

Chapter 16

Cognitive Dynamic Systems

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ABSTRACT

The main topics covered in this paper address the following four issues: (1) Distinction between how adaptation and cognition are viewed with respect to each other; (2) With human cognition viewed as the framework for cognition, the following cognitive processes are identified: the perception-action cycle, memory, attention, intelligence, and language. With language being outside the scope of the paper, detailed accounts of the other four cognitive processes are discussed; (3) Cognitive radar is singled out as an example application of cognitive dynamic systems that “mimics” the visual brain; experimental results on tracking are presented using simulations, which clearly demonstrate the information-processing power of cognition, and (4) Two other example applications of cognitive dynamic systems, namely, cognitive radio and cognitive control, are briefly described.

1. INTRODUCTION

The first seminal journal paper on Cognitive Radio appeared in February 2005 (Haykin, 2005), which was subsequently followed by the first seminal journal paper on Cognitive Radar that was published in January 2006 (Haykin, 2006a). Emboldened by the publication of those two papers and recognizing that, in reality, Cognitive Radio and Cognitive Radar are two important members

of a broadly defined new integrative field, named Cognitive Dynamic Systems, a predictive point-of-view article with this very title was published in November 2006 (Haykin, 2006b).

In this paper, an overview of Cognitive Dynamic Systems is presented. In a way, this overview provides some highlights of a new book with this very title, due to be published in late 2011 (Haykin, 2011).

The paper is organized as follows. Section 2 discusses the distinction between cognition and adaptation that should be carefully noted. Sec-

DOI: 10.4018/978-1-4666-2476-4.ch016

tion 3 discusses the five underlying principles of Cognitive Dynamic Systems, viewed with human cognition as the frame of reference. The five principles are: the perception-action cycle, multi-scale (layer) memory, attention, intelligence, and language.

With these principles in mind, Section 4 discusses Cognitive Radar with target tracking as the application of interest; the discussion also includes experimental results obtained using simulations. Section 5 briefly describes two other applications: Cognitive Radio and Cognitive Control.

2. DISTINCTION BETWEEN ADAPTATION AND COGNITION

The idea of adaptation may be traced back to the pioneering work of Widrow and associates at Stanford University, California. In particular, Widrow and Hoff (19xx) described an *adaptive filter*, consisting of the following components:

- **Linear Combiner:** Equipped with a set of free parameters.
- **Comparator:** Measures the difference between an externally supplied desired response and the actual output of the linear combiner produced in response to an input signal.
- **Control Mechanism:** Adjusts the parameters of the linear combiner so as to minimize the error signal in some statistical sense.

We may therefore offer the following definition:

Adaptation is a signal-processing paradigm, with a built-in mechanism, which adjusts the free parameters of a typically linear filter of finite-duration impulse response in accordance with statistical variations of the environment.

In direct contrast, we define cognition as follows:

Cognition is an information-processing paradigm with a built-in mechanism, which enables a dynamic system to learn from the experience gained through continued interactions with its environment.

Note that in cognition we speak of information processing rather than signal processing as in the case of adaptation.

3. THE FIVE PRINCIPLES OF COGNITIVE DYNAMIC SYSTEMS

For a dynamic system to be cognitive in the true sense of the word, it has to satisfy the five basic principles of human cognition (Haykin, 2011). The five principles are:

1. The perception-action cycle;
2. Multi-scale memory;
3. Attention;
4. Intelligence;
5. Language.

The fifth principle, language, provides the means for effective and efficient communications between the different parts constituting the cognitive dynamic system. With the language being outside the scope of this paper, the discussion will be focused entirely on principles (1, 2, 3, 4, and 5).

3.1 The Perception-Action Cycle

The human brain has two main parts, left and right. Correspondingly, a cognitive dynamic system also consists of two main parts, one part being responsible for *perception* of the world and the other part being responsible for *action* on or in the world; herewith, the two terms, world and environment, are used interchangeably. For

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