**THEME SECTION PAPER**

# Multi-paradigm modelling for cyber–physical systems: a descriptive framework

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**Abstract**

The complexity of cyber–physical systems (CPSs) is commonly addressed through complex *workflows*, involving models in a plethora of different *formalisms*, each with their own methods, techniques, and tools. Some *workflow patterns*, combined with particular *types of formalisms* and *operations* on models in these formalisms, are used successfully in engineering practice. To identify and reuse them, we refer to these combinations of workflow and formalism patterns as modelling *paradigms*. This paper proposes a *unifying (Descriptive) Framework* to describe these paradigms, as well as their combinations. This work is set in the context of Multi-Paradigm Modelling *(*MPM), which is based on the principle to model every part and aspect of a system explicitly, at the most appropriate level(s) of abstraction, using the most appropriate modelling formalism(s) and workflows. The purpose of the Descriptive Framework presented in this paper is to serve as a basis to reason about these formalisms, workflows, and their combinations. One crucial part of the framework is the ability to capture the *structural* essence of a paradigm through the concept of a *paradigmatic structure*. This is illustrated informally by means of two example paradigms commonly used in CPS: Discrete Event Dynamic Systems and Synchronous Data Flow. The presented framework also identifies the need to establish whether a paradigm *candidate* follows, or qualifies as, a (given) paradigm. To illustrate the ability of the framework to support *combining* paradigms, the paper shows examples of both workflow and formalism combinations. The presented framework is intended as a basis for characterisation and classification of paradigms, as a starting point for a rigorous formalisation of the framework (allowing formal analyses), and as a foundation for MPM tool development.

**Keywords** Multi-paradigm modelling · Foundations of model-based systems engineering · Cyber–physical systems

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## 1 Introduction

Cyber–Physical Systems (CPSs) are engineered systems that emerge from the networking of multi-physical processes (mechanical, electrical, biochemical, etc.) and computational