Prof. Neil Gershenfeld

Director

http://ng.cba.mit.edu
3D Printing: The Most Disruptive Technology Yet?

3D printing: new mother of invention

Welcome to the 3D printing revolution

3D Printing Revolution Could Re-Shape World

3-D printing is revolutionizing product development

Leading futurologist calls 3D printing a "true revolution"
ABSTRACT
A system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed at a selected surface of a fluid medium capable of altering its physical state in response to appropriate synergistic stimulation by impinging radiation, particle bombardment or chemical reaction, successive adjacent laminae, representing corresponding successive adjacent cross-sections of the object, being automatically formed and integrated together to provide a step-wise laminar buildup of the desired object, whereby a three-dimensional object is formed and drawn from a substantially planar surface of the fluid medium during the forming process.
PAPERS ON AUTOMATIC PROGRAMMING
FOR NUMERICALLY CONTROLLED
MACHINE TOOLS

Douglas T. Ross
6873-TM-3
January 7, 1958

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Approved by: 

Donald F. Clemente

Servomechanisms Laboratory
Department of Electrical Engineering
Massachusetts Institute of Technology
- metrology
- error correction
- functional
- reusable
- discrete set of parts
- discrete relative positions and orientations
- discrete set of parts
- discrete relative positions and orientations
= digital material
Digital materials for digital printing

George A. Popescu (MIT Center for Bits and Atoms), Thushar Mahale (North Carolina State University), Neil Gershenfeld (MIT Center for Bits and Atoms).

Abstract

Conventional three-dimensional printing processes are material-dependent, and are irreversible. We present an alternative approach based on three-dimensional assembly of mass-produced two-dimensional components of digital materials. This significantly enhances the available material set, allows reversible disassembly, and improves constraints that reduce the accommodation of local positioning errors in constructing a global shape. Experimental work on material properties and dimensional scaling of the digital material will be presented, with applications to assembling functional structures. We propose that assembling digital material will be the future of 3-dimensional free-form fabrication of functional materials.

Most existing commercial free-form fabrication printers build by putting together small quantities of no more than a few expensive materials. In order to make high-resolution objects they need to be very precise and therefore cost tens and hundreds of thousands of dollars and are operated by skilled technicians. On the other hand, children build 3-dimensional structures out of LEGO with their hands. LEGO structures are cheap, quick and easy to make. We envision a new type of material that is more precise and more important than the LEGO bricks they build them. However, they are big and are only made out of ABS plastic. We believe that digital materials bring reversibility, simplicity, low cost and speed to free-form fabrication in addition to a larger material set.

Previous research has focused on structures built out of many discrete parts involved self-assemble [1], and error correction of self-assembly [2]. In this paper, we present a new approach to assembling functional structures. We define a digital material as a discrete set of components of any size and shape, made out of various materials and can be assembled in various ways (press fit, friction fit, snap fit, reorienting, etc.). However, the components of a digital material must satisfy the following properties which are familiar to many everyday objects:

1. All components can be decomposed into smaller elementary geometric shapes.
2. Two components can form a finite number of links.
3. The links between two components are reversible.

Figure 2: GIK structures of different sizes & shapes: (a) 1000 GIK bricks (b) 10 mm (c) 1 mm (d) 0.1 mm (e) 0.01 mm (f) 0.001 mm. You can see the mm on and mm scale structures side by side in (g). The pm structure is on a log scale for scale purposes.

Figure 3: GIK parts made of different materials: plastic, metal, metal, and metal. GIK bricks can be seen in Fig. 1, 2, 3, and 4. They can be pressed fit together to form space filling voxels that can be connected and disconnected at will making the construction reversible. In addition, as seen in Fig. 3 they can be made out of a variety of materials. Below eye resolution GIK parts (50µm and smaller) will have macro-scale behavior but will form high resolution objects which will vary continuously. GIK building blocks can be compared to an atom that assembles to form a GIK.

GIK, initially Grace's Invention Kit, was developed by her inventor Gershenfeld, because the Great Invention Kit after Eli Gershenfeld contributed, that simply GIK.

GIK, initially Grace's Invention Kit, was developed by her inventor Gershenfeld, because the Great Invention Kit after Eli Gershenfeld contributed, that simply GIK.

Figure 4: vertical GIK bricks forming an incomplete 3 layer vertical GIK structure. One can notice the 90 degree rotation between layers for bonding.

Figure 5: GIK bricks forming an incomplete 3 layer vertical GIK structure. One can notice the 90 degree rotation between layers for bonding.
ON THE DECREASE OF ENTROPY IN A THERMODYNAMIC SYSTEM
BY THE INTERVENTION OF INTELLIGENT BEINGS

LEO SZILARD

Translated by Anatol Rapoport and Mechthilde Knoller from the original article "Über die Entropievermindering in einem thermodynamischen System bei Eingriffen intelligenter Wesen." Zeitschrift für Physik, 1989, 63, 840-856.

The objective of the investigation is to find the conditions which apparently allow the construction of a perpetual-motion machine of the second kind, if one permits an intelligent being to intervene in a thermodynamic system. When such beings make measurements, they make the system behave in a manner distinctly different from the way a mechanical system behaves when left to itself. We show that it is a sort of a memory faculty, manifested by a system where measurements occur, that might cause a permanent decrease of entropy and thus a violation of the Second Law of Thermodynamics, were it not for the fact that the measurements themselves are necessarily accompanied by a production of entropy. At entropy in connection with the measurement, therefore, need not be greater than Equation (1) requires.

There is an objection, already historical, against the universal validity of the Second Law of Thermodynamics, which indeed looks rather ominous. The objection is embodied in the notion of Maxwell's demon, who in a different form appears even now days again and again; perhaps not unreasonably, inasmuch as behind the precisely formulated question quantitative connections seem to be hidden which to date have not been clarified. The objection in its original formulation concerns a demon who catches the fast molecules and lets the slow
A SYMBOLIC ANALYSIS
OF
RELAY AND SWITCHING CIRCUITS

by

Claude Elwood Shannon
B.S., University of Michigan
1936

Submitted in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
from the
Massachusetts Institute of Technology
1940

THE
MATHEMATICAL
THEORY OF
COMMUNICATION

CLAUDE E. SHANNON
WARREN WEAVER
Lectures on
PROBABILISTIC LOGICS AND THE SYNTHESIS OF RELIABLE
ORGANISMS FROM UNRELIABLE COMPONENTS

delivered by

PROFESSOR J. von NEUMANN
The Institute for Advanced Study
Princeton, N. J.

at the

CALIFORNIA INSTITUTE OF TECHNOLOGY
January 4-15, 1952

Notes by
R. S. PIERCE
Threshold Theorems

\[3(3\varepsilon^2)^2 = \frac{1}{3} (3\varepsilon)^4\]

\[3^n\]

\[\frac{1}{3} (3\varepsilon)^{2n}\]
Thresholds

1940s: Communications (Shannon)
Thresholds

1940s: Communications
   (Shannon)

1950s: Computation
   (Winograd, von Neumann)
Thresholds

1940s: Communications (Shannon)

1950s: Computation (Winograd, von Neumann)

2000s: Fabrication
Digital Revolutions

analog → digital communication
~1945

analog → digital computation
~1955

analog → digital fabrication
~2005
A hierarchical model for evolution of 23S ribosomal RNA

Konstantin Bokov & Sergey V. Steinberg

The emergence of the ribosome constituted a pivotal step in the evolution of life. This event happened nearly four billion years ago, and any traces of early stages of ribosome evolution are generally thought to have completely eroded away. Surprisingly, a detailed analysis of the structure of the modern ribosome reveals a concerted and modular scheme of its early evolution.
1.0: computers → machines

2.0: machines → machines

3.0: codes → materials

4.0: programs → materials
An easy to use, affordable, computer controlled mill. Take all your DIY projects further with custom circuits and precision machining.

At Otherfab, we are interested in portable, accessible, computer-controlled machines, and how they can help us design our world. With the ability to make custom circuitry, we can now build our own smart objects - medicine bottles that email reminders, shoes that tell you how fast you went, and even glasses that know when you need to put on sunscreen. The Othermill is our contribution to custom circuit design and the desktop manufacturing revolution.

FORM 1: An affordable, high-resolution 3D printer for professional creators.

Thanks for an amazing Kickstarter campaign! The next chapter of 3D printing is just beginning.

Pre-order your Form 1 at Formlabs.com
Design and analysis of digital materials for physical 3D voxel printing

Jonathan Hiller and Hod Lipson
Cornell Computational Synthesis Lab, Cornell University, Ithaca, New York, USA

Figure 1 The principle of a digital manufacturing process, using spherical voxels

Figure 4 Sparse digital matter (GIKS)

Source: Popescu et al. (2006b)
Ultra-Light Materials Modulus Scaling with Density

- uni-directional aligned CFRP solid
- directional aligned CFRP cuboct digital composite
- quasi-isotropic CFRP solid
- quasi-isotropic CFRP cuboct digital composite
- acrylic solid
- acrylic cuboct lattice
- NiP micro-lattice (17)
- graphene cork (19)
- silica aerogel composite (14)

modulus $E$ (GPa)

density $\rho$ (g/cm$^3$)
prestress in top plane of wing

pitch actuation

roll actuation with torque tube

high speed actuation of roll torque tube
Hierarchical Fabrication by Coded Folding

DNA/Peptide Synthesis

EVEN

Stock of right and left turning polyhedra that stick only to polyhedra of opposite parity

ODD

OR

Flood with next type, depending on parity

Washable Substrate with nano-wire posts

Rinse and Repeat

X10 Stock from Folded Nanostructures
Complex shapes self-assembled from single-stranded DNA tiles

Bryan Wei1,2, Mingjie Dai1,2 & Peng Yin1,2

Figure 1 | Self-assembly of molecular shapes using single-stranded tiles. a. The canonical SST motif, adapted from ref. 12. b. Design of an SST rectangle structure: left and middle, two different views of the same secondary structure diagram. Each standard tile has 42 bases (labelled U), and each top and bottom boundary (half) tile has 21 bases (labelled L). Right, a simplified brick-wall diagram. Standard tiles are depicted as thick rectangles; boundary tiles are depicted as thin rectangles and the unstructured single-stranded portions of the boundary tiles are depicted as rounded corners. Each strand has a unique sequence. Colours distinguish domains in the left panel and distinguish strands in the middle and right panels. c. Selecting an appropriate subset of SST species from the common pool in b makes it possible to design a desired target shape, for example a triangle (left) or a rectangular ring (right). d. Design of a tube with prescribed width and length. e. Arbitrary shapes can be designed by selecting an appropriate set of monomers from a pre-synthesised pool that corresponds to a molecular canvas (top right). To make a shape, the SST strands corresponding to its constituent pixels (dark blue) will be included in the strand mixture and the remainder (light blue) will be excluded.

Figure 4 | Complex shapes designed using a molecular canvas. AFM images of 100 distinct shapes, including the 26 capital letters of the Latin alphabet, 10 Arabic numerals, 23 punctuation marks and other standard keyboard symbols, 10 emoticons, 9 astrological symbols, 6 Chinese characters and various miscellaneous symbols. Each image is 150 nm × 150 nm in size.
Bricks

(Charles Fracchia)
Assembly process

Pre-Neutered Bricks

Live Reversability

1. Attach anchoring elements to flow cell surface
2. Wash with first brick and allow linking
3. Add deprotecting clips for the specific site
4. Neuter the uncapped positions with clips that have no peel-off overhangs
5. Flow next brick and allow linking
6. Repeat steps 4-6 to grow geometry
MIT Reveals Wondrous Modular Robots Inspired By Proteins

AN INCREDIBLE RESEARCH PROTOTYPE MAY CHANGE THE WAY ALL OBJECTS ARE BUILT AND WORK IN THE FUTURE.

The computer—or more accurately, the Turing Machine—changed the world with a groundbreaking idea: Any piece of information could be coded in 0s and 1s. And so theoretically, any question could be answered by sorting these numbers through an automated process. Even today, in the era of microprocessors and 4G Internet, it's a rendition of these 0s and 1s that apply Instagram filters, power Google's predictive search, or render headshots in Call of Duty.

Working under a grant from DARPA, Neil Gershenfeld, head of MIT's Center for Bits and Atoms, along with graduate students Ara Finman and Kenneth Cheung, have flipped this idea on its head. Rather than turning real ideas into binary code, they're turning binary code into real ideas.

The Milli-Motein: A Self-Folding Chain of Programmable Matter with a One Centimeter Module Pitch

Ara N. Knaian, Kenneth C. Cheung, Maxim B. Lobovskiy, Ava J. Olesen, Peter Schrick-Nelson, and Neil A. Gershenfeld

Abstract—The Milli-Motein (Millimeter-Scale Motile protein) is a chiral, programmable matter that can fold itself into digitized approximations of arbitrary three-dimensional shapes. The small size of the 3D Milli-Motein segments is enabled by the use of our new electroporation wisdom stepper motor, described in this paper, and by a highly integrated electronic and mechanical design. The chain is an interlocked series of contractile motor units and servos, wrapped with a continuous flex circuit to provide communications, control, and power transmission capabilities. The Milli-Motein can off-theshelf electronic components and actuators, and custom parts fabricated by conventional and electro-discharge machining, assembled with screws, glue, and solder using tweezers under a microscope. We perform shape reconfiguration experiments using a four-segment Milli-Motein. It can switch these two straight lines in a 1-second span, consuming 2W power during reconfiguration. It can hold its shape indefinitely without power. During reconfiguration, a segment can lift the weight of one but not two segments as a horizontal cantilever.

I. INTRODUCTION

Programmable matter is a universal object or material which is able to change its shape or other physical properties on command. In the quest to realize programmable matter in the lab, much recent effort has focused on the development and miniaturization of electromechanical systems for controlled shape reconfiguration [8]. These systems operate on principles as diverse as hydrodynamic attraction of elastic strings using controlled flows [11], flexible circuitry able to self-fold itself into origami using embedded SMA wires [6], magnetic actuators to selfassemble rosettes on a lattice [14], and cylinders able to active roll over one another using electrostatic forces [16].

Programmable Assembly With Universally Foldable Strings (Moteins)

Kenneth C. Cheung, Erik D. Demaine, Jonathan R. Ratcliff, and Sam Griffin

Abstract—Understanding how linear strings fold into 2D and 3D shapes has been a long-sought goal in many fields of both academic and industry. This paper presents a technique to design self-assembling and self-reconstituting systems that are composed of strings of very simple robotic modules. We know that physical strings that are composed of the smallest set of discrete polygonal or spiral modules need to be programmatically generate a cylindrical region or volumetric shapes. These modules have one two degrees of freedom (DOFs) and simple actuation with only two or three states. We describe a subdivision algorithm to produce universal polygonal and polyhedral string folding schemes, and we prove the existence of a continuous motion to reach any such folding. This technique is validated with dynamic simulations as well as experiments with chains of modules that pack on a regular cubic lattice. We call robotic programmable universals foldable strings "Moteins" as a potential prototye.

Index Terms—Biologically inspired robots, cellular and modular robots, folding robots, kinematics, micro/nano robotics.

we show the ability of these systems to geometrically achieve the proposed results through continuous motion without self-intersections. While the examples that are provided show essentially orthogonal folding patterns, the concepts and algorithms are extensible to non-Euclidean lattices and space-time lattices through different simulations as well as experiments with chains of modules that pack on a regular cubic lattice. We call robotic programmable universals foldable strings "Moteins" as a potential prototye.
The Science of Digital Fabrication
March 7, 2013
MIT

8:00-9:00 Registration (E14-638)

9:00-10:30 Briefings: Materials and Mechanisms (E14-674)
   Introduction: Neil Gershenfeld
   History: Saul Griffith
   Fabricational Complexity: Joe Jacobson
   Digital Materials: Kenny Cheung
   Self-Assembly: Ned Seeman
   Nano-assembly: Peng Yin
   Micro-assembly: Will Langford
   Meso-assembly: Hod Lipson
   Macro-assembly: Skylar Tibbits
   Mega-assembly: Larry Sass

10:30-11:00 Break (E14-638)

11:00-12:30 Briefings: Processes and Workflows (E14-674)
   Simulation and Optimization: Wojciech Matusik
   3D Scanning: Philip Withers
   Design Representations and Interfaces: Matthew Keeler
   Path Planning: Sanjay Sarma
   Motion Control: Nadya Peek
   Printing: Jennifer Lewis
   Folding: Erik Demaine
   Programmable Matter: Daniela Rus
   Little Data: George Church
   Self-Reproducing Systems: John Glass

2:00-3:30 Briefings: Policy and Programs (E14-674)
   OSTP: Philip Rubin (video)
   NIST: John Slotwinski
   DARPA: Paul Eremenko
   NSF: Richard Vories
   NASA: LaNatra Tate
   DOE: Kelly Visconti
   DHS: Jose Vazquez
   Make: Dale Dougherty
   MacArthur Foundation: Connie Yowell
   Barcelona: Vicente Guallart
   Rep. Bill Foster

3:30-4:15 Working Groups (E14-638)
   Policy, Programs: Tom Kalil (video)
   Standards, Formats: Hod Lipson
   Facilities, Infrastructure: Jim Newton
   Communication, Publication: Joe Jacobson
   Education, Outreach: Sherry Lassiter

4:30-5:00 Discussion (E14-674)

5:00-6:30 Reception: Exhibition (E14-638,648)

6:30-8:00 Goldstein Lecture (10-250)
   The Design of Robotic Fabricated Architecture: Matthias Kohler

12:30-2:00 Lunch: Demonstrations (E14-638,648)