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# An Architectural Perspective of Soft Computing Methods

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***Abstract—***

***Intelligent system designing requires intelligent search and optimization, machine learning, automatic decision making as well as handling imprecision and uncertainty. These tasks can be effectively and efficiently implemented by utilizing soft computing methods. Soft computing is the emerging field of computational intelligence which has provided smart techniques to incorporate intelligent characteristics into machines. The paper presents an architectural perspective of soft computing methods. The prime contributors of soft computing paradigms are evolutionary algorithms, fuzzy logic and neural networks. The paper presents detailed discussion of constituents of soft computing paradigms. It presents procedural explanation of Genetic Algorithm, Genetic Programming, Evolutionary Algorithm and Evolutionary Programming, Fuzzy Logic and Neural Network. Knowledge representation in real life applications is possible using the theory of fuzzy logic and handling uncertainty is achieved using probability reasoning whereas neural network supports varieties of machine learning mechanisms and classification characteristics. The paper has explained processing capabilities and characteristics of each constituent. The paper highlights contribution of Evolutionary-Fuzzy, Evolutionary-Neural and Evolutionary-Fuzzy-Neural methods. A very brief description on major applications such as intelligent search and optimization, decision support, robotics, engineering, machine learning, etc. is presented. The paper concludes by showing justification of architectural perspective of soft computing methods.***

***Keywords—Evolutionary Algorithms, Fuzzy Logic, Intelligent System, Machine Learning, Neural Network***

## I. INTRODUCTION

Soft computing is an emerging field of computational intelligence. Soft Computing techniques are widely popular as they are integrated techniques and highly suitable to find solutions for the problems which are highly complex, ill-defined and difficult to model. Soft computing is enriched with set of different techniques which are complementary in nature of each other. These techniques include Genetic Algorithms,Genetic Programming,Evolutionary Programming and Evolutionary Strategies,Fuzzy Logic,Probabilistic Reasoning and Neural network. Designing intelligent system is a crucial task and cannot be fulfilled with traditional computing methods. Soft computing paradigms are highly suitable to implement design of intelligent systems as they can satisfy various demands of real life applications very efficiently. These includes implementing intelligent search and optimization, incorporating machine learning, handling imprecision and uncertainty as well as automatic decision making. Hybridization of soft computing methods has gaining popularity in recent years. The paper provides significant discussion on soft computing paradigms.

The second section of the paper provides role of soft computing and their characteristics. Constituents of Soft computing is presented in the same section. The third section provides discussion on evolutionary modelling. It presents detailed discussion on variants of evolutionary computing. These variants include Genetic Algorithm,Genetic Programming, Evolutionary Algorithm and Evolutionary Strategies. The paper has explained evolutionary life cycle and procedural information in detail. The Forth section presents views on approximate modelling. It includes discussion on Fuzzy Logic and Probabilistic Reasoning. It extensively discusses fuzzy computing, its characteristics and design steps of fuzzy systems. The fifth section explain neural network modelling which provides learning mechanism using neural network architecture. Salient characteristics of neural computing are provided in this section. The sixth section provides hybridization utilities of neural-fuzzy, evolutionary-fuzzy and evolutionary-neural-fuzzy computing. The seventh section highlights major application domain supported by soft computing constituents. The final section justifies the architectural perspective of soft computing methods.

## II. SOFT COMPUTING

Soft computing is a branch that deals with real life applications. Soft computing is viewed as a foundation component for the emerging field of computational intelligence [1]. All industrial and business sector problems can be efficiently solved using soft computing techniques. Soft computing possesses several methods which are suitable to provide solutions to problems which are highly complex, weakly defined and highly difficult to model. The guiding principle of soft computing is as follows: “To exploit the tolerance for imprecision, uncertainty, partial truth, and approximation to achieve robustness, low solution cost and better rapport with reality.”The salient characteristics of soft computing are narrated as follows [2]:

- It is observed that many times it is highly complicated to formulate model of problem of real life. It also happens that many problems do not require modeling of problem.
- Real time applications have to deal with different tasks. In order to provide solution of different tasks, there are varieties of methods available in soft computing family.

- The type of algorithm supported by soft computing is dynamic. Hence, to accommodate changes in the algorithm is become possible.
- Soft computing provides economical and feasible solutions with reduced complexity. This feature helps to design and deploy intelligent system.
- Soft computing provides intelligent search method which is capable to find best solution.
- Soft computing provides parallel computing environment which provides fastest solutions for real time applications.

Machine Learning methods provide framework for intelligent systems. Automatic learning has been always a critical task for intelligent system design [3].

### *A. Family of Soft Computing*

Soft computing is a consortium of methodology which has provided smart techniques for knowledge engineering, learning, searching, optimization and classification. The principal constituent methodologies in soft computing are complementary rather than competitive. Due to such quality, designing intelligent system becomes possible by hybridizing different methods. Synergetic effects of hybridization of different learning and adaptation techniques can be achievable using soft computing. The next generation of intelligent system can be effectively designed and deployed using fusion of soft computing constituents. The upcoming section explains different members of soft computing in detail. Fig.1 represents the members of soft computing family.

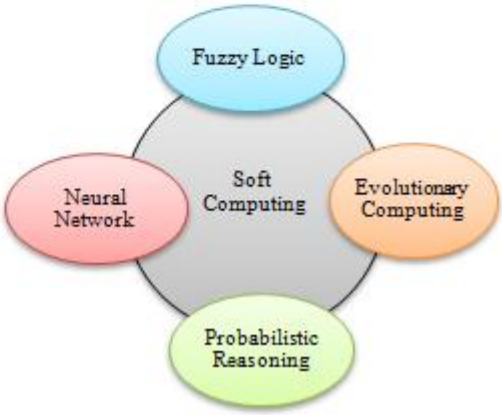
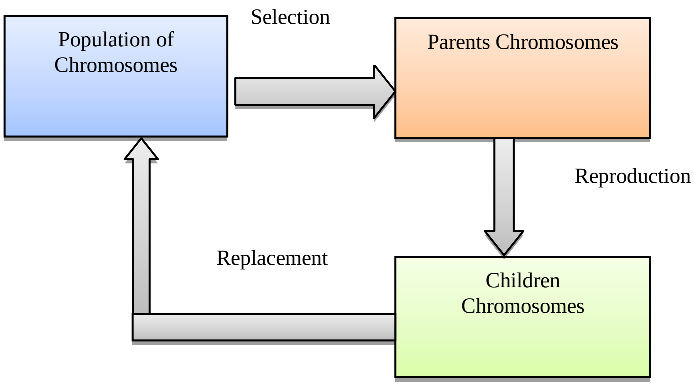



Fig.1: Members of Soft Computing Family

## III. EVOLUTIONARY MODELLING

Evolutionary modeling is basically the type of computing which is based on structuring of problem with the help of process of evolution. The process of evolution is the change in the inherited traits of a population from one generation to the next. Evolutionary modeling uses evolutionary algorithm in order to implement evolutionary characteristics in solving problems. Evolutionary Computation (EC) refers to the computer-based problem solving systems that use computational models of evolutionary process. In recent years, cognitive systems have gained prominence by implementing evolutionary approach to the computational modeling. Evolutionary characteristics are achieved using evolutionary modeling in which problem is structured using chromosome of different types in form of symbols or alphanumeric numbers. Evolutionary algorithms are basically computational models of evolutionary processes. Fig. 2 represents basic procedure of evolutionary modeling.




Basic Procedure of Evolutionary Modeling

A number of operators are applied to the individuals of the current population to generate the individuals of the population of the next generationat each iteration. Usually, EC algorithms use an operator called reproduction or crossover to recombine two or more individuals to produce new individuals. They also use mutation or modification operators which cause a self-adaptation of individuals. The fitness (how good the solutions are) of the resulting solutions are evaluated and suitable selection strategy is then applied to determine which solutions will be maintained into the next generation.Evolution is based on following types of selection methods [4]:

- Artificial selection: A selection process where specific features are retained or eliminated depending on a goal.
- Natural selection: A selection process is similar to Darwinian Theory of biological evolution. In natural selection process; there is no actor who does the selection. The selection is purely automatic or spontaneous, without plan or design involved.

Evolutionary modeling provides various techniques for designing evolutionary systems. These techniques are presented in Fig.3.

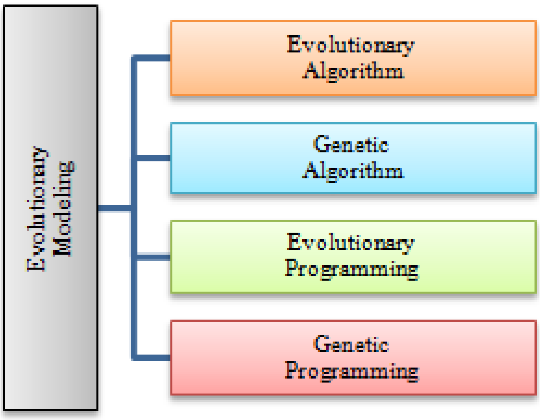



Fig.3: Consortium of Evolutionary Modeling

### A. *Genetic Algorithm*

Genetic Algorithms are pioneered by John Holland in 1970's [5]. Genetic Algorithms are one of the pioneer method that works on principle of natural genetics to provide search and optimization facility. Genetic Algorithms are widely used in engineering, scientific as well as business applications. They are successfully applied to the problems which are difficult to solve using conventional techniques such as machine learning and optimization. Genetic Algorithms are based on principle of natural evolution which is popularly known as "Darwinian Evolution". In evolutionary modeling, Genetic Algorithm simulates process of natural selection. The steps of natural selection are presented in Fig. 4 as under:

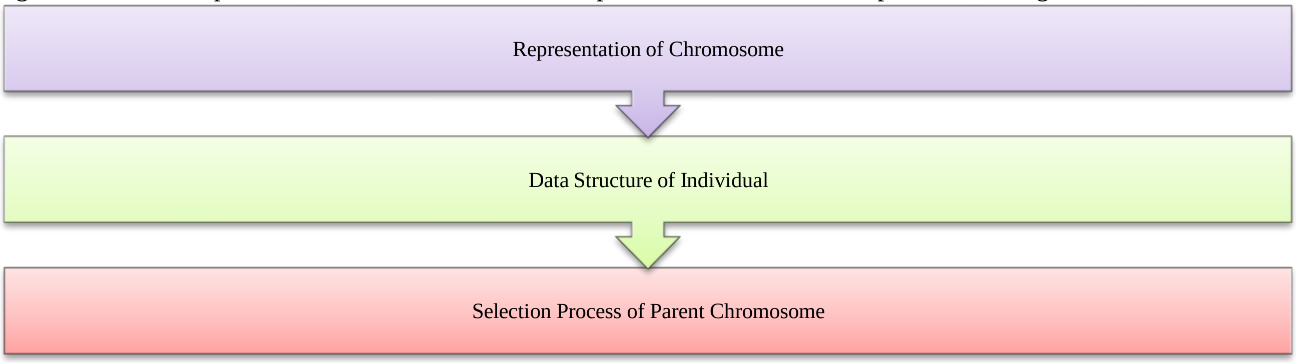



Fig.4: Steps of Natural Selection Process in GA

Fig.4 represents steps of natural selection process implemented in Genetic Algorithm. Each step is executed with the help of several operations. These operations include Fitness evaluation, genetic operators and selection mechanism. Genetic Operations make new generation as well as modification in chromosomes. Table 1 represents components of Genetic Algorithm and their role as follows:

TABLE 1: COMPONENTS OF GENETIC ALGORITHMS AND THEIR ROLES

| | |
|---|---|
| Population of chromosome | Population of chromosome is basically problem representation using encoding schemes. |
| Fitness evaluation | A fitness score is allocated to each solution. The individual with the optimal fitness score is required to be found. |
| Genetic operations | The entire population evolves towards better candidate solutions via the selection operations and genetic operators such as crossover mutation and selection. |
| Crossover and Mutation | These operators are responsible to generate new solutions. |
| Selection | It is responsible to select parent chromosome from available chromosome. These parent chromosomes will be processed further to generate new children chromosomes. |
| Termination Criteria | A condition which decides when to stop the process for generating outcome |

### *B. Genetic Programming (GP)*

It is specialized form of Genetic Algorithm. Specifically, genetic programming iteratively transforms a population of computer programs into a new generation of programs by applying analogs of naturally occurring genetic operations. The chromosome in a GP systems form hierarchical rather than linear structure. The basic procedure as under [6]:

1. Generate an initial population of random compositions of the functions and terminals of the problem (computer program).
2. Iteratively perform the following sub steps until the termination criteria has been satisfied:

a) Execute each program in the population and assign it a fitness value
b) Create a new population of computer programs by applying the following two primary operations. The operations are applied to computer programs in the population selected with a probability based on fitness

1) Reproduce an existing program by coping it into the new population
2) Create two new computer programs from existing programs by genetically recombining randomly chosen parts of two existing programs using the crossover operation applied at a randomly chosen crossover point within each program

Mutation operation is applied before crossover. But Crossover operator is essential to introduce diversity of the population.

### *C. Evolutionary Strategies*

Evolution strategies derive inspiration from principles of biological evolution. It is based on following two rules of evolution

1. It randomly changes all variables at a time ,and
2. If the new set of variables does not deteriorate the fitness keep it, else discard.

Initially, the strategy based on above stated rules was popularly known as simplest ES which became later the popular (1+1) ES. Evolution strategies typically use real-valued vector representations.Initially they were only working with the help of mutation operation.Evolution strategies are primarily employed for continuous parameter optimization. In a generational procedure, following steps are executed [7]:

3. One or several parents are picked from the population (mating selection) and new offspring are generated by duplication and recombination of these parents;
4. The new offspring undergo mutation and become new members of the population;
5. Environmental selection reduces the population to its original size.

### *D. Evolutionary Programming*

Evolutionary Programming (EP) is originated from Fogel [8,9]. It is a useful method of optimization when other techniques such as gradient descent or direct, analytical discovery are not possible to implement. It is capable to predict a symbol based on previous symbol. In EP, the chromosomes are presented as Finite State Machines. A finite state machine provides machine possessing with a finite number of different internal states. The basic EP method involves 3 steps (Repeat until a threshold for iteration is exceeded or an adequate solution is obtained) [10]:

1. Choose an initial population of trial solutions at random. The number of solutions in a population is highly relevant to the speed of optimization. But there is not any specification possible regarding number of appropriate solutions and inappropriate solutions.
2. Each solution is replicated into a new population. Each of these offspring solutions are mutated according to a distribution of types of mutation ranging from minor to extreme.

Each offspring solution is assessed by computing its fitness values. Typically, a stochastic tournament is held to determine N solutions to be retained for the population of solutions, although this is occasionally performed deterministically.

## IV. APPROXIMATE MODELLING

Soft computing can effectively solve problems of real life applications which deal with approximation and uncertainty. Fuzzy logic is a member of soft computing, which effectively handles approximation, imprecision and uncertainty. Machine learning systems require knowledge representation and manipulation in extensive manner. Real world knowledge is always uncertain and imprecise. Hence, Fuzzy logic is highly suitable constituent of soft computing to handle imprecise and uncertain knowledge representation in intelligent systems.

### *A. Fuzzy Logic*

Fuzzy logic has been considered as a practical, robust, inexpensive, and intelligent alternative for modeling and control of complex systems. The theory of Fuzzy Logic has been invented by Zadeh.In 1965,L.A. Zadeh introduced fuzzy sets, with which a more flexible sense of membership is possible. Practically, the values of variables are not known precisely; rather approximate values are more likely to be available. FL is concerned with imprecision and approximation reasoning. FL may be viewed as an extension to classical logic system which provides conceptual framework for handling problems of knowledge representation in uncertain and imprecise environment. The fuzzy logic is basically, a

multi-valued logic and that is used to describe fuzziness. It uses the continuum of logical values between 0 (completely false) and 1 (completely true). Fuzzy logic is the theory of fuzzy sets, which calibrate vagueness. It incorporates the idea that all things admit of degrees. The classical logic uses theory of crisp sets while Fuzzy Logic uses theory of fuzzy sets. Fuzzy sets were designed as a means of representing and manipulating data that was not precise, but rather fuzzy[11]. It provides an inference morphology that enables approximate human reasoning capabilities to be applied to knowledge-based systems. The theory of fuzzy sets is explained as under [4]:
A fuzzy set A(x) is a collection of objects x with a grading of the membership values in the closed interval [0,1] ,

$$A = \{(x, \mu A(x)) | x \in X\} \qquad (1)$$

where$\mu A(x)$ is called the membership function (MF) for the fuzzy set A. The MF maps each element of X to a membership grade (or membership value) between zero and one. 0 means complete exclusion, and 1 means full membership.Fuzzy logic is a set of mathematical principles for knowledge representation based on degrees of membership. Fuzzy rule based systems are extension to classical rule based system. The major reasons behind fuzzy systems development can be enlisted as follows [4]:

- Human reasoning is easy to implement using fuzzy system;
- Mathematical model can be easily developed;
- Provides a smooth transition between members and non-members
- Relatively simple, fast and adaptive;
- Less sensitive to system fluctuations; and
- Linguistic or description rules can be easily designed using fuzzy system which is not possible with conventional logic.

Linguistic variables are the input or output variables of the system. The values of these variables are words or sentences from a natural language, instead of numerical values. A linguistic variable is generally decomposed into a set of linguistic terms.

*1) Fuzzy Membership Functions*

Membership functions are used in the fuzzification and de-fuzzification steps of a FLS, to map the non-fuzzy input values to fuzzy linguistic terms and vice versa. A membership function is used to quantify a linguistic term. Membership functions are used to process numeric input data. For the implementation of a fuzzy controller it is necessary to determine membership functions representing the linguistic terms of the linguistic inference rules. The major types of membership functions are shown in Fig. 5(a), Fig.5(b) and Fig.5(c).

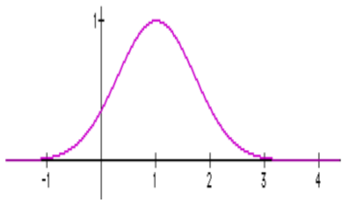


Fig. 5(a): Gaussian Membership Function

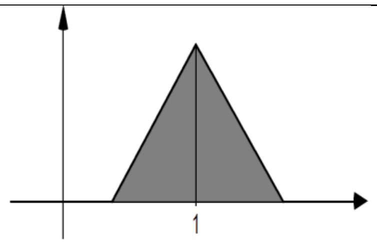


Fig. 5 (b): Triangular Membership Function

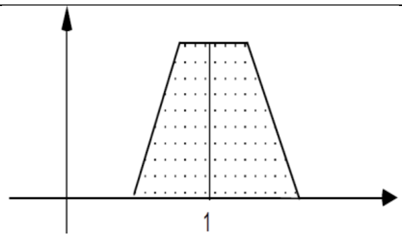


Fig.5(C): Trapezoidal Membership Function

The type of the membership function can be context dependent and it is generally chosen arbitrarily according to the user experience [12].A fuzzy system is any FL based system which either uses FL as different forms of knowledge. Application of FL leads to design of Fuzzy Rule Based system. Fuzzy rule based system is be structured using IF-THEN rules whose antecedent and consequents are composed of fuzzy rules. An important contribution of fuzzy systems theory is to provide a systematic procedure for transforming a set of linguistic rules into a nonlinear mapping. Fuzzy logic based system can play important role in designing intelligent system in which knowledge representation is made possible with linguistic variables and linguistic values. The basic structure of fuzzy system is shown using Fig.6 [13].

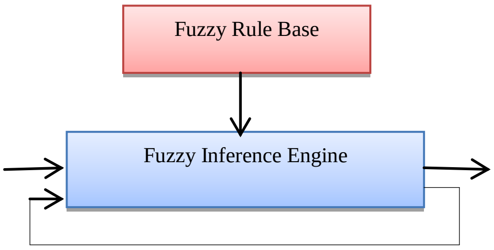


Fig. 6: Basic Structure of Fuzzy System

*2) Steps to Design Fuzzy Logic Based System*

Fuzzy rule based system can be designed using following steps [14]:

1. Define the linguistic variables and terms (initialization)

2. Construct the membership functions (initialization)
3. Construct the rule base (initialization)
4. Convert crisp input data to fuzzy valuesusing the membership functions (fuzzification)
5. Evaluate the rules in the rule base (inference)
6. Combine the results of each rule (inference)
7. Convert the output data to non-fuzzy values (de-fuzzification)

There are two major types of fuzzy rule based system available, which are as under:

1. Mamdani Fuzzy Rule Based System: Mamdani fuzzy systems became more popular due to providing fuzzy sets for consequent parts which is not possible with Takagi Sugeno FRBS.
2. Takagi-Sugeno-Kang (TSK) fuzzy systems: In order to solve problems of engineering systems where inputs and outputs are real-valued variables, TSK fuzzy systems are proposed.

### *B. Probabilistic Reasoning*

Uncertainty is an inherent and ubiquitous property of most types of knowledge. In order to deal with uncertainty, soft computing uses the theory of probabilistic reasoning. Uncertainty arises from sources like incomplete knowledge, disagreement between various information sources, linguistic imprecision, statistical variation in the measured population, measurement error, or approximations. The oldest and most widely used approach to handle uncertainty is the theory of probability. Uncertainty in probability theory is measured by a real number between 0 and 1. 0 refers to impossible event and 1 refers to sure event, called probability. The aim of a probabilistic logic (also probability logic and probabilistic reasoning) is to combine the capacity of probability theory to handle uncertainty with the capacity of deductive logic to exploit structure. Probabilistic reasoning may be viewed as an analogous manner to fuzzy reasoning, considering uncertainty in place of fuzziness as the concept of approximation that is applicable. Bayesian (also called Belief) Networks (BN) are a powerful knowledge representation and reasoning mechanism using Probabilistic reasoning [15].

## V. NEURAL NETWORKMODELLING

Soft computing plays very significant role in designing machine learning systems as they provide neural network which simulates biological nervous system in order to provide different types of learning.

### *A. Neural Networks*

Neural network being a simplified model of biological neuron system is a massively parallel distributed processing system made up of highly interconnected neural computing elements that have an ability to learn and thereby acquire knowledge and make it available for use [16].Neural networks (NN) are generally considered as learning machines that work on the basis of observed data. Connectionist system is able to acquire knowledge about the world from observational instances. There are no a priori conceptual patterns that could lead to a learning process [17]. NN is a network of many simple processors (”units”), each possibly having a small amount of local memory. The units are connected by communication channels (”connections”) which usually carry numeric (as opposed to symbolic) data, encoded by any of various means. NN is basically a nonlinear classification system of interconnected nodes that can learn the underlying behavior patterns in a collection of data using a set of examples. Neural networks can be taught to recognize specific patterns or they can be allowed to discover and arbitrarily learn patterns in large databases [18].Fig. 7 represents general structure of artificial neural network.

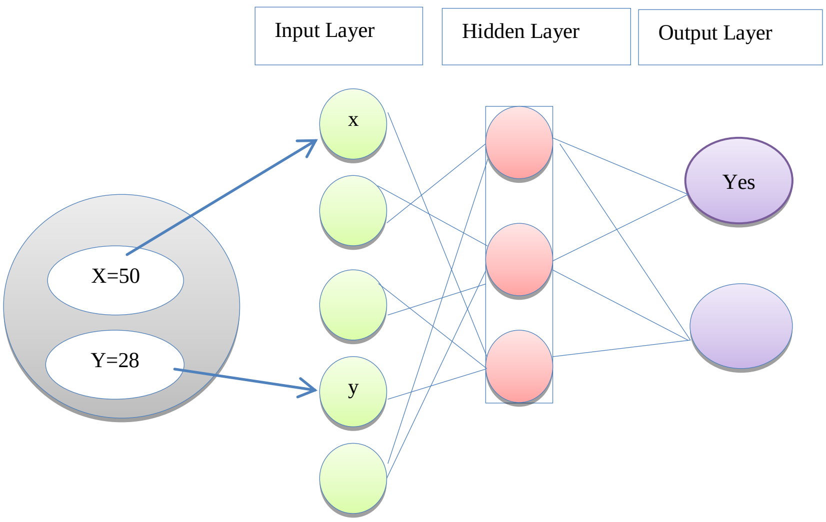



Fig. 7: General Structure of Artificial Neural Network

Neural network consists of three major layers: Input Layer, Process (Hidden) Layer and Output Layer. These layers are interconnected by means of unidirectional weighted signal channels which are known as connections or weights.

### *B. Characteristics of Neural Network*

Characteristics of neural network can be described as under [19]:

- NNs can compute any computable function
- NN can be difficult to apply successfully to problems that concern manipulation of symbols and memory. There are no methods available for training NNs that can magically create information that is not contained in the training data.
- NN can learn from experience in such a way that it become complex and difficult to solve problems with small amount of data, but with plenty of data that describe the problem easily
- NN is capable to provide generalization from examples.
- NN can be adaptable to a changing environment, if it is properly designed.
- NN provides good level of computational efficiency.
- Neural networks are not based on linear assumptions about the real word.

## VI. HYBRID MODELLING USING SOFT COMPUTING

Actually, soft computing constituents are derived from varied domains as logic, biology, physiology and statistics. In the initial stage of development of soft computing, independent methods were utilized among community of practitioners. Their success progressively attracted researchers in the other fields also. Indeed, they model in different extents natural processes such as evolution, learning, or reasoning [20]. Hybridization of any two is capable to eliminate the limitations and generate stronger solution by integrating advantages of each individual technique.

### *A. Evolutionary Fuzzy Hybrid Systems*

Recent years have contributed to large number of new hybrid evolutionary systems. There are several ways to hybridize a conventional evolutionary algorithm for solving optimization problems. In order to have learning and dealing with imprecise knowledge handling, Evolutionary algorithms are hybridized with FL. This is popularly known as evolutionary - fuzzy Hybridization. Evolutionary method is capable to encode and to evolve rule antecedent aggregation operators, different rule semantics, rule- based aggregation operators and de-fuzzification methods. Hence, it is considered as knowledge acquisition scheme [21].

### *B. Neural Fuzzy Hybrid Systems*

Neural network can model complex nonlinear relationships and are appropriately suitable for classification into predetermined classes. But at the same time, the precision of outputs is often limited and does not admit zero error but only minimizes least square errors.Fuzzy systems are capable to handle imprecision hence hybridization of NN with FL becomes powerful designers for intelligent systems. Neural network learning techniques could be used to learn the fuzzy inference system in a cooperative and an integrated environment. In an integrated neuro-fuzzy model, neural network learning algorithms are used to determine the parameters of fuzzy inference systems. Integrated neuro-fuzzy systems share data structures and knowledge representations. Some of the integrated neuro-fuzzy systems are GARIC, FALCON, ANFIS, NEFCON, NEFCLASS, NEFPROX, FUN, SONFIN, FINEST, EFuNN andEvoNF[22] .

### *C. Neural-Genetic-Fuzzy Hybrid*

In an integrated neuro-fuzzy model, there is no guarantee that the neural network-learning algorithm will converge and the tuning of fuzzy inference system be successful. Optimization of fuzzy inference systems could be further improved using a meta-heuristic approach combining neural network learning algorithm and evolutionary algorithms. This type of evolutionary Neural Fuzzy framework could adapt to Mamdani, Takagi-Sugeno or other fuzzy inference systems. The architecture and the evolving mechanism could be considered as a general framework for adaptive fuzzy systems, that is a fuzzy model that can change membership functions (quantity and shape), rule base (architecture), fuzzy operators and learning parameters according to different environments without human intervention [22].

## VII. MAJOR TYPES OF APPLICATIONS SUPPORTED BY SC

### *A. Intelligent Search*

Intelligent search can be possible to implement using evolutionary algorithms. Genetic algorithm does not require any problem specific knowledge of the search space because strings are evaluated with fitness quality and hence search is made possible through the strings which are basically constituents of its structure. Fitness based searching is implemented as evolutionary procedure. This type of search has capability to move towards multiple directions. Here, the fitness is measured at one point of time and at the same time population can be evolved also to next generation. This way parallel processing is possible to achieve.

### *B. Optimization*

Optimization is the process of finding decisions that satisfy given constraints, and meet a specific outcome in terms of its optimal value. Traditional methods of optimization include both gradient based as well as direct search techniques. Being one of the prominent representatives of evolutionary computation, Genetic Algorithm satisfies the requirement providing optimum solution. The objective of global optimization is to find the "best possible" solution in nonlinear decision models that frequently have a number of sub-optimal (local) solutions [23]. In the absence of global optimization methods, feasible solutions are only the solutions.

### *C. Machine Learning*

A computer system learns from data, which represent some "past experiences" of an application domain. In other words, a target function can be used to predict the values of a discrete class attribute, e.g., approve or not-approved, and high-risk or low risk. The task is commonly called: supervised learning, classification, or inductive learning. Classification can be viewed as supervised learning from examples[24]. Neural Networks are prime contributors in the stated area. Neural network are also capable to provide unsupervised, reinforcement as well as incremental learning in designing intelligent systems. Evolutionary hybrid structures have also contributed in the same area.

### *D. Decision Support Systems*

Various types of decision support systems have been developed in different areas such as educational DSS, Financial DSS,etc. using hybridization of constituents of soft computing [25,26].

### *E. Robotics*

In the area of Robotics, hybridization of soft computing methods specially evolutionary-fuzzy and evolutionary–neural methods have contributed many applications [27, 28].

### *F. Engineering Systems*

Applications in the field of various disciplines of engineering such as electrical, Mechanics, hydrodynamics, aeronautics, etc. have been developed using Fuzzy-Genetic and Neural Fuzzy hybridization [16].

Apart from above stated applications, there are numerous applications in the field of medicine, automobiles, forecasting, mathematics, social science, education, management, etc. have been successfully implemented using soft computing constituents.

## VIII. CONCLUSION

The paper has explained significance of soft computing methods. Evolutionary methods, Fuzzy logic and neural network are prime contributors in designing and deploying intelligent systems. The paper focuses on prime contribution offered by soft computing constituents. Soft computing has provided various types of computing mainly evolutionary computing, fuzzy computing, neural computing and hybrid computing. Intelligent systems require performing various tasks such as imprecision, uncertainty, machine learning, intelligent search and optimization, automatic decision making, etc. Soft computing members are efficient enough to satisfy the above stated requirements of intelligent system design. The paper has effectively explained architecture of each of soft computing methods namely Genetic Algorithms, Genetic Programming, Evolutionary Programming, Evolutionary strategies, Fuzzy Logic, Probabilistic Reasoning and Neural Networks. Hybridization of major constituents such as evolutionary-fuzzy, evolutionary-neural and evolutionary-neural-fuzzy have contributed a lot in achieving success to design next generation of intelligent system. The paper has briefly discussed contribution of soft computing methods in intelligent search and optimization, machine learning, decision making, robotics, engineering design, linguistic and fuzzy modeling, etc. The paper has provided significant review of soft computing architectures and their utilities.

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