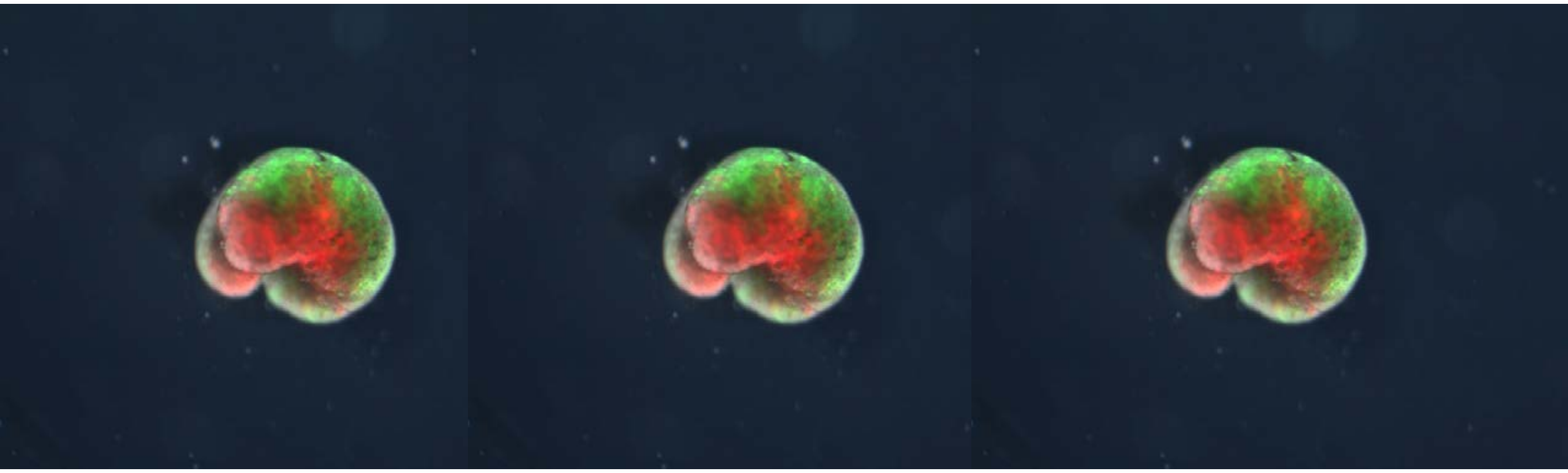
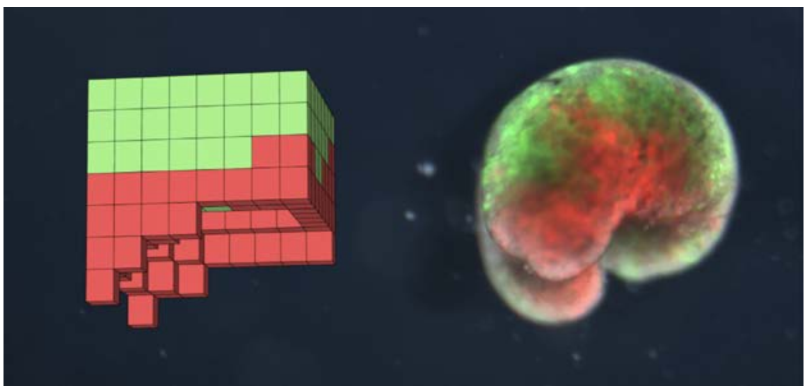
# Institute for Computationally Designed Organisms



## Overview

Imagine a world in which living machines – biobots – are commonly used for targeted drug delivery, chasing down cancer cells in the body, collecting toxins in the environment, and creating tinier biobots which work together in a swarm to micro-sculpt tissues for transplantation. Imagine that the insights learned from making and studying these new life forms are used to drive new advances in regenerative medicine – rebuilding complex organs to address birth defects, traumatic injury, aging, and cancer. Studying decision-making in these artificial organisms gives rise to a whole new class of artificial intelligence. This is no longer science fiction but is within reach, by fulfilling the research potential of a new science being developed in this interdisciplinary new Institute.

Evolving for eons, organisms have developed remarkable abilities to adapt to situations never before encountered. By exploiting this inherent adaptability, research in the Levin lab has recently revealed that cells can be 'reprogrammed', without altering their DNA, to form into stable large-scale forms, with new functions, never before seen in nature. This is accomplished by changing how cells communicate with one another, during growth, using external influences applied by human or machine scientists. Using this discovery, the Bongard lab has recently shown how to teach an AI to design such 'biobots' on its own: a researcher simply tells the AI what task the biobot should perform. The AI then designs one over days (rather than billions of years) in the cloud and manufactures as many copies of it as is needed. A first demonstration of this was reported by Levin and Bongard and led to global media attention, including a CNN appearance (youtu.be/Q_pFkP1PL8w). This work is poised to grow into a field that will transform regenerative medicine, environmental remediation, robotics, and AI.



**The world's first computer designed organism, revealed by the Institute co-directors in January 2020, captured global media attention. The computer-generated design (left) and its sand-grain sized physical counterpart, constructed from frog skin and heart muscle cells (right).**
**Image courtesy of D. Blackiston**

The remarkable capabilities of living organisms are usually thought to be the product of eons of evolutionary selection for specific traits. However, research in the Levin lab has uncovered massive plasticity in the ability of cell collectives to work together toward specific and novel large-scale form and function. We have shown that when liberated from their normal boundary conditions, the morphogenetic goal states of cell groups can be re-programmed, often without any changes to their DNA, by exploiting the powerful endogenous biophysical software that governs the behavior of cell collectives. These findings now make it possible to apply the Bongard lab's powerful evolutionary robotics approach to the design of functional novel life forms.

Overcoming the need to wait long periods of time for biological evolution, we can now use in silico approaches to evolve the configurations and inputs (experiences) that cells need to be given to create entirely new living machines. A first example is shown in the figure above, and was reported in the Proceedings of the National Academy of Sciences in January 2020. This work forms the basis of a new field that enriches both engineering (via insights from biology) and biology (with deep concepts from computer science) to transform areas including regenerative medicine, robotics, environmental remediation, public health, and even the existential risks and opportunities of AI.

# Institute Vision

Our team is ideally poised to address the key opportunities for bi-directional advances between artificial intelligence and biology, ranging from regenerative medicine to swarm and micro robotics. The current state of computational biology has only begun to scratch the surface of what is possible via a true integration of the deep concepts of these two fields. Our Institute vision sees the same foundational Big Question as the enabling step for the next century's advances in AI and biology: how do collectives of competent agents process information towards large-scale goals, and how can evolutionary and top-down strategies be designed so as to give rise to predictable, flexible, desired complex outcomes.

Current approaches to biomedicine are limited in that they are focused almost entirely on hardware of cells; genomic editing alone cannot address the needs of biomedicine because it is entirely unclear what aspects of the genome to change to get complex outcomes. Synthetic biology is largely stuck in single-cell approaches to reprogram metabolics and biochemistry, and has not yet tackled multi-cellular constructs via guided self-assembly and basal cognition in synthetic new anatomies. Without understanding the biological software that guides growth and form, stem cell biology and molecular medicine will soon hit a ceiling. Likewise, the search for flexible, adaptive machine intelligence and robotics is stymied by an exclusively neuro-centric view of AI and the failure to adopt multi-scale principles of organization of living tissues.

We are now ideally poised to combine our recent discoveries of how cell goals can be reprogrammed toward novel anatomies with new computational tools, to enable intelligent robotics based on biological principles and the discovery of strategies for regenerative repair of complex organs. Our institute will make fundamental advances and give rise to transformative applications at the intersection of computer science and developmental biophysics. We will not only revolutionize the field of soft-body and biological robotics for a myriad of near-term biomedical and ecological applications, but will also crack the unsolved problem of how groups of competent agents (cells, robots, communications devices) give rise to emergent "swarm minds" with novel goals and cognitive capabilities. Taming this as yet mysterious process by a tight integration of computational approaches and synthetic bio-morphology is a unique new roadmap for revolutionary advances in technology and regenerative medicine. Moreover, it represents the first essential steps on a roadmap for dealing with existential risks that arise from current gaps in knowledge about how goals and motivations emerge in new forms of life, whether biological or silicon AI.

# Leadership Team

Michael Levin is Vannevar Bush professor of Biology at Tufts University, and associate faculty at Harvard's Wyss Institute. He is director of the Allen Discovery Center at Tufts - a team of developmental biologists and bioengineers who work towards gaining control over biological growth and form. The Levin group were the first to create molecular and computational tools to probe the bioelectric software that guide tissue-level decision-making in the body during embryogenesis and regeneration, and to show how non-genetic information guides top-down control of anatomical structure. Their work has revealed previously unknown plasticity which they have employed to implement limb regeneration, tumor reprogramming, and birth defect repair.

Joshua Bongard is the Veinott Professor of Computer Science at the University of Vermont and the director of the Morphology, Evolution & Cognition Laboratory. His work involves computational approaches to the automated design and manufacture of soft-, evolved-, and crowdsourced robots, as well as computer-designed organisms. A PECASE, TR35, and Microsoft New Faculty Fellow award recipient, he has received funding from NSF, NASA, DARPA, the U.S. Army Research Office and the Sloan Foundation. He served as director of the Vermont Advanced Computing Core, Vermont's high-performance computing facility. In addition to many peer-reviewed journal and conference publications, he is the author of the book How The Body Shapes the Way we Think.

# Structure & Development Timeline

The Institute will span two locations: Tufts (Levin lab) and UVM (Bongard lab). The biological portion will be done in the Allen Discovery Center labs at Tufts – state-of-the-art biological research facilities that include numerous model species and unique biophysics instrumentation. The computational work will be conducted at UVM by Bongard's lab, using the now GPU-accelerated Vermont Advanced Computing Core (the VACC is in the top 100 supercomputers in the world). Additional PIs may be involved as needed for roll-out of specific applications (e.g., clinical testing).

The management will be 50/50 Bongard and Levin, both of whom will manage a tightly-integrated team of post-docs and technical personnel who will work both remotely and in person with back-and-forth visits. The mission of the Institute is to produce fundamental advances in the basic science of a new field (computational understanding and implementation of "life as it could be") and transitioning those advances into practical applications across biomedicine, robotics, and machine learning.

## Basic Science to Commercialization: Funding Model

As we build this effort we are particularly interested in founding partners that will help us launch a multi-million-dollar effort that will change the landscape of science.

We approach this process with some flexibility and we can imagine the following structures: (1) Core/founding partners will provide foundational support to fund launch and core operations and basic science which would establish the creation of the main discovery platform. (2) Additional partners could participate via a membership model that would provide access to Institute members' expertise and early view of discoveries, via a tiered model of levels of access. Funders will be given opportunity to license Institute IP which is aligned with the Institute and their organization's research and development strategies. (3) Specific subprojects could be taken on via sponsored research agreements, to the extent that these are fully aligned with the Institute mission. An essential aspect of the Institute is that a basic core of fundamental science is essential to continuously drive the creation of many expected spinoffs with specific commercial utility. The Institute will be able to apply for specific grants but the ideal model includes baseline funding every year for continuity and to enable focus on the mission vs. fundraising by the PIs.

# Conclusion

Computer science has made the leap from a focus on hardware to a focus on software, which resulted in the information technology revolution. Biology has not done it yet, still largely stuck in technologies addressing the hardware level of cells. We now have the opportunity to drive the same transformative advance in biomedicine and bioengineering as occurred for IT, and then exploit those discoveries to further catapult AI and robotics by implementing strategies gained from a better understanding of the biological software. Our Institute will initiate a unique feedback cycle of advances in both areas, using the deep insights of each field to transform the other, continuously. We invite anyone interested in helping to guide the development of technology and basic science that will massively impact society for the coming century, to join us in this new effort to truly understand Life and use that knowledge to develop numerous applications to benefit humanity. We seek founding gifts or investments, as well as memberships for sustainable annual funding. Foundation, corporate, and individual investors are all welcome.