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# Evolution of robot displacement and comparison between a quadruped and a hexapod model

## Abstract:

Evolution in general tends to alter the structure and function of organisms towards optimal performance. Using this foundation, one of the more fascinating aspects about Evolutionary Robotics is the ability to change some aspects of the robot and then be able to let evolution take its course and observe the final results. This can prove useful in situations where we want robots to be able to adapt to different environments.

For this project, I decided to work on the first research question and look at how morphology affects the evolution of gaits and their effectiveness depending on the robot's number of legs. The robots I used had the same neural network and optimizer, while one was quadrupedal and one was hexapedal. The optimizer and neural network were built in Python, and ODE was used to create a virtual simulation of the robots. The python code created a random matrix of weights for the synapses and these were passed on to ODE, where these values were used to determine how the motors would respond to environmental sensory input. The displacement of the robot from the point of origin after a certain amount of time was reported back to the optimizer and if this was an improvement of the previous trials it was kept, and mutations were made during each run. After running simulations for both robots over 500 generations on average, I found that there was no significant difference in the distance traveled, but in general the hexapedal robots reached a higher fitness faster, and then changed quite rarely, whereas the quadrupeds evolved more evenly.

## Introduction:

There has been a lot of research done with both quadruped and hexapod robots. One of the more interesting examples of quadruped robots is Boston Dynamic's *Big Dog,* which some claim it to be the most advanced in the world within its category. It is adapted to multiple terrains and can hold its balance in almost any environment, even while being pushed around. It might seem at first that a quadruped robot would not be as stable as one with more legs, but Big Dog is just one counterexample. In my evolutionary experiment I used a quadruped robot with one leg positioned on each of its sides, giving it radial symmetry and thus a better chance to balance itself.

One of the interesting things about legged locomotion is that many different gaits can be used, as opposed to locomotion through the use of wheels, which does not allow for many options. As the velocity of the robot increases, stability may decrease and there needs to be a tradeoff between the two. Evolutionary robotics solves this by evolving gaits that are more optimal and energy efficient, and studies have been done to find the best design for certain leg motion controllers. In one of these studies, Katsuyoshi Tsujita, Manabu Kawakami and Kazuo Tsuchiya looked at this using the phase difference among the oscillators as the optimization variable. Under a certain condition, they gait patterns that they obtained were trotting for a low speed locomotion and cantering for a high speed one. In another study, Nate Kohl and Peter Stone looked at machine learning for fast quadrupedal locomotion, using training done on physical robots, specifically the Aibo ERS-210A, a commercially available robot. They made a detailed empirical comparison of four different machine learning algorithms for learning quadrupedal locomotion and specified a fully automated environment in which this was accomplished. They used a genetic algorithm, an amoeba algorithm, a hill climber and a policy gradient, of which the last two yielded much better results, better than their best tuned manual walk. Even though the genetic algorithm and the amoeba algorithm are generally considered to be more sophisticated, they performed fairly poorly. They state in their paper that “One of the benefits of simple algorithms like the policy gradient algorithm and the hill climbing algorithm is that they could be considered a form of multi-robot learning, in that it would be relatively straightforward to implement these algorithms without the use of a central controller.”

Hexapod robots are those with six legs, and they are another type of robot frequently studied. Their larger number of legs allows for greater flexibility in motion. If evolved correctly, even if some of their legs are malfunctioning they should still be able to adapt, retain their stability and manage to perform the assigned tasks. Hexapod robots are have a similar design to hexapod organisms such as certain types of insects and the study of their mechanisms can help test theories on insect locomotion and function. Hexapods usually evolve to crawl, use quadrupedal locomotion or alternate having three legs on the ground at a time. As a generalization, they are more readily stable than quadrupeds and can have less difficulty navigating uneven terrain. In their study of biomimetic design and fabrication of a hexapedal running robot, J.E.Clark et al addressed the fact that even well designed hexapedal robots lack the robustness of naturally occurring hexapods. They studied these organisms and implemented their findings in their robots' design, control structure and leg configuration. They then proceeded to perform a series of tests over different terrains showing that the robots performance and robustness approached that of small animals.

## Materials and Methods:

To implement the study of the evolution and development of gaits in quadrupedal and hexapedal robots, Python and C/C++ in ODE were used. The hill climber and neural network were first created in Python. Following this, the robots were created in ODE, by building the body parts, adding joints, adding motors to those joints, and then actuating them. The synaptic weights in the robots originated from a random matrix of weights created in Python. This was sent to ODE, the simulation was run based on it, and the displacement of the robot was sent back to the Python program to be used as the fitness. In each run the original parental matrix was randomly mutated by 5%, and whichever variation had a higher fitness was retained.

The quadrupedal robot was radially symmetrical, with one leg on each of its sides (Fig 1). The ratio of its sizes was 0.75, 0.75, 0.55, for length, width and height. The diameter of the legs was 0.05 and the length of each component (lower and upper) was 0.75. The mass of the robot was set at 1.3. The hexapedal robot was bilaterally symmetrical, with three legs on each side(Fig 2). Its length was 2.0, width 1.0 and height 0.55. The diameter and length of the legs was the same as for the quadrupedal robot, as was the mass. There were 8 joints placed on the quadruped and 12 on the hexapedal robot, one between each upper and respective lower leg, and one between each upper leg and the main body. As is visible in the figures below, the hexapedal robot's body was larger in proportion to the length of the legs than was the quadruped's body, also adding to the robot's stability.

There were sensors on the lower legs of the robot that fired positively when they were in contact with the ground. Through a multiplication of the sensor values - 1 or 0 – with the values in the matrix of synaptic weights to the joints, actuation of the joints occurred. The difference was calculated between this desired angle and the current angle of the joint and it was moved accordingly.

The fitness of the robot was determined by measuring the distance it traveled within 1000 time steps. The x-coordinate of the main body was returned, and the higher this was, the higher the fitness of the robot.

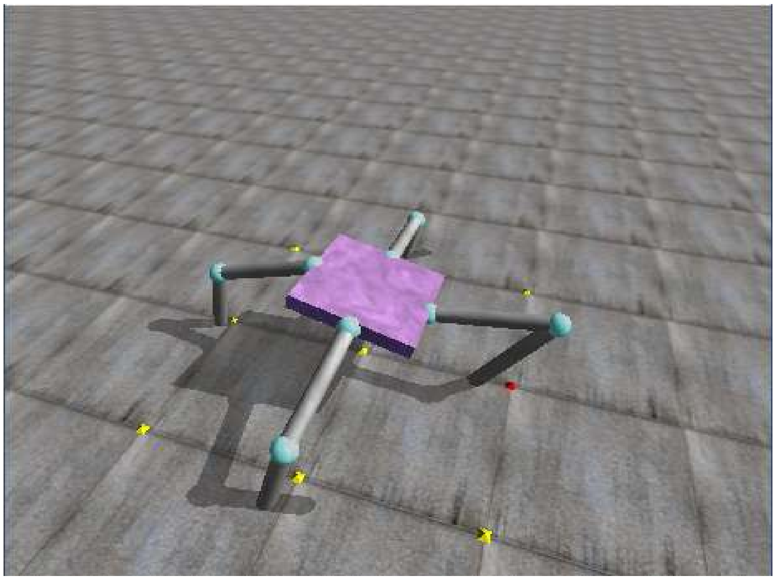

Figure 1: Quadrupedal Robot

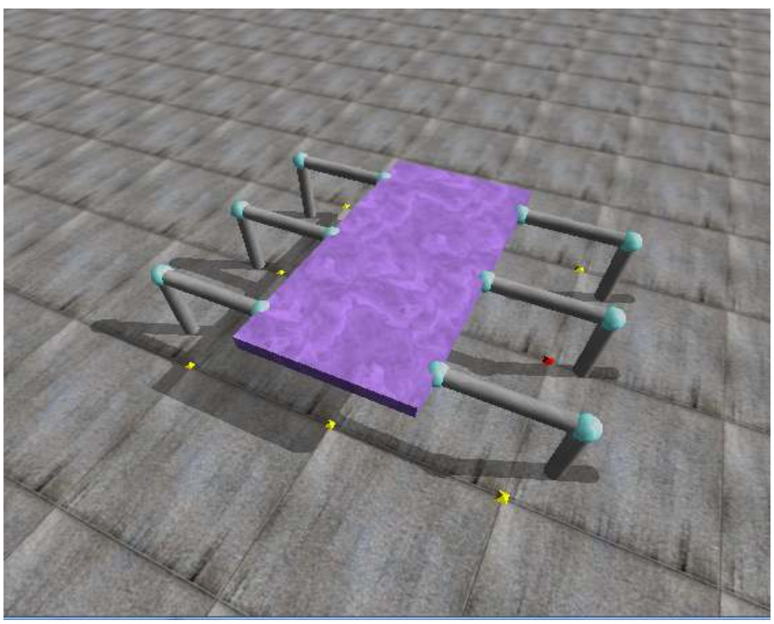

Figure 2: Hexapedal Robot

Due to mechanical difficulties with my computer, I was unable to run the simulation for more than a couple of hours, as it would crash. Therefore I performed multiple shorter experiments and noted the difference in the general development of the robots' gaits and the distances they traveled. Even though the simulations ran for a lot less than was ideal, I was still able to arrive to certain conclusions.

## Results:

Due to the mechanical difficulties I encountered, I only ran the simulations for a few hundred generations, 500 on average. Overall, I did not encounter significant differences between the distance attained by the two robots, they all averaged around 13, ranging from 8.0 to 15.9, with the hexapedal robot's distances being very slightly higher. Since the distance results were not conclusive, most likely due to the short runs, I decided to also look at the various gaits evolved by the robots.

With the quadruped robot I found that most of the time it resulted in a kind of galloping or skipping motion. On one occasion, it ended up using two of its legs (in the context of the direction it was moving in they would have been its side legs) to push itself forward (Fig 4), while at the same time using the front leg to pull and the back leg to propel itself. This movement was relatively effective compared to the others and it attained a displacement of 14.7. The original random motions of the quadruped were a lot less effective than those of the hexapod (Fig 3).

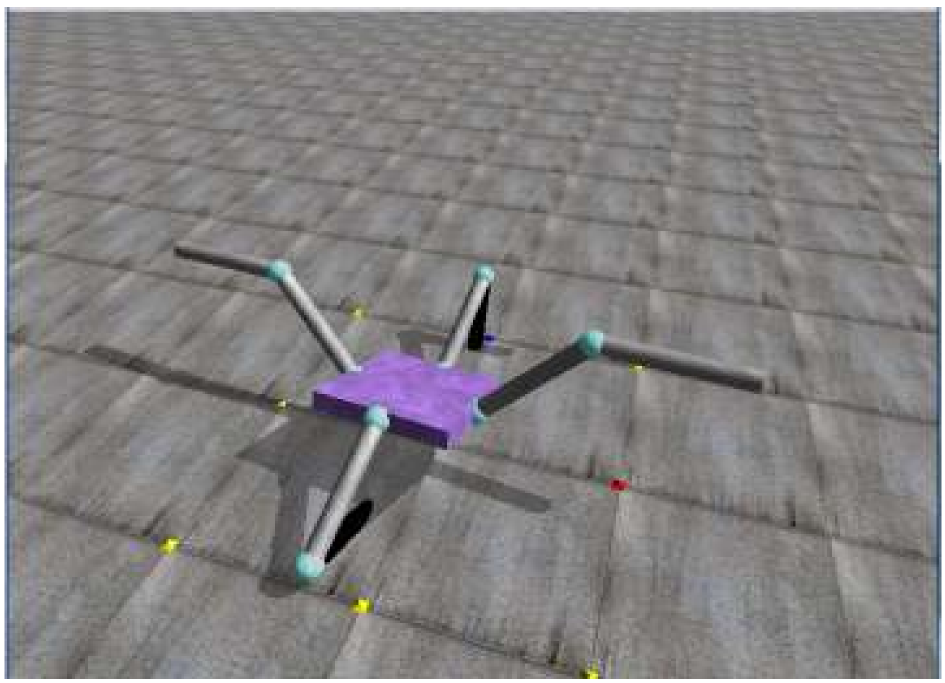

Figure 3: Random movement of the unevolved quadruped. This particular one was very ineffective as is did not move beyond lifting two of its legs.

Figure 4: Screenshot from the video capture of an evolved quadruped robot described above. The colors are negative due to the video capturing software.

The hexapodal robots developed a few different methods of displacing themselves. The majority of the time the movements of the robot resembled a crab walking sideways. Some times the legs on one side would move in unison, one side pushing and the other pulling. On one occasion, a centipede like motion resulted, with a wave staring on one side and moving up to the next set of legs, effectively displacing the robot forwards and sideways. When the hexapedal robot moved randomly (Fig 5), a lot of the time it had a significantly positive effect, causing the robot to evolve quite rapidly, but its improvement slowed down after a certain point, usually around 12 displacement units.

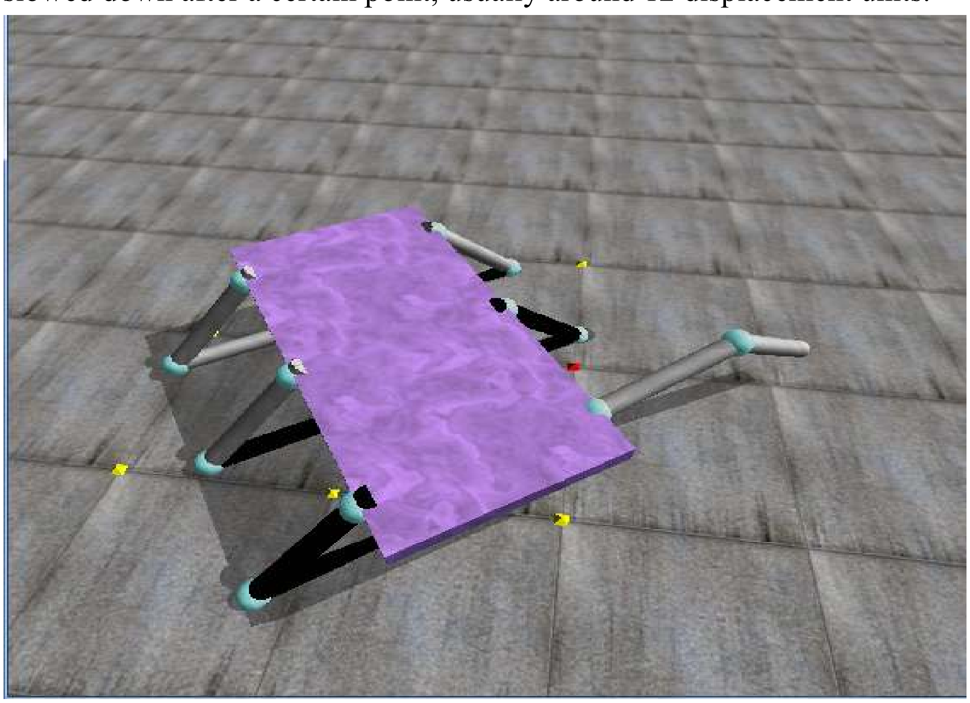

Figure 6: An example of a randomly behaving hexapedal robot. This particular robot's random movement was significantly worse than average, with all of its legs being underneath its body and not moving.

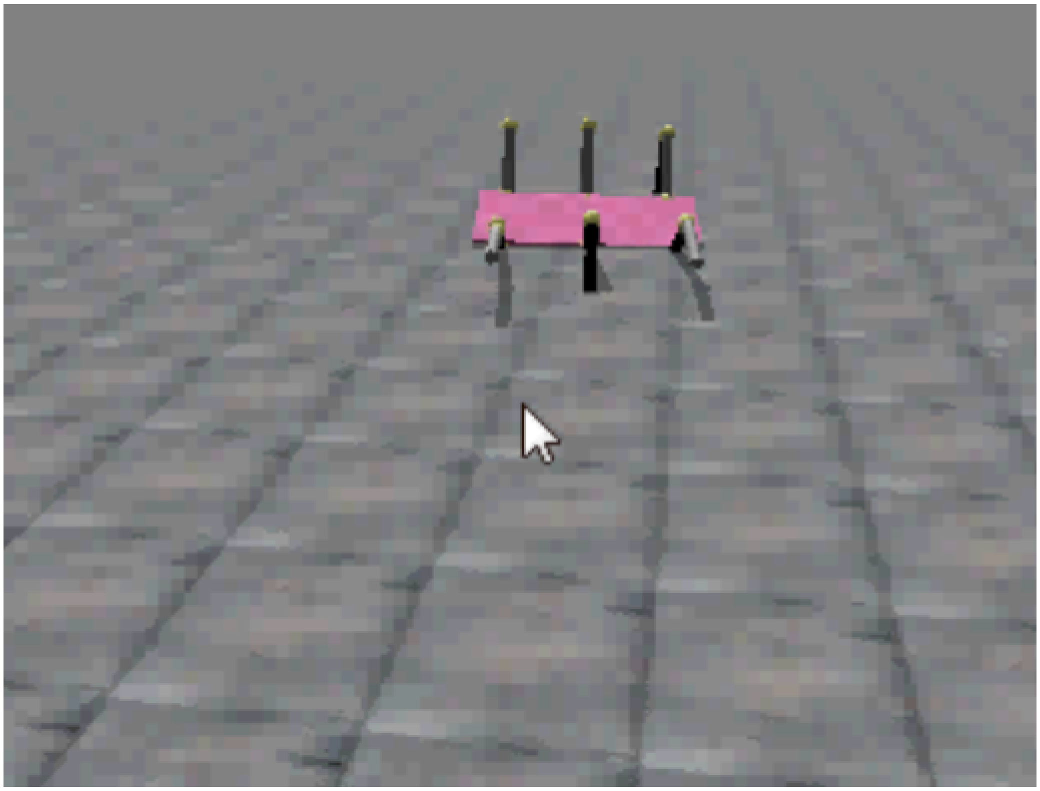

Figure 7: Evolved hexapedal robot. In this example the robot is moving the legs on each side in unison as it is moving away from the camera. The side in front is pulling it ahead while the side in the back is pushing it.

## Discussion:

I find one of the most interesting aspects about Evolutionary Robotics to be the mimicry of biological processes in the development of efficient techniques to carry out tasks. Natural evolution has taken billions of years and has resulted in very good solutions to the situations posed by organisms environments. Being able to use tools that drastically reduce this time and can show us efficient results according to different physiological and neural morphologies can not only prove useful in the developing field of robotics, but it can also help with our understanding of the world around us.

Even with this small experiment I was able to see vast differences in how different “organisms” carry out the same task. The result of the hexapedal robot's displacement was very similar to actual organisms such as insects and crabs, and it gives us hints as to why those species may have developed in the matter that they did. Even though the responses were all similar, there were different methods involved in completing the tasks, arising from different synapse weights. It is interesting to note that in bilaterally symmetrical hexapedal organisms a variety of types of movement also occurs, ranging from the sideways walk of the crab to the 360 degree movement of flies while on the ground. This is similar even in organisms with the same symmetry but a larger number of legs, such as the millipede, which display a wave like motion, and this was seen in one of the hexapedal evolved robots.

In the quadrupedal robots on the other hand, most of the time they evolved to use two legs to keep their balance on the side and the other two to push / pull themselves forward. This is not necessarily the most efficient way to get around and this may also be reflected in nature, where such a design does not readily occur. Most quadrupedal organisms naturally occurring display bilateral symmetry that allows them to efficiently displace themselves forward as well as keep a center of balance. As their speed increases though, their stability decreases and they have developed different gaits to deal with this. In the evolved quadrupedal robots, with increasing displacement / speed, they started using their two arms as support to keep their stability.

It would be very interesting to carry out a long term experiment where a variety of robots could be created and placed in different virtual environments. This could give us hints about what kinds of organisms we can expect to find in foreign environments, and could also help with the development of robots that can operate under any conditions. If such a robot were to be created it could be very useful in replacing human beings in hazardous conditions, or in being sent somewhere where it is simply impossible for us to go. In addition to the evolutionary aspect it could also be interesting to integrate artificial intelligence into the robots, and possibly create a small scale experiment in which a number of differently evolved robots could interact in a contained environment. If this was run for a sufficiently large period of time, we could potentially see a pattern emerging very similar to the world we live in. Overall I find Evolutionary Robotics to be an extremely interesting field that could be very useful in the future for environmental and scientific purposes.

## References:

Katsuyoshi Tsujita, Manabu Kawakami and Kazuo Tsuchiya. (2004) *A Study on Optimal Gait Pattern of a Quadruped Locomotion Robot.*

Clark, J.E et al.(2001) *Biomimetic design and fabrication of a hexapedal running robot.*

Nate Kohl and Peter Stone (2004). *Machine Learning for Fast Quadrupedal Locomotion.*