Chapter 4
Towards Cognitive Machines:
Multiscale Measures and Analysis

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ABSTRACT

Numerous attempts are being made to develop machines that could act not only autonomously, but also in an increasingly intelligent and cognitive manner. Such cognitive machines ought to be aware of their environments, which include not only other machines, but also human beings. Such machines ought to understand the meaning of information in more human-like ways by grounding knowledge in the physical world and in the machines' own goals. The motivation for developing such machines range from self-evidenced practical reasons such as the expense of computer maintenance, to wearable computing in health care, and gaining a better understanding of the cognitive capabilities of the human brain. To achieve such an ambitious goal requires solutions to many problems, ranging from human perception, attention, concept creation, cognition, consciousness, executive processes guided by emotions and value, and symbiotic conversational human-machine interactions. An important component of this cognitive machine research includes multiscale measures and analysis. This article presents definitions of cognitive machines, representations of processes, as well as their measurements, measures, and analysis. It provides examples from current research, including cognitive radio, cognitive radar, and cognitive monitors.

INTRODUCTION

Computer science and computer engineering have contributed to many shifts in technological and computing paradigms. For example, we have seen shifts (1) from large batch computers to personal and embedded real-time computers, (2) from control-driven microprocessors to data- and demand-driven processors, (3) from uniprocessors to multiple-processors (loosely coupled) and multiprocessors (tightly coupled), (4) from data-path processors to structural processors, for example, neural networks (Bishop, 1995), quantum processors (Nielsen & Chuang, 2000)

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and biomolecular processors (Sanz, Chrisley & Aaron Sloman, 2003), (5) from silicon-based processors to biochips (Ruaro, Bonifazi, & Torre, 2005), (6) from vacuum tubes to transistors to microelectronics to nanotechnology, (7) from large passive sensors to very small smart active sensors (Soloman, 1999), (8) from local computing to distributed computing and networkwide computing, (9) from traditional videoconferencing to telepresence (e.g., WearTel and EyeTap; Mann, 2002), (10) from machines that require attention (like a palmtop or a wristwatch computer) to those that have a constant online connectivity that drops below the conscious level of awareness of users (like autonomic computers; Ganek & Corbi, 2003; IBM, 2006), and eyeglass-based systems (Haykin & Kosko, 2001; Mann, 2002), (11) from crisp-logic-based computers to fuzzy or neurofuzzy computers (Pedrycz & Gomide, 1998), as well as (12) from control-driven (imperative) systems to cognitive systems such as cognitive radio (Haykin, 2005a), cognitive radar (Haykin, 2006), active audition (Haykin & Chen, 2005), and cognitive robots. These remarkable shifts have been necessitated by the system complexity which now exceeds our ability to maintain them (Ganek & Corbi, 2003), while being facilitated by new developments in technology, intelligent signal processing, and machine learning (Haykin, Principe, Sejnowski, & McWhirter, 2006).

Since the 1950s, philosophers, mathematicians, physicists, cognitive scientists, neuroscientists, computer scientists, and computer engineers have debated the question of what could constitute *digital sentience* (i.e., the ability to feel or perceive in the absence of thought and inner speech), as well as machine consciousness or artificial consciousness (e.g., Cotterill, 1988; Dennett, 1991; Klivington, 1989; Kurzweil, 1990; Rumelhart & McClelland, 1986; Minsky, 1986; Neumann, 1958; Posner, 1989; Searle, 1980; Penrose, 1989, 1994; Searle, 1992). Consequently, many approaches have been developed to modeling consciousness, including biological, neurological, and engineering (practical). The approach to cognition taken in this article is mostly engineering in which the behavior of a system can be observed, measured, characterized, modeled, and implemented as an artifact, such as a cognitive robot (either isolated or societal) to improve its interaction with people, or a cognitive radio to improve the utilization of a precious resource, that is, the frequency spectrum. In general, the intent of such cognitive systems is to improve their performance, to reduce waste in resource utilization, and to provide a testbed for learning about cognition and cognitive processes. If an approach is purely reductionist, it may not be capable of describing the complexities of cognition. Since our engineering approach considers not only the individual components of a system, but also their interactions, it may be capable of describing the dynamics of cognitive processes. Although engineering approaches have serious limitations (e.g., Chalmers, 1997; Parsell, 2005), they are intended to produce a range of specific practical outcomes.

The next section provides a few definitions and models of consciousness, and serves as a preamble for several applications. The article also identifies a few problems with the current status of cognitive machines.

What Is Cognition?

According to the Oxford Dictionary, cognition is "knowing, perceiving, or conceiving as an act." The Encyclopedia of Computer Science (Ralson, Reilly, & Hemmendinger, 2003) provides a computational point of view of cognition consisting of the following three attributes: (1) cognition can be described by *mental states and processes* (MSPs) intervening between input stimuli and output responses, (2) the MSPs can be described by algorithms, and (3) the MSPs should lend themselves to scientific investigations.

Another view of cognition is suggested by Pfeifer and Scheier (1999) as an interdisciplinary study of the general principles of intelligence