Chapter 9
Biologically-Inspired Learning and Intelligence:
Analog Circuit Design with Fuzzy Inference

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ABSTRACT
Since biologically-inspired intelligent systems with learning and decision-making capabilities vastly act upon comparison among inputs, the ability to select those inputs which satisfy certain conditions is of great significance in realization of such systems. Moreover intelligent systems need to operate with concurrency so as to reflect inherited capability of their biological counterparts like human. Due to difficulties in programmability, storage and design complexities, the analog implementation has been considerably less favored in most computational information processing systems. However, in the case of biologically-inspired computation, their suitability for concurrency, accuracy and capability in simulating the natural behavior of biological signals, analog neural information processing is regarded an attractive solution. Benefiting the full advantage involves comprehensive understanding and knowledge of what trade-offs can be established with design topologies available and theoretical necessities. On the other hand, fuzzy reasoning offers rule-based inferential manipulation on inputs where it expresses the input-output relationship in terms of clauses. Considering a nonlinear operation carried out by artificial neural networks based on experience, realization of rule-based clauses is much easier. This chapter introduces fundamental notions of fuzzy reasoning, and fuzzy-based analog design approaches. Rather than resorting on analytical derivation for the architecture of interest, the main focus is directed at suitability for use, which is expected to indicate possibility toward developing complex intelligent systems. It should be noted that the circuits having selectivity property in deciding maximum and/or minimum on inputs demonstrate their use in much broader field than inference, thus they have great importance in realization of information processing systems. The chapter presents a very compact selectivity circuit as decision maker for the minimum of its inputs. Further to it, a considerably simple yet elaborate membership structure is introduced. The circuit simplifies the fuzzy controller design. Since mostly decision making is performed on a (dis)similarity measure between inputs, e.g. the input and label patterns for
INTRODUCTION

Vast information processing capability of biological structures consists in immense parallelism and high-level of adaptability. The artificial systems and circuits which mimic such diversity obviously should rely on their natural counterparts so that most possible sources can be learned and identified appropriately. It is also this diversity which makes the mimicking difficult in implementation. Despite considerable progress in research on theoretical aspects of neural information processing, the implementation of biologically-inspired systems is not moving forward at the same pace and it is still undergoing design shortcomings.

Despite programmability, easy maintenance and continuously increasing speed of information processing with digital realization, efficiency for biological inspiration still needs better parallel processing capability for commuting between experiential knowledge, (Bezdek, Keller, Krishnapuram, & Pal, 2005; Kasabov, 2009). In most digital implementations, decision-making among a number of choices mainly relies on successive sub-operations, which is not coherent with adaptivity and intelligence. Such an objective can be accomplished with analog paradigm rather than pursuing sequential algorithms in digital computation. Furthermore, analog design has the capability in mimicking biological stimuli more inherently and naturally than digital approach.

Nevertheless, analog circuit realization for decision-making with processing stimuli has two major drawbacks: design difficulties and representation of compound features embedded in the quantity to be dealt with, (Toumazou, Ligey, & Haigh, 1990). The former involves consideration of design nonlinearities with active components while the latter require complicated structures to be projected onto highly nonlinear interconnected blocks, (Gottarredona, & Barranco, 2006). Major decision-making circuit blocks can be efficiently implemented in analog approach with almost predictable electrical and physical performance characteristics. Depending on the design quantity, i.e. current or voltage, design difficulties can be overcome significantly, which makes it suitable for attaining highly parallel decision-making operation.

Fuzzy logic (FL) or reasoning is an expert system approach which envisages human thinking and reasoning rather than being nonlinear analytical derivation. The rule-based inferential approach taken up by FL can be regarded a very handy tool to tackle major shortcomings concerning programmability and accuracy. Thus, FL has a considerable precedence to most other biologically-inspired design approaches. Thus, it can play a significant role in realization and implementation of intelligent systems combined with prominence of analog design availabilities.

Considerable studies on design of analog decision-making and associative inference fall into category in evaluating the membership of the input to certain pattern groups, (Lin, & Shi, 1999). Fuzzy-associative rules and membership functions are solid means of expressing possible association in terms of simple reasoning mechanism similar to human thinking. Thus, analog fuzzy design is an attractive candidate to develop systems operating intelligently. Analog inferential circuit design studies based on FL descriptions diversify in representing the design quantity, i.e. voltage or current. The current-mode design as will be shown brings in superiority compared to voltage-mode. With current-mode design, it is possible consider larger number of class labels to be attributed to concurrent (possibly sensory input) stimuli as well as design simplicity and suitability to merge nonlinearity to desired characteristics,
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