Sustainable: a dynamic, robotic, sound installation

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ABSTRACT
This paper details the motivations, design, and realization of *Sustainable*, a dynamic, robotic sound installation that employs a generative algorithm for music and sound creation. The piece is comprised of seven autonomous water gong nodes that are networked together by water tubes to distribute water throughout the system. A water resource allocation algorithm guides this distribution process and produces an ever-evolving sonic and visual texture. A simple set of behaviors govern the individual gongs, and the system as a whole exhibits emergent properties that yield local and large scale forms in sound and light.

Keywords
Music, Sound, Robotics, Generative Arts, Evolutionary Computing, Dynamic Systems, Sculpture, Installation Art.

1. INTRODUCTION
Sustainable, is a dynamic, autonomous, robotic installation that is comprised of a network of seven independent water gongs (see **Fig. 1**). The network models a water resource allocation algorithm that yields a perpetual evolution of the sonic, visual, and timbral aspects of the installation. Each gong node functions independently and autonomously, but through their simple interactions, the system as a whole exhibits dynamic, emergent behaviors that unfold over time.

A water gong is a musical gong that is dipped into a tank of water. As the gong is partially submersed, the water alters the resonant properties of the metal such that the sounding frequency of the gong descends as it is immersed below the water's surface. This instrumental effect is employed by composers of contemporary music, as it's shifting glissandi and timbres produces an intriguing and distinct sound.

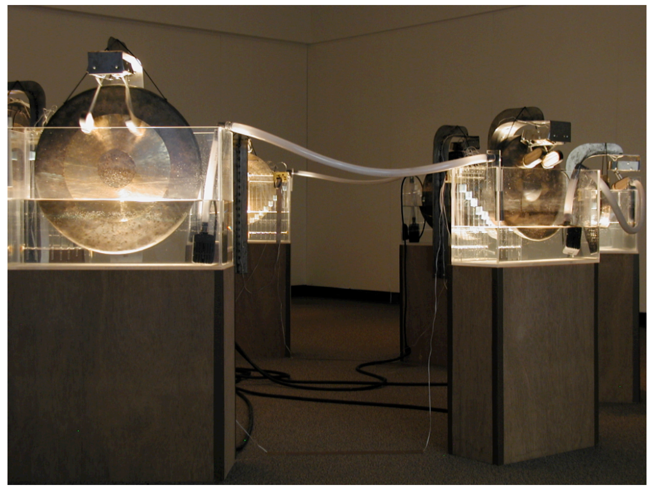

Fig. 1. Portion of the gong network

We have built a collection of robotic water gongs, each with two solenoid beaters that strike a gong that is fixed above a water tank. Rather than raising and lowering the gong itself, we raise and lower the water level in the tank with water pumps to produce the desired effect. Lamps positioned below the transparent tanks illuminate patterns on the surface of the water as it ripples and splashes. Each gong has one upstream and one downstream neighbor, and the gongs are networked together with water tubes. Thus, water is distributed throughout the system, and as the gongs resonate above the ever shifting water levels, chords and rhythms emerge that reflect the state of the population. A water resource sharing algorithm governs the global behavior of the system, and each water gong node is modeled as a water consumer with individual needs and behaviors.

This paper describes the goals and outcomes of the design and realization of this work. In Section 2 we outline the important themes and concepts that inform the aesthetic aspects of the work. Section 3 discusses the generative algorithm that governs the system. In Section 4 we describe the construction and behaviors of the individual gongs. Finally we discuss the results of this work, and outline directions for future work.

2. KEY THEMES AND CONCEPTS
A number of themes and concepts inform the design and realization of this installation. These concepts are reflected in the sonic and visual materials that comprise the piece, and in the technologies and algorithms that influence its behavior.

Water is an important force and metaphor. As residents of the western United States, where water rights and access are critically important, we are driven to address this issue in our work. The implementation of a real world water resource-sharing algorithm reflects this influence. In addition, the network of water gongs share a limited resource of water, and its perpetual re-allocation between the members of the system models the shifts of natural, cultural, and intellectual resources throughout the networks of our local and global communities. The installation is intended to highlight the interconnected nature of our social and physical environments. Finally, water serves as the means of communication between nodes in the network. This anachronistic mechanism references the use of waterways as the traditional vehicle for communication and transportation.

We explore the relationship between organic materials and technology in robotics, and seek to balance these forces in the piece. An important design principle for the work is that the technology should be downplayed rather than fetish-ized. This concept informs the decision to have the sound and sonic events originate from 'natural' (e.g., striking the physical gongs) and not electronic sources. Similarly, the technology is present in the background of the piece, thus allowing the audience to focus on the organic aspects of the work. The use of organic materials as core components of the evolutionary algorithm also introduces desirable irregularities that often yield interesting and compelling results as in biological evolutionary systems.

The evolution of sonic and visual materials addresses the passage of time on multiple levels. Through the influence of the evolutionary model, shifts in texture and sound unfold at a gradual rate. At the local level, viewers of the piece can experience transitions by focusing their attention on the actions of individual water gongs. At the global level, viewers can appreciate the more gradual sonic and visual transitions of the system as activity and textures will shift around the network, and diverse composite sonorities will emerge. In addition, the generative algorithm produces alternating modes of stability and instability that yield large-scale meta-pulses in the resulting sound.

3. DYNAMIC SYSTEM BEHAVIOR

Sustainable is influenced by related works in both music and the visual arts that utilize models of natural dynamic systems to guide artistic work [11-14]. In our own recent work [1, 2] we have utilized evolutionary computing techniques [5] to evolve virtual populations of intelligent musical structures. Through the implementation of software agents that exhibit local intelligence, and are governed by a simple set of behaviors, we have automatically generated music that is structurally rich, and exhibits emergent properties. We have had success with these previous models, but while such systems are feasible in the realm of software, their implementation is logistically impractical in hardware.

As a consequence, we have looked to other generative mechanisms that will exhibit these same dynamic behaviors in this piece. Inspired by water, we have modeled the distribution of resources according to a real world water resource allocation algorithm. Kelman [7] proposes a number of sophisticated mechanisms for market driven allocation algorithms. However, given the limited size of our network, and our desire to clearly simulate this real world system, we chose to implement a simple, yet practical model. In *Sustainable*, each water consumer acts selfishly and independently. In accord with the principles outlined below, there is no policing agent, and those 'upstream' in this closed system have priority to use the quantity of water they desire.

In our implementation of this allocation algorithm, we have sought to preserve the key principles of more complex evolutionary systems, and have implemented them in such a way that the network will exhibit emergent and dynamic behavior, while remaining practical and robust. These principles are as follows:

Each node of the network acts in an autonomous, selfish manner. As will be described in Section 4, a simple set of deterministic rules govern the behavior of the gong beating and illumination state. These are dictated by the relationship of the current water level to the gong's target water level. Each gong acts selfishly, and independently, either purging or conserving water to achieve its target.

Players in the system require only rudimentary, local interactions. In this network, the water gongs are linked to their two adjacent neighbors via input and output water tubes. There is no central processing or sophisticated interaction between the gongs.

There must be critical mass to achieve dynamic and emergent behavior. As described above, there are practical limitations when implementing a multi-node networked system in hardware. We have implemented a network of seven gongs, and practical experience has shown that this is a sufficient number that allows the system to explore a wide variety of textures in both the sonic and visual domains. These outcomes are compelling, and given of the number of variables and irregularities that are built into the network, they cannot be predicted. During the development stages of the work, testing with only three nodes proved to be insufficient number. Though multiple states could be achieved, transitions were abrupt and predictable. Certainly, increasing the network beyond seven nodes would produce even more varied outcomes, and we hope to expand the size of the piece in our future work.

Periods of both relative stability and instability are desirable. In time-based media such as music, tension can be created through the introduction of distortions to normative, stable structures [3, 9]. In evolutionary systems, periods of stability often alternate with periods of transition and instability [4, 10]. Our implementation of the water resource-sharing algorithm exhibits this same property, and allows for the realization of large-scale forms that unfold over time. The system will often become fixed in a given state, as the interconnected nodes will be incapable of changing states. However, because the consumer's water demands will periodically change over time, the system will lurch out of one state and sustain a period of transition before arriving at a new period of stability. This feature of the algorithm produces a meta pulsing that is satisfying musically, aesthetically, and conceptually.

4. REALIZATION

Sustainable, is comprised of seven autonomous water gong nodes that are networked via water tubes and modeled after real world water consumers. This section describes the features of the gongs and details their individual behaviors.

4.1 Physical Construction

The individual nodes share the same basic design and behaviors, including the following components:

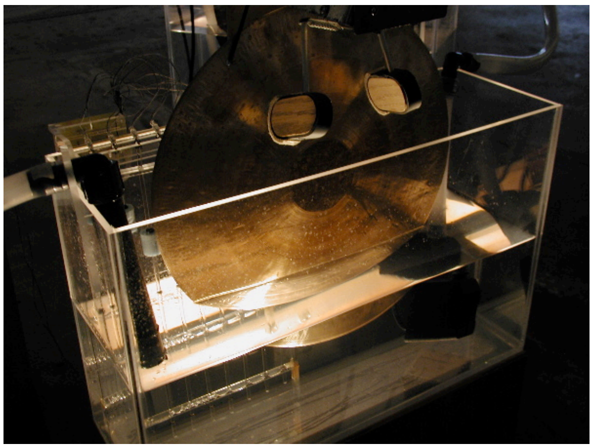

Fig. 1. Individual water gong node

- A gong or tam-tam suspended over a tank of water
- An eight element float-switch mechanism to sense the current water level in the tank
- Two solenoid beaters that strike the gong
- A submersible water pump whose output is linked to one downstream neighbor (all pump at the same rate)
- An input water tube from one upstream neighbor
- A light under the water tank that illuminates the water surface and gong
- Microprocessor (Atmel Mega16) and custom designed printed circuit board with circuitry for sensing and control

Each component has been custom designed and fabricated by the authors, and the nodes are intended to be physically functional as musical instruments, and visually compelling.

Although, the basic functions of the nodes are identical, some details are unique to the individual water gongs. For example, each gong is a different size and type. We have used 9" and 13" nipple gongs; 12", 20", and 24" tam-tams; and 14" and 18" wind gongs. The tank sizes, float switches, and mounting hardware have been custom fit to suit these dimensions. In addition, the beater striking surfaces of each gong is unique in order to elicit different timbres from each node. These variations provide critical variety and clarity to the choir of gongs and allow for a broad range of possible timbres, frequencies, and composite sonorities.

4.2 Individual Gong Behaviors

Each of the gongs behave according to a set of simple, deterministic rules that include sensing of their current water level, setting a target water level, purging or conserving water, striking the gong, and illuminating the lamp. These behaviors model the actions of consumers in a water-sharing network such as farmers or golf courses along a shared river. Each node has a cycle that is iterated perpetually, and control of these sensing and actuation tasks is implemented on the microcontroller circuit embedded within each water gong. There are five steps to each cycle: (1) sense the current water level, (2) update the water pump state, (3) update the striking mode, (4) update the lamp state, and (5) if appropriate update the target water level (i.e., water need).

4.2.1 Sensing Current Water Level

At the beginning of each cycle, the gong will read the state of the eight-level float switch mechanism to determine the current water level in its tank. This current water level will be subtracted from the desired water level to determine whether its need is over, under, or exactly met. Just as farmers along a river desire to have their water consumption equal to their target water need, if the current and target levels are not equal, the gong will act accordingly.

4.2.2 Update Water Pump State

If the current water level in a gong's tank exceeds its need, it will turn its water pump on to purge water. If the current level is below its desired level, it will shutdown its pump in order to conserve water. However, given that the gongs are connected only through their pumps, the water level in a given tank is dependent on the behavior of its upstream neighbor. For example, if node ***n*** turns its pump on in an effort to reduce its current volume, if upstream node ***n-1***, is simultaneously purging, because of the matched pump rates in the network, water will simply flow through node ***n*** with no change in its level. Similarly, if node ***n*** turns its pump off in hopes of raising its water level, it relies on overflow water from node ***n-1*** for the level to change.

4.2.3 Update Gong Striking Mode

There are four modes of gong striking: (1) silence, (2) sporadic single strikes, (3) alternating strikes at a constant rate, and (4) alternating strikes with an accelerating/decelerating rate. The gong striking mode reflects the distance of the current water level to the target level. As the current level approaches the target water level, the striking mode will transition from state 1 – 4. Thus, when the gong water level has met its target, it will be most vigorously active, and it will be silent when it is distant from its target.

4.2.4 Update the Illumination State

Inspired by the work of Hiroshi Ishii [6], we have implemented a visual complement to the changing sonic aspect of the installation. In relation to the distance of the gong's water level from its target level, a spotlight lamp below the water tank is switched either on or off. If the target level is attained, the lamp is turned off, and otherwise the lamp is illuminated. This lamp illuminates ripples on the surface of the water that change according to the characteristics of the gong, the rate of beating, and the quantity of water in the tank. In a darkened exhibition space, these water patterns are project onto the ceiling by the lamp, yielding a soft, ambient display of activity in the network.

4.2.5 Update the Target Water Level

Just as real world water demands will shift with changing seasons and years, each gong node will periodically update its target water level. After a fixed set of cycles (approximately 150), the gong node will update its target level to a new random number from one to seven. Each node shares the same random sequence, but through irregularities in the water networking, and depending on initial conditions in the system, these updates will quickly phase apart to the extent that new water demands cannot be anticipated.

5. CONCLUSIONS AND FUTURE WORK

We have described the concepts that underlie *Sustainable*, articulated the principles that govern its evolution, detailed of the realization of the system, and discussed the behavior of individual water gongs. The work was first shown in September of 2004. It was well received by viewers then, and has been successfully shown in several exhibitions since that time. Despite the challenges posed by the realization of a compelling and dynamic, robotic sound installation, we have been pleased with the achievement of our goals, and encouraged by the outcomes of the system.

In our future work, we intend to refine aspects of the model that will lead to an even greater diversity of sonic and visual textures. Firstly, we intend to explore more sophisticated resource allocation models. We will potentially borrow concepts of cost and expense from economic theory to enrich the behaviors of the modeled consumers. Secondly, we plan to implement a sense of history for each gong node. Such a history that includes details of how often target water levels are met, and which behaviors have been expressed could open new possibilities for sonic and visual forms to emerge over time. Finally, we hope to construct more water gongs to expand the installation beyond the existing seven nodes.

6. MEDIA DOCUMENTATION

Extensive documentation of the design, development and final realization of the piece can be found online at http://ame2.asu.edu/faculty/dab/sustainable.php. Still images, video clips, and diagrams are published that detail each stage of the design process and outcomes.

7. ACKNOWLEDGEMENTS

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