Edge of Chaos

Towards intelligent architecture through distributed control systems based on Cellular Automata.

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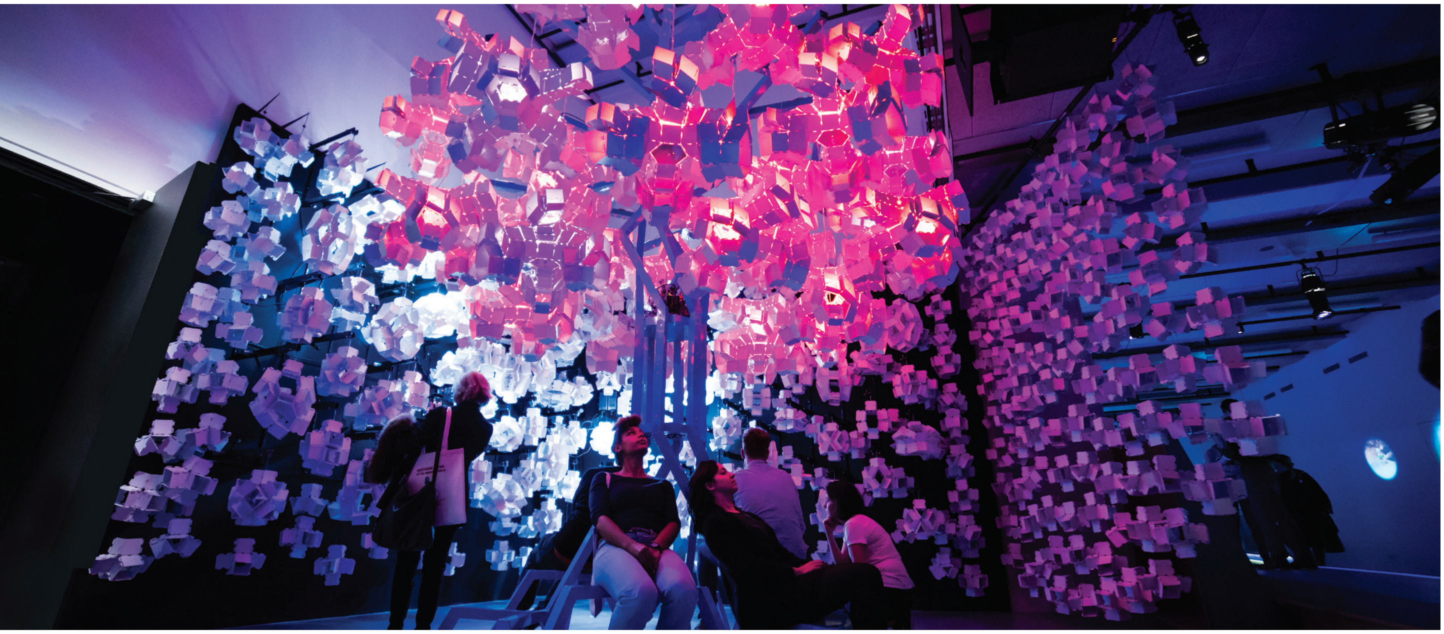

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1 Edge of Chaos Installation. Once the interaction with the visitors reaches its highest point, the kinetic tree comes into full bloom, demonstrating sequences of colors and kinetic transformation

ABSTRACT

From the "Edge of Chaos", a mathematical space discovered by computer scientist Christopher Langton (1997), compelling behaviors originate that exhibit both degrees of organization and instability creating a continuous dance between order and chaos. This paper presents a project intended to make this complex theory tangible through an interactive installation based on metamaterial research which demonstrates emergent behavior using Cellular Automata (CA) techniques, illustrated through sound, light and motion. We present a multi-sensory narrative approach that encourages playful exploration and contemplation on perhaps the biggest questions of how life could emerge from the disorder of the universe.

We argue a way of creating intelligent architecture, not through classical Artificial Intelligence (AI), but rather through Artificial Life (ALife), embracing the aesthetic emergent possibilities that can spontaneously arise from this approach. In order to make these ideas of emergent life more tangible we present this paper in four integrated parts, namely: narrative, material, hardware and computation. The Edge of Chaos installation is an explicit realization of creating emergent systems and translating them into an architectural design. Our results demonstrate the effectiveness of a custom CA for maximizing aesthetic impact while minimizing the live time of architectural kinetic elements.

INTRODUCTION

The "Edge of Chaos" (Figure 1) is the winning project to an international competition calling artists and architects to offer their "perspectives on the technological, dematerialized, complex environments and ubiquitous machines that have become natural elements in our lives" (Competition Brief 2017). The project is situated at the crossroad between architecture, design and physics, and this paper's primary focus is on the interaction and architectural design aspects of the work that reflect the use of reconfigurable metamaterials, distributed control, and bottom-up strategies for designing responsive environments. The work reflects the Interactive Architecture Lab's critical position on "Smart Architecture," "Intelligent Buildings," and corporate-led "Internet of Things," which, while espousing notions of ecology, remain dominantly driven by top-down strategies to controlling the behavior of the places we live, work, and play.

We have been examining ways of creating intelligent architecture not through Artificial Intelligence (AI) but rather through Artificial Life (ALife), embracing the aesthetic possibilities that can spontaneously arise from this approach. This attitude was first promoted to designers by John Frazer's pioneering work at Cambridge, UK and later at the Architectural Association (Frazer 1995), and have since propagated internationally, particularly in formal research. Our interest has been primarily in the behavior of real-time responsive and inhabitable environments, a less well explored field but with recent notable works by Beesley (2014) and Haque (2006).

The project we describe here is an interactive installation touring three venues in Europe in 2018 which, at the time of writing, is on exhibit for two months in the public gallery La Gaîté Lyrique in Paris. The competition brief provoked a response by our team to the statement, "We are entering an era of hybrid ecology: AI as landscape, networks as biotopes, data as organisms and media as humus. Where do we go from here?"

Taking inspiration from cellular automata, we developed an inhabitable interactive environment based on Christopher Langton's theory of the "Edge of Chaos". The theory examines the balancing point where "the components of a system never quite lock into place, and yet never quite dissolve into turbulence either... the edge of chaos is where life has enough stability to sustain itself and enough creativity to deserve the name of life" (Waldrop 1993). When John Conway published his binary-state cellular automata famously titled *The Game of Life* in 1970, it became the defining example of the enormous emergent potential of even the simplest of rule bases. William Gosper, a leading programmer at MIT's AI Lab described it as giving "the ability to do everything from animal husbandry to recursive function theory" (Levy 1993) and Conway himself believed The Game of Life might support the emergence of any known animal, as well as unlimited novel new creatures. In the development of our installation, however we were to discover that the Game of Life Algorithm did not suit our aims for spatial interaction and so we developed a custom CA presented in this paper.

Christopher Langton's theory of the "Edge of Chaos" describes a mathematical space and the relative locations of static, periodic, chaotic, and complex features. Periodic features can be considered like crystal growth. Patterns emerge, yet they are too limited to support life. Chaos is where information is completely unstructured, or cannot maintain structure for long. Only within a small region we find information with stability but enough dynamic interaction with its surrounding environment to have "life-like" behavior. The field of complex adaptive systems theory examines how order emerges in the chaos of the universe, how non-linear systems such as ecologies, markets, social systems, and the human brain self-organize.

In order to gain insight in this rather complex "Edge of Chaos" theory, we developed an interactive kinetic installation in which the immersion in the experience allows for the creation of life. In the context of the competition we found a means to make these ideas of emergent life more tangible in four integrated parts, namely, narrative, material, hardware and computation.

METHODS

Interactive Narrative

The installation is composed of three features. At its center, a kinetic tree (animated by servo motors and RGB LEDs) that represents "Life" (the peak of the Edge of Chaos). It is surrounded by an inert "Cloud" representing the vast unorganized matter of an entropic universe (Chaos), and between them an interactive surface (animated by DC motors and White LEDs) that represents the "Edge of Chaos".

The movement and proximity of inhabitants of the installation measured by proximity sensors activates the "Edge of Chaos", triggering spontaneous patterns that light up and reconfigure the surface. The spontaneous patterns originate from our custom cellular automata, leading to chain reactions of activity throughout the surface. When the "Edge of Chaos" surface becomes highly active, the tree "comes to life," blossoming into full color and performing its most dramatic kinetic movements (Figures 2-3). The design

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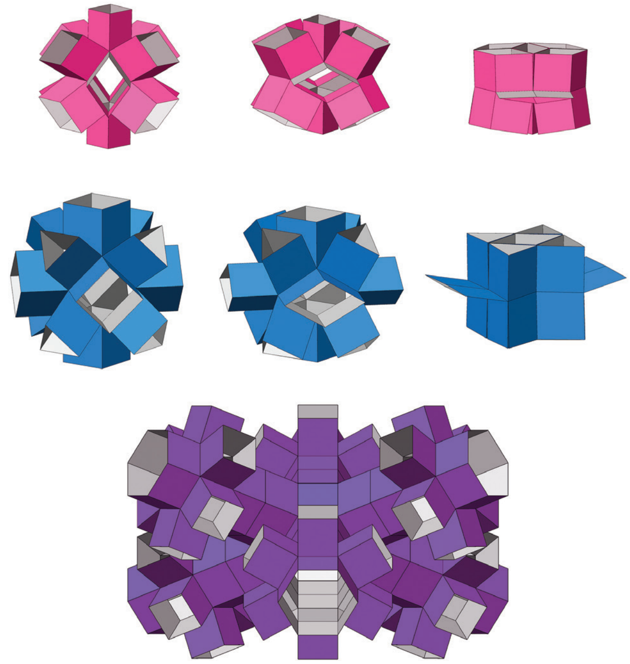


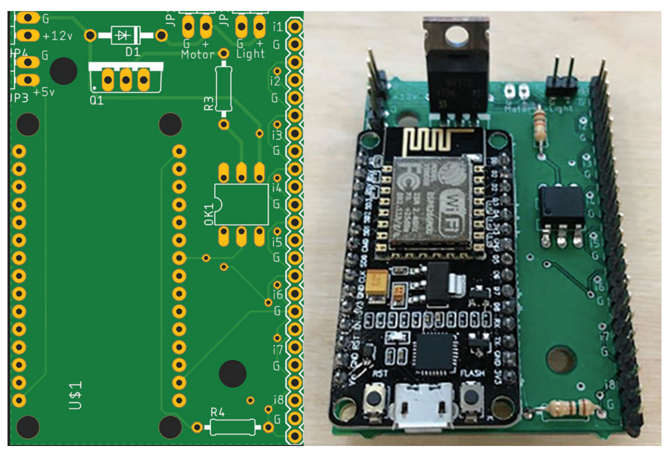
4

of the 3.5 meter high tree (made up of 52 meters of blue powder coated aluminum box section) offers a structure for visitors to sit and lay back to look up at the foliage creating a contemplative space at the center of the installation. Embedded speakers play a looping 20-minute-long bespoke soundtrack inspired also by the aforementioned theories of emergent behavior.

Metamaterial

Metamaterials are materials that get their properties from their structure, rather than their chemistry They are man-made materials of the future, and exhibit properties that do not yet exist in nature. Most such materials are characterized by a fixed geometry, but in the design of some materials it is possible to incorporate internal mechanisms capable of reconfiguring their spatial architecture, and in this way to enable tunable functionality. Inspired by a design strategy based on space-filling tessellation of polyhedra for the development of reconfigurable prismatic architectures (Overvelde et al. 2017), we grew interested in translating these thin-walled geometries into spatial design to create flexible and transformable spaces with tunable functionality.

We constructed a variety of three-dimensional reconfigurable elements using 25,000 identical building blocks. In total, we created 500 individual geometric units, of which 400 are found in the “Cloud” (Chaos) and the remaining 100 constitute the interactive layer depicting the “Edge of Chaos”. Different assemblies were used to differentiate chaos and complexity (Figure 4)—for the Chaos, we used more basic templates of polyhedra, such as the cube and triangular prism, while for the interactive surface we used the truncated octahedra, hexagonal prism, rhombic dodecahedron and cuboctahedron as more intricate structures. For the tree foliage, we designed 36 units based on a template comprising a combination of truncated octahedra and hexagonal prisms, representing larger units that in the context of the “Edge of Chaos” theory, could only exist in ordered systems.



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Embedded Hardware

Equipped with ultrasonic proximity sensors, the surface gets triggered and actuated by the presence of visitors, interacting through compelling physical transformation and light. Increased human movements stimulate the chaotic patterns on the surface until triggering the tree of life.

6

2-3 Tree foliage made of transformable kinetic geometries, consisting of 36 complex combinations of truncated octahedral and 6 hexagonal prisms

4 Pink: Rhombic Dodecahedron
Blue: Cuboctahedron
Purple Tree Foliage: made of combination of truncated octahedron modification and 6 hexagonal prisms

5 Custom made PCB breakout boards with NodeMCU boards and wireless integrated ESP8266 attached

6 Chaotic and orderly patterns appear across 100 haptic kinetic units on the interactive surface run by a cellular automata algorithm

The original goal was to use 100 modules working together as a cellular automaton, in which the local communication protocol would lead to global emergent behavior. While we implemented and achieved emergent behavior in our installation on a software level, for the Paris installation we used a centralized hardware approach. We did develop several working modules, but due to time and money constraints this was not a feasible approach for the current installation. For the modules, we adopted a layered approach. In the first layer, each module needed to be aware about its immediate neighboring module's states. The second layer was a variety of CA rules accessible to all the modules wirelessly. This would enable us to change the rules centrally and immediately observe the effect without the need to individually re-program all 100 microcontrollers.

The robustness and the cost were crucial aspects in the choice of controller. Several methods were tested (including a low-tech use of Morse code sound messaging). Finally, NodeMCU boards with wireless integrated ESP8266, a popular Internet of Things hardware solution were chosen using the 'io.adafruit.com' service. Effectively, each module acted like an IoT device, and could check and update rules periodically from an online database. Though the setting of CA rules was controlled wirelessly, the NodeMCU boards communicated with each other through direct wired connections to their nearest 8 neighbors (less with cells on edges of the surface). Finally, each module was designed to drive a 12V DC motor and White LED Capsule Bulb. After testing several electronic circuits, the final PCB was designed and manufactured (Figure 5)

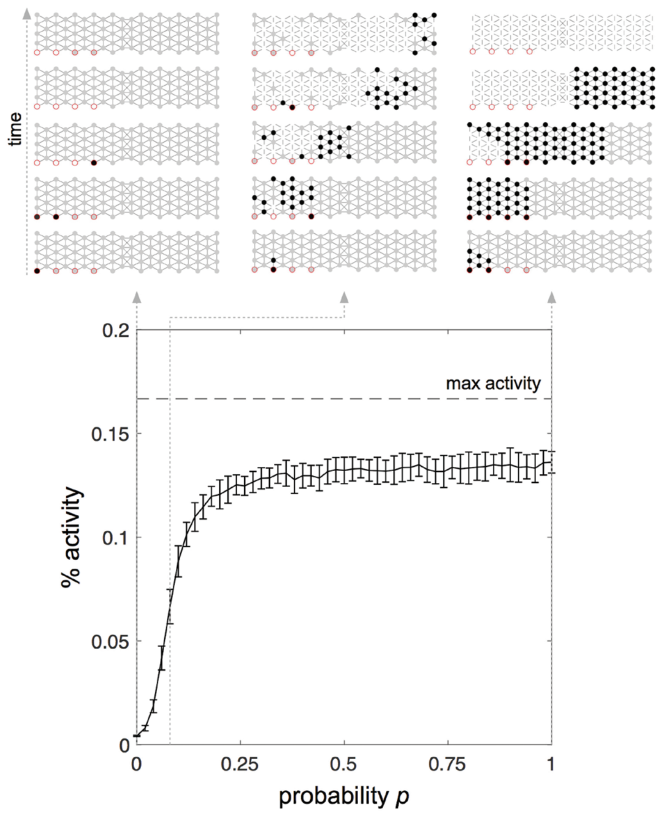
Computational

While for our Paris installation computation was performed on a central computer, we were able to simulate in our software distributed control of cellular automata so that effectively each unit is acting by itself and activity depends only on the state of the neighbors (Figure 6). Note that the typical implementation of CA such as the Game of Life (Conway 1970) is deterministic i.e., it always responds the same way to the same input. Moreover, creating stable patterns that are not overdamped or unstable requires precise tuning of the rules that govern the behavior of the CA.

RESULTS

To create emergent and stable patterns, on top of the Game of Life CA, we implemented an additional state leading to a total of three states for each cell: listening (0), active (1), and sleeping (2). Different behavior was achieved by implementing a stochastic response in the behavior of the CA (Hoekstra et al. 2010). During each time step, each listening cell checks the state of the neighbors. If the total sum of the neighbors being active is equal or higher than n, the cell becomes active but only with some probability p. Once active, the cell remains active for s_a steps, after which it goes to sleep. Finally, after sleeping for s_s steps, the cell starts listening again. Given a network of cells with connections to their neighbors, changing these four parameters tunes the behavior of the total system.

Figure 7 gives an example of different behavior that can be achieved by tuning the probability p, ranging from deterministic waves for p=1, to stochastic activation that moves



7 Simulation results of implemented CA-based code. Depending on the probability (p) of cells to become active, different behavior can be achieved. The graph shows the percentage of activity for each probability averaged over 40 simulations each with 1000 time steps, in which n=1, s_a=10 and s_s=60. To illustrate the connectivity between cells used for

through the whole network for p≈0.1, to overdamped behavior for p<0.05. On their own, the parts of the installation do not show any emergent behavior, while together as a group they do collectively reconfigure in stable, yet slightly stochastic patterns. Note that the behavior is always different, even when the same set of sensors is triggered. While popular CA algorithms such as Game of Life are compelling, they were not found to be as successful as an implementation in our architectural design. As the installation was intended to run for months at a time, interactive motion and lighting needed to be limited to periods where there is stimulation in the environment by visitors to the gallery space. When there are no inhabitants, the installation must in effect "die out". The results of this enquiry demonstrate alternative strategies for maximizing aesthetic use of CA rules which minimizes the live time of kinetic elements.

This approach also suggests modes of environmental activation and deactivation that are robust as well as playful, and suggests approaches to intelligent architecture based on ALife principles. The resulting interactive installation, physically built and operational (Figure 8), is currently exhibited in Paris. After this, the Edge of Chaos installation will travel to Amsterdam, Namur, and finally Togo, Africa, where we will be able to collect data on occupancy to further our research.

CONCLUSION

When observing the emerging patterns of our installation (Figure 9), we can recognize Langton's mathematic and theoretical principles of "Phase Transition" where the structures are able to grow, split, and recombine in spontaneous and surprising ways. This area represents neither Order nor Chaos but lives in between, thus never becoming predictable nor too unpredictable to lose the interest of observers. The installation also demonstrated the simple but compelling appeal of interaction that irresistibly appears with responsive objects that move.

Many people visiting the installation would promptly reach for moving geometries, whether in the wall or in the tree. When noticing that seemingly inanimate matter suddenly becomes alive, visitors initially pull back, but a moment later become inquisitive. The open-ended and semi-unpredictable behavior of the Edge of Chaos installation encourages continued play as inhabitants search for understanding in a field of interactions that while controlled by simple rules display complexity by virtue of emergent properties and complex and changing environmental stimuli. Our implementation of custom CA code is effective on aesthetic grounds but also in minimizing wear and tear of multiple long-running exhibitions which contributes to possible applications in longer term architectural applications. Our narrative and spatial approach proves a novel and tangible approach to communicating abstract mathematical theories of complexity. It is also a celebration of the creative possibilities of collaborating across science and architecture.

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8

8 Immersive atmosphere inside Edge of Chaos as visitors walk around the kinetic tree, triggering kinetic transformations at the Paris exhibition

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IMAGE CREDITS

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NOTE

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