Cyber-Physical Systems

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Architecture

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Cyber-physical systems: key properties and challenges

- Physicality
  - real world awareness
  - real time
  - probabilistic behavior
- Connectivity
  - systems of systems
  - connected to cloud services
- Systems of systems
  - Sub-system decomposition
  - Service decomposition
- Interoperability
- Openness
  - security
- HMI - Smartness
  - Human Centric Engineering
- Dynamic systems
  - Dynamic interfaces
  - Dynamic architectures
  - Dynamic change of behavior (adaptivity)
- Mobile systems
  - space awareness

CPSs are more than embedded systems integrated cyber-mechanical systems consisting of mechanics/hardware/software and communication connections
What is Architecture for CPS

• Functional Architecture: structuring a system into a
  ◊ family of functional features and
  ◊ describing their dependencies and feature interactions

• Logical Sub-system Architecture: structuring a CPS onto
  ◊ a set of sub-systems
  ◊ describing their connections and
  ◊ their role, cooperation and their
  ◊ interface behavior

• Technical Architecture: structuring a CPS into technical sub-systems
  ◊ software
  ◊ hardware
  ◊ mechanics and describing the way how they
  ◊ are interconnected, cooperate and work together
Key Notions and Areas of Research

Key Notions

• Modularity
  ◊ Abstraction
  ◊ Compositionality

• Interoperability
  ◊ Interfaces

• Homogeneity
  ◊ Fractal models - hierarchies

Areas of research

• Architecture Modeling
• Reference Architecture
• Architectural Patterns
• Architecture Engineering
From closed embedded systems to open systems connected to the cloud

Traditional embedded systems
• closed
• real time
• connected to the physical
• reliable
• high safety reqs
• low security reqs

Services in the cloud
• open
  ◊ open interfaces
• restricted availability
• easy extendibility
• high interoperability
• low safety reqs
• high security reqs

Smart systems - Cyber-physical systems: innovation
• adaptive
• context aware
• autonomous
• big data
• open interfaces
• dynamic
Modeling smartness of systems

- **Non-adaptive behavior**
- **Adaptive behavior**
  - Transparent
  - Non-transparent
  - Diverted
- **Monitoring**
- **Context Awareness**
- **Autonomy**
- **Robustness**
- **Dynamicity**
- **Mobility**

\[ F^+ [ I_{cs} \triangleright O_{sc} ] \text{ faithful} \implies \text{ user cannot influence the output of the system to the context - autonomy} \]

See: Survey of Modeling and Engineering Aspects of Self-Adapting & Self-Optimizing Systems
V. Bauer, M. Broy, M. Irlbeck, C. Leuxner, M. Spichkova (TUM)
M. Dahlweid, T. Santen (Microsoft Research)
An algebraic view onto modeling cyber-electromechanical systems

<table>
<thead>
<tr>
<th>HW:</th>
<th>electronic programmable hardware including sensors, actuators, HMI devices</th>
<th>⊗ composition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>⊗: SW × SW → SW</td>
</tr>
<tr>
<td>SW:</td>
<td>software</td>
<td>⊗: HW × HW → HW</td>
</tr>
<tr>
<td>ITS:</td>
<td>hardware and software integrated (example CPU)</td>
<td>⊗: MD × MD → HW</td>
</tr>
<tr>
<td>CN:</td>
<td>communication devices – bus systems</td>
<td>⊗: HW × SW → ITS</td>
</tr>
<tr>
<td>MD:</td>
<td>mechanical systems</td>
<td>⊗: ITS × ... × ITS × CN → ITS</td>
</tr>
<tr>
<td>CPS:</td>
<td>cyber physical systems</td>
<td>⊗: ITS × MD → CPS</td>
</tr>
</tbody>
</table>

Laws:

\[
[\text{md}_1 \otimes \text{md}_2] \otimes [\text{hw}_1 \otimes \text{hw}_2] \otimes [\text{sw}_1 \otimes \text{sw}_2] = ? = [\text{md}_1 \otimes \text{hw}_1 \otimes \text{sw}_1] \otimes [\text{md}_2 \otimes \text{hw}_2 \otimes \text{sw}_2]
\]
Re-thinking the role of time

- Ed Lee’s structure of an CPS is essentially an embedded system
  - Observation: a C program $sw$ does not say anything about timing – we need the platform to understand the timing

Observation

\[
\text{timing}[sw] \\
\neq \\
\text{timing}[hw \otimes sw]
\]