An Artificial Creature Approach to the Origin of Acoustic Communication

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Introduction

Constructive and evolutionary approaches have contributed to discuss the emergence and evolution of acoustic communication including human languages (Nolfi and Mirolli, 2010) because it is difficult to directly observe those processes from past materials. We are investigating the origin of acoustic communication by focusing on a hypothesis that acoustic communication in terrestrial animals started as noises that are contingent with breathing or gestures associated with predation or feeding, which then gradually ritualized, forming the fixed action patterns reflecting intentional or emotional states (Okanoya, 2012; Newman, 2012).

Since Sims’s seminal work on Blockies model (Sims, 1994), artificial creatures approaches have contributed to understanding the coevolution of morphology and behavior of physically embodied agents, and further been extended to consider intriguing evolutionary questions such as interactions among ecological, evolutionary and developmental (eco-evo-devo) processes (Arita et al., 2016; Kriegman et al., 2018; Chiba et al., 2020), and reality assisted evolution of soft robots (Howison et al., 2021). However, there have been few approaches to understand the emergence and evolution of acoustic communications, which originates from an inevitable noise generated by behaviors of embodied agents.

For understanding this scenario, we have been designing and implementing an evolutionary simulation framework of artificial creatures, called EvoCreature (Seki et al., 2020). This paper introduces the framework briefly, and reports on three initial experiments with different tasks to show various acoustic interactions can evolve using this framework.

An artificial creature model: EvoCreature

Fig. 1 provides an overview of the model. See (Seki et al., 2020) for details. There are multiple individuals of artificial creatures of which body is composed of several rectangular blocks connected with hinges, in a two-dimensional field (i). They can make sounds, of which volume is proportional to the magnitude of collision forces, when their bodies collide with each other (including self-collisions between body parts not connected directly) or with obstacles (including the field) (ii). These sounds (i.e., their volume and direction of arrival) can be perceived by their auditory sensors but their perceived volume decreases as the distance from the sound source increases (iii). The genotype of each individual is represented as a directed graph (iv), which is a simplified version of Sims’s Blockies model. This graph represents a developmental process of the phenotype graph (v), yielding both physical structures of bodies (e.g., the number and sizes of blocks, hinges between blocks) (vi) and the neural network inside each block that connects inputs from its several types of sensors (e.g., visual, auditory, contact, hinge angle, the information from other blocks) to outputs (e.g., the torque applied to the hinge connected with another block) (iv), which can create sensorymotor interactions. A genetic algorithm is used to evolve artificial creatures according to the fitness defined in each experimental condition.

Experiments

Aggregation task

First, we assumed a simple aggregation task to see if an adaptive behavior using sounds emitted by others can evolve in the proposed framework (Fig. 2 (i)) (Seki et al., 2020). Each individual can receive sounds emitted by the other individuals, excluding the sounds emitted by its own behavior. We distributed 50 individuals in a plane field, and conducted an evaluation for 5000 steps. The fitness was measured as...
the number of other neighboring individuals within a radius of 10 at the end of the evaluation.

The population evolved to aggregate successfully. Fig. 2 (i) (top) shows an example behavior of the population composed of clones of the best individual in a successfully evolved trial through 3000 generations, showing an emergence of a cluster of individuals. Fig. 2 (bottom) also shows the scatter diagram of the average sound volume emitted by each individual and its traveled distance during the same evaluation process. There were positive correlations among the indices, meaning that individuals moving and making sounds actively tended to be more adaptive. Note that individuals moving not so much also became adaptive (indicated by the circle size representing the fitness) if they make sounds actively, because they (i.e., leader) gathered other actively moving individuals (i.e. follower) by their sounds.

Resource acquisition and sharing task

We next assumed a resource acquisition and sharing task with a sound source (landmark signal) as a more complex acoustic environment (Banno et al., 2021). We placed four resource blocks close to a sound source emitting sound with a fixed volume to indicate the existence of resources. 70 individuals were distributed circularly around the source. The amount of each resource is equally shared by the individuals around it within a radius of 12, which is defined as the fitness for each individual.

Fig. 2 (ii) (top) and (bottom left) show a snapshot of the population and trajectories of individuals in a successfully evolved population after 3000 generations, respectively. The individuals evolved to move toward a closer resource and stayed around it, leading to equal sharing. Note that if we evaluate this population in a no sound source environment, the individuals tended to aggregate with each other (bottom right), which implies that the evolved behavior can be exapted for aggregation behavior.

Acoustic niche separation task

We further conducted a coevolutionary experiment to see if a separation of species-specific acoustic signals emerges in the frequency domain based on an acoustic niche hypothesis (Krause [1993] in Kawai et al. [2020]). This hypothesis and related concepts have been discussed using ALife approaches (Suzuki et al. [2012]; Suzuki and Arita [2014]; Eldridge and Kiefer [2018]; Suzuki and Cody [2019]; Kadish et al. [2019]; Masumori et al. [2020]).

We assumed two species, each consisting of 20 individuals. The frequency spectrum is calculated from the volume (by regarding it as signal strength) of sound emitted by each individual (with no effects from others) for every 32-step interval, and the main frequency value was defined as the frequency value at the center of mass in the spectrum image, averaged over the last 8 intervals. The fitness of each individual is measured as the difference between the main frequency and the average of those of the other species.

Fig. 2 (iii) shows the example morphology, the signal and the frequency spectrum of evolved individuals in the two species, clearly showing an emergence of acoustic niche separation. The species A (left) and B (right) evolved to emit low and high frequency signals, respectively.

Conclusion

We introduced an artificial creature framework for the evolution of acoustic communications. The initial experiments showed that the framework enables us to discuss the evolution of collective behaviors, exaptation, and acoustic niche separation, originating from an inevitable noise generated by behaviors of embodied agents.

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References


