Introduction to design patterns for middleware

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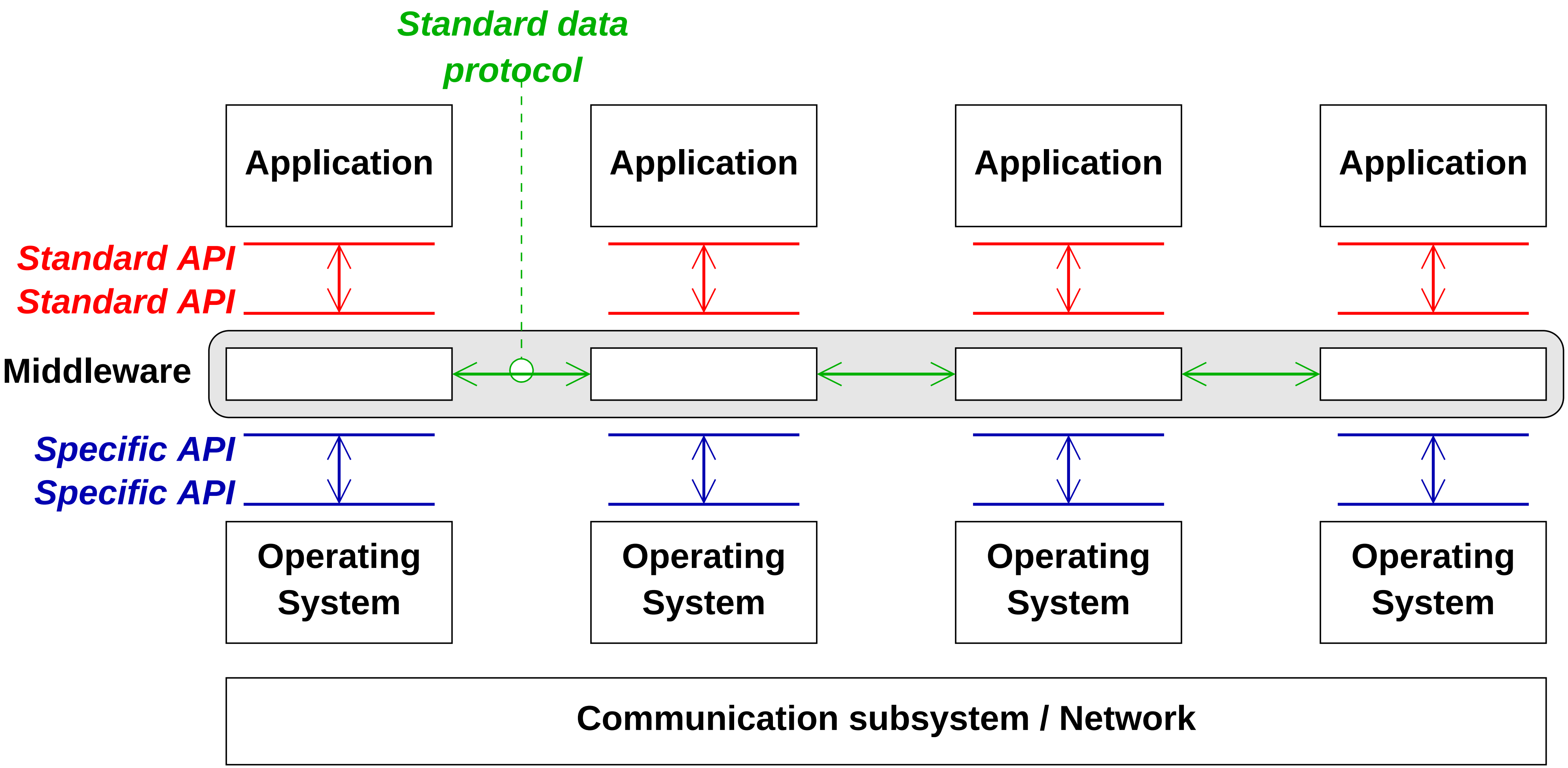
Foreword

- The sources of this presentation are:
  - S. Krakowiak (Université Joseph Fourier), “Patrons et canevas pour l’intergiciel”, ICAR 2006 French Speaking Summer School on Middleware and Construction of Distributed Applications, Autrans, France, August 2006.
    - URL of the slides in French: `http://sardes.inrialpes.fr/ecole/2006/ICAR-06-Intro.pdf`
  - S. Krakowiak “Chapitre 1: Introduction Ãă 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
- D.C. Schmidt, M. Stal, H. Rohnert and F. Buschmann “Pattern-Oriented Software Architecture, Volume 2, Patterns for Concurrent and Networked Objects”, Wiley, 2000.
- Buschmann, K. Henney and D.C. Schmidt “Pattern-Oriented Software Architecture, Volume 4, A Pattern Language for Distributed Computing”, Wiley, 2007

Outline

1 Distributed system organisation with a middleware



2 Design patterns

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]

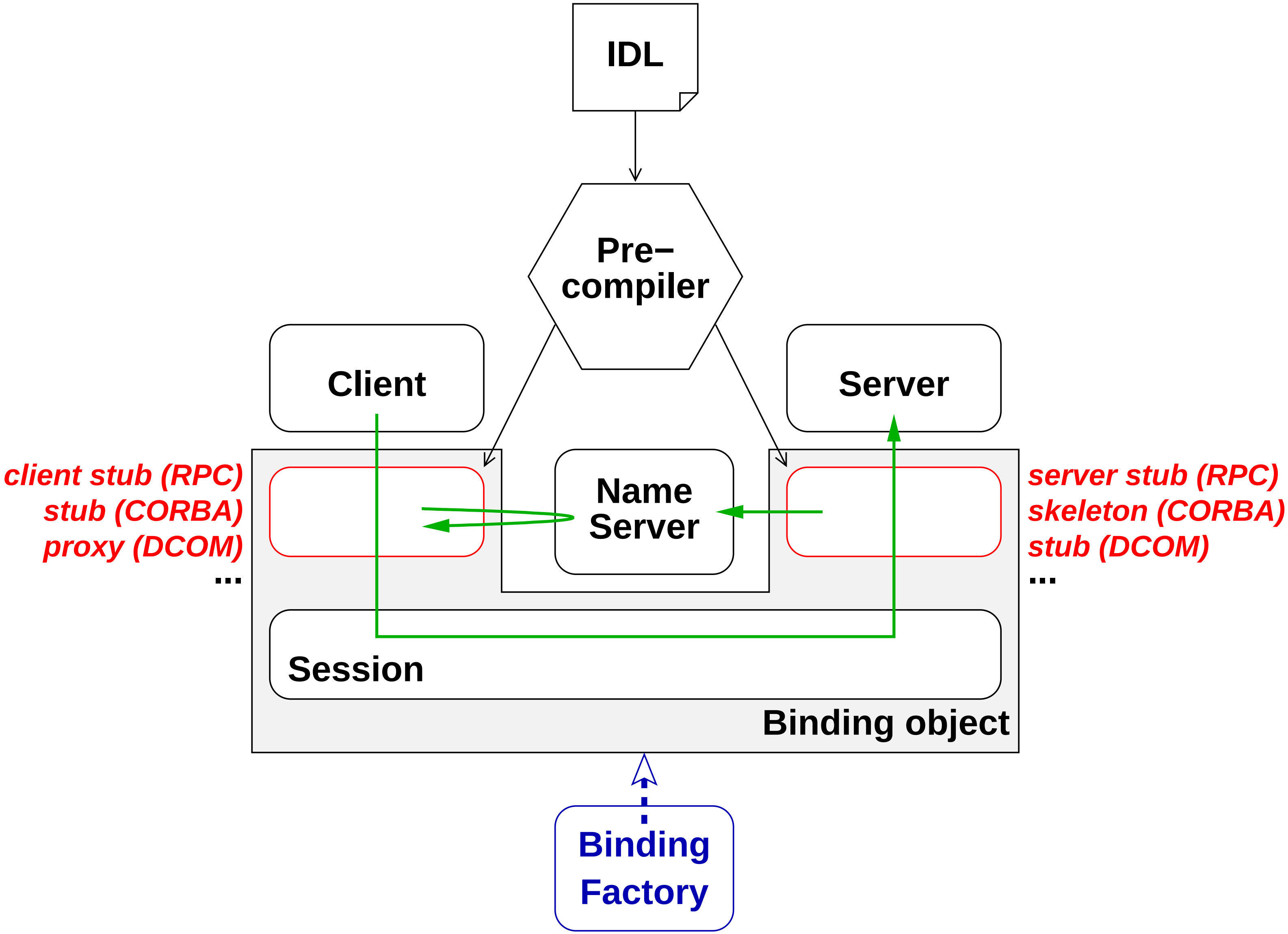
- Present the design principles of middleware architecture in a systematic way
  - Identify the main design and implementation problems
  - Exhibit the main design solutions relevant to middleware construction
  - Illustrate the patterns in frameworks in the teaching unit

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

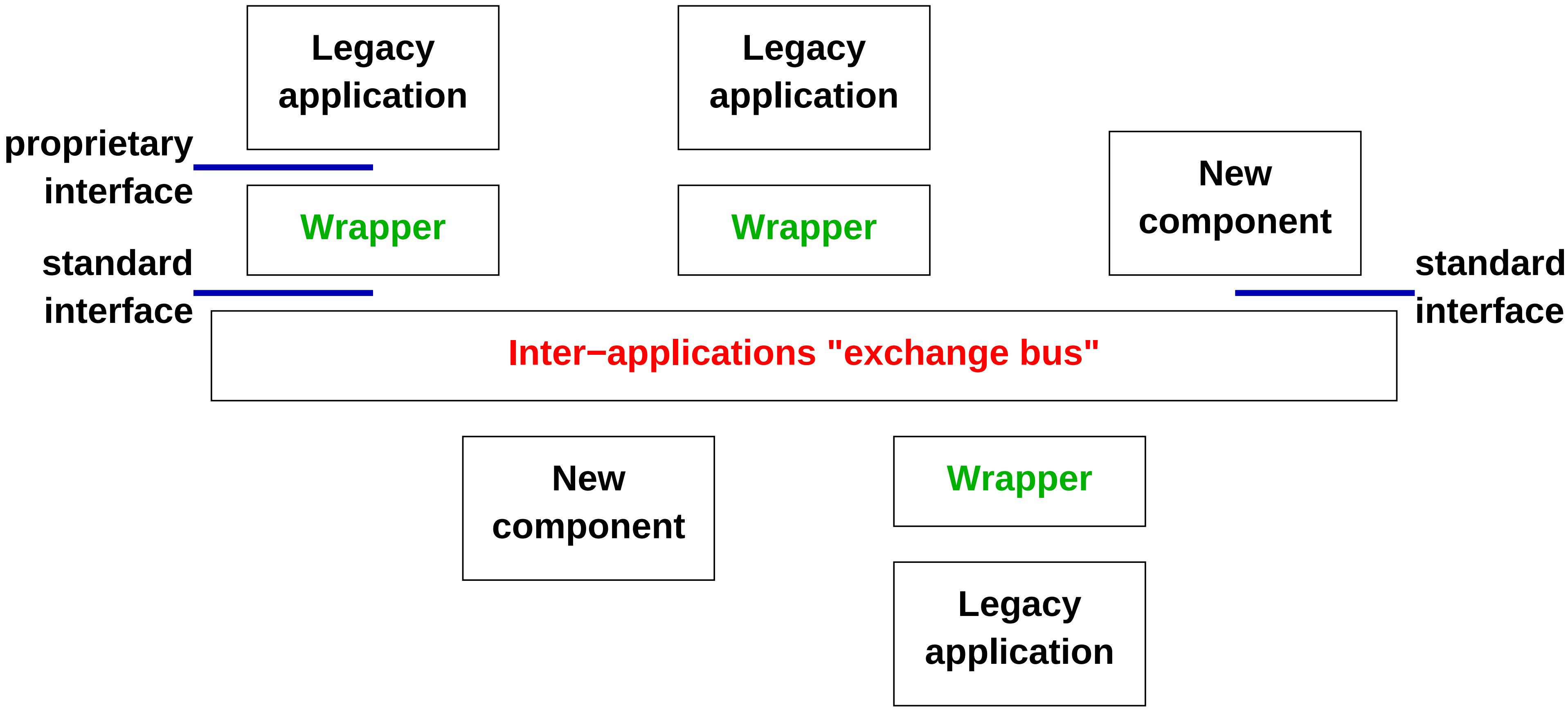
[a] Alexander, Christopher (1977). A Pattern Language: Towns, Buildings, Construction. Oxford University Press.

2.2 Some design pattern examples for middleware

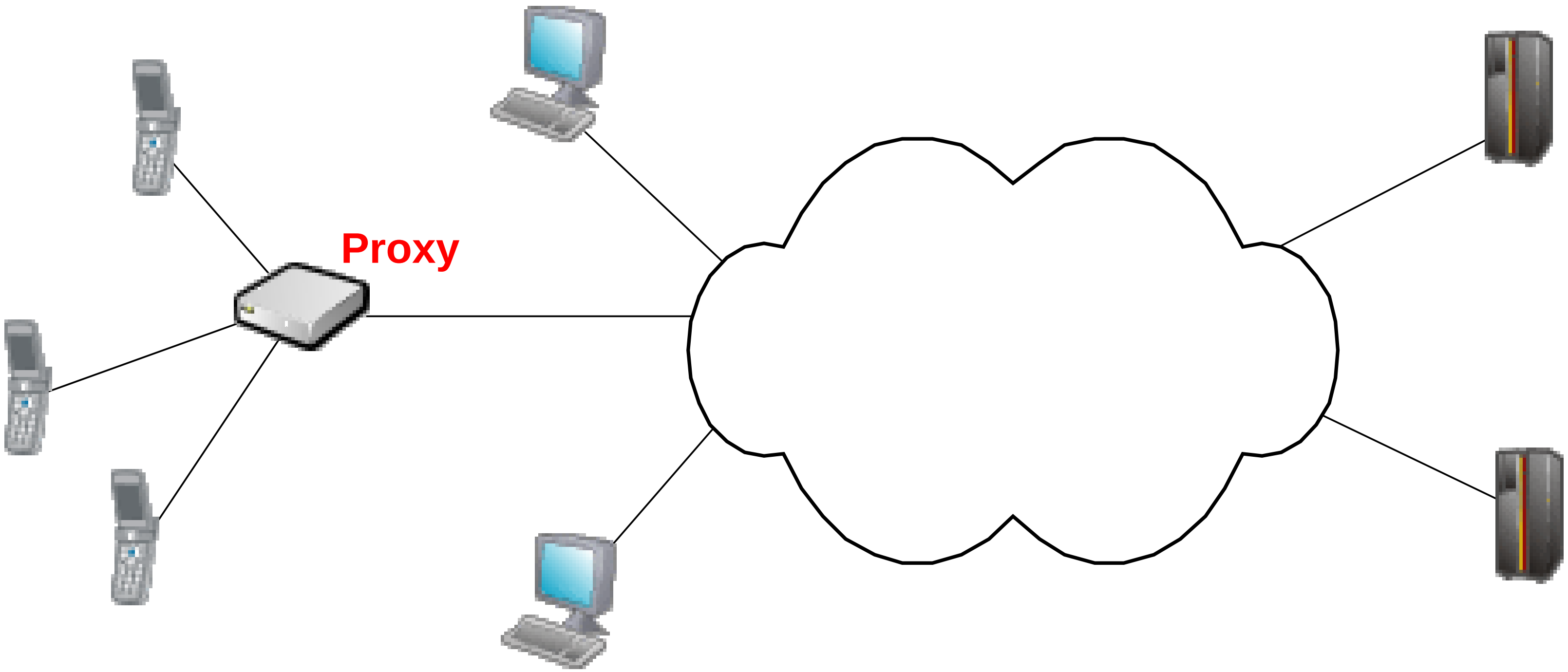
2.2.1 Example 1: A client/server middleware



2.2.2 Example 2: Integration of legacy applications

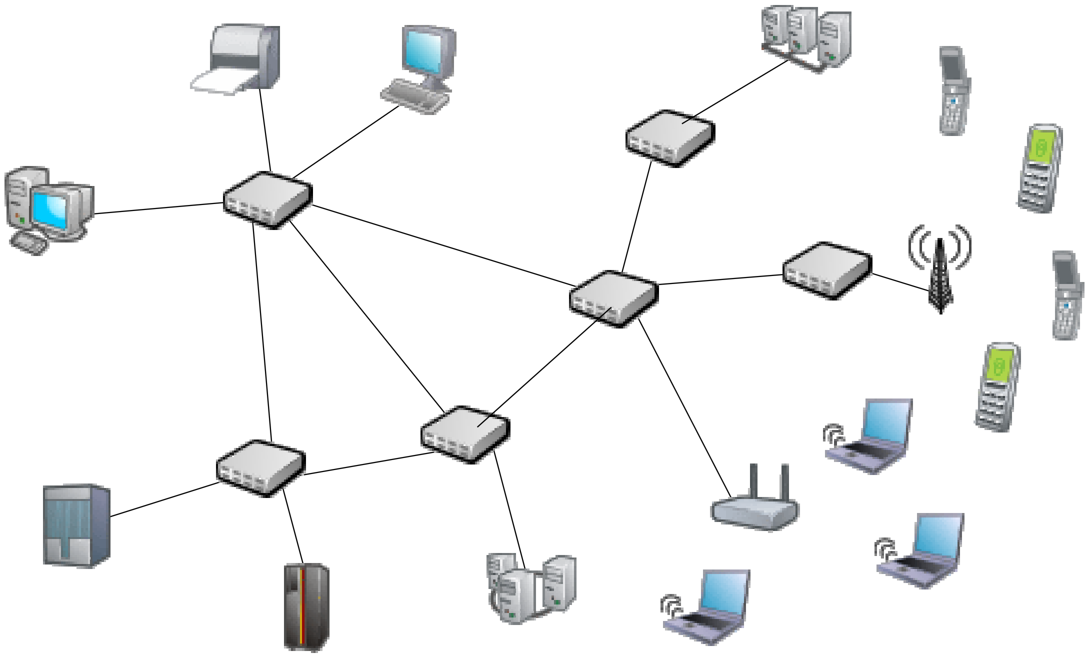


2.2.3 Example 3: Adaptation to client resources

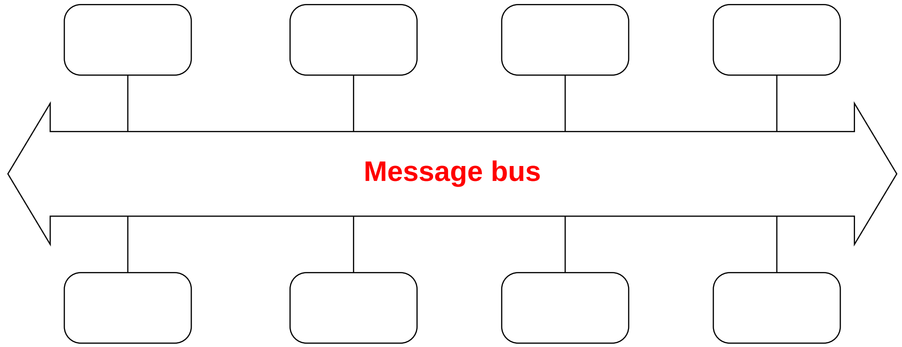


2.2.4 Example 4: Monitoring and control of networked equipments

- 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

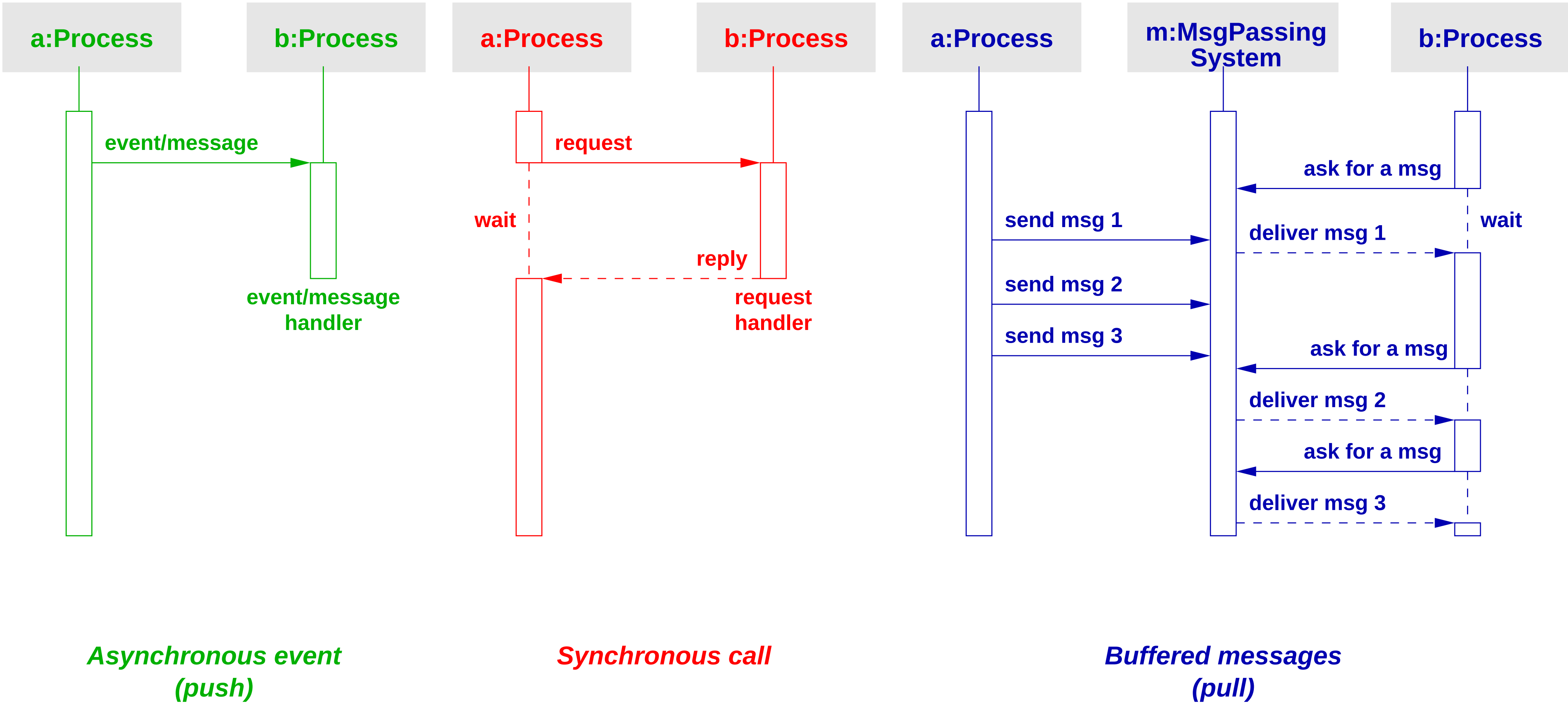
- Name: Higher abstraction which conveys the essence of the pattern succinctly
- Intent: Short statement stating what the pattern does, its rationale, and the particular design issue or problem addressed
- Motivation and context: Scenario illustrating the class of problems addressed; should be as generic 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

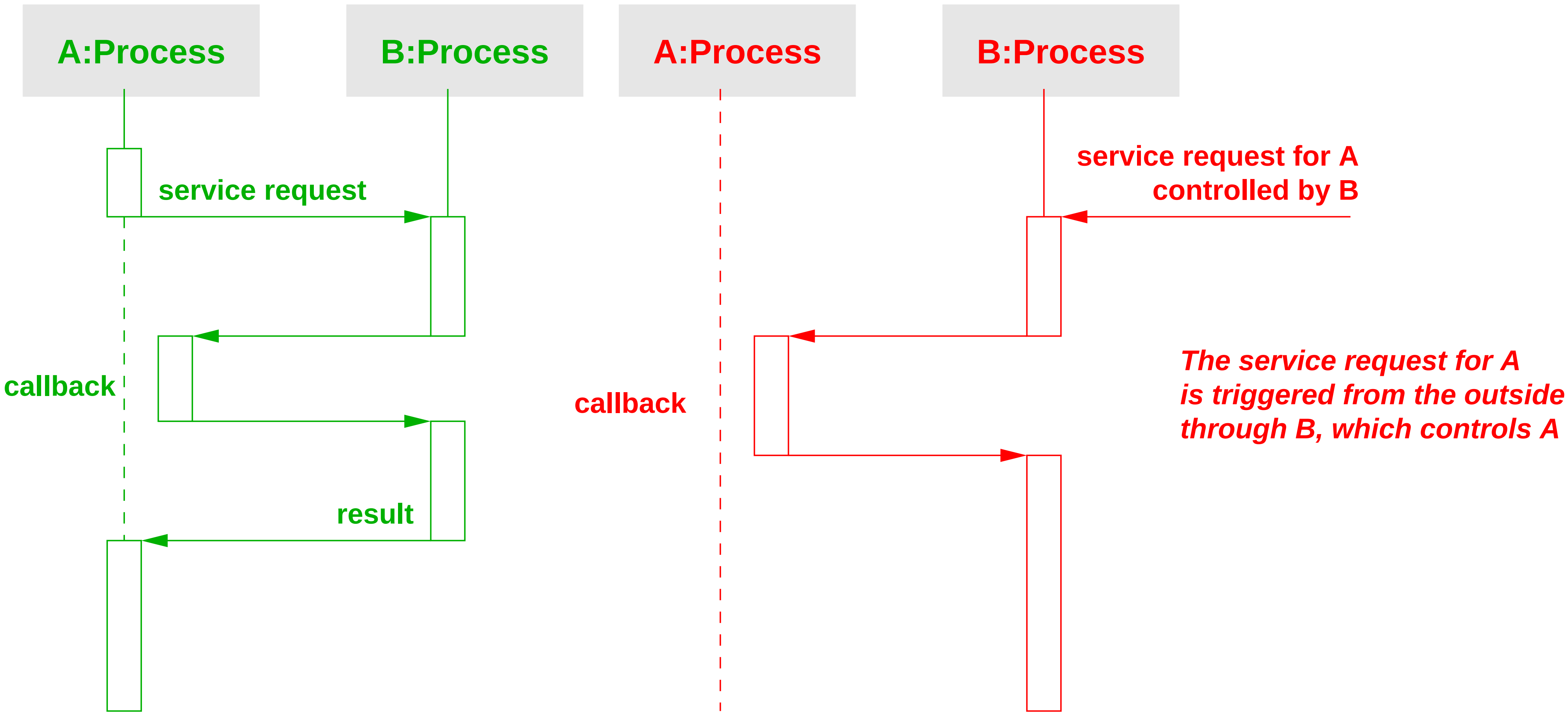
- Architectural: Large scale, structural organisation, subsystems and relationships between them
- Design: Small scale, commonly recurring structure within a particular context
- Idioms: Language specific, how to implement a particular aspect in a given language
- And many more: Software process, requirement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

3 Patterns for distributed interaction

3.1 Asynchronous call, synchronous call, buffered message



3.2 Call-back and Inversion of control



Synchronous call with callback

A callback is first registered
and later called asynchronously.

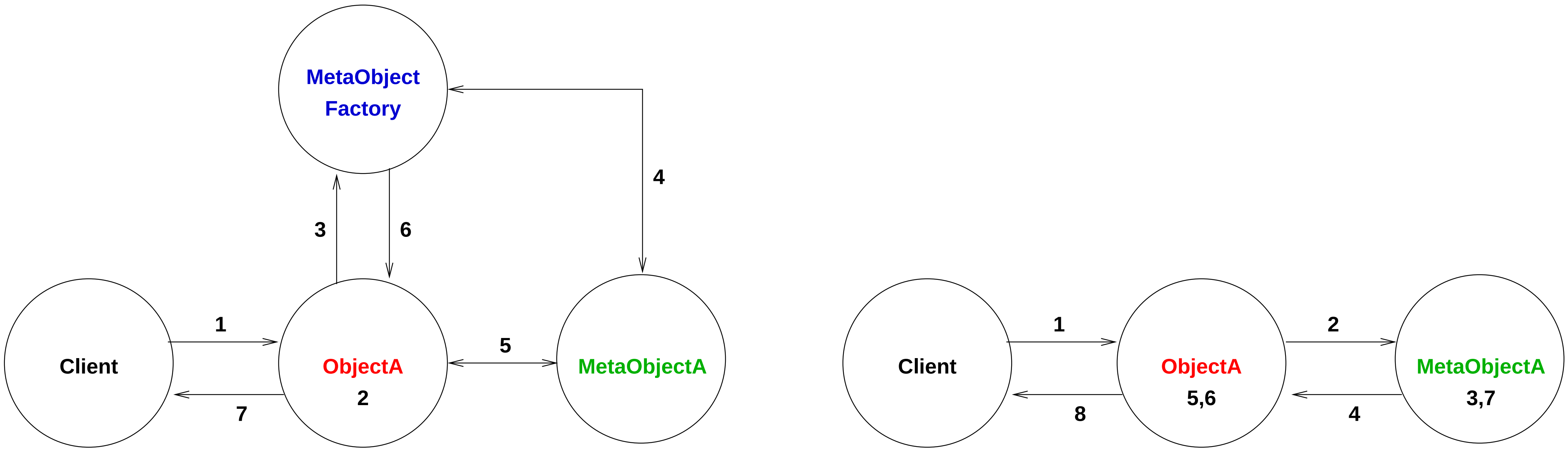
Inversion of control

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

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

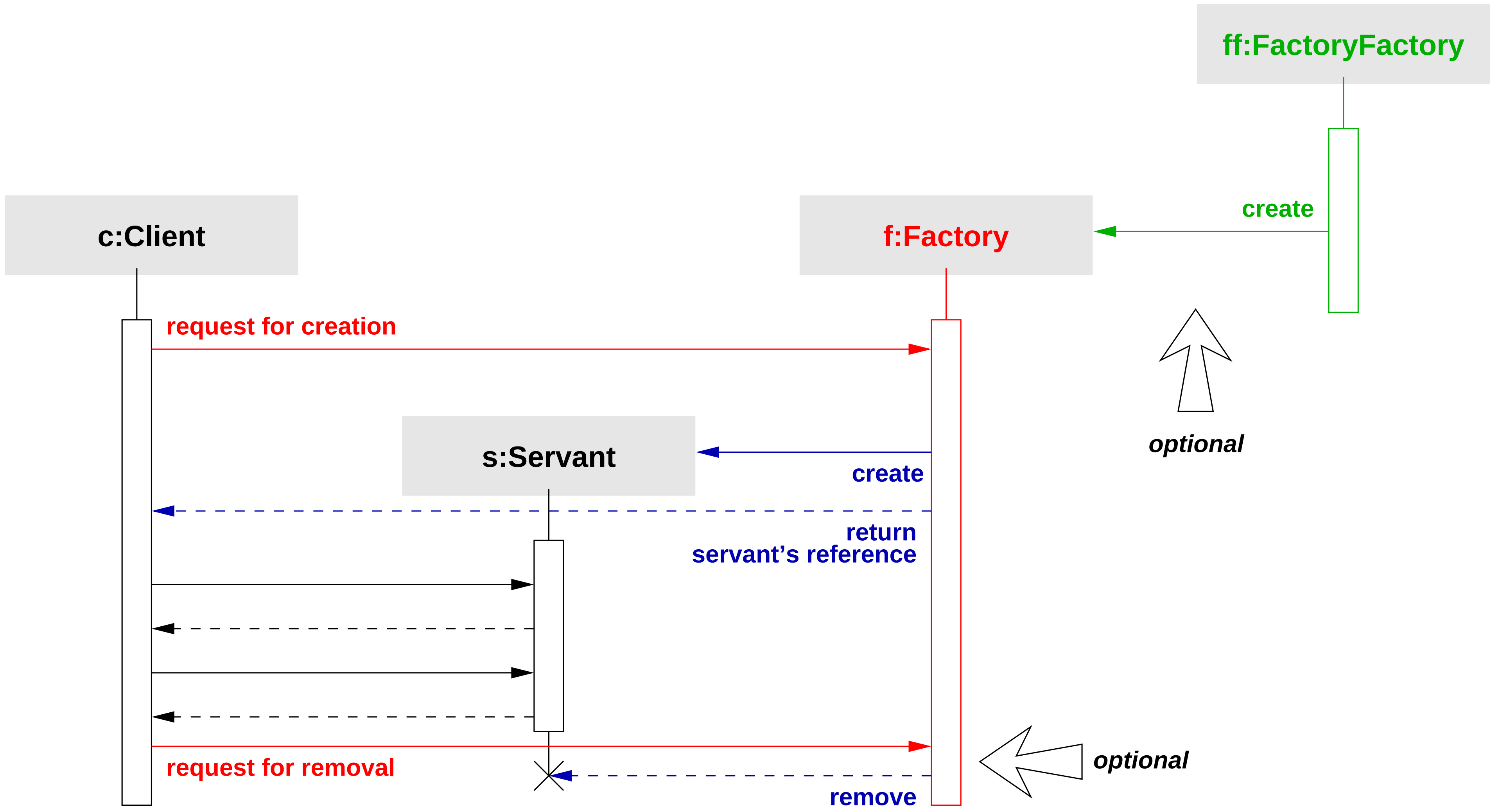
Architecture principle



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

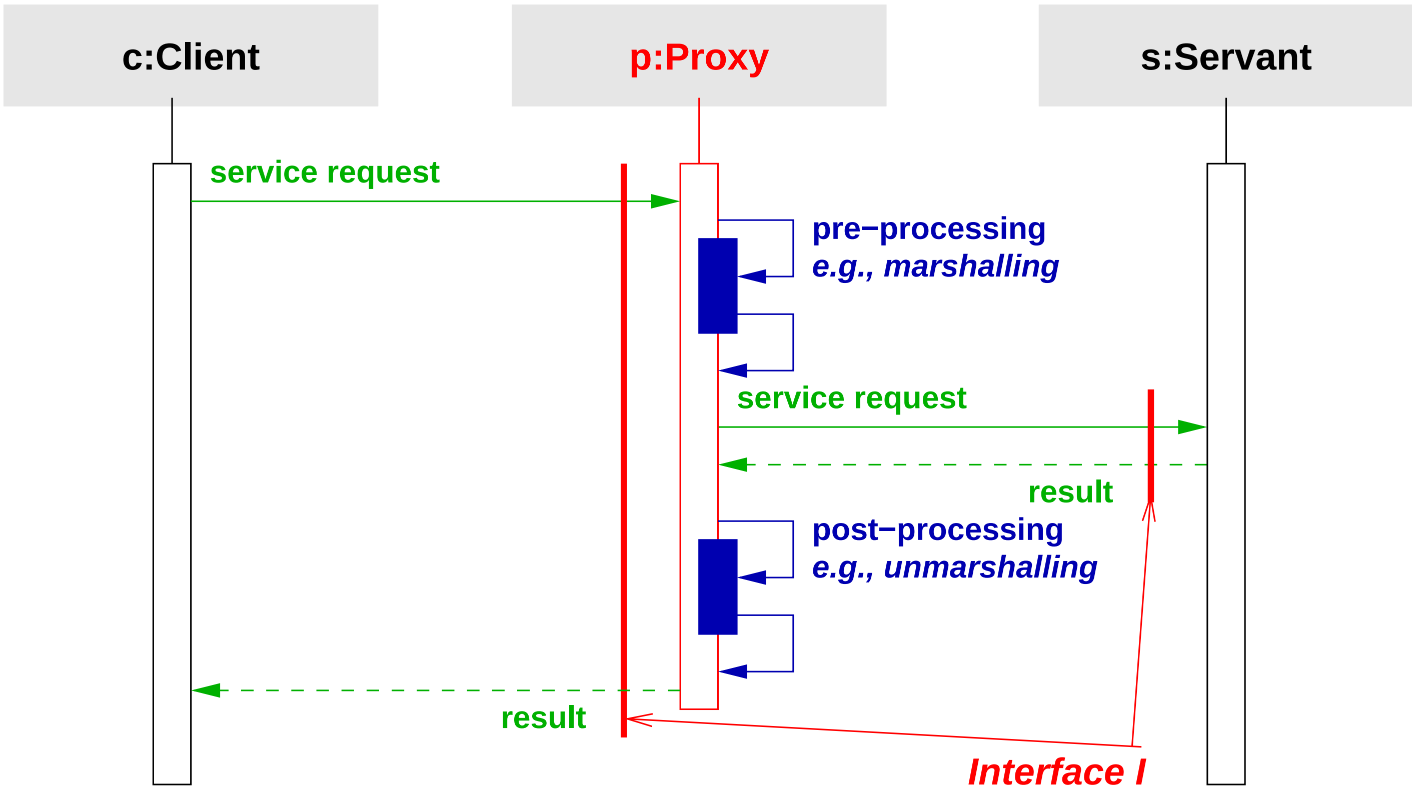
3.4.1 Sequence diagram of Factory



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

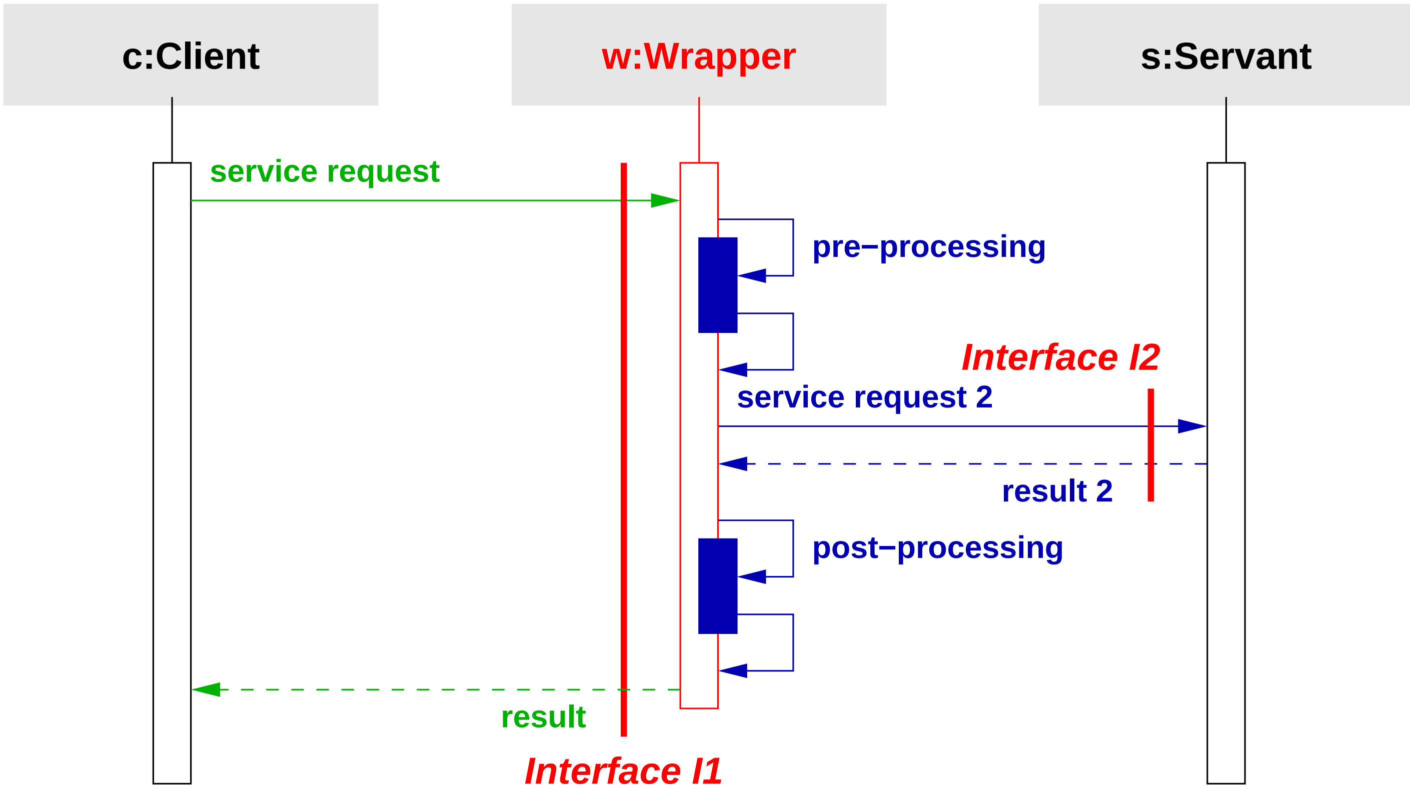
3.5.1 Sequence diagram of Proxy



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

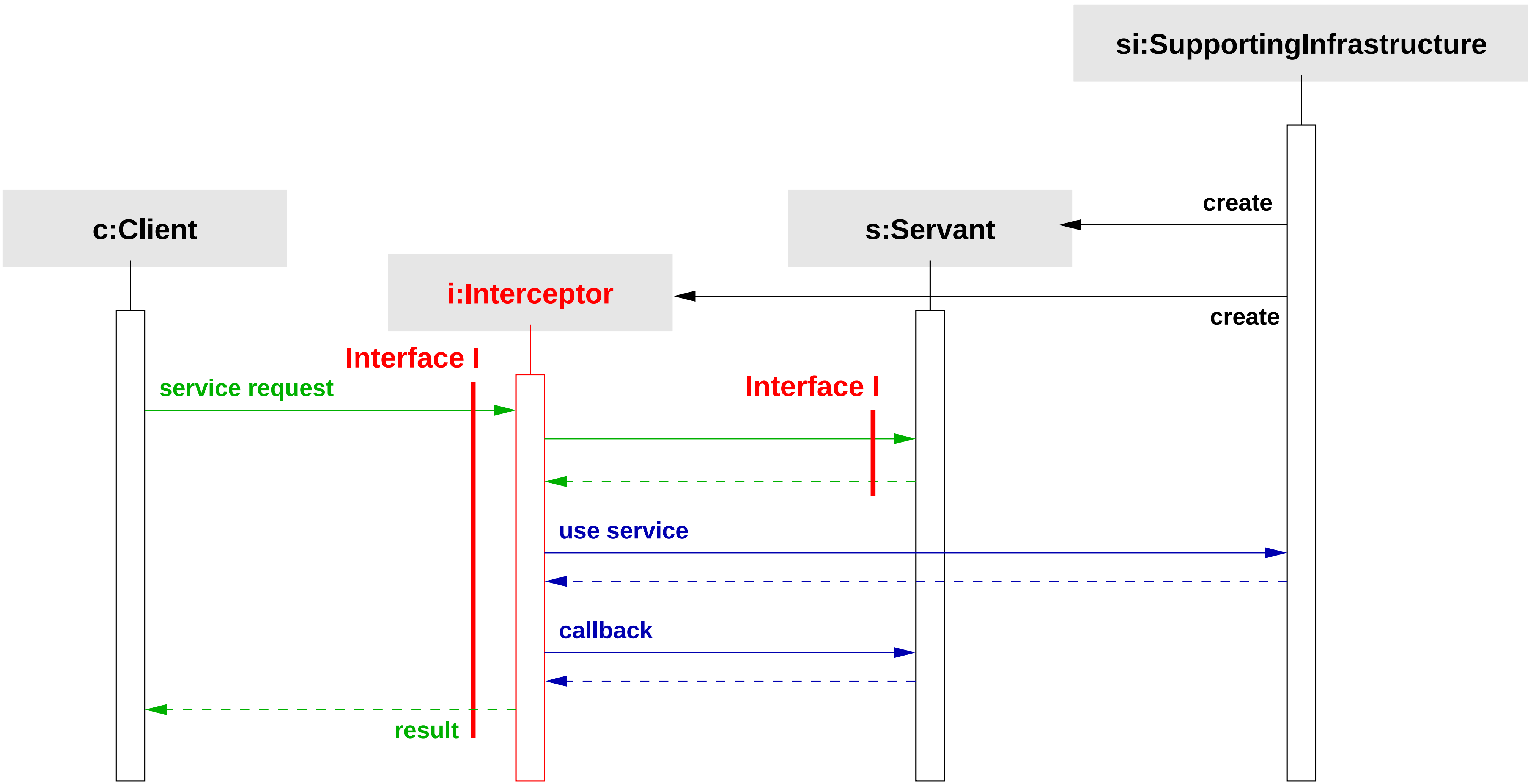
3.6.1 Sequence diagram of Wrapper/Adapter



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



3.8 Similarities and differences between the previous patterns

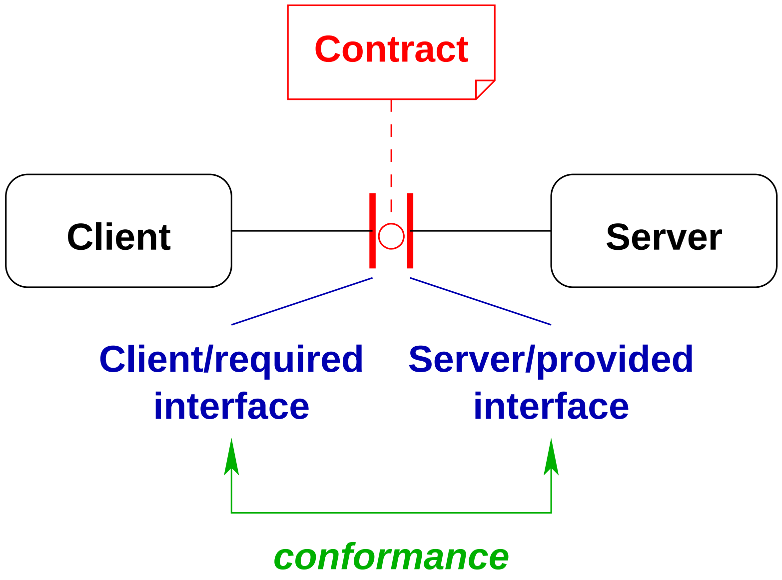
- Wrapper *Vs.* Proxy
  - Wrapper and Proxy have a similar structure
    - Proxy preserves the interfaces
      Vs. Wrapper transforms the interface
    - Proxy often (not always) involves remote access
      Vs. Wrapper is usually on-site
- Wrapper *Vs.* Interceptor
  - Wrapper and Interceptor have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

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

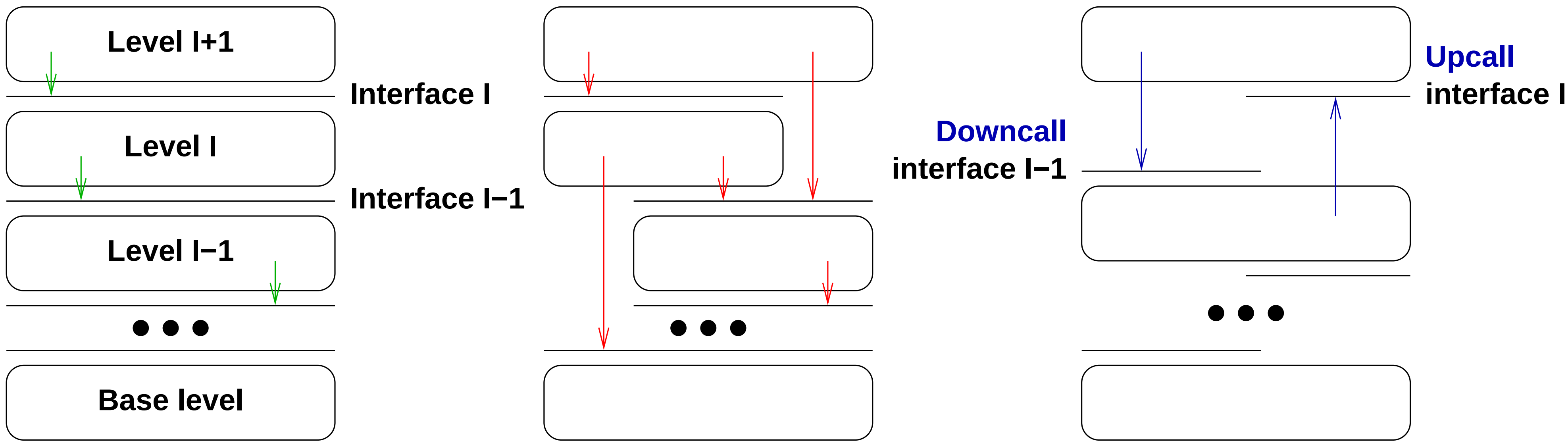
4.2 Contract: Qualified required/offered interfaces



- 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

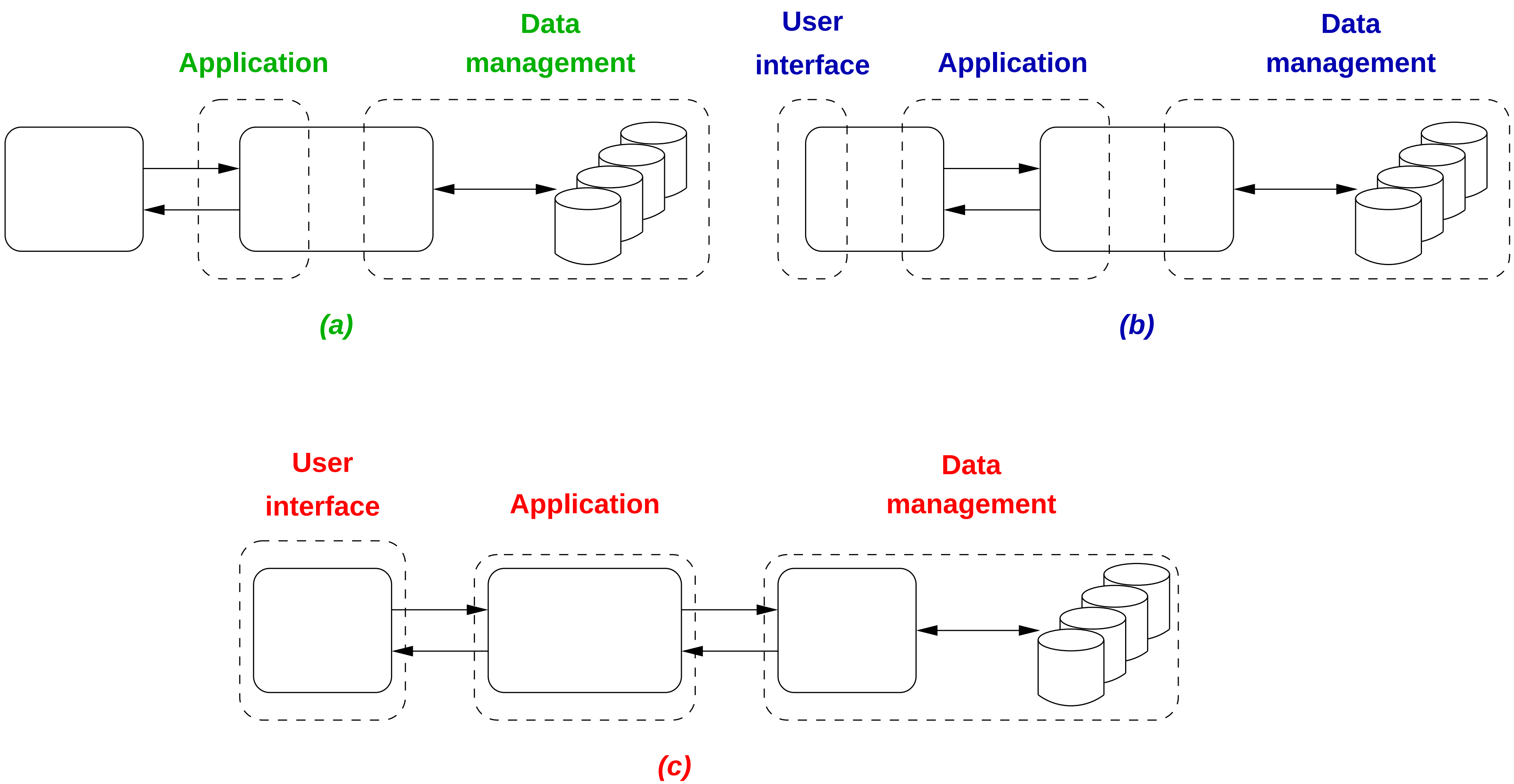
4.3 Layer or Abstract machine or Protocol stack: Vertical decomposition

- Context: Complex "local" system design
- Problem: Define different levels of abstraction/refinement
- Solution: Vertical decomposition with levels, and upper and lower interfaces



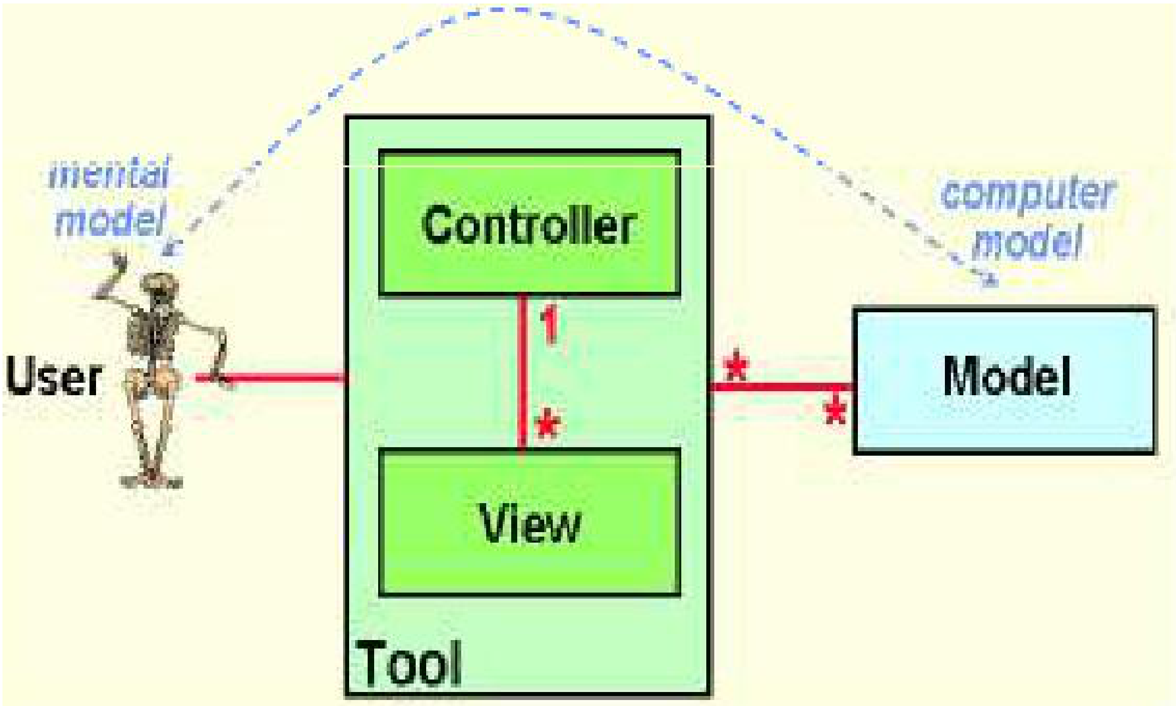
4.4 Multi-tier architecture: Horizontal decomposition

- 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

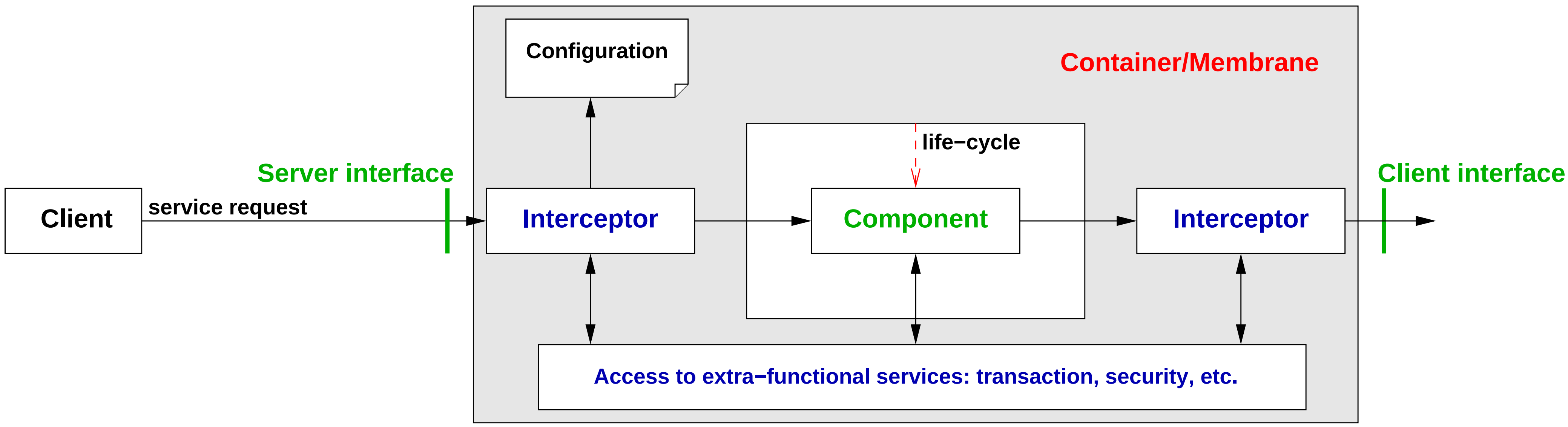


4.4.2 MVC pattern vs 3-tier architecture

- 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

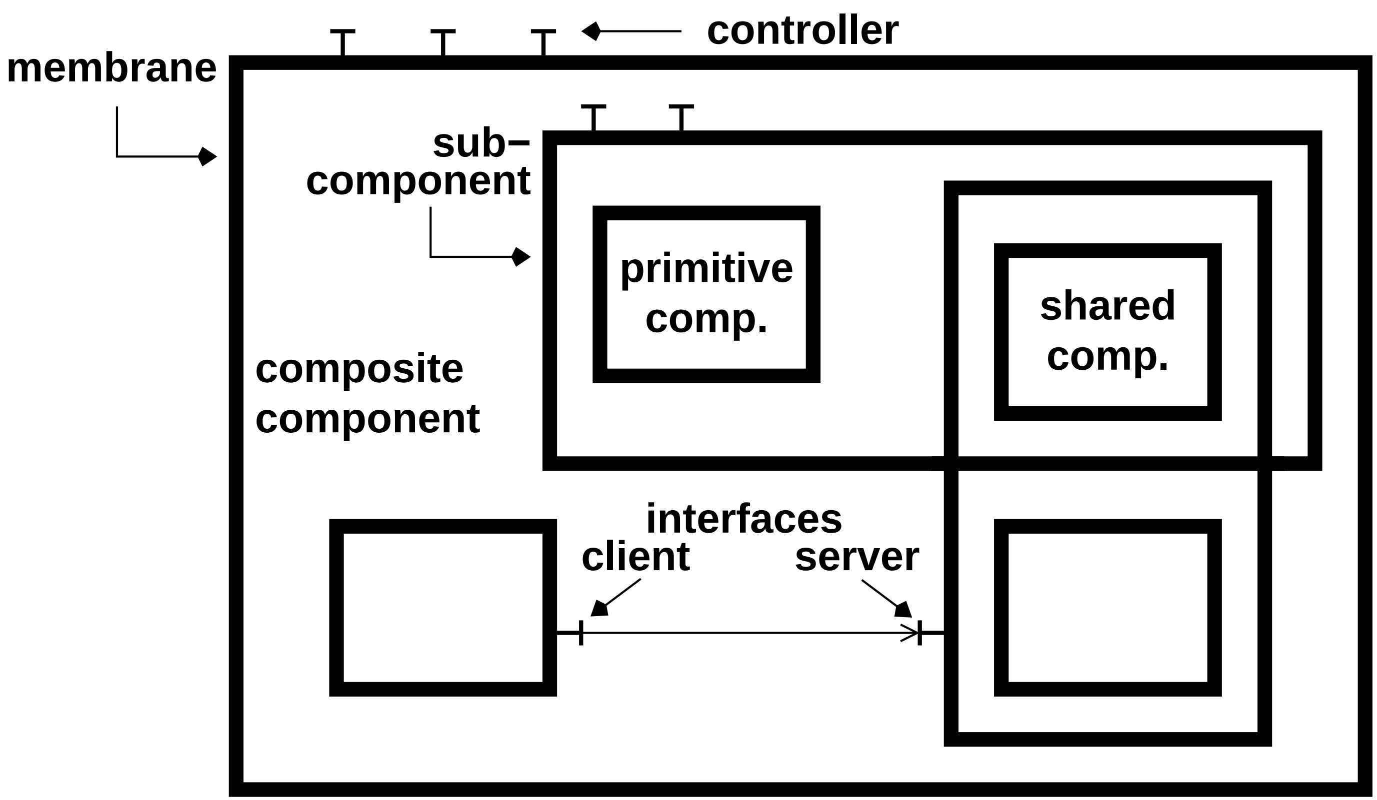


4.6 Composite with sharing: Component + Vertical decomposition + Sharing

- 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

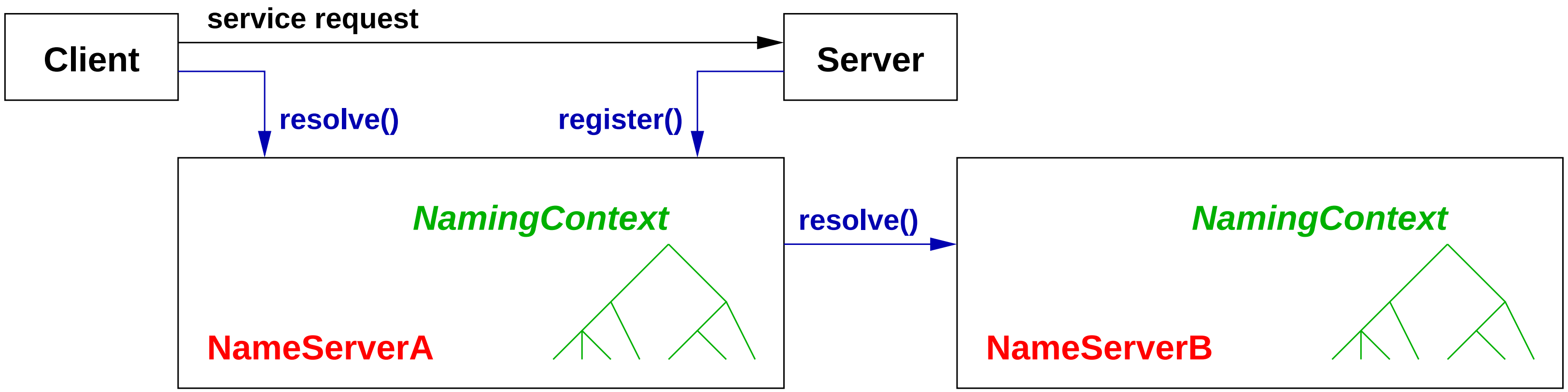
- É. Bruneton, T. Coupaye, M. Leclercq, V. Quéma, and J.-B. Stéfani “The Fractal Component Model and Its Support in Java” Software–Practice and Experience, 36(11), pp. 1257–1284, September 2006



5 Patterns for coordination

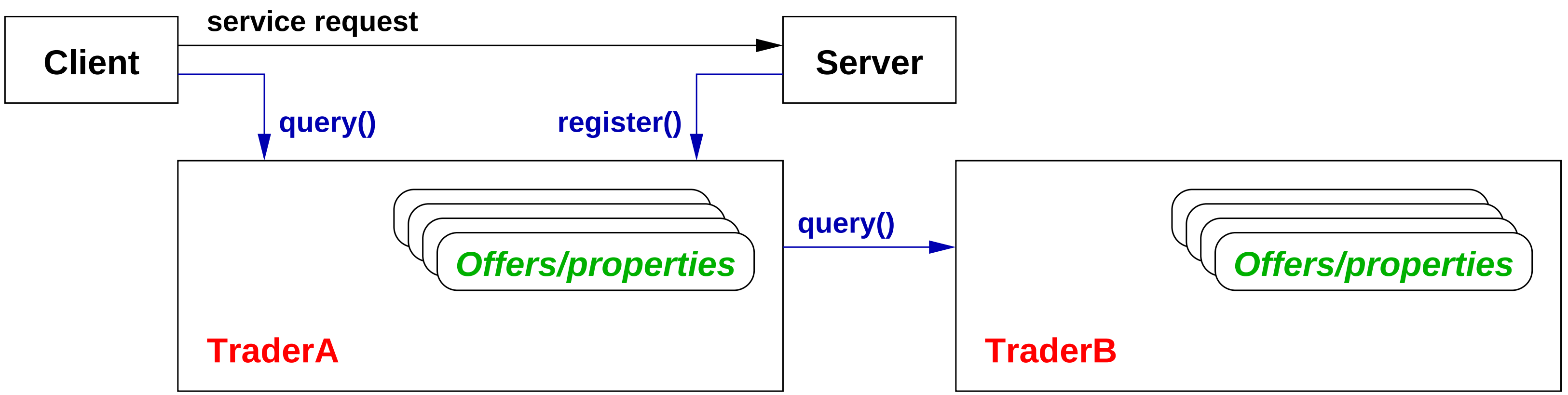
5.1 Naming: White pages service

- 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



5.2 Trading: Yellow pages service

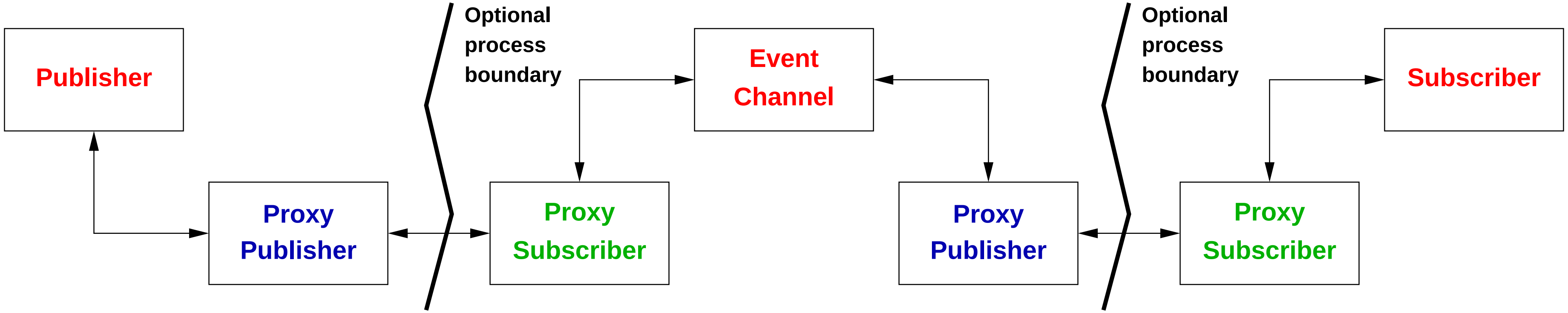
- Context: clients and servers distributed over the network
- Problem
  - Obtain a (distributed) reference to an entity
  - Only a property characterising the server is known by the client: Service name...
- Solution
  - The client specifies its requets by providing properties of the required service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



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)