endo/exo : Making Art and Music with Distributed Computing

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ABSTRACT
What do new possibilities for music and art making look like in a world in which the biological and mechanical are increasingly entangled? It is with this question in mind that the interactive mechanical sound art installation endo/exo came into being. Through the use of networked technology, the system becomes more like a self-aware organism, passing messages from node to node as cells communicate through "chemical signals" with their neighbors. In an artistic context, the communication network resembles, but differs from, other mechanical systems. Issues such as latency are often considered negative factors, yet when leveraged purposefully, they can contribute a touch of personality in this context.

This paper is a reflection on these and other considerations gained from the experience of designing and constructing endo/exo. Additionally, it considers future implications for the Honeycomb platform as a tool for creating musical interactions within a new paradigm that allows for emergent behavior across vast physical spaces. The use of swarming and self-organization, as well as playful interaction, creates an *aliveness* in the mechanism, and renders its exploration pleasurable, intriguing and uncanny.

Keywords
Robotic musical devices, emergent behavior, sound art, actuation, distributed computing, honeycomb, algorithmic composition

1. INTRODUCTION
Artists have always been interested in emerging expressive possibilities, and therefore often curious about the most recent technologies. Technology has always been a material projection of human ideas—an artifact—but recently the projections and the "projectors" have been developing closer relationships. Endo/exo was developed as part of the mechanism/organism exhibition at the David B. Smith Gallery in Denver, Colorado, USA. It is an interactive installation that participates in the traditions of kinetic sculpture, sound art, fiber art, and light works, while exploring new environments for creating sounds algorithmically and acoustically. It leverages a new networked microcontroller platform called the Honeycomb[3], in which each node is identical and creates a system of behaviors that are based on local conditions and communication with neighboring nodes.

At first glance, endo/exo is a study in stark contrasts. The large gridded exterior is fabricated from hard, industrial materials and features sound-producing mechanical objects, which are seen in silhouette. The silent interior, a volumetric textile membrane, is glowing with intense, continuously modulated color, and is constructed with soft materials that have been worked by hand into a web of amorphous shapes.

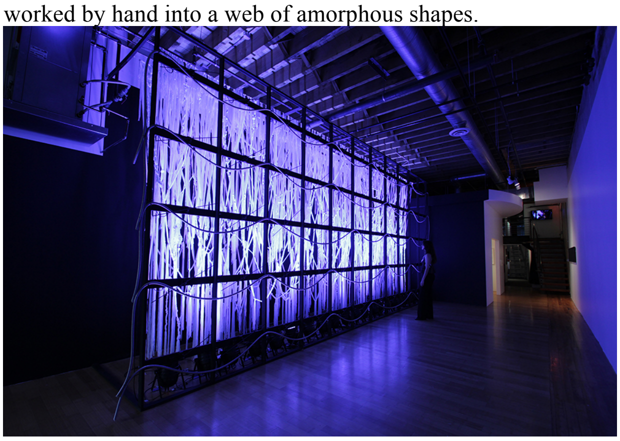

Figure 1: endo/exo, installed at the David B. Smith Gallery

Left to its own devices, the installation mimics various natural cycles, such as the winds that rhythmically rustle grasses in an open field, or waves that advance and recede in ever-changing patterns, resulting in a visual and auditory spectacle enabled by emergent properties of the networked system.

As we grow accustomed to new pervasive technologies, most of which serve us in our daily lives, a new level of comfort with connectedness to information and others is developing. However, interactions with systems, which impose their own preferences and tendencies, could still be unfamiliar to some. The response is typically fascination, and even uneasiness, as one proceeds to explore the unknown. We have learned to accept various roles of machines in our lives; new encounters with them allow us to explore the edges of the "uncanny valley"[8] of lifelike robotic organisms, while finding pleasure in the excitement of the eerily familiar. For instance, as the installation waves roll by and one listens to the sound of wood on metal, it becomes easy to imagine a creaking ship pitching in the sea.

2. RELATED WORK AND IMPLICATIONS
A number of installations have explored the boundaries of the biological and mechanical through the use of physical actuation to stimulate the uncanny sensations of life in the inanimate. Nils Völker's *One Hundred And Eight*[15] inflates and deflates plastic bags in patterns across a wall to create flow and movement that can be likened to breathing. Much of Philip Beesley's work, such as his installations in the *Hylozoic Soil*[2] series, uses physically imposing immersive environments to transport the viewer into another world. Through simple movements of the installation's tendrils, life is given to the lifeless. Meanwhile the design team Humans since 1982, developed the installation *A Million Times*[5], which

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beautifully exemplifies the way simple, choreographed oscillations cascading across a wall can create motions that mimic waves found throughout nature. *Endo/exo* shares the uncanny lifelike behavior of *One Hundred And Eight* and *Hylozoic Soil,* and the mimicry of natural waves found in *A Million Times*.

The study of flocking algorithms with distributed models for computer animations provides insight into how behaviors in distributed computational systems might be programmed[11]. Accordingly, the current installation further explores the self-organization and herding algorithms first utilized in *Swarm Wall*[4], a work based on the same hardware platform, and that also explored several interactive concepts revisited here. Like *Swarm Wall*, the overall aesthetic of *endo/exo* has drawn inspiration from biological forms, but here, the motion of the mechanism has been further refined and interactions made more convincing[14].

Mechanical musical actuators have been explored for years. In the 1800s player pianos and orchestrions became popular, usually powered pneumatically[10]. In more recent years electromechanical robotic actuators have been explored in a variety of settings [6, 13].

While *endo/exo* has drawn on a variety of artistic inspiration and technical fields, the combination used in the final execution yields a unique experience and exploration of a new paradigm for creating art and music with the aid of distributed computing.

3. INSTALLATION

The site-specific installation consists of a grid of 55 nodes, and is 8.5 m wide by 3.8 m tall and 1.5 m deep. The intelligence of endo/exo resides in a distributed network of custom microcontroller boards known as Honeycomb[3]. The installation is built out of light frame material that were built in sections off site. The gridded exterior provides the structure to mount the servo motors, with 75 cm wooden dowels fixed to the motors, draped conduit, long range infrared (IR) proximity sensors, and the circuit boards and corresponding cabling. The framing is left open, leaving picture windows to view the interior, which consists of meticulously hung, tied, braided and draped white polyester yarn, and which takes up much of the depth of the installation. The depth also leaves room for high powered, DMX programmable LED stage lights, for which the yarn becomes a projection surface, causing it to glow in continuously changing patterns of color and light. (The lights were controlled by an independent program that cycled at a much slower rate than the sound component.)

4. TECHNOLOGY AND MATERIALS

Each node consists of one Honeycomb board (depicted in green in figure 2) and one servo-motor. The boards are interconnected to have bi-directional communication with four neighbors (up, down, left and right): connections are depicted in figure 2 with orange cabling. Each node in the bottom row has a long-range IR proximity sensor attached to detect presence across the breadth of the system. Due to the configuration of the installation, a majority of the nodes are above the viewers, and therefore each column uses sensor data from the bottom row to identify presence on a column. The flexibility offered by this platform enables arbitrary configurations and numbers of nodes without any changes to the coding. A newly inserted node will be automatically programmed by the system and identify its position and associated role.

4.1 Honeycomb

Honeycomb is a microcontroller platform that can easily be networked into hexagonal lattices of hundreds of nodes to create novel materials that tightly integrate sensing, actuation, computation and communication. Each PCB consists of an Atmel Xmega 128A3 microcontroller and auxiliary electronics. This microcontroller was chosen for its seven hardware serial ports, which allows two-way communication with up to six neighbors (in addition to a debug output). The serial connections (two wires, one for sending, the other for receiving data) are made available via standard 8-pin RJ45 jacks, which allow using off-the-shelf Ethernet cabling for connections. The remaining six pins of the cable are used for power and ground. By this, all boards share a common power supply and can distribute power to its neighbors. Servos are connected to the microcontroller's built-in pulse-width modulation (PWM) outputs, and the IR proximity sensors are connected to one of the microcontroller's analog inputs.

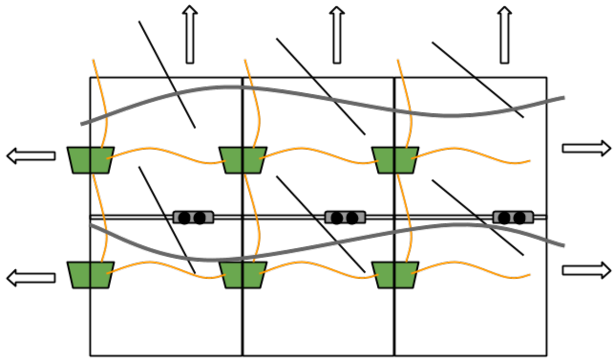

Figure 2: Depiction of 3x2 node section of endo/exo with Honeycomb connectivity

The boards use a viral bootloader that allows new programs to automatically propagate throughout the system by simply programming one board. The main program receives pertinent data from the neighbors, including sensor data, current angle and a strength variable, which represents physical presence detected some distance away in the system.

An alternative version of this platform was used to create a localization solution for the hearing impaired, with a wearable garment utilizing microphones to create a sensor array to perform the sound localization[9]. In that project, haptic feedback is provided with vibration motors sewn into the garment to indicate the direction of sound.

4.2 Sensing Presence

The detection of people for this installation was accomplished with a long range IR sensor (Sharp GP2Y0A710YK), which has a range of 100–550 cm. To create pronounced effect when presence is detected, a distance threshold with a programmed hysteresis was used to alert the program of presence at a given node to reduce false triggers. In order to be able to respond to presence in the system to varying degrees (depending on the location of the presence), a value of 1 is assigned to a column currently detecting presence. The messages are passed to the left and right, where the strength of the presence signal is diminished with an exponential decay, allowing immediate neighbors to "feel" the presence more strongly than nodes further away. Each board continually calculates and sets a new position for its servo motor based on the current mode (mood) of the system, stimulus from the environment as well as its neighbors state. In this way viewers can interact by moving throughout the space, influencing the movement and generated sound.

4.3 Sound Actuation

The sound component of the installation is created acoustically by wooden dowels physically scraping along a ridged, aluminum electrical conduit. The conduit becomes like the guiro, a Latin American percussion instrument, normally made of wood and played with a wooden stick. The wooden dowels are directly attached to a 180 degree servo motor, which is controlled by the Honeycomb board. When swept slowly, the individual ridges of the conduit are audible, while at high rates they become one brisk gesture. The physical motion of a node is inextricably tied to the associated sound created by the motion. The result is a satisfying stimulation of the visual and aural senses that the physical world readily offers us.

There is an incredible range of sounds offered by this setup. At times a single node interrupts silence, while at other times, all 55 nodes fill the space with powerful sound. The physical size of the installation spatializes the acoustic sound sources across the 32.5 square meters of the installation, which contributes significantly to the experience of space and the kinetic movement of the sculpture.

4.4 Programming for visuals and sound

A primary goal for the sculpture was the creation of a convincing, natural sense of movement and sound. To this end, we employed several approaches familiar to sound synthesis and audio effects, and developed a library of functions to enable rapid exploration of ideas. Our workhorse building block was simple harmonic motion, modeled as a sine wave. The sine function was used to set the angle of the servo, with the amplitude determining the angular sweep. Delay lines throughout the system were another important component. Because of the networked nature of the platform, it is convenient for each node to know the behavior of its neighbors, and to respond accordingly. By using a short delay, perceptible waves propagate throughout the system. When timed appropriately, these can create mesmerizing visuals and enhance the sense of space and movement when hearing the sound move across the room.

When these basic functions are combined and orchestrated across this large-scale network of sound actuators, they take on new life, with the relationship amongst neighbors making the end results considerably richer. Dowels sweep across the conduit in and out of phase, producing a pleasing audible and visible interplay between the nodes that can at times be likened to Steve Reich's phasing music[12]. In the following section some of the programmed behaviors are described.

4.4.1 Behavior Cycles

When left undisturbed the system cycles through seven behaviors, changing modes every 90 seconds. The transition between modes captures the last angle of the previous mode and linearly interpolates to the newly calculated.

One behavioral mode uses a modulated delay line to propagate waves across the installation. For these, the far left column determines the behavior, which is then mimicked to the right. The columns use messages from their neighbors relaying their current angle, which is stored in a circular buffer at each node. The delay from node to node is then slowly modulated with a low frequency oscillator (LFO)—spanning from no delay up to 1 second, depending on the specific mode. Types of movements that were passed across the structure included a sine wave, an amplitude modulated (AM) sine wave, and a frequency modulated (FM) sine wave. In addition to the wave based motions, a quarter wave "raised cosine" sweep (starting with a quick transition) was also used to accentuate the percussive nature of the medium. The periods and amplitudes of the various motions were selected experimentally, initially using Max/MSP for control to identify motions that looked and felt natural and interesting.

Another mode uses a weighted average of the neighbors' angles to mimic the natural flocking of birds, fish and herds of animals. Many of these principles are taken from concepts introduced in early computer flocking models[1]. Each node has a unique, preferred harmonic frequency, which it randomly selects upon initialization of the mode. It then listens to its four neighbors to determine their current angles, and comes up with a new angle based on its own preference and the neighbors' current states. This creates a mesmerizing pattern throughout the system that shows the influence of a cluster behaving similarly, but the influence of one node fades as your gaze moves across the system. The amount of weight the system gives to the neighbors is modulated with an LFO over 20 seconds, creating cycles of close unison, which then transition to a more chaotic behavior where the nodes more or less ignore their neighbors. The resulting emergent behavior is directly related to the size of the system and individual and algorithmic "personality" of each node.

The final mode contrasts the active modes previously described by remaining mostly at rest but randomly calculating a time at which it will briefly activate a quick and subtle twitch. In this mode, a single node may only move once in ten seconds, but with the whole system going, an intricate dance permeates the installation as the nodes sporadically activate.

4.4.2 Interaction Responses

By engaging one of endo/exo's sensors, the observer elicits a variety of responses, ranging from empathetic, mirrored movements to sudden and bemused silence. The audience realizes that the work is watching them, just as much as they are watching it. Each behavior in the cycle has a corresponding sensor response. Some of the responses are subtle, only affecting a local column, while others are quite overt, eliciting a response from the whole system. For instance, in the fast and chaotic finale of the cycle, the entire system abruptly stops and "points" at the viewer upon detecting presence: the closest column becomes vertical while other columns splay out at ever increasing angles to create a large-scale gradient of angles pointing at their object of affection. The abrupt response of the system in this case is impacted by a small amount of delay, allowing you to watch the messages get passed throughout the system as the motors respond successively. The delay is due to system latency based on the communication rate and overhead—not a programmed delay—although in this case it contributes to create a satisfying effect. Meanwhile, another mode chooses an angle at which to pause, perhaps nervously holding its breath, while the viewer is near. Another response is a joyful shake of the column, which sometimes remains local and sometimes spreads out in all directions.

An additional response leans toward the more human attributes of musical rhythm, which the system is well equipped to facilitate: a patterned rhythmic response that turns the installation into a massive, algorithmic drum machine. This interactive behavior derives from the world of compositional algorithms in computer music. For years people have been fascinated with using computers to generate new music based on algorithms[7]; only in recent decades have machines have become powerful enough to do so in real time. A novel feature of the current design is that the algorithms are computer via distributed computing, calculating a new pattern to play each time presence is detected. If more than one column detects presence, complicated patterns will emerge, spatialized by the physical distances of the different columns. This mode of interaction turns the entire installation into a large-scale, multi-user instrument, which can be played by stepping towards and away from the structure.

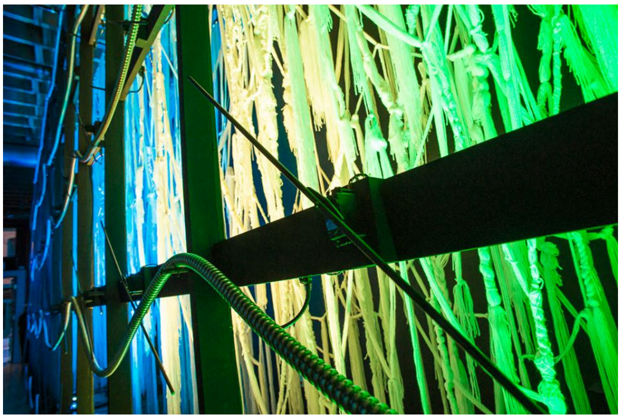

Figure 3: Close up of endo/exo showing servo motor, dowel scraping electrical conduit and yarn detail

5. REFLECTIONS

A number of challenges are unique to the particulars of this project. These include a paradigm shift towards distributed systems as opposed to a centralized computing model, synchronization of the nodes, mapping behaviors spatially, and prototyping, as well as the physical challenges when fabricating a new interface with off the shelf raw materials.

In distributed computing systems such as Honeycomb, each board is running an identical piece of software but is responding to its own context. For instance, with endo/exo, each board becomes aware of its location in the system by noting which ports it is actively receiving messages from.

One of the resulting challenges of such a system is synchronization. With no central computer keeping track of cycles, the variations in the boards' oscillators causes drift from their sense of time, which can in turn cause complications with time-based algorithms such as sine functions. For instance, if the columns are following a delayed version of their neighbor with the delay amount fluctuating with a sinusoidal LFO, clock drift will cause noticeable discontinuities as a wave propagates across the system. Some of these issues could be addressed by looking again to biological inspirations to make distributed computing systems more robust[1]. For instance, another potential approach might include exchanging more information with neighbors about a node's present state, including its sense of time.

6. FUTURE WORK

We believe the Honeycomb platform offers a promising approach worthy of further exploration in music making. The software that was developed for this project will be made open source, and we hope this will provide a stable starting point for future work. Algorithmic compositional approaches which take into account more information about the neighbors' patterns and current state as well as a more refined sense of musicianship will help produce a dynamic and scalable robotic musical ensemble. The affordances of the networked system create unique opportunities in this space.

Presently, we plan to create a small scale version of this system, which will result in a more personalized interaction and allow for each node to be physically accessible for a single user to stimulate and control as an instrument or interaction, with networked and emergent properties.

7. SUMMARY

We presented here the description and development details of the interactive art installation titled endo/exo and the development of its core technologies. It leverages a newly developed microcontroller platform called the Honeycomb, which utilizes distributed computing technology. Each percussive actuator creates sound acoustically with a wooden dowel and ridged conduit, which are physically spatialized across the installation. The motivations and programming of the behaviors and various interactions were described. The networked nature of this system offers a new paradigm for creating sound and visuals across vast physical spaces. The potential for further research into emergent behaviors for both visuals and sound provide interesting areas for further research.

8. ACKNOWLEDGMENTS

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