From Folding to to Programmable Matter

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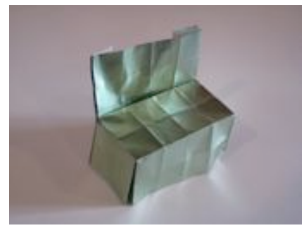
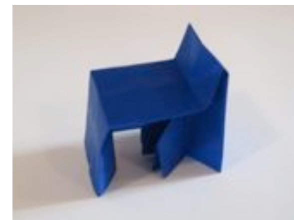
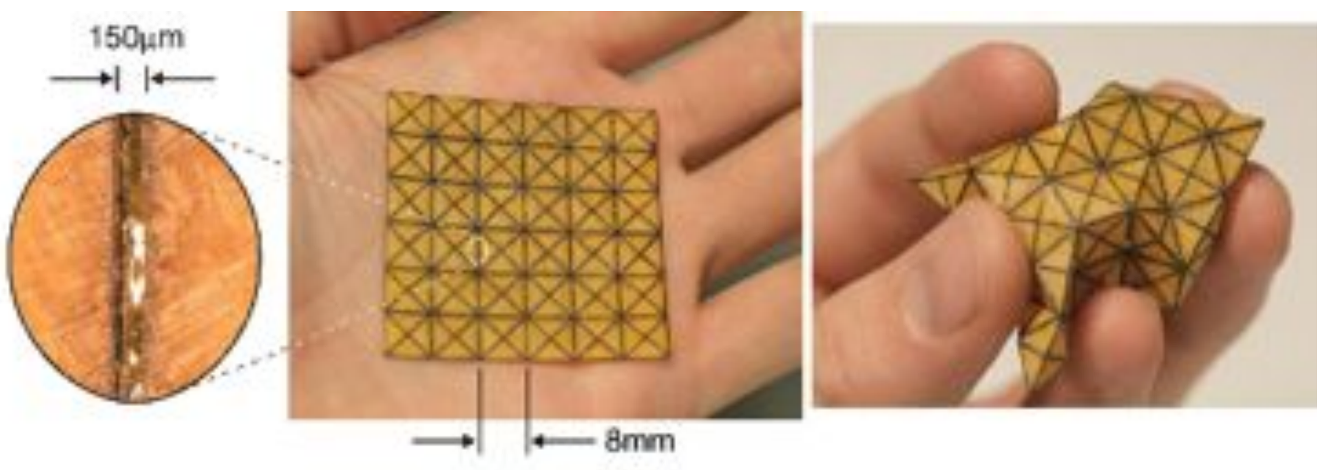
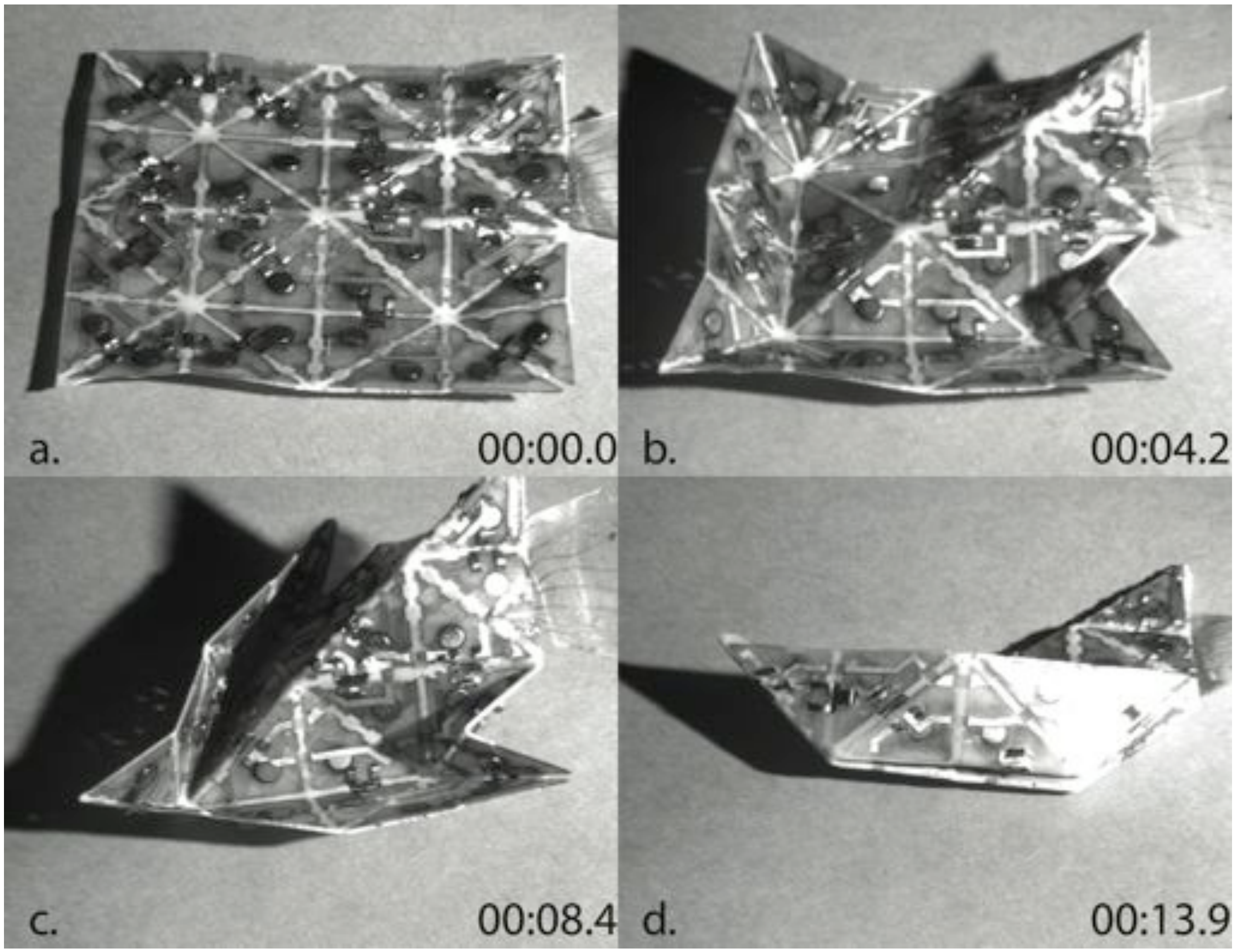
Convergence of Materials and Machines:



Making and Folding Smart Sheets

Smart Sheet (with R. Wood, E. Demaine)



Programmable Matter Challenges:

- Programming Shape
  - 3D Printing
  - Visualization
  - 3D Maps
  - Non-invasive procedures
  - Construction (e.g. ladder->tent)
  - On-demand tools
  - Self-Repair
  - Security: mechanical RSA
  - Paper-computer
  - Advanced Survival kit
- Going beyond shape: programming material's properties:
  - Mechanical
  - Optical
  - Acoustic
  - Electromagnetic
  - Thermal
  - Electrical properties
  - Chemical properties

Programmable Matter Questions

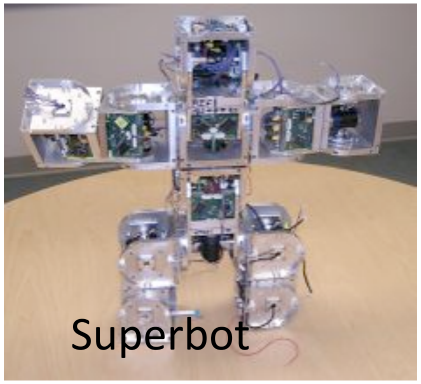
- What are the properties of matter than can be programmed?
- What is achieved by the body and what is achieved by computation?
- Is there a hierarchy of canonical problems in the space of Programmable Matter?
- What are the trade-offs between different sources of information in Programmable Matter?
- What is doable with Programmable Matter?
- What can Materials do for Information, Computation and Action?
- What can Information/Computation/Action do for Materials?

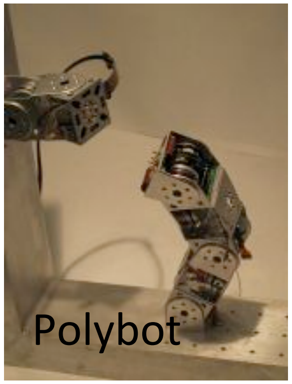
Robot Platform History

system	class	DOF	author	affiliation	year
CEBOT	mobile	various	Fukuda et al.	Nagoya	1988
Polypod	chain	2 3D	Yim	Stanford	1993
Metamorphic	lattice	3 2D	Chirikjian	JHU	1993
Fracta	lattice	3 2D	Murata	MEL	1994
Tetrobot	chain	1 3D	Hamlin et al.	RPI	1996
3D Fracta	lattice	6 3D	Murata et al.	MEL	1998
Molecule	lattice	4 3D	Kotay & Rus	Dartmouth	1998
CONRO	chain	2 3D	Will & Shen	USC/ISI	1998
PolyBot	chain	1 3D	Yim et.al	PARC	1998
TeleCube	lattice	6 3D	Suh et.al	PARC	1998
Vertical	lattice	2D	Hosakawa et al.	Riken	1998
Crystal	lattice	4 2D	Vona & Rus	Dartmouth	1999
I-Cube	lattice	3D	Unsal	CMU	1999
Pneumatic	lattice	2D	Inoue et.al.	TiTech	2002
Uni Rover	mobile	2 2D	Hirose et al.	TiTech	2002
MTRAN II	hybrid	2 3D	Murata et al.	AIST	2002
Atron	lattice	1 3D	Stoy et al.	U.S Denmark	2003
Swarm-bot	mobile	3 2D	Mondada et al.	EPFL	2003
Stochastic 2D	stochastic	0 2D	White et al.	Cornell U.	2004
Superbot	hybrid	3 3D	Shen et al.	USC/ISI	2005
Stochastic 3D	stochastic	0 3D	White et al.	Cornell U.	2005
Catom	lattice	0 2D	Goldstein et al.	CMU	2005
Prog. parts	stochastic	0 2D	Klavins	U. Washington	2005
Molecube	chain	1 3D	Zykov et al.	Cornell U.	2005
YaMoR	chain	1 2D	Ijspeert et al.	EPFL	2005
Miche	lattice	0 3D	Rus et al.	MIT	2006

[IRAM 2007]


Molecube


Superbot


Polybot


Miche


Prog parts

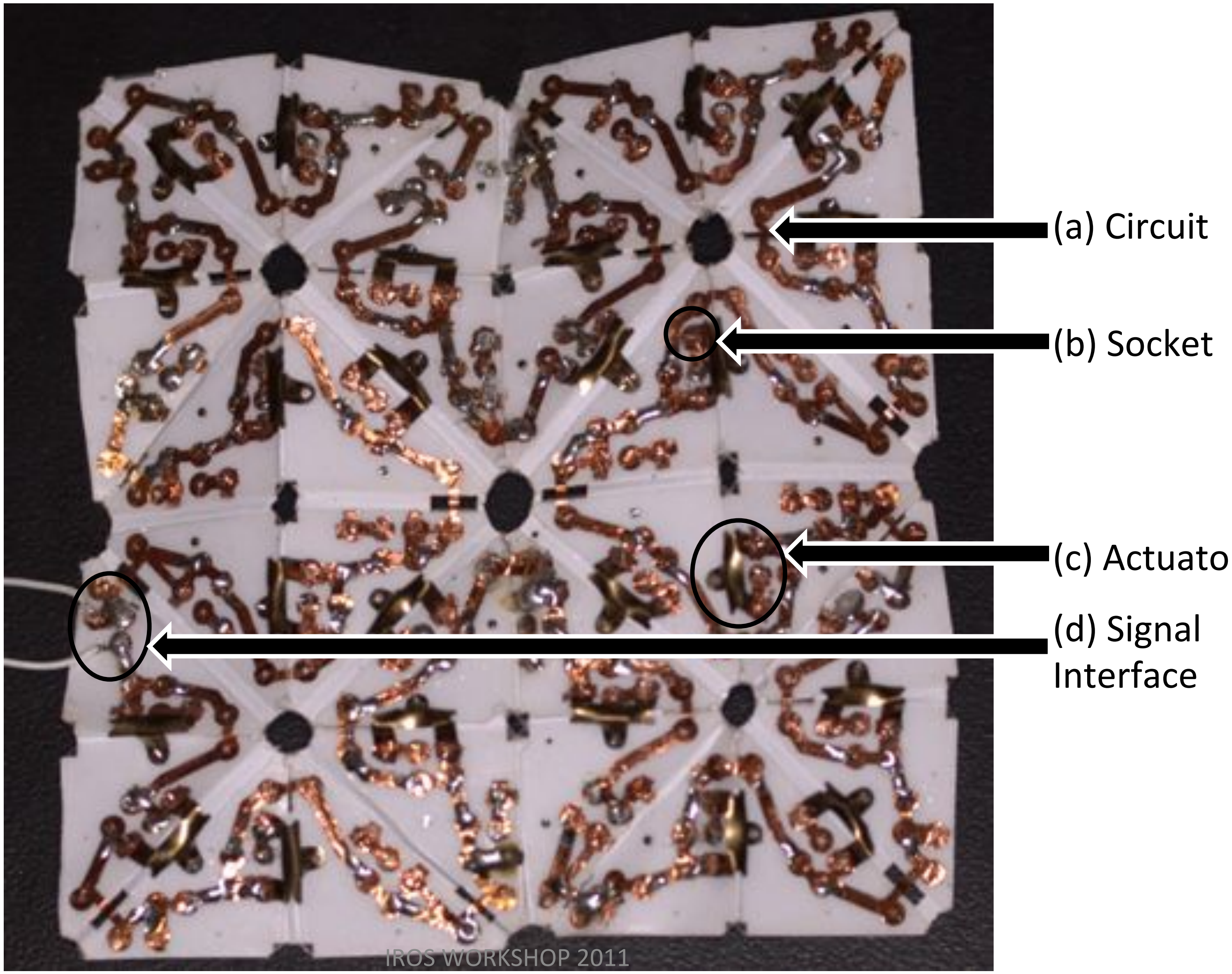
Achievements: Hardware

Task	Robot	Author	Quant.	Units
Largest systems	Polybot Miche	Yim et al Rus et al	56 30	modules modules together
Smallest modules	Miniature Scratchdrive	Yoshida et al Donald, Rus et al	40x40x50 80x20x5	mm microns, global control selective actuation
Longest distance	Superbot	Shen et al	750	meters
Most robust	MTRAN II Miche	Murata et al Rus et al	14 90%	Attach/detach sequence Overall success

Achievements: Algorithmic

Task	Software	Author	Quant.	Units
generic planner	CA planner	Rus et al	3 types Any type	hardware LT & Transitions
Tightest bounds Surface	N/A	Chirikjian et al		
Volume Travel	PAC planning	Rus & Vona	O(1)	General reposition 1 mod
Largest Simulatio n	Million module march	Butler & Fitch	2.2 mil	Modules Real-time

Completed 4x4 Sheet with Supporting Electronics for Actuators and Stickers



Experiment with 8x8 Sheet Folding Hat Shape

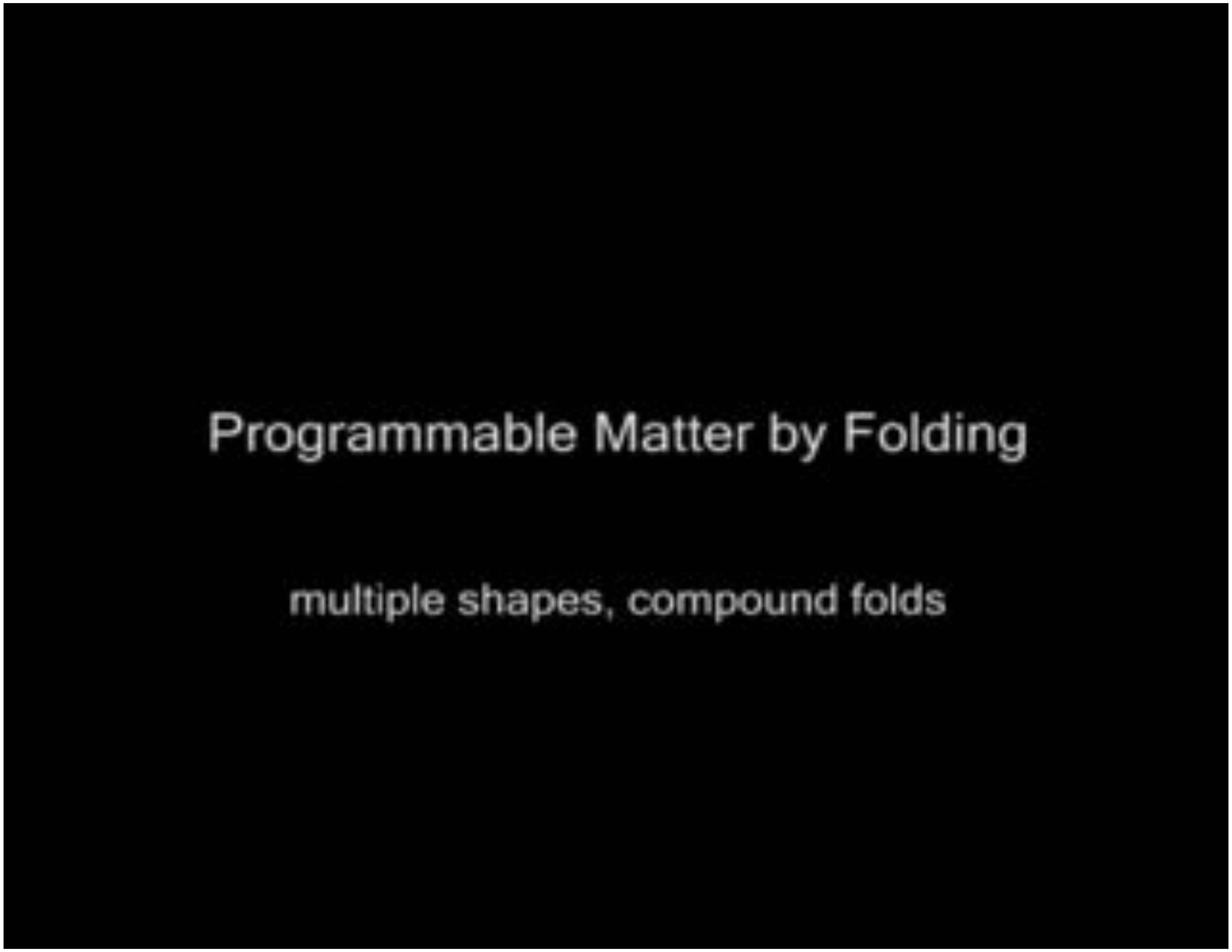
00:00

00:01

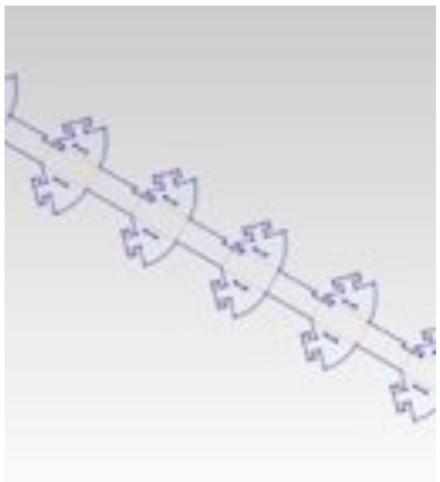
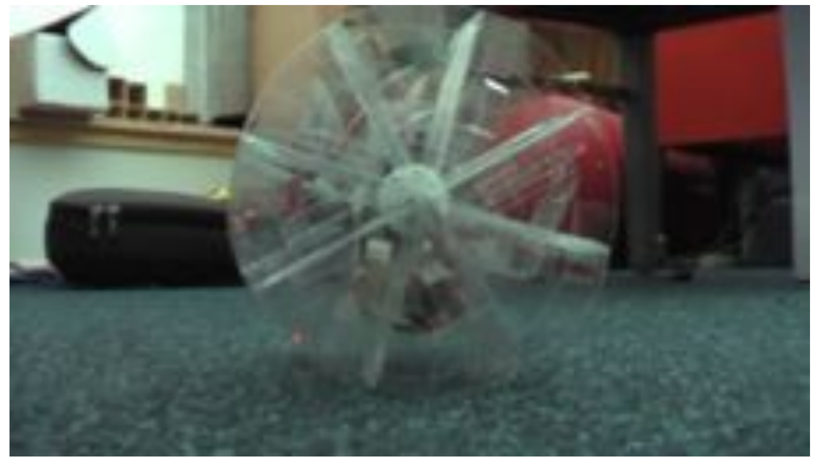
00:02

00:03

Boat and Plane (with Rob Wood's group)



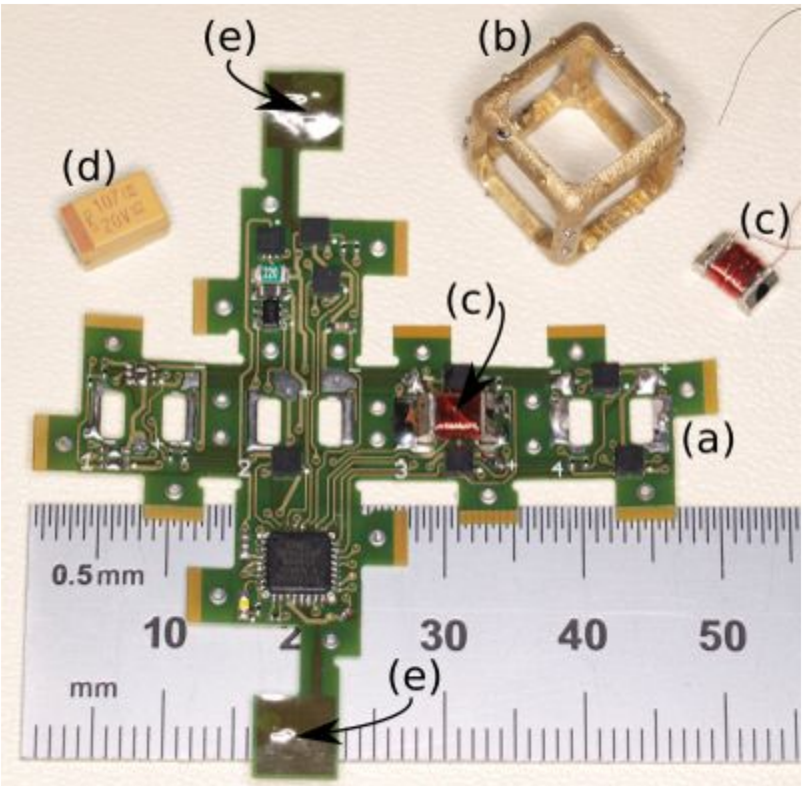
Smart Paper: Origami Robots

Smart Paper: MIT-SEG Robot: winner, AFRON $10 robot competition

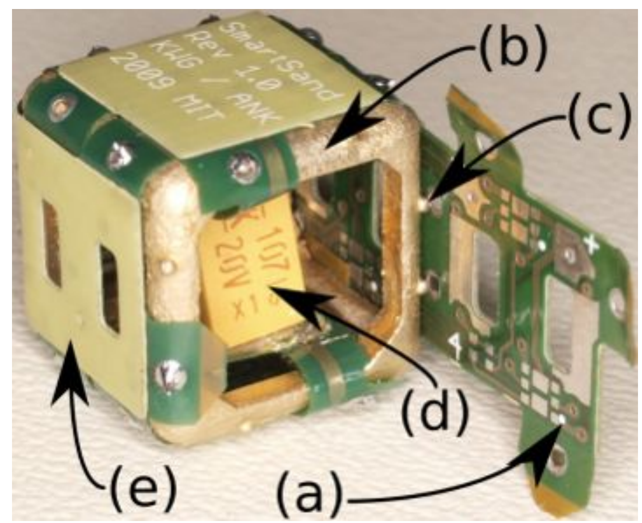
Another Approach: Smart Sand

Smart Pebbles Hardware



Assembly time: 2+ hours per module

- 12mm, 4g cube with 4 active faces
- Rigid/flex with 7/7mil spacing, 15mil vias
- Investment casted brass frame
- Electropermanent (EP) magnets:
  - Latching
  - Communication
  - DC Power transfer
- 150uF 20V capacitor, *no battery*
- ATMega328 processor (32K Flash, 2-wire debug)
- 2x2 dual MOSFET packages



Duplication

Smart Sand


Digital Fabrication by
Shape Duplication
Kyle Gilpin & Daniela Rus
MIT CSAIL

Conclusions

- Programmable Matter requires simultaneous innovation in bodies and computation
- Many material properties can be programmed
- Convergence in modular robotics and materials now
- Computation for interaction with the physical world requires a new type of computation theory
- Many challenges left on the way to programmable matter

- Time for a new survey article!