Autonomous Services and Workflows for Production Automation: *Managed Software Evolution*

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Examples from ongoing research as part of German Research Fund, Priority Programme (*Schwerpunktprogramm*) 1593:
„Design for Future: Managed Software Evolution“

LINKED EVOLUTION COMMUNITY FYPA2C

(Linked) Forever Young Production Automation with Active Components

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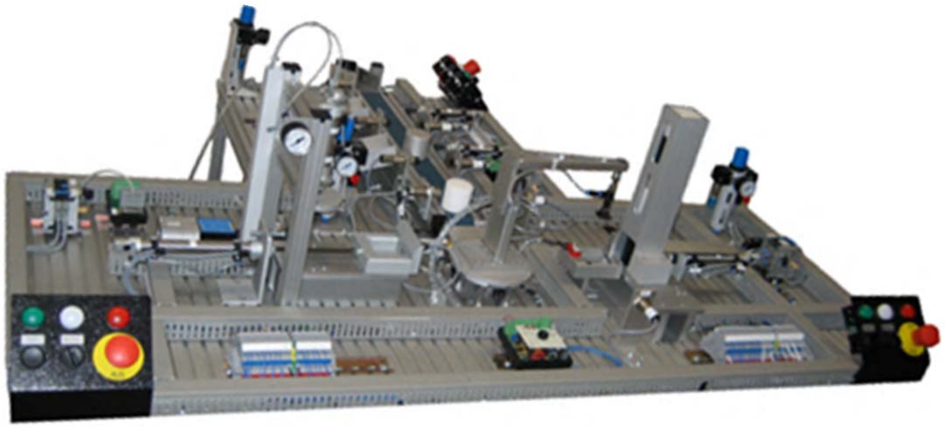
Services & Workflows for *Production Automation*

Example Application Area: **“Production Automation”:**

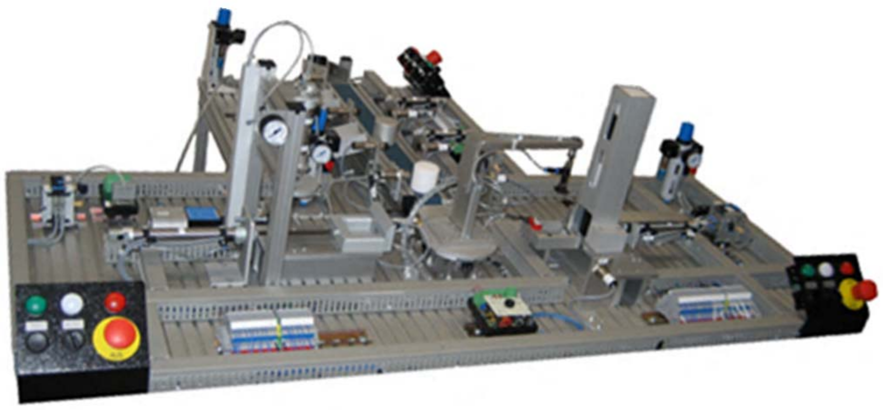
- Complex combination of hardware and software (“cyber-physical systems”)
- Hardware expensive and long-lasting
- Traditionally: little or only low-level software management
- Nowadays: increasingly software-driven (“Industry 4.0”)
- Software components represent (component) functionalities (“services”) & application (production) “workflows” (-> *“digital twin”*)



Example Application Scenario: *Production Automation*

Further characteristics of long-living applications such as “Production Automation”:

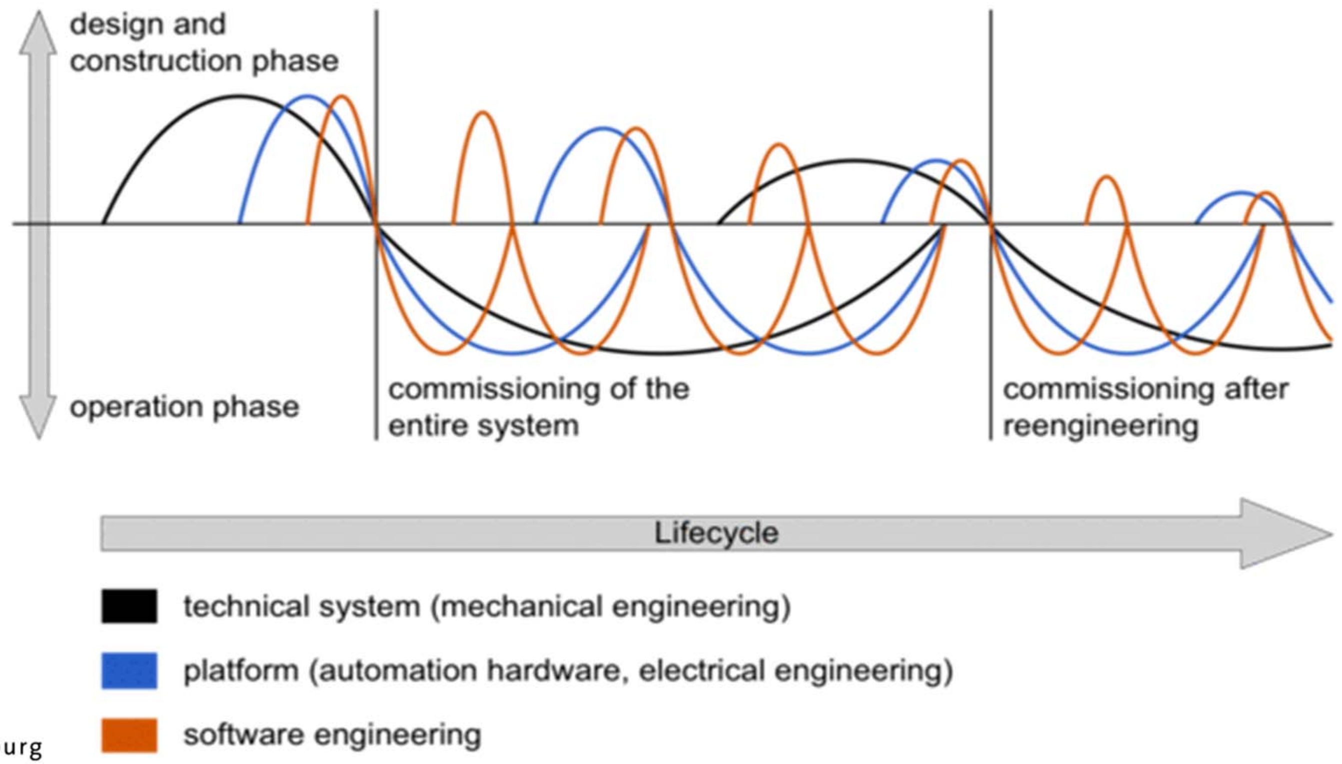
- Hardware changes occasionally (e.g. due to new/changed requirements)
- Software has to mirror that ASAP (often delayed/ done only partially/ forgotten…)
- **Question:** How to keep software – services as well as workflows – “in synch” with (changing) hardware components?
- **Goal:** coordinated development of hard- and software (system supported)
- Solution(?): “Autonomous” services & workflows which automatically “detect” such changes and then (also automatically?) “adapt” to them → **“Managed software evolution”**



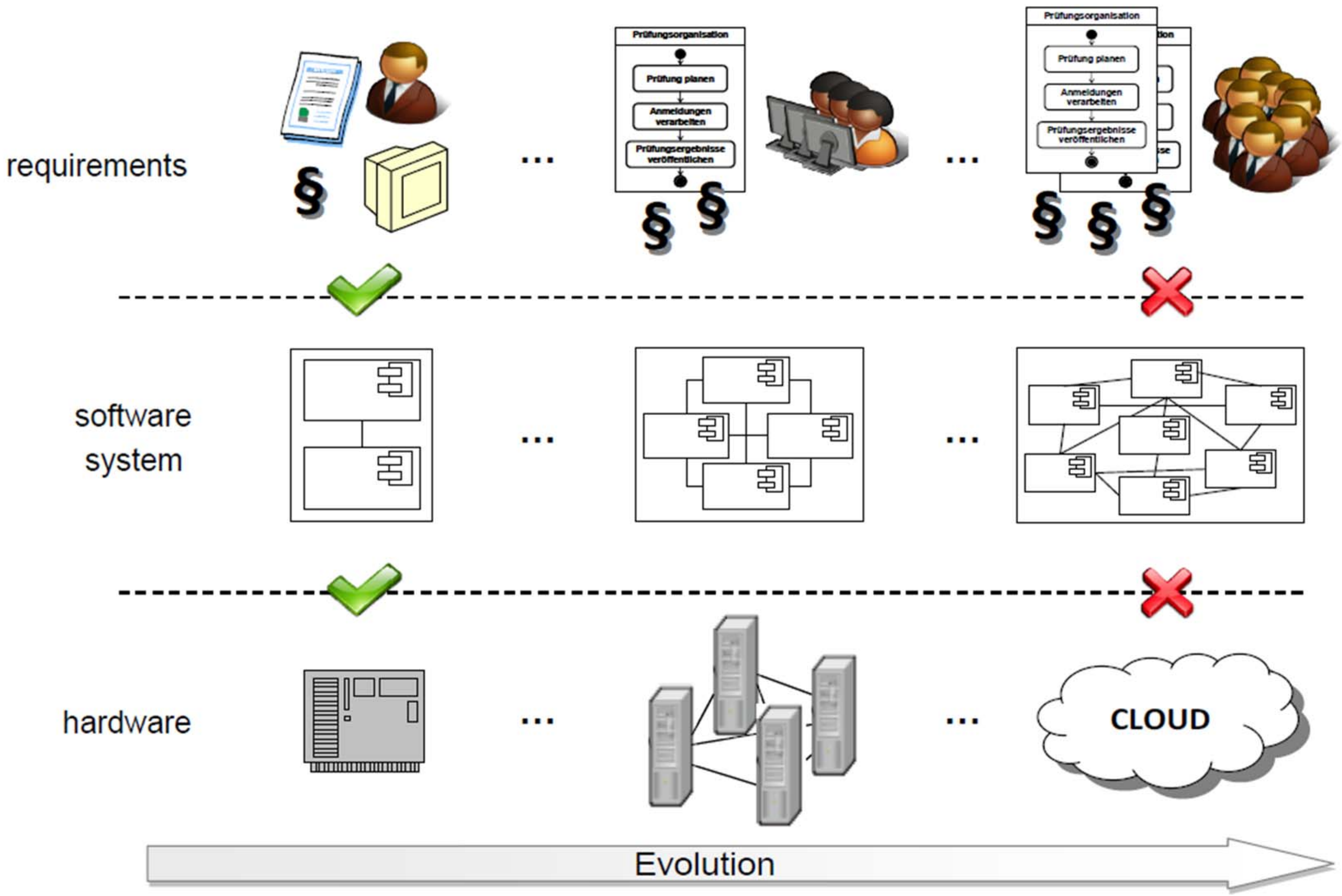
Motivation for “Managed Software Evolution”

Challenges during the whole lifecycle of software systems

- Legacy software
- New emerging technologies, and integration of new software, hardware and system components
- Adaption of software to new platforms and then continuous evolution of software systems with respect to continuously changing requirements
- Technical systems' evolution includes both *design and construction* phases as well as *operation* phases and involves different disciplines with different evolution process cycles

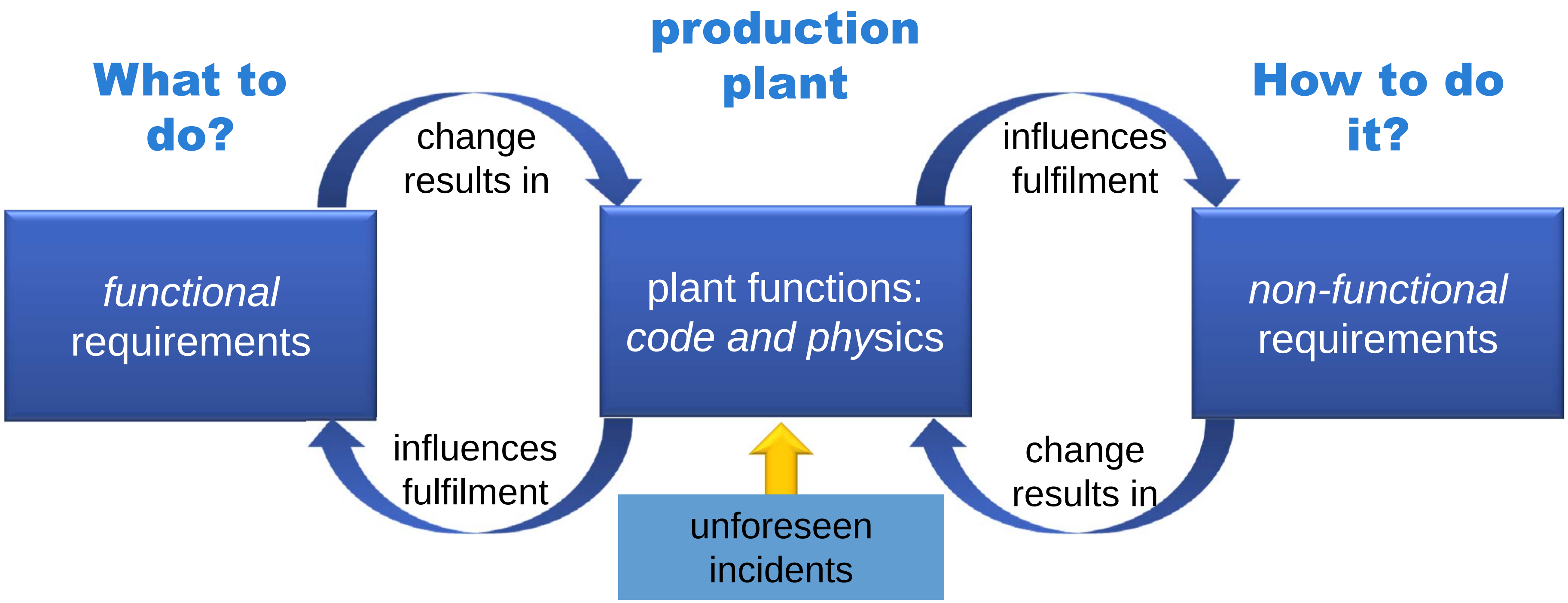


Different evolution of requirements, soft-, and hardware



[C. Momm, S. Sauer, GI AK L2S2 Presentation, 2009]

Interrelations of Changes and Requirements



Tasks:

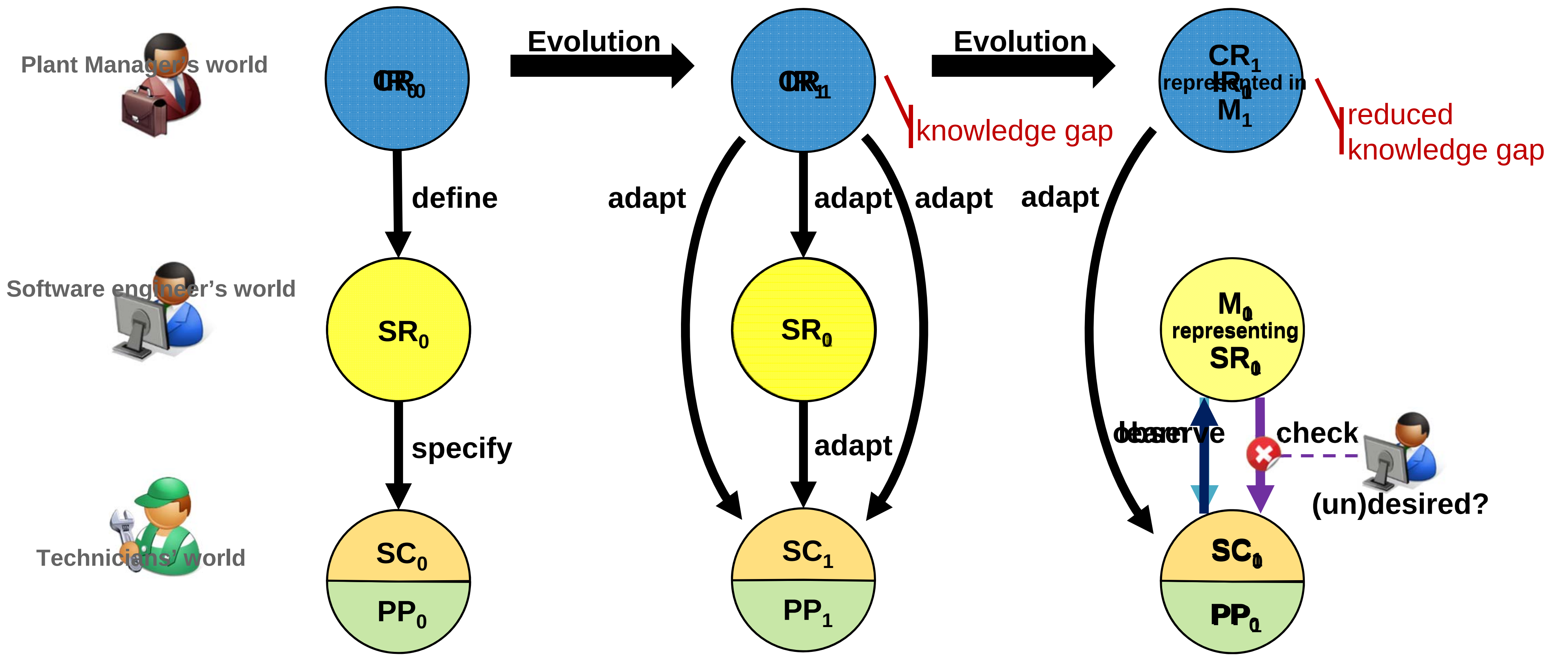
(1) detect changes within a plant and
(2) evaluate the (quality) influences of changes

„Forever Young Production Automation“

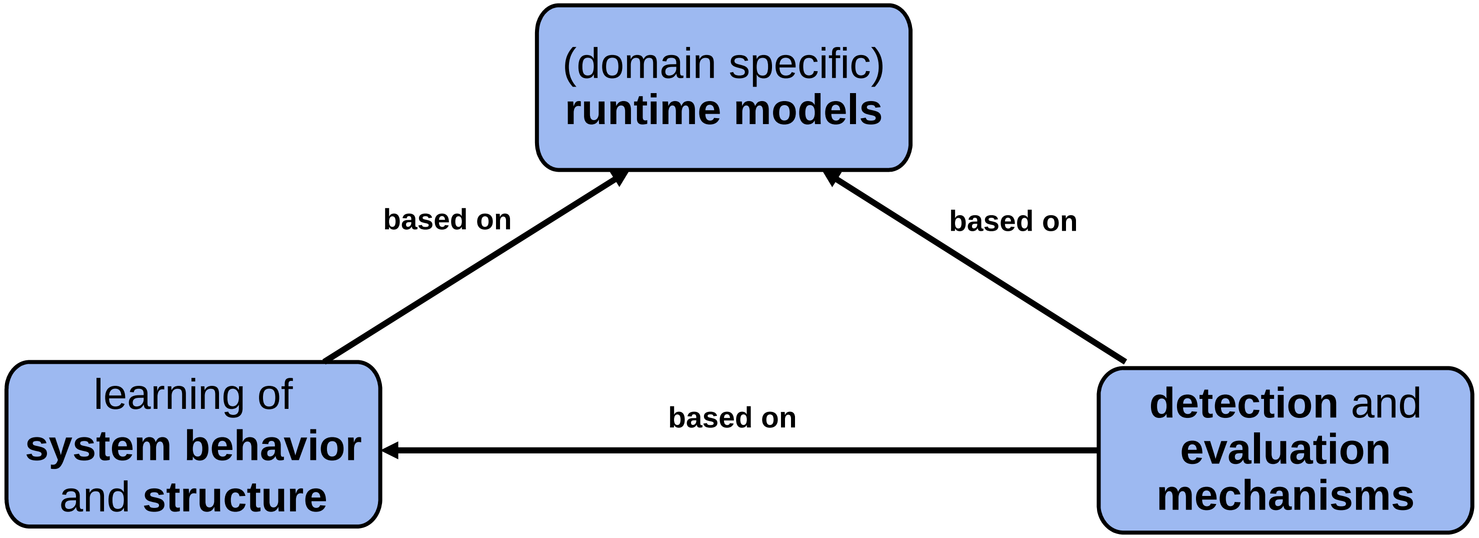
(*FYPA²C* – UHH 2013-2019)

IR_k – Informal Requirements
SR_k – Specified Requirements
CR_k – Covered Requirements
SC_k – Software Code
PP_k – Physical Plant
M_k – Model representation

at time k



FYPA²C: Keeping Pace with (Undocumented) Changes



Questions:

- How to **preserve available knowledge** during evolution?
- How can **evolutionary changes** be **detected and evaluated** at runtime?
- How to **construct** a **software that gathers knowledge** about a system **by observation**?

FYPA²C: Forever Young Production Automation with Active Components

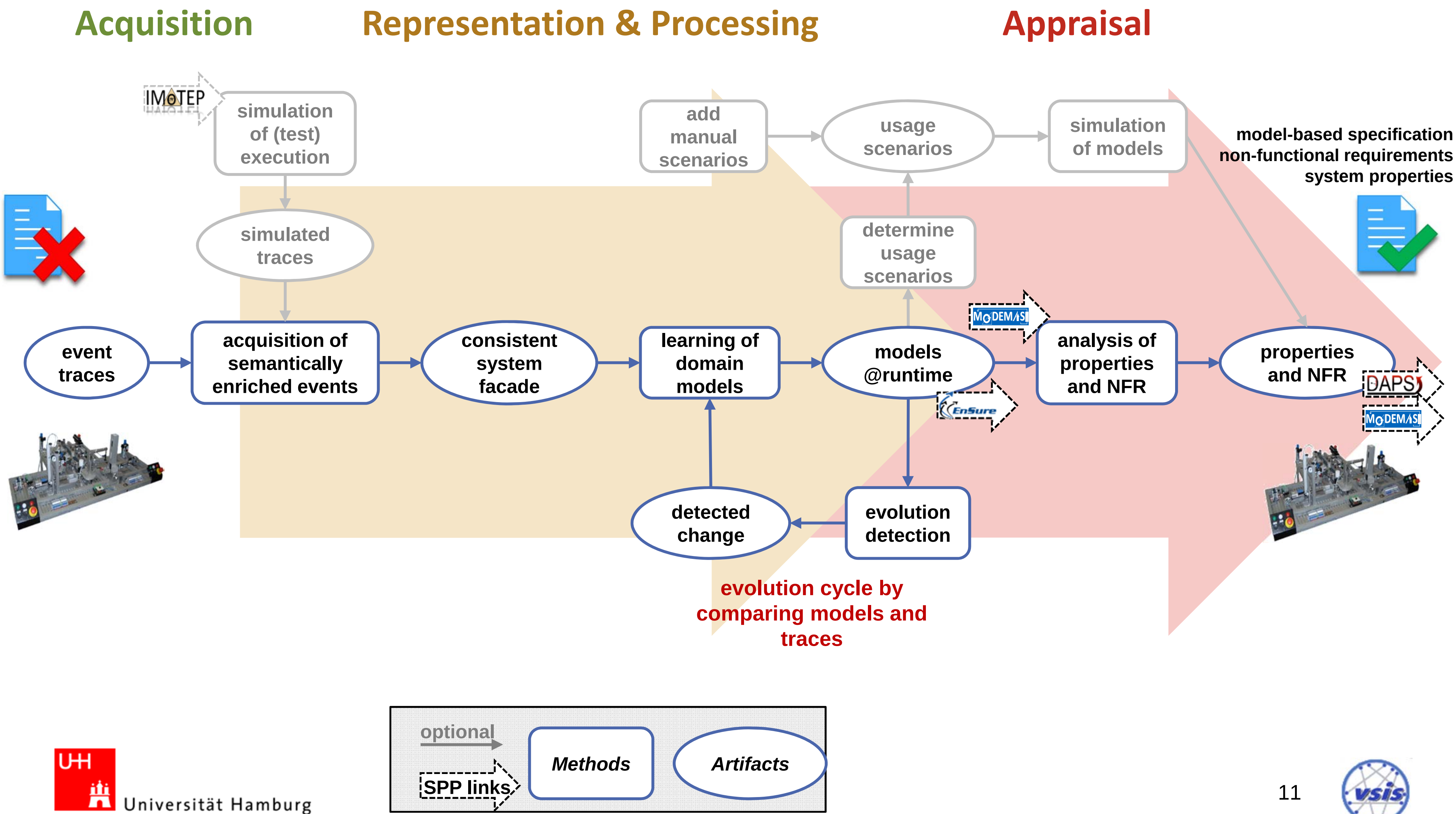
Goal: **Methods and processes for knowledge carrying software** (**KCS**) in order to counteract ***aging*** (i.e. undocumented changes) of evolving production systems

Questions:

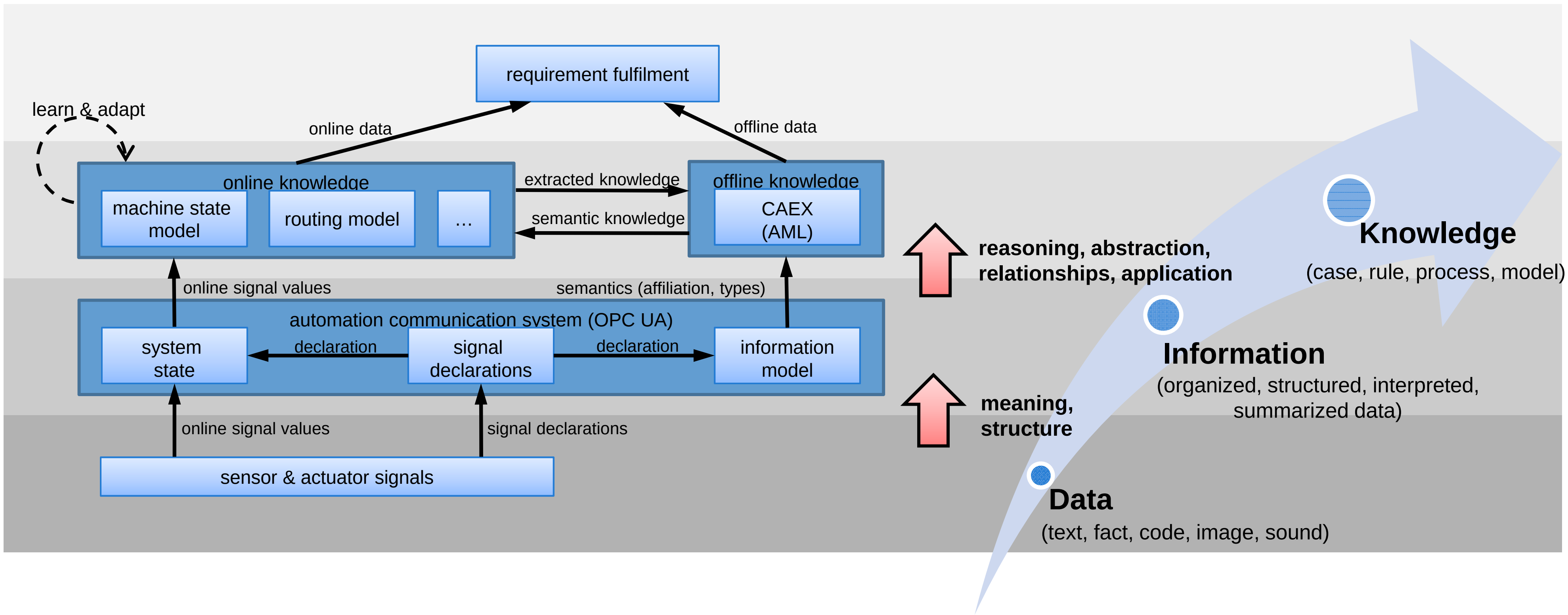
- How to **gain and preserve knowledge** about production processes by externally **available information** (i.e. I/O data)
  - without influencing execution
  - by establishing (formal) documentation that is constantly analyzable regarding typical non-functional requirements (**NFRs)**
- What is a **reasonable meta-model** and **software architecture** for **KCS** in an external monitoring context?
  - implementable mechanisms for the monitoring and analyzing processes
  - necessary components and services of an evolution support platform

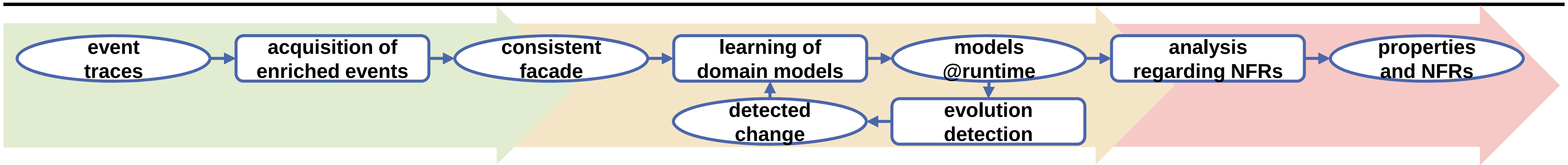
Approach: **Automatic generation** and scenario-based evaluation of **knowledge models** based on low-level signal (event) traces within an **Active Component architecture**.

Evolution Support Methods (overview)

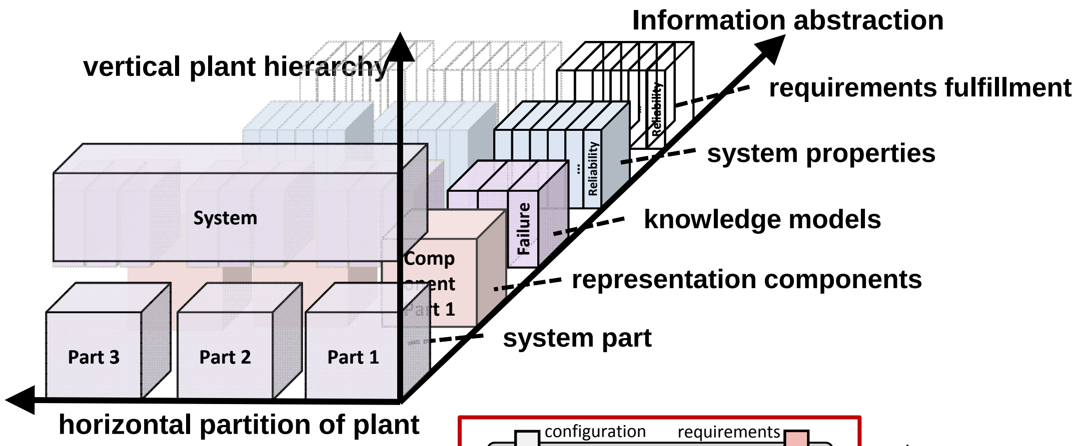


Overall Results – Knowledge Concept

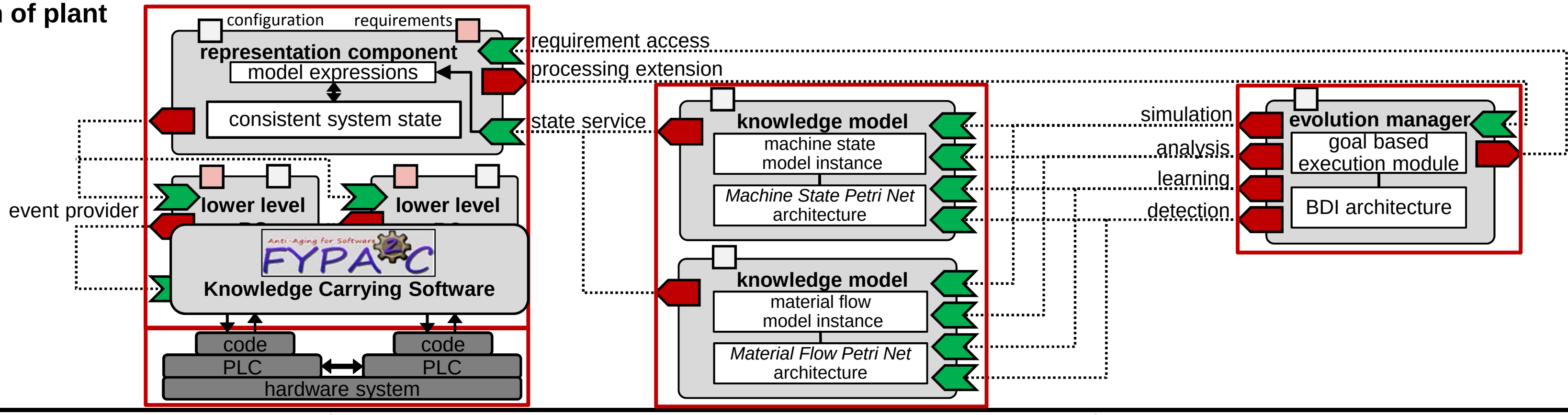


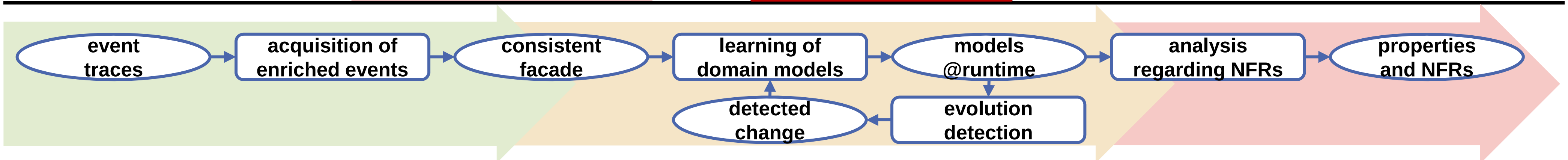


Overall Results – Knowledge Carrying Software (KCS)



- Knowledge information levels
- External KCS that uses monito-ring to support evolution
- Implemented in ***active compo-nent*** runtime artefacts





Question: How to represent theses components???

(In order to answer that…) Short excursus: Choices of *Software Development Paradigms*

Problem: No coherent overall view of application problems

- Many single separate problems
- Many single separate solutions

→Overall Approach needed!

- Consistent and intuitive concepts
- Adequate Abstraction level for distributed systems
- Close to real-world concepts
- Success factor: small delta to established paradigms

→***"Software paradigm":***

Fundamental principle for describing and implementing software systems

The Concept of a *Software Paradigm*

Software paradigms…

- determine concepts for the description and realization of software systems
- define the level of abstraction for the description („World Model“)
- support/hinder specific architectures
- lead to increasingly abstract concepts

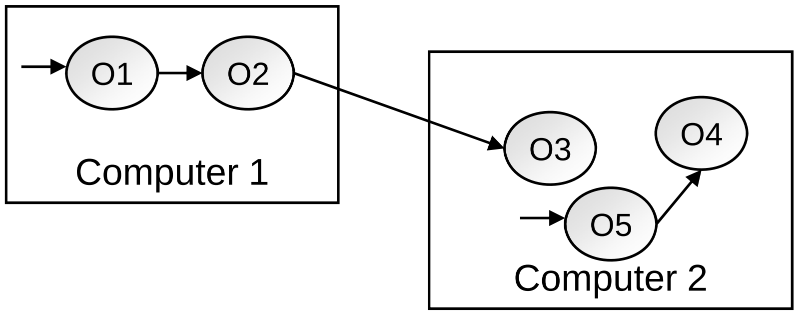
- *Historic examples* for the development of program paradigms – from imperative to object-oriented programming
  - imperative: program as linear sequence of commands
  - object-oriented: concealing data and methods to classes/objects

  - Conceptional background:
    - *imperative*: von-Neumann computer
    - *object-oriented*: real world of items and objects

Object-oriented Paradigm

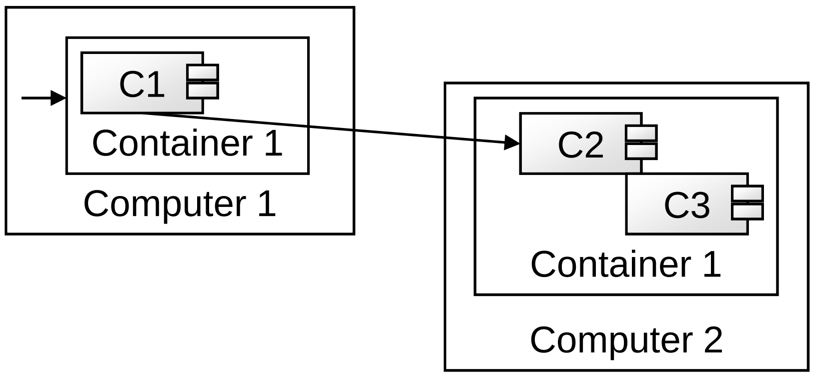
- Objects as units for data and behavior
- Based on method-oriented communication and client/server model
- Client/server are objects of any granularity
- Object identities allow for system-wide identification of clients/server
- Migration of objects allows for transparent runtime adaptation of application configuration

- Problems: Re-usability of objects low, based on no separation of complementary concepts (as, e.g., persistence- or security aspects)
- Examples: DCE, CORBA



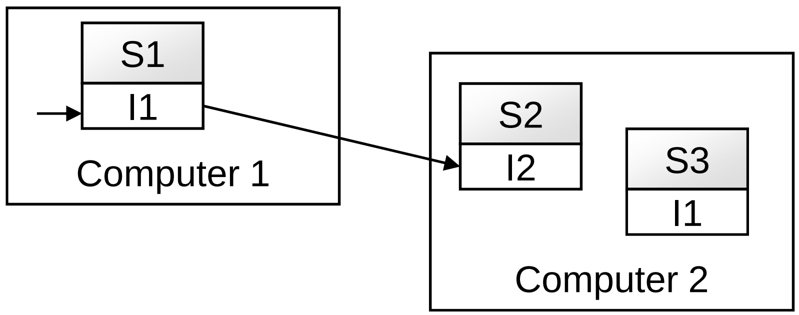
Component-oriented **Paradigm**

- Generalization of object-oriented paradigms
- Components are coarse-grained units on application level with clear interfaces
- Components are self-contained, resp. have well-defined dependencies
- Idea: Component repositories for clear composition of software from predefined components
- In general restricted to application logic, separate from application context, i.e. full configuration not before deployment (security, transactions, persistence, …)
- Unified deployment model
- Execution in specific “containers”
- Examples: Enterprise JavaBeans, .NET Components



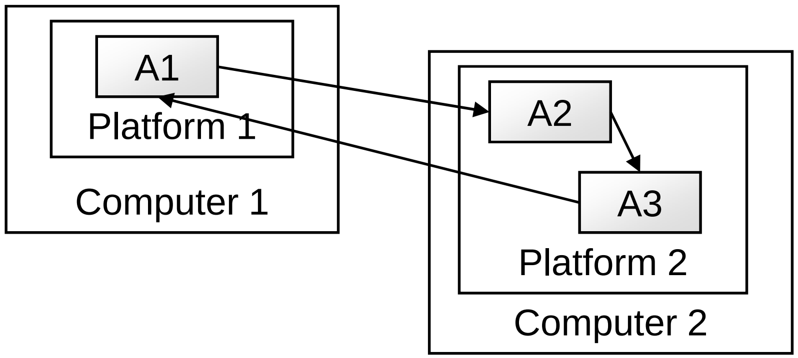
Service-oriented Paradigm

- SOA – Service Oriented Architecture
- Based on process-oriented view of application services
- Services are coarse-grained units of software systems, loosely coupled with business processes/workflows – can be integrated by means of
  - Orchestration
  - Choreography
- Have well-defined interfaces
- Could be used either synchronously or asynchronously
- Interoperability by use of standards (technology independent)
- Examples: Web Services (WSDL, SOAP, UDDI)

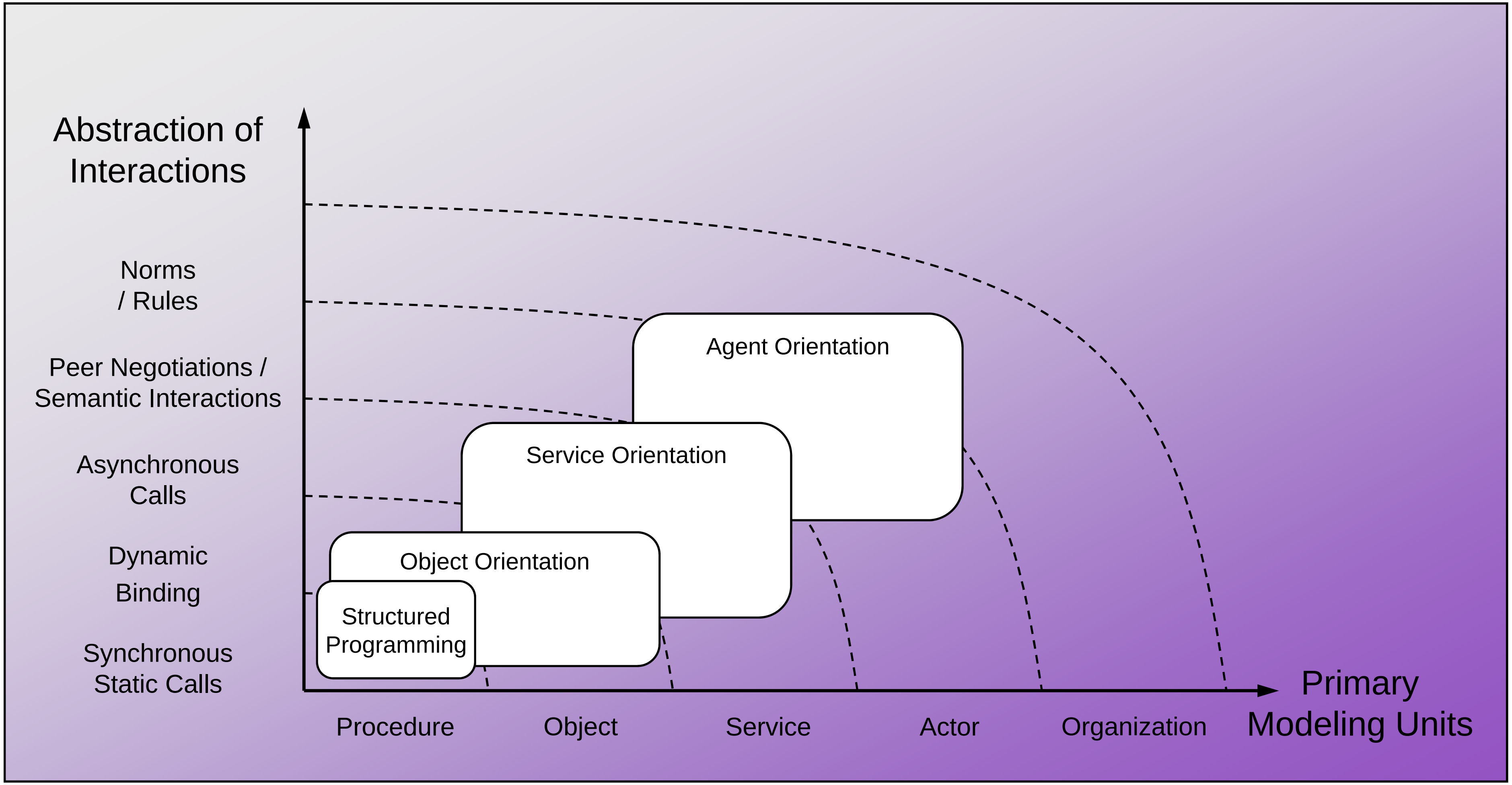


Agent-based Paradigm

- A System is viewed as a composition of independent actors (agents - i.e. multi-agent system)
- Communication is always asynchronous (message-based)
- Basic concept „agent“ as unit – in well-defined context – which uses sensors as well as effectors
- Agents make decisions autonomously, based on context as well as interpre-ting messages
- Behavioral specification of agents via internal architecture
- Behavioral specification of a multi-agent system via coordination of single agents („social architecture“)
- Examples: agent platforms as, e.g., JACK, JADE, Jadex



Categorization of Software Paradigms



MAS Application Areas

Sector / Class	*Industrial Applications* (A)	*Commercial Applications* (B)	*Entertainment Applications* (C)	*Medical Applications* (D)	*Military Applications* (E)	…
Multi-Agent Simulation (1)	Factory simulations	Market / trading simulations	Movie scene Productions / Games	Hospital simulations	Battlefield Simulations / Pilot training	…
Problem Solving (2)	Goods transport	E-Business	Strategy games	Hospital logistics	War logistics	…
Robot Control (3)	Production robots	Household robots	"Intelligent" toys	Medical device control	Unmanned aerial vehicles	…
Information Management (4)	Tracking and Tracing	Web search Email filtering	Artificial game reporters	Disaster management / Medical information management	Decision support / Smart dust	…
Human Computer Interface Mgmnt. (5)	Augmented reality tools	Shop bots / Help assistants	Avatars in games	Telemedicine / Home care management	Augmented reality tools for soldiers	…
…	…	…	…	…	…	…

Industry / Production

- Increase efficiency of production process
  - Flexibility when changing initial parameters (resources, characteristics of end product)
  - Application areas:
    - Whole production processes
    - Support for employees for single production steps
    - Production robots
    - Workflow simulation

- Examples:
  - CAARS – Project
    - Used for car production (BMW, GM)
    - HMDs (Head Mounted Displays) support employees
    - Mobile Augmented Reality System (MARS) → additional information to real world
    - Used for training
    - Agents support flow of information
    - Joint project of Juxtopia (HMDs) and Georgetown University, USA
  - Jadex application for Daimler production plant
    - agent-based simulation of (new) production processes
    - control of production steps and interrelationships
    - DFG transfer project with UHH

Industry / Transport Logistics

- Planning and executing logistic processes
- Optimal use of transport facilities
- Time management (e.g. for delivery)
- Many sub-systems are coordinated (e.g., storage, transporter, etc.)

Examples:

- Open ID Center
  - Fraunhofer Institut for Material and Logistics (IML)
  - System for delivery of products in real-time without manual intervention
  - Product identification via RFID (Radio Frequence Identification) labels
  - Shuttles controlled by agents fetch tasks for delivery (e.g. using an agent with minimal distance to store)
- Project AgentFly
  - Agent technology center (Czech University), http://exile.felk.cvut.cz/
  - Based on agent platform A-Globe
  - Simulation of autonomous control of airplanes
  - Real experiments with UAVs
- Jadex (agent)-based simulation and optimization of hospital logistics
  - Developed by UHH as part of DG SPP on agent use in logistics
  - Including evaluation against centralized approaches

Industry / Transport Logistics

Application Lab IML Dortmund

Commercial Applications / Electronic Assistents

- Support for humans for
  - Data management
  - Support for software problems
  - Mediation between information producers and consumers
  - Information search in the Internet
  - Home tasks

- Example: Kärcher RC 3000 Robo Cleaner
  - Robot
  - Autonomous cleaning
  - Uses sensors

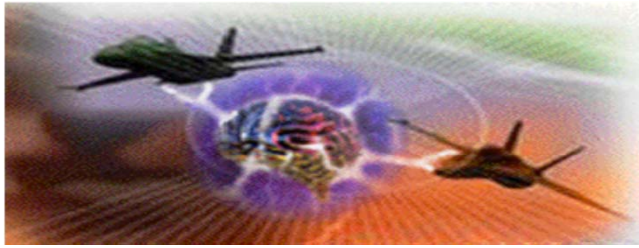
Computer Games

- Important for games: most realistic virtual world → fun!
- Reality view achieved by mirroring physical laws
- intelligent Non Player Characters (NPCs)
- Use of different AI approaches
  - Action: tactic capabilities of NPCs
  - Role play: Interaction with NPCs ...

- Examples:
  - *QUAKE*
    - Action play
    - Behavior of NPCs realized with BDI Agents
    - Quake Engine Basis for many Action Shooter

  - *AgentKeeper* (http://code.google.com/p/jadex-agentkeeper/)
    - Clone and extension of Dungeon Keeper
    - First development in teaching course at VSIS/UHH
    - Based on Jadex platform
    - Further developed as OpenSource project (P. Willuweit)

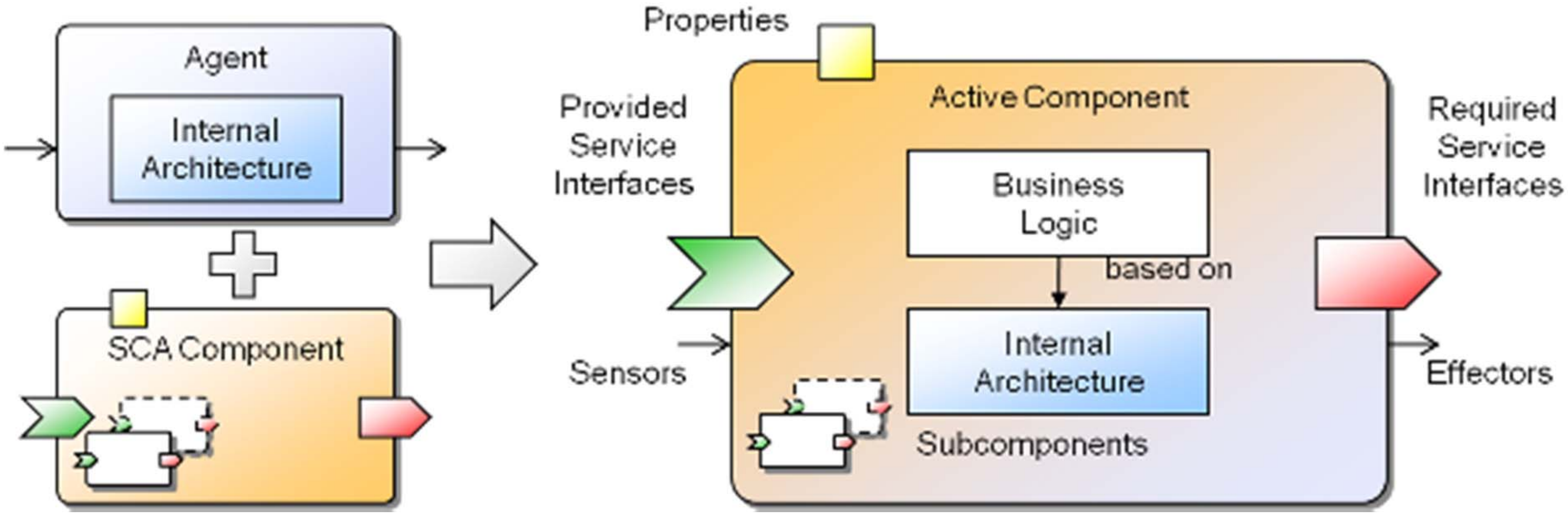
Military / Simulation



- Complex battle field simulations
  - Simulation of errors of dedicated (enemy) intervention
  - What determines a successful crossing of a (e.g. urban) area (e.g. number of forces, arms, etc.)
- Training simulation for soldiers
  - Intelligent agents play roles of other (ground or air) forces/units
- E.g. TacAirSoar (http://www.soartech.com/)
  - Training software for pilots of air forces
  - Computer-generated forces (CGFs)
  - Realized in Soar
    - Environment realized in if-the-else-rules
    - Airplanes realized with some 5000 rules
    - 15 alternative air plane types
  - First Simulation 1997 on 25 Pentium PCs
    - 722 Missions in 48 hours
    - Average time of missions: 3 hours
    - 30 – 80 flights per Mission
    - only 5% software problems

New Combined Approach to Software Development: "Active Components" (AC):

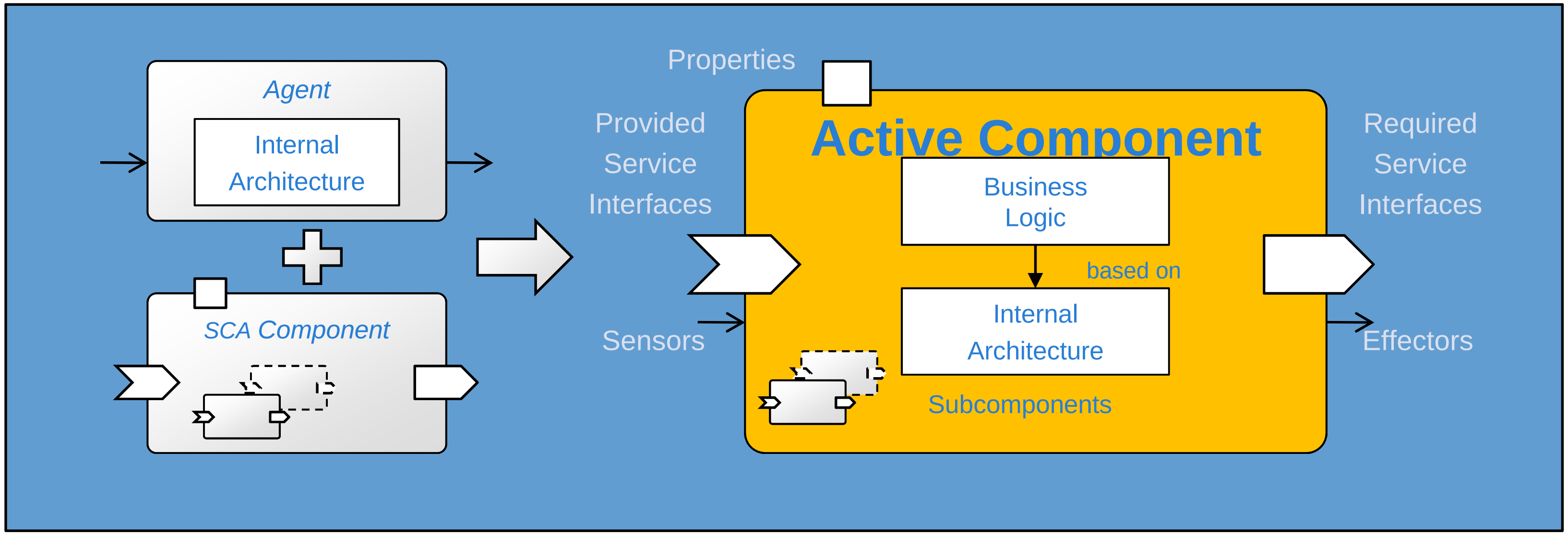
… based on *autonomous*, *adaptive*, *knowledge-carrying* software *components* using both software-engineering and agent technology



Active Components (AC):

Definition: *"An **active component** (AC) is an autonomous, managed and potentially hierarchical software entity that is capable of interacting with other active components in different modes including message passing and method calls."*

- management infrastructure and composability of components
- invocation styles like agents and services/active objects
- rich behavior styles like agent architectures or workflows

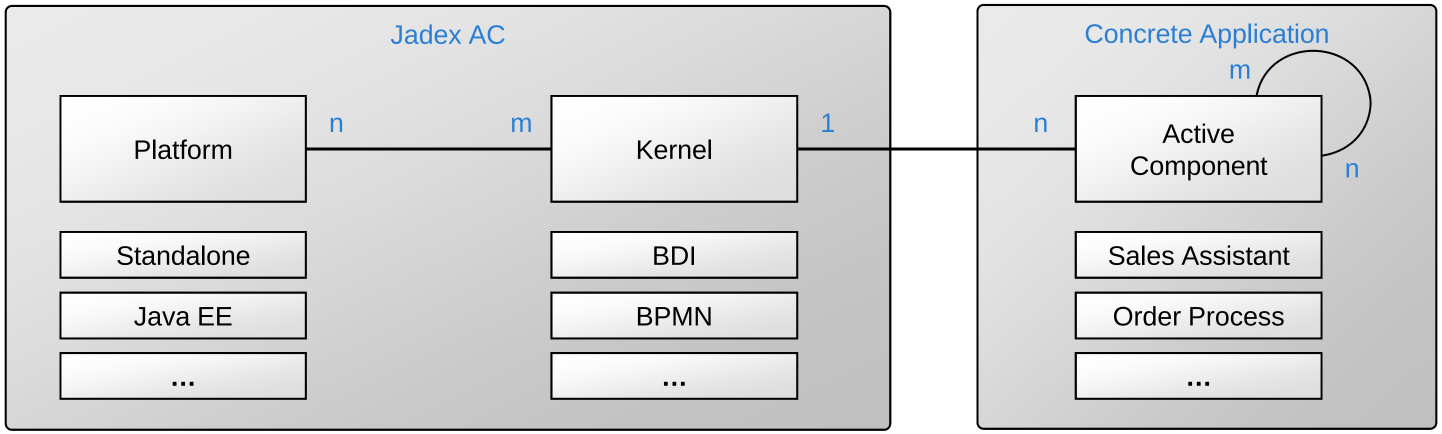


AC Implementation Platform: „Jadex v2"

*A **platform** is the* management infrastructure for components, *which is responsible for their execution as well as for providing administration capabilities like a messaging system or a component service registry.*

Design Goals:

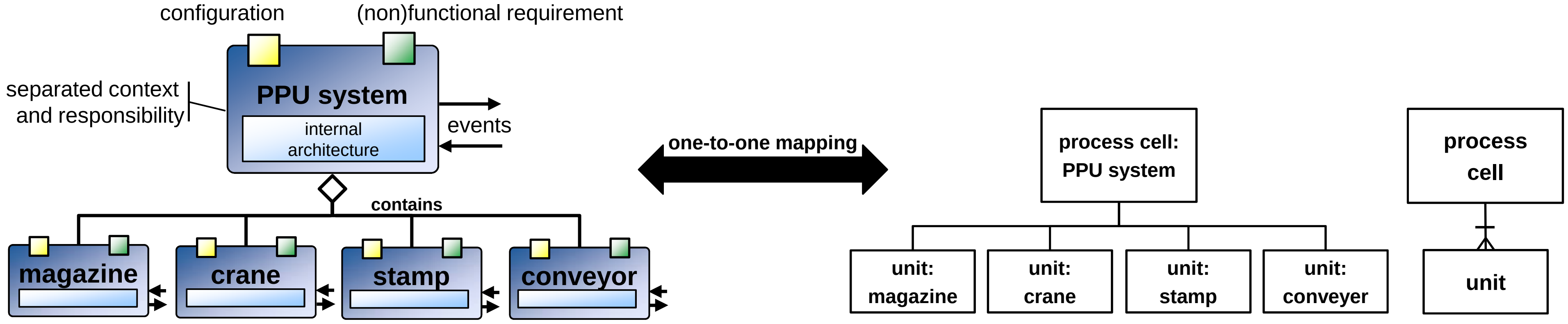
- Platform can execute different kinds of ("active") components
- Component kernels should be enabled to run on different platforms
- Applications should be platform independent
- Applications should be composable from arbitrary component types (heterogeneous applications)



Back to the application example: Knowledge Carrying Software for Production Automation Systems

Expected characteristics of a knowledge carrying software (KCS) for production systems

- Direct mapping between KCS and the physical plant hierarchy
- Reaction to plant events along its original responsibility chain
- Encapsulation of local knowledge in a separated processing context
- Enrichment of (non-) functional requirements at each granularity level
- Autonomous management of requirement verification



Representation components of KCS

Physical plant hierarchy according to IEC 61512

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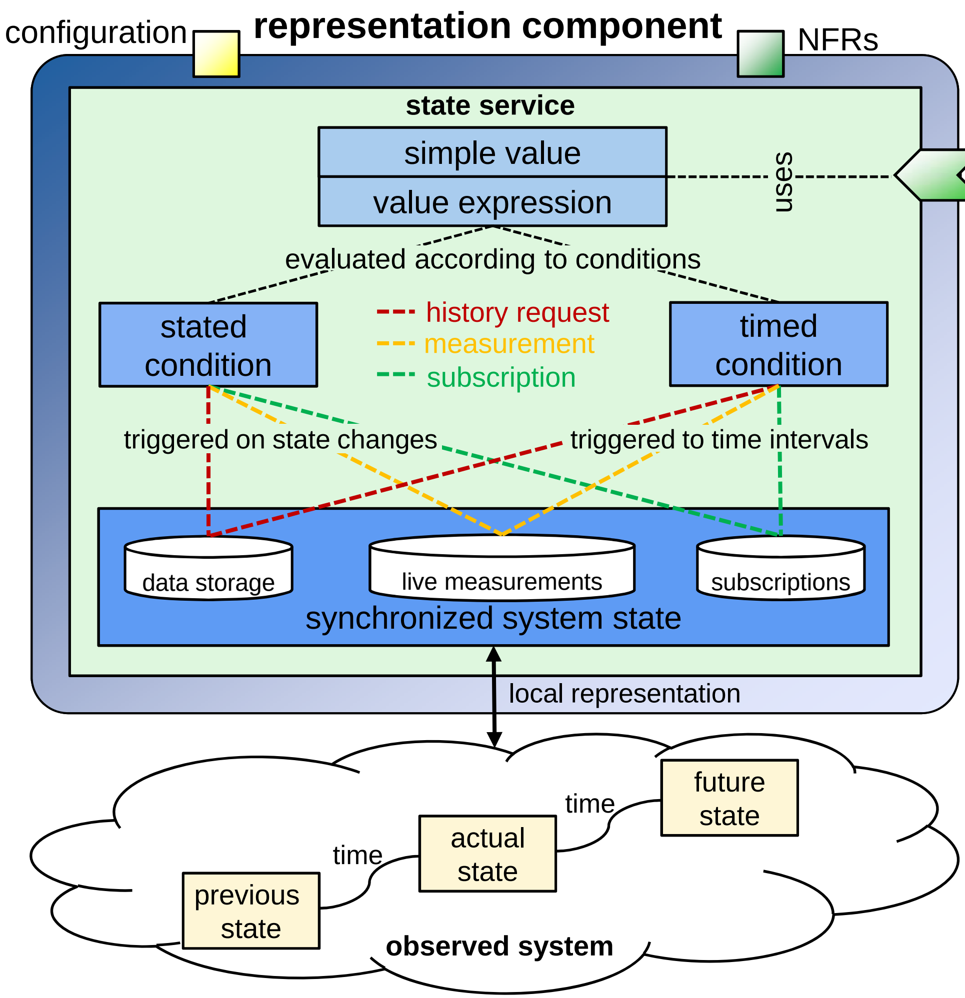
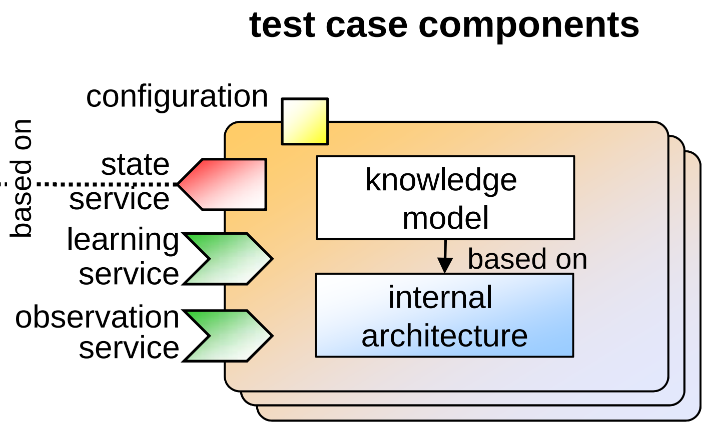
Generic Management of Knowledge within a KCS

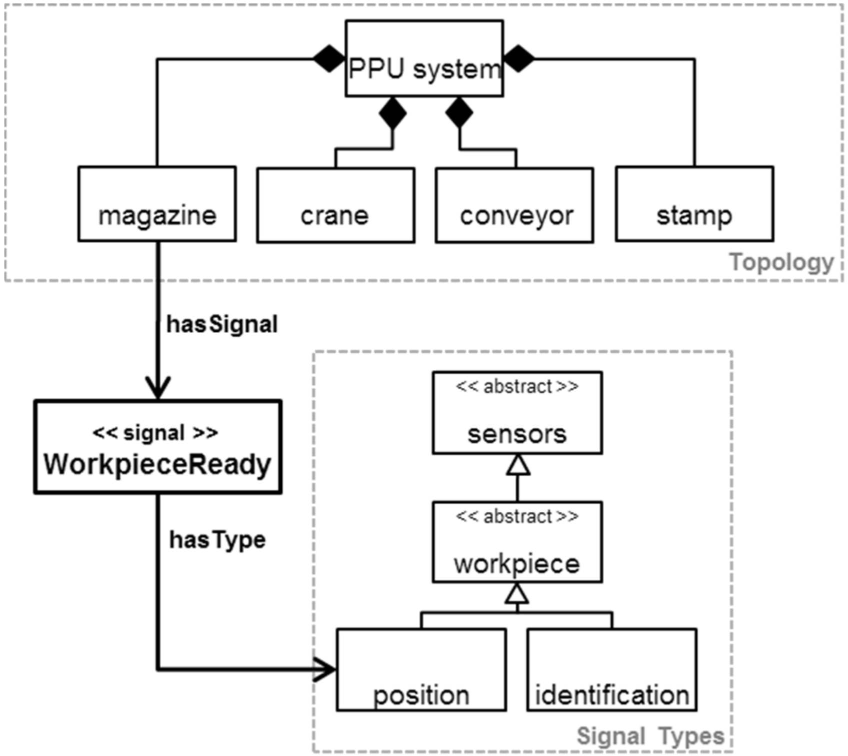




Execution of knowledge containing models

- Synchronization and consistency of the observed (partial) system via a component state
- Management of local and domain-specific knowledge in model-based test case components
- Knowledge modification methods incorporated in services allow calculations of NFRs
- Runtime dependence due to simple values or complex expressions according to stated or timed condition
- Executable on current values (by live measurement), history values (by data storage) and future values (by subscriptions)

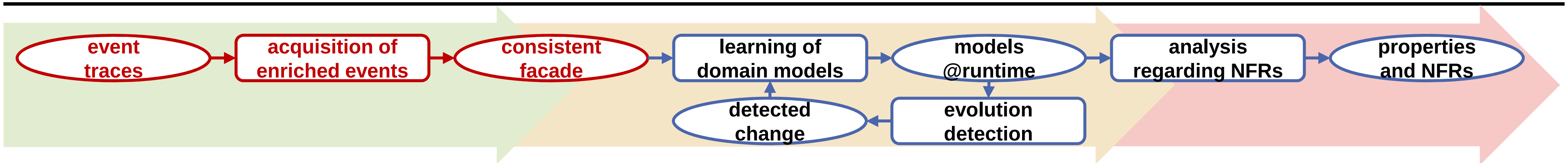
Knowledge Management for Production Automation: *Acquisition and Representation of Enriched Plant Data*



- Rule based selection of signals for model learning and analysis

Workpiece (WP) routing signals:
1: [affiliation = *ppu.crane*, type = *sensor.workpiece.position*]
2: [affiliation = *ppu.crane*, type = *sensor.machine.position*] AND
[affiliation = *ppu.crane*, type = *sensor.workpiece.WPInteract.hold*] CH

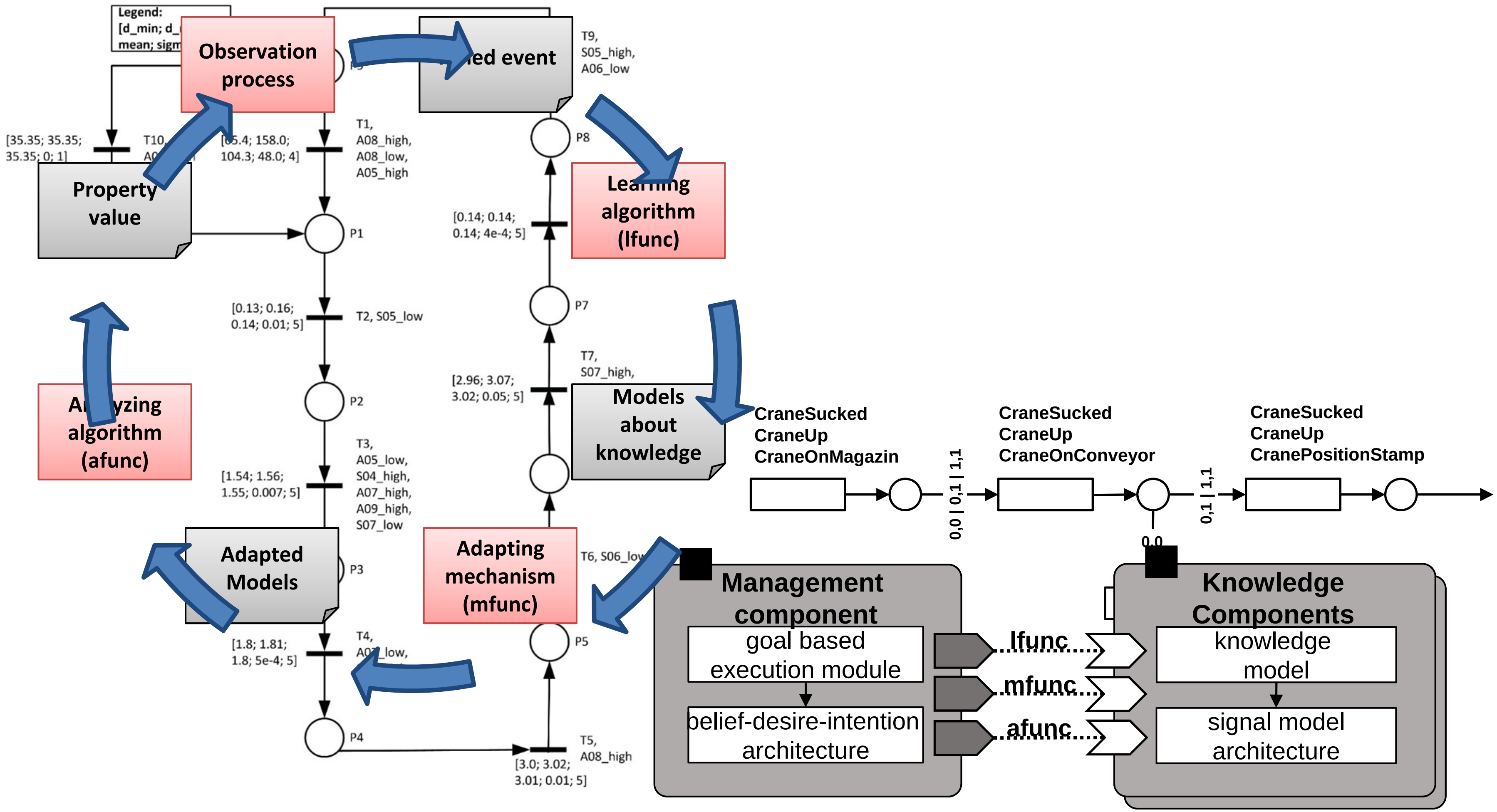
Workpiece (WP) identification signals:
3: [Affiliation = ppu.*crane AND* type = *workpiece.identification]*



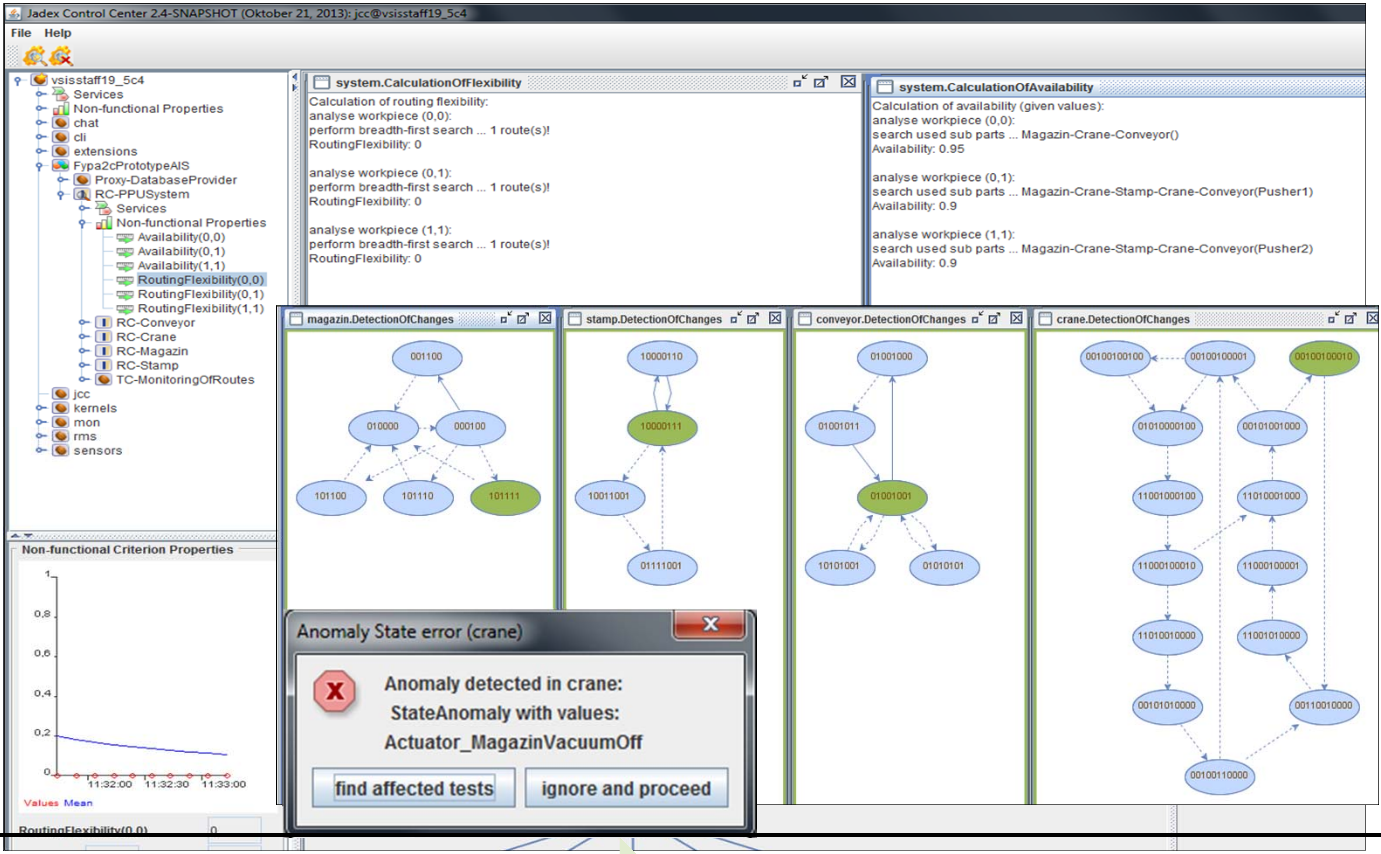
CH1 Hier noch gleiche Farbe wie oben bei AC

Christopher Haubeck; 23.02.2015

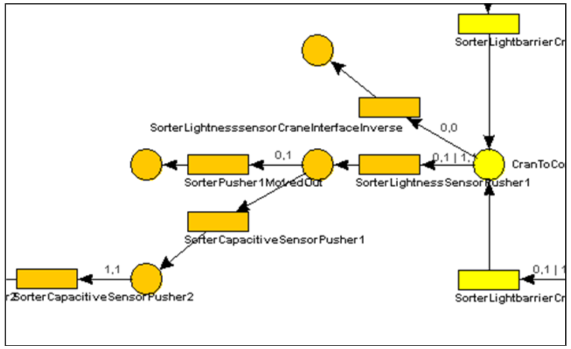
Evolution Support for Executable Specifications in Service Components

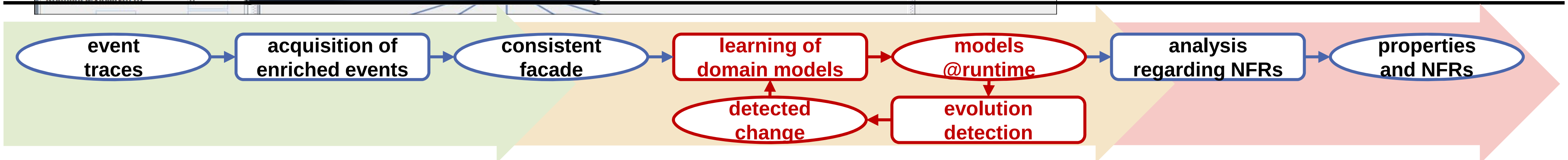


Model-based Specification at Runtime

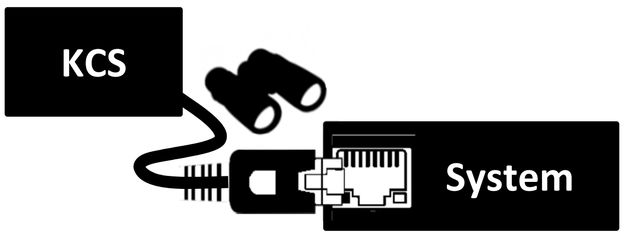


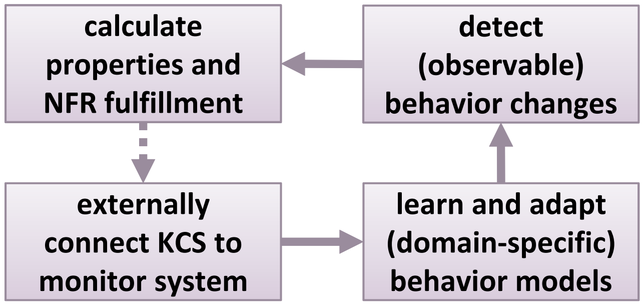
- Evolution detection
- First learning of knowledge models
- First calculation of
  - Routing Flexibility
  - Availability



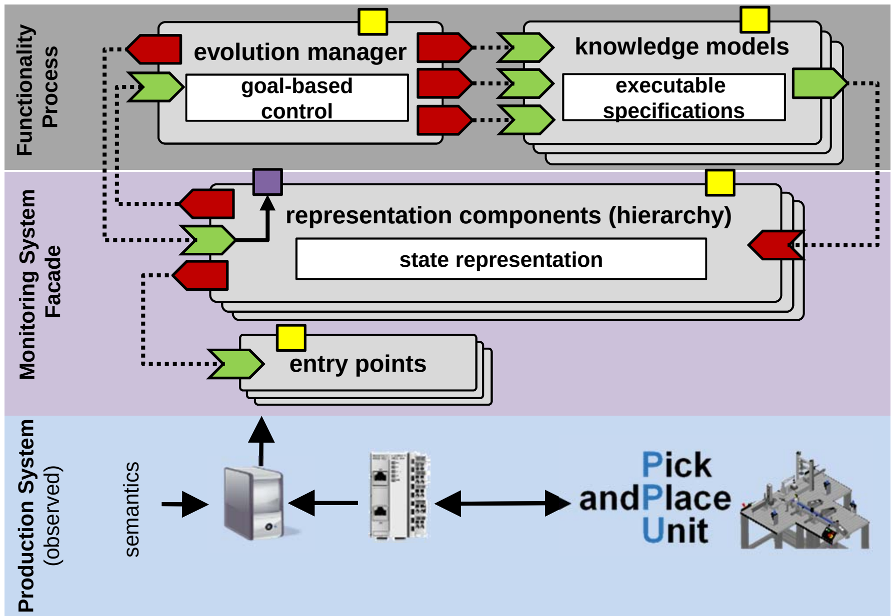


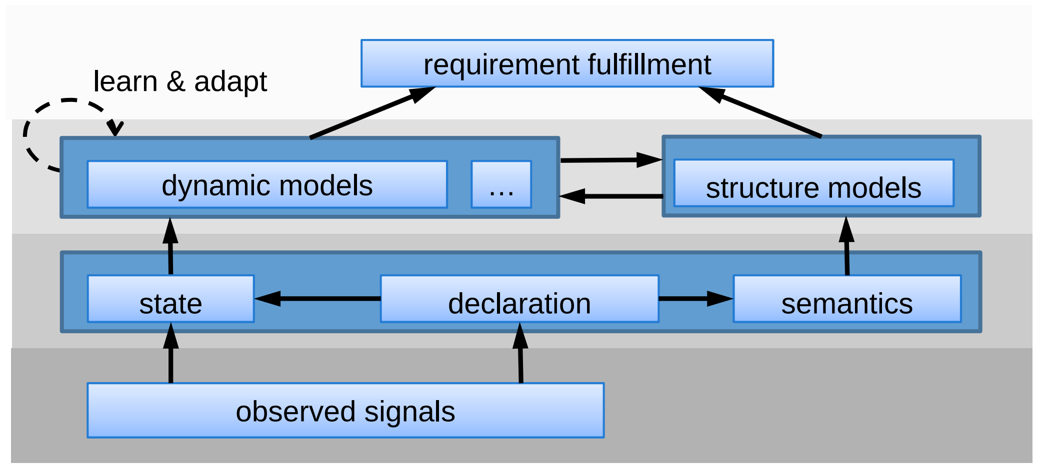
Summary: FYPA²C in a Nutshell – General Approach





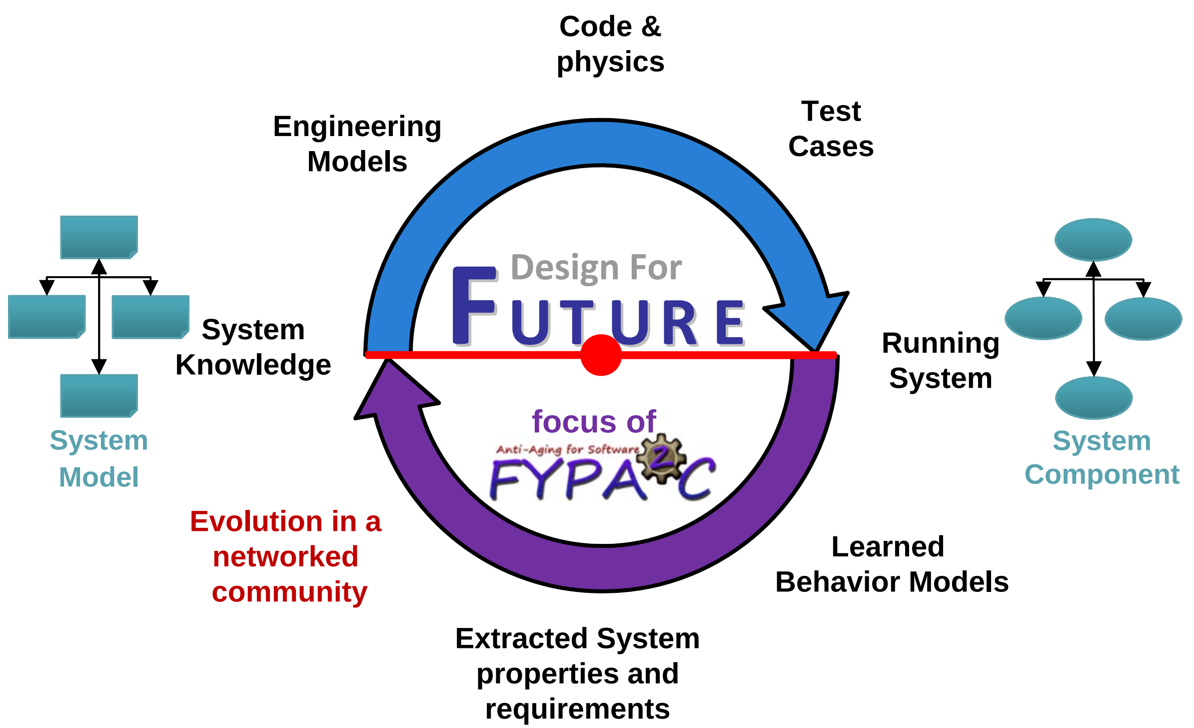
- Minimal setup costs for automated evolution support
- Generalizable concept of knowledge artefacts and evolution-handling KCS by exchanging model types





Future Work: Supporting Evolution in a Networked Community

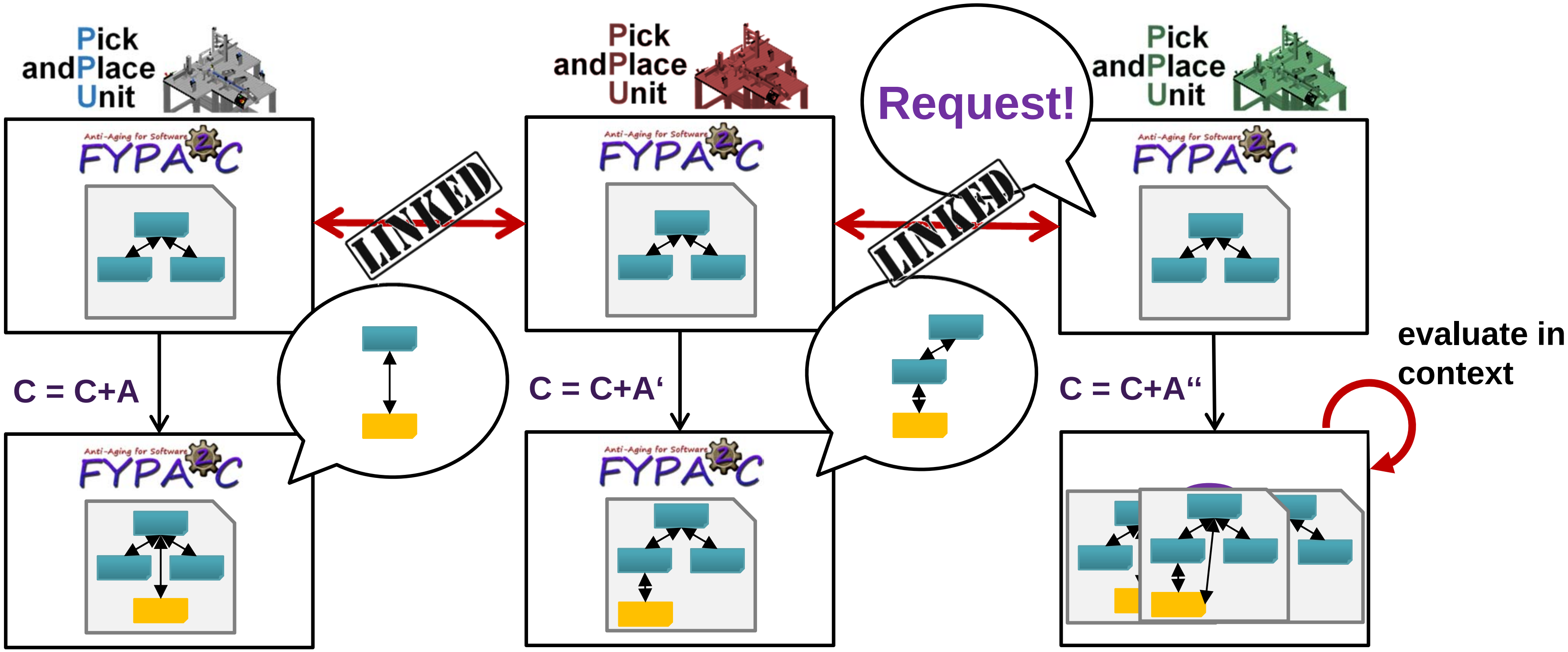
- Connecting systems in an evolution-aware network platform
- Co-evolution of system and model (also by integrating further SPP results)



Motivation and Idea – LinkedFYPA²C

FYPA²C allows collecting "experiences" with evolution steps

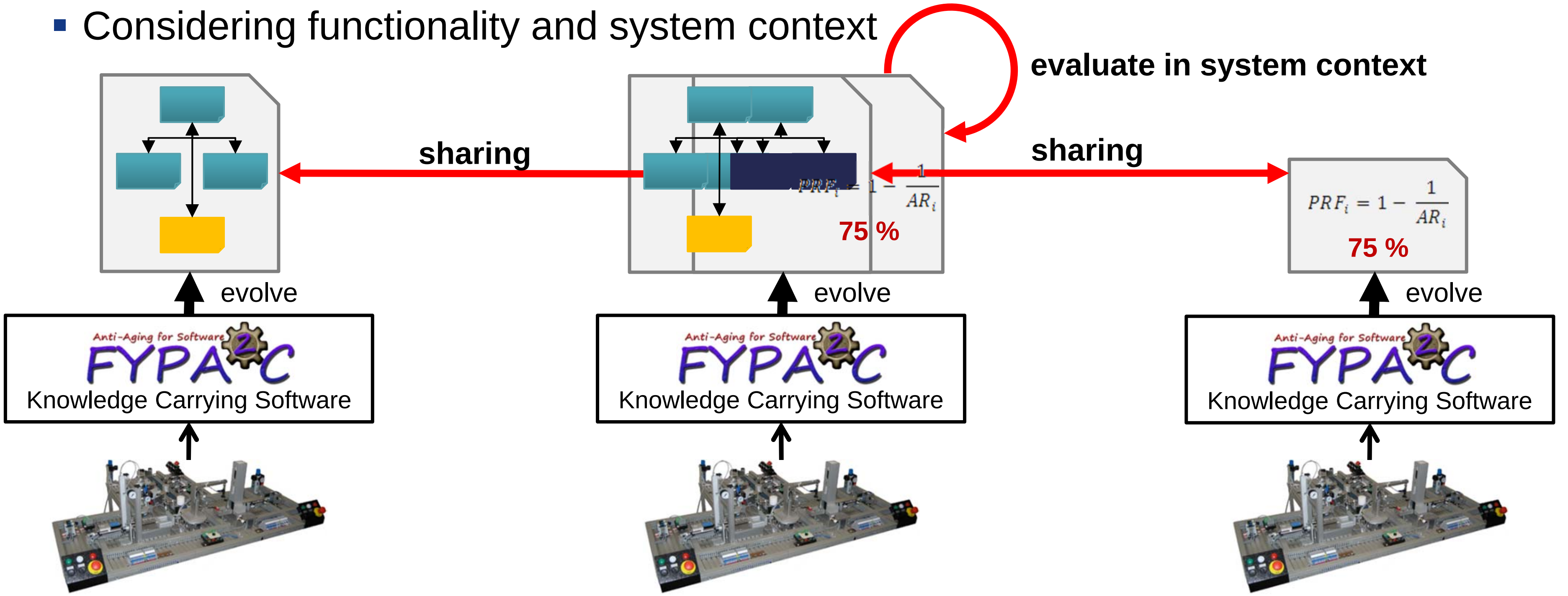
- Experiences could be used to actively support evolution of similar systems
- LinkedFYPA²C connects systems to a knowledge carrying evolution community



Future Work – Supporting Evolution in a Networked Community

Connecting systems in an evolution-aware network platform

- As part of co-evolution of systems and models (also by integrating further SPP results)
- Sharing evolution solutions by means of models and their differences
- Detecting suitability of evolution solution for a single connected system
  - Considering functionality and system context



plant picture courtesy of
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Future Project Goals and Research Questions

- **Machine interpretable base of evolution-relevant knowledge**
  - How can evolution relevant “experiences” be captured in artefacts?
  - How to capture the system context?
  - How can evolution steps and their influence be related to the system context?
- **Evolution assessment methods**
  - Under which conditions is an evolution step applicable on another system?
  - How can similarity between systems be measured and expressed?
  - Can evolution steps of several systems be aggregated and tailored for a specific system?
- **Proactive evolution support method**
  - Can “evolution trends” be recognized in a cooperative evolution network?
  - Which methods are needed for a proactive evolution recommendation?
- **Networked evolution support platform for knowledge exchange**
  - What is a suitable middleware to realize such an evolution support network?

Conclusion and Summary

Services and Workflows are needed for a variety of applications – preferably in an appropriate *Software Engineering Context*

Example application area here: *Production Automation*

Application Characteristic:

- **Cyber-physical** systems (hard- and software combined)
- (Often undocumented) **changes** – independently w.r.t requirements, hard- and software
- Automation support needed for continuous **hard- & software evolution**

***Implementation: Agent-/component-oriented* software development platform (*“Jadex”* => *“Active Components”*)**

- Implementation platform for autonomous *services* (with both functional and non-functional characteristics) as well as (embedded or separate) *work-flows*
- Potential for building and managing *knowledge models* (for application system services as well as workflows)
- Appropriate adaptation platform for change management (software evo-lution): *Active Components (AC)*