Translating Data from Cascading Failure Simulations into Actionable Information using Influence Graphs

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and Ian Dobson and Pooya Rezaei

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Journal reference:
"Cascading Power Outages Propagate Locally in an Influence Graph that is not the Actual Grid Topology," IEEE Transactions on Power Systems (online now)

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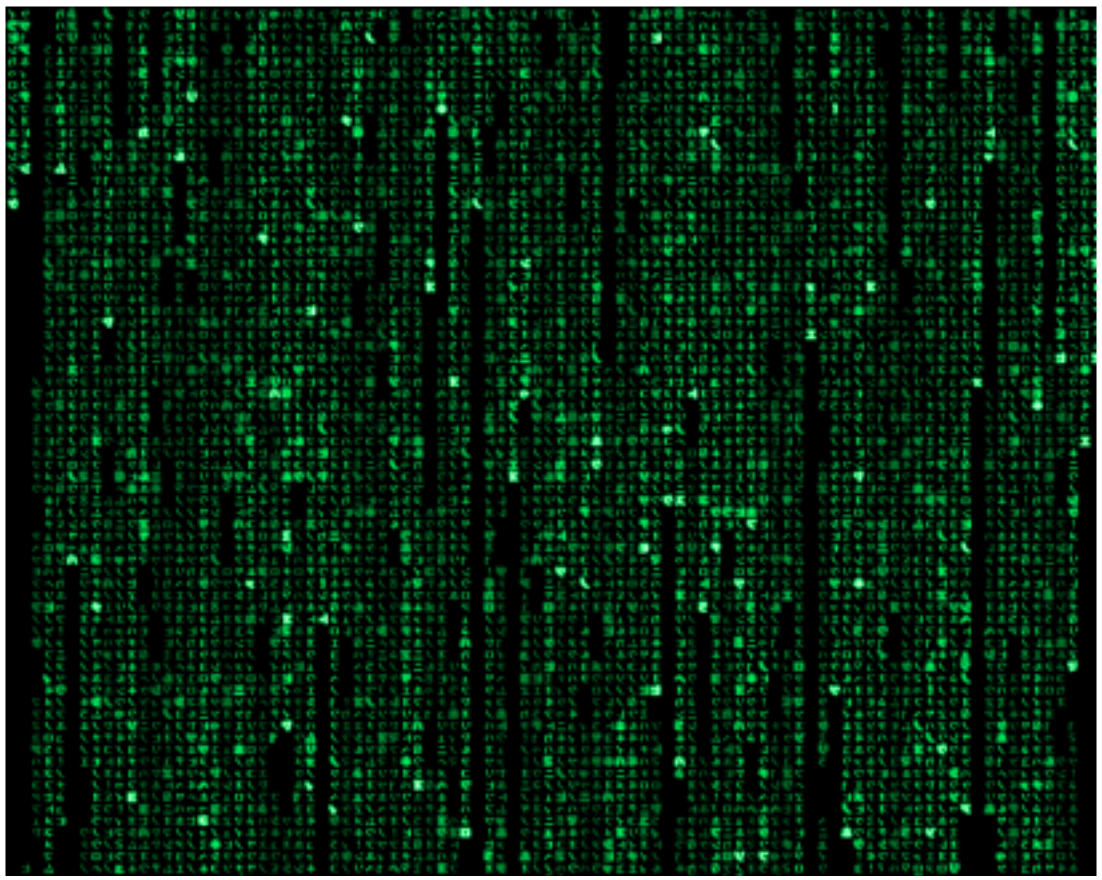
Computing is cheap and allows us to simulate many cascading failure scenarios

- If we simulate:
  - 10,000 sample cascades for a system with
  - 10,000 lines, and
  - 100 time steps per simulation, we have at least:
  - **10 billion** variables

How do we translate massive amounts of cascade simulation data into better decisions?



(c) Warner Bros, The Matrix

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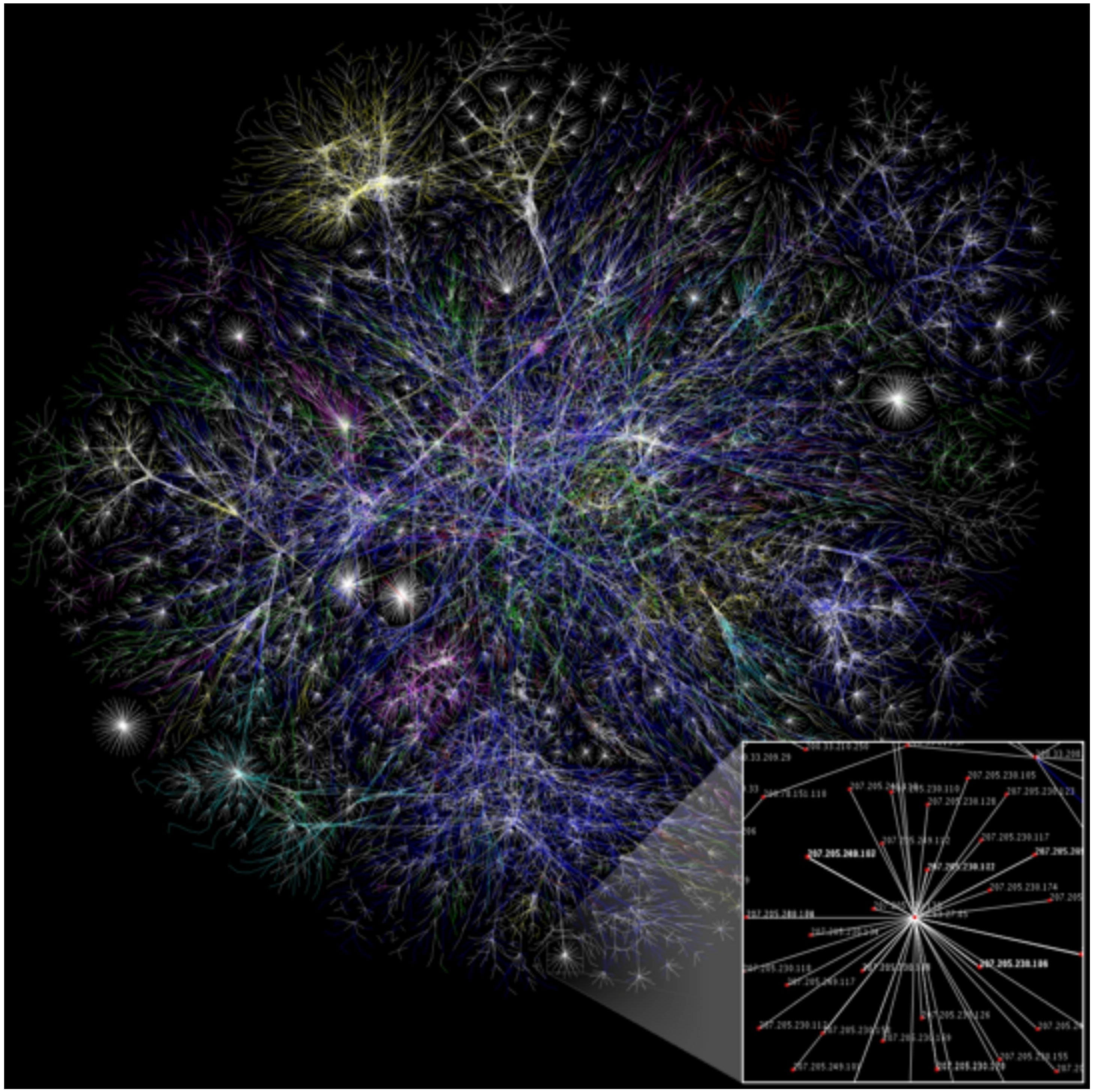
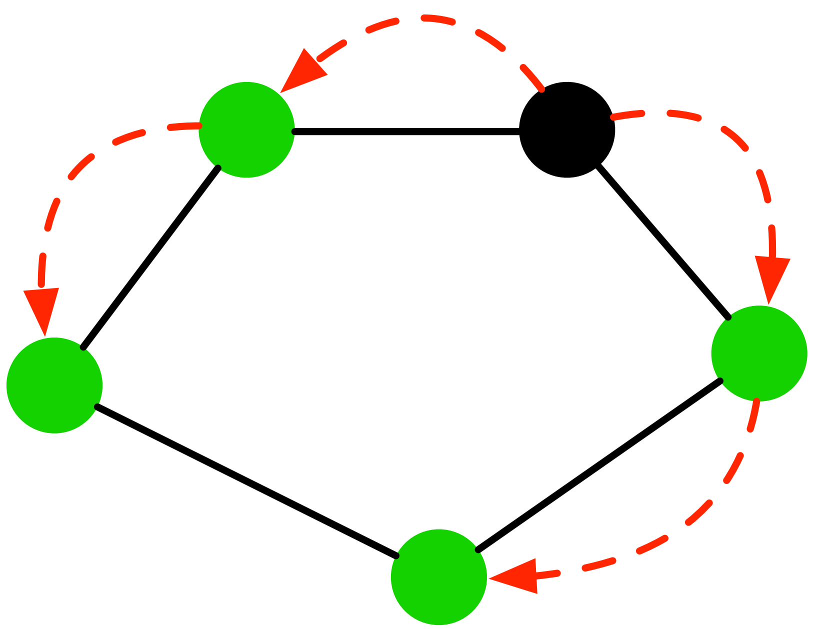
Network science?



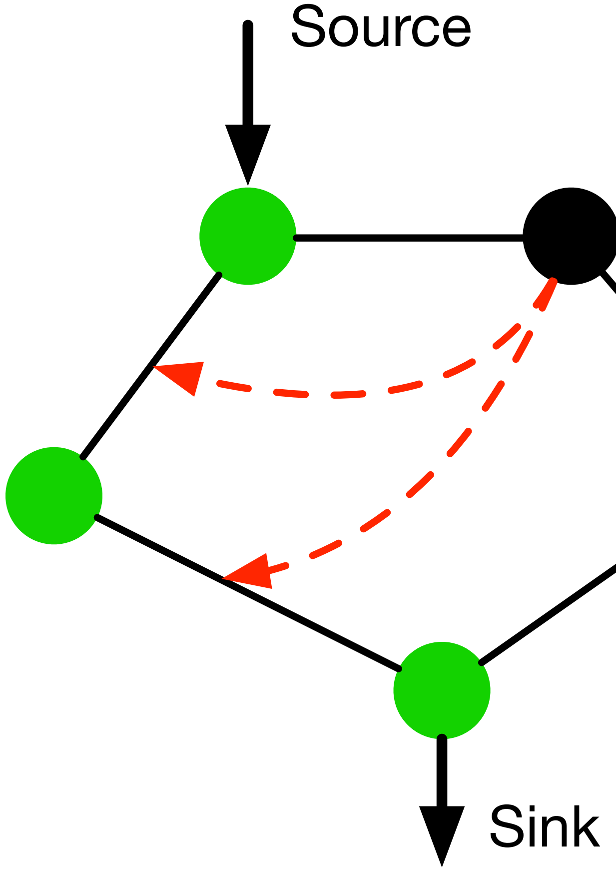
- By representing systems as networks (graphs) useful insight can result
- But applications of network science concepts to cascading have not generally proven successful

Why?

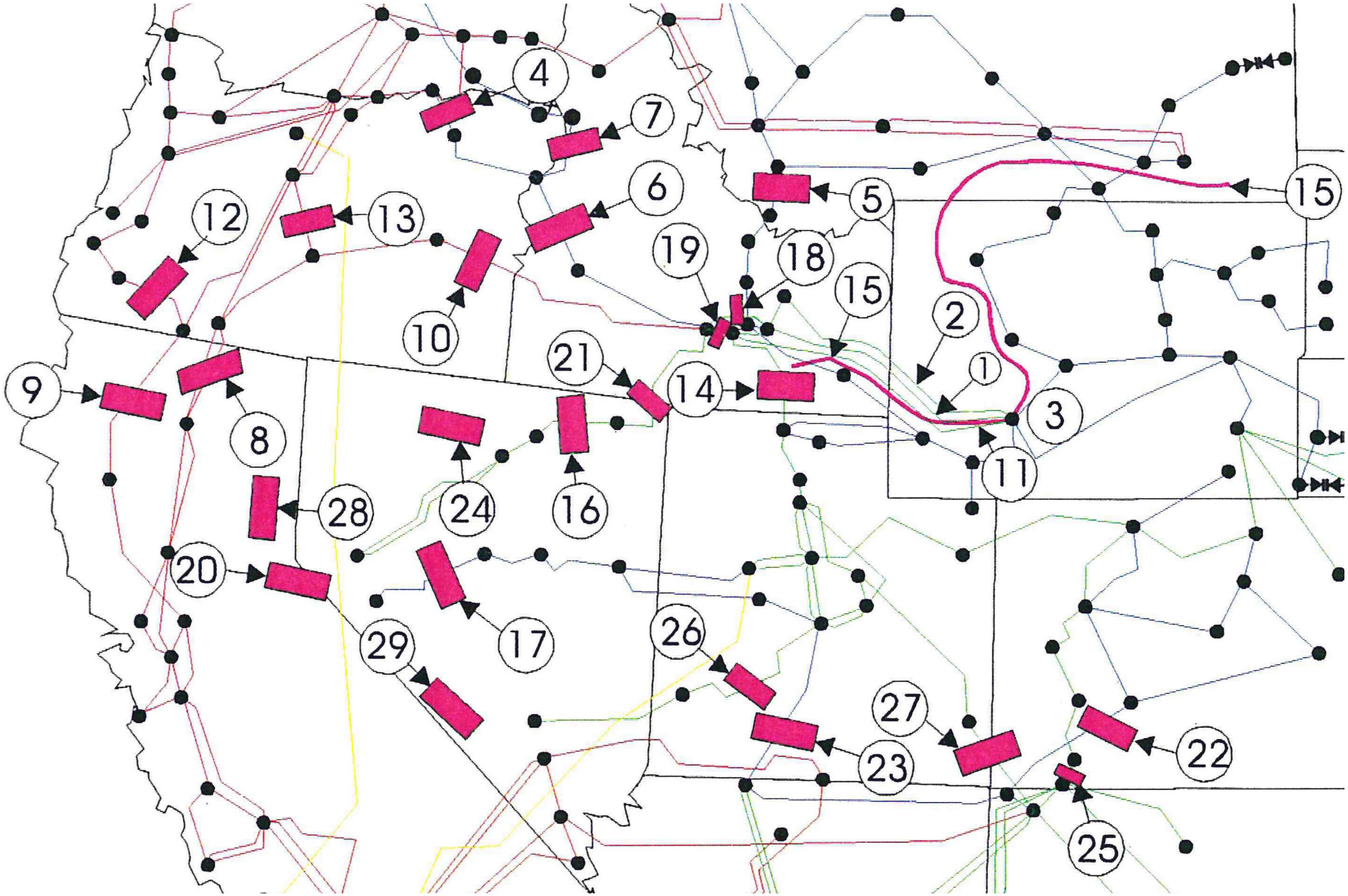
Conventional contagion model



Something closer to a power grid model



Cascading failures propagate non-locally



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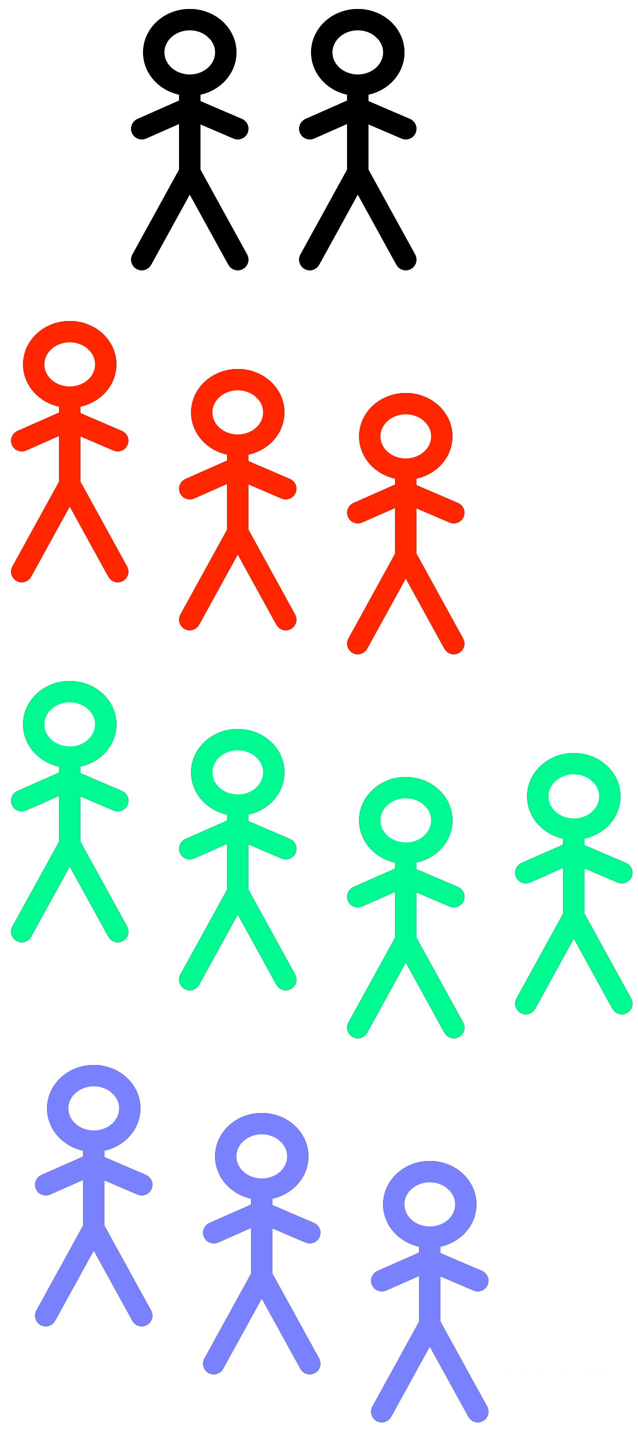
Can we translate data from many cascading failure simulations into a network model and then study this model to get useful insight into the many ways that cascades propagate?

The influence graph method



- Take outage sequence data from many cascades
- Group the cascades into generations
- Compute propagation rates, etc.

See, eg: Dobson, “Estimating the propagation and extent of cascading line outages from utility data with a branching process,” IEEE Trans. P.S. 2012.

Build two probability distributions

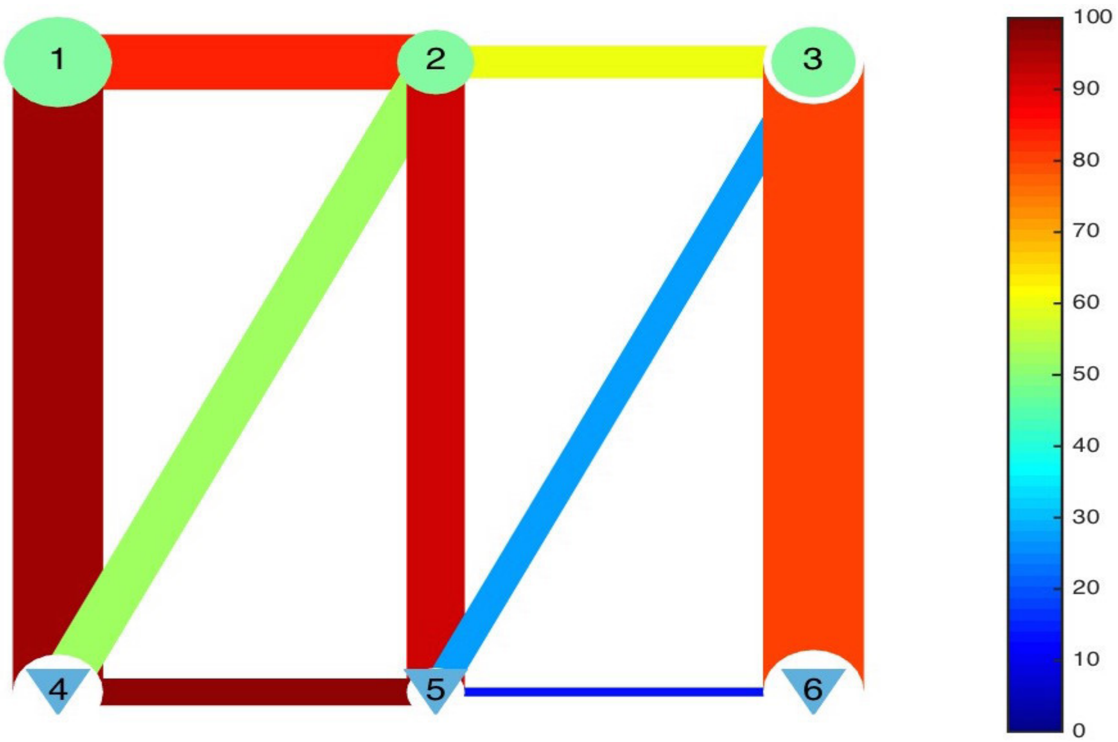
- How many outages tend to result from outage *i* ?

$$\begin{aligned} f[k|i,m] = \Pr[\, k \text{ outages in generation } m+1, \text{ given} \\ \text{a single outage of } i \text{ in generation } m] \end{aligned}$$

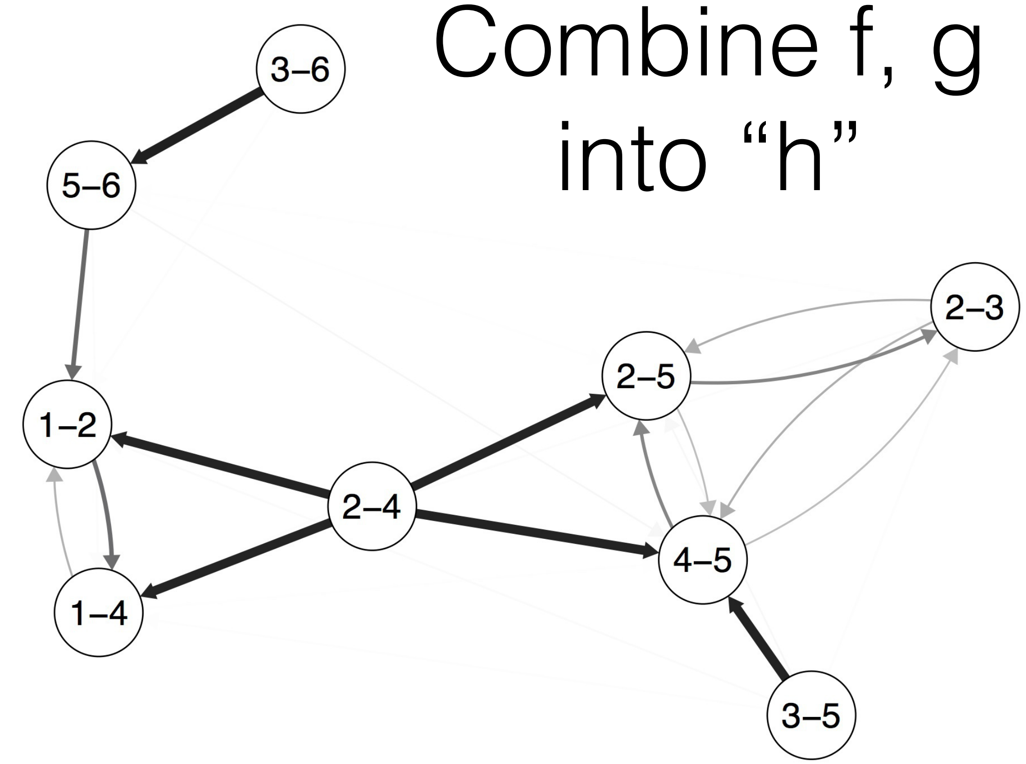
- Which particular components tend to outage if *i* outages?

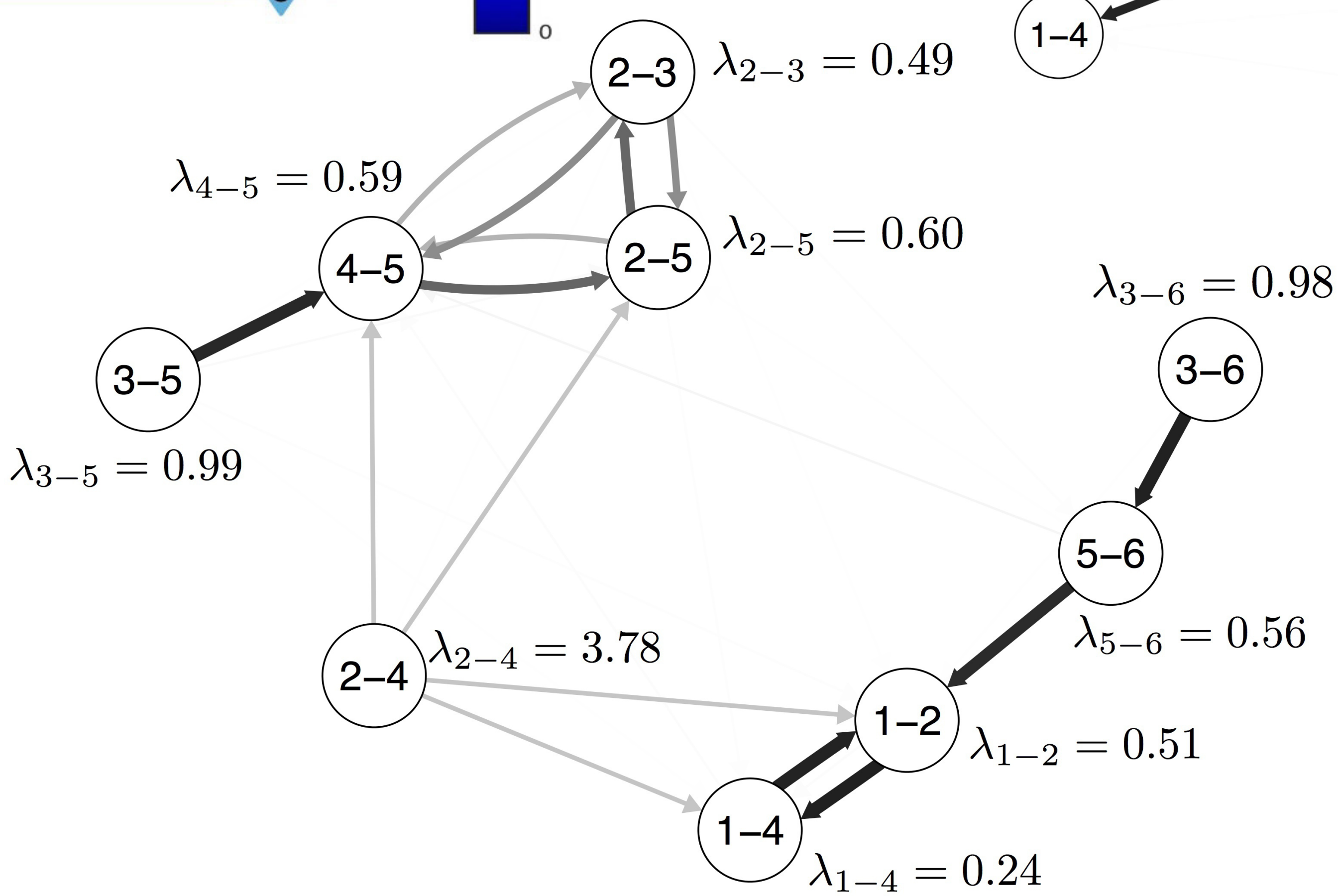
$$\begin{aligned} g[j|i,m] = \Pr[\, j \text{ fails in generation } m+1 \text{ given} \\ \text{a single outage of } i \text{ in generation } m \\ \text{and one outage in generation } m+1] \end{aligned}$$

Illustration with a 6-bus case

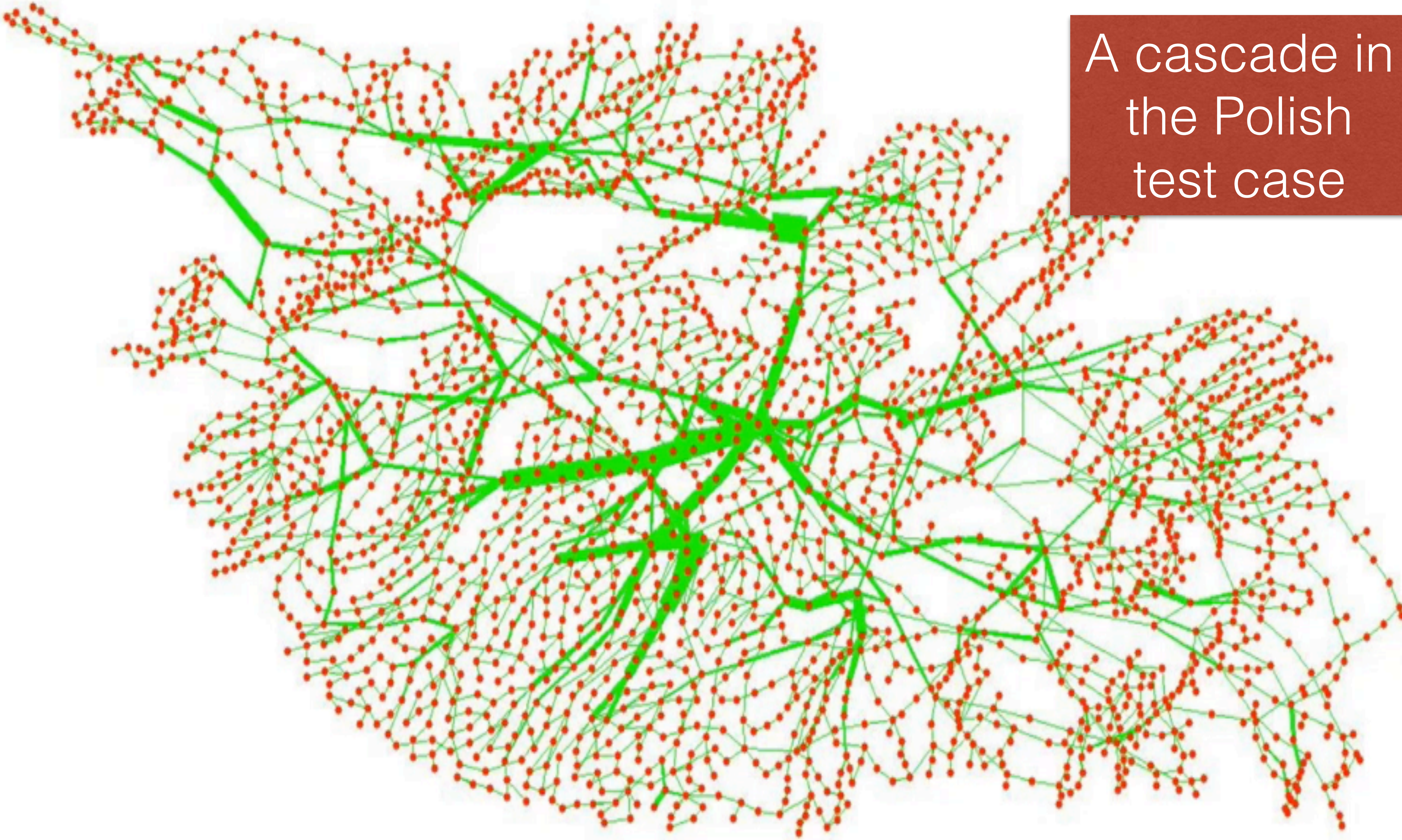


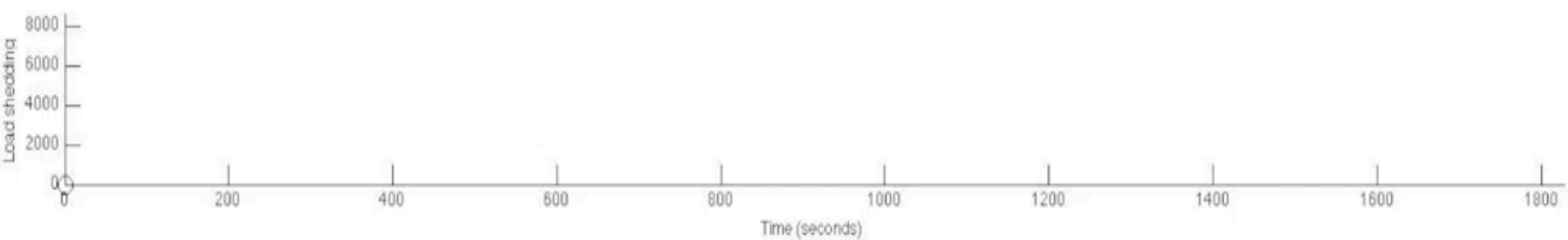
Combine f, g into "h"



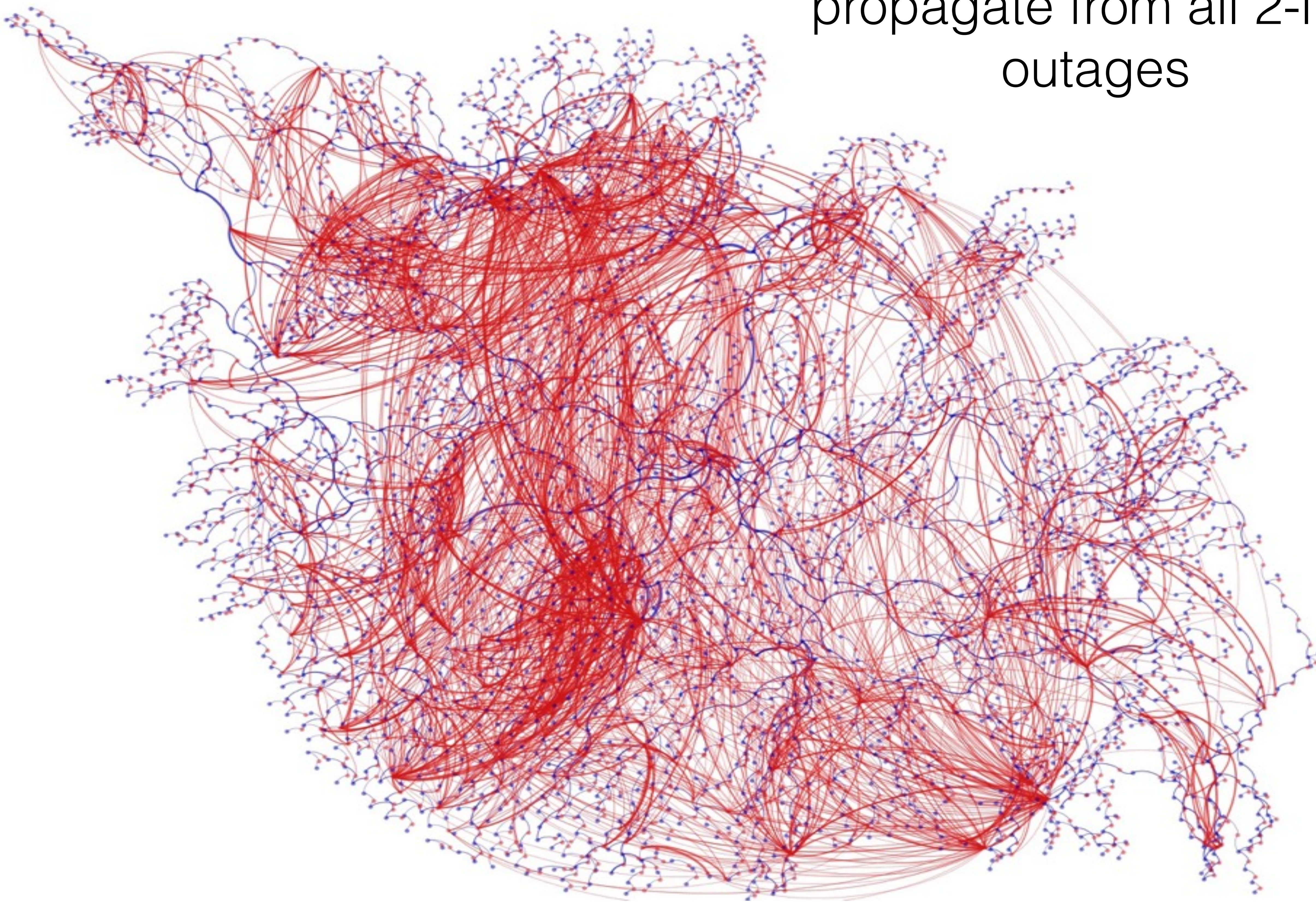


A cascade in the Polish test case

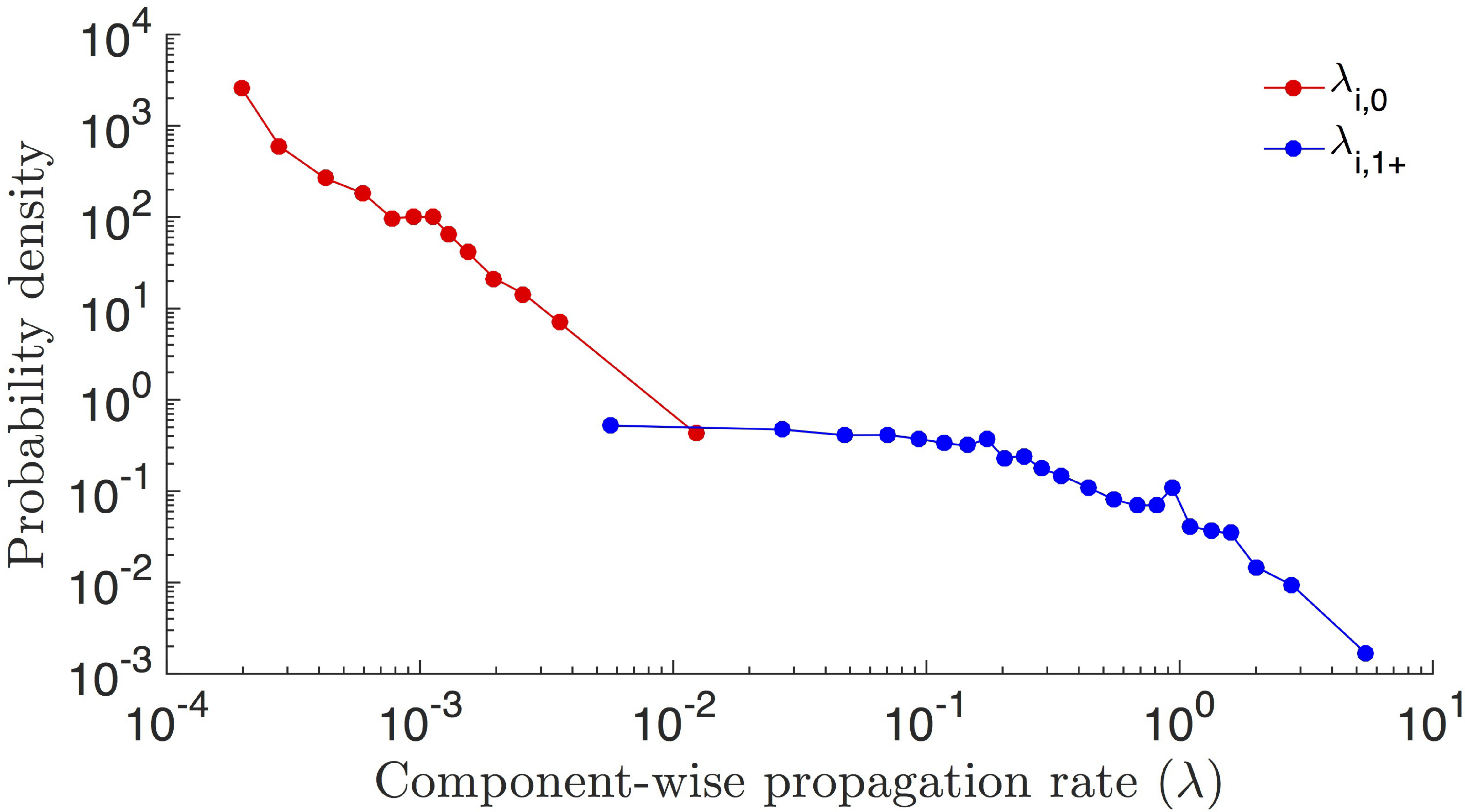




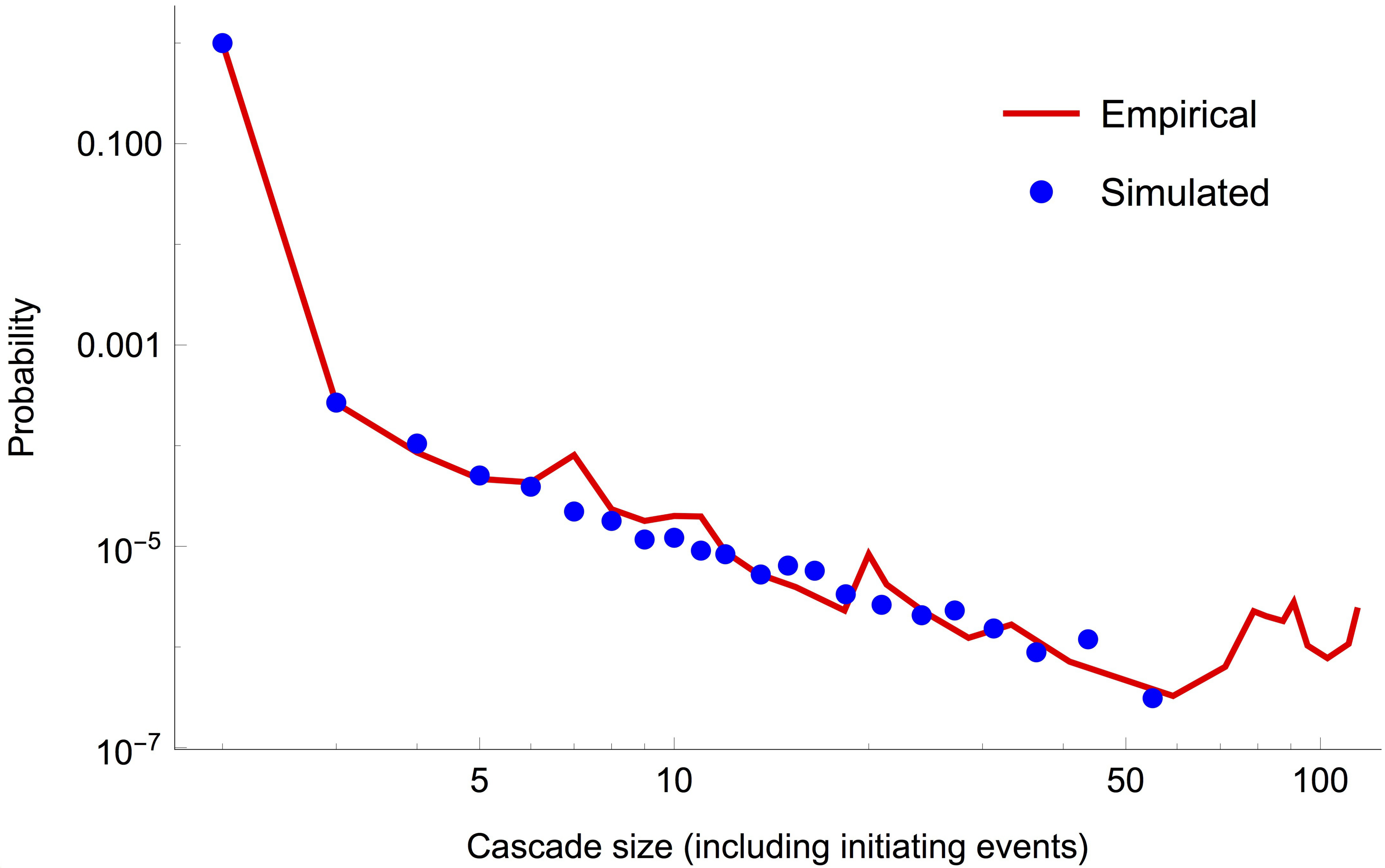
Influence graph representing the cascades that propagate from all 2-line outages



Some components propagate orders of magnitude more than others



Simulations from the influence graph (roughly) reproduce the statistics of real cascades



Using the Influence Graph to mitigate cascades

Initiating probabilities

$$\boxed{\mathbf{a}^\mathsf{T}} = \boxed{\mathbf{p}_0^\mathsf{T}} + \boxed{\mathbf{p}_0^\mathsf{T}\mathbf{H}_0}(\mathbf{I} - \boxed{\mathbf{H}_{1+}})^{-1}$$

Expected state after long cascade

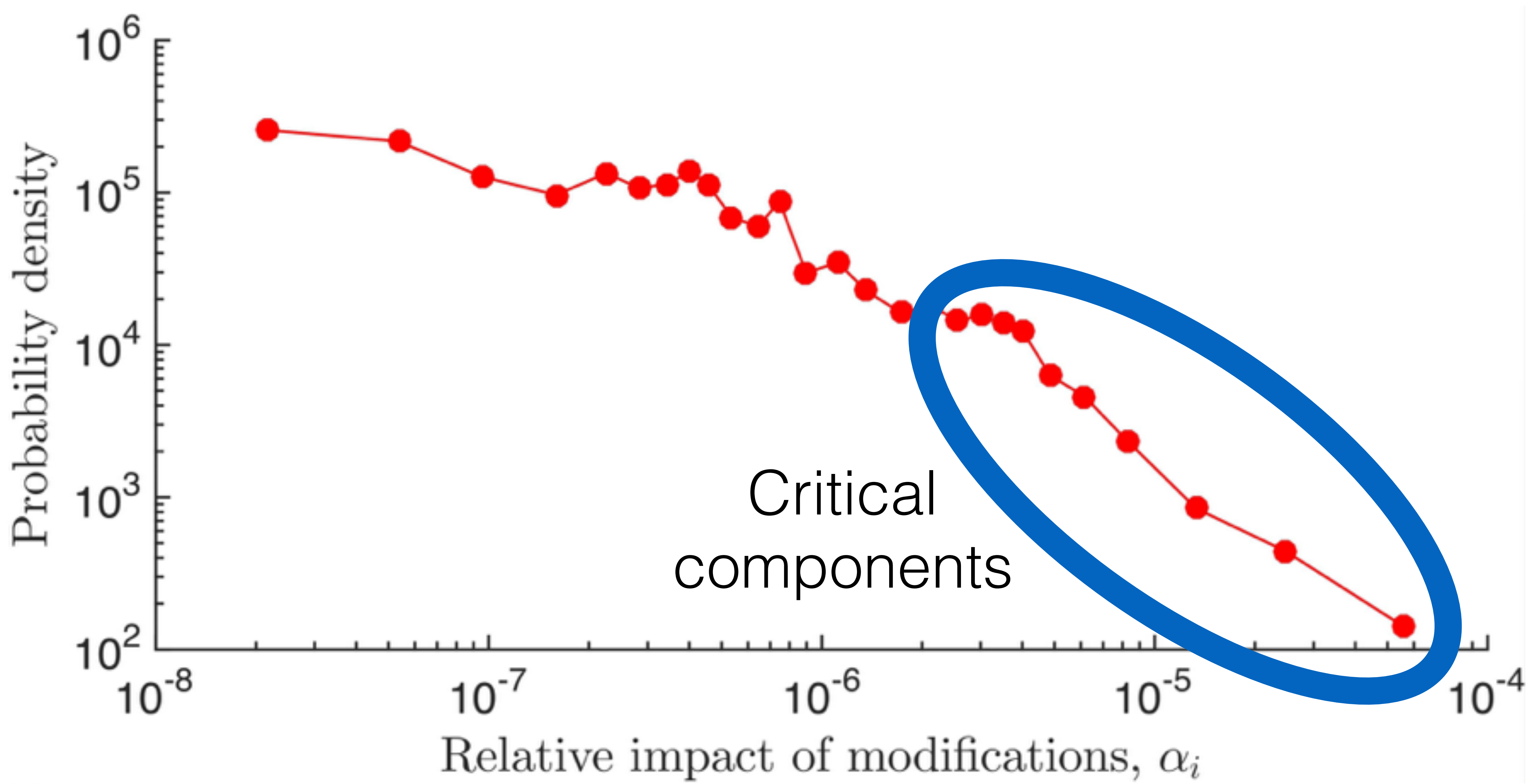
I-graph matrices

Modifications to propagation probabilities

$$\boxed{\Delta\mathbf{a}_j{}^\mathsf{T}} = \mathbf{p}_0^\mathsf{T}\boxed{\delta_0}\mathbf{e}_j^\mathsf{T}(\mathbf{I} - \mathbf{H}_{1+})^{-1} + \mathbf{p}_0^\mathsf{T}(\mathbf{H}_0 + \boxed{\delta_0}\mathbf{e}_j^\mathsf{T})\frac{(\mathbf{I} - \mathbf{H}_{1+})^{-1}\boxed{\delta_1}\mathbf{e}_i^\mathsf{T}(\mathbf{I} - \mathbf{H}_{1+})^{-1}}{1 + \mathbf{e}_i^\mathsf{T}(\mathbf{I} - \mathbf{H}_{1+})^{-1}\boxed{\delta_1}}$$

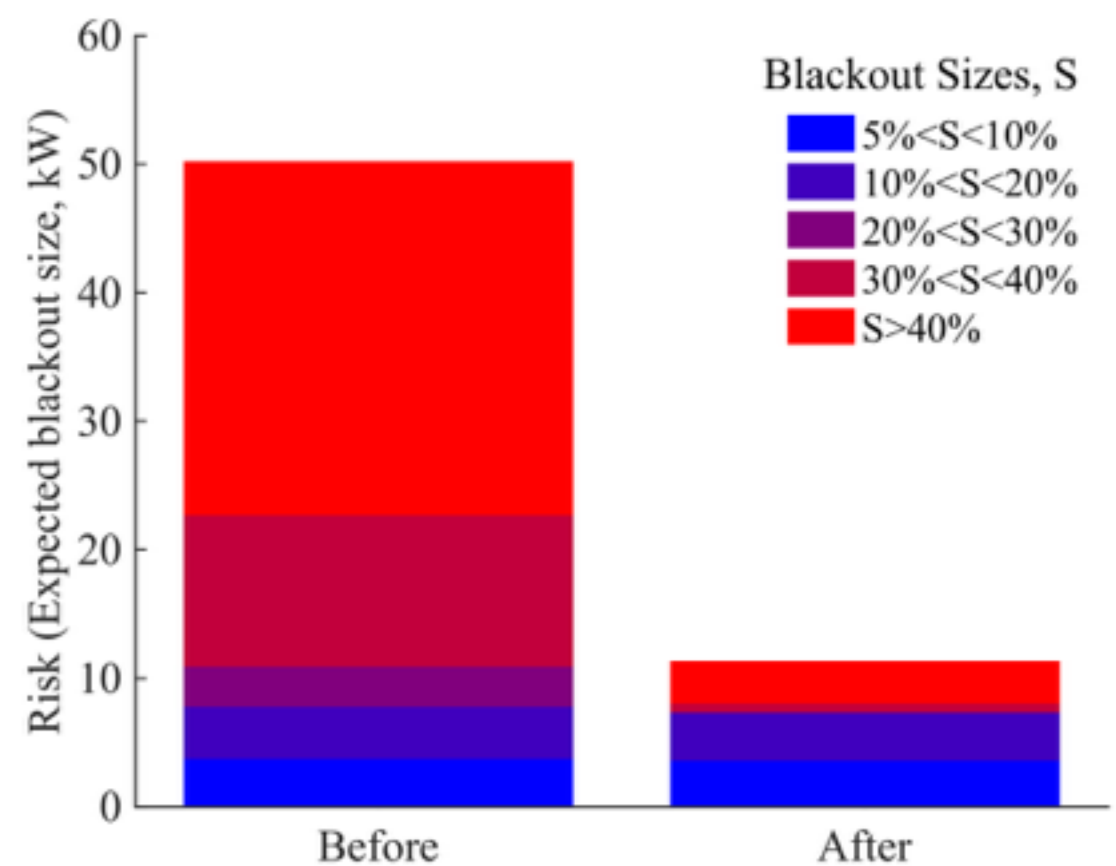
Changes to cascade sizes

Some component modifications are far more effective than others



The resulting upgrades do indeed substantially reduce blackout risk

- Upgrade (protection systems, tree trimming) so that they are 1/2 as likely to trip on overload.
  - Increase trip load level by a factor of 2.
- Recompute n-2 blackout risk



Conclusions

- Cascading failure simulators produce lots of data
- These data can be transformed into an influence graph
- Studying the influence graph can suggest locations that can be upgraded to substantially reduce cascading failure risk

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