Interactive Biomimetic Space: An Interactive Installation to Explore Living Architecture

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Abstract. This paper describes a computer-based Interactive Biomimetic Space (IBS) installation. Through an interactive process, a user creates and relates new spaces. The simulation of a simplified ecosystem populates the created space with life. The installation attempts to inspire architectural design ideas by integrating biological principles. In particular, the biological concepts of stochastic motion, interaction and reproduction of artificial swarms have been explored and applied. Both the user and the swarm agents contribute to the design process, which results in interesting design outputs with a certain degree of unpredictability. We introduce the theoretical background of our work, outline its technical implementation, and present various interaction examples and scenarios.

Keywords: Interactive art, architectural design, swarm dynamics, computational development

1 Introduction

With the development of various Computer Aided Design (CAD) techniques, many designers and artists today understand the computer as a tool for facilitating design processes and art creation. Computer technology is utilized not only as an effective approach to present final works but also as a practical assistance in formulating design ideas and inspiring innovative concepts. Computer scientists and biologists have developed numerous computational models of systems that retrace phenomena observed in nature [1,5]. Such bio-inspired models have the potential to provide solutions for challenges in other disciplines. In particular, they provide designers and artists with a new perspective to develop their aesthetic creation [2,4,6,7].

In this work, we present an Interactive Biomimetic Space (IBS) installation that utilizes several bio-inspired computational concepts to explore living architecture. Specifically, within architectural space that is initialized by the user, a swarm of agents are introduced as the actual inhabitants. Their habitat then grows gradually through the coordination and collaboration among the agents themselves and the interaction processes between the agents and the user.

Section 2 gives a brief review on the related works. Section 3 details the implementation and setup of the IBS installation and illustrates the interaction scenarios. Section 4 focuses on the design results. We conclude with an outlook on possible future works.

2 Related Work

The flocking behaviors of social animals, such as in flocks of birds or schools of fish, can be simulated by means of boids [5]. Given a set of simple interaction rules, such as *separation*, *alignment*, and *cohesion*, the boids simulation can be rather complex due to the large number of interaction events among the participating agents. By adding additional interaction rules to the original Boids implementation, the user can be involved in these interaction processes. Unemi and Bisig, for instance, developed the Flocking Orchestra by adding two forces to support human-swarm interactions: "an attractive force causes the agents to move towards the front part of the virtual world when they perceive visitor motion; a repellant force pushes the agents away from the front part in the absence of any visitor's motion" [6]. In the Flocking Orchestra, each agent controls a MIDI instrument and plays a music note according to its state. As the user varies his gestures or positions in front of the camera, the agents' states will be adjusted correspondingly, resulting in the generation of music. This example demonstrates how Boids can be harnessed for an artistic creation via human-swarm interactions.

Swarm Intelligence describes the collective behaviors of decentralized and self-organized systems, such as ant colonies [1]. There is no central leader or hierarchical command structure within the system to govern the individual agents' behaviors. Instead, the agents interact locally with one another and with their surroundings based on simple rules. Jacob et al. explored Swarm Intelligence in their SwarmArt project [2]. By means of video cameras and computer vision algorithms, the interaction between a user and the swarm agents was realized. As a result, a dynamic and evolving swarm system was developed as a new tool for artists. von Mammen and Jacob applied Swarm Intelligence to inspire architectural design by introducing the Swarm Grammar system [7]. This system allows agents to reproduce, communicate and build construction elements during simulations. Different architectural shapes emerge from the interaction processes of swarms with different behaviors. By breeding swarms through evolutionary algorithms, the system produces unexpected, creative architectural models.

Niche construction is the process in which an organism alters the environment to increase its own and its offspring's chance for survival [3]. McCormack and Bown applied principles of niche construction to an agent-based line drawing program to increase its output diversity [4]. An allele in the agent's genome is utilized to describe the agent's preference for the density of drawn lines in its environment. A favorable environment increases the probability of agent reproduction. In this way, parents may construct a niche and pass on a heritable environment well-suited to their offspring.

3 The IBS Installation

Inspired by the works described above, the IBS installation is a simple, computer-based interactive ecosystem, inhabited by swarm agents. Its motivation is the exploration of architectural design processes in and for complex, lively environments. A user engages with these swarm agents in a process of unfolding architectural spaces. Dynamically adding simple rooms to accommodate the demands of the swarm and the desires of the user, this collaborative effort yields interesting artificial design scenarios.

The user sees three windows on a computer screen (Fig. 1). The main window shows the IBS scene comprising the user's agent and the swarm agents, and displays the dynamic IBS in real-time. In the upper-right corner of the screen, a motion detection window is displayed to help the user to be aware of his motions in front of a camera. A 2D map window is located in the upper-left corner of the screen to assist the user in navigating through the scene. By default, the main window shows the scene in 3D mode.

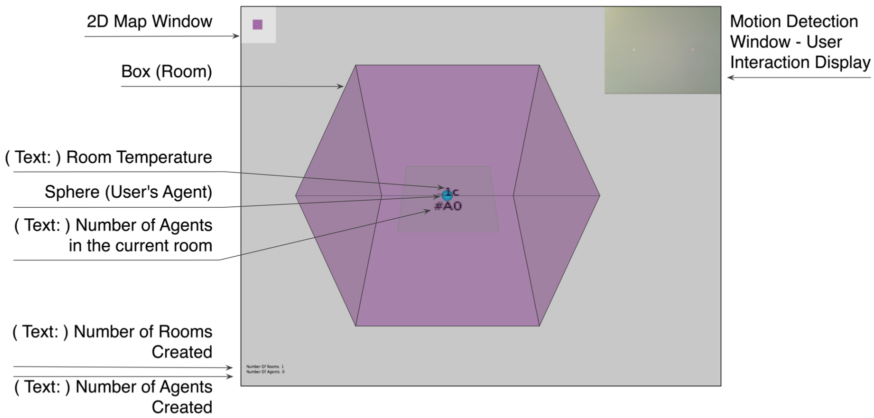


Fig. 1. In addition to the main view, the IBS installation displays a map view in the top-left and a user interaction display in the upper-right corner.

In the main window, the user, or audience, sees different graphical elements. The blue sphere represents a particular agent which is controlled by a motion detection system. Other smaller spheres might be shown that represent autonomous swarm agents that dwell in the simulated space. The IBS is made of individual rooms that are depicted as transparent cubes. The relationships among the three interactive components—user, agents, and IBS—are displayed in Fig. 2. Generally, the user creates the first several rooms and introduces a flock of swarm agents. Subsequently, according to the characteristics of the rooms, such as the room size and the room temperature, swarm agents are triggered to interact with their partners as well as the environment.

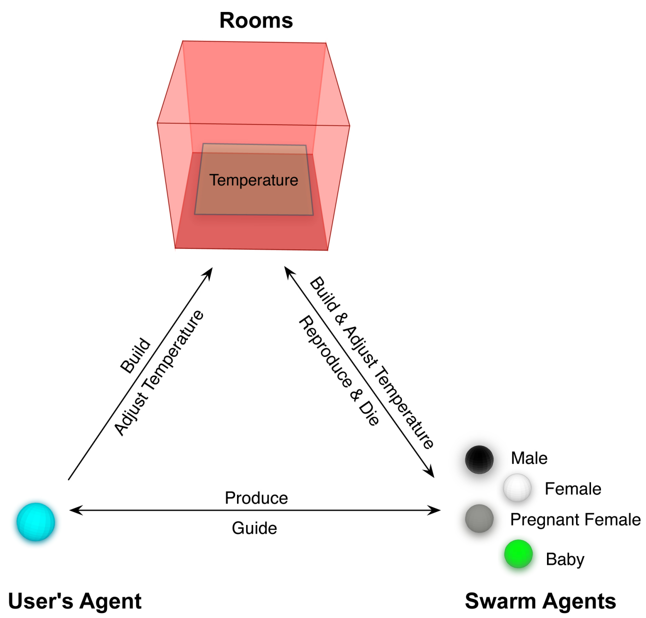


Fig. 2. The relationship triangle among three components: User's Agent, Swarm Agents and Rooms.

3.1 The User's Agent

A basic requirement for a meaningful simulation is a set of tools to direct and constrain the swarm agents to explore the architectural design space. We choose to implement that set of tools as a user's agent. The user's agent represents the user in the system and is controlled by him. It is rendered as a blue sphere, and its abilities are different then those of other swarm agents. The user's agent functions as an architect, coordinator and observer. It is responsible for shaping the initial space and leading the swarm agents to develop their habitat thereafter according to the user's will.

At the beginning of the simulation, the user's agent is located at the center of the first room. The user controls it via a motion detection system, which is introduced for facilitating the interaction between the user and the installation in a public exhibition space. In the motion detection window, there are three distinctly colored balls (red, green and blue) that the user can grab and move through gestures (Fig. 3). Among them, the red ball is used to direct the movements of the user's agent. Steering his agent, the user can build new rooms (as soon as a wall is reached) and increase or lower the current room's temperature. The user can use the green ball to control the swarm agents' moving directions or use the blue ball to make the swarm move towards the user's agent.

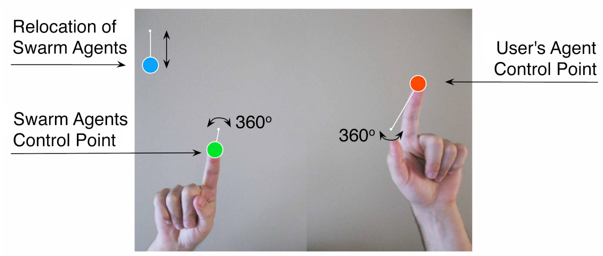


Fig. 3. Illustration of what the user sees in the motion detection window. Three colored balls are controlled by the user to direct the agents' movements.

3.2 The Rooms

The rooms are the building blocks of the architectural design; each room represents a spatial architectural unit that indicates the generation, structure and configuration of the space. Rooms can be assigned with attributes, such as the size and the room temperature.

The three-dimensional rooms are built on the xz-plane. New rooms are always attached to an already existing one, so that a continuous space is created (Fig. 4). Whenever a new room is created, an edge length for the new cube between 50 and 200 pixels is randomly chosen. The temperature in a newly built room is randomly selected from -30 to 30 °C. Rooms with a temperature over 0 °C are displayed in red colors, whereas rooms with a temperature below 0 °C are featured in blue colors. The room temperature can be influenced by both the user's agent and the swarm. In the meantime, different room temperatures trigger various behaviors of the swarm agents (Section 3.3).

3.3 The Swarm Agents

Lastly, the swarm agents function as both the constructors of the architecture and inhabitants of the built space. For instance, they could be seen as both the architects and construction workers of a mall, and the clients and vendors that

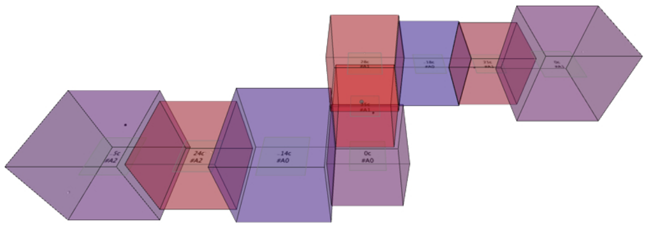


Fig. 4. Continuous space developed in the IBS installation.

make use of it. This dual identity is propitious to generate a lively architectural space.

Each time the user builds a room, a new swarm agent, whose gender is randomly assigned, appears at that room center. Without interferences from the user, swarm agents move freely in all directions inside the IBS. The perception field of a swarm agent extends to the whole room in which it is currently located. Its velocity correlates with the perceived room temperature, as explained in more detail in the following paragraphs.

Swarm Agents' Life Cycle A temperature between 1 and 20 °C is an ideal condition for an agent to reproduce, because it is neither too hot nor too cold. We call a room with this temperature range a delivery room, where male and female agents mate. During pregnancy, the female agent is depicted in grey color instead of white. After 300 frames, a baby agent is given birth to which is represented as a green sphere (Fig. 2). It takes another 300 frames for the baby agent to mature into adulthood. Again, the new agent's gender is randomly assigned. For the parent agents, the male agent has to leave the delivery room at least once before he can mate again; the female agent turns her color back to white after the delivery and is ready for mating again.

Room temperatures not only trigger mating and reproduction but also death. In rooms with temperatures below $-20\,^{\circ}$C, swarm agents die after 300 frames. We refer to these rooms as death traps.

Altering Local Environments The swarm agents have the ability to alter their local environments to achieve better living conditions. Firstly, the presence of five agents in any room increases the local temperature by 1 °C. Thus, given a certain number of swarm agents, the extremely low temperature in a death trap can be increased to a level suitable for the swarm to survive. However, this mechanism can also yield extremely high temperatures when large numbers of agents aggregate in one room. To avoid this situation, an additional rule is introduced to limit the individual agent's stay in the warm room (room temperature $> 0\,^{\circ}$C) to 600 frames. After that period of time, the agent has to leave.

Secondly, when there are 30 or more individuals in one room, the swarm agent that touches a wall first, will try to create a new room. If this new room does not intersect with any neighboring rooms, it will be built (Fig. 5). Consequently, the swarm agents can extend living spaces to alleviate their crowded living condition. The size of the new room is determined by the individual agent who builds it. Generally, the new room size is determined according to the agent gender. A male agent builds a room with a fixed value between 100 and 200 pixels, whereas the female one builds a room with a size between 50 and 100 pixels. The room dimensions of offspring follow their parents' preferences but introduce slight mutations (+/- 10 pixels).

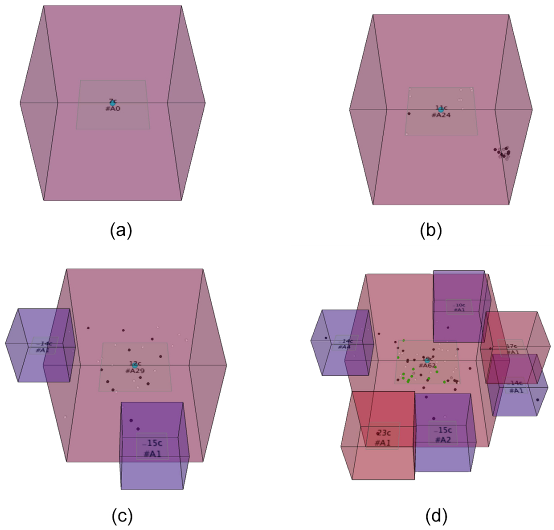


Fig. 5. Swarm agents shaping and exploring their new living space.

Observed Phenomenon By coding a set of rules, swarm agents have the tendency to stay at the warm rooms' centers, which makes them more likely to meet others for mating and reproduction. Conversely, swarm agents tend to escape from the center space when the room temperature is below $0\,^{\circ}\mathrm{C}$, so that they can increase their chances of survival. Therefore, over the course of a simulation, swarm agents have a tendency to congregate in warm rooms.

If it gets too hot (room temperature $> 20\,^{\circ}\mathrm{C}$) in delivery rooms due to overpopulation, those rooms are not used for reproduction any longer. On the other hand, since agents are only allowed to stay in a warm room for at most 600 frames at a time, agents gradually leave those rooms. As the agent numbers are decreased, room temperatures drop and the rooms can be used as delivery rooms again.

Pregnant agents are exempt from the rule of being rushed out of warm rooms after 600 frames. After the delivery, they are subjected to this rule again. Due to this special treatment for pregnant agents, male agents have a greater tendency of ending up in cold rooms. Therefore, it is more likely that male agents become the victims of death traps.

4 Design Results

By specifying a set of interaction rules, the IBS installation informs a self-organizing swarm. In addition, the user is capable of affecting swarm motions whenever it is necessary. During the simulation, both the user's agent and the swarm agents contribute to an architectural design process.

At the very beginning of the simulation, the user typically produces a number of rooms. These rooms are connected and form corridors that serve as the habitat for the swarm agents. Without the support by the swarm agents, the user creates orderly layouts as seen in Fig. 6. As the swarm population grows, the swarm agents begin to explore and extend their living space. The interactions of the self-organizing swarm agents result in interesting, organic-looking designs as shown in Fig. 7.

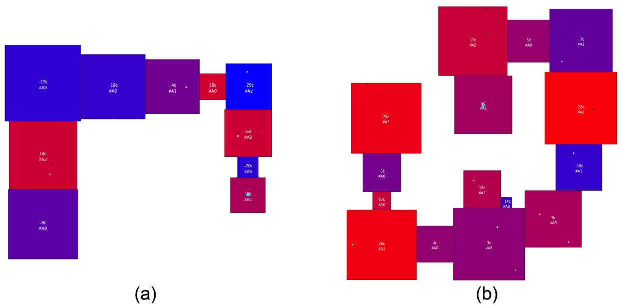
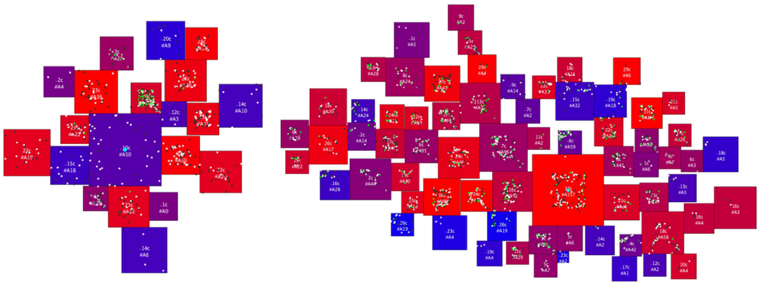


Fig. 6. Two 2D design examples developed by the user.

The simulation evolves an emotional connection between the user and the swarm. When there are few swarm agents in the system, the user usually feels responsible for populating the space with life. Specifically, when swarm agents went astray into the death traps, the user tends to redirect the agents' movements or tries to change local environmental conditions for the swarm, so that a small quantity of agents can survive. On the other hand, when swarm agents overpopulate the system, the user wants to limit the growth of the swarm agent population. Sometimes, the user might even actively try to reduce the number of



(a) (b)

Fig. 7. Two 2D design examples developed mainly by the swarm.

agents in the system. Such subtle relationships between the user and the swarm further diversify the design outputs, since the level of the user's intervention determines how much control is relinquished to an external force during the design process.

By combining the efforts by the user and the swarm agents, the design results achieve a balance between systematic, ordered planning and natural, organic growth. Fig. 8 documents such a collaborative work process. First, the user would develop the basic construction layout while swarm agents are busy in expanding their population (Fig. 8(a)). As their population grows to a certain level, swarm agents engage in the construction process (Fig. 8(b) and (c)). As a result, a number of newly built rooms are attached to the old structure (Fig. 8(d)). As time goes on, the original architectural layout by the user is gradually fused and merged into the new settlements. Fig. 8(e) finally exhibits these unfolding settlement patterns. For a personal experience with the IBS installation, please download it at: www.vonmammen.org/ibs/.

5 Future Work

The IBS installation allows a user to create and explore architectural design space. As everywhere on Earth, this space is populated with life, which re-shapes its environment. An interesting, collaborative design process between virtual swarm inhabitants and the user emerges that seeks an ecological balance between order and exploration.

For future work, we consider the following directions to improve the system's usability for architectural design processes. (1) Explore the IBS into the third direction by building new rooms in more than one layer. (2) Diversify the architectural forms by bringing in other building shapes rather than cubes only or even make the agents work on a generic 3D mesh itself by shifting, adding and removing its vertices. (3) Develop sophisticated behavior sets and allow rooms to disappear to achieve a greater structural complexity. (4) Enhance the practicality for architectural modeling by introducing evolutionary algorithms, e.g.

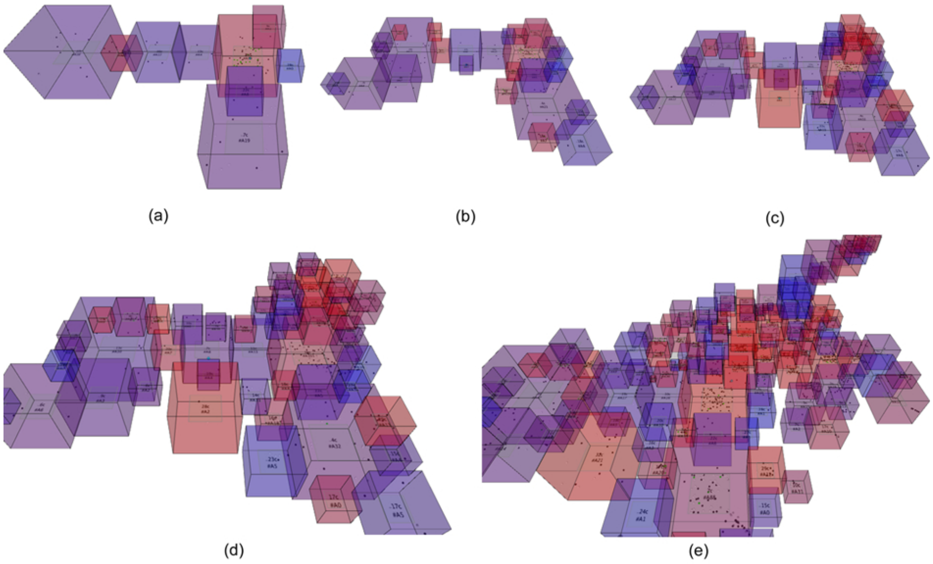


Fig. 8. A collaborative design process between the user and the swarm.

by providing separate breeding grounds for individuals swarms and means of interactive evolution to create swarms that support architectural design in unique ways. (5) Install the IBS in a public space and gain user feedback. (6) Translate the built constructions into real-world models and immerse the IBS into a complex virtual space with pre-existing architecture and diverse landscape.

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