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Coevolutionary Fuzzy Modeling

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with love...

to Sandra, my wife, for being there

to Paula, my daughter, for having arrived

Foreword

As we all know only too well, computers are rigid, unbending, unyielding, inflexible, and quite unwieldy. Let's face it: they've improved our lives in many a way, but they do tend to be a pain ... When interacting with them you have to be very methodical and precise, in a manner quite contrary to human nature. Step outside the computer's programmed repertoire of behavior, it will simply refuse to cooperate, or—even worse—it will “crash” (what a vivid term computing professionals have coined to describe a computer's breaking down!). Computers are notoriously bad at learning new things and at dealing with new situations. It all adds up to one thing: At their most fundamental computers lack the ability to *adapt*.

Adaptation concerns a system's ability to undergo modifications according to changing circumstances, thus ensuring its continued functionality. We often speak of an environment, and of the system's adjustment to changing environmental conditions. The archetypal examples of adaptive systems are not among Man's creations, but among Nature's: From bacteria to bumblebees, natural organisms show a striking capacity to adapt to changing circumstances, a quality which has not escaped the eyes of computing scientists and engineers. The influence of the biological sciences in computing is on the rise, slowly but surely inching its way toward the mainstream. There are many examples today of systems inspired by biology, known as *bio-inspired* systems.

Adaptation comes in many guises and forms. For one, computers are *crisp* creatures whereas we humans are *fuzzy*. So can we (beneficially) narrow this gap? There are two possible ways to go about this. The first is by forcing humans to behave more crisply—to be precise and unambiguous; this is exactly the stance that computer programmers must assume: Since they converse in the computer's tongue, they must be very “mechanic,” avoiding the use of imprecise concepts. There is another way to narrow the human-computer gap, though, which is much less “painful” to us: having the computer behave in a fuzzier manner. Can this be done—can we “fuzzify” computers? Yes—by using so-called *fuzzy logic*.

Fuzzy logic made its appearance in 1965, when Lotfi Zadeh, then at the University of California, Berkeley, published a paper entitled *Fuzzy Sets*. The field has gained prominence over the past two decades, finding its way beyond academic circles into industry: Many successful commercial applications—fuzzy systems—have been built to date, ranging from washing machines to medical diagnostic systems.

Perhaps the biggest obstacle in the field is that of design: How does one go about designing a fuzzy system, with all of its multifarious, interdependent parameters? In this book, Carlos Andrés Peña-Reyes presents a highly efficient methodology to overcome this debilitating obstruction, by resorting to Nature's *modus operandi* for designing complex systems: Evolution.

Natural evolution is a powerful force: It has brought about a plethora of complex machines—such as eyes, wings, and brains—the construction of which are still well beyond our current engineering capabilities. If natural evolution is so successful a designer, why not simulate its workings in an engineering setting, by using a computer to evolve solutions to hard problems? Researchers pursuing this idea in the 1950s and 1960s gave birth to the domain of evolutionary computation. Four decades later, the domain is flourishing—both in industry and academia—presenting what may well be a new approach to optimization and problem-solving.

Marriage, as discovered by social designers long ago, is a powerful force, able to bring about genius, ingenious, and heterogenous (albeit sometimes arsenious) offspring. Harnessing this unifying force of nature, Dr. Peña-Reyes has produced a winning offspring by marrying evolutionary computation and fuzzy logic. And, most propitiously, the marriage certificate itself—this book you know hold—is a joy to read!

Enjoy...

April 2004

Moshe Sipper

Preface

Anything is one of a million paths. [...] I warn you. Look at every path closely and deliberately. Try it as many times as you think necessary. Then ask yourself, and yourself alone, one question: [...] Does this path have a heart? [...] A path without a heart is never enjoyable. You have to work hard even to take it. On the other hand, a path with heart is easy; it does not make you work at liking it. **For my part** there is only the traveling on paths that have heart, on any path that may have heart. There I travel, and the only worthwhile challenge is to traverse its full length. And there I travel looking, looking, breathlessly.

Don Juan Matus,

quoted by Carlos Castaneda in The Teachings of Don Juan

Human thinking and in particular our capacity to make decisions has long interested scientists: philosophers, physiologists, psychologists, mathematicians, engineers. Philosophers are interested in the motivations and the implications of decisions, physiologists and psychologists in the different mechanisms leading to them, and mathematicians and engineers in obtaining a model that permits the reproduction of this capacity. The research presented in this book goes in this latter direction: it proposes a methodology for modeling and reproducing human decision-making processes.

Rather than seeing this research as the culmination of an effort, I prefer to see it like a landmark in a path ... my path with heart. This book exists thanks to the support and the teachings of many people. In particular, five people had direct effect on its contents and on its form: Sandra Parra, Moshe Sipper, Andrés Pérez-Uribe, Daniel Mange, and Eduardo Sánchez. To them, my most sincere and grateful acknowledgment. Each person we cross in our life modifies a little the course that our path can take. My gratitude goes to all those people—teachers, friends, and family—whose presence has modeled my path.

This book introduces *Fuzzy CoCo*, a novel approach for system design, conducive to explaining human decisions. Based on fuzzy logic and coevolutionary computation, Fuzzy CoCo is a methodology for constructing systems able to accurately predict the outcome of a decision-making process, while providing an understandable explanation of the underlying reasoning. Fuzzy logic provides a formal framework for constructing systems exhibiting both good numeric performance (precision) and linguistic representation (interpretability). From a numeric point of

view, fuzzy systems exhibit nonlinear behavior and can handle imprecise and incomplete information. Linguistically, they represent knowledge in the form of rules, a natural way for explaining decision processes. Fuzzy modeling—meaning the construction of fuzzy systems—is an arduous task, demanding the identification of many parameters. This book analyzes the fuzzy-modeling problem and different approaches to coping with it, focusing on evolutionary fuzzy modeling—the design of fuzzy inference systems using evolutionary algorithms—which constitutes the methodological base of my approach.

The central contribution of this work is the use of an advanced evolutionary technique—cooperative coevolution—for dealing with the simultaneous design of connective and operational parameters. Cooperative coevolutionary fuzzy modeling succeeds in overcoming several limitations exhibited by other standard evolutionary approaches: stagnation, convergence to local optima, and computational costliness.

Designing interpretable systems is a prime goal of my approach, which I study thoroughly herein. Based on a set of semantic and syntactic criteria, regarding the definition of linguistic concepts and their causal connections, I propose a number of strategies for producing more interpretable fuzzy systems. These strategies are implemented in Fuzzy CoCo, resulting in a modeling methodology providing high numeric precision, while incurring as little a loss of interpretability as possible.

The application of Fuzzy CoCo is validated by modeling the decision processes involved in three problems: Fisher’s iris data, a benchmark problem, and two breast-cancer diagnostic problems, the WBCD problem and the Catalonia mammography interpretation problem. Several aspects of Fuzzy CoCo are then thoroughly analyzed to provide a deeper understanding of the method. These analyses show the consistency of the results. They also help derive a stepwise guide to applying Fuzzy CoCo, and a set of qualitative relationships between some of its parameters that facilitate setting up the algorithm. Finally, this work proposes and explores preliminarily two extensions to the method: Island Fuzzy CoCo and Incremental Fuzzy CoCo, which together with the original CoCo constitute a family of coevolutionary fuzzy modeling techniques.

Morges, Switzerland
June 2004

Carlos Andrés Peña-Reyes

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