Electrical Engineering School
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A dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering, (Digital Systems).

Spike-IDS, A Novel Biologically Inspired Spiking Neural Model for Active Learning Method Fuzzy Modeling

(Modeling of Human Knowledge Acquisition through a Hybrid Approach)

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January 2011

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To my Mother who is my whole life,
And to my Father who is my whole hope for life

To Donald Hebb

"Share Your Knowledge, to Share Knowledge for You" *(Imam Ali)*

Abbreviations:

AI:	.....	Artificial Intelligence.
ANN	.....	Artificial Neural Network
ANFIS:	.....	Adaptive Neuro (Network) Fuzzy Inference System.
TSK:	.....	Takagi Sugeno Kang.
FRB:	.....	Fuzzy Rule Base.
ALM:	.....	Active Learning Method.
MIMO:	.....	Multi Input Multi Output.
SISO:	.....	Single Input Single Output.
IDS:	.....	Ink Drop Spread.
SRM:	.....	Spike Response Model.
CAM:	.....	Cellular Automata Machine.
CBM:	.....	CAM Brain Machine.
GA:	.....	Genetic Algorithm.
RBFN:	.....	Radial Base Function Network.
FFNN:	.....	Feed Forward Neural Network.
GARIC:	.....	Generalized Approximate Reasoning based Intelligent Control
COGD:	.....	Center of Gravity Defuzzification.
RIDS:	.....	Replacing Ink Drop Spread
PRIDS:	.....	Pipelined Replacing Ink Drop Spread.
STDP:	.....	Spike Time Dependent Plasticity.
FPGA:	.....	Field Programmable Logic Array.
SNN:	.....	Spiking Neural Network.

Summary:

Human brain is one of the most wonderful complex machines which are designed for ever. A huge complex network consists of neurons as tiny biological and chemical processors which are distributed and work together as a super parallel system to do control vital activities of human body. Today the main secrecies of operation mechanism in individual neurons as fundamental elements of the brain is reasonably understood, but network interactions of this wonderful processors and full understanding of information coding in brain seems elusive and remains as a big challenge in many interdisciplinary fields of science, from biology to cognitive science, engineering and robotics.

Thus human brain learning simulation and hardware implementation is one of the most interesting research areas as the purpose of exploiting human brain abilities and creating an artificial brain. It seems brain as machine of intelligence always has been studied through two different level of abstraction, Micro-Level and Macro-Level. The first one is started from neurophysiological findings of interactions among different types of neurons and memory stabilization in vivo. These investigations led to connectionism paradigm in Artificial Intelligence correspondingly. Connectionism is mentioned as structural representation and imitation of human brain information processing. Macro-Level brain studies concentrate on behavioral features of human-environment interactions which is known as one of the main topics of clinical psychology researches. Symbolism in AI arises from this viewpoint of brain studies. Symbolism paradigm looks to the human as intelligent machine that models surrounding phenomena by creating formal symbols and try to acquire knowledge by manipulating these qualitative objects. Rule based systems such as Expert System is a good example of Symbolic approach in AI.

Each aforementioned paradigm suffers from some drawbacks. In contrast with systematic learning process in neural networks as a most famous structural imitation of brain, the form of knowledge distributed through network plasticity is too intricate to manipulate and describe. The oral form of knowledge in symbolism is easier to understand and more manipulatable in comparison with weighting distribution of ANNs black box. However symbol manipulation and knowledge acquisition needs a kind of adaptive-recursive learning process to refine and adjust knowledge as human does. On the other hand because of qualitative non-exact nature of symbolic rules and oral form of knowledge, their mathematical description leads to awkward computational cost. Fuzzy Logic dramatically overcomes this drawback by proposing a new computational paradigm inspired by human natural language information processing. Also by combination of sub-symbolic tools such as ANNs to adjust rule parameters, the lack of learning process in rule based systems could be resolved. This new crossbreed approach which inherits beneficial features of symbolic and sub-symbolic systems simultaneously is

known as Hybrid Systems today. One of the most distinguished Hybrid Systems is Neuro-Fuzzy Systems such as ANFIS. ANFIS is a kind of TSK fuzzy inference system in which FRB parameters could be manipulated and refined adaptively using neural network learning algorithm (error back propagation).

Beside knowledge manipulation using neural machines, FRB representation of intricate form of knowledge captured through weighting distribution of ANNs, in other word finding an equivalent ANN for a specified FRB are still as a hot spot of research investigations today. Apart from philosophy of these research themes, today it is demonstrated that there is a deep connection between stabilization of human behavioral patterns as a macro-level view to the brain, and cell level neuronal pattern stability in living organs. It emphasizes the need for a hybrid paradigm in AI. First time in 1949 a Canadian psychologist Donald Hebb asserted that "*If neuronal activity patterns correspond to behavior, then stabilization of specific patterns implies learning of specific types of behaviors*". According to this hypothesis, Hebb proposed a simple reinforcement learning concept to model synaptic plasticity of inter-neural interactions. Today Hebb's postulate has been proved through neurophysiological findings, either in spike time temporal coding or rate coding.

According to what we mentioned about mutual interactions between behavioral and physiological interactions of human learning process, or in another prospect brain Micro-Level and Macro-Level specifications, in this research work we concern about necessity to integrate different looks into the brain to advance a plausible artificial realization of human brain. In fact the main resultant of this work is proposing a novel biologically inspired spiking neural model hereafter Spike-IDS, for Active Learning Method in brief ALM, as a distinguished investigation of Macro-Level engineering realization of brain.

ALM is an adaptive recursive fuzzy inference system with a novel fuzzy attitude inspired by two significant features of human information processing: active learning and brain qualitative modular processing that is free from complex mathematical computations. Brain composes modular structures with different areas processing different types of sensory patterns. There are complex interconnections and interactions among these modular sub-systems. For example the taste is strongly influenced by its odor. Correspondingly due to some psychological evidence it appears that human mind handles real world complex systems as a combination of simpler and more comprehensible aspects of entire system, the way that consumes less energy to acquire information and let us to discover each input-output correlation and their influence in whole system free from complex mathematical processing. This hypothesis is known as reductionism concept in philosophy of mind where a complex phenomenon is representing as combination of partial simpler phenomena or superposition of sub-causes effects. We gain our knowledge into higher resolution by breaking down the whole

concept into simpler parts in addition to refining prior knowledge by removing less valuable input-output (action-response) and imposing new valuable action-response using trial and error. This form of human knowledge acquisition is known as active learning, the ability of active pattern generation and elimination through environment feedback in absence of a supervisor teacher.

ALM has been developed by Shouraki & Honda according to mentioned opinions and findings to advance a new computational paradigm that is frankly mimicking human information processing, the paradigm that avoids complex mathematical computations and definitions in contrast with most conventional soft computing tools. ALM is about to express a Multi-Input Multi-Output system as a fuzzy combination of some simpler Single-Input Single-Output systems. Each SISO system has been described as x_i-y grid plane which has been called IDS unit. Each unit consists of projected data points corresponding to interval domains of other input variables. In other word IDS units represent sensory layer of ALM where a complex system has been broken down into set of simpler ones to acquire information in more comprehensible form. This attitude is dramatically compatible with reductionism in philosophy of mind in which a complex system is supposed as sum of its parts. In other words this fact can be represented more specifically in causal reductionism, where the causes acting on the whole are supposed as simply the sum of the effects of the individual causalities of the parts.

ALM has a basic operator which is called Ink Drop Spread in brief IDS. IDS as knowledge extraction engine have been inspired by non-exact operation paradigm in brain, whether in hardware level or inference layer. This operator that is considerably similar to fuzzy patch which is proposed by Bart Kosko; enables fine grained tunable knowledge extraction from information which is captured by sensory layer of ALM (IDS units). These captured data patterns are fed by IDS operator to extract two important features in partial knowledge space:

- Narrow trajectory which describes input-output characteristic of IDS units (SISO partial systems).
- Spread value which shows importance degree and effectiveness of partial knowledge in overall system.

Finally these features are consolidated by inference layer of algorithm to make final modeling surface.

As we said, in this work we propose a novel spiking neural network structure (Spike-IDS) for ALM which is inspired by sparse temporal coding in biological neural networks. In proposed neural structure the knowledge can be captured and stored in the form of Hebbian type Spike-Time Dependent Synaptic Plasticity as is the case in the brain. Spike-IDS comprises multiple delayed synaptic interconnections of SRM neurons in which

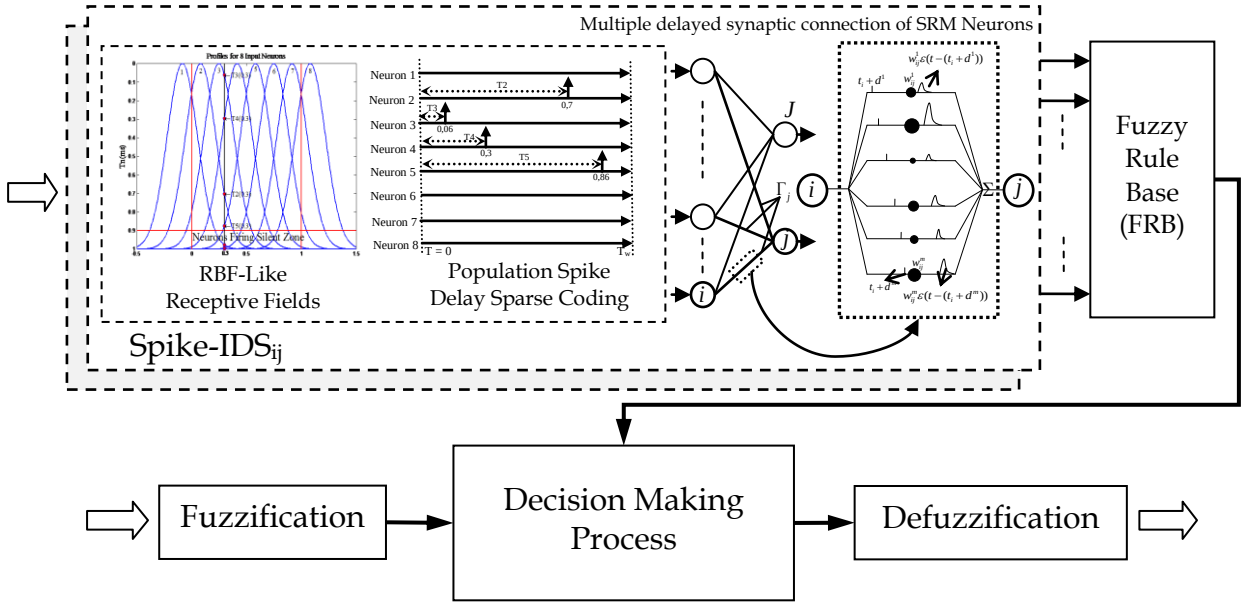

Figure.1 General Scheme of Spike-IDS as a Neuro-Fuzzy inference System

synaptic weights being adjusted using a kind of Spike Time Dependent Hebbian Reinforcement algorithm. Also each input and output neurons stand for a RBF-like receptive field in which spatial content is coded using sparse coding. These neural sub-systems could be adjusted adaptively through learning process and refines spatial partial knowledge using pattern generation and elimination process in accordance with validity of each data pattern. Finally this knowledge has been unified by inference layer. Inference layer is a FRB established for each IDS unit. Each fuzzy rule uses extracted narrow and spread values to integrate partial knowledge.

From another point of view, Spike-IDS is a Neuro-Fuzzy inference machine in which spatial partial knowledge can be captured by each multiple delayed synaptic spiking neural sub-systems through synaptic plasticity (Spike-IDS$_{ij}$ in Figure.1) and unified by a fuzzy rule base to extract human expertness. In fact narrow values as consequent part of fuzzy rules explicitly would be prepared by biologically plausible inference engine (Spike-IDS$_{ij}$). Also the effectiveness of each rule could be considered by Spread values and truth degrees. It is worth to mention that consequent parts could be adaptively changed by imposing new patterns similar to ANFIS through simple non-iterative learning process and free from gradient decent computations (Figure.1).

The integrative top-down approach of this system has been used in some related works such as CAM Brain Machine proposed by De Garis. At first CBM used in a kitten robot called ROBOKONEKO as an artificial brain. It consists of numerous little artificial neural network structures. Weighting distribution and topology of these connected neural sub-systems could be evolved using a GA machine in accordance with specified fitness

criteria. Apart from reasonability and main limitations of CBM, its perspective to the brain learning process as an interactive set of evolvable neural sub-systems is considerably consistent with theories in philosophy of mind and some neurophysiological evidences; the attitude by which Spike-IDS has been affected.

To evaluate Spike-IDS abilities in knowledge acquisition and modeling; it has been compared with ANFIS, ALM, RBFN and FFNNs. Sugeno-Yasukawa function as standard double-input, single-output modeling problem are used. Also iris data set as a simple classification benchmark and Two-Spiral problem as a complex classification problem is chosen. Experimental results demonstrate considerably good ability of Spike-IDS in modeling and classification problems as well as other soft computing tools. Also in this work it is depicted that because of fuzzy none-exact view of Spike-IDS into the experimental patterns, it encompasses less noise sensitivity along with ALM and RBFN in modeling problems.

To assess the viability of Spike-IDS in more realistic problems especially human-like control tasks, a single link inverted pendulum control problem has been investigated. Moreover we develop a GARIC-like actor-critic control strategy for Spike-IDS to achieve adaptively best actions during learning process. Proposed online reinforcement learning controller accomplishes successful control task without any undershoot and overshoot in less than one second for worst case situation.

It is worth mentioning that, Spike-IDS is more plausible than ALM and more compatible with AI paradigms. It is demonstrated that ALM's COGD operator is not T-Norm, so ALM domain does not gratify Logical Completeness. This drawback could be reduced using Spike-IDS. Also ALM is highly restricted for high dimensional problems. This problem arises from storage limitation for matrix-like memory of IDS units. We propose an optimization solution in this work to prevent redundancy in ALM. But IDS storage challenge seems elusive. Spike-IDS as neural implementation of IDS could overcome this challenge using dramatically memory efficient solution either for hardware or software platform.

In this research work in addition to proposed biologically inspired model for Active Learning Method, we present an efficient digital pipelined architecture for ALM as hardware solution. Because of matrix-like topology of IDS units; IDS engine causes ALM slow and memory-hungry. So an arithmetical form of IDS called Replacing IDS is presented in this work with same functionality and better performance especially in thinly scattered space. To improve learning time, we utilize a digital pipeline architecture of RIDS called PRIDS. It has been implemented on ALTERA Cyclone II FPGA chip and verified using ALTERA-DE2 evaluation board. PRIDS shows higher throughput and less learning time in comparison with former hardware solutions for ALM such as HIDS

which is proposed by Murakami in 2005 and analog memory proposed by Tarkhan in 2008. PRIDS has simpler digital hardware structure with more flexibility and scalability.

It is not to say that Spike-IDS establish a realization of artificial brain, but fairly it is a good promotion to investigate human bran information processing from two different paradigms simultaneously and through a hybrid view into the brain (micro-level and macro level). Spike-IDS use a biologically inspired infrastructure that is known as Spiking Neural Networks with SRM neurons and Hebbian STDP stabilization mechanism similar to brain. Also there is a theatrical spatial-temporal pattern-like form of knowledge which is captured through these spatially distributed SNN sub-systems which are combined by fuzzy rules. Another important key point is reciprocal stabilization of weighting distribution of neural sub-systems and behavioral patterns during trial. In other word when we learn how to deal correctly with an environmental stimulus by trial and error and penalty-reward mechanism, in fact this is arisen from stabilization of inter-neuronal activities of related parts of nerves system such as eye-hand coordination or interaction among muscles and sensory neurons of skin. However this prominence is clearly revealed when Spike-IDS is used as online reinforcement learning controller in cart-pole control task and successfully achieve target task.

***Index Terms*: *1*.*Spiking Neural Networks*, *2*.*Active Learning Method*, *3*.*Spike-IDS*, *4*.*Hebbian Spike Time Dependent Plasticity*, *5*.*Brain Learning Simulation*, *6*.*Knowledge Acquisition* *7*.*Hybrid Systems*, *8*.*Active Classification*, *9*.*Reinforcment Learning*, *10*.*Pipelined-RIDS*.**