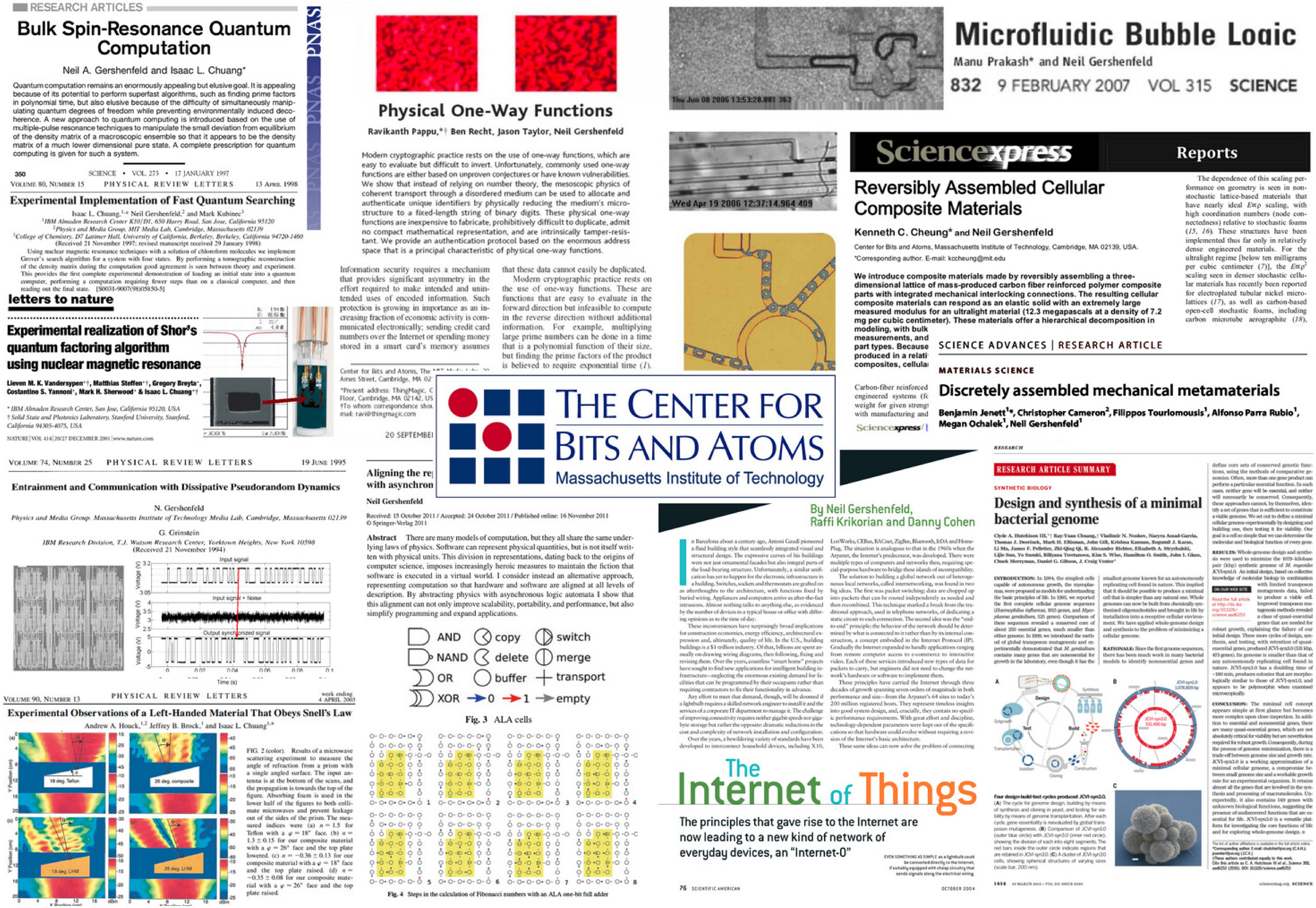
THE CENTER FOR BITS AND ATOMS
Massachusetts Institute of Technology

Prof. Neil Gershenfeld

Director

http://ng.cba.mit.edu


RESEARCH ARTICLES
Bulk Spin-Resonance Quantum Computation
Neil A. Gershenfeld and Isaac L. Chuang*
350 SCIENCE • VOL. 275 • 17 JANUARY 1997
PNAS
VOLUME 80, NUMBER 15 PHYSICAL REVIEW LETTERS 13 APRIL 1998
Experimental Implementation of Fast Quantum Searching
Isaac L. Chuang, Neil Gershenfeld, and Mark Kubinec
letters to nature
Experimental realization of Shor's quantum factoring algorithm using nuclear magnetic resonance
Lieven M. K. Vandersypen, Matthias Steffen, Gregory Breyta, Costantino S. Yannoni, Mark H. Sherwood & Isaac L. Chuang
NATURE | VOL 414 | 20/27 DECEMBER 2001 | www.nature.com
Physical One-Way Functions
Ravikanth Pappu, Ben Recht, Jason Taylor, Neil Gershenfeld
Microfluidic Bubble Logic
Manu Prakash* and Neil Gershenfeld
832 9 FEBRUARY 2007 VOL 315 SCIENCE
Sciencexpress
Reports
Reversibly Assembled Cellular Composite Materials
Kenneth C. Cheung* and Neil Gershenfeld
SCIENCE ADVANCES | RESEARCH ARTICLE
MATERIALS SCIENCE
Discretely assembled mechanical metamaterials
Benjamin Jenett, Christopher Cameron, Filippos Tourlomousis, Alfonso Parra Rubio, Megan Ochalek, Neil Gershenfeld
THE CENTER FOR BITS AND ATOMS
Massachusetts Institute of Technology
VOLUME 74, NUMBER 25 PHYSICAL REVIEW LETTERS 19 JUNE 1995
Entrainment and Communication with Dissipative Pseudorandom Dynamics
N. Gershenfeld
G. Grinstein
Aligning the re
with asynchron
Neil Gershenfeld
AND
NAND
OR
XOR
copy
delete
buffer
switch
merge
transport
empty
Fig. 3 ALA cells
Fig. 4 Steps in the calculation of Fibonacci numbers with an ALA one-bit full adder
VOLUME 90, NUMBER 13 PHYSICAL REVIEW LETTERS week ending 4 APRIL 2003
Experimental Observations of a Left-Handed Material That Obeys Snell's Law
Andrew A. Houck, Jeffrey B. Brock, and Isaac L. Chuang
By Neil Gershenfeld, Raffi Krikorian and Danny Cohen
The Internet of Things
The principles that gave rise to the Internet are now leading to a new kind of network of everyday devices, an "Internet-0"
76 SCIENTIFIC AMERICAN OCTOBER 2004
RESEARCH ARTICLE SUMMARY
SYNTHETIC BIOLOGY
Design and synthesis of a minimal bacterial genome

Jason Taylor

Vice President of Infrastructure Foundation at Facebook

San Francisco Bay Area | Internet

Current: Facebook
Previous: Ink2, Lucidity, Inc., BlueMountain.com
Education: Massachusetts Institute of Technology
Websites: Company Website

Jason Taylor is a Vice President of infrastructure at Facebook, where he leads the groups that manage hardware design & quality, supply chain, technical program management, server budget and allocation, and the long-term infrastructure plan. Prior to Facebook, he was integral in scaling the engineering teams and production environments of several consumer-facing tech companies. Jason holds a Ph.D. from MIT in Ultrafast Lasers and Quantum Computing and a B.E. From Vanderbilt University in Physics, Electrical Engineering and Math.

TED Watch Read Attend Participate About

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Perhaps you've punched out a paper doll or folded an origami swan? TED Fellow Manu Prakash and his team have created a microscope made of paper that's just as easy to fold and use. A sparkling demo that shows how this invention could revolutionize healthcare in developing countries … and turn almost anything into a fun, hands-on science experiment.

Edward S. Boyden
Massachusetts Institute of Technology
2016 Breakthrough Prize in Life Sciences

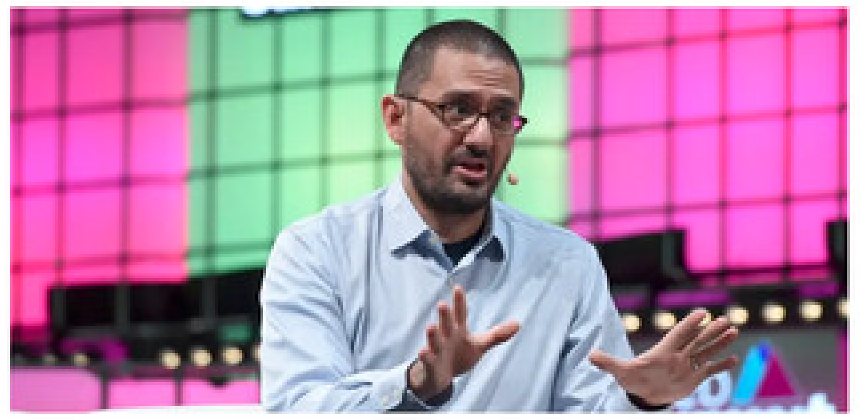
ASPEN IDEAS FESTIVAL

Nadya Peek

Graduate Student, Media Arts and Sciences School, Massachusetts Institute of Technology

Nadya Peek is a research assistant in the Center for Bits and Atoms at MIT. She works on digital fabrication, networking protocols for machine control, digital materials, machines that make machines, and rapid prototyping. In her spare time, she volunteers at Fab Lab (Fabrication Laboratories), a global network of digital fabrication facilities where anyone can make almost anything.

2012 Bio



Raffi Krikorian, 40, will return to California to join the Emerson Collective, the philanthropy company founded by Laurene Powell Jobs, a DNC official confirmed on Thursday. He served as Twitter's vice president of engineering and ran Uber's self-driving cars project before joining the Democratic Party in the summer of 2017, taking on his first job in politics at a time when the DNC faced an urgent need to reimagine its internal approach to tech and cybersecurity.

VB NEWS EVENTS RESEARCH

The odds are good that Lyric Semiconductor will change computing

Meet The Latest Unicorn: Formlabs, A 3-D Printing Startup Founded By Three Young MIT Grads

In 2016, Maxim Lobovsky, cofounder and CEO of Formlabs, made the cut for the Forbes 30 Under 30 list. Today, his 3-D printing company passed the $1 billion valuation mark with a new round of venture capital funding from New Enterprise Associates.

The New York Times

New Technique Reveals Centuries of Secrets in Locked Letters

M.I.T. researchers have devised a virtual-reality technique that lets them read old letters that were mailed not in envelopes but in the writing paper itself after being folded into elaborate enclosures.

By William J. Broad

Published March 2, 2021 Updated March 4, 2021

NATIONAL ACADEMY OF SCIENCES

William O. Baker
Award for Initiatives in Research

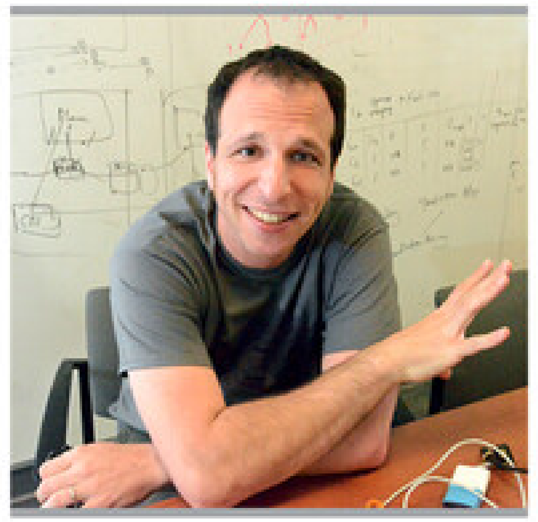
Benjamin Recht, assistant professor of electrical engineering, computer science, and statistics at the University of Berkeley is the recipient of the William O. Baker Award for Initiatives in Research, presented in 2015 in the field of machine learning.

NeurIPS | 2017

Thirty-first Conference on Neural Information Processing Systems

Test of time award:

Ali Rahimi, Benjamen Recht. Random Features for Large-Scale Kernel Machines. NIPS 2007



THE NEW YORKER

NEWS CULTURE BOOKS & FICTION SCIENCE & TECH BUSINESS HUMOR

ANNALS OF DESIGN | MAY 17, 2010 ISSUE

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THE INVENTOR'S DILEMMA

An eco-minded engineer discovers the limits of innovation.

BY DAVID OWEN

In 2004, while Saul Griffith was a Ph.D. student at the Massachusetts Institute of Technology, he won a thirty-thousand-dollar award that is given each year to a student who has shown unusual promise as an inventor. Griffith was an obvious candidate. Neil Gershenfeld, one of his professors, described him to me as "an invention engine," and said, "With Saul, you push 'Go' and he spews projects in every imaginable direction." The judging committee was especially impressed by a device that Griffith had created to custom-manufacture low-cost eyeglass lenses, intended primarily for people in impoverished countries.

A professor who taught Saul Griffith at M.I.T. described him as "an invention engine."

SEAN MCCABE

WIRED

NASA'S MIGHTY MORPHING WINGS MAKE FOR MORE EFFICIENT FLYING

"One of the things that we've been able to show is that this building block approach can actually achieve better strength and stiffness, at very low weights, than any other material that we build with," says NASA'S Kenny Cheung, one of the leaders of the project.

Better yet, when the team put the wings onto a dummy plane body and threw it into the wind tunnel at NASA's Langley Research Center in Virginia, the mock aircraft flashed some terrific aerodynamics. "We maxed out the wind tunnel's capacity," says Cheung.

CADE METZ BUSINESS 04.21.15 5:45 AM WIRED

DELIVERING THE INTERNET VIA DRONE…AND LASER

Yael Maguire | Engineering director | Facebook Connectivity Lab

SAMSUNG RESEARCH AMERICA

Think Tank Team

Rehmi Post
Science Lead

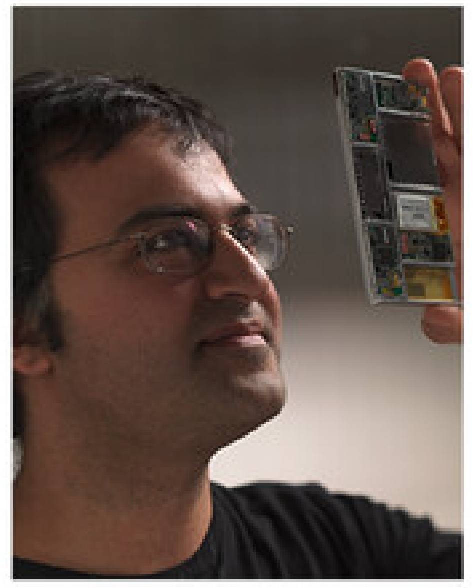
Project Ara: Inside Google's Bold Gambit to Make Smartphones Modular

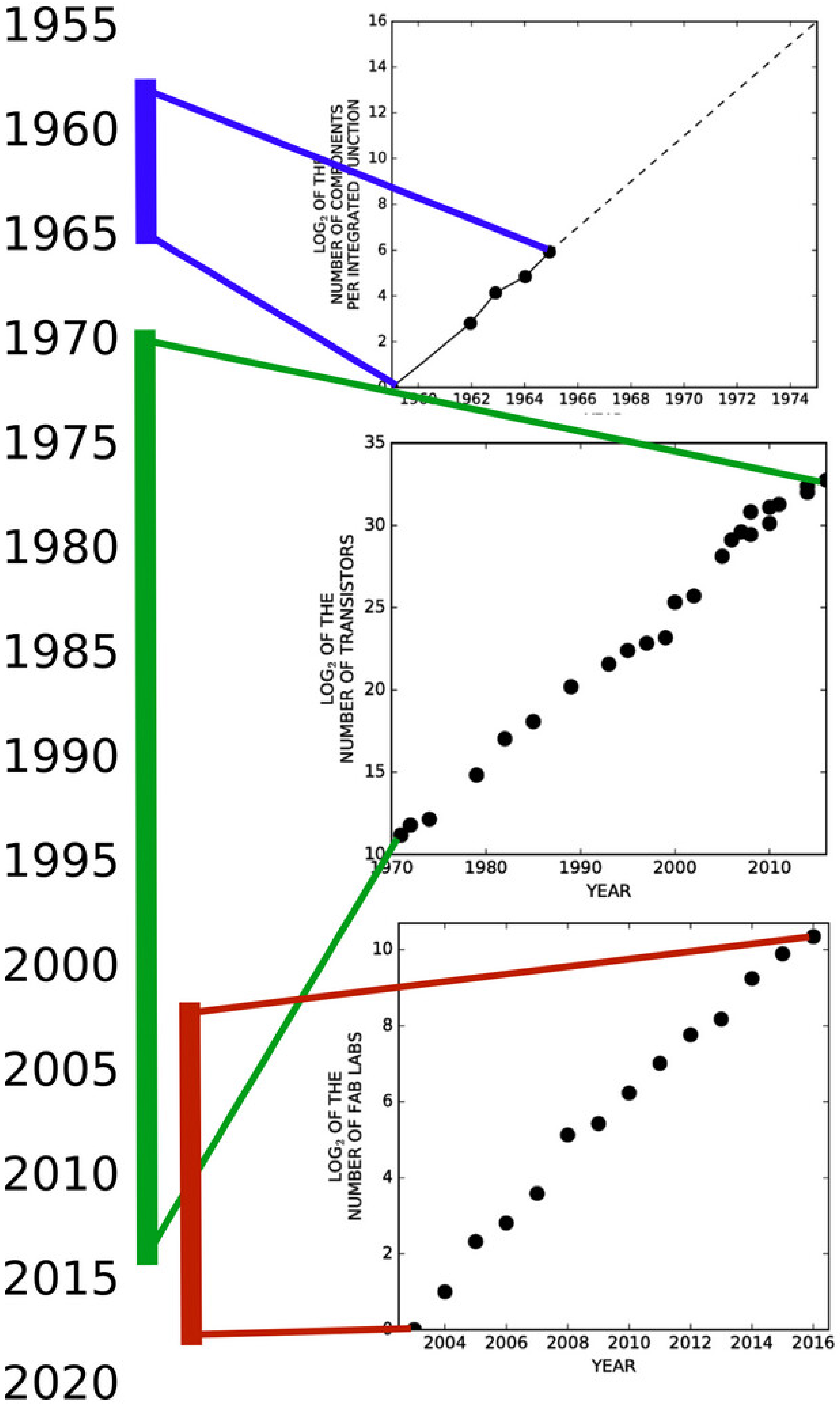
Harry McCracken @harrymccracken | Feb. 26, 2014

The two-year quest to create the ultimate customizable phone, inside and out.

On January 29, Google announced that it had agreed to sell Motorola, its phone-manufacturing business, to Chinese electronics giant Lenovo. Thus concluded the company's brief, unprofitable foray into smartphone hardware, which began when it revealed plans to acquire Motorola Mobility in August, 2011.

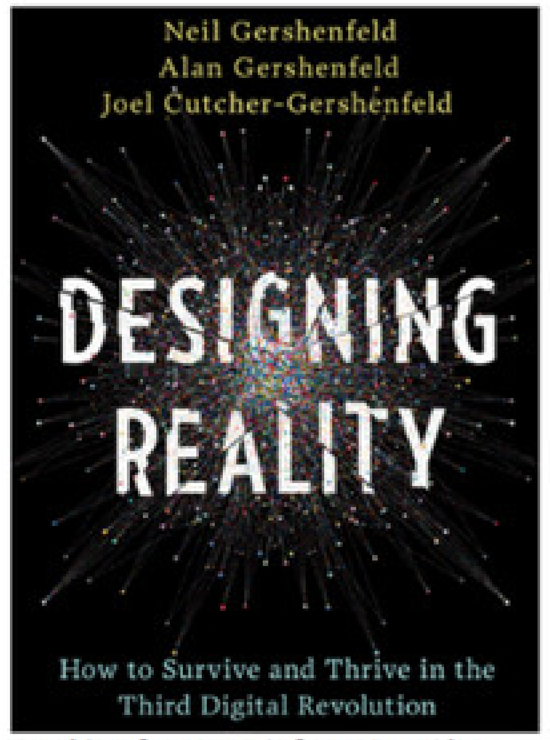
Ara Knaian, lead mechanical engineer on Project Ara, with the phone in its current functional prototype form





LASS' LAW IS KNOCKING AT THE DOOR

Roberto Saracco · March 9, 2018 · Blog · 858 Views



Looking for more info on Lass' law and the future of Fab Labs? Get Neil Gershenfeld new book "Designing Reality". Image Credit – Book Cover, Neil Gershenfeld

Our economy has grown and has been transformed by 60 years of Moore's Law, bringing electronics in any path of life. Moore's Law has now reached its endpoint (although progress in computation capabilities are still continuing, not a the previous pace and, most importantly, not with the cost decrease we have experienced in the last decades) but a new Law is knocking at the door of our economy and our society, promising to be as disruptive as Moore's: Lass' Law.

Sherry Lassiter, known as Lass, is the head of the Fab Foundation. A Fab, a Fab Lab, is a room full of computers managing tools that can manufacture objects, including 3D printers and laser cutters. The first Fab Lab was created back in 2003 at MIT Center's for Bits and Atoms by Neil Gershenfeld and in 2009 he set up the Fab Foundation. There "Lass" noticed that the number of "tools" for manufacturing doubled every year and by 2016 there were over 1,000 Fab Labs around the world.

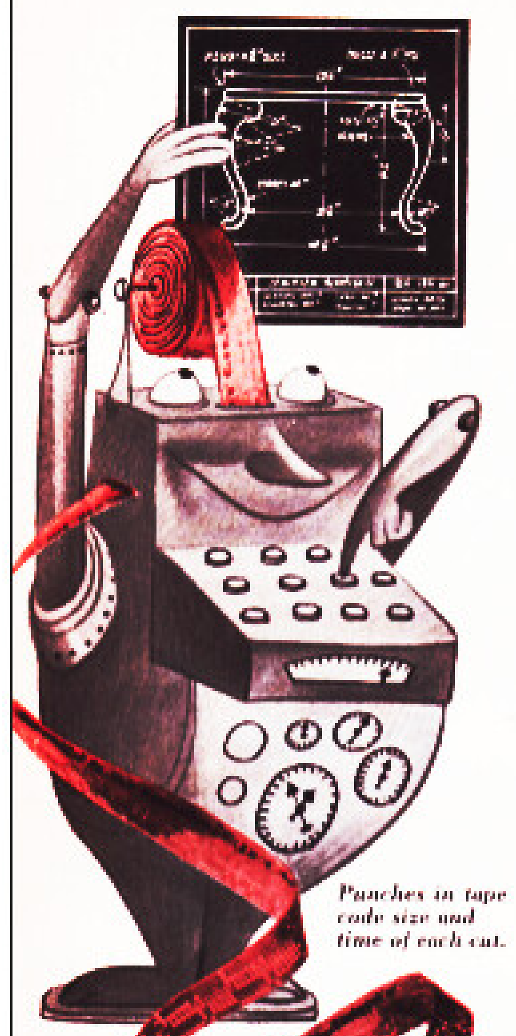
If Lass' Law will remain valid in the next ten years by 2030 there will be over 10 million fab labs, and clearly they will no longer be confined within research labs: there are simply not enough research labs around the world to host them. By that time Fabs will have percolated in small industries, retail stores and some will have found a place in consumers' homes. Give it 10 more years and 150 millions homes will have a fab lab as part of their furniture.

At the same time the whole value chain of manufacturing will be transformed bringing Industry 4.0 into Industry 5.0. Consumers will no longer buy products but products' specs and them will manufacture them at home. Of course one can imagine that a new slate of businesses will be there, providing support to customisation. Possibly some of these business will sell "intelligence" to make customisation decision possible at home.

The convergence of Artificial Intelligence with massively distributed / on site manufacturing is going to change the economy, the value chains and the players in manufacturing.

In twenty years time it will be difficult to find a product that is not a melange of atoms and bits. Many products will be aware of their "use" and will be able to reconfigure themselves to the point of creating their own offsprings (thanks to the availability of fab labs). The mixing of AI with fab labs and the self generation of offsprings will result in products evolution with an increasing symbiotic leverage of what is in the product's ambient.

Welcome to Industry 5.0, an Industry having people as player and product component!



Punches in tape code size and time of each cut.

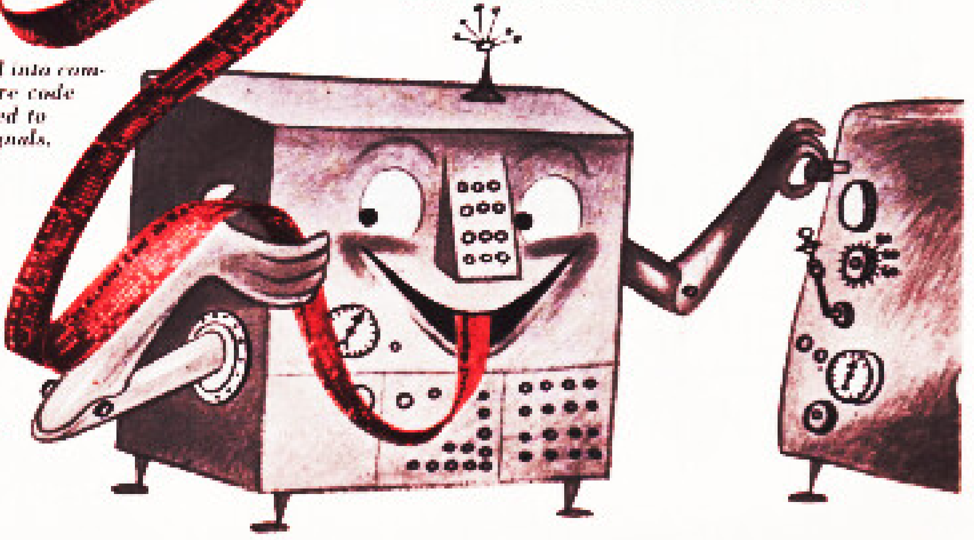
In an electronic lab at MIT, engineers now are

Teaching Power Tools to Run Themselves

By Hartley E. Howe

SO JOE WORKSHOPPER figures he'd like to turn out a set of dining-room chairs—and at the same time break in his new Model 100 Super Tapemaster. Joe whips down to the hardware store and looks over photographs of different designs. He settles on a Swedish pattern popular way back in 1955—delicate and handsome, but full of difficult reverse curves.

That doesn't worry Joe. He plunks down $10 for a week's rental of a batch



Tape is fed into computer where code is converted to electric signals.

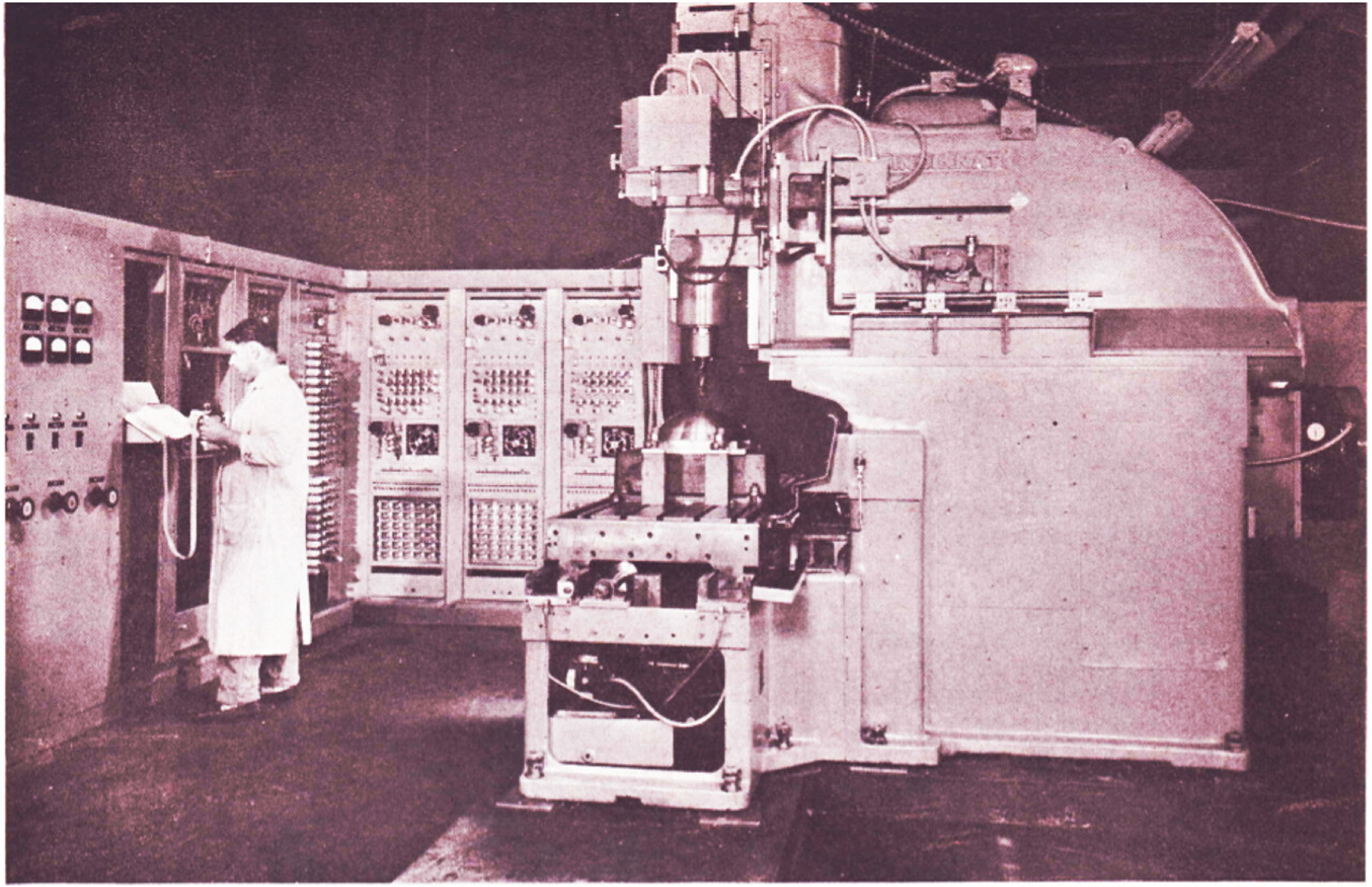
Founded in 1872, Vol. 167: No. 2

POPULAR SCIENCE Monthly
REG. U. S. PAT. OFF.

Mechanics and Handicraft
REG. U.S. PAT. OFF.

America's Leading New-Idea Magazine for 83 Years

AUGUST, 1955



Too big yet for home shop, this MIT milling machine is run by computer-control at left.

THE CENTER FOR BITS AND ATOMS
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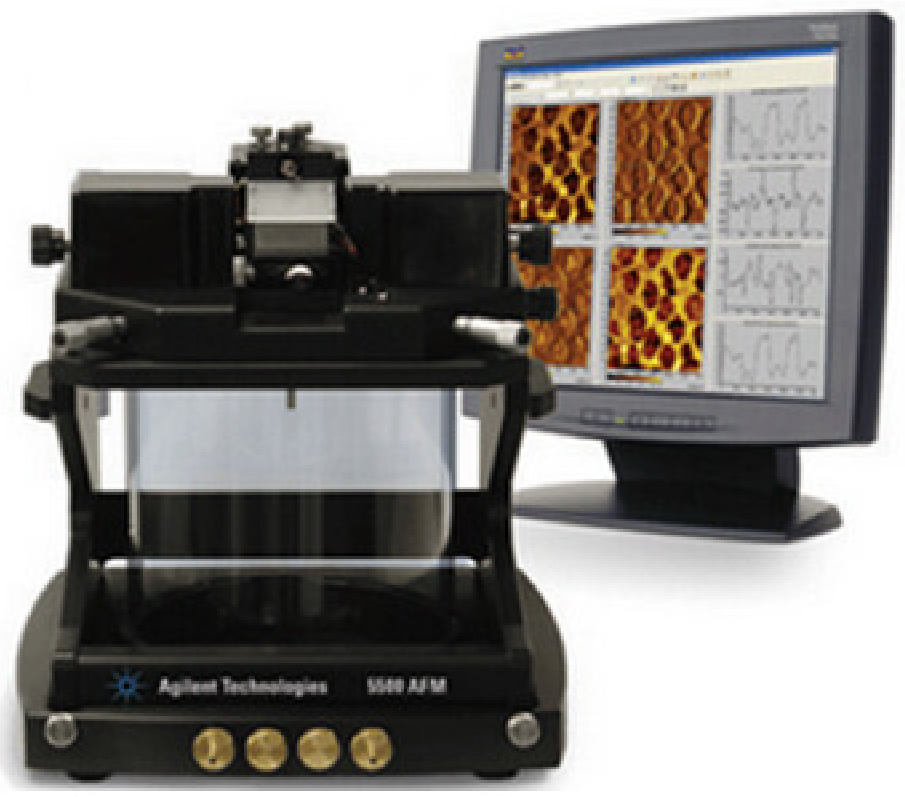

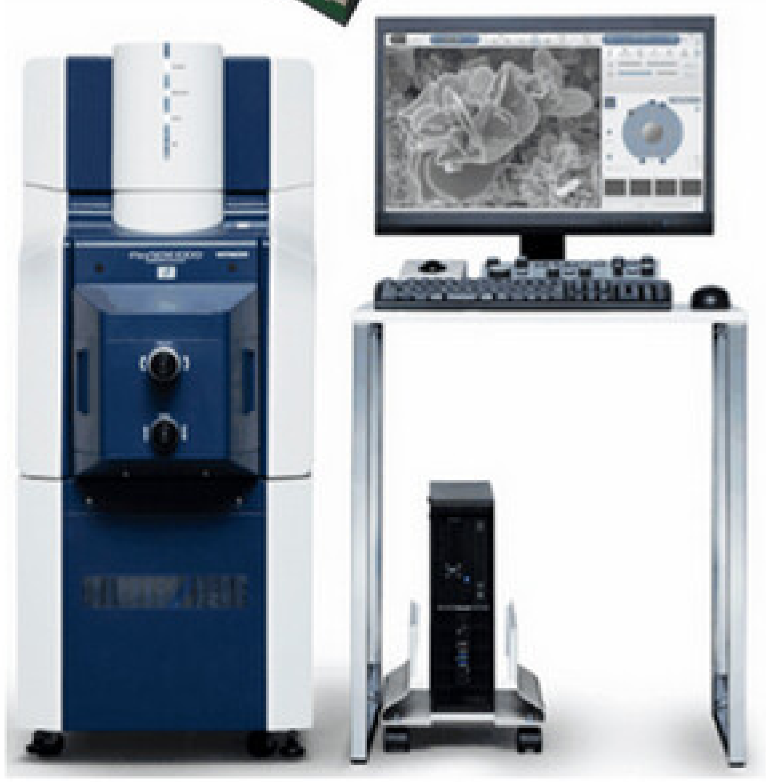

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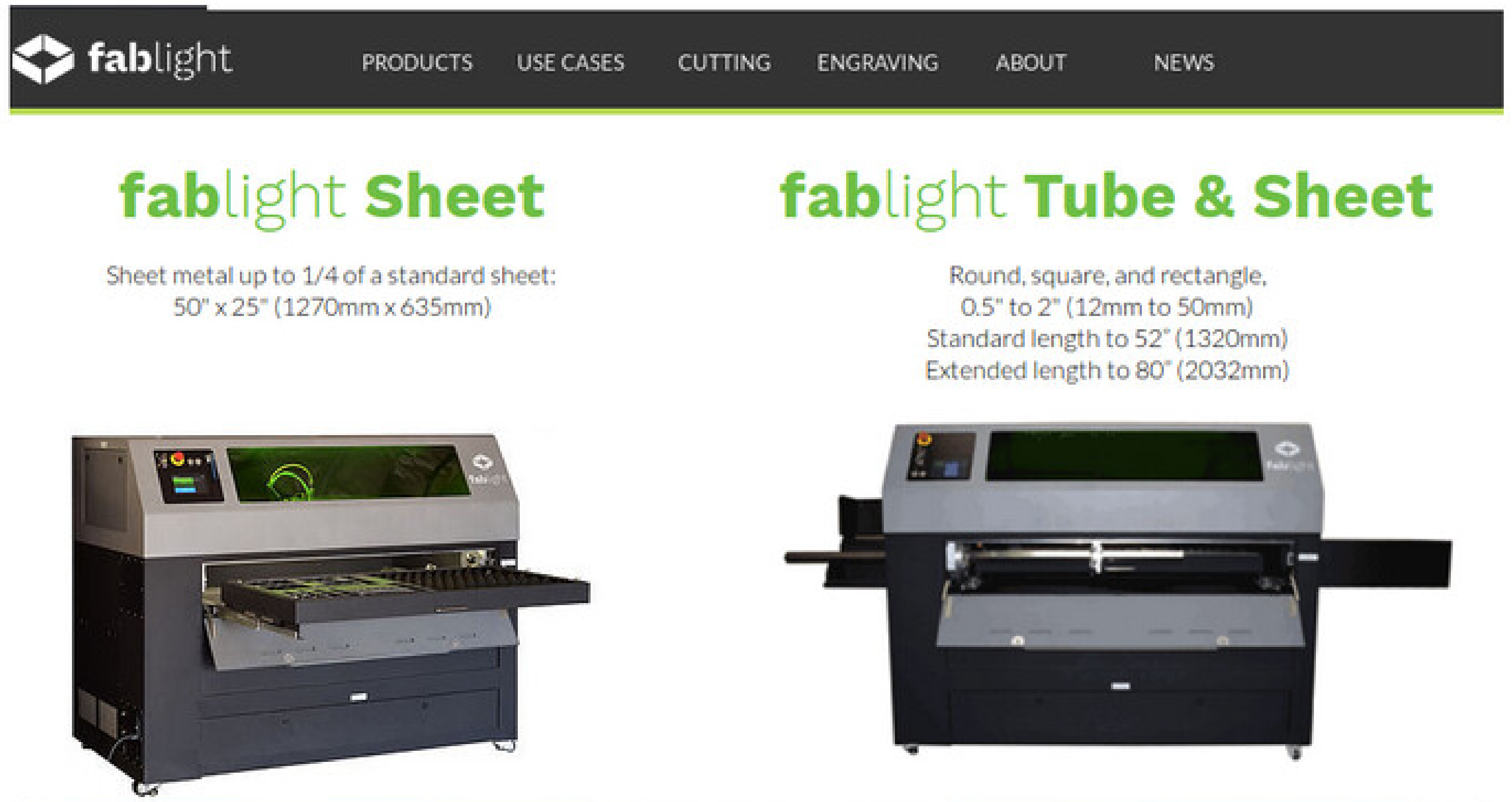
High-resolution 3D printing on the desktop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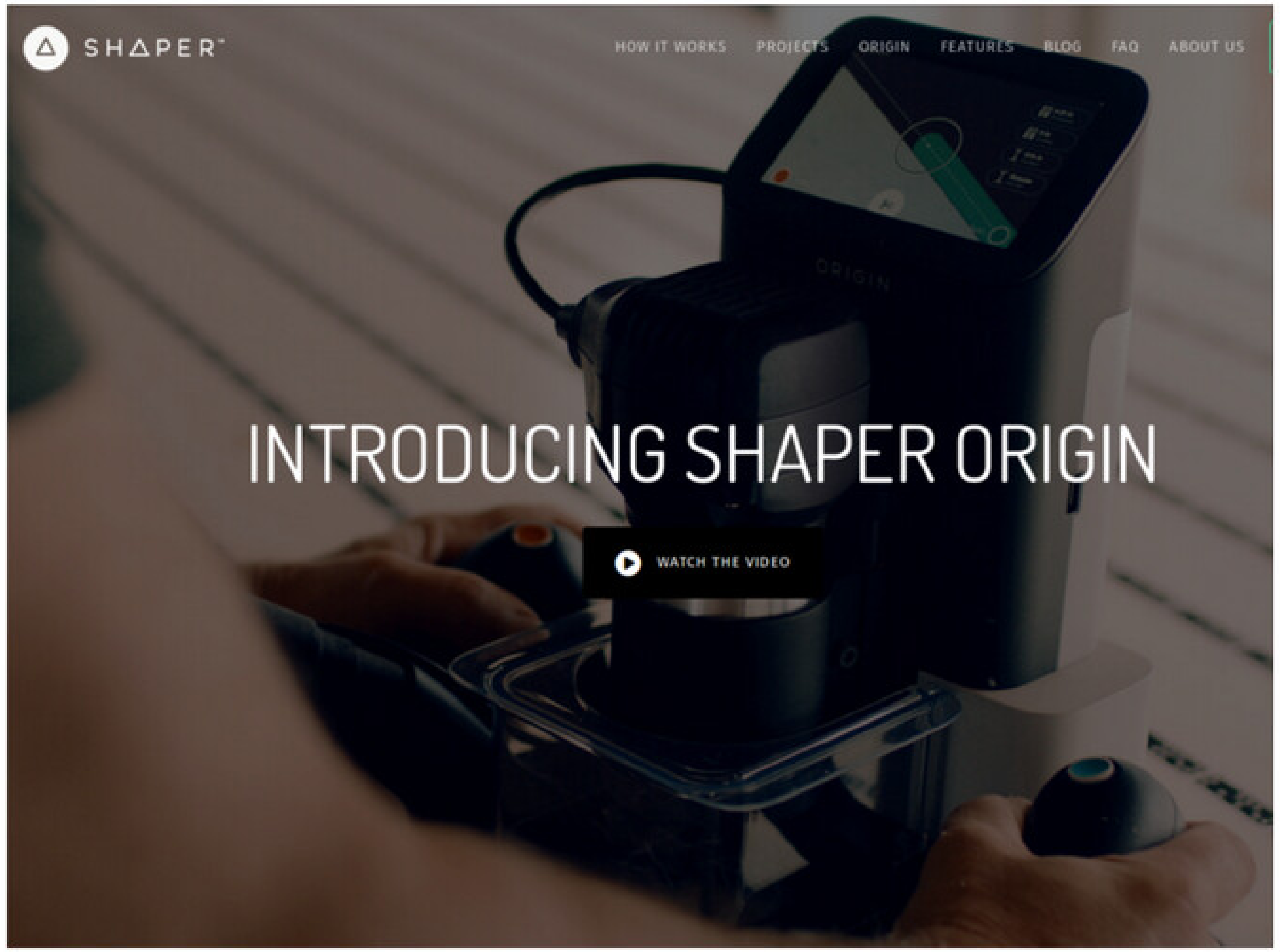
fablight Sheet
Sheet metal up to 1/4 of a standard sheet:
50" x 25" (1270mm x 635mm)
fablight Tube & Sheet
Round, square, and rectangle,
0.5" to 2" (12mm to 50mm)
Standard length to 52" (1320mm)
Extended length to 80" (2032mm)


Bantam Tools Desktop Milling Machines
Bantam Tools™ Desktop Milling Machines provide professional reliability and precision at an affordable price.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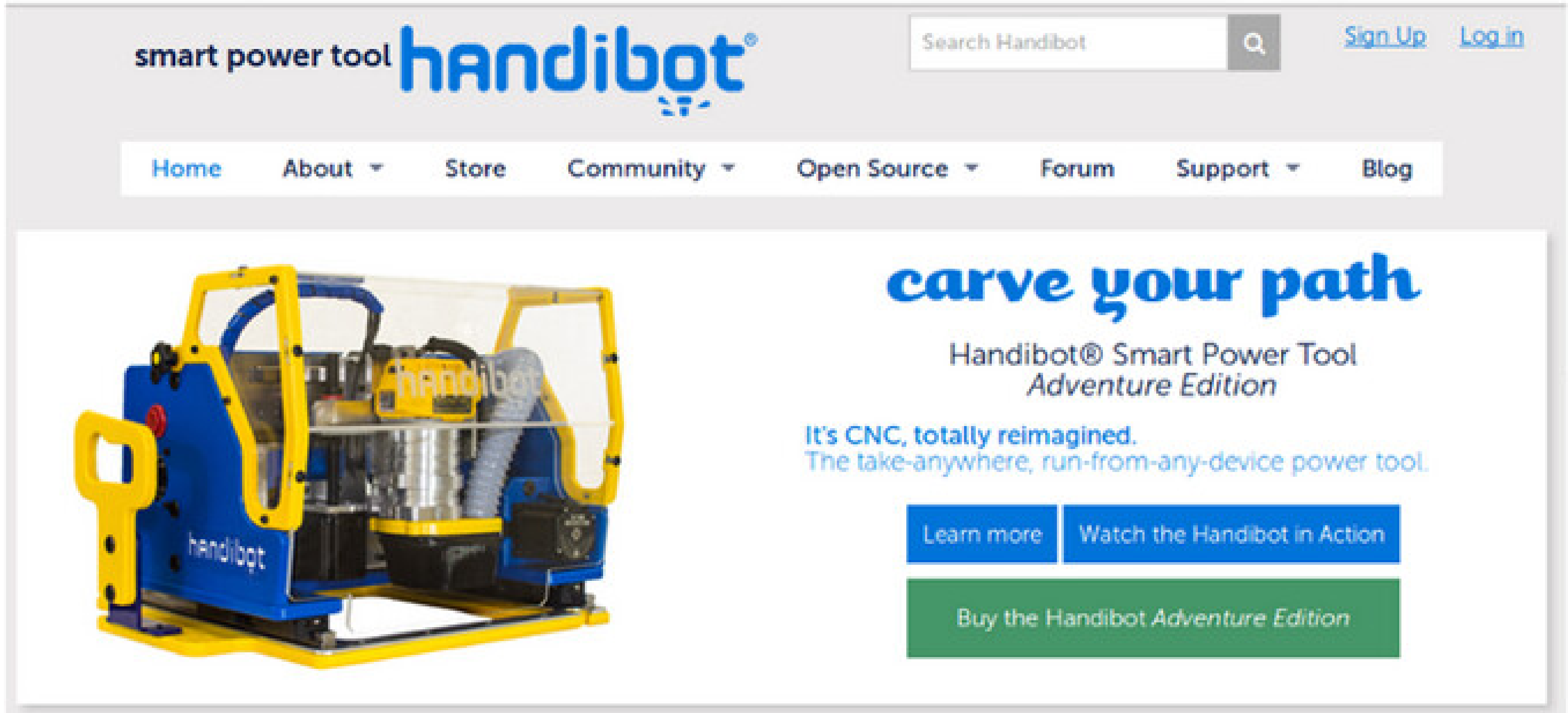
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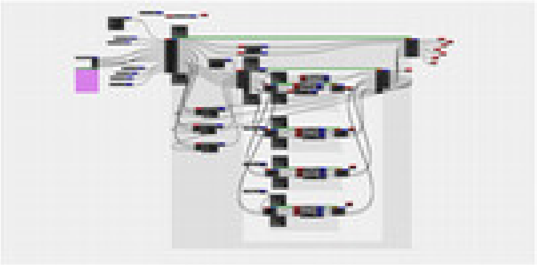
Machines that Make

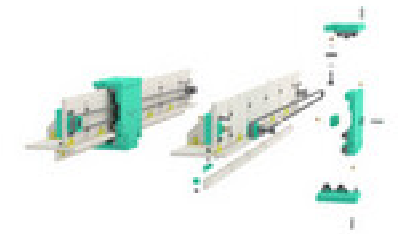
The Machine that Make project at the MIT Center for Bits and Atoms is developing rapid-prototyping of rapid-prototyping machines, that can be used in fab labs.

Squidworks



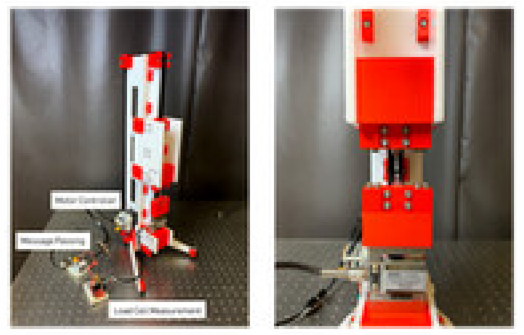
Graphs all the way down.

Platonic Gantry Design



Acrylic and 3D Printed Parametric Gantries.

The Displacement Exercise

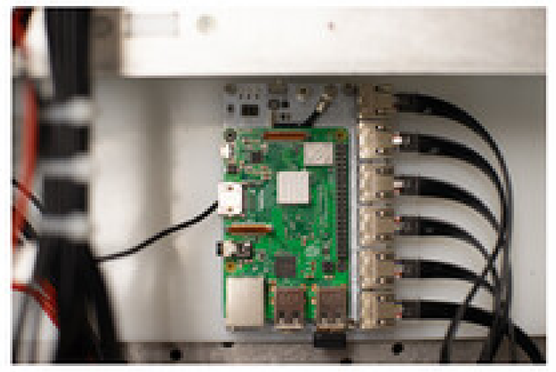


DEX: an open source, intelligent materials testing machine.

Roller Coaster Tycoon Gantries

Parametric Linear Axis: 2D Sheets for 3D CNC

ATK - AutomataKit

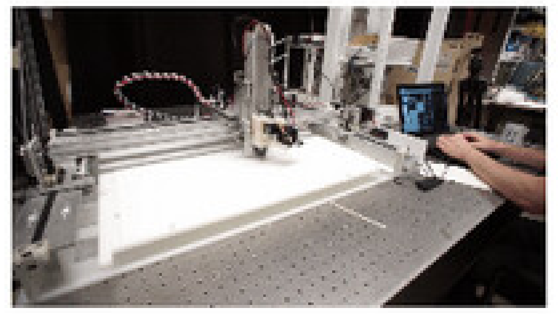


Networked Hardware Elements for Accessible Automation

RNDMC

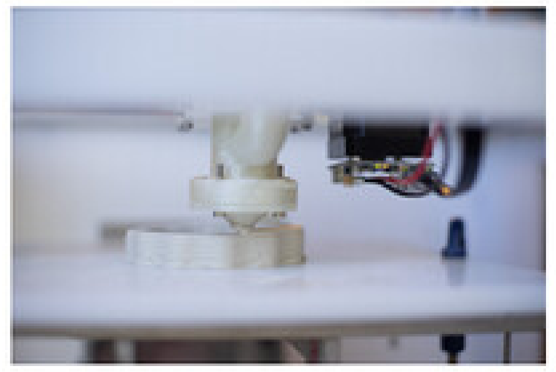
Reconfigurable Numeric Dataflow Machine Controller

Mother Mother



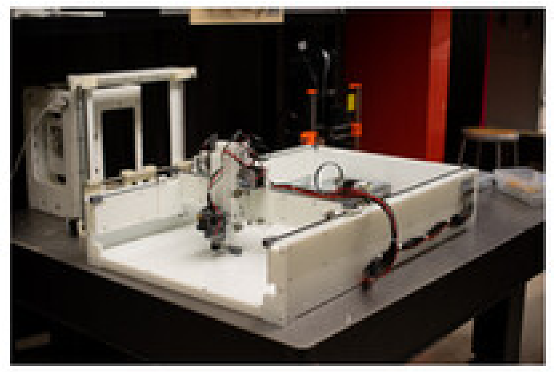
A Generalist, a Mechanical Breadboard. The Vise Grips of CNC.

Claystacking at Haystack



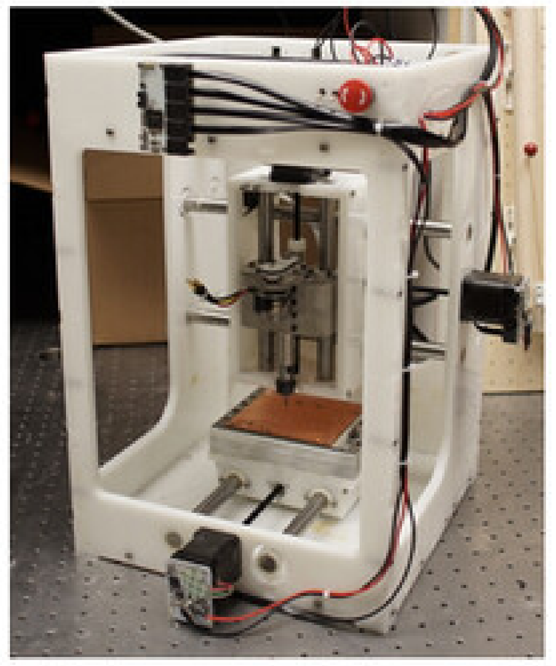
Mud Machine Liveth

Madison Park Vocational Machine



Mud Machine Liveth

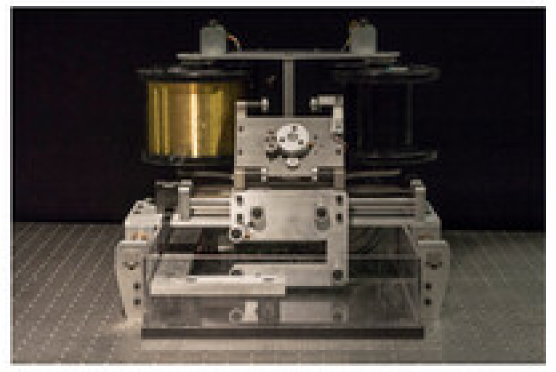
MTM class



Modular Machines and Mods

Modular Machines controlled with Modular Software

Desktop Wire-EDM

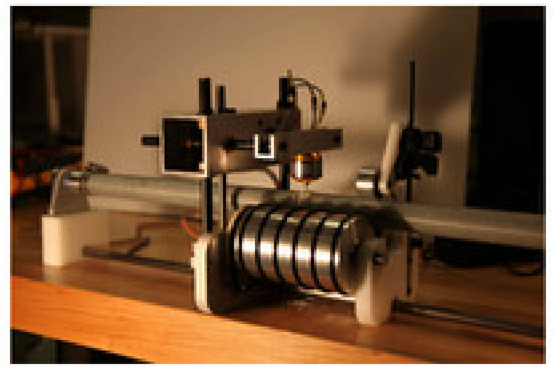


A Wire-EDM that fits on your desktop

Modular Robot

Reconfigurable modular robot with interchangeable end-effectors

Tube carver



Milling machine for round stock

[m]MTM: modular machines that make

More modular machines out of prototyping materials for prototyping

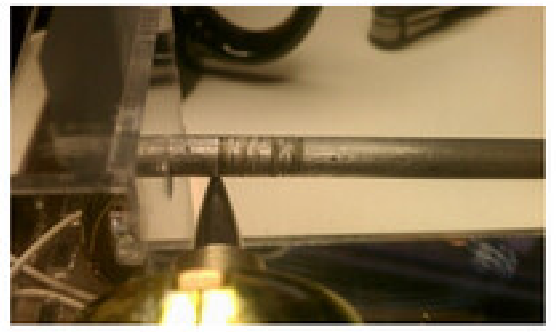
Reconfigurable Stages

Reconfigurable one-axis stages for multi-purpose motion

foldafab

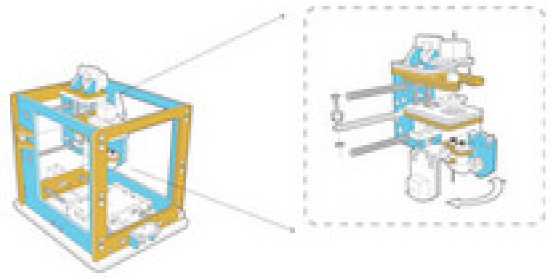
A deployable medium-format CNC router

DIY EDM



An entry level EDM machine for making carbide/HSS tooling and/or lead screws

5 Axis Timing Belt MTM

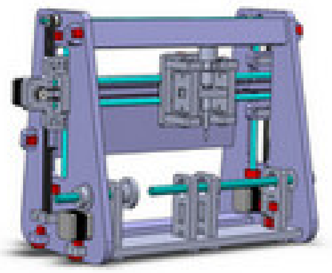


Low cost 5 axis machining

POP Fab

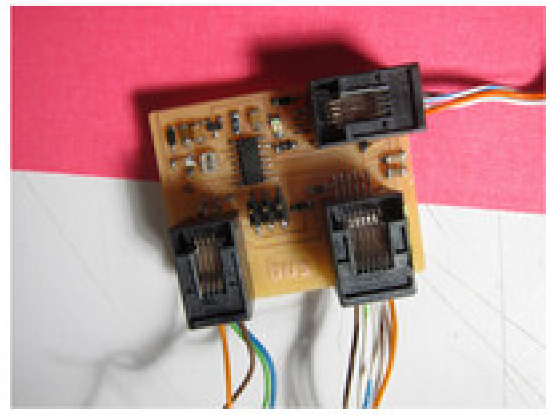
A suitcase milling machine, 3d printer, and vinyl cutter

Multi-processes lathe



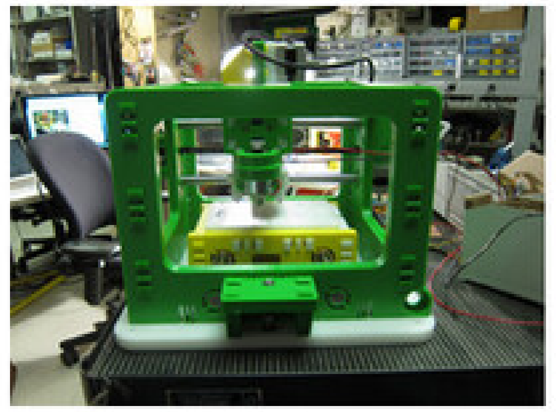
The additive lathe is a 3D printer that prints on rotation objects

Virtual Machine Network



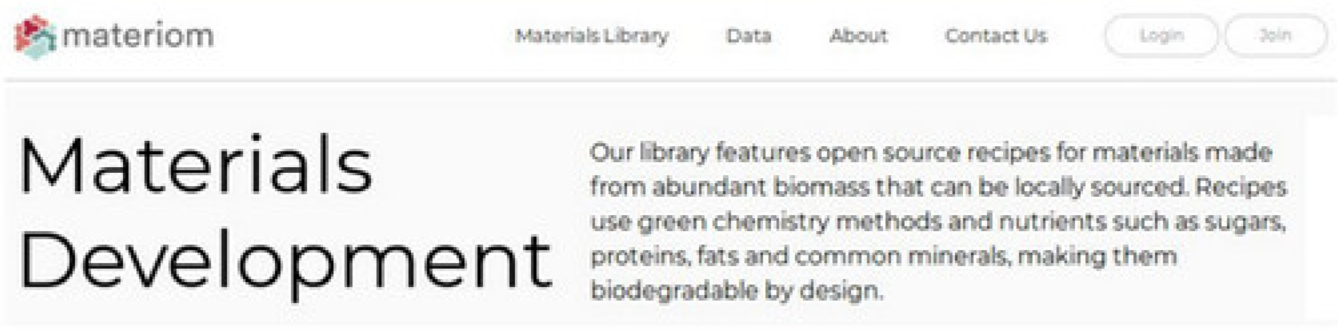
Modular control for the MTM project

Timing Belt MTM

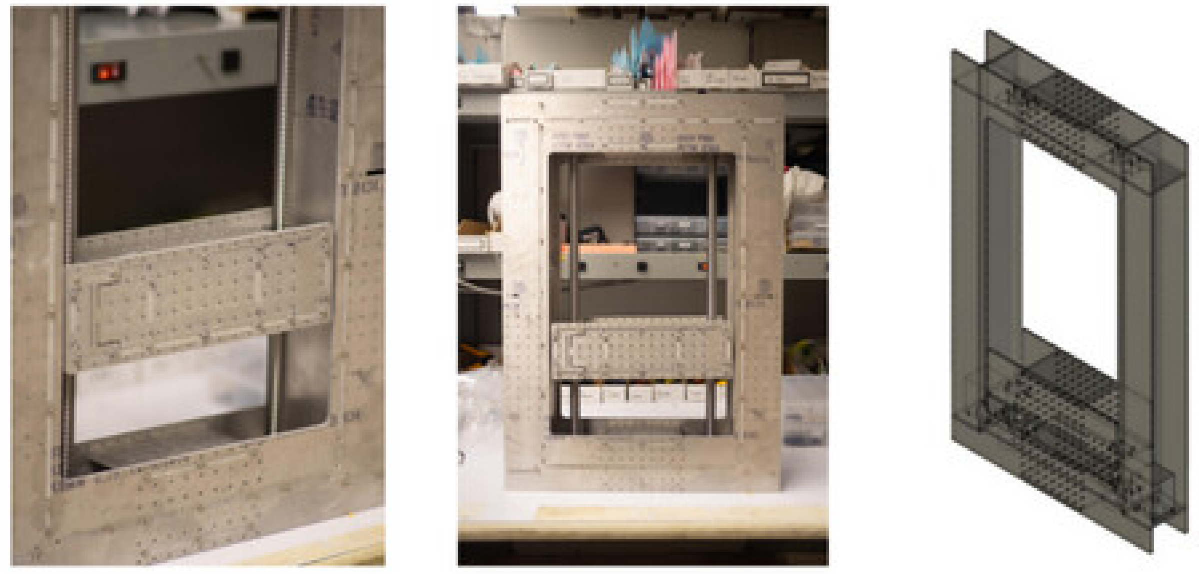


A design without lead screws, reducing cost

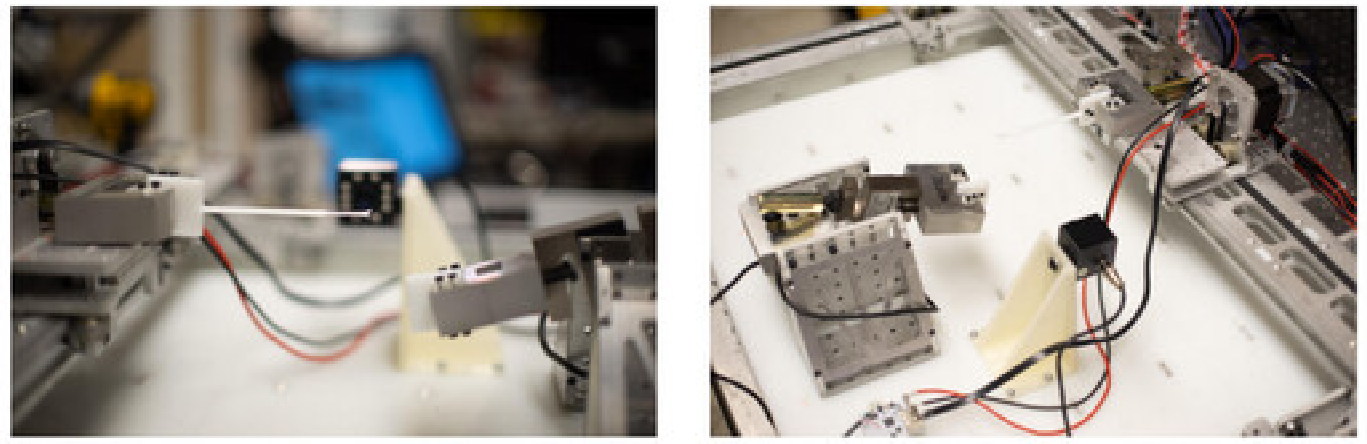
Fab-In-A-Box



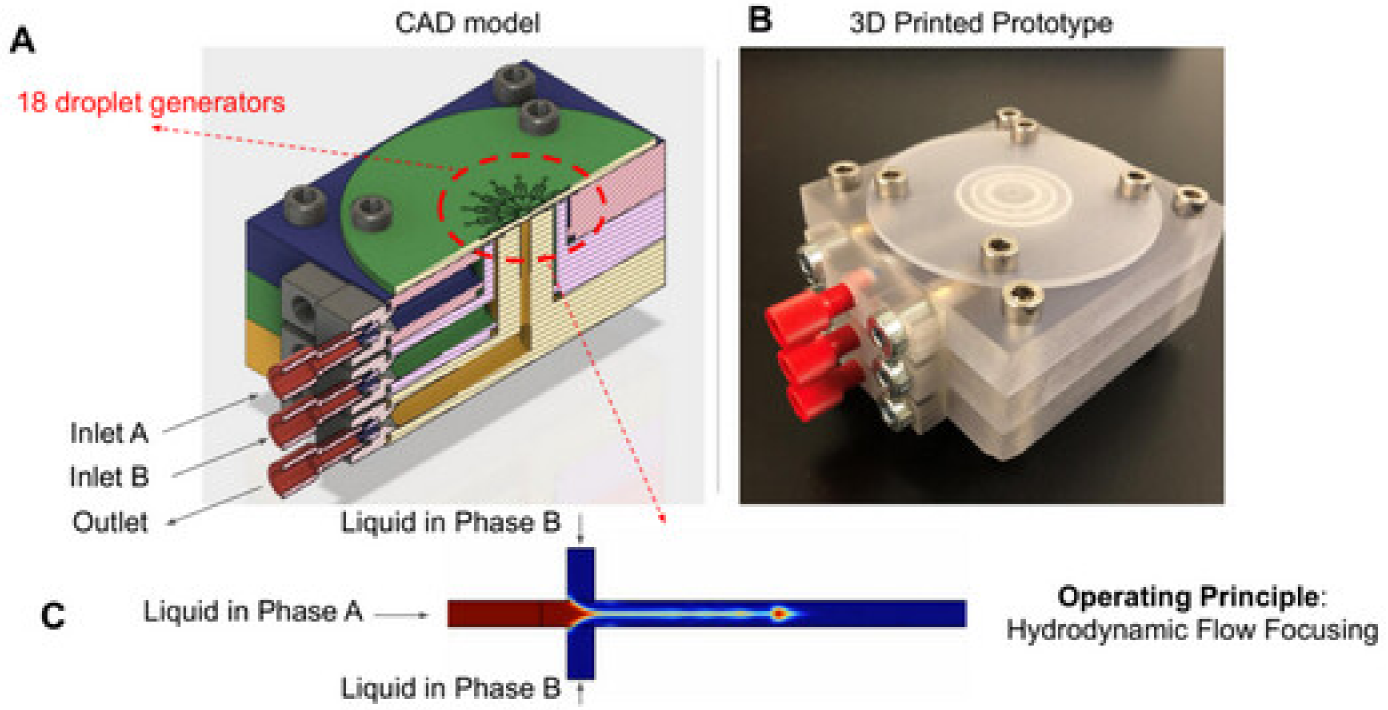
Open Stress and Strain Machine (uSSM)



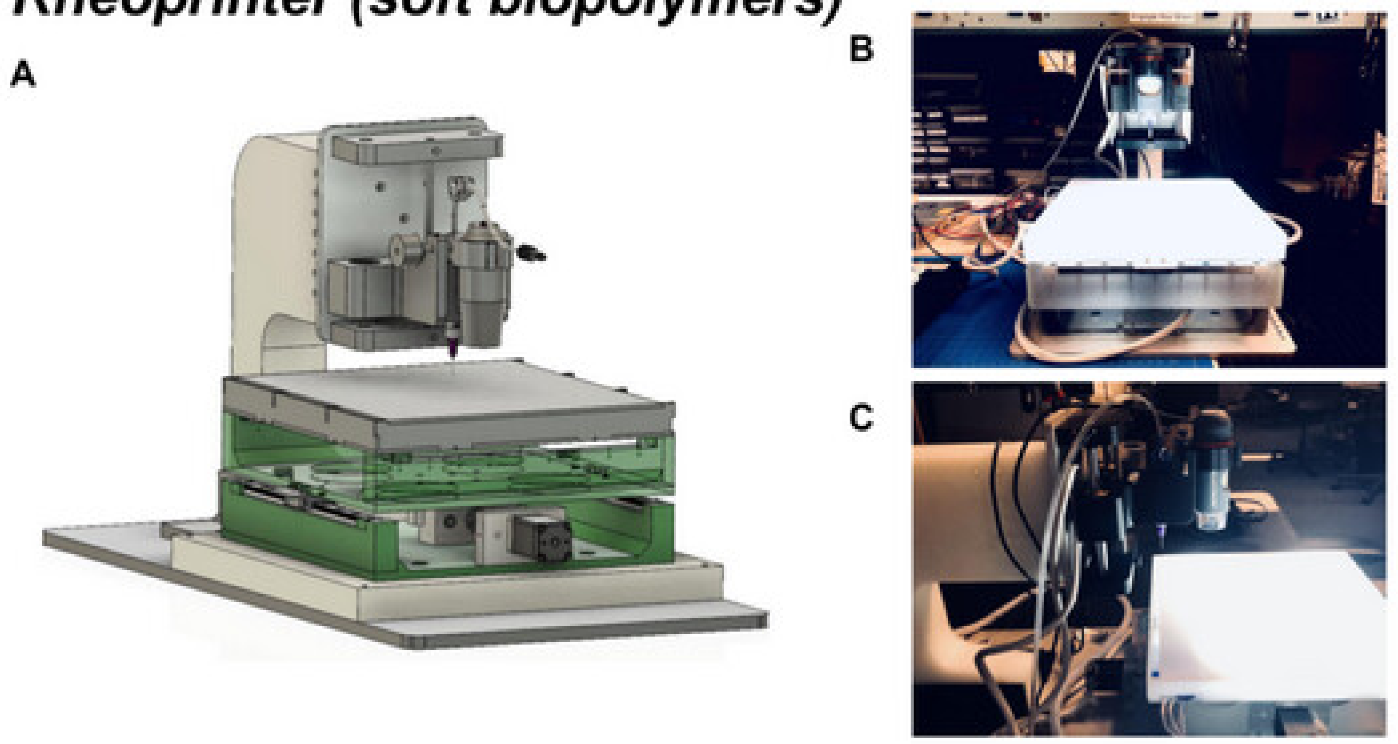
uSSM Prototype and Fixturing



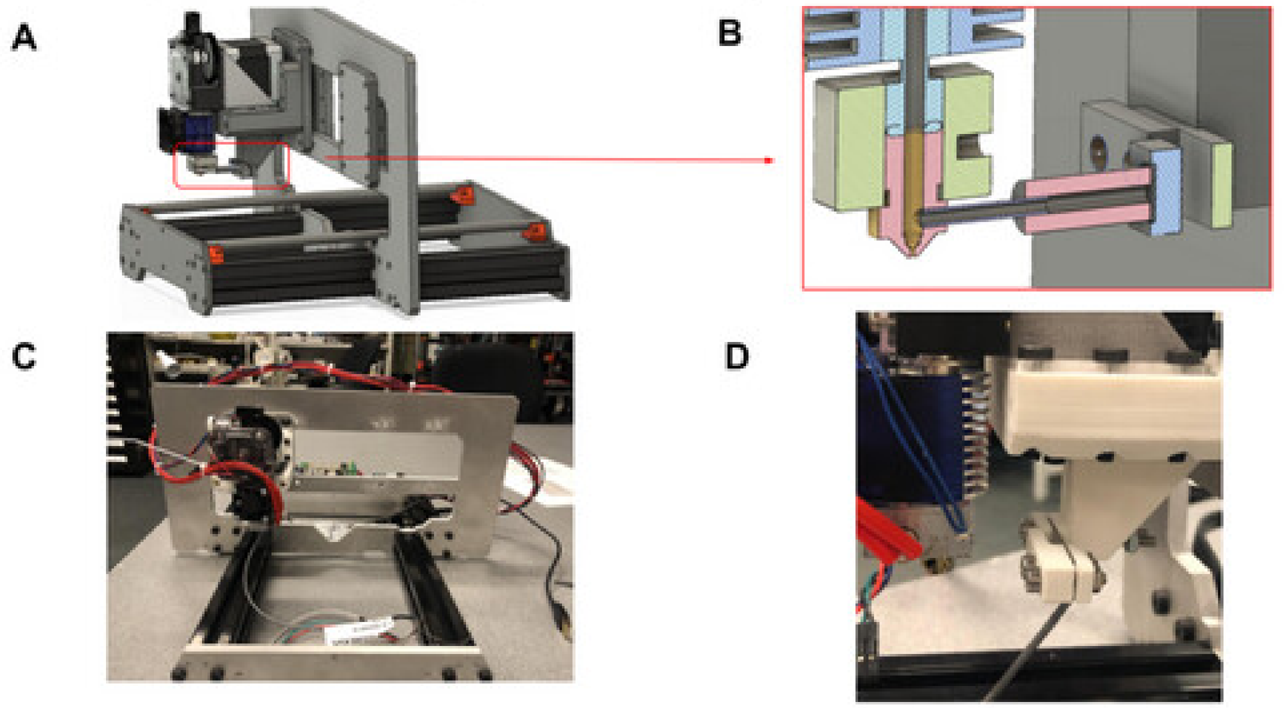
Parallelized Droplet Generator



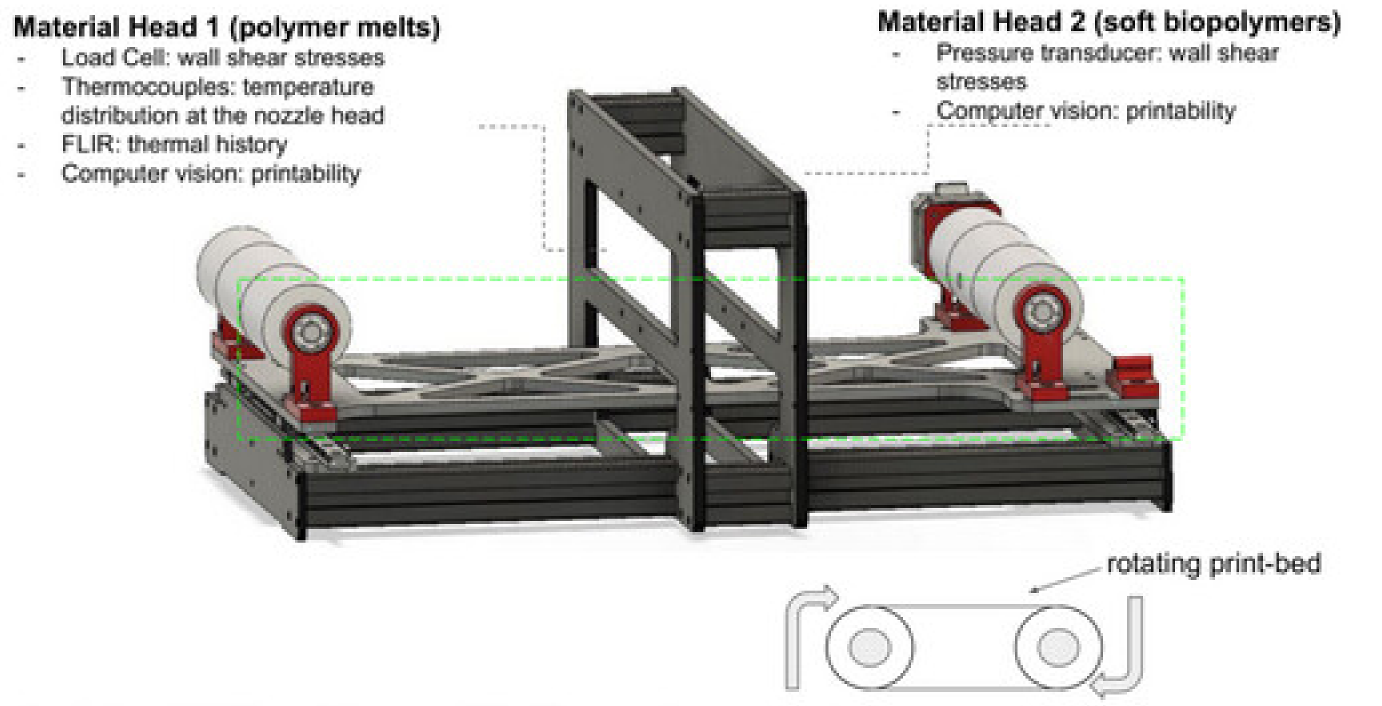
Rheoprinter (soft biopolymers)



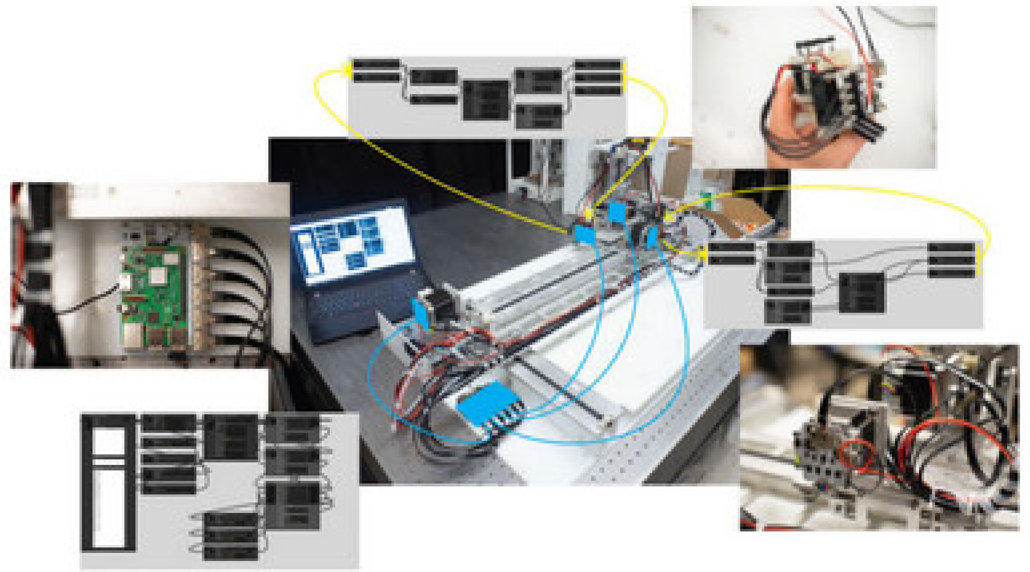
Rheoprinter (polymer melts)



Printomics Printer

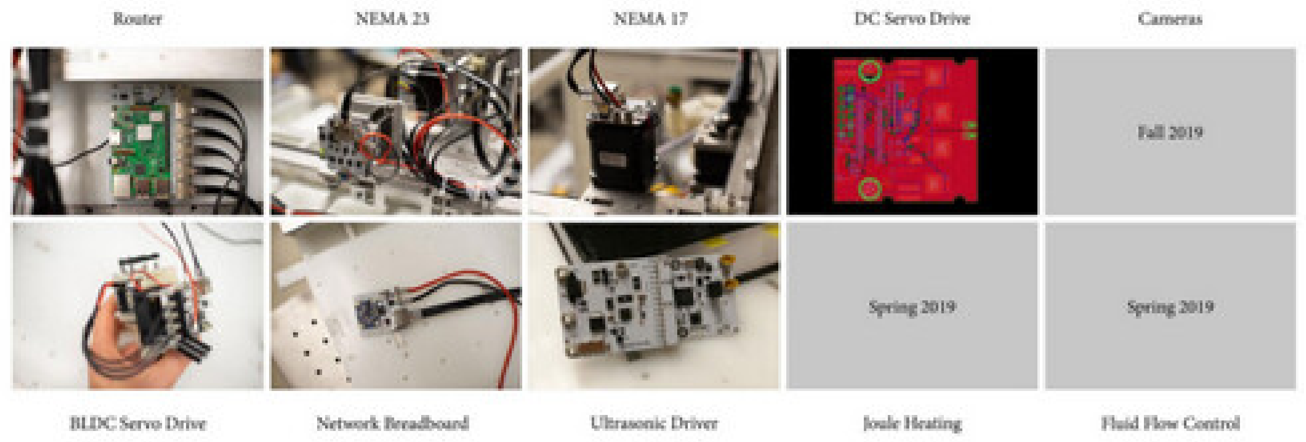


Graph Computing for Open Instrumentation

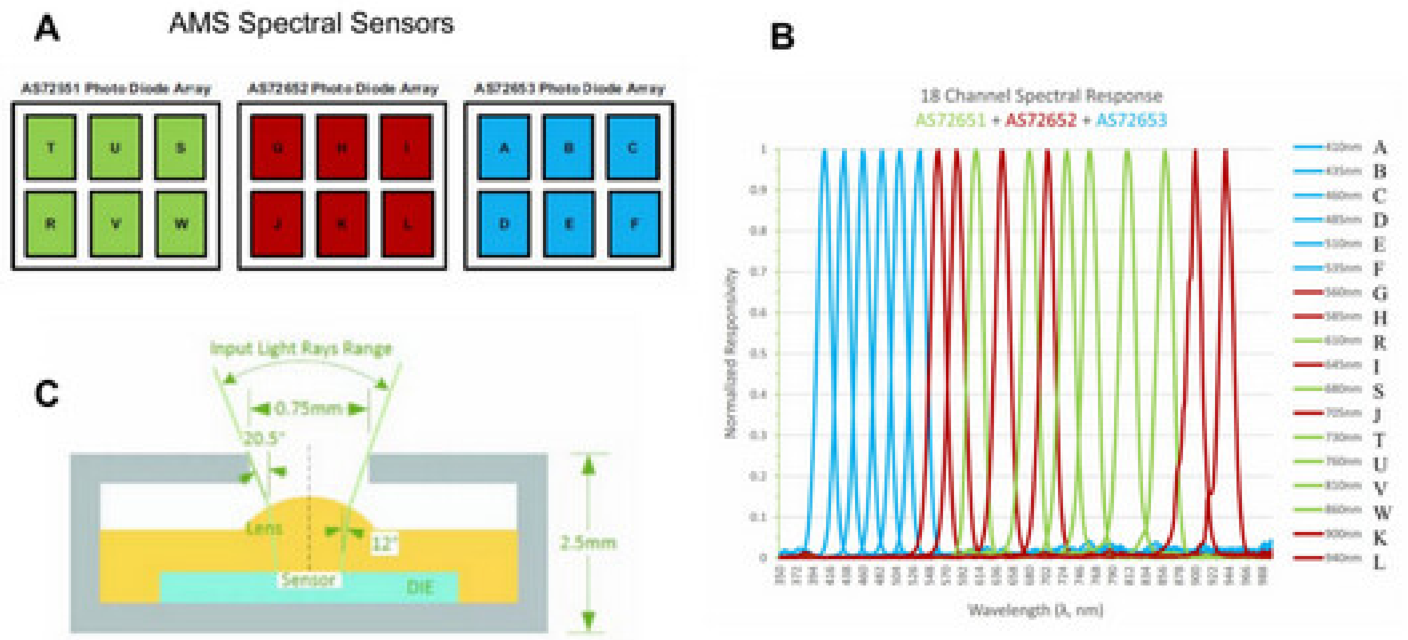


Hardware

Modular circuit boards are being developed from which to assemble instruments.



Portable VIS - Near IR Spectrometer



Fundamental Design (FUN Design)

Dr. Jan Vandenbrande

The goal of the Fundamental Design (FUN Design) program is to determine whether we can develop or discover a new set of building blocks to describe conceptual designs. The design building blocks will capture the components' underlying physics allowing a family of nonintuitive solutions to be generated. Successful outcomes of this program will give the designer the ability to evolve and adapt designs rapidly in response to changing requirements and provide a thorough understanding of trade-offs early in the design process.

Dr. Jan Vandenbrande

Defense Sciences Office (DSO)

Program Manager

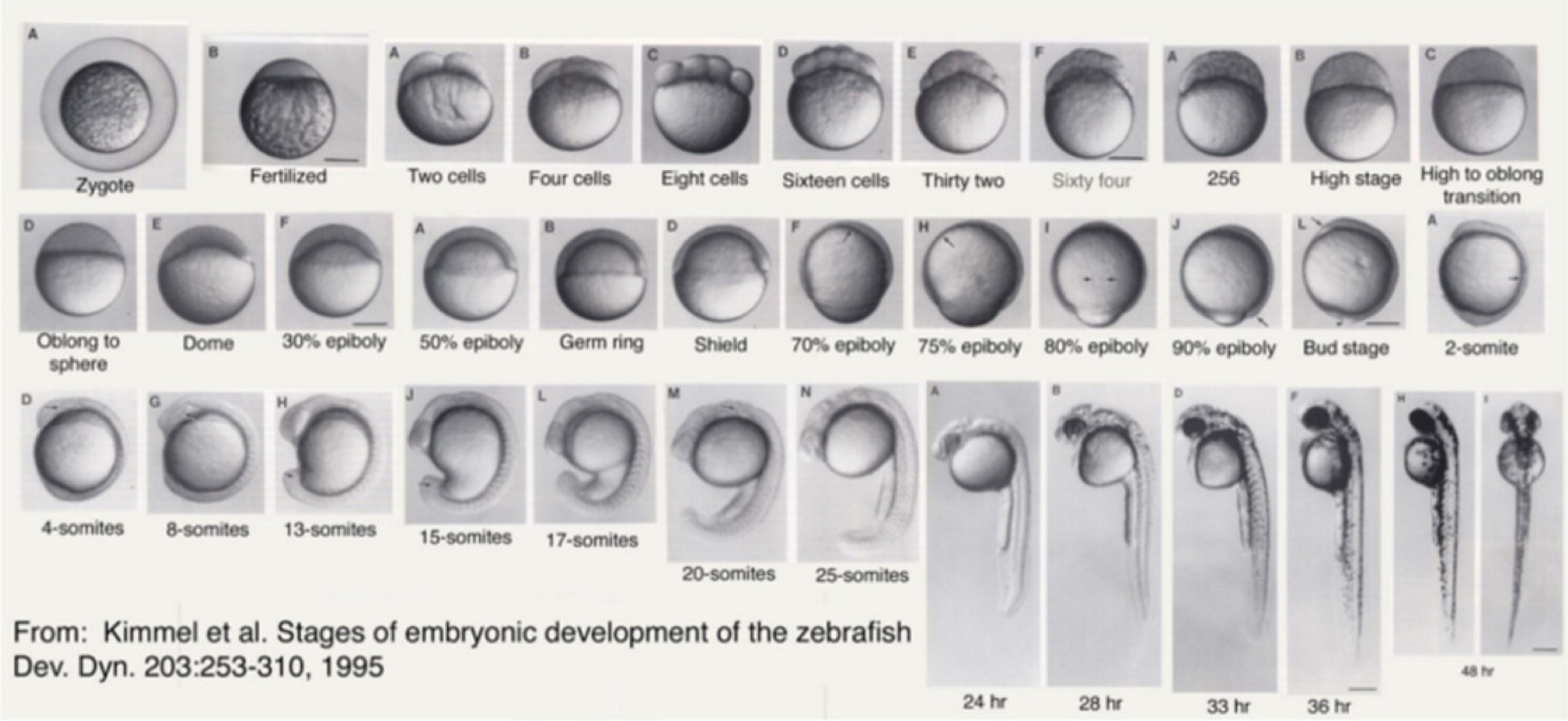
Dr. Jan Vandenbrande joined DARPA as a program manager in July 2015. He is interested in developing math and computational tools to radically improve the design of mechanical products. Topics of specific interest to Dr. Vandenbrande include: exploiting new design possibilities enabled by new materials and fabrication processes (3-D printing, composite fibers, micro truss structures) and enhancing design discovery.

Before joining DARPA, Dr. Vandenbrande was a technical fellow and senior manager of the Applied Math Geometry and Optimization group at Boeing. He leveraged his knowledge in geometric reasoning, production automation and design processes to create several advanced geometry processing systems to change how products are designed and made. Boeing uses these tools to conduct design trade and optimization studies, to enable proprietary composite layup fabrication processes, and to visualize metal machinability issues. Dr. Vandenbrande authored several parametric air and spacecraft models for design trade studies such as the hypersonic X-43C and the Orbital Space Plane study.

At Unigraphics, now Siemens NX, Dr. Vandenbrande worked on the architecture of the next-generation Computer Aided Manufacturing (CAM) system, improving tool path generation performance and revamping the CAM user interface. He received his Ph.D. in Electrical Engineering from the University of Rochester for his work on machinable feature recognition.

Open Manufacturing
Uncertainties in materials and component manufacturing processes are a primary cause of cost escalation and delay during the development, testing and early production of defense systems. In addition, fielded military platforms may have unanticipated performance problems, despite large investment and extensive testing of their key components and subassemblies. These uncertainties and performance problems are often the result of the random variations and non-uniform scaling of manufacturing processes. These challenges, in turn, lead to counterproductive resistance to adoption of new, innovative manufacturing technologies that could offer better results.

Enabling Quantification of Uncertainty in Physical Systems (EQUiPS)
Complex physical systems, devices and processes important to the Department of Defense (DoD) are often poorly understood due to uncertainty in models, parameters, operating environments and measurements. The goal of DARPA's Enabling Quantification of Uncertainty in



From: Kimmel et al. Stages of embryonic development of the zebrafish Dev. Dyn. 203:253-310, 1995

Development cell by cell

With a trio of techniques, scientists are tracking embryo development in stunning detail

By Elizabeth Pennisi | 20 December 2018

From at least the time of Hippocrates, biologists have been transfixed by the mystery of how a single cell develops into an adult animal with multiple organs and billions of cells. The ancient Greek physician hypothesized that moisture from a mother's breath helps shape a growing infant, but now we know it is DNA that ultimately orchestrates the processes by which cells multiply and specialize. Now, just as a music score indicates when strings, brass, percussion, and woodwinds chime in to create a symphony, a combination of technologies is revealing when genes in individual cells switch on, cueing the cells to play their specialized parts. The result is the ability to track development of organisms and organs in stunning detail, cell by cell and through time. *Science* is recognizing that combination of technologies, and its potential for spurring advances in basic research and medicine, as the 2018 Breakthrough of the Year.

Science

Cite as: D. E. Wagner *et al.*, *Science* 10.1126/science.aar4362 (2018).

Single-cell mapping of gene expression landscapes and lineage in the zebrafish embryo

Daniel E. Wagner, Caleb Weinreb, Zach M. Collins, James A. Briggs, Sean G. Megason,* Allon M. Klein*

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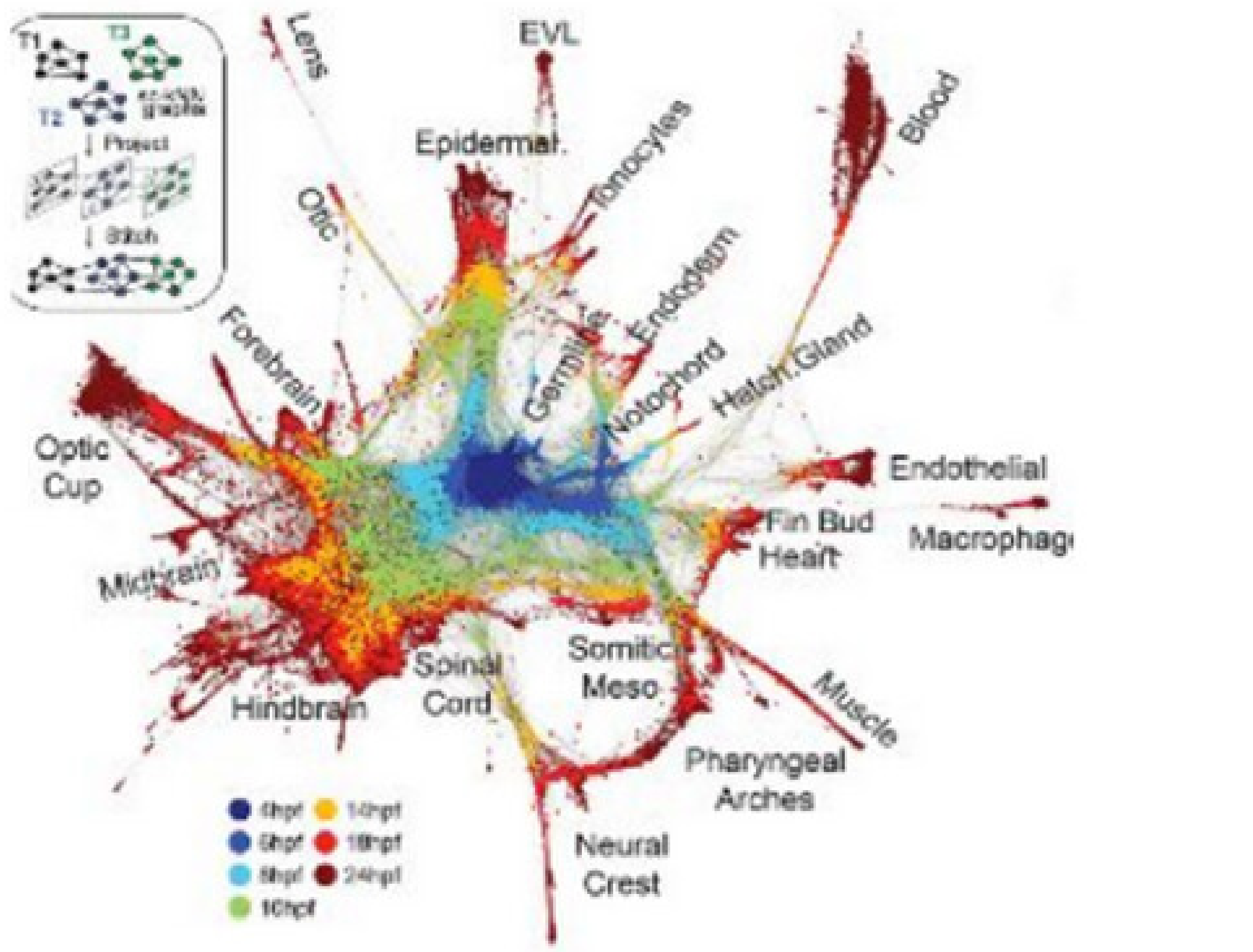
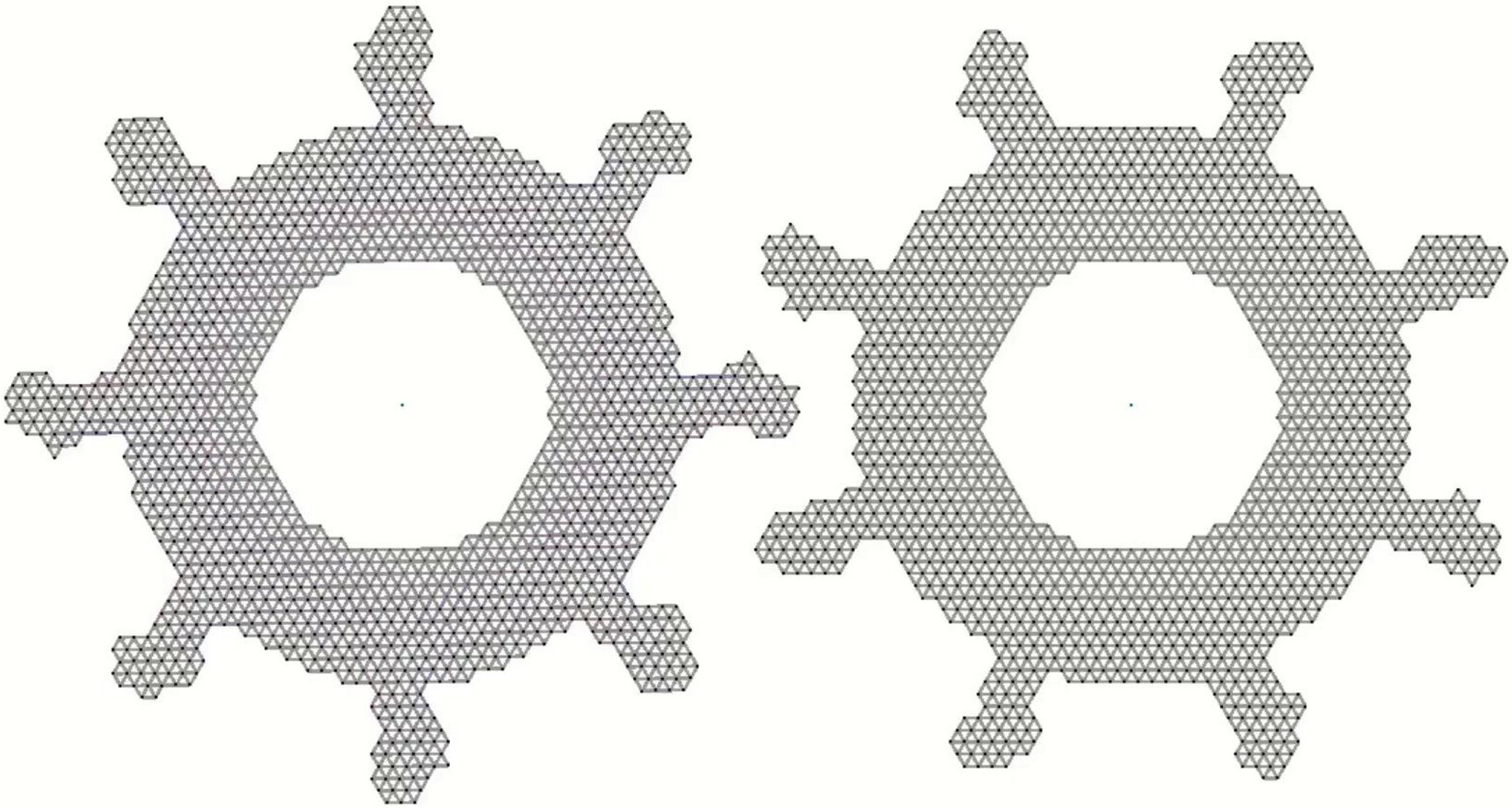
High-throughput mapping of cellular differentiation hierarchies from single-cell data promises to empowe systematic interrogations of vertebrate development and disease. Here, we applied single-cell RNA sequencing to >92,000 cells from zebrafish embryos during the first day of development. Using a graph-based approach, we mapped a cell state landscape that describes axis patterning, germ layer formation, and organogenesis. We tested how clonally related cells traverse this landscape by developing a transposon-based barcoding approach ("TracerSeq") for reconstructing single-cell lineage histories. Clonally related cells were often restricted by the state landscape, including a case in which two independent lineages converge on similar fates. Cell fates remained restricted to this landscape in *chordi* deficient embryos. We provide web-based resources for further analysis of the single-cell data.

First release: 26 April 2018 www.sciencemag.org (*Page numbers not final at time of first release*)





DIM3: Discrete Inverse Methods for Multiphysics Modeling

Partial Differential Equations

↕

"Macromolecular Dynamics"

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Atomic Physics

DARPA DSO DEFENSE SCIENCES OFFICE

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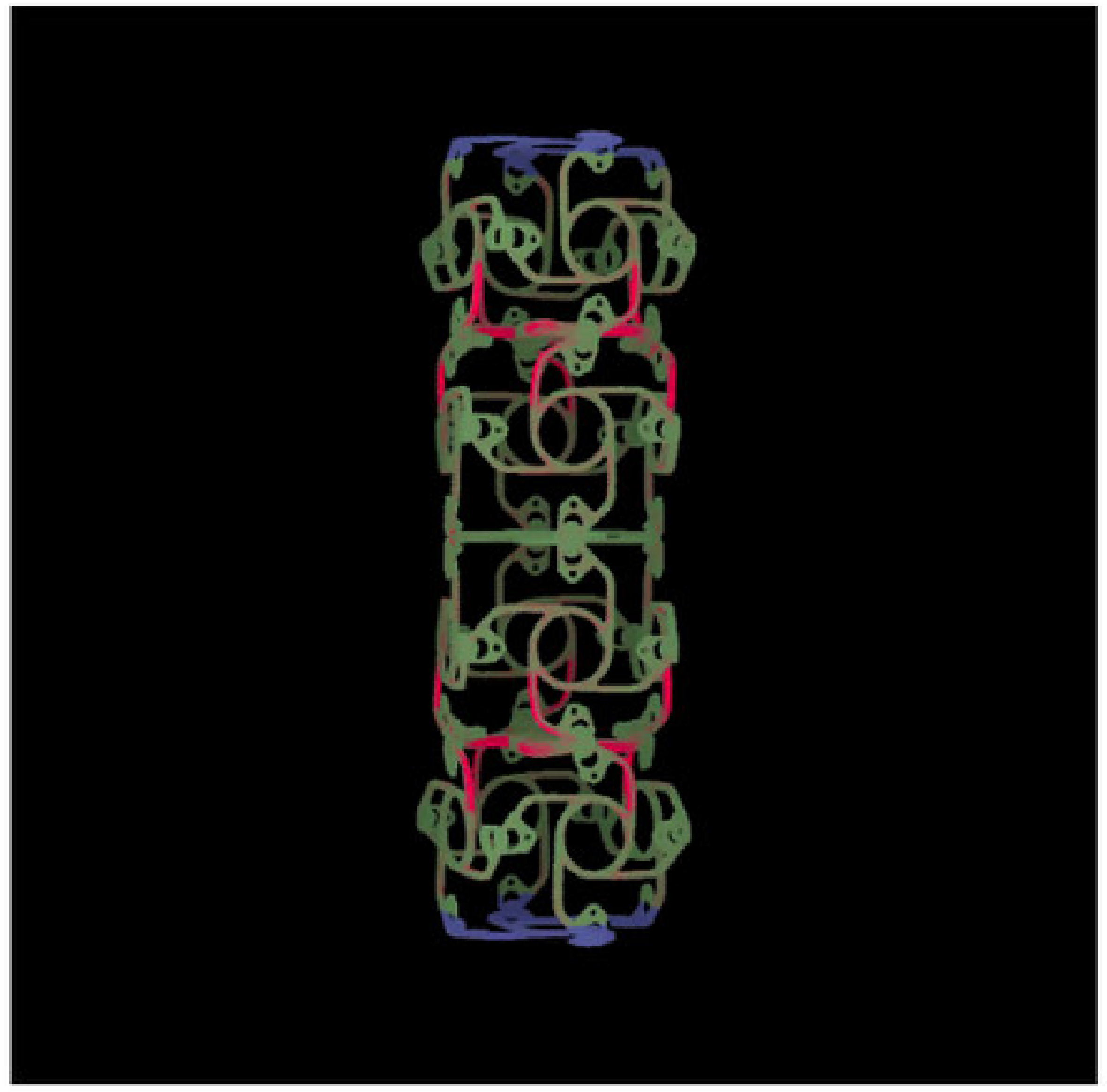
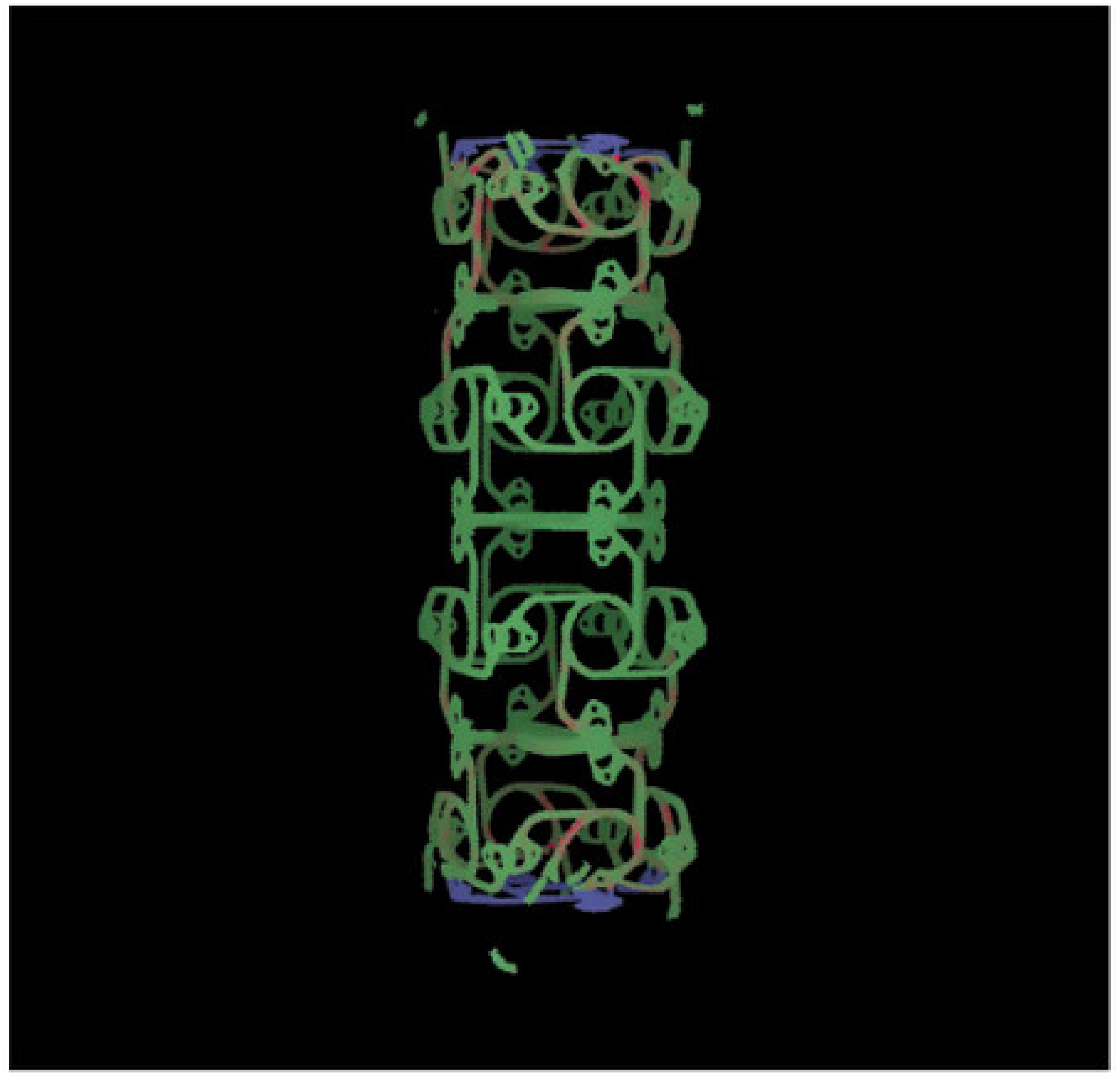
Massachusetts Institute of Technology

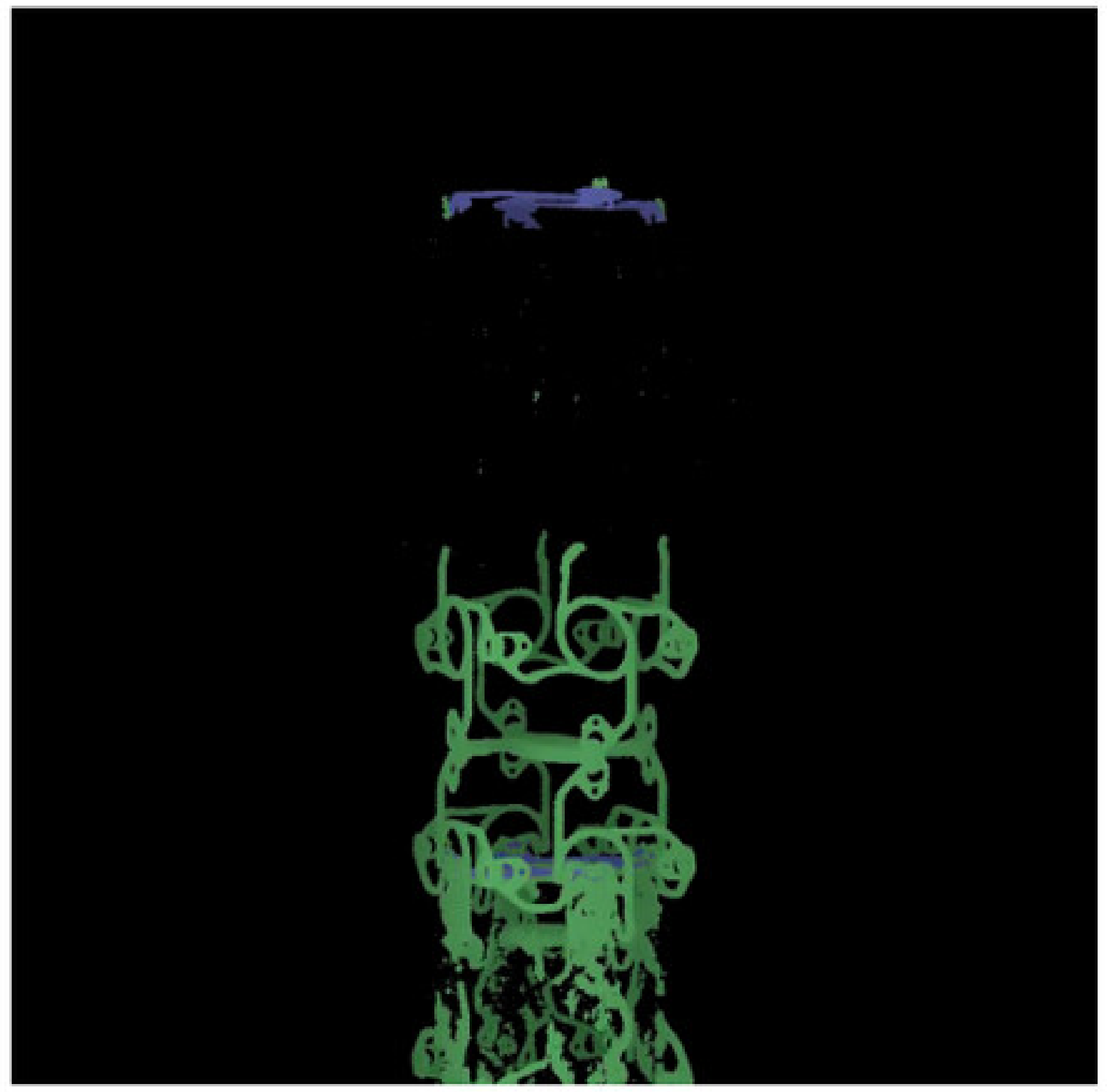
Solid Mechanics



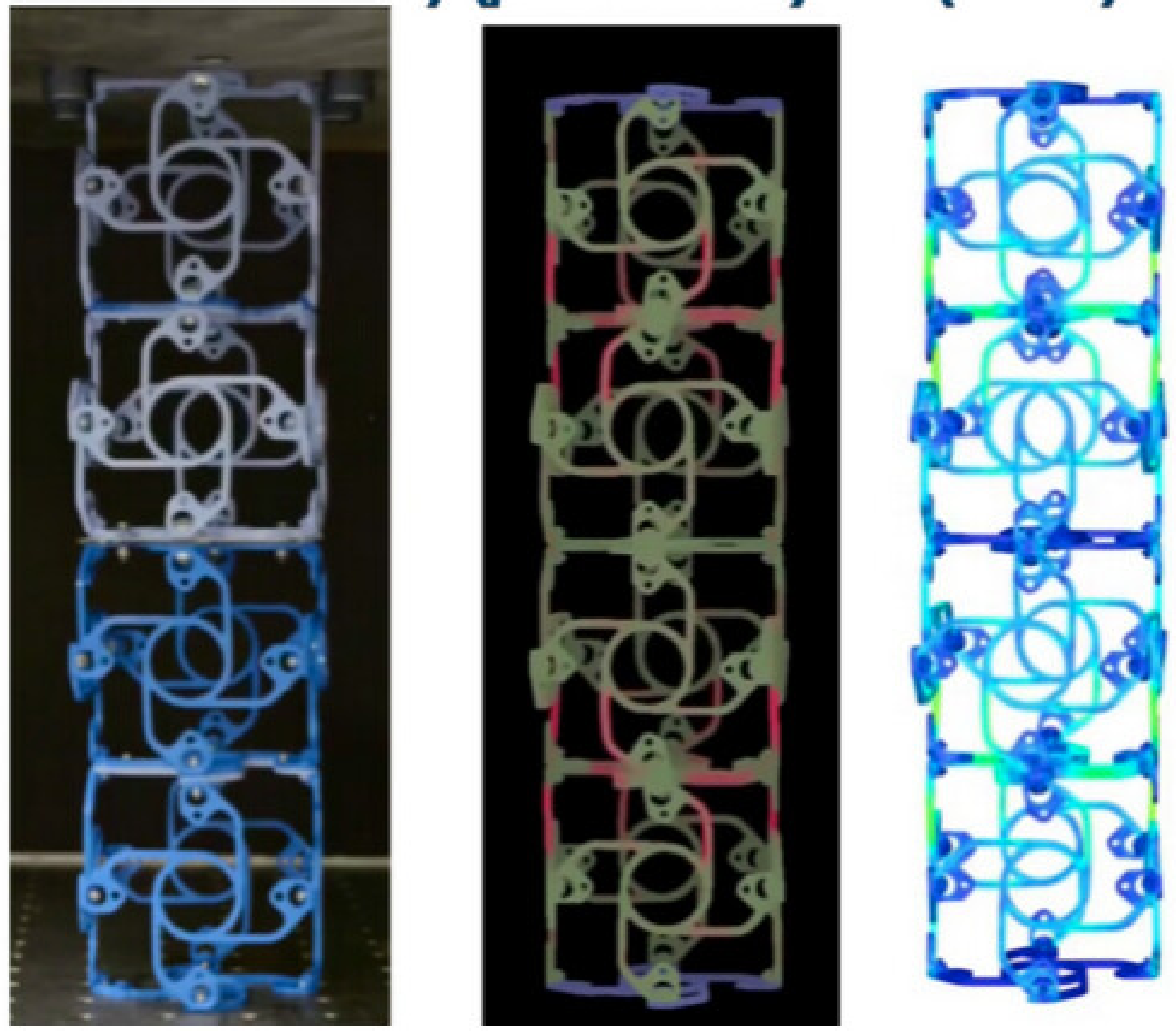
Fracture

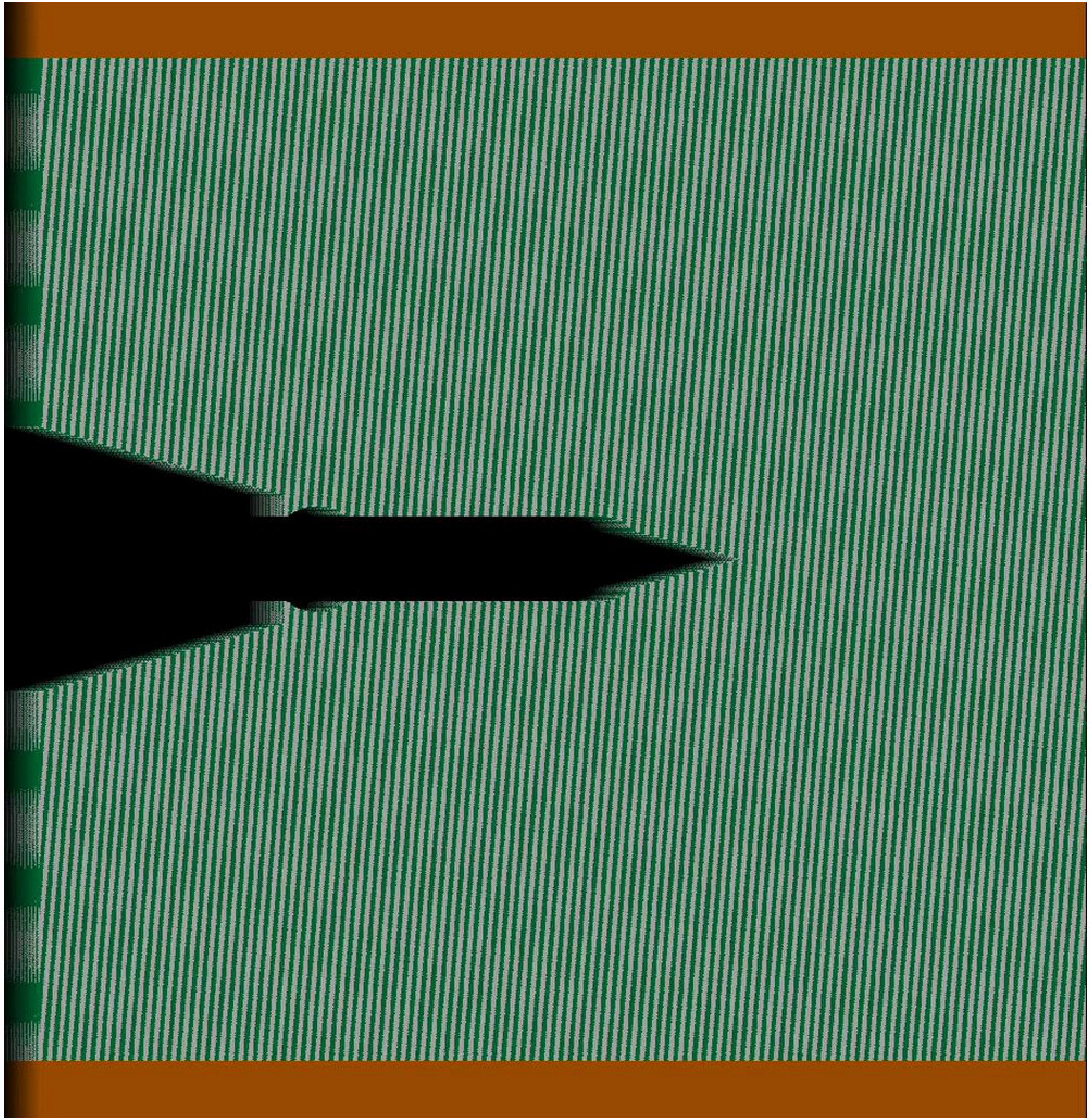


Rheology



Experiment (*metamaterial*) **CMods (*particles*)** **NASTRAN (*FEA*)**





Toylike blocks make lightweight, strong structures

Instead of reducing parts, engineers suggest building planes from thousands of identical pieces

By Meghan Rosen
Web edition: August 16, 2013

A carbon-fiber skeleton of Tinkertoy-like building blocks is 10 times as stiff as structures of similar densities. And because the framework is made of mostly identical pieces, broken parts can be easily swapped out for new ones, its inventors report in the Aug. 16 *Science*. The new design could one day form light, stiff, easy-to-repair bones of airframes, bicycles, bridges and even buildings.

ENLARGE
BUILDING BLOCKS
Thin slices of carbon fiber composite can link together to build lightweight lattices that could one day form the framework of airplanes and spacecraft.
Image © CC-BY-NC-SA Kenneth C. Cheung

"It's fascinating," says materials scientist Rainer Adelung of Kiel University in Germany. "When you read this article, you think, 'Why hasn't anyone done this before?' It's a simple idea, but it has such a large impact."

For years, fancy bicycles and luxury cars have used glued-together carbon fibers, called composites, to trim weight from their frames. Now, manufacturers are starting to craft huge sections of airplanes in single swaths of the lightweight materials. Fewer parts means fewer joints, which tend to be heavy and tricky to fix.

So manufacturers want to make even bigger plane pieces. In 2008, Spirit AeroSystems, a manufacturer that makes parts for Boeing and Airbus, came to MIT materials engineer Kenneth Cheung and his lab leader, Neil Gershenfeld, with a wild idea: What if they could 3-D print an entire plane in one gigantic piece?

Sciencexpress Reports

Reversibly Assembled Cellular Composite Materials

Kenneth C. Cheung* and Neil Gershenfeld

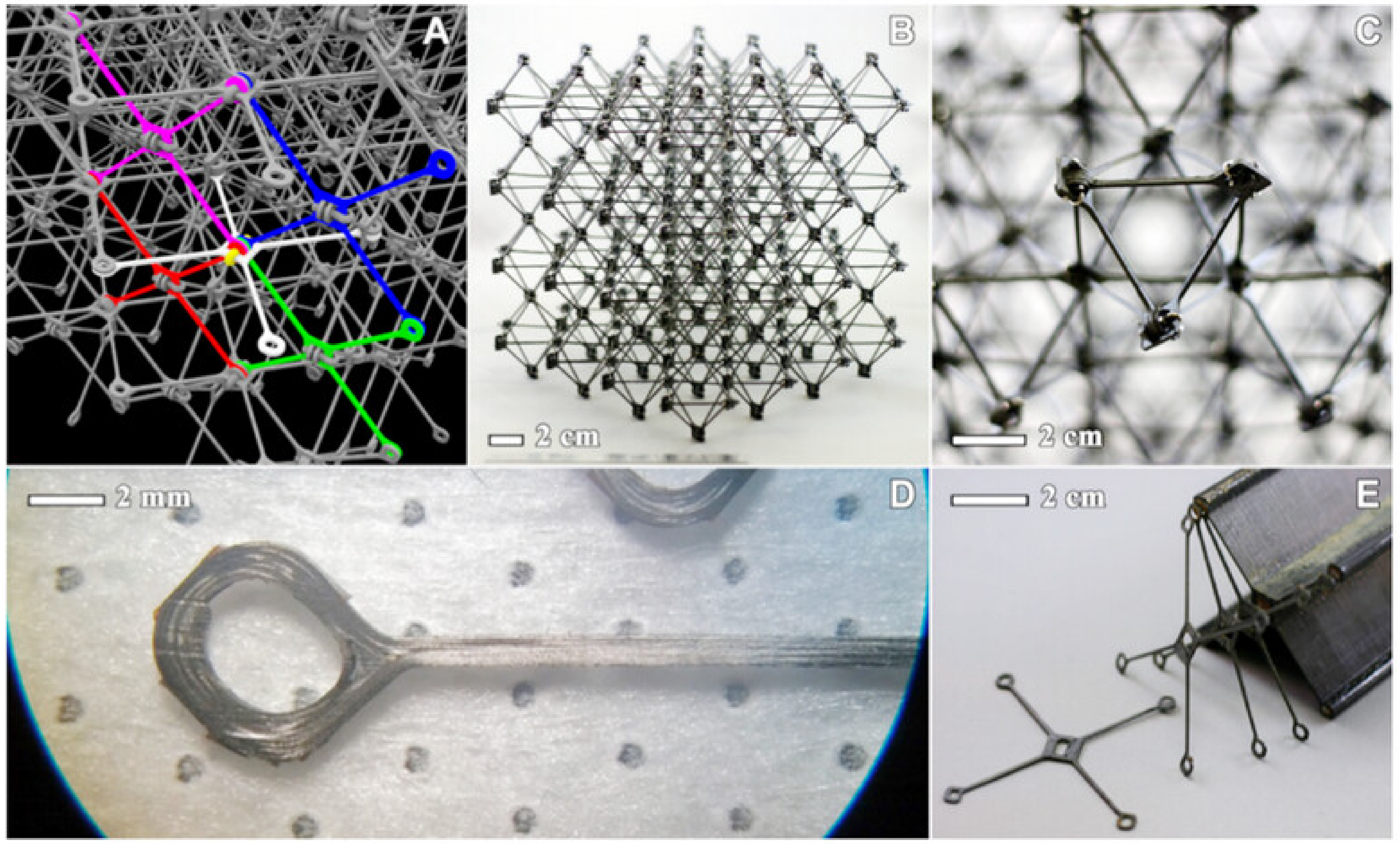
Center for Bits and Atoms, Massachusetts Institute of Technology, Cambridge, MA 02139, USA.

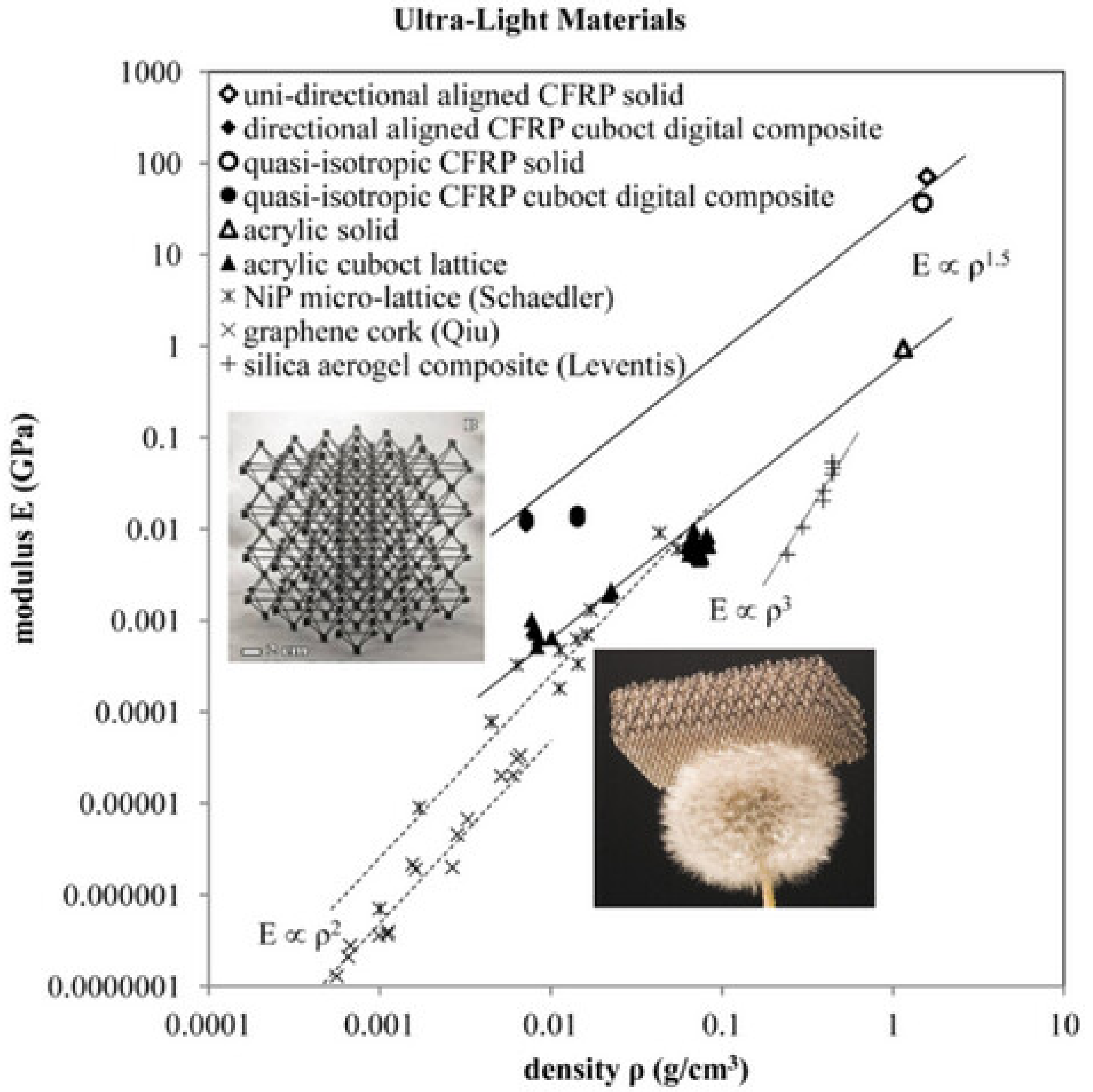
*Corresponding author. E-mail: kccheung@mit.edu

We introduce composite materials made by reversibly assembling a three-dimensional lattice of mass-produced carbon fiber reinforced polymer composite parts with integrated mechanical interlocking connections. The resulting cellular composite materials can respond as an elastic solid with an extremely large measured modulus for an ultralight material (12.3 megapascals at a density of 7.2 mg per cubic centimeter). These materials offer a hierarchical decomposition in modeling, with bulk properties that can be predicted from component measurements, and deformation modes that can be determined by the placement of part types. Because site locations are locally constrained, structures can be produced in a relative assembly process that merges desirable features of fiber composites, cellular materials, and additive manufacturing.

Carbon-fiber reinforced composite materials can improve efficiency in engineered systems (for example, airframes) by reducing structural weight for given strength and stiffness requirements (*1*), but challenges with manufacturing and certification have slowed their adoption. High-

The dependence of this scaling performance on geometry is seen in non-stochastic lattice-based materials that have nearly ideal $E \propto \rho$ scaling, with high coordination numbers (node connectedness) relative to stochastic foams (*15*, *16*). These structures have been implemented thus far only in relatively dense engineered materials. For the ultralight regime [below ten milligrams per cubic centimeter (*7*)], the $E \propto \rho^2$ scaling seen in denser stochastic cellular materials has recently been reported for electroplated tubular nickel micro-lattices (*17*), as well as carbon-based open-cell stochastic foams, including carbon microtube aerographite (*18*), and graphene cork (*19*). Reversibly assembled cellular composites extend stretch-dominated lattice-based materials to the ultralight regime, with three-dimensional symmetry derived from the linked geometry. The high performance characteristics of these new materials depend on the framework rigidity of the non-stochastic lattice geometry with high coordination number, the slenderness that can be achieved in buckling-limited fiber composite strut members, and the scaling of the density cost of reversible mechanical connections.





MATERIALS SCIENCE

Discretely assembled mechanical metamaterials

Benjamin Jenett[1]*, Christopher Cameron[2], Filippos Tourlomousis[1], Alfonso Parra Rubio[1], Megan Ochalek[1], Neil Gershenfeld[1]

Mechanical metamaterials offer exotic properties based on local control of cell geometry and their global configuration into structures and mechanisms. Historically, these have been made as continuous, monolithic structures with additive manufacturing, which affords high resolution and throughput, but is inherently limited by process and machine constraints. To address this issue, we present a construction system for mechanical metamaterials based on discrete assembly of a finite set of parts, which can be spatially composed for a range of properties such as rigidity, compliance, chirality, and auxetic behavior. This system achieves desired continuum properties through design of the parts such that global behavior is governed by local mechanisms. We describe the design methodology, production process, numerical modeling, and experimental characterization of metamaterial behaviors. This approach benefits from incremental assembly, which eliminates scale limitations, best-practice manufacturing for reliable, low-cost part production, and interchangeability through a consistent assembly process across part types.

INTRODUCTION

The notion of rationally designing a material from the microscale to the macroscale has been a long-standing goal with broad engineering applications. By controlling local cell properties and their global spatial distribution and arrangement, metamaterials with exotic behavior can be achieved. The foundation for mechanical metamaterials comes from the study of cellular solids (*1*), where natural materials, such as wood and bone (*2*), or synthetic materials, such as stochastic foams, are understood as a network of closed or open cells (*3*). In the latter case, edges form a network of beams, and on the basis of the connectivity of these beams and their base material, macroscopic behaviors can be predicted analytically (*4*). It was from this insight that the field of architected materials formed, enabling design of periodic structures with tailorable properties such as improved stiffness over foams at similar density due to higher degrees of connectivity (*5*).

Advances in digital fabrication, specifically additive manufacturing, have enabled these complex designs to be realized. Seminal work demonstrated stiff, ultralight lattice materials (*6*), and has since been improved, resulting in mechanical metamaterials with superior stiffness and strength at ultralight densities (*7*) with multiscale hierarchy (*8*). Benefits of nanoscale features further expand the exotic property parameter space (*9*), and architectures featuring closed-cell plates have shown potential for approaching the theoretical limit for elastic material performance (*10*). Other designs seek to use compliance, which can be attained through internal geometric mechanisms (*11*) or through base materials capable of large strain (*12*). Internal architectures can be designed to transmit or respond to load in other nonstandard ways. Auxetic metamaterials exhibit zero or negative Poisson's ratio (*13*). Internal, reentrant architectures produce contraction perpendicular to compressive loading, and expansion perpendicular to tensile loading, counter to traditional continuum material behavior (*14*). Chiral metamaterials exhibit handedness based on asymmetric unit cell geometry. These designs produce out-of-plane deformations, such as twist, in response to in-plane loading (*15*).

Nearly all of the aforementioned mechanical metamaterials are made with some forms of additive manufacturing, most of which are summarized in (*16*). These processes vary widely in terms of cost, precision, throughput, and material compatibility. The lower end of the cost spectrum, such as fused deposition modeling (FDM), also tends to have lower performance. Limits of thermoplastic extrusion include layer-based anisotropy (*17*) and errors resulting from build angles for complex three-dimensional (3D) geometry (*18*). Higher performance, and higher cost, processes such as selective laser melting (SLM) use materials such as stainless steel but require nontrivial setup for particulate containment and can suffer from layer-based anisotropy, thermal warping, and geometry irregularity (*19*). Some of the highest performance multiscale metal microlattice production techniques based on lithographic and plating processes are well studied and repeatable but are highly specialized and labor, time, and cost intensive. Polymerization, curing, plating, milling, and etching can require up to 24 hours from start to finish for sample preparation (*6*). Large-area projection microstereolithography (LAPμSL) is capable of producing lattices with micrometer-scale (10^{-6} m) features on centimeter-scale (10^{-2} m) parts (*8*) with significantly improved throughput, but extension to macroscale (>1 m) structures remains out of reach, due to practical limitations in scaling these processes and their associated machines.

The largest structure that can be printed with any given process is typically limited by the build volume of the machine. Therefore, substantial effort is focused on scaling up the machines. Meter-scale FDM platforms (*20*) and larger cementitious deposition machines (*21*) have been demonstrated, and coordinated mobile robots are proposed to achieve arbitrarily large work areas (*22*). However, there is a trade-off between precision, scale, and cost. Commercially available two-photon polymerization machines have resolution on the order of 1 μm (10^{-6} m), build size on the order of 100 mm (10^{-1} m), and cost on the order of $\$10^6$ per machine (*23*). Macroscale FDM machines boast build sizes of 10^1 m (*24*) but are unlikely to have better than millimeter (10^{-3} m) resolution. Thus, roughly the same dynamic range (scale per resolution) is offered, but with costs approaching $\$10^7$ per machine, we see a possible superlinear cost-based scaling of achievable dynamic range. Building large, precise machines is expensive, and due to the inherent coupling of machine performance, size, and cost, there are significant challenges

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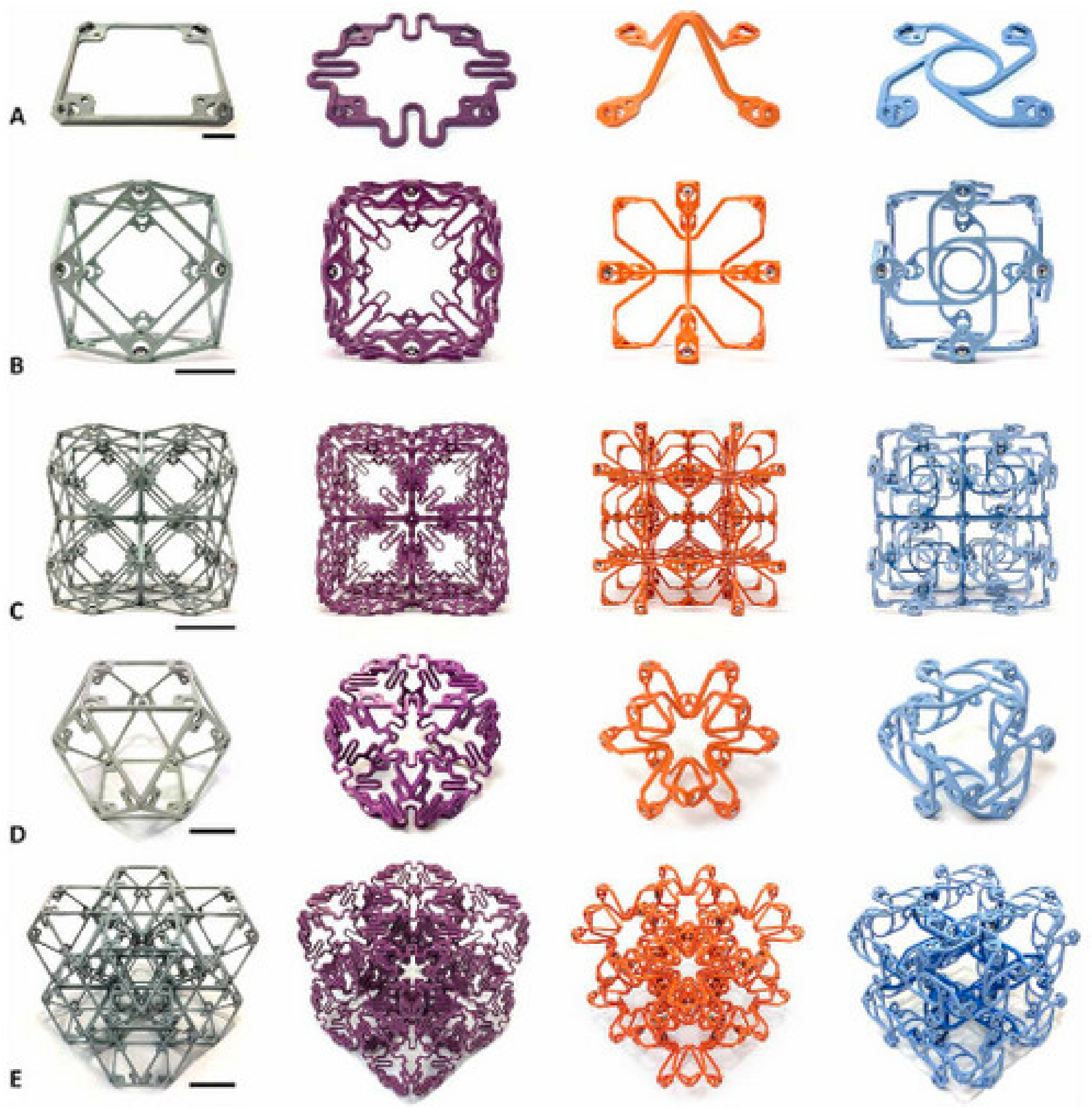


Fig. 2. Four types of discretely assembled mechanical metamaterials. Left to right: Rigid, compliant, auxetic, and chiral. **(A)** As-molded face parts. **(B)** Single voxel, front view. **(C)** A 2 × 2 × 2 cube, front view. **(D)** Single voxel, oblique view. **(E)** A 2 × 2 × 2 oblique view. Scale bars, 10 mm (A), 25 mm (B and D), and 50 mm (C and E). Photo credit: Benjamin Jenett, MIT.

to the continuum approximation (horizontal line, value for 10 × 10 × 10 determined numerically) of 9, 56, 73, and 89%, respectively. Discrepancy between experimental and numerical results is also calculated for specimens $n = 1$ to 4 to be 458, 10, 6, and 3%, respectively. This can be attributed to the ratio of internal to external beams increasing as voxel count increases (fig. S7). The internal beams, which are fully constrained and behave as a rigid network, asymptotically govern the effective global behavior.

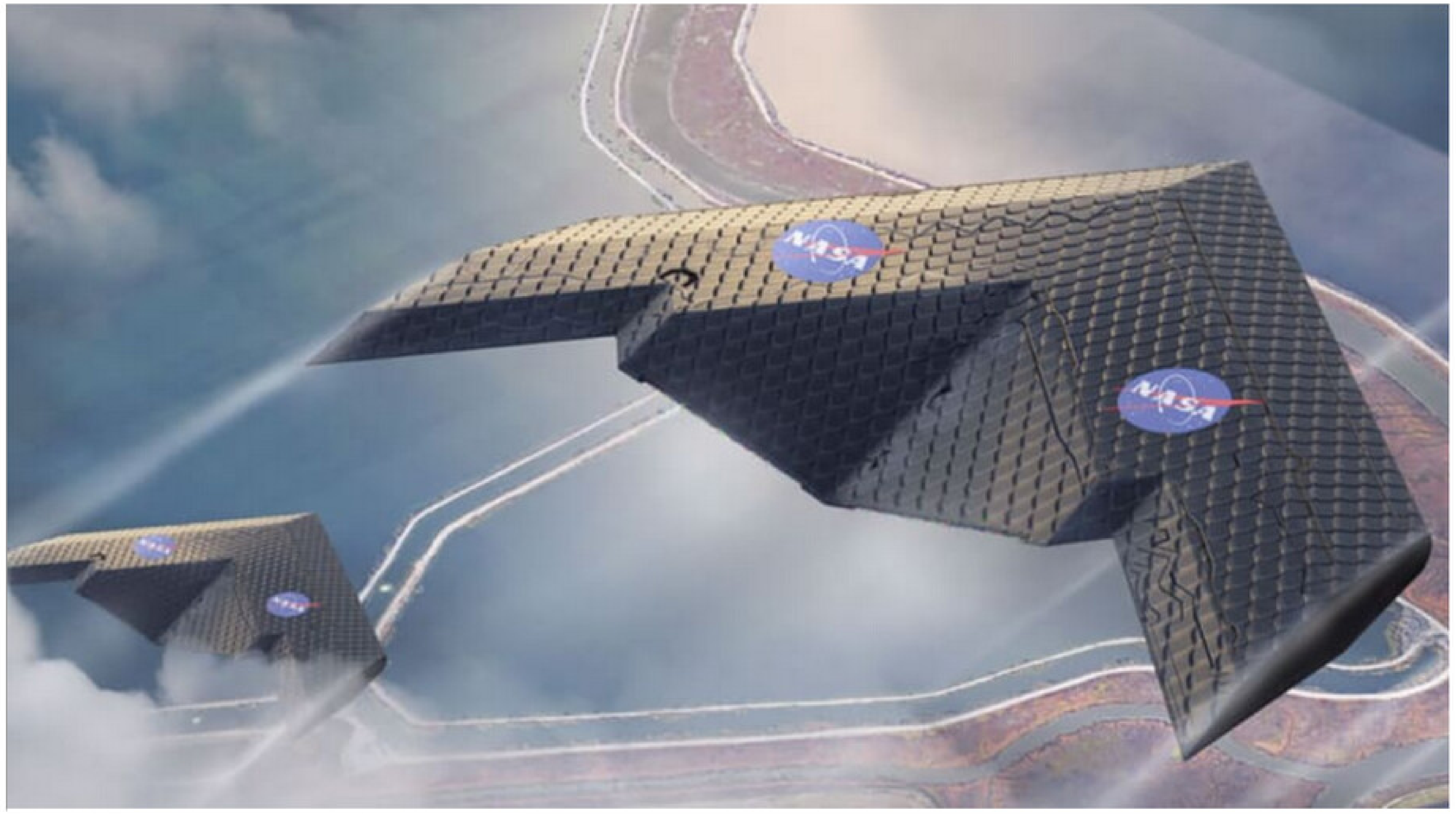
These predicted effective lattice properties over the range of effective densities are plotted relative to constituent values in Fig. 3E. The slope of the curve connecting these points, plotted on a log/log chart, provides the power scaling value, which is used to analytically predict lattice behaviors at the macroscopic scale (*4*). Effective lattice modulus and density are related to constituent material modulus and density by $\frac{E^*}{E} \propto \left(\frac{\rho^*}{\rho}\right)^b$, where b is 1 for stretch-dominated lattices and 2 for bending dominated. We find $b = 1.01$ for our rigid lattice. This scaling value had been shown previously for the monolithic (additively manufactured) cuboctahedron lattice (*28*) and for discretely assembled, vertex-connected octahedra (*27*), to which we now add our novel lattice decomposition. It should be noted that these effective values are from numerical simulations, not experiment, although we direct the reader to Figs. 3D and 4D for agreement between experimental and numerical results.

Next, we compare experimental yield stress results with analytical predictions of local beam failure based on relative density, as a function of beam thickness t and lattice pitch P. Here, we will use experimental data from the 4 × 4 × 4 specimen, as this is closest to demonstrating continuum behavior (effective modulus is 89% predicted continuum value). On the basis of the load at failure and lattice material and geometry, we can determine a given beam compressive failure load to be around 88 N. We determine the analytical critical beam load using either the Euler buckling formula or the Johnson parabola limit, depending on the compression member's slenderness ratio (fig. S5). We determine our beam slenderness ratio to be 29.5, which is over the critical slenderness ratio of 19.7 (see the Supplementary Materials for complete calculation); thus, we use Euler buckling formula. Because the as-molded material properties vary, we determine the critical load to range from 70 to 108 N, with the mean value of 89 N very closely approximating the experimental value. Thus, there is good correlation between both stiffness and strength based on the design of our discrete lattice material.

Design

New plane wing moves like a bird's and could radically change aircraft design

Updated 3rd April 2019



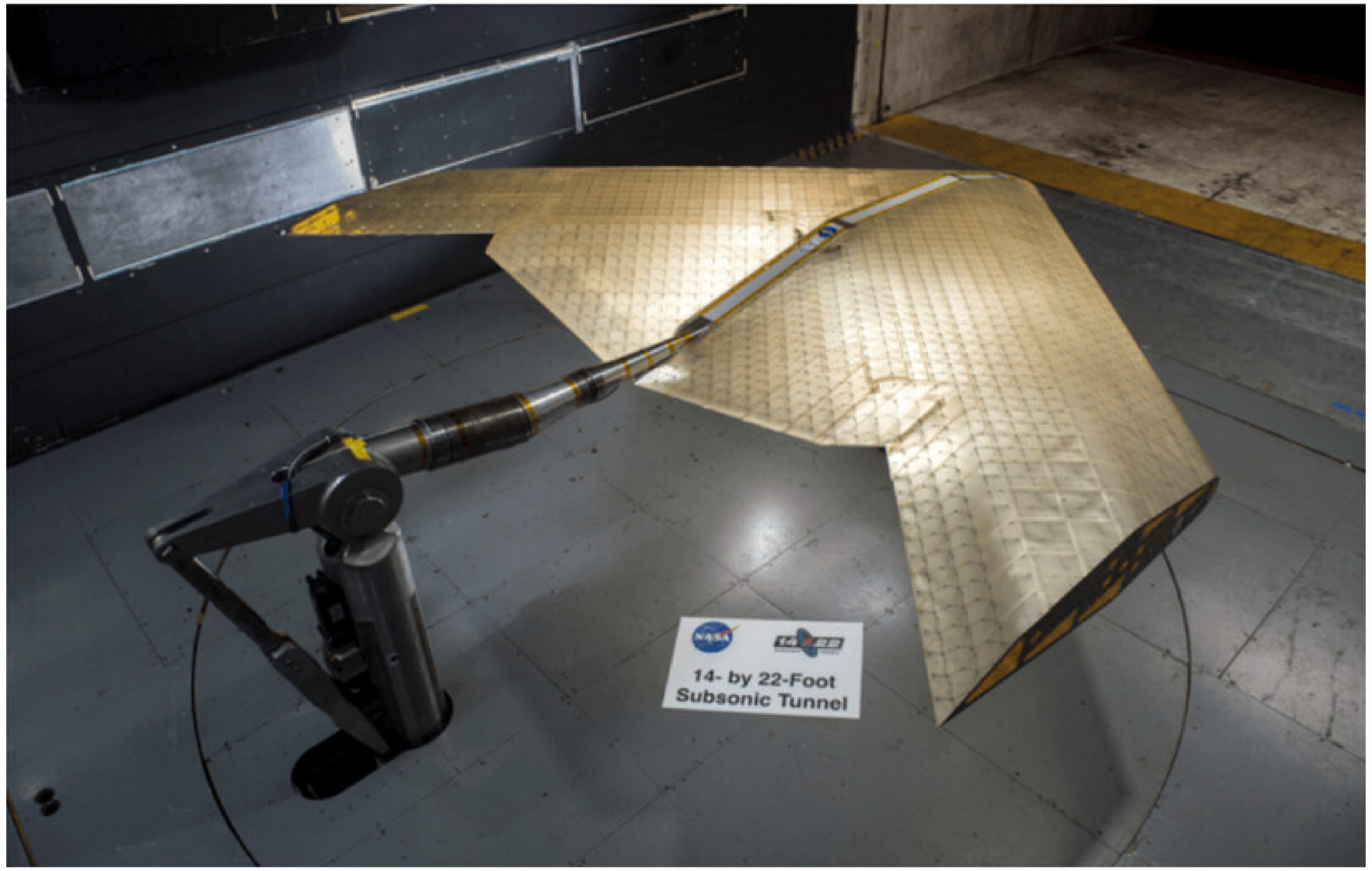
Credit: Eli Gershenfeld, NASA Ames Research Center

Written by
Hilary Whiteman, CNN

Plane wings are traditionally strong, thick and sturdy but a team of researchers led by NASA has created a flexible wing that morphs as it flies.

Measuring 14 feet or four meters wide, the new wing is constructed from thousands of units that fit together and function in a similar way to a bird's wing, says one of the report's authors, NASA research engineer, Nick Cramer.

"Something like a condor will lock its joints in while it's cruising, and then it (adjusts) its wing to a more optimal shape for its cruising, and then when it wants to do a more aggressive maneuver it'll unlock its shoulder. That's a similar response to what we're doing here," he said in a phone interview.



The wing's assembly is seen under construction, assembled from hundreds of identical subunits. Credit: Courtesy of NASA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Structural Robotics

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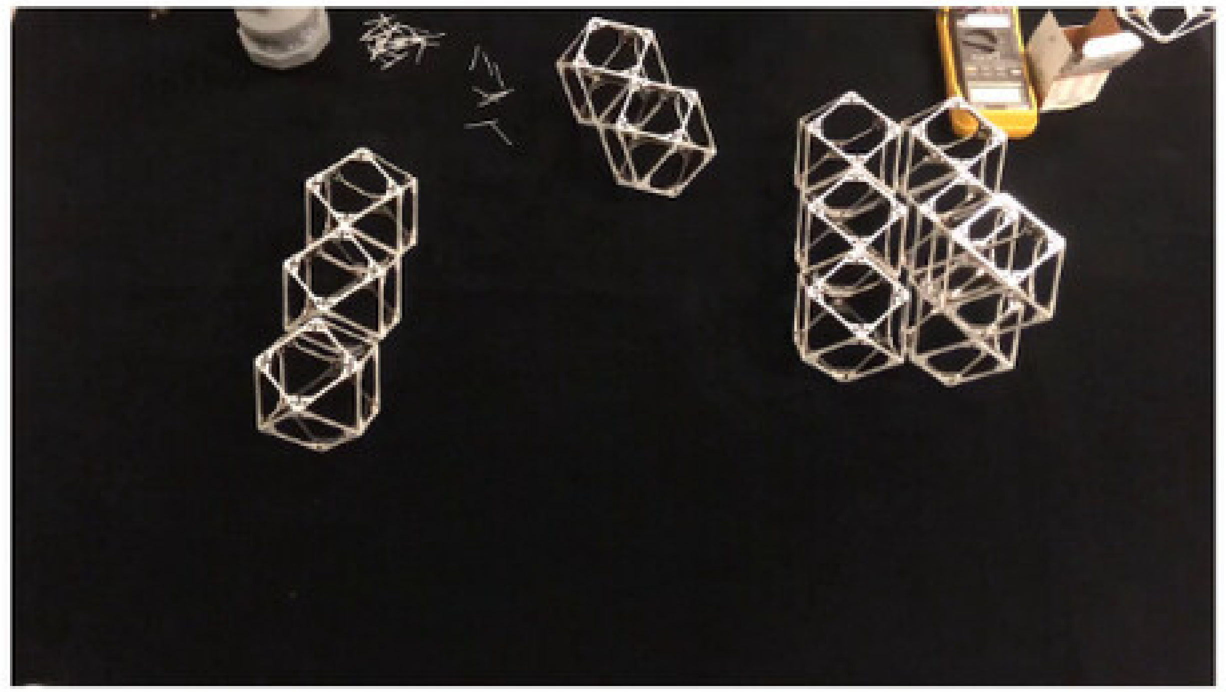
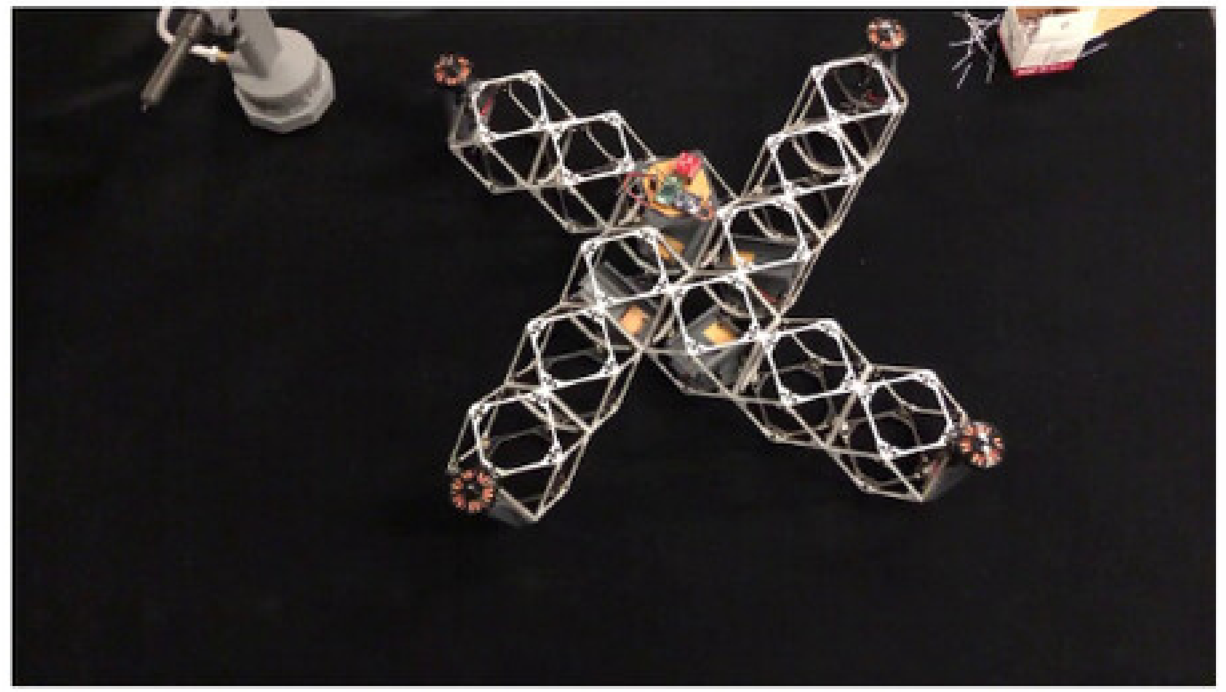
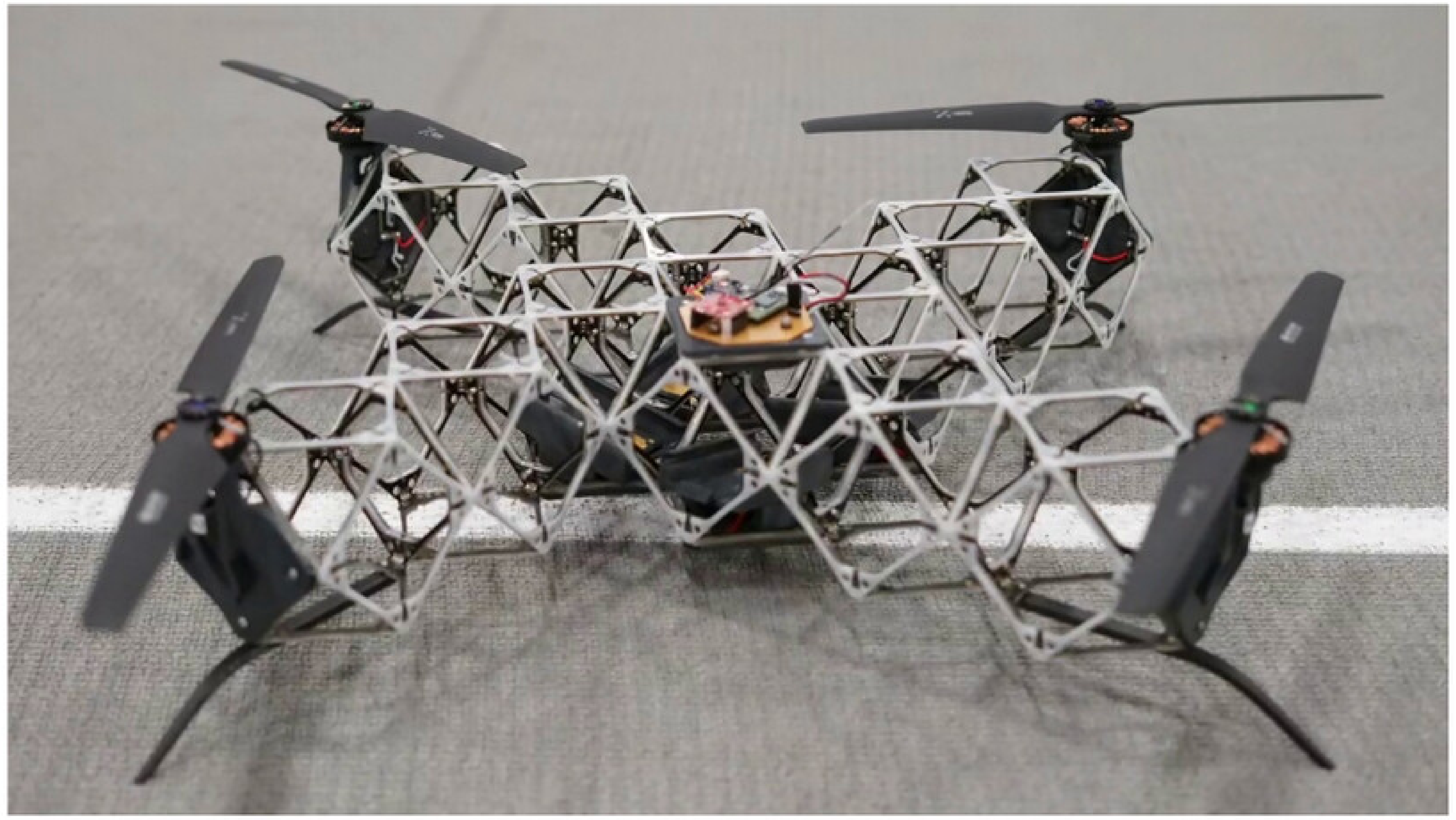
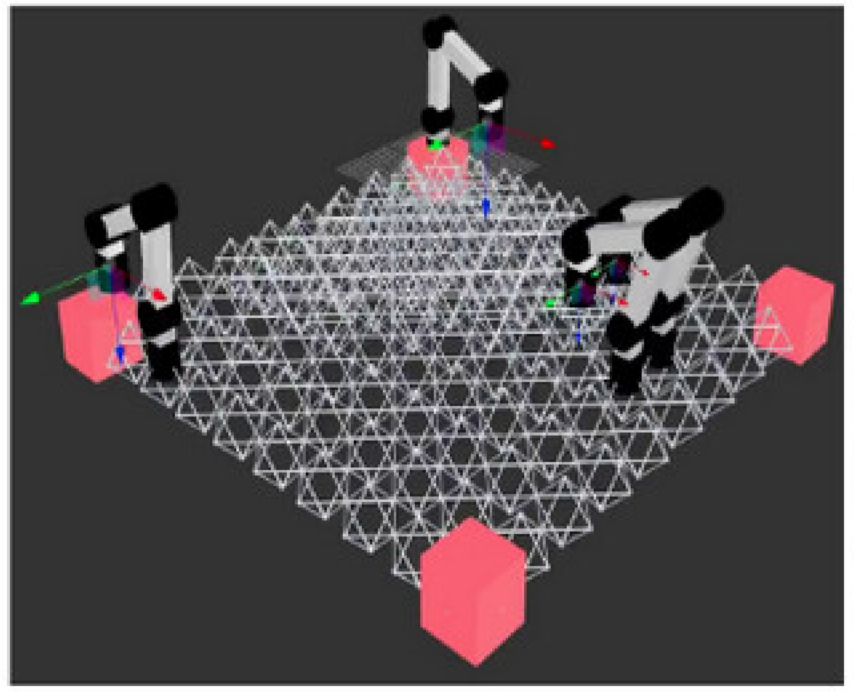
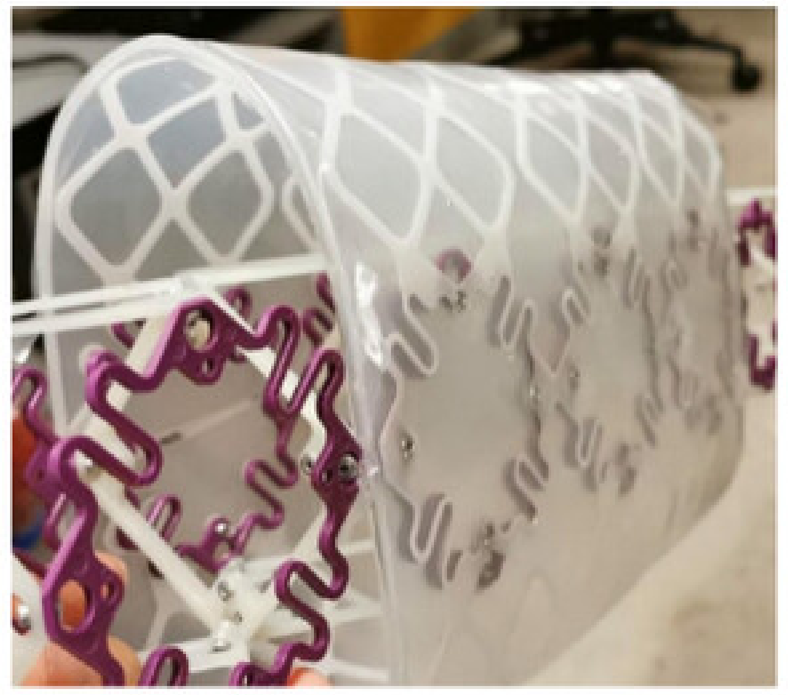
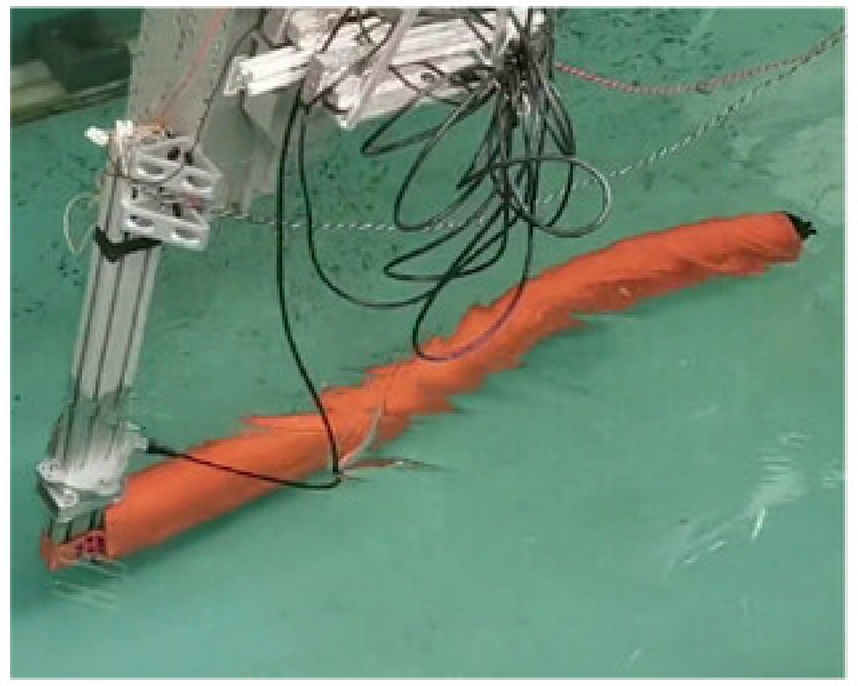


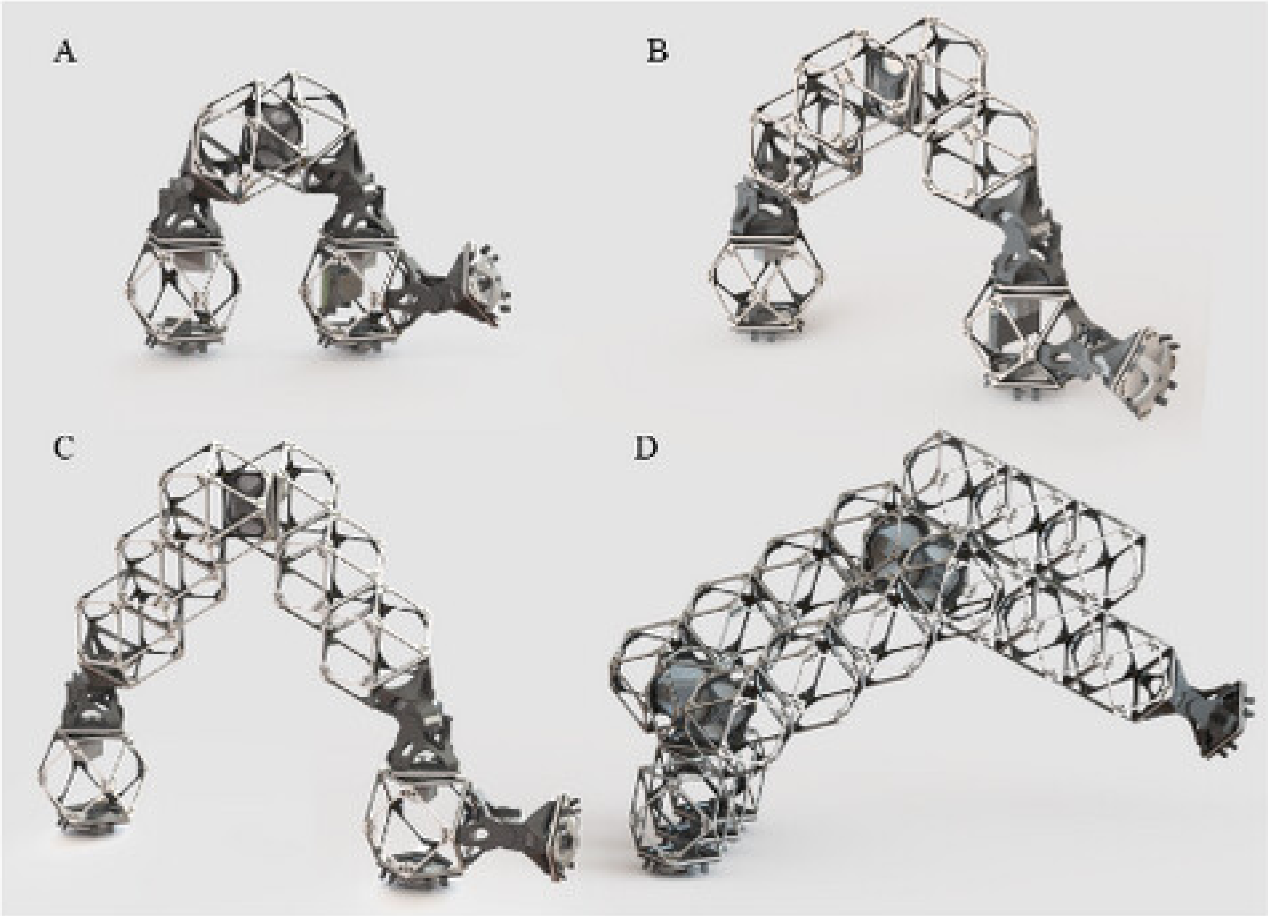


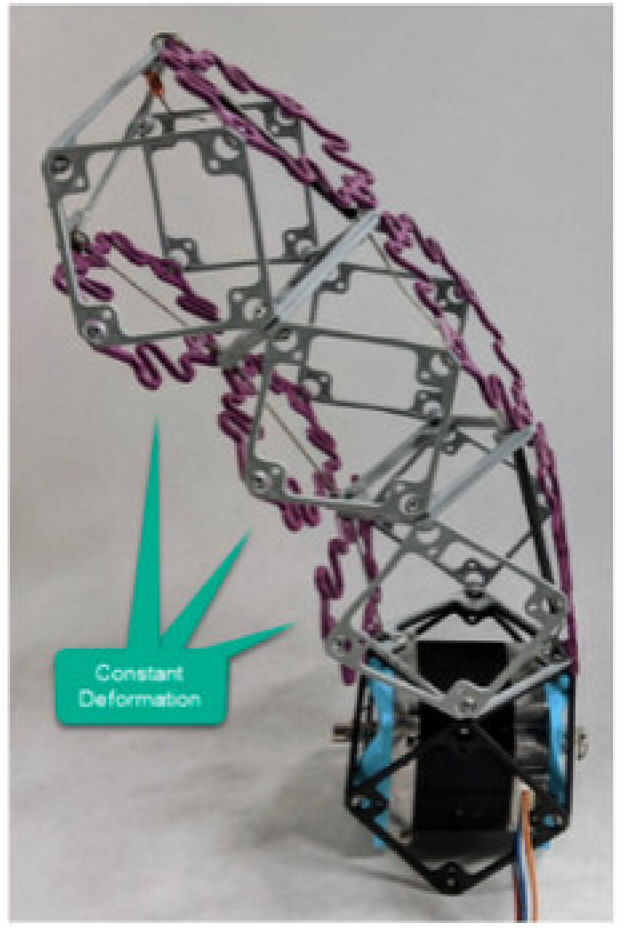


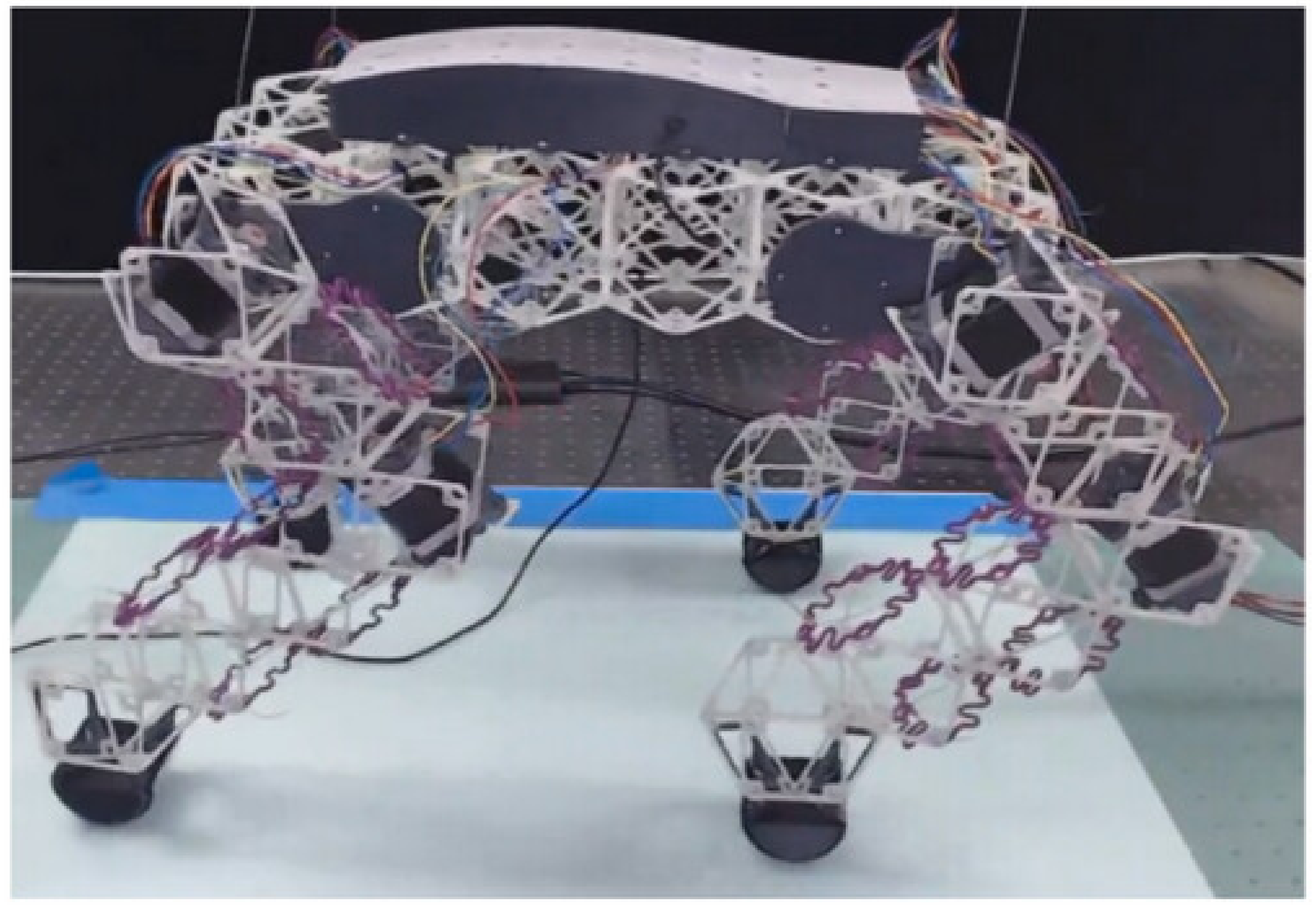


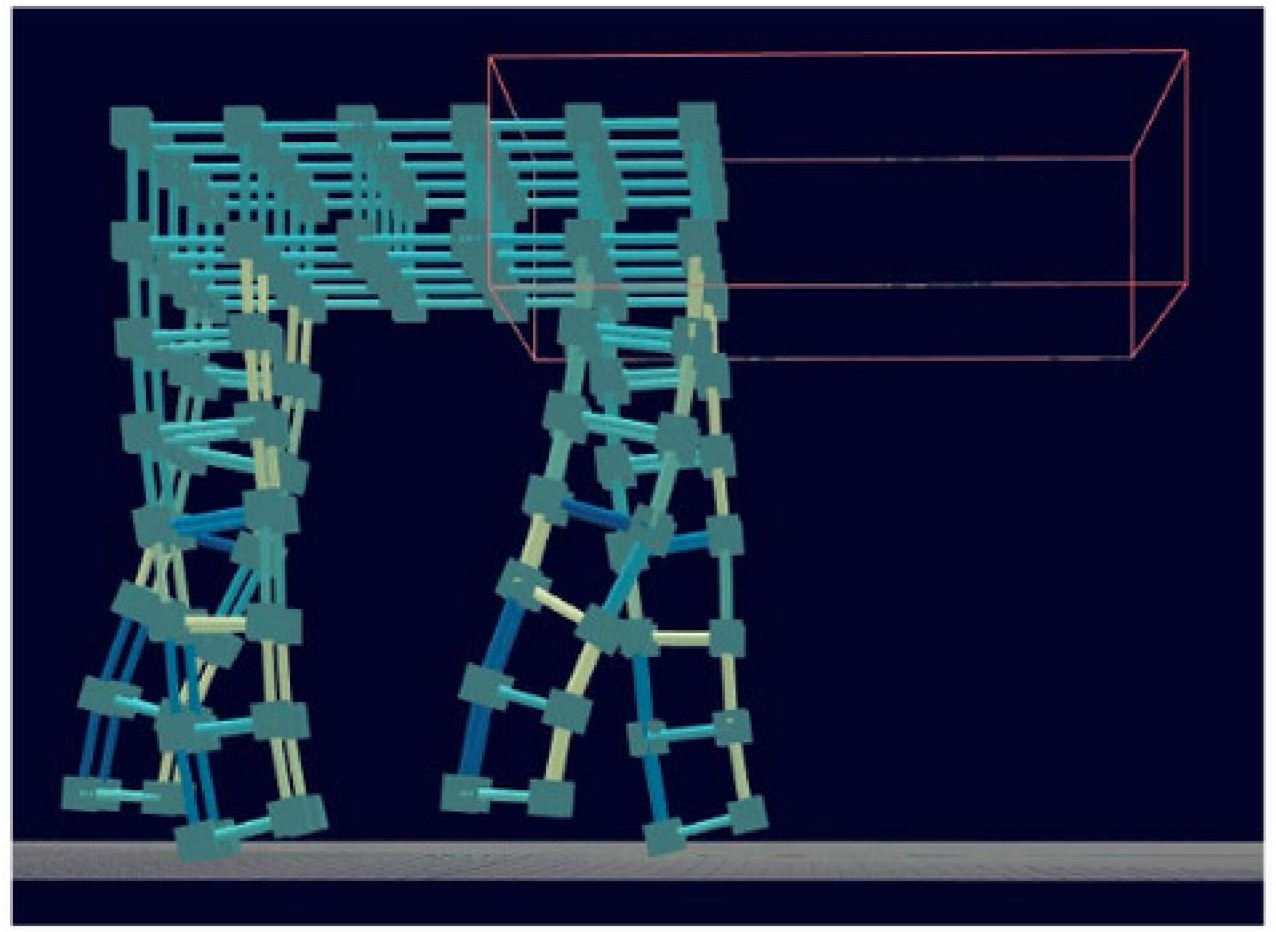




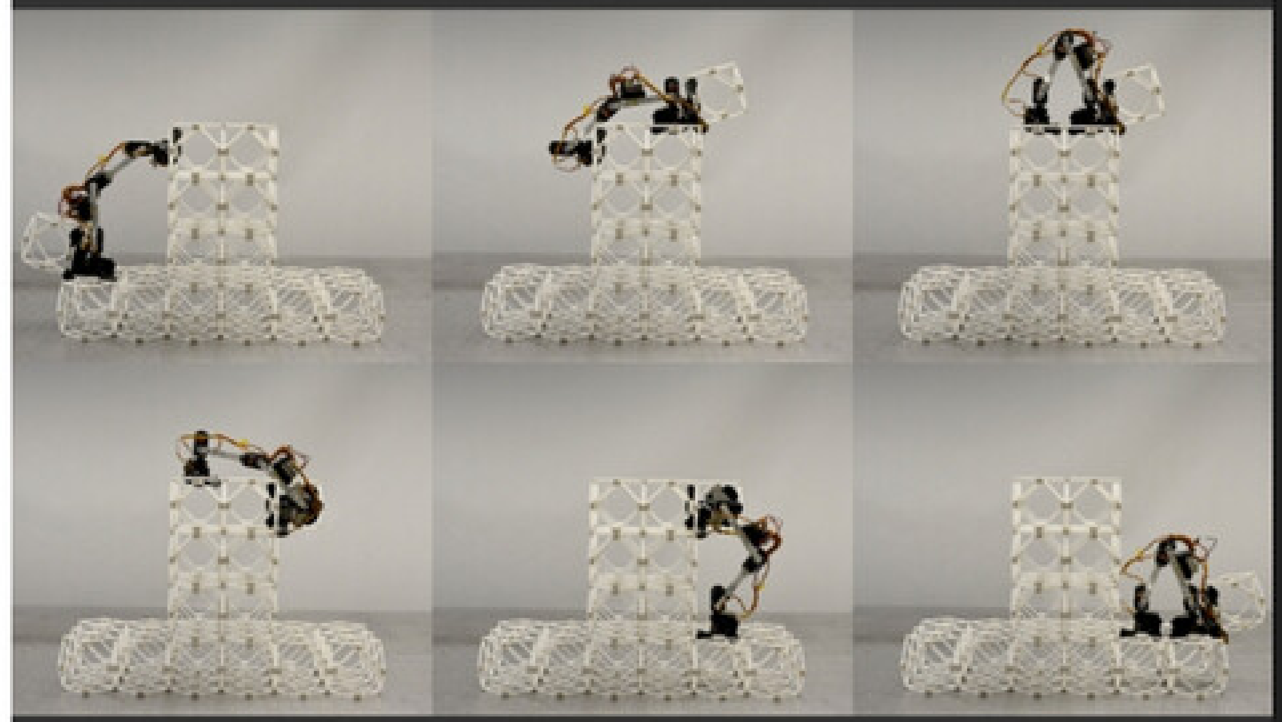








FULL SCREEN



Sequence of photos shows an assembler robot at work, carrying one structural unit over the top and down the other side of a structure under construction.

Image courtesy of Benjamin Jenett

Assembler robots make large structures from little pieces

Systems of tiny robots may someday build high-performance structures, from airplanes to space settlements.

David L. Chandler | MIT News Office
October 16, 2019

Press Inquiries

Today's commercial aircraft are typically manufactured in sections, often in different locations — wings at one factory, fuselage sections at another, tail components somewhere else — and then flown to a central plant in huge cargo planes for final assembly.

But what if the final assembly was the only assembly, with the whole plane built out of a large array of tiny identical pieces, all put together by an army of tiny robots?

That's the vision that graduate student Benjamin Jenett, working with Professor Neil Gershenfeld in MIT's Center for Bits and Atoms (CBA), has been pursuing as his doctoral thesis work. It's now reached the point that prototype versions of such robots can assemble small structures and even work together as a team to build up a larger assemblies.

The new work appears in the October issue of the *IEEE Robotics and Automation Letters*, in a paper by Jenett, Gershenfeld, fellow graduate student Amira Abdel-Rahman, and CBA alumnus Kenneth Cheung SM '07, PhD '12, who is now at NASA's Ames Research Center, where he leads the ARMADAS project to design a lunar base that could be built with robotic assembly.

"This paper is a treat," says Aaron Becker, an associate professor of electrical and computer engineering at the University of Houston, who was not associated with this work. "It combines top-notch mechanical design with jaw-dropping demonstrations, new robotic hardware, and a simulation suite with over 100,000 elements," he says.

RELATED

Paper: "Material–Robot System for Assembly of Discrete Cellular Structures."

Video: Multi-Agent Discrete Assembly

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NASA ARMADAS

Neil Gershenfeld

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Center for Bits and Atoms

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IEEE ROBOTICS AND AUTOMATION LETTERS. PREPRINT VERSION. ACCEPTED JULY, 2019

Material-Robot System for Assembly of Discrete Cellular Structures

Benjamin Jenett[1], Amira Abdel-Rahman[1], Kenneth Cheung[2], and Neil Gershenfeld[1]

***Abstract*— We present a material-robot system consisting of mobile robots which can assemble discrete cellular structures. We detail the manufacturing of cuboctahedral unit cells, termed voxels, which passively connect to neighboring voxels with magnets. We then describe "relative" robots which can locomote on, transport, and place voxels. These robots are designed relative to and in coordination with the cellular structure-- the geometry of the voxel informs the robot's global geometric configuration, local mechanisms, and end effectors, and robotic assembly features are designed into the voxels. We describe control strategies for determining build sequence, robot path planning, discrete motion control, and feedback, integrated within a custom software environment for simulating and executing single or multi-robot construction. We use this material-robot system to build several types of structures, such as 1D beams, 2D plates, and 3D enclosures. The robots can navigate and assemble structures with minimal feedback, relying on voxel-sized resolution to achieve successful global positioning. We show multi-robot assembly to increase throughput and expand system capability using a deterministic centralized control strategy.**

***Index Terms*— Assembly; Space Robotics and Automation; Path Planning for Multiple Mobile Robots or Agents**

I. Introduction

AUTOMATED processes for material deposition and manipulation are becoming more prevalent in state-of-the-art production of structural systems. Additive manufacturing can produce hierarchical, architected metamaterials with novel properties unattainable with traditional engineering materials [1]. High performance, continuous fiber composite aircraft components can be made by automated tape laying, utilizing large gantries, tooling, and autoclaves [2]. In these examples, high repeatability is achieved with computational control systems and stationary machines with stiff motion axes. However, the scale of the built object is limited to a fixed bounding envelope.

Mobile robots promise larger scale construction. Aerial, wheeled, and ambulatory platforms combine various material deposition techniques, yet tradeoffs remain between robotic complexity and the quality of the resulting artifact. Even with automation, some limits, such as stochastic errors, are inherent to the continuous, or monolithic, materials typically used.

An alternative strategy is based on the assembly of discrete, building-block elements into larger functional structures, using reversible connections to allow for disassembly and reuse. Here, the modularity of the structure can inform design of mobile robots for assembly. By ensuring local robot precision and reliability, robots can build structures larger and more precise than themselves. This approach is studied here, for assembly of a modular, space-filling lattice structure. We present the resulting material-robot system, control strategies, experiments to demonstrate core functionalities, and simulations to study system tradeoffs and scaling.

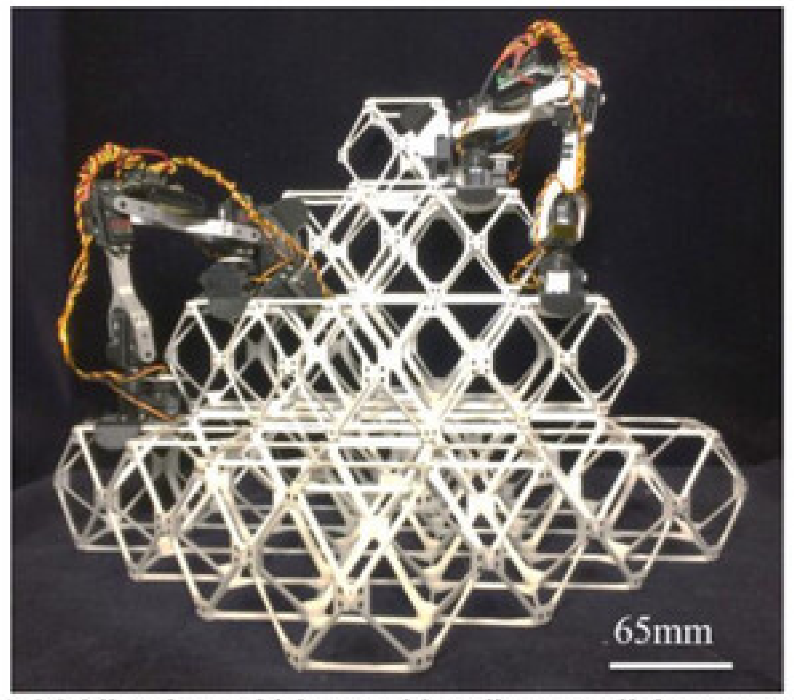
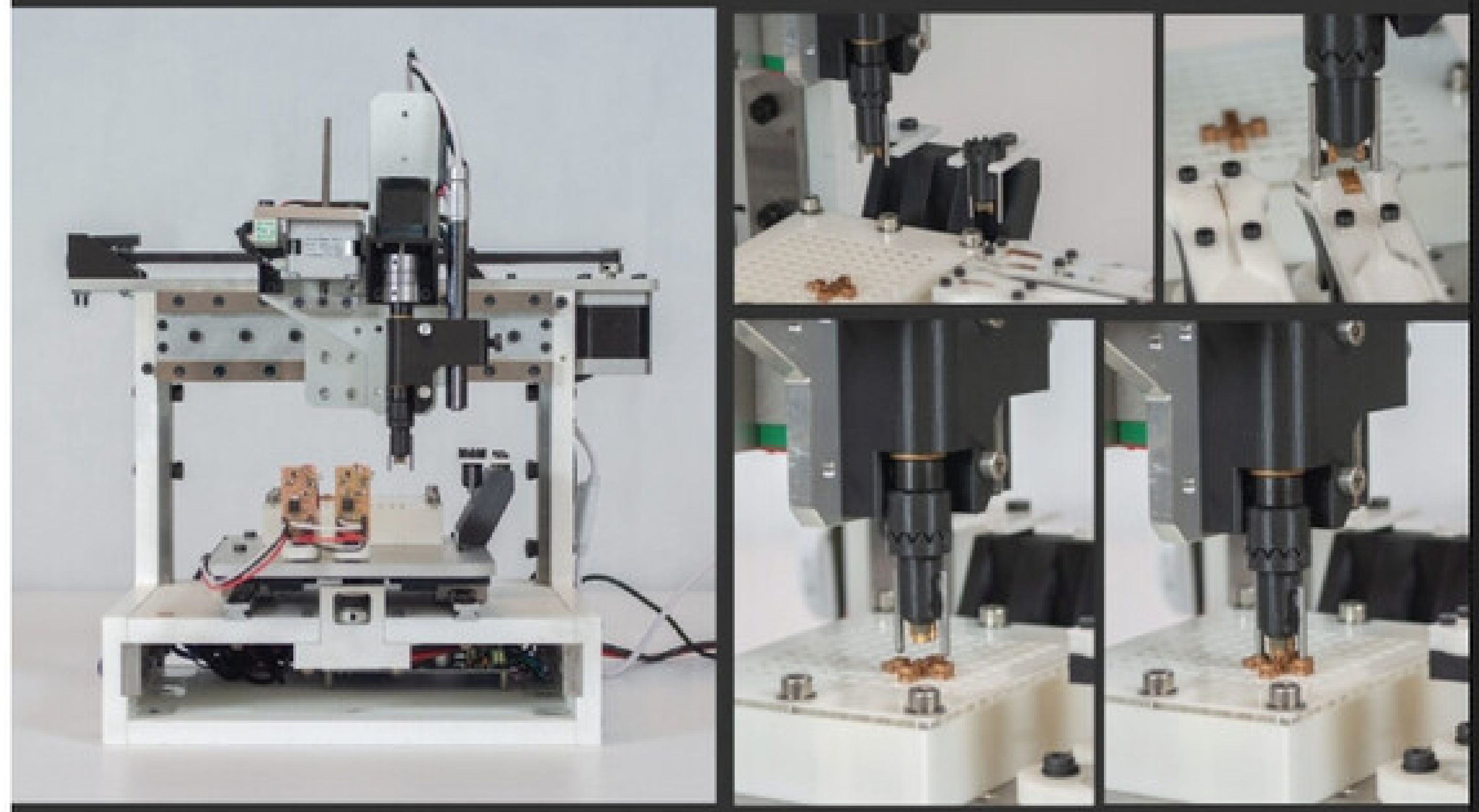


Figure 1: Mobile robots which assemble a discrete cellular structure. This pyramid structure consists of 30 cuboctahedral voxels.

II. Background

In this paper, we are motivated by the automated production of large scale, lightweight, high performance structures, with applications in aviation and aerospace. Aircraft manufacturing relies on expensive and precise tooling to produce designs which stray little from the "tube with wings" motif, primarily due to the reliance on legacy as a basis for cost, safety, and performance risk reduction [3]. Non-standard geometries are economic non-starters, even with performance gains [4], due to the cost-sensitive and risk-averse nature of the airline industry. The ability to produce arbitrary aerostructure geometries at low-cost can potentially disrupt this trend [5].

Manuscript received: February 24, 2019; Revised May 18, 2019; Accepted June 15, 2019. This paper was recommended for publication by Editor Dan Popa upon evaluation of the Associate Editor and Reviewers' comments. Research supported by NASA STMD Game Changing Development Program through the Automated Reconfigurable Mission Adaptive Digital Assembly Systems (ARMADAS) project, NASA Space Technology Research Fellowship (NNX14AM40H), and CBA consortia funding.
[1]B. Jenett and A. Abdel-Rahman, and N. Gershenfeld are with the Center for Bits and Atoms, Massachusetts Institute of Technology, Cambridge, MA 02139 USA (emails: bej@mit.edu, amira.abdel-rahman@cba.mit.edu, gersh@cba.mit.edu). Corresponding author: bej@mit.edu
[2]K. Cheung is with NASA Ames Research Center, Intelligent Systems Division (Code TI), Moffett Field, CA 94035 USA (email: kenny@nasa.gov)
Digital Object Identifier (DOI): see top of this page.



MIT graduate student Will Langford developed a machine that's like a cross between a 3-D printer and the pick-and-place machines that manufacture electronic circuits, but that can produce complete robotic systems directly from digital designs. (Video in "Related" sidebar below shows the assembly of a machine from five standard parts.)

Photo by Will Langford

Tiny motor can “walk” to carry out tasks

Mobile motor could pave the way for robots to assemble complex structures — including other robots.

David L. Chandler | MIT News Office
July 2, 2019

Years ago, MIT Professor Neil Gershenfeld had an audacious thought. Struck by the fact that all the world’s living things are built out of combinations of just 20 amino acids, he wondered: Might it be possible to create a kit of just 20 fundamental parts that could be used to assemble all of the different technological products in the world?

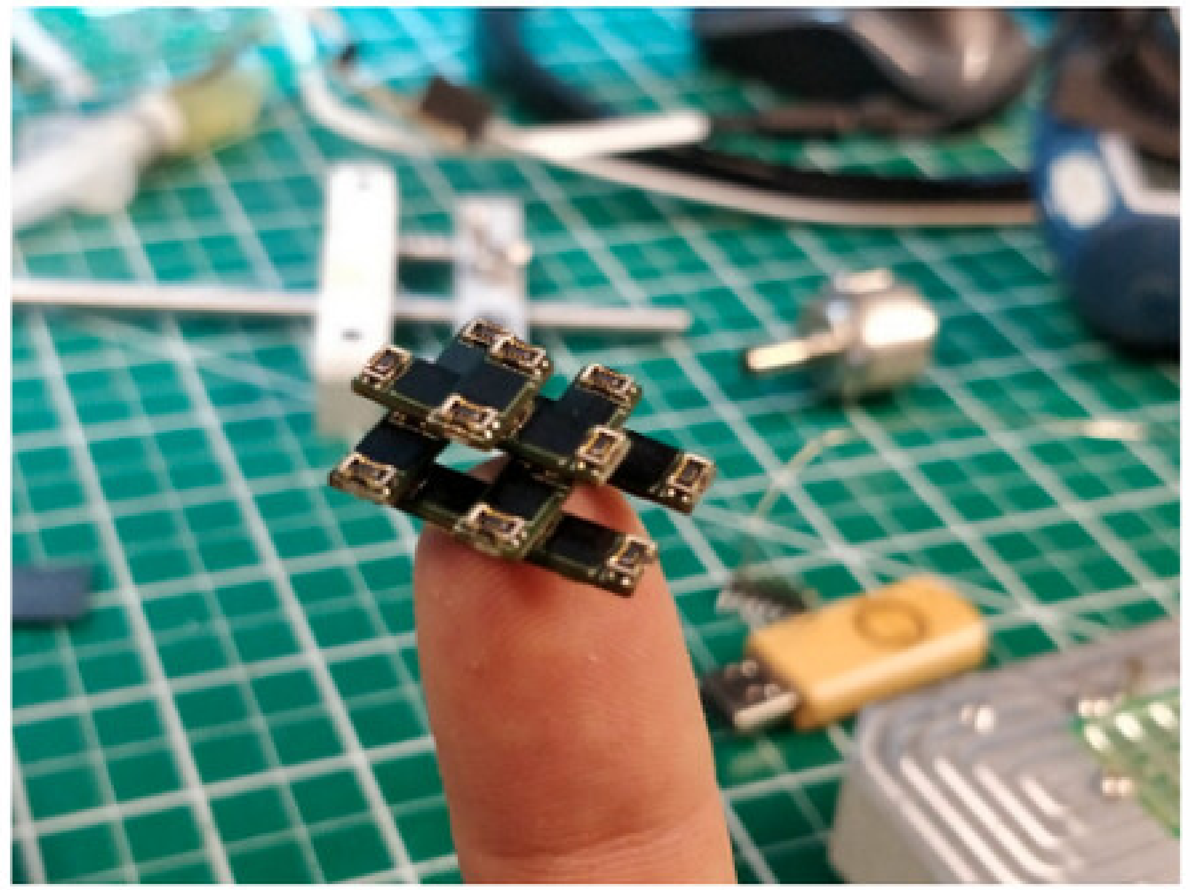
Gershenfeld and his students have been making steady progress in that direction ever since. Their latest achievement, presented this week at an international robotics conference, consists of a set of five tiny fundamental parts that can be assembled into a wide variety of functional devices, including a tiny “walking” motor that can move back and forth across a surface or turn the gears of a machine.

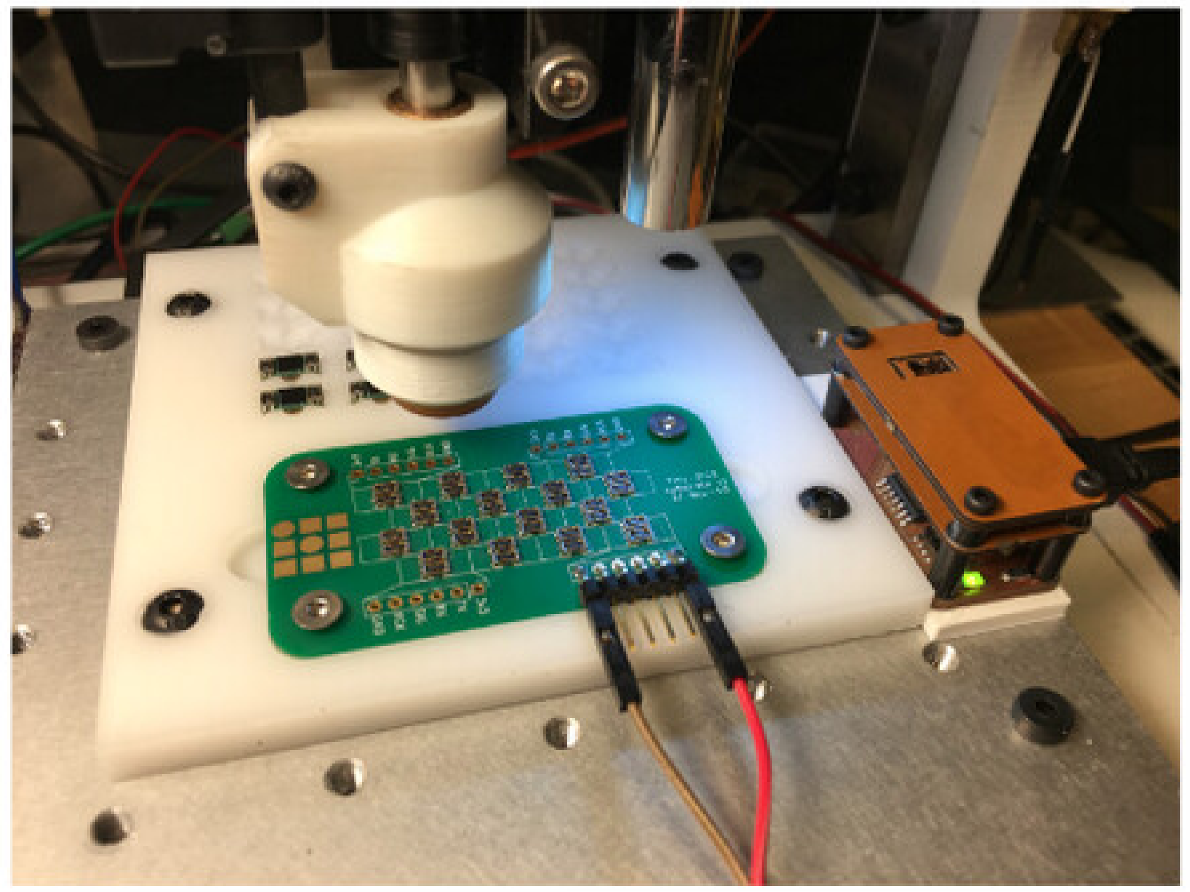
PRESS MENTIONS

MIT researchers have created an ambulatory motor that can “walk” back and forth or make the gears of another machine move. “On its own, this little moving microbe is impressive enough,” writes Darrell Etherington for *TechCrunch*, “but its real potential lies in what could happen were it to be assembled with others of its ilk, and with other building-block robotics components made up of simple parts.”

Discrete Integrated Circuit Electronics (DICE)

- *What are you trying to do?*
  - **Direct-write assembly of integrated three-dimensional electronics**
- *How is it done today ...*
  - **Separate development of chips, boards, blades, and systems**
- *... and what are the limits of current practice?*
  - **Diverging development cost and time, global supply chain dependency**
- *What's new in your approach ...*
  - **Cross between pick-and-place and 3D printing, with spatial programming**
- *... and why do you think it will be successful?*
  - **Demonstration of all of the enabling technologies in seed program**
- *Who cares? If you're successful, what difference will it make?*
  - **$O(10^5)$ reduction in HPC power consumption**
  - **Secure and trusted systems from untrusted components**
  - **AI software adapting its hardware (and *vice versa*)**
  - **Novel integrated electronic system form factors**
  - **Field reconfigurability and reusability**
- *What are the risks ...*
  - **Interconnect overheard (*vs* surface/volume), assembly throughput (*vs* recursion)**
- *... and the payoffs?*
  - **Alternative to existing fab vulnerabilities**





DARPA

THE CENTER FOR BITS AND ATOMS
Massachusetts Institute of Technology

First Draft of a Report on the EDVAC

by

John von Neumann

Contract No. W–670–ORD–4926

Between the

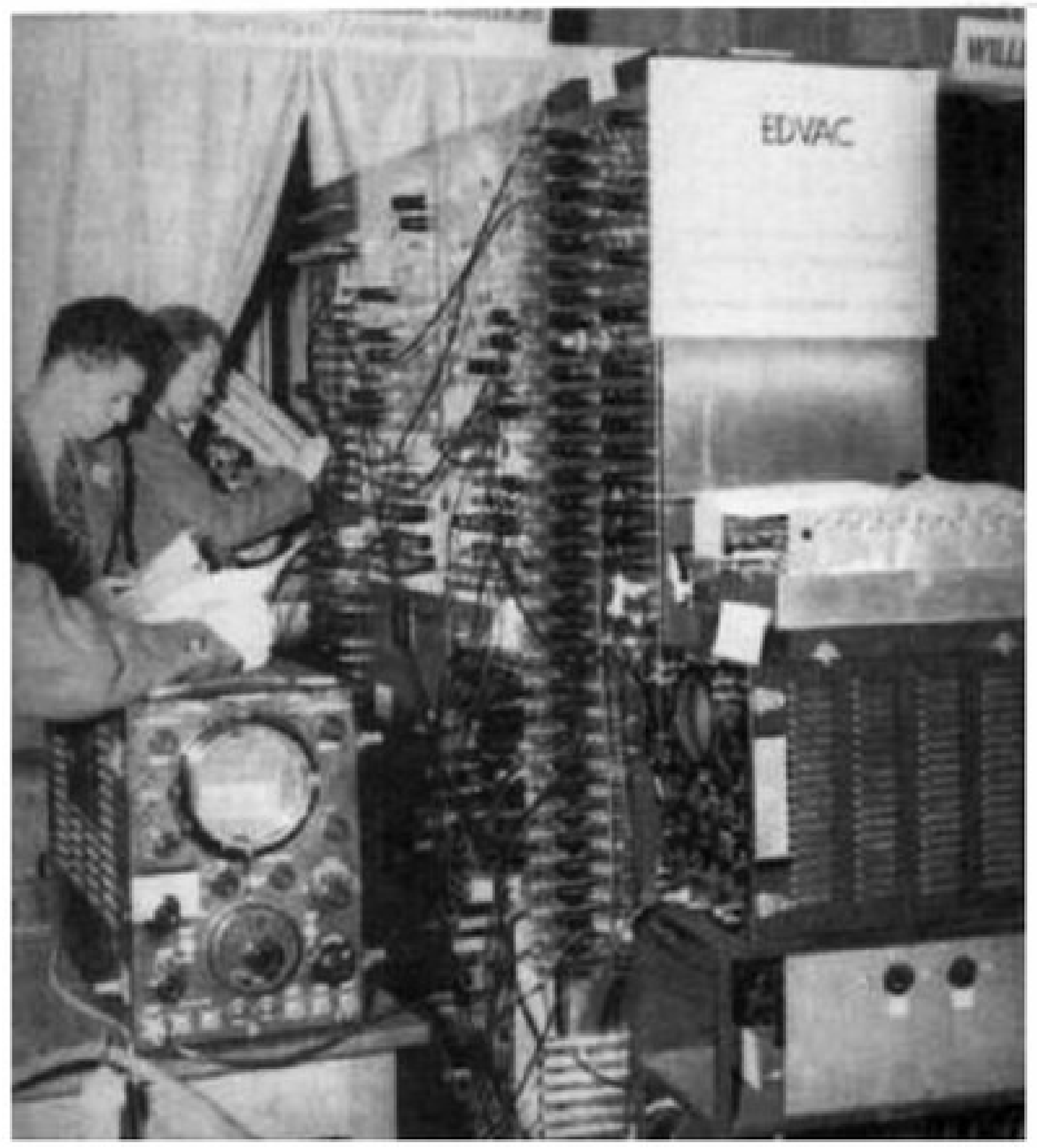
United States Army Ordnance Department

and the

University of Pennsylvania

Moore School of Electrical Engineering
University of Pennsylvania

June 30, 1945



ON COMPUTABLE NUMBERS, WITH AN APPLICATION TO THE ENTSCHEIDUNGSPROBLEM

By A. M. Turing.

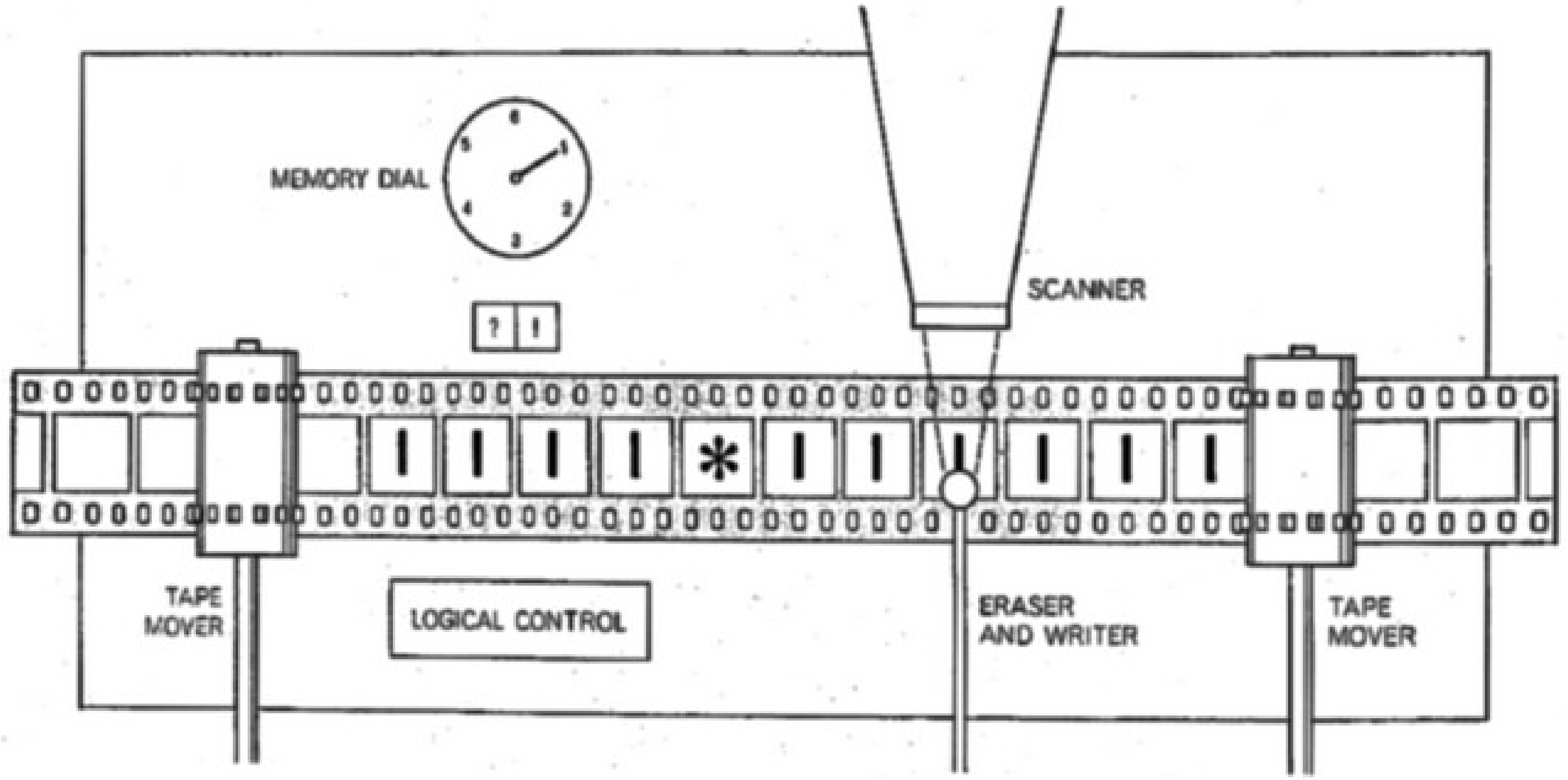
[Received 28 May, 1936.—Read 12 November, 1936.]

The "computable" numbers may be described briefly as the real numbers whose expressions as a decimal are calculable by finite means. Although the subject of this paper is ostensibly the computable *numbers*, it is almost equally easy to define and investigate computable functions of an integral variable or a real or computable variable, computable predicates, and so forth. The fundamental problems involved are, however, the same in each case, and I have chosen the computable numbers for explicit treatment as involving the least cumbrous technique. I hope shortly to give an account of the relations of the computable numbers, functions, and so forth to one another. This will include a development of the theory of functions of a real variable expressed in terms of computable numbers. According to my definition, a number is computable if its decimal can be written down by a machine.

In §§ 9, 10 I give some arguments with the intention of showing that the computable numbers include all numbers which could naturally be regarded as computable. In particular, I show that certain large classes of numbers are computable. They include, for instance, the real parts of all algebraic numbers, the real parts of the zeros of the Bessel functions, the numbers π, e, etc. The computable numbers do not, however, include all definable numbers, and an example is given of a definable number which is not computable.

Although the class of computable numbers is so great, and in many ways similar to the class of real numbers, it is nevertheless enumerable. In § 8 I examine certain arguments which would seem to prove the contrary. By the correct application of one of these arguments, conclusions are reached which are superficially similar to those of Gödel†. These results

† Gödel, "Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme, I", *Monatshefte Math. Phys.*, 38 (1931), 173–198.

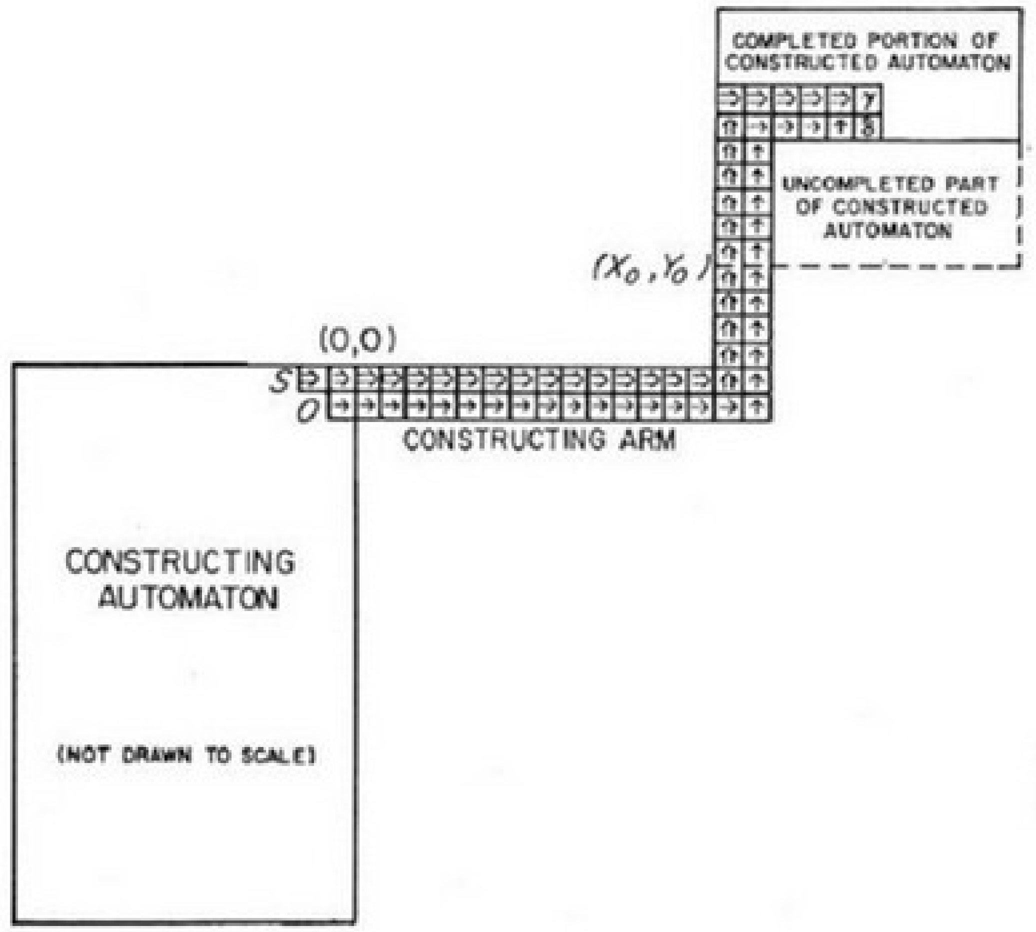


Theory of Self-Reproducing Automata

JOHN VON NEUMANN

edited and completed by Arthur W. Burks

University of Illinois Press
URBANA AND LONDON 1966



THE CHEMICAL BASIS OF MORPHOGENESIS

By A. M. TURING, F.R.S. *University of Manchester*

(*Received* 9 *November* 1951—*Revised* 15 *March* 1952)

It is suggested that a system of chemical substances, called morphogens, reacting together and diffusing through a tissue, is adequate to account for the main phenomena of morphogenesis. Such a system, although it may originally be quite homogeneous, may later develop a pattern or structure due to an instability of the homogeneous equilibrium, which is triggered off by random disturbances. Such reaction-diffusion systems are considered in some detail in the case of an isolated ring of cells, a mathematically convenient, though biologically unusual system. The investigation is chiefly concerned with the onset of instability. It is found that there are six essentially different forms which this may take. In the most interesting form stationary waves appear on the ring. It is suggested that this might account, for instance, for the tentacle patterns on *Hydra* and for whorled leaves. A system of reactions and diffusion on a sphere is also considered. Such a system appears to account for gastrulation. Another reaction system in two dimensions gives rise to patterns reminiscent of dappling. It is also suggested that stationary waves in two dimensions could account for the phenomena of phyllotaxis.

The purpose of this paper is to discuss a possible mechanism by which the genes of a zygote may determine the anatomical structure of the resulting organism. The theory does not make any new hypotheses; it merely suggests that certain well-known physical laws are sufficient to account for many of the facts. The full understanding of the paper requires a good knowledge of mathematics, some biology, and some elementary chemistry. Since readers cannot be expected to be experts in all of these subjects, a number of elementary facts are explained, which can be found in text-books, but whose omission would make the paper difficult reading.

was used and h was about 0·7. In the figure the set of points where $f(x, y)$ is positive is shown black. The outlines of the black patches are somewhat less irregular than they should be due to an inadequacy in the computation procedure.

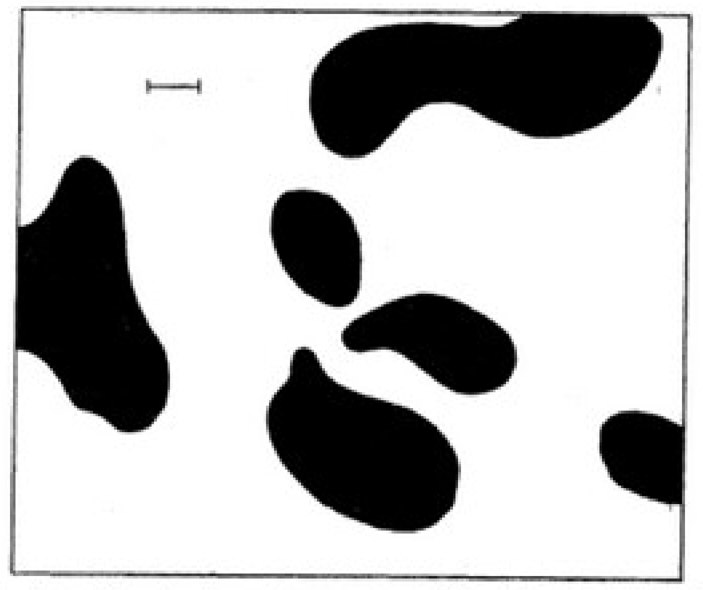
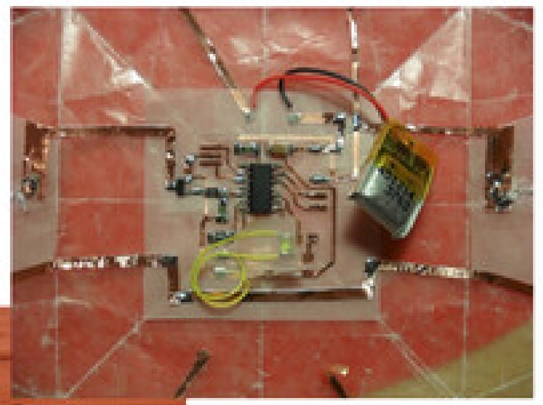


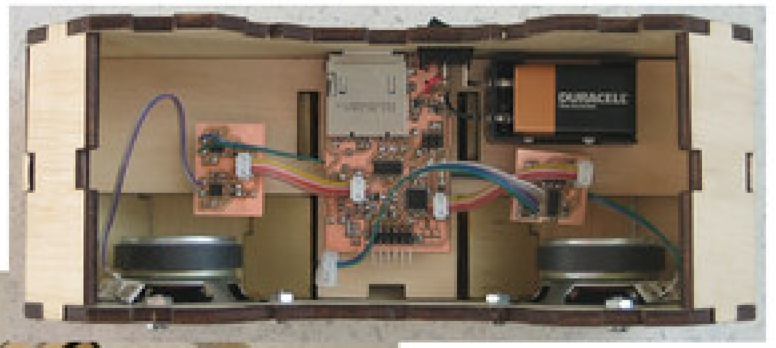
Figure 2. An example of a 'dappled' pattern as resulting from a type (*a*) morphogen system. A marker of unit length is shown. See text, §9, 11.


1:
Global
- 1,000:
Community
- 1,000,000:
Personal
- 1,000,000,000:
Universal
- 1,000,000,000,000:
Ubiquitous
$1,000,000 -
$100,000 -
$10,000 -
$1,000 -
$100 -
$10 -
ALTAIR 8800 COMPUTER
POPFAB
nest
IN 20 MIN
72
System
Microgripper
Z-axis
Assembler
Module
Module
Leg Motion Sequence

How To Make (almost) Anything

9/12: principles and practices
  section: computer-aided design
9/19: computer-controlled cutting
  section: project management
9/26: electronics production
  section: fab module internals
10/03: computer-controlled machining
  section: welding
10/10: Columbus Day
  section: electronics design
10/17: molding and casting composites
  section: vacuum forming, composite processing
10/24: embedded programming
  section: languages and environments
10/31: 3D scanning and printing
  section: real-time scanning
11/07: input devices
  section: circuits
11/14: output devices
  section: motion
11/21: interface and application programming
11/28: mechanical design, machine design
  section: MTM
12/05: networking and communications
  section: radios
12/12: project development
12/19: final presentations





MAS.863/4.140/6.943
How To Make (almost) Anything
People
2019

Students

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Harrison Allen
Maharshi Bhattacharya
Camron Blackburn
Morgan Blevins
Phil Brooks
Kevin Chen
Chi Po-hao
Lincoln Craven-Brightman
Ishani Desai
Serena Do
Nathaniel Elberfeld
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Aarti Sunder
Jordan Tappa
Lavender Tessmer
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Alexandra Waller
Xiqing Wang
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Emma Zhu
Andrew Zuckerman

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CBA shop
EECS shop
Harvard shop

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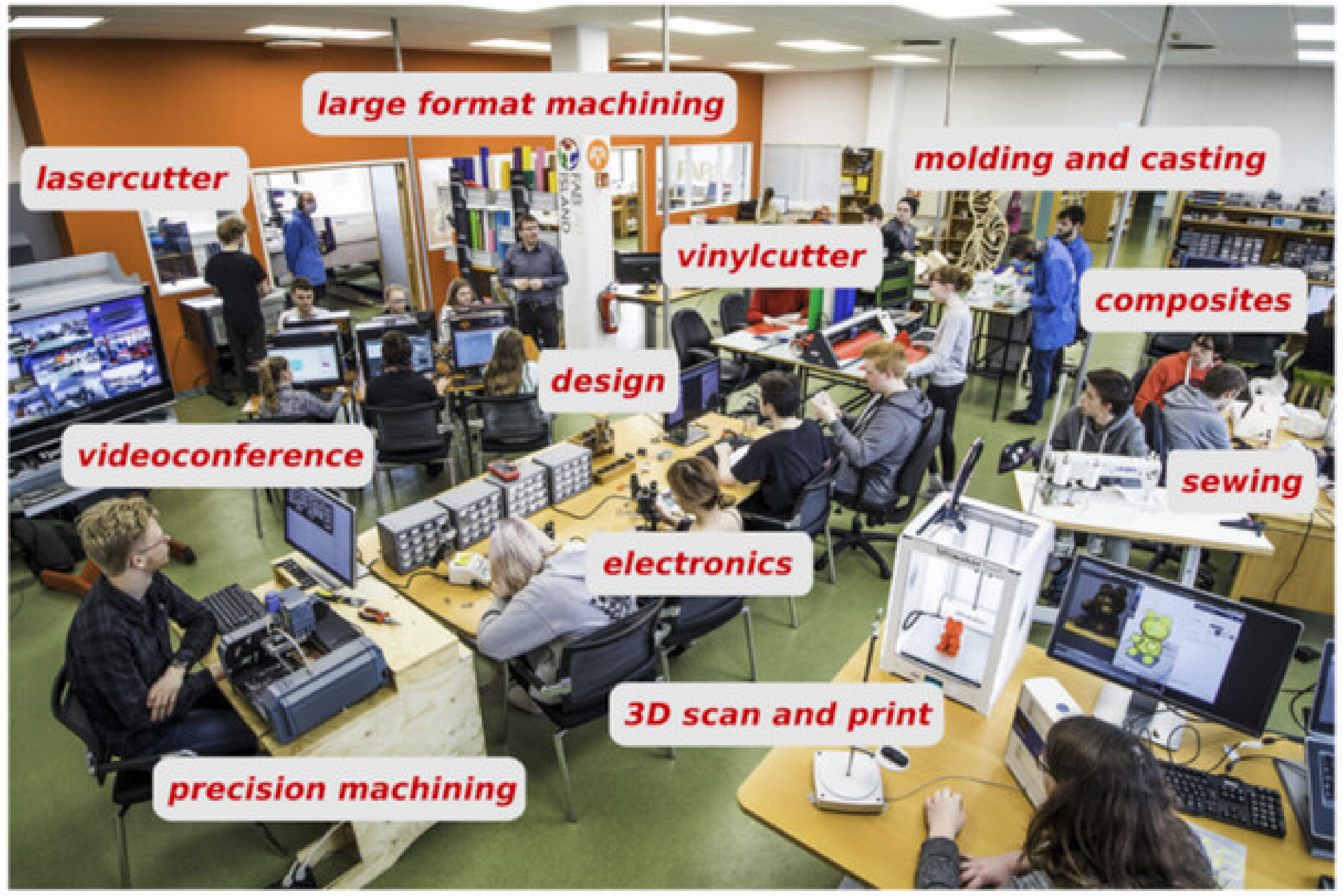
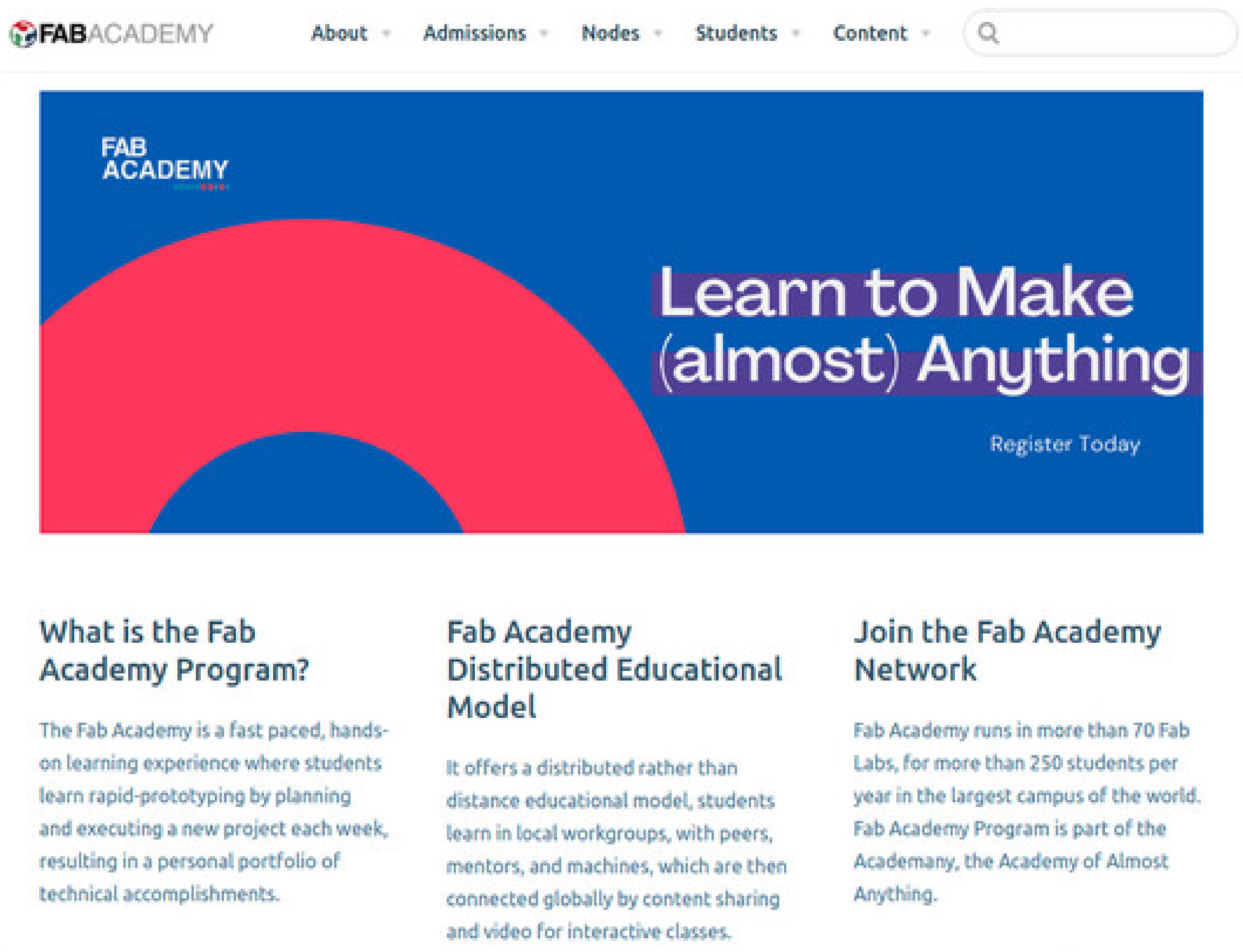
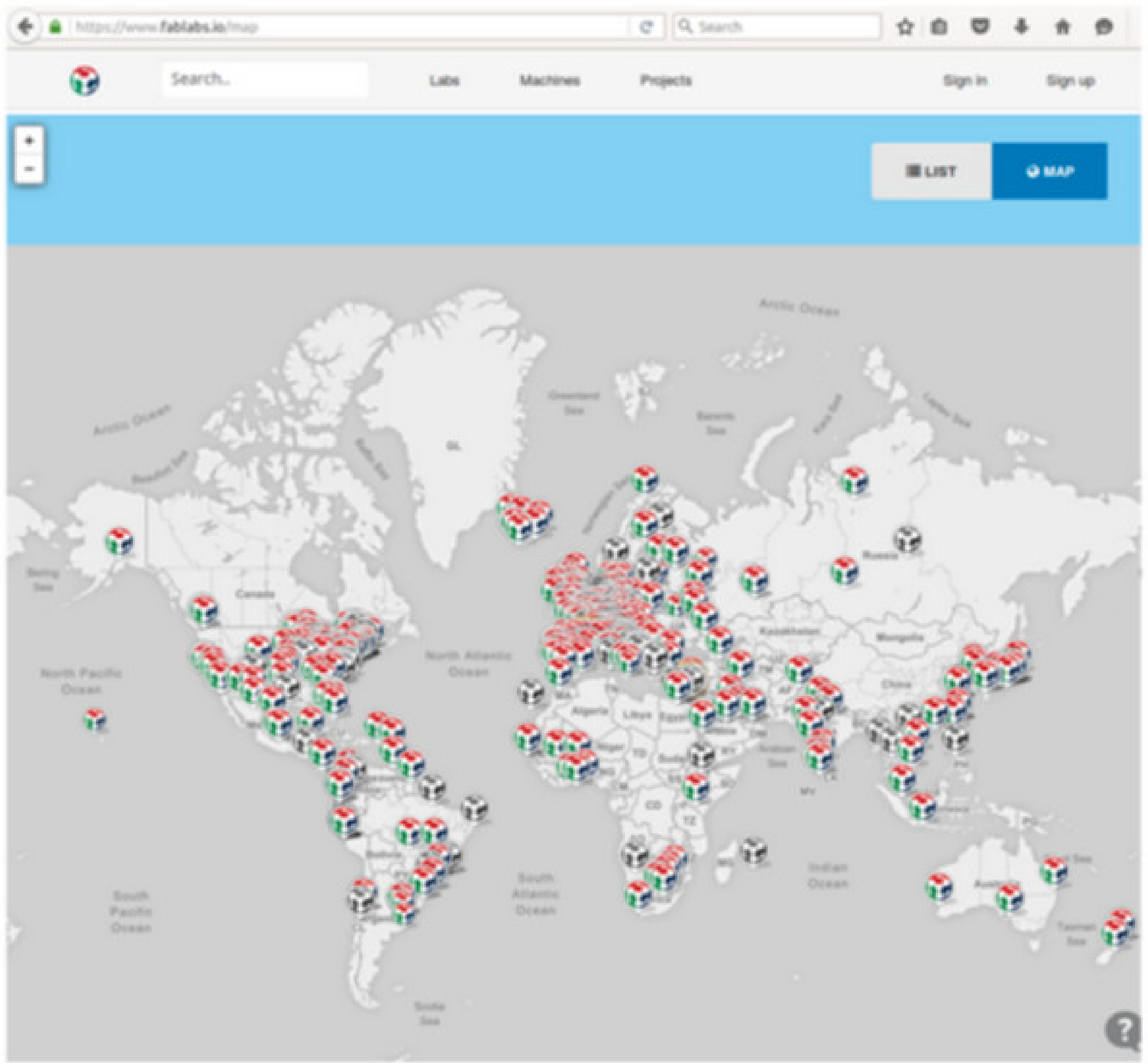
Jiri Zemanek

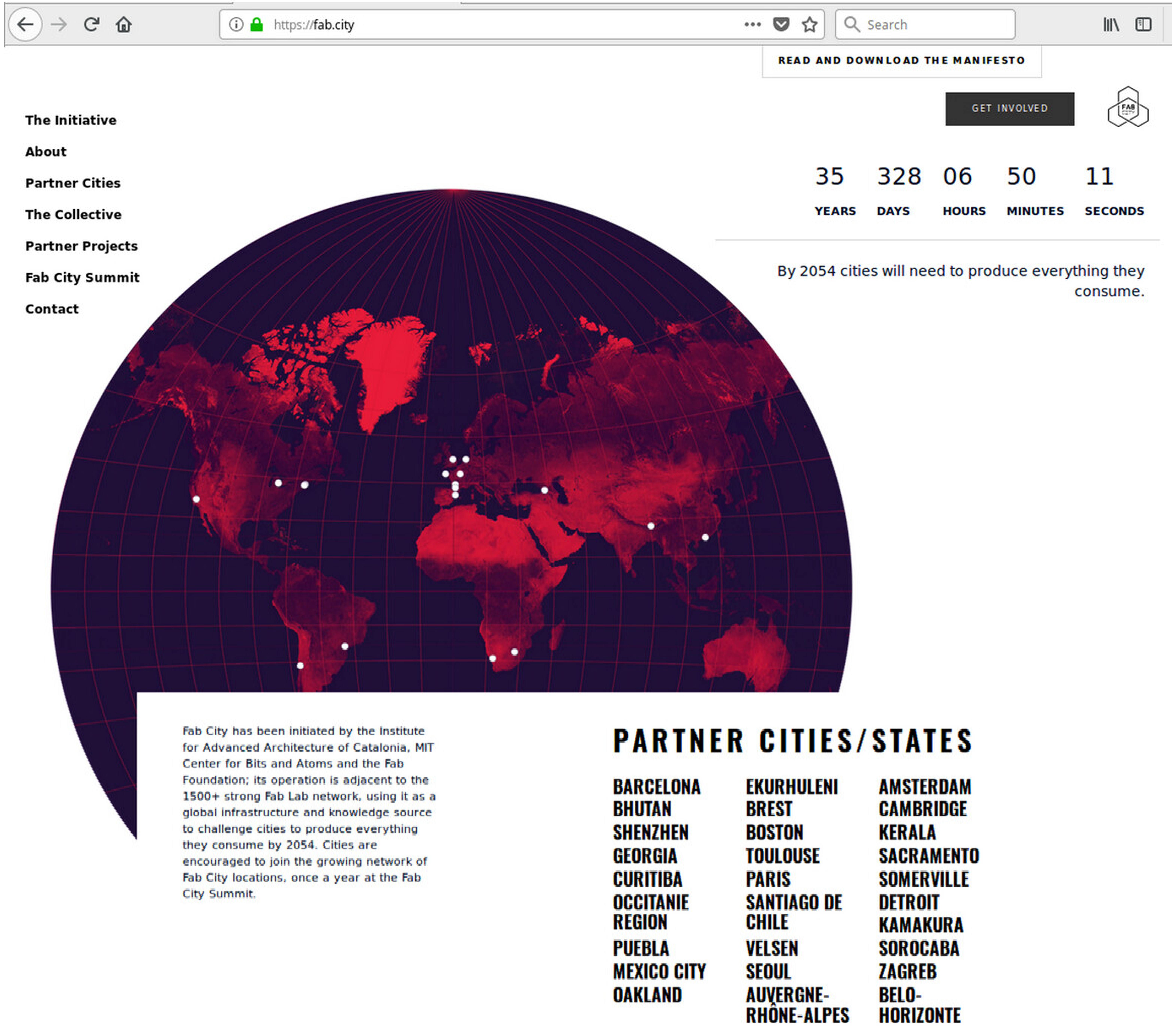






Lectures

- principles and practices, project management (Jan 27)
  - Recitation: Massimo Banzi, Arduino co-founder (Feb 1)
- computer-aided design (Feb 3)
  - Recitation: Primavera de Filippi, Berkman Center at Harvard (Feb 8)
- computer-controlled cutting (Feb 10)
  - Recitation: Bruce Mau, Massive Change (Feb 15)
- electronics production (Feb 17)
  - Recitation: Eric Pan, Seeed Studio (Feb 22)
- 3D scanning and printing (Feb 24)
  - Recitation: Vinay Gupta (Feb 29)
- electronics design (Mar 2)
  - Recitation: Kenny Cheung, How to make almost anything in Space (Mar 7)
- computer-controlled machining (Mar 9)
  - Recitation: Silvia Lindtner, Hacked Matter Group (Mar 14)
- embedded programming (Mar 16)
  - Recitation: Nadya Peek, Machines that Make Machines (Mar 21)
- break (Mar 23)
- mechanical design (Mar 30)
  - Recitation: Caleb Harper, Open Agriculture at MIT (Apr 4)
- machine design (Apr 6)
  - Recitation: Jessi Baker, Provenance (Apr 11)
- input devices (Apr 13)
  - No recitation (Apr 18)
- molding and casting (Apr 20)
  - Recitation: Beno Juarez, Amazon Floating Fab Lab (Apr 25)
- output devices (Apr 27)
  - Recitation (Postponed to May 23): Gian Paolo Bassi, SolidWorks (May 2)
- composites (May 4)
  - Recitation: James Coleman, A. Zahner Company (May 9)
- networking and communications (May 11)
  - Recitation: The State of the Fab Lab Network (May 16)
- interface and application programming (May 18)
  - Recitation: Gian Paolo Bassi, SolidWorks (May 23)
- applications and implications (May 25)
  - Recitation: Sylvia Martinez, Invent to Learn (May 30)
- invention, intellectual property, and income (Jun 1)
  - Recitation: Carl Bass, Autodesk (June 6)


https://fab.city
READ AND DOWNLOAD THE MANIFESTO
GET INVOLVED
The Initiative
About
Partner Cities
The Collective
Partner Projects
Fab City Summit
Contact
35 YEARS 328 DAYS 06 HOURS 50 MINUTES 11 SECONDS
By 2054 cities will need to produce everything they consume.
Fab City has been initiated by the Institute for Advanced Architecture of Catalonia, MIT Center for Bits and Atoms and the Fab Foundation; its operation is adjacent to the 1500+ strong Fab Lab network, using it as a global infrastructure and knowledge source to challenge cities to produce everything they consume by 2054. Cities are encouraged to join the growing network of Fab City locations, once a year at the Fab City Summit.
PARTNER CITIES/STATES
BARCELONA
BHUTAN
SHENZHEN
GEORGIA
CURITIBA
OCCITANIE REGION
PUEBLA
MEXICO CITY
OAKLAND
EKURHULENI
BREST
BOSTON
TOULOUSE
PARIS
SANTIAGO DE CHILE
VELSEN
SEOUL
AUVERGNE-RHÔNE-ALPES
AMSTERDAM
CAMBRIDGE
KERALA
SACRAMENTO
SOMERVILLE
DETROIT
KAMAKURA
SOROCABA
ZAGREB
BELO-HORIZONTE

THE WALL STREET JOURNAL. | WASHINGTON WIRE

THINK TANK | 2014 | 2016

HOT TOPICS: THINK TANK POLITICS COUNTS EMAIL SIGN UP: CAPITAL JOURNAL DAYBREAK

6:18 pm ET
Jun 18, 2014 WHITE HOUSE

Photos: The Six Wonders of Obama's 'Maker Faire' Tour

ARTICLE COMMENTS

BARACK OBAMA MAKER FAIRE WHITE HOUSE

Email Print

The White House hosted a **Maker Faire** on Wednesday, **inviting tinkerers, inventors and entrepreneurs** to the nation's capital on what turned out to be a blazingly hot day. President **Barack Obama** toured six outdoor displays, ranging from fuel-efficient cars to futuristic steel animals. Here are the highlights, based on the White House pool report, followed by some more photos from Twitter.

1. The Fab Lab

113TH CONGRESS
1ST SESSION

H. R. 1289

IN THE HOUSE OF REPRESENTATIVES

March 20, 2013

Mr. Foster (for himself, **Mr. Hultgren**, **Mr. Massie**, **Mr. Van Hollen**, **Mr. Capuano**, **Mr. Carney**, **Mr. Cicilline**, **Mr. Connolly**, **Mr. Danny K. Davis of Illinois**, **Mr. Loebsack**, **Ms. McCollum**, **Mr. Peters of Michigan**, **Mr. Pocan**, **Mr. Rush**, **Ms. Schakowsky**, and **Ms. Shea-Porter**) introduced the following bill; which was referred to the Committee on the Judiciary

A BILL

To provide a Federal charter to the Fab Foundation for the National Fab Lab Network, a national network of local digital fabrication facilities providing community access to advanced manufacturing tools for learning skills, developing inventions, creating businesses, and producing personalized products.

Section 1. Short title

This Act may be cited as the " National Fab Lab Network Act of 2013 ".

Sec. 2. Findings

Congress finds the following:

(1) Scientific discoveries and technical innovations are critical to the economic and national security of the United States.

(2) Maintaining the leadership of the United States in science, technology, engineering, and mathematics will require a diverse population with the skills, interest, and access to tools required to advance these fields.

(3) Just as earlier digital revolutions in communications and computation provided individuals with the Internet and personal computers, a digital revolution in fabrication will allow anyone to make almost anything, anywhere.

(4) The Center for Bits and Atoms of the Massachusetts Institute of Technology (CBA) has contributed significantly to the advancement of these goals through its work in creating and advancing digital fab labs in the United States and abroad.

(5) CBA's fab labs provide a model for a new kind of national laboratory that links local facilities for advanced manufacturing to expand access and empower communities.

(6) A coordinated national public-private partnership will be the most effective way to accelerate the provision of this infrastructure for learning skills, developing inventions, creating businesses, and producing personalized products.

Sec. 3. Establishment of national fab lab network

113TH CONGRESS
1ST SESSION

S. 1705

IN THE SENATE OF THE UNITED STATES

November 14, 2013

Mr. Durbin (for himself, **Mrs. Gillibrand**, and **Mr. Markey**) introduced the following bill; which was read twice and referred to the Committee on the Judiciary

A BILL

To provide a Federal charter for the National Fab Lab Network, a national network of local digital fabrication facilities providing community access to advanced manufacturing tools for learning skills, developing inventions, creating businesses, and producing personalized products.

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This Act may be cited as the " National Fab Lab Network Act of 2013 ".

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(3) Just as earlier digital revolutions in communications and computation provided individuals with the Internet and personal computers, a digital revolution in fabrication will allow anyone to make almost anything, anywhere.

(4) Fab labs like the Center for Bits and Atoms at the Massachusetts Institute of Technology provide a model for a new kind of national laboratory that links local facilities for advanced manufacturing to expand access and empower communities.

(5) A coordinated national public-private partnership will be the most effective way to accelerate the provision of this infrastructure for learning skills, developing inventions, creating businesses, and producing personalized products.

Sec. 3. Establishment of National Fab Lab Network

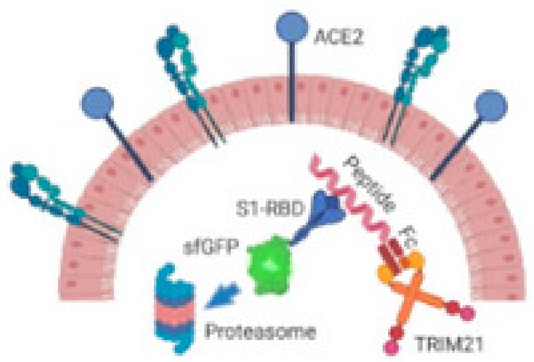
gitlab.cba.mit.edu/pub/coronavirus/tracking

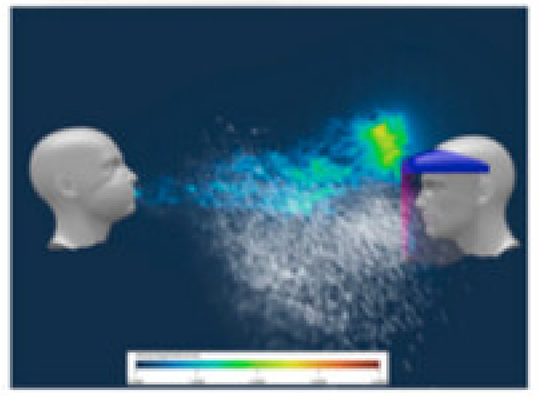
Projects Groups More

10:00A EDT Tue April 14 meeting

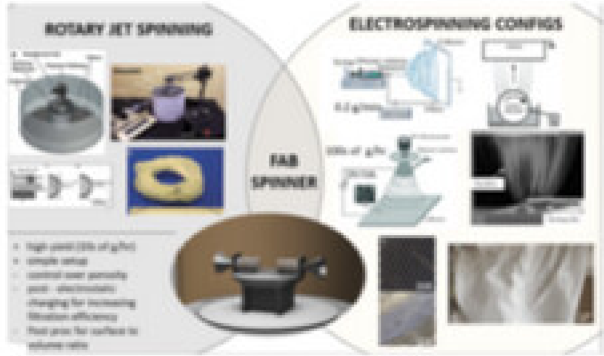
- video
  - https://vimeo.com/407740690
- background, process, schedule
- projects, intros
  - Jifei: swabs
    - http://optindustries.com/
    - https://drive.google.com/file/d/1jbAFmYRHwXmG5GV4wntYko
    - https://gitlab.cba.mit.edu/alfonso/swab-testing-for-covid-19
  - Avi, Izhar: swabs
    - https://gitlab.cba.mit.edu/pub/coronavirus/nexa3d-swab-design
  - Zach
    - HMI remote (live demo)
  - Alfonso: kirigami intubation station
    - https://gitlab.cba.mit.edu/alfonso/covid-isolation-box
  - Tim: mask machine
    - https://github.com/tbutters/Pleated-Surgical-Mask-Machine
  - Matt: mask CFD+testing
    - https://gitlab.cba.mit.edu/mcarney/maskproject

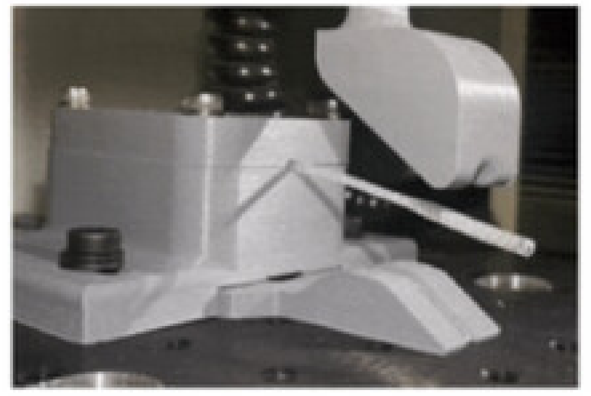
molecular and CFD modeling





filter media and swab production and testing





curved-crease folded shields and boxes

MIT initiates mass manufacture of disposable face shields for Covid-19 response

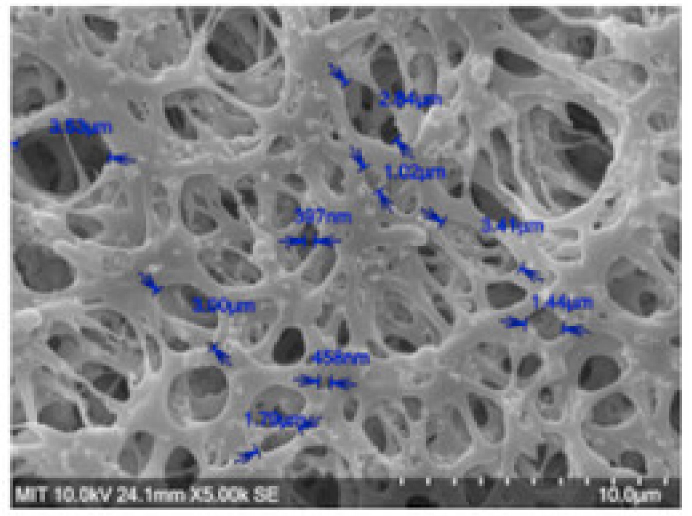
March 31, 2020

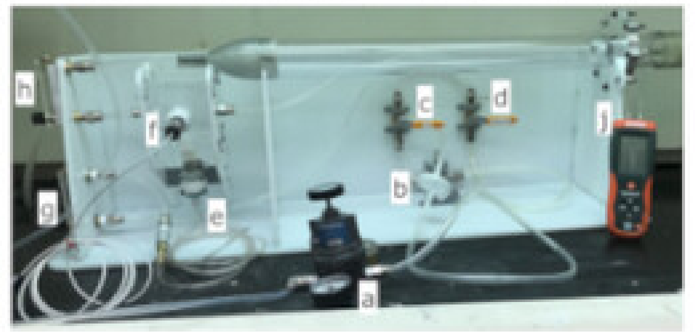
A team from MIT has designed disposable face shields that can be mass produced quickly to address hospitals' needs nationwide.

Graduate student Zach Fredin operates the Zund large-format cutter in MIT's Center for Bit and Atoms. The machine was used to make prototypes of the face shield.

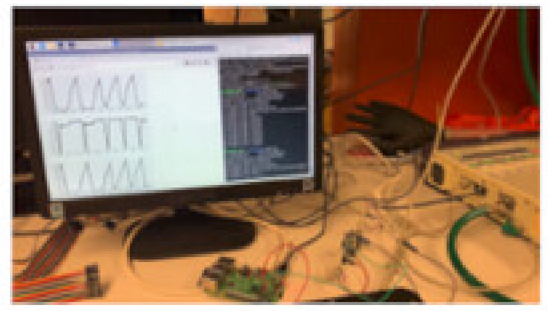
Image: Center for Bits and Atoms

nanoparticle filter media characterization





ventilator displays and UVC sterilization



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Watch our Live Panel With Neil Gershenfeld About Fab Labs

In his 2005 book, Fab, Dr. Neil Gershenfeld predicted a shift from personal computing to personal fabrication and how manufacturing could be decentralized through networks. The Fab Lab Network is an experiment in bringing Gershenfeld's vision a reality. Today, with the criisis of COVID-19, fab labs and makerspaces around the world are sharing designs that can be replicated in each community because the tools for digital fabrication are widely distributed. We want to hear what Neil thinks of seeing his vision plays such a powerful role in shape the civic response to COVID-19 but quite possibly providing the basis for a broad recovery.

Join Dorothy Jones-Davis of Nation of Makers and Dale Dougherty of Make: Community in an open discussion with our guest panelist and the maker community.

panelists for this event will include:

- Dr. Neil Gershenfeld of MIT Center for Bit and Atoms
- Sherry Lassiter, Executive Director of the Fab Foundation
- Zach Fredin has been working on rapid-prototyping responses
- Camron Blackburn has been working on lab measurements of rapid-prototyping responses
- Tim Butterworth – Artisans Asylum
- Megan J. Smith has been working on the civic response
- Danny Beesley – College of Alameda Fab Lab

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A fab lab in Iceland. | Frosti Gíslason/Saethor Vido

THE BIG IDEA

Soon You'll Be Able to Make Anything. It'll Change Politics Forever.

How digital fabrication is revolutionizing everything.

By NEIL GERSHENFELD, ALAN GERSHENFELD and JOEL CUTCHER-GERSHENFELD | April 17, 2018

The divide between those who want to open up and connect with the rest of the world—the globalists—and those who want to retrench behind barriers—let's call them the localists—is deepening. There was Remain vs. Leave in the Brexit debate, then there was Hillary Clinton vs. Donald Trump. Today, the divide is visible in the battle raging between those who want to make trade agreements and those who want to start trade wars.

Both sides are fighting over what's becoming a false dichotomy. Out of sight of these pitched partisan battles, a future is being invented in which we will no longer have to choose between global connectivity and local self-sufficiency. It is a future where anybody can make (almost) anything locally, while using knowledge that is shared globally. This future has important implications for politics today.

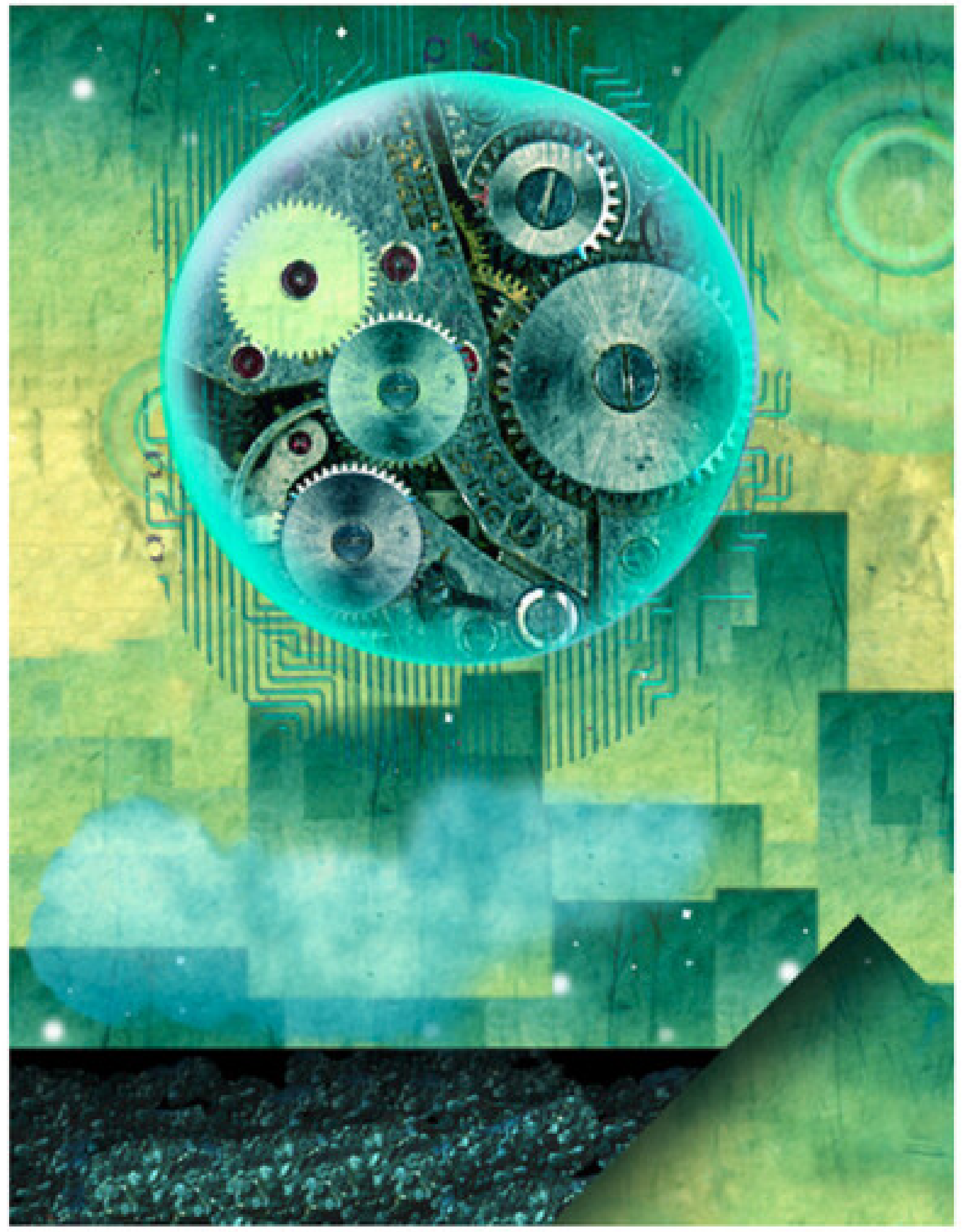
The Promise of Self-Sufficient Production

As global supply chains have revealed their vulnerabilities during the pandemic, digital fabrication technologies demonstrate a promising way forward.

BY JOEL CUTCHER-GERSHENFELD, ALAN GERSHENFELD, AND NEIL GERSHENFELD

It was a matter of life and death. During the early onslaught of the COVID-19 pandemic, a hospital in Brescia, Italy, was running out of ventilator valves. The normal suppliers couldn't meet the rapidly increasing demand for the parts, which were essential for keeping patients alive.[1] So, in a moment of desperation, the hospital reached out to the local community for help. Isinnova, a company in Brescia with rapid prototyping capabilities, responded to the call. It reverse-engineered, prototyped, and then produced hundreds of 3D-printed valves that proved a good fit for the emergency. The same company then developed an innovative idea to transform a snorkeling mask into an emergency ventilator. Since these emergency ventilators were needed extensively all over Italy, Isinnova connected with the digital fabrication community to make the materials available to the local hospitals, reported Martina Ferracane, founder of FabLab Western Sicily. Thousands of adapters were produced and donated to hospitals across the region. A distributed ecosystem of digital fabrication facilities — some community-based fabrication labs, some commercial — had become an important part of the local supply chain to provide health care facilities with personal protective equipment (PPE), spare parts, and medical devices.

At a time when global supply chains and large-scale manufacturing are being revealed as fragile and vulnerable, the role played by digital fabrication technologies and local ecosystems gives us a glimpse into a future in which new forms of



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