Engineering Change in Socio-Technical Systems

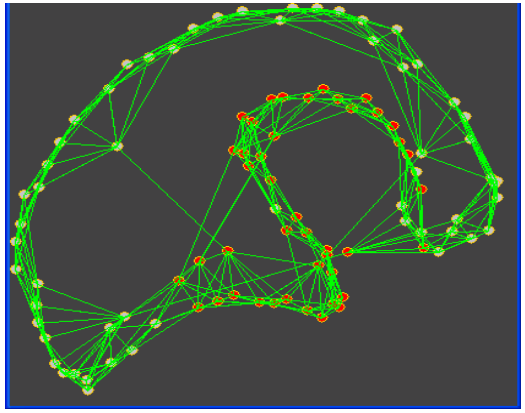
Robert Glass and Walt Beyeler

Sandia National Laboratories

1st Workshop on Information Sharing for Financial IT Infrastructure: Barriers and Opportunities

Rome - October 11th, 2010

Università di Roma "La Sapienza"



Slides pulled from presentations posted at:
http://www.sandia.gov/casos/

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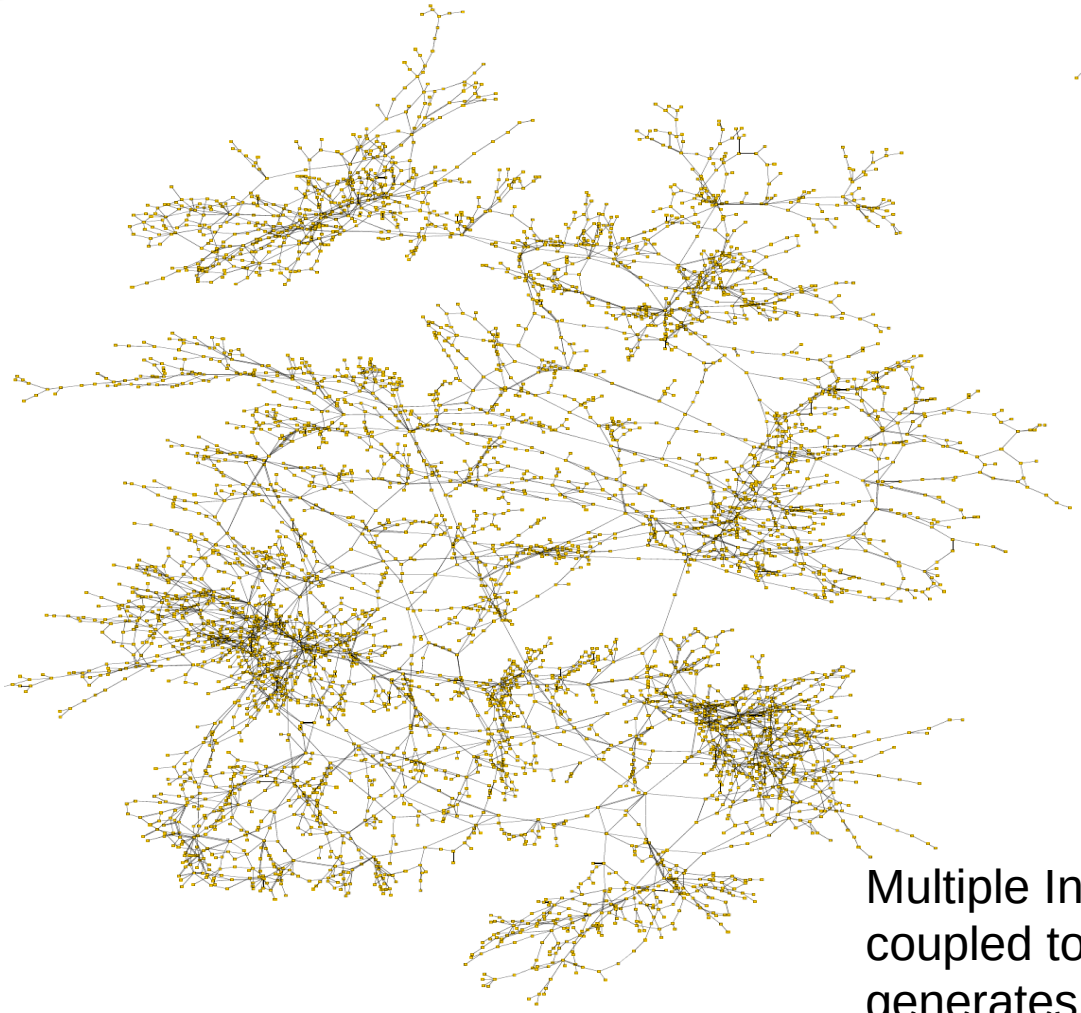
Infrastructures are Complex Adaptive Systems of Systems or “CASoS”



Western Power Grid (WECC),
69 kev lines and above

People design, use, construct, maintain, evolve...

LOAD & DRIVE

Multiple Interdependent Infrastructures coupled to socio-economic activity that generates both a Load and a Drive

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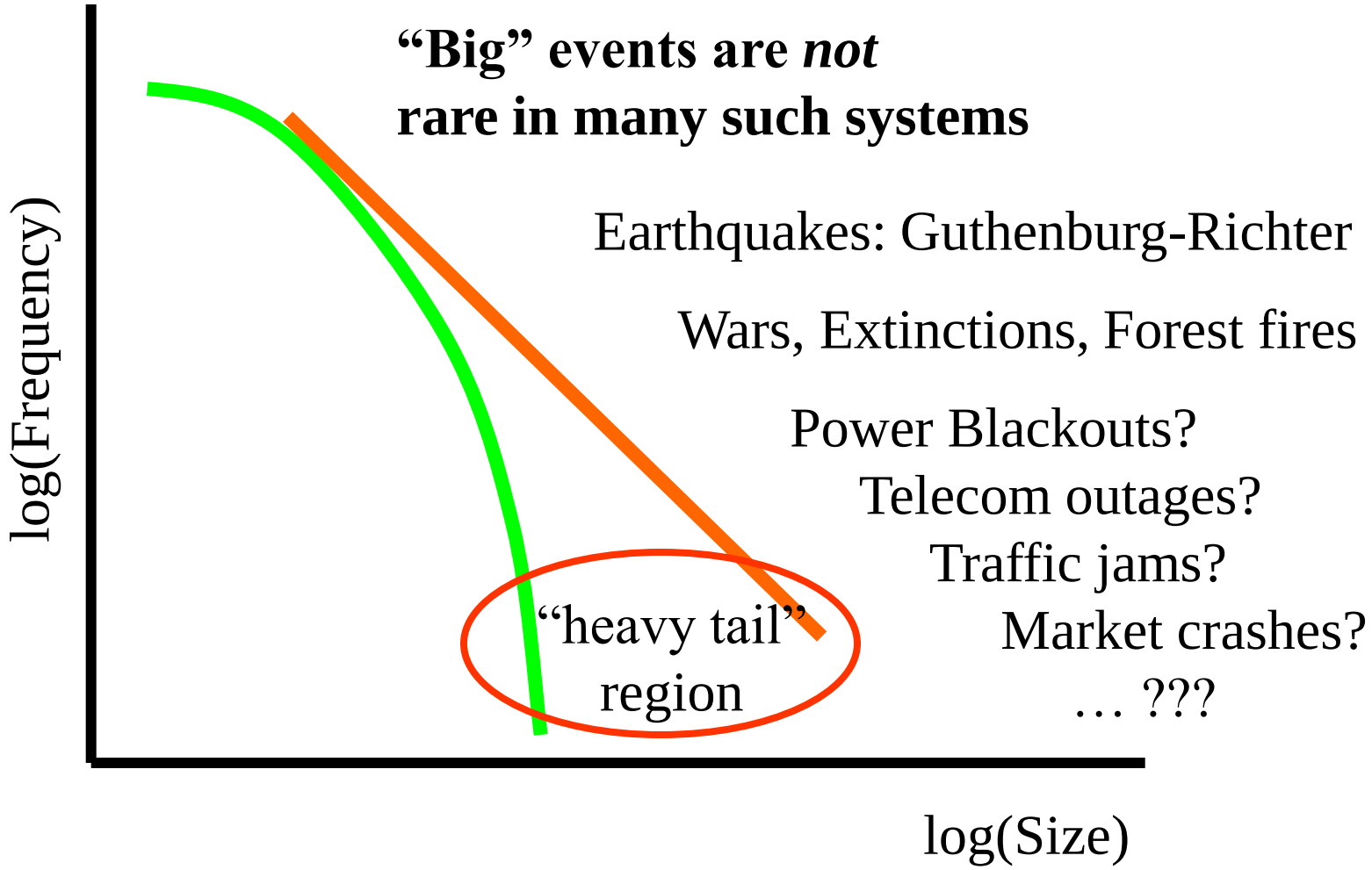
COMPLEX: Emergent Behavior



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COMPLEX: Emergent Structure

Food Web

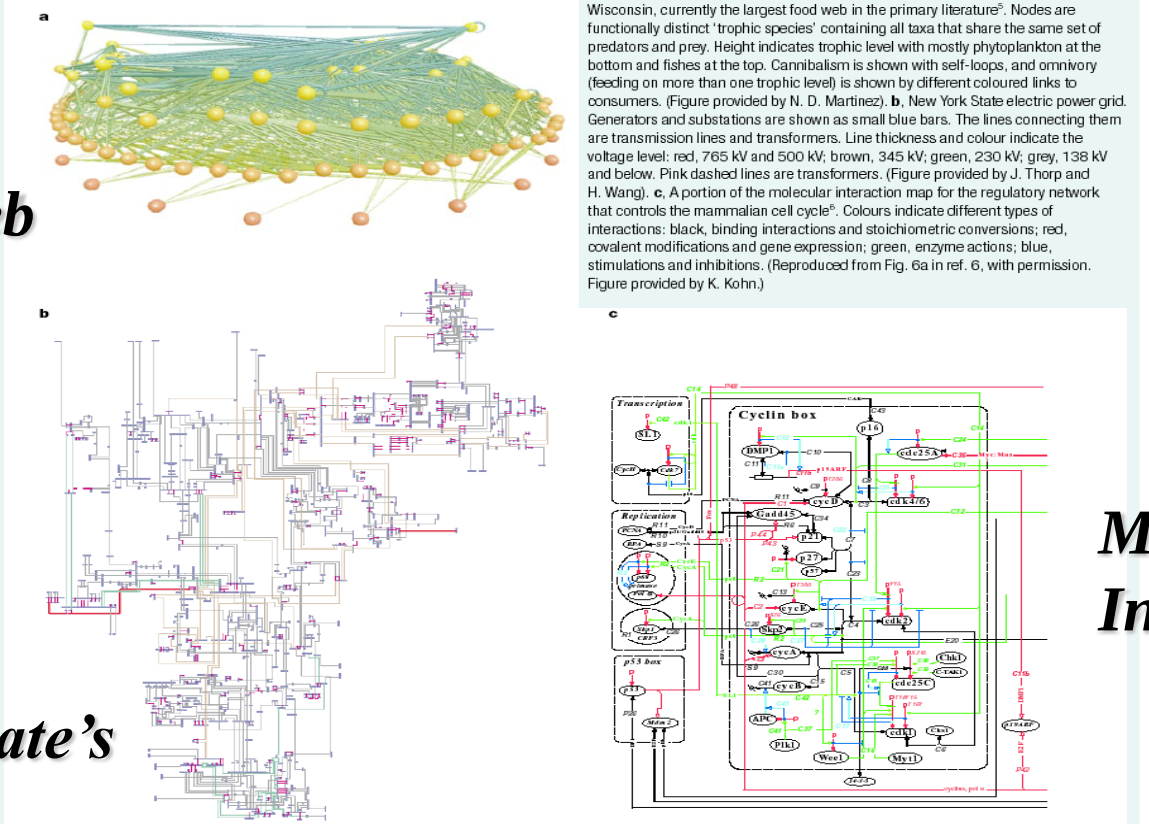

Figure 1 Wiring diagrams for complex networks. **a**, Food web of Little Rock Lake, Wisconsin, currently the largest food web in the primary literature[5]. Nodes are functionally distinct 'trophic species' containing all taxa that share the same set of predators and prey. Height indicates trophic level with mostly phytoplankton at the bottom and fishes at the top. Cannibalism is shown with self-loops, and omnivory (feeding on more than one trophic level) is shown by different coloured links to consumers. (Figure provided by N. D. Martinez). **b**, New York State electric power grid. Generators and substations are shown as small blue bars. The lines connecting them are transmission lines and transformers. Line thickness and colour indicate the voltage level: red, 765 kV and 500 kV; brown, 345 kV; green, 230 kV; grey, 138 kV and below. Pink dashed lines are transformers. (Figure provided by J. Thorp and H. Wang). **c**, A portion of the molecular interaction map for the regulatory network that controls the mammalian cell cycle[6]. Colours indicate different types of interactions: black, binding interactions and stoichiometric conversions; red, covalent modifications and gene expression; green, enzyme actions; blue, stimulations and inhibitions. (Reproduced from Fig. 6a in ref. 6, with permission. Figure provided by K. Kohn.)

New York state's Power Grid

Molecular Interaction

Illustrations of natural and constructed network systems from Strogatz [2001].

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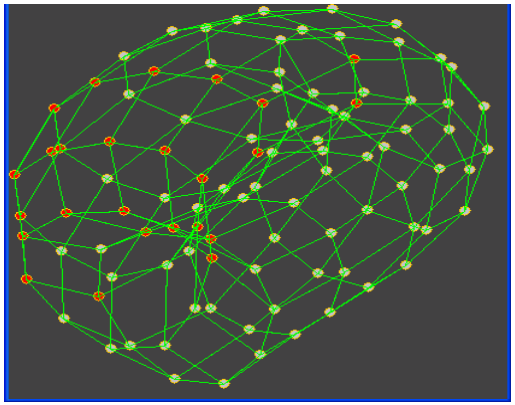
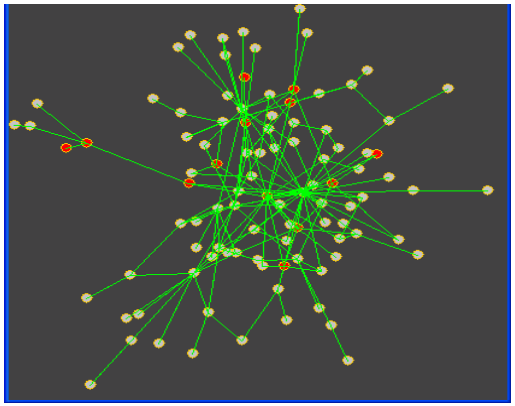
ADAPTIVE: Grow and Adapt

Temporal
Spatial
Relational
Multiple Scales





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

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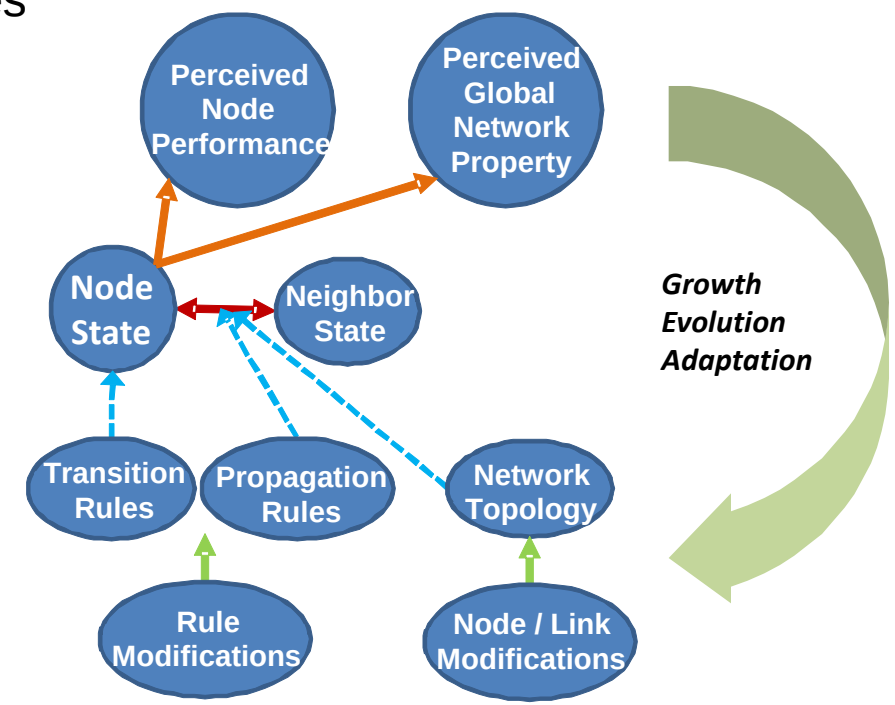
Conceptual Lens for Modeling/Design

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



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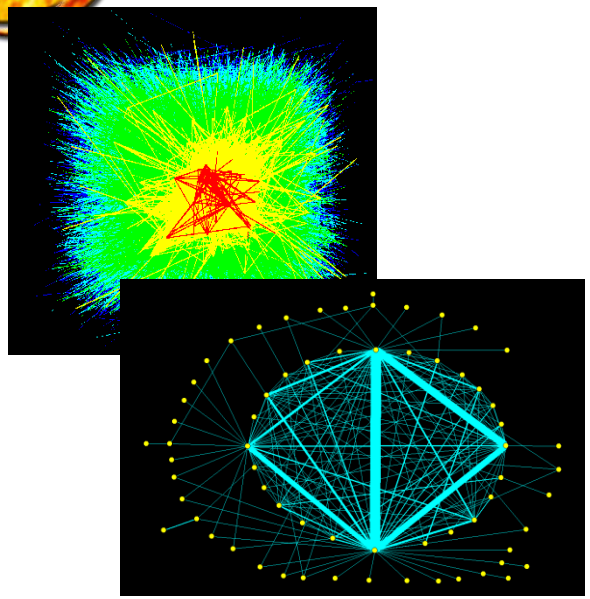
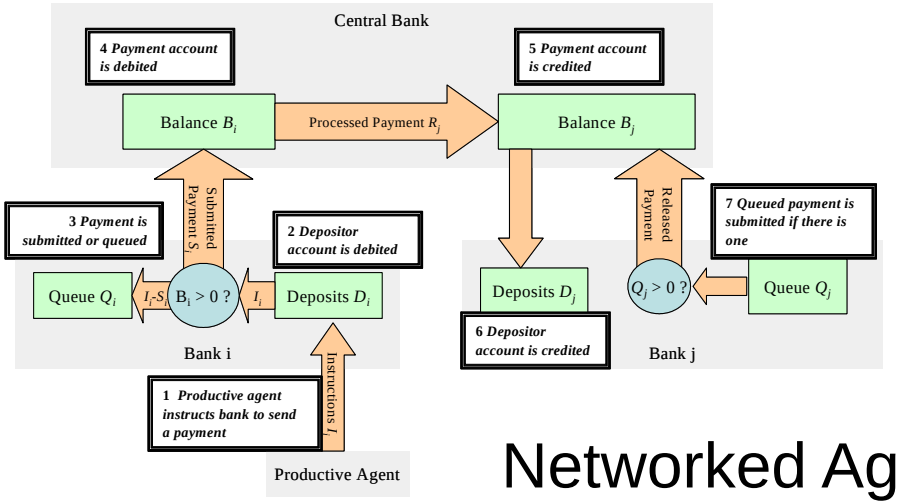
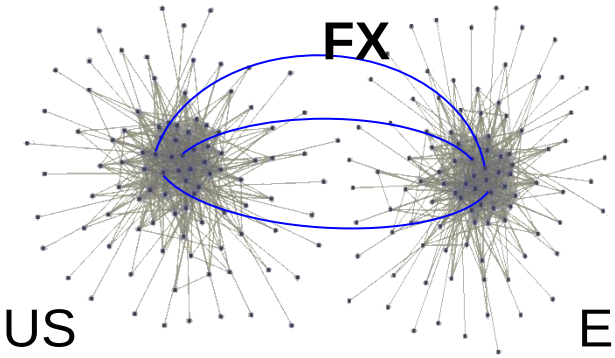
Application: Congestion and Cascades in Payment Systems



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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CASoS Engineering

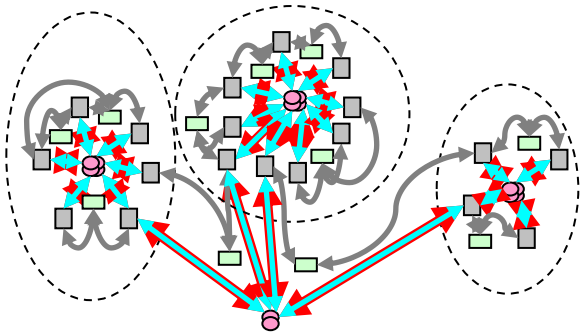
- Harnessing the tools and understanding of Complex Systems, Complex Adaptive Systems, and Systems of Systems to Engineer solutions for some of the worlds biggest, toughest problems:

The CASoS Engineering Initiative

See: Sandia National Laboratories: A Roadmap for the Complex Adaptive Systems of Systems CASoS) Engineering Initiative, SAND 2008-4651, September 2008.

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

http://www.sandia.gov/casos/



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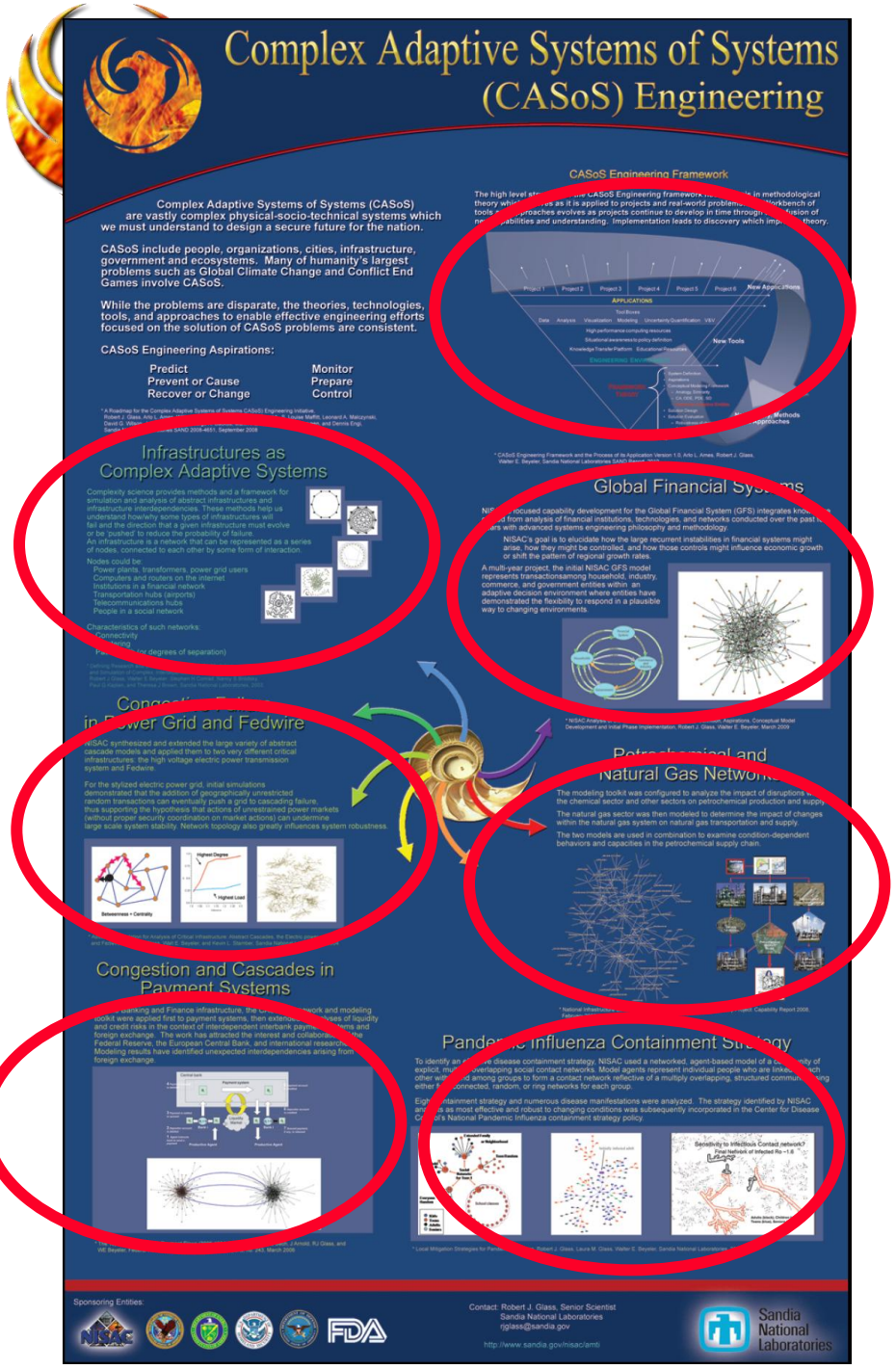
2003: Advanced Methods and Techniques Investigations (AMTI)

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



Engineering Change within CASoS:

- General infrastructures
- Congestive Failure
  - Power Grids
  - Payment systems (Fedwire: financial transfer system)
- Coupled payment systems (Fedwire: FX market: Target)
- Pandemics
- Petrochemicals and Natural gas networks
- Global Financial Systems
- … Combining understanding across all CASoS application domains

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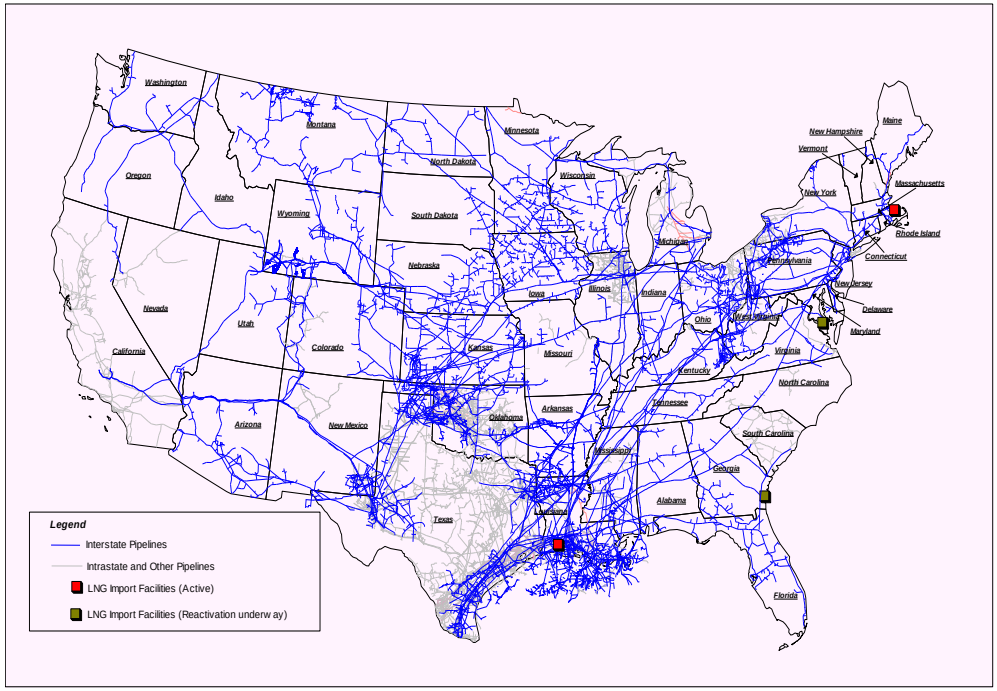
National Infrastructure Simulation and Analysis Center (NISAC)



Source: Energy Information Administration, Office of Oil & Gas

Active Refinery Locations, Crude and Product Pipelines

Multiple Interdependent infrastructures

Consequences of Perturbations
- Economic
- Social

Systemic Risk

…

NISAC

Los Alamos

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Socio-Technical Systems

Socio-Technical Systems are:

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

Socio-Technical Systems are

Complex

Adaptive

Systems of Systems

or "CASoS"

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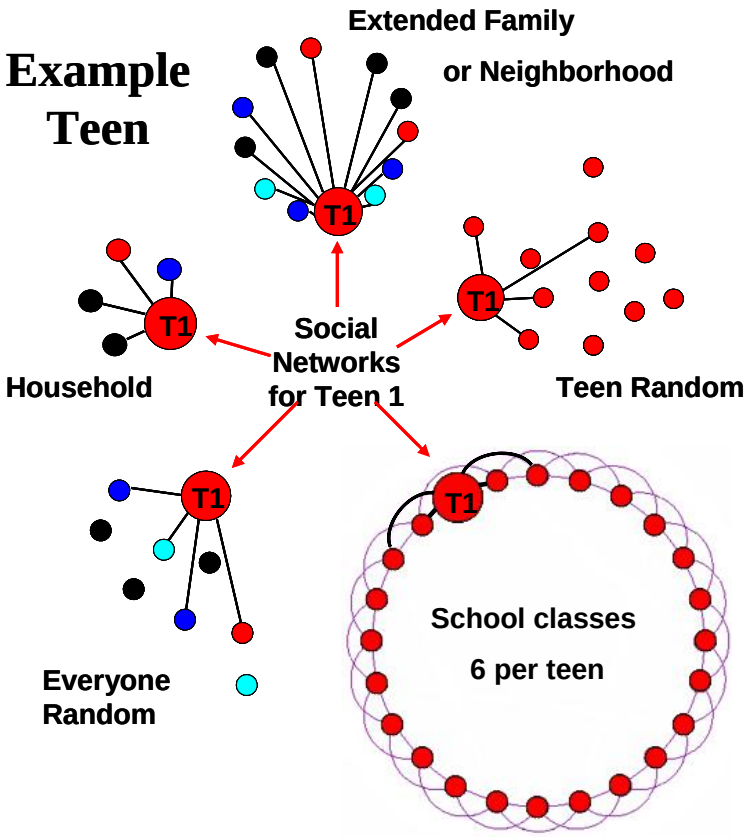
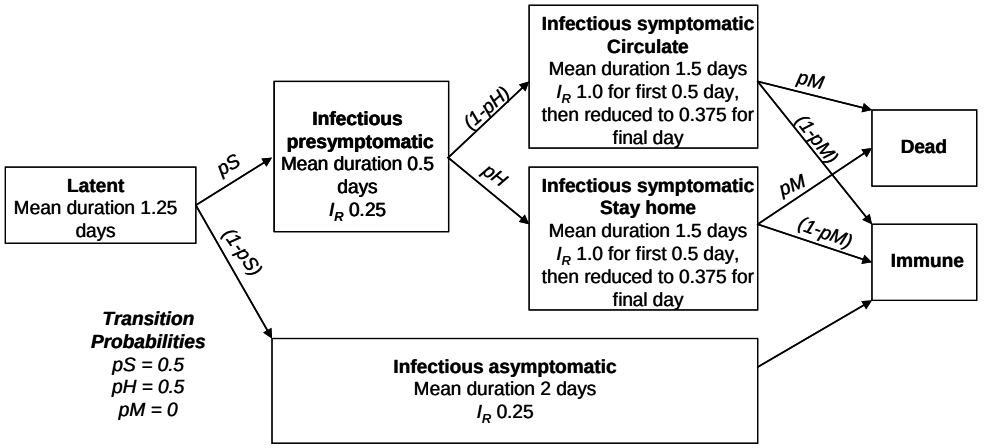
Application: Community Containment for Pandemic Influenza



Social Contact Network



Disease Manifestation

For Details see:

Local Mitigation Strategies for Pandemic Influenza, RJ Glass, LM Glass, an 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.

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.

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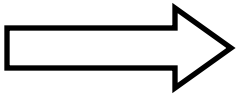
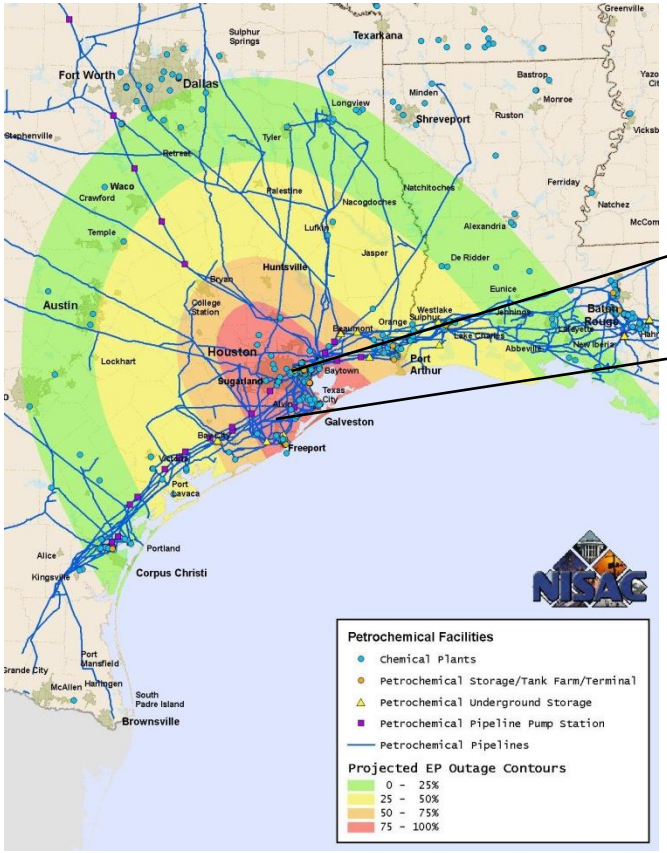
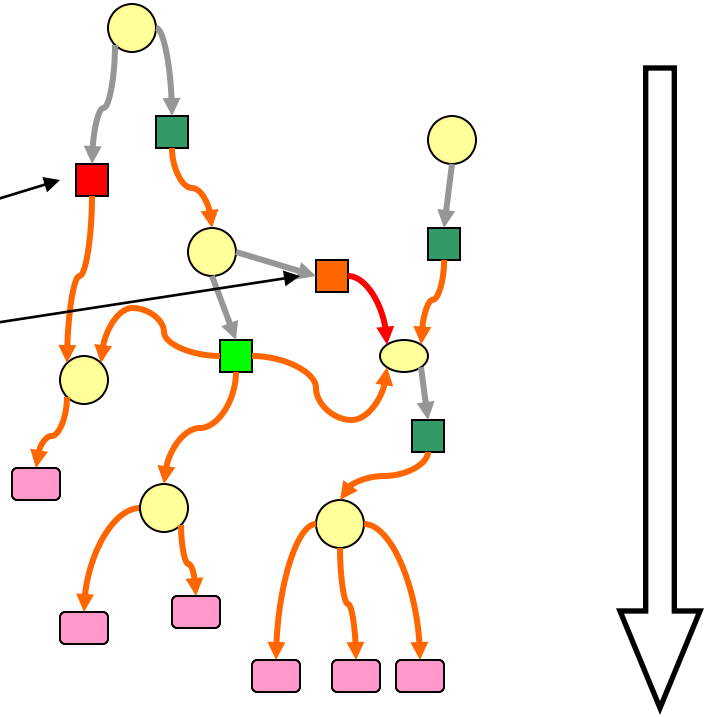
Application: Industrial Disruptions

Disrupted Facilities



Reduced Production Capacity





Diminished Product Availability

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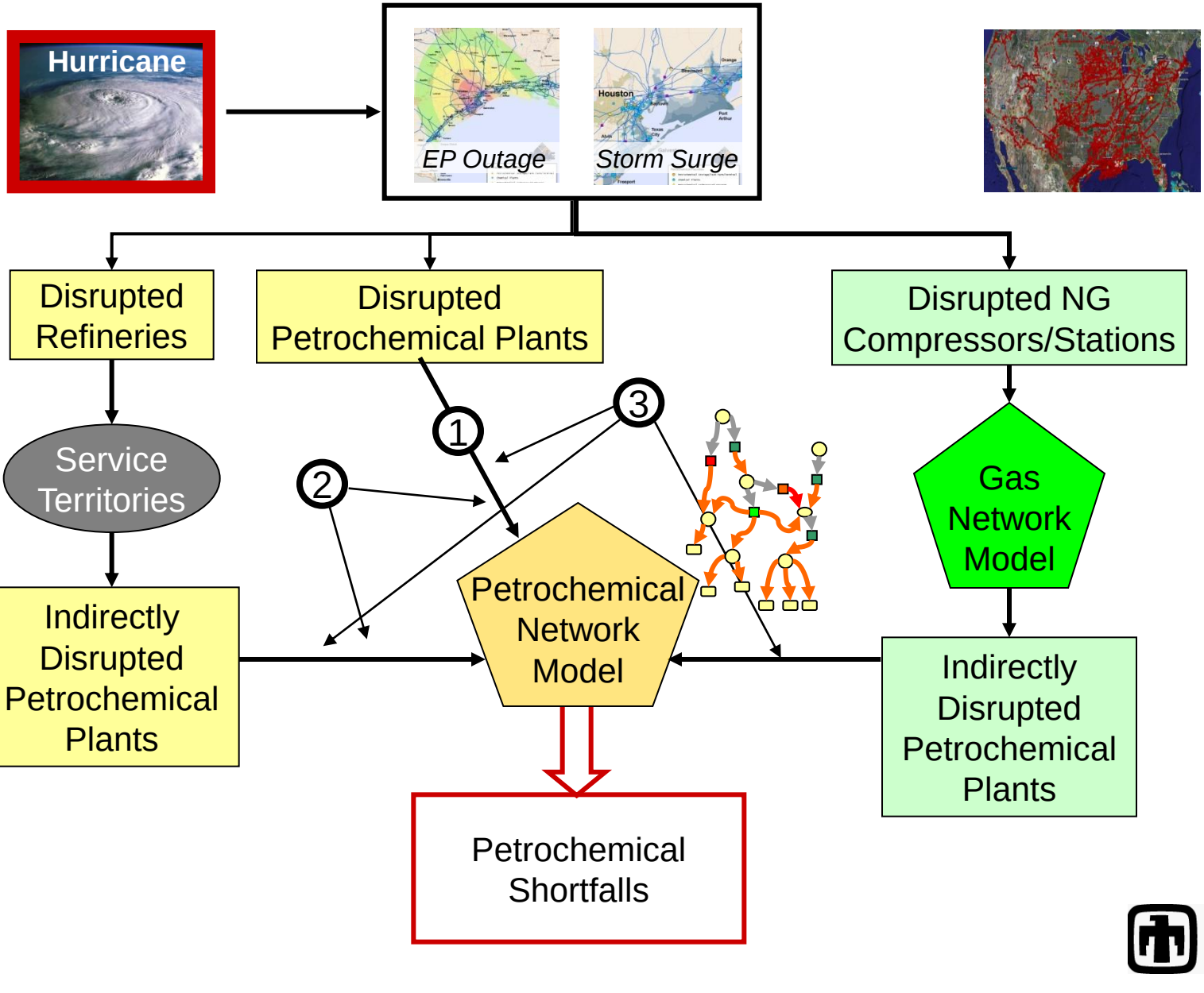
Application: Petrochemical & Natural Gas



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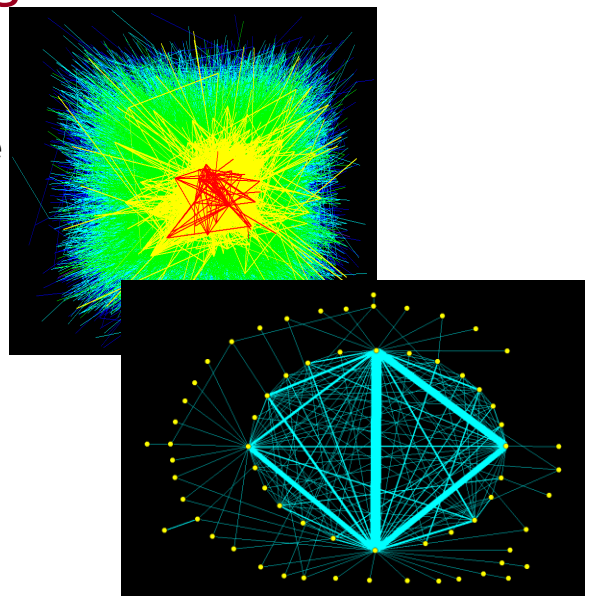
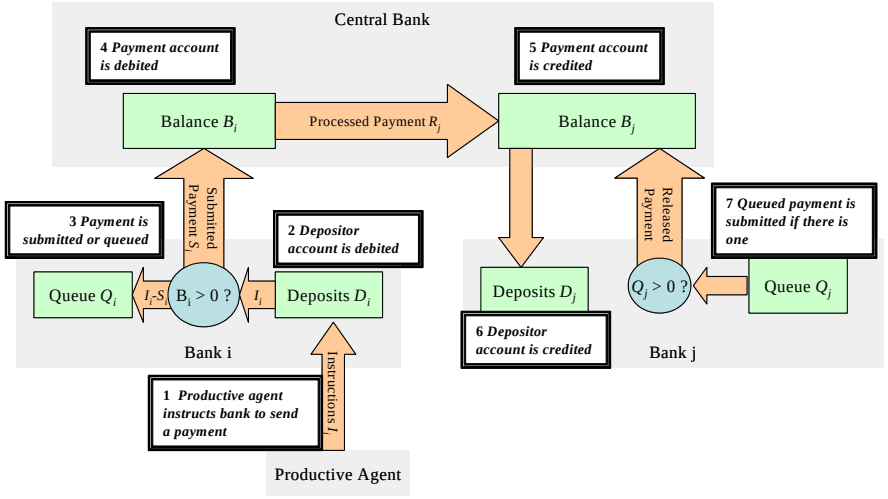
Application: Congestion and Cascades in Payment Systems

- **Network defined by Fedwire transaction data:**
  - Payments among more than 6500 large commercial banks
  - Typical daily traffic: more than 350,000 payments totaling more than $1 trillion
  - Node degree and numbers of payments follow power-lay distributions
- **Bank behavior controlled by system liquidity:**
  - Payments activity is funded by initial account balances, incoming payments, and market transactions
  - Payments are queued pending funding
  - Queued payments are submitted promptly when funding becomes available





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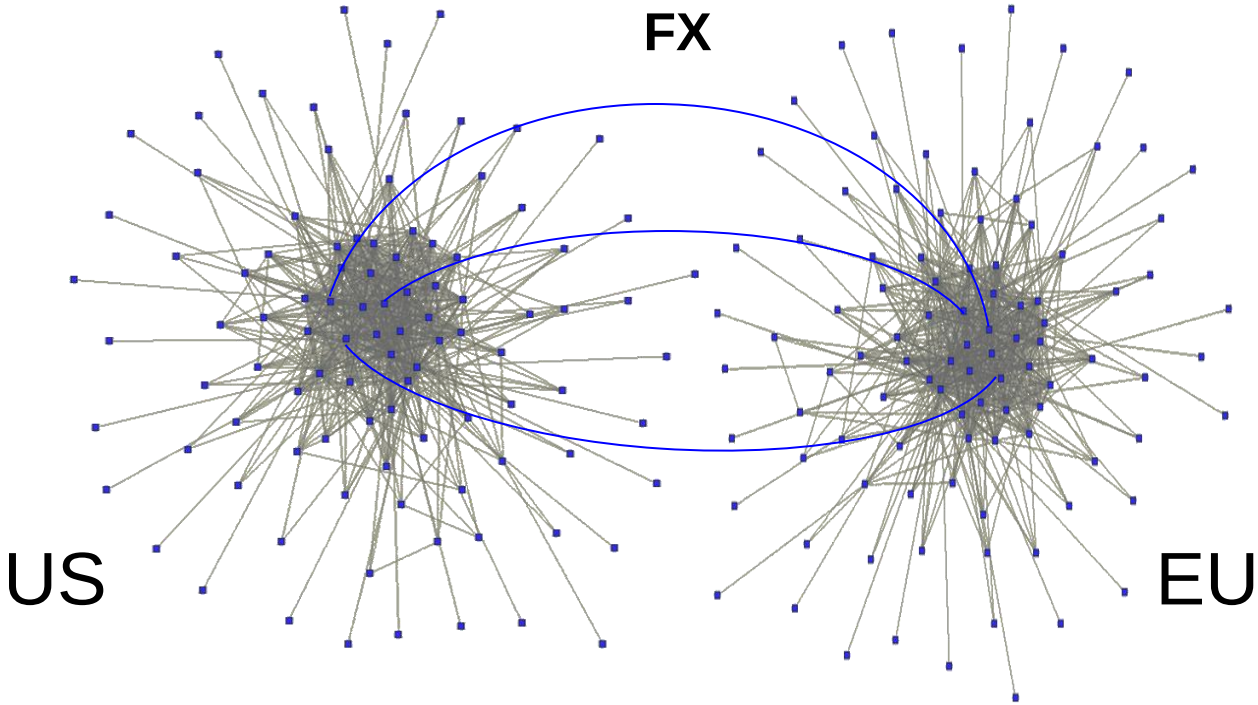
Application: Coupled Payment Systems



For Details See:
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