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Book Review: Evolutionary Robotics: The Biology, Intelligence, and Technology of Self-Organizing Machines

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As one reads through the book, it becomes clear that the volume is the fruit of subtle but persistent exchanges which spanned from Rome, Italy to Lausanne, Switzerland between the authors and several crucial researchers and a few engineers. In fact, the book is the end result of a massive collaboration, and hence its rich content easily justifies the book's cost. Had Francesco Mondada, with his colleagues at Swiss Federal Institute of Technology in Lausanne (EPFL), not committed to make Khepera robot possible and himself participate in some of the experiments, most of the experiments described in the volume would not have succeeded. If Jean-Daniel Nicoud had not sponsored the development of this research robot in the early 1990's, including the position orientation device (p. 54), the results of a few experiments would have suffered from a lack of accuracy and repeatability, thus compromising the claims made by the authors. If Domenico Parisi's management of research at the National Research Council (NRC) in Rome had not encouraged the authors and other collaborative researchers such as Orazio Miglino, then some of the theses discussed in detail in this book might not have been realized. Without these efforts that happened throughout the 1990's, founded on the already substantial body of research accumulated in Rome and elsewhere in neural networks, the research itself, as well as the book, might not have seen the light of day.

Reflecting this background, I felt that some chapters, (Chapters 4, 5, 7) went too deep into current research subjects, rendering the nature of the book a bit fuzzy (textbook, reference, or collection of research papers?). The authors are cautious whenever they make scientific statements (e.g., pp. 90, 115). Nolfi's serious investigation into robot behaviors through simulation is well supplemented by Floreano's talents in planning and executing sophisticated experiments. An ample number of innovative and appropriate simulations and experiments are used throughout the book to explain the relevant theses and analysis of their results is often astonishingly precise and detailed. Because of their vast experience, the authors are the best qualified at this point to write a book about Evolutionary Robotics (ER). Although there are many papers on the subject, there is no other book dedicated to ER.

There are no exercises offered in the book. Although not explained in this book, those who are new to the field should consider tutorials offered by the authors. In addition, a simulator developed by Nolfi can be downloaded and used to conduct one's own exercises. In fact, it would be a very good thing to try.

Although there are a few dozen typos and minor grammatical errors, the English is correct and clear throughout the book and involved situations are well explained. The idea of putting relevant subjects as an inset (box) is used effectively to explain the background of an issue in question, while Notes collected at the end of the book are too awkward to refer to in the middle of often intense reading. They should have been offered closer to the relevant text as footnotes. There is sufficient content on both the biological origins of the field and recent theories of intelligence to justify the subtitle of the book. All diagrams, graphs, and photographs are adapted or reproduced with explicit permission of the original authors. The references given at the end of the book are comprehensive and rich. The book is ideally suited for researchers seriously interested in the field such as graduate students in evolutionary computation or intelligent robotics. However, established researchers in those fields could also benefit from the book.

About the only thing that is annoying in the book is the interchangeable use of the terms *simulation* and *experiment* (e.g., pp. 66, 88, 105–107, 259). Simulation should remain *simulation* and never be confused with *experiment* as the two are completely different. This book surely requires a bookmark string to allow the reader to refer back to earlier sections. I also felt that the design of the cover did not do justice to the book.

There is a total of 11 chapters and a Conclusion in the book.

Chapter 1: The role of self-organization for the synthesis and the understanding of behavioral systems

The first chapter provides a very thorough introduction to the field, already entertaining various key issues including incremental evolution, an effective method when applying ER in the real world. The authors, however, did not stop at this level of utility and proceeded well into the depth of each subject in later chapters.

Chapter 2: Evolutionary and neural techniques

Again, coverage of common neural networks, and evolution and learning techniques applied to them are discussed in depth. The method of evolution is limited to Genetic Algorithm (GA).

Chapter 3: How to evolve robots

The chapter begins with the introduction of Khepera robot and its add-on modules. Khepera is used extensively in experiments (and simulations) throughout the rest of the book. The adherence to a certain robot might weaken the arguments and objectivity presented in the book. However, this robot, as well as a few others mentioned later in the book, is both functionally and morphologically suited for making points in ER.

The authors describe a general framework in which evolution of a species of robot controllers can be achieved using a single physical robot. Again, this would limit the scope of the study to robot-environment interactions, omitting evolution of inter-robot relationships. However, the latter only recently became possible, mostly thanks to the path-breaking efforts of the authors to establish ER as physically embodied research.

Chapter 4: Evolution of simple navigation

Here the world's first *embodied* and *situated* ER experiment began by Floreano and Mondada in 1993 is explained unpretentiously but with sufficient depth. Sussex's landmark experiment in ER is also described as a comparison, followed by a section on cross platform adaptation, also experimented by Floreano and Mondada. Since this method of incremental evolution has direct implications to applying ER to practical real world problems, the in-detail discussion given here should be helpful for other roboticists. The authors insist that ER often produces better behaviors of the robot than can be achieved by hand-engineered robots.

Chapter 5: Power and limits of reactive intelligence

Internal representation (or not) is a sensitive issue in intelligent robotics today and the criticism by Rodney Brooks which is mentioned in passing (p. 93) should have been explained more or references given. In contrast, the concept of perceptual aliasing (p. 94) is very clearly explained. The experiment described on p. 98 underwrites the theory of *enaction* by Francesco Varela. Again, it would have been helpful if there was a reference to Varela's work. The more difficult perceptual problems that intelligent robots encounter (type-2 problems) are also well explained using Geometric Separability Index (GSI). In fact, the authors are effectively laying out the crucial issues to go beyond type-1 intelligence. This chapter also expands on design methodology in intelligent robotics started in Chapter 4. The authors imply that in comparison with other approaches widely practiced, ER is a promising methodology in designing robots to deal with complex situations others could not handle.

Chapter 6: Beyond reactive intelligence

Two experiments ("garbage collection" and "run for energy") requiring complex behaviors on the part of evolved robots are described in painstaking detail. The depth of analysis offered by the authors is impressive and impacting, not only giving suggestions to others wanting to evolve complex robot behaviors but also showing pitfalls to avoid. Arguments on modularity and internal representation emerging out of a robot's interaction with its environment, and not as an observer would define, are well presented.

Chapter 7: Learning and evolution

Again, very thorough observations and discussions on the issues of learning in evolutionary systems make this chapter one of the most comprehensive documentations on the subject so far. But because of this, the chapter carries material from an historical perspective, key arguments linking learning and evolution, and a number of simulations and experiments to prove the authors' points. The chapter should have been broken into two: background and reporting of the results of their research. Nevertheless, the thorough investigation allowed the authors to make a competent statement that evolution and learning influence each other. This argument is more convincing than speculative arguments heard in evolutionary computation circles centered around Lamarkian and Darwinian theories of evolution. Their findings have good utility as well, but not expanded sufficiently in the chapter.

Chapter 8: Competitive co-evolution

First using simulation and then experiments with two modified Khepera robots, Floreano tackled the predator-prey problem. Here, two competing fitness requirements form a unique adaptation in local ecology for the survival of two competing species of robots. Simulation runs produced very interesting behaviors for both the prey and predator, and well-prepared experiments with real robots also confirmed the complex interactions not seen in single species evolution. Along with a few new discoveries on co-evolution such as cyclic mannerisms in evolution between the competing species, pros and cons of the "hall of fame" approach, and the emergence of "arms races," I found the chapter highly entertaining.

Chapter 9: Encoding, mapping, and development

Unlike in true Biology, the importance of genotype-to-phenotype mapping, or *development*, is for the most part ignored in today's ER research. In this chapter, however, the authors expound upon it as an immediate frontier by discussing a few pioneering works in the field. While well presented, this chapter lacks the strength seen in other chapters where the authors reported their first-hand experiences.

Chapter 10: Complex hardware morphologies: Walking machines

This chapter begins with a concise but well organized introduction to bio-inspired walking robots. By covering almost all work in the field at the time of writing, the authors create a good springboard to examine issues associated with the evolution of gaits, such as simulation vs. physical evolution, staged or incremental evolution vs. from scratch to end of cycle evolution, replication of single evolved leg vs. all legs independent, static gait vs. dynamic gait, and so on. The authors point out that when going from a few degrees of freedom (dof) to n (number of legs) times larger dofs, analytical methods to design robot's locomotion become very difficult and the return on investment increasingly diminishes. The role of evolution then becomes increasingly important. Future research toward more flexible and dynamic gait control accompanied by hardware advancement is suggested to achieve a model free evolution.

Chapter 11: Evolvable hardware

I felt that the authors over-stretched themselves on this subject. While the chapter is informative, the field of evolvable hardware (EHW) is still very young and things are moving. It could easily be justified if they had decided to leave it outside the scope of the book.

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