# Introduction to Component-Based Software Engineering

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# Topic overview

1 The challenges of SW- how can CBD help?

2 What is a software component?

3 Software Architecture and Software Components

4 Basic principles of component-based approach

5 Component-based Software Development Process

6 Problems and research issues

7 References

# Part 1

# The challenges of software development - how can component software help?

# Software problems

NATO conf 1968

SW crisis

SW engineering

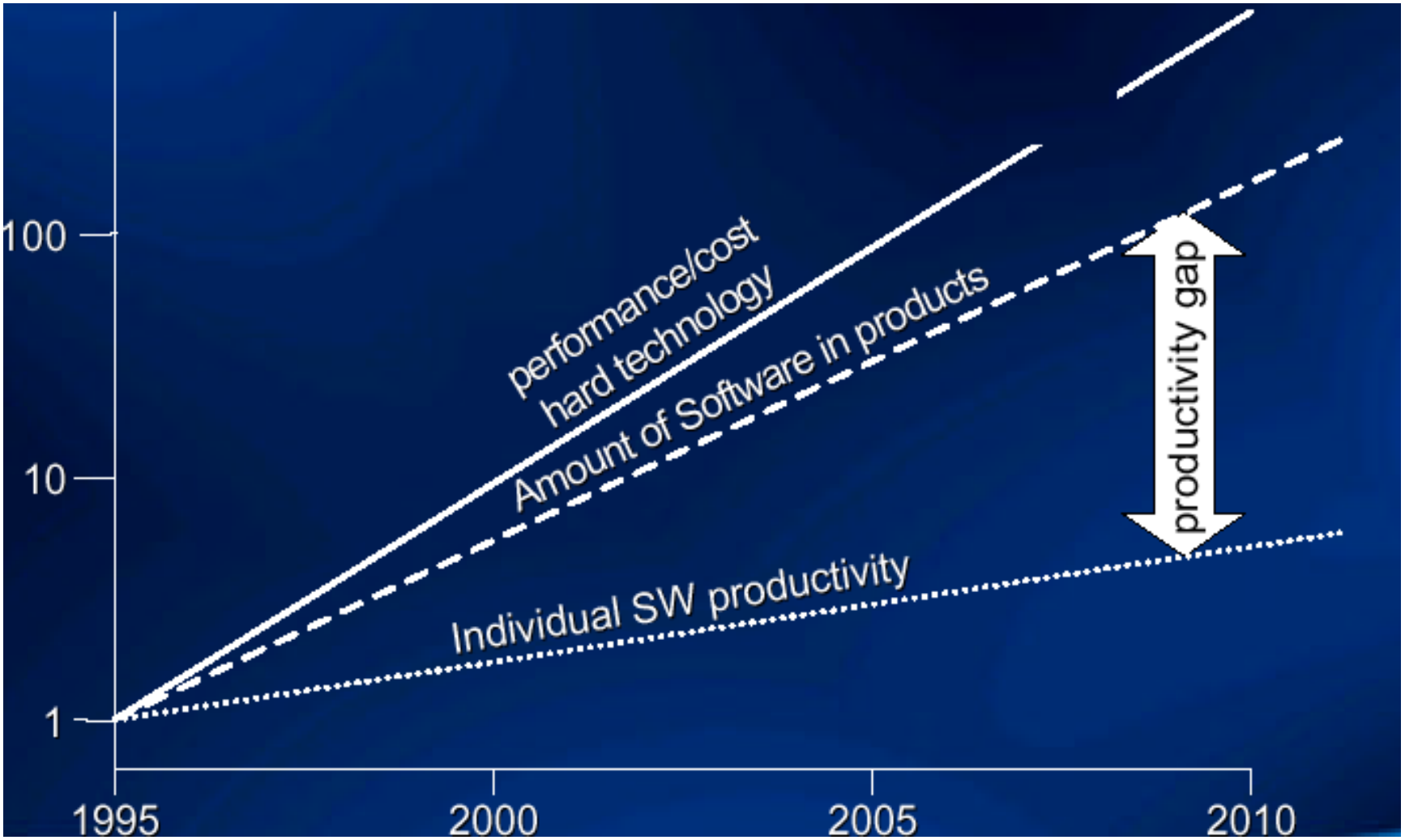
components

How to develop high quality software in an efficient and inexpensive way?

The “software crisis” (1968) still exists:

- SW is late
- SW is buggy
- SW is expensive
- SW is difficult to understand
- Software is difficult to maintain (problems with software life cycle)

# SW Productivity Gap (ITEA)



# Challanges of Software Engineering

## Problems of Software Engineering

- The size & complexity of software increases rapidly
- Single products become part of product families
- Software is upgraded after deployment
- The time-to-market must decrease significantly
- The cost of products must be reduced

**(The author of slides with blue background: Michel Chaudron, TUe**

# Observations on the practice of SE

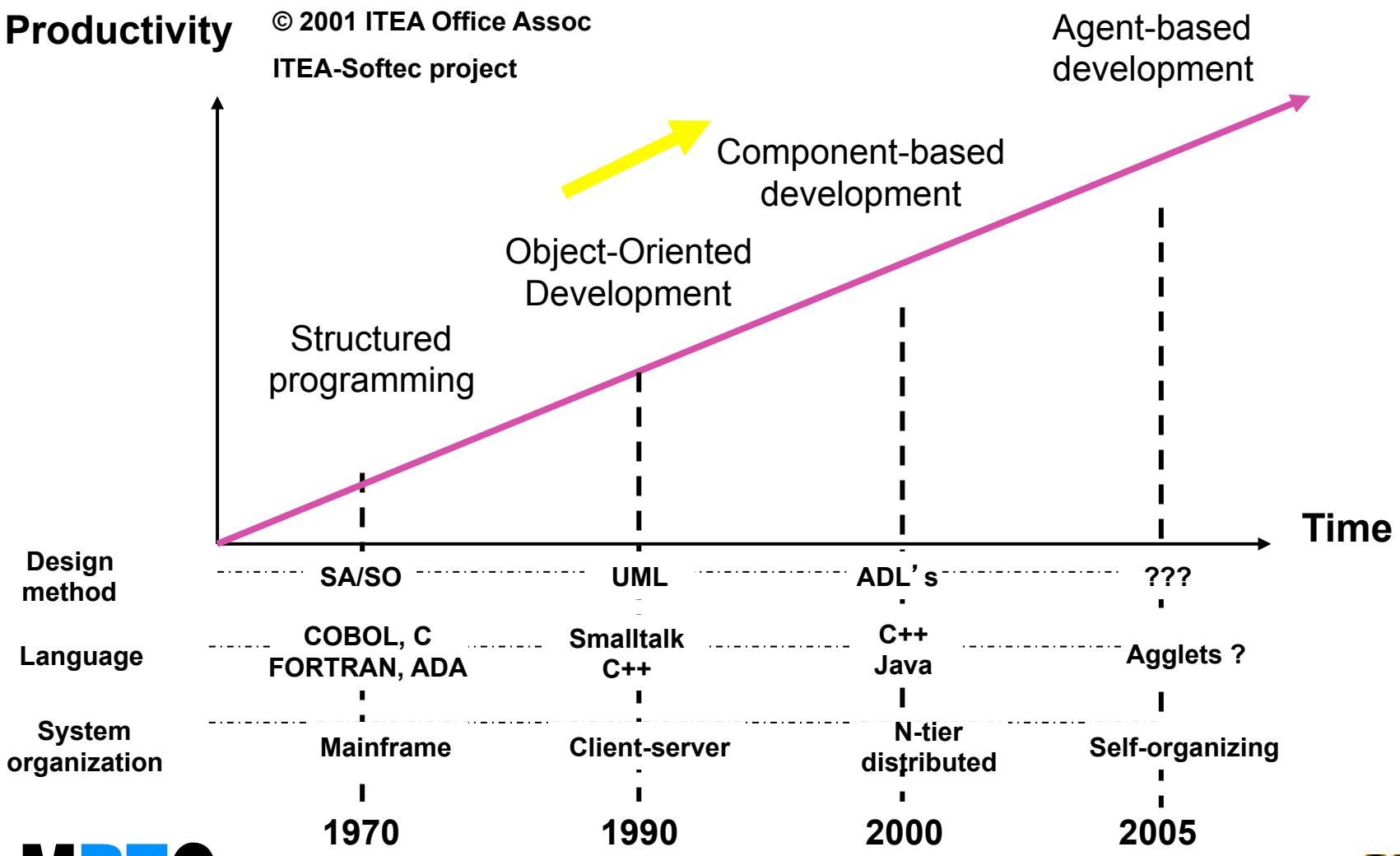
About 80% of software engineering deals with changing existing software

It is not the strongest of the species that survive, nor the most intelligent, but the ones most responsive to change.
-- Charles Darwin

Time to market is an important competitive advantage: incorporate successful innovations quickly

→ Systems should be built to facilitate change
→ easy removal and addition of functionality

# Software paradigm shift

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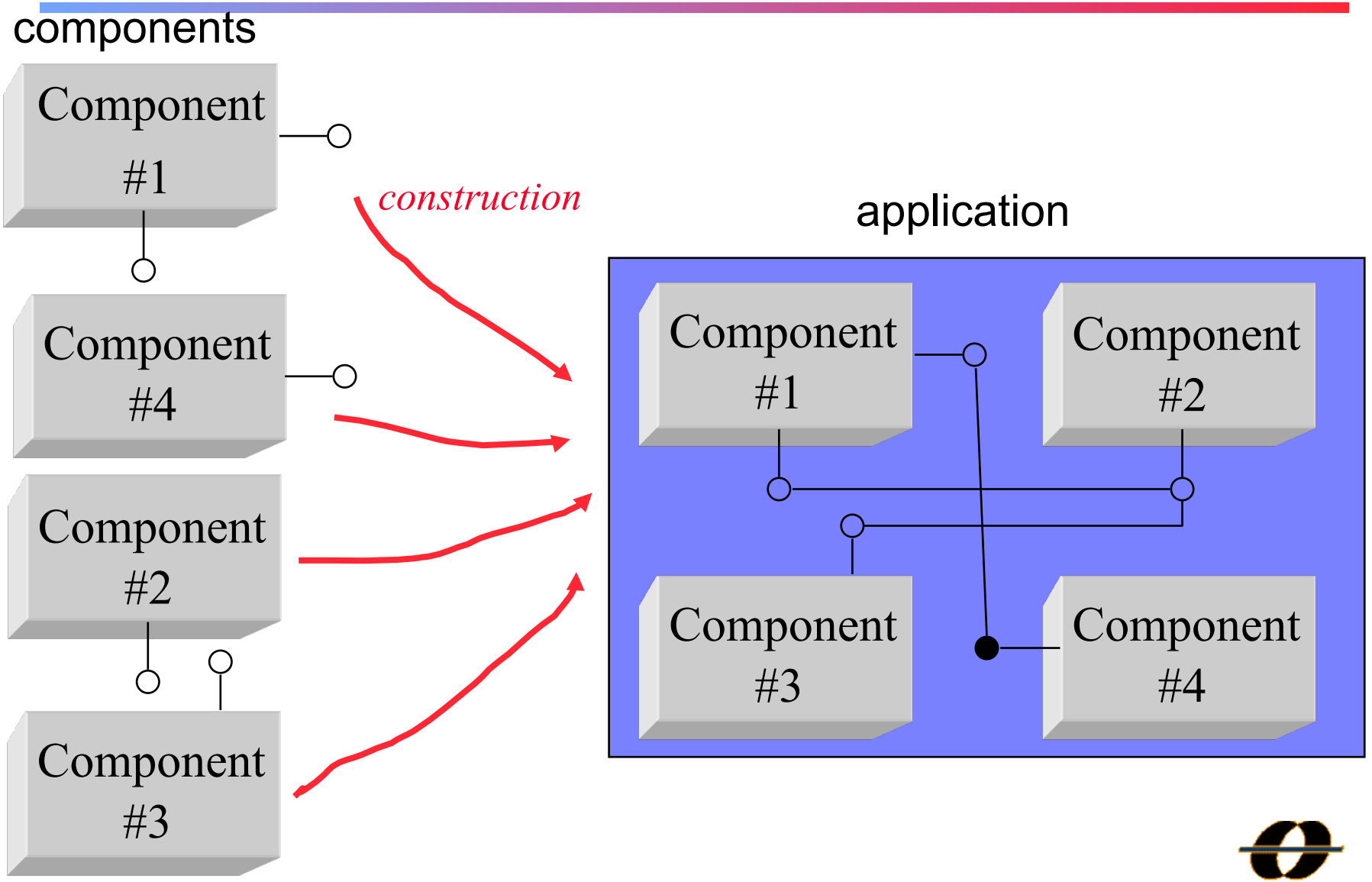
# Answer: Component-based Development

- **Idea:**
  - Build software systems from pre-existing components (like building cars from existing components)
  - Building components that can be reused in different applications
  - Separate development  of components from development of systems

# Component-Based Software Engineering (CBSE)

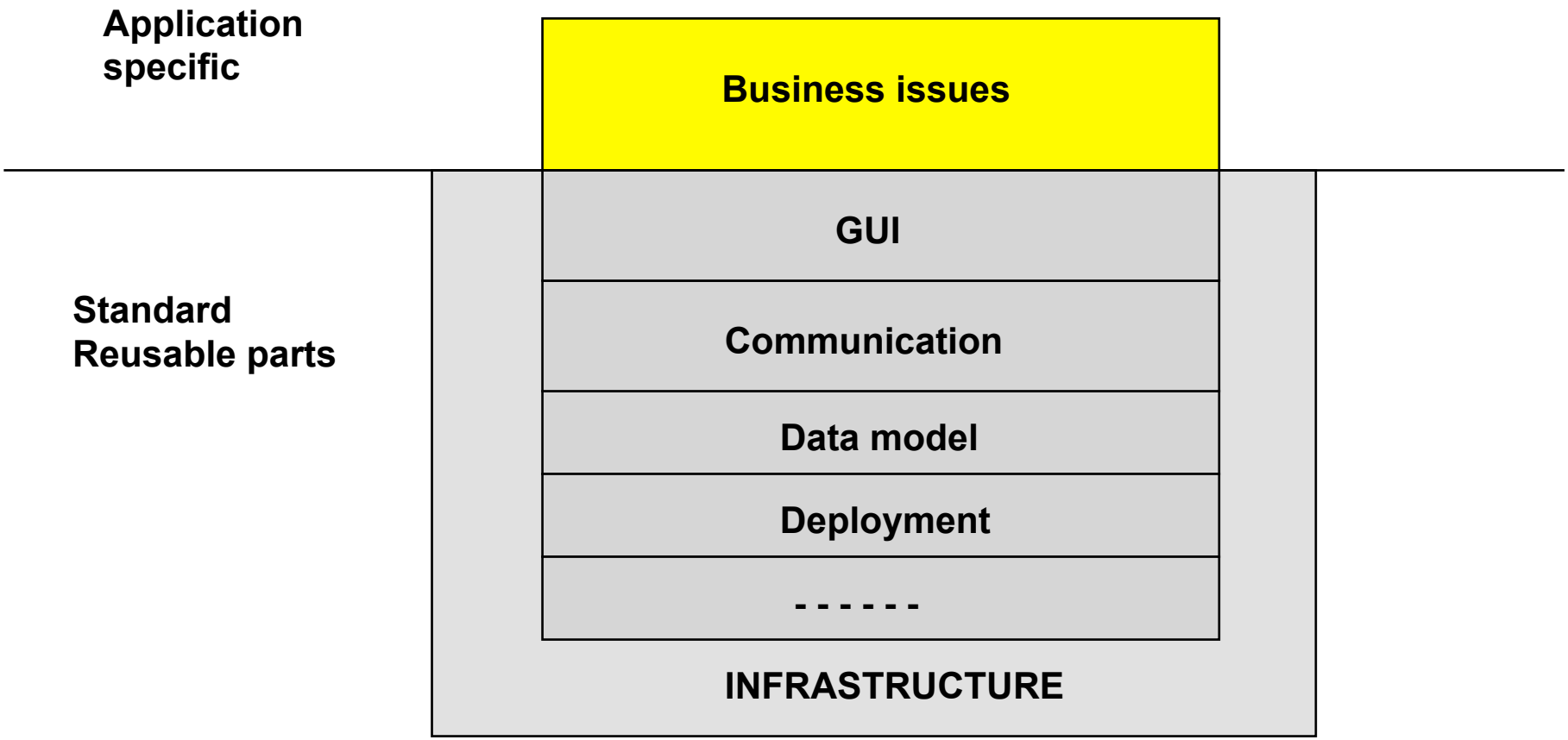
- **Provides methods and tools for**
  - Building *systems* from ***components***
  - Building components as reusable units
  - Performing maintenance by replacement of components and introducing new components into the system

# Component-based software construction (1)



# Concentration on the business parts

*"30 % of SW development effort is spent on infrastructure that adds no value"*

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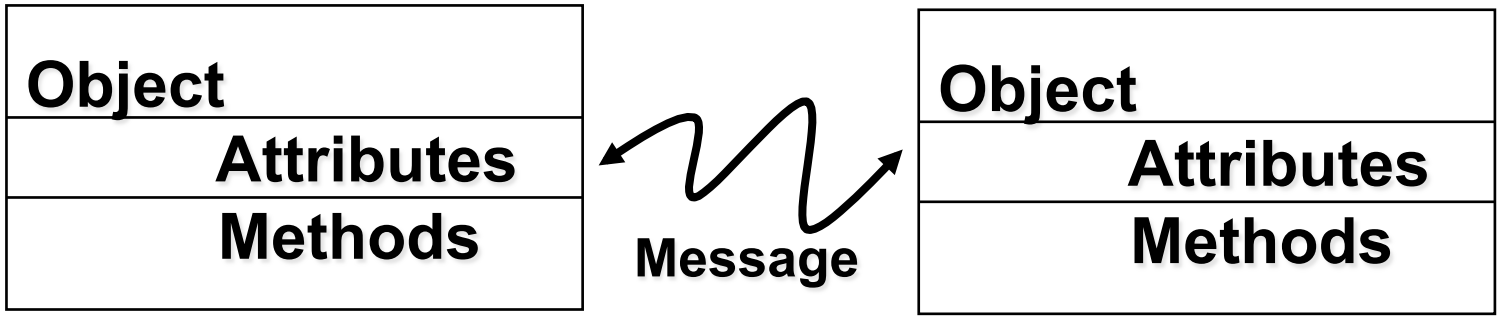
# Is CBD the same as OOP?

- Object-oriented programming




**Are objects the same as components?**

# Side remark: OO and reuse

**Object orientation is not primarily concerned with reuse, but with appropriate domain/problem representation**

**using the technological enablers**

- Objects, classes, inheritance, polymorphism

**Experience has shown that the use of OO does not necessarily produce reusable SW**

**CBD**

- scale reusable entities: Component = many objects in collaboration
- reusable parts on the execution level (plug-in)
- Additional services provided by component models

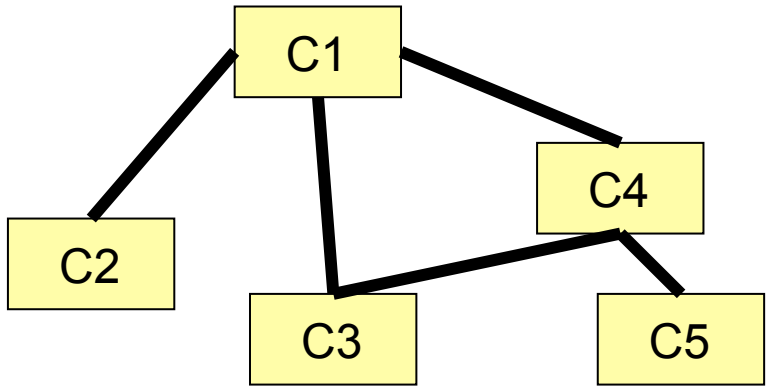
# Part 2

# What is a software component?

# Architectural point of view

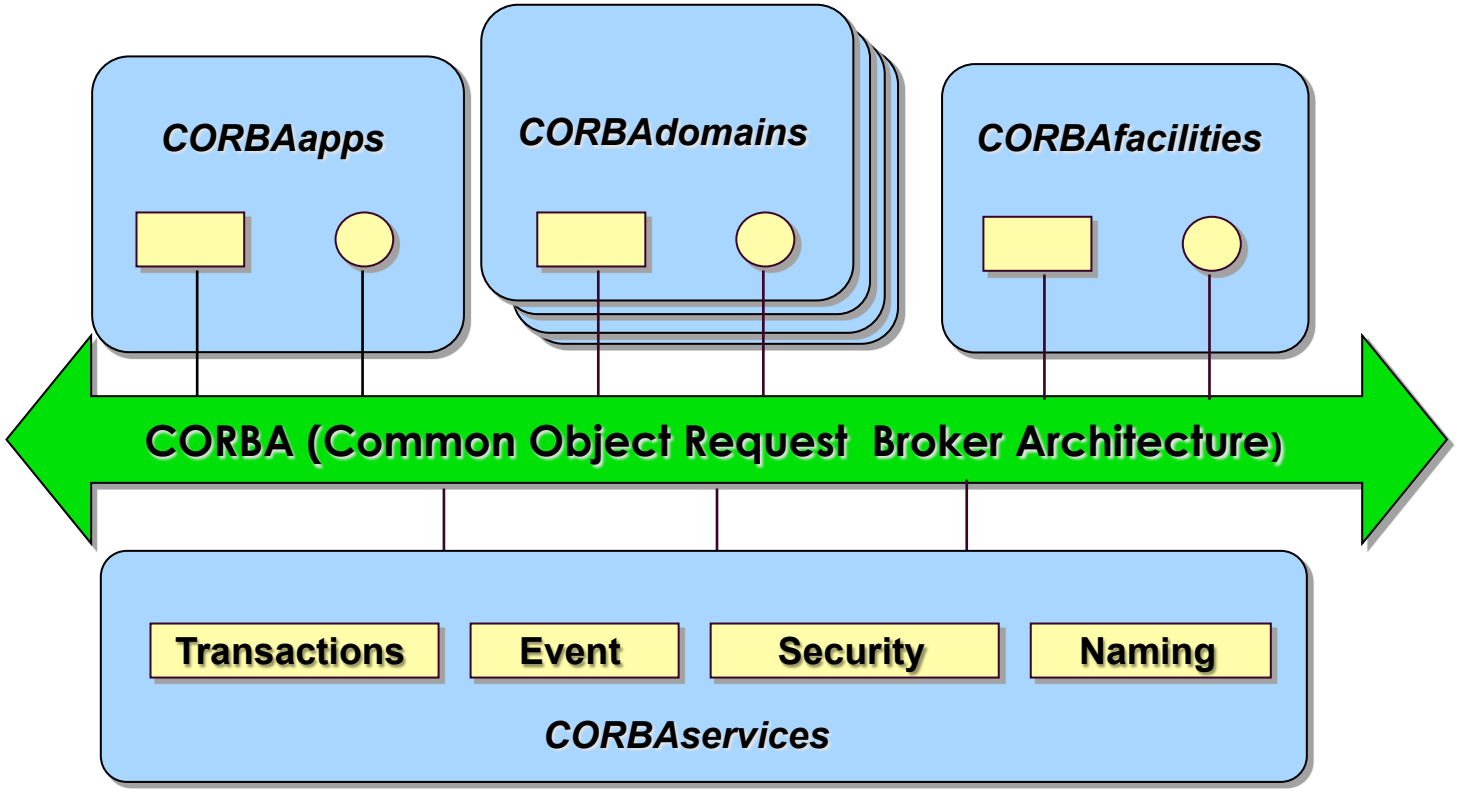
- The software architecture of a program or computing system is the structure or structures of the system, **which comprise software components** [and connectors], the **externally visible properties of those components** [and connectors] and **the relationships among them**."

Bass L., Clements P., and Kazman R., *Software Architecture in Practice*,

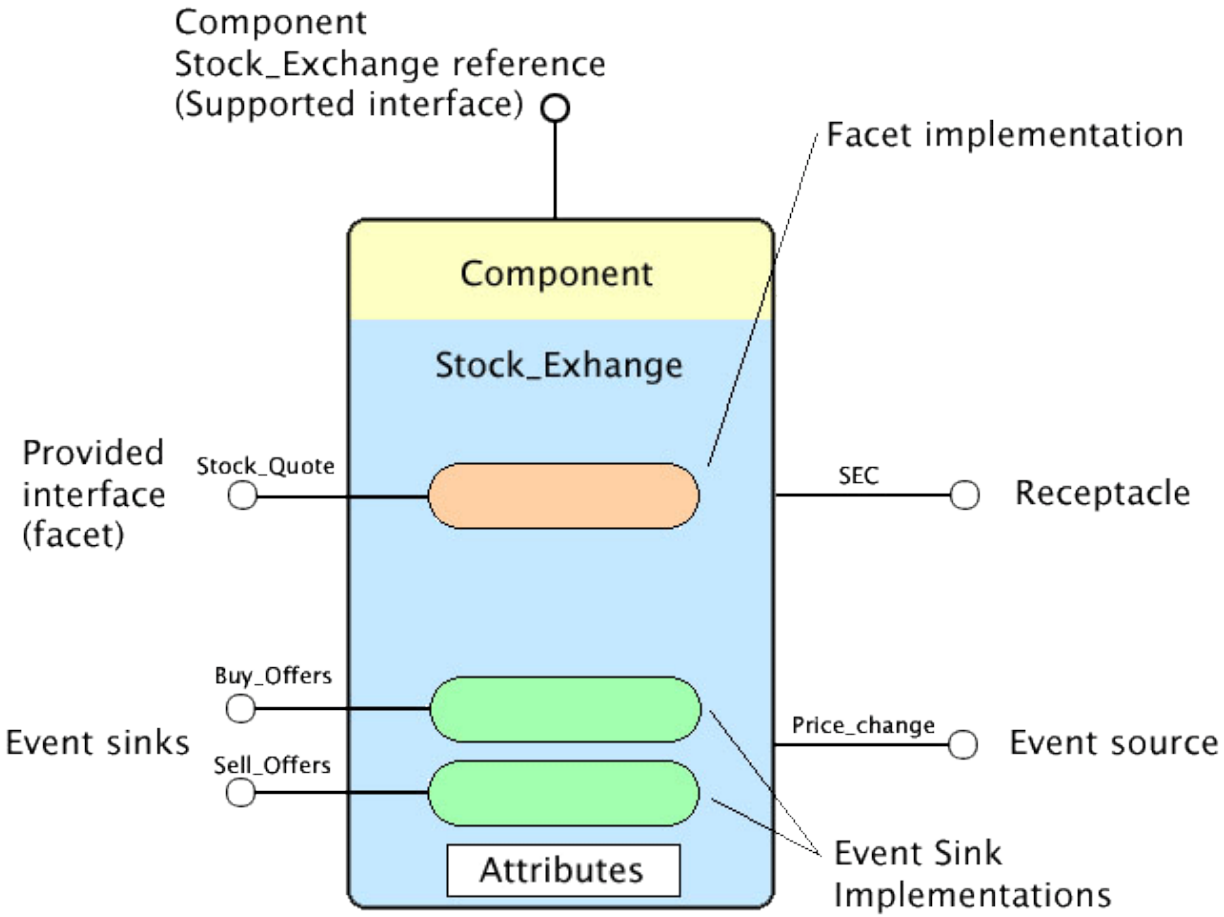


# Another example

## Object Management Architecture Overview



# Corba component model



# Some successful components: In the past...

- **Mathematical libraries**
  - NAGLIB - Fortran Library
  - Mathematical and physical functions
- **Characteristics**
  - \+ Well defined theory behind the functions - very well standardized
  - \+ Simple Interface - procedural type of communication between client (application) and server (component)
  - \+ Well defined input and output
  - \+ Relative good error handling
  - ✖ Difficult for adaptation (not flexible)

# Some successful components: The big ones…

**Client - server type**

- **Database**
  - Relational databases, (Object-oriented databases, hierarchical databases)
  - Standard  API - SQL
  - ✖ Different dialects of the standard
- **X-windows**
  - Standard API, callback type of communication
  - ✚ High level of adaptation
  - ✖ Too general - difficult to use it

# Even bigger components: Operating systems

- **Example - Unix**
  - A general purpose OS, used as a platform for dedicated purposes
  - Standard API - POSIX
  - \+ Commands uses as components in a shell-process

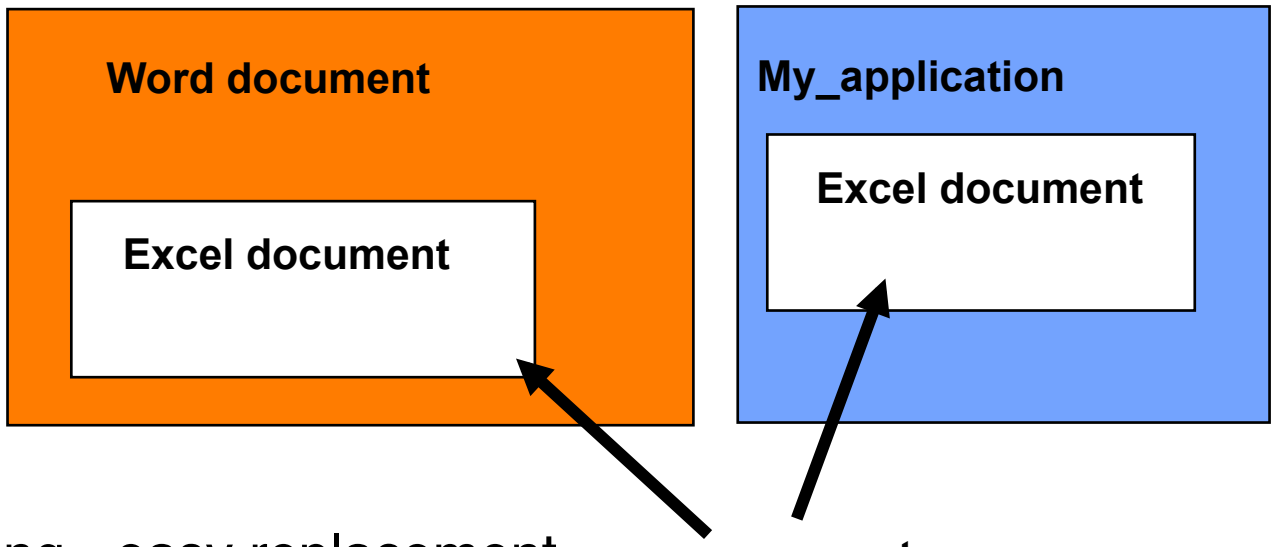
    Example: sort out words from text files:

    ```
    $ cat file1 file2 file3 ...  |  sed 's/ /\
     /g'  | sort -u >words.txt
    ```

  - ✖ Different variants, POSIX is not sufficient
  - ✖ Not a real component behavior (difficult to replace or update)
- **MS Windows ...**

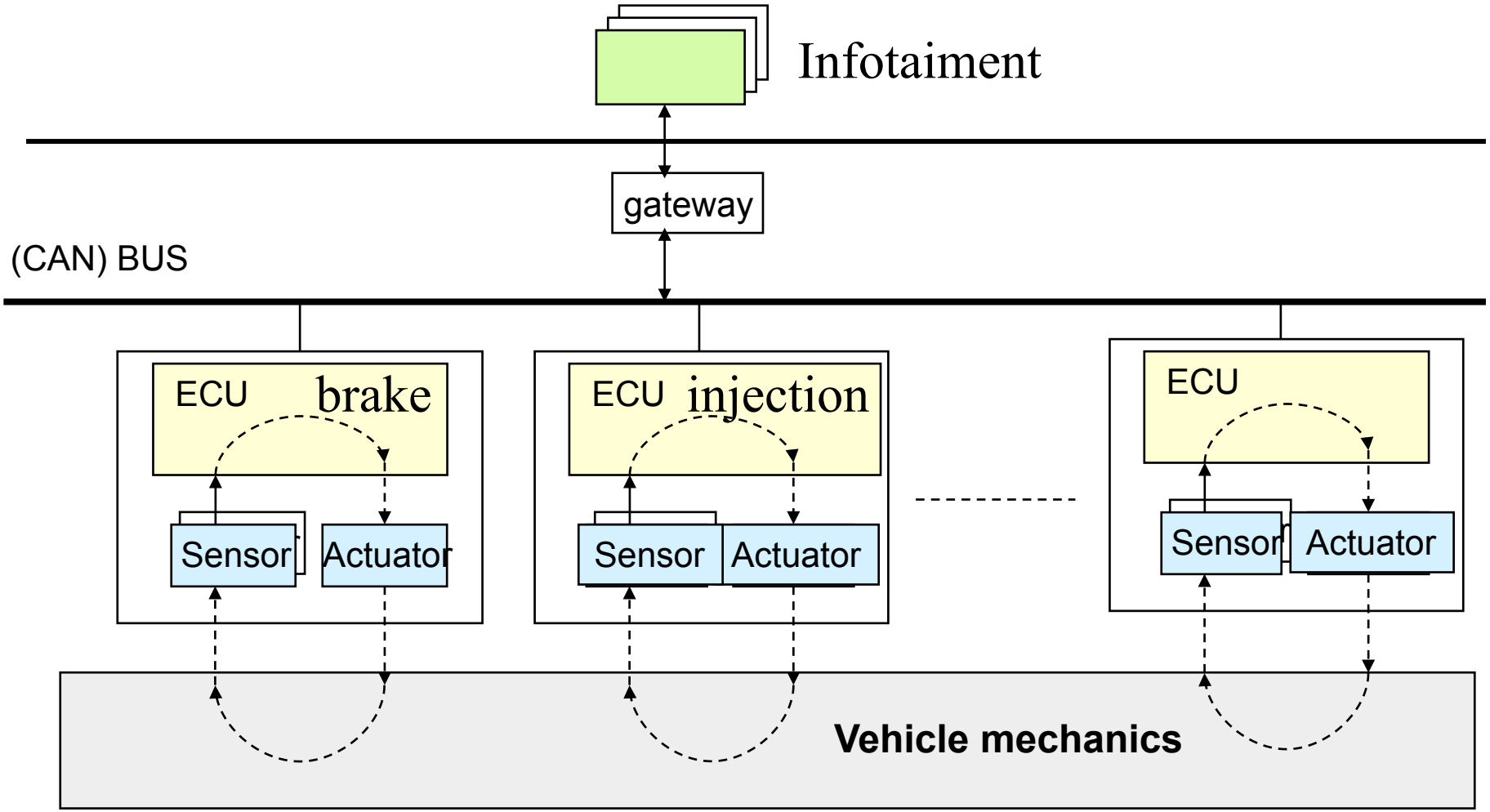
# Frameworks - building “the real components”

- Component Object Management - COM, Active X
- Enterprise JavaBeans
- CORBA components
- .NET



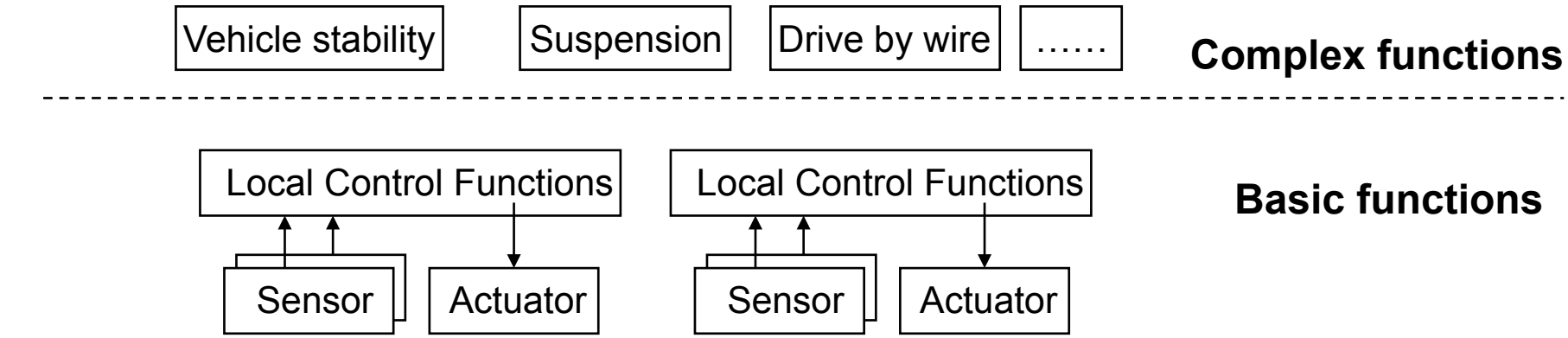

Late binding - easy replacement

# Example: The architecture of a car control system



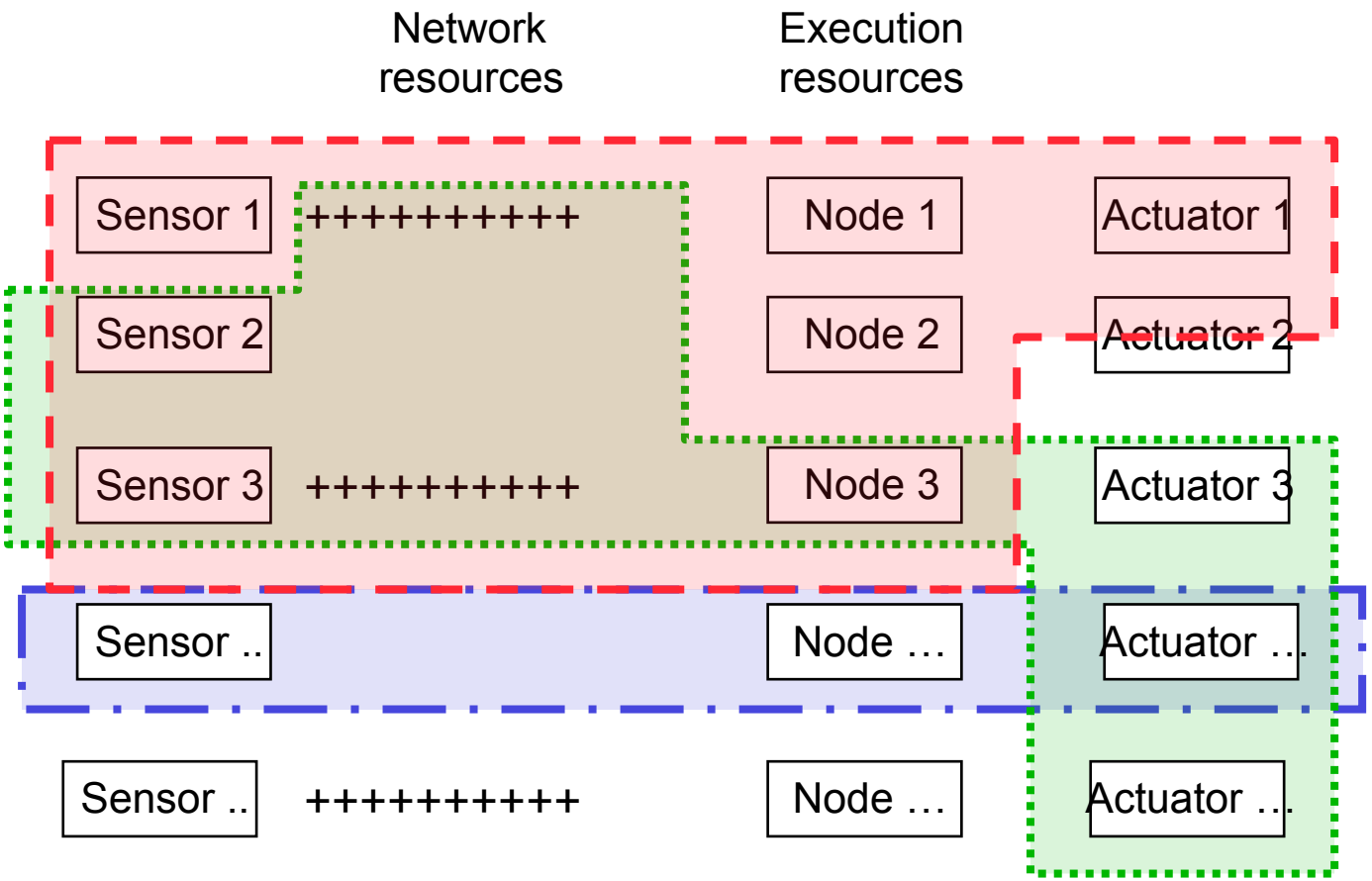

ECU – Electronic Control Unit

# The architectural design challenge



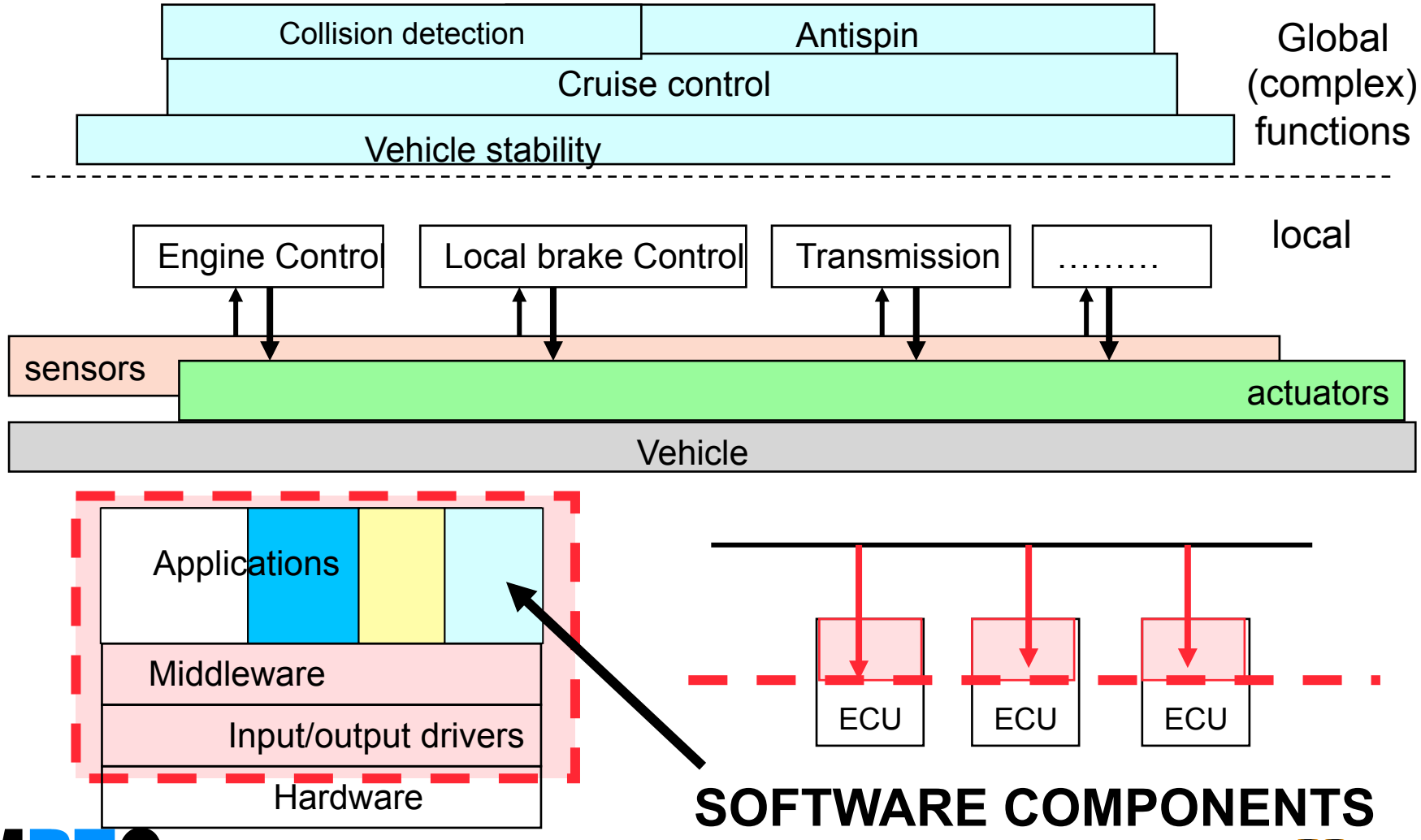

**How to implement complex functions based on local control functions?**

# Problem: resource sharing

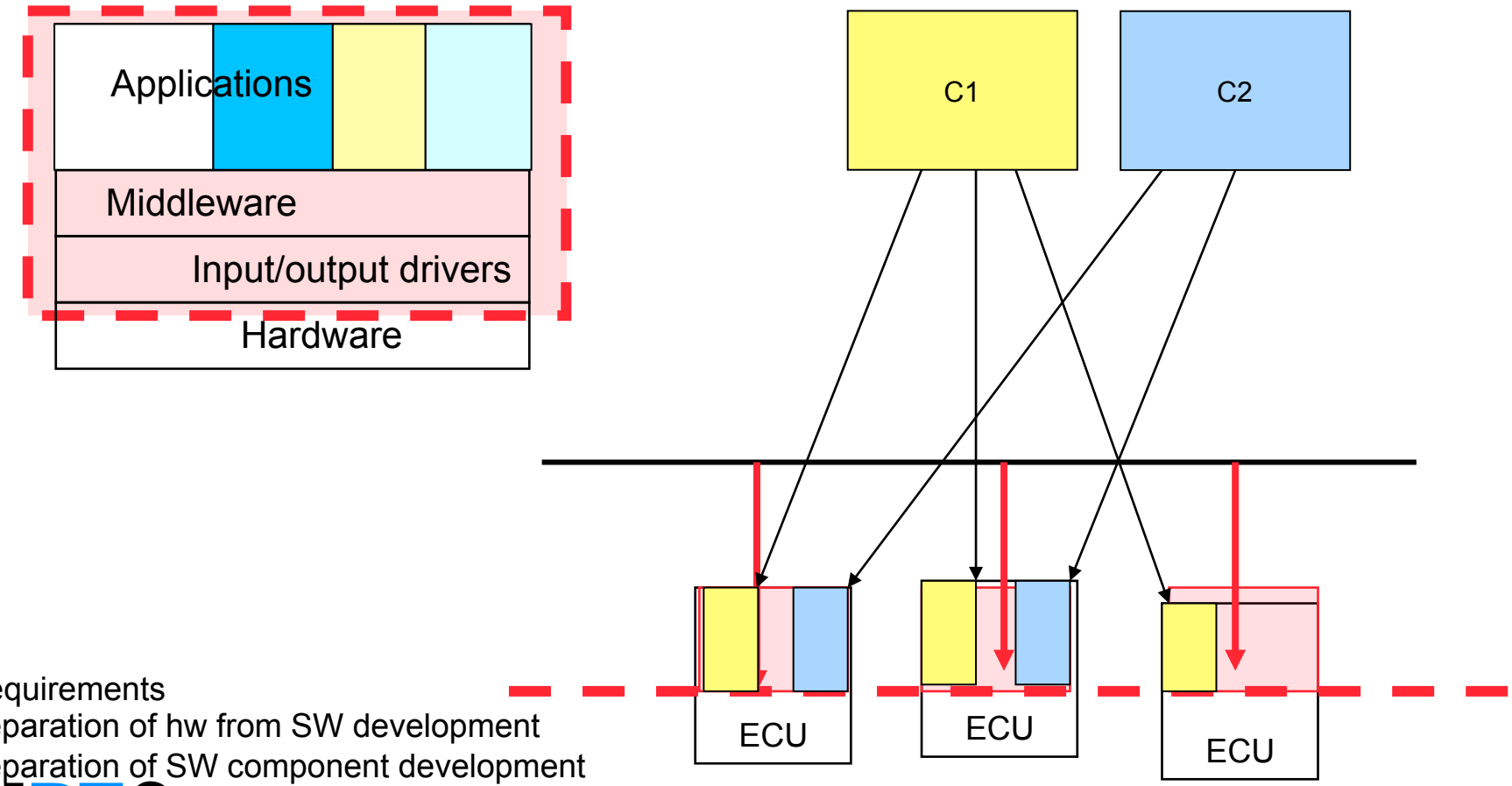



**Can functions of different criticality be allowed to share resources?**

# Challenge – open and dependable platform



# Challenge – open and dependable platform




Requirements
Separation of hw from SW development
Separation of SW component development

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# Szyperski: Software Component Definition

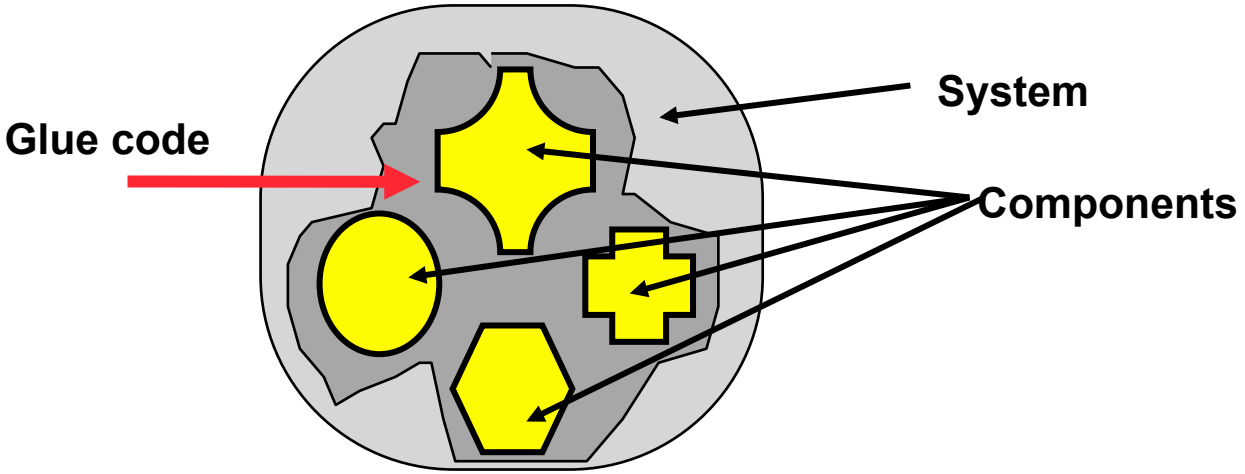
Szyperski (**Component Software beyond OO programming**)

- **A software component is**
  - a unit of composition
  - with contractually specified interfaces
  - and explicit context dependencies only.
- **A software component**
  - can be deployed independently
  - it is subject to composition by third party.

**Will you meet him?**

# Composition unit

**A software component is a unit of composition with contractually specified interfaces and explicit context dependencies only. A software component can be deployed independently and is subject to composition by third party. –Clemens Szyperski**




*How much components fit together?*

*How much costs the glue code?*

# What is a contract?

**A software component is a unit of composition with contractually specified interfaces and explicit context dependencies only. A software component can be deployed independently and is subject to composition by third party.**

- **Interface – component specification**

- **Contract - A specification attached to an interface that mutually binds the clients and providers of the components.**
  - **Functional Aspects (API)**
  - **Pre- and post-conditions for the operations specified by API.**
  - **Non functional aspects (different constrains, environment requirements, etc.)**

# What is an explicit context dependency?

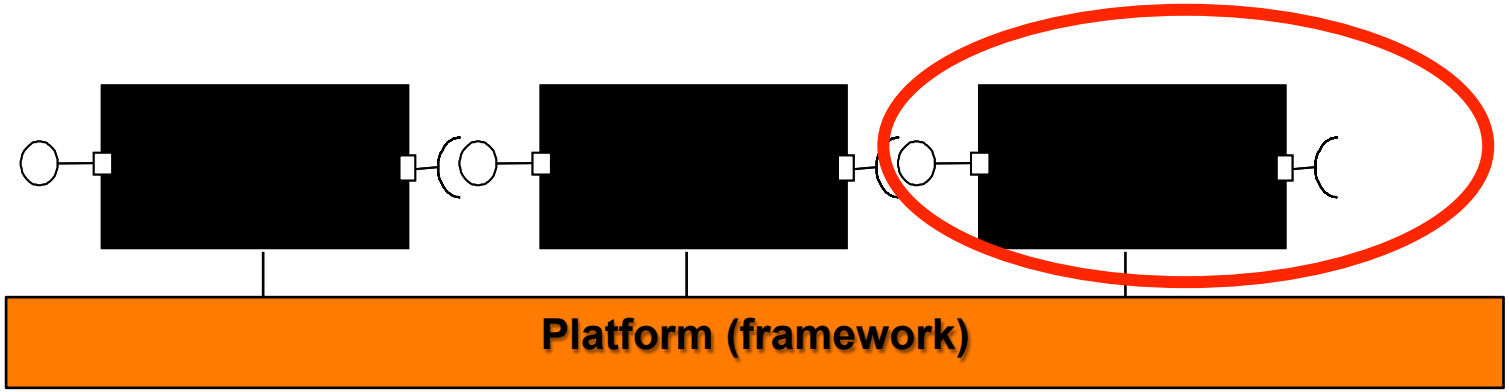
**A software component is a unit of composition with contractually specified interfaces and explicit context dependencies only. A software component can be deployed independently and is subject to composition by third party.**

- **Provided and Required Interface**

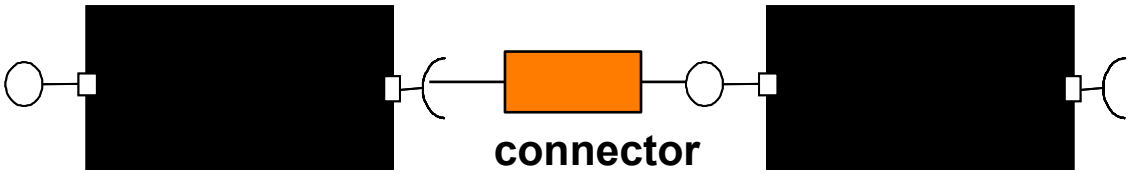
- **Context dependencies - Specification of the deployment environment and run-time environment**
  - **Example: Which tools, platforms, resources or other components are required?**

# What does it mean deployed independently?

A software component is a unit of composition with contractually specified interfaces and explicit context dependencies only. A software component can be deployed independently and is subject to composition by third party.




- Late binding - dependencies are resolved at load or run-time.



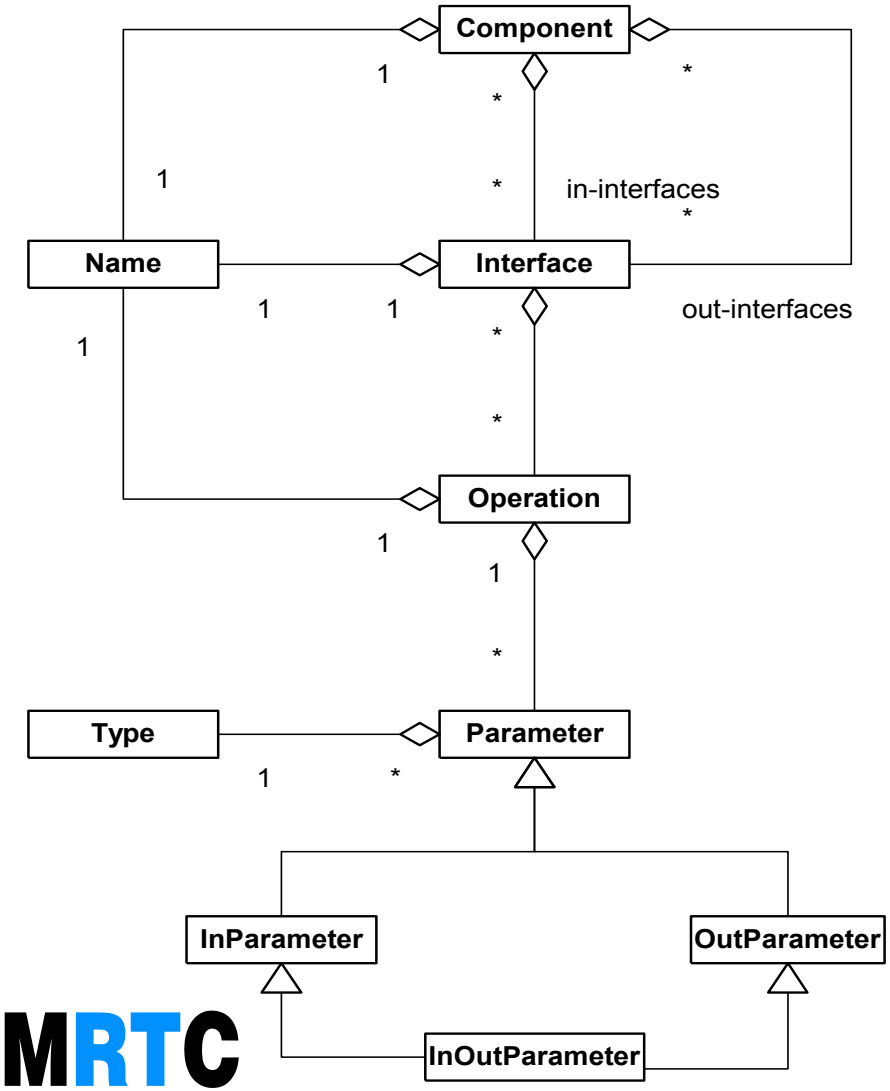
# Example: Interface description: (M)IDL

## (Microsoft) Interface Definition Language

```
[
        uuid(00112233-ABBA-ABBA-ABBA-BADBADBADBAD),
        object
]
interface IAddressList {
        HRESULT addAddress ([in] name, [in] address);
        HRESULT deleteAddress ([in] name, [in] address);
}
```

- language independent interface specification
- can be compiled into language dependent code skeletons

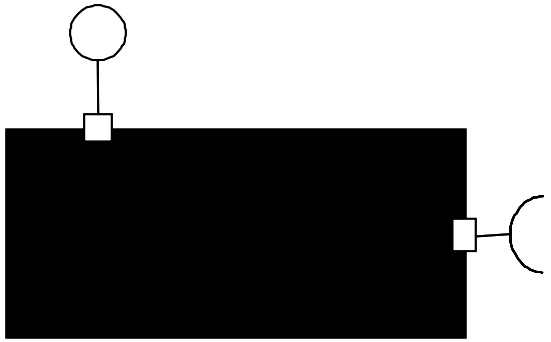
# Components and Interfaces - UML definition




Component – a set of interfaces
required (in-interfaces)
provided (out-interfaces)

Interface – set of operations

Operations – input and output parameters of certain type



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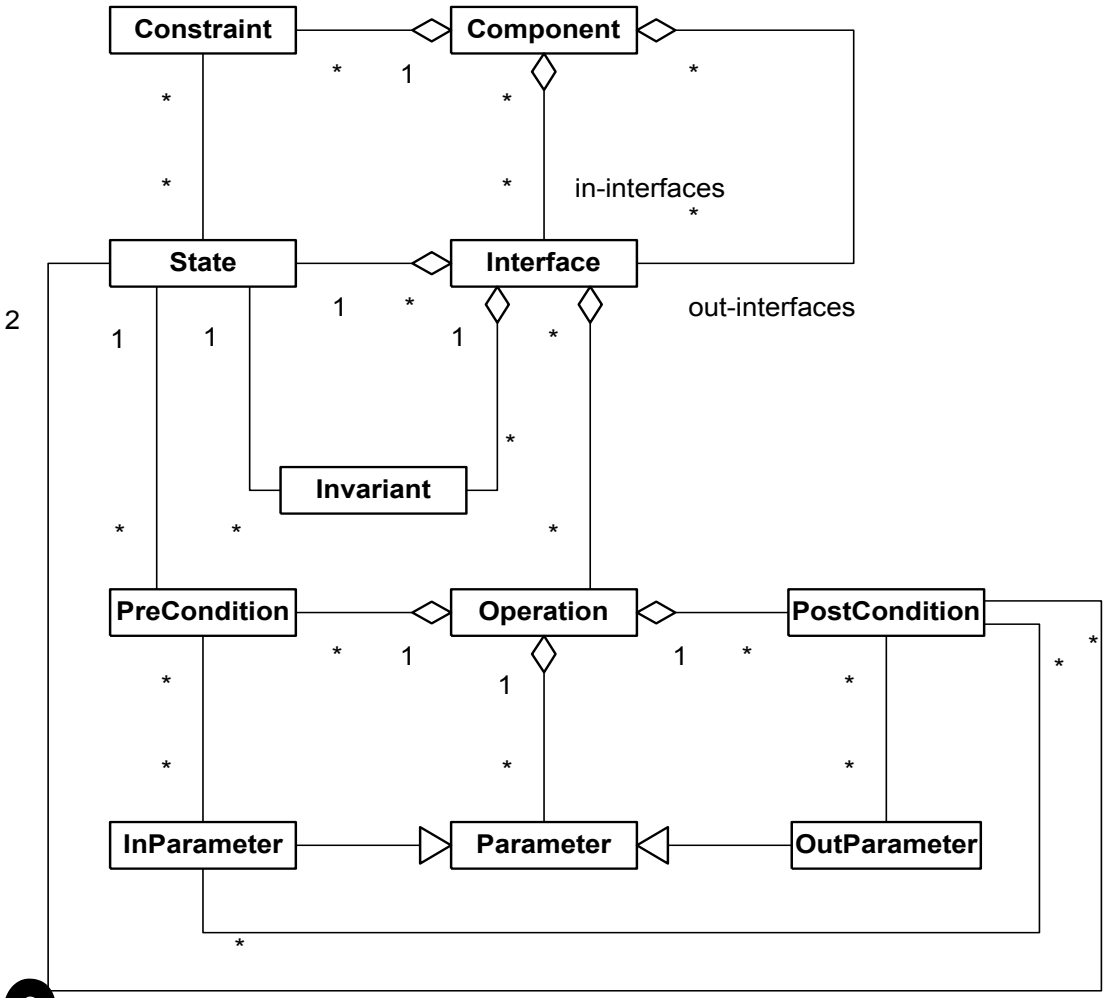
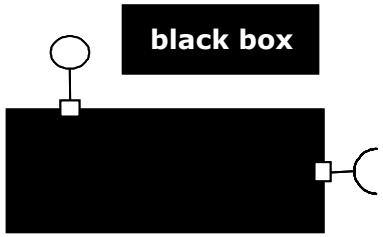
# Contractually specified interfaces in a UML metamodel

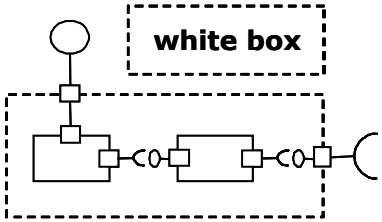


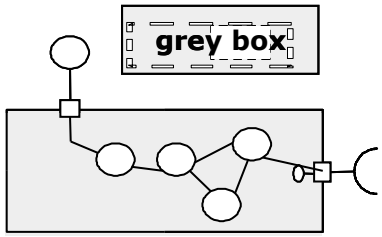
- Is Szyperski definition enough?

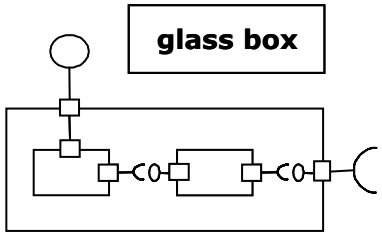
# Component specification

- Components are described by their interfaces
- (A black box character)

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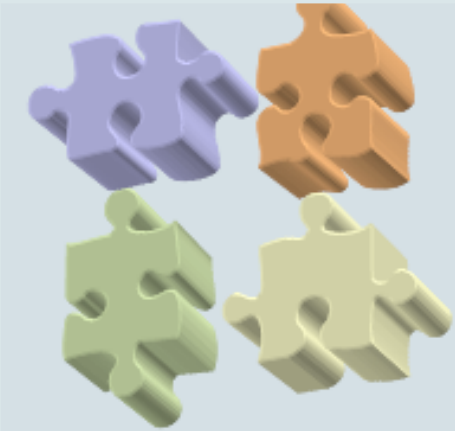
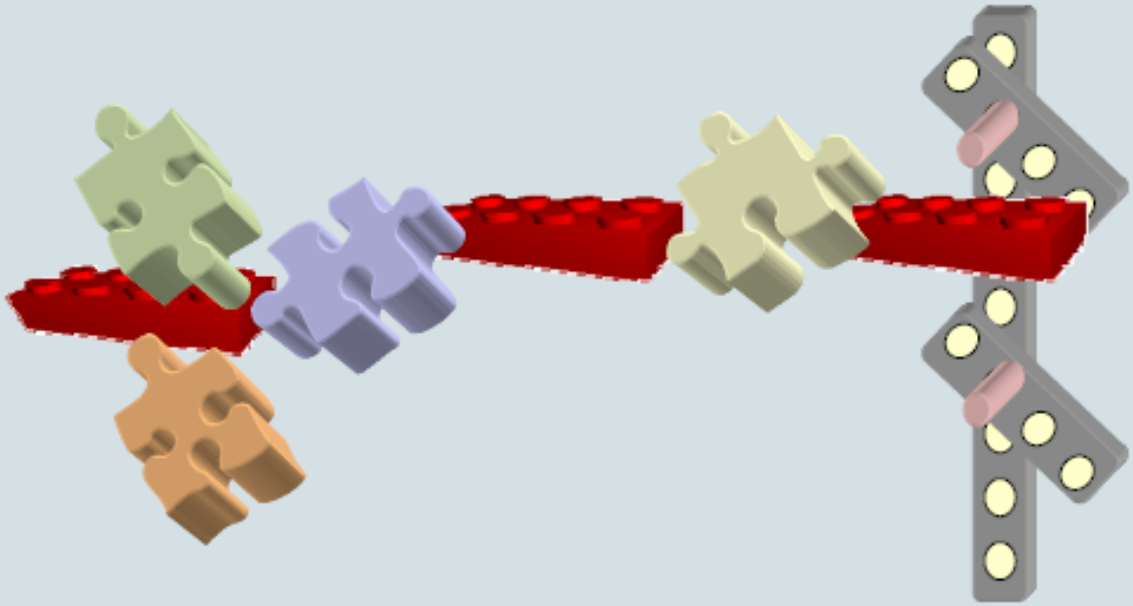


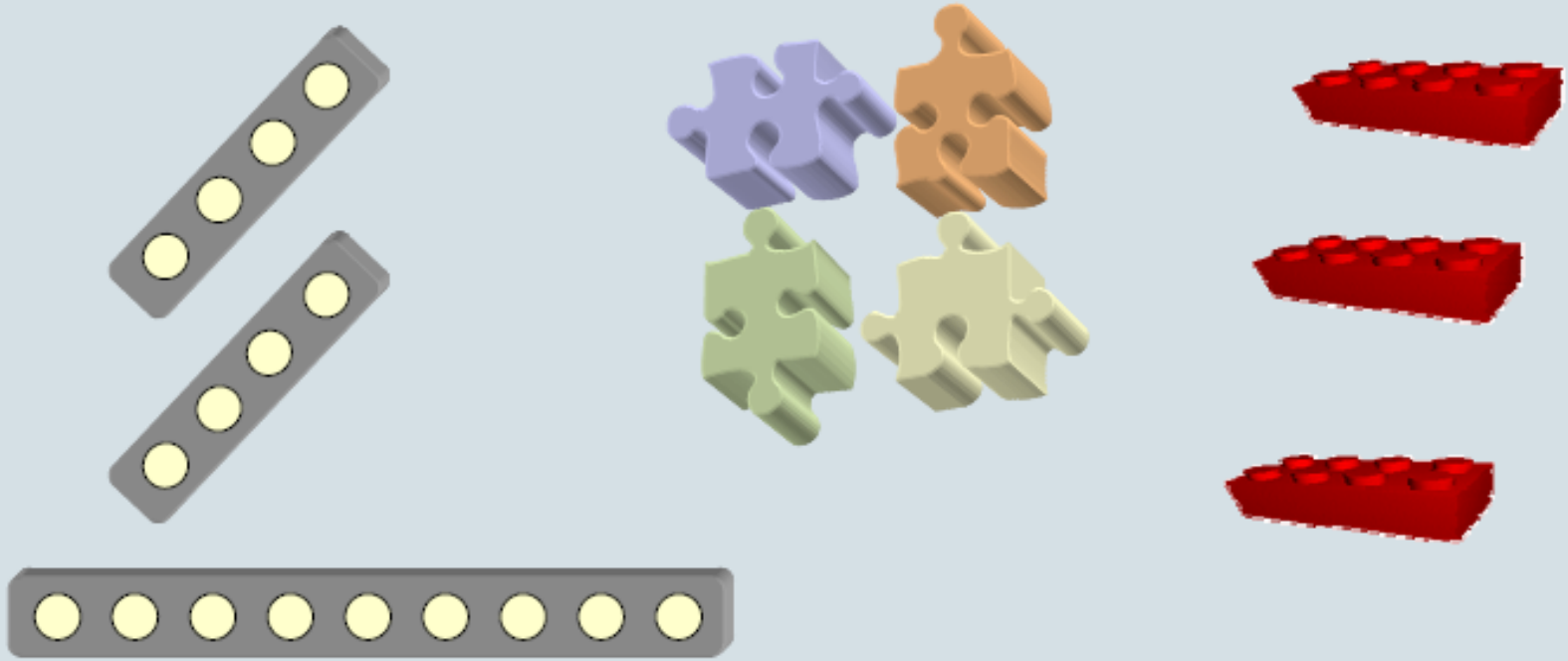
Nice components that can be composed (put together)

# CBD in Practice



Lego + Fisher Technik + Meccanno + Ministek + ...

# A component can be used within the scope of a component-model



# Another definition

- **A software component is a software element that**
  - confirms a component model
  - can be independently deployed
  - composed without modification according to a composition standard.
- **A component model defines specific interaction and composition standards.**

G. Heineman, W. Councel, Component-based software engineering, putting the peaces together, Addoson Wesley, 2001

# Variety of Component Models

- Different application(domain)s have different demands on component-based systems.
- Different extra-functional properties
  - Reliability, Resource use, Performance
  - Scalability, Adaptability, Extensibility, backward-compatible

Corba Components:

distributed, language independent, supports OO

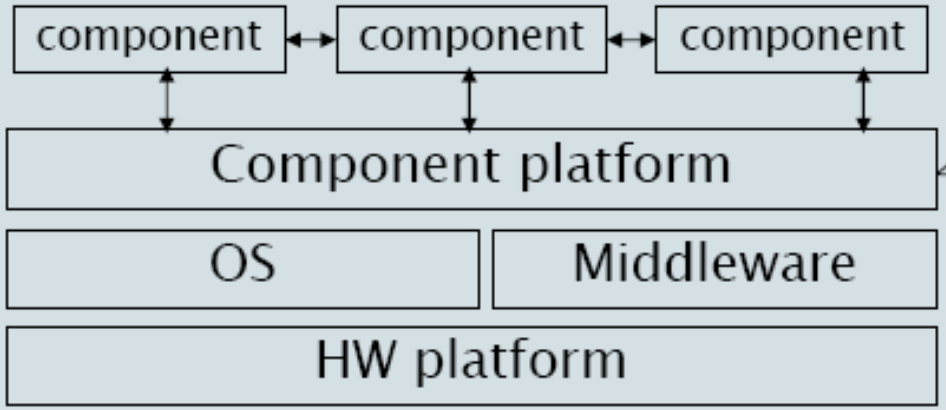
Enterprise Java Beans:

distributed, Java-oriented, transaction-facilities

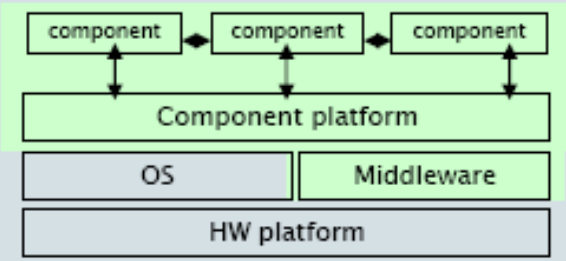
Robocop:

single machine, C/C++, low resource use

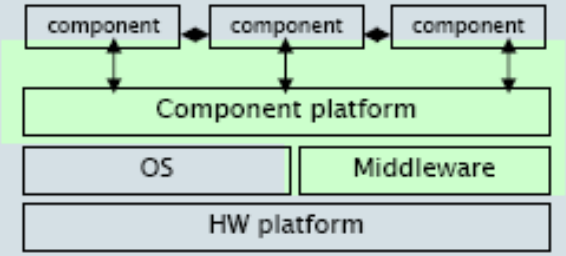
# Architecture of Component Models




Platform Services
more run-time flexibility
➔ more elaborate platform




J2EE:
rich services in platform




CORBA:
emphasis on middleware;
integration of legacy

# Design Choices in Component Models

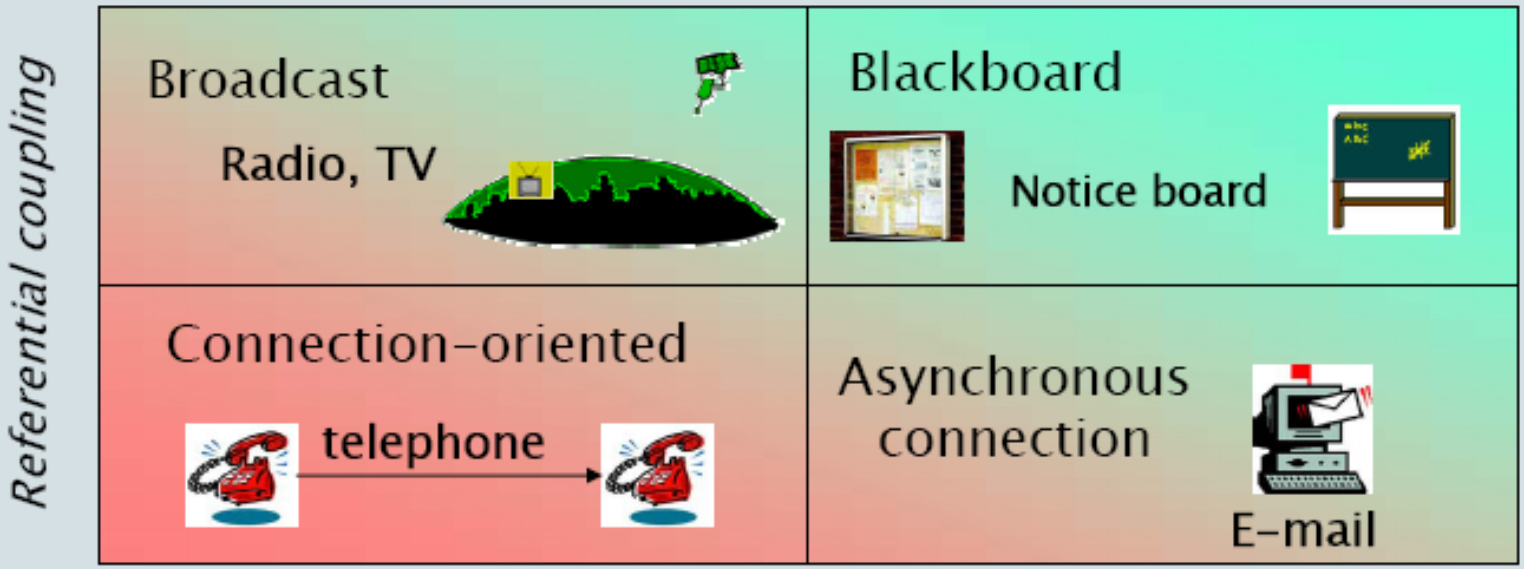
- control flow
- concurrency model
- distribution
- interaction style
  - data exchange format
- mobility
- topology

- binding time
- binding type
- platform features
- life-cycle management:
  - instantiation,
  - (de)activation,
  - removal

# Interaction Style and Coupling

Component Models often use one particular interaction style.

Interaction styles imply some type of coupling!

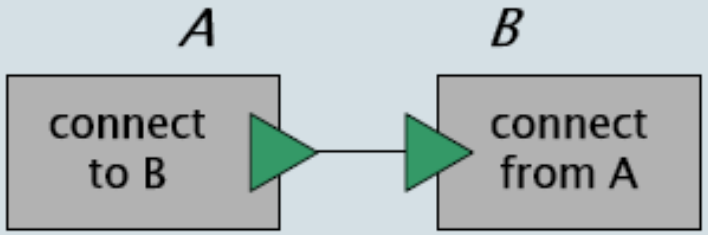



Referential coupling: sender has reference to receiver's name

Temporal coupling: sender and receiver synchronize in time

# Endogenous versus Exogenous composition

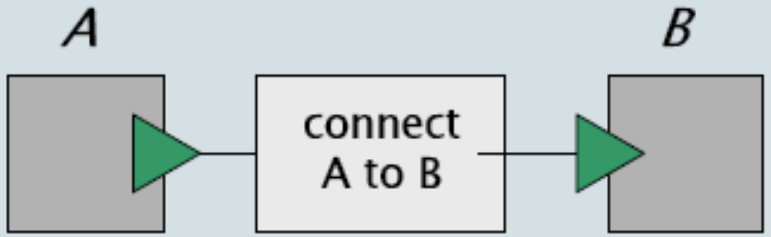
*Endogenous composition*:
composition is built into the items that are composed




e.g. method calls in OO languages

*Exogenous composition*:
composition is defined outside of the items that are composed.

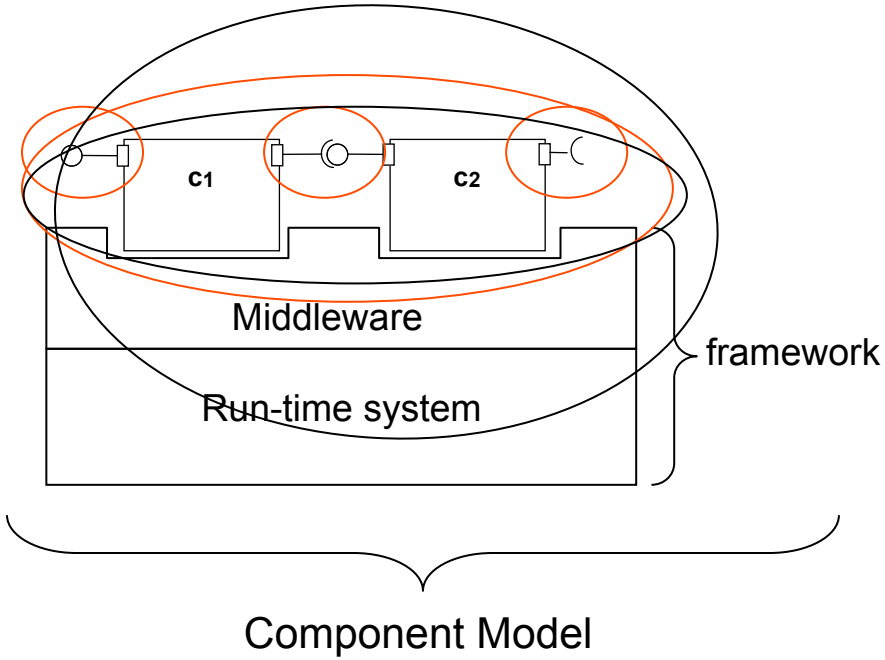
- localises changes in binding
- reduces dependencies between application components



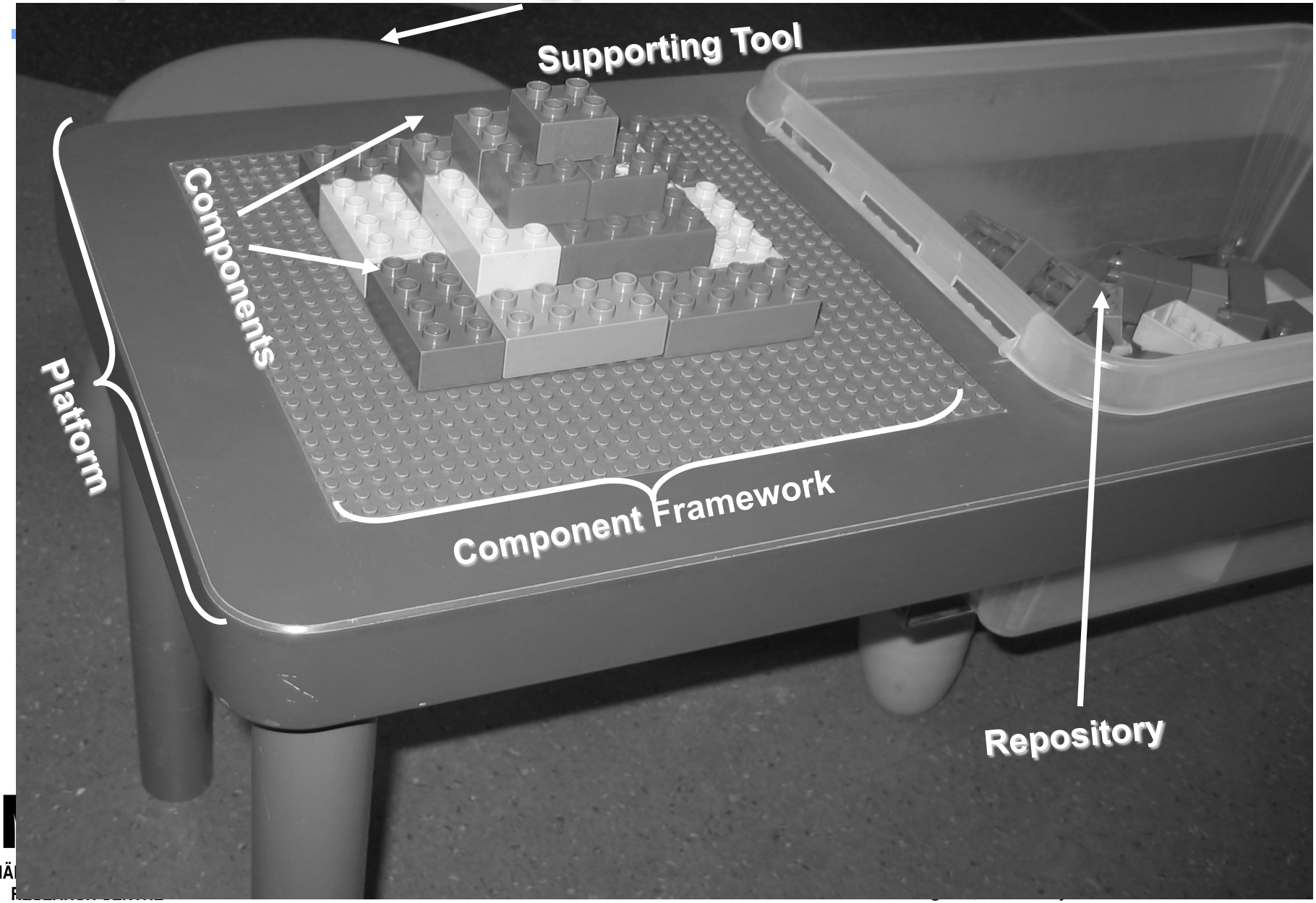

Benefits: consider changes in A or B or in the connections.

# Summary CBSE – basic definitions

- **The basis is the** Component
- **Components can be** assembled **according to the rules specified by the** component model
- **Components are assembled through their** interfaces
- **A** Component Composition **is the process of assembling components to form an assembly, a larger component or an application**
- **Component are performing in the context of a** component framework
- **All parts conform to the** component model
- **A** component technology **is a concrete implementation of a component model**



# Component Technology



# Part 3

# Software Architecture and Software Components

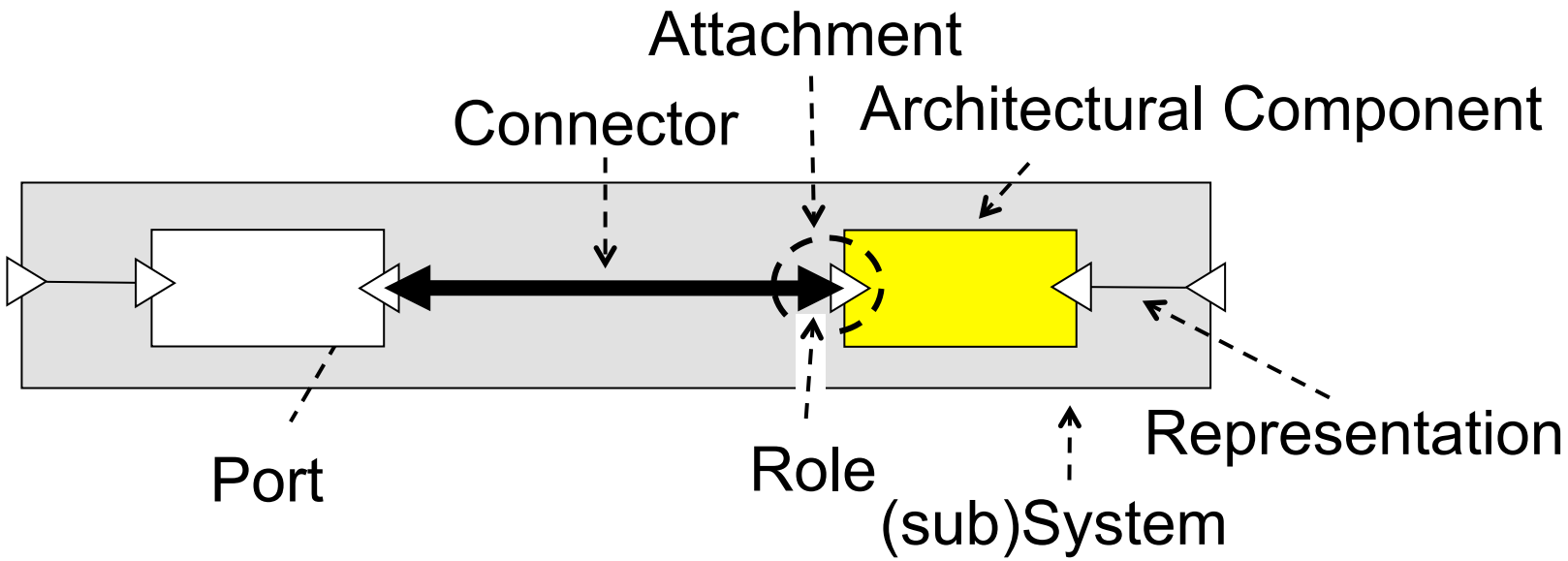
# Software Architecture

L. Bass, P. Clements, R. Kazman, *Software Architecture In Practice*

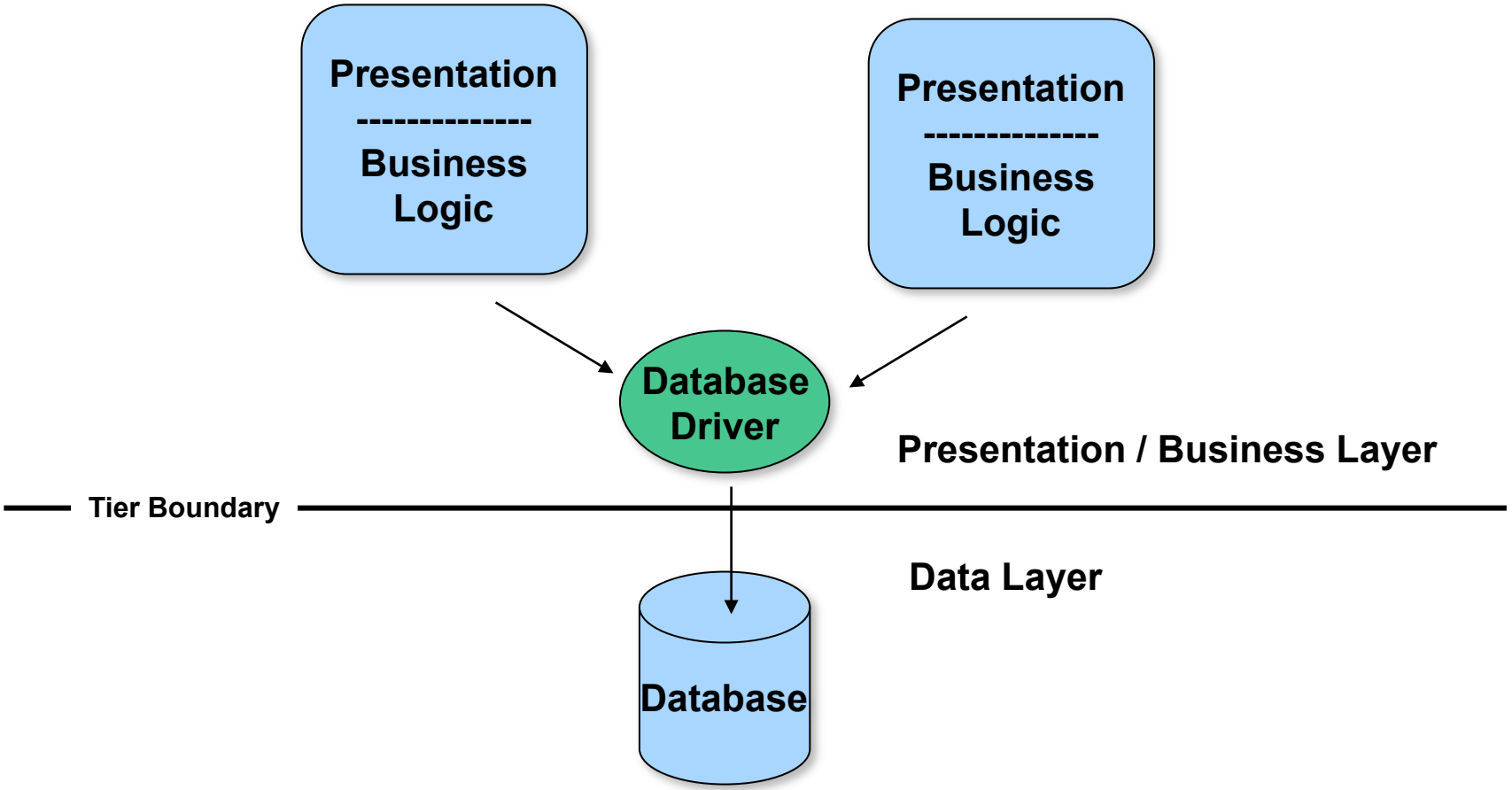
- ***The software architecture of a program or computing system is the structure or structures of the system, which comprise software components [and connectors], the externally visible properties of those components [and connectors] and the relationships among them."***

# Aspects of Software Architecture

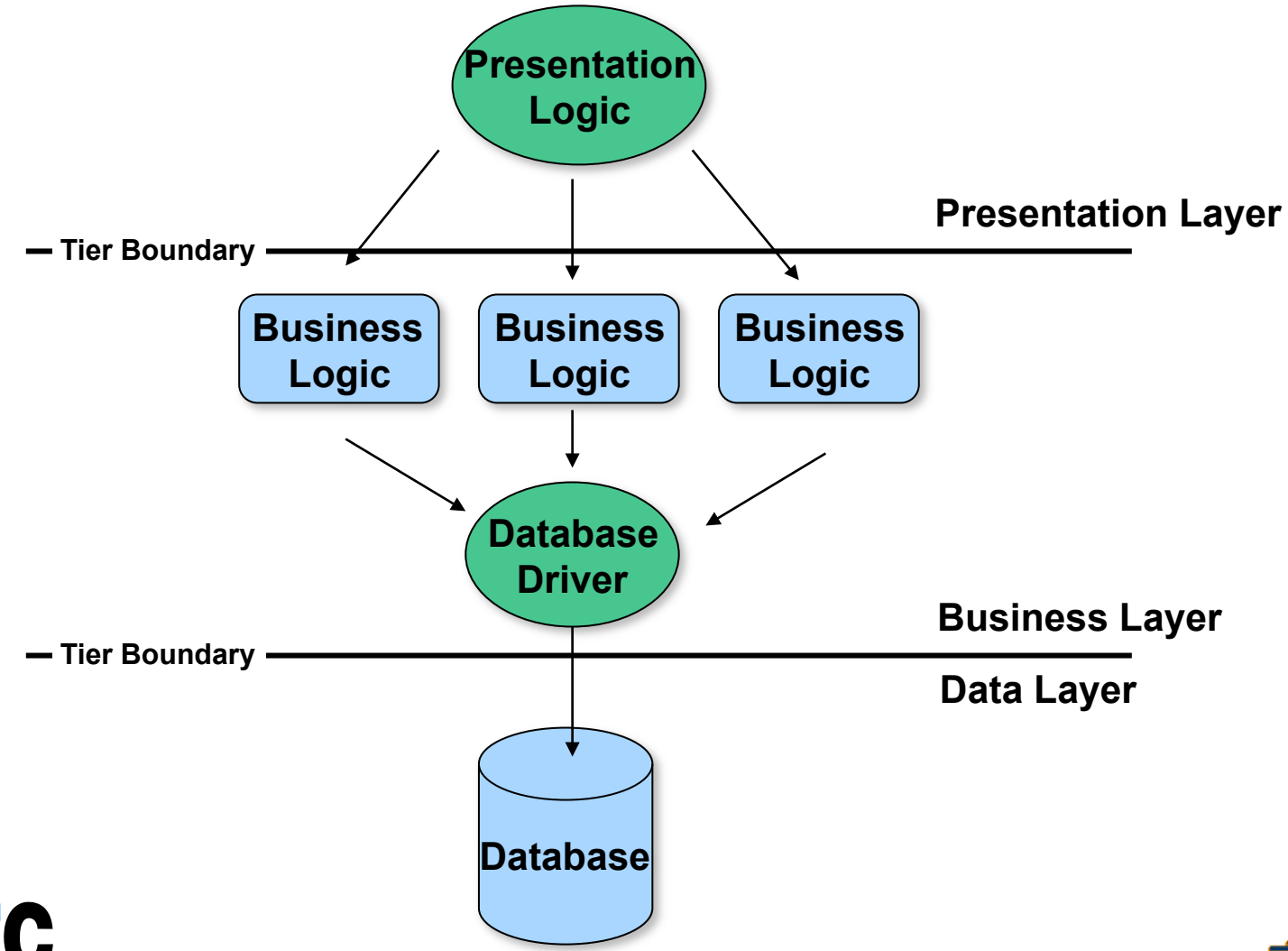
- Elements and Form
- (UniCon notation)



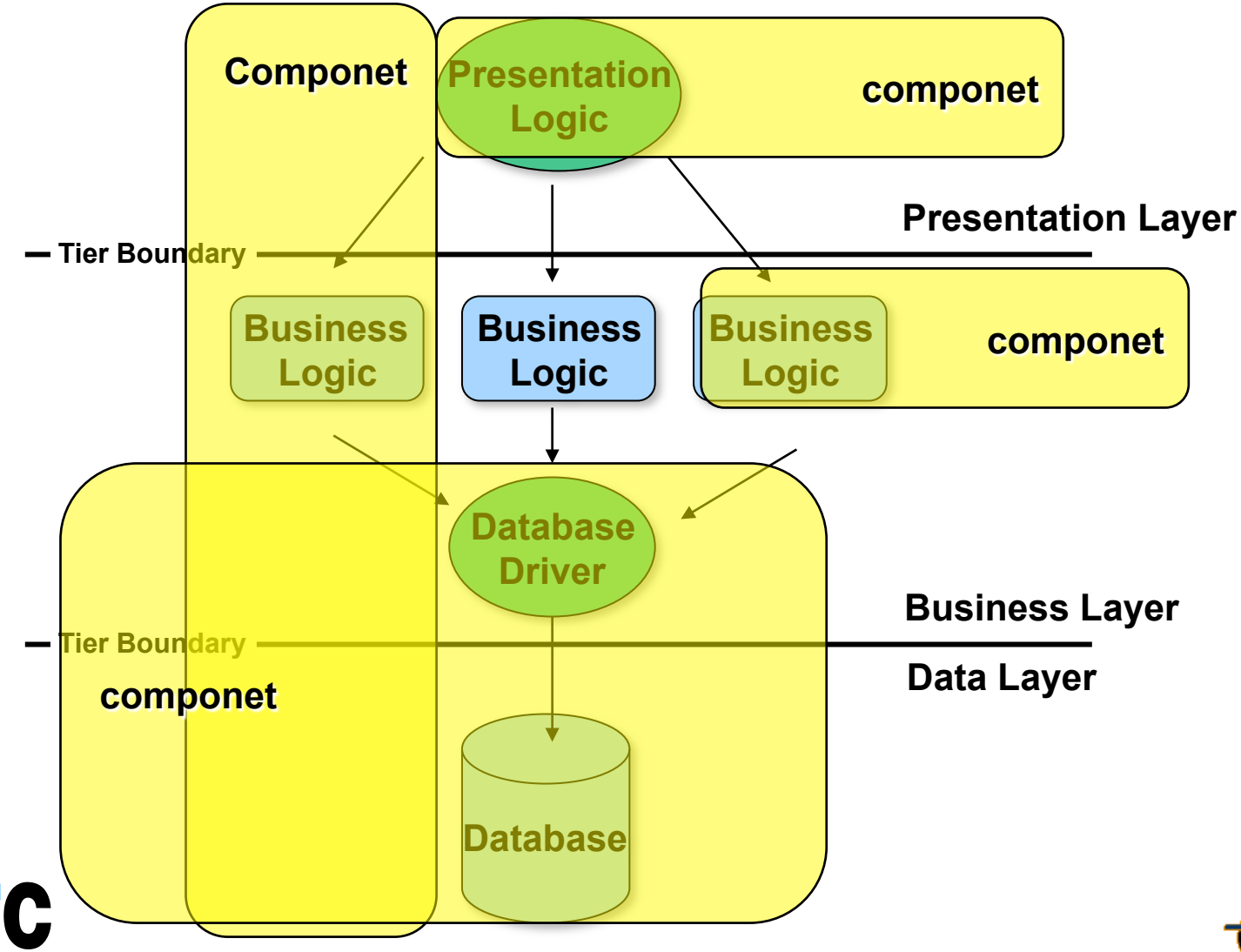
# Two Tier Architecture



# N-Tier Architecture

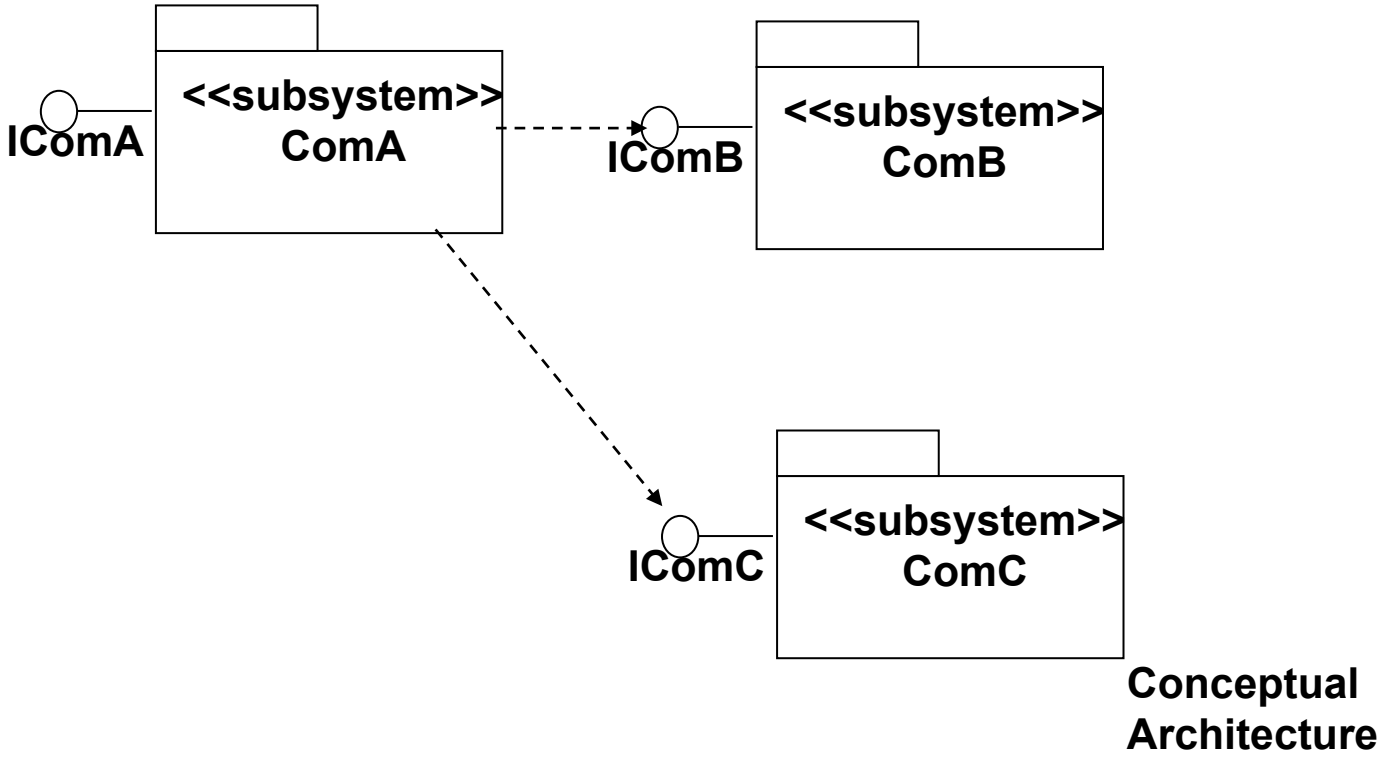


# N-Tier Architecture - and Components



# Different architecture view in different phases

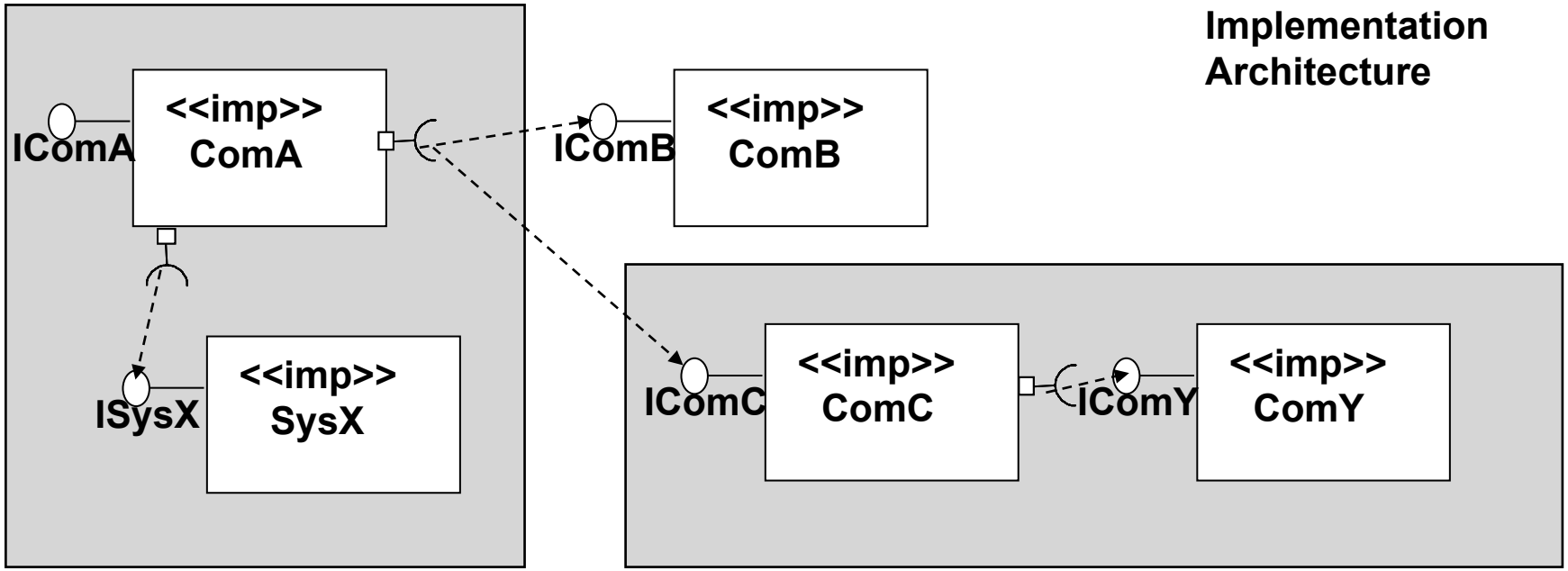
- **Phase I**
  - System architecture - Decomposition of the system




**Conceptual Architecture**

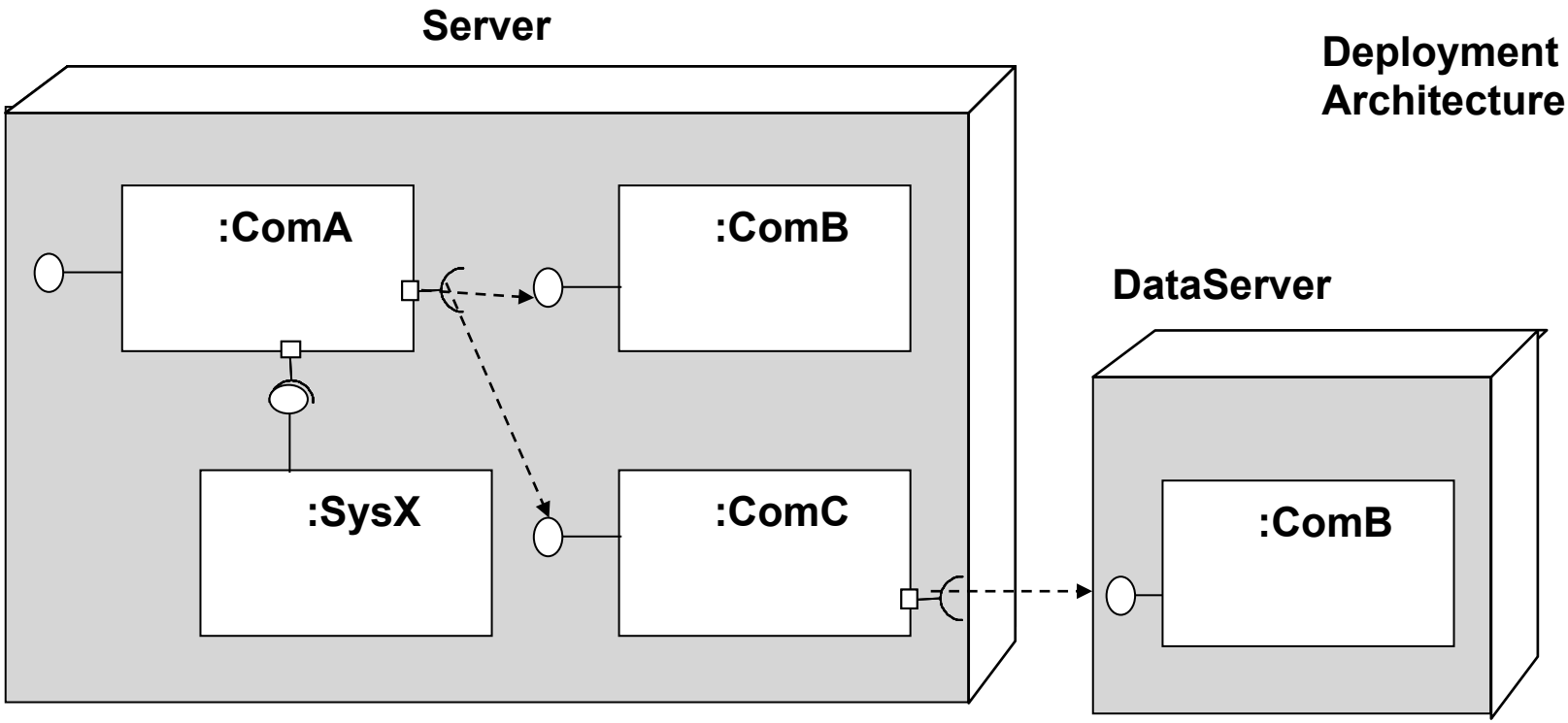
# System Design – Phase 2

- Implementation Architecture - Component Identification



# System Design – Phase 3

- Deployment architecture

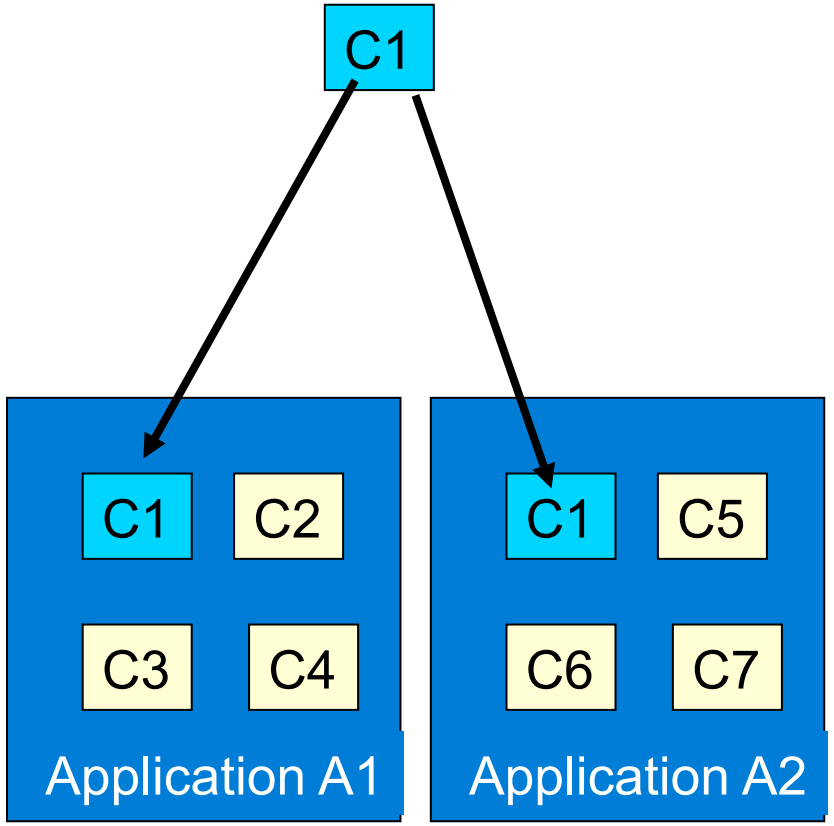


# Basic principles
# of
# Component-based approach

# Main principles: (1) Reusability

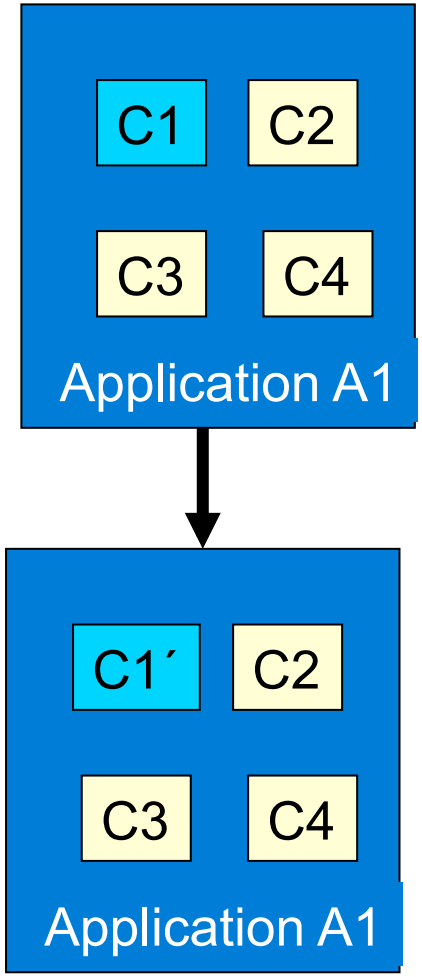
- **Reusing components in different systems**

- **The desire to reuse a component poses few technical constraints.**
  - Good documentation (component specification…)
  - a well-organized reuse process
  - Similar architecture
  - ….



# Main principles: (2) Substitutability

- **Alternative implementations of a component may be used.**
- **The system should meet its requirements irrespective of which component is used.**
- **Substitution principles**
  - Function level
  - Non-functional level
- **Added technical challenges**
  - Design-time: precise definition of interfaces & specification
  - Run-time: replacement mechanism



# Substitution principle

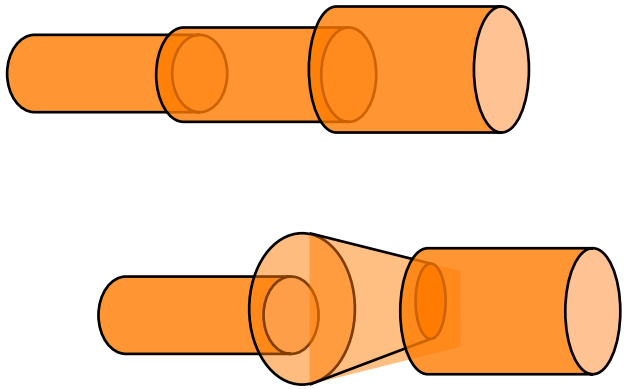
- **Substituting a component Y for a component X is said to be safe if:**
  - All systems that work with X will also work with Y
- **From a syntax viewpoint, a component can safely be replaced if:**
  - The new component implements at least the same interfaces as the older components
- **From semantic point of view?**
  - Contractual interface holds (pre-, postconditions and invariants)

# Substitution principle

## ❑ Principle:

- A component can be replaced if the new component
  - ✦ Provide a sub-range of the output
  - ✦ Can accept larger range of input

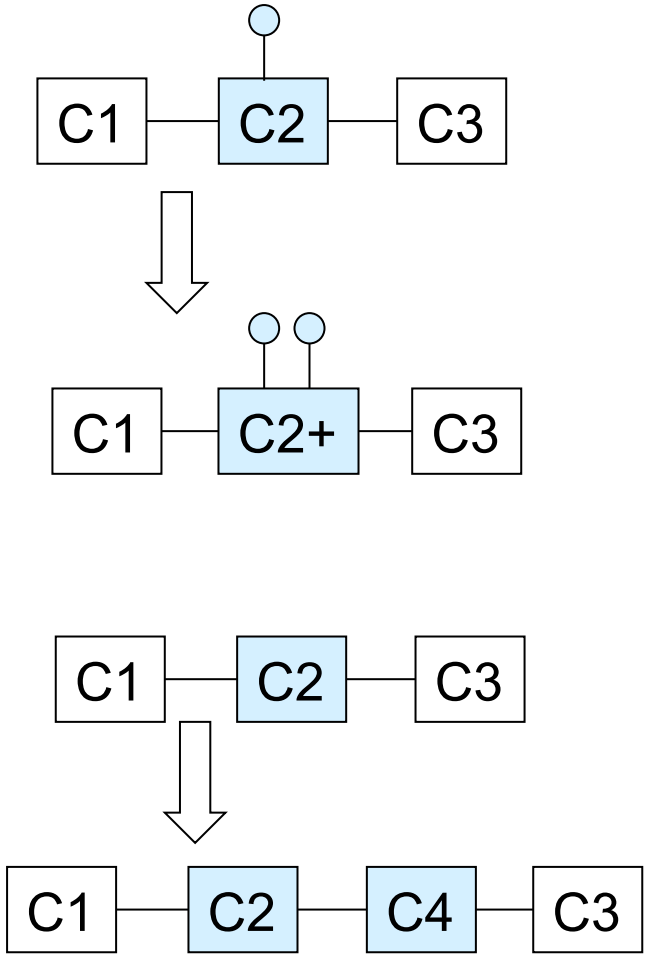
**C -→ C´**
**Input(c) <_ Input(c')**
**Output(C) _> Output(C')**



CONDITION.
Everything which comes from the first Tube fits to the second

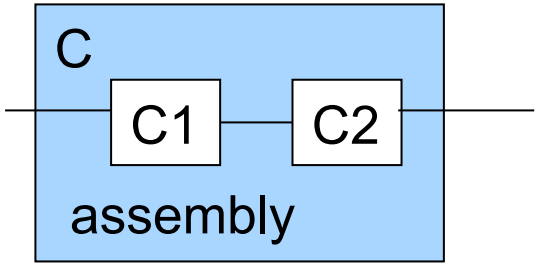
# Main principles: (3) Extensibility

- **Comes in two flavors:**
  - extending components that are part of a system
  - Increase the functionality of individual components
- **Added technical challenges:**
  - Design-time: extensible architecture
  - Run-time: mechanism for discovering new functionality



# Main principles: (4) Composability

- **Composition of components**
  - P(c1 o c2) =P(c1) o P(c2) ??
  - Composition of functions
  - Composition of extra-functional properties



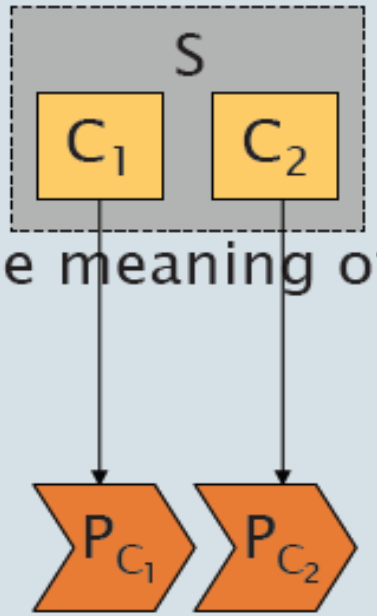

- **Many challenges**
  - How to reason about a system composed from components?
    - Different type of properties
    - Different principles of compositions

# Compositional Reasoning

- Calculating properties of a system by combining properties of its constituents.

- If $S = C_1 \circ C_2$
- Then $P(S) = P(C_1) * P(C_2)$

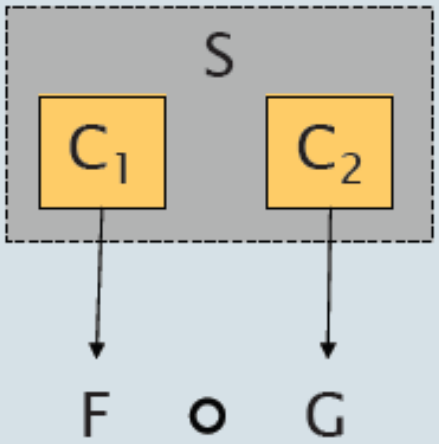
- 'Traditionally' $P(C_i)$ denotes the meaning of $C_i$



# Compositional Reasoning: Functions

- Meaning P(C) of program C can be a function from inputs to outputs

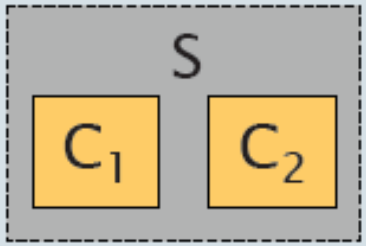
- Then composition is nicely modelled by function composition



# Predictable Assembly

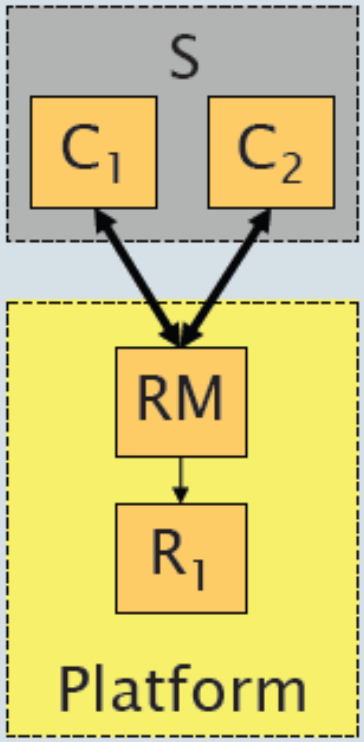
- Same question, now for extra-functional properties.

- Let's consider dynamic memory-use
- Given the dynamic memory-use of C1 and C1.
- Now what is the dynamic memory use of S?



# Complicating Factors in Compositional Reasoning about Extra-Functional Properties

- The property is not determined by the components only
- But also by the platform
  - platform may be OS + run-time environment
  - in particular the resource management
    - Scheduling
    - Memory management
- The information supplied by $C_1$ and $C_2$ is not sufficient to reason about the composition of their extra-functional properties.

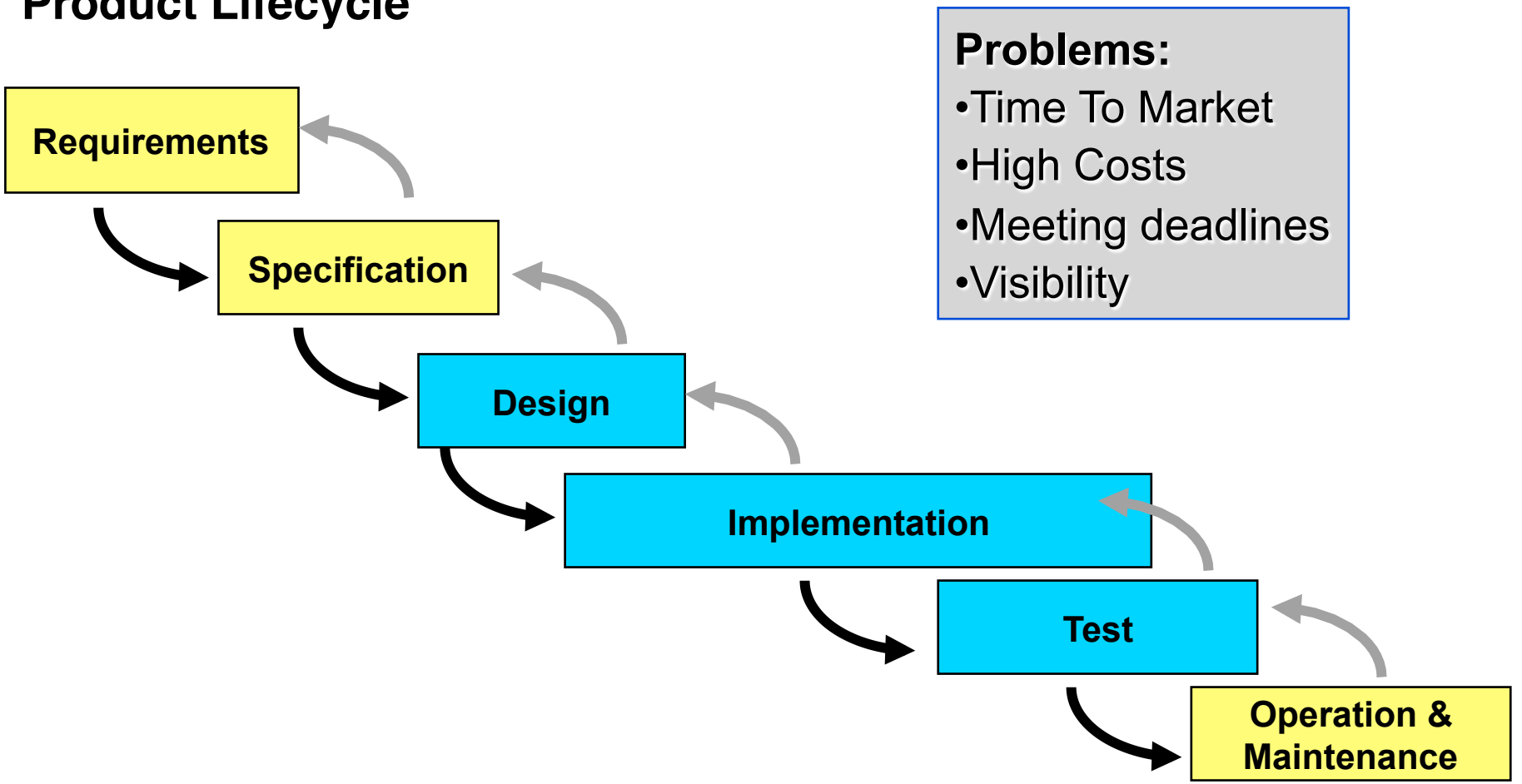


# Part 5

# Component-based software development process

# Time to Market – "Classical" Development Process?

## Product Lifecycle




**Problems:**
- Time To Market
- High Costs
- Meeting deadlines
- Visibility

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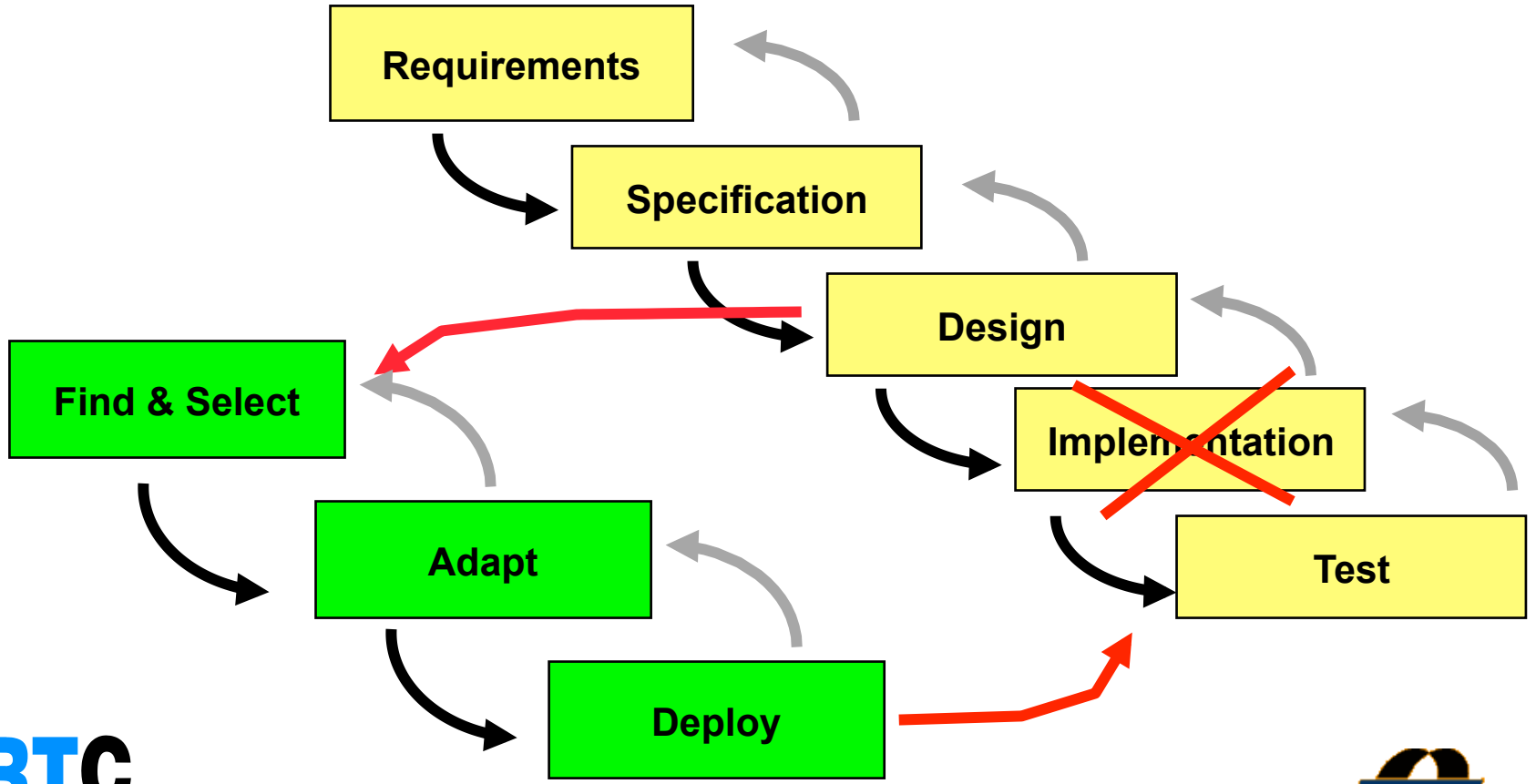
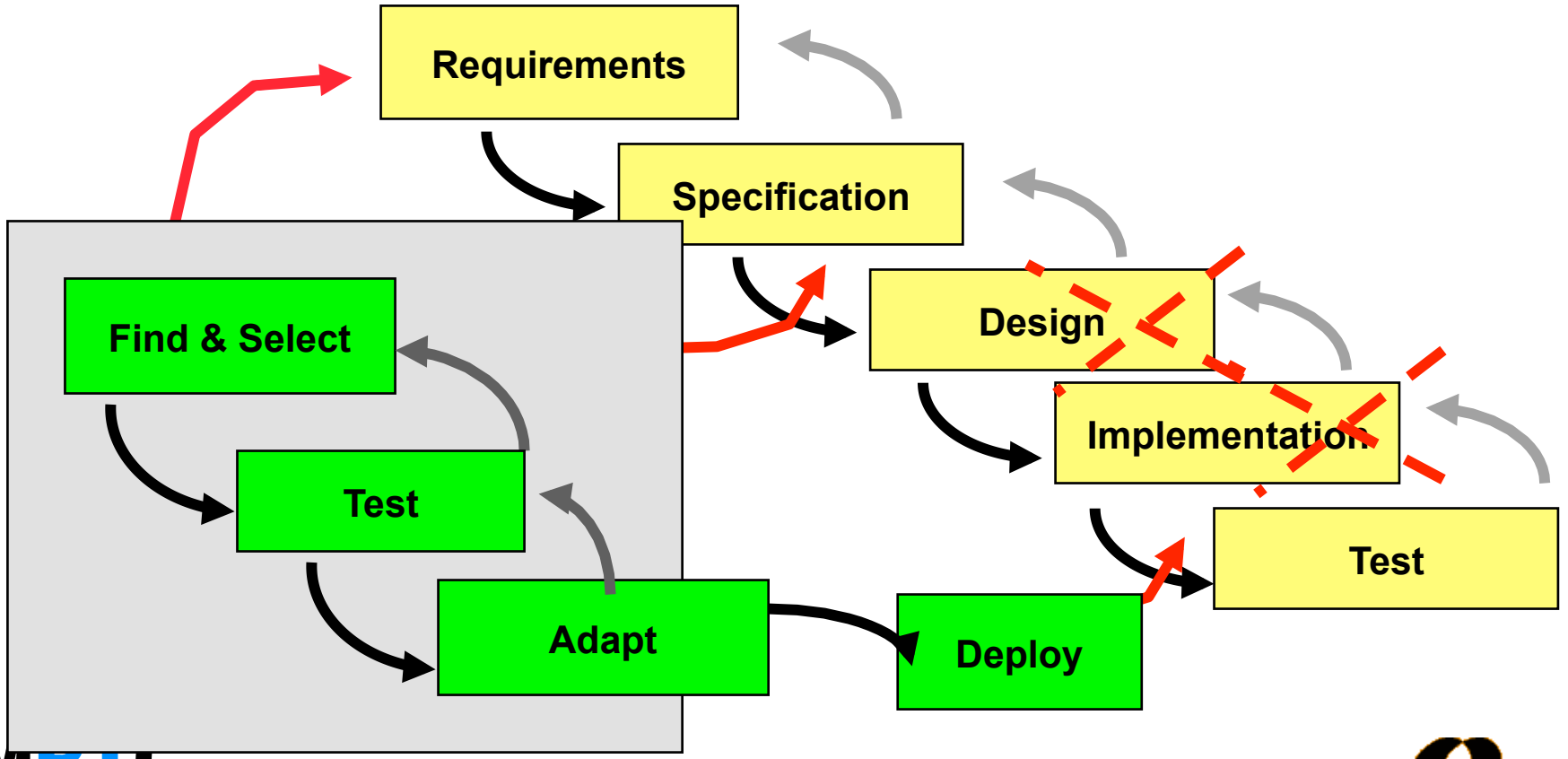
# Development process

- COTS and outsourcing require different development processes

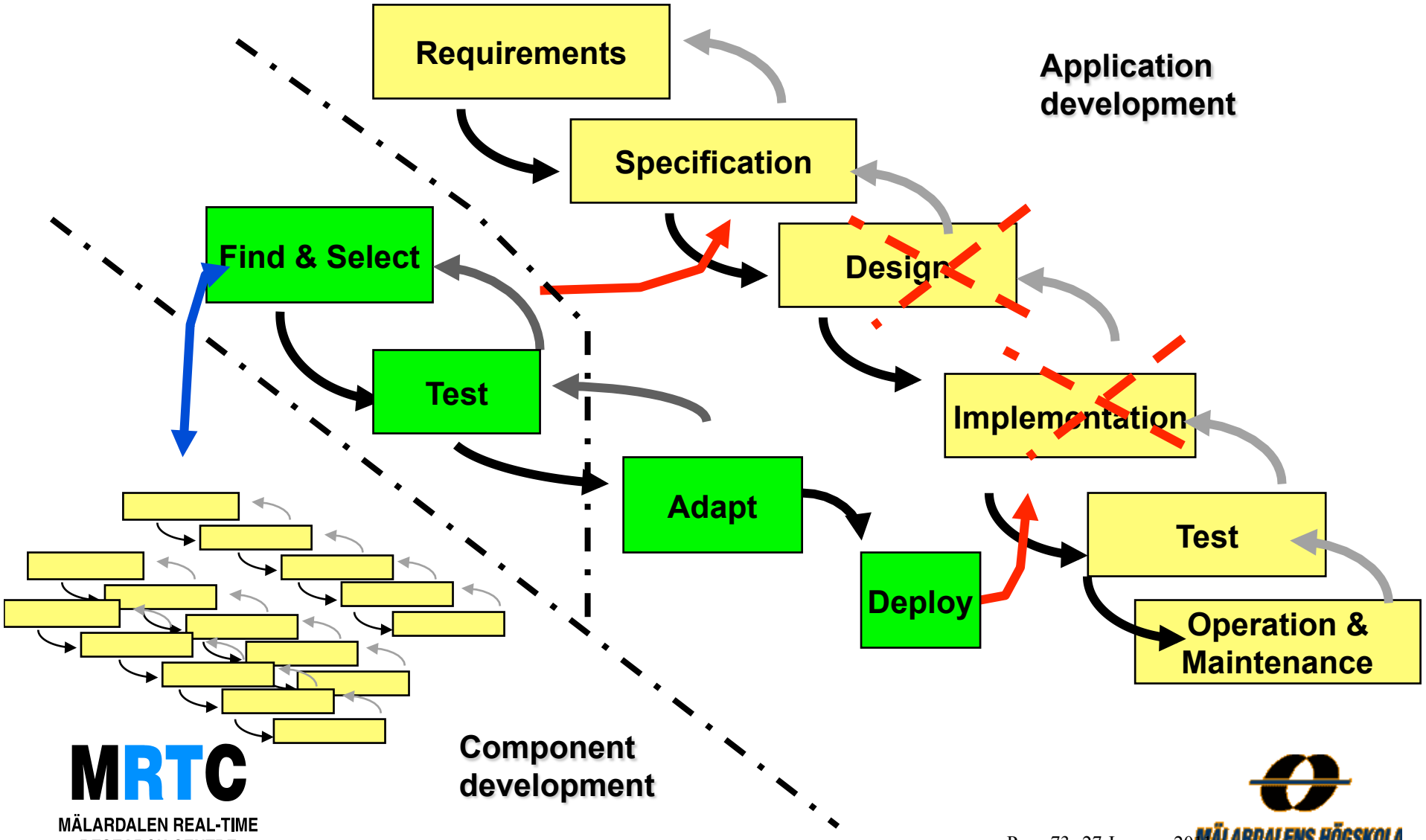


# Development process – emphasize reuse

- Managing COTS in the early stage of the development process



# CBD – separation of development processes

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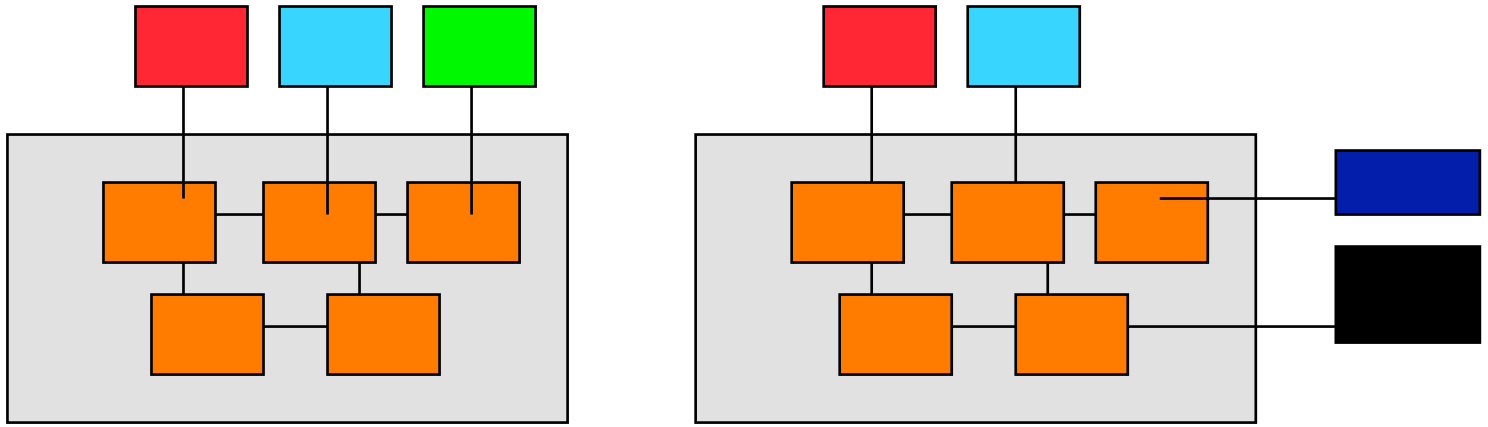
# Types of component-based development

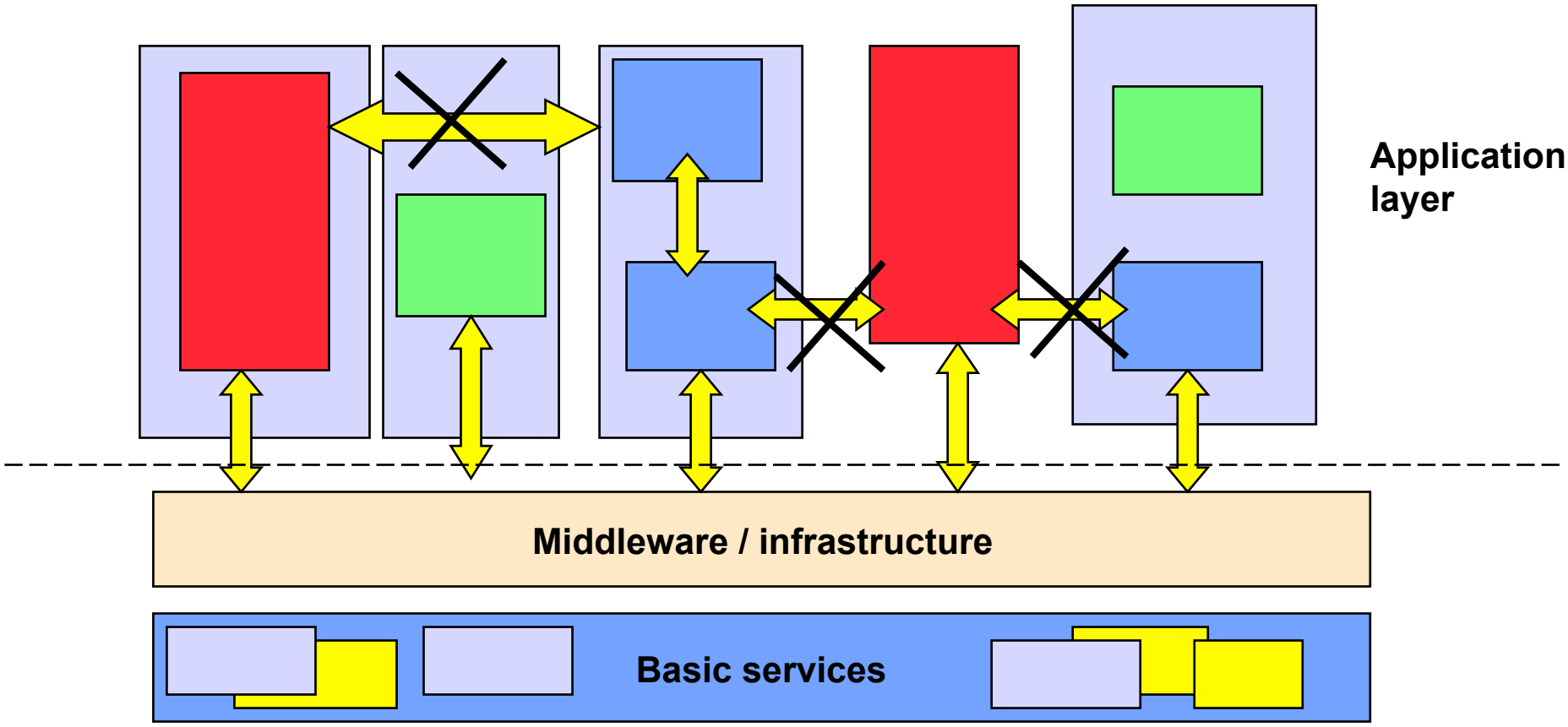
- Internal components as structural entities
- Reusable components developed in-house
- COTS (commercial off the shelf) components

# Product Line Architecture

- Core components building a core functionality (Basic platform)
- A set of configurable components combined building different products



# Platform-based products



# Advantages of Software Product Lines

- **Using existing infrastructure**
  - Savings 30%-40% of efforts per product
  - Time to Market - improved
- **Larger variety of products**
- **Uniform and recognizable functionality/interface**
- **Better scalability (not obvious!)**
- **Better maintainability (not obvious!)**
- **Better possibility of component replacement**

# Building platforms

The Cathedral and the Bazaar?

La Sagrada Familia, Barcelona

Building Started:
On March 19, 1882

Still not completed

Is it worth to build it in that way?

Similar with platform-based
And component-based development
Is it worth?

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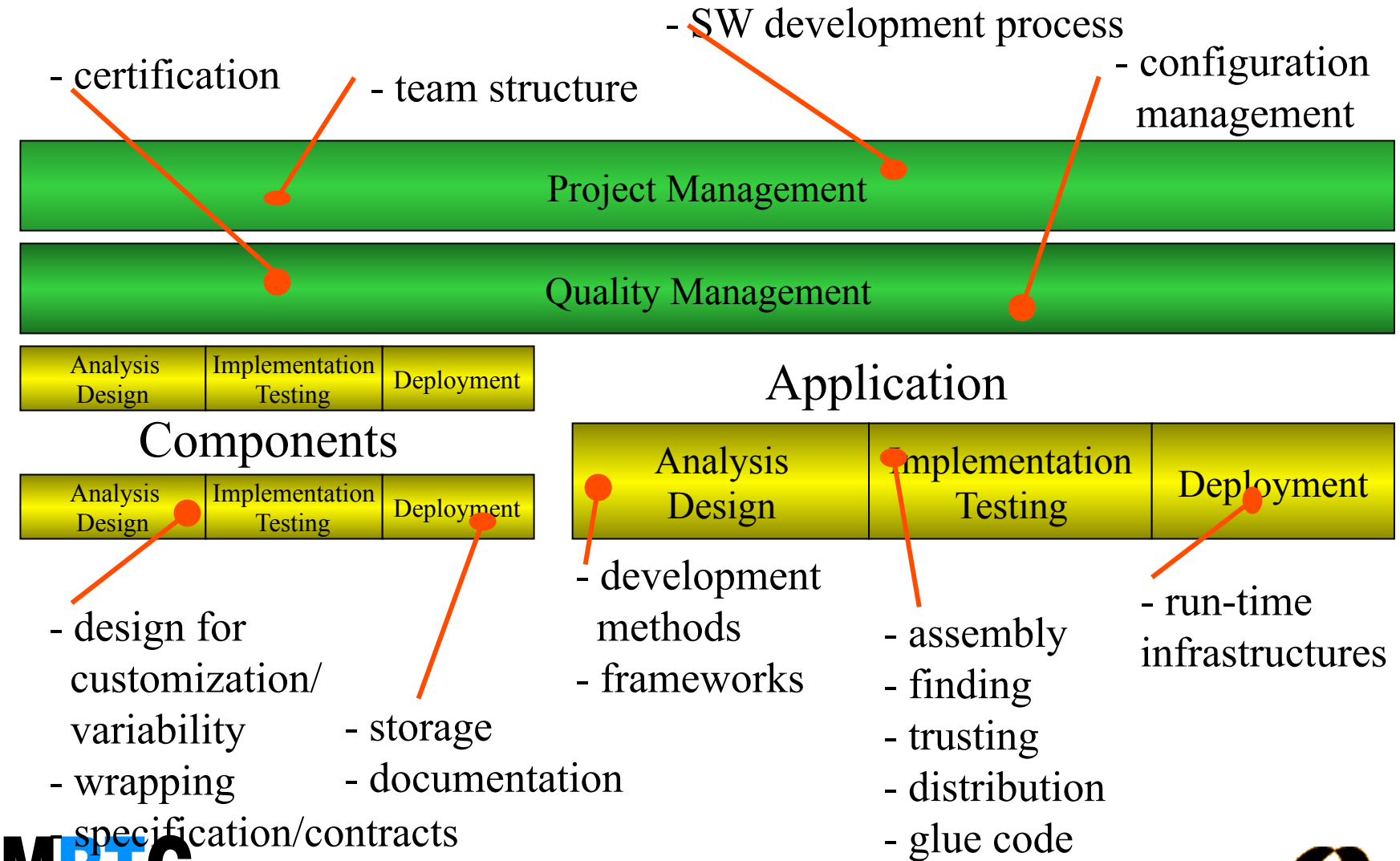
# Part 6

# Problems and research issues

# CBSE research and the SW life-cycle



# Specification

**Are more than interface method definitions**

- **How to specify?**
  - Interfaces, behavior (pre-/post conditions, invariants)
  - dependencies (required interfaces)
  - quality of service
- **How to test/verify component specifications?**
- **How to document component specifications?**
- **How to automatically connect components in builder tools using their specification?**
- **How to verify the correctness of a composite system?**
- **...**

# Design for reuse

**Design for reuse requires additional effort**

- **What is the best level of reuse (component granularity)?**
- **How can the benefit of reuse be measured?**
- **Development and documentation of component usage patterns**

# Repositories

- How to store components?
- How to classify and describe components?
- How to find components?
  - fast
  - different aspects
    - ✦interfaces
    - ✦functionality
    - ✦component model
    - ✦certification level
    - ✦previous usage, trust
  - negotiable requirements

# Software development process

- **Current approach**

  requirements - analyses - design - implementation - test

- **CBSE approach must include**
  - reuse component selection
  - component test
  - requirements reconciliation

- **CBSE must be supported by**
  - modeling formalisms and tools
  - development tools

# Developing a component market

**Imperative feature for component  success**

- **Have to establish framework for …?**
  - legal aspects (licensing and warranties)
  - technical abilities
  - economic forces
- **Proven business case**
- **Repositories, precise descriptions and search engines**
- **Documentations and application support**

# Versioning and configuration management

- **Is more complex than usually (DLL hell)**
  - especially in dynamic environments
- **Dependencies and composition constraints have to be resolved almost automatically**
  - consider systems comprising thousands of components
- **How to do safe exchange of components e.g. upgrade, without contractual specification and proof?**
- **All of the issues above are prerequisite for uploading and downloading of components**

# Security

- **Requires trust and certification**
- **complicated by large group of (small) vendors**
- **‘mobile code security’ important**
  - not user access control but code access control
- **current mechanisms**
  - sandboxing: restricted functionality, restricted availability
  - codesigning: not necessarily suitable to establish trust
    - ✦prove of problem origin
    - ✦difficulty of persecution

# Problems and research issues - Summary

- Contracts and documentation
- Design for reuse
- Repositories
- Software development process
- Organizational changes
- Developing a component market
- Versioning and configuration management
- Security
- Component models for embedded systems

# Part 7

# Information sources

# This presentations is based on:

- **Ivica Crnkovic, Magnus Larsson:**
  **Building reliable component-based systems**
  - Chapters:
  - **PART 1** **The Definition and Specification of Components**
    - ✦Chapter 1 Basic Concepts in Component-Based Software Engineering
    - ✦Chapter 2 On the Specification of Components
  - **PART 2** **SOFTWARE ARCHITECTURE AND COMPONENTS**
    - ✦Chapter 3 Architecting Component-based Systems
    - ✦Chapter 4 Component Models and Technology
  - **PART 3** **DEVELOPING SOFTWARE COMPONENTS**
    - ✦Chapter 6 Semantic Integrity in Component Based Development
- **Ivica Crnkovic: CBSE - New Challenges in Software Development**
- **Ivica Crnkovic et al:**
  **Specification, Implementation and Deployment of Components**

# Books

- **Clemens Szyperski: Component Software :** Beyond Object-Oriented Programming: (1998), 2003 – second edition
- **Alan W. Brown:** Large-Scale Component-Based Development
- **Betrand Meyer:** Object-Oriented Software Construction, 2nd
- **G.T. Heineman, W. Councill:** CBSE Putting the Pieces Together
- **J. Cheesmam, J. Daniels:** UML Components
- **K. Wallnau:** Building Systems form Commercial Components
- ***Ivica Crnkovic & Magnus Larsson: CBSE -*** *Building reliable component--based systems*

# Journals

- IEEE Computer
- IEEE Software
- IEEE Internet Computing
- IEEE Transactions on Software Engineering
- IEEE Transactions on Computers
- ACM Transactions on Programming Languages and Systems languages and programming systems.
- ACM Transactions on Software Engineering and Methodology
- ACM Transactions on Computer Systems
- Software Development (www.sdmagazine.com)
- … all major SW development magazines

# Conferences

- International Workshop on Component-Based Software Engineering, ICSE, CBSE

  http://www.csse.monash.edu.au/~hws/CBSE10/

- Euromicro CBSE track
  http://www.idt.mdh.se/ecbse/2007/

# Conferences

- International Conference on Software engineering (ICSE)
- ACM Conference on Object-Oriented Programming, Systems, Languages, and Applications (OOPSLA) (oopsla.acm.org)
- International Workshop on Component-Oriented Programming (WCOP)
- Symposium on Generative and Component-Based Software Engineering
- Technology of Object-Oriented Languages and Systems (TOOLS) (www.tools-conferences.com)
- International Conference on Software Reuse (ICSR)
- ESEC/FSE