Network Science

- What is Network Science?
- How can I use network science?
- Types of Networks
  - Brain Networks
  - Behavioral Networks
  - Social Networks
- Cautionary Tails
  - Model Definitions (Butts)
  - Mechanistic Assumptions (Stumpf & Porter)
- Looking Ahead to Lecture #8
  - Networks and Dynamical Systems

Dani S. Bassett
What is Network Science?

- Network science provides a set of representation rules for a complex system.
  - The system is separated into 2 types of parts:
    - Its components (nodes)
    - And their interactions with one another (edges)
  - Together, nodes and edges form what is called a graph or network.
How can I use network science?

- To understand the relationships between many variables

Neighbor-Scale

Community-Scale

Network-Scale

Clustering

Modularity

Path-length

Dani S. Bassett
Types of Networks

- Networks come in many flavors

  - Gene Networks
  - Brain Networks
  - Behavioral Networks
  - Social Networks

- Co-expression
- Connectivity
- Similarity in Behaviors or Traits
- Relationships Between Individuals
Example Gene Network

- **Similarity in expression over development**

Nodes:
- SPONGE: *A. queenslandica* (Aqu)
- CORAL: *A. millepora* (Ami)
- WORM: *C. elegans* (Cel)
- FLY: *D. melanogaster* (Dme)
- FISH: *D. rerio* (Dre)
- FROG: *X. tropicalis* (Xtr)

Edges: Correlations in gene expression over developmental stages

Conaco et al. 2012 PNAS In Press

Dani S. Bassett
What can we learn?

- We can begin to understand the co-regulation of specific genes sets over development and evolutionary time.

Conaco et al. 2012 PNAS In Press

Dani S. Bassett
Examples of Brain Networks

- **Neuron-Neuron Networks**
  - Multielectrode Array Recordings of Neuronal Cultures
    - Estimate neuron-neuron networks
    - Example: Bettencourt et al. 2007 PRE

- **Region-Region Networks**
  - Tract Tracing and Strichnine Neuronography
    - Estimate region-region structural or functional networks
    - Example: Stephan et al. 2000 Phil Trans R Soc Lond B
Human Brain Networks I: Structure

Hard-wiring Networks

<table>
<thead>
<tr>
<th>Imaging Modality</th>
<th>Data Type</th>
<th>Nodes:</th>
<th>Edges:</th>
<th>Resolution:</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRI</td>
<td>Wiring</td>
<td>Brain Regions or Voxel (example: Brodmann regions)</td>
<td>White matter tracts between regions/voxels (e.g., using diffusion tractography)</td>
<td>One network per person per window of time</td>
</tr>
</tbody>
</table>

Nodes: Brain Regions or Voxel (example: Brodmann regions)

Edges: White matter tracts between regions/voxels (e.g., using diffusion tractography)

Resolution: One network per person per window of time
### Human Brain Networks II: Function

<table>
<thead>
<tr>
<th>Imaging Modality</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRI</td>
<td>Blood Flow</td>
</tr>
<tr>
<td>EEG</td>
<td>Electrical Activity</td>
</tr>
<tr>
<td>MEG</td>
<td>Correlation in BOLD signal</td>
</tr>
</tbody>
</table>

**Nodes:** Brain Regions or Voxel (example: Brodmann regions)

**Edges:** Association between regional/voxel time series (example: correlation)

**Resolution:** One network per person per window of time
Human Brain Networks III: Morphology

<table>
<thead>
<tr>
<th>Imaging Modality</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRI</td>
<td>DLPFC</td>
</tr>
<tr>
<td></td>
<td>IFG</td>
</tr>
</tbody>
</table>

**Nodes:** Brain Regions or Voxel (example: Brodmann regions)

**Edges:** Association between morphological characteristics of regions over subjects (example: correlation in cortical thickness)

**Resolution:** One network per group

Covariation in Cortical Thickness

DLPFC → IFG
What can we learn?

Network organization changes with

- behavioral /cognitive variables
- genetic factors
- experimental task
- age & gender
- drugs
- disease such as Alzheimer’s, schizophrenia, epilepsy, multiple sclerosis, acute depression, seizures, attention deficit hyperactivity disorder, stroke, spinal cord injury, fronto-temporal lobar degeneration, and early blindness.
Nodes or Networks?

- Network organization provides complementary, and sometimes more sensitive measurements of brain function.
  - Connectivity, not activity, was found to be show gene dosage-dependent alterations (Esslinger et al. 2009 Science)
  - Connectivity, not activity, was found to be correlated with learning (Buchel et al. 1999 Science)
  - Connectivity, not activity, was found to discriminate schizophrenia vs. controls (Bassett et al. 2012 Neuroimage)
Example Behavioral Network I

- **Similarity in finger-movement durations**

**Nodes:** Inter-Key Intervals

**Edges:** Similarity in inter-movement durations

Wymbs et al. 2012 Neuron In Press

Dani S. Bassett
What can we learn?

- We can begin to understand how humans chunk movements (like they chunk numbers in a phone number or social security number), and what brain regions are important for that phenomenon.

Wymbs et al. 2012 Neuron In Press
Example Behavioral Network II

- Similarity in voting on UN resolutions

**Nodes:** Countries

**Edges:** Similar voting history in UN resolutions

Macon et al. 2012 Physica A

Dani S. Bassett
What can we learn?

- We can begin to understand how the formation of large-scale groups of countries relates to the changing social and political landscape.
Example Social Network I

- Friendships

**Nodes**: People

**Edges**: Friendship links on Facebook

*Facebook helps you connect and share with the people in your life.*

Traud et al. 2011 SIAM Review

Dani S. Bassett
What can we learn?

- We can begin to understand the relationship between the network communities and a set of self-identified user characteristics (residence, class year, major, and high school).

House affiliation at CalTech

Traud et al. 2011 SIAM Review
Example Social Network II

- Campmates in Hunter-Gatherer Population

Nodes: Hadza People

Edges: whether or not you are campmates

Apicella et al. 2012 Nature
What can we learn?

- People tend to connect to one another if they are similar on certain traits but not others.

Apicella et al. 2012 Nature
Looking Ahead to Lecture #8

- We have decomposed a dynamical system into nodes and edges.

- But each node really has a dynamic process associated with it.
Cautionary Tales

- Model Definitions
  - Nodes
  - Edges

- Mechanistic Assumptions
  - Degree Distributions
  - Graph Properties
Cautionary Tale I: Definitions

- We model the brain as a set of nodes and edges.
- Are the nodes that we use functionally or anatomically distinct entities?
- Are the edges that we use (e.g., correlation between BOLD activity or number of white matter tracts) actually indicative of the amount of communication between two regions?
Cautionary Tale II: Mechanistic Assumptions

1) Increased clustering is often interpreted as indicating increased local processing. Is it true?
2) Network modules are often interpreted as being functional modules. Is it true?
3) Decreased path-length is often interpreted as indicating more communication integration, but have we proved that?
Questions & Discussion

- **Stumpf & Porter Paper:**
  - Does "mechanistic sophistication" provide a good measure of power law validity? Are there more objective measures?
  - What is the significance of the actual value of the exponent ($\lambda$) in a power law? i.e. what would it mean, practically, if a complex brain network and a social network had the same power law exponent?
  - How can comparing different models (e.g. scale-free networks vs. small-world networks) lead to a better understanding of complex systems?
  - Can a model without statistical support still make quantitatively important predictions? Can it still help on a qualitative level?