BCS Advanced Programming
Specialist Group

Architecture-based Systems Management

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The challenge of complexity

- An increasing number of human activities now rely on computing systems.
  - Communication, transportation
  - Commerce, finance
  - Energy production
  - Health care

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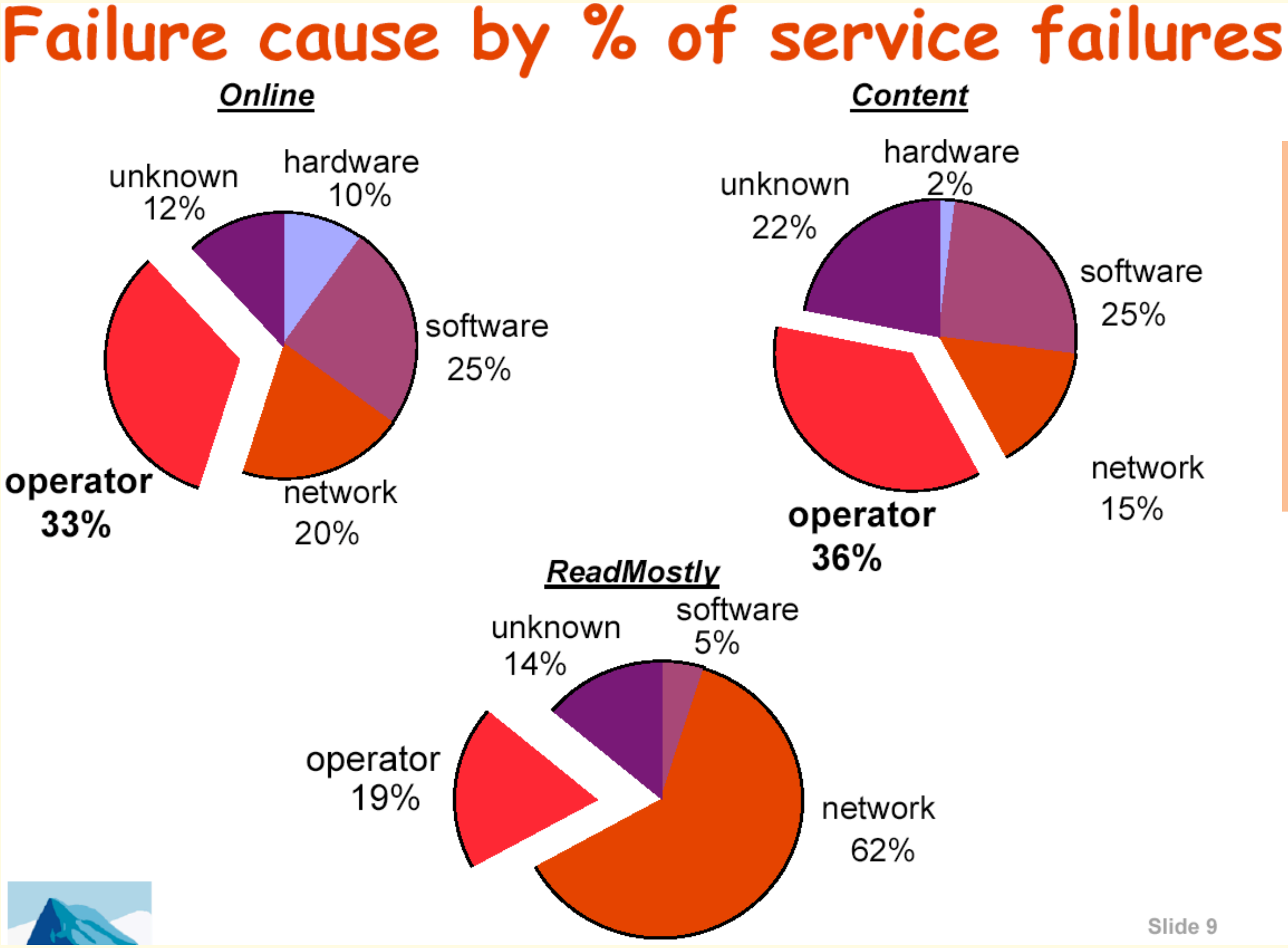
  - Communication, transportation
  - Commerce, finance
  - Energy production
  - Health care
- However, today's computing systems have become so complex that one hardly understands how they work...
- ... and one hardly understands why they fail.
  - Some investigations
    - Gray (1985, 1989)
    - Murphy (1993)
    - Oppenheimer, Ganapathi, Patterson (2003)

The origin of failures in Internet-based systems



Reminder:

A failure is a deviation from the specified behavior

A fault is any (potential) cause of a failure

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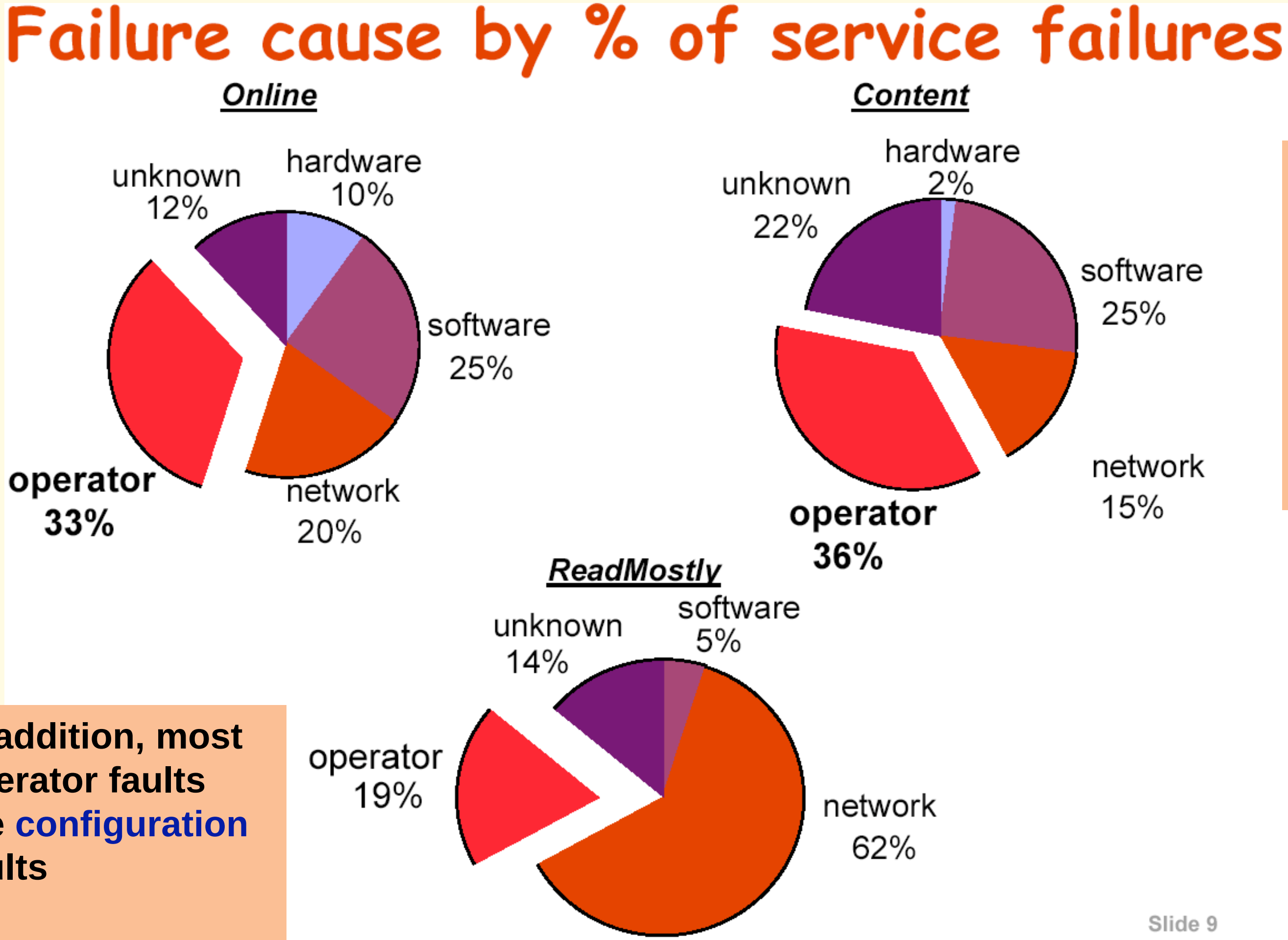

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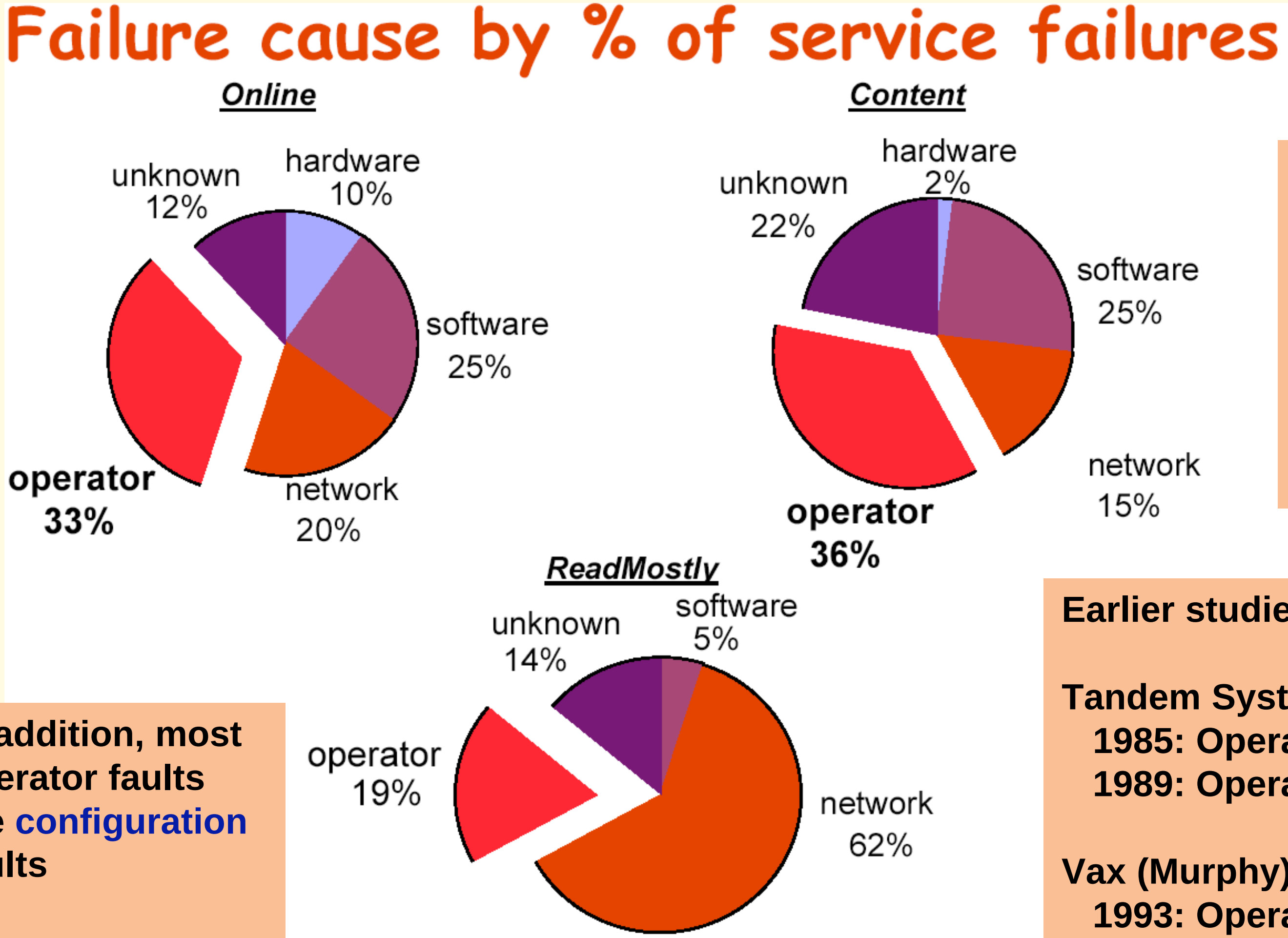

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Earlier studies:

Tandem Systems (Gray)
1985: Operator 42%, S/W 25%, H/W 18%
1989: Operator 15%, S/W 55%, H/W 14%

Vax (Murphy)
1993: Operator 50%, S/W 20%, H/W 10%

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The challenge of system administration

- System administration is getting too complex for humans
  - One remedy: computer-assisted administration
- What is system administration?
  - Ensuring that the system provides a given level of *quality of service*
  - Maintaining this QoS level in the face of adverse conditions.
- Quality of service has many facets
  - Availability
    - Including partial availability
  - Performance
    - Mean throughput, latency, etc.
    - Differentiated levels
  - Security
    - Well-known and new threats

System administration tasks

- Defining policies
  - Defining QoS evaluation criteria
  - Defining goals
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    - Security attack
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Can be (partially) automated

Architecture-based management

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  - A framework for describing a system as an assembly of parts (components)
- What is architecture-based management?
  - Using the architectural description of the managed system as a guide for defining and implementing management functions
- Why architecture-based management?
  - Higher abstraction level
  - Convenient mapping between management and architecture notions
  - Reduced architectural erosion (discrepancy between conceptual and actual architecture)
  - Automated support for management functions

Main concepts of software architecture (1)

- Describing a system as an assembly of parts
- Compositional entities
  - Component.
    - A unit of composition and independent deployment
    - Fulfils a specific function
    - May be assembled with other components
    - Has contractually specified interfaces (provided and required)
  - Connector
    - A device that allows assembling components, using provided and required interfaces
    - Two roles: binding and communication
  - Configuration
    - An assembly of components (may or may not be itself a component).

Main concepts of software architecture (2)

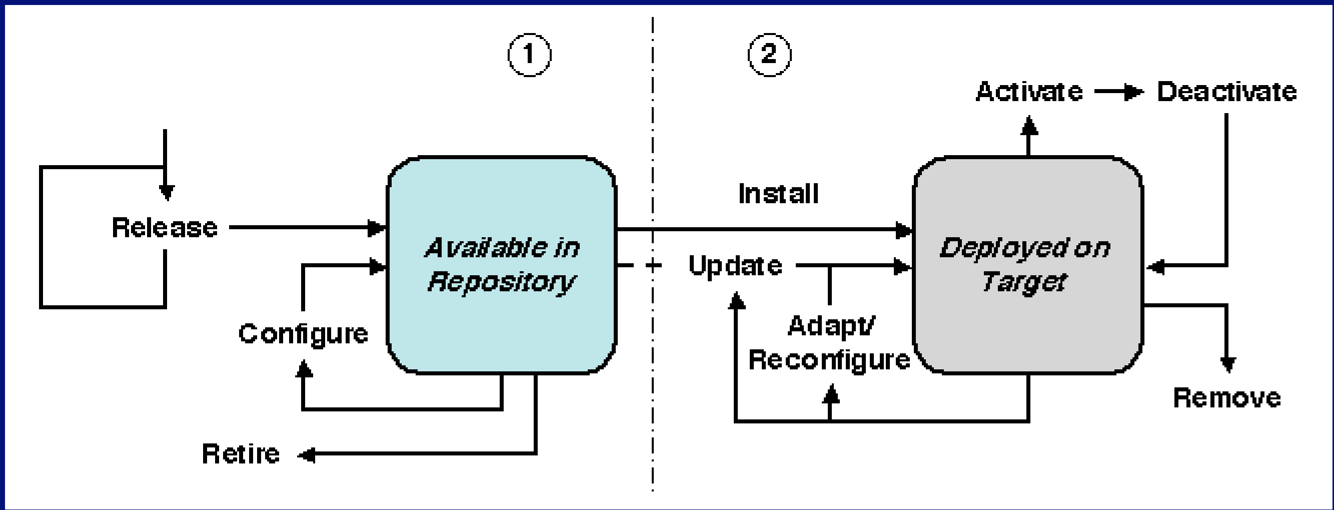
- Architecture Description Language (ADL)
  - Provides a common (formal or semi-formal) global description of a system, for designers and implementers
  - Can be used by various tools (visualisation, verification, code generation, deployment and reconfiguration, etc.)
  - Not all component systems use an ADL
    - Some use dependency descriptions (examples later)
    - No commonly accepted standard
- Current issues for ADLs
  - Extension mechanisms
    - Common core + extensions
    - XML as main notation
  - Dynamic ADLs
    - Executed at run time
    - Causes the structure to evolve

Plan of this talk

- Managing component-based systems
  - Configuration and deployment
    - Case study
      - The SmartFrog framework
  - Package-based software distributions
    - Case studies
      - EDOS
      - Nix
- Self-repair
  - Case study: the Jade framework
- Perspectives

Configuration and deployment (1)

- Configuration and deployment tasks
  - Selecting the components, setting parameters
  - Verifying the consistency of the system (e.g., dependencies)
  - Determining the sites on which the system is to be installed and placing each component on the appropriate site
  - Setting up the connections between the components
  - Starting the components in an appropriate order



Configuration and deployment (2)

- Requirements
  - Allow *variability* (ability to modify a system according to needs); this implies *flexibility*, i.e., ability to:
    - Apply changes at any point of the product’s lifecycle
    - Delay changes up to the latest possible moment
    - Use any policy for change management
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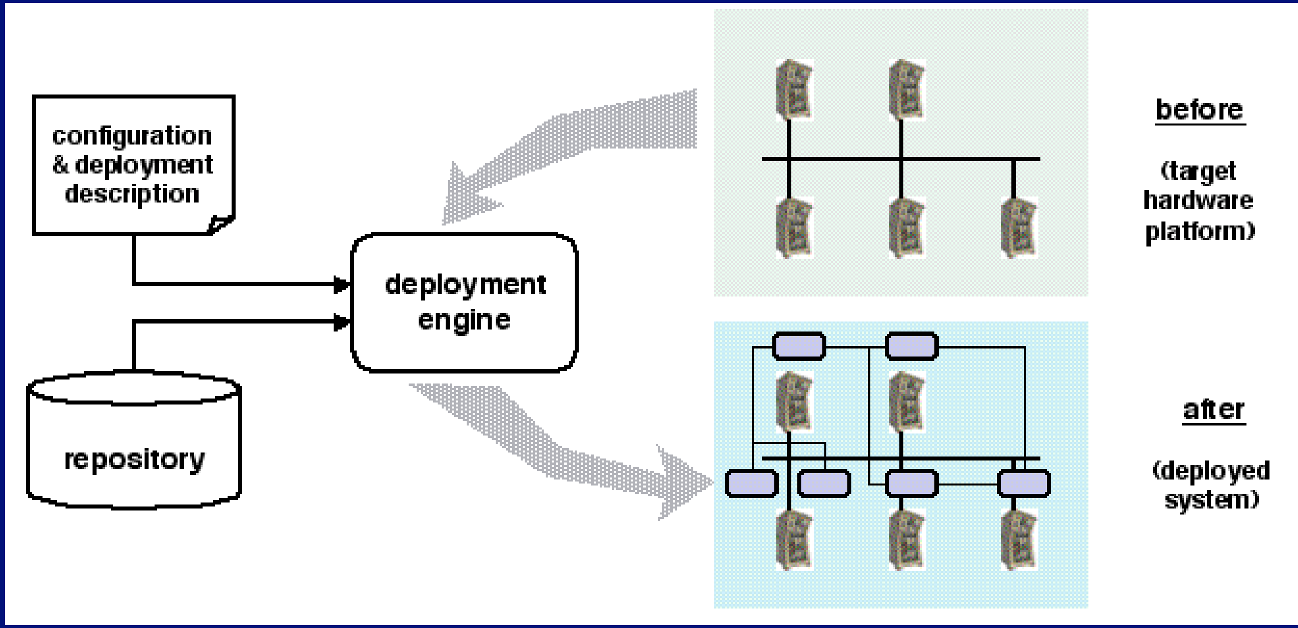
- Why is this difficult?
  - Large scale, complex systems
  - Keeping track of multiple configurations
  - Maintaining consistency in the face of change
- Bad practice
  - Configuration data scattered in many places (sometimes repeated)
  - Incompatible lifecycles between components
  - Ad hoc configuration and deployment procedures

Problems of configuration and deployment

- Preventing unresolved dependencies
  - Dependencies are not always explicit
  - Dependencies may occur at build time or at run time
  - Dependencies may even be unknown to the administrator
- Allowing multiple versions to coexist
  - Different applications may require different versions of a library
  - Multiple versions may be mutually incompatible
- Preventing component interference
  - An upgrade of a component may invalidate another component (file overwriting, etc.)
  - Using “standard” paths (e.g., in Unix) is a potential cause of interference

Architecture-based deployment

- The description of a system's configuration and deployment is separate from the code and expressed in terms of the system's architecture
- This description is used as a base for automating the process of configuration and deployment



Configuration and deployment: case study

- SmartFrog
  - “Smart Framework for Object Groups”
  - A configuration and deployment framework for (potentially large) distributed systems
    - Examples
      - a network monitoring system
      - a 3-tier web application
  - Developed by HP Labs
  - Available in open source
  - Used in production environments

Introducing SmartFrog

- SmartFrog provides capabilities for
  - Configuration: describing and composing a distributed application out of Java components
  - Deployment: installing a configuration on a set of computing resources
  - Lifecycle management: orchestrating the progress of components through their lifecycles (deploy, start, terminate, …)
  - Discovery and communication: locating components both statically and at run time; communicating between components
- SmartFrog consists of
  - A component model
  - A declarative language for configuration and deployment description
  - A run time system (distributed workflow engine)

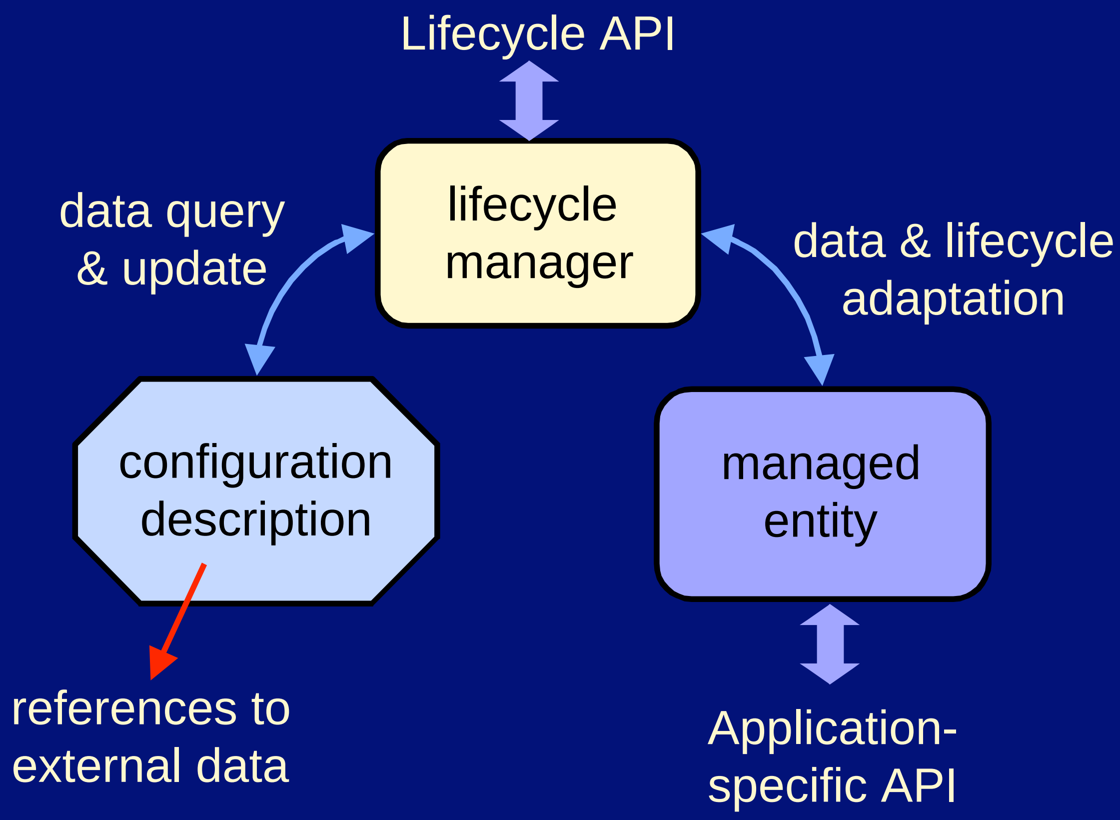
SmartFrog component structure

Standardised APIs:
- access to configuration data
- lifecycle API

Application-specific API
- interface of managed entity (component)

The lifecycle manager is used a wrapper for legacy software.

Components persist at run time (the component structure does not disappear after deployment)



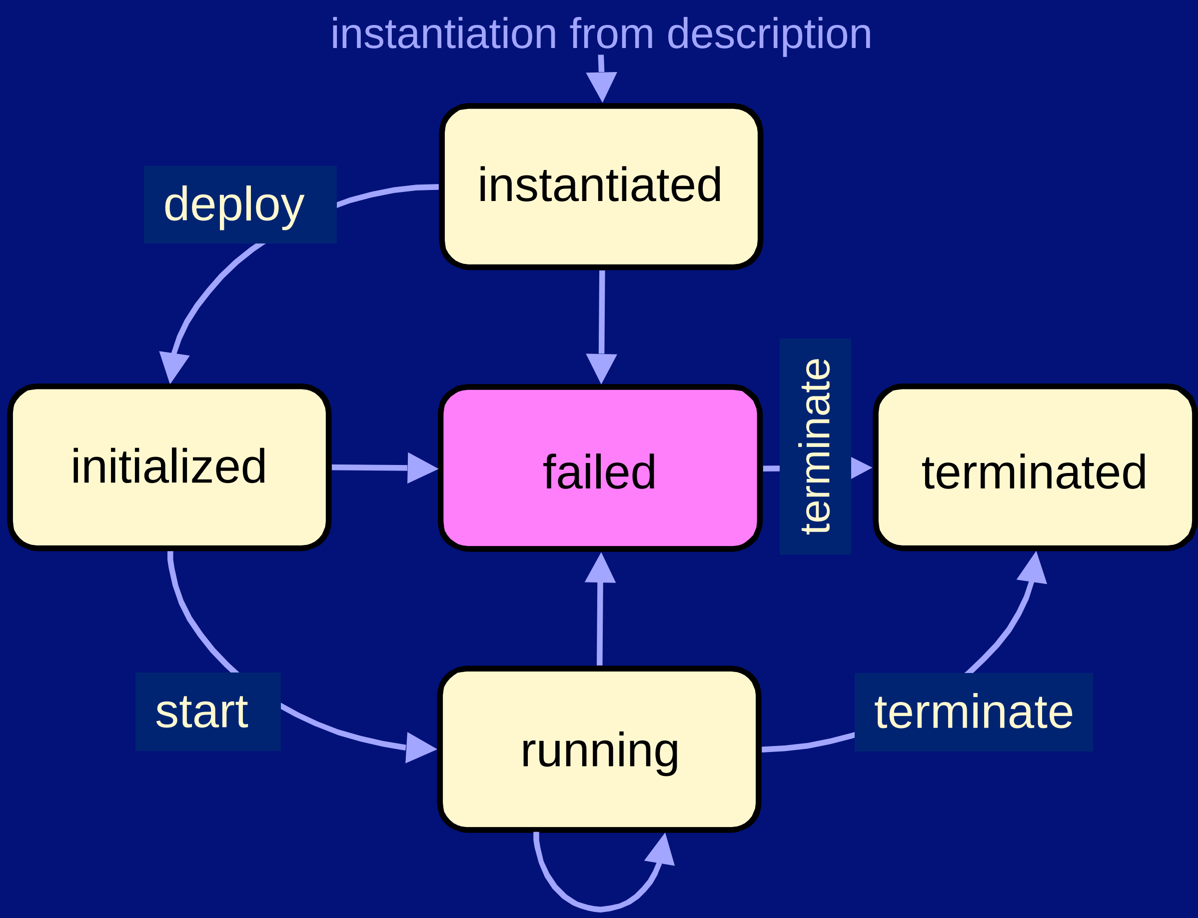
Configuration information may be statically provided or discovered at run time (see later)

SmartFrog component lifecycle

The lifecycle API for a component consists of the methods

- deploy
- start
- terminate

The lifecycle for a configuration (a compound component, extending the predefined *Compound* class) is implemented by lifecycle managers (described later on), which use the components' API



SmartFrog configuration description (1)

- Requirements
  - Composable description
  - Late binding
  - Ability to extend framework
  - Parameterised description (templates)
- Overview
  - A declarative data description language (not a programming language)
    - Attribute = name-value pair
  - Prototype-based (instance-inheritance)
  - Templates
    - May be extended, overridden, combined
  - May include assertions, to check validity of data
  - Interpreted by the run time system
    - No semantics built in the language

SmartFrog configuration description (2)

webservice.sf

```
#include "wstemplate.sf"
#include "dbtemplate.sf"

sfConfig extends {
   commonPort 8080;
   ws1 extends webServerTemplate {
      sfProcessHost "webserver1.hpl.hp.com;
      port ATTRIB commonPort;
   }
   ws2 extends webServerTemplate {
      sfProcessHost "webserver2.hpl.hp.com;
      port ATTRIB commonPort;
      useDB LAZY ATTRIB db;
   }
   db extends dbTemplate {
       userTable: rows 6;
   }
}
```

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webServerTemplate extends {
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  useDB;
}
```

dbtemplate.sf

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dbTemplate extends {
  userTable extends {
    columns 4;
    rows 3;
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- deployment
- configuration
- template import
- attribute overloading
- late binding

SmartFrog configuration lifecycle

A ilfecycle manager may be attached to any piece of configuration data (e.g., a compound configuration). This extends the notion of a lifecycle manager for a single component.

A lifecycle manager is an instance of a Java class (defined by the *sfClass* attribute).

A lifecycle manager for a compound configuration is responsible for the coordination and phasing of actions for its components (e.g., sequential, parallel, etc.). This extends to nested groups

```
webServer extends {
   port 80;
   // other generic
   // web server data }

jetty extends {
   sfClass "org.smartfrog.jetty.Jetty";
    // other jetty specific data

apache extends {
   sfClass "org.smartfrog.jetty.Jetty";
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}

myJettyServer extends webServer, jetty;
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  server1 extends webServer;
  server2 extends webServer;  }
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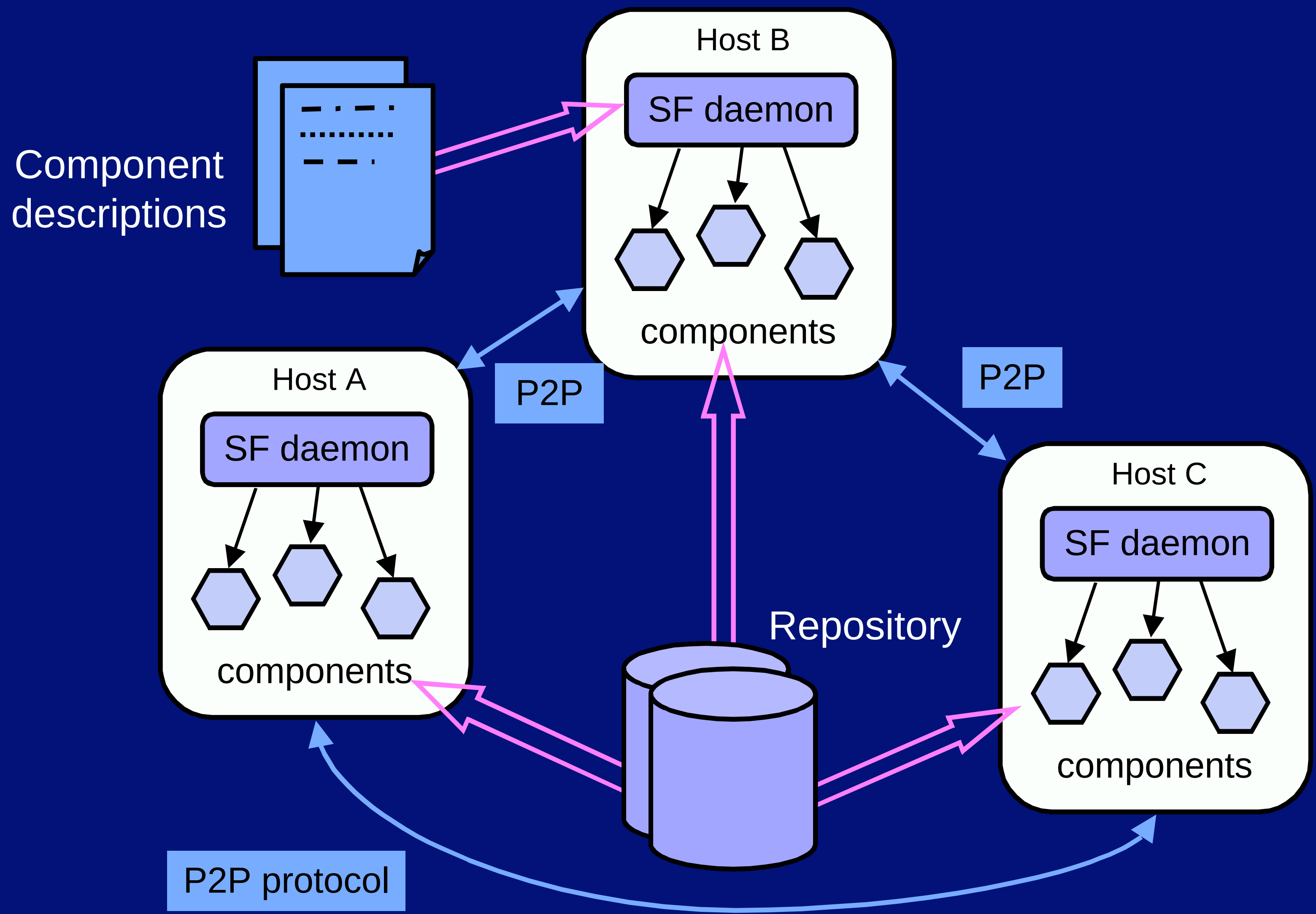
system2 extends Parallel {  // independent fate
  server1 extends webServer;
  server2 extends webServer;  }
```

The SmartFrog runtime system



SmartFrog Summary

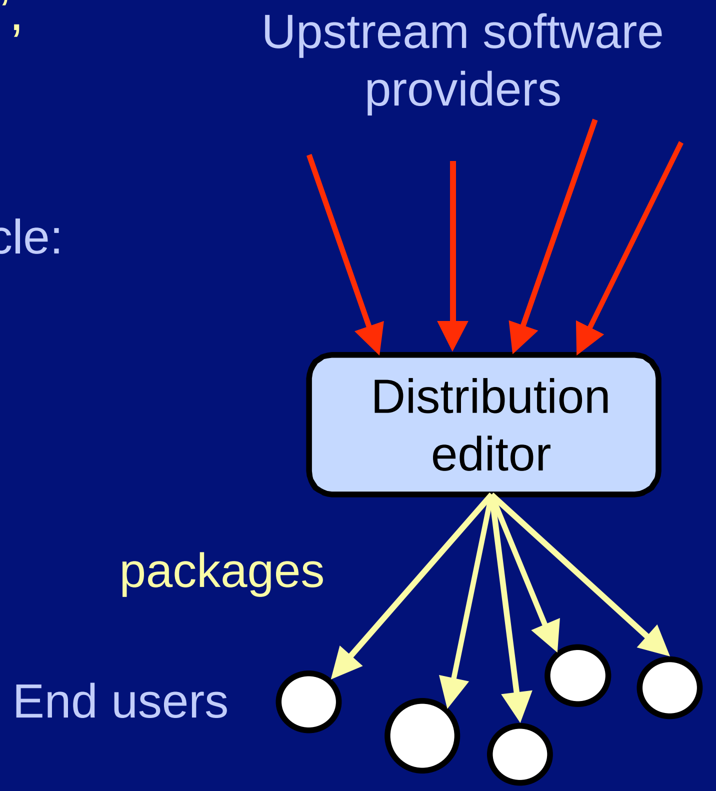
- Strengths
  - A highly flexible framework
    - Can be easily modified/extended (component-based)
    - Accommodates legacy components through wrapping techniques
  - Scales well
    - Loosely coupled workflow engine
  - Secure deployment
    - Based on PKI
- Limitations
  - No organised repository
  - No formal or conceptual base for language and component model
  - Language lacks higher-order constructions (parameterized deployment)

Managing package-based software distributions

- EDOS
  - Environment for the development & Distribution of Open Source Software
  - A collaborative research project funded under the European Sixth Framework
  - A formal statement and thorough analysis of installation and upgrade problems
  - A set of tools for safe and efficient management of free and open source software
- Nix
  - A research project, University of Utrecht, NL
  - A framework for organising component repositories, allowing various deployment policies
  - Safe, purely functional deployment

Package-based distribution: the EDOS view (1)

- Managing the distribution of Free and Open Source Software (FOSS)
  - To put some order in the “FOSS bazaar”,
    - a new actor: the distribution editor
      - A basic deployment unit: the *package*
      - A tool for managing the package lifecycle:
        - the package manager
  - The role of the distribution editor
    - Tracking source evolution
    - Integrating and testing
    - Distributing



Package-based distribution: the EDOS view (2)

Set of *files*
Configuration files

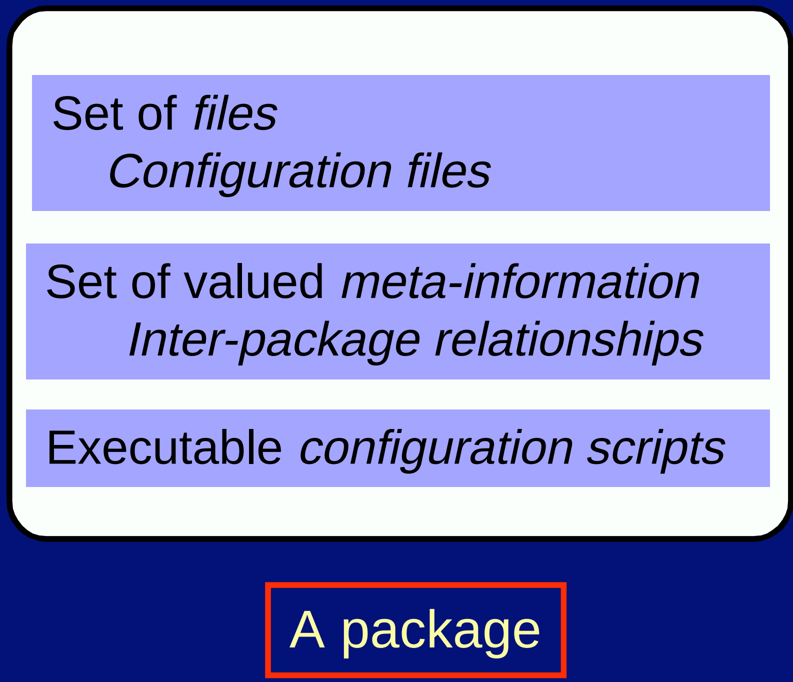
Set of valued *meta-information*
Inter-package relationships

Executable *configuration scripts*

A package

Package-based distribution: the EDOS view (2)

- What is in a package?
  - A set of files (binaries, data, documentation)
    - Configuration files have a special role
      (to be locally customised)
  - A set of meta-information
    - Identification, version, description
    - Inter-package relationships
      (dependencies, conflicts)
  - Executable configuration scripts
    - To be executed at installation or upgrade
    - May involve local files on the installation machine (not part of the package)



Package-based distribution: the EDOS view (3)

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- Managing relationships between packages
  - Depends
    - Specifies packages (including version numbers) that *must be present* to make the current package functional
  - Conflicts
    - Specifies packages that *cannot coexist* with the current package
  - Pre-Depends
    - Specifies packages that *must already be present* to successfully deploy the current package

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- Why is this difficult?
  - Typical size: 20,000 packages, 200,000 relationships
  - Package installability may be formulated as a boolean satisfiability problem (SAT)
    - Finding a combination of values that makes a Boolean formula evaluate to TRUE
  - Therefore, it is NP-complete in the general case!
  - However, it turns out to be practically tractable in most current situations

Formalizing package installability in EDOS

Deciding package installability is equivalent to boolean satisfiability (SAT)

- each package *p* (in version *v*) is denoted as a boolean variable p_v
- each version constraint (e.g., $v > 4.0$) is expanded into the disjunction of the packages that satisfy that constraint, e.g., $p_{v1} \vee p_{v2} \vee \ldots$
- each dependency is interpreted as an implication, e.g.,
  $aterm \rightarrow libc6 \wedge (libce6 \vee xlibs) \wedge \ldots$
- each conflict between packages *a* and *b* is interpreted as the formula $\neg (a \wedge b)$

Then a package p_v is installable iff there exists a boolean assignment that makes p_v TRUE and satisfies the conjunction of all the logical implications introduced by the dependencies and conflicts.

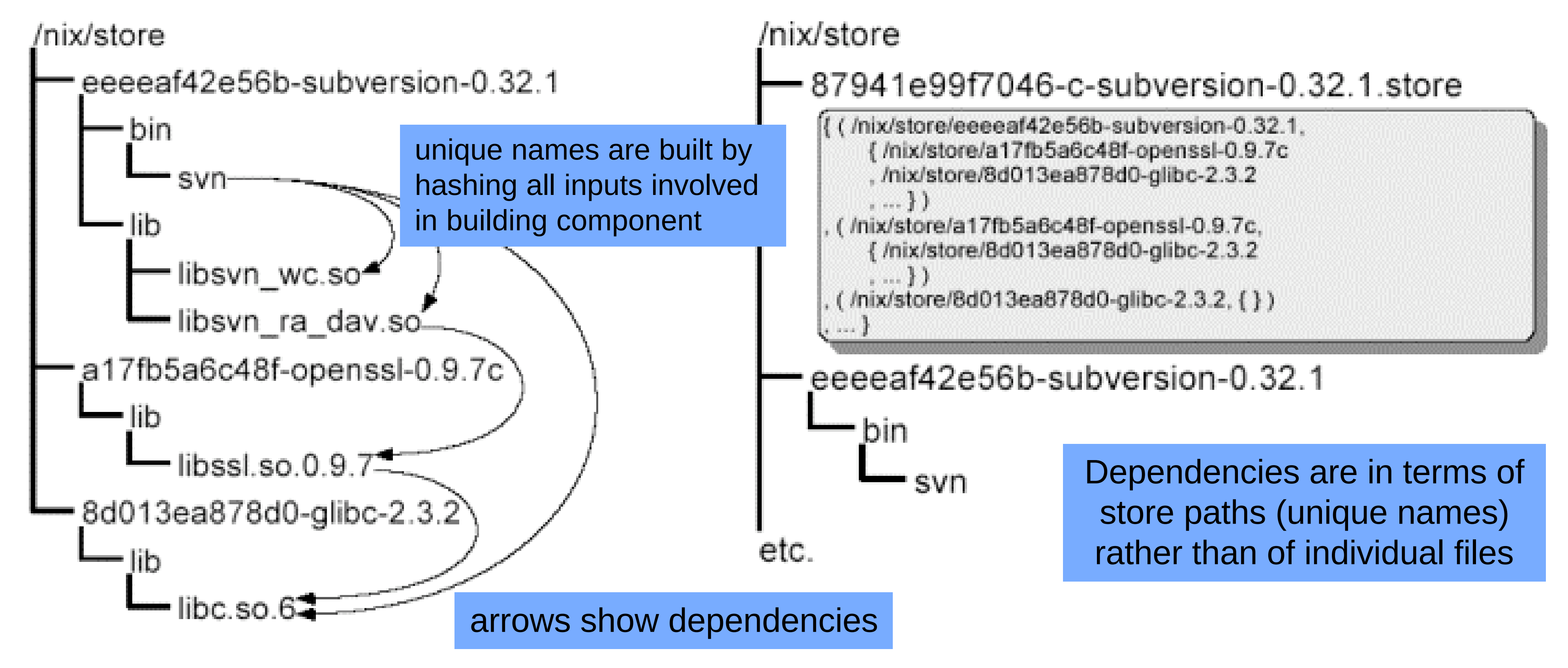
EDOS summary

- A formalisation of the package dependency problem
- A set of tools for the distribution editors
  - Not visible to the user
  - About 110 K lines of code in OCaml
    - Checker for package installability
    - Environment for repository inspection
    - Parser/converter between package list formats
  - Used by distribution editors: Debian, Mandriva, …
- A follow-on project: Mancoosi
  - Utilities for the user

Introducing Nix

- Nix is a safe and flexible package management system
  - Safe: guarantees that all dependencies are satisfied
  - Flexible: unconstrained choice of deployment policies
- Nix consists of
  - A store: repository for components (packages)
    - Each component has a *closure* (the set of components on which it depends)
  - A (functional) language for describing build actions (*derivations*)
    - Derivation expressions are interpreted
- Origin
  - Academic project (Eelco Dolstra's PhD thesis)
  - Univ. Utrecht, now Univ. Delft (NL)

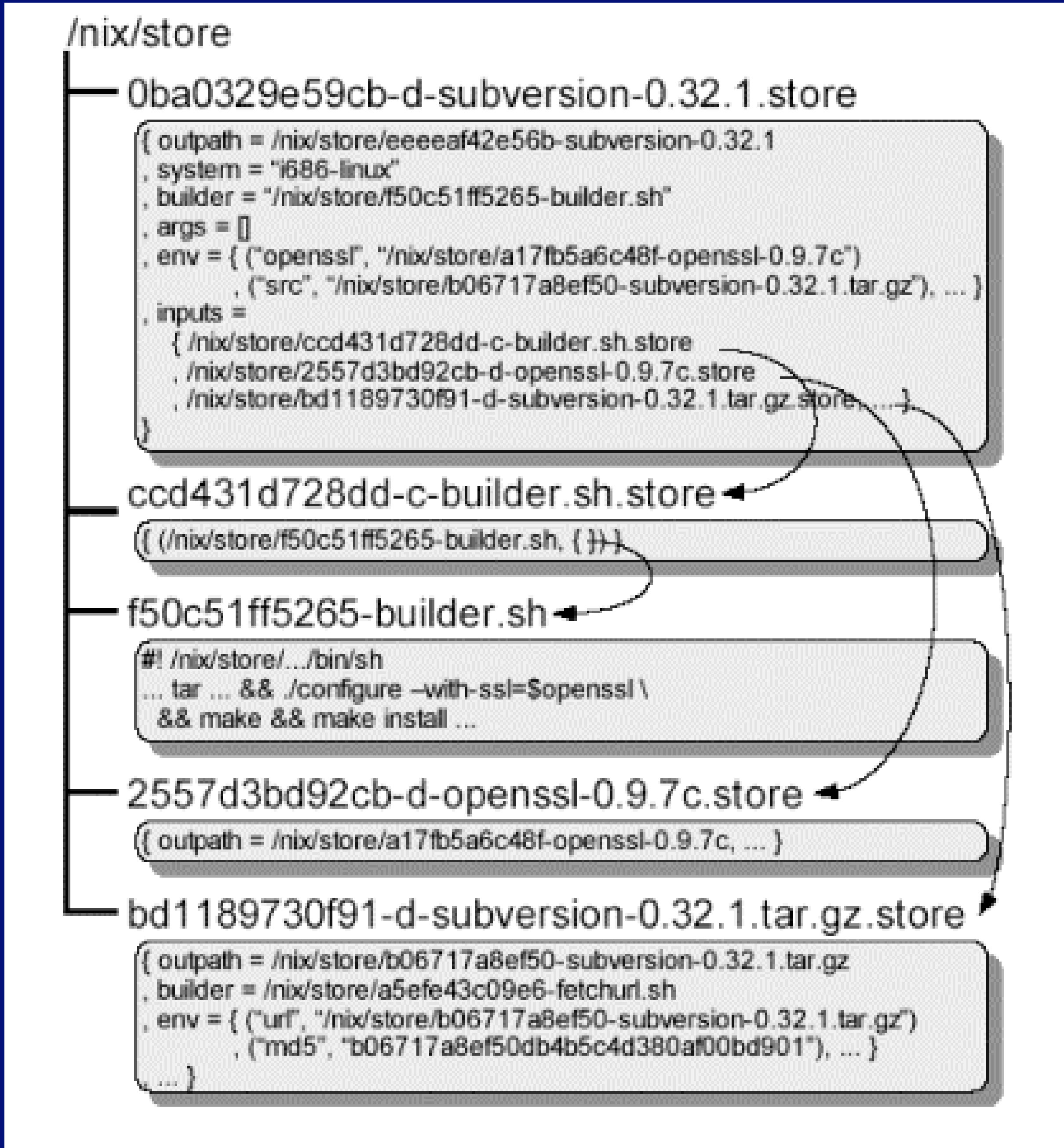
The Nix store



(a) Organization of the store

(b) Closure value for *subversion*

Dolstra, E., Visser, E., and de Jonge, M. Nix:Imposing a memory management discipline on software deployment. In Estublier, J. and Rosenblum, D., editors, *26th Int. Conf. on Software Engineering (ICSE'04)*, pp. 583-592, Edinburgh, Scotland. IEEE Computer Society



How Nix works

Example: derivation value for *subversion.*

This information is used to determine the closure value shown on the previous slide.

It includes both a deployment description and the program (shell scripts) of some of the deployment tasks

It is not intended to be written by hand, but to be generated from a higher level description
It is used as input for performing the actual build.

Dolstra, E., de Jonge, M., and Visser, E. Nix: A safe and policy-free system for software deployment. In Damon, L., editor, *18th LISA Conf.*, pp 79-92, Nov. 2004, Atlanta, Georgia, USA.

Nix Summary

- Strengths
  - A purely functional system
    - A language for expressing derivations (build actions)
    - No side effects
    - A configuration does not change once it has been built
  - Allows multiple versions of a package
    - Upgrading/uninstalling an application cannot break another one
  - Atomic upgrade/rollback
  - Allows both source code and binary components
- Limitations
  - No experience yet with distributed systems
  - Not compliant with Unix Standards Base

Configuration and deployment summary

- Achievements
  - The importance of configuration and deployment is recognized
  - Systematic architecture-based approaches are being developed (and find their way into products)
  - Formal methods are emerging, with some successful results
- Problems
  - Lack of standards
- Some current research directions
  - Using Model Driven Architecture
  - Investigating reconfigurable architectures (described by dynamic ADLs)

Self-repair

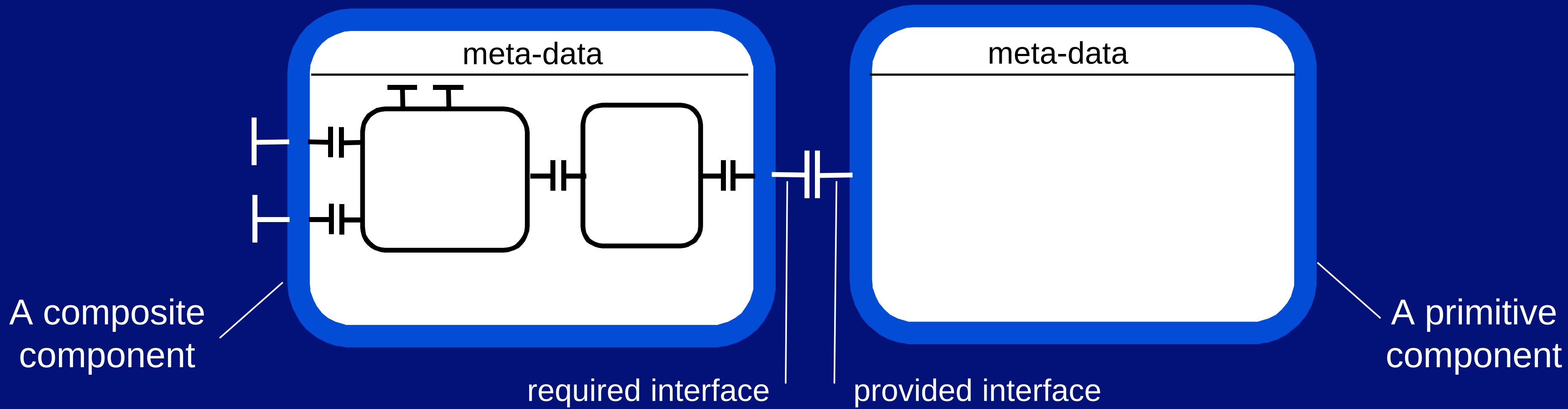
- Motivation
  - Maintain the system's availability in the face of failures
- Goal
  - Suppress or minimize the (user perceived) effects of a failure
- Problems
  - Many failures (specially in communication) do not follow the fail-stop mode
  - Tracing the precise location of a software failure may be difficult
  - Restoring state is a complex issue
- Approaches
  - Relate failure to system structure: architecture-based approach (see case study)
  - Reduce recovery time
    - Early detection
    - Fast restoration (example: Micro-reboot, after fine-grained location)
  - Consider degraded mode operation (not all failures are fatal)
    - Performability studies (fault injection, etc.)

Case study
Jade, an experiment in architecture-based self-management

- The Jade project
  - Developed by research team Sardes (Univ. of Grenoble and INRIA, 2003-2009)
  - A framework based on reflective components
  - Experiments in various aspects of autonomic computing (configuration, performance, security, fault tolerance)
  - Targeted to medium to large size clusters for Internet services
  - One industrial application (with Bull)
  - Site: http://sardes.inrialpes.fr/jade.html
  - Recent publications:
    - S. Bouchenak, F. Boyer, D. Hagimont, S. Krakowiak, A. Mos, N. De Palma, V. Quéma, and J.-B. Stefani. Architecture-Based Autonomous Repair Management: An Application to J2EE Clusters, *Proc. 24th IEEE Symposium on Reliable Distributed Systems (SRDS 2005)*, Orlando, FL, USA, October 2005.
    - S. Sicard, F. Boyer, N. De Palma. Using Components for Architecture-based Management: the Self-repair Case, *Proc. International Conference on Software Engineering (ICSE 2008)*, Leipzig, Germany, May 2008
  - The following presentation is mainly based on the last paper
    - Thanks to the authors

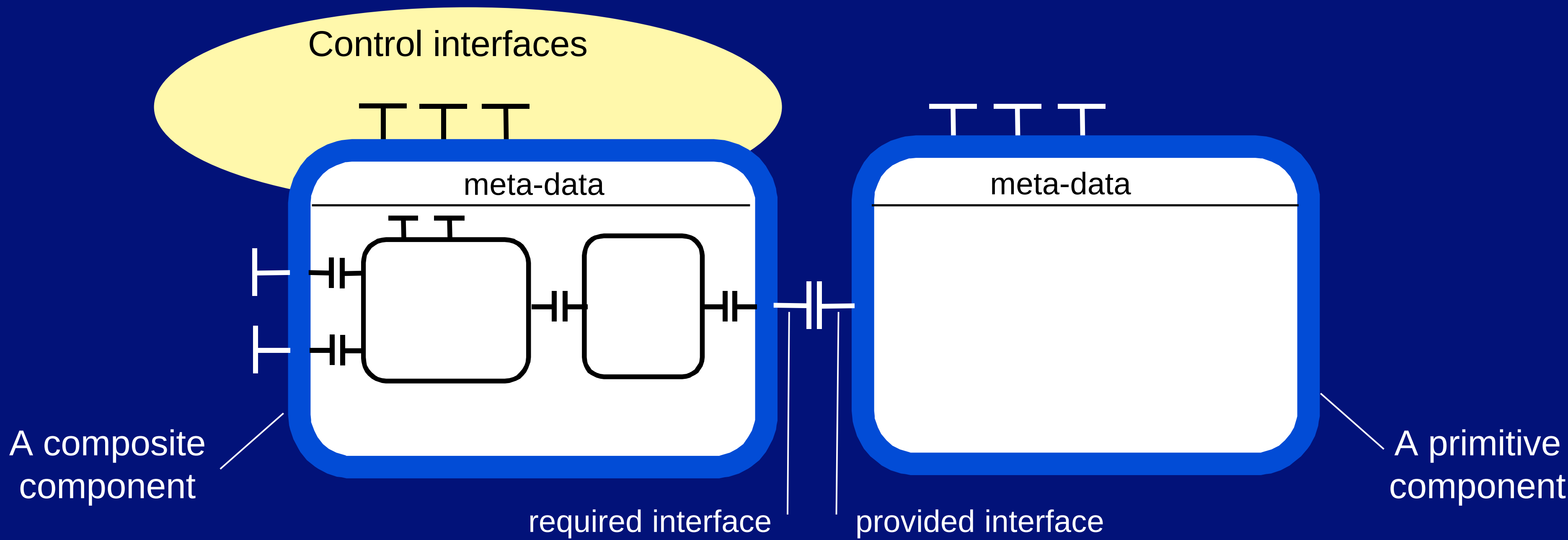
Fractal, a reflective component model

- Main features
  - A general component model, allows hierarchical composition and sharing
  - Three sorts of interfaces: provided, required, and control (meta—level)
  - Components are run time structures
  - High—level architectural description through an ADL



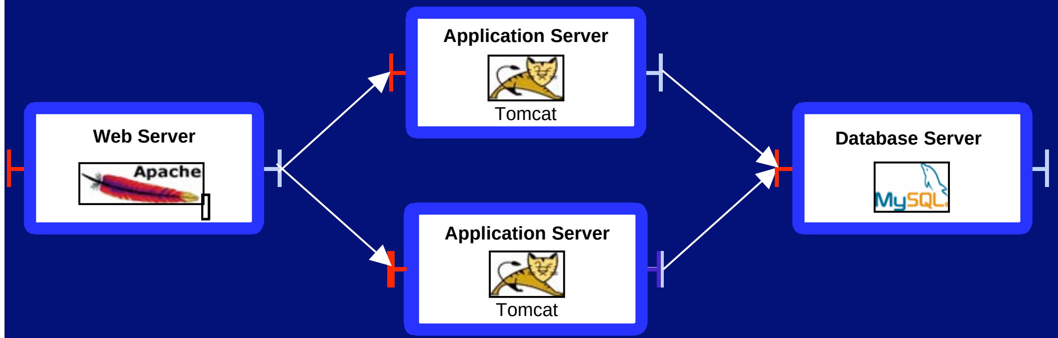
Fractal, a reflective component model

- Main features
  - A general component model, allows hierarchical composition and sharing
  - Three sorts of interfaces: provided, required, and control (meta—level)
  - Components are run time structures
  - High—level architectural description through an ADL
- The meta—level interface
  - Attribute controller: read/modify the state variables
  - Life cycle controller: start, stop
  - Binding controller: manages connections
  - Contents controller: manages included components
  - This list is optional and extensible



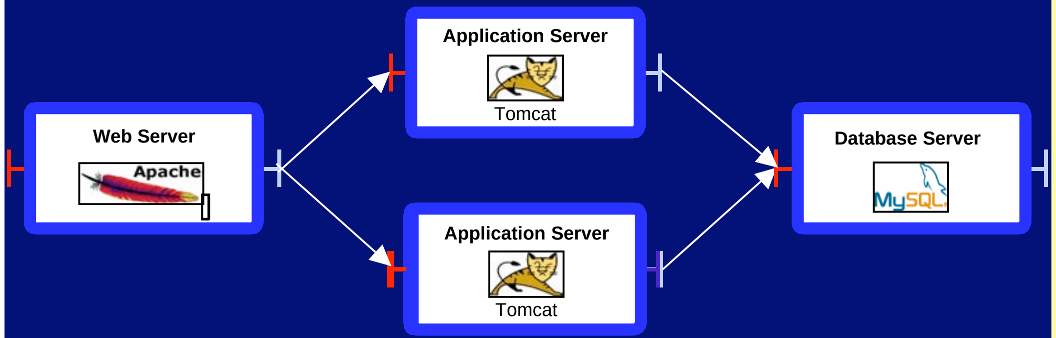
Fractal ADL

A J2EE 3-tier application



Fractal ADL

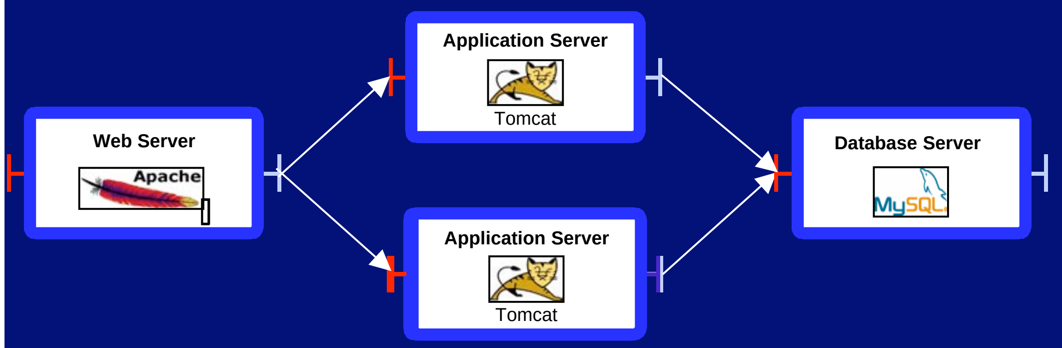
A J2EE 3-tier application




```xml
<!-- ==================================   -->
<!-- J2EE ARCHITECTURE                    -->
<!-- ==================================   -->
< component name="MyJ2EE">
 definition="fr.jade.resource.j2ee.J2eeResourceType">
<!-- ==================================   -->
<!-- APACHE                               -->
<!-- ==================================   -->
<component name="apache1"
    definition="fr.jade.resource.j2ee.apache.ApacheResourceType">
 <attributes>
    <attribute name="resourceName" value="apache" />
    <attribute name="dirLocal" value="/tmp/j2ee" />
    <attribute name="user" value=admin" />
    <attribute name="group" value="admin" />
    <attribute name="port" value="8081" />
    <attribute name="serverAdmin" value="  jade_admin@inrialpes.fr" />
 </attributes>
 <virtual-node name="node1" />
 <packages>
    <package name="Apache HTTP server v1.3.29 (linux x86)" />
    <package name="Apache Wrapper" />
 </packages>
</component>
```

Fractal ADL

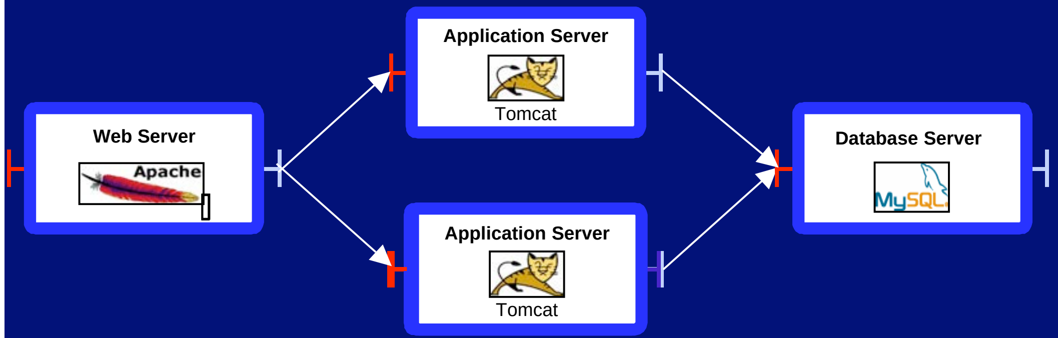
A J2EE 3-tier application




```
-- ==================================    -->
<!-- TOMCATS                             -->
<!-- ==================================    -->
<component name="tomcat1"
    definition="fr.jade.resource.j2ee.tomcat.TomcatResourceType">
    <attributes>
        <attribute name="resourceName" value="tomcat1" />
        <attribute name="dirLocal" value="/tmp/j2ee" />
        <attribute name="javaHome" value="/usr/local/java/jdk1.5.0_05" />
        <attribute name="workerPort" value="8098" />
    </attributes>
    <virtual-node name="node1" />
    <packages>
        <package name="Tomcat (linux x86)" />
        <package name="Tomcat Wrapper" />
    </packages>
</component>
<component name="tomcat2"
    definition="fr.jade.resource.j2ee.tomcat.TomcatResourceType">
    <attributes>
        <attribute name="resourceName" value="tomcat2" />
        <attribute name="dirLocal" value="/tmp/" />
        <attribute name="javaHome" value="/usr/local/java/jdk1.5.0_05" />
        <attribute name="workerPort" value="8099" />
    </attributes>
    <virtual-node name="node2" />
    <packages>
        <package name="Tomcat (linux x86)" />
        <package name="Tomcat Wrapper" />
    </packages>
</component><!--
```

Fractal ADL

A J2EE 3-tier application



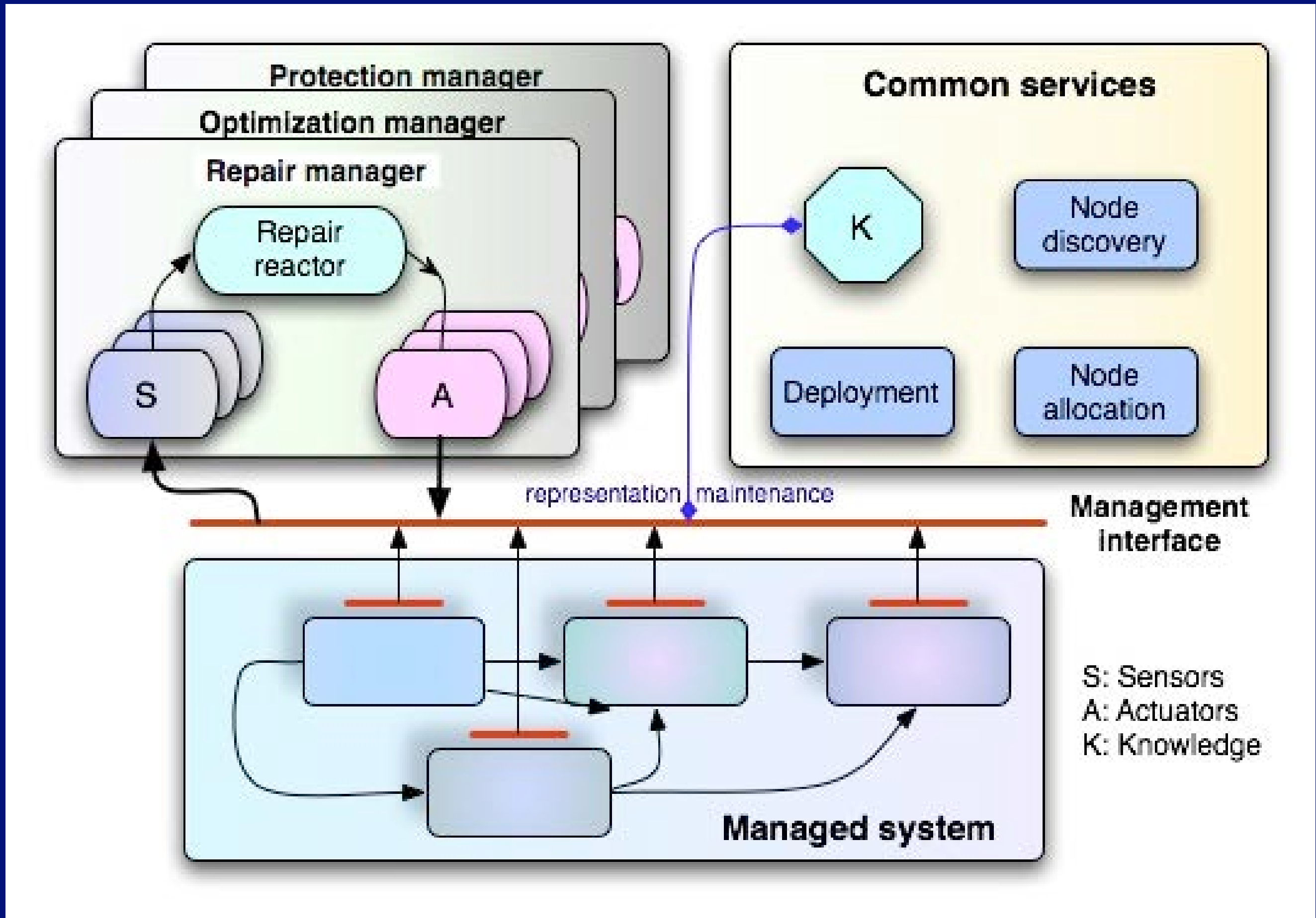

```
<!-- MYSQL                              -->
<!-- ================================== -->
<component name="mysql"
definition="fr.jade.resource.j2ee.mysql.MysqlResourceType">
    <attributes>
        <attribute name="resourceName" value="mysql" />
        <attribute name="dirLocal" value="/tmp/j2ee" />
        <attribute name="user" value="jlegrand" />
    </attributes>
    <virtual-node name="node1" />
    <packages>
        <package name="MySql (linux x86)" />
        <package name="MySql Wrapper" />
    </packages>
</component>
<!-- ================================== -->
<!-- BINDINGS                           -->
<!-- ================================== -->
    <binding client="apache.worker1" server="tomcat1.resource" />
    <binding client="apache.worker2" server="tomcat2.resource" />
    <binding client="tomcat1.jdbc" server="mysql.resource" />
    <binding client="tomcat2.jdbc" server="mysql.resource" />
    <virtual-node name="node1" />
</definition>
```

An overview of Jade

Both the managed system and Jade itself are organized as as an assembly of Fractal components.

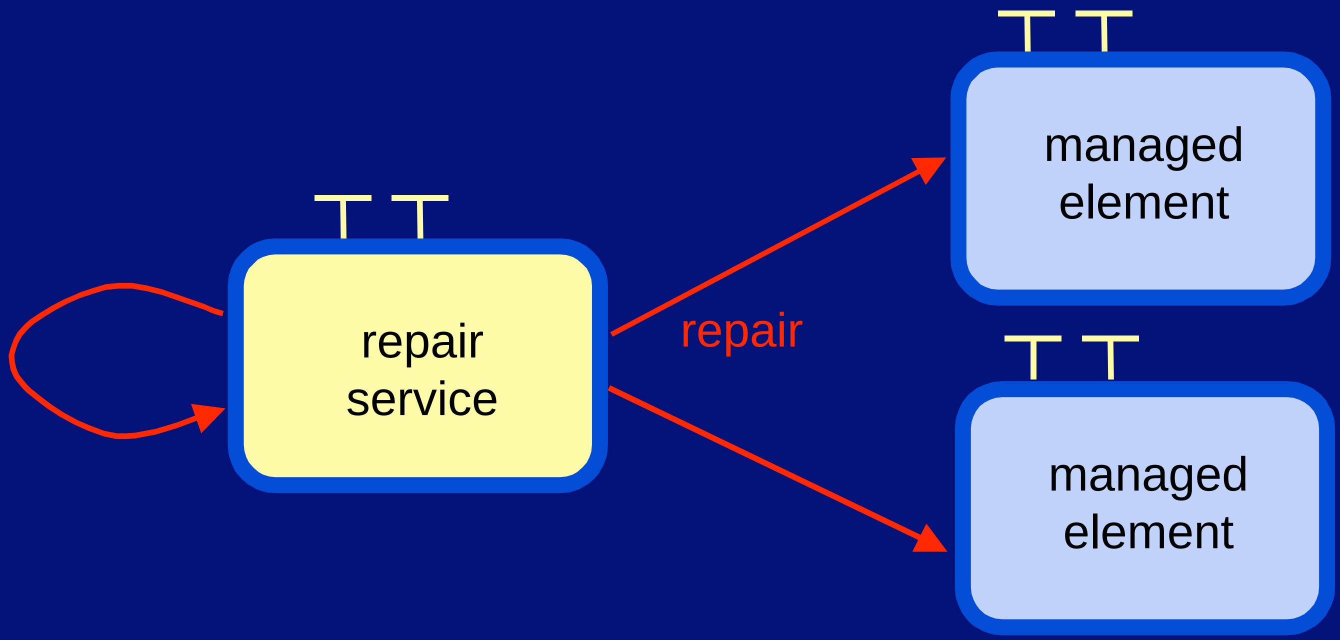
To manage legacy systems, one needs to wrap them into Fractal components.

The architecture of the managed system is described in Fractal ADL



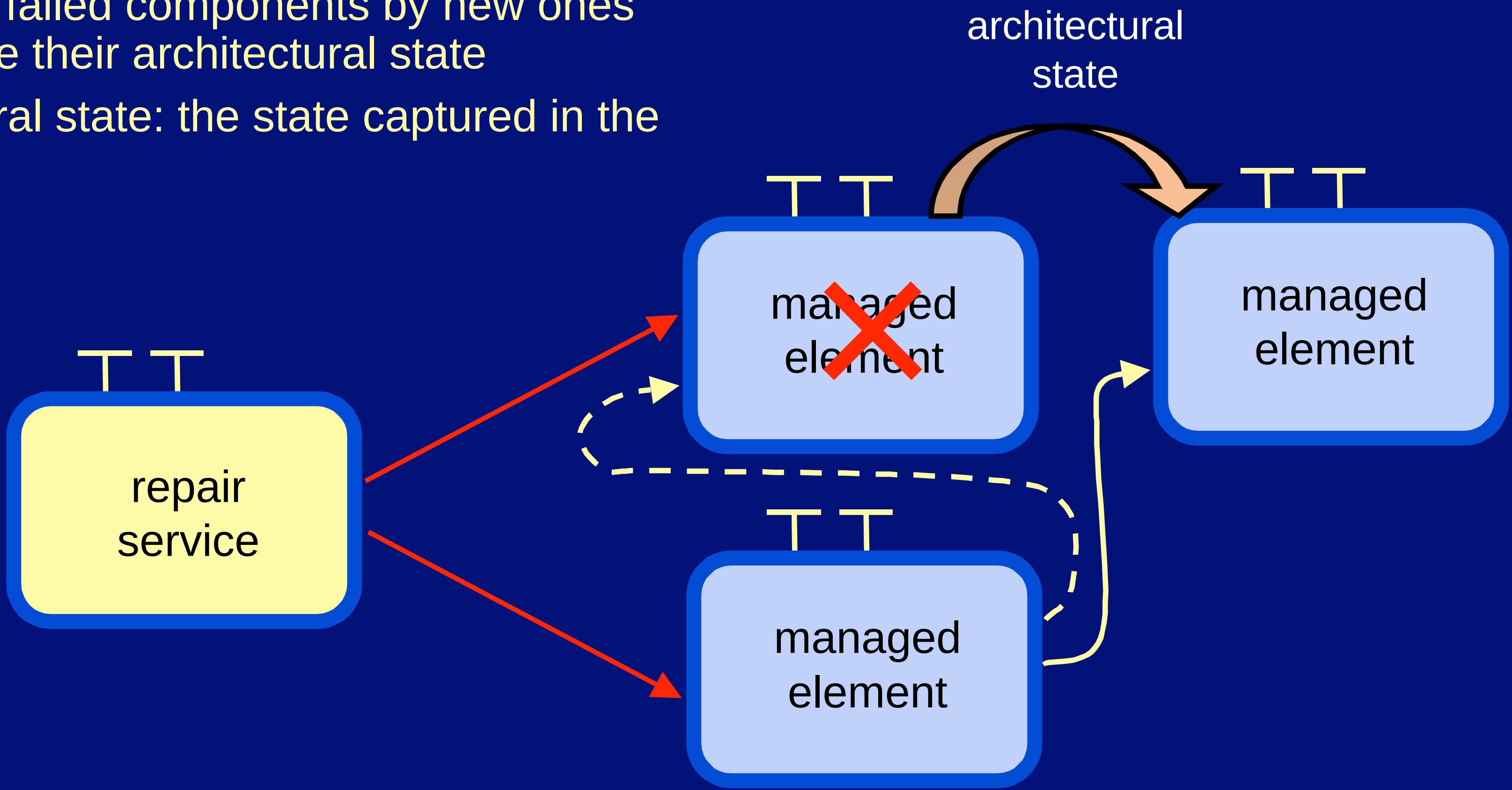
The Jade self-repair service

- Assumptions
  - The managed system runs on a cluster of nodes (with a pool of free nodes)
  - In this version, only node failures (fail-stop) are considered
- Objectives
  - To provide self-repair for the managed system
  - To provide self-repair for the self-repair service (self-self-repair)



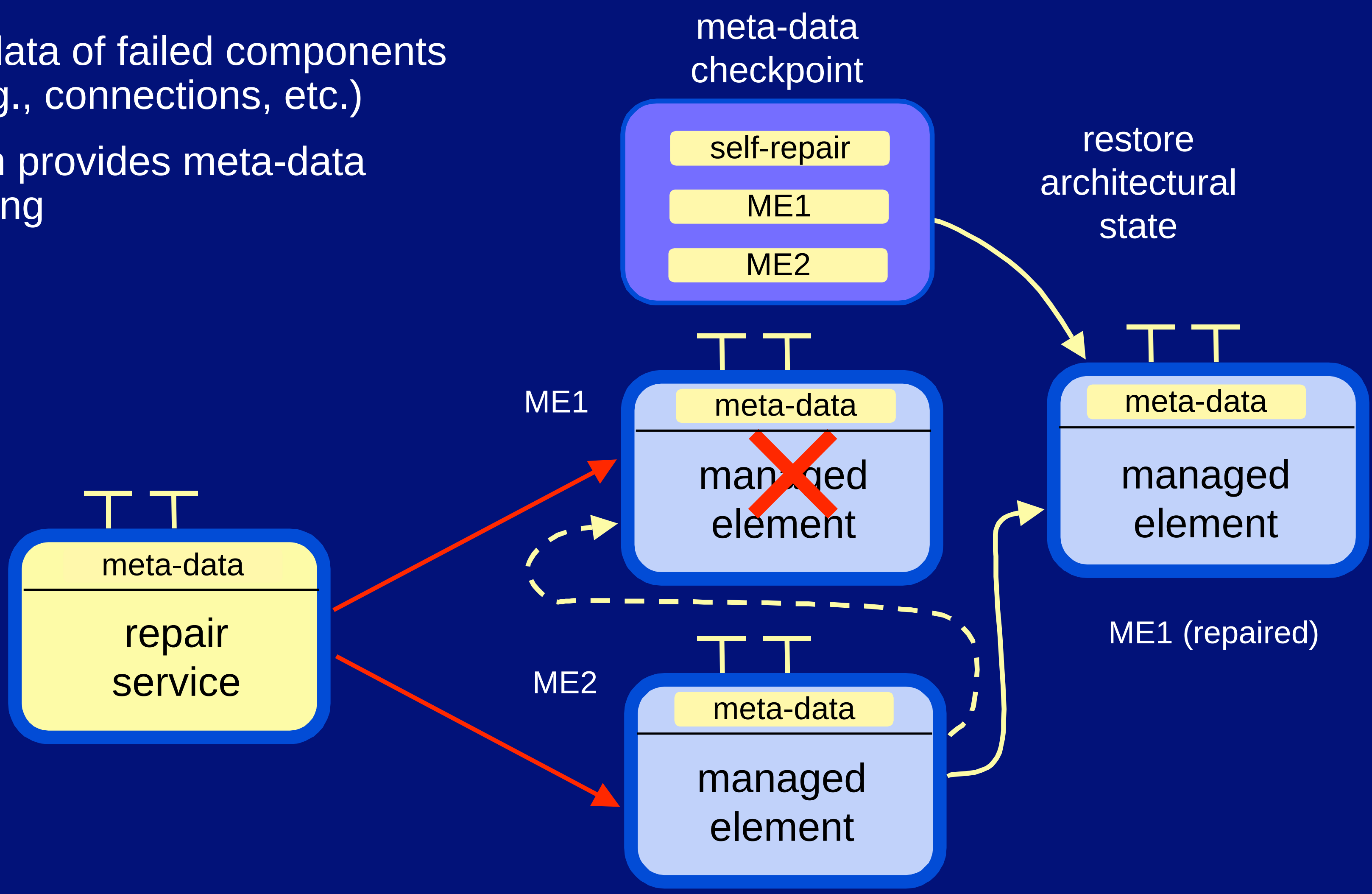
Self-repair principles

- Repair policy
  - Identify failed components and get their architectural state
  - Substitute failed components by new ones and restore their architectural state
  - Architectural state: the state captured in the meta-data

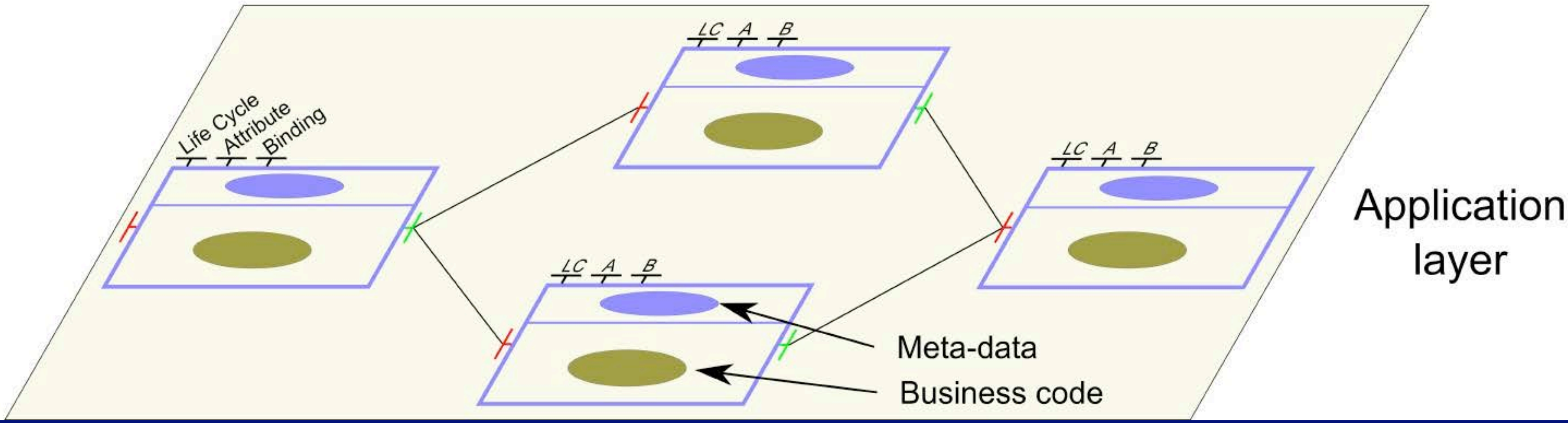


Checkpointing architectural state (1)

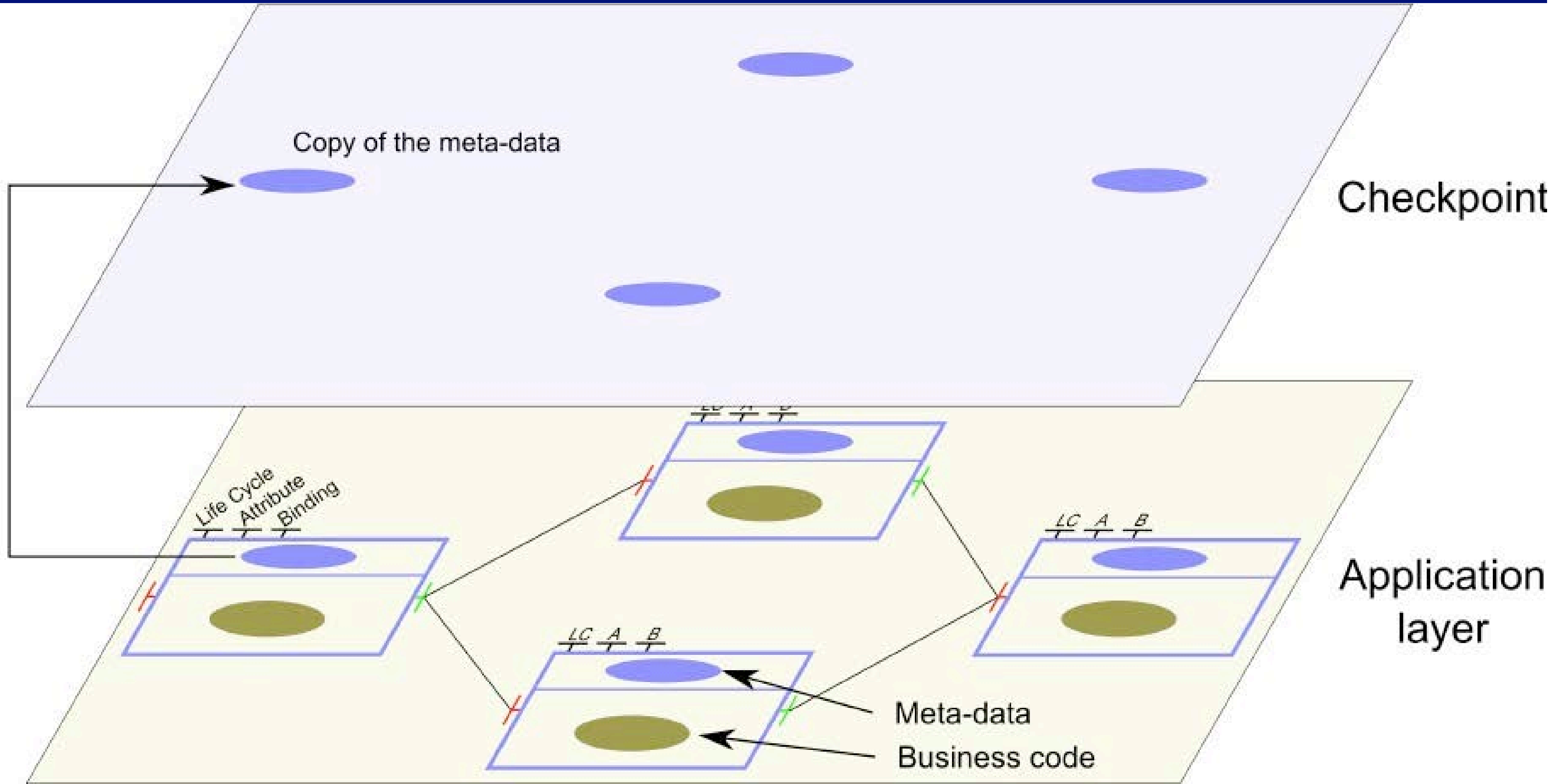
- The meta-data of failed components are lost (e.g., connections, etc.)
- The system provides meta-data checkpointing



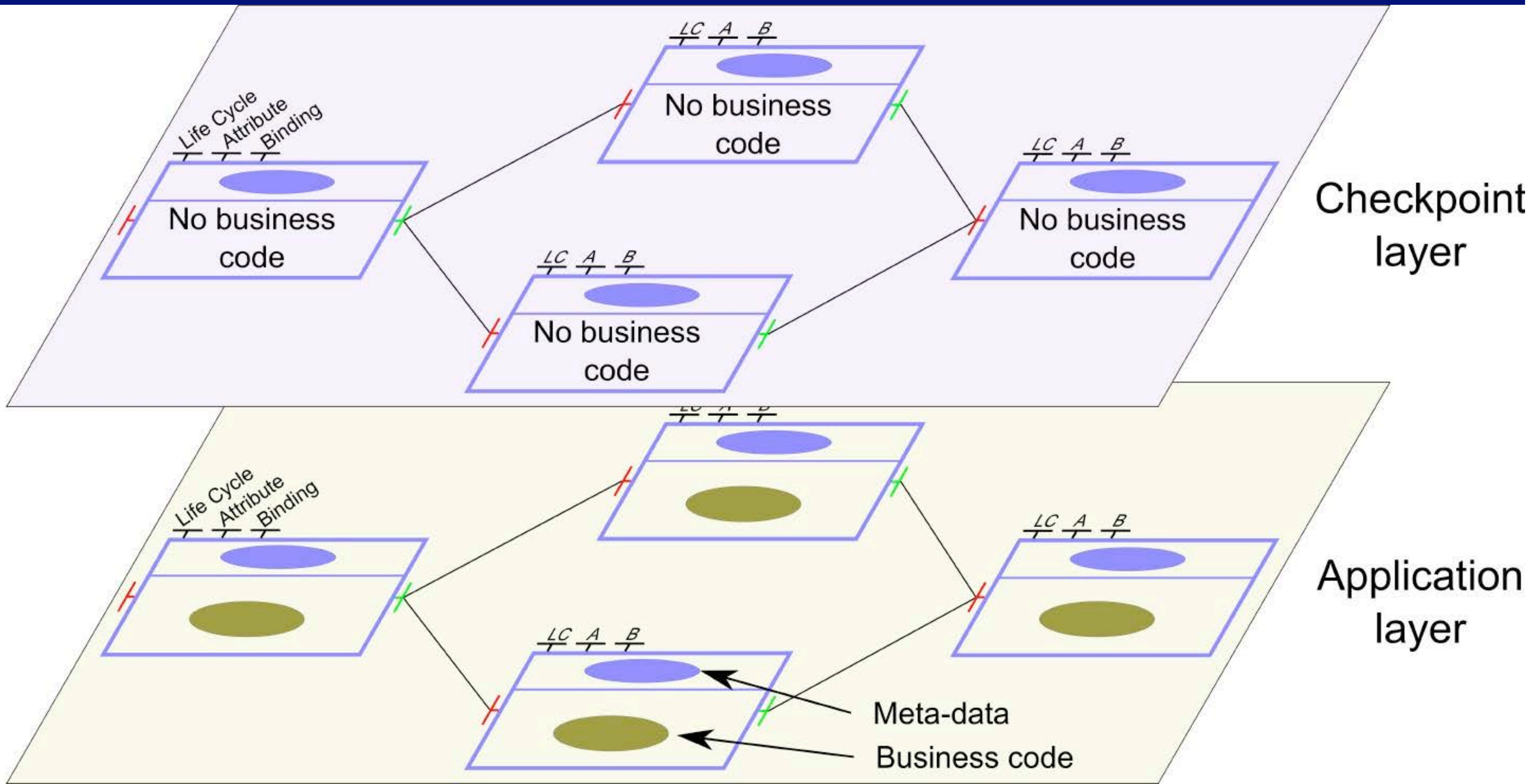
Checkpointing architectural state (2)



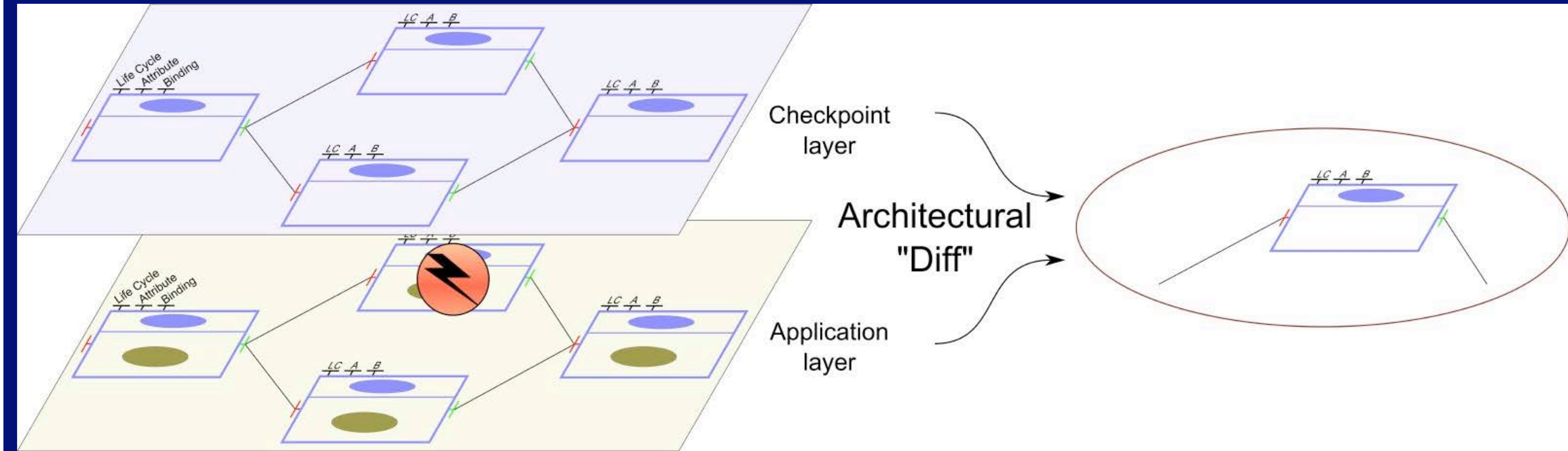
Checkpointing architectural state (2)



Checkpointing architectural state (2)



Failure analysis



Failed components are identified by comparing the current state of the layer with the checkpointed state
The current state is maintained using usual failure detection techniques (heartbeat)

Making the self-repair system robust (1)

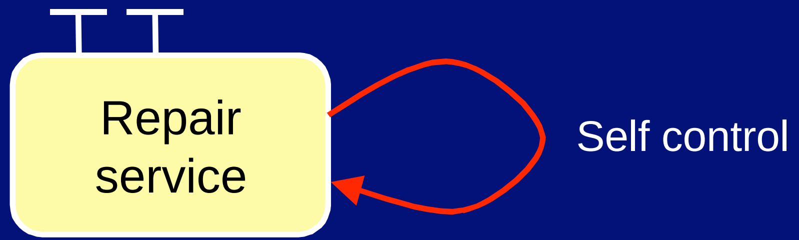
- Bases of self-repair
  - Reflective components
  - Architectural state checkpointing
  - Failure detection
- The self-repair system itself is a single point of failure…
- Self-self-repair
  - The same algorithm is applied recursively
  - This is possible since the self-repair system is structured in reflective components
  - Recursion stops at this level (no self-self-self repair…)

Making the self-repair system robust (2)

- Apply the repair algorithm on the components of self-repair system

Making the self-repair system robust (2)

- Apply the repair algorithm on the components of self-repair system
- Conceptual view



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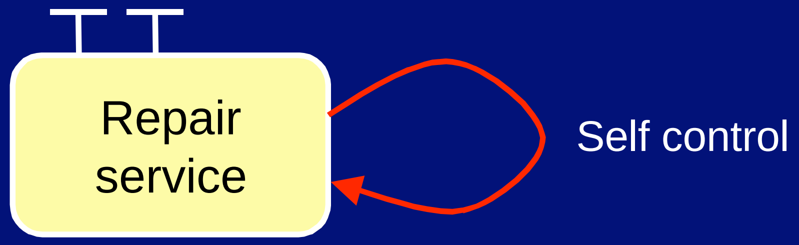
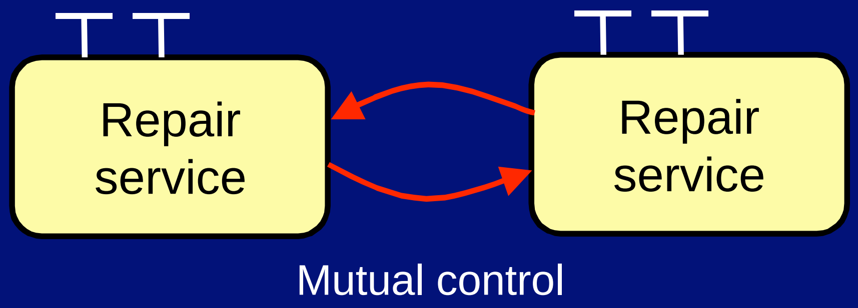


- Implementation view



Making the self-repair system robust (2)

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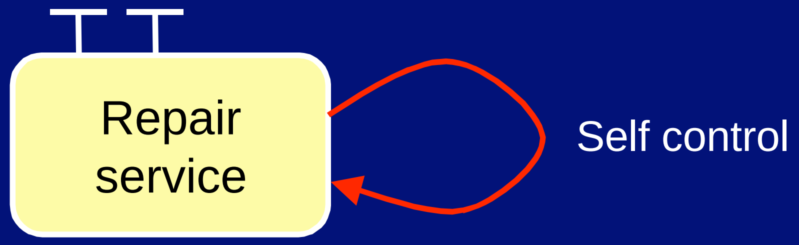

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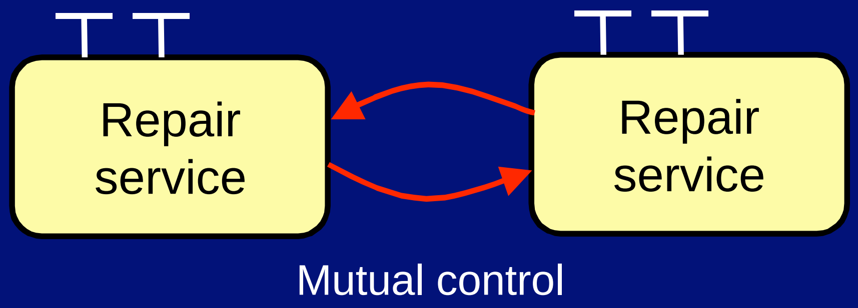
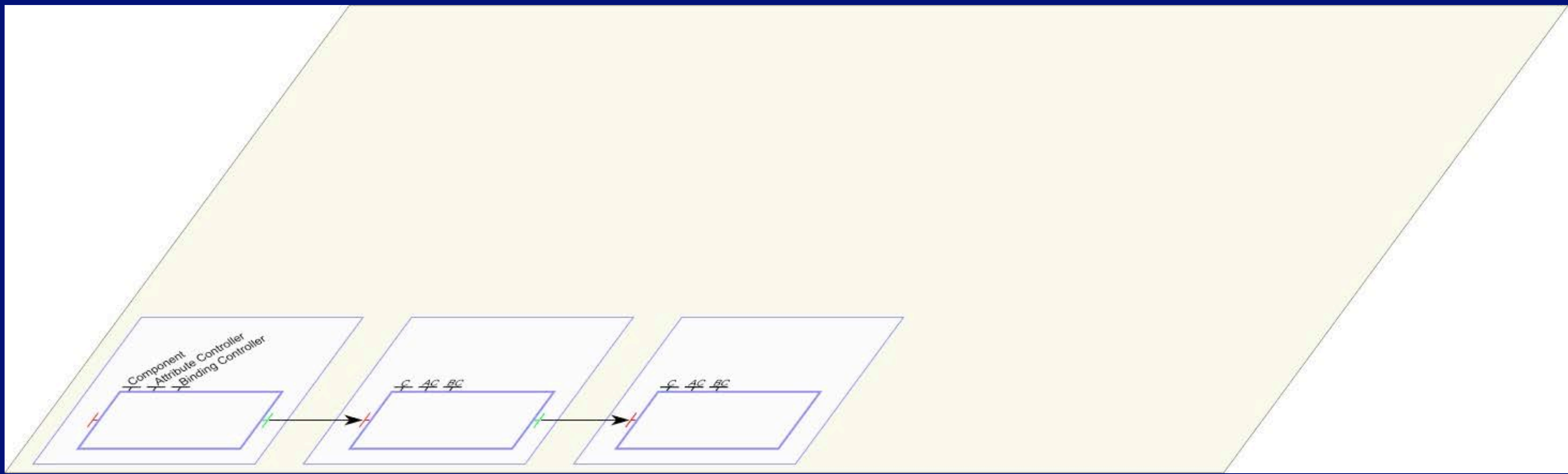


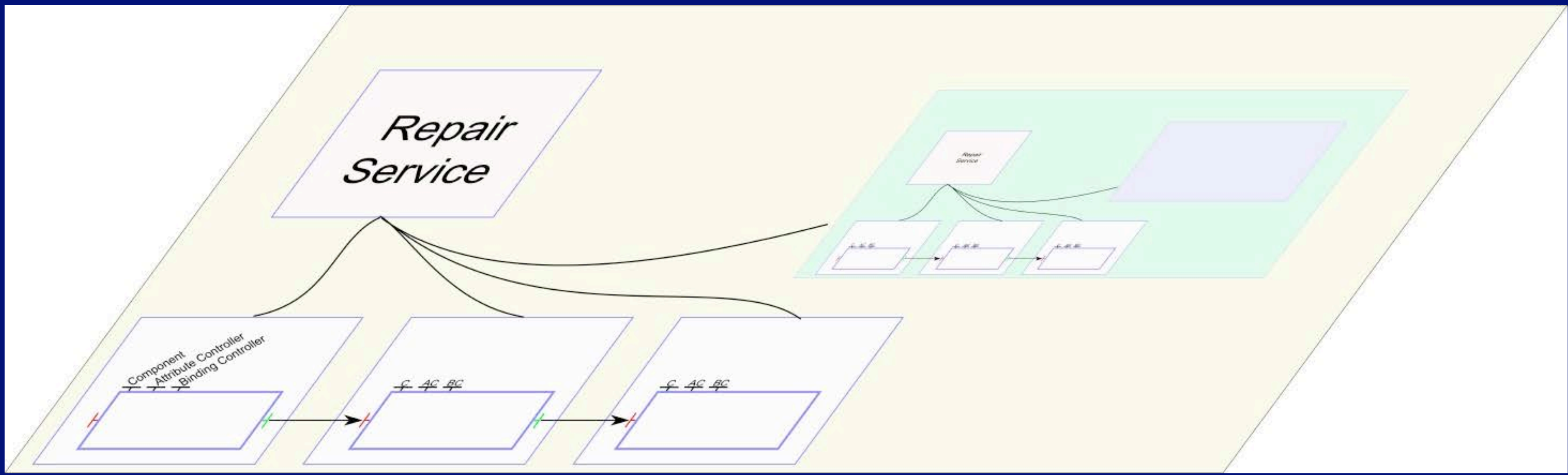
- Mutual control of replicas
  - Similar to classical process pairs (Tandem, etc.)
  - Each replica works as a component

Putting it all together



The managed application

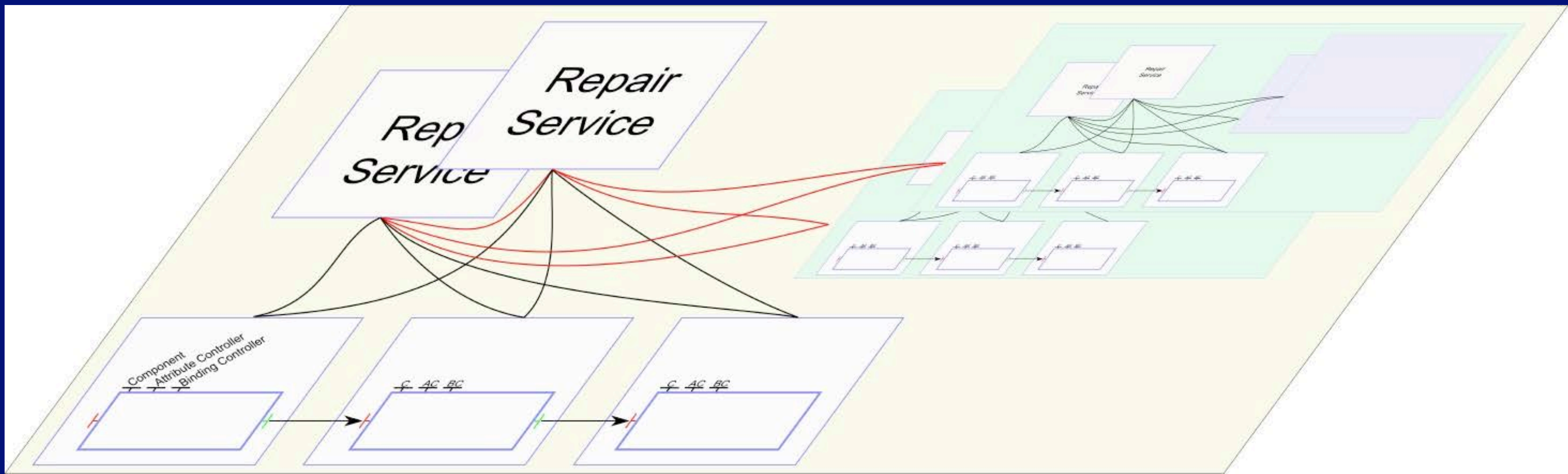
Putting it all together



The managed application

The self-repair service and the checkpoint layer

Putting it all together

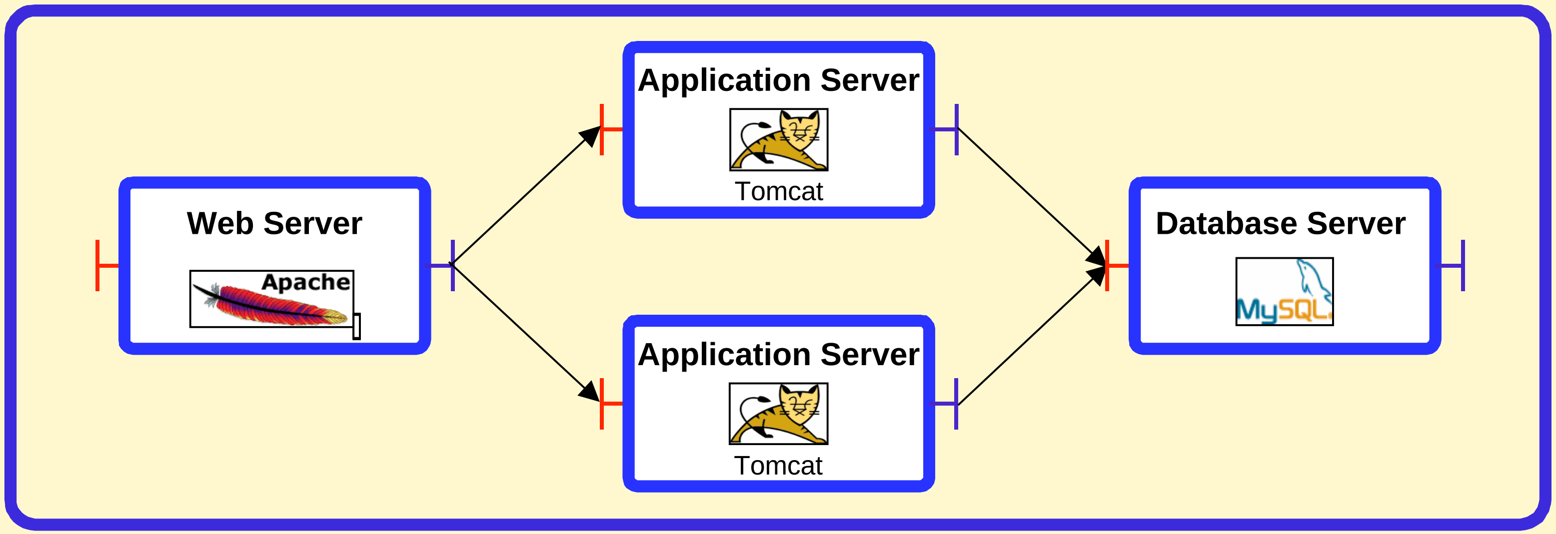


The managed application

The self-repair service and the checkpoint layer

Self self-repair

The repair algorithm in action



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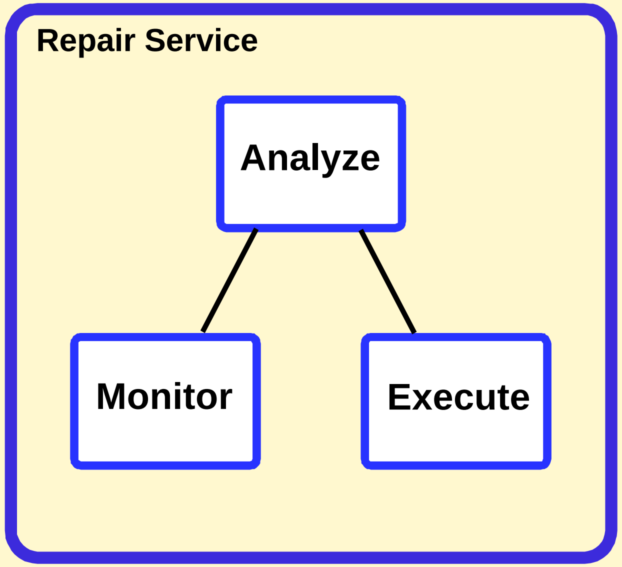

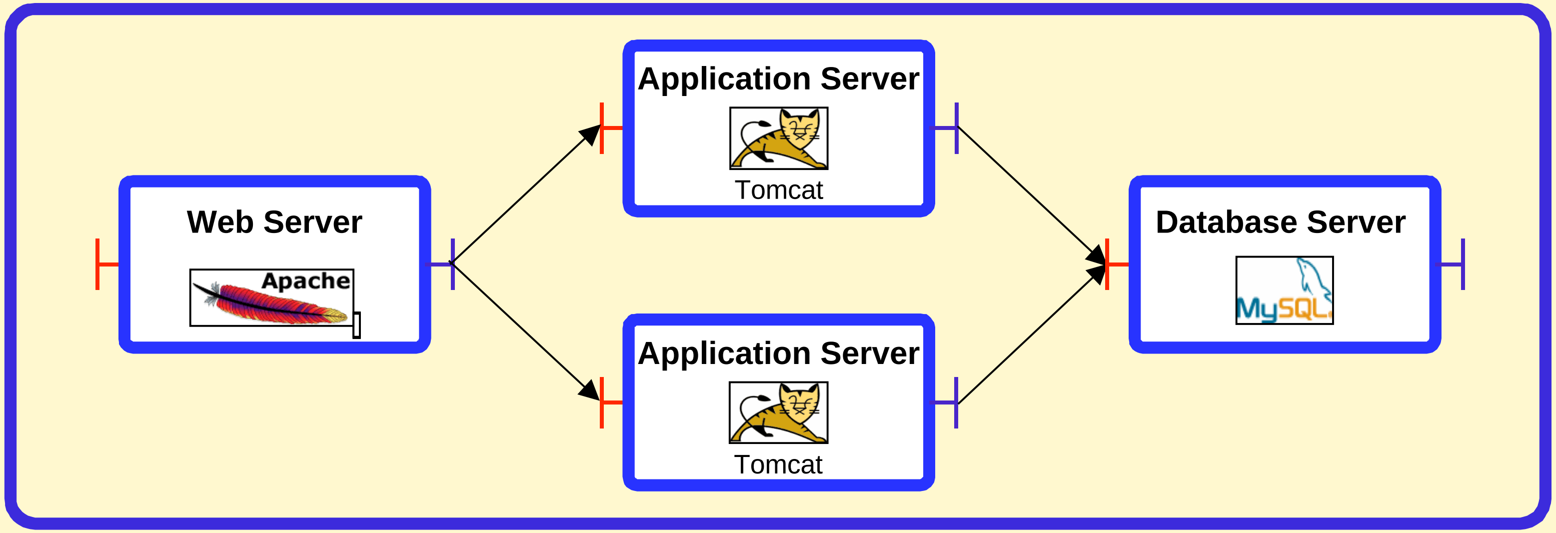

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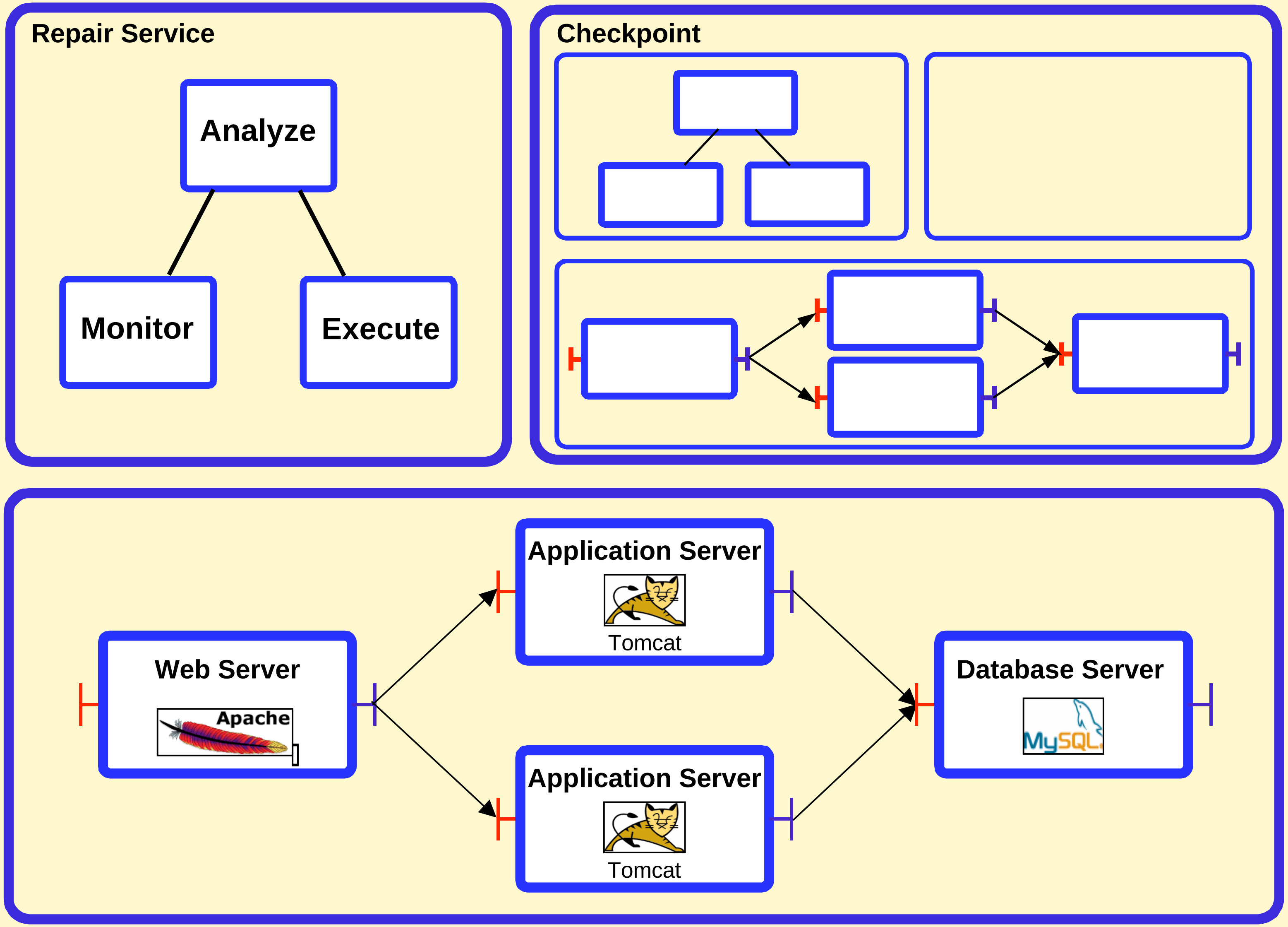

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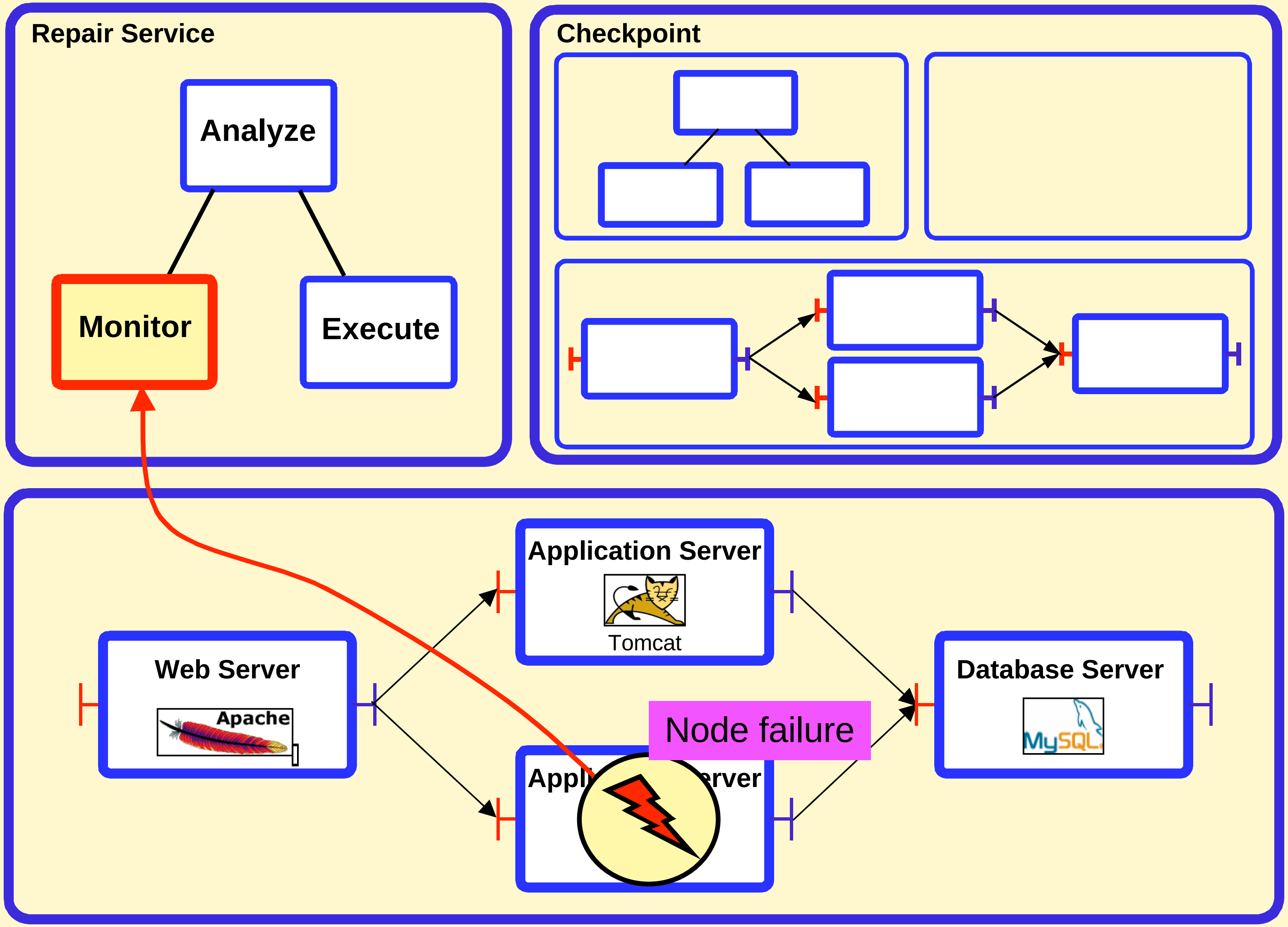

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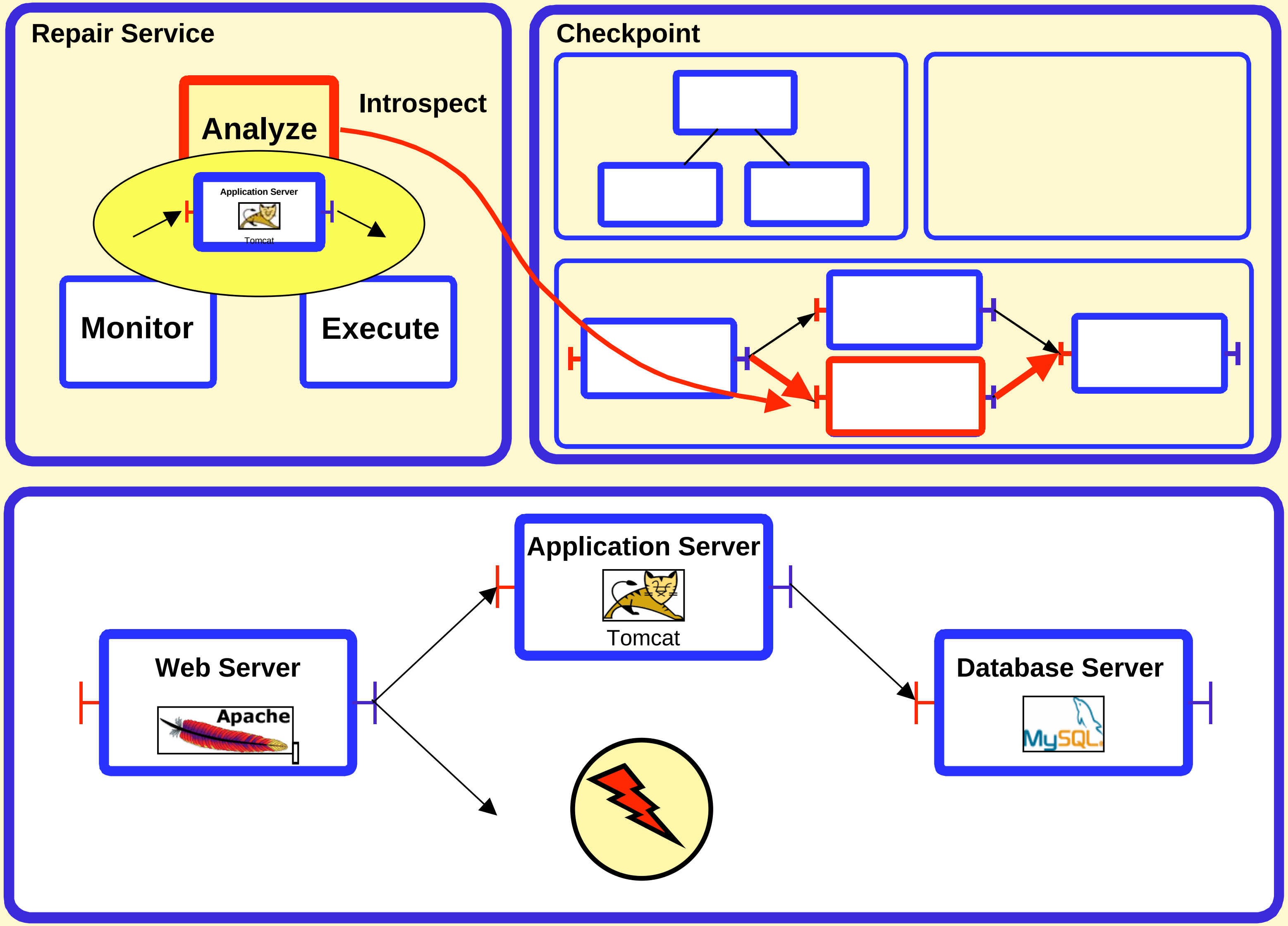

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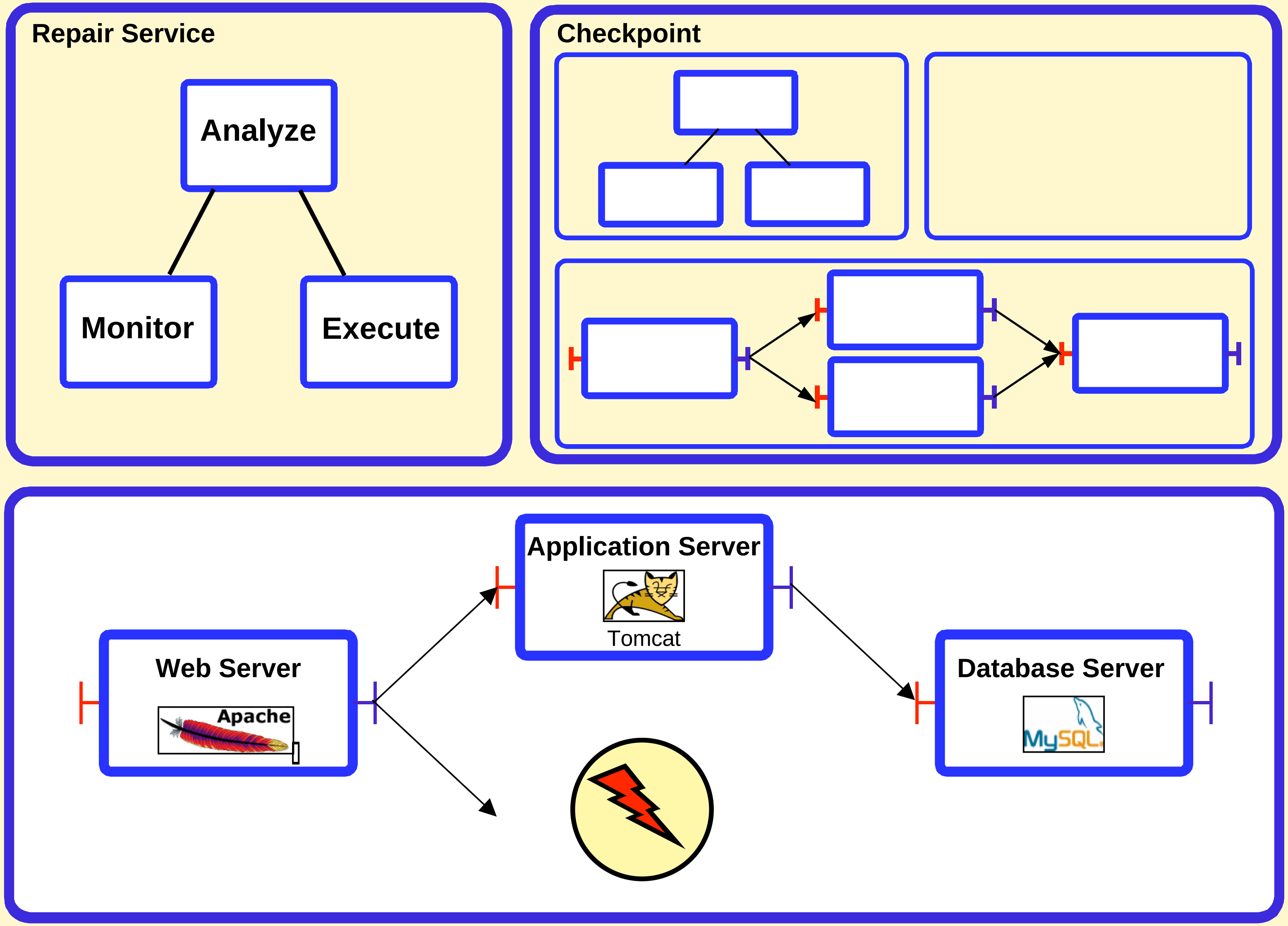

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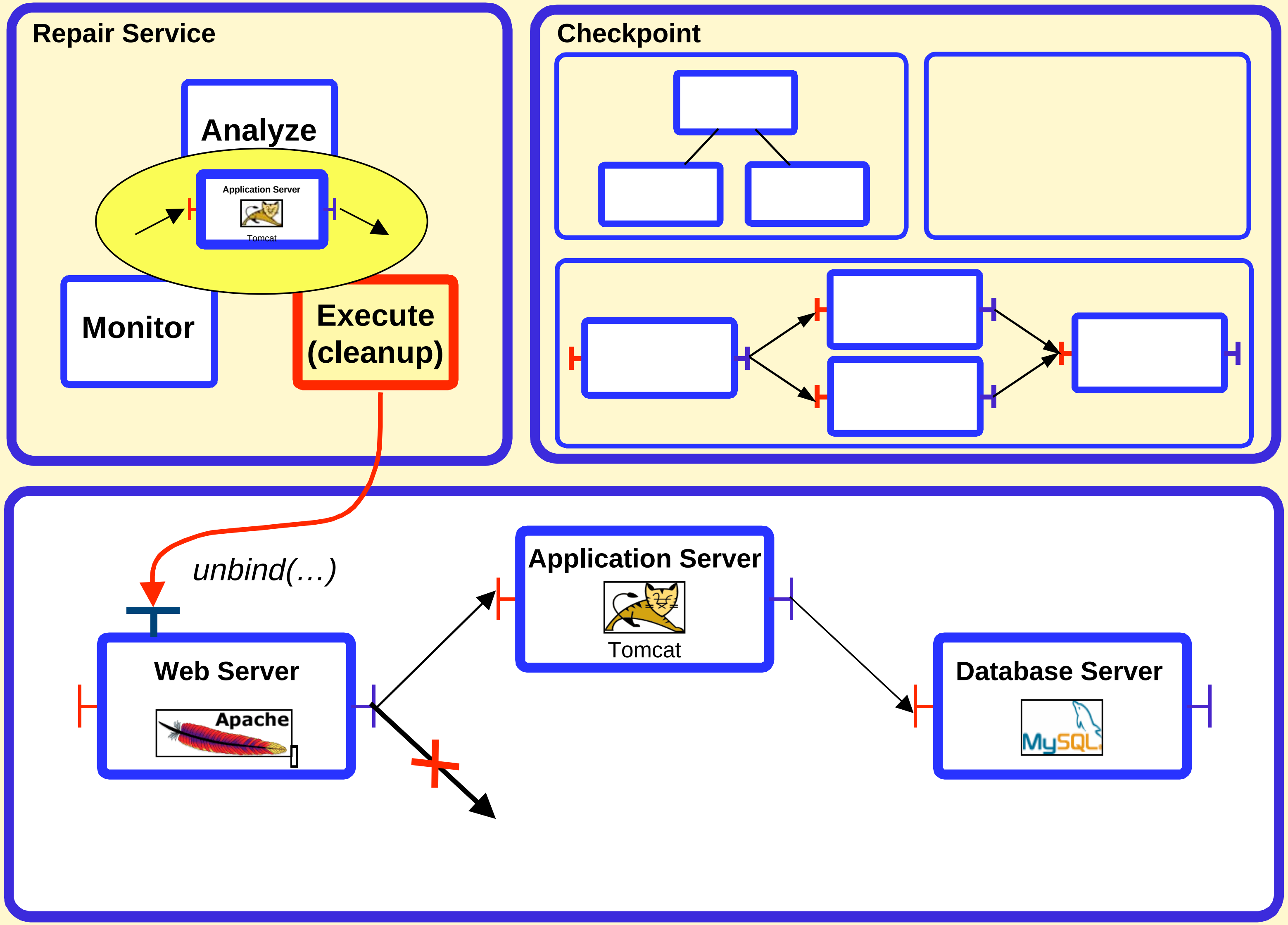

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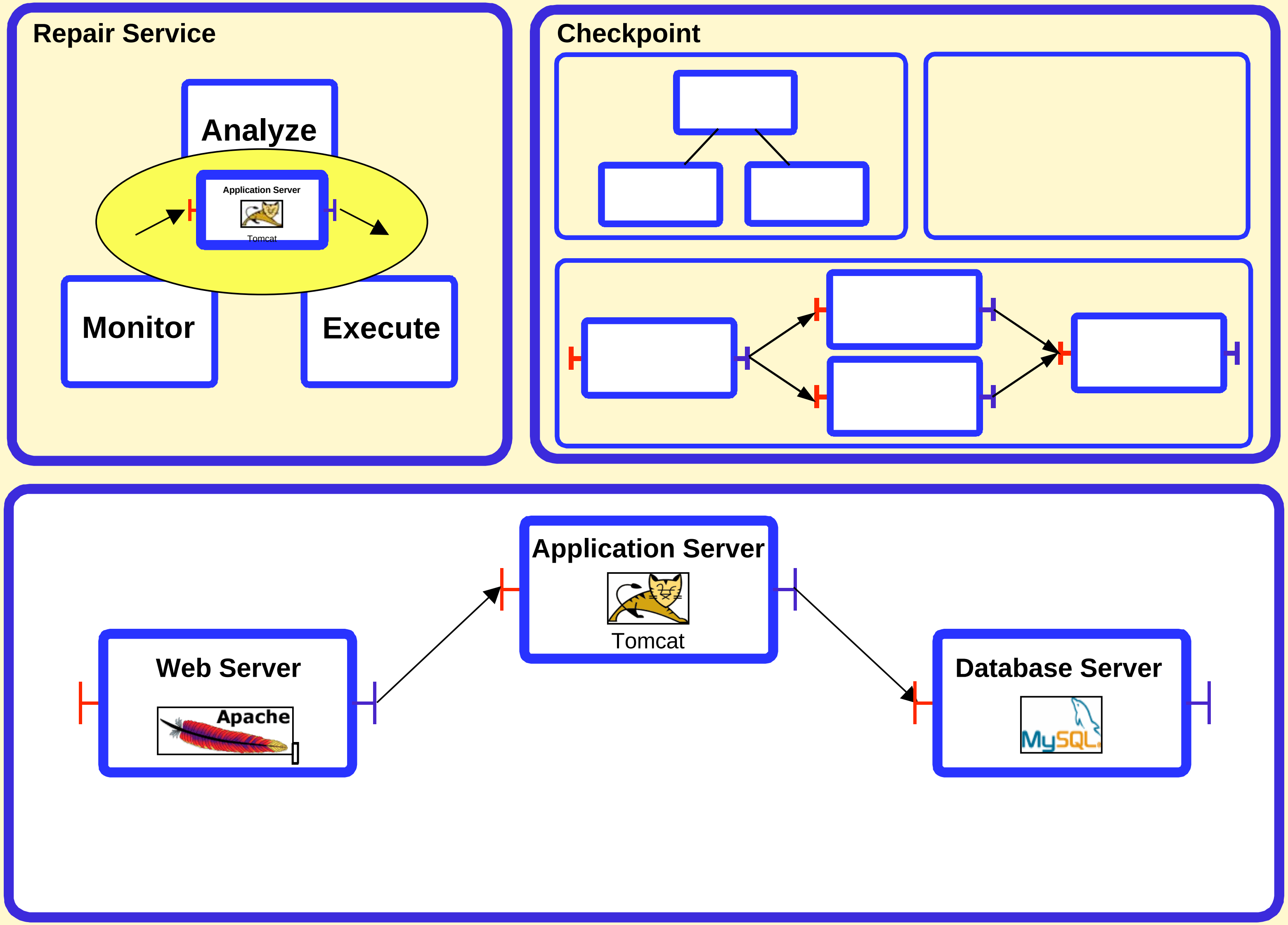

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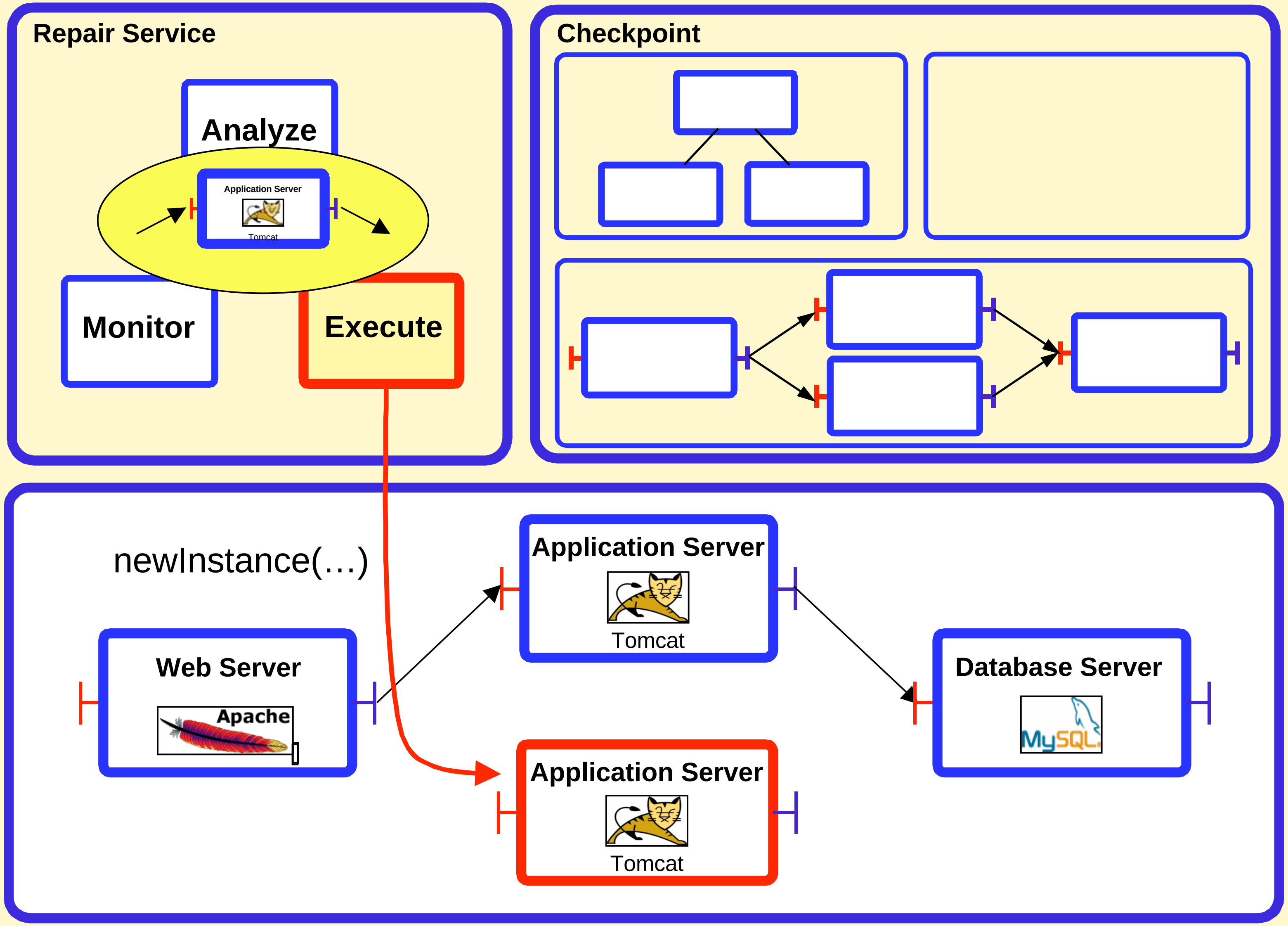

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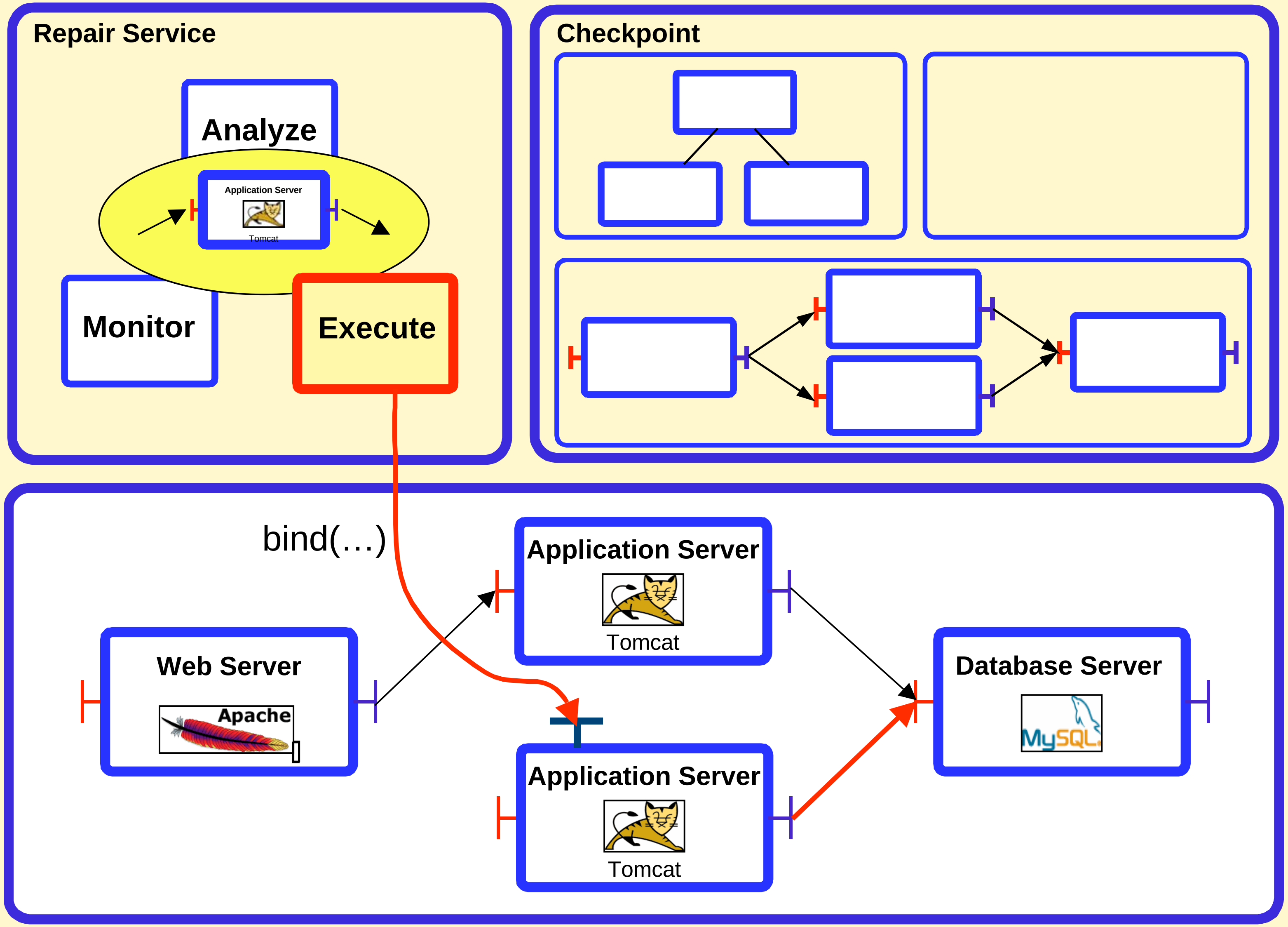

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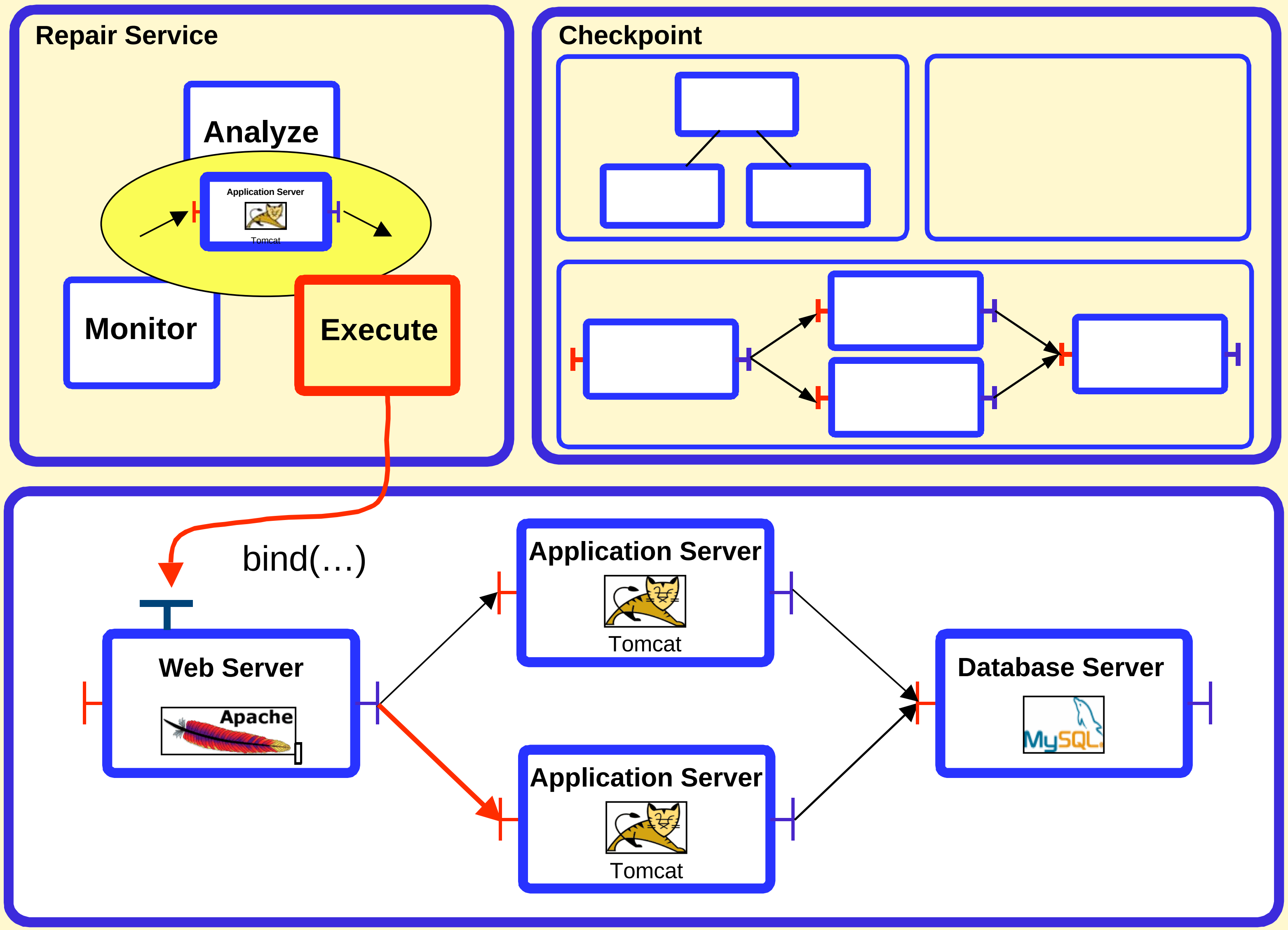

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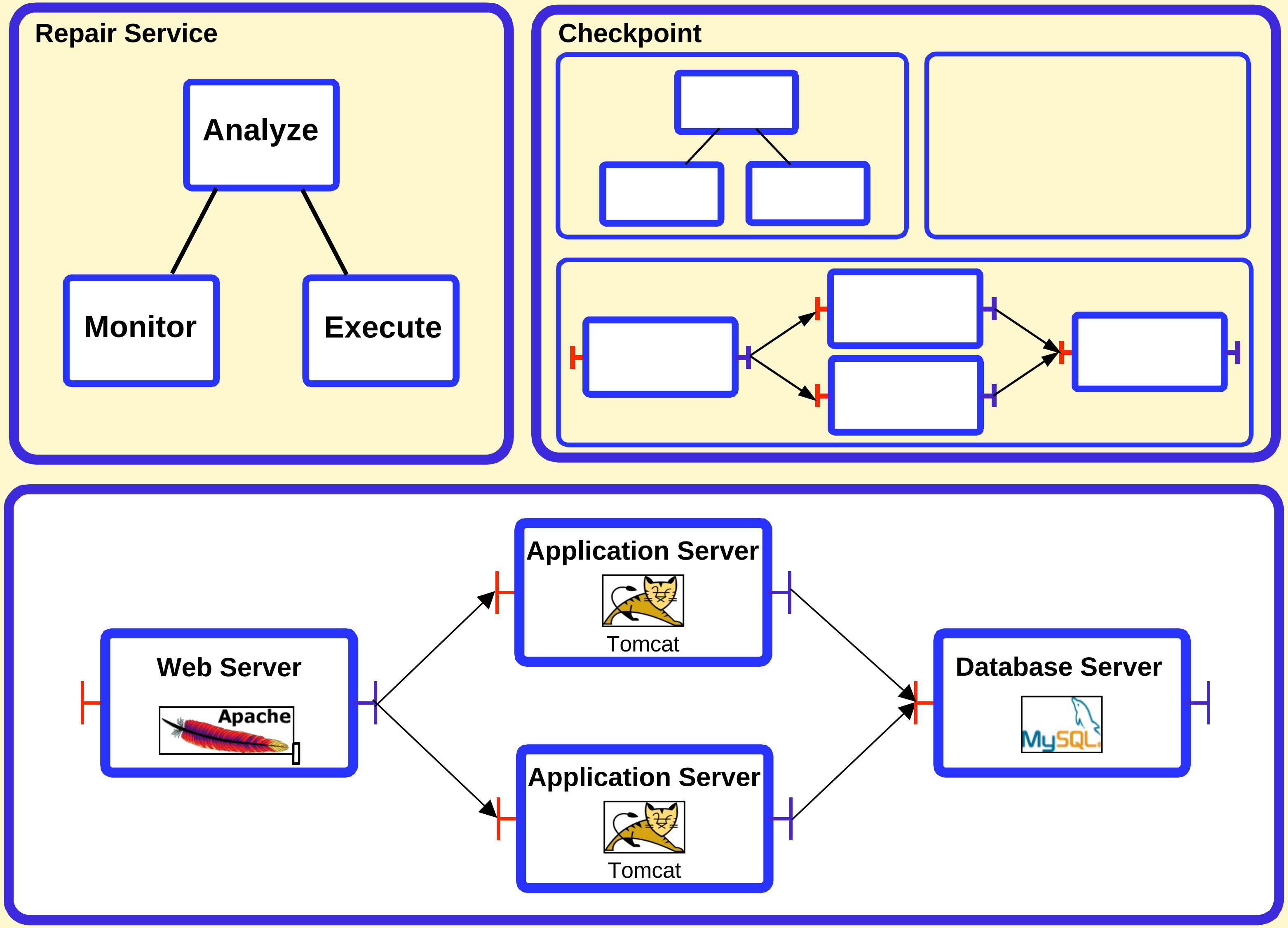

Self-repair summary

- Main results
  - Architecture-based repair is feasible
    - Components as units of confinement
  - Reflection is important (inspection / reconfiguration)
- Open issues
  - Efficient failure detection
    - in time and space
  - Handling dynamic architectures (e.g., mobile, etc.)
- Some related work
  - Rainbow (Carnegie Mellon Univ.)
    - a framework for architecture-based management
  - PinPoint / JAGR (ROC project, Berkeley-Stanford)
    - pinpointing software errors, repairing by micro-reboot
  - Partial availability
    - performability measures

Conclusion & Perspectives

- A new paradigm for systems management
  - Beyond the Manager-Agent model
- Main ingredients
  - Architectural system description
  - Reflection
    - both at component and architecture level
- Towards more formal models
- Towards a wider use of feedback control techniques

References

General

- e-book on Middleware (in progress): http://sardes.inrialpes.fr/~krakowia/MW-book
- Shaw, M. and Garlan, D. (1996). *Software Architecture: Perspectives on an Emerging Discipline*. Prentice Hall.
- van der Hoek, A., Heimbigner, D., and Wolf, A. L. (1998). Software Architecture, Configuration Management, and Configurable Distributed Systems: A Ménage à Trois. *Tech. Report CU-CS-849-98, Dept of Computer Science, Univ. of Colorado*, Boulder, Colo., USA.

Case studies

- SmartFrog: http://www.smartfrog.org/
- EDOS: http://www.edos-project.org/ see also Mancoosi: http://www.mancoosi.org/
- Nix: http://nixos.org/
- Jade: S. Sicard, F. Boyer, N. De Palma. Using Components for Architecture-based Management: the Self-repair Case, *Proc. International Conference on Software Engineering (ICSE 2008)*, Leipzig, Germany ; also http://sardes.inrialpes.fr/jade.html
- Rainbow: http://rainbow.self-adapt.org/