Distributed Systems

(3rd Edition)

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Chapter 02: Architectures

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Architectural styles

Basic idea

A style is formulated in terms of

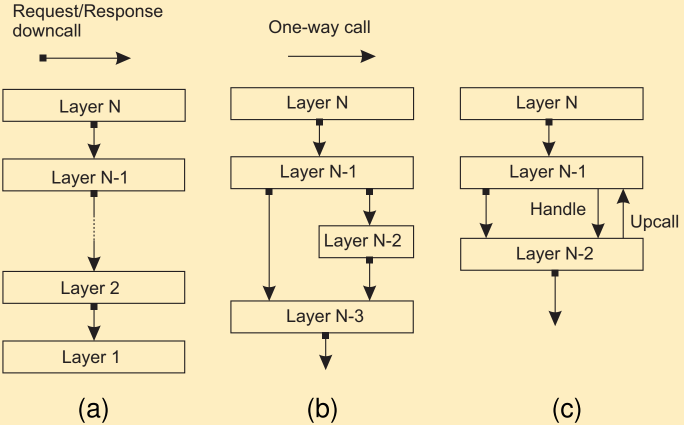
- (replaceable) components with well-defined interfaces
- the way that components are connected to each other
- the data exchanged between components
- how these components and connectors are jointly configured into a system.

Connector

A mechanism that mediates communication, coordination, or cooperation among components. Example: facilities for (remote) procedure call, messaging, or streaming.

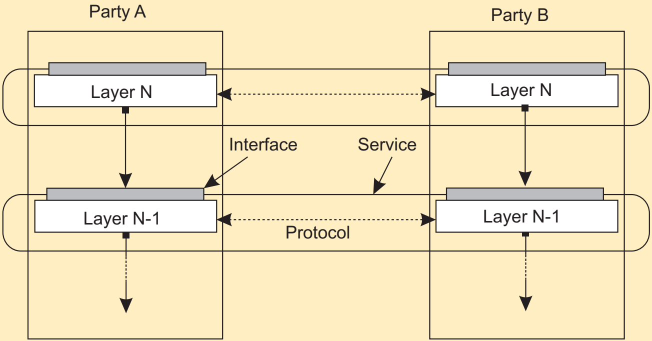
Layered architecture

Different layered organizations



Example: communication protocols

Protocol, service, interface



Application Layering

Traditional three-layered view

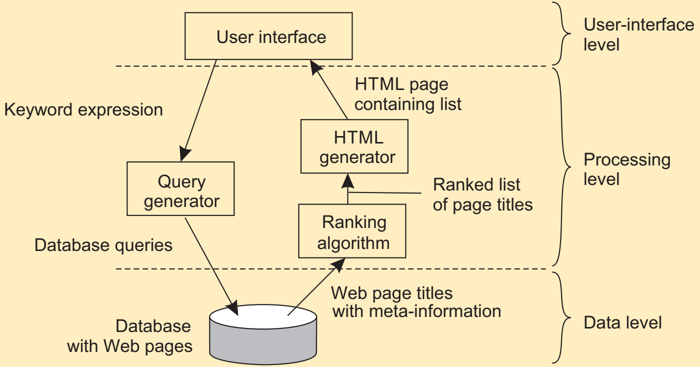
- Application-interface layer contains units for interfacing to users or external applications
- Processing layer contains the functions of an application, i.e., without specific data
- Data layer contains the data that a client wants to manipulate through the application components

Observation

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

Application Layering

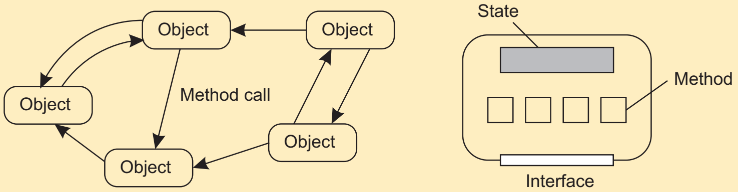
Example: a simple search engine



Object-based style

Essence

Components are objects, connected to each other through procedure calls. Objects may be placed on different machines; calls can thus execute across a network.



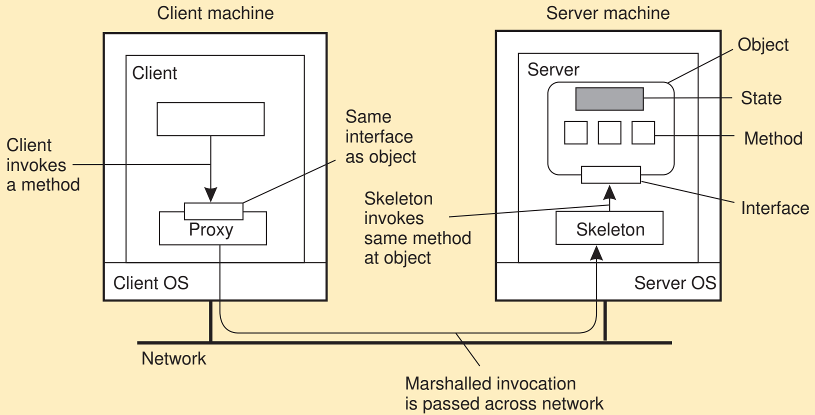
Encapsulation

Objects are said to encapsulate data and offer methods on that data without revealing the internal implementation.

Object-based style

Distributed Objects

The separation between interfaces and their implementing objects allows us to place an interface at one m/c, while the object itself resides on another m/c.



RESTful architectures

Essence

View a distributed system as a collection of resources, individually managed by components. Resources may be added, removed, retrieved, and modified by (remote) applications.

1. Resources are identified through a single naming scheme
2. All services offer the same interface
3. Messages sent to or from a service are fully self-described
4. After executing an operation at a service, that component forgets everything about the caller

Basic operations

Operation	Description
PUT	Create a new resource
GET	Retrieve the state of a resource in some representation
DELETE	Delete a resource
POST	Modify a resource by transferring a new state

Example: Amazon's Simple Storage Service

Essence

Objects (i.e., files) are placed into buckets (i.e., directories). Buckets cannot be placed into buckets. Operations on `ObjectName` in bucket `BucketName` require the following identifier:

`http://BucketName.s3.amazonaws.com/ObjectName`

Typical operations

All operations are carried out by sending HTTP requests:

- Create a bucket/object: `PUT`, along with the URI
- Listing objects: `GET` on a bucket name
- Reading an object: `GET` on a full URI

On interfaces

Issue

Many people like RESTful approaches because the interface to a service is so simple. The catch is that much needs to be done in the parameter space.

Amazon S3 SOAP interface

Bucket operations	Object operations
ListAllMyBuckets	PutObjectInline
CreateBucket	PutObject
DeleteBucket	CopyObject
ListBucket	GetObject
GetBucketAccessControlPolicy	GetObjectExtended
SetBucketAccessControlPolicy	DeleteObject
GetBucketLoggingStatus	GetObjectAccessControlPolicy
SetBucketLoggingStatus	SetObjectAccessControlPolicy

On interfaces

Simplifications

Assume an interface `bucket` offering an operation `create`, requiring an input string such as `mybucket`, for creating a bucket "mybucket."

SOAP

```
import bucket
bucket.create("mybucket")
```

RESTful

```
PUT "http://mybucket.s3.amazonsws.com/"
```

Conclusions

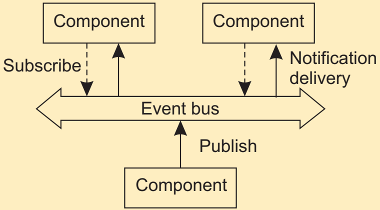
Are there any to draw?

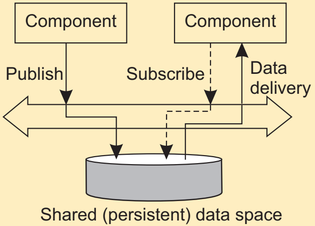
Coordination

Temporal and referential coupling

	Temporally coupled	Temporally decoupled
Referentially coupled	Direct	Mailbox
Referentially decoupled	Event-based	Shared data space

Event-based and Shared data space





Using legacy to build middleware

Problem

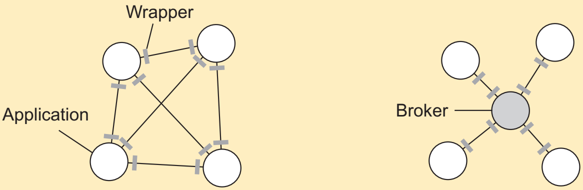
The interfaces offered by a legacy component are most likely not suitable for all applications.

Solution

A wrapper or adapter offers an interface acceptable to a client application. Its functions are transformed into those available at the component.

Organizing wrappers

Two solutions: 1-on-1 or through a broker



Complexity with N applications

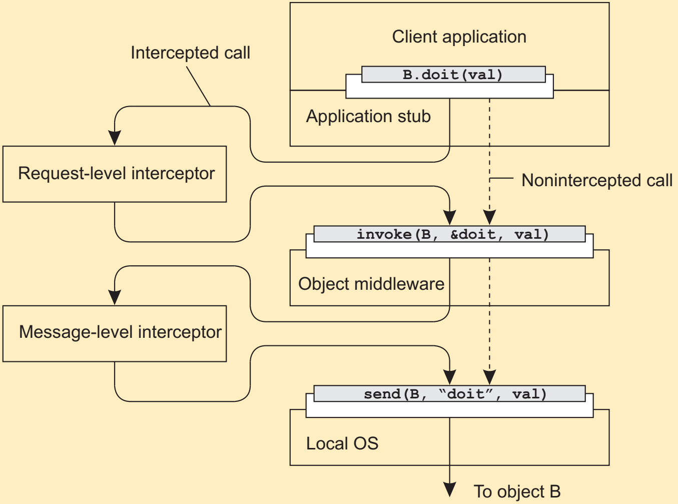
- 1-on-1: requires $N \times (N-1) = \mathscr{O}(N^2)$ wrappers
- broker: requires $2N = \mathscr{O}(N)$ wrappers

Developing adaptable middleware

Problem

Middleware contains solutions that are good for most applications $\Rightarrow$ you may want to adapt its behavior for specific applications.

Intercept the usual flow of control



Developing modifiable middleware

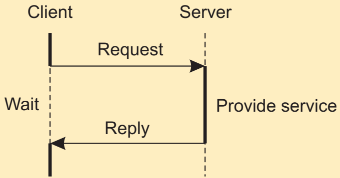
- The middleware is responsible for reacting to the continuous changes in the environment.
  - The increasing size of a distributed system mandates that changing its parts be done on-the-fly.
- The middleware may not only need to be adaptive, but we should be able to purposefully modify it without bringing it down.
  - Interceptors offer a means to adapt the standard flow of control.
  - Replacing software components at runtime is an example of modifying a system.
  - Dynamically constructing middleware from components.
- Component-based design focuses on supporting modifiability through composition.
  - A system may either be configured statically at design time, or dynamically at runtime.

Centralized system 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 with respect to using services

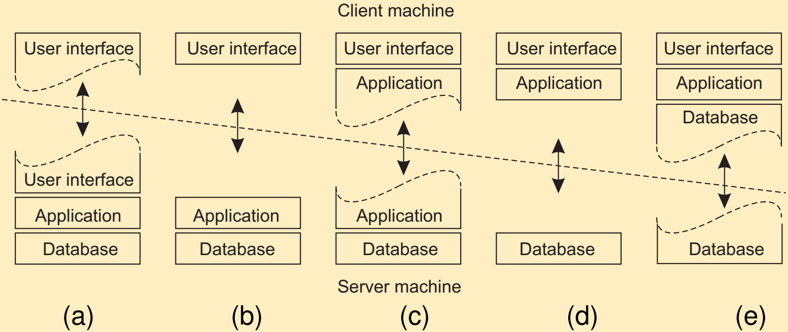


Multi-tiered centralized system architectures

Some traditional organizations

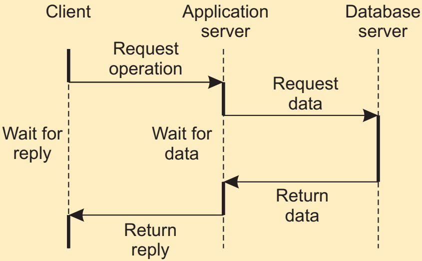
- Single-tiered: dumb terminal/mainframe configuration
- Two-tiered: client/single server configuration
- Three-tiered: each layer on separate machine

Traditional two-tiered configurations



Being client and server at the same time

Three-tiered architecture



Alternative organizations

Vertical distribution

Comes from dividing distributed applications into three logical layers, and running the components from each layer on a different server (machine).

Horizontal 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.

Peer-to-peer architectures

Processes are all equal: the functions that need to be carried out are represented by every process $\Rightarrow$ each process will act as a client and a server at the same time (i.e., acting as a servant).

Structured P2P

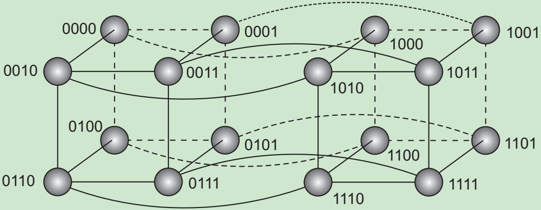
Essence

Make use of a semantic-free index: each data item is uniquely associated with a key, in turn used as an index. Common practice: use a hash function

$$key(data\ item) = hash(data\ item's\ value).$$

P2P system now responsible for storing (*key*,*value*) pairs.

Simple example: hypercube



Looking up d with key $k \in \{0,1,2,\ldots,2^4-1\}$ means routing request to node with identifier k.

Unstructured P2P

Essence

Each node maintains an ad hoc list of neighbors. The resulting overlay resembles a random graph: an edge $\langle u, v \rangle$ exists only with a certain probability $\mathbb{P}[\langle u, v \rangle]$.

Searching

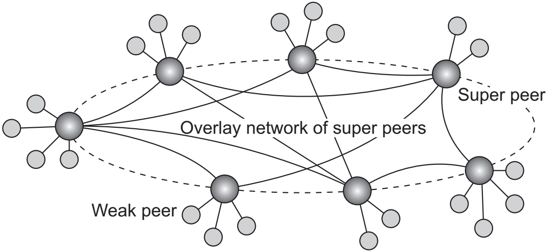
- Flooding: issuing node *u* passes request for *d* to all neighbors. Request is ignored when receiving node had seen it before. Otherwise, *v* searches locally for *d* (recursively). May be limited by a Time-To-Live: a maximum number of hops.
- Random walk: issuing node *u* passes request for *d* to randomly chosen neighbor, *v*. If *v* does not have *d*, it forwards request to one of *its* randomly chosen neighbors, and so on.

Super-peer networks

Essence

It is sometimes sensible to break the symmetry in pure peer-to-peer networks:

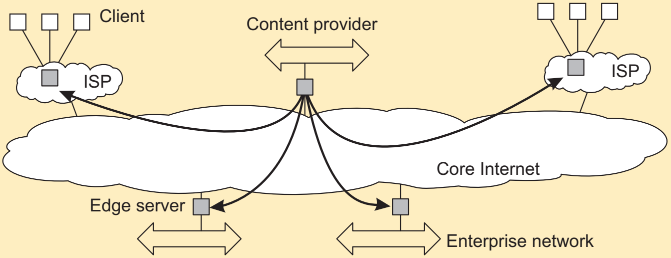
- When searching in unstructured P2P systems, having index servers improves performance
- Deciding where to store data can often be done more efficiently through brokers.



Edge-server architecture

Essence

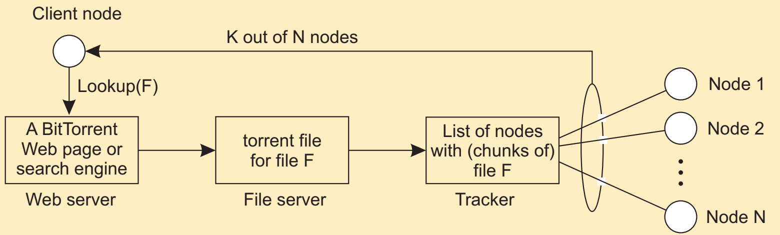
Systems deployed on the Internet where servers are placed at the edge of the network: the boundary between enterprise networks and the actual Internet.



Collaboration: The BitTorrent case

Principle: search for a file *F*

- Lookup file at a global directory ⇒ returns a torrent file
- Torrent file contains reference to tracker: a server keeping an accurate account of active nodes that have (chunks of) *F*.
- *P* can join swarm, get a chunk for free, and then trade a copy of that chunk for another one with a peer *Q* also in the swarm.



The Network File System (NFS) for Unix Systems

Remote file service - Remote access model

- Transparent access to a file system managed by a remote server.
- Clients are unaware of actual location of files.