From Agent-based Solutions to SOA Architectures in Industry 4.0

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CIIRC
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CIIRC, ČVUT

Czech Institute of Informatics, Robotics and Cybernetics (CIIRC)

- Based on experience – a new Institute of CTU established in 2013
- CIIRC should play the role of the national center of excellence in the subject fields

8 research programs - departments:
- Robotics (Prof. Václav Hlaváč)
- Intelligent Systems (Prof. Vladimír Mařík)
- Industrial Informatics (Prof. Zdeněk Hanzálek)
- Industrial Production Control (Prof. Michael Valášek)
- Cyber-Physical Systems (Prof. Michael Šebek)
- Cognitive Science and Biomedical Eng. (Dr. Lenka Lhotská)
- Assistive Technologies (Prof. Olga Štěpánková)
- Research Platforms: Center of Applied Cybernetics (Prof. Vladimír Kučera)

The goal: State-of-the-art, competitive and self-sustainable institution
New Building of CIIRC

- Completed in November 2016
- Investment 50 mil. EUR – 85% funded by the Czech government
New Building of CIIRC – situation of December 2, 2016
Department of Intelligent Systems
of CIIRC- CTU

Some of the Capabilities and Results
Holonic Agent Architecture – experience from the past

- **Low-level control (LLC) layer**
  - real-time control on PLC
  - still IEC61131 preferred (ladder logic, structured text, ...)
  - promising successor – IEC 61499

- **High-level control (HLC)**
  - software agent (C++/Java)
  - agent runtime environment (e.g. JADE)
  - usually running on PC or a general-purpose module in PLC chassis

- **HLC↔LLC control interface**
  - agents get notifications from LLC about important events (diagnostics data, task completion, ...)
  - agents send commands to LLC
  - different technologies: COM/DCOM, OLE, blackboard, IEC 61499 interface FBs, direct access to PLC data table (Rockwell patented)
Agent-based Control System Development - experience

- **Agent Development Environment**
  - supports complete agent-based control system development
  - library of control component templates
  - design of specific control application (facility editor)
  - code generation, download and run

- **PLC-based Agent Runtime Environment**
  - agents distributed over multiple controllers (e.g. ControlLogix)
  - message transport layer – various protocols (CIP, TCP/IP, HTTP)
  - compliant with FIPA specifications, can interact with JADE

- **Debugging and visualization (Sniffer)**

- **Simulation in industrial control domain**
  - Smooth shift to physical control
Ontologies in Agent-based Manufacturing

- **OWL ontology for discrete manufacturing**
  - customer order (product, parameters, ...)
  - production process (steps, operations, ...)
  - workstations and transportation

- **Integration of ontologies in agents**
  - agent knowledge – semantic representation of current state
  - agent communication – content of messages compatible with ontology
  - agent behavior – reasoning and acting on semantically-described data

- **Use in dynamic scheduling and production control**
  - automated generation of production plans based on order parameters
  - automated processing of plan by product agent (active product)
    - dynamic scheduling of production steps execution
    - negotiation with workstations agents about providing operations
A Reference Architecture & Exploration of Ontologies

- Aircraft Assembly process Optimization:
  - Pilot project ARUM
ARUM Project – Basic Facts

- **ARUM – Adaptive Production Management**
  - Large-scale European project (2012-2015)
  - 14 partners from Europe
    - Czech Republic (2x), Germany, England, Portugal, Greece, Russia
  - Total budget: 11,5 M€
    - EU contribution: 8,5 M€
- Main coordinators
  - Project coordinator: AIRBUS
  - Technical coordinator: Certicon a.s./CTU
- External advisory board
Airbus use-case

- **Airplane assembly ramp-up**
  - Assembly of highly complex and individualized products
    - 3-5 millions of parts – mainly manual assembly
  - Focus: production scheduling in ramp-up
    - Ramp-up usually takes 2-3 years
  - Frequent disturbances halt production
    - Missing resources (delayed deliveries of parts)
    - Non-conformities (defects, quality issues, wrong dimensions,....)

- **Airbus A350 XWB fuselage assembly line in Hamburg**
  - Several assembly stations organized in a line
  - Semi-finished product equipped with different components
    - Thousands of workorders, jobs and dependencies, hundreds of resources
  - Movement of products must be synchronized across the whole line
Overall ARUM Solution

- **Following the Service Oriented Architecture (SOA)**
  - functionality wrapped in interoperable services
  - Enterprise Service Bus (ESB)

- **Key services**
  - internally implemented using multi-agent systems (MAS)

- **Developed MAS-ESB Gateway**
  - Enables agents residing inside a service to communicate with other services

- **FIPA-based extension of ESB communication**
  - adding FIPA-ACL attributes to ESB messages
  - Support for various conversation protocols
Ontologies in ARUM

- **Ontologies used as a “common vocabulary”**
  - Providing semantic description/abstract model of the manufacturing domain
- **Designed set of ontologies**
  - Core ontology – modeling of assembly processes (resources, jobs, dependencies, ...)
  - Scene ontology – modeling flow of products
  - Events ontology – modeling various expected/unexpected events and disruptions
- **All services use “ontological” format for communication**
  - Data transformed from legacy ERP system into RDF format according to ontology
  - Ontology service provides data to schedulers and planners
    - Results also represented in RDF
- Participation @ CDL-Flex Research Laboratory at the Vienna University of Technology

- **Engineering Service Bus (EngSB):**
  - ESB Technology
  - Interface – tool independent – unifying access to various SW tools
  - **Objects shared** across various domains
  - Knowledge stored in **ontology structures** for model-based knowledge engineering purposes
  - AutomationML used for modelling and meta-modelling
SOA architecture in the SCADA system

- Piping & Instrumentation
  - Tool Data

- Electrical Plans
  - Tool Data

- Mechanical Plans
  - Tool Data

- Engineering Workflow Rules

- Engineering Knowledge Base (EKB)

- Simulation
  - Tool Data

- SCADA HMI
  - Tool Data

- Runtime Data

- Parameters

- Engineering Cockpit
Project DIGICOR: Decentralized Agile Coordination Across Supply Chains

- Horizon 2020 project (11 partners)
  - running: 2016 – 2019, total budget: 8 M€
- Project goals
  - To develop **governance rules and procedures for the collaboration in production networks** and the knowledge protection model for ad-hoc collaboration and SME cluster
  - To develop an **open ICT platform** and tools and services **to support management and control of collaboration networks** using Industry 4.0 methods and means
  - To develop **novel business models** for operation and further maintenance and improve the collaboration platform and tools and services
  - To demonstrate the **improved efficiency and speedy setup** and operation of the open collaboration platform
DIGICOR: Architecture

Service discovery tool
- Tools Registry and Look-up
- Semantic-based matchmaking

Tools store
- Tools management and distribution
  - Tool 1
  - Tool 2
  - Tool 3
  - Tools upload
  - Tools download

Semantic information models
- Planning
- Supply-chain
- Scheduling

Middleware (OPC UA based communication platform)

Security and governance

Tool 1: Market place
  (instantiated tool from Tools store)

Tool 2: Production Planning
  (instantiated tool from Tools store)

Tool 3: Operative support
  (instantiated tool from Tools store)

Tool 4: Risk evaluation
  (instantiated tool from Tools store)

Gateway Service
  (access to legacy systems data)
  - Data mapping and transformation

Legacy information system
  - SAP, XLS, ...

Legacy control system
  - PLC, sensors, ...

Big Data in Industry

- In collaboration with Rockwell Automation
- Big Data within the industrial domain
  - 3Vs of Big Data
    - Volume / Velocity / Variety
    - the “Big” in “Big Data” is not the major problem
      - it is about variety, not volume
  - Our focus – Big-data historian
    - Integration of heterogeneous automation data using ontologies
      - data flow from sensors, MES/ERP systems
      - external sources (surveillance systems, energy, weather, ...)
  - Data storage
  - Decision making in real-time
    - pattern recognition, clustering, trends, ...
- **Data Analytics** – KNIME, MAHOUT
Semantic Big Data Historian Architecture

- **Analytic layer**
  - *Knime*

- **Storage layer**
  - Big Data Storage
    - *Apache Hadoop*, *Jena Elephas*

- **Data transformation layer**
  - Data transformation into OWL format

- **Data acquisition layer**
  - Data gathering
    - Sensors
    - MES/ERP
    - Simulations
    - External data

Data sources are connected via OPC UA, WS, …
• Smart devices contain their definition in the form of RDF triples
• **Semantic metadata** are stored in the variable of the corresponding object from OPC UA address space
• **User can** immediately (after device connection) query triple store by SPARQL and conduct analytic tasks
• Previously **unknown devices** can be connected if their semantic metadata comply with SHS ontology
- **Processing and transformation of required information sources** for process automation in automotive industry
  - **Detection of required elements** (e.g. in 3rd party spare part database)
  - **Subsequent matching of elements on FORD Motor Comp. ontology concepts**
  - Matching with **external dictionaries (wordnet)** and other similarity measures (e.g. n-gram, etc.)
  - Measures are **aggregated by means of neural nets** (in cooperation with NII Tokyo)
Performance Analysis of Distributed Systems

- **Problem** – performance of large-scale, distributed systems
  - high number of asynchronously interacting components
  - emergent behavior patterns
    - performance is hardly predictable at design-time
- **Solution** – Architectural Performance Models (APM)
  - simulating the design software system prior deployment
  - usually done manually – time consuming
- **Our focus** – automatic creation of APM
  - input: semantically integrated event logs
  - output: Queueing Network (QN)
  - reaching QN steady state → estimation of performance indicators
    - waiting times, resource utilization, throughput, ...
Future - Key Research Topics

- **Self-Organizing Production**
  - Production planning
  - Automatic design of robotic operations

- **Production Data Analysis**
  - Data-Driven simulation model generation and validation
  - Predictive maintenance

- **Real-Time communication in flexible systems**
  - Time sensitive networking