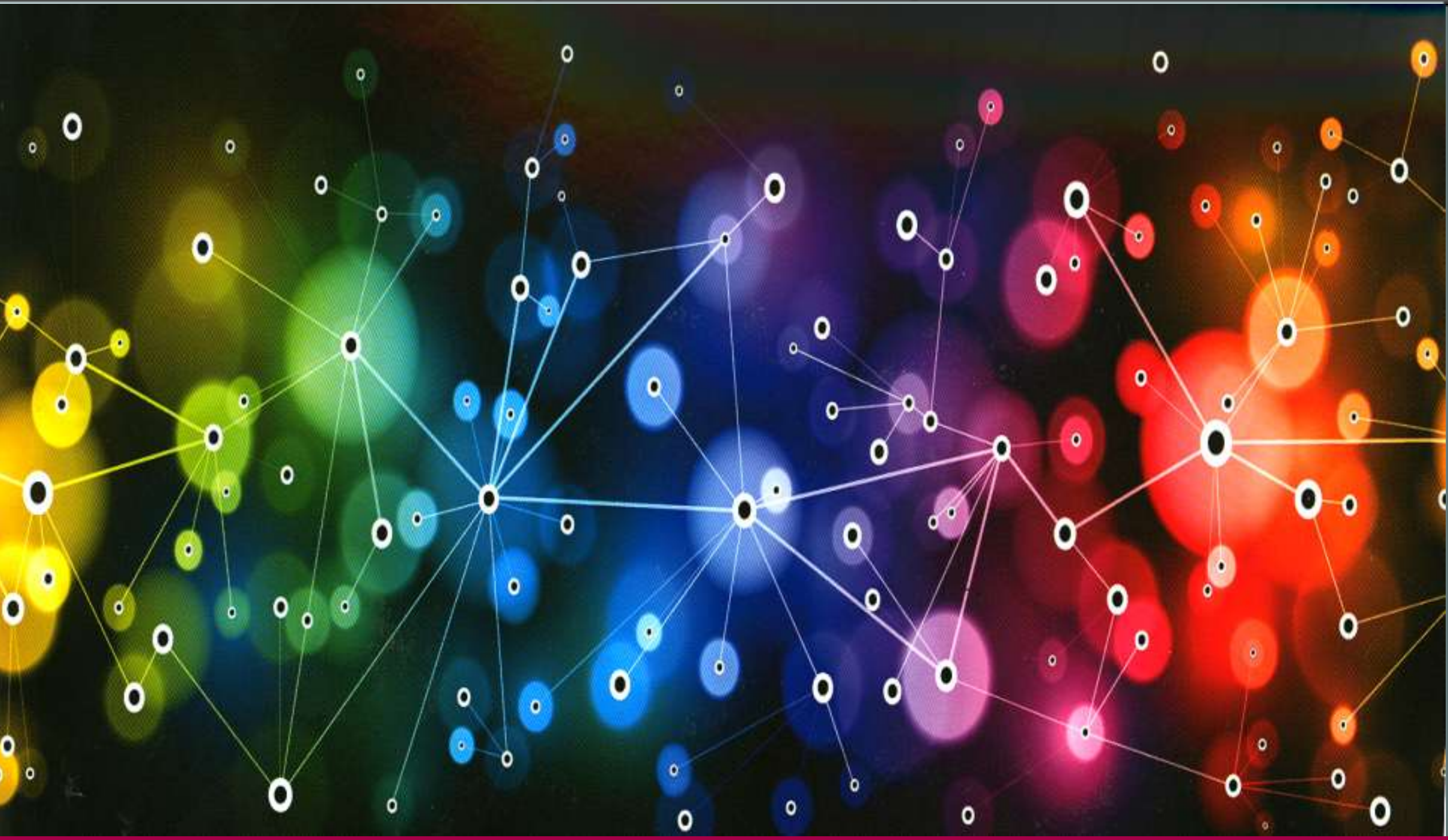
COMPLEX ADAPTIVE SYSTEMS at ASU (CAS at ASU)



COMPLEX ADAPTIVE SYSTEMS
ARIZONA STATE UNIVERSITY

Understanding the Design Principles and Dynamics of Complex Adaptive Systems

Building New Knowledge Networks to Study Complexity in Healthcare, Sustainability and Security

Dr. George Poste
Chief Scientist, Complex Adaptive Systems at ASU
and Del E. Webb Chair in Health Innovation
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www.casi.asu.edu

Workshop on Complexity and Complex Systems
Arizona State University 18 January 2013

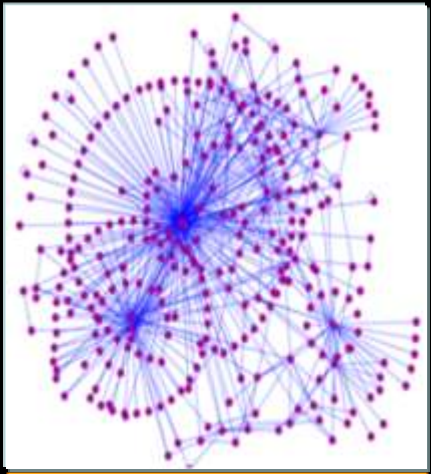
COMPLEX ADAPTIVE SYSTEMS at ASU (CAS at ASU)

QR Code Link to the CASI presentations page. Download any free QR-Code reader app to your smart phone.

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

The Ubiquity of Complex Adaptive Systems

Earth Systems	Eco-Systems	Food Webs	Coordinated Community Behavior



Host-Pathogen Interactions	Physiological Regulatory Networks	Genome Regulatory Networks	Microbiome Metagenomics

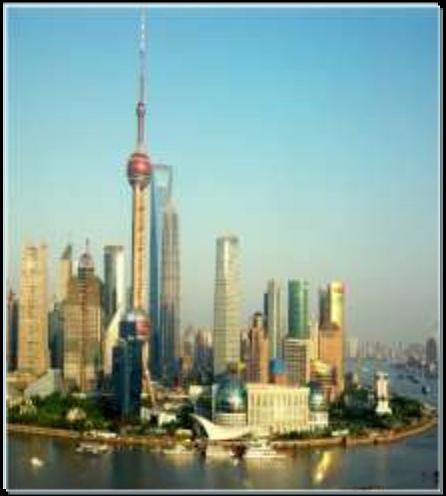
Complex (Adequately Adaptive?) Human-Engineered Systems

Financial Markets

Electrical Grids

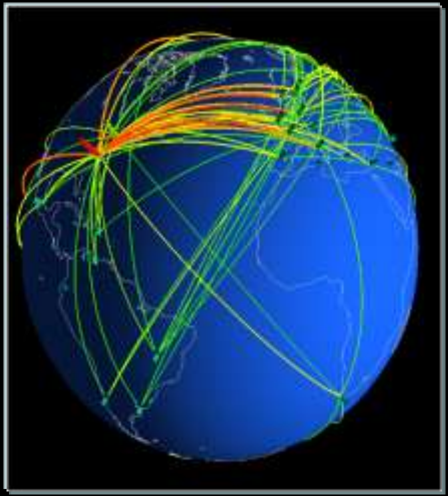
Transportation

Supply Chains



Urbanization and Mega-cities

Intensive Agriculture

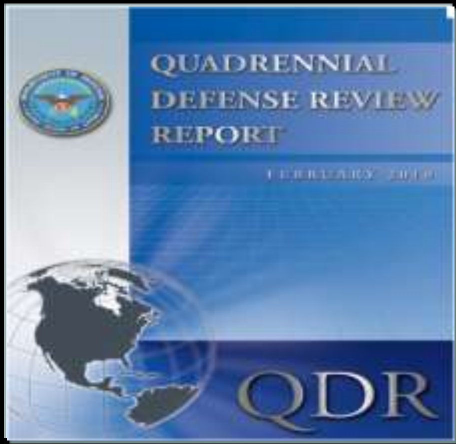


Internet and Metaweb

Social Media

Complex (Adequately Adaptive?) Human-Engineered Systems

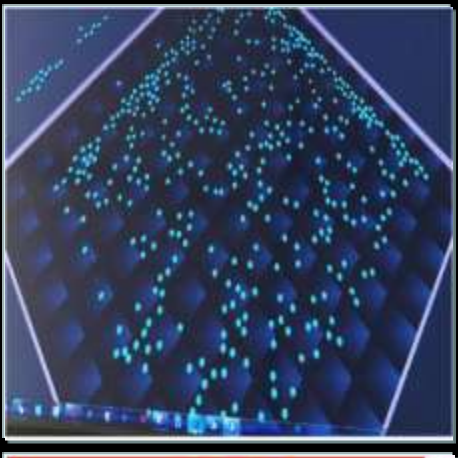
Net-Centric Defense Strategies



Advanced Avionics

Autonomous Drones

Robot Swarms



Food Security

Transportation Security

Cyber-Security

Oversight of Dual-use S&T

Innovation and Competitiveness

Dysfunctional Systems

healthcare

civil
disaster
preparedness

economic
theory,
banking
and
markets

prediction of
major social
upheavals

governance
and
public policy

confronting
climate
change and
depletion of
non-renewable
resources

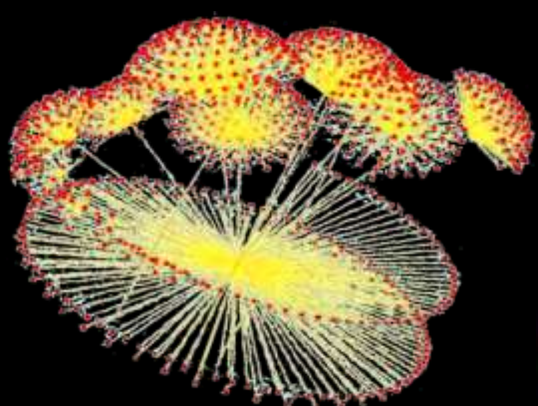
Talk Outline

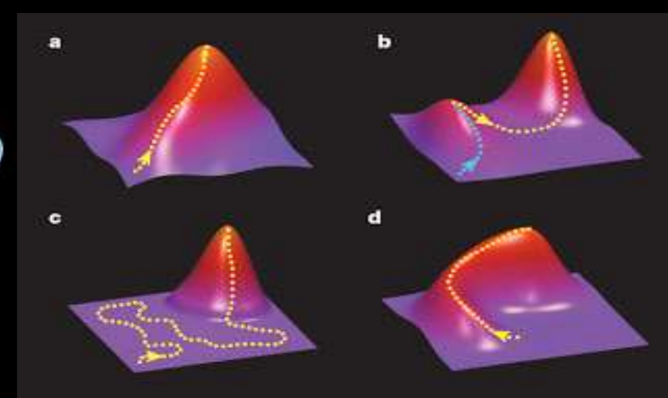
- principles of CAS design and dynamics
- need for new conceptual and analytical approaches to complexity and decision-science
  - engage with formidable global challenges
  - health, sustainability, national security
  - education and training
- launch of CAS at ASU
  - objectives, organization and initial project portfolio

Complex Adaptive Systems

- self-organizing interactions between multiple components (agents) across scaled hierarchies
- system behavior cannot be predicted from knowledge of the properties of individual components and even subnetworks



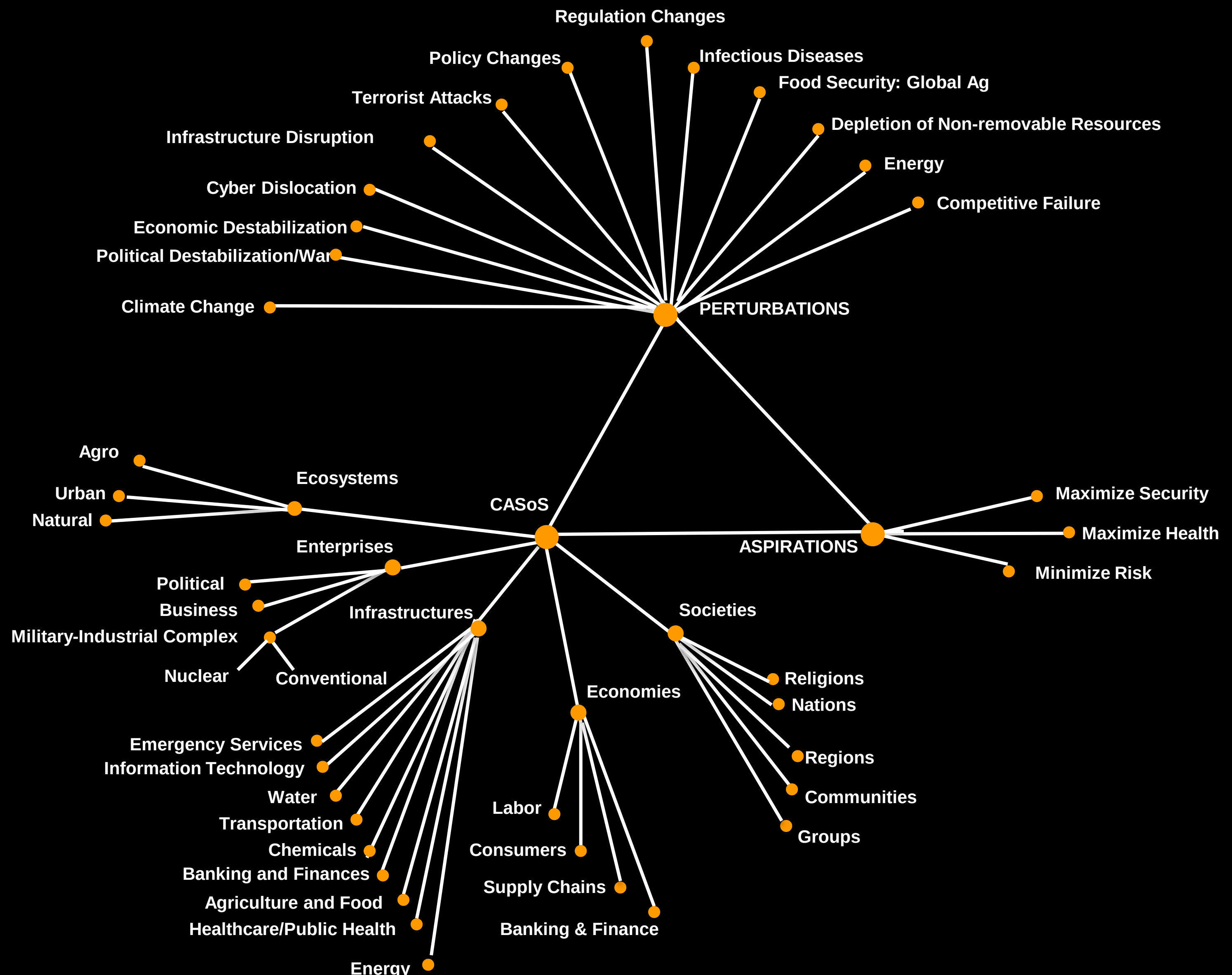





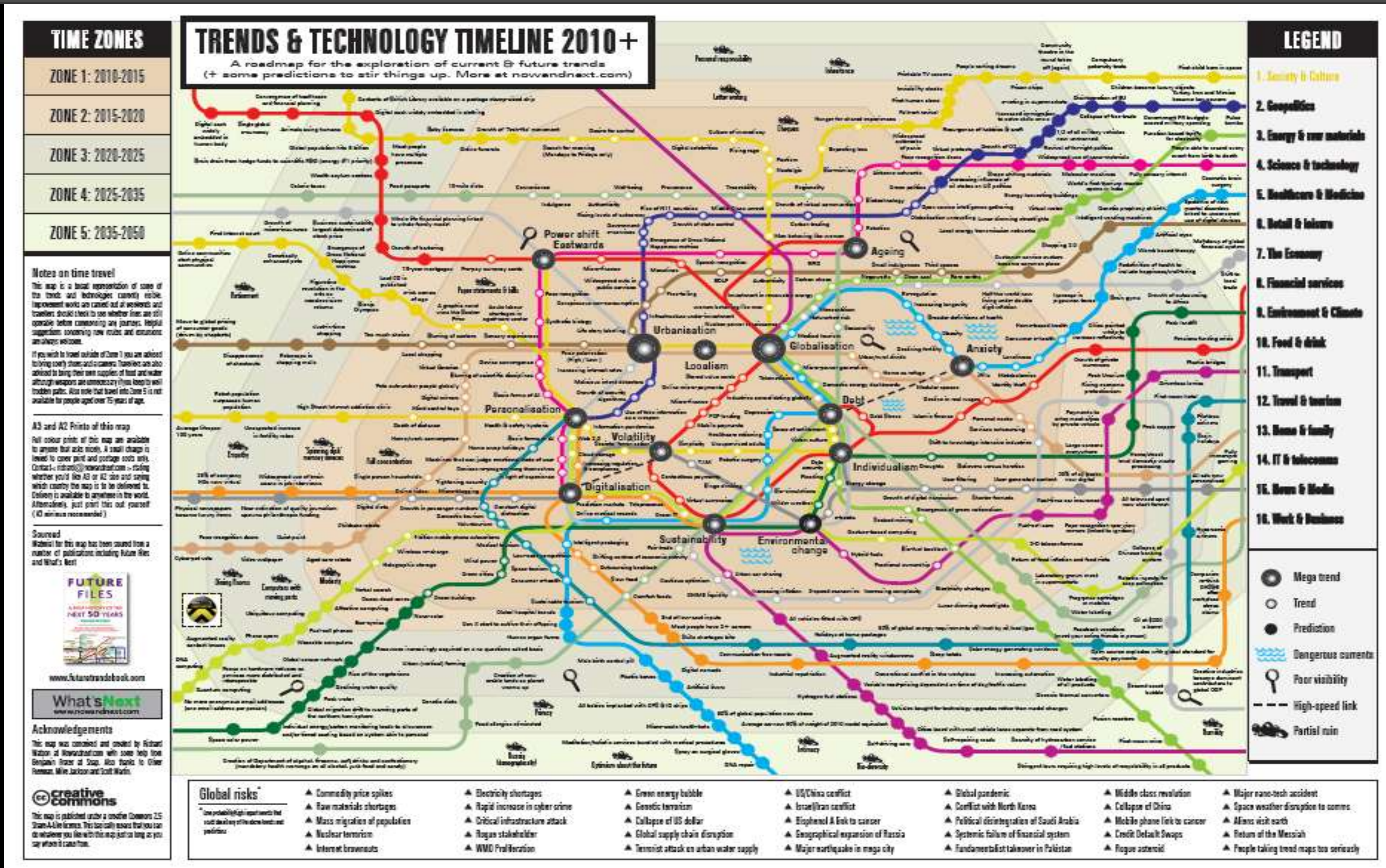
Complex Adaptive Systems

- few, if any, CAS exist as independent entities
- combinatorial effects of multiple interacting CAS
  - Complex Adaptive Systems of Systems (CASoS)
- analysis of CAS/CASoS design and dynamics central to better informed decision-making, public policy and risk management

Complex Adaptive Systems of Systems (CASoS)
Adapted from: T. J. Brown et al. (2012) SAND 2012-4641P



Acceleration of Discovery
and Convergence of Scientific Domains and Technologies



"It from Bits"
The Proliferation of Digital Design and Fabrication

Advanced Computing and Devices	Ubiquitous Sensing/ Social Networks	Biomedicine, Biotechnology, Synthetic Biology	Complex Autonomous Systems	Disruptive Technologies
				?
"Cyberspace"	"Connected Space"	"Bio-Space"	"Simulation Space"	"Opportunity: Threat Space"

Emerging and Evolving
Multi-Dimensional, Multi-Disciplinary Matrices

New Organizational Structures

New Knowledge Networks

New Networks of Intellectual Fusion

Acceleration and Convergence in Science and Technology

- massive data sets
- open source networks
- new analytical models/tools for non-linear systems
- multi-scale networks

Behavioral Economic and Social Technologies (BEST)

New Knowledge Networks and Systems of Innovation

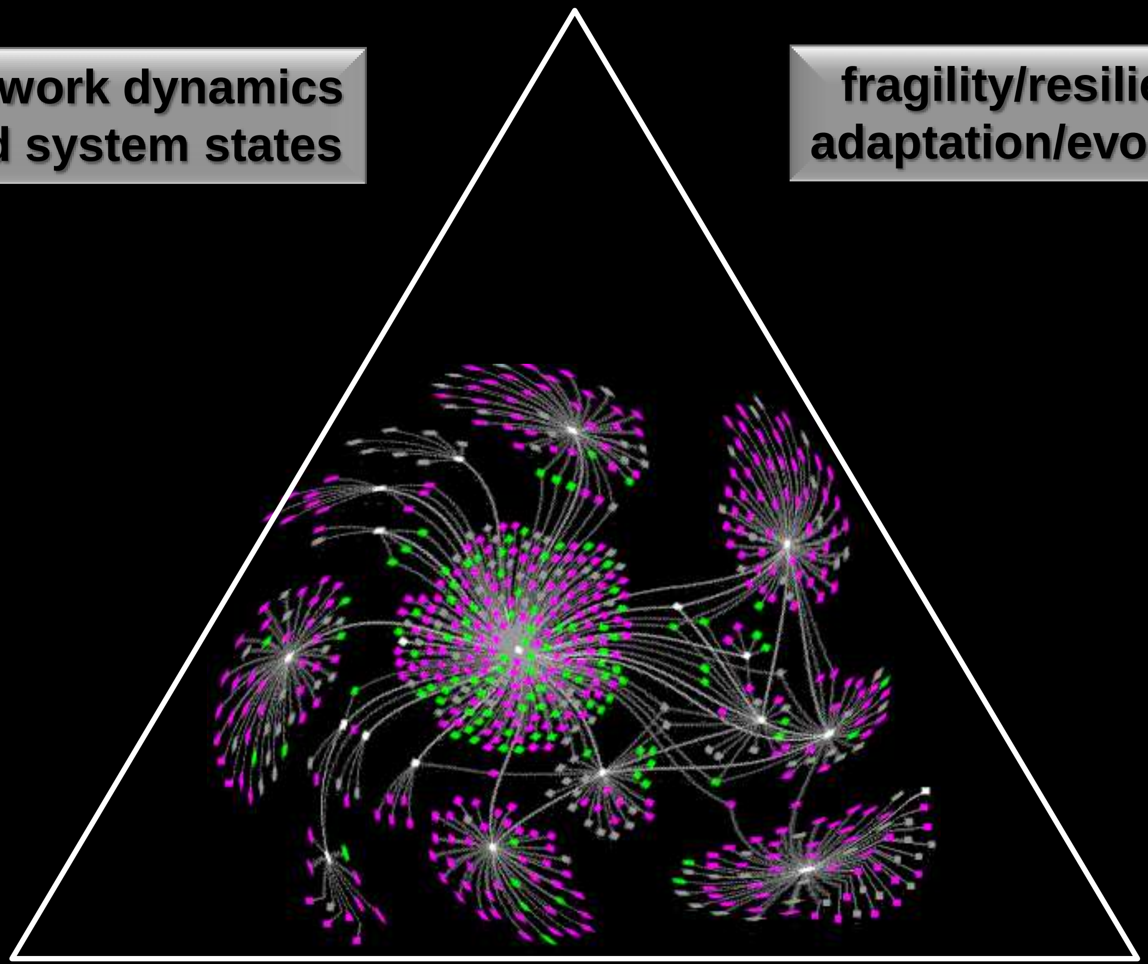
Big Data: Next Generation Cyber-Capability

Network Design in Complex Systems

network topology

network dynamics
and system states

fragility/resilience
adaptation/evolution



connectivity

composability

Fundamental Questions

- are there common design principles and organization of information networks in diverse CAS?
  - physiological homeostasis
  - disease pathogenesis
  - epidemics/epizootics: origin, spread and control
  - climate dynamics and ecosystem stability
  - invasive species and ecosystem disruption
  - information and communication networks
  - financial systems
  - industrial supply chains
  - social structure in populations, communities and ecosystems

Network Design Principles for CAS

- can design principles identified in CAS that are at more advanced stages of knowledge maturation (e.g. patterns of internet traffic, social networks, DDOS attacks and advanced avionics) be extrapolated to guide research in less mature systems domains (e.g. mapping molecular networks and information flow in biological cells and the perturbations that cause disease?)

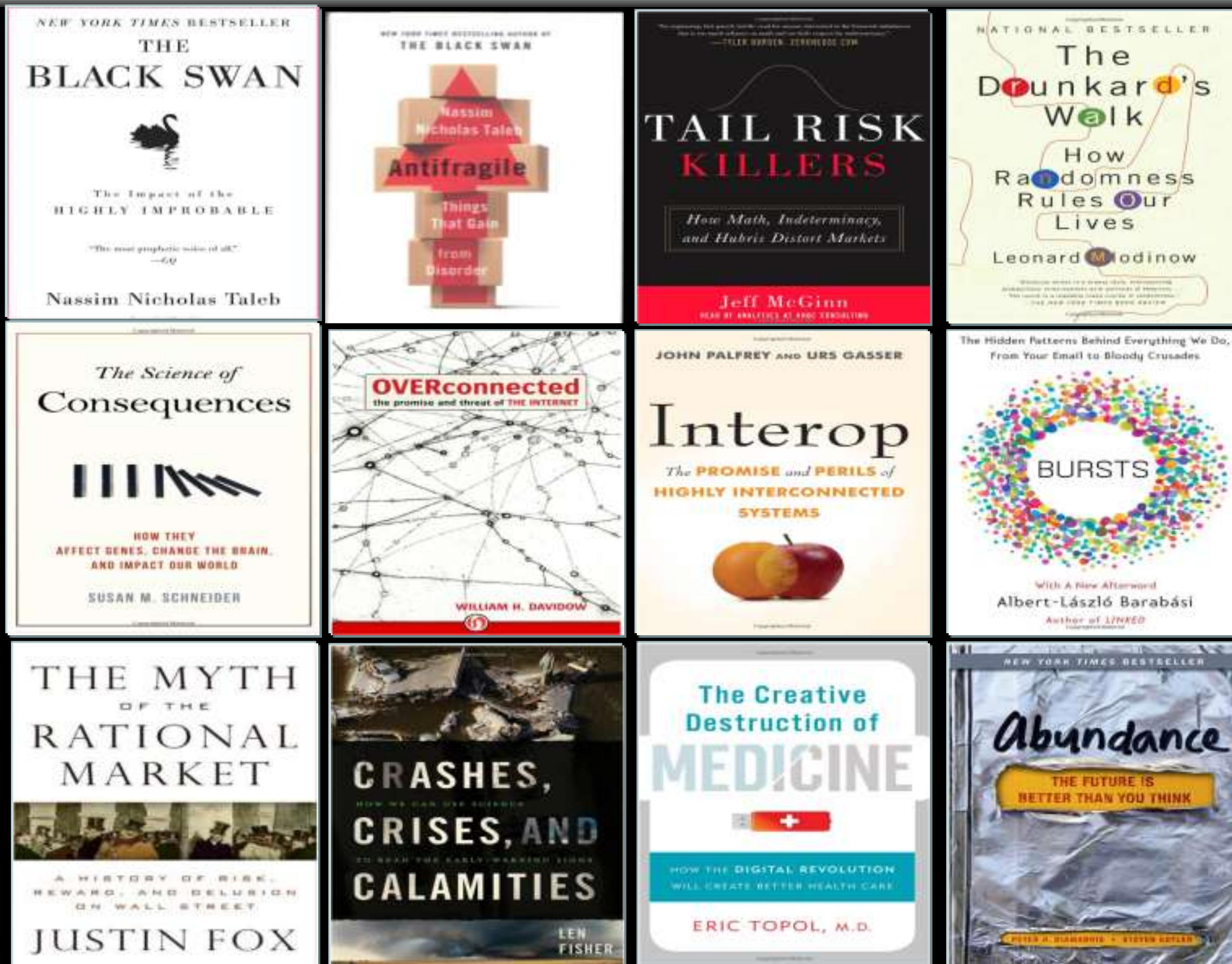
“For most of us design is invisible until it fails”: Bruce Mau. Massive Change. 2004




The Dynamics of Complex Systems

- volatility, randomness and uncertainty are ubiquitous
- the CAS world is non-deterministic and non-linear
- predictions, policies, processes, control systems and decisions based on flawed assumptions of linearity and certainty will fail
- failure to understand complexity, fragility and uncertainty generates unintended consequences, often with tragic/catastrophic outcomes
- the escalating complexity of anthropogenic systems and connectivity increases the probability and severity of disruptions and emergence of new ‘system states’ with radically different features

Managing Complexity and Uncertainty



Complex Adaptive Systems (CAS) at ASU

From Reductionism to Mapping Systems

From Components to Complexity

Building New Knowledge Networks
In Teaching and Research

Complex Adaptive Systems (CAS) at ASU

- complexity and CAS/CASoS network behavior central to solutions to global grand challenges
- obligate dependence on multi-/trans-disciplinary competencies and new translational capabilities
  - new ways of organizing
  - new scales of collaboration and infrastructure needs
  - new funding mechanisms
  - new ways of thinking

Complex Adaptive Systems at ASU: Research Competitiveness

- concept of ‘Architectural Firm’ to identify, launch and build CAS portfolio focused on ‘grand challenge’ problems
  - A:A′ projects
- purposeful focus on use-inspired research and accelerated translation to practice
- catalyze collaborations across ASU and with external public and private-sector entities
- establish requisite computational capabilities and infrastructure to accommodate the pervasive importance of data-intensive approaches to CAS/CASoS

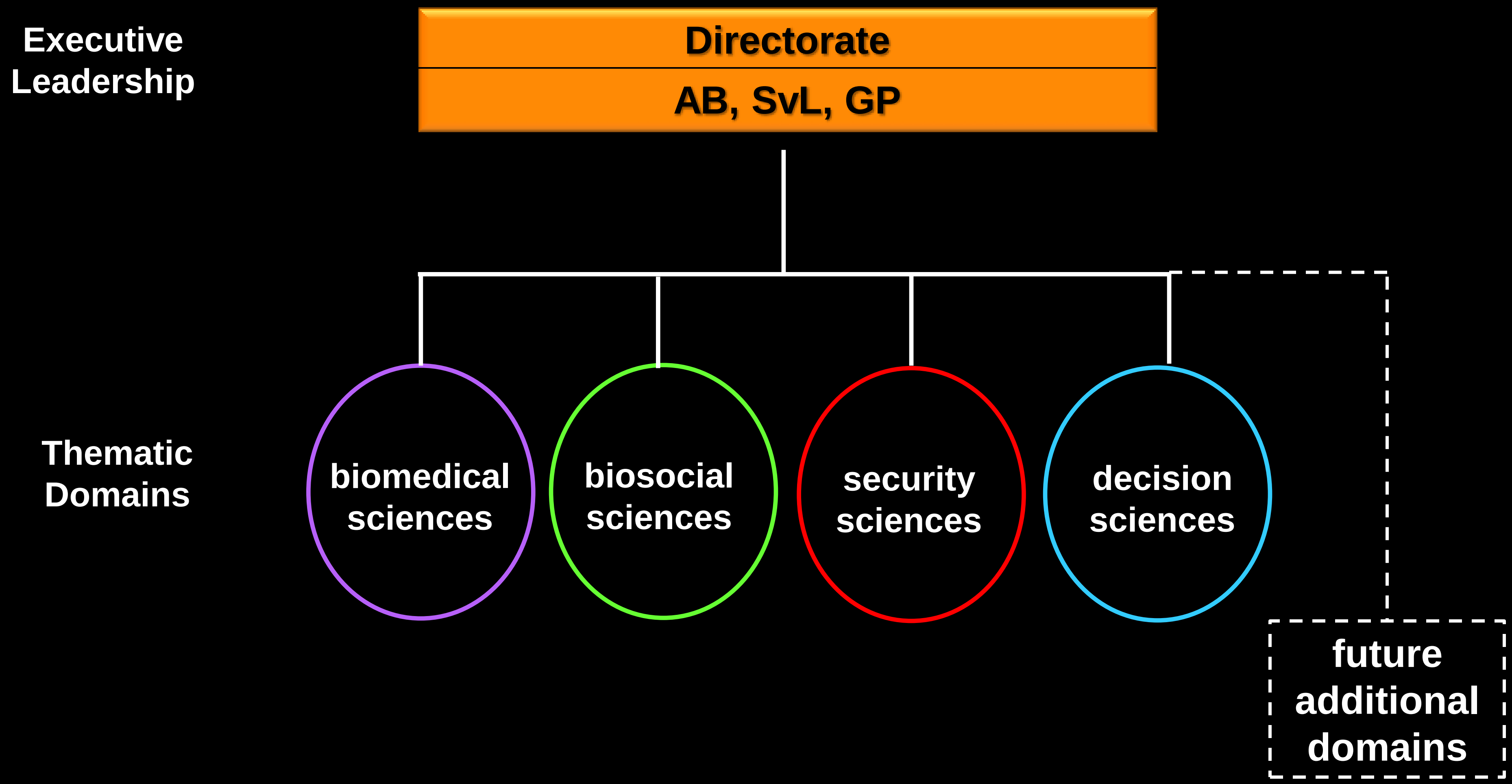
Complex Adaptive Systems (CAS) at ASU: Institutional Competitiveness and Revenue Growth

- continued vital importance of expanded RO1 (‘R’) grants and center (‘C’) award resources
  - $500MM target by 2020
- CAS at ASU as catalyst to build portfolio of ambitious, large-scale (A:A′) projects
  - additional $200MM target to achieve ASU strategic goal of $700MM research funding by 2020
- focus on disruptive innovation and attractiveness to non-traditional funding sources
- complementary/synergistic with ongoing ASU meta-planning initiatives

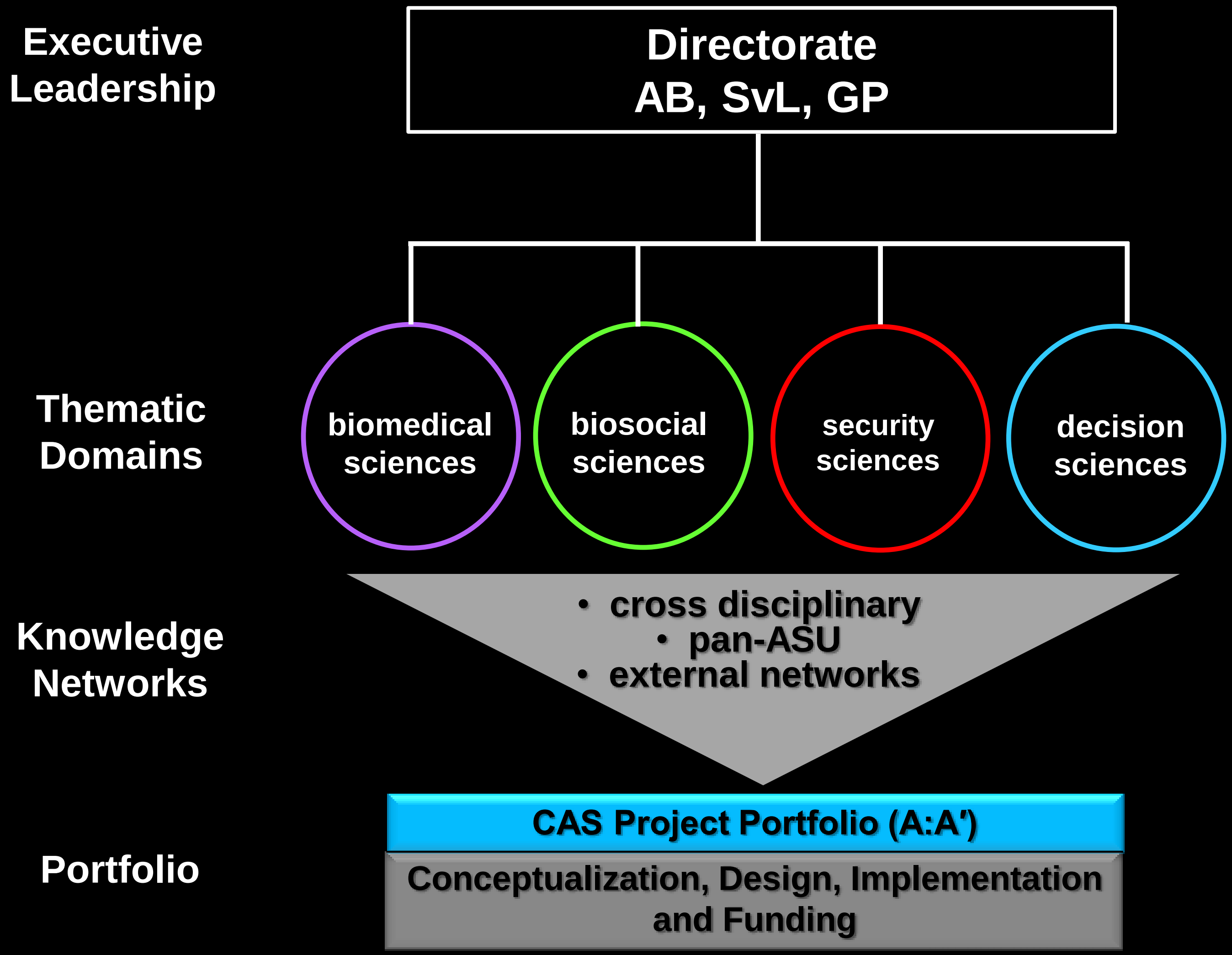
Complex Adaptive Systems (CAS) at ASU: Education and Public Policy

- progressive assimilation of complexity science and decision support systems as fundamental components of 21st century education (literacy!)
  - UG, PG and on-line courses
  - certificates and continuing education (eg. CME)
  - corporate training (reciprocal)
- development of new analytics for CAS/CASoS as intellectual foundation for improved decision-systems and public policy
  - modeling and simulation of non-linear complexities
  - regulation, law and legislation

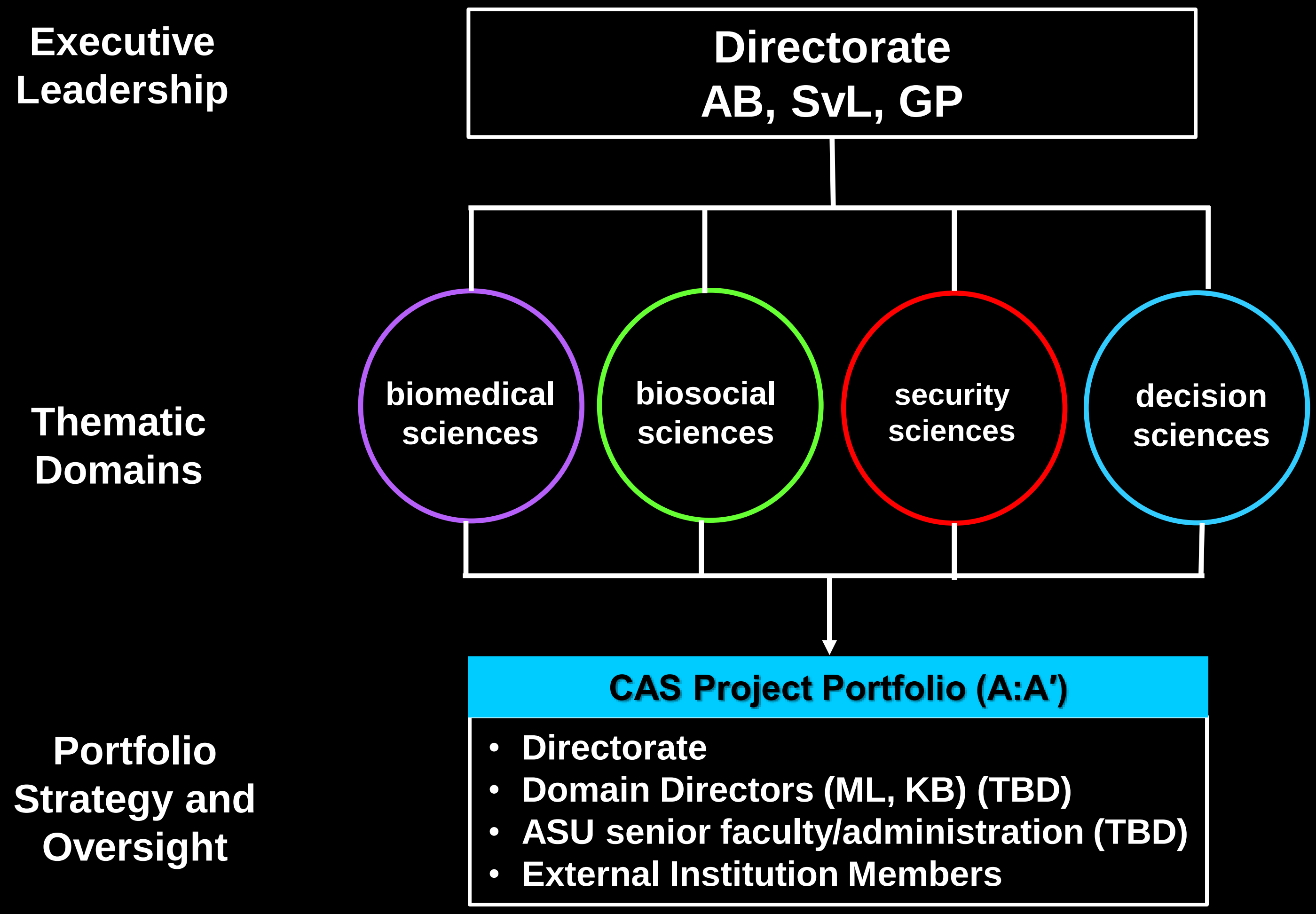
Organizational Structure



Organizational Structure



Organizational Structure



Structure and Operations

Executive Leadership

Directorate
AB, SvL, GP

Thematic Domains

- biomedical sciences
- biosocial sciences
- security sciences
- decision sciences

Portfolio Strategy and Oversight

CAS Project Portfolio (A:A′)

Portfolio Execution

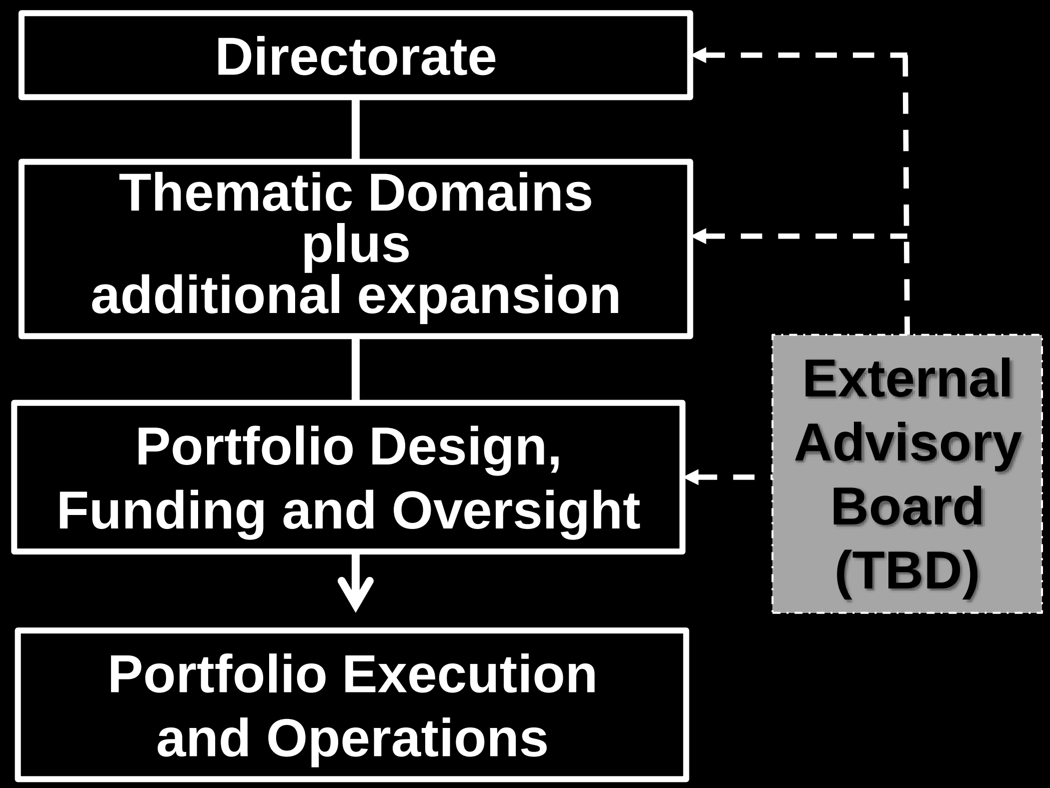
CAS at ASU Portfolio Operations

- project leaders (ASU or external)
- project managers (ASU)
- IT, finance, facilities, communications

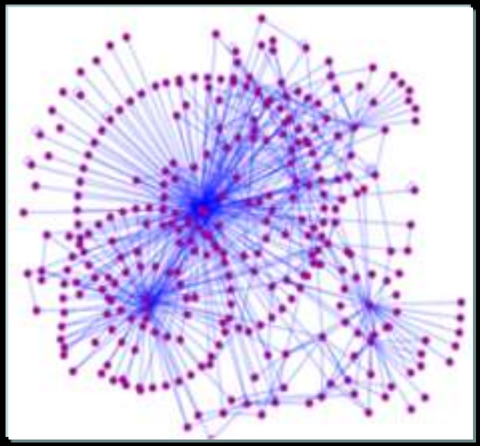
Complex Adaptive Systems

Arizona State University

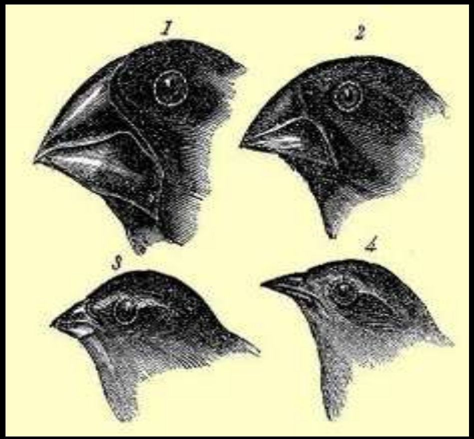
Governance



The Dynamics of Complex Systems



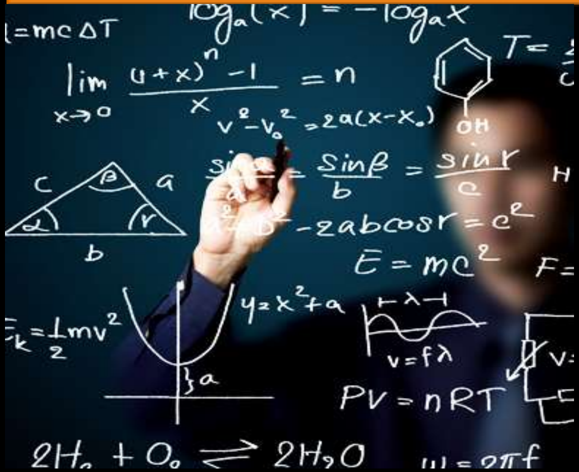
- the imperative for new insights into the design and dynamics of CAS
  - network topology and information flow
  - robustness, adaptation, evolvability
  - excursional and stability boundaries for defined system states
  - triggers of emergence and prodromal signals of imminent emergent shift(s)

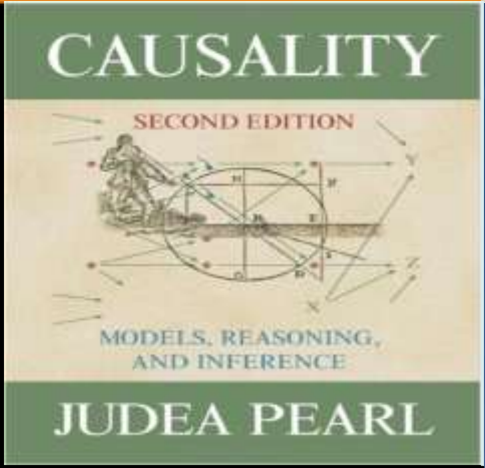


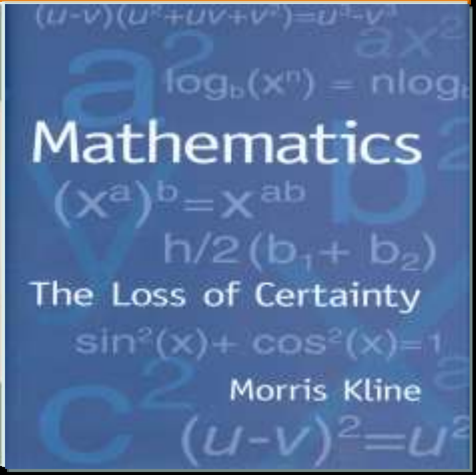
- neglect of evolutionary theory as instructive framework for improved analysis and manipulation of CAS
- ubiquity of scale-free network topologies in biosystems

The Inadequacy of Physics-Based ‘Rules’ to Formulate Explanatory and Robust Predictive Tools for Biological CAS

Newtonian, Invariant Rulesets and ODEs







New Analytics, Natural Algorithms, Models and Simulations for Non-Deterministic, Non-Linear and Stochastic ‘Systems Space’

“We need postmodern discrete algorithmic math
to understand biology,
not Newtonian differential equations,
not old math, not old analysis.”

Gregory Chaitin
Proving Darwin: Making Biology Mathematical
Pantheon Books, New York 2012, p.34

Natural Algorithms

- living processes are powered by nature’s ‘software’
- natural selection is the ultimate code optimizer
- natural algorithms represent processes evolved over extended time periods and diverse selection pressures
- need for tractable abstractions for computing collective behavior in networked, multi-agent systems characterized by non-linear, stochastic and parallel processes plus emergent properties

The “Near-Infinite State System” Problem

- near-infinite state systems have exceedingly high dimensionality
- only a small fraction of sample space can be measured
  - the sample poor challenge
- what confidence level is needed for “certifiable trust” in defining CAS properties?
  - V2: validate and verify
- formal methods for finite-state systems using abstraction and model-based checking unsuitable
- utility of probabilistic or statistical tests also limited by very large possible input/output states

COMPLEX ADAPTIVE SYSTEMS
ARIZONA STATE UNIVERSITY

A:A′ Project Portfolio*

Biomedical

- Complex Diseases as CAS (cancer, diabesity, Alzheimer's)
- Evolutionary Medicine
- In Silico Medicine Coalition
- National Biomarker Development Alliance
- Obesity Origins and Outcomes

Biosocial

- Climate Adaptation
- Innovation in Biological, Social, Technological Systems
- Urban Sustainability

Security

- Ångstrom Design
- Immunosignatures
- Synthetic Phages

Education

- course proposals in development

*Multiple projects dependent on Next Generation Cyber-Capability (NGCC)

Healthcare as a CASoS

Care Delivery as a CAS

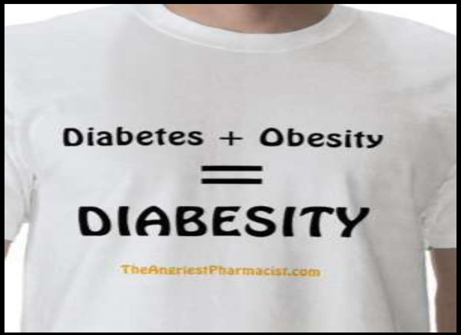
Demographics

Bill More: Do More

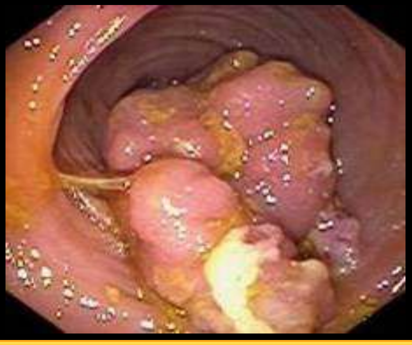
Fragmented Care

Lack of Political Will

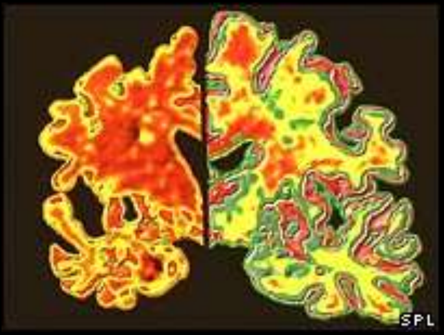
Disease as CAS



Diabesity



Cancer



Alzheimer's Disease

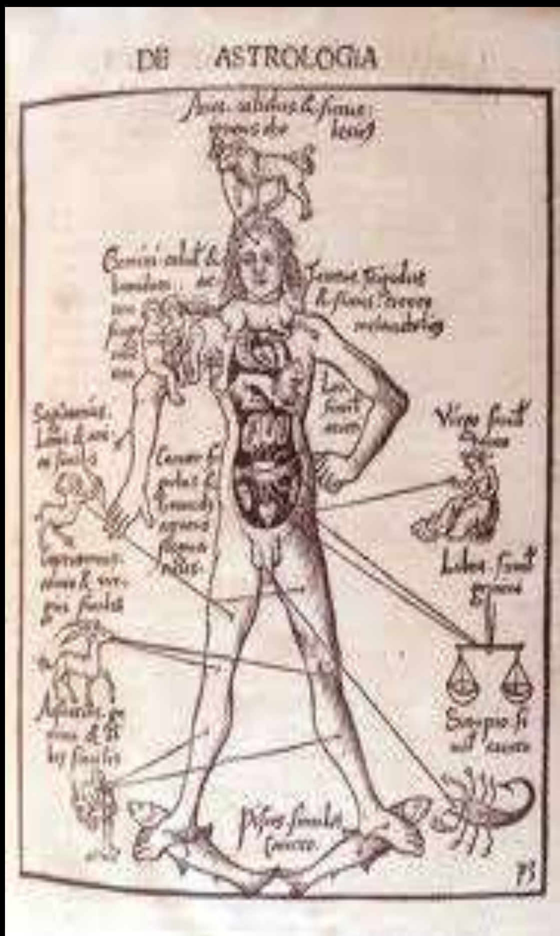
Antibiotic Resistance

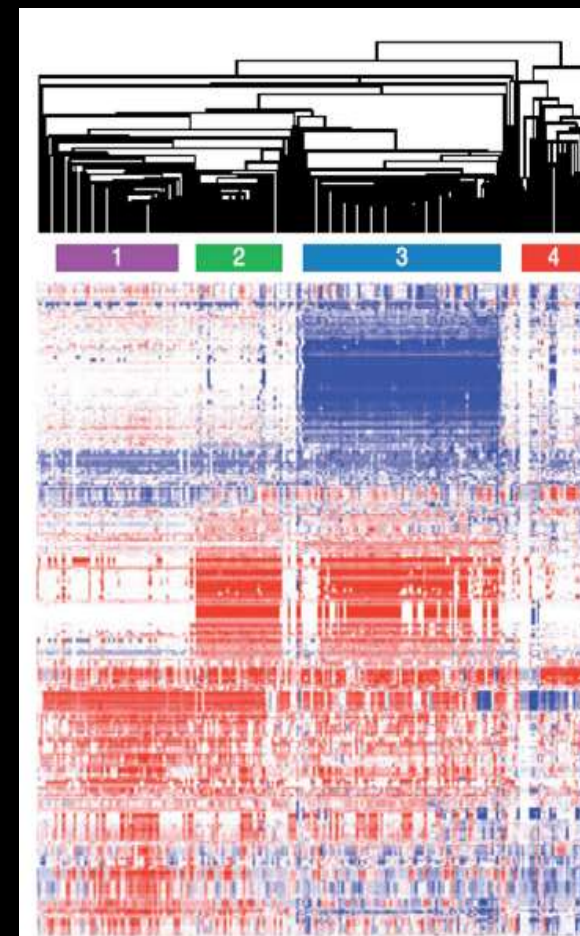
Complex, Multigenic Disease as CAS

Elucidation of the Design Principles and Dynamics of Complex Biological Systems in Health (Physiology) and Disease (Pathology)

Systems Medicine; Network Medicine; Personalized Medicine

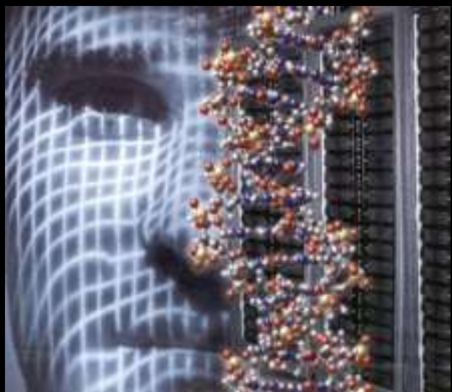
Medical Progress:
From Superstitions to Symptoms to Signatures



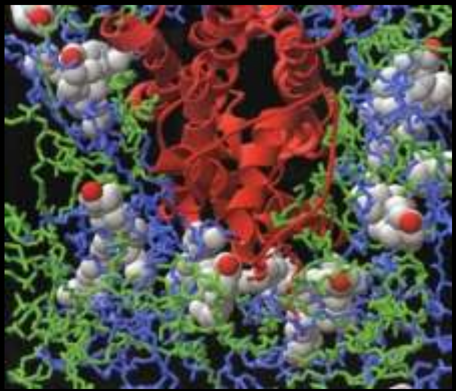


Integrative Omics (iOmics), Molecular Subtyping of Disease and the Primacy of Biomarkers and Molecular Diagnostics (MDx)

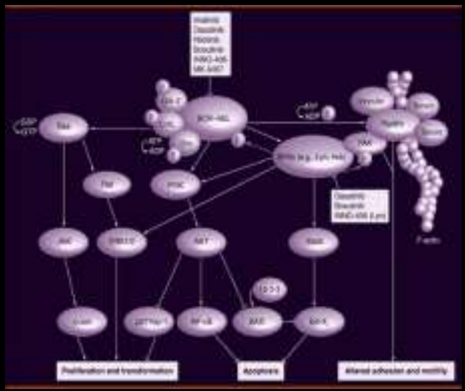
Genomics



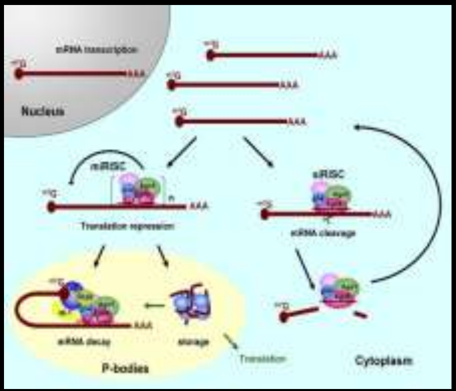
Proteomics

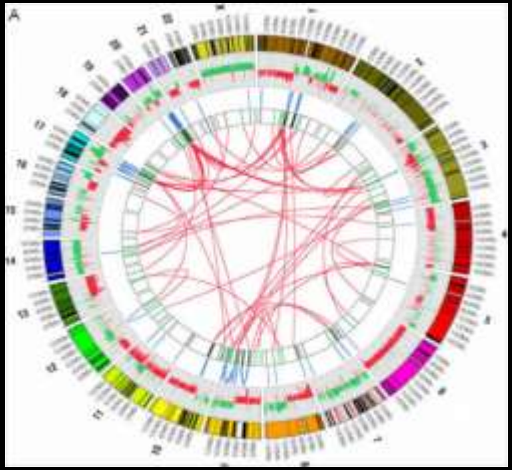


Molecular Pathways and Networks



Network Regulatory Mechanisms



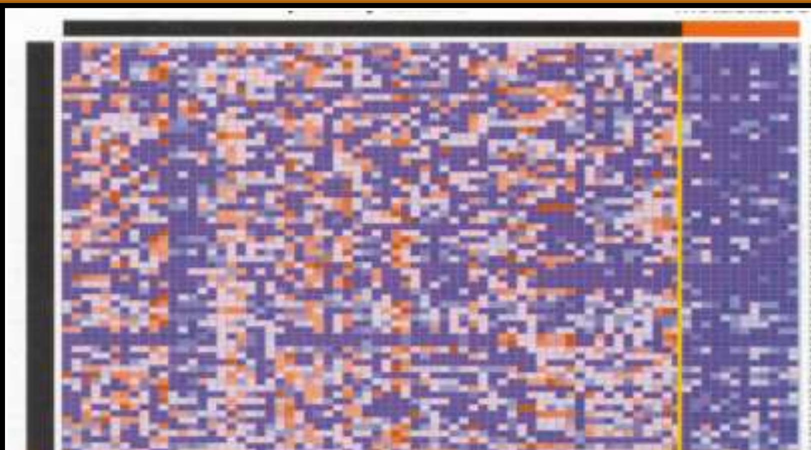


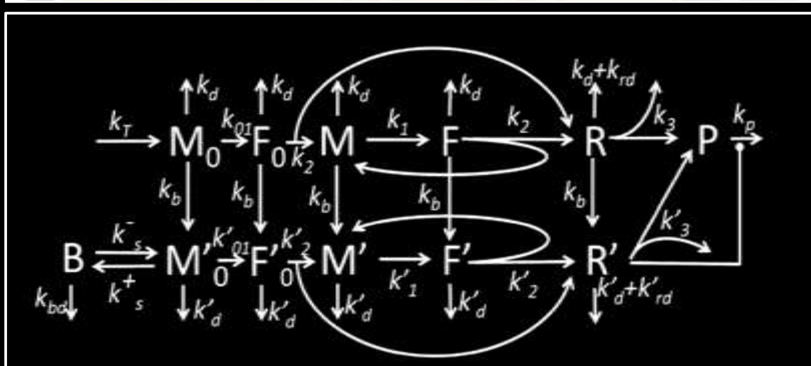
ID of Causal Relationships Between Network Perturbations and Disease Subtypes

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

Mapping Causal Perturbations in Molecular Pathways and Networks in Disease: Defining a New Taxonomy for Disease

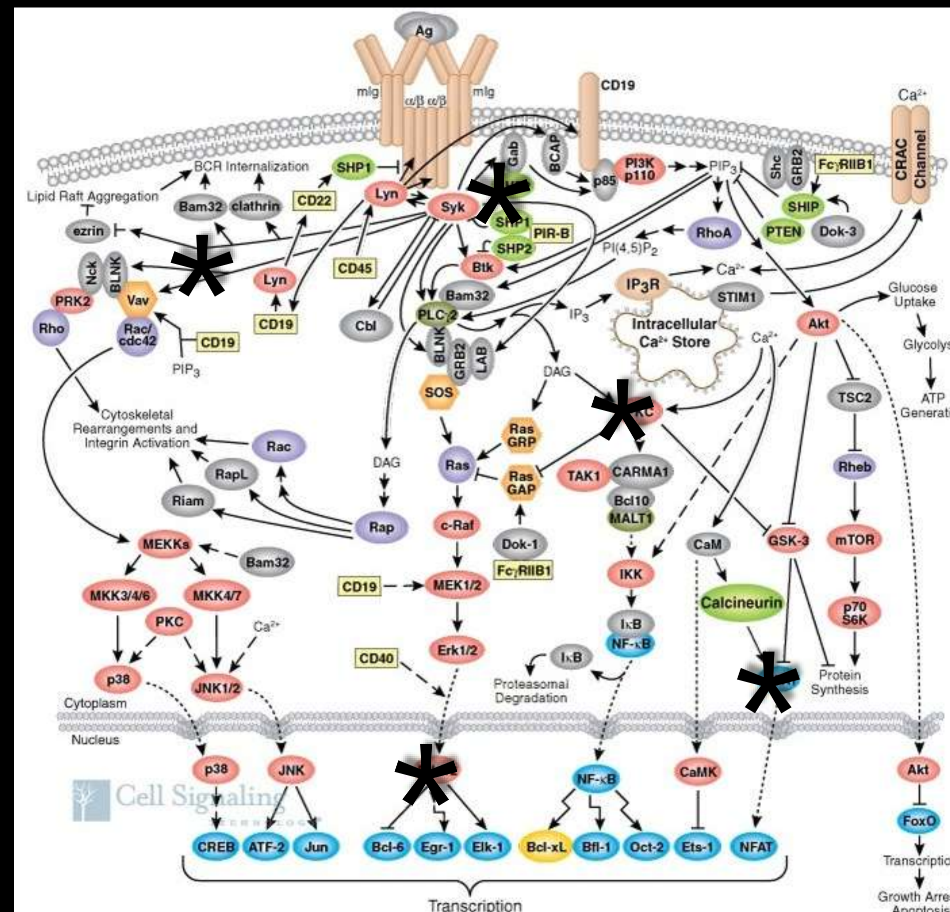
iOmics Profiling to Identify Disease Subtypes (+ or - Rx Target)





Modeling of Information Flow in Biological Networks

Altered Network Structure and ID of Molecular Targets for MDx and/or Rx Action



“Omics” Technologies and the Elucidation of Perturbations in Molecular Network ‘Wiring’ in Complex Diseases

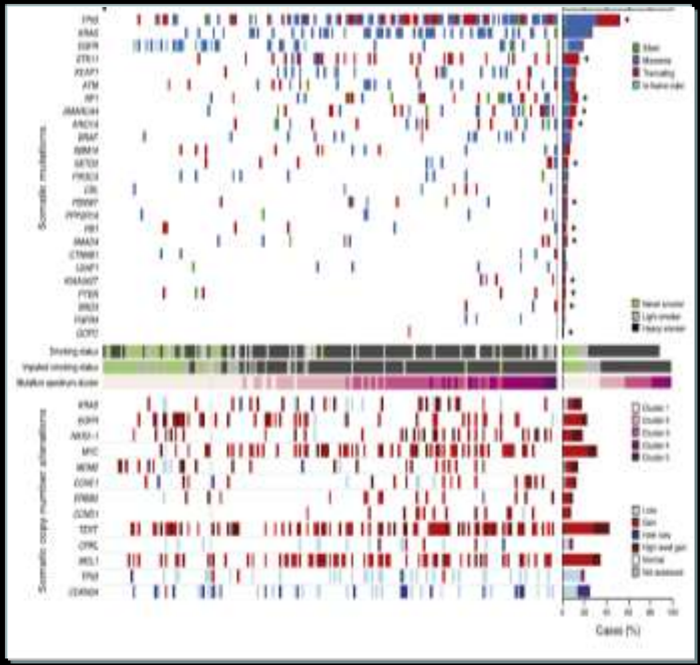
- the ‘dead hand’ of reductionism and “the trap of linearity” as barriers to progress
- delusional pursuit of individual Rx ‘targets’ in face of known, extravagant network-wide perturbations
  - extensive network redundancy via pathway coupling
  - rapid shift to compensatory wiring circuit to circumvent Rx efficacy
  - redundancy = resistance
- time for a serious re-assessment of current R&D strategies

Initial Response (A/B) of BRAF-V600 Positive Metastatic Miliary Melanoma After 15 Weeks Therapy with Vemurafenib (Zelboraf® - Roche) Followed by Rapid Recurrence of Rx-Resistant Lesions with MEKI C1215 Mutant Allele After 23 Weeks Therapy

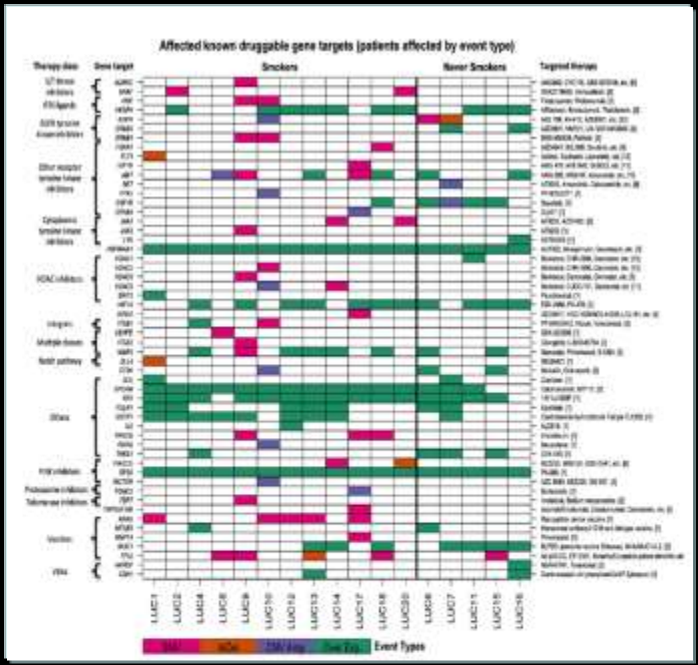
From: N. Wagle et al. (2011) J. Clin. Oncol. 29, 3085

http://jco.ascopubs.org/content/29/22/3085.full.pdf+html

The Extravagant Landscape of Genomic Alterations in Cancer (Cell 2012, 150, 1107 and 1121)



Mutations in Individual Non-small Cell Lung Cancer

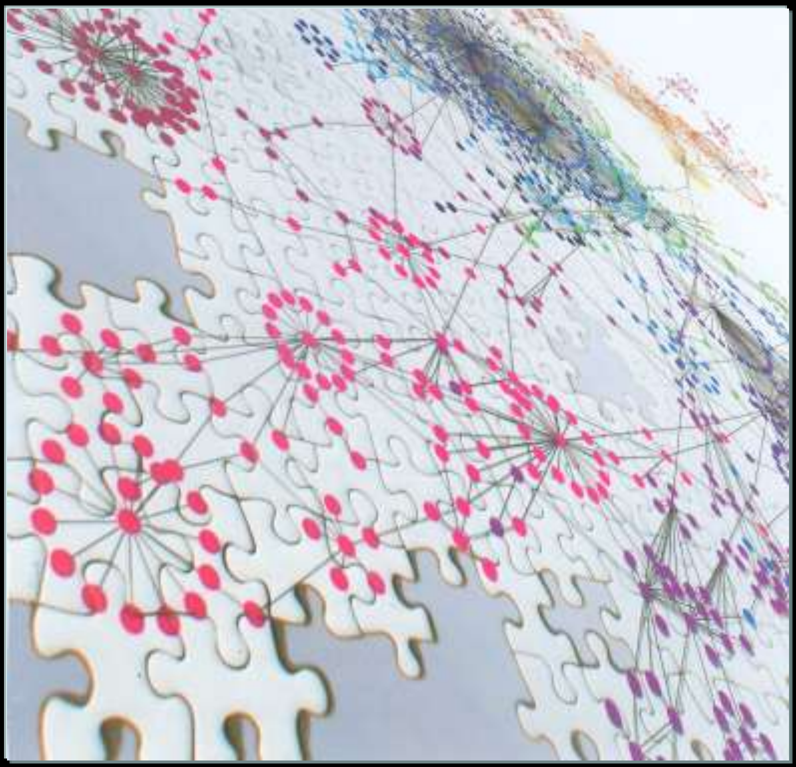


Drug Targets in Individual Non-Small Cell Lung Cancers

- **“malignant snowflakes”: each cancer carries multiple unique mutations and other genome perturbations**
- **disturbing implications for development of new Rx**

Is Unifocal Rx Modulation of Molecular Network Dysregulation in Advanced Chronic Diseases Feasible or a Delusion?

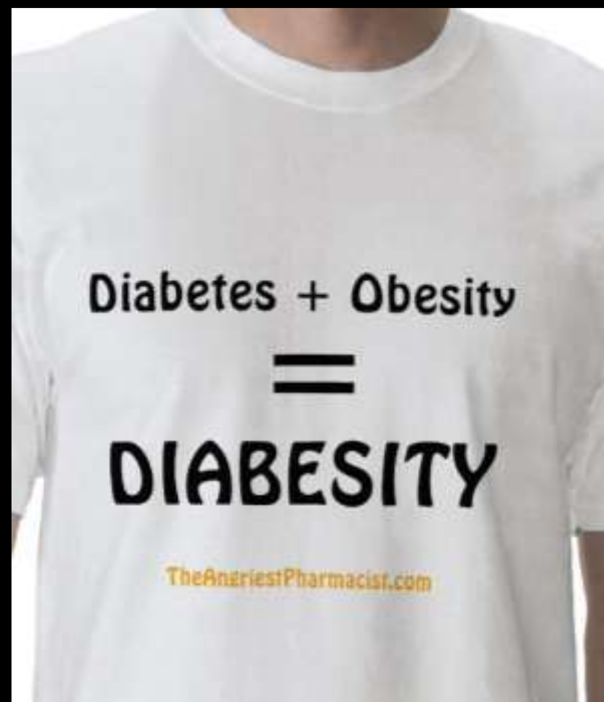
"too disrupted to restore?"

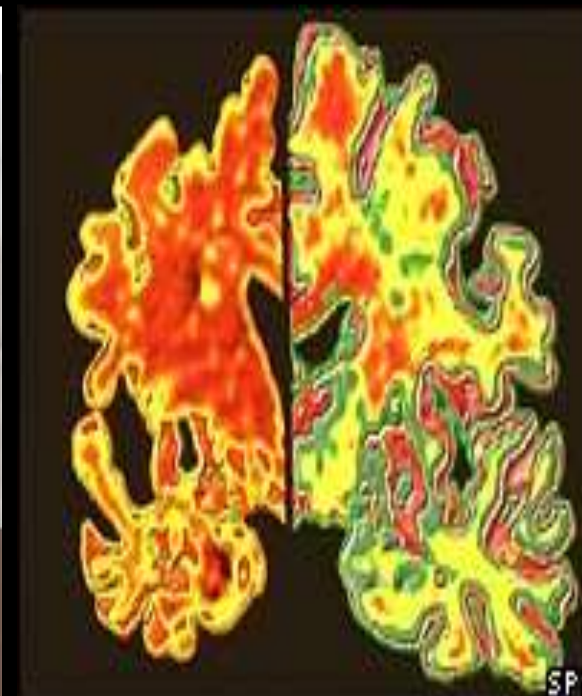


- multi-component/multi-module/ multi-subnetwork perturbations
- low feasibility of multi-Rx intervention against multiple targets
- even lower feasibility of design of promiscuous, multi-target actions in a single Rx molecule

National Biomarker Development Alliance: Major Clinical Needs

Cancer Detection Before Metastasis	Cardiovascular/ Metabolic Diseases	Neurodegenerative Diseases

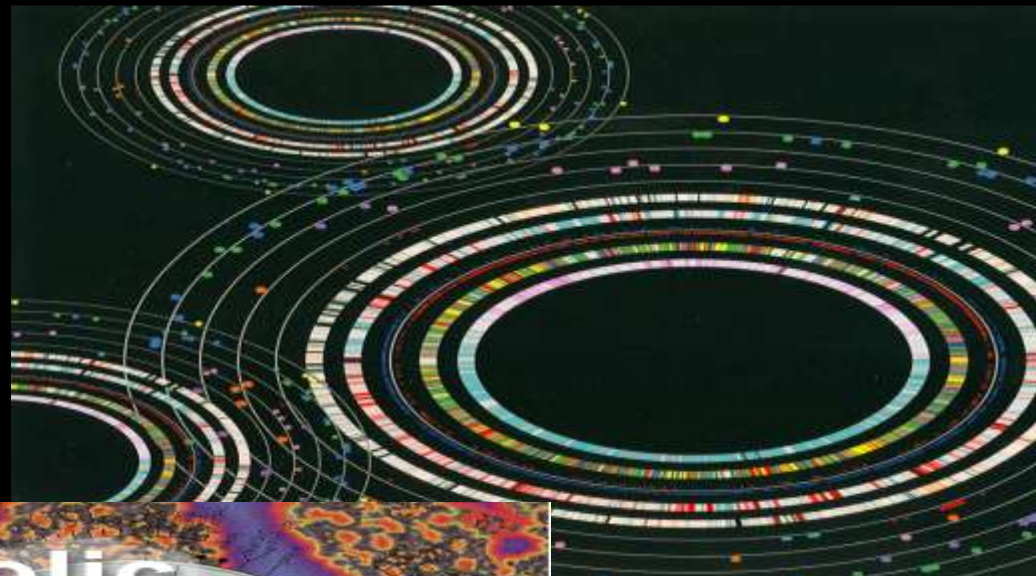


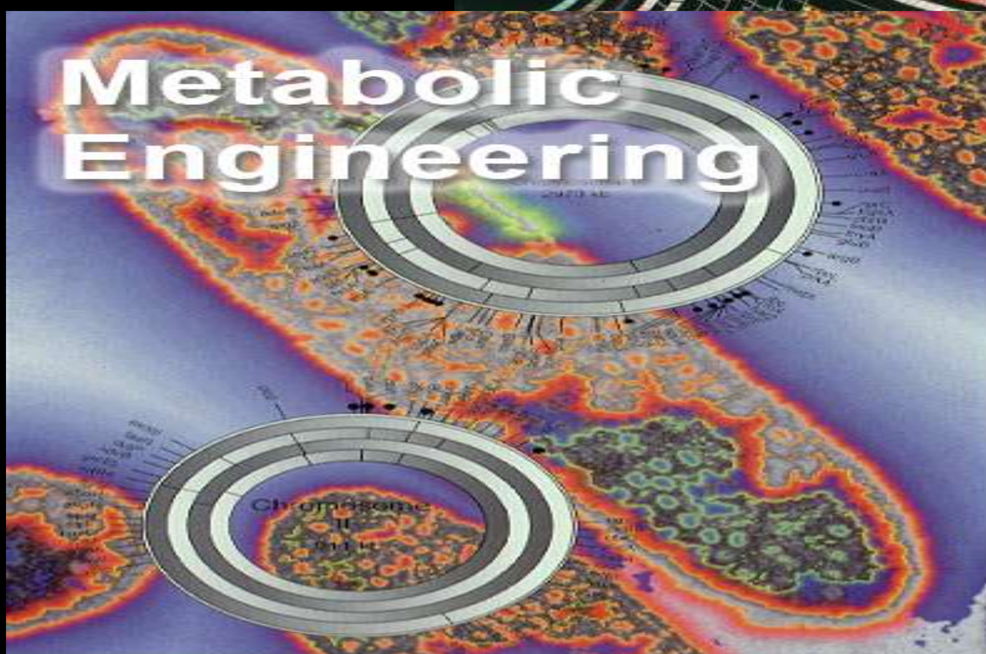


Early Diagnosis and Curative Surgery	Lifestyle Changes and/or Rx to Limit Risk	The Dilemma of Early Diagnosis Without Rx

Synthetic Biology: Engineering Biological Networks

Programmable Genomes





A New Industrial Ecology and Novel Biosynthesis

Synthetic Biology and a New Industrial Ecology

- manufacturing of complex chemical structures/materials unattainable via conventional chemistry
- biomimetic substitutes for petrochemical derivatives
  - oils, polymers, plastics
- biomimetics for function in extreme environments:
- bioremediation
- microdevices/sensors (ecosystems, medical, security)
- Ångstrom-level precision in molecular assembly
- hybrid biotic: abiotic composites

Opportunities for ASU Knowledge Networks in Synthetic Biology

ASU BIODESIGN INSTITUTE
ARIZONA STATE UNIVERSITY

ASU LightWorks
ARIZONA STATE UNIVERSITY

ASU MacroTechnology Works

ASU Arizona Institute for Nano-Electronics
ARIZONA STATE UNIVERSITY
CENTER FOR APPLIED NANOIONICS

ASU Ira A. Fulton school of engineering

School of Computing, Informatics, and Decision Systems Engineering

ASU W. P. CAREY SCHOOL of BUSINESS

- metagenomics
- ecogenomics
- bioinformatics

microbial genetics

biogeochemistry
astrobiology

- materials
- bioengineering
- biofoundry

- directed molecular assembly

- pattern analysis
- simulation of complex systems

sustainability initiatives

new markets, supply chains

ethics/science policy/regulation

ASU SCHOOL OF Life Sciences
ARIZONA STATE UNIVERSITY

School of Earth and Space Exploration
Fusing Science and Engineering

BEYOND

ASU College of Liberal Arts & Sciences
ARIZONA STATE UNIVERSITY

ASU Global Institute of Sustainability
ARIZONA STATE UNIVERSITY

CSPO

SANDRA DAY O'CONNOR COLLEGE OF LAW
ARIZONA STATE UNIVERSITY

The Arrival of the Zettabyte World
1,000,000,000,000,000,000,000 (10^{21})

Computational- and Data-Enabled Science

The Big Data Challenge

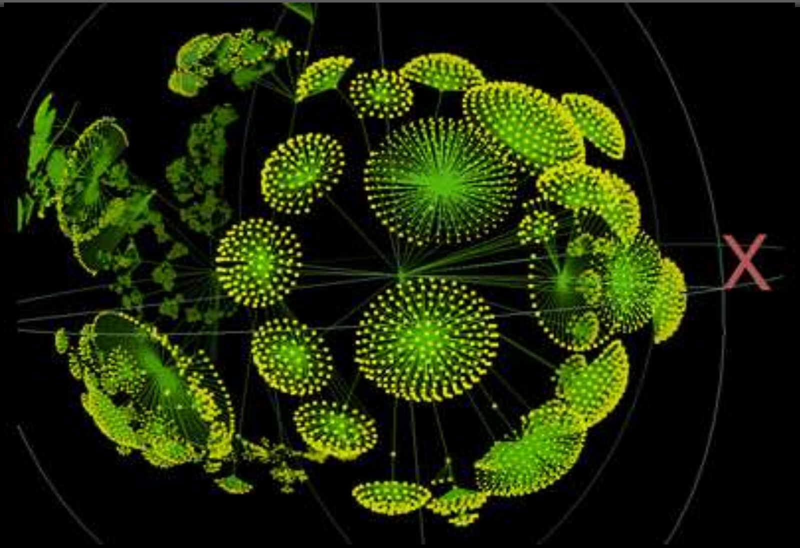
Bigger Data and Better Questions

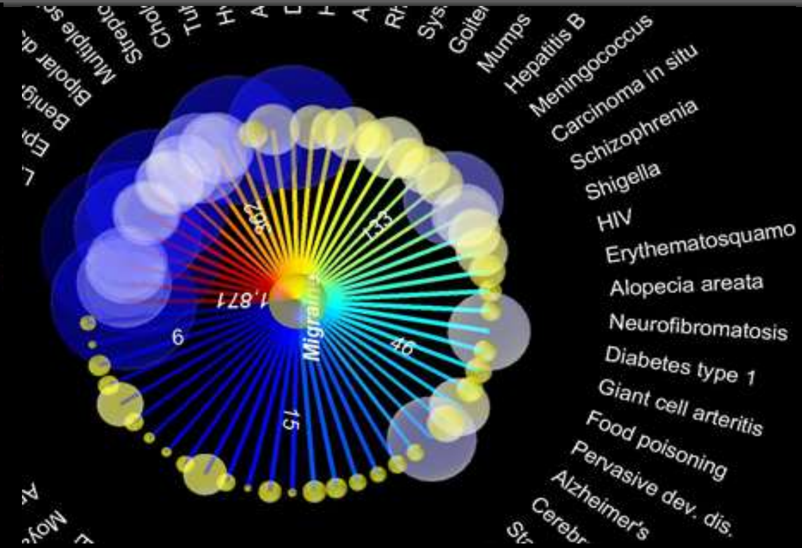
Thinking More Deeply About Data and Knowledge Generation

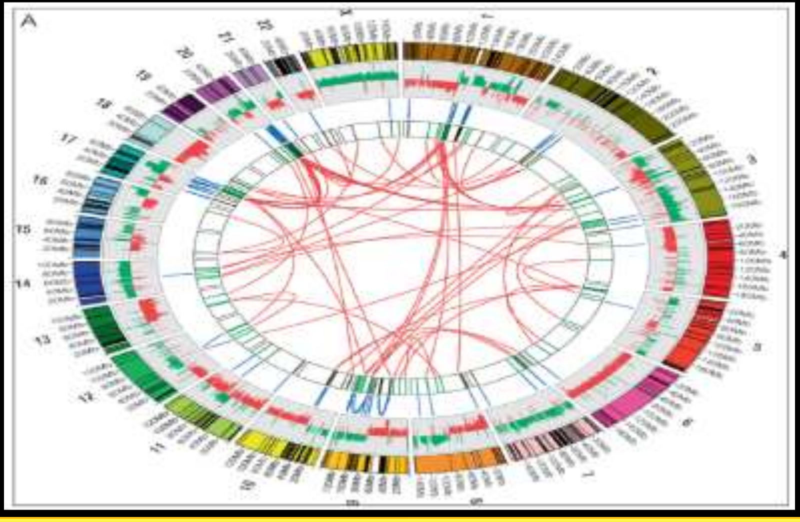
Planning Next Generation Cyber-Capability (NGCC)

- big data: volume, velocity, variety (V3)
- the lottabyte challenge
- integration of distributed heterogeneous datasets
- end-to-end storage strategies
  - scale, cost, location, access, security
- total-cost-of-ownership analysis for storage
  - cost per gigabyte
  - balance between physical and virtual storage
  - data retention policies
- public, private and hybrid ‘bursting’ cloud options
- encryption at rest/in flight and latency effects

Managing and Mining Massive Data







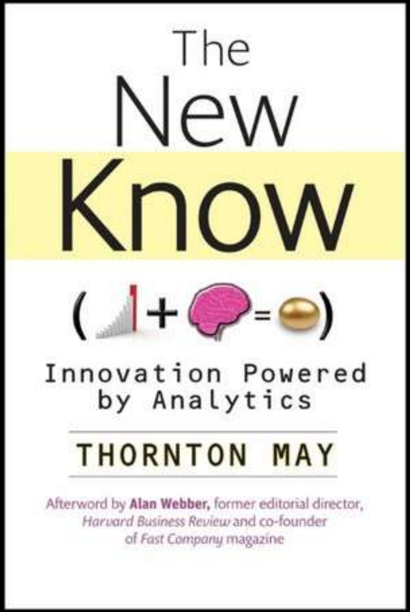
Design of Context-Dependent Data Mining and Visualization Tools and Integration with Advances in Cognitive Biology

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

What Are The Network and Computational Structures of Social Networks and Patterns of Social Change/Persistence?

Analytics of Social Networks and New Vistas in Decision Science



"Very few enterprises have taken it upon themselves to systematically analyze the human networks via which decisions are made and actions executed."

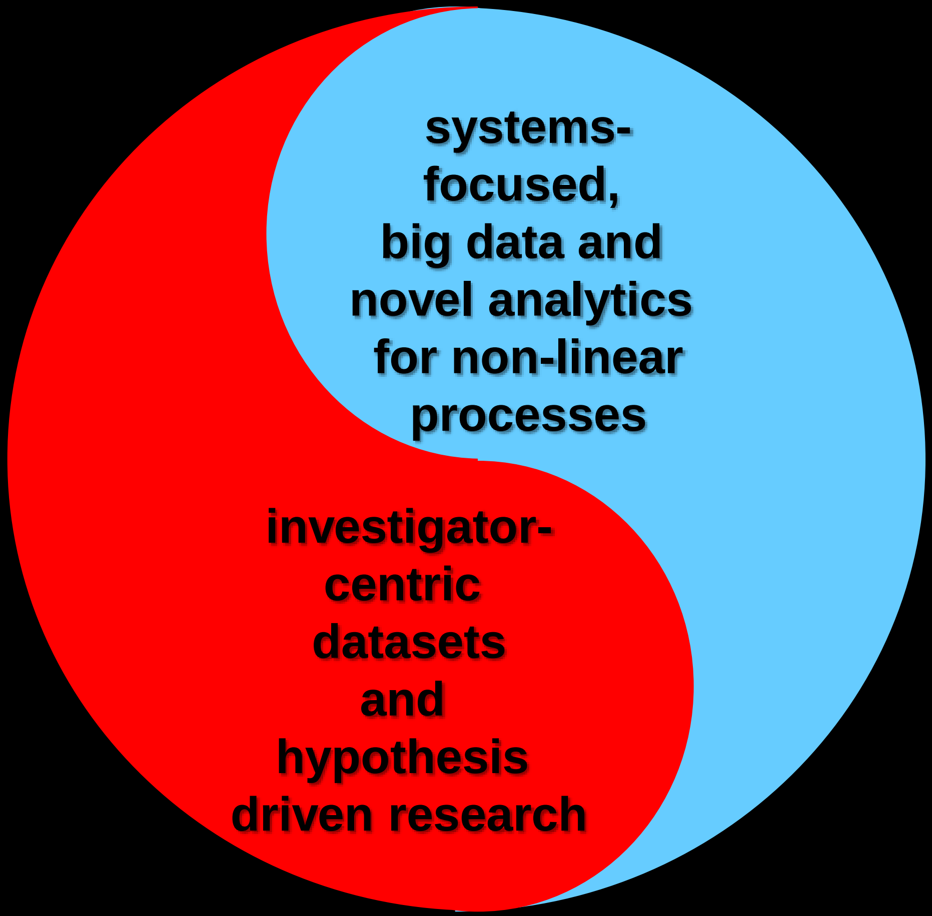
Thorton May: The New Know
J. Wiley, New York, 2009, p. 148

“History is the sum total of the things that could have been avoided.”

Chancellor Konrad Adenauer

“Integrate to Innovate”

Cross-Domain Convergence, Complexity and Increasing Dependency on Data-Intensive Methods and New Knowledge Networks



New Conceptual, Methodological and Organizational Frameworks for Data-Intensive R&D on CAS

increasing dependency on systems-based, data-intensive analytics and new knowledge networks

agile knowledge networks

cross-domain convergence and multi-institution collaboration

new education and training curricula

large scale, team based and increased automation

human-computer interfaces and intelligent systems

new algorithms for non-linear dynamics

integration and analytics for large scale datasets and cyber-infrastructure

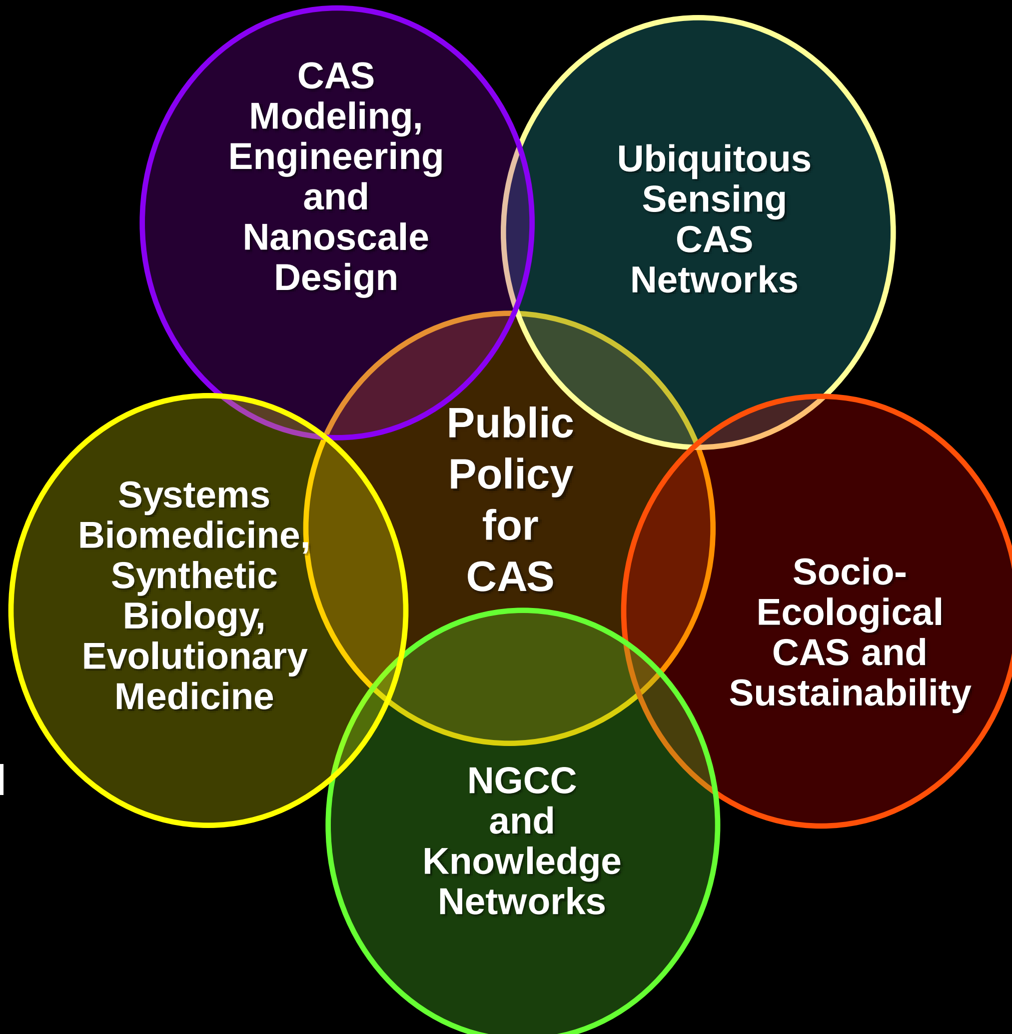
ontologies and semantics for facile data sharing and interoperabilities

Major Opportunities (and Needs) in Education and Training Related to Complexity, Consequences and Decisions

- new multidisciplinary/transdisciplinary curricula (UG, PG, CE) in multiple academic units
- team-based problem solving
- genomic medicine, mHealth for healthcare professionals
- evolutionary medicine
- sustainability
- synthetic-biology
- public policy implications of S&T convergence, escalating CAS complexity and dual-use proliferation
- making decision-science a science

Integration of Research Expertise Across ASU to Build New Research Capabilities in Complex Systems Research and Education

- multi-scale analytics
- systems and subnetworks design
- evolutionary theory and CAS
- synthetic biology
  - new industrial ecology
  - Ångstrom design



- biomarkers
- personalized medicine
- sensors, mhealth and remote health monitoring
- biomimetic materials
- sustainability
  - urbanization
  - infectious diseases
  - water
  - energy
  - ecosystem modeling
- national security

- complex signal deconvolution
- novel data visualization
- cognitive neuroscience and optimized analysis / learning
- novel IA for dynamic sensor networks
- large scale simulation

CAS at ASU

Complexity and Complex Systems

- engaging global challenges will require new knowledge networks in complexity science and decision theory
- the rise of transdisciplinary, multi-institution knowledge networks will drive major changes in education, research and business models
- understanding the design and dynamics of complex systems must draw more heavily from evolutionary theory and the determinants of adaptability and evolvability as key parameters in new approaches to complexity and uncertainty

Complexity and Complex Systems

- the momentum in forging multi-institution knowledge networks is accelerating
- ASU has opportunity to be in the vanguard of this profound shift in education and research
- ASU's success in building capabilities in complexity theory and decision sciences will depend on pan-university programs and networked multi-institutional relationships in the public and private sector
- launch of CAS at ASU and the initial A:A′ portfolio
- progressive integration of CAS into teaching curricula

CAS at ASU
Workshop 18 January 2013

- break
- review of CAS at ASU project portfolio
  - Sander van der Leeuw
  - Ann Barker
  - George Poste
  - Manfred Laubichler
  - Ken Buetow
  - panel Q&A
- box lunch
- interactive working lunch
  - continued Q&A
  - additional opportunities
- adjourn