Complex Brain Networks—
How Close or How Far?

Jonathan H. Burdette, MD

Symposium “Gehirn und Welt”
Düsseldorf, am 9. Oktober 2010

Wake Forest University
School of Medicine

Laboratory for Complex Brain Networks
Acknowledgements

- Laboratory for Complex Brain Networks

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<td>Karen Joyce</td>
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Introduced in the late 1700's by Franz Joseph Gall.

- The shape of the skull determined individual traits.
- Brain functions mapped to different brain regions.
fMRI of Cross-Modal Deactivations

Audition

Vision

“neuroreductionist wild goose chase”

“neo-phrenologist fad”
Neuroreductionism

• Reductionism:
  – elements themselves are important

  Versus

• Complexity:
  – interaction between microscopic individual elements
Emergent Complex Behaviors

- Memory
- Consciousness
- Perception
- Awareness
- Neurorehabilitation
Ameise
How should these systems be studied?
Network Science

- Study of the Interaction between nodes or elements in a network

- My Goal Today: show how Network Science can be used to learn about the brain and brain function.
Networks sind Überall
Modeling with networks
Network Theory
Internet

Hal Burch and Bill Cheswick. Opte Project. www.opte.org
Is Facebook Growing Up Too Fast?
By BRAD STONE
Published: March 28, 2009
New York Times

Social Networks: Facebook

UPDATE: August, 2010
More than 500 million Facebook users
Networks

http://www.aaronkoblin.com/
High School Sexual Network

Moody et al, AJS vol 110, 2004
From CARVALHO et al. PHYSICAL REVIEW E 80, 016106 2009
Robustness of trans-European gas networks
It’s a **Small World**...

Small World Networks

• High clustering
  – Friends are friends
  – Regional Specificity—visual cortex

• Short path lengths
  – 6 degrees of separation
  – Distributed Processing—share processing loads

• Unique information processing capabilities
  – Context of Neurorehabilitation
6 Degrees of...
Network Metrics

Clustering coefficient (C) REGIONAL SPECIFICITY
Probability of your friends also being friends with each other

Path length (L) DISTRIBUTIVE PROPERTIES
Average shortest distance between any two nodes
• **Degree or K**
  - Number of connections for each node
What is a hub (Nabe oder Mittelpunkt)?
Vulnerability

www.geology.com

www.nyc.metablogs.com
From CARVALHO et al. PHYSICAL REVIEW E 80, 016106 2009
Robustness of trans-European gas networks
Figure 2. Vein structure of a mature leaf in *Sorbus* L. (Rosaceae) obtained by using a scanning routine on greyscale images given by Merrill (1978): (a) whole leaf; (b) side lobe.
Human Brain Functional Network

Hayasaka, 2009
Extracting Network from fMRI
The Human Brain Network Model

Correlation Matrix

1

15000

15000
Connections of the Human Brain Network

Adjacency Matrix

15000
Network Parameter Maps

Small-world parameters

Degree maps
State-Based Network Changes

Young

Older

Rest

Degree

Clustering

0.06
0.33
0.66
Regional Clustering: Multisensory

% of Subjects

Young

Old
Anterior Cingulate Cortex: Clustering

YOUNG

OLD

% of Subjects
Musical Network Maps
Musical Network Maps
Take Home Messages

• Introduction to Network Science
Take Home Messages

• Introduction to Network Science
Take Home Messages

- Brain is a Complex Small-World Network
  - High Clustering
  - Short Path Lengths
Take Home Messages

• Implications of Small-Worlds
  – Local and global processing
  – Ubiquitous among self-organized systems
  – Promote synchrony
  – Model and predict behavior of networks

• Neurorehabilitation
Take Home Messages

Functional Brain Network

Metrics

Network Metrics → Image Maps
Take Home Messages

Small-world parameters

Degree maps
Erkenne Dich selbst
Complex Brain Networks—How Close or How Far?

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Complex Musical Brain Networks: Six Degrees of Mozart and the Beatles

Jonathan H. Burdette, MD

University of North Carolina, Greensboro
The First World Congress of Clinical Neuromusicology
Effects of Music on the Brain

- State-based phenomenon
  - Perfect for Network Approach
- Many possible questions
  - Genre specific?
  - What brain connection to favorite music?
  - What is going on when dislike music?
  - How do certain therapies alter our musical experience?
Experimental Setup

• Recruitment: genre-based
• Battery of questions

• fMRI Paradigms
  – 5 minutes of listening to music
6 fMRI Paradigms

• Favorite Song: person-specific

• All get the following
  – Classical: Beethoven’s 5th Symphony
  – Rap/Hip-Hop: Usher, OMG
  – Rock: Kiss, Rock ‘n Roll All Night
  – Country: Brad Paisley, Water
  – Chinese Jinna Opera, Spring Hall
Musical Network Maps

Global

Degree

Favorite
Dislike
Like
Musical Network Maps

Like

Dislike
Brain Perfusion Older Adults

Young

Older

Default-Mode Network

ml/100 gm tissue/min

T score
Default-Mode Network

Degree

T score

3 5

8 5
The Musical Brain

Degree

Global

Favorite
Take Home Messages

- **Music - Powerful Force**
  - Effects on Brain Network Properties
Facebooking the Musical Brain
## Small-world Parameters

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<tr>
<th>Global Properties</th>
<th>Cluster Coefficient</th>
<th>Path Length</th>
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<tr>
<td>Brain</td>
<td>0.24</td>
<td>4.86</td>
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Graph Theory

• Graph: representation of relationships by
  – Nodes corresponding to each unit
  – Edges connecting nodes

Bridges in Königsberg, ca. 1736
Take Home Messages

• Small-world properties altered
  - Epilepsy
  - Schizophrenia
  - Aging and AD

• Connectivity exhibits hubs

• Hubs change with
  - State
  - Disease
Figure 1. Drainage networks analysed: (a) Kumaun; (b) Loess Plateau, Shanxi Province, China; (c) Schoharie Creek, New York; (d) Nepal; (e) Kentucky River; (f) Mississippi River; and (g) Bhutan.

Figure 2. Vein structure of a mature leaf in *Sorbus* L. (Rosaceae) obtained by using a scanning routine on greyscale images given by Merrill (1978): (a) whole leaf; (b) side lobes; (c) 50 km; (d) 50 km; (e) 1000 km; (f) 50 km; (g) 50 km.
Small-World Phenomenon

- **Q:** How connected are two complete strangers?
- **A:** About six steps

Milgram’s small-world experiment (1967)

Stanley Milgram

Map showing the experiment:
- **Start:** Random volunteers in Nebraska
- **Target:** Stock broker in Boston
- Distance: 1400 miles (2250 km)
Phrenology

- Introduced in the late 1700’s by Franz Joseph Gall.
- The shape of the skull determined individual traits.
- Brain functions mapped to different brain regions.
- Dismissed by the mid 1800’s.
- Revival in the US in the 1860’s by L.N. Fowler.
- Dismissed again by early 1900’s
fMRI of Cross-Modal Deactivations

Centrality Measures: Flow of Information
“Parts of the critical system cannot be understood in isolation. Studying the individual grains under a microscope doesn’t give a clue as to what is going on in the whole sand pile. Nothing in the individual grain suggests the emergent properties of the pile.”
Nodes or Elements in a Network

- Interconnected
- Interdependent
- Diverse
- Adaptable