THE CENTER FOR BITS AND ATOMS

Massachusetts Institute of Technology

Prof. Neil Gershenfeld

Director

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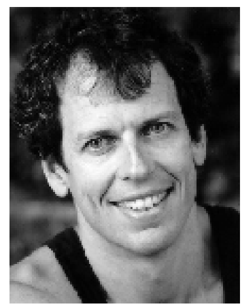

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Major power outage hits New York, other large cities

Thursday, August 14, 2003 Posted: 11:45 PM EDT (0345 GMT)
Thursday, August 14, 2003 Posted: 11:45 PM EDT (0345 GMT)

NEW YORK (CNN) -- Power began to flicker on late

Power blackout traps 250,000 Tube travellers

By Catriona Davies and John Crowley
(Filed: 29/08/2003)

An estimated 250,000 commuters were evacuated from the London Underground last night after a National Grid failure caused a power cut across the south of the capital.

Hundreds of thousands of homes and businesses lost all electricity and most of the Underground network was brought to a sudden halt during the rush hour.

Transport for London said the power failure, which

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Last Update: Wednesday, October 8, 2003. 0:37am (AEST) Print Email

Major power failure blacks out Czech Republic

Tens of thousands of people were left without electric
power failure in western parts of the Czech Republic
a spokesman for the local supplier ZSE says.

"We are investigating the reasons for the power failu

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Last Updated: Monday, 29 September, 2003, 05:29 GMT 06:29 UK

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Blackout exposes Italy power crisis

Nothing was moving fast on Sunday

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on a power supply bouring Switzerland omino effect, which id failure across Italy of seconds.

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THE WORLD

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Power restored in Scandinavia

From correspondents in Copenhagen

ELECTRICITY was restored to eastern Denmark and Sweden today, after a blackout that affected four million people in both countries, but experts warned that new power failures could occur because the causes remained unclear.

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THE CENTER FOR BITS AND ATOMS
Massachusetts Institute of Technology

Avogadro-Scale Engineering: Form and Function

November 18, 19 2003
The Bartos Theater
Building E15

Tuesday, November 18th: *Form*

8:00-9:00 **Breakfast & Registration**

9:00-9:15 **Introduction** (video)
Neil Gershenfeld

9:15-9:30 **Form**
Joseph Jacobson

9:30-10:30 **Foundations**
Marvin Minsky: *The History of Self-Reproduction*
Charles Bennett (IBM): *Brownian Computation*
Elebeoba May (Sandia): *Coding Theory and Protein Synthesis*

10:30-11:00 **Break**

11:00-12:30 **Research Talks** (video)
Shuguang Zhang: *Avogadro-Scale Molecular Self-Assembly in Biological Systems*
Drew Endy: *Genetic Design*
Rafael Reif: *Three-Dimensional Circuitry*
Saul Griffith: *Programmable Assembly*
Larry Sass: *Macroscale Self-Assembly*

12:30-1:30 **Lunch**

1:30-2:00 **Research Talks** (video)
Ehud Shapiro (Weizmann Institute): *Biomolecular Computers*

2:00-4:00 **Discussions and Demonstrations**

4:00-5:00 **Large-Scale Systems** (video)
George Chiu: *IBM's Blue Gene*
Juha Kortelainen: *UPM-Kymmene*
Mel King, Amy Sun: *Global Invention*

Wednesday, November 19th: *Function*

8:00-9:00 **Breakfast**

9:00-9:15 **Function** (video)
Neil Gershenfeld

9:15-10:30 **Research Talks**
Rahul Sarpeshkar: *Analog vs Digital*
Ben Vigoda: *Differential Belief Propagation*
Ben Recht: *Distributed Convex Optimization*
Bill Butera: *Virtual Self-Assembly*
Isaac Chuang: *Reliability is a Fungible Resource*
Sebastian Seung: *Reverse-Engineering the Brain*

10:30-11:00 **Break**

11:00-12:30 **Partner Presentations** (video)
Jonathan Yedidia (MERL): *Generalized Belief Propagation*
Scott Kirkpatrick (Hebrew University): *Computation Despite the Presence of Phase Transitions*
Susan Coppersmith (University of Wisconsin): *The Complexity of Physical Dynamics*
Pablo Parrilo (ETH): *Semidefinite Programs and Semialgebraic Relaxations*
Martin Wainwright (Berkeley): *Semidefinite Relaxations for Approximate Inference on Graphs with Cycles*
Raff D'Andrea (Cornell): *Distributed Control Systems*
John Doyle (Caltech): *Fragility and Complexity*

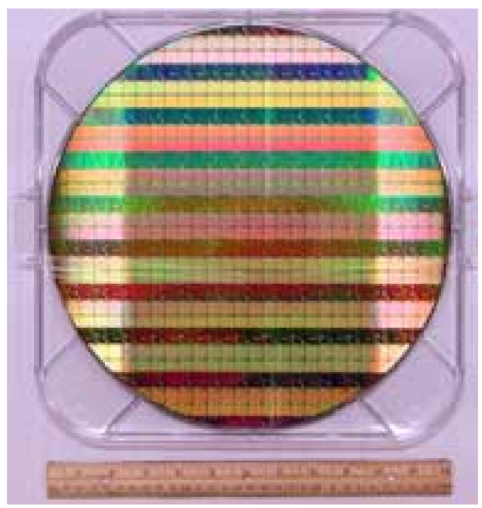
12:30-1:30 **Lunch**

1:30-3:30 **Working Groups**
Form: *Fabricating Complexity*
Function: *Statistical-Mechanical Engineering*
Foundations: *Fundamental Limits and Uncertainty Relations*
Formats: *Description Languages and Designs Tools*

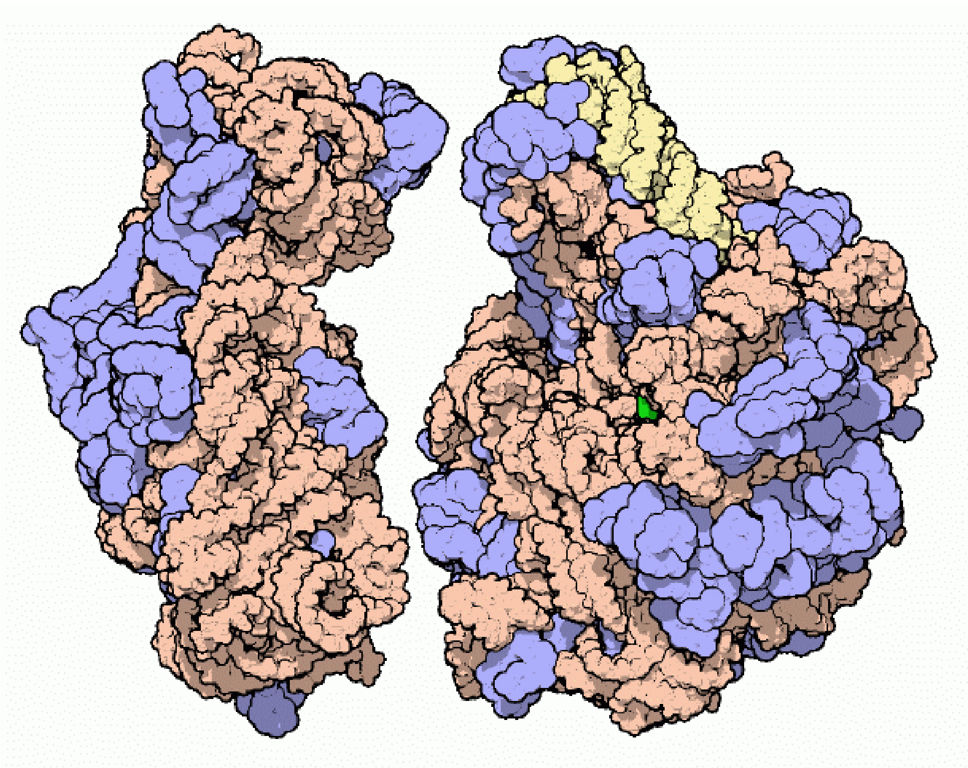
State-of-the-Art Fabrication?

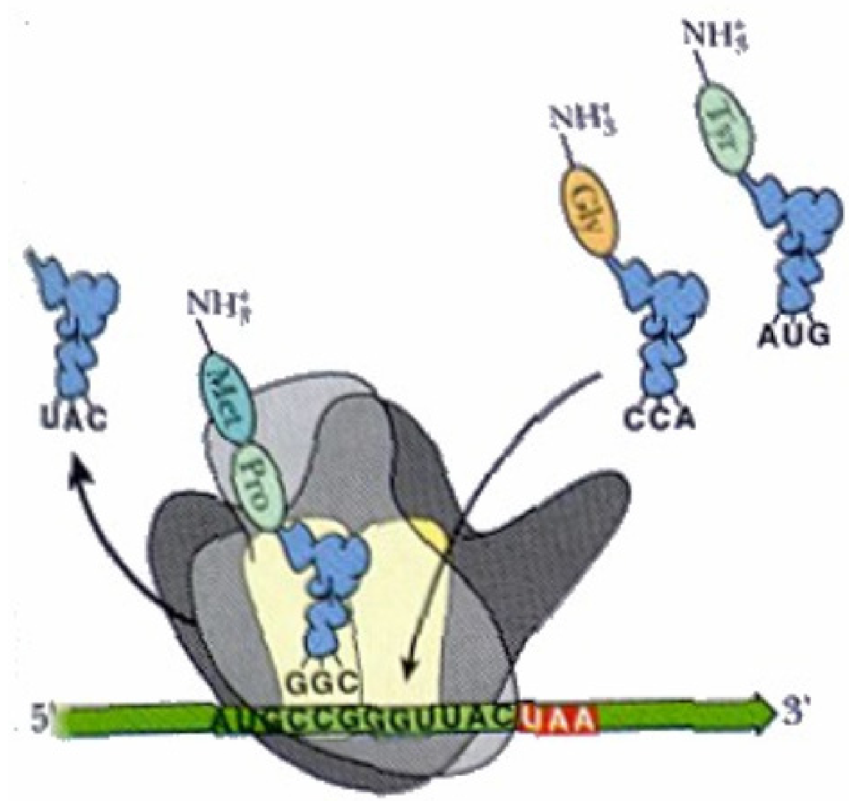






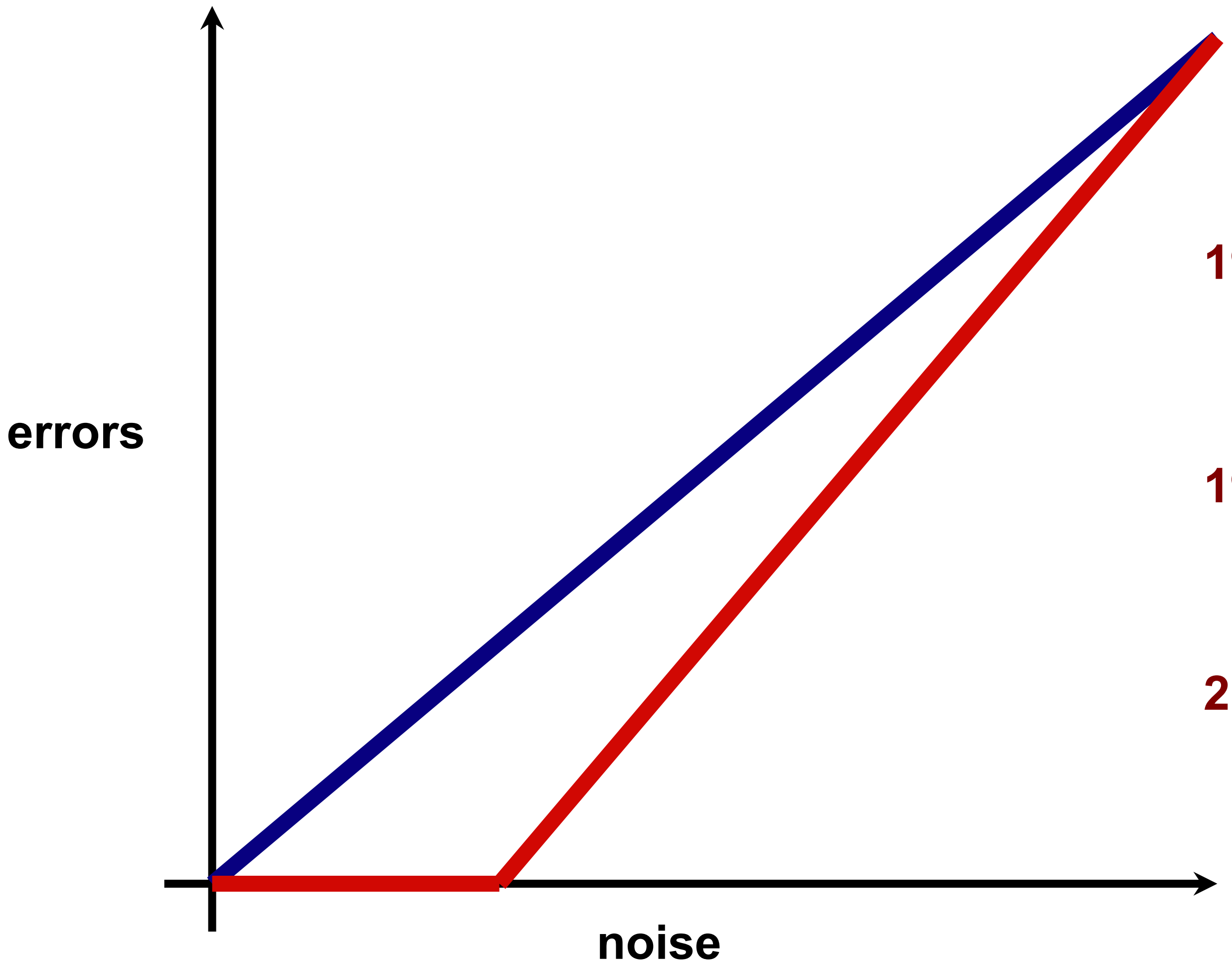

State-of-the-Art Fabrication!





The Ribosome

Thresholds



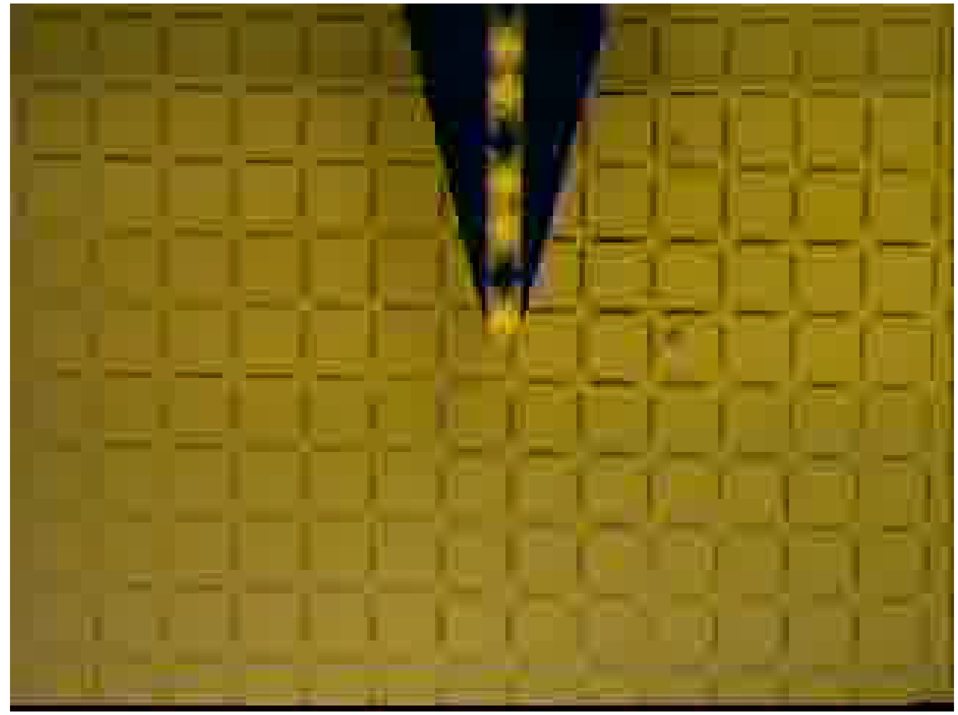
1940s: Communications
(Shannon)

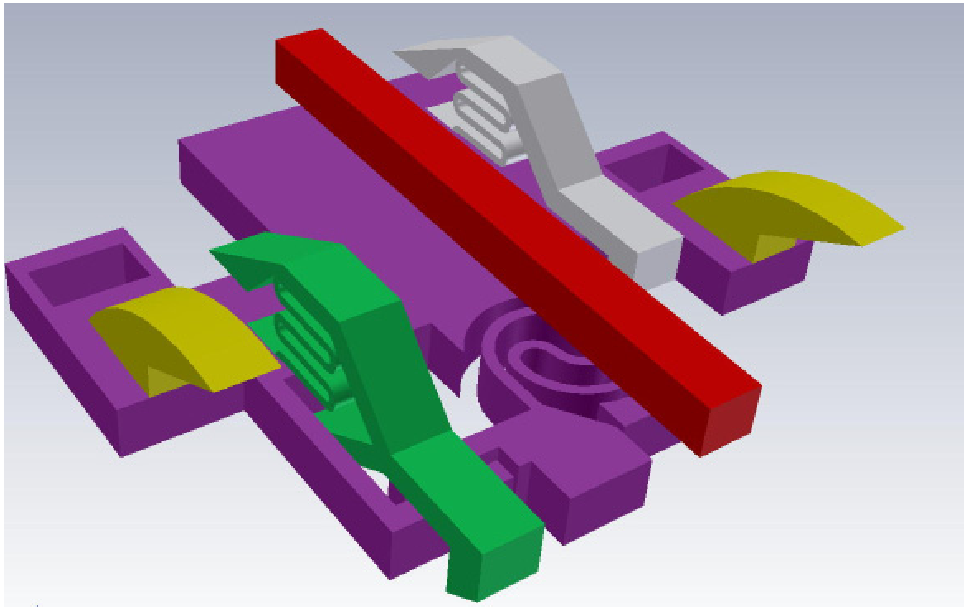
1950s: Computation
(Winograd, von Neumann)

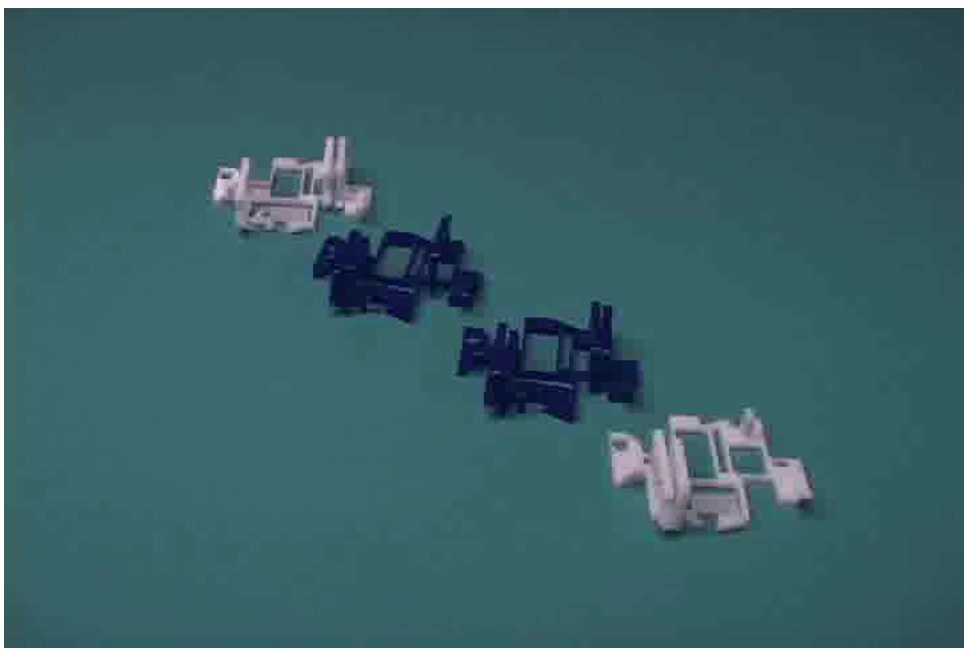
2000s: Fabrication

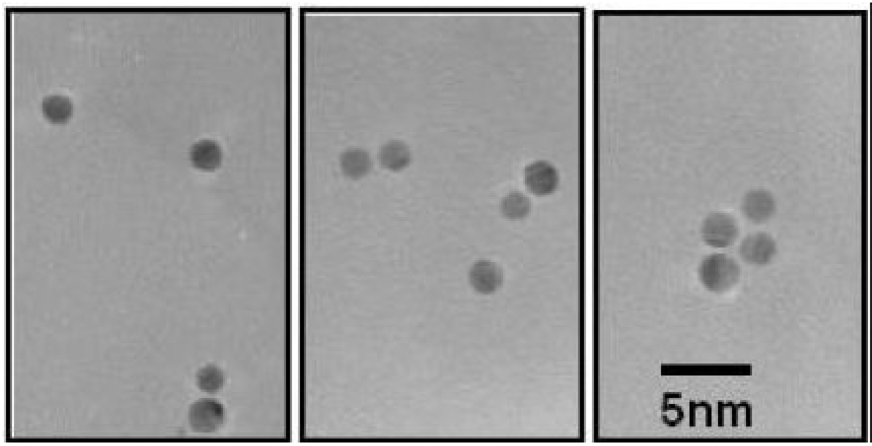
Logical Assembly

(Saul Griffith)



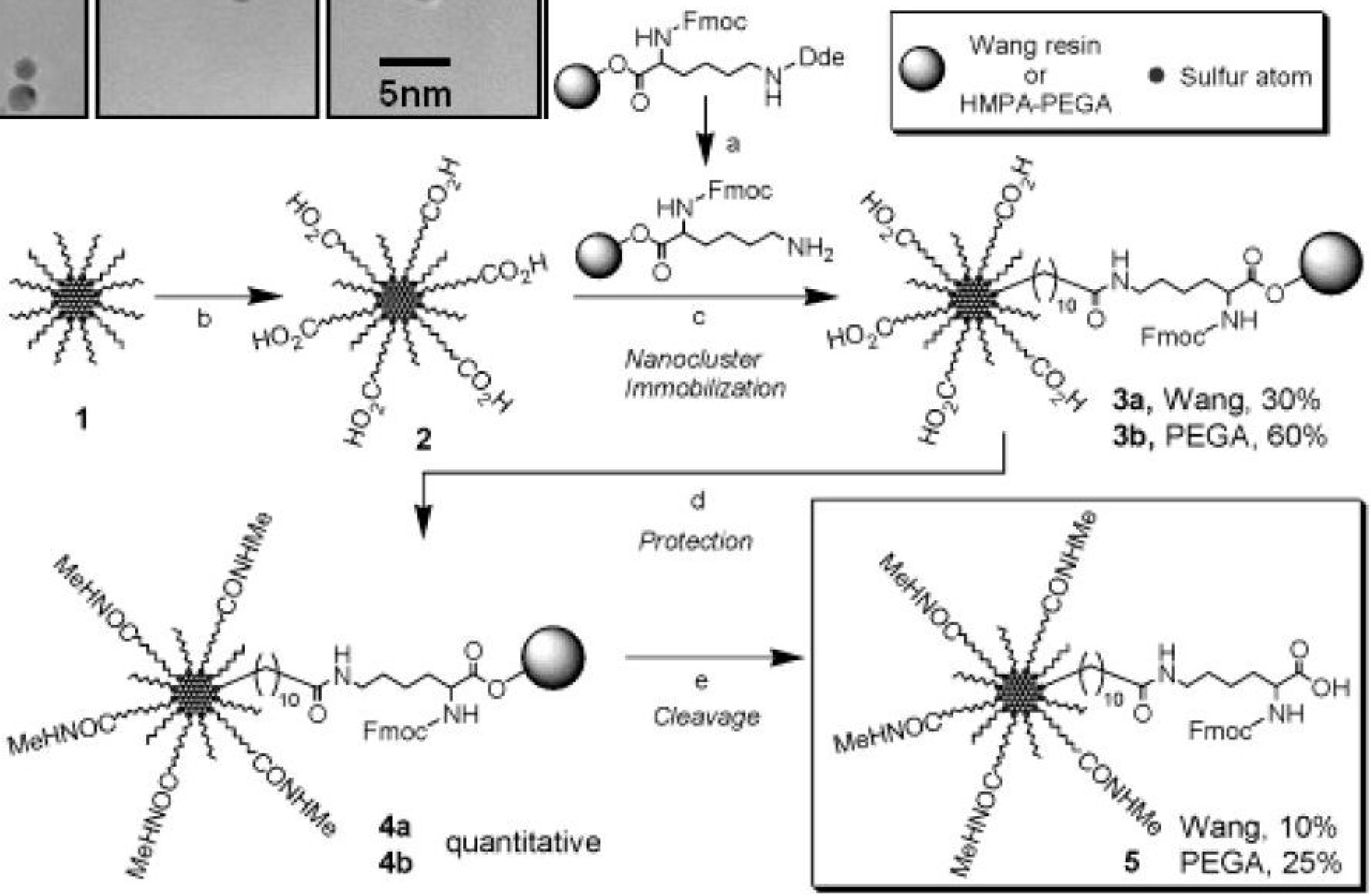






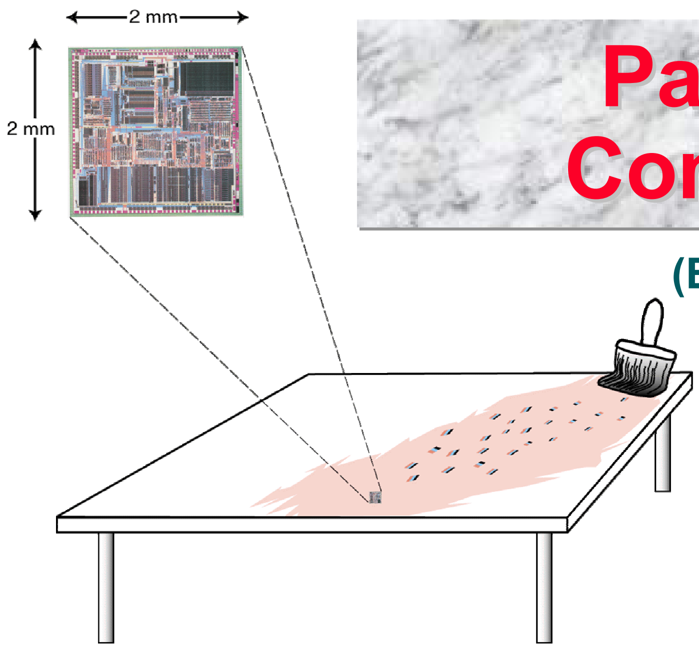
Monofunctionalized Nanoparticles

(K-M. Sung, D. Mosely, B. Peelle, S. Zhang, J. Jacobson)

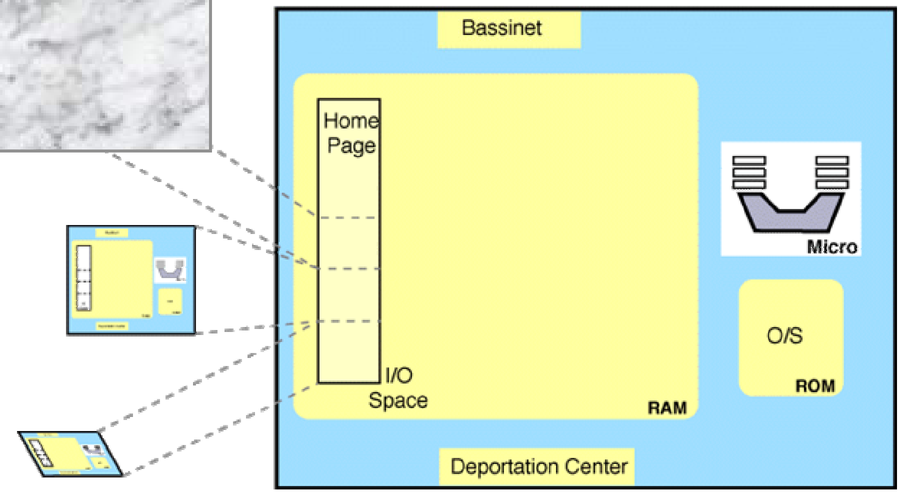


Paintable Computing

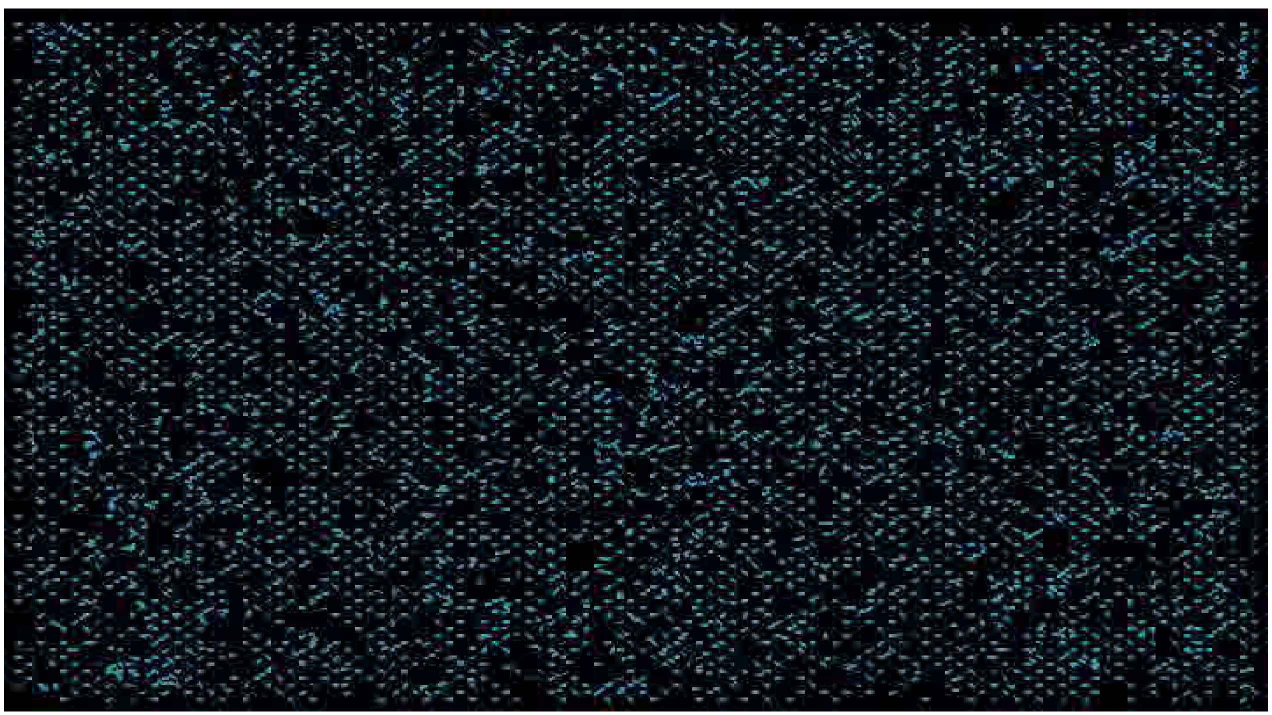
(Bill Butera)

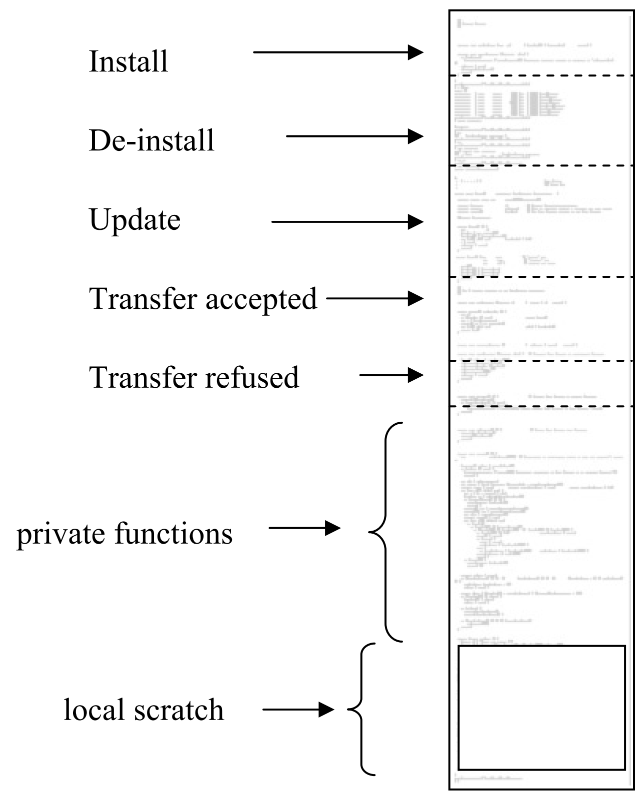


- reliable
- fungible
- distributed



Programming a Paintable Computer, W. Butera, Ph.D. thesis, MIT, 2001





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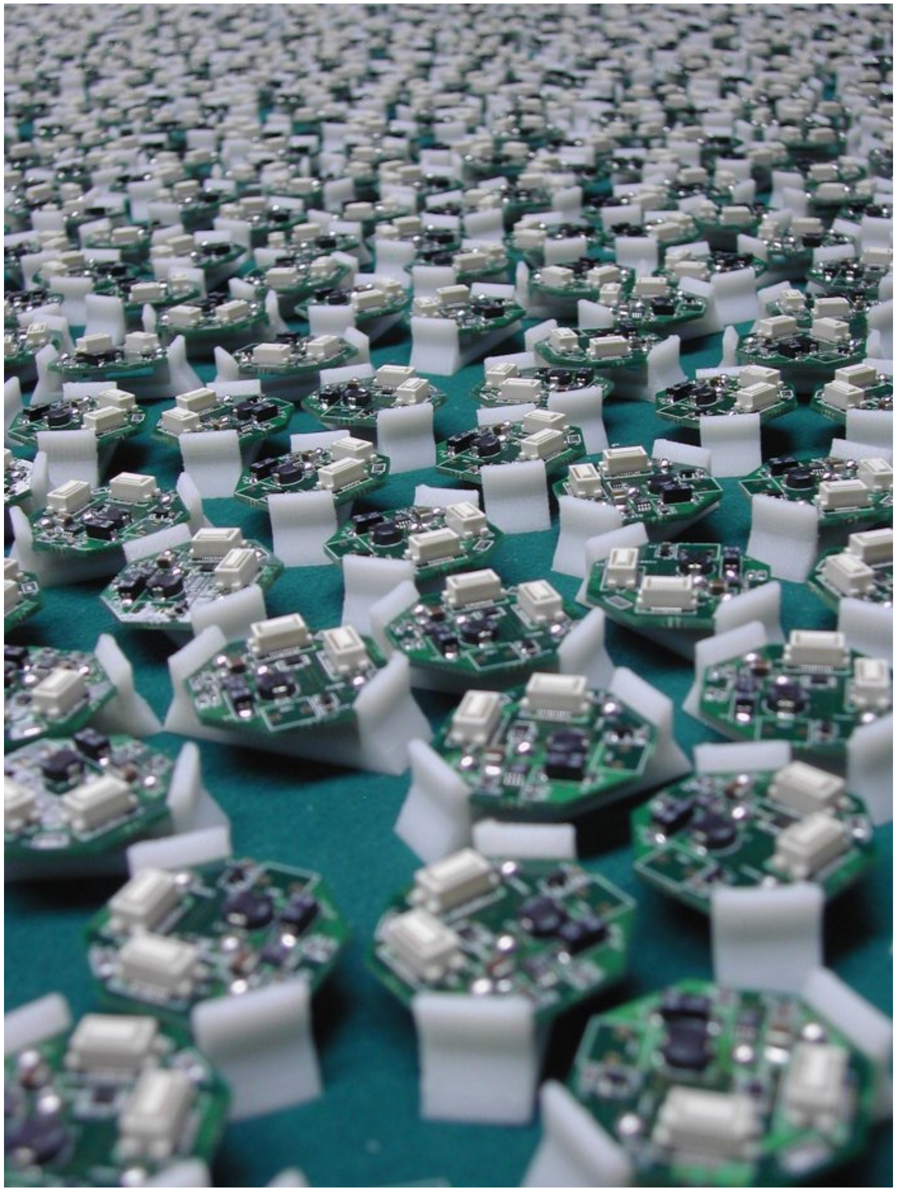
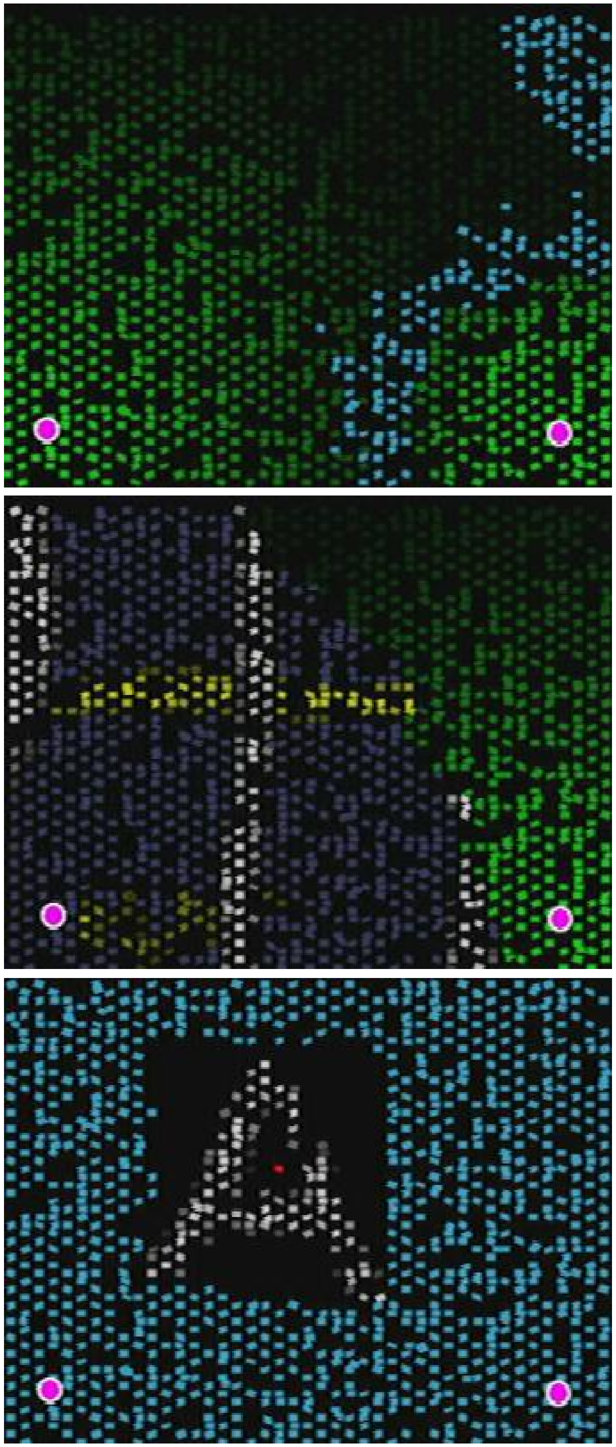
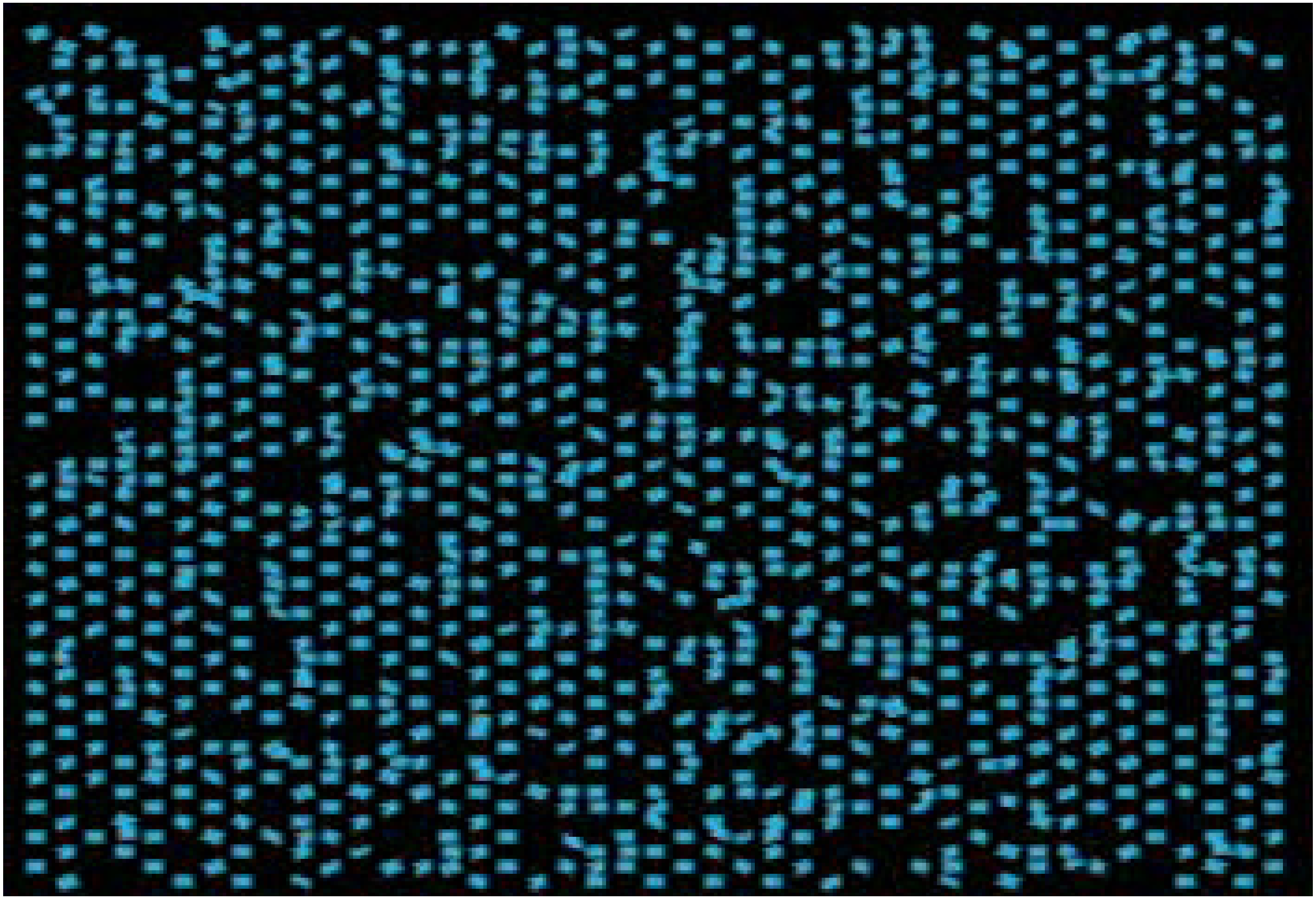




Statistical Displays



The Paintable Compiler

Ask Bill

Programming Distributed Systems

problem

↓

algorithm

↓

program

↓

executable

↓

protocol

↓

messages

↓

dynamics

Graphical Message-Passing

problem

algorithm

program

executable

protocol

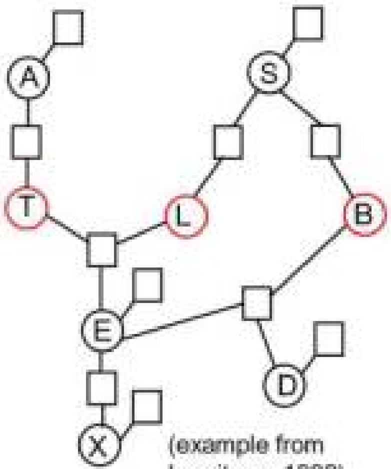
messages

dynamics

Graphical Networks

Bayesian Networks

(Pearl, 1988)

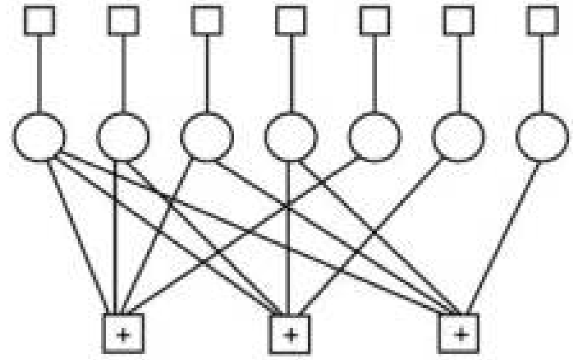


(example from Lauritzen, 1992)

Marginal Probabilities= "beliefs" about possible diagnoses

Error-correcting Codes

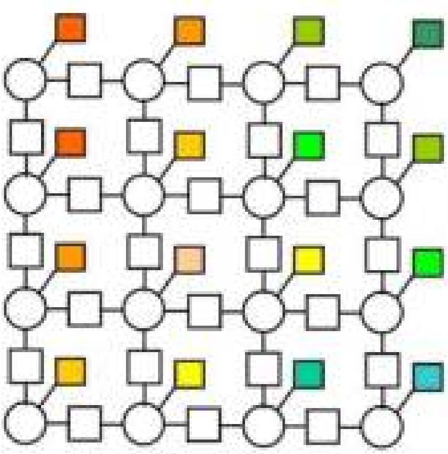
(Tanner, 1981 Gallager, 1963)



Marginal Probabilities = *A posteriori* bit probabilities

Computer Vision

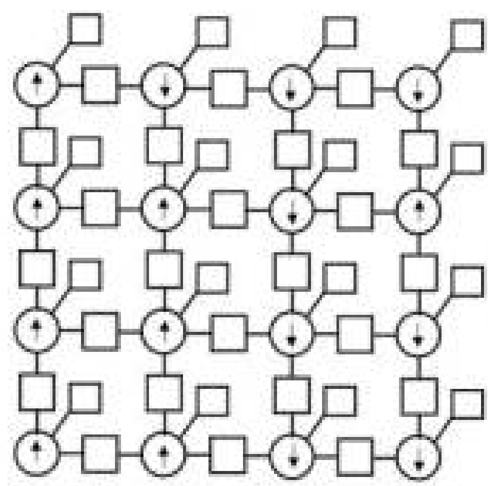
(Geman & Geman 1984)



Marginal Probabilities= "beliefs" about possible underlying scenes

Statistical Physics

(Ising 1925, Edwards & Anderson 1975)



Marginal Probabilities= local magnetization

Semirings

(Ali and McEliece)

$$f(x_i) = \sum_{\sim x_i} \cdots \sum \prod_n f(\vec{x}_n) \qquad \vec{x} = \arg\max_{x_1 \cdots x_N} \sum_n f_n(\vec{x}_n)$$

$$ab + ac = a(b + c) \qquad \max(a + b, a + c) = a + \max(b, c)$$

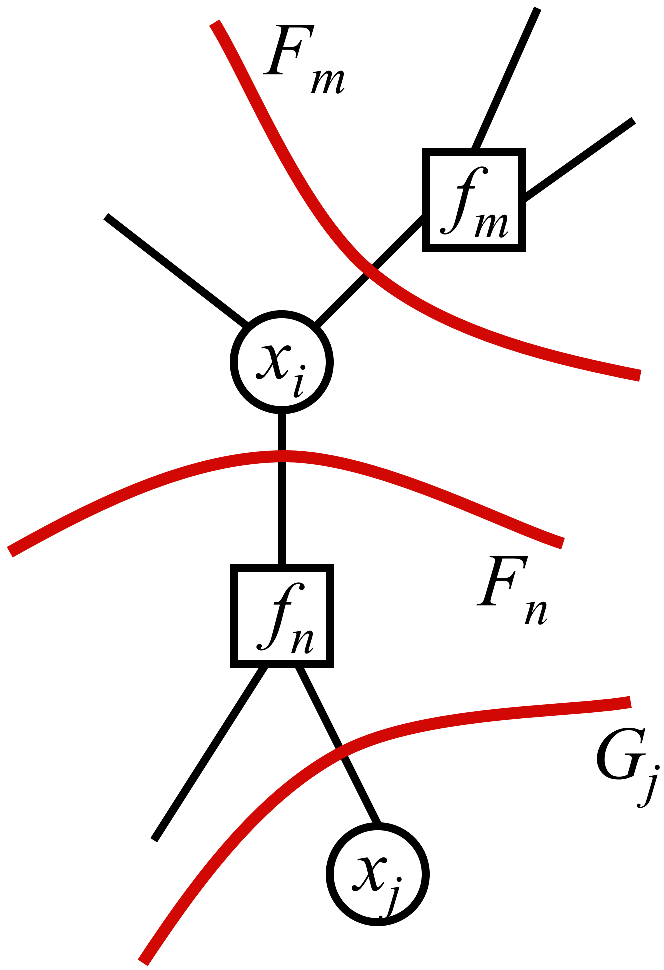
sum-product

(inference)

max-sum

(coding)

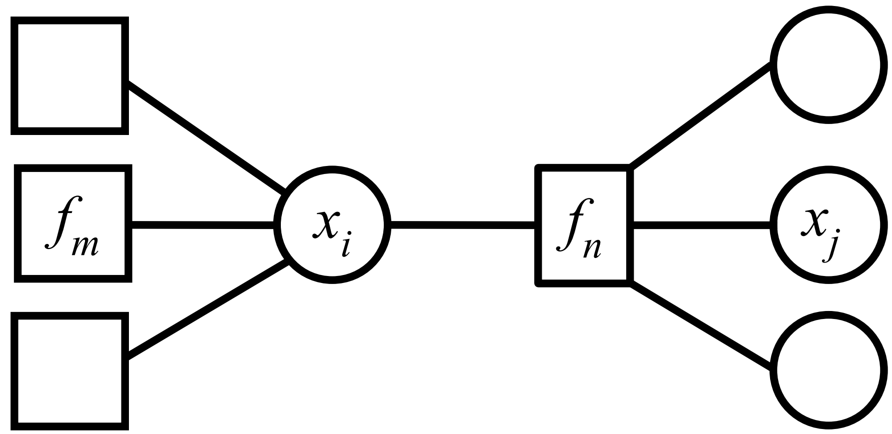
Recursion



$$
\begin{aligned}
f(x_i) &= \sum_{\vec{x}\backslash x_i} f(\vec{x}) \\
&= \sum_{\vec{x}\backslash x_i} \prod_n F_n(x_i, \vec{X}_n) \\
&= \prod_n \sum_{\vec{X}_n\backslash x_i} F_n(x_i, \vec{X}_n) \\
&= \prod_n \sum_{\vec{X}_n\backslash x_i} f_n(\vec{x}_n) \prod_j G_j(x_j, \vec{X}_j) \\
&= \prod_n \sum_{\vec{x}_n\backslash x_i} f_n(\vec{x}_n) \prod_j \sum_{\vec{X}_j\backslash x_j} G_j(x_j, \vec{X}_j) \\
&= \cdots
\end{aligned}
$$

Sum Product

Belief propagation, …, (Loeliger, …)

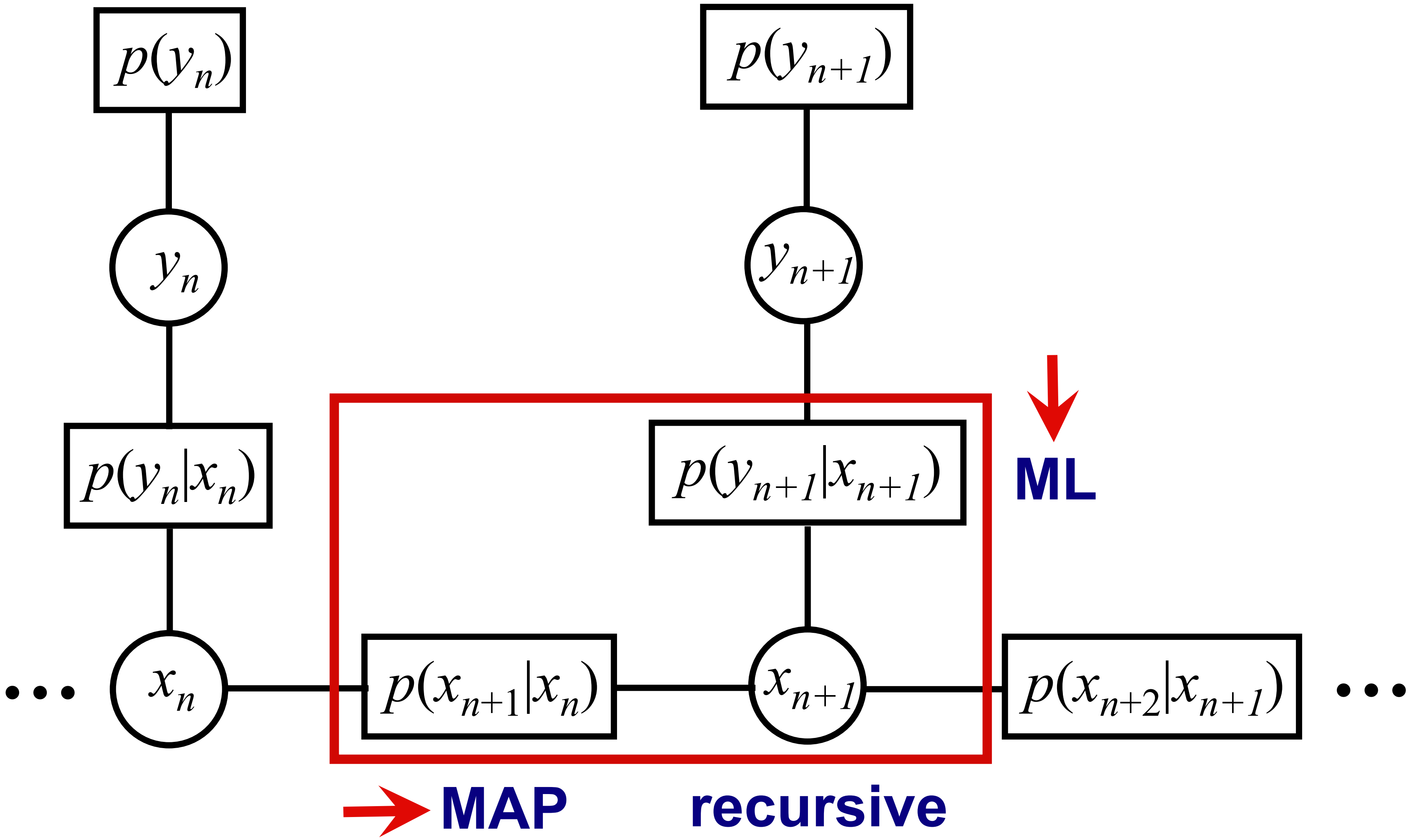


$$m_{x_i \to f_n}(x_i) = \prod_{f_m \in N(x_i) \setminus f_n} m_{f_m \to x_i}(x_i)$$

$$m_{f_n \to x_i}(x_i) = \sum_{\vec{x}_n \setminus x_i} f_n(\vec{x}_n) \prod_{x_j \in N(f_n) \setminus x_i} m_{x_j \to f_n}(x_j)$$

trees: exact **loops: approximations**

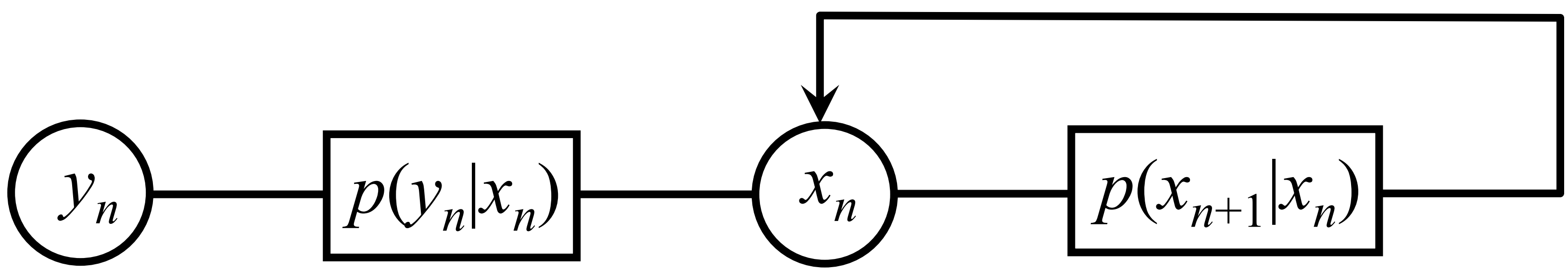
Estimation



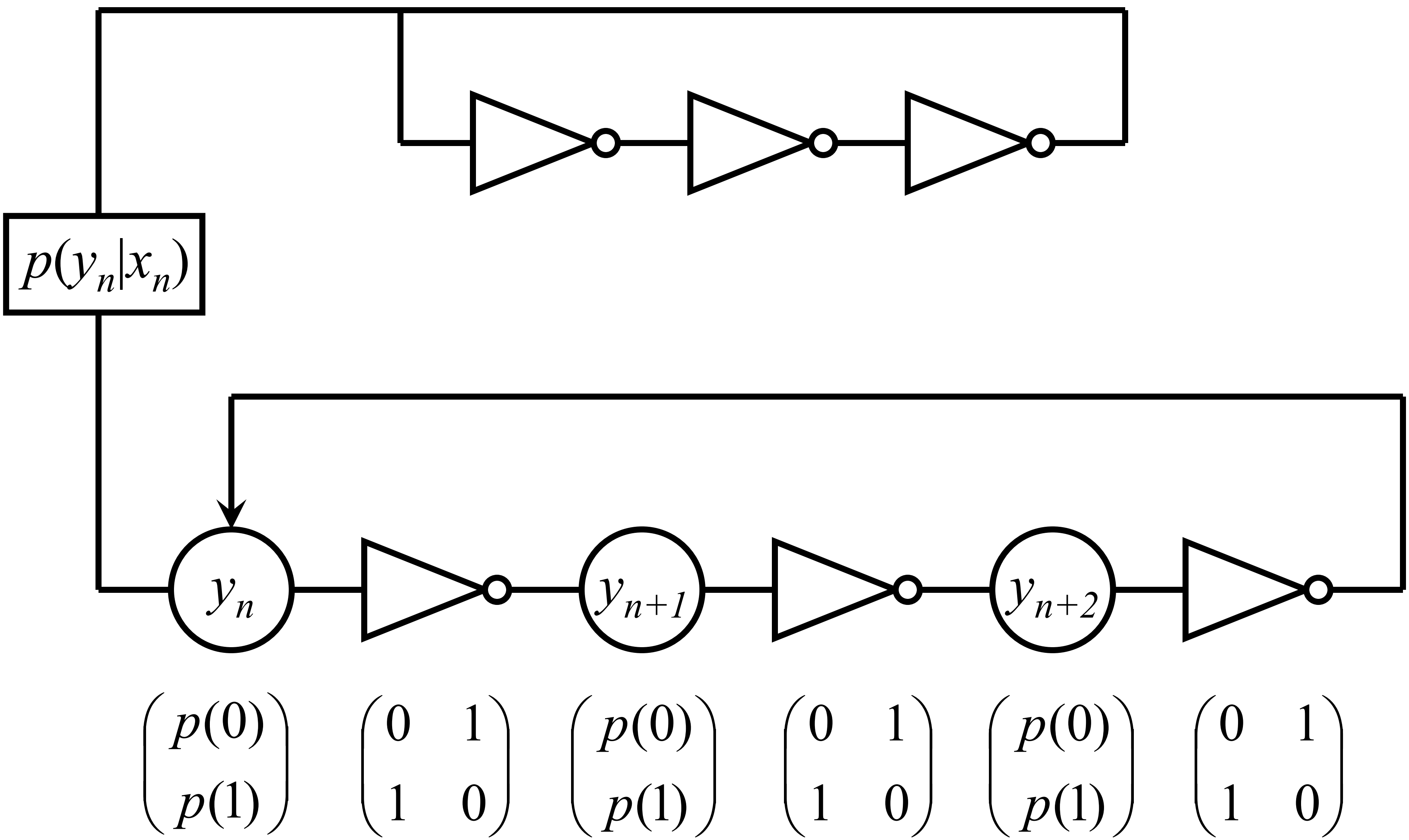
$p(y_n)$
$p(y_{n+1})$
y_n
y_{n+1}
ML
$p(y_n|x_n)$
$p(y_{n+1}|x_{n+1})$
$\cdots$
x_n
$p(x_{n+1}|x_n)$
x_{n+1}
$p(x_{n+2}|x_{n+1})$
$\cdots$
MAP
recursive

Feedback, Entrainment

(Ben Vigoda)



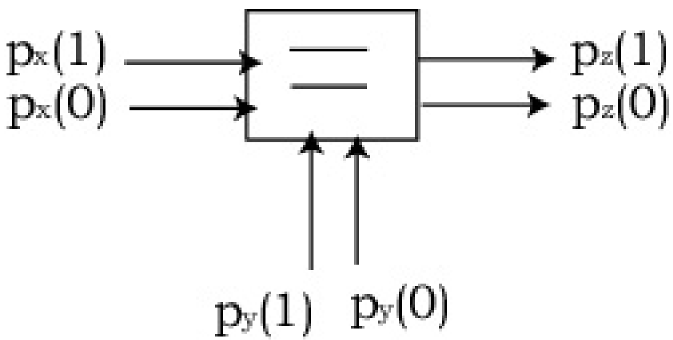
Phase-Locked Loop



Soft Gates

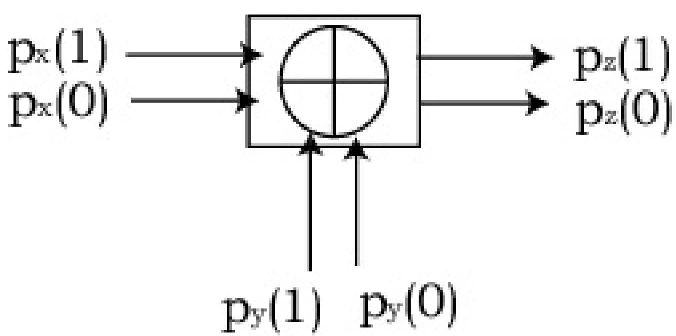
(Loeliger *et al.*, Ben Vigoda)

Soft equals



$$p_z(1) = p_x(1)\, p_y(1)$$
$$p_z(0) = p_x(0)\, p_y(0)$$

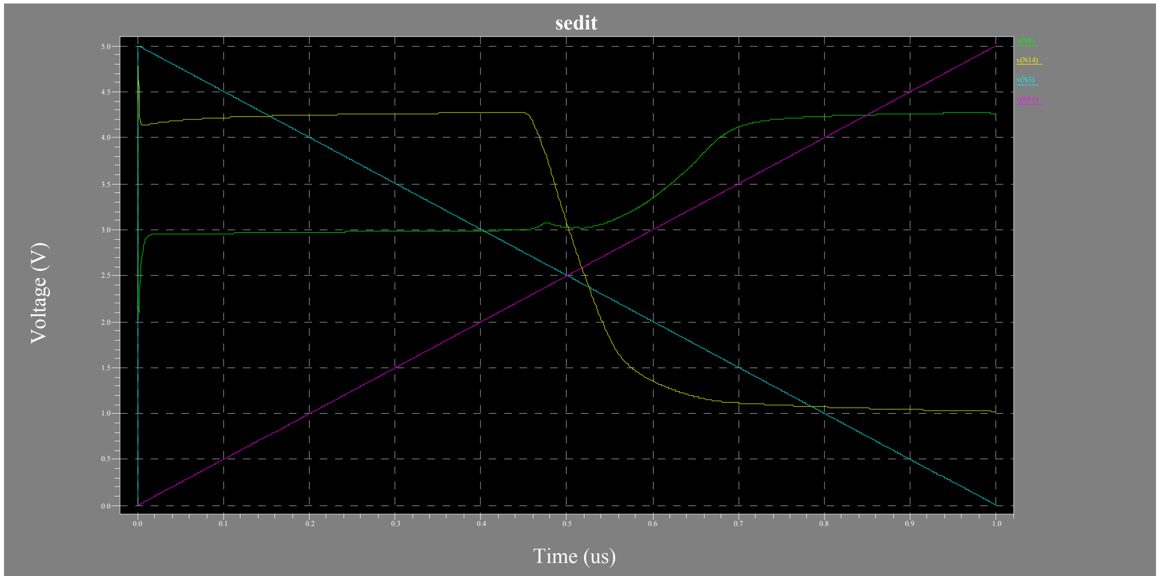
Soft XOR

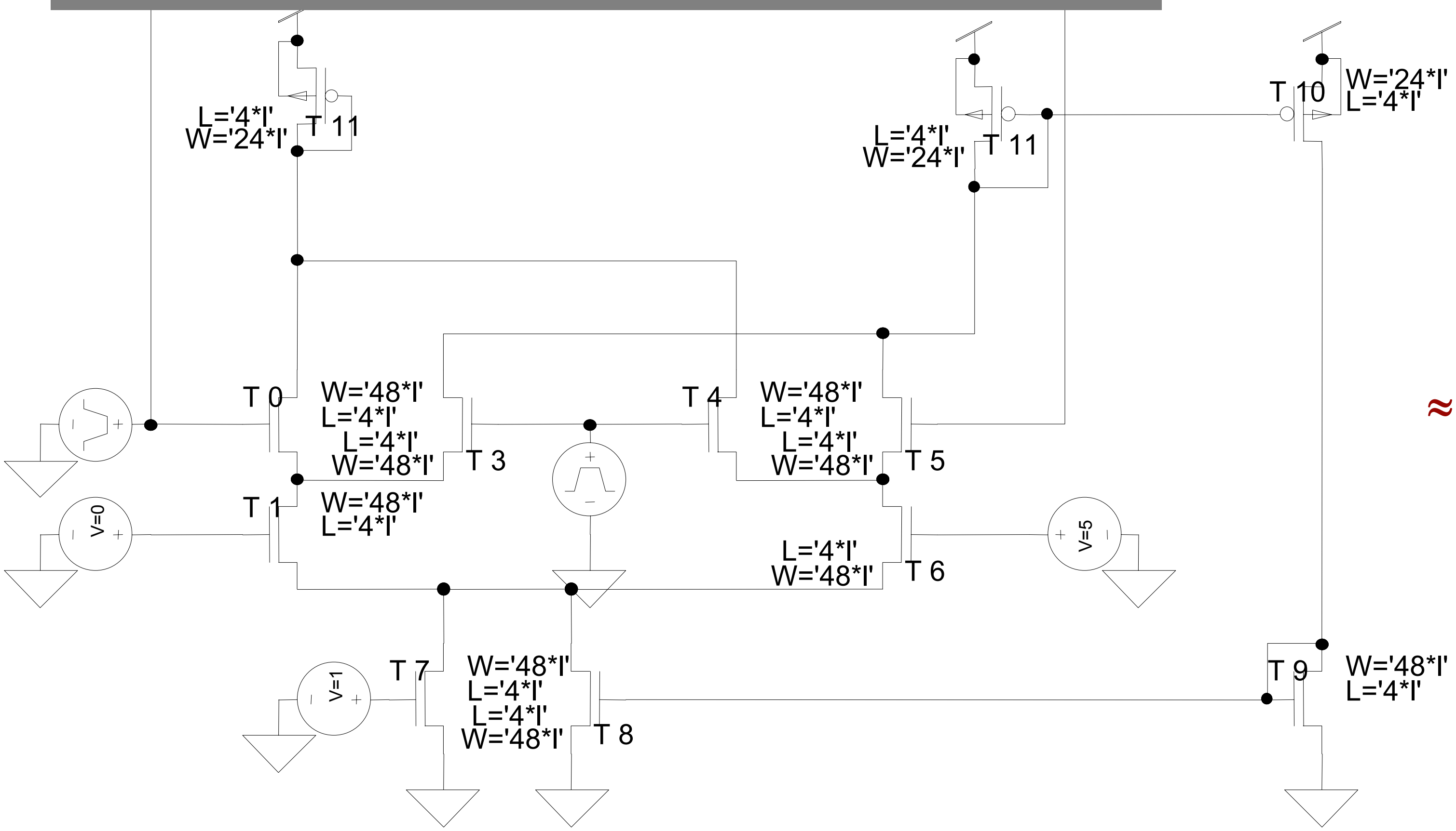


$$p_z(1) = p_x(0)\, p_y(1) + p_x(1)\, p_y(0)$$
$$p_z(0) = p_x(0)\, p_y(0) + p_x(1)\, p_y(1)$$

Soft Equals

(Ben Vigoda)

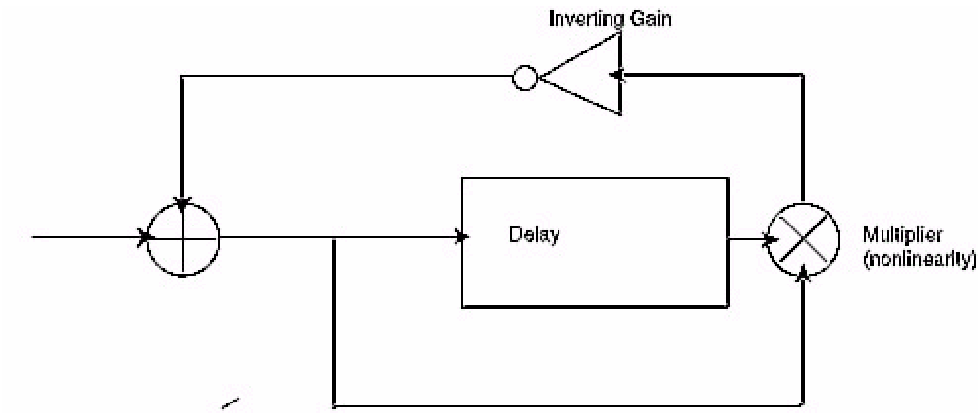


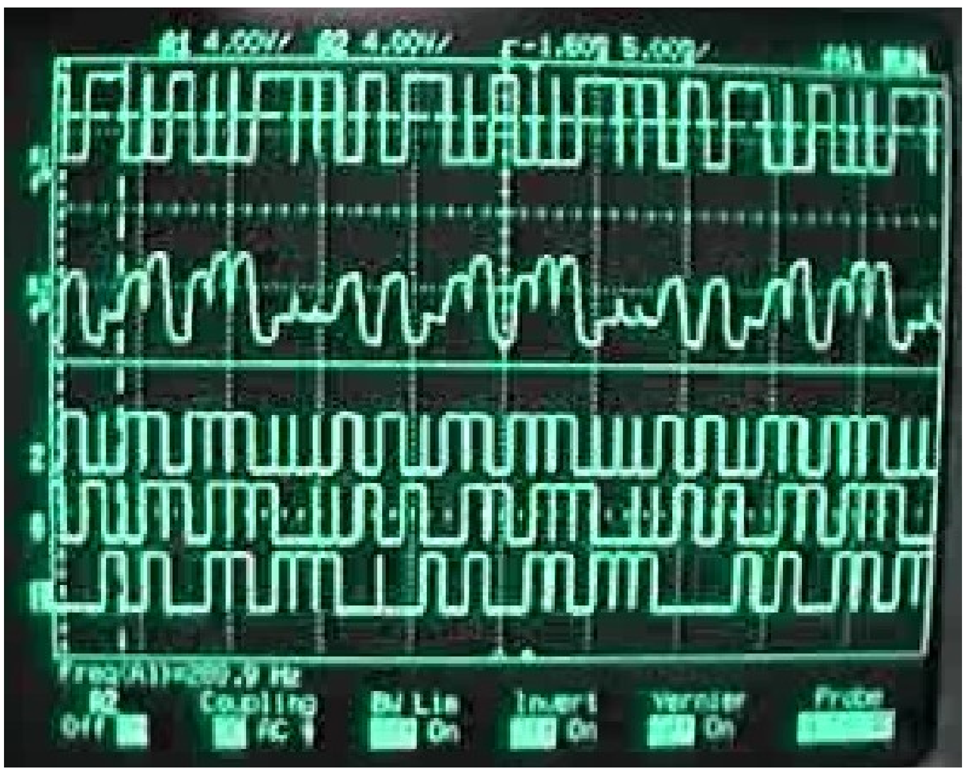


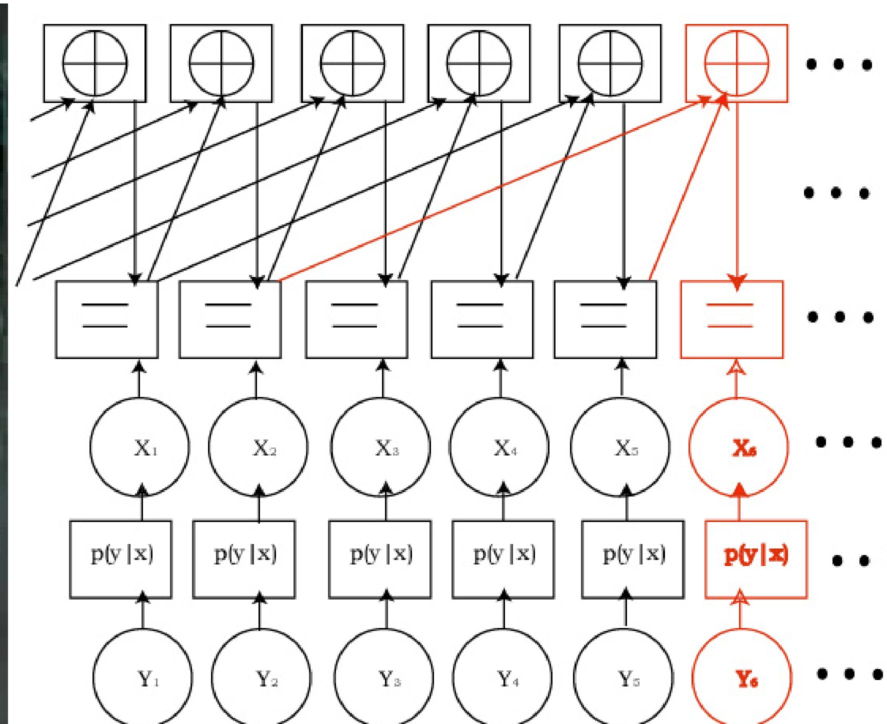
≈ Gilbert cell

Noise-Locked Loops

(Ben Vigoda)

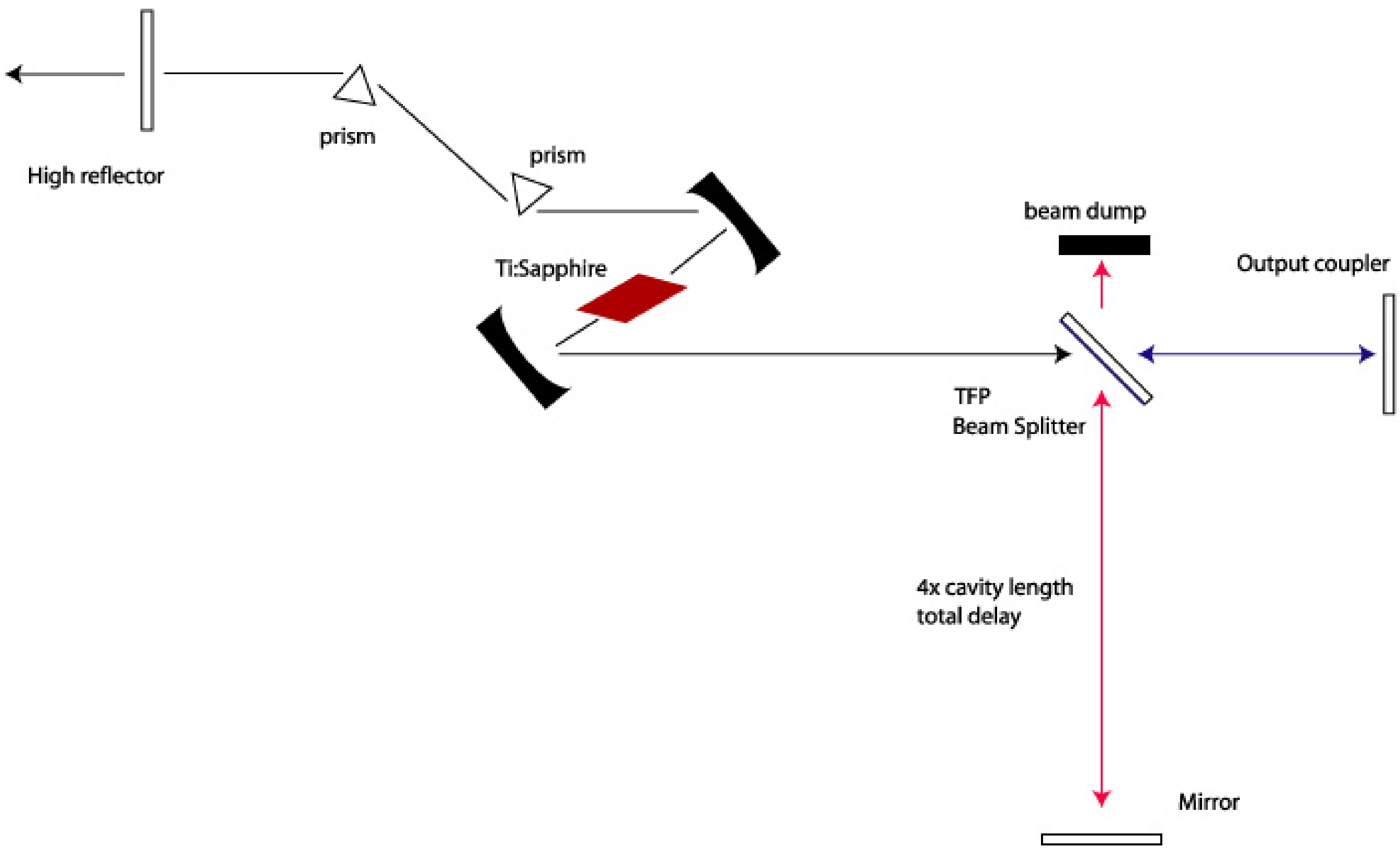






CDMA LFSR code acquisition

KLM NLL



High reflector
prism
prism
Ti:Sapphire
beam dump
Output coupler
TFP
Beam Splitter
4x cavity length
total delay
Mirror

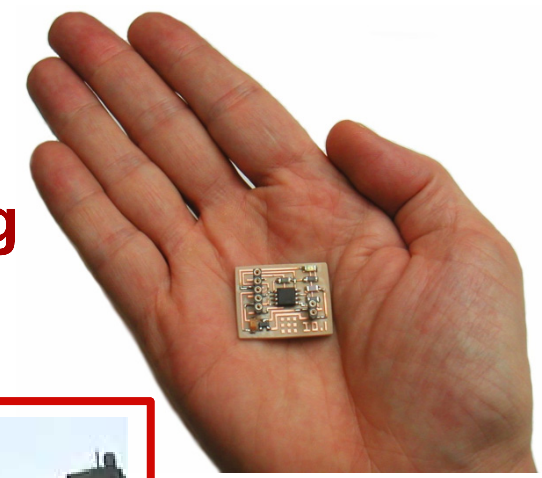
Internet 0 (I0)

(Raffi Krikorian, Danny Cohen, Doug Johnson)

- IP to leaf nodes
- peers don't need server
- physical identity
- compiled standards
- open standards
- big bits
- end to end modulation

IR	→	IRDA
RF	→	Bluetooth
powerline	→	Homeplug
multidrop	→	RS-485
RFID	→	EPC
bar codes	→	UPC
mag stripe	→	ANSI/ISO
telephone	→	V.92
telegraph	→	Morse Code

→ interdevice internetworking



3×10^8 m/s / 100 m = 3×10^6 s^{-1}

Thermodynamics

(Jonathan Yedidia)

$$p(\vec{x}) = \frac{e^{-E(\vec{x})/kT}}{\sum_{\vec{x}} e^{-E(\vec{x})/kT}} = \frac{e^{-E(\vec{x})/kT}}{Z} = \frac{e^{-E(\vec{x})}}{Z}$$

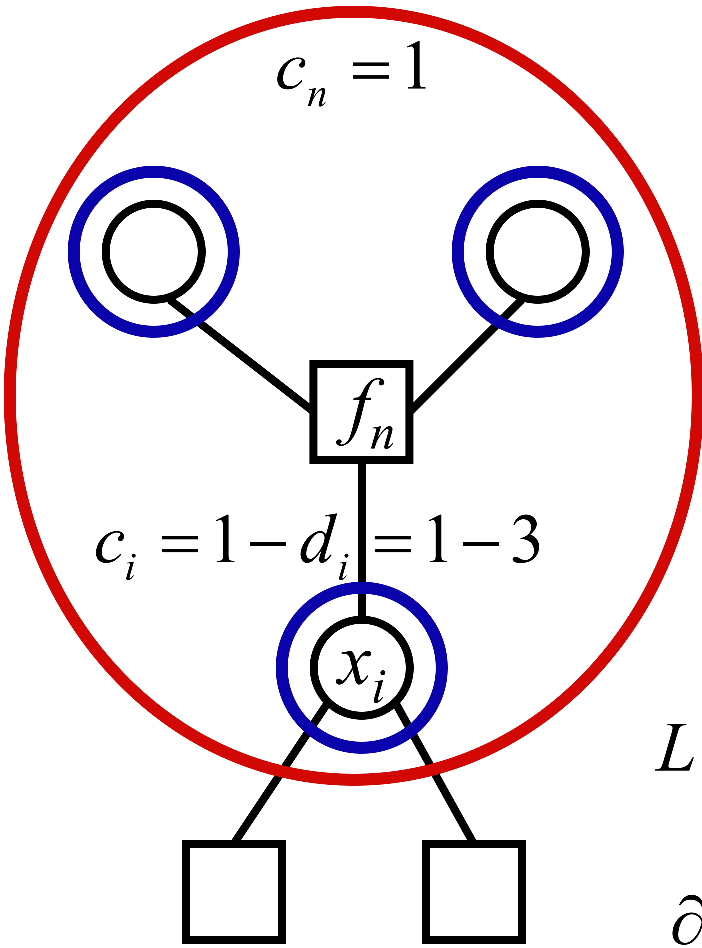
$$F_{\text{Helmholtz}} = -\ln Z$$

$$b(\vec{x}) \sim p(\vec{x})$$

$$\begin{aligned}
F_{\text{Gibbs}} &= U(b) - H(b) \\
&= \sum_{\vec{x}} b(\vec{x}) E(\vec{x}) + \sum_{\vec{x}} b(\vec{x}) \log b(\vec{x}) \\
&= \sum_{\vec{x}} b(\vec{x})(-)\log(p(\vec{x})Z) + \sum_{\vec{x}} b(\vec{x}) \log b(\vec{x}) \\
&= -\sum_{\vec{x}} b(\vec{x}) \log Z - \sum_{\vec{x}} b(\vec{x}) \log p(\vec{x}) + \sum_{\vec{x}} b(\vec{x}) \log b(\vec{x}) \\
&= -\sum_{\vec{x}} \log Z + \sum_{\vec{x}} b(\vec{x}) \log \frac{b(\vec{x})}{p(\vec{x})} \\
&= -\sum_{\vec{x}} \log Z + D\big(b \,\|\, p\big)
\end{aligned}$$

Bethe Approximation

(Jonathan Yedidia)



$$U \approx \sum_R c_R U_R(b_R) \quad H \approx \sum_R c_R H_R(b_R)$$

$$U_{\text{Bethe}} = \sum_n \sum_{\vec{x}_n} b_n(\vec{x}_n) \log f_n(\vec{x}_n)$$

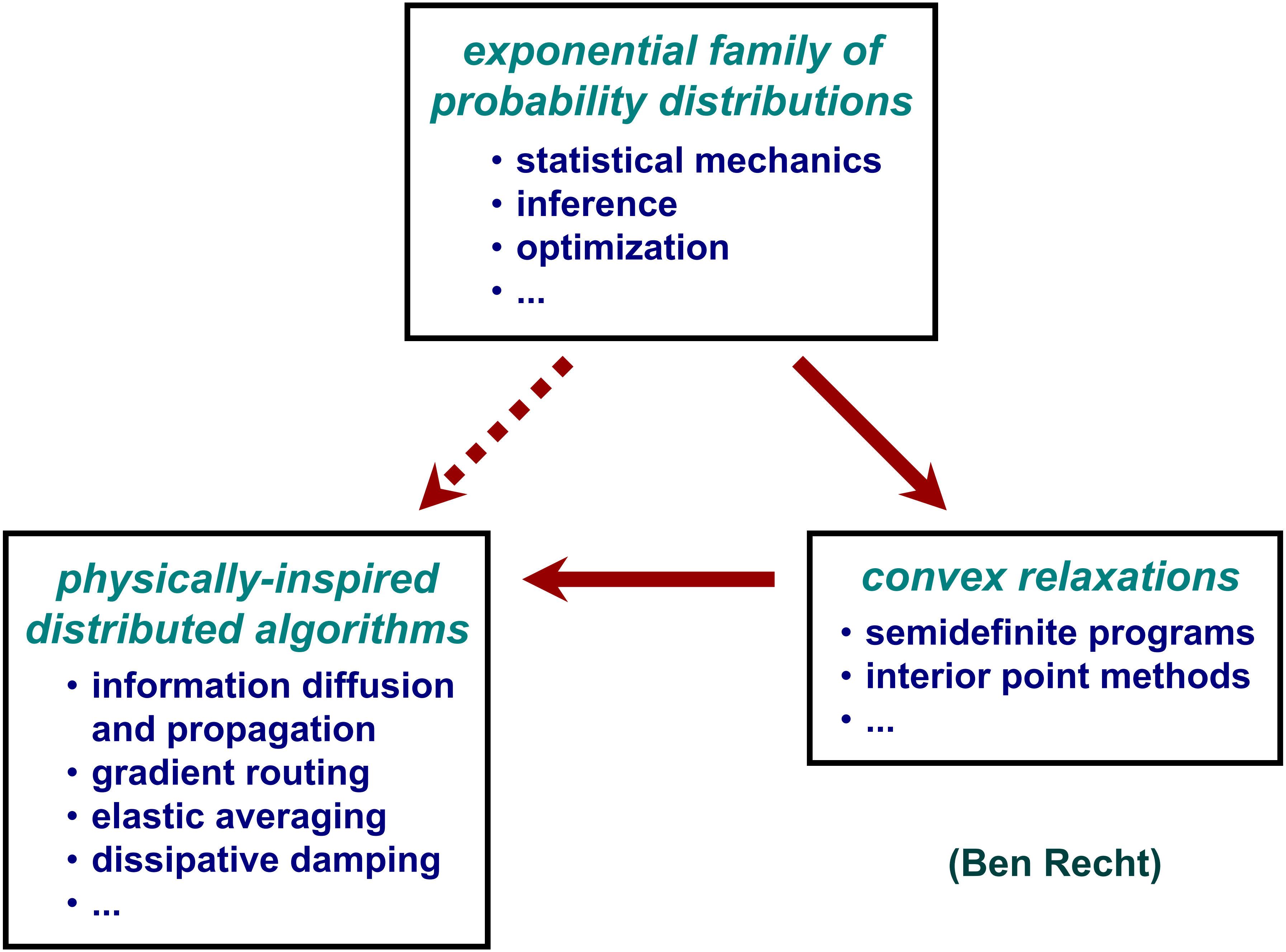
$$H_{\text{Bethe}} = \sum_n \sum_{\vec{x}_n} b_n(\vec{x}_n) \log b_n(\vec{x}_n)$$

$$- \sum_i (1 - d_i) \sum_{x_i} b_i(x_i) \log b_i(x_i)$$

$$L = U - H + \sum_i \sum_n \lambda_{in} \left(b_i(x_i) - \sum_{\vec{x}_n \setminus x_i} b_n(\vec{x}_n) \right)$$

$$\frac{\partial L}{\partial b_n} = 0 \Rightarrow b_n(\vec{x}_n) \propto f_n(\vec{x}_n) \prod_{x_i \in N(f_n)} e^{\lambda_{in}}$$

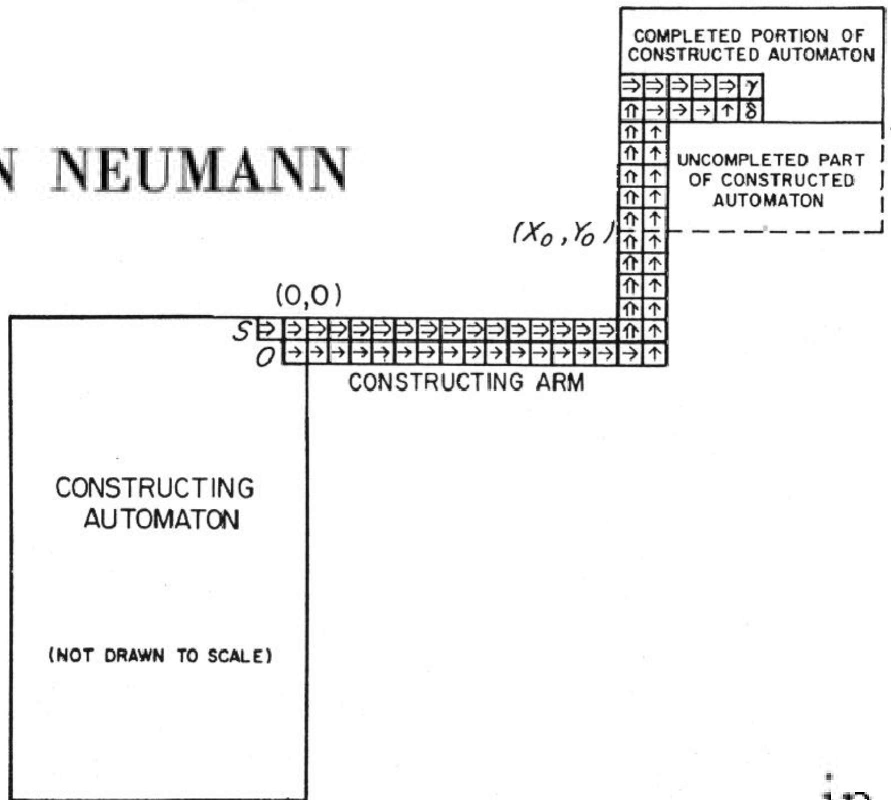
$$\lambda_{in} = \log m_{x_i \to f_n}(x_i)$$


exponential family of probability distributions
• statistical mechanics
• inference
• optimization
• ...
physically-inspired distributed algorithms
• information diffusion and propagation
• gradient routing
• elastic averaging
• dissipative damping
• ...
convex relaxations
• semidefinite programs
• interior point methods
• ...

(Ben Recht)

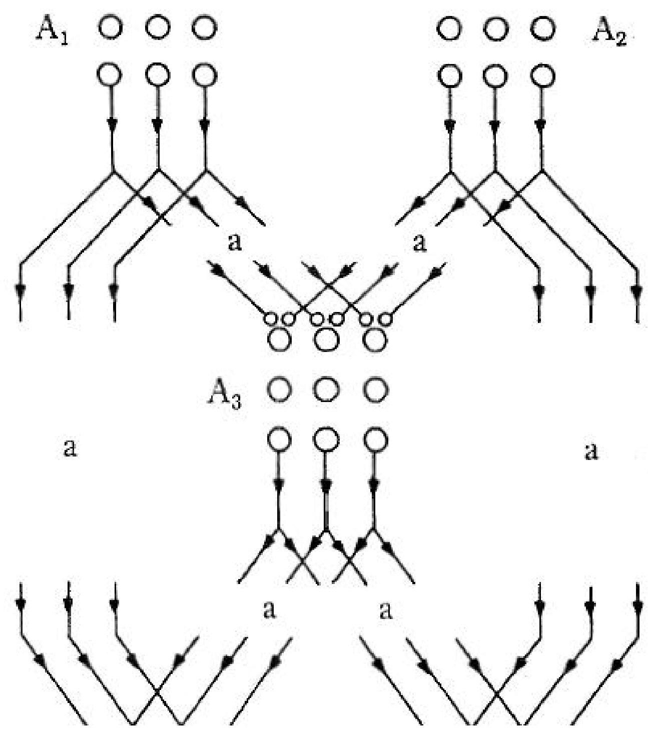
Theory of Self-Reproducing Automata

JOHN VON NEUMANN



Fourth Lecture

THE ROLE OF HIGH AND OF EXTREMELY HIGH COMPLICATION



Reliable Computation in the Presence of Noise

S. Winograd and *J. D. Cowan*

Graduate Study in Design and the Natural Sciences

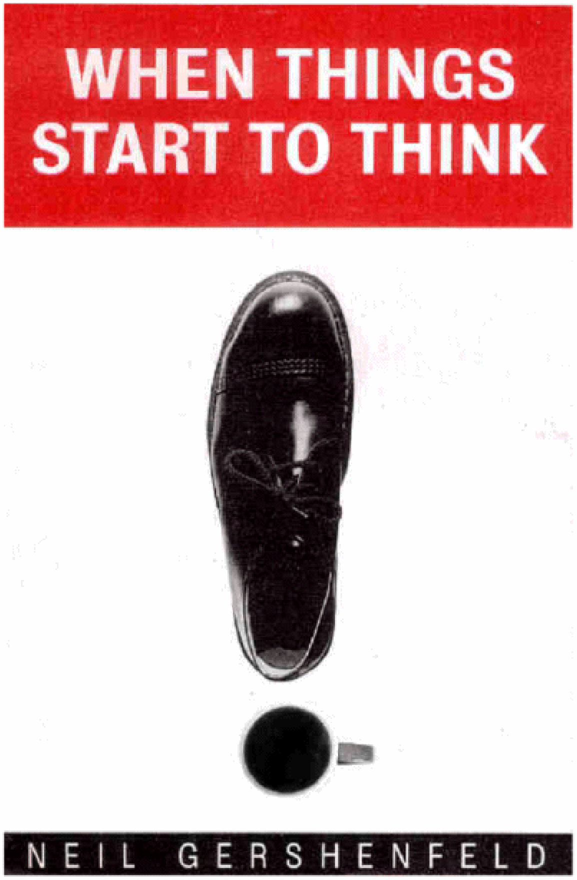
draft proposal: **6/23/04**

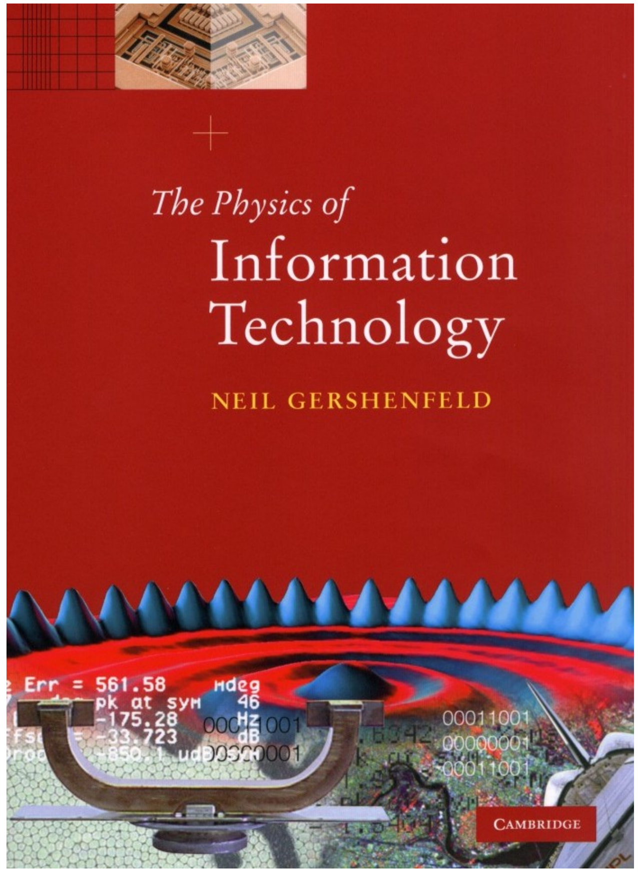
Design and the Natural Sciences is a graduate academic program asking how the resources of natural systems can be used to embody functional designs in physical forms, and conversely how functional descriptions can be abstracted from physical forms. The goal is to bring the programmability of the digital world to the physical world, with applications ranging from fundamental scientific practice for studying computationally-universal physical systems, to engineering in a limit of thermodynamic complexity, to the personalization of fabrication rather than computation. To accomplish this, DNS provides training in the interdisciplinary research areas associated with MIT's Center for Bits and Atoms (CBA), bringing together faculty from across campus in departments including Physics, Chemistry, Biology, Mathematics, Computer Science, and Electrical and Mechanical Engineering, all working at the interface between logical and physical representations of information. DNS is part of the Media Arts and Sciences (MAS) program, which provides a broader context for studying the social as well as intellectual impact of emerging technologies on human expression.

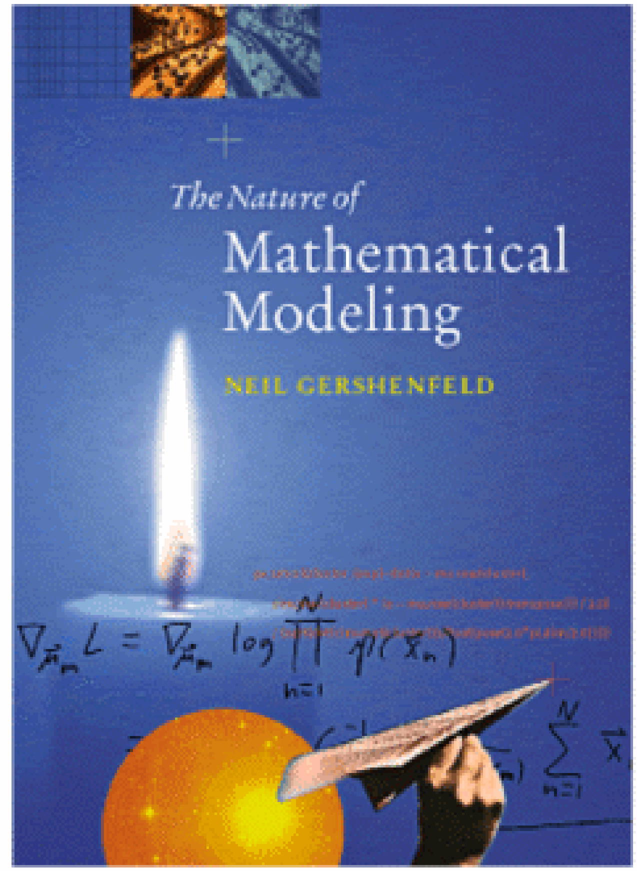
DNS teaches design practice in science, rather than scientific practice in design. Herbert Simon first articulated the goal of a "science of design", in The Sciences of the Artificial. This program sought to create desired artificial systems rather then describe existing natural ones, and was realized in the development of CAD and machine optimization, Artificial Intelligence and Artificial Life, and ultimately whole virtual digital worlds. The Sciences of the Artificial was itself a response to the growing dominance of physical science in engineering. The success of science in World War II was followed by the growth of engineering as a scientific rather than empirical discipline; a scientific approach to design was then seen as being needed to counter the rise of experimental studies in new areas such as condensed matter physics which emphasized observation over problem-solving skills.

DNS now seeks to transcend this historical division between the artificial and natural. Abstractions that isolate the process of design from underlying physical degrees of freedom are increasingly unsustainable, driven by the demands of fundamental physical scaling limits as well as:

To Follow Up







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