Frontiers of Network Science
Fall 2017
Class 4: Introduction
(Chapter 1 in Textbook)
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based on slides by
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FROM SADDAM HUSSEIN TO NETWORK THEORY
A SIMPLE STORY (1) The fate of Saddam and network science

[Image: TIME magazine cover with the text "WE GOT HIM!" and a photograph of Saddam Hussein.]

[Diagram: A network of individuals, including Saddam Hussein, Khalil Ibrahim Mussilii, Sulwan Ibrahim Mussilii, Mohammad Khudayr, Basim Latif, Sabha Talfah Mussilii, Barzan Ibrahim Khataab, Uday Hussein Majid, Saddam Hussein Majid, Ibrahim Hasan Khataab, Qusay Hussein, and Abid Hamid, connected by lines indicating relationships.]
The capture of Saddam Hussein:

→ shows the strong predictive power of networks.

→ underlies the need to obtain accurate maps of the networks we aim to study; and the often heroic difficulties we encounter during the mapping process.

→ demonstrates the remarkable stability of these networks: The capture of Hussein was not based on fresh intelligence, but rather on his pre-invasion social links, unearthed from old photos stacked in his family album.

→ shows that the choice of network we focus on makes a huge difference: the hierarchical tree, that captured the official organization of the Iraqi government, was of no use when it came to Saddam Hussein's whereabouts.
VULNERABILITY DUE TO INTERCONNECTIVITY

Section 3

VULNERABILITY DUE TO INTERCONNECTIVITY

August 14, 2003: 9:29pm EDT
20 hours before

August 15, 2003: 9:14pm EDT
7 hours after
An important theme of this class:

→ we must understand how network structure affects the robustness of a complex system.

→ develop quantitative tools to assess the interplay between network structure and the dynamical processes on the networks, and their impact on failures.

→ We will learn that failures in reality follow reproducible laws, that can be quantified and even predicted using the tools of network science.
NETWORKS AT THE HEART OF COMPLEX SYSTEMS
Complex

[adj., v. kuh m-pleks, kom-pleks; n. kom-pleks] –adjective

1. composed of many interconnected parts; compound; composite: a complex highway system.
2. characterized by a very complicated or involved arrangement of parts, units, etc.: complex machinery.
3. so complicated or intricate as to be hard to understand or deal with: a complex problem.

Complexity, a scientific theory which asserts that some systems display behavioral phenomena that are completely inexplicable by any conventional analysis of the systems’ constituent parts. These phenomena, commonly referred to as emergent behaviour, seem to occur in many complex systems involving living organisms, such as a stock market or the human brain.

Source: John L. Casti, Encyclopædia Britannica

Source: Dictionary.com
The "Day of 7 Billion" has been targeted by the United States Census Bureau to be in July 2012.

http://en.wikipedia.org/wiki/World_population
Human Brain has between 10-100 billion neurons.
The world economy produced goods and services worth almost $55 trillion in 2005.
(http://siteresources.worldbank.org/ICPINT/Resources/ICPreportprelim.pdf)
How Many Genes are in the Human Genome?

23,299

"I think the next century will be the century of complexity."

Stephen Hawking
January 23, 2000
Behind each complex system there is a network, that defines the interactions between the component.
The “Social Graph” behind Facebook

STRUCTURE OF AN ORGANIZATION

www.orgnet.com

Network Science: Introduction
Human Brain has between 10-100 billion neurons.
The subtle financial networks
The not so subtle financial networks: 2011
Network Science: Introduction
In the generic networks shown, the points represent the elements of each organism’s genetic network, and the dotted lines show the interactions between them.
Complex systems
Made of many non-identical elements connected by diverse interactions.
Behind each system studied in complexity there is an intricate wiring diagram, or a network, that defines the interactions between the component.

We will never understand complex system unless we map out and understand the networks behind them.
TWO FORCES HELPED THE EMERGENCE OF NETWORK SCIENCE
Graph theory: 1735, Euler

Social Network Research: 1930s, Moreno

Communication networks/internet: 1960s

THE HISTORY OF NETWORK ANALYSIS

- Erdos-Renyi
  1959
- Granovetter
  1973


The emergence of network maps:

C elegans neural wiring diagram 1990
Movie Actor Network, 1998
Citation Network, 1998
World Wide Web, 1999
Metabolic Network, 2000
PPI network, 2001
The universality of network characteristics:

The architecture of networks emerging in various domains of science, nature, and technology are more similar to each other than one would have expected.
THE EMERGENCE OF NETWORK SCIENCE

Data Availability:
- C elegans neural wiring diagram, 1990
- Movie Actor Network, 1998
- Citation Network, 1998
- World Wide Web, 1999
- Metabolic Network, 2000
- PPI network, 2001

Universality:
The architecture of networks emerging in various domains of science, nature, and technology are more similar to each other than one would have expected.

The (urgent) need to understand complexity:
Despite the challenges complex systems offer us, we cannot afford to not address their behavior, a view increasingly shared both by scientists and policy makers. Networks are not only essential for this journey, but during the past decade some of the most important advances towards understanding complexity were provided in context of network theory.
THE CHARACTERISTICS OF NETWORK SCIENCE
The characteristics of network science

Interdisciplinary

Empirical

Quantitative and Mathematical

Computational
THE CHARACTERISTICS OF NETWORK SCIENCE

Interdisciplinary

Empirical, data driven

Quantitative and Mathematical

Computational
THE CHARACTERISTICS OF NETWORK SCIENCE

Interdisciplinary

Empirical

Quantitative and Mathematical

Computational
THE CHARACTERISTICS OF NETWORK SCIENCE

Interdisciplinary

Empirical

Quantitative and Mathematical

Computational
THE IMPACT OF NETWORK SCIENCE
Quantum Mechanics: 1900

- electron microscope 1931
- transistor 1947
- laser 1957
- magnetic resonance imaging 1973
- quantum computing 2015

Much of modern technology operates at a scale where quantum effects are significant.

At least a 30 year gap between the science and technology.
THE TOOLS OF MODERN NETWORK THEORY

- Graph theory
- Social network theory
- Statistical physics
- Computer science
- Biology
- Statistics
Google
Market Cap (2010 Jan 1): $189 billion

Cisco Systems
networking gear Market cap (Jan 1, 2019): $112 billion

Facebook
market cap: $50 billion

www.bizjournals.com/austin/news/2010/11/15/facebooks... - Cached
Reduces
Inflammation
Fever
Pain

Prevents
Heart attack
Stroke

Causes
Bleeding
Ulcer

Reduces the risk of
Alzheimer's Disease

Reduces the risk of
breast cancer
ovarian cancers
colorectal cancer

COX2

Network Science: Introduction

Drug Design, Metabolic Engineering:
Network Biology/Network Medicine
The network behind a military engagement
Real Projected

Epidemic Forecast: Predicting the H1N1 pandemic
In September 2010 the National Institutes of Health awarded $40 million to researchers at Harvard, Washington University in St. Louis, the University of Minnesota and UCLA, to develop the technologies that could systematically map out brain circuits.

**The Human Connectome Project (HCP)** with the ambitious goal to construct a map of the complete structural and functional neural connections in vivo within and across individuals.

http://www.humanconnectomeproject.org/overview/
SCIENTIFIC IMPACT
Complex systems and networks.

• **Science:**

Special Issue for the 10 year anniversary of Barabas i& Albert 1999 paper.
• 1998: Watts-Strogatz paper in the most cited *Nature* publication from 1998; highlighted by ISI as one of the ten most cited papers in physics in the decade after its publication.

• 1999: Barabasi and Albert paper is the most cited *Science* paper in 1999; highlighted by ISI as one of the ten most cited papers in physics in the decade after its publication.

• 2001: Pastor-Satorras and Vespignani is one of the two most cited papers among the papers published in 2001 by *Physical Review Letters*.

• 2002: Girvan-Newman is the most cited paper in 2002 *Proceedings of the National Academy of Sciences*. 

Original papers:
The first review of network science by Albert and Barabasi (2001) is the second most cited paper published in *Reviews of Modern Physics*, the highest impact factor physics journal, published since 1929. The most cited is Chandrasekhar’s 1944 review on solar processes, but it was by far surpassed by Albert *et al.* who in 2016 had 8280 but was itself surpassed by materials paper on graphene.

The SIAM review of Newman on network science is the most cited paper of any SIAM journal.

BIOLOGY: “Network Biology”, by Barabasi and Oltvai (2004), is the second most cited paper in the history of *Nature Reviews Genetics*, the top review journal in genetics.
Handbook of Graphs and Networks: From the Genome to the Internet (Wiley-VCH, 2003).

S. N. Dorogovtsev and J. F. F. Mendes, Evolution of Networks: From Biological Nets to the Internet and WWW (Oxford University Press, 2003).


How Everything Is Connected to Everything Else and What It Means for Business, Science, and Everyday Life

Linked

Mark Buchanan

SMALL WORLDS and the Groundbreaking THEORY OF NETWORKS

"The best explanation yet of small-world theory." — New York Times

A lbert-László Barabási

With a New Afterword

SIX DEGREES

THE SCIENCE OF A CONNECTED AGE

DUNCAN J. WATTS
If you were to understand the spread of diseases, can you do it without networks?

If you were to understand the WWW structure, searchability, etc, hopeless without invoking the Web’s topology.

If you want to understand human diseases, it is hopeless without considering the wiring diagram of the cell.
CLASS INFORMATION