An Approach for Knowledge-Based IT Management of Air Traffic Control Systems

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Air Traffic Control (ATC) Systems

- **Tasks**
  - Collection of sensor data
  - Data transfer
  - Data fusion (e.g. track estimation)
  - Situation visualization for controllers

- **Subsystems**
Administrative Tasks in ATC Systems

- Monitoring
  - Log data
  - Monitoring interfaces
  - Observations from controllers
  - etc.

- Analysis of the system's state
  - Statistics (e.g. number of track drops)
  - Quality of Service (QoS) assessment
    - Conformance to fault tolerance requirements
    - Output quality
    - Time to delivery
    - etc.

- Planning and reconfiguration of the system
Administrative Problems

- High requirements on reliability and traceability
- Administration of steadily-growing ATC systems has become a
  - Time-intensive and
  - Cost-intensive task.
- Similar problems in almost every domain
  - IT applications/infrastructure essential for business goals
  - IT systems have grown over years
  - Heterogeneous components from different vendors
  - High requirements on reliability and robustness

→ High demand for intelligent, overarching, automated management tools
Ontology-based IT Management (1/2)

- Recent advances of Semantic Web technologies
- Ontologies experienced revival as domain spanning knowledge models
  - Web Ontology Language (OWL)
  - Semantic Web Rule Language (SWRL)
  - SPARQL Protocol And RDF Query Language (SPARQL)
- Advantages of ontologies in IT Management
  - Integration of different domains
  - Semantics are part of the model (no hard-coded logic)
- First applications
  - Mapping of existing models to OWL (CIM, MOF, GMDO, SMI) [1]
  - Ontology-based network management [2]
  - Architecture for automated knowledge-based IT management [3]
Ontology-based IT Management (2/2)

- Performs well for small, timeless models
- Real systems are complex, dynamic and have various timing aspects
- That leads to the following problems:
  - Reasoning complexity of OWL ontologies is NP-hard
  - There is no concept of time in ontologies

These two characteristics turn the exclusive use of ontologies for IT Management of complex systems infeasible
Approach

• Combination of
  • Ontologies as a domain spanning semantic model for low-frequency data
  • Complex Event Processing (CEP) for the processing of high-frequency data

• Central requirement:
  All components of the Management System are configured by one homogeneous model to
  • Avoid inconsistencies
  • Avoid knowledge fragmentation

• Architecture based on IBM's MAPE-K Loop
Knowledge Component

- Data storage for models used in the management cycle
- Can be queried or updated
- Models divided into system-independent and system-specific

**System Independent Models**
- Common Base Event
- Event Processing Language
- SLA Management Handbook

**System Specific Models**
- Event Ontology
- Complex Event Processing Ontology
- Service Level Agreement Ontology
- System Event Ontology
- System Aggregation Ontology
- System Topology Ontology
- System Service Level Ontology
- Runtime Model
Knowledge Component

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Transformation

Event Ontology

Complex Event Processing Ontology

Service Level Agreement Ontology
Knowledge Component

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- System Service Level Ontology
- Runtime Model
Composed Architecture

- Monitoring Adapter
- Monitoring Events
- Monitoring Data
- Monitor
- Managed System
- Execute Adapter
- Execute Commands
- Event Concepts
- Runtime Model
- Ontology
- Reasoner
- Aggregations & Runtime Data
- CEP Engine
- Analysis and Plan
- Reconfiguration Events
- Low-frequent Events
Application on the ATC System

- Use case: Automated radar reconfiguration in case of underperforming radars
- Subject: Air Traffic Management (ATM) System PHOENIX of DFS Deutsche Flugsicherung GmbH
- Map is split into geographic tiles
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- Map is split into geographic tiles
- Tiles have assigned radars
- Underperforming radar is detected
- Potential radar is assigned
Application on the ATC System

ATC System

Adapter

Complex Event Processing

Tile Assignment Command

Ontology

Knowledge Base

Configuration

Adapter

Radar Status

Evolution of Light
Application on the ATC System

System Topology Ontology
- Radar
  - id
  - position
  - range
- Tile
  - origin
  - dimension
  - assigned Radar
- Potential Radar
- Potential Radar Rule

Adapter

Complex Event Processing

Ontology

Knowledge Base

Configuration

ATC System

Adapter

Radar Status

Tile Assignment Command
Application on the ATC System

Adapter

Complex Event Processing

Tile Assignment Command

Potential Radars

Tile Assignments

Ontology

Potential Radar Rule

Knowledge Base

Configuration

Radar Status

Adapter

ATC System
Application on the ATC System

System Event Ontology
- POD Event
  - radarId
  - pod
- Avg. POD Event
  - radarId
  - avgPod
- Underperforming Radar Event
  - radarId
- Compromised Tile Event
  - tileId
- Tile Assignment Event
  - tileId
  - radarId

Tiles Assignment Command
Complex Event Processing

Adapter

Radar Status

ATC System

Knowledge Base

Potential Radar Rule

Configuration

Pod Event

POD Event

Avg. POD Event

Underperforming Radar Event

Compromised Tile Event

Tile Assignment Event
Application on the ATC System

- Adapter
  - Tile Assignment Event
  - Compromised Tile Event
  - Underperforming Radar Event
  - Avg. POD Event
  - POD Event
  - Radar Status

- Complex Event Processing
  - Potential Radars
  - Tile Assignments
  - Ontology
    - Potential Radar Rule
    - Knowledge Base
    - Configuration

- ATC System
  - Adapter
Application on the ATC System

- **System SLA Ontology**
  - Underperforming Radar SLA
  - podTreshold
  - Compromised Tile SLA
  - radarThreshold

- **Tile Assignment Command**
  - Complex Event Processing
    - Compromised Tile Event
    - Underperforming Radar Event
    - Avg. POD Event
    - POD Event
    - Radar Status

- **Adapter**

- **ATC System**
Application on the ATC System

Diagram showing the flow of events and components in the ATC System:

- **Adapter**
  - Tile Assignment Event
  - Compromised Tile Event
  - Underperforming Radar Event
  - Avg. POD Event
  - POD Event
  - Radar Status

- **Complex Event Processing**
  - Potential Radars
    - Tile Assignments
      - Radar Treshold
      - POD Threshold
      - Potential Radar Rule
        - Knowledge Base
          - Configuration

- **ATC System**

Application on the ATC System

- **System Aggregation Ontology**
  - Avg. POD Aggregation
  - Underperforming Radar Aggregation
  - Compromised Tile Aggregation
  - Tile Assignment Aggregation

- **Ontology**
  - Potential Radar Rule
  - Knowledge Base

- **Configuration**

- **Adapter**

- **Tile Assignment Command**

- **Tile Assignment Event**

- **Compromised Tile Event**

- **Underperforming Radar Event**

- **Avg. POD Event**

- **POD Event**

- **Radar Status**

- **ATC System**

- **Distributed Systems Lab**

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Application on the ATC System

- Adapter
  - Tile Assignment Event
    - Tile Assignment Aggregation
      - Compromised Tile Event
        - Compromised Tile Aggregation
          - Underperforming Radar Event
            - Underperforming Radar Aggregation
              - Avg. POD Event
                - Avg. POD Aggregation
                  - POD Event
                    - Adapter
                      - Radar Status
                          - ATC System

- Potential Radars
  - Tile Assignments
    - Radar Treshold
      - POD Threshold
        - Ontology
          - Potential Radar Rule
            - Knowledge Base
              - Configuration
                - System
Status

- Modeling of ontologies partially done
- Management software implemented prototypically using
  - OSGi as component framework
  - OWL API for ontology handling
  - Pellet as semantic reasoner
  - Esper as CEP engine
- Monitoring adapter to ATC system is implemented
- Presented use case was implemented
Lessons Learned and Future Work

- Finalization of the ontologies
- Data interchange between reasoner and CEP engine difficult
  → Transfer to Drools rule engine
    - Drools Expert as OWL-RL reasoner
    - Drools Fusion as CEP engine
    - Drools Planer for optimization
- Modeling of aggregations in ontology complex and time-consuming
  → Domain Specific Language (DSL) for easier modeling of aggregations under development
Thank you for your attention!