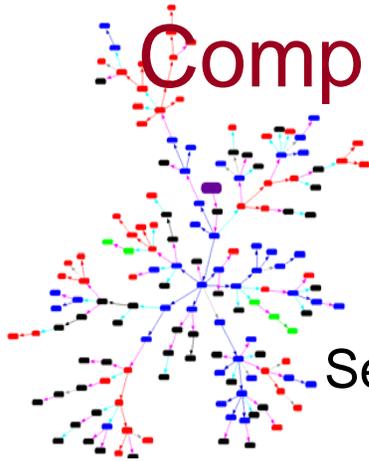




Complex Adaptive System of Systems  
(CASoS) Engineering Initiative  
<http://www.sandia.gov/CasosEngineering/>

SAND 2011-3354 P

# Designing Influence in Complex Adaptive Systems of Systems: *CASoS Engineering*



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*and*

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March 23, 2012

Slides selected from keynote presentation for:

[Association for Public Policy Analysis & Management \(APPAM\) 33rd Fall Research Conference,](#)

Washington, DC, November 2011 and other material available at: <http://www.sandia.gov/CasosEngineering/>

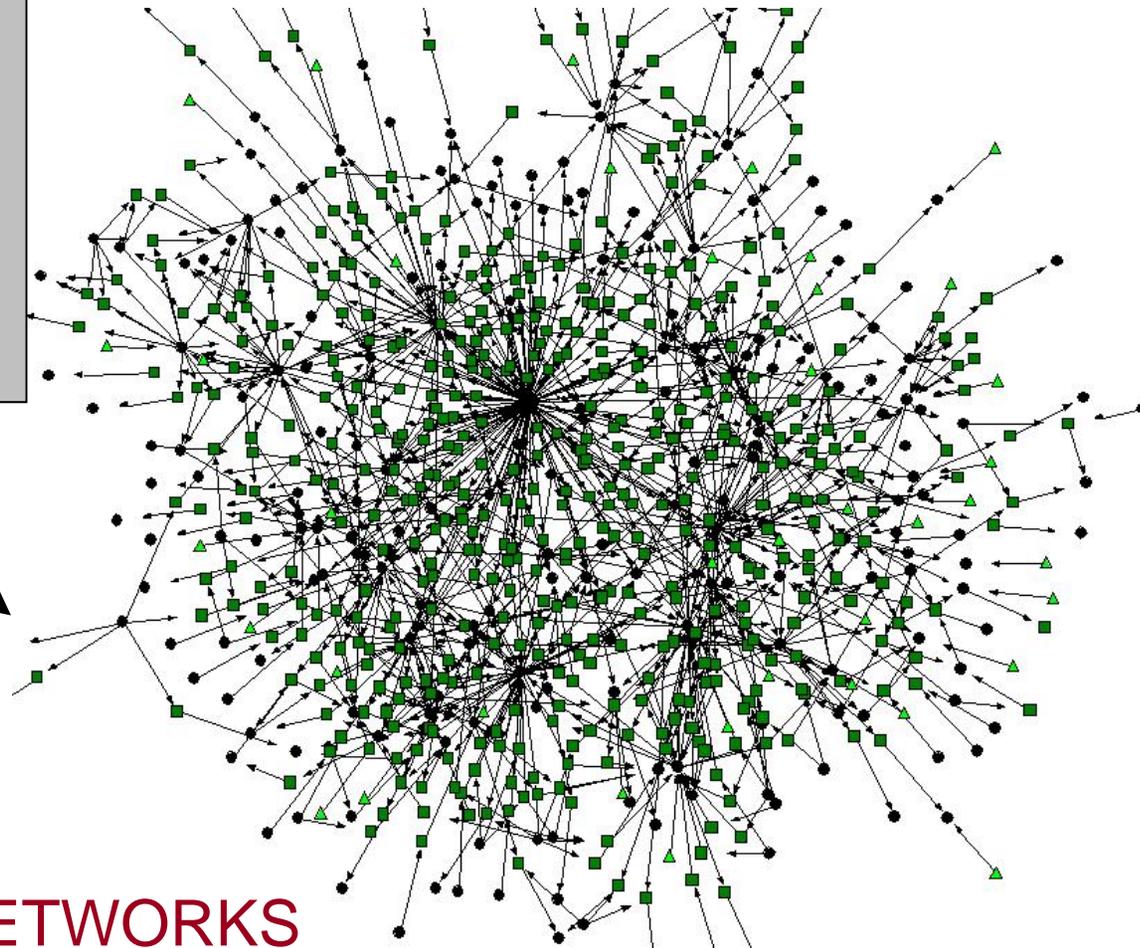
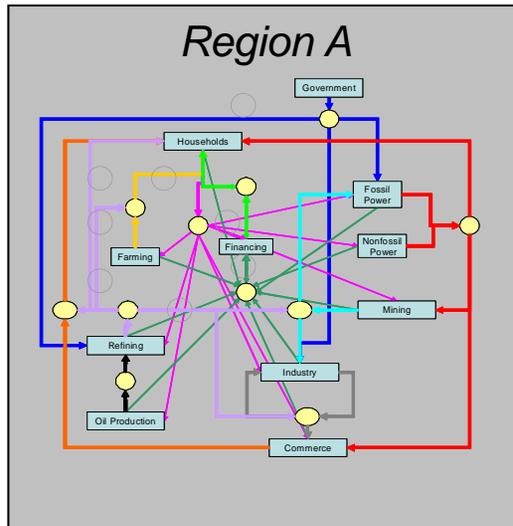


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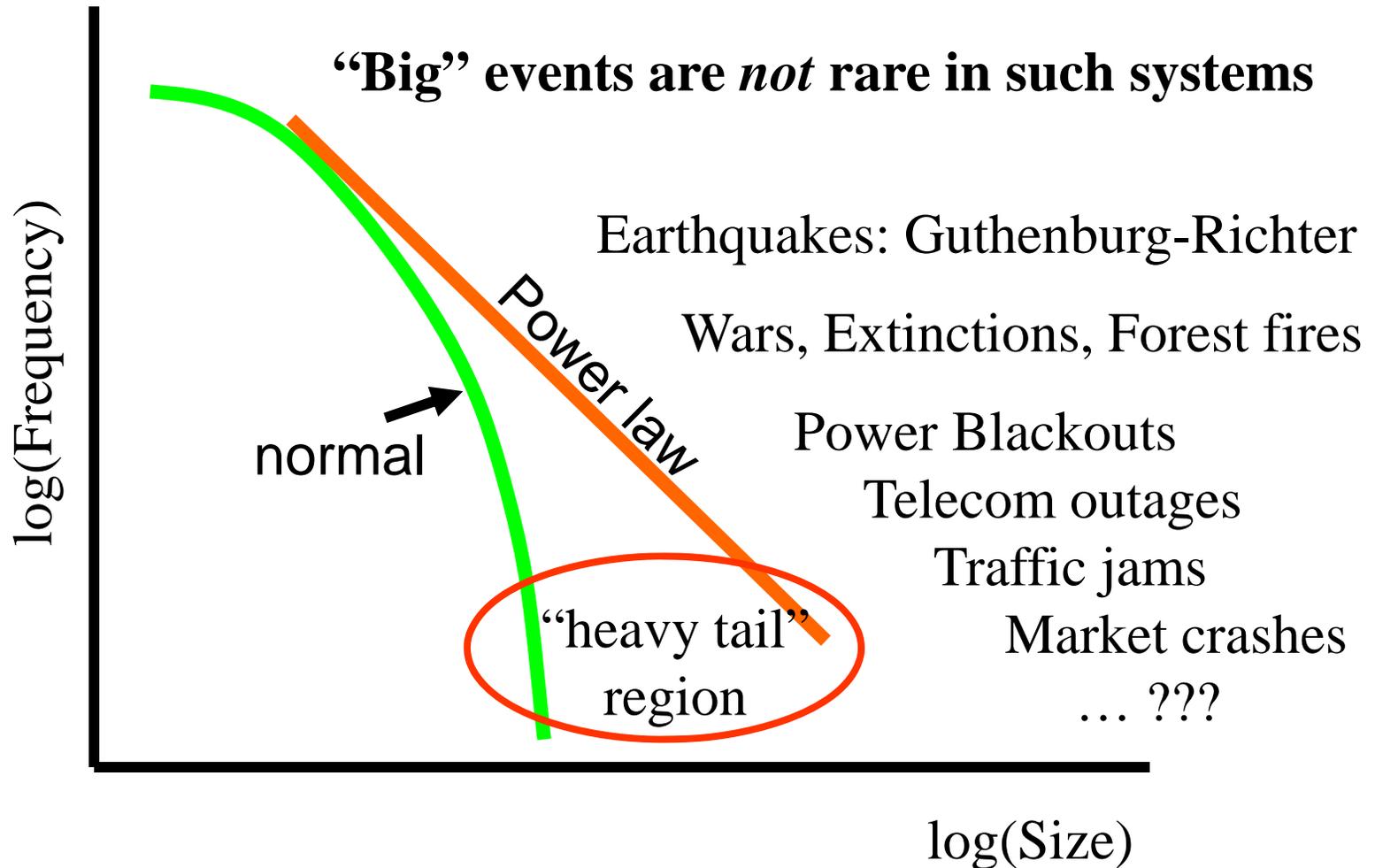
# EMERGENT STRUCTURE: Complex



NETWORKS  
within NETWORKS



# EMERGENT BEHAVIOR: Complex



Cascades with power-laws & “heavy tails”



## 2002: Advanced Methods and Techniques Investigations (AMTI)

### Critical Infrastructures:

- Are **Complex**: composed of many parts whose interaction via local rules yields **emergent structure (networks) and behavior (cascades)** at larger scales
- **Grow and adapt** in response to local-to-global **policy**
- **Contain people**
- Are interdependent “**systems of systems**”



Critical infrastructures are -

**Complex**

**Adaptive**

**Systems of Systems:**

**“CASoS”**

<http://www.sandia.gov/nisac/amti.html>



## Many Examples of CASoS

- Tropical Rain forest
- Agro-Eco system
- Cities, Megacities and Interdependent infrastructure (local to regional to national to global)
- Government and political systems, educational systems, health care systems, financial systems, economic systems and their supply networks (local to regional to national to global)...  
Global Energy System and Green House Gasses





## A Defining Example: The Pandemic Story

On Halloween (2005) NISAC got a call from DHS. Public health officials worldwide were afraid that the H5NI “avian flu” virus would jump species and become a pandemic like the one in 1918 that killed 50M people worldwide.

DHS asked NISAC to put together a briefing package to prepare DHS Sec Chertoff for a White House table top exercise the second week of December.

*Pandemic NOW.  
No Vaccine, No antiviral.*



*Chickens being burned in Hanoi*

Glass, R.J., Pandemic Influenza and Complex Adaptive System of Systems (CASoS) Engineering, International System Dynamics Conference, July, 2009.

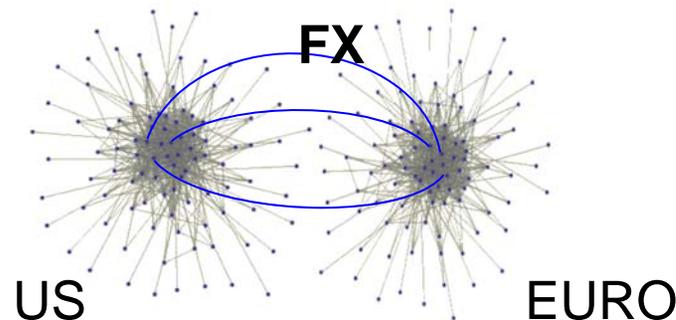
[[www.systemdynamics.org/conferences/2009/proceed/papers/P1400.pdf](http://www.systemdynamics.org/conferences/2009/proceed/papers/P1400.pdf)]





## Our CASoS Applications in NISAC at the time

- We were applying a generic CASoS approach to **power grids**, to the movement of funds from bank to bank within the FED's **Fedwire** system (2+ $\$T$  a day) and between the ECB's **Target** system and Fedwire, to the contagious transfer of ideas and action in settings of **civil disobedience...**
- In these systems we see **cascades** of activity, **emergence** of **power-laws** for distribution of event sizes vs event frequency, **fractals**, all the hallmarks of Complex Systems
- In context of these systems, we were interested in questions that had to do with **keeping a system from cascading** and if it did, defining the right **corrective action** to dissipate the cascade.





## Definition of the CASoS

- **System:** Global transmission network composed of person to person interactions beginning from the point of origin (within coughing distance, touching each other or surfaces...)
- **System of Systems:** People belong to and interact within many groups: Households, Schools, Workplaces, Transport (local to regional to global), etc., and health care systems, corporations and governments place controls on interactions at larger scales...
- **Complex:** many, many similar components (Billions of people on planet) and groups
- **Adaptive:** each culture has evolved different social interaction processes, each will react differently and adapt to the progress of the disease, this in turn causes the change in the pathway and even the genetic make-up of the virus

### HUGE UNCERTAINTY

*How could we avert the carnage?*



# Analogy with other Complex Systems

## Simple analog:

- **Forest fires:** You can *build fire breaks* based on where people throw cigarettes... or you can *thin the forest* so no that matter where a cigarette is thrown, a percolating fire (like an epidemic) will not burn.



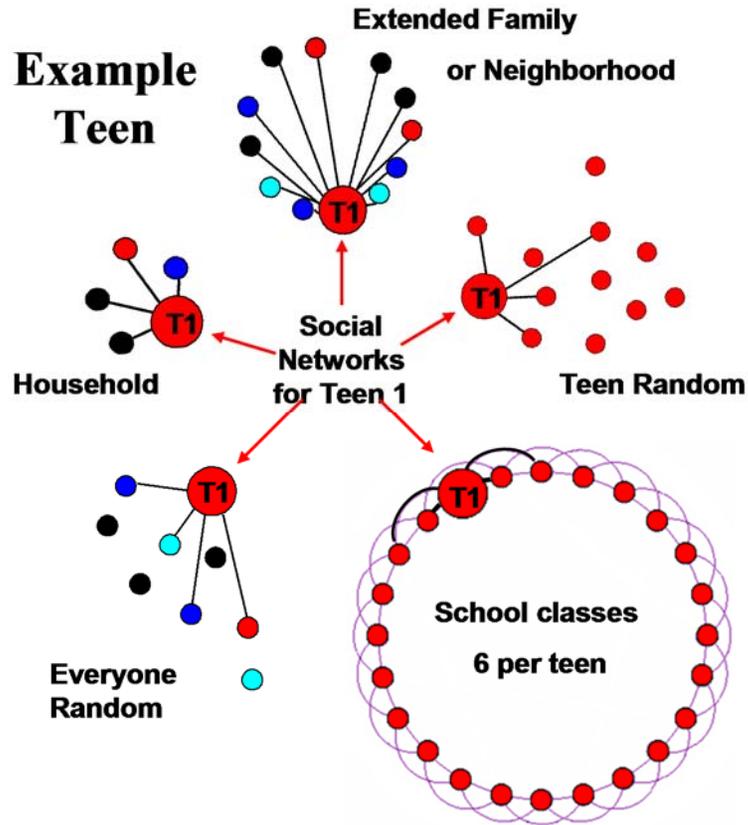
## Problem Definition:

- Could we target the social network within individual communities and thin it?
- Could we thin it intelligently so as to minimize impact and keep the economy rolling?

## Focus on Local Community Mitigation



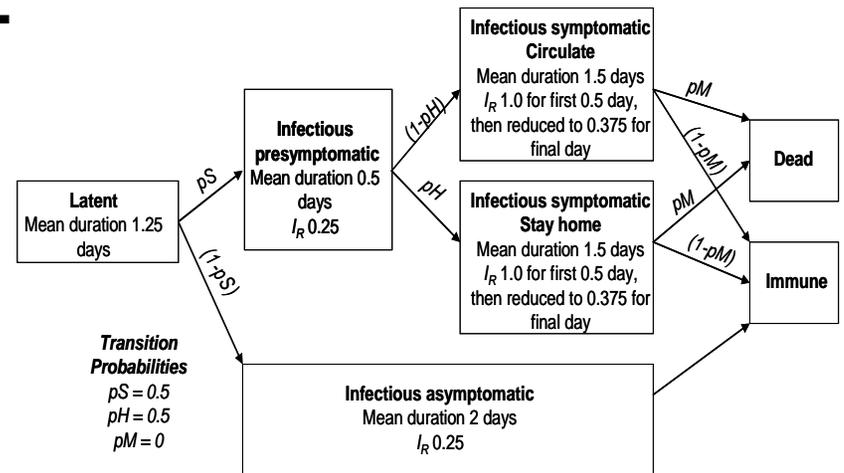
# Generic Networked Agent Approach



Stylized Social Network (nodes, links, frequency of interaction)

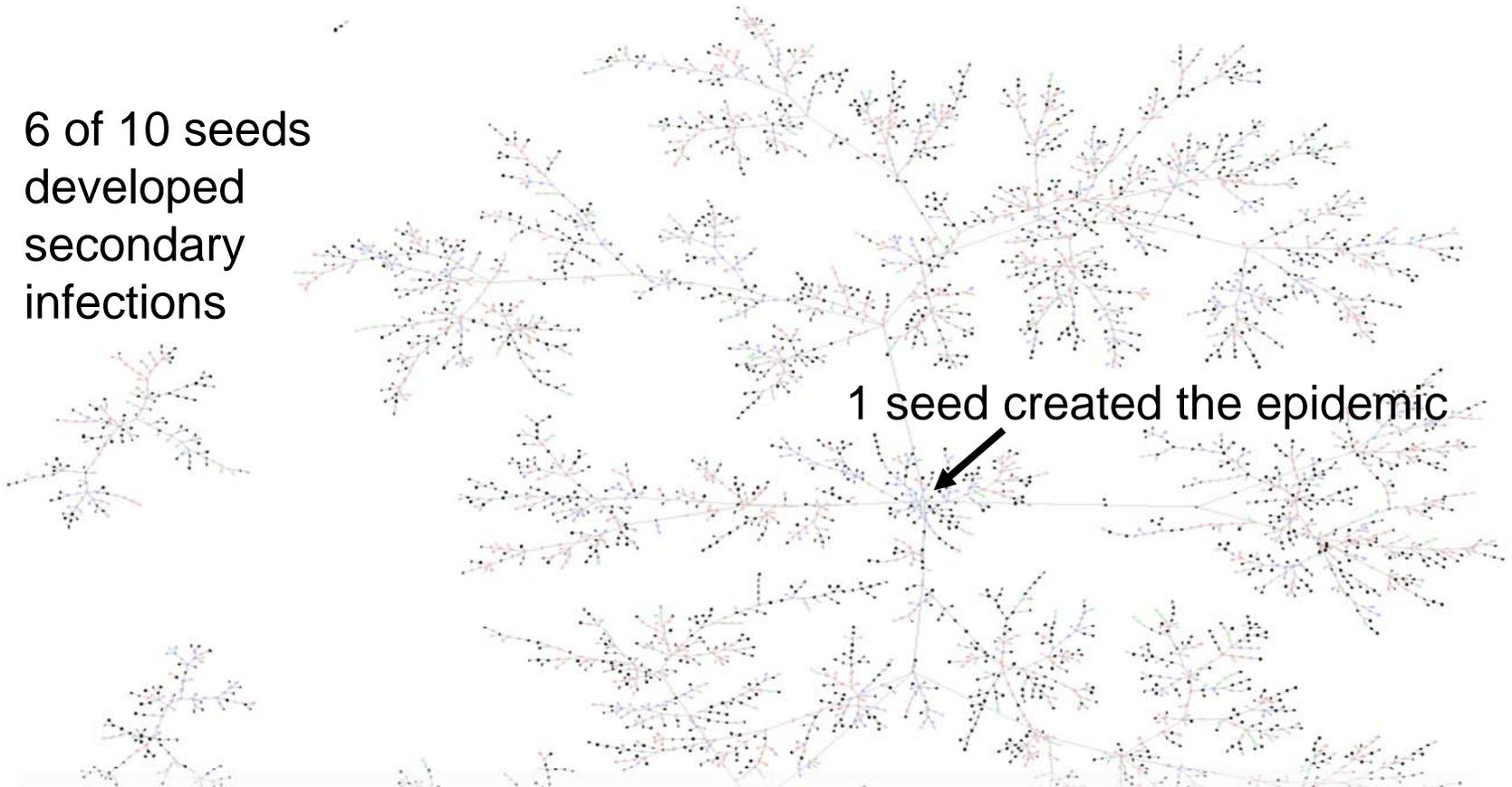
Disease manifestation based on data from the literature (node and link behavior)

+





6 of 10 seeds  
developed  
secondary  
infections



We ran the model and it hit the numbers by age class from past pandemics when single overall “infectivity” of the disease tuned to yield the attack rate. We had representative node and link behavior and contact network; we had the right “physics”.

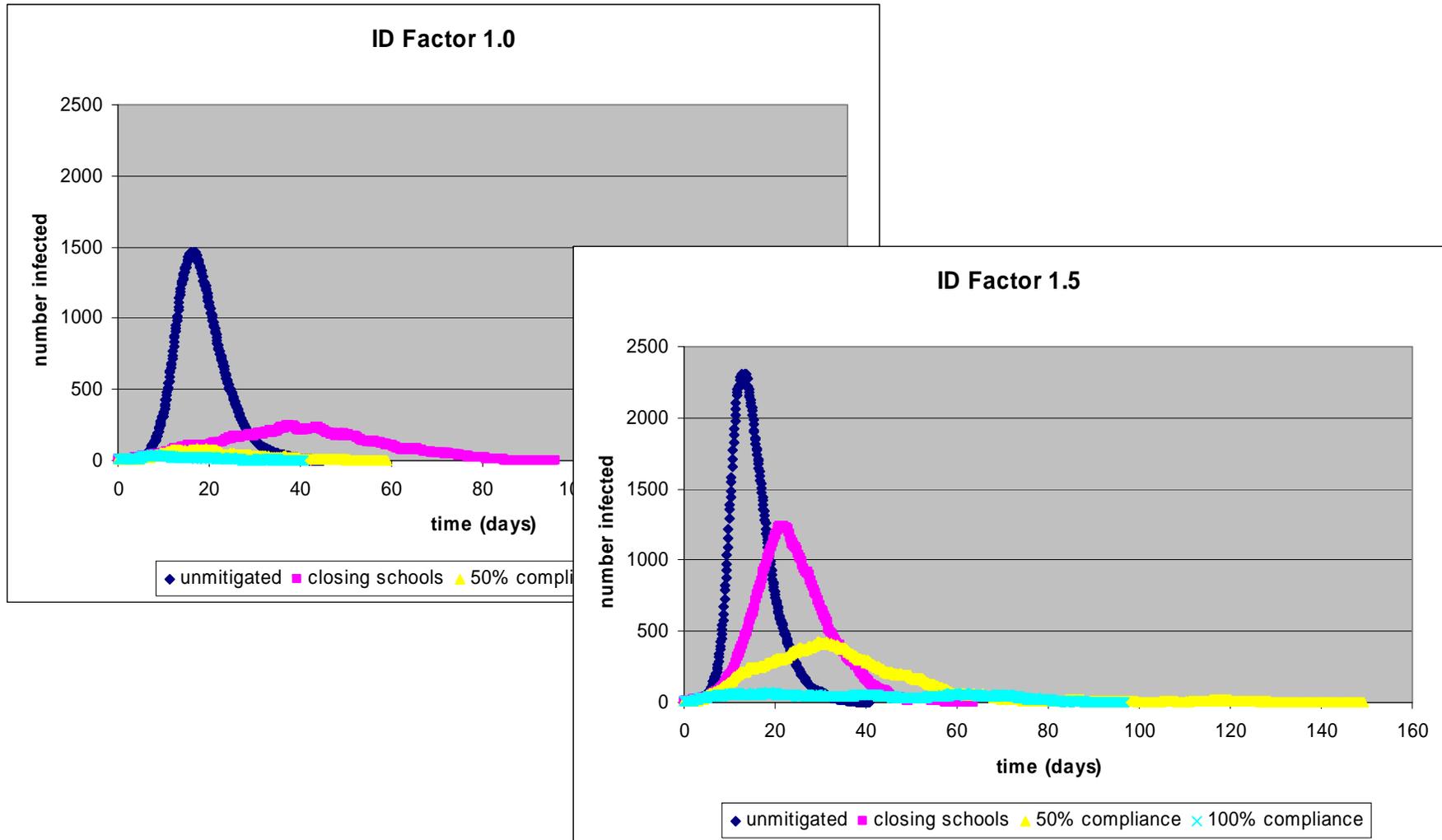
# Network of Infectious Contacts

Adults (black)  
Children (red)  
Teens (blue)  
Seniors (green)

*Children and teens form the Backbone of the Epidemic*



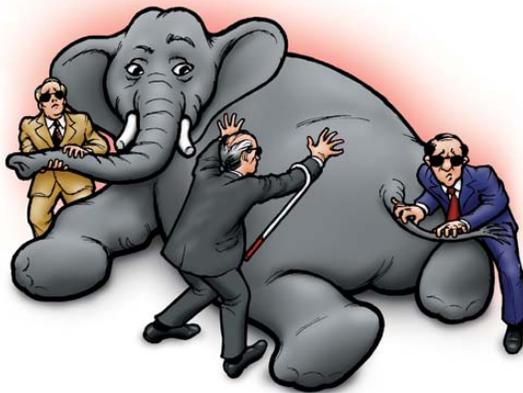
# Closing Schools and Keeping the Kids Home





## The Clouds Thicken...

- Sec Chertoff briefed, open release SAND report written.
- White House table top: everyone several steps behind our thinking, fixated on closing borders, etc. Closing borders = building fire breaks. *They don't solve the problem.*
- Meanwhile, big names in epidemiology modeling the movement of the disease across the US with massive models at LANL and in Great Britain (published rapidly in Science and Nature) suggested there was little that could be done. The pandemic would wash over the US without antivirals.



*But their tools were not built to consider the intricacies of the underlying social network on which the pandemic would spread in a local community.*



## Getting our results used...

- We needed to **INFLUENCE PUBLIC POLICY** and quickly.
- I submitted to **Science**... Rejected
- I tried to enlist the help of **the big names** in the field... they didn't reply.
- I then decided to use the **informal social-influence network** instead of the command and control hierarchy to get our work to the critical nodes with control.
- I sent our SAND report to a **acquaintance** at the VA who sent it to a **colleague** who was the VA's rep on the White House Homeland Security Council (HSC) Pandemic Implementation Plan Writing Team, who sent it to the **team lead** who sent it to the **Senior Director for Biodefense Policy, HSC**.

**Four Degrees of Separation!**



## Getting our results used...

I got on a plane and after a 4 hour presentation-interrogation-brain storming session, the HSC team and I had *changed the course of public policy* and started an avalanche of activity.





## With the White House Pandemic Implementation Plan writing team and VA OPHEH

### Identified critical questions/issues and worked with us to answer/resolve them

- How sensitive were results to the social net? Disease manifestation?
- How sensitive to compliance? Implementation threshold? Disease infectivity?
- How did the model results compare to past epidemics and results from the models of others?
- Is there any evidence from past pandemics that these strategies worked?
- What about adding or “layering” additional strategies including home quarantine, antiviral treatment and prophylaxis, and pre-pandemic vaccine?

**ALL IN THREE WEEKS**



## Systematic Evaluation of Choice

**We extended the model and put it on Sandia's 10,000 node computational cluster... 10's of millions of runs later we had the answers to:**

- What is the best mitigation strategy combination?  
**(choice)**
- How robust is the combination to model assumptions?  
**(robustness of choice to model uncertainty)**
- What is required for the choice to be most effective?  
**(critical enablers of system resilience)**

Davey, V.J., R.J. Glass, H.J. Min, W.E. Beyeler and L.M. Glass, [Effective, Robust Design of Community Mitigation for Pandemic Influenza: A Systematic Examination of Proposed U.S. Guidance](#), *PLoSOne*, July 2008, 3(7): e2606.  
doi:10.1371/journal.pone.0002606.



## Meanwhile a set of parallel efforts were set in motion...

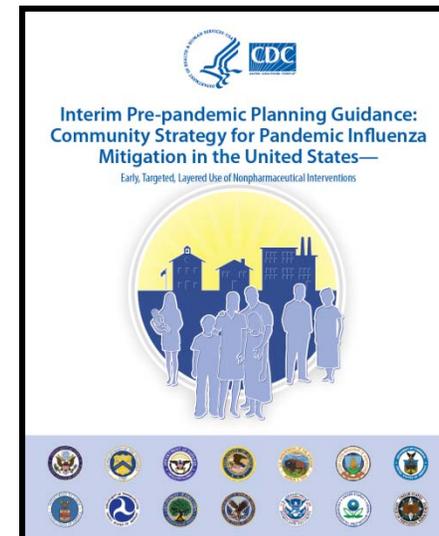
- Our original report **expanded and published** in Emerging Infectious Diseases (Glass et al., 2006).
- **Targeted Layered Containment or “TLC”** was socialized across a set of critical governmental departments and institutions by the HSC-PIP team.
- Our **results were evaluated and corroborated** by modelers within the Models of Infectious Disease Agents Study (MIDAS) group funded by NIH (Halloran et al., 2008).
- **Triggers and whistles** were systematically evaluated with the Deputy Chief Officer of OPHEH (Davey et al., 2008a).
- **Epidemiological Forensics** were applied to previous pandemics to determine if community mitigation measures were effective (Hatchett et al., 2007; Markel et al, 2007)
- A comprehensive survey-based method applied to characterize the **social contact network of school aged children and teenagers** (Glass and Glass, 2008).
- A comprehensive study of the influence of pandemics on **critical infrastructure and the economy** was conducted (NISAC, 2007).



- In October, 2006 the Institute of Medicine conducted a review (IOM 2006a,b).
- On February 1, 2007 issued “*Interim Pre-Pandemic Planning Guidance: Community Strategy for Pandemic Influenza Mitigation in the United States--Early, Targeted, Layered Use of Non-pharmaceutical Interventions*”

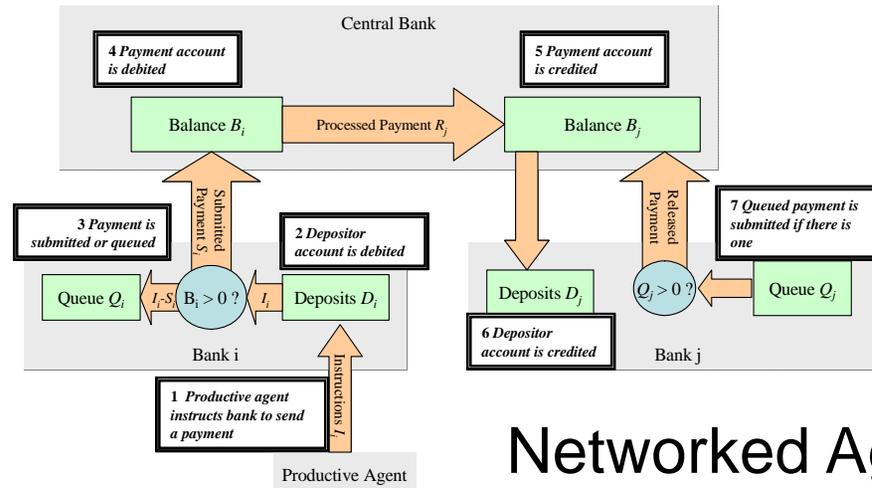
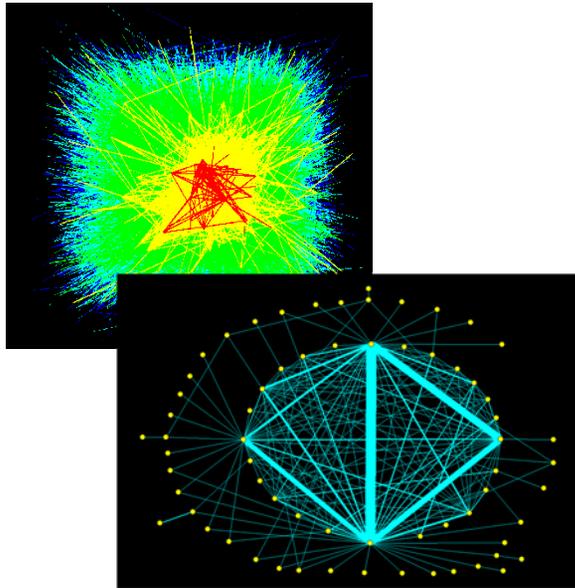
For Details see:

- **Local Mitigation Strategies for Pandemic Influenza**, RJ Glass, LM Glass, and WE Beyeler, SAND-2005-7955J (Dec, 2005).
- **Targeted Social Distancing Design for Pandemic Influenza**, RJ Glass, LM Glass, WE Beyeler, and HJ Min, *Emerging Infectious Diseases* November, 2006.
- **Design of Community Containment for Pandemic Influenza with Loki-Infect**, RJ Glass, HJ Min WE Beyeler, and LM Glass, SAND-2007-1184P (Jan, 2007).
- **Social contact networks for the spread of pandemic influenza in children and teenagers**, LM Glass, RJ Glass, *BMC Public Health*, February, 2008.
- **Rescinding Community Mitigation Strategies in an Influenza Pandemic**, VJ Davey and RJ Glass, *Emerging Infectious Diseases*, March, 2008.
- **Effective, Robust Design of Community Mitigation for Pandemic Influenza: A Systematic Examination of Proposed U.S. Guidance**, VJ Davey, RJ Glass, HJ Min, WE Beyeler and LM Glass, *PLoSOne*, July, 2008.
- **Pandemic Influenza and Complex Adaptive System of Systems (CASoS) Engineering**, Glass, R.J., Proceedings of the 2009 International System Dynamics Conference, Albuquerque, New Mexico, July, 2009.
- **Health Outcomes and Costs of Community Mitigation Strategies for an Influenza Pandemic in the U.S.**, Perlroth, Daniella J., Robert J. Glass, Victoria J. Davey, Alan M. Garber, Douglas K. Owens, *Clinical Infectious Diseases*, January, 2010.





# Another Similar Example: Payment System Structure and Function



## Networked Agent Based Model

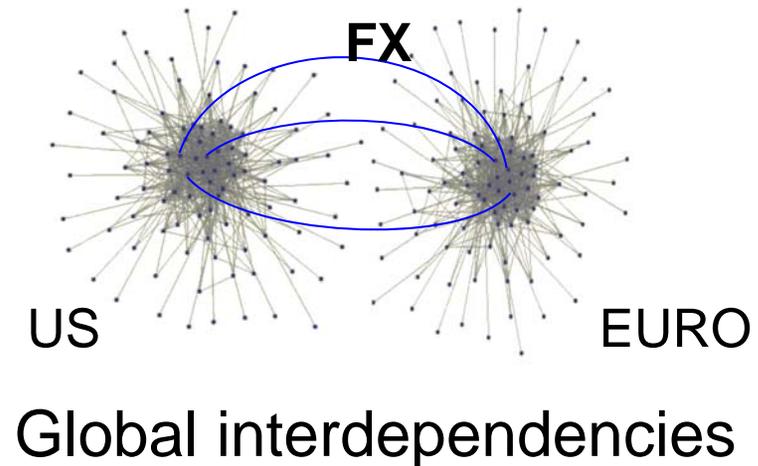
## Payment system network

For Details see:

**The Topology of Interbank Payment Flows**, Soramäki, et al, *PhysicaA*, 1 June 2007; vol.379, no.1, p.317-33.

**Congestion and Cascades in Payment Systems**, Beyeler, et al, *PhysicaA*, 15 Oct. 2007; v.384, no.2, p.693-718.

**Congestion and Cascades in Coupled Payment Systems**, Renault, et al, Joint Bank of England/ECB Conference on Payments and monetary and financial stability, Nov, 12-13 2007.



## Global interdependencies



- Harnessing the tools and understanding of Complex Systems, Complex Adaptive Systems, and Systems of Systems to Engineer solutions for some of the worlds biggest, toughest problems:

## The CASoS Engineering Initiative

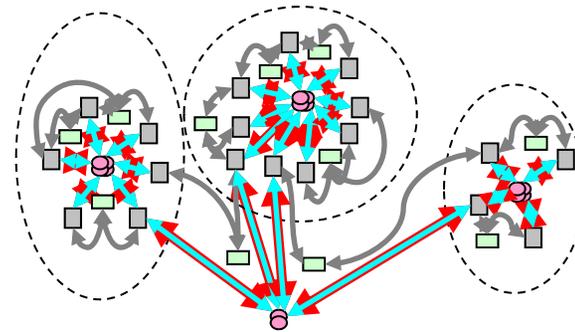
**See:** [Sandia National Laboratories: A Roadmap for the Complex Adaptive Systems of Systems \(CASoS\) Engineering Initiative](#),

SAND 2008-4651, September 2008

And our Web site at:

<http://www.sandia.gov/CasosEngineering/>

- Current efforts span a wide variety of CASoS and Problem Owners:
  - DOE, DHS, DoD, DVA,  
HHS, FDA and others





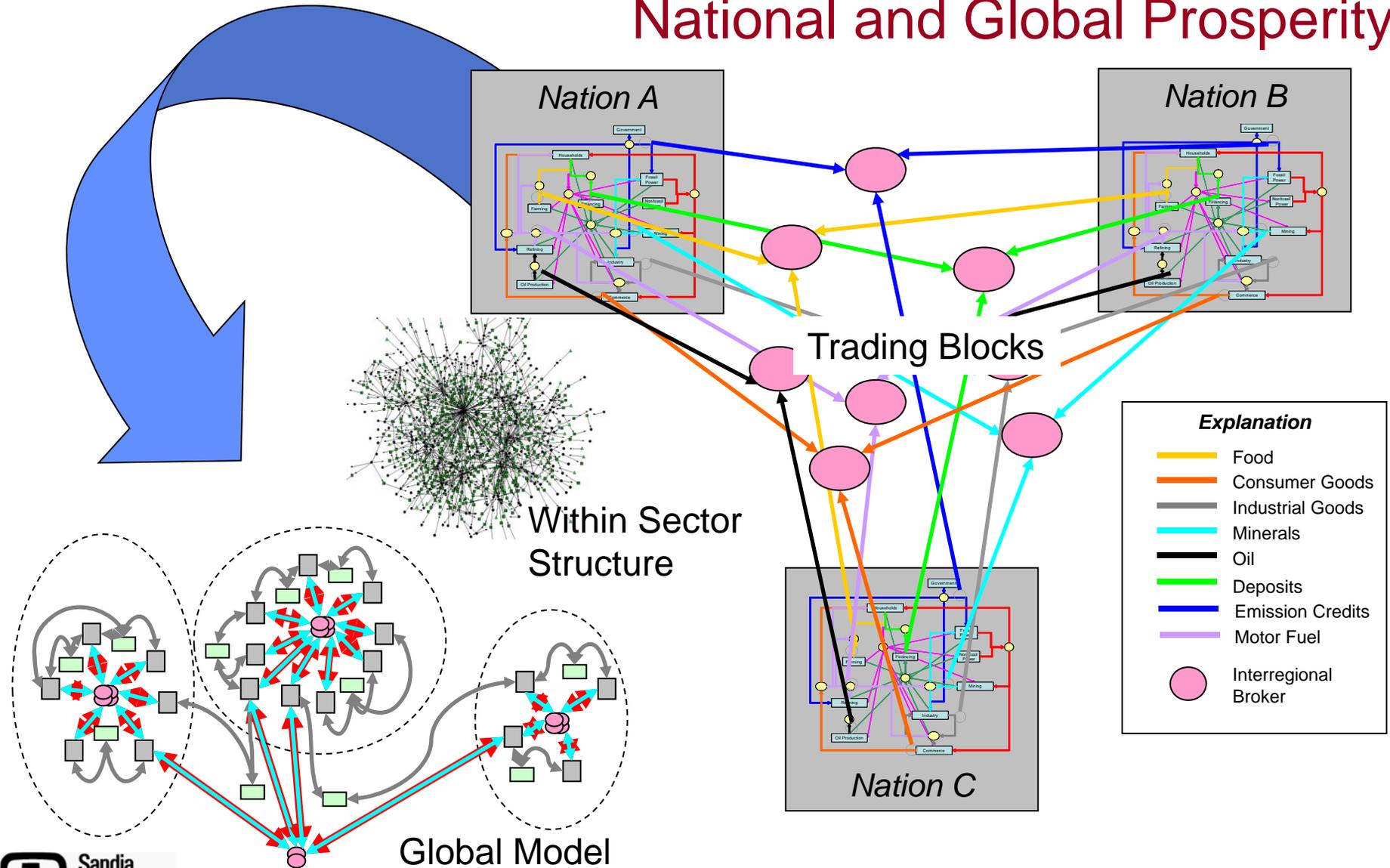
Complex Adaptive  
System of Systems  
(CASoS) Engineering

# Aspirations





# 2011-12 Stanford-CISAC Perry Fellow: Implications of National Security Policy for National and Global Prosperity

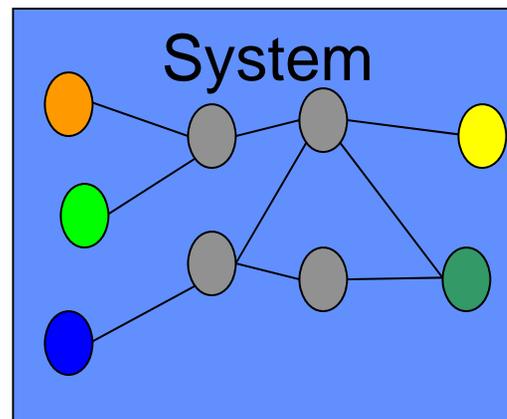




## Challenge: Finding the Right Model

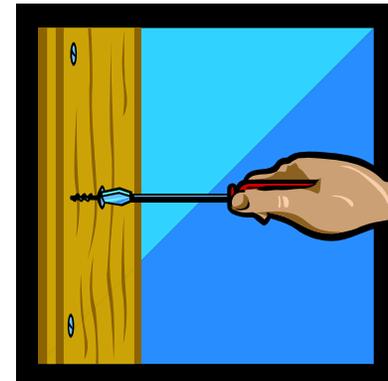
- There is no general-purpose model of any system
- A model describes a system for a purpose

What to we care about?



Model

What can we do?

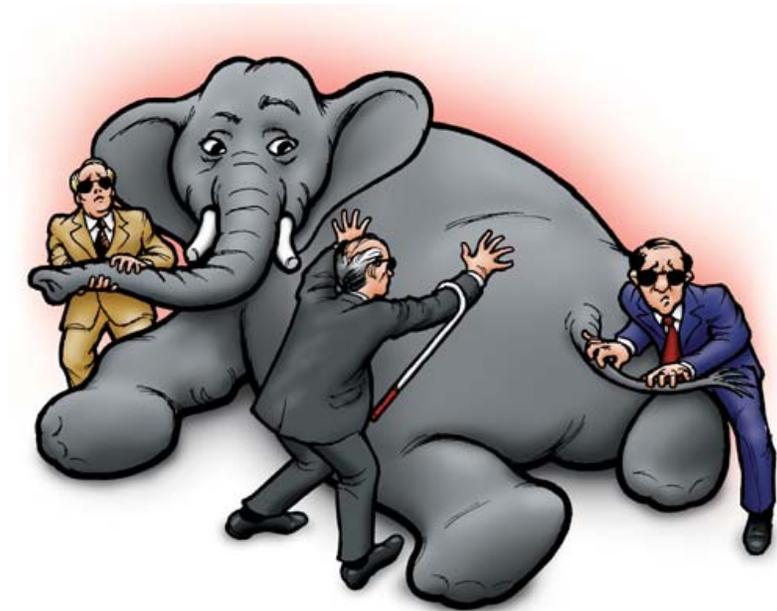


Additional structure and details are added *as needed*



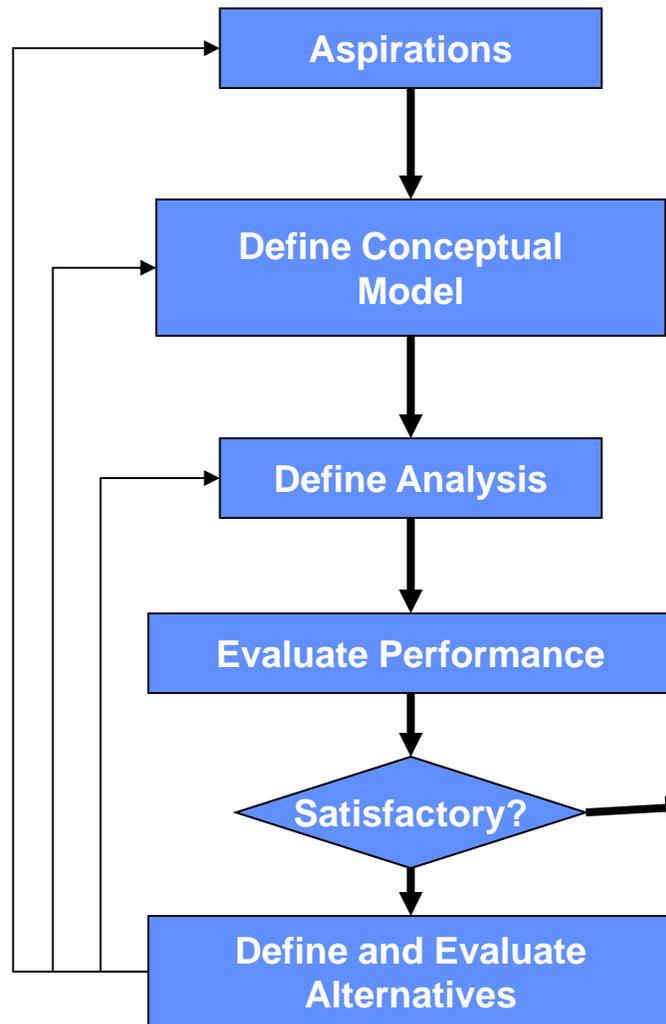
## Challenge: Uncertainty

- Aspects of Complex systems can be unpredictable (e.g., Bak, Tang, and Wiesenfeld [BTW] sandpile)
- Adaptation, Learning and Innovation
- Conceptual model or Structural uncertainty
  - Beyond parameters
  - Beyond ICs/BCs
    - Initial Conditions
    - Boundary Conditions





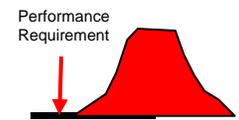
# Approach: Model development as an iterative process that uses uncertainty



Decision to refine the model  
Can be evaluated on the same  
Basis as other actions



Action A

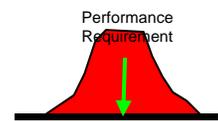


Action B

Model uncertainty  
permits distinctions



Action A

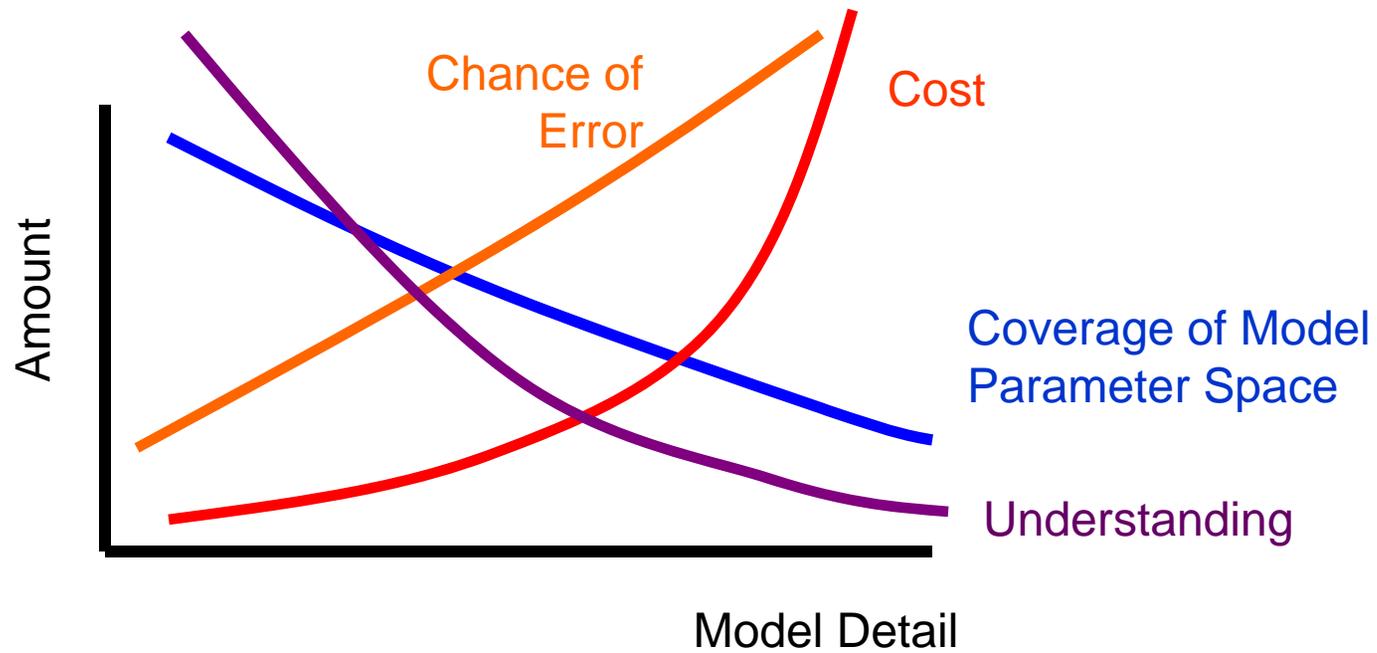


Action B

Model uncertainty  
obscures important  
distinctions, and  
reducing uncertainty  
has value



## Approach: Pragmatic Drive for Detail where More can be Less



1. Recognize the tradeoff
2. Characterize the uncertainty with every model
3. Buy detail when and where its needed



## Summarizing across many Applications:

Model based Design of Influence can be quite effective but requires:

- Policy makers **OWN** the models of their systems
- Models be as **SIMPLE** as possible
- Models be **CAUSAL** and **DYNAMIC**
- Models be **PROBLEM SPECIFIC** and connect **MEANS** (policy) and **ENDS** (system health)
- **UNCERTAINTY QUANTIFICATION** be used to evaluate and build models that can **RANK** policy choices to find those whose choice is **ROBUST TO UNCERTAINTY**
- Recognition that systems are **LIVING**





Complex Adaptive  
System of Systems  
(CASoS) Engineering

# Thanks!

**Robert J. Glass**

**Theresa J. Brown, Arlo L. Ames, John M. Linebarger,  
Walter E. Beyeler, S. Louise Maffitt, Nancy S. Brodsky,  
and Patrick D. Finley**

DHS



NIH

**Stephen H. Conrad, Thomas F. Corbet, Jr., P. Sue Downes,**

**Mark A. Ehlen, Paul G. Kaplan, Andjelka Kelic,**

**Kirin Lakkaraju, Michael D. Mitchell,**

**Roger A. Mitchell, Thomas W. Moore,**

**Alexander V. Outkin, Janis L. Schubert,**

**Vanessa N. Vargas, Stephen J. Verzi,**

**Eric D. Vugrin, and**

**Aldo A. Zagonel**

DHHS



DVA



DOD



DOE



SNL



Stanford

