

Eyal Kolman and Michael Margalio

Knowledge-Based Neurocomputing: A Fuzzy Logic Approach

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Eyal Kolman and Michael Margaliot

Knowledge-Based Neurocomputing: A Fuzzy Logic Approach



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To my parents and my wife. All that I am, I owe to you – E.K.

To three generations of women: Hannah, Miri, and Hila – M.M.

*I have set before you life and death,
the blessing and the curse.
So choose life in order that you may live,
you and your descendants. (Deuteronomy 30:19)*

Preface

Artificial neural networks (ANNs) serve as powerful computational tools in a diversity of applications including: classification, pattern recognition, function approximation, and the modeling of biological neural networks. Equipped with procedures for learning from examples, ANNs can solve problems for which no algorithmic solution is known.

A major shortcoming of ANNs, however, is that the knowledge learned by the network is represented in an exceedingly opaque form, namely, as a list of numerical coefficients. This *black-box* character of ANNs hinders the possibility of more widespread acceptance of them, and makes them less suitable for medical and safety-critical applications.

A very different form of knowledge representation is provided by *fuzzy rule-bases* (FRBs). These include a collection of If-Then rules, stated in *natural language*. Thus, the knowledge is represented in a form that humans can understand, verify, and refine. In many cases, FRBs are derived based on questioning a human expert about the functioning of a given system. Transforming this information into a complete and consistent set of rules, and determining suitable parameter values, is a nontrivial challenge.

It is natural to seek a synergy between the plasticity and learning abilities of ANNs and the transparency of FRBs. Indeed, considerable research attention has been devoted to the development of various neuro-fuzzy models, but this synergy is a target yet to be accomplished.

In this monograph, we introduce a novel FRB, referred to as the *Fuzzy All-permutations Rule-Base* (FARB). We show that inferring the FARB, using standard tools from fuzzy logic theory, yields an input-output relationship that is *mathematically equivalent* to that of an ANN. Conversely, every standard ANN has an equivalent FARB. We provide the explicit bidirectional transformation between the ANN and the corresponding FARB.

The FARB-ANN equivalence integrates the merits of symbolic FRBs and subsymbolic ANNs. We demonstrate this by using it to design a new approach for knowledge-based neurocomputing using the FARB. First, by generating the equivalent FARB for a given (trained) ANN, we immediately obtain a symbolic representation of the knowledge learned by the network. This provides a novel and simple method for knowledge extraction from trained ANNs.

The interpretability of the FARB might be hampered by the existence of a large number of rules or complicated ones. In order to overcome this, we also present a systematic procedure for rule reduction and simplification. We demonstrate the usefulness of this approach by applying it to extract knowledge from ANNs trained to solve: the Iris classification problem, the LED display recognition problem, and a formal language recognition problem.

Second, stating initial knowledge in some problem domain as a FARB immediately yields an equivalent ANN. This provides a novel approach for knowledge-based design of ANNs. We demonstrate this by designing recurrent ANNs that solve formal language recognition problems including: the AB language, the balanced parentheses language, and the 0^n1^n language. Note that these languages are context-free, but not regular, so standard methods for designing RNNs are not applicable in these cases.

Some of the results described in this work appeared in [89, 88, 90, 91]. We are grateful to several anonymous reviewers of these papers for providing us with useful and constructive comments.

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Michael Margaliot

Abbreviations

AI	Artificial Intelligence
ANN	Artificial Neural Network
COG	Center Of Gravity
DFA	Discrete Finite-state Automaton
DOF	Degree Of Firing
FARB	Fuzzy All-permutations Rule-Base
FFA	Fuzzy Finite-state Automaton
FL	Fuzzy Logic
FRB	Fuzzy Rule-Base
IFF	If and only if
IO	Input-Output
KBD	Knowledge-Based Design
KBN	Knowledge-Based Neurocomputing
KE	Knowledge Extraction
LED	Light Emitting Diode
MF	Membership Function
MLP	Multi-Layer Perceptron
MOM	Mean Of Maxima
RBFN	Radial Basis Function Network
RNN	Recurrent Neural Network
SVM	Support Vectors Machine

Symbols

\mathbf{x}	column vector
\mathbf{x}^T	transpose of vector \mathbf{x}
x_i	i th element of the vector \mathbf{x}
$\ \mathbf{x}\ $	Euclidean norm of the vector \mathbf{x}
$[j:k]$	set of integers $\{j, j+1, \dots, k\}$
\mathbb{R}^n	space of n -dimensional real-valued numbers
$\mu_{term}(\cdot)$	membership function for the fuzzy set $term$
i-or	interactive-or operator (see p. 8)
$\sigma(\cdot)$	logistic function (see p. 8)
$\sigma_L(\cdot)$	piecewise linear logistic function (see p. 18)
$h^{-1}(\cdot)$	inverse of the function $h(\cdot)$
$\&$	logical and operator
L_4	language generated by Tomita's 4th grammar
$t^k(\mathbf{x})$	truth value of Rule k for input \mathbf{x}
$Prob(A)$	probability of event A
$E\{x\}$	expected value of the random variable x

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