Effect of Polygamy with Selection in Genetic Algorithms

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Abstract: Genetic algorithms are based on evolutionary ideas of natural selection and genetics. Important operators used in GA are selection, crossover and mutation, where selection operator is used to select the individuals from a population to create a mating pool which will participate in reproduction process. A number of selection operators have been used in the past like roulette wheel selection, ranked selection, elitism etc. where elitism is used to enforce the preservation of best solution found so far unless a new best individual is discovered. Elitism is implemented by copying the best individual of a generation into the next generation without any change. In this paper a particular form of elitism, polygamy, is proposed and implemented in which in each generation the best individual is selected and that participates in crossover with all other individuals in the mating pool created by any other selection mechanism. Polygamy has also been observed in a number of animals like lion, elk, baboons etc. Results obtained show the improvement over traditional selection operators available in literature.

Index Terms—genetic algorithm, polygamy, rank selection, roulette wheel, selection.

I. INTRODUCTION

Genetic algorithms are stochastic algorithms, pioneered by John Holland in 1975 [1], simulating the genetic process of biological evolution. David E. Goldberg described genetic algorithms as adaptive heuristic search algorithms based on the evolutionary ideas of natural selection and natural genetics [2]. They have been applied to wide variety of search and optimization problems for more than four decades.

In genetic algorithms, the mechanics of natural selection and genetics are emulated artificially. The search for a global optimum to an optimization problem is conducted by transforming an old population of individuals to a new population using genetics-like operators. Each individual represents a candidate solution to the problem. An individual is modeled as a fixed length string of symbols called chromosome. Each chromosome is evaluated by its fitness value as computed by the objective function of the problem. The fitness value is measure for the quality of an individual. A typical genetic algorithm involves four major procedures, namely, fitness evaluation, selection, recombination and mutation. Recombination refers to crossover operation. Crossover and Mutation operators are used to maintain diversity in the population. The cycle of genetic algorithm continues until the optimal solution is achieved.

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Genetic Algorithms are based on Darwin's principle of survival of fittest, so better fit individuals have more chances to survive and carried forward to next generation leaving behind the less fit ones. As per Darwins's theory of natural Selection, the best individual's traits are carried to next generation. In elitism, an approach to selection, best individual is carried forward to next generation as such. Simple elitist strategy enforces the preservation of best solution found so far unless a new best individual is discovered. Elitism helps to speed up the search process, but its drawback is contribution to decrease in diversity of the population. Good balance has to be maintained between exploitation and exploration while implementing elitism.
In this paper, the focus is to introduce the concept of polygamy in addition to the selection with an aim to retain the best chromosome characteristics in the new generation. Polygamy refers to special case of elitism where the best individual is treated as one parent for mating with other chromosomes. The paper is organized in the following sections. In section 2, literature review is given on biological references and different researches related to polygamy, elitism and selection, . Different notations used throughout the paper are given in section 3. Different selection methods used in addition to polygamy and their computation formulae are described in section 4. Algorithms related to selection methods and genetic algorithms implementing proposed polygamy are presented in section 5. Implementation procedure and computational results are provided in section 6 and concluding remarks are given in section 7.

II. RELATED WORK

Elitism was first proposed by De Jong in 1975 to ensure that the quality of the best individual does not decrease from one generation to the other [3]. Elitism provides a means for reducing genetic drift by ensuring that the best chromosomes are allowed to pass or copy their traits to next generation.

Mating systems differ from species to species in environment and vary due to different reproductive adaptations in varying ecological conditions. Polygamy is a mating system in which a single individual of one gender mates with to several individuals of opposite gender to produce offsprings. Polygamy is found to be beneficial genetically in various species [4]. Polygyny is a form of polygamy in which one male mates with several females. This type of polygamy is commonly seen in various species like elk, fur seals, lion, dog, some baboons and many more. Polyandry is another form of polygamy in which female mates with more than one male during a breeding season, resulting in offsprings of more than one father. Honey bees are said to be polyandrous because a queen bee typically mates with multiple males. Mating between queen and a number of male bees provides the advantage of genetic diversity in the colony [4].

De Jong considered genetic algorithms in function optimization and applied it to various domains. He used five test problems. De Jong started with R1 model having three primary operators. De Jong introduced the elitist model (R2) to copy the best fit individual of previous generation to the next generation. The elitist model improved both offline and online performance. Dejong also combined R2 model with expected value model (R3) to form elitist expected value model (R4) and considerable improvement was observed in performance of four test functions [3].

Holland showed that both exploration and exploitation are used optimally by genetic algorithm at the same time using k-armed bandit analogy [3]. This work is also described by David Goldberg [2]. One problem with genetic algorithms is premature convergence which occurs when the population reaches a state where genetic operators can no longer produce offspring that outperforms their parents [Fogel 1994)]. This would likely trap the search process in a region containing a non-global optimum and would further lead to loss of diversity.

Ahn and Ramakrishna presented two elitism based CGAs by employing elitism in order to solve the problems associated with inadequate memory in the CGA by proposing persistent elitist compact genetic algorithm (pe-CGA) and non-persistent elitist compact genetic algorithm (ne-CGA). The two algorithms combined the existing genetic algorithm with elitism in an effective manner. The models were simulated and compared with SGA and CGA. It demonstrated that elitism improved the solution quality and enhanced the convergence speed. It was found that the two models could search the solution space effectively and speedily without comprising on memory and computational requirements [5].

Musnjak and Golub presented a new method of selection of individuals. The selected individuals for crossover are always member of elite group (n elite individuals) currently in population as per modied 3-tournament selection. They performed the experiments on multiprocessor scheduling problem and the results achieved by this method were better than the earlier simple version of tournament selection [6]. Zhong et al presented the comparison of performances of different selection operators by using SGA on 7 test functions with same crossover and mutation. The simulation results were compared and results showed that SGA with tournament selection strategy converged faster than roulette wheel selection [7].

Francisco B. Pereira and Jorge M. C. Marques had proposed an improved elitism strategy to be applied in hybrid evolutionary algorithm for cluster geometry optimization. Structural elitism allowed preservation of certain diversity in the population and is based on classification of clusters as spheric, oblate, prolate or asymmetric according to their shape. The algorithm was simulated for global optimization of more clusters and results showed that structural elitism enhanced the ability of the algorithm to discover global minima [8].

Gu Min and Yang Feng proposed an improved genetic algorithm based on polygymy – one father , many mothers and some bachelors. Crossover occurs between father and mothers. Mutation occurs among bachelors. The function optimization results show that the proposed algorithm has higher convergence speed and alleviates the problem of premature convergence[9]. Cheng et al described a pattern discovery algorithm for multistreams mining in wireless sensor networks. The algorithm chose elite method of selection. Elitism involved copying a small part of the fittest individuals, unchanged into next iteration. Simulated results showed that introduction of elitism reduced the reconstruction error and decreased the number of hidden variables which supported multistreams mining in WSNs [10].

III. NOTATIONS

Some of the symbols and notations used in the algorithms are listed below:

ngen → total number of generations
nogen → current number of generation
n → total population size
F_j → fitness of jth individual in population
r_j → rank of jth individual in population
$rsum_i$ → sum of ranks in i^{th} generation
mpool → number of chromosomes in mating pool
F_{best} → Best Fitness i.e. minimum value of tour length in TSP
F_{avg} → Average Fitness of the population
FX_j → fitness of jth individual in Annealed Selection

IV. SELECTION AND POLYGAMY

Selection operation is the primary operation in genetic algorithm. It is used to choose the best fit individuals in the population to create the mating pool. Individuals in the mating pool will participate in further genetic operations to create the next generation of population. The next generation of population is created with a hope to reach the optimal solution. Selection of individuals in the population is fitness dependent and is done using different algorithms [11]. Selection chooses more fit individuals in analogy to Darwin's theory of evolution – survival of fittest [12]. Too strong selection would lead to sub-optimal highly fit individuals and too weak selection may result in too slow evolution [13]. There are many methods in selecting the best chromosomes such as roulette wheel selection, rank selection, steady state selection and many more. The paper reviews roulette wheel selection, rank selection and annealed selection operator [14] and then effect of these selection operators in combination with the proposed polygamy selection has been observed. Polygamy is special case of selection and has biological evidences in natural evolution. The paper would compare the performance of genetic algorithm using six different selection criteria namely roulette wheel selection, rank selection, annealed selection, polygamy with roulette wheel, polygamy with rank selection and polygamy with annealed selection.

A. Roulette Wheel Selection

Roulette wheel is the simplest selection technique. In this technique, all the chromosomes in the population are placed on the roulette wheel according to their fitness value [3,11]. Each individual is assigned a segment of roulette wheel whose size is proportional to the value of the fitness of the individual. The bigger the fitness value is, the larger the segment is. Then, the virtual roulette wheel is spinned. The individual corresponding to the segment on which roulette wheel stops is then selected. The process is repeated until the desired number of individuals is selected. Individuals with higher fitness have more probability of selection. It can possibly miss the best individuals of a population at certain times. There is no guarantee that good individuals will find their way into next generation. Roulette wheel selection uses exploitation technique in its approach.

The average fitness of the population for any generation in roulette wheel selection is calculated as

$$F_{avg} = \sum^{N}_{j=1} F_j / \ N \qquad (1)$$

where j varies from 1 to N.

B. Rank Selection

Rank Selection sorts the population first according to fitness value and ranks them. Then every chromosome is allocated selection probability with respect to its rank [15]. Individuals are selected as per their selection probability. Rank selection is an explorative technique of selection. Rank selection prevents too quick convergence and differs from roulette wheel selection in terms of selection pressure. Rank selection overcomes the scaling problems like stagnation or premature convergence. Ranking controls selective pressure by uniform method of scaling across the population. Rank selection behaves in a more robust manner than other methods[16,17].

In Rank Selection, sum of ranks is computed and then selection probability of each individual is computed as under:

$$rsum_i = \sum^{N}_{i=1} r_{i,j} \qquad (2)$$

where i varies from 1 to ngen and j varies from 1 to N.

$$PRANK_i = r_{i,j} / rsum_i \qquad (3)$$

C. Annealed Selection

The annealed selection approach is to move the selection criteria from exploration to exploitation so as to obtain the perfect blend of the two techniques. In this method, fitness value of each individual is computed as per the current generation number [14]. Selection pressure is changed with changing generation number and new fitness contribution, FX_i of each individual is computed. Selection probability of each individual is computed on the basis of FX_i .

The proposed blended selection operator computes fitness of individual depending on the current number of generation as under:

$$FX_i = F_i / ((ngen+1) - nogen) \qquad (4)$$

D. Proposed Polygamy with Selection

In the proposed polygamy with selection operation, the best fit individual of the population is treated as one parent for crossover operation. The other parent for crossover is selected using any of the three selection methods discussed earlier. The best fit individual in the current generation would act as one parent in all the crossover operations to create the next generation. This approach is based on the biological fact that selecting the most fit parent would lead to fitter offsprings for the next generation. This technique can be referred to as special case of elitism. Here, the best individual is not copied as such but used in mating to extract the best features of the individual.

V. ALGORITHMS

In order to analyze the performance of proposed polygamy operator, the performances of followings have been compared: (i) GA using Roulette wheel selection, (ii) GA using Rank selection, (iii) GA using annealed selection, (iv) GA using polygamy with roulette wheel selection, (v) GA using polygamy with Rank selection, (vi) GA using polygamy with annealed selection. Here, c_i is variable storing cumulative fitness and r is random number generated between given interval.

A. Roulette wheel selection

```
Set l=1, j=1, i=nogen, S=0
 While j<=N  { S=S+F_{i,j}}
While l <= mpool
{
   Generate random number r from interval (0,S)
   Set j=1
   While j <= N
   {
   c_j=c_{j-1}+F_{i,j}
   If r<=c_j, Select the individual j
   }
   l=l+1
}
```

B. Rank Selection

```
 Set l=1, j=1, i=nogen
 While j<=N
 { rsum_{,I} =rum_j+r_{i,j} }
Set j=1
While j<=N
{PRANK_j=r_{i,j}/rsum_j }
While l <= mpool
{
      Generate random number r from interval (0,rsum)
      Set j=1, S=0
      While j<=N
     {
       c_j=c_{j-1}+PRANK_j
       If r<=cj, Select the individual j
     }
      l=l+1
}
```

C. Annealed selection

```
    Set l=1, j=1, i=nogen
    While j<=n
    {
       FX_j = F_j / ((ngen+1)-nogen)
       //compute fitness for annealed selection
    }
     Set j=1, S=0
     While j<=n
     {S=S+FX_j }
     While l <= mpool
     {
        Generate random number r from interval (0,S)
        Set j=1, S=0
        While j<=n
         {
             c_j=c_j-1+FX_j
             If r<=c_j, Select the individual j
         }
          l=l+1
      }
```

D. Genetic Algorithm implementing Selection

```
Procedure GA(fitfn, n, r, m,ngen)
//fitfn is fitness function to evaluate chomosomes
// n is population size in each generation (say 100)
// r is fraction of population generated by crossover (say 0.7)
// m  is mutation rate ( say 0.01)
 //ngen is total number of generations
   P := generate n individuals at random
    // initial generation is generated randomly
   i:=1
  //define the next generation S  of size n
   while i <=ngen do
   {    //Selection step:
          L:= Select(P,n)
         // n/2 individuals of P will be selected using any of
        // the three selection methods
         //Crossover step:
          S:= Crossover(L,n,r)
        //     Generates   n   chromosomes   with   crossover probability
        //r using PMX crossover
         //Mutation step:
             Mutation(S,m)
        //Inversion of chromosomes with  mutation rate m
        //Replacement step:
             Replace(P,S,n)
               //Replaces old population using
              //generational replacement
            pb(i):=min(fitfn(P))
           // store best individual in population
              i:=i+1
    }
    best:=min(pb)
  //finds best individual in all generations
end proc
```

E. Genetic Algorithm implementing proposed Polygamy with selection

```
Procedure GA(fitfn, n, r, m,ngen)
//fitfn is fitness function to evaluate chomosomes
// n is population size in each generation (say 100)
// r is fraction of population generated by crossover (say 0.7)
// m  is mutation rate ( say 0.01)
 //ngen is total number of generations
   P := generate n individuals at random
  // initial generation is generated randomly
   i:=1
  //define the next generation S  of size n
   while i <=ngen do
   {    //Selection step:
   k1:=min(fitfn(P))
   // best individual selected to be one parent  for polygamy
            L:= Select(P,n)
             // n/2 individuals of P will be selected using any of
            // the three selection methods
        //Crossover step:
         S:= Crossover(L,k1,n,r)
        //  Generates n chromosomes with crossover
        // probability r  using PMX crossover between
       //  k1 and L
        //Mutation step:
            Mutation(S,m)
        //Inversion of chromosomes with  mutation rate m
       //Replacement step:
            Replace(P,S,n)
        //Replaces old population using
        //generational replacement
          pb(i):=min(fitfn(P))
         // store best individual in population
             i:=i+1
    }
    best:=min(pb)
    //finds best individual in all generations
end proc
```

VI. IMPLEMENTATION AND OBSERVATION

In this paper, MATLAB code has been developed for assessing genetic algorithm considering the Travelling Salesman Problem (TSP) as the test problem. The problem is to find the shortest tour or Hamiltonian path through a set of N vertices so that each vertex is visited exactly once [18]. The code uses the same initial population, same crossover and mutation probability and PMX crossover operation in all the selection cases to compare the performance of genetic algorithm in each case. Only the selection operator is changed. Six different cases of selection have been considered - roulette wheel selection (RWS), rank selection (RS), annealed selection (AS), polygamy with roulette wheel (PRWS), polygamy with rank selection (PRS) and polygamy with annealed selection (PAS).

The test problem has been considered for four different problem sizes (PS) – 10 cities, 20 cities, 50 cities and 100 cities. The solution was run for 100 generations and performance was compared in terms of minimum tour length and average tour length.

Average and minimum tour length in each generation was plotted to compare the performance of six different approaches. Figure 1 depicts the comparison of average tour length F_{avg} and Figure 2 depicts the comparison of minimum tour length F_{best} in six different selection methods for 50 cities.

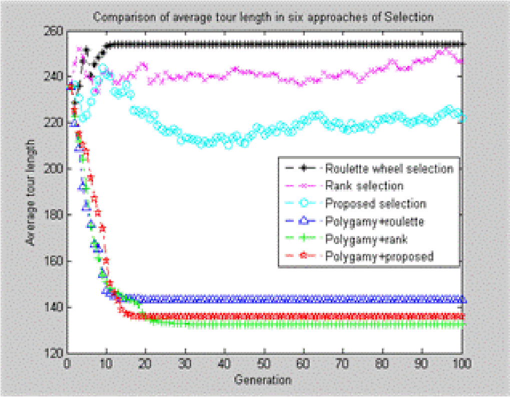

Fig. 1. Average Tour Length vs Generation

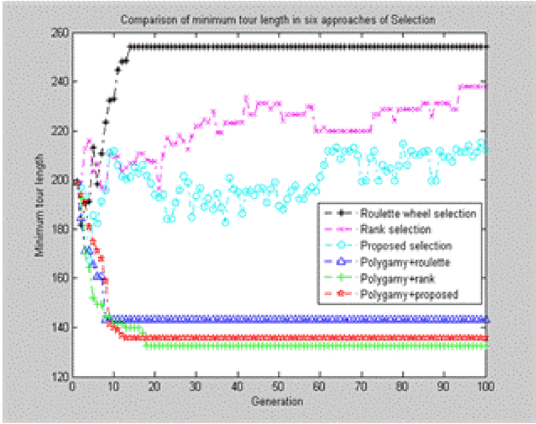

Fig. 2 Minimum Tour Length vs Generation

Table 1 : Comparison of Six Selection Approaches

PS	***RS***		***RWS***		***AS***		***PRS***		***PRWS***		***PAS***	
	$\mathbf{F_{best}}$	F_{avg}	$\mathbf{F_{best}}$	F_{avg}	$\mathbf{F_{best}}$	F_{avg}	$\mathbf{F_{best}}$	F_{avg}	$\mathbf{F_{best}}$	F_{avg}	$\mathbf{F_{best}}$	F_{avg}
100	404.43	519.46	424.78	513.52	413.55	493.72	342.83	353.44	338.49	345.73	358.03	363.45
50	196.09	241.79	181.72	252.95	167.6	220.94	132.58	139.17	143.13	147.39	135.65	142.36
20	68.43	105.73	71.94	92.97	62.08	82.84	47.49	49.24	56.62	60.74	56.29	57.29
10	25.83	48.42	22.05	48.55	25.83	43.25	25.83	26.38	22.19	22.9	20.15	25.98

Table 1 lists the detailed data for four different problem sizes and various parameters to analyse performance of the six methods. Comparison of F_{avg} in each case is presented in Figure 3 and comparison of F_{best} in Figure 4.

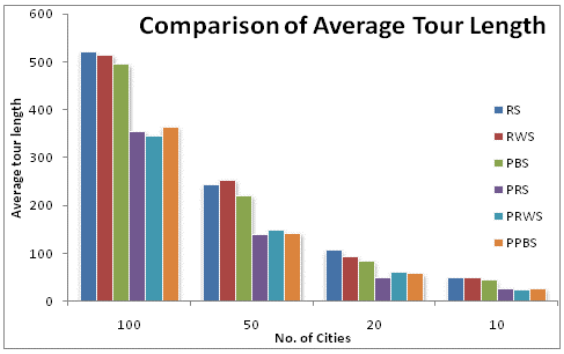

Fig. 3. Comparison of Average tour Length

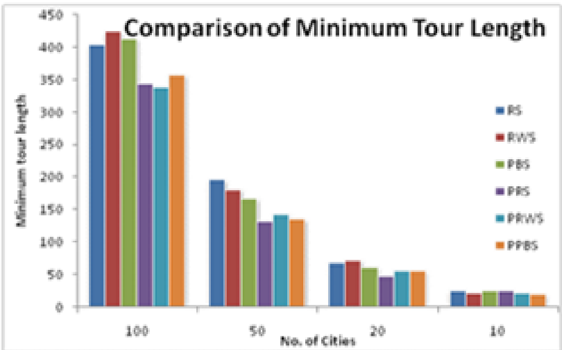

Fig. 4 Comparison of Minimum Tour Length

It was observed that the annealed selection is more promising of the considered selection methods. Roulette wheel selection had more of exploitation approach and converged earlier than rank selection. On the contrary, rank selection had more of exploratory nature and kept on exploring new solutions. In case of annealed selection, Favg and Fbest reduced gradually with increasing number of generation. In early runs of generation, the annealed selection showed exploratory nature and with increasing generation, it had exploiting nature and converged to find the better solution. Further, when polygamy was combined with these selection methods, the results drastically improved. It was observed that polygamy helped in getting better results than simple selection techniques. It is clear from the Figure 1 and Figure 2 that annealed selection performs better than the other two selection methods and polygamy is beneficial in addition to the selection method. Further, figure 3 and figure 4 show the comparison of results for different number of cities. It has been found that with increasing problem size, problem did not converge prematurely and the same trend of results is observed in each problem size.

VII. CONCLUSION

In genetic algorithm as

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well as in nature, the selection of individuals on the basis of some fitness function to create the mating pool is the key of evolution. A number of selection mechanisms has been observed in nature and accordingly implemented as such in genetic algorithms and some time with some modification. In the nature, polygamy has been observed as a mating system in a number of animals like elk, fur seals, baboons etc. and has been shown by the scientist that it results in evolution. This motivated the authors to imitate the polygamy behavior in genetic algorithm. Results found were promising and show the improvement over other selection operators. The proposed solution has been implemented on TSP problem but the authors are of the opinion that more work should be carried out on other problems to further substantiate the results.

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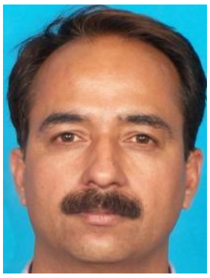

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