Orthogonal Uncertainty Model: Documenting Uncertainty in the Engineering of Cyber-Physical Systems

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Abstract: In this talk, we present our contribution "Orthogonal Uncertainty Modeling in the Engineering of Cyber-Physical Systems" published in IEEE Transactions on Automation Science and Engineering in July 2020 [Ba20]. We have proposed a modeling language for "Orthogonal Uncertainty Models" (OUMs). OUMs constitute a dedicated, central artifact to document, analyze, understand, and discuss potential uncertainties that may occur during operation. Thereby, OUMs support the systematic consideration of potential uncertainties the system might face during operation. OUMs allow documenting various aspects of uncertainty (e.g., cause and effect) in a dedicated artifact. Trace links are used to relate uncertainty to, e.g., system requirements across different model-based artifacts. We have applied OUMs to an industrial case study from the industry automation domain.

Keywords: Uncertainty; Uncertainty Modeling; Model-Based Engineering; Cyber-Physical Systems

1 Motivation

Cyber-physical systems (CPS) typically operate in highly dynamic and uncertain contexts. Many kinds of uncertainty occur in the operation of CPS, e.g., due to imperfection of sensors. Other concerns, such as the real-time criticality of CPS increases the complexity of uncertainty consideration as well [BWD21]. Uncertainty needs to be handled systematically in the engineering. If uncertainty remains unconsidered, severe safety hazards may occur during operation.

Engineering CPS that are able to safely handle uncertainty requires identifying and documenting such uncertainty. In requirements engineering, potential operational uncertainty must be uncovered, modelled, and discussed with stakeholders. Integrating information about potential uncertainty into other development artifacts (e.g., behavioral models of the system and the context) has two major drawbacks: 1) It causes redundancy of uncertainty information, and 2) related uncertainty information (e.g., cause and effect of an uncertainty) is spread across several models. Uncertainty is in fact a cross-cutting concern, similar to, e.g., variability in software product line engineering.

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2 The OUM Modeling Language

OUMs allow engineers to capture uncertainty information in a dedicated, model-based development artifact. OUMs can be connected to any other development artifact via trace links. That way, e.g., the effect of uncertainty on the fulfillment of system requirements can be documented. OUMs are graphical models, which are easy to understand and support the identification, documentation, analysis and communication of uncertainty.

The OUM language is based on common ontological concepts for uncertainty. However, in contrast to existing uncertainty modeling approaches, OUMs are specifically focused on modeling uncertainty from the point of view of a system in operation. Among others, one specific modeling concept is the so-called *Observation point*, which allows specifying how (e.g., based on which inputs) the system will become aware of uncertainty during operation. OUMs also depict the *Rationale*, *Effect*, *Activation Condition*, and *Mitigation* of uncertainty. Furthermore, it is possible to explicitly model relationships between different uncertainties.

We have applied the OUM approach to the case examples of a fleet of transport robots [Ba18], a smart factory [Ba20], and a cooperative ACC system [Ba21]. The results from these case studies show that OUMs support systematically uncovering and investigating uncertainty in several interrelated development artifacts and at different levels of abstraction.

3 Data Availability

The OUM notation has become part of a comprehensive modeling tool suite for CPS development, which is implemented as a Microsoft Visio extension and publicly available [7].

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[7] See `https://github.com/SSEPaluno/SPES-Modeling-Tool`