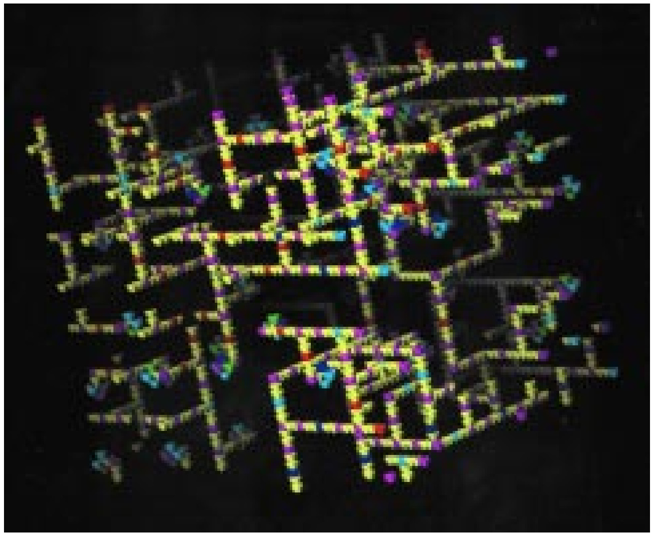
UltraScale Computing
Program Vision

"What the ancients called a clever fighter is one who not only wins, but excels in winning with ease" -- Sun Tsu

Machines with Human-Like Cleverness



Humans with Machine-Like Precision

E.D. (Sonny) Maynard, Jr.
Information Technology Office

UltraScale Computing Program Structure

Swarm Computing

Artificial Nervous System

Quantum Computing

Explore The Upper Reaches Of Computer Complexity

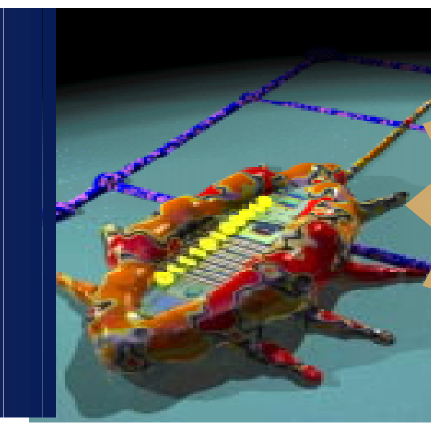
<u>Inorganic</u>
Machine Inference & Creativity

DNA Computing

Cellular Engineering

Living Neuronal Networks

Enable Computation Based On Biological Material



<u>Organic</u>
Biology That Computes

Why Is UltraScale Computing Important to DOD?

Warrior Robots

Disposable Supercomputers

Materials That Think

Fly-By-Thought

Instant Training

The Inorganic World

Swarm Computing

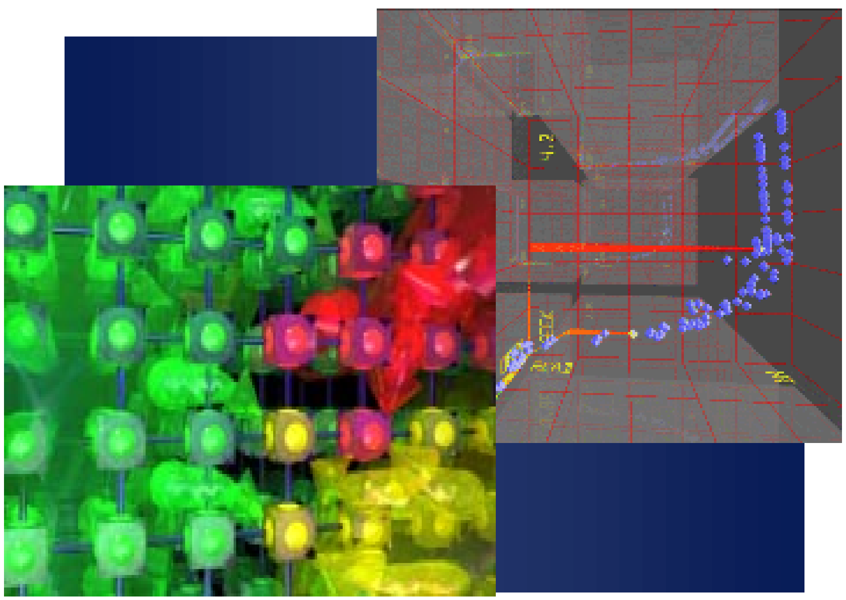
Expected Results: Simulation & test show >1,000,000 cellular automata can solve partial differential equations

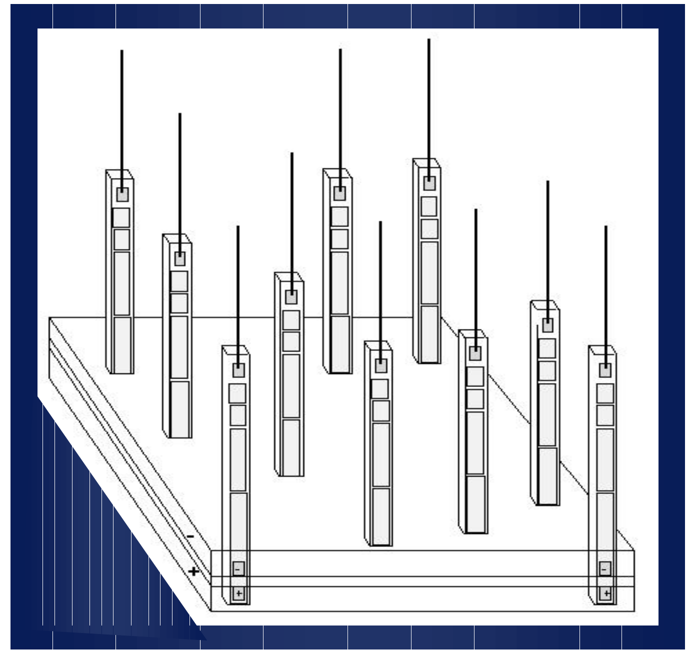
Swarm Computing
Two Representative Projects

DARPA

Continuum Computer Architecture
California Institute of Technology

Context: Applications with very high I/O bandwidth requirements such as image and signal processing including SAR, passive and active SONAR, and satellite reconnaissance images.





Amorphous Computing
Massachusetts Institute of Technology

Context: To reliably obtain a desired behavior by engineering the cooperation of many parts, without assuming any precision interconnect or precision geometrical arrangement of the parts

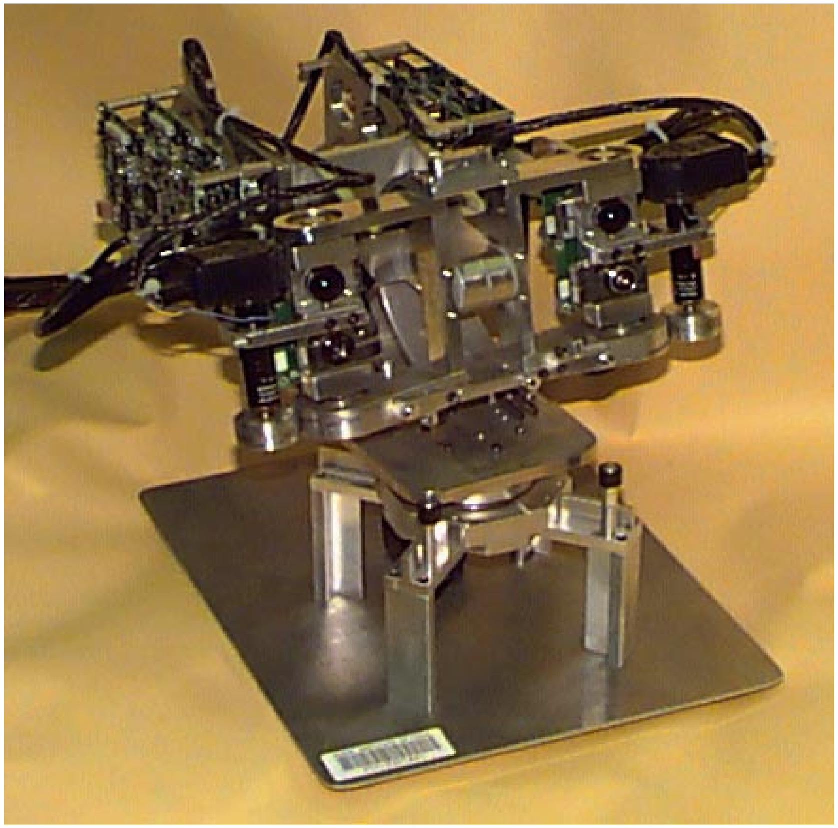
Swarm Computing
Artificial Nervous System
Quantum Computing

The Inorganic World

DARPA

Artificial Nervous System

Expected Results: Machine inference and creativity result from interaction with the environment

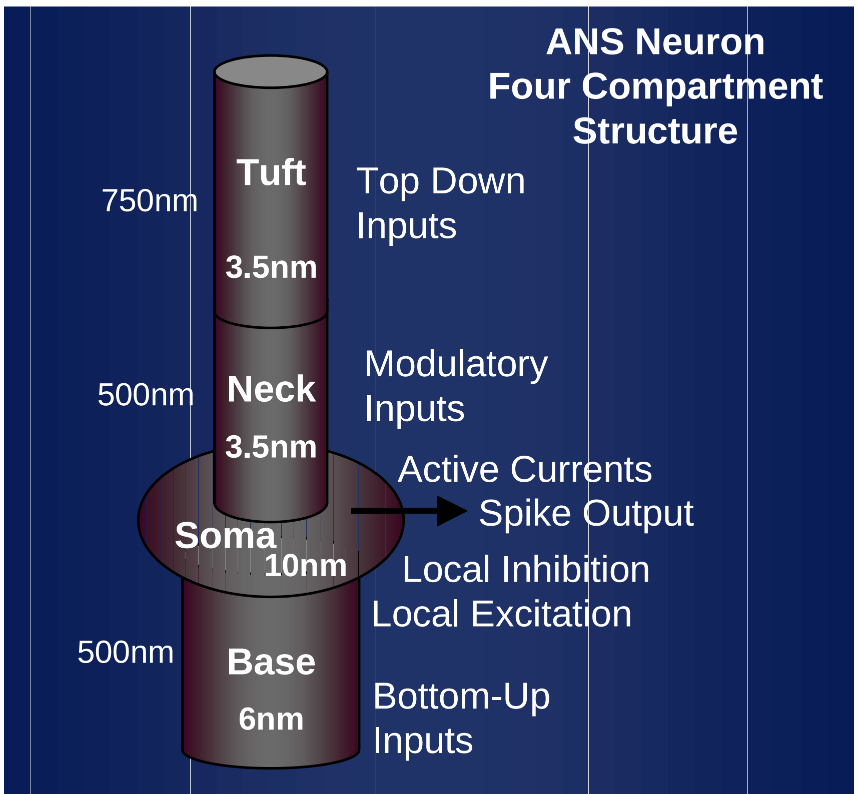


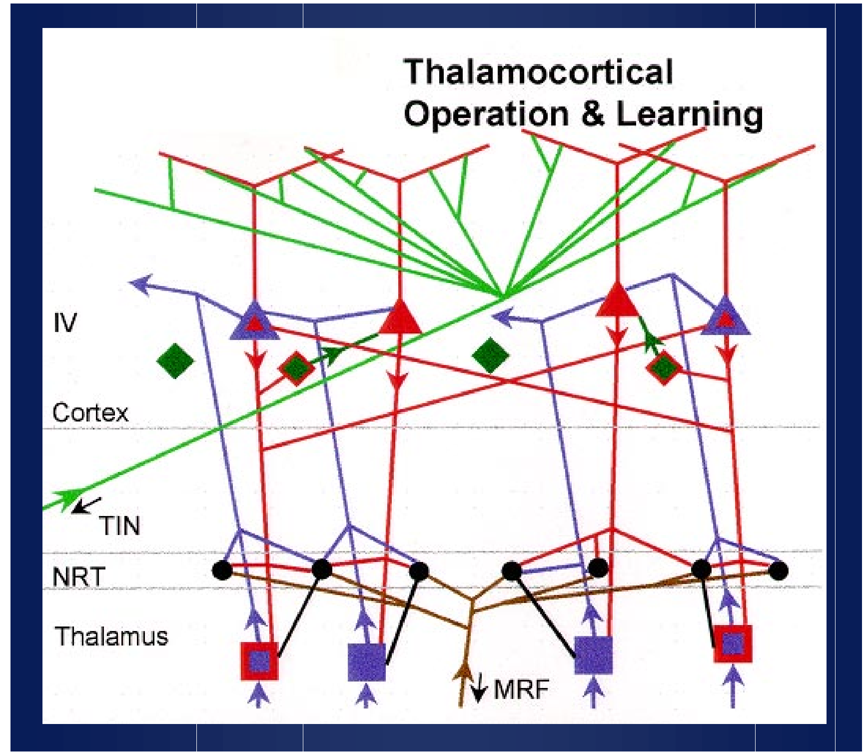
Artificial Nervous Systems
Two Representative Projects

DARPA

Artificial Nervous System, Raytheon/TI

Context: Construct realistic electronic nervous system that acquires a world view through sensory motor controls to provide the central nervous system for battlefield robots.





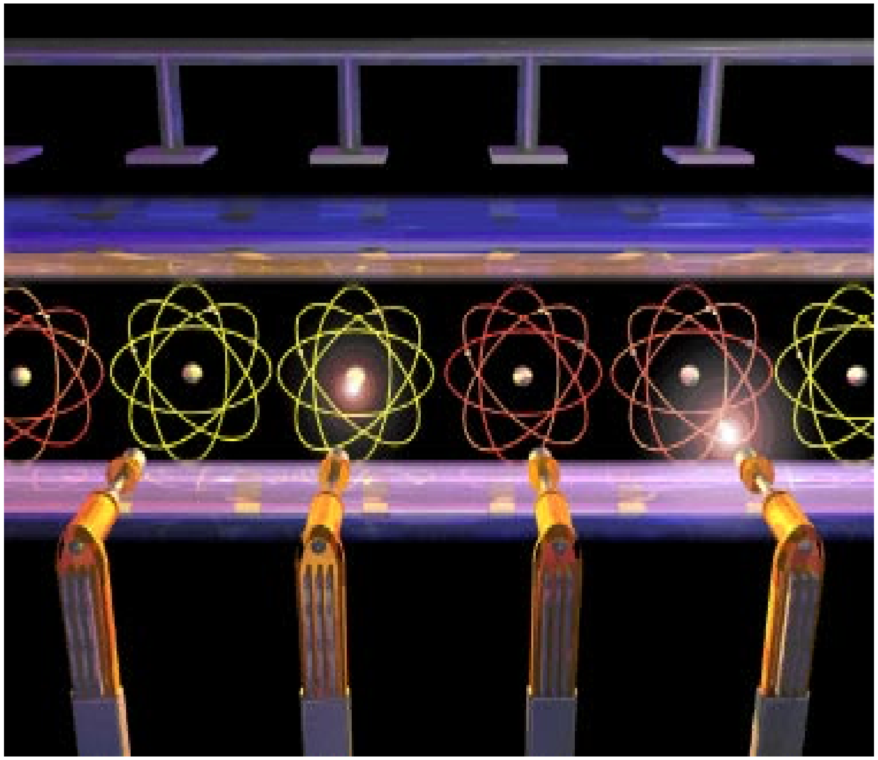
NeuroModem
HNC Software Inc./Robert Hecht-Nielsen

Context: Demonstrates the ability to encode desired machine input to that region so it is correctly interpreted by the rest of the brain

The Inorganic World

Quantum Computing

Expected Results:
An N-bit quantum processor solves a problem of order 2^N

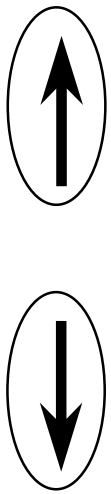


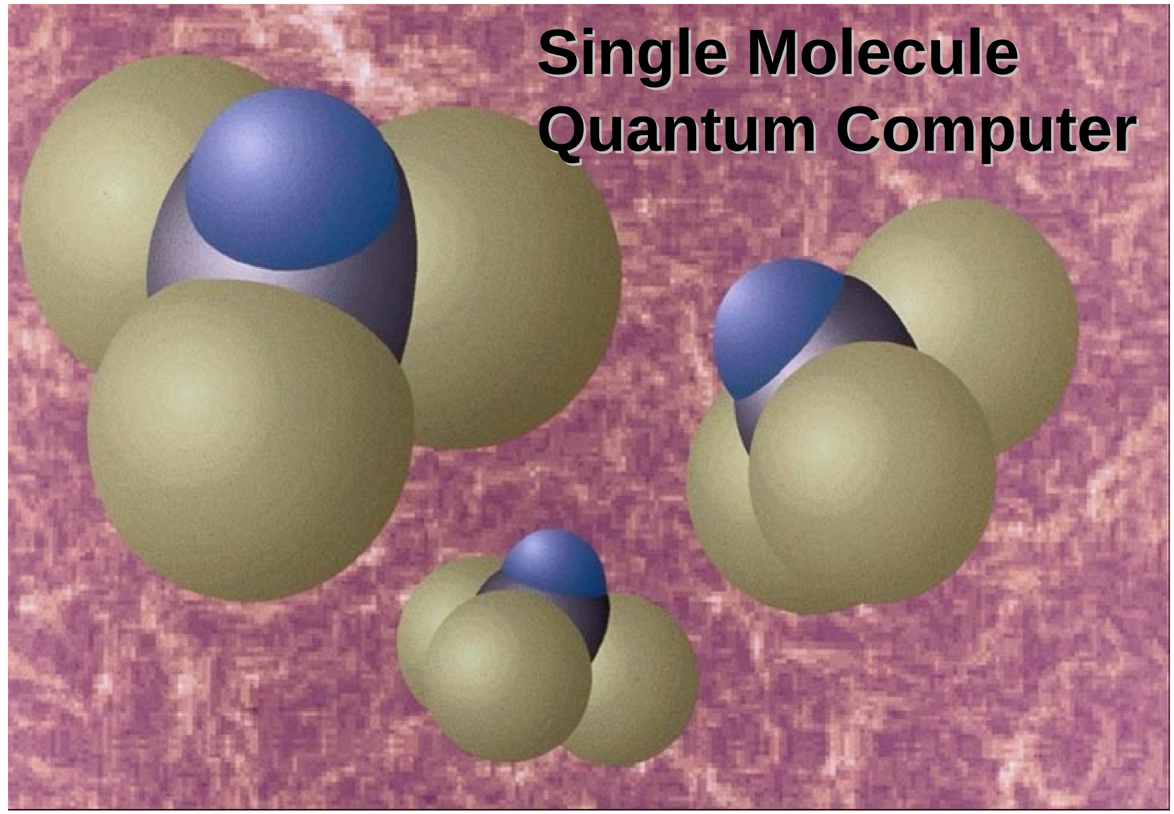
Quantum Computing

(Gershenfeld and Chuang, Science 275, p.350, 1997)

1 =

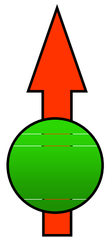
0 =

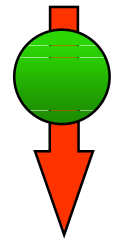


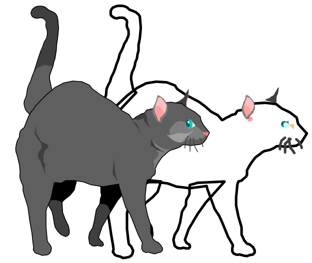


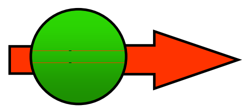
- Information (qubits) = Nuclear spins
- Interactions = Chemical bonds
- Circuits = Electromagnetic field pulses

Quantum Computing

1 = 

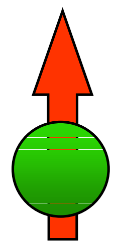
0 = 

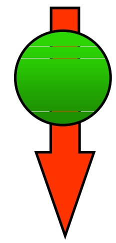


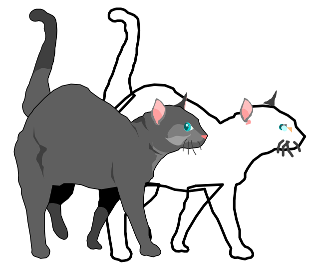
 = ?

Quantum Computing

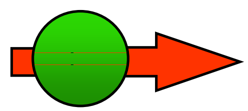
DARPA

1 = 

0 = 

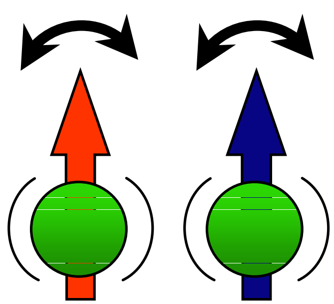


Superposition of 0 and 1!



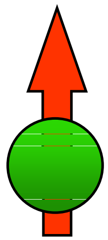
$$= \frac{1}{\sqrt{2}}\,\mathbf{0} + \frac{1}{\sqrt{2}}\,\mathbf{1}$$

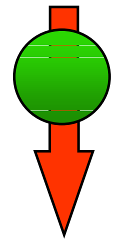
- **Two spins: four states in superposition**

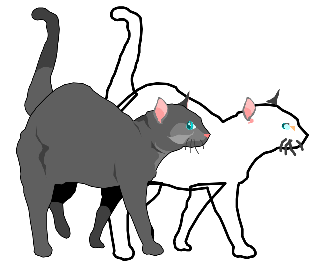


$$c_0\left|\mathbf{00}\right\rangle + c_1\left|\mathbf{01}\right\rangle + c_2\left|\mathbf{10}\right\rangle + c_3\left|\mathbf{11}\right\rangle$$

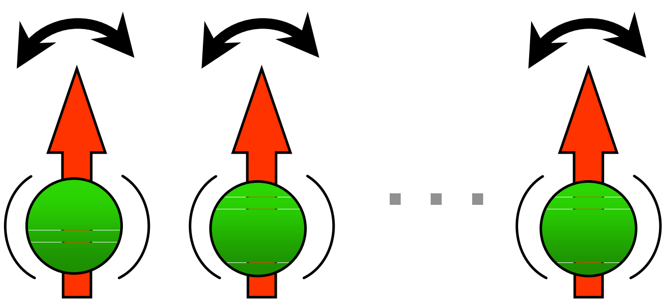
Quantum Computing

1 = 

0 = 



- **N spins -- 2^N states in superposition**



0...00 + 0…01 + … + 1…11

Quantum Computing

DARPA

Why don't we have Quantum computers today?

- Coupling between quantum computation medium and physical world
    - Must be isolated during computation
    - Must be coupled for input/output
- Error correction
- Large scale packaging

Quantum Computing
Two Representative Projects

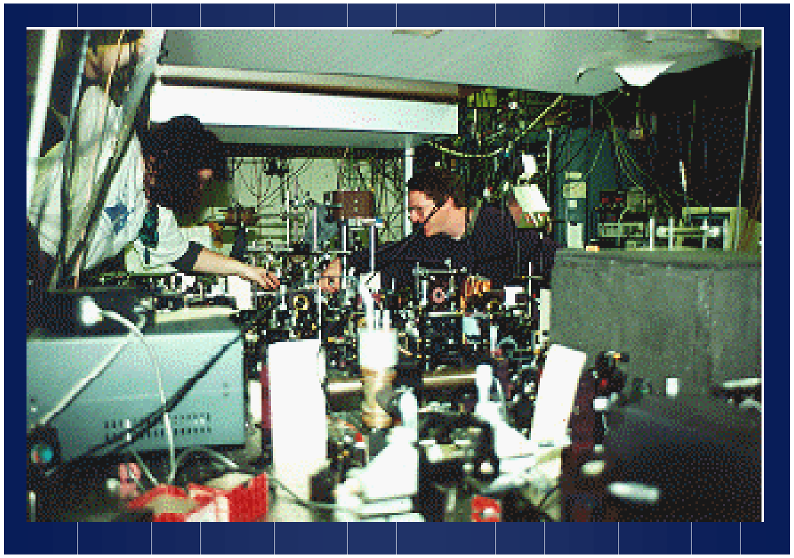
DARPA

Bulk Quantum Computation with NMR
Stanford, MIT, U-California-Berkeley

Context: Desktop quantum computer with NMR I/O.

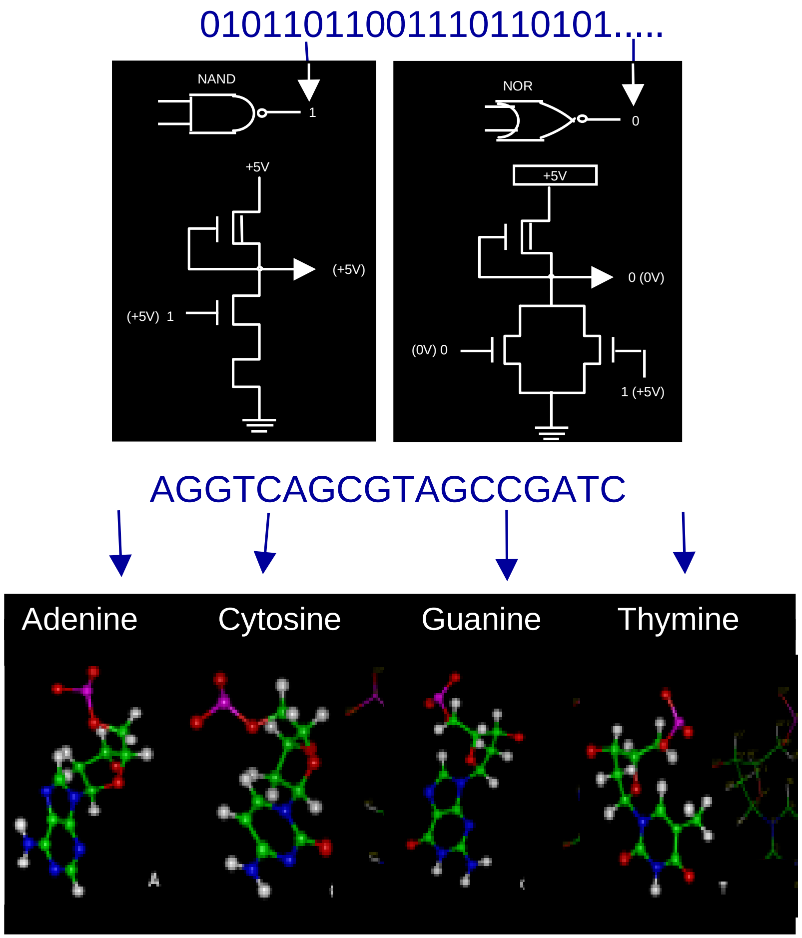
Quantum Information Computation
CalTech, U-Southern California, MIT

Context: Quantum computers solve problems impossible for classical computers; quantum computation impacts cryptographic security; quantum communication enables new secure cryptographic protocols



DNA Computing
Cellular Engineering
Living Neuronal Networks

The Organic World



DNA Computing

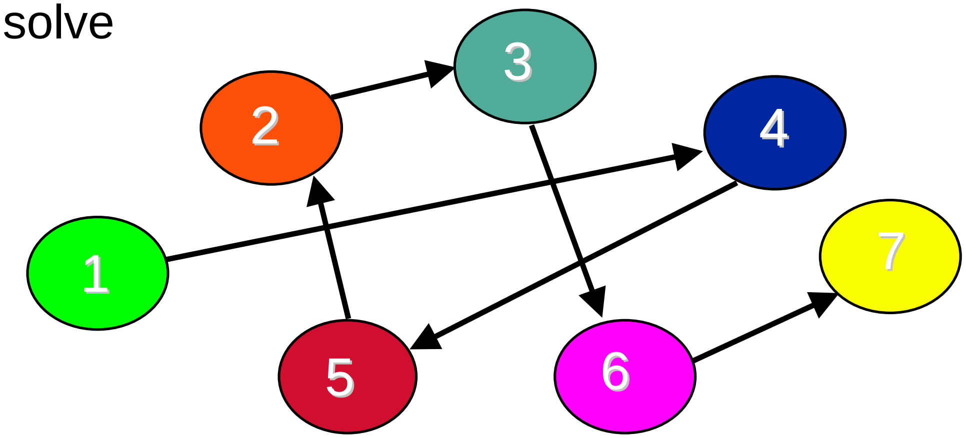
Expected Results: Data has been stored & retrieved from DNA & a simulated problem, order $>2^{56}$, is solved

DNA Computing
Representative Project

DARPA

Theoretical & Experimental Aspects of Biomolecular Computing
University of Southern California

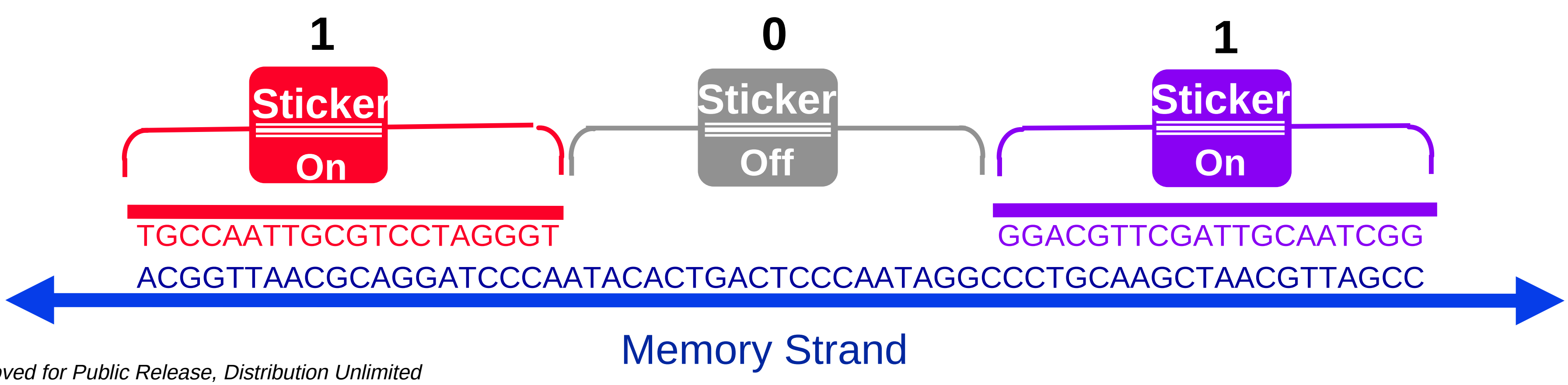
- Draw a path from the first city to the last while passing through all cities only once
  - This is known to be a hard problem
- When the number of cities is > 70, the problem is too complex for even a supercomputer to solve



- Generate all possible paths
- Keep only those paths that go from “start” to “end”
- Find the ones passing through 7 cities
- Isolate paths with 7 different cities

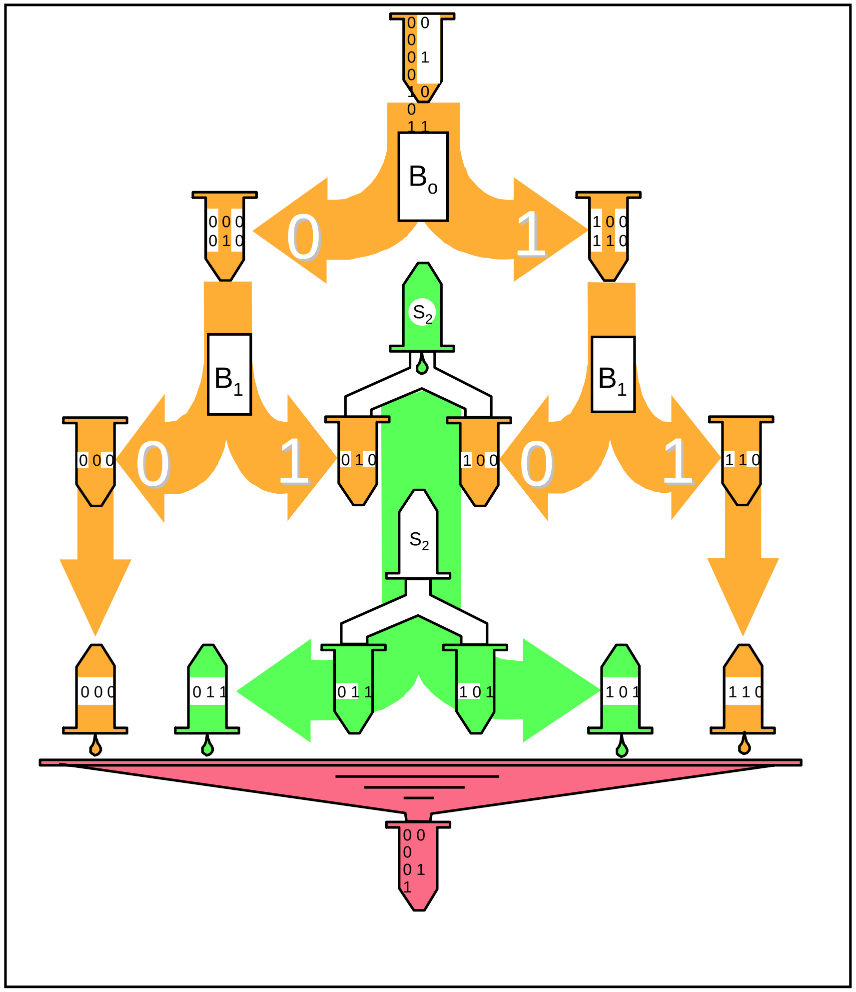
DNA Mk 1
The Stickers Model

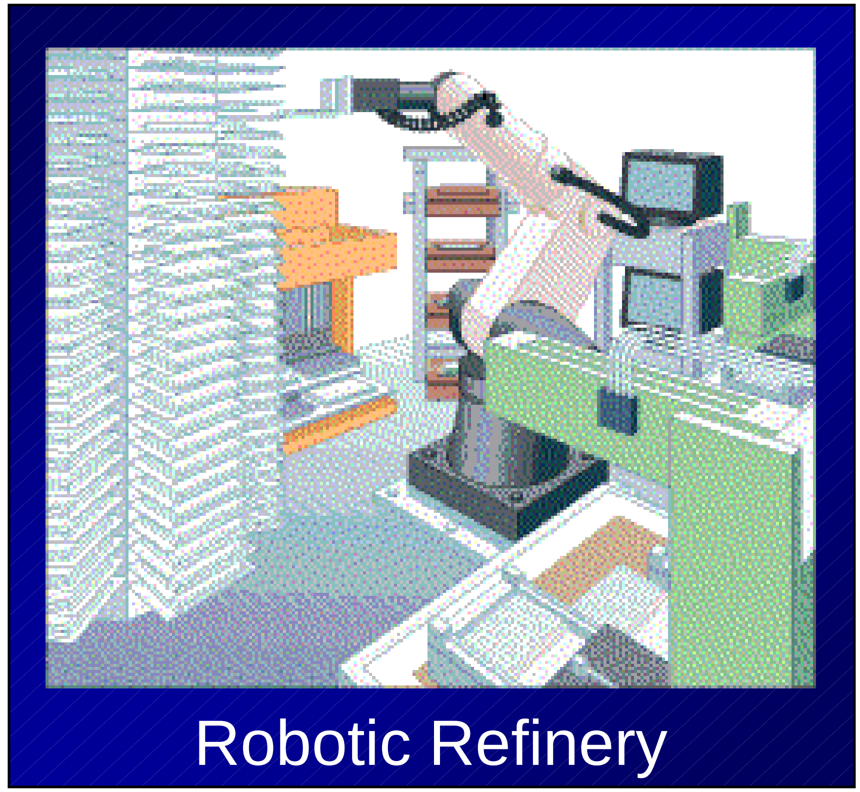
- **Memory Strand for Breaking DES**
  - 11580 bases in length
  - Subdivided into 579 non-overlapping regions, 20 bases long
- **Stickers**
  - Each sticker is 20 bases long
  - Complementary to one and only one of the 579 memory regions
- **Each Region is One Bit**
  - Bit On: Sticker is annealed to memory strand
  - Bit Off: No sticker



DNA + Robotics = DNA Computing

DARPA



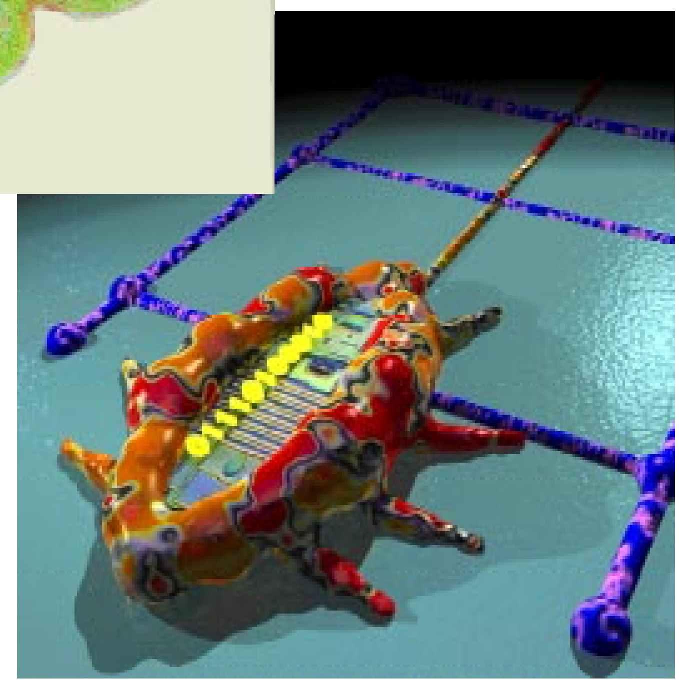


Context: If the biochemical error rate is <1:10,000 and unit operation is one second, then a computer of <1m^3 breaks DES in 2 hours.

The Organic World

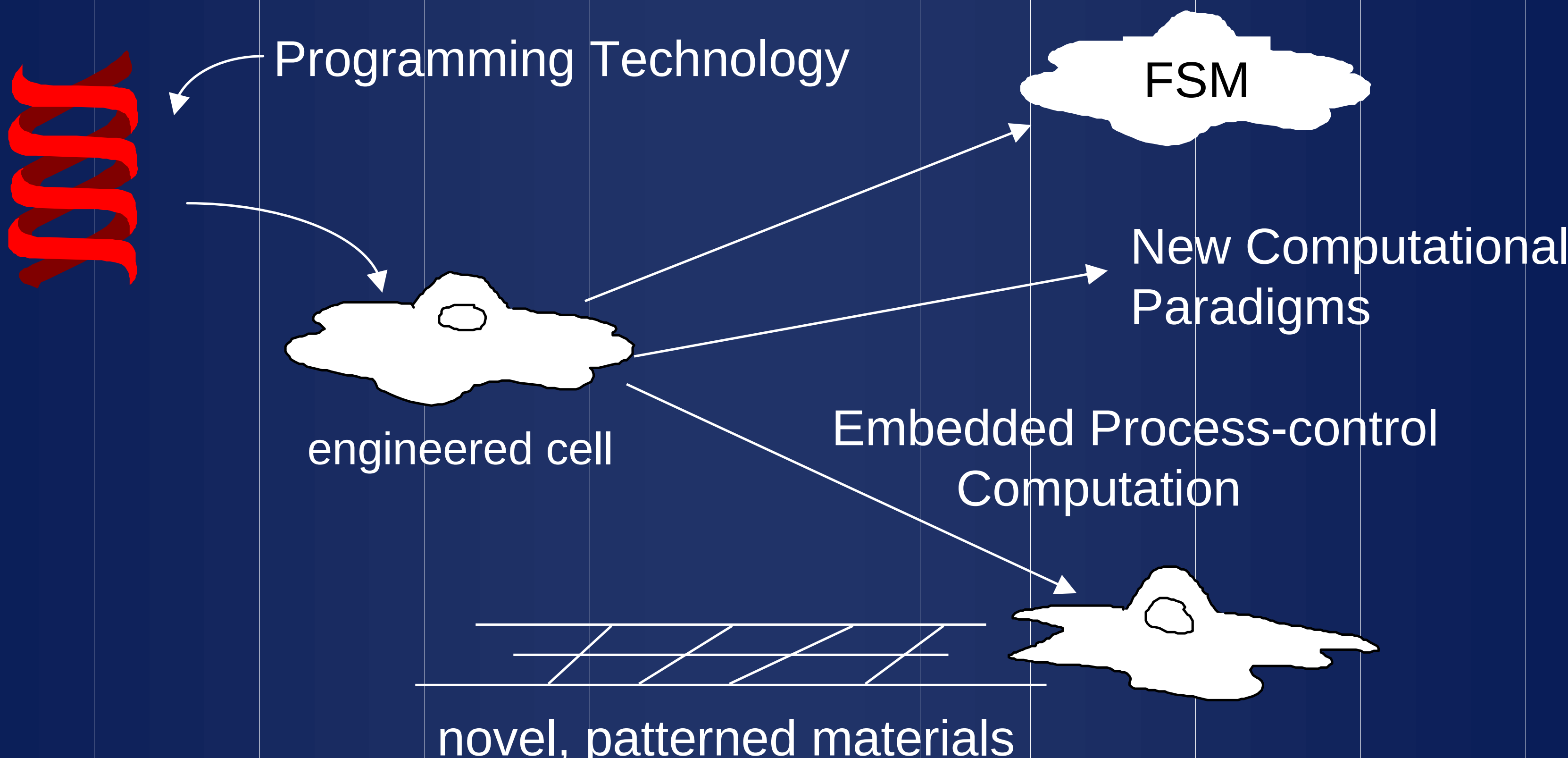
Cellular Engineering

Expected Results: Finite state machines implemented via gene expression & transcription of a bacterium



Cellular Engineering

Create and exploit a novel technology for information processing and manufacturing by controlling processes in living cells

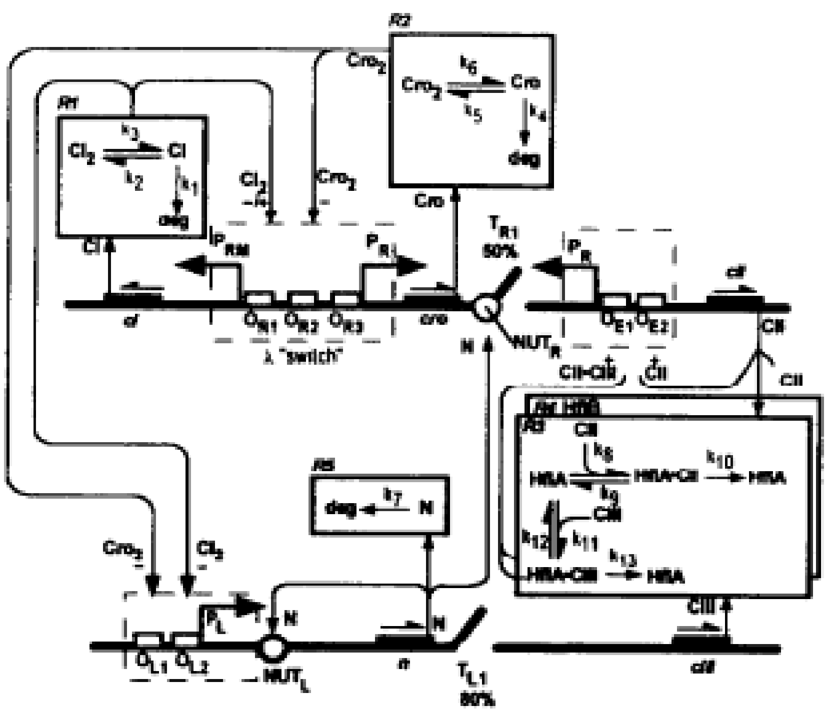


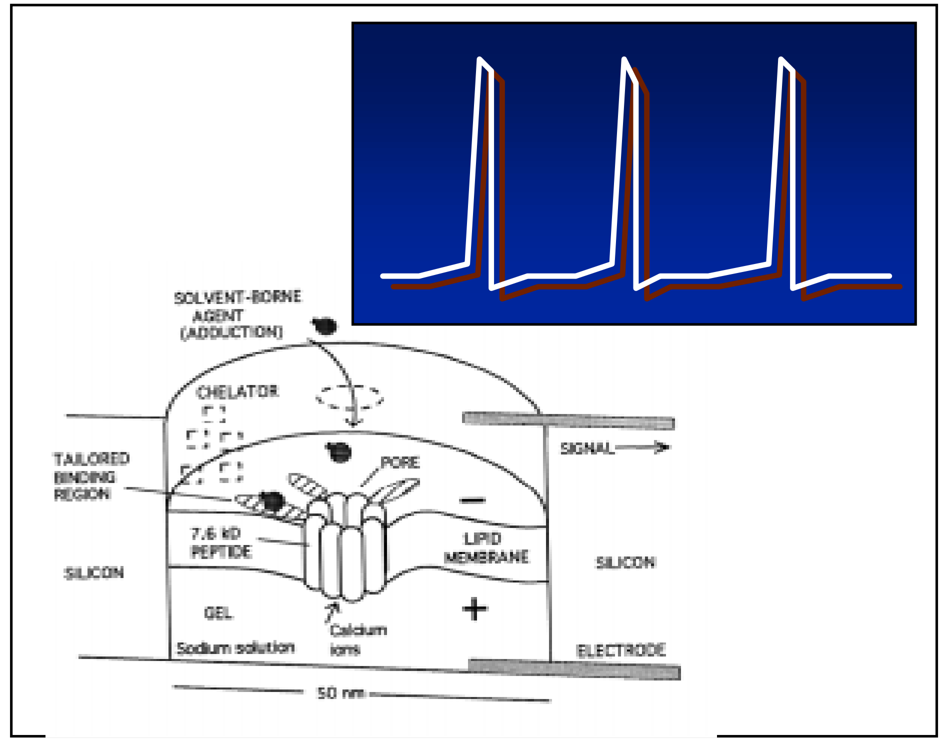
Cellular Engineering
Two Representative Projects

DARPA

Gene Regulatory Modeling
Stanford University

Context: Model the interior processes of bacteria to demonstrate external control of internal computation.



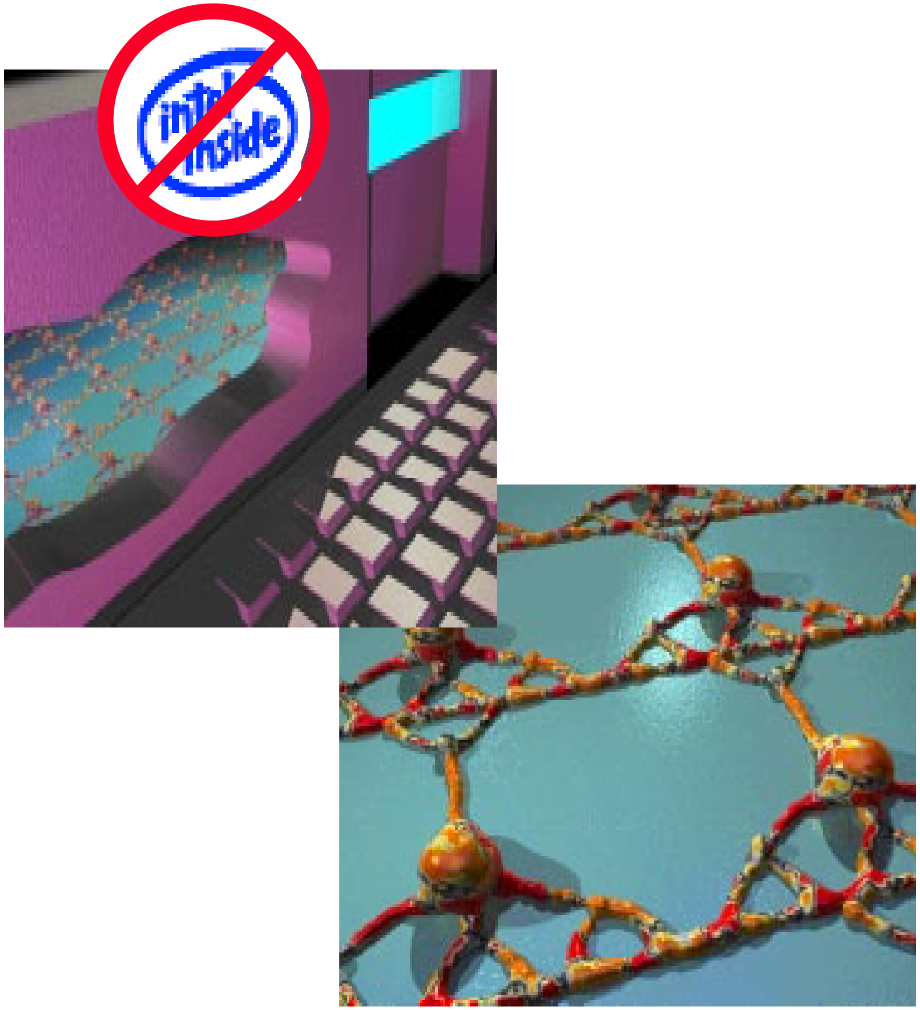


Oscillating Channels and Sensors
Harvard University

Context: Establish the viability of an implantable electrical to chemical transducer.

DNA Computing
Cellular Engineering
Living Neuronal Networks

The Organic World



Living Neuronal Networks

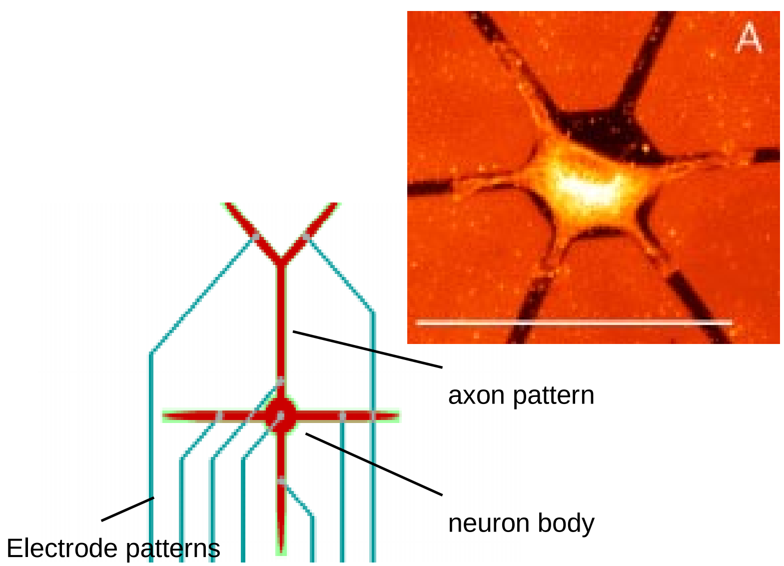
Expected Results:
Hybrid information appliances, such as computers, peripherals, and storage devices.

Living Neuronal Networks

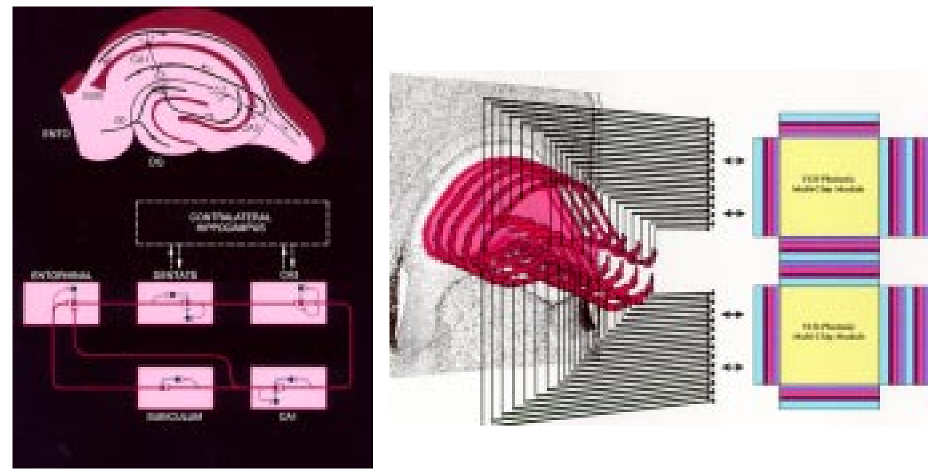
Two Representative Projects

Interfacing Directed Neuron Systems with Silicon Electronics Cornell University, Wadsworth Center, and U-Va

Context: Form neuronal circuits connected to electronics so that powerful, cheap signal processing is enabled.



Schematic of Neuraonl element



A Hybrid Neuron-Silicon Computational System University of Southern California

Context: Develop novel, hybrid neuron-silicon technology to harness computational capacity of cultured networks of hippocampal neurons for temporal and spatio-temporal pattern recognition applications.

The Organic world

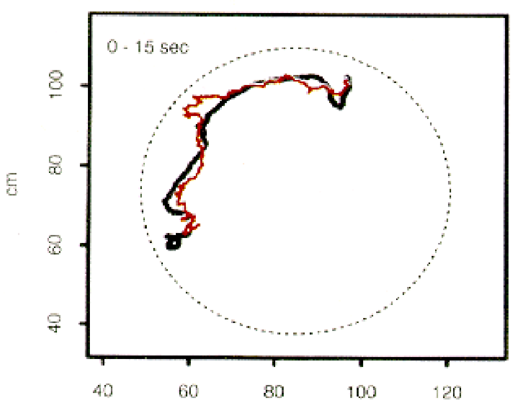
- DNA Computing
- Cellular Engineering
- Living Neuronal Networks

Living Neuronal Networks
Representative Project

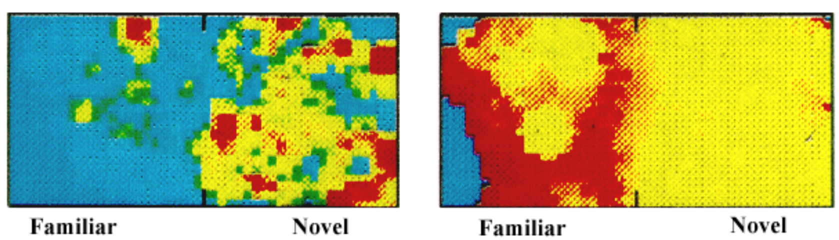
DARPA

Interfacing with Large-Scale Neuronal Ensembles
Massachusetts Institute of Technology

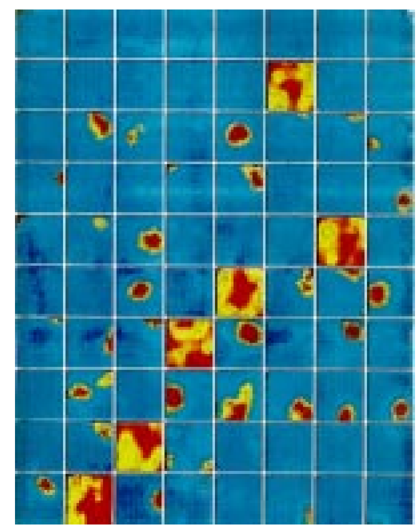
Context: Deliver synthetic inputs directly into sensory and memory systems of the brain; demonstrate direct, remote access to the outputs of these systems in biological organisms performing high level information processing.



Decoding patterned neural activity for location



Detection of novel environment through neural monitoring


Responses of 80 monitored hippocampal cells

How Can DoD Use UltraScale Computing?

Warrior Robots

Disposable Supercomputers

Materials That Think

Fly-By-Thought

Instant Training