ARCHITECTURAL PATTERNS-UNIT 3

- ✓ Introduction, Distributed Systems: Broker
- ✓ Interactive Systems: MVC
- ✓ Presentation-Abstraction-Control
- ✓ Adaptable Systems: Microkernel; Reflection.

ARCHITECTURAL PATTERNS-UNIT 3

Architectural patterns express fundamental structural organization schemas for software systems. They provide a set of predefined subsystems, specify their responsibilities, and include rules and guidelines for organizing the relationships between them.

INTRODUCTION

Architectural patterns represent the highest-level patterns in our pattern system. They help you to satisfy the fundamental structure of an application. We group our patterns into four categories:

- ***From Mud to Structure.*** The category includes the Layers pattern, the Pipes and Filters pattern and the Blackboard pattern.
- ***Distributed systems.*** This category includes one pattern, Broker and refers to two patterns in other categories, Microkernel and Pipes and Filters.
- ***Interactive systems.*** This category comprises two patterns, the Model-View-Controller pattern and the Presentation-Abstraction-Control pattern.
- ***Adaptable systems.*** The Reflection pattern and the Microkernel pattern strongly support extension of applications and their adaptation to evolving technology and changing functional requirements.

DISTRIBUTED SYSTEMS

What are the advantages of distributed systems that make them so interesting?
Distributed systems allow better sharing and utilization of the resources available within the network.

- Economics: computer network that incorporates both pc's and workstations offer a better price/performance ratio than mainframe computer.
- Performance and scalability: a huge increase in performance can be gained by using the combine computing power of several network nodes.
- Inherent distribution: some applications are inherently distributed. Ex: database applications that follow a client-server model.
- Reliability: A machine on a network in a multiprocessor system can crash without affecting the rest of the system.

Disadvantages
They need radically different software than do centralized systems.

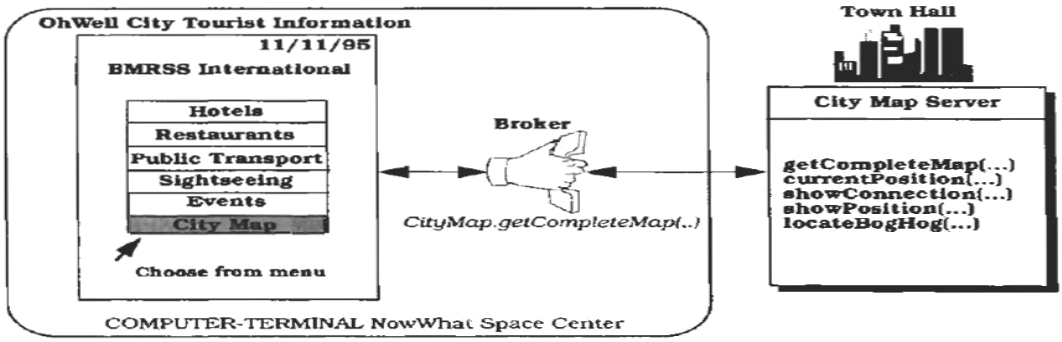
We introduce three patterns related to distributed systems in this category:

- The **Pipes and Filters pattern** provides a structure for systems that process a stream of data. Each processing step is encapsulated in a filter component. Data is passed through pipes between adjacent filters.
- The **Microkernel pattern** applies to software systems that must be able to adapt to changing system requirements. It separates a minimal functional core from extended functionality and customer-specific parts
- The **Broker pattern** can be used to structure distributed software systems with decoupled components that interact by remote service invocations.

BROKER

The broker architectural pattern can be used to structure distributed software systems with decoupled components that interact by remote service invocations. A broker component is responsible for coordinating communication, such as requests, as well as for transmitting results and exceptions.

Example:



Suppose we are developing a city information system (CIS) designed to run on a wide area network. Some computers in the network host one or more services that maintain information about events, restaurants, hotels, historical monuments or public transportation. Computer terminals are connected to the network. Tourists throughout the city can retrieve information in which they are interested from the terminals using a World Wide Web (WWW) browser. This front-end software supports the on-line retrieval of information from the appropriate servers and its display on the screen. The data is distributed across the network, and is not all maintained in the terminals.

Context:

Your environment is a distributed and possibly heterogeneous system with independent co operating components.

Problem:

Building a complex software system as a set of decoupled and interoperating components, rather than as a monolithic application, results in greater flexibility, maintainability and changeability. By partitioning functionality into independent components the system becomes potentially distributable and scalable. Services for adding, removing, exchanging, activating and locating components are also needed. From a developer's viewpoint, there should essentially be no difference between developing software for centralized systems and developing for distributed ones.

We have to balance the following forces:

- Components should be able to access services provided by other through remote, location-transparent service invocations.
- You need to exchange, add or remove components at run time.
- The architecture should hide system and implementation-specific details from the users of component and services.

Solution:

- Introduce a broker component to achieve better decoupling of clients and servers.
- Servers registers themselves with the broker make their services available to clients through method interfaces.
- Clients access the functionality of servers by sending requests via the broker.

- A broker's tasks include locating the appropriate server, forwarding the request to the server, and transmitting results and exceptions back to the client.
- The Broker pattern reduces the complexity involved in developing distributed applications, because it makes distribution transparent to the developer.

Structure:

The broker architectural pattern comprises six types of participating components.

★ **Server:**

- Implements objects that expose their functionality through interfaces that consists of operations and attributes.
- These interfaces are made available either through an interface definition language (IDL) or through a binary standard.
- There are two kind of servers:
  - ♠ Servers offering common services to many application domains.
  - ♠ Servers implementing specific functionality for a single application domain or task.

★ **Client:**

- Clients are applications that access the services of at least one server.
- To call remote services, clients forward requests to the broker. After an operation has executed they receive responses or exceptions from the broker.
- Interaction b/w servers and clients is based on a dynamic model, which means that servers may also act as clients

Class Client	Collaborators • Client-side Proxy
Responsibility • Implements user functionality. • Sends requests to servers through a client-side proxy.	• Broker

Class Server	Collaborators • Server-side Proxy
Responsibility • Implements services. • Registers itself with the local broker. • Sends responses and exceptions back to the client through a server-side proxy.	• Broker

★ **Brokers:**

- It is a messenger that is responsible for transmission of requests from clients to servers, as well as the transmission of responses and exceptions back to the client.
- It offers API'S to clients and servers that include operations for registering servers and for invoking server methods.
- When a request arrives from server that is maintained from local broker, the broker passes the request directly to the server. If the server is currently inactive, the broker activates it.
- If the specified server is hosted by another broker, the local broker finds a route to the remote broker and forwards the request this route.
- Therefore there is a need for brokers to interoperate through bridges.

Class Broker	Collaborators • Client • Server • Client-side Proxy • Server-side Proxy • Bridge
Responsibility • (Un-)registers servers. • Offers APIs. • Transfers messages. • Error recovery. • Interoperates with other brokers through bridges. • Locates servers.	

★ **Client side proxy:**

- They represent a layer b/w client and the broker.
- The proxies allow the hiding of implementation details from the clients such as
- The inter process communication mechanism used for message transfers b/w clients and brokers.
- The creation and deletion of blocks.
- The marshalling of parameters and results.

★ **Server side proxy:**

- Analogous to client side proxy. The difference that they are responsible for receiving requests, unpacking incoming messages, un marshalling the parameters, and calling the appropriate service.

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

Class Server-side Proxy	Collaborators • Server • Broker
Responsibility • Calls services within the server. • Encapsulates system-specific functionality. • Mediates between the server and the broker.	

★ **Bridges:**

- These are optional components used for hiding implementation details when two brokers interoperate.

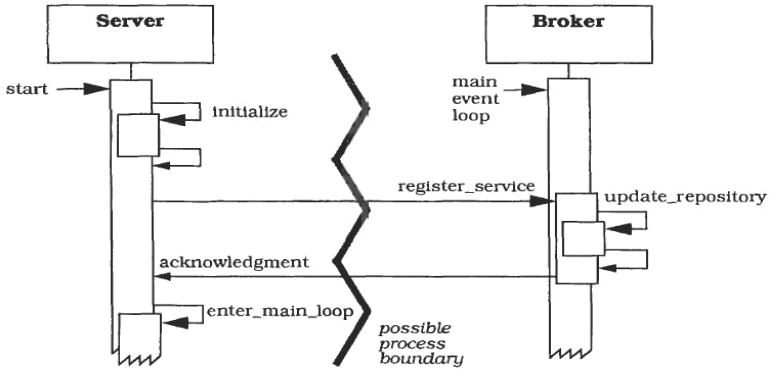
Class Bridge	Collaborators • Broker • Bridge
Responsibility • Encapsulates network-specific functionality. • Mediates between the local broker and the bridge of a remote broker.	

The following diagram shows the objects involved in a broker system

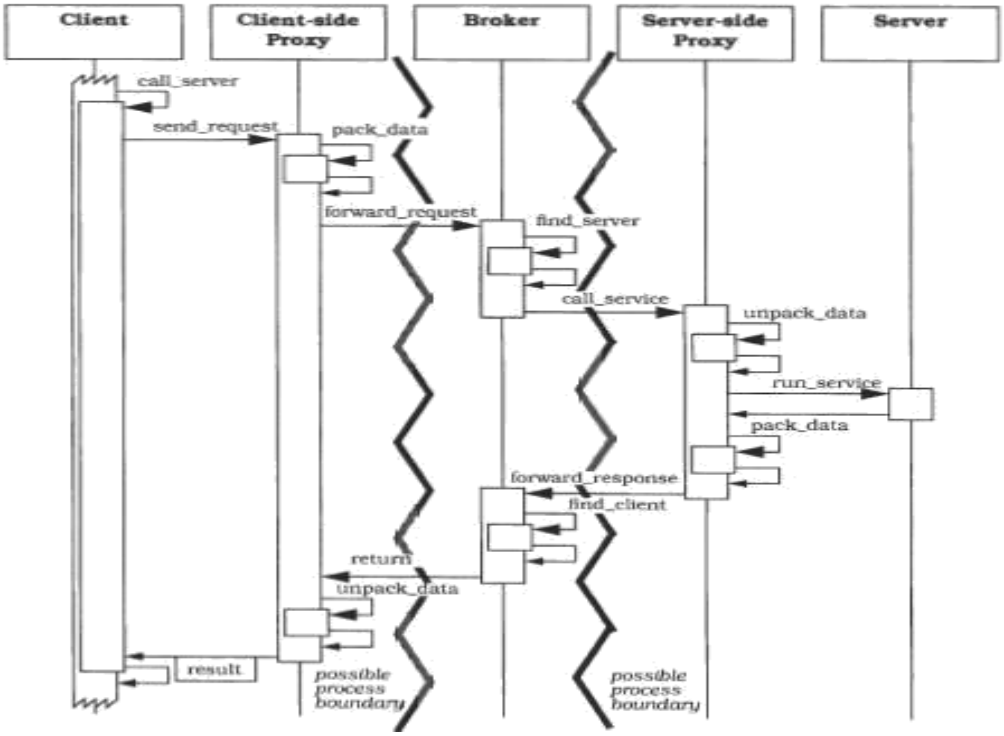
Dynamics:

♠ **Scenario 1.** illustrates the behaviour when a server registers itself with the local broker component:

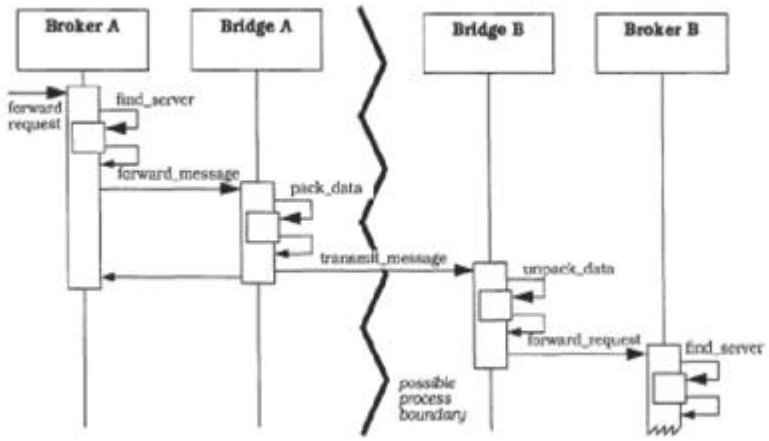
♠



- **Scenario II** illustrates the behaviour when a client sends a request to a local server. In this scenario we describe a synchronous invocation, in which the client blocks until it gets a response from the server. The broker may also support asynchronous invocations, allowing clients to execute further tasks without having to wait for a response.



Scenario III illustrates the interaction of different brokers via bridge components:



Implementation:

1) **Define an object existing model, or use an existing model.**
   Each object model must specify entities such as object names, requests, objects, values, exceptions, supported types, interfaces and operations.
2) **Decide which kind of component-interoperability the system should offer.**

- You can design for interoperability either by specifying a binary standard or by introducing a high-level IDL.
- IDL file contains a textual description of the interfaces a server offers to its clients.
- The binary approach needs support from your programming language.

3) Specify the API'S the broker component provides for collaborating with clients and servers.

- Decide whether clients should only be able to invoke server operations statically, allowing clients to bind the invocations at complete time, or you want to allow dynamic invocations of servers as well.
- This has a direct impact on size and no. of API'S.

4) **Use proxy objects to hide implementation details from clients and servers.**

- Client side proxies package procedure calls into message and forward these messages to the local broker component.
- Server side proxies receive requests from the local broker and call the methods in the interface implementation of the corresponding server.

5) Design the broker component in parallel with steps 3 and 4

During design and implementations, iterate systematically through the following steps

5.1 Specify a detailed on-the-wire protocol for interacting with client side and server side proxies.

5.2 A local broker must be available for every participating machine in the network.

5.3 When a client invokes a method of a server the broker system is responsible for returning all results and exceptions back to the original client.

5.4 If the provides do not provide mechanisms for marshalling and un marshalling parameters results, you must include functionality in the broker component.

5.5 If your system supports asynchronous communication b/w clients and servers, you need to provide message buffers within the broker or within the proxies for temporary storage of messages.

5.6 Include a directory service for associating local server identifiers with the physical location of the corresponding servers in the broker.

5.7 When your architecture requires system-unique identifiers to be generated dynamically during server registration, the broker must offer a name service for instantiating such names.

5.8 If your system supports dynamic method invocation the broker needs some means for maintaining type information about existing servers.

5.9 Plan the broker's action when the communication with clients, other brokers, or servers fails.

6) Develop IDL compliers

An IDL compiler translates the server interface definitions to programming language code. When many programming languages are in use, it is best to develop the compiler as afrarnework that allows the developer to add his own code generators.

Example resolved:

Our example CIS system offers different kinds of services. For example, a separate server workstation provides all the information related to public transport. Another server is responsible for collecting and publishing information on vacant hotel rooms. A tourist may be interested in retrieving information from several hotels, so we decide to provide this data on a single workstation. Every hotel can connect to the workstation and perform updates.

Variants:

- **Direct communication broker system:**
  - ★ We may sometime choose to relax the restriction that clients can only forward requests through the local brokers for efficiency reasons
  - ★ In this variant, clients can communicate with server directly.

- ★ Broker tells the clients which communication channel the server provides.
- ★ The client can then establish a direct link to the requested server

- **Message passing broker system:**
  - ✓ This variant is suitable for systems that focus on the transmission of data, instead of implementing a remote produce call abstraction.
  - ✓ In this context, a message is a sequence of raw data together with additional information that specifies the type of a message, its structure and other relevant attributes.
  - ✓ Here servers use the type of a message to determine what they must do, rather than offering services that clients can invoke.
- **Trader system**:
  - ✓ A client request is usually forwarded to exactly one uniquely – identified servers.
  - ✓ In a trader system, the broker must know which server(s) can provide the service and forward the request to an appropriate server.
  - ✓ Here client side proxies use service identifiers instead of server identifiers to access server functionality.
  - ✓ The same request might be forwarded to more than one server implementing the same service.
- **Adapter broker system:**
  - ✓ Adapter layer is used to hide the interfaces of the broker component to the servers using additional layer to enhance flexibility
  - ✓ This adapter layer is a part of the broker and is responsible for registering servers and interacting with servers.
  - ✓ By supplying more than one adapter, support different strategies for server granularity and server location.
  - ✓ Example: use of an object oriented database for maintaining objects.
- **Callback broker system:**
  - ✓ Instead of implementing an active communication model in which clients produce requests and servers consume then and also use a reactive model.
  - ✓ It's a reactive model or event driven, and makes no distinction b/w clients and servers.
  - ✓ Whenever an event arrives, the broker invokes the call back method of the component that is registered to react to the event
  - ✓ The execution of the method may generate new events that in turn cause the broker to trigger new call back method invocations.

Known uses:

- ♠ CORBA
- ♠ SOM/DSOM
- ♠ OLE 2.x
- ♠ WWW
- ♠ ATM-P

Consequences:

The broker architectural pattern has some important *Benefits*:

- **Location transparency:**
  Achieved using the additional 'broker' component
- **Changeability and extensibility of component**
  If servers change but their interfaces remain the same, it has no functional impact on clients.
- **Portability of a broker system:**
  Possible because broker system hides operating system and network system details from clients and servers by using indirection layers such as API'S, proxies and bridges.
- **Interoperability between different broker systems.**
  Different Broker systems may interoperate if they understand a common protocol for the exchange of messages.

- **Reusability**
  When building new client applications, you can often base the functionality of your application on existing services.

The broker architectural pattern has some important *Liabilities:*

- ♠ **Restricted efficiency:**
  Broker system is quite slower in execution.
- ♠ **Lower fault tolerance:**
  Compared with a non-distributed software system, a Broker system may offer lower fault tolerance.

Following aspect gives benefits as well as liabilities.

- ★ **Testing and debugging:**
  Testing is more robust and easier itself to test. However it is a tedious job because of many components involved.

INTERACTIVE SYSTEMS

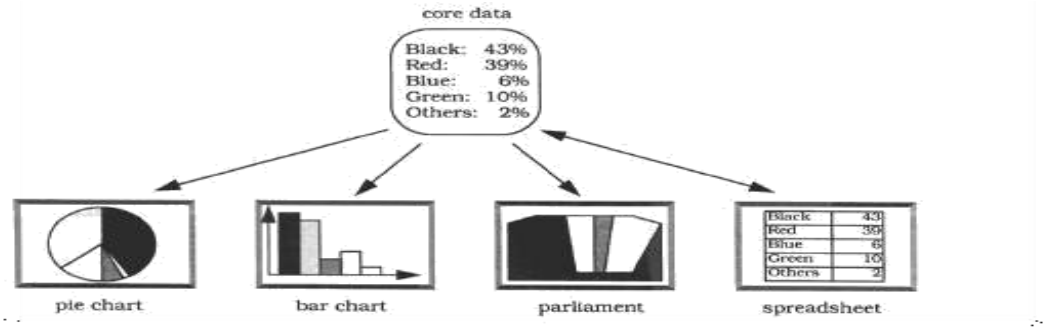
These systems allow a high degree of user interaction, mainly achieved with the help of graphical user interfaces.
Two patterns that provide a fundamental structural organization for interactive software systems are:

- ➢ Model-view-controller pattern
- ➢ Presentation-abstraction-control pattern

MODEL-VIEW-CONTROLLER (MVC)

- *MVC architectural pattern divides an interactive application into three components.*
  - ✓ *The model contains the core functionality and data.*
  - ✓ *Views display information to the user.*
  - ✓ *Controllers handle user input.*
- *Views and controllers together comprise the user interface.*
- *A change propagation mechanism ensures consistence between the user interface and the model.*

Example:



Consider a simple information system for political elections with proportional representation. This offers a spreadsheet for entering data and several kinds of tables and charts for presenting the current results. Users can interact with the system via a graphical interface. All information displays must reflect changes to the voting data immediately.

Context:
Interactive applications with a flexible human-computer interface

Problem:

Different users place conflicting requirements on the user interface. A typist enters information into forms via the keyboard. A manager wants to use the same system mainly by clicking icons and buttons. Consequently, support for several user interface paradigms should be easily incorporated. How do you modularize the user interface functionality of a web application so that you can easily modify the individual parts?

The following forces influence the solution:

- ✓ Same information is presented differently in different windows. For ex: In a bar or pie chart.
- ✓ The display and behavior of the application must reflect data manipulations immediately.
- ✓ Changes to the user interface should be easy, and even possible at run-time.
- ✓ Supporting different 'look and feel' standards or porting the user interface should not affect code in the core of the application.

Solution:

- ★ MVC divides an interactive application into the three areas: processing, output and input.
- ★ Model component encapsulates core data and functionality and is independent of o/p and i/p.
- ★ View components display user information to user a view obtains the data from the model. There can be multiple views of the model.
- ★ Each view has an associated controller component controllers receive input (usually as mouse events) events are translated to service requests for the model or the view. The user interacts with the system solely through controllers.
- ★ The separation of the model from view and controller components allows multiple views of the same model.

Structure:

- ★ **Model component:**
  - o Contains the functional core of the application.
  - o Registers dependent views and controllers
  - o Notifies dependent components about data changes (change propagation mechanism)

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

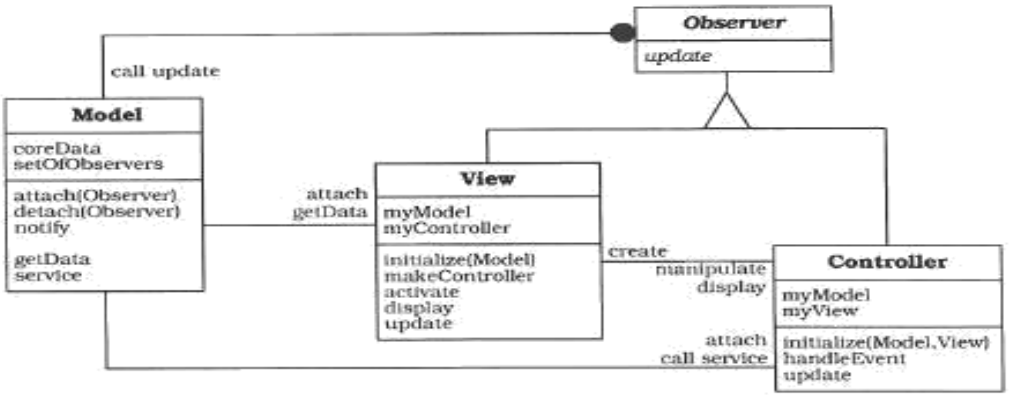
- ★ **View component:**
  - o Presents information to the user
  - o Retrieves data from the model
  - o Creates and initializes its associated controller
  - o Implements the update procedure
- ★ **Controller component:**
  - o Accepts user input as events (mouse event, keyboard event etc)

- Translates events to service requests for the model or display requests for the view.
  - The controller registers itself with the change-propagation mechanism and implements an update procedure.

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

Class: Controller	Collaborators
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.	• View • Model

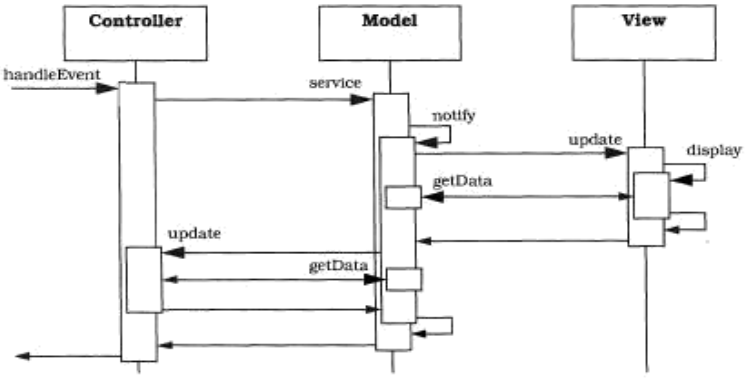
An object-oriented implementation of MVC would define a separate class for each component. In a C++ implementation, view and controller classes share a common parent that defines the update interface. This is shown in the following diagram.



Dynamics:

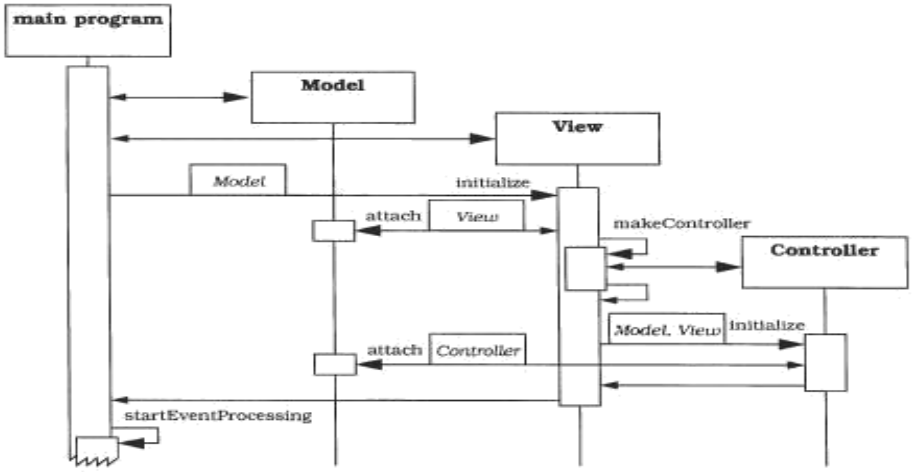
The following scenarios depict the dynamic behavior of MVC. For simplicity only one view-controller pair is shown in the diagrams.

- **Scenario** I shows how user input that results in changes to the model triggers the change-propagation mechanism:
  - The controller accepts user input in its event-handling procedure, interprets the event, and activates a service procedure of the model.
  - The model performs the requested service. This results in a change to its internal data.
  - The model notifies all views and controllers registered with the change-propagation mechanism of the change by calling their update procedures.
  - Each view requests the changed data from the model and redisplays itself on the screen.
  - Each registered controller retrieves data from the model to enable or disable certain user functions..
  - The original controller regains control and returns from its event handling procedure.



- **Scenario II** shows how the MVC triad is initialized. The following steps occur:

- The model instance is created, which then initializes its internal data structures.
- **A** view object is created. This takes a reference to the model as a parameter for its initialization.
- The view subscribes to the change-propagation mechanism of the model by calling the attach procedure.
- The view continues initialization by creating its controller. It passes references both to the model and to itself to the controller's initialization procedure.
- The controller also subscribes to the change-propagation mechanism by calling the attach procedure.
- After initialization, the application begins to process events.



Implementation:

1) Separate human-computer interaction from core functionality

- Analysis the application domain and separate core functionality from the desired input and output behavior

2) Implement the change-propagation mechanism

- Follow the publisher subscriber design pattern for this, and assign the role of the publisher to the model.

3) Design and implement the views

- design the appearance of each view
- Implement all the procedures associated with views.

4) Design and implement the controllers

- For each view of application, specify the behavior of the system in response to user actions.
- We assume that the underlying pattern delivers every action of and user as an event. A controller receives and interprets these events using a dedicated procedure.

5) Design and implement the view controller relationship.

- A view typically creates its associated controller during its initialization.

6) Implement the setup of MVC.

- The setup code first initializes the model, then creates and initializes the views.
- After initialization, event processing is started.
- Because the model should remain independent of specific views and controllers, this set up code should be placed externally.

7) Dynamic view creation

- If the application allows dynamic opening and closing of views, it is a good idea to provide a component for managing open views.

8) 'pluggable' controllers

- The separation of control aspects from views supports the combination of different

controllers with a view.

- This flexibility can be used to implement different modes of operation.

9) Infrastructure for hierarchical views and controllers

- Apply the composite pattern to create hierarchically composed views.
- If multiple views are active simultaneously, several controllers may be interested in events at the same time.

10) Further decoupling from system dependencies.

- Building a framework with an elaborate collection of view and controller classes is expensive. You may want to make these classes platform independent. This is done in some Smalltalk systems

Variants:

Document View - This variant relaxes the separation of view and controller. In several GUI platforms, window display and event handling are closely interwoven. You can combine the responsibilities of the view and the controller from MVC in a single component by sacrificing exchangeability of controllers. This kind of structure is often called Document-View architecture. The view component of Document-View combines the responsibilities of controller and view in MVC, and implements the user interface of the system.

Known uses:

- **Smalltalk** - The best-known example of the use of the Model-View-Controller pattern is the user-interface framework in the Smalltalk environment
- **MFC** - The Document-View variant of the Model-View-Controller pattern is integrated in the Visual C++ environment-the Microsoft Foundation Class Library-for developing Windows applications.
- **ET++** - ET++ establishes 'look and feel' independence by defining a class **`Windowport`** that encapsulates the user interface platform dependencies.

Consequences:

Benefits:

- **Multiple views of the same model:**
  It is possible because MVC strictly separates the model from user interfaces components.
- **Synchronized views:**
  It is possible because of change-propagation mechanism of the model.
- **'pluggable views and controller:**
  It is possible because of conceptual separation of MVC.
- **Exchangeability of 'look and feel'**
  Because the model is independent of all user-interface code, a port of MVC application to a new platform does not affect the functional core of the application.
- **Framework potential**
  It is possible to base an application framework on this pattern.

Liabilities:

- **Increased complexity**
  Following the Model-View-Controller structure strictly is not always the best way to build an interactive application
- **Potential for excessive number of updates**
  If a single user action results in many updates, the model should skip unnecessary change notifications.
- **Intimate connection b/w view and controller**
  Controller and view are separate but closely-related components, which hinders their individual reuse.

- **Closed coupling of views and controllers to a model**
  Both view and controller components make direct calls to the model. This implies that changes to the model's interface are likely to break the code of both view and controller.
- **Inevitability of change to view and controller when porter**
  This is because all dependencies on the user-interface platform are encapsulated within view and
  controller.

★ **Difficulty of using MVC with modern user interface tools**
If portability is not an issue, using high-level toolkits or user interface builders can rule out the use of MVC.

PRESENTATION-ABSTRACTION-CONTROL

PAC defines a structure for interactive s/w systems in the form of a hierarchy of cooperating agents.

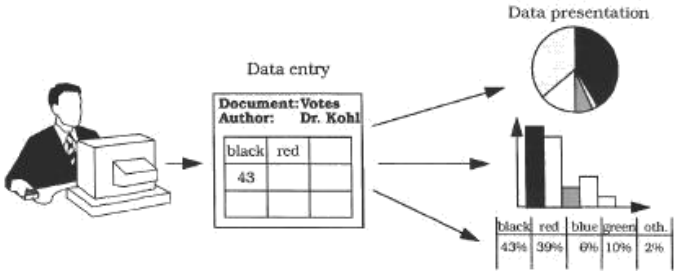
Every agent is responsible for a specific aspect of te applications functionality and consists of three components

- ✓ *Presentation*
- ✓ *Abstraction*
- ✓ *Control*

The subdivision separates the human-computer interaction aspects of the agent from its functional core and its communication with other agents.

Example:

Consider a simple information system for political elections with proportional representation. This offers a spreadsheet for entering data and several kinds of tables and charts for presenting current standings. Users interact with the software through a graphical interface.



Context:

Development of an interactive application with the help of agents

Problem:

Agents specialized in human-comp interaction accept user input and display data. Other agents maintain the data model of the system and offer functionality that operates on this data. Additional agents are responsible for error handling or communication with other software systems

The following forces affect solution:

★ Agents often maintain their own state and data however, individual agents must effectively co operate to provide the overall task of the application. To achieve this they need a mechanism for exchanging data, messages and events.

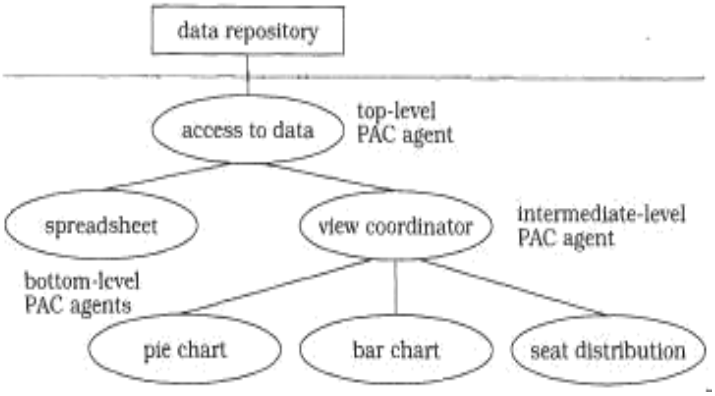
★ Interactive agents provide their own user interface, since their respective human-comp interactions often differ widely

★ Systems evolve over time. Their presentation aspect is particularly prone to change. The use of graphics, and more recently, multimedia features are ex: of pervasive changes to user interfaces. Changes to individual agents, or the extension of the system with new

agents, should not affect the whole system.

Solution:

- Structure the interactive application as a tree-like hierarchy f PAC agents every agent is responsible for a specific agent of the applications functionality and consists of three components:
  - Presentation
  - Abstraction
  - Control
- The agents presentation component provides the visible behavior of the PAC agent
- Its abstraction component maintains the data model that underlies the agent, and provides functionality that operates on this data.
- Its control component connects the presentation and abstraction components and provides the functionality that allow agent to communicate with other PAC agents.
- The top-level PAC agent provides the functional core of the system. Most other PAC agents depend or operate on its core.
- The bottom-level PAC agents represent self contained semantic concepts on which users
- of the system can act, such as spreadsheets and charts.
- The intermediate-level PAC agents represent either combination of, or relationship b/w. lower level agent.



Structure:

★ **Top level PAC agent:**

- Main responsibility is to provide the global data model of the software. This is maintained in the abstraction component of top level agent.
- The presentation component of the top level agent may include user-interface elements common to whole application.
- The control component has three responsibilities
  - Allows lower level agents to make use of the services of manipulate the global data model.
  - It co ordinates the hierarchy of PAC agents. It maintains information about connections b/w top level agent and lower-level agents.
  - It maintains information about the interaction of the user with system.

★ **Bottom level PAC agent:**

- Represents a specific semantic concept of the application domain, such as mail box in a n/w management system.
- The presentation component of bottom level PAC agents presents a specific view of the corresponding semantic concept, and provides access to all the functions users can apply to it.
- The abstraction component has a similar responsibility as that of top level PAC agent maintaining agent specific data.
- The control component maintains consistency b/w the abstraction and presentation

components, by avoiding direct dependencies b/w them. It serves as an adapter and performs both interface and data adaption.

★ **Intermediate level PAC agent**

- Can fulfill two different roles: composition and co ordination.
- It defines a new abstraction, whose behavior encompasses both the behavior of its component, and the new characteristics that are added to the composite object.
- Abstraction component maintains the specific data of the intermediate level PAC agent.
- Presentation component implements its user interface.

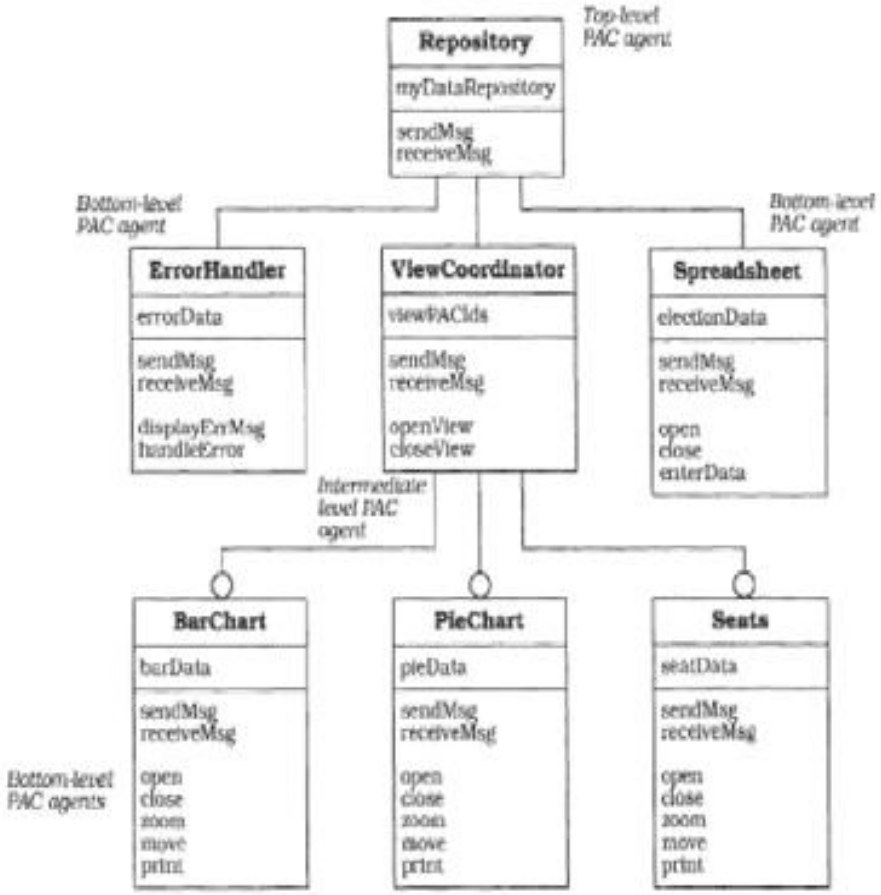
 Control component has same responsibilities of those of bottom level and top level PAC agents.

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

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

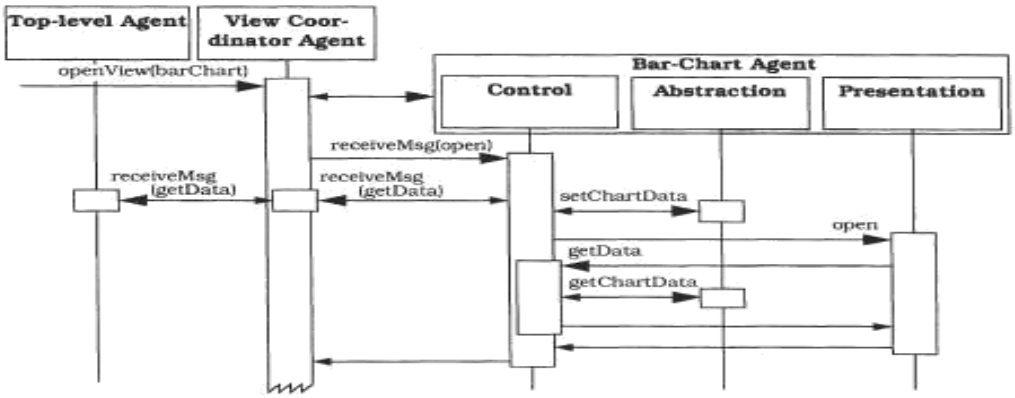
Class	Collaborators
Bottom-level Agent	• Top-level Agent • Intermediate-level Agent
Responsibility	
• Provides a specific view of the software or a system service, including its associated human-computer interaction.	

The following OMT diagram illustrates the PAC hierarchy of the information system for political elections

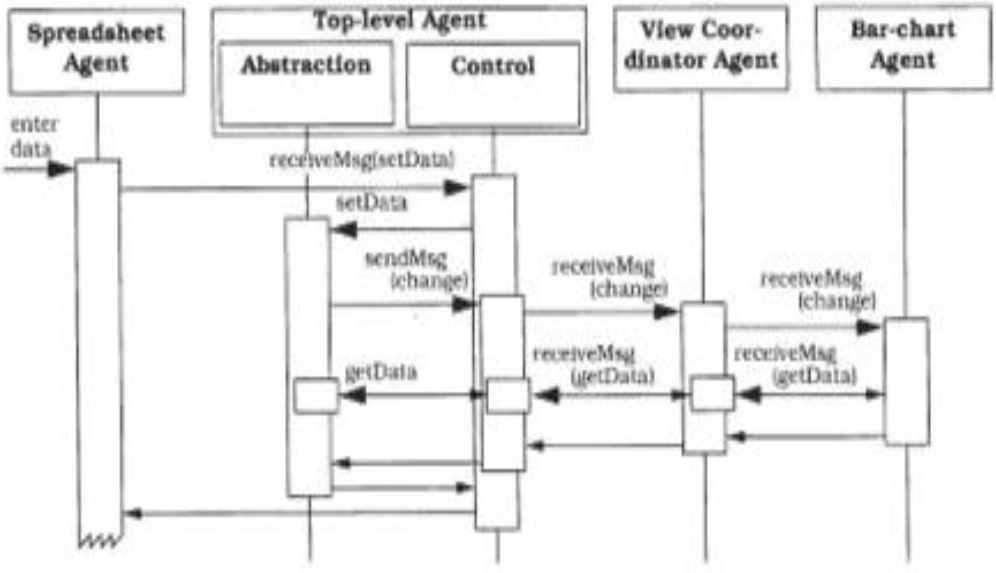


Dynamics:

- **Scenario I** describes the cooperation between different PAC agents when opening a new bar-chart view of the election data. It is divided into five phases:
-
  - A user asks the presentation component of the view coordinator agent to open a new bar chart.
  - The control of the view coordinator agent instantiates the desired bar-chart agent.
  - The view coordinator agent sends an 'open' event to the control component of the new bar-chart agent.
  - The control component of the bar-chart agent first retrieves data from the top-level PAC agent. The view coordinator agent mediates between bottom and top-level agents. The data returned to the bar-chart agent is saved in its abstraction component. Its control component then calls the presentation component to display the chart.
  - The presentation component creates a new window on the screen, retrieves data from the abstraction component by requesting it from the control component, and finally displays it within the new window.



- **Scenario II** shows the behavior of the system after new election data is entered, providing a closer look at the internal behavior of the toplevel PAC agent. It has five phases:
  - The user enters new data into a spreadsheet. The control component of the spreadsheet agent forwards this data to the toplevel PAC agent.
  - The control component of the top-level PAC agent receives the data and tells the top-level abstraction to change the data repository accordingly. The abstraction component of the top-level agent asks its control component to update all agents that depend on the new data. The control component of the top-level PAC agent therefore notifies the view coordinator agent.
  - The control component of the view coordinator agent forwards the change notification to all view PAC agents it is responsible for coordinating.
  - As in the previous scenario, all view PAC agents then update their data and refresh the image they display.



Implementation:

1) **Define a model of the application**
   Analyze the problem domain and map it onto an appropriate s/w structure.
2) **Define a general strategy for organizing the PAC hierarchy**
   Specify general guidelines for organizing the hierarchy of co operating agents.
   One rule to follow is that of "lowest common ancestor". When a group of lower level agents depends on the services or data provided by another agent, we try to specify this agent as the root of the sub tree formed by the lower level agents. As a consequence, only agents that provide global services rise to the top of the hierarchy.
3) **Specify the top-level PAC agent**
   Identify those parts of the analysis model that represent the functional core of the system.
4) **Specify the bottom-level PAC agent**
   Identify those components of the analysis model that represent the smallest self-contained units of the system on which the user can perform operations or view presentations.
5) **Specify bottom-level PAC agents for system service**
   Often an application includes additional services that are not directly related to its primary subject. In our example system we define an error handler.
6) **Specify intermediate level PAC agents to compose lower level PAC agents**
   Often, several lower-level agents together form a higher-level semantic concept on which users can operate.
7) **Specify intermediate level PAC agents to co ordinate lower level PAC agents**
   Many systems offer multiple views of the same semantic concept. For example, in text editors you find 'layout' and 'edit" views of a text document. When the data in one view changes, all other views must be updated.
8) **Separate core functionality from human-comp interaction.**
   For every PAC agent, introduce presentation and abstraction component.
9) **Provide the external interface to operate with other agents**
   Implement this as part of control component.
10) **Link the hierarchy together**
    Connect every PAC agent with those lower level PAC agents with which it directly co operates

Variants:

★ **PAC agents as active objects** - Every PAC agent can be implemented as an active object that lives in its own thread of control.

★ **PAC agents as processes** - To support PAC agents located in different processes or on remote machines, use proxies to locally represent these PAC agents and to avoid direct dependencies on their physical location.

Known uses:

- **Network traffic management**
  - Gathering traffic data from switching units.
  - Threshold checking and generation of overflow exceptions.
  - Logging and routing of network exceptions.
  - Visualization of traffic flow and network exceptions.
  - Displaying various user-configurable views of the whole network.
  - Statistical evaluations of traffic data.
  - Access to historic traffic data.
  - System administration and configuration.

Mobile robot

- Provide the robot with a description of the environment it will work in, places in this environment, and routes between places.
- Subsequently modify the environment.
- Specify missions for the robot.
- Control the execution of missions.
- Observe the progress of missions.

Consequences:

Benefits:-

- **separation of concerns**
  - Different semantic concepts in the application domain are represented by separate agents.
- **Support for change and extension**
  - Changes within the presentation or abstraction components of a PAC agent do not affect other agents in the system.
- **Support for multi tasking**
  - PAC agents can be distributed easily to different threads, processes or machines.
  - Multi tasking also facilitates multi user applications.

Liabilities:

✓ **Increased system complexity**

Implementation of every semantic concept within an application as its own PAC agent may result in a complex system structure.

✓ **Complex control component**

- Individual roles of control components should be strongly separated from each other. The implementations of these roles should not depend on specific details of other agents.
- The interface of control components should be independent of internal details.
- It is the responsibility of the control component to perform any necessary interface and data adaptation.

✓ **Efficiency:**

- Overhead in communication between PAC agents may impact system efficiency.
- Example: All intermediate-level agents are involved in data exchange. if a bottom-level agent retrieve data from top-level agent.

✓ **Applicability:**

- The smaller the atomic semantic concepts of an applications are, and the greater the similarly of their user interfaces, the less applicable this pattern is.

ADAPTABLE SYSTEMS

The systems that evolve over time - new functionality is added and existing services are changed are called adaptive systems.

They must support new versions of OS, user-interface platforms or third-party components and libraries. Design for change is a major concern when specifying the architecture of a software system.

We discuss two patterns that helps when designing for change.

- ***Microkernel pattern*** → applies to software systems that must be able to adapt to changing system requirements.

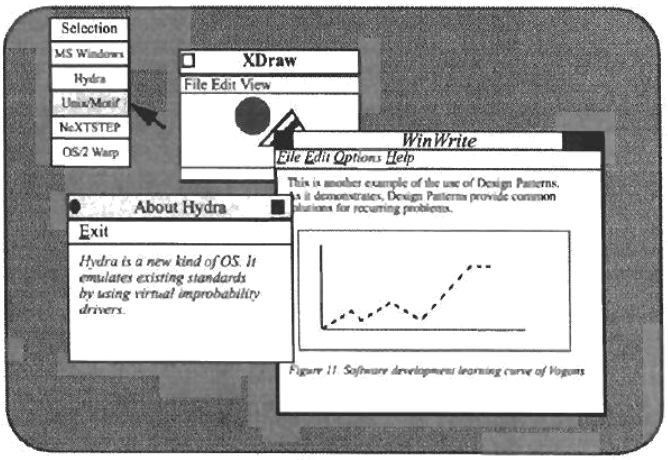
- ♥ ***Reflection pattern*** → provides a mechanism for changing structure and behavior of software systems dynamically.

MICROKERNEL

The microkernel architectural pattern applies to software systems that must be able to adapt to changing system requirements. It separates a minimal functional core from extended functionality and customer-specific parts the microkernel also serves as a socket for plugging in these extensions and coordinating their collaboration.

Example:

Suppose we intend to develop a new operating system for desktop computers called Hydra. One requirement is that this innovative operating system must be easily portable to the relevant hardware platforms, and must be able to accommodate future developments easily. It must also be able to run applications written for other popular operating systems such as Microsoft Windows and UNIX System V. A user should be able to choose which operating system he wants from a pop-up menu before starting an application. Hydra will display `all` the applications currently running within its main window:



Context:

The development of several applications that use similar programming interfaces that build on the same care functionality.

Problem:

Developing software for an application domain that needs to cope with a broad spectrum of similar standards and technology is a nontrivial task well known. Ex: are application platform such as OS and GUI'S.

The following forces are to be considered when designing such systems.

- ♣ The application platform must cope with continuous hardware and software evolution.
- ♣ The application platform should be portable, extensible and adaptable to allow easy integration of emerging technologies.

Application platform such as an OS should also be able to emulate other application platforms that belong to the same application domain. This leads to following forces.

- ♠ The applications in your domain need to support different but, similar application platforms.
- ♠ The applications may be categorized into groups that use the same functional core in different ways, requiring the underlying application platform to emulate existing standards. Additional force must be taken to avoid performance problem and to guarantee scalability.
    - The functional core of the application platform should be separated into a component with minimal memory size, and services that consume as little processing power as possible.

Solution:

- Encapsulates the fundamental services of your applications platform in a microkernel component.
- It includes functionality that enables other components running in different process to communicate with each other.
- It provides interfaces that enable other components to access its functionality.
    - Core functionality should be included in ***internal servers.***
    - ***External servers*** implement their own view of the underlying microkernel.
    - ***Clients*** communicate with external servers by using the communication facilities provided by microkernel.

Structure:

Microkernel pattern defines 5 kinds of participating components.

- ♠ Internal servers
- ♠ External servers
- ♠ Adapters
- ♠ Clients
- ♠ Microkernel

❖ **Microkernel**

- The microkernel represents the main component of the pattern.
- It implements central services such as communication facilities or resource handling.
- The microkernel is also responsible for maintaining system resources such as processes or files.
- It controls and coordinates the access to these resources.
- A microkernel implements atomic services, which we refer to as mechanisms.
- These mechanisms serve as a fundamental base on which more complex functionality called policies are constructed.

Class Microkernel	***Collaborators*** • Internal Server
Responsibility • Provides core mechanisms. • Offers communication facilities. • Encapsulates system dependencies. • Manages and controls resources.	

❖ **An internal server (subsystem)**

- Extends the functionality provided by microkernel.
- It represents a separate component that offers additional functionality.
- Microkernel invokes the functionality of internal services via service requests.
- Therefore internal servers can encapsulates some dependencies on the underlying hardware or software system.

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

❖ **An external server (personality)**

- Uses the microkernel for implementing its own view of the underlying application domain.
- Each external server runs in separate process.
- It receives service requests from client applications using the communication facilities provided by the microkernel, interprets these requests, executes the appropriate services, and returns its results to clients.

 Different external servers implement different policies for specific application domains.

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

❖ **Client:**

- It is an application that is associated with exactly one external server. It only accesses the programming interfaces provided by the external server.
- Problem arises if a client accesses the interfaces of its external server directly (direct dependency)
  - ✓ Such a system does not support changeability
  - ✓ If ext servers emulate existing application platforms clients will not run without modifications.

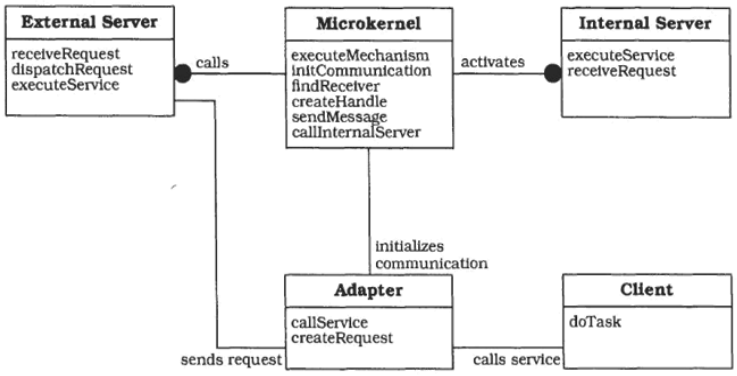
❖ **Adapter** (emulator)

- Represents the interfaces b/w clients and their external servers and allow clients to access the services of their external server in a portable way.
- They are part of the clients address space.
- The following OMT diagram shows the static structure of a microkernel system.

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.	

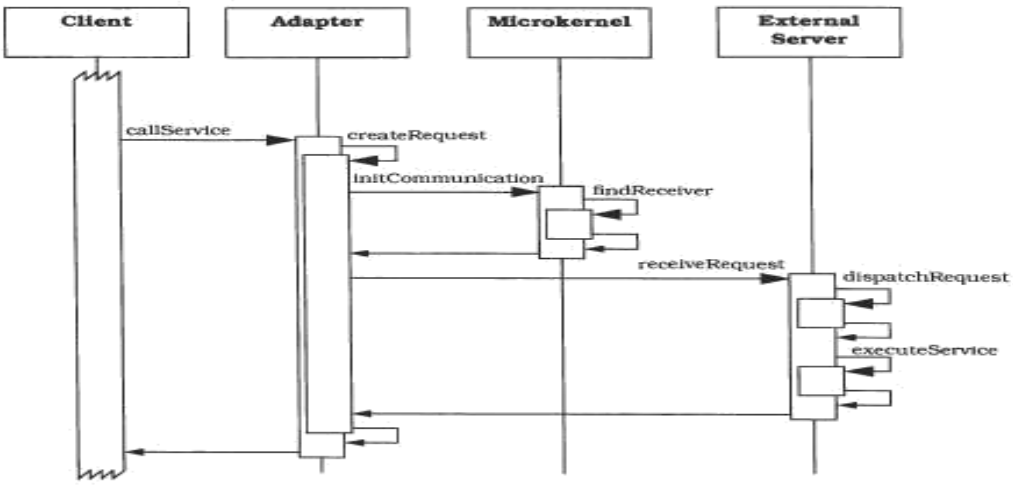
The following OMT diagram shows the static structure of a Microkernel system.



Dynamics:

Scenario I demonstrates the behavior when a client calls a service of its external server:

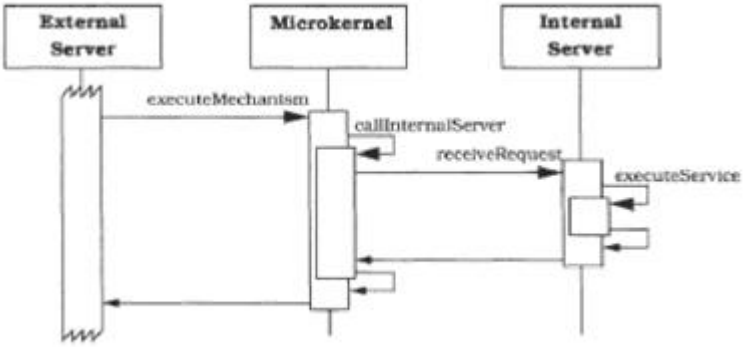
- At a certain point in its control flow the client requests a service from an external server by calling the adapter.
- The adapter constructs a request and asks the microkernel for a communication link with the external server.
- The microkernel determines the physical address of the external server and returns it to the adapter.
- After retrieving this information, the adapter establishes a direct communication link to the external server.
- The adapter sends the request to the external server using a remote procedure call.
- The external server receives the request, unpacks the message and delegates the task to one of its own methods. After completing the requested service, the external server sends all results and status information back to the adapter.
- The adapter returns to the client, which in turn continues with its control flow.



Scenario II illustrates the behavior of a Microkernel architecture when an external server requests a service that is provided by an internal server

- The external server sends a service request to the microkernel.
- A procedure of the programming interface of the microkernel is called to handle the service request. During method execution the microkernel sends a request to an internal server.
- After receiving the request, the internal server executes the requested service and sends all results back to the microkernel.
- The microkernel returns the results back to the external server.

★ Finally, the external server retrieves the results and continues with its control flow.



Implementation:

1. **Analyze the application domain:**
   Perform a domain analysis and identify the core functionality necessary for implementing ext servers.
2. **Analyze external servers**
   That is polices ext servers are going to provide
3. **Categorize the services**
   Group all functionality into semantically independent categories.
4. **Partition the categories**
   Separate the categories into services that should be part of the microkernel, and those that should be available as internal servers.
5. **Find a consistent and complete set of operations and abstractions** for every category you identified in step 1.
6. **Determine the strategies for request transmission and retrieval.**
   - Specify the facilities the microkernel should provide for communication b/w components.
   - Communication strategies you integrate depend on the requirements of the application domain.
7. **Structure the microkernel component**
   Design the microkernel using the layers pattern to separate system-specific parts from system-independent parts of the kernel.
8. **Specify the programming interfaces of microkernel**
   To do so, you need to decide how these interfaces should be accessible externally.
   You must take into an account whether the microkernel is implemented as a separate process or as a module that is physically shared by other component in the latter case, you can use conventional method calls to invoke the methods of the microkernel.

9. The microkernel is responsible for **managing all system resources** such as memory blocks, devices or **device contexts** - a handle to an output area in a GUI implementation.

10. **Design and implement the internal servers as separate processes or shared libraries**
    - Perform this in parallel with steps 7-9, because some of the microkernel services need to access internal servers.
    - It is helpful to distinguish b/w active and passive servers
      ✓ Active servers are implemented as processes

✓ Passive servers as shared libraries.

- Passive servers are always invoked by directly calling their interface methods, where as active server process waits in an event loop for incoming requests.

11 Implement the external servers

- Each external server is implemented as a separate process that provide its own service interface
- The internal architecture of an external server depends on the policies it comprises
- Specify how external servers dispatch requests to their internal procedures.

12. Implement the adapters

- Primary task of an adapter is to provide operations to its clients that are forwarded to an external server.
- You can design the adapter either as a conventional library that is statically linked to client during complication or as a shared library dynamically linked to the client on demand.

13. **Develop client applications**
or use existing ones for the ready-to-run microkernel system.

Example resolved:

Shortly after the development of Hydra has been completed, we are asked to integrate an external server that emulates the Apple MacOS operating system. To provide a MacOS emulation on top of Hydra, the following activities are necessary:

✓ *Building an external server* on top of the Hydra microkernel that implements all the programming interfaces provided by MacOS, including the policies of the Macintosh user interface.

✓ *Providing an adapter* that is designed as a library, dynamically linked to clients.

✓ *Implementing the internal servers* required for MacOS.

Variants:

- *Microkernel system with indirect client-server communications.*
  In this variant, a client that wants to send a request or message to an external server asks the microkernel for a communication channel.
- *Distributed microkernel systems.*
  In this variant a microkernel can also act as a message backbone responsible for sending messages to remote machines or receiving messages from them.

Known uses:

- The **Mach** microkernel is intended to form a base on which other operating systems can be emulated. One of the commercially available operating systems that use Mach as its system kernel is NeXTSTEP.
- The operating system **Amoeba** consists of two basic elements: the microkernel itself and a collection of servers (subsystems) that are used to implement the majority of Amoeba's functionality. The kernel provides four basic services: the management of processes and threads, the low-level-management of system memory, communication services, both for point-to-point communication as well as group-communication, and low-level I/O services.
- **Chorus** is a commercially-available Microkernel system that was originally developed specifically for real-time applications.
- **Windows NT** was developed by Microsoft as an operating system for high-performance
- servers. **MKDE** (Microkernel Datenbank Engine) system introduces an architecture for database engines that follows the Microkernel pattern.

Consequences:

The microkernel pattern offers some important *Benefits:*

- **Portability:**
  High degree of portability
- **Flexibility and extensibility:**
  - ✓ If you need to implement an additional view, all you need to do is add a new external server.
  - ✓ Extending the system with additional capabilities only requires the additional or extension of internal servers.
- **Separation of policy and mechanism**
  The microkernel component provides all the mechanisms necessary to enable external servers to implement their policies.

Distributed microkernel has further benefits:

- ♠ **Scalability**
  A distributed Microkernel system is applicable to the development of operating systems or database systems for computer networks, or multiprocessors with local memory
- ♠ **Reliability**
  A distributed Microkernel architecture supports availability, because it allows you to run the same server on more than one machine, increasing availability. Fault tolerance may be easily supported because distributed systems allow you to hide failures from a user.
- ♠ **Transparency**
  In a distributed system components can be distributed over a network of machines. In such a configuration, the Microkernel architecture allows each component to access other components without needing to know their location.

The microkernel pattern also has *Liabilities:*

- **Performance:**
  Lesser than monolithic software system therefore we have to pay a price for flexibility and extensibility.
- **Complexity of design and implementation:**
  Develop a microkernel is a non-trivial task.

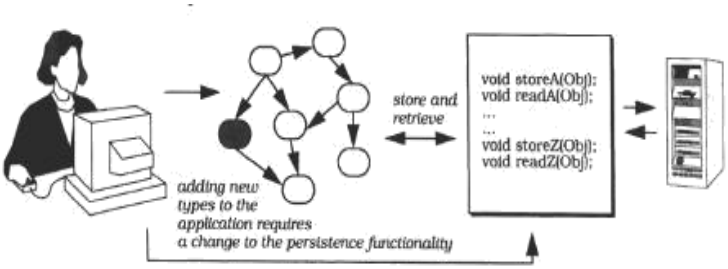
REFLECTION

The reflection architectural pattern provides a mechanism for changing structure and behavior of software systems dynamically. It supports the modification of fundamental aspects, such as the type structures and function call mechanisms. In this pattern, an application is split into two parts:

- ♠ *A Meta level provides information about selected system properties and makes the s/w self aware.*
- ♠ *A base level includes application logic changes to information kept in the Meta level affect subsequent base-level behavior.*

Example:

Consider a C++ application that needs to write objects to disk and read them in again. Many solutions to this problem, such as implementing type-specific store and read methods, are expensive and error-prone. Persistence and application functionality are strongly interwoven. Instead we want to develop a persistence component that is independent of specific type structures



Context:

Building systems that support their own modification a prior

Problem:

- Designing a system that meets a wide range of different requirements a prior can be an overwhelming task.
- A better solution is to specify an architecture that is open to modification and extension i.e., we have to design for change and evolution.
- Several forces are associated with the problem:
  - ✓ Changing software is tedious, error prone and often expensive.
  - ✓ Adaptable software systems usually have a complex inner structure. Aspects that are subject to change are encapsulated within separate components.
  - ✓ The more techniques that are necessary for keep in a system changeable the more awkward and complex its modifications becomes.
  - ✓ Changes can be of any scale, from providing shortcuts for commonly used commands to adapting an application framework for a specific customer.
  - ✓ Even fundamental aspects of software systems can change for ex. communication mechanisms b/w components.

Solution:

- ★ Make the software self-aware, and make select aspects of its structure and behavior accessible for adaptation and change.
  - This leads to an architecture that is split into two major parts: A Meta level A base level
- ★ Meta level provides a self representation of the s/w to give it knowledge of its own structure and behavior and consists of so called *Meta objects* (they encapsulate and represent information about the software). Ex: type structures algorithms or function call mechanisms.
- ★ Base level defines the application logic. Its implementation uses the Meta objects to remain independent of those aspects that are likely to change.
- ★ An interface is specified for manipulating the Meta objects. It is called the *Meta object protocol* (MOP) and allows clients to specify particular changes.

Structure:

- ♥ Meta level
- ♥ Meta objects protocol(MOP)
- ♥ Base level

❖ **Meta level**

- ✓ Meta level consists of a set of Meta objects. Each Meta object encapsulates selected information about a single aspect of a structure, behavior, or state of the base level.

  There are three sources for such information.
  - It can be provided by run time environment of the system, such as C++ type identification objects.
  - It can be user defined such as function call mechanism
  - It can be retrieved from the base level at run time.
- ✓ All Meta objects together provide a self representation of an application.
- ✓ What you represent with Meta objects depends on what should be adaptable only system details that are likely to change r which vary from customer to customer should be encapsulated by Meta objects.
- ✓ The interface of a Meta objects allows the base level to access the information it maintains or the services it offers.

❖ **Base level**

✓ It models and implements the application logic of the software. Its component represents the various services the system offers as well as their underlying data model.

✓ It uses the info and services provided by the Meta objects such as location information about components and function call mechanisms. This allows the base level to remain flexible.

✓ Base level components are either directly connected to the Meta objects and which they depend or submit requests to them through special retrieval functions.

Class Base Level	***Collaborators*** • Meta Level
Responsibility • Implements the application logic. • Uses information provided by the meta level.	

Class Meta Level	***Collaborators*** • Base Level
Responsibility • Encapsulates system internals that may change. • Provides an interface to facilitate modifications to the meta-level.	

❖ **Meta object protocol (MOP)**

✓ Serves an external interface to the Meta level, and makes the implementation of a reflective system accessible in a defined way.

✓ Clients of the MOP can specify modifications to Meta objects or their relationships using the base level

✓ MOP itself is responsible for performing these changes. This provides a reflective application with explicit control over its own modification.

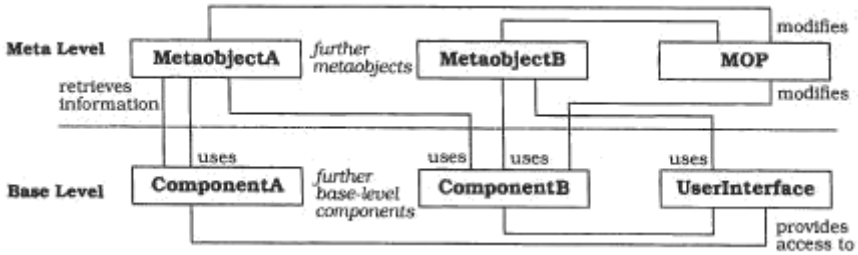
✓ Meta object protocol is usually designed as a separate component. This supports the implementation of functions that operate on several Meta objects.

✓ To perform changes, the MOP needs access to the internals of Meta objects, and also to base level components (sometimes).

One way of providing this access is to allow the MOP to directly operate on their internal states. Another way (safer, inefficient) is to provide special interface for their manipulation, only accessible by MOP.

Class Metaobject Protocol	***Collaborators*** • Meta Level • Base Level
Responsibility • Offers an interface for specifying changes to the meta level. • Performs specified changes	

The general structure of a reflective architecture is very much like a Layered system



Dynamics:

students refer text book for scenarios

Implementation:

Iterate through any subsequence if necessary.

1. Define a model of the application

Analyze the problem domain and decompose it into an appropriate s/w structure.

2. Identify varying behavior

- ✓ Analyze the developed model and determine which of the application services may vary and which remain stable.
- ✓ Following are ex: of system aspects that often vary
  - o Real time constraints
  - o Transaction protocols
  - o Inter Process Communication mechanism
  - o Behavior in case of exceptions
  - o Algorithm for application services.

3. **Identify structural aspects** of the system, which when changed, should not affect the implementation of the base level.

4. Identify system services that support both the variation of application services identified

In step 2 and the independence of structural details identified in step 3 Eg: for system services are

- ✓ Resource allocation
- ✓ Garbage allocation
- ✓ Page swapping
- ✓ Object creation.

5. Define the meta objects

- ✓ For every aspect identified in 3 previous steps, define appropriate Meta objects.
- ✓ Encapsulating behavior is supported by several domain independent design patterns, such as objectifier strategy, bridge, visitor and abstract factory.

6. Define the MOP

- ✓ There are two options for implementing the MOP.
  - Integrate it with Meta objects. Every Meta object provides those functions of the MOP that operate on it.
  - Implement the MOP as a separate component.
- ✓ Robustness is a major concern when implementing the MOP. Errors in change specifications should be detected wherever possible.

7. Define the base level

- ✓ Implement the functional core and user interface of the system according to the analysis model developed in step 1.
- ✓ Use Meta objects to keep the base level extensible and adaptable. Connect every base level component with Meta objects that provide system information on which they depend, such as type information etc.
- ✓ Provide base level components with functions for maintaining the relationships with their associated Meta objects. The MOP must be able to modify every relationship b/w base level and Meta level.

Example resolved:

Unlike languages like CLOS or Smalltalk. C++ does not support reflection very well-only the standard class type_info provides reflective capabilities: we can identify and compare types. One solution for providing extended type information is to include a special step in the compilation process. In this, we collect type information from the source files of the application, generate code for instantiating the' metaobjects, and link this code with the application. Similarly, the 'object creator' metaobject is generated. Users specify code for instantiating an 'empty' object of every type, and the toolkit generates the code for the metaobject. Some parts of the system are

compiler-dependent, such as offset and size calculation.

Variants:

- ♥ *Reflection with several Meta levels*

  Sometimes metaobjects depend on each other. Such a software system has an infinite number of meta levels in which each meta level is controlled by a higher one, and where each meta level has its own metaobject protocol. In practice, most existing reflective software comprises only one or two meta levels.

Known uses:

- ❖ **CLOS.**

  This is the classic example of a reflective programming language [Kee89]. In CLOS, operations defined for objects are called generic functions, and their processing is referred to as generic function invocation. Generic function invocation is divided into three phases:

  - ♣ The system first determines the methods that are applicable to a given invocation.
  - ♣ It then sorts the applicable methods in decreasing order of precedence.
  - ♣ The system finally sequences the execution of the list of applicable methods.

- ❖ **MIP**

  It is a run-time type information system for C++. The functionality of MIP is separated into four layers:

  - ♣ The first layer includes information and functionality that allows software to identify and compare types.
  - ♣ The second layer provides more detailed information about the type system of an application.
  - ♣ The third layer provides information about relative addresses of data members, and offers functions for creating 'empty' objects of user-defined types.
  - ♣ The fourth layer provides full type information, such as that about friends of a class, protection of data members, or argument and return types of function members.

- ❖ **PGen**

  It allows an application to store and read arbitrary C++ object structures.

- ❖ **NEDIS**

  NEDIS includes a meta level called run-time data dictionary. It provides the following services and system information:

  - ♣ Properties for certain attributes of classes, such as their allowed value ranges.
  - ♣ Functions for checking attribute values against their required properties.
  - ♣ Default values for attributes of classes, used to initialize new objects.
  - ♣ Functions specifying the behavior of the system in the event of errors
  - ♣ Country-specific functionality, for example for tax calculation.
  - ♣ Information about the 'look and feel' of the software, such as the layout of input masks or the language to be used in the user interface.

- ❖ **OLE 2.0**

  It provides functionality for exposing and accessing type information about OLE objects and their interfaces.

Consequences:

The reflection architecture provides the following *Benefits:*

- **No explicit modification of source code:**

  You just specify a change by calling function of the MOP.

- **Changing a software system is easy**

MOP provides a safe and uniform mechanism for changing s/w. it hides all specific techniques such as use of visitors, factories from user.

- **Support for many kind of change:**
  Because Meta objects can encapsulate every aspect of system behavior, state and structure.

The reflection architecture also has *Liabilities:*

- **Modifications at meta level may cause damage:**
  - ✓ Incorrect modifications from users cause serious damage to the s/w or its environment. Ex: changing a database schema without suspending the execution of objects in the applications that use it or passing code to the MOP that includes semantic errors
  - ✓ Robustness of MOP is therefore of great importance.
- **Increased number of components:**
  It includes more Meta objects than base level components.
- **Lower efficiency:**
  Slower than non reflective systems because of complex relnp b/w base and meta level.
- **Not all possible changes to the software are supported**
  Ex: changes or extensions to base level code.
- **Not all languages support reflection**
  Difficult to implement in C ++