Approaching complex networks with power system models and data

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IOWA STATE UNIVERSITY

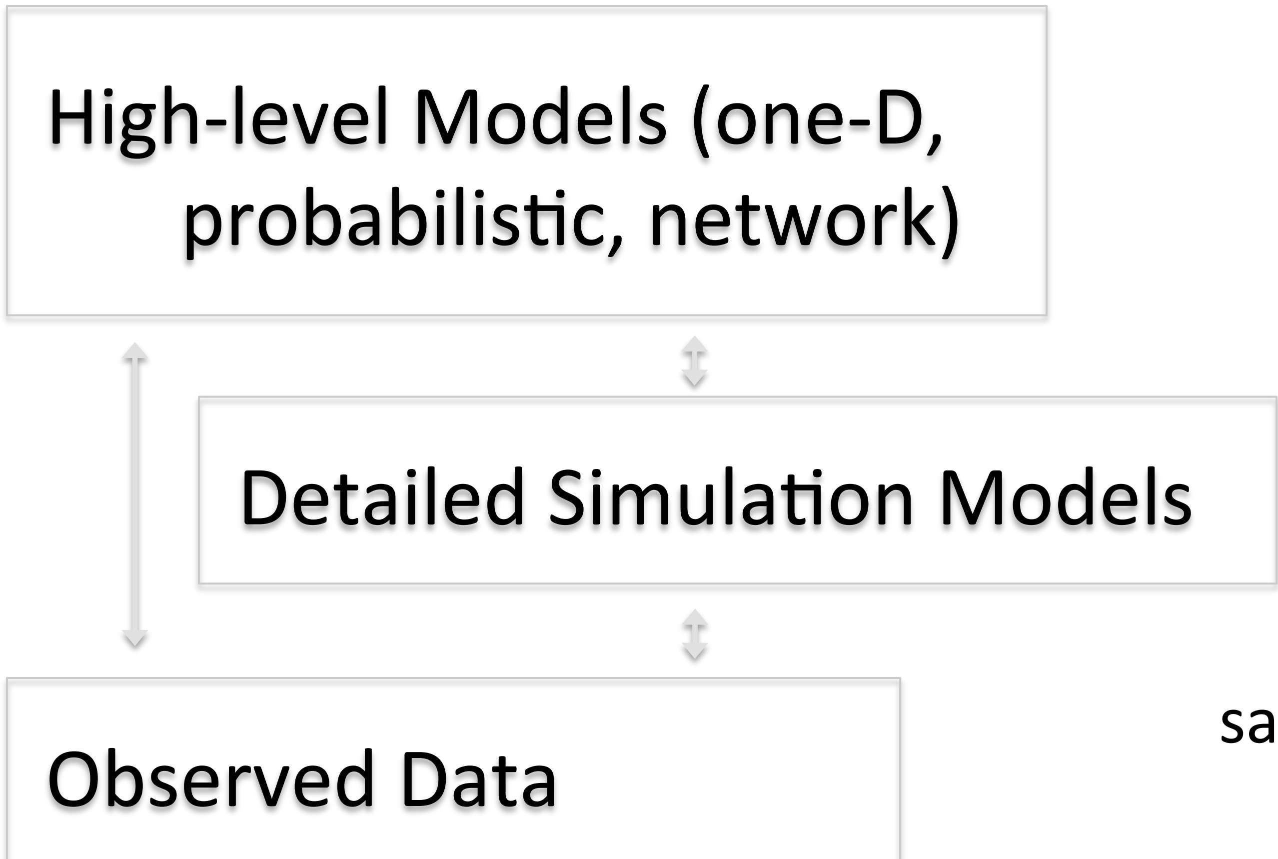
Some infrastructures for study:

electric grid
electric grid PLUS
 - communications
 - controls
 - human operators
 - effects of engineering, society
electric grid COUPLED with
 - communications
 - water
 - gas

There is no general model for the grid; there are specific models useful for specific phenomena at different time scales, such as

Lightning
Faults and protection
Synchronization/Transient stability
Oscillations
Voltage collapse (slow type)
Operational planning
Planning and upgrades
National energy flows

Types of models
(all are needed for tough problems)



insights, metrics, tractability

experiments OK

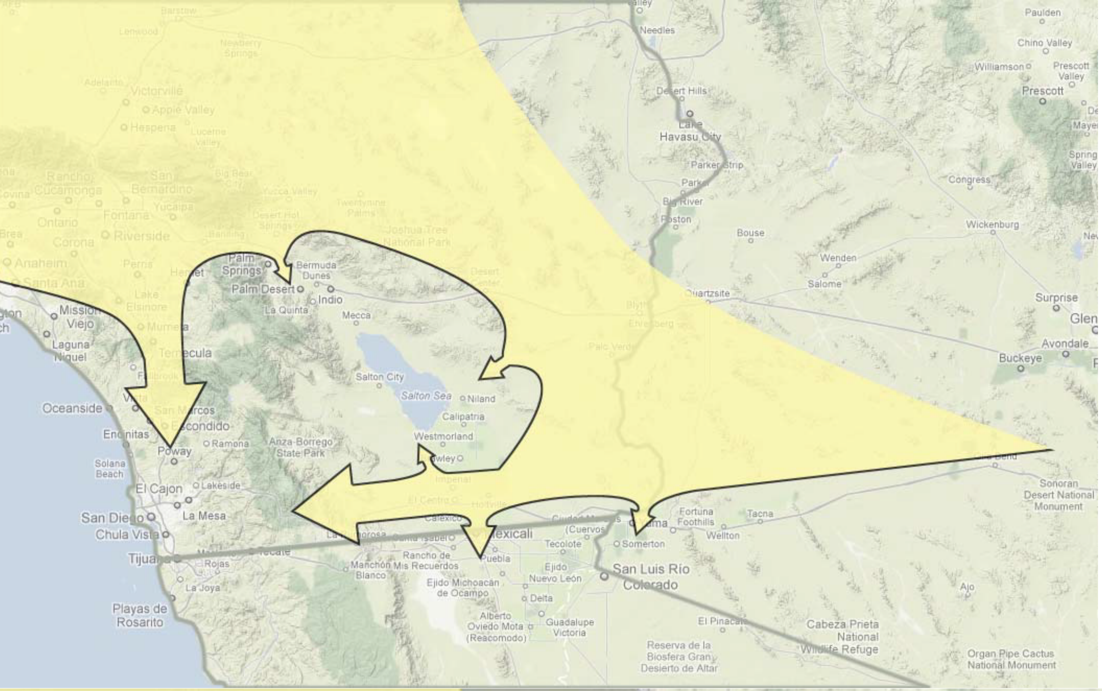
sample of reality; no model assumptions

Arrows show validations

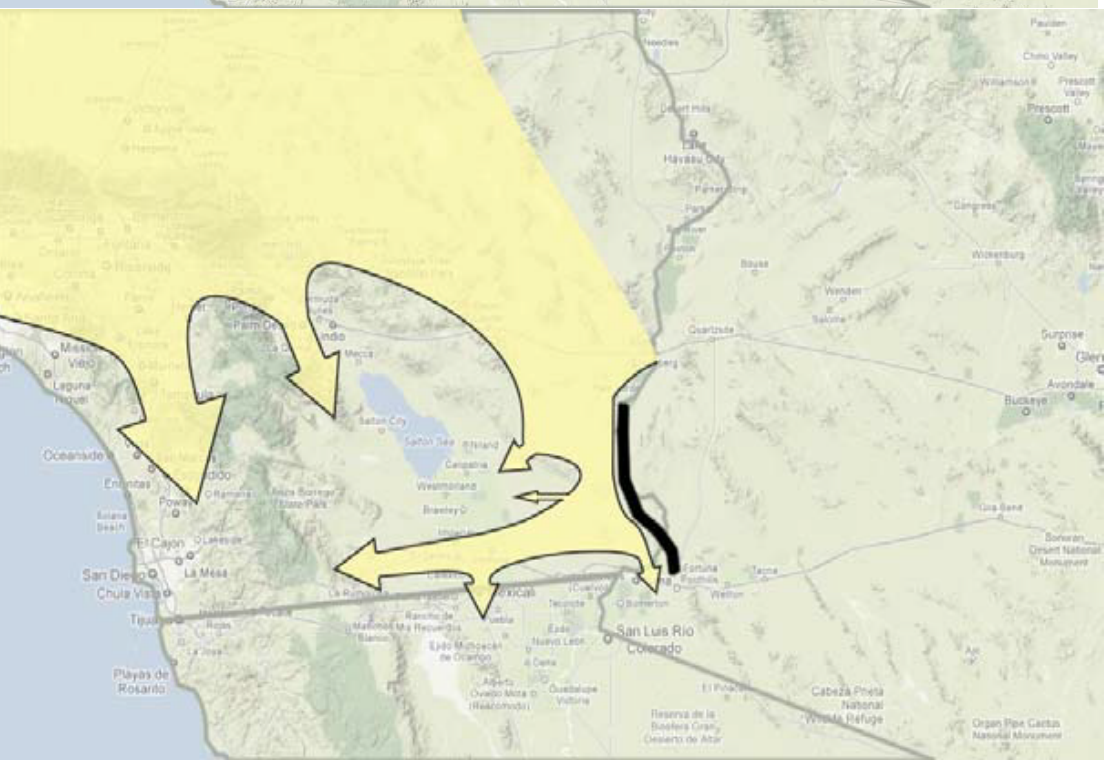
The physical network of the grid is intimately involved in the grid behavior, but does not by itself capture the network dynamics or interactions.

The complex network of interest must be the physical network plus other attributes or an entirely different network of interactions.

Hassayampa-N. Gila line trip



power flows
BEFORE



power flows
AFTER

FERC/NERC
Staff Report

Examples of phenomena common to power systems and complex networks

(de)synchronization – transient stability

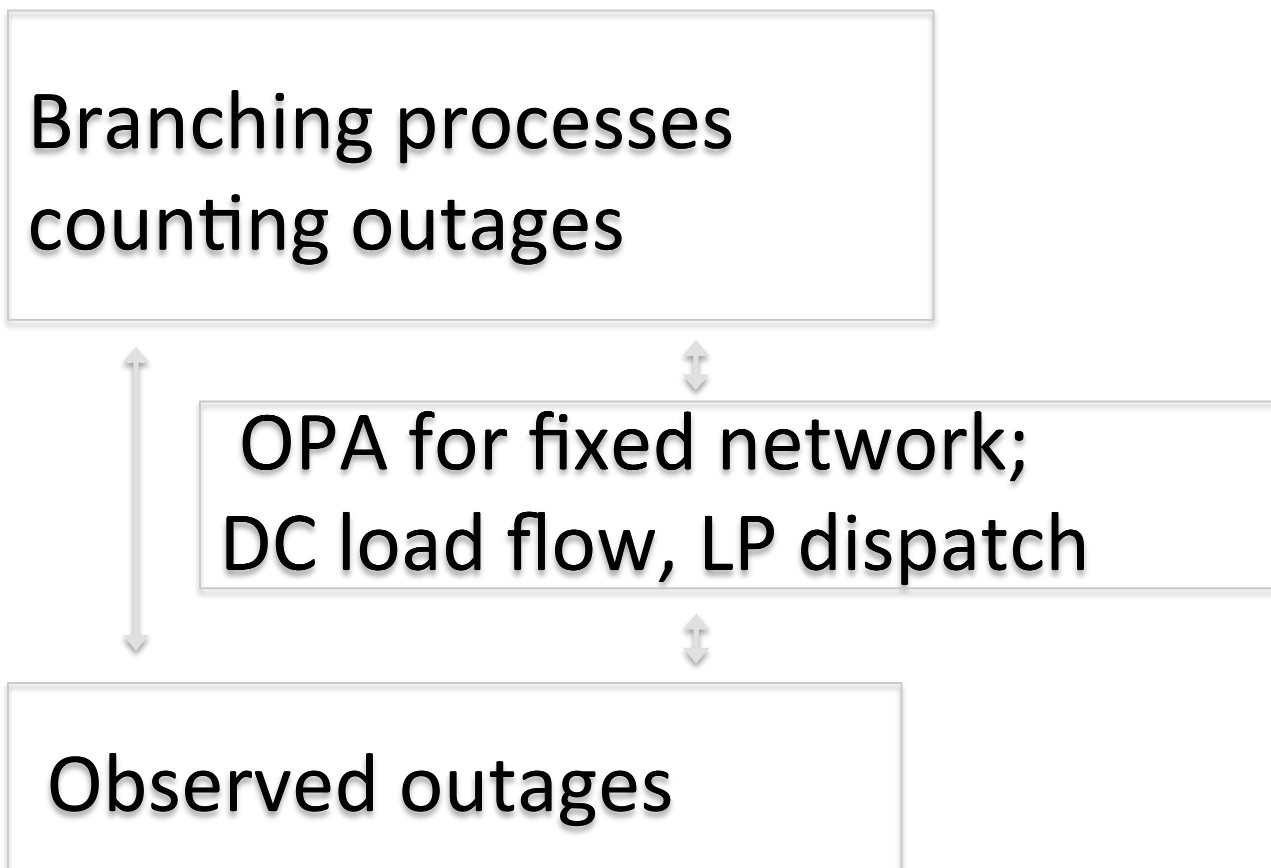
phase transitions in cascading

SOC/power laws

other phenomena?

Complex network theory can and does inspire work in power systems, but the application is not direct and the work should be done with validated models of power systems

Example 1: Cascading line outages



How do outages propagate in blackouts?

- many mechanisms, from physics to human
- both local and global effects (many mechanisms do not move along the graph topology e.g. overloads propagate along cutsets)

Example 1: Cascading line outages

Branching processes counting outages

Can estimate distribution of total number of line outages from 1 year of utility data

OPA for fixed network; DC load flow, LP dispatch

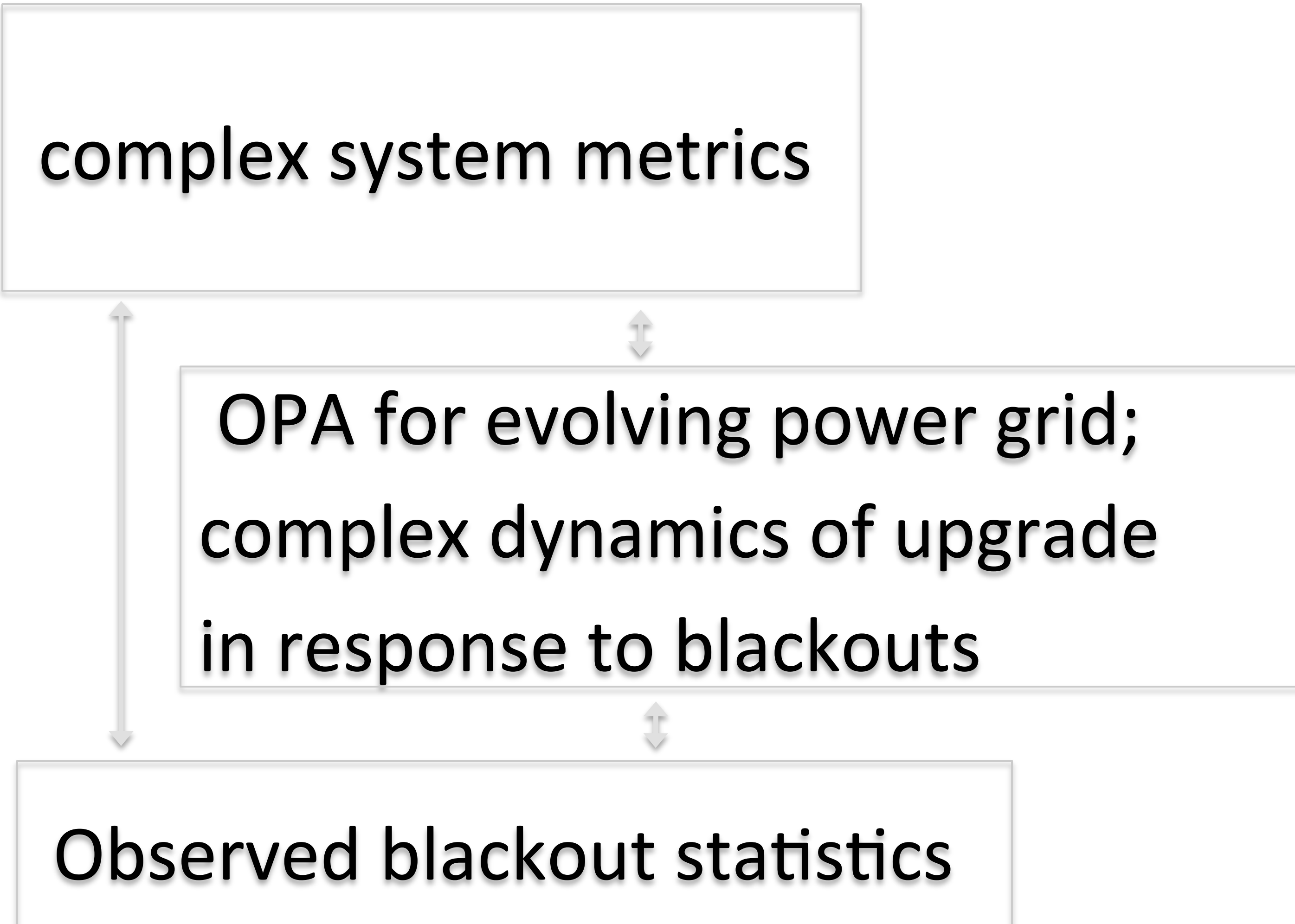
Only a few mechanisms; Many approximations

Observed outages

TADS line outage data that is reported to NERC

Solve problem of estimating probability of rare events by estimating parameter of high-level model

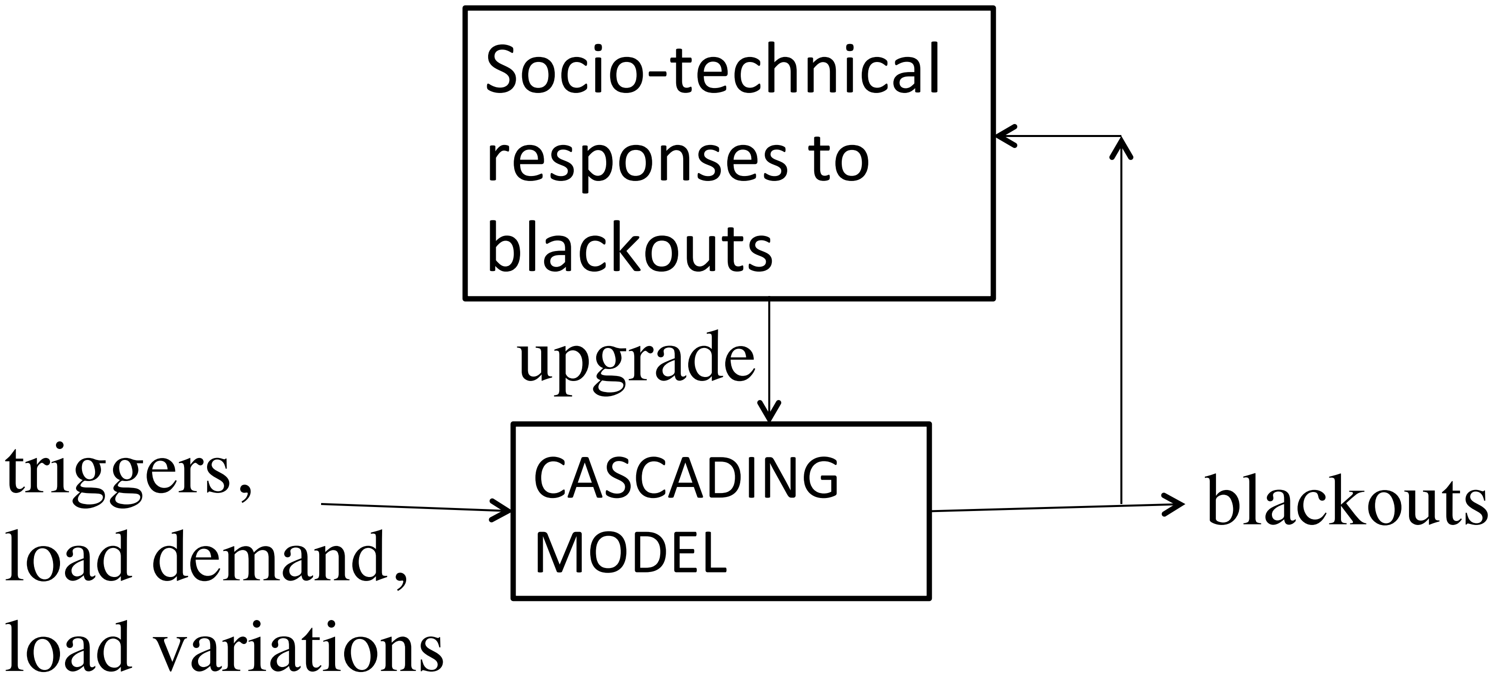
Example 2: SOC in series of blackouts



OPA model Summary (closed loop, slow evolution)

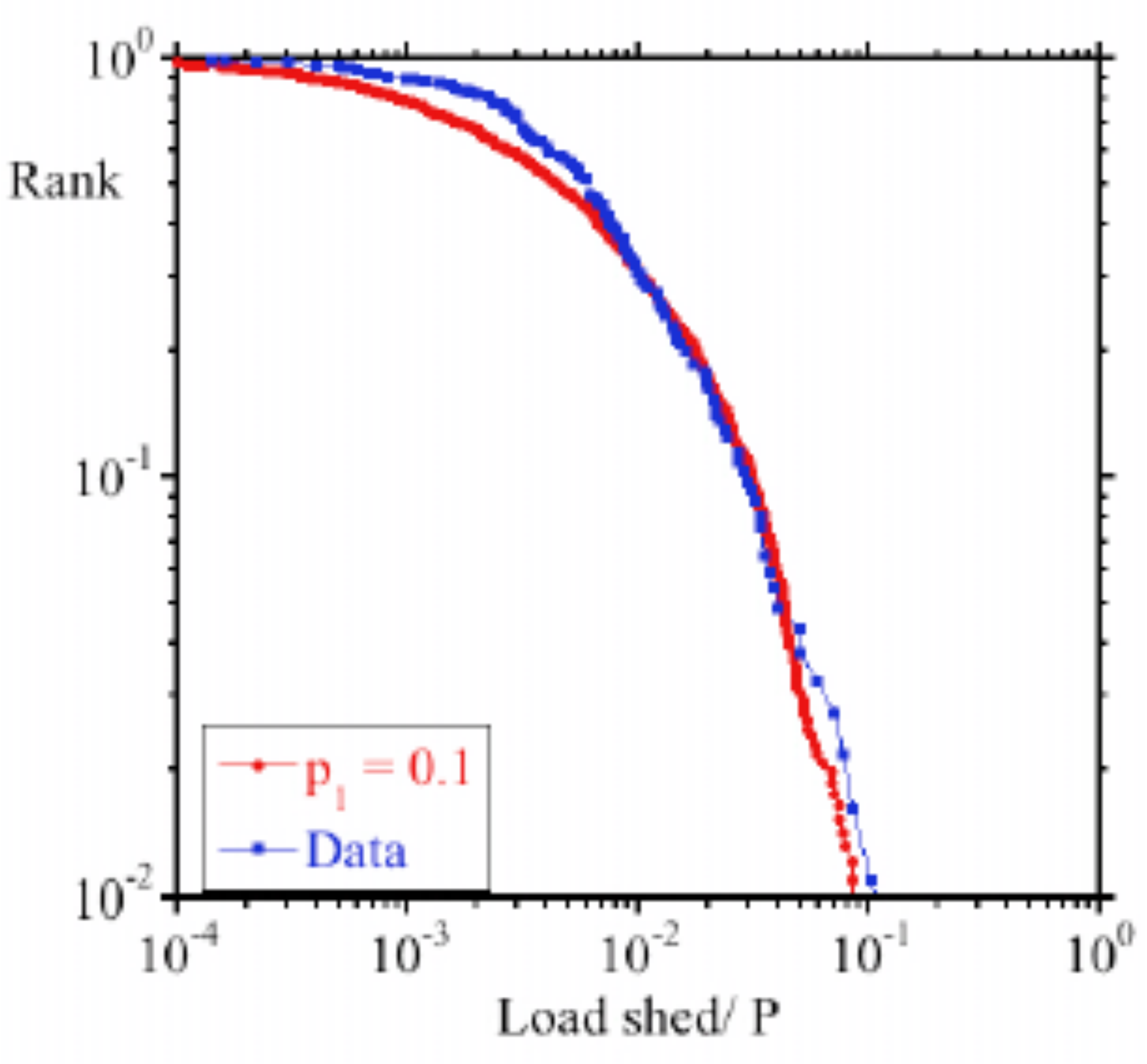
- underlying slow load growth + noisy load variations
- engineering responses to blackouts: upgrade lines involved in blackouts; upgrade generation: Respond to failures by fixing and improving the weakest parts!
- conventionally look at short-term reliability of a fixed network; here we are looking at long-term reliability accounting for evolution under complex system dynamics.

Modeling with complex systems feedback upgrading system



Analogy with control theory suggests that outcome largely depends on feedback and depends much less on cascading model

Distribution of blackout size: match between OPA on 1553 node model of WECC and NERC data



Example 3: inter-area oscillations

compute generator redispatch to suppress oscillations

dynamic power system simulation

real time monitoring of mode

New algorithms can exploit real time monitoring of dynamics

Problem: poorly known dynamic models, particularly loads

New synchrophasor (PMU) technology can monitor modes

Power grids are engineered and evolving networks, *not* general networks
– engineers coordinate the parameters and operating rules to provide reliable function at minimum cost

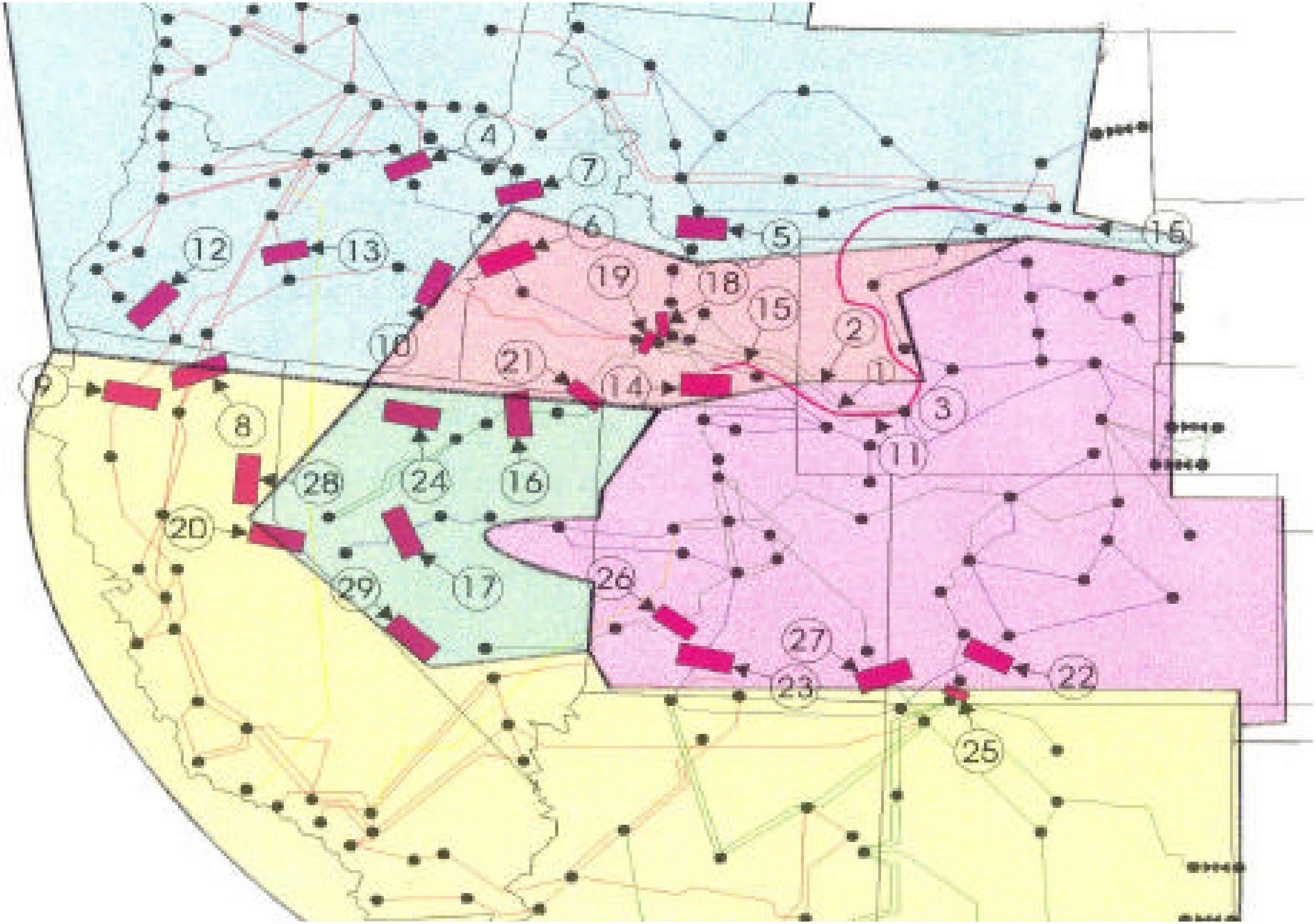
1) These remarks obvious in biological systems!
2) Use realistic power system parameters, OR
3) Model the engineering feedback. Example: complex systems feedback of upgrading parts that outage in blackouts can self-organize system towards criticality and explain power laws in observed blackout size distributions

QUESTIONS?

Papers available from

http://iandobson.ece.iastate.edu

Sequence of outages in Western blackout, July 2 1996



from NERC 1996 blackout report

Preliminary data on observed outage spreading