Chapter 33
A Novel Machine Learning Algorithm for Cognitive Concept Elicitation by Cognitive Robots

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ABSTRACT

Cognitive knowledge learning (CKL) is a fundamental methodology for cognitive robots and machine learning. Traditional technologies for machine learning deal with object identification, cluster classification, pattern recognition, functional regression and behavior acquisition. A new category of CKL is presented in this paper embodied by the Algorithm of Cognitive Concept Elicitation (ACCE). Formal concepts are autonomously generated based on collective intension (attributes) and extension (objects) elicited from informal descriptions in dictionaries. A system of formal concept generation by cognitive robots is implemented based on the ACCE algorithm. Experiments on machine learning for knowledge acquisition reveal that a cognitive robot is able to learn synergized concepts in human knowledge in order to build its own knowledge base. The machine–generated knowledge base demonstrates that the ACCE algorithm can outperform human knowledge expressions in terms of relevance, accuracy, quantification and cohesiveness.

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1. INTRODUCTION

The taxonomy of machine learning can be classified into six categories including object identification, cluster classification, pattern recognition, functional regression, behavior acquisition (gaming) and knowledge learning (McCarthy et al., 1955; Chomsky, 1956; Simon, 1983; Zadeh, 1999; Mehryar et al., 2012; Wang, 2016b; Wang et al., 2017). The sixth category of Cognitive Knowledge Learning (CKL) is recently revealed (Wang, 2016a), which challenges traditional theories and methodologies for machine learning in artificial intelligence, cognitive robotics, cognitive computing and computational intelligence (Berkeley, 1954; Zadeh, 1983; Albus, 1991; Bender, 1996; Widrow & Lehr, 1990; Miller, 1995; Jordan, 1999; Meystel & Albus, 2002; Wang, 2002a, 2003, 2015b; Wang et al., 2006, 2016).

Fundamental problems for CKL are identified as lack of semantic theories, pending for suitable mathematical means, demand for formal models of knowledge representation and the support of a cognitive knowledge base. The problems are inherited in human knowledge expressions in natural languages due to subjection, diversity, redundancy, ambiguity, inexplicit semantics, incomplete intensions/extensions, mixed synonyms, and fuzzy concept relations (Miller, 1995; Zadeh, 1999; Mehryar et al., 2012; Wang, 2015c; Wang & Berwick, 2013). The problems also challenge traditional learning theories, machine cognition abilities, mathematical means for rigorous knowledge manipulations and machine semantical comprehension (Simon, 1983; Zadeh, 1983; Bender, 1996; Wang, 2008). Both fundamental theories and novel technologies are yet to be sought in order to gain breakthrough on the persistent problems of deep machine learning for knowledge acquisition.

The problems of machine learning in particular and AI challenges in general stem from the nature that they have been out of the traditional mathematical domain of real numbers and classical manipulations. It is recognized that the basic structural model of human knowledge is a *formal concept* (Wang, 2016a). Knowledge is acquired by a set of interacting cognitive processes such as object identification, concept elicitation, perception, inference, learning, comprehension, memorization, reasoning, analysis and synthesis (Wang et al., 2006). All cognitive processes are supported by a structural model of rigorous knowledge representation focusing on the attributes and objects of formal concepts as well as their relations (Wang, 2015a). Therefore, novel denotational mathematics (Wang, 2008, 2012) such as concept algebra (Wang, 2015a) and semantic algebra (Wang, 2013) are introduced to formally manipulate knowledge and semantics in CKL.

This paper elaborates a basic study on CKL by cognitive robots. It is presented by a novel algorithmic methodology and a set of experimental results for concept elicitation and generation by machine learning. In the remainder of this paper, Section 2 creates a set of mathematical models for formal knowledge representation and manipulation by concept algebra. Section 3 describes the algorithm of cognitive knowledge learning via formal concept generation. Section 4 demonstrates a set of machine-generated formal concepts obtained in the experiments according to the cognitive machine learning methodologies and the algorithm of cognitive concept elicitation.

2. MATHEMATICAL MODELS FOR COGNITIVE KNOWLEDGE LEARNING

The universe of discourse of knowledge $\mathfrak{U}$ as the context of concepts and semantics is a triple, i.e., $\mathfrak{U} \triangleq (\mathfrak{O}, \mathfrak{A}, \mathfrak{R})$, encompassing finite and nonempty sets of objects $\mathfrak{O}$, attributes $\mathfrak{A}$ and relations $\mathfrak{R}$ as a Cartesian product $\mathfrak{O} \times \mathfrak{A}$ (Wang, 2015a, 2016a).