

## Chapter 1

# Teaching emergence and evolution simultaneously through simulated breeding of artificial swarm behaviors

**Hiroki Sayama**

Department of Bioengineering  
Binghamton University, State University of New York  
P.O. Box 6000, Binghamton, NY 13902-6000  
sayama@binghamton.edu

We developed a simple interactive simulation tool that applies the simulated breeding method to evolve populations of Reynolds' Boids system. A user manually evolves swarm behaviors of artificial agents by repeatedly selecting his/her preferred behavior as a parent of the next generation. We used this tool as part of teaching materials of the course "Mathematical Modeling and Simulation" offered to engineering-major junior students in the Department of Human Communication at the University of Electro-Communications, Japan, during the Spring semester 2005. Students actively engaged in the simulated breeding processes in the classes and voluntarily evolved a rich variety of swarm behaviors that were not initially anticipated.

## 1 Introduction

Emergence and evolution are the two most important concepts that account for how complex systems may become organized. They are intertwined deeply to each other at a wide range of scales in real complex systems. Typical examples

of such connections include evolution of swarm behaviors of insects and animals [1] and formation of large-scale patterns in spatially extended evolutionary systems [2]. These two concepts are often treated, however, as somewhat distant subjects in typical educational settings of complex systems related programs, being taught using different examples, models and/or tools. Sometimes they are even considered as antagonistic concepts, as seen in the “natural selection vs. self-organization” controversy in evolutionary biology. There is a need in complex systems education for a tool with which students can acquire a more intuitive and integrated understanding of these concepts and their linkages.

To meet with the above need, we developed a simple interactive simulation tool *BoidsSB*, which applies the simulated breeding method [3] to evolve populations of Reynolds’ Boids system [4]. In *BoidsSB*, each set of parameter settings that describe local interaction rules among individual agents in a swarm is considered as a higher-level individual. A user manually evolves swarm behaviors of artificial agents by repeatedly selecting his/her preferred behavior as a parent of the next generation. While some earlier work implemented Boids with interactivity [5], our system is unique in that it dynamically evolves parameter settings that determine the characteristics of swarm behaviors.

In this article we introduce the model and briefly report our preliminary findings about a wide variety of dynamics of the model and its potential educational effects indicated by the responses of participating students who played with it.

## 2 Model

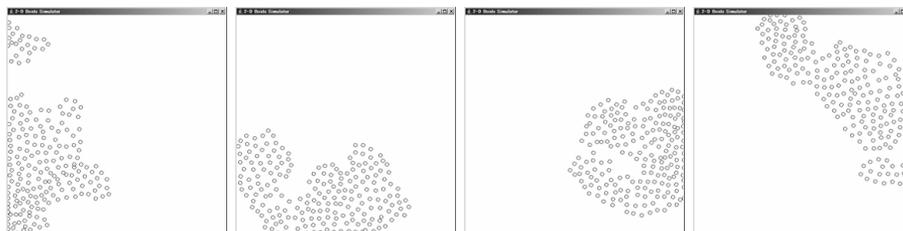
Our model *BoidsSB* simulates a swarm behavior of artificial agents in a continuous two-dimensional square space using local interaction rules similar to those of Reynolds’ Boids system [4]. Each individual agent in *BoidsSB*, represented by a directionless circle, perceives relative positions and velocities of other agents within its local perception range and changes its velocity in discrete time steps according to the following rules:

- If there is no local agents within its perception range, steer randomly (**Straying**).
- Otherwise:
  - Steer to move toward the average position of local agents (**Cohesion**).
  - Steer towards the average velocity of local agents (**Alignment**).
  - Steer to avoid collision with local agents (**Separation**).
  - Steer randomly with a given probability (**Whim**).
- Approximate its speed to its normal speed (**Pacekeeping**).

The size of space is assumed to be  $600 \times 600$ . Parameters used in simulation are listed in Table 1. This system can produce a natural-looking swarm behavior if those parameters are appropriately set (Fig. 1).

**Table 1:** Parameters used in each simulation run.

Name	Min	Max	Meaning
$N$	1	500	Number of agents
$R$	0	300	Radius of perception range
$V_n$	0	20	Normal speed
$V_m$	0	40	Maximum speed
$c_1$	0	1	Strength of the cohesive force
$c_2$	0	1	Strength of the aligning force
$c_3$	0	100	Strength of the separating force
$c_4$	0	1	Strength of the pacekeeping force
$c_5$	0	0.5	Probability of the random steering

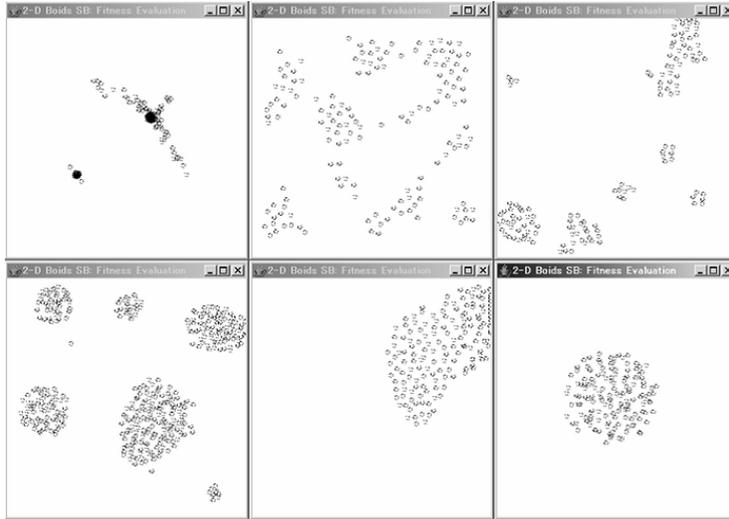
**Figure 1:** Example of swarm behavior that looks like fish schooling. Parameter values used are  $(N, R, V_n, V_m, c_1, c_2, c_3, c_4, c_5) = (200, 30, 3, 5, 0.06, 0.5, 10, 0.45, 0.05)$ .

*BoidsSB* was developed using Java 2 SDK Standard Edition 1.4.2. It runs as a stand-alone application on any computer platform equipped with Java 2 Runtime Environment. Its source code is freely available from the ICCS website<sup>1</sup>.

In *BoidsSB*, the simulated breeding method [3] is used to better engage students in the simulated phenomena, where students will interact with the system and actively participate in the evolutionary process by subjectively selecting their preferred swarm behaviors. Each set of parameter values is considered as a higher-level individual subject to selection and mutation. The simulated evolutionary process is an interactive search within a nine-dimensional parameter space.

Figure 2 shows a screen shot of *BoidsSB*. The number of candidate populations used for simulated breeding is fixed to six due to the limitations in computational capacity for simulation and display space for visualization. A student can left-click on any of the frames to select his/her preferred swarm behavior. The parameter settings used in a frame can be output by right-clicking on it, which is helpful for students to consider how the observed swarm behavior depends on the parameter values. Once one of the six populations is selected, a new generation of six offspring is produced by randomly mutating (i.e., adding random noise to) each parameter value in the selected parent, among which one

<sup>1</sup><http://necsi.org/community/wiki/index.php/ICCS06/191>



**Figure 2:** Screen shot of *BoidsSB*. Swarm behaviors of six different populations are simultaneously simulated and demonstrated in six frames. A user can click on one of the frames to select a population that will be a parent for the next six populations.

inherits exactly the same parameter settings from the parent with no mutation. To enhance the speed of exploration, the mutation rate is set rather high to 50%, i.e., noises are added to about half the parameters in every reproduction. This selection and reproduction cycle continues indefinitely until the student manually quits the application.

### 3 Implementation in classes

We used *BoidsSB* as part of teaching materials of the course “Mathematical Modeling and Simulation” offered to engineering-major junior students in the Department of Human Communication at the University of Electro-Communications, Japan, during the Spring semester 2005. This course aimed to introduce various examples of self-organization to students and help them understand these phenomena experientially and constructively by actively playing with simulations and modifying simulator codes. It also aimed to help students acquire fundamental skills of object-oriented programming in Java. Class meetings were held in a computer lab once a week for fourteen weeks. Each class was for 90 minutes, starting with a brief explanation about the topical models and simulator codes followed by supervised lab work. The actual class schedule is shown in Table 2.

*BoidsSB* was used as one of the materials for the Week 10 “Evolution and Adaptation”, where it was discussed how dynamic emergent patterns (swarm behaviors) could evolve using explicit fitness criteria, either hard-coded or interactively selected. By this time students were already acquainted with the

**Table 2:** Class schedule of the course “Mathematical Modeling and Simulation” that was offered to juniors in the Department of Human Communication at UEC during Spring 2005. The proposed *BoidsSB* was used as a teaching material for the Week 10: Evolution and Adaptation.

Week	Subject	Models	Examples
1	Course introduction	–	–
2	Intro to Java Programming	–	–
3	Intro to Java Programming	–	–
4	Spatial Pattern Formation (1)	Cellular automata	Droplet formation and phase transition in its dynamics
5	Spatial Pattern Formation (2)	Cellular automata	Majority rule, Turing pattern formation, dynamic clusters in host-parasite systems, spiral formation
6	Networks (1)	Network growth models	Random network, random and preferential network growth
7	Networks (2)	Network growth models	Tree growth, simple self-replication, cell division
8	Collective behaviors (1)	Individual-based models in discrete space	Random walk, diffusion-limited aggregation, garbage collection by ants
9	Collective behaviors (2)	Individual-based models in continuous space	Swarm behaviors of insects, Boids, traffic jams
10	Evolution and Adaptation (1)	Evolutionary models with explicit fitness	Evolution of swarm behaviors by genetic algorithm and simulated breeding
11	Evolution and Adaptation (2)	Evolutionary models with implicit fitness	Spontaneous evolution in closed systems (Boids ecosystem, Evoloop)
12	Team Projects	–	–
13	Team Projects	–	–
14	Final Presentations	–	–

concept of swarm behaviors of Boids and other aggregate systems.

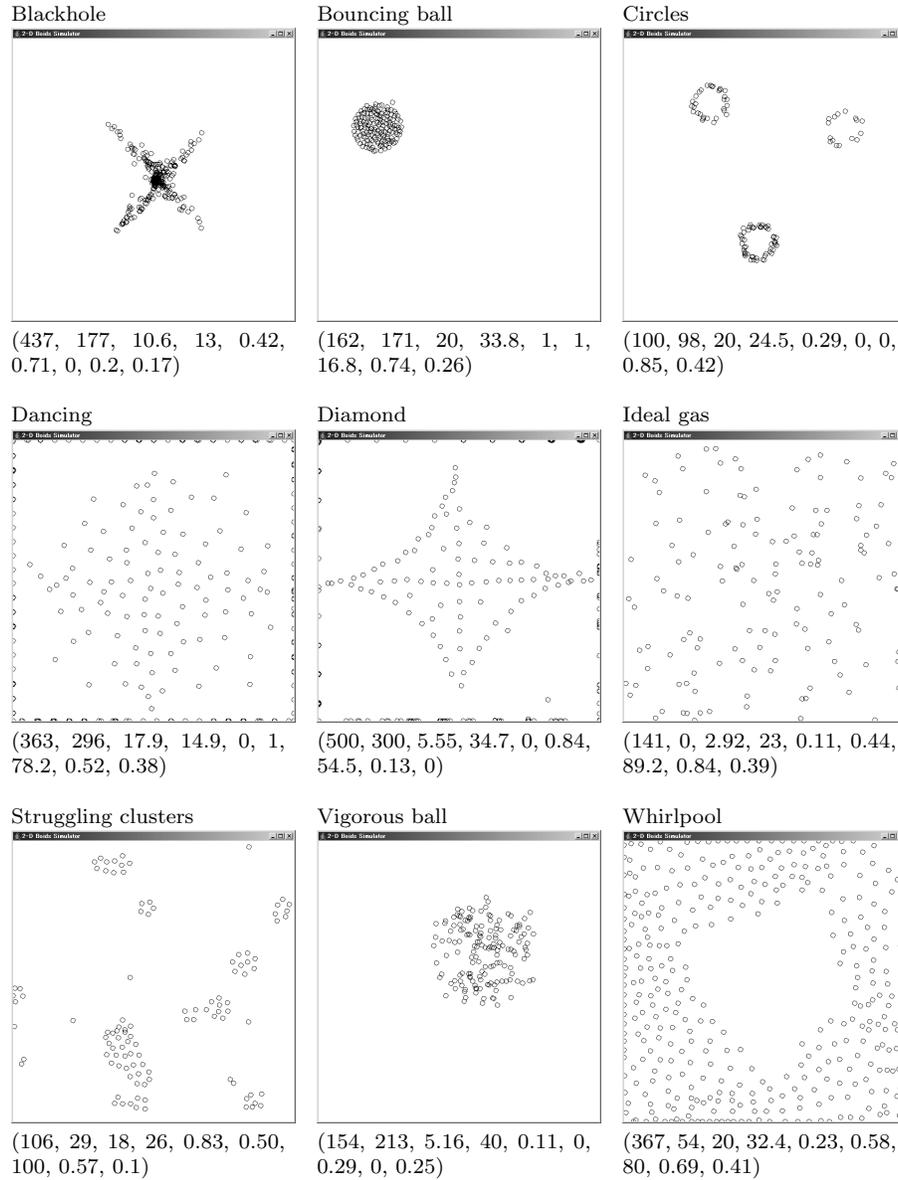
## 4 Results

In the Week 10 class, students first learned the concept of genetic algorithms and worked on the exercise to write a code of an explicit fitness function to automatically evolve vortex behavior of Boids. A majority of the students were unsuccessful in this attempt, especially because of the technical difficulty in evaluating the “vortex-ness” of populations by a measurable quantity. Then the concept of simulated breeding was introduced, and students used *BoidsSB* to achieve the same goal. They were quite surprised when a nicely swirling behavior of swarms came up just after several clicks of artificial selection. This experience helped them intuitively understand the strength of evolutionary principles, especially in the context of the emergence of nontrivial dynamic swarm behaviors. They also appreciated the diversity of different swarm behaviors that appeared during the processes of evolution.

Throughout the class time, students actively engaged in the simulated breeding processes and voluntarily evolved a rich variety of swarm behaviors that were not initially anticipated. Figure 3 showcases several examples found through the exploration by the students. Some of them were totally unexpected results even to the instructor (the author) who created the system.

No systematic evaluation has been conducted to measure educational impact of this model yet. Here we limit ourselves to probe its potential by looking at the comments given from the participating students. Below are some exemplar statements taken from their homework reports (translated from Japanese to English):

- “It was a fairly pleasing simulation. It was as if I was watching the behavior of water drops in a weightless space.”
- “The material of this week was very interesting. I have been vaguely thinking of doing some simulations like that, and now I feel I have found what I really wanted to do.”
- “Before playing with *BoidsSB* I was not successful in evolving Boids using GA, so I was fascinated by the process of the appearance of (vortex) behavior through evolution.”
- “In *BoidsSB* a human user serves as a fitness function, so its possibility should be virtually infinite. Results should therefore be infinite too. However, I found that the actual results of simulated breeding had some trend to fall into several typical classes of behaviors. Can we reduce this trend by either improving the selection criteria or diversifying parameters?”
- “During the selection process I saw several typical behaviors appearing many times, but what I felt more exciting varied from time to time. I sometimes selected by comparing the six candidates. At some other times



**Figure 3:** Examples of swarm behaviors evolved by participating students using *BoidsSB*. Parameter settings are shown beneath each example in the  $(N, R, V_n, V_m, c_1, c_2, c_3, c_4, c_5)$  format. Some of these may even appear to exploit weakness in the simulation algorithm.

I had a concrete image of specific behavior in mind and kept selecting those that were similar to that. These are all subjective to each user and therefore hard to predict. I thought that it would produce more interesting results than purely computational algorithms.”

In addition to the above, it was also notable that quite a few students developed detailed discussions on how each parameter contributed to the emergence of the observed swarm behaviors (omitted due to the lack of space). These responses may indicate that *BoidsSB* had an impact for students that led them to both intuitive experience and analytic reflection of emergence and evolution of swarm behaviors. A more systematic and objective evaluation would be necessary to ascertain the effectiveness of the model, which is beyond the scope of our attempt at this time.

## 5 Conclusion

We proposed *BoidsSB*, a simple interactive simulation tool that applies the simulated breeding method to the evolution of swarm behaviors of artificial agents. We used this tool as a teaching material in the mathematical modeling and simulation classes to provide students with opportunities to intuitively and constructively understand emergence and evolution in an integrated manner. In the responses from the participating students were several noticeable comments on their evoked interest in the emergence of global collective dynamics out of local interaction rules, and on their admiration for the power of evolution that gives rise to nontrivial outcomes through repetition of simple processes. The fact that these positive responses were obtained from a single simulation tool may indicate the effectiveness of our approach.

## Bibliography

- [1] Camazine, S. et al. (2001) *Self-Organization in Biological Systems*. Princeton University Press.
- [2] Bar-Yam, Y. et al. NECSI Evolution and Ecology Research Project. <http://www.necsi.org/research/evoeco/>.
- [3] Unemi, T. (2003) Simulated breeding – a framework of breeding artifacts on the computer. *Kybernetes* 32:203-220.
- [4] Reynolds, C. W. (1987) Flocks, herds, and schools: A distributed behavioral model. *Computer Graphics* 21(4):25-34.
- [5] Unemi, T. & Bisig, D. (2004) Playing music by conducting BOID agents - A style of interaction in the life with A-Life. In *Artificial Life IX: Proceedings of the Ninth International Conference on the Simulation and Synthesis of Living Systems*, MIT Press, pp.546-550.