Intro to Brain networks

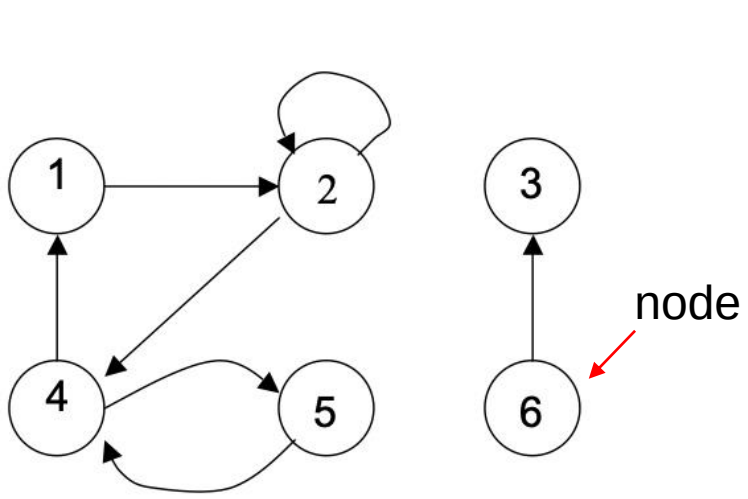
COGNESTIC 2023

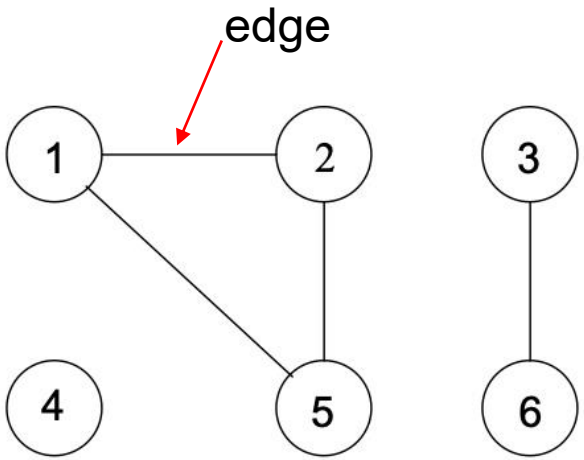
Isaac Sebenius

https://www.psychiatry.cam.ac.uk/people/postgraduate-students/isaac-sebenius/

What is a network?

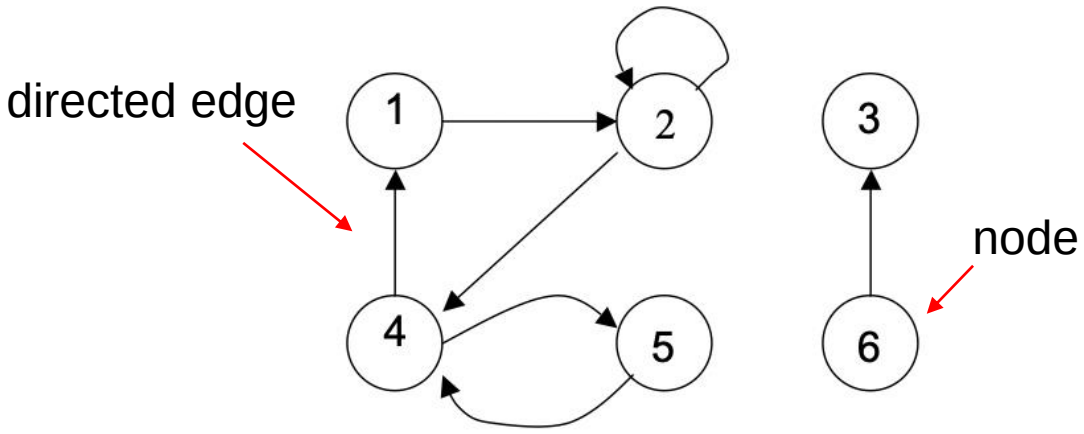
- **Network = Graph**
- **A graph/network is simply a set of nodes (a.k.a vertices) and edges**

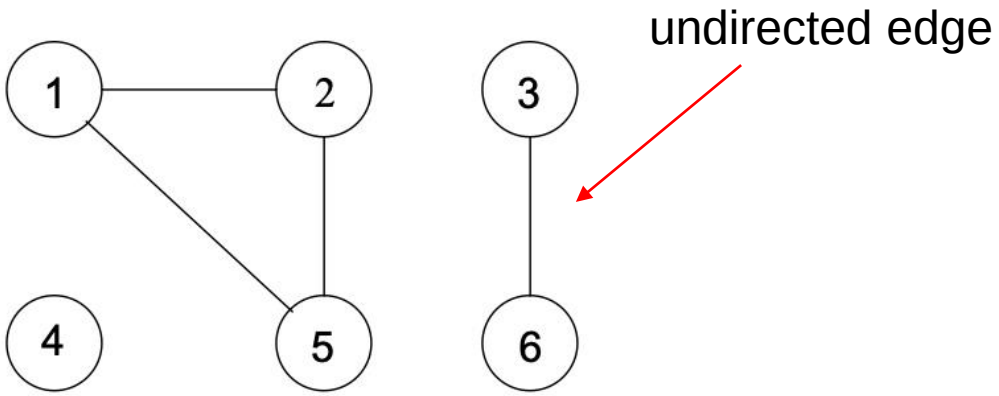




What is a network?

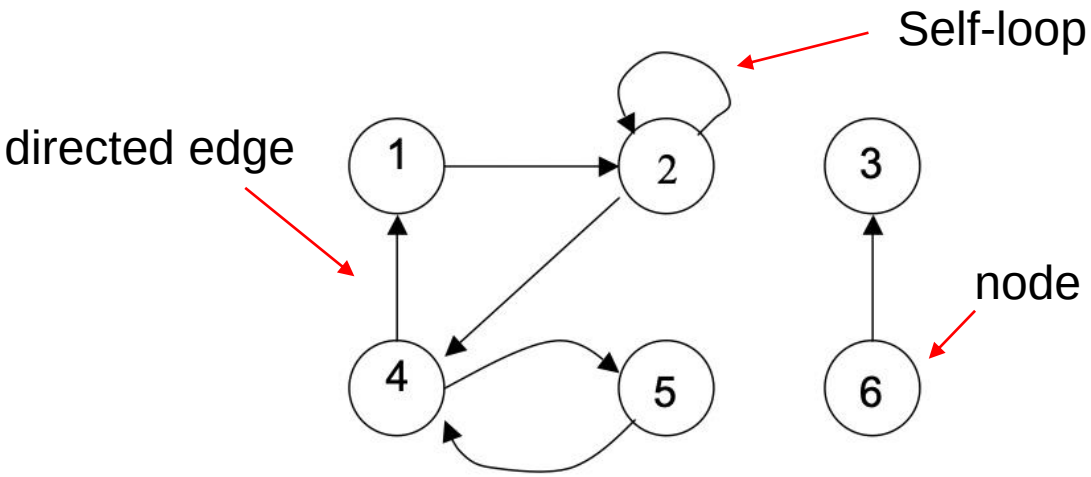
- **Network = Graph**
- **A graph/network is simply a set of nodes (a.k.a vertices) and edges**

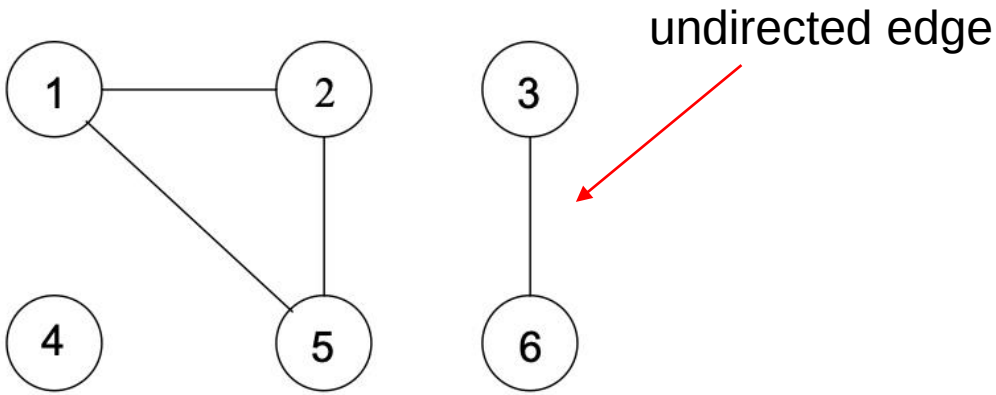




What is a network?

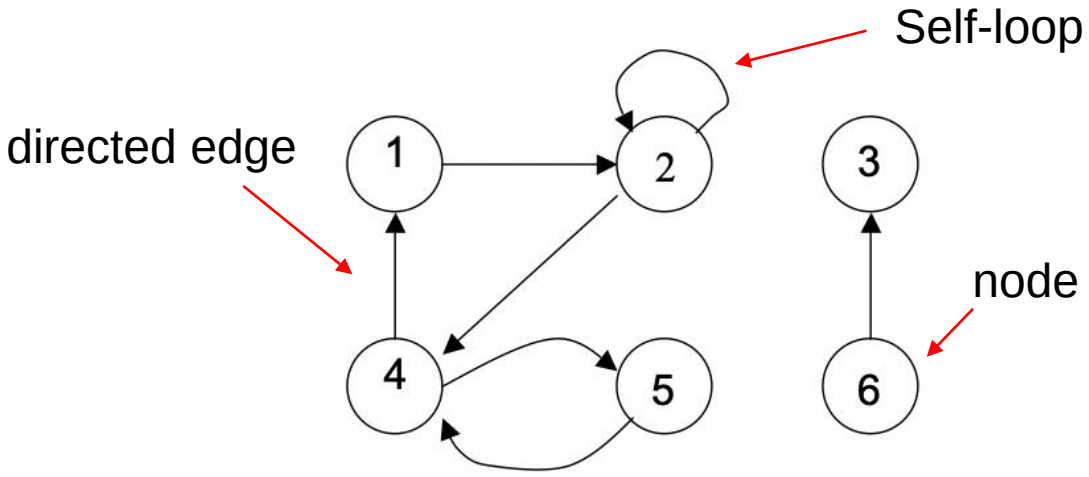
- **Network = Graph**
- **A graph/network is simply a set of nodes (a.k.a vertices) and edges**

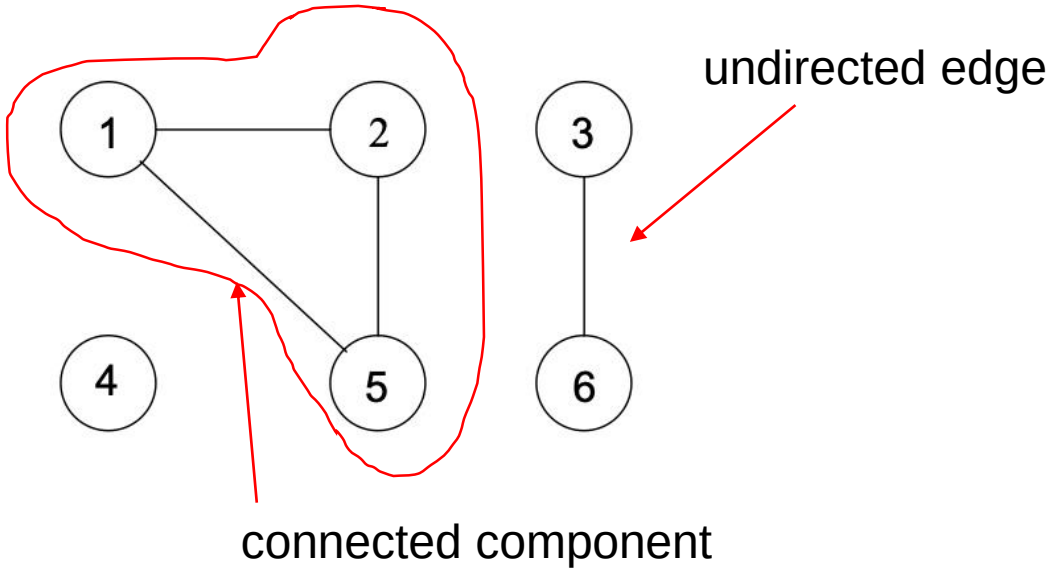




What is a network?

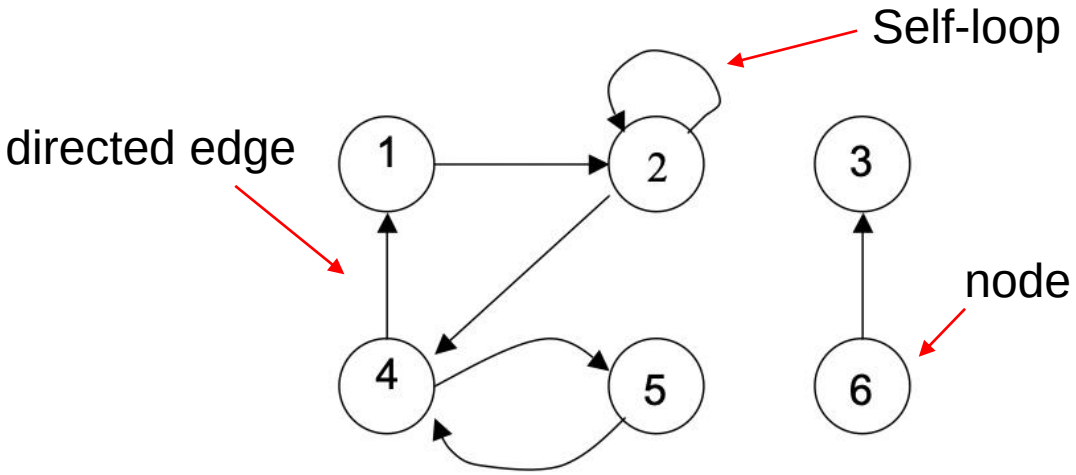
- **Network = Graph**
- **A graph/network is simply a set of nodes (a.k.a vertices) and edges**

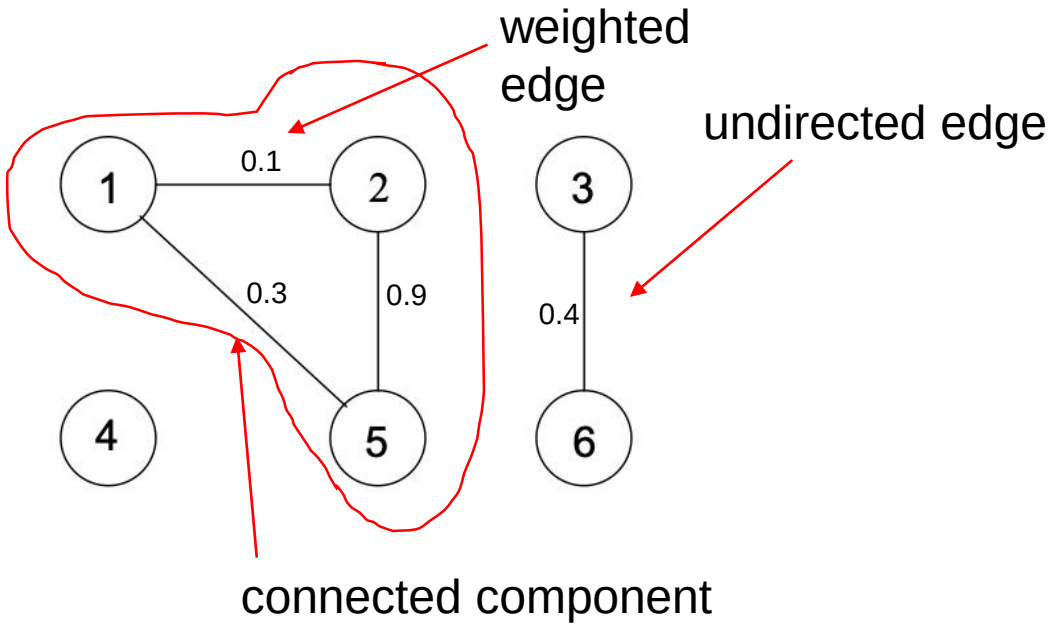




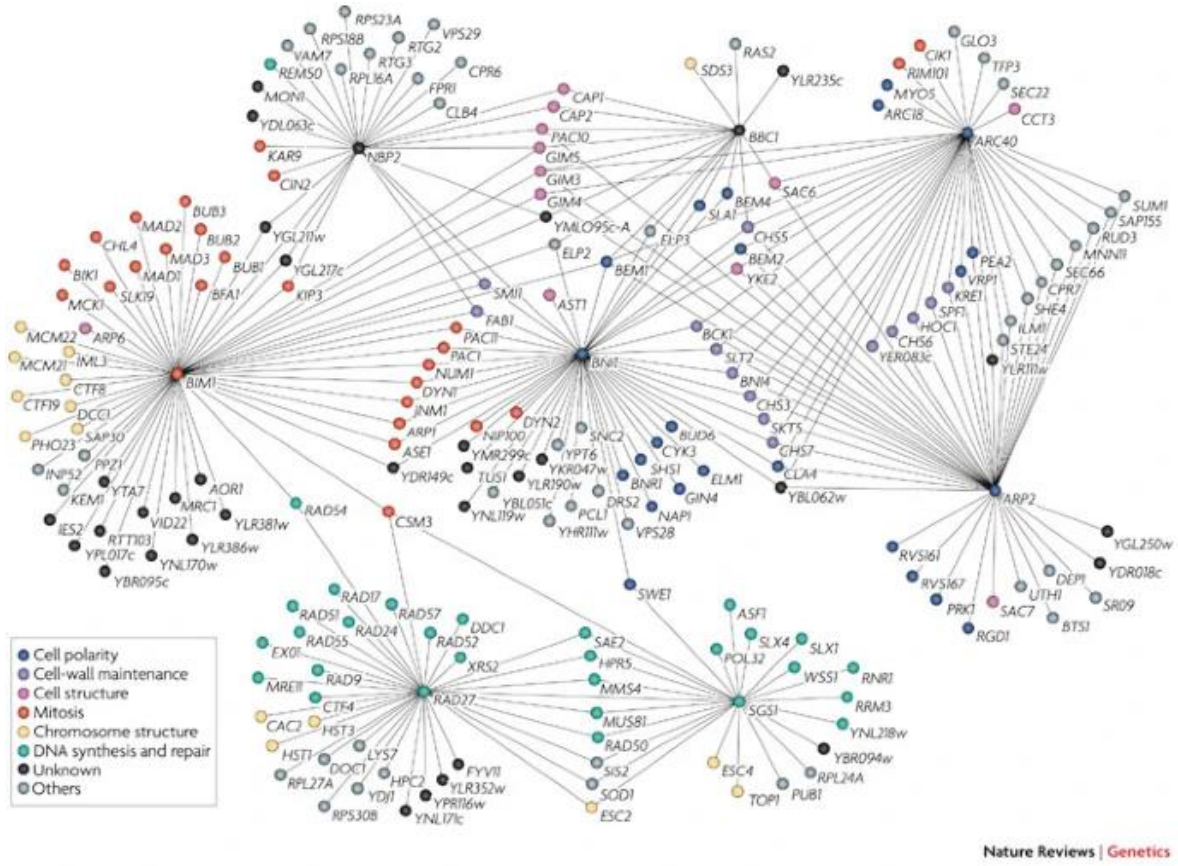
What is a network?

- **Network = Graph**
- **A graph/network is simply a set of nodes (a.k.a vertices) and edges**

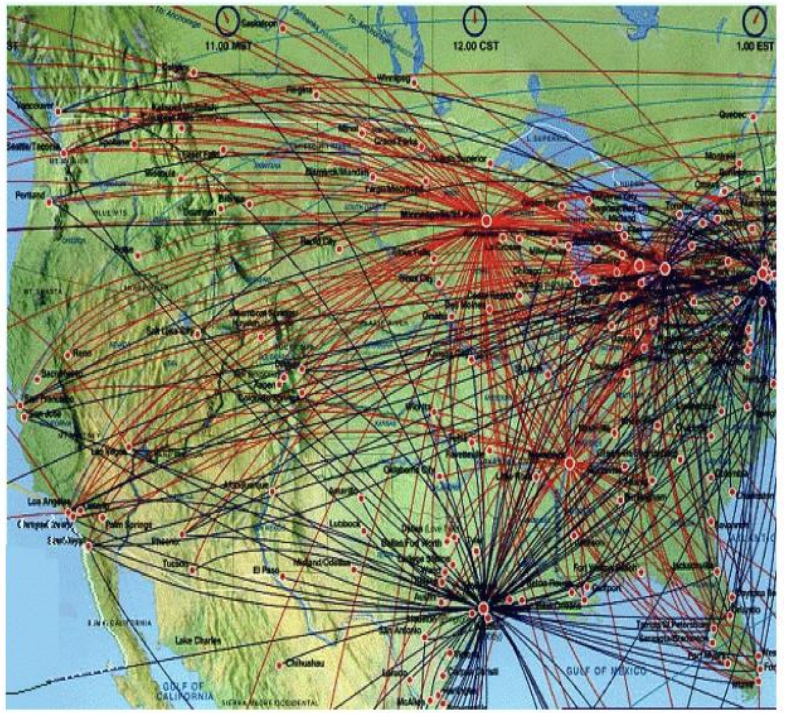




Sample Networks: Gene networks



Sample networks: transportation



Sample networks: Speech networks

"I see a man in the dark standing against a light post . It seems to be in the middle of the night ; I think because the lightbulb is working . On the picture there seems to be like a park and ... Or trees but in those trees there are little balls of light reflections as well . I can not see the ... Anything else because it is very dark . But the man on the picture seems to wear a hat and , and has a jacket on and he seems to have a hoodie on as well . The picture is very , very mysterious , which I like about it , but for me I would like to understand more concept , context of the picture ."

Brain networks: brief discussion

Let’s say you are interested in studying a brain, parcellated into a set of regions of interest.

How would we turn it into a brain network? What could be the edges?

What are some justifications for turning it into a ‘connectome’?

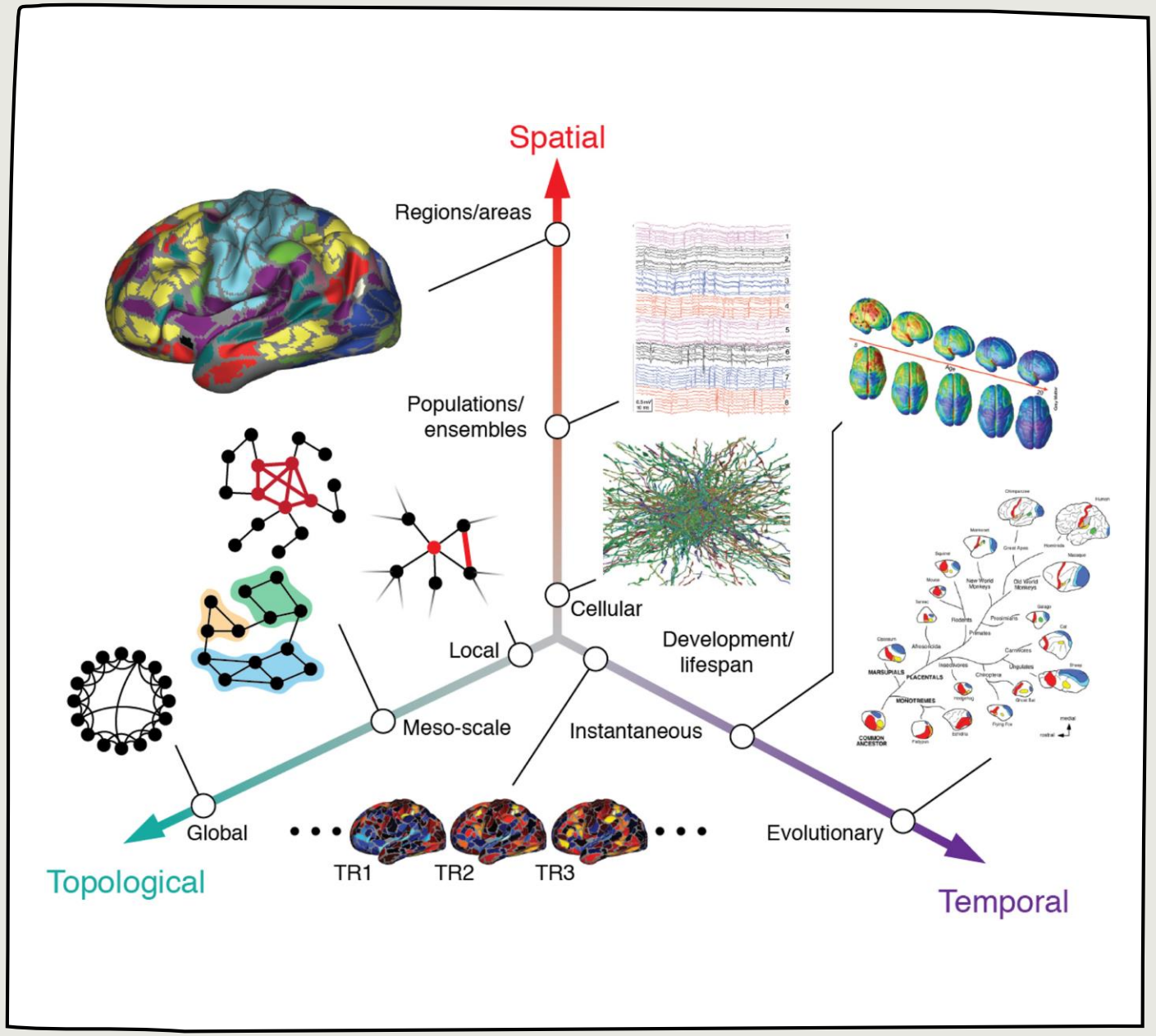
Brain networks: brief discussion

Let’s say you are interested in studying a brain, parcellated into a set of regions of interest.

How would we turn it into a brain network? What could be the edges?

What are some justifications for turning it into a ‘connectome’?

- **Communication between regions across white matter tracts.**
- **Harmonized activity patterns between distant regions suggest network-structure of activity.**
- **Developmental coordination across different areas of the brain.**
- **Strong genetic and phenotypic covariance between different brain regions.**
- **More???**



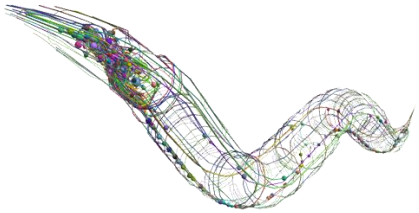
The brain as a multiscale network

Brain networks can be studies at various:

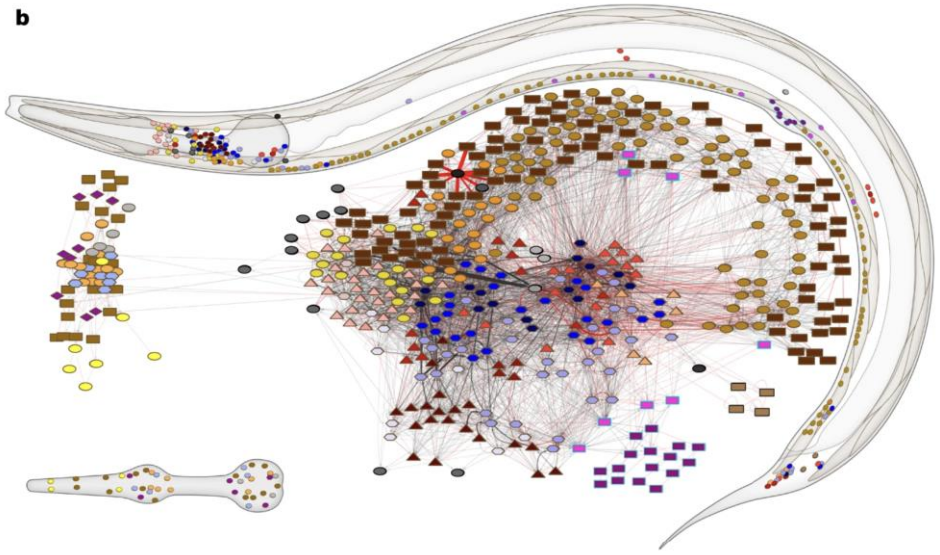
- **Temporal scales**
- **Spatial scales**
- **Topological scales**

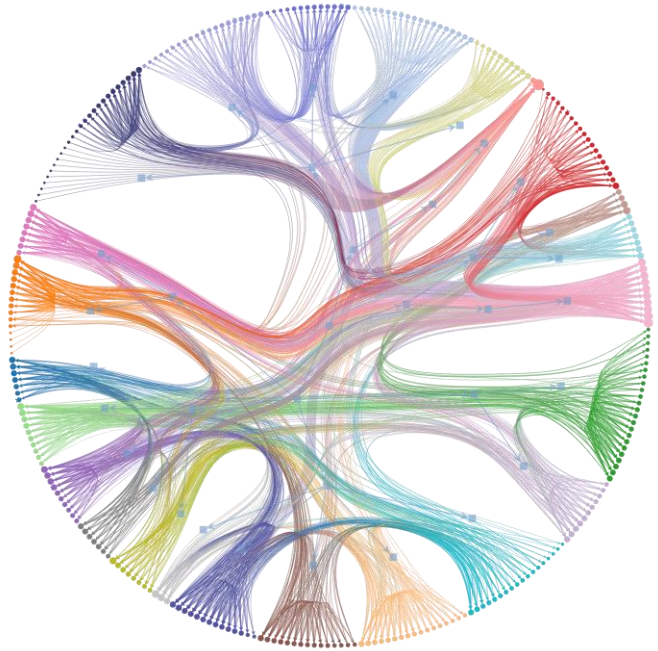
(And even within the same scale, multiple types of connections can be considered!)

The complete c. Elegans synaptic connectome



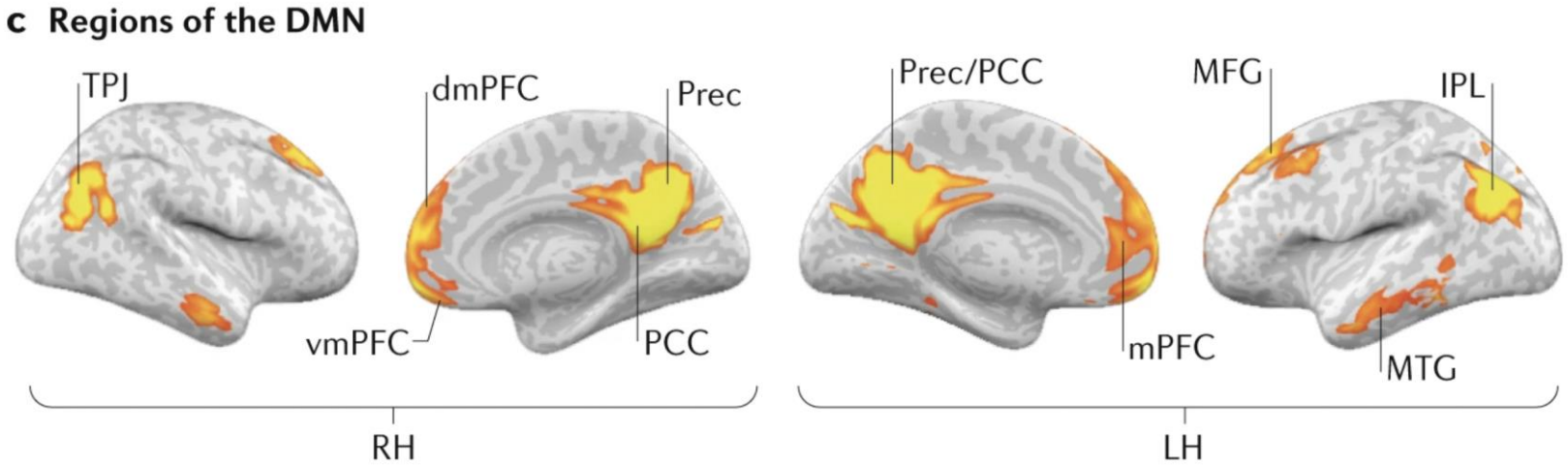
Synaptic connectome





Reverse engineering a famous human brain network

What are the nodes? What are the edges?



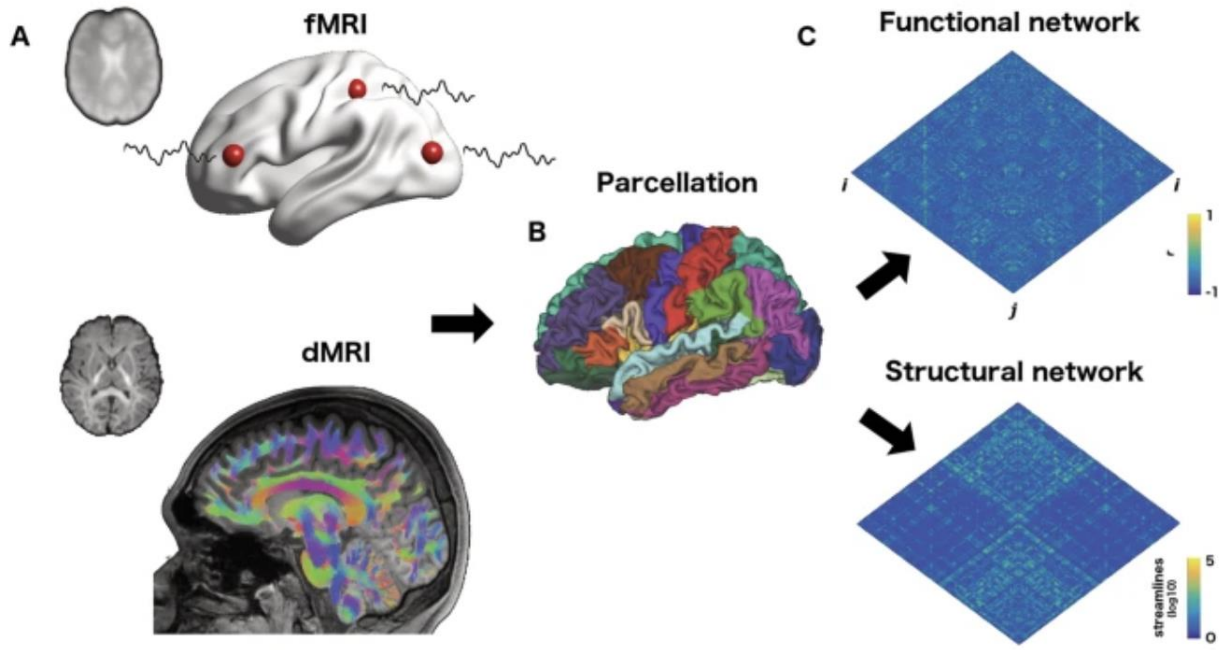
Classic views on human brain networks

Steps:

1. **Parcellate brain into regions (ROIs)**
2. **Define pairwise metric of connectivity**
3. **Calculate it for all pairs of ROIs**

Common types of brain connectivity:

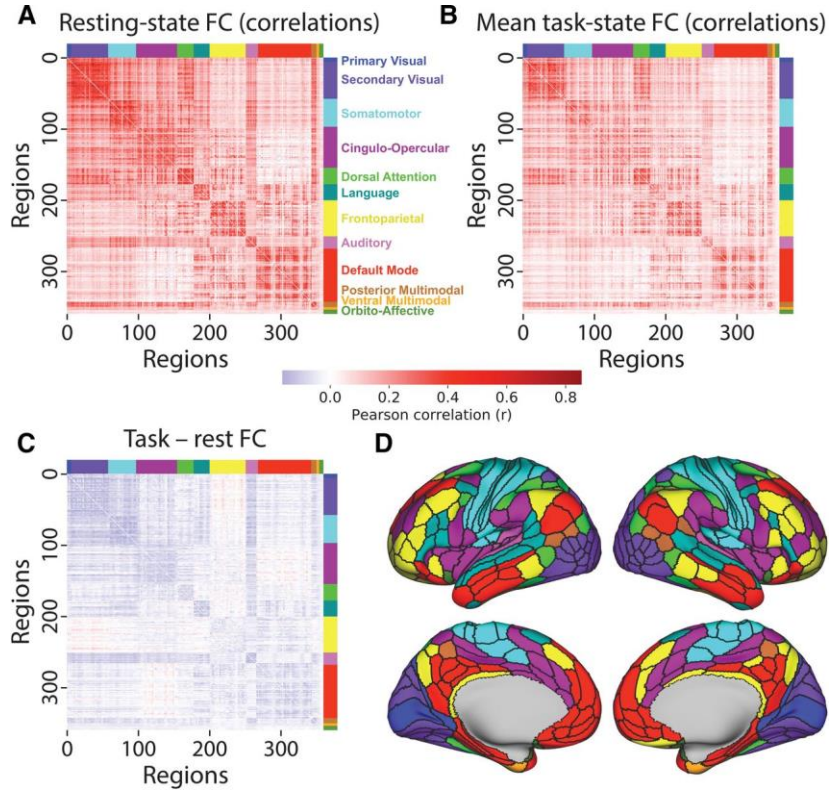
1. **fMRI-derived estimates of functional connectivity**
2. **dMRI-derived estimates of structural connectivity.**



Functional brain connectivity

Different paradigms:

- **Task-based vs. resting-state**



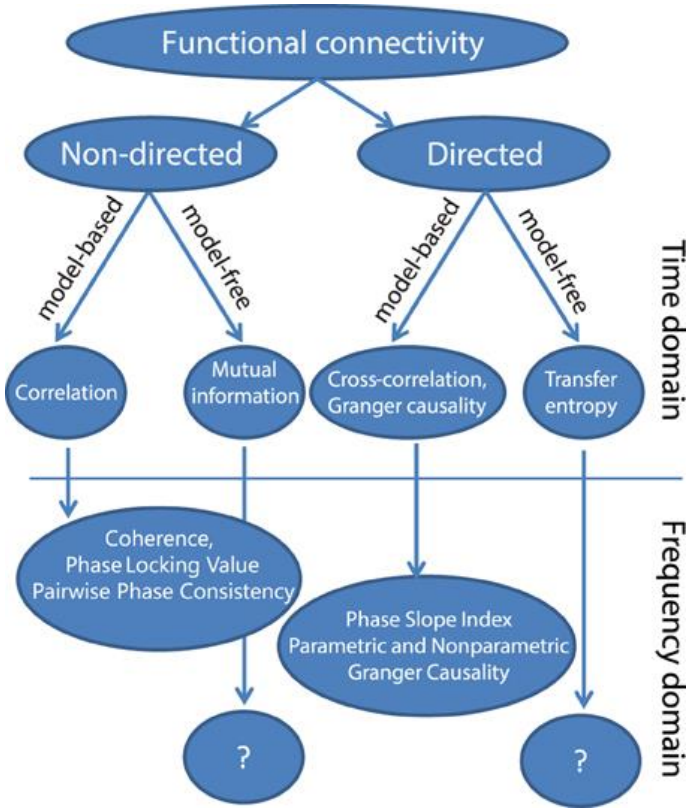
Functional brain connectivity

Different paradigms:

- **Task-based vs. resting-state**

Different metrics of connectivity:

- **Pearson correlation (most common!), partial correlation, Granger causality, etc...**



Functional brain connectivity

Different paradigms:

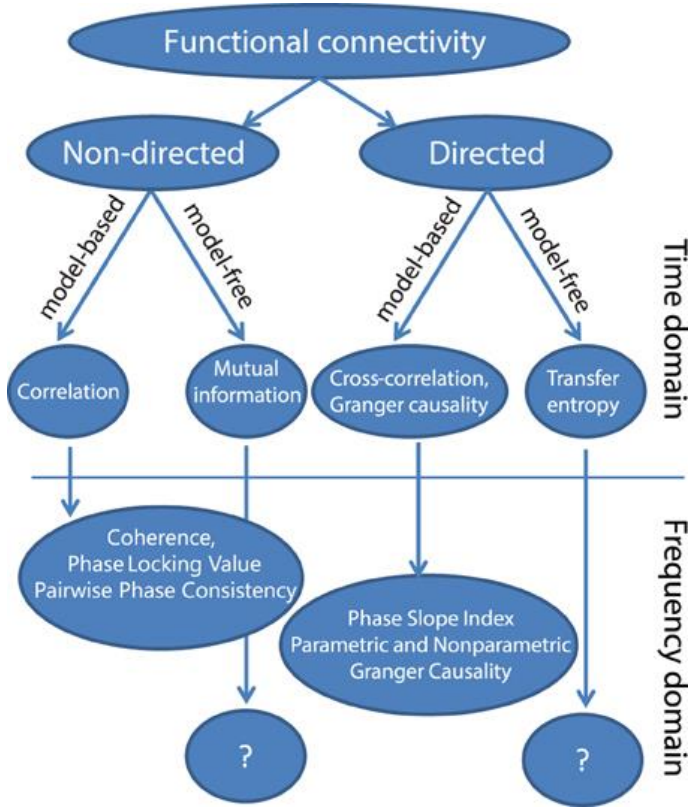
- **Task-based vs. resting-state**

Different metrics of connectivity:

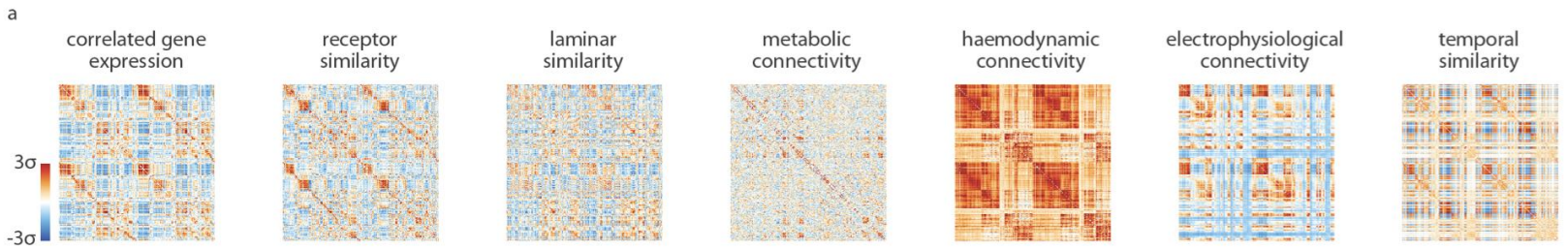
- **Pearson correlation (most common!), partial correlation, Granger causality, etc...**

Different modalities:

- **fMRI, EEG, etc.**

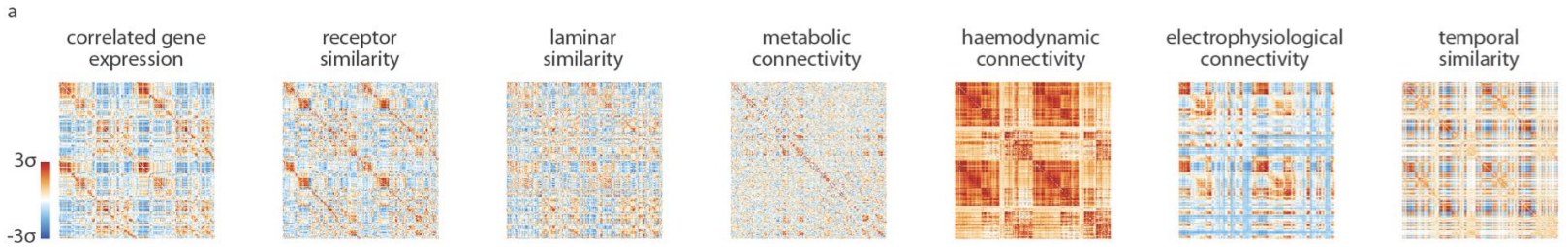


Alternate conceptions of brain connectivity



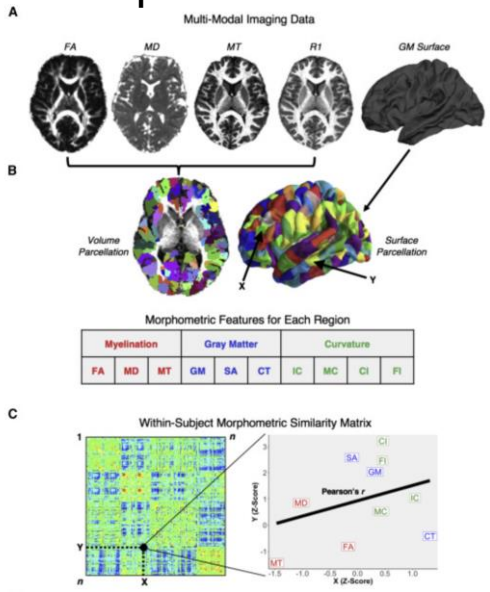
Hansen et al., PloS Biology (2023).

Alternate conceptions of brain connectivity



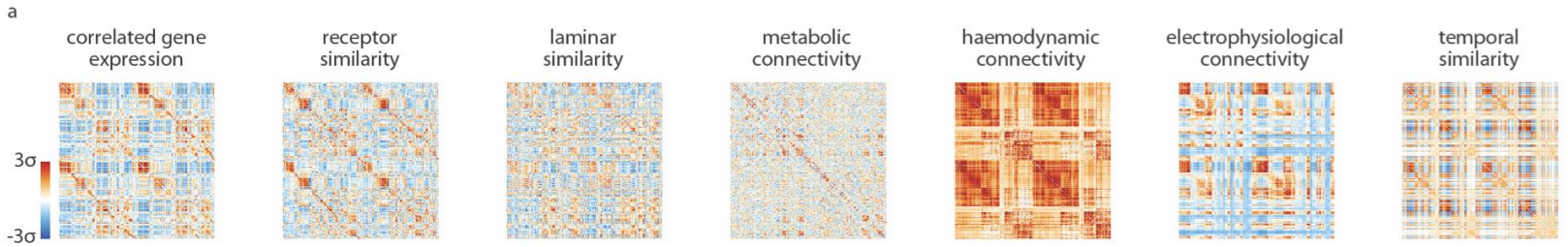
Hansen et al., PloS Biology (2023).

Morphometric similarity networks



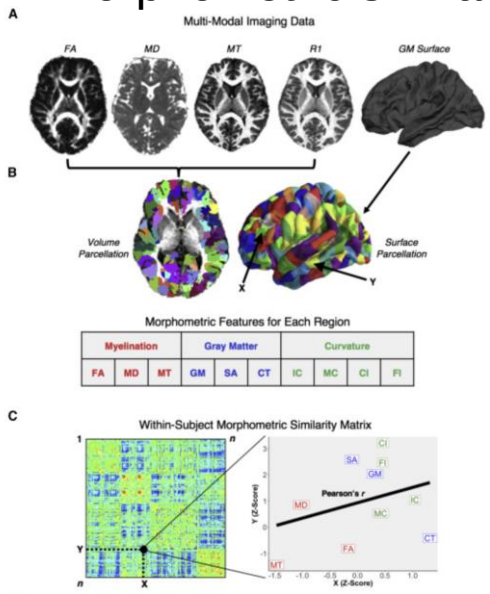
Seidlitz et al., Neuron (2018)

Alternate conceptions of brain connectivity



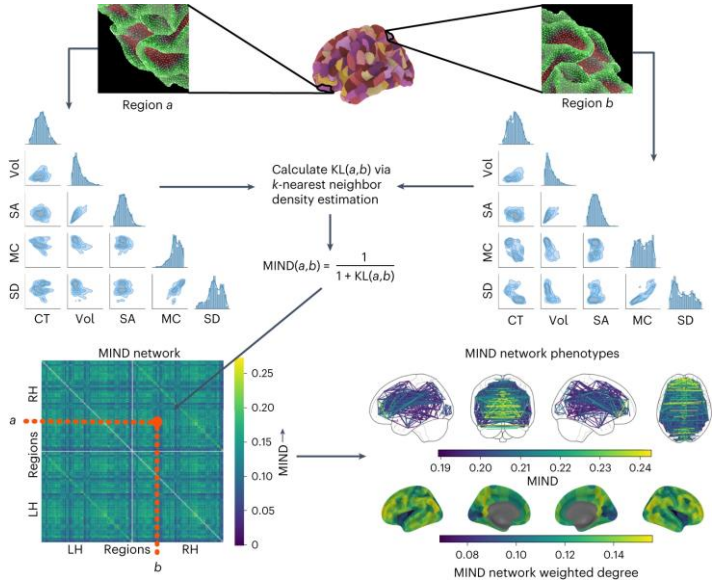
Hansen et al., PloS Biology (2023).

Morphometric similarity networks



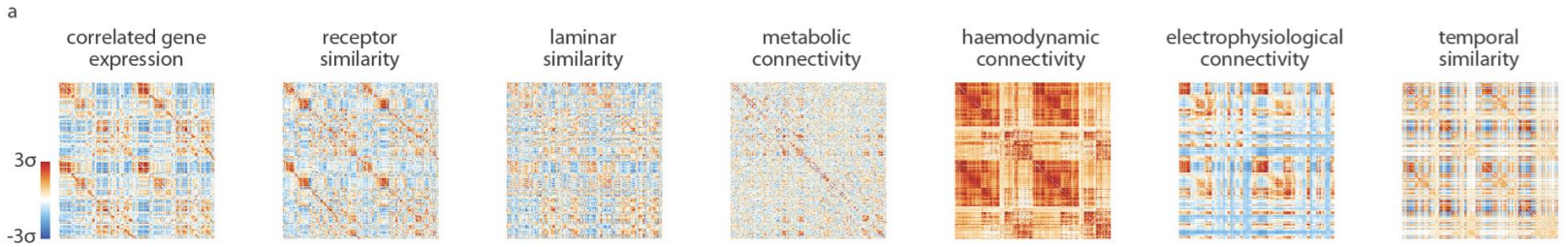
Seidlitz et al., Neuron (2018)

MIND networks



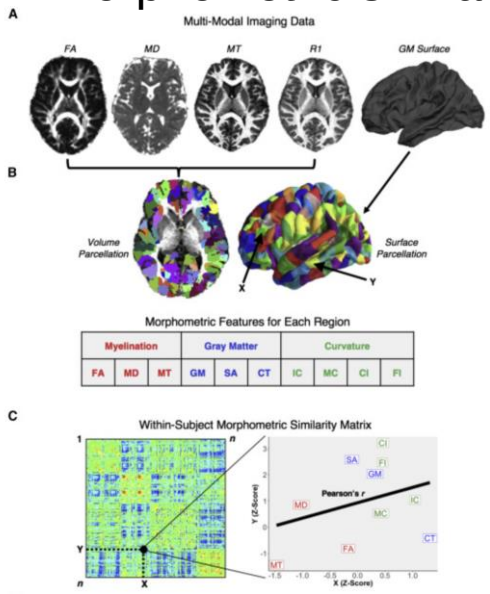
Sebenius et al., Nat. Neuro. (2023)

Alternate conceptions of brain connectivity



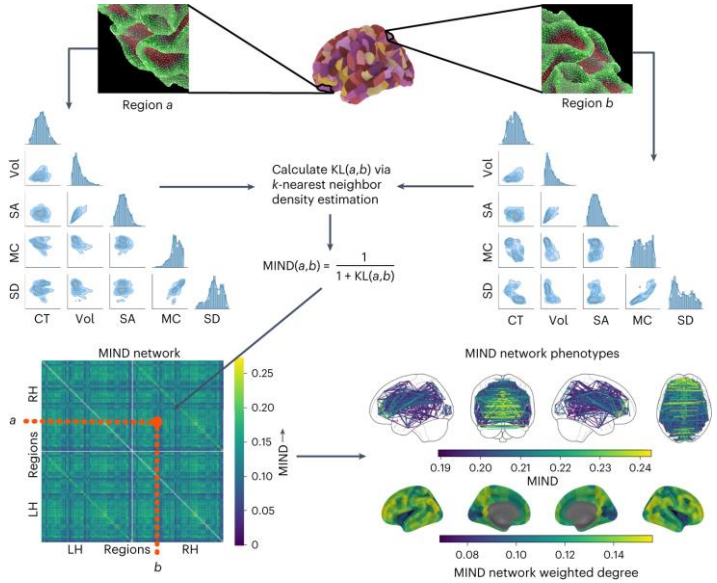
Hansen et al., PloS Biology (2023).

Morphometric similarity networks



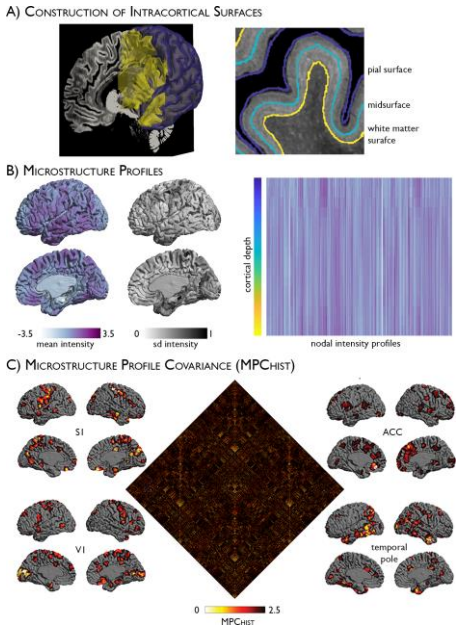
Seidlitz et al., Neuron (2018)

MIND networks



Sebenius et al., Nat. Neuro. (2023)

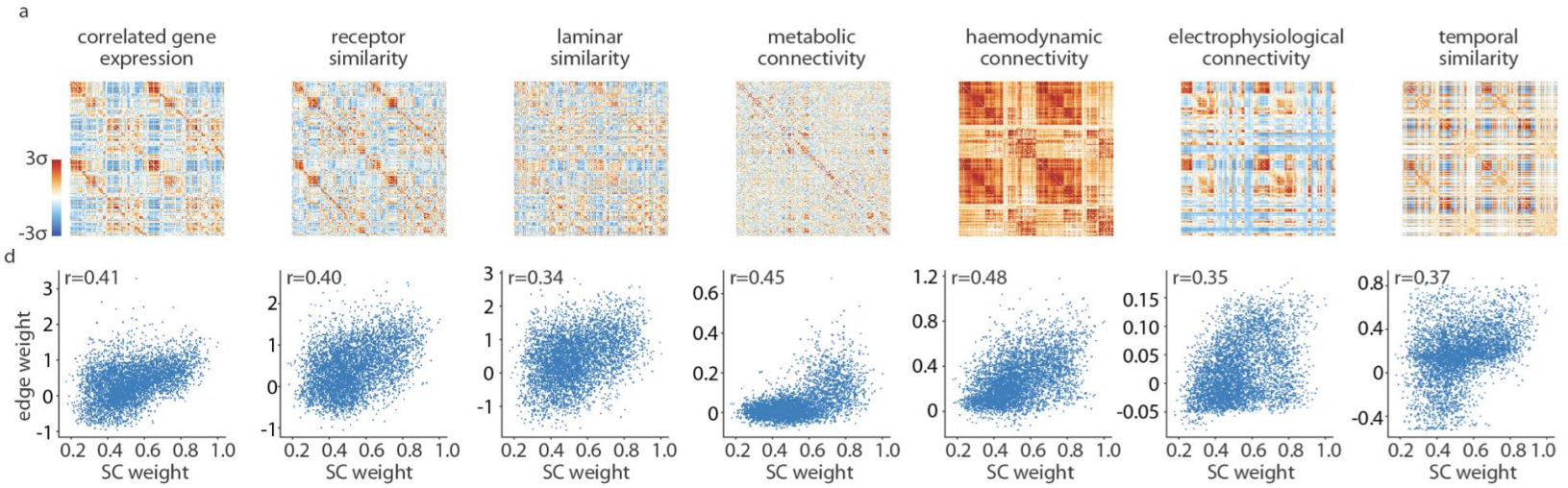
MPC networks



Paquola et al., PLoS ON

Network neuroscience can bridge multiscale connectivity

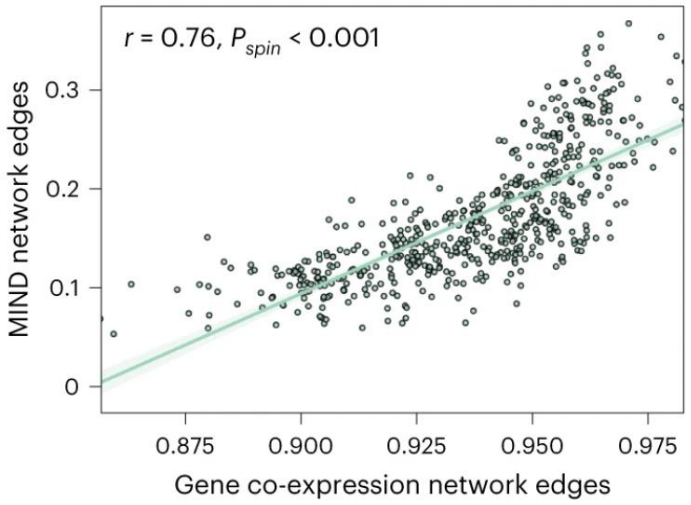
Axonally-connected brain regions tend to be more similar across a wide range of definitions of biological similarity.



Network neuroscience can bridge multiscale connectivity

Axonally-connected brain regions tend to be more similar across a wide range of definitions of biological similarity.

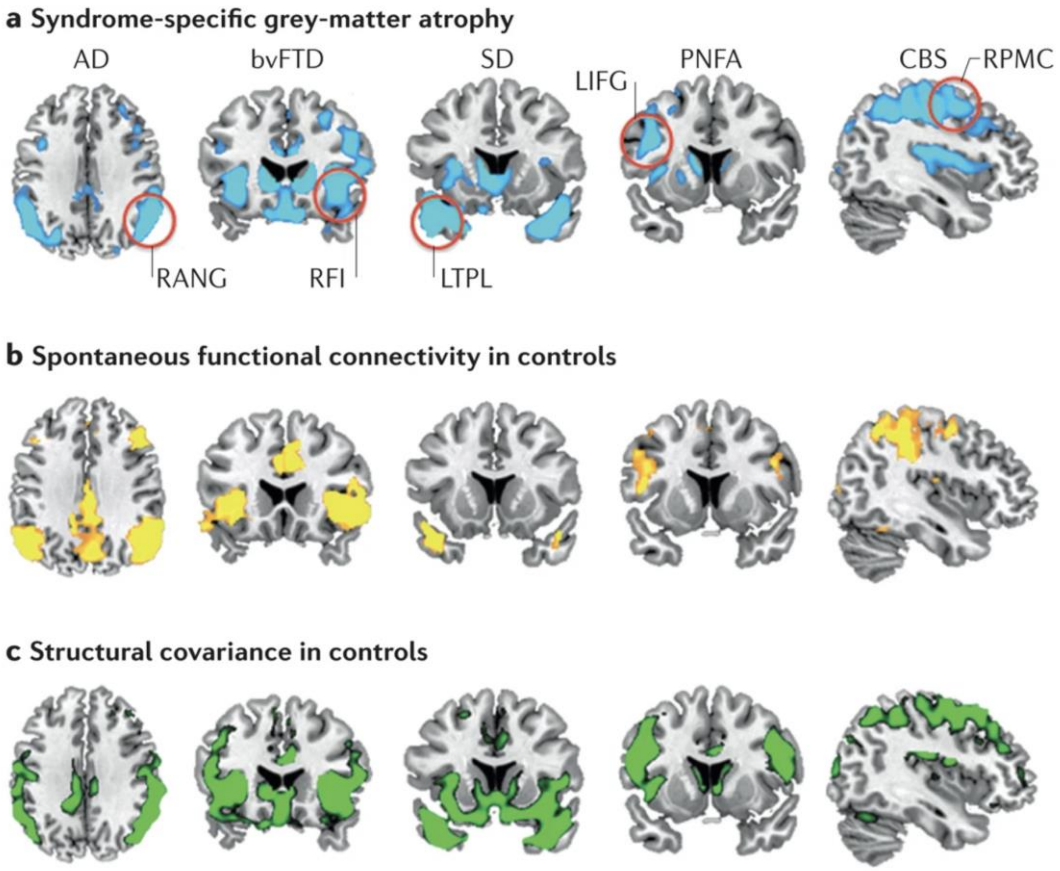
Brain regions with similar gene expression have similar structure, tend to be more connected by white matter, and are more likely to be functionally connected



Sebenius et al., Nat. Neuro

Selected Insights from brain network connectivity

Brain networks constrain patterns of degeneration in psychiatric and neurodegenerative diseases.



Seeley et al., Neuron (2009)

Selected Insights from brain network connectivity

Brain networks constrain patterns of degeneration in psychiatric and neurodegenerative diseases.

Article | Open Access | Published: 14 August 2023

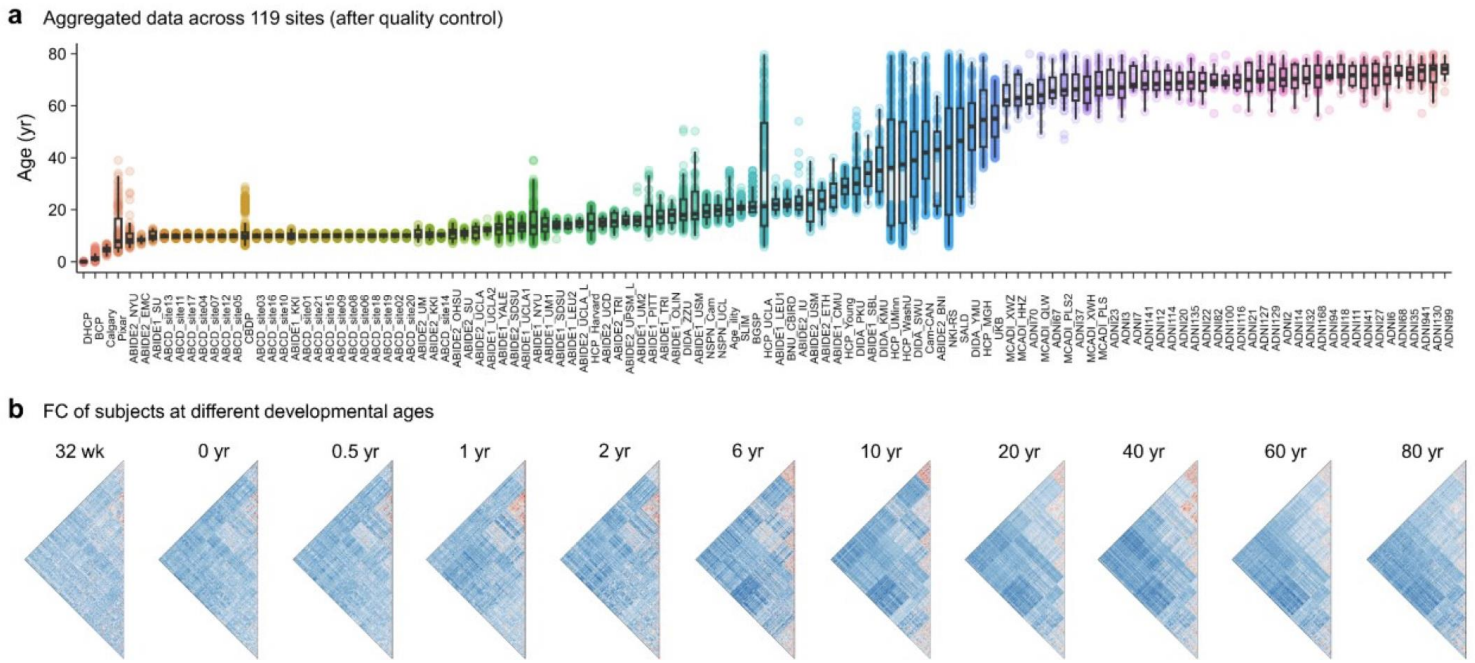
Regional, circuit and network heterogeneity of brain abnormalities in psychiatric disorders

Ashlea Segal ✉, Linden Parkes, Kevin Aquino, Seyed Mostafa Kia, Thomas Wolfers, Barbara Franke, Martine Hoogman, Christian F. Beckmann, Lars T. Westlye, Ole A. Andreassen, Andrew Zalesky, Ben J. Harrison, Christopher G. Davey, Carles Soriano-Mas, Narcís Cardoner, Jeggan Tiego, Murat Yücel, Leah Braganza, Chao Suo, Michael Berk, Sue Cotton, Mark A. Bellgrove, Andre F. Marquand & Alex Fornito ✉

Nature Neuroscience **26**, 1613–1629 (2023) | Cite this article

Selected Insights from brain network connectivity

Brain network analysis can shed light on development of the human brain and its relationship to cognition and psychiatric disorders



properties of brain networks

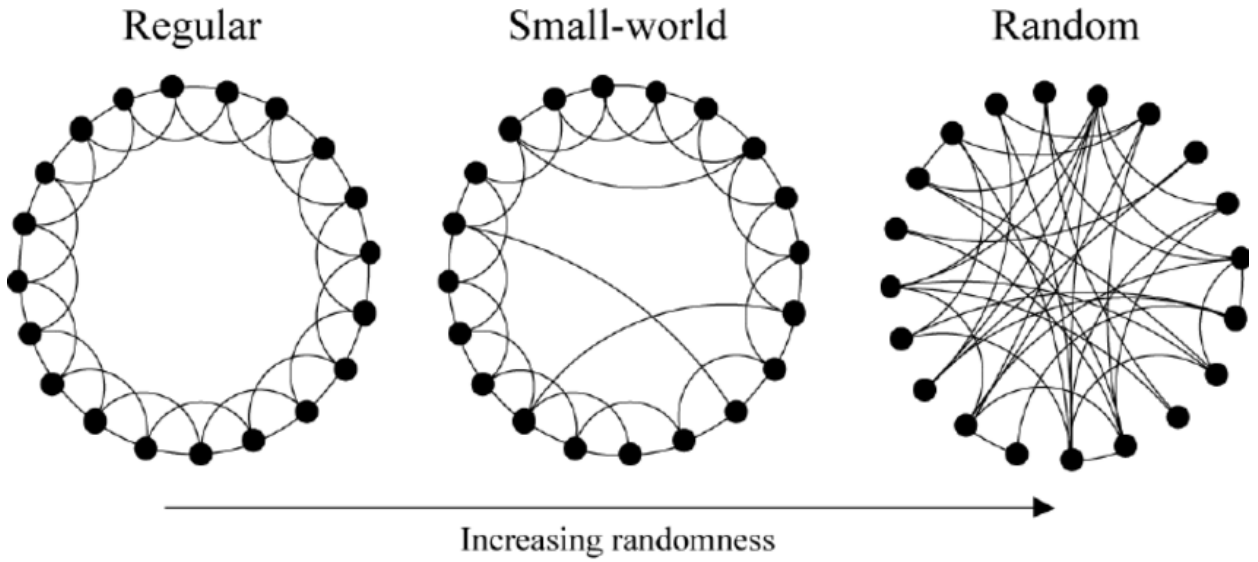
Special properties of nodes:

- Spatially-embedded

- Nodes are not interchangeable

- Tend to be fully-connected (thresholding often must therefore often be applied).

The cost-efficiency tradeoff of ‘small-world’ brain networks



Based on: Watts & Strogatz, Nature (1998).