plex Adaptive Systems of Systems (CASoS) Engineering

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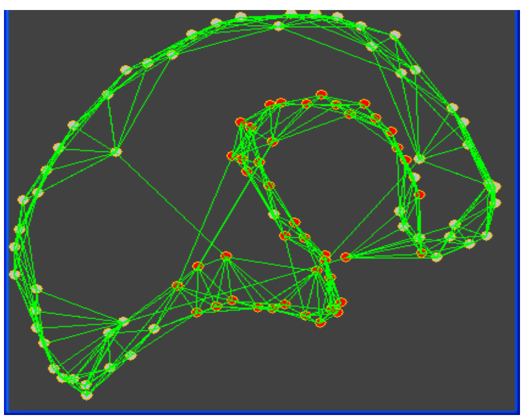

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http://www.sandia.gov/nisac/amti.html

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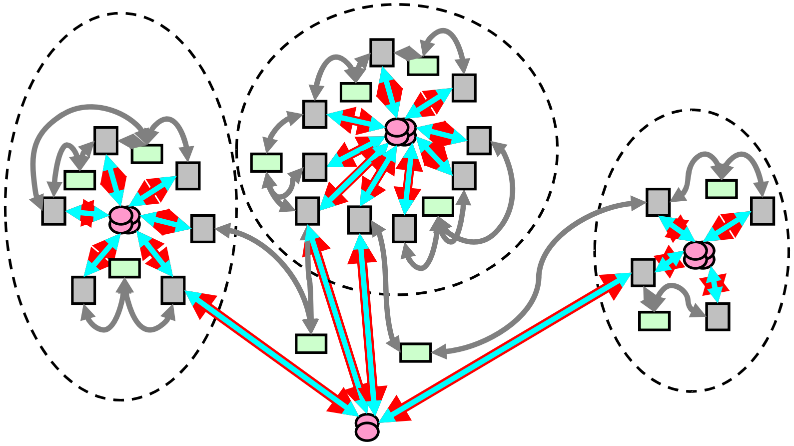
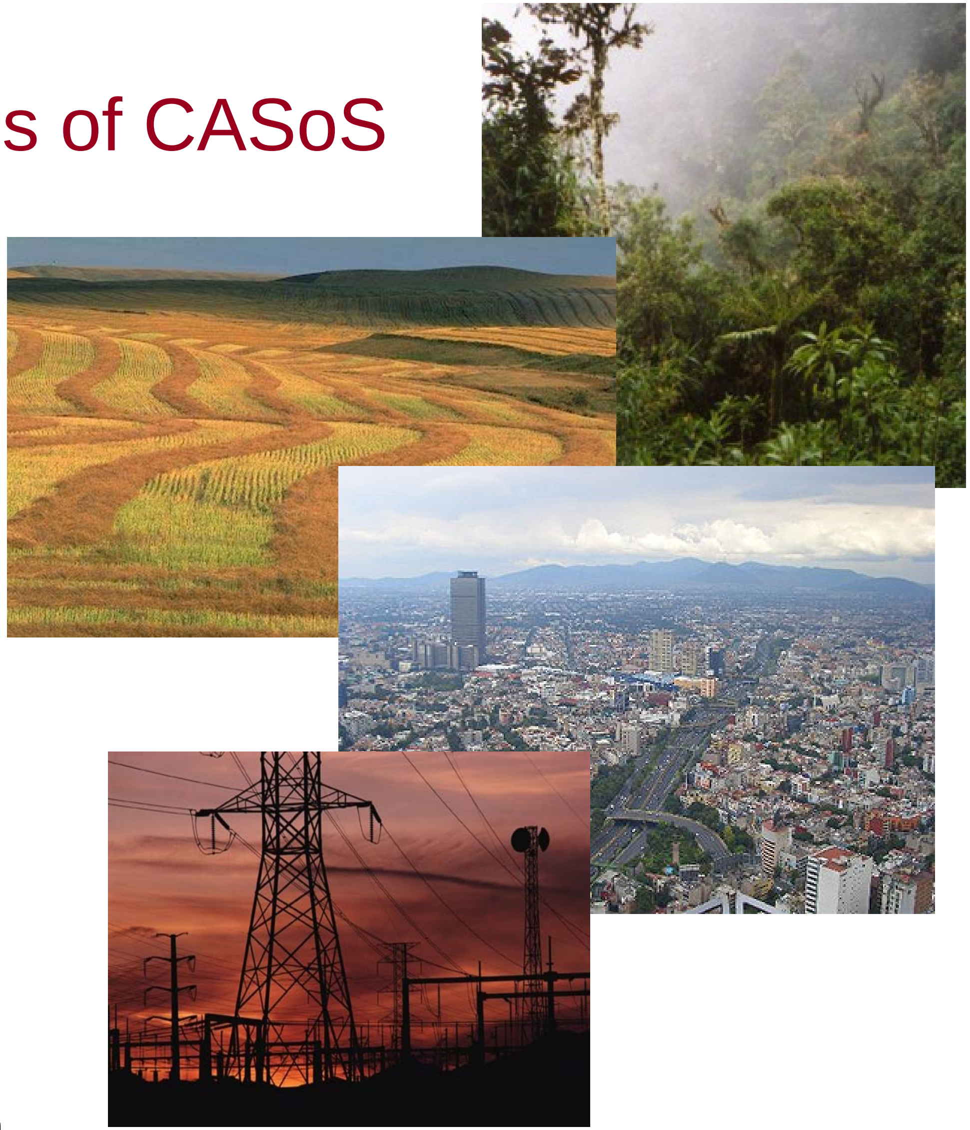
Outline

- What is a CASoS and it's attributes?
- Conceptual Lens for Modeling/Thinking
- CASoS Engineering
- Engineering within a CASoS: Example of Influenza Pandemic Mitigation Policy Design
- Other Applications



Many Examples of CASoS

- Tropical Rain forest
- Agro-Eco system
- Cities and Megacities (and their network on the planet)
- 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



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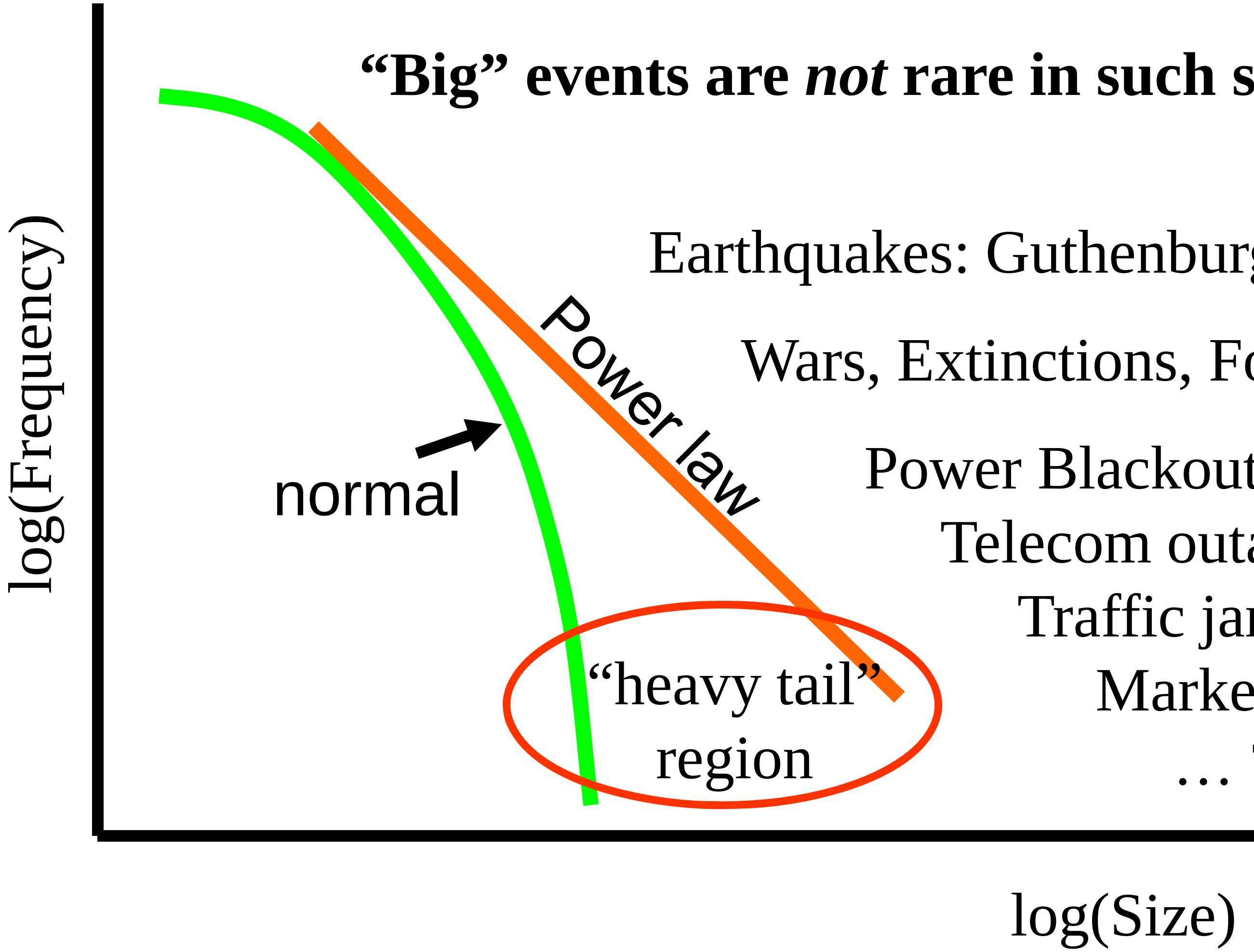
COMPLEX: Emergent cascades with power-laws & "heavy tails"



Earthquakes: Guthenburg-Richter

Wars, Extinctions, Forest fires

Power Blackouts

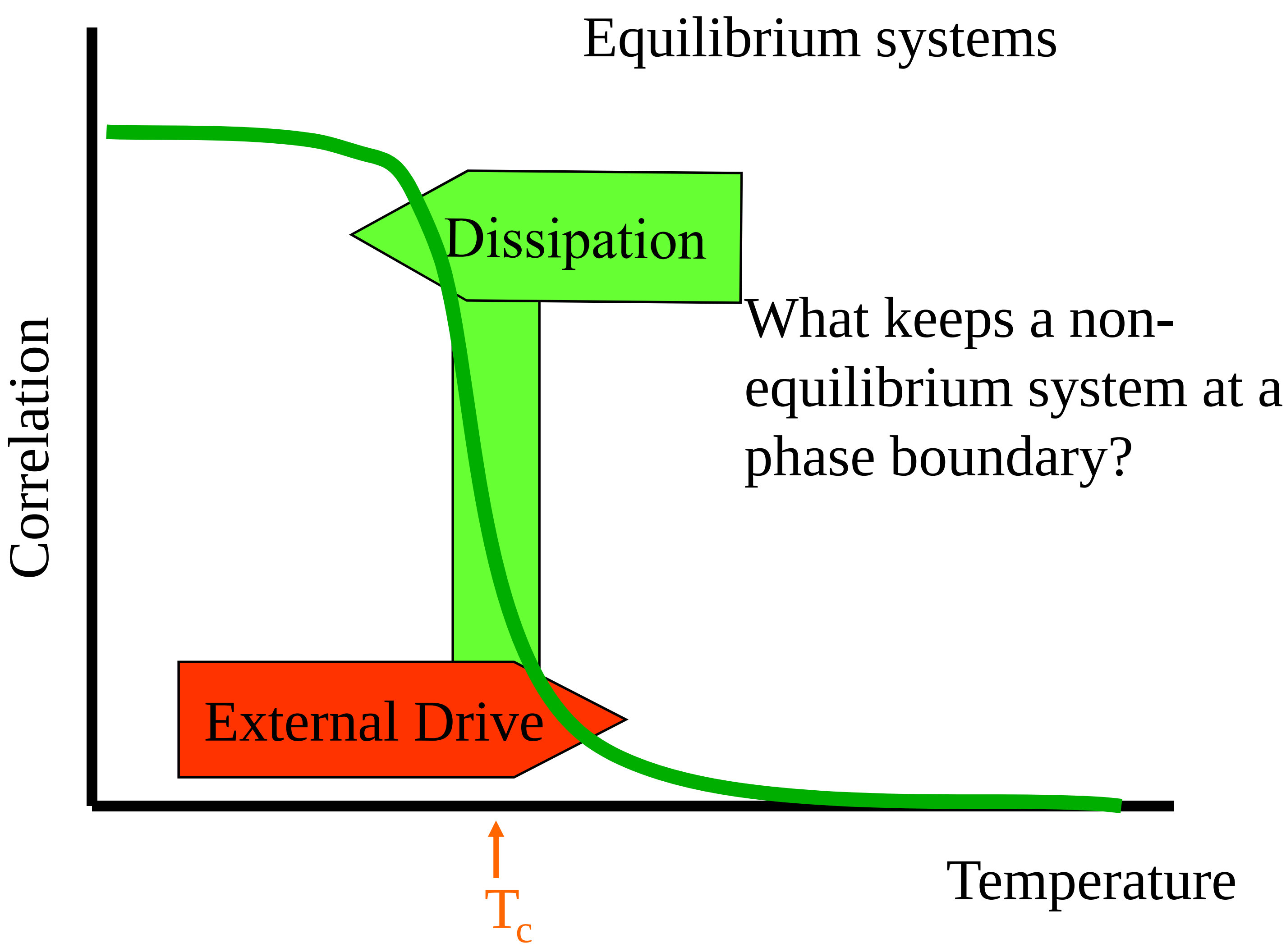
Telecom outages

Traffic jams

Market crashes

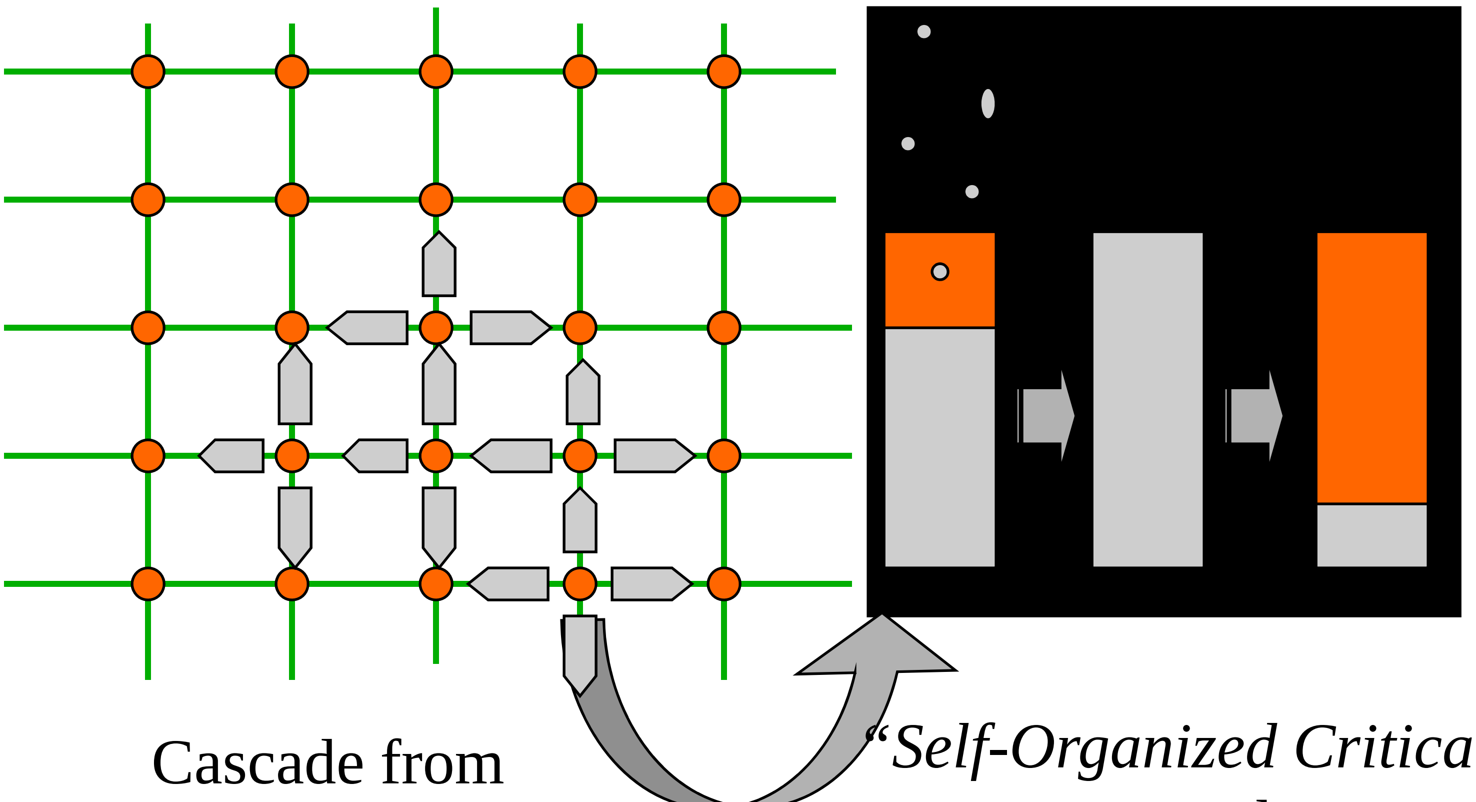
… ???

Power Laws - Critical behavior - Phase transitions



1987 Bak, Tang, Wiesenfeld's "Sand-pile" or "Cascade" Model

Lattice Drive Relaxation



Cascade from
Local Rules

"Self-Organized Criticality"
power-laws
fractals in space and time
time series unpredictable

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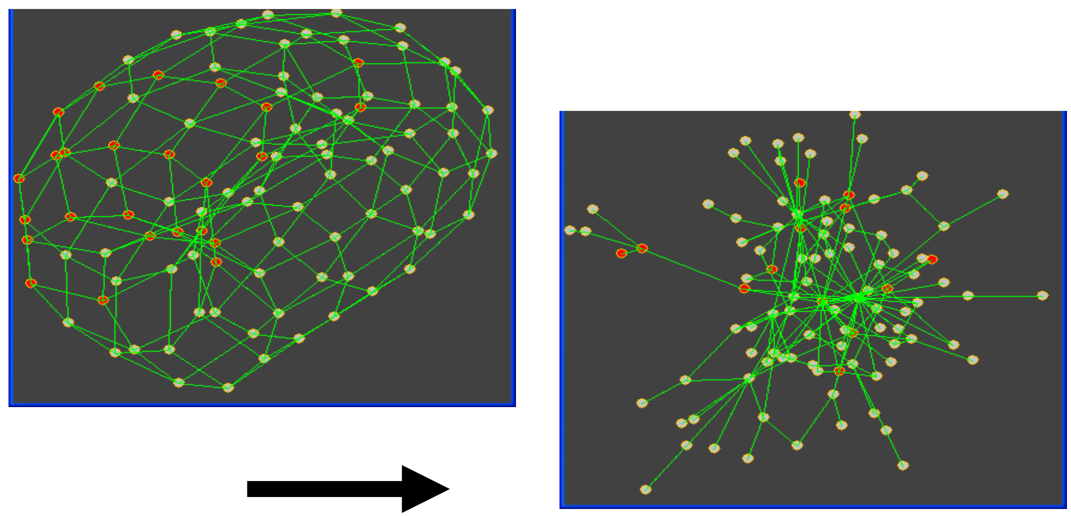
ADAPTIVE: Adaptation occurs at multiple scales

Adaptive: The system's behavior changes in time. These changes may be within entities or their interaction, within sub-systems or their interaction, and may result in a change in the overall system's behavior relative to its environment.

Temporal
Spatial
Relational



Grow and adapt
in response to local-to-global ***policy***

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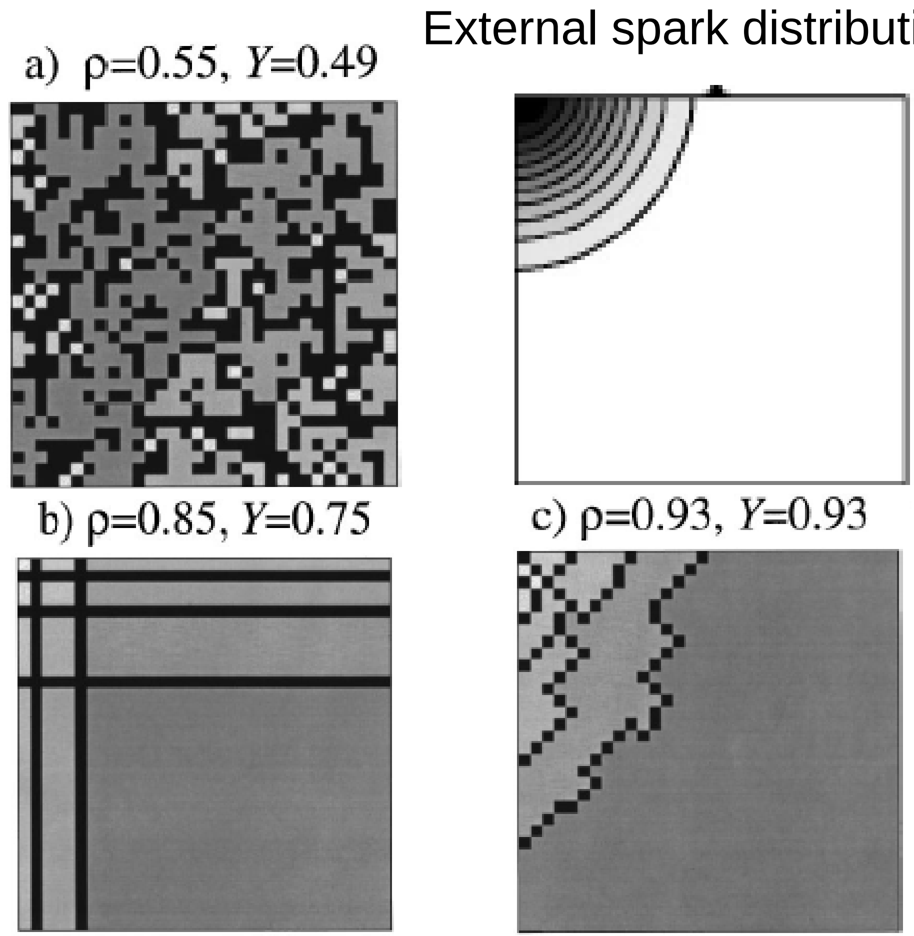
1999 Carson and Doyle's Highly Optimized Tolerance "HOT"

Simple forest fire example

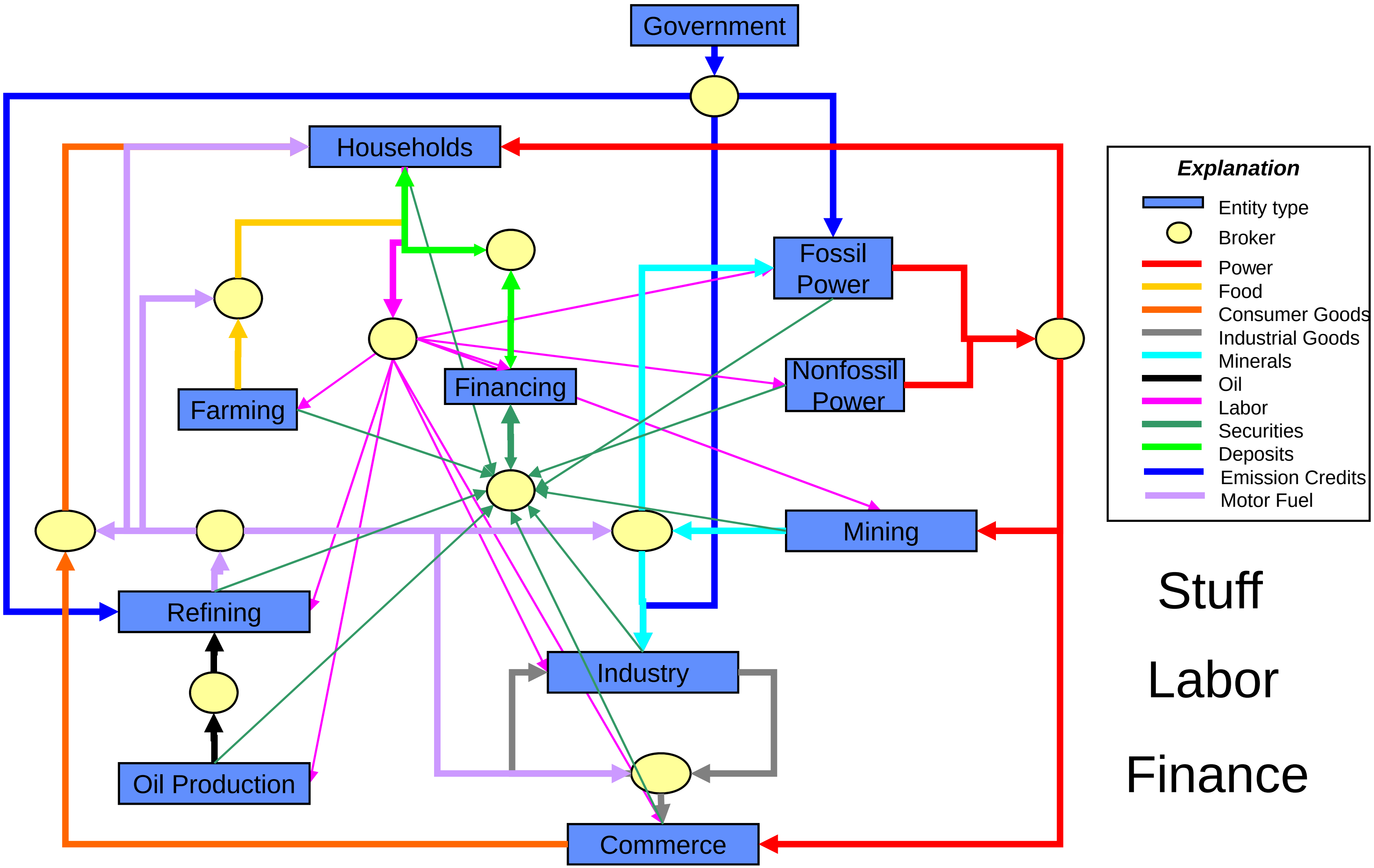
- Robust yet Fragile
- Structure
- Power laws



designed

adapted

SYSTEM: Core Economy

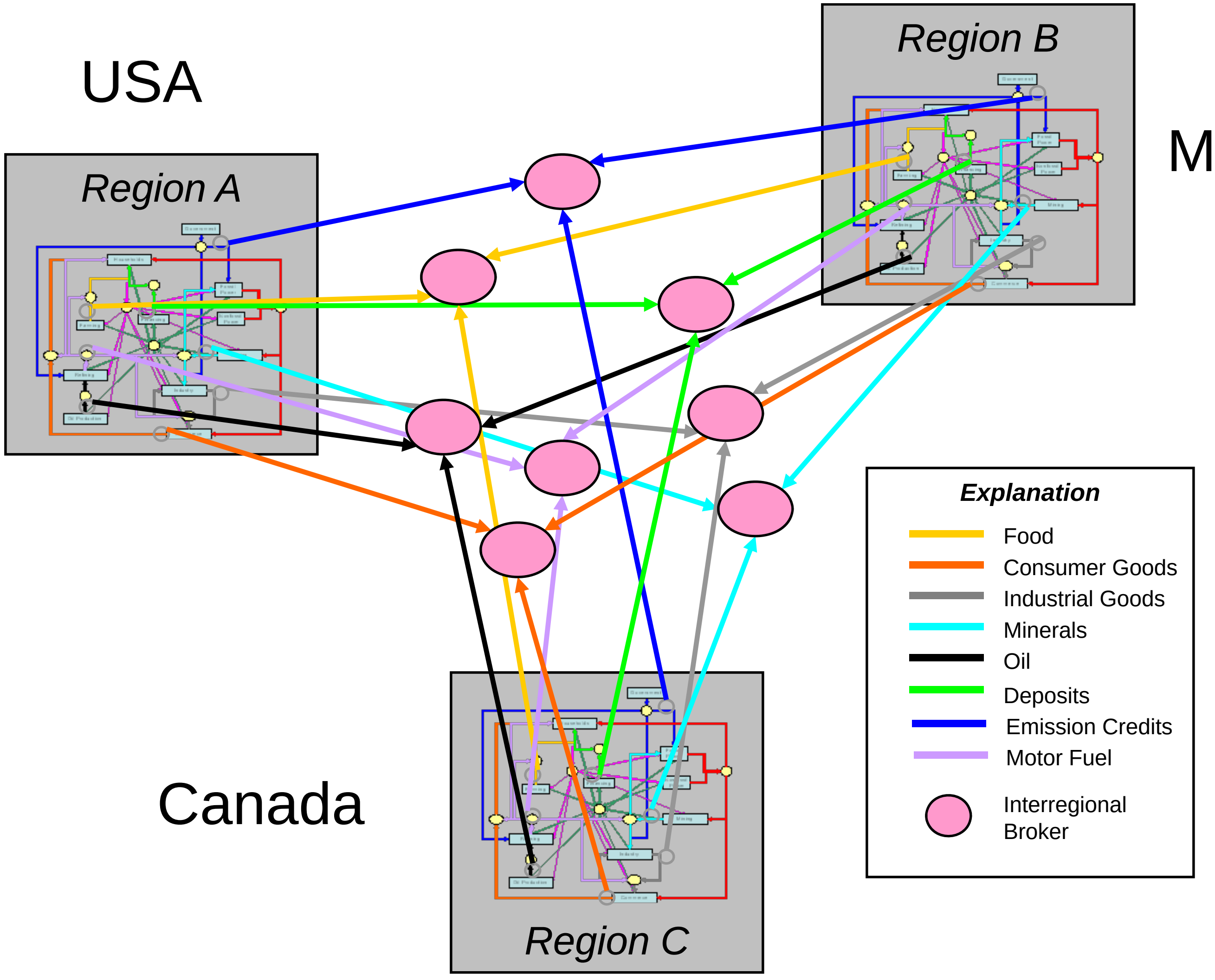


Stuff

Labor

Finance

SYSTEM OF SYSTEMS: Trading Blocks composed of Core Economies



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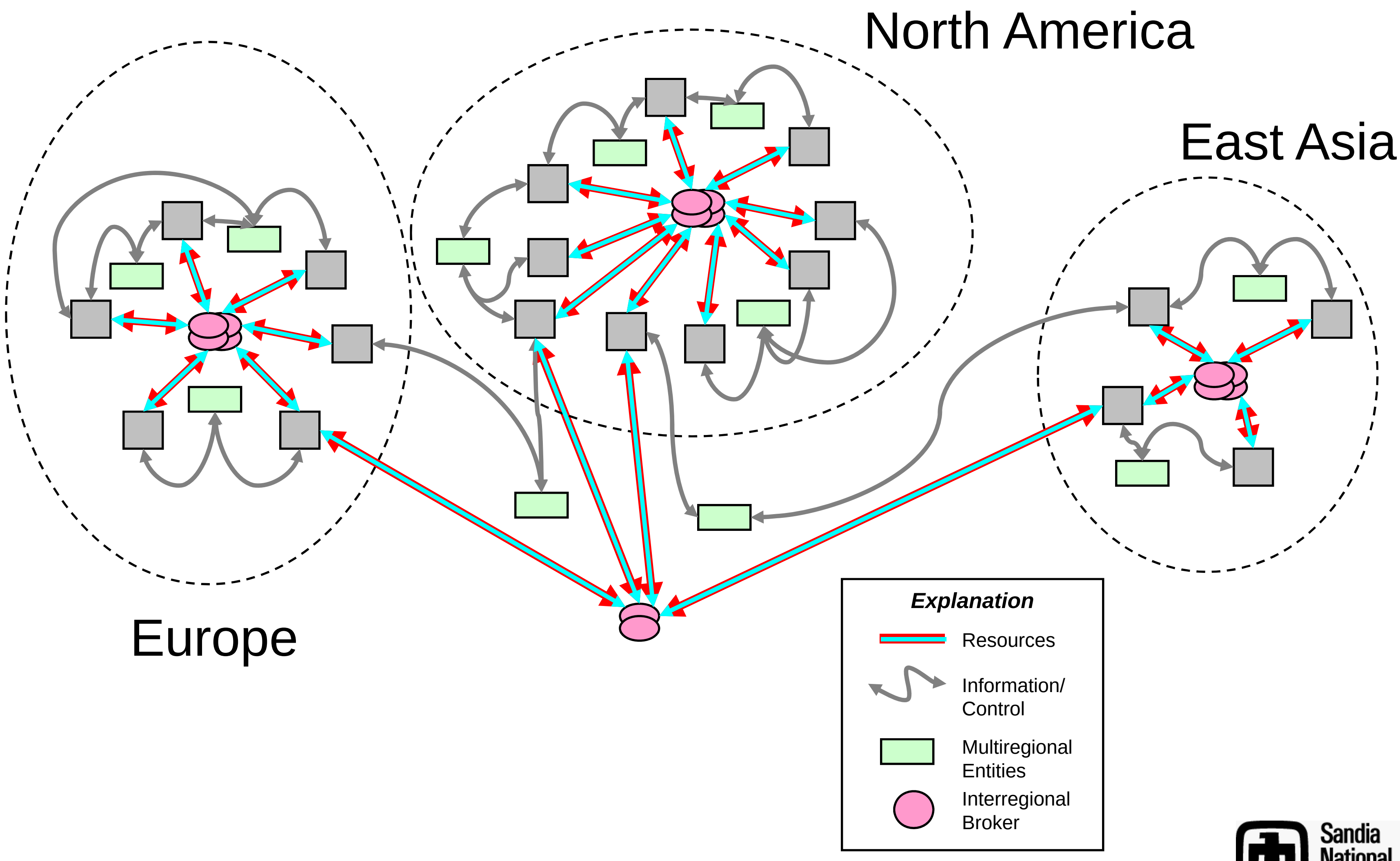
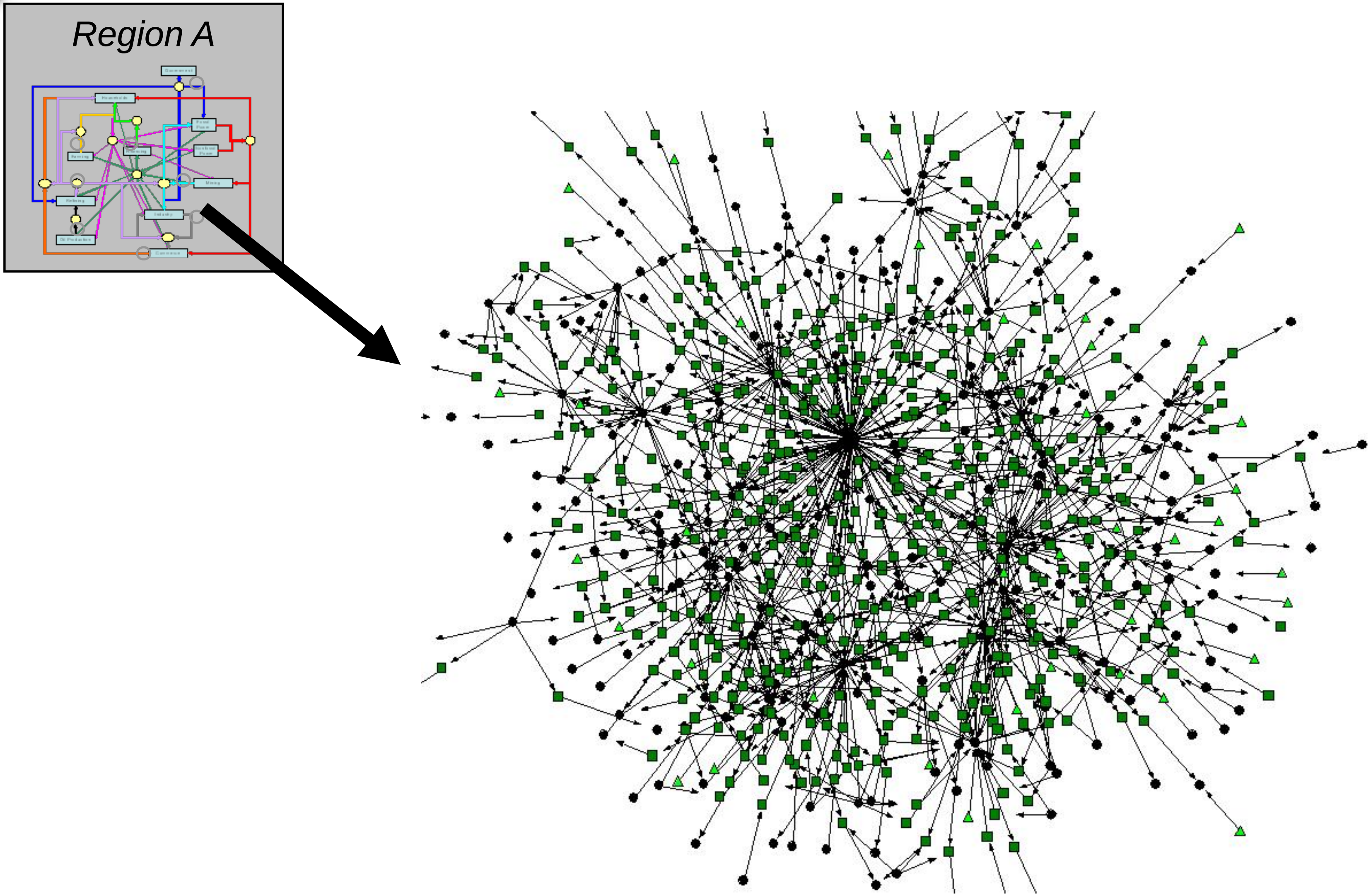
SYSTEM OF SYSTEM of SYSTEMS: Global Energy System



NETWORKS within NETWORKS



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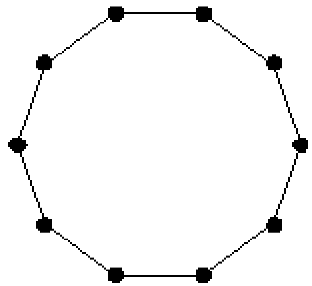
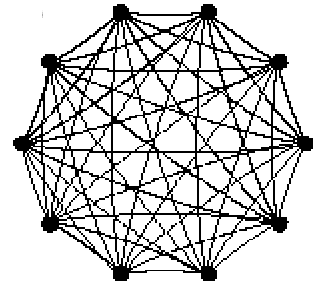
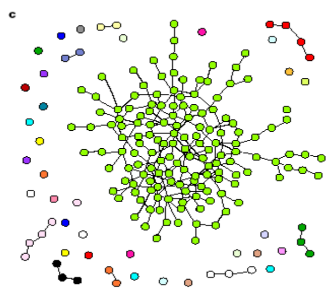
Idealized Network Topology

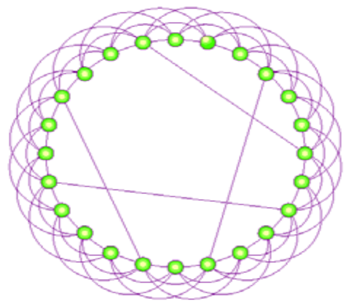
Regular

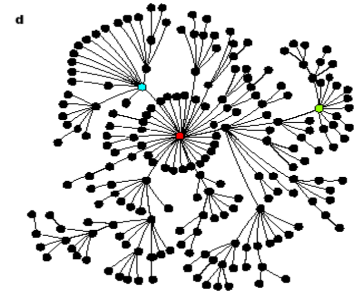




Fully connected







Degree
Distribution
Heavy-tailed

Random
“small world”
Erdos–Renyi

“Blended”
“clustering”
+
“small world”

“Scale-free”

Illustrations from Strogatz [2001].

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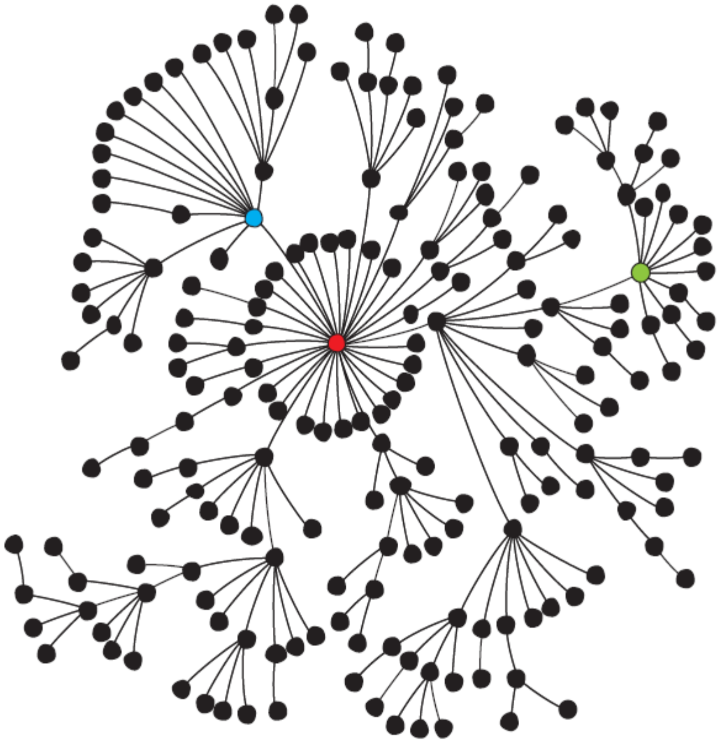
1999 Barabasi and Albert's "Scale-free" network



Simple Preferential attachment model: "*rich get richer*" yields Hierarchical structure with "King-pin" nodes

Properties:

tolerant to random failure…

vulnerable to informed attack

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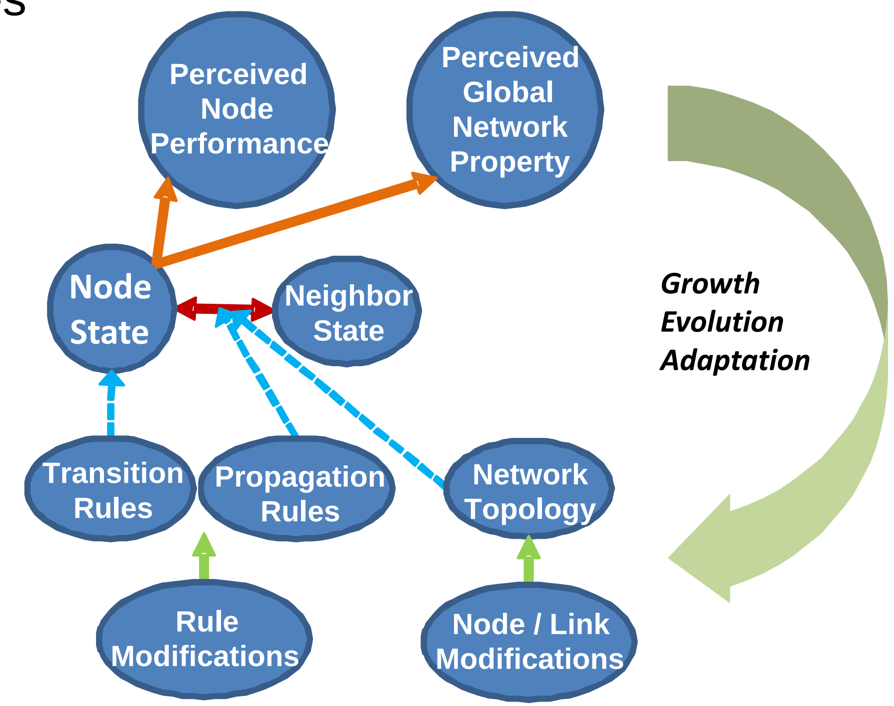
Conceptual Lens for Modeling/Thinking

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

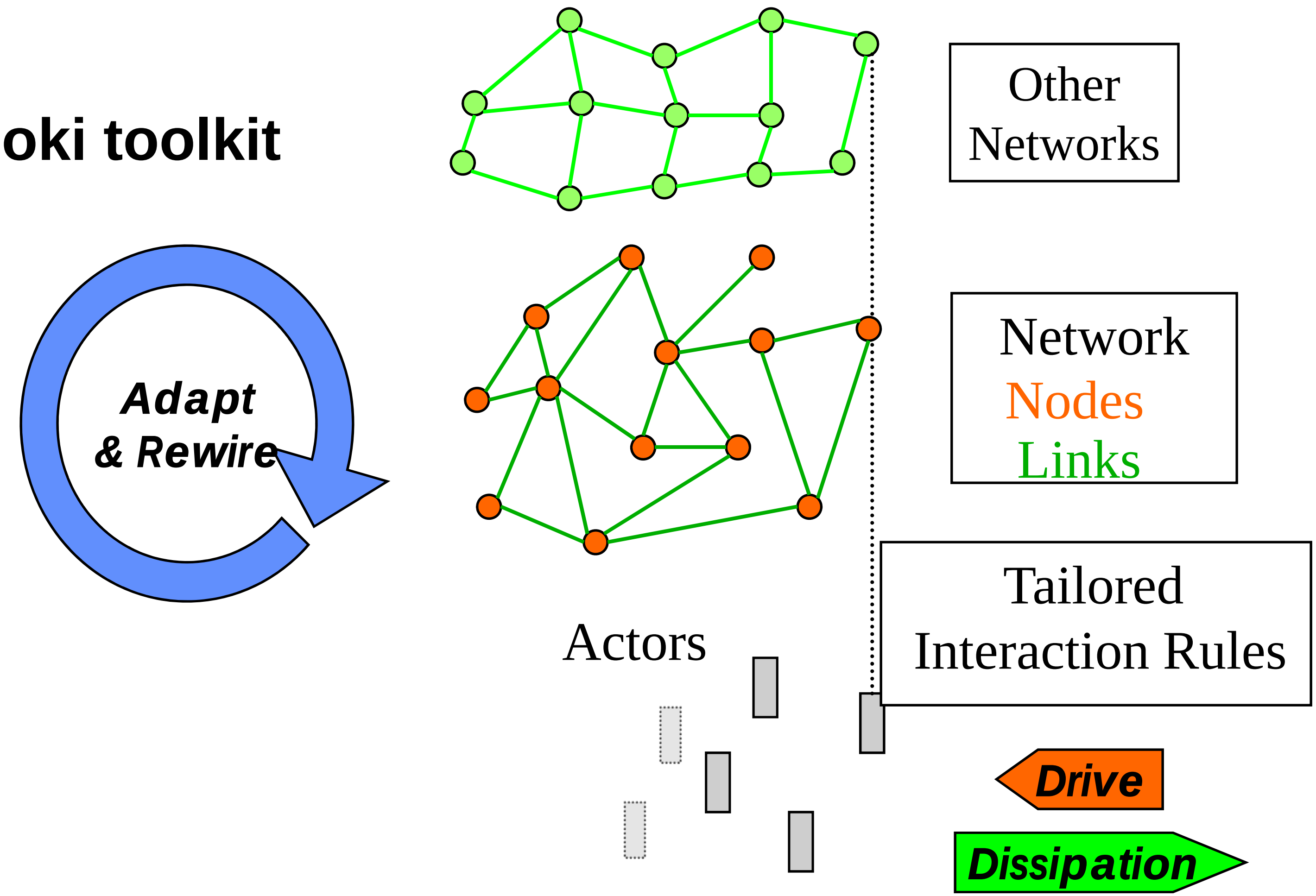
Connect nodes appropriately to form a system (network)

Connect systems appropriately to form a System of Systems



Graphical Depiction: Multi-Network Agent Based Modeling

Loki toolkit



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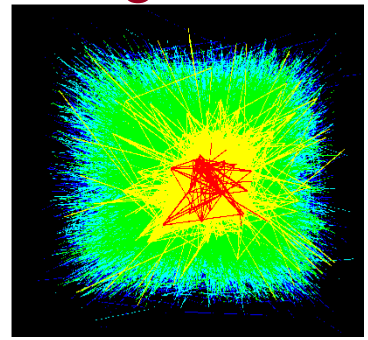
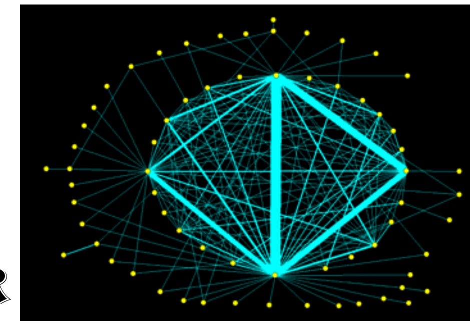
Loki Toolkit: Modeling and Analysis



Applications VERY Important



Re-Past & Jung 2003 → Polynet 2004 → LOKI 2005

LOKI 2005 →
- NET GENERATOR
- NET ANALYZER
- GENERALIZED BEHAVIOR
- POWER
- GAS
- INFECT
- SOCIAL
- OPINION
- PAYMENT
- CONTRACT

…

Modeling and analysis of multiple interdependent networks of agents,
e.g., Physical+SCADA+Market+Policy Forcing

CASoS Engineering

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** an artificial CASoS.

Similar Questions emerge

Within each category, three sets of similar questions naturally emerge:

- What are my **Choices**? What are their intended and unintended costs and benefits? How do I rank them?
- Can choices be made that are **uninfluenced by uncertainties**? How different would the system have to be to decide differently?
- Could we move towards conditions that enable choices to work better or yield better choices and end conditions?

The first of these sets has to do with ***Decision***, the second with the ***Robustness of Decision***, and the third with ***Evolving the System towards Resilience***. All of these have to do with ***Informing Policy***.

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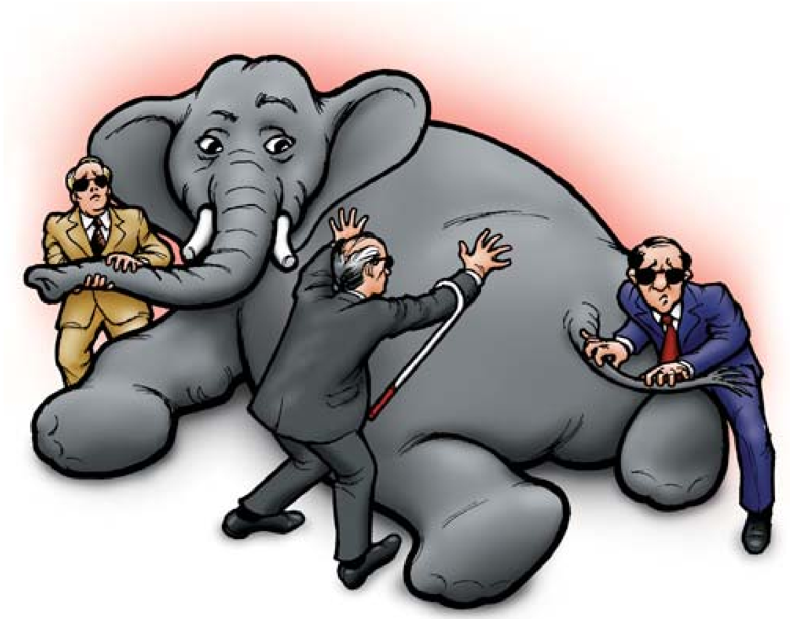
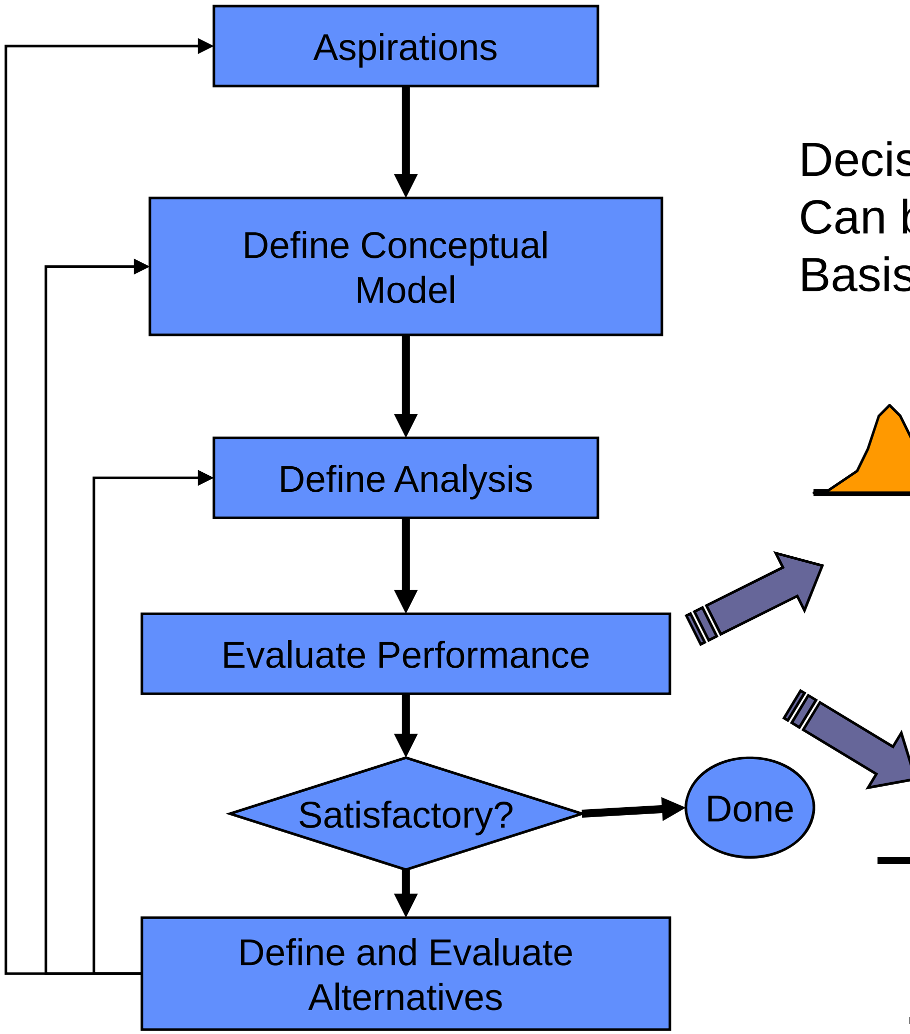
Uncertainty

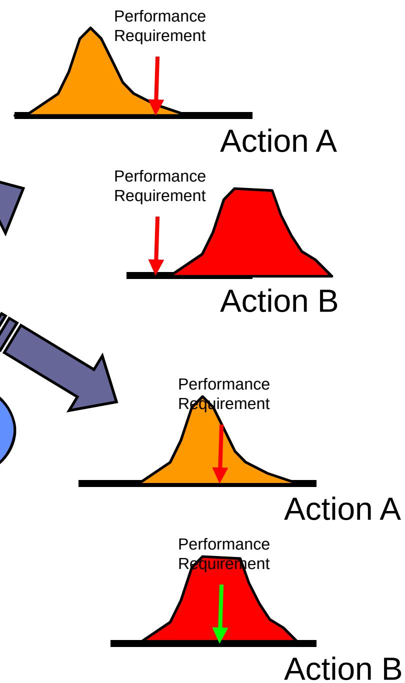
- Aspects of Complex systems can be unpredictable (e.g. BTW sandpile, …)
- Adaptation, Learning and Innovation
- Conceptual model or Structural uncertainty
  - Beyond parameters
  - Beyond IC/BC



Model development: an iterative process that uses uncertainty



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



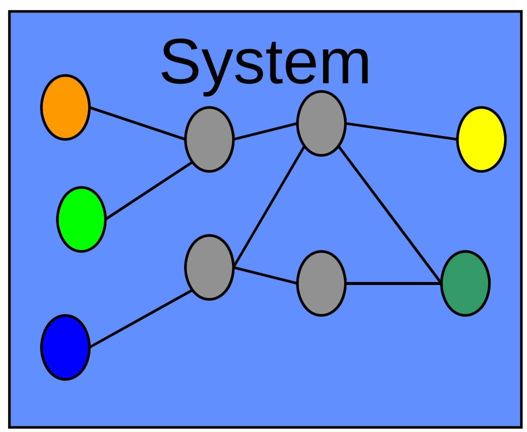
Model uncertainty permits distinctions

Model uncertainty obscures important distinctions, and reducing uncertainty has value

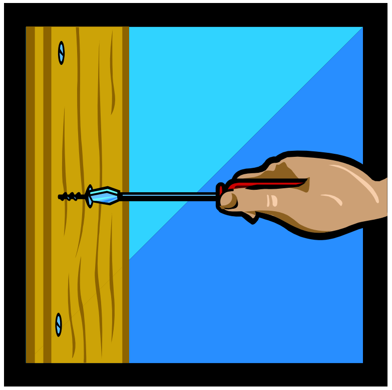
Finding the right model

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

What to we care about?



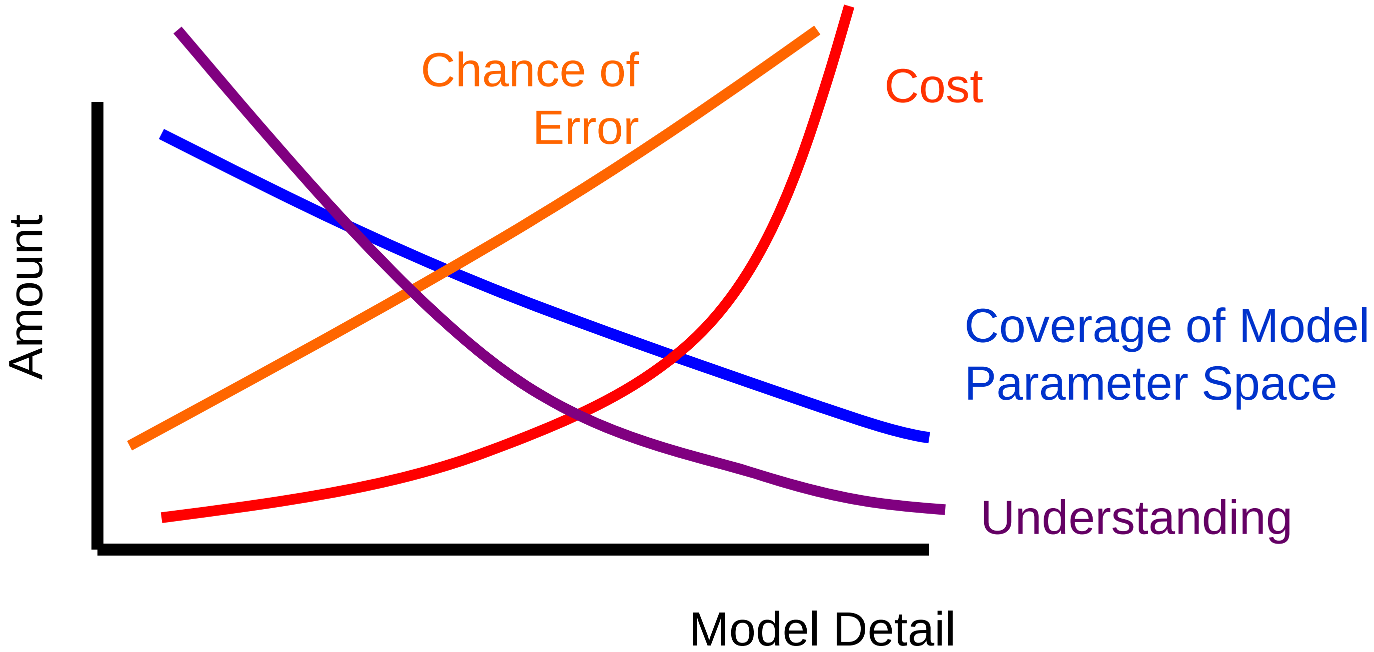
What can we do?



Model

Additional structure and details added *as needed*

Pragmatic Detail : More can be less



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

Engineering within a CASoS: Example

Three years ago on Halloween 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.

Pandemic now.

No Vaccine, No antiviral.
What could we do?

Chickens being burned in Hanoi

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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

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Analogy with other Complex Systems

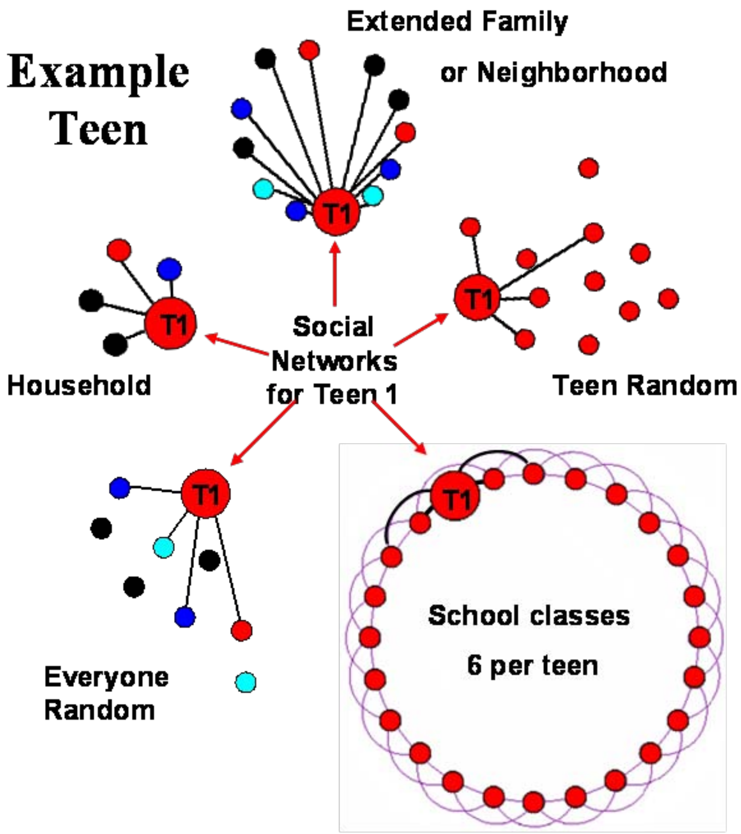
Simple analog:

- **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.

Aspirations:

- 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?

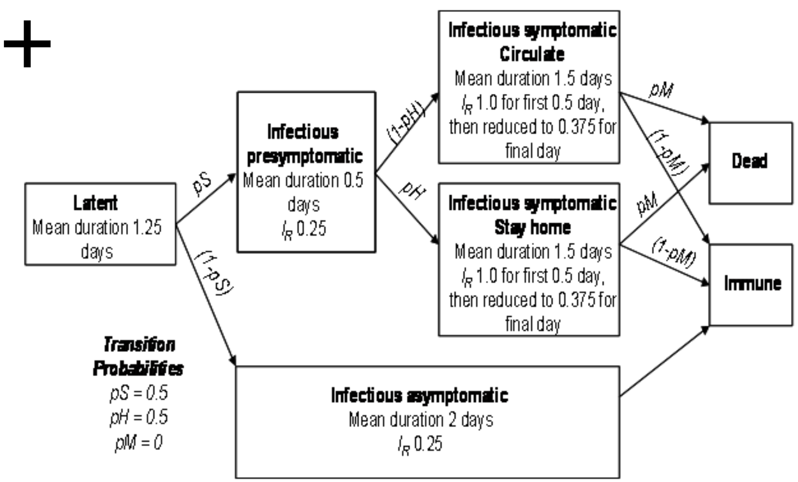
Application of Networked Agent Method to Influenza



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

+

Disease manifestation
(node and link behavior)



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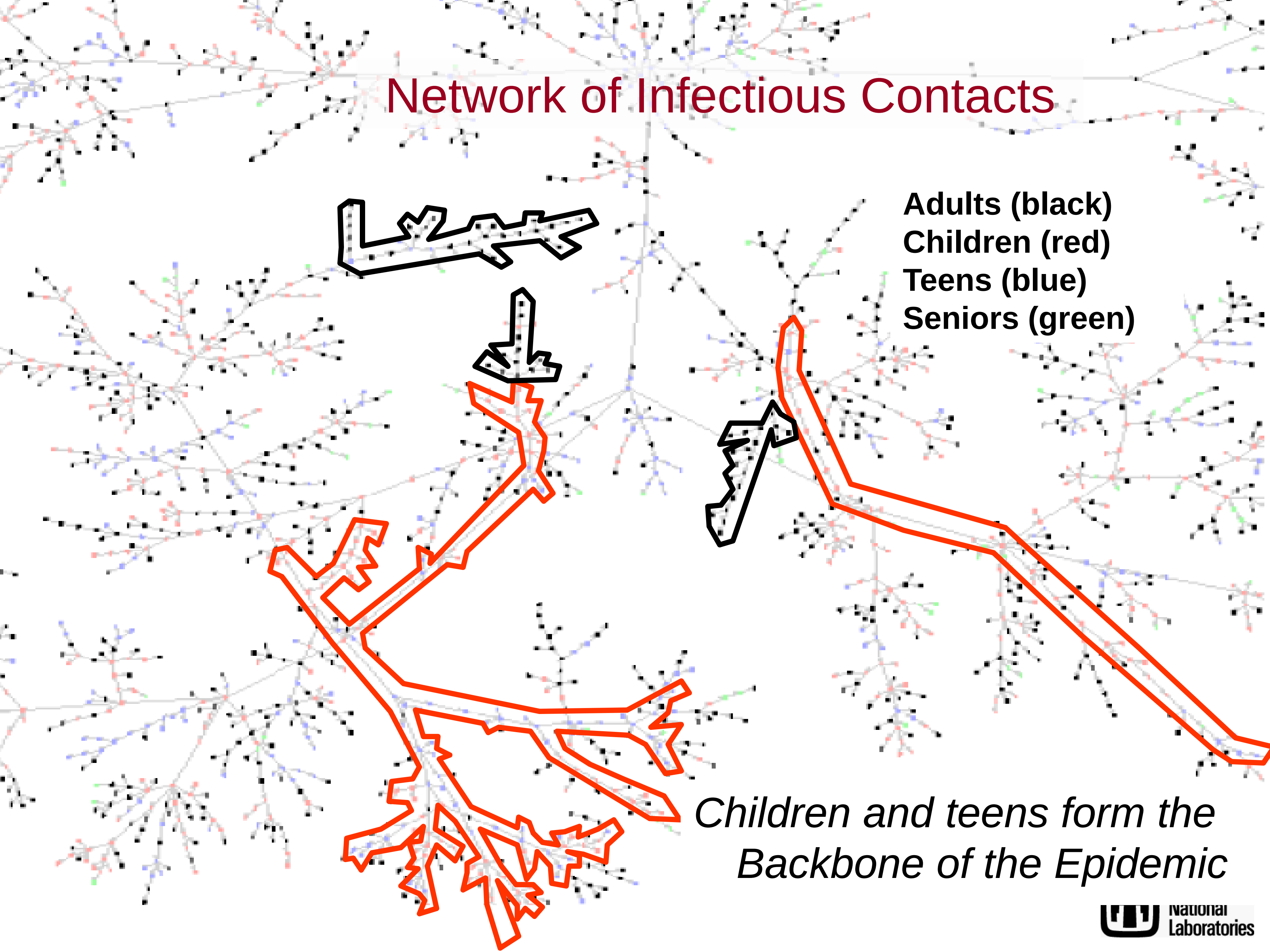
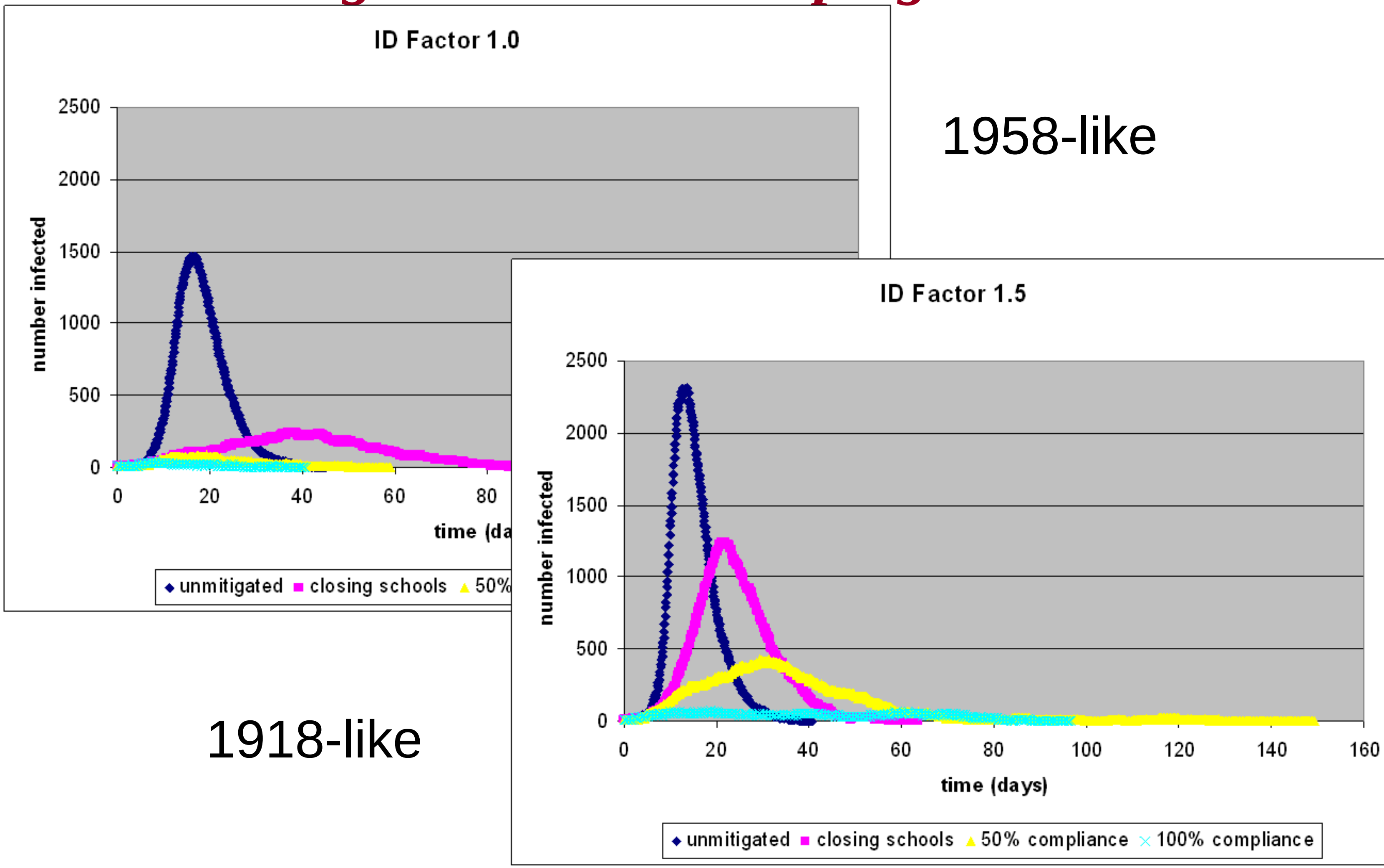
Network of Infectious Contacts



Children and teens form the Backbone of the Epidemic

Closing Schools and Keeping the Kids Home



1958-like

1918-like

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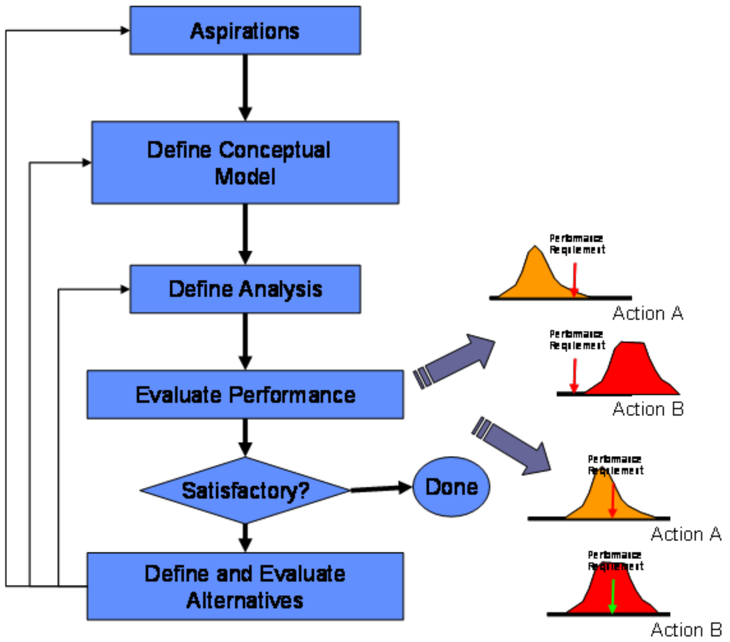
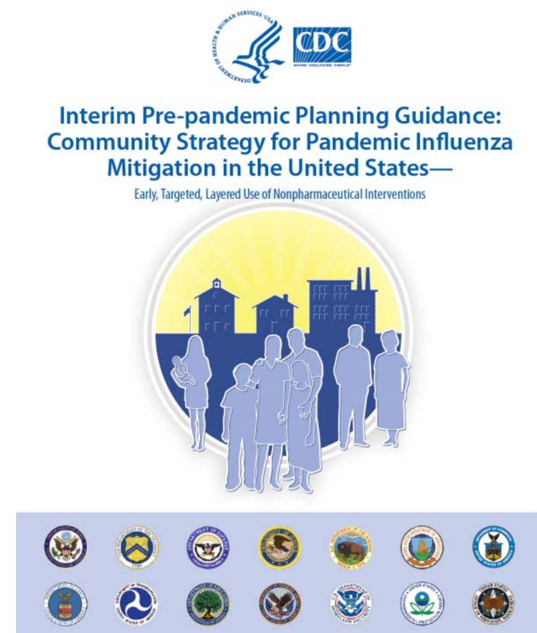
Connected to White House Pandemic Implementation Plan writing team and VA OPHEH

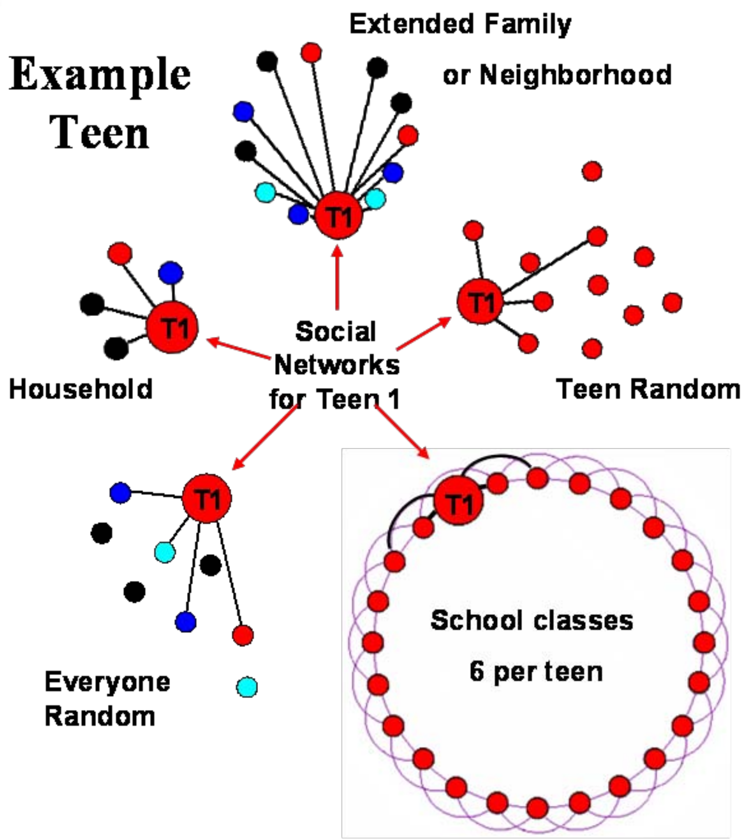




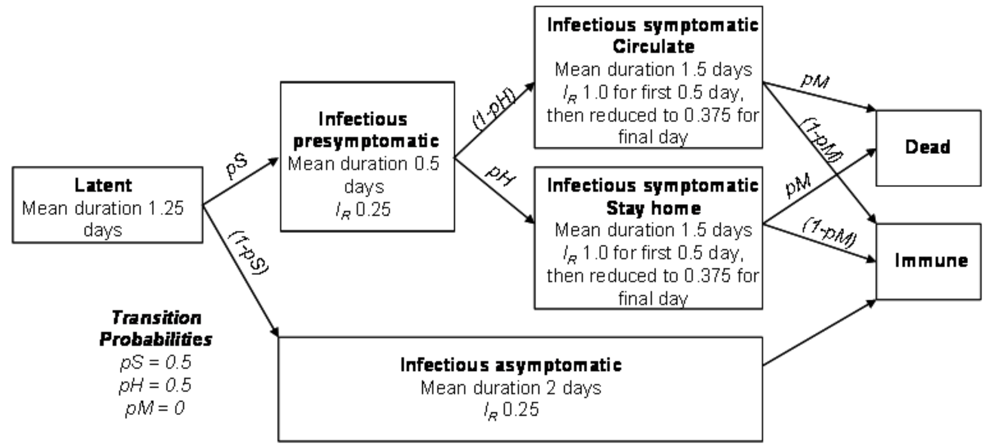
We extended the model and put it on Tbird… 10's of millions of runs later we had the answers to:

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

Application: Community Containment for Pandemic Influenza



Social Contact Network



Disease Manifestation

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.

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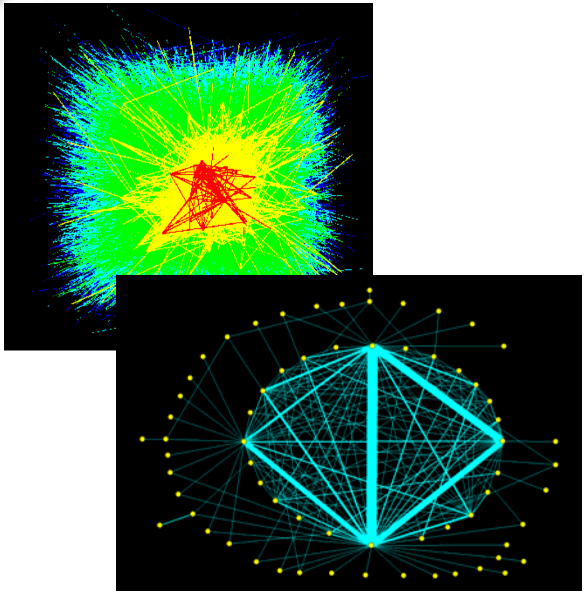
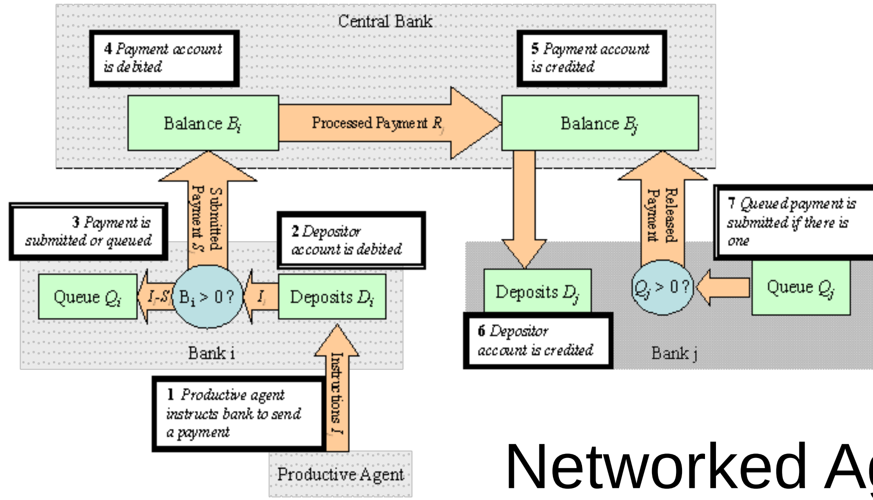
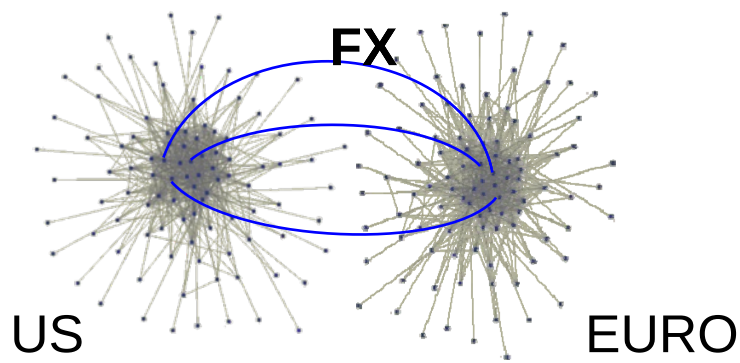
Application: Congestion and Cascades in Payment Systems



Payment system network



Networked Agent Based Model



Global interdependencies

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.

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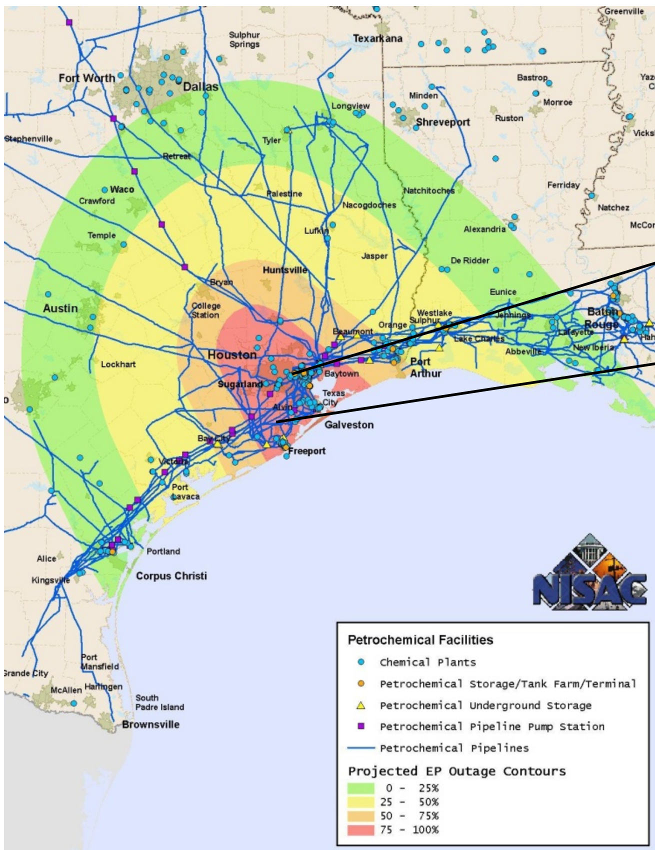
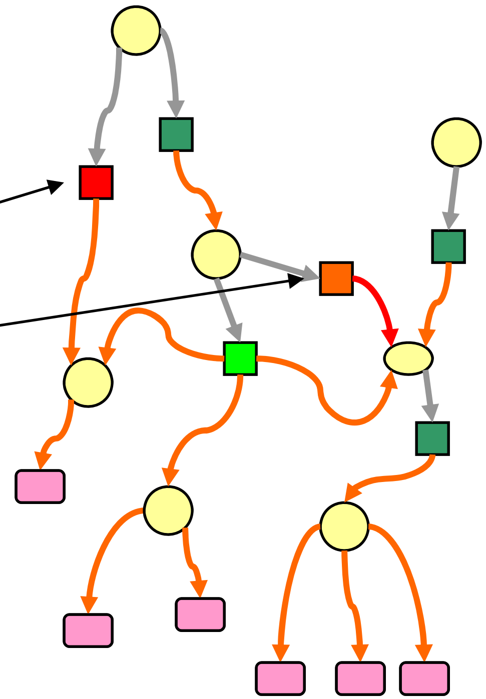
Application: Industrial Disruptions

Disrupted Facilities

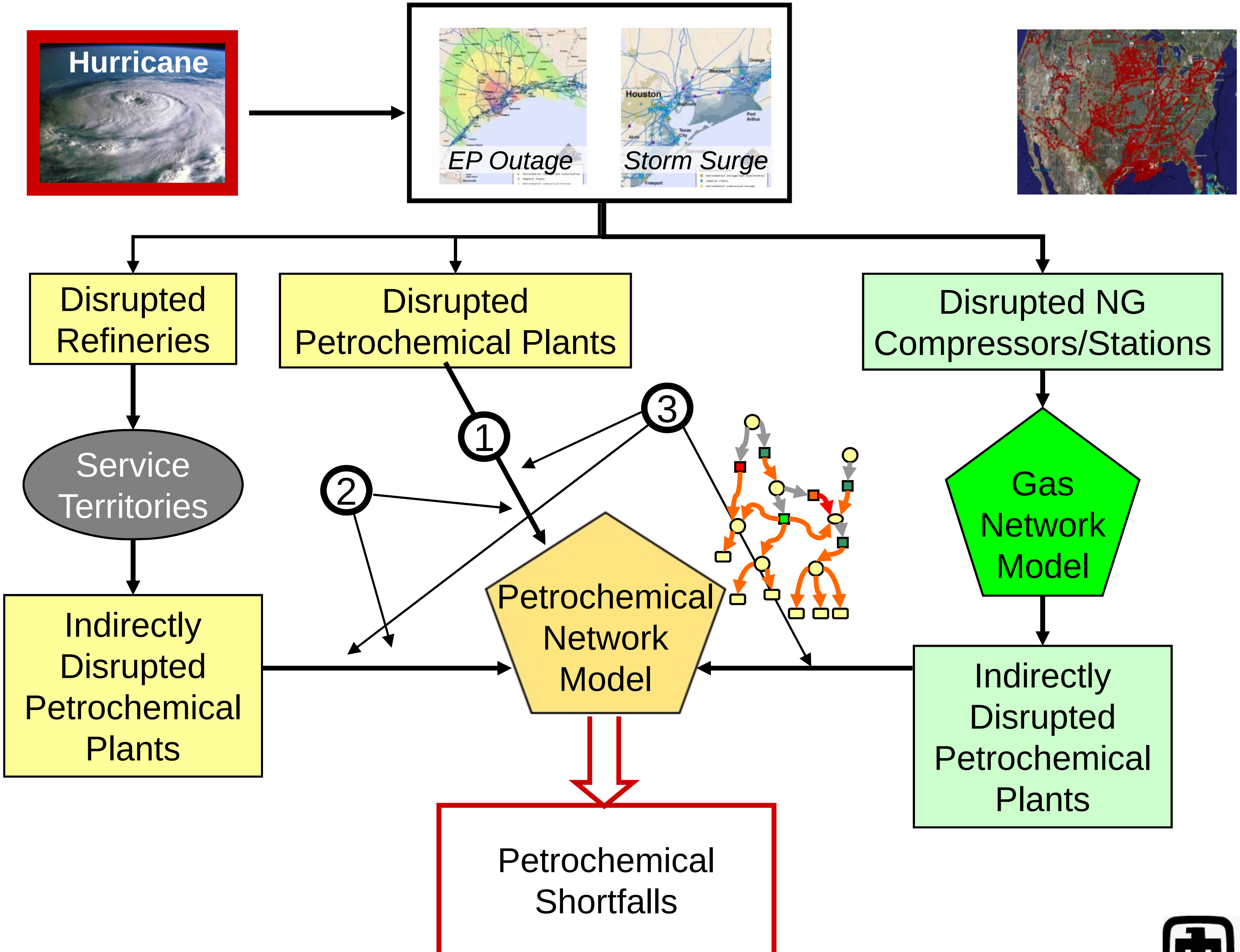
Reduced Production Capacity



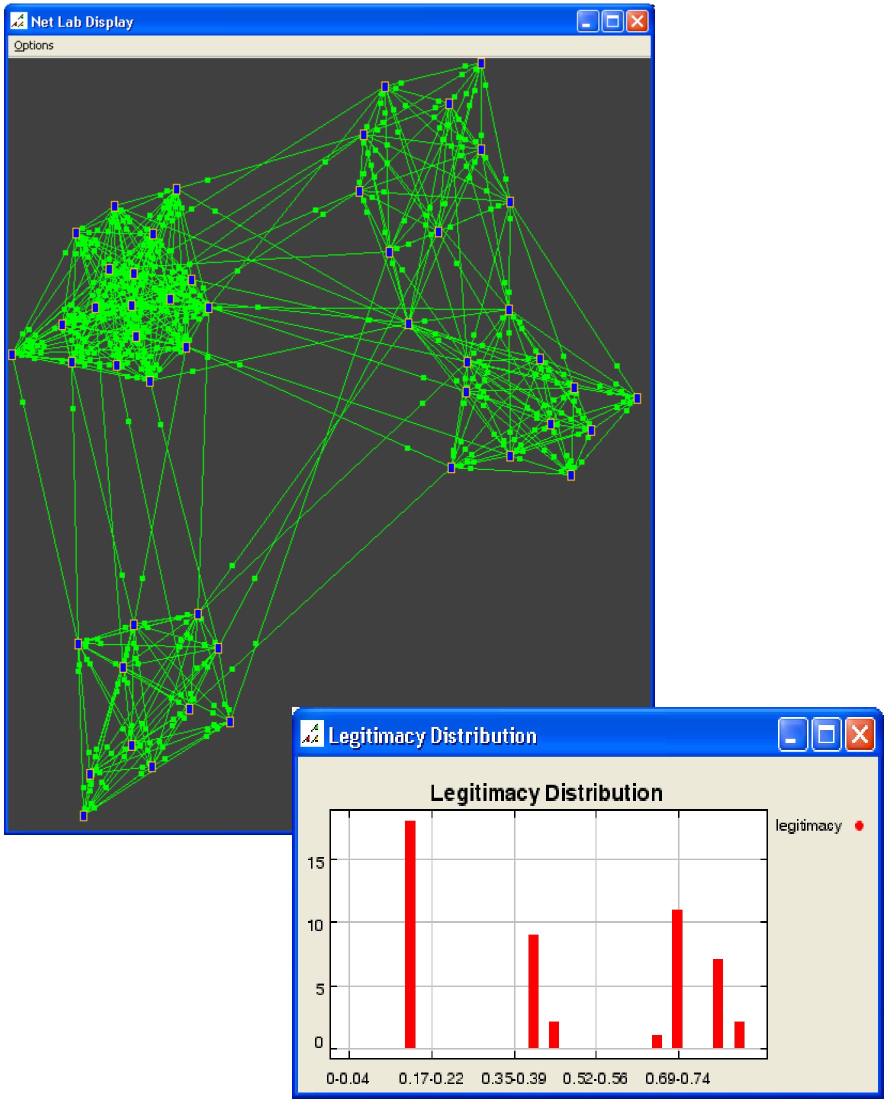


Diminished Product Availability

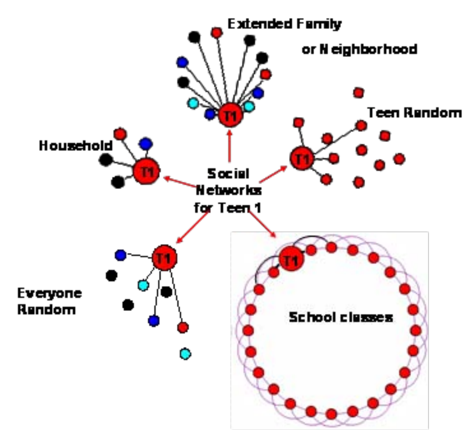
Application: Petrochemical & Natural Gas



Application: Group Formation and Fragmentation



- Step 1: Opinion dynamics: tolerance, growing together, antagonism
- Step 2: Implementation of states with different behaviors (active, passive)
- Consider self organized extremist group formation, activation, dissipation
- **Application:** Initialization of network representative of community of interest



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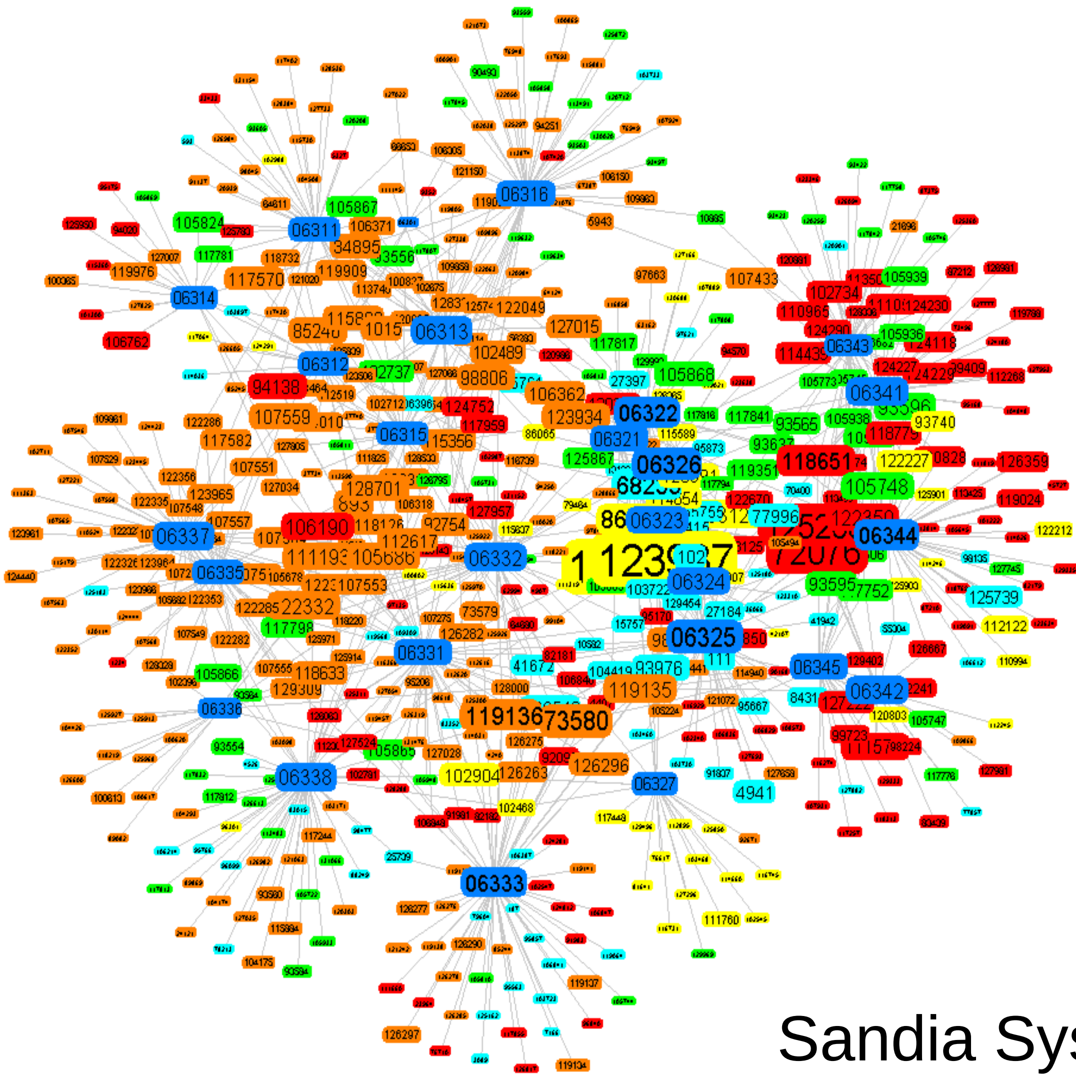
Application: Engineering Corporate Excellence



Step 1:

- Render the Corporation as a set of networks:
  - Individuals
  - Organizations
  - Projects
  - Communication (email, telephone, meetings
  - Products (presentations, reports, papers)
- Investigate structure and statistics in time
- Develop network measures of organizational Health

Step 2:

- Conceptual modeling…

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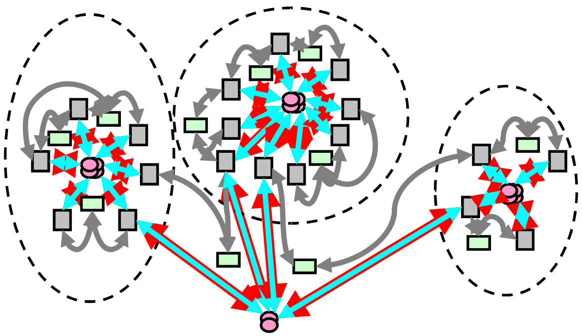
CASoS Engineering

- 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**
- Example efforts across a variety of Funders:
  - Global Financial System (DHS-Federal Reserve)
  - Global Energy System (DOE)
  - Health Care Systems (DVA)
  - Cascading in Interdependent Networks (DOE-DHS)
  - Building out the critical national infrastructures (NISAC)
  - Educational systems
  - Agricultural systems
  - Food distribution systems



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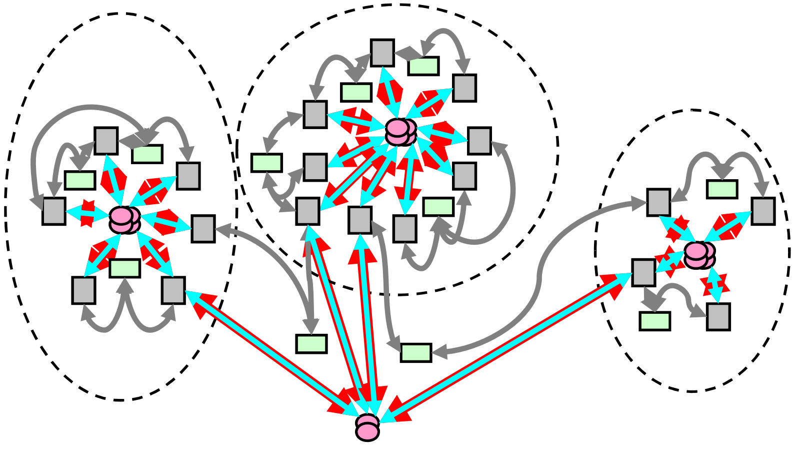
CASoS Engineering:
An Opportunity and Challenge for Educating the next generation of Engineers and Problem Solvers



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