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DEPARTMENT: ART ON GRAPHICS

Michael Sedbon: Explorations in Coupling Artificial and Natural Systems

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As a timely artist investigating the potential of coupling natural systems with silicon-based systems, Michael Sedbon's work suggested a unique perspective on the relationship of manmade information processing technologies to computing, intelligence, and consciousness found in nature. His hope for a better world through building systems based on biomimicry exploration piqued our interest as we interviewed him for this article.

Francesca: Thank you for joining us Michael. Can we start by talking about the evolution of your work and how you arrived at putting sensors on plants as part of your art practice?

Michael: I would say all my work fits into the same conceptual framework. I build biocomputers that provide a perspective on the tension between artificial intelligence (AI) and biological sciences research. I'm looking at concepts that extend ideas in artificial intelligence to the life sciences. We are looking at how life processes information, and how that compares to artificial intelligence.

I am interested in suggesting potential impact in ecosystems and life science research. For example, taking an engineering problem like the design of cryptographic systems, it is useful to look at how biology computes information about its environment to engineer bio-mimicked Artificial Intelligences. Interestingly, as we understand more about this, we start using the same terms that were originally coined to describe manmade computers.

For example, with Boolean logic, George Boole invented Boolean logic, but it is interesting to notice similarities between this logic and the logic found in the regulation of gene expression discovered much later (in the 1960s). So the work asks many conceptual and philosophical questions as to whether we invented or discovered Boolean logic. George Boole framed it as an invention, but didn't it already exist in nature? Isn't it a natural phenomenon? If it is, then maybe evolution and human culture discovered it to deal with our environment. That's the general line of work I pursue, and I think it is a question that exists in AI.

From this line of thinking, what is artificial and what is natural in artificial intelligence is hard to identify. Most people would say computers are artificial because they are made of plastic and metal and do things not done in nature. But if we study nature and find computation that is very similar, then it changes a perspective on what is artificial. So far we have not found plastics interacting with metals in nature, but we may soon see computers made of materials closer to those found in cells. If you remove the material part of it and only consider the information, then you might find greater similarities. This can blur the line even more as to what is artificial.

If we can have machines that are made of natural materials, but also artificial materials, then this leads to a lot of philosophical questioning. And generally, those are the kinds of things I am trying to question across all my projects.

F: As one example, could we look specifically at *Cryptographic Beings*, starting with a physical description and then diving into the conceptual foundation?

M: Technically it is a storage device that is capable of storing five bytes of information in binary states of living algae. I call it *Vegetal Bits*, a five-story tower in which at every level there are six bits derived from

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FIGURE 1. As new kinds of machines interacting through hard, soft, and wet mediums find applications in various fields such as medicine, computing, architecture, and design, they also deeply question our conception of the nature of life and machines. *Cryptographic Beings* is a technological proposal that leverages our ability to control and abstract biology to perform digital information storage.

living marimo (filamentous algae originally found in Northern Japan in Northern Europe). During photosynthesis, they produce gas vesicles visible to the naked eye. When enough bubbles are produced they become buoyant and float on the surface.

Basically the algae has two states, floating or sinking, and, like with other things that you can control to create two states, you can encode binary data. In this case, it stores the first version of something I would like to carry on further. I would like the storage to be based on ideas of cryptography, to hide a message in the sense of traditional computer science. You could introduce a key and encode with the key, then also use the key to decrypt the message.

Historically, using such keys introduced a technological race pitting those who can create a useful key versus those who can discover the key once created. You can improve your competitiveness with hardware—with more or with new computing hardware—but if you embed it in algae you are connected to the speed in which the algae produce the information. You cannot use hardware tricks. You have to use other tricks. This is just a proof of concept version.

F: So the encoding is being done by the algae, thus decoding must also be translated by the algae; therefore, you cannot speed up that process?

M: Kind of... The storage that you saw (see Figure 1) is what is needed to make the next iteration. What I have currently is a storage system with lights that determine what is being stored. For now, I am storing random strings.

F: And where does the movement come from? It is a natural movement that you are then capturing?

M: There is a tower system with two mechanical arms that can rotate at the top and bottom and go up and down. To the arms are attached the LED lights, and those lights can trigger the photosynthesis in the algae and that controls the motion of the algae.

F: Can you describe the components of the system?

M: There is a symmetry goal so it is the same from the bottom as from the top. A tower chassis holds the algae, to activate photosynthesis processes in any of the vessels holding the vegetal bits. Each of the five levels can hold 6 bits of information in the state of the algae. In the middle of the tower, I have an algae reader which provides a service similar to what a reader head performs on a hard drive. There is a controller motor that allows the mechanical arms to rotate.

F: Where is *Cryptographic Beings* installed?

M: Currently it is installed in my studio. Previously it has been exhibited in Paris.

F: You touch upon a lot of different fields. You have many disciplines you weave together. I am curious about your collaborators or your preparation over time. If you can tell me a bit about your background?

M: I am a trained designer and have a master's degree in design that focused on human–computer interaction so as to look at how humans interact with machines and systems. For me, the most fascinating systems were always biological ones so I started early in interacting and collaborating with life science researchers in labs who helped me frame my projects, but also helped technically as they gave technical support.

Right now I am going back to school to do a master degree in system and synthetic biology, which I will look at through a lens of bioengineering.

F: So, you touched upon artificial intelligence and encoding. Can you elaborate? I am interested in how AI overlaps with your work.

M: Ah OK. So in AI there is artificial and there is intelligence. Those are two rough concepts to me. Artificial intelligence is something that belongs to the world of science fiction. It is a cultural object that says a lot about the ambitions we have for this field.

The ambition we have as far as I can tell is that we know humans are intelligent, we know we are conscious. Artificial intelligence aim at producing de novo systems that achieve a human level of intelligence and consciousness. As we lack quantitative methods to measure intelligence and consciousness, it is hard to tell the extent of intelligence artificial systems have.

We need to be able to quantify intelligence to move away from a dichotomy of what is intelligent and what is not so that we can start thinking about a continuum of intelligent behaviors. Artificial intelligence is a goal to produce the intelligence we have in our bodies, in our brains, in our culture, and in our society. There has been a unique attempt to do this with computers which is what I am interested in. We are reaching the time when it will be possible to engineer life and even neurons that do things we have wanted to do traditionally with computers in a more efficient way. This could also allow us to solve complex computational problems that cannot be approached by traditional computer sciences: where the computations are not possible, are too slow, or are too expensive.

The amount of information processed by the human brain is big. But you cannot have a brain in a box running an application like Facebook. We just don't know how to program a brain. Potentially you could imagine this one day could happen, with the component of processing not being the transistor but a neuron or something else. This would be extremely cool because it would mean we understand the brain very, very well. We would know how cognition exists in animals, including humans of course. It could go a long way toward how we handle disease, social cognition, mankind, and life overall.

What we want is a computation that is much more available in the world, much cheaper, and consumes less energy. Those are my thoughts on AI.

F: So I hear you saying that what you care about is the potential for connecting some of those networks, because you care about systems—especially the physical ramifications of all those things put together. Do you think that is true?

M: Yes, but I think that I go about it differently. On top of analysing these phenomena scientifically, it is relevant to consider them through their cultural aspects. What is more important to me is exploring the culture that has all this data and how we qualify life and how we qualify AI and the way we conceptualize the computer sciences. I am interested in our political decisions and how we manage our ecosystems and live with nature.

Perhaps I can bring this back to a previous work I did. *Cmd* is a project of mine that fits into a general approach of having a critical view on how this technology influences our culture. *Cmd* is comprised of competing ecosystems that are sharing a light source (see Figure 2). In this apparatus are cyanobacteria, which perform photosynthesis when they are exposed to light. Through photosynthesis they produce oxygen and in this system, oxygen is converted to money.

The cyanobacteria can then use the money to buy access to light on a market. This in itself creates a very interesting feedback loop. In this virtual market, rules are added to determine how the market works. In my system, which contains a virtual market that lives in a computer, you have to add rules to determine how the market works. How often do you sample oxygen production? If you sample too often, there is a lot of noise in the system's behavior. Oversampling also slows down the computer unexpectedly—another cost to the system.

There are physical aspects to the system and political aspects. For example, if you buy a light for yourself it can cost you X amount of money. The rules can be set such that it costs more to buy for a neighbor, or is less expensive, which affects the market. As the system's aim is to optimize the market for the production of oxygen, the resource allocation problem is non-trivial. I used a genetic algorithm to optimize these rules. The doubling time of these cyanobacteria is 24 hours in optimal conditions. Every time the bacteria divide, mutations occurring in the DNA replication process might confer an evolutionary and adaptive advantage

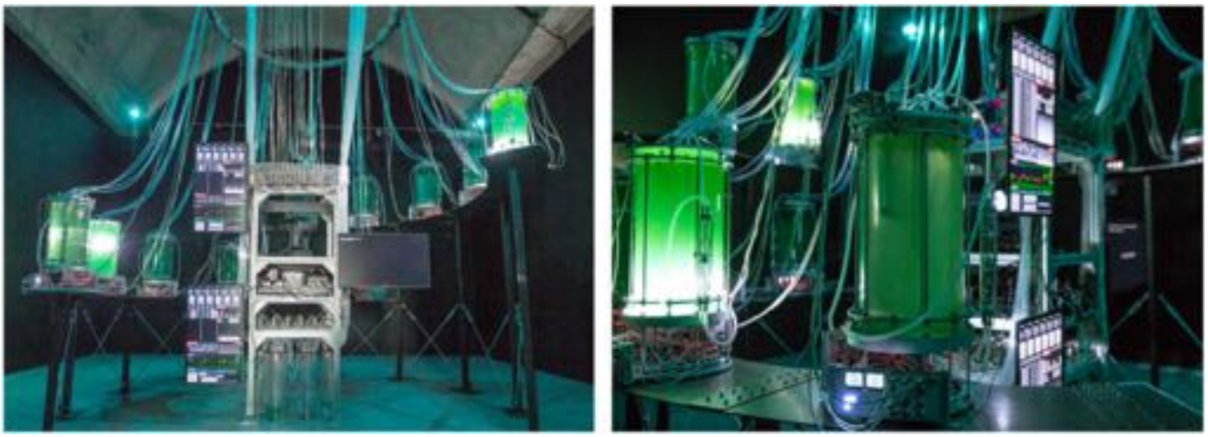

FIGURE 2. *Cmd* is an experiment in bioalgorithmic politics where the sum of a microscopic series of events determines the status of the system at a macroscopic scale.

to this population. The genetic algorithm that optimizes the market also has a generation time of 24 hours. Like so, political and genetic systems are inherited from the parents to the offspring's. I could then play with inheritance and the percentage of your parents' money that you were able to inherit.

The interesting thing that happened is that the financial equity of the system drifted toward a highly competitive state of rules where I could see a form of monopoly rising at some point. The monopoly was a complicated thing. If you monopolized the light such that your neighbor did not receive light, your neighbor could die. The other thing that could happen is called bleaching whereby when cyanobacteria are exposed to too much light they die. That's a complicated tradeoff that the algae are unaware of, obviously.

But the computer code regulating the system was vaguely aware through tracking the behavior. Attracting too much light caused bleaching which led to a drop in oxygen production and the inability to buy more light. But the dynamic depends much on the rules of the market. Complexity becomes a resultant subject of it all. With a limited number or rules, which are way less than the physical and social rules we have in a human financial market, you end up with a system that is super hard to predict. It would be interesting to explore this purely computationally.

F: It's about complexity but also social commentary and an interesting way of demonstrating how our financial systems go about determining social equity—an example of how you bring in other fields of study. What was the reaction to that work, when you showed it?

M: There was a lot of discussion as to whether what was learned could be applied to human markets and financial systems. No, I would say, of course you cannot extrapolate what happens to algae to humans. It is interesting as a critique of political systems and ecology. I was really happy it got such an amount of publicity and won some awards.

F: *Cryptographic Beings* is less political commentary—a shift, yes?

M: Yes, right, it is less political commentary. I didn't think about the political metric when making it but it became clear it was very, very political. I made it because it was a space for exchanges that I could make—a conceptual link that was very obvious. The economic consideration that seemed relevant on my campus was resource allocation. Cells need to allocate resources to different processes and this is an aspect of politics, and a byproduct of culture.

You find this pattern in nature and it is almost too complicated not to anthropomorphize it.

In general I'd say I am doing less political work, but information storage is also a political thing.

F: Sometimes my work evolves intentionally and sometimes the evolution takes me by surprise. It appears a bit of both is occurring here.

M: Right. As I was saying earlier, this work should eventually be about cryptography work and communication between two AIs that encode information in algae. I haven't finished conceptualizing the cryptographical part of it yet. I don't know what information is going to be encoded, how it is going to be encoded, or how it will be erased. But probably this will be a political subject.

F: You said you are back in school, what is motivating that endeavor?

M: I want to make computers made of living material. I need to understand better how things work—the skills and knowledge about engineering biology. That's the master's degree I am doing now: synthetic biology and bioengineering. Synthetic biology has been influenced by computer science greatly which is amazing as I imagine the feedback loop. I am also interested in basic research in biology, but part of that is to advise the engineering. How do you make bio-computers or bio-robots? I think of it as a design practice that integrates the gene, the bit, and the atom where wetware, hardware, and software are designed seamlessly to enable computations or functions that would not be possible with traditional hardware–software stacks.

Bruce: As you speak, you keep reinforcing a thought you elicited early in the interview when you mentioned that artificial intelligence was the attempt to create an intelligence that would serve humanity faster and cheaper. You make me think that the first computers could have been called artificial computers so as to better identify the focus on architectures that serve humanity through faster and cheaper computation. There is a similar hubris there. Both are but subsets of the complete intelligence and computation of the planetary biota.

M: I agree with you. The kinds of things we are finding in synthetic biology are in regards to the massive computer that is the entire living world. A natural planetary-sized computer that is happening in the natural world. It does process a huge amount of information, such as data related to climate change. Some of that information is what we would like to tap into but don't have the ability. But if we use biology to investigate biology, we get an interface into how to study and perhaps can listen to conversations that take place.

F: That's really fascinating. I work with many facets of climate change. I hear scientists talk about all the variables and data to collect just from bacteria, and then I think about all the ice and the ocean and so many other sources of data the complexity is just mind-boggling. We understand just this tiny, teeny sliver on the top.

B: There's something about our culture where people are more interested in what Kim Kardashian is doing today than walking out in the natural world to see what is happening around us. It took a lot of perturbations to get here from where our distant ancestors were when there were not so many distractions to attend to. There was a lot of added artificiality added along the way as I see it, using the word artificial as we have been using it.

F: As I hear you talking, I hear you talking about a new computation system and how it brings in biology. It also brings to mind quantum computing turning to physics to make advances on our silicon-based systems. Now you are suggesting we take silicon further by bringing in a biology-based system.

M: I don't think about it as one step further. They address different problems. I don't know much about quantum computers, but I understand it is an attempt to get computation that is very fast and provides useful answers. It can solve some problems we have in computer science but not all of them.

With the biological computer, we don't need to understand everything about *E. coli* (a model organism for synthetic biology). We just need to tap into the things that they already do. It can be just one gene you understand well that you use as a biosensor. Researchers create bacterial-based sensors that are sensitive to as little as a few molecules in large volumes. This kind of performance cannot be achieved by traditional computers.

While you are learning how to engineer *E. coli*, you are also making potential contributions to medicine and agriculture—fields that aren't immediately connected to information processing.

F: As you explore molecules and how they provide information, are you finding people who are interested in more practical considerations, or are you not there yet?

M: Synthetic biology and bioengineering in general are trying to exploit nature. There is a lot of interest in taking biological organisms out of the lab and into places as concrete applications. Many synthetic biology projects approached problematics related to COVID and general application of biotechnology in health.

F: The area of synthetic biology is vast. I'm wondering what aspects attract you specifically. What are you excited to explore next?

M: Lately there has been increasing interest in biological robots that were made out of skeletal muscles connected to neurons. I hope I will get a chance to explore that deeply. In the past 10 years, the field of bio-hybrid robotics was driven by projects where skeletal muscles, grown on PDMS structures, were actuating motile robots. Recently, researchers managed to co-culture these muscles with motor neurons and show control of the robot's motion by these neurons. The resulting structure is a hybrid robot made of living and artificial material where computations occurring in neurons drive the motion of muscles.

It's important for understanding the mechanics of the cell by studying muscles outside of the usual environment it grows in within the human body. It also allows for insight into how the neuron works, by bringing it outside of the complexity of the rest of the brain. These insights can be useful to problems, such as how memory works, which is a big open avenue in biology where we don't really know how the brain does it exactly.

FIGURE 3. *Alt-C* is another example of a system where Michael couples artificial and natural elements that are not explicitly mentioned in the interview. *Alt-C* is an installation that uses electricity produced by plants to power a single board computer mining a cryptocurrency. Other examples can be explored at michaelsedbon.com.

With conventional robots, we have a silicon-based memory where we store variables and behavior from past time. It would be good to understand how our brains do it. This is a very beautiful area of study that touches upon the nature of intelligence, cognition, and computation. It's also a beautiful challenge to engineering to make a system completely out of neurons.

F: Can you describe the structure? What are the muscles and neurons growing on?

M: The muscles and neurons are growing on millimeter scale PDMS structures and are capable of locomotion across centimeters in liquid environments. This scale limit is due to the complexity of managing waste and resources without complex transport systems such as our veins. It would be interesting to see how the field develops beyond these limitations in the coming years.

F: I feel like you have given our readers many fascinating directions and concepts—represented in your work—to think about with regard to science's application to art. I wish we had time to discuss more of your installations (see Figure 3). Thank you.

B: To consider them, I encourage readers to explore your home page at michaelsedbon.com as we did. Thank you.

M: Thank you.

MICHAEL SEDBON explores digital networked technologies and systems through their convergence with nonhuman intelligence (plants, unicellular organisms, insects, bacterias, etc.) in regards to the Infocene problematics. Sedbon received his master's degree in interaction design from the London College of Communication, London, U.K., and is studying synthetic and system biology with CRI, Paris. Contact him at michaelsedbon@gmail.com.

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