**IGI PUBLISHING** **ITJ 4628**

701 E. Chocolate Avenue, Suite 200, Hershey PA 17033-1240, USA
Tel: 717/533-8845; Fax 717/533-8661; URL-http://www.igi-global.com

This paper appears in the publication, International Journal of Cognitive Informatics and Natural Intelligence, Volume 3, Issue 1
edited by **Yingxu Wang © 2009, IGI Global**

# A Cognitive Informatics Reference Model of Autonomous Agent Systems (AAS)

*Yingxu Wang, University of Calgary, Canada*

## ABSTRACT

*Despite the fact that the origin of software agent systems has been rooted in autonomous artificial intelligence and cognitive psychology, their implementations are still based on conventional imperative computing techniques rather than autonomous computational intelligence. This paper presents a cognitive informatics perspective on autonomous agent systems (AAS's). A hierarchical reference model of AAS's is developed, which reveals that an autonomous agent possesses intelligent behaviors at three layers known as those of imperative, autonomic, and autonomous from the bottom up. The theoretical framework of AAS's is described from the facets of cognitive informatics, computational intelligence, and denotational mathematics. According to Wang's abstract intelligence theory, an autonomous software agent is supposed to be called as an intelligent-ware, shortly, an intelware, parallel to hardware and software in computing, information science, and artificial intelligence.*

*Keywords:* *AI; abstract intelligence; agent systems; autonomic computing; behavioral models; computational intelligence; enotational mathematics; intelligence models; intelware; LRMB; mathematical models; multi-agent; RMAAS; software agent; system behaviors; tonomous agent*

## INTRODUCTION

A *software agent* is an intelligent software system that autonomously carries out robotic and interactive applications based on goal-driven cognitive mechanisms. The studies on software agent are rooted in the essences of computing science and cognitive science such as automata theory (von Neumann, 1946, 1958, 1963, 1966; Shannon, 1956), Turing machines (Turing, 1950), cognitive psychology (Newell, 1990; Sternberg, 1997; Anderson and Rosenfeld, 1998; Matlin, 1998), artificial intelligence (*McCarthy,* 1955, 1963; McCulloch, 1943, 1965; Barr and Feigenbaum, 1981), computational intelligence (Poole et al., 1997; Wang, 2008a), and decision theories (Wald, 1950; Newell and Simon, 1972; Berger et al., 1990; Bronson and Naadimuthu, 1997; Wang and Ruhe, 2007; Wang, 2008b).

The history towards software agents may be traced back to the work as early as in the 1940s. J. *McCarthy,* W. McCulloch, *M.L. Minsky, N. Rochester, and C.E. Shannon* proposed the term *Artificial Intelligence* (AI) (*McCarthy,* 1955, 1963; McCulloch, 1943, 1965). S.C. Kleene analyzed the relations of *automata* and nerve nets (Kleene, 1956). Then, Bernard Widrow developed the technology of *artificial neural networks* in the 1950s (Widrow and Lehr, 1990). The concepts of *robotics* (Brooks, 1970) and *expert systems* (Giarrantans and Riley, 1989) were developed in the 1970s and 1980s, respectively. In 1992, the notion of *genetic algorithms* was proposed by J.H. Holland (Holland, 1992). Then, *distributed artificial intelligence* and *intelligent system* technologies emerged since late 1980s (Bond and Gasser, 1988; Kurzweil, 1990; Chaib-Draa et al., 1992; Meystel and Albus, 2002, Meystel and Albus, 2002).

The origin of the term *autonomous agent* is based on Carl Hewitt and his colleagues' *artificial intelligence actor models* proposed in 1973 (Hewitt et al., 1973, 1991). Then, as a novel approach of artificial intelligence, agent technologies have been proliferated since the early 1990s (Foner, 1993; Genesereth and Ketchpel, 1994; Hayes-Roth, 1995; Axelrod, 1997; Huhns and Singh, 1997; Wooldridge and Jenings, 1995; Wooldridge, 2002, Wang, 2003b). Pattie Maes perceived that a software agent is a process that lives in the world of computers and networks and that can operate autonomously to fulfill a set of tasks (Maes, 1991). Dimitris N. Chorafas described a software agent as a new software paradigm of things that think (Chorafas, 1998). Software agents are characterized by knowledge, learning, reasoning, and adaptation, which are rational to the extent that their behaviors are predictable by given goals and the solution environment (Russell and Norvig 1995; Poole, Mackworth, and Goebel 1997; Nilsson 1998).

*Multi-agent systems* are proposed in (Wittig, 1992; Wellman, 1999) as distributed intelligent systems (Bond and Gasser, 1988) in which each node is an autonomous software agent. The key technology of autonomous agent systems is how a variety of heterogeneous agents allocate their roles, coordinate their behaviors, share their resources, and communicate their information, beliefs, and needs (Maes, 1991). The interaction mechanisms of multi-agent systems, such as cooperation, negotiation, belief reconciliation, information sharing, and distributed decision making, are identified as important issues in the design and implementation of multi-agent systems.

*Autonomic computing* is one of the fundamental technologies of software agents, which is a mimicry and simulation of the natural intelligence possessed by the brain using general computers. Autonomic computing was first proposed by IBM in 2001, where it is perceived that "Autonomic computing is an approach to self-managed computing systems with a minimum of human interference. The term derives from the body's autonomous nervous system, which controls key functions without conscious awareness or involvement (IBM, 2006)." Various studies on autonomic computing have been reported following the IBM initiative (Kephart and Chess, 2003; Murch, 2004; Wang, 2004).

According to Wang's *abstract intelligence* theory (Wang, 2008a, 2009), software agents are a paradigm of abstract and computational intelligence, which is a subset of or an application-specific virtual brain. Behaviors of a software agent are mirrored human behaviors. Therefore, a software agent may be more accurately named as an *intelligent-ware*, shortly, an *intelware*, parallel to hardware and software in computing, information science, and artificial intelligence. In this notion, intelware will be treated as a synonym of an autonomous agent system.

This paper presents a coherent theoretical framework of autonomous agent systems (AAS's) or *intelware* from the facets of cognitive informatics, computational intelligence, and denotational mathematics. The nature of software agents and intelware is elaborated. A reference model of AAS with intelligent behaviors at three layers known as those of imperative, autonomic, and autonomous is developed from the bottom up. The theoretical