**Headline:** The Frontier Research of Michael Levin’s Biology Lab

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**[Article Body:]**

The laboratory of developmental biologist Michael Levin at Tufts University, with its dozen or so postgrads, is a hub of ideas, experiments, and discoveries. Most exciting is the focus on cognition as a process involving the entire human organism—not just the brain—and what this implies for new ways to cure cancer and other diseases.

The “ethical imperative” to find the cause of—and relieve—pain and disease is a guiding concept for the lab’s biomedical work. Underpinning all Levin’s work is the remarkable idea that some form of cognition (thinking) is the “glue” that allows cells to communicate bioelectrically. This concept expands the study of cognition from a brain-only approach to one that extends to every cell in the body. Expanding the notion of consciousness to all living cells helps researchers at the lab to discover new things about humans and about whatever else exists or can be created.

Using AI (artificial intelligence) in the quest for new therapies, the lab has released frog skin cells from their two-dimensional confinement into a three-dimensional water container to study their behavior. The new entities, called [Xenobots](https://now.tufts.edu/2021/03/31/scientists-create-next-generation-living-robots), are tiny robots used to help understand the general laws that govern both human and synthetic behavior. Once freed from being two-dimensional skin cells, the Xenobots exhibit new types of behavior. For example, they can swim in different directions and figure out how to get through a maze.

Professor Levin directs both the Allen Discovery Center and the Center for Regenerative and Developmental Biology at Tufts University in Massachusetts. His lab is unusual for the field of biology, a fact that Levin, writing on the lab’s website, attributes to his training as a computer engineer and his “[deep interest in the philosophy of mind](https://drmichaellevin.org/resources/).”

The concept of intelligence as being ubiquitous has proved to be a fruitful research approach, but it is far from mainstream biology. I interviewed Levin for Human Bridges and asked what the response of other scientists was to this idea. He replied that “there is a community of scientists who work on this (the diverse intelligence community). But there is resistance from the mainstream, reductionist/mechanist camp, who expect everything to be handled at the molecular level, with no need for cognitive tools.”

His response to the reductionists helps to understand what is special about the Levin lab’s work. “To them I say that we are currently in biology where computer science was in the 1950s—programming by rewiring the hardware. A good start, but the reason we have these amazing information technologies is that we understood the magic of reprogramming and software: We don’t operate our laptop with a soldering iron anymore, and we don’t communicate with humans and animals by reaching in and tweaking their synaptic proteins. We use communication interfaces to reprogrammable or (in the case of life) agential materials.”

In addition to reductionists, Levin said: “There is another community that resists my message—the organicists who believe that life is a binary, special category which has magic that cannot be replicated in ‘mere machines,’ and that it’s a category error to place living intelligence on the same spectrum with that of materials. To them, I point out that even minimal matter and simple algorithms (as we’ve discovered) do things beyond what their algorithms dictate.”

He continued: “For the same reason that the laws of biochemistry don’t tell the whole story of the human mind, the laws of physics and algorithms don’t tell the whole story even of ‘machine.’ Cognition is baked into the universe, arising from the properties of mathematical objects that guide the behavior of even simple molecular networks. It is fundamental, and our formal models of machines, computers, etc., don’t capture it fully in living, engineered, or hybrid media.”

“That’s perhaps the hardest idea for people to assimilate,” Levin said in his interview, “because they expect the world to be neatly divided into magical categories of ‘dumb matter’ and ‘majestic life.’ It is one spectrum, and we are now starting to understand how things scale along that spectrum. Like back when we had no theory of electromagnetism and thought that light, magnets, static electricity, and lightning were all totally different phenomena; then we were blind to many wavelengths, as we are now blind to unconventional minds all around us.”

So how, as a traditionally trained biologist, did he come to the view that cognition—thinking—is a process involving the whole organism?

Levin told me that he was “thinking about the origin of brain-based cognition: where did it come from? How did it arise, in evolution, but also in the embryonic development, where each of us develops from a single cell.”

“In both cases,” he said, “there is no single magical time point where we suddenly go from being just physics to being a mind; it scales slowly and gradually from competencies of the material inside a single cell. So I spent a lot of time thinking about what cognition really is, not just limited to medium-sized brainy animals navigating 3D space, but the much more general concept, which enables the tools of behavioral science to apply to things that are very small, very large, very fast, or very slow, operating in many different spaces that are hard for us to recognize. I’ve been working on a framework that can help us think about, and ethically relate to, minds with very different origin stories, compositions, and cognitive light cone sizes,” as Levin calls the varying cognitive capacities of different organisms.

**Fundamental Questions of Life**

The cognitive tools at the center of the Levin lab experiments make for a fascinating way to learn about biology, especially for a nonscientist. They get to fundamental questions about life and ethics, and engage you in thinking about how things biological work, even if you have no training in the field. It’s learning about biology in what is considered a nontraditional method.

For example, how do we know that the human organism cannot successfully survive by neural processing alone? Levin’s answer to this question is straightforward: “Your embryonic cells had to join into a collective with the same shared commitment to a journey in anatomical space, to cooperate to build a body of specific shape and size, long before you had any neurons,” he said.

“Further, each of your cells has to constantly make decisions about navigating the space of metabolic, physiological, and gene expression states to solve problems that your nervous system knows nothing about. Cells can improvise novel solutions (by figuring out which genes to turn on or off, for example) to stressors and challenges they’ve never seen before.”

Levin then gave a specific example: “When early embryos, including human embryos, are split into pieces, you don’t get half-bodies; you get normal monozygotic twins, triplets, and so on. This is because each clump of cells can determine what’s missing (that it’s been deviated from its correct pattern, which it has to know), rebuild to a specific anatomy, and stop when it’s done. This classic homeostatic (goal-driven) process is the basis of all cognition.”

When asked at what point he realized that the traditional, prevailing view of neurons interacting in the brain was not an accurate description of cognition, Levin’s answer was surprising. He said he had thought about it when he was a kid, “when I learned about embryonic development, watching caterpillars come out of butterfly eggs. It became obvious that whatever we have as cognition needed to scale up gradually from things that even the molecules inside of cells can do to some extent.”

“Later,” he said, “reading about how cells can solve problems, can get to the same goal by different paths when circumstances change, and improvise solutions to anatomical problems they’ve never seen before,” reinforced this idea. He added: “Neural networks in the brain are just one example of an architecture that provides intelligence, and it evolved from others that were doing it long before neurons evolved.”

**Electrical Networking and Cancer**

In Levin’s view, single cells use voltage changes to communicate electrically with other cells to keep the body running smoothly. Cancer occurs when cells
“disconnect from their network,” Levin said. “They roll back to their ancient unicellular past and treat the rest of the body as ‘outside environment’: go where you want, eat what you want, reproduce as much as you can.”

In other words, Levin told me, this is “metastasis: The cells’ cognitive light cone, the size of their goals, or the boundary of the self they care about and maintain, with the edge of the outside world, grows in evolution and development, but can shrink: That is cancer.”

Levin came to this view of cancer when he was working on understanding how individual goals at the cell level, such as maintaining metabolic or physiological states, “get scaled up to huge, grandiose anatomical goals.” One example of this, he said, is “the salamander, which makes a hand, repairs it back to that shape if it is damaged, and stops when it’s perfect.”

The question, he said, “should not be why there is cancer, but *why there is anything but cancer*. Why do individual cells, which take care of themselves, as amoebas, etc., work together as a whole that does bigger things? The answer, like in the brain, turned out to be electrical networking.”

The question then becomes how to use voltage and electrical networking to reverse cancer. Levin described what the lab did: “We developed a therapeutic approach where we force the cells to reconnect to the network. We don’t kill them, we don’t fix the oncogene (if there is one); we simply change the voltage so that their electrical synapses can reconnect and they become part of the network again.”

The method the lab has developed to detect cancer early involves looking for voltage changes. “Tracking voltage using fluorescent voltage-reporting dyes is a great diagnostic,” Levin said. “We can see the regions that are going to become cancerous because their voltage changes in specific ways.”

The lab looks at the bioelectric signature before a tumor becomes apparent and can tell from the voltage changes where the tumor will be.

One of the experiments the lab did was to inject a human oncogene mRNA into a tadpole to cause a tumor to form. They found that by intervening with voltage, they could then suppress the tumor by preventing it from disconnecting from the rest of the cells. Manipulating the cell voltage non-invasively was enough to stop the tumor growth. The voltage change signals the cells to keep their connections.

The lab is now investigating various types of “electroceuticals” that will work with human cancers. Under development, Levin said, are strategies that normalize and prevent cancer “without targeting the genome.”

“To be clear,” Levin said during the interview, “others before me have realized there’s a bioelectric component to cancer. What is new here is the cognitive science angle, that cancer is literally a dissociative identity disorder of the morphogenetic intelligence.” Also new, he said, is “the specific approach we use to reintegrate cells back into the group-mind, focused on making and maintaining healthy organs.”

**Exploring the World of Xenobots**

The Xenobots created in the Levin lab are not old-fashioned robots—passive and metal with preprogrammed functions. Instead, the Levin researchers view the Xenobots as living cells, “liberated” from a boring two-dimensional existence as tadpole skin to have a new life in three dimensions, and practice problem-solving in a totally new environment. As Levin wrote on his lab [website](https://drmichaellevin.org/resources/): “Xenobots are an ideal example of robotics as a collaborative process between the human designer and materials that have competency at multiple scales.”

By using living material to construct Xenobots, the researchers can observe how the Xenobots react in a new environment and how they can solve problems, without human micromanagement of each step. They found that the Xenobots, acting without a full genome, had four types of behavior in a petri dish, including swimming in different directions and knitting together wounded neurons. Studying this microscopic behavior and how it develops gives researchers clues to understand more complex living systems and eventually to intervene and optimize human and animal development.

Eventually, Levin expects that the Xenobot experiments will allow researchers to construct anatomical compilers, organisms that will get cells to build whatever part of the anatomy that is needed. [This will help provide the capability to correct birth defects, injuries, aging, and problems of information processing](https://www.youtube.com/watch?v=EUwMNplNidM).

What about objections to creating these capabilities, or even just synthetic life forms, because they are considered “unnatural?” Levin thinks that we need a new kind of ethics that encompasses different life forms, not one simply based on where the organism came from or what it looks like.

Mankind has a history of changing living things to suit man’s purposes, Levin pointed out. For example, why not focus on factory farming? “The abhorrent conditions for complex animals in factory farms are by far a bigger problem world-wide than anything that is happening with skin cells allowed to reboot their multicellularity,” Levin wrote on the lab [website](https://drmichaellevin.org/resources/).

**The Ethical Imperative**

Considering cognition to be ubiquitous requires a new ethical code, which is something Levin stresses in his lab and his public presentations. He often mentions the requests he gets from people desperate for a cure or relief from pain for themselves or their children. Levin said during the interview that “Right now, a huge percentage of the world’s population is experiencing massive medical suffering. I get emails every day—people whose kids have birth defects, who have spinal cord injuries, burns, cancer, degenerative disease, and syndromes you can’t even imagine, such as consequences of surgery that leave them in unimaginable pain 24/7.”

Compassion is what should drive a new ethical code, Levin stressed to me: “It is very difficult to have a meaningful existence when you’re in pain, can’t move, or have to spend all day arranging medical care (if you can get it). The ethical imperative is to recognize that it is on all of us to help each other get out of this condition, where lack of knowledge and imagination prevents us from elevating from the often horrible embodiment that we’ve been given by random cosmic rays (mutation selection) that cares nothing for our happiness, our values, or our dreams and potential.”

Levin went further: “More than relief of disease and morbidity, I feel an ethical imperative to move applied life sciences to the point where everyone, everywhere, can have freedom of embodiment; that is, live in the kind of body they want, without pain or random limitations, so that they can pursue their creative potential.”

**What’s Next at the Lab?**

Asked what the lab is working on now, Levin listed many things in the interview, including: “better imaging of bioelectric states of complex tissues *in vivo;* better ways to communicate new goals to cells in regenerative contexts using the bioelectric interface; cracking the bioelectric code so that we can specify for cells what we want them to build; using AI to communicate with cells and learn to copy their amazing ways to improvise solutions to novel stressors they’ve never seen before; understanding the plasticity of what cells, with a normal genome, are willing and able to build (in the context of our work on the synthetic living machines or biobots); and learning to communicate not just with matter (cells and tissues) but the information ‘patterns’ that traverse bodies.”

How close are we to using cells to repair defects, combat disease, and regenerate limbs? Levin said: “I can’t give specific dates, because it depends on the course of the science, but also the course of the funding and regulatory decisions. I expected to see applications in cancer, birth defects, traumatic injury, and aging in my lifetime (I’m 57), except that recent events have thoroughly disrupted the pipeline of talent, progress, and innovation, and many things that could positively impact public health are now delayed or shelved indefinitely.”

“What keeps me up at night,” Levin wrote on his [website](https://drmichaellevin.org/resources/), “is the risk of committing *the ethical lapse of not moving these discoveries to their full positive impact for humanity and other life forms*, current and future. I worry about limitations of drive, vision, intellect, and commitment that would prevent us from implementing the moral imperative to use our minds to improve life for all, and live up to our full potential as living beings.”