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Analysis of Fitness Function in Genetic Algorithms

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Abstract**—**Genetic algorithm is an optimization technique which is based on the process of natural selection that drives biological evolution. It repeatedly modifies a population of individual solution and chooses individuals randomly on the basis of fitness value from the current population to be parent and uses them to produce the offspring for the next population. The main components of genetic algorithm consists of fitness function, cross over, mutation etc. The design of fitness function is very essential in genetic algorithm as the desired output depends heavily on the design of fitness function. The fitness value of each individual is computed by applying the fitness function to it. A fitness function is an application specific objective function used to evaluate relative effectiveness of the potential solutions. For standard optimization algorithm, it is known as objective function. In this paper, some of the fitness functions, applied in different domains, have been selected and analyzed. It has been observed that formulation of specific fitness function is very significant and different classes of applications depend on different parameters for designing such functions. The study may further be enhanced to design specific and optimized fitness function for future research.

Keywords**—**Fitness function; genetic algorithm; image processing; intrusion detection; robotics.

I. Introduction

Genetic algorithm is one of very important approach to solve different problems that require high complexities. It is an optimization tool that mainly implements the survival of the fittest idea into search algorithm and is used to solve constrained and unconstrained problems based on natural selection. Genetic algorithm process mainly includes encoding, evaluation, and cross over, mutation and decoding. The initial population is selected at random and the fitness of each individual is then computed; i.e. How well the individual fits the problem. This fitness is used to find the individual's probability of crossover. An individual having high probability is more likely to be chosen to crossover as it is closer to optimum than the rest of its generation. Crossover then takes place to combine two parents to form off springs for the next generation and mutation applies random changes to individual parent to form children. Genetic algorithms are being increasingly applied to solve different problems in computer science like bioinformatics, phylogenetics, computational science, image processing, bayesian inference, machine learning, robotics, etc. Traditional algorithm generates a single point at each step and sequence of those points approach an optimal solution whereas in genetic algorithm, population of points is generated during every step and best point represents the optimal value. It gives better optimized value as compared to other search techniques.

II. Ffitness Criteria

In genetic algorithm, at each stage the fitness criteria is applied to the population either to evaluate the part of population that should be selected for further computations or to stop the algorithm. Fitness function is application specific, and incorporates different constraint according to the requirement of the application to generate optimum results. The working of Genetic algorithm is based on the fitness function and is generally implemented in the form: GA (fitness, fitness threshold, ps, f, m); where '*fitness'* is the function evaluates how good a hypothesis is, 'fitness threshold' is minimum acceptable hypothesis, '*sp'* is the size of the population, '*f*' is the fraction of population to be replaced and '*m'* is the mutation rate. The design of fitness function is very essential step in genetic algorithm as performance of genetic algorithm mainly depends upon the effort involved in designing a workable fitness function. In order to get optimum result for non-trivial problems, genetic algorithm must be iterated many times. We can approximate fitness value if fitness function is uncertain or noisy, execution time is very high. Fitness function can be implemented in two ways: one in which it is mutable and other in which it is constant.

A. Types of Fitness Function

There are various fitness functions that are currently applied in various domains of computer sciences. This function can be of any type as per requirement of application. The function should be designed such that genetic algorithm produces better results than any other functions would have given otherwise. Some of the fitness functions are given below:

- Single variable single argument: In this case, the fitness function will take one input x where x is a one variable. E.g. Function y = simple_fitness(x); y = 3* (x^2) + (2 - x^2).
- Multiple variable single arguments: In this case, the fitness function will take one input x where is a row vector with as many elements as number of variables in the problem. E.g. function y = simple_fitness(x) ; y = 5 * (x(1)^2 + (2 - x(1))^2.
- Multiple variables multiple arguments: In this case, the fitness function will take multiple arguments where x is a row vector with as many elements as number of variables in the problem. E.g. function y = parameterized_fitness(x,m,n); y = m* (x(1)^3 - x(2)) ^2 + (n - x(1)).

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- Vectorization of Fitness Function: Vectorization of fitness function is done to speed up execution. Generally, the 'GA' solver only passes in one point at a time to the fitness function. This vectorized version of the fitness function takes a matrix 'x' with an arbitrary number of points, the rows of x, and returns a column vector y with the same number of rows as x. It need to specify that the fitness function is vectorized using the options structure created using gaoptimset.
  function y = vectorized_fitness(x,a,b); y = a * (x(:,1).^2).^4 + (b - x(:,2))^3 [1]

III. Aims and Objectives

In this paper, study has been done on selected genetic algorithms and its components used in various applications. An analysis is done to understand the behavior of various control parameters of different selected fitness functions and its impact on the result produced.

IV. Literature Review

In order to understand the behavior of fitness function; a review has been done on many research papers and found that various fitness functions have been evaluated for different applications (based on genetic algorithm) which is depicted as follow:

A. Detection of Denial of Service

To detect DOS (denial of service) and probe type of attack, the fitness function (FF) is in the form

a. FF=f(x)/ f (sum),

Where f(x) is the fitness of entities of entity x and f (sum) is the sum of all entities [2].

B. To Detect Intrusion by GA

The fitness function is defined as:

$$\text{Outcome}=\sum_{i=1}^{57} \text{matched} * \text{weight (i)};$$

$$\text{Div} =| \text{outcome- suspicious level}|;$$

$$\text{Penalty=div*ranking/100};$$

$$\text{FF} = 1 - \text{penalty}.$$

Suspicious level reflects observation from historical data and ranking shows whether intrusion is easy to identify or not [2].

C. The reward penalty based fitness function to compute DOS, normal, probe, U2R attacks is:

$$\text{FF}=2+ (\text{AB-A})/ (\text{AB+A}) + (\text{AB/X}) - (\text{A/Y}),$$

Where (AB/AB+A) reflects the strength (i.e. reward) of record and (A/AB+A) reflects the weakness (i.e. penalty) of the record. The value of fitness function lies in the range of [0, 4] [2].

D. Image Enhancement

Mean absolute error (MAE) criterion was used to evaluate fitness of individuals, Fitness values fv (j), for j=1, 2,.., Np are computed ;

$$\text{FF (j)} = 1-(\text{MAE}_j/\text{MAE}_{max}),$$

Where MAE_{max} is the maximum possible MAE of the image and N_p is the size of population [3].

E. Image Segmentation

GA is used to optimize parameters of various segmentation techniques and to develop new techniques. Several approaches applied GA-based search for optimal configuration of edge pixels. It evaluates each chromosome by using a cost function. The form of the point cost function is a linear combination of five weighted point factors. It includes fragmentation, thickness, local length, region similarity and curvature.[3] This algorithm was modified where each chromosome encodes only small portion of image as a 8x8 window and they were represented by a bit array. These windows are connected with their neighboring windows to keep track of edges connectivity at window corners [4].

F. Image Reconstruction

The fitness function used for image reconstruction by using BGA is:

$$\text{FF}= (1+E_m)^{-1},$$

Where E_m represent root mean squared error (RMSE), mean squared error (MSE), mean absolute error (MAE), relative squared error (RSE), root relative squared error (RRSE) and relative absolute error (RAE).[5]

G. Evolutionary Robotics

Fitness function is also used in robotics to determine which solutions (controllers in the case of Evolutionary Robotics) within a population are better at solving the particular problem at hand. The fitness function is often the limiting factor in achievable controller quality. The fitness functions used for selection contained relatively little a priori knowledge, and allowed evolution to proceed in a relatively unbiased manner and includes training data fitness functions, Behavioral fitness functions, Aggregate fitness functions Very low, tailored fitness functions etc. [6].

The fitness values , then obtained , are used in a process of natural selection to choose which potential solutions will continue on to the next generation, and which will be eliminated. This is carried out on the basis of results produced by Fitness function on the population.

V. Analysis

From the study of above applications, the fitness function is found to be the problem dependent and key criteria for achieving optimized results in genetic algorithms. The Fitness Function is defined over the genetic representation and measure the quality of representation solution. Fitness function is found to be problem dependent. In some problems; it is hard to define the fitness expression; in these cases, a simulation may be used to determine the fitness function value of a phenotype or interactive genetic algorithm is used. During the application of genetic algorithm, we must put main emphasis on design of fitness function. The "fitness function" is responsible for performing the evaluation that how "good" a potential solution is relative to other potential solutions. Table 1 summarizes the overall analysis done in this paper.

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Table 1. Analyzed fitness functions.

Application Problem Area	Problem Area	Fitness Function	Results
Intrusion detection in networks[2]	To detect Misuse Network Intrusion	Reward penalty based	Yields better results.
Image enhancement[3]	To construct new filters, to optimize parameters for existing filters.	Mean absolute error	better results and faster processing time.
Image segmentation[3]	Edge detection	Cost function	3better in case of large solution space.
Image reconstruction[5]	To reconstruct image of various size and shape complexities by using BGA	MAE, MSE, RMSE, RSE, RRSE, RAE	RMSE and MAE outperformed for small and large size images with different shape complexities.

VI. CONCLUSION

Genetic algorithm is one of the important techniques suitable for the class of problems that require repeated modification of population under study. In the current study, it has been concluded that genetic algorithm is used in various applications in computer science and fitness function plays an important role in those applications as success of genetic algorithm (in those applications) depends upon how effective fitness function is. If fitness function is designed badly, then latter operations in genetic algorithm cannot yield optimsed result. There is a wide scope for Genetic algorithm to be implemented in various applications in coming future.

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