Claytronics, Synthetic Reality, And Robotics

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8/30/04
Robotics IC

www.cs.cmu.edu/~claytronics

Joint work with Sitti, Hoburg, Lee, Aldrich, Seshan, Pfenning, Veloso, Sukthankar, Baker, Kirby, Rister, Reshko, Bowers

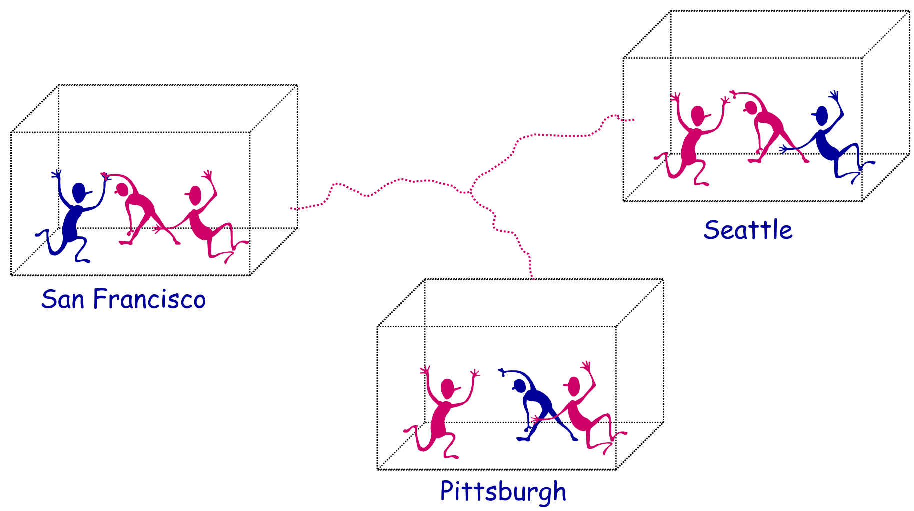
audio

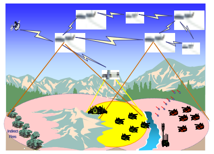
video

pario

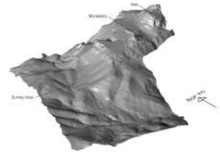
Latin: *to bear, bring forth, produce; create, make, get*

Telepario





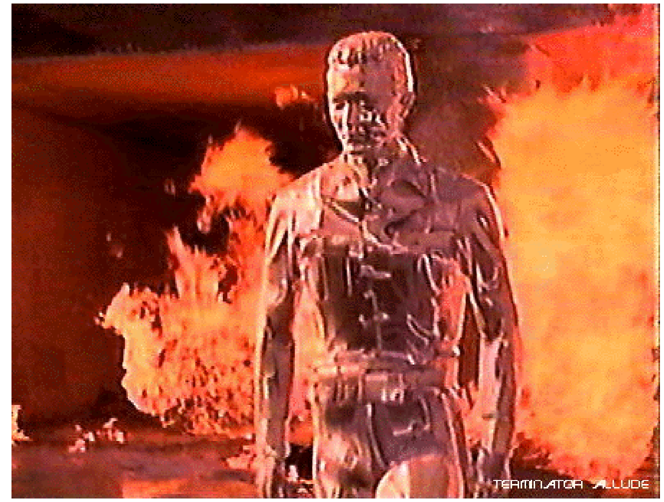
pariomodeling



parioconferencing

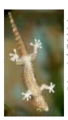
pariopresence

Science fiction?



Science fiction?

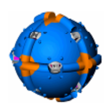
Fearing/UCB



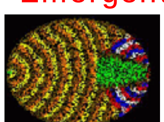
Sitti/CMU

MEMS/Nanotech

Sensor Nets



Amorphous Computing/ Emergent Behavior



Amorphous Computing/MIT

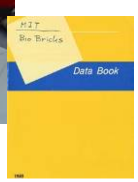
Modular Robots

Yim/Parc

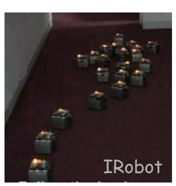
Materials

Flynn

Flynn/SRI

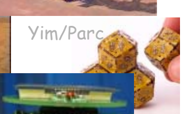


Multi-Robot Teams



IRobot

Rabinett&BBC



Veloso/CMU

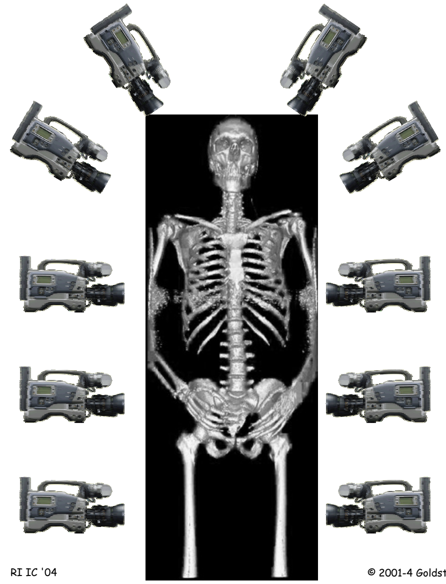
Programmable matter

- An ensemble of material that contains sufficient
  - local computation
  - actuation
  - storage
  - energy
  - sensing & communication
- Which can be programmed to form interesting dynamic shapes and configurations.

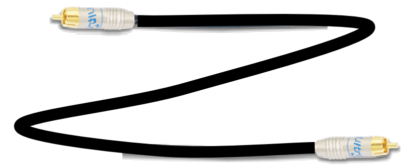
Claytronics

- Bring matter under computer control i.e., programmable matter
- Path to the future
  - 1 micron cubed catom
  - Creation of useful artifacts
- Create a enticing system that explores ALL the computer science issues of programmable matter
- Basis for Synthetic Reality/Future Robots

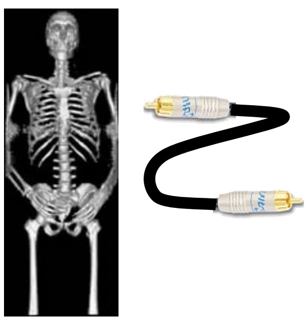
Synthetic Reality - Capture

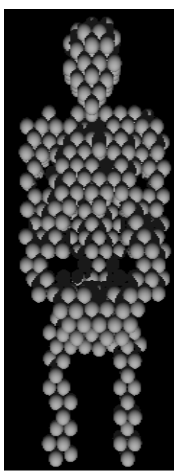


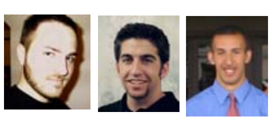
1. Capture 3D Object
2. Encode 3D model
3. Transmit data



Synthetic Reality - Reproduce



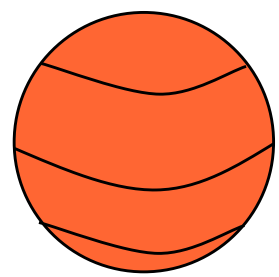




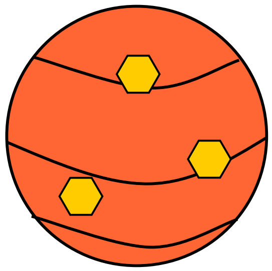
3-5 years

5+ years

A Claytronic Atom: Catom



A Claytronic Atom: Catom



The outside is studded with contacts

A Claytronic Atom: Catom

The outside is coated with organic LEDs

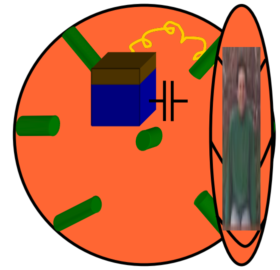
- Low power
- Conforms to shape

Inside the Catom

Inside the Catom

Inside the Catom

Inside the Catom



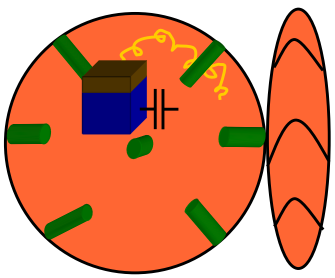
Inside the Catom

Communication

Antenna

SuperCap

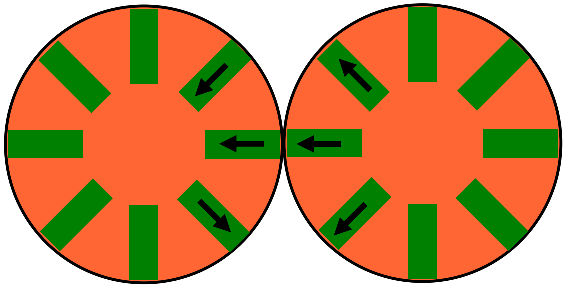
Computer



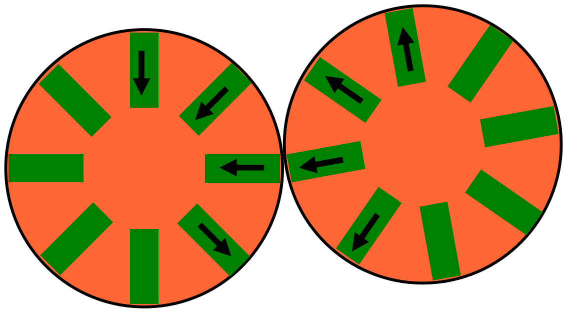
Programmable Magnets

We can buy these today!

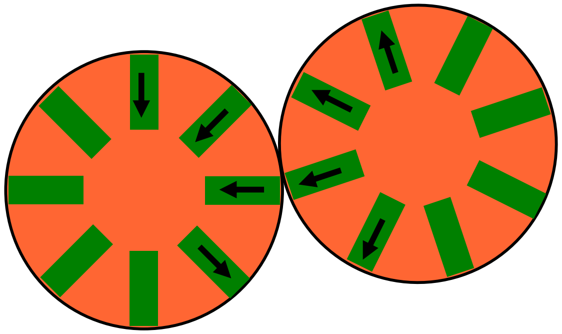
Moving the Catom



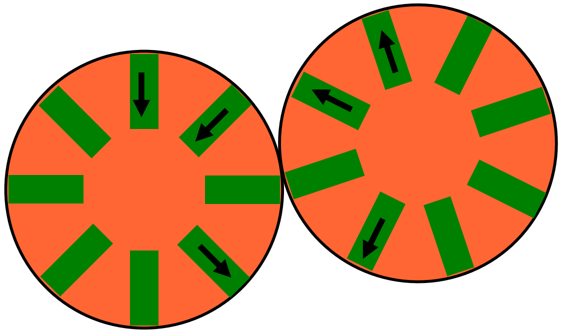
Moving the Catom



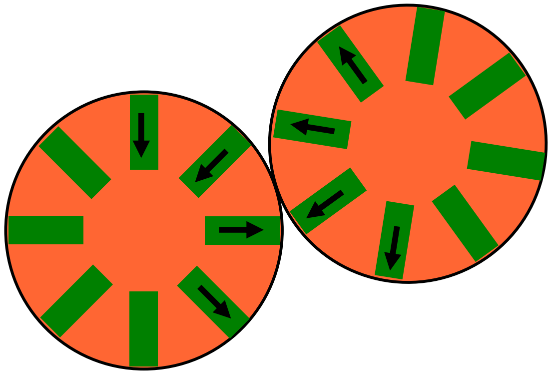
Moving the Catom



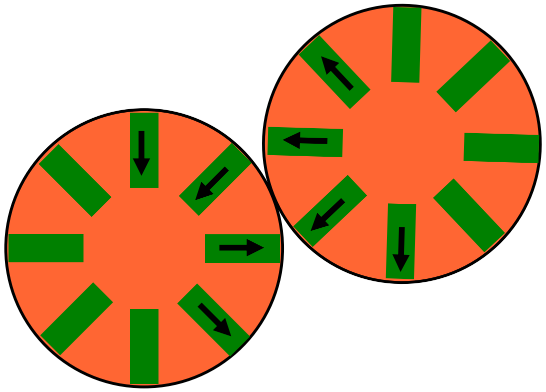
Moving the Catom



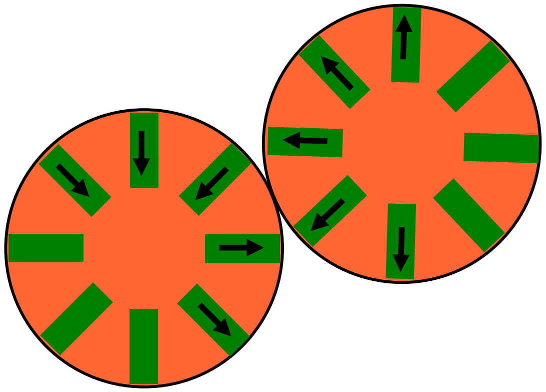
Moving the Catom



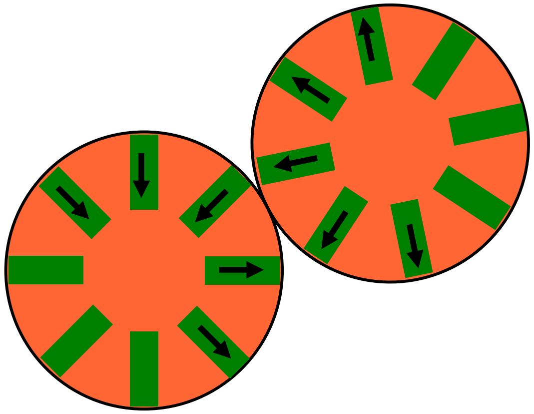
Moving the Catom



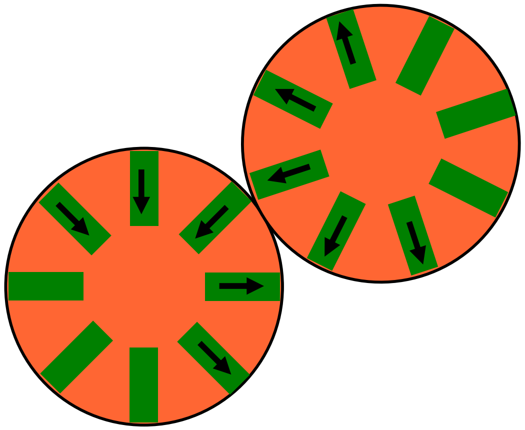
Moving the Catom



Moving the Catom

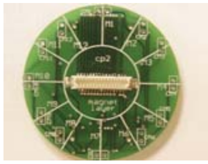


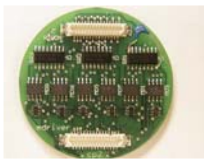
Moving the Catom



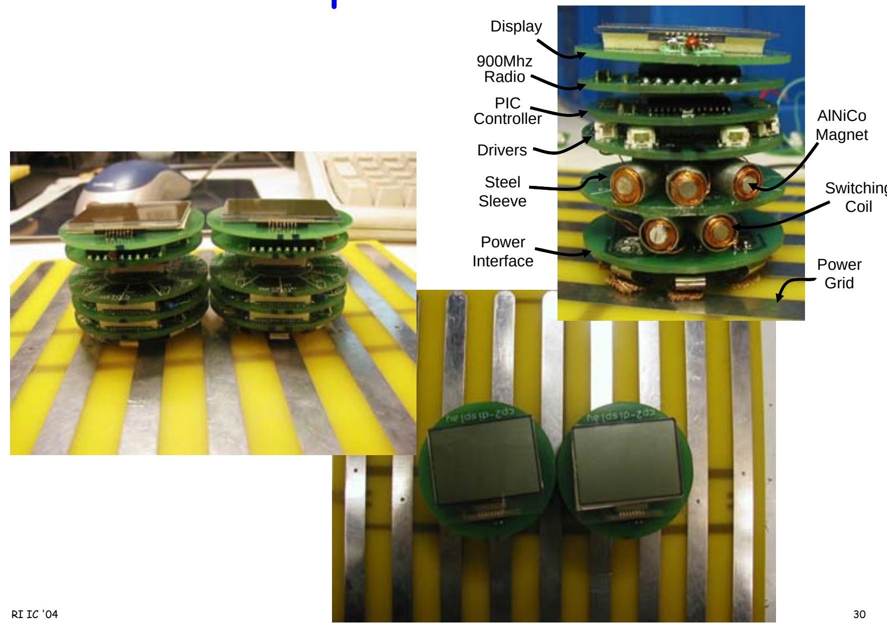
Claytronics Today

- 2D system
- Modular design

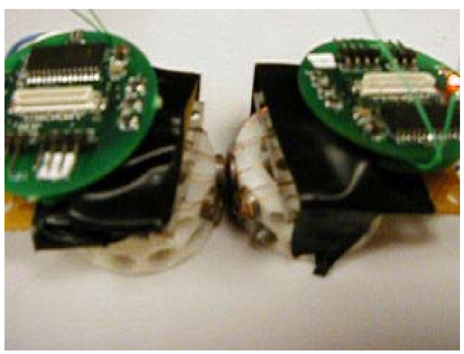




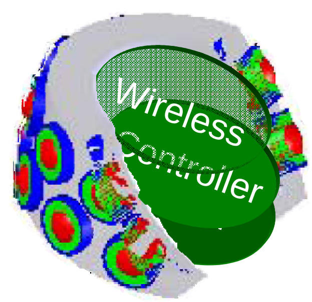
Complete Catoms

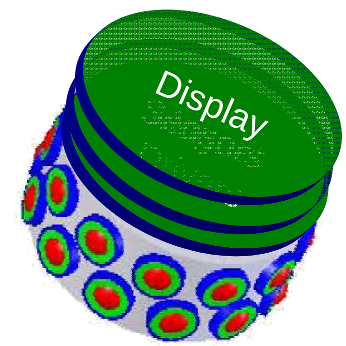


Magnets For Locomotion



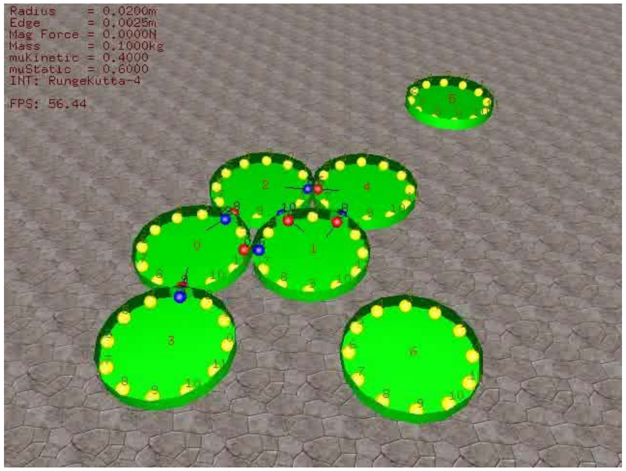
Next Generation 2D catom



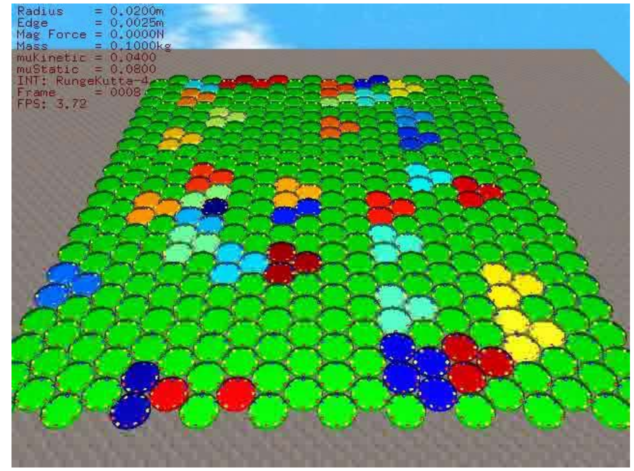


ETA: November 15, 2004

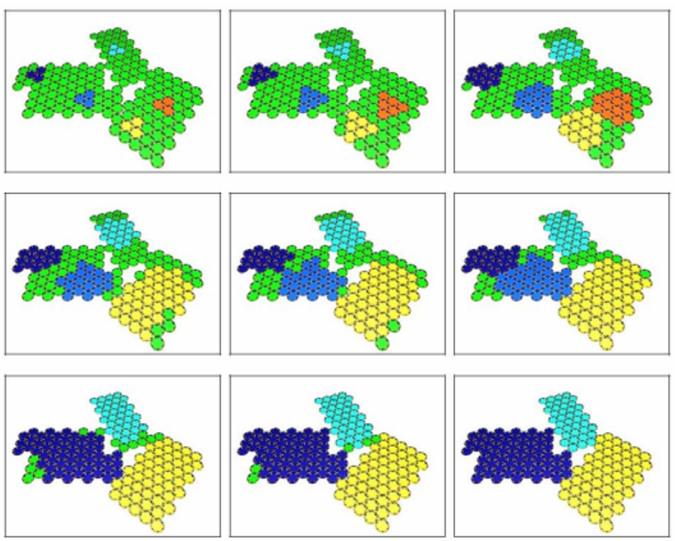
First Step, Find and localize



Distributed Localization

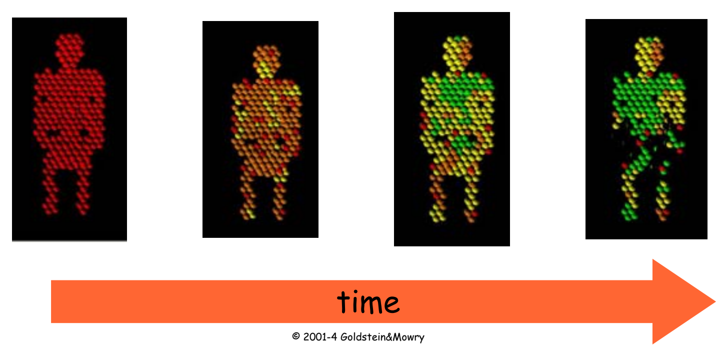


Handling Grain Boundaries

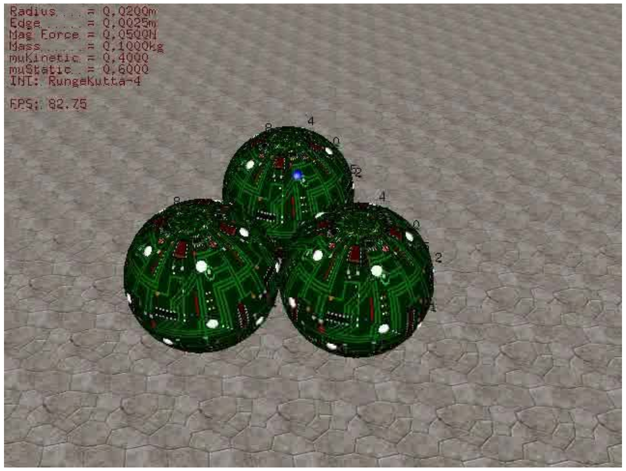


Next Step, Create Network

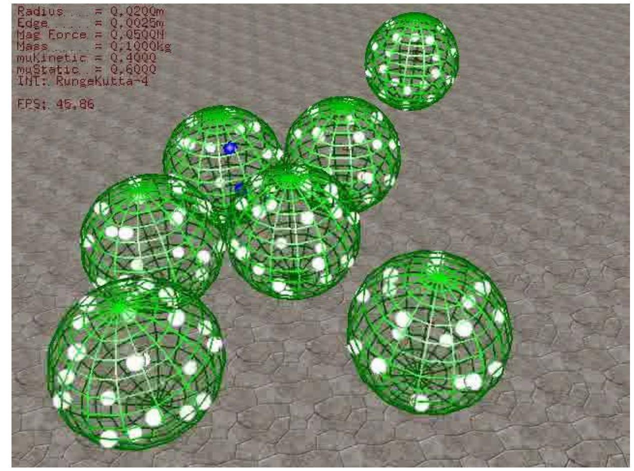
- Use simple local rules to form hierarchy
- 10 line program does this!
- Local only decisions → Global effect

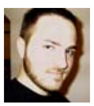


Simulation of Future Catoms

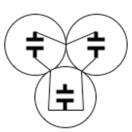


And Localization



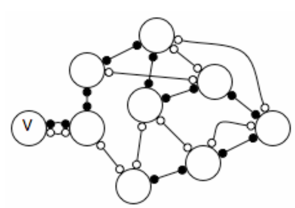


Multiple Networks



Unlike current systems, we can only create a single electrical contact between devices, so cooperation is needed to form circuits

An external source provides V_{dd} and ground lines, and separate pathways are formed through the object to power each catom

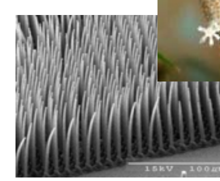


We have developed an algorithm that keeps basic static shapes powered.

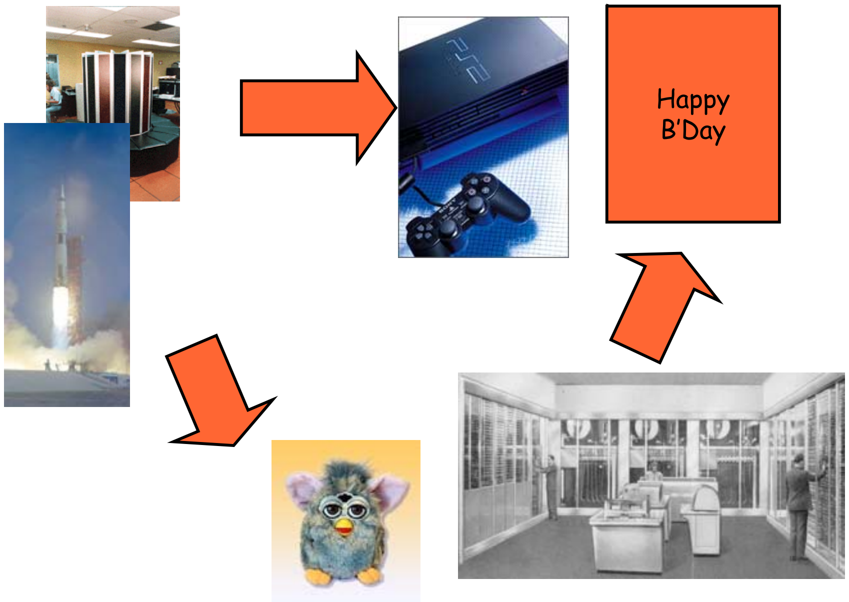
Future work includes leveraging the hierarchy and powering dynamic structures.

Getting There From Here

- Goal: Robust ensemble of millions of catoms
- Claytronics Design Principles
  - No Moving Parts
  - Local Control
  - No Static Power



Moore's Law



Where are we in 50 years?

	1949 Eniac	2003 greeting card	2050 Programmable matter
Cost	5M-23M (2002 $)	1$	1 millicent
Weight	30 tons	1 oz	20 μg
Volume	450 M^3	1 cm^3	1 nm^3?? (1 μm^3)
Power	200KW	20mW	2 attowatts
Cycle time	>200μs	25ns	2 picosec
Storage	<800B	4KB	16KB

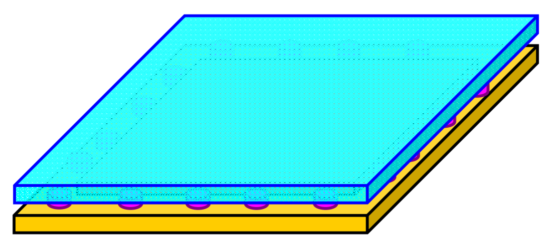
Cogent arguments for both sooner and later exist

Scaling of Claytronics

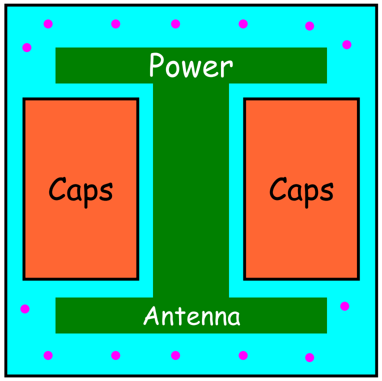
	Macro	Micro	Nano
Dimensions	>1 cm	>1 mm	<10 microns
Weight	10's gr	100's mg	<1 mg
power	<2 Watts	10's mW	10's nW
Locomotive mechanism	Programmable magnets / Electromagnets	Electrostatics	Aerosol
Adhesion mechanism	Nanofiber adhesives / Magnets	Programmable nanofiber adhesives	Molecular surface adhesion and covalent bonds
Manufacturing methods	Conventional manufacturing and assembly	Micro/Nano-fabrication and micro-assembly	Chemically directed self-assembly and fabrication
Resolution	Low	High	High
Cost	$$$/catom	$/catom	Millicents/catom

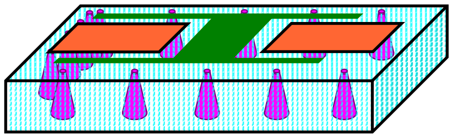
3D Catom Proposal

- Three die
  - Compute die
  - Sense/actuate die
  - Power die
- Connect back-to-back use through die vias

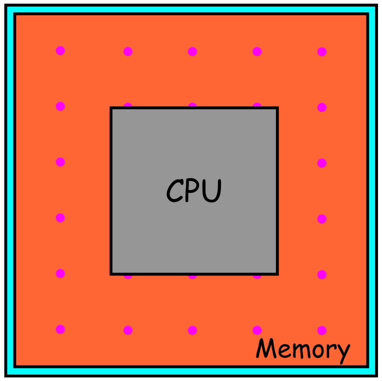


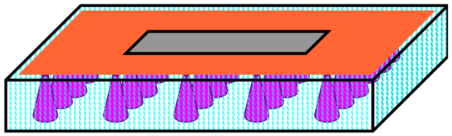
Power



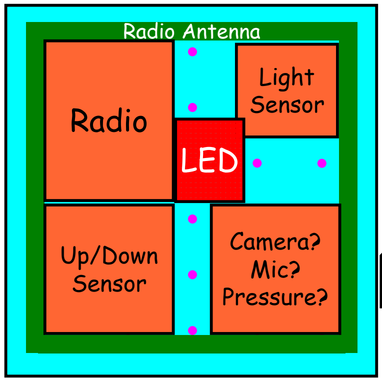


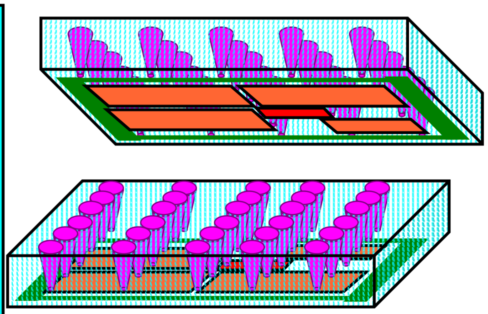
Processing



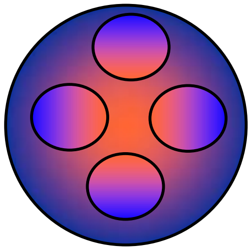


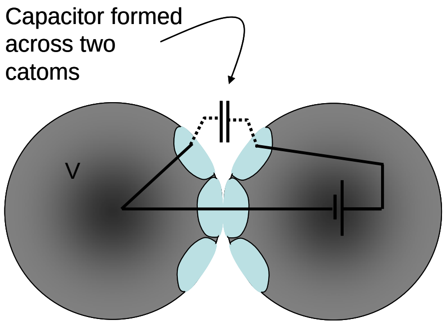
Sensors and Actuators





The Case/Motion





What about the software?

- Distributed Planning
- Programming Models
- Networking
- …

Networking: Naming & Routing

Naming

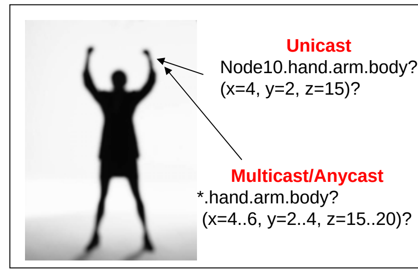
How will programs address catoms?

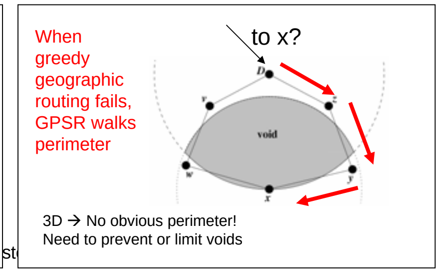
- **Granularity:** Individual, multicast, anycast
- **Identity:** Geographic, based on shape (e.g. arm catoms)
- **Our approach**
  - Driven by application needs
  - Support multiple naming schemes (at higher cost) until application needs are clear

Routing

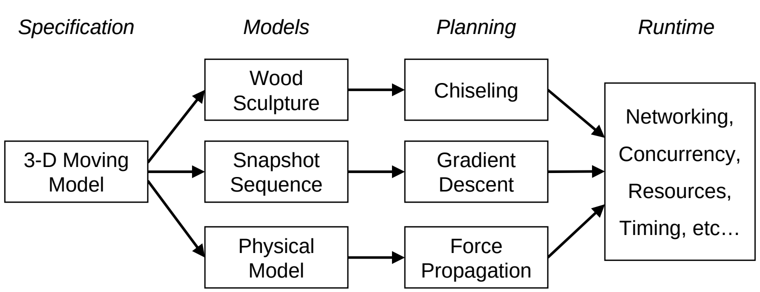
How to identify path to destination catoms?

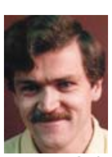
- **Traditional ad hoc routing (DSR, AODV, etc.)**
  - Relies on flooding → not scalable to Claytronic network sizes
- **Geographic (GPSR)**
  - Requires planar network interconnect → cannot support arbitrary 3d structures
- **Our approach**
  - Use programs to control 3d structure such that GPSR-like routing is possible
  - Develop localization techniques





Programming Language/Software Engineering Research






Claytronics & Pario

- Open up an entire new application space
  - Entertainment (interactive clay)
  - Training (live-fire exercises)
  - Design (100x protein model)
  - Interaction (telepario)
  - Rescue (paramedic on demand)
  - Metal Man (fault tolerant robotics)
- Vehicle for studying CS problem of the future:

  How do you design, program, maintain, and use a billion component system?

Claytronics & Pario

- Open up an entire new application space
- Vehicle for studying CS problem of the future:
  How do you design, program, maintain, and use a billion component system?
- Vehicle for creating robot of the future
  How to design and program a collection of micro/nanorobots to create a useful macroscale robot?

Claytronics & Pario

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Claytronics & Pario

- Open up an entire new application space
- Vehicle for studying CS problem of the future.
- Vehicle for creating robot of the future
  How to design and program a collection of micro/nanorobots to create a useful macroscale robot?
- Our Approach:
  - Make scaling work for us
  - Exploit scale invariance
  - Design for scalability in both number & size

Software Systems

- Distributed Computing
  - how to write a program for 1M+ machines? what is the programming model?
- Robot planning, distributed robotics
  - how to plan the coordinated movement, communication and sensing?
- Networking and sensor nets
  - how to geolocate, communicate?
- Emergent Behavior
  - how to self-organize and operate in uncertain environments with unreliable components?
- Many others…

Hardware Systems

- Microrobots, modular robots
  - what is the design of the elements?
- MEMS/nanotech materials
  - how to achieve small scale economically?
- Magnetics and other actuation
  - how to do locomotion, actuation?
- High voltage silicon processing
  - how to achieve manufacturing economies of scale?
- Power systems
  - how to distribute power?
- ...