Introduction to design patterns for middleware

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Foreword

The sources of this presentation are:

  ➤ URL of the slides in French:

♦ S. Krakowiak “Chapitre 1 : Introduction à l’intergiciel” dans “Intergiciel et Construction d’Applications Réparties”, 2006,
  http://sardes.inrialpes.fr/ecole/livre/pub/Chapters/Intro/intro.html

♦ S. Krakowiak “Chapitre 2 : Patrons et canevas pour l’intergiciel” dans “Intergiciel et Construction d’Applications Réparties”, 2006,
  http://sardes.inrialpes.fr/ecole/livre/pub/Chapters/Patterns/patterns.html

♦ S. Krakowiak “Middleware Architecture with Patterns and Frameworks”,
  2007, http://sardes.inrialpes.fr/~krakowiak/MW-Book/ (see the first two chapters)
♦ E. Gamma, R. Helm, R. Johnson, J. Vlissides “Design Patterns : Elements of Reusable Object-Oriented Software”, Addison-Wesley, 1994
  ▶ Has been translated in French
♦ F. Buschmann, R. Meunier, H. Rohnert, P. Sommerlad and M. Stal
  “Pattern-Oriented Software Architecture : Volume 1, A System of Patterns”, Wiley, 1996
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1 Distributed system organisation with a middleware

**Standard data protocol**

Application → Middleware → Operating System

**Standard API**

Application → Middleware → Operating System

**Specific API**

Application → Middleware → Operating System

**Communication subsystem / Network**
2 Design patterns

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2.1 Objectives of the pattern orientation

Each pattern describes a problem that occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice.\(^a\)

- Present the design principles of middleware architecture in a systematic way
  - Identify the main design and implementation problems
  - Exhibit the main design solutions relevant to middleware construction
  - Illustrate the patterns in frameworks in the teaching unit

- Well known software design patterns:
  - Factory
  - Singleton
  - Iterator

2.2 Some design pattern examples for middleware

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2.2.1 Example 1: A client/server middleware
2.2.2 Example 2: Integration of legacy applications

Diagram:

- Legacy application
  - Wrapper
  - Proprietary interface
- Legacy application
  - Wrapper
  - Standard interface
- New component
  - Inter-applications "exchange bus"
  - Wrapper
  - Standard interface
  - New component
  - Legacy application

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2.2.3 Example 3: Adaptation to client resources
2.2.4 Example 4: Monitoring and control of networked equipments

- Physical organisation
- Logical organisation
2.3 Definition of design patterns

- Definition (not limited to program design)
  - A set of design rules (element definitions, element composition principles, rules of usage) that allow the designer to answer a class of specific needs in a specific environment

- Properties
  - Elaborated from the experience acquired: Class of problems, capture of the solution elements common to those problems
  - Defines design principles, not specific to the implementation
  - Provides an aid to documentation: Common terminology, even formal description ("pattern language")
2.4 Writing patterns

- Name: Higher abstraction which conveys the essence of the pattern succinctly
- Intent: Short statement stating what the pattern does, its rationale, and the particular design issue or problem addressed
- Motivation and context: Scenario illustrating the class of problems addressed; should be as generic as possible
- Problem: Requirements, desirable properties of the solution; constraints of the environment
- Solution
  - Structure: Static aspects, i.e. components, relationships; may be depicted in a classes/components diagram
  - Interactions: Dynamic aspects, i.e. run-time behaviour, life-cycle; may be depicted in a communications/sequence/timing diagram
- Also known as & related patterns: Other well-known names & closely related patterns
2.5 Classifying patterns

- Architectural: Large scale, structural organisation, subsystems and relationships between them
- Design: Small scale, commonly recurring structure within a particular context
- Idioms: Language specific, how to implement a particular aspect in a given language
- And many more: Software process, requirement elicitation, analysis, etc.
3 Patterns for distributed interaction

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### 3.1 Asynchronous call, synchronous call, buffered message

**Asynchronous event (push)**

- a:Process
- b:Process

**Synchronous call**

- a:Process
- b:Process

**Buffered messages (pull)**

- a:Process
- b:Process
- m:MsgPassing System

Example diagrams showing the interaction between processes and messages.
3.2 Call-back and Inversion of control

**Synchronous call with callback**

A callback is first registered and later called asynchronously.

**Inversion of control**

The control flow is no more under the responsibility of the application but controlled by the framework.

The service request for A is triggered from the outside through B, which controls A.
3.3 Reflection : Observe and act on its own state and behaviour

- Context : Support different types of variations/adaptations of an application
- Problem : Particular variations must be hidden to the client
- Solution
  ♦ Make the system self-aware
    ▶ Select aspects of its structure and behaviour accessible for adaptation
      ★ Objectify/reify information about properties and variant aspects of the application’s structure, behaviour, and state into a set of meta-objects
  ♦ Split the architecture into two major parts
    ▶ Meta-level : Self-representation of the system in meta-objects
      ★ Type structures, algorithms, or even function call mechanisms
    ▶ Base level : Application logic
      ★ Uses the meta-objects to remain independent of those aspects that change
  ♦ An interface is specified for manipulating the meta-objects
    ▶ Meta-Object Protocol responsible for performing changes
Architecture principle
3.4 Factory : Entity creation

- **Context**: Applications organised as a set of distributed entities
- **Problem**
  - Dynamically create multiple instances of an entity type
  - Desirable properties
    - Instances should be parameterised
    - Evolution should be easy, i.e. no hard-coded decisions
  - Constraints: Distributed environment, i.e. no single address space
- **Solution**
  - Abstract factory: Defines a generic interface and organisation for creating entities; the actual creation is deferred to concrete factories that actually implement the creation methods
  - A further degree of flexibility is achieved by using Factory Factory, that is the creation mechanism itself is parameterised
3.4.1 Sequence diagram of Factory

- **c**: Client
- **f**: Factory
- **s**: Servant

1. **c**: Client requests creation from **f**: Factory
2. **f**: Factory creates a **s**: Servant
3. **s**: Servant returns reference to **f**: Factory
4. Optional: **c**: Client requests removal from **f**: Factory
5. **f**: Factory removes **s**: Servant

**UML Diagram:**
- Sequence diagram showing the flow of messages between the components.
3.5 Proxy : Representative for remote access

- **Context**: A client needs access to the services by some entity (the “servant”)

- **Problem**
  - Define an access mechanism that does not involve
    - Hard-coding the location of the servant into the client code
    - Deep knowledge of the communication protocols by the client
  - Desirable properties
    - Access should be efficient at run-time and secure
    - Programming should be simple: No difference between local and remote access
  - Constraints: Distributed environment (no single address space)

- **Solutions**
  - Use a local representative of the server on the client side that isolates the client from the communication system and the servant
  - Keep the same interface for the representative as for the servant
  - Define a uniform proxy structure to facilitate automatic generation
3.5.1 Sequence diagram of Proxy

- **c**: Client
- **p**: Proxy
- **s**: Servant

- Service request from **c** to **p**
- Pre-processing (e.g., marshalling)
- Service request from **p** to **s**
- Post-processing (e.g., unmarshalling)
- Result from **s** to **p**
- Result from **p** to **c**

**Interface I**
3.6 Wrapper or Adapter: Interface transformation

- **Context**: Clients requesting services; servers providing services; services defined by interfaces
- **Problem**
  - Reuse an existing server by modifying either its interface or some of its functions in order to satisfy the needs of a client (or class of clients)
  - Desirable properties: Should be run-time efficient; should be adaptable because the needs may change and may not be anticipated; should be itself reusable (generic)
- **Solutions**
  - The wrapper screens the server by intercepting method calls to its interface
  - Each call is prefixed by a prologue and followed by an epilogue in the wrapper
  - The parameters and results may need to be converted
3.6.1 Sequence diagram of Wrapper/Adapter
3.7 Interceptor: Adaptable service provision

- Context: Service provision (in a general setting)
  - Client-server, peer-to-peer, high-level to low-level
  - May be uni- or bi-directional, synchronous or asynchronous

- Problem
  - Transform the service (adding new treatments), by different means
    - Interposing a new layer of processing (like wrapper)
    - Changing the destination (may be conditional)
  - Constraints: Services may be added/removed dynamically

- Solutions
  - Create interposition entities (statically or dynamically). These entities
    - Intercept calls (and/or return statements) and insert specific processing, that may be based on content analysis
    - May redirect call to a different target
    - May use call-backs
3.7.1 Sequence diagram of Interceptor

![Sequence diagram of Interceptor](image-url)
3.8 Similarities and differences between the previous patterns

■ Wrapper Vs. Proxy
  ♦ Wrapper and Proxy have a similar structure
    ▶ Proxy preserves the interfaces
    Vs. Wrapper transforms the interface
    ▶ Proxy often (not always) involves remote access
    Vs. Wrapper is usually on-site

■ Wrapper Vs. Interceptor
  ♦ Wrapper and Interceptor have a similar function which is behavioural reflection
    ▶ Wrapper transforms the interface
    Vs. Interceptor transforms the functionality (may completely screen servant)

■ Reflection Vs. Interceptor
  ♦ Interceptor provides a means to implement reflective mechanisms
    ▶ Not the only way to implement reflection (others = language, byte code transformation, etc.)
Interceptor exposes only part of the state of the base level

Reflection can define a type of interception mechanism in the form of a meta-object protocol
4 Patterns for composition

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4.1 Principle of de/composition in distribution

Objective

♦ Ease the design
  ▶ Show the design approach through the means of the structure
  ▶ Show off the interfaces and the dependencies

♦ Ease the evolution
  ▶ Apply the encapsulation principle
  ▶ Standardise the exchanges

Examples

♦ Multi-level structure
  ▶ “Vertical” decomposition : e.g., Layer
    Vs. “horizontal” decomposition : e.g. Multi-tier
    Vs. both of them : e.g. Middle-tier/Component

♦ Leverage the concept of Contract
  ▶ From “simple” interfaces to
    Offered/server, required/client, and internal and external interfaces
4.2 Contract : Qualified required/offered interfaces

- Four levels of contract
  1. Syntactic contract : Types of operations, verified statically
  2. Behavioural contract : Dynamic behaviour (semantics) of operations, assertion-based
  3. Synchronisation contract : Interactions between operations, synchronisation
  4. Quality of service contract : extra-functional aspects such as performance, availability, security
4.3 Layer or Abstract machine or Protocol stack: Vertical decomposition

- Context: Complex “local” system design
- Problem: Define different levels of abstraction/refinement
- Solution: Vertical decomposition with levels, and upper and lower interfaces
4.4 Multi-tier architecture: Horizontal decomposition

- Context: Complex distributed system; incremental upgrade
- Problem: Evolution of the client and the server sides, load-balancing, scalability
- Solution: Horizontal decomposition into tiers, separation of system functionalities
4.4.1 Focus on presentation tier : The MVC pattern

- Context : Management of the client view or user interface
- Problem : Confusion in the roles of objects prevents evolution.
- Solution : Separate the data (Model), the HMI on screen (View) and the control logic (Controller) which is the glue between the two
- Proposed in 1978-79 by Trygve Reenskaug et al. from XEROX PARC for the Smalltalk language
4.4.2 MVC pattern vs 3-tier architecture

- **MVC pattern**
  - Focus on the presentation layer to improve code evolutivity
  - Triangular architecture: The view sends updates to the controller, the controller updates the model, and the view gets updated directly from the model.

- **vs 3-tier architecture style**
  - Focus on the distribution of the architecture to favor scalability
  - Linear architecture: The presentation tier never communicates directly with the data tier. Communication goes through the middle tier.
4.5 Component/Container: Contract + Factory + Interceptor + extra-functionalities

- **Context**: Distributed application accessing extra-functional services
- **Problem**: Control life-cycle; separate business/extra-functional parts
- **Solution**:
  - Contract to make explicit server and client interfaces
  - Container that implement Factory + Interceptor to manage extra-functional services

![Diagram](image-url)
4.6 Composite with sharing : Component + Vertical decomposition + Sharing

- **Context**
  - Part-whole hierarchies of components

- **Problem**
  - Make the client simple
    - Ignore the difference between composite entities and individual components
  - A component can have more than one parent
  - Make it easier to add new kinds of components
  - Make the design overly general

- **Solution**
  - Abstract component entity which represents both a primitive or a composite
  - Control the content of composite components
  - Extend the reference/naming system to explicitly express sharing
### 4.6.1 Example of the Fractal Component Model

5 Patterns for coordination

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5.1 Naming : White pages service

- Context : clients and servers distributed over the network
- Problem
  - Obtain a (distributed) reference to an entity
  - Only the logical name is known by the client
- Solution
  - The server registers its reference under a logical name to a name server
  - The name server has a “well-known” reference
  - The client retrieves the server’s reference by providing the logical name
  - Logical names are organised as a hierarchy

![Diagram of naming service](image-url)
5.2 Trading : Yellow pages service

- Context : clients and servers distributed over the network
- Problem
  - Obtain a (distributed) reference to an entity
  - Only a property characterising the server is known by the client : Service name...
- Solution
  - The client specifies its requests by providing properties of the required service
  - The trader answers by giving a set of server's references matching the client's query

```
Client \[\text{service request} \] \rightarrow Server

TraderA \[\text{Offers/properties}\] \quad \text{query()}

TraderB \[\text{Offers/properties}\]
```

5.3 Publish/subscribe or Observer or Event channel: Change-propagation mechanism

- **Context**
  - Keep the state of cooperating components synchronised

- **Problem**
  - Be notified about state changes in a particular entity
  - Number and identities of dependent entities not known *a priori*
  - Explicit polling not feasible or not efficient
  - Notifiers and notified entities not tightly coupled

- **Solution**
  - Notifier also called publisher or subject: Maintains a registry of subscribers
  - Notified entities also called subscribers or observers: Subscribe to notification
  - Push model (publisher sends all changes)
    - Vs. pull model (publisher sends nature of data change and subscriber gets retrieves data)
5.3.1 Example of OMG CORBA Event channel
5.4 Pipes and filters: Structure for processing streams of data

- **Context**: Distributed application processing data streams
- **Problem**
  - Flexibility by reordering/recombining processing steps
  - Small processing steps are easier to reuse in a different setting
  - Non-adjacent steps do not share information
- **Solution**
  - Each processing step is encapsulated in a filter component
  - Data is passed through pipes between adjacent filters
  - Filters are the processing units of the pipeline
    - Consume data incrementally to achieve low latency and enable parallelism
  - Push mode Vs. pull mode Vs. active mode (pull + push)