# Distributed Systems

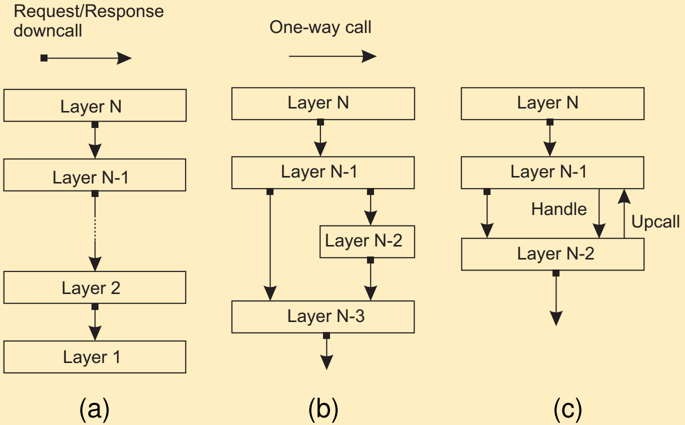
(3rd Edition)

## Chapter 02: Architectures

Version: February 25, 2017

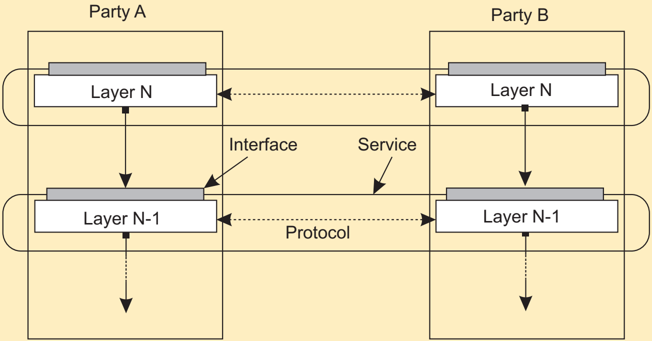
# Layered architecture

## Different layered organizations



# Example: communication protocols

## Protocol, service, interface



# Application Layering

## Traditional three-layered view

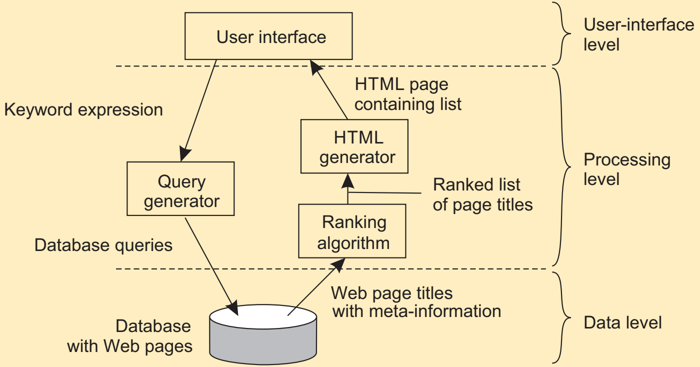
- Application-interface layer contains units for interfacing to users or external applications
- Processing layer contains the functions of an application, i.e., without specific data
- Data layer contains the data that a client wants to manipulate through the application components

## Observation

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

# Application Layering

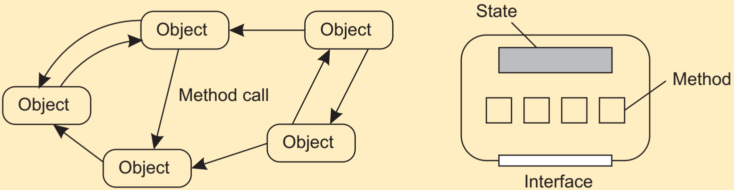
## Example: a simple search engine



# 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.

# 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

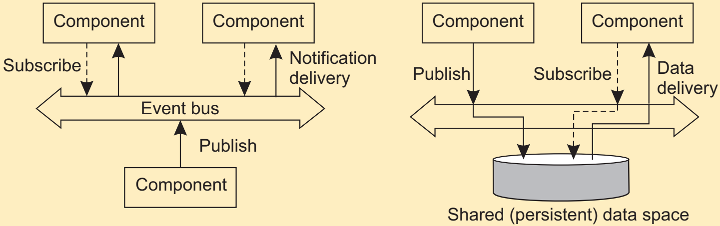
Are there any to draw?

# 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

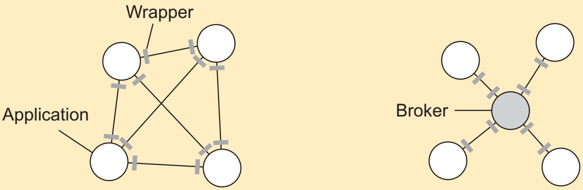
The interfaces offered by a legacy component are most likely not suitable for all applications.

## 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

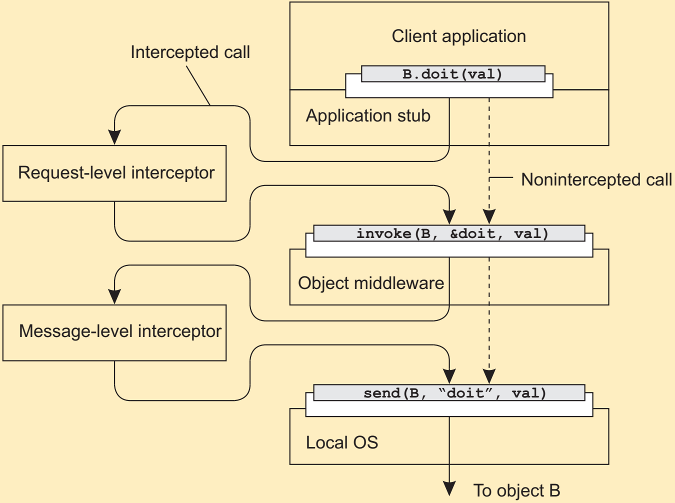
- 1-on-1: requires $N \times (N-1) = \mathcal{O}(N^2)$ wrappers
- broker: requires $2N = \mathcal{O}(N)$ wrappers

# 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

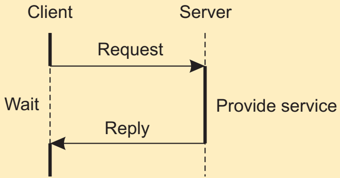


# Centralized system architectures

## 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

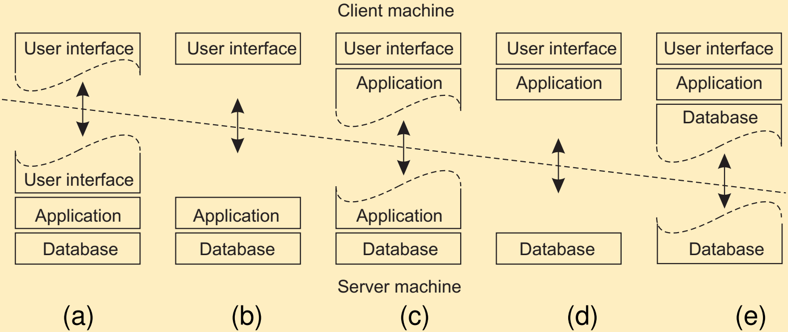


# Multi-tiered centralized system architectures

## Some traditional organizations

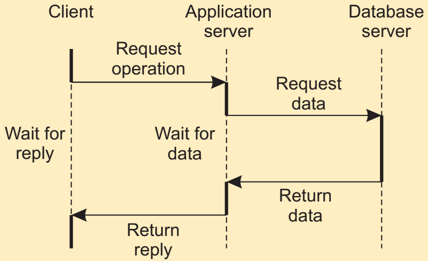
- Single-tiered: dumb terminal/mainframe configuration
- Two-tiered: client/single server configuration
- Three-tiered: each layer on separate machine

## 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

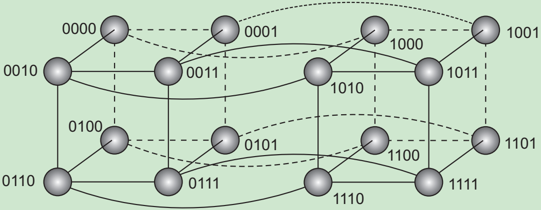
## Essence

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

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

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

## Simple example: hypercube



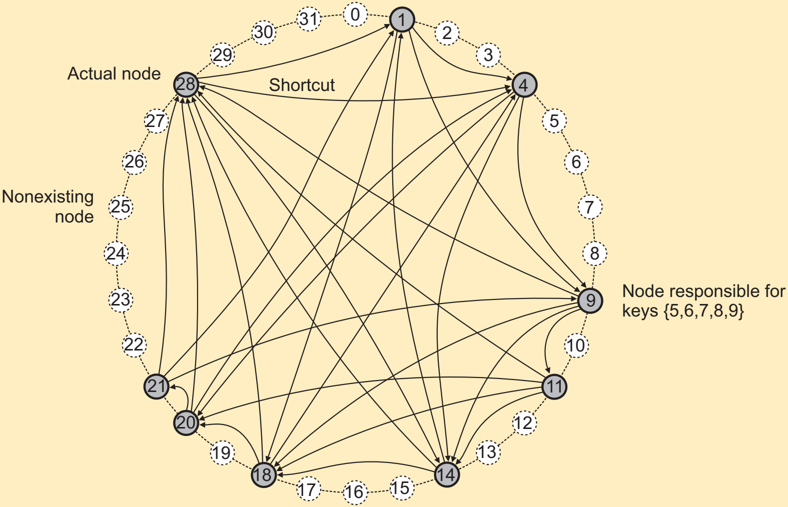

Looking up $d$ with key $k \in \{0,1,2,\ldots,2^4-1\}$ means routing request to node with identifier $k$.

# Example: Chord

## Principle

- Nodes are logically organized in a ring. Each node has an $m$-bit identifier.
- Each data item is hashed to an $m$-bit key.
- Data item with key $k$ is stored at node with smallest identifier $id \geq k$, called the successor of key $k$.
- The ring is extended with various shortcut links to other nodes.

# Example: Chord




$lookup(3)@9 : 28 \rightarrow 1 \rightarrow 4$

# 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

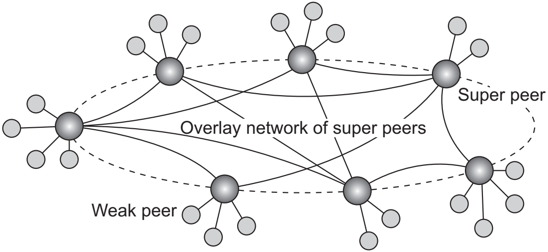
- Flooding: issuing node *u* passes request for *d* to all neighbors. Request is ignored when receiving node had seen it before. Otherwise, *v* searches locally for *d* (recursively). May be limited by a Time-To-Live: a maximum number of hops.
- Random walk: issuing node *u* passes request for *d* to 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.



# Skype's principle operation: *A* wants to contact *B*

## Both *A* and *B* are on the public Internet

- A TCP connection is set up between *A* and *B* for control packets.
- The actual call takes place using UDP packets between negotiated ports.

## *A* operates behind a firewall, while *B* is on the public Internet

- *A* sets up a TCP connection (for control packets) to a super peer *S*
- *S* sets up a TCP connection (for relaying control packets) to *B*
- The actual call takes place through UDP and directly between *A* and *B*

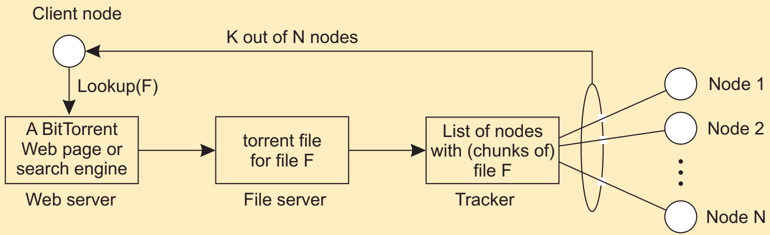
## Both *A* and *B* operate behind a firewall

- *A* connects to an online super peer *S* through TCP
- *S* sets up TCP connection to *B*.
- For the actual call, another super peer is contacted to act as a relay *R*: *A* sets up a connection to *R*, and so will *B*.
- All voice traffic is forwarded over the two TCP connections, and through *R*.

# 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.



# BitTorrent under the hood

## Some essential details

- A tracker for file $F$ returns the set of its downloading processes: the current swarm.
- $A$ communicates only with a subset of the swarm: the neighbor set $N_A$.
- if $B \in N_A$ then also $A \in N_B$.
- Neighbor sets are regularly updated by the tracker

## Exchange blocks

- A file is divided into equally sized pieces (typically each being 256 KB)
- Peers exchange blocks of pieces, typically some 16 KB.
- $A$ can upload a block $d$ of piece $D$, only if it has piece $D$.
- Neighbor $B$ belongs to the potential set $P_A$ of $A$, if $B$ has a block that $A$ needs.
- If $B \in P_A$ and $A \in P_B$: $A$ and $B$ are in a position that they can trade a block.