The Impact of Jointly Evolving Robot Morphology and Control on Adaptation Rate

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ABSTRACT

Embodied cognition emphasizes that intelligent behavior results from the coupled dynamics between an agent's body, brain and environment. In response to this, several projects have jointly evolved robot morphology and control to realize desired behaviors. However, which aspects of a robot's morphology should be placed under evolutionary control remains an open question. Here it is shown that subjugating more of the robot's body plan to selection pressure may either slow or increase the rate of evolution, depending on the desired behavior. More specifically, it is shown that for the legged locomotion behavior evolved and described here, increasing the number of evolved morphological parameters slows adaptation. For a more complex behavior involving legged locomotion toward an object followed by manipulation of that object, increasing the number of evolved morphological parameters accelerates adaptation. This suggests that subjugating more of the robot's design to evolution may be of increasing utility for increasingly complex tasks.

Categories and Subject Descriptors

I.2.9 [**Computing Methodologies**]: Artificial Intelligence—*Robotics*

General Terms

Algorithms

Keywords

Evolutionary robotics, embodied cognition, artificial intelligence

Growing bodies of work in artificial intelligence, cognitive science and robotics indicate that intelligent behavior arises out of the coupled dynamics between an agent's body, brain and environment [4, 1, 7, 2]. This suggests that for the field of evolutionary robotics [6], both the controller and body plan should be evolved together to automatically realize intelligent (or at least non-trivial) behavior, rather than only evolving the controller, because the robot designer may not know *a priori* what body plan best supports the evolution of a given behavior. However, in addition to the technical challenges of jointly evolving robot controllers and body plans, it is poorly understood which aspects of a robot's body plan should be placed under evolutionary control.

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Four sets of 100 evolutionary trials were conducted using a virtual quadrupedal robot that behaved in a physics-based simulator[1] (Fig. 1). In the first set (`E_2BP_L`), the robot was evolved to locomote, while the controller and two body parameters (leg length and leg joint range) were evolved. In the second set (`E_3BP_L`), locomotion was again evolved, but three body parameters were evolved along with the controller: leg length, and the vertical and horizontal rotation range of the leg joints. In the third set (`E_2BP_LM`), locomotion and object manipulation were selected for by optimizing the controller as well as leg length and joint range. In the final set (`E_3BP_LM`), locomotion and object manipulation were evolved by optimizing the controller, leg length, vertical rotation range of the leg joints, and horizontal rotation range. The robot was evolved using a version of the incremental shaping method described in [3]. Fig. 1 illustrates the evolutionary progression of a typical trial.

At the end of each trial, the forward displacement achieved by the robot was measured. These displacements were averaged over the 100 trials for the first two regimes, and are reported in Fig. 2a. As can be seen, giving the optimization process more control over the robot's morphology actually reduces mean performance: robots for which three body parameters were evolved rather than two did not locomote as far at the end of the trial as those for which only two parameters were evolved. It seems likely, although not yet proven, that the degradation in performance is due to the fact that evolving locomotion for this robot does not require separate evolution of the horizontal and vertical joint ranges, and the additional dimension introduced to the search space slows evolutionary search.

During the third and fourth regimes, when the robot successfully learns to grasp the object when it is close by, the object is moved a slight distance away, and evolution continues. For this reason, at the end of each trial in the third and fourth regimes, the distance of the target object from the robot at the end of the trial was recorded. Adaptation rate is therefore indicated by the final distance of the object from the robot at the end of the trial: the more rapidly the robot adapts to a new object placement, the more often the object will be moved further away during the trial, and therefore will be further away from the robot at the end of the trial. The final distance of the object from the front of the robot was averaged over the 100 trials, for both regimes, and is reported in Fig. 2b. As can be seen, adaptation rate was significantly increased when three morphological parameters were placed under evolutionary control, as opposed to only two.

[1]Open Dynamics Engine; `www.ode.org`

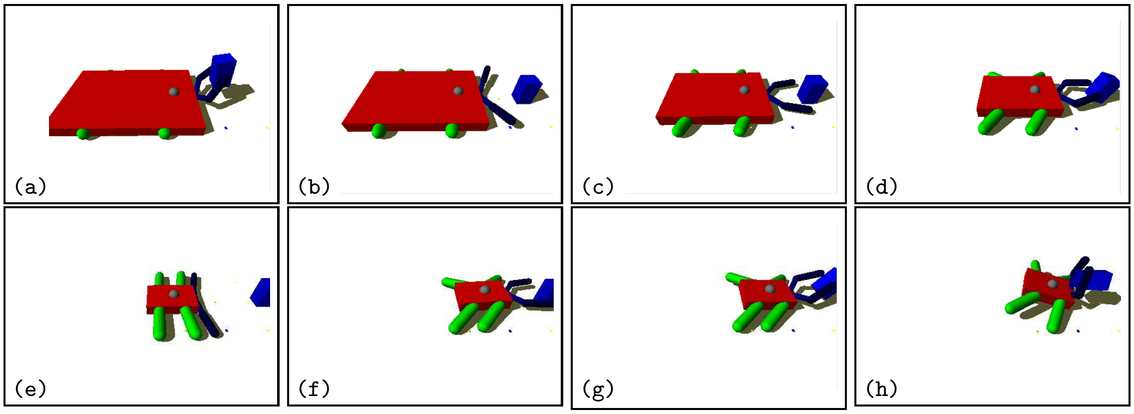

Figure 1: Results from a typical trial selecting for locomotion and object manipulation. At the outset of the trial the robot learns to grasp and lift the object (a). When the object is moved further away, the robot evolves longer legs in order to lean forward and manipulate the object (b-d). When the object is placed beyond its reach (e), it evolves to locomote to the object and then lift it (f-h).

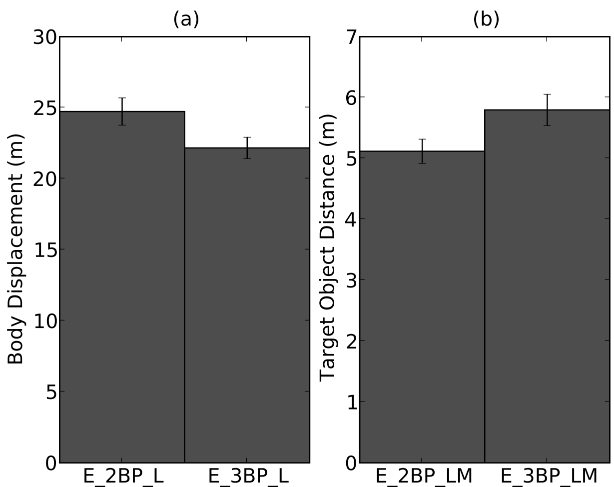

Figure 2: Impact on evolution of just locomotion (a), and locomotion followed by object manipulation (b) when two (left bar) or three (right bar) morphological parameters are placed under evolutionary control. Error bars indicate two units of standard error of the mean.

For the four regimes, the values of the morphological parameters were extracted from the final robot and averaged across each of the 100 trials. It was found that when the robot evolved to locomote and manipulate objects, the legs were significiantly shorter than when the robot was evolved for just locomotion. Similarly, more narrow joint ranges evolved when locomotion and object manipulation were selected for, compared to selecting only for locomotion. This same pattern was observed when the ranges of the horizontal leg joints were evolved independently of the vertical leg joints. This suggests that long legs and the ability to take long strides (provided by a wide joint range) leads to the evolution of more rapid locomotion. However, when selecting for locomotion and object manipulation, shorter legs and shorter strides keep the body more level, allowing the gripper to better grasp and manipulate the target object. More specifically, the robot is better able to grasp the object when the gripper is kept horizontal and therefore perpendicular to the vertical object by minimizing roll around the robot's long axis while it approaches and grasps the object.

This paper provides evidence for why both morphology and control should be evolved to realize increasingly complex behaviors for autonomous robots: subjugating more of the robot's morphology to evolutionary control can, for some behaviors, increase the rate of adaptation. This was demonstrated for a legged robot which must locomote to and then manipulate an object. This is considered a complex task in that the same controller must coordinate motion of the legs during locomotion and motion of the gripper during manipulation. Future work will investigate other behavior learning programmes such as locomotion, lifting and carrying, and transitions from solitary to cooperative object transport [5], to determine whether subjugating more of the robot's morphology to evolutionary control may become of increasing utility for the more complex behaviors. Also, algorithms that might automate which aspects of the robot's morphology are placed under evolutionary control, as a function of the task at hand, will be explored.

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