# Distributed Systems
# Principles and Paradigms

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## Chapter 02: Architectures

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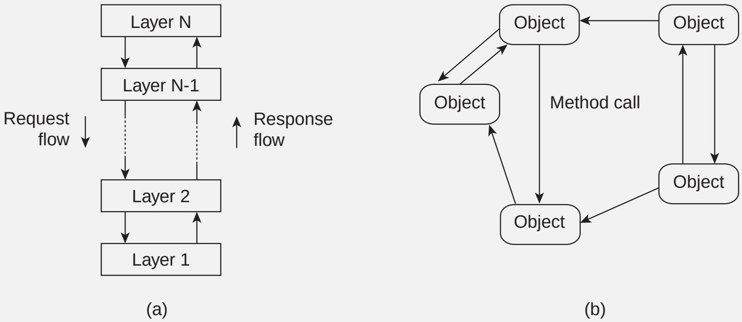
# Architectures

- Architectural styles
- Software architectures
- Architectures versus middleware
- Self-management in distributed systems

# Architectural styles

## Basic idea

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

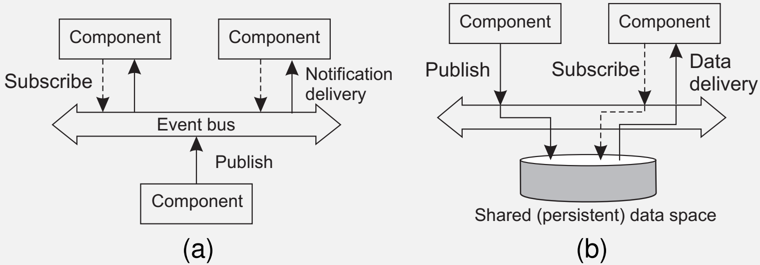



(a) Layered style is used for client-server system
(b) Object-based style for distributed object systems.

# Architectural Styles

**Observation**

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



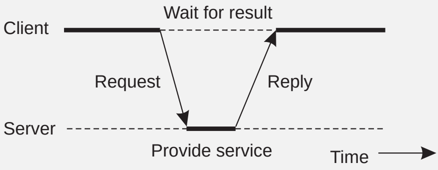

(a) Publish/subscribe [decoupled in space]
(b) Shared dataspace [decoupled in space and time]

# 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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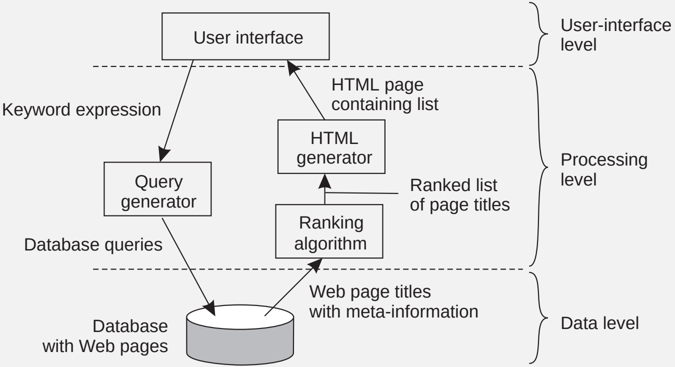
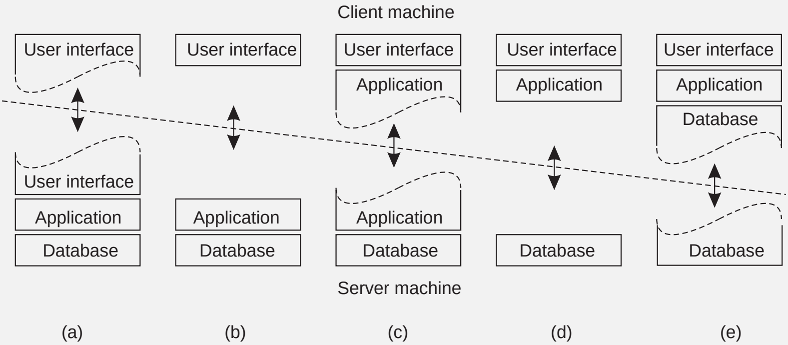


# Multi-Tiered Architectures

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

Traditional two-tiered configurations:



# 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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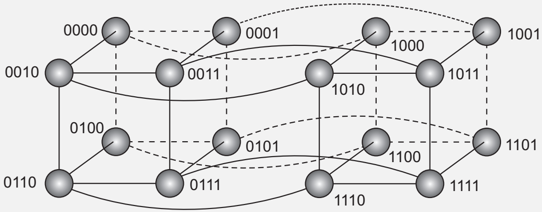
# Structured P2P Systems

## Basic idea

Organize the nodes in a structured overlay network such as a logical ring, or a hypercube, 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.

# Unstructured P2P Systems

## Essence

Many unstructured P2P systems are organized as a random overlay: two nodes are linked with probability $p$.

## Observation

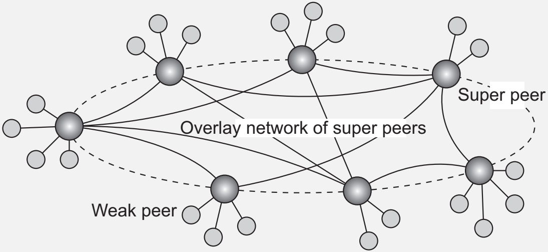
We can no longer look up information deterministically, but will have to resort to searching:

- Flooding: node $u$ sends a lookup query to all of its neighbors. A neighbor responds, or forwards (floods) the request. There are many variations:
  - Limited flooding (maximal number of forwarding)
  - Probabilistic flooding (flood only with a certain probability).
- Random walk: Randomly select a neighbor $v$. If $v$ has the answer, it replies, otherwise $v$ randomly selects one of *its* neighbors. Variation: parallel random walk. Works well with replicated data.

# Superpeers

## Observation

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



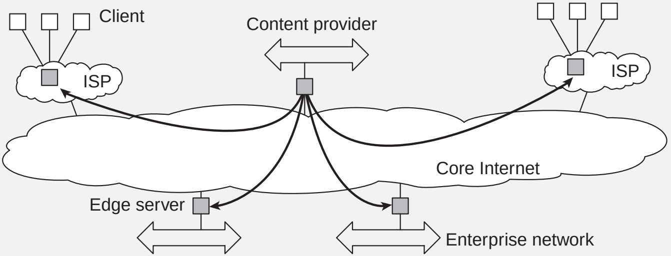

## Examples

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

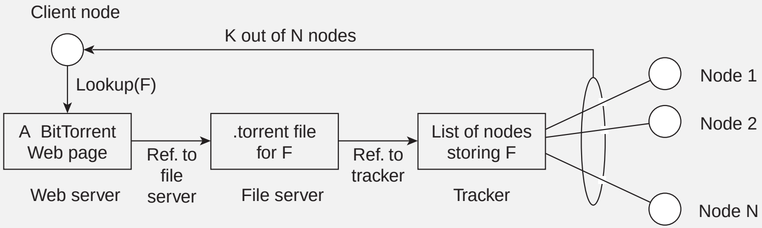
# Hybrid Architectures: Client-server combined with P2P

## Example

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



# 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.

# Architectures versus Middleware

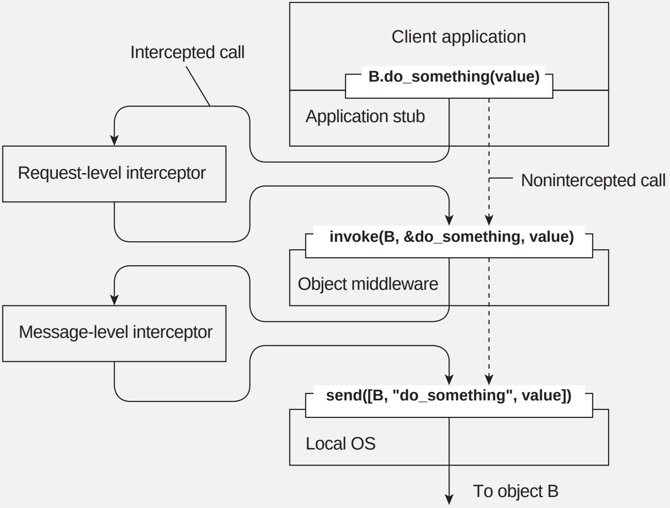
## Problem

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.

# Interceptors



# 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.

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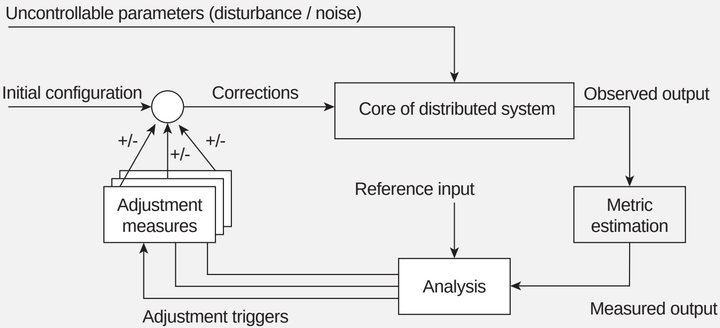
# Feedback Control Model

## Observation

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



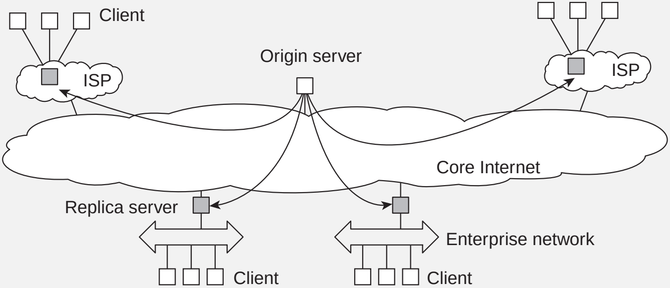
# Example: Globule

## Globule

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

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

# Example: Globule

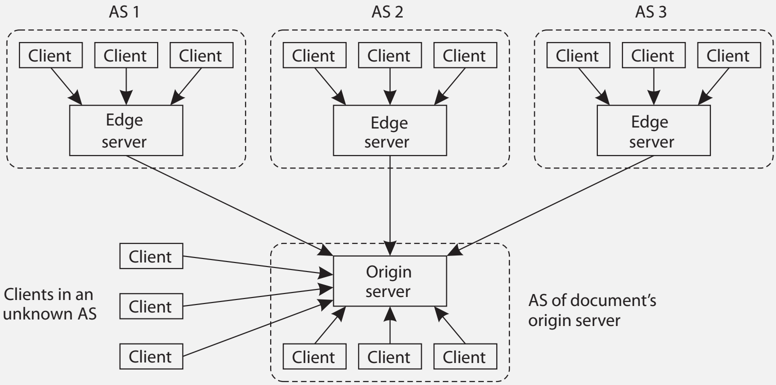



- Globule origin server collects traces and does what-if analysis by checking what would have happened if page *P* would have been placed at edge server *S*.
- Many strategies are evaluated, and the best one is chosen.

# An experiment

## Research question

Does it make sense to distribute each Web page according to its own best strategy, instead of applying a single, overall distribution strategy to all Web pages?



# An experiment

- We collected traces on requests and updates for all Web pages from two different servers (in Amsterdam and Erlangen)
- For each request, we checked:
  - From which autonomous system it came
  - What the average delay was to that client
  - What the average bandwidth was to the client's AS (randomly taking 5 clients from that AS)
- Pages that were requested less than 10 times were removed from the experiment.
- We replayed the trace file for many different system configurations, and many different distribution scenarios.

# An experiment

| Issue | Site 1 | Site 2 |
|---|---:|---:|
| Start date | 13/9/1999 | 20/3/2000 |
| End date | 18/12/1999 | 11/9/2000 |
| Duration (days) | 96 | 175 |
| Number of documents | 33,266 | 22,637 |
| Number of requests | 4,858,369 | 1,599,777 |
| Number of updates | 11,612 | 3338 |
| Number of ASes | 2567 | 1480 |

# Distinguished strategies: Caching

| Abbr. | Name | Description |
|---|---|---|
| NR | No replication | No replication or caching takes place. All clients forward their requests directly to the origin server. |
| CV | Verification | Edge servers cache documents. At each subsequent request, the origin server is contacted for revalidation. |
| CLV | Limited validity | Edge servers cache documents. A cached document has an associated expire time before it becomes invalid and is removed from the cache. |
| CDV | Delayed verification | Edge servers cache documents. A cached document has an associated expire time after which the origin server is contacted for revalidation. |

# Distinguished strategies: Replication

| Abbr. | Name | Description |
|---|---|---|
| SI | Server invalidation | Edge servers cache documents, but the origin server invalidates cached copies when the document is updated. |
| SU$x$ | Server updates | The origin server maintains copies at the $x$ most relevant edge servers; $x$ = 10, 25 or 50 |
| SU50 + CLV | Hybrid SU50 & CLV | The origin server maintains copies at the 50 most relevant edge servers; the other intermediate servers follow the CLV strategy. |
| SU50 + CDV | Hybrid SU50 & CDV | The origin server maintains copies at the 50 most relevant edge servers; the other edge servers follow the CDV strategy. |

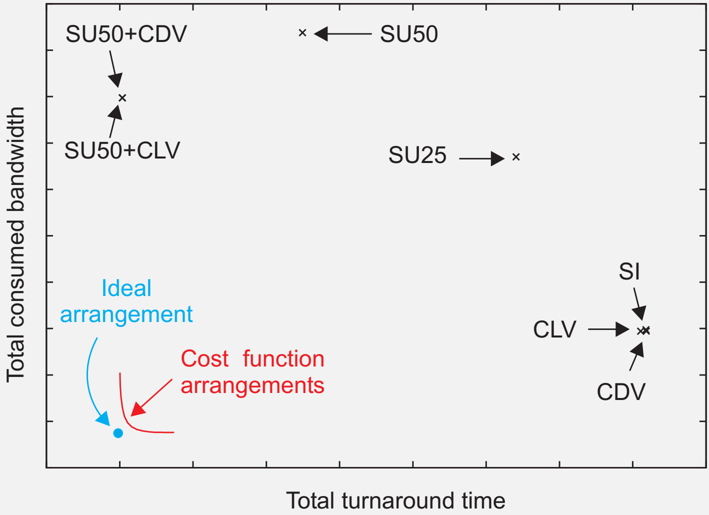
# Trace results: One global strategy

*Turnaround time (TaT) and bandwidth (BW) in relative measures; stale documents as fraction of total requested documents.*

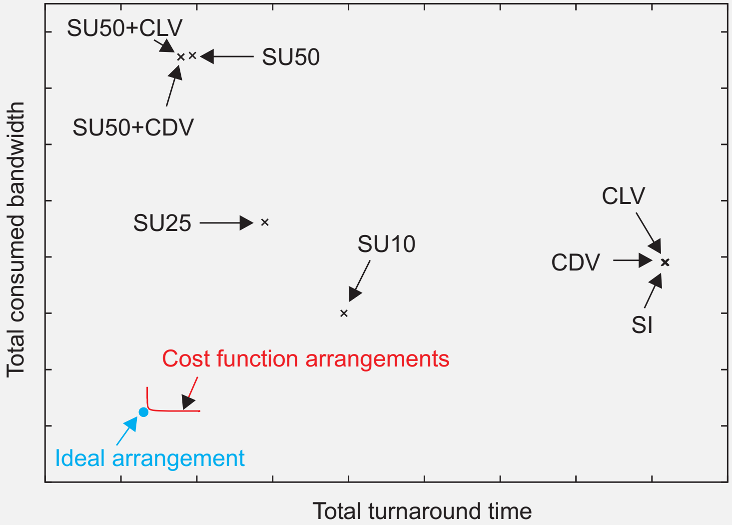
| Strategy | Site 1 | | | Site 2 | | |
|---|---|---|---|---|---|---|
| | TaT | Stale docs | BW | TaT | Stale docs | BW |
| NR | 203 | **0** | 118 | 183 | **0** | 115 |
| CV | 227 | **0** | 113 | 190 | **0** | **100** |
| CLV | 182 | 0.0061 | 113 | 142 | 0.0060 | **100** |
| CDV | 182 | 0.0059 | 113 | 142 | 0.0057 | **100** |
| SI | 182 | **0** | 113 | 141 | **0** | **100** |
| SU10 | 128 | **0** | **100** | 160 | **0** | 114 |
| SU25 | 114 | **0** | 123 | 132 | **0** | 119 |
| SU50 | 102 | **0** | 165 | 114 | **0** | 132 |
| SU50+CLV | **100** | 0.0011 | 165 | **100** | 0.0019 | 125 |
| SU50+CDV | **100** | 0.0011 | 165 | **100** | 0.0017 | 125 |

*Conclusion: No single global strategy is best*

# Assigning an optimal strategy per document: Site 1



# Assigning an optimal strategy per document: Site 2



# Useful strategies

*Fraction of documents to which a strategy is assigned.*

| Strategy | Site 1 | Site 2 |
|---|---|---|
| NR | 0.0973 | 0.0597 |
| CV | 0.0001 | 0.0000 |
| CLV | 0.0131 | 0.0029 |
| CDV | 0.0000 | 0.0000 |
| SI | 0.0089 | 0.0061 |
| SU10 | 0.1321 | 0.6087 |
| SU25 | 0.1615 | 0.1433 |
| SU50 | 0.4620 | 0.1490 |
| SU50+CLV | 0.1232 | 0.0301 |
| SU50+CDV | 0.0017 | 0.0002 |

*Conclusion: It makes sense to differentiate strategies*

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