Distributed Systems
Principles and Paradigms

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Chapter 02: Architectures

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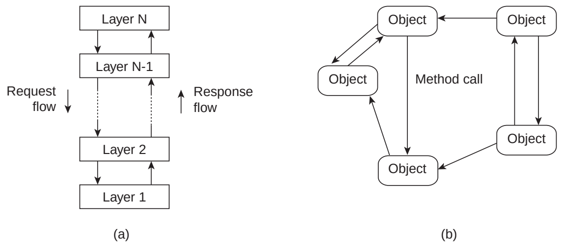
Architectural styles

Basic idea

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

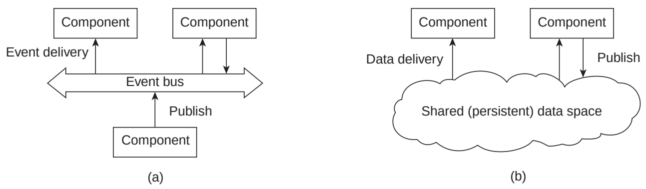


(a) Layered style is used for client-server system
(b) Object-based style for distributed object systems.

Architectural Styles

Observation

Decoupling processes in space (“anonymous”) and also time (“asynchronous”) has led to alternative styles.



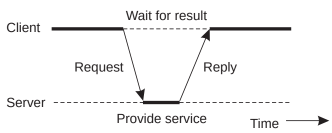
(a) Publish/subscribe [decoupled in space]
(b) Shared dataspace [decoupled in space and time]

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

Traditional three-layered view

- User-interface layer contains units for an application's user interface
- Processing layer contains the functions of an application, i.e. without specific data
- Data layer contains the data that a client wants to manipulate through the application components

Observation

This layering is found in many distributed information systems, using traditional database technology and accompanying applications.

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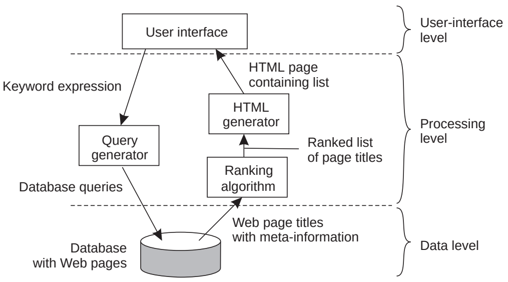
Application Layering



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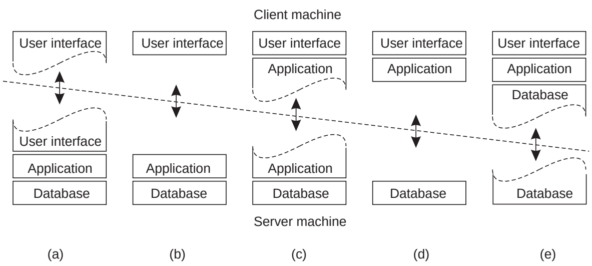
Multi-Tiered Architectures

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

Traditional two-tiered configurations:



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Decentralized Architectures

Observation

In the last couple of years we have been seeing a tremendous growth in peer-to-peer systems.

- 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

Note

In virtually all cases, we are dealing with overlay networks: data is routed over connections setup between the nodes (cf. application-level multicasting)

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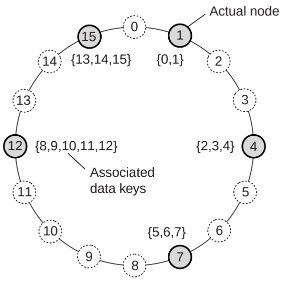
Structured P2P Systems

Basic idea

Organize the nodes in a structured overlay network such as a logical ring, and make specific nodes responsible for services based only on their ID.



Note

The system provides an operation *LOOKUP(key)* that will efficiently route the lookup request to the associated node.

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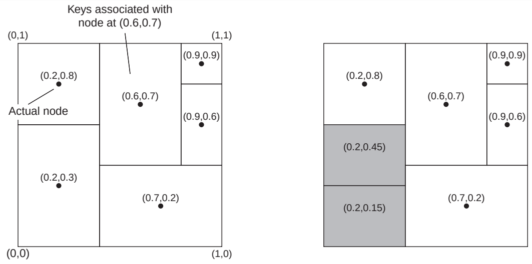
Structured P2P Systems

Other example

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.



(a) (b)

Architectures 2.2 System Architectures

Unstructured P2P Systems

Observation

Many unstructured P2P systems attempt to maintain a random graph.

Basic principle

Each node is required to contact a randomly selected other node:

- Let each peer maintain a partial view of the network, consisting of c 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

Note

It turns out that, depending on the exchange, randomness, but also robustness of the network can be maintained.

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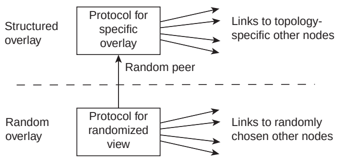
Topology Management of Overlay Networks

Basic idea

Distinguish two layers: (1) maintain random partial views in lowest layer; (2) be selective on who you keep in higher-layer partial view.



Note

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

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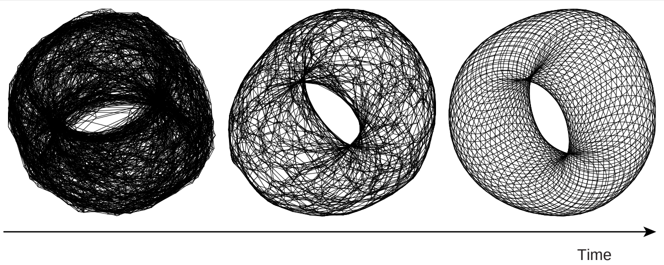
Topology Management of Overlay Networks

Constructing a torus

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

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

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



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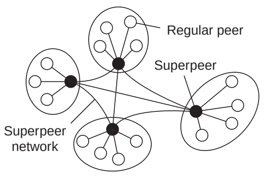
Superpeers

Observation

Sometimes it helps to select a few nodes to do specific work: superpeer.



Examples

- Peers maintaining an index (for search)
- Peers monitoring the state of the network
- Peers being able to setup connections

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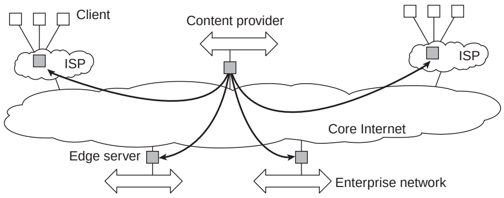
Hybrid Architectures: Client-server combined with P2P

Example

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



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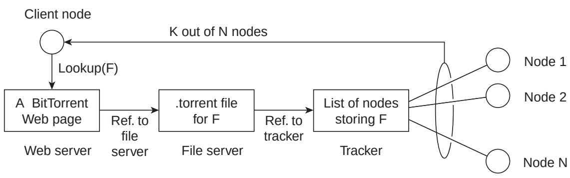
Hybrid Architectures: C/S with P2P – BitTorrent



Basic idea

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.

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Architectures 2.3 Architectures versus Middleware

Architectures versus Middleware

Problem

In many cases, distributed systems/applications are developed according to a specific architectural style. 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.

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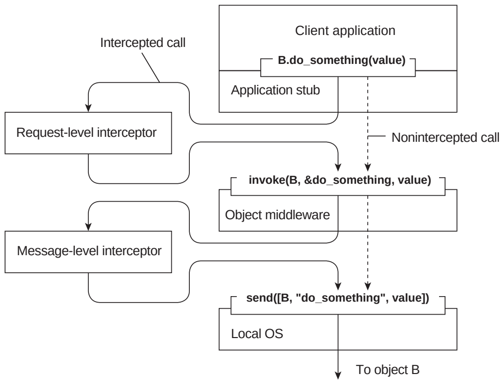
Architectures 2.3 Architectures versus Middleware

Interceptors



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Architectures 2.3 Architectures versus Middleware

Adaptive Middleware

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.

Fundamental question

Do we need adaptive software at all, or is the issue adaptive systems?

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Self-managing Distributed Systems

Observation

Distinction between system and software architectures blurs when automatic adaptivity needs to be taken into account:

- Self-configuration
- Self-managing
- Self-healing
- Self-optimizing
- Self-*

Warning

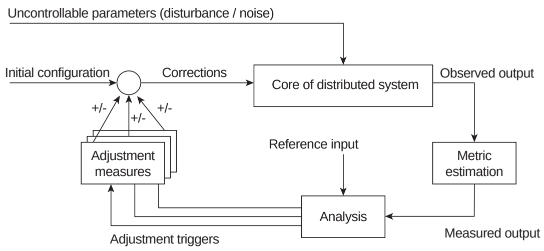
There is a lot of hype going on in this field of autonomic computing.

Architectures 2.4 Self-management in Distributed Systems

Feedback Control Model

Observation

In many cases, self-* systems are organized as a feedback control system.



Architectures 2.4 Self-management in Distributed Systems

Example: Globule

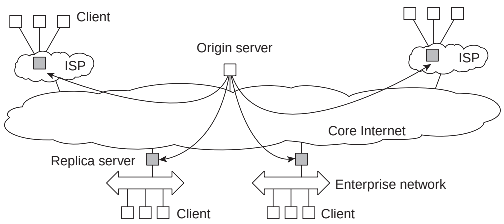
Globule

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

$$cost = (w_1 \times m_1) + (w_2 \times m_2) + \cdots + (w_n \times m_n)$$

Architectures 2.4 Self-management in Distributed Systems

Example: 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.

Architectures 2.4 Self-management in Distributed Systems

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