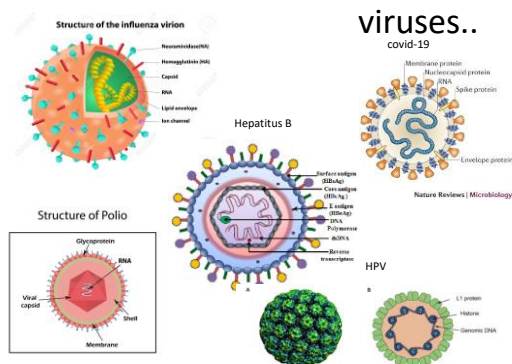
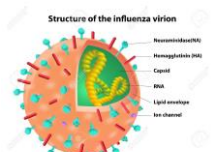


1



2



viruses..

On the spikes of influenza virion: Hemagglutinine (H) and Neuraminidase (N)

H is being used for entering the cell , there are 16 types

N is being used for leaving the host cell, there are 9 types

Immune system can recognize H and N

RNA virus, mutates quickly

Avian flu (one of the variants) H5N1

Recombination of different influenza virions in different hosts (zoonose)

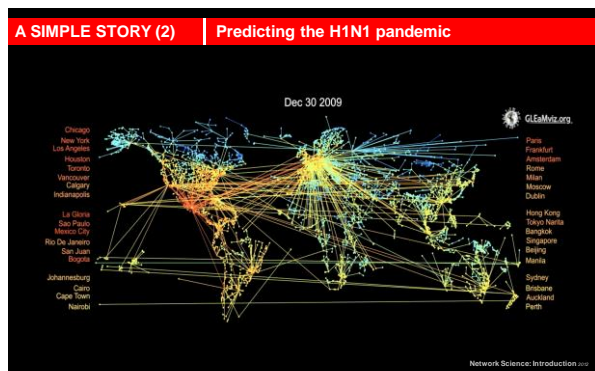
3



viruses..

Spanish flu H1N1: 1918-1919, 20 -100 million deaths

4



5

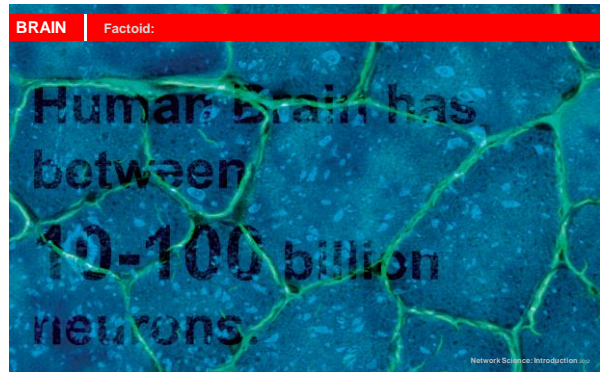


6

# Complexity

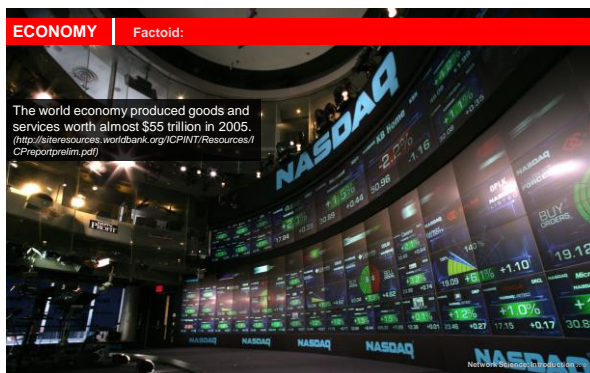
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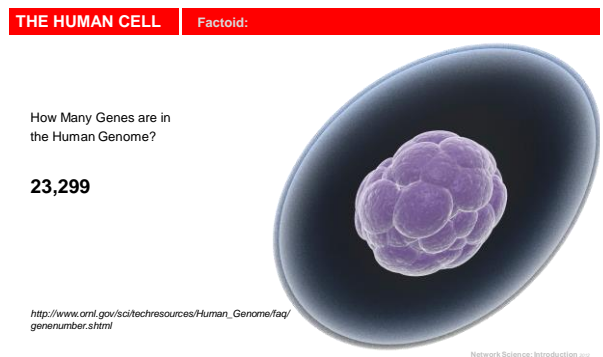


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8



9



[http://www.cnl.gov/scitechresources/Human\\_Genome/faq/genenumber.shtml](http://www.cnl.gov/scitechresources/Human_Genome/faq/genenumber.shtml)

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## 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.

Source: Dictionary.com

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, *Encyclopaedia Britannica*

### Complexity

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## COMPLEX SYSTEMS

No blueprint

No “master-mind”

**Self-organization**

**Evolution**

**Adaptation**



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# Networks

Network Science: Introduction 13.1

14

## THE ROLE OF NETWORKS

Behind each complex system there is a **network**, that defines the interactions between the component.

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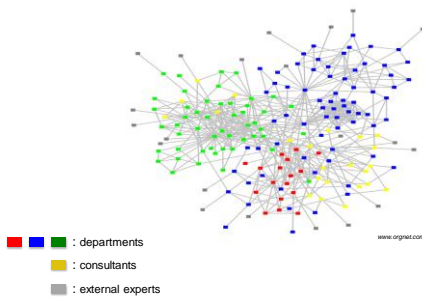
## SOCIETY

Factoid:



16

## STRUCTURE OF AN ORGANIZATION

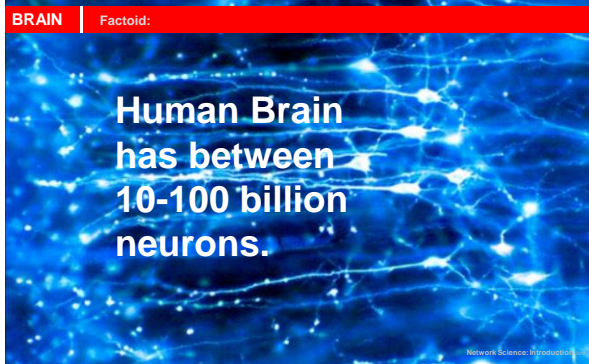


17

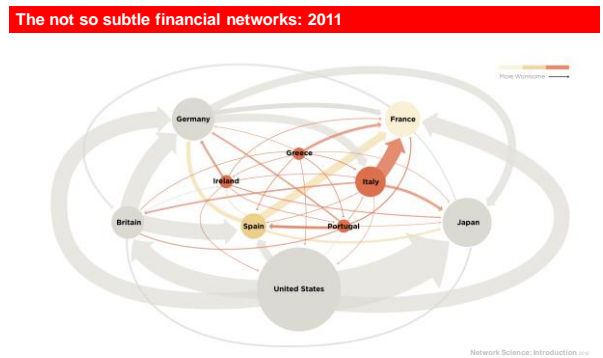
## STRUCTURE OF AN ORGANIZATION



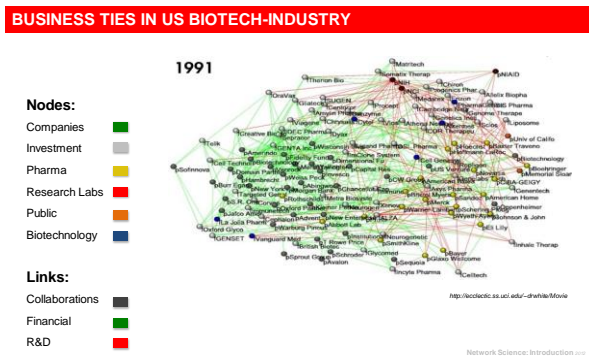
18



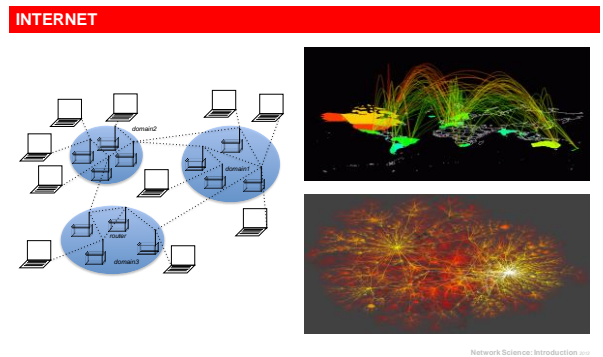
19



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21



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## THE ROLE OF NETWORKS

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.

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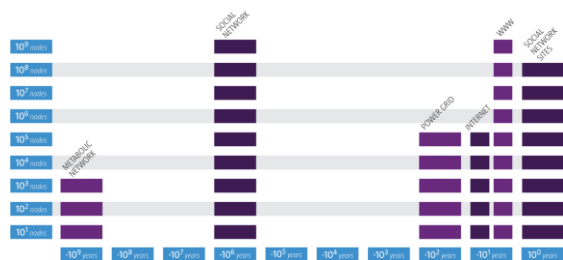
WHY NOW?

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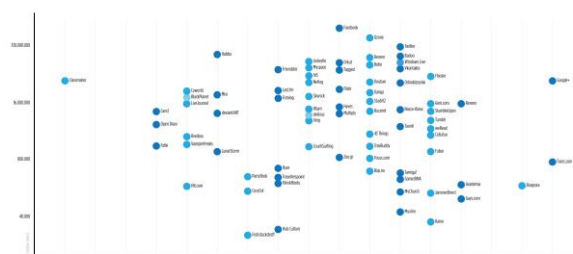
## THE LIFE OF NETWORKS



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## THE LIFE OF NETWORKS



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## THE HISTORY OF NETWORK ANALYSIS

Graph theory: 1735, Euler

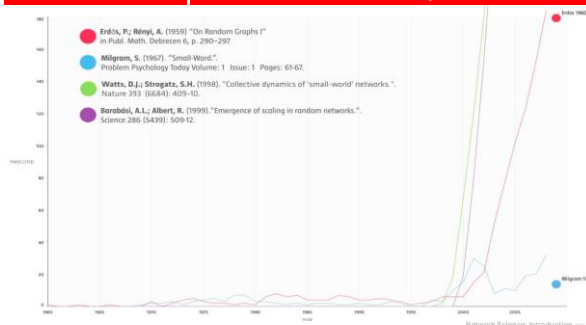
Social Network Research: 1930s, Moreno

Communication networks/internet: 1960s

Ecological Networks: May, 1979.

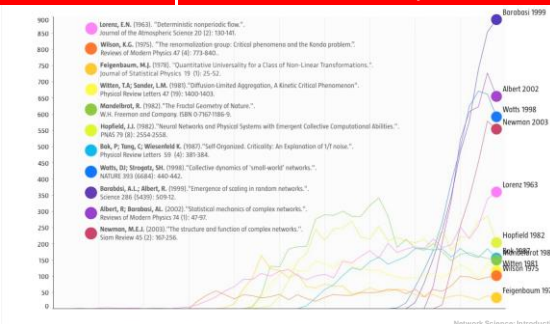
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NETWORK SCIENCE | The science of the 21<sup>st</sup> century

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NETWORK SCIENCE | The science of the 21<sup>st</sup> century

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29

NETWORK SCIENCE | The science of the 21<sup>st</sup> century

Why now?

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## THE EMERGENCE OF NETWORK SCIENCE

**Data Availability:** Movie Actor Network, 1998;  
World Wide Web, 1999.  
C elegans neural wiring diagram 1990  
Citation Network, 1998  
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.

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## THE CHARACTERISTICS OF NETWORK SCIENCE

*Interdisciplinary*

*Empirical*

*Quantitative and Mathematical*

*Computational*

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## THE TOOLS OF MODERN NETWORK THEORY

- > Graph theory
- > Social network theory
- > Statistical physics
- > Computer science
- > Biology
- > Statistics

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## ECONOMIC IMPACT



**Google**  
Market Cap(2010 Jan 1):  
\$189 billion

**Cisco Systems**  
networking gear Market  
cap (Jan 1, 2919):  
\$112 billion

**Facebook**  
market cap:  
\$50 billion

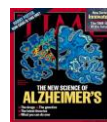
[www.bizjournals.com/austin/news/2010/11/15/facebook...](http://www.bizjournals.com/austin/news/2010/11/15/facebook...) - Cached

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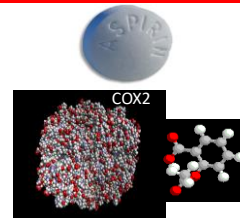
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## DRUG DESIGN, METABOLIC ENGINEERING:

Reduces  
Inflammation  
Fever  
Pain



Reduces the risk of  
Alzheimer's Disease



Reduces the risk of  
breast cancer  
ovarian cancers  
colorectal cancer

Prevents  
Heart attack  
Stroke

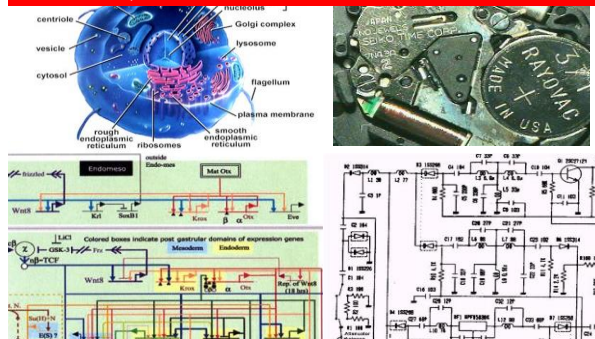


Causes  
Bleeding  
Ulcer

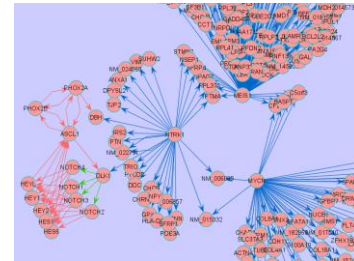
Network Science: Introduction 100

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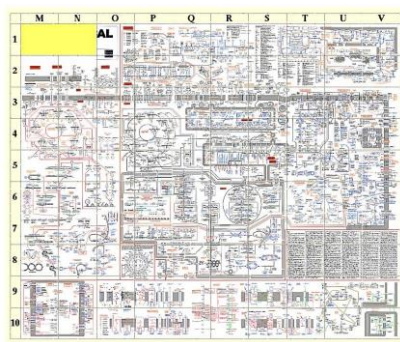
## DRUG DESIGN, METABOLIC ENGINEERING:



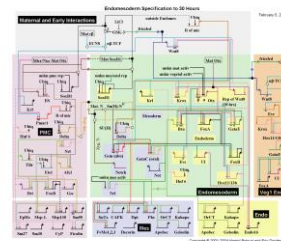
38



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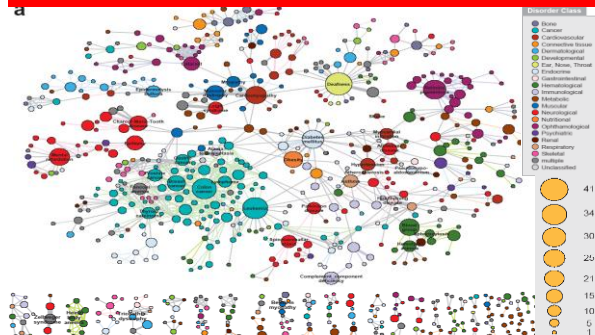


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## HUMAN DISEASE NETWORK

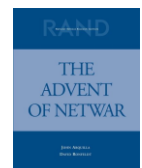
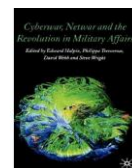


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## FIGHTING TERRORISM AND MILITARY



<http://www.slate.com/id/2245232>



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## FIGHTING TERRORISM AND MILITARY

Network Science Center  
West Point



<http://www.ns-cta.org/ns-cta-blog/>

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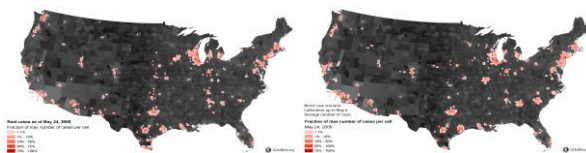
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## EPIDEMIC FORECAST

## Predicting the H1N1 pandemic

Real

Projected



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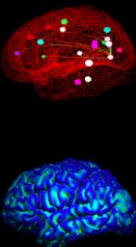
45

## BRAIN RESEARCH

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.

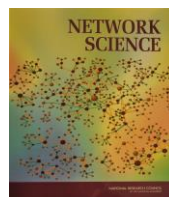
<http://www.humanconnectomeproject.org/overview/>



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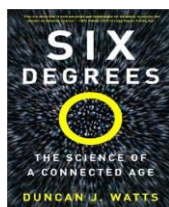
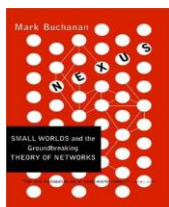
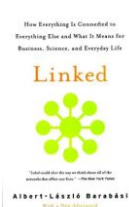
## National Research Council:



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## GENERAL AUDIENCE



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## BOOKS



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).



S. Goldsmith, W. D. Eggers, Governing by Network: The New Shape of the Public Sector (Brookings Institution Press, 2004).



P. Csermely, Weak Links: The Universal Key to the Stability of Networks and Complex Systems (The Frontiers Collection) (Springer, 2006), 1st edn.



M. Newman, A.-L. Barabási, D. J. Watts, The Structure and Dynamics of Networks (Princeton Studies in Complexity) (Princeton University Press, 2006), 1st edn.



L. L. F. Chung, Complex Graphs and Networks (CBMS Regional Conference Series in Mathematics) (American Mathematical Society, 2006).

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## BOOKS



R. Pastor-Satorras, A. Vespignani, *Evolution and Structure of the Internet: A Statistical Physics Approach* (Cambridge University Press, 2007), 1st edn.



F. Kops, *Biological Networks* (Complex Systems and Interdisciplinary Science) (World Scientific Publishing Company, 2007), 1st edn.



B. H. Junker, F. Schreiber, *Analysis of Biological Networks* (Wiley Series in Bionformatics) (Wiley-Interscience, 2008).



T. G. Lewis, *Network Science: Theory and Applications* (Wiley, 2009).



E. Ben Naim, H. Frauenfelder, Z. Torozai, *Complex Networks* (Lecture Notes in Physics) (Springer, 2010), 1st edn.



M. O. Jackson, *Social and Economic Networks* (Princeton University Press, 2010).

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## Original papers:

• 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**.

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## REVIEWS:

• 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 will be surpassed by the end of 2012 by Albert *et al.*

• 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.



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## JOURNAL

• **Science:**

Special Issue for the 10 year anniversary of Barabasi&Albert 1999 paper.



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## MOST IMPORTANT | Networks Really Matter

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.**

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## Labs for Networks

## Gephi

We will use the free **GEPHI** software for the labs.

Quite simple to use and can make nice pictures.



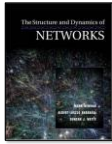
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## Reading Material

## Newman &amp; Barabasi

There should be a copy of the **Mark Newman** book in the UvA library:



**Barabasi** has free eBook online:

<http://barabasilab.neu.edu/networksciencebook/>



Very detailed – all the mathematics....

....Follows the lectures closely

Network Science: Introduction 2019