ECON5152 — Network Analysis

Week 1: Introduction to Networks

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Housekeeping: Course Logistics

- Lectures focus on motivation and formal description
- Labs will focus on visualization and programming
- Assessments
  1. Individual project (40%): guided replication
  2. Group project (50%): perform your own network analysis
  3. Reflection (10%): attached to group project, graded separately
- Office hours 1–3 pm on Thursdays

Reading for the week

- Jackson, *Social and Economic Networks*, Chapters 1–2
- Newman, *Networks*, Chapter 1

Outline

1. Motivation: why networks?
2. Formal definition
3. Directed, undirected, weighted networks
4. Graph and adjacency representations
5. Examples
    - Internet
    - Social network
    - Financial risk
    - Trade networks
    - Geography
    - Biological networks
    - Disease spread
    - Diffusion (products, knowledge, etc.)

Course Motivation

- Most economic, financial, and social systems are inherently interconnected
- Networks provide a unified language to represent interdependence
- Examples:
  - Trade and production networks
  - Financial interbank exposures
  - Social and information networks
  - Transportation
  - Biological systems
- This course provides you with the tools to study networks regardless of the field of interest
- Take a formal approach backed by visualization and statistical methods

What Is a Network?

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- Networks encode relationships or interactions between units.

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A *network*, or formally, a *graph* $\mathcal{G}(\mathcal{N}, \mathcal{E})$ consists of:

- a set of *nodes* (or vertices) $\mathcal{N}$
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- Elements of $\mathcal{E}$ are pairs of nodes in $\mathcal{N}$
- Example: $\mathcal{N} = \{1, 2, 3\}$ with $\mathcal{E} = \{(1, 2), (2, 3)\}$

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Nodes

- Represent entities in the system
- Examples:
  - Individuals in a social network
  - Firms or industries in an economic network
  - Banks in a financial network
  - Webpages on the internet
- Nodes are often labeled and may have attributes

Edges

- Represent relationships between nodes
- Can encode:
  - Trade flows
  - Financial exposures
  - Communication or friendship
  - Technological dependence
- May differ in direction, strength, or type

Directed and Undirected Networks

- *Undirected network*:
  - Edges have no direction
  - Relationship is symmetric
  - Example: mutual friendship
- *Directed network*:
  - Edges have a direction
  - Relationship is asymmetric
  - Example: supplier $\rightarrow$ customer

Weighted and Unweighted Networks

- *Unweighted networks*:
  - Edges indicate presence or absence of a relationship
- *Weighted networks*:
  - Edges carry a numerical value
  - Example: trade volume, loan size, input share
- *Signed networks*:
  - Edges can take positive or negative values
  - Example: trade balance, social interactions (like and dislike)
- Weights allow networks to capture intensity and heterogeneity

Graph Representation

- Networks can be visualized in their graph representation
- Nodes are points; edges are lines (undirected) or arrows (directed)
- Visualization helps build intuition
- It does not replace formal analysis
- Explore visualization further in lab

Caveat: Graph representations are not unique and depend on layout choices.

Adjacency Representation

Adjacency Matrix

For a network with n nodes, the adjacency matrix A is an $n \times n$ matrix where:

$$A_{i,j} = \begin{cases} 1 & \text{if there is an edge from } j \text{ to } i, \\ 0 & \text{otherwise.} \end{cases}$$

Weighted networks have $A_{i,j} \in \mathbb{R}$ representing the edge weight.

Graphs vs Matrices

- Graphs:
  - Intuitive and visual
  - Useful for exploration
- Matrices:
  - Encode relationships using linear algebra
  - Enable computation and theory
- Focus on the interplay between both representations

Internet Networks

- Nodes represent computers, servers, or routers
- Edges represent physical or logical connections
- Highly heterogeneous and decentralized structure

Internet Networks

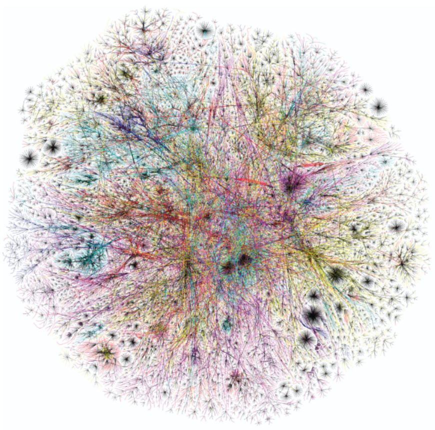

Figure: Network structure of the internet

Social Networks

- Nodes represent individuals
- Edges represent social relationships or interactions
- Structure shapes information flow and behavior

Social Networks

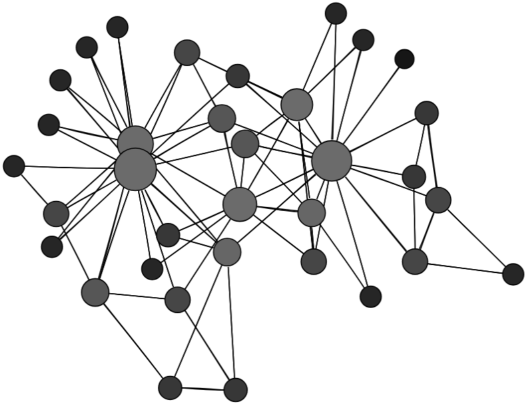

Figure: Friendship between club members

Financial Networks

- Nodes represent financial institutions
- Edges represent exposures, loans, or obligations
- Network structure influences systemic risk

Financial Networks

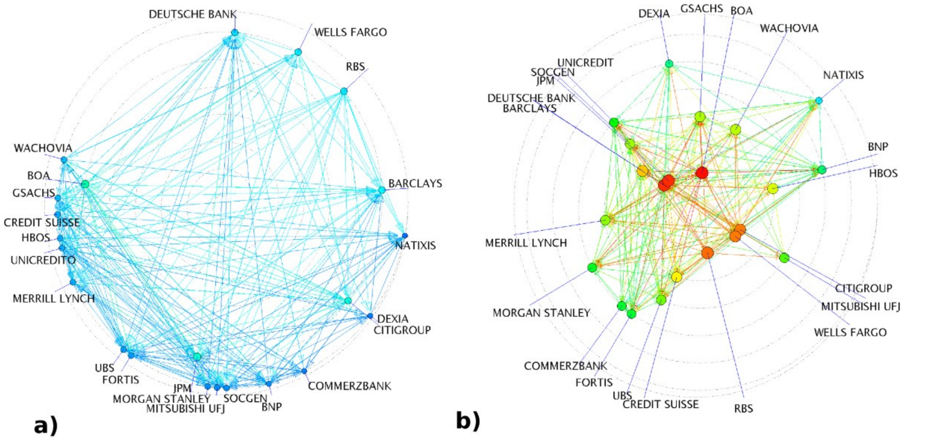

Figure: Spread of financial risk between institutions

Trade Networks

- Nodes represent countries or sectors
- Edges represent trade flows
- Direction and weight capture exporter–importer relationships

Trade Networks

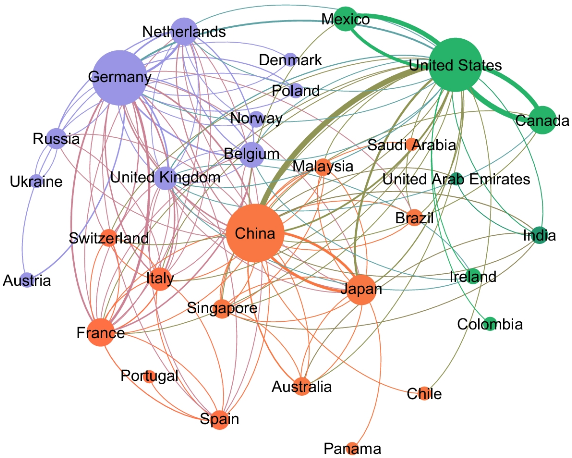

Figure: Trade flows between selected countries

Geographic Networks

- Nodes represent locations or regions
- Edges represent physical proximity or transport links
- Spatial constraints shape network structure

Geographic Networks

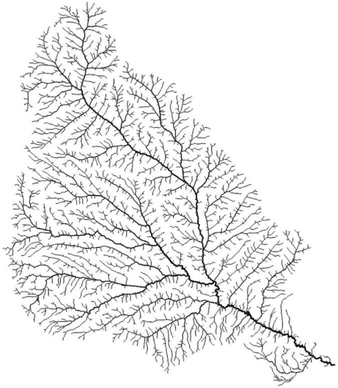

Figure: Drainage basin of the Loess plateau

Geographic Networks

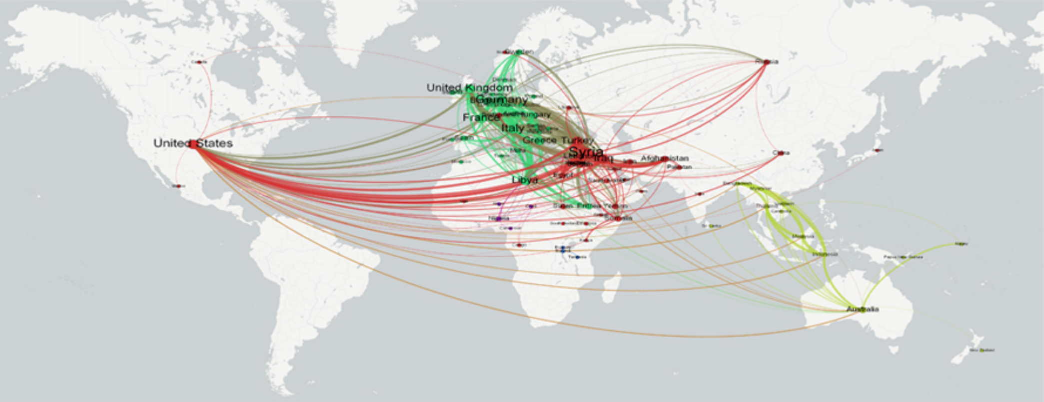

Figure: Refugee flows between countries

Biological Networks

- Nodes represent genes, proteins, species or neurons
- Edges represent interactions or dependencies
- Network structure underlies biological function

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Biological Networks

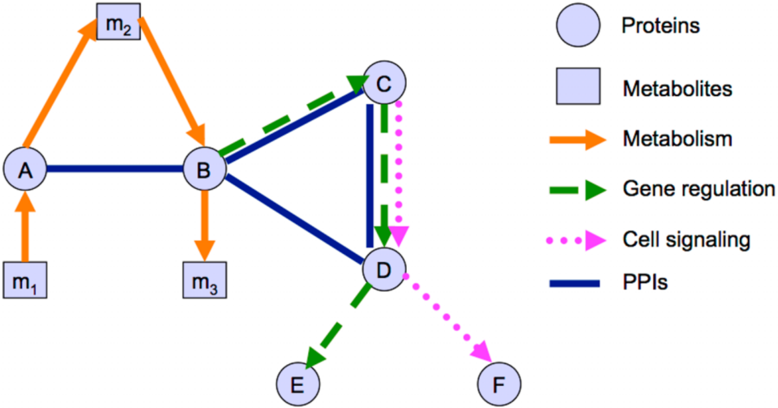

Figure: Protein interactions

Biological Networks

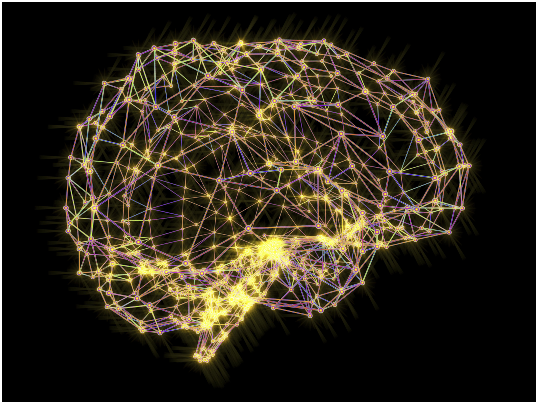

Figure: Brain network between neurons

Disease Spread

- Nodes represent individuals or populations
- Edges represent contact or transmission pathways
- Network topology affects epidemic dynamics

Disease Spread

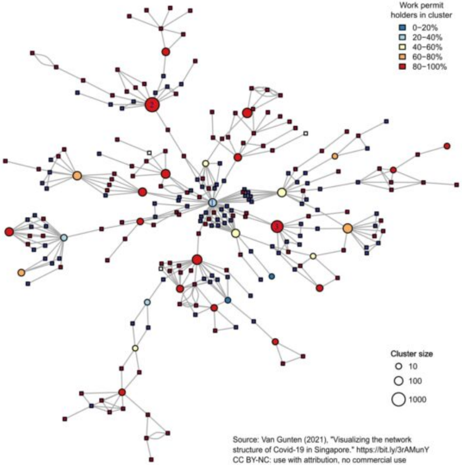

Figure: Visualization of COVID-19 spread

Diffusion Networks

- Nodes represent agents or firms
- Edges represent communication or influence channels
- Networks shape adoption and diffusion patterns

Diffusion Networks

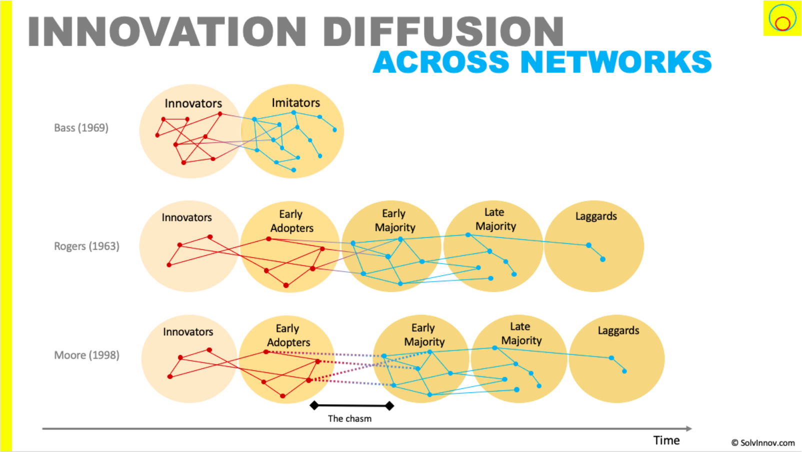

Figure: Stages of product diffusion

Why Study Networks?

- Individual behavior depends on network position
- Aggregate outcomes depend on network structure
- Networks generate amplification, persistence, and fragility
- Provide a bridge between micro and macro analysis

What Comes Next

- Structural properties of networks
- Measures of importance and centrality
- Linear and nonlinear processes on networks
- Statistical models of network formation

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