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Overview: Converging, Combining, Emerging

Dr. George Poste, Director
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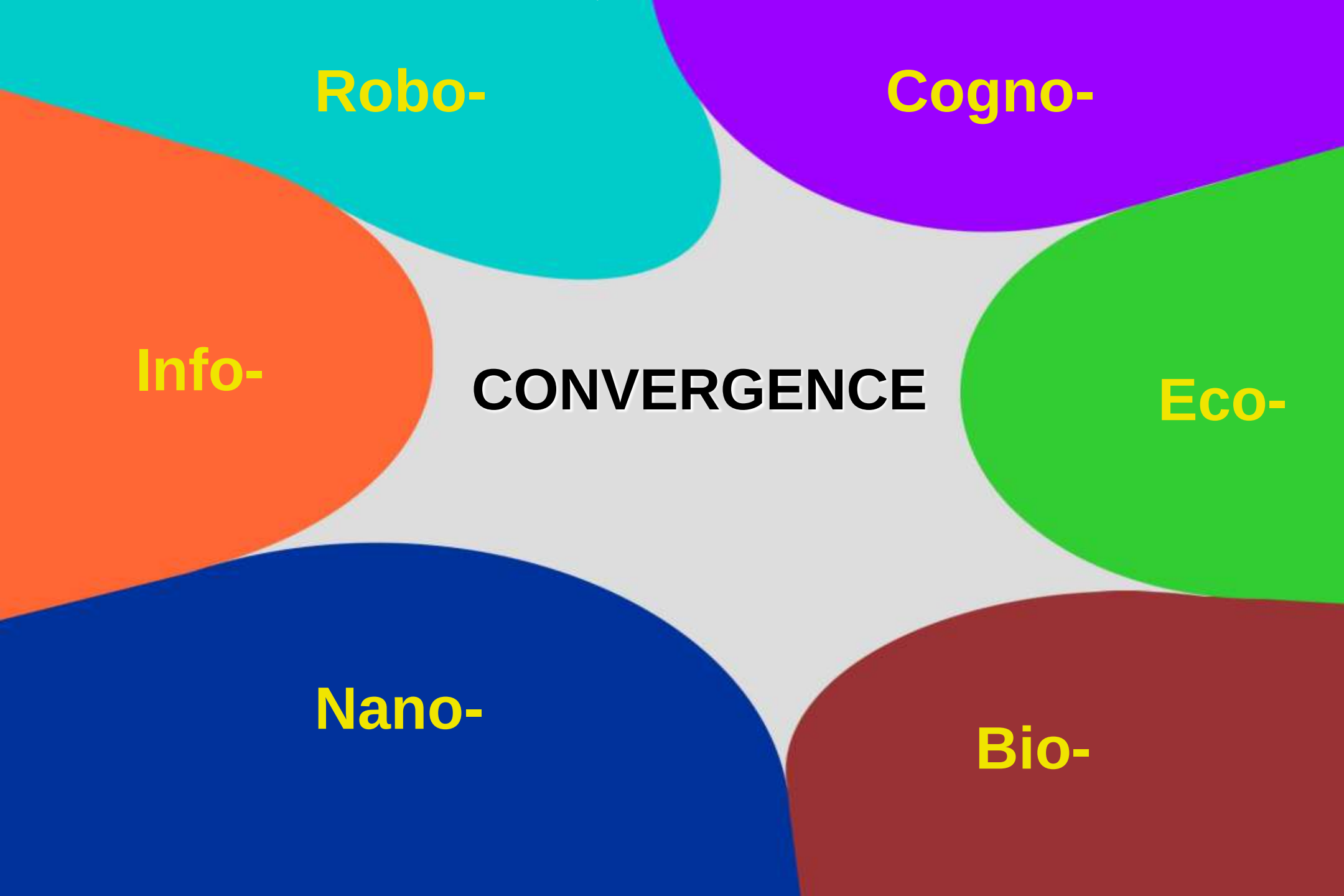
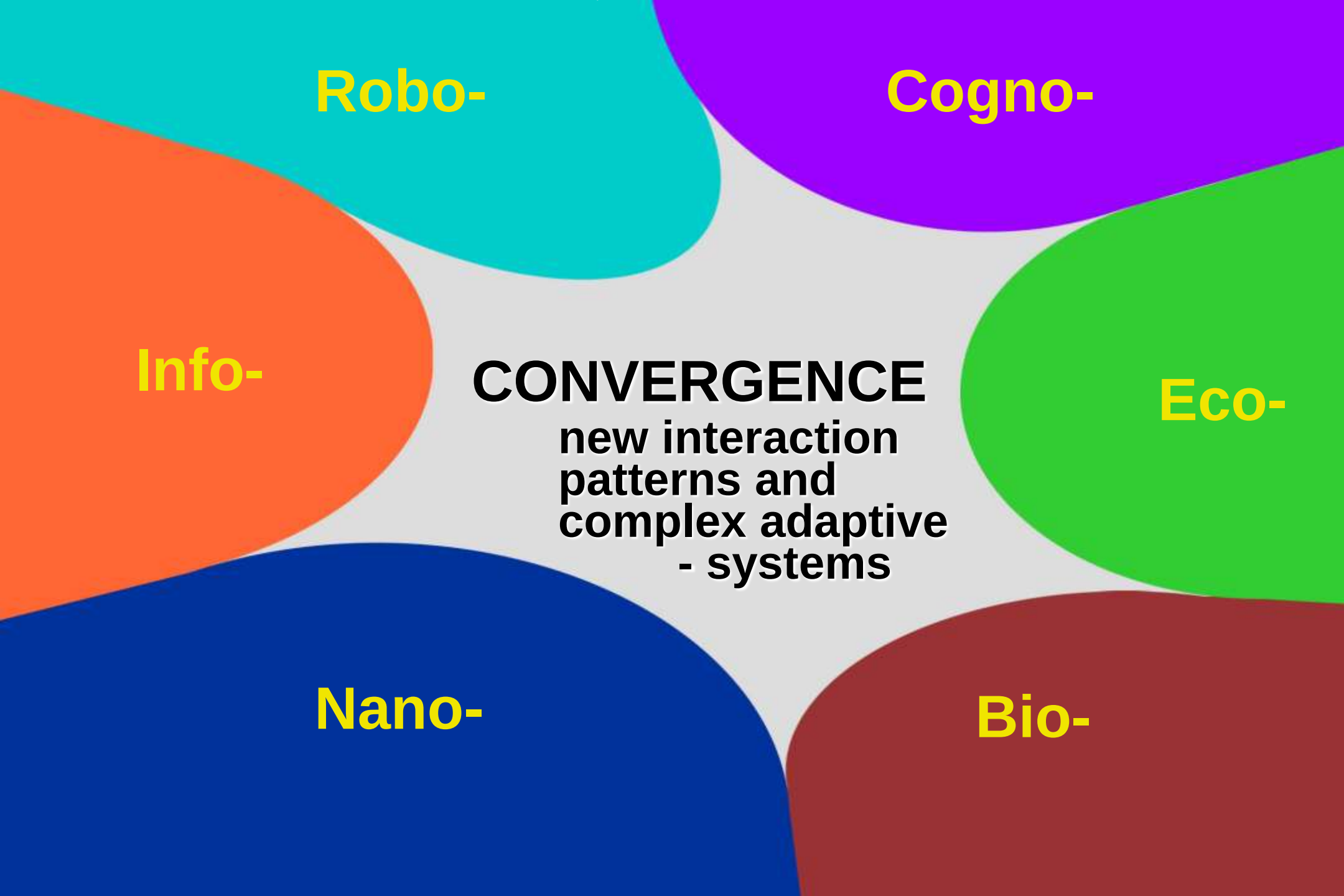
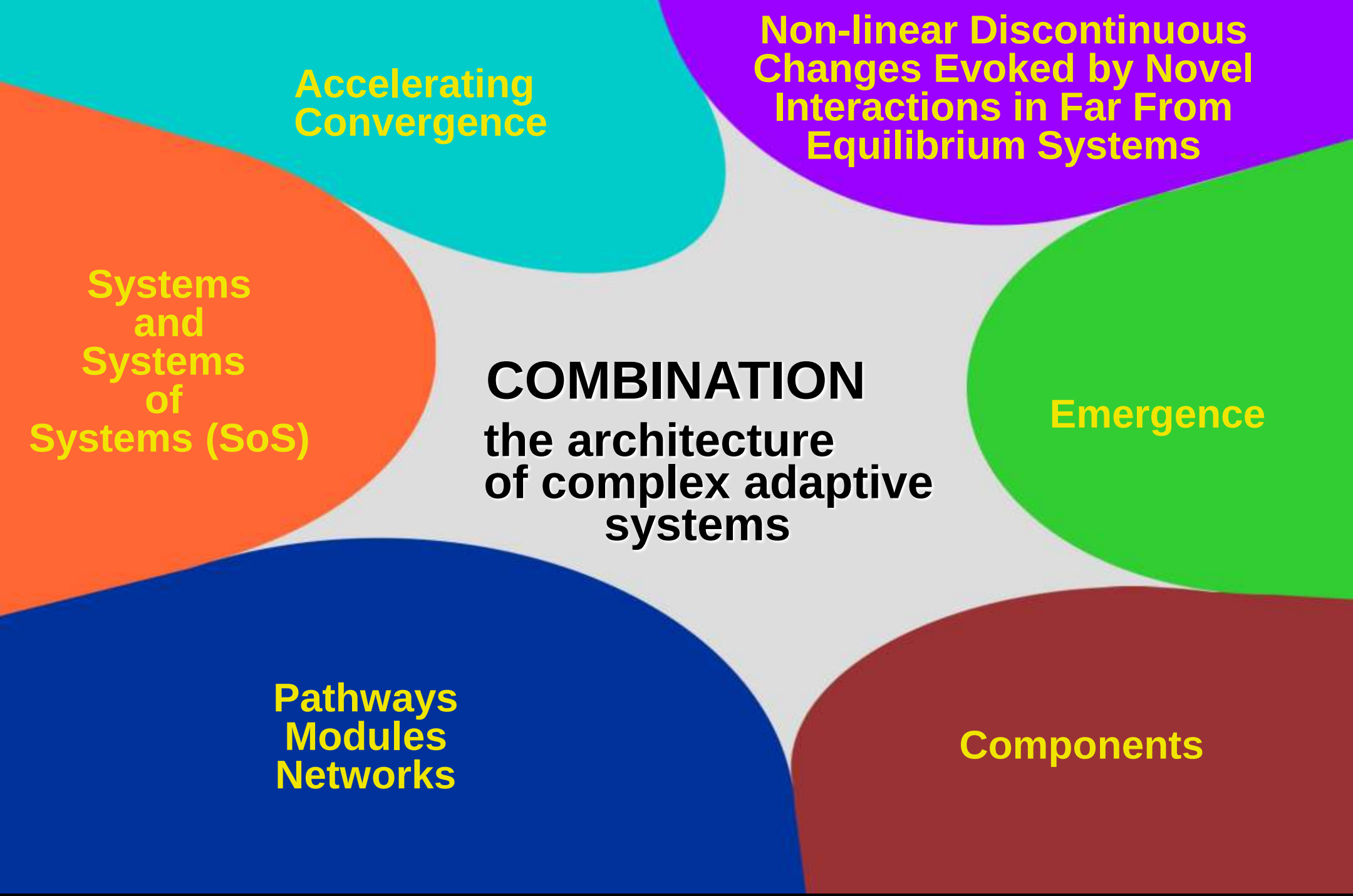
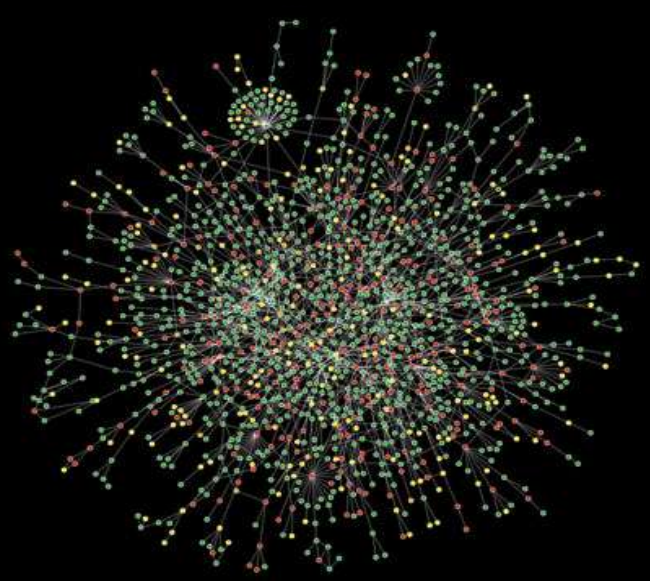
E.mail: george.poste@asu.edu

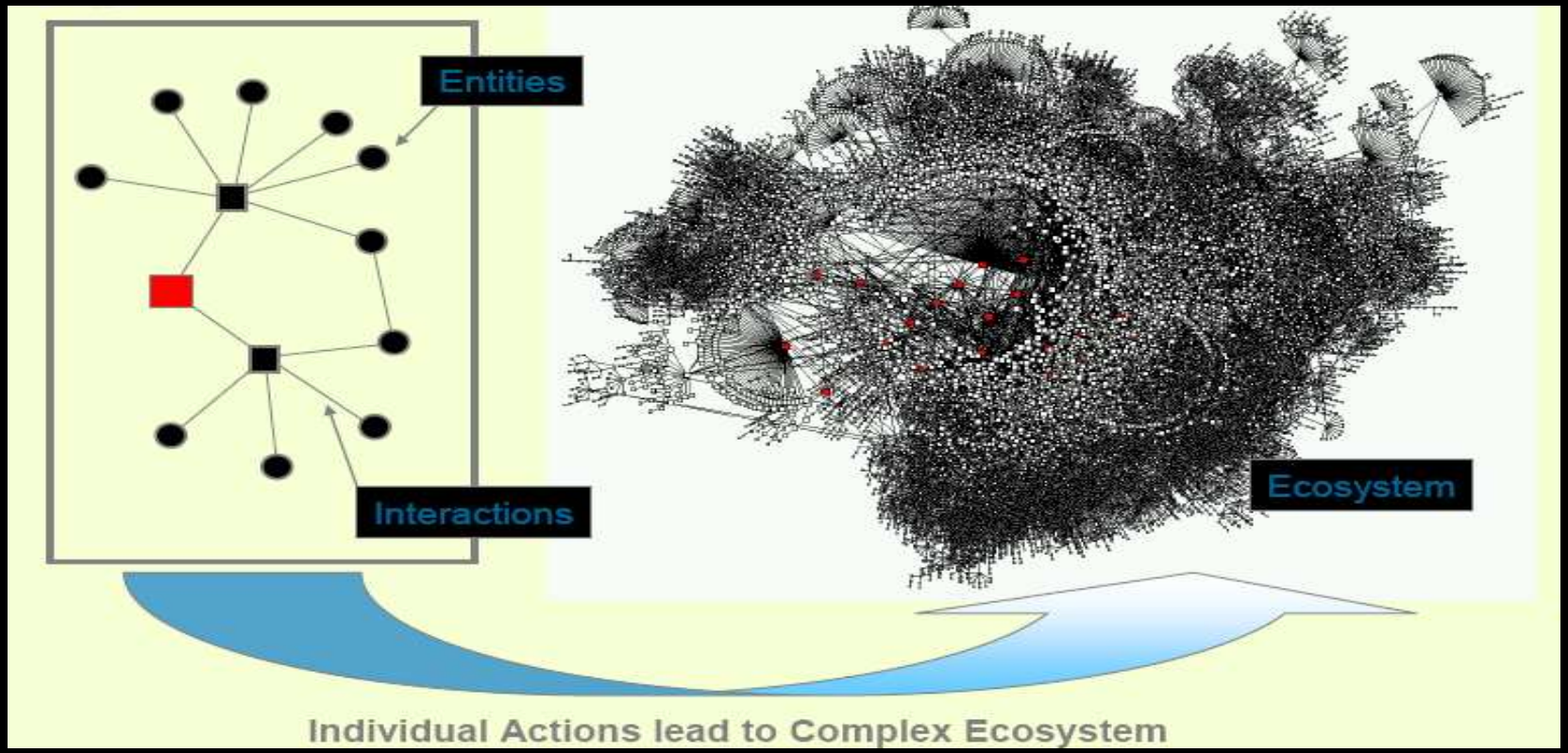
Highlands Forum 32, Arizona, 29 May 2007


Robo-
Cogno-
Info-
CONVERGENCE
Eco-
Nano-
Bio-


Robo-
Cogno-
Info-
CONVERGENCE
new interaction patterns and complex adaptive - systems
Eco-
Nano-
Bio-


Accelerating Convergence
Non-linear Discontinuous Changes Evoked by Novel Interactions in Far From Equilibrium Systems
Systems and Systems of Systems (SoS)
COMBINATION
the architecture of complex adaptive systems
Emergence
Pathways Modules Networks
Components




Entities
Interactions
Ecosystem
Individual Actions lead to Complex Ecosystem

Complex Adaptive Systems

- specialized, modular, hierarchical multiscale structures with enormous ‘hidden’ complexity
- robust to uncertainties that are commonly encountered
- highly optimized tolerance
- vulnerable to unknown or neglected perturbations and design flaws

ROBUST BUT FRAGILE

- far-from-equilibrium systems
- edge-of-chaos, criticality, near bi-furcation, phase changes, inflection points, tipping points

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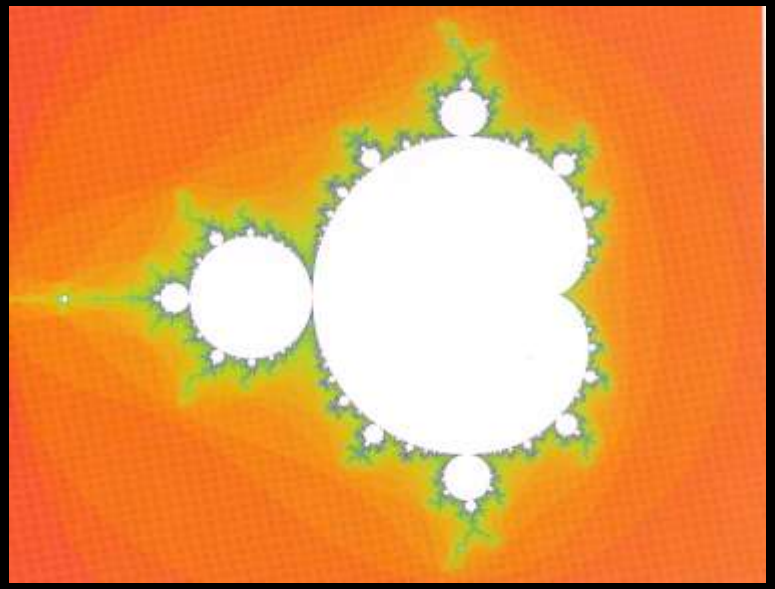
Emergence: Discontinuous Non-Linear Macro-Level Change Triggered by Convergence of Micro-Level Events



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"For most of us design is invisible. Until it fails" Bruce Mau. Massive Change. 2004

The Poverty of Imagination

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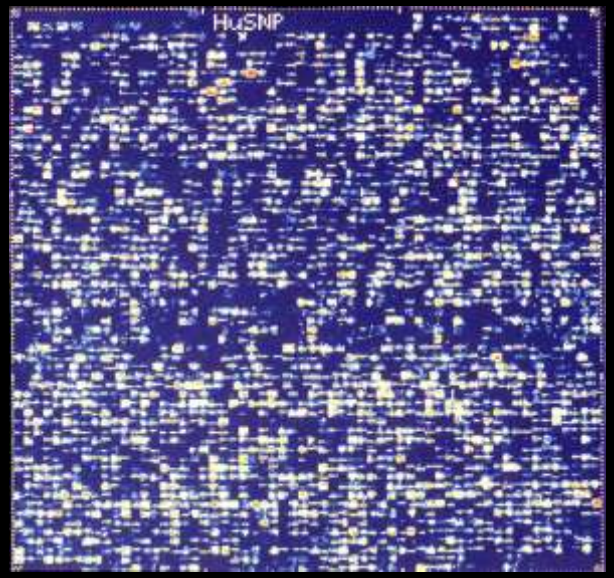
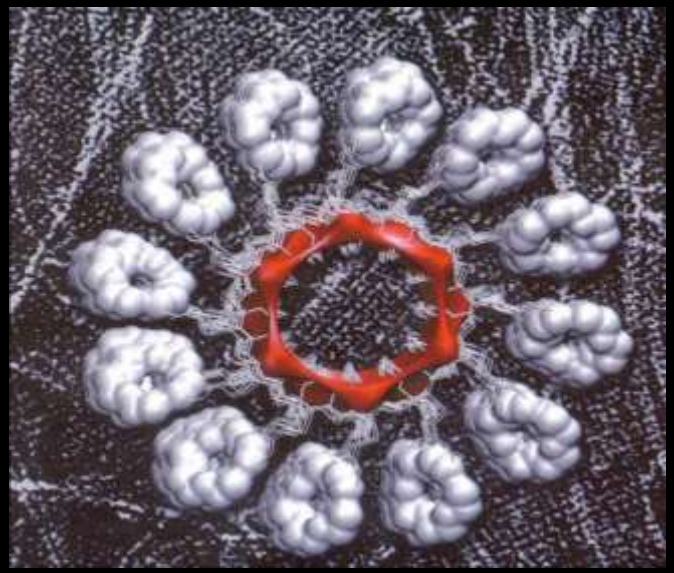
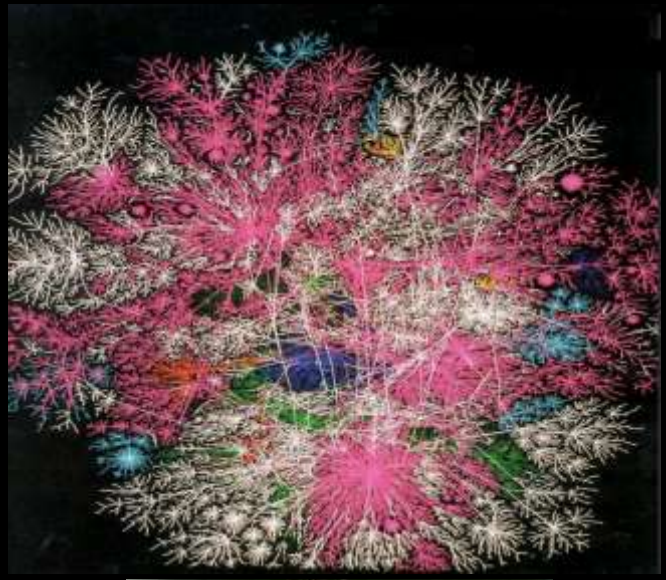
The Poverty of Imagination: An Enduring Theme in History

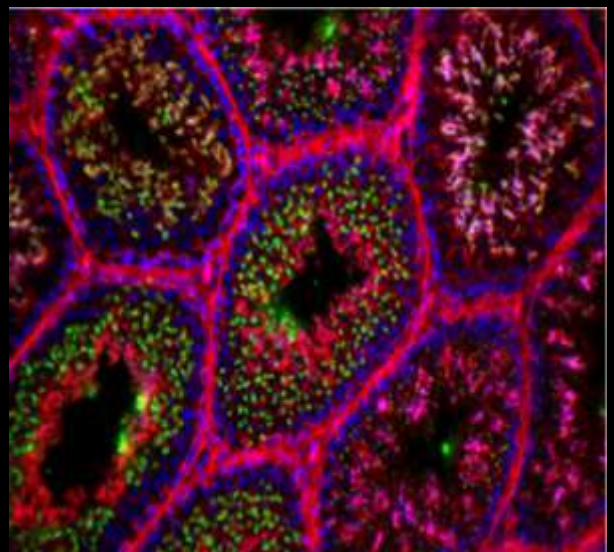
- foveal vision: focus on known indicators and threats
- the recurrent myopia of individuals, companies and nations in recognizing new disruptive technologies
  - complacency, risk aversion
- disruptive technologies are created disproportionately by individuals/companies operating at the mainstream margins
  - risky topics, investor timidity, corporate arrogance and conservatism
- profound societal implications of ‘rude surprises’
  - recurrent conflicts, crises, catastrophes

Comprehending Biological Design: The Design of Complex, Adaptive Networks of Increasingly Higher Structural Order









The Life Sciences

- from descriptive to mechanistic
  - the rise of molecular biology
- from reductionism to systems biology
  - assembly and regulation of complex adaptive systems
- from systems biology to synthetic biology
  - exploring ‘combinatorial’ biospace

Rapid Proliferation of Dual-Use Technology Platforms

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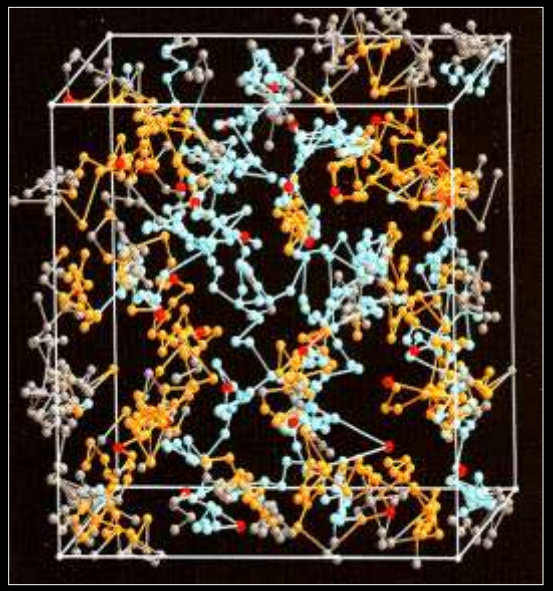
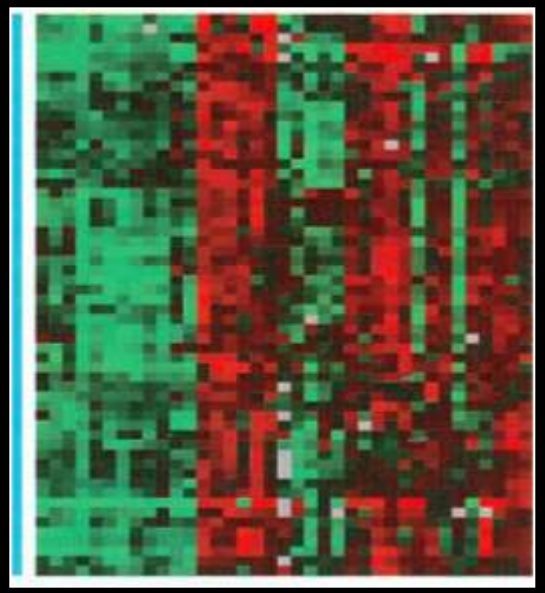
From Treatment of Illness to Aggressive Promotion of Wellness

- mapping the molecular ‘signatures’ of disease
- proactive detection of disease
- predictive medicine
- preventive medicine
- personalized medicine





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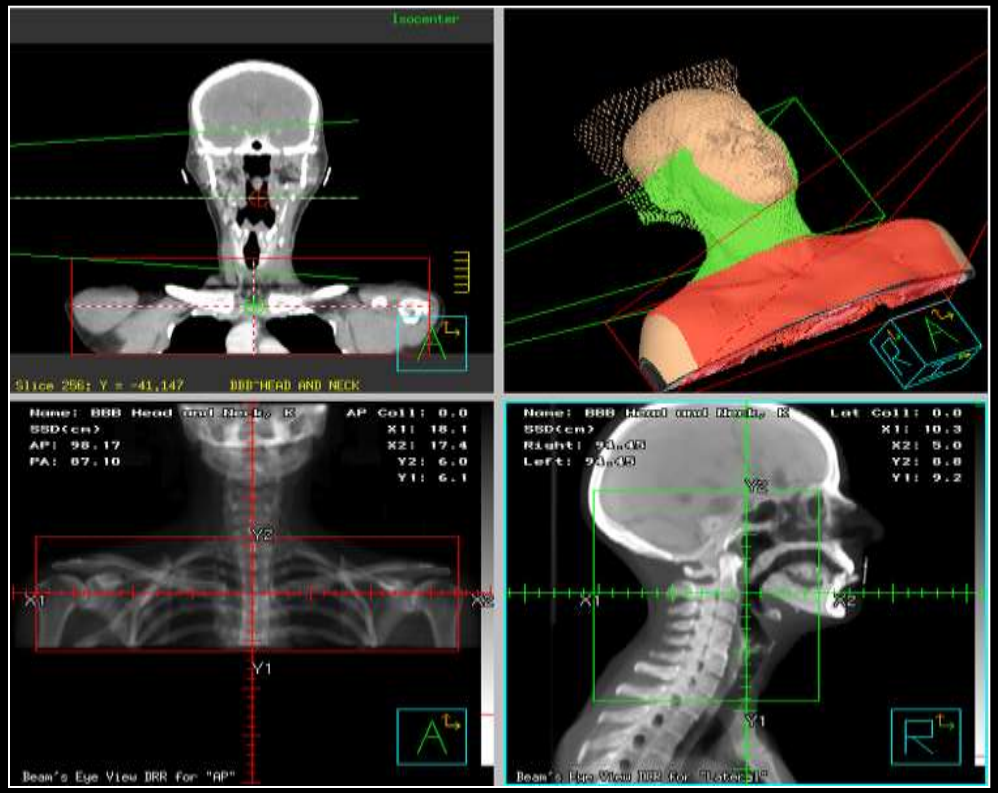
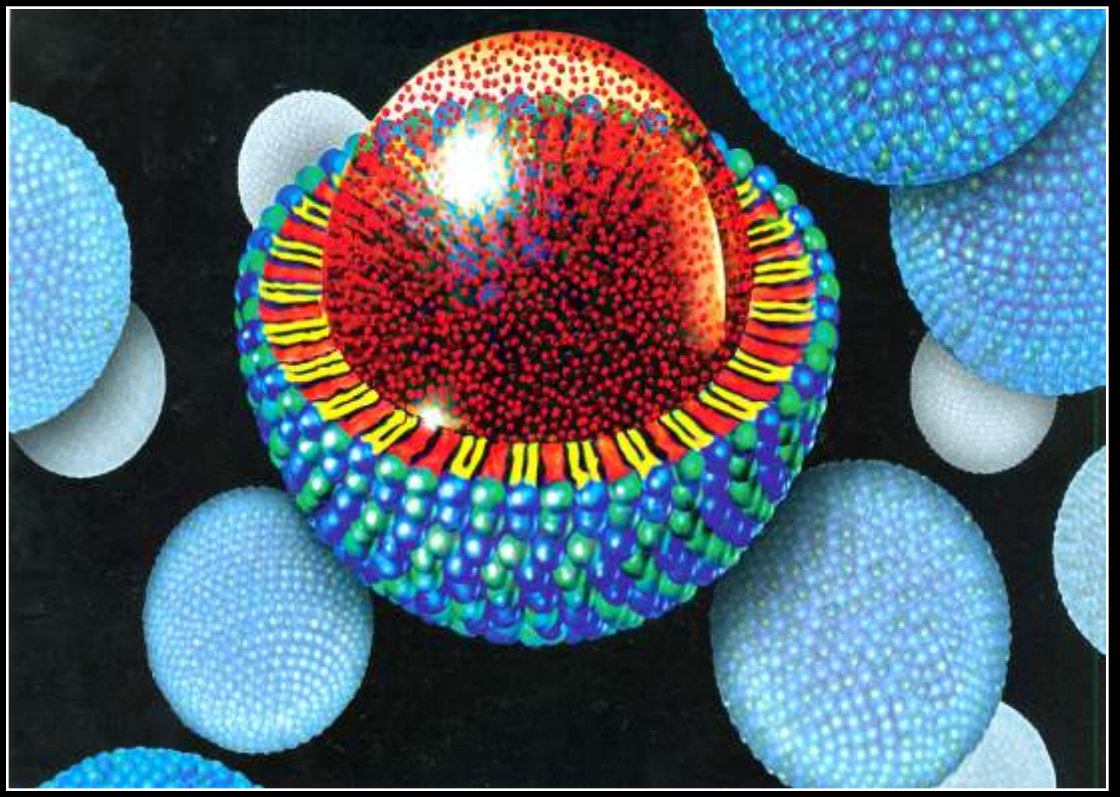
Advanced Body Imaging Systems



Nanoscale Encapsulation of Drugs and Imaging Agents for Targeted/Stealth Delivery Systems



Imaging at Cellular Level and Real Time Dynamics

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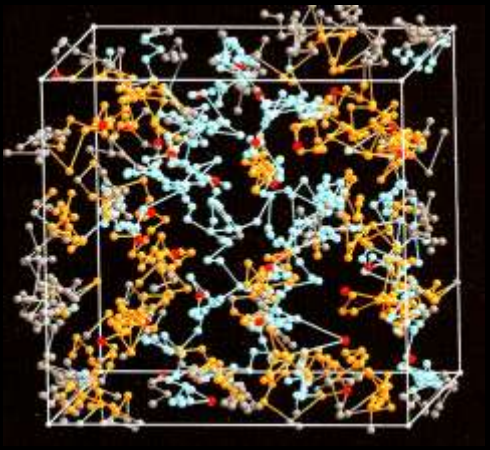
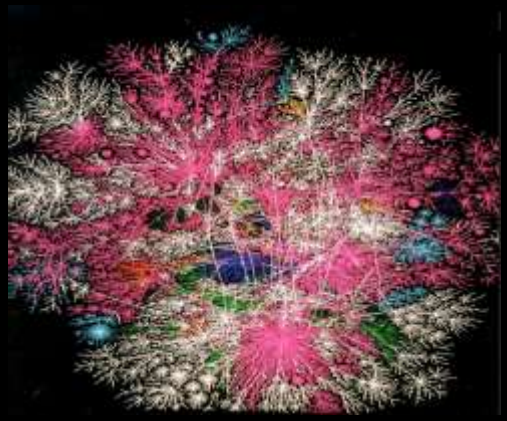
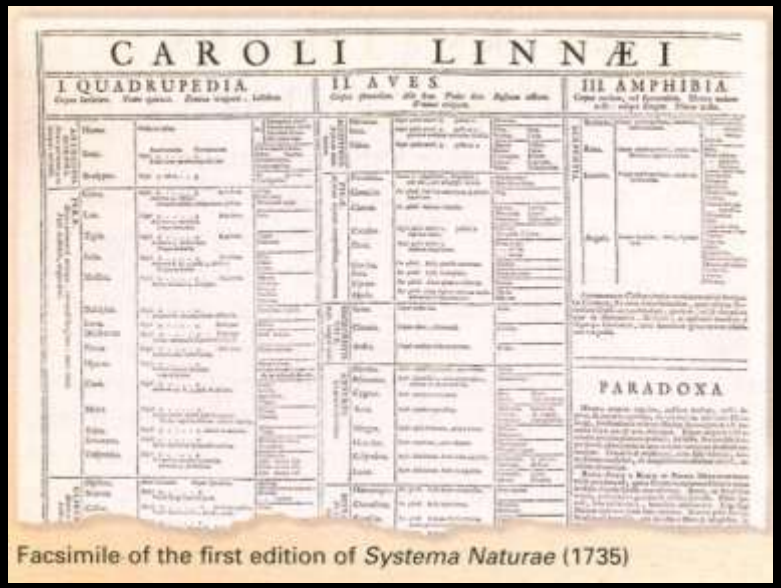
The Dual Use Dilemma in Life Sciences R&D





- future biothreats will not be limited to microorganisms
- mapping of genetic control circuits/networks for key homeostatic functions
  - major advances in medicine
  - simultaneous ID of “nodes” for perturbation
- creation of biological circuit disrupters (BCDs) will be easier than microbial modification
  - screening of large combinatorial chemical libraries
  - small molecule BCDs

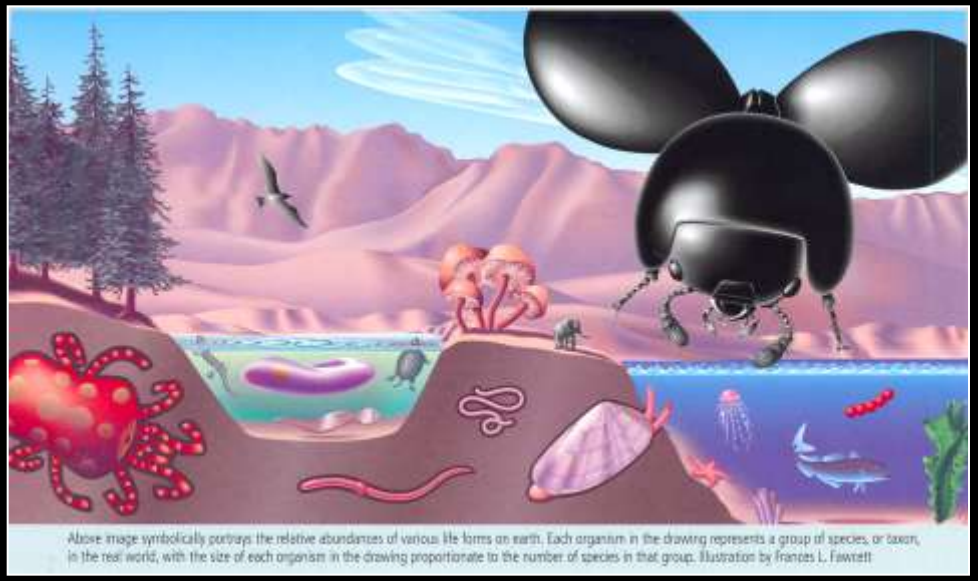
Constructing The Tree of Life


CAROLI LINNÆI

I. QUADRUPEDIA | II. AVES | III. AMPHIBIA

PARADOXA

Facsimile of the first edition of *Systema Naturae* (1735)


Above image symbolically portrays the relative abundances of various life forms on earth. Each organism in the drawing represents a group of species, or taxon, in the real world, with the size of each organism in the drawing proportionate to the number of species in that group. Illustration by Frances L. Fawcett

eol

Encyclopedia of Life

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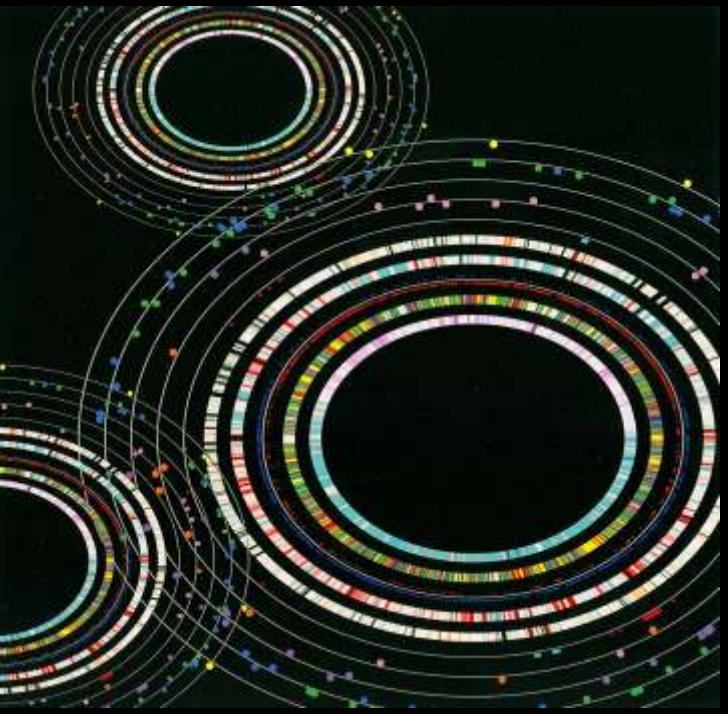
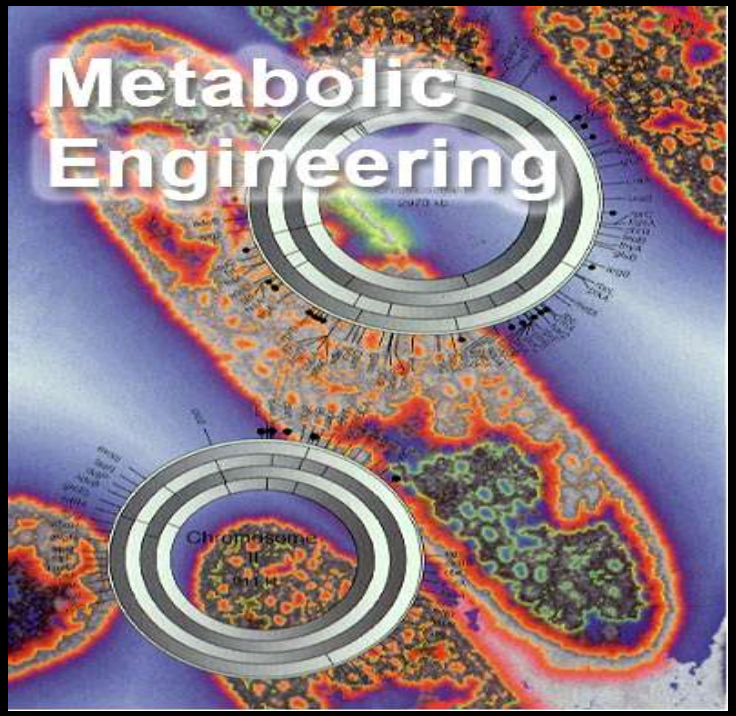
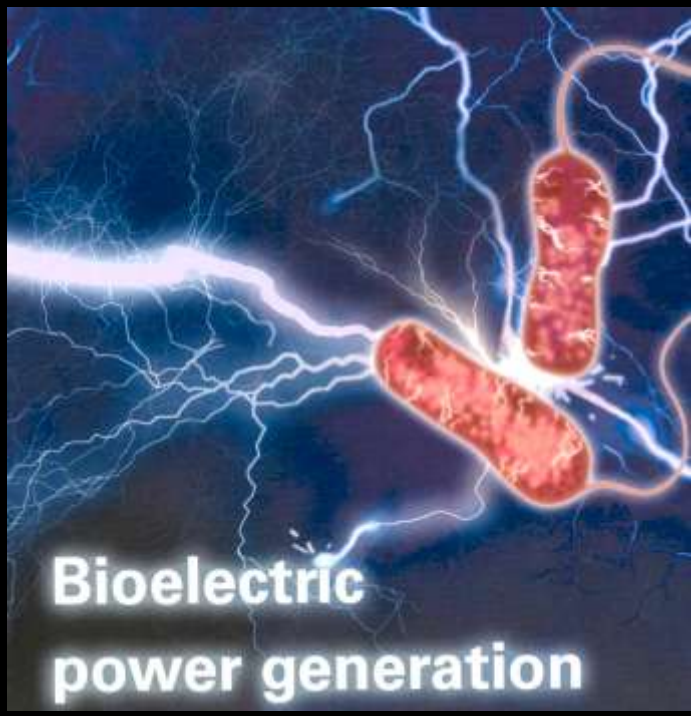
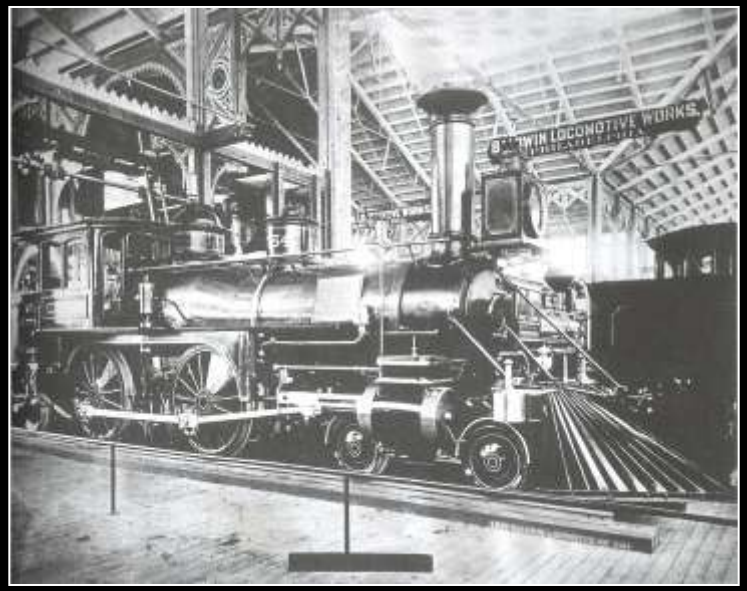
Synthetic Biology and Biomimetic Design: Forging a New Industrial Ecology

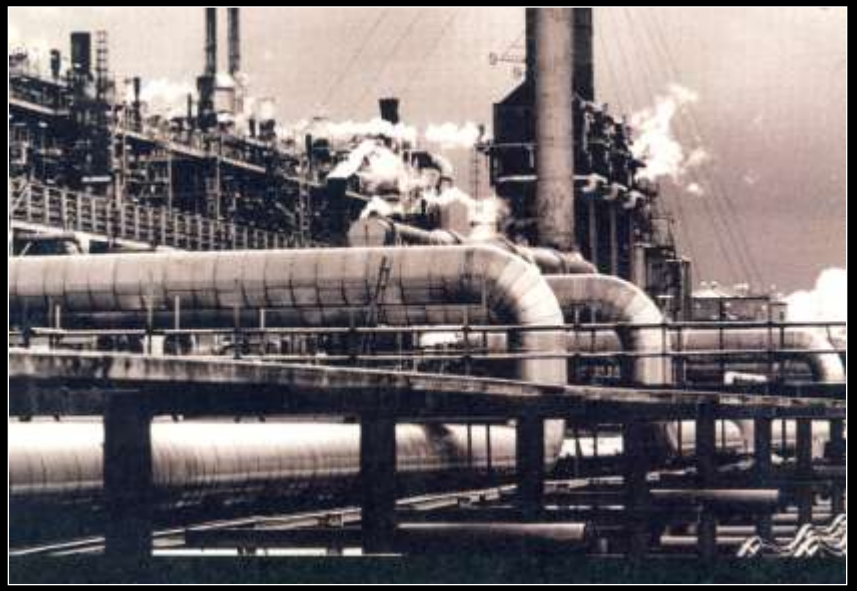






The Industrial Era: The Machine Metaphor





"The mechanical explanation of nature
finally hardened into a dogma of science"

Alfred North Whitehead

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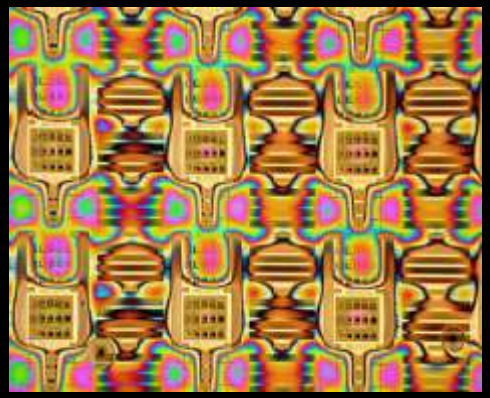
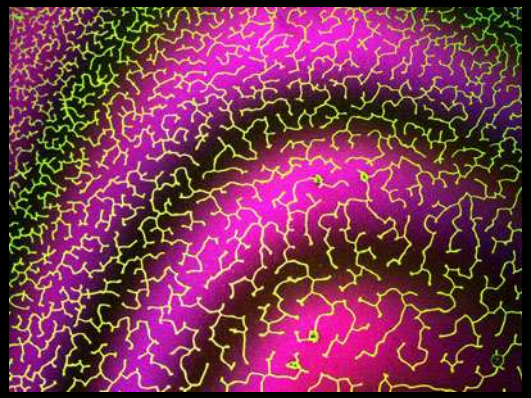
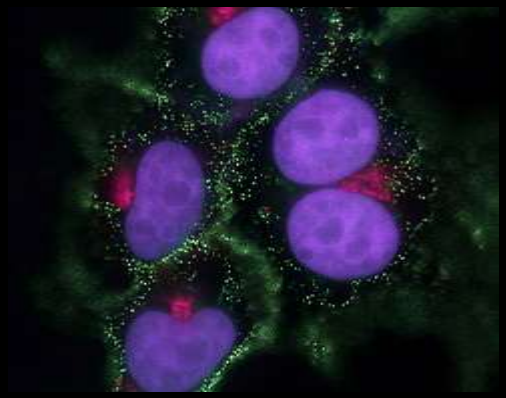
The Era of Biological Design: "Exploring Biospace"

"The machine age is about to meet a new challenger.
The machine age view is incomplete…….
Our best innovations will increasingly look like living things.
Not life in the traditional sense,
but a biology that has been consciously crafted by humans
- a new biology

Robert Freynay (2006)
Pulse,
Farrar, Straus, Giroux, New York

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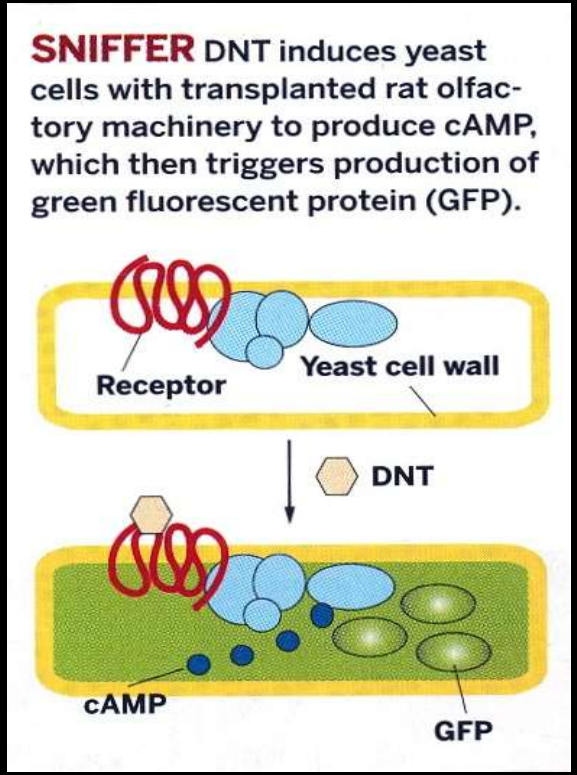
"Exploring Biospace"
The Design and Construction of Novel Biological Functions and Life Forms

Minimal Genomes	Building Increasingly Complex Modules and Feedback Controls	De Novo Design and Incorporation of Novel Functions
• building cellular chassis' as universal recipients for transferred genes	• modulation and control at different hierarchical levels - subcellular - cellular - tissue - organ	• novel combinatorial assemblies • synthetic genes and regulators • non-natural coding/information elements

"Plug and Play Genetics"

Engineering Sentinel Organisms as Environmental Sensors



D. N. Dhanasekaran et al (2007) Nature Chem. Biol.

DOI: 10.1038/nchembio882

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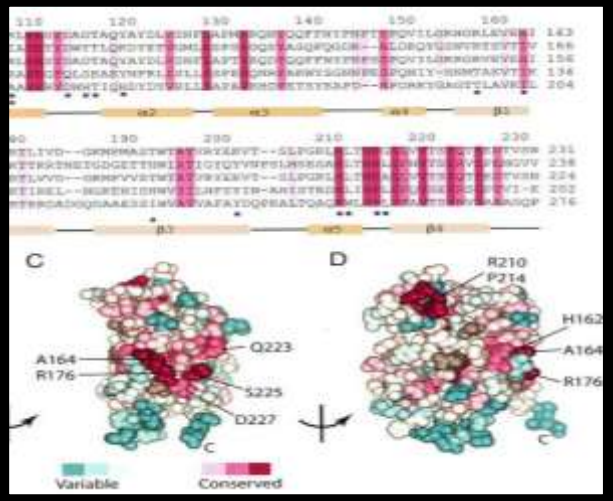
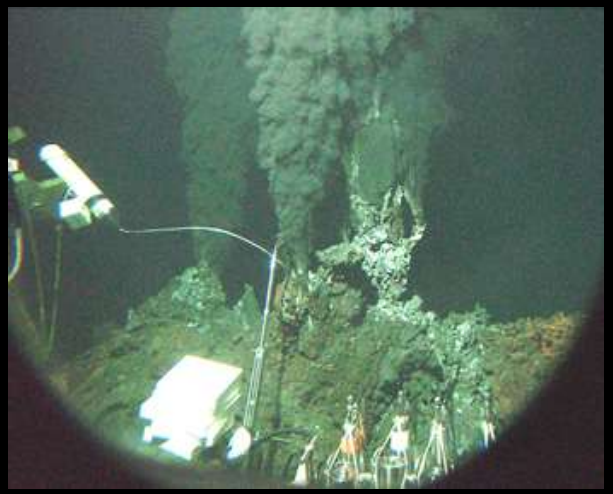
Metagenomics and Ecogenomics: Mapping the Extraordinary Genomic Diversity and Biosynthetic Capabilities of Microbial Life

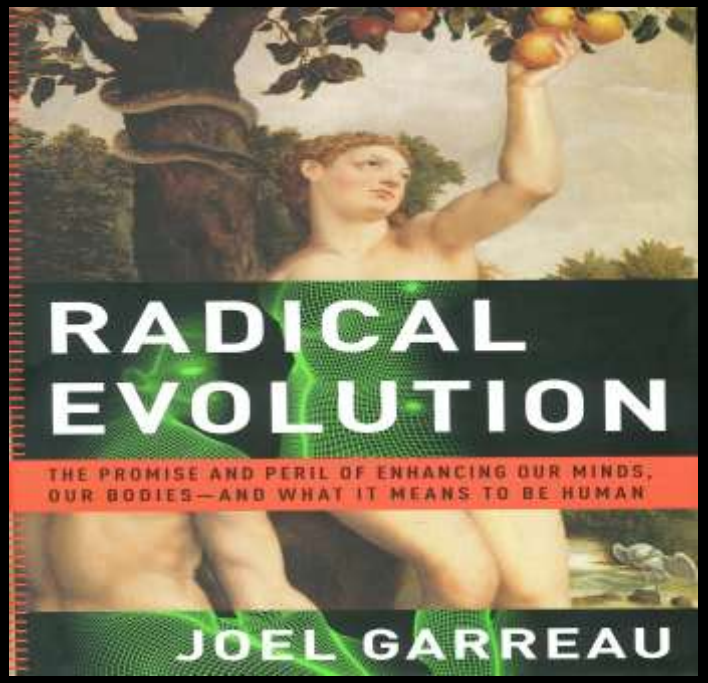
eco-niches

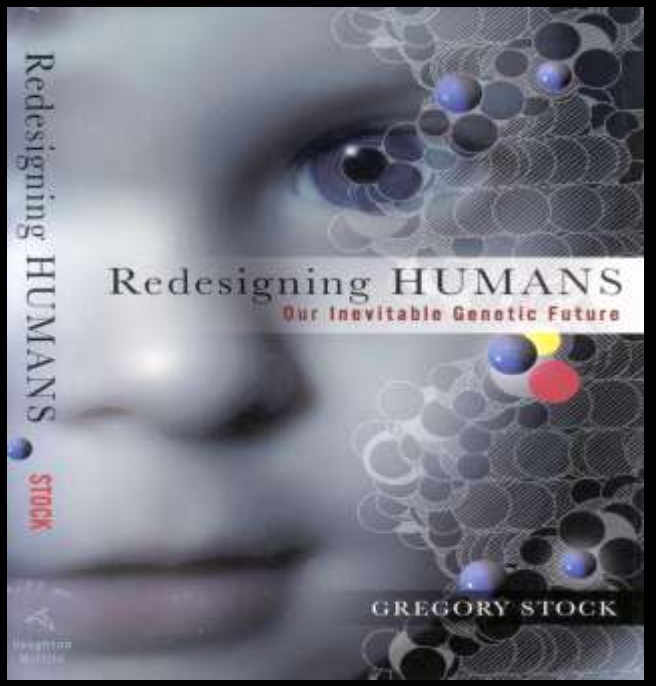
comparative genomics

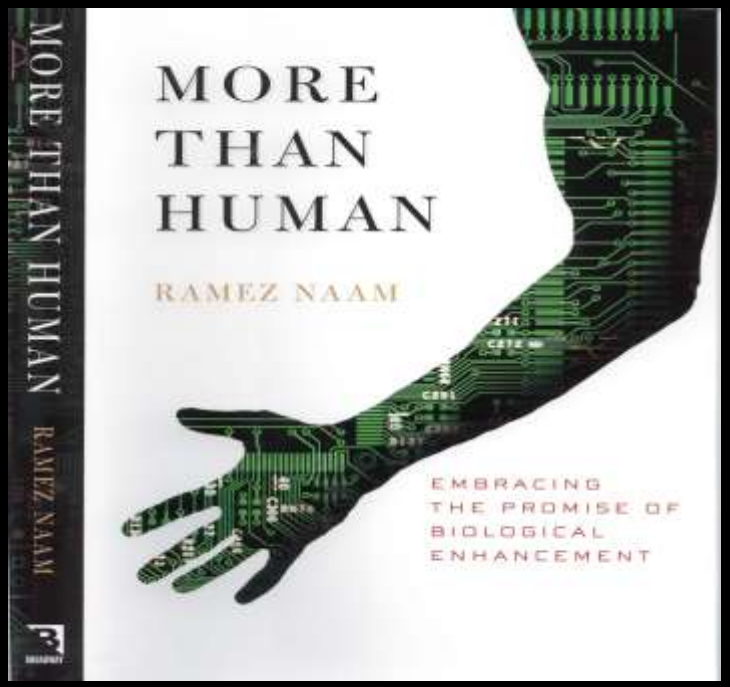


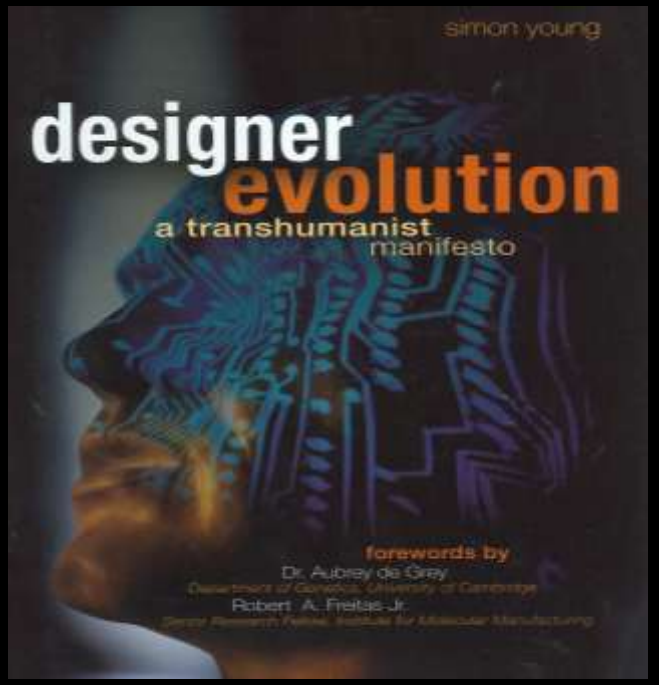


extremophiles


RADICAL
EVOLUTION
THE PROMISE AND PERIL OF ENHANCING OUR MINDS, OUR BODIES—AND WHAT IT MEANS TO BE HUMAN
JOEL GARREAU


Redesigning HUMANS
Our Inevitable Genetic Future
GREGORY STOCK


MORE THAN HUMAN
RAMEZ NAAM
EMBRACING THE PROMISE OF BIOLOGICAL ENHANCEMENT


simon young
designer evolution
a transhumanist manifesto
forewords by
Dr. Aubrey de Grey
Robert A. Freitas Jr.

Science (2007) 315, 1723

Emergence of Novel Color Vision in Mice Engineered to Express a Human Cone Photopigment

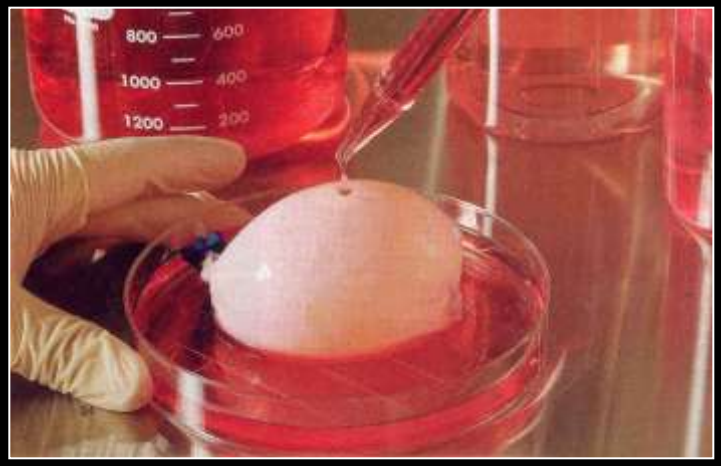
Gerald H. Jacobs,[1*] Gary A. Williams,[1] Hugh Cahill,[2,3,4] Jeremy Nathans[2,3,4,5]

Changes in the genes encoding sensory receptor proteins are an essential step in the evolution of new sensory capacities. In primates, trichromatic color vision evolved after changes in X chromosome–linked photopigment genes. To model this process, we studied knock-in mice that expressed a human long-wavelength–sensitive (L) cone photopigment in the form of an X-linked polymorphism. Behavioral tests demonstrated that heterozygous females, whose retinas contained both native mouse pigments and human L pigment, showed enhanced long-wavelength sensitivity and acquired a new capacity for chromatic discrimination. An inherent plasticity in the mammalian visual system thus permits the emergence of a new dimension of sensory experience based solely on gene-driven changes in receptor organization.

Regenerative Medicine

Embryonic Stem Cells

Tissue Engineering



Xenografts: A Distant Future

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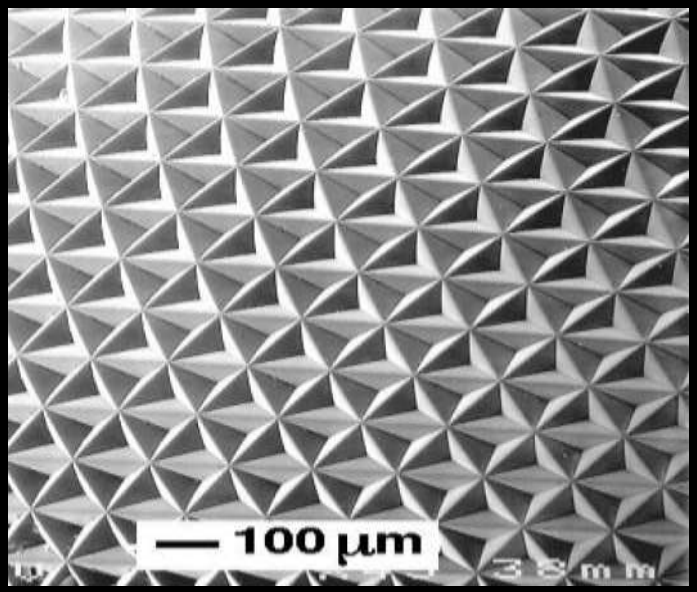
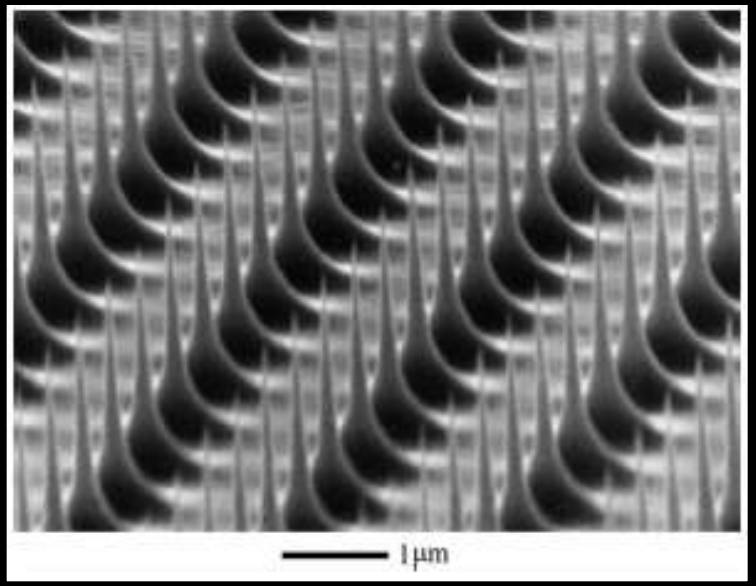
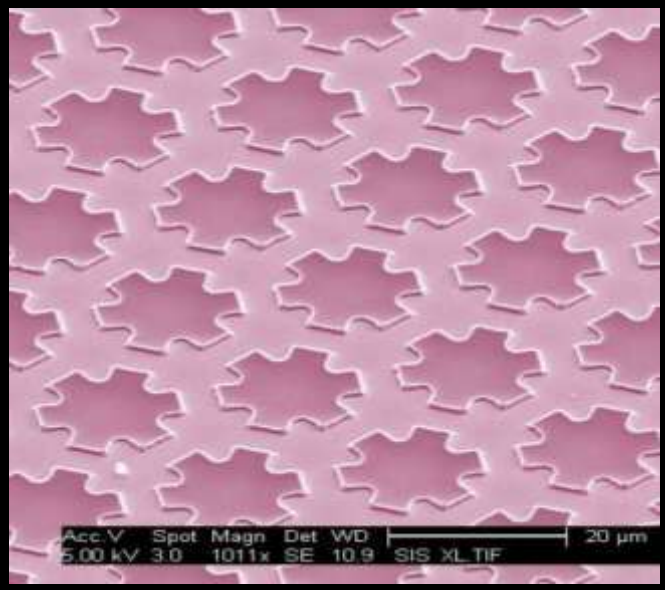
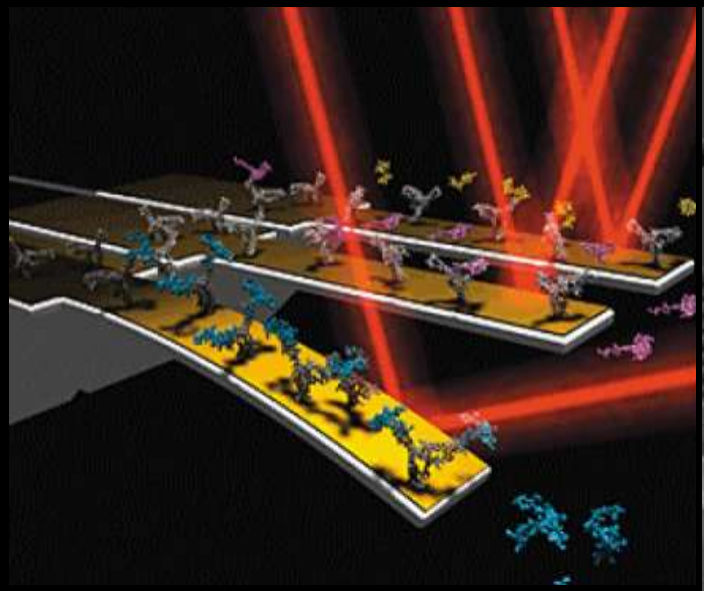
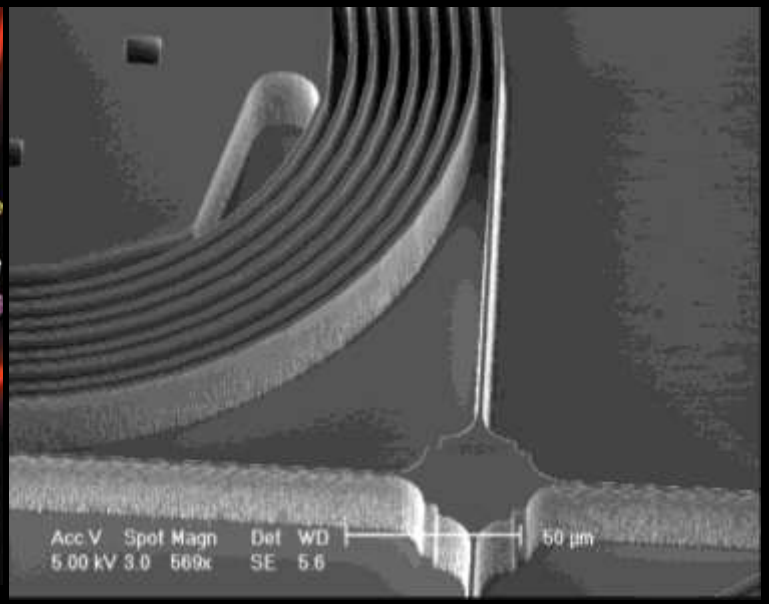
Nanotechnology: Our Shrinking Prospects

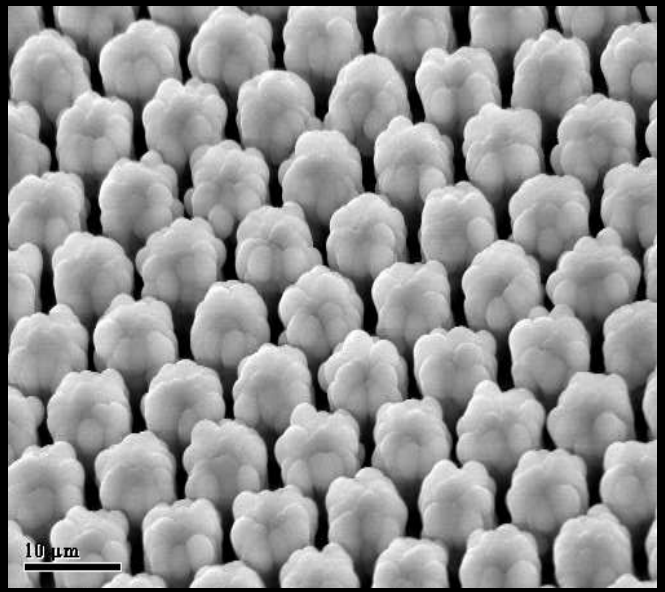












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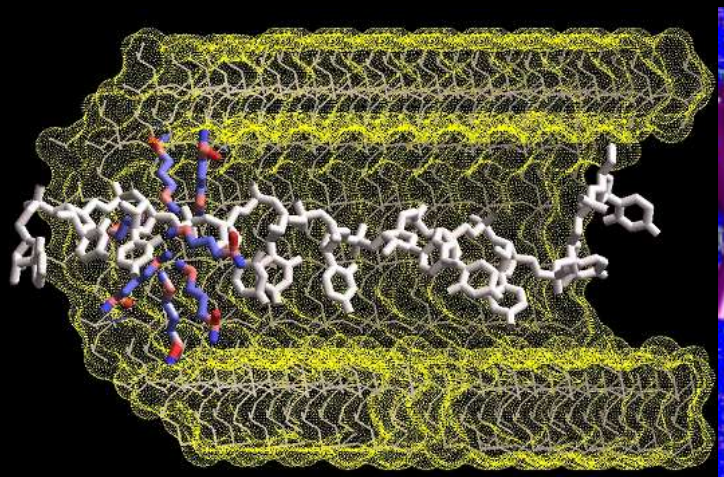
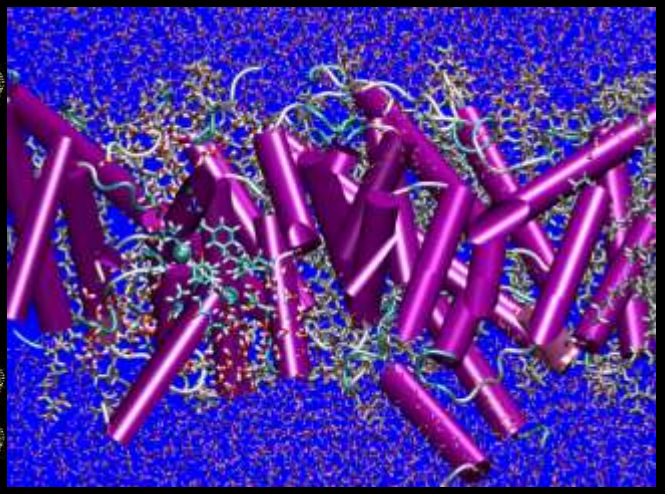
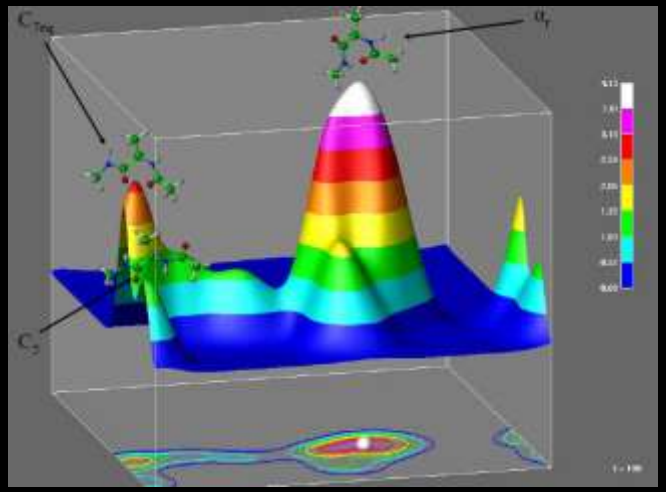
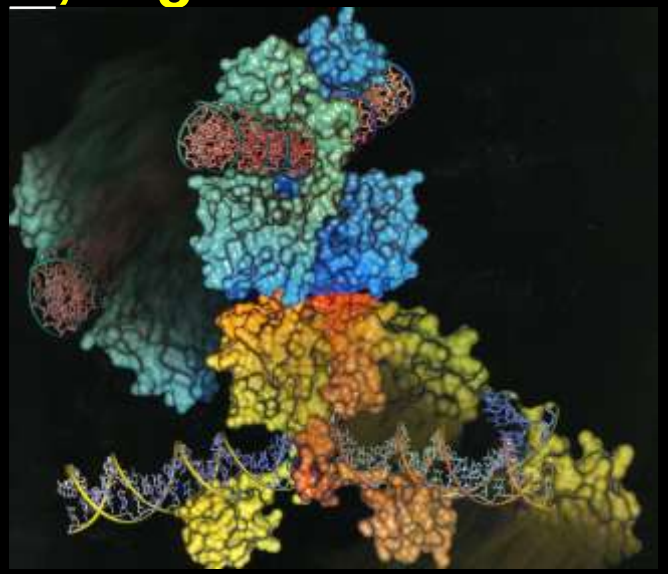
Understanding Molecular Dynamics and Quantum Scale Effects

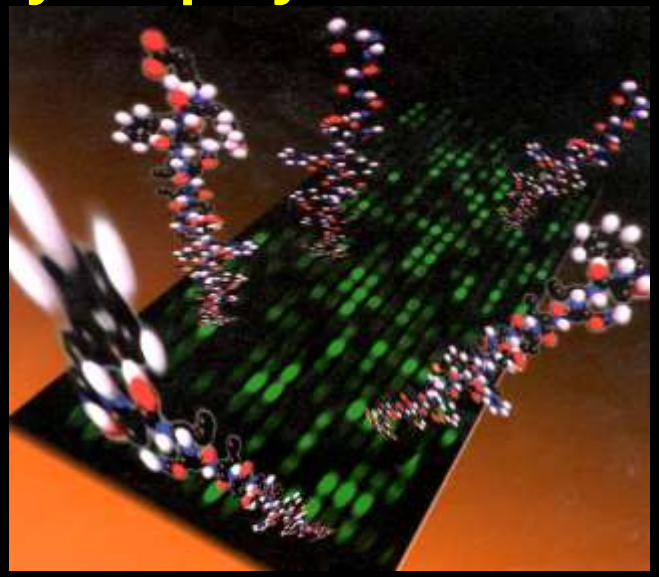




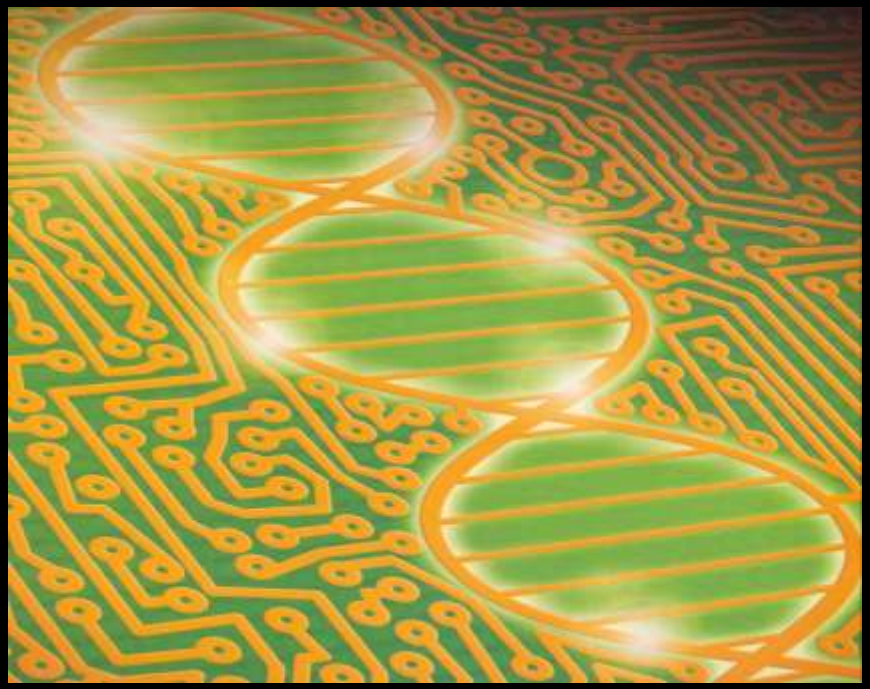


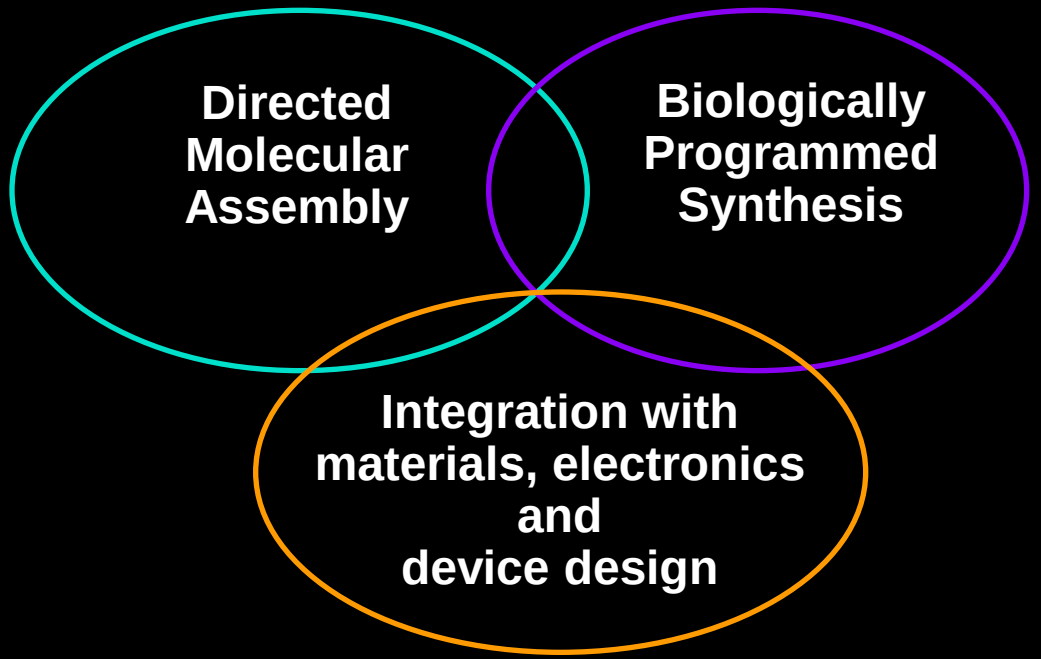
Directed Molecular Assembly: Addressable, High Feature Density Displays





Novel Hybrid Materials: Combining Biological (Organic) and Non-Biological (Inorganic) Components





Novel Materials

- flexible superfast silicon electronics

- non-reflective coatings
- black body materials

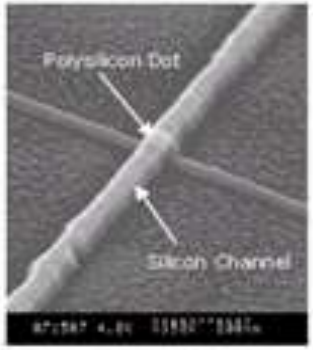
- metamaterials

- switchable materials

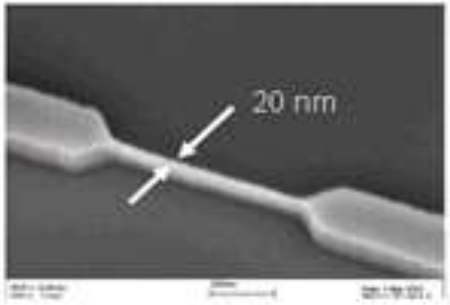
Nanoelectronics

Quantum Transistors
(d ~ λe)

Single electron transistors



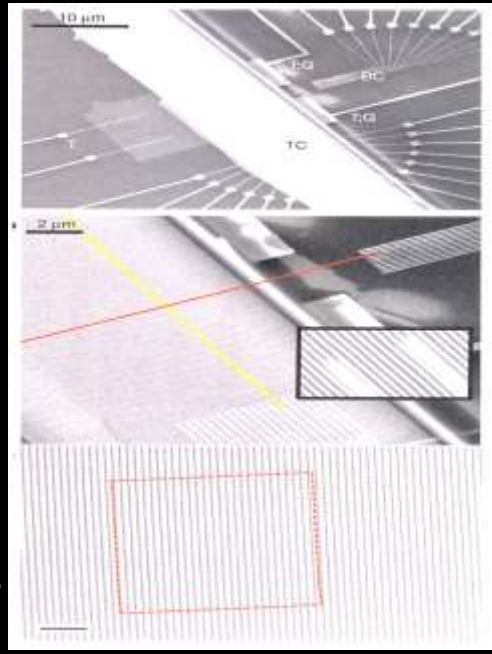
Carbon nano tube Molecular devices

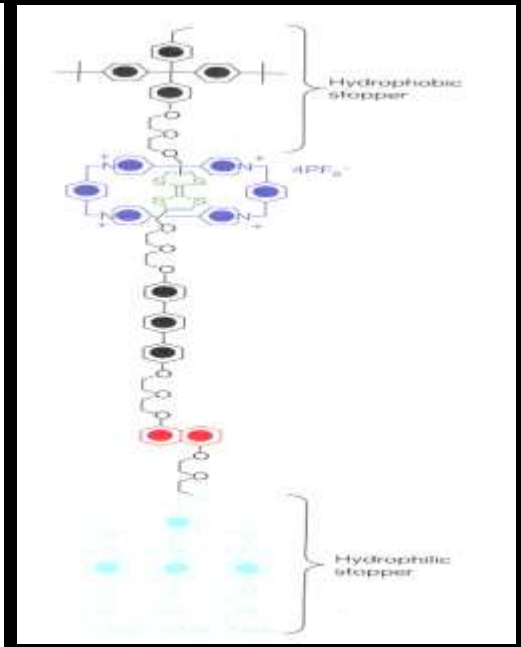


LETTERS

A 160-kilobit molecular electronic memory patterned at 10^{11} bits per square centimetre

Jonathan E. Green[1]*, Jang Wook Choi[1]*, Akram Boukai[1], Yuri Bunimovich[1], Ezekiel Johnston-Halperin[1]†, Erica DeIonno[1], Yi Luo[1]†, Bonnie A. Sheriff[1], Ke Xu[1], Young Shik Shin[1], Hsian-Rong Tseng[1]†, J. Fraser Stoddart[1] & James R. Heath[1]





- 400 Si bottom-nanowire electrodes
  - 16 nm wide, 33 nm pitch, phosphorus-doped, n=5x1019 cm-3
- 400 Ti top-nanowire electrodes
  - 16 nm wide, 33 nm pitch
- sandwiched monolayer of bistable rotoxanes
- memory cell size 0.0011 um2

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The Infocosm: Emerging Networks of Global Connectivity

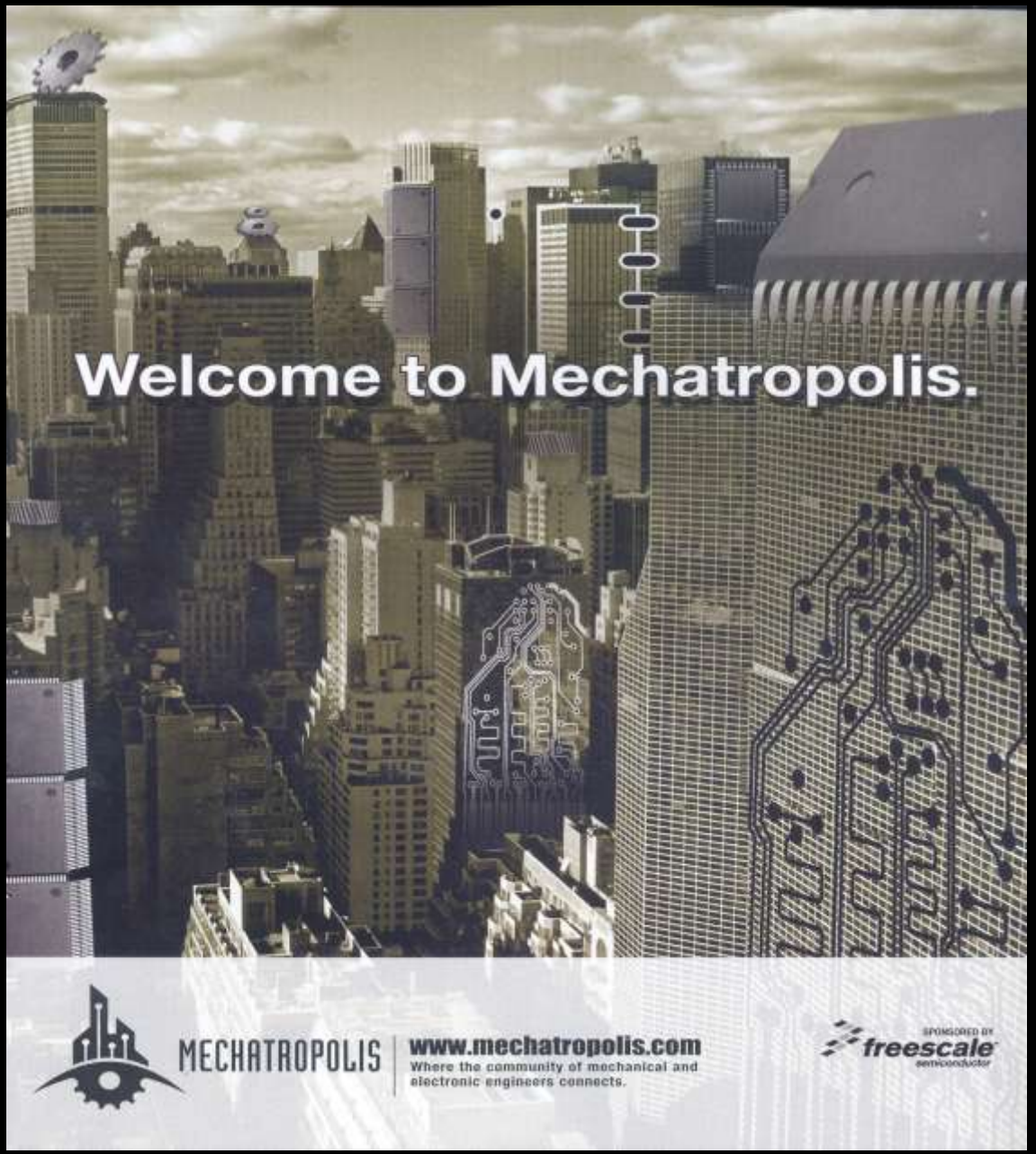
Everything of Value Will Be Tracked Everywhere: Challenges for a Trustworthy Information Society

- decentralized systems design and network topology
- heterogeneous data and semantic interoperability
- complexity limit of scaling up
- quantum limit of down scaling
- consequences of open systems
- multi-scale concepts (emergence)
- new computing paradigms

SECURITY, PRIVACY, LEGALITY

Tagging, Tracking and Locating (TTL)

New Technological Platforms
for
Enhanced National Security Capabilities
in
Surveillance and Interdiction


Welcome to Mechatropolis.
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Where the community of mechanical and electronic engineers connects.
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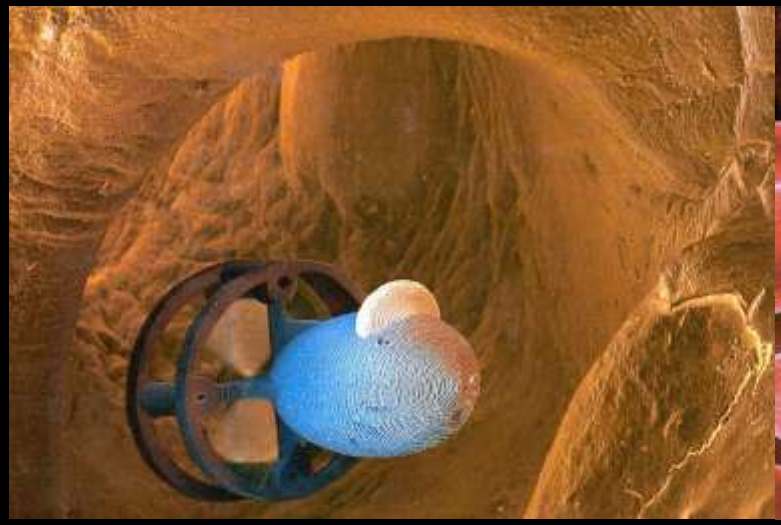
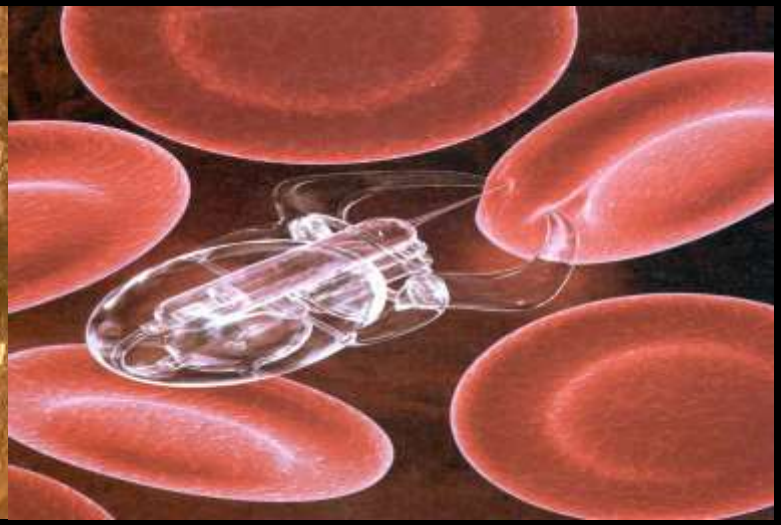
semiconductor

On Body: In Body Sensors/Devices





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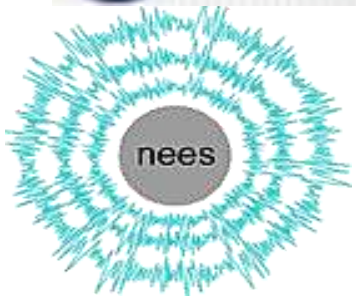
Human Signatures Analysis and Profiling

“Invisible” Customized Networks

Mr. Smith… please remember to get your annual physical

Grids of All Flavors



TeraGrid™

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Ubiquitous Sensing and Ambient Intelligence: Embedded Sensors and "Disappearing Electronics"

- environment sensitive, adaptive and responsive to people and objects
- augmenting individuals and systems via smart non-explicit assistance
- from 10's cm^3 to 10's of mm^3 /μm^3 /nm^3
- from 10's to 100's μW to 0.001 to 1μW

Privacy and Information

- 2010: 15 Petabits (10^{16}) / $250,000
- Human Genome: 10 Gigabits (10^{11})

For a few million dollars, one could store the complete genome of every American and European

...for several more, could add credit card records, telephone logs, travel history,...

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Who Controls the Information, Wins?

Business Week 9 April 2007

Google

"Google might pose a national defense concern at some point simply by virtue of its singularly massive storehouse of data, the crude oil of the information economy"

George Dyson
Author: Darwin Among the Machines: The Evolution of Global Intelligence
Quoted in Business Week 9 April 2007

Google

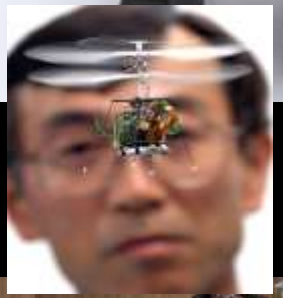
"If Google succeeds in its mission, then we're doing everything."

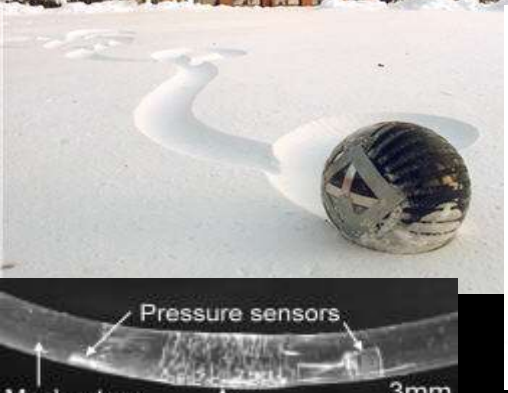
L. Page
Co-Founder, Google
Business Week 9 April 2007, p. 52

"As we improve our machines
they will become more organic, more biological,
more like life itself, ……
Someday the difference between machines and biology
will be hard to discern ……
The organic and the machine are merging"

Kevin Kelly (1994)
Out of Control: The New Biology of Machines

Robots of All Shapes and Sizes





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UAVs and UAV VTOL Technology











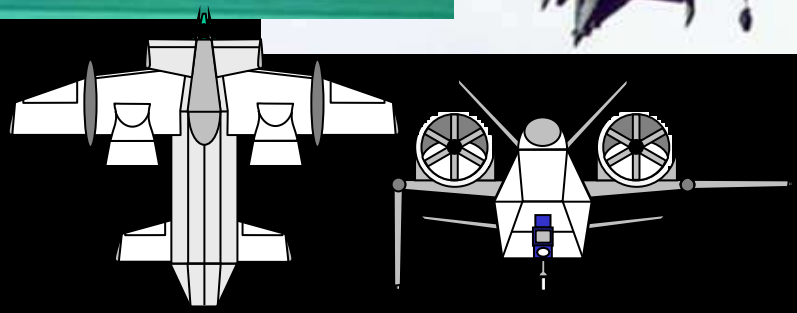

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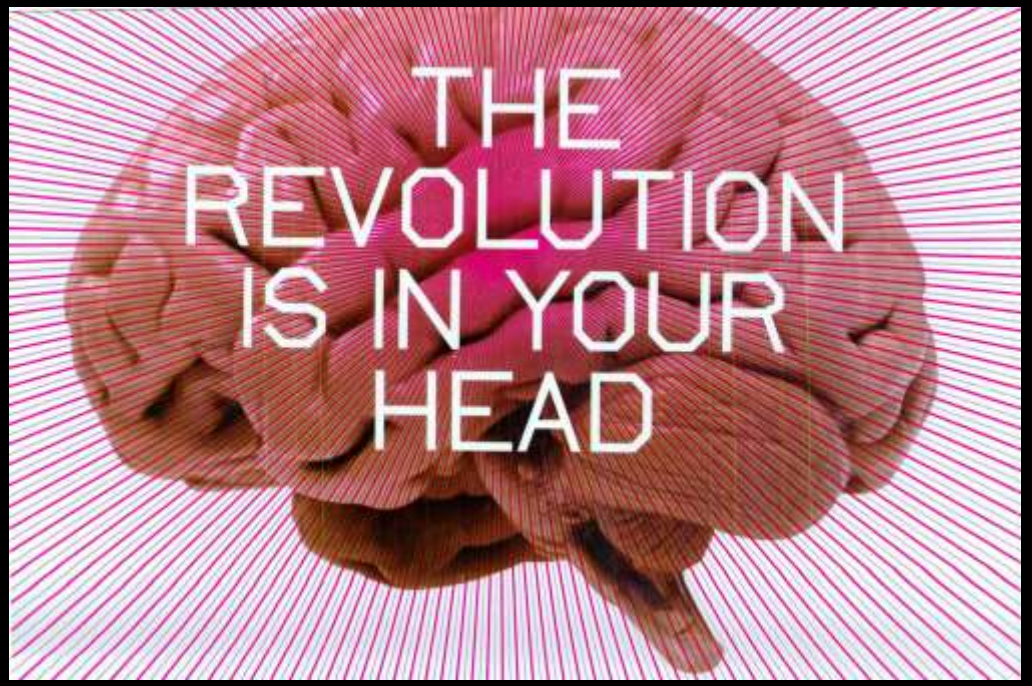
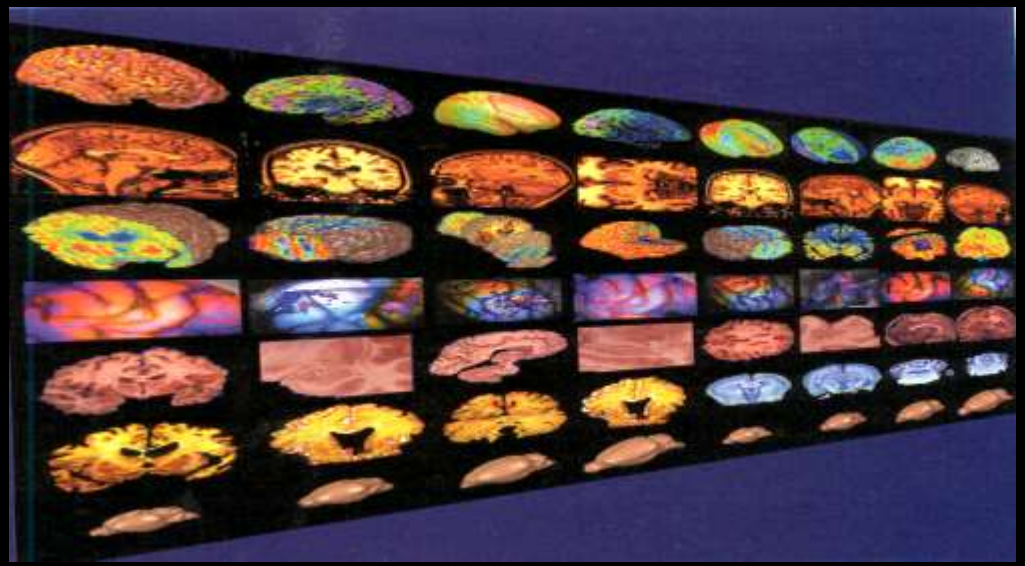
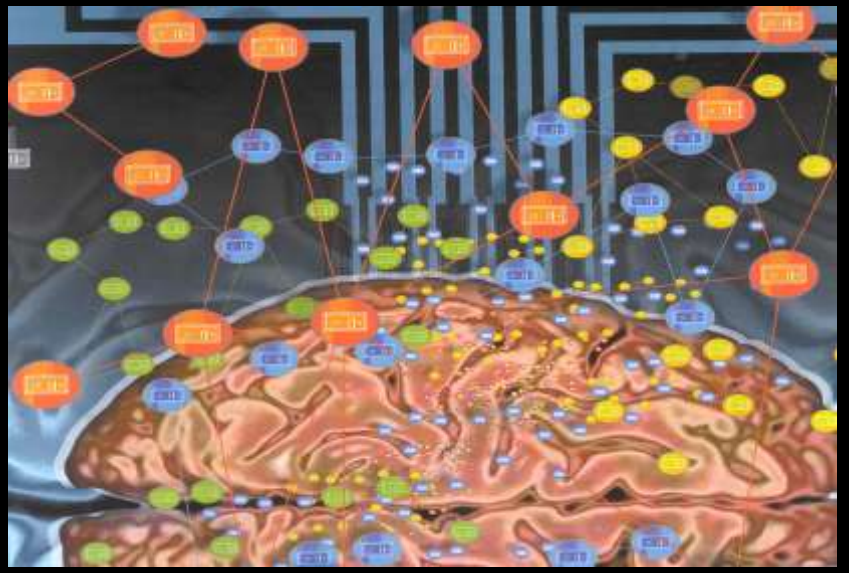
Towards Sociable Robots: Evolving Human-Robot Relationships



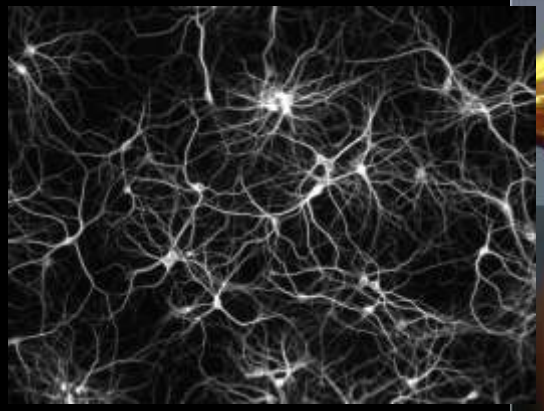

- human aware
- interact, communicate, understand, respond and teach humans
- pro-active intelligent (?) instrument (creature?), not an appliance
- control of adverse behavior
- ethics

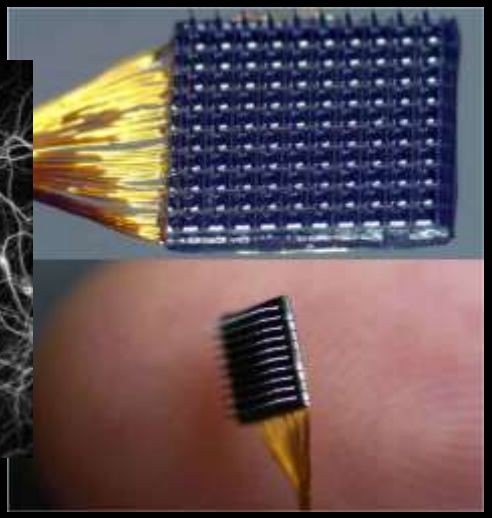


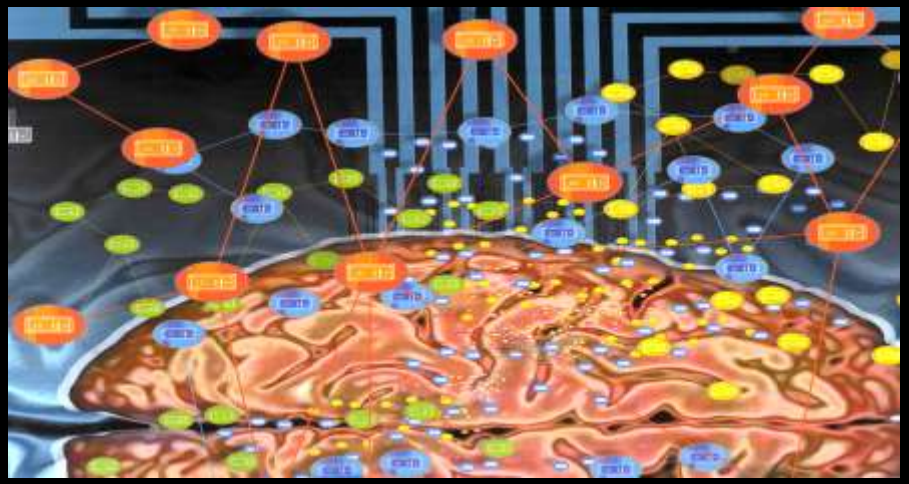




Intelligent Adaptive Neural Systems and Devices for Circumventing Disability

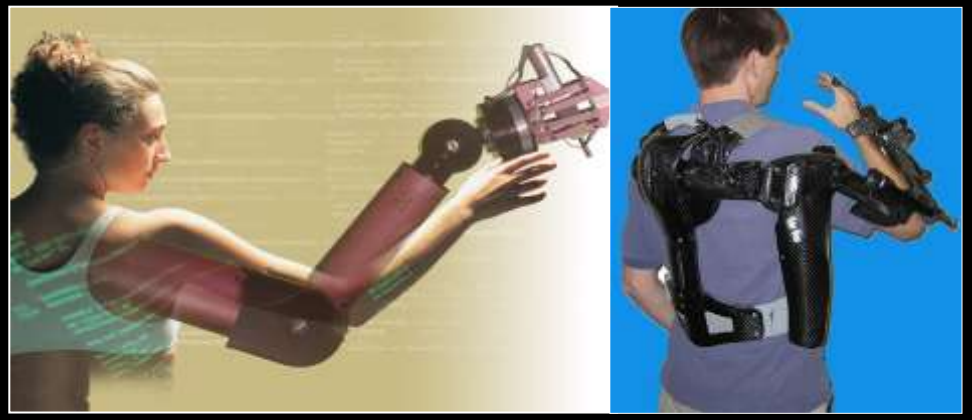






Neural Signatures of Motor and Cognitive Functions

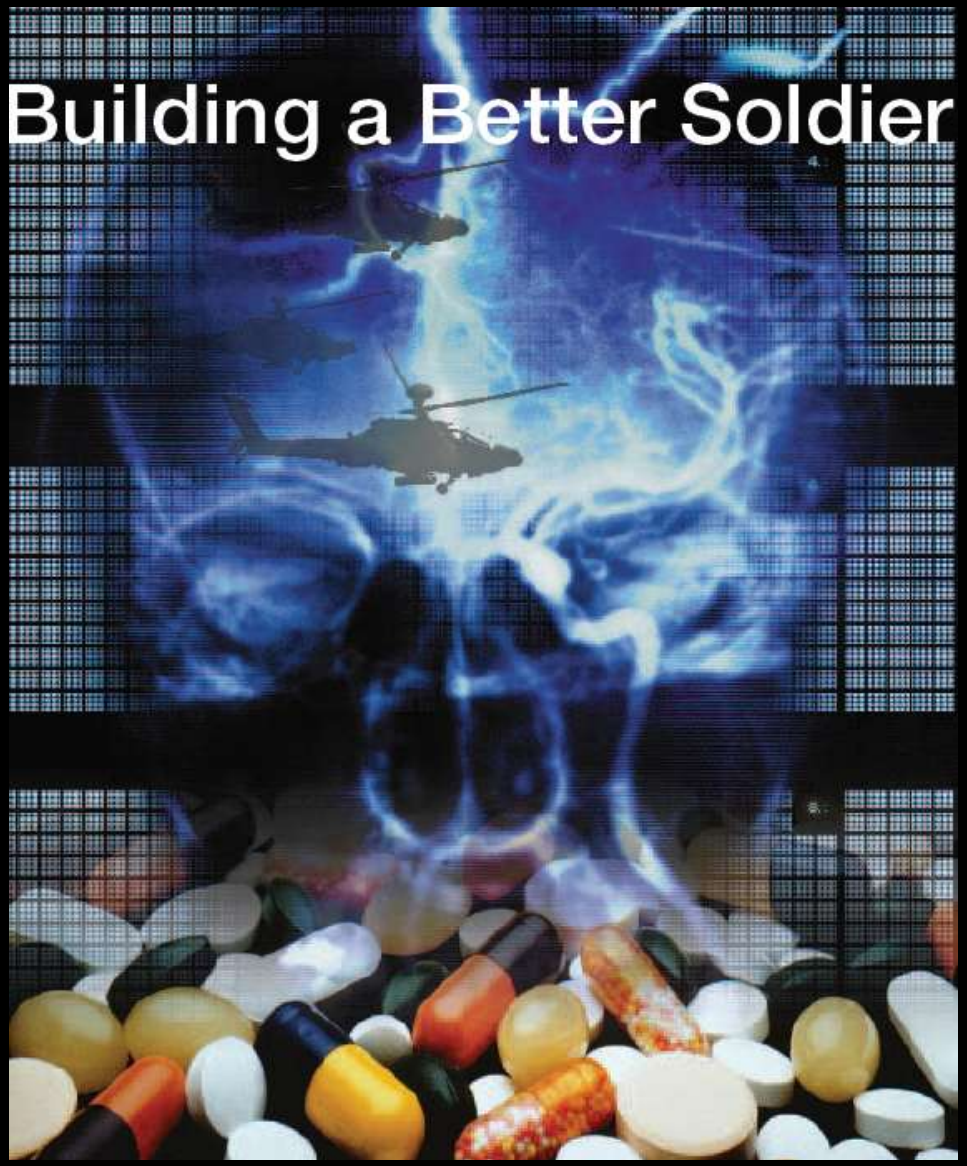
Neuro-Controlled Robotics



Intelligent Prosthetics

Neural Control of Peripheral Devices

- from invasive to non-invasive controls
- non-invasive, real-time coupling of brain decision codes to control peripheral devices or systems
- ID of neural and force dynamic codes for complex motor/sensory activities
- novel materials for device design and responsiveness to neural code instructions



Human Performance Optimization and Military Missions

May 2005

Human Performance Optimization

Final Report

Written by:
Dr. Adam Russell
Bartlett Bulkley
Christina Grafton

Completed for:
Director, Office of Net Assessment

SAIC Project No. 01-1536-04-2520
Contract No. GS-10F-0297K

SAIC
An Employee-Owned Company

Human Performance Optimization and Military Missions

Neuropharmacology and Neuromodulation

"Accentuate the positives, medicate the negatives"

Actress Amy Sedaris

- human performance optimization
- optimized learning
- memory modulation
- induced states
  - aggression, fear, lethargy, addiction

Neuroenhancement

"Mental health is the ultimate competitive weapon.
Even if just a few people choose to use neuro-enhancements,
their choice will change the basis of business competition
for the rest of us"

Zack Lynch
Managing Director, NeuroInsights
AAS Symposium on Impact
of Human Enhancement
www.aas.org/news/releases/
2006/0609enhancement.shtml

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www.aas.org/news/releases/
2006/0609enhancement.shtml

(and nations too . . . . . .?)

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"Cogint"

- mapping neurocircuitry: the 'signatures' of motor, sensory and cognitive states
- coupled feedback from attentive computer interface and on-body: in-body sensors
- language translation
- inter-memetic engineering: sharing concepts
  - specialized knowledge
  - cultural fusion
  - conflict reduction

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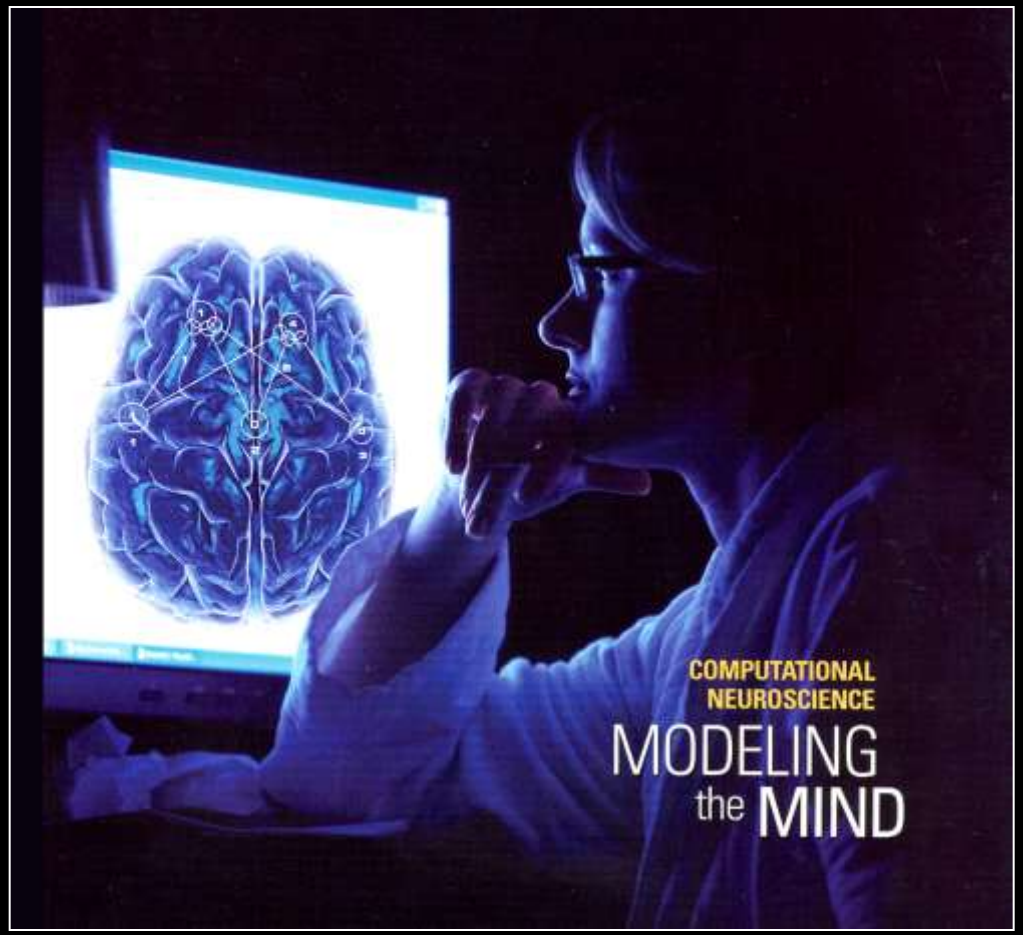
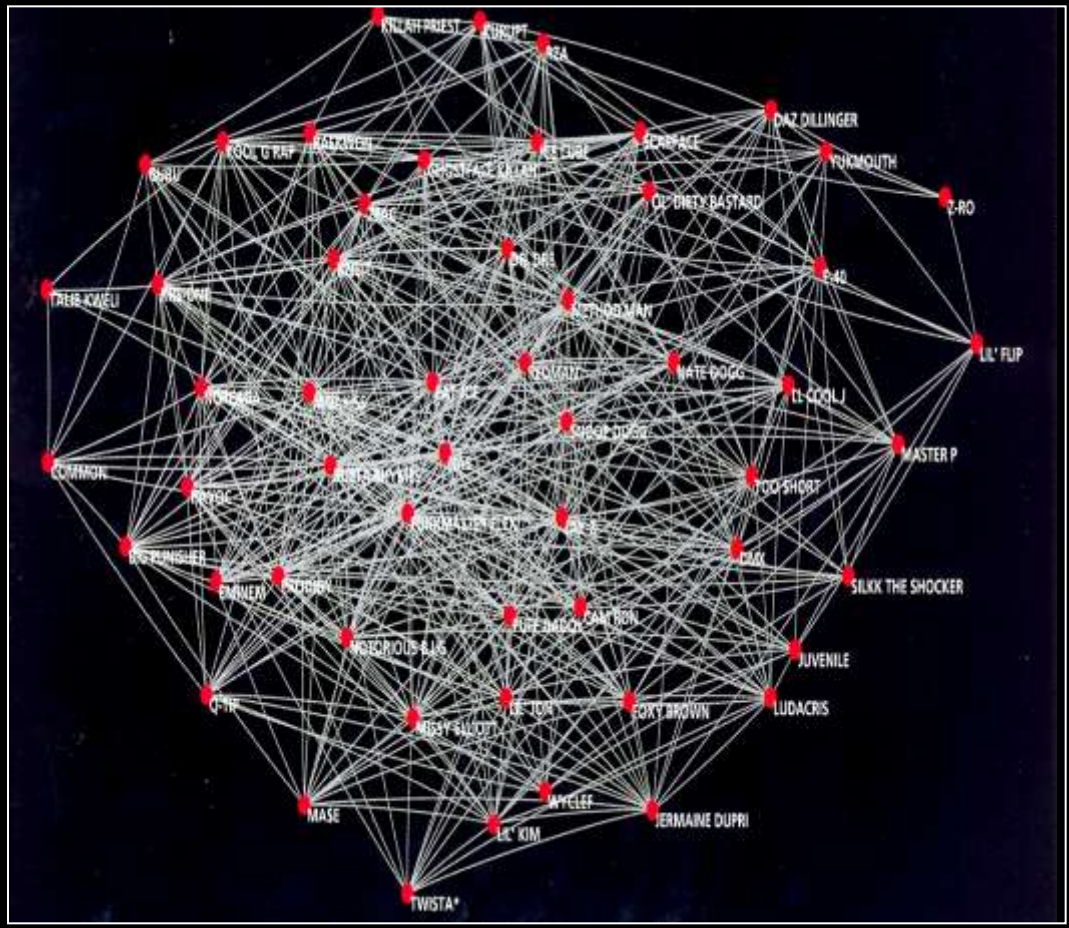
Social Network Analysis and Predictive Behavioral Modeling





Herd Behavior: 1.3 Million Bathers, Coney Island 1951

The changing nature of social interaction

The new “virtual” community

Virtual Worlds: The Largest Design Space in Technology Today

- avatar-inhabited, multiuser on-line worlds
- immersive spaces in web-based ecosystems
- accommodate complexity, dynamism, diversity and selection
- the emergent synthesis of the global collaboratory
- irreversible, symbiotic (?) interaction with the human nervous system

Q (Bus. Week):

"Is Google really creating a true artificial intelligence or thinking machine, as Goggle's founders have set up as a goal?"

A (Eric E. Schmidt, CEO, Google)

"In the next few years, cognition, or real understanding, remains a research goal"

Bus. Week 9 April 2007

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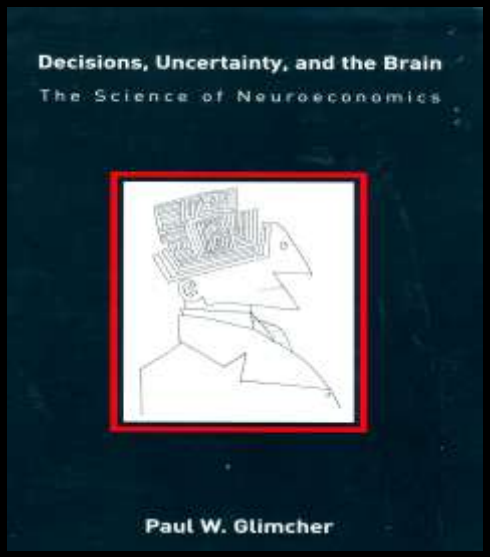
The Neurobiology of Decision

choice

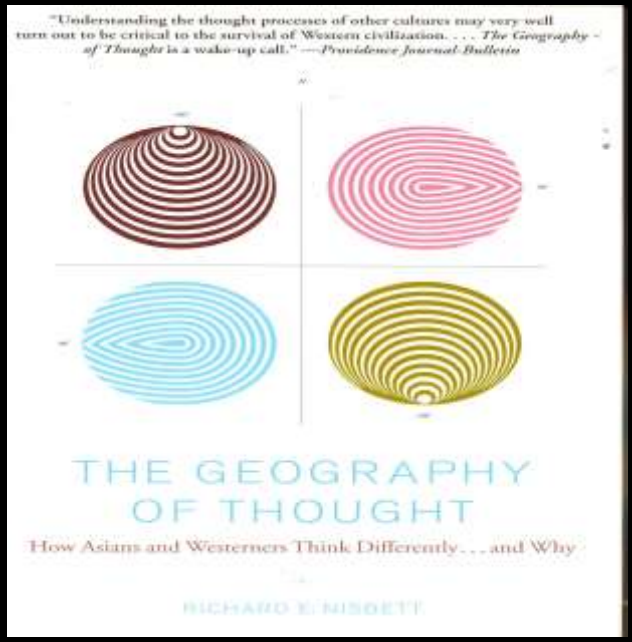
risk reward

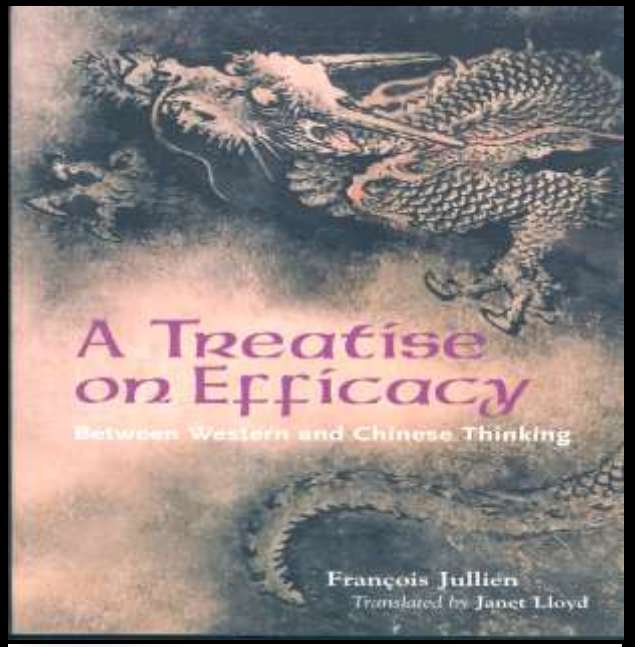


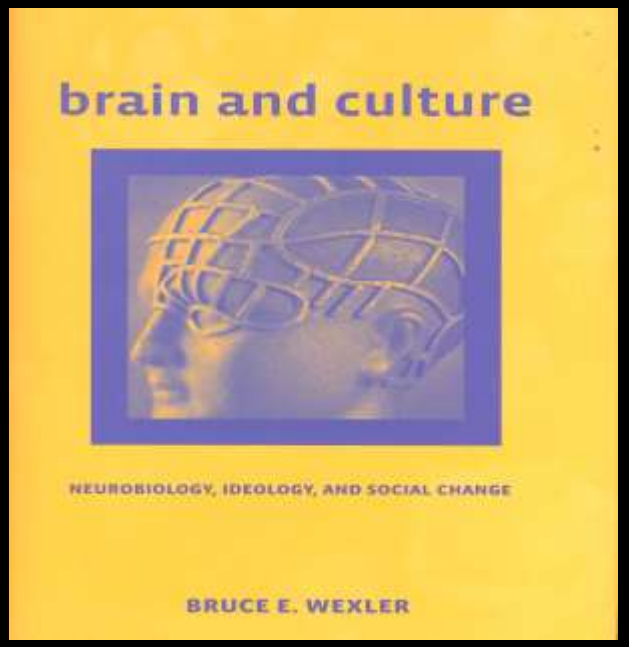
rational (?) economics

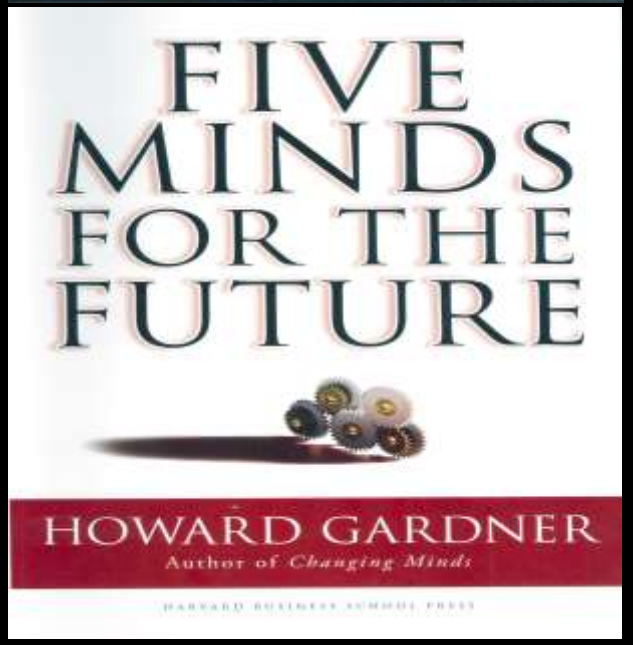
religion

Kinds of Minds?









Behavioral Genetics: A Non-PC But Unavoidable Domain of Cognitive Neurosciences

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Eco-: The System of Systems
Sustainable Society: "Finite Earth"

- understanding complex adaptive systems (CAS) and evolutionary dynamics
  - networks, interdependence and prediction of emergent properties
  - the choreography of materials, energy and information
- superimposition of complex interactions of human activities
  - accelerating pace of S&T
  - rapid technology diffusion
  - industrialization of developing countries

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Sustainability Imperatives

Reduced GHG
and Carbon Footprint

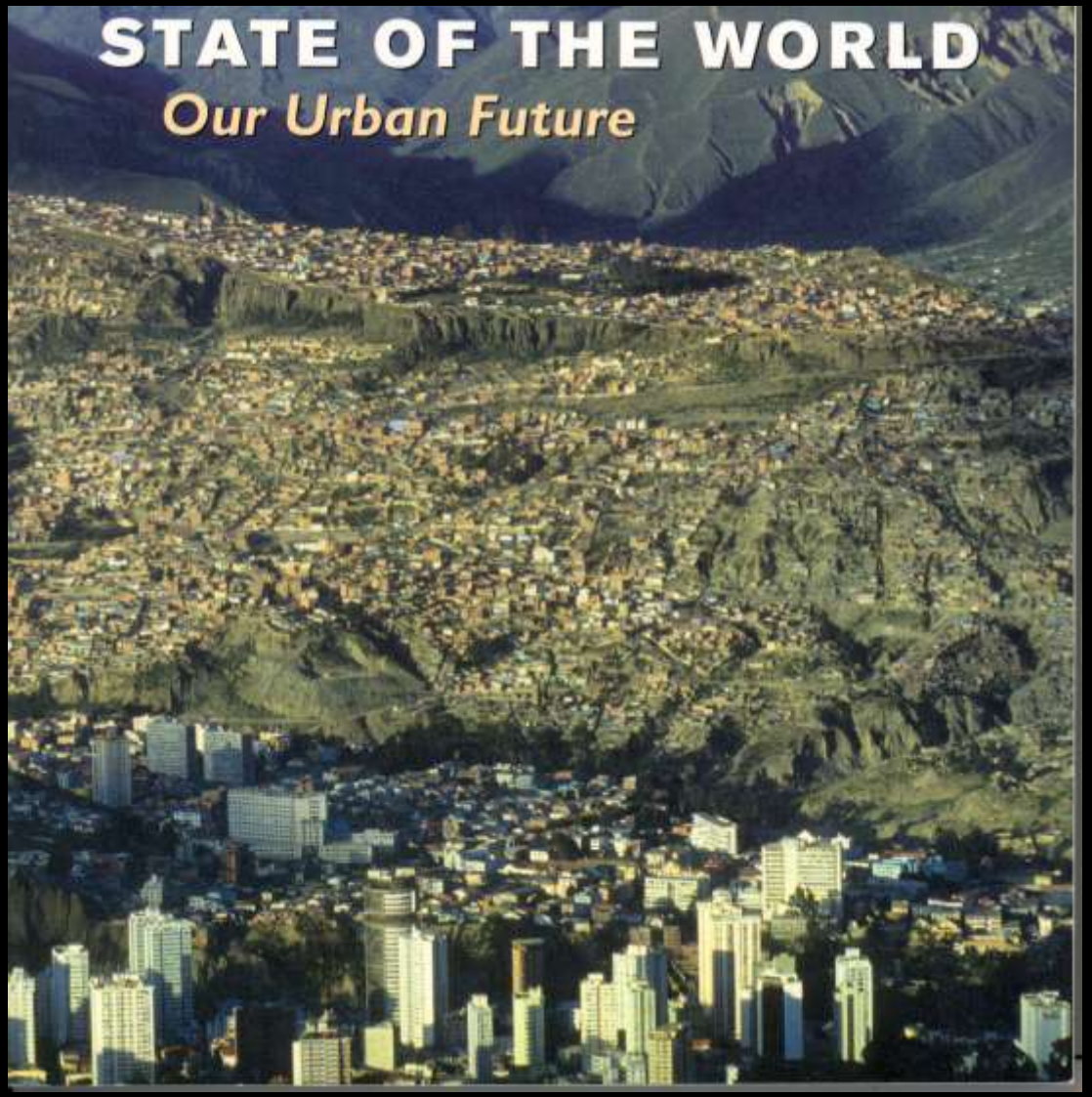
Energy Independence
and Security

Reduced Depletion
of Non-Renewable Resources

Urbanization and Global Public Health

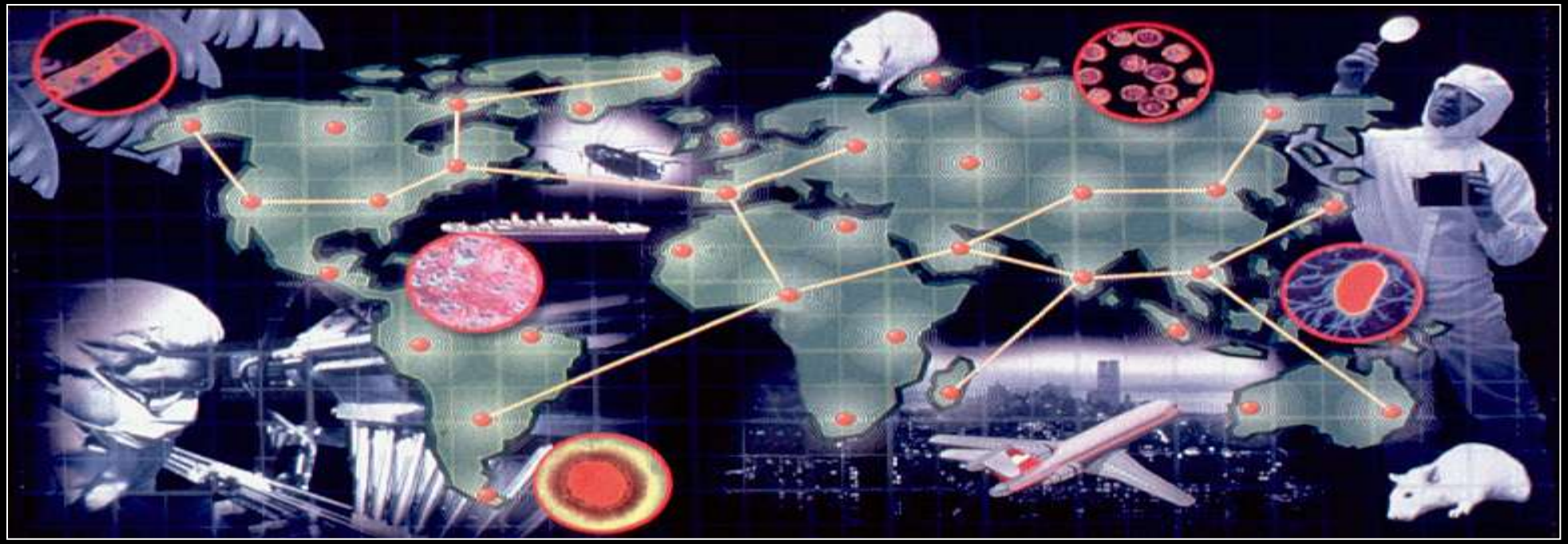
Safe Water Supplies and Health

Toxic Waste and Bioremediation



The Lack of Public Health Infrastructure in Developing Countries: Urbanization and New Zoonoses

EIDs: Global Reach and Global Consequences



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Water: Supply and Safety
A Source of Future Geopolitical and Economic Instabilities






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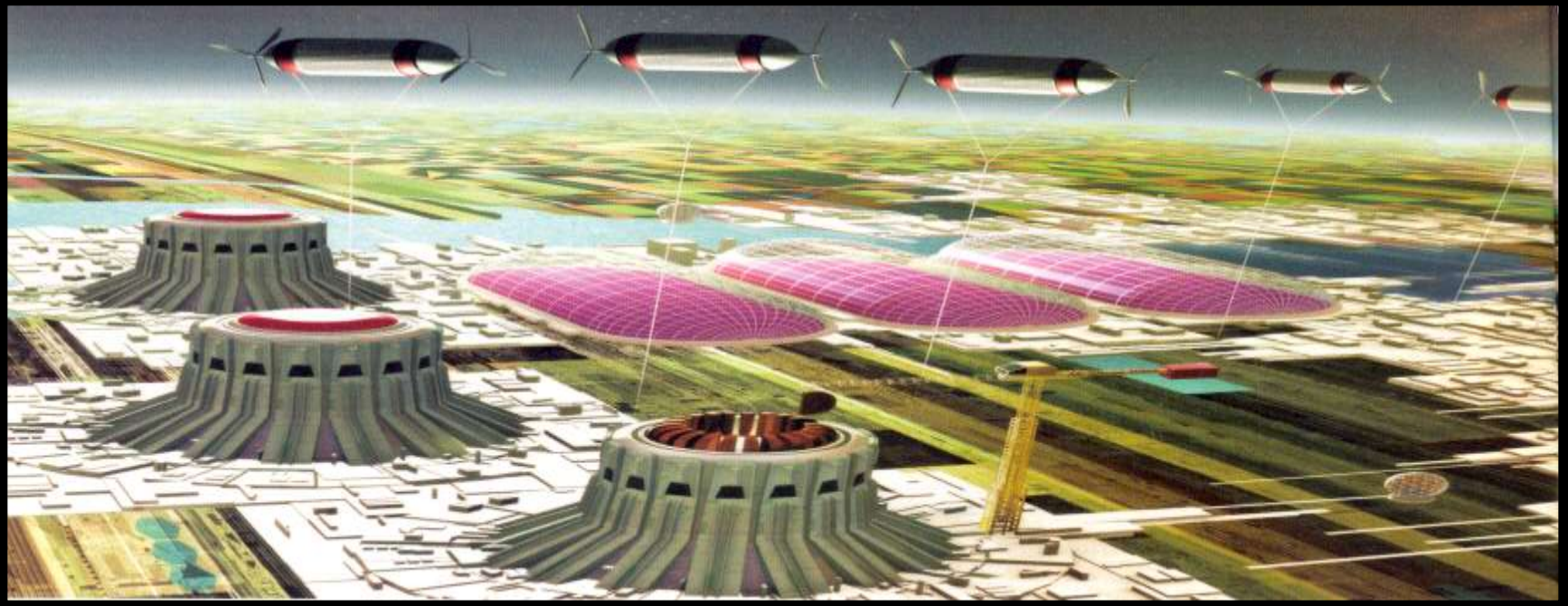
Charting Sustainable Energy Sources



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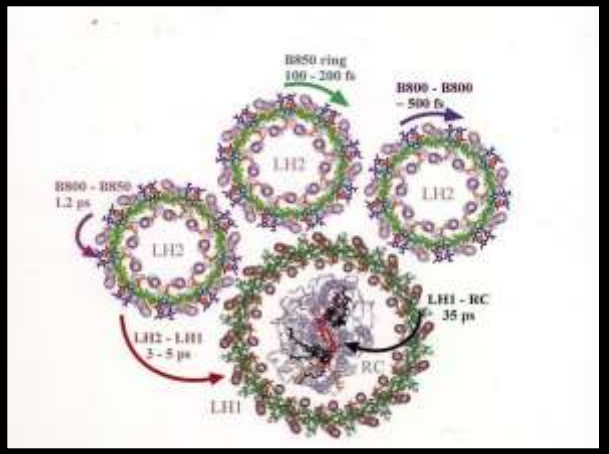
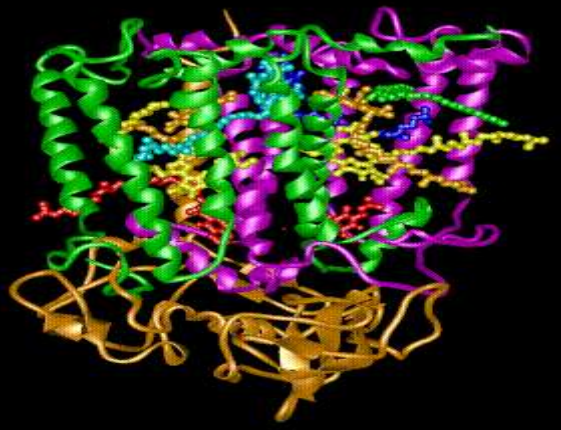
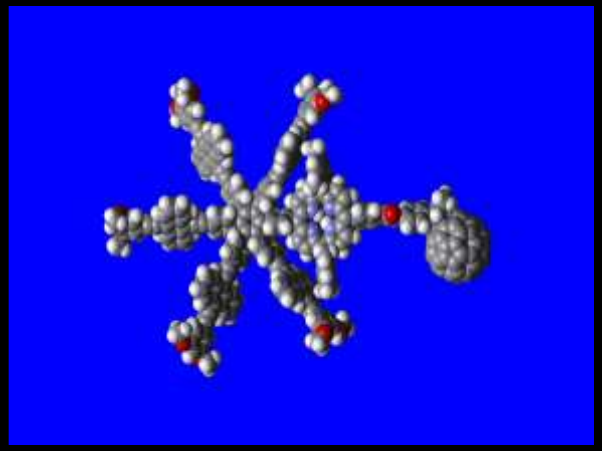
Design of Biomimetic Molecular Photovoltaics by Directed Molecular Assembly on DNA Scaffolds

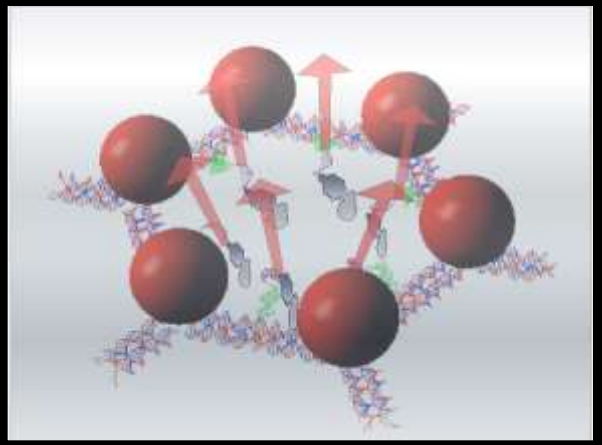




Natural Photosynthetic (PS) Systems



Artificial PS Reaction Center



Artificial Reaction Centers on DNA Grid

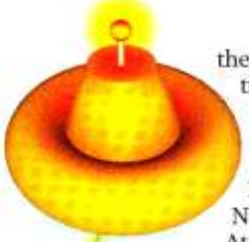
The Tiniest Power Plants

Scientists are seeing a host of possibilities in electricity produced by microbes

BY JOHN CAREY

LEONARD M. TENDER HAD A little demo in his office at the Naval Research Laboratory in Washington that could wow visitors. His computer screen showed air and water temperature data transmitted from a buoy in the nearby Potomac River. The surprise was the power "the microbes are starved for a place to put the electrons." When scientists bury an electrode in sediment and connect it in a circuit, the bugs glom on to it and happily supply electricity. The result is one of the world's most unlikely power plants.

Tender hopes to turn these microbes into power supplies for sensors and instruments in lakes and oceans. That will be a boon for researchers and military sleuths

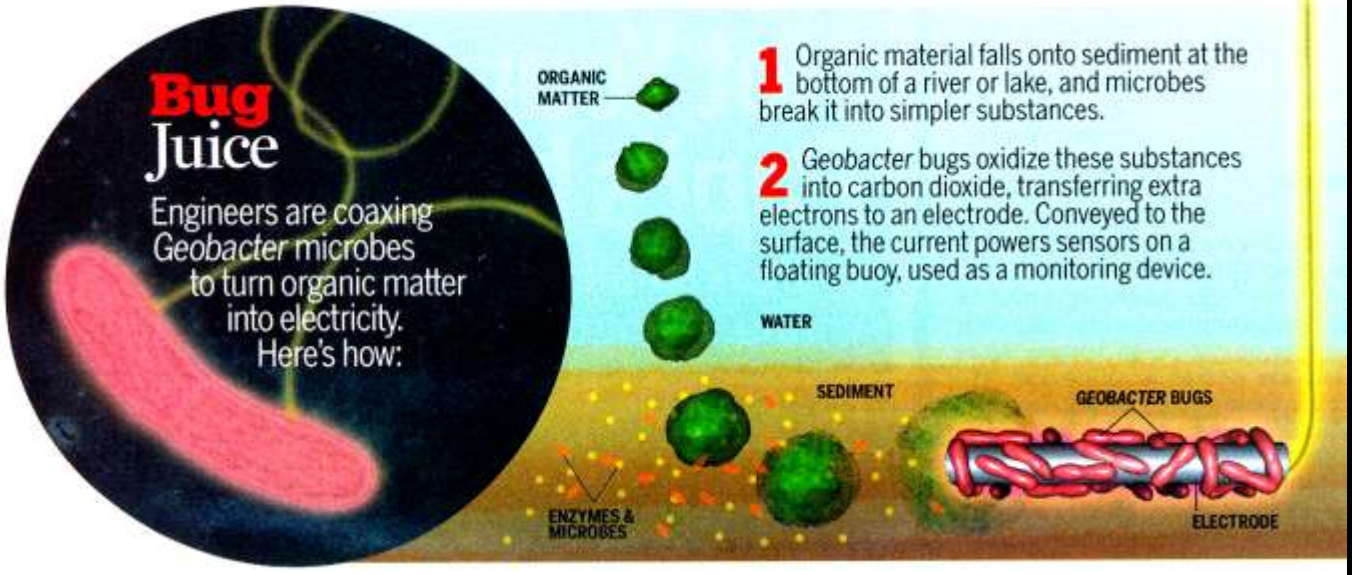


the grip of oil-producing nations by providing alternatives. The research "is at a very, very early stage, but the potential is huge," says Patrick L. Brezonik of the National Science Foundation. At the University of Massachusetts at Amherst, microbiologist Derek R. Lovley has figured out how these bugs work. To prove their potential, he has designed microbial cells powerful enough to drive toy SUVs and other devices.

FILAMENT FLOW

LOVLEY RECENTLY made an important discovery. Some species of electricity-producing microbes, such as *Geobacter*, have long, wispy filaments extending out from their cells. At one of his son's soccer games, Lovley broached the "crackpot" idea with another dad that the filaments could be natural wires. The talk led to experiments proving that electrical current flowed down the filaments. "It's still quite amazing to me," says Lovley.

The find has important practical implications. Lovley and others had though



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Synthetic Biology: Bioremediation and Ecologically Sound Bio-inspired Manufacturing Processes

"You can't throw things away.
There is no away"

Paul Hawken

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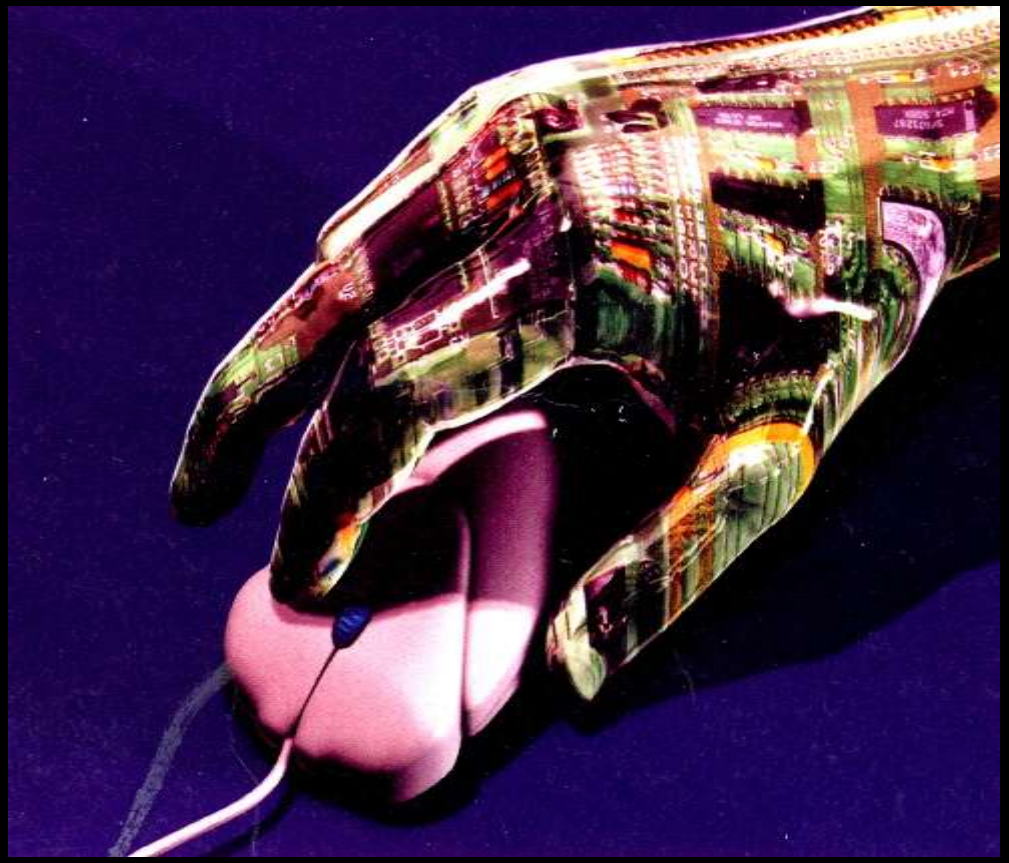
Convergent Technologies and Radical Shifts in Complex Adaptive Systems (Emergence)

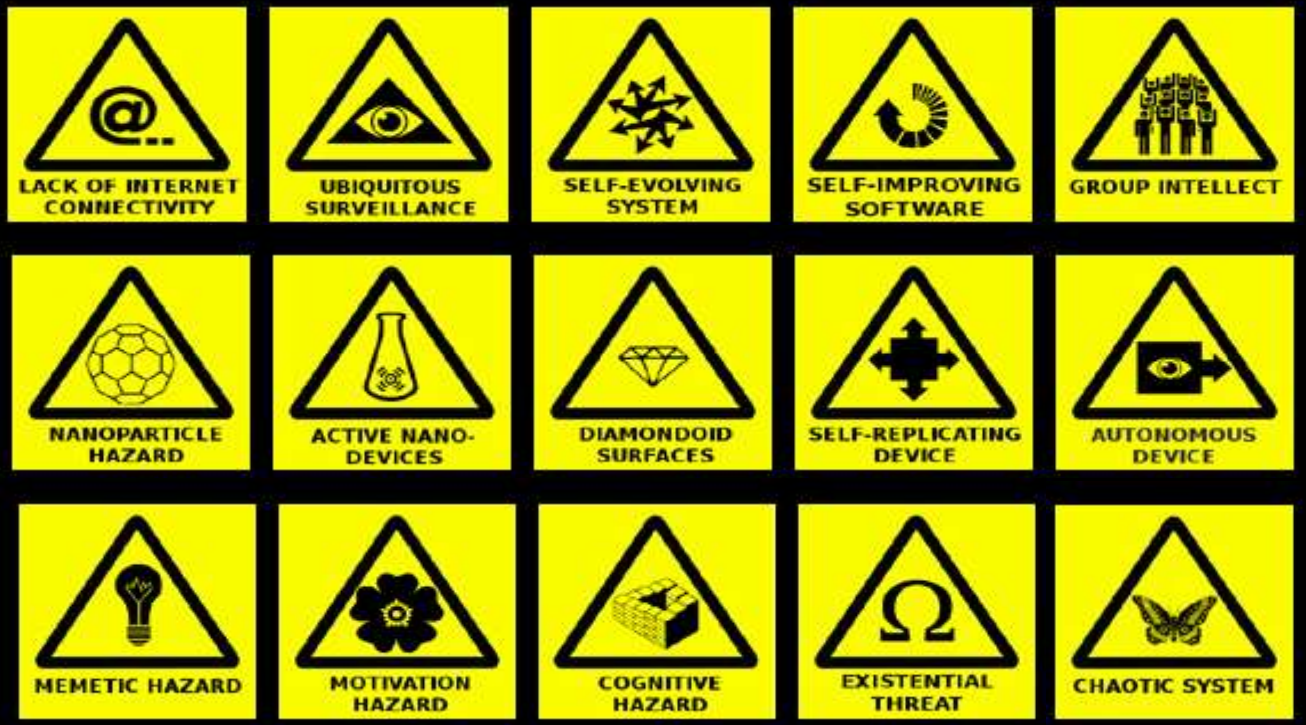


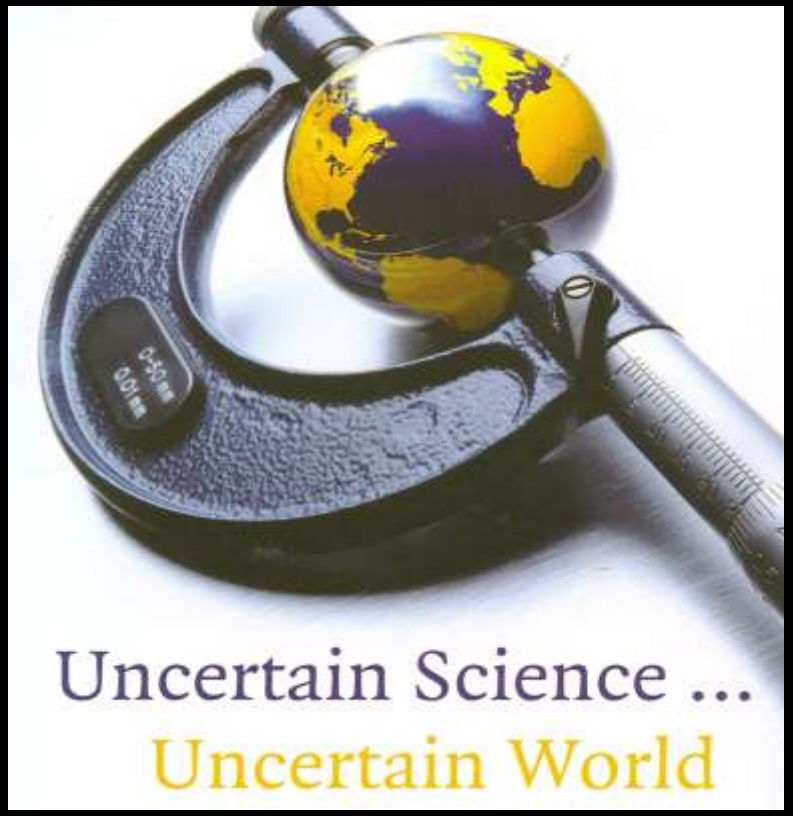
Transformational Technologies and the Relentless Destabilization of Societal and Institutional Relationships



- globalization and cultural homogenization
- new aspirants and future competitiveness
- the widening economic divide between the haves and have nots
- new political tensions, fundamentalism and anti-western ideologies

Managing Technological Risks: Oversight and Regulation





"The aim of science
is not to open the door to infinite wisdom
but to set a limit to infinite error"

Bertolt Brecht

No Ambiguity, No Error (No Problem)

Mr. Spock: "Insufficient data, Captain"

Captain Kirk: "Insufficient data is not sufficient, Mr. Spock.
You're the Science Officer.
You're supposed to have sufficient data
all the time"

Star Trek
The Immunity Syndrome

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"Transcending the Limits of Us"
Michael M. Crow (2007) Issues in Science and Technology, Winter p 1

- affluence, comfort and complacency reinforced by political populism: a potent prescription for "Quick Fixes"
- pervasive and dangerous scientific illiteracy among policy makers and socio-economic elites
- current educational system and institutional structures lack the flexibility, resilience and responsiveness to assess large-scale and long-term consequences
- better understand the limits of collective ability to acquire, integrate and apply knowledge
- imperative for new approaches to comprehend and manage complex adaptive systems


is that an implant?
The future went that way . . . sir
MCGINN