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Volume 3

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Seng-Beng Ho

Principles of Noology

Toward a Theory and Science of Intelligence

Springer

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To Leonard Uhr

Preface

Despite the tremendous progress made in the past many years in cognitive science, which includes sub-disciplines such as neuroscience, psychology, artificial intelligence (AI), linguistics, and philosophy, there has not been an attempt to articulate a principled and fundamental theoretical framework for understanding and building intelligent systems. A comparison can be made with physics, which is a scientific discipline that led to the understanding of the physical universe and the construction of various human artifacts. The feats we have achieved through physics are indeed incredible: from mapping the cosmos to the end of space and time to the construction of towering skyscrapers and rockets that took human beings to the moon. Physics provides the principles and theoretical framework for these incredible feats to be possible. Is it possible to construct a similar framework for the field of cognitive science?

Whether intelligent systems are those that exist in nature, such as animals of all kinds, or the various kinds, of robots that human beings are trying to construct, they are all autonomous intelligent agents. Moreover, animals are *adaptive* autonomous intelligent agents (AAIAs), and the robots that human beings construct are also intended to be adaptive, though we have been falling short of the achievement of nature in this regard so far.

Interestingly, neuroscientists and psychologists do not seem to construe their respective disciplines as attempting to uncover the nature and principles of intelligence per se nor do they often characterize the systems they study as AAIAs. Neuroscientists are primarily concerned with uncovering the neural mechanisms in various human and animal brain subsystems such as the perceptual systems, affective systems, and motor systems, and how these various subsystems generate certain behaviors. Psychologists also attempt to understand human and animal behaviors through behavioral experiments and fMRI. But it is not just behavior per se but *intelligent* behavior that the various animals and humans exhibit that improve their chances of survival, allow them to satisfy certain internal needs, etc. They are also *adaptive* and *autonomous* intelligent agents. Hence, the numerous experimental works conducted in the fields of neuroscience and psychology so far

have not benefitted from or been guided by a principled theoretical framework that characterizes adequately the systems that they are studying.

On the other hand, AI has been concerned with constructing AAIAs (also called “robots”) right from the beginning. However, the shortcoming of AI at its current state of development is that the major “successes” are in creating *specialized* intelligent systems – systems such as the Deep Blue chess playing system that can beat human chess masters, the Watson questioning-answering system that can outperform human opponents, the upcoming autonomous vehicles (such as the Google self-driving car) that can drive safely on the roads, etc. But some researchers in the AI community do attempt to strive toward constructing *general* AAIAs in the long run. This is reflected in the emergence of a field called artificial general intelligence (AGI), though ironically, AI, in its very inception, was meant to be AGI to begin with.

An interesting question arises concerning human-constructed intelligent systems. Can a system that is not mobile in itself but that has remote sensors and actuators benefit from the principles guiding adaptive *autonomous* intelligent systems? The answer is yes, and we can think of the system as a kind of “static” robot. Because, with remote sensors and actuators, it can achieve the same effect as in the case of an AAIA as it learns about the environment through observation and interaction, and enriches its knowledge and changes its future behavior accordingly.

AGI can certainly learn from the rest of cognitive science. For example, in traditional AI research, the issues of *motivation* and *emotion* for an adaptive intelligent system, which provide the major driving force behind the system and are hence critical in its adaptive behavior, are never discussed (a scan of the major current textbooks in AI would reveal that these terms do not even exist in the index), while these are often studied extensively in neuroscience and psychology. The issues of affective processes, however, are gaining some attention recently in the field of AGI/AI.

In this book we therefore set out toward a more systematic and comprehensive understanding of the phenomenon of intelligence, thus providing a principled theoretical framework for AAIAs. The methodology is similar to that of AGI/AI, in which representational mechanisms and computational processes are laid out clearly to elucidate the concepts and principles involved. This is akin to the quantitative and mathematical formulation of the basic principles of physics that embodies rigorous understanding and characterization of the phenomena involved. There are two advantages to this approach: on the one hand, these mechanisms translate to directly implementable programs to construct artificial systems; on the other hand, these mechanisms would direct neuroscientists and psychologists to look for corresponding mechanisms in natural systems. Because of the relatively detailed specifications of the representational mechanisms and computational processes involved, they may guide neuroscientists and psychologists to understand brain and mental processes at a much higher resolution, and also understand them in the context of AAIAs, which is a paradigm that is currently lacking in these fields.

The representational mechanisms and computational processes employed in this book are not strange to people in the field of AI: predicate logic representations,

search mechanisms, heuristics, learning mechanisms, etc. are used. However, they are put together in a new framework that addresses the issues of *general* intelligent systems. Some novel computational devices are introduced, notably the idea of rapid effective causal learning (which provides a rapid kind of learning subserving critical intelligent processes), learning of scripts (which provides a foundation for knowledge chunking and rapid problem solving), learning of heuristics (which enhances traditional AI's methodology in this regard which often employs heuristics that are built-in and not learned in a typical problem solving situation), semantic grounding (which lies at the heart of providing the mechanisms for a machine to "really understand" the meaning of the concepts that it employs in various thinking and reasoning tasks), and last but not least, the computational characterizations of motivational and affective processes that provide purposes and drives for an AAIA and that are critical components in its adaptive behavior.

From the point of view of identifying fundamental entities for the phenomenon of intelligence (much in the same spirit in physics of identifying fundamental particles and interactions from which all other phenomena emerge), two ideas stand out. One is *atomic spatiotemporal conceptual representations* and their associated processes, which provide the ultimate semantic grounding mechanisms for meaning, and the other is the *script*, which encodes goal, start state, and solution steps in one fundamental unit for learning and rapid problem solving operations.

We think it necessary to introduce the term "noology" (pronounced nō-ä-lə-jē\, in the same vein as "zoology") to designate the principled theoretical framework we are attempting to construct. Noology is derived from the Greek word "nous" which means "intelligence." The Merriam-Webster dictionary defines noology as "the study of mind: the science of phenomena regarded as purely mental in origin." The function of noology – a theoretical framework for and the science of intelligence – is like the function of physics. It provides the principled theoretical framework for, on the one hand, the understanding of natural phenomena (namely all the adaptive autonomous intelligent systems (AAISs) that cognitive scientists are studying), and on the other, the construction of artificial systems (i.e., robots, all kinds of autonomous agents, "intelligent systems," etc., that are the concerns of AGI/AI).

In cognitive science, it has been quite a tradition to use "cognitive systems" to refer to the "brain" systems that underpin the intelligent behavior of various kinds of animals. However, as has been emphasized in a number of works by prominent neuroscientists such as Antonio Damasio and Edmund Roll, cognition and emotion are inseparable and together they drive intelligent behaviors as exhibited by AAISs. Therefore, "noological systems" would be a more appropriate characterization of systems such as these.

We do not pretend to have all the answers to noology. Therefore, the subtitle of this book is "*toward* a theory and science of intelligence." But we believe it sets a new stage for this new, and at the same time old, and exciting endeavor.

For readers familiar with the computational paradigm (e.g., AI researchers), it is recommended that they jump ahead to take a look at Chaps. 6 and 7 and perhaps also 8 and 9, where our paradigm is applied to solve some problems that would typically be encountered by AI systems, before returning to start from the beginning

of the book. Our method derives “noologically realistic” solutions that use very different processes than that of traditional AI methods. After having a rough idea of what we are trying to achieve, the purpose of the relatively extensive groundwork covered in the first few chapters would then be clearer.

Singapore, Singapore

Seng-Beng Ho

A Celebration of Concavity

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“Science and art in the pursuit of beauty, and hence, truth”

Acknowledgements

In a sense the beginning of this book is lost in the author's personal mist of time. My formal journey on the path to understand intelligence began in the Fall of 1981 when I started my graduate school program at the University of Wisconsin-Madison. Because the effort culminating in this book was an incessant effort from more than 30 years ago, some acknowledgements are due to some of the people from that time.

My Ph.D. supervisor was the late Professor Leonard Uhr who was one of the pioneers in artificial intelligence, as reflected by the fact that one of his important works is collected in the book, *Computers and Thought*, published in 1963, 8 years after John McCarthy coined the term "artificial intelligence (AI)." One of the editors of the book was Edward Feigenbaum of Stanford University, a well-known researcher in AI. Leonard Uhr's research was a little off "mainstream AI" and hence he was not as well-known as, say, Edward Feigenbaum or Marvin Minsky of MIT in the field of AI.

However, my thanks are due to Leonard Uhr for allowing me the freedom to think outside the mainstream research trend in AI of that time, which allowed me to address critical issues ignored by others. This constituted my Ph.D. thesis work of that time and it set the stage for my subsequent pursuit in understanding intelligence in the same spirit, and which then led to this book of today. Thanks are also due to Chuck Dyer, Josh Chover, Gregg Oden, Lola Lopes, Robin Cooper, and Berent Enc, who were professors of that time who interacted with me in one way or another and who were equally encouraging and supportive of my unique focus on issues related to intelligent systems.

The intellectual origin of this book can be traced back to more than 30 years ago but the bulk of the work contained herein was carried out in the Temasek Laboratories of the National University of Singapore in the period 2011–2014. I wish to thank the Head of the Cognitive Science Programme at Temasek Laboratories, Dr. Kenneth Kwok, who, like the professors before him, fully supported my research that addressed critical and important issues not attended to by other AI researchers.

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Erik Cambria's work on sentic computing was an inspiration. My own approach to computational affective processes started on a different track, but knowing about Erik's work and exchanging ideas with him provided me with the confidence that we are moving in the right direction with regards to a more complete computational characterization of intelligent systems.

My immediate family has always provided great intellectual companionship. Thanks are absolutely due to them for keeping me intellectually alive all through the years.

Singapore, Singapore
January 1, 2016

Seng-Beng Ho

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