Smart Skins and Restless Lights: A New Theory of Nervous Activity

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Each succeeding decade brings a fundamental change in the way we use computers. Today computers are so small that they are being embedded into many different vehicles, appliances, clothing, and even building components. Up until the last decade, however, the computational paradigm remained almost the same as it was for the first electrical thinking machines during the Second World War. These machines all relied on dependable written instruction sets, from the precise but opaque hexadecimal machine language, to the easier to understand natural language scripting. Heinz von Foerster's early successes in the 1950's with machine vision, using this computing paradigm, coaxed later research into the same paradigm over the years (figure 1).

Certain other problems seem easy for living systems to compute, but they remain hard for traditionally instructed computers. We think of vision as one of the higher animal functions, and walking as one of the lower ones, but walking machines are devilishly hard to make. The variety of gaits used by simple animals as they negotiate changing terrain has always been among the most difficult behaviors to model using the old paradigm, no matter how powerful the computer.

Over the last decade, embedded computers have continued to get smaller and smarter, but today the savvy designer's emphasis is on the new kind of intelligence that can be seen in a loose grouping of dumber'– not smarter–– electronic controllers. Colonies, crowds, and flocks offer a window into a kind of behavior that can't exactly be programmed and computed in the traditional way. The colony's objects need not be particularly "smart," because when large numbers of devices are hooked up to each other in networks, a new kind of intelligence resides in the interconnection patterns. Simple individual behavioral protocols can lead to the larger-scale "emergent behavior" of this""ecology of objects."

The breakthrough in understanding walking happened ten years ago with purely mathematical investigations of "strange attractors." The nature of oscillations, their variety, and their manner of supple change across this variety, gave the necessary insights to Ian Stewart among others (note 1). Another insight was that walking was fundamentally a lower behavior, not located in the brain like the visual cortex, but more likely in the spinal cord, involving a much simpler electrical activity than the processes we use in our minds to reassemble a memory, for instance.

To better understand this simplicity, it helps to look at the ancestors of neurons, which were slightly differentiated cells in ancient creatures like today's sponges, jellyfish, polyps, and hydras. Curiously, some of these "creatures" are also "colonies" - more like a neighborhood of cells than a singular organism. They can be pushed gently through a very fine screen, until the creature dissociates into its separate cells, without killing it exactly. These cells can then, all by themselves, reconstitute their""animal" by following chemical traces, with each of the three types of cells taking up their proper location in the expanded field that is the organism. The more "nervous" cells are mixed with, and only slightly differentiated from, the rest of the cells. They lead the slow propagation of electrochemical waves that pass, for a period of about three seconds, through the creature — or the neighborhood—— while it contracts, feeds and respires, which are the same thing for the creature.

Rhythmically moving while ingesting water and food, the jellyfish has a coordinated ring of nerves that communicate with each other. Its nervous waves spread at about 20 cm. per second — slow compared to the reaction time of a sports star — but they can oscillate for days while continuously traveling over 600 kilometers. The behavior of this kind of nervous net can be approximated with very simple circular chains of inverting electronic buffers, with variable propagation delays introduced by a resistor and a simple capacitor, which holds and then releases the electrical pulse.

Symmetrical chains like this occur all over the entire animal kingdom, according to Ian Stewart (note 2). Similar groups of coordinated neurons apparently underlie locomotion in a wide variety of animals with differing numbers of legs— from insects to mammals. Central pattern generating ganglia have only recently been definitively isolated in the lamprey, but the topology and mathematics, which underlie these neural mechanisms, are now known (note 3)(figure 2), and have even been physically modeled (figure 3).

Miniature robots (figure 4) like those by Mark Tilden at the Los Alamos National Labs, have perfected artificial walking over a wild variety of terrain. These do not involve traditional computing via precise digital instructions. They use a net of simple electronic pattern generators, which can be influenced by adjacent pattern generators and sensors (figure 5). They adapt their oscillations to work efficiently in different loading conditions. The robust adaptive advantages of these potentially microscopic entities (note 4) also underlie the fears conjured up by Michael Crichton in his recent book "Prey." But while the military has its eyes on this technology, it can also be used for benign walking minesweepers, wheelchairs, gurneys, and even a variety of building components.

Tilden's simple electronics occupy an order of functionality way below the microprocessor and the memory chip (figure 6), with electrical behavior that is not exactly digital. They are a radical repurposing of the flip-flop (1 or 0) memory elements that underlay much of what we think of a digital computing (figure 7). Their behavior needs to be tuned, like an old radio, rather than instructed. Its behavior is somewhere between analog and digital — similar to living neurons. The repurposing of genetically predesigned mechanisms is at the root of most of evolution, according to Richard Dawkins (note 5) and Stephen Gould (note 6). How we understand this type of autonomous lower behavior, and use it in our designs, will determine the development of a new architecture of wider material electrochemical investigations'— and one that is driven by event.

We have all heard about the smart house; one that has been colonized by a junta of appliances — some hidden, some out in the open — that communicate at radio frequency about our needs. Signaling secretly right through our power systems or the air we breath, they purport to solve simple problems for us, all the while keeping us entertained and educated via broadband streams. This sort of intelligence, however, is based on the old computing paradigm, however fluidly they communicate over their various networks.

In contrast, the research I have been describing, which sprang up separately in the fields of biology and mathematics, and produced results only over the last decade, involves examining, modeling, and using decentralized weak computation and autonomic nervous systems. These are systems too simple to ever get so confused that they need to be rebooted. They are like your heart - which operates on similar principles.

The cost per transistor has dropped to the point where we can just imbed a PC wherever a simple task needs to be done— as I have in some of my own previous projects (figure 8) — but we don't yet conceive of its integral manufacture as an indivisible part of a building product, like the paper on the back of insulation. The necessary integral manufacturing is now being developed, however. For example, "E-Ink" uses a modified ink-jet printer technology to imprint very simple electronic circuitry and reflective display technology directly into and onto paper (note 7). Fibrous selectively conductive material like this will revolutionize both architecture and product design. Seamlessly embedded low intelligence will bring the most interesting changes in how we conceive of a sensate, somewhat alert, and responsive architecture.

The examples I've made in my research still use traditional electronic components, but they anticipate a time very soon when these electronics can be manufactured as an integral part of a building component. For instance, the Laptop Easel was designed to act as an autonomous responsive agent in a two-node network – in conjunction with the person sitting on it. It was born out of the pain I experienced while working in front of a computer. A message popping up telling me to stretch is ineffective, because it is easy to ignore in the flow of my thoughts. Someone grabbing my shoulders — physical intervention — more effectively interrupts my slumping, frozen behavior. This furniture notices an unhealthy behavior pattern in which only my wrists and fingers are moving slightly for long periods of time, and offers me a strong physical invitation to correct my posture.

A simple camera, like the one designed to recognize and count beans on a conveyor belt, was originally used to send out numerical data about the slumping head and shoulders (figure 9). That proved unnecessary during beta testing, particularly because it involved too much standard brute force computation. Instead, simply tracking variations in the furniture's vibration – those caused by the user's work movements — was all that was necessary, in order to watch for an unhealthy posture and working behavior (figure 10). Lifting the user's body slightly by the knees is enough to cause people to correct their own posture, without interrupting their mental flow of work.

This responsive furniture is like an extension of the user's autonomous nervous system, because its activity occurs outside of the user's level of conscious thought. The system can be understood as the interplay between the digital computation in a design's control center, and its interaction with less'"conscious" autonomic systems that are not exactly computing in the purely digital manner – the user in the case of the Laptop Easel. The most important lesson I learned from this first piece of smart furniture was that my initial reliance on the brute force of traditional code-driven computing limited my ability to make an autonomous, simple system. I should have been concentrating on forms of computation that could be simply imbedded during the act of manufacturing, with its sensors and actuators build integrally into a building component, like nerves and muscles into a skin.

In my current research I am deploying these sentient autonomous systems within energy grazing systems that use only what they can get easily and naturally—— parasitic when necessary, but low impact in general. The Nervous Wall System is an interior architectural component in which the sensing, logic, power usage, and power collection, are distributed into a field of small units throughout the piece (figure 11). It is designed to sense the light and cold conditions as they change around a glazed building, and open or close its "fabric" as appropriate to let in more or less light, and prevent excessive radiant heat loss (figure 12)(figure 13). An analogy for the intent of the design is the way in which stoma open up on leaves, as the conditions and respiration needs change during the day around the perimeter of a tree.

The basic nervous net in this piece normally oscillates at a rate that provides a wave pattern that a standard servomotor — adapted from radio-controlled airplanes — can interpret in its hardware as a request to move to a particular rotation point. Because the servo involves a gear motor, its position can be held for a while even without electricity. Power can be intermittently applied, and it can also be gathered very slowly and intermittently, and stored for short bursts of nervous activity and motion, using a solar burst engine (figure 14).

Changes in light and temperature that move along the fabric of the piece during the day are interpreted by different kinds of variable resistors that sense and respond to these environmental qualities. The changing resistance to an electrical pulse, when coupled with a simple capacitor, or charge-storage device, gives a variable pulse delay that can be fed into the basic nervous net. This causes the pulse widths to vary, and that changes the angle of gear motor rotation, which modifies the openings in the fabric of the piece.

The basic nervous net that I have used in my most recent work is adapted directly from the simple locomotion nets invented by Mark Tilden ten years ago (note 8). In a sense they represent a benign colonization of the entities he conceived as purely independent agents. They share his idea of simple variable oscillation rates in a chain of simple buffers or "artificial neurons" using only dozens of transistors, not millions.

Tilden's discovery of what Stewart understood as the neural oscillations that underlie the autonomous leg behavior that creates a variety of walking gates, became my inspiration for a light fixture that walks across the ceiling looking for shadows to put out. My design goal was to colonize the low voltage two wire systems that are so prevalent, with semi-intelligent lights that come out of hiding at night. Instead of legs and a walking gate, however, they have two simple eye-like sensors, and they roll back and forth looking for a particular light condition. The look a bit light lightning bugs at dusk when they come out.

It is important to understand that the nervous net which drives these lights is the same as the one that drives the smart skin system. Each node, or synapse, in the net has only eight transistors, not millions, and it is clear that within a couple of years we will be printing these onto building components with a version of an ink-jet printer in the factory. In each case, there is a rhythm of beating waveforms that carries an index of information – this is like the beat science mentioned by Sanford Kwinter in his recent lectures – and the interpretation of these wave forms by the actuators is the real source of solid-state intelligence in each system. This is a long way from the brute force of mid-20th century computation, and it is much closer to the way real nerves work.

Because natural light, in all its variation, is a pervasive communication medium, in these building components the distinction between network and architecture begins to disappear. The information intrinsic to the quality of light can spread across a nervous net, using one sensor and oscillator and then another as stepping stones to form a peer to peer 'mesh networks.' Because the individual responsive nodes modify the quality of light as well as responding to it, the system's behavior becomes adaptive, and perhaps emergent. This works the same way in both the smart skin system, and the colony of restless lights.

This research is essentially an investigation concerning solid-state materials with integral, quantitative, and dynamic flows of electrons, which carry information into and out of the material in real time. It is concerned with the way in which that information causes the material arrangements to reorganize. It manipulates the performance of those materials, as indexed by waveforms legible on an oscilloscope, and by the observed behavior of the material in real time. No code is involved, but computation is.

Using this material investigation we can develop an event-driven architecture with sensate embedded control nodes. Architectural space is slowly revealing its information density in new ways, becoming responsive to, and ultimately collaborating with the people moving through it.

NOTES:

Note 1: Collins, J. J., and Stewart, I. N., "Coupled nonlinear oscillators and the symmetries of Animal Gaits," Journal of Nonlinear Science 3 (1993)

Note 2, Note 3: Stewart, Ian, Life's Other Secret, Wiley (1998)

Note 4: Tilden, Hasslacher, Mainieri, and Moses, Autonomous Biomorphic Robots as Platforms for Sensors, U. S. Department of Energy Office of Scientific and Technical Information (1996)

Note 5: Dawkins, Richard, River Out of Eden, Basic Books (1995)

Note 6: Gould, Stephen J., The Structure of Evolutionary Theory, The Belknap Press (2002)

Note 7: Gershenfeld, Neil, When Things Start To Think, Henry Holt (1999)

Note 8: Tilden, Mark, Patent No. 5,325,031, United States Patent Office (June 28, 1994)

Selected figures uploaded separately.