The Acceleration, Convergence and Globalization of Advanced Technologies: Escalating Complexity, Disruptive Change and New Networked Organizations

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Technology Acceleration, Convergence and Disruption

- Engineering, materials science and robotics
- Genomics, biomedicine, biotechnology, synthetic biology
- Telecommunications and social media
- Computing, big data and human: machine interactions
Transcending Boundaries: Technology Convergence in Biomedicine

(0)Gene and Precision Medicine  |  Systems and Synthetic Biology  |  Targeted Rx and Gene Controls  |  Regenerative Medicine  |  HPO

Bio-Enhancement  |  Bionic-Enhancement  |  Cognitive Enhancement  |  Genetic Enhancement  |  Microbiome Metagenomics
“Engineered Negligible Senescence”

Aubrey de Grey
Synthetic Biology:
Engineering Novel Organisms with Novel Functions

Programmable Genomes

A New Industrial Ecology and Novel Biosyntheses
The BRAIN Initiative (2 April 2013)
Brain Research Through Advancing Innovative Neurotechnologies
New Technologies and National Security

- Net-Centric Strategies
- Advanced Avionics
- Drones
- Robot Swarms
- Food Security
- Transportation Security
- Cyber-Security
- Dual-Use Technologies
Sensor World

- Molecular Foundries
- Novel Materials
- Micro-Devices
- Ubiquitous Sensing
- Reconfigurable Sensors
- Ambient Intelligence
- Digital Cultures
- Cogint
- Intelligent Machines
- Competition and Espionage
Novel Materials

- flexible superfast electronics
- non-reflective coatings
- black body materials
- metamaterials
- switchable materials
Directed Molecular Assembly and Materials Science

Sensors and Molecular Machines

Biomimetic Design: Organic-Inorganic Hybrids
Sensor World:

- self-assembling and self-repairing ‘intelligent’ materials
- miniaturization, automation, networked sensors and devices
- nano-and Å-scale fabrication and spatial molecular assemblies
- wireless technologies and biomimetic power sources
Advanced Manufacturing
Digital Programming of 3-D Fabrication and New Assembly Technologies
Future Trajectory Trends and Threat Expansion

New ‘Dual-Use’ Technologies
The Expanded Dimension of the ‘Bio’ Challenge

- thinking beyond ‘bio’ as just infectious agents (bugs)

- systems biology
  - targeted disruption of ANY body function
  - novel C and B threats

- synthetic biology
  - exploring biospace: designing new life forms
  - designer organisms to attack materials/infrastructure
Adaptations of avian flu virus are a cause for concern

Members of the US National Science Advisory Board for Biosecurity explain its recommendations on the communication of experimental work on H5N1 influenza.
Accelerating Convergence: Conceptual, Technological, Informational and Commercial

- Biomedicine, Biotechnology, Synthetic Biology
- Ubiquitous Sensing/Devices & Social Networks
- Advanced Computing and Modeling
- Neurosciences and Human-Machine Interactions
- Disruptive Technologies

- “Bio-Space”
- “Connected Space”
- “Cyberspace” and “Simulation Space”
- “Cognitive Space”
- “Competition and Opportunity Space”

New Patterns of Technology Fusion, Evolution and Adoption

- New Knowledge Networks
- New Participants
- New Markets and Business Models
The Evolution of Production

Agrarian

Industrial

Digital
Major Themes in Technological Innovation

- automation
- miniaturization
- ubiquitous sensing/ambient intelligence
- networked connectivities and clouds
- massive parallelism
- big data and analytics
- co-evolution of human: machine relationships
- the digital infocosm
The Internet of Things
Embedded Sensors, Image Recognition and Mobile Devices

- over 50% of 15 billion internet connections are “things”
- 50 billion intermittent connections
- 70 billion mobile app downloads
- rise of ‘virtual appliances’ and software/services for infrastructure and application workloads
- two thirds of new products now come with some electronic component with performance/tracking potential
“The fourth site of care is going to be the Internet.”

George Halvorson
CEO, Kaiser Permanente
Statement at ONC 2012 Annual Meeting
m.Health

Real Time Remote Health Monitoring and Chronic Disease Management

Lifestyle and Fitness

Information for Proactive Health Awareness (Wellness)
The Proliferation of Mobile Devices in Healthcare

Siri, does this look malignant?
Mobile Devices and Telemedicine
Robotics: Telemedicine and Home Healthcare

RP-VITA Remote Presence Robot: (iRobot Corp) FDA 510(k) clearance 1/24/13
Geodemographic Information Systems (GIS): Real-Time, Front Line, Ground Zero Data from Field Sampling and Sentinels
Miniaturization of Analytical Technologies

“Lab-on-a-Chip”

“Lab-on-a-Tip”

“Lab-Always On”
and
“Lab-On-Me”
The Measured (Quantified) Self: Real Time Biometrics of Health Status

Every Individual Becomes Their Own Control
Health eHeart: Framingham Meets e.World

- recruitment of 1 million participants
- from profiling every two years (Framingham) to daily monitoring
- longitudinal observational monitoring with every individual acting as own control
- large sample size and avoidance of selection bias
- 1.5% cohort = entire Framingham study (15,000 participants)
Gray Technologies:
Independent But Monitored Living for Aging Populations

- Compliance
- Cognitive stimulation
- Fujitsu’s ‘smart walking stick’
- Early Alert to Clinical Deterioration
- Use of Appliances
Mobile Devices, Sensors and Remote Health Status Monitoring: The Changing ‘Care Space’ and Improved Continuity in Care Provision

- from fixed, tethered, compartmentalized, provider-centric facilities to
- distributed- and virtual-architectures linking multiple providers, home, work and the internet

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expanded ‘points-of-touch’ with the health systems
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improved continuity of care and data integration
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- from reactive, incident-centric, poorly coordinated and sequential referrals and inefficient post-incident follow-up(s) to
- pervasive, persistent monitoring of health status for pre-emptive risk mitigation, improved compliance and personal stewardship of health
Retail Healthcare:
New Services and Value-Based Shopping for Healthcare
Data: The Fastest Growing Resource on Earth
Ubiquitous Sensing: (Ambient Intelligence)
AORTA: Always On, Real Time Analytics

- instant information: anything, anywhere, anytime
- the internet of things
- miniaturized sensors and a monitored world
  - infrastructure, agriculture, health, finance, ecosystems, security, military
- from deep blue to deep space to inner space
- “intelligent” adaptive sensor networks (swarms)
- global connectivity and network information architecture(s)
- large scale simulation and modeling capabilities
Digital Traces

- every click you make
- every twitter feed you update
- every Facebook friend you add
- every Four Square location you log
- every cell phone call you transmit
- every time you use your credit card
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 numbers reveal increasingly predictable behavior and individual risk patterns
• new business opportunities in multiple sectors including healthcare
• new ethical and legal issues regarding privacy and data security
Natural Language Processing, ‘Trained Systems’ and Big Data Analytics
The Emergence of Big Data Changes the Questions That Can Be Asked

- Isolated Data
- Complex Networked Data
- Complex Computational Data
Big Data: Volume, Variety, Velocity, Veracity, Value

The Pending Zettabyte Era
1,000,000,000,000,000,000,000,000,000
The Increasing Complexity of Informed Decision Making

Data Deluge

Cognitive Bandwidth Limits

Automated Analytics and Decision Support

Facile Formats for Actionable Decisions
Cognitive Biology, Customized Data Formats and Visualization for Improved Decision-Making
Computing Systems and Interactive Displays:
From Defense to Gaming to Interactive Dynamics for R&D
and Business Processes
Pervasive Computing: The Next Major Transition?
Does Anyone Read Printed Journals Anymore?
Open Data Systems and Crowd Sourcing in Biomedical R&D

CANCER COMMONS

Sage BioNetworks

inspire2live

ChEMBL

creative commons

crowdmap

SGC

Ushahidi

myexperiment

Cytoscape

patientslikeme

WIN Worldwide Innovative Networking in personalized cancer medicine

Taverna

Open Network Biology

ELIXIR

Partners for a Cure Foundation, Inc.
The Pending Era of Cognitive Computing 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
Touch the Future:
Computing Platforms as Socio-Biological Systems

- modification of social patterns
- modification of cognitive structures
- memes as selection agents
- “the brain(s) in the cloud”
‘Here’s Where you made your mistake.’
Computer, Explain It To Me Again

- exponential growth of big datasets and multi-dimensional datasets
- bumping up against our conceptual and cognitive constraints (limits?)
- computational theorems, discoveries and explanations that transcend our interpretive capacities
- neuromorphic computing: learned tasks and improvements without explicit programming
- our last invention? (Jack Good and Alan Turing)
  - creation of machines able to develop ever more intelligent machines
Cyberinfrastructure for High Performance Computing (HPC) and Cloud Computing (CC) for Large Scale Datasets
Not All Digital Pipes are Created Equal
“Digital Darwinism”

- a pending digital divide
  - growing imbalance between different end user populations and their ability to embrace data scale and complexity
  - institutions unable to access and analyze large data sets will suffer ‘cognitive starvation’ and relegation to competitive irrelevance

- understanding the structure of information and its productive application/customization will emerge as a critical institutional competency
“This new world of data-centric computing requires use to rethink, from the ground up, how we build our computers where we do our computations how do we do our statistics and, ultimately, how we do our science.”

Alexander S. Szalay (Johns Hopkins Univ.)
Computing in Science and Engineering, Nov. 2011 p. 34
Computational- and Data-Enabled Science

The Big Data Challenge: Scale, Infrastructure, Personnel

Bigger Data and Better Questions

Thinking More Deeply About Data and Knowledge Generation
“We certainly know how to produce scientific knowledge, including knowledge relevant to policy options. But where is our science of the use of science?

Ken Prewitt
Vice-President, Global Initiatives
Columbia University
cited in Lancet (2010) 376, 500
Global Networks, Connectivities and Interdependencies

- **Shared Environment**

- **Shared Resources**

- **Shared Economy**

- **Shared Networks**
Living With Escalating Complexity and Systems We Don’t Understand

Reducing Decision Uncertainty and Risk in Increasingly Interconnected Global Networks

Mapping the Design and Dynamics of Complex Systems

Understanding Complexity: A Dangerous Void in Seeking Solutions to Global “Grand Challenge” Problems
“For most of us design is invisible until it fails”:
Bruce Mau. Massive Change. 2004
Comprehension of Complex Systems Requires Holistic, Systems-Based Analyses

- increasing evidence of dysfunctional nature of large organizational systems and institutions in addressing complexity
  - energy
  - environmental sustainability
  - healthcare
  - financial systems
  - education
  - national security

A MASSIVE AND DANGEROUS VOID IN NATIONAL AND INTERNATIONAL GOVERNANCE
The “Too World” and The Retreat from Complexity

- “too fast”
- “too complex”
- “too competitive”
- “too hard”
- “too long”
- “too risky”
- “too uncertain”
- “too unfair”
The Retreat from Complexity: Politics and Populism

- quick wins and superficial fixes to meet public expectancy and media scrutiny
- limits of elected office define strategic horizons
- selling zero-risk (US) and precautionary principle paralysis (EC)
- ideological polarization and divisiveness
- the rise of the blame and victim culture
- reinforcement by media appetite for celebrity, controversy and conflict and anti-corporatism
The Lights in the Tunnel

Automation, Accelerating Technology and the Economy of the Future

Martin Ford
• continued disruption and displacement of labor-intensive, low skill activities
• undermine current advantage of low cost, low-wage countries?
• reversal of out-sourcing trend or intensification via distributed manufacturing?
• distributed manufacturing services and reversal of urbanization driven by earlier labor-intensive industrialization?
Emergence: The Cardinal Feature of Complex Systems

creative destruction

disruptive change

inflection points

tipping points

‘Black Swans’

discontinuities

critical transitions

fragility

dislocations

phase transitions

volatility

new attractors

known unknowns and unknown unknowns
“We overestimate what we know and underestimate uncertainty, by compressing the range of uncertain states.”

Nicholas Taleb
The Black Swan
“Fitness, Competition and Selection”: An Enduring, Shared Conceptual Lineage

Adam Smith

“The Invisible Hand” (financial selection)

Charles Darwin

“Red in Tooth and Claw” (natural selection)

Joseph Schumpeter

“Creative Destruction” (innovation selection)
Future Thinking for Thinking About the Future:

- how do we develop and apply new tools to understand complex systems?
  - scientific research
  - technological solutions
  - education and training
  - public policy, oversight and regulation
  - institutional organization

- what is possible?
- what is probable?
- what is preferable?
- what is preventable?
The Impact, Implications and Economic Value of Massive Digital Information Networks
Complicated Systems versus Complex Systems

Distributed Degrees of (Design) Freedom (DDOF)
Complicated Versus Complex Systems

- complicated systems (low DDOF)
  - anthropogenic engineered systems
  - predictable performance of components, the assembled whole and their likely failure points

- complex systems (increasing DDOF)
  - anthropogenic and natural systems
  - more than the sum of their parts
  - levels of autonomous behavior: components, networks, system(s)
  - design of infinite-state systems
  - escalating challenge of predicting overall system behavior and state shifts (emergence) in ever more complex inter-connected networks
predictable performance of components, the assembled whole and likely failure points
Complex Adaptive Systems: Increasing DDOF

- graded levels of autonomous behavior (components, system)
- escalating challenge of predicting system behavior and state shifts
Cyber-Attacks and Vulnerable Infrastructure: Compromising Critical Systems
Silos Subvert Solutions!
Silos of Expertise as Obstacles to Understanding Complex Systems

- Siloed organizations are typically reductionist and slow to recognize and evaluate systemic risk(s).
- Reductionistic analytical methods and fragmented responsibilities for oversight and decision making predispose to hidden (undetected) risk(s).
- Hidden risk(s) will eventually (inevitably?) be manifest as unanticipated events with unintended consequences.
- Comfort and complacency: the two most dangerous threats the proactive recognition of disruptive change.
Intrinsic Tensions in the Growing Dependency of the Academic Research Community on Data-Intensive Methods and the Rise of New Knowledge Networks

Systems-focused, big data sets, mining and analytics

Investigator-centric datasets and hypothesis-driven research
New Conceptual, Methodological and Organizational Frameworks for Data-Intensive Biomedical R&D

- increasing dependency on systems-based, data-intensive analytics and new knowledge networks
- cross-domain convergence
- team based
- large scale
- increased automation
- quantitative data
- integration and analytics for large scale datasets
- intelligent systems
- new curricula
- agile knowledge networks
- ontologies and semantics and facile data sharing interoperabilities
Technology Acceleration and Convergence

- new patterns of disruptive intellectual fusion
- profound implications for education, research, business models, national security and public policy
- the siloed structure of current academic, industrial and governmental institutions is a major obstacle to assessment of the implications of the increased dependency on new trans-disciplinary, cross-sector networks and their accompanying complexity
society is increasingly dependent on inter-connected networks of complex systems whose dynamic behavior and stability is poorly understood

limitations in understanding complex systems, and increasingly stark inadequacies in current methods and institutions to design, monitor and direct these systems, renders society vulnerable to major disruptions

technology convergence and acceleration, together with massive expansion in the volume, velocity and variety of data, will exacerbate these deficits and increase the probability of major disruptive events
society is increasingly remote from the drivers and implications of emerging technologies

the pervasive scientific illiteracy among policy makers and socio-economic elites, political populism and short-term horizons in public policy and financial systems poses a pernicious and dangerous threat to the critical evaluation of the long-term consequences of new patterns of technological change
success in solving increasingly urgent global challenges in health, sustainability and security will require new analytical tools, organizational structures and knowledge networks to define the behavior of inter-connected complex systems

integration of complexity science and decision theory will assume increasing importance in education and research, drive new business models and must become a key component of better informed public policy
The Evolution of Scientific Enquiry: Robust Methods, Networked Knowledge and the Emergent Digital Infocosm

“Scienta potentia est” (Knowledge is power)

“Nullius in verba” (Take nobody’s word for it)

“Omnis serta est” (Everything is connected)

0011010100110… (Code is power)

- Experimental Design
- Standards and Reproducibility
- Mapping Network Dynamics
- Design, Monitoring and Control of Complex Digital Networks
“Oh, God help us! We’re in the hands of engineers.”

Dr. Ian Malcolm
‘Chaotician’: Jurassic Park