Ecological Complexity 24 (2015) 57–68

Contents lists available at ScienceDirect

Ecological Complexity

journal homepage: www.elsevier.com/locate/ecocom

Original Research Article

How morphology of artificial organisms influences their evolution

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ARTICLE INFO

Article history:
Received 29 April 2015
Received in revised form 23 September 2015
Accepted 28 September 2015
Available online 10 November 2015

Keywords:
Artificial organisms
Morphology
Competition
Evolution

ABSTRACT

The purpose of this work is to study virtual populations of artificial organisms with their genotype, morphology, mechanism of motion, search and competition for food, reproduction, mutations. The genotype determines the phenotype (morphology), while morphology determines efficiency of motion and success in the search for food in the competition with other individuals; sufficient amount of food allows reproduction. Ensemble of these elements constitutes the minimal model to study natural selection of artificial organisms. Considering only some of them, as it is often the case in artificial life models, can be used for the optimization of some properties (for example, robot's gait or embryo's form) but not to study natural selection in the evolutionary context.

Artificial organisms are considered in this work in the form of polygons (triangles) on the plane. Their genotype is given by three positive numbers associated to the vertices and their morphology is determined by the lengths of the sides equal the sum of the numbers in the adjacent vertices. Behavior of the individuals and their success in the search for food depend on their morphology. More efficient individuals will reproduce more than the others and will transmit their advantageous variations to their offsprings. Hence we can observe how natural selection chooses more efficient morphology and how it evolves due to random mutations.

We develop an individual based model where the individuals recognize food and move to it with the speed determined by their morphology (and not prescribed in the algorithm). If they have enough food, they survive and reproduce. Therefore morphology and evolution are tightly interconnected and should be studied together. Dynamics of such populations appears to be different from the dynamics described by conventional models of competition and evolution of species. In particular, a new phenotype can emerge due to a different strategy of foraging (related to a different morphology) and not only due to a difference in consumed resources with the existing phenotype. We also observe that realization of Cope's rule (increase of body size in the process of evolution) can depend on parameters of the model.

1. Introduction

The principle of natural selection implies that variations are transmitted from parents to offsprings. The individuals with advantageous variations have better fitness. Consequently, such variations spread in the population and influence its evolution. This schematic description is conventionally accepted but it jumps over an important step: how variations are related to fitness. In the other words, how the phenotype is related to the reproduction and mortality rates. It is important to note that this relation will not be imposed by the assumptions of the model but it should follow from the morphology of the artificial organisms. In order to study this question, we will introduce in this work virtual populations of artificial organisms and will observe their behavior. The main idea of this study is that we prescribe individual characteristics of the organisms (size, form) but not their behavior in the search for resources. The model presented below will allow us to study on a simple example the interaction between morphology and natural selection, or, in a more general formulation, the evolution of the phenotype.

1.1. Artificial life models

Artificial life models are largely used to study behavior of biological organisms at the individual level, their collective behavior and evolution. We will consider a complete life cycle model which includes the genotype of the organisms in its relation to the phenotype, the mechanism of motion and food search determined by the morphology of the organisms, and reproduction (Fig. 1).

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http://dx.doi.org/10.1016/j.ecocom.2015.09.005
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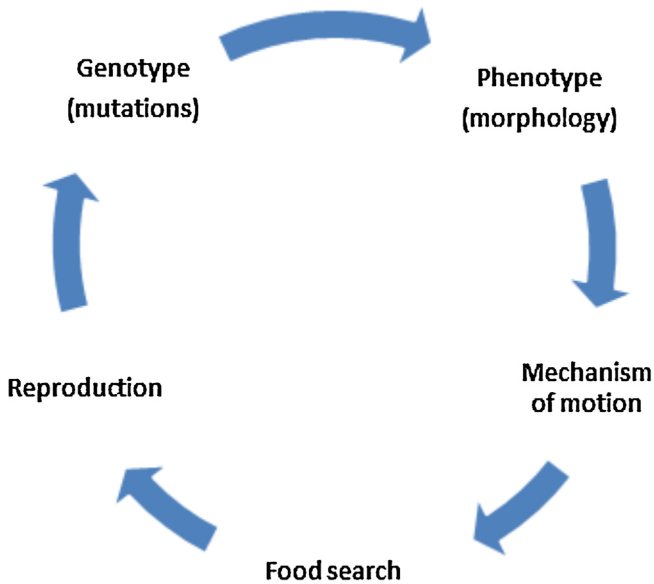

Fig. 1. Schematic representation of the model. Morphology of artificial organisms determines their mechanism of motion and their efficiency in the search for food. If they have enough food, they reproduce and transmit their genotype to their offsprings with possible mutations.

1.1.1. Genotype and phenotype

Artificial embryogeny studies the development of the organism on the basis of some set of rules considered as genotype (see Matos et al., 2009; Stanley and Miikkulainen, 2003 and the references therein). These rules determine cell division, differentiation, death and possibly some other properties (motion, production of signaling molecules, etc.) resulting in the emergence of certain morphology. As a result of this development, we obtain a cellular structure which should satisfy some criteria about its form, function or regeneration (Andersen et al., 2009; Basanta et al., 2008; Hogeweg, 2000).

Development of artificial organism can be considered in the evolutionary context with selection based on fitness according to some criteria [for example, to preserve homeostasis (Basanta et al., 2008) or to move on longer distance (Clune et al., 2009)]. In this case, natural selection is replaced by artificial selection where the organisms are not chosen according to their capacity to survive and to reproduce but according to some specific properties.

1.1.2. Motion

The mechanism of motion of terrestrial animals represents consecutive displacement of their members. Some of them are fixed to the ground to provide support, while some other change their position. Gait optimization is an important problem for virtual and real robots (Clune et al., 2009). Genetic algorithms are used for this optimization with artificial selection based on some criteria (Sims, 1994). The mechanism of motion is determined by the morphology of the organism and in its turn it determines the success in the search for food in the competition with other individuals.

1.1.3. Food search

The process of food search has the principal importance for survival and multiplication of individuals. It contains several steps: identify food, move to it and catch it, compete with other individuals searching food. Food can be considered as a signal received by the individual through its perception system. It can be for example a visual information transmitted to the brain and identified there. Once it is recognized as food, the corresponding neurons fire and the signal is sent to the muscles. They contract and the individual starts its motion.

The signal from food and the mechanism of motion act in such a way that the individual approaches food. This assertion seems obvious but it is the most important and complex element of the process of food search. It should be stressed that there is no force here attracting the individual to the food (as in various particle dynamics models). There are neurons and muscles that react on the signal, and the mechanism of motion.

Thus we have the following chain of events: signal, neuron firing, muscle contraction, motion. Direction and speed of this motion are not prescribed. They depend on the work of neurons and muscles, and they determine how fast the individual gets to the food and whether it is more efficient than other individuals. The individuals can differ from each other by their phenotype that influences their motion.

1.1.4. Reproduction

More efficient individuals will get more food, will reproduce more and will transmit their phenotype (through the genotype) to their offsprings. We will consider below only asexual reproduction assuming that it is determined only by available food. The offsprings have the same genotype as parents with possible mutations. Introduction of mutations in the model will allow us to study the evolution of the phenotype.

1.2. The model developed in this work

The main goal of this work is to develop a model which includes not only some steps of the life cycle discussed above but all of them. This is important in order to describe natural selection of artificial organisms where they survive and multiply in the competition with other organisms depending on their individual properties and on the environment.

We do not characterize artificial organisms in the model by their fitness as it is conventionally done in artificial life models and in other evolutionary models. If the model imposes how fitness depends on the phenotype, then advantageous phenotypes are suggested by the model itself, and natural selection is excluded from the model.

The key property of the model developed in this work is that behavior of individuals is not prescribed. We do not impose their direction and speed of motion. They move according to their individual characteristics (phenotype), and more efficient individuals get more resources and reproduce more. In this case advantageous variations will be transmitted to offsprings and will determine the evolution of the population.

We develop a minimal model that allows us to study the phenotypic evolution due to natural selection. Each stage of the model (genotype, morphology, mechanism of motion, food search, reproduction) can be developed in a more complex and sophisticated way but this is not the goal of this work. We intend to show here the main idea of the approach to study the interaction of morphology and evolution. It opens numerous avenues for further investigation.

Artificial organisms are considered in this work in the form of polygons on the plane. We will deal here only with triangles. This is the simplest polygon that can move to the food. The interval, degenerate polygon consisting of two points, is not sufficient to insure motion to the food.

The vertices of the polygon serve as sensors that receive signals from food and act on adjacent sides changing their length. We can interpret vertices as neurons and sides as muscles, though this analogy is limited because real biological processes are much more complex.