System Architecture

- Microsoft Application Architecture Guide
  - Chapter 3
- An Introduction to Software Architecture
  - http://www.cs.cmu.edu/afs/cs/project/able/ftp/intro_softarch/intro_softarch.pdf

- Problem
  - How to design components?
  - How to structure a logical solution?
  - How to organize the codebase?
- Solution
  - Architectural Patterns and Styles

Architectural Patterns and Styles

- An architectural style, sometimes called an architectural pattern
  - is a set of principles—a coarse grained pattern that provides an abstract framework for a family of systems.
  - An architectural style improves partitioning and promotes design reuse by providing solutions to frequently recurring problems.
  - You can think of architecture styles and patterns as sets of principles that shape an application.

Architectural Patterns and Styles

- More specifically, an architectural style determines the
  - vocabulary of components and connectors that can be used in instances of that style,
  - together with a set of constraints on how they can be combined.
    - These can include topological constraints on architectural descriptions (e.g., no cycles).
    - Other constraints—say, having to do with execution semantics—might also be part of the style definition.”

Architectural Patterns and Styles

Category	**Architecture styles**
Structure	Component-Based Object-Oriented Data Abstraction Layered Architecture Table Driven Interpreters State transition systems
Deployment	Client/Server N-Tier / 3-Tier Peer-to-peer
Communication	RPC Service-Oriented Architecture (SOA Message Bus, Pipes and Filters, Repositories Event-based, Implicit Invocation

Structure Patterns

Structure Patterns Problem

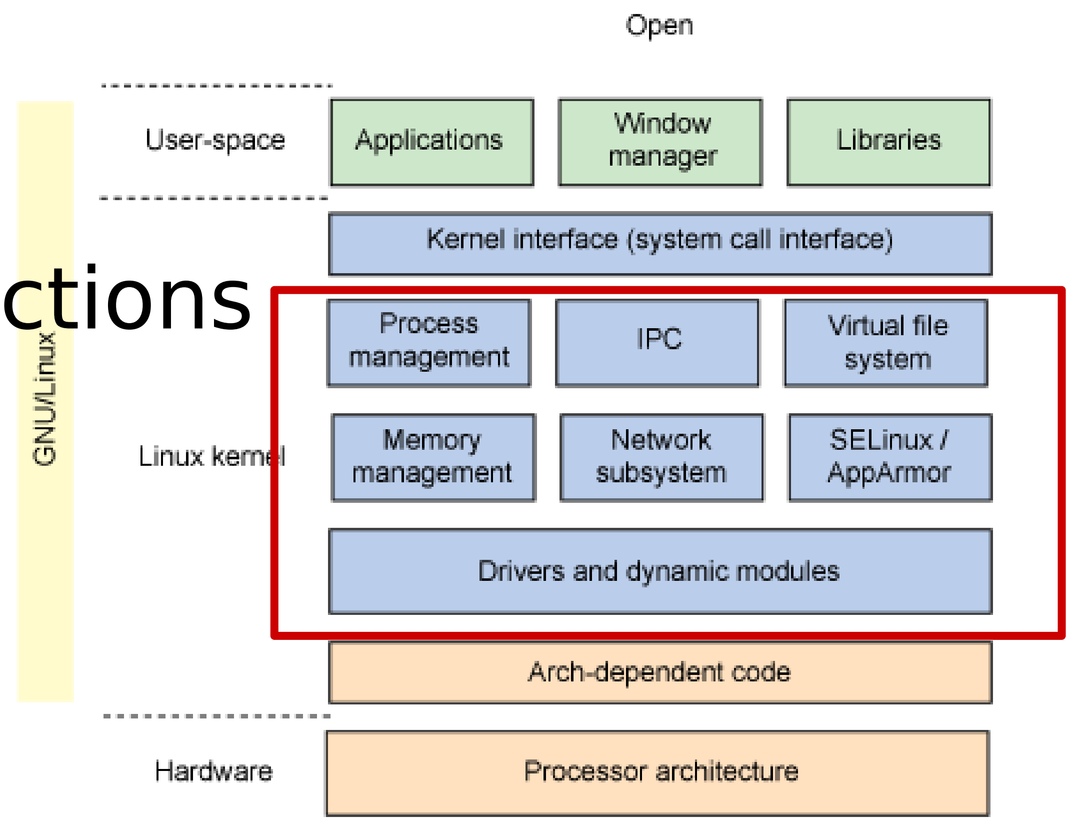
- How to design components?
- How to structure a logical solution?
- How to organize the codebase?
- Structure
  - Component-Based
  - Object-Oriented
  - Data Abstraction
  - Layered Architecture
  - Table Driven Interpreters
  - State transition systems

Structure Patterns
Data Abstraction

- data representations and their associated primitive operations are encapsulated in an abstract data type
- The components are modules
  - and structures
- Modules interact through functions and procedures
- Modules should preserve
  - integrity of representation (interface)
  - hide implementation

Structure Patterns
Data Abstraction

- Each modules is implemented in independent files
- Exports a set of functions
- Hide internal representation



Structure Patterns
Components, Modules, and Functions

- A component or an object should not rely on internal details of other components or objects.
  - Each component or object should call a method of another object or component,
  - that method should have information about how to process the request and, if appropriate, how to route it to appropriate subcomponents or other components.
  - Helps to create an application that is more maintainable and adaptable.

Structure Patterns
Components, Modules, and Functions

- Do not overload the functionality of a component.
  - Applying the single responsibility and separation of concerns principles will help you to avoid this.
- Overloaded components
  - often have many functions and properties
  - providing business functionality mixed with crosscutting functionality
    - such as logging and exception handling.
  - The result is a design that is very error prone and difficult to maintain.

Structure Patterns
Components, Modules, and Functions

- Understand how components will communicate with each other.
  - Requires an understanding of the deployment scenarios your application must support.
  - You must determine if all components will run within the same process, or if communication across physical or process boundaries must be supported
    - perhaps by implementing message-based interfaces.

Structure Patterns
Components, Modules, and Functions

- Keep crosscutting code abstracted from the application business logic as far as possible.
  - Crosscutting code refers to code related to security, communications, or operational management such as logging and instrumentation.
  - Mixing the code that implements these functions with the business logic can lead to a design that is difficult to extend and maintain. Changes to the crosscutting code require touching all of the business logic code that is mixed with the crosscutting code.
  - Consider using frameworks and techniques (such as aspect oriented programming) that can help to manage crosscutting concerns.
-

Structure Patterns
Components, Modules, and Functions

- Define a clear contract for components.
  - Components, modules, and functions should define a contract or interface specification that describes their usage and behavior clearly.
- The contract should describe
  - how other components can access the internal functionality of the component, module, or function;
  - the behavior of that functionality in terms of pre-conditions, post-conditions, side effects, exceptions, performance characteristics, and other factors.

Structure Patterns Object-Oriented

- Components are objects
  - encapsulate data and associated operations
- Connectors are messages and method invocations
- Advantages
  - “Infinite malleability” of object internals as long as interface is maintained
  - System decomposition into sets of interacting agents
  - Easily produce concurrent systems
- Disadvantages
  - Objects must know identities of other objects
  - Side effects in object method invocations

Structure Patterns Component-Based

- Decomposition of the design into individual functional or logical components
  - that expose well-defined communication interfaces containing methods, events, and properties.
- This provides a higher level of abstraction than object-oriented design principles
  - does not focus on issues such as communication protocols and shared state.
- Depend upon a mechanism within the platform that provides an environment in which they can execute,
  - often referred to as component architecture
  - component object model (COM), distributed component object model (DCOM) in Windows,Common Object Request Broker Architecture (CORBA) and Enterprise JavaBeans (EJB)

Structure Patterns Component-Based

- The key principle is the use of components that are:
- Reusable.
  - Components are usually designed to be reused in different scenarios in different applications.
- Replaceable.
  - Components may be readily substituted with other similar components.
- Not context specific
  - Specific information, such as state data, should be passed to the component instead of being included in or accessed by the component.
- Extensible
  - A component can be extended from existing components to provide new behavior.
- Encapsulated.
  - Components expose interfaces and do not reveal details of the internal processes or stat
- Independent
  - Components are designed to have minimal dependencies on other components.

Structure Patterns Component-Based

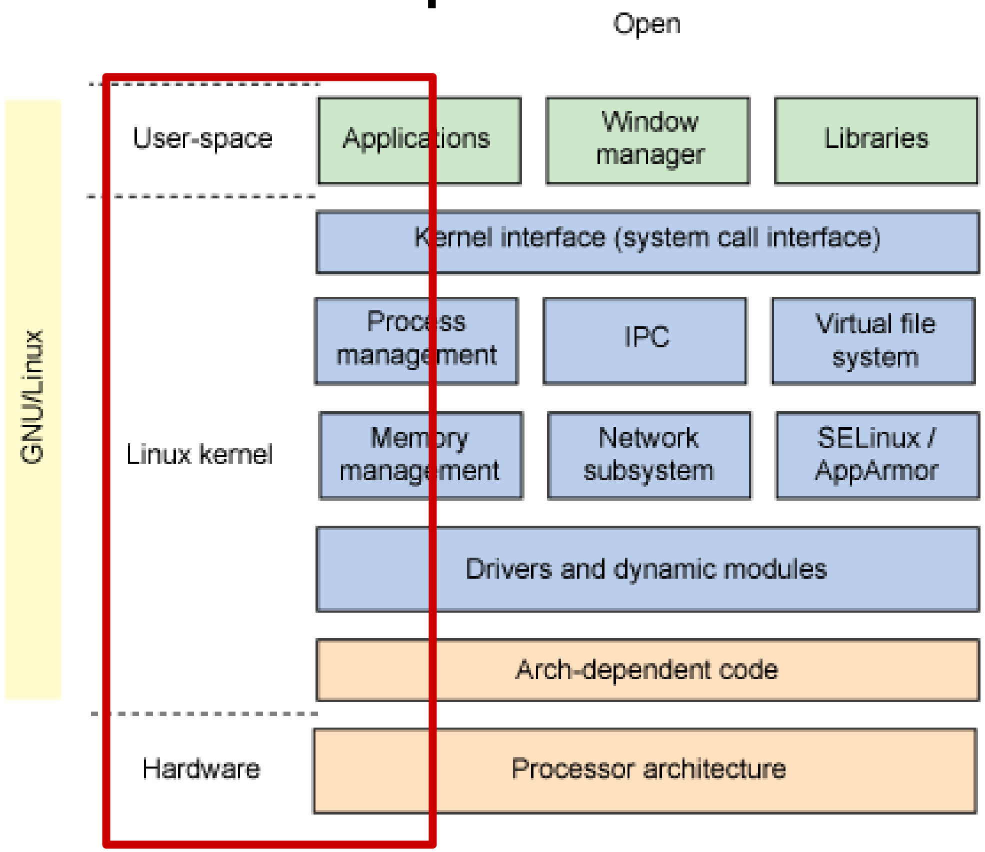
- Ease of deployment
  - As new compatible versions become available, you can replace existing versions with no impact on the other components or the system as a whole.
- Reduced cost.
  - The use of third-party components allows you to spread the cost of development and maintenance.
- Ease of development.
  - Components implement well-known interfaces to provide defined functionality, allowing development without impacting other parts of the system.
- Reusable.
  - The use of reusable components means that they can be used to spread the development and maintenance cost across several applications or systems.
- Mitigation of technical complexity.
  - Use of a component container and its services.
  - Example component services include component activation, lifetime management, method queuing, eventing, and transactions.

Structure Patterns
Layered Architecture

- Focuses on the grouping of related functionality within an application into distinct layers.
  - Functionality within each layer is related by a common role or responsibility.
- A layered system is organized hierarchically,
  - each layer providing service to the layer above it and serving as a client to the layer below.
- Communication between layers is explicit and loosely coupled.
- Helps to support a strong separation of concerns that, in turn, supports flexibility and maintainability.

Structure Patterns
Layered Architecture

- The most widely known examples
  - Layered commu-nication protocols
  - Other application areas for this style include database systems and operating systems



Structure Patterns
Layered Architecture

- Support design based on increasing levels of abstraction.
  - Allows implementors to partition a complex problem into a sequence of incremental steps.
- Support enhancement.
  - Each layer interacts with at most the layers below and above, changes to the function of one layer affect at most two other layers.
- Support reuse.
  - Like abstract data types, different implementations of the same layer can be used interchangeably, provided they support the same interfaces to their adjacent layers.
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Structure Patterns
Layered Architecture

- Isolation
  - Allows you to isolate technology upgrades to individual layers in order to reduce risk and minimize impact on the overall system.
- Manageability
  - Separation of core concerns helps to identify dependencies, and organizes the code into more manageable sections.
- Performance.
  - Distributing the layers over multiple physical tiers can improve scalability, fault tolerance, and performance.
- Testability.
  - Increased testability arises from having well-defined layer interfaces, as well as the ability to switch between different implementations of the layer interfaces.

Structure Patterns
Layered Architecture

- Not all systems are easily structured in a layered fashion.
  - considerations of performance may require closer coupling between logically high-level functions and their lower-level implementations.
- It can be quite difficult to find the right levels of abstraction.
  -

Structure Patterns Application Layers

- Separate the areas of concern.
  - Break your application into distinct features that overlap in functionality as little as possible.
  - A feature or functionality can be optimized independently of other features
  - The fail of one functionality will not cause other features to fail as well, and they can run independently of one another.
  - Makes the application easier to understand and design, and facilitates management of complex interdependent systems.
- Be explicit about how layers communicate with each other.
  - Make explicit decisions about the dependencies between layers and the data flow between them.
- Use abstraction to implement loose coupling between layers.
  - Use Interface types or abstract base classes to define a common interface or shared abstraction (dependency inversion) that must be implemented by interface components.

Structure Patterns Application Layers

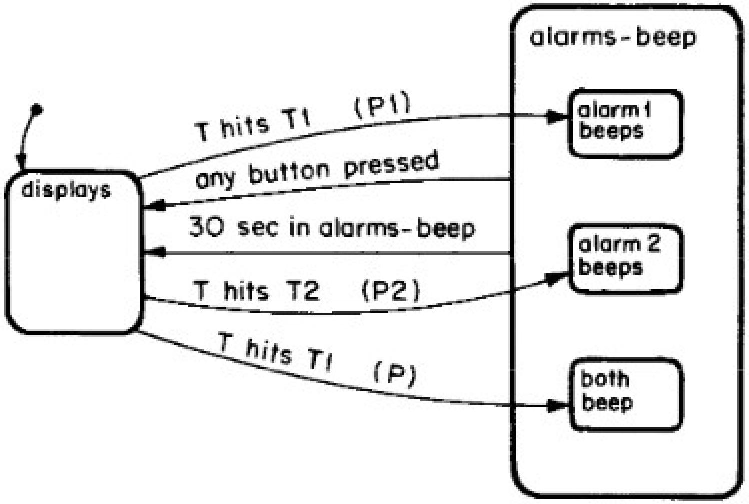
- Do not mix different types of components in the same logical layer.
  - Start by identifying different areas of concern, and then group components associated with each area of concern into logical layers.
  - For example, the UI layer should not contain business processing components, but instead should contain components used to handle user input and process user requests.
- Keep the data format consistent within a layer or component.
  - Mixing data formats will make the application more difficult to implement, extend, and maintain.
  - Every time you need to convert data from one format to another, you are required to implement translation code to perform the operation and incur a processing overhead.

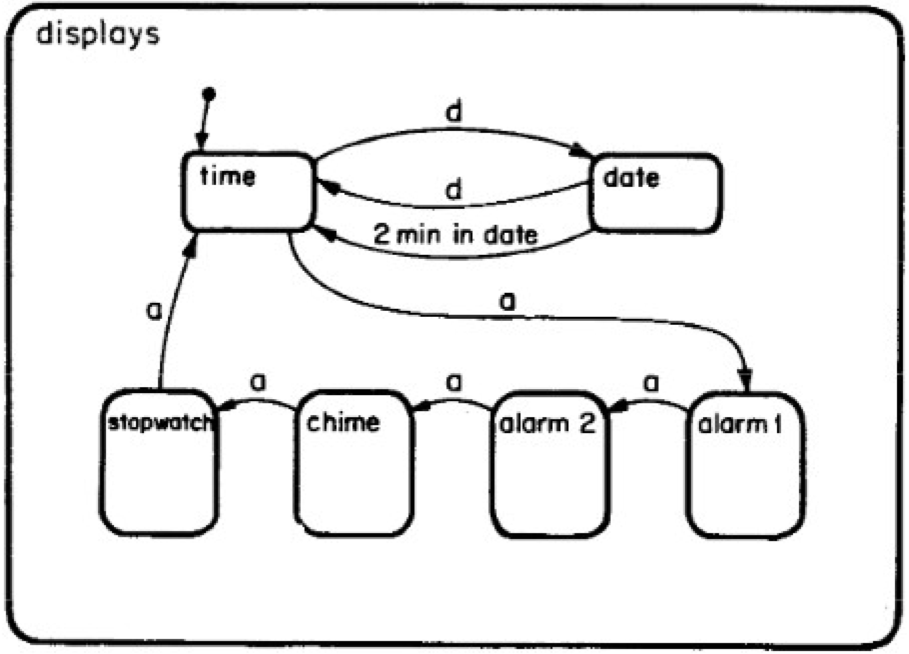
Structure Patterns
Table Driven Interpreters/VMs

- Virtual machines are used as interpreters
- An interpreter generally has four components:
  - an interpretation engine to do the work,
  - a memory that contains the pseudo-code to be interpreted
  - a representation of the control state of the interpretation engine,
  - a representation of the current state of the program being simulated.
- Interpreters are commonly used to build virtual machines
  - Close the gap between the computing engine expected by program (e.g Java) and the computing engine available in hardware.
  - Java program executed in windows, linux or mac os

Structure Patterns
State transition systems

- Organization reactive systems
- Systems are defined in terms of
  - set of states
  - set of named transitions that move a system from one state to another.





Deployment Patterns

Deployment Patterns Problem

- How to distribute/deploy components sub-systems on different hardware
- how to distribute responsibilities among node?
- Deployment
  - Client/Server
  - N-Tier / 3-Tier
  - Peer-to-peer

Deployment Patterns Client/Server

- Distributed systems that
  - involve a separate client and server system,
  - and a connecting network.
- The simplest form of client/server system involves a server application that is accessed directly by multiple clients,
  - referred to as a 2-Tier architectural style.
- Describes the relationship between a client and one or more servers,
  - where the client initiates one or more requests (perhaps using a graphical UI),
  - waits for replies,
  - processes the replies on receipt.
- The server typically authorizes the user and then carries out the processing required to generate the result.
- The server may send responses using a range of protocols and data formats to communicate information to the client.

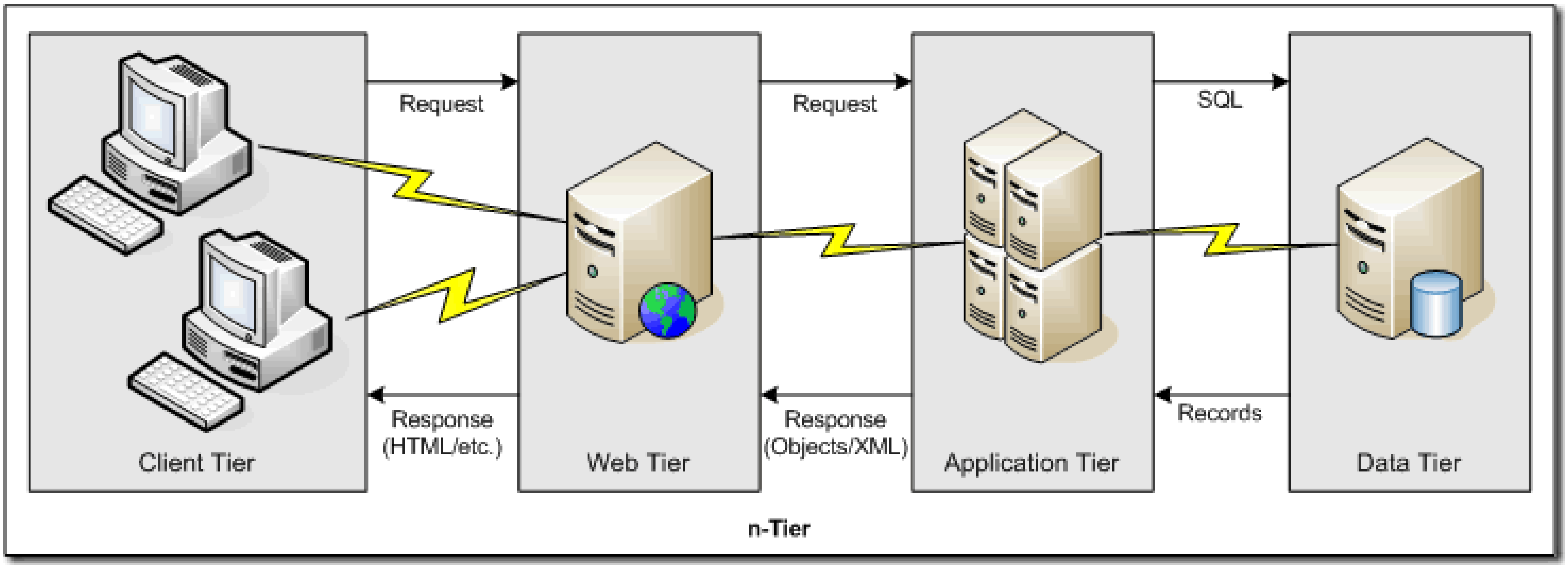
Deployment Patterns Client/Server

- Higher security.
  - All data is stored on the server, which generally offers a greater control of security than client machines.
- Centralized data access.
  - Because data is stored only on the server, access and updates to the data are far easier to administer than in other architectural styles.
- Ease of maintenance
  - Roles and responsibilities of a computing system are distributed among several servers that are known to each other through a network.
  - Ensures that a client remains unaware and unaffected by a server repair, upgrade, or relocation.

Deployment Patterns
N-Tier / 3-Tier

- Ddescribe the separation of functionality into segments
  - in the same way as the layered style,
  - but with each tier on a separate computer.
- N-tier application architecture is characterized by
  - the functional decomposition of applications, service components
  - their distributed deployment, providing improved scalability, availability, manageability, and resource utilization.
  - Each tier is completely independent from all other tiers, except for those immediately above and below it.

Deployment Patterns
N-Tier / 3-Tier



Deployment Patterns N-Tier / 3-Tier

- Maintainability.
  - Each tier is independent of the other tiers,
  - updates or changes can be carried out without affecting the application as a whole.
- Scalability
  - Tiers are based on the deployment of layers,
  - scaling out an application is reasonably straightforward.
- Flexibility.
  - Each tier can be managed or scaled independently
- Availability
  - Applications can exploit the modular architecture of enabling systems using easily scalable components, which increases availability.

Deployment Patterns
Peer-to-peer

- Client-Queue-Client systems.
  - This approach allows clients to communicate with other clients through a server-based queue.
    - Clients can read data from and send data to a server that acts simply as a queue to store the data.
    - This allows clients to distribute and synchronize files and information.
    - This is sometimes known as a passive queue architecture.

Deployment Patterns
Peer-to-peer

- Peer-to-Peer (P2P) applications.
  - Developed from the Client-Queue-Client style,
  - P2P style allows the client and server to swap their roles in order to distribute and synchronize files and information across multiple clients.
  - It extends the client/ server style through multiple
    - responses to requests,
    - shared data,
    - resource discovery,
    - resilience to removal of peers.

Deployment Patterns Peer-to-peer

- State and behavior are distributed among peers which can act as either clients or servers.
  - A single component can be a client and a server
- Design ensures users contribute resources to the system
- All nodes have the same capabilities and responsibilities
- Correct operation not dependent on a central system
- Can be design to offer some anonymity
- Data placement (access) algorithm
  - Key issue for efficient operation

Deployment Patterns Peer-to-peer

- Nodes responsibilities can be replicated
  - Increases Availability
  - Increases reliability,
  - Increases faul-tolerance
- Simple algorithms
  - Eases management, configuration

Communication Patterns

Communication Patterns Problem

- How to connect 2 components
  - Just one main.c
  - Copy & paste of A.c B.c into main.c
  - gcc main.c
- How to connect 2 components
  - Just one main.c
  - Transform B.c → libB.o A.c → libA.o
  - gcc main.c -lB -lA

Communication Patterns Problem

- How to connect 2 components
  - Just one main.c
    - gcc *.c
- How to integrate multiple applications
  - so that they work together
  - and can exchange information
  - and guarantee consistency?
  - With ease of programming
- Communication
  - RPC
  - Service-Oriented Architecture (SOA
  - Message Bus,
  - Pipes and Filters,
  - Repositories
  - Event-based, Implicit Invocation

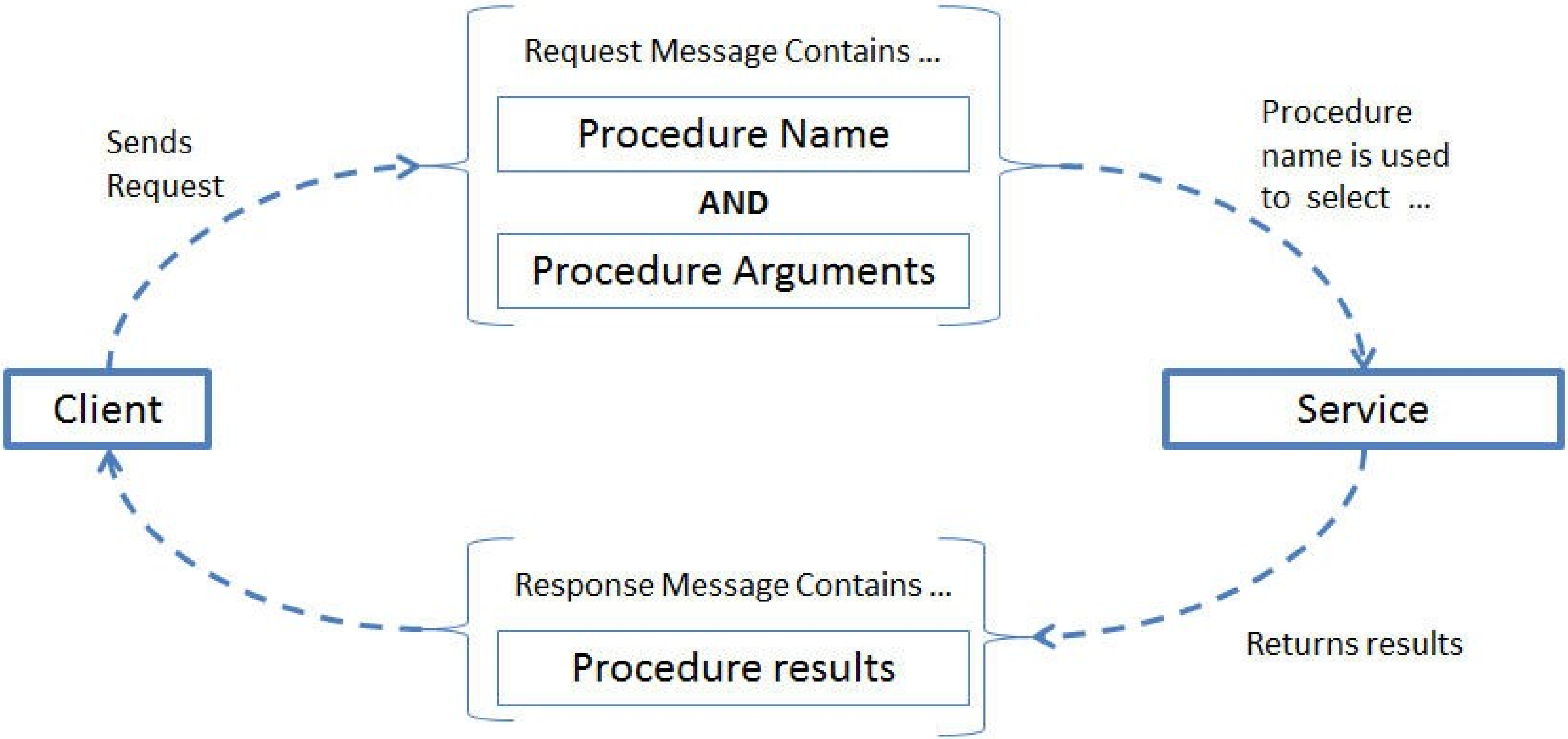
Communication Patterns Problem

- How to connect 2 components
  - Make them independent components
  - Select a communication pattern
    - RPC
    - Service

Communcation Patterns
Remote Procedure Call

- Component functionality is provided as a set of function calls
  - Applications call methods/function that are executed by a different component
- Is tightly coupled
  - use specific technics to perform communication
  - No standards-based mechanisms to be invoked, published, and discovered
- Application functionality are provided as a set o functions

Communication Patterns
RPC



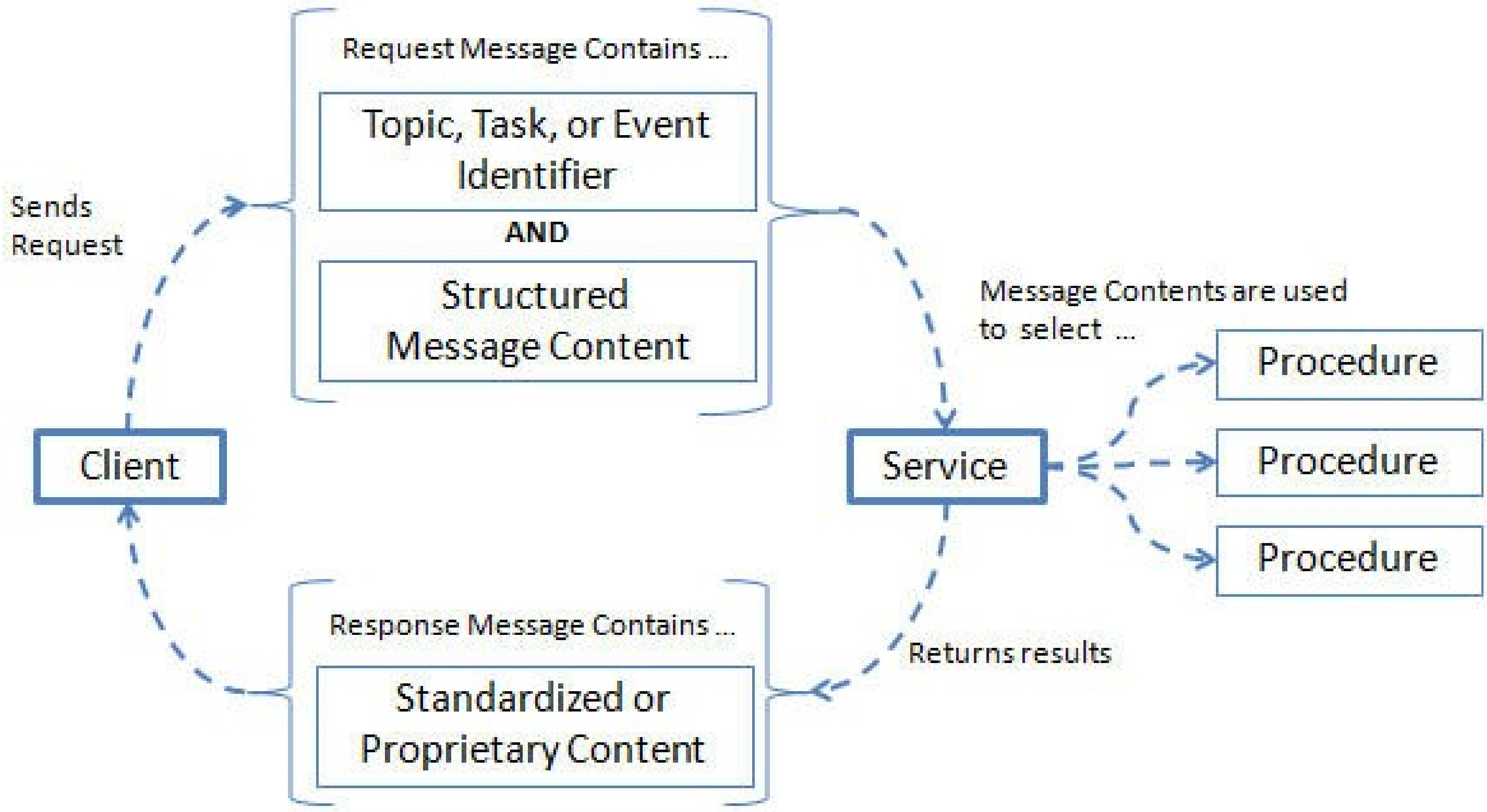
Communication Patterns RPC

- Services are autonomous.
  - each service is maintained, developed, deployed, and versioned independently.
- Services are distributable
  - Services can be located anywhere on a network, locally or remotely
  - as long as the network supports the required communication protocols
- Services share interfaces
  - Functions (names, arguments, return)
- Just provides programming abstractions
  - Network implementation hiding

Communication Patterns Service-Oriented Architecture

- application functionality is provided as a set of services,
  - Other applications make use of those services
- Services are loosely coupled
  - use standards-based interfaces to be invoked, published, and discovered.

Communication Patterns Service-Oriented Architecture



Communication Patterns Service-Oriented Architecture

- Services are autonomous.
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- Services are distributable
  - Services can be located anywhere on a network, locally or remotely
  - as long as the network supports the required communication protocols.

Communication Patterns
Service-Oriented Architecture

- Services share schema and contract, not interfaces.
- Compatibility is based on policy
  - Definition of features such as transport, protocol, and security.
-

Communication Patterns Service-Oriented Architecture

- Domain alignment
  - Reuse of common services with standard interfaces
  - Increases business and technology opportunities and reduces cost.
- Abstraction
  - Services are autonomous and accessed through a formal contract,
  - provides loose coupling and abstraction.
- **Discoverability**
  - Services can expose descriptions that allow other applications and services to locate them and automatically determine the interface.
- **Interoperability**
  - Formats are based on industry standard
  - provider and consumer of the service can be built and deployed on different platforms
- **Rationalization**
  - Services can be granular in order to provide specific functionality,
  - rather than duplicating the functionality in number of applications, which removes duplication.

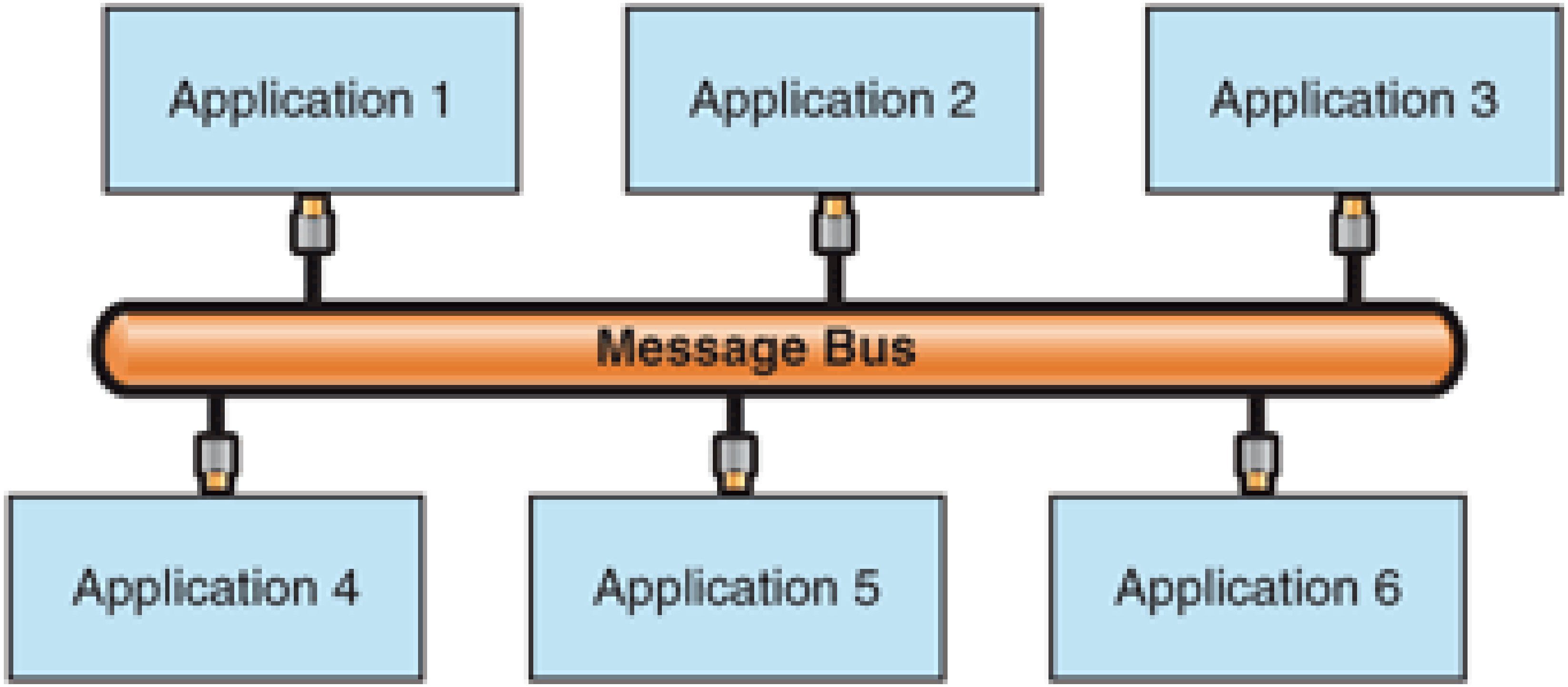
Communication Patterns Problem

- How to connect several components
  - Message bus
    - Broadcast
    - Reliability
    - ...
  - Pipes and filters
    - chaining of components

Communication Patterns Message Bus

- Describes the principle of using a software system that
  - Can receive and send messages using one or more communication channels
  - without needing to know specific details about each other.
- Interaction between applications is accomplished by passing messages
  - usually asynchronously
  - over a common bus.

Communication Patterns
Message Bus



Communication Patterns Message Bus

- Message-oriented communications.
  - All communication between applications is based on messages
- Complex processing logic.
  - Complex operations can be executed by combining a set of smaller operations
- Modifications to processing logic.
  - interactions based on common schemas and commands,
  - you can insert or remove components on the bus to change the logic that is used to process messages.
- Integration with different environments.
  - Messages follow a common standard
  - Applications (producer and consumers) can be implemented in different technologies

Communication Patterns Message Bus

- Extensibility
  - Applications can be added to or removed from the bus
  - without impact on the existing components.
- Low complexity
  - Application only needs to know how to communicate with the bus.
- Flexibility
  - The set of applications that make up a complex process can be changed
  - the communication patterns between applications, can be changed

Communication Patterns Message Bus

- Loose coupling
  - with a suitable interface for communication with the message bus,
  - there is no dependency on the application
    - allowing changes, updates, and replacements that expose the same interface.
- Scalability/ fault tolerance
  - Multiple instances of the same application can be attached to the bus in
    - to order to handle multiple requests at the same time.
    - to add fault tolerance

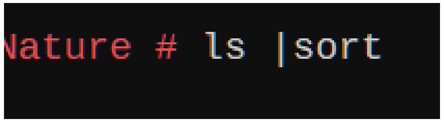
Communication Patterns Message Bus

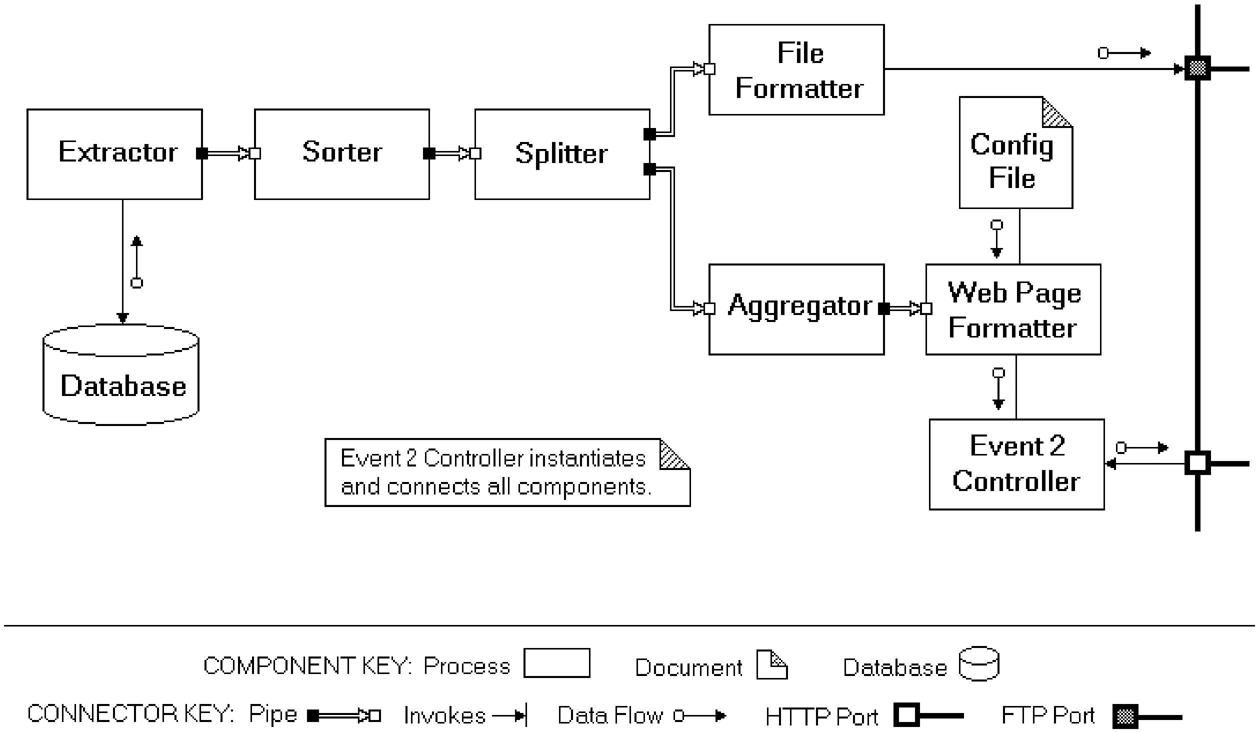
- Complex processing logic
  - Point-to-Point Channel
    - A Point-to-Point Channel ensures that only one receiver consumes any given message.
    - The bus can have multiple receivers
      - but only a single receiver consumes any one message
  - Publish-Subscribe Channel
    - A message is delivered to all consumers that register for that class of messages

Communication Patterns
Pipes and Filters

- Each component (filter) has a set of inputs and a set of outputs.
- A component reads streams of data on its inputs
  - and produces streams of data on its outputs, delivering a complete instance of the result in a standard order
  - applying a local transformation to the input streams and computing incrementally so output begins before input is consumed.
    - “filters”

Communication Patterns
Pipes and Filters





Communication Patterns Pipes and Filters

- filters must be independent entities
  - in particular, they should not share state with other filters.
- filters do not know the identity of their upstream and downstream filters.
- Their specifications might restrict what appears on the input pipes or make guarantees about what appears on the output pipes,
  - but they may not identify the components at the ends of those pipes.
- ~~The correctness of the output of a pipe and filter network should not depend on the order in which the filters perform their incremental processing~~

Communication Patterns
Pipes and Filters

- Allow the designer to understand the overall behavior of a system
  - simple composition of the behaviors of the individual filters.
- Support reuse:
  - any filters can be connected together,
    - if they agree on the data that is being transmitted between them.
- Systems can be easily maintained and enhanced:
  - new filters can be added to existing systems
  - old filters can be replaced by improved ones.
- Allows specialized analysis
  - such as throughput and deadlock analysis.
- Naturally support concurrent execution.
  - Each filter can be implemented as a separate task and potentially executed in parallel with other filters.

Repositories

- Include two kinds of components:
  - a central data structure represents the current state
  - a collection of independent components that operate on the central data store

Communication Patterns Repositories

- Repositories are bridges between data and operations that are in different domains.
- Provide consistency
  - If several application accesses the same data
- Provides transaction management
- Allows client interoperability
  - clients can be writen in multiple technologies
  - they only needs to use the catalog repository interface.

Communication Patterns Repositories

- Can be implemented as a database
- can be implemented as a file system
- can be implemented as a cache
- Can be implemented as Shared Memory

Communication Patterns Event-based, Implicit Invocation

- Traditionally, systems provide a collection of procedures and functions
  - components interact with each other by explicitly invoking those routines
- In real-time/asynchronous/parallel systems
  - procedures are hard to handle
- Implici invocation based on events eases the development of such systems

Communication Patterns
Event-based, Implicit Invocation

- instead of invoking a procedure directly,
  - a component can announce (or broadcast) one or more events
  - expect for the event to be processed
- Other components in the system can register an interest in an event
  - by associating a procedure with the event
- event announcement
  - asynchronously
  - implicitly causes the invocation of procedures in other modules

Communication Patterns
Event-based, Implicit Invocation

- provides strong support for reuse.
  - Any component can be introduced into a system simply by registering it for the events of that system.
- Implicit invocation eases system evolution
  - Components may be replaced by other components without affecting the interfaces of other components in the system.
- Good for parallel systems

Communication Patterns Event-based, Implicit Invocation

- Components relinquish control over the computation performed by the system.
  - When a component announces an event, it has no idea what other components will respond to it.
  - It know when they are finished.
- Data exchange
  - Data can be passed with the event.
  - But in other situations event systems must rely on a shared repository for interaction.
- Reasoning about correctness can be problematic
  - The meaning of a procedure that announces events will depend on the context of bindings in which it is invoked.
  - The order of the processing of events is not known