ASU Complex Adaptive Systems Initiative
Arizona State University

IQT In-Q-Tel

The Accelerating Trajectory of The Life Sciences: Implications for Health, Industrial Innovation and National Security

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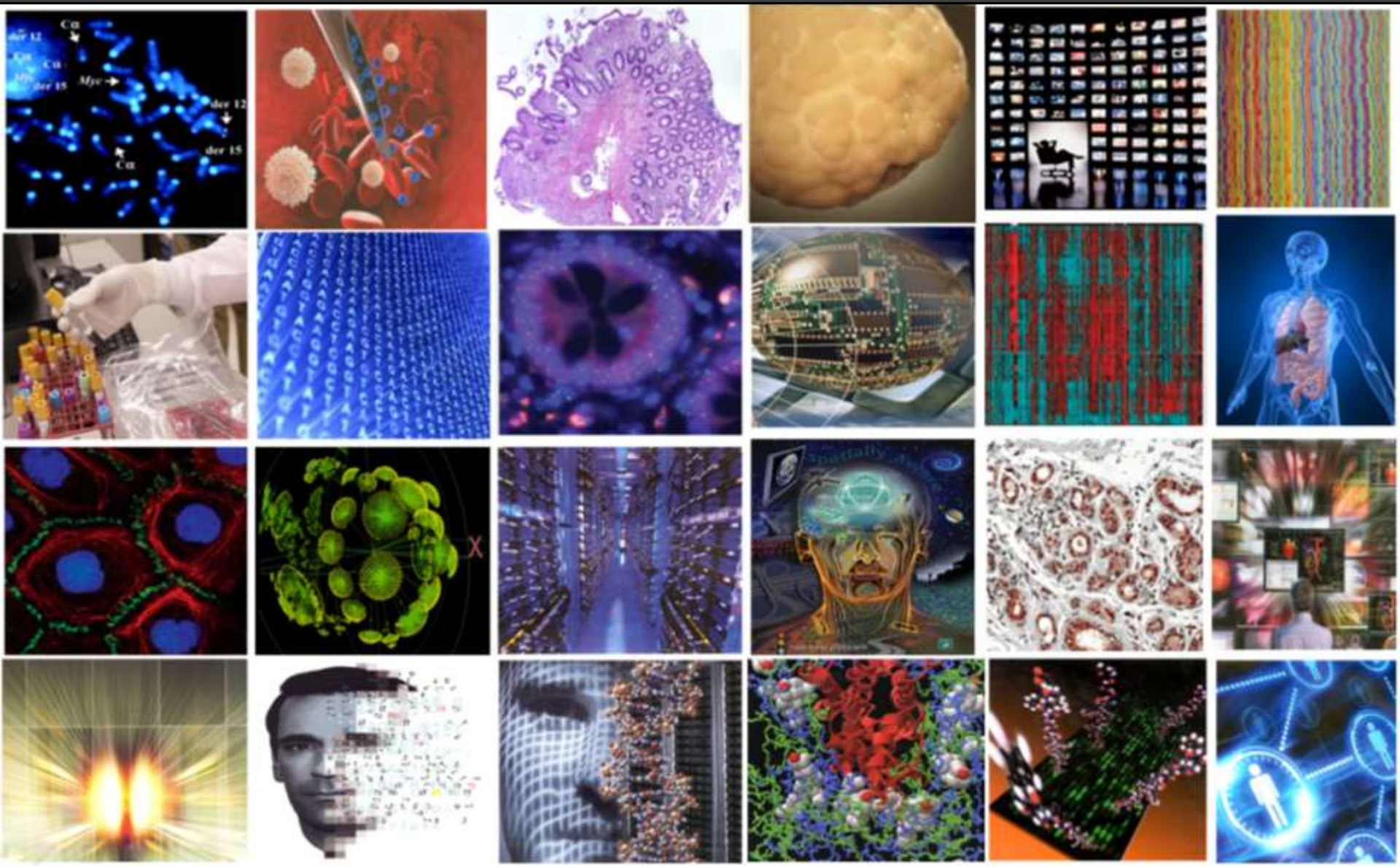
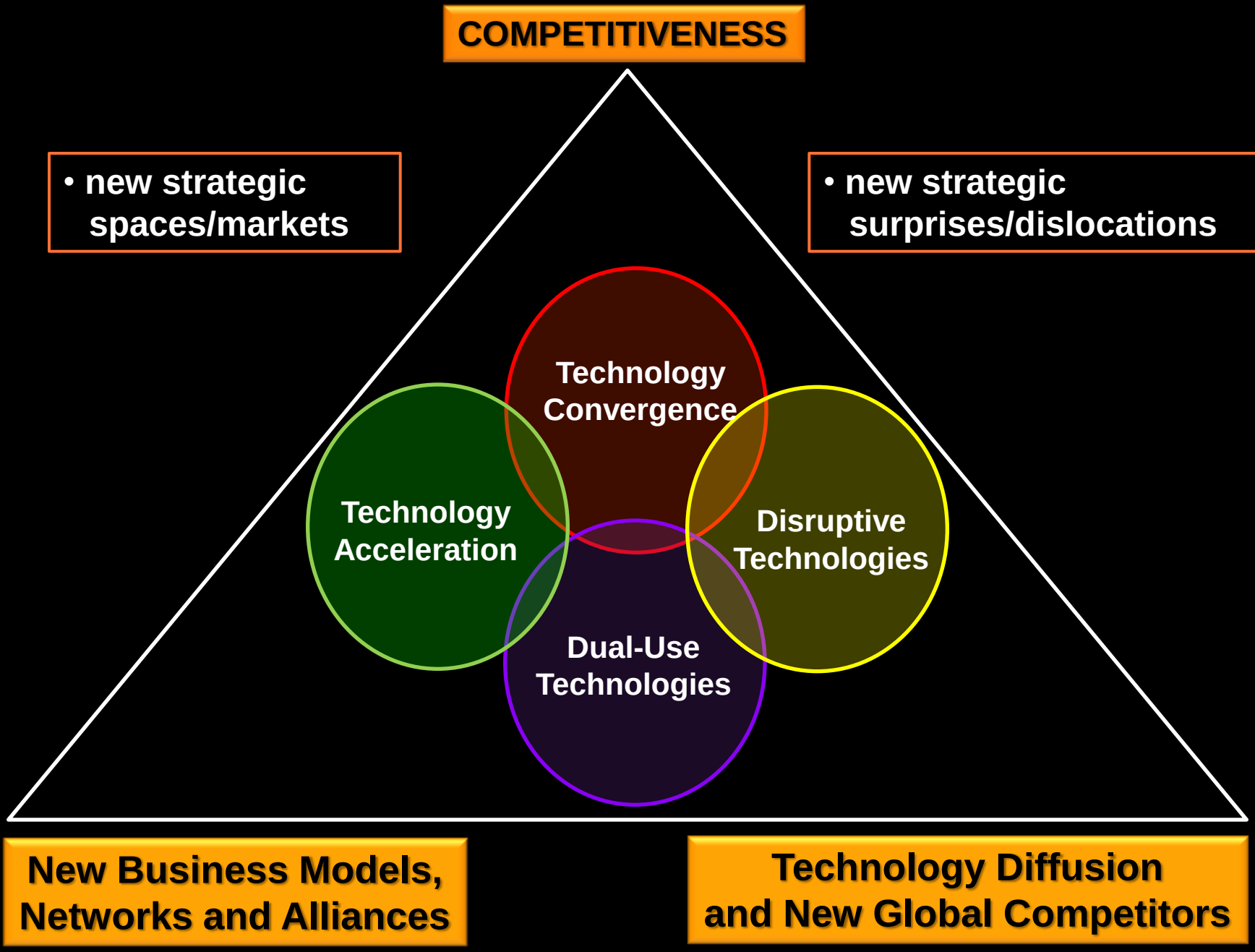
Keynote Presentation to In-Q-Tel CEO Summit
The Portola Hotel and Monterey Conference Center
4 February 2015

Slides available @ http://casi.asu.edu/

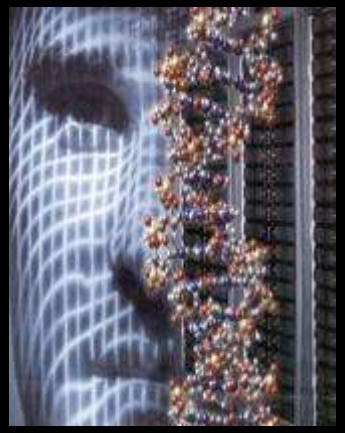


The Strategic Environment for Technology



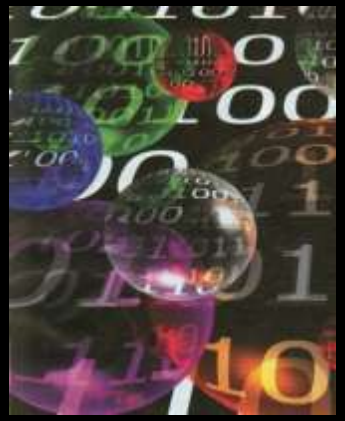
Accelerating Technology and Escalating Complexity: Conceptual, Technological, Informational and Commercial

Biomedicine, Biotechnology, Synthetic Biology



“Bio-Space”

Ubiquitous Sensing/ Devices & Social Networks



“Connected Space”

Advanced Computing Mega-Metadata

“Analytics Space” and “Surveillance Space”

Robotics and Advanced Autonomous Systems

“Design Control Space”

Neurosciences and Human-Machine Interactions

“Cognitive Space”

New Patterns of Technology Fusion, Evolution and Adoption

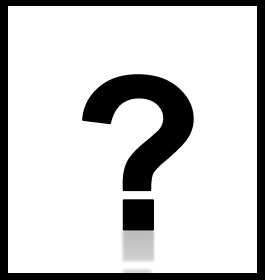
New Knowledge Networks

New Participants

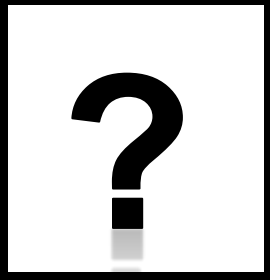
New Markets and Business Models

Convergence and Acceleration in Advanced Technologies

"threat space"



"competition space"



"possibility space"

Monitoring and Analysis of Complex Adaptive Systems

- **connectivities of complex networks (systems of systems)**
- **escalating complexity and decision making in the face of uncertainty**

The Ubiquity of Complex Systems: Understanding the Determinants of Complexity

Earth Systems	Eco-Systems	Host-Pathogen Interactions	Molecular Signaling Networks
			
Financial Systems	**Urban Systems**	**Information Systems**	**Societal Disruption**
			

Complex Systems and New Challenges in National Security and Military Strategy

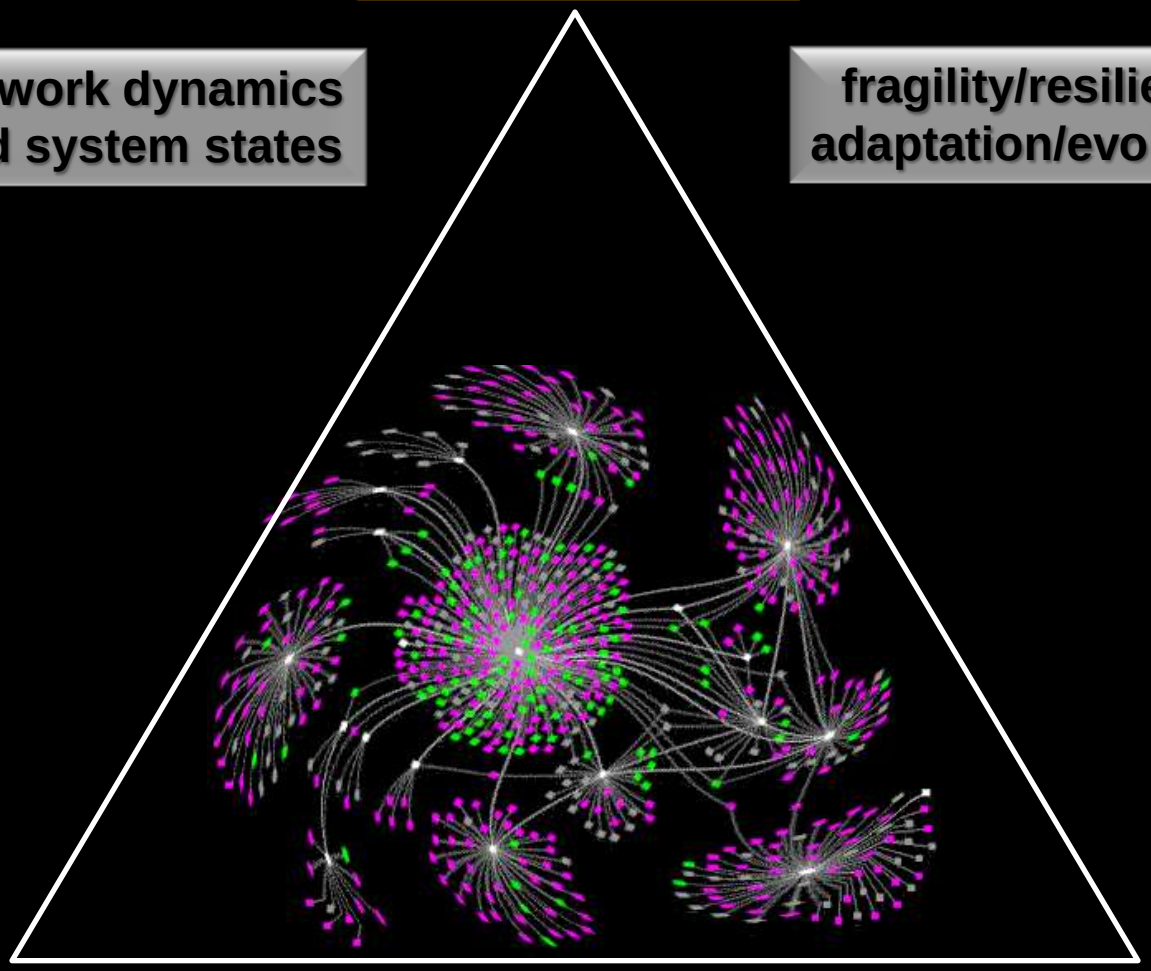
Expanding Conflict Zones, Political Instabilities and Terrorism

WMD Proliferation

New Power Centers

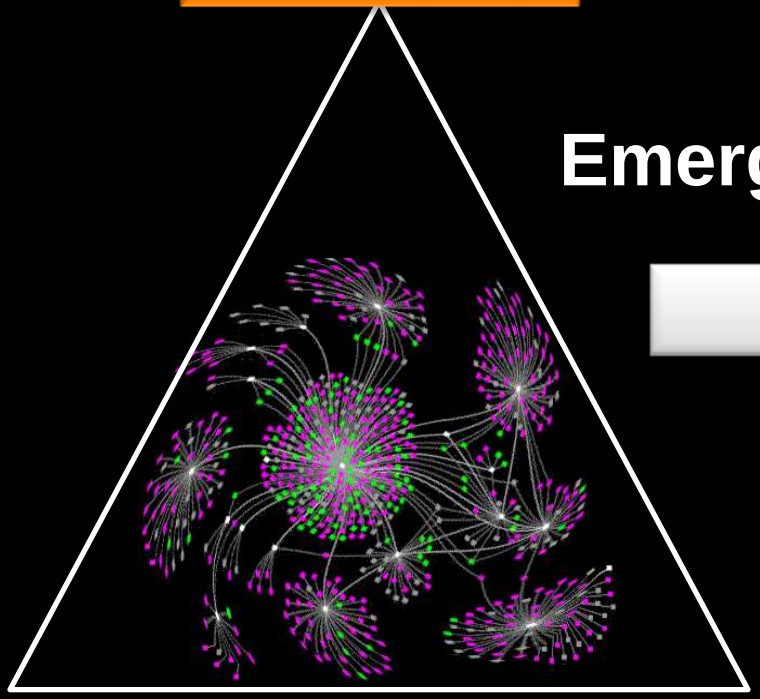
US Retrenchment: Geopolitical/Fiscal

Network Design in Complex Systems



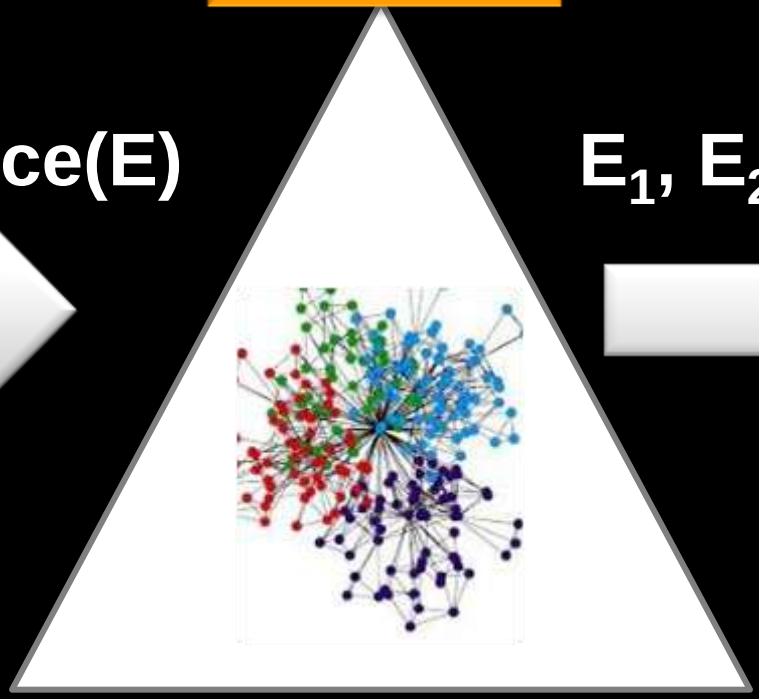
Understanding State Shifts in Complex Adaptive Systems and Identification of Triggers of Emergence

network topology



Emergence(E)

state shifts



$E_1, E_2 \ldots E_n$

- Black Swans
- dislocations
- tipping points
- irreversible cascades
- phase shifts
- perturbations
- inflection points
- critical thresholds
- bifurcations
- trigger points
- unintended consequences

Convergence of Large Scale Biology with Engineering, Computing and Digital Technologies

Precision Medicine

Outpacing Infectious Disease

Urbanization and Sustainable Ecosystems

Securing a Safer World

Synthetic Biology

Shared Cross-Domain Technology Platforms

Unique Signatures of Biological System States

Multiplex Signature Detection Systems: Diagnostics, Sensors & Taggants

Ubiquitous Sensing: Remote Monitoring of Network Architectures and Dynamics

Massive Data: Complex Signal Deconvolution, Data Formats & Visualization

Convergence of Large Scale Biology with Engineering, Computing and Digital Technologies

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Synthetic Biology

Common Themes: Multiplex Profiling, Integrated Analytics, Informed Decisions

Massive Data and New Analytics for Non-Linear Events: Intelligence at Ingestion

Cognitive Systems, Human-Machine Interactions and Artificial Intelligence

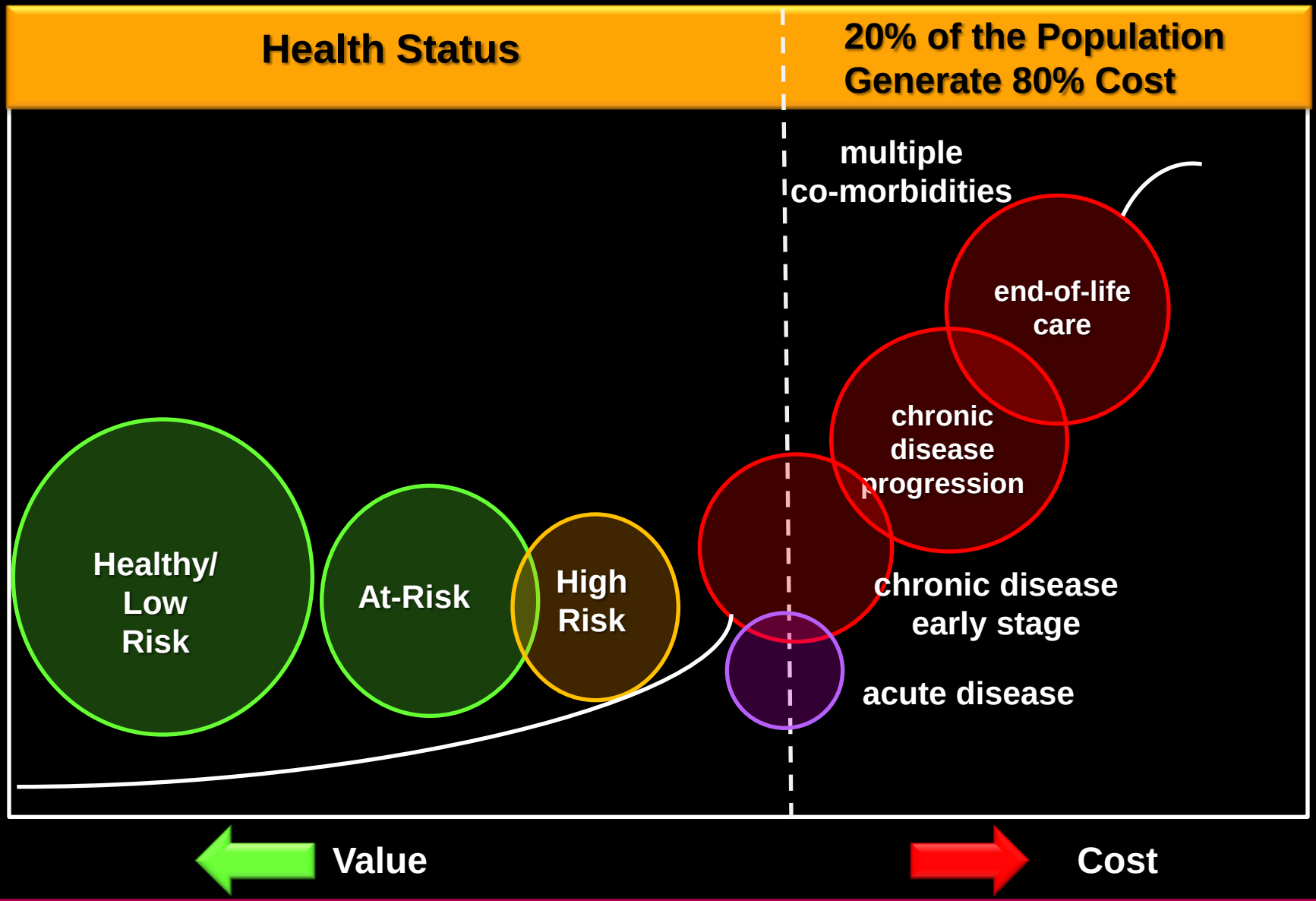
Managing Complexity: Decision-Making, Regulation and Public Policy

Ethical, Legal and Societal Implications of New Technologies

Challenges and Ugly Realities Facing US Healthcare

- Balancing Infinite Demand Versus Finite Resources
- More Effective Management of Chronic Diseases in Aging Populations
- Improving Clinical Outcomes at Lower Cost and the Wellness Premium
- Technology, Innovation and New Value Propositions

The Economic, Social and Clinical Benefits of Proactive Mitigation of Disease Risk and Chronic Disease Co-Morbidities



Economic and Clinical Icebergs About to Collide with US Healthcare

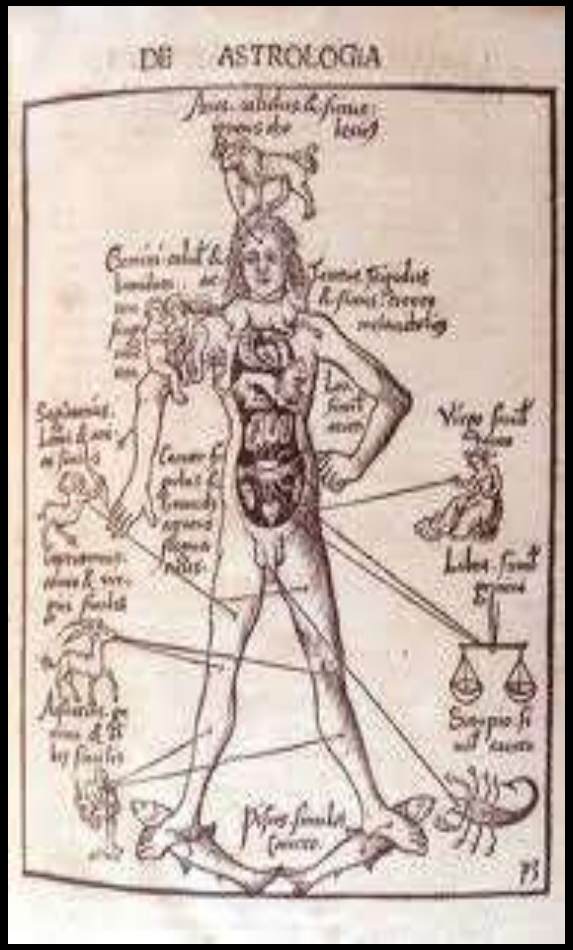
Cancer	Neurodegeneration	Chronic Disease, Frailty and QOL

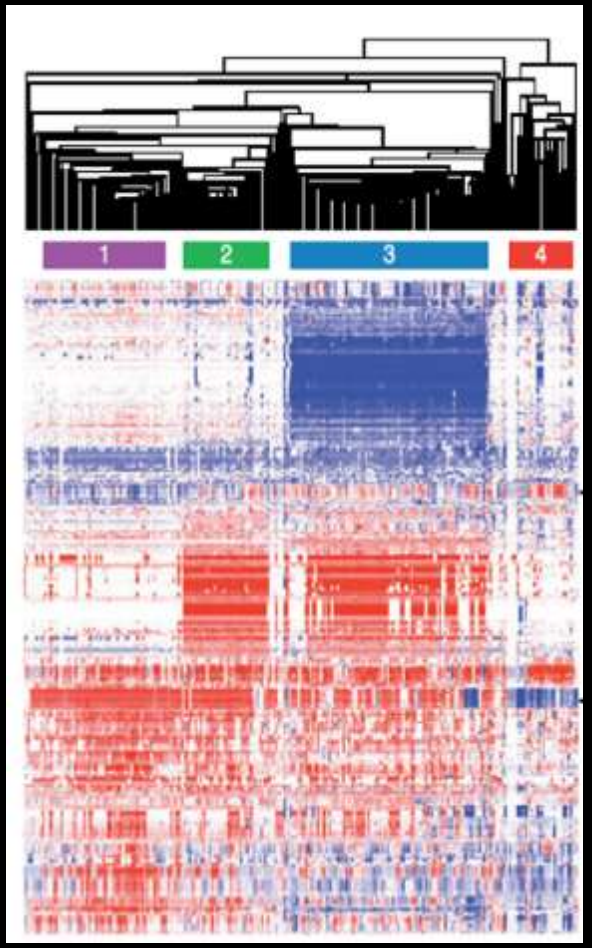
- 20-30% projected increase by 2025
- inadequate clinical and infrastructure resources
- economically unsustainable

- ageing well
- new products and services

Extending Life: Balancing Time, Cost and Quality of Life

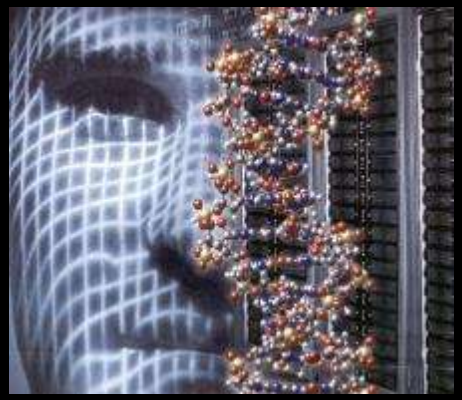
Medical Progress:
From Superstitions to Symptoms to Signatures



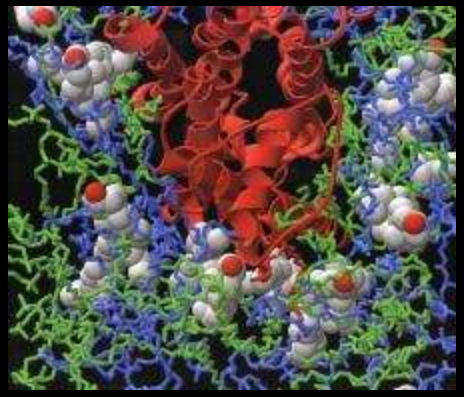


Precision Medicine: Understanding Molecular Signaling (Information) Pathways in Health and Disease

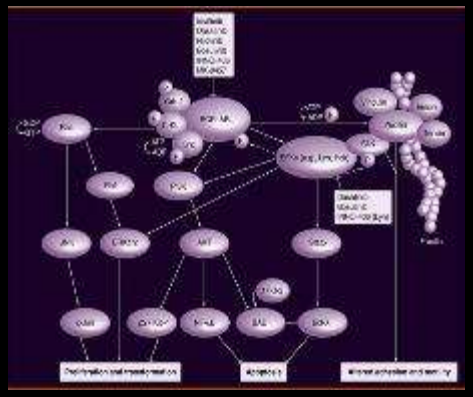
Genomics



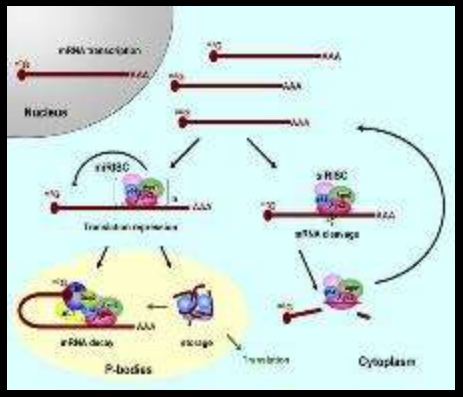
Proteomics

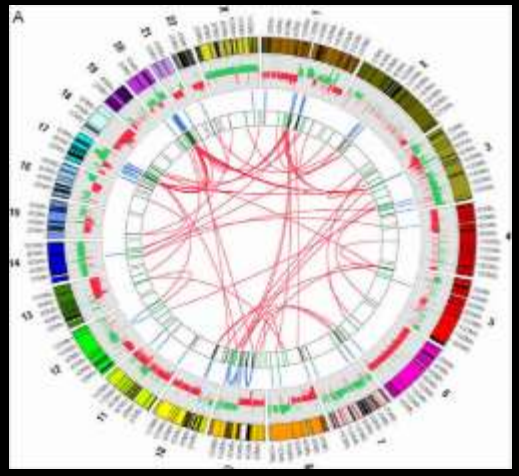


Molecular Pathways and Networks



Network Regulatory Mechanisms





ID of Causal Relationships Between Network Perturbations and Disease Subtypes

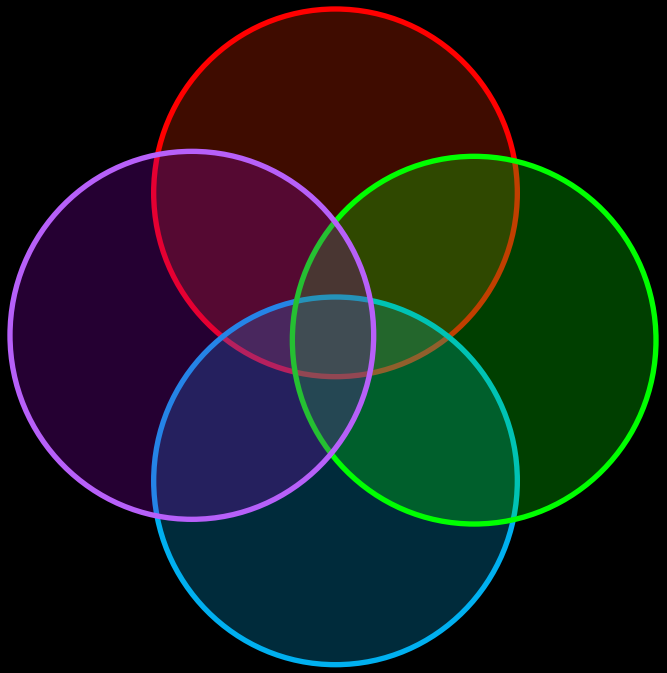
Patient-Specific Signals and Signatures of Disease or Predisposition to Disease and Targeted Rx

The Principal Forces Shaping Biomedical R&D and Healthcare Delivery

device-based medicine

- molecular diagnostics
- sensors

- remote health monitoring
- telemedicine



molecular (precision) medicine

- panOmics profiling
- integrated analytics of biological networks

information-based healthcare

- m.health/e.health
- data- and evidence- based decisions and Rx selection

outcomes-based healthcare and sustainable health

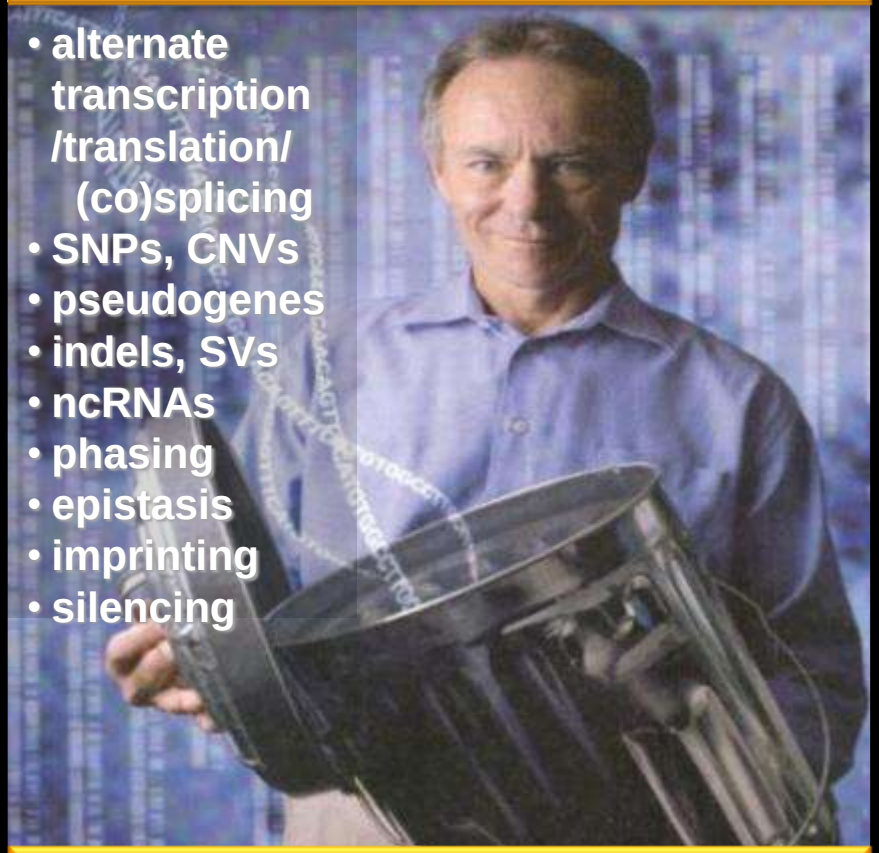
new value propositions, new business models and services

Genome Sequencing and Precision Medicine

- **Clinical Utility: Not If, but When and What**
- **Hype Is Always Followed by the Hard Work of Demonstrating Value**

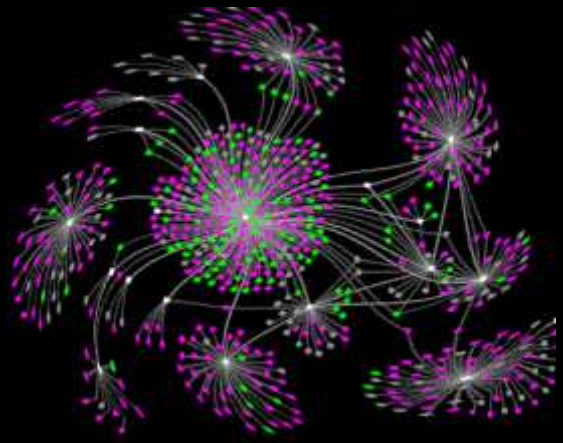
Precision Medicine: Individual Variation, Genome Complexity and the Need for Systems-Based Approaches to Analyze Disease

Junk No More: 'Dark DNA' and Pervasive Transcription

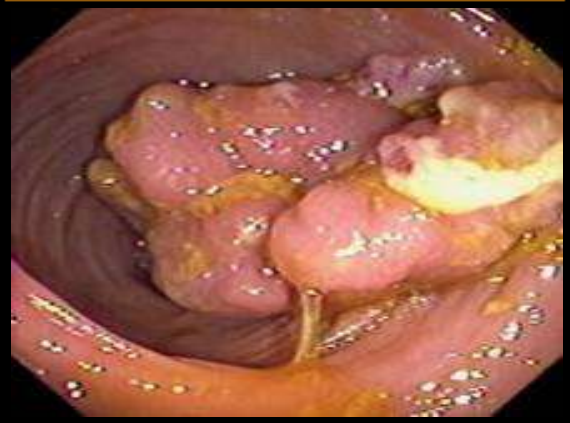


recognition of the complexity of genome organization and regulation

Cell-specific Molecular Interaction Networks

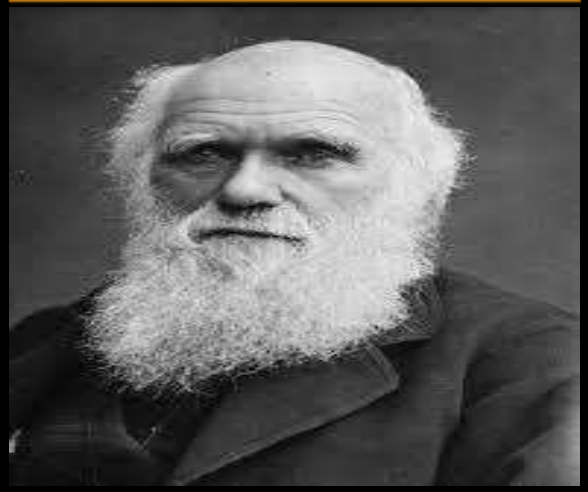


Perturbed Networks and Disease



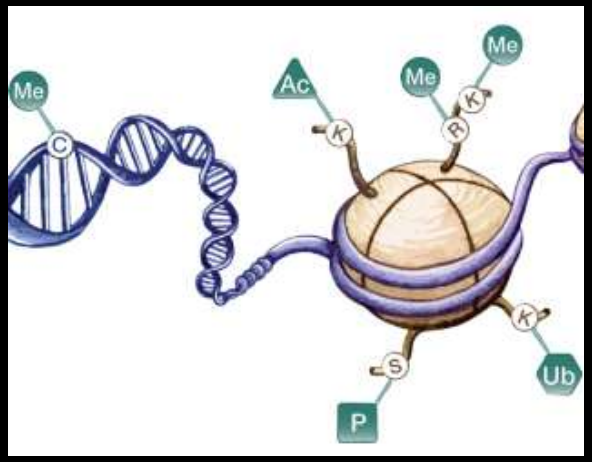
The Inheritance of Acquired Characteristics Epigenetics, Imprinting and Inter-generational Inheritance of Environmentally-Induced Genome Changes

Darwin

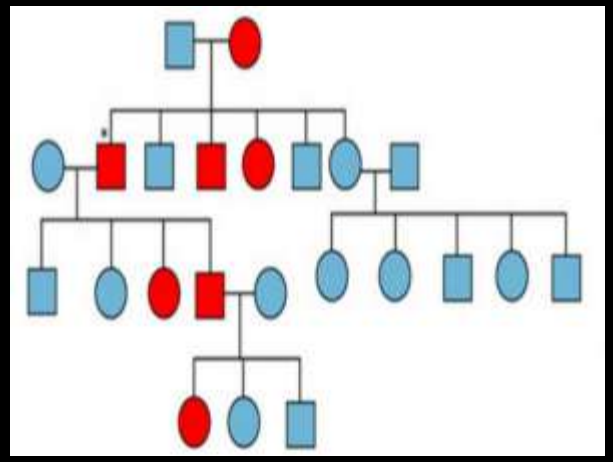


Lamarck

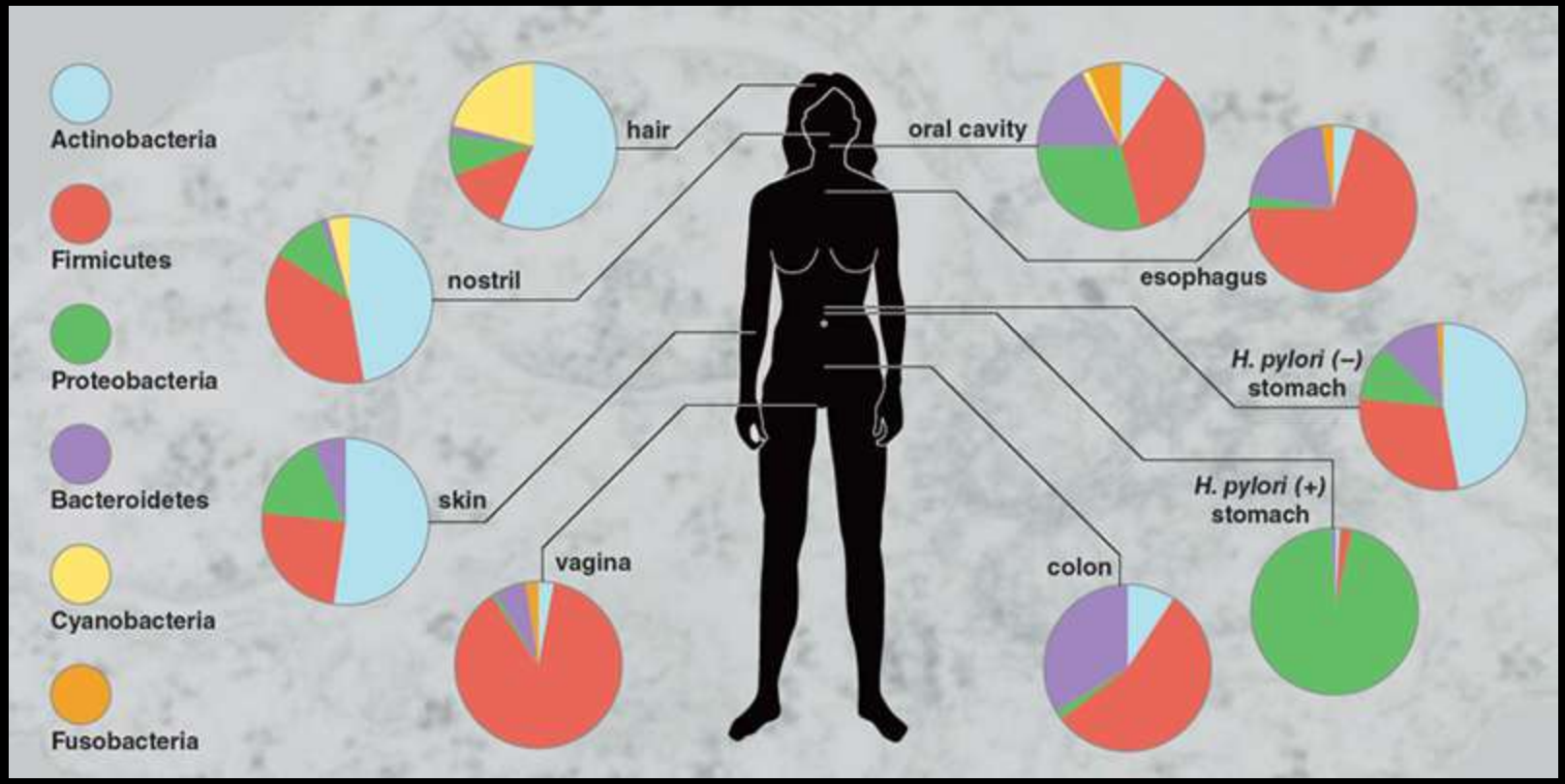
The Exposome and Epigenetic Modification



Trans-Generational Imprinting/Inheritance



We Are Not Alone: Microbiome Metagenomics
Mapping the Human Microbiome and Its Role in Health and Disease



From: R. Dorit (2014) Am. Sci. 102, 330

Variation of Microbial Species Across Anatomical Sites Within the Same Individual

The Changing ‘Touch Points’ in Healthcare Delivery

Sensors, Smart Devices, Social Media and
New Distributed Channels for Remote Health Monitoring

M4: Making Medicine More Mobile

m.Health

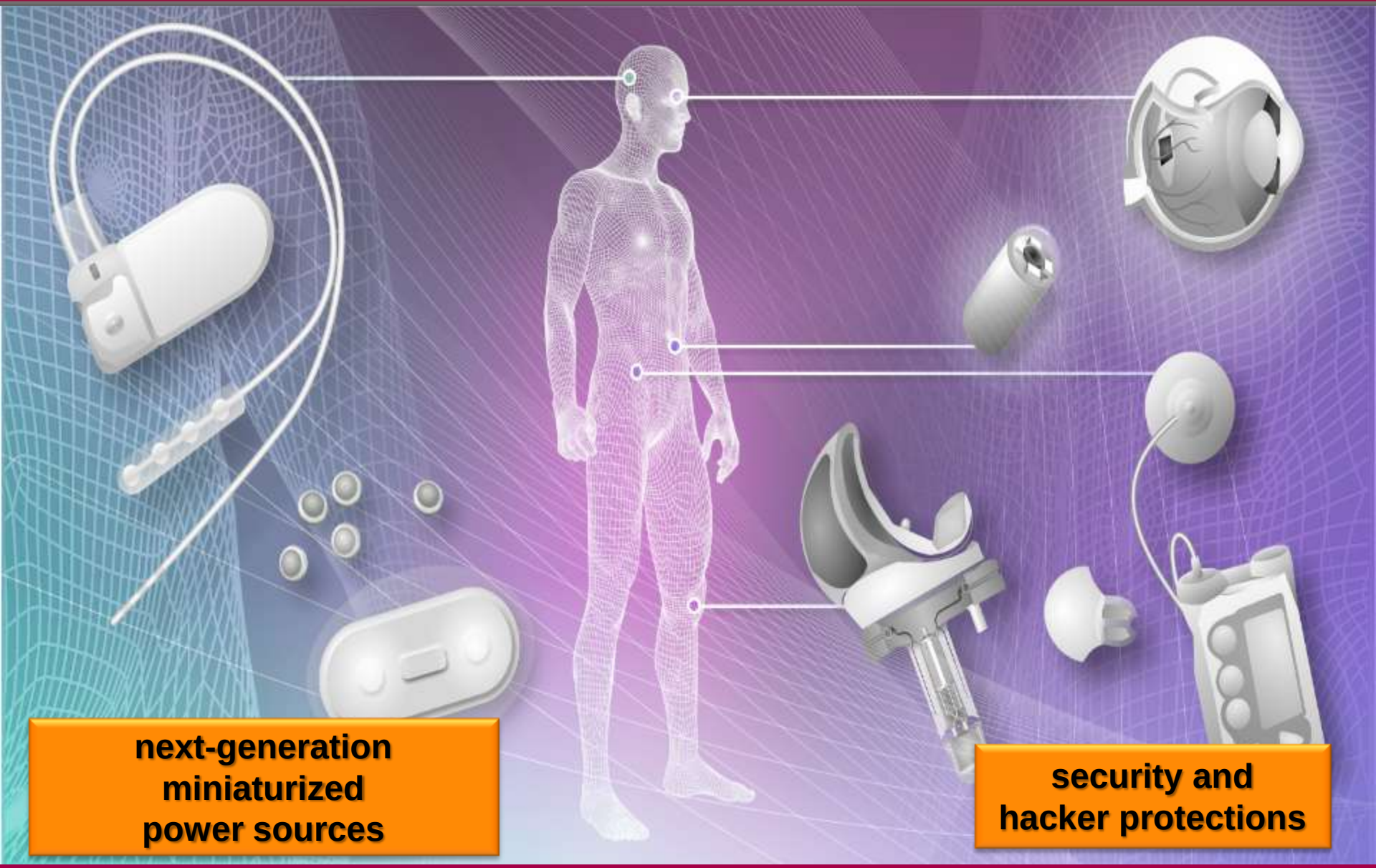
Real Time Remote Health Monitoring and Chronic Disease Management

Lifestyle and Fitness

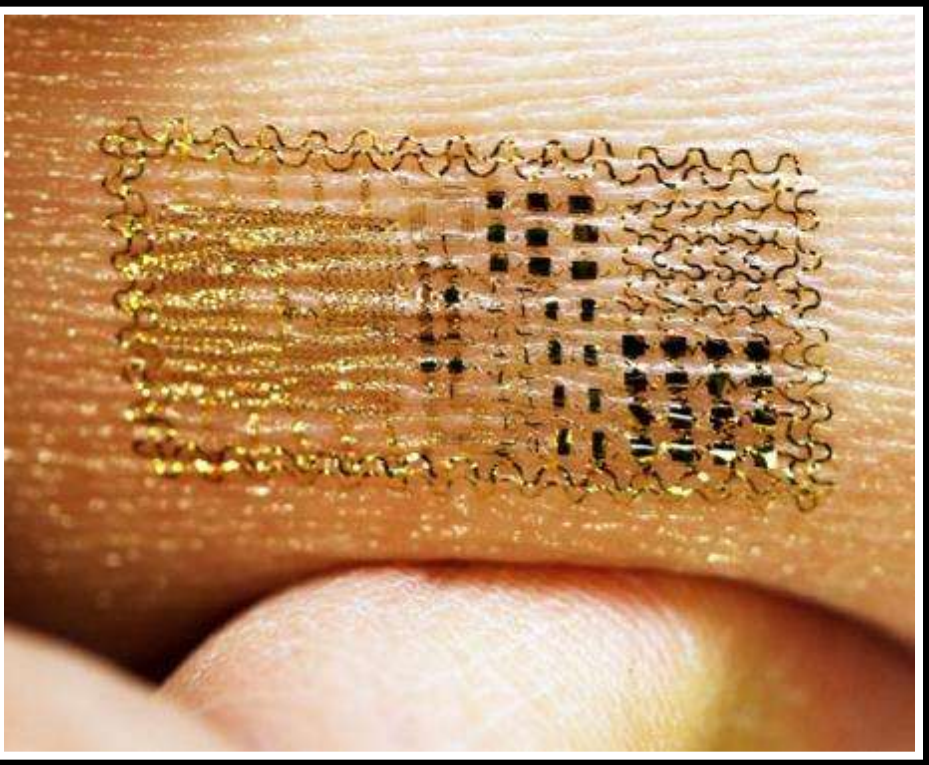
Information for Proactive Health Awareness (Wellness)

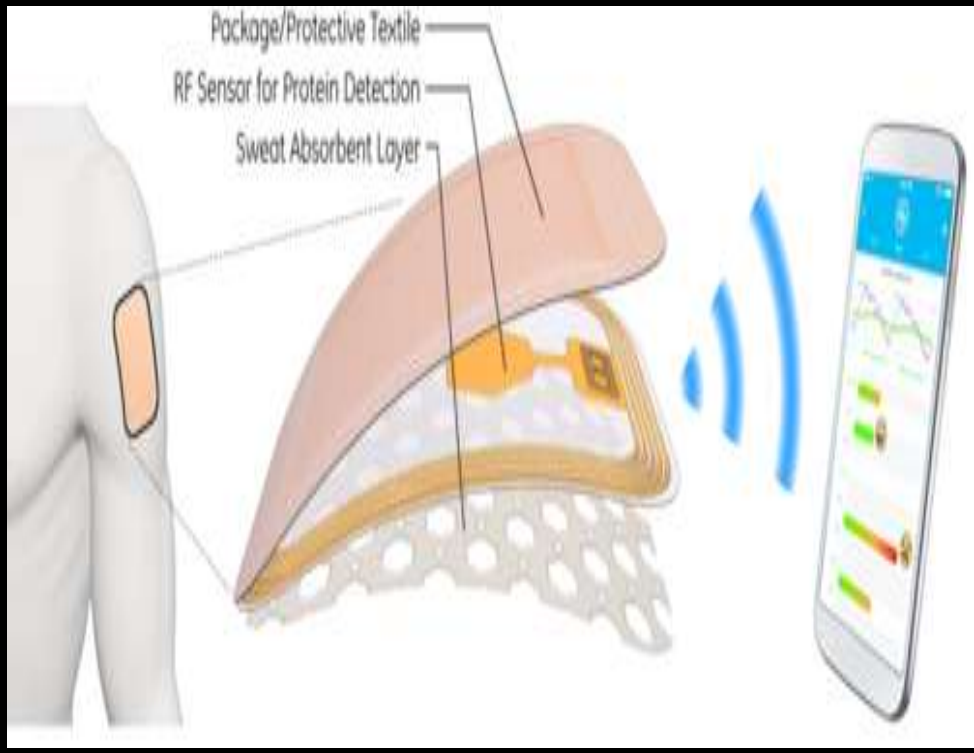
Telemedicine: Diagnosis, Monitoring and Education

Implantable Devices and Wireless Monitoring (and Modulation)



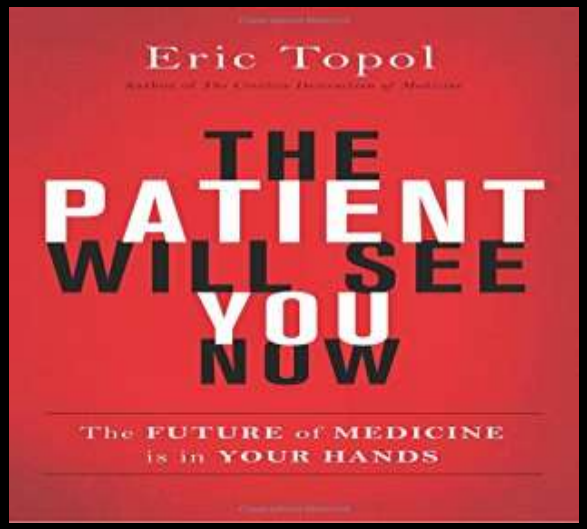
“Lab-On-Me” and “Lab-Always-On” Dissolvable Electronics and Biodegradable Sensors





- dissolution of electronic circuits in physiological conditions
- construction from water-soluble, non-standard electronic materials with specific dissolution rates

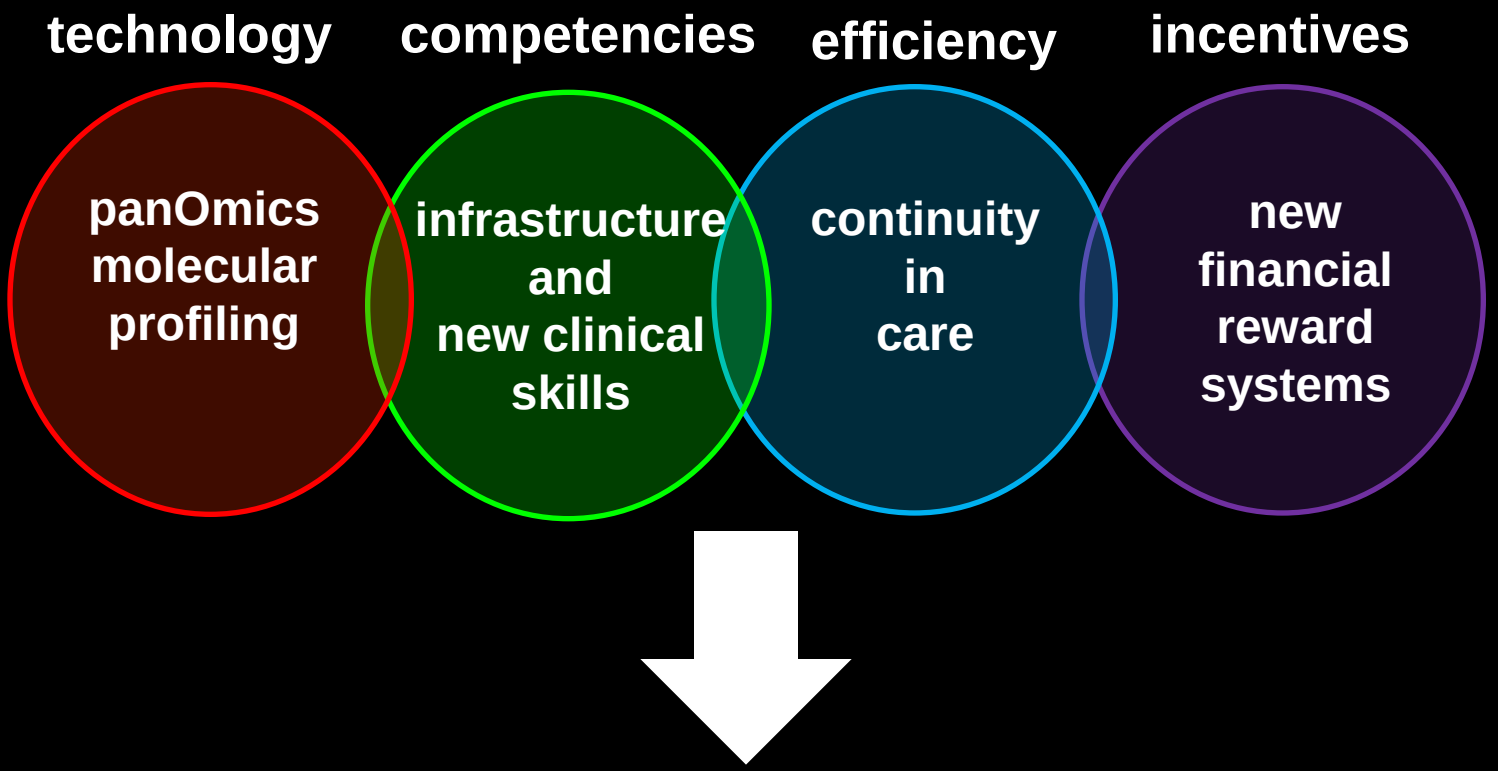
Retail Healthcare:
New Services and Value-Based Shopping for Healthcare



Consumers and Digital Health

- generational differences in receptivity
- increased personal responsibility for wellness and treatment compliance
  - economic carrots and sticks
  - pricing transparency and shopping for services
- e.health and m.health
  - real-time monitoring:
  - individuals become their own controls (delta)
  - passive versus active monitoring
- behavioral economics and new models for health engagement

Leveraging the Potential of Precision Medicine Will Require Changes in the Organization and Proficiency of Healthcare Services



- earlier intervention to reduce/prevent disease impact
- seamless integration of healthcare data for real-time access and improved care decisions

Biosecurity and Global Health: Understanding the Implications of Major Economic Disparities and Environmental Dislocations











The Biosecurity Triad

Infectious Diseases of Natural Origin

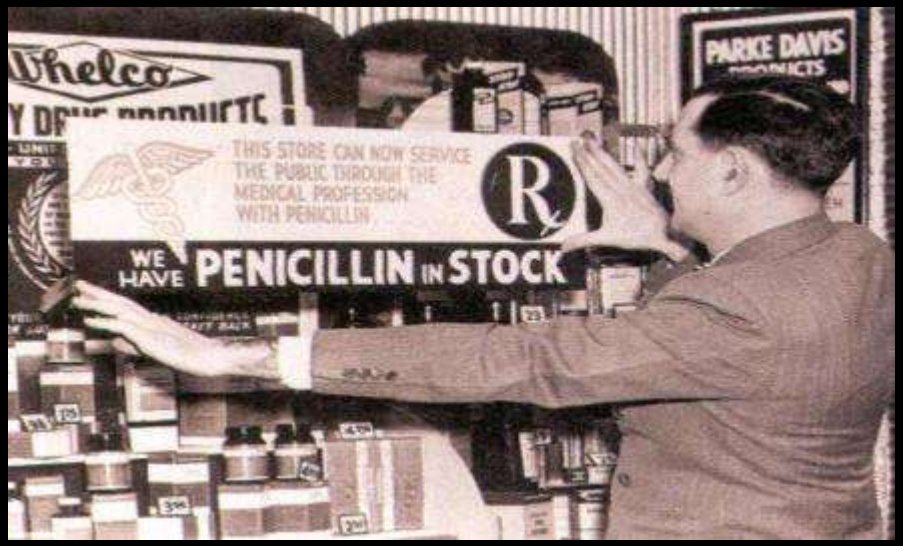
Urbanization, Environmental and Ecological Impacts on Disease Emergence

Bioterrorism, New Dual-Use Technologies and Expanded Threat Spectrum

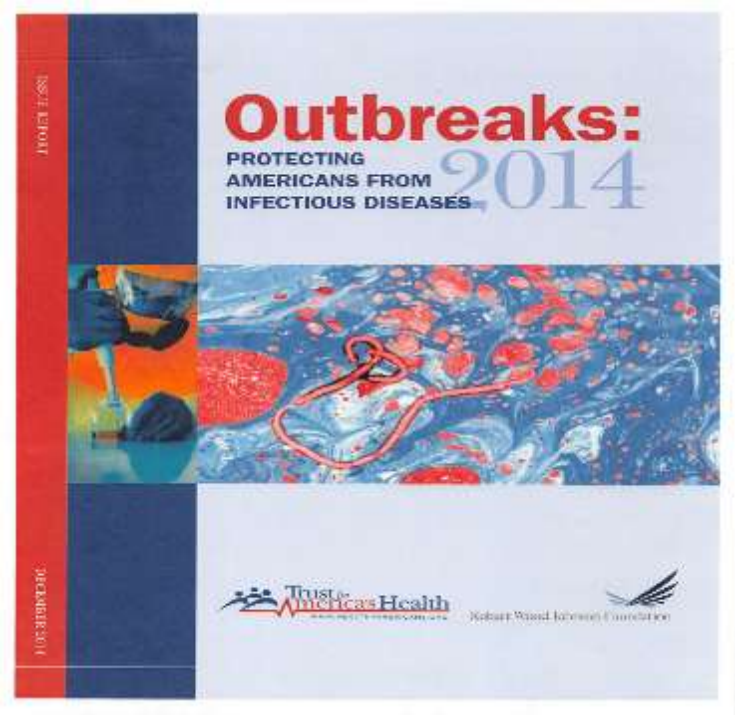
Asleep at the Switch!

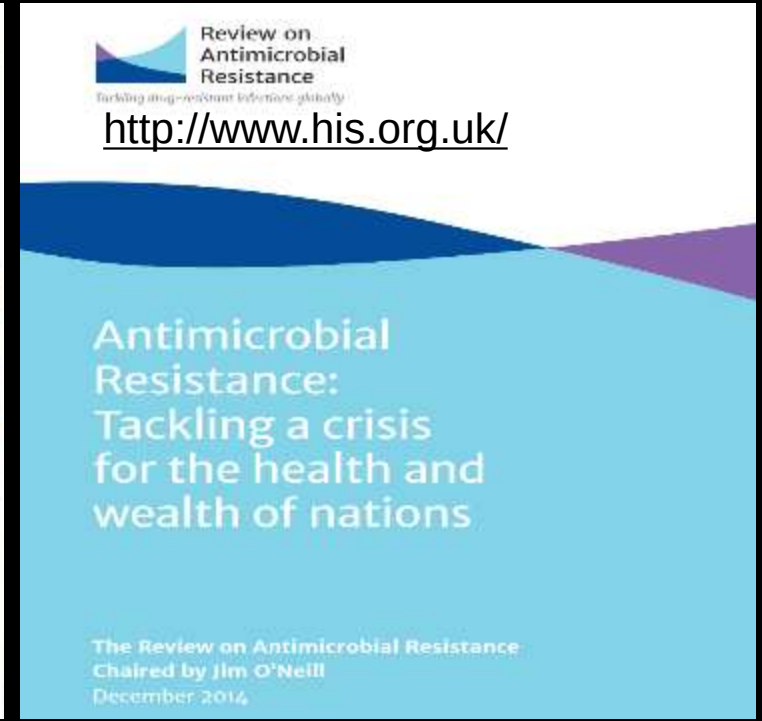
- The Resurgence of Infectious Diseases
- Major Gaps in US and Global Preparedness for a Major Pandemic (or Bioattack)
- The Imperative to (Re)Build Robust Global Public Health Capabilities
- The Critical Role of the Private Sector: New Incentives for Engagement

Comfort and Complacency: The Enemies of Vigilance and Preparedness



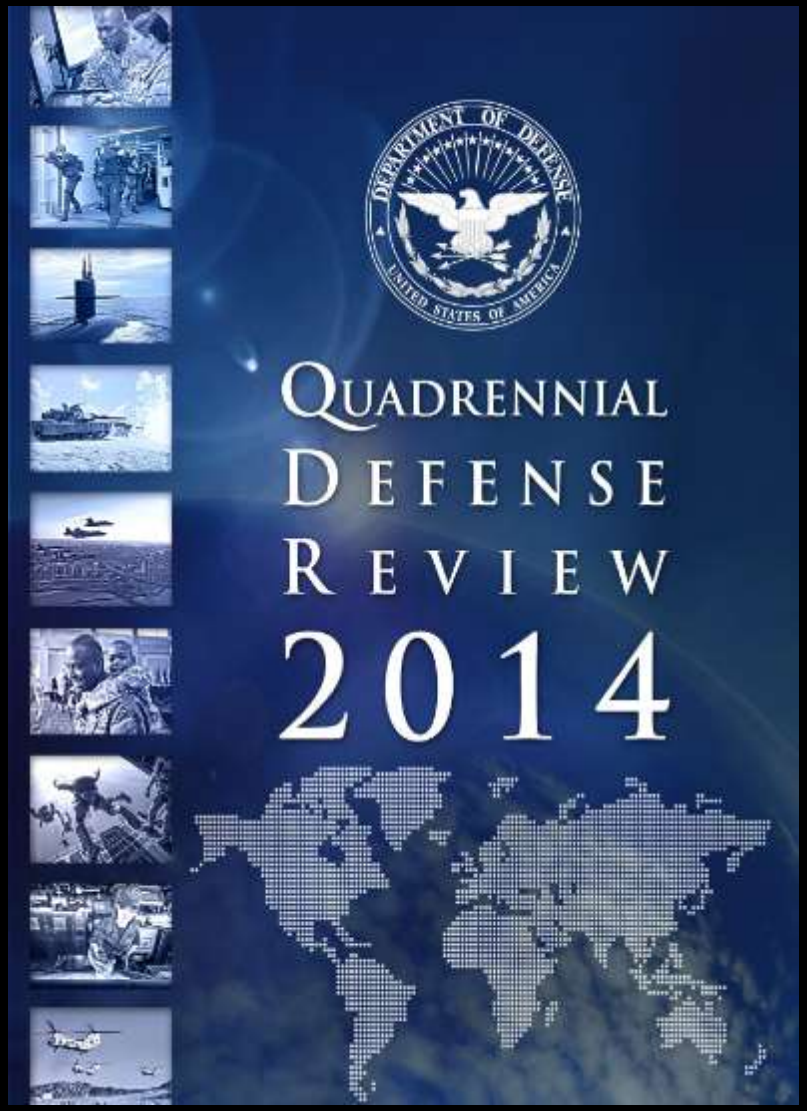
The Microbial Antibiotic Resistance Problem
How Quickly We Forget!





- Darwinian evolution at work
- an entirely predictable (and avoidable!) problem
- industry R&D retreat in late 80's due to lack of financial returns
- new incentives introduced but major gap/risk until 2020/2025
- in 2020/2025 restart new R&D cycle to combat next wave of resistant organisms emerging 2035/2045

The VUCA World

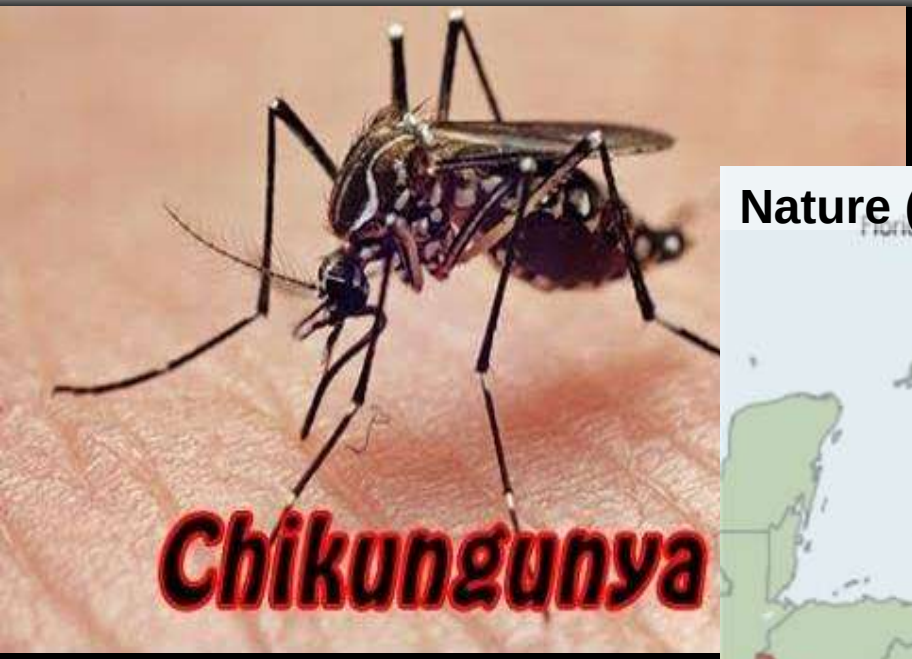


- **V**olatility
- **U**ncertainty
- **C**omplexity
- **A**mbiguity

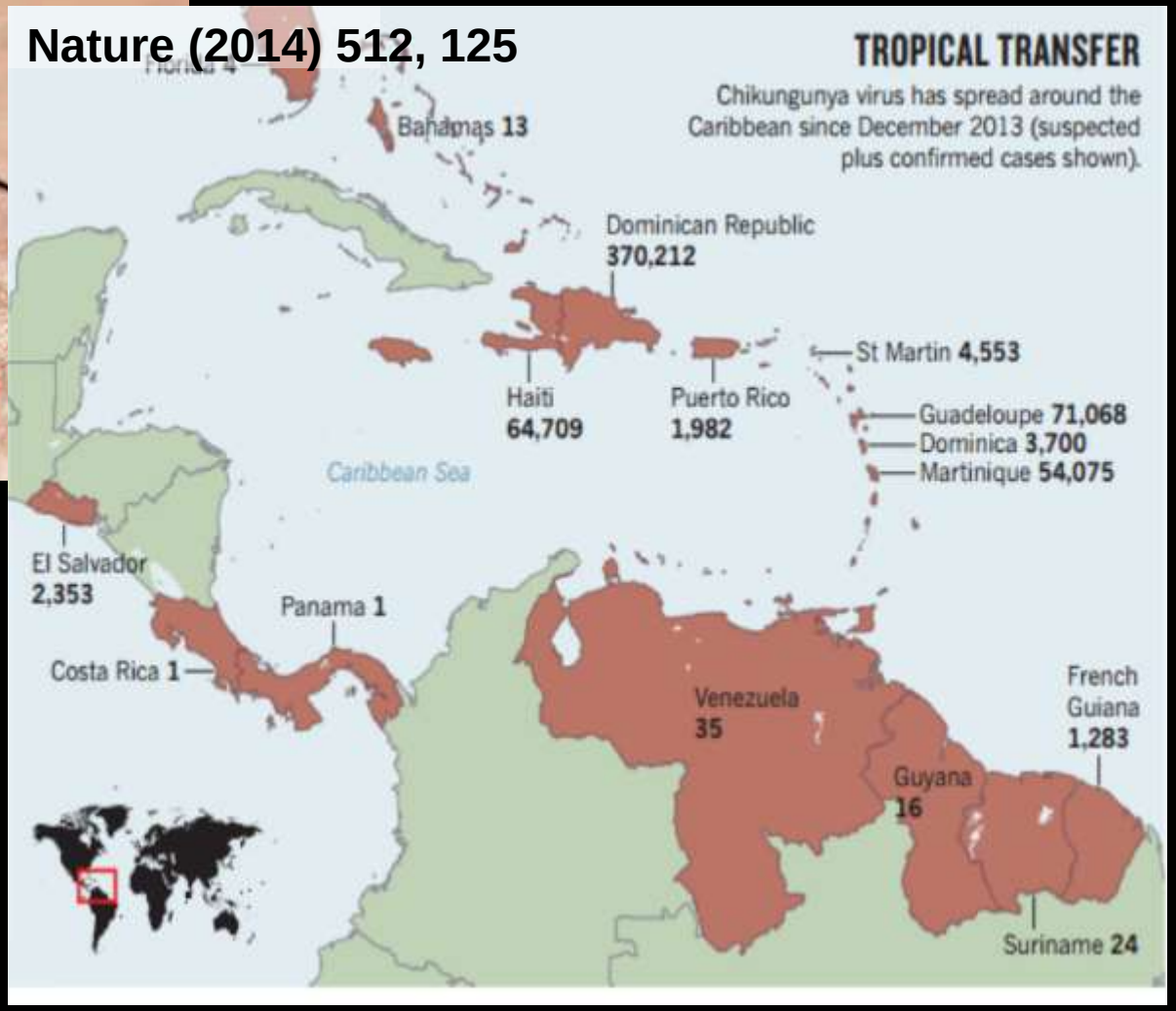
WHAT TO EXPECT,

WHEN NO ONE'S EXPECTING

DOD Mobilization in Ebola Virus Epidemic: West Africa 2014



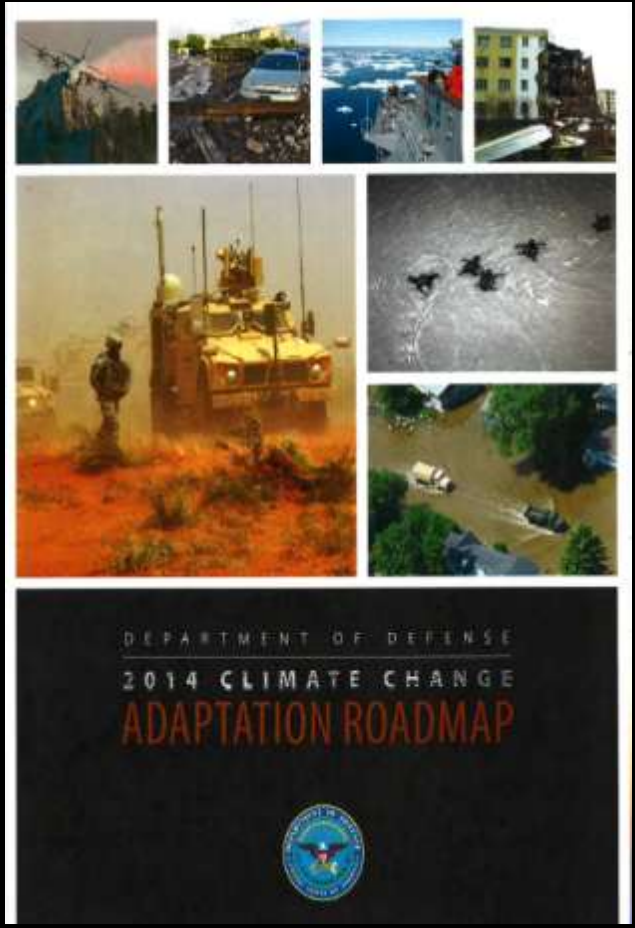
Nature (2014) 512, 125

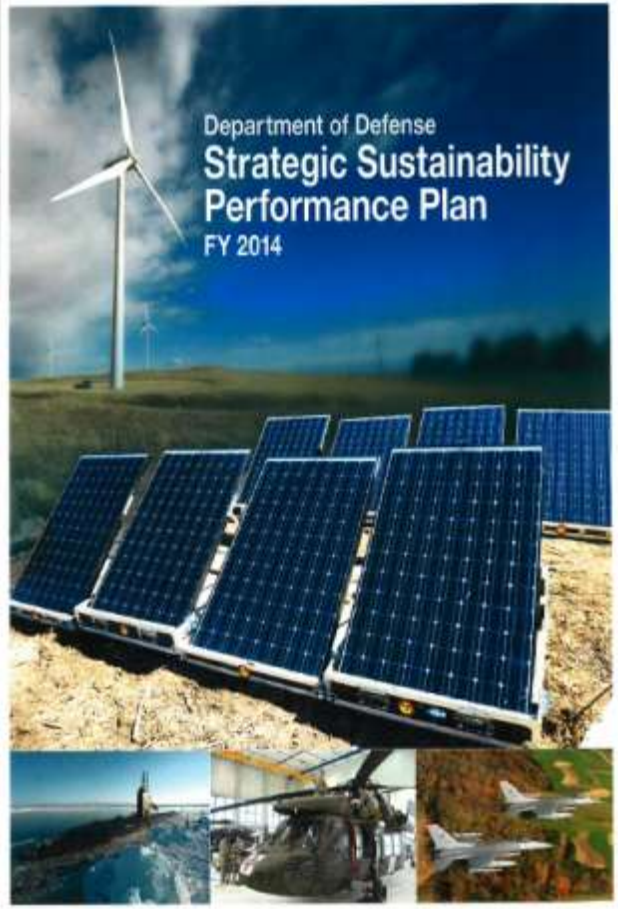


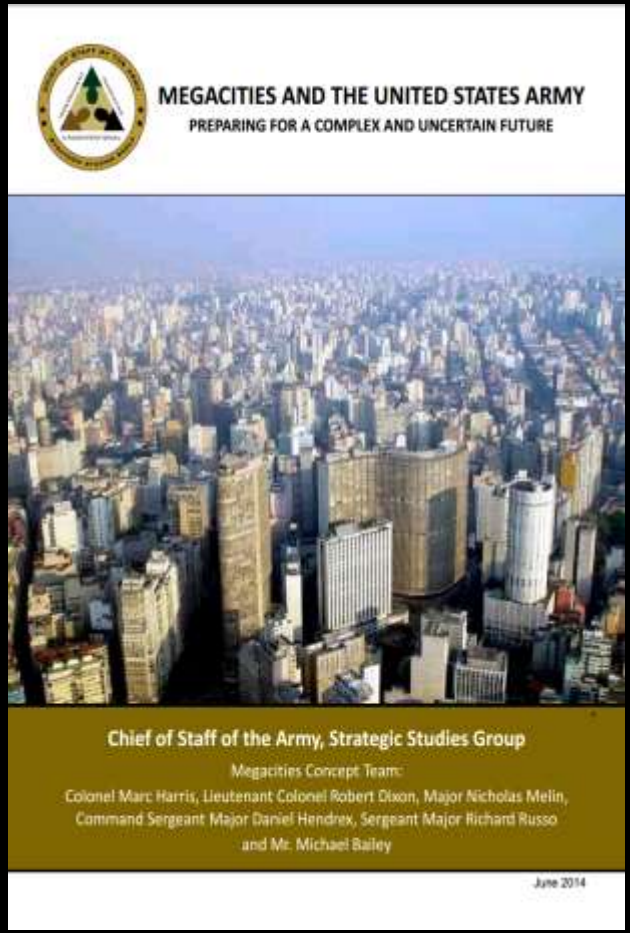
DOD and Epidemic/Pandemic Disease

Pandemic Risk in the Homeland

Posse Comitatus Applies But DOD as the Only USG Agency With the Logistical Resources to Integrate the Complexity of Responding to Major Bioincidents


DEPARTMENT OF DEFENSE
2014 CLIMATE CHANGE
ADAPTATION ROADMAP


Department of Defense
Strategic Sustainability
Performance Plan
FY 2014


MEGACITIES AND THE UNITED STATES ARMY
PREPARING FOR A COMPLEX AND UNCERTAIN FUTURE
Chief of Staff of the Army, Strategic Studies Group
Megacities Concept Team:
Colonel Marc Harris, Lieutenant Colonel Robert Dixon, Major Nicholas Melin,
Command Sergeant Major Daniel Hendrex, Sergeant Major Richard Russo
and Mr. Michael Bailey
June 2014

Megacities and New Biosecurity Challenges

- urban population projected to triple by 2030 with 70% occurring in developing countries (DCs)
- most growth will occur in resource-poor, highly fragile and often politically unstable regions
- many situated in low-lying coastal areas and vulnerable to flooding and sea level changes

The Global Public Health Challenge Posed by Rapid Urbanization in Developing Countries

High Disease Transmission

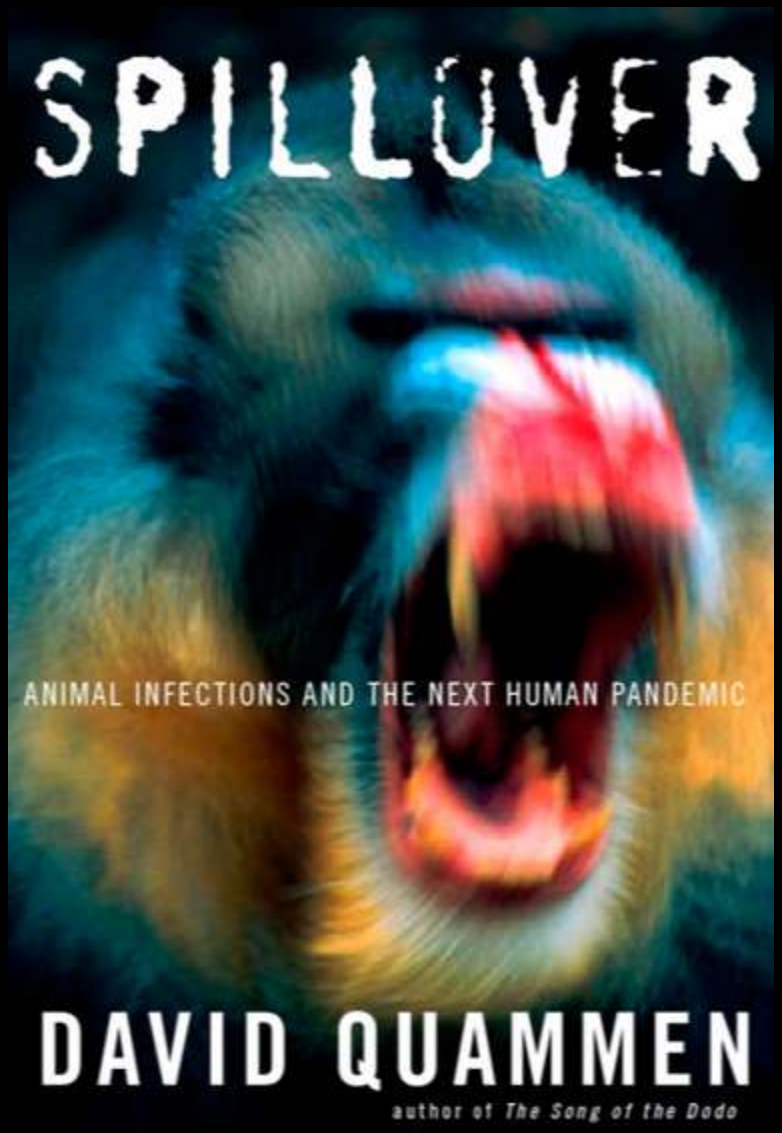
Lack of Safe Water

Bush Meat Food Chain

Major Deficits in Health Infrastructure

Expanded Eco-niches and Increased Zoonotic Risks

The Dominant Role of Zoonoses in Emerging Infectious Diseases



Pandemic Influenza: Still the Largest EID Threat?

- H1N1: high transmissibility - low virulence/mortality
- H5N1: low transmissibility – high virulence/mortality
- H5N1 x (H1N1) or (X): potential for devastating pandemic

Biosecurity Implications of the Rise of Intensive Agriculture in BRIC Countries

- disruption of global food chain via diversion of grain to animal feed
- new famine risks in DCs

- intensive agriculture and proximity of large avian and mammalian populations
- increased influenza zoonotic risk via bird-pig-human transmission chain

New Technologies for Major Unmet Needs in Biosecurity

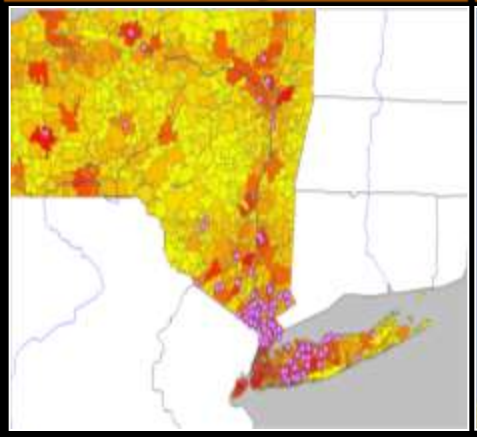
Biosurveillance and Accurate Diagnosis: Early Detection Saves Lives!

- Ebola: West Africa
  - December 2013 to March 21 2014
  - IHE not declared until August 2014

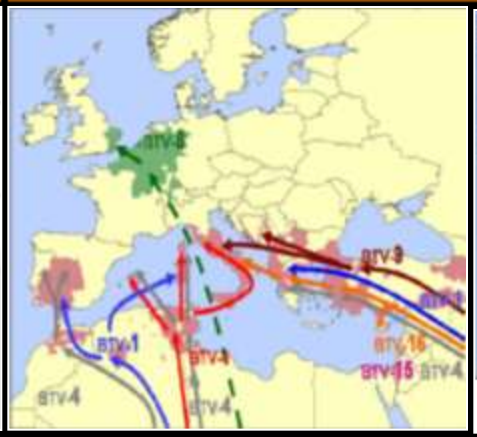
http://www.darpa.mil/uploadedImages/Content/Our_Work/DSO/Programs/7-Day_Biodefense/Biodefense_a.jpg

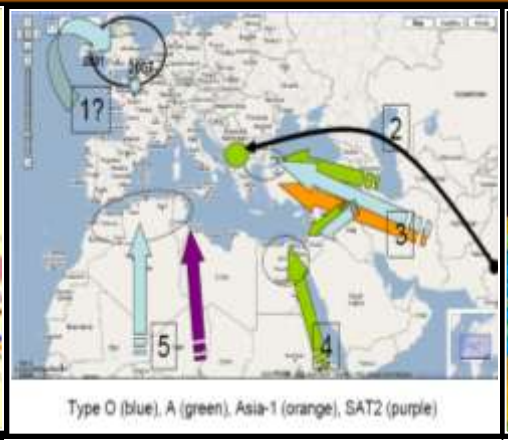
Geodemographic Information Systems: Mapping Disease Patterns and Modeling Trends

Anomaly Detection and Early Alert

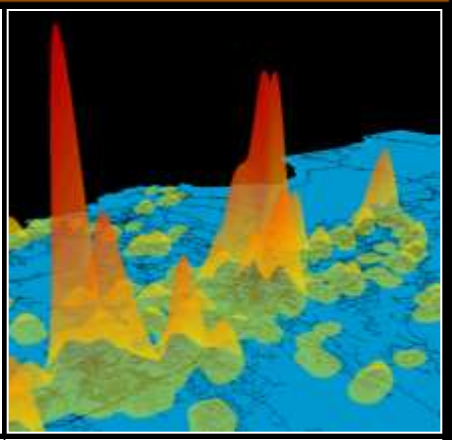


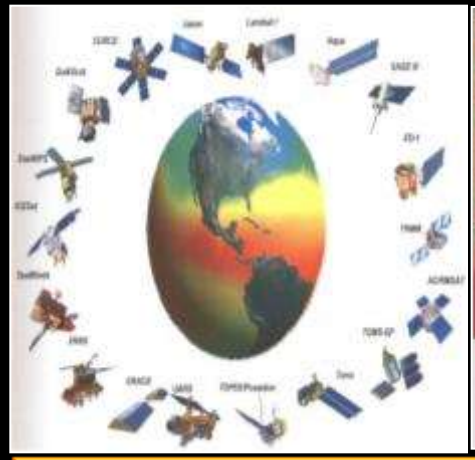
Disease Progression

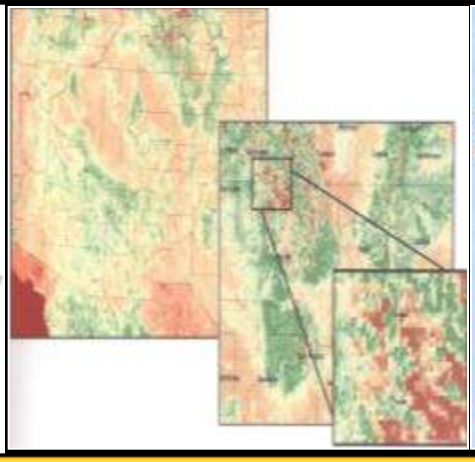


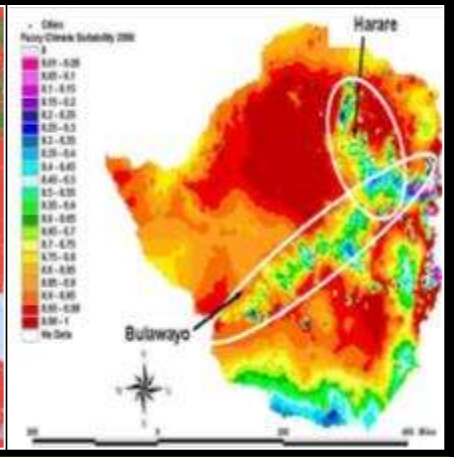


Type O (blue), A (green), Asia-1 (orange), SAT2 (purple)





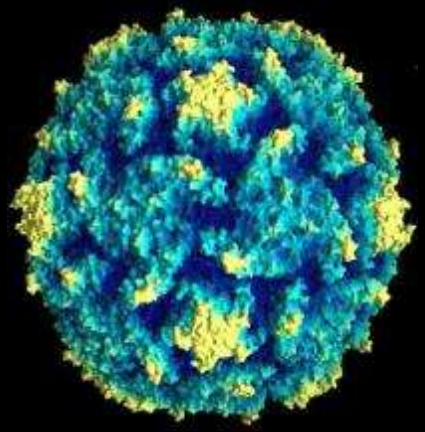




Satellite Surveillance and Predictive Modeling of Disease Trends

The Imperative for New Platforms for Global Biosurveillance and Rapid Point-of-Need Diagnostics

Molecular Signatures of New Classes of Threats…….



……. to Detect and Defeat Novel Agents

in their earliest stages of emergence…

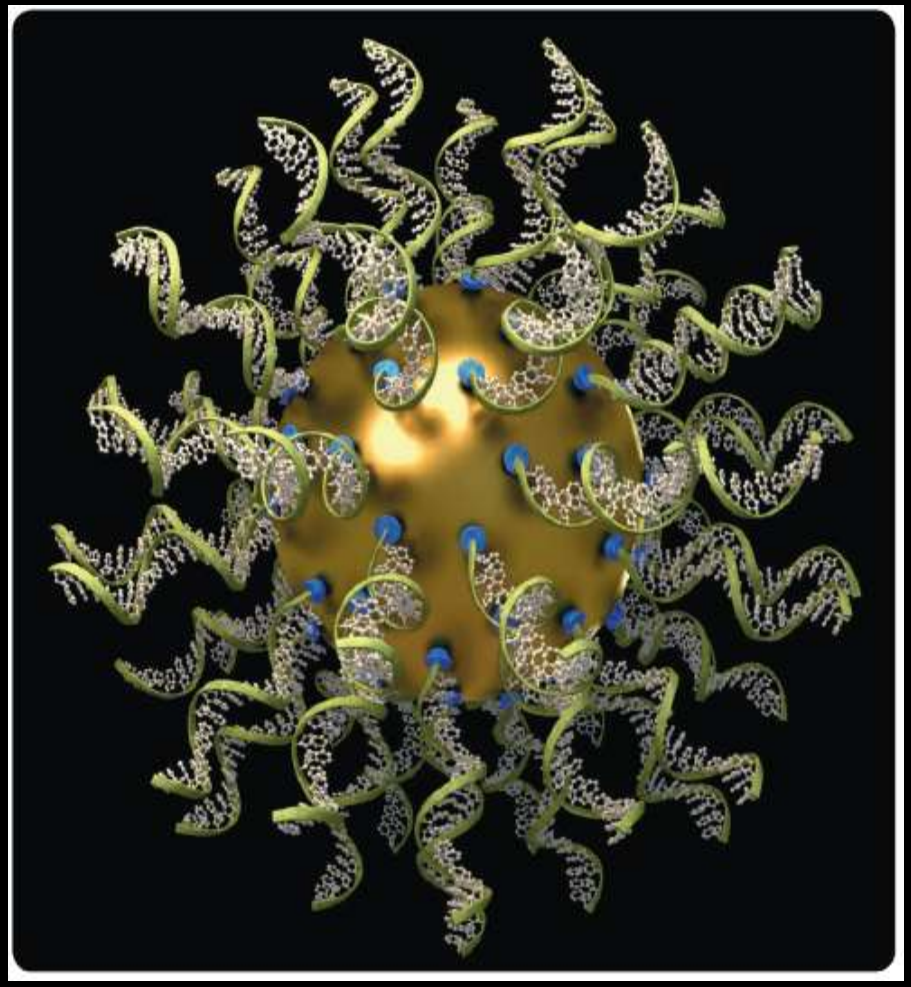
… in both rural and urban environments

Notice the Resemblance?
Hygiene and Quarantine as the Only Controls
Absent Drugs or Vaccines

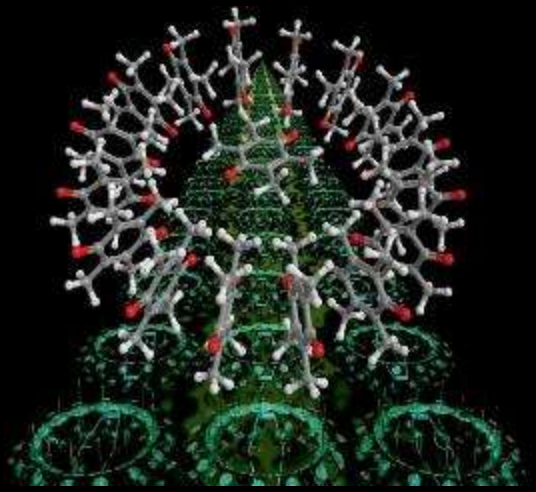
Bubonic Plague
Physician 15th Century

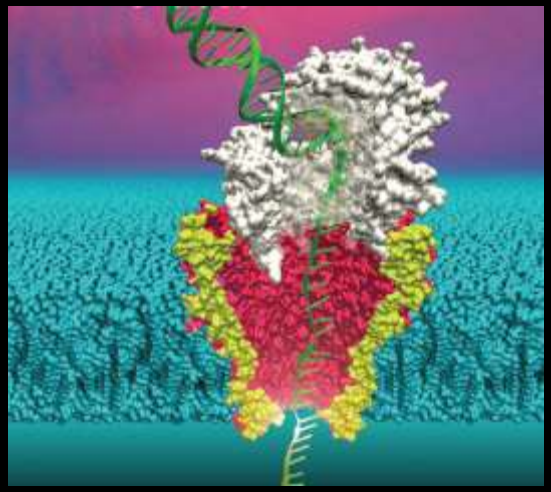
Ebola, Liberia
21st Century

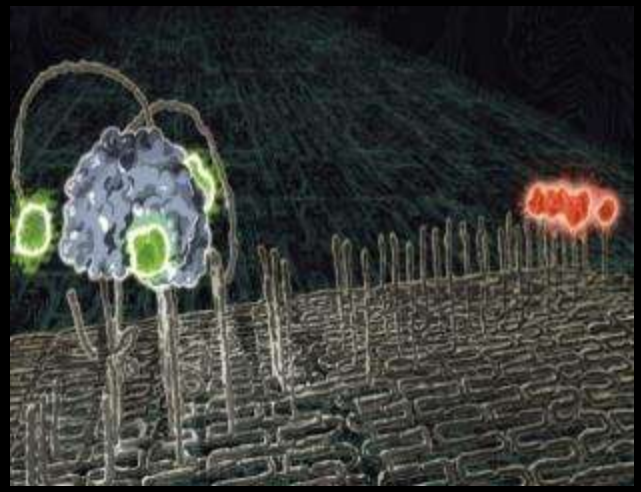
Molecular Lego: Ångstrom Level Design
Controlled Assembly of Biomolecules and Design of Novel Sensors and Nanoscale Delivery Systems



Bio-Inspired Sensor Nets and Robotic Systems







- miniaturized, automated and PON deployment
- self-assembly (sensors plus robot carriers)
- self-repair and extended duty cycle
- dynamic reconfiguration and swarms

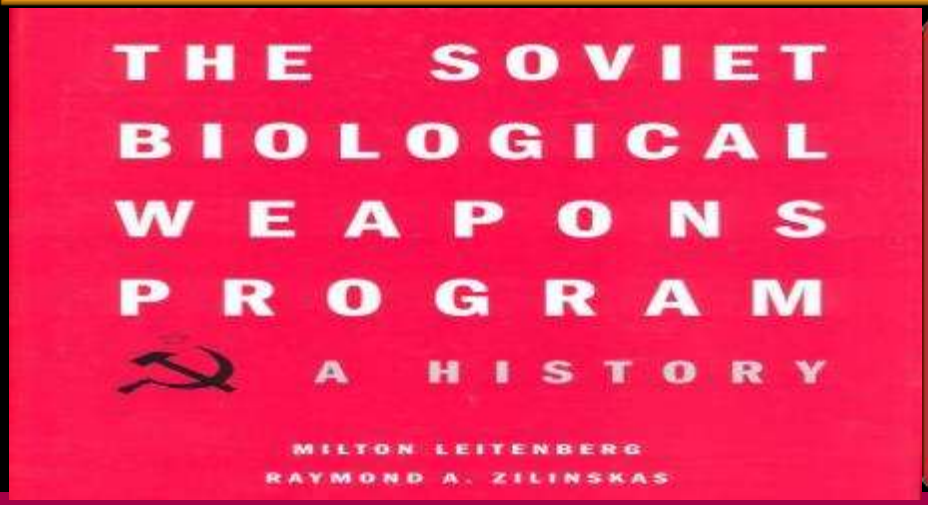
Responding to Agent-X

Faster Mobilization for Development of Diagnostics and Counter-Measures for Pandemic/Panzootic Risks

Acceleration of Counter-Measure Responses to “Agent-X”

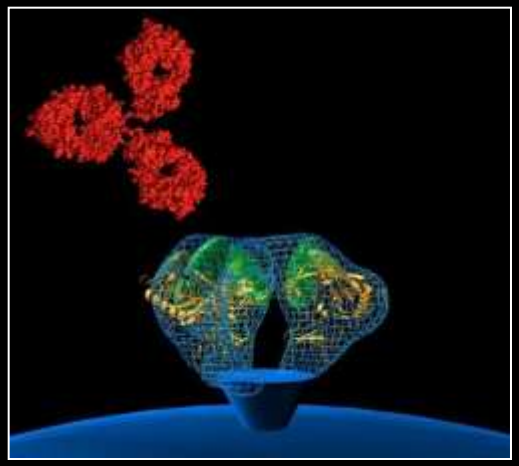
Pandemics and Epizootics of Natural Origin

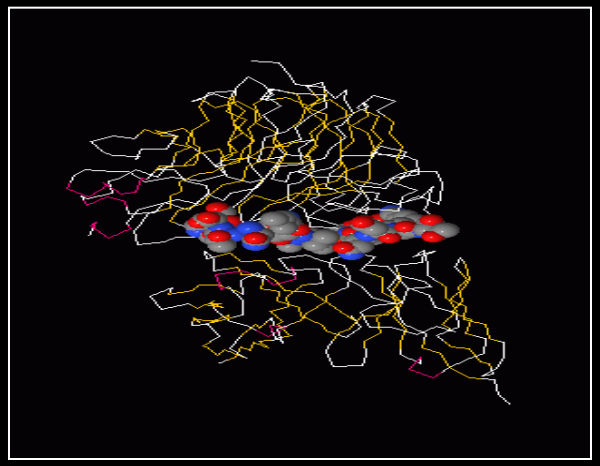
Bioweapons and Bioterrorism



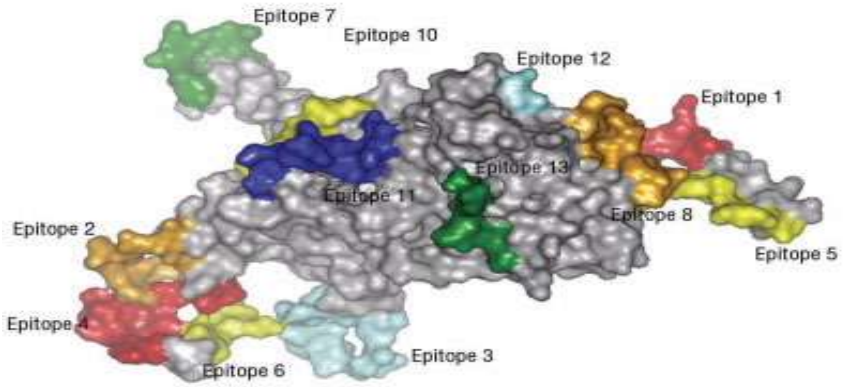
Transforming Vaccine Technology for Rapid, Agile and Distributed Manufacturing

From Pasteur to Predicted Epitopes

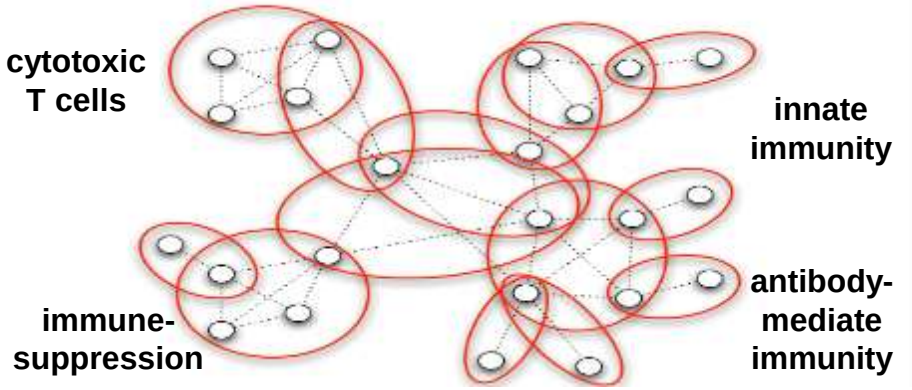




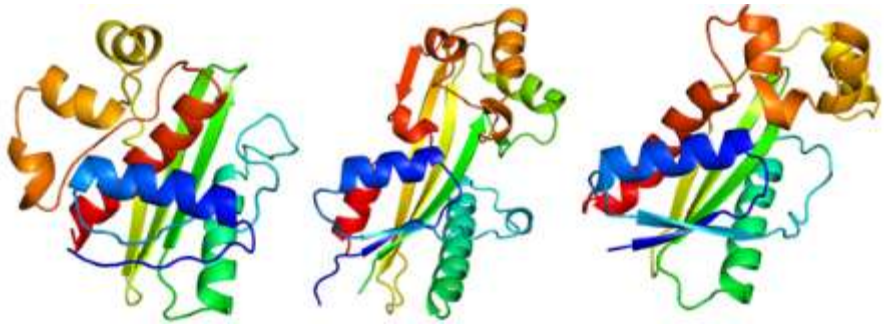
Conversion of Vaccine Production from Protracted "Biological" Manufacturing to a Rapid "Synthetic" Chemical Process and New PON Capabilities



- computational epitope mapping

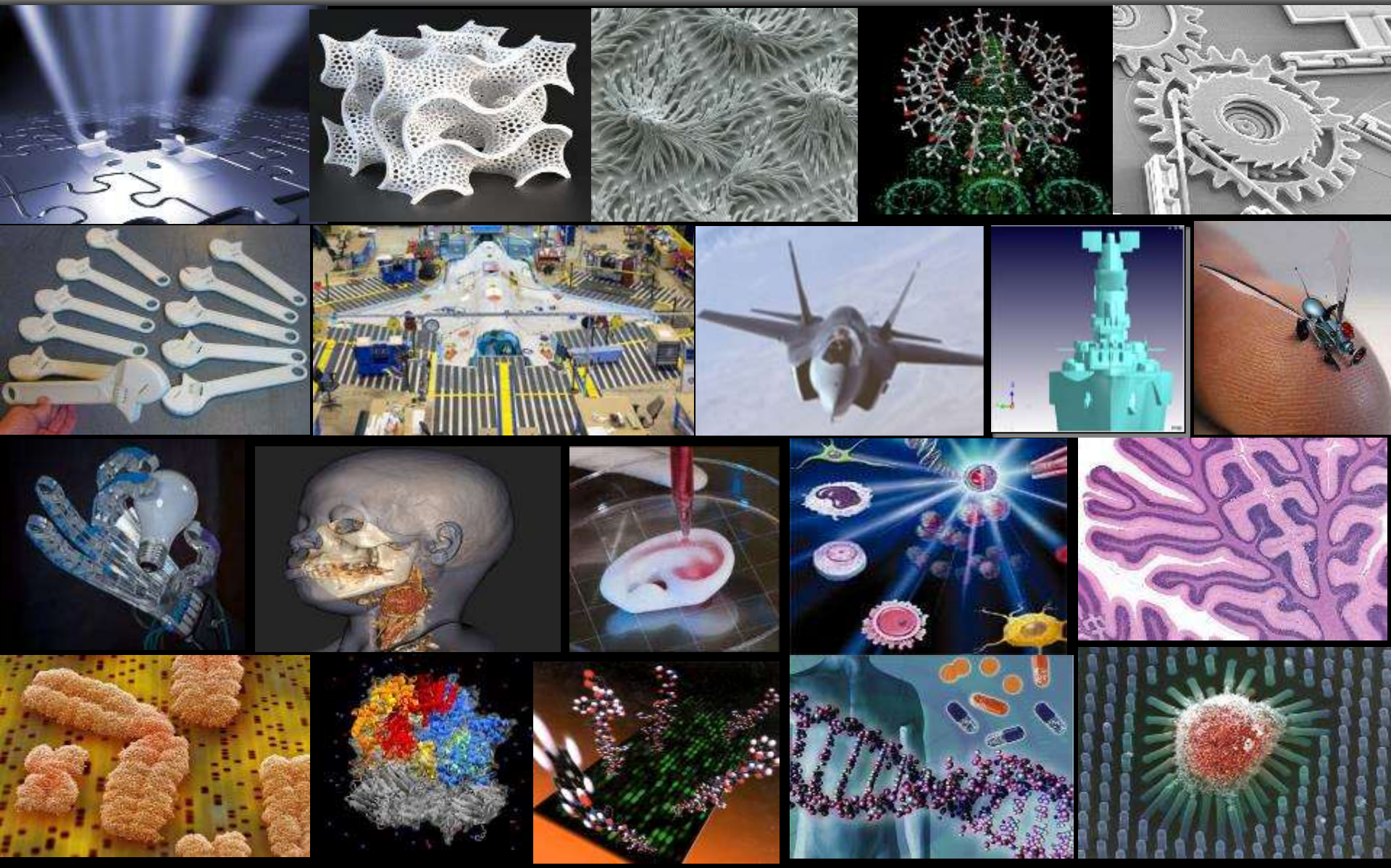


- analytics to identify commonalities (rule sets) in the composition and structure of proteins that trigger different types of immune responses



- rapid profiling of 'Agent X' for 'epitope rule matching' and chemical synthesis of epitopes at point-of-need facilities

Advanced Manufacturing

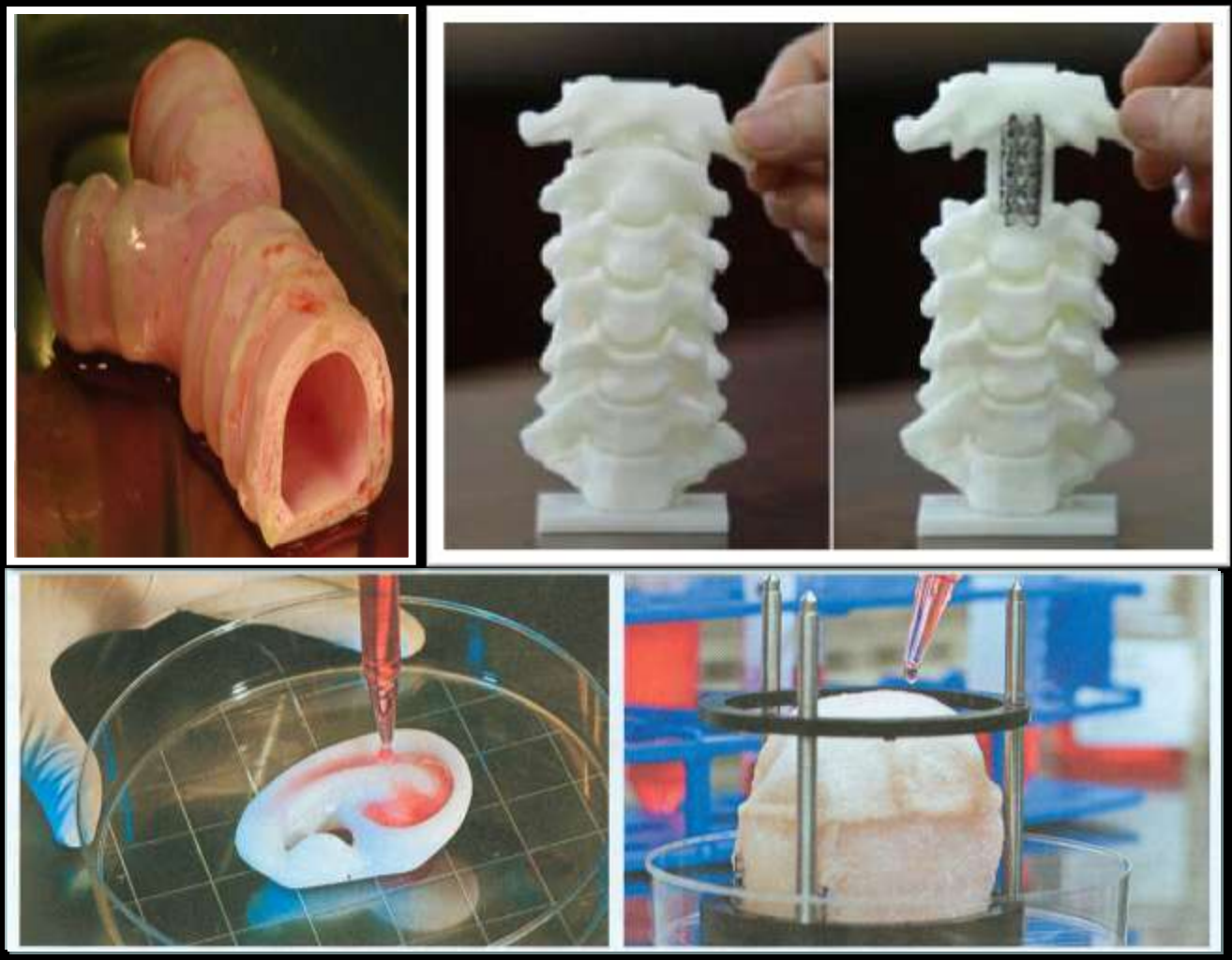


Next Generation Bio-inspired Manufacturing Platforms

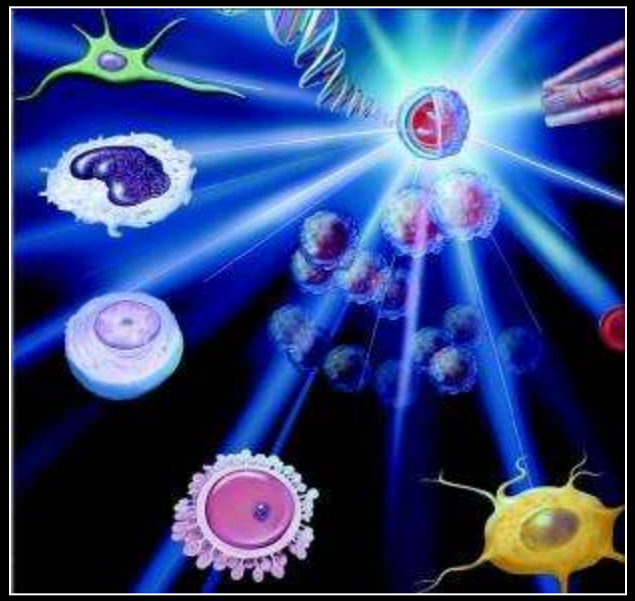
Regenerative Medicine

Synthetic Biology

3D Assembly of Biological Cells Seeded Onto/Into Synthetic Biomaterial "Scaffolds"



Stem Cell Biology and Cell Therapies: Understanding the Genetic Programs Encoding the Development of Specialized Cell Types



- stem cell signatures and molecular pathways for directed differentiated cell fates

- embryonic stem cells

- reprogramming somatic cells

Synthetic Biology

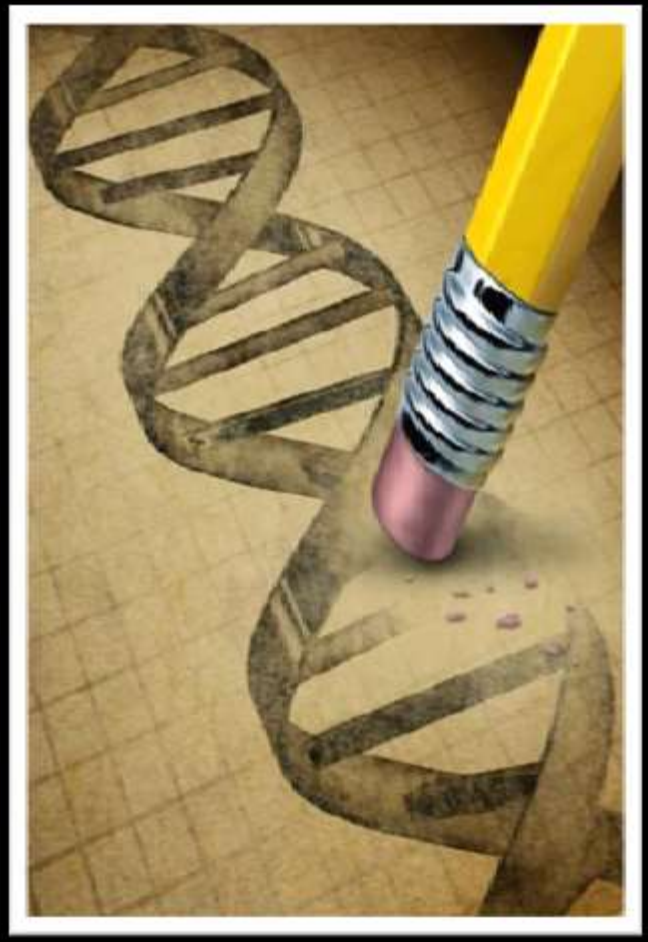
Understanding the Instruction Codes for the Assembly and Control of Complex Biological Systems

Reading, Writing and Editing Genomes

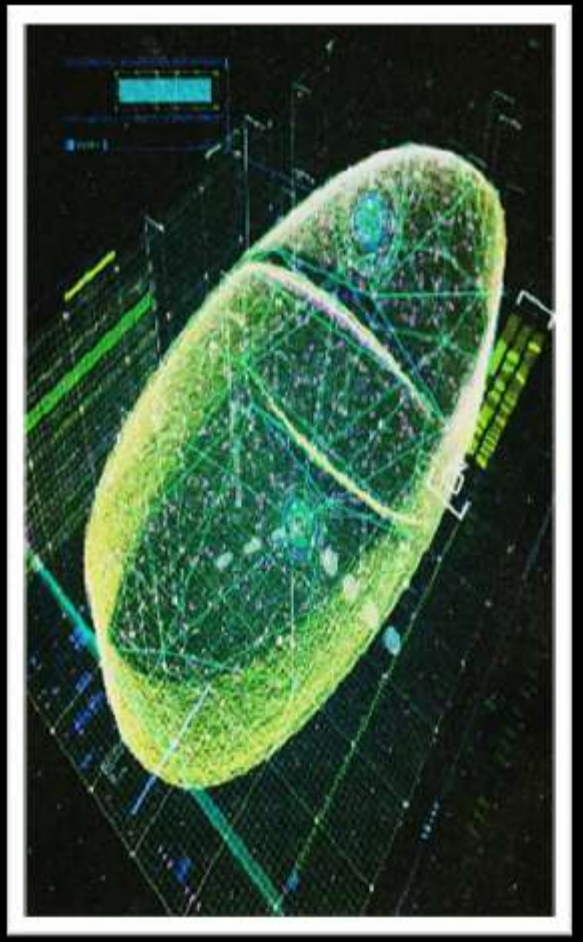
‘Exploring Biospace’: Design and Assembly of Genomes and Biological Systems With No Known Evolutionary Predicate

Emerging Technologies for Precision Modification of Genomes and Their Coding Instructions (Biological Software)

Cost-Effective Synthetic Production of DNA



Genome Editing

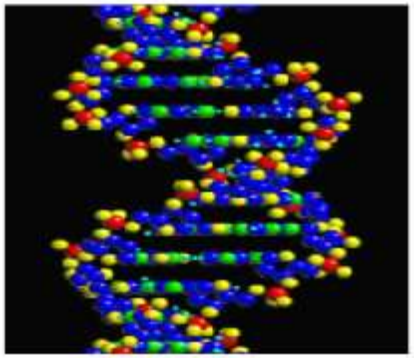
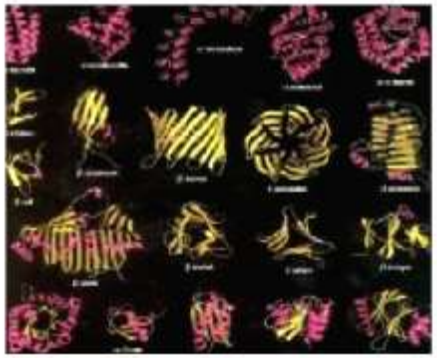
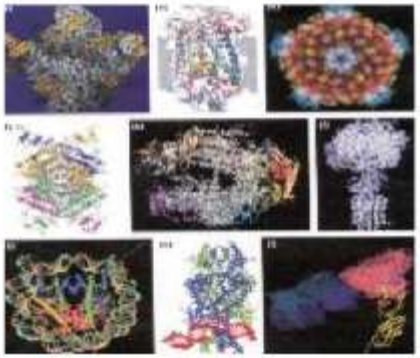
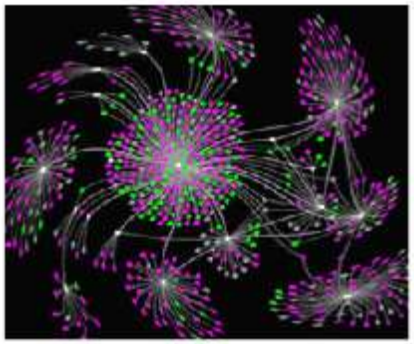


Construction of 'Cellular Chassis' For Designed Genes

Biological Diversity and Variation: "Endless Forms Most Beautiful"

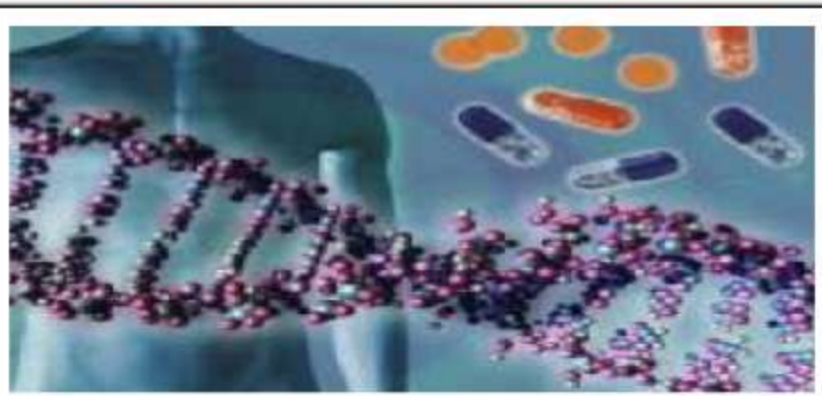
Biological Diversity and Variation: "Endless Forms Most Beautiful"

Understanding Biological Organization: The Construction of Increasing Hierarchical Complexity and Mapping the Underlying Instructional Information

common genetic (digital) code in all life forms	tool box of protein motifs for combinatorial assembly ("molecular lego")	assembly of structurally and functionally diverse proteins	protein interactions and nanoscale intracellular structures
			
			
molecular signaling networks	cells and tissues	organs	organism

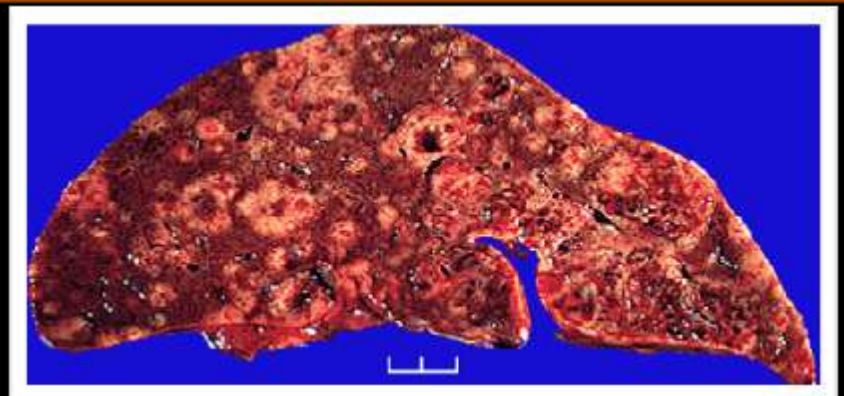
Digital Biology and Molecular Medicine
Mapping Instructional Coding Landscapes and Information Networks

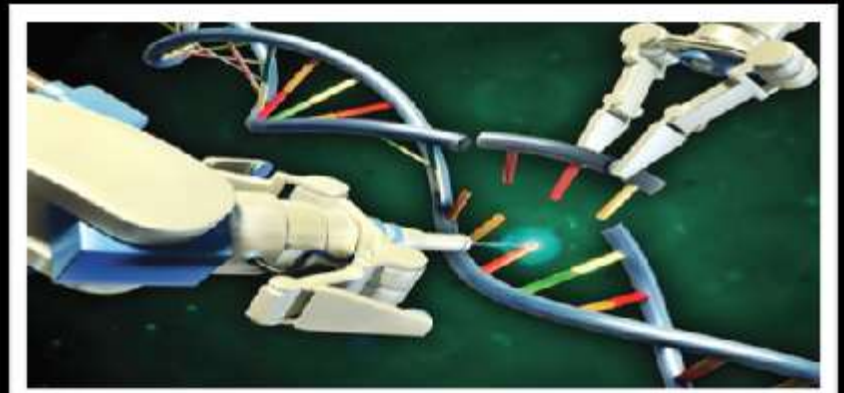
stable information signaling networks (health)



therapeutic modulation of perturbed networks

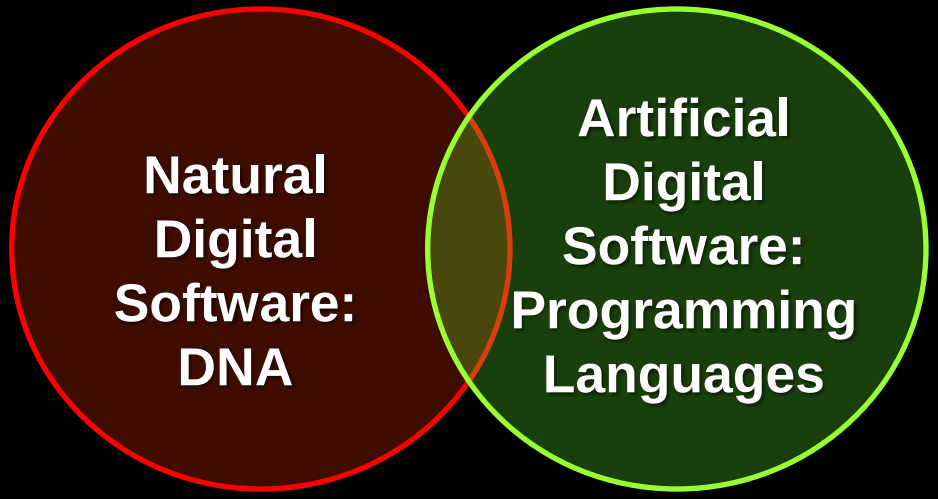
disrupted (dysregulated) information signaling networks (disease)





engineering novel gene constructs (code) to program biological information networks

Convergence



$3 – 4 \times 10^9$ years old	60 - 70 years old

Digital Biology and Synthetic Biology
"It from Bits"

- 'It' (hardware, wetware)

- 'Bits' (software)

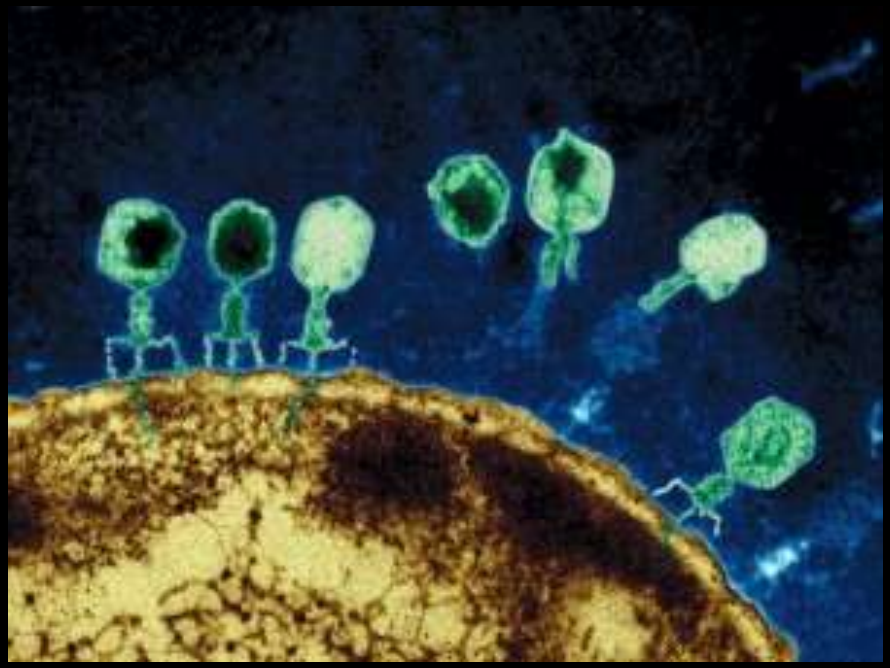
- Reading and Writing Genomes
- Construction of Desired Network Topology and Control of Information Flow in Biological Signaling Networks

Exploring Biospace
The Power of Combinatorial Interactions and Molecular Assembly

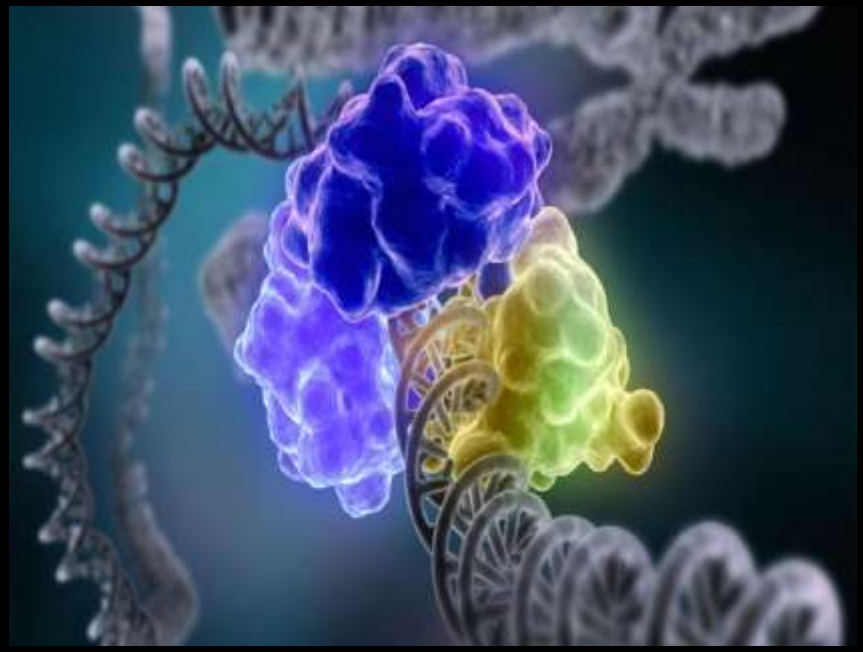
- estimated 22,000 human genes
- two genes cooperate to create a function =(22,000 x 21,999)/2 = 241,989,000 potential combinations
- 100 genes generate a complex function $=10^{65794}$ potential combinations
- number of theoretical possibilities for synthetic assembly (biospace) far exceed narrow molecular space sampled in evolutionary time to date

Genome Editing

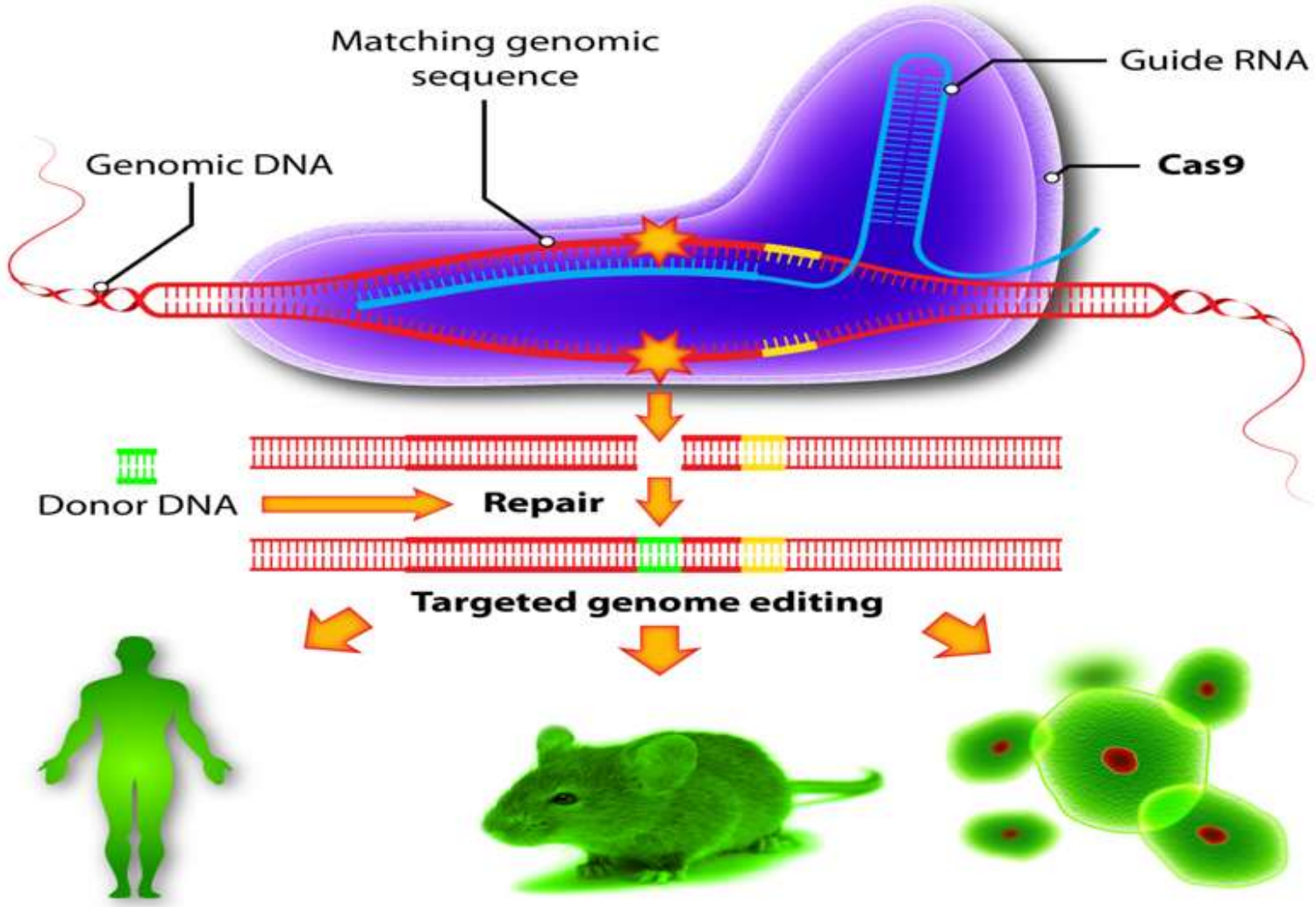
Microbial CRISPR Defense System Against Viruses



CRISPR-Cas Guided Excision and Insertion of New Genes



CRISPR-Cas Guided Gene Excision/Insertion for Genome Modification



gene therapy

disease models

cell therapies

Synthetic Biology

- emerging technology with myriad applications across diverse industrial sectors

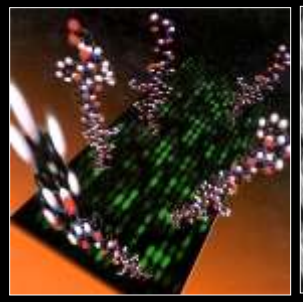
Healthcare

Public Health

Agriculture

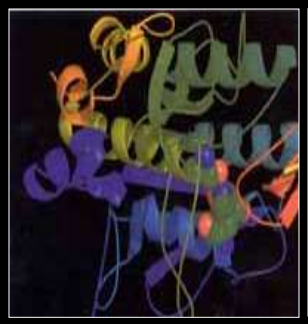
Functional Foods

Novel Materials

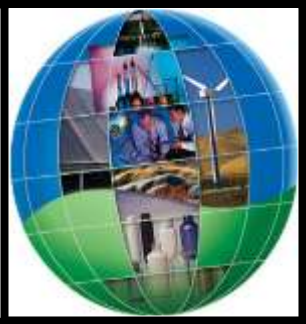


Textiles

Bioenergy and Biofuels



Industrial Enzymes



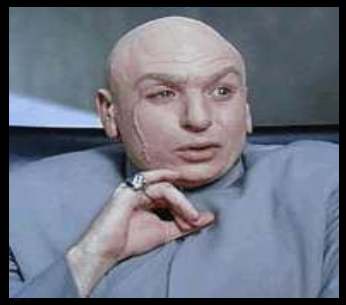
'Green' Mfg

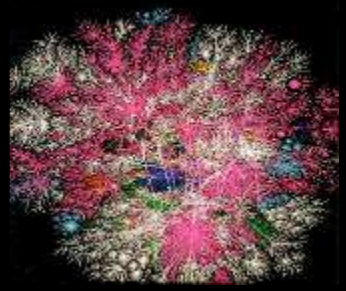
Bio-remediation

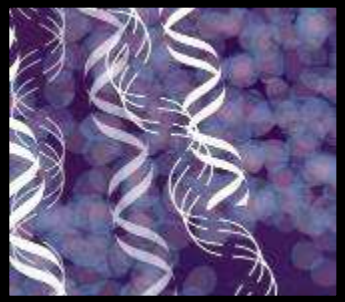
Clean Water

Ubiquitous Sensors

The Expanded Dimension of the 'Bio' Threat Challenge Dual Use Research of Concern (DURC):







- the 'bio' threat becomes more than just infectious agents
- potential targeted disruption of ANY body function
  - novel C and B threats
- synthetic biology
  - exploring biospace: designing new life forms

Big Biology and Biomedicine Meets Big Data

The Pending Zettabyte Era
1,000,000,000,000,000,000,000

Volume, Variety, Velocity, Veracity, Value

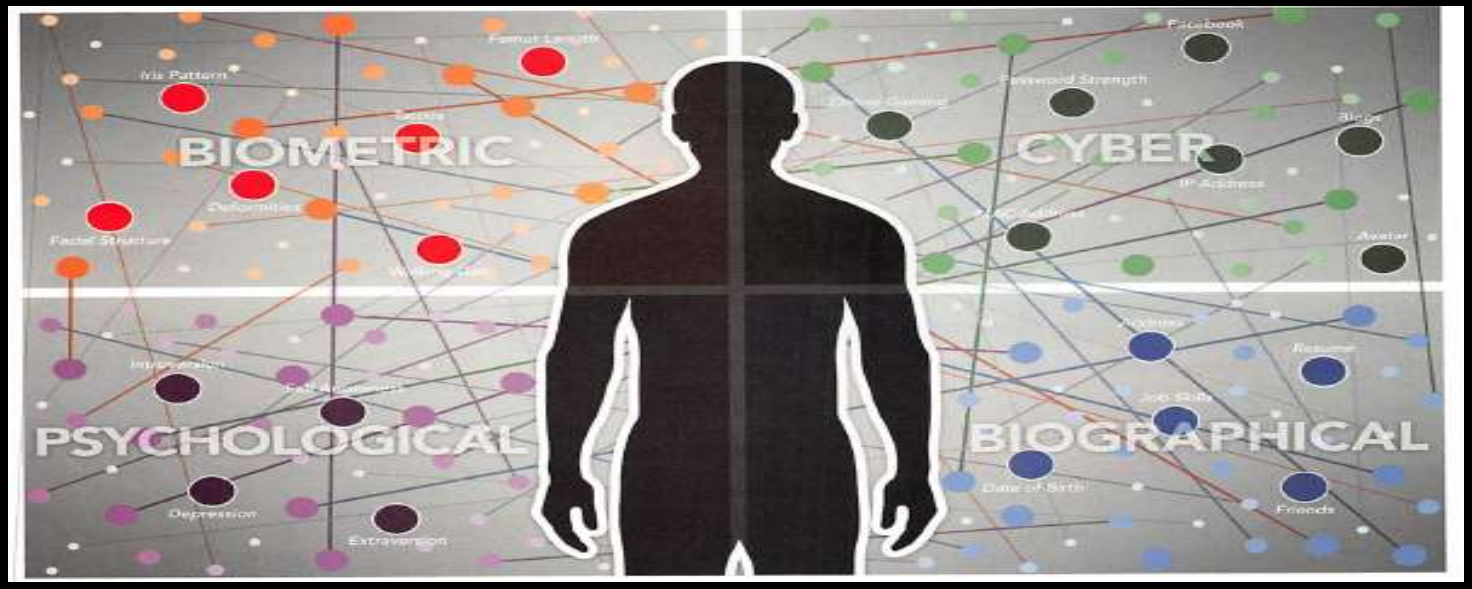
Sensor Webs and the Internet-of-Things (IoT)

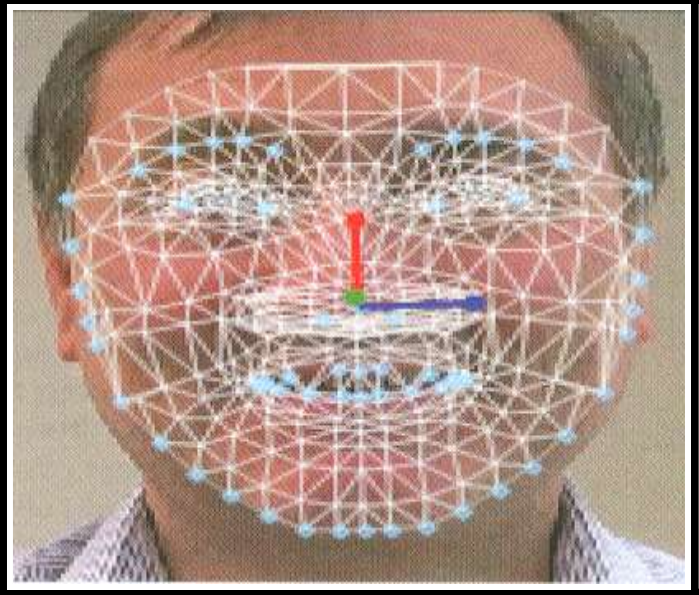
- pervasive/ubiquitous sensing of diverse environments/analytes
- critical features
  - sense-compute-actuate (SCA) loops
- next-generation features/traits
  - reconfiguration, repair and regeneration
  - intelligence and evolvability

Social Behavior Becomes Quantifiable

- who knows why people do what they do?
  - the fact is that they do!
- these actions can now be traced and measured with unprecedented precision
- with sufficient data, the patterns reveal increasingly predictable behavior and individual risk patterns
- new opportunities in multiple business sectors
- broad utility in national security, intelligence and military operations
- new ethical and legal issues regarding privacy and data security

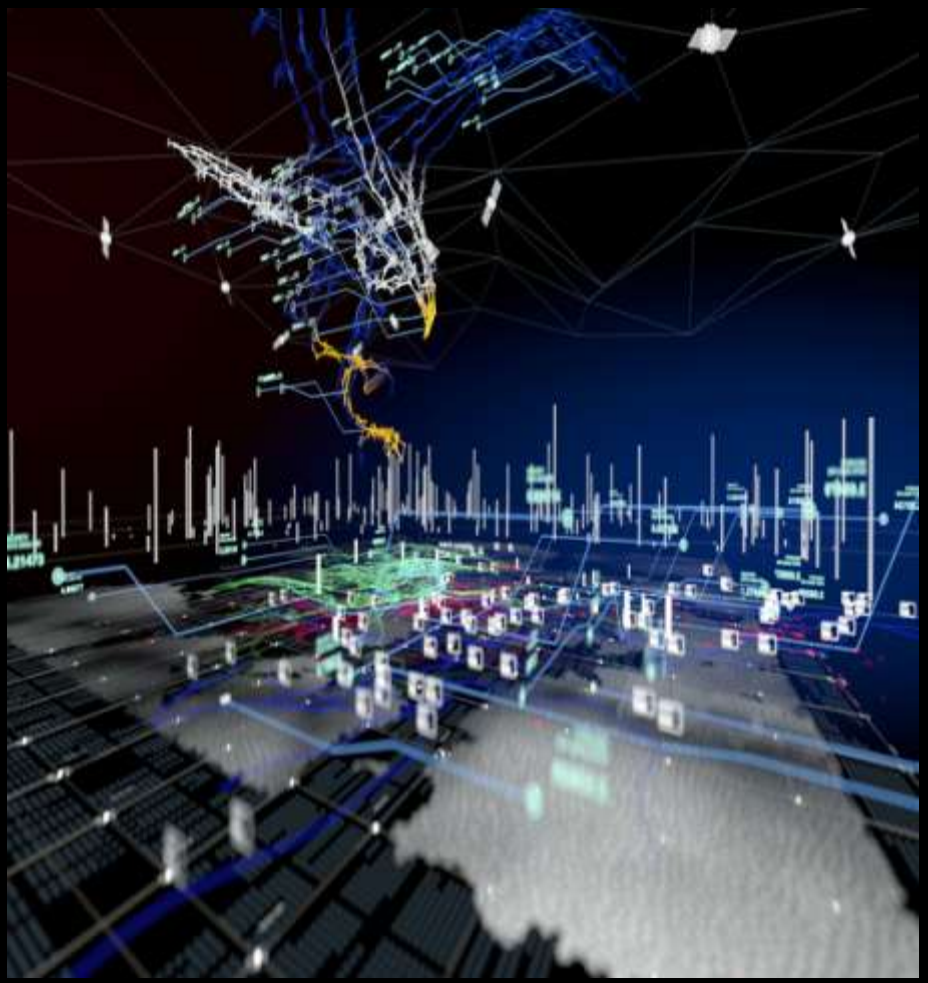
Large Scale Integration of Diverse Data Streams for Situational Awareness of Health Status and Biosecurity Risks





Integration of Diverse Data Streams for Real-Time Situational Awareness and Preemptive Intervention/Awareness

Healthcare

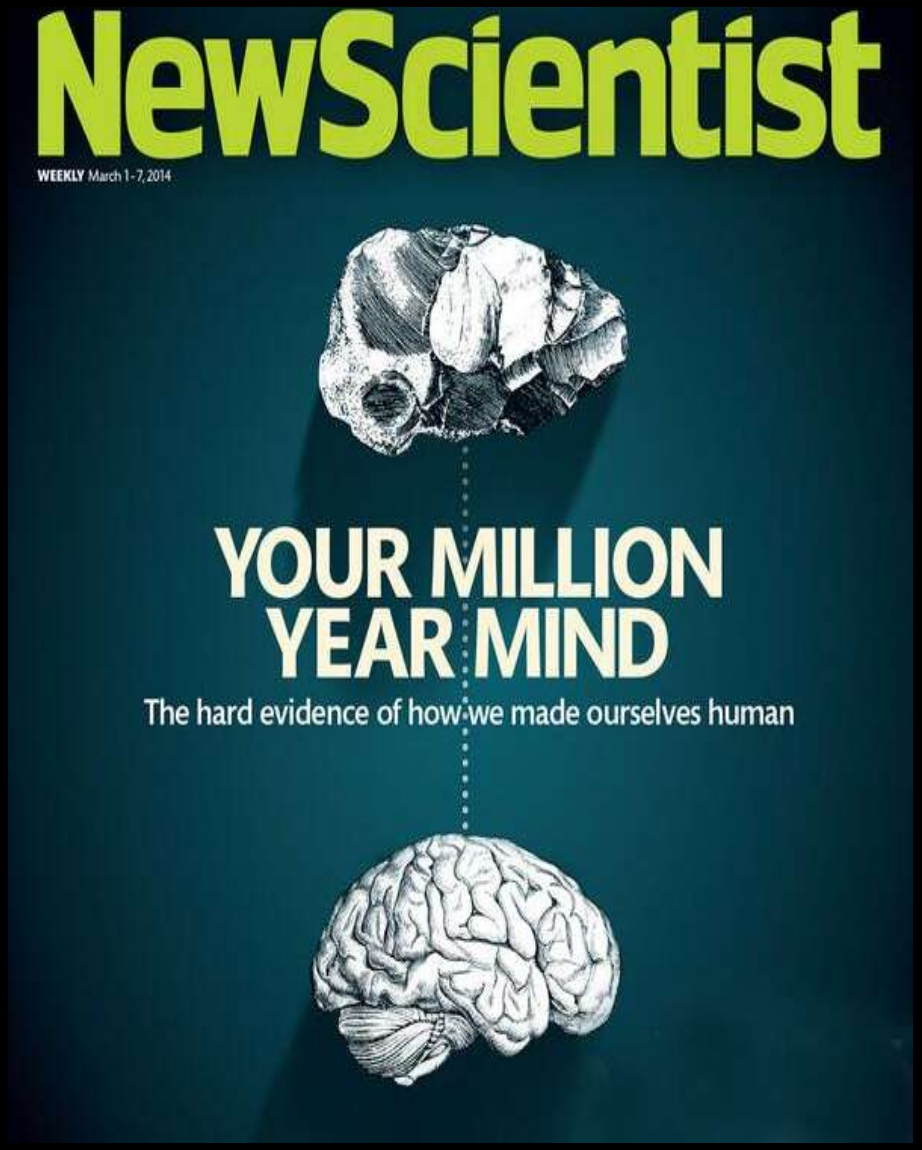


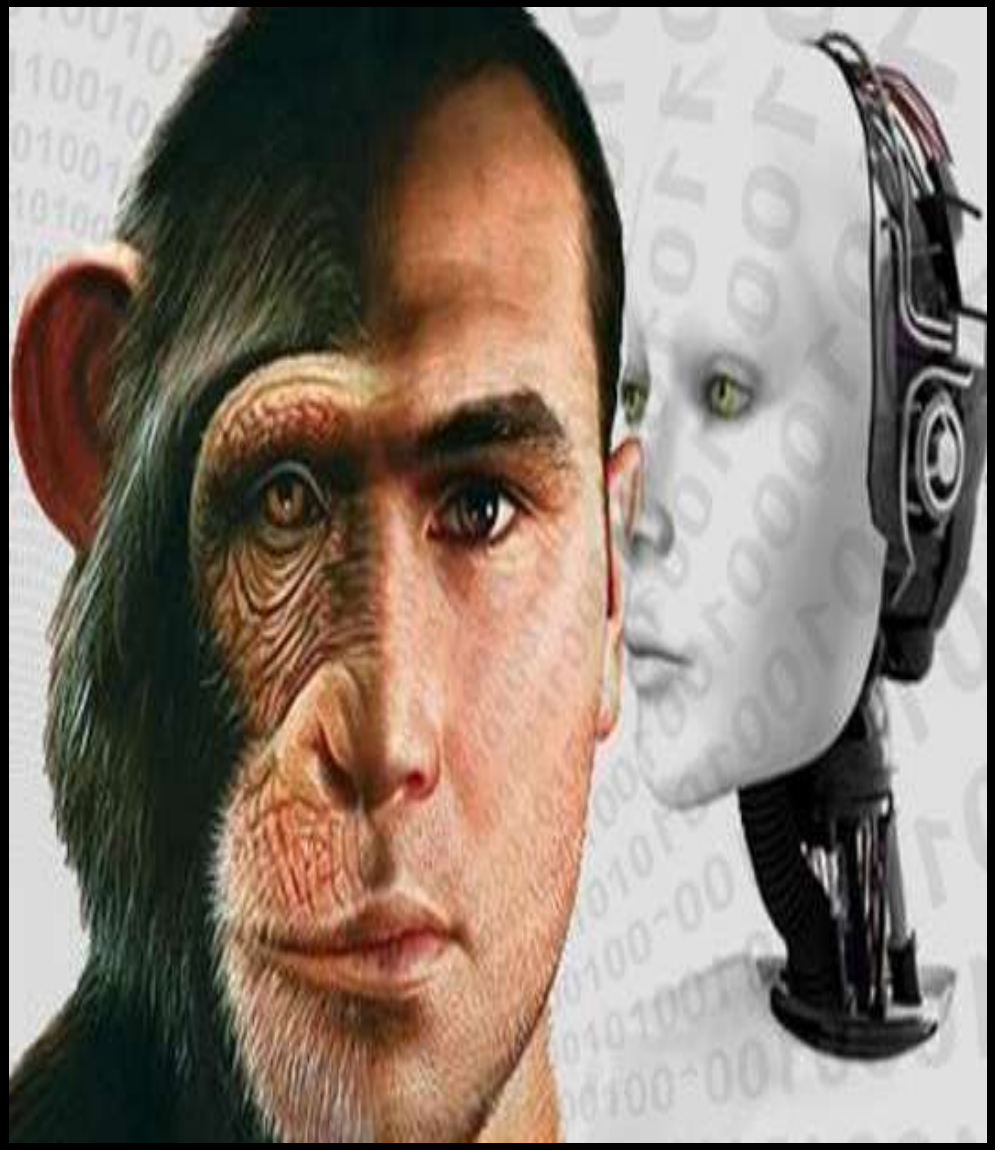
Military Operations

Interactive Interfaces and Customized Visualization Formats for Simulation, Education, Training and Decisions

Brain: Machine Interface Technologies
Direct Cognitive Control of External Devices

Cognitive Constraints

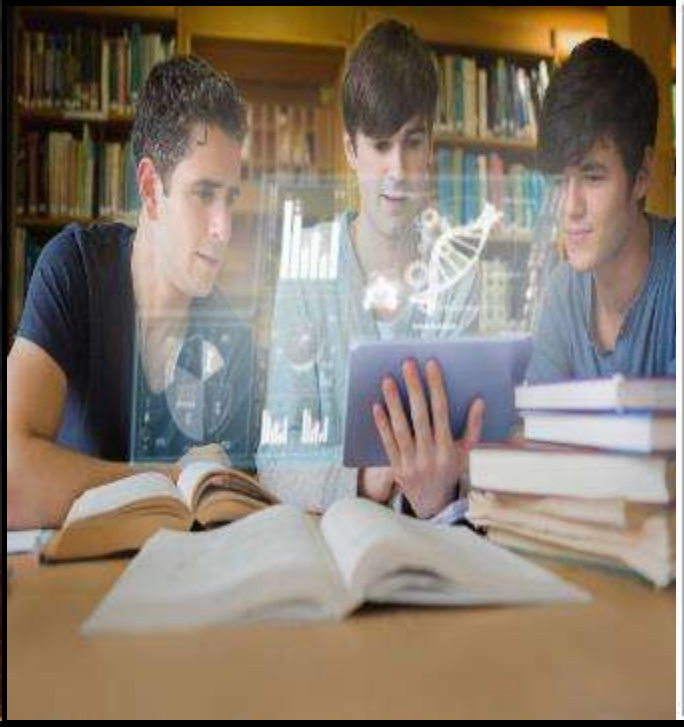


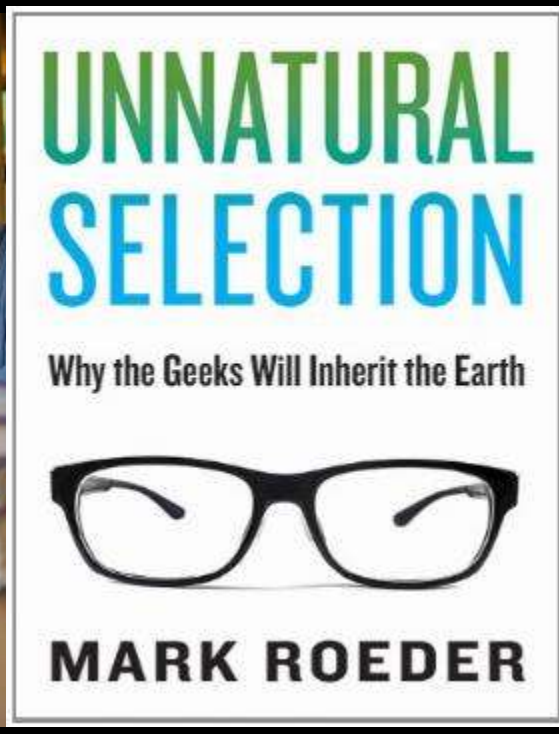


The Pending Era of Cognitive Systems: Overcoming the "Bandwidth" Limits of Human Individuals

- limits to our expertise
- limits to our multi-dimensionality
- limits to our sensory systems
- limits to our experiences and perceptions
- limits to our objective decision-making

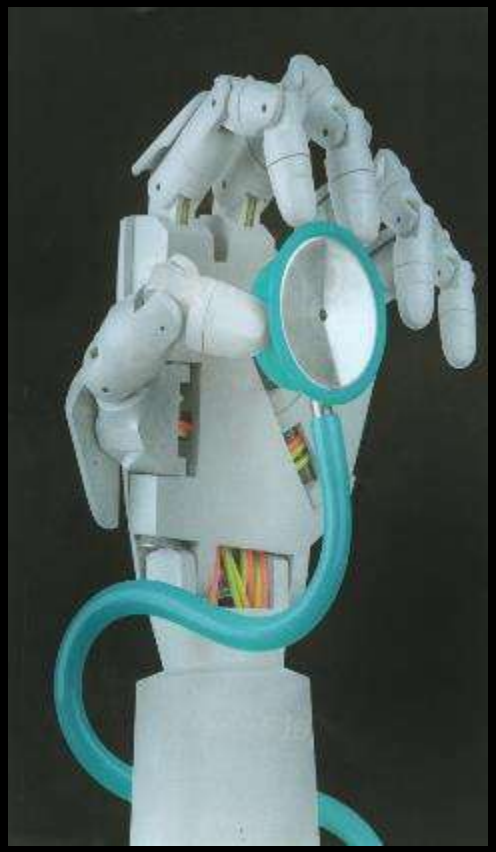
Advances in Cognitive Neurosciences and New Patterns of Cognitive Processing





- optimize information representation (perception)
- neuroplasticity and selection of new cognitive mechanisms
- modulation of brain function to optimize comprehension

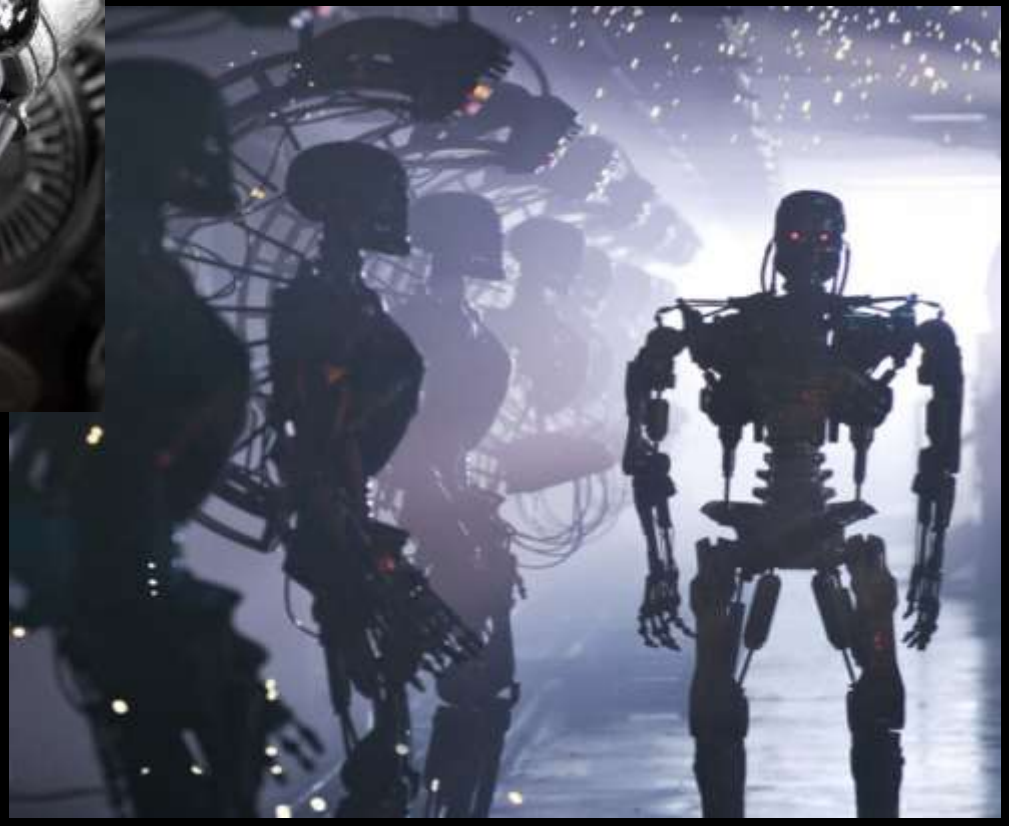
Transcending Human Cognitive Bandwidth: The Rise of Robotic Diagnostic Devices and Machine Intelligence for Decisions



Massive Computing Power and Analytic Parsing

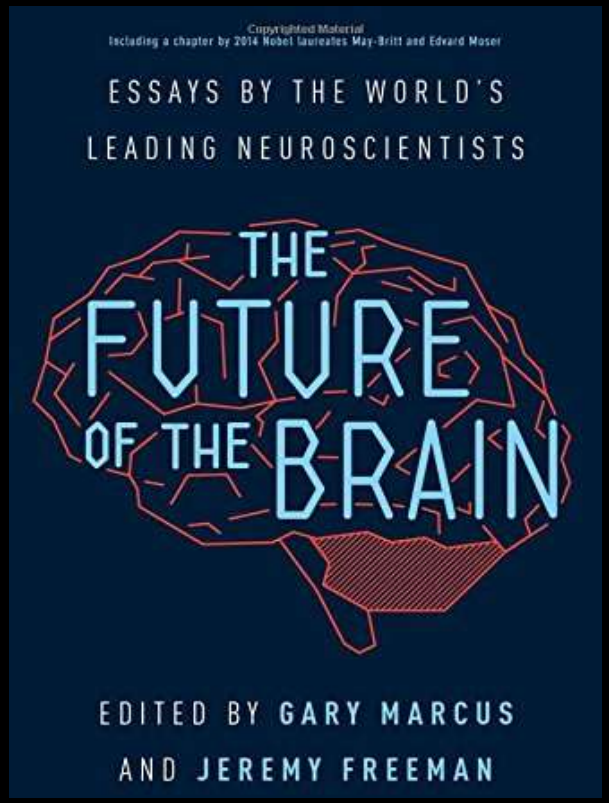
• mega-meta data • open source data • personalized data

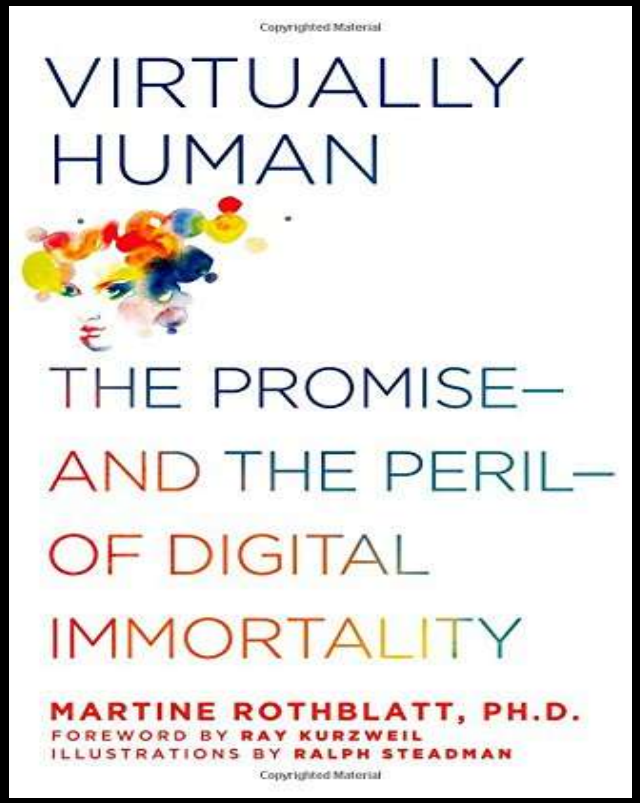
Original Sin Updated?
Artificial Intelligence and the Existential Expulsion of Mankind?

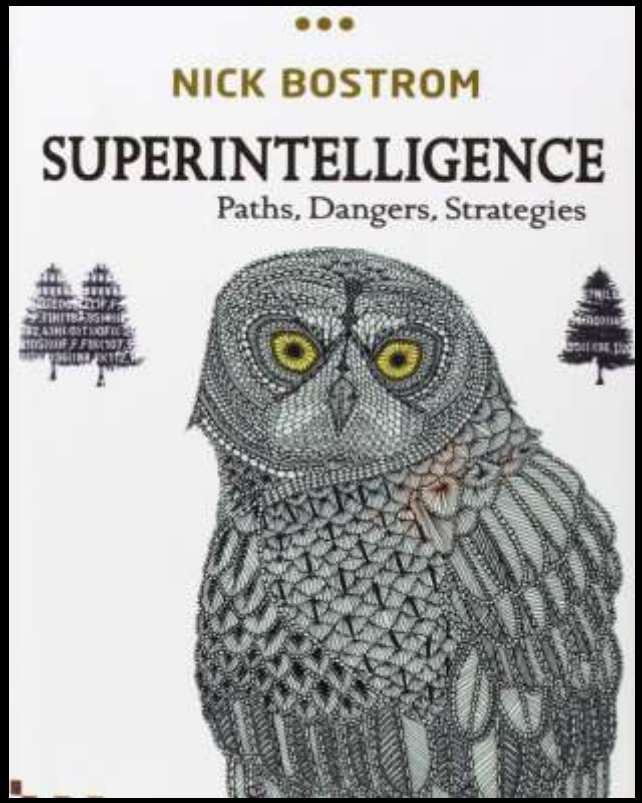


Debating the Dangers of Artificial Intelligence (AI)

Artificial Intelligence and Deep Learning
Why Wait for the Slow Brain to Catch Up With the Fast Machine







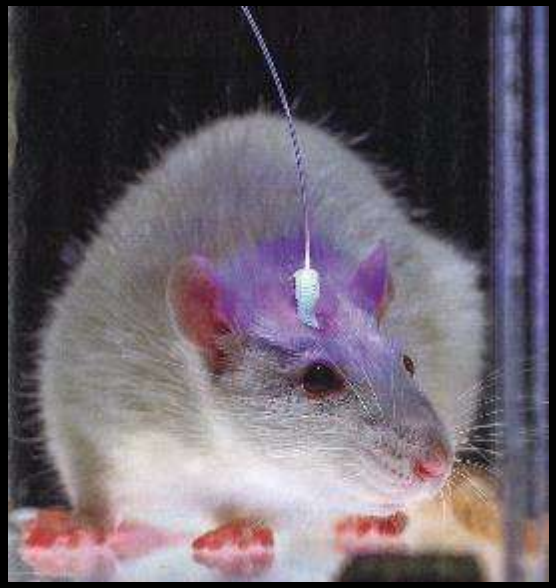
3D Mapping of Brain Structure and CNS Network Functions

the WHITE HOUSE

BRAIN INITIATIVE

BRAIN RESEARCH THROUGH ADVANCING INNOVATIVE NEUROTECHNOLOGIES

“Brain Net”



- first brain-to-brain link via remote transfer of encoded brain pattern to decoder animal and triggering of behavioral mimicry
- build inventory of codes to elicit specific behavior in target (decoder)
  - design of new control systems for robots
- legal and ethical implications of extension to elicited behavior (control, modulation) of humans

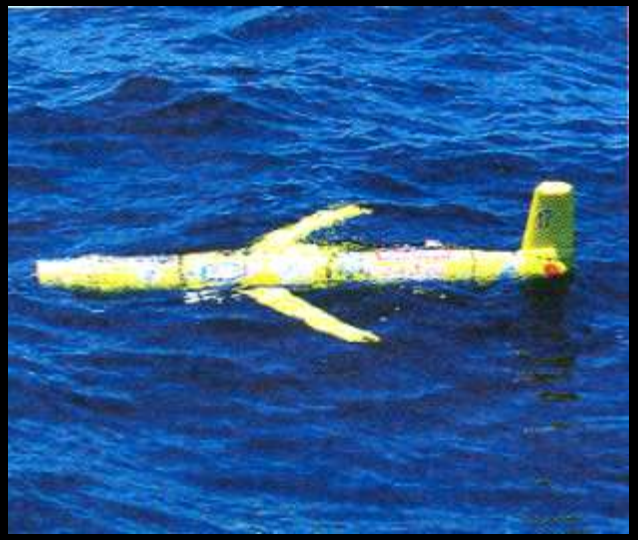
Smarter Than The Average Mouse
Engraftment and Colonization of Mouse Brain by Human Glial Cells

- M.S. Windrem et al. (2014) J. Neurosci. 34, 16153
- immature human glial progenitors engraft and myelinate hypomyelinated shiverer mice
- progressive colonization of host (mouse) glial cells
- human astrocytes x10-20 size of mouse astrocytes and carry x100 times as many tendrils
  - higher level of synaptic plasticity
- glial chimeric mice exhibited improved memory and learning tasks
- ethical barrier to similar transplant into non-human primates?

Robotics
4D Jobs: Dull, Dirty, Detailed and Dangerous

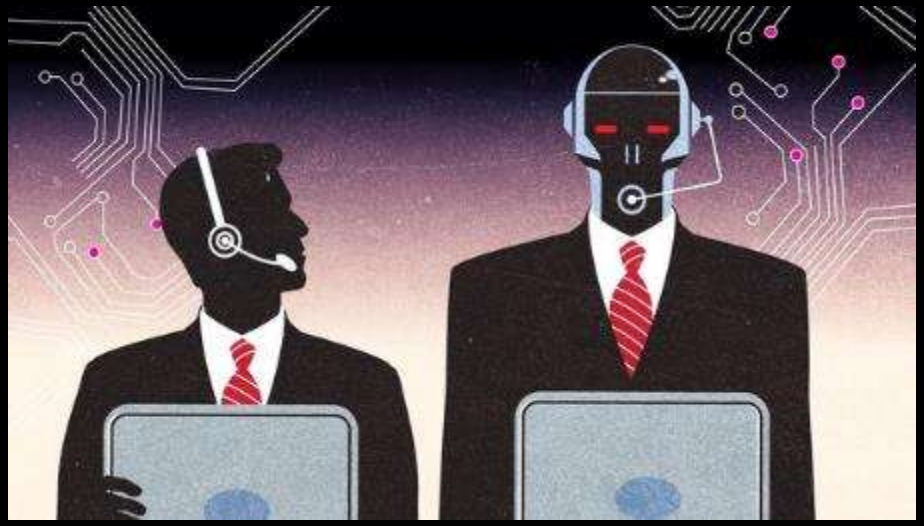







The Momentum for Transition to Autonomous Systems

Automation, Robotics, Machine Intelligence and the Future Workforce



Living With Systems We Don’t Understand

Escalating Complexities Imposed by Technology Convergence and Acceleration and Increased Connectivities of Diverse Global Networks

Reducing Decision Uncertainty and Risk in Increasingly Complex Systems of Systems

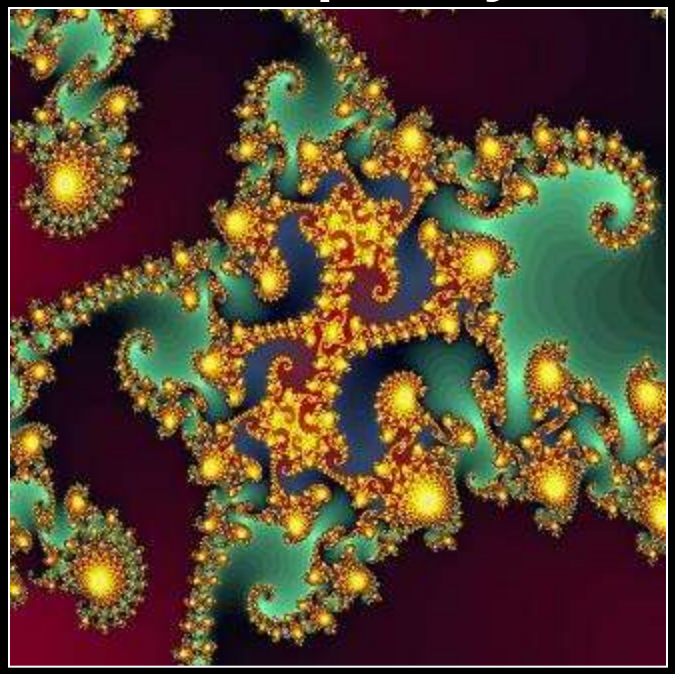
Understanding Complexity: A Dangerous Void in Public Policy and Governance of Advanced and Emerging Technologies

Features of Complex Adaptive Systems: Highly Optimized Tolerance and Far-From Equilibrium States

Convergence

- novel interactions between previously distinct agents/ networks/systems

Complexity



- system behavior cannot be predicated from properties of the component parts

Emergence

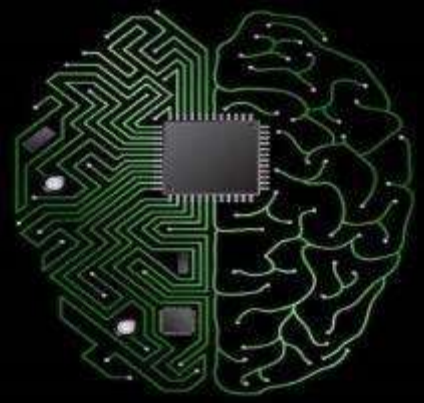
- new patterns of convergence trigger new system with highly different and typically unpredicted and undesired features

Complex Adaptive Systems: Increasing Design Degrees of Freedom (DDOF)









- increasing number of interacting elements/coding complexity
- graded levels of autonomous behavior (components, system)
- escalating challenge of predicting system behavior and state shifts

Oversight and Decision Making Regarding Systems |We Don’t Fully Understand

Development of Systems Too Complex to be Understood and Too Important to be Turned Off

Pervasive Problems in Addressing Complexity in Contemporary Government and Industrial Innovation

- silos subvert solutions
  - expertise, turf, budgets, egos
  - protection of the status quo
- comfort and complacency dominates absent a perceived existential threat (national, corporate, academic tenure)
- timid incrementalism versus bold disruptive innovation
- the tyranny of Wall Street
  - quick returns and short-termism
- kicking the can down the road
  - political and media appeal of cosmetic, unidimensional quick fixes for problems that require multi-dimensional solutions and long term commitment

The “Too World” and The Retreat from Complexity

- “too hard”
- “too complex”
- “too long”
- “too risky”
- “too uncertain”
- “too unfair”

Three Epochs in Harnessing Science and Technology for National Security

Big Innovation

- big bang
- big metal

- cold war existential threat
- unparalleled innovation and leadership by mil. labs/nat. labs/academia with shared goals
- catalyst for myriad new technology industries and US competitiveness

Three Epochs in Harnessing Science and Technology for National Security

Big Buyer

- advanced computing
- artificial intelligence

- DOD/IC highly sophisticated users
- primary role as purchaser with majority of innovation in private sector
- strong DOD/IC relationships with private sector for timely, creative acquisition/customization

Three Epochs in Harnessing Science and Technology for National Security

Big Void

- life sciences/ biomedicine

- growing USG gap in analysis of technology vectors and implications
- biosecurity largely ignored element in national security calculus
- translation is counter-cultural to biomedical USG agencies and academia
  - ROI/accountability for $150 billion investment in biodefense since 9/11?


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

Innovation Demands Boldness: Reconceptualize, Reset, Redesign and Recommit

- set aggressive metrics to meet grand challenges in education, health and environment sustainability
- more proactive analysis of new national security risks and intelligence requirements arising from technology acceleration and convergence in the life sciences
- accelerate new military capabilities for major shifts in CONOPs
  - urban warfare in unstable/anarchic environments
  - megacities, global health and humanitarian missions
  - robotics, autonomous systems and artificial intelligence

10 C's Shaping the Trajectory of the Life Sciences

- convergence (technology)
- complexity (systems of systems, exponential exponentials, emergence)
- capacity (sustainability)
- cities (megacities and new risks)
- connectivity (massive networks)
- computing (data science, brain:machine interfaces)
- cognition (neuroscience, artificial intelligence)
- competition (new business models, markets, national security)
- consequences (benefit and risk)
- choices (decision making in era of escalating complexity)

CREATIVITY AND COURAGE

Slides available @ http://casi.asu.edu/