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# Evolution of software composition mechanisms

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# Outline

- Historical evolution of composition mechanisms for software
  - From monolithic to highly decentralized
  - From static to highly dynamic
- Evolution at “product level” in parallel with evolution of “process level”
- Challenges
- Some research directions
- Conclusions

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# The concept of binding

- Architecting software requires defining relationships among elements
- Relationships define the logical/physical structure
- Binding is the establishment of a relationship

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# More on binding

- Binding occurs at all levels
  - programming level
    - a variable refers to its type, value, scope...
    - a subclass refers to its parent class
  - component level
    - a component refers to other components through a *use* relationship

the focus here is on binding as a the gluing mechanism among components

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# Binding time and persistence

- When is the binding established?
  - typical distinction between run-time and “pre” run-time
- How stable is the established binding?
  - can it change?
  - how does it change?
    - explicit
    - automatic

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# Evolution thread

- Continuous evolution to accommodate increasing degrees of
  - dynamicity
  - decentralizationto achieve flexibility
- Concurrent evolution at the process/organizational/business level

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## Early days: the "static" scenario (1)

- The **closed, static, centralized, fixed** world assumption
  - requirements are there
    - just elicit them right
  - they are stable
    - if not, we got them wrong
  - changes should be avoided
  - static and centralized system compositions, frozen at design time
  - monolithic, systematic, top-down processes

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## Early days: the "static" scenario (2)

- Response
  - The waterfall process model
    - Refinement, from clearly and fully specified requirements down to code
    - Top-down development → formal deductive approaches
  - Programming languages and methods producing static verifiable architectures
    - static binding → static type checking

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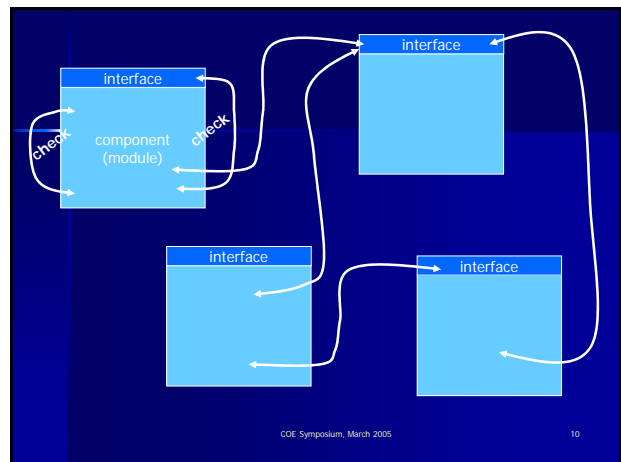
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## Early days: the "static" scenario (3)

- Software structure
  - From monolithic
    - Changes implied recompilation
  - To separately compiled parts
    - Linked statically and then loaded
    - Changes required partial recompilations
  - Interface separated from implementation
    - From FORTRAN to Ada

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## General lessons learned

- Requirements cannot be fully gathered upfront
- Requirements are frozen
- Systems are intrinsically decentralized, complete control and pre-plan illusory
- When changed, impact whole product/process

*The source of change is in the world*

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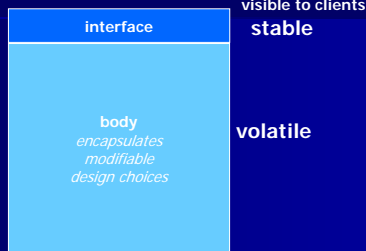
## Initial solutions

- Evolutionary process models
  - Spiral, prototyping-based
- Design for change
  - Information hiding
  - Careful distinction between
    - specification & implementation
    - interface & body
- Object oriented design and languages
  - Accommodate limited anticipated product changes
  - Towards an open world

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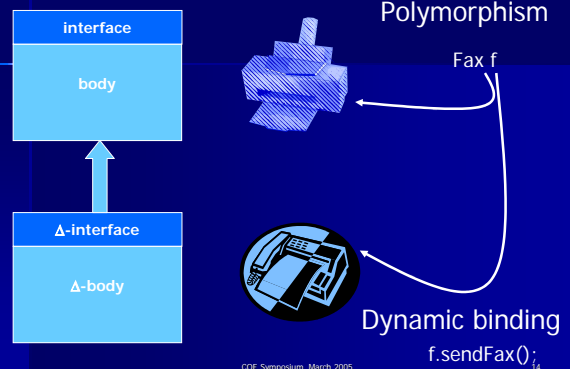
## Design for change



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## OO design



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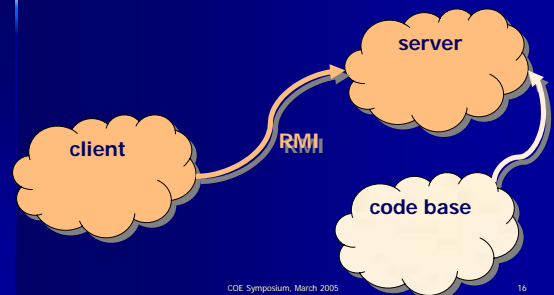
## Open world and type safety

- New subclasses (and new objects) defined as the system is running → methods invoked may become known at run time
- If changes are anticipated and changes can be cast in the subclass mechanism, dynamic evolution and dynamic binding can co-exist with static checking (and type safety)

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## Binding may cross network boundaries



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## Conceptual tools

- Distinguish between **logical** structure and **physical** structure
  - modularity vs. allocation
- The goal of a seamless transition from centralized to decentralized deployment

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## The "components" scenario

- Systems not developed from scratch, but rather out of existing parts
  - Decentralized developments
- Bottom-up integration vs. top-down decomposition
  - Component-based development

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## Gluing software becoming dominant

- Distinction between components and connectors
- Wrappers for components
- Middleware provides binding mechanisms
  - Middleware as a decoupling layer
    - separation of concerns
      - separate component logic from intricacies of communication/cooperation

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## Middleware

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

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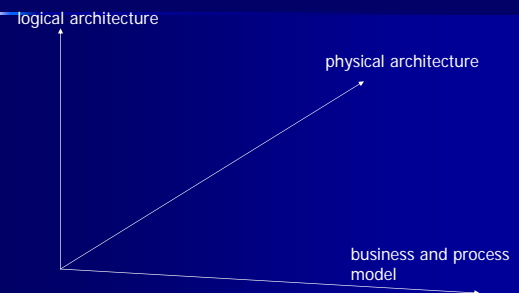
## Mobile scenarios

- With mobility the structure may evolve dynamically
  - physical nodes may appear and disappear
- Logical mobility also possible (i.e., software/agents migrate)
  - physical and logical topology may change dynamically

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## Decentralization dimensions



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## Dynamicity and decentralization in processes and organizations

- **From** software developed by a single organization or by a group of collaborating organizations
- **To** components developed by independent organizations with different degrees of contractual obligations

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## The old world

- Product
  - monolithic
  - centralized
  - static, closed
- Process
  - single authority
  - pre-planned
  - monolithic

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## Achievements

- Product
  - monolithic → modular
  - centralized → distributed
  - static, closed → controlled dynamic binding
- Process
  - single authority → static task decomposition
  - pre-planned → pre-planned evolution
  - monolithic → spiral, agile, extreme

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## A vision: the “global computing” scenario

- Applications dynamically federated out of distributed components, **even at run time**
- Motivations
  - the network as a bazaar of components
  - mobility, ubiquitous computing
  - multimodality
- This pushes dynamicity, decentralization and distribution to unprecedented levels
- Problems range from **technical** to **business models**

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## Problem scale

- From in-the-tiny
  - sensor networks
    - huge numbers of autonomous cooperating devices
- To in-the-large
  - web services
    - different scales possible

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## Challenges—1

- How to design components?
- How to federate them?
- How to manage composite systems (without centralized control)?
- How to reason about the “total” quality of provided services?
- What types of business models?

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## Challenges—2

- What kind of interface should components provide in such a fluid environment?
  - Interface should support establishment of “contracts”
    - Beyond import/export typed lists
- How to ensure a correct “global” behavior?
  - Need for new theories and models?

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## Service-oriented architectures

- From now on, I cast my presentation in the context of service-oriented architectures
- in particular, web services

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## A definition

"Web services are a new breed of Web application. They are **self-contained, self-describing**, modular applications that can be **published, located**, and **invoked** across the Web. Web services perform functions, which can be anything from simple requests to complicated business processes. ...

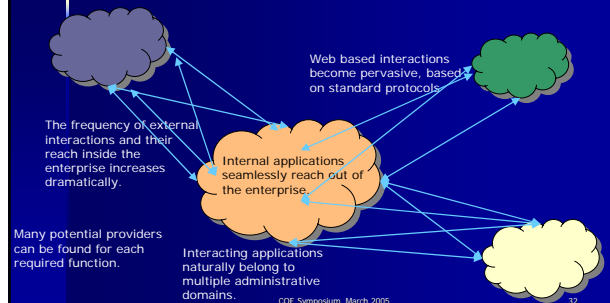
Once a Web service is deployed, other applications (and other Web services) can discover and invoke the deployed service."

*IBM web service tutorial*

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## Motivation: networked enterprises



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## More on "service" (1)

- Component encapsulating a business function of possible value for others
  - Different level granularity – coarse grained business services vs. fine grained objects
- Services must support **explicit contracts** to allow independent party access
  - Allow for SLAs that deal not just with functionality
- Services can be the basis for **service compositions**
  - New value is created through integration and composition
  - New components are recursively created

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## More on "service" (2)

- Services lifecycle phases
  - specified
  - published
  - discovered
  - negotiated
  - delivered
  - composed
  - monitored

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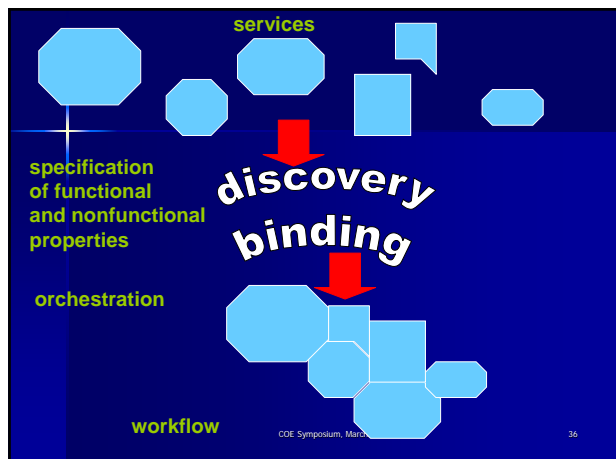
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## Types of services

- Atomic services: run to completion without interaction with service client
  - a search service
- Service packages: logically related, not interacting, group of atomic services
  - reservation for different theatres
- Workflow services: workflow includes composition of other services
  - state is shared
    - buying a book

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## Discovery and binding

- Design time
- Deployment time
- Run time

unstable, evolving environments

ubiquitous, mobile applications

self-organizing behavior

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## Dynamic SOAs

- Composite services are specified by workflows
- Workflows contain abstract service invocations
- Concrete services bound dynamically, at run time

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## Dynamic SOAs

- Dynamic discovery and dynamic binding
  - the “broker” role
- Self-organizing, self-healing composite services
- Opportunities
  - enjoy use of the “best” available services
  - binding can be “context-aware”
- Threats
  - many things can go wrong

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## Service contracts

- Contracts in terms of pre and post conditions
- Exposed services specify what they promise to fulfill
- Workflows specify what they expect from concrete services
- A broker negotiates a contract upon which a binding is established

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## Threats: contracts can be broken

- We bind to a concrete service that does not satisfy its stated specification
- The bound service evolves autonomously and breaks the contract
- The service is “temporarily down”

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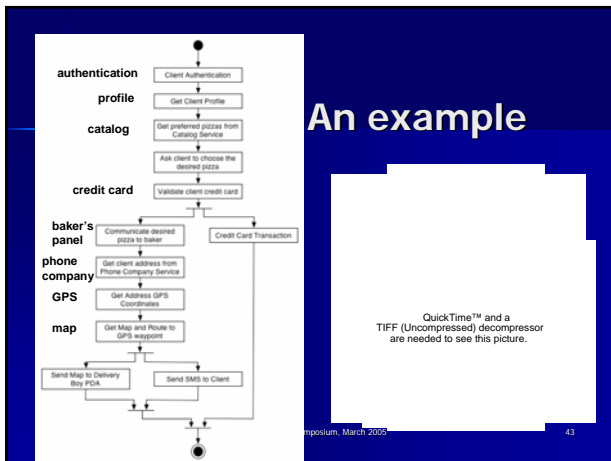
## Consequences

- Traditional good software engineering methods stress static reasoning on software architectures
- This has little value in the new world of run time variability
- Improved techniques are needed to monitor and react to unexpected deviations at run-time
  - reaction can lead to self-healing systems

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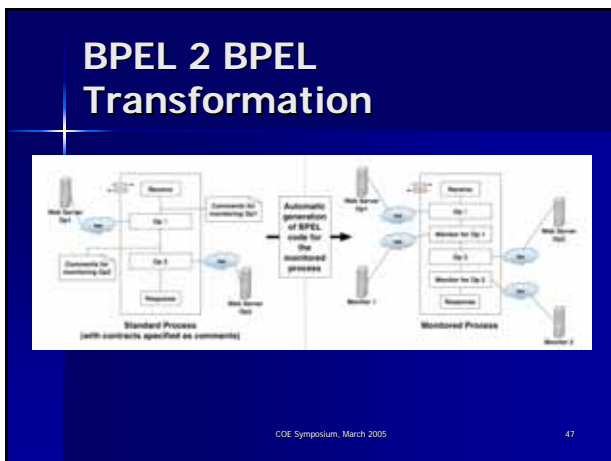




- ## Monitoring
- In an **open** environment, reacting to abnormal behaviors is of greater importance than in **closed** environments
  - Recovering from problems has to do with knowing what to do when something goes wrong. But before that we have to:
    - Decide **what** should not go wrong
    - Detect **if and when** that happens
- This is where monitoring comes in!**
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- ## Monitoring
- Defensive programming
    - Workflow handles timeouts and exceptions raised by remote service
  - External contract monitoring
    - Collect data
    - Process data
    - Notify workflow
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- ## An assertion-based approach
- Contracts expressed in terms of pre- and post-conditions
  - These assertions are inserted as comments into our process definition
  - External monitors (**services**) are used to check the assertions
- We cast our proposal in terms of BPEL processes
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- ## What are the advantages?
- Limited design overhead
    - Comments are easy to add and transformation to a monitored BPEL process is automatic
  - Business logic remains separate from the monitoring logic
  - We stick to BPEL
    - No need for a special workflow engine
  - Monitor alternatives
    - Different implementations, possibly co-existing
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## Recovery and repair actions

- Retry
  - transient faults
- Rebind
  - find a suitable replacement for previous service
- Restructure (local reconfiguration)
  - find a collection of services that satisfies request, or merge given collection into one

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## Restructure

- Workflow process as a graph
- Graph transformation rules express possible local changes
  - sequential composition
  - parallel composition
  - branch composition

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## What kind of problems due we monitor?

- Three different kinds of problems:
  - Timeouts
  - External exceptions -> these can be implementation errors in the services or mismatches between how we call the service and how the service expects to be called
  - Functional (and/or non functional) contract enforcement -> this requires an external monitor service

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## Monitoring contracts

- An external monitor is needed to monitor a functional or a non-functional contract
- We implemented two different monitors for our assertion-based approach:
  - The first uses C# and .NET framework
  - The second uses CLIX and XlinkIt

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## Conclusions (1)

- We are moving towards unprecedented degrees of flexibility, dynamicity, and decentralization *at all levels*
- New challenges to correctness/reliability, security, performance
- Crucial to understand how we can build on previous approaches and where new ones are needed

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## Conclusions (2)

- The global computing scenario requires more intelligence to be moved to run time
- Traditional pre-deployment tools must be moved to run time in a seamless fashion
  - continuous testing
  - run-time verification

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## Our work

- We have seen an **initial attempt** to use defensive programming and an assertion-based approach to monitoring to make system partially self-healing
- The advantage of our approach is that it can coexist with current "standards" developed for SOAs

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## Our work

- We developed prototypes for assertion-based monitoring and recovery mechanisms
- We are completing a second wave of prototypes that take into account performance and usability issues
- We will address non-functional properties
- We will try to achieve a better separation between business and monitoring logic to support different monitoring activities for different stakeholders
- Definition of more complex exception handling routines

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## Acknowledgments

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- Members of the group
  - C. Ghezzi, L. Baresi, E. Di Nitto, S. Guinea and several graduate students
- More on this
  - L. Baresi, C. Ghezzi, S. Guinea, "Smart Monitors for Composed Services", Int.I Conf. on Service Oriented Computing, New York, Nov. 2004.
  - L. Baresi, C. Ghezzi, and S. Guinea, "Towards Self-healing Compositions of Services" Proceedings of PRISE'04, First Conference on the PRInciples of Software Engineering, November 2004, Buenos Aires, Argentina.

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