Chapter 1
A Formal Knowledge Representation System (FKRS) for the Intelligent Knowledge Base of a Cognitive Learning Engine

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ABSTRACT
It is recognized that the generic form of machine learning is a knowledge acquisition and manipulation process mimicking the brain. Therefore, knowledge representation as a dynamic concept network is central in the design and implementation of the intelligent knowledge base of a Cognitive Learning Engine (CLE). This paper presents a Formal Knowledge Representation System (FKRS) for autonomous concept formation and manipulation based on concept algebra. The Object-Attribute-Relation (OAR) model for knowledge representation is adopted in the design of FKRS. The conceptual model, architectural model, and behavioral models of the FKRS system is formally designed and specified in Real-Time Process Algebra (RTPA). The FKRS system is implemented in Java as a core component towards the development of the CLE and other knowledge-based systems in cognitive computing and computational intelligence.

1. INTRODUCTION
Knowledge representation is recognized as a central problem in machine learning. Traditional technologies for knowledge representation are relational knowledge bases, natural language processing (NLP) technologies, and ontology (Crystal, 1987; Pullman, 1997; Brewster et al., 2004; Leone et al., 2010; Wang, 2009b; Tian et al., 2009). Knowledge base technologies represent knowledge by lexical and semantic relations (Debenham, 1989). WordNet and ConceptNet are typical lexical databases (Fellbaum, 1998;
Various rule-based systems are developed for knowledge representation using logical rules (Bender, 1996) and fuzzy rules (Zadeh, 1965, 2004; Surmann, 2000). NLP technologies are developed for text processing in natural languages (Liddy, 2001; Wilson & Keil, 2001). Although various methods were proposed in NLP, fundamental technologies of them can be classified into two categories such as the symbolic approach (Chomsky, 1957) and the computational linguistic approach (Pullman, 1997). The former treats language as character strings with syntactic relations such as formal grammars (Chomsky, 1957; Burton, 1976; Kaplan & Bresnan, 1982; Wang, 2009a) and text parsing (McDermid, 1991; Wang, 2010b). The latter studies computational processing of natural languages such as the translation theory (Weaver, 1949; Crystal, 1987) and information retrieval techniques (Chang et al., 2006; Zhao & Sui, 2008; Reisinger & Pasca, 2009; Hu et al., 2010). However, the NPL technologies lack detailed analytic power at the concept and attribute levels underpinning semantic analyses at the word-level (Burton, 1976; Wang, 2008b, 2010b). Ontology is the third approach to knowledge representation and modeling, which is a branch of metaphysics dealing with the nature of being, which treats a small-scale knowledge as a set of words and their semantic relations in a certain domain (Gruber, 1993; Cocchiarella, 1996; Brewster et al., 2004; Tiberino et al., 2005; Sanchez, 2010; Hao, 2010; Wang et al., 2011). However, ontology may only represent a set of static knowledge and is highly application specific. Therefore, ontology was not designed to enable machines to automatically generate and manipulate concept networks for knowledge representation as that of human beings.

In recent studies in cognitive informatics (Wang, 2007c) and cognitive computing (Wang, 2009c, 2010a), it is recognized that concepts are the basic unit of human thinking, reasoning, and communications (Pojman, 2003; Wang, 2008b). An internal knowledge representation theory known as the Object-Attribute-Relation (OAR) model is proposed by Wang (2007a), which reveals the logical foundation of concepts and their attributes based on physiological and biological observations (Wilson & Keil, 2001). The OAR model provides a logical view of the long-term memory of the brain, which is a triple \((O, A, R)\), where \(O\) is a finite set of objects identified by unique symbolic names; \(A\) is a finite set of attributes for characterizing the objects; and \(R\) is a set of relations between an object and other objects or their attributes.

A denotational mathematical structure known as concept algebra was developed by Wang (2008b) for formal knowledge representation and manipulations, which is a novel mathematical means for the formal treatment of concepts and their algebraic relations, operations, and associative rules. In concept algebra, the generic mathematical model of concepts is elicited from both abstract and concrete concepts. A set of relational and compositional operators are modeled in concept algebra on the basis of the general concept model. The operational semantics of concept algebra is formally described in Wang et al. (2011). In concept algebra, attributes of concepts are identified as the meta-properties of a concept known as the intension (Wang, 2007a). New attributes are explored to refine a certain concept in order to make it more precise. For example, the entire organisms in biology can be modeled as a hierarchical structure known as kingdoms, phyla, classes, orders, families, genus, and species from the top down when more attributes are introduced into a certain level of concepts. Various studies have been conducted on attribute extraction in either manual approaches or semi-automatic approaches (Yan, 2006; Poesio & Almuhareb, 2008; Zhao & Sui, 2008; Sanchez, 2010).

This paper presents the design and implementation of a formal knowledge representation system (FKRS) based on the OAR model (Wang, 2007a) and concept algebra (Wang, 2008b). In order to rigorously design and implement FKRS, real-time process algebra (RTPA) (Wang, 2002, 2007b, 2008a, 2008c) is adopted to formally describe...
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