



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

# Complex Adaptive System of Systems (CASoS) Engineering: Mapping Aspirations to Solutions

Robert J Glass  
Sandia National Laboratories

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Slides selected from material on:  
<http://www.sandia.gov/CasosEngineering/>



# 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>

# 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.

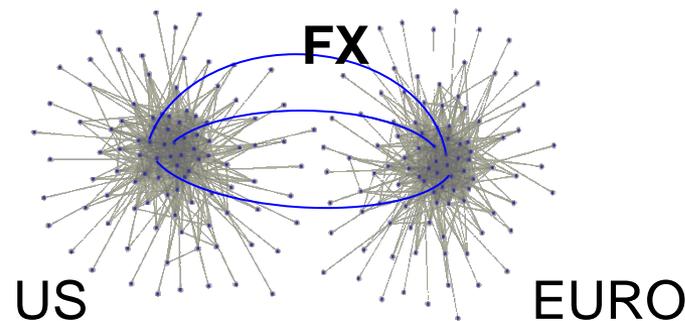
*Pandemic NOW.  
No Vaccine, No antiviral.*



*Chickens being burned in Hanoi*

# 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.



- **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



# A Conceptual Lens for CASoS Modeling

**Take any system and Abstract as:**

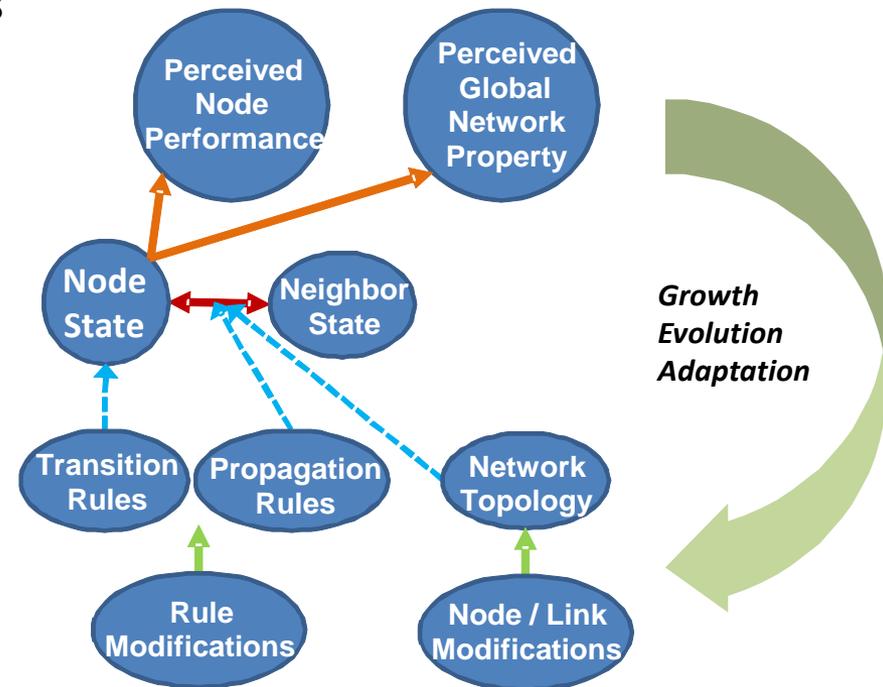
- Nodes (with a variety of “types”)
- Links or “connections” to other nodes (with a variety of “modes”)
- Local rules for Nodal and Link behavior
- Local Adaptation of Behavioral Rules
- “Global” forcing, Local dissipation

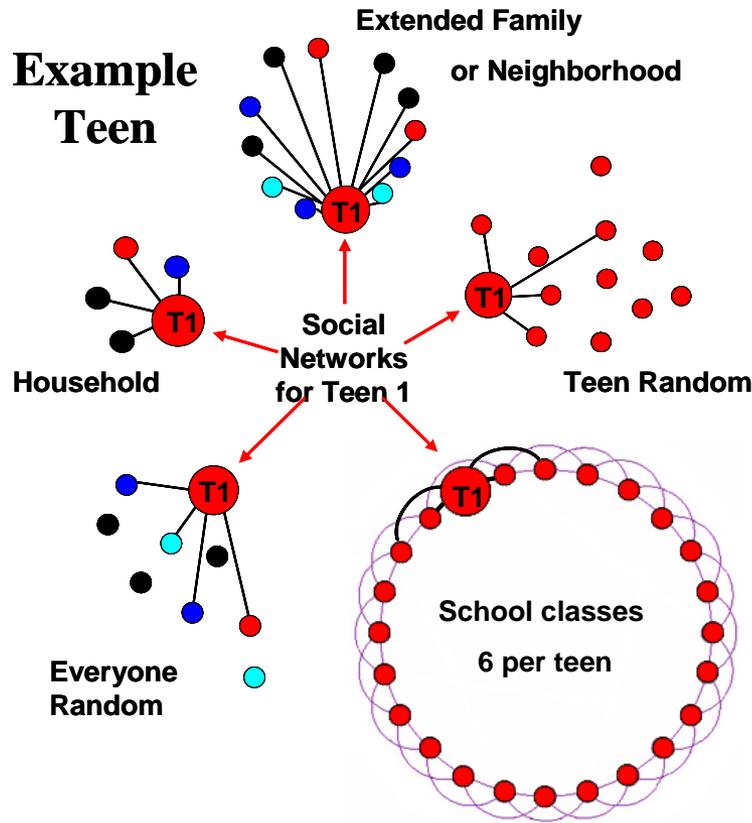
**Connect nodes appropriately to form a system (network)**

**Connect systems appropriately to form a System of Systems**

**Lumped to discrete  
System dynamics to agent based  
Infinite to Finite State machines**

**Hybrid**

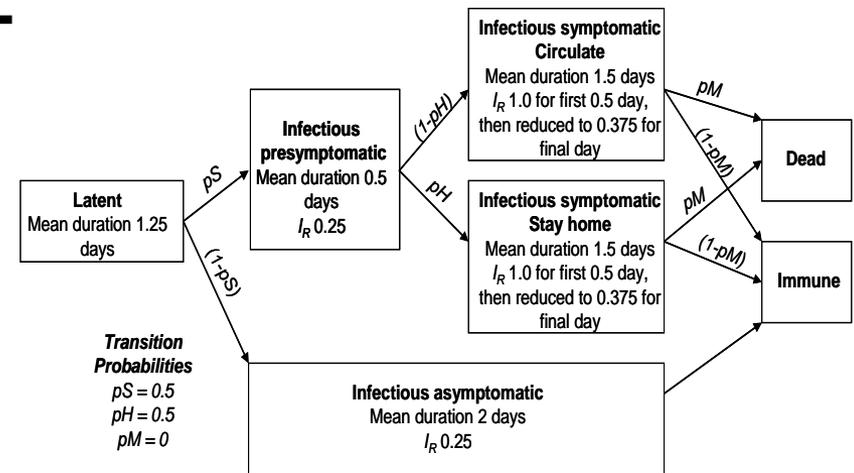




**Stylized Social Network**  
(nodes, links, frequency of interaction)

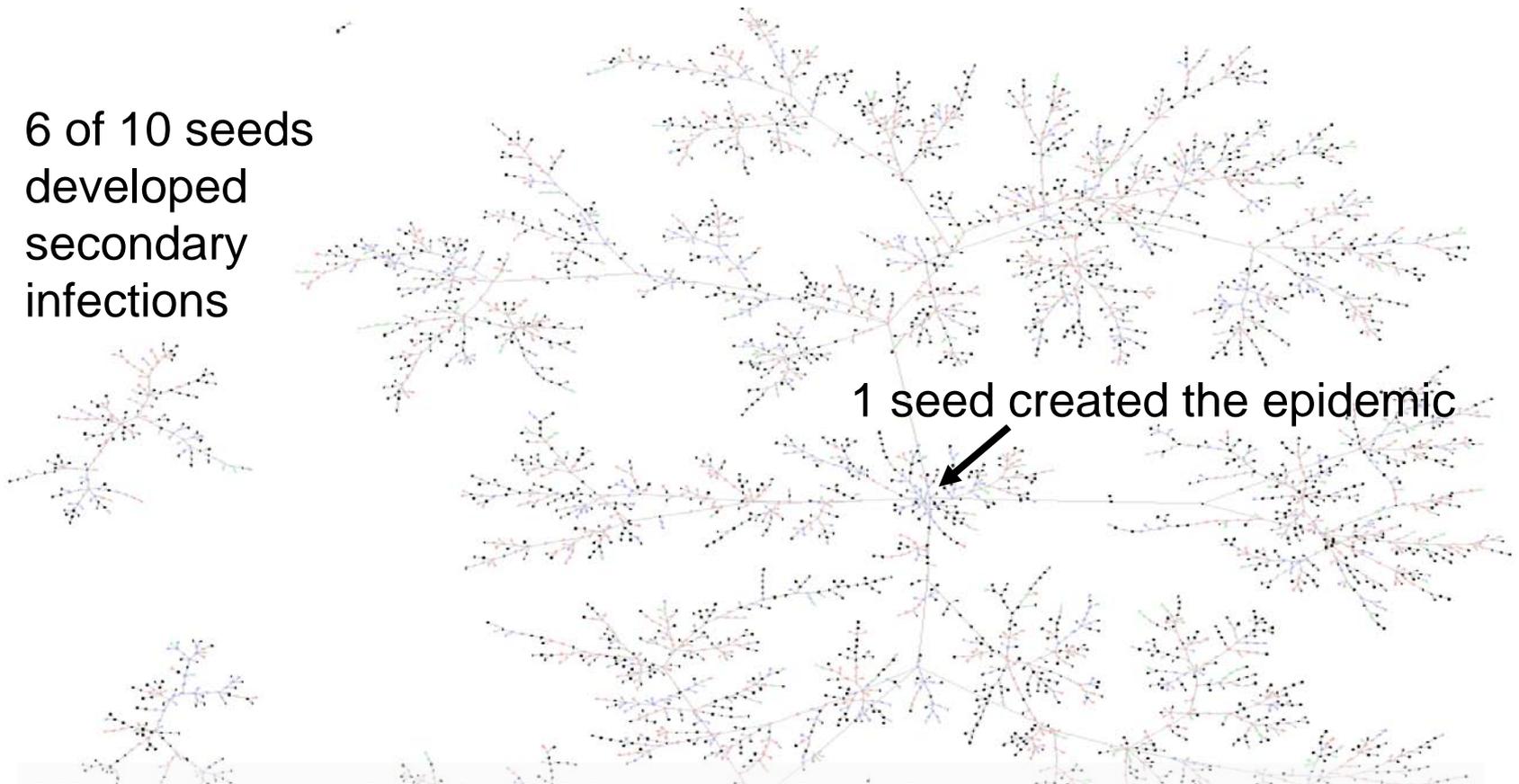
Disease manifestation based on data from the literature (node and link behavior)

+



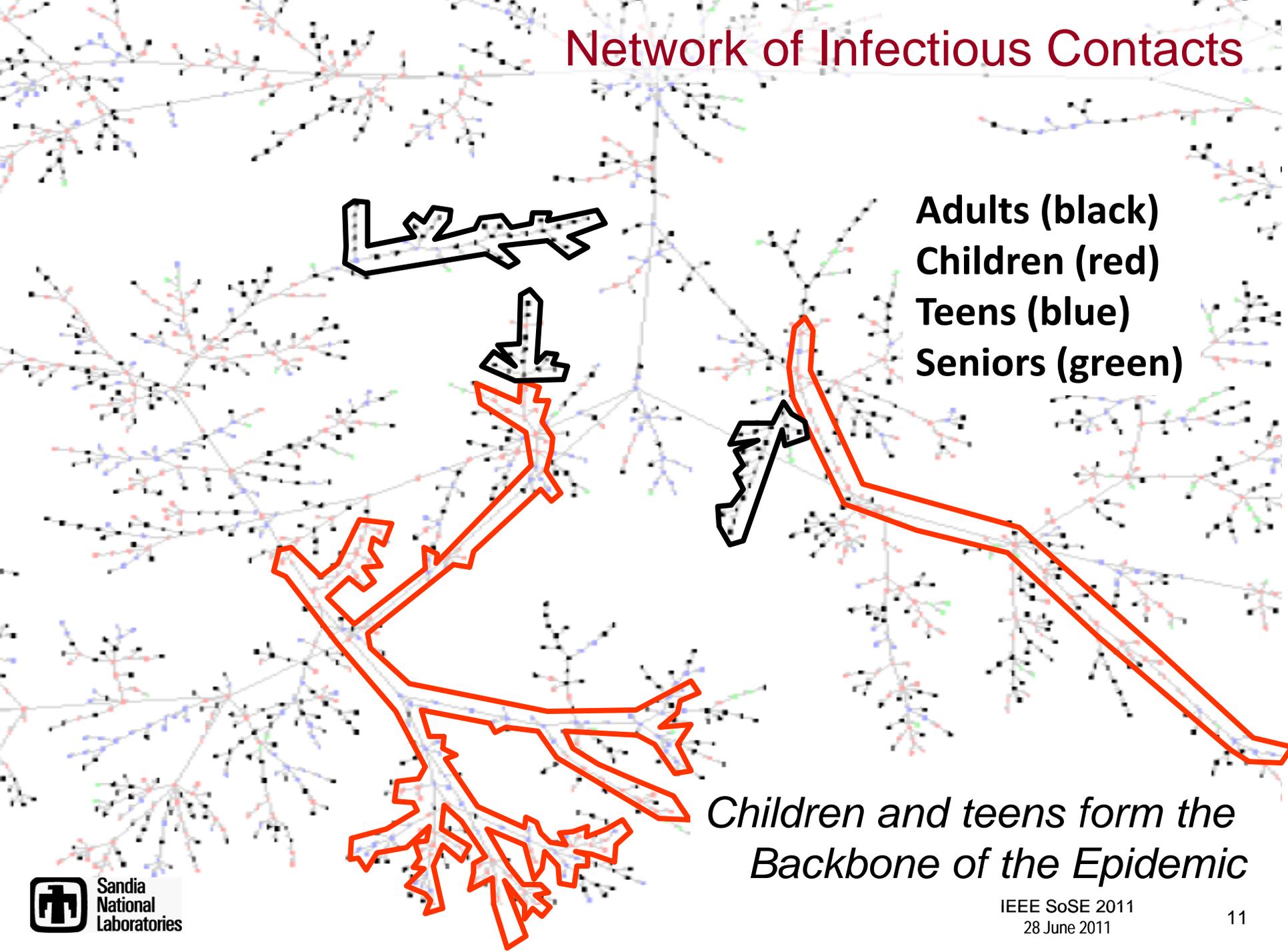


6 of 10 seeds  
developed  
secondary  
infections



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”.

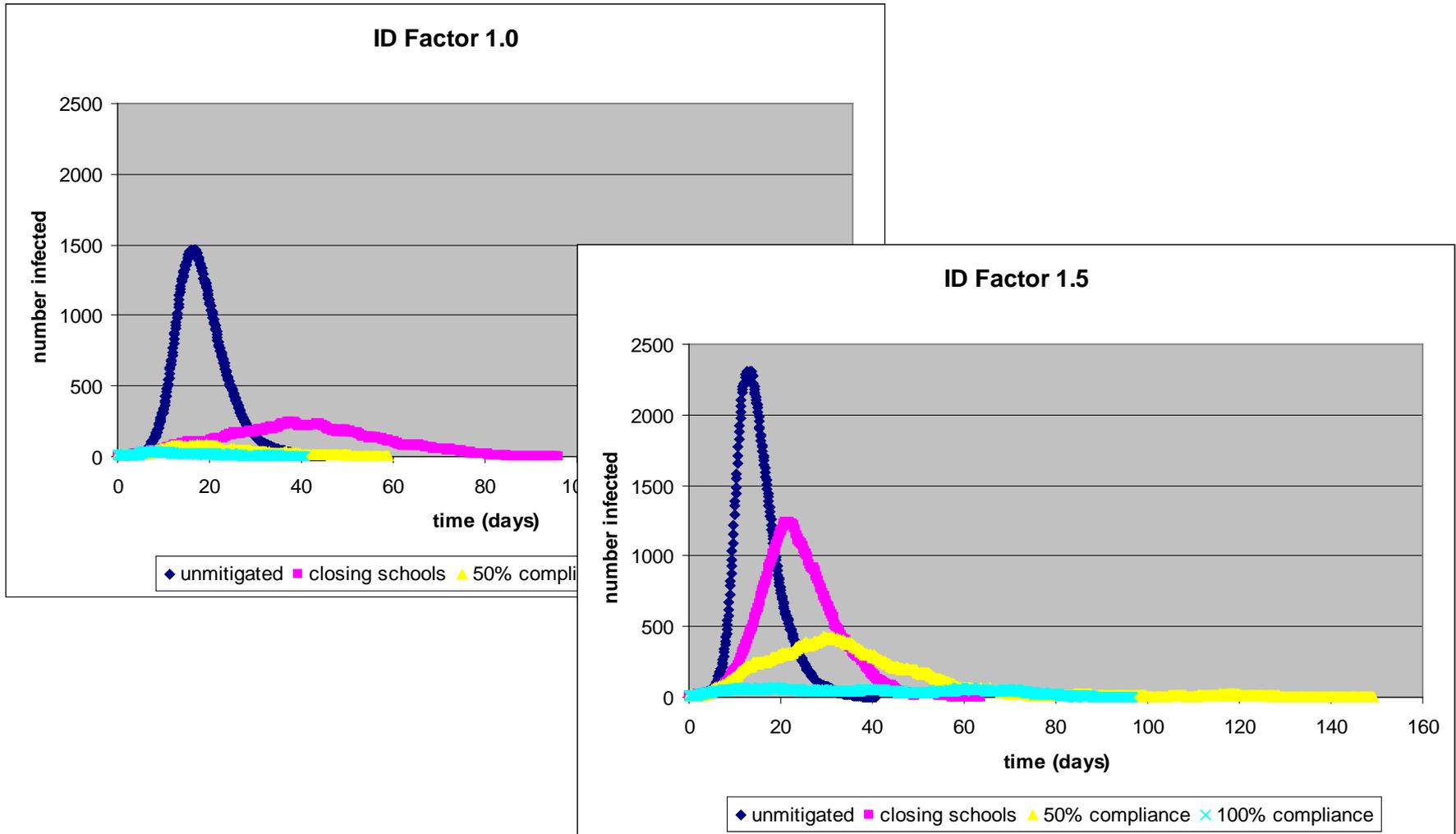
# Network of Infectious Contacts



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

*Children and teens form the Backbone of the Epidemic*

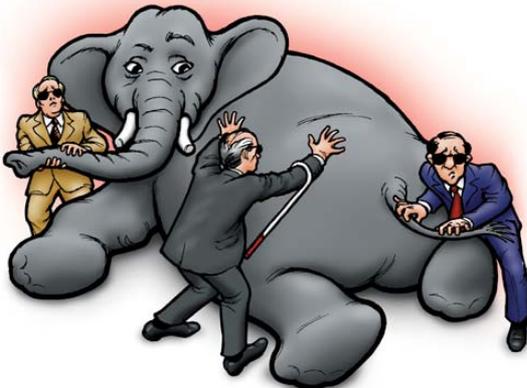
# Closing Schools and Keeping the Kids Home





# 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.*
- 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**

**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...

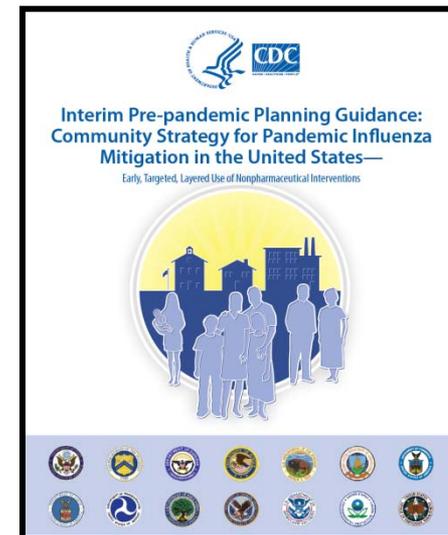
- Our original report **expanded and published** in Emerging Infectious Diseases (Glass et al., 2006).
- **Targeted Layered Containment or “TLC”** was socialized across a set of critical governmental departments and institutions by the HSC-PIP team.
- Our **results were evaluated and corroborated** by 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*”

And then came H1N1 (2009)...

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.**, Perthroth, Daniela J., Robert J. Glass, Victoria J. Davey, Alan M. Garber, Douglas K. Owens, *Clinical Infectious Diseases*, January, 2010.



# Summarizing the main points

- We were dealing with a large complex adaptive system, a CASoS: a global pandemic raging across the human population within a highly connected world (social, economic, political)
- By similarity with other such systems, their problems, their solutions, we
  - defined **THE CRITICAL PROBLEM** for the pandemic
  - applied a **GENERIC APPROACH** for simulation and analysis
  - came up with a **ROBUST SOLUTION** that would work with minimal social and economic burden independent of decisions made outside the local community (e.g., politics, borders, travel restrictions).
- Through recognition that the **GOVERNMENT's** global pandemic preparation was a CASoS, we
  - used CASoS concepts (social net, influence net, people) to **INFLUENCE PUBLIC POLICY** in short time. These concepts continue to be used by the HSC folks to implement the policy that we identified. And work continues...

- 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

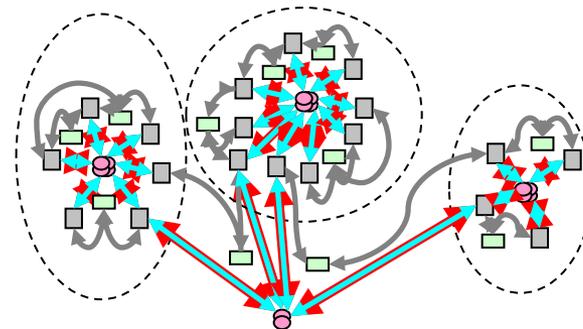
**See:** [Sandia National Laboratories: A Roadmap for the Complex Adaptive Systems of Systems \(CASoS\) Engineering Initiative](#),

SAND 2008-4651, September 2008

And our Web site at:

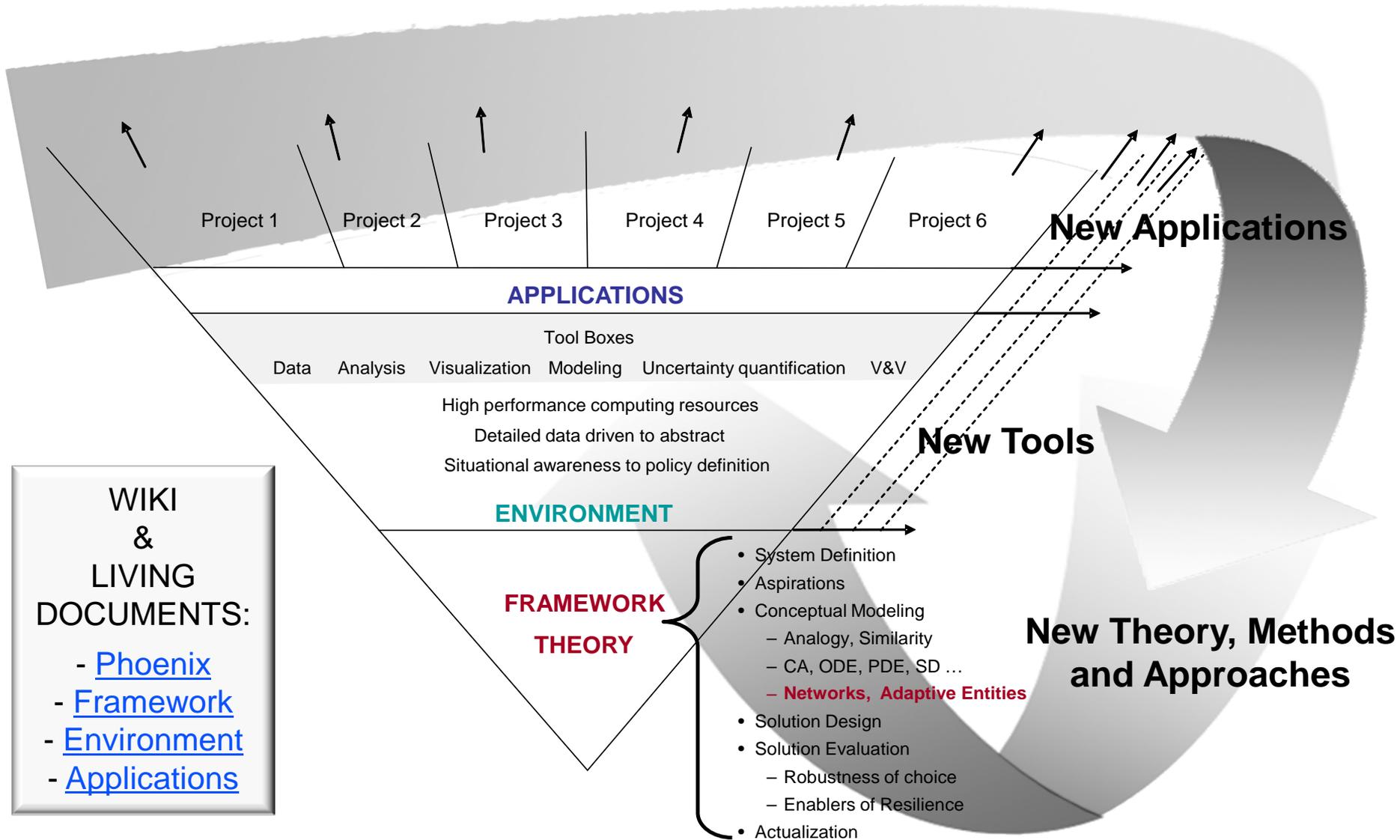
<http://www.sandia.gov/CasosEngineering/>

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





# 2008: CASoS Engineering Pilot: Phoenix





# Global Aspirations



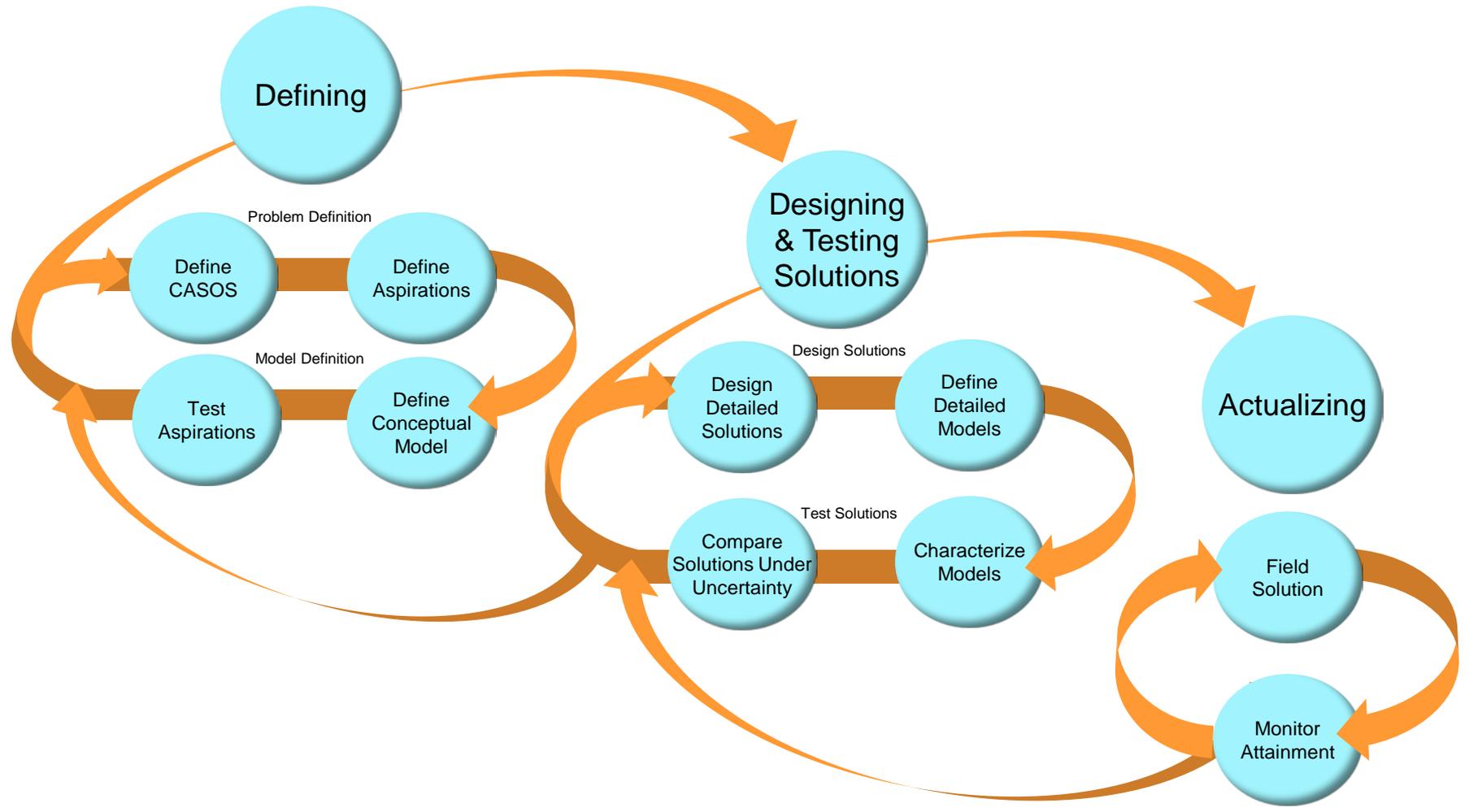
# Building a Taxonomy of Aspirations

**From an engineering perspective, *Aspirations* fall into a set of clearly identified categories:**

- **Predict** the evolution of the system and, in particular, the results of events (e.g., perturbations of a variety of qualities and quantities) with direct and consequential changes in system health.
- **Prevent or Cause** an event to occur.
- **Prepare** elements of the system for impending events (e.g., minimize/maximize influence).
- **Monitor** important aspects of a system to record the response of the system to events.
- **Recover or Change** in response to events.
- **Control** system behavior to avoid or steer the system towards specified regimes through the design of appropriate incentives and feedback.

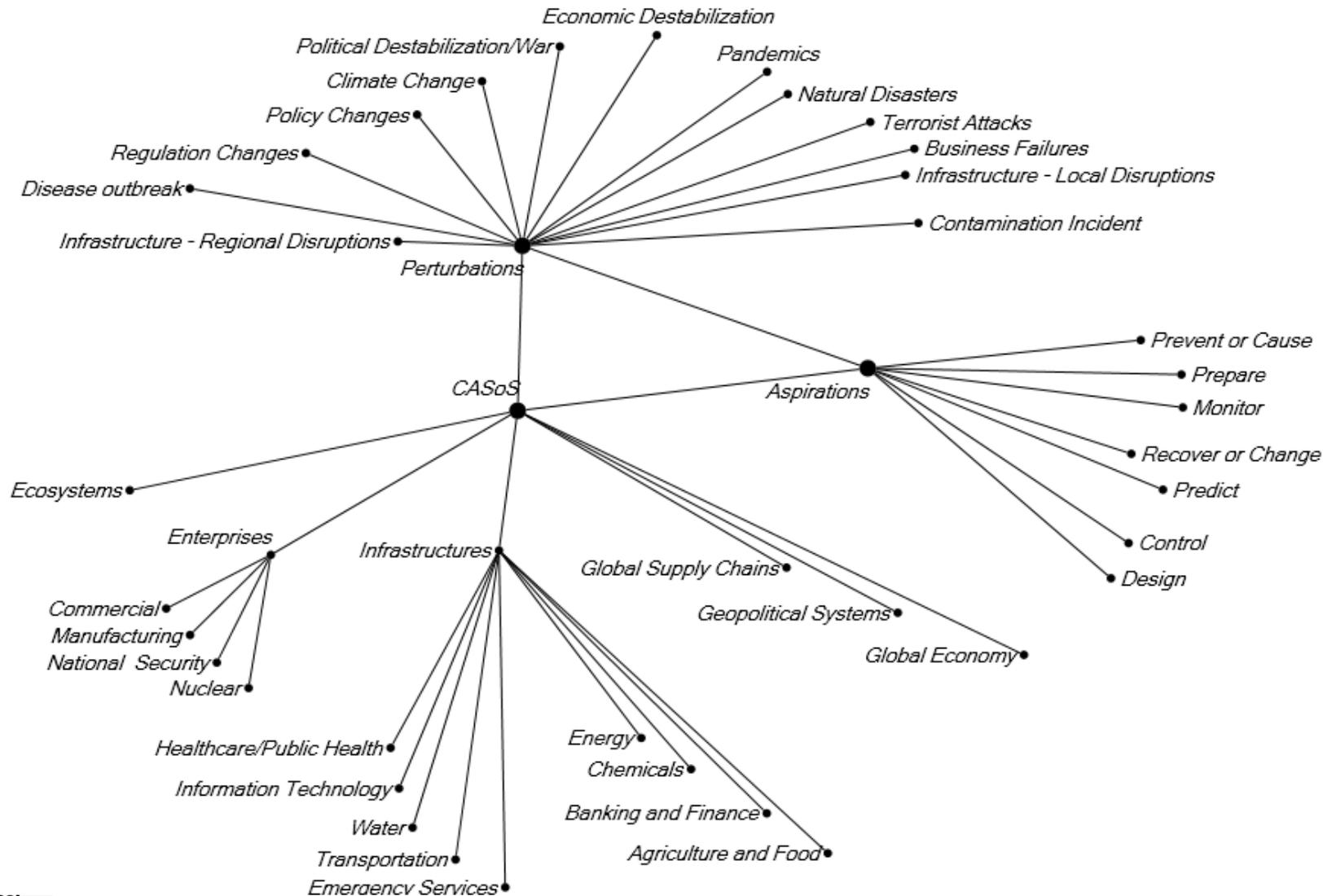
————→ **Design a *CASoS Solution*.**

# Building a CASoS Engineering Framework to Define and Solve Problems





# Building a Taxonomy of Problems and their Solutions



# Audacious: Trans-Spectrum Global Security



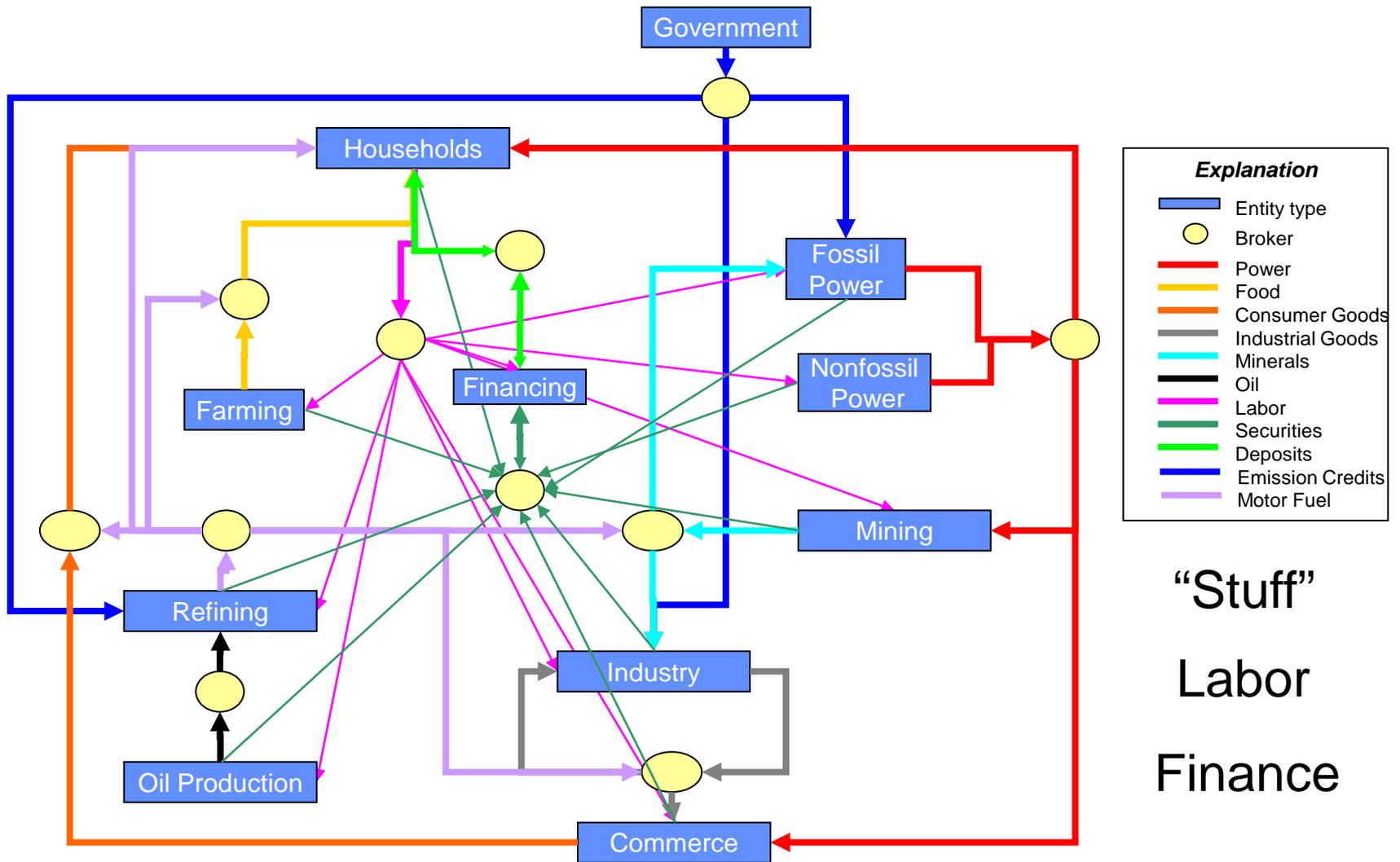
## Trans-Spectrum Global Security is intrinsically Trans-Scale and Trans-Network

- **Trans** is a Latin noun or prefix, meaning "across", "beyond" or "on the opposite side".
- **Trans Spectrum** combines and goes beyond the single components necessary for Security: Food, Water, Energy, Goods, Finance, Health, Education, Information, Technology, Military, Weapons (conventional, nuclear) and Government
- **Trans Spectrum** is intrinsically **Trans-Network**: there are influence/consumption/production supply networks for each productive entity/sector/scale and they are combined into a single network that transcends the multi-network view.
- **Global Security** is **Trans-Scale**: security is recognized to cross multiple scales: communities, regions, states, nations, groups of nations, global (for government), or similar progressions for other spectra components such that it security maintained at all scales (scale independent).

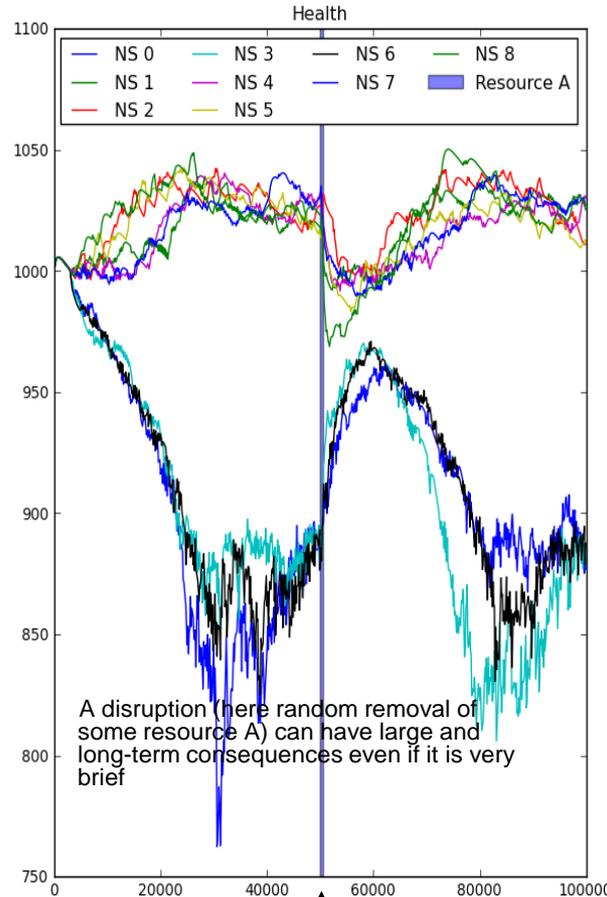
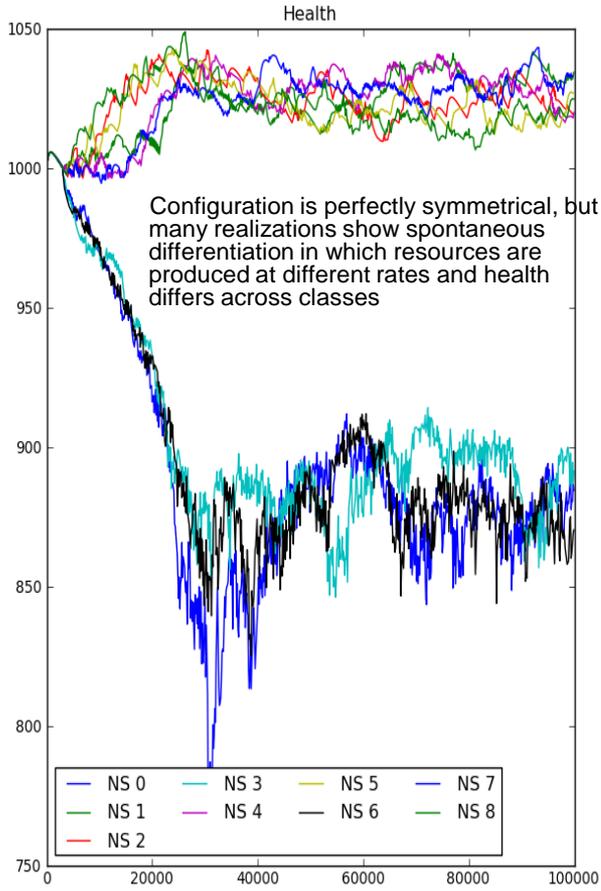
- Global eco-socio-economic interdependent CASoS
- Evaluate System "Health" or "Goodness" in context Perturbations and Stressors (e.g., climate, energy, food, nuclear and conventional exchanges)
- Evaluate and Design policy that enhances system resilience and decreases risk



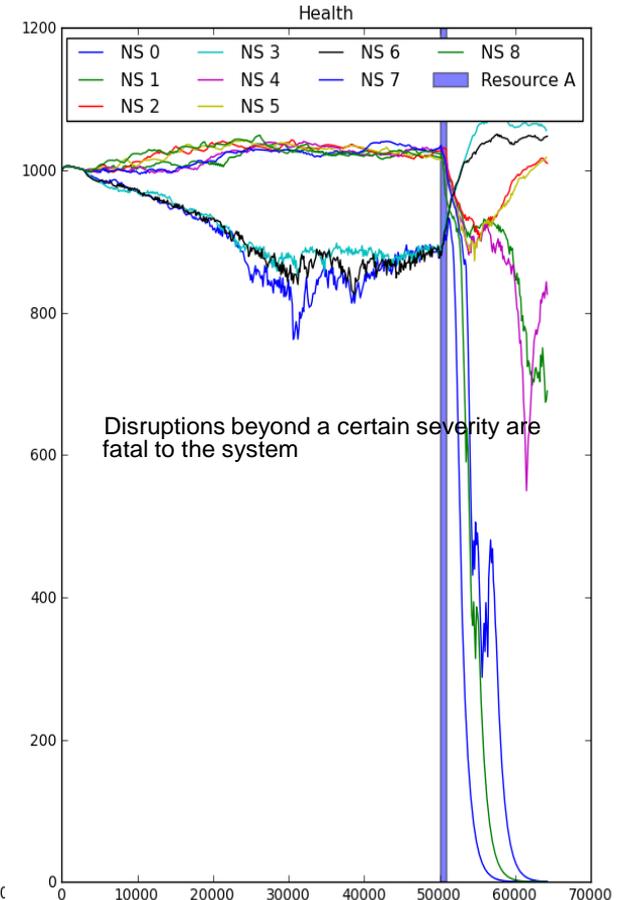
# Individual Nations as CASoS



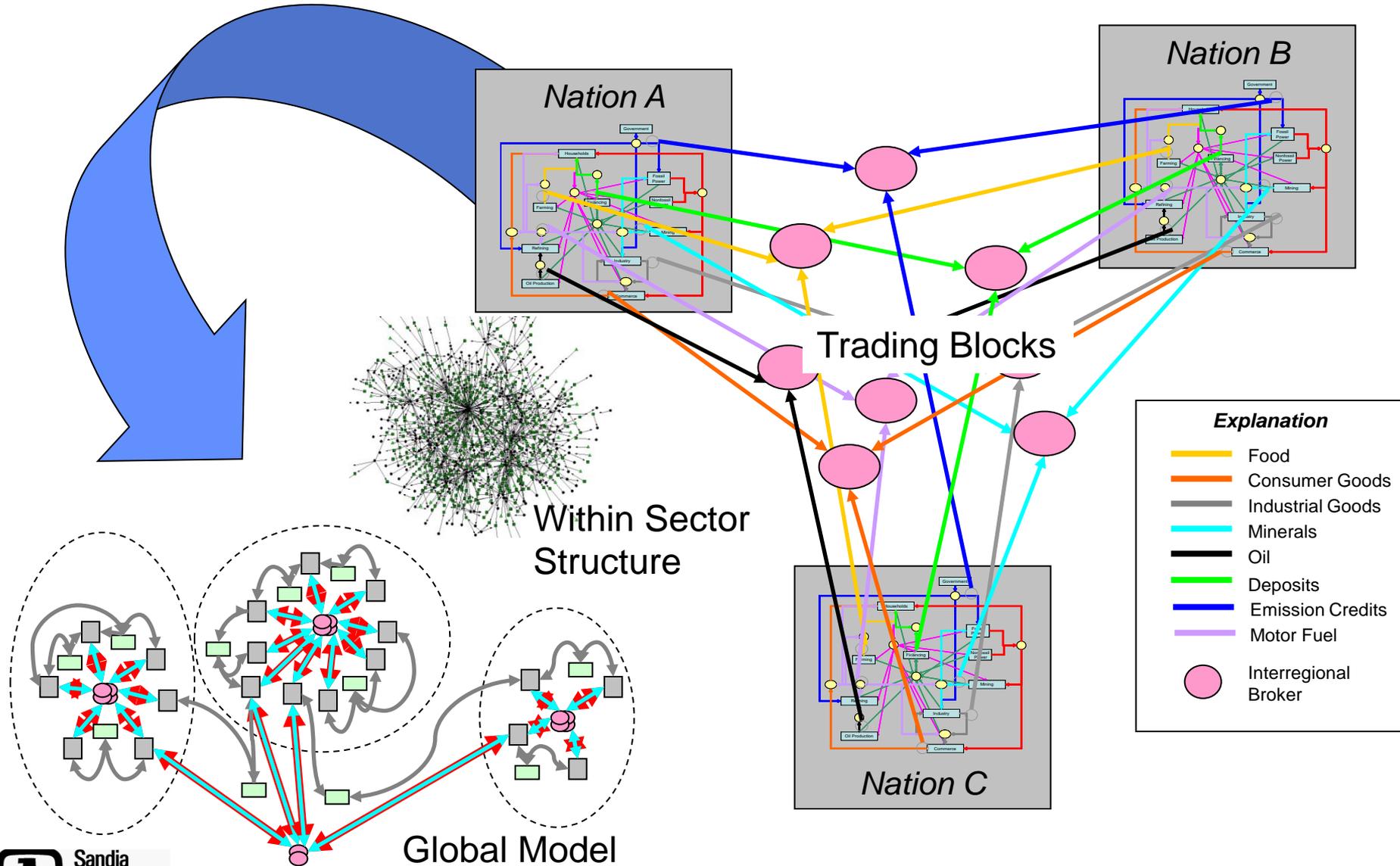
# Sector and National "Health" in context of finite energy shocks



Small Shock ↑



Large Shock ↑



# Core Phoenix and Sponsoring Partners

**Robert J. Glass**

**Arlo L. Ames**

**Walter E. Beyeler**

**Theresa J. Brown**

**Nancy S. Brodsky**

**Patrick D. Finley**

**John M. Linebarger**

**S. Louise Maffitt**

**Thomas W. Moore**

**Alexander V. Outkin**

**Stephen J. Verzi**

**Aldo A. Zagonel**



DHS



SNL



DVA



DOE



DOD