



Donders Institute
for Brain, Cognition and Behaviour

Brain Reading (MKI43)

Decoding of Functional Network Graphs

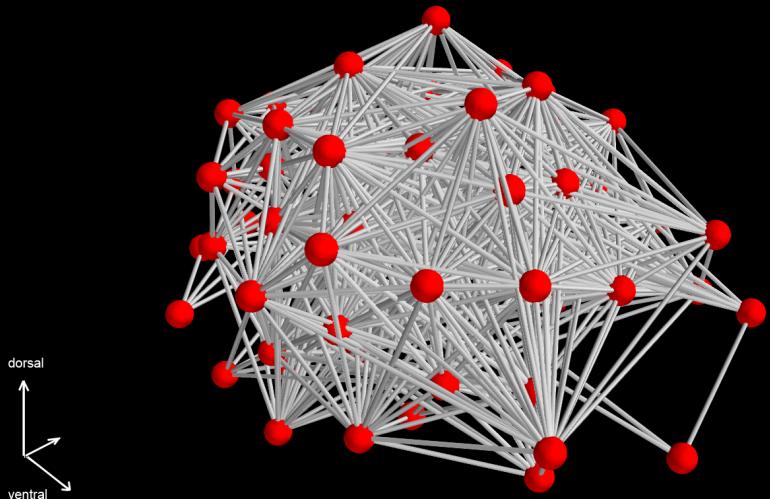
Guest lecture
Matthias Ekman

Docent
Marcel van Gerven

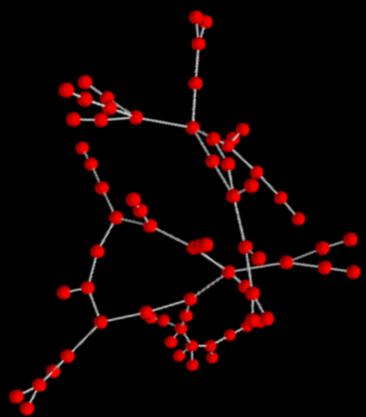
Radboud University Nijmegen



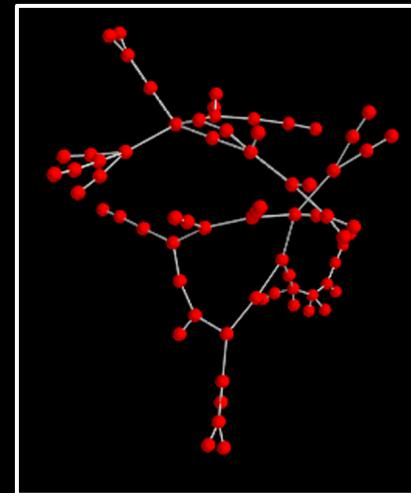
Reconfiguration of brain networks



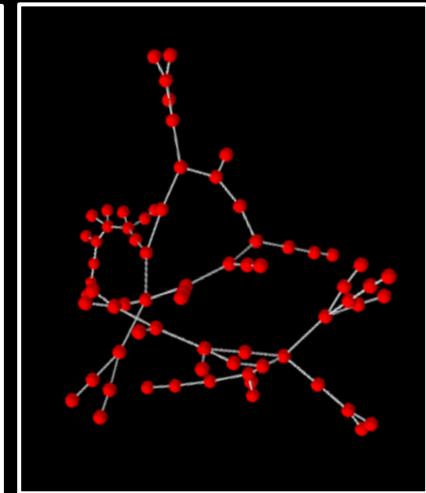
Functional brain network



Graph representation



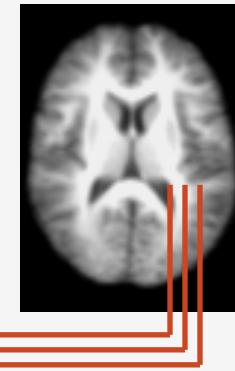
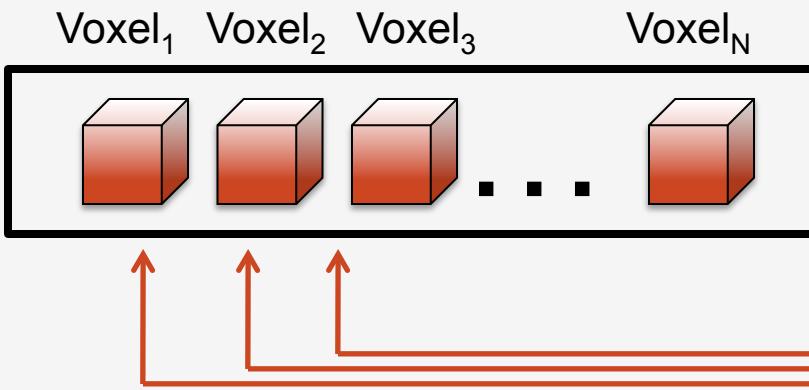
Task A



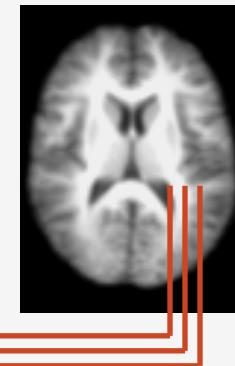
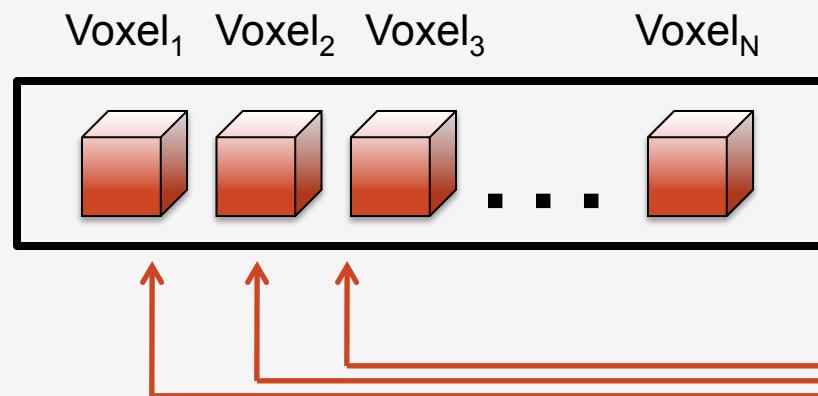
Task B

Reconfiguration

Decoding



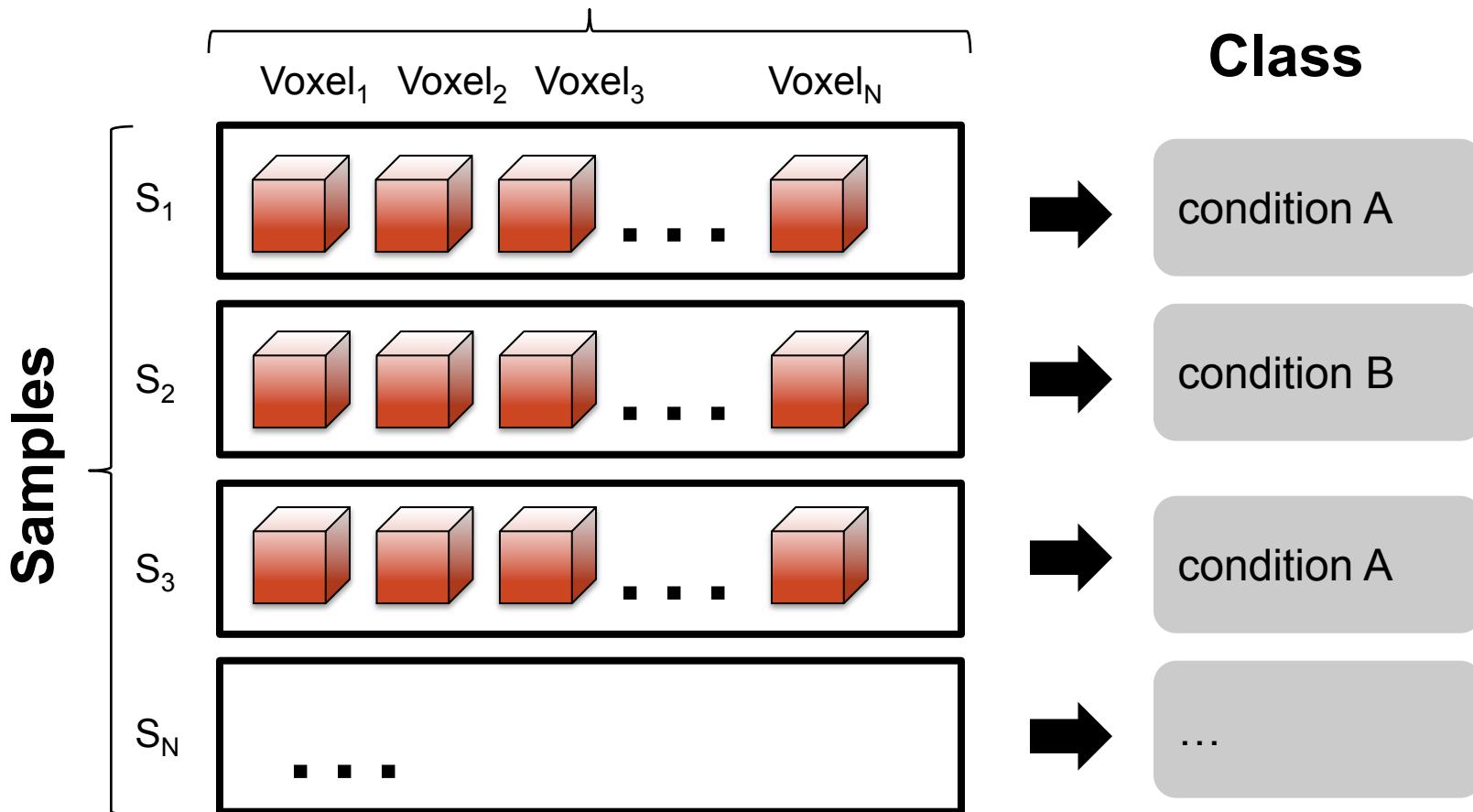
Trial 1:
condition A



Trial 2:
condition B

time

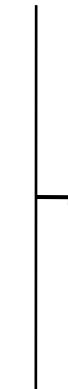
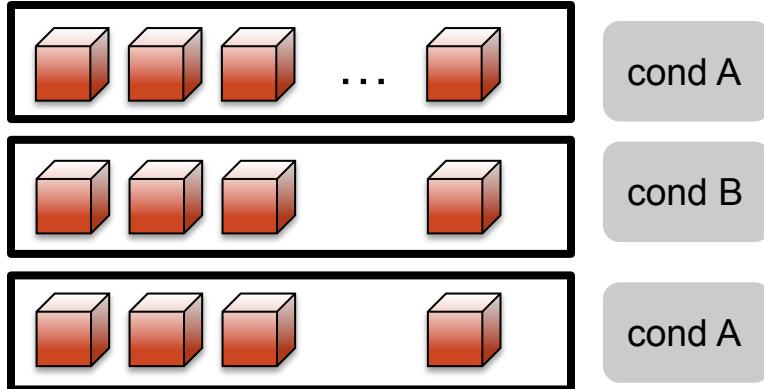
Features



Decoding



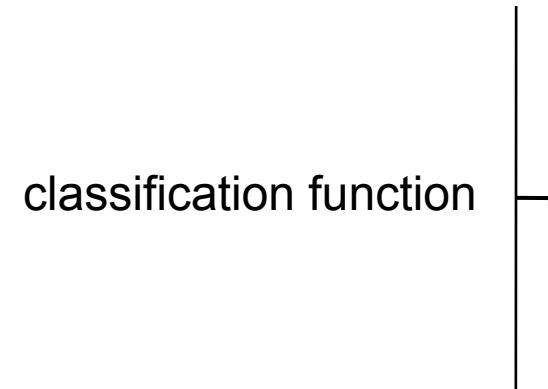
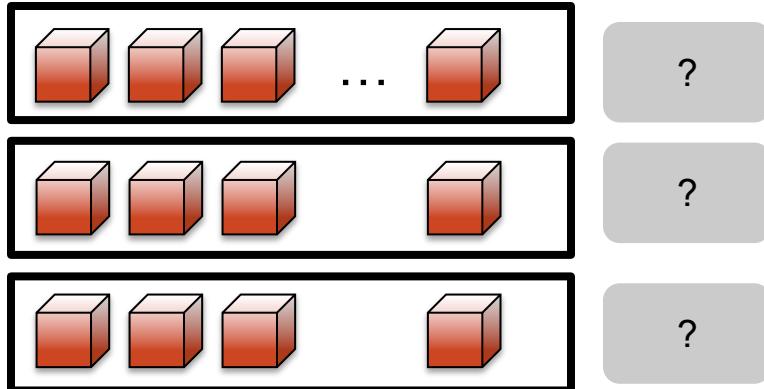
train



classifier training
→ **classification function**



test



cond A



cond B

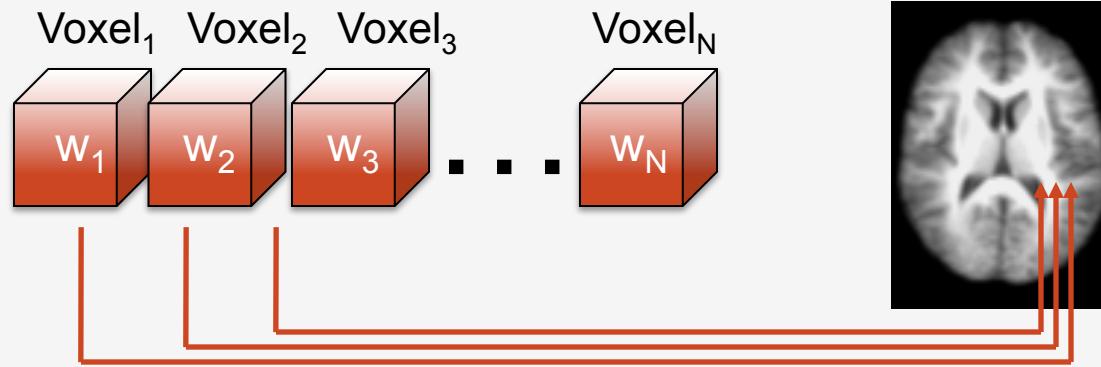


cond B

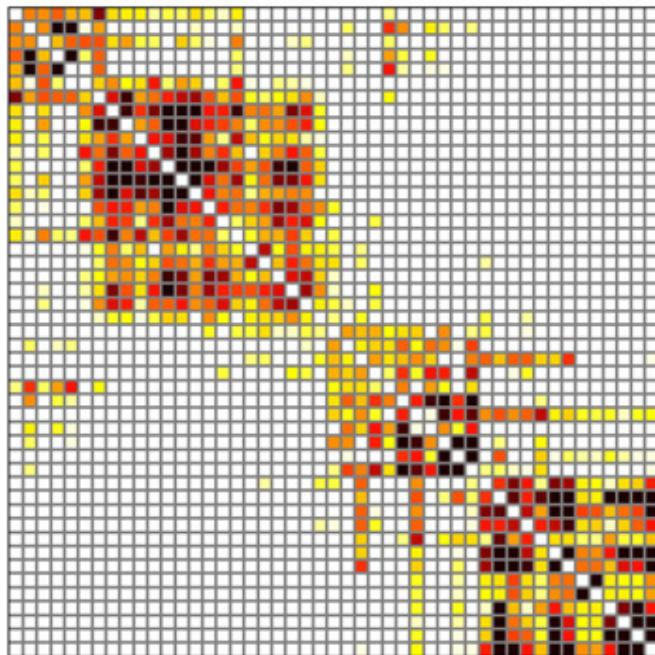
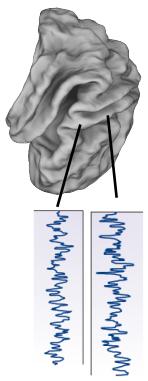
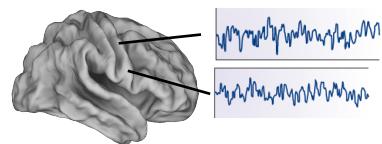


Classification function

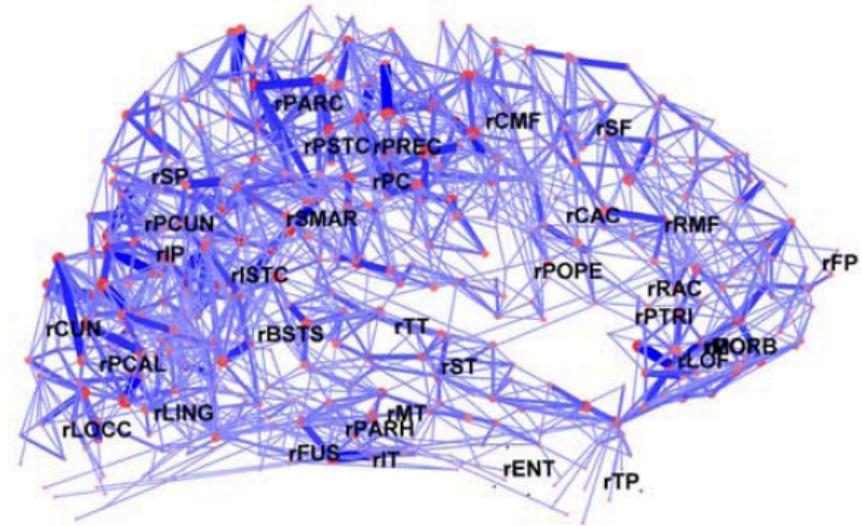
w: weights



Connectivity-based decoding



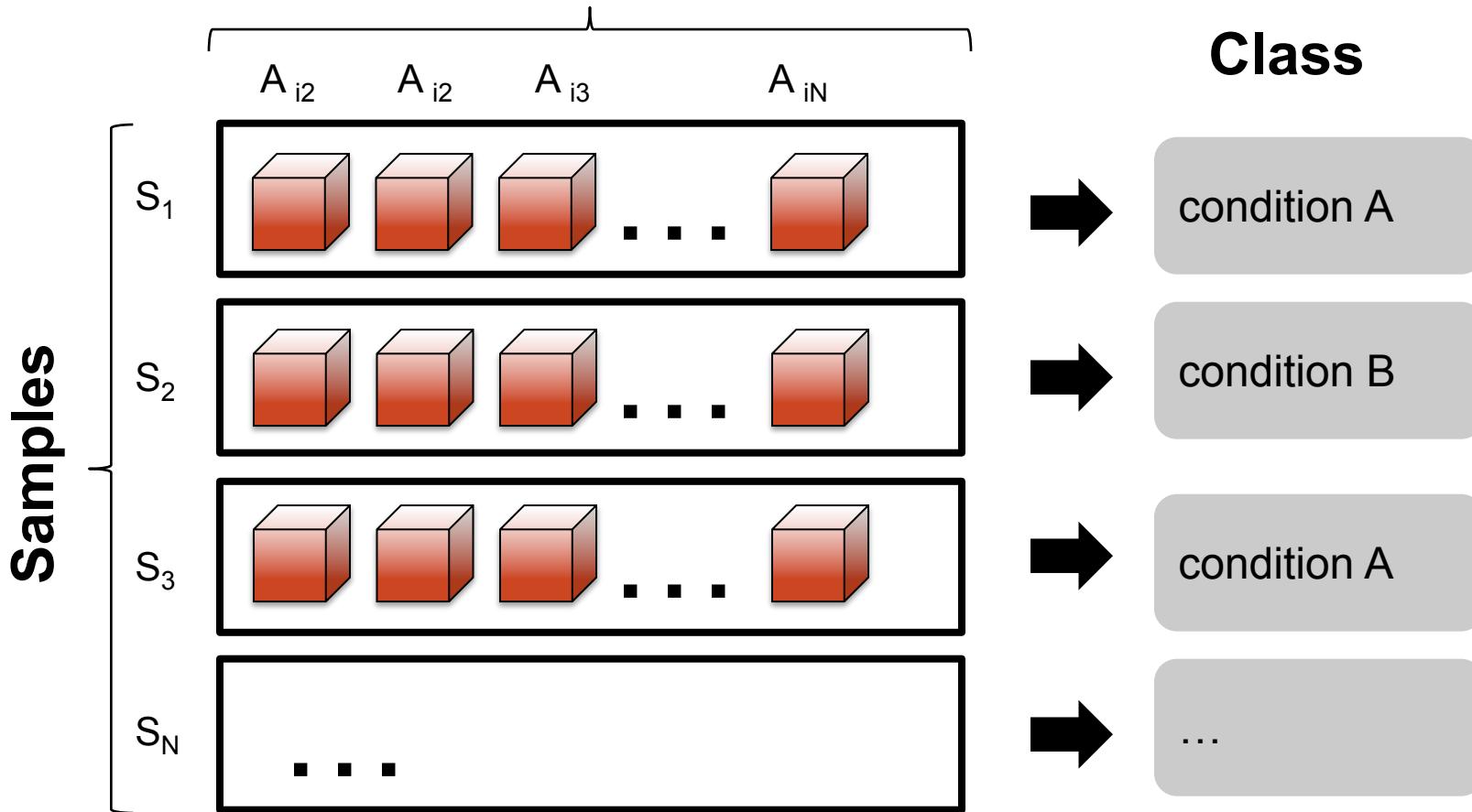
Adjacency matrix



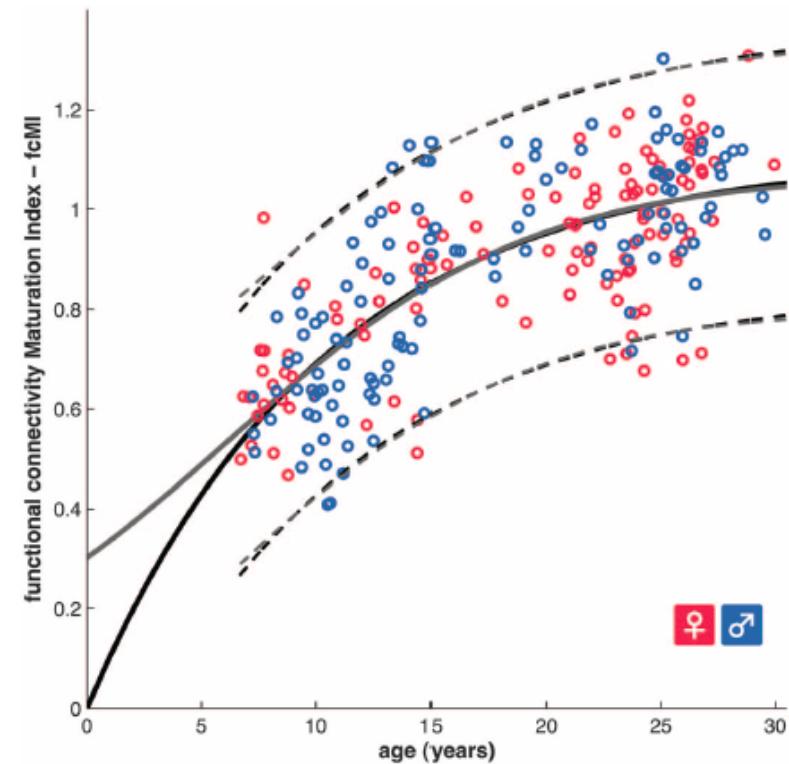
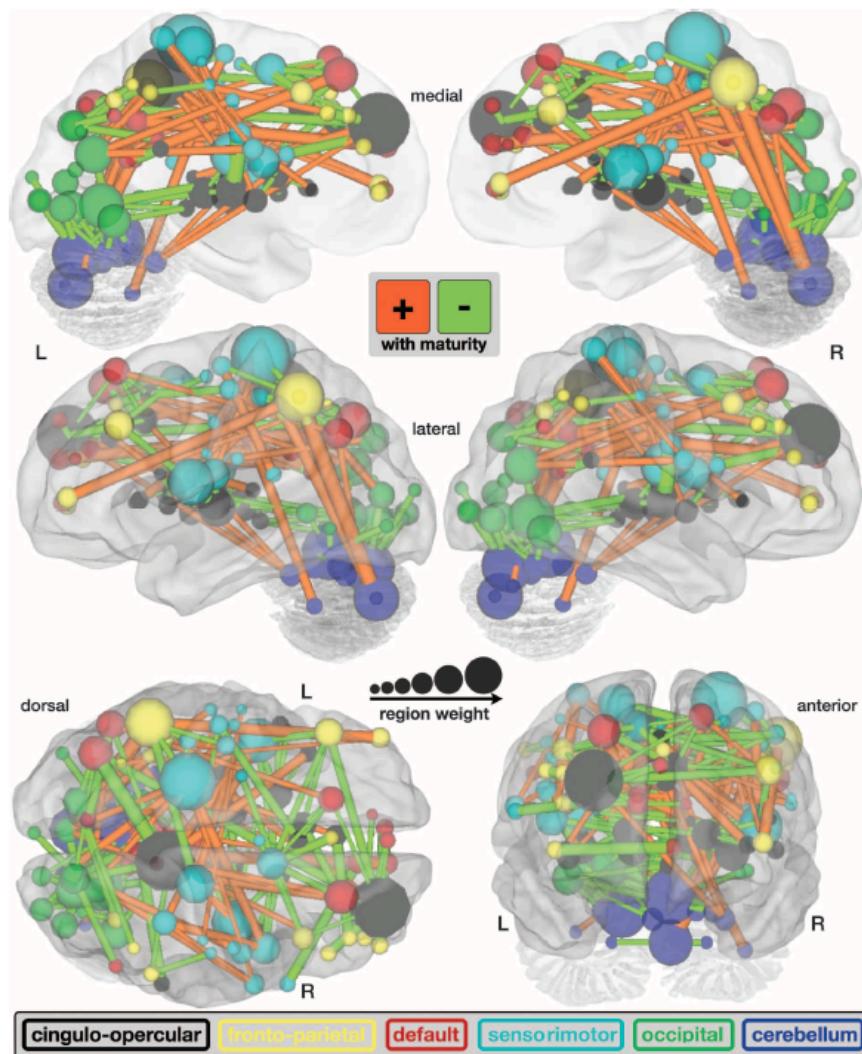
Graph



Features



Connectivity-based decoding



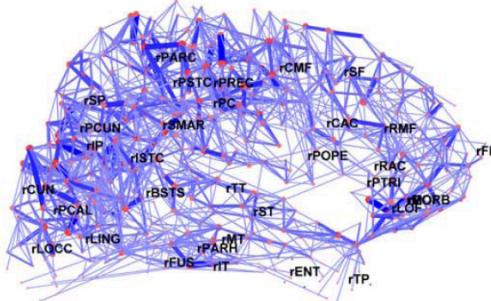
Using functional connectivity during resting-state to predict individual age ($r^2 \sim .55$)

Dosenbach et al. (2010). Prediction of individual brain maturity using fMRI. *Science* (New York, NY), 329(5997), 1358–1361. doi:10.1126/science.1194144

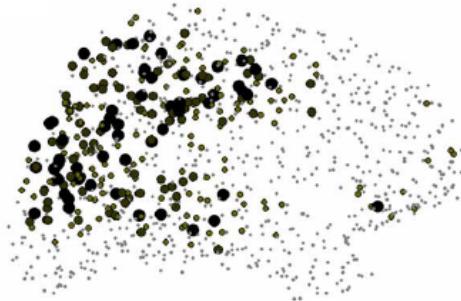
Connectivity-based decoding



- Connectivity-based decoding
 - many advantages, e.g. increase in statistical sensitivity
- But...
 - interpretability of results sometimes not so easy (complexity)
 - complexity is increasing (exponentially) with number of network nodes N
- Proposed solution
 - Using graph-theory to describe the connectivity pattern
 - Reduce complexity and (potentially) increase interpretability



Connectivity: $N \times N$

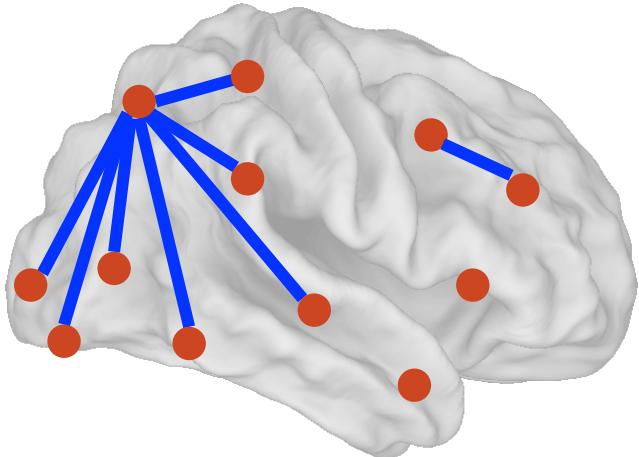


Graph Theory: N

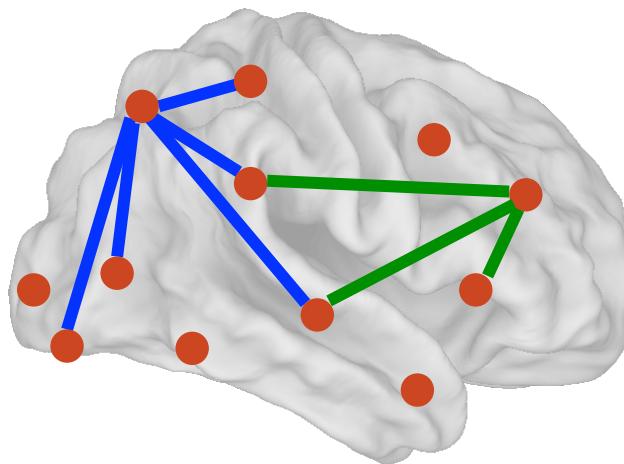
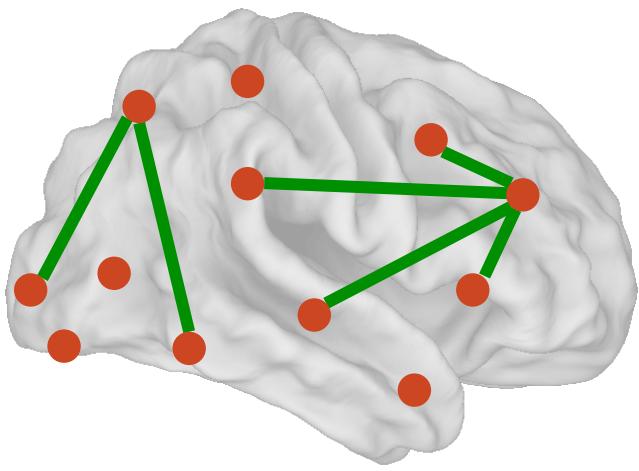
Connectivity-based decoding



Condition A

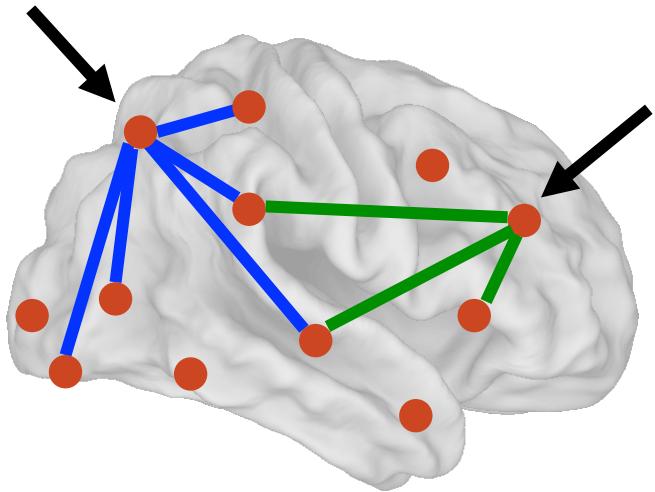


Condition B

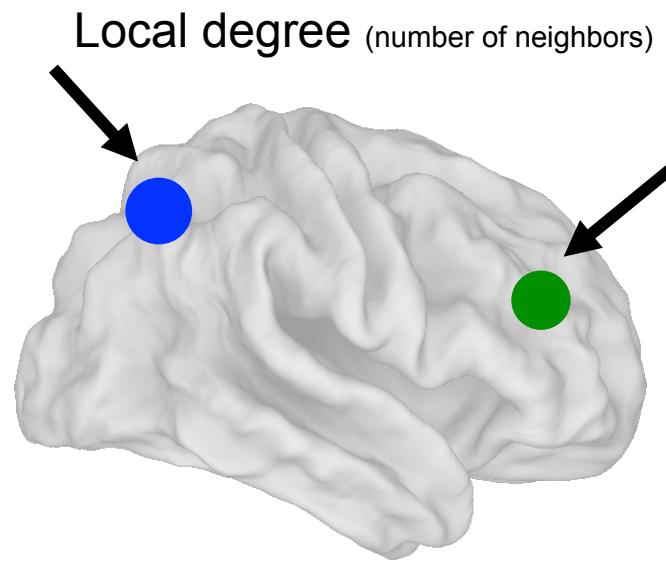


Connectivity difference pattern: A vs. B

Connectivity-based decoding



Connectivity-based difference pattern:
A vs. B

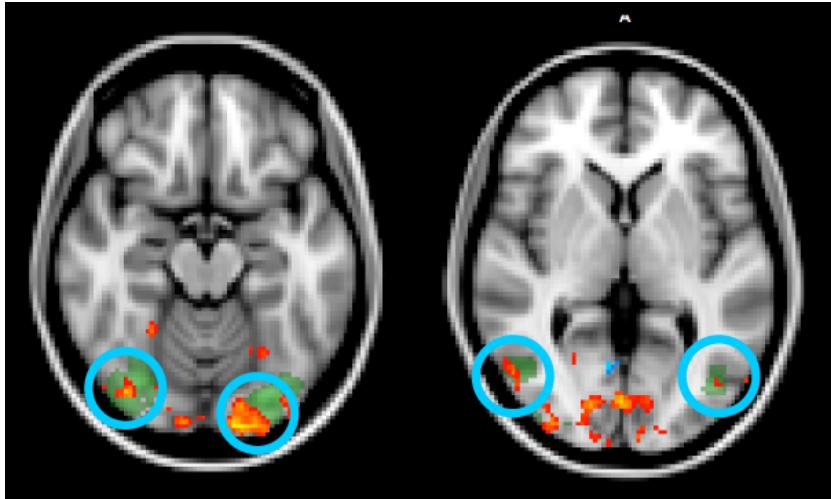


Graph theory difference pattern:
A vs. B

Connectivity-based decoding



- High-resolution functional connectivity maps
 - 126.000×126.000 Nodes = 15.876.000.000 connections
 - Interpretable decoding results using local graph theoretical metrics



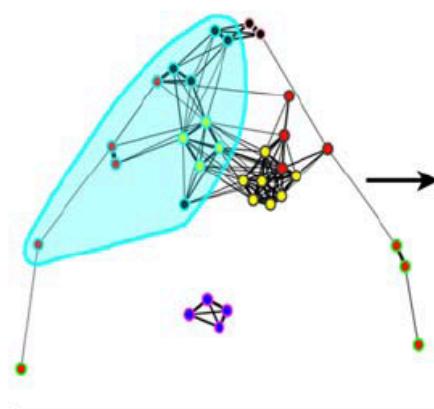
Ekman et al. (in preparation). Predicting Response Time Variations from Anticipatory Modulation of Large-scale Brain Networks



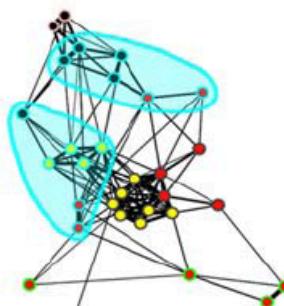
Graph-theory & complex connectivity relationships



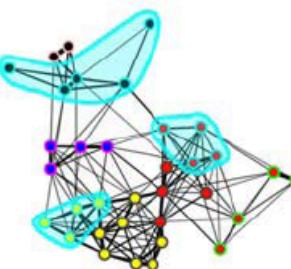
A 8.48 Years



13.21 years



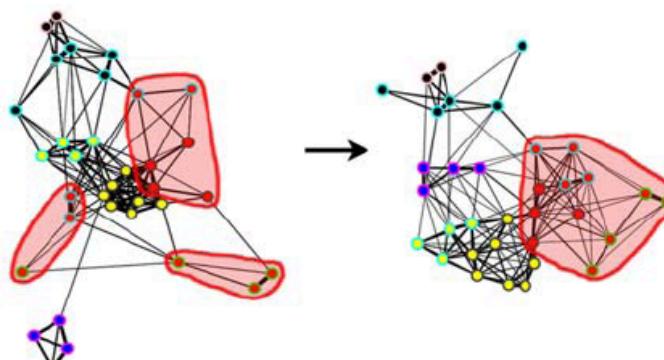
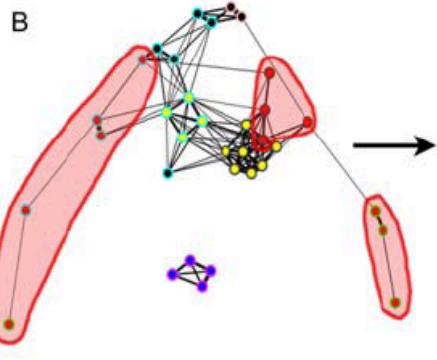
25.48 years



Frontal regions
(blue)



Increase in
“segregation”
with age



Default mode network
(red)



Increase in
“integration”
with age

Network

- Cingulo-opercular
- Fronto-parietal
- Default
- Cerebellar

Lobe

- Frontal
- Parietal
- Temporal
- Cerebellum

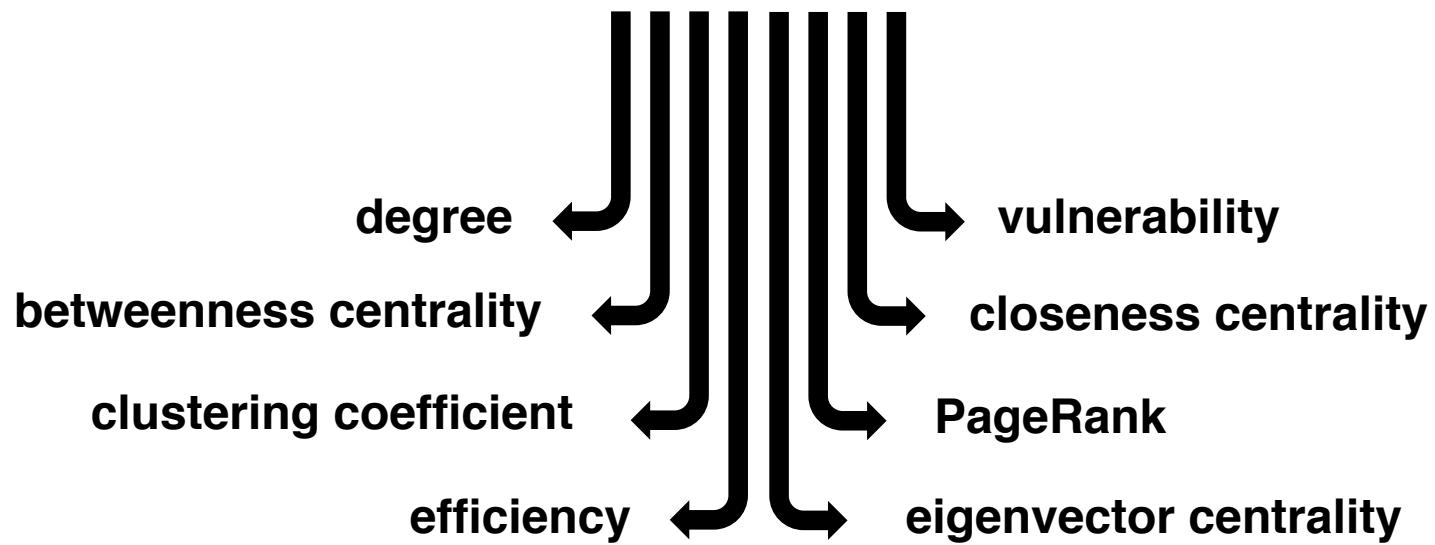
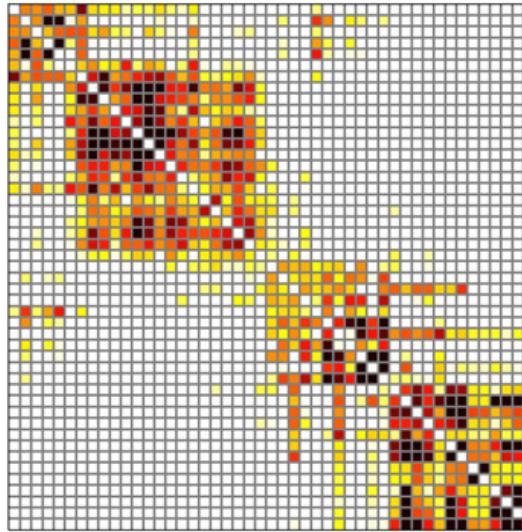
Fair et al. (2009). Functional brain networks develop from a “local to distributed” organization.
PLoS Computational Biology, 5(5), e1000381. doi:10.1371/journal.pcbi.1000381



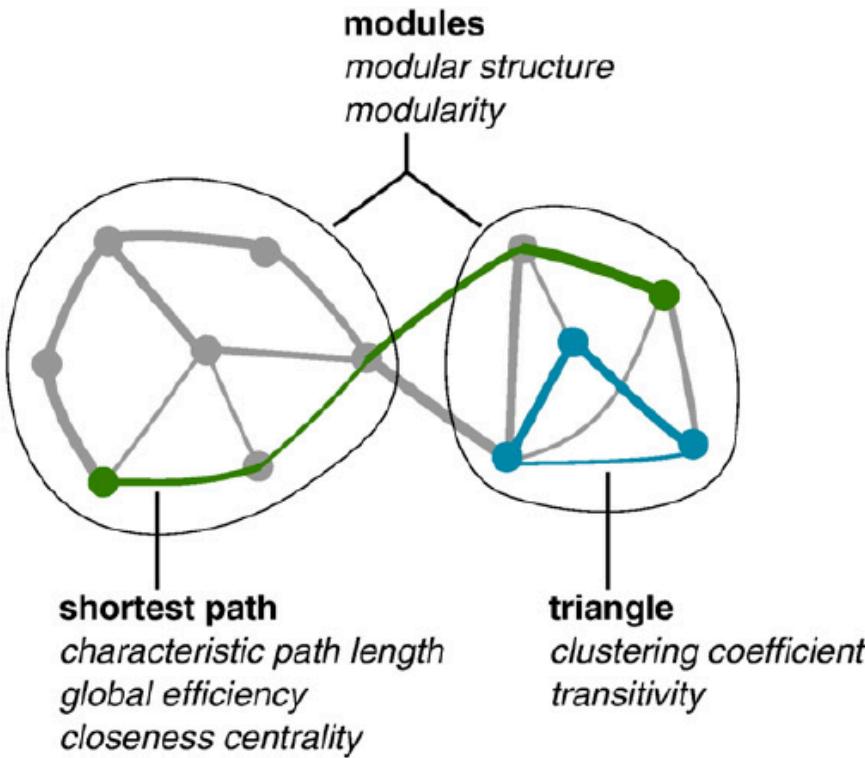
- Combining decoding techniques and functional connectivity analysis is a *promising approach*.
- Using **graph-theory** to summarize complex connectivity patterns in abstract metrics (e.g. degree) might increase the **interpretability** of your results.
- Graph-theory can also capture more **complex connectivity relationships** (e.g. segregation, integration).
- Combining decoding techniques and functional connectivity analysis – based on graph-theory - is a *very promising approach*.



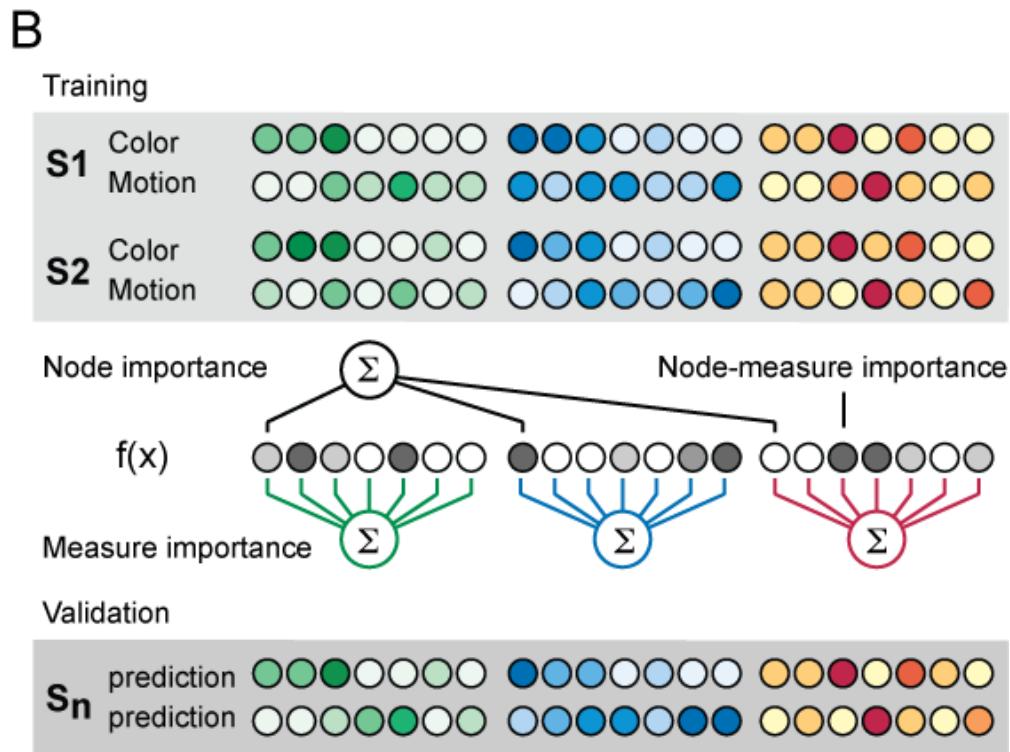
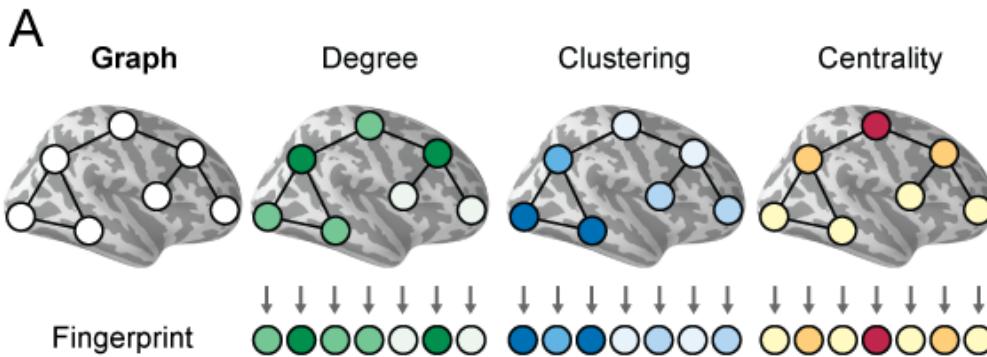
Graph Theory: What is the right metric to choose?



Graph Theory: What is the right metric to choose?



Inverse network modeling



Ekman et al. (2012). Predicting errors from reconfiguration patterns in human brain networks. *PNAS*, 109(41), 16714–16719. doi:10.1073/pnas.1207523109



- Graph-theory offers a large set of metrics
 - It is not always clear what is the “best” metric to choose
 - Using and testing all metrics leads to a huge multiple-comparison problem; increase in false positive rate.
- Proposed solution
 - Using decoding techniques to combine graph metrics into one statistical model (*inverse network modeling*).
- Inverse network modeling
 - Select important metrics in a data-driven way
 - Potential sensitivity gain in combining all metrics (e.g. interaction effects)

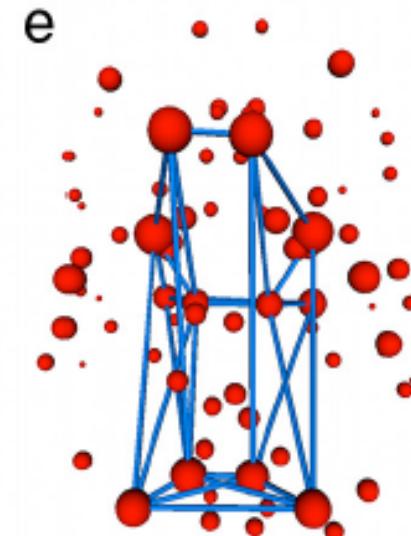
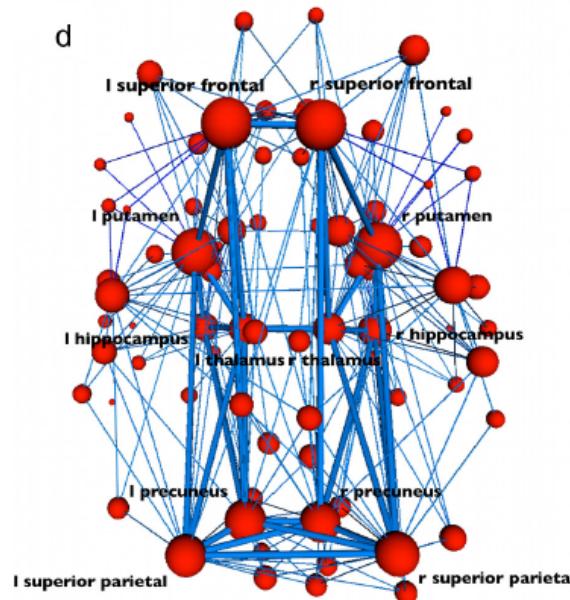
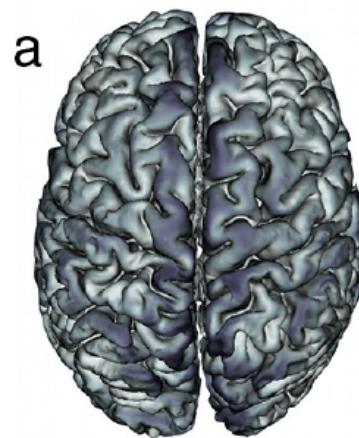


Rich-Club Organization of the Human Connectome

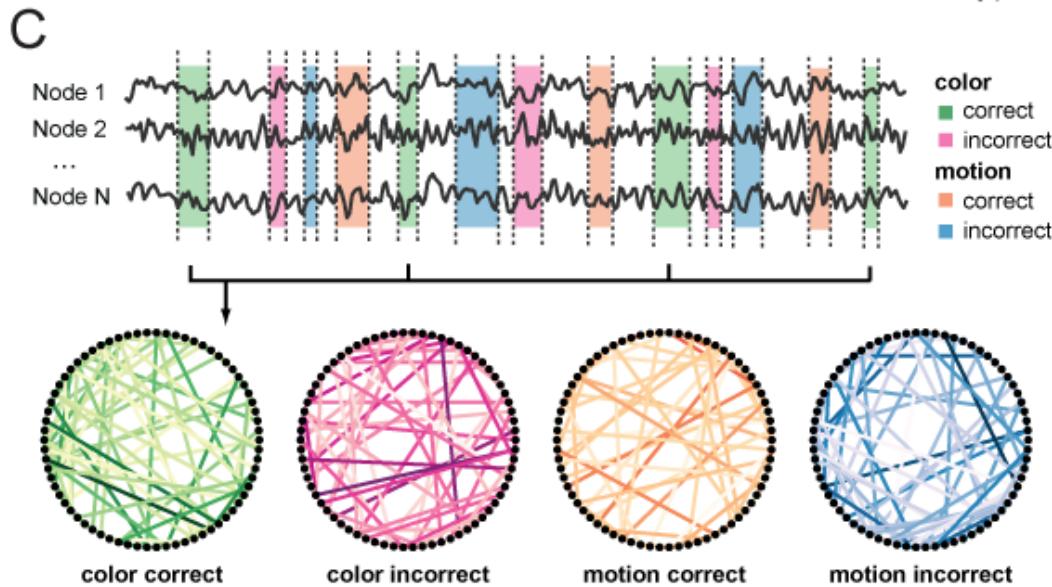
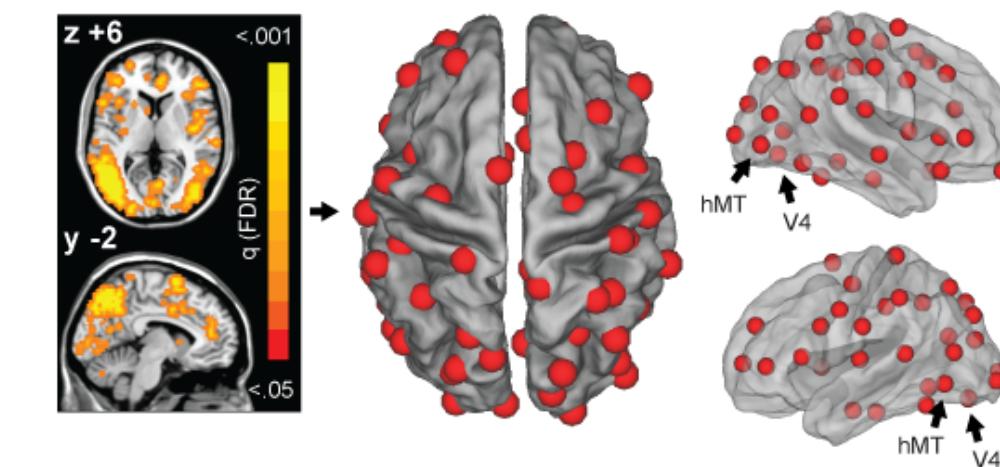
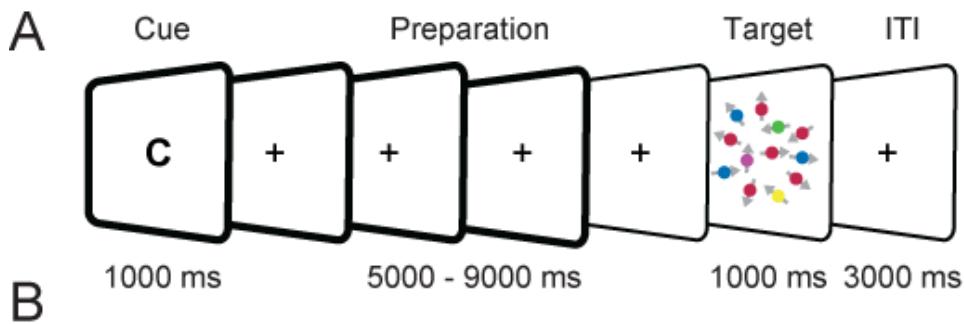
Martijn P. van den Heuvel¹ and Olaf Sporns²

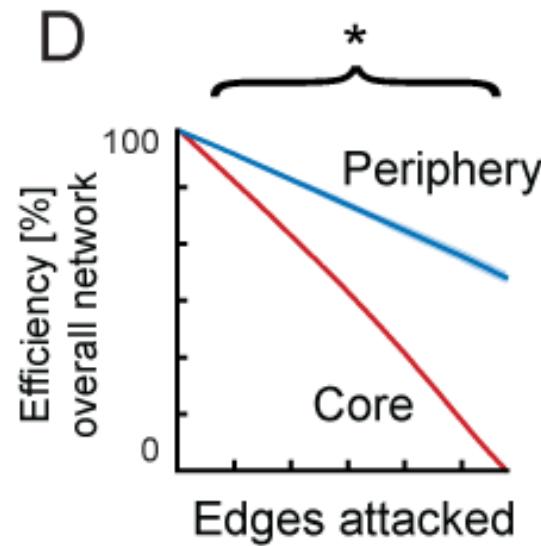
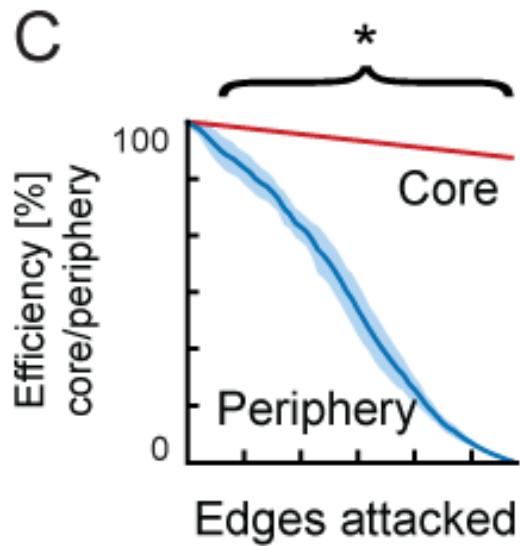
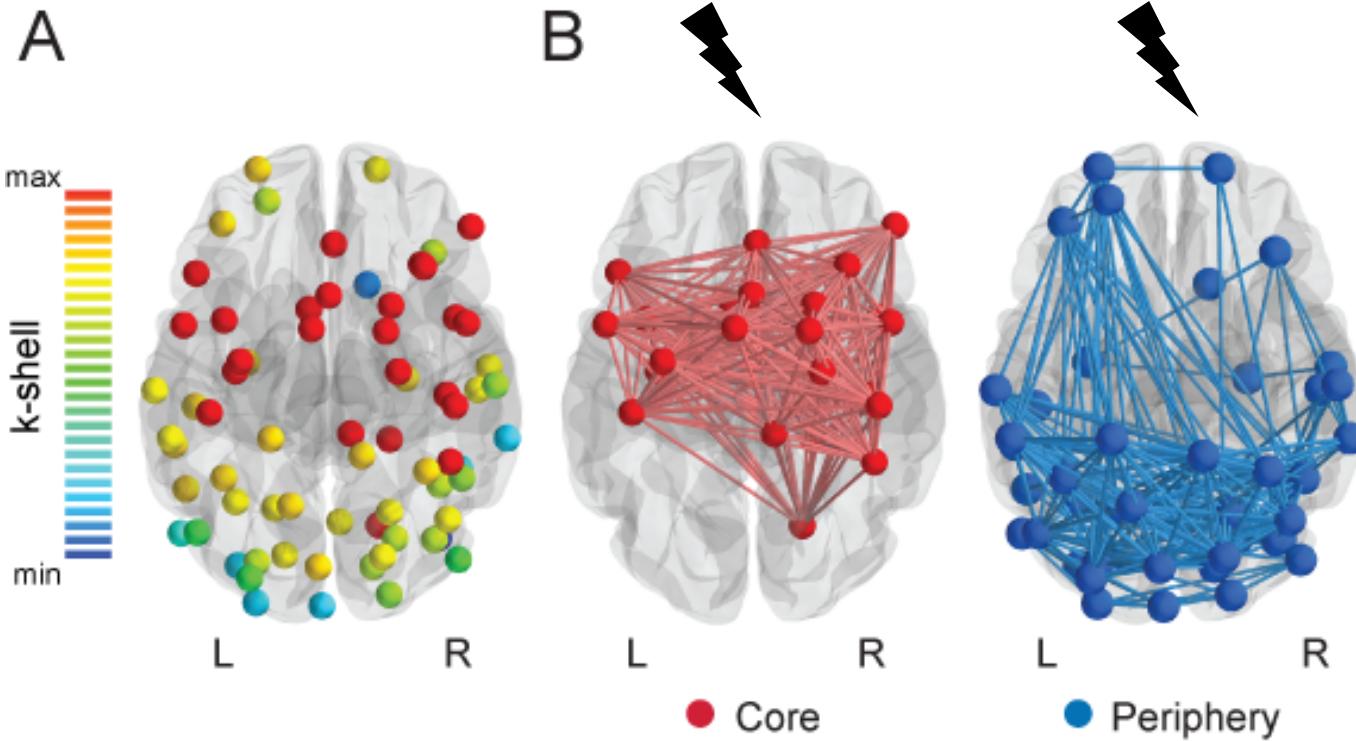
¹Department of Psychiatry, University Medical Center Utrecht, Rudolf Magnus Institute of Neuroscience, 3508 GA Utrecht, The Netherlands, and

²Department of Psychological and Brain Sciences and Program in Cognitive Science, Indiana University, Bloomington, Indiana 47405

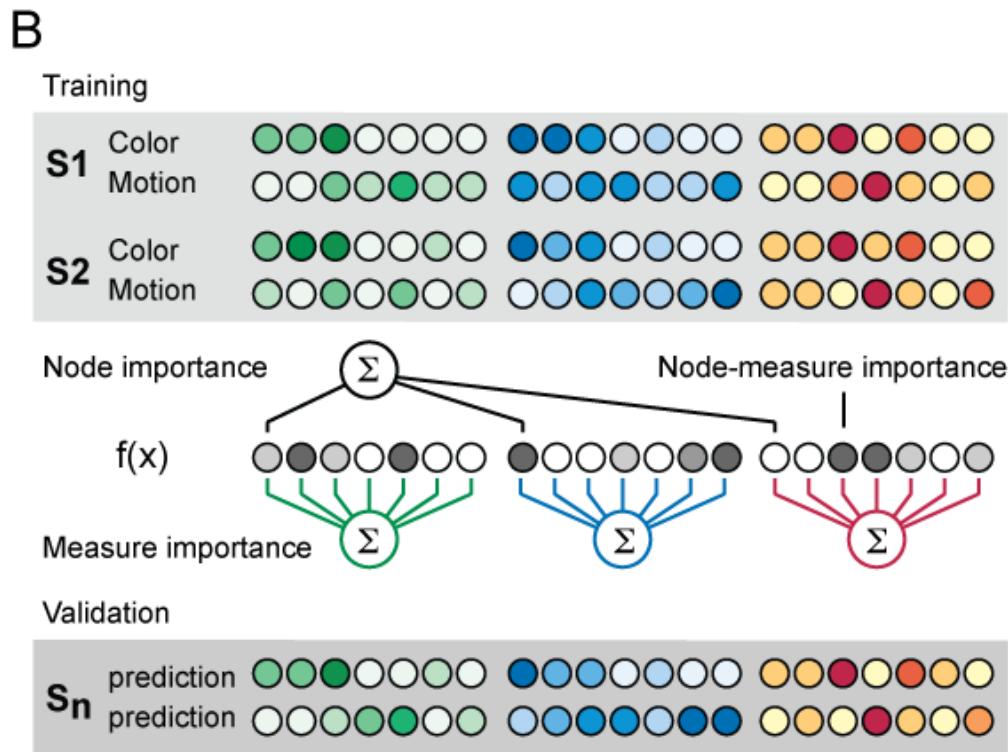
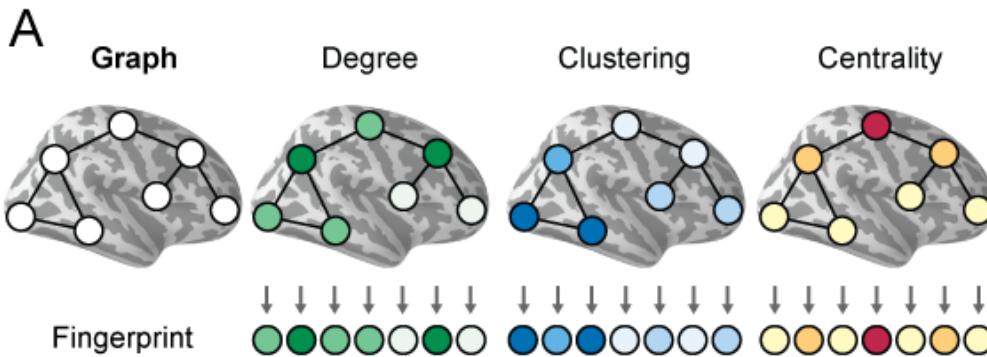


Van den Heuvel (2011) JN; Van den Heuvel (2012) PNAS

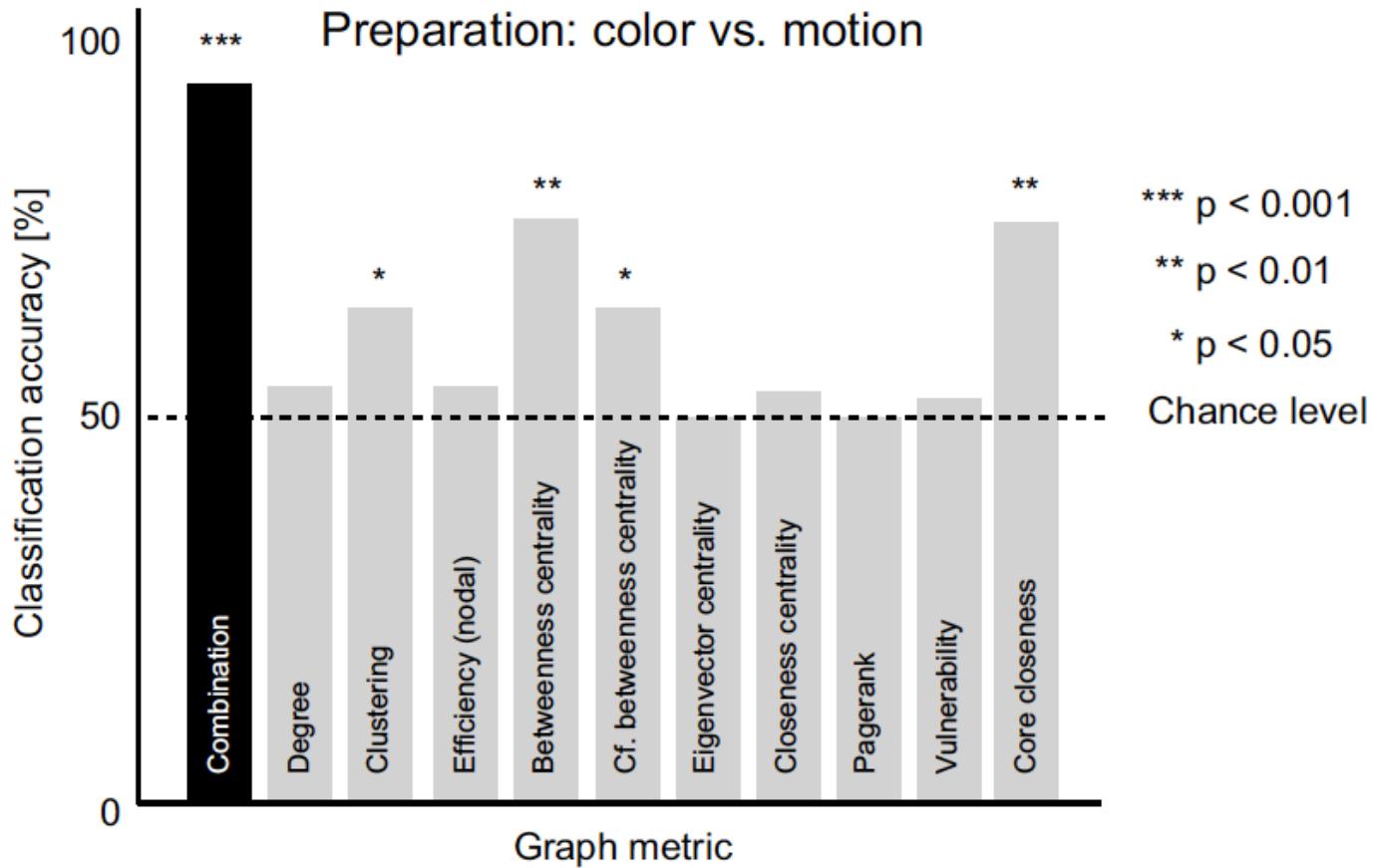




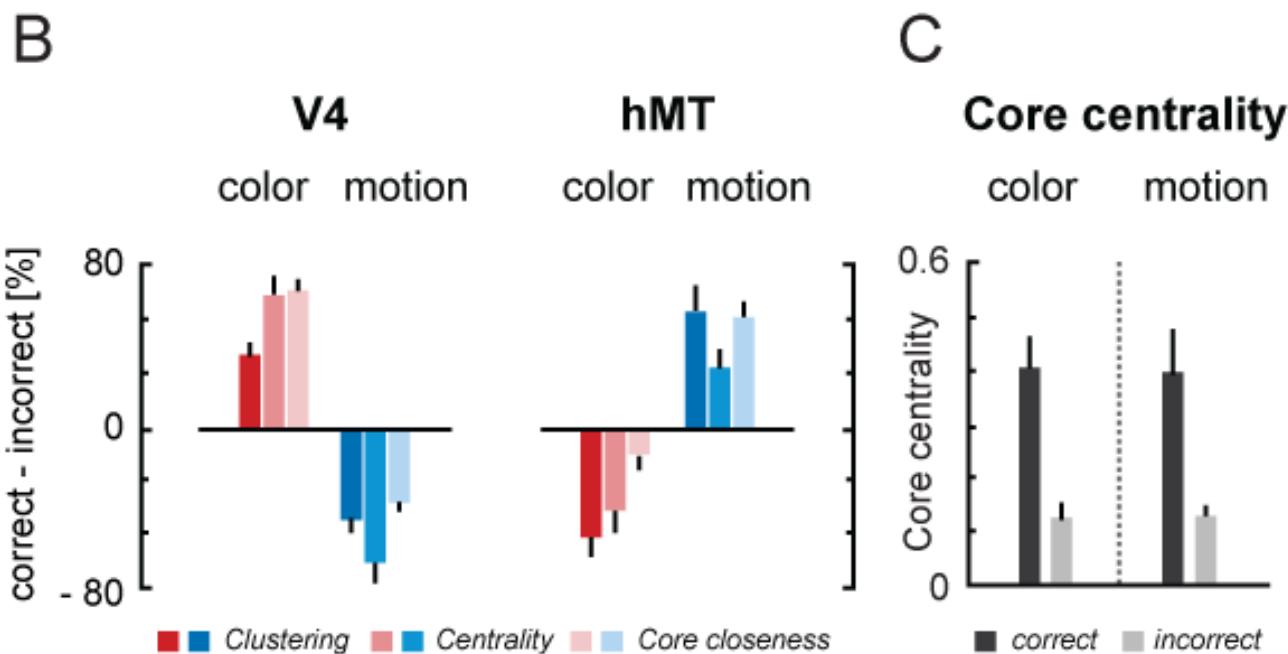
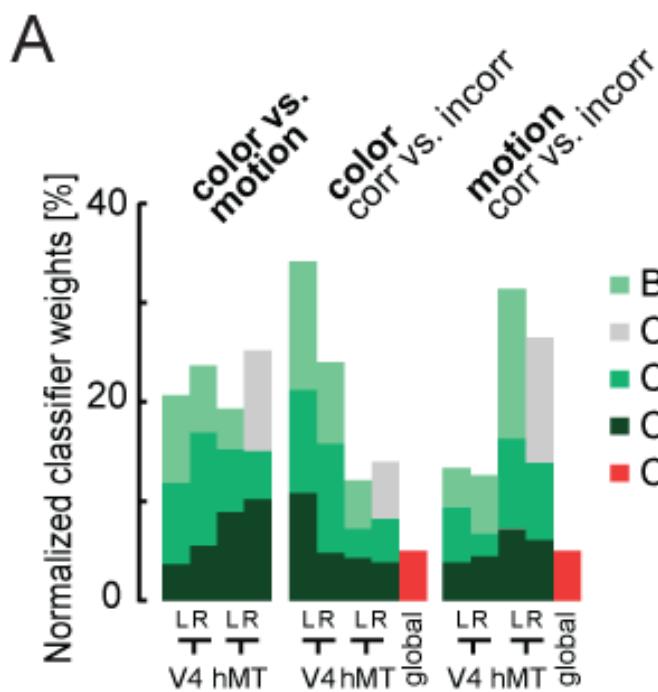
Inverse network modeling

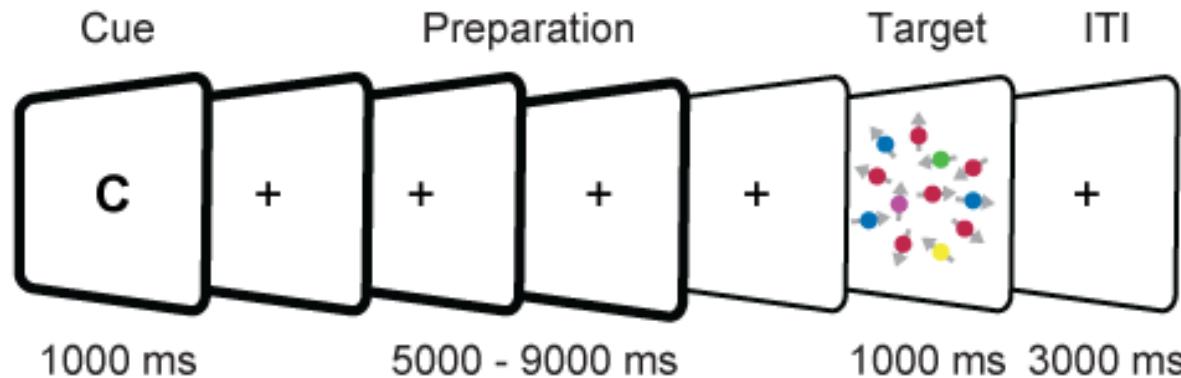


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- The topology of brain networks is dynamically reconfigured during preparation for an upcoming task
- Reconfiguration involves
 - enhanced **segregation**
 - adjustments in **information flow** through task-relevant visual areas
 - changes in their **topological proximity** to a frontally-dominated network core

Learning objectives



- Fruitful combination of functional connectivity analysis and graph-theory
 - capture complex relationships
 - generate interpretable results
- Using decoding techniques to combine graph-theoretical metrics into one model (Inverse network modeling).

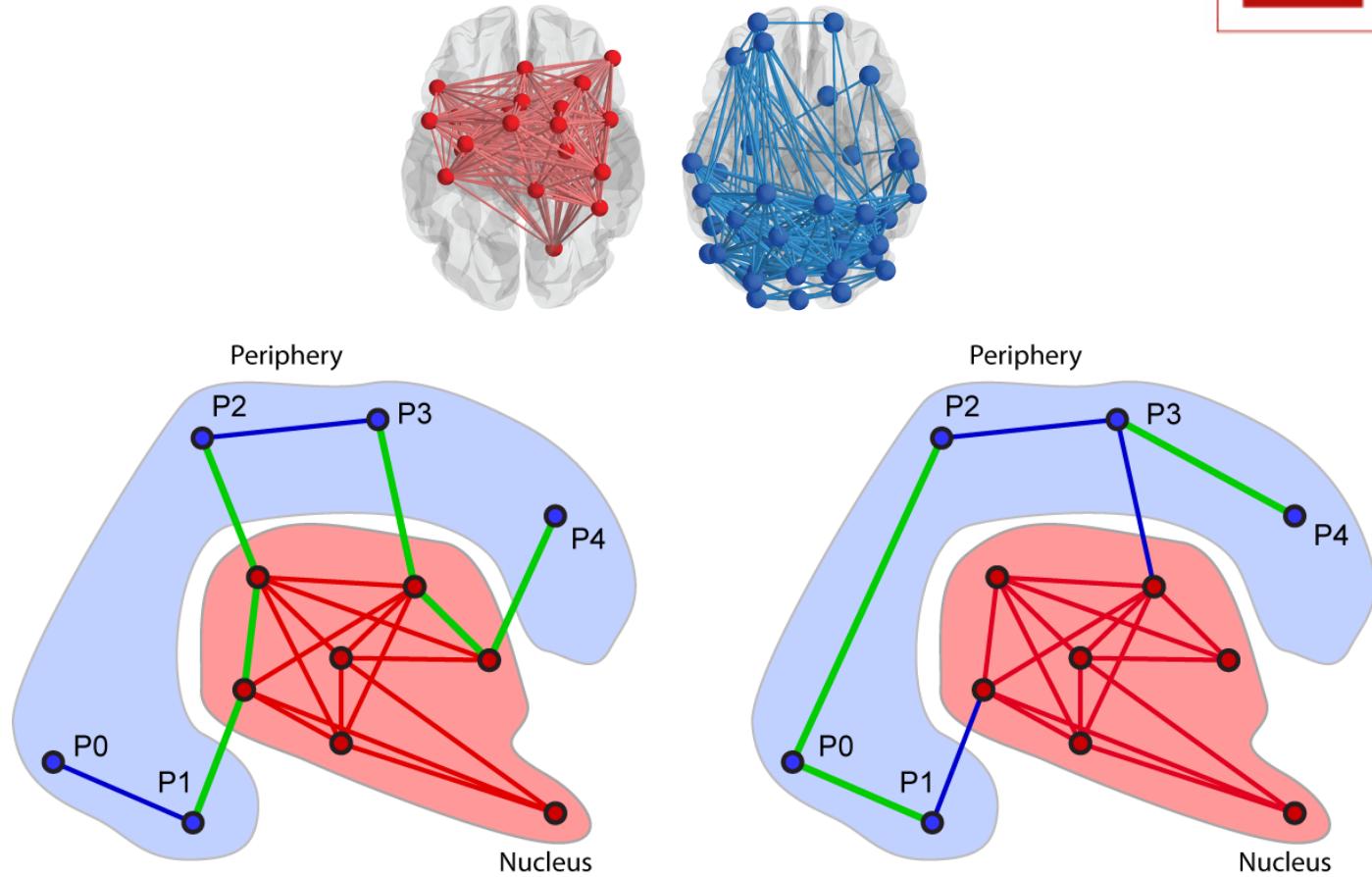




Thank you!



Results

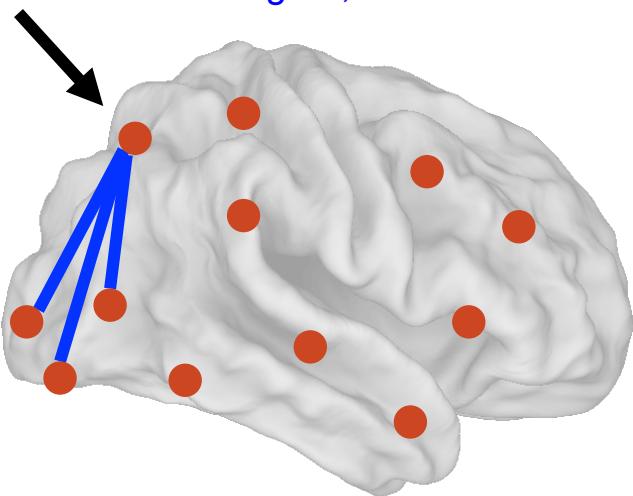


● Periphery ● Nucleus — Shortest path

GT-based decoding fails

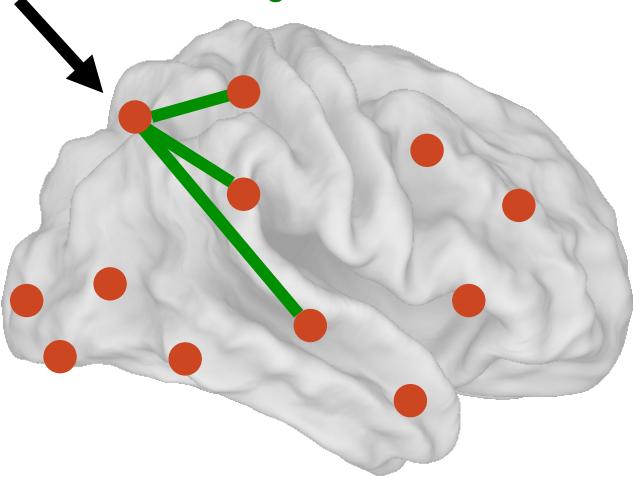


Condition A



Local degree, $k=3$

Condition B



Local degree, $k=3$