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Quantitative Semantic Analysis and Comprehension by Cognitive Machine Learning

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ABSTRACT

Knowledge learning is the sixth and the most fundamental category of machine learning mimicking the brain. It is recognized that the semantic space of machine knowledge is a hierarchical concept network (HCN), which can be rigorously represented by formal concepts in concept algebra and semantic algebra. This paper presents theories and algorithms of hierarchical concept classification by quantitative semantic analysis based on machine learning. Semantic equivalence between formal concepts is rigorously measured by an Algorithm of Concept Equivalence Analysis (ACEA). The semantic hierarchy among formal concepts is quantitatively determined by an Algorithm of Relational Semantic Classification (ARSC). Experiments applying Algorithms ACEA and ARSC on a set of formal concepts have been successfully conducted, which demonstrate a deep machine understanding of formal concepts and quantitative relations in the hierarchical semantic space by machine learning beyond human empirical perspectives.

KEYWORDS

Algorithms, Cognitive Learning, Concept Algebra, Concept Classification, Knowledge Learning, Knowledge Representation, Machine Learning, Semantic Algebra, Semantic Analysis

1. INTRODUCTION

It is recognized that a fundamental challenge to machine learning is knowledge learning mimicking the brain (Wang, 2015a, 2016) beyond traditional object identification, cluster classification, pattern recognition, functional regression, and behavior acquisition (Russell & Norvig, 2010; Mehryar et al., 2012; Russell & Norvig, 2010; Wang, 2015a). This leads to an emerging field of *cognitive machine learning* (Wang, 2010, 2015a, 2016a) on the basis of recent breakthroughs in *denotational mathematics* (Wang, 2002, 2012, 2013, 2015b) and *mathematical engineering* (Wang, 2015c, 2016a) such as *concept algebra* (Wang, 2015b), *semantic algebra* (Wang, 2013; Wang & Berwick, 2013), *inference algebra* (Wang, 2011), and *Real-Time Process algebra* (RTPA) (Wang, 2002). Cognitive machine

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learning is underpinned by basic studies on *cognitive informatics* (Wang, 2003, 2007) and *cognitive computing* (Wang, 2009) such as the Layered Reference Model of the Brain (LRMB) (Wang et al., 2006), the Theory of Abstract Intelligence (αI) (Wang, 2007a), Mathematical Models of Human Memories (Wang, 2007b), Mathematical Models of Cognitive Computing (MMCC) (Wang, 2009), Mathematical Models of Cognitive Neuroinformatics (MMCN) (Wang, 2003), Mathematical Models of Cognitive Linguistics (MMCL) (Wang & Berwick, 2012, 2013), and the Cognitive Models of Brain Informatics (CMBI) (Wang, 2015a; Wang & Wang, 2006).

Concepts as the basic carrier of semantics in human memory for knowledge representation are studied in linguistics and cognitive psychology (Belohlave & Klir, 1956; Chomsky, 1956, 2007; Harris, 2006; Sternberg, 2006; Lefton et al., 2008; Saeed, 2009; Machery, 2011; Wang & Berwick, 2012). In computational linguistics, lexis and semantics are studied in order to represent the relational composition of words in machine-interpretable lexical structures such as WordNet (Miller, 1990) and ConceptNet (Havasi et al., 2007). The cognitive properties of language expressions and knowledge are explored in cognitive science, computational linguistics, and cognitive computing (Harris, 2006; Sternberg, 2006; Machery, 2011; Wang, 2003; Wang & Berwick, 2013).

Concept algebra is a denotational mathematics for rigorously manipulating formal concepts and their algebraic operations in knowledge representation, semantic analysis, and machine learning (Wang, 2008, 2015b). Formal concept is a general and dynamic mathematical structure that encapsulates the intension and extension of language entities and semantics (Wang, 2015b, 2016b). Formal concepts and their algebraic operators are rigorously defined in concept algebra, which provides a powerful mathematical means for modeling and manipulating cognitive learning. The mathematical operators of concept algebra encompass those of relational, reproductive, and compositional operations (Wang, 2015b; Valipour & Wang, 2016). The category of relational operators of concept algebra is designed for cognitive machine learning on hierarchical concept classifications and semantic analyses. The relations between formal concepts can be classified as equivalent concept (synonym), superconcept (hypernym/ holonym), subconcept (hyponym/meornym), and partial synonym where the terms in brackets are linguistic ones (Chomsky, 1956; Chomsky, 2007; Saeed, 2009; Wang, 2013, 2015b) whose mathematical definitions are rigorously provided in the formal terms of concept algebra. The quantitative determination of semantic relations and weights of formal concepts (Wang et al., 2016) will enable cognitive machines to rigorously build a semantic hierarchy of knowledge bases and formal manipulations of knowledge in cognitive machine learning (Wang, 2016b).

This paper presents cognitive algorithms and experiments for machine knowledge learning based on concept algebra and semantic algebra. In the remainder of this paper, mathematical models of formal concepts and their hierarchical semantic space are created in Section 2. The algorithm of concept equivalence analysis is formally elaborated in Section 3 based on numerical experiments. The algorithm of hierarchical semantic classification for formal knowledge is rigorously described in Section 4 with the support of experimental results. This work encouragingly demonstrates a fundamental breakthrough in cognitive knowledge learning and quantitative semantic comprehension by deep machine learning.

2. MATHEMATICAL MODELS OF FORMAL CONCEPTS AND THE SEMANTIC SPACE OF KNOWLEDGE

According to concept algebra (Wang, 2015b), a formal concept is a hyperstructure that represents the basic structural unit of knowledge denoted by its intension (attributes), extension (objects), and internal/external semantic relations.