The AMADEOS SysML Profile for Cyber-physical Systems-of-Systems

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• AMADEOS Conceptual modeling
  • Basic concepts and their relationships
  • Viewpoints-driven approach

• From Conceptual to SysML modeling
  • High-level representation
  • Semi-formalization into the AMADEOS profile
  • Application to toy example

• Conclusions
A Conceptual Model

- It expresses the **meaning of terms** and **concepts** used by domain experts to discuss the problem.
- It ensures that problems with different interpretations of the terms and concepts cannot occur.
- It is the basis for subsequent development of applications in a domain.
The AMADEOS conceptual model

- Establishing a domain specific ontology on Cyber-physical Systems-of-Systems, serving as a vocabulary for the domain of discourse

- Forming a reference for the AMADEOS work
  - Supporting the definition of a reference architecture for SoSs
  - Supporting the definition of methodologies and techniques to be proved in a concrete case study on smart energy grids
Basic concepts and relationships

• Definition of **basic** SoS concepts
  • Not domain specific
  • Applicable to any SoS

• Definition of **relationships** among basic SoS concepts
SoS Basic concepts

High-level representation

Semi-formalization
Viewpoints composing the model

- Basic concepts defined according to 7 viewpoints
  - Structure
  - Dynamicity
  - Evolution
  - Dependability and Security
  - Time
  - Multi-criticality
  - Emergence

- Viewpoints represent core AMADEOS issues

- Concepts (and viewpoints) have been integrated by defining their relationships

- Viewpoints approach facilitate the conceptual modeling itself and the design process
High-level representation

• Explicates relations among basic SoS concepts per viewpoint

• Supports their graphical visualization

• Semantic
  • **Boxes** represent concepts
  • **Arrows** represents semantic relationships among concepts (labels in natural language)
Relating basic SoS concepts in Structure view

• “System-of-Systems (SoS): An SoS is an integration of a finite number of constituent systems (CS) which are independent and operable, and which are networked together for a period of time to achieve a certain higher goal.”

• “Constituent System (CS): An autonomous subsystem of an SoS, consisting of computer systems and possibly of a controlled objects and/or human role players that interact to provide a given service.”
Dynamicity: The property of an entity that is constantly changing in terms of offered services, built-in structure and interactions with other entities.

Managed SoS evolution: Process of modifying the SoS to keep it relevant in face of an ever-changing environment.

Business value: Overarching concept to denote the performance, impact, usefulness, etc. of the functioning of the SoS.
• “Critical service: A critical service is the service of a system that requires a specific criticality level.”

• “Criticality level: The criticality level is the level of assurance against failure.”
**Clock**: A (digital) clock is an autonomous system that consists of an oscillator and a register. Whenever the oscillator completes a period, an event is generated that increments the register.

**Reference clock**: A hypothetical clock of a granularity smaller than any duration of interest and whose state is in agreement with TAI.

**Emergence**: A phenomenon of a whole at the macro-level is emergent if and only if it is new with respect to the non-relational phenomena of any of its proper parts at the micro level.

**Weak emergence**: …if a trans-ordinal law that explains the occurrence of the emergent phenomenon at the macro level out of the properties and interactions of the parts at the adjacent micro level is known.

**Strong Emergence**: …if, after a careful analysis of the emergent phenomenon, no trans-ordinal law that explains…. is known (at least at present).
Towards a semi-formal representation

- Describe AMADEOS viewpoints via a SysML profile

- UML-like representation
  - Improve the understanding by using different levels of abstraction and different views
  - Foster information sharing and reuse among SoS stakeholders
  - Enable analysis and experimentation at early stage of the SoS lifecycle process
AMADEOS Profile: Rationale

- A SysML profile to implement SoS basic concepts and their relationships
  - Strong focus on conceptual modelling
  - Capturing both SoS static structure and dynamic behavior
- The profile makes use of
  - New added constructs
  - Constructs already available in related profiles (MARTE, CONCERTO)
- Organized in viewpoints driven-components
- Profile implementation
  - Open source Eclipse integrated development environment along with Papyrus plug-in
• Starting from the high-level graphical representation of Structure…

• ...we implemented three SysML profile components:
  • SoSArchitecture component
  • SoSCommunication component
  • SoSInterface component
Dynamics / Evolution
Toy Example: Smart Grid Household

• Applying the profile to a toy example to check:
  • soundness of a subsets of semi-formalized concepts
  • which concepts were missing

• Toy Example
  • Improving the efficiency and the reliability of the production and distribution of electricity in a Smart Grid
  • Keeping production and consumption rate as much balanced as possible for a set of connected households
  • Electronic appliances forward requests of energy by interacting with higher-level sub-systems which decides to grant or deny each request
Toy Example: structure view
AMADEOS profile – possible applications

• Model-based definition of an SoS with AMADEOS profile
  • Platform Independent Model of an SoS

• Platform-Specific Models can be defined and used at different stages of system design and validation (MDE approaches)

• The profile can be integrated into existing SysML MDE tool-chain platforms, such as CONCERTO, Eclipse, to perform e.g.
  • System analysis
    • E.g. Hazard Analysis (HA), Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), etc.
  • Source code generation
  • System testing
Profile application for supporting HA

• Hazard Analysis application example
  • Typically it identifies and mitigates hazards leading to detrimental situations
  • In our case, it supports the identification of emergent conditions based on the information exchanged through the interfaces

• Input:
  • Events and interfaces

• Output
  • Identification of consequences and emergent behaviors
Workflow: Profile application

Step 1
- SoS Profile
- Smart Grid Model

Step 2
- Internal

Step 3
- Set of Events
Workflow: Interface Identification

Step 1

- SoS Profile
- Smart Grid Model

Step 2

- Internal Interfaces

Interface among Constituent Systems | ID Interface
-----------------------------------|-----------------|
EMG and Coordinator                 | INT_01          |
Coordinator and DSO                 | INT_02          |
Smart meter and Meter Aggregator    | INT_03          |
Meter Aggregator and DSO            | INT_04          |
Command Display and EMG             | INT_05          |
Command Display and Smart meter     | INT_06          |
Smart Meter and Flexible load       | INT_07          |
Smart Meter and EMG                 | INT_08          |
EMG and Flexible load               | INT_09          |
PEL EMG and Coordinator             | INT_10          |

Interface Analysis

<table>
<thead>
<tr>
<th>Id int</th>
<th>Guideword</th>
<th>Id cons</th>
<th>mitig</th>
</tr>
</thead>
<tbody>
<tr>
<td>INT_01</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>INT_03</td>
<td>...</td>
<td>...</td>
<td>...</td>
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<tr>
<td>INT_09</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>INT_10</td>
<td>...</td>
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Workflow: Events

**Event Description**

**Event1** A new functionality is added to the command display HMI. The latter can send a message to EMG containing the name/type of electrical appliance involved.

**Event2** A new EMG is connected to the Smart Grid to support the provision of energy for public event lighting.
# Workflow: Hazards identification

<table>
<thead>
<tr>
<th>Id Event</th>
<th>Id Interface</th>
<th>Guideword</th>
<th>Hazard</th>
<th>Emergent Behavior</th>
<th>Consequence</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event 1</td>
<td>INT_05</td>
<td>More</td>
<td>EMG receives additional information from the new Command Display on the electrical appliance switched on</td>
<td>YES - beneficial</td>
<td>EMG can forward additional information to the Coordinator for better balancing the Smart Grid</td>
<td>not needed</td>
</tr>
<tr>
<td>Event 2</td>
<td>INT_10</td>
<td>More</td>
<td>The Coordinator receives a request for a very high amount of energy to support the public event lighting</td>
<td>YES - detrimental</td>
<td>Coordinator, in order to keep balanced production and consumption values, decides to limit the provision of energy for the electrical appliances</td>
<td>MIT_03: EMG can communicate the energy decrease to the Command Display (INT_05). The latter supports the reconfiguration of the electrical appliances</td>
</tr>
</tbody>
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Conclusion

- Viewpoint-based conceptual modeling
  - Basic SoS concept definition
  - Representation of their semantic relationships
  - SysML semi-formalization: AMADEOS profile

- Vision for the Applicability of the profile for SoS description and analysis

- Conceptual model refinement to be continued until the end of the project
Thank You for Your attention