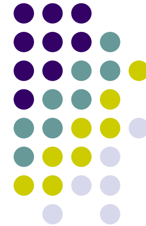
Introduction to adaptive computing systems



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Objectives

- Advanced aspects of middleware, software engineering tools and adaptive systems
- Real applications
- Prepare to
  - Implement adaptive applications in an industrial context
  - Conduct research in the area of middleware and distributed systems

Organization

- Two parts
  - Techniques for building adaptive applications
  - Methods and tools for software engineering
- Theoretical vs. practical aspects
  - 40% of lectures, 60% of practice
  - Implementation, use-cases

Agenda

Week	Friday, 8:00 – 11:15 / F316 – F216
S6	Introduction (CM), S. Bouchenak
S7	AOP-based adaptive systems (CM), S. Bouchenak
S8	Introduction to AspectJ (TD), S. Bouchenak
S9	Interruption week
S10	Software engineering tools (CM), D. Donsez
S11	Logging with AspectJ (TD), S. Bouchenak
S12	Security with AspectJ (TD), S. Bouchenak
S13	Transactions with AspectJ (TD), S. Bouchenak
S14	Software engineering tools (CM), D. Donsez
S15	Software engineering tools (TD), D. Donsez
S16	Software engineering tools (TD), D. Donsez
S17	Interruption week

Additional information

- Web Page
  - http://sardes.inrialpes.fr/~bouchena/teaching/TAG/
- Evaluation
  - Mid-term evaluation
    - Demonstration and evaluation of practical work
  - Final exam

Contact

- Techniques for building adaptive applications
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    Associate Professor, University of Grenoble I
    Researcher, LIG Laboratory, ERODS research group
- Methods and tools for software engineering
  - Didier Donsez (Didier.Donsez@imag.fr)
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Outline

- *Introduction*
  - *Objectives*
  - *Organization*
- **Background**
- Introduction to middleware
- Main adaptation techniques

Applications

- Application
  - role: answer to a specific problem
  - provide services to its end-users (or other applications)
  - use general services provided by the underlying system
- System
  - role: manage shared resources
  - linked to the underlying hardware
  - examples: operating system, communication system
  - hide complexity of underlying hardware,
    provide higher-level common services

Services

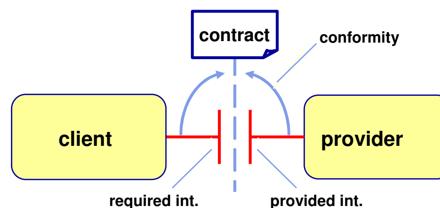
- Definition
  - A software system is a set of cooperating software components
  - “A service is a contractually defined behavior that can be implemented and provided by any component for use by any component, based solely on the contract” *

** Bieber and Carpenter, Introduction to Service-Oriented Programming, http://www.openwings.org*

Services and interfaces

- Implementation
  - A service is accessible via one or multiple interfaces
  - An interface describes the interaction between serice povider and service client
    - Operational point of view:
      define operations and data structures for service implementation
    - Contractual point of view:
      define contract between service provider and service customer

Interface definition



- A service involves <u>two</u> interfaces
  - Required interface (from client side)
  - Provided interface (from provider side)

Interface definition (2)

- Contract specifies compatibility (i.e. conformity) between interfaces
  - Client and provider see each other as a "black-box" (encapsulation)
  - Consequence: client and provider can be replaced, as long as the contract is met
- Contract may specify aspects non-included in the interface
  - Non-functional properties, i.e. Quality-of-service (QoS) properties

Interface definition (3)

- From an operational point of view
  - Interface Definition Language (IDL)
    - No standard
    - Based on an existing language
      - CORBA IDL in C++
      - Java et C# define their own IDL

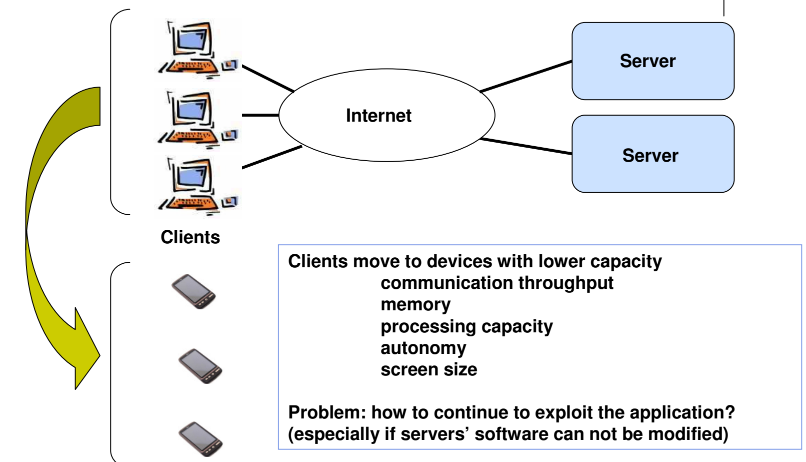
Interface definition (4)

- From a contractual point of view
  - Several levels of contracts
    - Type specification: syntactic conformity
    - Behavior (1 method assertions): semantic conformity
    - Interaction between methods: synchronisation
    - Non-functional aspects (performance, etc.): QoS contract

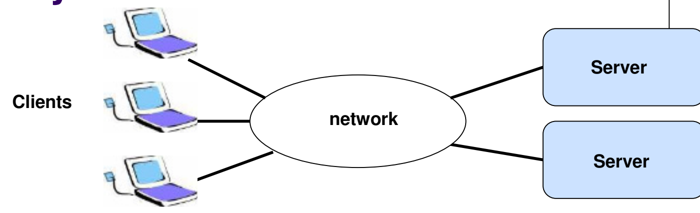
Application needs: examples

- Common objective
  - Maintain different QoS aspects …
    - Performance
    - Security
    - Availability
  - … in a changing environment
    - Resource capacity
    - Communication conditions
    - Service spécification
- General principle
  - A *middleware* for adaptation

Example 1: Service adaptation based on client device capacity

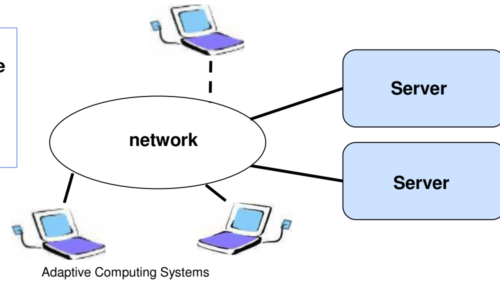


Example 2 : Service adaptation in case of client mobility

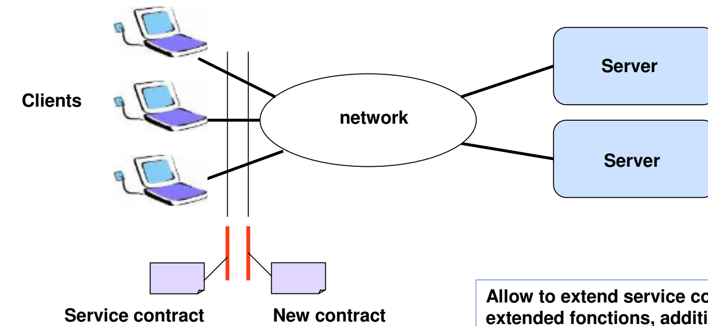


Allow geographical mobility of client devices (with possible change in environnement and QoS).

Probleme: how to continue to exploit the application?



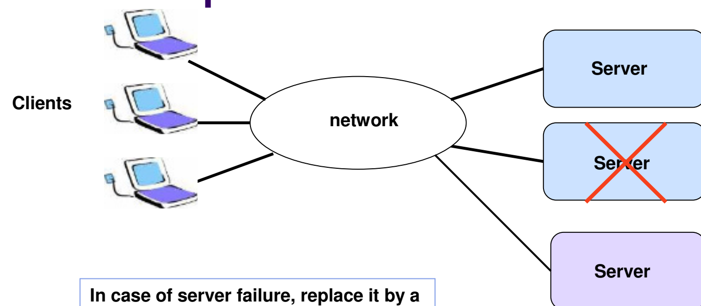
Example 3 : Service extension and evolution



Allow to extend service contract (e.g. extended fonctions, additional non-functional properties)

Problem: how to allow this evolution (without service interruption)?

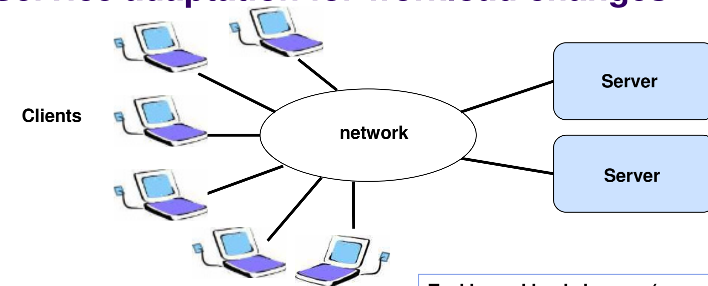
Example 4 : Service adaptation for fault-tolerance



In case of server failure, replace it by a new (equivalent) server

Problem: how to tolerate failures (failure detection, server replacement), without service interruption?

Example 5 : Service adaptation for workload changes



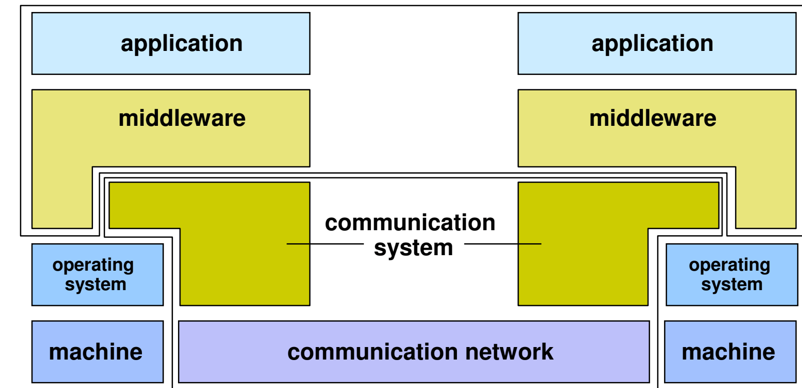
Tackle workload changes (e.g. #concurrent clients)

Problem: how to maintain an acceptable level of QoS (e.g. service request response time) ?

Outline

- *Introduction*
- *Background*
  - *Services and interfaces*
  - *Application needs*
- **Introduction to middleware**
- Main adaptation techniques

Middleware



Middleware functionalities

- Middleware has four main functions
  - High-level interface or API (*Application Programming Interface*) to applications
  - Mask heterogeneity of underlying hardware and software systems
  - Transparency of distribution
  - General/reusable services for distributed applications

Middleware examples

- CORBA
- Sun JVM
- Microsoft .NET
- Sun J2EE / EJB
- …

Why adaptable middleware?

- Needs of applications evolve
  - Scalability
  - Quality-of-service
- Distributed applications hosted in changing environment
  - Mobility
    - Logical mobility (mobile code and data)
    - Physical mobility (mobile users and devices)
  - Dynamic connection and disconnection
  - Variable communication quality

Why adaptable middleware?(2)

- Adaptation of middleware and applications
  - Dynamic discovery of services
  - Dynamic reconfiguration
  - Adaptive behavior

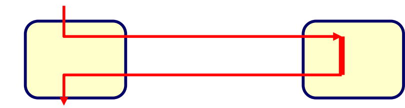
Types of middleware

- Classification criteria
  - Nature of communicating entities
    - Objects
    - Components
    - Others
  - Access mode to services
    - Synchronous (client-server)
    - Asynchronous (event-based)
    - Hybrid
  - Other criteria
    - Static vs. mobile entities
    - Guaranteed vs. non-guaranteed QoS

No rigorous classification, different implementations

Interaction patterns

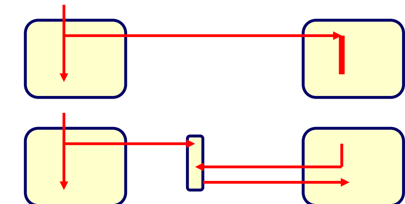
- Synchronous



Tight coupling

RMI, CORBA, COM, …

- Asynchronous

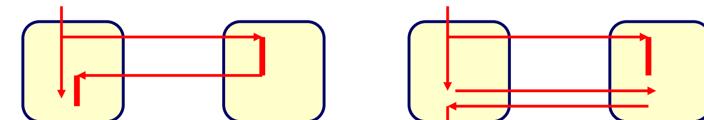


Loose coupling

Events

Message queues

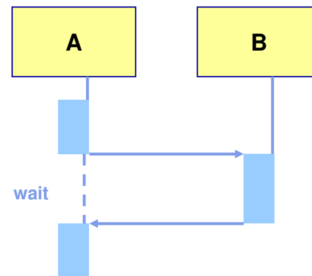
- Semi-synchronous



Combining synchronous - asynchronous

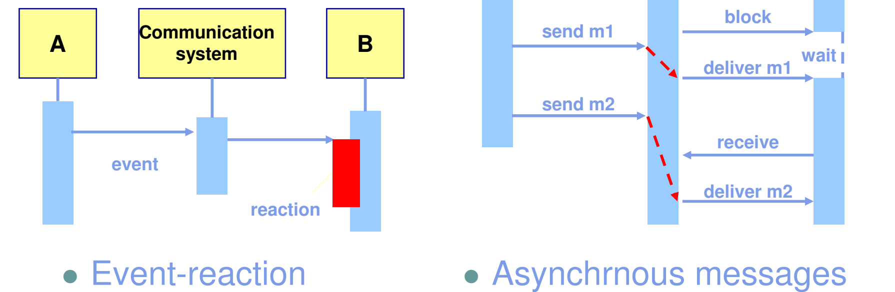
Interaction patterns (2)

- Synchronous interaction
  - Sender (client) blocks until it receives the results
  - Tight coupling



Interaction patterns (3)

- Asynchronous interaction
  - Parallel execution of sender (client) and receiver (server)
  - Loose coupling



- Event-reaction
- Asynchrnous messages

Design patterns

- Definition [not only for software design]
  - Set of rules to provide a response to a family of needs that are specific to a given environment
  - Rules can have the form of
    - element definitions,
    - composition principles,
    - usage rules

Design patterns (2)

- Properties
  - A pattern is designed based on experience when solving a family of problems
  - A pattern captures common elements of solution
  - A pattern defines design principles, not implementations
  - A pattern provides help to documentation (e.g. terminology definition, formal description, etc.)

E. Gamma et. al. *Design Patterns - Elements of Reusable Object-Oriented Software*, Addison-Wesley, 1995
F. Buschmann et. al. *Pattern-Oriented Software Architecture* - vol. 1, Wiley 1996
D. Schmidt et. al. *Pattern-Oriented Software Architecture* - vol. 2, Wiley, 2000

Design patterns (3)

- Definition of a pattern
  - Context:
    - Situation rising a design issue
    - Must be as generic as possible (but not too generic)
  - Problem:
    - Specifications
    - Desired solution properties
    - Constraints on the environment
  - Solution:
    - Static aspects: components, relations between components (described with class or collaboration diagrams)
    - Dynamic aspects: behavior at runtime, life cycle (described with sequence or state diagrams)

F. Buschmann et. al. *Pattern-Oriented Software Architecture* - vol. 1, Wiley 1996

Patterns

- Categories of patterns
  - Design pattern
    - Small scale,
    - Recurrent structures used in a given context
  - Architecture pattern
    - Large scale,
    - Structural organization
    - Definition of subsystems and their relationships
  - Idiomatic pattern
    - Constructions specific to a given language

F. Buschmann et. al. *Pattern-Oriented Software Architecture* - vol. 1, Wiley 1996

Examples of patterns

- *Proxy*
  - Design pattern: representative for remote access
- *Factory*
  - Design pattern: object creation
- *Wrapper* [*Adapter*]
  - Design pattern: interface transformation
- *Interceptor*
  - Architecture pattern: service adaptation

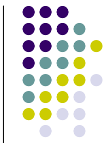
These patterns are largely used in middleware implementations

Proxy (Representative)

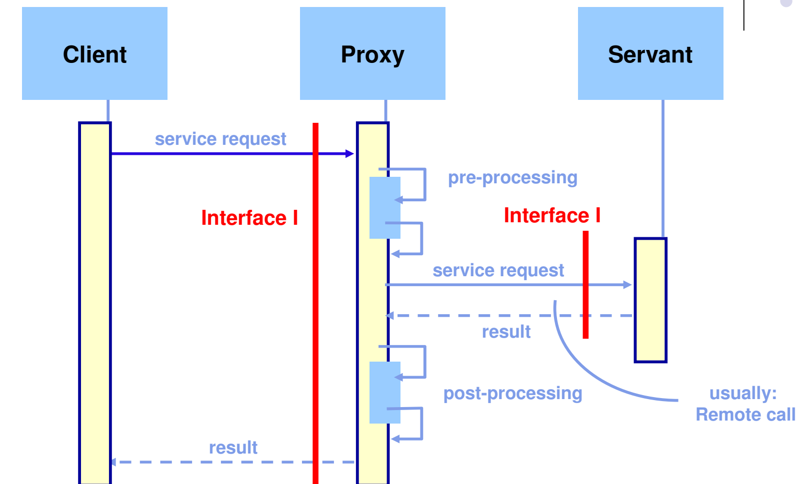
- Context
  - Applications as sets of distributed objects;
  - Client accesses services provided by a possibly remote object (servant)
- Problem
  - Define service access mechanisms that prevent
    - hand-coding server location in client code
    - having a detailed knowledge of communication protocols
  - Desired properties
    - efficient and dependable acces
    - simple programming model for client (ideally, no difference between local and remote service access)
  - Constraints
    - Distributed environment (no shared memory)

Proxy (Representative) (2)

- Solutions
  - Servant representative used locally at client-side (hide servant, and communication system to client)
  - Servant representative exposes same interface as servant
  - Define a uniform servant structure to ease its automatic generation



Use of *Proxy*



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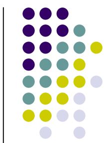


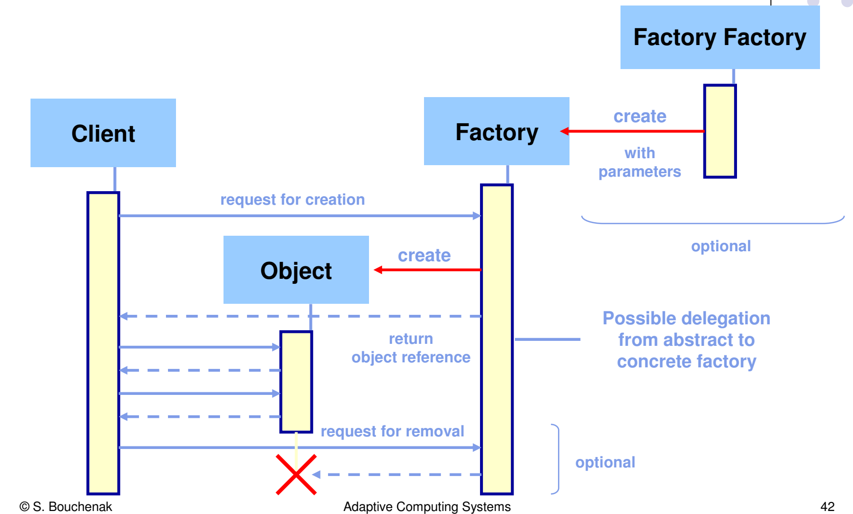
Factory

- Context
  - Application = set of objects in a distributed environment
- Problem
  - Dynamic creation of multiple instances of a class of objects
  - Desired properties
    - Instances may be parameterized
    - Easy evolution (no hand coded decision)
  - Constraints
    - Distributed environment (no shared memory)

Factory (2)

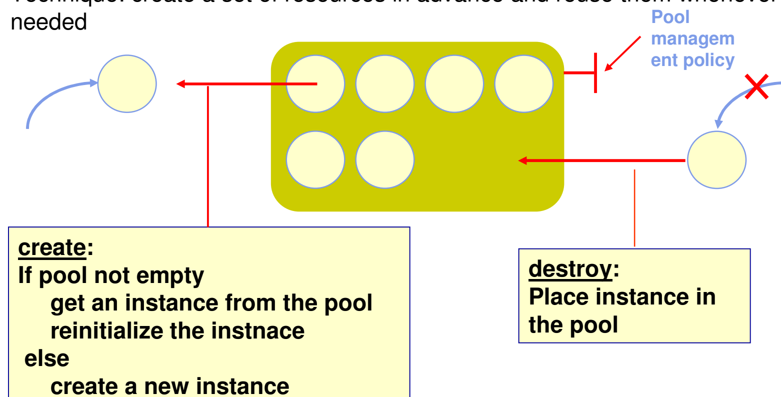
- Solutions
  - *Abstract Factory*
    - Define an interface and a generic organization for object creation
    - Effective object creation is delegated to a concrete factory that implements creation methods

Use of *Factory*



Use of a Pool in a *Factory*

- Problem: online resource (e.g. objet) creation is expensive
- Objective: reduce costs underlying resource creation
- Technique: create a set of resources in advance and reuse them whenever needed



create:
If pool not empty
get an instance from the pool
reinitialize the instnace
else
create a new instance

destroy:
Place instance in the pool

Examples of use of *Pool*

- Memory management
  - *Pool* of memory regions (of possibly different sizes)
  - Prevent the overhead of garbage-collection
- Activity management
  - *Pool* of *threads*
  - Prevent overhead of online thread creation
- Communication management
  - *Pool* of connections
  - Prevent cost of online communication channel creation

Examples of patterns

- *Proxy*
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- ***Wrapper* [*Adapter*]**
  - **Design pattern: interface transformation**
- *Interceptor*
  - Architecture pattern: service adaptation

These patterns are largely used in middleware implementations

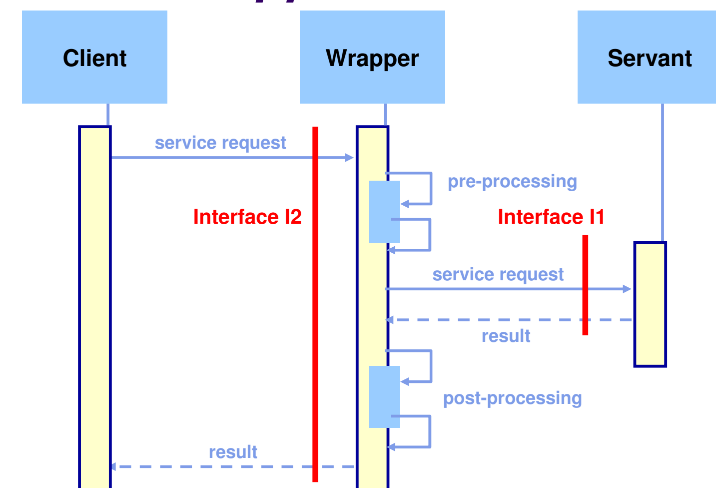
Wrapper (or *Adapter*)

- Context
  - Clients require services
  - Servants provide services
  - Services defined through interfaces
- Problem
  - Reuse an existing servant, while modifying its interface/functions to satisfy client needs (or a subset of clients)
  - Desired properties: efficiency, reusable and adaptable to different needs

Wrapper (or *Adapter*) (2)

- Solutions
  - *Wrapper* isolates servant by intercepting calls to servant interface
  - Each call to servant interface is preceded by by a prologue and followed by an epilogue in the *Wrapper*
  - Parameters of servant interface calls and results of calls can be modified

Use of *Wrapper*



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- ***Interceptor***
  - **Architecture pattern: service adaptation**

These patterns are largely used in middleware implementations

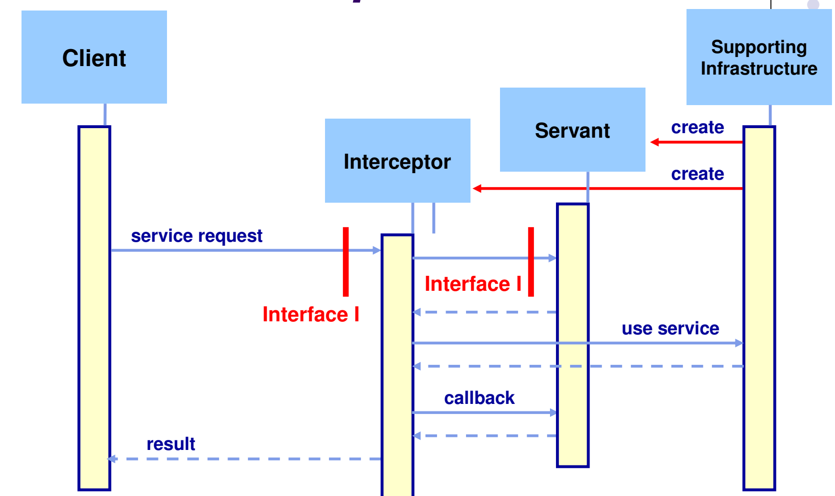
Interceptor

- Context
  - Provide services
    - Client-server, peer-to-peer, hiérarchical
    - Uni- or bi-directional, synchronous or asynchronous
- Problem
  - Transform a service (add new functions)
    - Add a new processing level (cf. *Wrapper*)
    - Modify the target of the call
  - Constraints
    - Client and server programs must not be modified
    - Services may be dynamically added or removed

Interceptor (2)

- Solutions
  - Create interposition objects (statically or dynamically)
  - Interposition objets intercept service calls (and/or returns) and insert specific processing
  - Interposition objects may forward calls to other targets

Use of *Interceptor*



Comparison of patterns

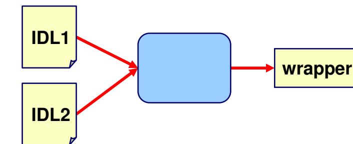
- *Wrapper* vs. *Proxy*
  - *Wrapper* and *Proxy* have a similar structure
    - *Proxy* preserves interface ; *Wrapper* transforms interface
    - *Proxy* used for remote access; *Wrapper* used for local access
- *Wrapper* vs. *Interceptor*
  - *Wrapper* and *Interceptor* have a similar function
    - *Wrapper* transforms interface
    - *Interceptor* transforms function
- *Proxy* vs. *Interceptor*
  - *Proxy* is a simple form of *Interceptor*
    - An *Interceptor* may be added to a *Proxy* (*smart proxy*)

Implementation of patterns

- Automatic generation
  - From a declarative description

Proxy :

Wrapper :



Implementation of patterns (2)

- Optimizations
  - Eliminate indirections (performance overhead)
    - Shorten indirection chains
    - Code injection (insertion of generated code in application code)
    - Low-level code generation (e.g. Java bytecode)
    - Reversible techniques (for adaptation)

Software frameworks

- Definition
  - A framework is a programme "squeleton" that can be used (adapted) for a famility of applications
  - A framework implements a model (not always explicit)
  - In object-oriented languages, a framework consists in
    - A set of (abstract) classes that must be adapted (via inheritance) to different contexts
    - A set of usage rules for these classes

Software frameworks (2)

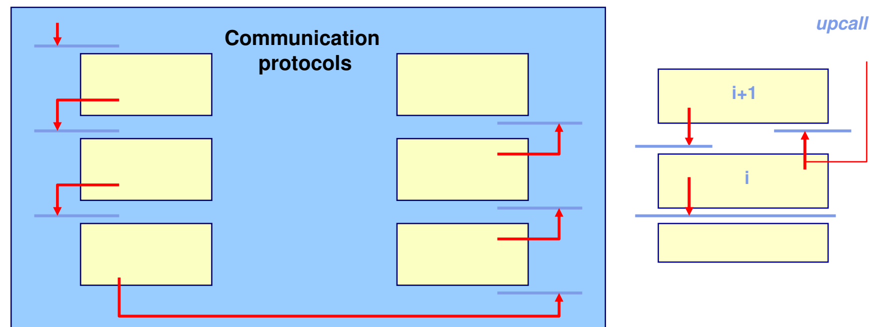
- Patterns and frameworks
  - Two techniques for reuse
  - Pattrens reuse design principles
  - Frameworks reuse code implementation
  - A framework usually implement one or more patterns

Decomposition schemes

- Objectives
  - Ease software development
    - Structure reflects design approach
    - Interfaces and inter-dependencies are exhibited
  - Ease software evolution
    - Encapsulation
- Example
  - Multi- level structures
    - “verticale” or “horizontal” decomposition

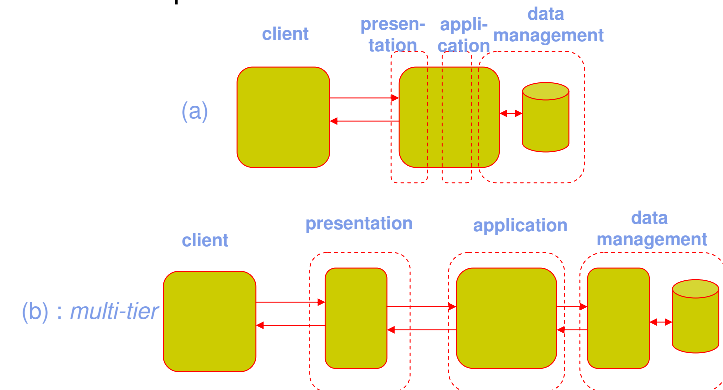
Decomposition in levels

- Hierarchy of “abstract machines”
  - Implementation of levels < i is invisible to level i
  - Example: virtual machines (multiple OS, JVM, etc.)



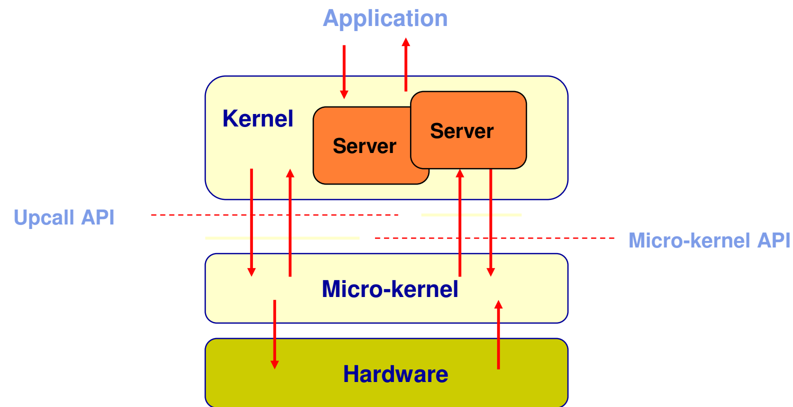
“Horizontal” decomposition

- Example: evolution of client-server schema



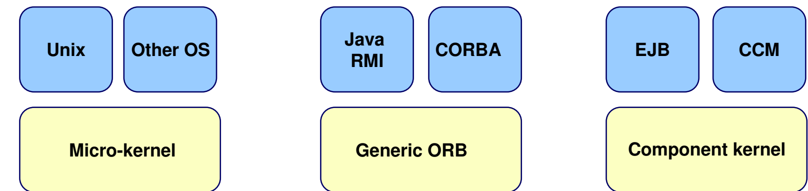
Example of a global framework

- Architecture of a micro-kernel



Frameworks and personalities

- Motivation: reuse of generic mechanisms
  - A general framework implements entities defined in an abstract model
    - Criteria: genericity, modularity, adaptability
  - "Personnalities" use APIs of the general framework to build concrete implementations of the model
  - Advantages: reusability, reconfiguration
  - Issue: efficiency
- Exemples



Outline

- *Introduction*
- *Background*
- *Introduction to middleware*
  - *Motivations of middleware*
  - *Design patterns*
  - *Frameworks*
- **Main adaptation techniques**

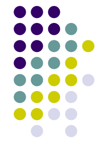
Adaptation of computing systems

- What is adaptation?
  - Changing the structure and/or functions of an application
  - Dynamic adaptation
    - Occurs at application runtime
    - Without stopping application
- Why adaptation?
  - To answer evolution of
    - Needs
      - New functionalities, new quality criteria
    - Execution environment
      - Resource capacity, mobility, communication conditions, failures, etc.

Adaptation of computing systems (2)

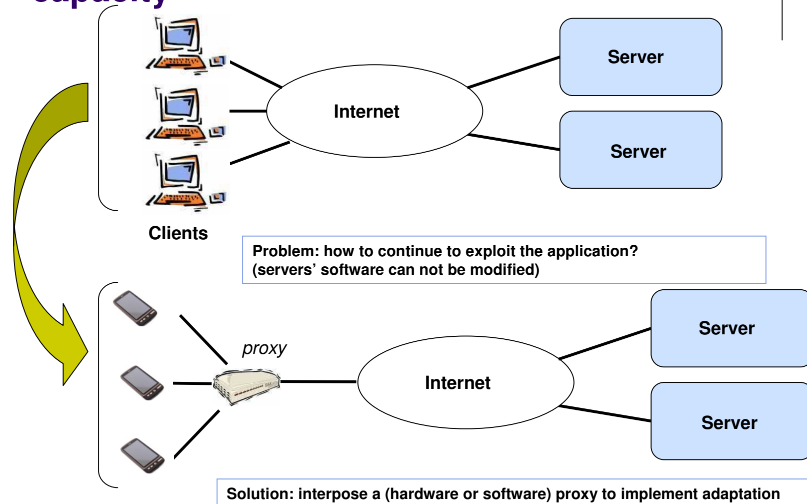
- How?
  - Main principle:
    - Reflective system
    - System provides a representation of itself
    - Allows introspection, modification, reconfiguration
- Techniques
  - Ad-hoc techniques (interceptors)
  - Meta-object protocols (MOP)
  - Aspect-oriented programming (AOP)

Ad-hoc adaptation – Interceptors

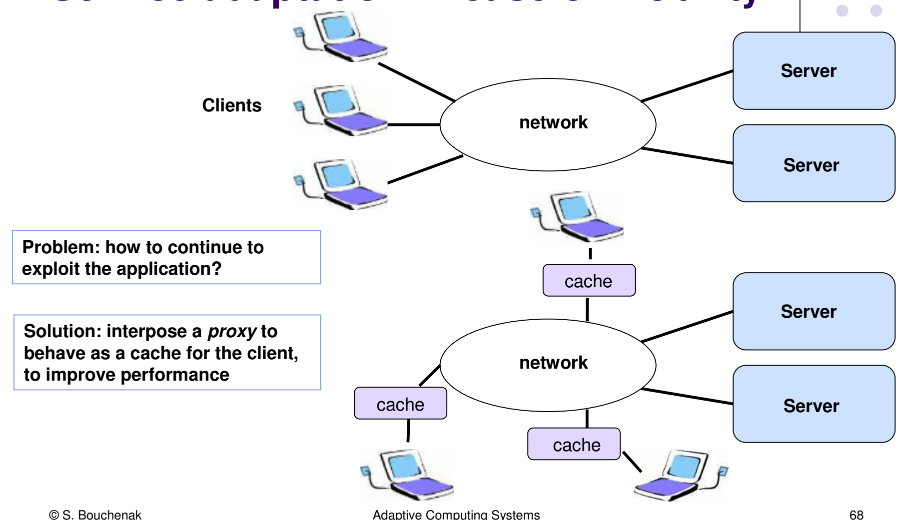


- Examples
  - Service adaptation according to client device capacity
  - Service adaptation in case of mobility
  - Service extension, evolution
  - Service adaptation for fault tolerance
  - Service adaptation for workload variation
  - Internet Content Adaptation Protocol (ICAP)

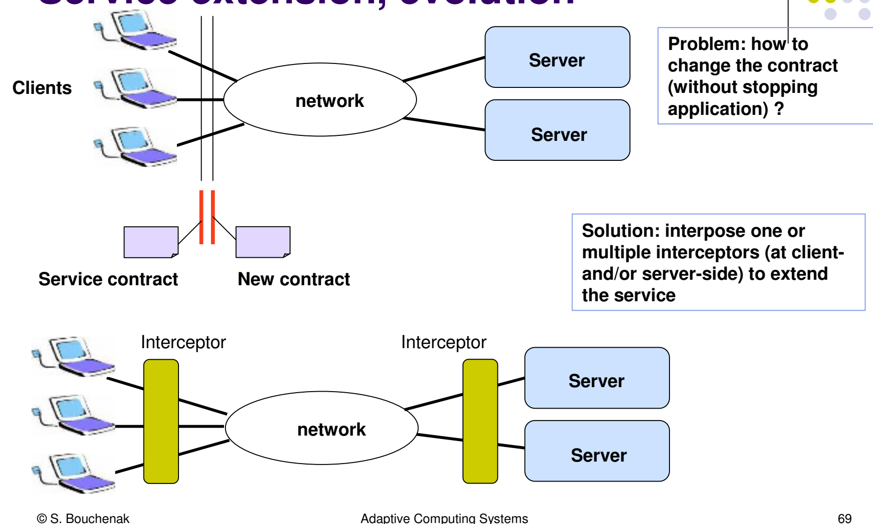
Example 1: Service adaptation according to client device capacity



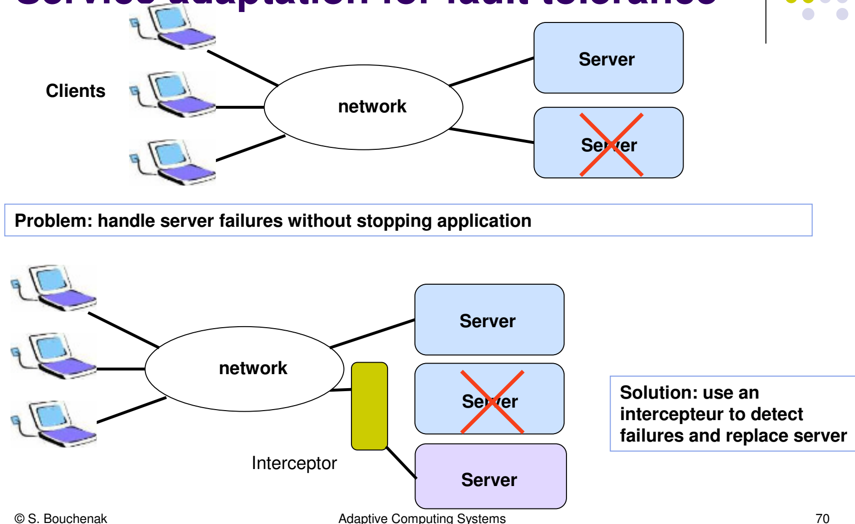
Example 2: Service adaptation in case of mobility



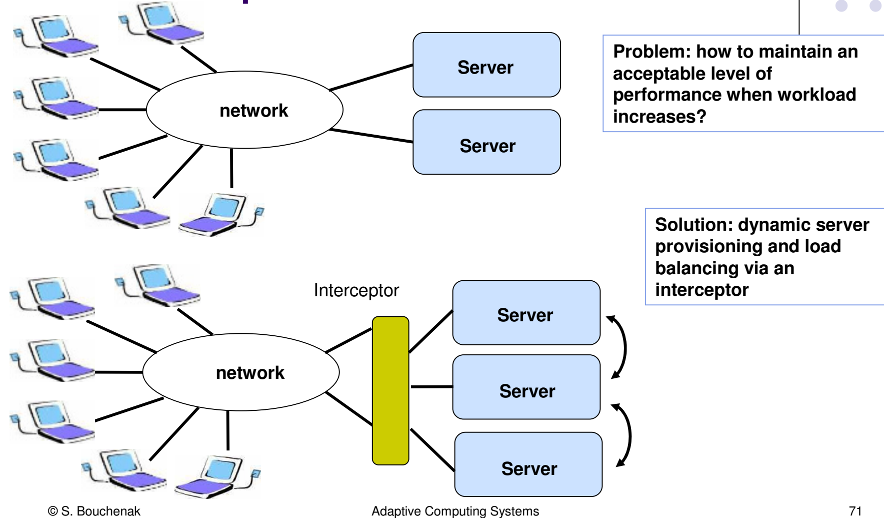
Example 3: Service extension, evolution



Example 4: Service adaptation for fault tolerance

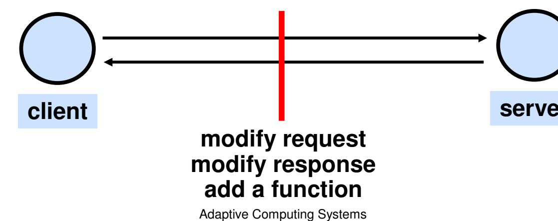


Example 5: Service adaptation for workload variation

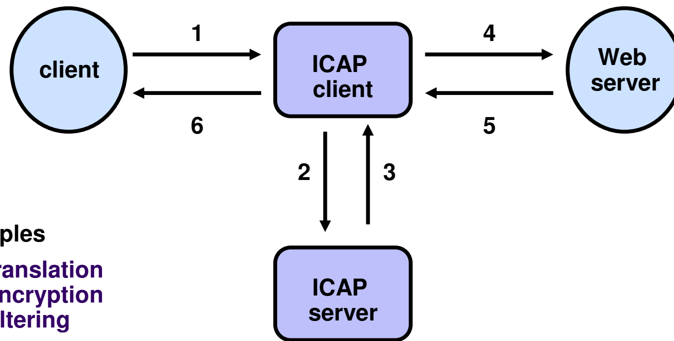


Example 6: ICAP (Internet Content Adaptation Protocol) protocol

- Definition
  - A lightweight HTTP-like protocol used to extend transparent proxy servers
- Motivations
  - Implement functions (virus scanning, content filtering, etc.)
  - Off-loading value-added services from Web servers to ICAP servers
- How it works
  - interposition in an HTTP client-server system



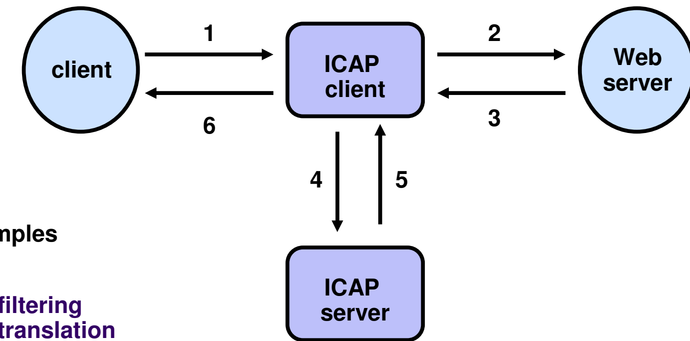
ICAP protocol: modify a request



Examples

translation
encryption
filtering

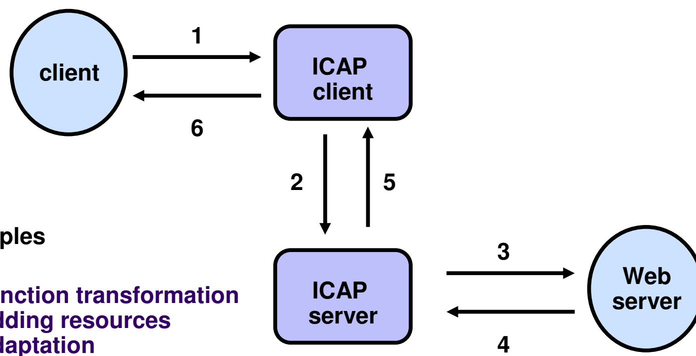
ICAP protocol: modify a response



Examples

filtering
translation
adaptation
Advertisemnt insertion

ICAP protocol: interpose a function



Examples

function transformation
adding resources
adaptation

Adaptation of computing systems

- How?
  - Main principle:
    - Reflective system
    - System provides a representation of itself
    - Allows introspection, modification, reconfiguration
- Techniques
  - *Ad hoc techniques (interceptors)*
  - **Meta-object protocols (MOP)**
  - Aspect-oriented pogramming (AOP)

Meta-object protocol (MOP)

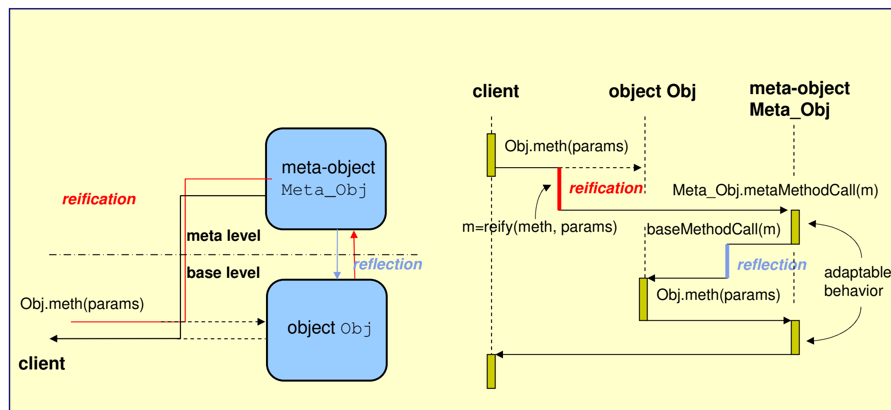
- An adaptable service is organized in two levels
  - Base level
    - Implement functions defined by specifications
  - Meta-level
    - Use a representation of the base level to observe or modify its behavior
    - This meta-level representation is causally connected to the base level

Meta-object protocol (2)

- Relations between levels
  - Creation of the representation of an entity: reification
  - Action of the meta level on the base level: reflection
- This organization may be repeated recursively
  - "Reflective tour" : meta-meta-level, etc.
  - In practice, 2 or 3 levels

Meta-object protocol: example

- Reification of a method call:



Adaptation of computing systems

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  - *Meta object protocols (MOP)*
  - **Aspect-oriented pogramming (AOP)**

Aspect-oriented programming (AOP)

- Main principle
  - Separate concerns
  - Idenify a basic behavior and additional “aspects” as independent as possible
  - Separately describe the basic behavior and aspects
  - Integrate all elements in a unique program
- Methodology
  - Individual description of each aspect
  - Integration (“weaving”) of aspects, static or dynamic weaving

Aspect-oriented programming (2)

- Definitions
  - *Join point*
    - point where to insert aspect code
  - *Pointcut*
    - Set of join points logically correlated
  - *Advice*
    - definition of relations basetween inserted code and base code (e.g.before, after, etc.)

Aspect-oriented programming: example

- Implementing a *Wrapper* in AspectJ

```
public aspect MethodWrapping  {

/* point cut definition */
    pointcut Wrappable(): call(public * MyClass.*(..));

 /* advice definition */
    around(): Wrappable() {
            <prelude>      /* a sequence of code to be inserted before the call */
            proceed();     /* performs the call to the original method  */
            <postlude>   /* a sequence of code to be inserted after the call */
    }
}
```

Result: encapsulate a call to a public method of class MyClass with <prelude> and <postlude>

Possible usage: logging, assertion test, etc.

Outline

- *Introduction*
- *Background*
- *Introduction to middleware*
- *Main adaptation techniques*
  - *Motivations*
  - *Ad hoc adaptation techniques*
  - *Meta object protocols (MOP)*
  - *Aspect oriented programming (AOP)*

Agenda

Week	Friday, 8:00 – 11:15 / F316 – F216
S6	*Introduction (CM), S. Bouchenak*
S7	**AOP-based adaptive systems** (CM), S. Bouchenak
S8	Introduction to AspectJ (TD), S. Bouchenak
S9	Interruption week
S10	Software engineering tools (CM), D. Donsez
S11	Logging with AspectJ (TD), S. Bouchenak
S12	Security with AspectJ (TD), S. Bouchenak
S13	Transactions with AspectJ (TD), S. Bouchenak
S14	Software engineering tools (CM), D. Donsez
S15	Software engineering tools (TD), D. Donsez
S16	Software engineering tools (TD), D. Donsez
S17	Interruption week

References

- **Lecture partly based on the following documents:**
  - Sacha Krakowiak, http://sardes.inrialpes.fr/people/krakowia/