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INVITED ARTICLE

# Design and validation of a metamodel for metacognition support in artificial intelligent systems

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**Abstract**
Computational metacognition is a technical area of artificial intelligence whose aim is to increase the degree of autonomy and awareness an intelligent system has about its own reasoning and learning. In the literature, different models of metacognition are applied to artificial intelligent systems. However many of these models have a narrow focus, because they do not address comprehensively the elements of metacognition. This paper presents an analysis of metacognitive models discussed in the literature in order to discover the common (invariants) and varying (variants) elements. The main contribution of this work is the development of a comprehensive and general purpose metamodel named MISM that covers and describes a broad range of commonly referenced concepts in metacognitive models in the area of artificial intelligence. A validation process was conducted to ensure the reliability of MISM in terms of generality, expressiveness and completeness. The validation was performed using three techniques for improvements and adjustments to the metamodel: (i) comparison with other models; (ii) frequency-based selection; and (iii) model tracing. The adjusted and improved version of the metamodel was named MISM 1.1.
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## Introduction

Metacognition is a field of study that emerged from cognitive science and psychology in the 1970s with the work of Flavell and Wellman (1977). Metacognition from cognitive science is defined as mental awareness and regulation of one's thinking (Jozefowiez, Staddon, & Cerutti, 2009). Metacognition involves two executive processes performed by the subject over its cognitive processes: monitoring and control (Anderson, Oates, Chong, & Perlis, 2006). Several authors (Gaeta, Mangione, Orciuoli, & Salerno, 2011; Vockell, 2004) have identified the following three major classes of metacognition: (i) self-regulation that relates to the learners' ability to make adjustments to their own learning processes (Soh & Blank, 2008) in response to the perception about their current state of learning (Azevedo, Witherspoon, Chauncey, Burkett, & Fike, 2009; Josyula, Hughes, Vadali, & Donahue, 2009); (ii) metamemory that refers to the processes involved in self-regulation or self-awareness of memory (Nelson, Narens, & Dunlosky, 2004; Nelson & Narens, 1990); and (iii) metacomprehension that addresses the abilities to adjust the cognitive activities in order to promote more effective comprehension and understanding of information (Cox, 2005; Pule & Anderson, 2009).

Computational metacognition has been widely used in AI for designing robust Intelligent Systems. The term metacognition in AI refers to the ability of an intelligent system to monitor and control its own learning and reasoning processes (Cox & Raja, 2012). However, the design of a new system with metacognitive capability is a difficult and time consuming task (Gaeta et al., 2011; Soh & Blank, 2008) due to the diversity and complexity of the available metacognitive models such as EM-ONE (Singh, 2005), Meta-AQUA (Cox & Ram, 1999), and CLARION (Sun & Mathews, 2006). The modeling process of metacognition in *an intelligent system* is a difficult task in terms of the diversity of constituent elements and to the complexity of the relationships between them; in particular, when the integration of several metacognitive components such as self-regulation with metamemory or meta-comprehension in a new system is necessary. Moreover, computational models (Alonso, Arnold, & Havasi, 2010; Kennedy, 2010; Shapiro, Rapaport, Kandefer, Johnson, & Goldfain, 2007) of metacognition do not present formalisms of software engineering methodologies that allow the development of an intelligent system in a systematic way. The focus of current metacognitive models on specific domains, poses difficulty in adaptation of elements of the model to other domains.

In this context, we propose a metamodel-based approach to identify the concepts commonly used in the design of metacognitive support for intelligent systems. A metamodel is a special kind of model which describes an abstract syntax of another model (Reina & Torres, 2007). Metamodels facilitate the transfer of knowledge and provide a set of transformations that automate important steps of model design such as refinement and re-factoring to improve maintainability and readability of the designed model (Gascueña, Navarro, & Fernandez-Caballero, 2012; Sen, Baudry, & Mottu, 2009). Thus, in a metamodel, the metacognitive components required for monitoring and executive control of the reasoning processes that take place in each module of an intelligent system can be specified.

The main objective of this work is to develop a comprehensive metamodel that includes concepts which are commonly referenced in metacognitive models used for the development of an intelligent system. The developed metamodel integrates the concepts and relationships related to the three following types of metacognition: self-regulation, metamemory and meta-comprehension. The concepts and relationships commonly used for the three components compose the MetaCore. MetaCore is a package that allows the reuse of components (relationships and concepts), reducing the complexity in the design of the structure of metacognition components.

The paper is structured as follows. In Section 'Meta-modeling of metacognition in intelligent systems', we describe the meta-modeling process used for metamodel creation and present the first version of the metamodel named MISM 1.0. In this section metacognitive model sets used for the creation and validation of MISM 1.0 are presented. Section 'Validation of metamodel' presents the results of three validation processes implemented to improve and correct bugs in the metamodel. Section 'Version MISM 1.1' describes the revised and validated version of MISM. Finally, we present the discussion and conclusions.

## Meta-modeling of metacognition in intelligent systems

Meta-modeling is a technique promoted by the Object Management Group (OMG) (OMG, 2013). To create the metacognition metamodel, we use a 6-step Meta-modeling Creation Process adapted from FAML (Beydoun et al., 2009) (see Fig. 1).

Adaptations in the methodology of meta-modeling with respect to FAML include: (i) addition of step 0 for the

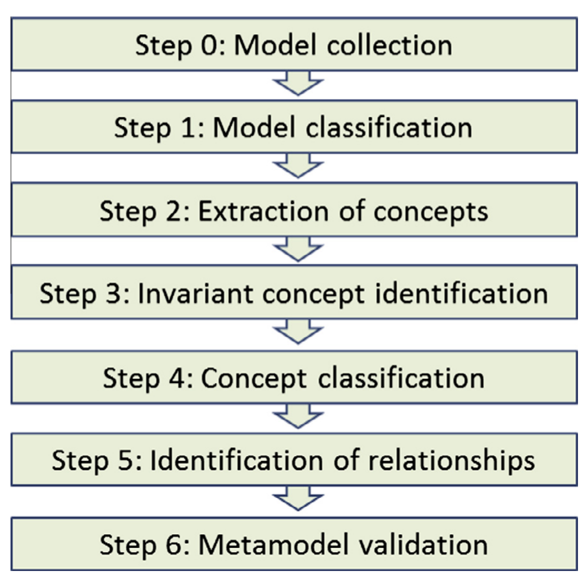


**Fig. 1** Meta-modeling process.

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