Understanding the Design Principles and Dynamics of Complex Adaptive Systems

Dr. George Poste
Chief Scientist, Complex Adaptive Systems Initiative and Regents Professor of Health Innovation
Arizona State University
george.poste@asu.edu
www.casi.asu.edu

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Technology Acceleration and Convergence: Escalating Complexities

Genetics, Biotechnology, Synthetic Biology

Ubiquitous Sensing/Devices & Social Networks

Advanced Computing Mega- & Meta- Data

Robotics and Advanced Autonomous Systems

Neurosciences and Human-Machine Interactions

“Bio-Space”

“Connected Space”

“Analytics Space” and “Surveillance Space”

“Design Control Space”

“Cognitive Space”
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New Patterns of Technology Fusion, Evolution and Adoption

New Knowledge Networks
New Participants
New Markets and Business Models
Complex Adaptive Systems

- Biological Organisms and Eco-Systems
- Engineered Systems
- Financial Systems
- Information Systems
- Infrastructure Systems and Urban Systems
- Socio-Cultural Systems and Public Policy
- Military Systems and Global Governance
- Emergent Systems

multiscale structure and spatio-temporal scale
Convergence, Connectivity and Complexity

- living systems
- mechanical systems
- digital systems
## Cross-Sector technology Convergence and New Patterns of Complexity

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<th>Sector</th>
<th>Image</th>
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<td>Nanotechnology and Novel Materials</td>
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<td>Photonics and Optics</td>
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<td>Sensors and IoT</td>
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<td>Cognitive Computing and Neurotechnology</td>
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Complex Adaptive Systems

- emergence of complex, coherent, large scale collective behavior and very rich structure by repeated non-linear interactions of simpler components (agents)
- self-organizing complexity and non-linear behavior
- operate at far-from-equilibrium states: highly optimized tolerance (HOT)
- robust (resilient) to frequently encountered perturbations (fitness) but fragile to major disruption by rarely encountered perturbations/novel convergent forces
  - triggered ‘emergence’ of shift to new system state with highly different properties
  - unintended (unanticipated) consequences
Understanding State Shifts in Complex Adaptive Systems and Identification of Triggers of Emergence

- network topology
- state shifts

Emergence ($E$)

- $E_1$, $E_2$, $...$, $E_n$

- Black Swans
- dislocations
- tipping points
- irreversible cascades
- phase shifts
- perturbations
- inflection points
- unintended consequences
- critical thresholds
- bifurcations
- trigger points
12 May 2011

TAMING COMPLEXITY

The mathematics of network control — from cell biology to cellphones

PAGES 158 & 167
Understanding Network Organization and Dynamics in Complex Adaptive Systems

new analytical tools for proactive monitoring of system state space(s) and timely intervention(s) to channel emergent behavior to most desired trajectories
what is the minimum amount of information about past and current behavior of a system that is needed to optimally predict the behavior of the system in the future?

what are the signals of pending major shifts in system state and what are the most likely emergent trajectories and end states

how can CAS design principles used to better inform construction and safety of human-engineered systems and generate methods for improved analysis and behavior prediction in both technological and social networks?
The CAS Landscape

knowledge and institutional frameworks for informed policy

conflict resolution and WMD
climate/ ecosystem sustainability resources depletion
internet

financial systems
transportation

power grid

infec. diseases epidemiology

healthcare

nanoscale engineering

biosystems engineering

global supply chains

large scale systems engineering (civilian)

large scale systems engineering (military/nat. sec)

resources depletion

financial systems

transportation

power grid

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large scale systems engineering (civilian)

large scale systems engineering (military/nat. sec)

major conceptual, methodological organizational and infrastructure limitations for analysis and prediction

medium

high

low

technological maturity, robustness and predictability
A Strategic Planning Matrix for the Design of New Large Scale Pan-University Research Projects

GRAND CHALLENGE APPLICATION DOMAIN TEAMS (ADTs)
- Precision Medicine
- Sustainability
- Earth and Space Systems
- Synthetic Biology and Organism Engineering
- National Security

CROSS-CUTTING EXPERTISE DOMAIN TEAMS (CETs)
- directed molecular assembly and novel materials: design of novel diagnostics, sensors, devices and targeted therapeutics and vaccines
- mapping the design architecture, topology and patterns of information flow in complex networks
- big data analytics, cognitive computing, man-machine interactions, machine learning and artificial intelligence
- ethical, legal and public policy implications of new technologies
Sensor World

Ubiquitous Sensing

Internet – of – Things (IoT)

Biometrics and Surveillance

AORTA: Always On, Real Time Awareness

Faster Data, Smarter Analytics, Better Decisions
Integrated Functional Platforms to Exploit Technology Convergence

Classification of Unique Signatures

Signature ID in Diverse Settings and ID of Rare/Anomalous Events

Actionable Information for Optimum Decisions

Profile

Biotechnology, Clinical Medicine, Ecosystems and Mathematical/Statistical Tools for Complex Signal Profiling

Sense

Nanotechnology, Automation and Miniaturization Engineering, Materials Science, Electronics

Act

Large Scale Informatics, Data Science, Decision Theory
Escalating Complexity: The Interaction of Complex Systems and Ever Denser Systems-of-Systems

- biosecurity
- urbanization
- bioincident management and sustaining critical systems
- dual use technologies and the expanded biothreat spectrum
- monitoring individual behavior
- big data analytics, deep learning and artificial intelligence
- keeping humans-in-the-loop: new vistas in education for a data-centric world
The Biosecurity Triad

Infectious Diseases of Natural Origin

Urbanization, Environmental and Ecological Impacts on Disease Emergence

Bioterrorism and Dual-Use Technologies
Anthropogenic Effects on Ecosystem Stability and Altered Patterns of Infectious Diseases

- Famine
- Contaminated water
- Desertification
- Depletion of natural resources
- Climate change and new vector ranges
- New vulnerabilities
Urbanization and Mega-Cities in Developing Countries and the Increased Threat of Exotic Zoonotic Diseases

- High Population Density With Inadequate Biosurveillance
- Major Gaps in Health Infrastructure and Disease Reporting
- Expanded Eco-niches and New Zoonotic Exposures/Risks
One Health: Recognition of the Importance of Zoonotic Diseases as Human Health Threats

- Pandemic (avian) influenza
- HIV
- West Nile virus
- MERS-CoV
- Ebola virus
- Bush meat food chain
- Zika virus
- What's out there?
Geodemographic Information Systems (GIS): Ground Zero Data

Comprehensive Front Line Sampling of Sentinel Species

Real-time Intelligence and Faster Preparedness
Mobile Devices, Disease Tracking, Contact-Tracing and Education
Coming to an Airport Near You:

Modeling Airport Connectivities, Traffic and Distance Relationships and Implications for Epidemic Spread via the Global Aviation Network

Global Urbanization

- 28 megacities in 2016
- 70% current/projected megacities in countries with Global Conflict Risk Index probability of conflict within 10 years
- unprecedented stresses on infrastructure and services by 2030
  - food (35%↑), water (40%↑), energy (50%↑)
- susceptibility to extreme weather/natural disaster
  - littoral locations, slums
ASU DECISIVE Project: Institute for Humanitarian Support

DEPLOYABLE CITIES

There are presently 60 million global refugees, many in difficult and conditions with limited resources. The encampments to which they are confined frequently become unintended long-term communities. The Deployable Cities initiative responds to this dire situation by creating the premier center for the design and delivery of empowering environments for this deserving population. The proposed facility, located on the Polytechnic Campus of ASU, will bring together the following: 1) the research/academic assets of the university, 2) a full capacity airport, 3) a research park for corporate partners, 4) a digital platform for distance education delivery, and 5) a selected group of supporting organizations/foundations. The essential element of the proposal is the focus on capacity building for the tons of thousands of trainers, field, and leaders who will gain skills under simulated conditions comparable to those in the field. This experience will be supplemented by state-of-the-art labs, classrooms, conference facilities, and housing designed to accommodate an on-site population of 5000.

ASU DEPLOYABLE SYSTEMS

- WATER PRODUCTION
- ENERGY PRODUCTION
- FOOD SYSTEMS
- HEALTH SUPPORT
- DISTRIBUTED EDUCATION
- DEPLOYABLE STRUCTURES
- PROVISIONAL “CITY” DESIGN

SUPPORTING GOV./NGO’S

- UNHCR
- UNICEF
- CARE
- World Bank
- Int. Org. for Migration
- Doctors w/o Borders
- World Vision
- Mercy Corps
- Gates Foundation
- OCHA
- OFDA
- USCIRF
- USAID
- DHS
- Industry Corporations

CAMP PROTOTYPING

1000 person working encampment
full-scale, on-site situation modeling
environment technology proving ground
cargo loading/deployment/set up
global event space, conferences
housing, clinic, school, agriculture communication/digital networks

CAPACITY BUILDING

4000 person training center
air travel/fellowships/expenses
culture exchange/language skills
multicultural governance
camp design institute

UNIVERSITY AND REGIONAL ASSETS TO BE DIRECTED TOWARD PROJECT

- ENGINEERING
- GROSS/ WATSON
- GATEWAY AIRPORT
- RESEARCH PARK
- POLY CAMPUS
- ED PLUS
- CANNING SCHOOL
- SERVICE ACADEMY
- ASU GLOBAL
The Three Core Components of Bioincident Management

- Command and Decision Authorities
- Healthcare System and Public Health Capabilities
- Maintenance of Civil Order and Public Trust

- robust inter-operable communication networks for real-time situational awareness and rapid actions
- managing the media and the ‘worried well’
- transparency, credibility and public trust
The ‘Fog of Disaster’: Crisis Standards of Care and Proliferation of Unanticipated Events and Consequences
Breakdown of Civil Order and Incident Management

Constrained Mobility

Constrained Access
Sustaining Critical Systems and Infrastructure
Vulnerability of Global, National and Local Supply Chains in a Major Epidemic/Pandemic

Energy

Net Power Generation in the US by Fuel Source, 2007

- Coal, 48.70%
- Nuclear, 19.40%
- Natural Gas, 21.50%
- Hydroelectric, 6%
- Other Renewables, 2.50%
- Other, 0.30%
- Other Gas, 0.40%
- Petroleum, 1.60%

Other major fuel sources include:
- Other, 0.30%
- Other Gas, 0.40%
- Petroleum, 1.60%
- Other Renewables, 2.50%
- Hydroelectric, 6%
- Natural Gas, 21.50%
- Coal, 48.70%


Map of the United States showing various energy regions and fuel sources.
New Technologies and Increased Complexity of Dual-Use Issues in Biosecurity: Synthetic Biology, Genome Editing and Manipulation of Biological Circuits

digital biology: “it from bits”
de novo synthesis of organisms
engineered virulence

targeted modification of any biological circuit in any organ
mapping neural circuitry and brain – machine interfaces
accelerating technological diffusion
Synthetic Biology, Genome Editing and National Security: The Ultimate Dual-Use Technology for Modification of Biological Systems?

Technology Diffusion, Automation, Simplification and Cost Reduction

New Oversight Mechanisms and International Harmonization
Tracking Personal Behavior and Activities

Non-Consented Digital Signatures (Trails/Exhaust/Dust)

Predictive Behavioral Analytics
Digital Exhaust

- every move you make
- every twitter feed you update
- every facebook friend you add
- every internet search you log
- every cell phone call you transmit
- every time you use your credit card

SOMETHING AND/OR SOMEONE IS TRACKING YOU
Facial Recognition and Identification of Terrorism Suspects
Computer-Based Facial Recognition Plus Idiosyncratic Patterns of Body Language and Movement
Evolution of Dynamic Interfaces for Computer-Based Individual Recognition and Real Time Decisions
Your Molecular Uniqueness

- genome
- proteome
- exposome
- immunosignature
Big Data and Analytics: Integration of Diverse Data Streams for Comprehensive Real Time Situational Awareness

“Actionable Intelligence Starts at Ingestion”
The Big Data V6 Challenge: The Pending Zettabyte-Brontobyte Worlds

- volume
- velocity
- variety
- veracity
- visualization
- value
Convergence:
Computational Rationality and Convergence of Intelligence Paradigms in Brains, Minds and Machines
The Pending Era of Cognitive Computing and Decision-Support Systems: Overcoming the “Bandwidth” Limits of Human Individuals

- limits to individual expertise
- limits to our multi-dimensionality
- limits to our sensory systems
- limits to our experiences and perceptions
- limits to our objective decision-making
Automated Learning Systems: The Future of ‘Search’ and Decision Support

- deeper understanding of content and context structured text plus natural language processing of unstructured inputs

- search all things
  - integrated traditional document semantic sources with video, objects, speech

- why should you have to ask first?
  - smart machines and understanding where/what the user is doing

- why wait for the slow brain to catch up to the fast machine (S. Redmore, Lexalytics)
The Emergence of Big Data Changes the Questions That Can Be Asked

- Isolated Data
- Complex Networked Data
- Complex Computational Data
Automated Context: Data Finding Data

“Intelligence at Ingestion”

- Feature Extraction and Classification
- Context Analysis
- Persistent Context
- Relevance Detection
- Learning Systems
- Situational Awareness
- Rapid, Robust Decisions
The Evolution of Automated Combat Systems
Deep Learning, Smart Machines, Artificial Intelligence and Decision Support Systems

“I Can’t Let You Do That Dave”

Automated Decision Support Tools and “Gated Autonomy” in the Management of Complex Systems
Deep Learning, Smart Machines and Ethical, Legal and Socio-Cultural Complexities
Security: The Education and Training of the Future Workforce

- Low US - STEM Education Rankings
- K-12 Education
- Higher Education
- Life-Long Learning

- STEM icons
- Student with lab equipment
- Book cover: "Designing the New American University"
- Einstein quote: "Once you stop learning, you start dying"

- The bias of the mainstream media is toward sensationalism, conflict, and laziness. (Jon Stewart)
- U.S. Capitol Building
- Book cover: "Unscientific America"
- H1B 2016 visa

- Media Sensationalism
- Reactive Policies and Political Populism
- Public Literacy
- Immigration Policy for Skilled Workers
Major Opportunities (and Needs) in Education and Training in Complexity Science, Computing and Decision Science

- on-line interactive learning
- web-based collaboration tools
- multi-institutional education and training
- externships, public: private partnerships for future workforce preparation
Virtual and Augmented Realities and Training for Complex, Dynamic Tasks
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
Mapping the Connectome: Deconvolution of Signal Flow in the CNS

Graph theory has revealed dense short-range connections within brain areas, but not the way one area is linked to another.

Now studies using topology have identified those long-range connections. They form loops with "holes" at the centre.

That means signals must travel around a hole's periphery - no shortcuts across the gap. This might explain how the brain combines inputs from multiple senses without getting confused.

New Knowledge Networks for the Study of Complex Adaptive Systems

- New organizational models
- New investment models
- New business models

- Complexity
- Convergence
- Computation

- Better informed public policy and decision tools
- Education
- Research
- Infrastructure
Systems of Innovation: Building a Competitive Knowledge Enterprise

- human and knowledge capital
- entrepreneurial translation
- future workforce education

Engagement with Global Challenges

Use-Inspired Research

Public Policy

R&D Ecosystems and New Knowledge Networks

• social systems
• informed decisions for public policy

• CAS ubiquity
  - Intellectual fusion
  - emergent disruptive technologies
  - big data: machine intelligence

• CAS as integration theme
  - concepts
  - organization
  - operations
  - education
  - funding
Slides available @ http://casi.asu.edu/