **Increase Concurrency**
    - **Add Servers**: Scale horizontally by adding more web servers behind a load balancer.
    - **Use Content Delivery Networks (CDNs)**: Serve static content from CDNs to reduce load on the origin server.
- **Optimize Database Performance**
    - **Indexing**: Add appropriate indexes to speed up queries.
    - **Database Sharding**: Distribute the database across multiple servers.

4. Improve Application Code

- **Optimize Algorithms**: Refactor inefficient code, replacing nested loops with more efficient data structures.
- **Reduce Overhead**: Remove unnecessary middleware layers in performance-critical paths.
- Implement Asynchronous Processing

- **Background Jobs**: Move non-critical, long-running tasks to background processes.
    - *Example*: Send order confirmation emails asynchronously after the transaction is complete.

5. Monitoring and Resource Management

- **Set Up Monitoring Tools**: Use application performance monitoring (APM) tools to track performance metrics in real-time.
- **Auto-Scaling**: Configure auto-scaling policies to add resources during peak times automatically.

Outcome

By applying these tactics, the website achieves:

- **Reduced Latency**: Average page load times decrease from 5 seconds to under 2 seconds.
- **Improved Throughput**: The system handles increased traffic during peak periods without degradation.
- **Enhanced User Experience**: Faster response times lead to higher customer satisfaction and increased sales.

Summary

- **Performance** is about ensuring timely responses and efficient resource utilization

in software systems.

- **Performance General Scenarios** help in understanding and specifying performance requirements by outlining the source, stimulus, environment, artifact, response, and response measure.
- **Performance Tactics** include controlling resource demand and managing resources:
    - **Control Resource Demand**: Reduce load through tactics like managing sampling rates, limiting event responses, and optimizing code.
    - **Manage Resources**: Improve resource utilization by increasing resources, introducing concurrency, and optimizing data handling.
- **Design Checklist for Performance** guides architects in considering key aspects like allocation of responsibilities, coordination models, data models, mapping of elements, resource management, binding time, and technology choices.

- **Case Studies** illustrate practical applications of performance tactics to solve real-world problems.

Conclusion

Designing for performance is crucial for building responsive and efficient software systems. By understanding performance requirements and applying appropriate tactics, architects can ensure that systems meet user expectations and handle increasing loads gracefully.

Key Takeaways:

- **Early Consideration**: Address performance during the initial design phase, not as an afterthought.
- **Holistic Approach**: Combine multiple tactics and consider all aspects of the system.
- **Continuous Monitoring**: Implement monitoring to detect performance issues promptly.
- **Optimization and Scaling**: Regularly optimize code and plan for scalability.

By integrating these principles into software architecture, organizations can deliver high-performing systems that provide value to users and stakeholders

Understanding Usability and Other Quality Attributes in Software Architecture

Introduction

Software architecture plays a crucial role in determining not only the functionality but also the quality attributes of a system. Among these attributes, **usability** is vital as it directly impacts user satisfaction and productivity. Additionally, there are other important quality attributes that architects must consider to create robust, efficient, and user-friendly systems.

This guide covers:

1. **Usability**
    - What is Usability?
    - Usability General Scenario
    - Tactics for Usability
    - A Design Checklist for Usability
    - Summary
2. **Other Quality Attributes**
    - Other Important Quality Attributes
    - Other Categories of Quality Attributes
    - Software Quality Attributes and System Quality Attributes
    - Using Standard Lists of Quality Attributes
    - Dealing with "X-ability"
    - Summary

Throughout this document, we will provide clear explanations, examples, scenarios, and diagrams where appropriate to enhance understanding.

Part 1: Usability

What is Usability?

Usability refers to how easy and efficient it is for users to achieve their goals using a system. It encompasses the user's ability to learn, use, and interact with the software effectively and efficiently.

Key aspects of usability include:

- **Learning System Features**: How quickly can a new user become proficient?
- **Using the System Efficiently**: How effectively can a user accomplish tasks?
- **Minimizing the Impact of Errors**: How does the system help users recover from mistakes?
- **Adapting the System to User Needs**: Can users customize or configure the system to suit their preferences?
- **Increasing Confidence and Satisfaction**: Does the system provide a pleasant and satisfying user experience?

Importance of Usability:

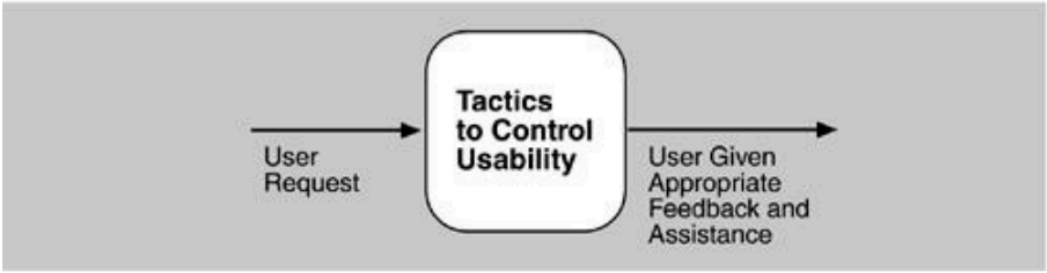
- Enhances user satisfaction and productivity.
- Reduces training and support costs.
- Increases adoption and user retention rates.

Example:

- A photo editing application that allows users to easily find tools, provides helpful tutorials, and offers undo/redo functionality contributes to better usability.

Usability General Scenario

To design for usability, architects create **general scenarios** that outline potential user interactions and how the system should respond.



Components of a Usability General Scenario:

1. **Source of Stimulus**: The user initiating an action.
2. **Stimulus**: The user's attempt to perform a task (e.g., learn, use efficiently, recover from errors).
3. **Environment**: The context in which the interaction occurs (e.g., runtime, configuration time).
4. **Artifact**: The part of the system the user interacts with.
5. **Response**: How the system assists or responds to the user's action.
6. **Response Measure**: Metrics to evaluate usability (e.g., task completion time, number of errors).

Example General Scenario:

- **Source**: End user.
- **Stimulus**: Attempts to learn a new feature.

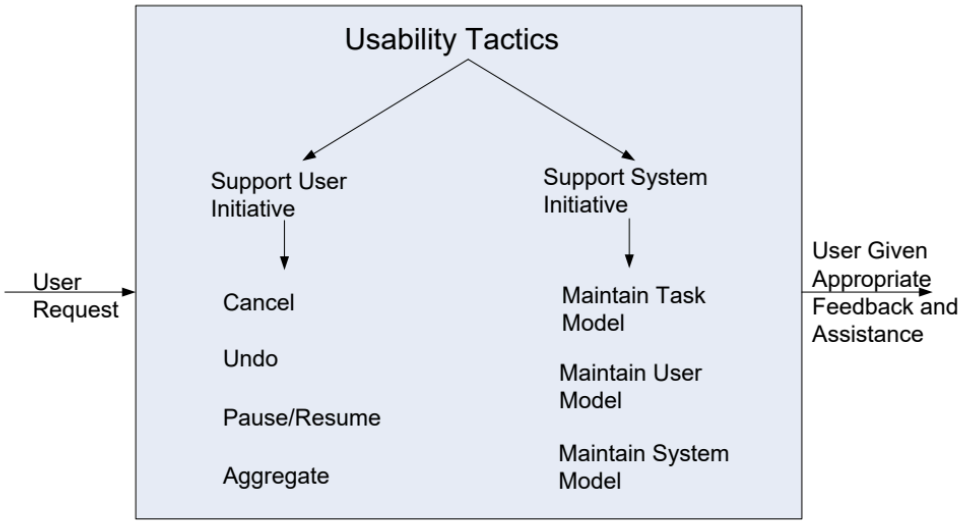
- **Environment**: While using the system at runtime.
- **Artifact**: User interface of the system.
- **Response**: The system provides intuitive guidance and tooltips.
- **Response Measure**: User learns the feature within 5 minutes with no external help.

Sample Concrete Scenario:

- A user downloads a new mobile app and starts using it productively within two minutes without needing a tutorial.

Tactics for Usability

Usability tactics are strategies architects employ to enhance the usability of a system. These tactics are divided based on whether they **support user initiative** or **system initiative**.



Support User Initiative

These tactics empower users to control their interactions with the system.

1. **Cancel**:
    - **Description**: Allow users to halt an ongoing operation.
    - **Implementation**:
        - System listens for cancel requests.
        - Terminates the operation gracefully.
        - Frees up resources.
        - Notifies other components if necessary.
    - **Example**: A user cancels a file download mid-way; the system stops downloading and cleans up partial files.
2. **Undo**:
    - **Description**: Enable users to revert to a previous state.
    - **Implementation**:
        - System maintains a history of actions.
        - Provides an undo stack.
    - **Example**: A text editor allows users to undo their last typing or formatting action.
3. **Pause/Resume**:

- **Description**: Let users temporarily halt and later continue an operation.
- **Implementation**:
  - System saves the current state.
  - Frees resources for other tasks.
- **Example**: A video player allows pausing and resuming playback.

4. **Aggregate**:
   - **Description**: Allow users to group multiple elements and apply actions collectively.
   - **Implementation**:
     - Provide mechanisms to select and manipulate groups.
   - **Example: Selecting multiple emails to delete them all at once.**

Support System Initiative

These tactics enable the system to assist users proactively.

1. **Maintain Task Model**:
   - **Description**: System understands the user's current task.
   - **Implementation**:
     - Track user actions to infer context.
     - Provide relevant assistance or shortcuts.
   - **Example**: An email client suggests recipients based on the email content.
2. **Maintain User Model**:
   - **Description**: System adapts to the user's preferences and expertise.
   - **Implementation**:
     - Store user settings and behavior patterns.
   - **Example**: A software application adjusts the complexity of menus based on user proficiency.
3. **Maintain System Model**:
   - **Description**: System keeps an explicit model of its own state.
   - **Implementation**:
     - Provide feedback on system status.
     - Anticipate and handle potential errors.
   - **Example**: A printer driver informs the user about ink levels and potential issues before printing.

Diagram: Usability Tactics Overview

Imagine a diagram with two main branches:

- **Support User Initiative:**
  - Cancel
  - Undo
  - Pause/Resume
  - Aggregate
- **Support System Initiative**:
  - Maintain Task Model
  - Maintain User Model
  - Maintain System Model

A Design Checklist for Usability

When designing for usability, architects should consider the following aspects:

1. Allocation of Responsibilities

- **Ensure Additional Responsibilities**:
  - Assist users in learning the system.
  - Help users achieve tasks efficiently.
  - Provide means for adapting and configuring the system.
  - Facilitate recovery from errors.
- **Example:**
  - Implement a help system or tutorial mode for new users.

2. Coordination Model

- **Assess Coordination Properties**:
  - Timeliness: Can the system respond quickly to user actions?
  - Consistency: Are the system's responses predictable?
  - Correctness: Does the system behave as expected?
- **Example**:
  - Ensure that clicking a button provides immediate feedback.

3. Data Model

- **Design User-Perceivable Data Abstractions**:
  - Support undo and cancel operations.
  - Ensure data operations are efficient and intuitive.
- **Example**:
  - In a drawing application, shapes can be grouped and manipulated together.

4. Mapping Among Architectural Elements

- **Visibility to End Users**:
  - Determine which components are exposed to users (e.g., local vs. remote services).
  - Ensure this visibility aids usability.
- **Example**:
  - A cloud-based application abstracts network details, so users don't need to know where data is stored.

5. Resource Management

- **User Control Over Resources**:
  - Allow users to configure resource usage without compromising performance.
- **Example**:
  - Let users set preferences for image quality vs. performance in a graphics application.

6. Binding Time

- **User-Controlled Binding Decisions**:
  - Enable users to make runtime choices that enhance usability.

- **Example**:
    - Allow users to install plugins to extend functionality.

7. Choice of Technology

- **Select Technologies That Enhance Usability:**
    - Support creation of help systems, user feedback mechanisms.
    - Ensure technologies do not hinder usability.
- **Example**:
    - Choose a UI framework that supports accessibility features.

Case Study: Enhancing Usability in an Email Client

Scenario:

A software company is developing a new email client and wants to prioritize usability to differentiate it from competitors.

Design Approach:

1. **Support User Initiative**:
    - **Undo Send**: Allow users to recall emails within a few seconds of sending.
    - **Aggregate Actions**: Enable users to select multiple emails and apply actions like delete or move.
2. **Support System Initiative**:
    - **Maintain User Model**: Adapt suggestions based on user's emailing habits (e.g., frequent contacts).
    - **Maintain System Model**: Notify users of connectivity issues and provide offline mode.
3. **Design Checklist Application**:
    - **Allocation of Responsibilities**:
        - Include a comprehensive search function to help users find emails efficiently.
    - **Coordination Model**:
        - Ensure quick response times when opening emails or switching folders.
    - **Data Model**:
        - Implement efficient data synchronization to keep emails up-to-date without lag.
    - **Mapping Among Elements**:
        - Hide complexity of email protocols; present a simple interface.
    - **Resource Management**:
        - Allow users to set limits on data usage, beneficial for metered connections.
    - **Binding Time**:
        - Provide options to add third-party integrations at runtime.

Outcome:

- Users find the email client intuitive and efficient.
- Positive feedback highlights features like undo send and personalized suggestions.

- Adoption rates increase due to the enhanced usability.

Summary

Usability is a critical quality attribute that directly affects user satisfaction and system adoption. By employing tactics that support both user and system initiatives, architects can design systems that are easy to learn, efficient to use, and adaptable to user needs.

Key takeaways:

- **Empower Users**: Provide control through features like cancel, undo, and customization.
- **Proactive Assistance**: Use system initiative tactics to anticipate user needs.
- **Design Thoughtfully**: Apply the design checklist to ensure all aspects of usability are considered.

Part 2: Other Quality Attributes

Beyond usability, there are several other quality attributes that architects must consider to ensure a comprehensive and effective software system.

Other Important Quality Attributes

1. Variability

- **Definition**: The ability of a system to support the production of different variants in a planned manner.
- **Importance**: Facilitates product line development where a core system is adapted for different markets or customers.

Example:

- A mobile operating system that can be customized by different manufacturers to include specific features.

2. Portability

- **Definition**: The ease with which software can be transferred from one environment to another.
- **Importance**: Allows software to run on multiple platforms, increasing its reach and usability.

Example:

- A web application that works seamlessly across different browsers and devices.

3. Development Distributability

- **Definition**: The quality that supports distributed software development across different teams or locations.
- **Importance**: Enables collaboration in large or global projects.

Example:

- Using microservices architecture to allow different teams to develop services independently.

4. Scalability

- **Definition**: The ability of a system to handle increased load by adding resources.
    - **Horizontal Scaling (Scaling Out)**: Adding more nodes to a system (e.g., adding servers to a cluster).
    - **Vertical Scaling (Scaling Up)**: Adding more resources to existing nodes (e.g., increasing CPU or memory).

Example:

- A social media platform scales horizontally by adding servers to handle more users.

5. Deployability

- **Definition**: How easily and quickly a system can be deployed to its target environment.
- **Importance**: Affects the speed of delivering updates and new features.

Example:

- Using containerization (e.g., Docker) to simplify deployment processes.

6. Mobility

- **Definition**: The ability of the system to support users on the move, considering device constraints.
- **Importance**: Essential for applications targeting mobile devices.

Example:

- A mobile banking app optimized for different screen sizes and varying network conditions.

7. Monitorability

- **Definition**: The ability of operations staff to monitor the system's performance and health.
- **Importance**: Critical for maintaining system reliability and performance.

Example:

- Implementing logging and monitoring tools like Prometheus and Grafana.

8. Safety

- **Definition**: The ability of the system to avoid causing harm and to recover from hazardous states.
- **Importance**: Vital in systems where failures can lead to injury or loss of life.

Example:

- An autonomous vehicle system includes safety mechanisms to prevent accidents.

Other Categories of Quality Attributes

1. Conceptual Integrity

- **Definition**: Consistency in design and approach throughout the system.
- **Importance**: Improves understandability and maintainability.

Example:

- Using a consistent coding style and architectural patterns across all modules.

2. Marketability

- **Definition**: The degree to which the system's architecture enhances its appeal in the marketplace.
- **Importance**: Can be a differentiator in competitive markets.

Example:

- Advertising a product as "cloud-based" or "AI-powered" to attract customers.

3. Quality in Use

- **Definition**: Attributes that affect the user's experience with the system.
- **Effectiveness**: Accuracy and completeness in achieving goals.
- **Efficiency**: Resources expended in relation to the results achieved.
- **Freedom from Risk**: Mitigating potential negative consequences.

Example:

- A medical application that provides accurate diagnostics efficiently while ensuring patient data privacy.

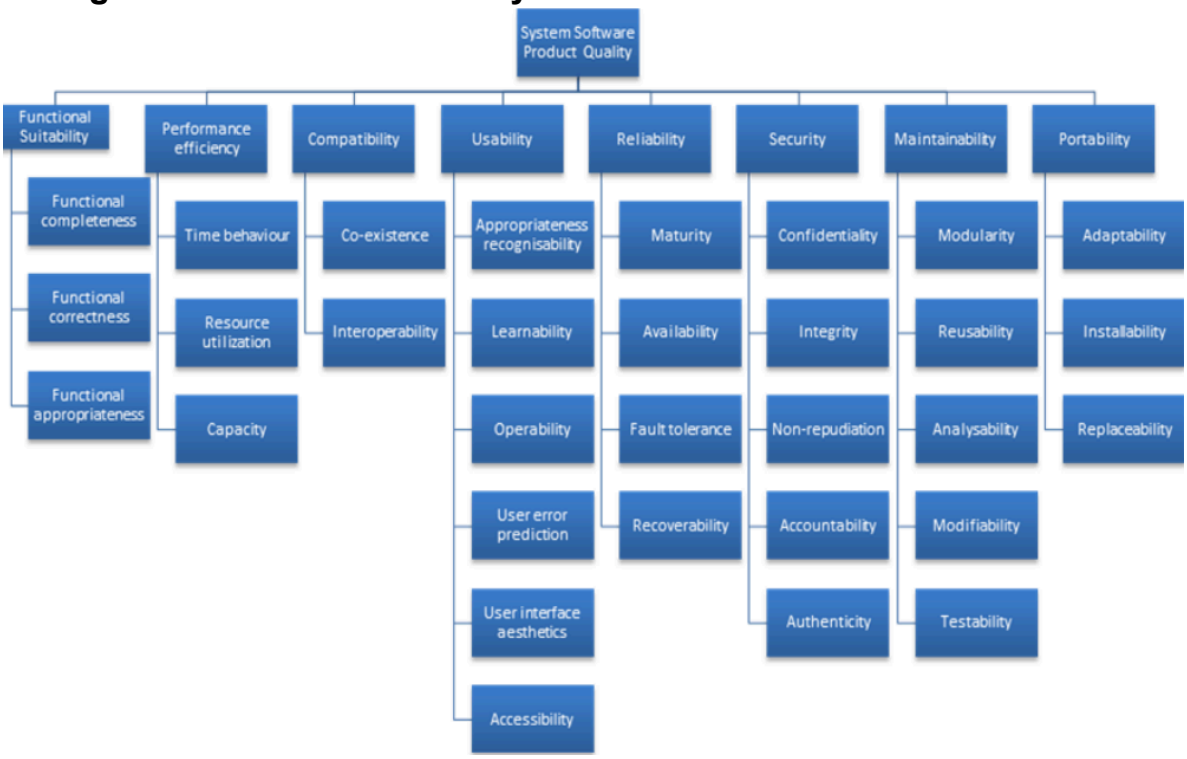
Software Quality Attributes and System Quality Attributes

Software systems often exist within larger physical systems (e.g., cars, airplanes) that have their own quality attributes like weight, power consumption, or durability. The software architecture can significantly influence these system-level attributes.

Example:

- In an electric vehicle, software efficiency can impact battery life, affecting the vehicle's range.

Using Standard Lists of Quality Attributes



Standards like the **ISO/IEC 25010** provide comprehensive lists of quality attributes.

Advantages

- **Completeness**: Helps ensure no important quality attributes are overlooked.
- **Consistency**: Provides a common language and understanding.
- **Guidance**: Assists in requirements gathering and architectural decision-making.

Disadvantages

- **Complexity**: Lists can be extensive and overwhelming.
- **Controversy**: Different interpretations can lead to misunderstandings.
- **Irrelevance**: Some attributes may not apply to the specific system being designed.

Dealing with "X-ability"

When faced with a quality attribute not well-defined in literature (e.g., "green computing"), architects can:

1. **Model the Quality Attribute**:
    - Define what it means in the context of the system.
    - Identify how it impacts architecture.
2. **Assemble a Set of Tactics**:
    - Develop strategies to achieve the desired attribute.
    - Adapt existing tactics where possible.
3. **Construct Design Checklists**:
    - Create guidelines to ensure the attribute is considered throughout design.

Example:

- For "green computing," tactics might include optimizing code for energy efficiency, using energy-efficient hardware, and implementing power-saving modes.

Summary

Architects must consider a wide range of quality attributes beyond the commonly discussed ones like performance and security. While standard lists provide a starting point, it's essential to tailor considerations to the specific context and requirements of the system.

Key takeaways:

- **Holistic Approach**: Consider all relevant quality attributes to create a well-rounded system.
- **Customization**: Adapt tactics and checklists to address unique or emerging attributes.
- **Continuous Learning**: Stay informed about new quality concerns and how they affect architecture.

Overall Conclusion

Understanding and addressing usability and other quality attributes is crucial in software architecture. By applying appropriate tactics and design considerations, architects can build systems that meet user needs, perform efficiently, and adapt to changing requirements.

Final Tips:

- **Engage Stakeholders**: Involve users, developers, and other stakeholders to understand priorities.
- **Iterative Design**: Continuously refine the architecture based on feedback and testing.
- **Documentation**: Keep detailed records of decisions and rationales for future reference.

By integrating these practices, architects can ensure that their systems are not only functionally sound but also excel in quality attributes that matter most to users and stakeholders.

Understanding Security in Software Architecture

Introduction

In the modern digital landscape, **security** is a paramount concern in software architecture. As systems become more interconnected and handle sensitive data, protecting them from unauthorized access and malicious activities is crucial. This guide provides an in-depth understanding of security in software architecture, covering:

- What is Security?
- Security General Scenario
- Tactics for Achieving Security
- A Design Checklist for Security
- Summary

We will explore each topic with clear explanations, examples, scenarios, case studies where appropriate, and descriptions of diagrams to enhance comprehension.

What is Security?

Security in software architecture is the measure of a system's ability to protect data and services from unauthorized access, misuse, or malicious attacks while still providing functionality to authorized users.

Key Security Principles (CIA Triad)

Security revolves around three main principles, often referred to as the **CIA Triad**:

1. **Confidentiality**: Ensuring that sensitive information is accessible only to those authorized to have access.
    - *Example*: A user's personal data is encrypted and can only be viewed by the user and authorized personnel.
2. **Integrity**: Maintaining the accuracy and completeness of data over its entire lifecycle.
    - *Example*: A banking transaction is processed correctly without unauthorized alteration.
3. **Availability**: Ensuring that information and resources are available to authorized users when needed.

    - *Example*: A website remains accessible to legitimate users even during high traffic or attempted denial-of-service attacks.

Supporting Security Characteristics

In addition to the CIA triad, other important security characteristics include:

- **Authentication**: Verifying the identity of users or systems.
    - *Example*: A login system requires a username and password to authenticate users.
- **Authorization**: Granting or denying users' access to resources based on their permissions.
    - *Example*: An employee can access internal company files relevant to their department but not others.
- **Non-repudiation**: Ensuring that a party in a transaction cannot deny the authenticity of their signature or the sending of a message they originated.
    - *Example*: Digital signatures on documents prevent signers from denying their involvement.

Types of Security Threats

- **Attacks**: Actions taken against a system with the intention of causing harm or unauthorized access.
    - **External Attacks**: From outside the organization (e.g., hackers).
    - **Internal Attacks**: From within the organization (e.g., disgruntled employees).
- **Common Attack Forms**:
    - Unauthorized data access or modification.
    - Denial-of-Service (DoS) attacks to disrupt services.
    - Phishing attempts to steal user credentials.

Security General Scenario

To design secure systems, architects use **general scenarios** that describe potential security threats and system responses.

Components of a Security General Scenario

1. **Source of Stimulus**: The entity initiating an attack or unauthorized action.
    - Examples: External hacker, internal employee, malicious software.
2. **Stimulus**: The attack or unauthorized attempt.
    - *Examples*: Attempt to access data, modify data, disrupt services.
3. **Environment**: The conditions under which the attack occurs.

    - *Examples*: System online or offline, behind a firewall, during peak hours.
4. **Artifact**: The part of the system being targeted.
    - *Examples*: Database, authentication service, network resources.
5. **Response**: How the system should respond to the attack.
    - *Examples*: Deny access, alert administrators, log the attempt.
6. **Response Measure**: Metrics to evaluate the effectiveness of the response.
    - *Examples*: Time to detect the attack, extent of damage prevented.

Example General Scenario

- **Source of Stimulus**: External attacker (unknown hacker).
- **Stimulus**: Attempts to gain unauthorized access to confidential data.
- **Environment**: System is online and connected to the internet.
- **Artifact**: User account database.
- **Response**:
    - System detects the unauthorized access attempt.
    - Blocks the attacker by denying access.
    - Logs the incident and notifies security personnel.
- **Response Measure**:
    - Attack detected within 5 seconds.
    - No data compromised.
    - Security team alerted immediately.

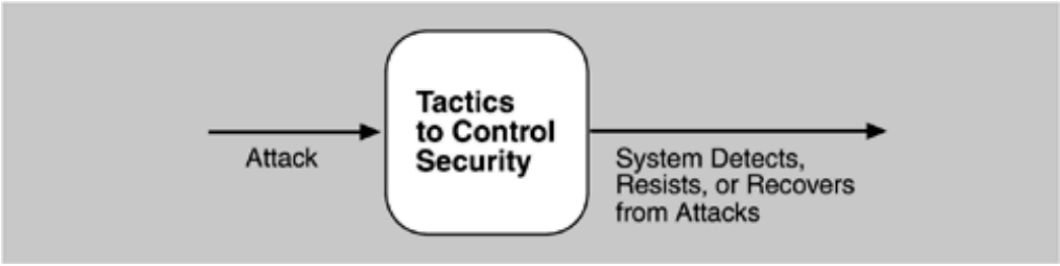
Sample Concrete Scenario

Scenario: A disgruntled employee tries to modify the payroll data remotely during normal operations.

- **Source of Stimulus**: Disgruntled internal employee.
- **Stimulus**: Unauthorized attempt to alter the pay rate table.
- **Environment**: System operating under normal conditions.
- **Artifact**: Payroll database.
- **Response**:
    - System detects unauthorized modification attempt.
    - Blocks the action and revokes the employee's access.
    - Records the incident in an audit log.
    - Notifies the system administrator.
- **Response Measure**:
    - Unauthorized access attempt detected immediately.
    - No changes made to the payroll data.
    - System administrator notified within 1 minute.

Tactics for Achieving Security

Security tactics are design strategies that architects use to protect a system from attacks and ensure the CIA principles are upheld. These tactics are grouped into four main categories:



1. **Detect Attacks**
2. **Resist Attacks**
3. **React to Attacks**
4. **Recover from Attacks**

1. Detect Attacks

These tactics focus on identifying potential security breaches or suspicious activities.

Common Tactics:

- **Intrusion Detection**:
    - **Description**: Monitor system activities to detect signs of malicious behavior.
    - **Implementation**:
        - Use intrusion detection systems (IDS) to compare network traffic patterns against known attack signatures.
    - **Example**: An IDS alerts administrators when unusual login attempts are detected.
- **Service Denial Detection**:
    - **Description**: Identify patterns indicating a Denial-of-Service (DoS) attack.
    - **Implementation**:
        - Monitor network traffic for excessive requests that match DoS attack profiles.
    - **Example**: Detecting a flood of requests from a single IP address aiming to overwhelm the server.
- **Message Integrity Verification**:
    - **Description**: Ensure messages have not been tampered with during transit.
    - **Implementation**:
        - Use checksums or hash functions to validate message integrity.
    - **Example**: Verifying a file's checksum after download to ensure it's not corrupted or altered.
- **Message Delay Detection**:
    - **Description**: Detect delays that may indicate message interception or replay attacks.
    - **Implementation**:

        - Monitor message delivery times and flag significant delays.
    - **Example**: Detecting delayed authentication responses that could signify a man-in-the-middle attack.

2. Resist Attacks

These tactics aim to prevent unauthorized access and mitigate vulnerabilities.

Common Tactics:

- **Identify and Authenticate Actors**:
    - **Description**: Verify the identity of users and systems.
    - **Implementation**:
        - Require credentials like passwords, biometrics, or digital certificates.
    - **Example**: Using multi-factor authentication (MFA) for user logins.
- **Authorize Actors**:
    - **Description**: Grant access rights based on authenticated identity.
    - **Implementation**:
        - Implement role-based access control (RBAC).
    - **Example**: Only administrators can modify system configurations.
- **Limit Access**:
    - **Description**: Restrict access to resources to minimize potential damage.
    - **Implementation**:
        - Use firewalls, network segmentation, and least privilege principles.
    - **Example**: Employees can only access files relevant to their role.
- **Encrypt Data**:
    - **Description**: Protect data confidentiality during storage and transmission.
    - **Implementation**:
        - Use encryption algorithms like AES for data at rest and TLS for data in transit.
    - **Example**: Encrypting database fields containing sensitive information.
- **Separate Entities**:
    - **Description**: Isolate critical components to prevent lateral movement by attackers.
    - **Implementation**:
        - Deploy critical services on separate servers or virtual machines.
    - **Example**: Hosting the database server on a different network segment from the web server.
- **Change Default Settings**:
    - **Description**: Force changes to default configurations that may be insecure.
    - **Implementation**:
        - Require users to set strong passwords during initial setup.
    - **Example**: Prompting users to change default administrative passwords.

3. React to Attacks

These tactics define how the system responds when an attack is detected.

Common Tactics:

- **Revoke Access**:
    - **Description**: Temporarily or permanently remove access rights.
    - **Implementation**:
        - Automatically disable user accounts after suspicious activity.
    - **Example**: Locking an account after multiple failed login attempts.
- **Lock Computer/Resource**:
    - **Description**: Restrict access to resources under attack.
    - **Implementation**:
        - Isolate affected systems from the network.
    - **Example**: Disconnecting a compromised server to prevent further damage.
- **Inform Actors**:
    - **Description**: Notify relevant parties about the attack.
    - **Implementation**:
        - Send alerts to administrators and potentially affected users.
    - **Example: Emailing the security team when an intrusion is detected.**

4. Recover from Attacks

These tactics focus on restoring normal operations and minimizing damage.

Common Tactics:

- **Audit**:
    - **Description**: Keep records of system activities to investigate incidents.
    - **Implementation**:
        - Log all access attempts, changes, and transactions.
    - **Example**: Reviewing logs to trace how an attacker gained access.
- **Backup and Restore**:
    - **Description**: Regularly backup data and have procedures to restore it.
    - **Implementation**:
        - Automated backup systems with secure storage.
    - **Example**: Restoring a database from backups after data corruption.
- **Redundancy**:
    - **Description**: Use redundant components to ensure availability.
    - **Implementation**:
        - Implement failover systems and load balancers.
    - **Example**: A secondary server takes over if the primary server fails.

A Design Checklist for Security

When designing for security, architects should systematically consider various aspects to ensure comprehensive protection.

1. Allocation of Responsibilities

- **Identify Security-Critical Responsibilities**:
    - Determine which system functions need to be secured.
- **Implement Security Measures**:
    - **Identify Actors**: Determine who interacts with the system.
    - **Authenticate Actors**: Verify identities using appropriate methods.
    - **Authorize Access**: Define access controls based on roles and permissions.
    - **Encrypt Data**: Protect sensitive data at rest and in transit.
    - **Log Activities**: Record access attempts and system changes.
    - **Monitor Resources**: Detect unusual activities or resource usage.
    - **Prepare for Recovery**: Have plans for responding to security incidents.

Example:

- In a financial application, ensure that all transactions are authenticated, authorized, and logged.

2. Coordination Model

- **Secure Communication Channels**:
    - Use secure protocols (e.g., HTTPS, SSH) for data transmission.
- **Authenticate Systems**:
    - Verify the identity of external systems communicating with your system.
- **Monitor Connections**:
    - Detect and handle unexpected connection patterns.

Example:

- An API requires clients to present valid API keys and uses TLS for encryption.

3. Data Model

- **Classify Data Sensitivity**:
    - Identify which data is sensitive and requires protection.
- **Implement Access Controls**:
    - Enforce permissions at the data level.
- **Encrypt Sensitive Data**:
    - Use strong encryption methods.
- **Protect Data Integrity**:
    - Use checksums or digital signatures.

Example:

- Encrypting user passwords in the database using bcrypt hashing.

4. Mapping Among Architectural Elements

- **Assess Security Impact of Deployment**:
    - Understand how component placement affects security.
- **Implement Network Segmentation**:
    - Isolate critical components.
- **Ensure Secure Interactions**:
    - Secure all interfaces between components.

Example:

- Deploying the database server behind a firewall separate from the application server.

5. Resource Management

- **Protect Critical Resources**:
    - Monitor resource usage to prevent exhaustion (e.g., memory, CPU).
- **Limit Exposure**:
    - Restrict access to resources only to necessary components.
- **Implement Quotas and Limits**:
    - Prevent abuse of resources.

Example:

- Setting rate limits on API calls to prevent DoS attacks.

6. Binding Time

- **Secure Late Binding Components**:
    - Validate and authenticate dynamically loaded modules.
- **Manage Dependencies**:
    - Ensure third-party components are secure and trusted.
- **Restrict Access for Untrusted Components**:
    - Sandbox or isolate untrusted code.

Example:

- Verifying digital signatures of plugins before loading them into the application.

7. Choice of Technology

- **Select Secure Technologies**:
    - Choose platforms and libraries with strong security features.
- **Stay Updated**:
    - Use the latest versions to benefit from security patches.

- **Evaluate Security Support**:
    - Consider the community and vendor support for security issues.

Example:

- Using a web framework that provides built-in protection against SQL injection and cross-site scripting (XSS).

Case Study: Securing an Online Banking System

Scenario:

A bank is developing an online banking platform and needs to ensure high security to protect customer data and transactions.

Design Approach

1. Allocation of Responsibilities

- **Authentication and Authorization**:
    - Implement multi-factor authentication (MFA).
    - Use role-based access control to restrict user permissions.
- **Data Encryption**:
    - Encrypt sensitive data in the database.
    - Use HTTPS with strong TLS configurations for all communications.
- **Logging and Monitoring**:
    - Log all user activities and system events.
    - Monitor for suspicious activities (e.g., multiple failed login attempts).

2. Coordination Model

- **Secure Communication**:
    - Use secure APIs with authentication tokens.
- **System Authentication**:
    - Verify identities of third-party services (e.g., credit bureaus).

3. Data Model

- **Data Classification**:
    - Identify PII (Personally Identifiable Information) and financial data.
- **Access Controls**:
    - Restrict database access to necessary services.
- **Data Integrity**:

    - Implement checksums for transaction data.

4. Mapping Among Architectural Elements

- **Network Segmentation**:
    - Separate public-facing web servers from internal servers.
- **Firewalls and Gateways**:
    - Use firewalls to control traffic between network segments.

5. Resource Management

- **Rate Limiting**:
    - Prevent abuse by limiting transaction rates per user.
- **Resource Monitoring**:
    - Detect unusual resource usage that may indicate an attack.

6. Binding Time

- **Secure Plugins and Extensions**:
    - Validate any third-party components before integration.
- **Runtime Checks**:
    - Perform integrity checks on dynamically loaded modules.

7. Choice of Technology

- **Secure Frameworks**:
    - Use frameworks with built-in security features.
- **Updated Libraries**:
    - Keep all dependencies up-to-date with security patches.

Outcome

By applying these security tactics:

- **Enhanced Security**: The platform resists unauthorized access and protects user data.
- **Compliance**: Meets regulatory requirements like PCI DSS for handling financial data.
- **User Trust**: Customers have confidence in the security of their online transactions.

Diagrams

Diagram 1: Security Tactics Overview

Imagine a hierarchical diagram illustrating the security tactics categories and their tactics:

- **Security Tactics**
  - **Detect Attacks**
    - Intrusion Detection
    - Service Denial Detection
    - Message Integrity Verification
    - Message Delay Detection
  - **Resist Attacks**
    - Identify and Authenticate Actors
    - Authorize Actors
    - Limit Access
    - Encrypt Data
    - Separate Entities
    - Change Default Settings
  - **React to Attacks**
    - Revoke Access
    - Lock Computer/Resource
    - Inform Actors
  - **Recover from Attacks**
    - Audit
    - Backup and Restore
    - Redundancy

Diagram 2: Security General Scenario Flow

Visual representation of how a security general scenario unfolds:

1. **Source of Stimulus**
   - External attacker
2. **Stimulus**
   - Unauthorized access attempt
3. **Environment**
   - System online
4. **Artifact**
   - Database server
5. **Response**
   - Detect attack
   - Resist attack by denying access
   - React by informing administrators
6. **Response Measure**
   - Time to detect
   - No data compromised

Summary

Security in software architecture is essential for protecting systems from malicious attacks and unauthorized access. By understanding the key principles of confidentiality, integrity, and availability, and by employing strategic security tactics, architects can design robust systems that safeguard data and services.

Key Takeaways:

- **Proactive Design**: Incorporate security considerations from the beginning.
- **Layered Defense**: Use multiple tactics to provide defense-in-depth.
- **Continuous Monitoring**: Implement mechanisms to detect and respond to attacks promptly.
- **Regular Updates**: Keep systems and components updated with the latest security patches.
- **Education and Policies**: Ensure that users and administrators understand security policies and best practices.

By following the design checklist and applying appropriate tactics, architects can build secure systems that maintain user trust and comply with legal and ethical standards.

Understanding Modifiability in Software Architecture

Introduction

In software architecture, **modifiability** is a critical quality attribute that focuses on the ease and cost-effectiveness with which a system can accommodate changes. Modifiability concerns itself with managing change and minimizing the risks and expenses associated with modifying a system.

This guide covers:

- **What is Modifiability?**
- **Modifiability General Scenario**
- **Tactics for Modifiability**
- **A Design Checklist for Modifiability**
- **Summary**

We will explore each topic with clear explanations, examples, scenarios, and diagrams where appropriate to enhance understanding.

What is Modifiability?

Modifiability refers to the ability of a software system to undergo changes with minimal impact on existing functionality and quality attributes. It is about preparing for change and controlling the costs and risks associated with making modifications.

Key Questions in Modifiability Planning

When planning for modifiability, architects consider the following questions:

1. **What can change?**
    - Identifying potential areas of change, such as functionality, quality attributes, capacity, or technology.
2. **What is the likelihood of the change?**
    - Estimating the probability of changes based on technical, legal, social, business, and customer factors.
3. **When is the change made and who makes it?**

- Determining the timing of the change (design time, compile time, build time, runtime) and the stakeholders involved (developers, system administrators, end-users).

Modifiability General Scenario

To effectively design for modifiability, architects use **general scenarios** that describe potential changes and their impact on the system.

Components of a Modifiability General Scenario

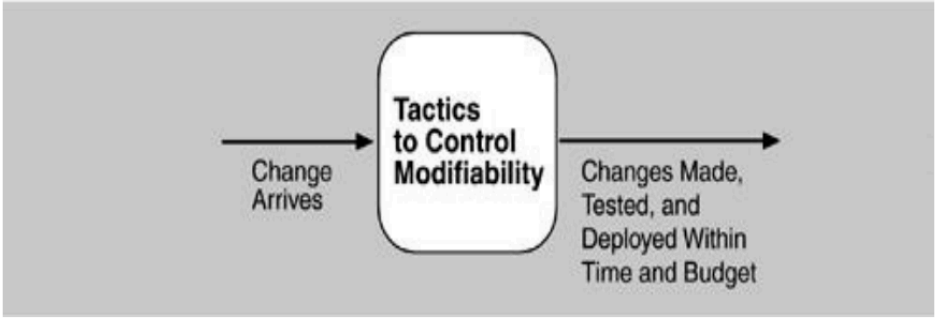
1. **Source of Stimulus**: Who initiates the change?
   - *Possible Values*: End-user, developer, system administrator.
2. **Stimulus**: What triggers the need for modification?
   - *Possible Values*: Directive to add/delete/modify functionality, change a quality attribute, capacity, or technology.
3. **Artifacts**: What parts of the system are affected?
   - *Possible Values*: Code, data, interfaces, components, resources, configurations.
4. **Environment**: Under what conditions is the change made?
   - *Possible Values*: Runtime, compile time, build time, initiation time, design time.
5. **Response**: How does the system accommodate the change?
   - The system should allow the modification to be made with controlled effort and minimal side effects.
6. **Response Measure**: How do we measure the impact of the change?
   - *Possible Values*:
     - Number, size, complexity of affected artifacts.
     - Effort, calendar time, cost.
     - Extent to which the modification affects other functions or quality attributes.
     - New defects introduced.

Sample Concrete Modifiability Scenario

- **Scenario**: A developer wishes to change the user interface by modifying the code at design time. The modifications are made with no side effects within three hours.

Tactics for Modifiability

Tactics are design decisions that influence the achievement of modifiability. They aim to control the complexity, time, and cost of making changes to a system.



Goals of Modifiability Tactics

- **Control Complexity**: Simplify the system to make changes easier.
- **Reduce Time and Cost**: Minimize the effort required to implement changes.
- **Minimize Side Effects**: Prevent changes from negatively impacting other system parts.

Modifiability Tactics Overview

Figure: Modifiability tactics categorized by their goals.

1. Reduce Size of Modules

- **Split Module**: Break down large modules into smaller, more manageable ones.
    - **Description**: If a module is large and complex, splitting it into smaller modules can reduce the cost and complexity of making changes.
    - **Example**: A single module handling both user authentication and data processing is split into two separate modules.

2. Increase Cohesion

- **Increase Semantic Coherence**: Ensure that the responsibilities within a module are closely related.
    - **Description**: Responsibilities that serve different purposes should be placed in separate modules to increase cohesion.
    - **Example**: Separating logging functionality from data processing logic into different modules.

3. Reduce Coupling

- **Encapsulate**:
    - **Description**: Introduce explicit interfaces to modules, hiding internal implementations.
    - **Example**: A database access module exposes an API for data operations without revealing underlying database details.
- **Use an Intermediary**:
    - **Description**: Break dependencies between modules by introducing an

intermediary component.
    - **Example**: Implementing a facade or adapter that mediates interactions between subsystems.
- **Restrict Dependencies**:
    - **Description**: Limit the modules that a given module depends on.
    - **Example**: A utility module is designed to be self-contained, avoiding dependencies on other modules.
- **Refactor**:
    - **Description**: Reorganize code to eliminate duplication and improve structure without changing external behavior.
    - **Example**: Merging duplicate functions from different modules into a single, shared function.
- **Abstract Common Services**:
    - **Description**: Generalize similar services into a single, abstract service.
    - **Example**: Creating a common authentication service used by multiple applications.

4. Defer Binding

- **Defer Binding Time**:
    - **Description**: Delay the binding of certain decisions until later in the development process (e.g., runtime).
    - **Example**: Using configuration files to specify behavior that can be changed without modifying code.

A Design Checklist for Modifiability

When designing for modifiability, architects should consider the following aspects:

1. Allocation of Responsibilities

- **Identify Likely Changes**: Consider changes due to technical, legal, social, business, and customer forces.
- **Group Related Responsibilities**: Allocate responsibilities that are likely to change together into the same module.
- **Separate Independent Responsibilities**: Place responsibilities that change at different times into separate modules.
- **Example**: In a web application, separate the presentation layer from the business logic to allow independent changes.

2. Coordination Model

- **Assess Coordination Changes**: Determine if functionality or quality attributes that can change at runtime affect coordination.
- **Limit Impact of Changes**: Ensure that changes affect only a small set of modules.
- **Use Decoupled Coordination Mechanisms**: Implement patterns like publish/subscribe

or use an enterprise service bus.

- **Example**: Using event-driven architecture to decouple components and allow independent evolution.

3. Data Model

- **Determine Data Changes**: Identify which data abstractions may change and who will make the changes (end-user, administrator, developer).
- **Minimize Impact**: Design data abstractions to minimize the number and severity of modifications.
- **Group Related Data**: Ensure that data elements likely to change together are placed together.
- **Example**: Encapsulating database access through an ORM (Object-Relational Mapping) layer.

4. Mapping Among Architectural Elements

- **Flexibility in Mapping**: Determine if changing the mapping of functionality to computational elements is desirable.
- **Use Deferred Binding**: Perform changes using mechanisms that allow late binding of mapping decisions.
- **Example**: Deploying services in a microservices architecture where services can be moved between servers without code changes.

5. Resource Management

- **Assess Resource Impact**: Determine how changes affect resource usage.
- **Encapsulate Resource Managers**: Ensure resource managers and their policies are encapsulated.
- **Defer Resource Binding**: Allow resource management policies to be changed without modifying resource managers.
- **Example**: Implementing a resource pool that can be reconfigured without changing the modules that use it.

6. Binding Time

- **Determine Latest Binding Time**: For each change, decide the latest time the change needs to be made (e.g., runtime).
- **Choose Appropriate Mechanisms**: Use mechanisms that support binding at the desired time.
- **Balance Flexibility and Complexity**: Avoid excessive binding choices that complicate dependencies.
- **Example**: Using plugins or modules that can be added or removed at runtime.

7. Choice of Technology

- **Evaluate Technology Impact**: Determine how technology choices affect modifiability.
- **Support Modifications**: Choose technologies that facilitate making, testing, and deploying modifications.
- **Plan for Obsolescence**: Consider how easy it is to modify or replace the chosen technologies.
- **Example**: Selecting a programming language or framework with strong support for modularity and extensibility.

Case Study: Enhancing Modifiability in a Content Management System

Scenario: A company wants to update its content management system (CMS) to allow for easy addition of new content types and customization without extensive code changes.

Design Approach

1. **Allocation of Responsibilities**
    - **Modular Design**: Separate content rendering from content management logic.
    - **Plugin Architecture**: Allow new content types to be added as plugins.
2. **Coordination Model**
    - **Event-Driven Communication**: Use events to notify the system of changes, reducing direct dependencies.
    - **Message Queues**: Implement message queues for asynchronous processing.
3. **Data Model**
    - **Flexible Schema**: Use a schema-less or flexible database to accommodate new content types.
    - **Abstract Data Access**: Encapsulate data access to isolate database changes.
4. **Mapping Among Architectural Elements**
    - **Dynamic Module Loading**: Enable the CMS to load modules at runtime.
    - **Service-Oriented Architecture**: Use services that can be independently updated or replaced.
5. **Resource Management**
    - **Resource Encapsulation**: Implement resource managers for caching and database connections.
    - **Scalable Resources**: Design resource managers to scale with added functionality.
6. **Binding Time**
    - **Runtime Configuration**: Allow administrators to configure settings without restarting the system.
    - **Late Binding of Modules**: Support adding or updating modules without downtime.

7. **Choice of Technology**
    - **Use Extensible Frameworks**: Choose a CMS platform that supports plugins and extensions.
    - **Adopt Standard Technologies**: Use widely supported languages and libraries for better longevity.

Outcome

- **Improved Flexibility**: New content types can be added without modifying core code.
- **Reduced Maintenance Costs**: Isolated modules mean changes are localized, reducing the risk of side effects.
- **Enhanced User Satisfaction**: Faster implementation of features leads to a better user experience.

Summary

Modifiability is essential for building software systems that can adapt to changing requirements with minimal effort and risk. By employing tactics such as reducing module size, increasing cohesion, reducing coupling, and deferring binding, architects can design systems that are easier to modify.

Key Takeaways:

- **Anticipate Change**: Understand potential changes and design the system to accommodate them.
- **Control Complexity**: Simplify modules and increase cohesion to make modifications easier.
- **Manage Dependencies**: Reduce coupling to minimize the impact of changes on other parts of the system.
- **Leverage Late Binding**: Defer decisions to allow greater flexibility in making changes.
- **Choose the Right Technologies**: Select technologies that support modifiability and are adaptable to future needs.

By integrating these principles into software architecture, organizations can reduce maintenance costs, improve adaptability, and extend the lifespan of their systems.

Understanding Interoperability in Software Architecture

Introduction

Interoperability is a key quality attribute in software architecture that focuses on the ability of two or more systems to exchange and usefully interpret shared information. This guide covers:

- **What is Interoperability?**
- **Interoperability General Scenario**
- **Tactics for Interoperability**
- **A Design Checklist for Interoperability**
- **Summary**

We will explore each topic with clear explanations, examples, scenarios, and diagrams where appropriate to enhance understanding.

What is Interoperability?

Interoperability refers to the degree to which systems can exchange meaningful information and use it effectively. It is not simply a "yes or no" attribute but varies in levels of effectiveness based on the systems and the context of their interaction.

Key Characteristics of Interoperability

- **Discoverability**: Systems must be able to locate each other to exchange information.
- **Meaningful Exchange**: The information exchanged must be interpretable by all parties.
- **Effective Communication**: Systems must follow agreed-upon protocols for successful communication.

Interoperability General Scenario

To effectively design for interoperability, architects use **general scenarios** that describe the interaction between systems.

Components of an Interoperability General Scenario

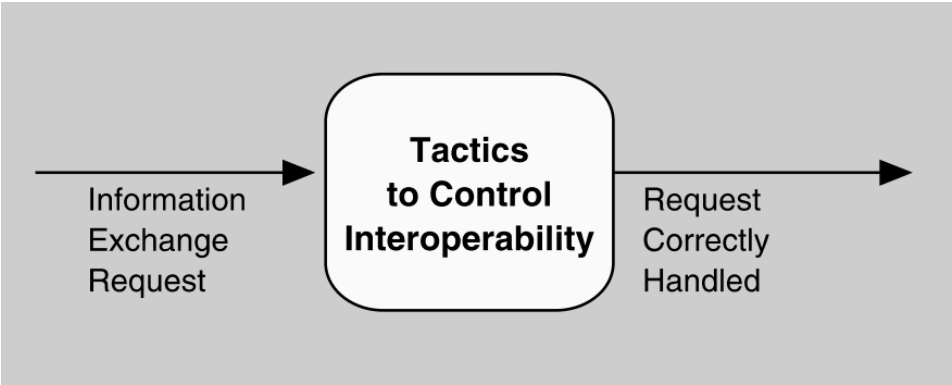
1. **Source**: The system or actor initiating the information exchange.
    - *Example*: A web service or external application.
2. **Stimulus**: The request to exchange information between systems.
    - *Example*: A request to share GPS location data between two systems.
3. **Artifacts**: The systems involved in the exchange.
    - *Example*: A vehicle's navigation system and a traffic monitoring service.
4. **Environment**: The context in which the exchange happens (e.g., runtime or compile time).
    - *Example*: During real-time system operations.
5. **Response**: How the system handles the request.
    - The system either successfully exchanges the information or rejects the request, notifying the necessary parties.
6. **Response Measure**: Metrics to evaluate the success of the exchange.
    - *Possible Values*:
        - Percentage of successful exchanges.
        - Number of rejected exchanges.
        - Time taken to exchange information.

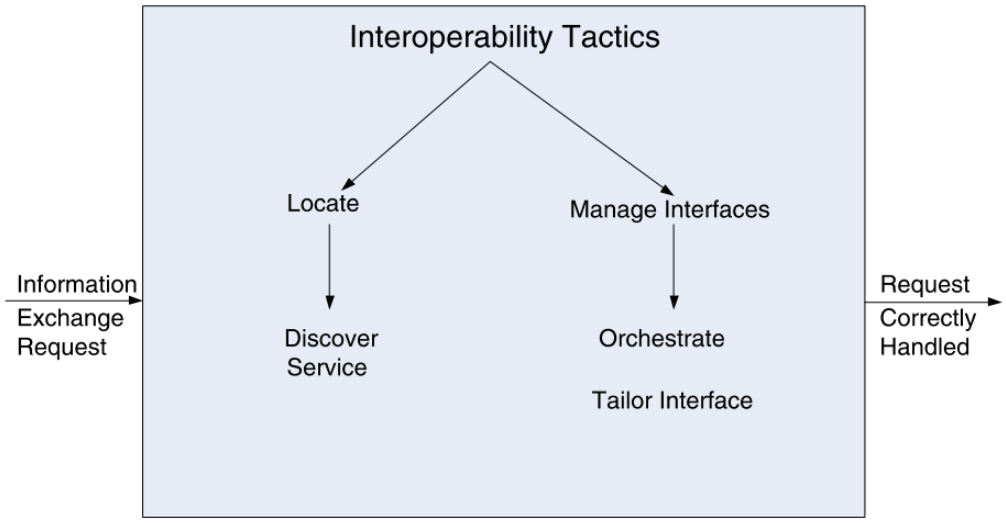
Sample Concrete Interoperability Scenario

- **Scenario**: A vehicle's navigation system sends its current location to a traffic monitoring system. The traffic system combines this location with data from other vehicles and displays it on a map.
- **Response Measure**: The location information is correctly processed and displayed with a 99.9% success rate.

Tactics for Interoperability

Tactics for interoperability focus on ensuring systems can locate each other, manage interfaces, and exchange information correctly.





1. Locate Tactics

Discover Service

- **Description**: A system locates other systems or services through a known directory or discovery service.
- **Example**: A weather application discovers available APIs to fetch weather data for a specific location.

Multiple Levels of Indirection

- **Description**: The system may use multiple references to locate a service.
- **Example**: A service directory provides a link to another directory, which in turn provides the actual service.

---

2. Manage Interfaces

Orchestrate

- **Description**: Use a control mechanism to coordinate the sequence of services to accomplish complex tasks.
- **Example**: A workflow engine orchestrates the interaction between an e-commerce website and a payment gateway.

Tailor Interface

- **Description**: Modify an interface by adding or removing capabilities, such as data translation or buffering.
- **Example**: An API adjusts its response format to be compatible with an older client.

A Design Checklist for Interoperability

When designing for interoperability, architects should consider the following aspects:

1. Allocation of Responsibilities

- **Identify Interoperable Responsibilities**: Determine which system components must interoperate with other systems.
- **Handle Requests**: Ensure the system can detect, accept, or reject interoperability requests.
- **Log Requests**: For security and auditing, log all interoperability actions, especially in untrusted environments.
- **Example**: A database management system logs every query request from external applications for auditing purposes.

2. Coordination Model

- **Traffic and Performance**: Consider network traffic, message timeliness, and consistency when communicating with other systems.
- **Protocol Consistency**: Ensure that all systems assume consistent protocols and underlying network structures.
- **Example**: A real-time messaging app uses message queues to ensure messages are delivered with low latency.

3. Data Model

- **Define Syntax and Semantics**: Ensure that data shared between systems is consistent and meaningful.
- **Transform Data**: If data models are incompatible, apply necessary transformations.
- **Example**: A customer information system shares data with a billing system, converting internal data fields to match the billing system's format.

4. Mapping Among Architectural Elements

- **Components to Processors**: Ensure components communicating externally are hosted on processors with network access.
- **Consider Security and Performance**: Map architectural elements to meet security and performance needs during communication.
- **Example**: A secure payment gateway service is mapped to specific processors to ensure high availability and secure communication.

5. Resource Management

- **Prevent Resource Exhaustion**: Ensure that accepting or rejecting interoperability requests does not exhaust system resources.
- **Manage Shared Resources**: If systems share resources, implement an arbitration policy for fair use.
- **Example**: A cloud-based service limits the number of simultaneous API requests to prevent overload.

6. Binding Time

- **Early vs. Late Binding**: Decide whether systems are known to each other at runtime or compile time. Late binding supports dynamic discovery of services.
- **Log and Manage Bindings**: Ensure systems can log attempts to bind to external systems and reject unauthorized bindings.
- **Example**: A smart home system dynamically binds to new devices when they are added, discovering the appropriate protocols at runtime.

7. Choice of Technology

- **Technology Visibility**: Ensure that chosen technologies do not hinder interoperability. Some technologies may introduce complexities or limitations.
- **Select Interoperability-Friendly Technologies**: Consider using technologies like Web Services or APIs designed for interoperability.
- **Example**: A healthcare management system uses RESTful APIs to ensure it can interoperate with various third-party applications.

Case Study: Interoperability in a Smart Home System

Scenario: A company is designing a smart home system that allows different devices—such as lights, thermostats, and security cameras—to communicate and work together seamlessly.

Design Approach

1. **Allocation of Responsibilities**
    - **Device Discovery**: The system uses a service discovery mechanism to locate and interact with new devices.
    - **Logging**: All device interactions are logged for security purposes.
2. **Coordination Model**
    - **Protocol Consistency**: The smart home system uses a standard protocol (e.g., Zigbee) to ensure all devices can communicate consistently.
    - **Performance**: Real-time communication ensures that commands, such as turning off lights, are executed with minimal delay.
3. **Data Model**
    - **Unified Data Representation**: The system ensures that data from different devices (e.g., temperature, motion detection) is presented in a standardized format.
    - **Data Transformation**: If a new device uses a different format, the system converts the data accordingly.
4. **Mapping Among Architectural Elements**
    - **Component Hosting**: Devices are mapped to processors capable of handling their communication and computation needs.
    - **Security Considerations**: Sensitive devices, such as security cameras, are hosted on secure processors.
5. **Resource Management**

    - **Resource Arbitration**: The system manages network bandwidth and prioritizes critical devices like security cameras during high traffic periods.
6. **Binding Time**
    - **Dynamic Device Binding**: The system binds to new devices dynamically when they are added to the network.
    - **Late Binding for Flexibility**: This allows users to add or remove devices without disrupting the system.
7. **Choice of Technology**
    - **Interoperability-Friendly Technologies**: The system uses standard technologies like MQTT (Message Queuing Telemetry Transport) for device communication.

Outcome

- **Seamless Communication**: Devices interact with each other smoothly, allowing users to control their home environment effortlessly.
- **Scalability**: New devices can be added to the system without major modifications.
- **Security**: Logs ensure traceability of device interactions, enhancing system security.

Summary

Interoperability is a crucial aspect of modern software systems, enabling them to exchange and use information effectively. By implementing interoperability tactics such as locating services, managing interfaces, and ensuring consistent data models, architects can design systems that work well together.

Key Takeaways:

- **Discover and Manage**: Systems must locate each other and manage interfaces for effective communication.
- **Control Resource Usage**: Interoperating systems should manage resources to avoid overloading and ensure fair use.
- **Technology Choices Matter**: Choose technologies that facilitate interoperability without introducing unnecessary complexity.

By following a well-structured design checklist and applying relevant tactics, systems can achieve robust interoperability, ensuring they are future-proof and adaptable to new challenges.

Understanding Testability in Software Architecture

Introduction

Testability in software architecture refers to how easy it is to test a system and identify faults during testing. It measures the probability that, if the system has a fault, it will fail during the next test. The quicker faults are revealed during testing, the more reliable and robust the software will be.

What is Testability?

Testability focuses on making software easier to test by controlling each component's inputs and outputs and monitoring its internal state. This means ensuring the system's components are accessible for testing and can reveal faults early.

Key concepts:

- **Control Inputs**: Ability to manipulate the system’s inputs for testing.
- **Observe Outputs**: Ability to observe and capture the system’s outputs and state.

Testability General Scenario

To design for testability, software architects define **general scenarios** that describe testing conditions.

Components of a Testability General Scenario:

1. **Source**: The actor or system performing the tests (unit testers, system testers, etc.).
2. **Stimulus**: A set of tests initiated due to software development activities such as coding, integration, or deployment.
3. **Environment**: The context in which the test is conducted (e.g., design time, compile time, runtime).
4. **Artifacts**: The system components being tested (e.g., classes, modules, services).

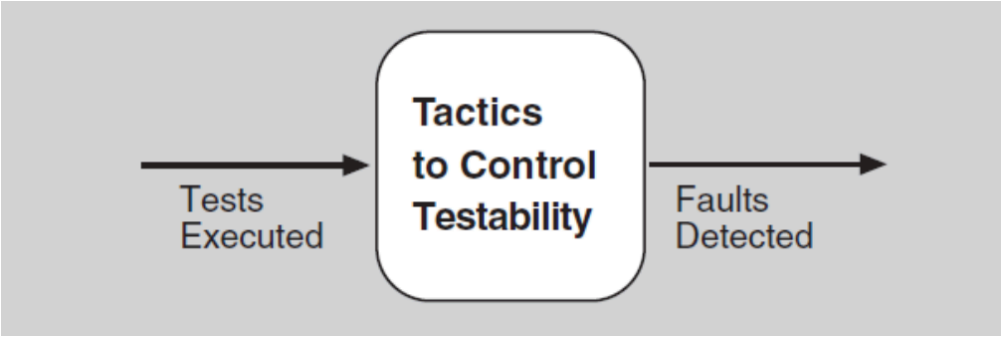
5. **Response**: The system's response to testing, such as executing the test suite, capturing results, or logging faults.
6. **Response Measure**: Metrics to evaluate the success of the testing (e.g., time to find faults, state space coverage, probability of fault detection).

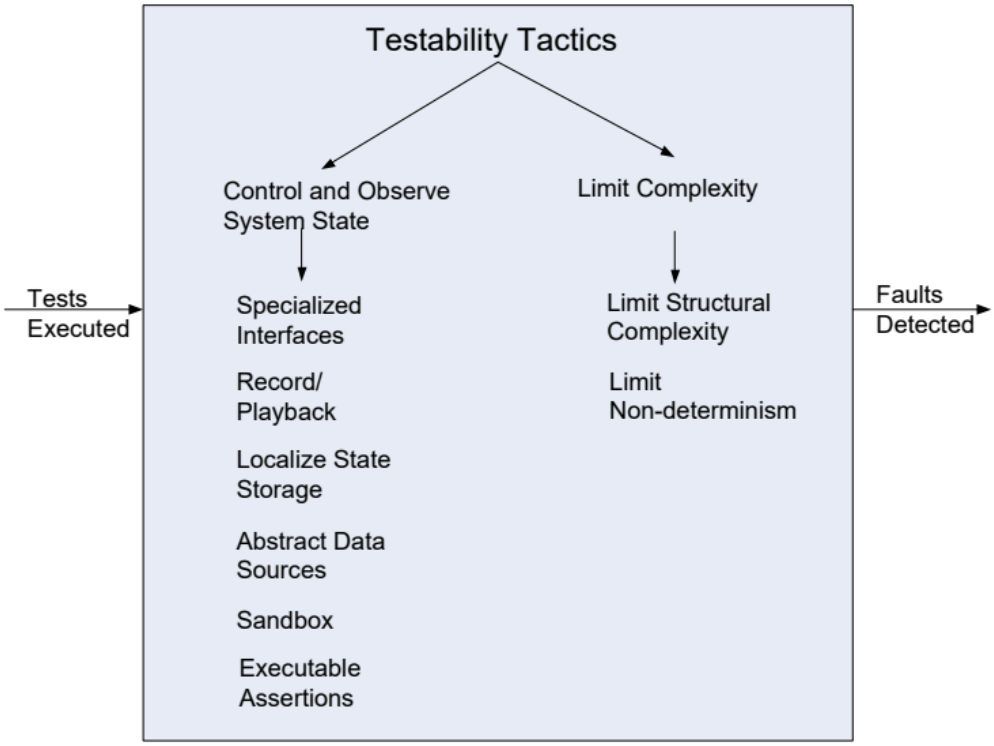
Sample Concrete Testability Scenario:

- **Scenario**: A unit tester finishes coding a module and runs a test suite, achieving 85% path coverage within three hours.
- **Response Measure**: The percentage of code paths covered by the tests.

Tactics for Testability

Tactics for testability focus on making the system easier to test by improving **controllability** and **observability** and **limiting complexity**.





1. Control and Observe System State

Specialized Interfaces

- **Description**: Implement interfaces specifically for testing to control inputs and capture outputs.
- **Example**: A test harness simulates inputs for a module to monitor its behavior during testing.

Record/Playback

- **Description**: Record system interactions and play them back during testing to recreate specific scenarios.
- **Example**: Recording user input during a session and replaying it to test a new feature.

Localize State Storage

- **Description**: Store the system's state in a single location to reset or modify the state during testing.
- **Example**: A database reset to a known state before each test run.

Abstract Data Sources

- **Description**: Abstract the data interfaces to allow easier substitution of test data.
- **Example**: Replacing live data feeds with pre-recorded data during testing.

Sandbox

- **Description**: Isolate the system from its real environment to safely perform tests without affecting actual operations.
- **Example**: Testing a payment system in a sandbox environment to prevent real transactions.

Executable Assertions

- **Description**: Use assertions in the code to check for expected conditions and identify faults during execution.
- **Example**: An assertion checks whether a value is within a specific range during a financial transaction.

---

2. Limit Complexity

Limit Structural Complexity

- **Description**: Reduce the complexity of the system's structure by minimizing dependencies between components.
- **Example**: Refactoring a tightly coupled system into loosely connected modules.

Limit Non-determinism

- **Description**: Minimize non-deterministic behavior, such as parallelism, to ensure consistent test results.
- **Example**: Avoiding race conditions by using synchronization mechanisms in multi-threaded applications.

A Design Checklist for Testability

When designing for testability, architects should consider the following aspects:

1. Allocation of Responsibilities

- Identify critical system components that require thorough testing.
- Allocate responsibilities for executing tests, capturing results, and logging faults.
- Ensure high cohesion and low coupling for easier testing.
  Example: Assigning a logging module the responsibility to capture test results and error logs.

2. Coordination Model

- Ensure communication mechanisms support test execution, result capture, and fault logging.
- Avoid introducing unnecessary non-determinism in the coordination model.
  Example: A message queue system is designed to log all communication for later analysis during testing.

3. Data Model

- Ensure the ability to capture, set, and manipulate data abstractions during testing.
- Test the creation, initialization, and manipulation of data to identify faults.
  Example: Testing whether a shopping cart can handle large quantities of items without breaking.

4. Mapping Among Architectural Elements

- Ensure the ability to test the mapping of components to processes and identify potential race conditions.
- Validate possible mappings between architectural elements to prevent illegal configurations.
  Example: Testing how modules mapped to different processors handle concurrent data access.

5. Resource Management

- Ensure sufficient resources are available to execute tests in a realistic environment.
- Test the system under different resource conditions (e.g., low memory) to identify resource-related issues.
  Example: Simulating high traffic loads to test a web server’s performance under stress.

6. Binding Time

- Ensure late-bound components can be tested in their final context.
- Capture and recreate system states during failures to troubleshoot faults.
  Example: Testing a plugin system where plugins are added at runtime to ensure they function correctly.

7. Choice of Technology

- Choose technologies that support testing, such as tools for fault injection, recording, and playback.
- Ensure technologies do not hinder testing efforts and provide necessary flexibility.
  Example: Using a continuous integration tool that automates testing and provides test result analytics.

Case Study: Testability in a Financial System

Scenario: A company is building a financial transaction system and wants to ensure it is easily testable for faults such as incorrect balances or failed transactions.

Design Approach

1. **Specialized Interfaces**: Test harnesses are built for the financial modules to simulate transaction inputs and capture outputs.
2. **Record/Playback**: User interactions are recorded during test sessions and replayed to verify that transactions process correctly.
3. **Localize State Storage**: The database is reset to a known state before each test to ensure consistent starting conditions.
4. **Executable Assertions**: Assertions are placed in the code to check for invalid balance changes after each transaction.
5. **Limit Non-determinism**: Synchronization mechanisms are introduced to avoid race conditions in transaction processing.

Outcome

- **Increased Fault Detection**: Faults are detected early in the development process, improving system reliability.
- **Efficient Testing**: Automated tests achieve high code coverage, allowing the team to identify and resolve issues faster.
- **Reduced Complexity**: Refactoring the system to reduce coupling and non-determinism made the system easier to test and maintain.

Summary

Testability ensures that systems are easy to test, improving the likelihood that faults will be identified during development. By using testability tactics such as controlling system state, limiting complexity, and choosing testable technologies, software architects can build systems

that are easier to maintain and more reliable.

Key Takeaways:

- **Control and Observe**: Ensure the system allows for controlling inputs and observing outputs during tests.
- **Limit Complexity**: Reduce system complexity to simplify testing.
- **Effective Testing Tools**: Use tools and technologies that facilitate automated testing, fault injection, and monitoring.

By integrating these tactics, testability can be improved, reducing testing costs and enhancing the system's overall quality.

Simple Documentation for Requirements, Designing, and Documentation in Software Architecture

1. Architecture and Requirements

Architecture and requirements go hand in hand. The process of gathering architecturally significant requirements (ASRs) ensures that the architecture reflects the system's key functional and non-functional requirements.

Key Methods for Gathering ASRs:

- **From Requirements Documents**: Review existing system requirements.
- **Interview Stakeholders**: Directly engage with those who use or depend on the system.
- **Understand Business Goals**: Align the architecture with organizational goals.
- **Utility Tree**: Prioritize ASRs in a utility tree, focusing on critical system qualities like performance, scalability, and security.

Example:

A financial system might emphasize security and data integrity as ASRs, while an e-commerce platform may prioritize performance and scalability.

---

2. Designing an Architecture

Designing software architecture involves creating a blueprint that balances quality attributes like security, performance, and modifiability.

Key Design Strategies:

- **Attribute-Driven Design (ADD)**: Focuses on breaking down the architecture into parts that meet quality attribute goals.
- **Steps of ADD**:
    1. Identify the system's quality attribute goals (e.g., security, performance).
    2. Decompose the architecture into components that fulfill those goals.
    3. Refine components to ensure they work together to meet the system's needs.

Example:

In an e-commerce platform, ADD may guide the design to include a secure, high-performance payment system while ensuring modifiability for future features.

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3. Documenting Software Architecture

Importance of Documentation:

Good documentation communicates the architecture clearly to stakeholders, developers, and future maintainers.

Documentation Elements:

- **Uses and Audiences**: Tailor documentation for different readers—developers, testers, and project managers.
- **Notations**: Use standard diagrams like UML to describe components, data flow, and system interactions.
- **Views**:
    - **Logical View**: Shows how components interact.
    - **Process View**: Describes how processes communicate and manage resources.
    - **Deployment View**: Maps the architecture to the physical hardware (servers, cloud, etc.).
- **Combining Views**: Bring together different views to give a complete picture of the system.
- **Documenting Behavior**: Capture how the system behaves under different scenarios, such as high traffic or component failure.

Example:

For a microservices architecture, you might document each service's role (Logical View), how services communicate (Process View), and where services are deployed (Deployment View).

---

4. Agile and Architecture

Agile methods aim to deliver working software quickly and respond to changing requirements, but this doesn't mean skipping architectural planning.

Key Considerations:

- **How Much Architecture?**: In smaller projects, minimal upfront architecture may suffice, but for large systems, careful upfront design can prevent costly rework later.

How Much Architecture?

innovate achieve

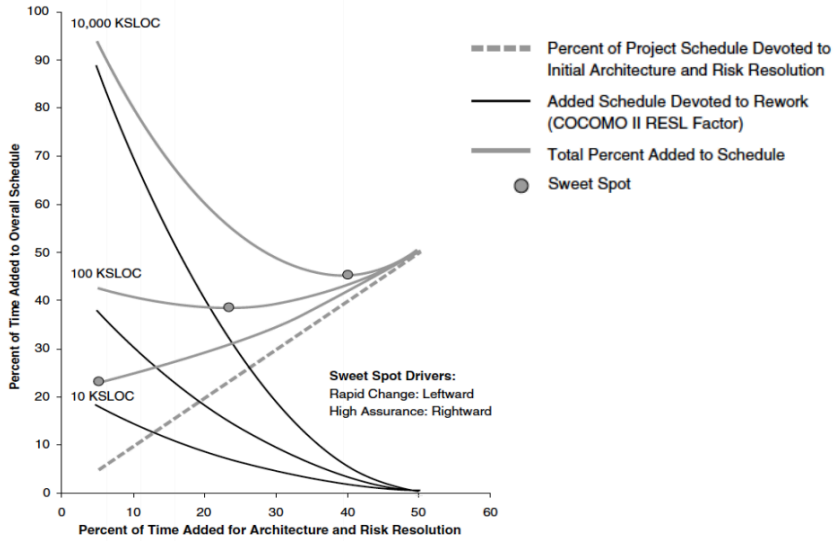
There are two activities that can add time to the project schedule:

- Up-front design work on the architecture and up-front risk identification, planning, and resolution work
- Rework due to fixing defects and addressing modification requests.

Intuitively, these two trade off against each other.

Boehm and Turner plotted these two values against each other for three hypothetical projects:

- One project of 10 KSLOC
- One project of 100 KSLOC
- One project of 1,000 KSLOC



- These lines show that there is a sweet spot for each project.
  - For the 10KSLOC project, the sweet spot is at the far left. Devoting much time to up-front work is a waste for a small project.
  - For the 100 KSLOC project, the sweet spot is around 20 percent of the project schedule.
  - For the 1,000 KSLOC project, the sweet spot is around 40 percent of the project schedule.
- A project with a million lines of code is enormously complex.
- It is difficult to imagine how Agile principles alone can cope with this complexity if there is no architecture to guide and organize the effort.

- **Agile and Architecture Together**: Agile methods focus on rapid iterations, but architecture provides a foundation that supports growth and change over time.

The Agile Manifesto Values:

1. **Individuals and interactions** over processes and tools.
2. **Working software** over comprehensive documentation.
3. **Customer collaboration** over contract negotiation.
4. **Responding to change** over following a plan.

Example:

In a project like developing a mobile app, the initial architecture might just define the core services (e.g., user management, notifications), with the details evolving as the project grows.

---

5. Example of Agile Architecting: WebArrow

WebArrow Case Study:

WebArrow, a web-conferencing system, used an agile architecture approach that balanced top-down and bottom-up design strategies.

- **Top-down**: Focus on architectural structure to meet quality goals (e.g., scalability, performance).
- **Bottom-up**: Address implementation constraints and real-world issues (e.g., network latency, server load).

Example Experiments (or Spikes):

- Moving from local flat files to a distributed database: Would it improve scalability without hurting performance?
- Testing mod_perl versus standard Perl: Would it increase the number of participants hosted by a single meeting server?

Lessons:

- Agile architecture doesn't require reinventing the wheel—it involves adapting to changes while maintaining a solid architectural foundation.
- Experimentation (spikes) helps guide decisions about performance and scalability.

---

6. Guidelines for the Agile Architect

Key Guidelines:

- **Large, complex systems**: Perform more upfront architecture work to handle the complexity and distribute development tasks efficiently.
- **Unstable requirements**: Start with a basic architecture and refine it over time as requirements evolve.
- **Smaller projects**: Prioritize getting the major patterns and components agreed upon without over-investing in documentation.

Example:

For a large banking application, architecture work upfront would establish security protocols, transaction systems, and data storage. In contrast, a startup's small web app could quickly iterate on architecture as requirements change.

---

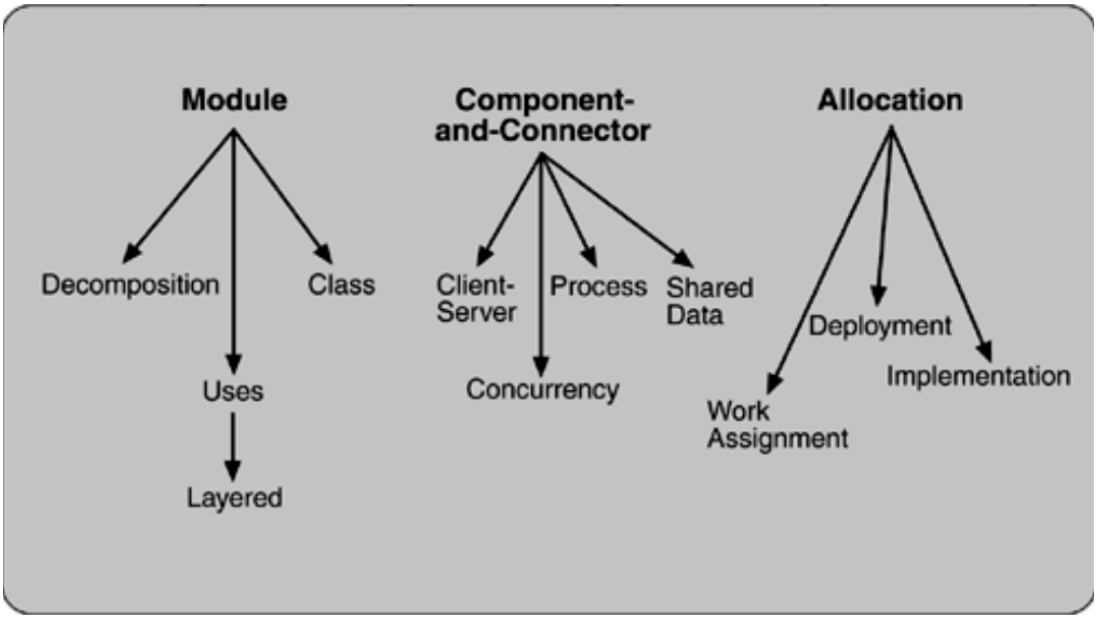
7. Summary

- **Architecture and Requirements**: Architects need to gather ASRs from various sources and align them with business goals.
- **Designing an Architecture**: Use Attribute-Driven Design (ADD) to meet quality goals and balance system constraints.
- **Documenting Architecture**: Tailor your documentation to your audience, using multiple views to capture the system's structure and behavior.
- **Agile and Architecture**: Agile and architecture complement each other, balancing quick iterations with thoughtful architectural planning.

In conclusion, blending Agile practices with solid architecture leads to systems that are flexible, scalable, and easy to maintain—no matter the project size or complexity.

Architectural Structures: An Overview

Software architecture is a blueprint of a system that defines its structure and behavior. Architectural structures help to understand the system in terms of its **modules**, **components**, and their relationships with external environments. This document covers the three primary types of structures: **Module Structures**, **Component-and-Connector Structures**, and **Allocation Structures**, along with examples, diagrams, and practical case studies.



1. Module Structures

Overview:

Module structures represent the **static structure** of a system, focusing on the code base and the responsibilities assigned to various parts of the system. This structure answers questions about functional responsibility, usage, and relationships between modules.

- **Key Elements**: Modules, interfaces, dependencies.
- **Examples**:
    - A **module** could represent a specific feature or service in the system, such as **User Authentication** or **Payment Processing** in an online shopping system.

Key Questions:

- What is the **responsibility** of each module?
- What software does a module use or depend on?
- What modules share relationships like **inheritance**?

---

2. Component-and-Connector Structures

Overview:

This structure focuses on **dynamic aspects** of the system, showing how runtime components interact with each other through communication paths, data flows, and synchronizations. It answers questions about system execution, parallel processing, and how the system evolves over time.

- **Key Elements**: Components (e.g., processes, services) and connectors (e.g., communication protocols).
- **Examples**:
    - **Components** like **Database** and **Application Server** interact through connectors like **APIs** or **Message Queues**.

Key Questions:

- What are the **major components** and how do they interact?
- How does data flow between components?
- Which parts of the system run in **parallel**?

Practical Case Study: Client-Server System

- In a **client-server architecture**, the **Client** (browser) interacts with the **Server** (backend services) via HTTP requests. The **Server** handles these requests and processes data in the **Database**.

---

3. Allocation Structures

Overview:

Allocation structures define how **software components** are mapped to the **physical or virtual environments** in which they operate. This includes the deployment of software on hardware, file structures, and how work is divided among teams.

- **Key Elements**: Hardware entities (processors, storage), software components, development teams.
- **Examples**:
    - A **web application** could be allocated across multiple servers, with the frontend on a web server and backend services on different application servers.

Key Questions:

- On which **processors** does each software element run?
- Where are the **files** stored?
- How are responsibilities divided among **development teams**?

Types of Module Structures:

1. **Decomposition Structure**:
    - Breaks down the system into **submodules**, each with a specific functional responsibility.
    - Example: A **Shopping Cart** module can be decomposed into **Cart Management**, **Discounts**, and **Recommendations**.
2. **Uses Structure**:
    - Focuses on the **dependencies** between modules.
    - Example: A **Checkout Module** uses services from both **Payment** and **Order Management** modules.
3. **Layered Structure**:
    - Organizes modules into **layers**, with higher layers depending on lower ones for services.
    - Example: A system with **Presentation**, **Business Logic**, and **Data Access** layers.

Component-and-Connector Structures:

1. **Process Structures**:
    - Represent the **runtime processes** and how they interact.
    - Example: A **Booking Service** interacts with a **Notification Service** to send confirmation messages.
2. **Concurrency Structure**:
    - Shows components and their **parallel execution**.
    - Example: In a **video streaming service**, multiple components for buffering, playing, and rendering work concurrently.
3. **Shared Data (Repository) Structure**:
    - Focuses on components that **share and store data**.
    - Example: A **central database** shared by multiple microservices in an e-commerce platform.

Allocation Structures:

1. **Deployment Structures**:
    - Shows how software is assigned to **hardware components**.
    - Example: In a cloud system, different microservices are deployed on **virtual machines** or **containers**.
2. **Implementation Structures**:
    - Maps software elements (modules) to the **file structure** used in the system's development environment.
    - Example: The **source code** for different modules is stored in separate directories for easier version control and development.
3. **Work Assignment Structures**:

    - Assigns **modules or components** to different teams for development.
    - Example: A **frontend team** works on UI components, while a **backend team** handles database interactions and logic.

Case Study Example: PABX System (Private Branch Exchange)

- **Module Structure**: The system is decomposed into **Call Management**, **User Interface**, and **Signal Processing** modules.
- **Component-and-Connector Structure**: These modules communicate at runtime through **data streams** and **protocols** to handle calls.
- **Deployment Structure**: The software is deployed on multiple hardware devices, such as **user devices** and **central servers** for managing calls.

Summary:

Understanding the different **architectural structures** (module, component-and-connector, and allocation structures) is critical for designing, developing, and managing complex systems. Each structure answers specific questions about the system's functionality, interaction, and

deployment, helping developers and system architects ensure modularity, scalability, and efficient resource allocation.

Using diagrams and practical examples helps stakeholders understand how different components interact and contribute to the overall system behavior.

Understanding Software Architecture: 4+1 Views Model

The **4+1 Views Model**, introduced by Philippe Kruchten, is a way to describe the architecture of software-intensive systems based on different stakeholders' needs. This model organizes the system's architecture using five views, each focused on specific aspects of the system: **Logical View**, **Process View**, **Development View**, **Physical View**, and **Scenarios**.

Here's a simplified explanation of each view, along with examples and diagrams to make things clear.

---

1. Logical View

What is it?

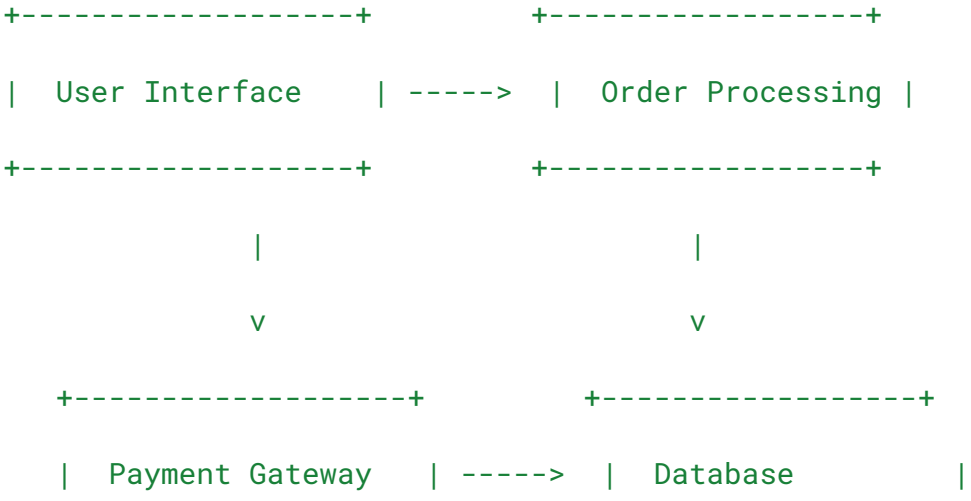
The **Logical View** describes the system's functional requirements and how various components interact to deliver the system's functionality. It shows how the system's objects and classes communicate to provide the desired services to users.

- **Viewer**: End-users, designers.
- **Purpose**: Focuses on the **functionality** of the system.
- **Example**: In an **online shopping system**, the Logical View might show how the **User Interface (UI)** interacts with the **Product Catalog**, **Order Management**, and **Payment System**.

Logical View Diagram:

sql

Copy code



Notation: UML Class Diagrams, Sequence Diagrams, Component Diagrams

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2. Process View

What is it?

The **Process View** describes the system's dynamic behavior, focusing on how different processes interact, the concurrency between tasks, and synchronization of those tasks. This view also deals with system performance, scalability, and reliability.

- **Viewer**: Integrators, developers.
- **Purpose**: Deals with **non-functional requirements** like scalability, performance, and concurrency.
- **Example**: In the **online shopping system**, the Process View would show how the **Checkout Process** and **Payment Processing** tasks are handled concurrently.

Process View Diagram:

lua

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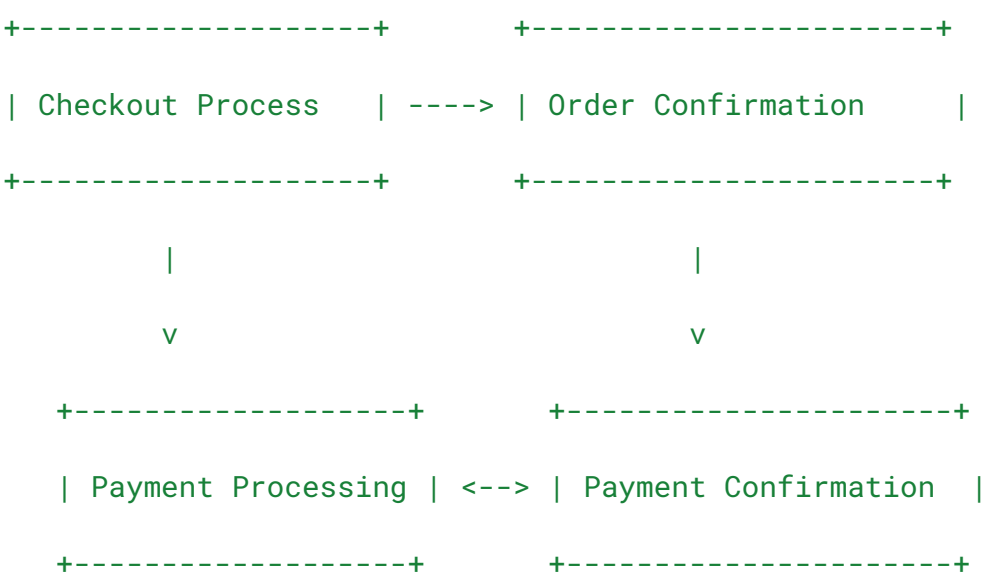


Notation: UML Activity Diagrams, Sequence Diagrams

---

3. Development View

What is it?

The **Development View** (also called the **Implementation View**) focuses on the **static structure** of the software. It shows the organization of software modules in the development environment, like how files, packages, or libraries are organized for development.

- **Viewer**: Programmers, software managers.
- **Purpose**: Focuses on the **software structure** and organization (code structure, packages, libraries).
- **Example**: In the **online shopping system**, the Development View might show how the system is divided into **modules** like UI, Backend, Database, and APIs.

Development View Diagram (Layered Style):

diff

Copy code

```
+-------------------+

| Presentation Layer |

+-------------------+

         |

+-------------------+

|   Business Layer   |

+-------------------+

         |

+-------------------+

|   Data Access      |

+-------------------+
```

```
        |
+-------------------+
|  Database Layer    |
+-------------------+
```

Notation: UML Package Diagrams, Component Diagrams

---

4. Physical View

What is it?

The **Physical View** shows how the system's components are deployed across the hardware infrastructure. It maps software components onto physical nodes (servers, computers) and deals with non-functional requirements like **scalability** and **performance** in relation to the hardware.

- **Viewer**: System engineers, network engineers.
- **Purpose**: Focuses on **deployment** and how the software is physically distributed across hardware.
- **Example**: In the **online shopping system**, the Physical View shows how the application is distributed across multiple servers, including **Web Servers**, **Database Servers**, and **Payment Gateways**.

Physical View Diagram:

sql

Copy code

```
+---------------------+           +-------------------+
|   Web Server        |  -------->  |  Database Server  |
|   (UI, Logic Layer) |            +-------------------+
+---------------------+                    ^
        |                                   |
```

Notation: Deployment Diagrams

---

5. Scenarios (Use Case View)

What is it?

The **Scenario View** describes how the system responds to specific **use cases** and how the various architectural components work together to fulfill system requirements. This is used to validate the architecture and show that it satisfies the user's needs.

- **Viewer**: All stakeholders.
- **Purpose**: To verify that the architecture can handle real-world use cases.
- **Example**: In an **online shopping system**, a Scenario might be a **user purchasing a product**, which involves interaction between the **UI**, **Order Processing**, and **Payment System**.

Scenario Example:

- **Step 1**: User selects a product.
- **Step 2**: UI sends the request to the Order Processing system.
- **Step 3**: Order Processing confirms the stock and proceeds with the payment.
- **Step 4**: Payment Gateway processes the payment.

Notation: UML Sequence Diagrams

How the Views Work Together:

The **4+1 Model** ensures that different aspects of the system architecture are well-documented and understood by various stakeholders:

1. **Start with the Logical View** to focus on functionality.
2. Move to the **Process View** to deal with concurrency and scalability.
3. Build the **Development View** to show how the system is structured for coding.
4. Use the **Physical View** to show how the system is deployed.
5. Validate all views with **Scenarios** to ensure that the architecture meets real-world needs.

Case Study: PABX System (Private Automatic Branch Exchange)

- **Logical View**: Describes the interaction between components like the call manager, signal processor, and user interface.
- **Process View**: Shows how concurrent processes (like managing multiple calls) are synchronized.
- **Development View**: Illustrates how the software modules (UI, signal processing, database) are organized.
- **Physical View**: Maps these components to different servers and devices in the actual network setup.
- **Scenario**: Example of a **local call setup** where the system handles the routing and processing of the call request.

Summary:

The **4+1 View Model** ensures that software architecture is documented comprehensively from different perspectives, making it easier for all stakeholders to understand the system. Each view provides specific insights, ensuring that concerns related to functionality, concurrency, software structure, physical deployment, and real-world use cases are addressed properly.

By using **UML diagrams**, **sequence diagrams**, and **deployment diagrams**, these views give a holistic understanding of a system's architecture.

Layered Architecture, Techniques, and Examples

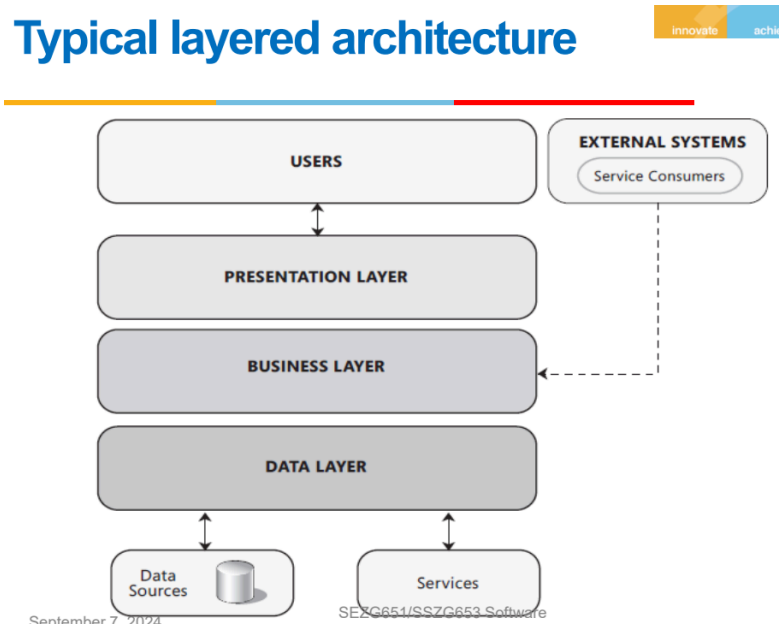
Layered Architecture Overview: Layered architecture is a software design pattern that organizes the system into different layers, each with a specific responsibility. This pattern promotes separation of concerns, loose coupling, and reusability of components. Each layer performs a specific role and communicates with adjacent layers.

---

1. Typical Layers in Layered Architecture

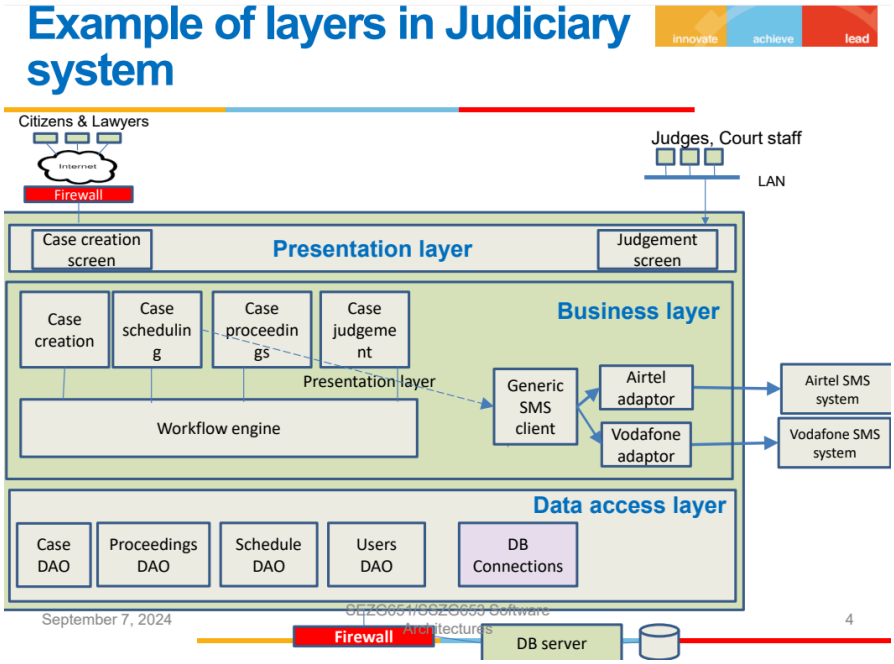
The following are the typical layers in a layered architecture:

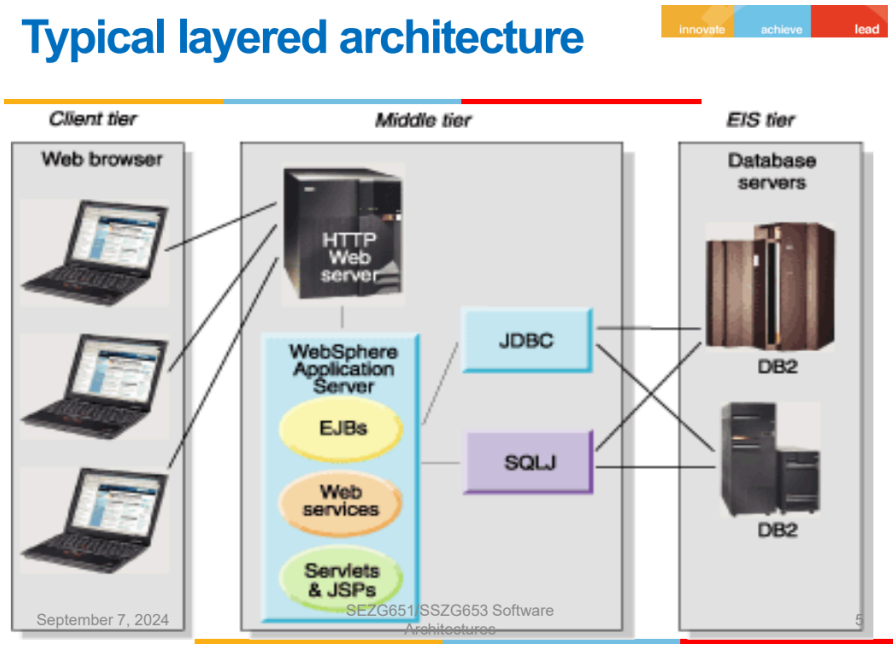
- **Presentation Layer:** Handles the user interface and user interaction. It translates user actions into requests for the next layer, and shows the output to users.
- **Business Layer:** Contains the core logic and business rules. This layer processes requests from the presentation layer and returns the results.
- **Data Access Layer:** Provides access to the database or other data sources. It isolates the business logic from the data source's specifics.
- **Service Layer:** Offers functionality to external systems and handles service requests and responses.



Example: Judiciary System Architecture

The diagram below shows the layers in a judiciary system, where each layer has specific responsibilities, such as case scheduling, user management, and SMS system integration.



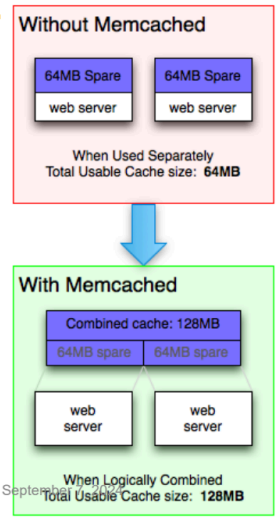


2. Techniques Used in Different Layers

Presentation Layer Techniques:

- **Client-Side vs. Server-Side Caching:**
  - **Client-Side Caching:** Stores frequently used data like user preferences in the browser.
  - **Server-Side Caching:** Stores common data on the server, such as product details, to reduce database load.

Memcached



memcached is a high-performance, distributed memory object caching system, generic in nature, but originally intended for use in speeding up dynamic web applications by alleviating database load.

You can think of it as a short-term memory for your applications.

memcached allows you to take memory from parts of your system where you have more than you need and make it accessible to areas where you have less than you need.

Asynchronous communication with web server

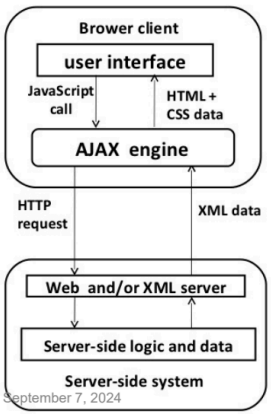
Example use cases:

- Show product list depending on the product category selected by user
- Validating a user input such as loan amount - whether it is within permissible limits, depending on user profile
- Displaying a chat panel
- Reloading Captcha

- **AJAX for Asynchronous Communication:** AJAX allows dynamic updates to a web page without refreshing the entire page. This technique is used in systems like Google Maps, which updates parts of the map as users drag the screen.

Asynchronous communication with web server

AJAX Architecture



AJAX stands for **A**synchronous **Ja**vaScript and **X**ML.

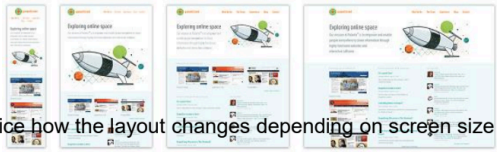
AJAX is a technique for creating better, faster, and more interactive web applications with the help of XML, HTML, CSS, and Java Script.

Some famous web applications that use AJAX:

Google Maps (Drag entire map)
Google Suggest (Google suggests as you type)

- **Responsive Design:** Adjusts the layout of a website depending on the screen size, using HTML5 and CSS3.

Responsive web design: Examples

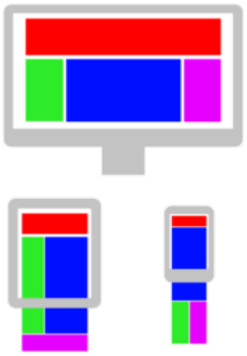


Notice how the layout changes depending on screen size

Responsive web design is an approach that renders web pages well on a variety of devices or screen sizes.

Consider different form factors – Use Responsive design

Ref: Wikipedia



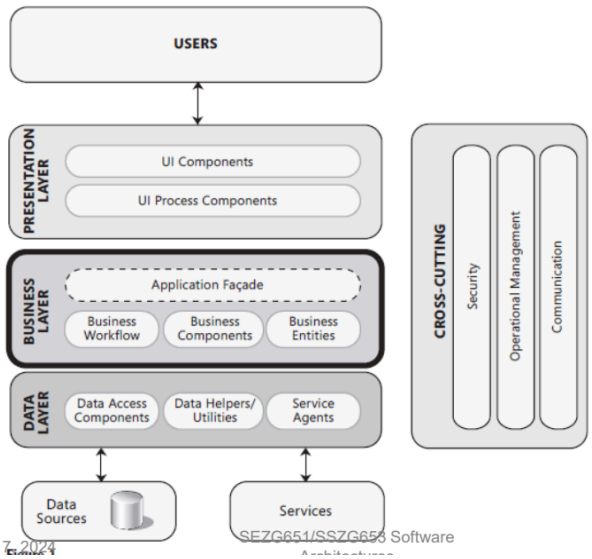
Flexible grids

Allows varying layout depending on screen size

HTML5 and CSS3 help in specifying the display arrangement

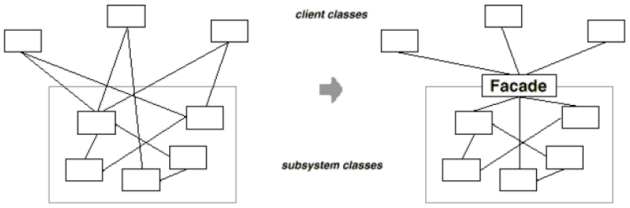
Business Layer Techniques:

Business layer



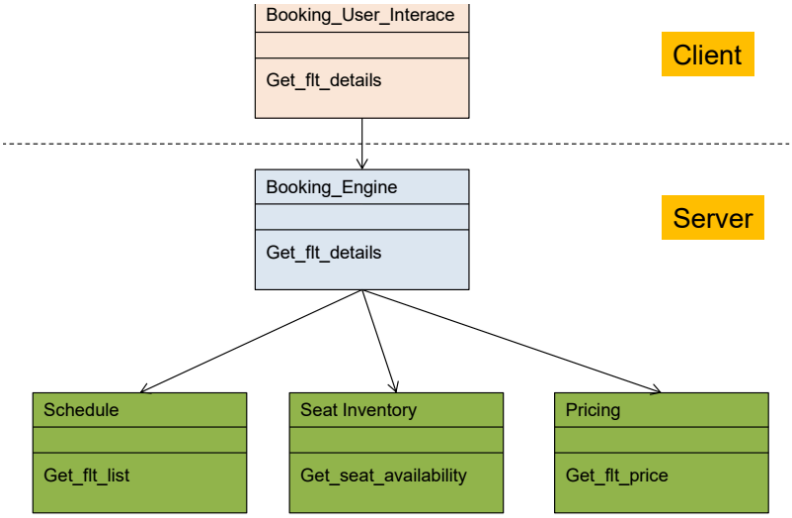
- **Application Façade:** Provides a unified interface to a set of underlying services, simplifying the usage of complex systems for the presentation layer.

Facade: Making sub-system easier to use



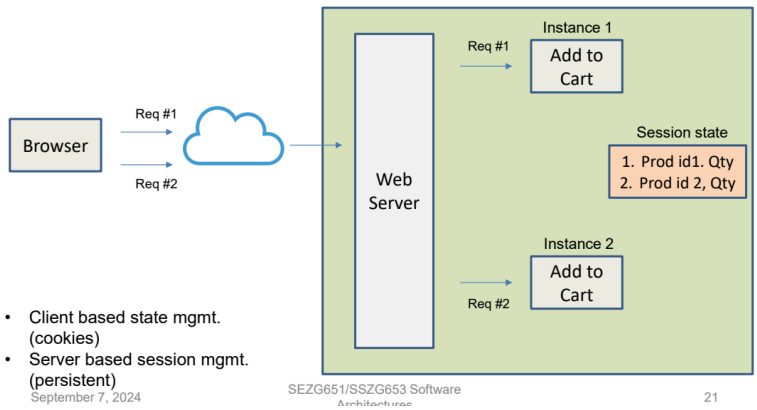
Intent:
- Provide a unified interface to a set of interfaces in a subsystem.
- Facade defines a higher-level interface that makes the subsystem easier to use.
- It typically involves a single wrapper class which contains a set of members required by client.

  - **Example:** In a flight booking system, a façade can provide a single API for booking flights, checking availability, and processing payments.

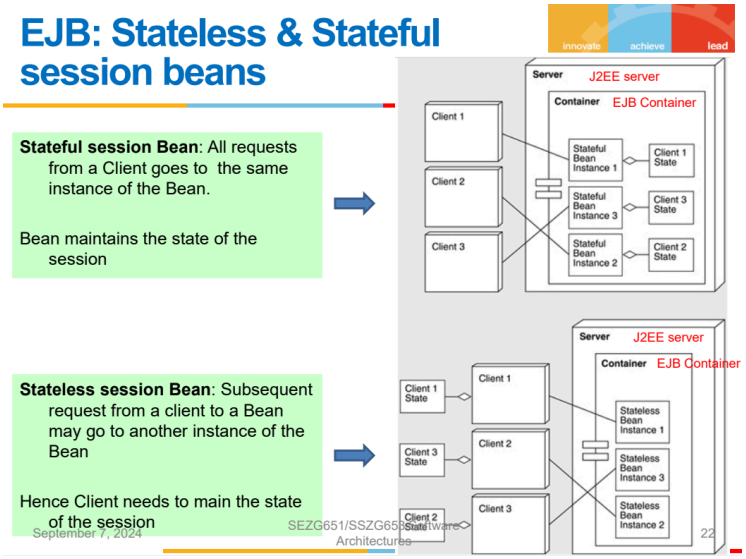


- **Session Management:** Manages user sessions to maintain state between different requests. This can be done through:
  - **Client-Based State Management (e.g., Cookies)**
  - **Server-Based Session Management (Persistent Sessions)**

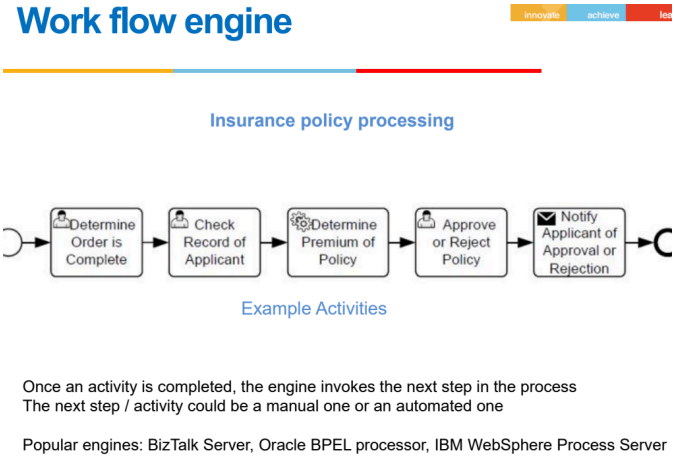
Session management



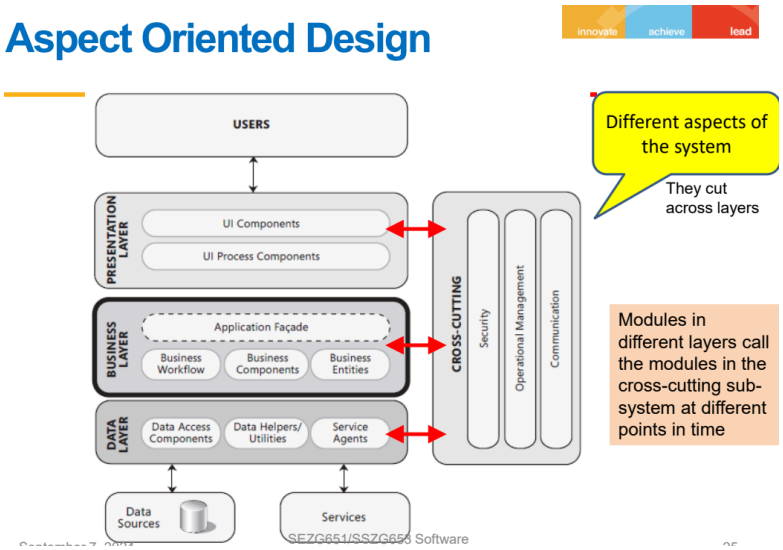
- Client based state mgmt. (cookies)
- Server based session mgmt. (persistent)



- **Work Flow Engine:** Automates business processes by controlling the sequence of activities.
    - **Example:** In an insurance system, the work flow engine automates processes like policy creation, approval, and claims processing.



- **Aspect-Oriented Design (AOP):** Encapsulates cross-cutting concerns, like logging, security, and caching, into separate "aspects" that cut across multiple layers.

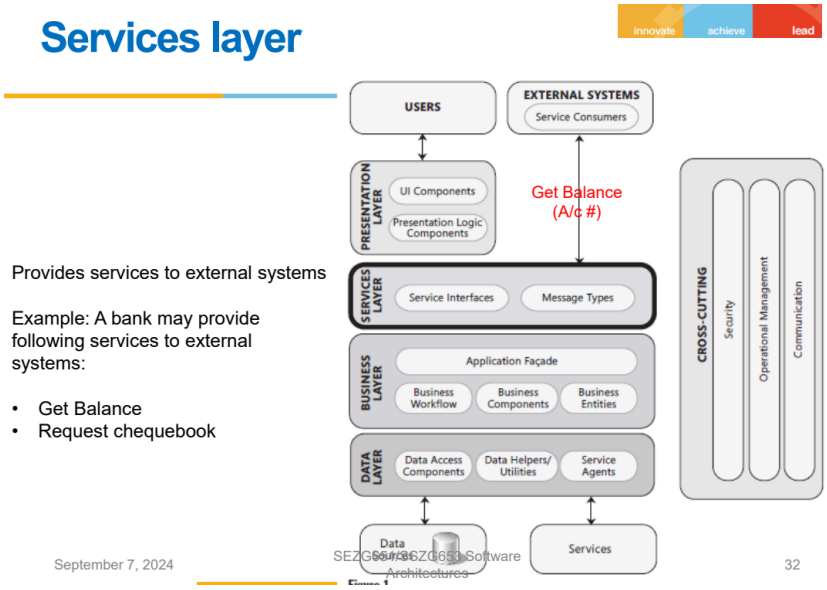


Data Access Layer Techniques:

- **DB Connection Pooling:** Maintains a pool of connections that can be reused by multiple users, improving system efficiency.
- **Object-Relational Mapping (ORM):** Maps objects in code to relational databases, enabling smoother data interaction.
    - **Example:** Hibernate framework allows developers to work with objects rather than SQL queries directly.
- **Parameterized SQL Queries:** Avoids SQL injection attacks by using parameters in SQL queries, ensuring that user inputs are treated safely.

Service Layer Techniques:

- **Provides Services to External Systems:** Handles requests from external systems (e.g., check room availability, make reservations in a hotel system).
- **Error Handling:** The service layer should handle errors like duplicate requests, message sequence errors, and communication failures.



Exercise 1: Identify components in different layers of DCS (Departure Control System)

Components in Layers:

1. **Presentation Layer:**
    - Passenger check-in screen
    - Boarding pass generation interface
    - Flight status display
2. **Business Layer:**
    - Flight check-in logic
    - Boarding sequence management
    - Baggage weight calculations
3. **Data Layer:**
    - Passenger information database
    - Flight schedule database
    - Luggage tracking database
4. **Service Layer:**

- Integration with airline reservation systems
- Notification services (e.g., email, SMS for boarding updates)
- APIs for flight scheduling and coordination with other systems

---

Exercise 2: Performance Optimization for Aadhaar Citizen Registration Screen

Problem:

- The screen for citizen registration has dropdown fields for **State**, **District**, and **Town**, and it takes time to load due to a large dataset.

Solution:

1. **Cache frequently used data:**
   - Cache the list of **States**, **Districts**, and **Towns** on the backend server for quicker access.
   - Cache can be refreshed periodically or based on updates.
2. **Dynamic loading with AJAX:**
   - Use AJAX to dynamically load **Districts** and **Towns** based on the selected **State**.
   - This ensures that only relevant data is fetched, reducing initial load time.

Exercise 3: Hotel Reservation System Integration with External Applications

Problem:

- Provide an interface for external systems like **Makemytrip.com** to check room availability and make reservations.

Solution:

1. **Layer Required:**
   - **Service Layer**
2. **Components in the Service Layer:**
   - **Get Room Availability:**
     - Input: From date, To date
     - Output: Number of available rooms by room type
   - **Reserve Room:**
     - Input: Number of rooms, room type, from date, to date
     - Output: Reservation success/failure
3. **Purpose:**
   - Expose APIs to external systems while encapsulating business logic.

Exercise 4: Hiding Modules in Logistics System

Problem:

- Users place requests for container shipping. The system involves multiple modules, such as:
  - Finding the nearest empty container
  - Finding the best transporter
  - Finding an available ship
- The architect wants to hide these modules from the client layer.

Solution:

1. **Layer for the Solution:**
    - **Business Layer**
2. **Technique:**
    - Use a **Façade Pattern** to provide a unified API in the business layer.
3. **Façade Functionality:**
    - **PlaceShippingRequest API:**
        - Input: Goods details, source, destination, date
        - Functionality:
            - Calls module to find the nearest container.
            - Calls module to find the best transporter.
            - Calls module to find the most suitable ship.
        - Output: Confirmation or failure of the request.
4. **Purpose:**
    - Simplifies the client layer by hiding the complexity of multiple modules.
    - Ensures modularity and easier maintenance.

---

3. Benefits of Layered Architecture

- **Separation of Concerns:** Each layer has a well-defined responsibility, allowing different parts of the system to evolve independently.
- **Loose Coupling:** Layers are loosely coupled to each other, making it easier to modify one layer without impacting others.
- **Reusability:** Lower layers can be reused by multiple systems or applications.

Practical Case Studies

Case Study 1: Hotel Reservation System

- **Challenge:** The system needs to provide an API to external platforms like Makemytrip.com to inquire about room availability and make bookings.
- **Solution:** Use a **Service Layer** with components such as `GetRoomAvailability` and `ReserveRoom`. The service layer interfaces with external systems, ensuring loose coupling and scalability.

Case Study 2: Shipping Logistics System

- **Challenge:** A logistics company needs a system that can hide the complexity of finding containers, transporters, and ships from the client.
- **Solution:** Implement a **Business Layer** using a façade to simplify access to the complex modules handling containers, transporters, and ships. The client interacts only with the façade, which handles the detailed business logic.

Techniques for Performance Improvement (Example Exercise)

Exercise Scenario:

In the Aadhaar system, the **citizen registration** screen has drop-down fields for "State", "District", and "Town". Loading this data can slow down the screen.

Solution:

- Use **backend caching** to store state, district, and town data.
- Implement **AJAX** to load district and town data dynamically based on the selected state.

Conclusion:

Layered architecture is a powerful design pattern that helps organize a system into manageable, distinct layers, each responsible for a different concern. By using various techniques in each layer (such as caching, façades, session management, and ORM), we can optimize the performance, scalability, and maintainability of the system. Additionally, by separating the concerns in different layers, systems can be more easily modified, maintained, and extended.

Simplified Document: Evaluation of Software Architectures

Contents

---

1. Purpose of Evaluation

- **Why Evaluate?**
    - To identify architectural risks, sensitivities, and trade-offs early.
    - To ensure alignment with business goals and quality attributes.
    - To validate the architecture's ability to meet functional and non-functional requirements.
- **Benefits:**
    - Reduce the cost of late-stage changes by uncovering risks earlier.
    - Align stakeholders on quality attribute priorities (e.g., performance, security).

---

2. Three Forms of Evaluation

a. Designer Evaluation

- Conducted during the architecture design process by the designer.
- **Steps:**
    - Evaluate decisions at every key milestone.
    - Compare alternatives and eliminate infeasible options quickly.
    - Use a “good enough” approach when differences between alternatives are minimal.
- **Factors Affecting Analysis Depth:**
    - Importance of the decision.
    - Number of potential alternatives.
    - Balancing effort vs. the decision's impact.

---

b. Peer Review

- Involves reviewing the architecture with team members (peers).

- **Steps:**
    1. Identify quality attribute scenarios (e.g., modifiability, security).
    2. Present the architecture to reviewers.
    3. Walkthrough scenarios and check if they are addressed.
    4. Capture and resolve potential risks or trade-offs.
- **Example Output:** A peer review might reveal inefficient data handling in a module, risking performance under load.

---

c. External Evaluation

- Conducted by evaluators external to the project, organization, or company.
- **Why External Evaluation?**
    1. Provides an unbiased analysis.
    2. Brings expertise or experience with similar systems.
- **Process:**
    1. Review architecture artifacts (e.g., design diagrams, requirements documents).
    2. Engage stakeholders to validate assumptions.
    3. Provide recommendations for risk mitigation or improvement.

---

3. Architecture Tradeoff Analysis Method (ATAM)

Overview:

- A structured method to evaluate architecture against quality attributes.
- Designed for large, high-risk projects with multiple stakeholders.
- Enables identification of trade-offs, risks, and sensitivity points.

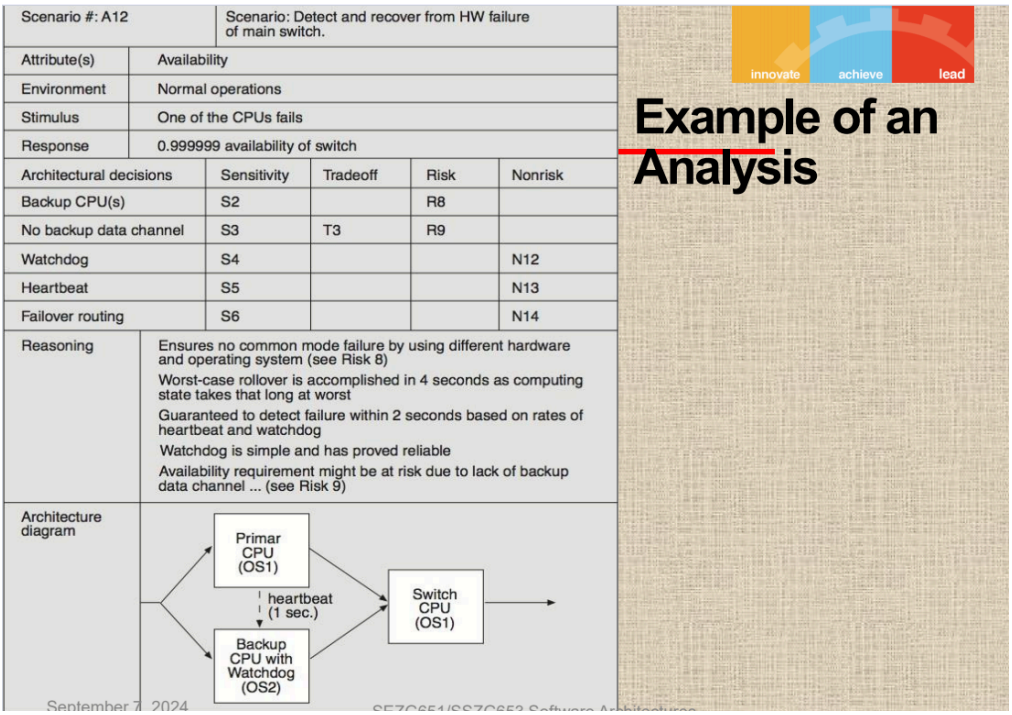
Participants in ATAM:

1. **Evaluation Team:**
    - External experts (3–5 people) recognized for their neutrality and expertise.
2. **Stakeholders:**
    - Developers, testers, architects, project managers, and business leaders.
3. **Architect:**
    - Responsible for presenting the architecture and answering queries.

Steps in ATAM:

1. **Step 1: Present the ATAM**
    - Evaluation leader explains the process, its goals, and expected outputs.
    - **Key Outputs:** Stakeholder alignment and context setting.
2. **Step 2: Present Business Drivers**
    - Project manager or customer presents:
        - Business goals (e.g., market positioning, customer satisfaction).

        - Architectural drivers (key requirements shaping the design).
        - Constraints (e.g., budget, platform limitations).
3. **Step 3: Present the Architecture**
    - Architect presents architectural views, patterns, and tactics.
    - Includes operating systems, middleware, and any technical constraints.
4. **Step 4: Identify Architectural Approaches**
    - Evaluation team catalogs the architectural patterns and tactics used.
    - Patterns/tactics serve as the basis for analysis in subsequent steps.
5. **Step 5: Generate Utility Tree**
    - Utility tree captures quality attributes as scenarios.
    - Scenarios are prioritized based on their importance (High, Medium, Low).
    - Example: A **security** scenario might involve "prevent unauthorized access in under 1 second."
6. **Step 6: Analyze Architectural Approaches**
    - Evaluation team traces each high-priority scenario through the architecture.
    - **Outputs:** Risks, non-risks, sensitivity points, trade-offs.
    - Example:
        - **Risk:** High transaction rates might overwhelm the database.
        - **Tradeoff:** Frequent heartbeat signals improve availability but reduce performance.



7. **Step 7: Brainstorm and Prioritize Scenarios**
    - Stakeholders propose additional scenarios.
    - Scenarios are ranked and compared to the utility tree for alignment.
8. **Step 8: Analyze Additional Scenarios**
    - Evaluate newly identified scenarios.
    - Focus on architectural decisions addressing these scenarios.
9. **Step 9: Present Results**
    - Summarize findings and share with stakeholders:

        - Risks, non-risks, sensitivity points, trade-offs, and risk themes.
        - Outputs include a risk mitigation plan.

---

4. Lightweight Architecture Evaluation

Overview:

- A simplified version of ATAM for smaller, less risky projects.
- Can be completed in a single day or half-day meeting.

Steps:

1. Present architecture and business drivers briefly.
2. Identify quality attributes and key scenarios.
3. Analyze the architecture for the top scenarios.
4. Summarize risks and recommendations.

- **Advantages:**
    - Faster, cost-effective alternative for low-complexity projects.
    - Suitable for internal teams familiar with the system.

---

5. Summary

1. **Purpose of Evaluation:**
    - To validate architectural decisions and ensure alignment with quality attributes and business goals.
2. **Evaluation Methods:**
    - Designer evaluations, peer reviews, and external evaluations offer multiple levels of scrutiny.
3. **ATAM Highlights:**
    - Comprehensive evaluation for high-risk projects.
    - Outputs include prioritized scenarios, risks, trade-offs, and recommendations.
4. **Lightweight Evaluation:**
    - A quicker alternative for smaller projects.
    - Focuses on core scenarios and architectural decisions.
5. **Key Takeaway:**
   "Architectural evaluations ensure that the design aligns with both technical and business needs, minimizing risks and maximizing value."

Case Studies and Examples

1. **Case Study: Banking Application**
    - **Challenge:** Ensure high availability and security for online banking.
    - **ATAM Output:** Identified sensitivity points in encryption and redundancy strategies,

leading to design changes.

2. **Lightweight Evaluation: E-commerce Platform**
    - **Challenge:** Improve modifiability for adding payment methods.
    - **Outcome:** Quick evaluation recommended using modular service-oriented architecture.

Simple Documentation on Maintaining Code and Architecture Consistency

This documentation discusses the issues of code drifting away from the architecture, techniques to maintain consistency between code and architecture, and examples of frameworks, templates, and practices to avoid drift.

---

1. Code Drift: What It Is and Examples

Code drift occurs when the implementation starts deviating from the architectural design. This happens when the team bypasses architectural guidelines or violates design principles.

Examples of Code Drift:

- **Layer violation**: An object in one layer directly accessing another object from a non-adjacent layer, bypassing intermediate layers.
    - Example: A UI layer component directly accessing the database, bypassing the business logic layer.
- **Direct database access**: Accessing the database directly without passing through the data access layer (DAO).
- **Skipping publish-subscribe mechanisms**: Directly notifying different modules one by one instead of using a publish-subscribe model.
- **Logging violations**: Not using a common logging mechanism (e.g., directly printing to the console instead of using a logging framework like Log4J).

Case Study Example:

In a **healthcare system**, the architecture defines a strict separation of concerns with presentation, business logic, and data access layers. A violation would occur if a UI component directly queries the database, ignoring the business logic, which could introduce security risks and make future changes difficult to manage.

---

2. Techniques to Prevent Code Drift

Several techniques can help ensure that code remains aligned with the architectural design.

2.1. Embed Design Concepts in Code

- **Architecturally evident coding style**: Make it evident in the code how it reflects architectural decisions. This includes comments and annotations.

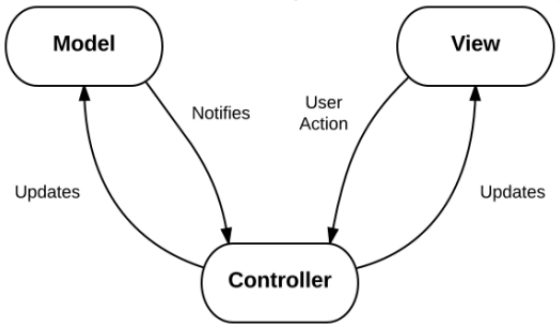
Example:

  - In layered architecture, each module should clearly indicate which layer it belongs to.
  - In a message-driven system using **publish-subscribe**, comments should identify publishers and subscribers explicitly.

2.2. Use Frameworks

Frameworks enforce consistency by providing predefined architectural patterns.

- **Spring MVC**: Enforces the **Model-View-Controller (MVC)** pattern, ensuring that the presentation logic (View) remains separate from the business logic (Controller) and data (Model).
  - **Model** encapsulates the application data
  - **View** renders screens on browser
  - **Controller** processes user requests, interacts with Model components and passes information to View components for rendering



- **JMS (Java Message Service)**: Supports **publish-subscribe** models for messaging.

Case Study Example:

In a **financial system**, using **Spring MVC** ensures that all requests pass through the controller, maintaining separation between the business logic and data layers.

---

3. Using Code Templates

Code templates provide a pre-defined structure for developers to follow, ensuring that the code adheres to specific architectural guidelines, such as handling events in a fault-tolerant manner.

Example of a Fault-Tolerant Template:

```
// Event Handling Template
Get event
Case (Event
```

```
  type) Normal:
    Process X;
    Send state to backup process;
    Process Y;
    Send state to backup process;
    Update State Data; Switch over:
    Notify clients about change in the primary process;
End case;
```

Templates ensure that critical architecture patterns, like fault tolerance, are embedded in the code from the beginning.

---

4. Synchronizing Architecture Documentation with Code

To prevent documentation from becoming outdated:

- **Synchronize the architecture document with the code during each release**.
- **Mark outdated sections** as "No longer applicable" to improve trust in the remaining documentation.

Technique:

During release, ensure the architecture documentation reflects code changes and that any irrelevant sections are identified. For example, if a module's architecture has changed, mark the previous version of the module as outdated.

---

5. Exercises: Other Techniques to Prevent Code Drift

5.1. Educate Team Members

- Ensure that every team member understands the system architecture, including new developers.

5.2. Conduct Code Reviews

- Regular **code reviews** help ensure that the implementation follows the architectural guidelines.

5.3. Organize Code into Folders by Architecture

- Create folders for each architectural aspect such as layers (UI, service, data access) and maintain a clear structure. This will help developers follow the architectural design when organizing their code.

---

6. Frameworks for Maintaining Consistency

Spring Framework:

- Enforces **MVC architecture**: Separates the presentation layer (View), business logic (Controller), and data (Model).

Hibernate Framework:

- Provides **Object-Relational Mapping (ORM)**: Ensures a consistent mapping between the database and the object-oriented application.

Log4J Framework:

- Provides a common logging mechanism, ensuring consistency in logging events and errors.

Case Study Example:

In a **web application**, using **Spring MVC** ensures a clean separation between the components, making it easier to maintain and scale the application without violating the architectural structure.

---

7. Publish-Subscribe Frameworks

Publish-Subscribe frameworks (e.g., JMS) manage how different parts of a system communicate. Instead of directly invoking methods on other components, a component (publisher) sends out messages, and any interested components (subscribers) listen for those messages.

Case Study Example:

In a **news distribution system**, the publisher (news agency) pushes out news updates, and the subscribers (news apps) receive those updates without needing to directly communicate with the publisher.

---

8. Diagram: Architecture Layers and Drift Example

Here's an example diagram showing a **typical layered architecture** and examples of code drift.

```
+                             +
| Presentation Layer          | <-- Accessed by UI
+                             +
           |
           v
+                             +
| Business Logic Layer        | <-- Processes business rules
+                             +
           |
           v
+                             +
| Data Access Layer           | <-- Manages DB interactions
+                             +
           |
           v
+                             +
| Database                    | <-- Stores persistent data
+                             +

Examples of Drift:
1. Presentation layer directly accesses the database.
2. Data Access Layer is bypassed for custom queries.
3. Logging mechanisms ignored, leading to inconsistent logs.
```

---

9. Summary

Maintaining consistency between code and architecture is crucial to the long-term maintainability and scalability of any system. Techniques such as embedding design in code, using frameworks, applying code templates, and keeping architecture documentation up-to-date are essential for avoiding code drift. Regular peer reviews and organized folder structures also

help prevent the implementation from deviating from the architecture. By adopting these practices, development teams can ensure that the system remains aligned with its architectural goals and requirements.

This concludes the documentation, providing techniques, examples, and case studies for keeping code and architecture consistent while preventing common violations.

Architecture & Testing: Simple Overview

Software architecture plays a crucial role in testing activities by providing a structured approach to defining, prioritizing, and executing test cases. Here's a simplified document explaining the relationship between architecture and testing with examples and case studies:

---

1. How Does Architecture Help in Testing Activities?

- **Prioritization of Test Cases**: Software architecture helps to prioritize test cases by analyzing **Architectural Significant Requirements (ASRs)**. These requirements have a high impact on the system's performance, security, and scalability, which guide the testing process.
- **Creation of Integration Test Plan**: Architecture defines module interactions and dependencies, which allows testers to create a structured integration testing plan.
- **Support Testability**: Architecture must be designed to support the testability of the system. For instance, it should allow switching between production data and test data easily or enabling rollback features after test execution.

---

2. Work Product of Architecture Design to Prioritize Test Cases

- **Utility Tree**: The utility tree is a work product in architecture design used to identify **high-priority scenarios** based on business value and architectural impact. This tree structure helps prioritize test cases by identifying the most critical aspects of the system that need rigorous testing.

- **Example**:

    - In an e-commerce platform, the payment gateway is crucial, having high business value and architectural impact. Thus, test cases related to payment integration are prioritized.

---

3. How Architecture Helps Create an Integration Test Plan?

- **Module Interaction**: Architecture outlines the modules and how they interact, providing the **sequence** and **dependencies** for integration testing. This information helps the team plan integration tests that validate how different parts of the system work together.
- **Example**:
    - In a banking software system, the architecture shows the relationship between the transaction module and the user authentication module. Testing the

interaction ensures that transactions are only processed after proper authentication.
- **Dependency Identification**: Architecture helps identify **module dependencies** which define the **order of testing**. Modules with the most dependencies are tested first.

---

4. Architecture and Testability Requirements

- **Switch Data Sources**: Architecture should allow easy switching between test data and production data. This enables test environments to simulate real-world scenarios without affecting live data.
    - **Example**: A healthcare system architecture allows switching between real patient data and dummy data for testing without violating privacy rules.
- **Rollback Changes**: Architecture should support rolling back changes made during testing to restore the system to its original state, ensuring that multiple tests can be run without side effects.
    - **Example**: In an online ordering system, after testing a payment process, the transaction should roll back to its pre-test state.
- **Component Replacement**: Test environments often require **simulators** for components like external payment gateways or sensors. Architecture should support the easy replacement of real components with mock components.
    - **Example**: During testing, a flight booking system might use a simulated payment gateway to avoid real transactions.

---

5. Experience Sharing: How Architecture Helps Testing Teams

- **Real-world Scenario**: In a software project for a financial institution, the architecture defined clear module boundaries and integration points between the **transaction processing system** and the **user management system**. This clear architectural separation allowed the testing team to:
    - Identify key areas for performance testing.
    - Develop integration tests to ensure proper data flow between these modules.
    - Create test cases for edge scenarios like system overload or partial system failures.

Benefits to Testing Team:

- Streamlined **integration testing** by focusing on module dependencies.
- Easier identification of **critical test cases** based on the architecture's impact on business objectives.
- Enabled **simulated environments** to test interactions with external systems without using real-time data.

Case Study: E-Commerce Application Testing Using Architecture

Scenario: An online retail company wants to test the payment processing feature in its e-commerce application. The architecture highlights interactions between:

- **User authentication module**
- **Product catalog**
- **Shopping cart**
- **Payment gateway**

Architecture Support:

- **Integration Test Plan**: Based on the architecture, the team identifies that the **user authentication** and **shopping cart** modules must be tested before moving to **payment processing**.
- **Testability Features**: The architecture supports a **mock payment gateway** so that multiple test cases can be run without real transactions.

Outcome:

- The architecture helps create a sequence of integration tests, ensuring that each module functions correctly before integrating them together. By prioritizing payment gateway testing, critical defects are caught early, preventing potential losses in real transactions.

Solution to Exercises:

Exercise: How does architecture prioritize test cases based on ASRs?

- **Answer**: Architecture helps prioritize test cases by identifying critical **Architecturally Significant Requirements (ASRs)**. Test cases targeting these ASRs are executed with higher priority, ensuring that the most important aspects of the system (e.g., performance, security, scalability) are thoroughly tested. The **utility tree** provides a guide to find the highest business value and architectural impact areas, which should be tested first.

Exercise: What does architecture tell us about module interactions?

- **Answer**: Architecture provides a clear picture of how different modules in the system interact and depend on each other. This information is used to design the **integration test plan**, ensuring that modules are tested in the correct sequence based on their dependencies.

Architecture Reconstruction

Contents

---

1. Purpose of Architecture Reconstruction

Architecture reconstruction serves the following purposes:

- **Understanding undocumented systems**: To uncover the architecture of a system when no prior documentation exists.
- **Technology migration**: For example, migrating from legacy systems (e.g., Mainframe) to modern platforms like the Web.
- **Identifying reusable components**: To isolate and reuse common components, such as logging or security modules.

Diagram Placeholder: Architecture Reconstruction Process

---

2. Phases of Architecture Reconstruction

a. Identify Components and Their Relationships

Extract data from:

- Source code
- Execution traces
- Build scripts

This process gathers information about:

- Classes
- Caller-callee relationships
- Global data accessed

Diagram Placeholder: Component Extraction Process

Examples of component extraction

Table 20.1. Examples of Extracted Elements and Relations

Source Element	Relation	Target Element	Description
File	`includes`	File	C preprocessor `#include` of one file by another
File	`contains`	Function	Definition of a function in a file
File	`defines_var`	Variable	Definition of a variable in a file
Directory	`contains`	Directory	Directory contains a subdirectory
Directory	`contains`	File	Directory contains a file
Function	`calls`	Function	Static function call
Function	`access_read`	Variable	Read access on a variable
Function	`access_write`	Variable	Write access on a variable

Execution trace of method calls

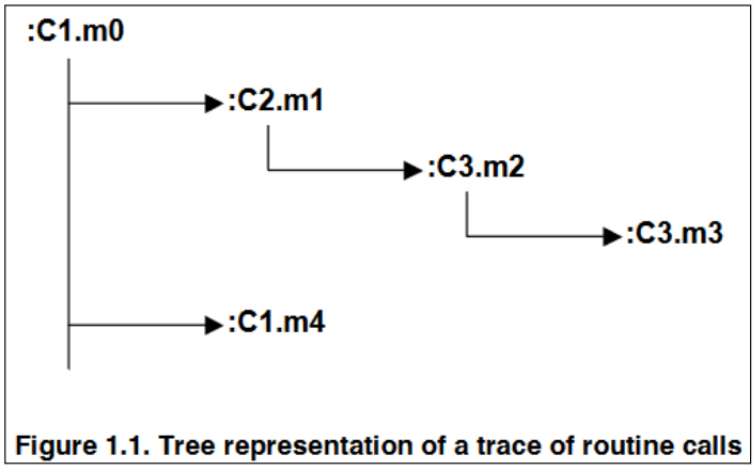


Figure 1.1. Tree representation of a trace of routine calls

b. Aggregate Components into Abstract Layers

- Group components based on their relationships.
- Use tools to visualize and create higher-level abstractions of the system.
- Example: Grouping classes into architectural layers like presentation, business logic, and database.

c. Analyze the Architecture

- Examine architecture diagrams for patterns or violations.
- Example: Identify issues like non-layered dependencies or missing abstractions.

3. Reconstruction Tools

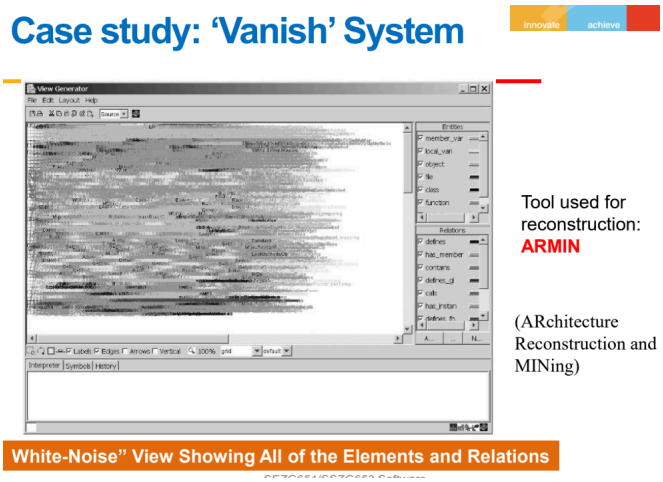
Popular Tools:

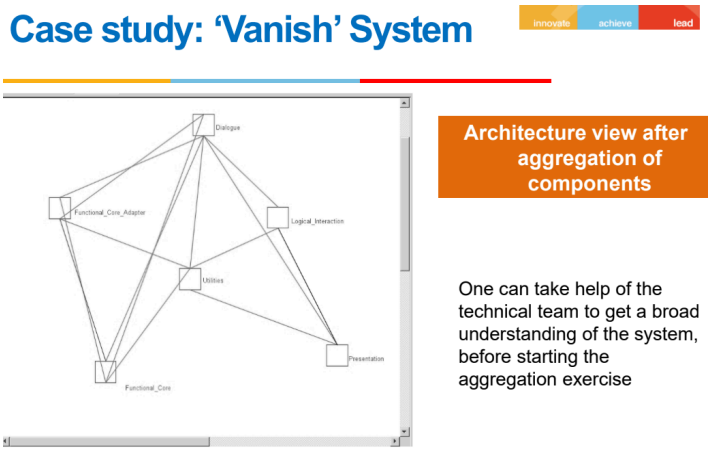
1. **Dali**
2. **ARMIN**: Architecture Reconstruction and Mining.
3. **Lattix**: Identifies dependencies within systems.
4. **SonarQube**: Tracks violations in execution paths.
5. **Structure 101**: Simplifies architectural views.

Case Study: Vanish System

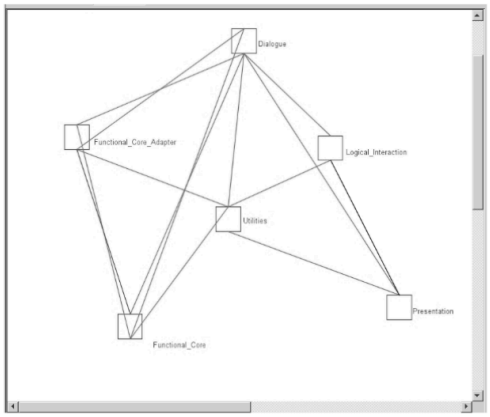
- Tool Used: **ARMIN**
- Reconstruction Phases:
    - **Raw View Extraction**: Retrieved execution traces and caller-callee relationships.
    - **Aggregation**: Components were grouped into broader architectural layers.
    - **Analysis**: Detected that the system was not strictly layered.

Diagram Placeholder: Architecture Reconstruction of the Vanish System





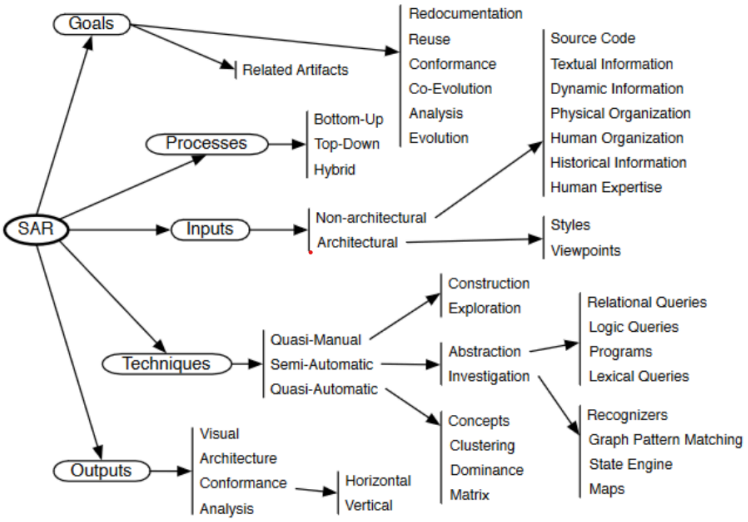
Case study: 'Vanish' System



Analyse architecture

One can notice that the architecture of 'Vanish' is not strictly layered

SAR: Sw Arch Reconstruction



Detailed Phases of Architecture Reconstruction

Step 1: Raw View Extraction

- Extracts data from source code, traces, and scripts.
- Example Outputs: Classes, global variables, method calls.

Step 2: Database Construction

- Consolidates extracted data into a database for further analysis.

Step 3: View Fusion

- Combines static (source code) and dynamic (execution trace) views into a unified perspective.
- Expert groups these into layers for better abstraction.

Diagram Placeholder: View Fusion Example

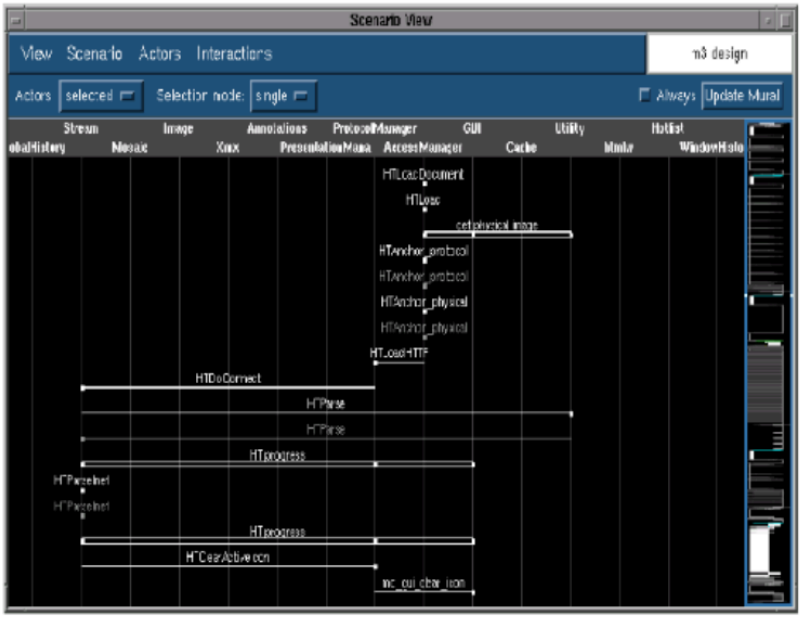
Step 4: Architecture Analysis

- Ensures conformance with defined architectural rules.
- Example: Verify that database access happens only via entity beans.

Diagram Placeholder: Architecture Conformance Check

Iterative Refinement

- Revisit and refine the architecture as necessary based on additional insights.



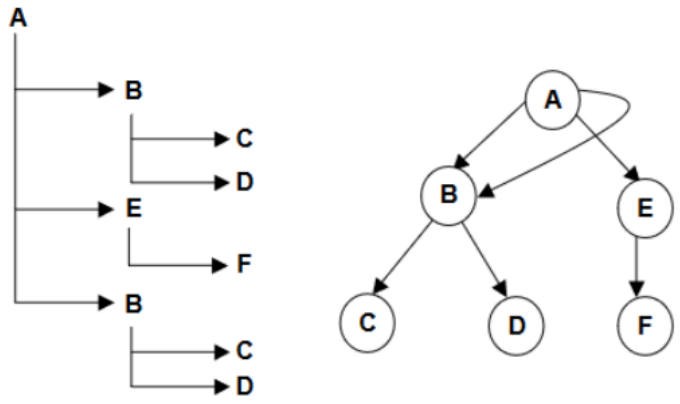


Figure 3.1. The graph representation of a trace is a better way to spot the number of distinct subtrees it contains

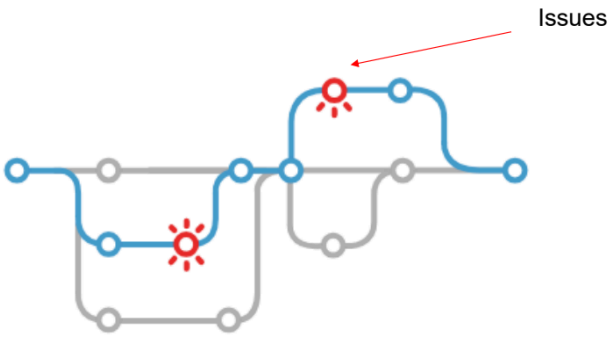
Sample Architecture Violations

Detected Violations:

1. **Layer Dependency Violation**: A component bypassing an intermediate layer.
2. **Database Access Rule Violation**: Direct database access without using entity beans.

Diagram Placeholder: Architecture Violation Detected by SonarQube

SonarCube Explores All Execution Paths



Sample View fusion using Sonar tool

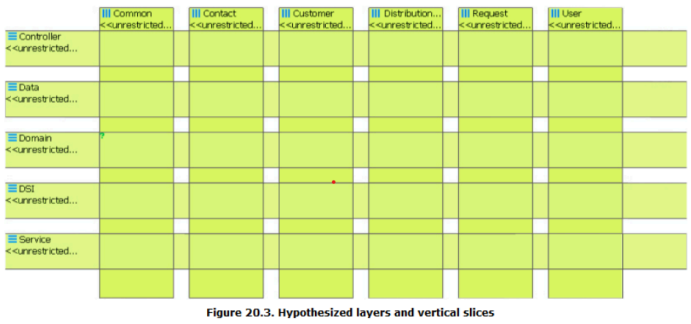


Figure 20.3. Hypothesized layers and vertical slices

Sonar tool allows definition of layers and vertical slices through the layers
The tool will populate the layers & slices with components / elements

Reflection Questions with Answers

1. Have you been part of reconstructing a system's architecture

Yes, the reconstruction process involved a legacy application for order management in a retail company. The goal was to migrate it from a monolithic system on mainframes to a microservices-based architecture. The existing system had no documentation, so we used tools like **SonarQube** and **ARMIN** to extract and analyze components.

2. What techniques and tools did you use

Techniques Used:

1. **Static Analysis**: Examined the source code to understand dependencies, caller-callee relationships, and module interactions.
2. **Dynamic Analysis**: Captured execution traces to observe runtime behaviors, such as dynamic method invocations.
3. **Layered Aggregation**: Grouped components into logical layers like UI, business logic, and database.

Tools Used:

1. **SonarQube**: For detecting code smells, architectural violations, and dependencies.
2. **ARMIN**: To visualize and mine the architectural structure of the system.
3. **Lattix**: To identify and document inter-module relationships.

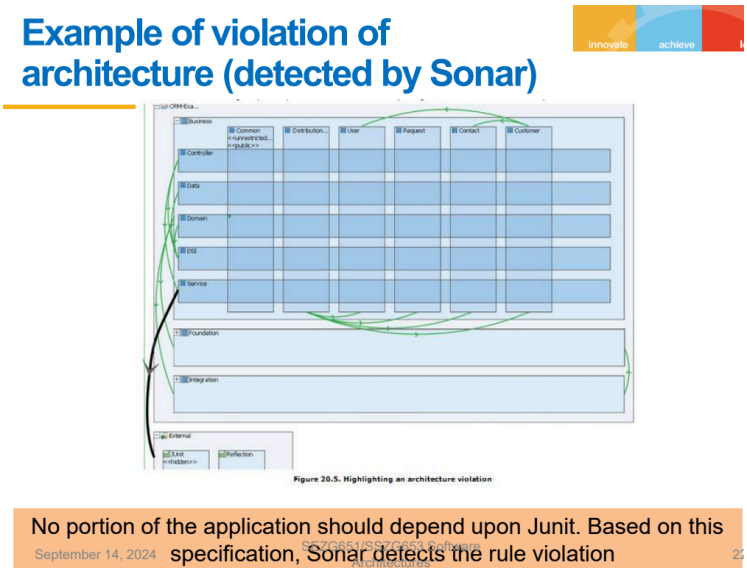
3. How did you validate architectural conformance

Validation Steps:

1. **Rule Definition**: Established rules for layer communication, such as ensuring all database access occurs through a repository layer or service layer.
2. **Tool Execution**: Used **SonarQube** to run rule checks and identify violations.
3. **Manual Review**: Conducted expert reviews to confirm critical business rules were followed.
4. **Iteration**: Adjusted components and relationships based on feedback and repeated validation.

Example of a Violation Detected:

- Direct database access from the UI layer bypassing the service layer was flagged and corrected by refactoring the code.



Example of architecture violation (detected by Sonar)

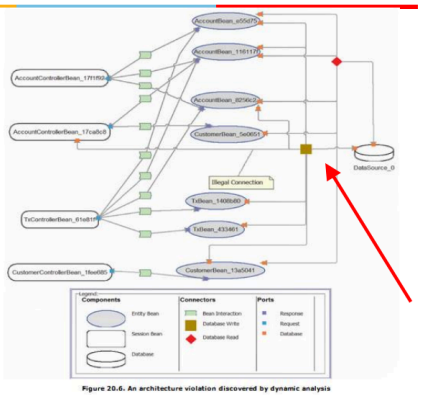


Figure 20.6: An architecture violation discovered by dynamic analysis

All database access is supposed to be managed by entity beans. Discovered by tool Disco Tect

---

Summary

Architecture reconstruction is critical for modernizing, understanding, and reusing existing systems. It involves identifying system components, creating abstractions, and analyzing the overall architecture using advanced tools like ARMIN and SonarQube. A systematic approach ensures accuracy, efficiency, and scalability in handling complex systems.

Documentation for Layered, Broker, and Pipe-and-Filter Patterns

---

Introduction to Patterns

Architectural patterns provide a structured approach to solving recurring design problems in software systems. Each pattern addresses a specific problem within a defined context and offers a proven solution.

Pattern Overview

1. **Layered Pattern**
2. **Broker Pattern**
3. **Pipe-and-Filter Pattern**

Layered Pattern

Context

In complex software systems, the development and evolution of system components need to be handled independently. The system must be segmented to allow modules to be developed separately, supporting modularity, flexibility, and reuse.

Problem

How to separate software into independent units that can be developed, tested, and maintained independently, while maintaining clear communication between them?

Solution

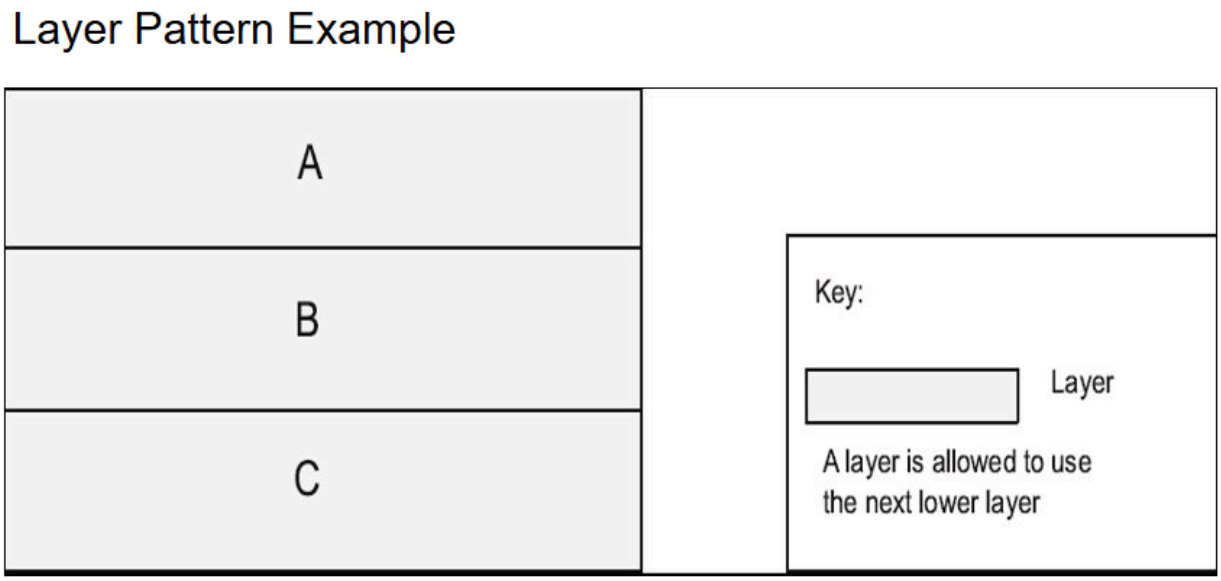
The Layered Pattern divides the software into distinct layers, where each layer performs a specific set of tasks and interacts only with the layer directly below or above it. Each layer offers a cohesive set of services exposed through a public interface, ensuring a unidirectional flow of communication.

Example

- **Use Case**: In a web application, the architecture is divided into three main layers:
    - **Presentation Layer**: Manages user interfaces.
    - **Business Logic Layer**: Handles business rules and operations.

- **Data Access Layer**: Manages data storage and retrieval from the database.

Diagram: Layer Pattern Example



Elements

- **Layers**: Grouping of modules, each offering a set of related services.
- **Relations**: Defines allowed usage between layers, typically in a top-down manner.
- **Constraints**:
  - Each module belongs to one layer.
  - No circular dependencies between layers.

Strengths

- Clear separation of concerns.
- Improved maintainability and scalability.
- Easier to test individual layers.

Weaknesses

- Increases initial complexity and overhead.
- Potential performance penalty due to multiple layers.

Broker Pattern

Context

Distributed systems often consist of services spread across multiple servers. These services must communicate with each other seamlessly, without users needing to know the location or nature of service providers.

Problem

How to structure distributed software so that service users do not need to know the specific details or locations of the service providers, allowing for dynamic service bindings?

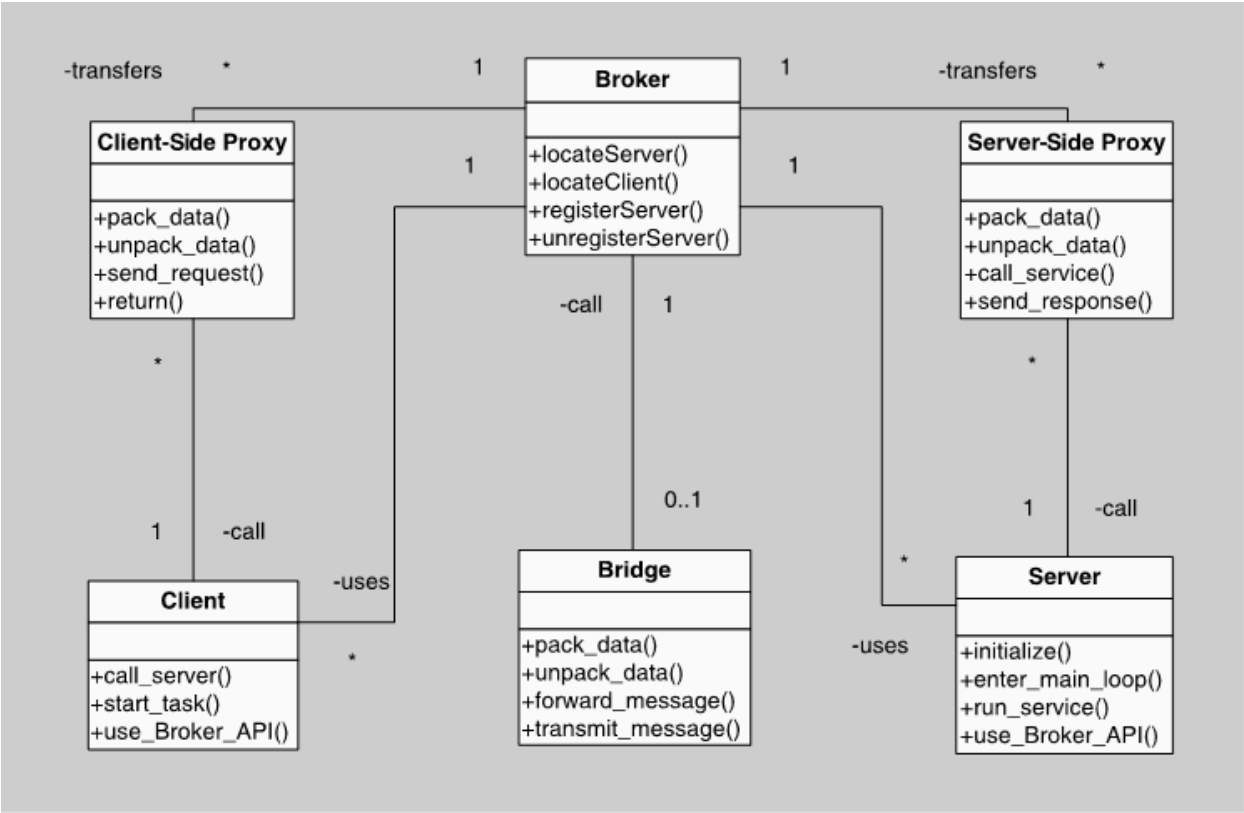
Solution

The Broker Pattern introduces an intermediary called a **broker** that manages communication between service clients and service providers. Clients communicate with the broker, which then forwards requests to the appropriate servers and returns the results to the client.

Example

- **Use Case**: In an e-commerce platform, users interact with a broker to access various services like order processing, payment, and inventory management. The broker handles requests and responses, making service details transparent to users.

Diagram: Broker Pattern



Elements

- **Client**: Requests services.
- **Server**: Provides services.
- **Broker**: Mediates communication between clients and servers.
- **Client-Side Proxy**: Handles client communication with the broker, including message handling.
- **Server-Side Proxy**: Manages server communication with the broker.

Relations

- Clients and servers connect to brokers, possibly through proxies.

Constraints

- Communication must pass through the broker.
- The broker must handle service discovery, forwarding, and result handling.

Strengths

- Decouples clients and servers, allowing for easier modifications.
- Supports dynamic binding and scalability.

Weaknesses

- Adds latency due to the intermediary layer.
- Single point of failure if the broker is not designed for redundancy.
- Can be a target for security attacks.

Pipe-and-Filter Pattern

Context

Many software systems require processing streams of data through successive transformations. These transformations are often repetitive and need to be implemented as reusable components.

Problem

How to create a system with loosely coupled components that can perform data transformations in sequence, allowing for parallel execution and flexibility?

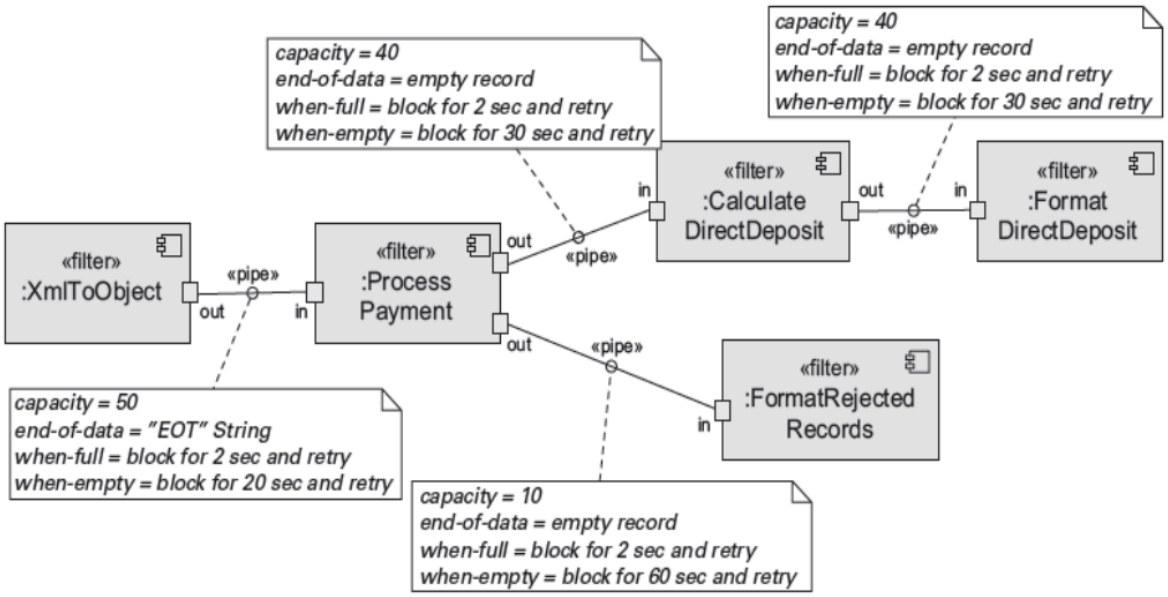
Solution

The Pipe-and-Filter Pattern divides the system into components called **filters**, which perform data processing. Data flows through **pipes** that connect the filters, allowing for independent, parallel, and reusable transformations.

Example

- **Use Case**: A data processing pipeline that reads raw sensor data (input), cleans it, performs analysis, and outputs the results in a report.

Diagram: Pipe-and-Filter Pattern



Elements

- **Filter**: A processing component that transforms data.
- **Pipe**: A connector that transmits data between filters.

Relations

- Pipes connect filter outputs to filter inputs, enabling sequential data flow.

Constraints

- Filters must have well-defined inputs and outputs.
- Filters should not maintain state between invocations.

Strengths

- High reusability of filters.
- Supports parallel processing and dynamic reconfiguration.

Weaknesses

- May introduce performance bottlenecks if filters are not optimized.

- Error handling can be complex in the pipeline.

Use Cases and Scenarios

Layered Pattern Use Case

- **Scenario**: In a banking system, the layered architecture separates the presentation layer (user interface), business layer (loan processing), and data layer (customer data). This separation allows for independent updates and testing of each layer.

Broker Pattern Use Case

- **Scenario**: In a cloud-based service, the broker manages requests from users to different cloud providers for storage, processing, or database services. The broker ensures service continuity even if providers change.

Pipe-and-Filter Pattern Use Case

- **Scenario**: In a video streaming service, data is processed in filters for decoding, buffering, and rendering, connected by pipes. This setup allows for parallel processing of video data for better performance.

Conclusion

The **Layered Pattern** is suitable for modular systems, the **Broker Pattern** is essential for distributed systems, and the **Pipe-and-Filter Pattern** is effective for sequential data processing. Each pattern has its strengths and weaknesses but provides a structured approach to building scalable, maintainable, and adaptable software architectures.

Software Architectural Patterns - Detailed Documentation

Introduction to Architectural Patterns

Architectural patterns offer a repeatable solution to recurring design problems in software systems. They provide a structured approach by defining a **context**, the **problem** that arises in that context, and a **solution** to solve the problem. These patterns represent proven best practices based on experience and are crucial for building efficient, scalable, and maintainable software systems.

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1. Context

The **context** of a pattern refers to the recurring situation or environment where the problem arises. It could involve scenarios where a system is complex and difficult to maintain or situations requiring scalability and flexibility.

Example Scenario:

- A large enterprise wants to develop an application where multiple teams work on different parts of the system. The teams need to avoid overlapping responsibilities to ensure smooth development and maintenance. This situation creates the need for a pattern that separates concerns across the system components.

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2. Problem

A **problem** is a challenge or issue that commonly arises in a particular context. Patterns generalize these problems to provide reusable solutions. The problem may relate to ensuring modularity, achieving scalability, or providing flexibility.

Example Scenario:

- An e-commerce platform needs to handle a growing number of users and a rapidly expanding product catalog. The current monolithic architecture becomes too rigid and hard to modify, leading to a need for a better-organized system that can scale efficiently without major overhauls.

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3. Solution

The **solution** in an architectural pattern provides a structured method to resolve the problem. It defines the system components, their responsibilities, interactions, and how they should be arranged to solve the problem efficiently.

- **Element Types**: Defines the components involved in the solution, such as data repositories, processes, objects, etc.
- **Interaction Mechanisms**: Describes how components interact, such as through method calls, events, or message buses.
- **Topology**: Specifies the layout of components and how they are arranged and connected.

Example Scenario:

- In the e-commerce platform mentioned above, the **Microservices Architecture Pattern** could be the solution. It breaks the monolithic system into independent services, each responsible for a specific domain (like user management, product catalog, order processing). These services communicate over well-defined APIs, making the system scalable and flexible.

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4. Properties of Patterns

Patterns exhibit certain beneficial properties, which make them an essential part of software architecture.

- **Documentation of Well-Proven Designs**: Patterns capture and document design solutions that have been used successfully in the past.
- **Provide a Common Vocabulary**: Patterns give architects and developers a shared language for discussing design challenges.
- **Support Complex Software Construction**: Patterns help organize complex systems into manageable components, supporting easier development and maintenance.

Example Use Case:

- In a large team, developers can discuss how to structure an application by referencing patterns like **Model-View-Controller (MVC)** or **Broker**. Instead of lengthy explanations, they can simply refer to these patterns to quickly convey their design approach.

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5. Categories of Patterns

Patterns can be classified into various categories based on the types of problems they address.

From Mud to Structure

- These patterns help organize chaotic systems into well-defined structures.
    - **Layers Pattern**: This pattern divides the system into layers, each responsible for a specific concern.
    - **Pipes and Filters Pattern**: The system is broken into components (filters) that process data streams, connected by pipes that pass the data.
    - **Blackboard Pattern**: Different components work on solving parts of a problem, sharing their knowledge on a central “blackboard”.

Distributed Systems

- **Broker Pattern**: Provides infrastructure to facilitate communication between components in a distributed system. Commonly used in systems where components are located across a network.

Interactive Systems

- **Model-View-Controller (MVC)**: Commonly used in user interface design, it separates application logic (Model), the user interface (View), and user interactions (Controller).

Adaptable Systems

- **Microkernel Pattern**: Provides a core system that can be extended with plug-in modules, ensuring adaptability and scalability.
- **Reflection Pattern**: Supports dynamic adaptation of a system to evolving requirements by modifying the system structure and behavior at runtime.

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6. Detailed Example: Layers Pattern

Context:

In large systems, developers need to separate concerns so that different parts of the system can be developed, maintained, and evolved independently.

Problem:

The system needs to be modular to enable easy evolution and maintenance. Each module must be independent, allowing parts of the system to change without affecting the others.

Solution:

The **Layers Pattern** divides the software into distinct layers, each responsible for a specific part of the system’s functionality. Each layer interacts only with the layer directly beneath it, ensuring a unidirectional flow of control.

- **Elements**: The system is broken into layers, each containing modules that provide specific services.
- **Interaction**: Higher layers can access the services of the layer directly below them, but lower layers should not access higher layers.
- **Constraints**: Circular dependencies among layers are avoided. The number of layers typically ranges from two to three, but there may be more in complex systems.

Diagram Placement: A diagram illustrating the layers (such as the application layer, business logic layer, and data access layer) would be placed here to show how each layer provides services to the one above it. Each layer must be clearly separated with arrows indicating the unidirectional flow.

Use Case:

- In a banking application, the system is divided into three layers:
    - **Presentation Layer**: Handles user input and displays information.
    - **Business Logic Layer**: Contains the core rules of banking (e.g., calculating interest, processing transactions).
    - **Data Access Layer**: Manages interactions with the database (e.g., storing and retrieving customer information).

This layered approach allows changes in one layer (e.g., changing the user interface) without affecting other layers (e.g., the business rules).

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7. Benefits of Patterns

- **Simplify Complex Architectures**: Patterns help organize large systems into well-defined components, reducing complexity.
- **Reusability and Flexibility**: Proven solutions can be reused across different projects, speeding up development.
- **Support Maintainability**: Well-structured systems are easier to maintain, allowing independent updates to different components.

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8. Managing Software Complexity

Patterns help in managing the complexity of software systems by defining clear roles and responsibilities for each component. By following a structured pattern, developers can avoid the chaos that often accompanies large-scale software development.

Example Scenario:

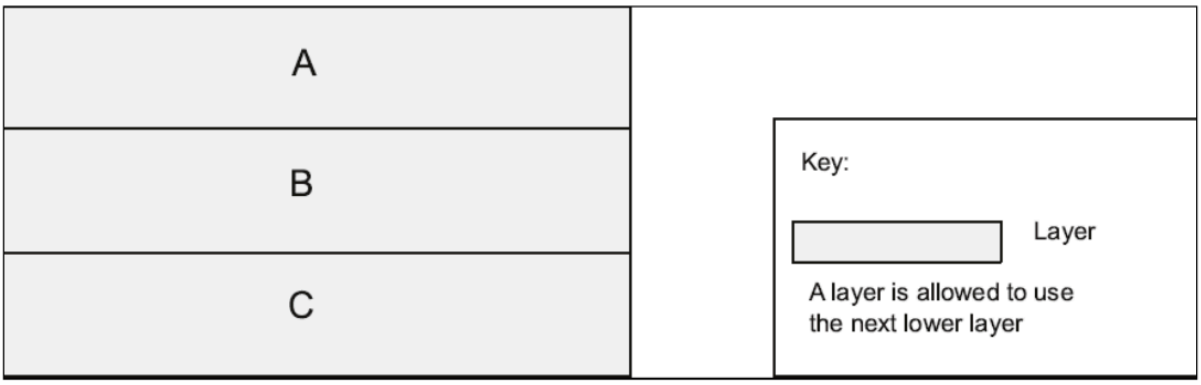
- A video streaming platform uses the **Pipes and Filters** pattern to process media data. Each filter handles a specific task (such as decoding, buffering, or applying subtitles), and the data flows through these filters via pipes, making the system modular and easier to manage.

Summary of Architectural Patterns

Patterns are an essential tool for addressing recurring design problems in software systems. By providing a common vocabulary and a structured approach to problem-solving, they enable architects and developers to build reliable, scalable, and maintainable systems. Use cases, such as separating user interfaces from core logic (MVC), or dividing a system into manageable layers, demonstrate the value of applying architectural patterns in real-world projects.

Diagram Placement Suggestion

- **Layered Pattern Diagram**: Should be placed in the section that describes the "Layers Pattern" to visualize the hierarchy of layers and their unidirectional relationships.



Software Architectural Patterns - Simple and Understandable Documentation

This document summarizes the architectural patterns used to structure software systems effectively. The key categories include patterns that help manage complexity, distribute components, support interactive systems, and ensure adaptability.

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1. From Mud to Structure

These patterns help you avoid a disorganized collection of components by breaking down a system into manageable subtasks. Common patterns include:

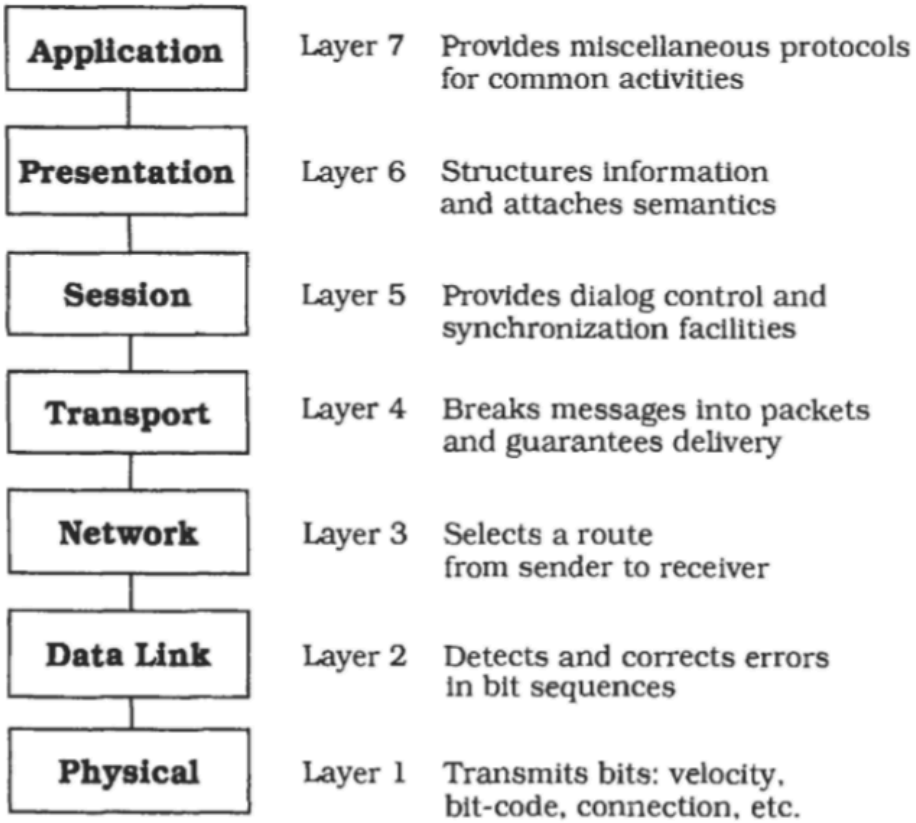
- **Layers Pattern**
- **Pipes and Filters Pattern**
- **Blackboard Pattern**

Layers Pattern

The **Layers Pattern** divides a system into layers, where each layer provides specific services and interacts only with the layer directly below it.

- **Example**: The OSI 7 Layer Model in networking is a classic example of the Layers Pattern.

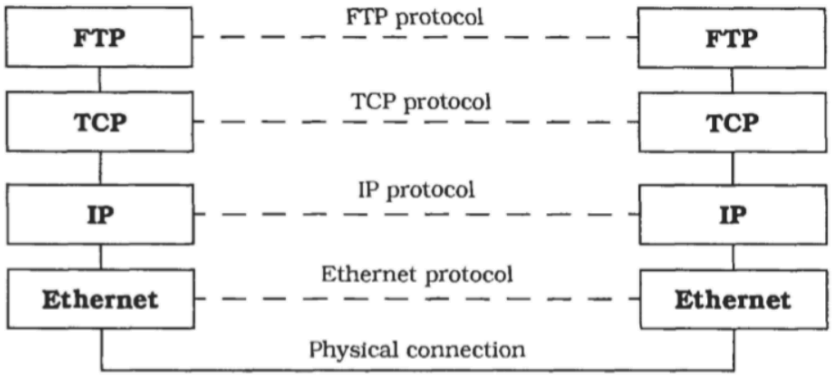
Diagram: OSI 7 Layer Model



Implementation Steps for the Layers Pattern:

1. Define criteria for grouping tasks into layers.
2. Determine the number of abstraction levels needed.
3. Assign tasks and name the layers.
4. Specify services for each layer.
5. Refine the layer structure and interfaces.
6. Ensure adjacent layers communicate properly.
7. Decouple layers for flexibility.

Diagram: TCP/IP Layer Model



Variants of the Layers Pattern

- **Relaxed Layered System**: In this variant, layers can use the services of any layer below them, not just the next lower one. This increases flexibility but reduces maintainability.
- **Layering Through Inheritance**: In object-oriented systems, lower layers can act as base classes for higher layers, which inherit and modify services. However, this can create tight coupling and problems if lower layers change.

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2. Distributed Systems

Broker Pattern

The **Broker Pattern** provides a structure for distributed applications. It decouples components (clients and servers) and allows them to communicate via a broker, making the system flexible and scalable.

- **Context**: Used in distributed systems where components operate independently and need to interact remotely.
- **Problem**: Direct communication between components leads to dependencies and makes scalability difficult.
- **Solution**: A broker handles all communication between clients and servers, forwarding requests and responses.

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3. Interactive Systems

These systems need patterns that support user interactions.

Model-View-Controller (MVC) Pattern

The **MVC Pattern** separates the application into three components:

- **Model**: Handles the data and business logic.
- **View**: Manages the user interface.
- **Controller**: Acts as an intermediary between the model and the view, handling user input and updating the view.
- **Example**: In a web application, the MVC pattern separates the presentation layer (HTML/CSS) from the business logic (JavaScript) and the data (backend database).

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4. Adaptable Systems

These patterns support system adaptability and evolution over time.

Microkernel Pattern

The **Microkernel Pattern** separates the core system from optional services. The core system (or microkernel) manages essential tasks, while additional features are added through plug-ins or modules.

- **Example**: Operating systems like Windows NT use the microkernel architecture to allow for easy updates and system extensions without modifying the core.

Reflection Pattern

The **Reflection Pattern** enables a system to adapt at runtime by modifying its structure and behavior dynamically. This is useful for systems that need to change based on evolving requirements.

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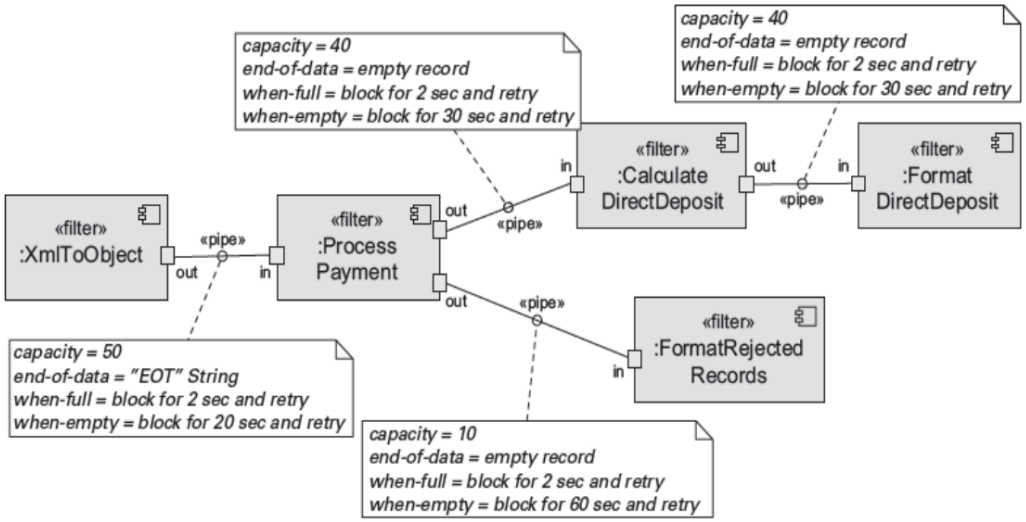
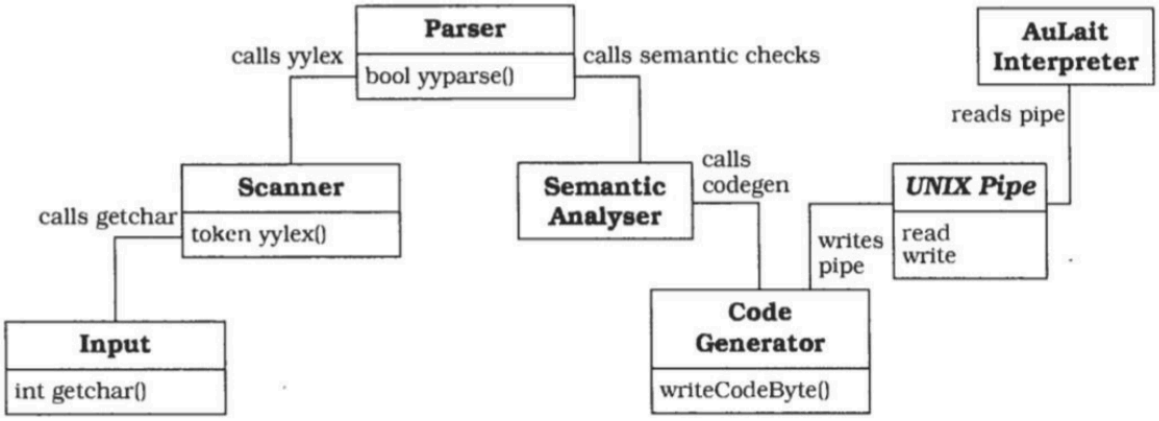
5. Pipes and Filters Pattern

The **Pipes and Filters Pattern** structures a system that processes a stream of data through a sequence of processing steps (filters). Each filter transforms the data and passes it to the next step through pipes.

- **Context**: Systems that process data streams, such as data pipelines.
- **Problem**: Systems need to be broken down into reusable, loosely coupled components.
- **Solution**: The system is divided into independent filters, each processing the data and passing it along to the next filter via pipes.

Diagram: Pipe and Filter Example





Implementation Steps for the Pipes and Filters Pattern:

1. Divide the system's task into processing stages.
2. Define the data format for each pipe.
3. Implement the connections between pipes and filters.
4. Design the filters and error-handling mechanisms.
5. Set up the pipeline and allow flexibility for reordering filters.

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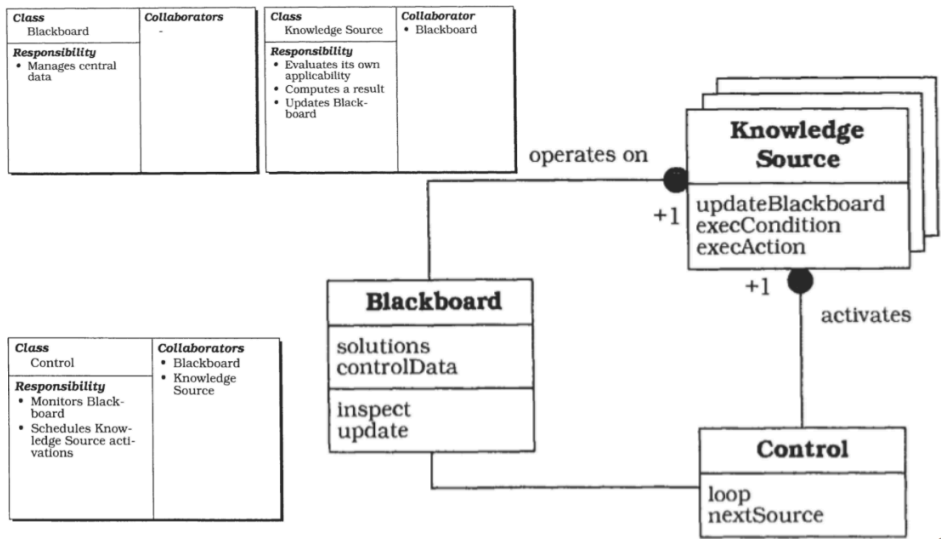
6. Blackboard Pattern

The **Blackboard Pattern** is used for complex problems where no deterministic solution exists. Multiple independent subsystems contribute partial solutions to build a complete solution.

- **Context**: Used in systems with no clear solution, such as speech or image recognition.
- **Problem**: The problem requires different algorithms, representations, and solutions to be combined dynamically.
- **Solution**: A central "blackboard" stores partial solutions contributed by independent components, which work together to solve the overall problem.

Diagram: Blackboard Architecture



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7. Benefits of Architectural Patterns

- **Reuse**: Patterns like Layers and Pipes and Filters promote reusability of components.
- **Scalability**: Broker and Microkernel patterns allow systems to scale by decoupling components and extending functionality easily.
- **Flexibility**: Patterns such as MVC and Blackboard provide flexibility by separating concerns and allowing dynamic problem-solving.

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8. Liabilities of Architectural Patterns

- **Complexity**: Some patterns, like Broker, add complexity to the system, especially in testing and debugging.
- **Efficiency**: Patterns like Pipes and Filters can introduce overhead, especially when filters are chained together in a sequence.

- **Tight Coupling**: Inheritance-based layering can create tight coupling, making it harder to modify components independently.

Simplified Documentation on Distributed Systems: Broker Pattern

From Mud to Structure

This category helps manage complex systems by breaking down a large task into smaller, cooperative subtasks. The goal is to avoid a system overwhelmed by numerous components.

- **Patterns**:
    - **Layers Pattern**: Organizes the system into layers.
    - **Pipes and Filters Pattern**: Breaks down tasks into sequential steps.
    - **Blackboard Pattern**: Multiple subsystems contribute to a solution.

Distributed Systems

In distributed systems, components are decoupled and communicate through intermediaries. The **Broker Pattern** provides a framework for distributed systems where independent components interact remotely.

Broker Pattern

The **Broker Pattern** allows components of a distributed system to communicate without needing to know the details of the other components' locations or interfaces. The broker coordinates all communication, forwarding requests, results, and exceptions.

Context

- A distributed and possibly heterogeneous system with independent and cooperating components.

Problem

When building complex distributed systems, allowing components to handle communication themselves can create dependency issues and limit the system to specific technologies. These systems also need dynamic service management like adding, removing, or locating components without compromising portability.

Solution

A broker component is introduced to manage communication. Servers register their services with the broker, and clients request these services through the broker. The broker forwards client requests to the appropriate server, and then returns the results.

How the Broker Pattern Works

1. **Clients** request services from the broker.
2. The **broker** forwards the request to the appropriate **server**.
3. The **server** executes the request and returns results to the broker.
4. The broker transmits the results back to the client.

- **Components of the Broker Pattern**:
    - **Clients**: Applications that request services.
    - **Servers**: Applications that provide services.
    - **Brokers**: Components that manage communication between clients and servers.
    - **Proxies**: Client-side and server-side proxies that handle message transmission.
    - **Bridges**: Handle communication between brokers in different networks.

Example Scenario

Imagine a web browser (client) requesting a webpage from a web server (server). Instead of the client directly managing communication with the server, the request goes through an internet broker. The broker locates the server, retrieves the webpage, and sends it back to the client. This decouples the client from the server, ensuring flexibility and scalability.

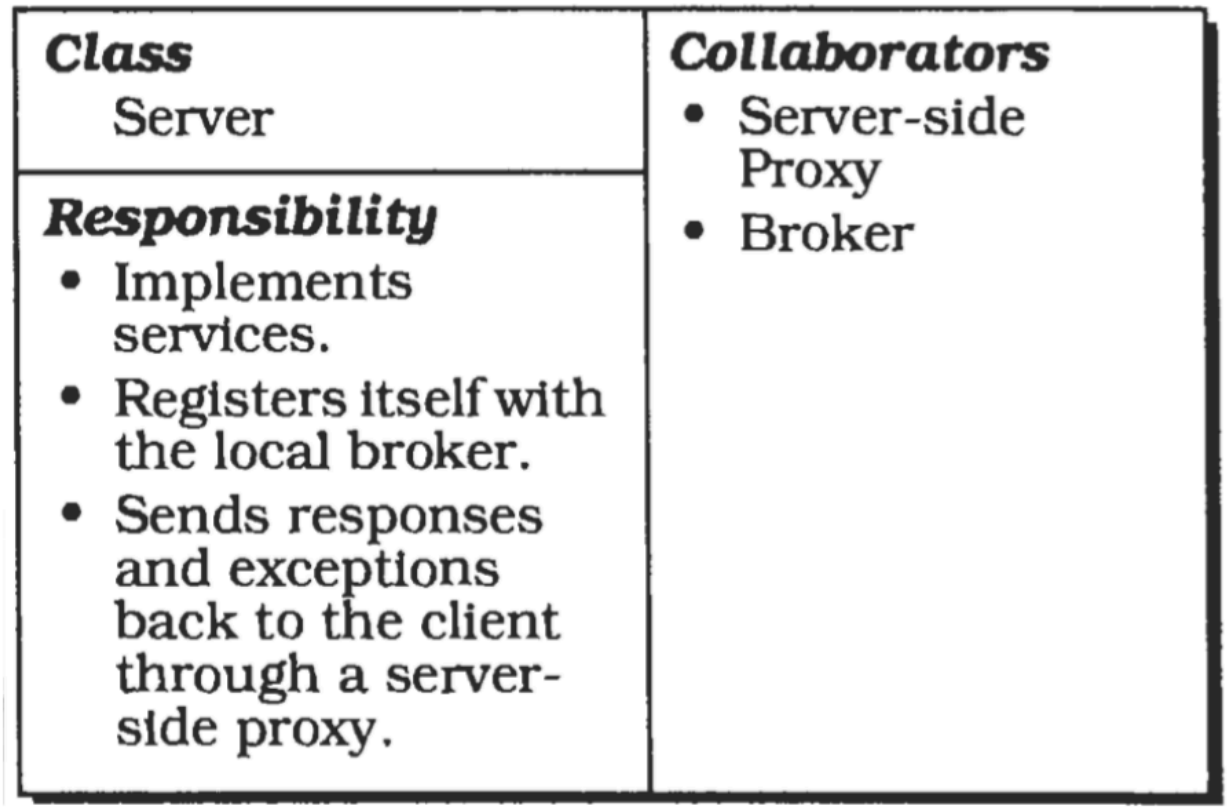
Diagram: Client-Broker-Server Communication (insert diagram here)

Components of the Broker Pattern

1. Servers

Servers implement objects that expose their functionality through interfaces, either via an interface definition language (IDL) or a binary standard. They can offer general services for many applications or domain-specific functionality.

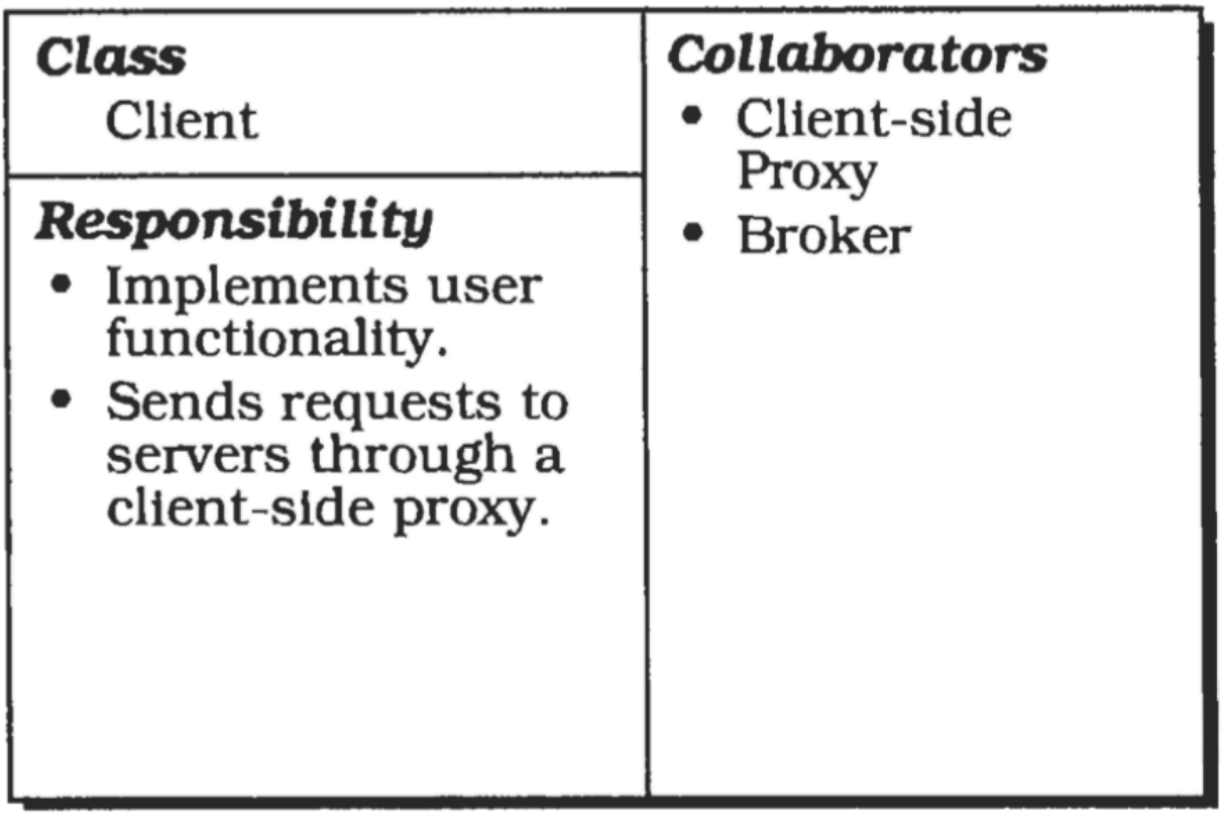
Diagram: CRC Diagram for Server



2. Clients

Clients request services from the broker. They don’t need to know the location of the servers providing the services, allowing services to be added, changed, or moved dynamically without affecting the system.

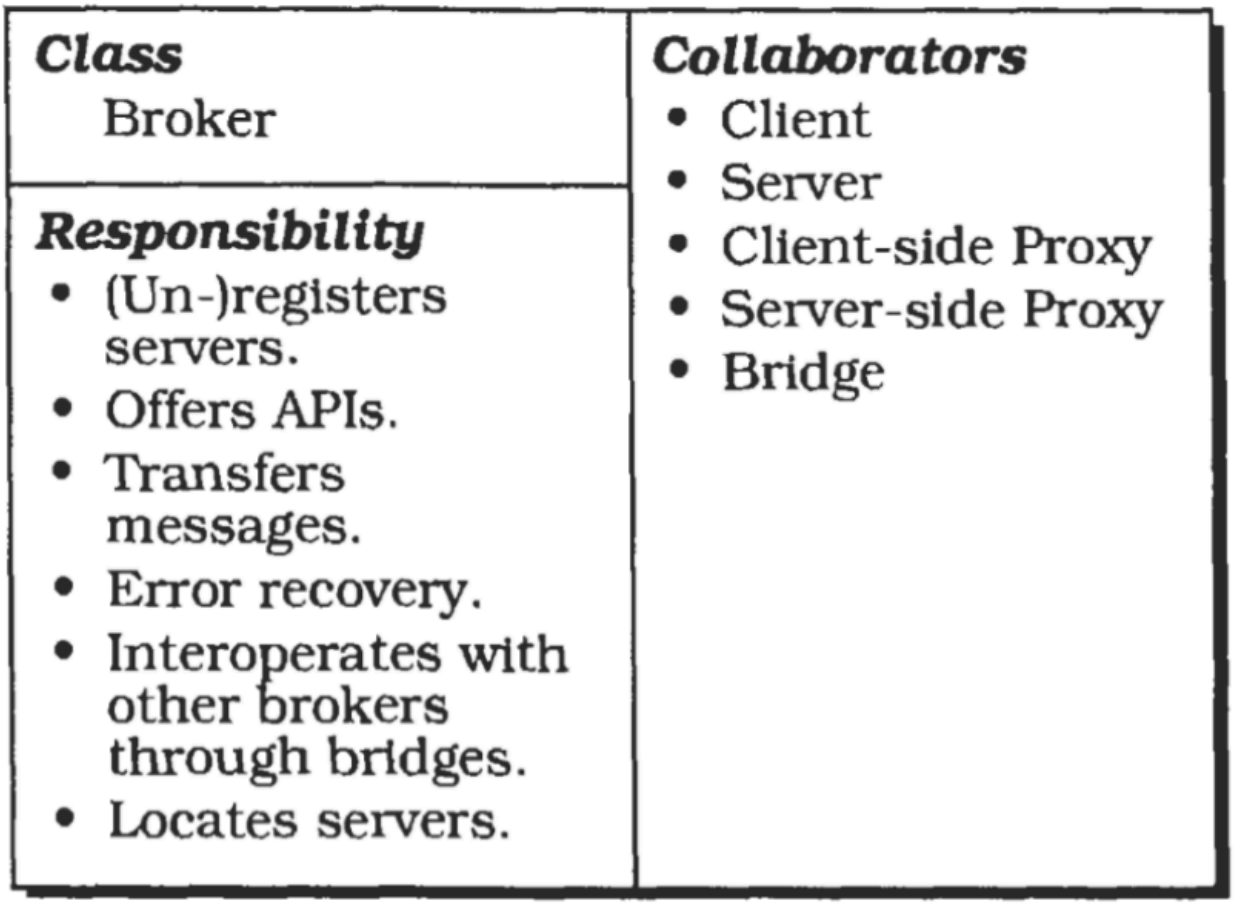
Diagram: CRC Diagram for Client



3. Brokers

Brokers are responsible for forwarding client requests to the correct servers and returning the results. If the requested server is inactive, the broker activates it. Brokers also handle communication between different brokers (if needed).

Diagram: CRC Diagram for Broker



4. Proxies

Proxies act as intermediaries between clients and servers. They hide the implementation details, manage communication, and handle marshalling/unmarshalling of data (converting data into formats suitable for transmission).

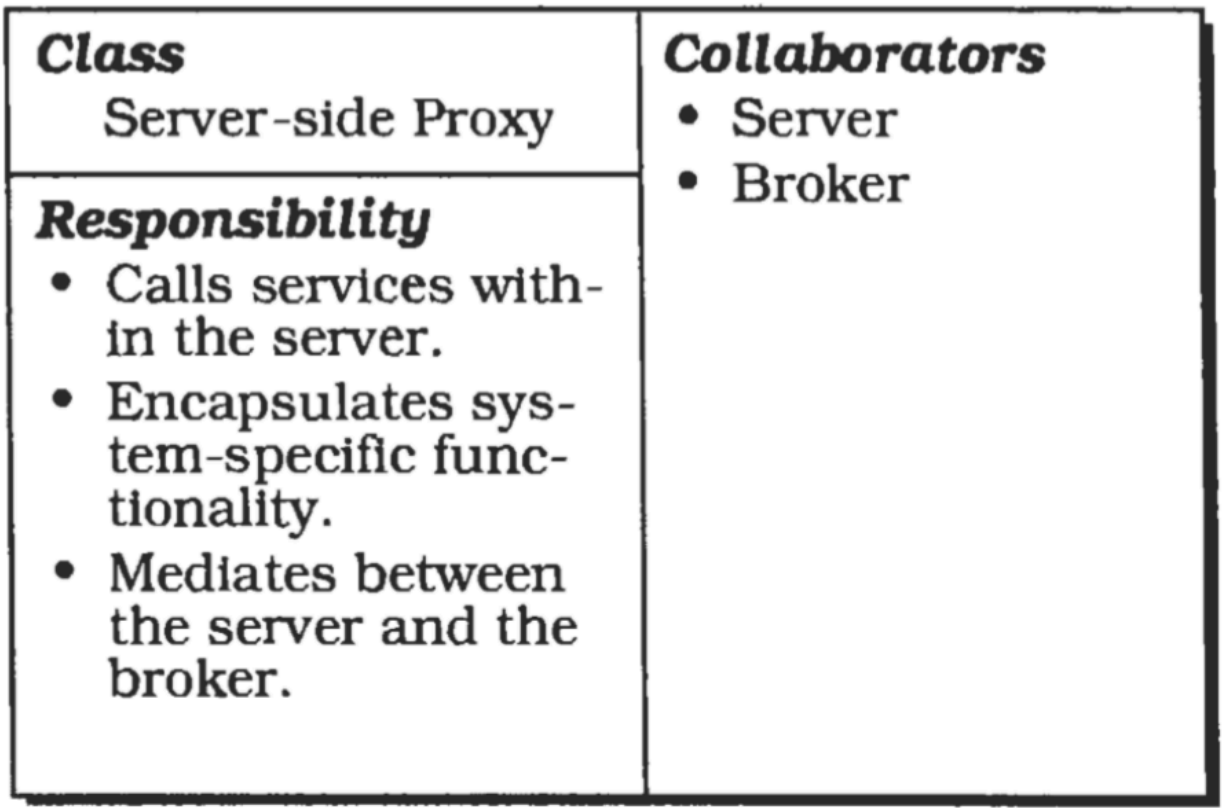
- **Client-side Proxies**: Handle requests from the client side.
- **Server-side Proxies**: Handle requests from the server side.

Diagram: CRC Diagram for Proxies

- **Client-side Proxies**

Class	***Collaborators***
Client-side Proxy	• Client • Broker
Responsibility • Encapsulates system-specific functionality. • Mediates between the client and the broker.	

- **Server-side Proxies**



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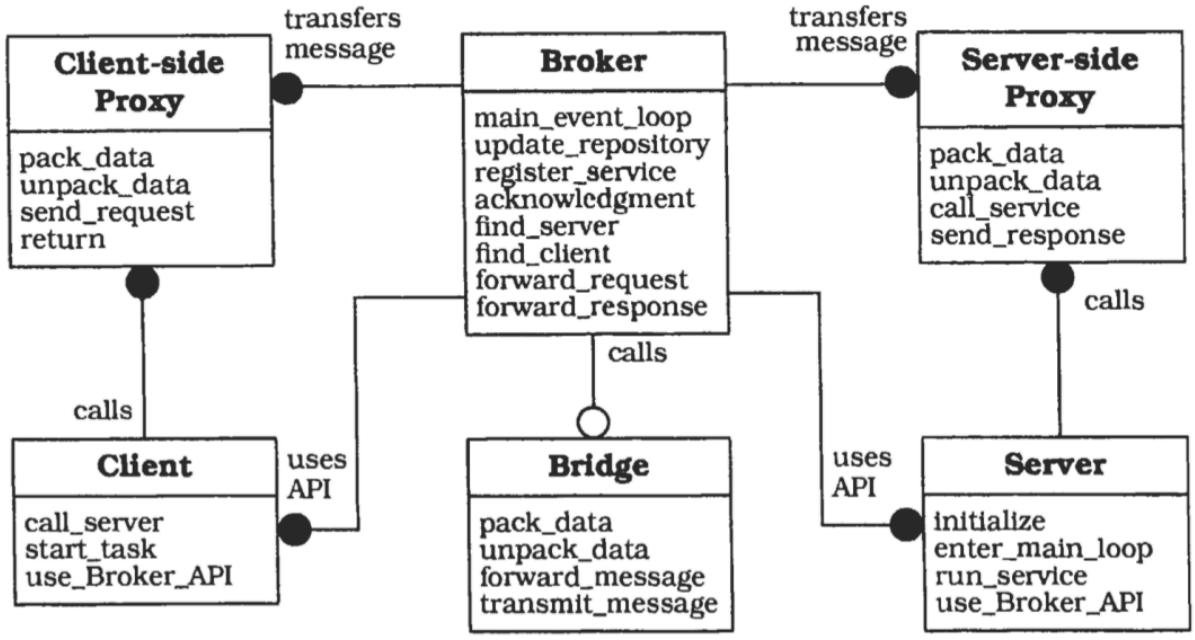
5. Bridges

Bridges manage communication between brokers in heterogeneous networks, hiding differences in operating systems or network protocols.

Diagram: CRC Diagram for Bridges

Class Bridge	Collaborators • Broker • Bridge
Responsibility • Encapsulates network-specific functionality. • Mediates between the local broker and the bridge of a remote broker.	

Broker Pattern



Implementation Steps

1. Define the object model for system communication.
2. Decide the kind of component interoperability the system should offer.
3. Design APIs that the broker component will provide.
4. Use proxy objects to hide implementation details from clients and servers.
5. Design the broker and proxy components in parallel.
6. Develop compilers for Interface Definition Language (IDL).

Variants of Broker Pattern

- **Direct Communication Broker System**
- **Message Passing Broker System**
- **Trader System**
- **Adapter Broker System**
- **Callback Broker System**

Known Usages

- **CORBA**: Common Object Request Broker Architecture for enabling communication between systems in different languages.
- **Microsoft OLE**: Object Linking and Embedding for communication between different applications.
- **World Wide Web**: Internet communication through HTTP and web servers.

Consequences of Using the Broker Pattern

Benefits:

- **Location Transparency**: Clients don't need to know where the server is located.
- **Extensibility**: New services can be added or changed dynamically.
- **Portability**: The system can operate on different platforms.
- **Interoperability**: Different systems can communicate using the broker.

Liabilities:

- **Reduced Efficiency**: Adding a broker layer may add overhead.
- **Fault Tolerance**: The system relies on the broker's stability.
- **Testing and Debugging**: More complex due to distributed nature.

Documentation for Distributed Systems and Interactive Systems Architecture Patterns

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1. From Mud to Structure

In complex software systems, there can be an overwhelming number of components and interactions. Patterns help structure these systems by breaking down the overall tasks into smaller, cooperating subtasks. Common patterns that help achieve this are:

- **Layers Pattern**: Divides the system into layers where each layer has a specific role and only interacts with adjacent layers.
- **Pipes and Filters Pattern**: The system is divided into processing steps (filters), connected by pipes that pass data between them.
- **Blackboard Pattern**: Multiple subsystems (agents) share a common knowledge base (the blackboard), collaborating to find a solution to complex problems.

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2. Distributed Systems

Distributed systems are composed of components that are distributed across different locations and connected via a network. In this category, the **Broker Pattern** is the key pattern used to manage communication between independent, distributed components.

Broker Pattern

- **Context**: Used in distributed systems where independent components need to interact and exchange data.
- **Problem**: If distributed components directly manage communication, it creates dependencies that reduce flexibility and scalability.

Solution: Introduce a **Broker** to act as an intermediary, forwarding client requests to the appropriate server and returning results. The broker decouples clients from servers, allowing each to function independently.

Components of the Broker Pattern

1. **Clients**: Applications that request services from the broker.
2. **Servers**: Applications that register their services with the broker and provide functionality to clients.

3. **Brokers**: Act as intermediaries between clients and servers, managing communication and service coordination.
4. **Proxies**: Handle message exchange, helping to hide details of the communication between the broker, clients, and servers.
5. **Bridges**: Used to enable communication between brokers located on different networks.

Use Case Example: A web browser (client) requests a web page from a web server (server) via the broker. The broker locates the correct server and forwards the request without requiring the client to know the server's physical location.

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3. Interactive Systems

Interactive systems feature a high level of user interaction, typically using graphical user interfaces (GUIs). The goal is to create usable systems where the functional core is separated from the user interface, allowing for flexibility in modifying the interface without affecting core functionality.

Model-View-Controller (MVC) Pattern

The **MVC Pattern** divides an interactive application into three main components:

1. **Model**: Contains the core functionality and data of the application.
2. **View**: Presents information to the user.
3. **Controller**: Handles user input and updates the model or view accordingly.

Components of MVC

1. **Model**:
    - Encapsulates core data and functionality.
    - The model is independent of the user interface, making it reusable and easier to maintain.
    - Notifies views of any changes to data via a change-propagation mechanism.
2. **Use Case Example**: In a banking application, the model manages account balances and transactions.
   Diagram:

Class Model	Collaborators • View • Controller
Responsibility • Provides functional core of the application. • Registers dependent views and controllers. • Notifies dependent components about data changes.	

3. **View**:
    - Displays information from the model.
    - Multiple views can show the same data differently (e.g., a bar chart or pie chart).
4. **Use Case Example**: A dashboard may display a financial report in multiple views such as graphs or tables.
   Diagram: View Structure

Class View	Collaborators • Controller • Model
Responsibility • Creates and initializes its associated controller. • Displays information to the user. • Implements the update procedure. • Retrieves data from the model.	

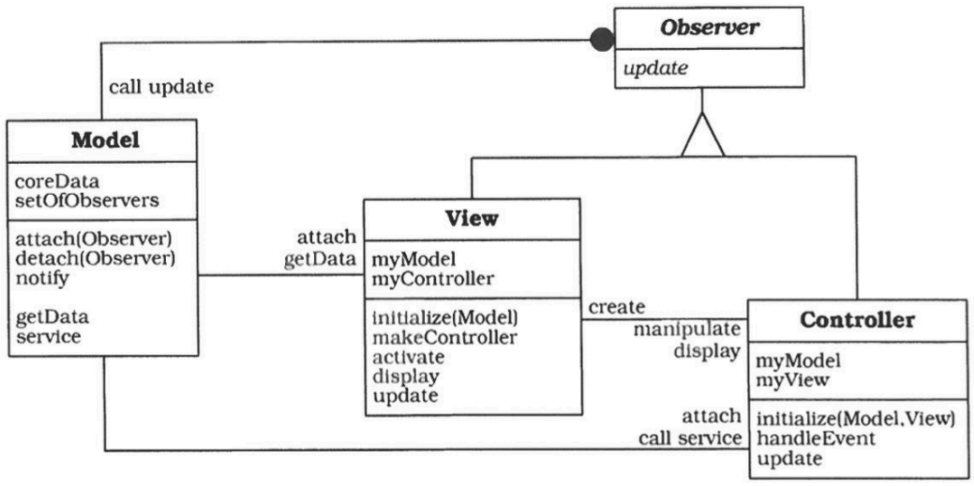
5. **Controller**:
    - Manages user input like mouse clicks or keyboard inputs.
    - Updates the model or view based on user interactions.
6. **Use Case Example**: In a photo editing app, the controller listens for clicks on toolbar icons to apply filters to an image.
   Diagram: Controller Structure

Class Controller	**Collaborators** • View • Model
Responsibility • Accepts user input as events. • Translates events to service requests for the model or display requests for the view. • Implements the update procedure, if required.	

Change-Propagation Mechanism in MVC

The model component notifies all registered views whenever data changes. Each view then retrieves the updated data and refreshes the displayed information. This mechanism ensures consistency between the view and the model across multiple views.

Structure: C++



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4. Presentation-Abstraction-Control (PAC) Pattern

The **PAC Pattern** is another architectural model used for interactive systems, particularly suited for systems that can be divided into multiple cooperating agents. Each agent is responsible for a specific aspect of the system's functionality and is composed of three components: **presentation**, **abstraction**, and **control**.

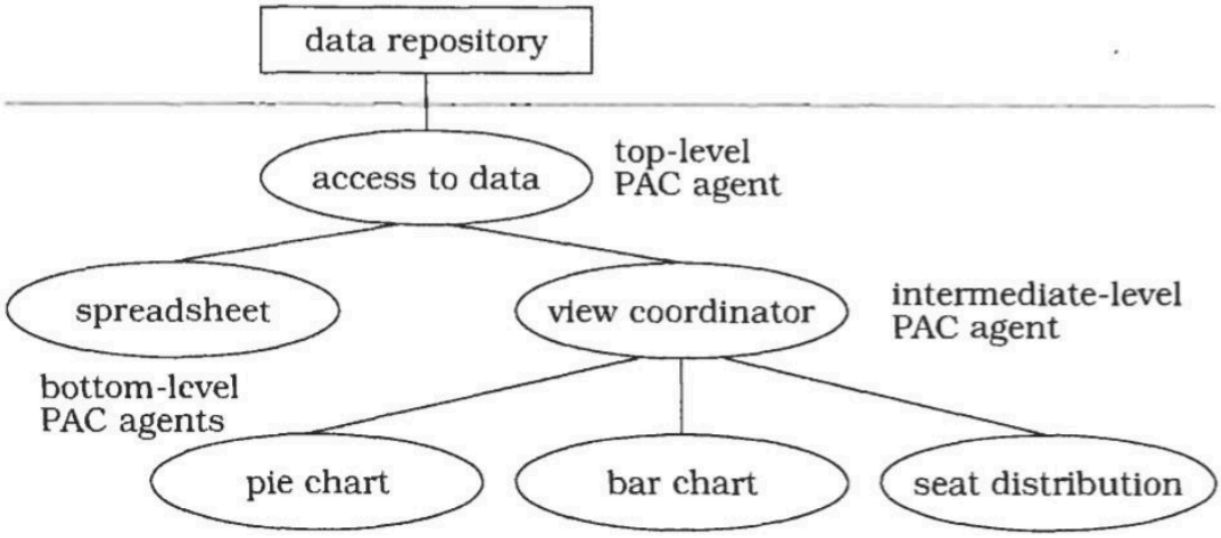
- **Context**: Used in complex interactive systems where different tasks can be broken down into smaller, independent agents.

Solution: Organize the system into a hierarchy of PAC agents. Each agent manages a specific part of the application, with higher-level agents overseeing broader functionality and lower-level agents managing specific, smaller tasks.

Components of PAC Agents

1. **Top-Level Agents**:
    - Represent the core functionality of the system.
    - Provide system-wide services such as the data model or global settings.
2. **Use Case Example**: In a traffic control system, the top-level agent manages the overall flow of traffic data.
3. **Bottom-Level Agents**:
    - Handle specific, self-contained tasks or user interface elements.
    - Present user interaction features, like buttons, charts, or widgets.
4. **Use Case Example**: A bottom-level agent in a CAD system might control the layout of a specific drawing component.
5. **Intermediate-Level Agents**:
    - Coordinate or combine the actions of multiple lower-level agents.
    - Serve as mediators between top-level and bottom-level agents.
6. **Use Case Example**: An intermediate-level agent might manage the coordination of various data views in a dashboard, ensuring consistency across the system.
   Diagram: Top-Level Agent Structure, Bottom-Level Agent Structure, Intermediate-Level Agent Structure

Typical Hierarchy of Agents



Class Top-level Agent	***Collaborators***
Responsibility • Provides the functional core of the system. • Controls the PAC hierarchy.	• Intermediate-level Agent • Bottom-level Agent

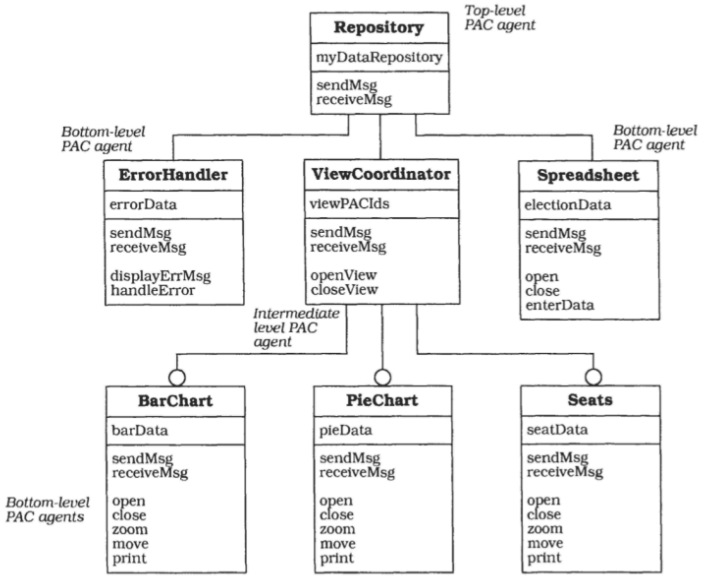
Class Interm. -level Agent	***Collaborators***
Responsibility • Coordinates lower-level PAC agents. • Composes lower-level PAC agents to a single unit of higher abstraction.	• Top-level Agent • Intermediate-level Agent • Bottom-level Agent

Class Bottom-level Agent	***Collaborators***
Responsibility • Provides a specific view of the software or a system service, including its associated human-computer interaction.	• Top-level Agent • Intermediate-level Agent

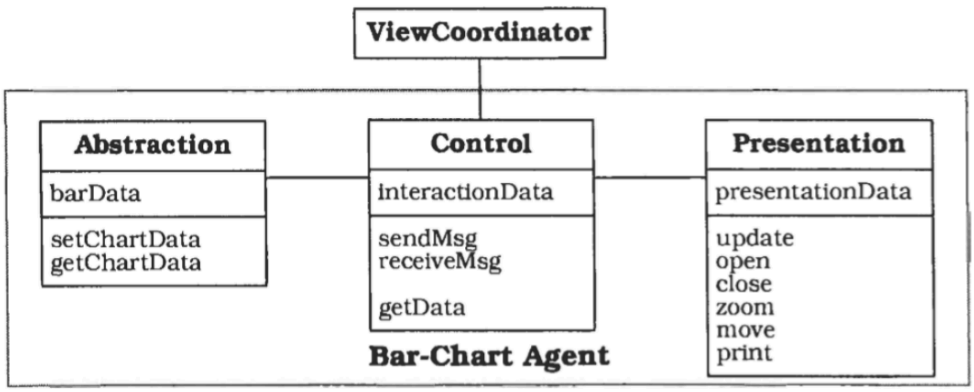
Implementation Steps for MVC and PAC

1. **Separate User Interaction from Core Functionality**: Ensure the user interface can be changed independently of the core functionality.
2. **Implement a Change-Propagation Mechanism (MVC)**: Establish a system where the model notifies all dependent views of changes.
3. **Design and Implement Views and Controllers (MVC)**: Create multiple views and controllers for different ways to interact with the model.
4. **Set Up PAC Agent Hierarchy (PAC)**: Organize PAC agents in a tree structure, with top-level agents overseeing core functionality and lower-level agents managing specific tasks.

Typical PAC Object Model



Internal Structure of a PAC Agent



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5. Use Cases and Scenarios

Broker Pattern Use Case:

A company uses a cloud service broker to manage their multi-cloud environment. The broker abstracts the cloud services and forwards requests between the internal applications (clients) and various cloud service providers (servers), without the clients needing to know which provider hosts the requested service.

MVC Pattern Use Case:

A task management app uses the MVC pattern. The **model** manages tasks and deadlines, the **view** shows a list of tasks, and the **controller** handles user actions like adding or removing tasks.

PAC Pattern Use Case:

In a network traffic monitoring system, the **top-level agent** controls data flow, the **intermediate-level agents** manage specific networks, and **bottom-level agents** display traffic data for individual users.

Conclusion

The **Broker Pattern** supports distributed systems by decoupling clients and servers, while **MVC** and **PAC** patterns help structure interactive systems. These patterns make systems more flexible, scalable, and maintainable by separating core functionality from the user interface or communication mechanisms.

Documentation for Model-View-Controller (MVC) and Service-Oriented Architecture (SOA) Patterns

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Model-View-Controller (MVC) Pattern

Context

User interface software frequently undergoes modifications in interactive applications. Users often need to view data from multiple perspectives (e.g., bar graph or pie chart), which should reflect the current state of the data consistently.

Problem

How can the user interface be separated from the application functionality while ensuring responsiveness to user input and changes in application data? How can multiple views be created, maintained, and synchronized when the underlying data changes?

Solution

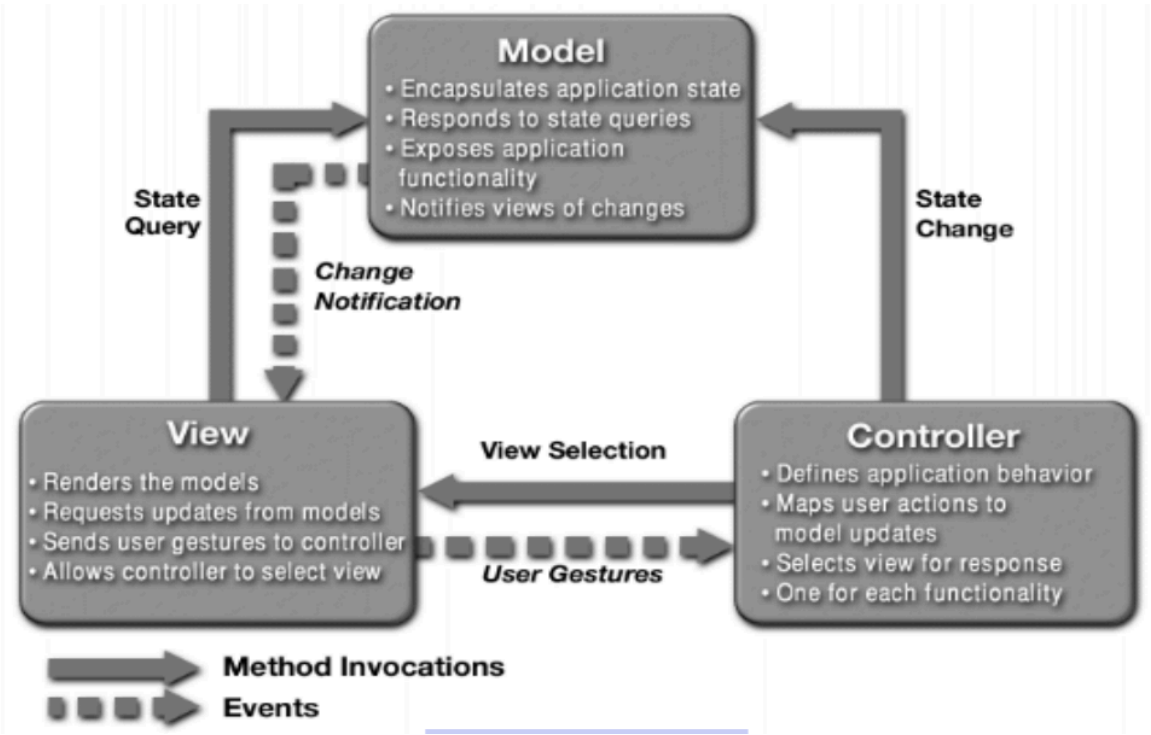
The MVC pattern divides the application into three distinct components:

1. **Model**: Manages the data and logic of the application.
2. **View**: Displays data and handles user interaction.
3. **Controller**: Acts as a mediator between the model and view, updating views when data changes and modifying the model based on user inputs.

Example

- **Use Case**: In a retail application, the MVC pattern allows users to view product information as a list or as individual cards. The model manages product data, the view displays it in the chosen format, and the controller updates the view based on user selections.

Diagram: MVC Example



Elements

- **Model**: Holds the application data and logic.
- **View**: Represents the data visually and interacts with the user.
- **Controller**: Translates user actions into updates to the model and view.

Relations

- The **notifies relation** ensures changes in the model are reflected in the view, keeping the system synchronized.
- The model and controller do not directly interact.

Constraints

- At least one instance of model, view, and controller must exist.
- Direct interaction between model and controller is not allowed.

Strengths

- Clear separation of concerns, making each component easier to maintain.
- Supports multiple views of the same data, providing flexibility.

Weaknesses

- Adds complexity for simple interfaces.
- May not be compatible with some user interface toolkits.

Service-Oriented Architecture (SOA) Pattern

Context

SOA deals with distributed components that provide services, consumed by service users. Consumers need to understand and use these services without knowing implementation details.

Problem

How can distributed components on different platforms, using different programming languages, provided by different organizations, and distributed across the Internet, interoperate seamlessly?

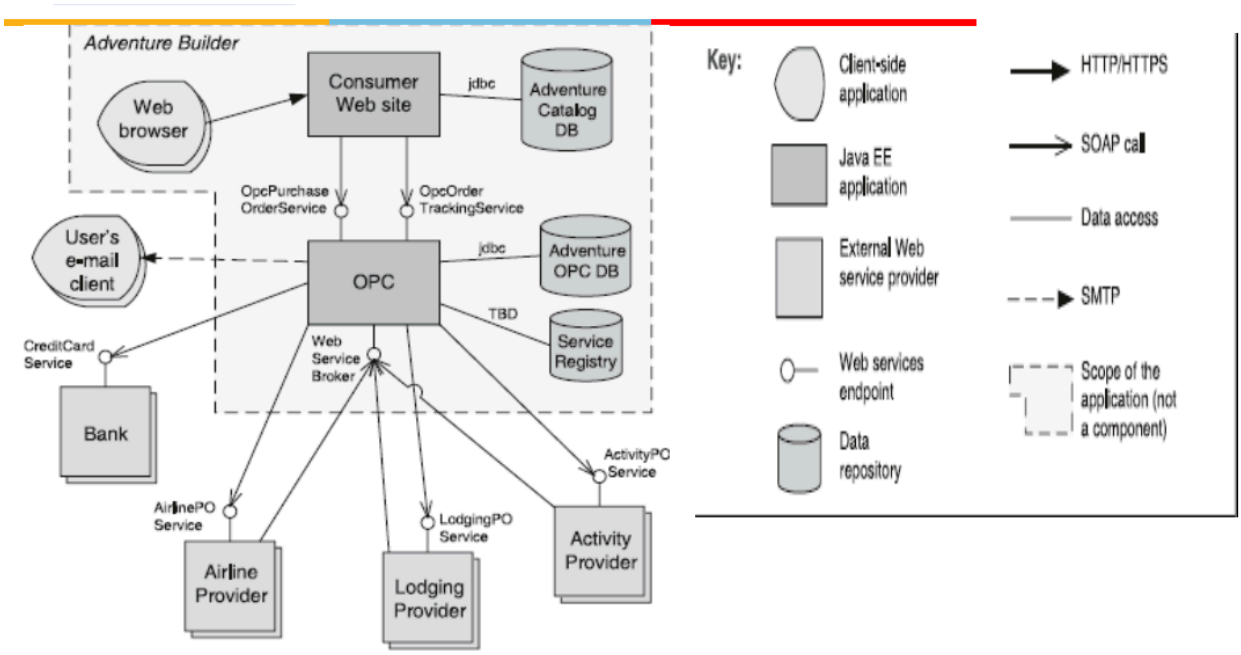
Solution

SOA describes distributed components that provide and consume services over a network. Services are exposed through interfaces, enabling interoperability among heterogeneous systems.

Example

- **Use Case**: In an online travel booking system, services for flights, hotels, and car rentals are provided by different providers. The SOA pattern allows users to access these services through a unified interface, regardless of how each service is implemented.

Diagram: Service-Oriented Architecture Example



Elements

- **Service Providers**: Offer services through interfaces.
- **Service Consumers**: Invoke services directly or through an intermediary.
- **Enterprise Service Bus (ESB)**: Facilitates message routing and transformation between providers and consumers.
- **Registry of Services**: Helps providers register services and consumers discover services at runtime.
- **Orchestration Server**: Coordinates interactions between services, managing workflows and business processes.

Connectors

- **SOAP Connector**: Uses SOAP protocol for synchronous communication.
- **REST Connector**: Relies on HTTP request/reply for communication.
- **Asynchronous Messaging Connector**: Supports point-to-point or publish-subscribe messaging.

Relations

- Components connect through connectors to exchange messages. Intermediaries like ESB and orchestration servers may be used.

Constraints

- Service consumers connect to service providers, possibly through intermediaries.

Strengths

- Enables interoperability across heterogeneous systems.
- Supports scalability by decoupling service providers from consumers.

Weaknesses

- Complex to build and manage.
- Independent services evolve unpredictably.
- Performance overhead due to middleware and potential bottlenecks.

Use Cases and Scenarios

MVC Use Case

- **Scenario**: In a library management system, MVC enables users to view book information in different formats (e.g., list view, detailed view). The controller manages user interactions, updating the model and refreshing the view accordingly.

SOA Use Case

- **Scenario**: In an online banking system, the SOA architecture allows for seamless interaction between different services like account management, loan processing, and credit card services, enabling consistent user experience across different channels.

Conclusion

The **MVC Pattern** is ideal for creating modular user interfaces, while the **SOA Pattern** facilitates distributed service interactions across heterogeneous environments. Both patterns enable separation of concerns, enhancing maintainability, flexibility, and scalability.

Documentation for Patterns and Architectural Solutions

From Mud to Structure

Overview

Patterns in this category help to prevent a 'sea' of unstructured components by breaking down a system task into smaller, cooperating subtasks. These patterns are used to manage complexity and establish clearer system structure.

Patterns Included

1. **Layers Pattern**
    - Divides software into multiple layers, each providing a specific set of services.
2. **Pipes and Filters Pattern**
    - Processes data streams step-by-step through sequential filters.
3. **Blackboard Pattern**
    - Uses a central data repository (blackboard) to coordinate independent components solving a problem.

Distributed Systems

Overview

This category focuses on systems distributed across multiple servers, emphasizing communication and coordination between services.

Patterns Included

1. **Broker Pattern**
    - Provides an infrastructure for distributed applications, enabling seamless communication between clients and servers.
2. **Microkernel**
    - Primarily focuses on adaptability, supporting distribution as a secondary concern.
3. **Pipes and Filters**
    - Supports data transformation and distribution as a secondary aspect.

Interactive Systems

Overview

Interactive systems require patterns that enable structured human-computer interactions.

Patterns Included

1. **Model-View-Controller (MVC) Pattern**
    - Separates the application into three parts: model (data), view (UI), and controller (logic).
2. **Presentation-Abstraction-Control (PAC) Pattern**
    - Organizes the system as a hierarchy of agents, each with its own presentation, abstraction, and control components.

Adaptable Systems

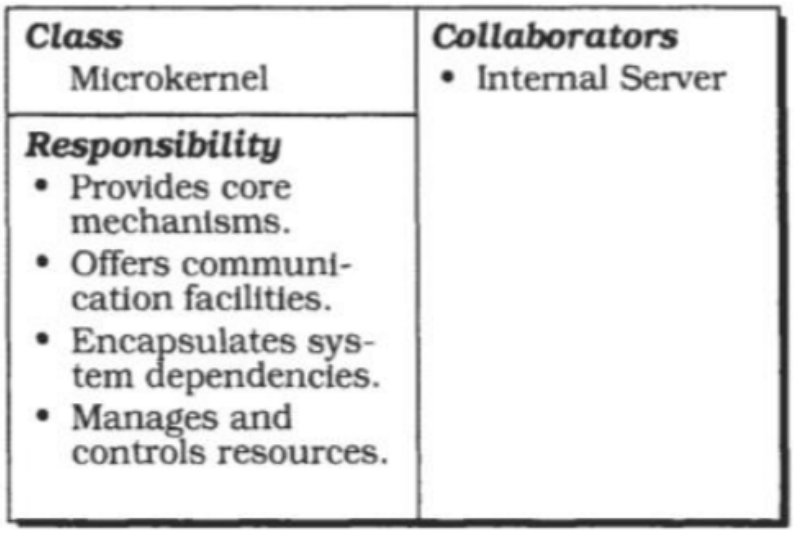
Overview

Adaptable systems focus on supporting extension and evolution to accommodate new functionality, standards, and changing requirements.

Patterns Included

1. **Reflection Pattern**
    - Allows software to change its behavior dynamically.
2. **Microkernel Pattern**
    - Separates a minimal core from additional functionality, supporting modifications and extensions.

Diagram: Microkernel Component



Adaptable Systems Context

Adaptable systems must support new versions of operating systems, user interfaces, and third-party components. These systems need to be flexible and prepared for changing requirements, even during later stages of development.

Design for Change

- Systems should be designed with change in mind, allowing modifications without affecting core functionality. This approach helps maintain system stability while accommodating changes efficiently.

Microkernel Pattern

Context

The Microkernel pattern applies to systems that must adapt to evolving requirements. It is useful for software that supports similar interfaces but different extensions.

Problem

Building software for varying standards and technologies can be challenging. Examples include operating systems and graphical user interfaces.

Solution

The Microkernel separates minimal core functionality from extensions and customizations. It coordinates communication among components, maintains system resources, and allows extensions through internal and external servers.

Structure

The Microkernel pattern includes:

- **Internal Servers**: Extend core functionality.
- **External Servers**: Add specialized services.
- **Adapters**: Connect clients to external servers.
- **Clients**: Request services via adapters.
- **Microkernel**: Central component managing resources and communication.

Diagram:

Internal Server Component

Class Internal Server	Collaborators • Microkernel
Responsibility • Implements additional services. • Encapsulates some system specifics.	

External Server Component

Class External Server	Collaborators • Microkernel
Responsibility • Provides programming interfaces for its clients.	

Client & Adapter

Class Client	Collaborators • Adapter
Responsibility • Represents an application.	

Class Adapter	Collaborators • External Server • Microkernel
Responsibility • Hides system dependencies such as communication facilities from the client. • Invokes methods of external servers on behalf of clients.	

Reflection Pattern

Context

The Reflection pattern allows systems to change their structure and behavior dynamically. It supports evolving requirements by enabling modifications without altering core components.

Problem

Software systems must be flexible to accommodate changes in technology and user requirements. Designing for all possible changes upfront is difficult, but a reflection-based architecture enables changes as needed.

Solution

The Reflection pattern splits the system into:

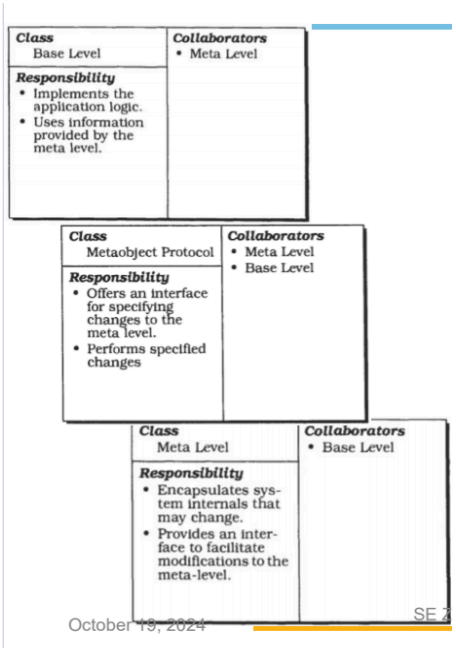
- **Meta Level**: Manages system self-awareness and change.
- **Base Level**: Implements core application logic, relying on meta-level information.

Metaobject Protocol (MOP)

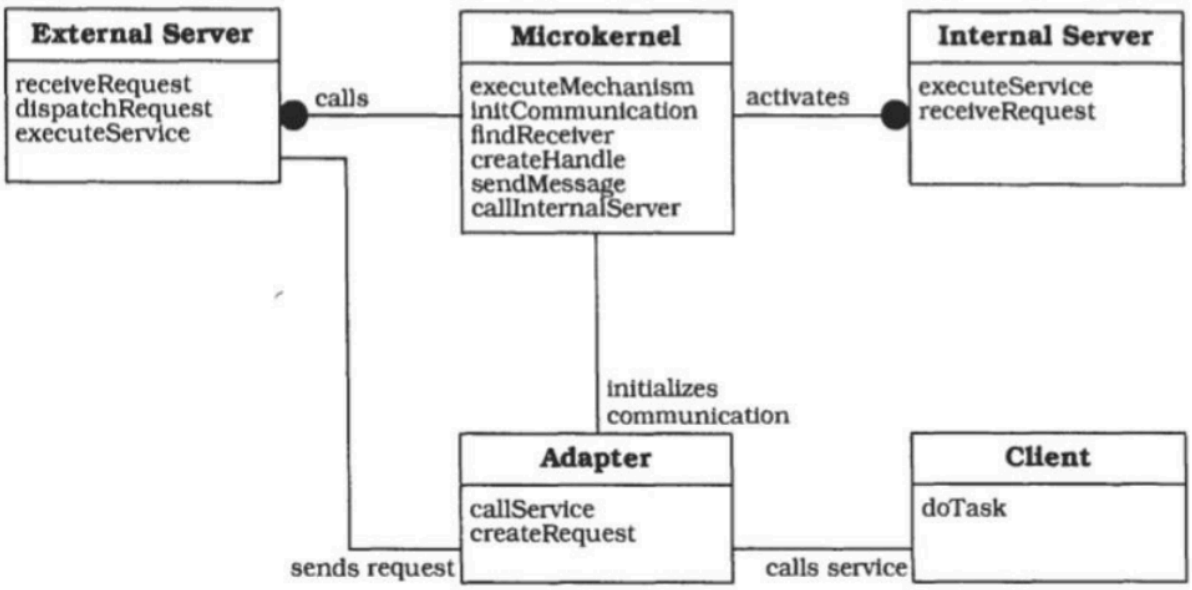
Defines how metaobjects can be manipulated, allowing changes to affect base-level behavior.

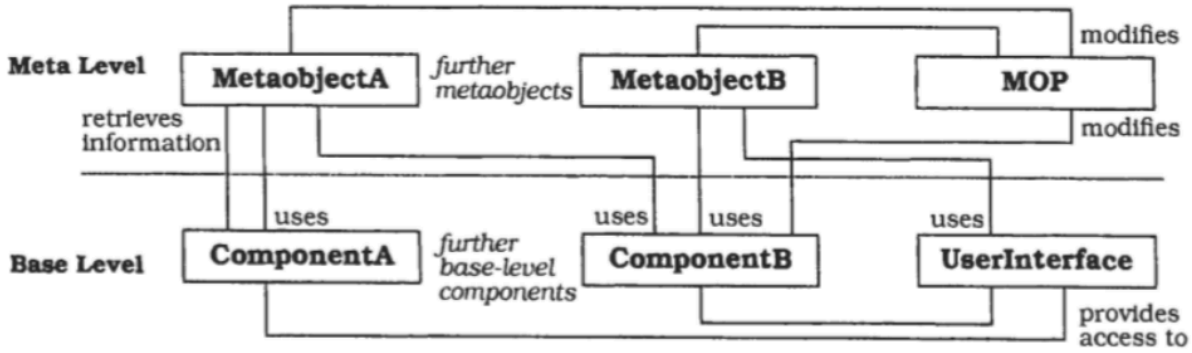
Diagram:

Structure



OMT Diagram





Use Cases, Scenarios, and Examples

From Mud to Structure

- **Use Case**: In a document processing system, the Layers pattern can be used to separate text formatting, file handling, and user interface into different layers.

Distributed Systems

- **Scenario**: In an e-commerce platform, the Broker pattern helps manage communication between customer services, payment processing, and inventory management, ensuring seamless transactions.

Interactive Systems

- **Example**: In a customer relationship management (CRM) application, the MVC pattern allows sales representatives to view customer data in different formats (list, card view) while maintaining synchronized updates.

Adaptable Systems

- **Scenario**: In an IoT platform, the Microkernel pattern supports adding new device drivers (internal servers) without changing the core system.

Reflection Pattern

- **Example**: In a data analytics system, the Reflection pattern allows modifying the data aggregation method dynamically based on new algorithm requirements.

Conclusion

The patterns covered—Layers, Pipes and Filters, Broker, MVC, Microkernel, and Reflection—are essential for building structured, distributed, interactive, and adaptable software systems. Each pattern has distinct roles, strengths, and challenges but contributes to creating flexible, scalable, and maintainable software architectures.

Documentation for Software Architecture Patterns

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1. Client-Server Pattern

Overview

The client-server pattern structures systems to provide shared services to multiple clients, centralizing the management of resources and services.

Context

Used when multiple clients need access to shared resources and services, aiming to improve modifiability, scalability, and centralized control.

Problem

The challenge is to centralize resource management while distributing resources across multiple physical servers, ensuring easier modification, reuse, scalability, and availability.

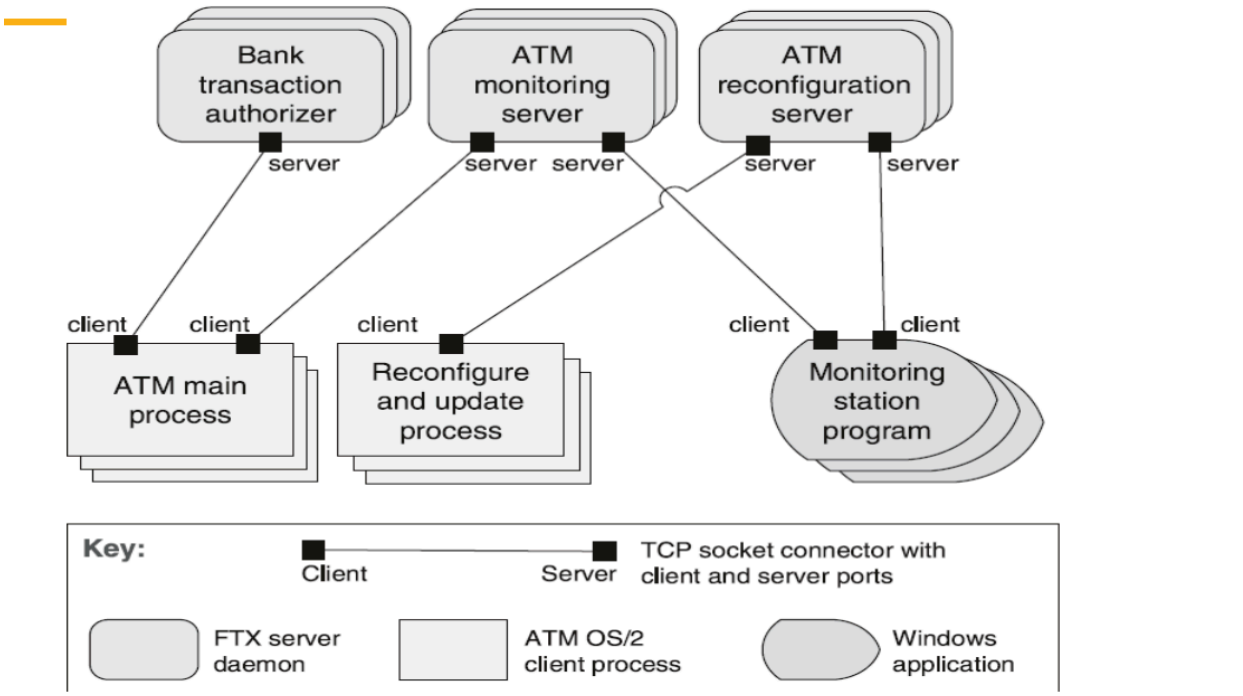
Solution

- **Clients** request services.
- **Servers** provide services.
- Clients interact with servers via request/reply protocols.
- Components can act as both clients and servers.

Use Case Example

In a banking system, the server manages customer accounts, while clients (e.g., web apps, ATMs) send requests to access or modify account data.

Diagram: Client-Server Example



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2. Peer-to-Peer (P2P) Pattern

Overview

In the peer-to-peer pattern, components (peers) directly interact with each other to provide distributed services.

Context

Used in systems where distributed computational entities need to collaborate equally, without a central controlling component.

Problem

How to enable a set of distributed, "equal" computational entities to connect, share, and organize services while maintaining high availability and scalability.

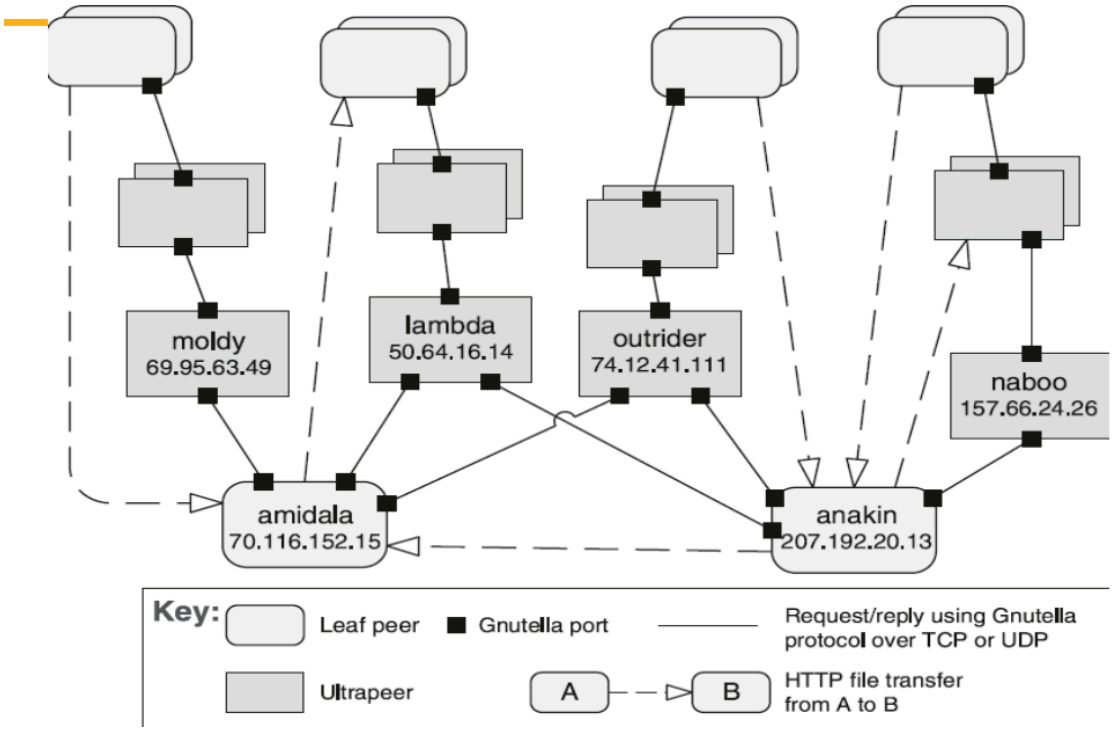
Solution

- **Peers** interact directly as equals, requesting and providing services.
- **Request/reply connectors** are used to search for and communicate with other peers.

Use Case Example

In a file-sharing system, users can both share (provide) and download (request) files from other users' devices.

Diagram: Peer-to-Peer Example



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3. Publish-Subscribe Pattern

Overview

The publish-subscribe pattern enables components to interact by publishing events that are distributed to subscribed components.

Context

Useful when the number and nature of data producers and consumers are variable and unpredictable.

Problem

How to enable data integration among independent producers and consumers without knowing each other's identity or existence.

Solution

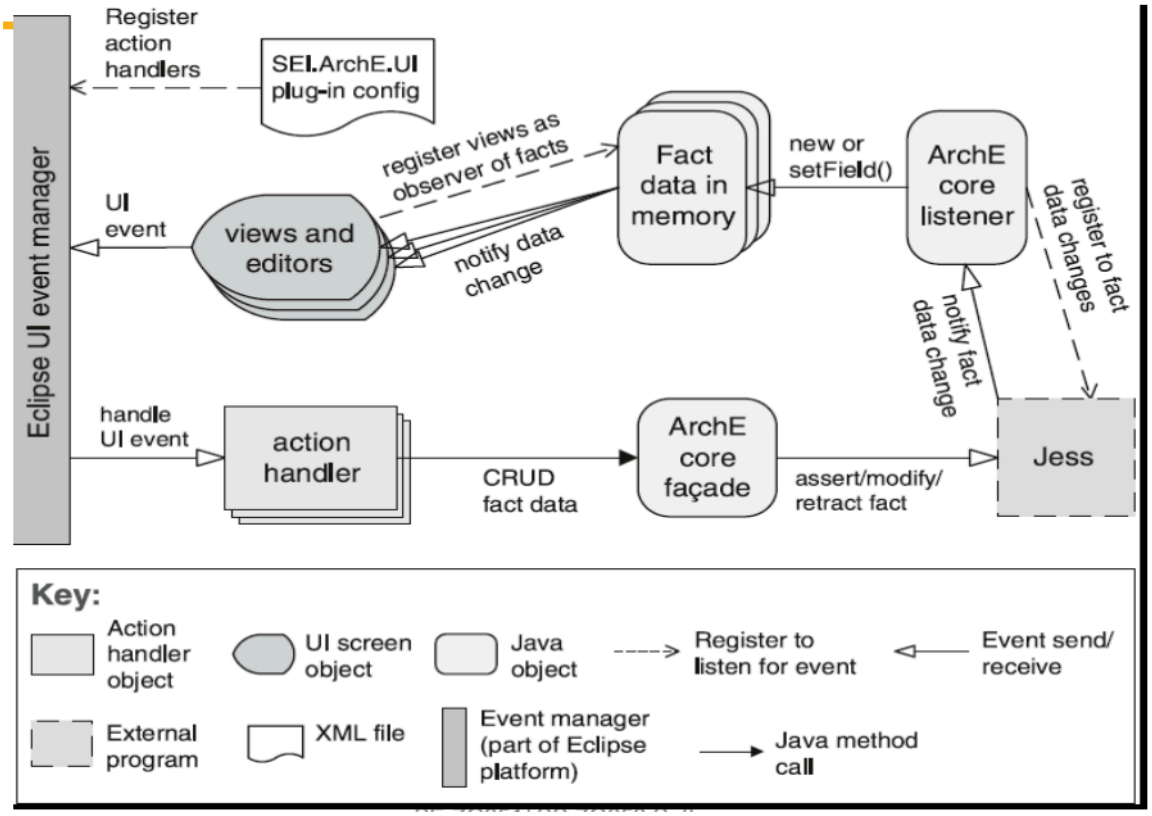
- **Publishers** announce events.

- **Subscribers** listen for events.
- The **publish-subscribe connector** delivers events from publishers to subscribers.

Use Case Example

In a news delivery system, different channels publish news updates, and users subscribe to channels of interest to receive updates.

Diagram: Publish-Subscribe Example



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4. Shared-Data Pattern

Overview

The shared-data pattern is used when multiple independent components need to access and manipulate large, persistent data.

Context

Applied when persistent data needs to be shared among several components without being exclusive to any one of them.

Problem

How to manage persistent data that needs to be accessed by multiple, independent components.

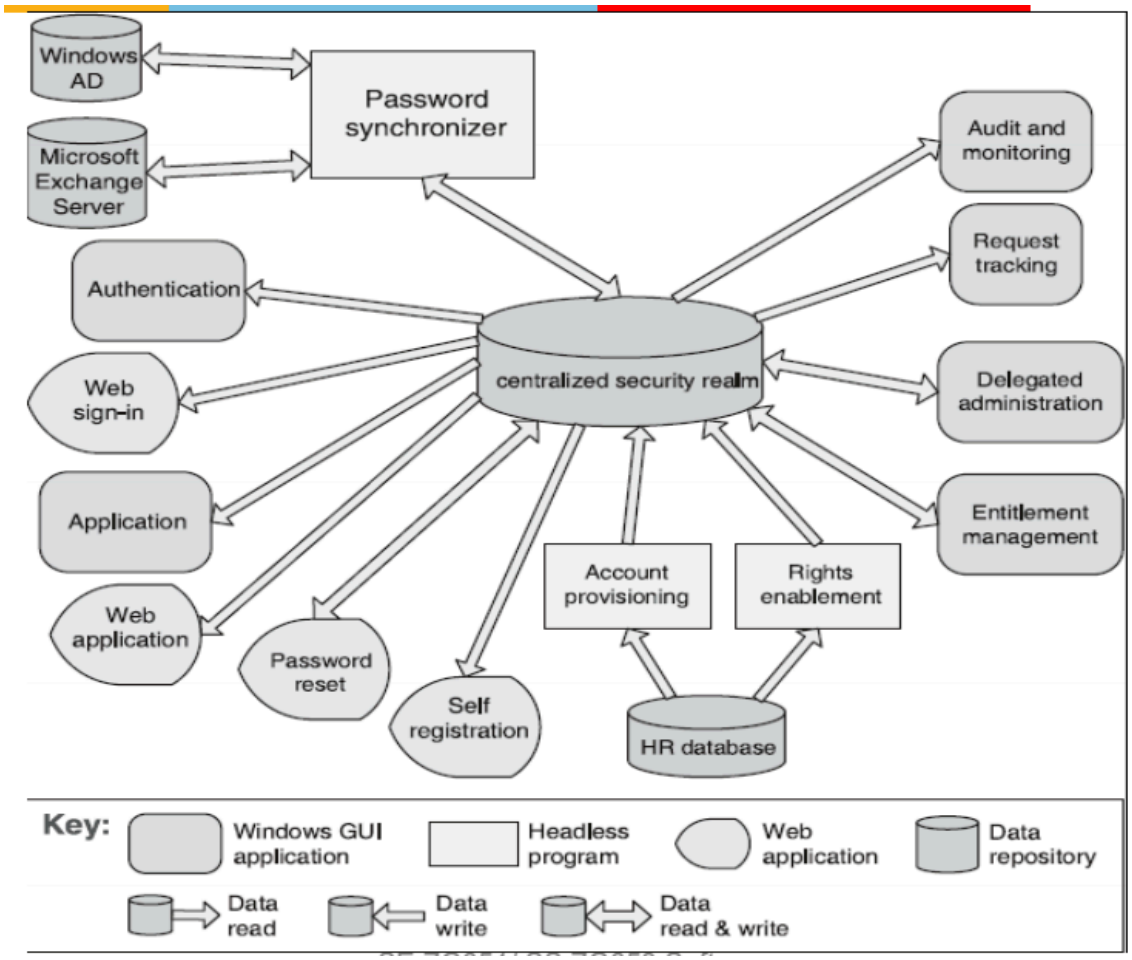
Solution

- A **shared-data store** maintains persistent data.
- **Data accessors** read from and write to the shared-data store.

Use Case Example

In a hospital management system, the shared database holds patient records, which are accessed by doctors, nurses, and administrative staff.

Diagram: Shared-Data Example



Additional Details for Each Pattern

1. Client-Server Pattern

- **Elements:**
  - **Client**: Invokes services of servers.
  - **Server**: Provides services to clients.
  - **Request/reply connector**: Manages client-server communication.
- **Relations**: Clients connect to servers via request/reply connectors.
- **Constraints**:
  - Servers may act as clients to other servers.
- **Weaknesses**:
  - Servers can become performance bottlenecks or single points of failure.

2. Peer-to-Peer (P2P) Pattern

- **Elements:**
  - **Peer**: A component that both requests and provides services.
  - **Request/reply connector**: Handles peer communication.
- **Relations**: Peers are connected via request/reply connectors.
- **Constraints**:
  - Number of connections and search depth may be limited.
- **Weaknesses**:
  - Complexity in managing security, data consistency, and availability.

3. Publish-Subscribe Pattern

- **Elements:**
  - **Publisher**: Publishes events.
  - **Subscriber**: Listens for events.
  - **Publish-subscribe connector**: Distributes events.
- **Relations**: Components connect via the publish-subscribe connector.
- **Constraints**: All components are linked to an event distributor.
- **Weaknesses**:
  - Can increase latency, reduce scalability, and create unpredictable message delivery.

4. Shared-Data Pattern

- **Elements:**
  - **Shared-data store**: Holds persistent data.
  - **Data accessor**: Reads and writes data.
  - **Data reading/writing connector**: Manages data exchange.
- **Relations**: Accessors connect to data stores via data connectors.
- **Constraints**: Data accessors interact only with the shared-data store.
- **Weaknesses**:
  - Performance bottlenecks and single points of failure.

Documentation for Software Architecture Patterns

Map-Reduce Pattern

Overview

The Map-Reduce pattern is used for analyzing vast amounts of data in a distributed, parallel manner. It splits large data sets, performs parallel processing, and combines the results efficiently.

Context

Businesses need to process enormous volumes of data (at petabyte scale) rapidly for analysis.

Problem

Efficiently sorting and analyzing ultra-large data sets that can be parallelized and distributed across multiple processors.

Solution

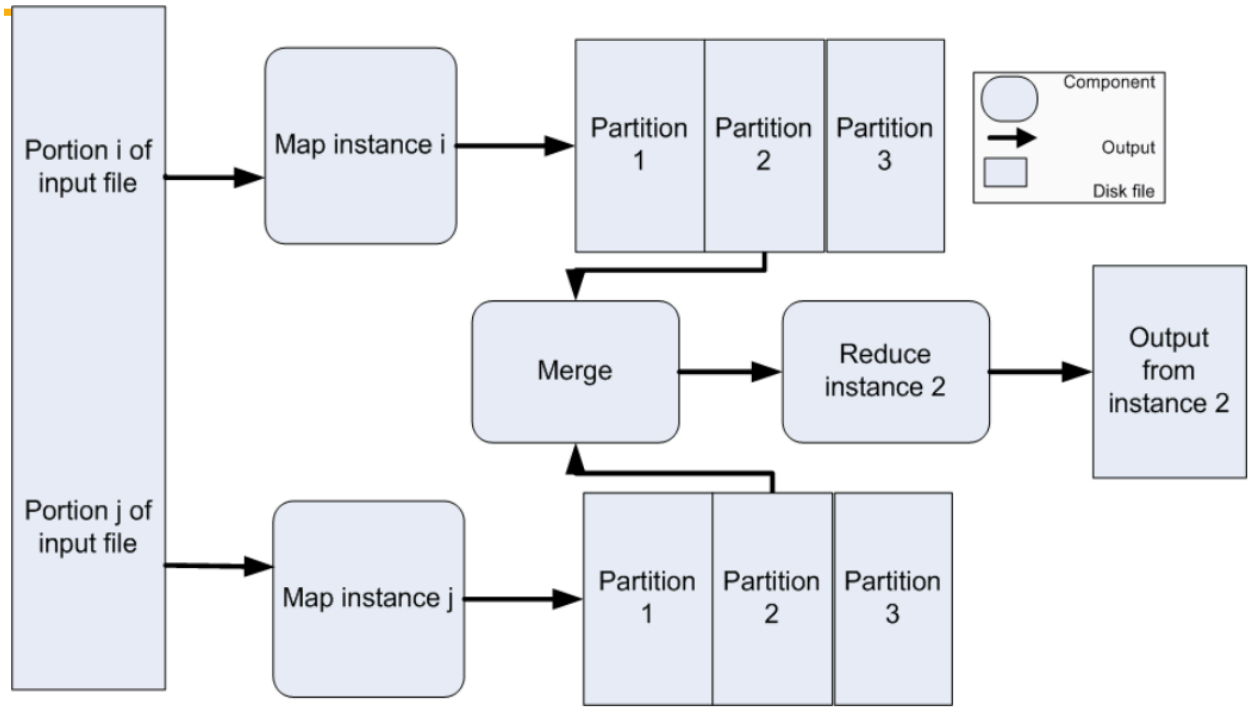
The Map-Reduce pattern consists of three main parts:

1. **Infrastructure**: Handles software allocation to hardware nodes, data sorting, and error recovery.
2. **Map Function**: Filters and extracts relevant data.
3. **Reduce Function**: Aggregates the results from the map functions.

Use Case Example

In search engines, Map-Reduce can be used to index web pages. The map function extracts keywords, while the reduce function aggregates the frequency of these keywords.

Diagram: Map-Reduce Example



Multi-Tier Pattern

Overview

The Multi-Tier pattern organizes a system's architecture into logical tiers, each containing specific groups of components.

Context

Commonly used in distributed systems where infrastructure needs to be organized into separate, logical layers for better modularity and scalability.

Problem

Efficiently splitting a system into independent execution structures, each handling specific tasks, while facilitating communication between these tiers.

Solution

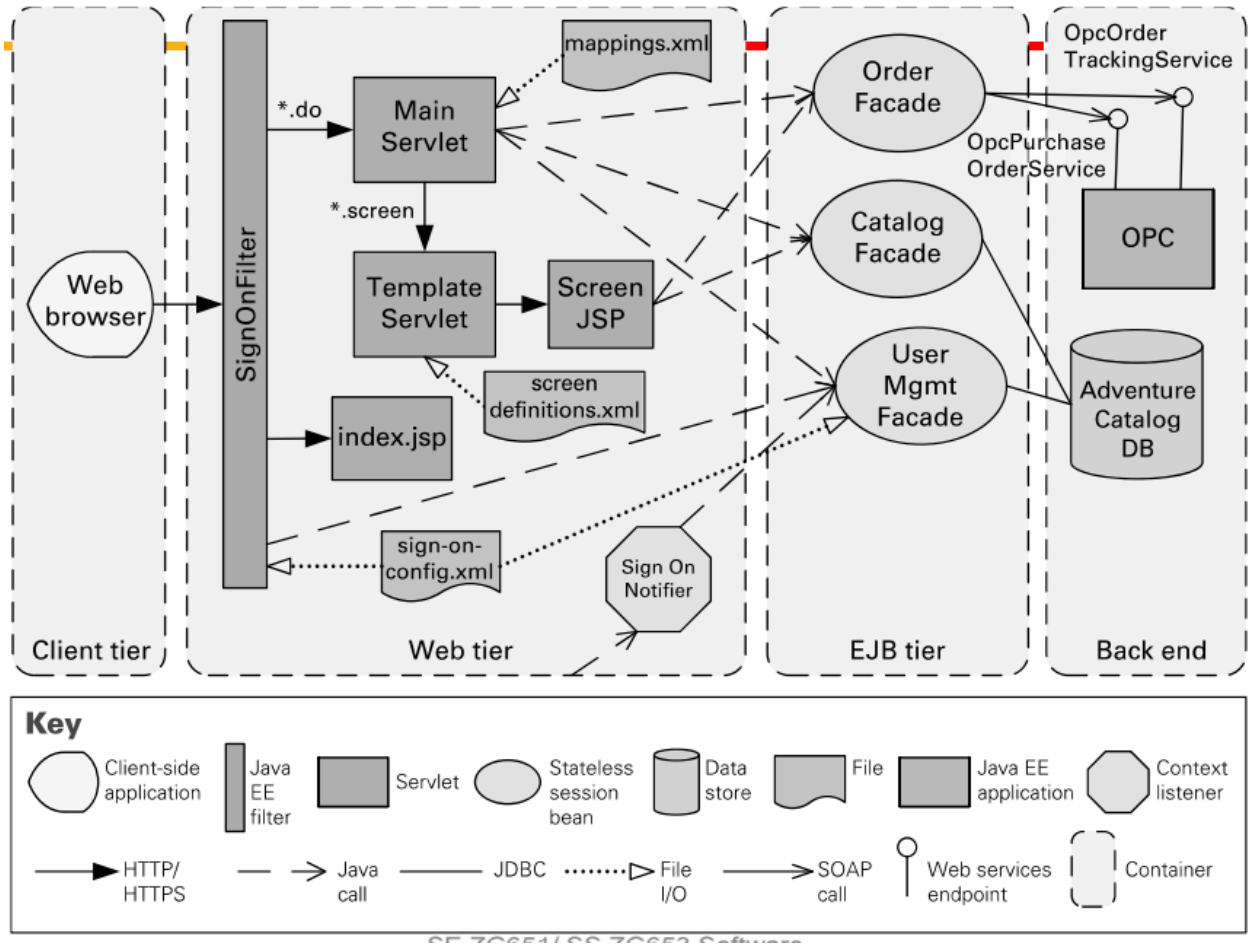
- Components are grouped into tiers that handle specific tasks.
- Tiers communicate with one another through defined interfaces and protocols.

Use Case Example

In e-commerce applications, there are typically three tiers:

1. **Presentation Tier**: Manages the user interface.
2. **Logic Tier**: Processes commands and makes logical decisions.
3. **Data Tier**: Stores and retrieves data from the database.

Diagram: Multi-Tier Example



Tactics and Interactions (1-10)

Overview

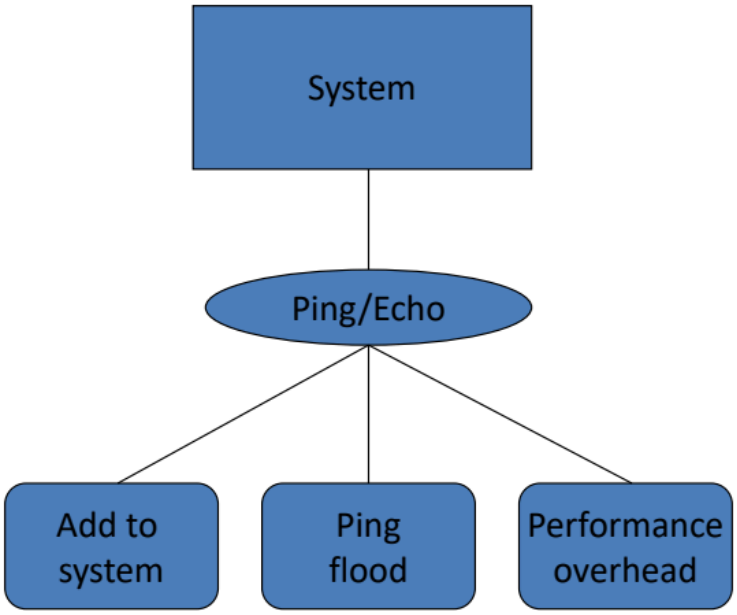
Tactics enhance software patterns by addressing specific quality attributes like performance, modifiability, and reliability. Each tactic introduces new considerations and potential side effects, leading to interactions that require additional tactics to resolve.

Tactics and Interactions Details

1. **Ping/Echo Tactic**

- **Purpose**: Detects faults by sending "ping" messages and expecting "echo" responses.
- **Common Side-Effects**:
  - **Security**: Vulnerable to ping flood attacks.
  - **Performance**: Can introduce latency due to frequent checks.
  - **Modifiability**: Integrating ping/echo mechanisms can be challenging.

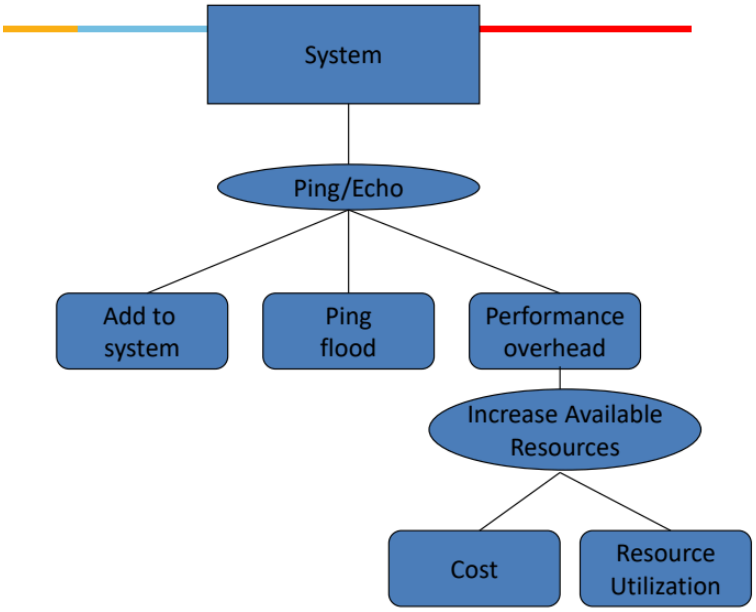
2. **Increase Available Resources**
   - **Purpose**: Enhances system performance by adding more hardware resources (e.g., servers, memory).
   - **Common Side-Effects**:
     - **Cost**: Additional resources require higher financial investment.
     - **Resource Utilization**: Effective use of increased resources must be ensured.
3. **Scheduling Policy**
   - **Purpose**: Optimizes how resources are allocated over time to improve performance.
   - **Common Side-Effects**:
     - **Modifiability**: Adding or changing scheduling policies can complicate the architecture.
     - **Adaptability**: Adjusting the scheduling policy to future needs requires careful planning.
   - **Diagram**: Tactics and Interactions - 3



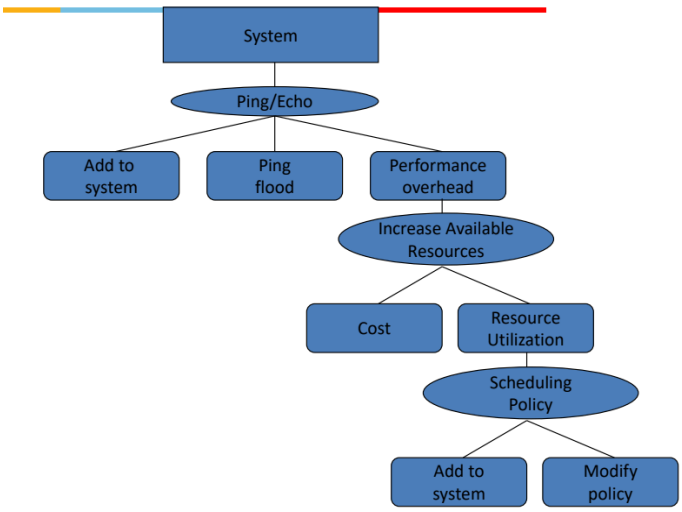
4. **Use an Intermediary**
   - **Purpose**: Introduces an intermediary (e.g., a broker or gateway) to manage communication.

- **Common Side-Effects**:
  - **Performance**: The intermediary may slow down communication.
  - **Modifiability**: Ensuring that all interactions go through the intermediary can be complex.

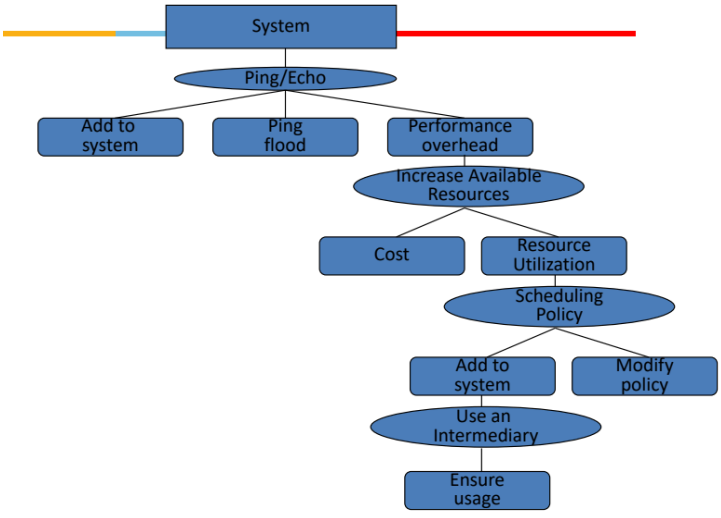
5. **Restrict Communication Paths**
   - **Purpose**: Limits communication paths to enforce security and control.
   - **Common Side-Effects**:
     - **Performance**: Restricting paths can introduce latency.
     - **Scalability**: It may limit the system's ability to scale.
   - **Diagram**: Tactics and Interactions - 5



6. **Maintain Multiple Copies**
   - **Purpose**: Increases availability by having redundant copies of components or data.
   - **Common Side-Effects**:
     - **Consistency**: Keeping all copies updated can be complex.
     - **Performance**: Synchronization of multiple copies can slow down the system.
7. **Load Balancing**
   - **Purpose**: Distributes workloads evenly across resources to prevent bottlenecks.
   - **Common Side-Effects**:
     - **Overhead**: The load balancer itself can become a bottleneck.
     - **Complexity**: Implementing effective load balancing adds architectural complexity.
   - **Diagram**: Tactics and Interactions - 7



8. **Checkpoint/Restart**
    - **Purpose**: Saves the system's state periodically to allow recovery after failures.
    - **Common Side-Effects**:
        - **Performance**: Frequent checkpoints can reduce performance.
        - **Storage Requirements**: Additional storage is needed for checkpoint data.
9. **Use Cache**
    - **Purpose**: Enhances performance by temporarily storing frequently accessed data.
    - **Common Side-Effects**:
        - **Consistency**: Ensuring data consistency between the cache and the main data source can be difficult.
        - **Resource Utilization**: Caching requires additional memory and management.
    - **Diagram**: Tactics and Interactions - 9



10. **Adjustable Granularity**
    - **Purpose**: Changes the granularity of tasks, data processing, or communication to balance performance and complexity.
    - **Common Side-Effects**:
        - **Modifiability**: Adjusting granularity can complicate system modifications.
        - **Performance**: Both coarse and fine granularity can have negative performance impacts, depending on the context.

Summary

- **Patterns** are reusable architectural structures addressing common problems in software design.
- **Tactics** enhance patterns by focusing on specific quality attributes.
- The combination of tactics and patterns helps create robust architectures that meet system requirements.

Architectures for the cloud Overview

1. Basic Cloud Definitions

- **NIST Definition**: The National Institute of Standards and Technology (NIST) defines the following essential characteristics of cloud computing:
    - **On-Demand Self-Service**: Users can provision resources like server time and network storage automatically, without human involvement.
    - **Ubiquitous Network Access**: Cloud services are accessible over the network via standard protocols, making them usable across various devices.
    - **Resource Pooling**: The provider's resources (e.g., storage, processing) are pooled to serve multiple consumers.
    - **Location Independence**: The exact physical location of the resources is irrelevant to the user.
    - **Rapid Elasticity**: Resources can be scaled rapidly, both up and down, to meet demand.
    - **Measured Service**: Resource usage is monitored, controlled, and reported, ensuring users are billed based on consumption.
    - **Multi-Tenancy**: Multiple users share resources without affecting one another.

2. Basic Service Models

- **Software as a Service (SaaS)**:
    - End users access applications running on the cloud.
    - Examples include email services and cloud storage like Google Drive.
    - **Use Case**: An organization uses a cloud-based CRM like Salesforce, enabling its sales team to access customer data from anywhere.
- **Platform as a Service (PaaS)**:
    - Developers deploy applications using programming languages and tools provided by the cloud provider.
    - Examples include Google App Engine and Microsoft Azure App Services.
    - **Use Case**: A developer builds a web app using Microsoft Azure's PaaS offerings, using pre-configured databases, development tools, and APIs.
- **Infrastructure as a Service (IaaS)**:
    - Users can provision processing, storage, and networks to run operating systems and applications.
    - Examples include Amazon EC2 and Microsoft Azure VMs.
    - **Use Case**: A company runs its own custom applications on virtual machines provided by Amazon EC2, with control over OS and installed software.

3. Deployment Models

- **Private Cloud**:
    - Exclusive use by a single organization, ensuring high security and control.

    - **Use Case**: A government agency uses a private cloud for sensitive data management.
- **Public Cloud**:
    - Available to the general public, owned by third-party providers like AWS or Microsoft Azure.
    - **Use Case**: Startups host their websites on public clouds for cost-effectiveness.
- **Community Cloud**:
    - Shared by multiple organizations with similar requirements (e.g., compliance, mission).
    - **Use Case**: Healthcare organizations share a community cloud to manage patient data while complying with healthcare regulations.
- **Hybrid Cloud**:
    - A combination of private, public, or community clouds, ensuring flexibility.
    - **Use Case**: An e-commerce site uses public cloud for its customer-facing services while maintaining a private cloud for sensitive transaction data.

4. Economic Justification

- **Economies of Scale**:
    - Large data centers (100,000+ servers) are more cost-efficient than small ones (<10,000 servers).
    - **Cost Factors**:
        - **Power Costs**: Lower per-server costs due to shared infrastructure, bulk power negotiation, and cheaper power sources like wind or solar energy.
        - **Labor Costs**: More efficient system administration, with one administrator managing over 1,000 servers in large data centers versus 150 in smaller centers.
        - **Security and Reliability**: Larger centers can distribute fixed costs of security, redundancy, and disaster recovery over more servers.
        - **Hardware Costs**: Discounts of up to 30% on hardware for large data center operators.
- **Utilization of Equipment**:
    - Virtualization allows multiple applications to co-locate on the same hardware, improving server utilization.
    - **Factors Enhancing Utilization**:
        - **Random Access**: Random user access results in uniform server load.
        - **Time of Day**: Co-location of workplace and consumer services adjusts workloads by time zones.
        - **Time of Year**: Seasonal demand adjustments (e.g., tax season) help manage resource allocation.
        - **Resource Usage Patterns**: Co-locating CPU-intensive services with I/O-intensive services ensures balanced resource consumption.
        - **Uncertainty**: Cloud services can manage unexpected spikes due to news events or marketing campaigns.

    - **Use Case**: An online streaming service uses a public cloud to manage sudden spikes in demand during popular events like sports finals.
- **Multi-Tenancy**:
    - A single application serves multiple users, reducing costs in:
        - **Help Desk Support**: Centralized support for a single app.
        - **Simultaneous Upgrades**: One update applies to all users.
        - **Unified Development**: Easier maintenance with one version of software.
    - **Use Case**: A SaaS CRM platform hosts a single instance of its application for different businesses, lowering maintenance costs and simplifying updates.

5. Summary

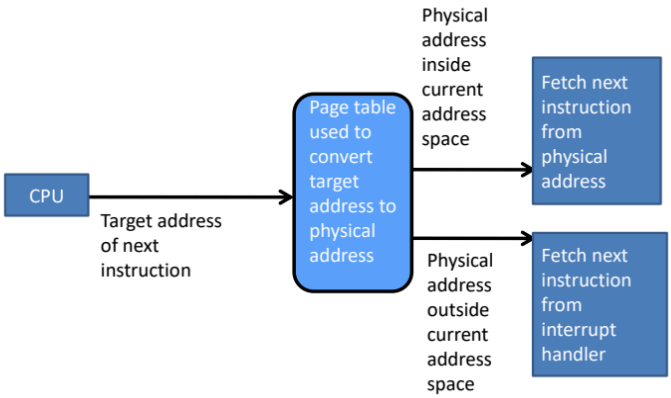
- Cloud computing offers a scalable, flexible, and cost-effective platform for various applications.
- It supports different service models (SaaS, PaaS, IaaS) and deployment models (Private, Public, Community, Hybrid).
- Economic advantages include economies of scale, increased equipment utilization, and multi-tenancy, making it attractive for organizations aiming to optimize costs and efficiency.

Architectures for the cloud Overview 2

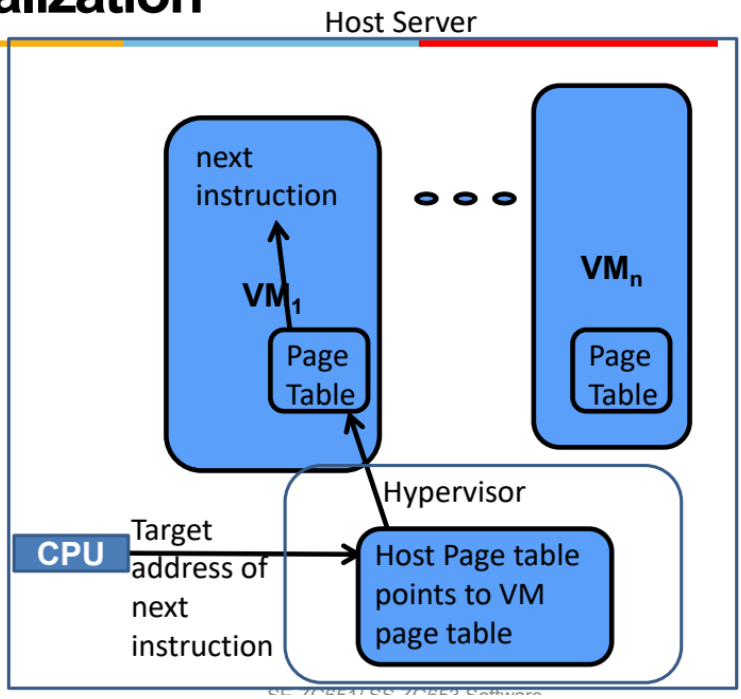
Virtual Memory Page Table

Virtual Memory Page Table

Virtual memory for non-virtualized application

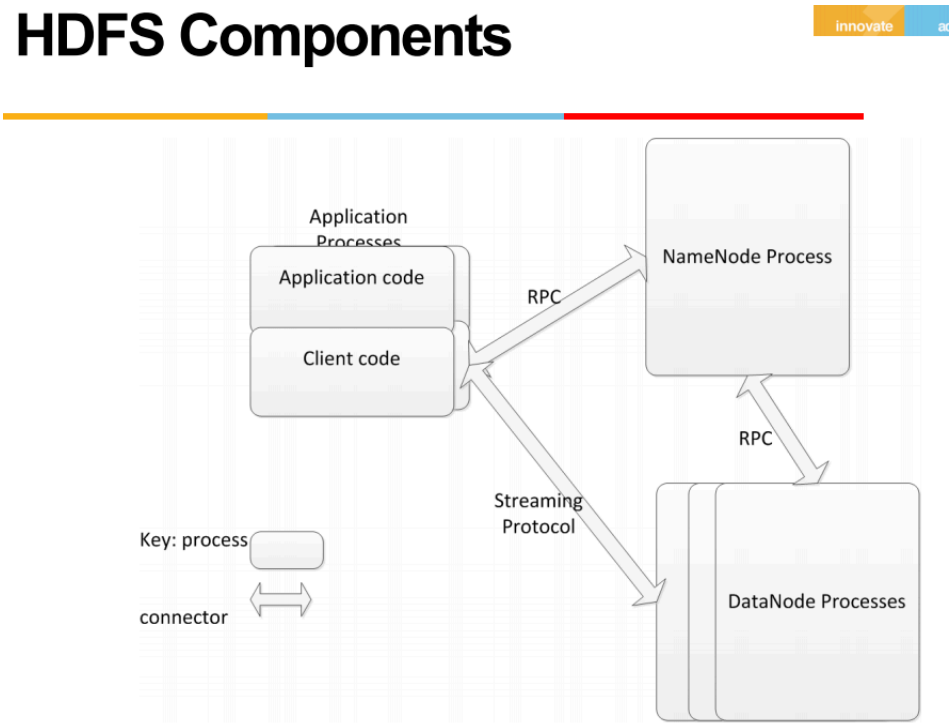


Hypervisor Manages Virtualization



1. Base Mechanisms

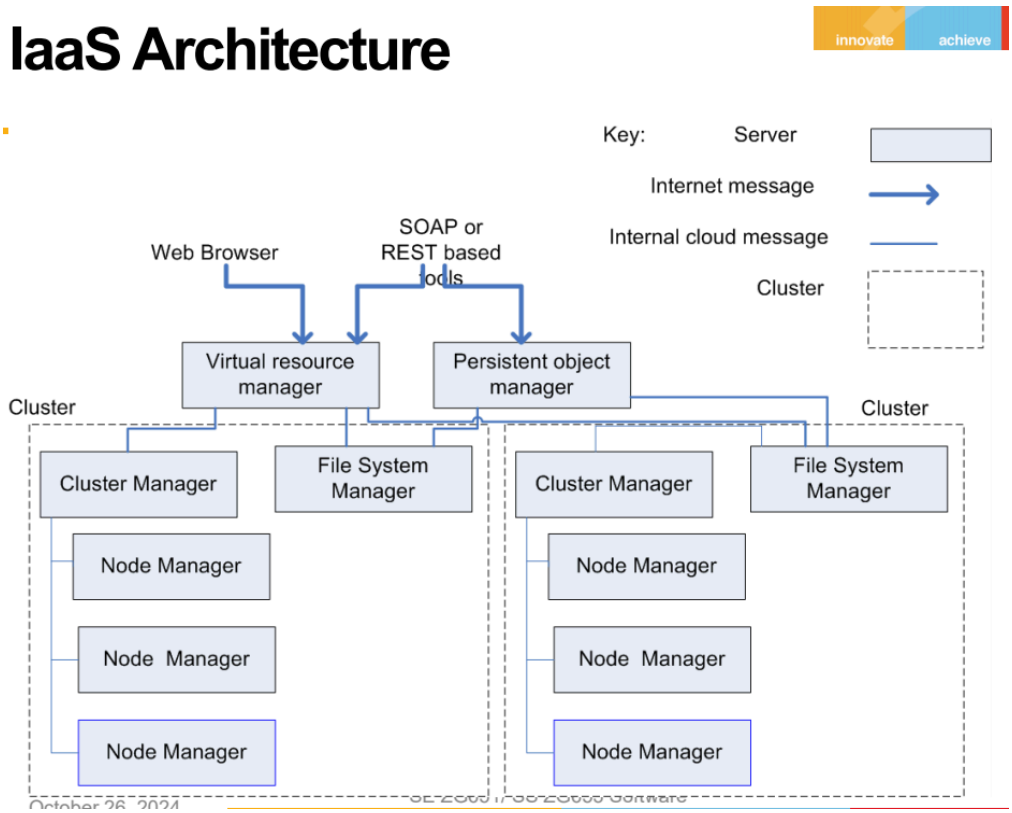
- **Hypervisor**:
  - The core of cloud infrastructure, enabling virtualization by managing multiple virtual machines (VMs) on a single physical server.
  - **Use Case**: VMware ESXi or Microsoft Hyper-V as hypervisors that allocate resources among different VMs running on the same server.
- **Virtual Machine (VM)**:
  - A software emulation of a physical computer, isolating each VM's address space.
  - VMs appear as independent machines to applications, have their own IP addresses, and can run various operating systems.
  - **Diagram**: Illustrates how VMs interact with the hypervisor on a host server.
  - **Use Case**: Deploying multiple VMs on a single server to run different services like web servers, databases, and app servers concurrently.
- **File System**:
  - Cloud file systems ensure persistent storage, often using distributed systems like Hadoop Distributed File System (HDFS).
  - **HDFS Write - Sunny Day Scenario**:
    - The client writes a block to a DataNode, which replicates it to additional DataNodes for redundancy.
    - **Failure Scenarios**: Handles client, NameNode, or DataNode failures, ensuring data persistence via replication and retries.
  - **Diagram**:



- **Network**:
  - Every VM is assigned an IP address, enabling communication via standard TCP/IP protocols.
  - Gateways adjust IP addresses for communication management.
  - **Use Case**: Cloud applications dynamically adjusting network configurations to maintain communication efficiency.

2. Sample Technologies

- **Infrastructure as a Service (IaaS)**:
  - Provides hardware resources like servers, storage, and networking as virtualized components.
  - **Architecture Components**:
    - **Cluster Manager**: Manages clusters of servers.
    - **Persistent Object Manager**: Manages persistent storage.
    - **Virtual Resource Manager**: Acts as a gateway for resource allocation and messaging.
    - **File System Manager**: Manages network-wide file storage, similar to HDFS.
  - **Services Provided**:
    - **Automatic IP Reallocation**: Handles IP changes in case of VM failure.
    - **Automatic Scaling**: Adjusts the number of VMs based on demand.
  - **Diagram**:



    - **Use Case**: AWS EC2 or Microsoft Azure managing cloud infrastructure for scalable applications.
- **Platform as a Service (PaaS)**:
    - Provides an integrated stack for development, e.g., LAMP stack (Linux, Apache, MySQL, Python).
    - **Use Case**: Developers build web applications on Heroku or Google App Engine, relying on PaaS to manage infrastructure, databases, and middleware.
- **Databases**:
    - **Why Relational Databases Fell Short**:
        - Challenges with massive web data processing, the CAP theorem's constraints, and relational models' limitations in handling dynamic data.
        - New models emerged:
            - **Key-Value Databases (e.g., HBase)**:
                - Uses keys to access values without schemas; time stamps detect collisions.
            - **Document-Centric Databases (e.g., MongoDB)**:
                - Stores data as objects, with flexible schemas and eventual consistency.
    - **What is Omitted from These Databases**:
        - Transactions, normalization, and strict consistency are often compromised for scalability.

3. Architecting in a Cloud Environment

- **Security**:
    - Multi-tenancy raises new security concerns:
        - **Information Sharing Risks**: Possible data leaks from shared resources (e.g., disks).
        - **VM Escape Risks**: Theoretical attacks that break hypervisor isolation.
        - **Side Channel Attacks**: Exploit shared resources like caches to gather information.
        - **Denial of Service (DoS) Attacks**: Resource exhaustion attacks by one user affecting others.
    - **Mitigation Strategies**: Use encryption, strict resource isolation, and proactive monitoring.
    - **Use Case**: Banking applications implementing enhanced encryption and resource isolation when hosted on public clouds.
- **Performance**:
    - **Auto-Scaling**: Adjusts resources dynamically based on load.
        - Response times for scaling may not always match demand spikes.
        - **Use Case**: An e-commerce platform scaling servers during flash sales but facing potential latency in adding new resources.
    - **Proactive Resource Management**: Applications should anticipate resource requirements and request them before bottlenecks occur.
- **Availability**:

    - With thousands of servers, failure is expected; cloud providers ensure the infrastructure remains available.
    - Applications should detect and manage instance failures, with built-in recovery mechanisms.
    - **Use Case**: A content delivery network (CDN) ensuring redundancy across multiple data centers to maintain availability during regional outages.

4. Summary

- Cloud architecture requires special attention to virtualization, network management, and distributed storage systems.
- Architecting for the cloud involves considering additional concerns like security, performance, and availability.
- Cloud environments offer benefits like scalability, flexibility, and cost-efficiency, but also introduce challenges in terms of data management, system complexity, and dynamic resource allocation.

AWS Cloud Architecture

1. The Cloud Computing Difference

- **Programmable IT Resources**:
    - IT assets become configurable via software, enabling automation, scaling, and integration.
    - **Example**: AWS Elastic Compute Cloud (EC2) allows launching and managing servers programmatically.
- **Global Availability & Unlimited Capacity**:
    - Cloud infrastructure offers worldwide coverage with seemingly limitless resources.
    - **Scenario**: Deploying a web app across AWS regions to ensure global reach and low latency.
- **Higher-Level Managed Services**:
    - AWS offers services like Amazon RDS, Lambda, and DynamoDB that eliminate infrastructure management.
    - **Use Case**: A developer using AWS Lambda for serverless computing to run event-driven functions without managing servers.
- **Built-in Security**:
    - AWS emphasizes secure access, encryption, and compliance at all service levels.
    - **Example**: Using AWS Identity and Access Management (IAM) to control user permissions.

2. Design Principles for AWS

- **Disposable Resources**:
    - Cloud architecture replaces fixed servers with ephemeral, replaceable resources.
    - **Scenario**: Using Auto Scaling to terminate and launch EC2 instances based on load.
- **Automation**:
    - Automating infrastructure deployment using tools like AWS CloudFormation or Terraform.
    - **Example**: Automating backup and recovery using Lambda triggers.
- **Loose Coupling**:
    - Building modular systems where services communicate via APIs or message queues.
    - **Use Case**: A microservices architecture using Amazon Simple Queue Service (SQS) to pass messages between services.
- **Services, Not Servers**:
    - Design applications to leverage services like S3 for storage, DynamoDB for databases, and API Gateway for APIs.
- **Database**:

    - Use cloud-native databases like Amazon RDS for relational data or DynamoDB for NoSQL data.
- **Removing Single Points of Failure**:
    - Implement redundancy with services like ELB (Elastic Load Balancer), RDS Multi-AZ deployments, and S3 versioning.
    - **Scenario**: Deploying an RDS instance across multiple availability zones for high availability.
- **Optimize for Cost**:
    - Use Reserved Instances, Spot Instances, and S3 storage tiers to minimize costs.
    - **Example**: A data analysis pipeline using EC2 Spot Instances to process batch jobs.
- **Caching**:
    - Use caching with services like Amazon ElastiCache or CloudFront to enhance performance.
- **Security**:
    - Ensure security with encryption (e.g., S3 server-side encryption), network isolation (VPCs), and IAM policies.

3. Scalability on AWS

- AWS supports horizontal scaling by adding more instances to handle increased loads.
- **Use Case**: Scaling web applications using Elastic Load Balancer (ELB) to distribute traffic across EC2 instances.

Multi-Tenant Applications: Microsoft Azure Case Study

1. Windows Azure Overview

- **Goals and Requirements**:
    - Build applications that accommodate multiple tenants while maintaining performance, security, and customizability.
- **Tenant Perspective**:
    - Tenants expect secure access, data isolation, and the ability to customize services.
- **Provider Perspective**:
    - Providers need to ensure efficient resource utilization, tenant isolation, and scalability.
- **Single vs. Multi-Tenant Architecture**:
    - **Single-Tenant**: Separate resources for each tenant.
    - **Multi-Tenant**: Shared resources for all tenants.
- **Multi-Tenancy Architecture in Azure**:
    - Azure offers both approaches, with shared compute, database, and storage resources for efficiency.
- **Selecting Architecture Type**:

    - Consider cost, customization needs, security requirements, and scalability when choosing between single-tenant and multi-tenant models.

2. Architectural Considerations

- **Application Life Cycle**:
    - Implement strategies for versioning, deployment, and upgrade paths.
- **Customization**:
    - Allow tenants to tailor the application while maintaining overall stability.
- **Financial Considerations**:
    - Assess cost implications of single vs. multi-tenant models in terms of development, maintenance, and hosting.

3. Other Topics: Microsoft Azure

- **Multi-Tenant Data Architecture**:
    - Choose between partitioned databases, shared tables with tenant IDs, or fully separate databases for each tenant.
- **Partitioning Multi-Tenant Applications**:
    - Use horizontal partitioning to split data among tenants to enhance scalability.
- **Maximizing Availability, Scalability, and Elasticity**:
    - Leverage Azure's autoscaling and load balancing features.
- **Securing Multi-Tenant Applications**:
    - Implement role-based access control (RBAC) and data encryption to ensure tenant isolation.
- **Managing & Monitoring**:
    - Use Azure Monitor, Application Insights, and Log Analytics to manage tenant performance and diagnose issues.

Microsoft Application Architecture Guide

1. Software Architecture and Design Fundamentals

- **What is Software Architecture?**
    - The set of structures needed to reason about a system, including software elements, their relationships, and properties.
- **Key Principles of Software Architecture**:
    - Include modularity, scalability, maintainability, and security.
- **Architectural Patterns & Styles**:
    - Use patterns like MVC, microservices, or layered architecture to address design problems.
- **Techniques for Architecture and Design**:
    - Use domain-driven design (DDD), event storming, and prototyping to create robust architectures.

2. Layered Application Guidelines

- **Presentation Layer**:
  - Handles UI and user interactions.
  - **Example**: A React front-end consuming backend APIs.
- **Business Layer**:
  - Manages business logic and workflows.
  - **Use Case**: A Java Spring Boot service processing customer orders.
- **Data Layer**:
  - Manages data access and persistence.
  - **Scenario**: An application using Entity Framework to interact with SQL databases.
- **Service Layer**:
  - Facilitates communication between layers via services like REST APIs.
  - **Example**: Exposing business functions as RESTful services in an ASP.NET application.

3. Application Archetypes

- **Web Applications**:
  - For browser-based interfaces, using frameworks like ASP.NET, Angular, or React.
- **Rich Client Applications**:
  - Desktop applications with robust user interfaces.
- **Rich Internet Applications (RIAs)**:
  - Applications combining desktop-like features with web accessibility.
- **Mobile Applications**:
  - Optimized for iOS and Android using frameworks like Xamarin or Flutter.
- **Service Applications**:
  - Offer services via APIs, often using cloud platforms.
- **Hosted and Cloud Services**:
  - Applications designed to run entirely on cloud platforms like Azure or AWS.
- **Office Business Applications**:
  - Extend Microsoft Office capabilities with custom apps.
- **SharePoint LOB Applications**:
  - Leverage SharePoint for line-of-business solutions.

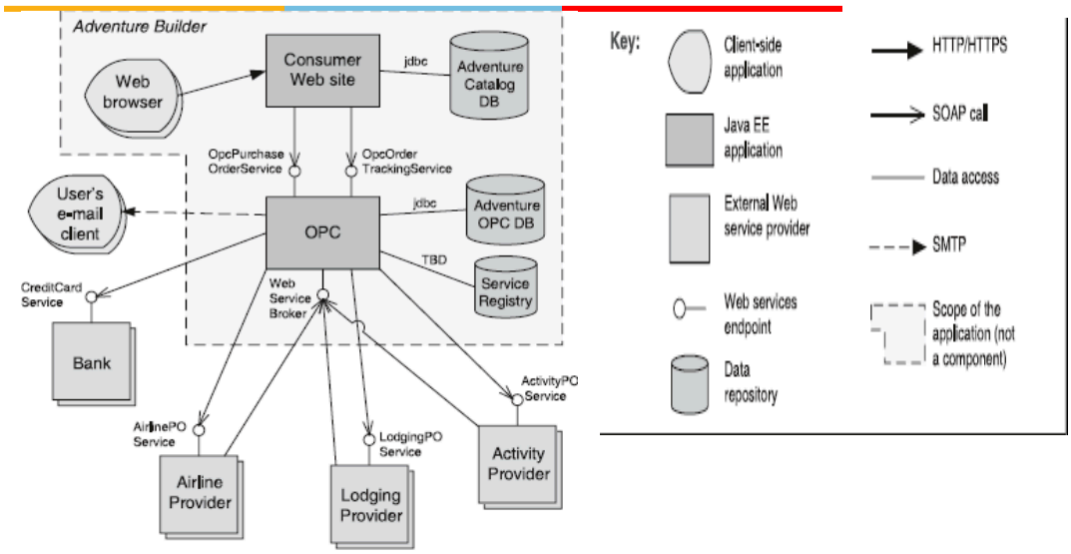
This document covers AWS cloud architecture, Azure multi-tenant applications, and Microsoft application design fundamentals, with use cases and examples as needed. Let me know if you require further details!

The Road Ahead: SOA, Cloud, and CAP Theorem

1. Service-Oriented Architecture (SOA) Pattern

- **Context**:
  - Services are offered by providers and consumed by users over a network. Consumers need to understand and use these services without knowing their implementation details.
- **Problem**:
  - Supporting interoperability across distributed components running on different platforms, written in diverse languages, and offered by various organizations.
- **Solution**:
  - SOA comprises distributed components that provide or consume services.
  - **Example**: Multiple web services interacting via APIs to perform tasks like authentication, payment processing, and notifications.
- **Elements**:
  - **Service Providers**: Offer services through defined interfaces.
  - **Service Consumers**: Invoke services either directly or through intermediaries.
  - **ESB (Enterprise Service Bus)**: Routes and transforms messages between providers and consumers.
  - **Registry of Services**: Helps consumers discover available services at runtime.
  - **Orchestration Server**: Manages interactions between services based on workflows.
- **Connectors**:
  - **SOAP Connector**: For synchronous communication using the SOAP protocol.
  - **REST Connector**: Uses HTTP operations for request/reply interactions.
  - **Asynchronous Messaging Connector**: Facilitates asynchronous communication via messaging systems.
- **Weaknesses**:
  - SOA-based systems can be complex, with middleware introducing performance overhead and potential bottlenecks.
- **Diagram**:

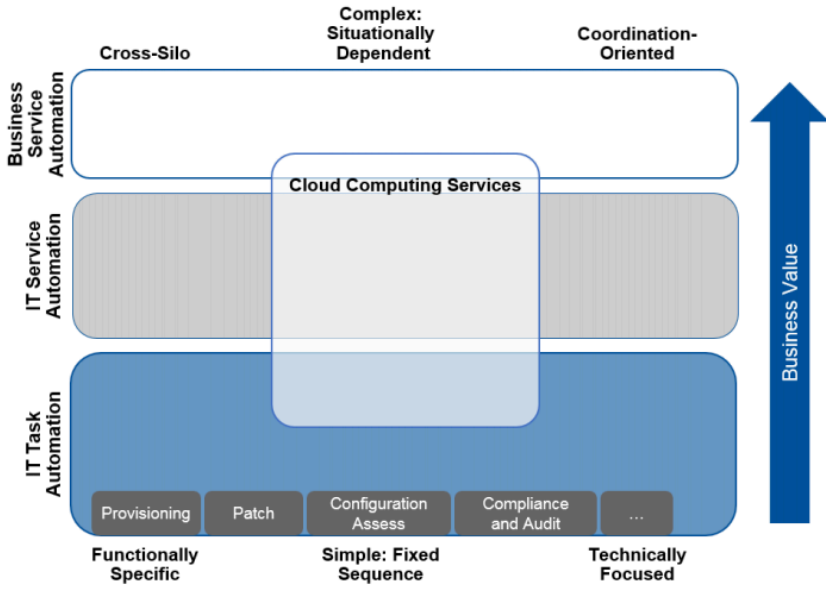
Service Oriented Architecture Example



2. Cloud Computing Strategies

- **Key Challenges**:
  - Many organizations fail in cloud implementation due to the lack of a cloud strategy linked to business outcomes.
  - Uncertainty about starting cloud projects can hinder timely business opportunities.
- **Recommendations**:
  - Identify the cloud services to offer or procure.
  - Document internal processes impacted by cloud services.
  - Map applications and workloads to cloud services.
- **Diagram**:

Source: Gartner Report (July 2016)



3. CAP Theorem

- **Definition**:
  - The CAP Theorem explains that a distributed system cannot simultaneously provide all three guarantees:
    - **Consistency**: All nodes should have the same data at the same time.
    - **Availability**: System remains operational despite node failures.
    - **Partition-Tolerance**: Continues operation even with network partitions.
- **CAP Theorem Scenarios**:
  - **AP Database (Not Consistent)**:
    - **Scenario**: Data is read from one node, while data is being written to another node.
    - **Examples**: CouchDB, Cassandra, ScyllaDB.
  - **CP Database (Not Available)**:
    - **Scenario**: Data in one partition is locked for consistency, but node is unavailable.
    - **Examples**: MongoDB, Redis.
  - **CA Database (Not Partition-Tolerant)**:
    - **Scenario**: All nodes show the same data, but cannot handle network partitions (theoretical).

Architecting Mobile Applications

1. Introduction

Mobile applications serve various purposes and have different architectural requirements depending on their functionality, performance needs, and target platforms.

Examples of Mobile Apps:

- **Uber**: Ride-hailing app
- **Swiggy**: Food delivery
- **Spotify**: Music streaming
- **Where Is My Train**: Train tracking
- **eCommerce**: Shopping apps like Amazon

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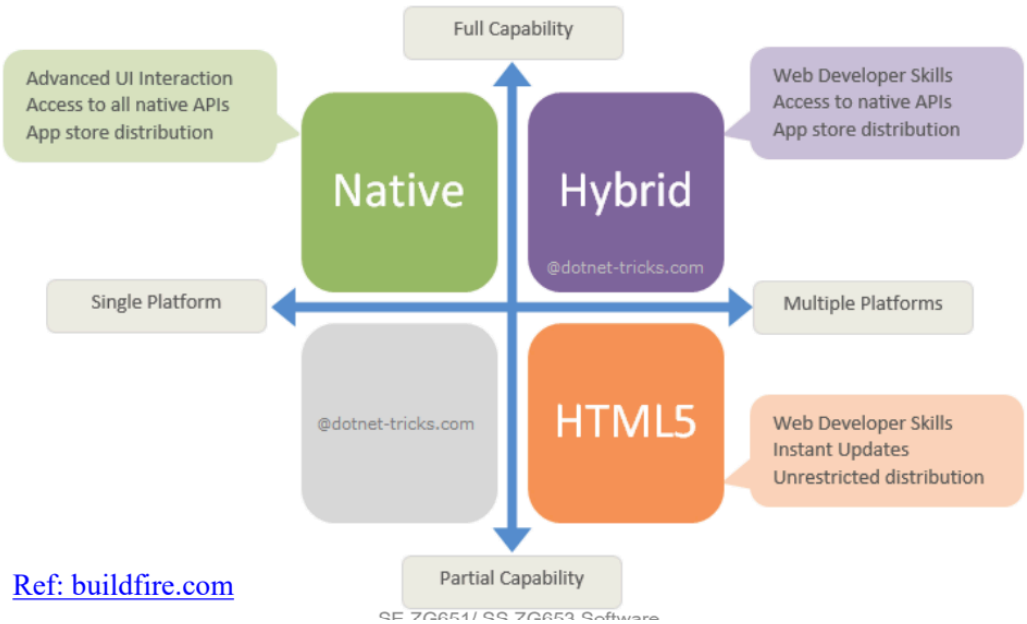
2. Design Considerations for Mobile Applications

- **User Interface**: Simple, easy to navigate with large buttons and minimal features.
- **Responsive Design**: Adjusts to different screen sizes and orientations.
- **Performance**: Compact code for efficient CPU, memory, and storage usage.
- **Connectivity**: Ability to store data locally and sync later if connectivity is poor.

Diagram Placeholder: Types of Mobile Apps



Ref: buildfire.com

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3. Types of Mobile Applications

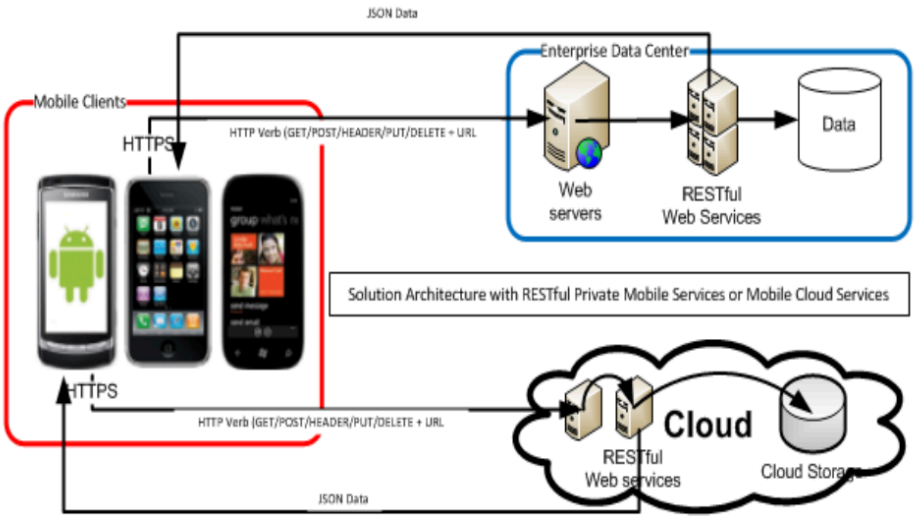
Native Apps

- **Platform-Specific**: Developed separately for Android and iOS using Swift, Objective-C (iOS), Java, or Kotlin (Android).
- **Examples**: Google Maps, Facebook
- **Development Tools**: Android Studio, Xcode

Web Apps

- **Browser-Based**: Accessed via a web browser and use HTML5, CSS3, JavaScript.
- **Examples**: Flipkart, BookMyShow

Diagram Placeholder: Mobile Web Application



Hybrid Apps

- **Combines Native and Web Elements**: Written in HTML, CSS, JavaScript but runs in a native shell to access device features.
- **Examples**: Uber, Twitter
- **Development Tools**: Xamarin, React Native

Diagram Placeholder: Pros & Cons of App Types

App type	Pro	Con
Native	• High performance • Superior user experience • Access to all features of OS	• Runs only on one platform • Need to know special language • Need to update versions
Web App	• Easy to deploy new versions • Common code base	• Little scope to use device hardware • Lower user experience • Need to search for app
Hybrid	• Does not need browser • Single code base • Access to device hardware	• Slower

---

4. User Interface (UI) Design Patterns

- **Quick Access**: Action bars for frequently used actions.
- **Third-Party Login**: Allow sign-in through social platforms like Google or Facebook.
- **Notifications**: Alerts for recent activity.
- **Discoverable Controls**: Buttons and options appear only when relevant, e.g., WhatsApp's "Forward" button.

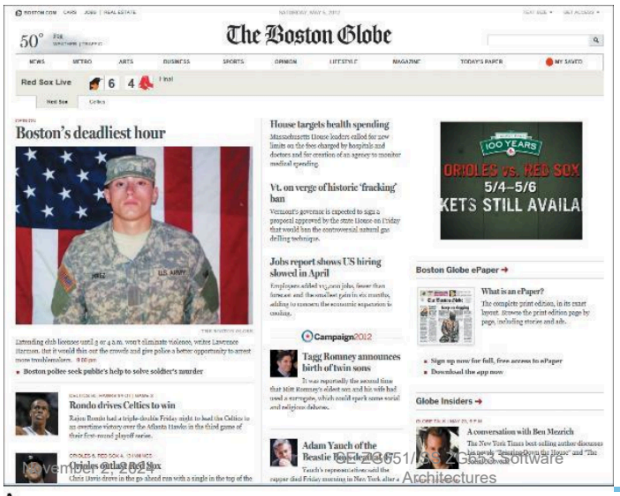
Diagram Placeholder: UI Design Patterns

5. Responsive Design

Responsive design ensures that the application adjusts to different devices (laptops, tablets, phones) with a single codebase, by using flexible grids, CSS media queries, and percentage-based images.

Diagram Placeholder: Responsive Design Example (Desktop & Mobile)

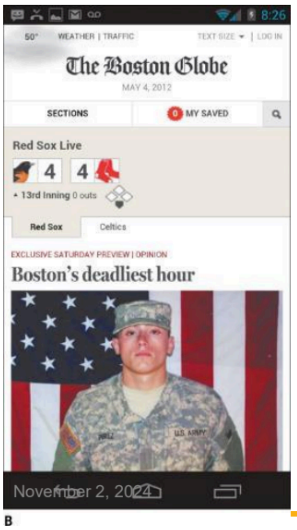
Example: Boston Globe News



A

This is how the display looks on desktop

Example: Boston Globe News



B

C

This is how the display looks on mobile

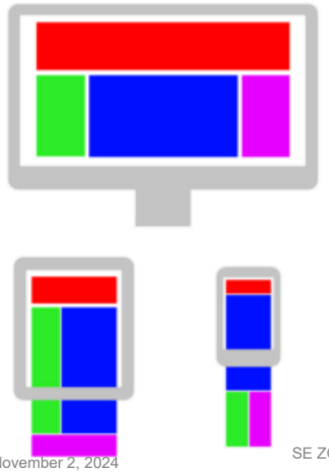
Adjusted vertically

Single website for laptop & mobile & tablet

Principle: Adapt rendering depending on screen sizes & orientation

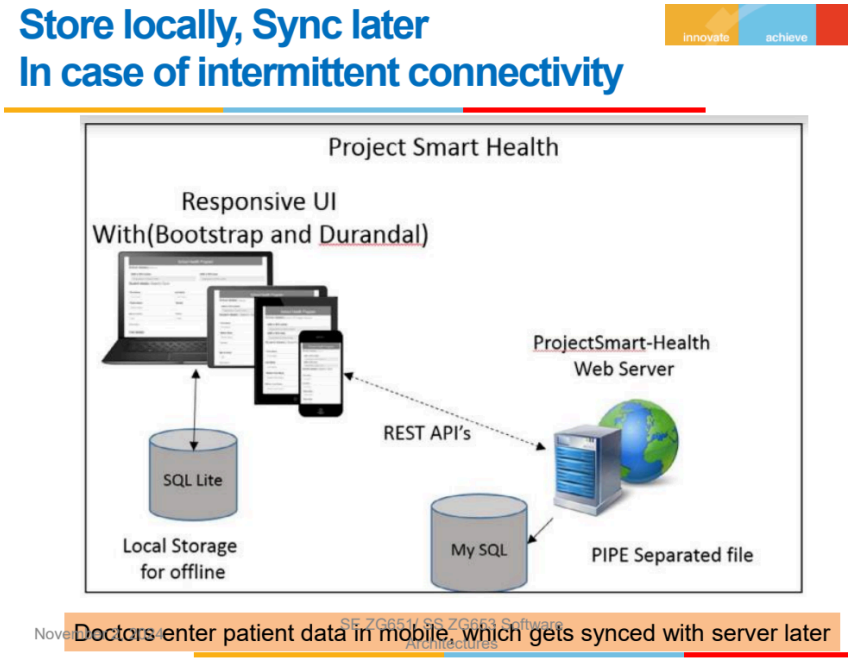
Ref: Wikipedia

Ref: Wikipedia



Flexi grids

- Divide a screen into multiple columns
- Assign HTML elements to one or more columns
- Choose a different layout depending on screen size



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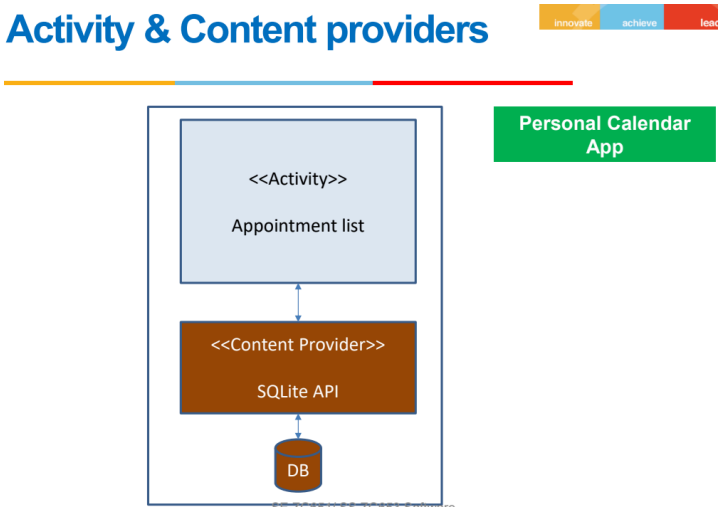
6. Android Application Architecture

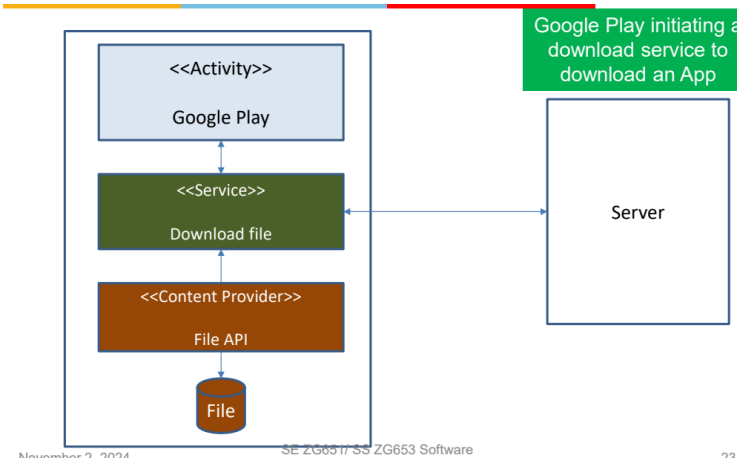
Android applications consist of four main components:

- **Activity**: User interface.
- **Service**: Background operations, e.g., music playback, file download.
- **Content Provider**: Data storage, e.g., SQLite.
- **Broadcast Receiver**: Responds to system events, e.g., SMS arrival.

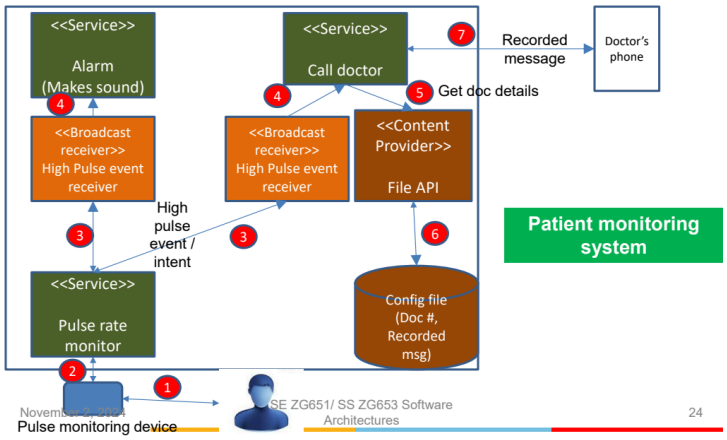
Diagram Placeholder: Android Application Structure



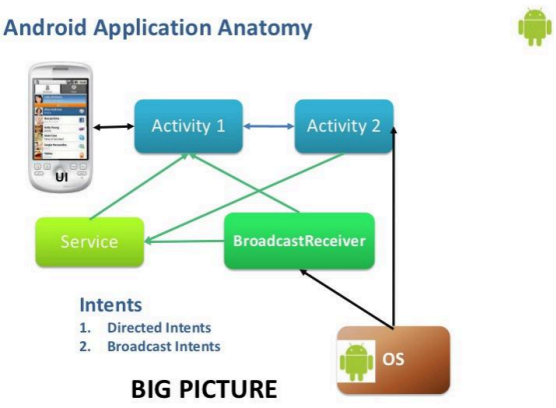
(Background) Service



Broadcast receiver (Event handlers)



Android application structure



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7. Example Components in a Mobile App (Uber)

- **UI**: Booking screen to select and view available cabs.
- **Broadcast Receiver**: Receives real-time cab location updates and sends location updates during the trip.
- **Database**: Stores configuration and user data.

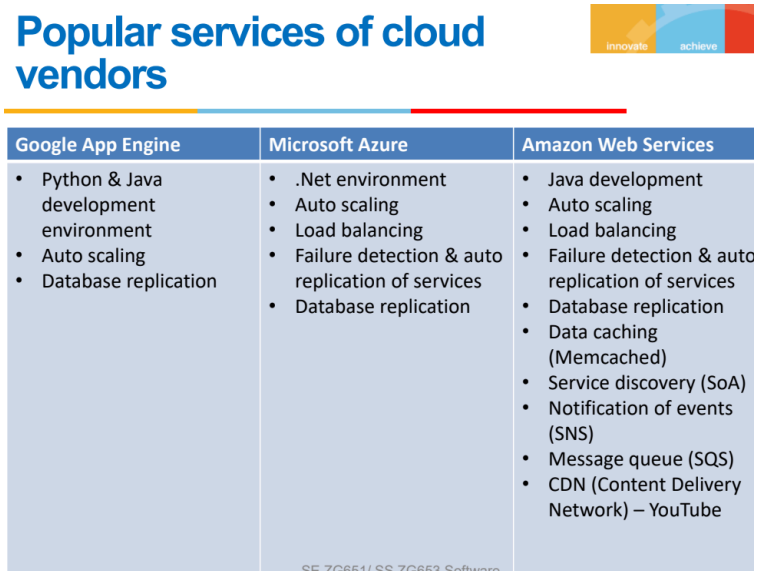
---

8. Cross-Platform and Cloud Integration

Cross-platform tools (e.g., Xamarin) allow developers to write a single codebase that can be deployed on multiple platforms (Android, iOS).

Cloud Services: Mobile apps often rely on cloud services like Google App Engine, AWS, or Microsoft Azure for scalability, load balancing, and data storage.

Diagram Placeholder: Mobile Software Platform



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9. Mobile Application Architecture Layers

Software Platform Layers:

1. **Applications**: End-user apps.
2. **Framework**: Core APIs for application development.

3. **Core Libraries**: Essential libraries for operations and data handling.
4. **Kernel & Device Drivers**: Interface between hardware and software.

Diagram Placeholder: Mobile Software & Hardware Platform

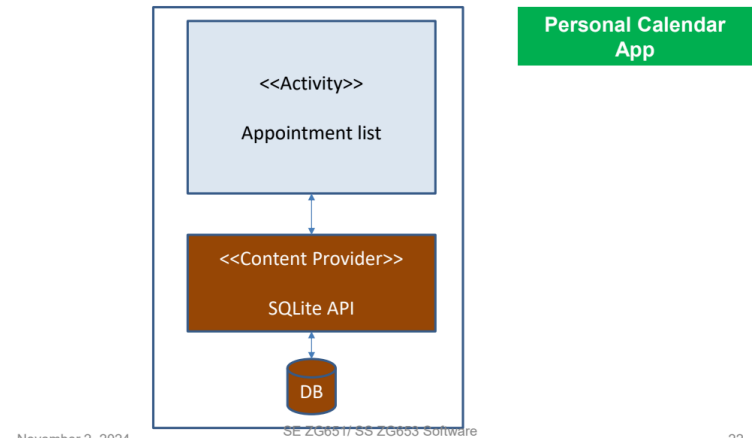
Mobile Application Architecture

Android application architecture

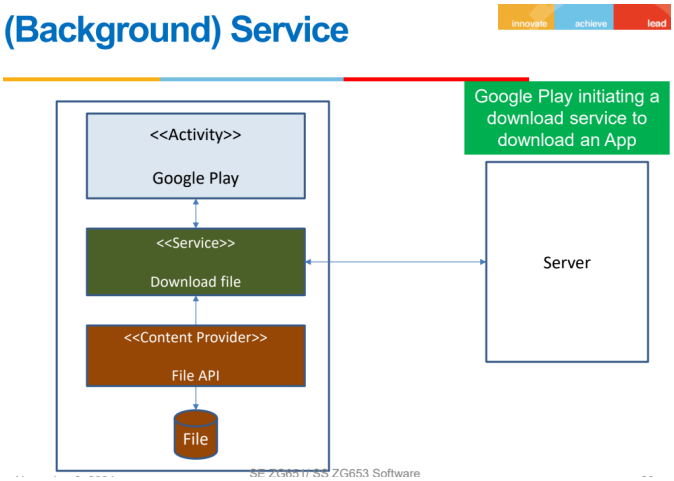
4 types of components

- Activity (UI)
- Service (background process) - ex. playing music, download
- Content provider (Storage) - ex. SQLite, files,
- Broadcast receiver (Acts on events received from OS and other apps) - Ex arrival of SMS

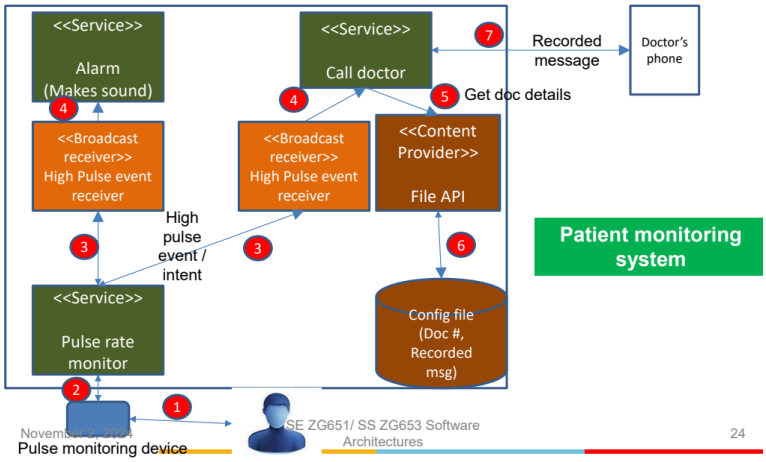
Activity & Content providers



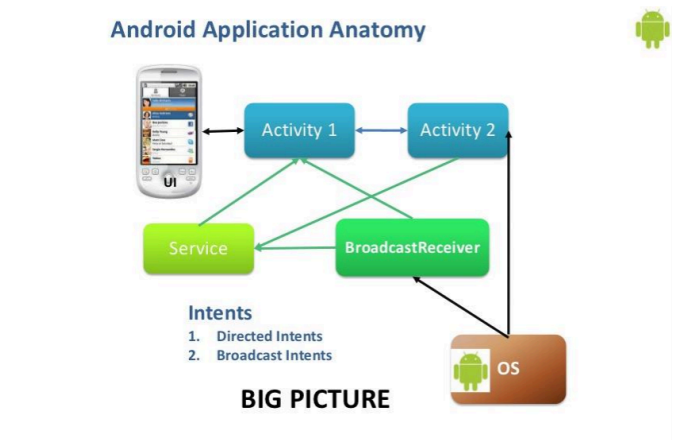
(Background) Service



Broadcast receiver (Event handlers)



Android application structure



Exercise

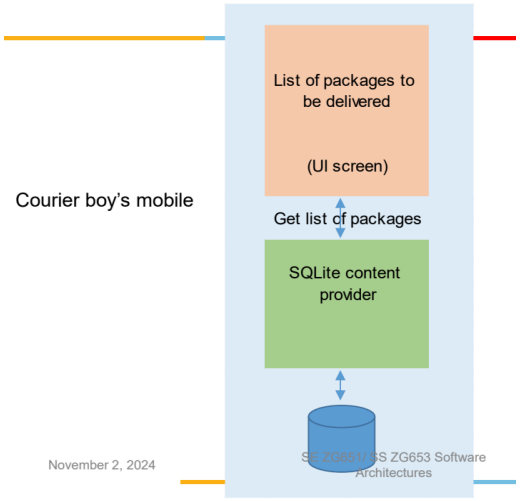
Consider a mobile app carried by the courier delivery boy.

The app should support the following functions:

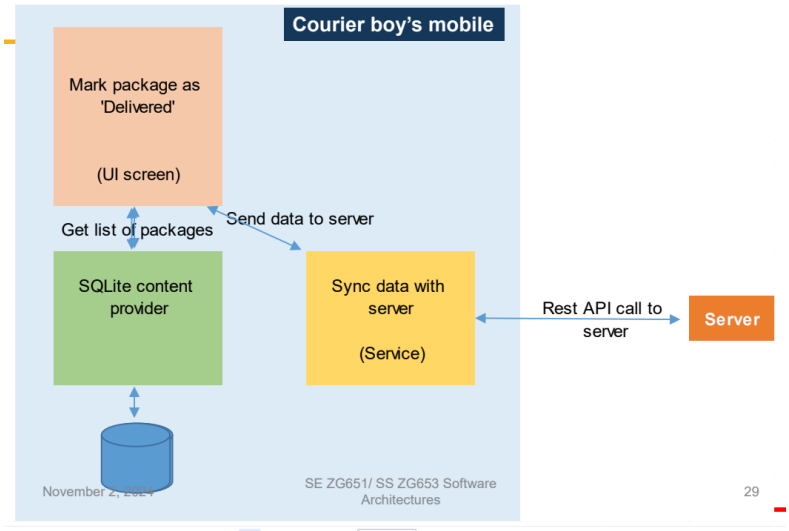
a) View courier packages to be delivered
b) Mark a package as delivered.
c) Upon this event, the app should send information to central server

Identify the components of a mobile app & its inter-connections and draw an appropriate software architecture diagram

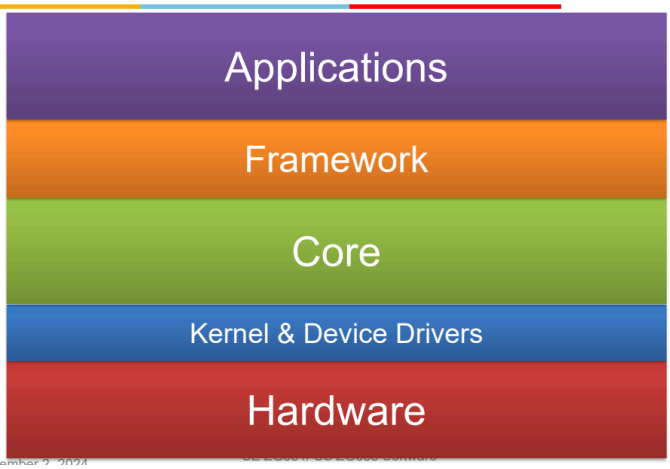
a) View courier packages to be delivered



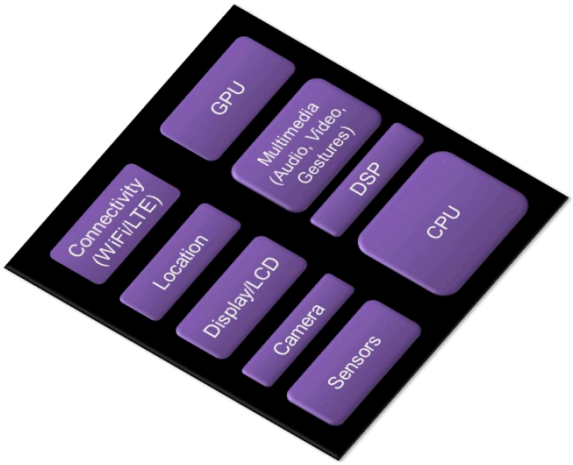
b) Mark a package as delivered. Upon this event, the app sends information to central server



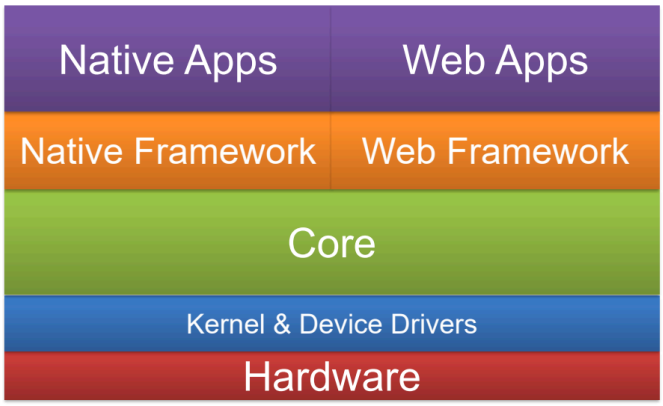
Mobile - Software Platform



Mobile – Hardware Platform



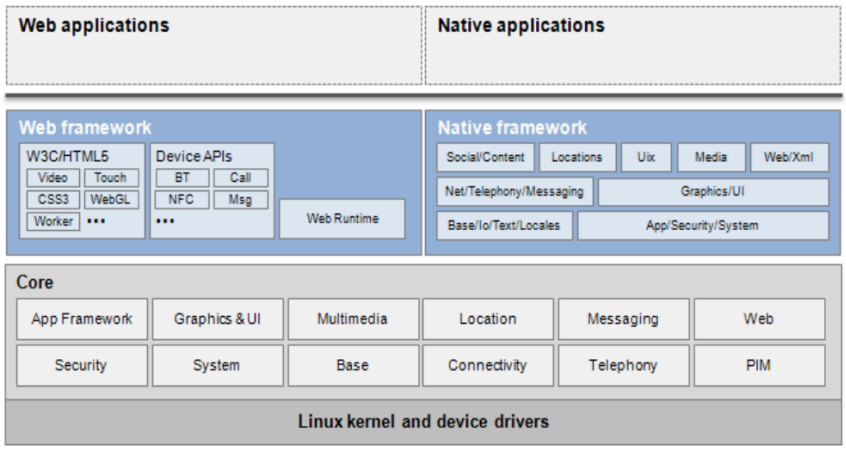
Typical Software Platform



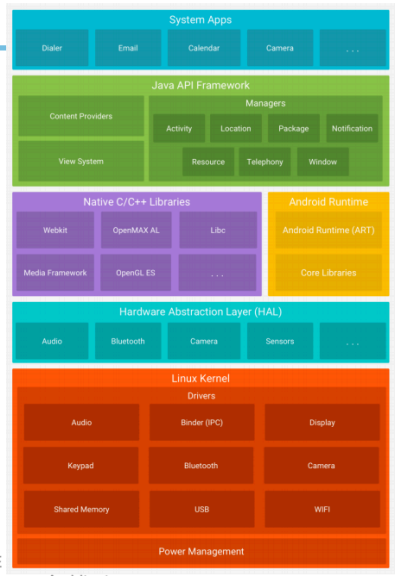
Typical Software Platforms

iOS	• Mobile Operating System by Apple • Multitasking • Supports iPhone, iPad and other devices
Windows	• Windows Phone OS by Microsoft • Multitasking • Features Metro (Modern UI, Tiled UI)
Android	• Google's Mobile OS based on Linux Kernel • Multitasking • Software Stack
Tizen	• An open source standards based platform • Based on Linux, part of the Linux Foundation • OS with Multiple profiles

Tizen Architecture

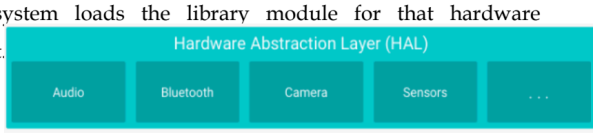


Android Stack



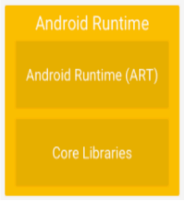
Hardware Abstraction Layer (HAL)

- HAL provides standard interfaces that expose device hardware capabilities to the higher-level Java API framework.
- The HAL consists of multiple library modules, each of which implements an interface for specific hardware components, such as the camera or BlueTooth module.
- When a framework API makes a call to access device hardware, the Android system loads the library module for that hardware component.



Android Runtime (ART).

- Each app runs in its own process and with its own instance of the Android Runtime (ART).
- ART is written to run multiple virtual machines on low-memory devices by executing DEX files, a bytecode format designed especially for Android that's optimized for minimal memory footprint.

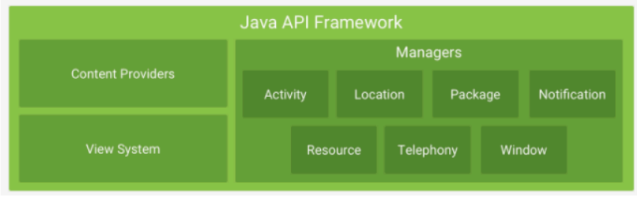


Android Runtime
- Include core libraries and the Dalvik VM
- Engine that powers the applications
- Forms the basis of the application framework
- Dalvik VM is a register-based VM to ensure the device can run multiple instances efficiently

Native C/C++ Libraries

- Many core Android system components and services, such as ART and HAL, are built from native code that requires native libraries written in C and C++.
- The Android platform provides Java framework APIs to expose the functionality of some of these native libraries to apps

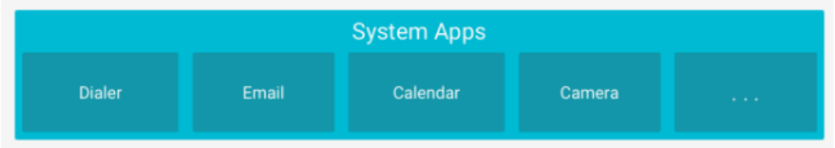
Java API Framework



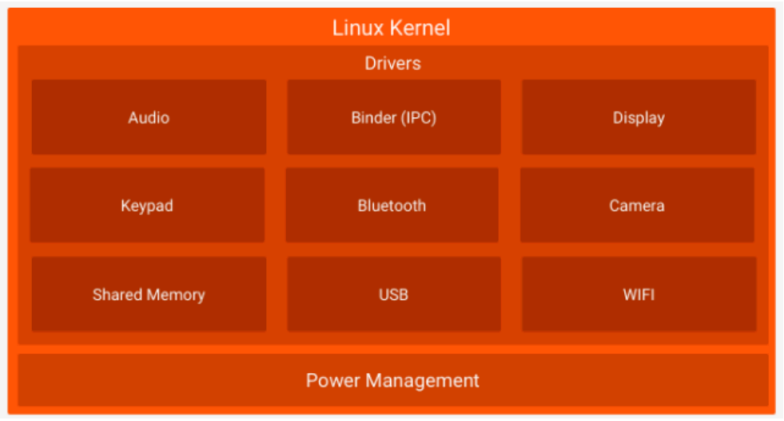
- The entire feature set of the Android OS is available to you through APIs written in the Java language.
- These APIs form the building blocks you need to create Android apps by simplifying the reuse of core, modular system components, and services,

System Apps

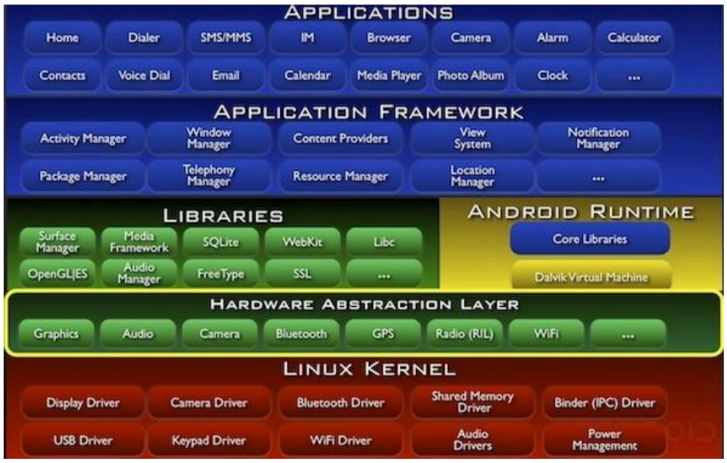
- Android comes with a set of core apps for email, SMS messaging, calendars, internet browsing, contacts, and more.
- Apps included with the platform have no special status among the apps the user chooses to install.
- So, a third-party app can become the user's default web browser, SMS messenger, or even the default keyboard (some exceptions apply, such as the system's Settings app).



Linux Kernel



Android Architecture



10. Cloud-Based System Challenges

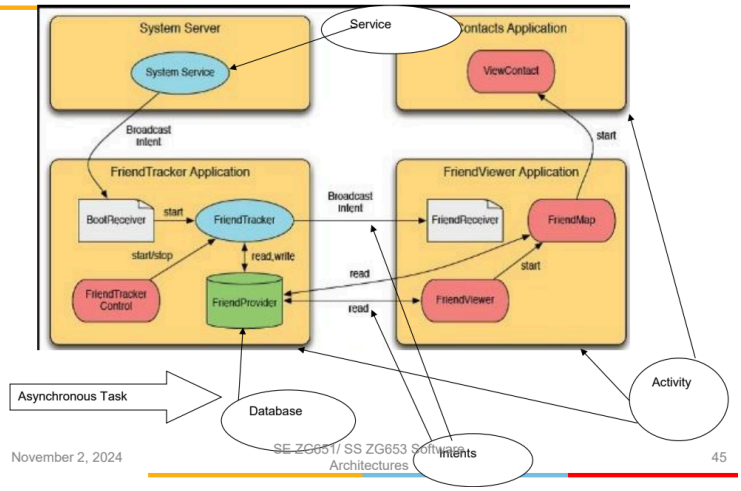
- **Availability**: Cloud providers ensure high uptime (e.g., 99.95%) but may not guarantee 100% availability.
- **Consistency vs. Availability**: Critical systems like e-commerce carts prioritize availability, while others, such as banking, prioritize consistency.

Diagram Placeholder: Issues in Cloud-Based Systems

Popular services of cloud vendors

Google App Engine	Microsoft Azure	Amazon Web Services
• Python & Java development environment • Auto scaling • Database replication	• .Net environment • Auto scaling • Load balancing • Failure detection & auto replication of services • Database replication	• Java development • Auto scaling • Load balancing • Failure detection & auto replication of services • Database replication • Data caching (Memcached) • Service discovery (SoA) • Notification of events (SNS) • Message queue (SQS) • CDN (Content Delivery Network) – YouTube

Mobile app: Example



Different ways to deploy applications on the cloud

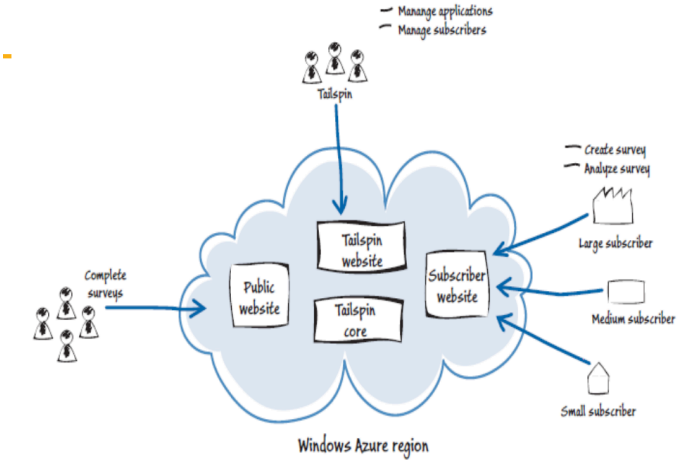
Scenario

A start-up company – Tailspin - is developing a **customer survey & analysis** application. This software will be deployed on the Cloud and offered to clients as a SaaS.

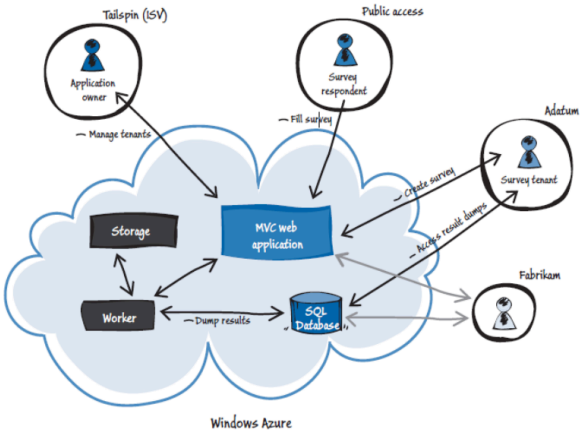
- The clients (subscriber of the application) can create and launch a survey.
- After this the survey participants will access the application and answer the survey questions.
- After the data has been gathered the application will perform analysis and present the results to the client organization

What options exist for Tailspin to deploy the application on the cloud?

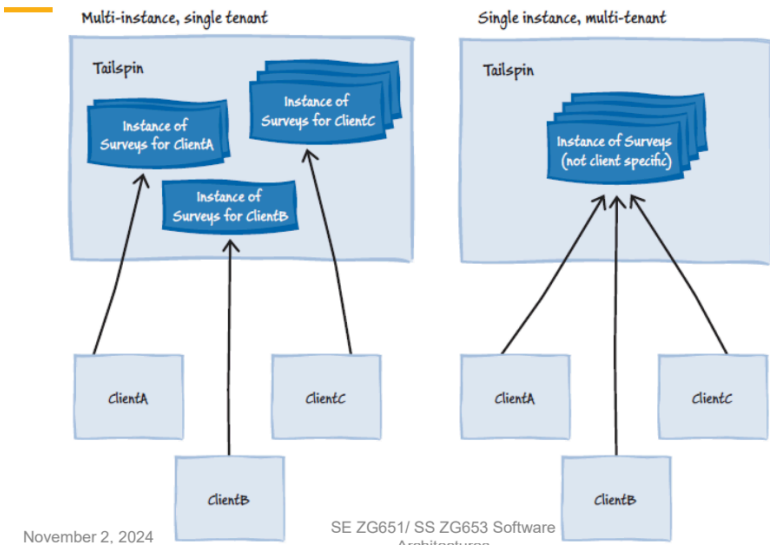
Context diagram



Multi-tenant application Architecture – High level



Architecture Options – High level

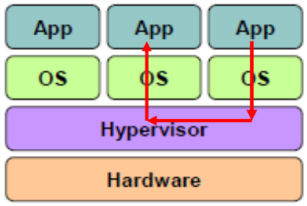


Issues in Cloud based systems

- Security issue due to multi-tenancy
  - Poor design leading to inadvertent sharing of information
  - Virtual machine 'Escape'

Other fields of the table					OU_ID
					Org1
					Org1
					Org1
					Org2
					Org2

Same table contains data of different organizations



Virtual machine 'Escape'

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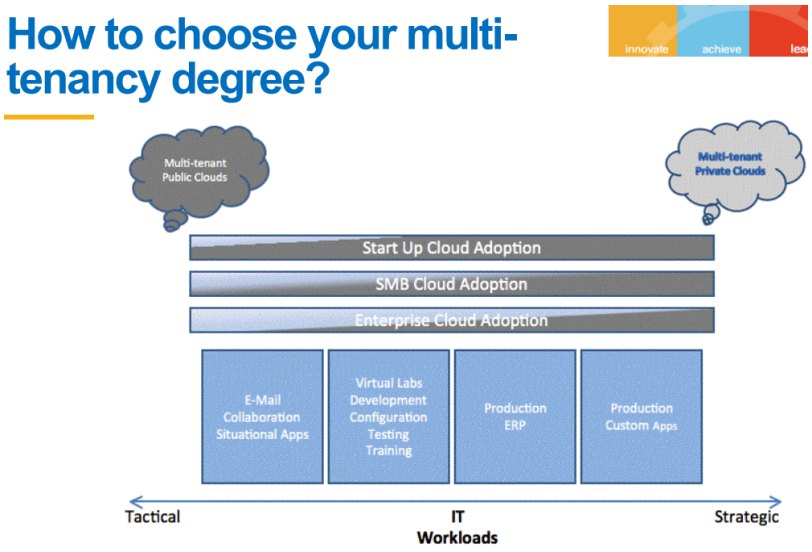
11. Multi-Tenancy and Cloud-Native Applications

Multi-Tenancy: Determines resource sharing in cloud applications. Higher multi-tenancy is suited for general-purpose applications like email, while lower multi-tenancy is better for data-sensitive applications.

Cloud-Native: Embraces modern development practices (PaaS, microservices, CI/CD, containers).

Diagram Placeholder: Multi-Tenant Application Architecture



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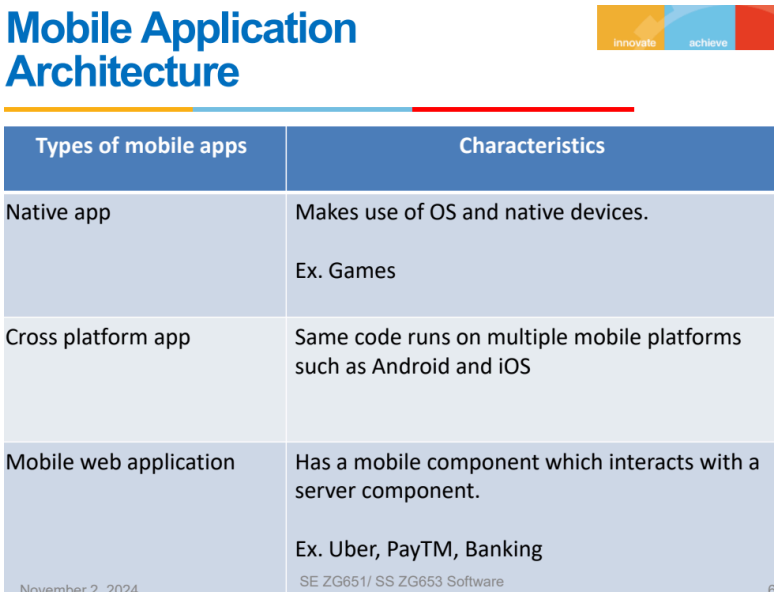
12. Android Software and Hardware Stack

- **HAL (Hardware Abstraction Layer)**: Interfaces hardware with higher-level APIs.
- **Android Runtime (ART)**: Each app runs in its own process, optimized for low-memory devices.
- **Native Libraries**: Core system components and services.
- **Java API Framework**: Building blocks for creating Android apps.

Diagram Placeholder: Android Stack and Architecture



Tools and technology for mobile app development

Development Approach	Native	Cross-Mobile Platforms	Mobile Web
Definition and Tools	Build the app using native frameworks: - iPhone SDK - Android SDK - Windows Phone SDK	Build once, deploy on multiple platforms as native apps: - RhoMobile - Titanium Appcelerator - PhoneGap - Worklight - Etc.	Build using web technologies: - HTML5 - Sencha - JQuery Mobile - Etc.
Underlying Technology	- iPhone: Objective C - Android: Java - Windows Phone: .NET	- RhoMobile: Ruby on Rails - Appcelerator: Javascript, HTML - PhoneGap: Javascript, HTML - Worklight: Javascript, HTML	- Javascript, HTML

---

13. Example of Cloud Service Providers and Their Offerings

- **Amazon Web Services (AWS)**: Offers features like auto-scaling, load balancing, and data caching.
- **Google App Engine**: Provides Java and Python environments with auto-scaling.
- **Microsoft Azure**: .NET environment with failure detection, load balancing, and database replication.

---

14. Exercises and Review Questions

1. **Mobile App Exercise**: List components for a courier delivery app, with features like viewing deliveries, marking deliveries, and syncing with the server.
2. **Questions**:
    - What is a cross-platform app?
    - How is data consistency maintained with poor connectivity?
    - What is a Broadcast Receiver in Android?

---

15. Scenarios for Multi-Tenancy in Cloud Applications

- **Example**:
    - App 1: Multi-tenant web and data tiers, single-tenant application tier (high availability).

- App 2: Single-tenant web and data tiers, multi-tenant application tier (data sensitivity).

---

16. Conclusion

This document outlines the architecture of mobile applications, covering types of apps, UI/UX design principles, Android architecture, cloud integration, and challenges in cloud-based systems.

NoSQL Databases Overview

Introduction

Traditional relational databases (SQL databases) are ideal for transaction management but aren't suitable for all types of applications. Many web applications, IoT solutions, and systems needing high data processing speed but no transaction management turn to **NoSQL databases** as an alternative.

Characteristics of NoSQL Databases

NoSQL databases offer several benefits, including:

- **Scalability** (Sharding)
- **Speed** (In-Memory)
- **High Availability** (Replication)
- **Flexibility** to handle semi-structured and unstructured data

However, NoSQL databases often lack traditional SQL features like:

- **ACID Transactions** (Atomicity, Consistency, Isolation, Durability)
- **Join operations**

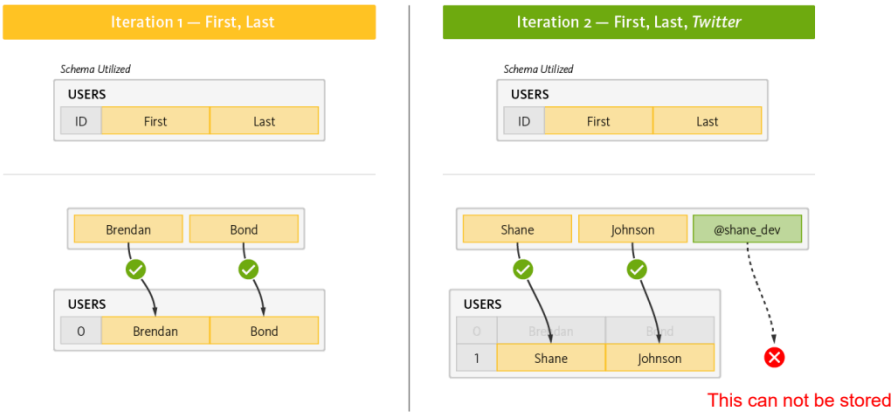
Real-World Examples of NoSQL Use

1. **Tesco**: Manages millions of products and promotions.
2. **Ryanair**: Supports its mobile app for over 3 million users.
3. **Marriott**: Uses NoSQL for a $38 billion reservation system.
4. **Gannett (USA Today)**: Uses NoSQL for a custom content management system.
5. **GE**: Employs NoSQL for the Predix platform in the Industrial Internet.

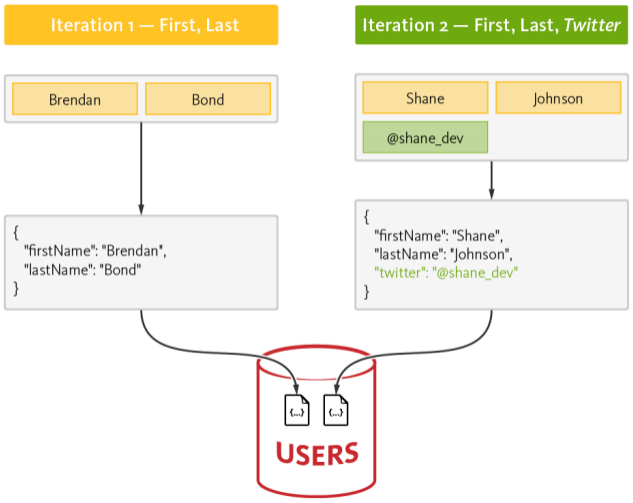
Benefits of NoSQL Databases

Diagram Placeholder: NoSQL - Flexibility

In RDBMS, if we want to add a new column, we need to change the schema



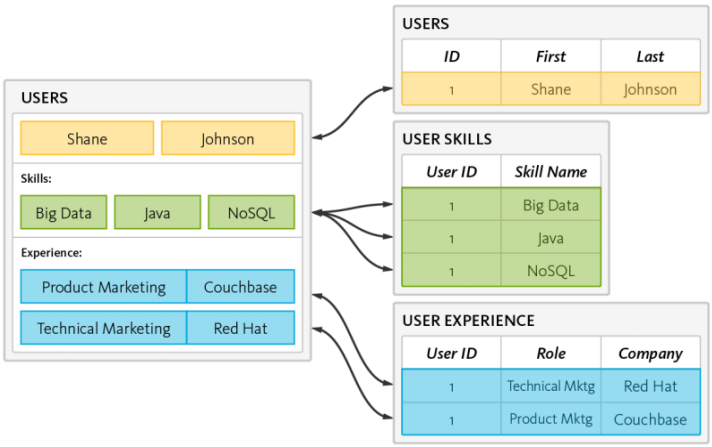
In NoSQL DB, we can easily add new columns.

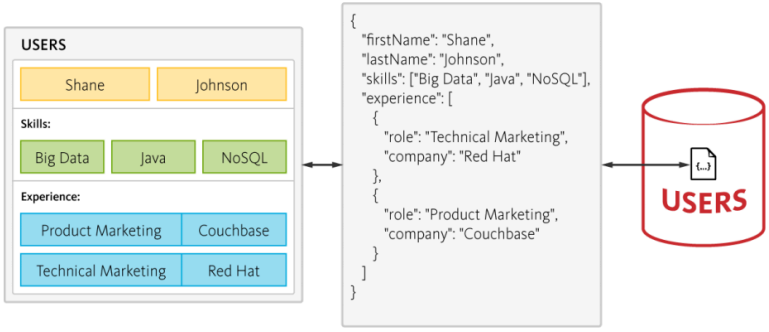


Flexibility

In relational databases, modifying the schema (e.g., adding a new column) requires changing the entire structure. In contrast, NoSQL databases easily accommodate new fields without modifying the overall schema.

Diagram Placeholder: NoSQL - Simplicity

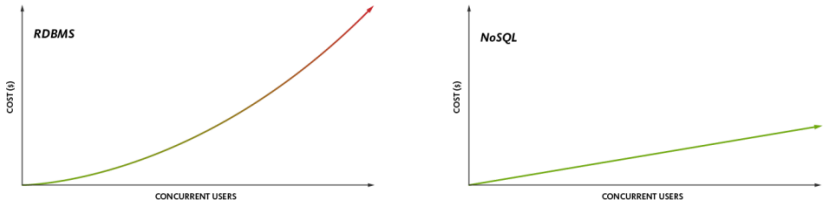




Simplicity

NoSQL offers straightforward structures, making it simpler to store and retrieve data without complex query operations.

Diagram Placeholder: NoSQL - Cost-Effectiveness



Cost: Memory, CPU, storage

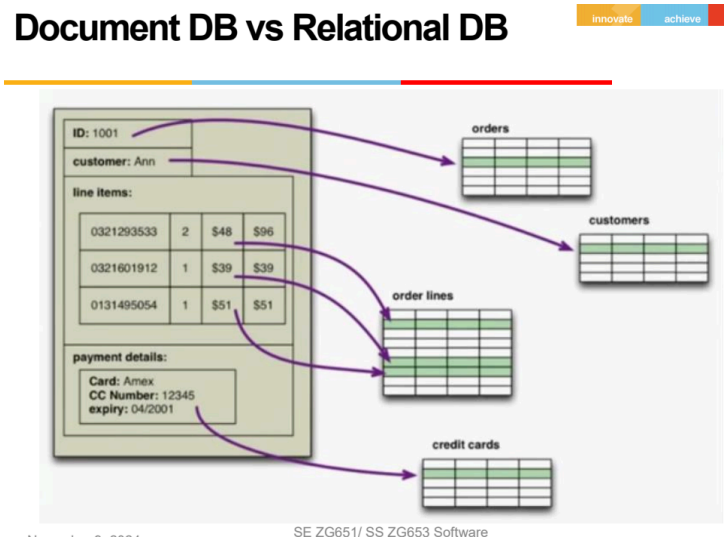
Cost-Effectiveness

NoSQL solutions typically have lower hardware and operational costs, especially for high-volume data applications.

Types of NoSQL Databases

1. **Document Databases**
   - **Structure**: Stores data in document formats (e.g., JSON, BSON).
   - **Examples**: MongoDB, CouchDB.
   - **Use Cases**: Content management, e-commerce.
2. *Diagram Placeholder: Example of a Document Record*

Example of one record



3. **Key-Value Databases**
    - **Structure**: Simple key-value pairs; efficient for fast retrieval.
    - **Examples**: Redis, Amazon DynamoDB.
    - **Use Cases**: Caching, session management.
4. *Diagram Placeholder: Example of a Key-Value Database*

Phone Directory

Key	Value
Bob	(123) 456-7890
Jane	(234) 567-8901
Tara	(345) 678-9012
Tiara	(456) 789-0123

Example of key value database

Stock Trading

This example uses a list as the value.

The list contains the stock ticker, whether its a "buy" or "sell" order, the number of shares, and the price.

Key	Value
123456789	APPL, Buy, 100, 84.47
234567890	CERN, Sell, 50, 52.78
345678901	JAZZ, Buy, 235, 145.06
456789012	AVGO, Buy, 300, 124.50

5. **Column-Oriented Databases**
    - **Structure**: Data stored in columns, suitable for analytical queries.
    - **Example**: Calculate average electricity usage in a specific region.
    - **Use Cases**: Data analysis, summarization.
6. *Diagram Placeholder: Column-Oriented Database Example*

Column oriented database

innovate achieve

This is useful for data analysis scenarios

Example: Calculate the average usage of electricity in 2018 in East Bangalore region

Traditional way: Read all the billing records of 2018

Cust id, Name, Addrs, Region, Month, Year, Usage, Amt,

Record 1: 001, John Mancha, Addr 1, East, Jan, 2018, 100, 600
Record 2: 002, Vivek Kulkarni, Addr 2, East, Jan, 2018, 90, 540
Record 3: 003, Shanti Sharma, Addr 3, West, Jan, 2018, 110, 660

Instead if we store the data as follows:

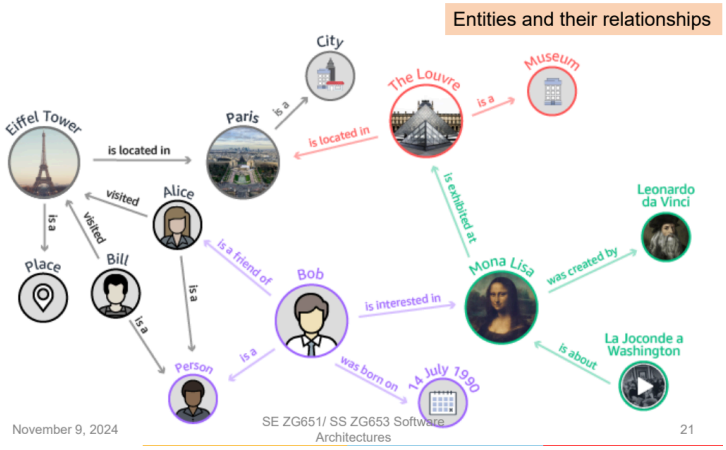
Record 1: 001, John Mancha, Addr 1, East // Customer details
Record 2: 002, Vivek Kulkarni, Addr 2, East

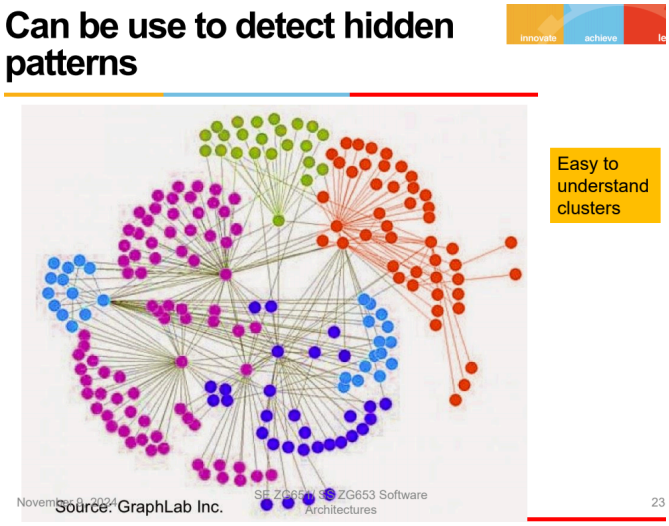
Record A: Jan, 2018, 100, 90, 110, … // Usage – in customer order
Record B: Feb, 2018, 110, 92, 115, …

Only one record 'Record A' is needed to calculate average usage in Jan 2018

Good for summarization

7. **Graph Databases**
   - **Structure**: Stores data as nodes (entities) and edges (relationships).
   - **Examples**: Neo4J, OrientDB.
   - **Use Cases**: Fraud detection, social networks.
8. *Diagram Placeholder: Graph Database with Entities and Relationships*



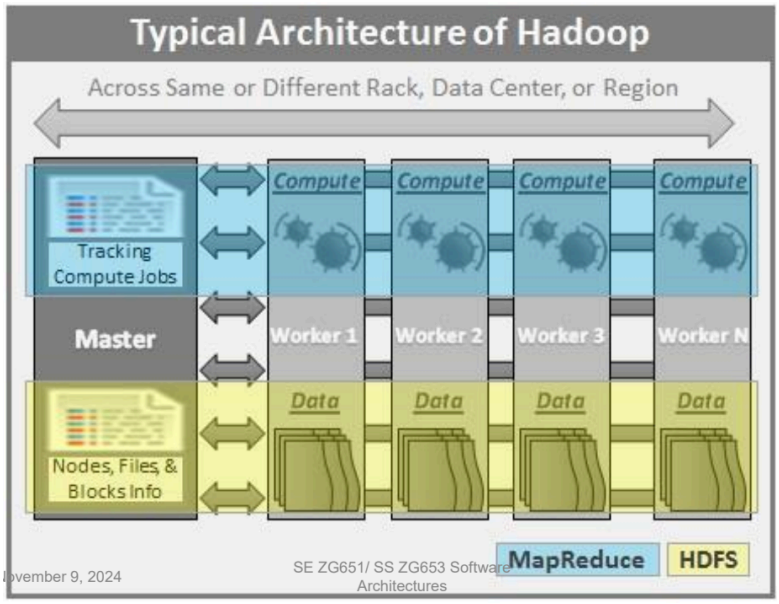


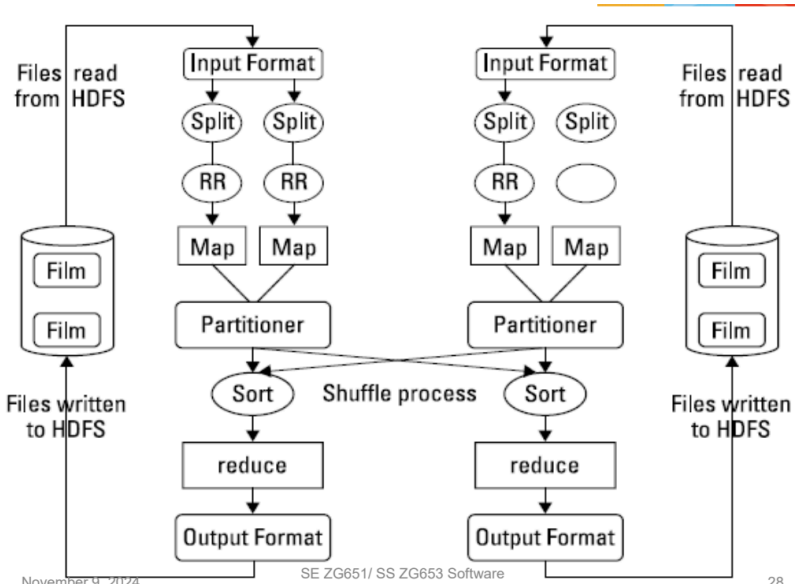
In-Memory Databases (IMDB)

An **in-memory database** relies on main memory for data storage, offering extremely fast response times. It's useful for applications requiring high-speed data retrieval, such as telecommunications and mobile advertising networks.

Examples:

- SAP HANA
- IBM DB2 BLU
- Oracle



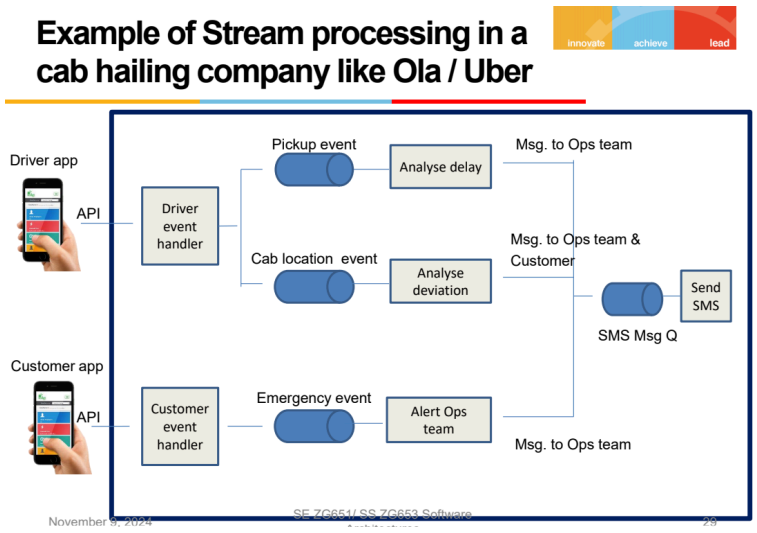


Stream Processing in NoSQL

NoSQL databases, coupled with real-time data processing tools, support applications needing rapid event handling.

Example: Cab Hailing Service (e.g., Uber or Ola)

Diagram Placeholder: Stream Processing Architecture in Cab Hailing



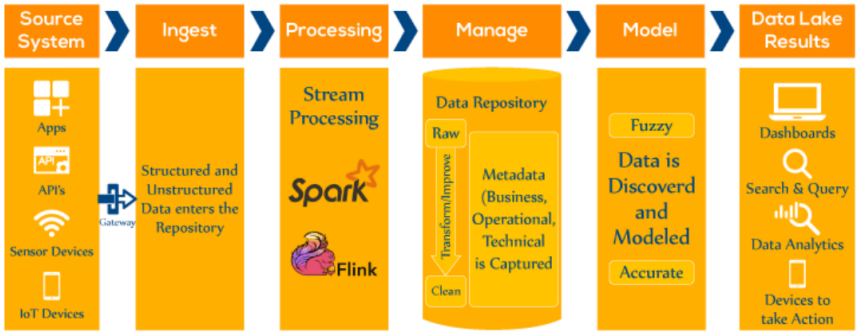
- **Driver Events**: Process location, emergency events.
- **Customer Notifications**: Send alerts based on driver's location or delays.
- **Operations Alerts**: Notify teams of issues or emergencies.

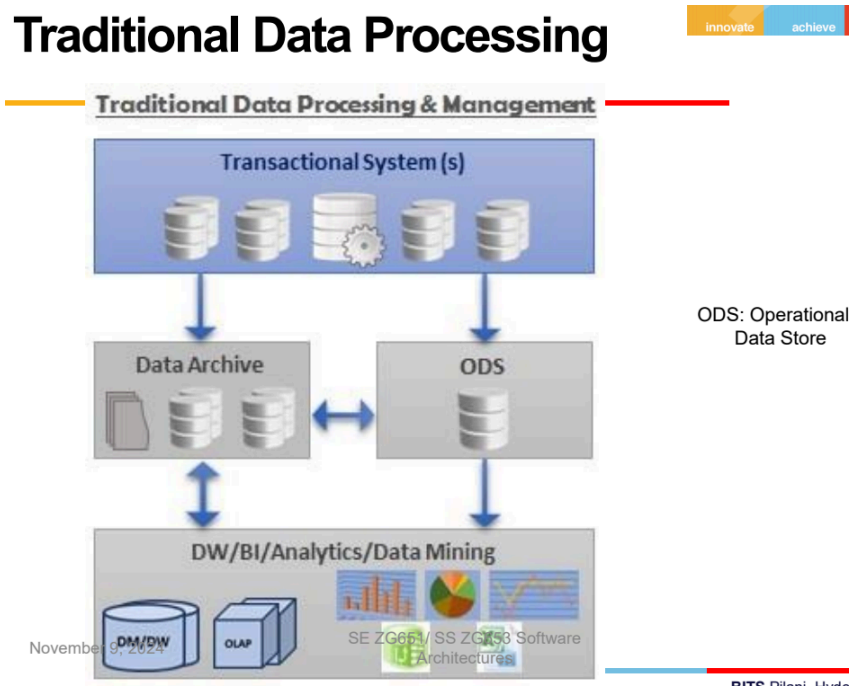
Use Cases for Stream Processing

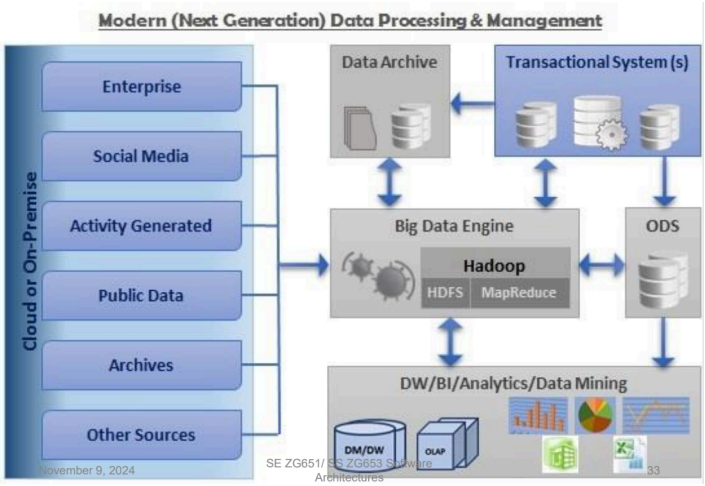
Stream processing in NoSQL supports various real-time applications:

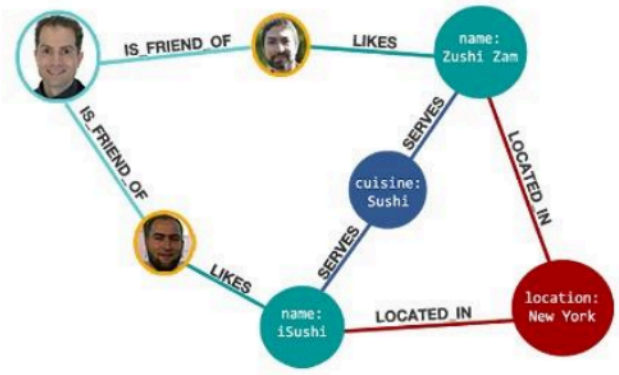
- **Algorithmic Trading**: High-speed stock trading.
- **Smart Patient Care**: Continuous monitoring of patient health.
- **Supply Chain Optimization**: Real-time updates on logistics.
- **Fraud Detection**: Instantaneous detection of unusual transactions.
- **Traffic Monitoring**: Real-time traffic and geo-fencing alerts.

Diagram Placeholder: Real-Time Streaming Use Cases









Graph database

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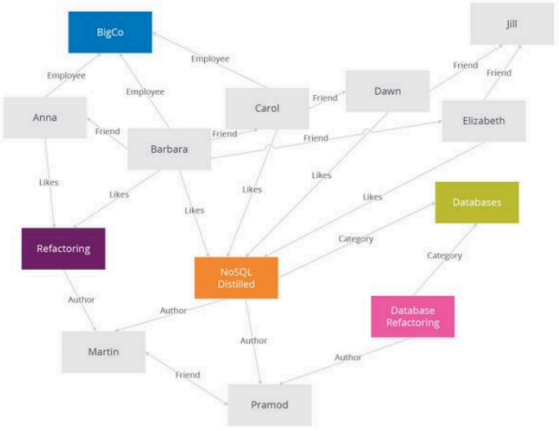
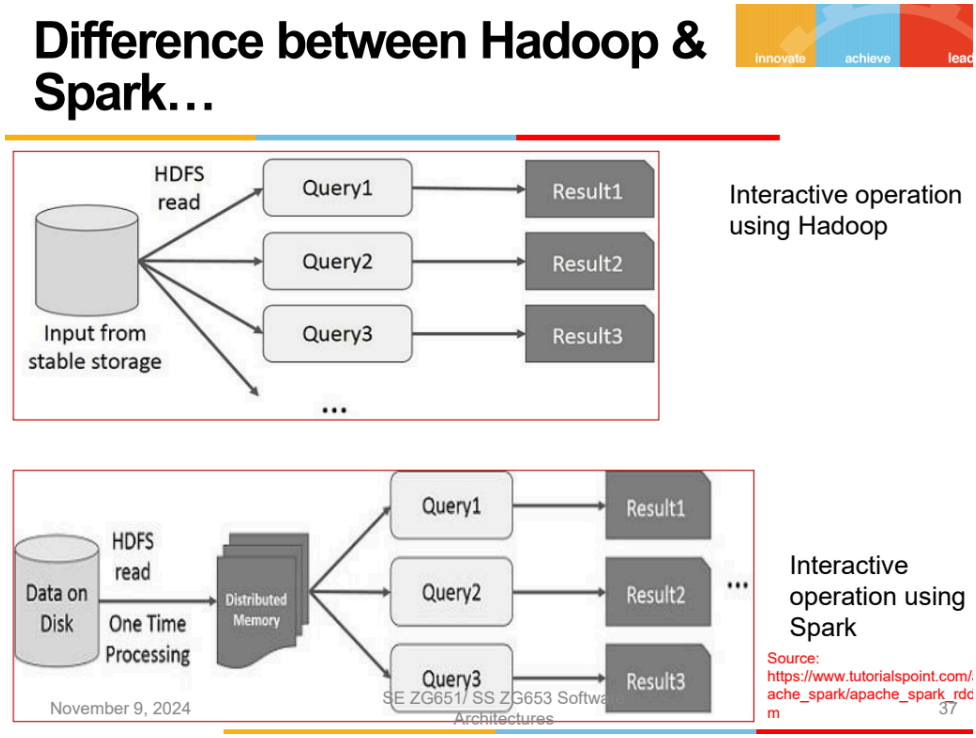
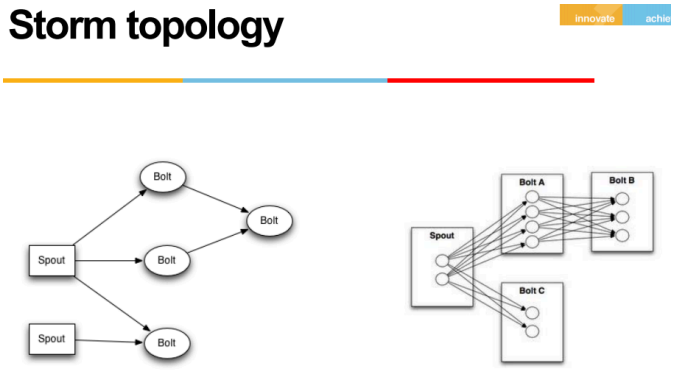


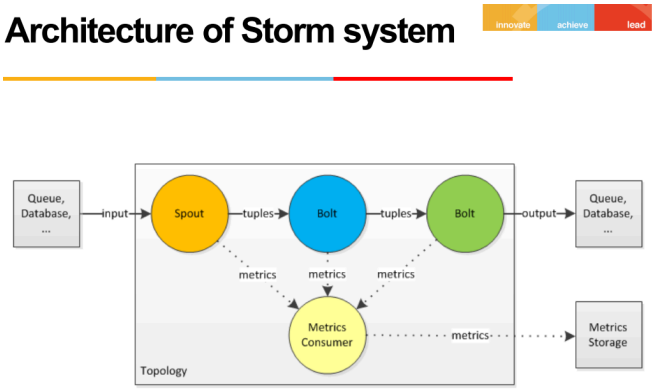


Real-Time Analytics with Tools like Storm and Kafka

For applications requiring real-time processing, tools like Apache Storm and Kafka are commonly used.

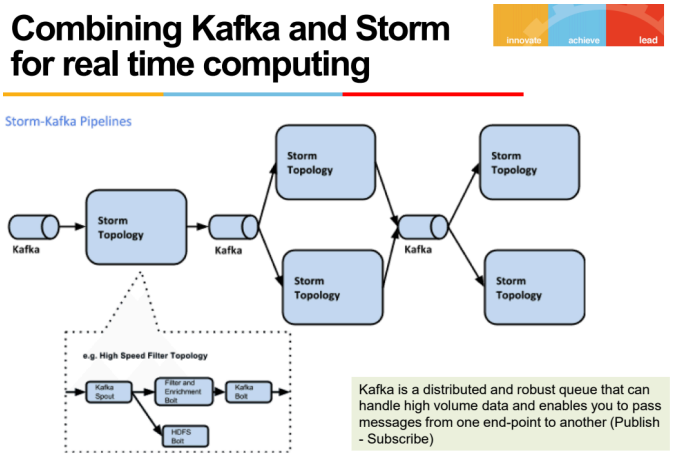
- **Storm**: Processes unbounded data streams in real time. It's scalable, fault-tolerant, and widely used by companies like Twitter for analytics.
  Diagram Placeholder: Architecture of Storm System





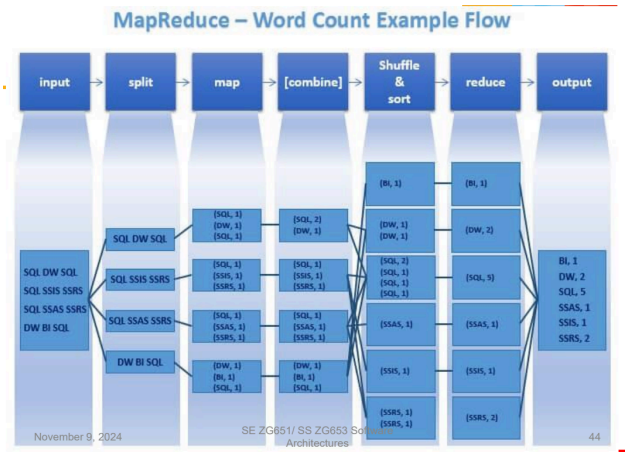
- **Kafka**: A robust, distributed messaging system. Kafka works as a publish-subscribe model to relay high-volume data between systems.

Diagram Placeholder: Combining Kafka and Storm for Real-Time Computing



Example Workflow

1. **Event Source** → Kafka → Storm → NoSQL → Analytics



Big Data and Analytics

1. Big Data

Definition: Big Data refers to massive and complex data sets that traditional database management systems cannot efficiently handle. This data is generated from various sources, such as social media, eCommerce, IoT, and more.

2. History of Big Data

The growth of Big Data is attributed to:

- **Proliferation of the Internet**
- **Rise of social media**
- **Increase in eCommerce** activities

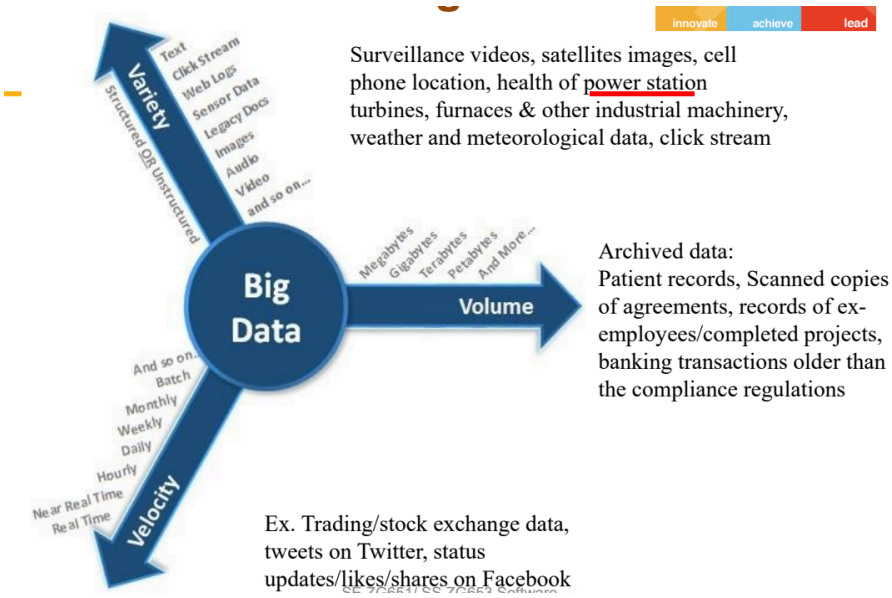
---

3. Big Data Characteristics

Big Data is characterized by:

- **Volume**: Large amounts of data.
- **Velocity**: Rapid data generation and processing.
- **Variety**: Diverse data types, including structured and unstructured data.

Diagram Placeholder: Characteristics of Big Data



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4. Applications of Big Data

Examples:

- **Healthcare**: Recommending cancer treatment based on similar patient cases.
- **Weather Forecasting**: Alerts for farmers and fishermen.
- **Fraud Detection**: Monitoring transactions for suspicious patterns.

Big Data Technologies

1. Google BigTable

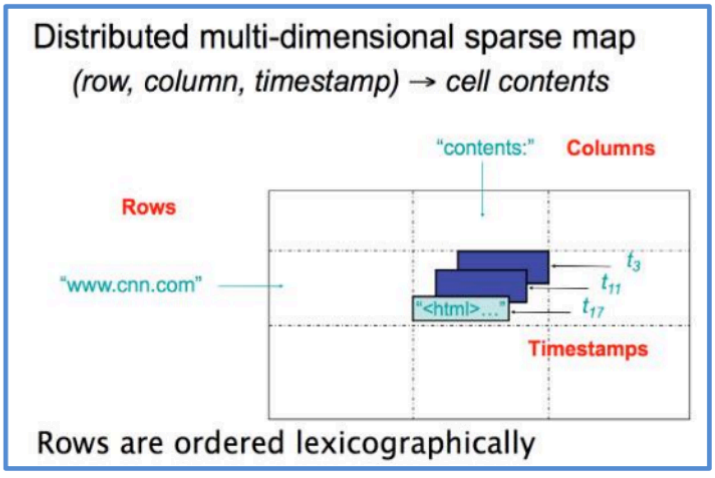
Google BigTable is a distributed storage system developed by Google to handle vast amounts of structured data. BigTable is optimized for scalability, allowing fast access across thousands of servers.

Key Features:

- **Versioning of data**
- **Data compression**
- **Distributed storage across servers**
- **Fault tolerance and fast access**
- **Dynamic addition of servers and load balancing**

Diagram Placeholder: Google BigTable

So Google invented a data storage structure called Big Table



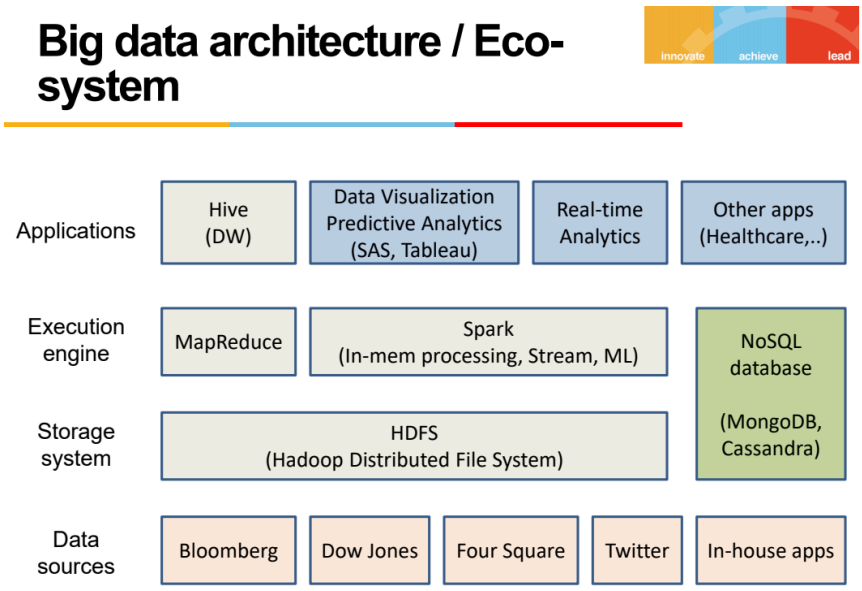
Uses of BigTable:

- Google services like **Google Maps** and **Google Analytics** rely on BigTable for storing and managing data.

Data Structure: BigTable stores data in a **wide table format** with various attributes, such as:

- **Content of the webpage**
- **Anchor text (text of hyperlinks)**
- **Websites referencing the page**
- **Timestamp for stored data**

Diagram Placeholder: Example of BigTable Structure



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2. Hadoop, HDFS, and MapReduce

Hadoop: An open-source framework from Apache for distributed processing of large datasets.

- **HDFS (Hadoop Distributed File System)**: Distributes data across nodes, providing high availability and fault tolerance.
- **MapReduce**: A programming model for processing large datasets by distributing the workload across multiple servers.

Diagram Placeholder: Big Data Architecture

Hadoop - HDFS

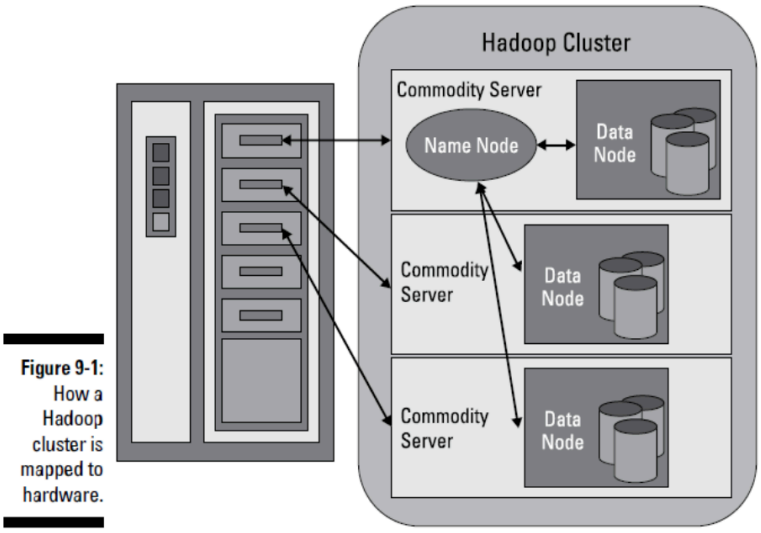


Figure 9-1: How a Hadoop cluster is mapped to hardware.

Ref: Big data for Dummies

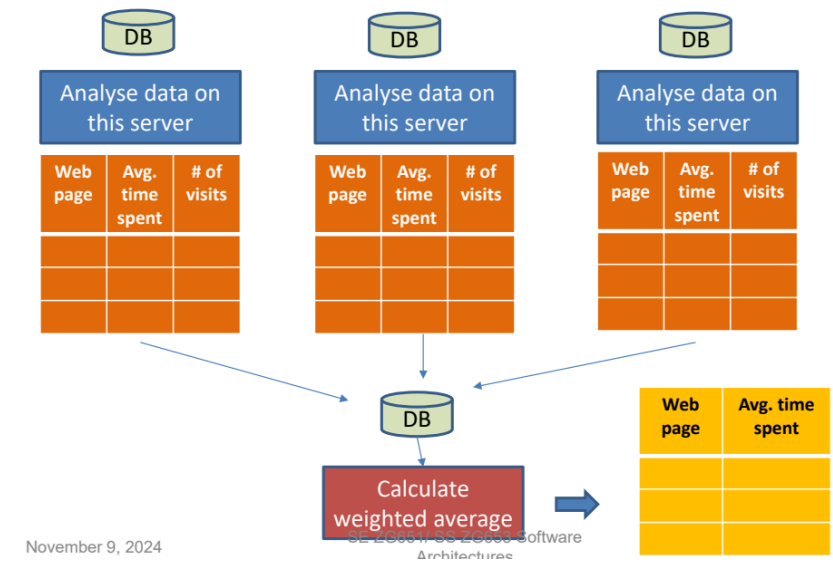
HDFS Features:

- Data split into blocks, distributed across nodes, and replicated for reliability.

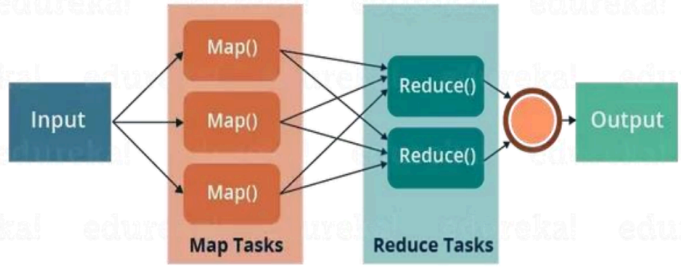
MapReduce Example: Calculates average time spent by users on each webpage by processing data in parallel.

Diagram Placeholder: MapReduce Example

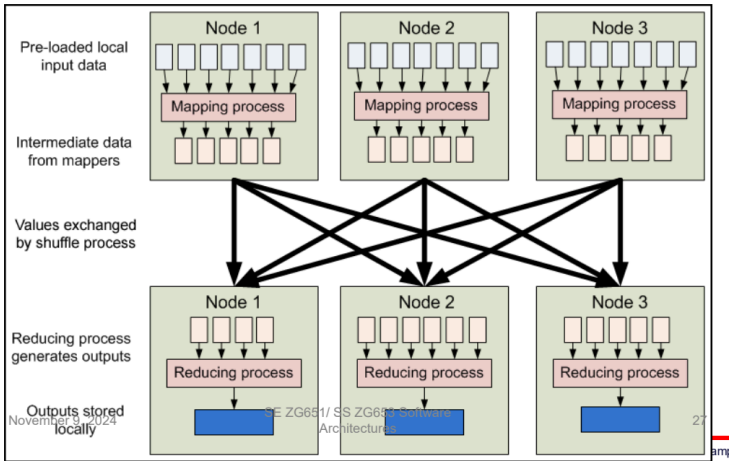
Map-Reduce pattern: Example



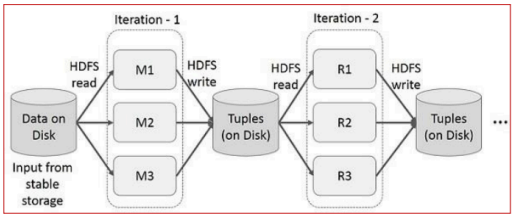
Map Reduce pattern



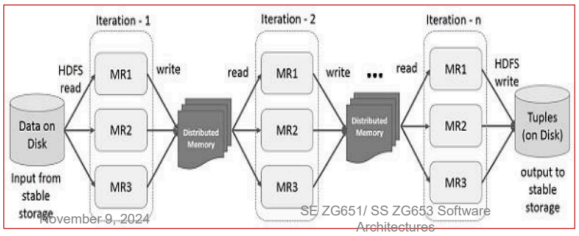
Example: Determine the average duration spent by users on different web pages



Difference between Hadoop & Spark



Iterative operation using Hadoop using disk



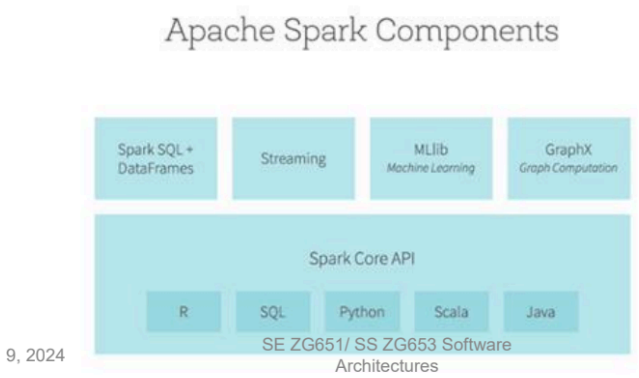
Iterative operation using Spark using memory

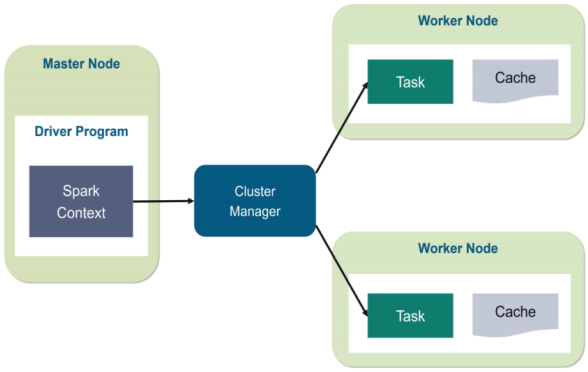
Source: https://www.tutorialspoint.com/apache_spark/apache_spark_rdd.htm

3. Apache Spark

Apache Spark: An open-source distributed computing engine for big data processing, enabling in-memory data processing, which is faster than disk-based processing in Hadoop.

Diagram Placeholder: Spark Architecture





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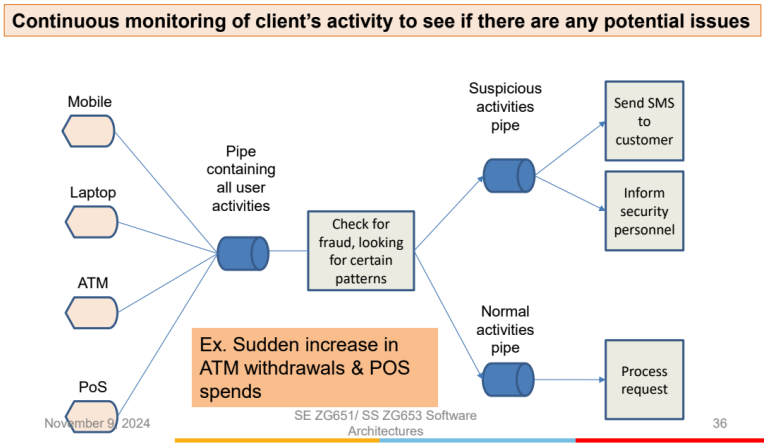
4. Real-Time Analytics

Real-Time Analytics allows users to gain insights from data as it arrives, enabling immediate actions.

Examples:

- **Real-Time Advertising**: Dynamic ad placements based on user behavior.
- **Fraud Detection**: Identifies suspicious activities in banking transactions.
- **Sensor Data Processing**: Predictive maintenance in industrial machines.

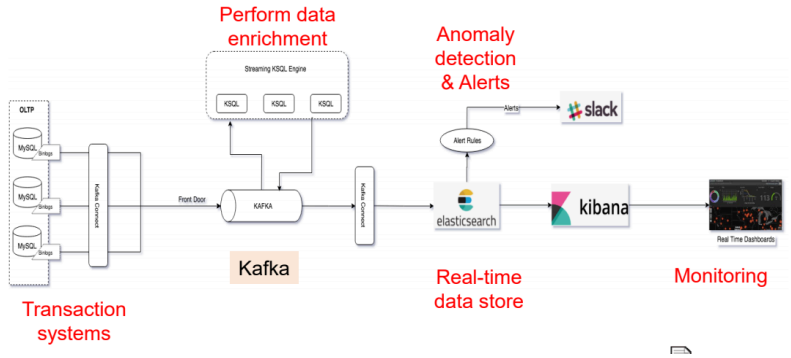
Diagram Placeholder: Real-Time Analytics - Fraud Detection



Case Study: Dream11

- Objectives: Monitor real-time contest participation, payment status, and detect unusual traffic.

Diagram Placeholder: Real-Time Analytics at Dream11



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4. In-Memory Databases

In-Memory Databases: Store data in the main memory (RAM) instead of on disk, offering faster data access for applications that require real-time processing.

Examples:

- **SAP HANA**
- **IBM DB2 BLU**
- **Oracle In-Memory Database**

---

5. NoSQL Databases

NoSQL databases are designed for flexibility and scalability. Unlike SQL databases, they often lack support for transactions but are optimized for horizontal scaling.

Types of NoSQL Databases

1. **Document Databases**: Store data in document format (e.g., JSON), ideal for flexible and semi-structured data. Example: MongoDB.
2. **Key-Value Databases**: Store data as simple key-value pairs, which is ideal for caching. Example: Redis.
3. **Column-Oriented Databases**: Store data in columns, optimized for analytical tasks. Example: HBase.
4. **Graph Databases**: Represent data as nodes and edges, ideal for applications with interconnected data, such as social networks and fraud detection. Example: Neo4J.

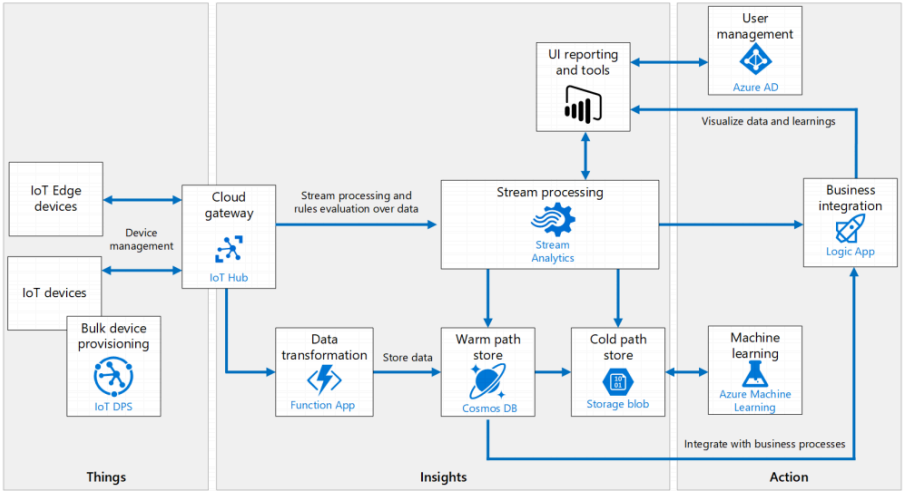
Internet of Things (IoT)

IoT: A network of interconnected devices that collect and share data with minimal human intervention, used in various applications.

Examples:

- **Smart Agriculture**: Soil moisture sensors control irrigation.
- **Supply Chain**: Real-time tracking of goods.

Diagram Placeholder: Azure IoT Reference Architecture



Examples of Big Data Use Cases

1. **Retail**:
    - **Fraud Detection**: Identifies suspicious transactions using patterns.
    - **Customer Targeting**: Customizes offers based on demographic and behavioral data.
2. **Banking and Financial Services**:
    - **Credit Risk**: Assess customer creditworthiness.
    - **Sentiment Analysis**: Analyzes customer feedback from social media.
3. **Industrial Equipment Monitoring**:
    - Monitors equipment for early fault detection.
4. **Weather Forecasting**:
    - Processes satellite data to predict weather patterns, including alerts for cyclones and heavy rainfall.

Summary

This document provides an overview of Big Data, Hadoop, Real-Time Analytics, In-Memory and NoSQL Databases, Google BigTable, and IoT applications. It introduces the characteristics, applications, and technologies enabling Big Data processing, and highlights various use cases across industries.

Introduction to Machine Learning (ML)

Contents

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1. Introduction

Machine Learning (ML) is the ability of computers to detect patterns and perform tasks that traditionally required human intelligence.

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2. What is Machine Learning (ML)?

Machine Learning enables systems to learn from data, identify patterns, and make decisions with minimal human intervention.

---

3. Applications of ML

Examples:

1. **Healthcare**: Predicts treatments based on patient demographics, genetics, and lifestyle.
2. **Industry**: Enables proactive maintenance by monitoring equipment health parameters.
3. **Finance**: Detects credit card fraud by analyzing spending patterns.

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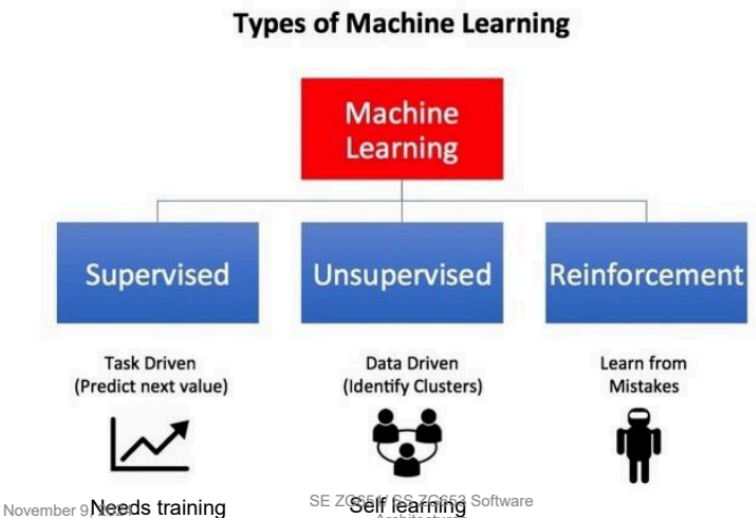
4. Different Types of Machine Learning

Diagram Placeholder: Major Types of Machine Learning



1. Supervised Learning

- **Definition**: The model learns from a labeled dataset (where outcomes are already known).
- **Example**: Predicting house prices based on features like size and location.

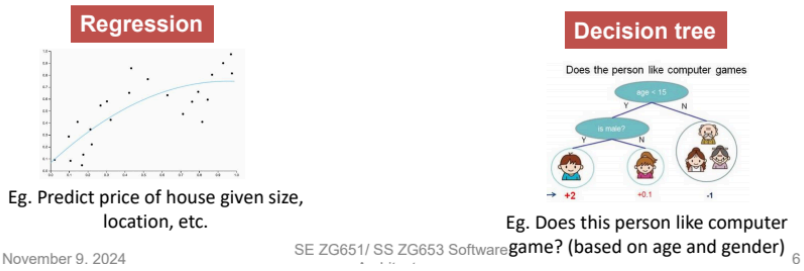
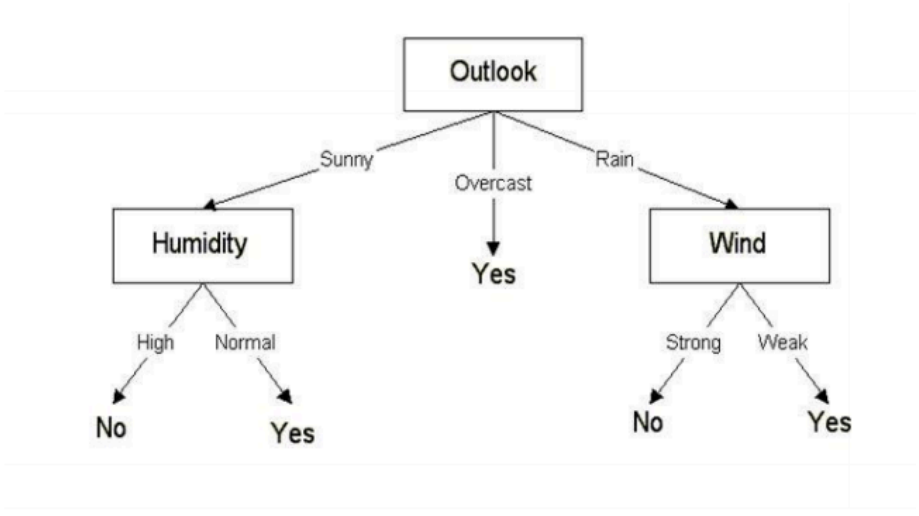


Diagram Placeholder: Supervised Learning Decision Tree

Decision tree: Data provided to algorithm

Day	Outlook	Temperature	Humidity	Wind	Play Golf
D1	Sunny	Hot	High	Weak	No
D2	Sunny	Hot	High	Strong	No
D3	Overcast	Hot	High	Weak	Yes
D4	Rain	Mild	High	Weak	Yes
D5	Rain	Cool	Normal	Weak	Yes
D6	Rain	Cool	Normal	Strong	No
D7	Overcast	Cool	Normal	Strong	Yes
D8	Sunny	Mild	High	Weak	No
D9	Sunny	Cool	Normal	Weak	Yes
D10	Rain	Mild	Normal	Weak	Yes
D11	Sunny	Mild	Normal	Strong	Yes
D12	Overcast	Mild	High	Strong	Yes
D13	Overcast	Hot	Normal	Weak	Yes
D14	Rain	Mild	High	Strong	No

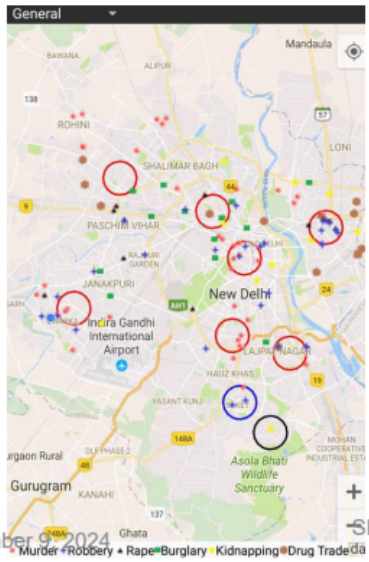
Decision tree built by algorithm to predict whether to play or not



2. Unsupervised Learning

- **Definition**: The model works with an unlabeled dataset and finds patterns or clusters.
- **Example**: Segmenting customers based on purchasing behavior, age, income, etc.

Diagram Placeholder: Clustering in Unsupervised Learning



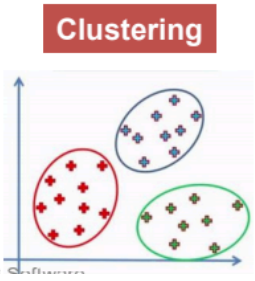
Circles indicates clusters of crime areas in Delhi

Ref: Crime Prediction using K-mea
Global Research and Developmer
Volume 2 | Issue 5 | April 2017

Clustering

innovate achieve

- Customers can be segmented (clustered) based on Gender, age, annual income, products purchased, etc. (Luxury car buyers)
- We can source potential customer data and determine to which segment they belong to.
- Based on the segment, we can target them and send promotion details for the right product



3. Reinforcement Learning

- **Definition**: The model learns through trial and error, interacting with an environment to maximize rewards.
- **Example**: Robots learning to navigate or play chess.

4. Deep Learning

- **Definition**: A subset of ML that uses neural networks to understand and analyze images, sounds, and text.
- **Example**: Image recognition, Natural Language Processing (NLP) for chatbots.

Diagram Placeholder: Neural Network for Deep Learning

Neural networks

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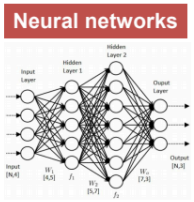
- These networks can learn and model the relationships between inputs and outputs that are complex.
- **Examples**: Detecting rare events such as frauds, help doctors with an opinion

Neural networks - SAS



How does a neural network look like?

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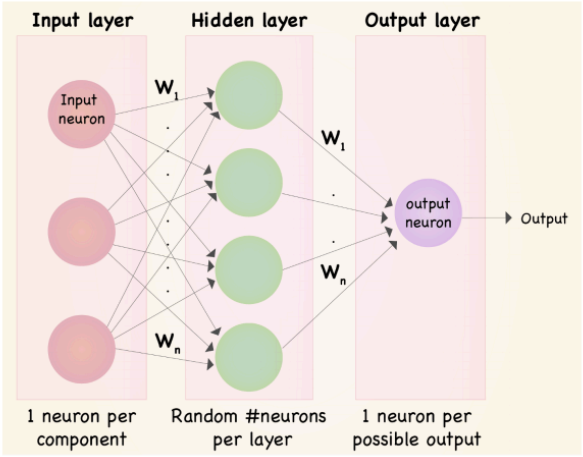
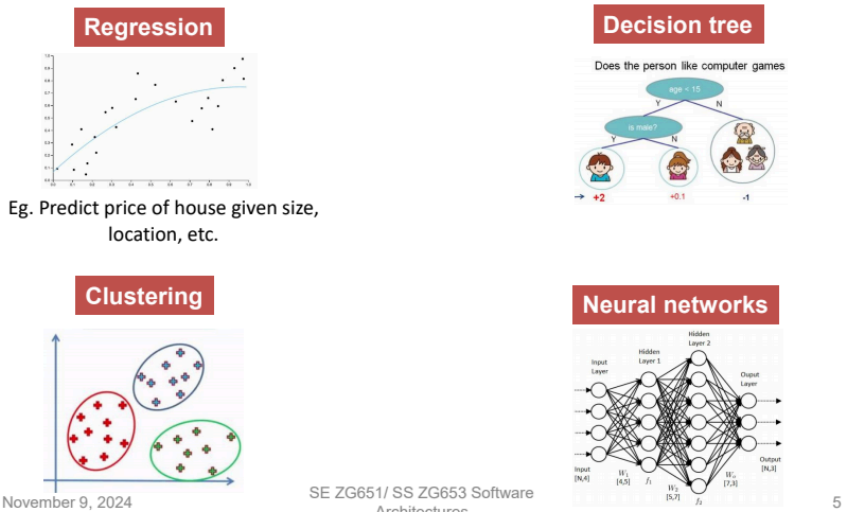


5. Algorithms Used in ML

Diagram Placeholder: Types of Algorithms Used in ML



- **Regression**: Used for predicting continuous values (e.g., price prediction).
- **Decision Trees**: Used for classification tasks (e.g., determining if someone likes a product).
- **Neural Networks**: Mimic the human brain to analyze complex data patterns, especially useful in deep learning applications.

---

6. Steps to Build an ML Model

1. Identify the Problem

- Determine the business value and objective of the model.

2. Select Features

- Use domain knowledge to choose features that impact predictions.
    - **Example**: Age, income, and purchasing behavior for customer segmentation.

3. Choose the Model Type

- Decide on a supervised, unsupervised, or reinforcement learning model.

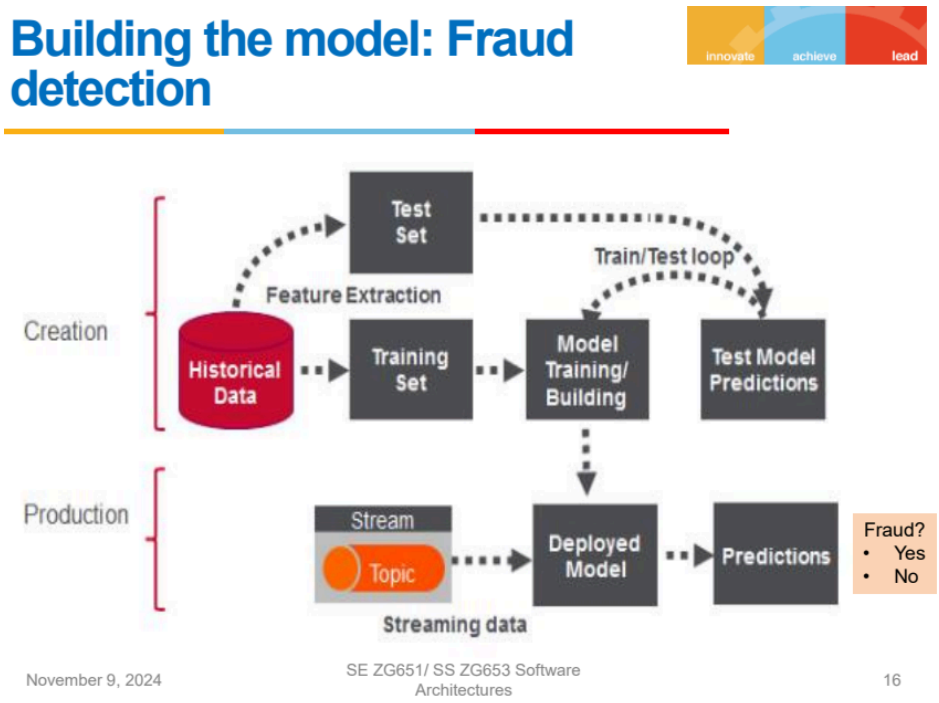
4. Train, Test, and Validate the Model

- Split the data into training and testing sets to evaluate performance.

5. Experiment and Improve

- Continuously refine the model to improve accuracy.

Diagram Placeholder: Steps to Build ML Model for Fraud Detection



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7. Architecture of an ML System

An ML system architecture may involve various components and data flows to handle tasks such as image processing, data storage, and prediction.

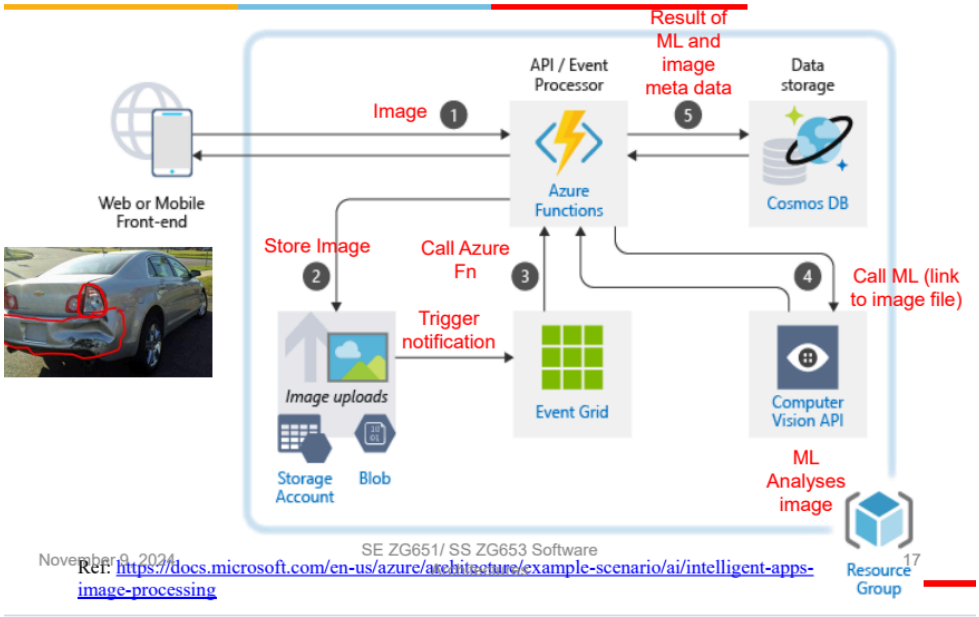
Example: Insurance Claim Image Classification

- **Step 1**: Image is uploaded.
- **Step 2**: Image is analyzed by an ML model.
- **Step 3**: Classification result is stored along with metadata.
- **Step 4**: Notifications are triggered based on the classification.

Diagram Placeholder: ML System Architecture for Image Classification

Architecture of ML system:

Image classification for insurance claims



Ref: https://docs.microsoft.com/en-us/azure/architecture/example-scenario/ai/intelligent-apps-image-processing

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8. Popular Tools for ML

- **Scikit Learn**: Provides models for classification, regression, clustering, and more.
- **PyTorch**: Popular for building neural networks, especially in research.
- **TensorFlow**: Widely used for neural networks and deep learning.
- **Apache Mahout**: Tools for clustering, regression, and recommendation.
- **Spark MLib**: Scalable ML library that integrates with Apache Spark.

Experience Sharing

Reflect on these questions to gain insights from real-world ML applications:

1. What problem did you solve using ML?
2. What steps did you follow to develop the system?
3. What were the key challenges you faced?

Security Technology and Tools

Introduction to Key Technology Concepts

Contents

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1. Transport Layer Security (TLS)

Overview

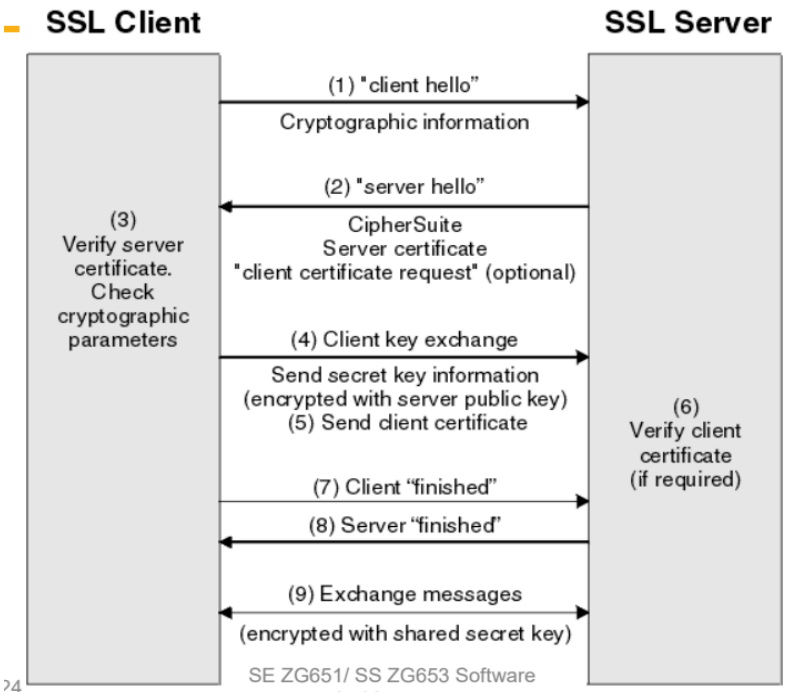
Transport Layer Security (TLS) is essential for secure communication between a client and server, such as a browser and a website. It ensures:

- **Privacy**: Protects communication from being intercepted.
- **Data Integrity**: Ensures data cannot be tampered with undetected.

How TLS Works

1. **Agree on TLS Version**: Client and server select the version to use.
2. **Select Algorithms**: Cryptographic algorithms for encryption are chosen.
3. **Authenticate with Certificates**: Both sides authenticate using digital certificates.
4. **Generate Shared Secret Key**: A key for faster symmetric encryption is generated.

Diagram Placeholder: TLS / SSL Steps



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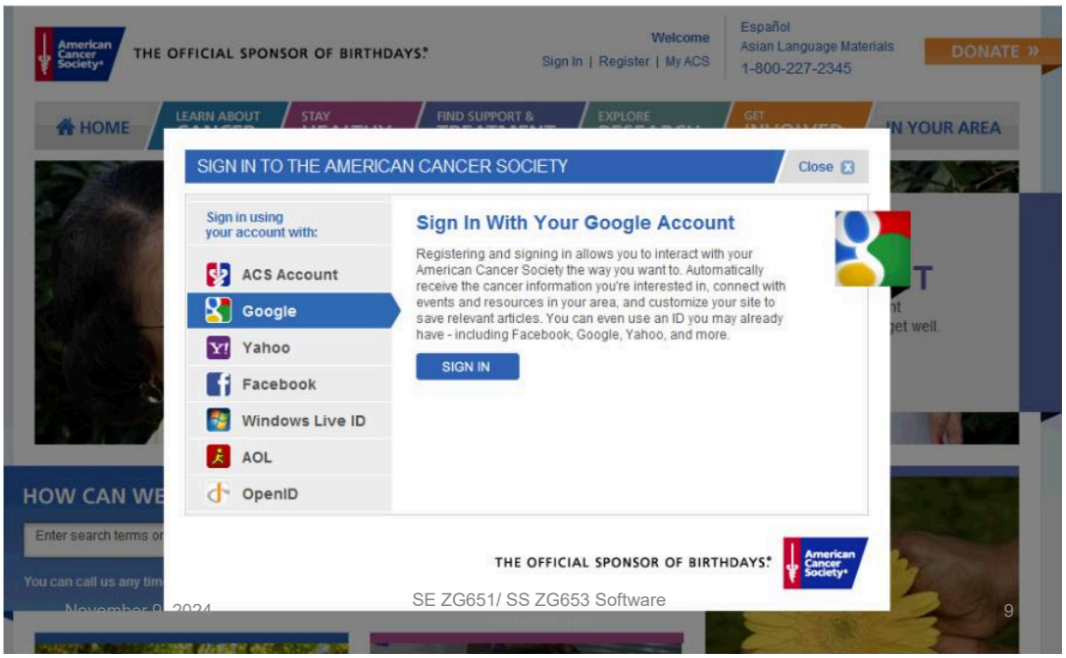
2. OpenID & OAuth

OpenID

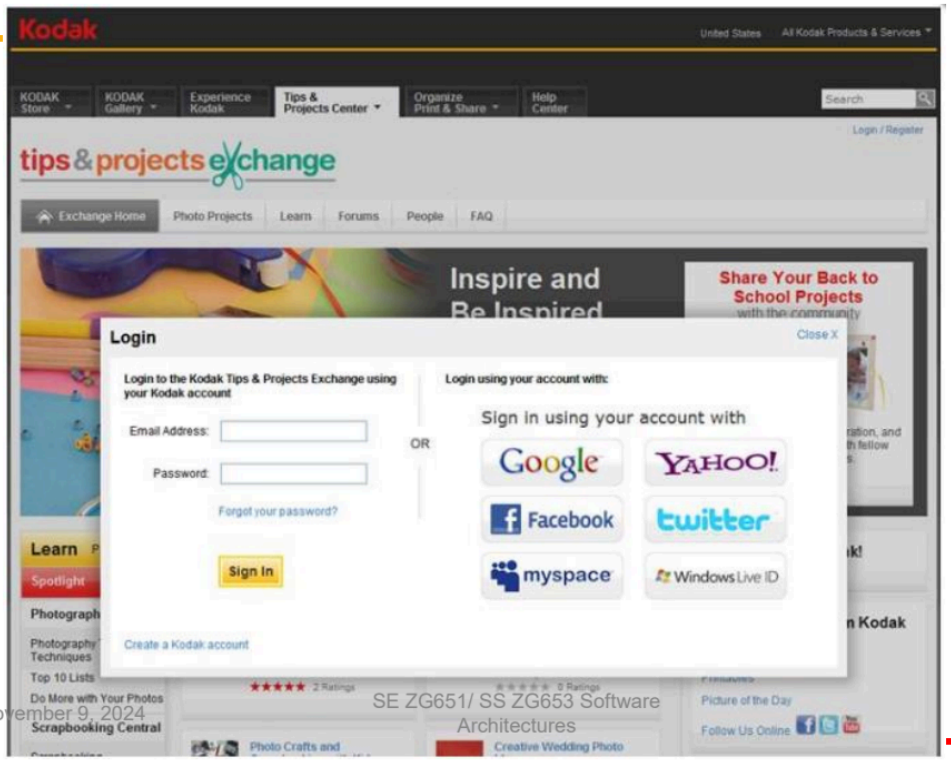
OpenID allows users to sign in to multiple websites using one account, such as Google or Facebook. This reduces the need to remember multiple credentials.

- **Example**: Use your Google account to sign in to other websites without creating new usernames and passwords.

Sample login page: American Cancer Society



Sample login page: Kodak Tips and project Exchange



How OpenID Works

1. **Website Redirects to OpenID Provider**: (e.g., Google).
2. **User Authenticates with Provider**: OpenID provider verifies the user.
3. **Website Receives Authentication**: The user is redirected back with credentials.

OAuth

OAuth authorizes third-party applications to access a user's data stored on another website.

- **Use Case 1**: A photo app accesses photos on Google Drive.
- **Use Case 2**: A printing service accesses images from a photo storage website.

---

3. LDAP (Lightweight Directory Access Protocol)

Overview

LDAP is a protocol used to access and manage directory information in a structured, hierarchical format, often used in large organizations to validate user information.

- **Example**: Using LDAP for user validation on a website with a high volume of registered users to improve performance.

Scenario Suitable for LDAP

LDAP is ideal when:

- You need quick access to frequently requested data.
- Data doesn't change often.
- Data entries are small in size.

---

4. Identity & Access Management (IAM)

Overview

IAM ensures the right people have access to the right technology resources in an organization. It's crucial for regulatory compliance and secure access management.

Features of IAM

1. **Authentication**: Verifying user identity.
2. **Authorization**: Granting permissions to users.
3. **Roles**: Defining user roles with specific permissions.

4. **Delegation**: Allowing users to delegate permissions.
5. **Interoperability**: Sharing identity information across platforms (e.g., using OpenID).

Leading IAM Products

- **IBM Security Identity and Access Assurance**
- **Oracle Identity Cloud Service**
- **Okta**
- **Azure Active Directory**

---

5. Firewalls

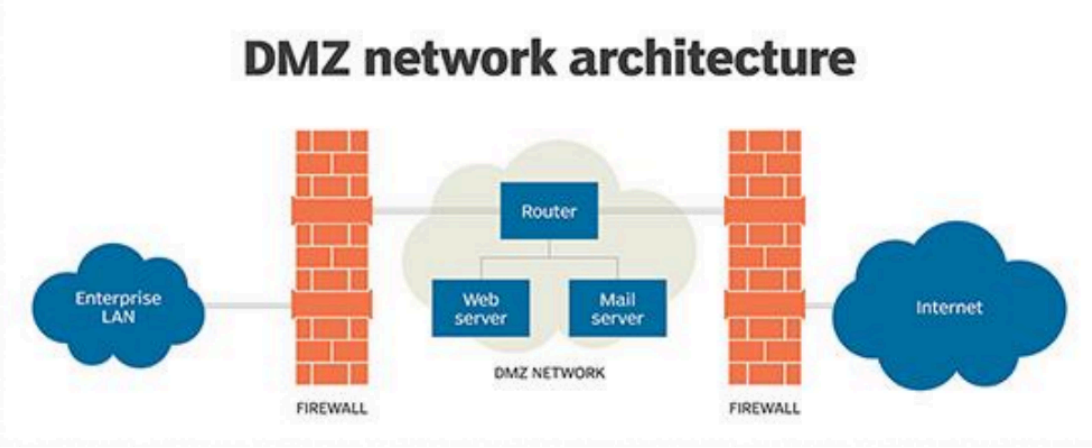
Overview

A firewall is a network security tool that monitors and controls incoming and outgoing traffic based on security rules, helping to protect the network.

De-Militarized Zone (DMZ)

A DMZ is a buffer zone between the internet and an organization's internal network, designed to add an additional layer of security.

Diagram Placeholder: DMZ Structure



Features of Firewalls

- **Intrusion Detection**: Identifies and blocks threats like malware.
- **Access Control**: Allows access based on business needs.
- **Bandwidth Management**: Allocates bandwidth to prioritized applications (e.g., Salesforce over YouTube).

Firewall Techniques

1. **Packet Filtering**: Blocks packets based on IP address or port.
2. **Circuit-Level Gateways**: Monitors sessions between endpoint pairs.
3. **Application Layer Filtering**: Blocks unauthorized applications and protocols.
4. **Address Hiding & NAT**: Protects internal IP addresses.

Diagram Placeholder: Firewall Techniques

Additional Concepts

Business Process Management (BPM) Tools

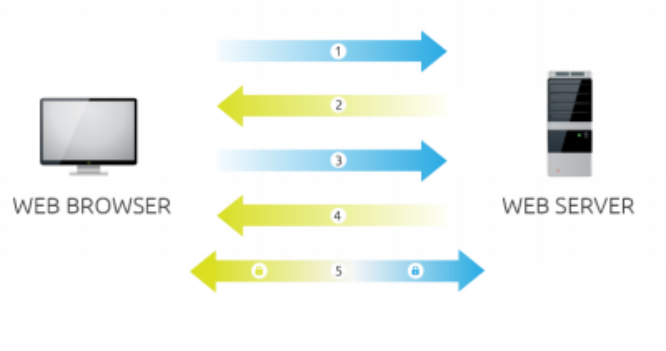
BPM tools help automate, measure, and optimize business processes, providing meaningful metrics to decision-makers.

- **Examples**: Appian, Zoho.

SSL Process

1. **Browser Requests Identity**: Connects to a secured server.
2. **Server Sends SSL Certificate**: Includes server's public key.
3. **Browser Verifies Certificate**: Checks trustworthiness of the certificate.
4. **Symmetric Key Exchange**: Browser creates a session key.
5. **Encrypted Communication**: All data is now encrypted.

Diagram Placeholder: SSL Handshake Process

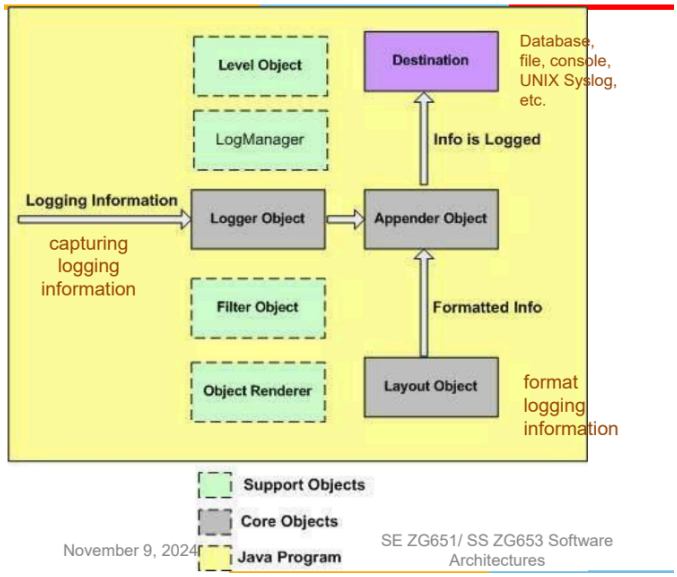


Logging

Logging is crucial for debugging and maintenance, offering a structured way to store application runtime information.

- **Example**: Apache Log4j logs information to databases, files, or consoles.

Diagram Placeholder: Logging Mechanism

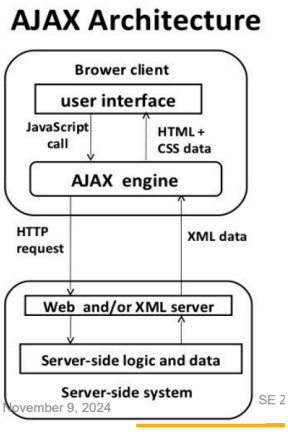


Asynchronous Operations (AJAX)

AJAX enables asynchronous web applications, allowing page updates without reloading.

- **Examples**: Google Maps, where users can drag the map; Google Suggest, where suggestions appear as users type.

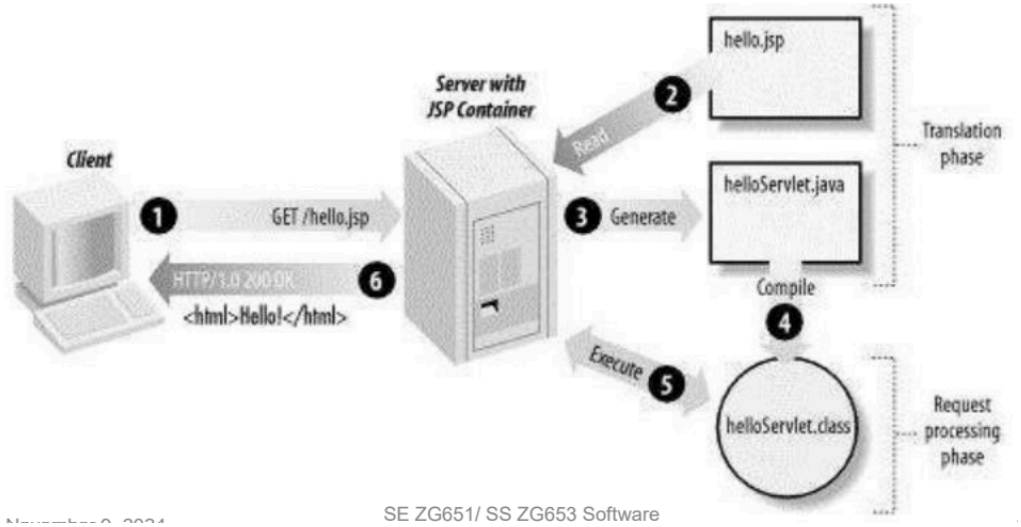
Diagram Placeholder: AJAX Operation



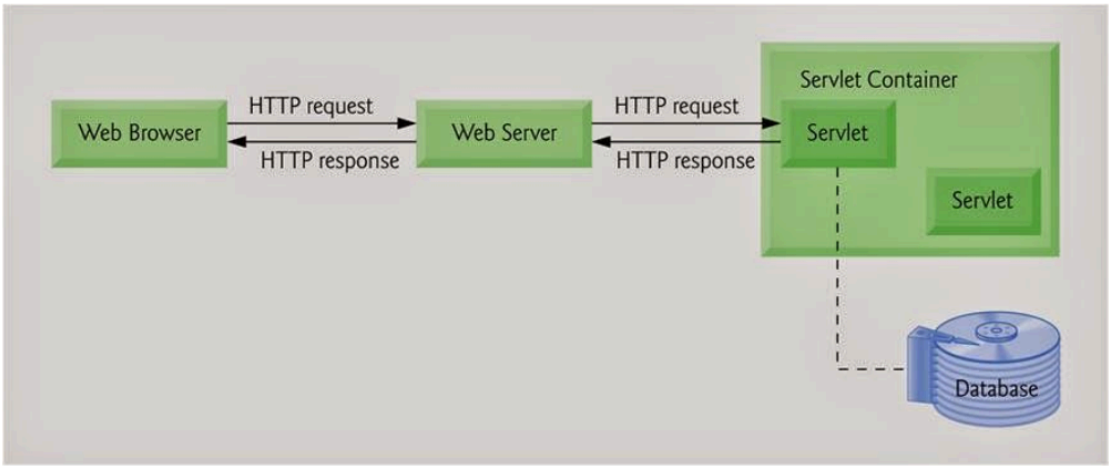
Web Application Architecture

Web applications use a client-server model, often involving dynamic content generated through JSP and Servlets.

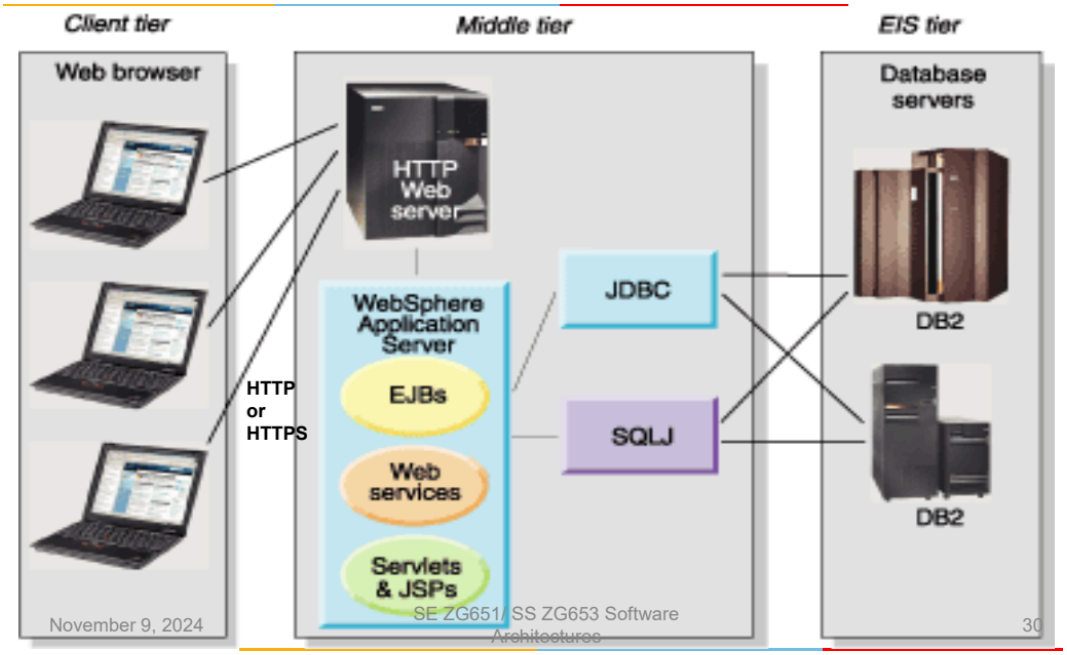
Diagram Placeholder: Web Application Architecture



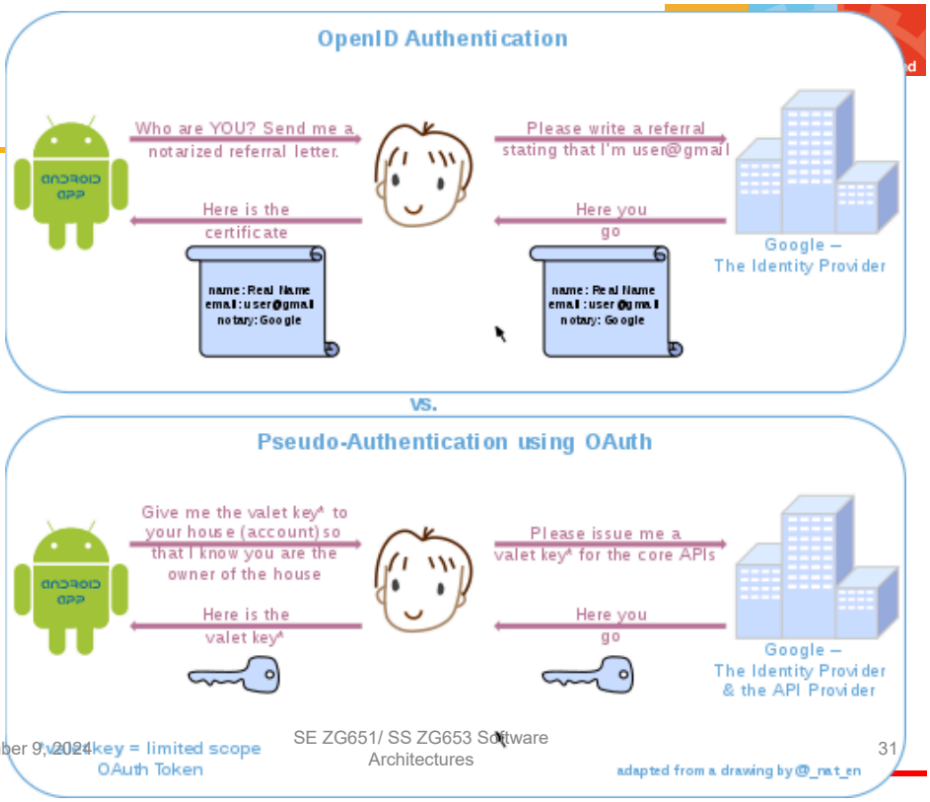
Dynamic web pages



Web application architecture



Source: Wikipedia



Management and Governance

Outline

1. **Planning**
2. **Organizing**
3. **Implementing**
4. **Measuring**
5. **Governance**
6. **Summary**

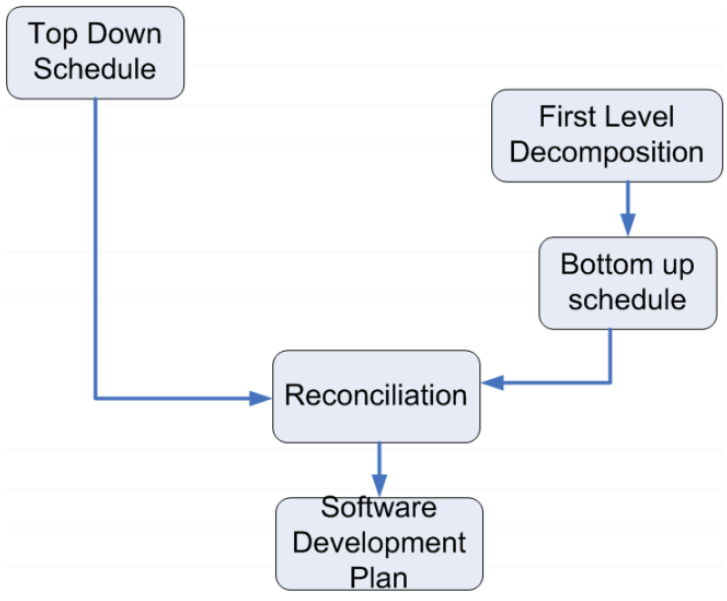
---

1. Planning

The planning process involves creating a roadmap for the project. It starts with an initial top-down plan to get approval from upper management and estimate costs and schedule.

Example: A company planning to build a new software estimates the high-level tasks and costs to get budget approval.

Diagram: The Planning Process



Top-Down Schedule

A top-down schedule helps management decide whether to initiate the project and allocate resources.

- **Example:** For a medium-sized project (e.g., 150,000 lines of code), the team estimates time for designing, coding, and testing.

Remaining Planning Steps

The architecture team develops an initial system design and a bottom-up schedule, which is then aligned with the top-down schedule to create the project's final schedule.

---

2. Organizing

Organizing defines roles, responsibilities, and the team structure.

Project Manager and Software Architect Collaboration

The Project Manager (PM) and Software Architect (SA) must coordinate and respect each other's roles for effective project management.

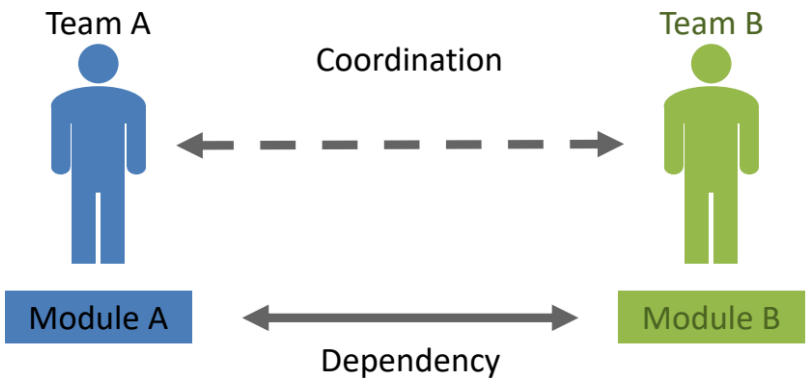
- **Example:** The PM handles schedules and resources, while the SA focuses on technical design and team organization.

Global Software Development

Global development requires teams across different locations to coordinate closely.

- **Example:** A company with development teams in India and the US needs structured communication to synchronize tasks.

Diagram: Coordination Induced by Module Interaction



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3. Implementing

Implementation covers executing tasks, making trade-offs, and tracking progress.

Trade-Offs

PMs and SAs make trade-offs between quality, schedule, and scope.

- **Example:** A feature might be delayed to prioritize critical bug fixes.

Incremental Development

Releases are developed in increments, allowing for continuous feedback and improvements.

Tracking Progress

Progress is monitored through personal contact, meetings, metrics, and risk management.

- **Example:** Regular status meetings identify risks and ensure tasks are on track.

---

4. Measuring

Metrics are essential for evaluating project progress and performance.

Global Metrics

Global metrics, such as size, schedule deviation, and defect count, give an overall view of project health.

- **Example:** Tracking open issues and unresolved risks helps PMs manage potential delays.

Phase Metrics and Cost to Complete

Phase metrics track specific phases of the project, helping the team gauge completion status and costs.

---

5. Governance

Governance ensures compliance, accountability, and control over the project.

Responsibilities of a Governing Board

1. Implement control over architectural components and activities.
2. Ensure compliance with standards and regulations.
3. Support effective management of project processes.
4. Ensure accountability to stakeholders.

Use Case Example: A Web Application Development Project

1. **Planning:** The PM creates an initial high-level plan and budget. After approval, the architecture team refines the schedule and designs the architecture.
2. **Organizing:** Roles are defined – the PM manages resources and deadlines, while the SA designs the technical solution.
3. **Implementing:** The team works in sprints, continuously delivering and testing small increments of the application.
4. **Measuring:** The PM tracks metrics like team productivity, bug counts, and feature completion.
5. **Governance:** Regular reviews ensure that the application meets internal quality standards and regulatory requirements.

Summary

Management and governance are essential for successful project delivery. Key steps include planning, organizing, implementing, measuring progress, and governing the project. Strong coordination between the PM and SA, structured metrics, and governance mechanisms are vital to keep the project on track.

Economic Evaluation through Cost-Benefit Analysis (CBAM)

Outline

1. **Decision-Making Context**
2. **Basis for Economic Analyses**
3. **Utility-Response Curves**
4. **Putting Theory into Practice: The CBAM**
5. **Case Study: The NASA ECS Project**
6. **Summary**

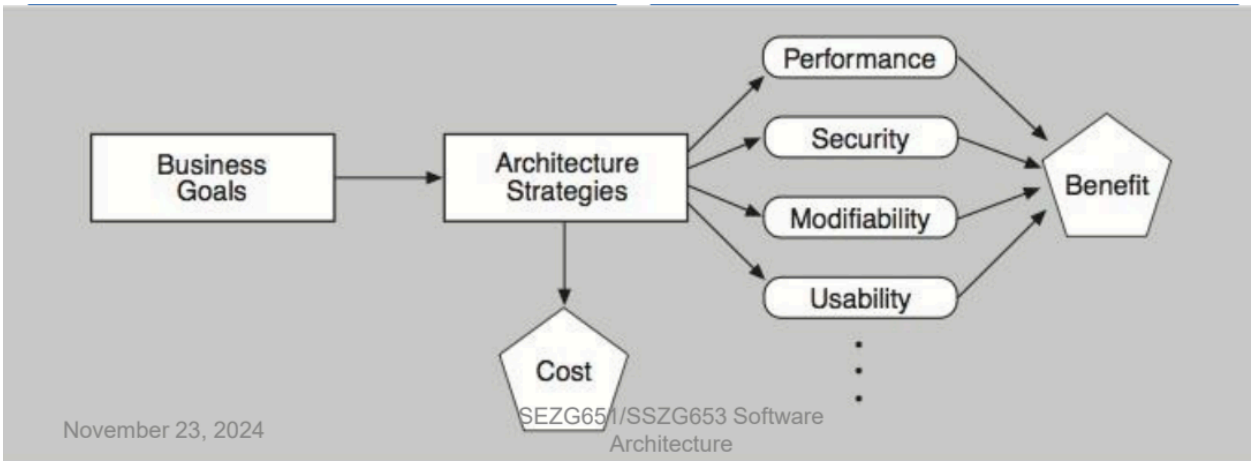
---

1. Decision-Making Context

In software architecture, every architectural decision has economic implications, influencing the project's overall cost and benefit.

- **Example:** Choosing to use redundant hardware for higher availability incurs additional costs but may significantly enhance system reliability.
- **Use Case:** When building a high-availability system, the architect compares different approaches to determine which provides the best value at an acceptable cost.

Diagram: Decision-making Context



2. Basis for Economic Analyses

Economic analyses begin with scenarios derived from requirements and architectural evaluations. Each scenario reflects different architectural strategies with associated costs and quality attribute impacts.

1. **Scenario Generation:** Scenarios represent different project requirements (e.g., performance, availability).
2. **Utility Assignment:** Each scenario is given a utility score based on its value to stakeholders.

- **Example:** A high-performance scenario might have a high utility for a real-time application.

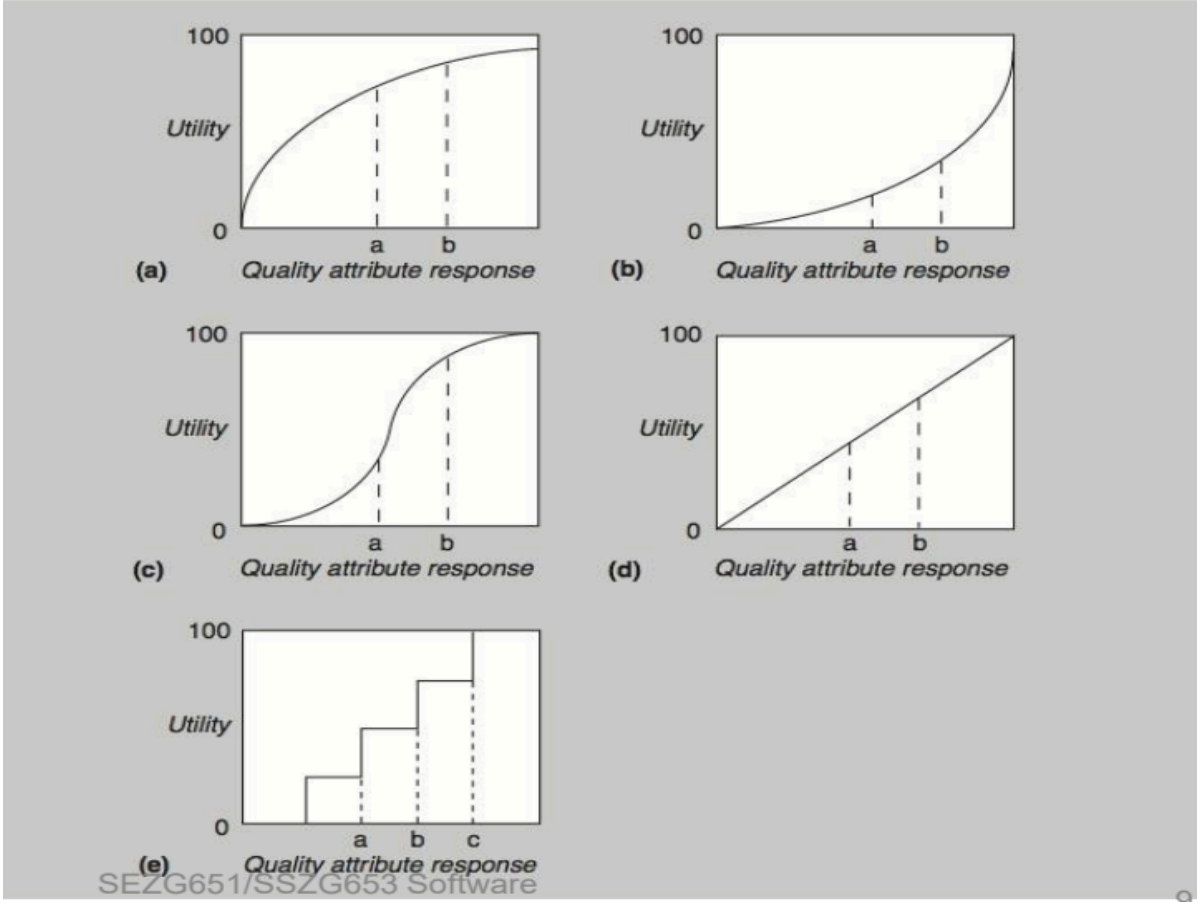
---

3. Utility-Response Curves

Utility-response curves represent the relationship between architectural decisions and their utility (value) to stakeholders. The curve helps in comparing different quality attributes, like performance vs. modifiability.

- **Example:** Stakeholders may value "99.999% availability" highly, but slightly lower availability might still be acceptable if it significantly reduces cost.

Graph: Example Utility-Response Curves



Weighting Scenarios

Scenarios are prioritized based on their importance to stakeholders.

- **Example:** A scenario for high security might be weighted more heavily than a scenario for ease of maintenance if security is critical for the project.

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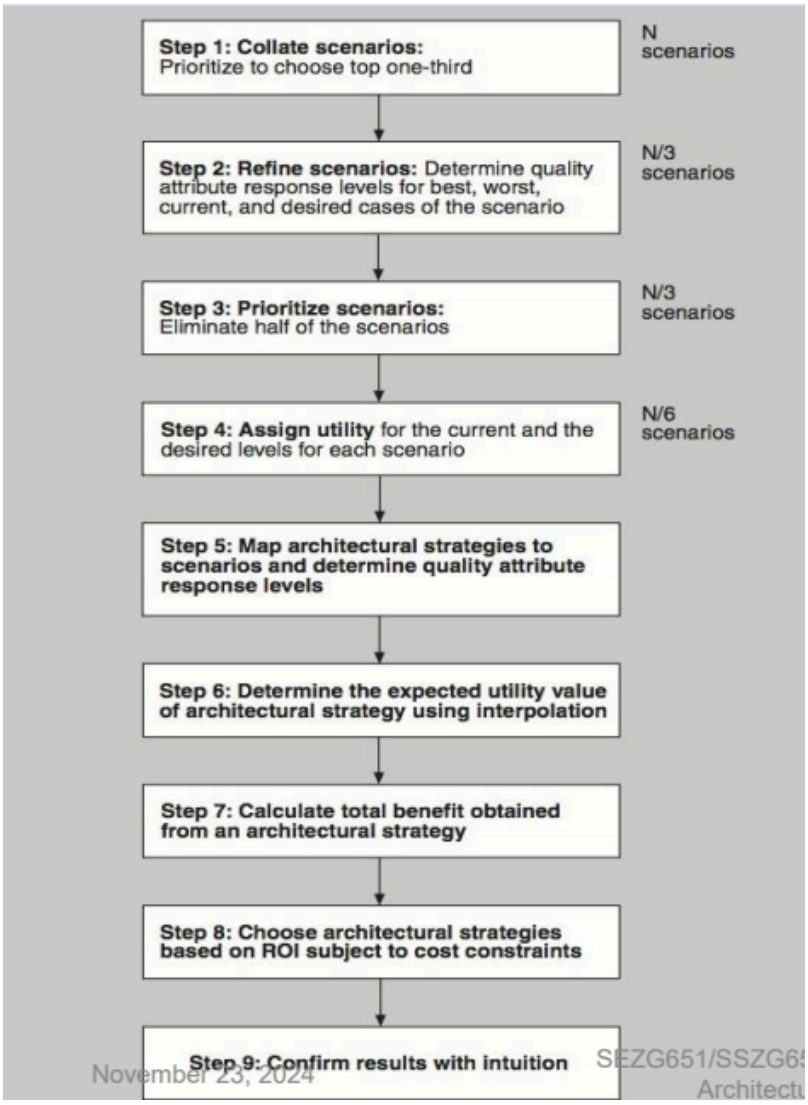
4. Putting Theory into Practice: The CBAM Process

The CBAM process includes several steps to assess the costs and benefits of different architectural strategies. Each step is illustrated with practical examples.

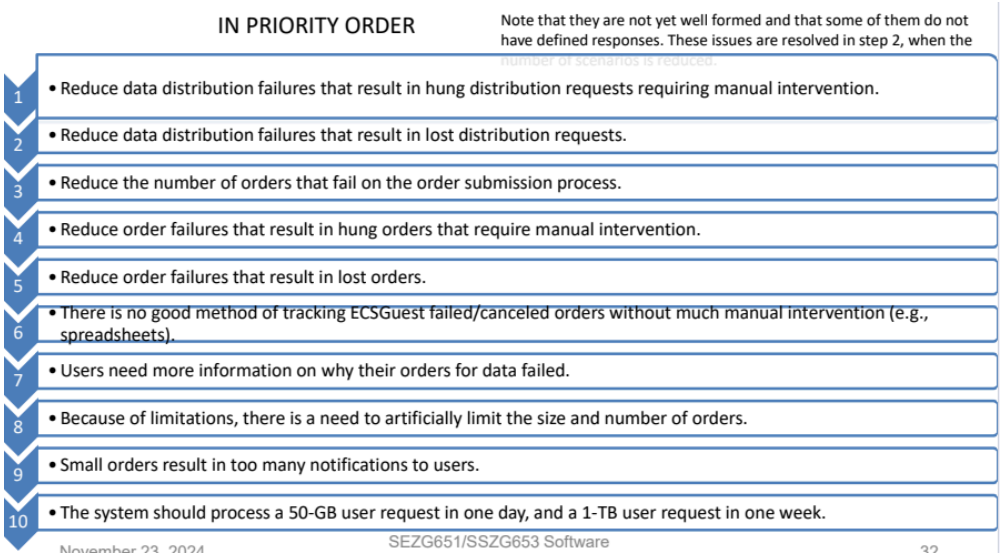


Step 1: Collate Scenarios

Gather all relevant scenarios and prioritize them.

- **Example:** List scenarios such as "reduce data processing failures" or "improve system response time."

Table: Scenarios List and Priorities



Step 2: Refine Scenarios

Refine scenarios by setting specific goals for best-case, worst-case, current, and desired responses.

- **Example:** The desired response time for a system might be 0.5 seconds, while the worst-case response could be 2 seconds.

Table: Scenario Refinement with Goals

Scenario	Worst	Current	Desired	Best
1	10% hung	5% hung	1% hung	0% hung
2	> 5% lost	< 1% lost	0% lost	0% lost
3	10% fail	5% fail	1% fail	0% fail
4	10% hung	5% hung	1% hung	0% hung
5	10% lost	< 1% lost	0% lost	0% lost
6	50% need help	25% need help	0% need help	0% need help
7	10% get information	50% get information	100% get information	100% get information
8	50% limited	30% limited	0% limited	0% limited
9	1/granule	1/granule	1/100 granules	1/1,000 granules
10	< 50% meet goal	60% meet goal	80% meet goal	> 90% meet goal

Step 3: Prioritize Scenarios

Stakeholders vote on scenario priorities to assign weights.

- **Example:** Allocate 100 points among scenarios to represent their importance.

Table: Scenario Prioritization

Scenario	Votes	Worst	Current	Desired	Best
1	10	10% hung	5% hung	1% hung	0% hung
2	15	> 5% lost	< 1% lost	0% lost	0% lost
3	15	10% fail	5% fail	1% fail	0% fail
4	10	10% hung	5% hung	1% hung	0% hung
5	15	10% lost	< 1% lost	0% lost	0% lost
6	10	50% need help	25% need help	0% need help	0% need help
7	5	10% get information	50% get information	100% get information	100% get information
8	5	50% limited	30% limited	0% limited	0% limited
9	10	1/granule	1/granule	1/100 granules	1/1,000 granules
10	5	< 50% meet goal	60% meet goal	80% meet goal	> 90% meet goal

Step 4: Assign Utility Scores

Determine the utility scores for each response level in each scenario.

- **Example:** A response time of 0.5 seconds might have a utility score of 100, while a response time of 2 seconds might score 20.

Table: Utility Scores for Response Levels

Scenario	Worst Case	Current	Desired	Best Case
Scenario #17: Response to user input	12 seconds	1.5 seconds	0.5 seconds	0.1 seconds
	Utility 5	Utility 50	Utility 80	Utility 85

		Utility Scores			
Scenario	Votes	Worst	Current	Desired	Best
1	10	10	80	95	100
2	15	0	70	100	100
3	15	25	70	100	100
4	10	10	80	95	100
5	15	0	70	100	100
6	10	0	80	100	100
7	5	10	70	100	100
8	5	0	20	100	100
9	10	50	50	80	90
10	5	50	50	80	90

Step 5: Develop Architectural Strategies

Identify architectural strategies and their expected impact on each scenario.

- **Example:** One strategy might be to implement load balancing to improve response time.

Table: Expected Quality Attribute Response Levels

Strategy	Name	Description	Scenarios Affected	Current Response	Expected Response
1	Order persistence on submission	Store an order as soon as it arrives in the system.	3	5% fail	2% Fail
			5	<1% lost	0% lost
			6	25% need help	0% need help
2	Order chunking	Allow operators to partition large orders into multiple small orders.	8	30% limited	15% limited
3	Order bundling	Combine multiple small orders into one large order.	9	1 per granule	1 per 100
			10	60% meet goal	55% meet goal
4	Order segmentation	Allow an operator to skip items that cannot be retrieved due to data quality or availability issues.	4	5% hung	2% hung
5	Order reassignment	Allow an operator to reassign the media type for items in an order.	1	5% hung	2% hung
6	Order retry	Allow an operator to retry an order or items in an order that may have failed due to temporary system or data problems.	4	5% hung	3% hung
7	Forced order completion	Allow an operator to override an item's unavailability due to data quality constraints.	1	5% hung	3% hung
8	Failed order notification	Ensure that users are notified only when part of their order has truly failed and provide detailed status of each item; user notification occurs only if operator okays notification; the operator may edit notification.	6	25% need help	20% need help
			7	50% get information	90% get information
9	Granule-level order tracking	An operator and user can determine the status for each item in their order.	6	25% need help	10% need help
			7	50% get information	95% get information
10	Links to user information	An operator can quickly locate a user's contact information. Server will access SDSRV information to determine any data restrictions that might apply and will route orders/order segments to appropriate distribution capabilities, including DDIST, PDS, external subsetters and data processing tools, etc.	7	50% get information	60% get information

Step 6: Calculate Utility of Expected Responses

Use interpolation to calculate the utility of each expected response level.

- **Example Calculation:** For a response time of 0.7 seconds, interpolate utility between 50 (for 1.0 seconds) and 80 (for 0.5 seconds).

Table: Utility of Expected Responses

- Using the elicited utility values (that form a utility curve), determine the utility of the expected quality attribute response level for the architectural strategy.
- Do this for each relevant quality attribute enumerated in step 3.
- For example, if we are considering a new architectural strategy that would result in a response time of 0.7 seconds, we would assign a utility proportionately between 50 (which it exceeds) and 80 (which it doesn't exceed).
- The formula for interpolation between two data points (x_a, y_a) and (x_b, y_b) is:

$$y = y_a + (y_b - y_a)\frac{(x - x_a)}{(x_b - x_a)}$$

- For us, the *x* values are the quality attribute response levels and the *y* values are the utility values. So, employing this formula, the utility value of a 0.7-second response time is 74 .

Strategy	Name	Scenarios Affected	Current Utility	Expected Utility
1	Order persistence on submission	3	70	90
		5	70	100
		6	80	100
2	Order chunking	8	20	60
3	Order bundling	9	50	80
		10	70	65
4	Order segmentation	4	80	90
5	Order reassignment	1	80	92
6	Order retry	4	80	85
7	Forced order completion	1	80	87
8	Failed order notification	6	80	85
		7	70	90
9	Granule-level order tracking	6	80	90
		7	70	95
10	Links to user information	7	70	75

Step 7: Calculate Total Benefit

Calculate the total benefit of each architectural strategy by summing the benefits across all scenarios.

- **Formula:** Bi=∑(bi,j×Wj)Bi = \sum (bi,j \times Wj)Bi=∑(bi,j×Wj)

Table: Total Benefit Calculation

Strategy	Scenario Affected	Scenario Weight	Raw Architectural Strategy Benefit	Normalized Architectural Strategy Benefit	Total Architectural Strategy Benefit
1	3	15	20	300	
1	5	15	30	450	
1	6	10	20	200	950
2	8	5	40	200	200
3	9	10	30	300	
3	10	5	–5	–25	275
4	4	10	10	100	100
5	1	10	12	120	120
6	4	10	5	50	50
7	1	10	7	70	70
8	6	10	5	50	
8	7	5	20	100	150
9	6	10	10	100	
9	7	5	25	125	225
10	7	5	5	25	25

Step 8: Choose Architectural Strategies Based on VFC

Evaluate strategies based on their Value for Cost (VFC) ratio, choosing those with the highest VFC scores within budget constraints.

- **Example:** If one strategy has a VFC score of 1.5 and another 2.0, prioritize the latter for its higher cost-effectiveness.

Table: VFC Scores and Ranking

Strategy	Cost	Total Strategy Benefit	Strategy VFC	Strategy Rank
1	1200	950	0.79	1
2	400	200	0.5	3
3	400	275	0.69	2
4	200	100	0.5	3
5	400	120	0.3	7
6	200	50	0.25	8
7	200	70	0.35	6
8	300	150	0.5	3
9	1000	225	0.22	10
10	100	25	0.25	8

Step 9: Confirm Results with Stakeholders

Verify that the chosen strategies align with stakeholder expectations and business goals.

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5. Case Study: The NASA ECS Project

NASA's Earth Observing System Data Information System (ECS) processes large volumes of environmental data. To maintain system performance and availability within budget, the ECS project team used CBAM to prioritize architectural strategies.

1. **Scenario Example:** Reduce data distribution failures to ensure scientists receive accurate data on time.
2. **Steps in Practice:** The ECS project manager prioritized scenarios, refined them, and applied utility scores, finally choosing strategies based on VFC.

Diagram: ECS Project Case Study Workflow

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6. Summary

The CBAM process allows architects and stakeholders to make informed decisions by evaluating the costs and benefits of architectural strategies. By using structured steps and utility-response curves, teams can ensure that decisions align with project goals and stakeholder priorities.