Sexual Selection: Furthering the "Evolution" Metaphor

Cynthia Ma

5/9/2014

Abstract

Computational evolution is based on biological evolution, primarily using the features of natural selection including heritable traits, standing variation, selection pressure, and mutations and crossovers. However, a major driving force behind the diversity and complexity of the natural world is sexual selection. Previous research has explored the use of gender groups and differing mate choice to result in diversity during computational evolution. This study focuses on exploring a different aspect of sexual select - the need to evaluate fitness before the end of an individual's lifespan.

1 Introduction

Biological evolution is 'descent with modification' [11]. Successful evolution is dependent on a series of factors and mechanisms, including the presence of a selecting pressure, standing variation in a population, and the ability for offspring to inherit traits that are selected for.

Computational evolution is based on this natural phenomenon. A genetic algorithm might start with an initial population of random samples of whatever structure a programmer wishes to develop. Each individual is evaluated with a fitness function, and the better examples create the next generation through simple processes also borrowed from biology - mutation and crossover. Repeatedly, this continues until a sufficiently 'fit' individual is produced to solve whatever problem had been the original goal [5]. Successful evolution here also depends on many variables, including the presence of a selecting pressure, standing variation in a population, and the ability for offspring to inherit traits that are selected for.

An incredibly important driving force of the awe-inspiring diversity and complexity of the natural world, however, is sexual selection [11]. If biological evolution were simulated with a genetic algorithm, it might make the most sense to calculate fitness by how long an individual manages to survive. In reality, however, an individual's chance to pass on its traits to the next generation is not solely dependent on its ability to find sufficient food and escape predators. In sexual species, it is necessary to attract or select a mate, and preferably a fit mate to give the offspring a fitness boost. This mating condition highlights the main difference between selection in biological evolution and selection in computational evolution: in the real world, the 'choice' to create offspring for the next generation must be made before 'fitness' is known.

The ability to attract a mate is an individual's sexual fitness, and whether or not a species manages to survive depends on whether or not sexual fitness is an indicator of survival fitness. Sexual fitness can be positively correlated, negatively correlated, or not correlated at all with survival fitness. The hypothesis, then, is that sexually selecting for a trait that is positively correlated with survival fitness will result in similar improvements to survival fitness as traditional selection, sexually selecting for a trait that is negatively correlated with survival fitness will result in decreased survival fitness, and sexually selecting for a trait that is not correlated with survival fitness will result in survival fitness stabilizing around mating age.

A great deal of experimentation is still being done to explore and improve the capabilities of computational evolution. This study attempts to model some of the simpler logistics of sexual selection using the genetic algorithm of NEAT.

2 Background

2.1 Sexual Selection

It may not initially be obvious why it would be advantageous to include sexual selection in a genetic algorithm. Being able to know actual survival fitness before choosing 'parent' individuals seems like a benefit over the alternative of evaluating sexual fitness at some earlier, mating age. Some examples of sexual selection in biological evolution may better illustrate the possibilities of sexual selection in computational evolution.

A common example of the consequences of sexual evolution is the peacock tail. While it is aesthetically pleasing, it is rarely a goal of computational evolution to develop such large ornamental features that handicap survival fitness as the peacock tail must by attracting predators. However, it is theorized that these handicaps in biological evolution are indicators of an individual's quality. The logic is that if a male peacock survives to mating age despite being handicapped, he must be 'fit' in some other, less noticeable, fashion [12]. The greater the handicap, the greater a male peacock's innate survival traits must be to compensate. In certain situations, then, it may be plausible to computationally evolve such handicaps to add pressure for increased fitness in other areas, before simply removing the handicap from the end result.

While a 'handicap module' can be removed from a product like robot architecture, it's not likely to work on something like an artificial neural network (ANN). Sexual selection doesn't only result in handicap traits, however. A stag's large antlers, for example, are sexually selected for through male-male combat and female choice. In rare situations, such large antlers may also greatly improve survival fitness by driving off predators. Such events may not occur often enough to pressure selection for large antlers, but the sexual selection pressure is sufficient. Replicating this kind of logic in a genetic algorithm may be useful regardless of the structure being evolved.

2.2 Previous Research

There has been previous research into the use of sexual selection in computational evolution. As early as 1994, Miller presented the possible applications of sexual selection in computational problems [6]. In 1995, Miller and Todd explored the theoretical arguments that sexual selection can result in faster evolution, greater diversification and speciation, and more complexity [7].

In 1997, Ratford et al. used sexual selection to evolve multiple, distinct solutions during a single run of evolution [8]. Their experiments were successful, though it was also found that using sexual selection may interfere with the simultaneous use of other methods for diversification. In 2003, Sanchez-velazco simulated gender groups with their own partner-selecting criteria to delay convergence and expand search-scope [10]. In 2007, Drezewski and Cetnarowicz used a sexual selection mechanism "to introduce and maintain a useful population diverisity" [1].

Leitao and Machado have explored the possibilities of using mate choice to evolve fitness functions, which often conveys better results than a single, hardcoded fitness function [4, 3]. Each individual has its own fitness, but also some fitness function or problem solution that indicates its mate preference. Poor evaluation of mates results in unfit offspring that do not pass on their mate preference, eventually leading to better fitness functions that select for more fit individuals during the same run of evolution.

All of the above uses sexual selection by taking advantage of the inherent diversity that results from gender groups, whether or not they are explicitly considered 'female' and 'male' groups. This study removes the concept of 'sex,' using the NEAT algorithm to maintain diversity. Instead, this study explores the logic and the consequences of evaluating individuals with a sexual fitness, rather than survival fitness.

2.3 NEAT

NeuroEvolution of Augmenting Topologies (NEAT) is a method for evolving neural networks [9]. It starts with a population of ANNs like most neuro-evolution methods, but the starting population includes only simple ANNs with no hidden nodes. As evolution progresses, not only are edge weights changed, but nodes and new edges may be added, and topographies of two individual 'parents' can be crossed over to create a new individual for the next generation. Additions are numbered and kept track of in the genotypes of individuals that record nodes and edges for effective recombination. Since complexified ANNs may initially do more poorly than simpler ANNs that have already evolved effective edge-weights, similar ANNs speciate to preserve a limited diversity of ANN topographies and allow more complex ANNs the chance to evolve to their full potential [9].

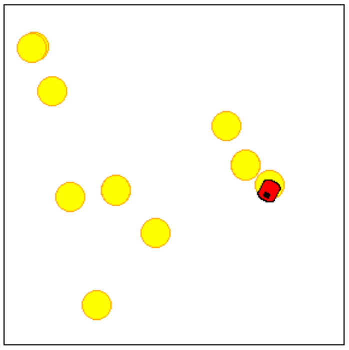

Figure 1: An example starting point of the world used for the Pyrobot simulation. The pioneer robot is set randomly in the world. There are a total of ten lights, also randomly placed, for the robot to "eat".

3 Experiments

All experiments were conducted using Pyrobot simulation to evaluate ANNs. A pioneer robot and ten lights are placed randomly in a world (Figure 1). In this world, the robot starts with 20 units of energy, and living costs 0.3 units per time step. To continue surviving, the robot must run over the lights, 'eating' them for 10 additional units of energy, each.

The structure evolved is a controlling ANN. There were three input nodes: data from two light sensors and a warning flag. The warning flag is a value normalized between 0 and 1 when energy is below 10, and 0 otherwise. There were two output nodes: motor speed and motor rotation.

Fitness evaluations were done on data collected over the course of three trials. Survival fitness was defined as the number of time steps the robot manages to survive. Sexual fitness was experimentally modeled three times with different traits: lights eaten before mating age, area of the world explored before mating age, and motor speed at mating age.

In all experiments, a population of 20 was evolved with the following parameters: probablity to add a connection is 0.05, probability to add a node is 0.03, probability to mutate was 0.2. The first part of each experiment was evolving 300 generations using the survival fitness. The population from generation 50 was then re-run for 250 generations using a sexual fitness. Both sexual fitness and survival fitness were recorded throughout all runs.

3.1 Traditional selection on survival fitness

In each of the three trials an individual recieves, the number of time steps it manages to survive is divided by the maximum number of time steps it can survive, which is calculated by the simple equation:

(initialEnergy + foodEnergy*numFood) * numTrials

In this experiment, the maximum number of time steps to survive is 1200. Robots are allowed to do whatever they wish with their time, and 'die' when their energy hits 0. If a robot stalls against the edges of the world, however, the trial is terminated and the robot 'dies.'

3.2 Sexual selection on lights eaten

Mating age is defined as 175 time steps into a single trial, which is a survival fitness of 0.5. The number of lights eaten before mating age during each trial was summed and divided by the total number of lights available. This value was then used as an individual's sexual fitness.

3.3 Sexual selection on area traveled

Mating age is 175 time steps into a single trial. The world is divided into a 10x10 grid and the number of blocks visited before mating age during each trial is summed and divided by the total number of blocks possible to visit. This value was used as an individual's sexual fitness.

3.4 Sexual selection on motor speed

Mating age is 175 time steps into a single trial. The motor speed at mating age during each trial was summed and divided by the number of trials, and used as an individual's sexual fitness. Because it is possible to have negative motor speeds when the robot is moving backwards, this is the only experiment where sexual fitness is not normalized between 0 and 1. Rather, the full range of motor speeds between -1 and 1 is used.

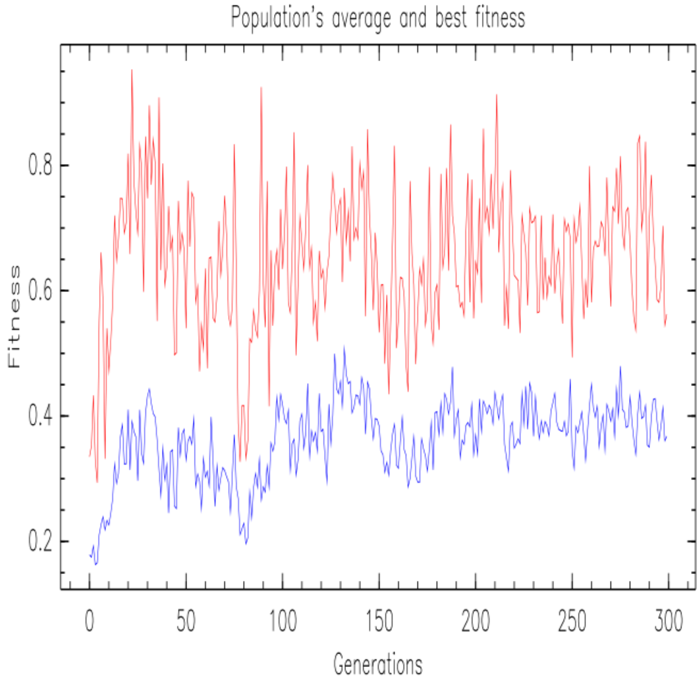

Figure 2: The best (in red) and average (in blue) fitness of a sample run with NEAT using traditional selection for 300 generations. Survival fitness is defined as how many time steps an individual can survive, normalized by dividing by the maximum number of time steps.

4 Results

4.1 Traditional selection on survival fitness

In survival fitness based evolution, average fitness fluctuated between 0.2 and 0.4 during the first hundred generations. After generation 150, average fitness usually stabilized around 0.4. In this particular run (Figure 2), the fitness of the best individual occasionally peaked above 0.9, although average fitness barely surpassed 0.5 once around generation 120.

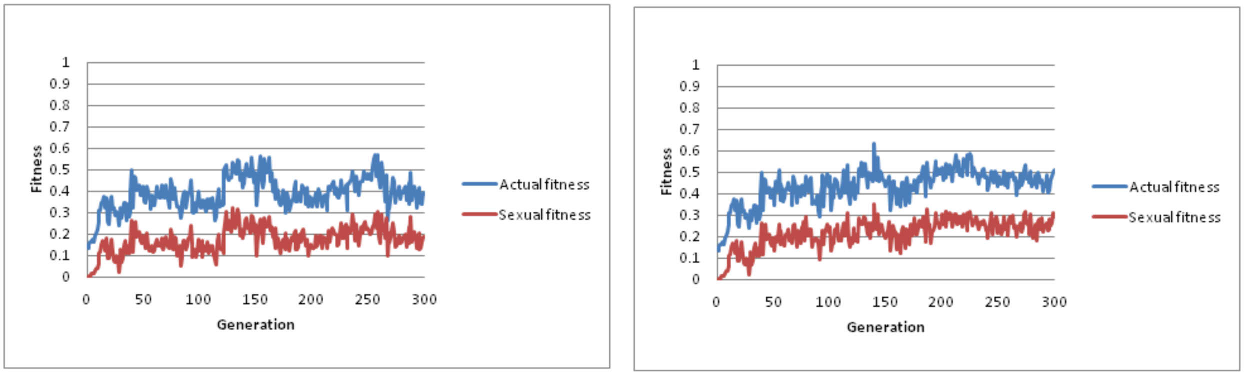

Figure 3: Left: A single run of NEAT for 300 generations using survival fitness, referenced as "actual fitness" in the charts. In blue is the average survival fitness of the population during evolution, and in red is the average sexual fitness. Survival fitness is defined as timesteps survived and sexual fitness is defined as number of lights eaten before mating age of 175 timesteps, both normalized between 0 and 1. Note the high correlation between the two. Right: A single run of NEAT where the first 50 generations used survival fitness and the next 250 generations used sexual fitness. Note the similarity in fitness between this graphs the one above.

4.2 Sexual selection on lights eaten

During traditional selection, it can be seen that sexual fitness as evaluated by the number of lights eaten before mating age is positively correlated with traditional fitness (Figure 3, chart 1). The average survival fitness of individuals continued to improve at least at the same rate during sexual selection as during traditional selection (Figure 3, chart 2). In fact, the survival fitness during sexual selection is arguably better than the survival fitness during traditional selection. In the latter, average survival fitness never surpassed 0.6, fluctuating mostly around 0.4. In the former, average survival fitness peaked above 0.6 just before generation 150, and fluctuated mostly around 0.5.

4.3 Sexual selection on area traveled

During traditional selection, the sexual fitness barely rose above 0, showing no clear correlation between survival fitness and sexual fitness (Figure 4, chart 1). During sexual selection, the sexual fitness arguably improved, but survival fitness continued to fluctuate around 0.4.

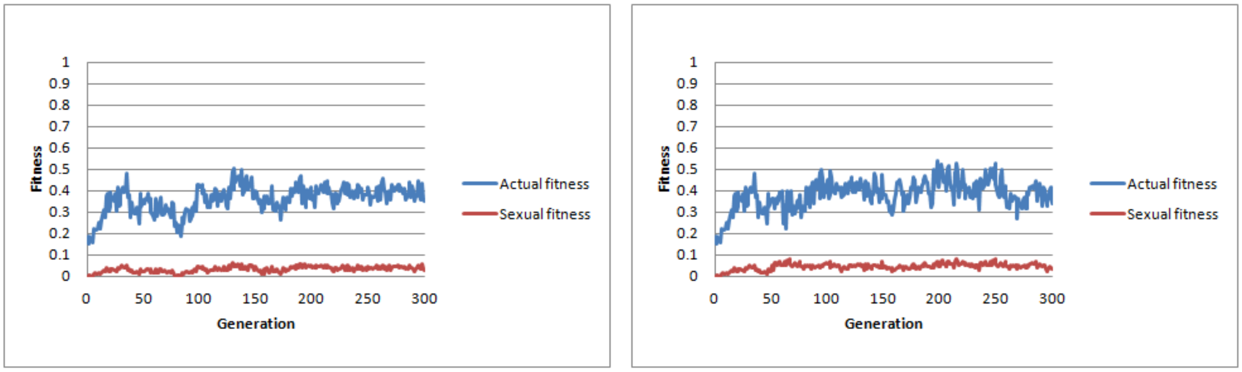

Figure 4: Left: A single run of NEAT for 300 generations using survival fitness, referenced as “actual fitness” in the charts. In blue is the average survival fitness of the population during evolution, and in red is the average sexual fitness. Survival fitness is defined as timesteps survived and sexual fitness is defined as number of blocks visited before mating age of 175 timesteps when the world is divided by a virtual 10x10 grid. Both fitnesses are normalized between 0 and 1. Right: A single run of NEAT where the first 50 generations used survival fitness and the next 250 generations used sexual fitness.

4.4 Sexual selection on motor speed

During traditional selection, there is a negative correlation between survival fitness and sexual fitness (Figure 5, chart 1). The longer a population manages to survive, the faster the backwards movement individuals of that population have at mating age. The change in selection increases sexual fitness into positive values, but survival fitness first drops to 0.2, then increases to almost 0.6 for approximately a hundred generations, before it drops down below 0.4 (Figure 5, chart 2).

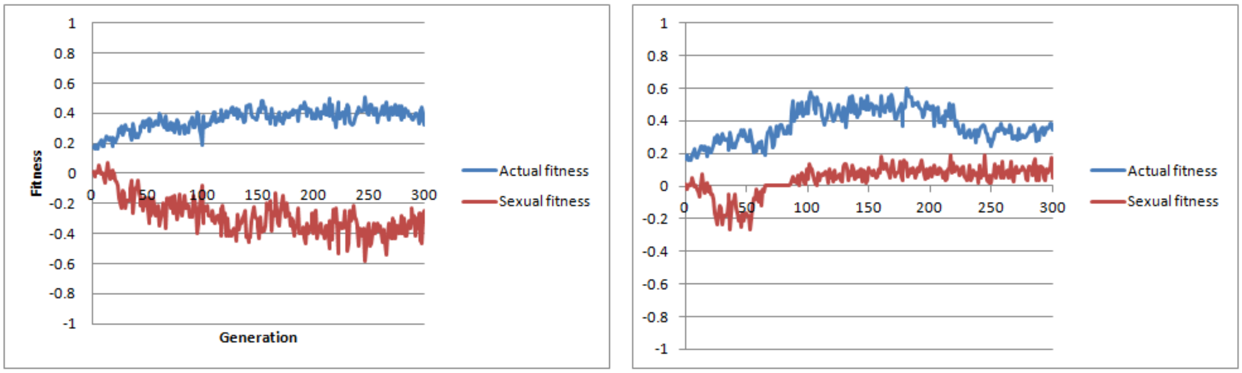

Figure 5: Left: A single run of NEAT for 300 generations using survival fitness, referenced as “actual fitness” in the charts. In blue is the average survival fitness of the population during evolution, and in red is the average sexual fitness. Survival fitness is defined as timesteps survived and sexual fitness is defined as motor speed at mating age of 175 timesteps. Survival fitness is normalized between 0 and 1, but sexual fitness ranges between -1 and 1, where negative values indicate the backwards movement of the robot. Note the negative correlation between survival fitness and sexual fitness. Right: A single run of NEAT where the first 50 generations used survival fitness and the next 250 generations used sexual fitness.

5 Discussion

The three models of sexual selection chosen here cover three possible correlations between survival fitness and sexual fitness: positive, negative, and none. It was hypothesized that sexually selecting for a trait positively correlated with survival fitness would result in similar improvements to survival fitness as traditional selection, sexually selecting for a trait negatively correlated with survival fitness will result in decreased survival fitness, and sexually selecting for a trait not correlated with survival fitness will result in survival fitness stabilizing around mating age.

Positive correlation was found in the sexual trait of lights eaten before mating age and survival fitness. This makes sense, as the more lights eaten, the more energy an individual has, which should result in more timesteps survived provided the robot doesn't end of stalling and 'dieing' early.

The hypothesis for this scenario, then, is that survival fitness would reflect traditional selection. However, survival fitness improved more during sexual selection than during traditional selection (Figure 3). While the reason for this cannot be determined conclusively, an explanation can certainly be theorized. From the high correlation between survival fitness and sexual fitness, it can be argued that eating lights during the first 175 timesteps of an individual's lifespan is crucial to survival fitness. Thus, by selecting directly for this trait, other factors that may expand the search space unnecessarily are ignored. The sexual fitness improved more during sexual selection, resulting in improved survival fitness.

While more studies are needed to fully explore the scenario of positively correlated sexual fitness and survival fitness, the idea that a primary objective (survival fitness) can be more efficiently pursued by evaluating for a secondary objective (sexual fitness) could have potential in other applications. The concept is a little like the idea of using stepping stones to reduce search space.

No correlation was found in the sexual trait of area traveled before mating age and survival fitness. This was initially an unexpected result, since it would make sense that traveling more would result in more lights eaten, a trait that is positively correlated with survival fitness. However, as the lights are not evenly scattered across the world, nor located in approximately the same locations between trials and runs, more area traveled probably doesn't result in more lights eaten on a regular basis. Thus, the lack of correlation is logical.

For this scenario, it was hypothesized that there would be a stabilizing of survival fitness at mating age. However, while survival fitness centered around 0.4 for all 250 generations of sexual selection, it does so during traditional selection as well (Figure 4), making it difficult to differentiate between "stabilizing around mating age" and "reflecting traditional selection." In addition, mating age is 0.5, not 0.4. The latter point is easier to explain. In NEAT, individuals are not selected to create the next generation based solely on their fitness. Newer species are given a certain amount of leeway, resulting in lower average population fitnesses than might be expected, but greater population diversity. The former problem will likely require more testing in the future using a lower mating age.

Something to note, however, is how survival fitness was much more stable during the last hundred generations of traditional selection, and fluctuated greatly during the last hundred generations of sexual selection. A possible explanation for this is that focusing on the sexual trait would favor different behaviors than focusing on traits for long survival. These different behaviors may result in a down-swing of survival, at which point mating age becomes the greater selective pressure, favoring behaviors that allow the robot to live longer. This then results in an up-swing of survival fitness. This pattern may repeat indefinitely without convergence, or until the discovery of a set of behaviors that simultaneously maintain survival fitness and improve sexual fitness.

Further study of this scenario is needed. Should the original hypothesis be validated, there could be interesting applications of sexual selection for evolving complexity. The "mating age" can be replaced by a primary trait, the fitness of which a programmer wishes to maintain, while the sexual trait can be replaced by any secondary trait of which needs to be further evolved.

Negative correlation was found in the sexual trait of motor speed and survival fitness. Why this is can be explained in two parts. The negative values is a result of the behaviors NEAT tended to evolve. Robots would eat lights by approaching them with their rear end, so the majority of the time they were moving backwards with a negative motor speed value. The increase in absolute value of motor speed makes sense since moving faster means eating faster and gaining more energy before running out of reserves.

The hypothesis was that sexual selection would result in decreased survival fitness in this scenario. However, this isn't what occurred. While survival fitness stabilized around 0.4 during traditional selection, it first dropped to 0.2 after the introduction of sexual selection, climbed up to fluctuate around 0.5 for a hundred generations, before sinking to between 0.3 and 0.4. The initial drop was expected, but the brief period of better survival fitness than in traditional selection was unexpected. A possible explanation might be the introduction of new behaviors. With sexual selection pressuring for forward movement, robots are forced to approach lights with their front ends. This may actually be a better strategy for locating and eating lights that had previously been unexplored, perhaps because the backwards approach was a local maxima. However, as sexual selection continued to select based on motor speed, other traits necessary to prolong survival was ignored, possibly explaining the eventual decrease in survival fitness.

The idea that the jump in survival fitness is possibly attributed to new behaviors is reflective of the concept of novelty search [2]. By selecting against the fittest individuals in the population, the local maximum that the population was stuck on disappeared in a similar manner to how novelty search tries to elimate local maxima completely. While the resulting fitness values are interesting, there likely aren't many applications to take away from this scenario that wouldn't be better helped by novelty search

6 Conclusions

This paper summarized the results of a study modeling the effect of 'sexual' selection on survival fitness using the NEAT algorithm. In general, the use of traits that are positively correlated with survival fitness results in improvements on survival fitness between traditional selection and sexual selection. The use of less correlated traits did not move survival fitness far from mating age while sexual fitness increased. The use of negatively correlated traits resulted in eventual decreased survival fitness and increased sexual fitness, but with some interesting changes in the first few hundred generations. Possible future uses of sexual selection were suggested, but further study is needed.

References

[1] R. Drezewski and K. Cetnarowicz. Sexual selection mechanism for agent-based evolutionary computation. In Y. Shi, G. D. van Albada, J. Dongarra, and P. M. A. Sloot, editors, *Computational Science - ICCS 2007, 7th International Conference, Beijing, China, May 27 - 30, 2007, Proceedings, Part II*, volume 4488 of *LNCS*, pages 920–927, Berlin, Heidelberg, 2007. Springer-Verlag.

[2] Joel Lehman and Kenneth Stanley. Abandoning objectives: Evolution through the search for novelty alone. *Evolutionary Computation*, 19(2), 2011.

[3] António Leitão, Jose Carlos Neves, and Penousal Machado. A self-adaptive mate choice model for symbolic regression. In *IEEE Congress on Evolutionary Computation*, pages 8–15, 2013.

[4] Penousal Machado and António Leitão. Evolving fitness functions for mating selection. In Sara Silva, James A. Foster, Miguel Nicolau, Penousal Machado, and Mario Giacobini, editors, *Genetic Programming - 14th European Conference, EuroGP 2011, Torino, Italy, April 27-29, 2011. Proceedings*, volume 6621 of *Lecture Notes in Computer Science*, pages 227–238. Springer, 2011.

[5] Lisa Meeden and Deepak Kumar. Trends in evolutionary robotics. *Soft Computing for Intelligent Robotic Systems*, 1998.

[6] Geoffrey F. Miller. Exploiting mate choice in evolutionary computation: Sexual selection as a process of search, optimization, and diversification. In TerenceC. Fogarty, editor, *Evolutionary Computing*, volume 865 of *Lecture Notes in Computer Science*, pages 65–79. Springer Berlin Heidelberg, 1994.

[7] Geoffrey F. Miller and Peter M. Todd. The role of mate choice in biocomputation: Sexual selection as a process of search, optimization, and diversification. In Wolfgang Banzhaf and FrankH. Eeckman, editors, *Evolution and Biocomputation*, volume 899 of *Lecture Notes in Computer Science*, pages 169–204. Springer Berlin Heidelberg, 1995.

[8] Michael Ratford, Andrew Tuson, and Henry Thompson. An investigation of sexual selection as a mechanism for obtaining multiple distinct solutions. Technical report, 1997.

[9] Kenneth Stanley. Competitive coevolution through evolutionary complexification. *Journal of Artificial Intelligence Research*, 21, 2004.

[10] Jos Snchez-velazco. A gendered selection strategies in genetic algorithms for optimization. In *University of Bristol*, pages 217–223, 2003.

[11] Berkeley University. Understanding evolution, http://evolution.berkeley.edu/evolibrary/home.php.

[12] Amotz Zahavi. Mate selection - a selection for a handicap. *J. theor. Biol.*, 53, 1975.