Software Architectures
Distributed Systems
Sistemi Distribuiti

Andrea Omicini
andrea.omicini@unibo.it

Dipartimento di Informatica – Scienza e Ingegneria (DISI)
Alma Mater Studiorum – Università di Bologna a Cesena

Academic Year 2013/2014
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*. 

Andrea Omicini (DISI, Univ. Bologna)
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
Components & Connectors I

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
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
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 Architecture Style

(a) [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
Object-based Architecture Style

(b)

[Tanenbaum and van Steen, 2007]
Architectural Styles

Data-centred Architectures I

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
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*
Event-based Architecture Style

Component → Event delivery → Event bus → Publish

Component

(a)

[Tanenbaum and van Steen, 2007]
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*
Shared Data-space Architecture Style

[b]Component[/b]  \rightarrow \text{Data delivery}  \rightarrow \text{Component}

\text{Shared (persistent) data space}

(b)

[Tanenbaum and van Steen, 2007]
Outline

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
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
- Hybrid architectures
Outline

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
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
Client-server Interaction

Scheme of client-server interaction: *request-reply behaviour*

[Tanenbaum and van Steen, 2007]
Client-Server Communication

**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
Application Layering

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
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
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
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]
Outline

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
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.
Horizontal Distribution: Main Example I

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*
Horizontal Distribution: Main Example II

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
Outline

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
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*
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
BitTorrent as a Collaborative Distributed System

[Image of a diagram showing the architecture of BitTorrent]

The principal working of BitTorrent [Tanenbaum and van Steen, 2007]
Outline

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
Which Middleware for Which Architecture? I

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.
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]
Outline

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
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
Three basic techniques [McKinley et al., 2004]

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

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

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
- Computational reflection
- Component-based design

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]

- Separation of concerns
- 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
Outline

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


Software Architectures
Distributed Systems
Sistemi Distribuiti

Andrea Omicini
andrea.omicini@unibo.it

Dipartimento di Informatica – Scienza e Ingegneria (DISI)
Alma Mater Studiorum – Università di Bologna a Cesena

Academic Year 2013/2014