Co-evolution of Sensor Morphology and Behavior

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ABSTRACT

This research tests the co-evolvability of sensor morphology and behavior as a function of the sensing modality (scent versus touch). The results show that the evolved sensor morphology and behavior are tightly coupled and influenced by sensor type and environment. Implying that co-evolution of physical morphology, behavior, and sensor morphology can generate better performance than using fixed sensor morphologies, but that this is often a more difficult task than evolving physical morphology for a fixed behavior or vice versa.

Keywords

Evolutionary computation, artificial agents, sensors, sensor morphology, co-evolution

1. INTRODUCTION

Research on the co-evolution of robot morphology and behavior has been extremely successful at creating unique and very effective robots for a variety of real world applications (see for example [3]). Not only has this research lead to many successful robot designs it has generated solutions to a number of difficult, real world, problems, such as creating robots that can adapt when damaged [2], creating robots that are difficult for human engineers to design, such as soft robots [1, 5] and tensegrity based robots [4], and helping to bridge the reality gap [6]. These results show that co-evolving robots' physical morphologies and behaviors has significant benefits for real world problems.

Surprisingly, there has been much less research on the co-evolution of *pure* sensor morphology (e.g. the position, orientation, and other features of the sensors) and behavior. By pure sensor morphology we mean studies in which the morphology of the sensors is free to evolve *independently* of the physical morphology.

This research address several questions that are critical to understanding how allowing sensor morphology to evolve will impact real world robotics applications. First, given different sensory modalities (e.g. touch versus scent) does evolution find different sensor morphologies? Second, is the evolved morphology for a given sensor modality different for different environments?

GECCO'16 Companion July 20-24, 2016, Denver, CO, USA

ACM ISBN 978-1-4503-4323-7/16/07.

DOI: http://dx.doi.org/10.1145/2908961.2909050

2. METHODS AND RESULTS

This research is done in a simulated environment. The agents collect resources, which they use as energy. When an agent gets sufficient energy it reproduces, creating an offspring agent. If an agent runs out of energy it dies. Evolvable traits of the agents are: angle of sensors, length of sensors, turning force, and traits related to the agents' color and shape. Color and shape can also evolve to allow for easy differentiation of agents. Trait values are determined using an additive, quantitative trait model.

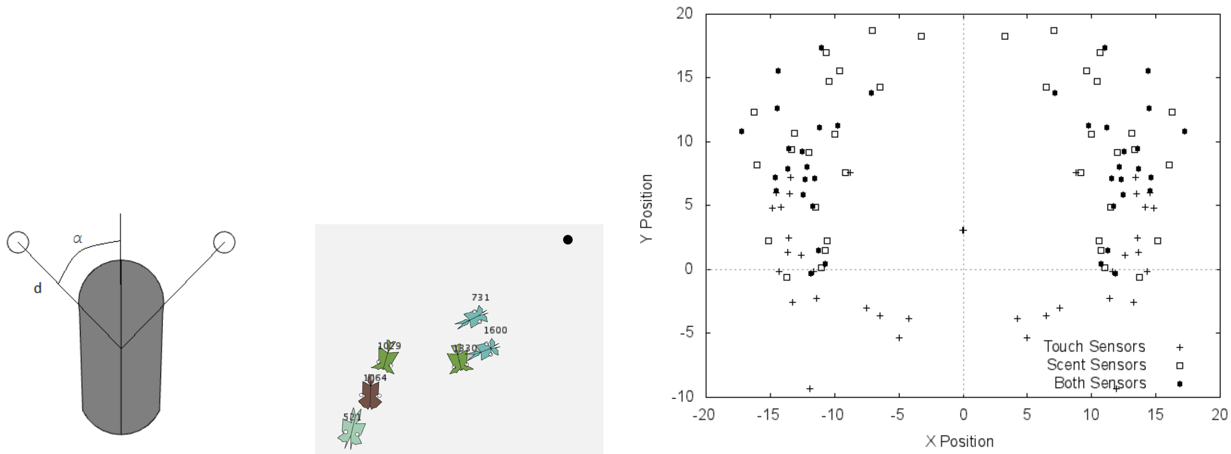
Agents sense the environment by querying two cells in the environment whose location is determined by the evolving sensor parameters (Figure 1a). Agents evolve how strongly they rotate towards or away from the sensor detecting food or stronger scent.

Two sensor types are used: touch and scent. With touch the agent can determine "by touch" if there is food under either of its sensors. With scent the agents can determine whether the amount of scent is higher under the left or right sensor. If sensors can respond to both scent and touch the agents receive data on both scent and touch from the same pair of locations. Each trial is run for 100,000 time steps, data is recorded every 1000 time steps.

The locations of the evolved sensors for touch, scent, and both are plotted in Figure 1c. Only a single angle and length are evolved to determine the location of both sensors, i.e. bilateral symmetry is imposed.[1]

Student's two-tailed, t-tests confirm that difference in average *x-position* of the touch sensors versus scent sensors is not statistically significant ($p > 0.05$), but that the difference in *y-position* is statistically significant ($p < 0.05$). I.e. both sets of sensors evolve to be the same "width", but the scent sensors are statistically further in front of the agent, while the touch sensors are behind the agent. The average y-position of the sensors for both scent and touch is significantly different from the average y-position of the touch sensors (Student's two-tailed, t-test, $p < 0.05$), but is not

[1] In most organisms symmetry is imposed by the developmental process rather than being directly evolved. Thus, we felt that imposing it was a reasonable approach. However, it would be an interesting future experiment to determine what forms, if any evolution favored when symmetry was not imposed.



(a) Sample agent (b) Evolved agents (c) Evolved Sensor Distributions

Figure 1: (A) Sample agent. The circles are the locations of its sensors, which measure either scent, presence of food or both. The location of the sensors is determined by evolving an angle α and a length d as shown. (B) Evolved agents targeting a resource pellet (black dot). The agents' physical morphology and color do not effect their performance or fitness, but are useful for identifying related individuals. (C) Location of the evolved sensor pairs for touch, for scent, and for both senses. For touch many of the sensors are behind the agent's center and the sensors in front of the agent are spaced roughly 28 units (pixels) apart, slightly larger than the environment grid size, allowing an agent to "sweep" multiple cells. In one case the sensors are nearly co-located this is the trial in which effective touch sensing never evolved. In contrast, for scent this case the sensors form an arc in front of the agent. When both scent and touch are used the sensors positions are mainly in the overlapping region.

significantly different from the y-position of the scent sensors (Student's two-tailed, t-test, $p > 0.05$). I.e. the sensors for both generally evolve to be more similar to the scent sensors than the touch sensors. This confirms that different sensor morphologies evolved for different sensing modalities.

In experiments with a smaller grid size the average x-position of sensors of all types was significantly smaller (confirmed via Student's two-tailed, t-test) confirming that evolved sensor morphologies are also a function of environmental parameters.

3. CONCLUSIONS

This research presents an initial, systematic study of the co-evolution of sensor morphology and behavior with the long term goal of determining the usefulness of evolving sensor morphology for real world robotics applications. The results support a number of conclusions. First, evolution does find different sensor morphologies (e.g. sensor placement) for different sensor modalities (e.g. scent versus touch). Second, that the evolved morphology is a function of the environment. These two results support the use of evolved sensor morphologies for real world applications because they show that the evolutionary process does adapt the sensor morphology to real world parameters in much the same way that previous research showed evolving physical morphologies adapt to the environment. However, they also indicate that for optimal performance it may be necessary to re-evolve sensor morphology if the sensors or the environment changes.

4. ACKNOWLEDGMENTS

This material is based in part upon work supported by the National Science Foundation under Cooperative Agreements No. DBI-0939454 and DMS-1029485. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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