



# Network Science Analytics

Gonzalo Mateos

Dept. of ECE and Goergen Institute for Data Science

University of Rochester

`gmateosb@ece.rochester.edu`

`http://www.ece.rochester.edu/~gmateosb/`

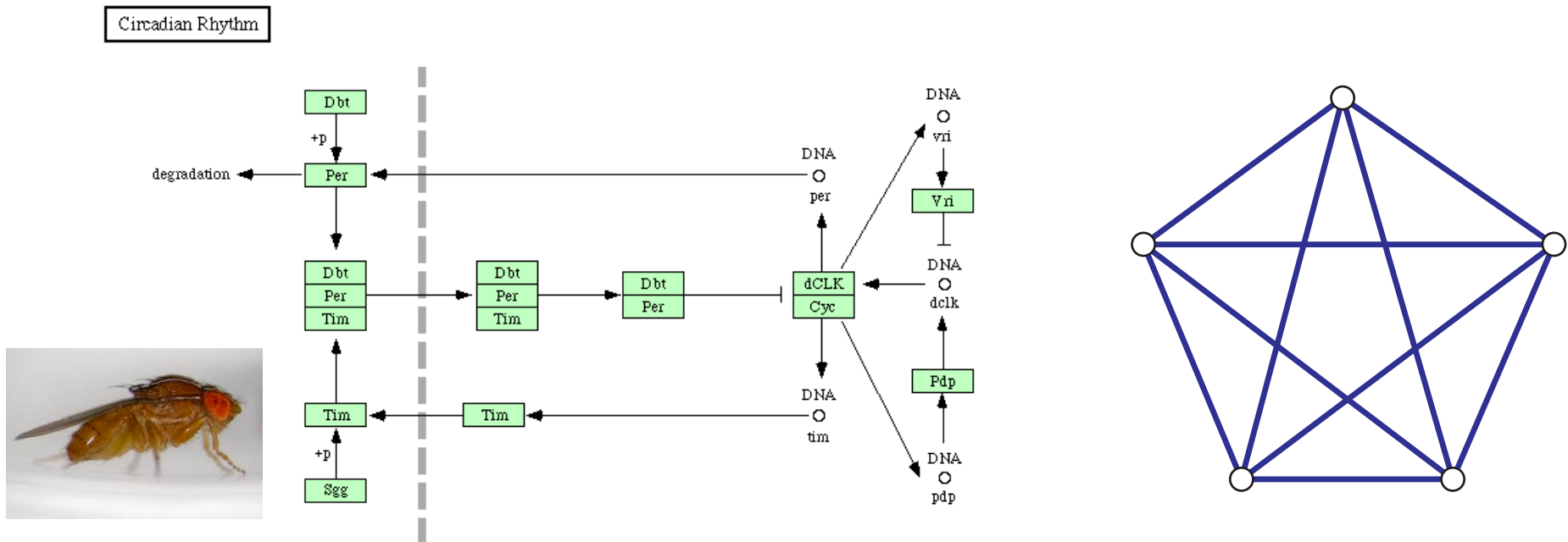
January 11, 2022

Introductions

Networks - A birds-eye view

Class description and contents

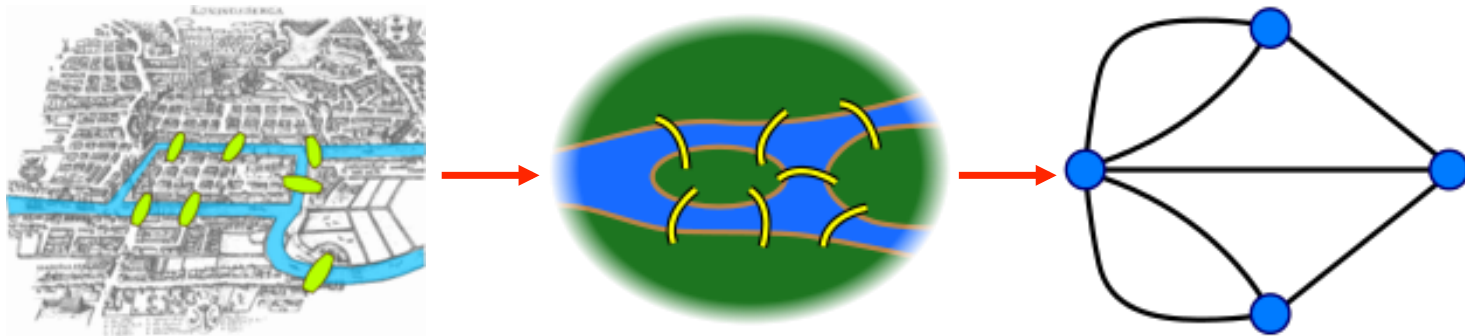
- ▶ As per the dictionary: *A collection of inter-connected things*
- ▶ Ok. There are **multiple things**, they are **connected**. Two extremes



- 1) A real (complex) system of inter-connected components
- 2) A graph representing the system

- ▶ Understand **complex systems**  $\Leftrightarrow$  Understand **networks** behind them

- ▶ Network-based analysis in the sciences has a long history
- ▶ Mathematical foundations of graph theory (L. Euler, 1735)



- ▶ The seven bridges of Königsberg
- ▶ Laws of electrical circuitry (G. Kirchoff, 1845)
- ▶ Molecular structure in chemistry (A. Cayley, 1874)
- ▶ Network representation of social interactions (J. Moreno, 1930)
- ▶ Power grids (1910), telecommunications and the Internet (1960)
- ▶ Google (1997), Facebook (2004), Twitter (2006), ...

# Why networks? Why now?

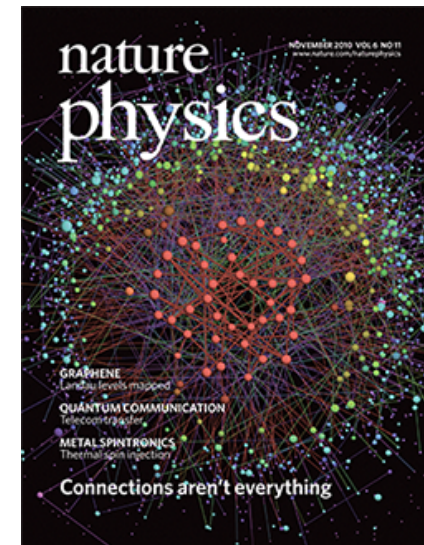
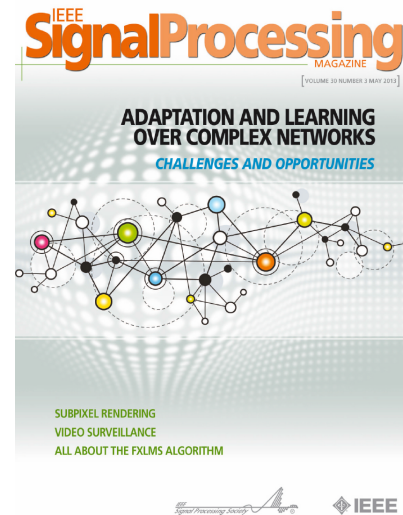
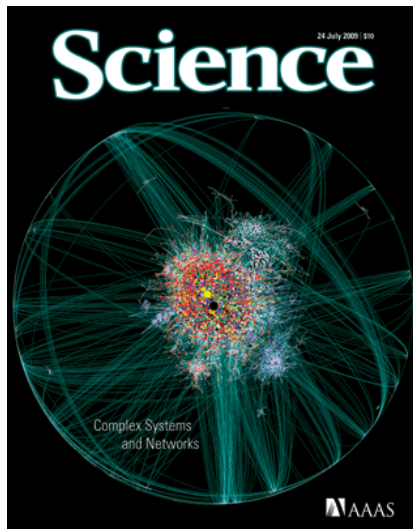


- ▶ Understand **complex systems**  $\Leftrightarrow$  Understand **networks** behind them



- ▶ Relatively small field of study up until  $\sim$  the mid-90s
- ▶ **Epidemic-like explosion of interest recently.** A few reasons:
  - ▶ Systems-level perspective in science, away from reductionism
  - ▶ Ubiquitous high-throughput data collection, computational power
  - ▶ Globalization, the Internet, connectedness of modern societies

- ▶ Study of complex systems through their network representations  
**Ex:** economy, metabolism, brain, society, Web, ...
- ▶ Universal language for describing complex systems and data
  - ▶ Striking similarities in networks across science, nature, technology
- ▶ Shared vocabulary across fields, cross-fertilization
  - ▶ From biology to physics, economics to statistics, CS to sociology



- ▶ **Impact:** social networking, drug design, smart infrastructure, ...

# Economic impact

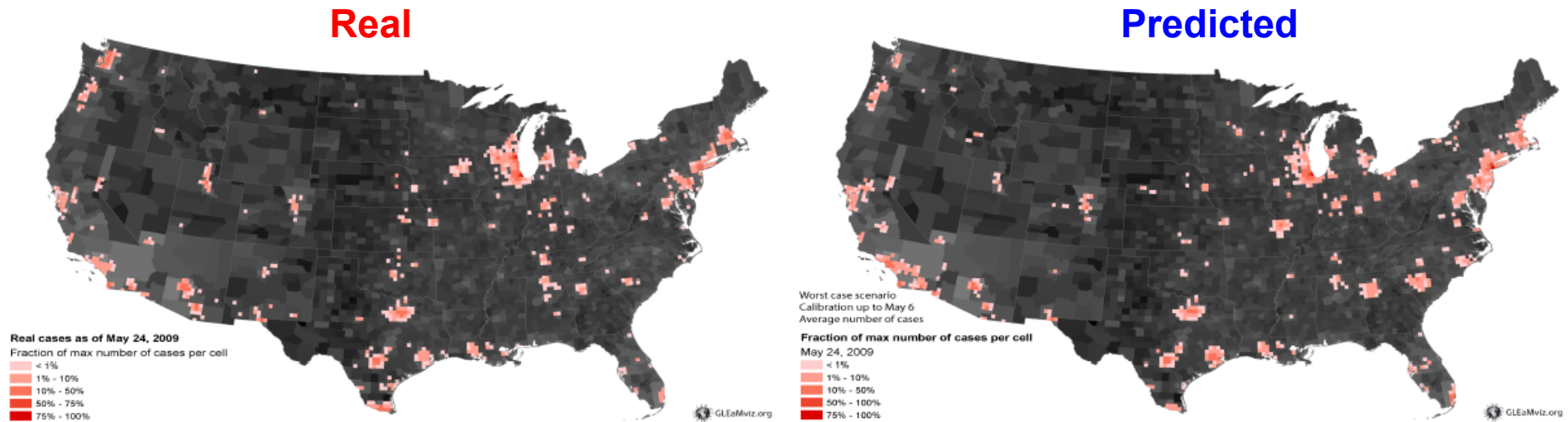


UNIVERSITY of ROCHESTER

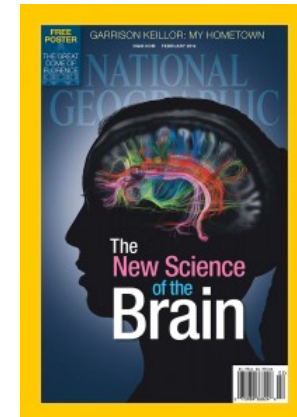
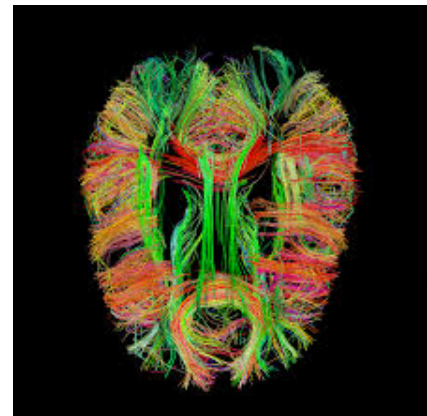
- ▶ **Google**  
Market cap:  
\$1.24 trillion
- ▶ **Facebook**  
Market cap:  
\$736 billion
- ▶ **Cisco**  
Market cap:  
\$188 billion
- ▶ **Apple**  
Market cap:  
\$2.22 billion



- ▶ Prediction of **epidemics**, e.g. the 2009 H1N1 pandemic

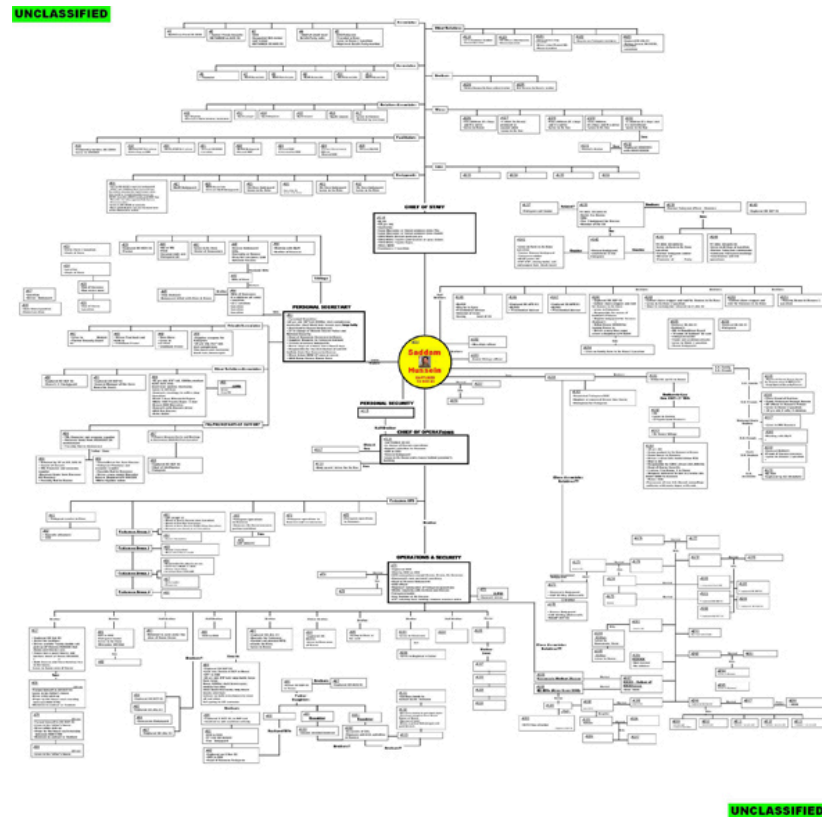
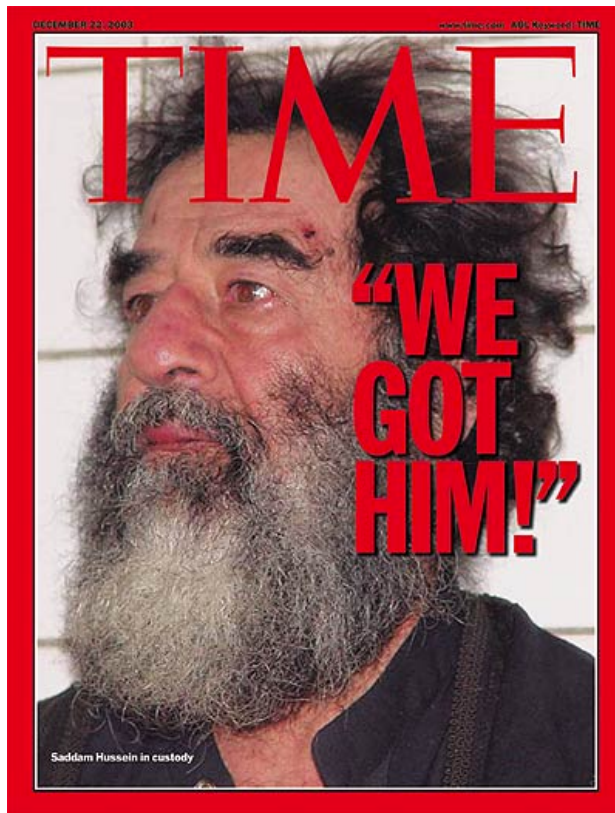


- ▶ Human Connectome Project to map-out **brain** circuitry





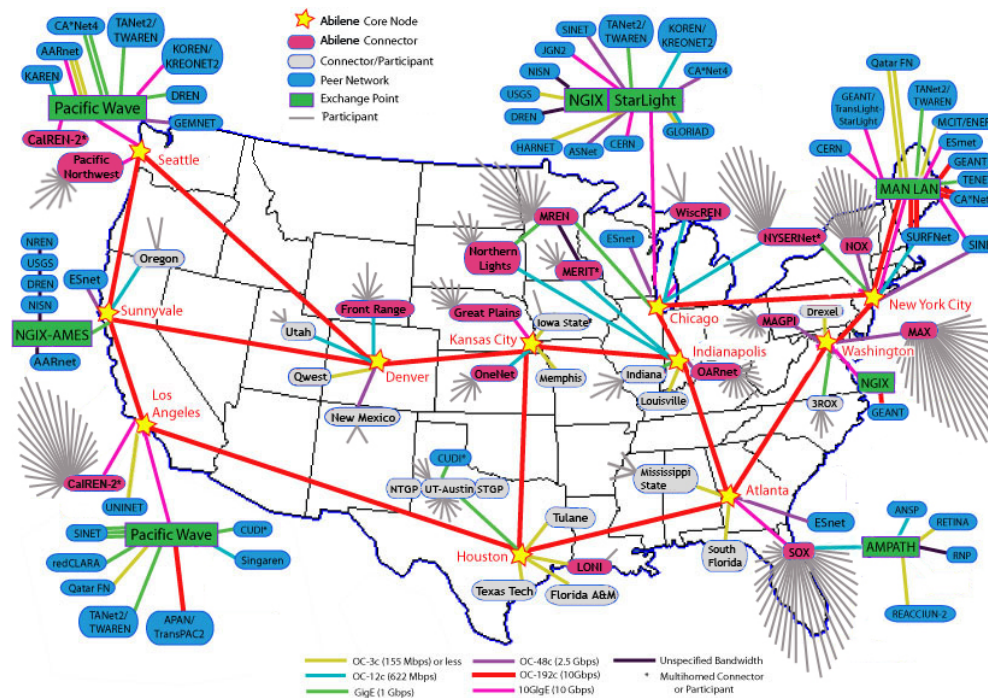
- ▶ Social network analysis key to capturing S. Hussein



- ▶ What are the **goals** of Network Science?
  - ▶ **Reveal** patterns and statistical properties of network data
  - ▶ **Understand** the underpinnings of network behavior and structure
  - ▶ **Engineer** more resource-efficient, robust, socially-intelligent networks
- ▶ **Characteristics**: interdisciplinary, empirical, quantitative, computational
- ▶ **Empirical** study of graph-valued data to find patterns and principles
  - ▶ Collection, measurement, summarization, visualization?
- ▶ Mathematical **models**. Graph theory meets statistical inference
  - ▶ Understand, predict, discern nominal vs anomalous behavior?
- ▶ **Algorithms** for graph analytics
  - ▶ Computational challenges, scalability, tractability vs optimality?

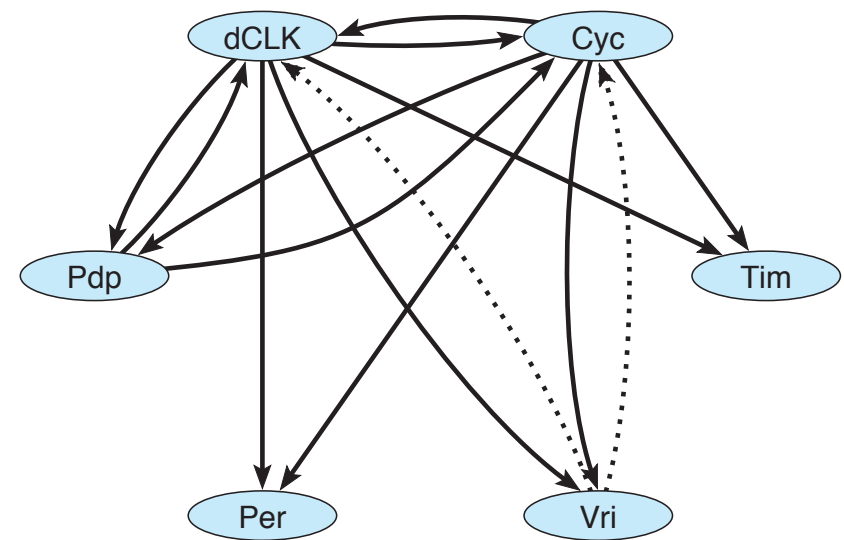
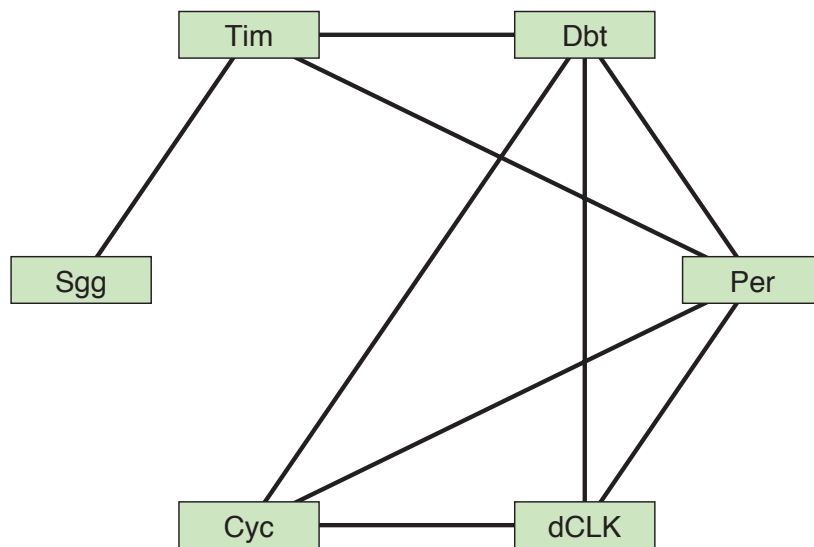
- ▶ Network analysis spans the sciences, humanities and arts
- ▶ Let's see a few examples from four general areas
  - ▶ Technological
  - ▶ Biological
  - ▶ Social
  - ▶ Informational
- ▶ Standard taxonomy, by no means the only one
  - ⇒ “Soft” classification, networks may fall in multiple categories

- ▶ **Ex:** communication, transportation, energy, sensor networks



- ▶ **Q1:** What does the Internet look like today? How big is it?
- ▶ **Q2:** How will the traffic from New York to Chicago look tomorrow?
- ▶ **Q3:** How can we unveil anomalous traffic patterns?

- ▶ **Ex:** neurons, gene regulatory, protein interaction, metabolic paths, predator-prey, ecological networks



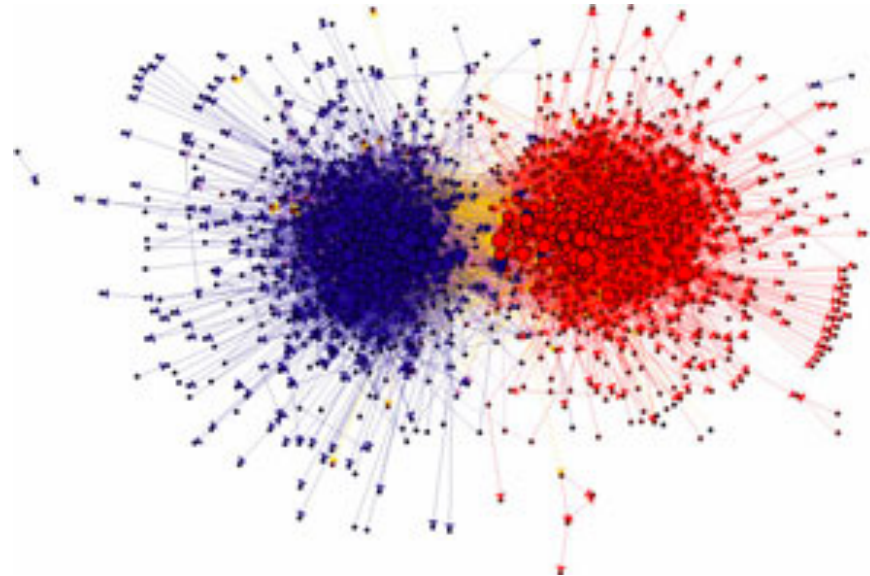
- ▶ **Q1:** Are certain gene interactions more common than expected?
- ▶ **Q2:** Which parts of the brain “communicate” during a given task?
- ▶ **Q3:** Can we predict biological function of proteins from interactions?

- ▶ **Ex:** friendship, corporate, email exchange, international relations, financial networks



- ▶ **Q1:** What are the mechanisms underpinning friendship formation?
- ▶ **Q2:** Which actors are central to the network and which peripheral?
- ▶ **Q3:** Can we identify overlapping communities?

- ▶ **Ex:** WWW, Twitter, co-citation between academic journals, blogosphere, paper co-authorship, peer-to-peer networks



- ▶ **Q1:** How does the size and structure of the WWW change in time?
- ▶ **Q2:** How can we use network analysis for authorship attribution?
- ▶ **Q3:** Can we track information cascades in online social media?