Digital Machines Teach Basic Principles of Balance in Eco-Friendly Design

JUSTIN TAYLOR
Mississippi State University

Architects and designers have always impacted the ecosystem. Today, however, we are acutely conscious of the fragile balance within and around these complex systems. Scientist, engineers, designers and artists study how these systems adapt and change behavior, evolve and adjust to balance the existing natural systems. It is imperative that all who are involved in the design designers understand this process at its most basic level. While it is possible to create virtual systems and use them for teaching, there is value for students of design in creating the equivalent of a physical ecosystem that uses manual manipulation.

A simple prototyping board can be used with a variety of sensory and motor functions to study the ecosystem. Some tasks using the board are simple but are essential to the system's ultimate survival. Some tasks are complex and others are decorative. The system functions with solar chargers, miniature wind turbines, and batteries. Each of these components is separated into distinct parts with limitations placed on the function of each part. This process extends simple mechanics into a decision-making process and places emphasis on how the smallest of changes can influence the system as a whole. This is a teaching method that reinforces both a commitment to our ecosystem and the imperative that designers recognize the complexities that both nature and technology bring to future design.

APPROACHING THE STUDY

Designers often look toward nature for inspiration. Buckminster Fuller saw nature as the greatest technology. In an article "Invisible Architecture" Bonnie DeVarco describes Fuller's vision: "to look at the way 'she' designed was to unlock the most useful direction one could take in designing the artifacts that would make the world work for humanity." Nature is a seemingly never-ending source for inspiration. In particular, the idea of an ecosystem is the epitome of balance. Scientist, engineers, designers and artists have studied how these systems adapt and change behavior, evolve and adjust to balance the existing natural systems. In the current political and social climate, we are bombarded by "green" both as a lifestyle and as something that is a moral necessity. No argument exists against the necessity for sustainability. However, in the past, architects rarely suffered the consequences of their mistakes and the building process consumed and wasted resources unnecessarily. Today's students must address not only their design vision, but also the impact of the vision on the larger system we all share.

Ecosystems are complex adaptive systems with each inclusive organism having an impact on the system as a whole. Each organism in the systems is autopoietic "simultaneously producers and products, it could also be said that they are circular systems, that is, they work in terms of productive circularity." [Mariotti] All ecosystems adjust and adapt to change; some organisms have a greater impact on the balance of the system while others have a very marginal impact on the system. "The structure of a given system is the way by which their components interconnect with no changes in their organization. Let us see an example related to a non-living system — a table. It can have any of its parts modified, but keeps being a table as long as these parts are left articulated. However, if we disconnect and separate them, the system can no longer be recognized as a table, because its organization is lost. Thus, we could say that the system is extinguished. In the same way, the structure of a living system changes all the time, which demonstrates that it is continuously adapting itself to the equally continuous environmental changes. Nevertheless, the loss of the organization would result in the death of the system." [Mariotti]

The principle of an ecosystem is something that is taught in grade school and yet we still stand on the outside looking in. Often this "god" view is due to the impact our presence has on a system. By the very nature of observing a system, we are having an impact on its balance. To avoid this impact we create artificial systems. These designer ecosystems are assembled and artificially balanced, but these systems rely on an informed individual choosing organisms that will live in harmony and artificially balance each other. These systems often require sustained human interaction to maintain the balance. There are also virtual systems that require no biological organisms but rely solely on a computer to create and manage each organism. These virtual systems are wonderful tools for education but there are no consequences to the destruction of the system. Students actively participate in the creation and destruction of the system without regard for the philosophical implication of this teaching. This is often treated more as short-term entertainment rather than a serious pursuit of understanding. Thus this artificial ecosystem has the most potential for education but lacks the long-term investment required to have significant impact on the student's behavior in future design decisions. The idea that something can be saved and then restarted as a previously "saved" state creates complacency.

TEACHING FOR LARGER UNDERSTANDING

While virtual systems can be valuable, there is value in creating the equivalent of a physical ecosystem that uses manual manipulation and approaches autopoiesis. This is the most basic of systems, not filled with the complexities of programming that may mask both the underlying ecological principles and the design principles.

To teach the principals of balance in design, a course was structured around creating a digital ecosystem. The hope was that through investment in the system students would attach themselves to the success and failure of the system. This would have a greater psychological impact on the students. This was an attempt at removing the complacency of destruction. Creating an equivalent physical ecosystem that is completely digital presents its challenges. "Natural ecosystems are characterized by flows: flows of nutrients and energy, flows of materials, and flows of information." The interconnection of these flows are what transform individual species into an integrated whole (Levin). To create flows in the physical system we need various building blocks (Figure 1).

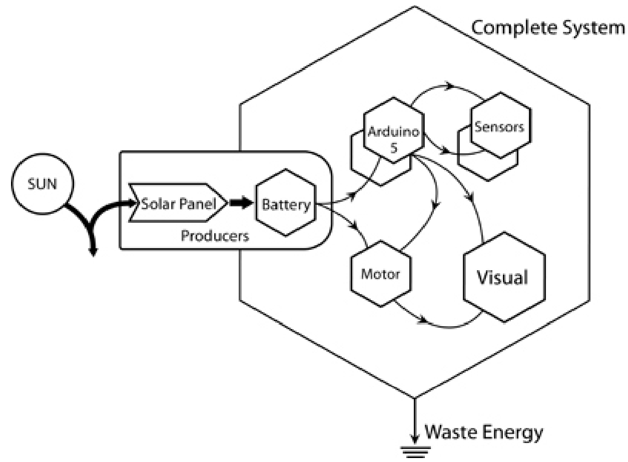

Figure 1. Energy Diagram of Digital System

The Arduino prototyping platform was chosen as the controller for our digital organisms. This selection was made due to the volume of examples and information available to the students. This simple prototyping board can have a variety of sensory and motor functions, "... machines with very simple internal structures, too simple in fact to be interesting from the point of view of mechanical or electrical engineering." [Braitenberg] These boards balance limited capacity with minimal complexity to create an ideal learning platform.

PROJECT DESIGN

Students involved in this project all had designer backgrounds but none had any prior experience with the Arduino or programming. This was not a significant hurtle due to the simplicity of the system and the programming itself.

The students were given a basic outline for creating the system. The system must be self-sustaining. It cannot use uninterrupted power supplies. The system must functions off solar chargers, miniature wind turbines, and /or batteries. Some limitations were placed on the function of each part; the batteries can supply power to the decorative visual machines or charge from the solar machines, but not both.

The students needed to have a functional “flow” that provided nutrients and energy or life support, a material flow that moved the energy, and an information flow referred to as the visual display or “peacocking” as it became affectionately labeled by the students.

The students were divided into groups and given tasks in the system to complete. Some tasks are simple but are essential to the system’s ultimate survival. Some tasks are complex and decorative. The tasks are divided so that each group must utilize another group’s function.

Group 1 was responsible for light tracking. Group 2 was responsible for solar collection and orientation. Group 3 was responsible for battery movement and connection. Group 4 and 5 were responsible for the visual display. Group 1 and 2 control the nutrient energy flow, Group 3 was responsible for material flow, and Group 4 and 5 were responsible for information flow. All of these interconnect to form the complete system.

Students referred to components as “organisms” with each group controlling one organism for a total of five organisms in this very simple system. Each organism had a task and made a simple decision based on the students’ programming. This programming gave the system its basic autonomous function. The students had the added advantage of testing the individual parts outside of the whole system.

One of the more notable developments in this process was the interaction of the groups. Although the groups were sometimes independent and at other times interdependent, they developed attachment to the system as a whole early in the process. The students were not given a design to follow. The initial idea was form would follow function, but this changed dramatically as it became very apparent that the system need a larger habitat for the individual organisms. Although this decision was left entirely to the groups, the habitat took on a secondary role as a storage vessel for collected energy. While this habitat was a joint effort, Group 4 and 5 then had the most impact on its final form.

The functionality of each organism contributed to the over all success or failure of the system as a whole. The students’ perception of the importance of their organism was quickly abolished by the nature of complexity in each of the five organisms.

Group 1 Organism 1 was responsible for light tracking. This was a straightforward task with subtle complexities. The tracking of light can be accomplished by many methods but the groups soon found out that keeping an object oriented to the sun is a relatively complex task. The group started with the very thing they were trying to mimic, nature. They briefly studied Heliotropism, the term used to describe the mechanism plants use to track the sun. This method is not uncommon to modern sun tracking mechanisms that sample the light at various points and calculate the relative strongest across the sample. The complicated nature of this method ultimately resulted in a very simple straightforward approach to tracking. The group used a photocell, which provides a numerical value for the level of brightness of a light source. The group established a numerical base value. This base value represents the minimum accepted value. The photocell was attached to a Servo then swept 180 degrees in increments of 1 degree. The new incoming value was compared to the base value. When the base value was reached, the sweeping action would stop. When the value falls below the base value the photocell would continue sweeping between 180 and 0 until the value was reached again. The programming also took into consideration night. When the value reached near zero, the organism would “sleep” to save energy. The method proved reliable with some unintended results. At times, the minimum accepted value was reached without regard to the sun. For instance, if a reflection were bright enough the organism would orient to the reflection.

Group 2 Organism 2 was heavily dependent on Group 1. These two groups morphed into a hybrid organism with two distinct functions. The solar collection was accomplished with photovoltaic cells. This group chose to cannibalize an existing product to provide a necessary feature to the system as a whole. A nine-volt battery, wall adapter, or USB powers the Arduino. By cannibalizing a Solio hybrid solar charger, they could utilize the built in USB connectivity to power the five Arduinos (Figure 2).

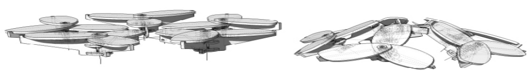

Figure 2. Digital Habitat.

This solved several problems but also presented several challenges. By using the Solio, the students gained a built-in solar array, and a lithium ion battery that is stronger and lasts longer but they then had the added challenge of interfacing with the Solio's electronics (Figure 3).

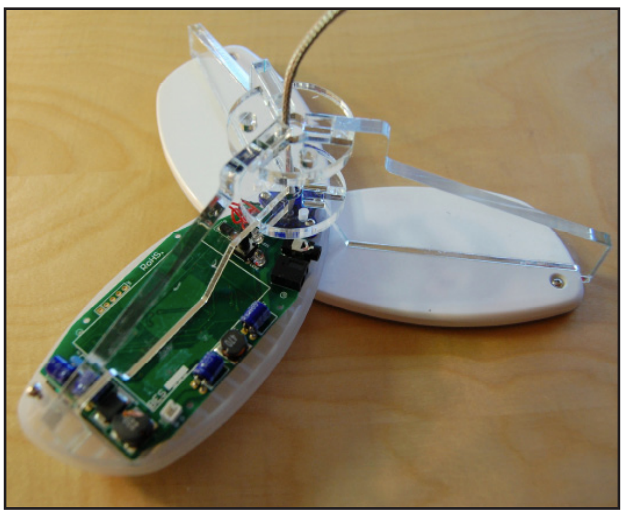

Figure 3. Solio Electronic Interface.

Group 3 Organism 3 was given the task of controlling material flow, interpreted as the power from one group of organisms to another. This group was responsible for all functionality of the entire system. What seemed like a simple task of unplugging from the supply of energy and plugging into the information visual display was in fact much more of a challenge. This group was responsible for resolving one of the limitations placed on the system. They could not charge the battery and supply power to the decorative visual organisms. This group quickly realized the complexity of their task. Because of the decision to use the Solio, which has a lithium ion battery that plugs directly into the electronics and built in USB connectivity, they were not allowed to simply push the on /off button. They were required to disconnect from the Solio and reconnect to the electronics using a different method. Then they would need to turn on the USB power. This was ultimately accomplished by moving the battery from one set of leads to another set. This would also allow the groups to use multiple batteries, ultimately extending the life of the system.

As the students worked out switching connections, they realized that their organism would require power during the transfer; this posed some problems that Group 1, 2, 4, and 5 did not have to consider. The other group's organism reset if power was lost with minimum loss to the system. If Group 3 lost power, the organism would fundamentally cease to function. This was a major hurtle that was only overcome by carefully monitoring the battery itself. For instance, if organism 3 was to let the battery complete deplete then it would cease to function, rendering the system useless. So, it needed to be smarter and keep track of the remaining battery capacity. When it reached a critical point it disconnected the battery and reconnected it to the supply power.

Group 1 and 2 were ultimately forced to add a special solar power supply just for this organism. This power supply was always on, so if its batteries were depleted, it would restart once the photovoltaic had collected the minimum to power the USB. This special photovoltaic array was fixed to an optimal angle as a precaution. This organism also had to make a decision on when to remove the battery. The group decided to link it to the amount of light around the habitat. This provided for some interesting observation. On stormy days when the ambient light was below the set value, the system would come to life.

Group 4 and 5 took a very philosophical approach to the system. Once again, the groups turned to nature and philosophy and looked at why things bloom, why do organism illuminate in the dark, finally, why is nature appealing.

The idea of display or "peacocking" generated the most in depth exploratory conversations amongst the groups. The translation of display ultimately took the form of lighting and minimal movement. This group also was given the task of using sensory data to engage with the surrounding space. This engagement could take any form and be either active or passive in nature. The groups changed the amount of illumination and the quality of illumination based on the CO_2 levels surrounding the habitat (Figure 4). The habitat itself, which was group collaboration, brought all the organisms together into a digital biosphere.

Figure 4. Visual Display "peacocking"

PROJECT CONCLUSIONS

As the final habitat was assembled, it was evident that the students had become very attached to the system and worked well beyond the boundaries of the project to assure it would function and perform. As the project was complete there were in-depth conversations about how the system could be serviced and the philosophical implication of the life of this system and any system. At the conclusion of the project, the significance of the built ecosystem and the responsibility and power designers have to influence change led to serious discussion of balance. "Nature is trying very hard to make us succeed, but nature does not depend on us. We are not the only experiment." (Fuller)

In comparing this system to those of a building the students were more critical about the lack of balance: "These giant power pumps push energy into the system to keep the polar bear cold in the desert." The students were referring to the idea that comfort is more important than the system only taking what it needs. When the question was posed what role does passive methods have in architecture as it relates to the systems and it position in the larger system, the students were quick to point out that passive methods are our way of adapting to the larger system we inhabit.

If we look at natures' model of a pond we will find a closed loop system that only relies on one source of energy, the sun. Only one outside energy source keeps the system balanced. This project was an attempt to create a real organism that behaves in a very simple way and is in theory a closed loop system.

IMPLICATIONS

Today's students are technically oriented, comfortable with electronics and hopefully well taught in basics of design and structure. If their curriculum has been broad, they also should have a basic understanding of the natural world. Instructors then must find ways to insure that tomorrow's designers are capable of embracing the complexities of both the natural and the technical world. The students must design the electronic marvels of the future with not only a creative vision and smart technology but with an awareness of the complex and dynamic interchange of the multiple entities that shape and reshape our world constantly. Static design principals and basic skills are essential learning, but success will come with embracing the complexity of life's experiment and with incorporating that complexity into good design.

REFERENCES

Braitenberg, Valentiono, 1986. *Vehicles: Experiments in Synthetic Psychology .* Cambridge: MIT Press.

DeVarco, Bonnie G. , 1997. Invisible Architecture: The NanoWorld of Buckminster Fuller.. (Webpage) http://members.cruzio.com/~devarco/nature.htm (accessed January 01, 2010).

Howard T. Odum, 2007. *Environment, Power and Society for the Twenty-First Century: Hierarchy of Energy.* Sussex: Columbia University Press.

Levin, Simon A., 1998. Ecosystems and the biosphere as complex adaptive systems. *Ecosystems,* 1(5): 433.

Mariotti, Humberto, 1999. Autopoiesis, Culture and Society. (Webpage) http://www.humbertomariotti.com/autopoie.html (accessed Febuary 14, 2010).

Orazio Miglino, Henrik Hautop Lund, Maurizio Cardaci, 1999. Robotics as an Educational Tool. *Journal of Interactive Learning Research,* 10(1): 25-47.