Software Architectures
Distributed Systems
Sistemi Distribuiti

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Ingegneria Due
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Academic Year 2011/2012
Outline

1. Architectural Styles
2. System Architectures
3. Architectures vs. Middleware
4. Self-Management in Distributed Systems
These Slides Contain Material from [Tanenbaum and van Steen, 2007]

Slides were made kindly available by the authors of the book

- Such slides shortly introduced the topics developed in the book [Tanenbaum and van Steen, 2007] adopted here as the main book of the course
- Most of the material from those slides has been re-used in the following, and integrated with new material according to the personal view of the teacher of this course
- Every problem or mistake contained in these slides, however, should be attributed to the sole responsibility of the teacher of this course
1. Architectural Styles

2. System Architectures
   - Centralised Architectures
   - Decentralised Architectures
   - Hybrid Architectures

3. Architectures vs. Middleware
   - General Approaches to Adaptive Software

4. Self-Management in Distributed Systems
Distributed systems are complex

- In order to manage their intrinsic complexity, distributed systems should be properly organised.
- Organisation of a distributed system is mostly expressed in terms of its software components.

Software architectures express component organisation

- Many ways to organise components of a distributed system, classified as *software architectures*.
- Many instantiations where components have their actual placed in a distributed system—often called *system architectures*.
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Architectural Style

An architectural style is formulated in terms of...

- components
- the way in which components are connected to each other
- the data flowing through the components
- the way in which all the above things are configured altogether to build the system

The notion of architectural style...

- encompasses a way to cluster and classify groups of similar systems, that is, having the same sort of organisation
- allow distributed systems to be compared
- but also provide general patterns for their overall design
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Components & Connectors

Components
- A component is a modular unit with well-defined *interfaces*
- which is *replaceable* within its environment
- interfaces are both *required* and *provided*—both ways, then

Connectors
- A connector is an abstraction *mediating* communication, coordination, cooperation among components
- that is, anything providing a *mechanism for interaction* among components

Putting together components and connectors
- ... produces a huge range of possible organisations and configurations
- that are then classified in terms of architectural styles
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Architectural Styles for Distributed Systems

Identification of architectural styles

- Architectural styles – like patterns in software engineering – are to be devised out rather than invented
- Today, four different architectural styles have been identified as the main ones for distributed systems

Important styles of architecture for distributed systems

- Layered architectures
- Object-based architectures
- Data-centered architectures
- Event-based architectures
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Layered Architectures

Basic idea

- Components are organised in a *layered fashion*
- where components of a layer *only* call components of the layer below, and are *only* called by the components of the layer above

Data flow

- The request-response flow is always top-down / bottom-up
- Control flow follow the same pattern along with data
Layered Architectures

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Layered Architecture Style

[Omicini, 2011]

[Tanenbaum and van Steen, 2007]
Object-based Architectures

Basic idea

- Components are objects
- Components are connected through a RPC mechanism

Client-server architectures

- ... are built out of this style

Layered and object-based architectures

- are the most important styles for distributed systems today
- However, a lot of things are going to happen in the future, which may change such an overall picture
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Object-based Architecture Style

(b)

[Tanenbaum and van Steen, 2007]
Data-centred Architectures

Basic idea
- Communication among processes occurs through a shared repository
- The repository might be either passive (reactive) or (pro)active

Main features
- ... depends on the choice made for the shared repository
- how information is represented
- how events are handled
- how the shared repository behave in response to interaction
- how processes interact with / through the shared repository

Examples are everywhere
- Web-based systems, for instance, are largely data-centric
- Also, many distributed applications still work by sharing files around the network
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## Event-based Architectures

### Basic idea
- Processes communicate through an event bus
- through which events are propagated
- possibly carrying data along

### Main example: Publish / subscribe systems
- Publishers publish events through the middleware
- Subscribers receive events to which they have subscribed

### Main feature
- Processes can communicate with no need of reference each other / to know each other, they are *referentially decoupled*
- Processes can communicate with no need to share the same space, they are *decoupled in space*
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Event-based Architecture Style

Event delivery

Event bus

Publish

Component

Component

Component

(a)

[Tanenbaum and van Steen, 2007]
Shared Data-space Architectures

Basic idea

- Putting together Data-centric and Event-based architectures
- The shared repository is a shared persistent data-space, and also an event bus
- where data is stored and accessed
- along with related events

Main example: Blackboard systems

- Processes put data in the blackboard
- The blackboard aggregates knowledge, implements policies and drive the coordination of processes

Main feature

- Processes can communicate with no need of compresence
- Processes are also *decoupled in time*
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Shared Data-space Architecture Style

[Omicini, 2011/2012]
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4. Self-Management in Distributed Systems
Where are Software Components?

Component Topology

- When a software architecture is actually instantiated, components are placed somewhere in a distributed system.
- This is typically taken as an instantiation of a software architecture in a system architecture.

Sorts of System Architectures

- Centralised architectures
- Decentralised architectures
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Clients & Servers

Main feature

- In a centralised architecture, *clients* request *services* from *servers*—and that is all, more or less.
- In the basic client-server model, processes are classified in two groups—obviously, clients and servers.
- Possibly, the two groups may overlap.

Servers

A server is a process implementing a specific service—like, say, a database service.

Clients

A client is a process requiring a specific service from a server.
Clients & Servers

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Client-server Interaction

Scheme of client-server interaction: request-reply behaviour
[Tanenbaum and van Steen, 2007]
### Efficiency vs. reliability

- Connectionless protocols is ok for *idempotent* operations
  - that is, operations that could be repeated more than once without harm
- Connection-oriented protocols are less efficient, but ensure reliability
- For instance, Internet protocols are typically based on TCP/IP connections—reliable but relatively costly for small-grain communication
Logical layering in client-server architectures

**User-interface level** contains the interface with the user

**Processing level** contains the logic of the control, in short, the core of the applications

**Data level** manages the actual data that are relevant to the applications

Typical organisation for client-server applications

- with a part handling user interaction,
- a part dealing with data and files,
- and a part containing the core functionality of an application
Application Layering

Logical layering in client-server architectures

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Example: Internet Search Engine

The simplified organisation of an Internet search engine into three different layers

[Tanenbaum and van Steen, 2007]
Multi-tiered Architectures

How to physically distribute logical layers?

- Logical organisation is not physical organisation
- Clients and servers could be placed on the same node, or be distributed according to several different topologies

Two-tiered architecture

- The simplest choice is to have just two sort of machines hosting either servers or clients
- resulting in the (physically) two-tiered architecture

Choices for two-tiered architecture

- Where are the three application-layers placed?
- On the client machines, or on the server machines?
- a range of possible solutions, accordingly
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Possible Two-tiered Organisations

Alternative client-server organisations
[Tanenbaum and van Steen, 2007]
Current Trends in Two-tiered Architectures

Moving toward the clients

- Scalability pushes charge far from servers
- Along with more efficient network connections, more powerful client machines, and above all more expressive technologies for distributing applications

Thin vs. fat clients

- Thin clients are simpler
- Fat clients are more complex, but are typically more efficient from the user’s viewpoint, and more scalable from the engineer’s viewpoint
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Three-tiered Architectures

Servers may sometimes act as clients

- Servers might be layered, in turn
- We may (physically) distinguish between application servers and database servers
- Example: the Transaction Processing Monitor discussed in the previous lessons

An example of a server acting as client

[Tanenbaum and van Steen, 2007]
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4 Self-Management in Distributed Systems
Vertical vs. Horizontal Distribution

**Vertical distribution**

- Multi-tiered client-server architectures directly derive from the three levels of applications
- Logical organisation is mapped onto the tiers
- Often, distributed processing amounts at building a client-server application according to a multi-tiered architecture
- This is typically called *vertical distribution*

**Horizontal distribution**

- Sometimes, the physical distribution of the clients and the servers is what actually counts
- Clients and servers may be physically split into logically-equivalent parts, each one working on its own portion of the whole data set
- This is typically called *horizontal distribution*
- This is an obviously decentralised class of systems
Vertical vs. Horizontal Distribution

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**Horizontal Distribution: Main Example**

### Peer-to-peer systems
- All the processes in a peer-to-peer system are equal.
- So, every process works to the system main function, whatever it is.
- Each process works then at the same time as a client and as a server.
- So, it is typically called *servent*.

### Overlay network
- Peer-to-peer architectures are symmetric.
- So, the main problem of peer-to-peer architectures is how to organise the network whose nodes are the servents and the links are the communications among them.
- Such a network organisation is typically called an *overlay network*.

### Types of overlay networks
- Processes communicate through available communication channels.
- Overlay networks may be either structured or unstructured.
- Accordingly, the two main sorts of peer-to-peer architectures are:
  - Structured peer-to-peer architectures.
  - Unstructured peer-to-peer architectures.
Horizontal Distribution: Main Example

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4. Self-Management in Distributed Systems
Combining the Benefits

Hybrid architectures

- Many distributed systems require properties from both client-server and peer-to-peer architectures
- So, they put together features from both centralised and decentralised architectures
- These are typically called *hybrid architectures*
Edge-Server Systems

Servers are “on the edge” of the network:

- The “edge” is formed by the boundary between the enterprise network and the actual Internet.
- For instance, home clients connecting through an ISP (Internet Service Provider).

Viewing the Internet as consisting of a collection of edge servers
[Tanenbaum and van Steen, 2007]
Main idea

- The main problems of these systems is to get started: a traditional client-server scheme is then used here.
- Once a node has joined the system, collaboration proceeds using a fully decentralised scheme.

Main example: BitTorrent

- BitTorrent is a peer-to-peer file downloading system.
- When a user needs a file in BitTorrent, he/she gets chunks of the file from other users around until he/she gets it all.
- A file can be downloaded by a client only when the client is providing files to other clients.
- A global directory provides `.torrent` files that points to the `trackers`.
- Trackers are servers knowing `active`, collaborating nodes that can provide the requested chunks.
- Collaboration of nodes is promoted by suitable reward / punishment policies.
Collaborative Distributed Systems

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BitTorrent as a Collaborative Distributed System

The principal working of BitTorrent
[Tanenbaum and van Steen, 2007]
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Which Middleware for Which Architecture?

Main problem

- In practice, middleware commonly incorporates some architectural element / abstraction / component / style
- For instance, CORBA is designed around the object-oriented architectural style
- This means that middleware tends to be not adaptable to every application scenario
- The solution of adding different abstractions and elements affects conceptual integrity of middleware and of the resulting applications

The typical solution

- As usual and as generic as it may seem, it is again separating mechanisms from policies
- This allow the behaviour of the middleware to be modified according to the application needs
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Interceptors

Main idea

- A software construct
- Intercepting the normal flow of control
- Allowing policies to be added that are application-specific

Using interceptors to handle remote-object invocations [Tanenbaum and van Steen, 2007]
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Adapting Middleware

Main idea
- The problem of (unpredictable) change
- Any fixed solution / response may fail when facing an unpredictable modification
- E.g., interceptors represent a generic solution to adaptation in terms of a naive mechanism

Adaptive software?
- Easier said than done
- Preparing for the unpredictable might result quite an issue, indeed
- Said that, this is one of the hottest fields of research in computer science
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Three basic techniques [McKinley et al., 2004]

- Separation of concerns
- Computational reflection
- Component-based design
Toward Adaptive Software

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Separation of concerns

Separating functional and non-functional
- Non-functional properties like reliability, performance, security, ..., should be faced separately
- ????
- OK, forget about this, this does not work really
- Aspect-oriented programming and aspect-oriented software development deals with cross-cutting concerns
Toward Adaptive Software

Three basic techniques [McKinley et al., 2004]

- Separation of concerns
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Computational reflection

The ability to inspect oneself and possibly self-adapt behaviour

- Reflection if at the core of modern programming language like Java
- Observing the state of a program by the program itself
- Reification is changing the state of the program after reflection
- Observing oneself state related with the environment makes it possible to change behaviour adaptively
Toward Adaptive Software

Three basic techniques [McKinley et al., 2004]
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- Computational reflection
- Component-based design

Component-based design
Adaptation through composition
- Once an architecture is open—e.g., hot-pluggable
- A new behaviour may be added by adding a component on the fly
- Once an architecture for open systems is available, the point is how to select a component that may add the required behaviour to the system
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Main idea

- Unpredictability of change makes guided adaptation essentially faulty.
- Systems should be able to detect (relevant) change in the environment and consequently change / adapt.
- This is the field of *autonomic computing* [Kephart and Chess, 2003] and of *self-* systems* [Babaoglu et al., 2005].

Many views on self-* systems

- What all of them have in common is that adaptations come from some *feedback loop* of some sort.
- Including some perception of the environment and of its change in the loop.
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The Feedback Control Model

Feedback control model: Logical organisation
[Tanenbaum and van Steen, 2007]
Summing Up

Organisation of distributed systems

- Software architectures and system architectures deal with software organisation
- They are approximative and maybe non-scientific ways to model systems
- However they are expressive and abstract enough to help distributed system engineering

Main issues

- Software architectures are concerned with logical organisation
- System architectures are concerned with component placement in a distributed setting
- Adaptation is a must in modern and forthcoming systems
- Autonomic computing and self-* systems are at the edge of research in distributed systems nowadays
Summing Up

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Software Architectures

Distributed Systems
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Academic Year 2011/2012