Murmur: Kinetic Relief Sculpture, Multi-Sensory Display, Listening Machine

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ABSTRACT
In this paper we describe the concept, design, and implementation of *Murmur*, an interactive kinetic display made of one hundred computer CPU fans. Murmur responds to sound input from its environment via embedded microphones to produce patterns on a reactive surface. The reactive surface consists of hinged paper pieces situated in front of each fan. When activated by sonic elements in the environment, including sounds intentionally generated by an interactor, Murmur responds by turning on and off its fans in a sequence. The wind pressure generated by the movement of the fans stimulates the surface, forcing the paper up and out to create a variety of dynamic patterns. Each pattern represents characteristics of the sonic environment. We also analyze the feedback received from the interactors and discuss the possible ways of making the interaction more immersive.

Author Keywords
Multi-sensory displays, ambient displays, mechatronic art, interactive art, information visualization, CPU fan, wiring

ACM Classification Keywords
H.5.1 [Information interfaces and presentation]: Multimedia Information Systems----*Audio input/output* H.5.2 [Information Interfaces and Presentation]: User Interfaces---Auditory (non-speech) feedback, interaction styles; Screen design (e.g., text, graphics, color) J.5 [Arts and Humanities]: Fine arts, Performing arts.

INTRODUCTION
Murmur is a multi-sensory display, interactive kinetic relief sculpture and listening machine. The design intention is to balance these elements so they enhance one another and are still compelling when considered separately. This installation utilizes the qualities of multi-sensory displays, mechatronic art, ambient displays and interactive art, while addressing aspects of information visualization.

TEI 2008, February 18–20, 2008, Bonn, Germany.

Figure 1. Close up of *Murmur*'s reactive surface at the *Listening Machines* exhibition at Eyedrum in Atlanta.

The installation has been designed with conceptual and interaction goals as follows:

Conceptual Goals
- Appropriate computer fans as a medium for information delivery
- Create a cohesive work by integrating the sensors in the art object instead of locating them near the object
- Take inspiration from the appealing union of form and function in CPU fans to create a more complex object which embodies these qualities.
- Create a multi-sensory display that appeals to at least three senses (audio-visual-tactile)
- Balance the use of analog and digital elements.

Interaction Goal
- Create an object that connects people with the space they occupy by bringing awareness to how their presence affects their environment.

In this paper, we begin by situating *Murmur* within the context of related works. Next, we describe the components and mechanics of the piece, our implementation process, and the interaction patterns that *Murmur* provides. In addition to these, we discuss feedback received from the interactors at a public exhibition of the piece, and indicate direction for future work.

RELATED WORK

Analogue media is based on a continuous representational plane while digital media operates on a discrete system. There is a long tradition of painting, film, architecture, sculpture, and new media works that use analog equipment to produce discrete signals. These works include: pointillist paintings by Seurat, Signac, and Cross; Alexandre Alexeieff and Claire Parker's pinscreen animations such as *The Nose* [1]; Jean Nouvel's building *Arab Institute* [2] in Paris; Daniel Rozin's *Wooden Mirror* [3]; Aram Barttholl's *Random Screen* [4]; Chaos Computer Club's (CCC) *Blinkenlights* [5], Duncan Wilson's *Pixelnotes* [6]. Scott Snibbe's *Blow Up* [7]; Hiroshi Ishii, Sandia Ren, and Phil Frei's *Pinwheel Installation* [8]. Dan Roosegaarde's *Flow* [9]. Christopher Bauder's *Electric moons* [10]. *Charles Forman's Interactive Waterfall* [11].

Our installation, *Murmur* takes inspiration from all of these works to utilize analog media for creating discrete signals. However, *Murmur* differs from such sculptural and new media works as it addresses a novel design problem: using intentionally or non-intentionally crated audio input to illustrate the presence of people in a room by cohesively combining a novel set of materials. The environmental, conceptual and material constraints of this design problem constitute Murmur's differences from the relevant-prior work.

Environmental Constraints

Specifically, *Murmur's* interaction with its environment is designed to be dependent on the nature of the sonic space it inhabits. It is designed to respond to both intentionally and non-intentionally created sounds in the space. In contrast, Scott Snibbe's *Blow Up* takes intentionally created audio as an input.

Conceptual Constraints

Even though fans are the basic material of Scott Snibbe's *Blow Up*, Snibbe's work separates input and output parts of his installation. *Murmur* aims to be a cohesive work by integrating the sensors in the art object instead of locating them near the object.

Material Constraints

Flow and *Murmur* seems similar with their use of material. However, *Murmur* is different from *Flow* because of two main reasons. Firstly, we began designing *Murmur* in 2006, prior to the exhibition of *Flow* in 2007. Consequently, we were not aware of the presence of *Flow*. Secondly, *Murmur* has a paper-based interface in between fans and interactors. It creates discrete signals by using two layers of analog media: computer fans and a display surface made of paper pieces while *Flow* uses only fans.

Moreover, *Murmur* takes only audio input and executes audio-visual-tactile output by using CPU fans acting on paper pieces while *Flow* takes audio and movement inputs and converts them to visual output. The CPU fans transform continuous sound waves into discrete beats and reflect these discrete signals on a reactive surface made of paper pieces that respond in an analog fashion to the gradual speeding up and slowing down of the fan motors. None of the digital interactive new media works based on CPU fan construction explores this set of material constraints.

MURMUR: A LISTENING MACHINE

Murmur experiences the world through its 'ears' and 'speaks' through motion. In essence, *Murmur* is designed to represent aural information through the movement of DC-driven fans acting on a reactive surface as seen in Figure 1 and 2. *Murmur* is a 2.5 by 10 foot wide wooden frame with one hundred CPU fans organized in a grid structure. It takes intentionally or unintentionally created ambient sound as input via microphones embedded in its structure. It reacts to sound by separately blowing one hundred paper pieces attached to each fan. When fitted with different sensors, *Murmur* can represent many different types of information.

The aural information that *Murmur* presently displays is representative of the combination of environmental as well as self-produced sounds picked up by its sensors. Microphones are situated externally and monitor the surrounding sonic environment. The software processing this incoming data analyzes the sound over time and can be modified to average various elements such as pitch, amplitude, direction and timbre to influence the future movement of the fans. The result is stimulation of the display surface.

Figure 2. *Murmur* during construction at the Synaesthetic Media Lab. The photo shows the internal structure of the piece, which consists of a grid of one hundred CPU fans.

The sonic element(s) suited for visualization should be determined by analyzing the acoustic space where Murmur is to be installed, including the space's function and the resultant nature of movement within that space. For the first installation of *Murmur* in the *Listening Machines* show at Eyedrum Gallery in Atlanta, GA, the sonic elements (variables) and method of handling those variables (software and hardware) were customized for the environment and were further manipulated *in situ* to enhance responsiveness.

Internal Components

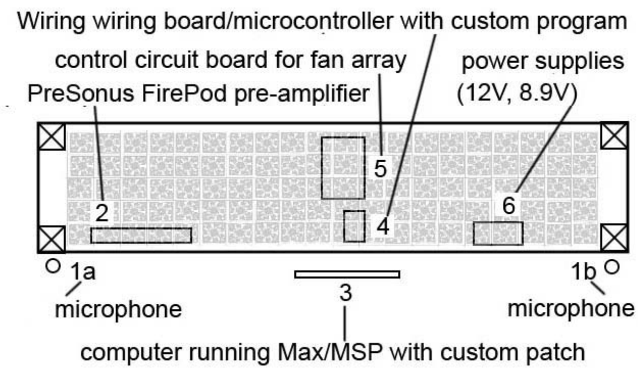

Figure 3. Internal component layout

The diagram above (Figure 3) illustrates the component placement inside the structure. Left and right microphone sensors (*1a, 1b*) pick up sonic data from the environment. The incoming signals are then amplified by a *PreSonus FirePod* (*2*) via XLR inputs and travel to a computer running Max/MSP (*3*) via a Firewire output. Here the signals are analyzed and variables are created, which have to do with various aspects of the sound. For the *Listening Machines* exhibition, amplitude data was the primary variable source. Once the variables have been established, they are sent via serial/USB to the Wiring I/O board (*4*) where a custom program written in *Wiring* [12] and uploaded to the microcontroller, handles strings of variables, which are plugged into equations that dictate how the fans should be turned on and off to reflect the signal data. The binary voltage control signals (5V) are transmitted to the circuit board (*5*) by way of 20 I/O pins on the wiring board, which corresponds to *Murmur's* 20 columns of fans. Twenty H-bridge rows arranged in groups of five on the circuit board receive signals from the wiring board and bus the signal to the next four H-bridges in the row. These components act as switches, turning the fans on and off by opening and closing the path to the fan's source of power when a 5V signal is received from the wiring board.

Physical / Environmental Set up

The ideal environment for the work in its present form is one where the 2.5 by 10 foot wide object is hanging on a white wall in order to reduce the contrast between the environment and *Murmur*'s current minimalist white façade. By reducing the contrast with its surroundings, focus falls on the motion of the display surface. This motion is synonymous with the aural information it represents. Part of *Murmur's* functional minimalist aesthetic is the elimination of unnecessary visual information.

Without sufficient input, a rippling wave-like motion is created by the fans and moves across the entire length of the surface. This can be considered the steady state of the system. As the microphone sensors pick up aural information that falls outside of the normal range, the wave patterns begin to fluctuate, which reflects this new data. The viewer/participant may observe the correlation between the sonic input and emergent response.

Sensory Experience

The particular nature of the reactive surface will give rise to various types of sensory communication. The following designs illustrate a sampling of the various sensory interaction and visual effects possible through this interface.

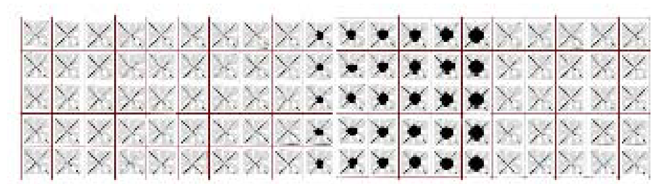

Figure 4. Grid surface with 'x' cuts into material centered over each fan. Left to right motion is shown.

In this design, the modulated air pressure produced by the fans forces open the material in front of each fan, changing the black to white ratio of the surface (the surface material being white and the fans dark grey) as depicted in Figure 4 and 5. In this method, the modulation of the fan's speed will open the surface material to a greater or lesser degree with the resultant effect producing halftones across the surface. Visual, aural, tactile and thermoception (temperature change) senses are stimulated.

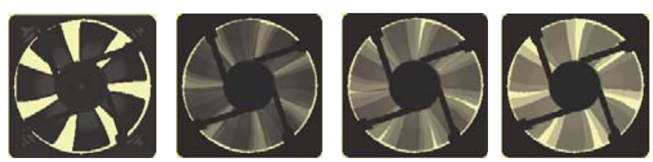

Figure 5. Stroboscopic motion of fans speeding up and slowing down

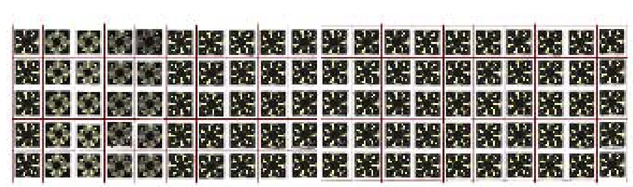

Figure 6. Fans behind semi-transparent material with backlighting or without display surface.

In the above illustrations, the fans can be left exposed or silhouetted behind semi-transparent windows and modulated at different speeds to create various effects, and at times produce a stroboscopic effect as they speed up or slow down.

Figure 7. Flaps hinged from the top catch light as fans blow them open and up. Left to right motion is shown.

As in the first design, the openings in the display surface depicted in Figure 6 and 7 allow for the stimulation of the visual, aural, tactile, and thermoception senses. If a light source is positioned at the top and directed down across the surface, the flaps, opening at various degrees, will create patterns in light and shadow much like the effect produced in Daniel Rozin's *The Wooden Mirror*. This design was chosen for *Murmur's* installation in the recent *Listening Machines* show.

ITERATIVE DESIGN PROCESS

During the implementation process, the design of *Murmur* went through a series of transformations. In this section we will describe the early stages of the work, its transformation, and the motives of these transformations such as individual fan control, simplification of the circuit, and PCB (Printed Circuit Board) design and circuit modifications.

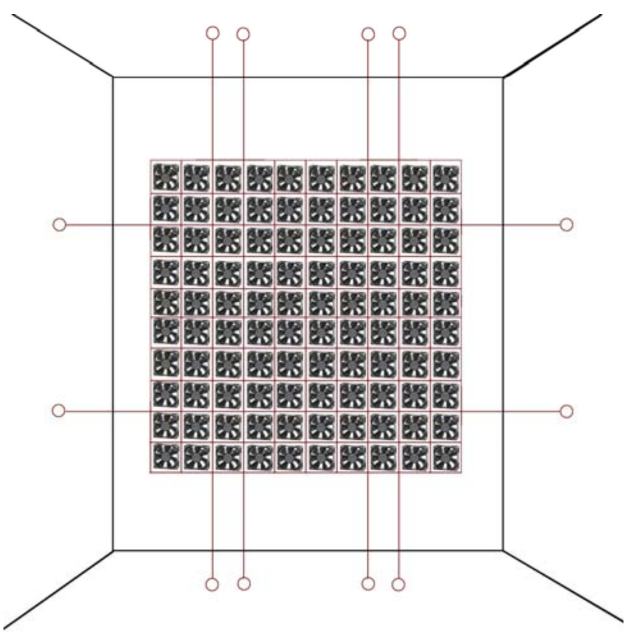

Figure 8. Initial concept sketch of a grid of 10x10 fans suspended in a space.

Version 1

Since we aimed to locate input and output components as a whole, we were able to narrow down the methods for sensor-based interaction for *Murmur*. Use of vibration sensors or microphone sensors to monitor wave-like structures in the environment constitutes the basis of *Murmur*'s design. Using the fans to create wave patterns across the reactive surface in response to other types of waves (such as sound waves) provided a strong unity of form. The initial aspect ratio was 1:1. (see Figure 8, 9, 10a, and 10b)

Version 2

In order to emphasize the movement across the surface and to better size the work into the area of peripheral vision when standing in front of the piece, the aspect ratio was changed from 1:1 to 1:4 (five fans high and twenty fans long). This new aspect ratio served us better on several levels. Not only did it evoke the idea of a landscape (as it would sense its environmental acoustic/vibration landscape), it also accommodated circuit constraints that were later discovered. The affordances of using fans beyond their ability to create wind pressure made it apparent that *Murmur* was to be a multi-sensory display, as it appealed to at least three senses.

The initial idea was to build the project from analog components alone in order to better integrate everything into the structure itself, including both motor driver and sound processing components. For fan control, transistors to switch the individual fans are used. By sending a low signal voltage (usually 5V) to the base of the transistor, a connection is made between the ground and power, which completes the circuit and turns on the fan's motor.

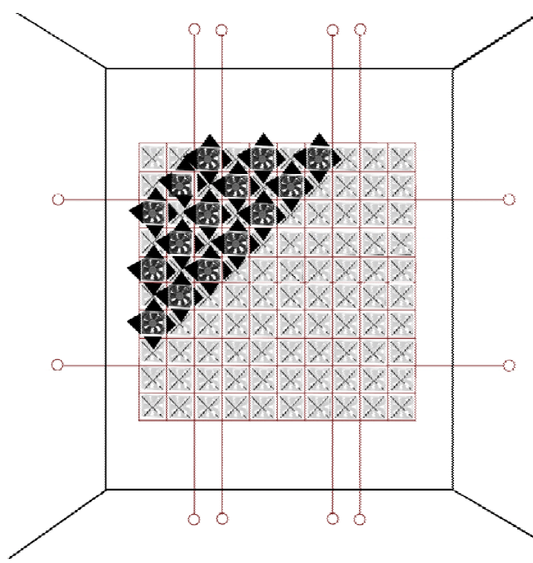

Figure 9. Initial concept sketch of a grid of 10x10 fans acting on a reactive surface

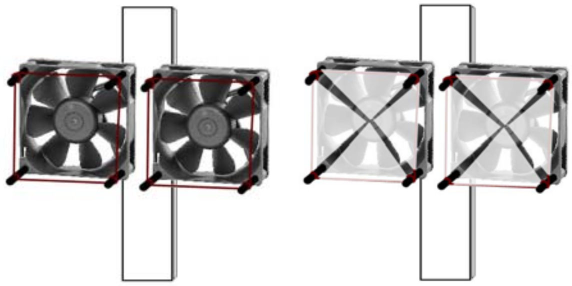

Figure 10a. Initial design sketch for the kinetic paper pieces envisioned to be placed over individual fans.

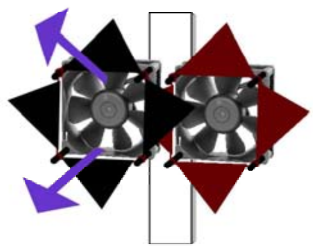

Figure 10b. As the fans are activated, the kinetic paper pieces blow open, changing their visual look.

To be able to control 100 fans individually with only 40 I/O pins several possible solutions were considered:

1. Daisy chain multiple wiring boards using I2C output of board.
2. Build a power control matrix to bus signal, giving each fan a row/column address.
3. Bus a signal to a row of 5 fans, circumventing the problem because only 20 I/O pins are needed
4. USB hub with multiple wiring boards.

Option 4 was immediately excluded since it required the purchase two more wiring boards, which seemed excessive.

Option 2 is implemented in our current version of *Murmur*. The idea of building a control matrix was inspired by LCD circuits, and a similar approach was applied for the control of *Murmur*. We thus eliminated all the transistor circuits from our initial prototype for switching the fans, and instead replaced them with AND logic gates.

Option 1 is our most recent idea, but has not yet been implemented. Our discovery of the I2C control (Wiring boards with designated Master/Slave relationships) happened after we already chose to realize option 2.

Version 3:
In the third version of *Murmur*, H-bridges are used for controlling DC motors, servos, and stepper motors. By integrating a more complex transistor circuit into a manageable package, not only do H-bridges simplify the circuit, but allow for a range of control including backwards motion to help instantly stop the fans. The L293 motor drivers are thus used to replace all our fan circuits.

Although these components simplified the circuit and made the breadboard test circuits much more manageable, they restricted the amount of current and consequently, the amount of fans that could run at once. The L293 bridges maxed out at around 2 amps, allowing us to run up to ten fans at once. Seeing no difference in running ten fans or five fans (one column) at once, we decided to not run the components at maximum capacity and just turn on one column at a time. Thinking back, our design decision to move from the 10x10 fan matrix to a 5x20 one allowed us to use these new digital components.

Version 4:
While designing the printed circuit board (PCB), we performed more test circuits. After getting mixed results we reformulated our plan since the current leak could be coming from anywhere. We removed the AND gates and bounced the control signal to a column of fans so that all fans in that column would turn on at the same time. To ease debugging and setup of the piece, we use Hirose snap connectors to connect the fan cables to the PCB. Since these connectors allow us to unplug the fans from the circuit board, we could also design different types of circuits to drive the fan display and change them out at will.

MAPPINGS AND INTERACTION DESIGN

The variable mapping for the first *Murmur* exhibition was based on the type of sonic environment we expected to find in the gallery space. A major challenge in machine listening is how to do pattern recognition on the incoming acoustic signals in order to attribute discreet sound events to categories and source identities. With more research and sophisticated programming, *Murmur* could one day respond to acoustic events with recognizable accuracy. In order to produce an installation that would be responsive to its environment and appreciated through interaction and observation during the exhibition opening, working within the possibility space became imperative. The creation of a discernable response to environmental variables was necessary for the success of *Murmur's Listening Machines* installation. To help facilitate an observable mapping of input to response, we decided to forgo complex variables such as pitch and spectral averaging which are not easily discernable in a cacophonous setting. Amplitude comparison seemed to be the most fitting sonic variable to create an understandable mapping for a mixed audience in a loud space. The incoming amplitude data was broken down in Max/MSP (an audio programming environment) into three variables and resultant mapping of fan motion:

V1: Difference between amplitude of left and right microphone → where to start the wave. The smaller the difference, the more towards the middle of the 20 columns the wave starts.

V2: Highest average over time of amplitude data contained in the buffer → the wave travels in the direction toward the microphone with the highest averaged amplitude since the last time the buffer was cleared.

V3: Overall amplitude → the value of the average of the microphone with the highest amplitude determined how long the wave is, particularly, where the wave will end.

The incoming amplitude data was amplified *in situ* to cater to the specific sonic environment and pre-coded variable ranges once the installation was in place. The responses to the variables described above approximated logarithmic spacing in the Wiring code. For instance, the range of values that were most likely to occur in the environment made up most of the response mapping that can be described as:

If value == x then
start at fan column y for V1

If value == x then
continue in the direction of fan column y for V2

If value == x then
end at fan column y for V3

It was pre-determined that the incoming amplitude would exist in a 50-decibel range starting at 25 dB and ending at 75 dB. In order to provide variation in the visual response, with the notion that longer waves would generally be more interesting to watch than shorter ones, the incoming signal from the microphones was amplified in Max/MSP to an average that would produce a wave of 6-10 columns long which resided in the 65-70 dB range. Any amplitude average at or above 75 dB would produce a maximum of a 20-column wave.

Figure 11. Photograph taken at the *Listening Machines* event at Eyedrum Gallery in Atlanta.

EXHIBITION AND AUDIENCE FEEDBACK

Murmur was installed at the *Listening Machines* event at the Eyedrum Gallery in Atlanta, GA, in April 2007. This allowed us to observe how audience members engaged with the piece. The week following the *Listening Machines* event, we presented *Murmur* at a Dorkbot meeting in the Music Department at Georgia Tech. Dorkbot is a monthly gathering of "people doing strange things with electricity" and has chapters in many major cities. We summarize our observations in terms of the quality of the sound environment, the variable mapping and response time, and the audience interaction.

Sound Environment

The sound environment at the *Listening Machines* show was that of a crowded gallery opening. At its apex, about 150 to 200 people were simultaneously present in the space(s) directly surrounding the installation. Audio from other installations mixed with the chatter of conversation and reverberated from concrete floors and hollow walls. The general response of *Murmur* to this environment fluctuated little as the sonic elements in the environment remained relatively uniform. Generally, the motion started near the middle of the work and moved towards the direction of the microphone with the highest incoming amplitude. The waves usually fluctuated between 5 and 14 columns as the overall amplitude increased and decreased.

Because *Murmur* was located on a wall in the gallery space (see Figure 11) that only slightly biased the right microphone, the difference between the right and left microphone was small and the wave generally started in the middle 5 (out of 20) columns and proceeded to move to one side or another. Also, because the right microphone was in a location slightly biased to receive higher amplitude data, the majority of the waves also moved in the direction of the right microphone. This was generally the case when the event gallery space was most crowded. After realizing this bias, the amplification of the left microphone was adjusted so as to balance the input with the right microphone, which helped to vary the direction of the wave. This modification helped (in this situation) to create a more direct response when the gallery participants involved themselves in interacting with *Murmur*.

Audience Interaction

Based on our observations of audience interaction with *Murmur*, we noticed that the initial expectation was one of immediate feedback. Visitors would clap or yell into one of the microphones and directly look to the display surface in anticipation of an immediate response. They did not know that the amplitude data was averaged over time (generally between 5-10 seconds), and this lack of immediate response to their input caused some confusion as to what *Murmur* was responding to. As a result, we often needed to explain the mapping to visitors after their interaction. We believe this dilemma can be partly attributed to the exposure of the microphones as well as the type of microphones used. *Murmur* is equipped with two dynamic stage microphones, selected based on their XLR inputs, which were needed for the FirePod pre-amplifier. Although the exposure of these rather large microphones helped in illustrating the nature of *Murmur's* response, they also made visitors anticipate direct feedback. These types of microphones are designed to be held in the hand and are generally used to microphone an individual person or instrument, and hence they lead people to believe that *Murmur* uses the same form of interaction.

Post-Exhibition Feedback

Both at the *Listening Machines* event at the Eyedrum Gallery and at Dorkbot, the following two comments were made in regard to our choice of reactive surface. Firstly, Daniel Rozin's *Wooden Mirror* was mentioned as a work with aesthetic similarities to *Murmur*. Secondly, two people who had seen the *Eyedrum* installation suggested that the work might have been more dynamic had we left the reactive surface off all-together as illustrated in Figure 6. They reasoned that fans stimulated with audio input are a unique method for information delivery, and in covering them up, the affordances of using them for their tactile and thermoception sensation are reduced, instead of emphasizing the visual aspects of its communication. We agree with this point, and have considered alternative designs proposed for *Murmur's* surface, which include the absence of any reactive surface over the fans. For the initial design targeting the *Listening Machines* event, emphasis was placed on the situational aspects of *Murmur* existing within a gallery context, focusing on its integration into a typical white-walled gallery environment.

It was our intention to highlight the features of *Murmur*-as-prototype of information architecture in the physical as well as the figurative sense. By integrating an interactive/reactive surface into the fundamental architecture of a space, new dimensions of communication emerge between the space's physical characteristics and the social fabric present in the space at the time. As described in the introduction, the minimalist white surface and casing help to direct focus to the subtle surface changes as the fans blow open flaps, which catch light and cast shadow. Although this surface effect is similar to the one employed in *The Wooden Mirror*, the idea of using changes in light across a surface to convey information is an archaic practice used in Kabuki Theater, magic lanterns displays and shadow plays, and is a basic consideration when creating relief sculpture.

CONCLUSION AND FUTURE WORK

With our work on *Murmur*, we wanted to investigate a set of goals as presented in the introduction:

Appropriate computer fans as a medium for information delivery: Even though we had to instruct the interactors, we managed to establish a correlation between the audio input and the fan speed.

Create a cohesive work by integrating the sensors in the art object instead of locating them near the object: Interactors recognized the microphones as separate objects and directly spoke to them. Smaller microphones can be embedded in the structure.

Take inspiration from CPU fans appealing union of form and function to create a more complex object, which embodies these qualities: We managed to create a complex whole with the use of many individual CPU fans arranged in a grid.

Create a multi-sensory display that appeals to at least three senses (audio-visual-tactile): The sound of the paper pieces, their movement, and the wind produced by the fans stimulated at least three senses.

Balance the use of analog and digital elements: Even though it is not easy to categorize analog and digital elements, we explored and integrated elements ranging from pure software to paper in an installation that communicates with its environment.

Create an object which connects people with the space they occupy by bringing awareness to how their presence effects their environment: Since *Murmur* takes unintentionally created sound as an input, we managed to create an abstraction about how people's presence affects their environment.

In addition to *Murmur's* current status, we also conceived of it as a prototype for an architectural feature in a public space as well as an art object. We envision an entire wall made up of these fans reacting to sound generated by human movement. This arrangement will help unify the object as it is integrated in an architectural space and the social landscape.

It is also our intention that a future version of *Murmur* will incorporate a thermochromic display surface. Thermochromic materials such as plastic pellets used for injection molding, paints and inks, are becoming increasingly accessible. These materials would take advantage of the cooling effect the fans have on a surface. The temperature change can be specified to occur within a wide range of temperature to produce a change in color. The cooling effect could be tuned to hover around the region of the thermochromically-induced color conversion. This would allow us to explore temperature for controlling a display surface for *Murmur*.

ACKNOWLEDGMENTS

We would like to thank Ayoka Chenzira who helped shape the early stages of the project. We would also like to thank the members of the Synaesthetic Media Lab for their feedback throughout the project. Finally, we would like to thank the Georgia Institute of Technology GVU Center and School of Literature, Communication & Culture for their continued support of the Synaesthetic Media Lab and its projects.

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