COMBINATORIAL MANUFACTURING:
HARNESSING NATURAL PROCESSES

when everything is programmable: LIFE IN A COMPUTATIONAL AGE

Humans have always been makers, but the way humans manufacture is undergoing a radical transformation. Tools for computational programming are converging with material science and synthetic biology to give us the ability to actually program matter—that is, to design matter that can change its physical properties based on user input or autonomous sensing. Nanotechnology is allowing us to manipulate the atomic world with greater precision toward the construction of molecular assemblers. Researchers are designing "claytronics": intelligent robots that will self-assemble, reconfigure, and respond to programmatic commands. And synthetic biologists are creating artificial organic machines to perform functions not seen in nature.

ROOM AT THE BOTTOM

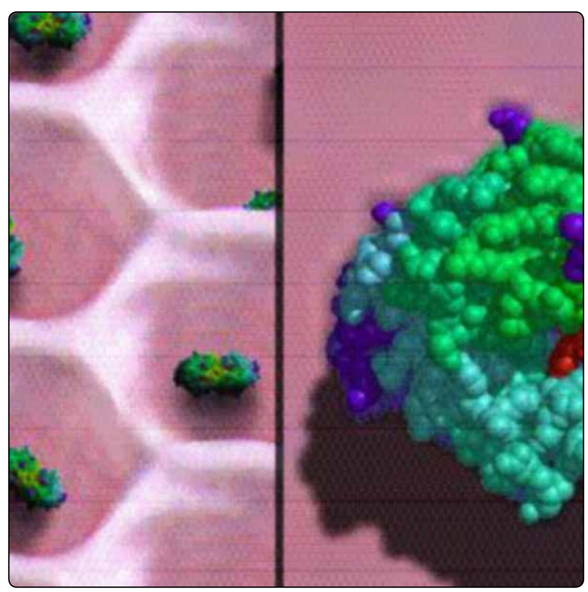
After years of exuberant forecasts around nanotechnology, we are now seeing the acceleration of practical applications. Tools like atomic force manipulators, nanolithography, and "nanohands" are enabling the precise placement of individual atoms. Rudimentary molecular assemblies are being incorporated into a host of devices from drug delivery systems to advanced water and air filtration systems. Nanoscale gears are leading to new and more efficient ways to capture energy and toward the construction of simple assembly lines that will enable programmable nanoscale machines for "desktop manufacturing." The power unleashed by realizing molecular manufacturing and programmable matter will revolutionize every aspect of our world.

MATTER AS CODE

Scientists at Carnegie Mellon University (CMU) are building an entirely new form of smart matter. Claytronic atoms, or "catoms," are millimeter-scale spherical components capable of self-assembly and directed coordination. Researchers seek a near future where billions of microscopic intelligent catoms will be programmed to dynamically assemble into virtually anything. They envision claytronics being used in many diverse domains, from real-time 3D collaborative design to remote surgery where claytronic devices can be programmed to enter the body, remove tissue, and suture the wound—all without the need for hospital support.

THE RISE OF BIOMIMETIC MACHINES

Biological systems, seen from an engineering perspective, are providing a useful model for building sturdy and efficient nanomachines. Researchers are looking to biological systems to overcome the engineering challenges of nanoscale molecular design and build truly functional molecular machines. Current applications include augmenting microorganisms to produce fuels, engineering "DNA origami" to direct the construction of 3D molecular structures, and modeling nanosprings and nanohinges on resilin protein. These machines will be the foundation for new forms of precise, small-scale manufacturing.



Engineered protein machines from U.S. Department of Energy Genomes to Life Program

Programmable Matter: Morphing materials

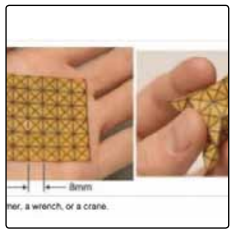
Molecular Engineering: Building from the bottom up

MEMS: Micromachines on the head of a pin

Personal Fabrication: From the factory to the desktop

Signals:

DARPA'S PROGRAMMABLE MATTER PROGRAM (ROOM AT THE BOTTOM)



The Programmable Matter Program at DARPA's Defense Sciences Office is seeking to demonstrate a new form of matter based on mesoscale particles that can reversibly assemble into complex 3D objects on command. DARPA projects are often ambitious, but the massive amount of funding they provide drives remarkable advances in research. The program is investigating nanotechnology, DNA origami, MEMS, and DNA velcro as possible constructors for programmable materials and machines. Their ultimate goal is on-the-spot fabrication of reactive tools and equipment from a smart liquid substrate, either via nanoassemblers or claytronic assemblies.

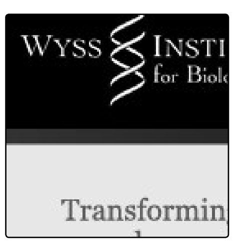
Source: http://www.popsci.com/military-aviation-amp-space/article/2009-06/mightily-morphing-powerful-range-objects

CMU'S CLAYTRONICS PROJECT (MATTER AS CODE)

The School of Computer Sciences at Carnegie Mellon University and Intel Corporation at its Pittsburgh Laboratory have joined together to direct the Claytronics Project, collaborative research in programmable matter. Their goal is "to give tangible, interactive forms to information so that a user's senses will experience digital environments as though they are indistinguishable from reality." Researchers are seeing unexpected progress and hope to achieve miniaturization of functional catom spheres down to mesoscales by 2014. The computational challenges of programming massive assemblies of millions of catoms will be aggressively tackled once compelling early demonstrations of assembly are achieved.

Source: http://www.cs.cmu.edu/~claytronics/index.html

WYSS INSTITUTE FOR BIOLOGICALLY INSPIRED ENGINEERING (THE RISE OF BIOMIMETIC MACHINES)



What molecular manufacturing and nanotechnology struggle toward, nature does as a matter of simplicity. Complex nanosystems will likely be hybrids of synthetic and organic life. Building molecular machines requires a deep understanding of natural systems. Researchers at Harvard University recently founded the Wyss Institute for Biologically Inspired Engineering aim to understand enough about how nature builds, controls, and manufactures to arrive at entirely new engineering principles. These and other researchers are studying biosystems to derive the governing laws and emergent behaviors of complex biology, yielding functional DNA-based constructors and rudimentary 3D nanoscale components.

Source: http://wyss.harvard.edu

What difference does this make?

Though many challenges exist, the realization of programmable matter will change how we think of and interact with the physical world around us. When matter can be programmed to change form, our entire system of exchange will be revolutionized, from production and transportation of goods to the way we communicate with one another.

CONVERGENCE OF MACHINES AND HUMAN BIOLOGY

Wrapping prosthetics, implants, drugs, and microscopic agents in hybridized biosynthetics will confer resistance to rejection and enable high-resolution direct cellular communication and manipulation. Brain-computer interfaces (BCI) will be smaller, more robust, wireless, and capable of precise interface with neural bodies. Nanotechnology, MEMS, pharma, and synthetic biology are converging to construct micromachines and engineered viruses that clear arterial plaque, target and attack cancers, and modify brain function with increasing precision.

RISE OF A MARKETPLACE OF TEMPLATES

In the years ahead, as assemblers become more common, the templates that drive them will command a premium. Template designers will use CAD systems to make instruction sets for machine parts, furnishings, electronics, and anything else that can be produced by assemblers. A new class of workers will arise, as will new challenges in defending existing markets and regulating the production of dangerous and illegal goods.

DISRUPTION OF THE ECONOMICS OF SCARCITY

Sophisticated local fabrication will directly challenge the foundations of economics and erode the system of manufactured scarcity. Desktop nanoassemblers will enable construction of basic necessities, converting waste products into food and clothing. Unreliable global supply chains will be challenged by local just-in-time manufacturing. Specialized toolsets and technologies will arise from regional makers who program sophisticated machines to construct their innovations.

GROWTH OF FEARS OF UNINTENDED CONSEQUENCES

Both the democratization of manufacturing and the construction of autonomous molecular agents present tremendous challenges to the natural world. New drivers for energy consumption, generation of waste products, and unintended consequences of local manufacturing could disrupt ecosystems and destroy towns. Engineering synthetic organisms and self-replicating nanobots will be constrained by fears of runaway matter and the possibility of sudden emergent behaviors. Some may intentionally pursue such apocalyptica.

What to do differently?

Organizations will need to be alert to new developments and opportunities, as well as to think through long-term consequences to avoid negative impacts.

TRACK DEVELOPMENTS IN MATERIAL SCIENCE AND SYNTHETIC BIOLOGY

Watch for increasing use of engineered nanodevices in human medicine, augmentation, and enhancement. Consider how molecular manufacturing could impact your organization over the next ten years. What opportunities are presented by new materials and smart objects? How might cheap desktop fabricators and a template marketplace affect innovation and revenues or impact crime and poverty? Look to opportunities with smart objects, machines, cities, crowds, and bodies.

ALIGN YOUR ORGANIZATION WITH THE EMERGING MARKETPLACE OF LOCAL MANUFACTURING

Work directly with DIY fabrication communities and makers. Identify and engage seats of innovation that overlap with your organization. Encourage and subsidize education in 3D modeling tools. For businesses, consider how your supply chain and market reach could benefit from alliances with local just-in-time makers. Develop scenarios for how nanomaterials and molecular manufacturing can help optimize supply chains and shipping costs.

EMBRACE DEMATERIALIZATION AND THE SHIFT FROM HARD GOODS TO SERVICES AND INTELLECTUAL PROPERTY

Are there opportunities in your organization to convert the manufacturing of hard goods into data services, digital content, or templates sold to local fabricators? Use life cycle analysis to identify expenses across supply chains, looking at shipping costs, energy and materials overhead, and the social and environmental costs passed on to communities. Map the full reach of your organization to enable modeling and optimization.

AVOID UNINTENDED CONSEQUENCES AND SHORTSIGHTED IMPLEMENTATION

Consider how molecular machines and smart matter might impact ecosystems, what effects new resource and energetic requirements may have, and how waste will be managed. Use cradle-to-cradle design principles to inform the development of molecular machines and smart objects, controlling for safe end-of-life decay and recapture. Engineer traceable tags and molecular signatures into emergent nanocomponents to create greater transparency and accountability.

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