Advanced Topics in Operating Systems

MSc in Computer Science
UNYT-UoG

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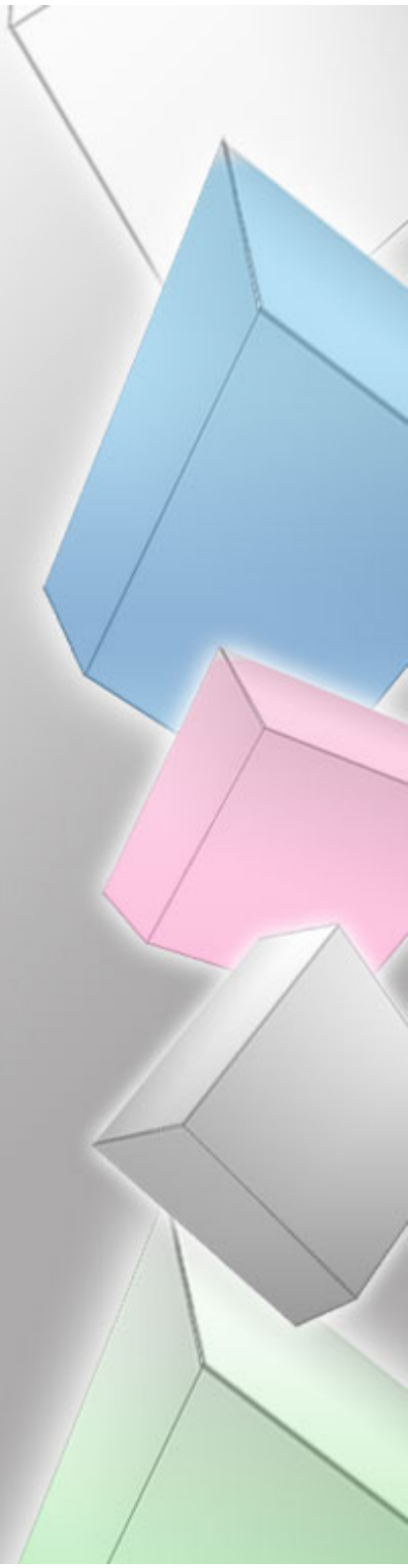

Lesson 2

01: Introduction
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09: Security
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11: Distributed File Systems
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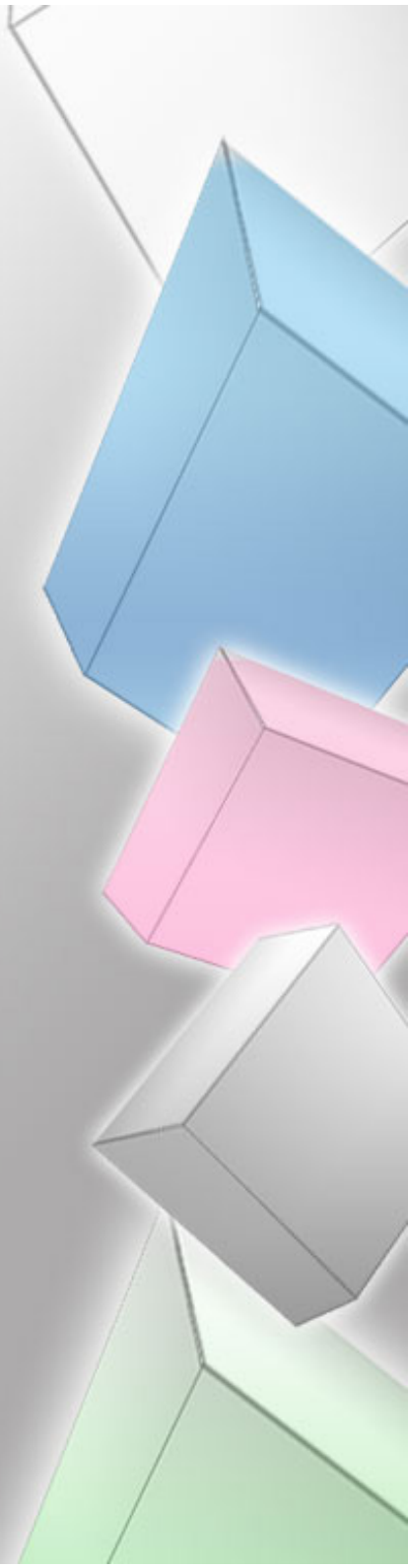


Organization of DSs

- Distributed systems are often complex pieces of software of which the components are by definition dispersed across multiple machines.
  - To master their complexity, it is crucial that these systems are properly organized.

- There are different ways on how to view the organization of a distributed system, but an obvious one is to make a distinction between:
  - the logical organization of the collection of software components
  - the actual physical realization.

- The organization of distributed systems is mostly about the software components that constitute the system.

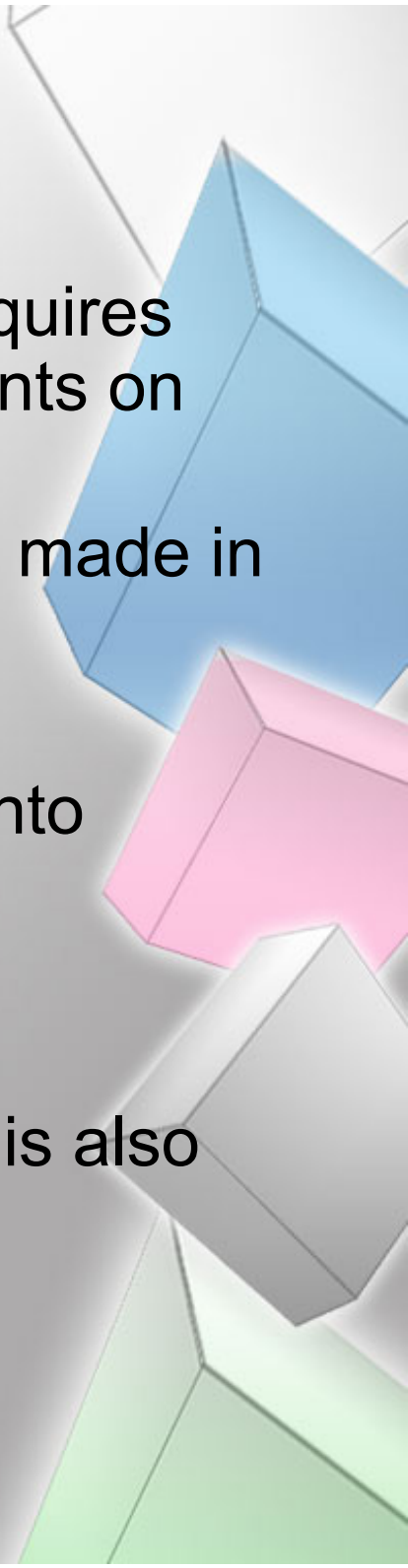
- These software architectures tell us how the various software components are to be organized and how they should interact.

System Architecture

- The actual realization of a distributed system requires that we instantiate and place software components on real machines.
  - There are many different choices that can be made in doing so.

- The logical organization of distributed systems into software components is referred to as software architecture.

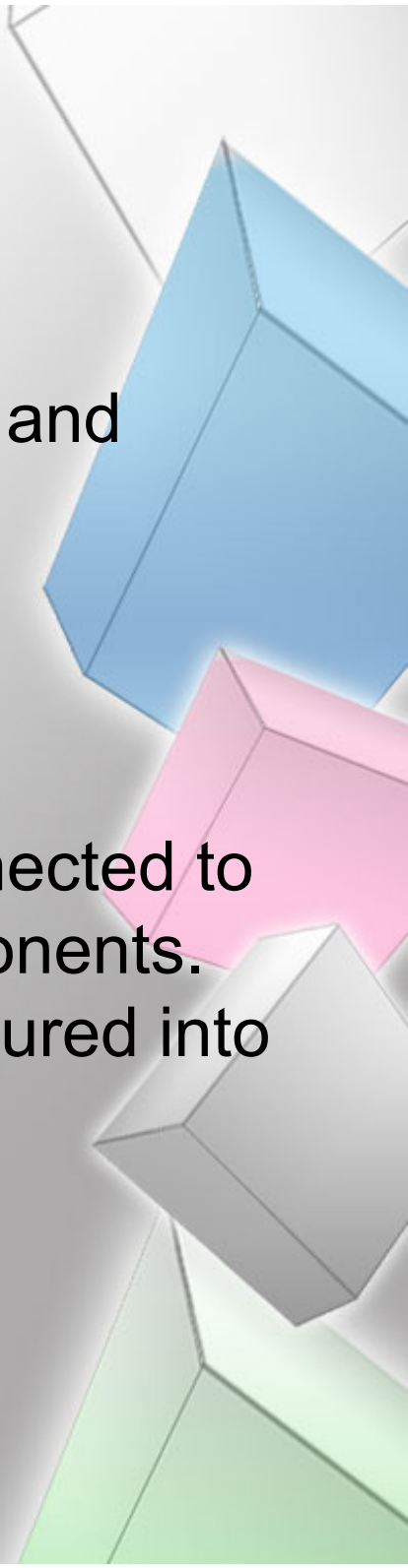
- The final instantiation of a software architecture is also referred to as a system architecture.



Architectural Style

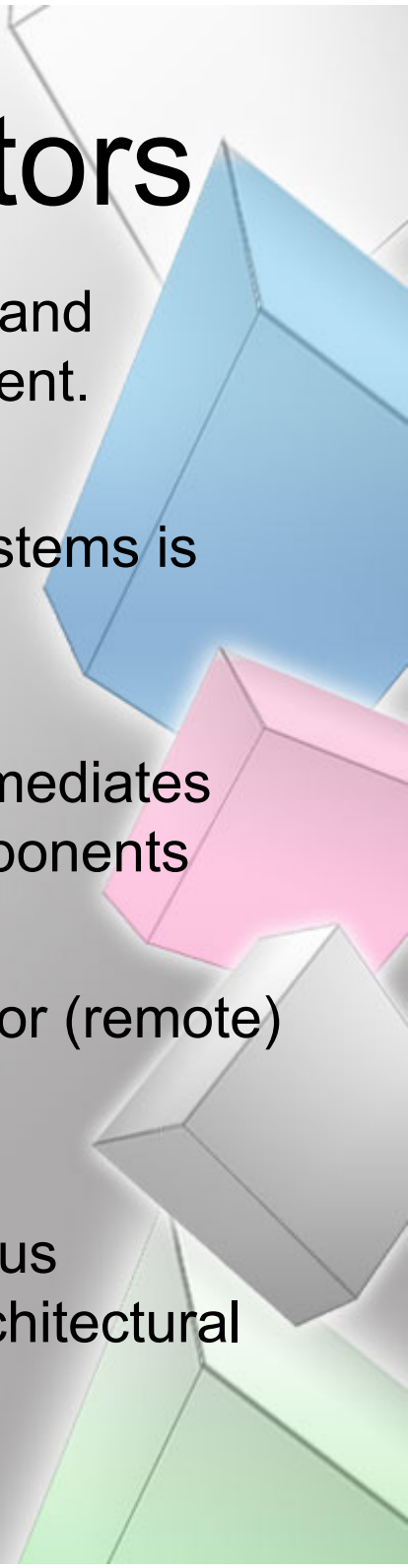
- Basic idea
  - Organize into logically different components, and distribute those components over the various machines.

- An architectural style is formulated in terms of components, the way that components are connected to each other, the data exchanged between components. and finally how these elements are jointly configured into a system.



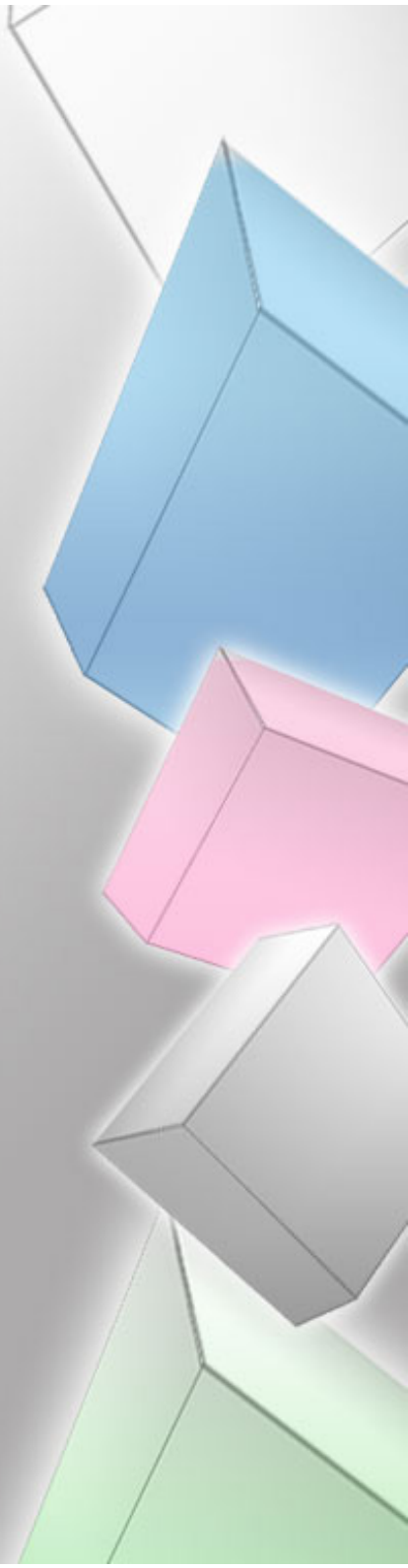
Components and Connectors

- A component is a modular unit with well-defined required and provided interfaces that is replaceable within its environment.
- The important issue about a component for distributed systems is that it can be replaced, provided we respect its interfaces.
- A connector is generally described as a mechanism that mediates communication, coordination, or cooperation among components
- For example, a connector can be formed by the facilities for (remote) procedure calls, message passing, or streaming data.
- Using components and connectors, we can come to various configurations, which, in turn have been classified into architectural styles.

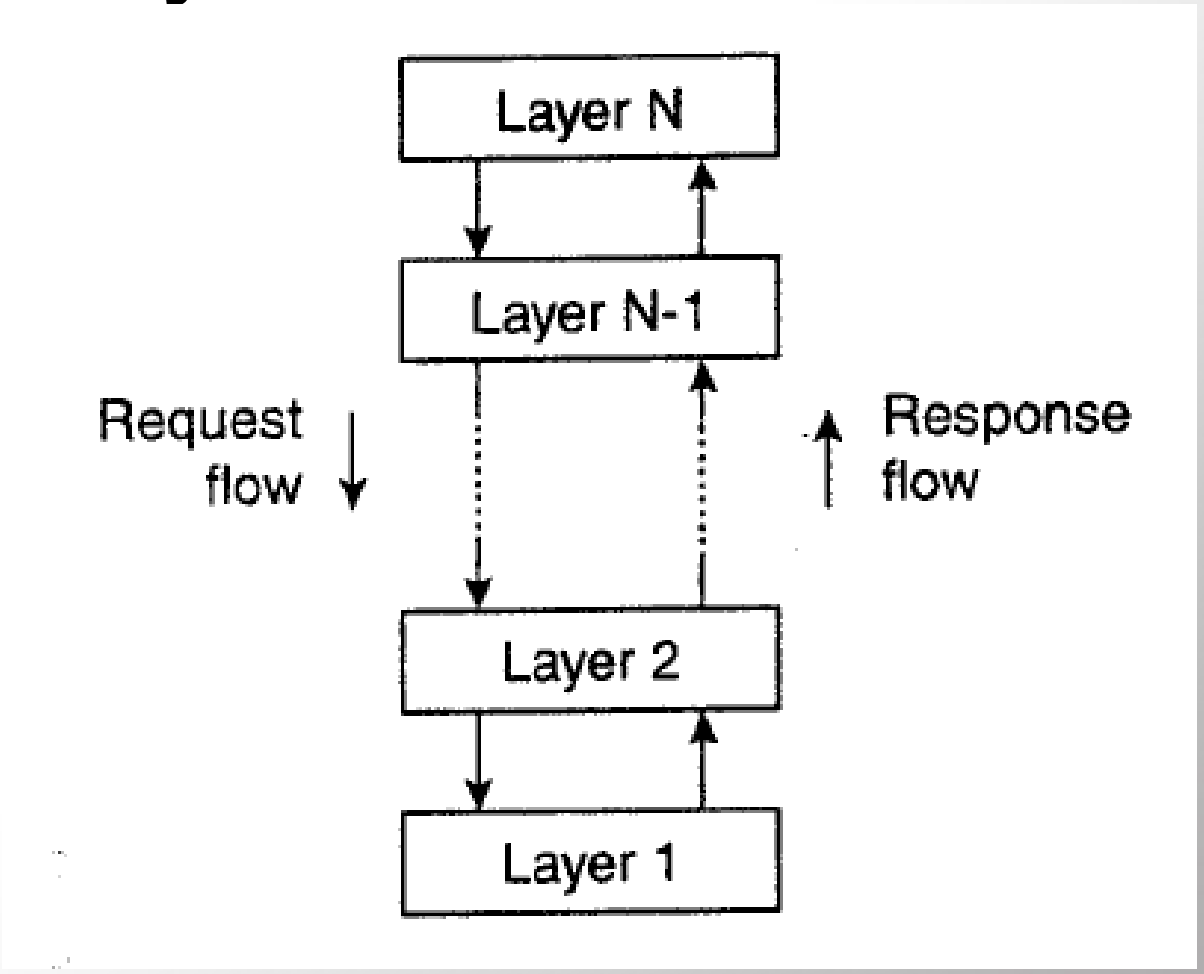


Architectural Styles

1. Layered architectures
2. Object-based architectures
3. Data-centered architectures
4. Event-based architectures



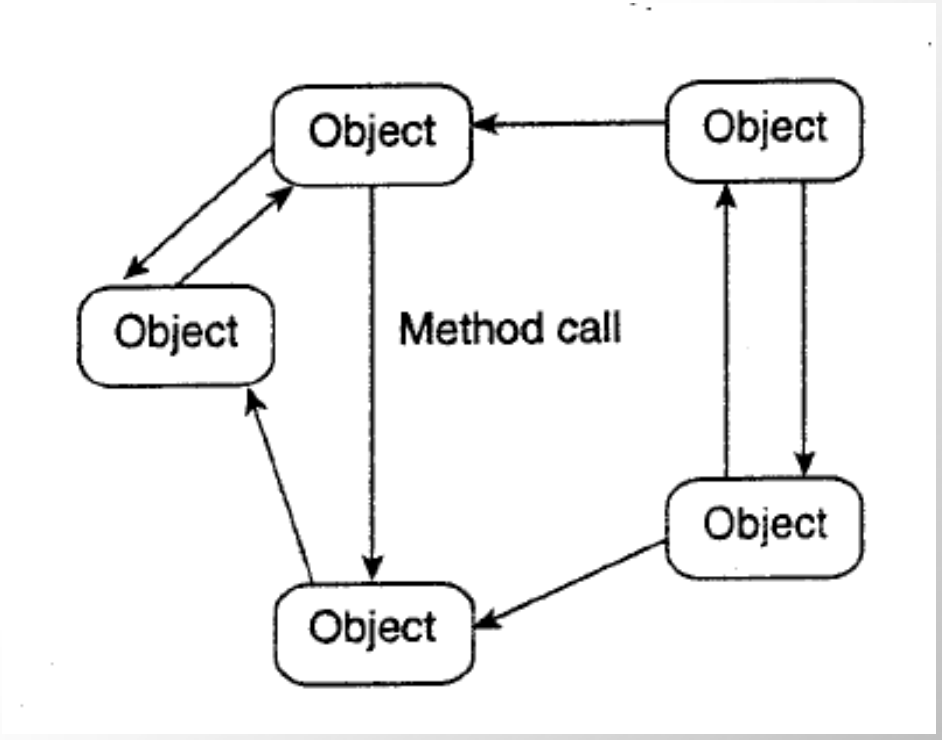
Layered architectures



A component at layer *L* is allowed to call components at layer L_{i-1} but not the other way around.

This model has been widely adopted by the networking community

Object-based Architectures



In essence, each object corresponds to what we have defined as a component, and these components are connected through a remote procedure call (RPC) mechanism.

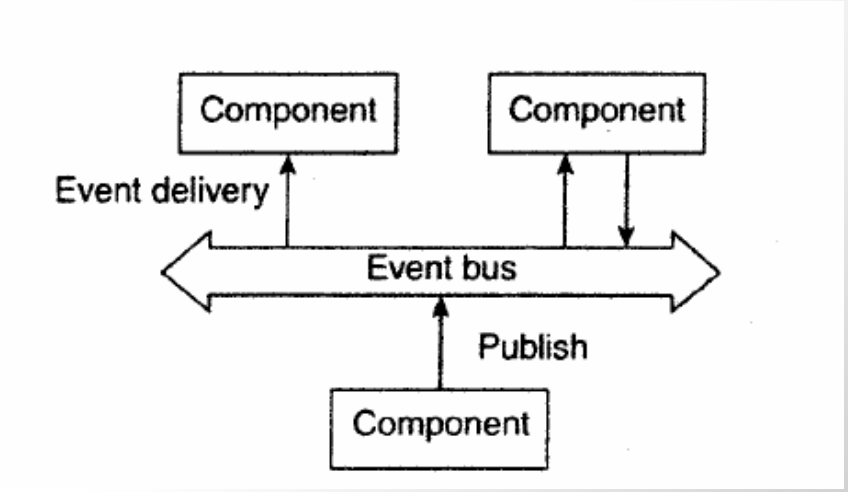
Not surprisingly, this software architecture matches a client-server system architecture.

The layered and object-based architectures still form the most important styles for large software systems

Data Centered Architectures

- Data-centered architectures evolve around the idea that processes communicate through a common (passive or active) repository.
- It can be argued that for distributed systems these architectures are as important as the layered and object-based architectures.
- For example, a wealth of networked applications have been developed that rely on a shared distributed file system in which virtually all communication takes place through files.
- Likewise, Web-based distributed systems are largely data-centric: processes communicate through the use of shared Web-based data services.

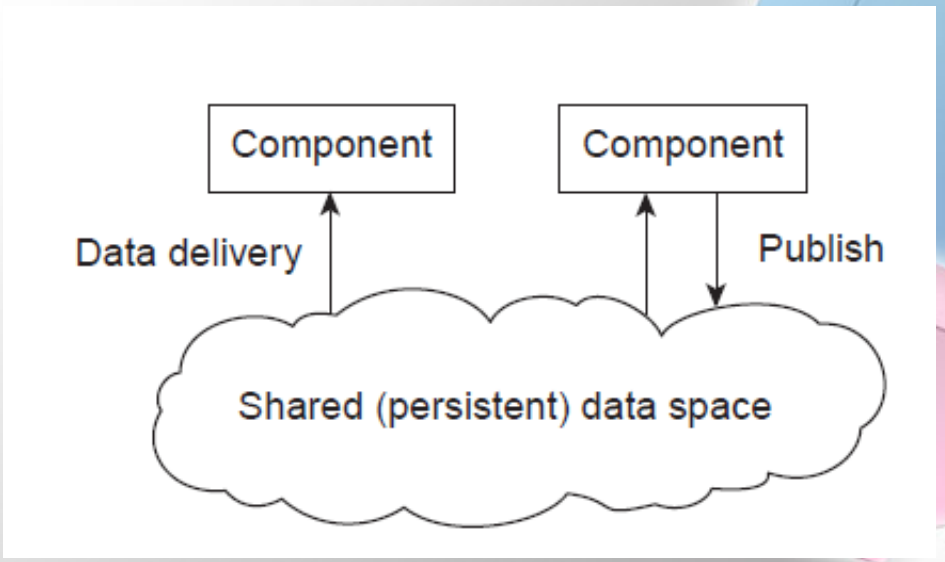
Event-based Architectures



- In event-based architectures, processes essentially communicate through the propagation of events, which optionally also carry data.
- For distributed systems, event propagation has generally been associated with what are known as publish/subscribe systems.
- The basic idea is that processes publish events after which the middleware ensures that only those processes that subscribed to those events will receive them. The main advantage of event-based systems is that processes are loosely coupled. In principle, they need not explicitly refer to each other. This is also referred to as being decoupled in space, or referentially decoupled.

Shared Data Spaces

- Decoupling processes in space (“anonymous”) and also time (“asynchronous”) has led to alternative styles.
- Event-based architectures can be combined with data-centered architectures, yielding what is also known as shared data spaces.
- The essence of shared data spaces is that processes are now also decoupled in time: they need not both be active when communication takes place.
- Furthermore, many shared data spaces use a SQL-like interface to the shared repository in that sense that data can be accessed using a description rather than an explicit reference, as is the case with files.



Distribution Transparency and Architectural Styles

- What makes the software architectures important for distributed systems is that they all aim at achieving (at a reasonable level) distribution transparency.

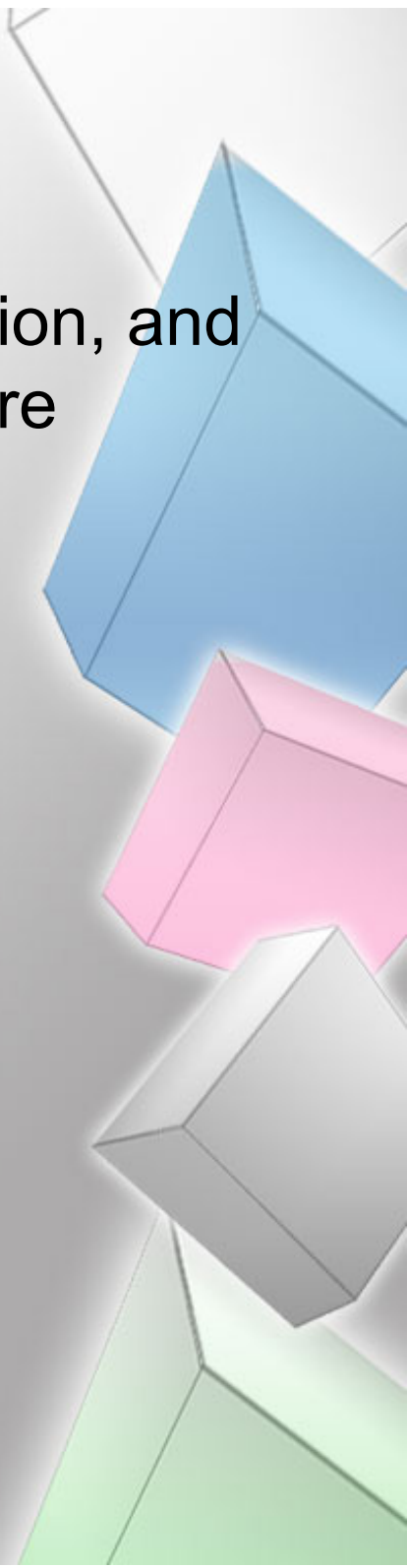
- However, distribution transparency requires making trade-offs between performance, fault tolerance, ease-of-programming, and so on.

- As there is no single solution that will meet the requirements for all possible distributed applications, researchers have abandoned the idea that a single distributed system can be used to cover 90% of all possible cases.

System Architectures

- Deciding on software components, their interaction, and their placement leads to an instance of a software architecture also called a system architecture

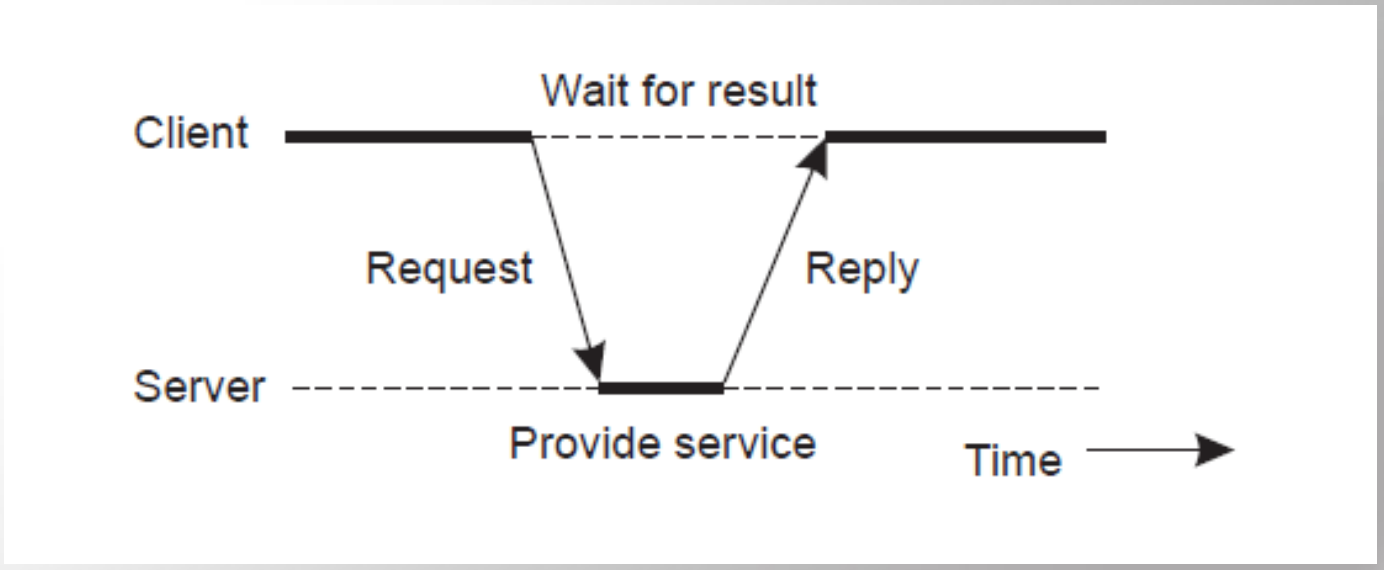
- These are of three types:
  - Centralized Architectures
  - Decentralized Architectures
  - Hybrid forms



Centralized Architectures

Basic Client–Server Model

- Characteristics:
  - There are processes offering services (servers)
  - There are processes that use services (clients)
  - Clients and servers can be on different machines
  - Clients follow request/reply model wrt to using services

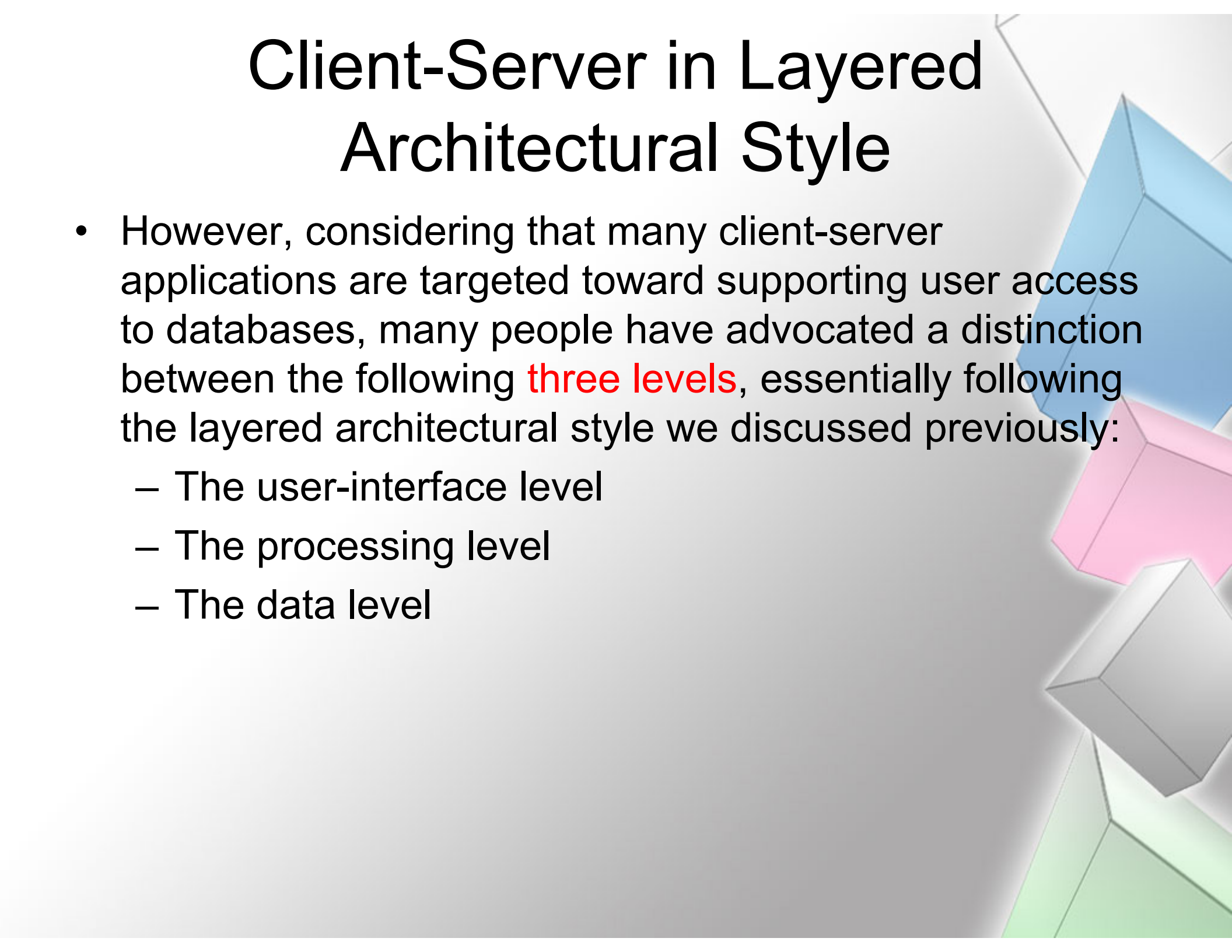


Application Layering

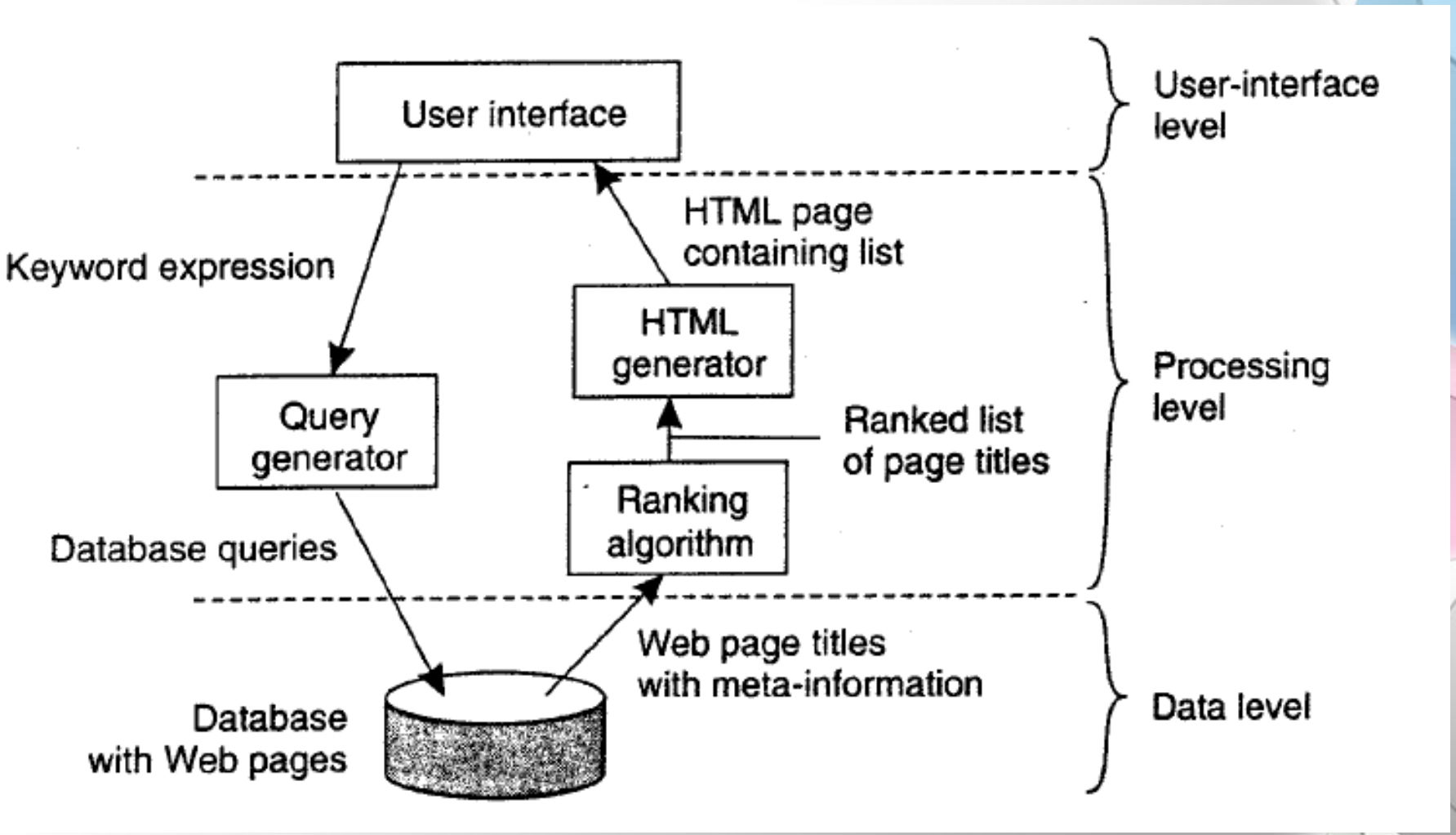
- The client-server model has been subject to many debates and controversies over the years.
- One of the main issues was how to draw a clear distinction between a client and a server.
  - Not surprisingly, there is often no clear distinction.
- For example, a server for a distributed database may continuously act as a client because it is forwarding requests to different file servers responsible for implementing the database tables.
- In such a case, the database server itself essentially does no more than process queries.

Client-Server in Layered Architectural Style

- However, considering that many client-server applications are targeted toward supporting user access to databases, many people have advocated a distinction between the following three levels, essentially following the layered architectural style we discussed previously:
  - The user-interface level
  - The processing level
  - The data level



Example: Internet Search Engine



Example: Decision support for stock brokerage

- As a second example, consider a decision support system for a stock brokerage.

- Such a system can be divided into:
  - a front end implementing the user interface,
  - a back end for accessing a database with the financial data
  - the analysis programs between these two.

- Analysis of financial data may require sophisticated methods and techniques from statistics and artificial intelligence.

- In some cases, the core of a financial decision support system may even need to be executed on high-performance computers in order to achieve the throughput and responsiveness that is expected from its users.

Business-Oriented Environments

- In most business-oriented environments, the data level is organized as a relational database.
  - Data independence is crucial here.

- The data are organized independent of the applications in such a way that changes in that organization do not affect applications, and neither do the applications affect the data organization.

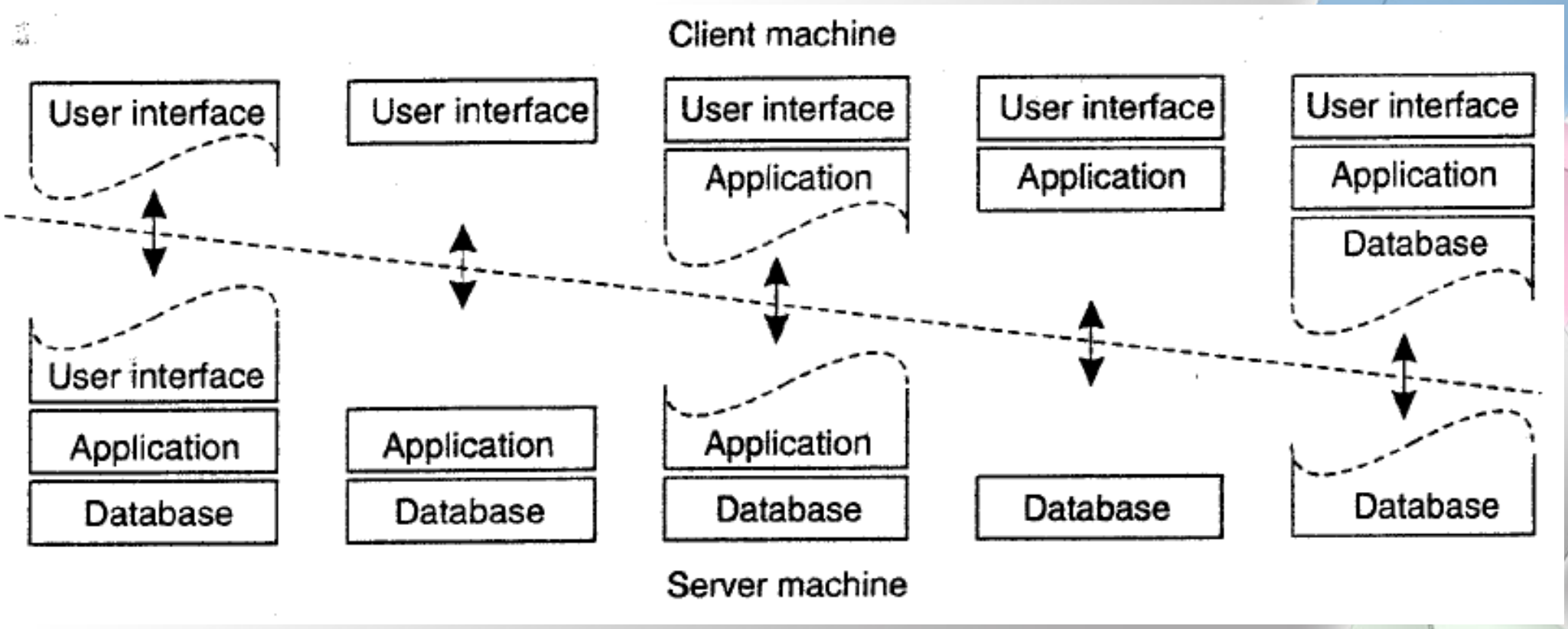
- Using relational databases in the client-server model helps separate the processing level from the data level, as processing and data are considered independent.

Multi-tiered Architectures

- The distinction into three logical levels as discussed so far, suggests a number of possibilities for physically distributing a client-server application across several machines.
- The simplest organization is to have only two types of machines:
  1. A client machine containing only the programs implementing (part of) the user-interface level
  2. A server machine containing the rest, that is the programs implementing the processing and data level

Two-tiered Architecture

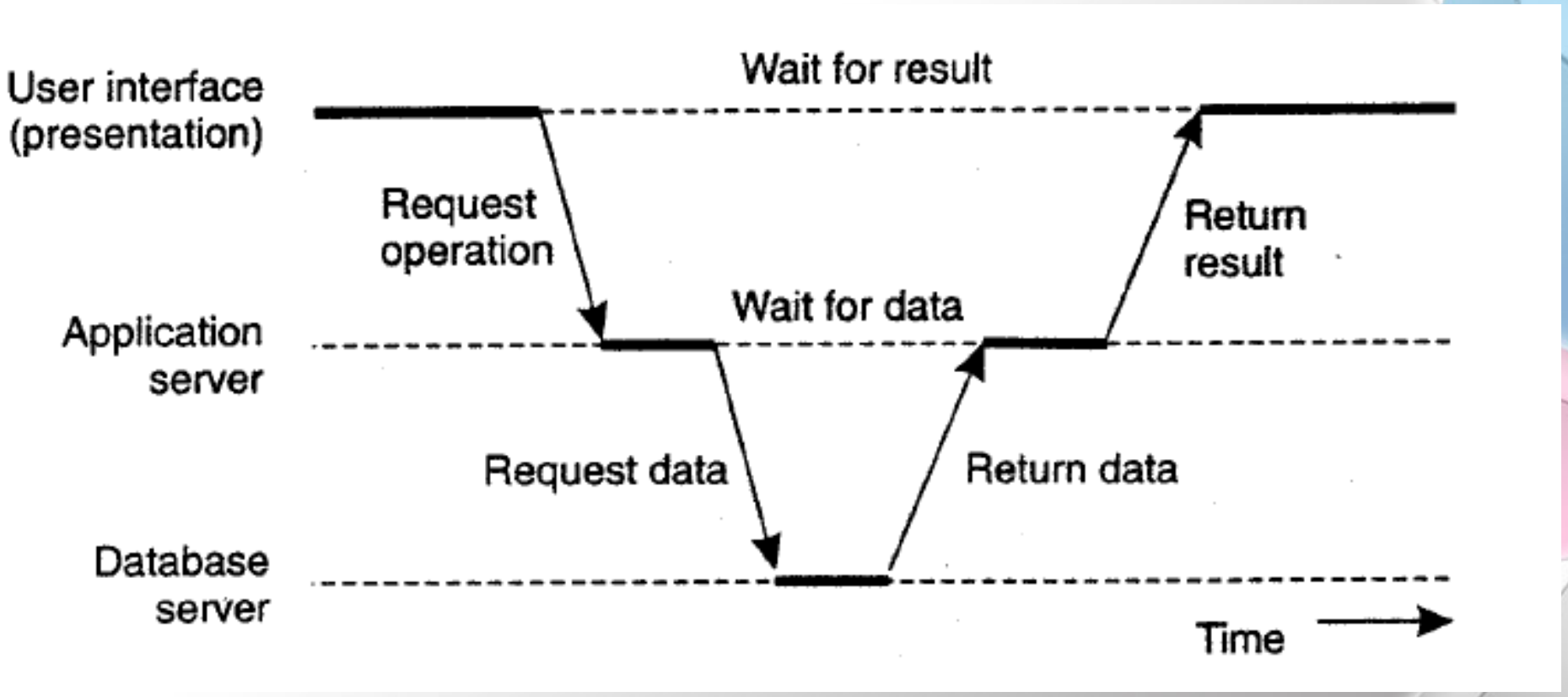
- Single-tiered: dumb terminal/mainframe configuration
- Two-tiered: client/single server configuration
- Three-tiered: each layer on separate machine



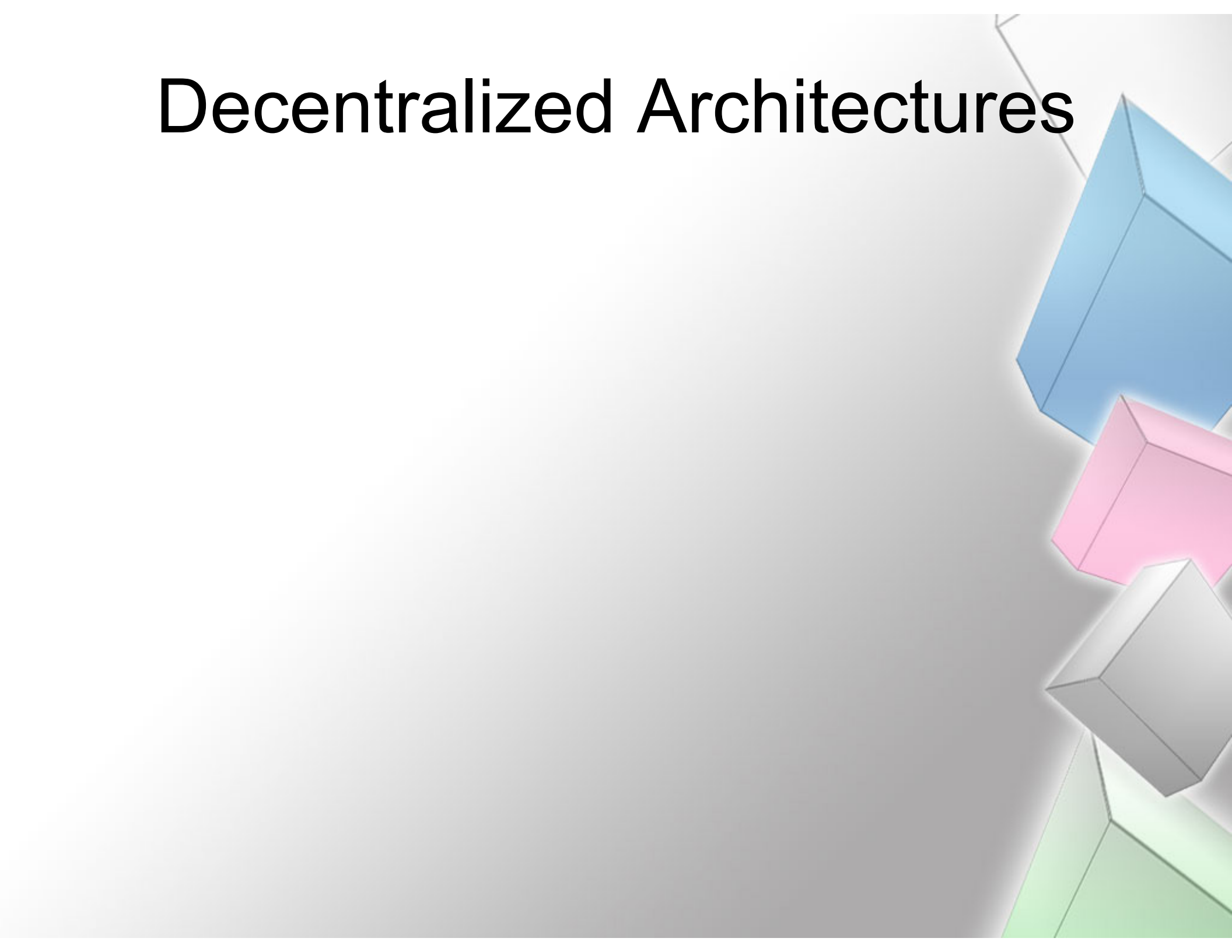
Three-tiered Architecture

- The two-tiered trend does not imply that we no longer need distributed systems.
- On the contrary, what we are seeing is that server-side solutions are becoming increasingly more distributed as a single server is being replaced by multiple servers running on different machines.
- In particular, when distinguishing only client and server machines as we have done so far, we miss the point that a server may sometimes need to act as a client, leading to a (physically) three-tiered architecture.

Three-tiered Architecture



Decentralized Architectures



Vertical Distribution

- Multitiered client-server architectures are a direct consequence of dividing applications into a user-interface, processing components, and a data level.
  - The different tiers correspond directly with the logical organization of applications.
- In many business environments, distributed processing is equivalent to organizing a client-server application as a multitiered architecture.
- We refer to this type of distribution as vertical distribution.
  - The characteristic feature of vertical distribution is that it is achieved by placing *logically* different components on different machines.

Horizontal Distribution

- From a system management perspective, having a vertical distribution can help: functions are logically and physically split across multiple machines, where each machine is tailored to a specific group of functions.
- In modem architectures, it is often the distribution of the clients and the servers that counts, which we refer to as horizontal distribution.
- In this type of distribution, a client or server may be physically split up into logically equivalent parts, but each part is operating on its own share of the complete data set, thus balancing the load.
- A class of modern system architectures that support horizontal distribution, known as peer-to-peer systems (P2P).

Peer-to-Peer Systems

- From a high-level perspective, the processes that constitute a P2P system are all equal.
- This means that the functions that need to be carried out are represented by every process that constitutes the distributed system.
- As a consequence, much of the interaction between processes is symmetric: each process will act as a client and a server at the same time (which is also referred to as acting as a servent).

Overlay Networks

- Given the symmetric behavior, P2P architectures evolve around the question how to organize the processes in an overlay network, that is, a network in which the nodes are formed by the processes and the links represent the possible communication channels (which are usually realized as TCP connections).

- In general, a process cannot communicate directly with an arbitrary other process, but is required to send messages through the available communication channels.

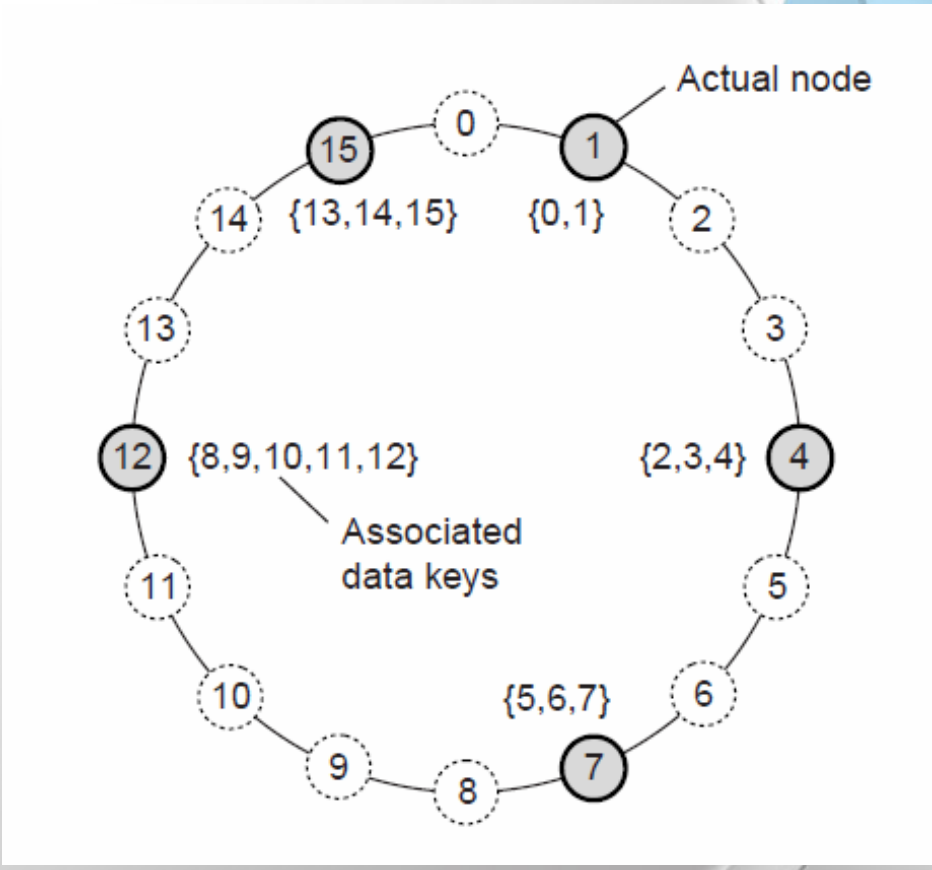
- Types of overlay networks:
  - Structured P2P: nodes are organized following a specific distributed data structure
  - Unstructured P2P: nodes have randomly selected neighbors
  - Hybrid P2P: some nodes are appointed special functions in a well-organized fashion

Structured P2P

- In a structured peer-to-peer architecture, the overlay network is constructed using a deterministic procedure.
- By far the most-used procedure is to organize the processes through a distributed hash table (DHT).
  - In a DHT-based system, data items are assigned a **random key** from a large identifier space, such as a 128-bit or 160-bit identifier.
  - Likewise, nodes in the system are also assigned a **random number** from the same identifier space.
- The crux of every DHT-based system is then to implement an efficient and deterministic scheme that uniquely maps the key of a data item to the identifier of a node based on some distance metric
- Most importantly, when looking up a data item, the network address of the node responsible for that data item is returned. Effectively, this is accomplished by *routing* a request for a data item to the responsible node.

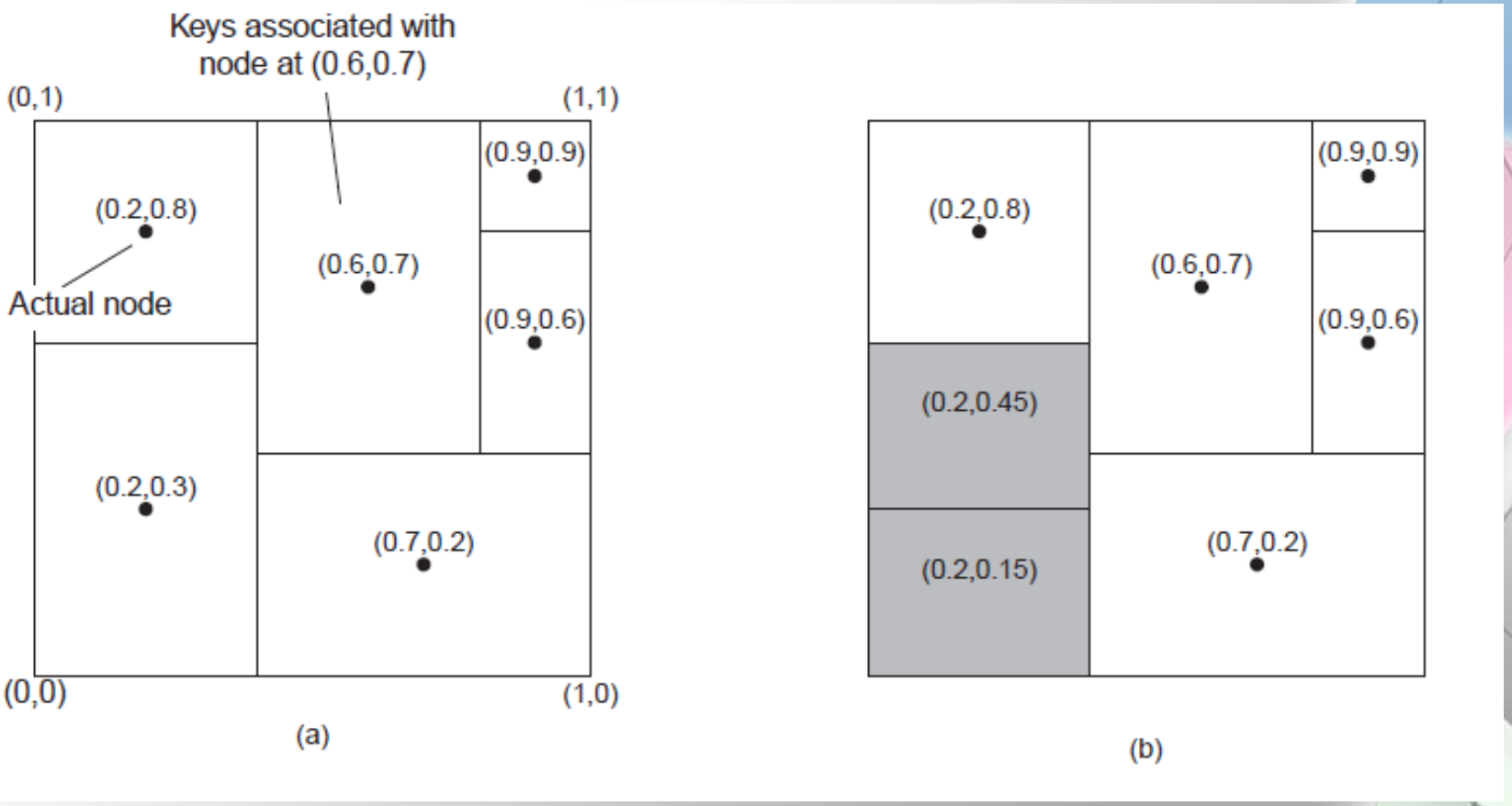
The Chord System

- The system provides an operation LOOKUP(key) that will efficiently route the lookup request to the associated node.
- A data item with key k is mapped to the node with the smallest identifier id ≥ k.



Content Addressable Network

- Organize nodes in a d-dimensional space and let every node take the responsibility for data in a specific region. When a node joins) split a region.



Unstructured P2P Networks

- Unstructured peer-to-peer systems largely rely on **randomized algorithms** for constructing an overlay network.
- The main idea is that each **node maintains a list of neighbors**
  - This list is constructed in a more or less random way.
- Likewise, data items are assumed to be **randomly placed** on nodes.
- As a consequence, when a node needs to locate a specific data item, the only thing it can effectively do is flood the network with a search query.

Unstructured P2P Networks

- Many unstructured P2P systems attempt to maintain a random graph.
- Each node is required to contact a randomly selected other node:
  - Let each peer maintain a partial view of the network, consisting of other nodes
  - Each node P periodically selects a node Q from its partial view
  - P and Q exchange information and exchange members from their respective partial views

Topology Management of Overlay Networks

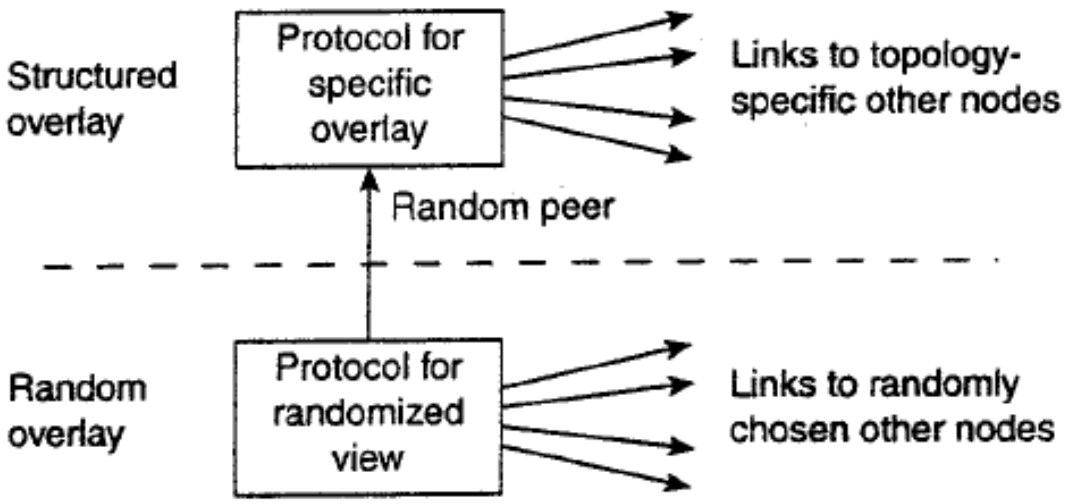


Figure 2·10. A two-layered approach for constructing and maintaining specific overlay topologies using techniques from unstructured peer-to-peer systems.

Lower layer feeds upper layer with random nodes; upper layer is selective when it comes to keeping references.

Ranking Function

- Jelasity and Babaoglu (2005) propose to use a *ranking function* by which nodes are ordered according to some criterion relative to a given node.
- A simple ranking function is to order a set of nodes by increasing distance from a given node *P.* In that case, node *P* will gradually build up a list of its nearest neighbors, provided the lowest layer continues to pass randomly selected nodes.
- As an illustration, consider a logical grid of size *N* x *N* with a node placed on each point of the grid.
- Every node is required to maintain a list of c nearest neighbors, where the distance between a node at *(a1*,*a2*) and *(b1*,*b2*) is given by (next slide =>)

Topology evolution: Torus

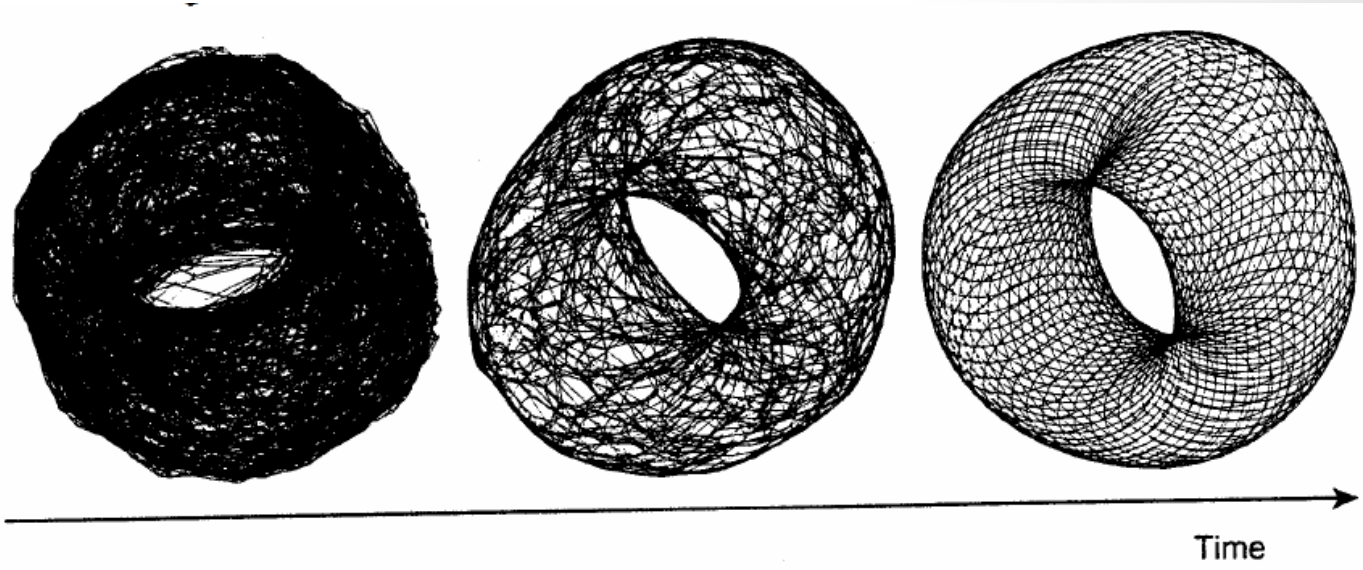


Figure 2-11. Generating a specific overlay network using a two-layered unstructured peer-to-peer system [adapted with permission from Jelasity and Babaoglu (2005)].

Constructing a torus

Consider a $N \times N$ grid. Keep only references to nearest neighbors:

$$\| (a_1, a_2) - (b_1, b_2) \| = d_1 + d_2$$

$$d_i = \min\{N - |a_i - b_i|, |a_i - b_i|\}$$

Superpeers

- Notably in unstructured peer-to-peer systems, locating relevant data items can become problematic as the network grows.

- The reason for this scalability problem is simple:
  - As there is no deterministic way of routing a lookup request to a specific data item, essentially the only technique a node can resort to is flooding the request.

- Many peer-to-peer systems have proposed to make use of special nodes that maintain an index of data items.

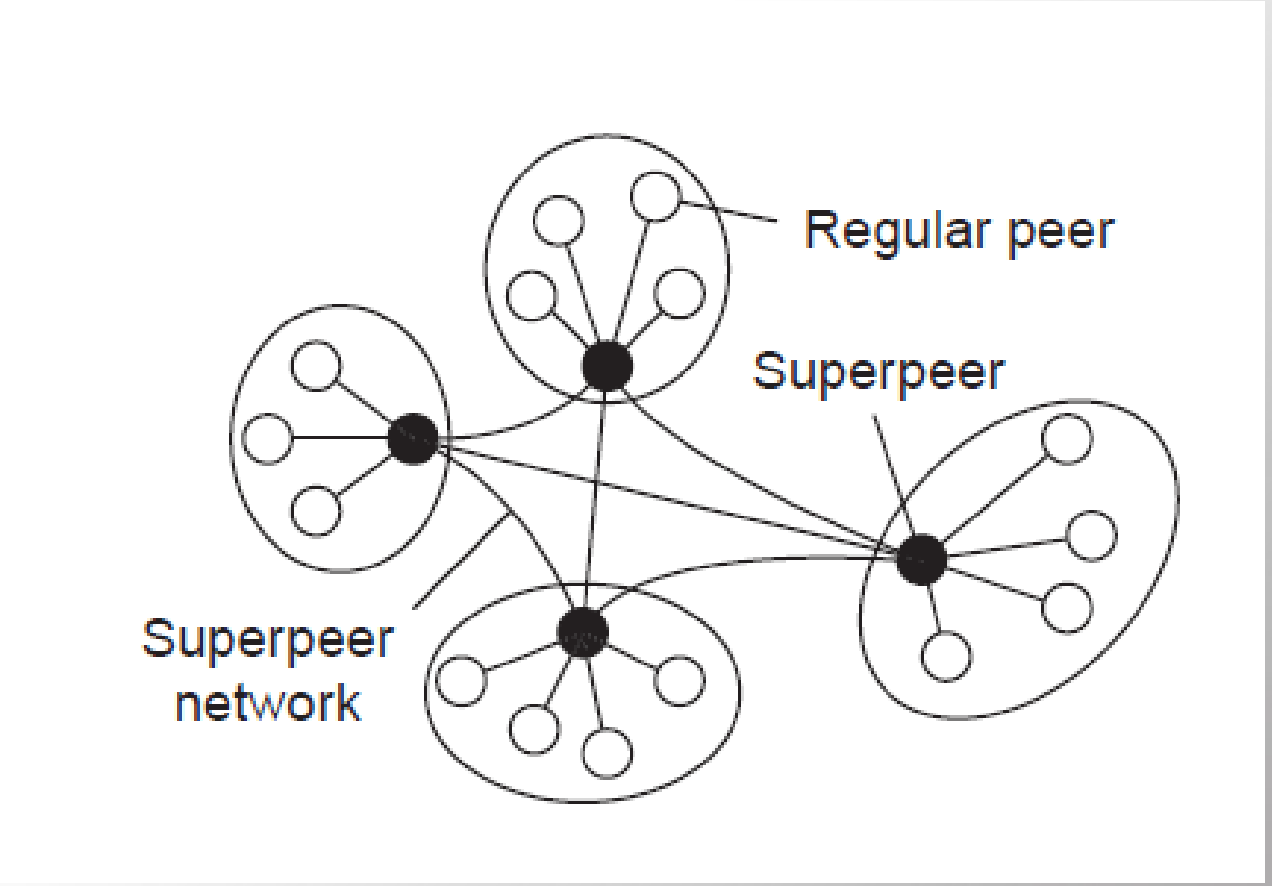
Superpeers Example: CDNs

- In a collaborative content delivery network (CDN), nodes may offer storage for hosting copies of Web pages allowing Web clients to access pages nearby, and thus to access them quickly.
  - In this case a node *P* may need to seek for resources in a specific part of the network.

- In that case, making use of a broker that collects resource usage for a number of nodes that are in each other's proximity will allow to quickly select a node with sufficient resources.

- This broker is called superpeer.

Superpeers



Hybrid Architectures
Client-Superpeer relation

- In many cases, the client-superpeer relation is fixed: whenever a regular peer joins the network, it attaches to one of the superpeers and remains attached until it leaves the network.
- Having a fixed association with a superpeer may not always be the best solution.
  - For example, in the case of file-sharing networks, it may be better for a client to attach to a superpeer that maintains an index of files that the client is generally interested in.
  - In that case, chances are bigger that when a client is looking for a specific file, its superpeer will know where to find it.

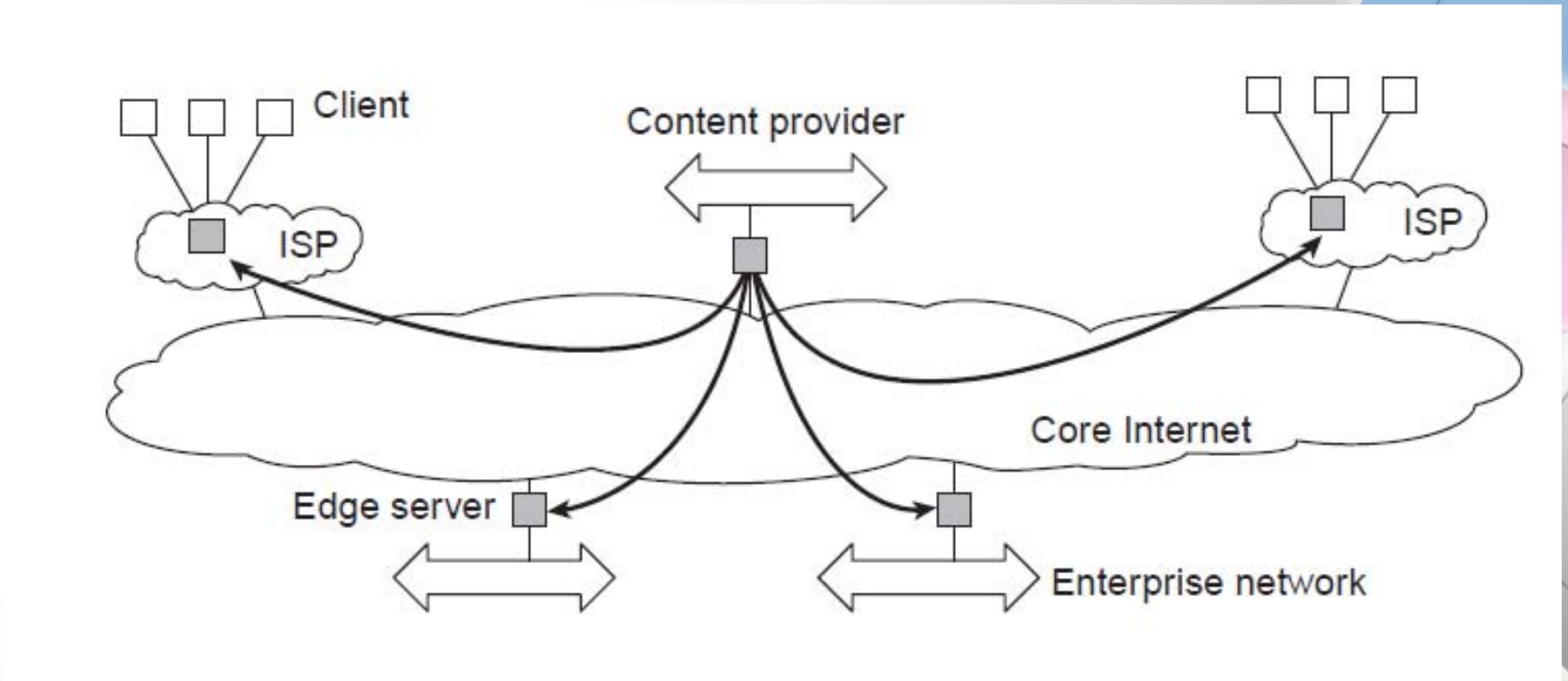
Edge-server Systems

- An important class of distributed systems that is organized according to a hybrid architecture is formed by edge-server systems.
  - These systems are deployed on the Internet where servers are placed "at the edge" of the network.

- This edge is formed by the boundary between enterprise networks and the actual Internet, for example, as provided by an Internet Service Provider (ISP).
  - Likewise, where end users at home connect to the Internet through their ISP, the ISP can be considered as residing at the edge of the Internet.

Hybrid Architectures
Client-server combined with P2P

- Edge-server architectures, which are often used for Content Delivery Networks.



Collaborative Distributed Sytems

- Hybrid structures are notably deployed in collaborative distributed systems.
- Once a node has joined the system, it can use a fully decentralized scheme for collaboration.
- Example: BitTorrent file-sharing system
  - BitTorrent is a peer-to-peer file downloading system

BitTorrent

- To download a file, a user needs to access a global directory, which is just one of a few well-known Web sites.
  - Such a directory contains references to what are called *.torrent* files. A *.torrent* file contains the information that is needed to download a specific file.
  - In particular, it refers to what is known as a tracker, which is a server that is keeping an accurate account of *active* nodes that have (chunks) of the requested file.
- An active node is one that is currently downloading another file.
- Obviously, there will be many different trackers, although (there will generally be only a single tracker per file (or collection of files).

Hybrid Architectures: C/S with P2P – BitTorrent

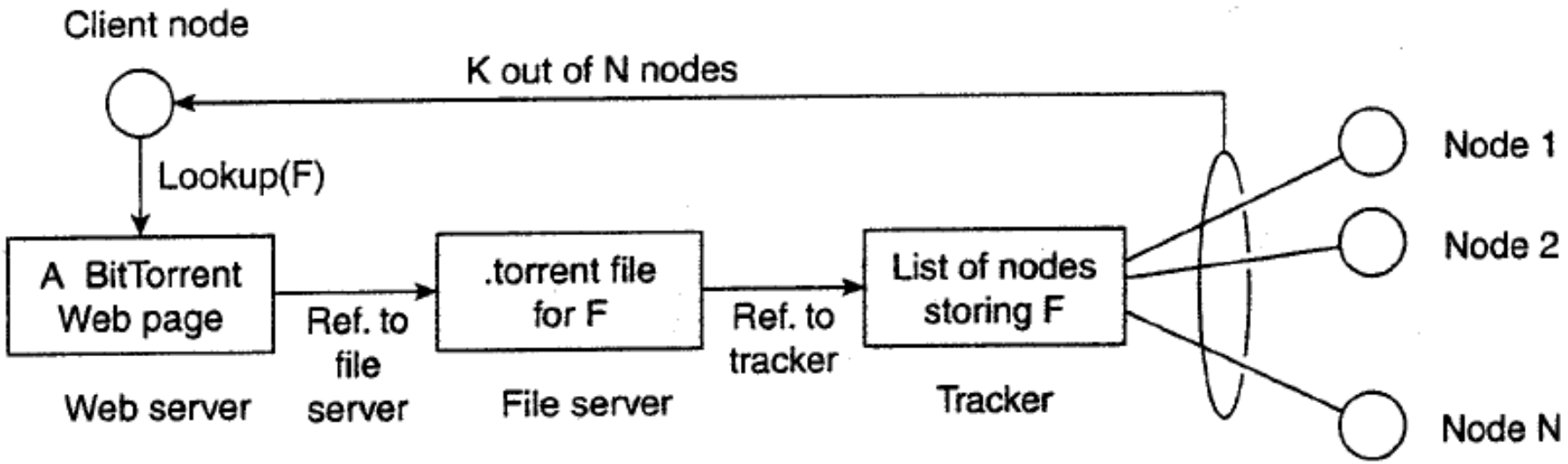


Figure 2-14. The principal working of BitTorrent [adapted with permission from Pouwelse et al. (2004)].

Once a node has identified where to download a file from, it joins a swarm of downloaders who in parallel get file chunks from the source, but also distribute these chunks amongst each other.

Globule System

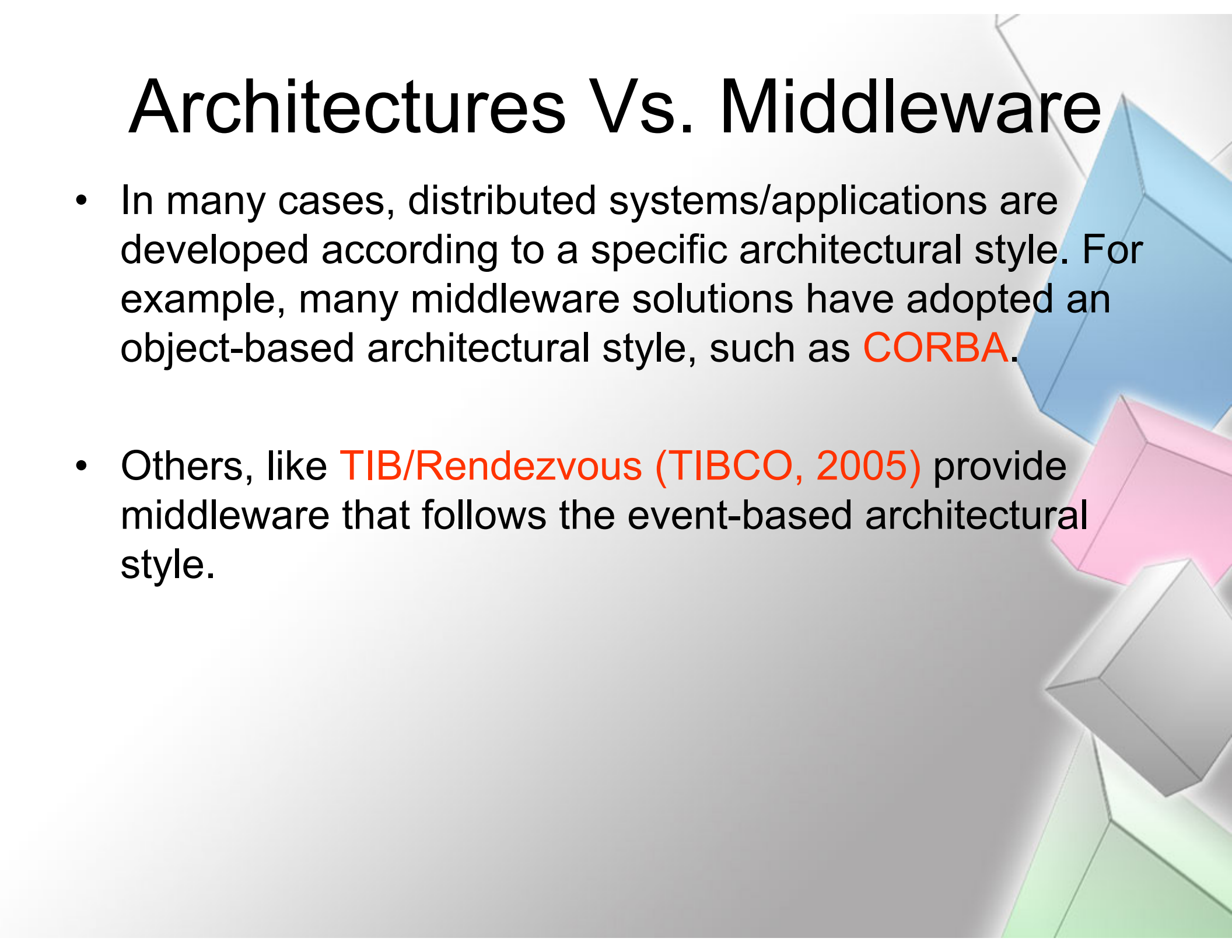
- Globule strongly resembles the edge server architecture.
- In this case, instead of edge servers, end users (but also organizations) voluntarily provide enhanced Web servers that are capable of collaborating in the replication of Web pages.
- In its simplest form, each such server has the following components:
  - A component that can redirect client requests to other servers.
  - A component for analyzing access patterns.
  - A component for managing the replication of Web pages.

- http://www.globule.org/

Architectures Vs. Middleware

- In many cases, distributed systems/applications are developed according to a specific architectural style. For example, many middleware solutions have adopted an object-based architectural style, such as CORBA.

- Others, like TIB/Rendezvous (TIBCO, 2005) provide middleware that follows the event-based architectural style.



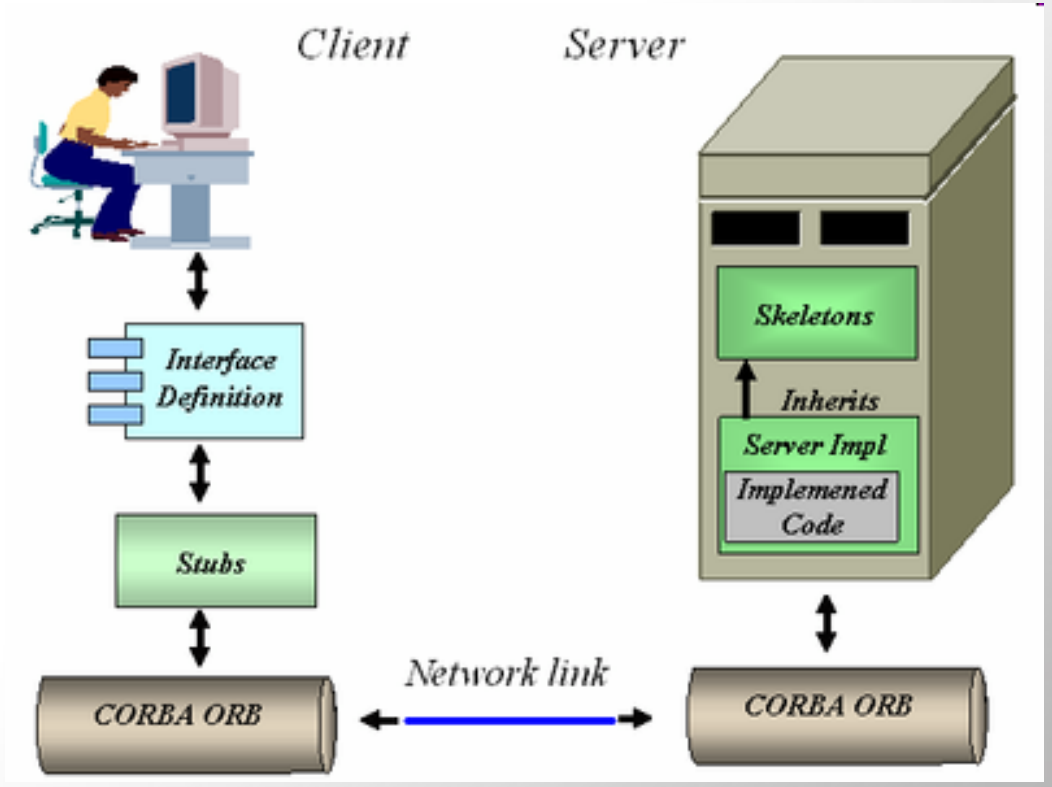
CORBA

- The Common Object Request Broker Architecture (CORBA) is a standard defined by the Object Management Group (OMG) that:
  - enables software components written in multiple computer languages and running on multiple computers to work together, i.e. it supports multiple platforms.

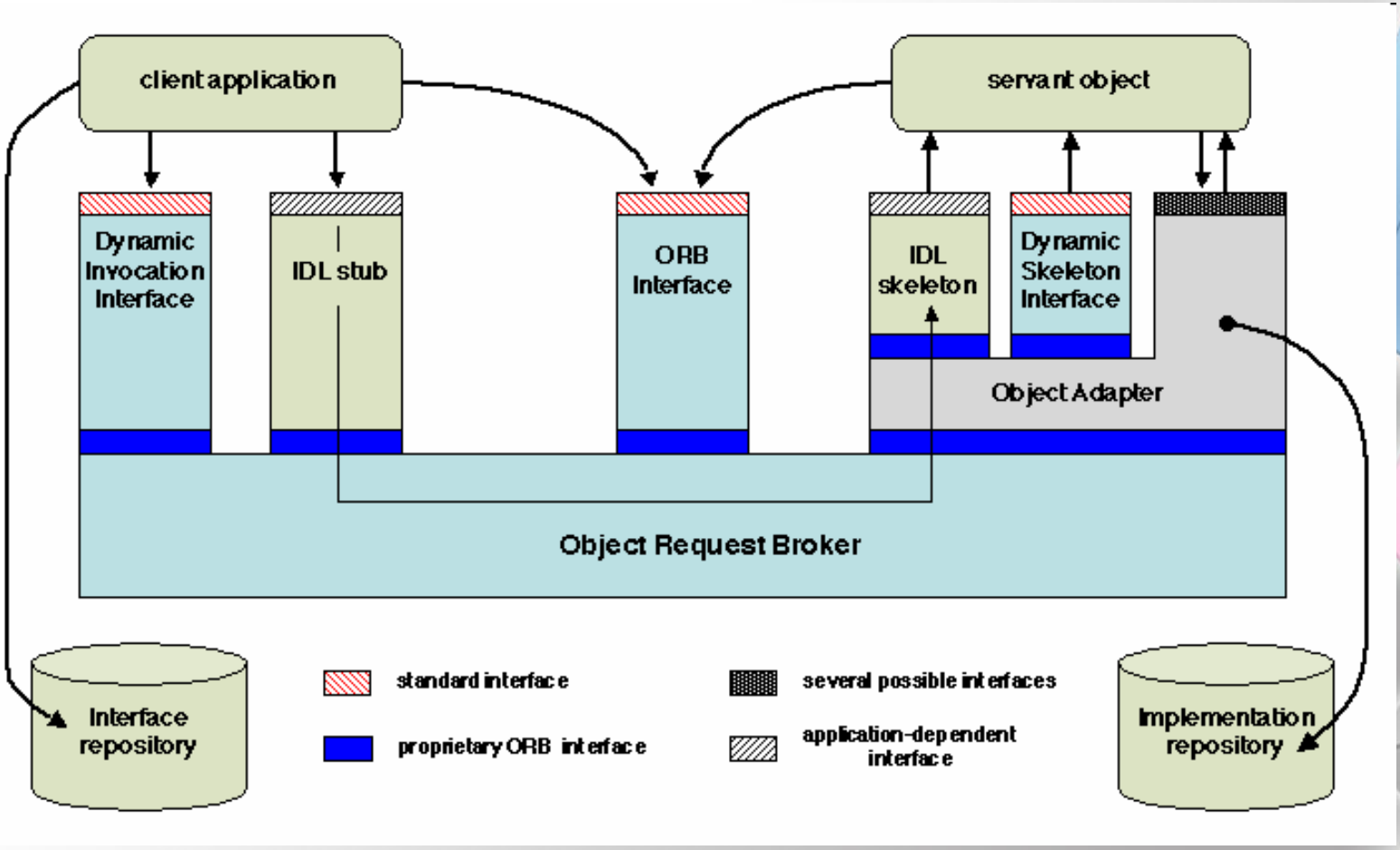
- DCOM and Web Services
  - Microsoft's counterpart to CORBA is its COM-based Distributed COM (DCOM) architecture. COM/CORBA interoperability is required to integrate Windows desktops into a CORBA-based system.

- Although CORBA and DCOM have achieved some success, Web services on the Internet are expected to be far more triumphant.
- CORBA software from different vendors may not always interoperate at all levels, and DCOM is a Windows-based solution only.

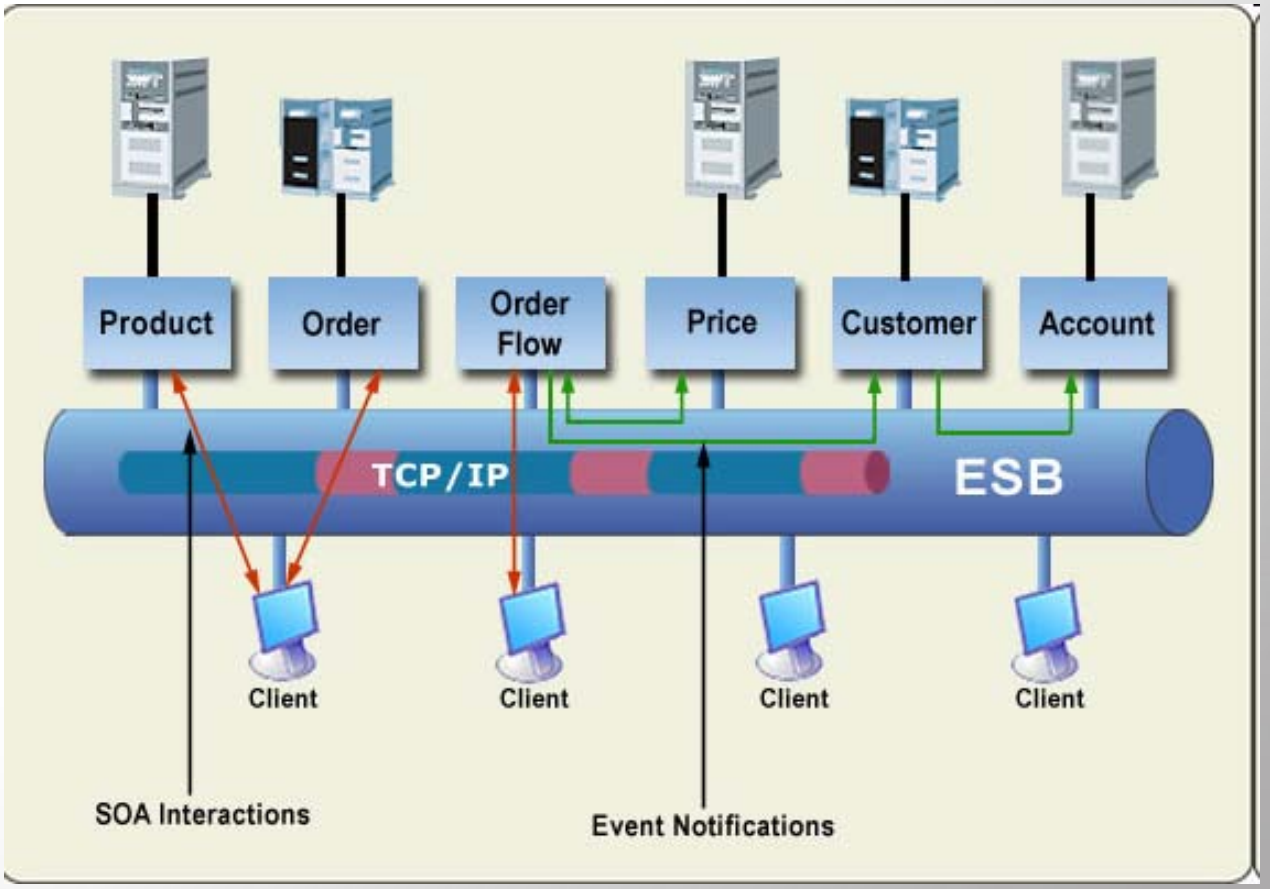
CORBA: simple schema



CORBA: general architecture



Event-based architecture



TIBCO

- TIBCO Software Inc. is a global company that develops integration software for companies including those in the energy, manufacturing, retail, healthcare, and financial services industries. Its headquarters is in Palo Alto, California, with offices in North America, Europe, Asia, the Middle East, Africa and South America.
  - The company's major commercial competitors are IBM, Oracle Corporation, and SAP AG.

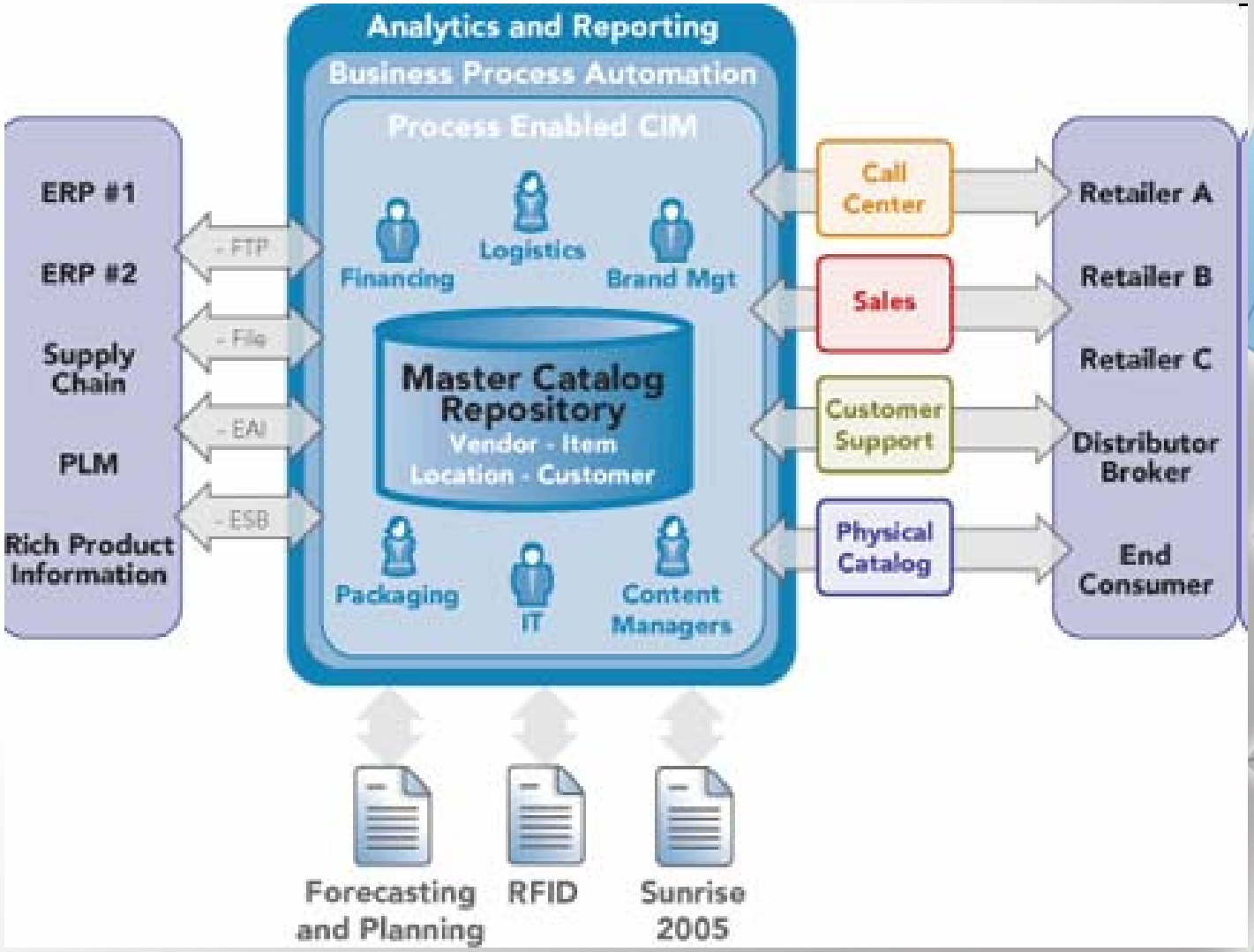
- Enterprise application integration
- Business Process Management
- Enterprise service bus
- And many more….

- http://www.tibco.com/

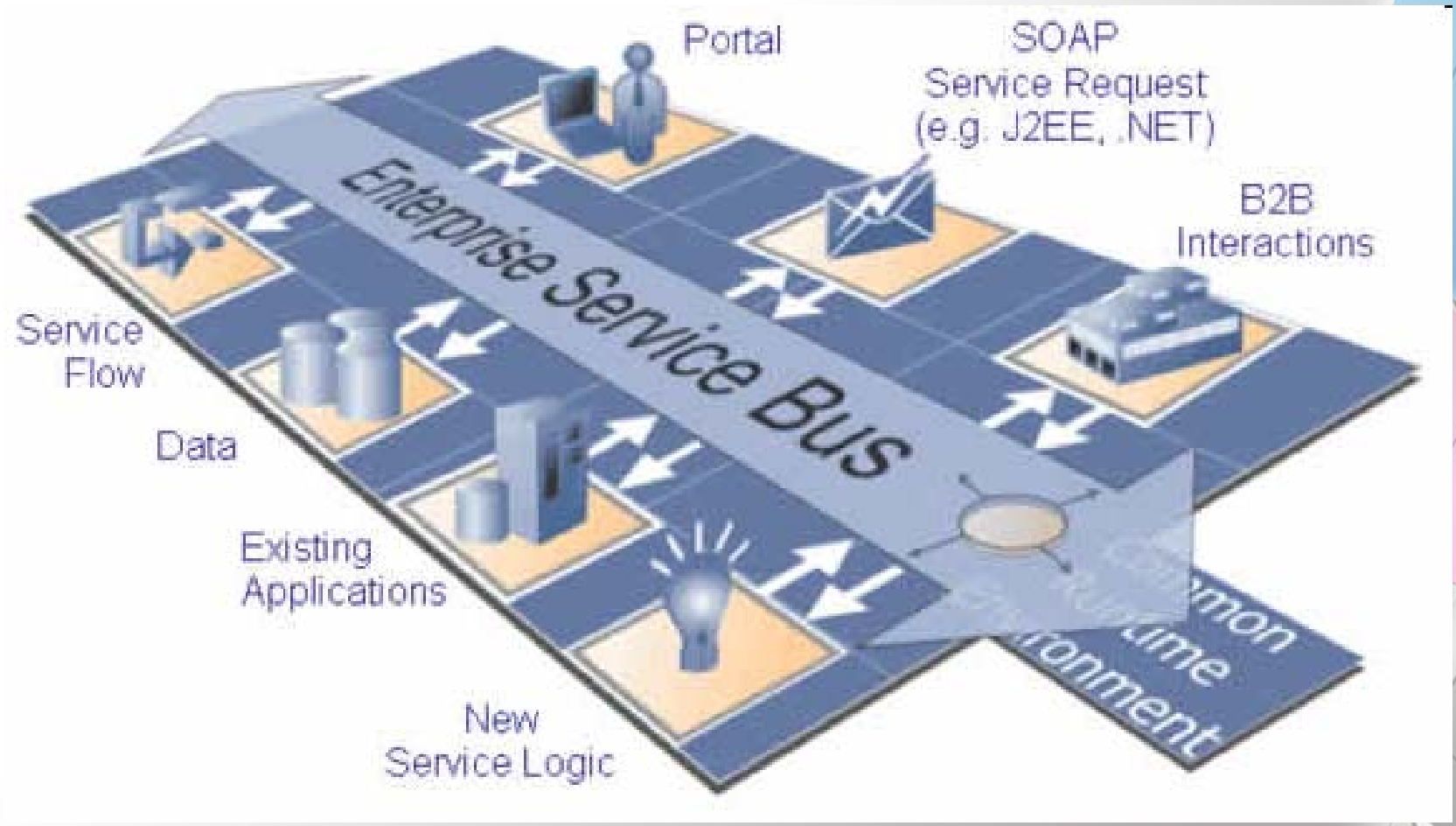
TIBCO: Rendezvous

- In addition, TIBCO offers the message-oriented middleware product Rendezvous.
- TIBCO Rendezvous is a software product that provides a message bus for enterprise application integration (EAI).
- TIBCO provides messaging APIs in C, C++, Java, Visual BASIC , Perl and .NET to receive data feeds on MS Excel spreadsheets and other applications of choice.
- Considerable "Enterprise" functionality is layered onto this

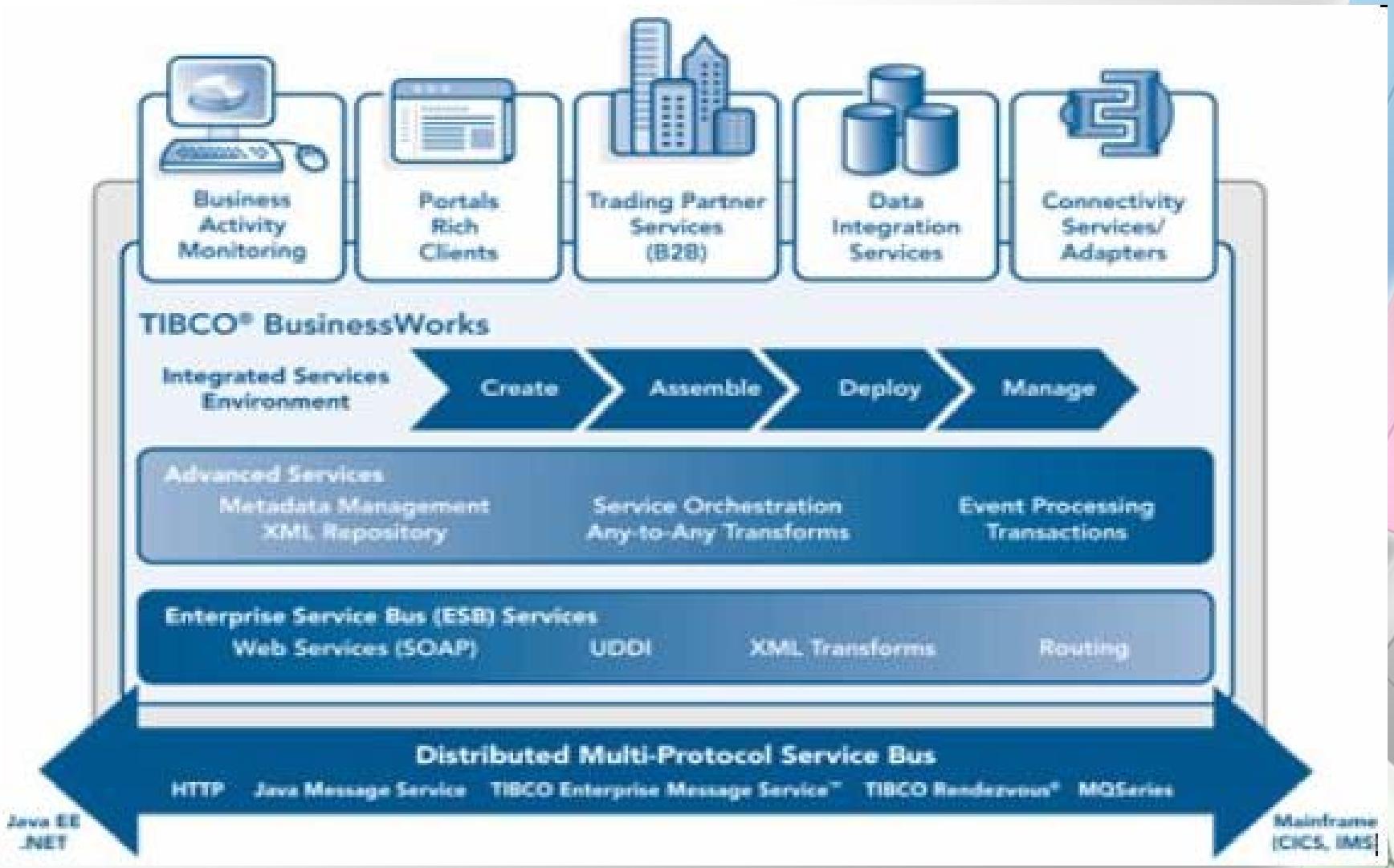
TIBCO: Master Data Management



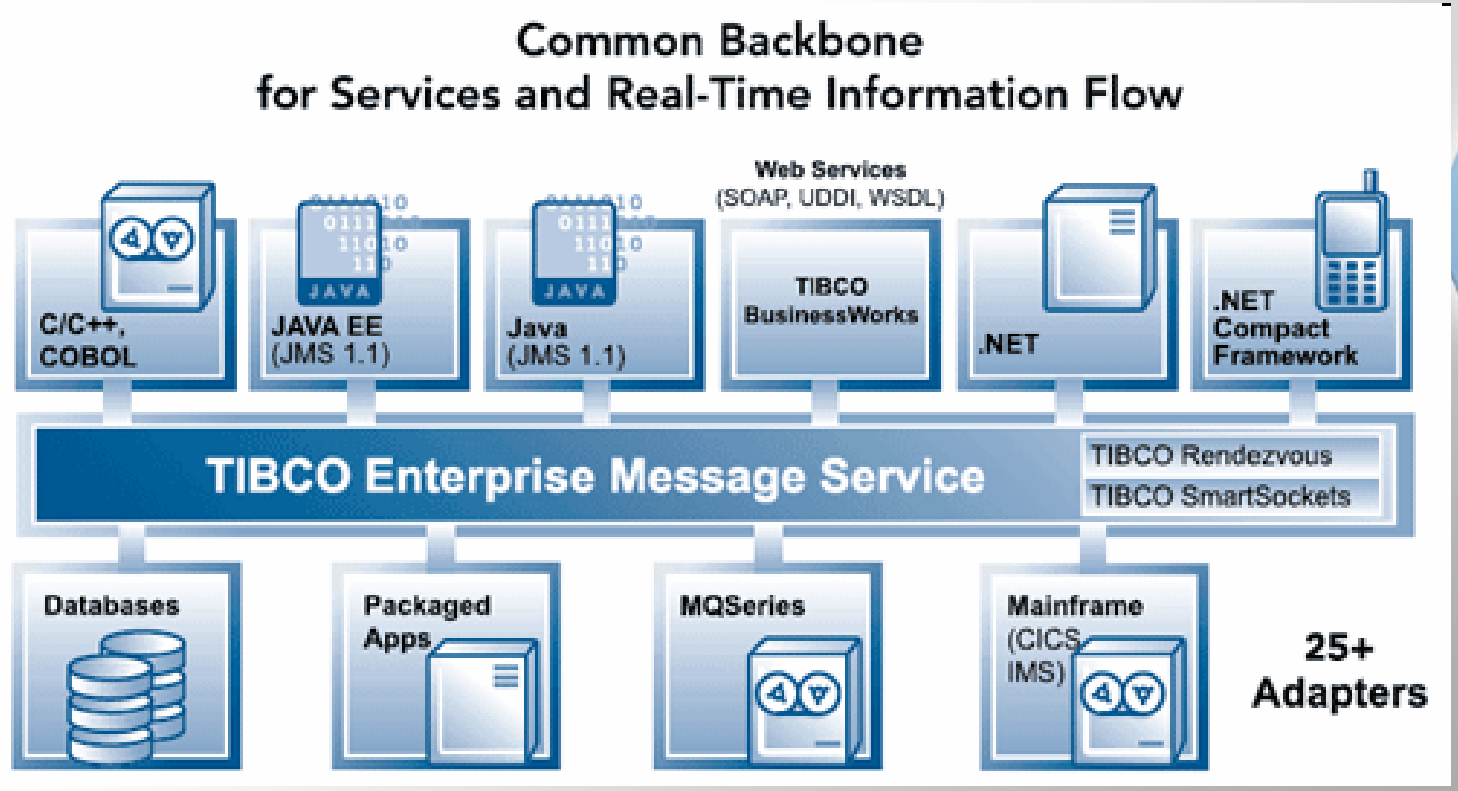
Enterprise Service Bus



TIBCO: Enterprise Service Bus

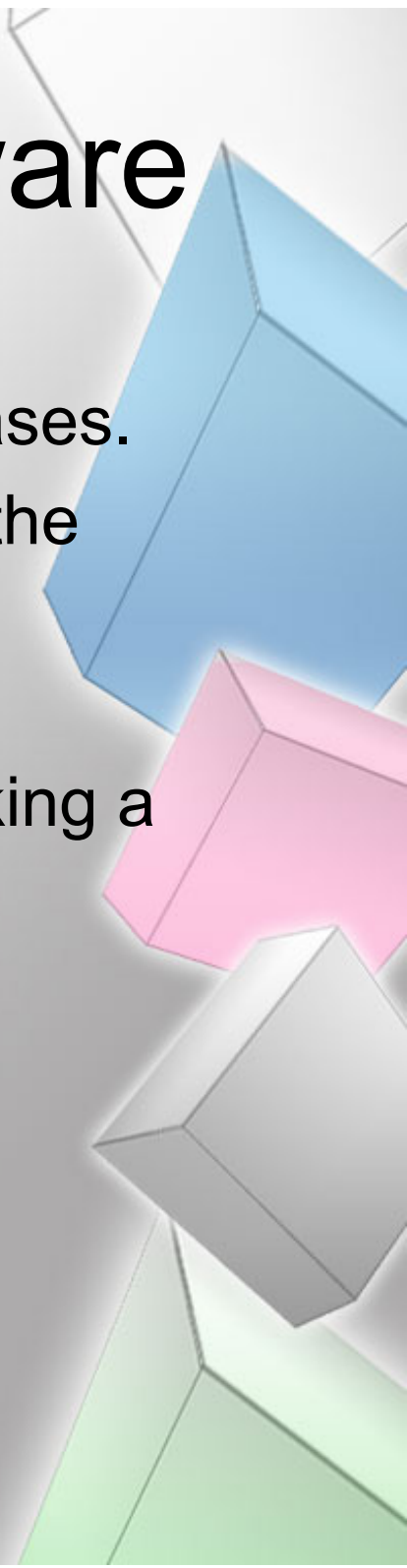


TIBCO: Enterprise Message Service



Architectures Vs. Middleware

- **Problem**
  - The chosen style may not be optimal in all cases.
  - Need to (dynamically) adapt the behavior of the middleware.
- **Interceptors**
  - Intercept the usual flow of control when invoking a remote object.



Adaptive Middleware

- Although middleware is meant to provide distribution transparency, it is generally felt that specific solutions should be adaptable to application requirements.
- One solution to this problem is to make several versions of a middleware system, where each version is tailored to a specific class of applications.
- An approach that is generally considered better is to make middleware systems such that they are easy to configure, adapt, and customize as needed by an application.
  - As a result, systems are now being developed in which a stricter separation between policies and mechanisms is being made.
- This has led to several mechanisms by which the behavior of middleware can be modified.

Interceptors

- Conceptually, an **interceptor** is nothing but a software construct that will break the usual flow of control and allow other (application specific) code to be executed.

- To make interceptors generic may require a substantial implementation effort, and it is unclear whether in such cases generality should be preferred over restricted applicability and simplicity.

- Also, in many cases having only limited interception facilities will improve management of the software and the distributed system as a whole.

Interceptors in Object-based DSs

- Imagine that object *B* is replicated.
- In that case, each replica should actually be invoked.
- This is a clear point where interception can help.
- What the request-level interceptor will do is simply call invoke(B, &do_something, value) for each of the replicas.
- The beauty of this is that the object *A* need not be aware of the replication of *B*

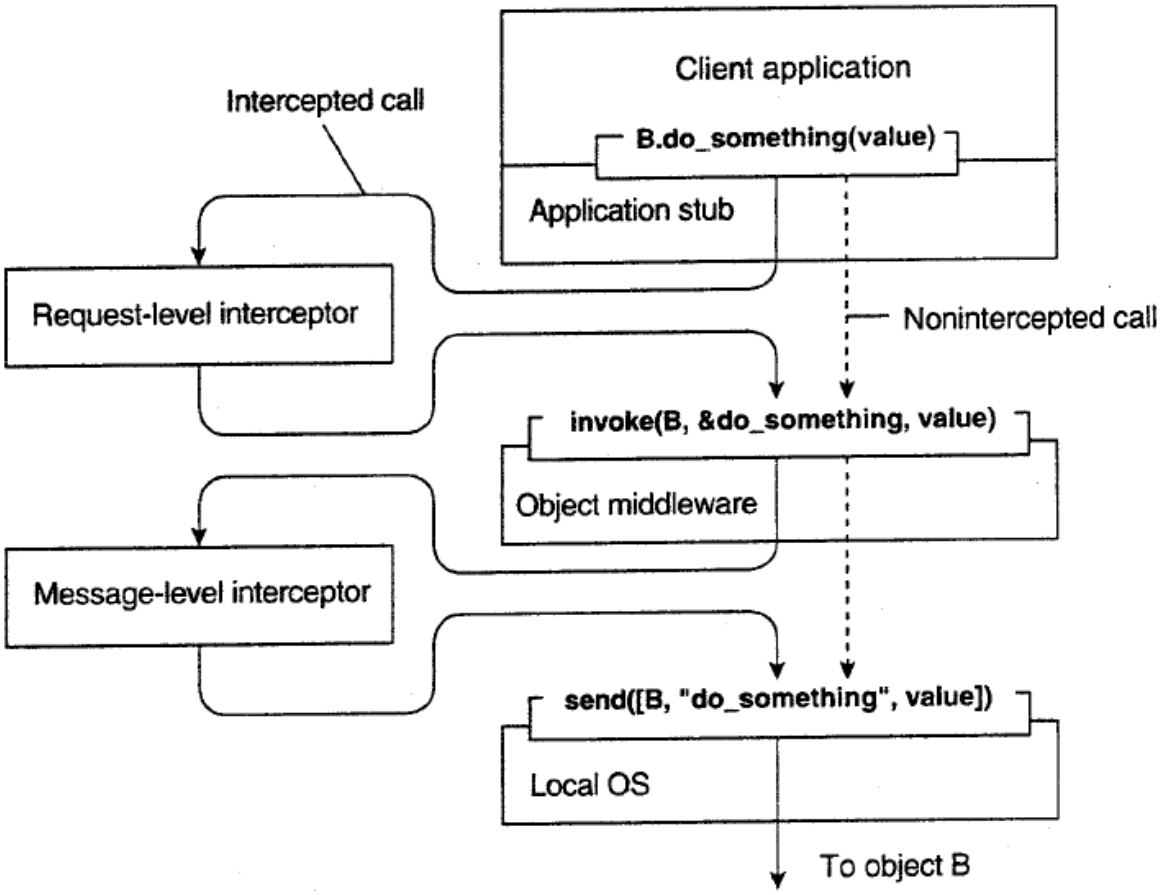


Figure 2-15. Using interceptors to handle remote-object invocations.

Adaptive Software

- What interceptors actually offer is a means to adapt the middleware.
- The need for adaptation comes from the fact that the environment in which distributed applications are executed changes continuously.
  - Changes include those resulting from mobility, a strong variance in the quality-of-service of networks, failing hardware, and battery drainage, amongst others.
- Rather than making applications responsible for reacting to changes, this task is placed in the middleware.
- These strong influences from the environment have brought many designers of middleware to consider the construction of ***adaptive software.***
- However, adaptive software has not been as successful as anticipated.

Software Adaptation

- We distinguish three basic techniques to come to software adaptation:
  - Separation of concerns: Try to separate extra functionalities and later weave them together into a single implementation => only toy examples so far.
  - Computational reflection: Let a program inspect itself at runtime and adapt/change its settings dynamically if necessary => mostly at language level and applicability unclear.
  - Component-based design: Organize a distributed application through components that can be dynamically replaced when needed => highly complex, also many intercomponent dependencies.

Do we need Adaptive software?

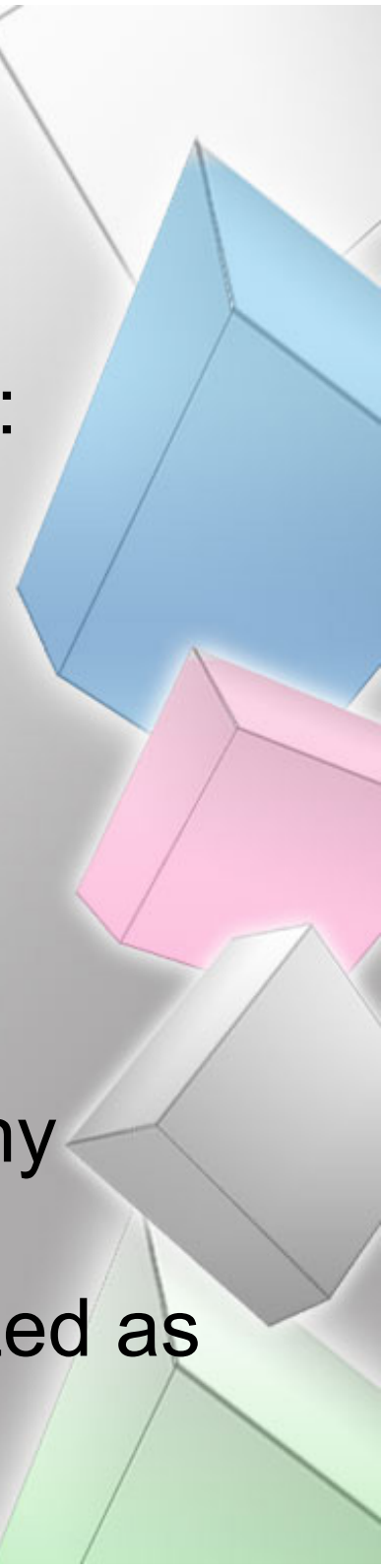
- The underlying assumption is that we need *adaptive software* in the sense that the software should be allowed to change as the environment changes.
  - However, one should question whether adapting to a changing environment is a good reason to adopt changing the software.
  - Faulty hardware, security attacks, energy drainage, and so on, all seem to be environmental influences that can (and should) be anticipated by software.
- The strongest, and certainly most valid, argument for supporting adaptive software is that many distributed systems cannot be shut down.
- This constraint calls for solutions to replace and upgrade components on the fly, but is not clear whether any of the solutions proposed above are the best ones to tackle this maintenance problem.

Self-managing Distributed Systems

- When adaptation needs to be done automatically, we see a strong interplay between system architectures and software architectures.
  - On the one hand, we need to organize the components of a distributed system such that monitoring and adjustments can be done, while on the other hand we need to decide where the processes are to be executed that handle the adaptation.
- Explicit attention is dedicated to organizing distributed systems as high-level feedback-control systems allowing automatic adaptations to changes.
- This phenomenon is also known as **autonomic computing**

Autonomic Computing

- This name indicates the variety by which automatic adaptations are being captured:
  - self-managing
  - self-healing
  - self-configuring
  - self-optimizing
  - Self-*
- We resort simply to using the name self-managing systems as coverage of its many variants.
- In many cases, self-* systems are organized as a feedback control system.



Feedback control system

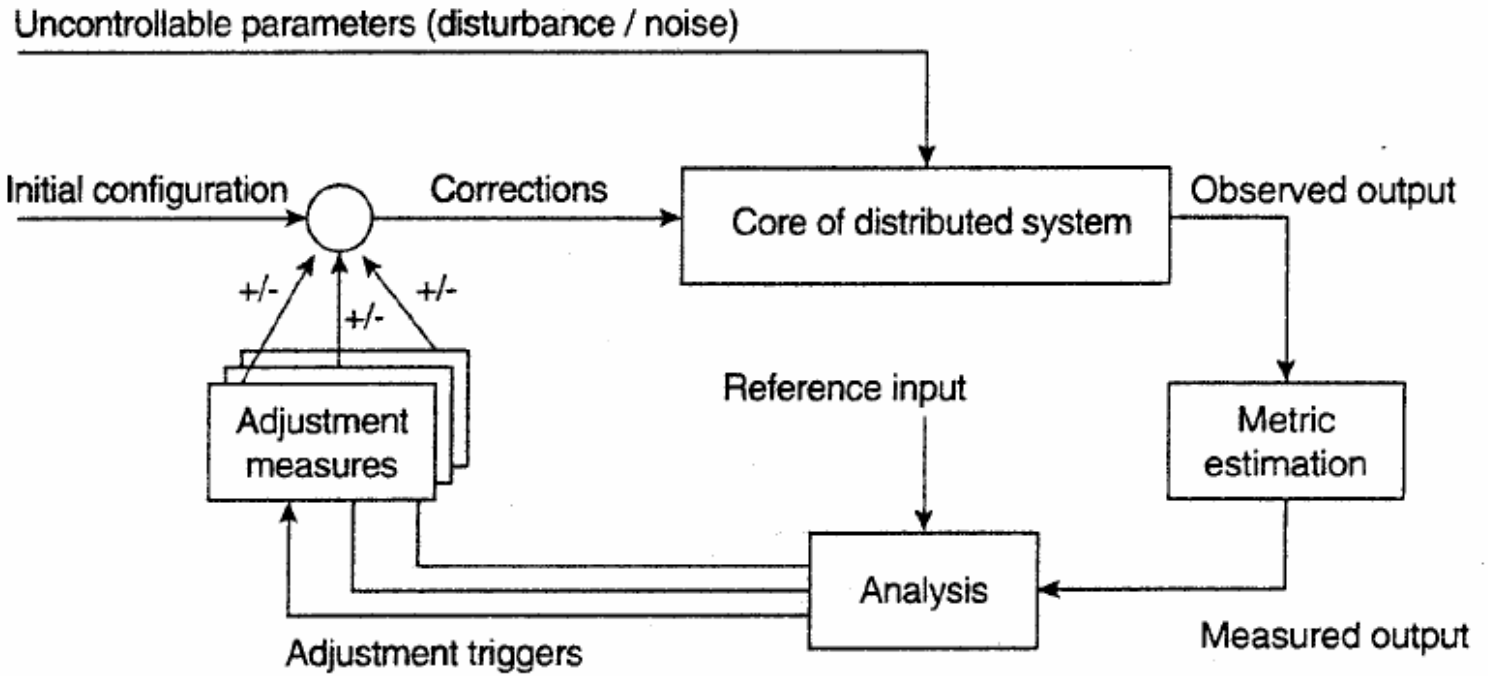


Figure 2-16. The logical organization of a feedback control system.

This shows the *logical organization* of a selfmanaging system, and as such corresponds to what we have seen when discussing software architectures. However, the *physical organization* may be very different. For example, the analysis component may be fully distributed across the system.

Astrolabe

- As our first example, we consider Astrolabe which is a system that can support general monitoring of very large distributed systems.
  - In the context of self-managing systems, Astrolabe is to be positioned as a general tool for observing systems behavior. Its output can be used to feed into an analysis component for deciding on corrective actions.

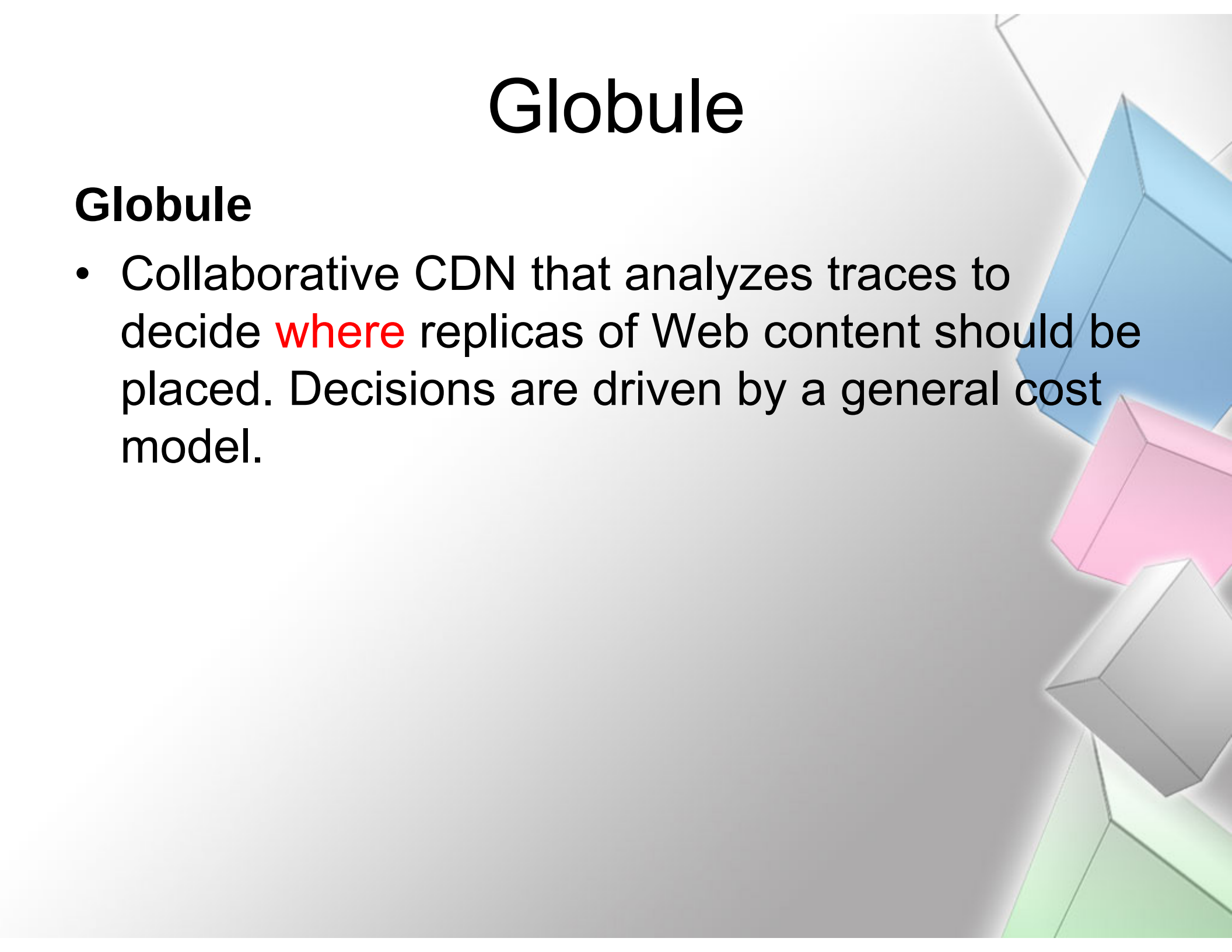
- Astrolabe organizes a large collection of hosts into a hierarchy of zones. The lowest-level zones consist of just a single host, which are subsequently grouped into zones of increasing size. The top-level zone covers all hosts.

- Every host runs an Astrolabe process, called an *agent,* that collects information on the zones in which that host is contained. The agent also communicates with other agents with the aim to spread zone information across the entire system.

Globule

Globule

- Collaborative CDN that analyzes traces to decide where replicas of Web content should be placed. Decisions are driven by a general cost model.



Globule

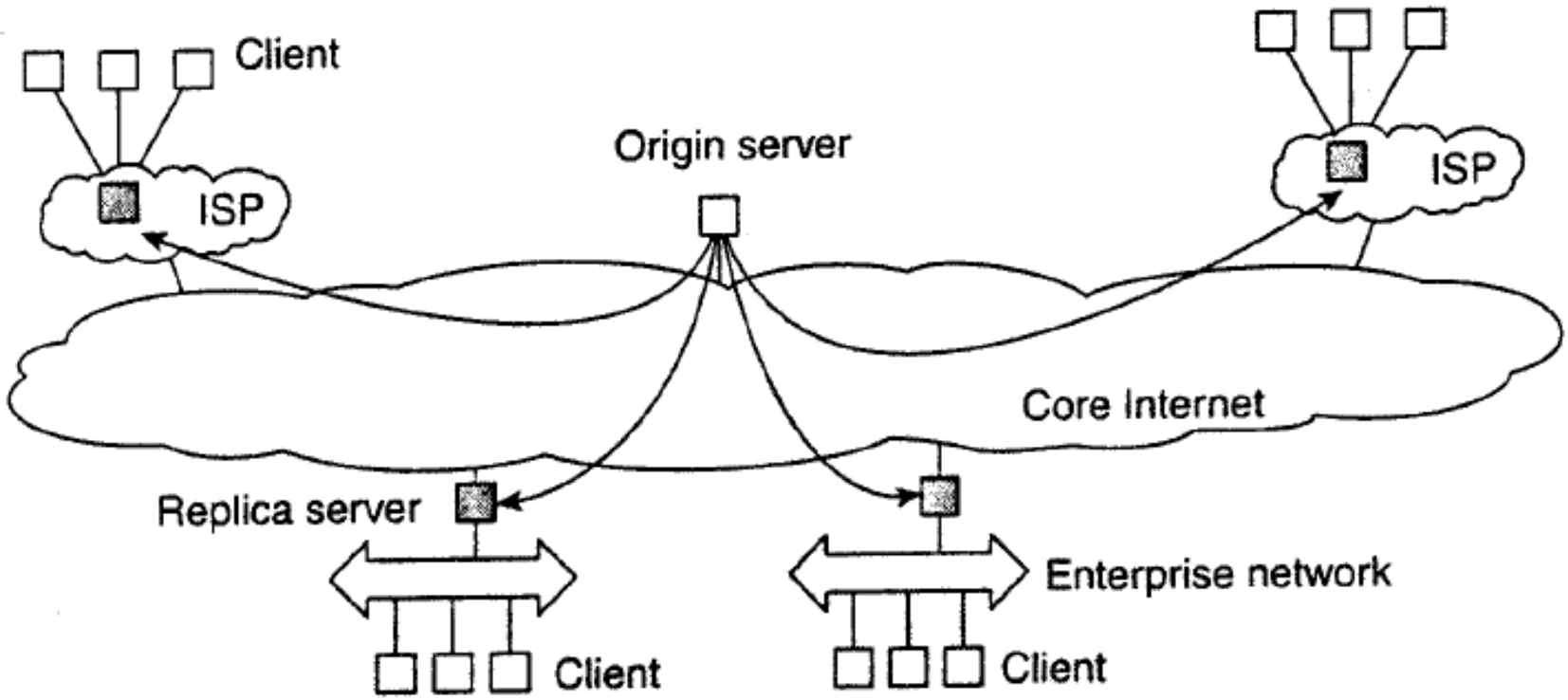


Figure 2-18. The edge-server model assumed by Globule.

Globule origin server collects traces and does what-if analysis by checking what would have happened if page P would have been placed at edge server S.

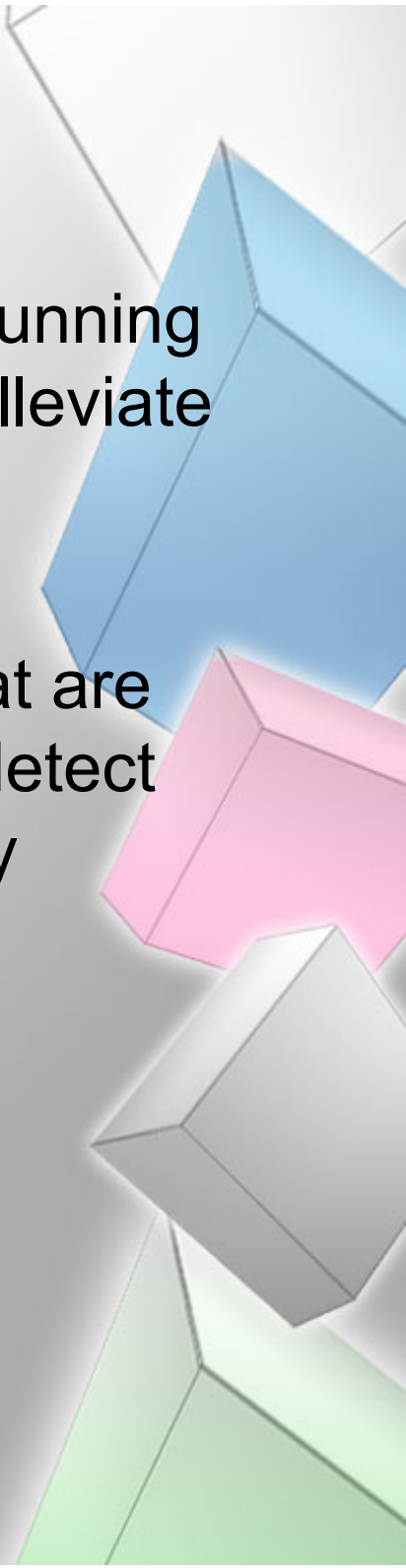
Many strategies are evaluated, and the best one is chosen.

The Jade system

- When maintaining clusters of computers, each running sophisticated servers, it becomes important to alleviate management problems.

- One approach that can be applied to servers that are built using a component-based approach, is to detect component failures and have them automatically replaced.

- The Jade system follows this approach



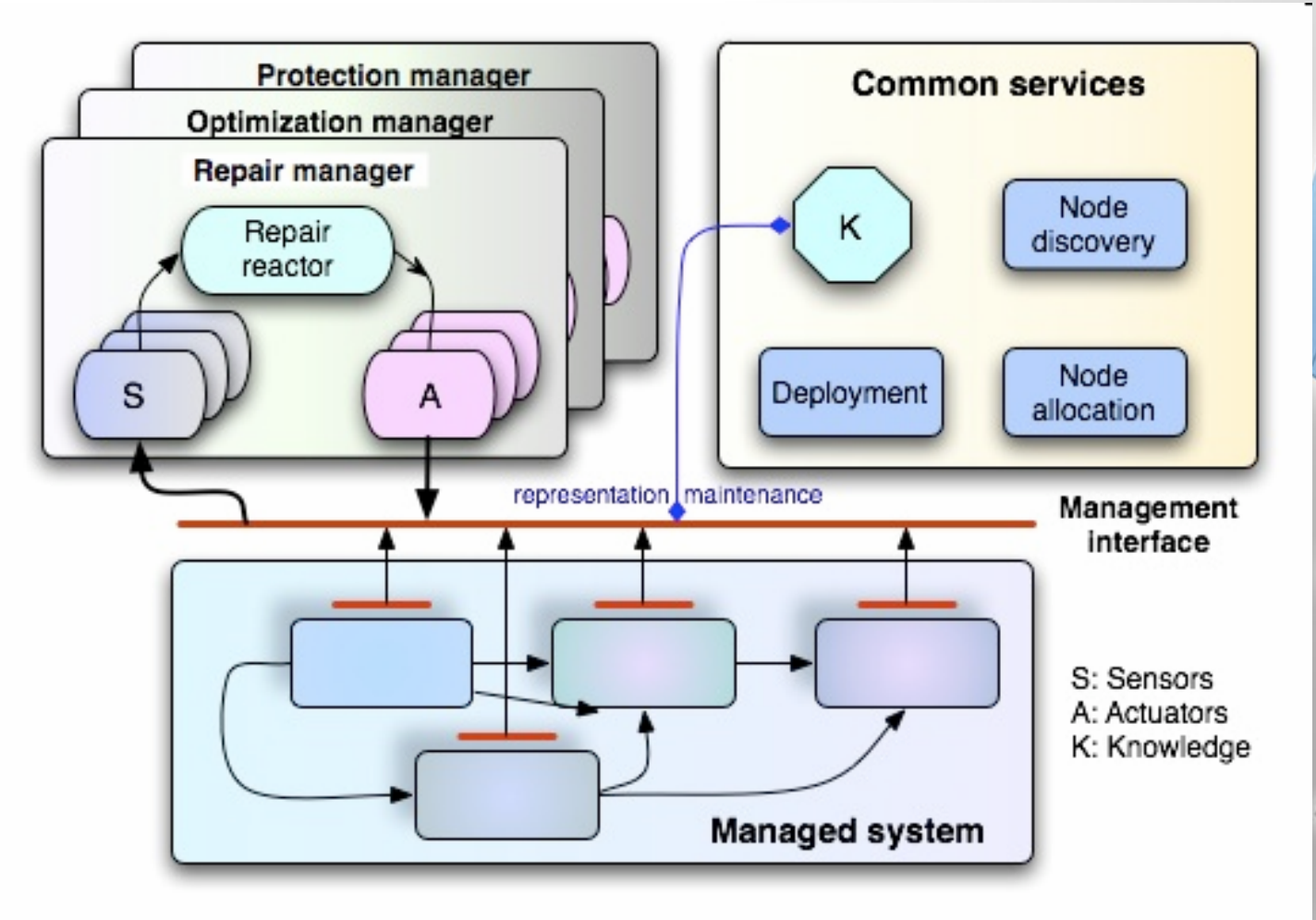
Jade

- Jade is built on the Fractal component model, a Java implementation of a framework that allows components to be added and removed at runtime.

- A component in Fractal can have two types of interfaces:
  - A server interface is used to call methods that are implemented by that component.
  - A client interface is used by a component to call other components.

- Components are connected to each other by binding interfaces.

Jade



JADE: http://sardes.inrialpes.fr/jade.html

End of Lesson 2

- Readings
  - Distributed Systems, Chapter 2.