



Introduction to Engineering Systems, ESD.00

Networks II

Lecture 8

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Outline

Introduction to networks

Infrastructure networks

Institutional networks

The military and networks

MIT as a network

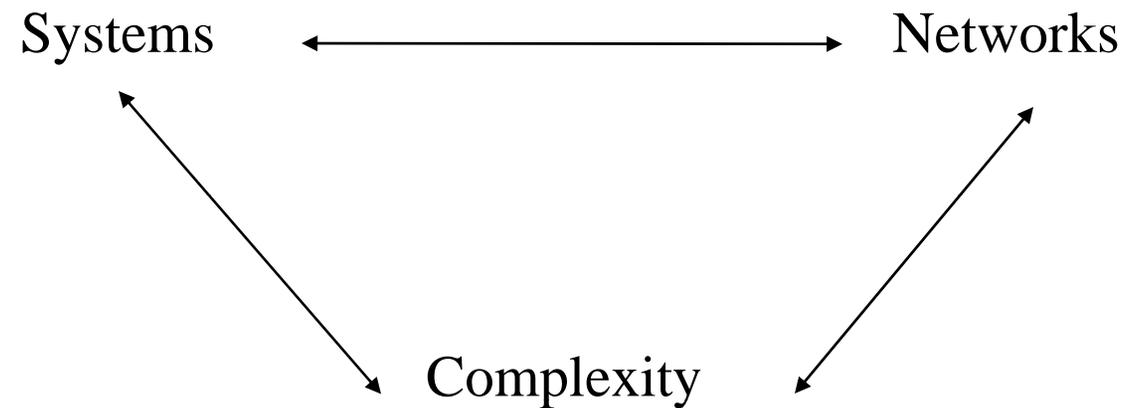
ESD.00 as a network

Bay Area transportation

Freight railroad networks

Random and non-random networks

Networks, “Systems” and Complexity



- It is very difficult (for me) to separate these ideas

Networks - Introductory Concepts

- The idea of networks is intuitive - we sketch our nodes and links connecting them.
- But you need to think about
 - What do the nodes represent?
 - What do the links represent
 - What does connectivity imply?
- Complexity often arises in systems that have a network structure
- Network behavior is an emergent property of network structure and link and node characteristics

Network Types

- Physical
 - Transportation
 - Energy
 - Water
- Organizational
 - US Government
 - US Military
 - MIT
 - Social networks-- Facebook, for example
- Conceptual
 - Systems Dynamics
- Other?

Networks - Some Basic Questions

- What flows on the links?
 - In physical network
 - In organization network
 - In conceptual network
- How do you characterize a link?
- What processes are performed at the nodes?
- How do you characterize the node?
- Level of network detail?
- Dynamic Vs. Static Network Structure

An Interesting Research Area:

- How do we analyze/design/understand systems composed of networks of different types - physical, organizational, conceptual?

Infrastructure Systems

Infrastructure systems often have a network structure

Infrastructure networks are often critical to the functioning of society

Infrastructure networks are not simply physical; they are also organizational

Critical Infrastructure

- What makes an infrastructure “*Critical*” -- YOUR IDEAS, PLEASE

Critical Infrastructure

- What makes an infrastructure “*Critical*”
- A matter of “taste”-- a failure leads to.....
 - Life safety issues?
 - HILP (High impact, low probability) events?
 - Large economic disruption?
 - Large societal disruption?
 - “You bet your company”?
 - “You bet your job”?

•Identify Different Classes of Infrastructure and Think About Their Interactions

- Transportation
- Communication
- Water Supply
- Energy
- Materials

All are Network-based--development of common methodologies across classes is the goal

Institutional Issues I

- And we should NOT lose sight of the *Institutional Issues* we face in CI
 - Organizational structure and institutional interactions (there are organizational cultures which are slow to change)
 - Need for huge resources and the notion of public/private partnerships to give access to new sources of capital and expertise
 - Legacy issues: we usually have an infrastructure in place - rarely a greenfield development

Institutional Issues II

- Multiple stakeholders with different perspectives, about which they often feel strongly-- evaluative complexity
- Interaction of the institutional issues with the technological questions-- nested complexity
- Working across classes of infrastructure presents additional institutional issues (and it was hard enough already!)

Questions

- Networks interact with each other - how to deal with cascading failures?
 - Intra-infrastructure - on highways, a crash at important node causes congestion throughout - or intermodally, the interplay between passenger air transportation and HSR for trips of less than 500 miles
 - Inter-infrastructure - the interaction between communications and transportation networks (ITS, eg)
- Interaction of the technologies with organizations - local deployment and communications issues - can the firefighters communicate with the police?
- What does 'failure' mean? Spatially? Temporally?

• Military Example:

- It takes a network; the new frontline of modern warfare
 - By Stanley A McChrystal

Governing by Network

The New Shape of the Public Sector

Stephen Goldsmith and William D. Eggers



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□ “From business to warfare, networked organizational forms are supplanting hierarchies. Now, Goldsmith and Eggers, two of America’s most innovative policy thinkers, show how the networking trend is transforming government. This book is a must read for anyone concerned with how to make government better and more cost effective.”

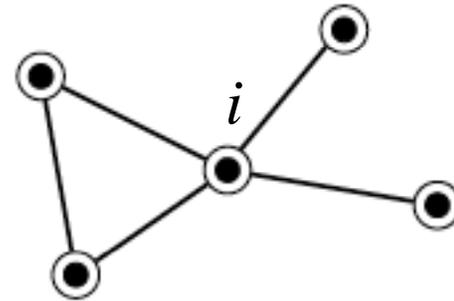
-*Mitt Romney*, Governor of Massachusetts

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- MIT and ESD.00 as networks
 - Bay Area ground transportation
 - Freight railroads

- Random and non-random networks

Network Properties: Clustering Coefficient

- It is a measure of clustering of a graph's vertices .
- In a friendship network it gives a measure of the extent to which friends of v are also friends of each other- it measures the cliquishness of a friendship circle.
- If a vertex i has k_i neighbors, then at most $k_i(k_i-1)/2$ edges can exist between them (when every neighbor of i is connected to every other neighbor of i). C_i is the fraction of edges that actually exist.
- C_i is also called the local clustering coefficient



$$C_i = \frac{2|\{e_{jk}\}|}{k_i(k_i-1)} \quad v_j, v_k \in N_i, e_{jk} \in E$$

Network Properties: Betweenness

- Betweenness of a node v , $C_B(v)$, is the number of paths from all nodes (except v) to all other nodes that must pass through node v .

$$C_B(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}} s, v, t \in V$$

- Betweenness measures the power of an intermediary.
- It is useful in applications related to network navigation, transmission of information etc.

σ_{st} : # of paths between vertices s and t

$\sigma_{st}(v)$: # of paths between vertices s and t passing through v

Network Properties: Degree Distribution

- A histogram of the degrees of vertices is the degree distribution of the network.
- The degree distribution, $P(k)$, is the fraction of vertices with degree k in the network with a total of n vertices:
 - $P(1)$ = fraction of vertices with degree 1 = n_1/n
 - $P(2)$ = fraction of vertices with degree 2 = n_2/n
 - :
 - $P(k_{\max})$ = fraction of vertices with largest degree $k_{\max} = n_{k_{\max}}/n$

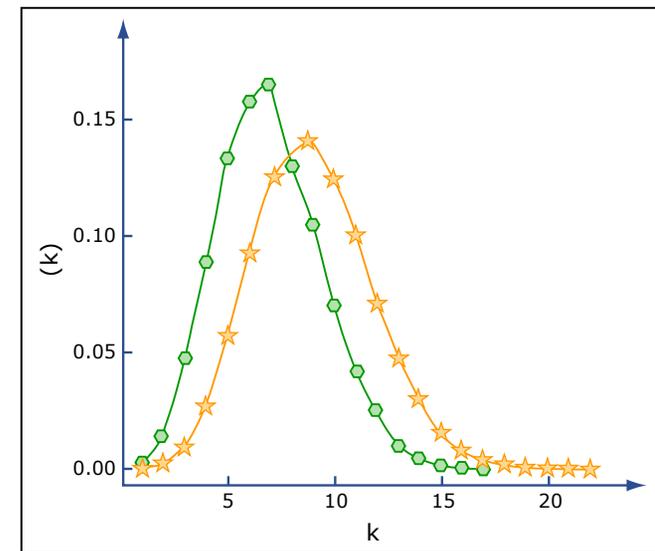


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In a **random graph**, each edge is present or absent with equal probability, and the **degree distribution is binomial**:

$$P(k) = \binom{n-1}{k} p^k (1-p)^{n-1-k}$$

Scale-Free Networks

- A **scale-free** network is a type of graph that has a degree distribution described (at least asymptotically) by a power law:

$$P(k) \sim ck^{-\gamma}, \gamma > 1$$

- A number of natural and man-made systems have been found to be 'scale-free' networks such as the world wide web, the internet, metabolic networks, citations between scientific papers etc.
- Scale-free networks contain some large hubs, but most vertices are connected to a few edges (have low degree).

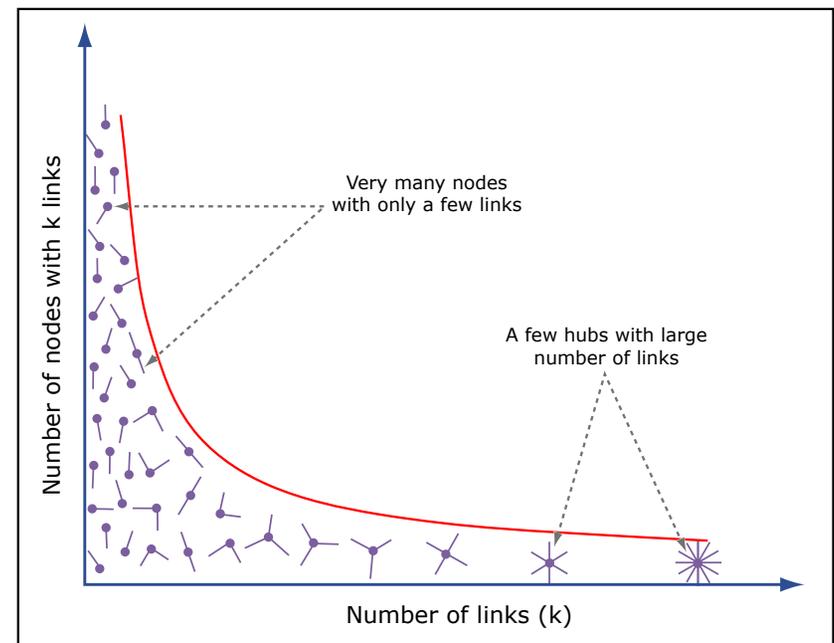


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Scale-free networks are fault tolerant – failure (or removal) of a node at random does not significantly affect network connectivity.

Additional Network Properties

- Network resilience is often a property of interest.
 - how well can the network maintain its connectivity when vertices are removed (due to failures, disruptions etc.)
 - what happens to the average path lengths etc.
- Degree correlations
 - do high-degree vertices connect mostly to other vertices of high-degrees or mostly to vertices with low degrees?
- Others...

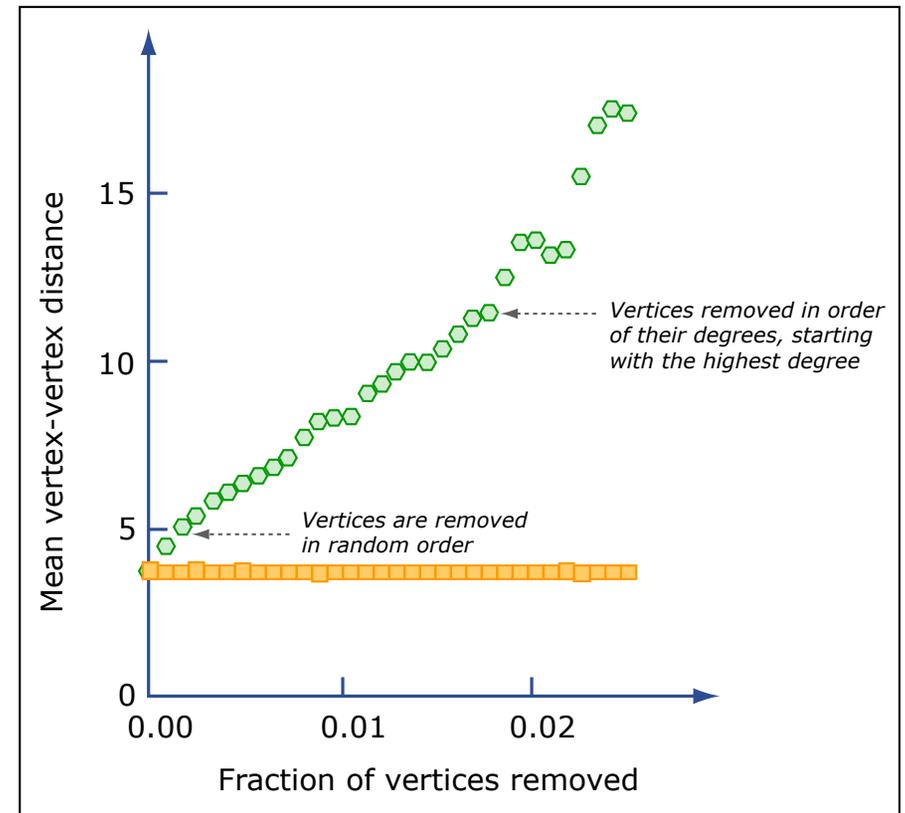


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Ref [1]

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[1] M.E.J. Newman, “The structure and function of complex networks”, SIAM review, 2003

[2] Duncan J. Watts & Steven H. Strogatz, “Collective dynamics of ‘small world’ networks”, Nature, Vol. 393, 4 June 1998

[3] Introduction to Graph Theory, Koh Khee Meng et. al

[4] Graph Theory: Modeling, Applications, and Algorithms, Geir Agnarsson, Raymond Greenlaw

Any comments or questions?



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