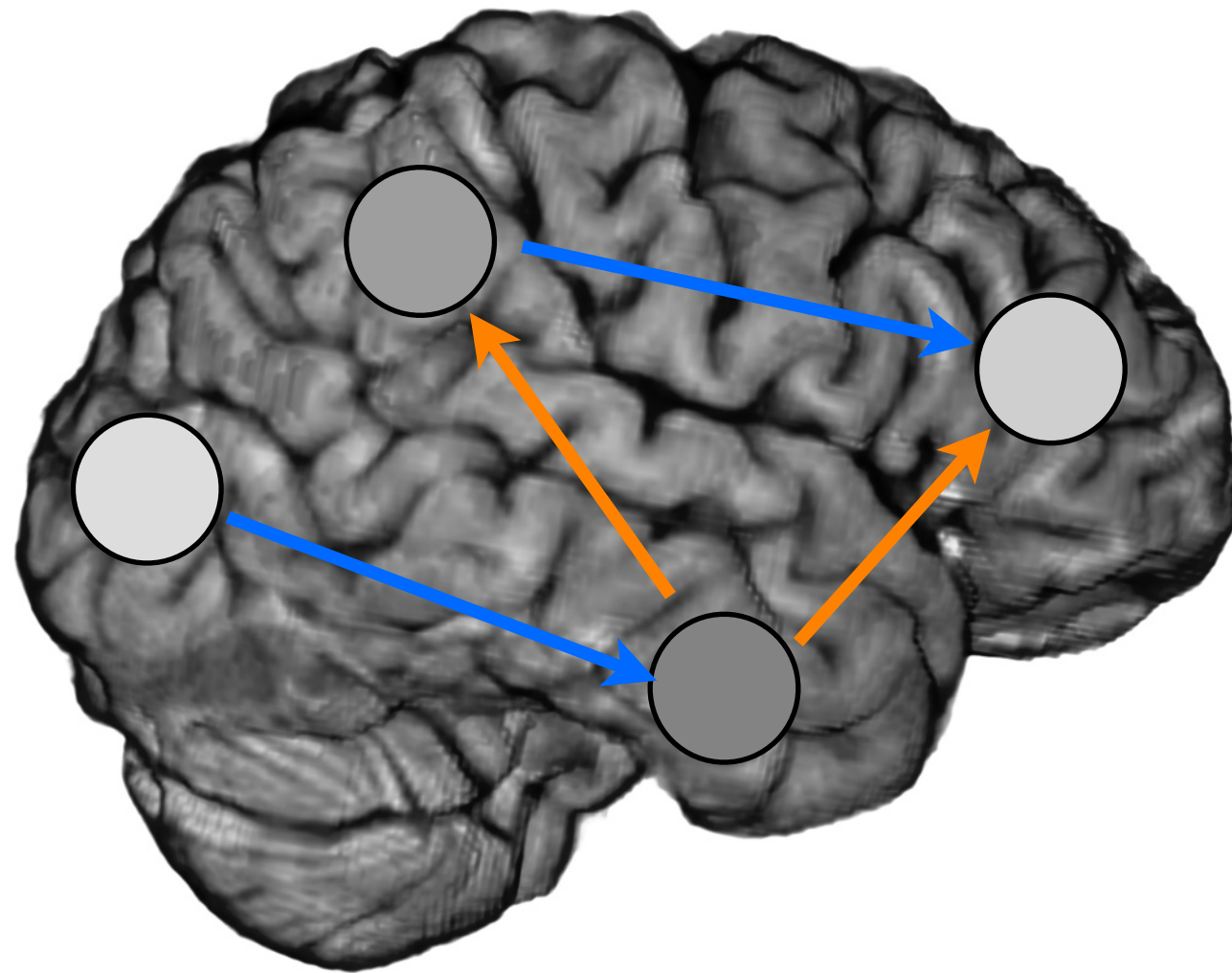


This is your brain on graphs



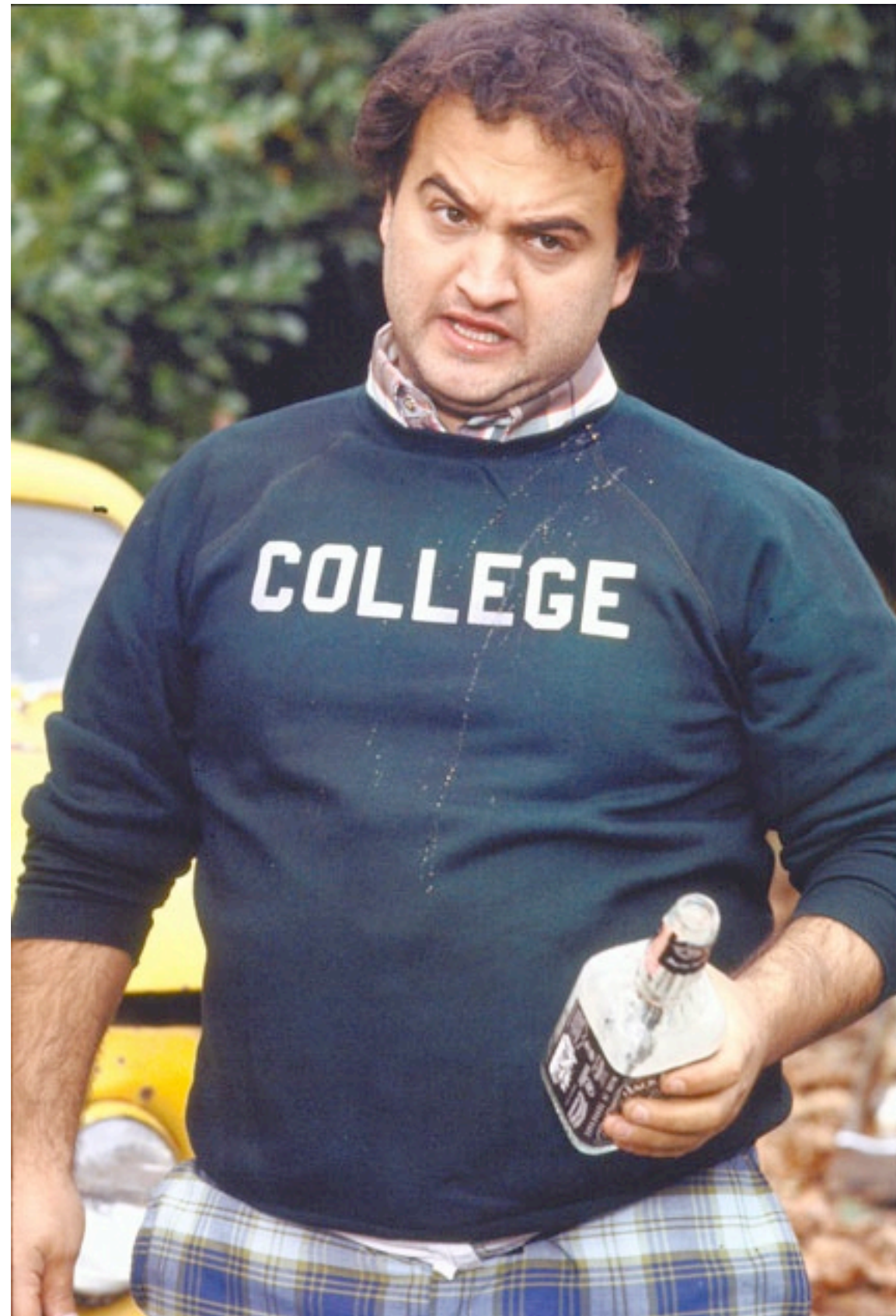
Mark Daley

Department of Computer Science

Department of Biology

The Brain and Mind Institute

Western University



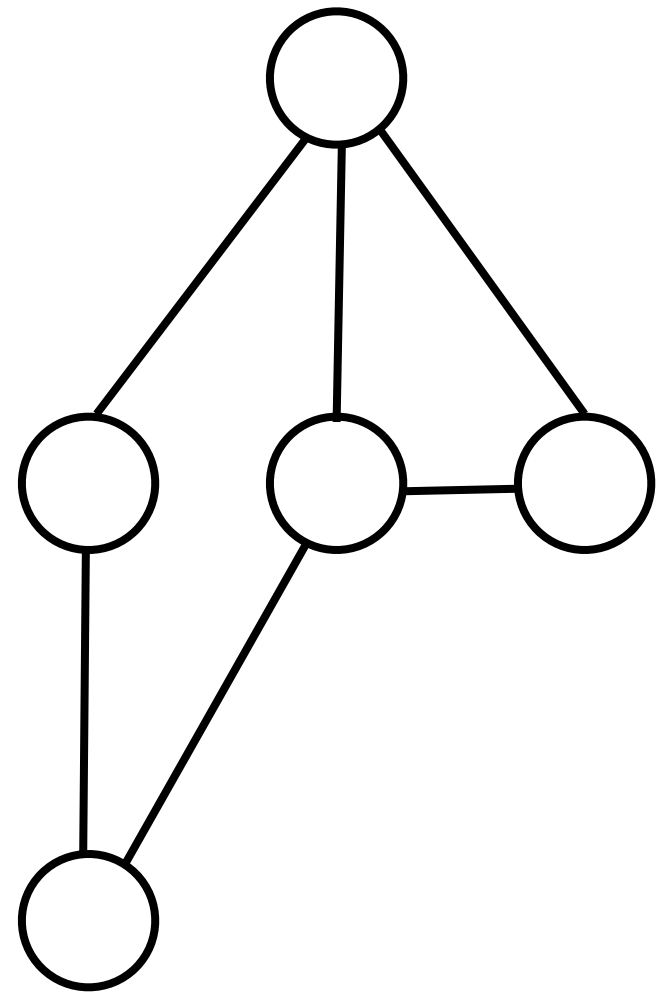
Background

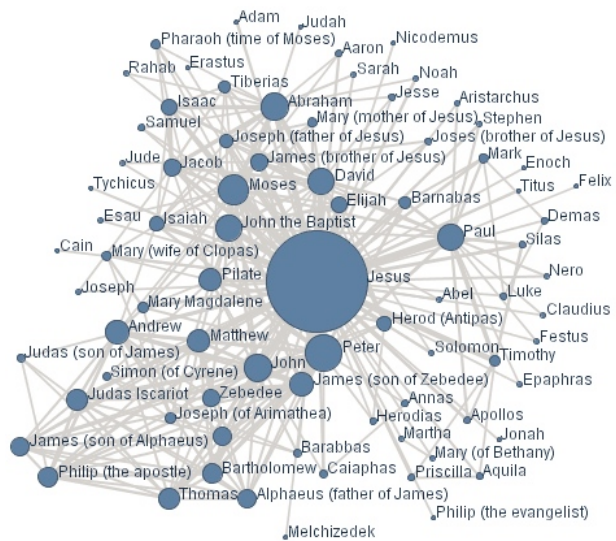
Graphs

○ Node / Vertex

— Edge (undirected)

→ Edge (directed)

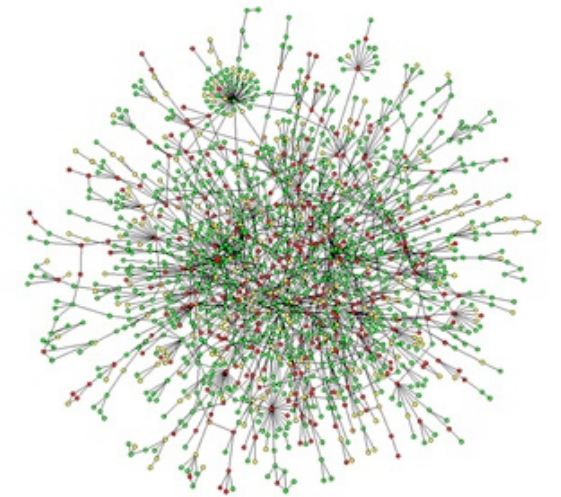




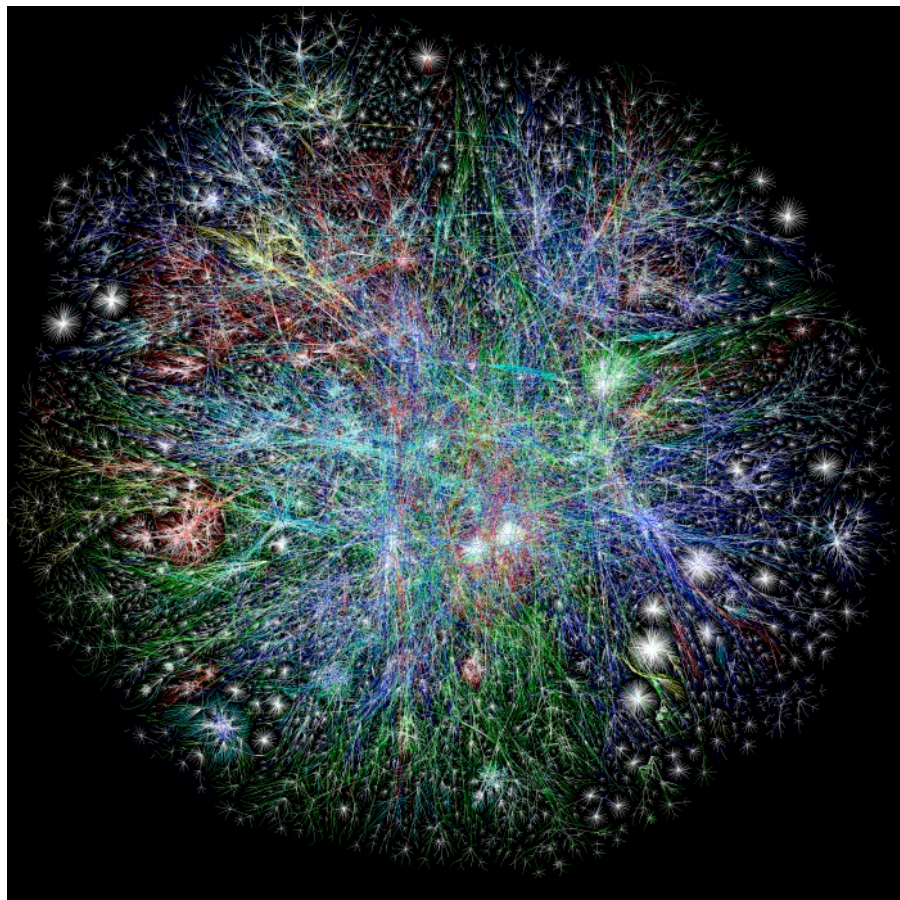
Social



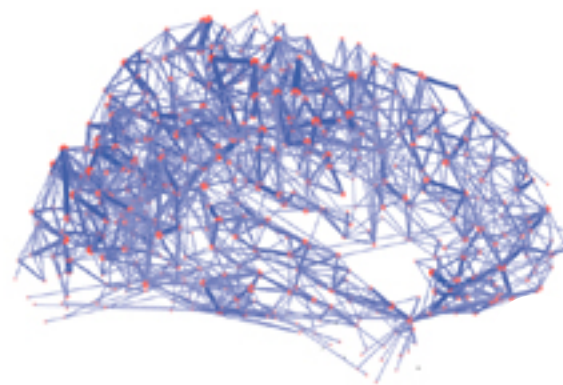
Power



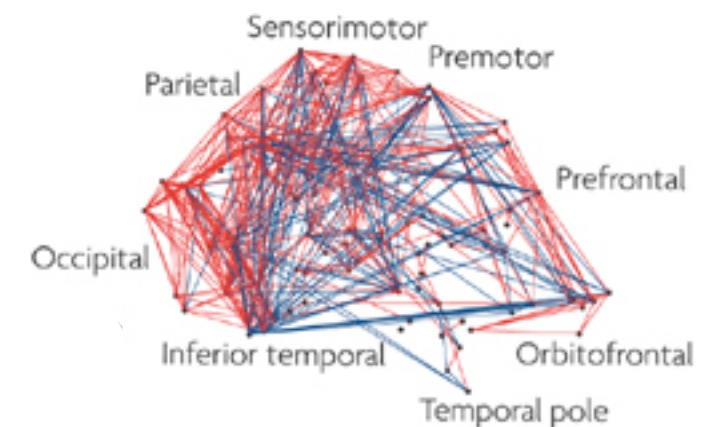
Protein Interaction



Internet

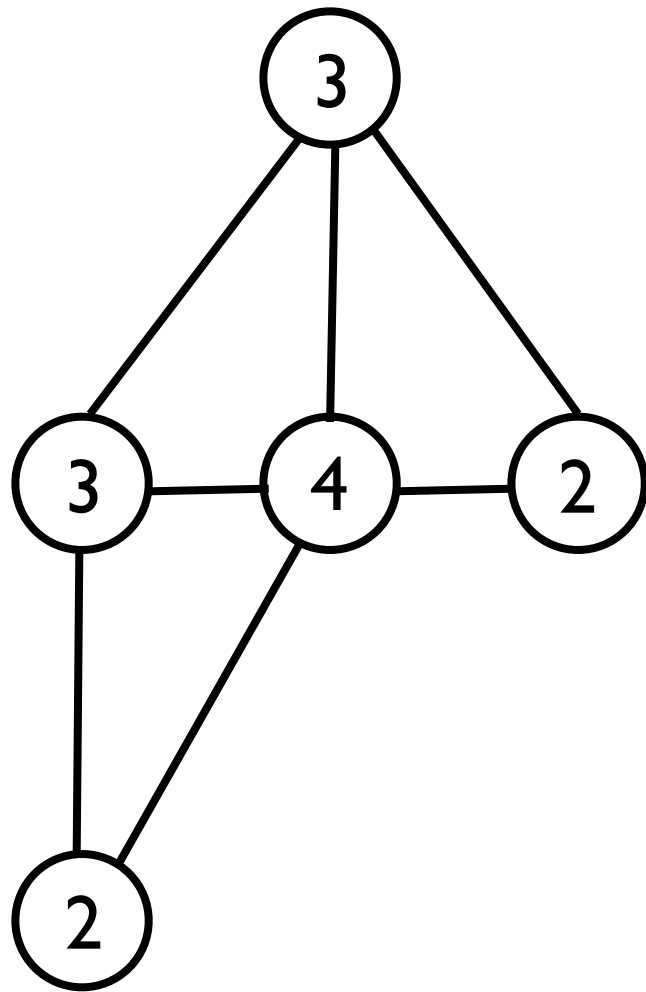


Brain Structural

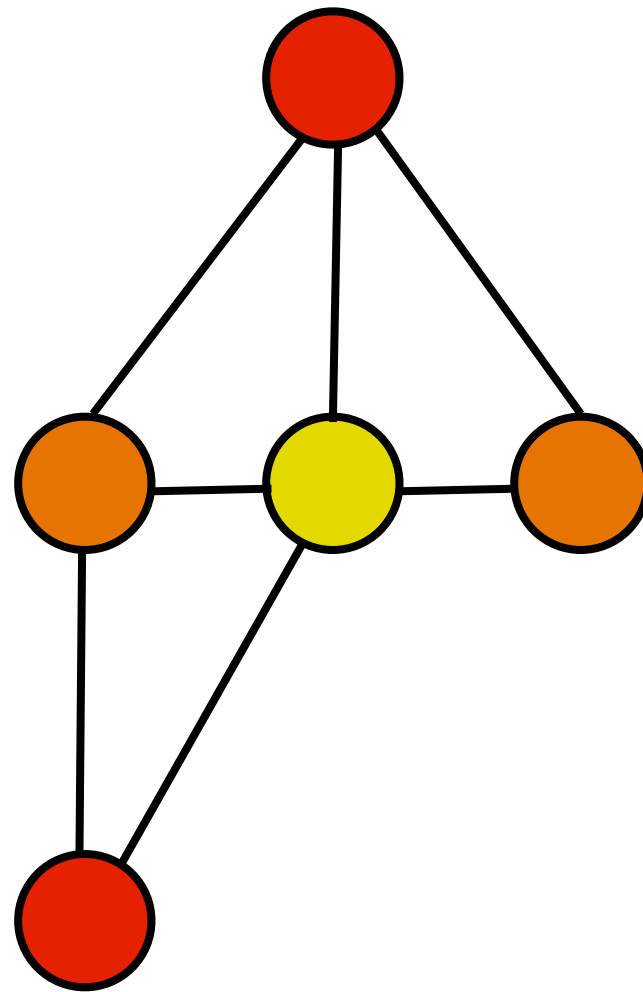


Brain Functional

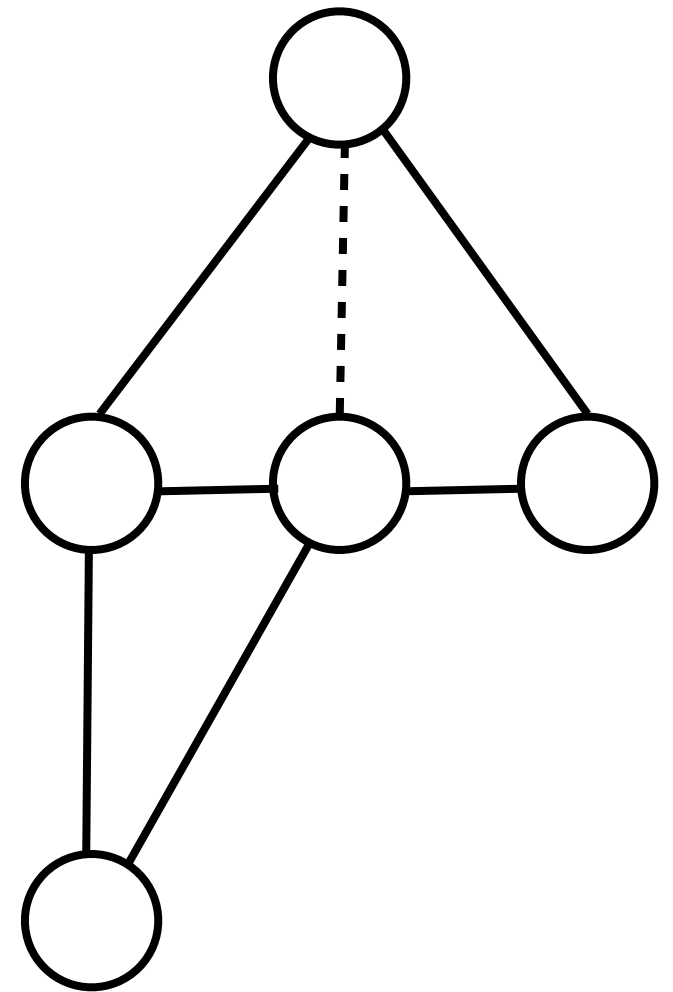
Node properties



Degree

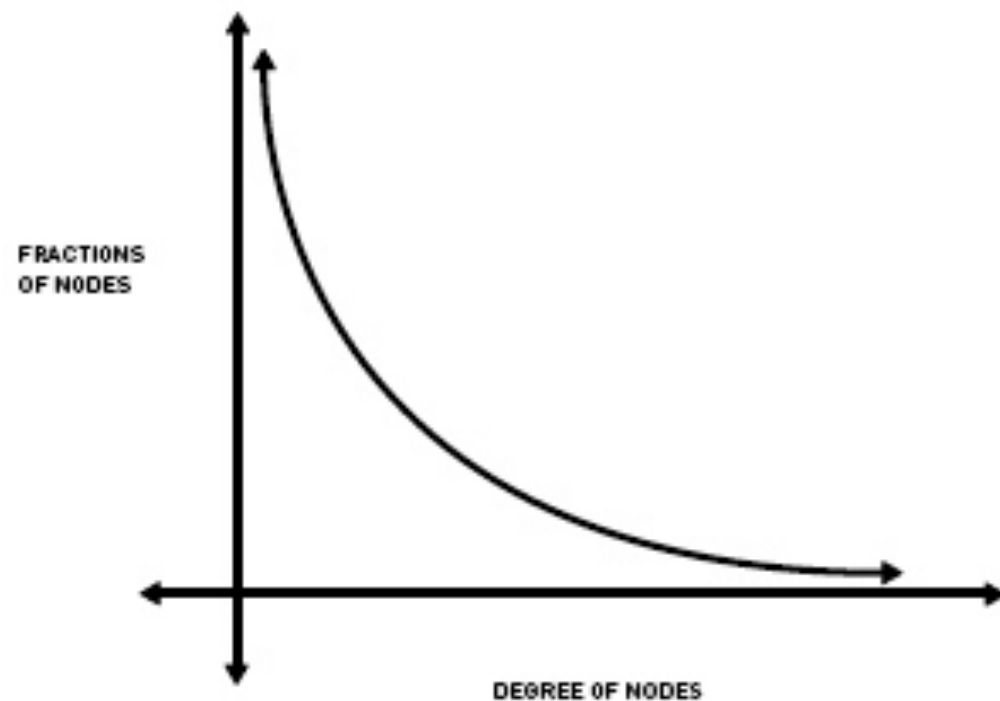


Betweenness

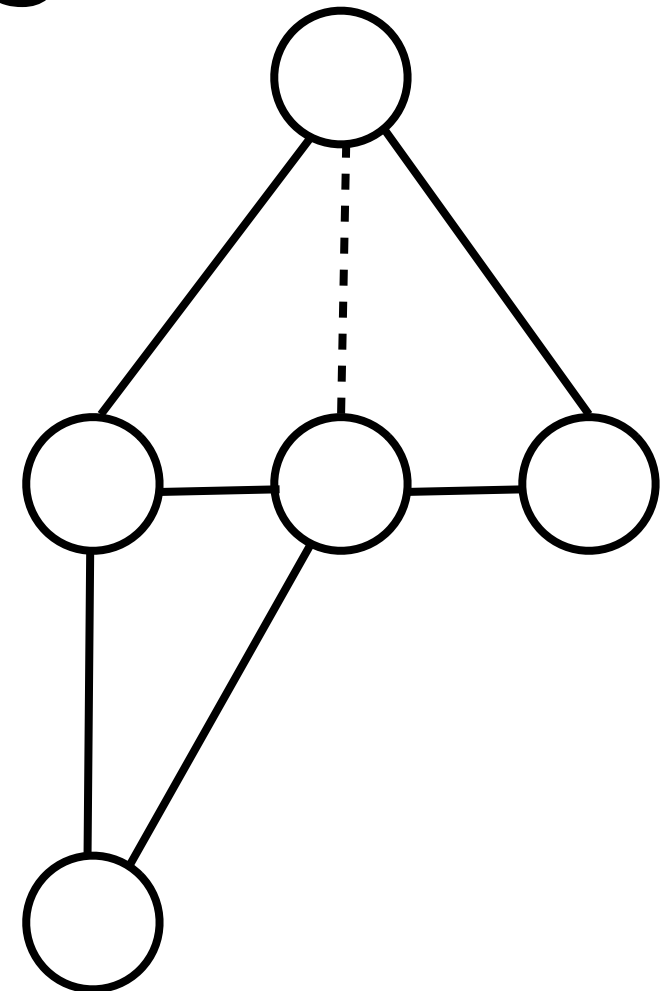


Transitivity

Whole-graph properties

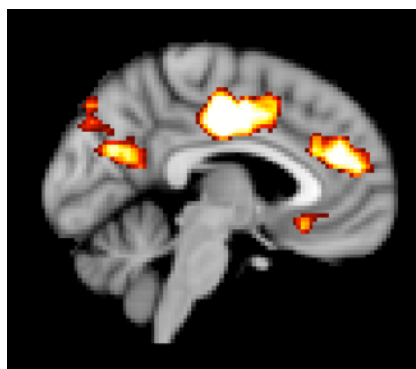
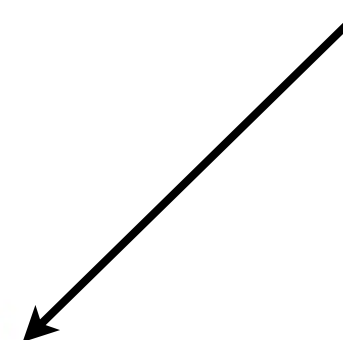
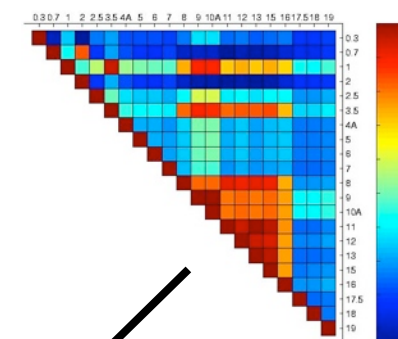
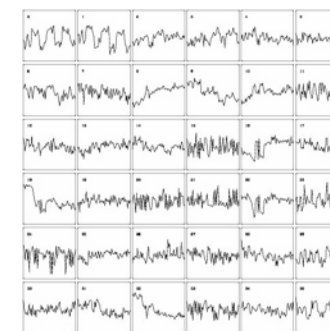
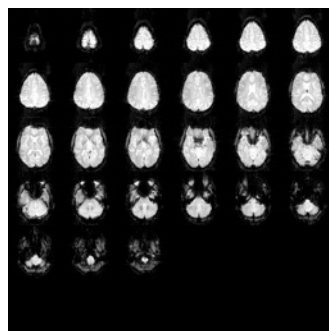


Degree distribution



Clustering coefficient

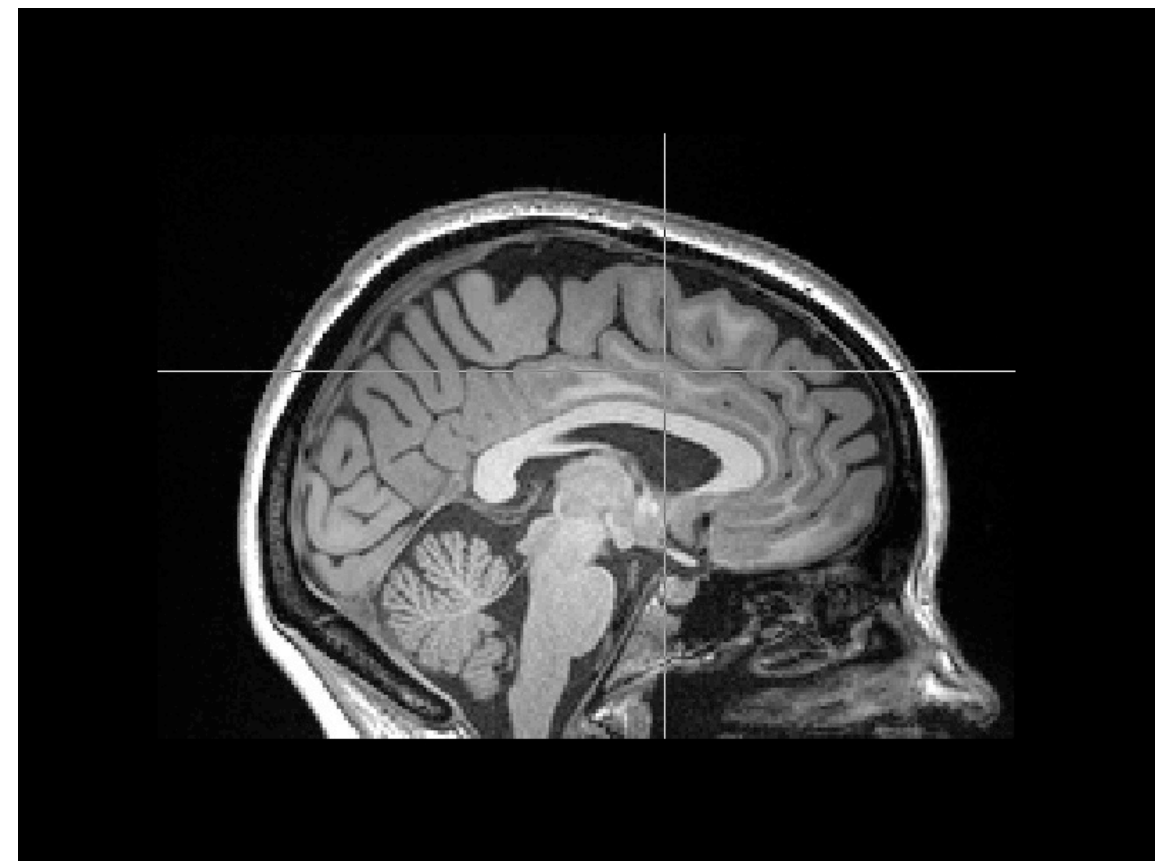
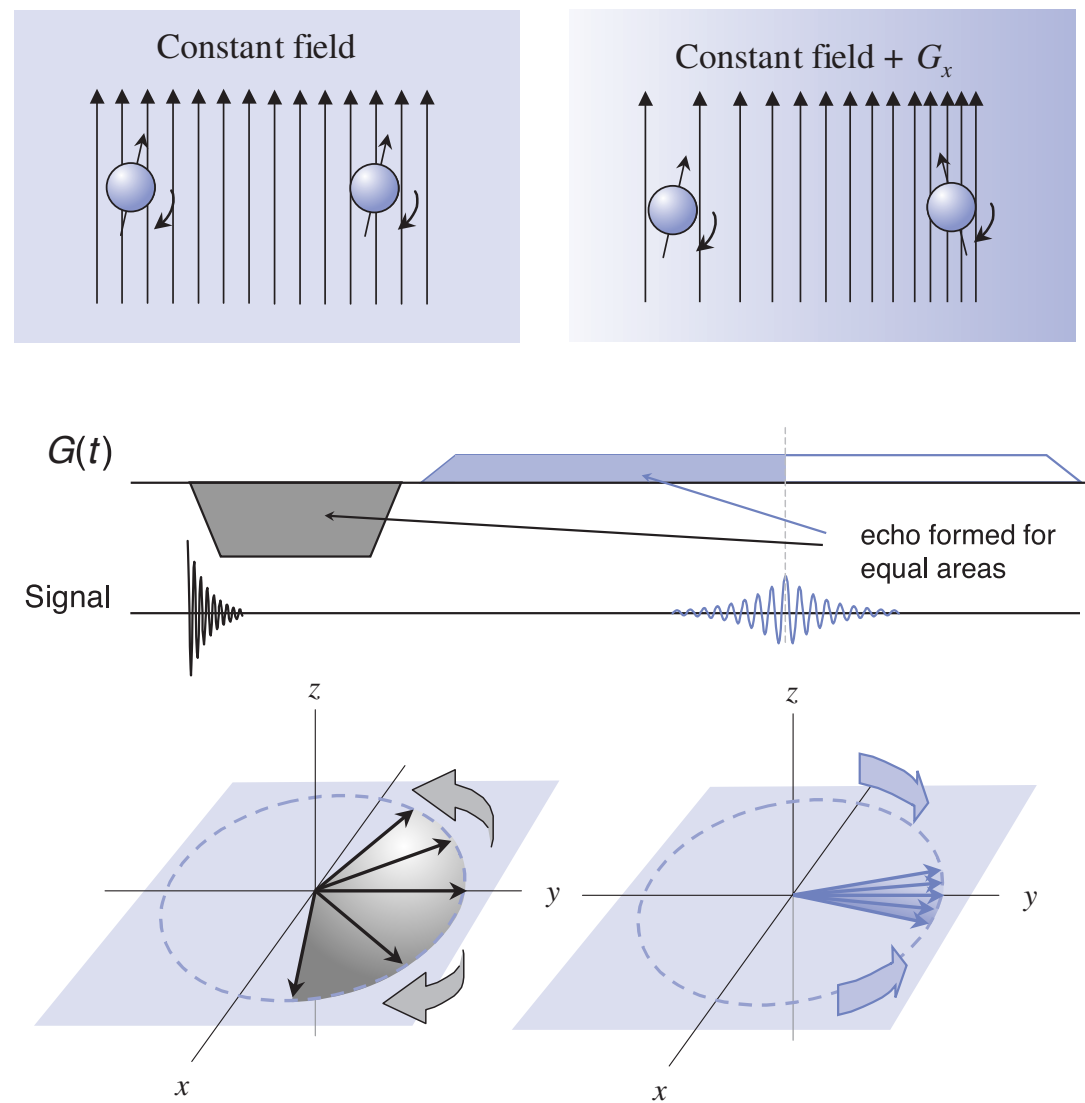
Data



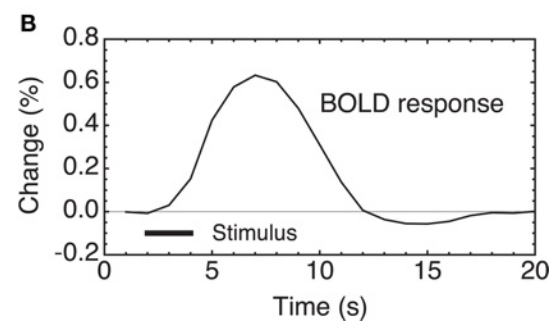
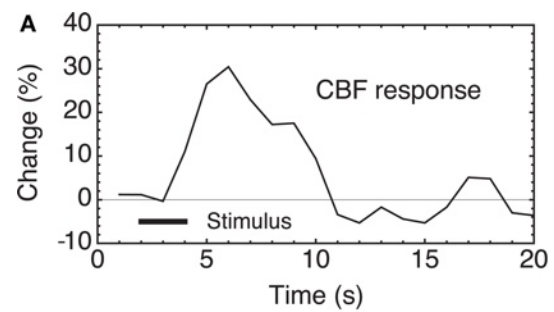
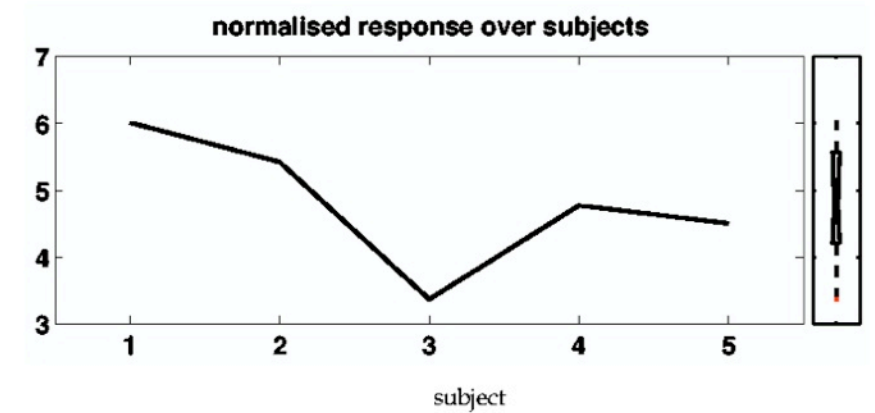
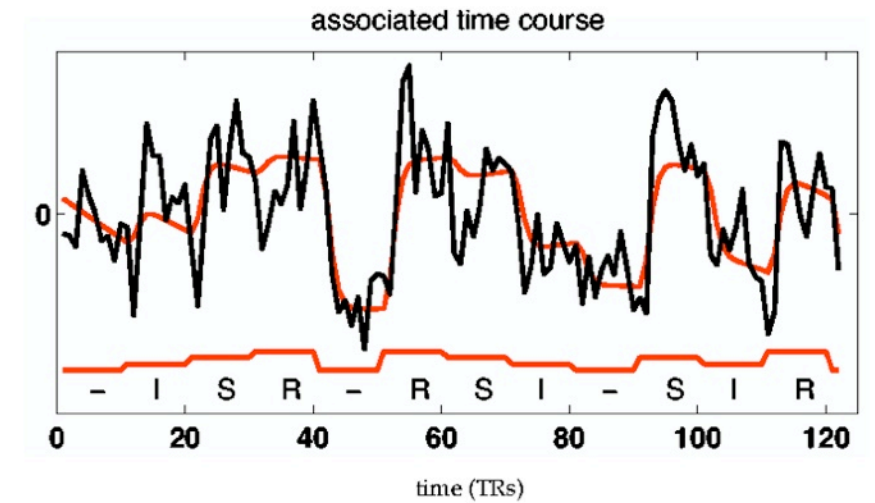
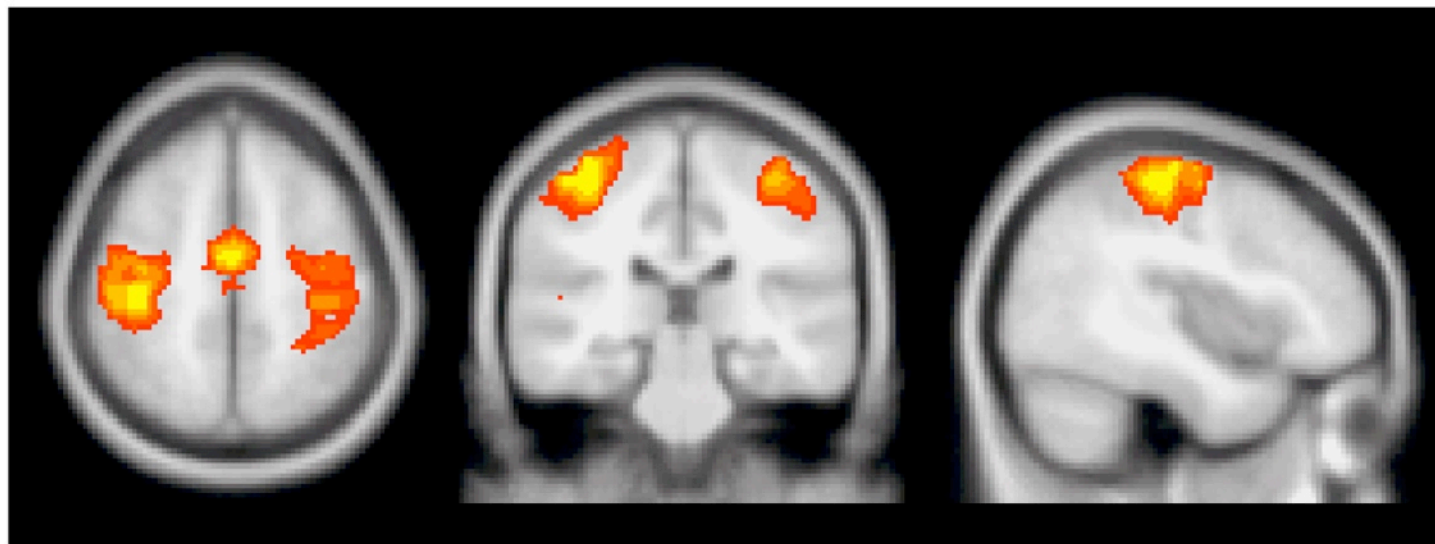
Region	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.30	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
2	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
3	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
4	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1
5	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2
6	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3
7	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4
8	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5
9	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6
10	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
11	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
12	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
13	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1
14	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2
15	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3
16	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4
17	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5
18	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6
19	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7



MRI



fMRI



Interpreting oxygenation-based neuroimaging signals: the importance and the challenge of understanding brain oxygen metabolism

Richard B. Buxton*

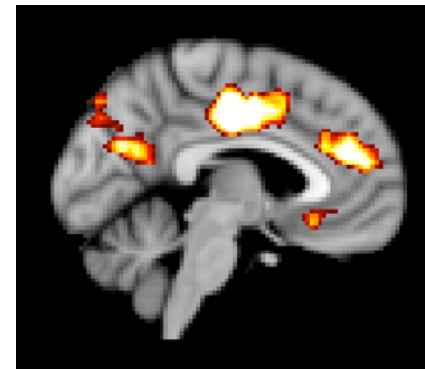
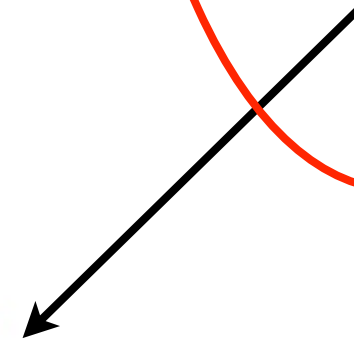
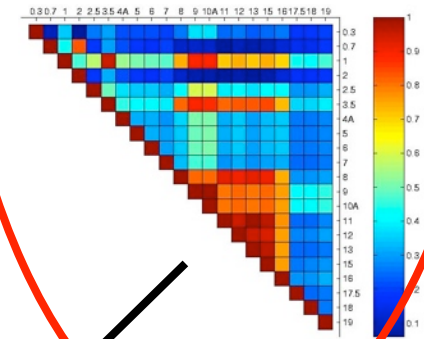
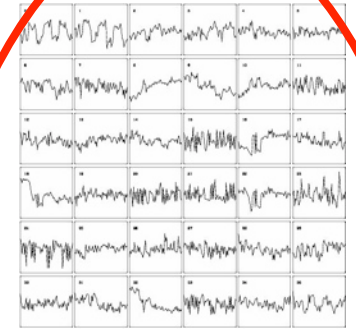
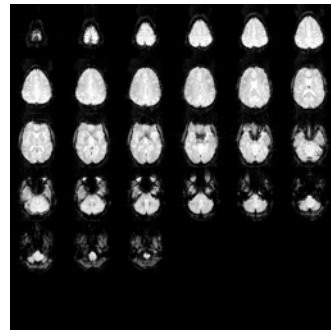
Preprocessing

Intrinsic Functional Connectivity As a Tool For Human Connectomics:
Theory, Properties, and Optimization

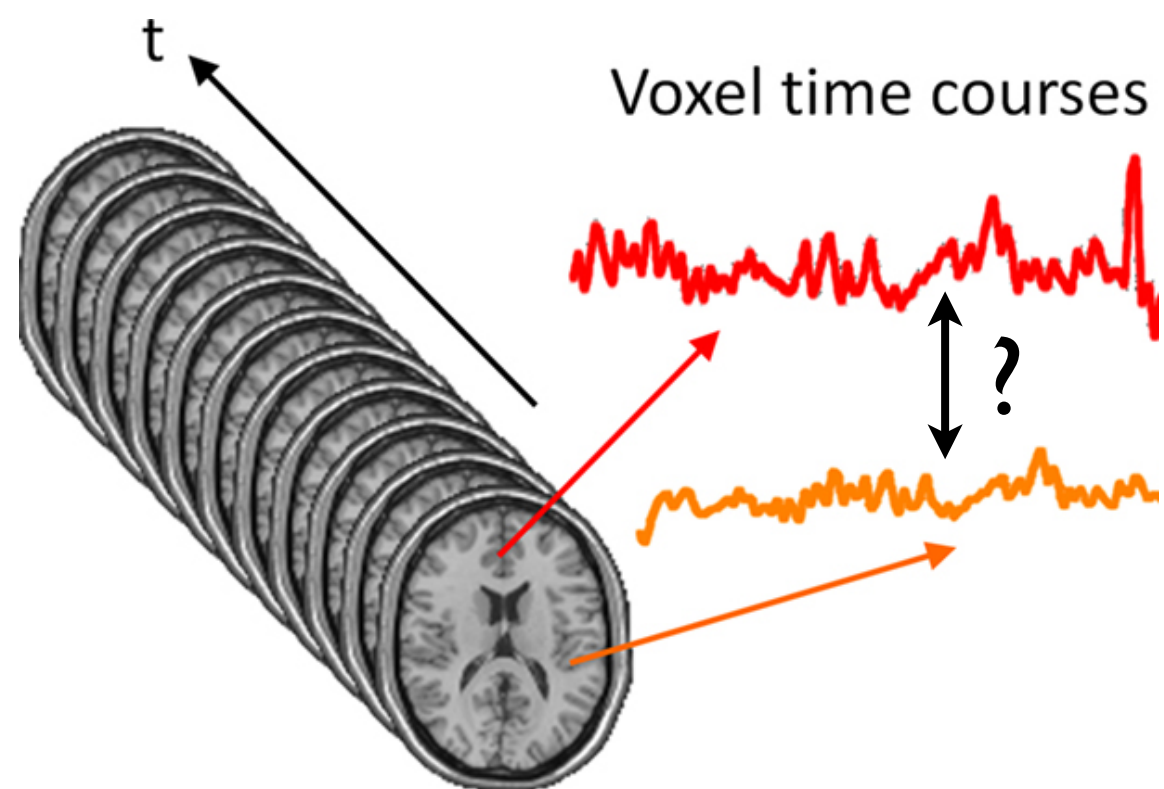
Koene R. A. Van Dijk,^{1,2,3} Trey Hedden,^{1,2} Archana Venkataraman,⁴ Karleyton C. Evans,⁵ Sara W. Lazar,⁵
and Randy L. Buckner^{1,2,5,6}

- Regress out WM/CSF signal
 - BPF 0.009 to 0.1 Hz
- Extract only grey matter voxels.

BOLD Timeseries

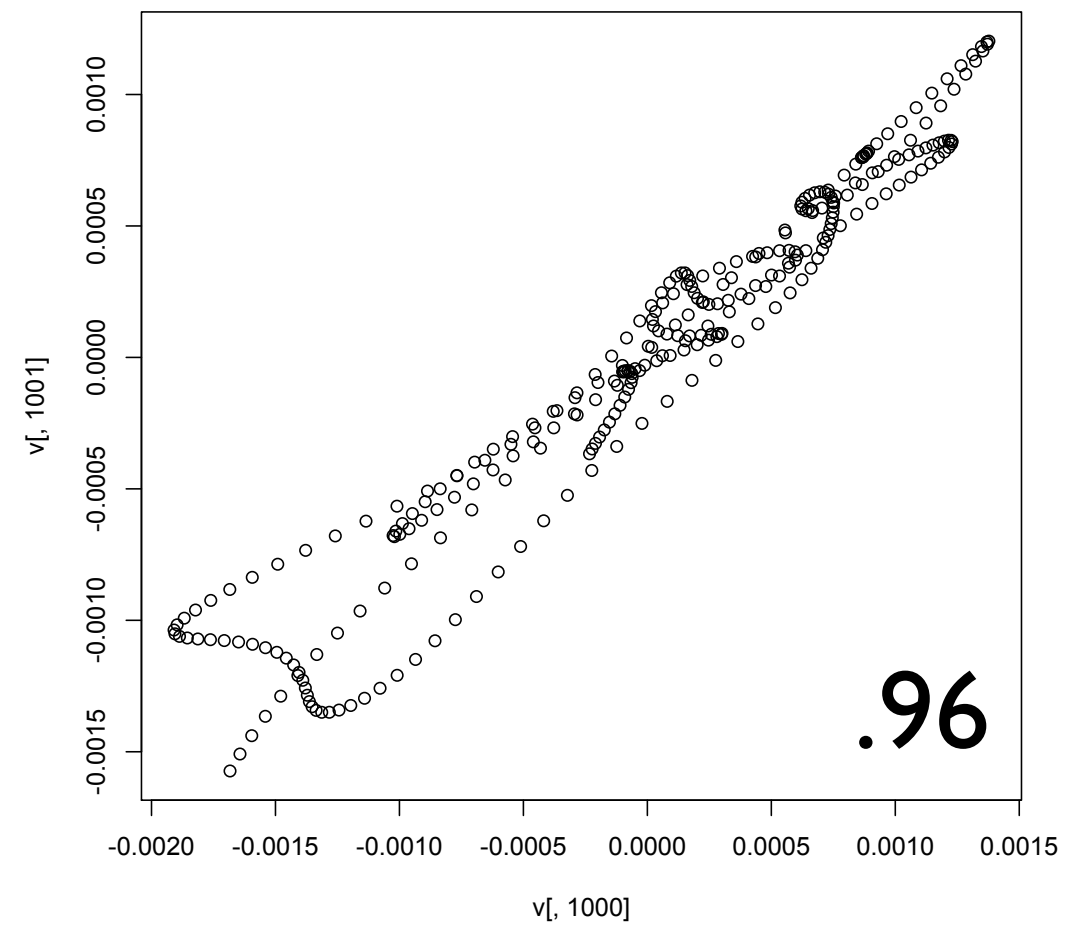
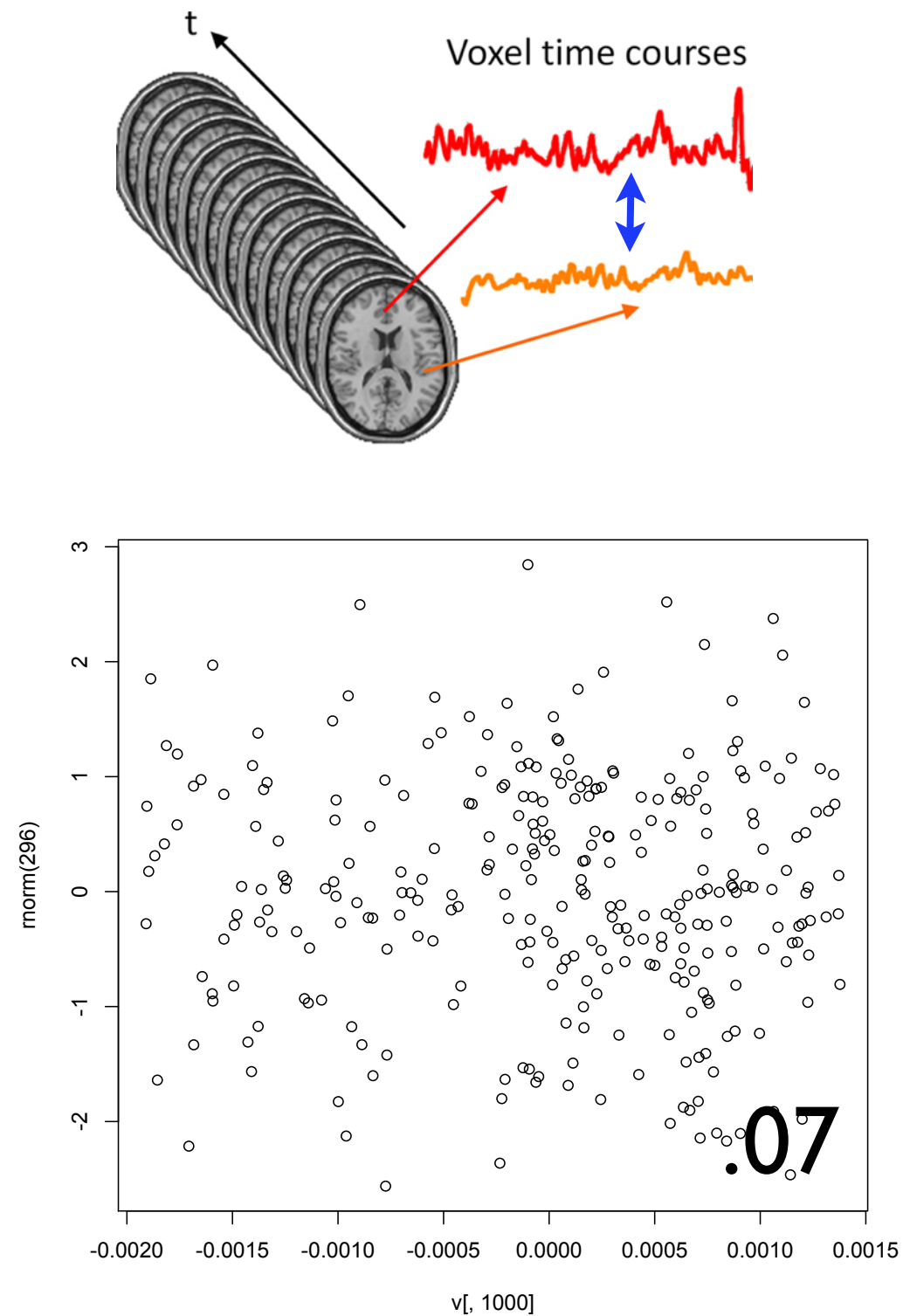


Region	Volume	Mean	SD	Min	Max	Cluster Size	Cluster Label
1	1000000	0.000000	0.000000	0.000000	0.000000	1000000	1
2	1000000	0.000000	0.000000	0.000000	0.000000	1000000	2
3	1000000	0.000000	0.000000	0.000000	0.000000	1000000	3
4	1000000	0.000000	0.000000	0.000000	0.000000	1000000	4
5	1000000	0.000000	0.000000	0.000000	0.000000	1000000	5
6	1000000	0.000000	0.000000	0.000000	0.000000	1000000	6
7	1000000	0.000000	0.000000	0.000000	0.000000	1000000	7
8	1000000	0.000000	0.000000	0.000000	0.000000	1000000	8
9	1000000	0.000000	0.000000	0.000000	0.000000	1000000	9
10	1000000	0.000000	0.000000	0.000000	0.000000	1000000	10
11	1000000	0.000000	0.000000	0.000000	0.000000	1000000	11
12	1000000	0.000000	0.000000	0.000000	0.000000	1000000	12
13	1000000	0.000000	0.000000	0.000000	0.000000	1000000	13
14	1000000	0.000000	0.000000	0.000000	0.000000	1000000	14
15	1000000	0.000000	0.000000	0.000000	0.000000	1000000	15
16	1000000	0.000000	0.000000	0.000000	0.000000	1000000	16
17	1000000	0.000000	0.000000	0.000000	0.000000	1000000	17
18	1000000	0.000000	0.000000	0.000000	0.000000	1000000	18
19	1000000	0.000000	0.000000	0.000000	0.000000	1000000	19
20	1000000	0.000000	0.000000	0.000000	0.000000	1000000	20

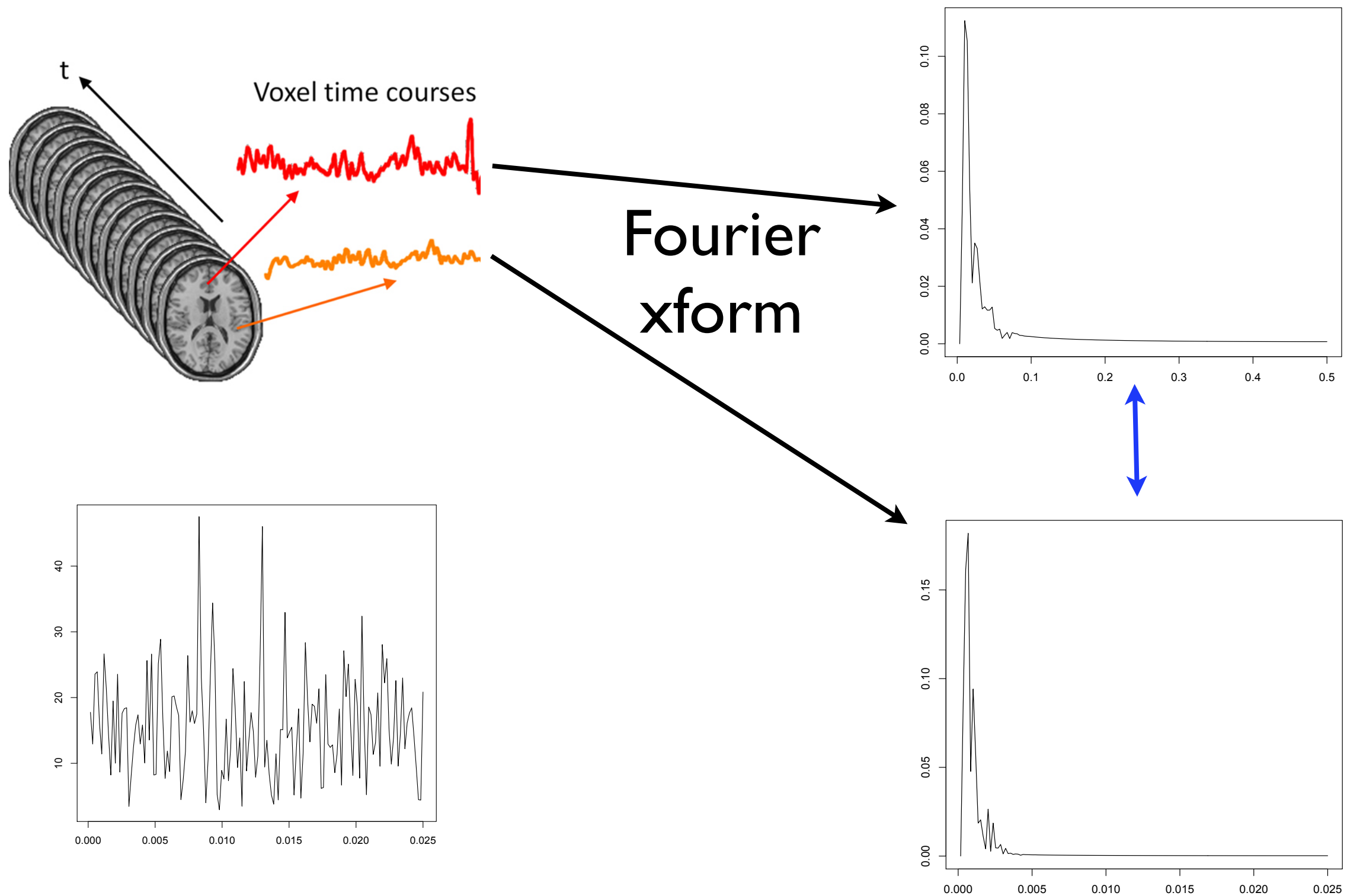


How much does
this timeseries
“look like”
this timeseries?

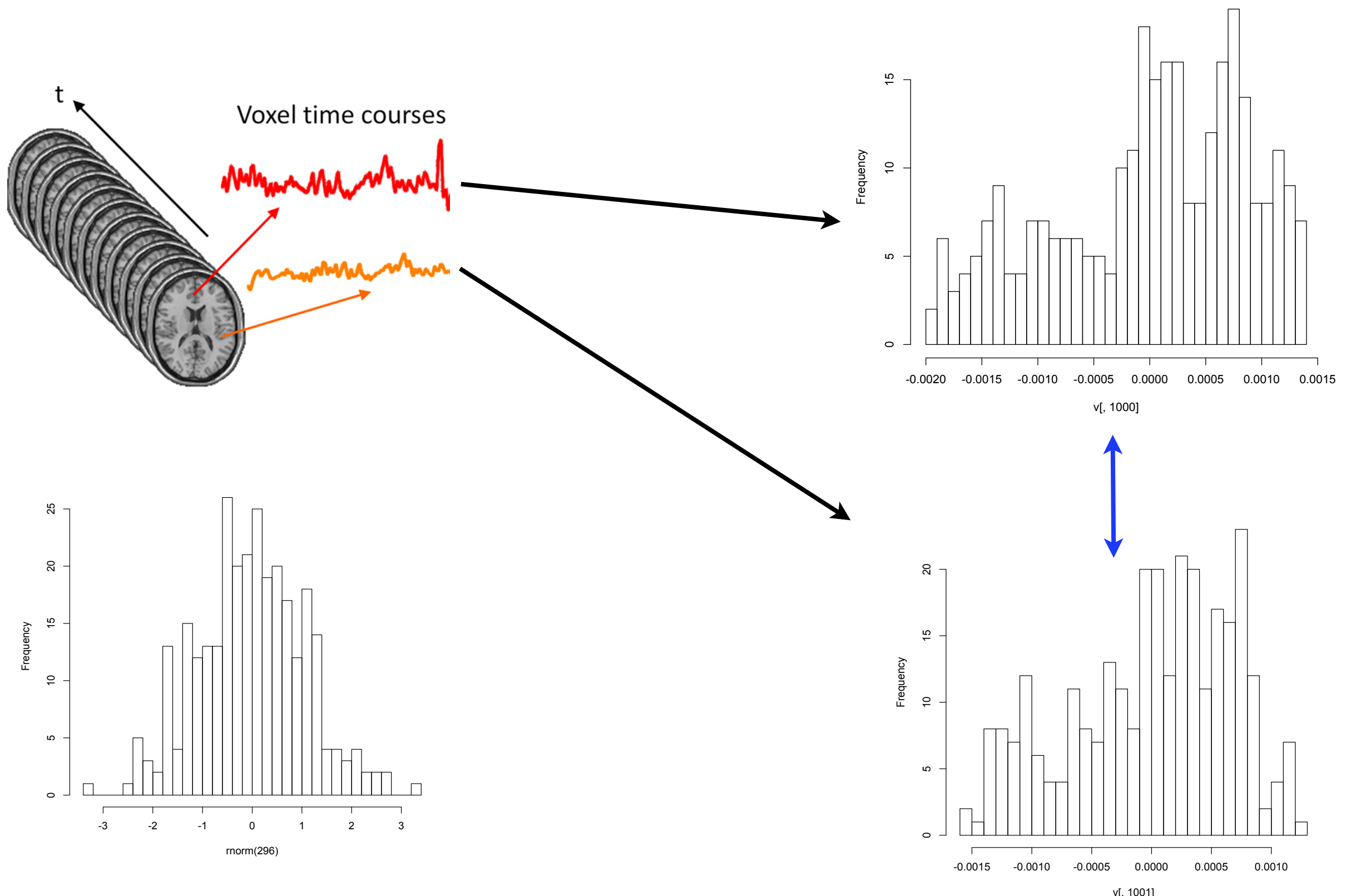
Pearson Correlation



Spectral Coherence



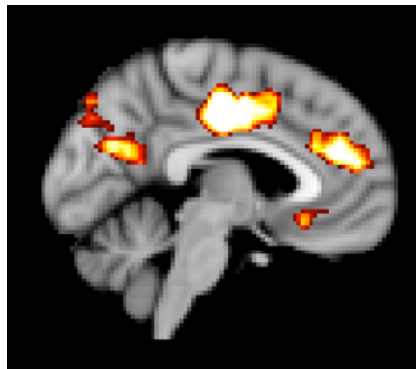
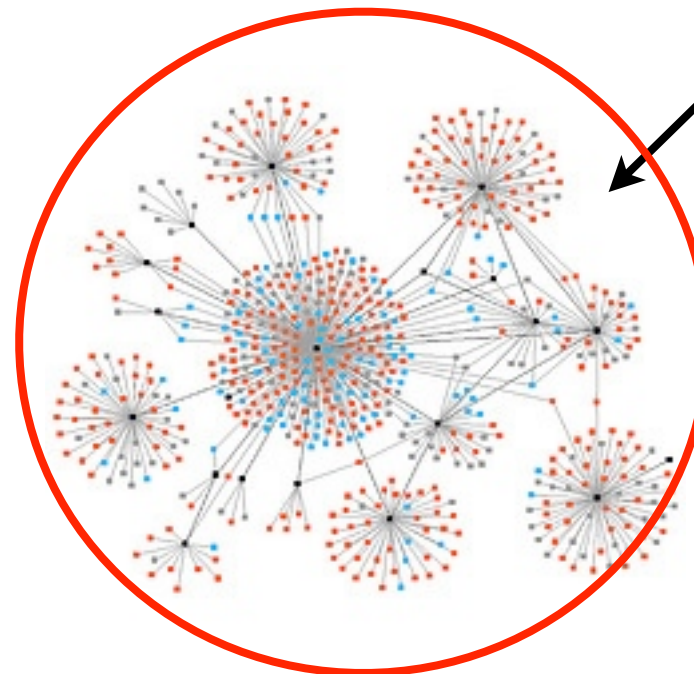
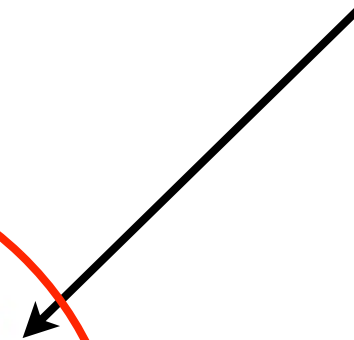
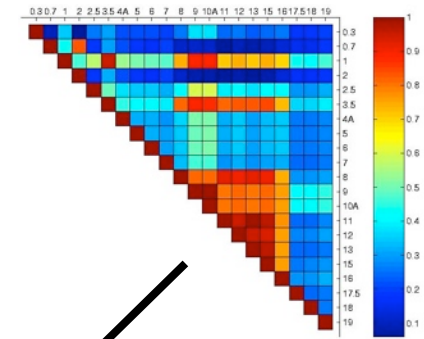
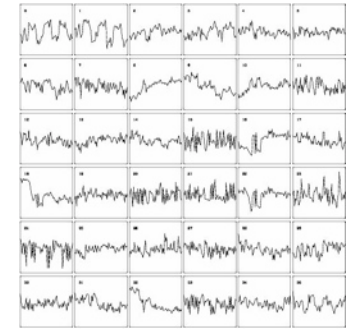
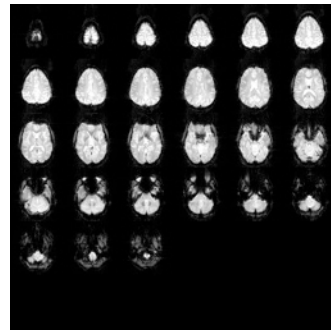
Mutual Information



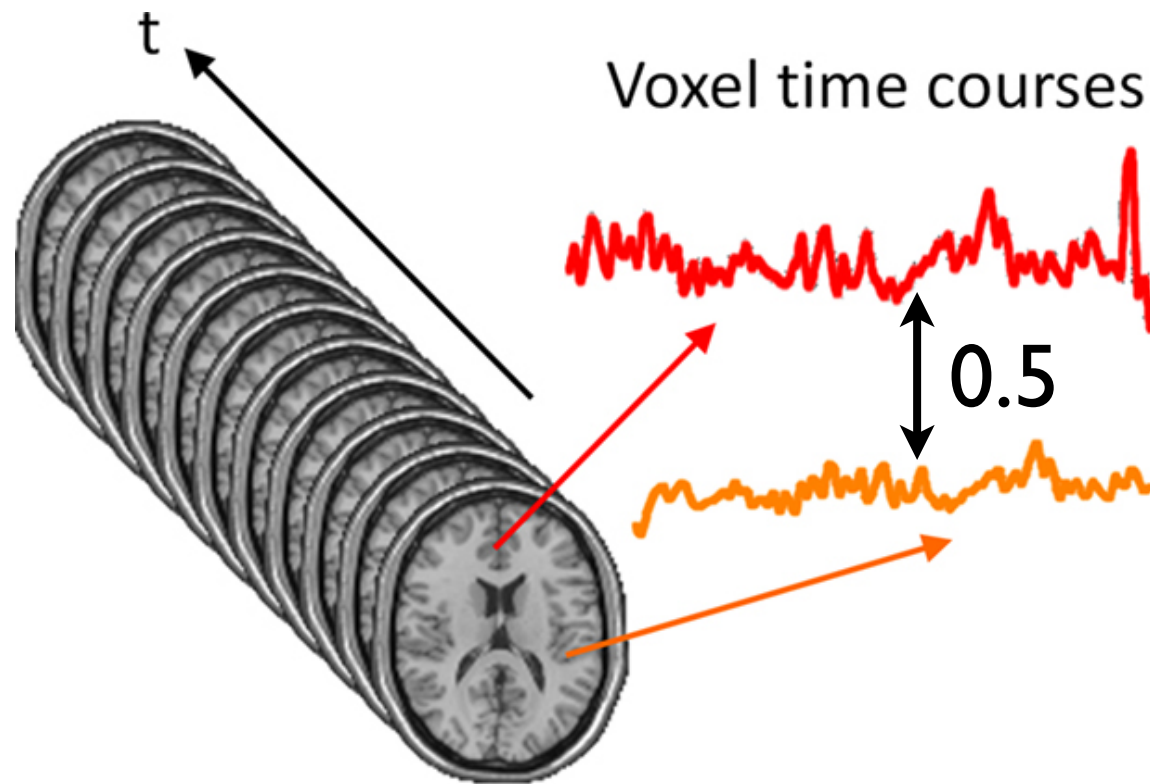
Pearson	~3 min	2.2 GHz Core i7 (OpenMP/ SIMD)
Coherence	~50 min	2.2 GHz Core i7 (OpenMP/ SIMD)
MI	~60 min	10 x 2.2 Ghz Opteron (MPI)

Time to process 1 typical subject (3T).

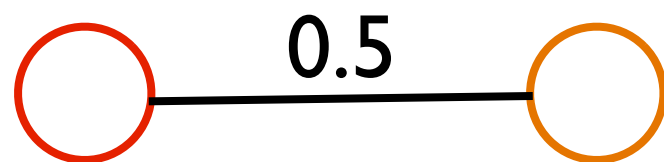
Building the graph



Region	Cluster	Size	Mean	SD	Min	Max	Significance
1	1	100	0.5	0.1	0.3	0.7	0.001
2	2	150	0.6	0.2	0.4	0.8	0.001
3	3	120	0.4	0.1	0.2	0.6	0.001
4	4	80	0.3	0.1	0.1	0.5	0.001
5	5	90	0.4	0.1	0.2	0.6	0.001
6	6	110	0.5	0.1	0.3	0.7	0.001
7	7	130	0.6	0.2	0.4	0.8	0.001
8	8	140	0.7	0.2	0.5	0.9	0.001
9	9	160	0.8	0.3	0.6	1.0	0.001
10	10	170	0.9	0.3	0.7	1.0	0.001
11	11	180	1.0	0.4	0.8	1.0	0.001
12	12	190	1.1	0.4	0.9	1.0	0.001
13	13	200	1.2	0.5	1.0	1.0	0.001
14	14	210	1.3	0.5	1.1	1.0	0.001
15	15	220	1.4	0.6	1.2	1.0	0.001
16	16	230	1.5	0.6	1.3	1.0	0.001
17	17	240	1.6	0.7	1.4	1.0	0.001
18	18	250	1.7	0.7	1.5	1.0	0.001
19	19	260	1.8	0.8	1.6	1.0	0.001
20	20	270	1.9	0.8	1.7	1.0	0.001



Compare the voxel
time series.



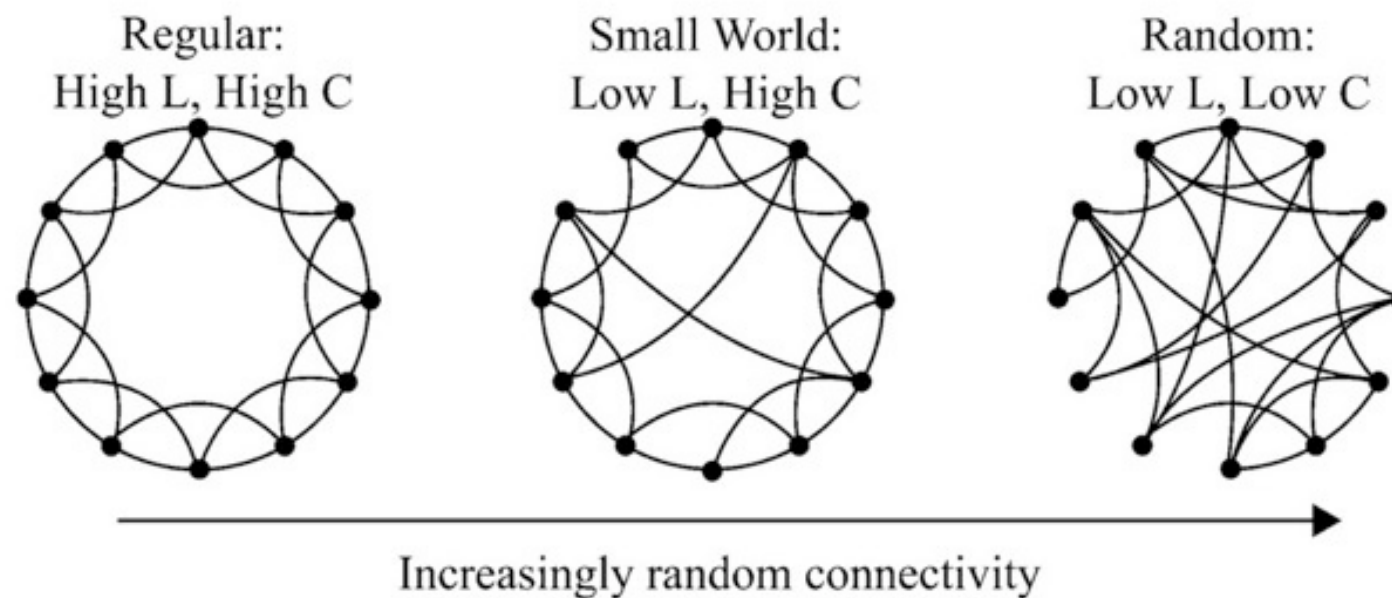
If the result is above
some threshold,
add an edge to graph.

Typical Graph sizes

	3T	7T
 V 	15,000 ~ 30,000	50,000 ~ 100,000
 E 	300,000 ~ 3,000,000	3,000,000 ~ 300,000,000

Computing Problem

Our graphs all end up being
small world graphs.



Guarantee of non-locality of memory accesses.

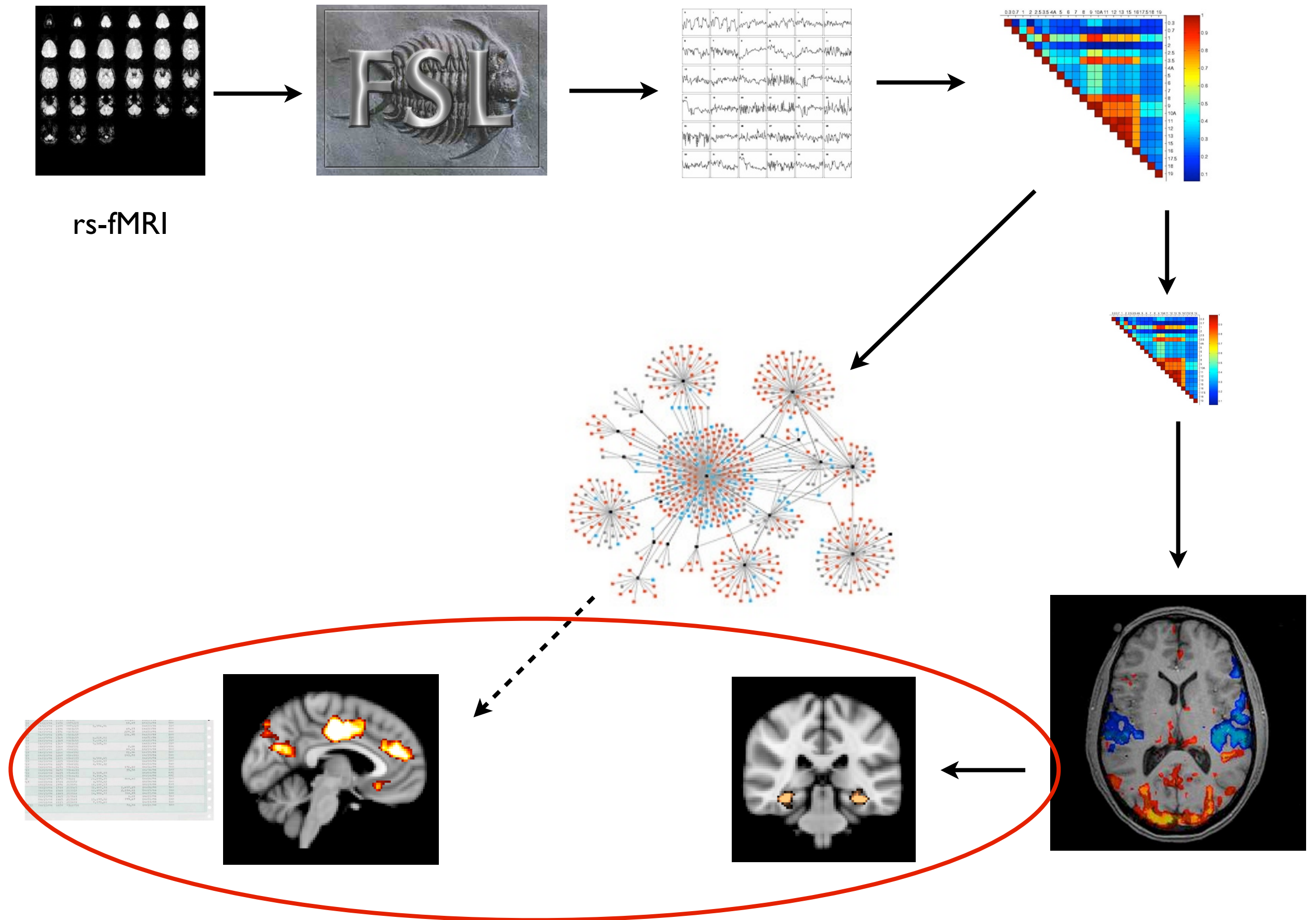
Fortunately...



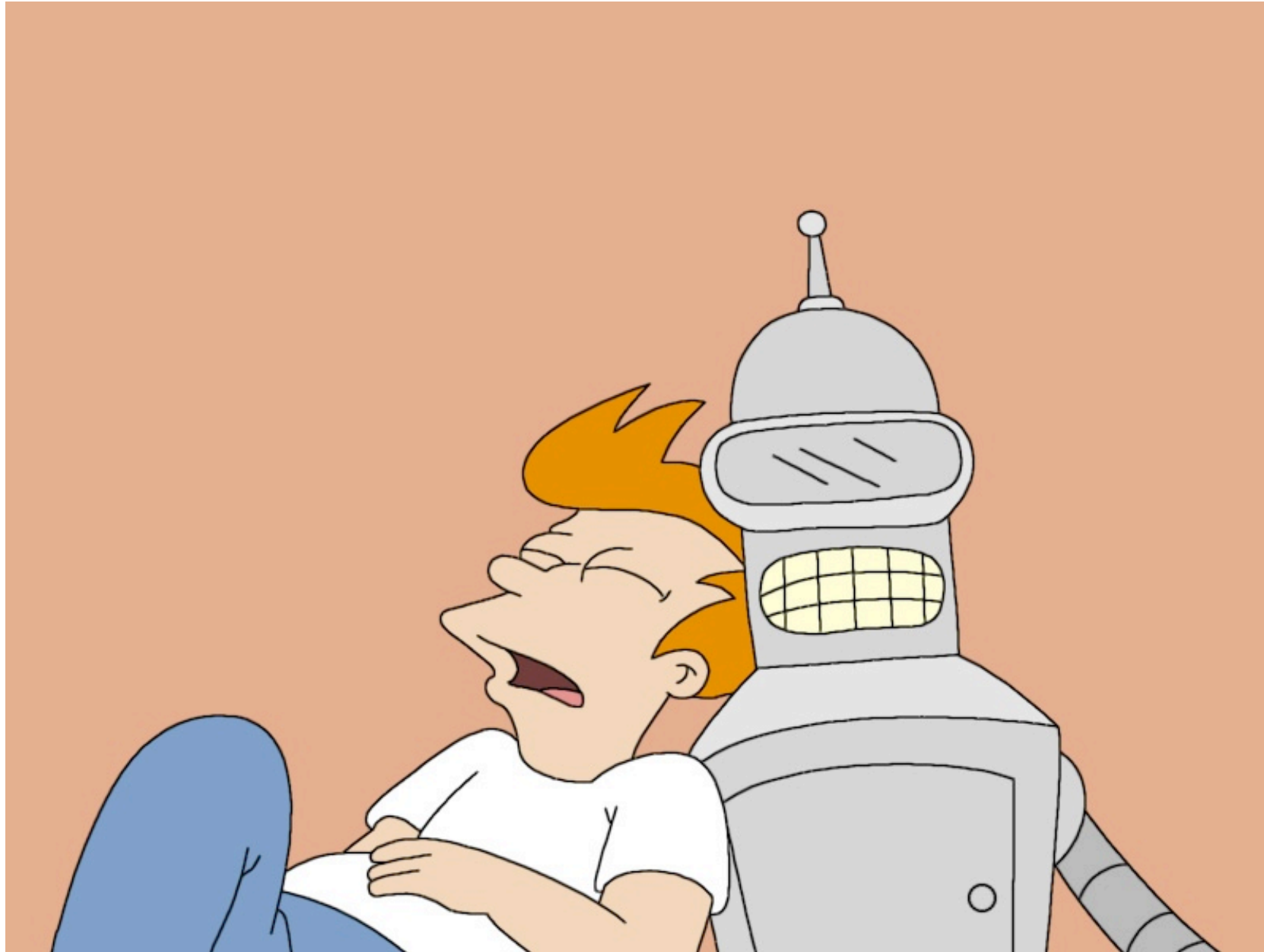
compute • calcul
CANADA



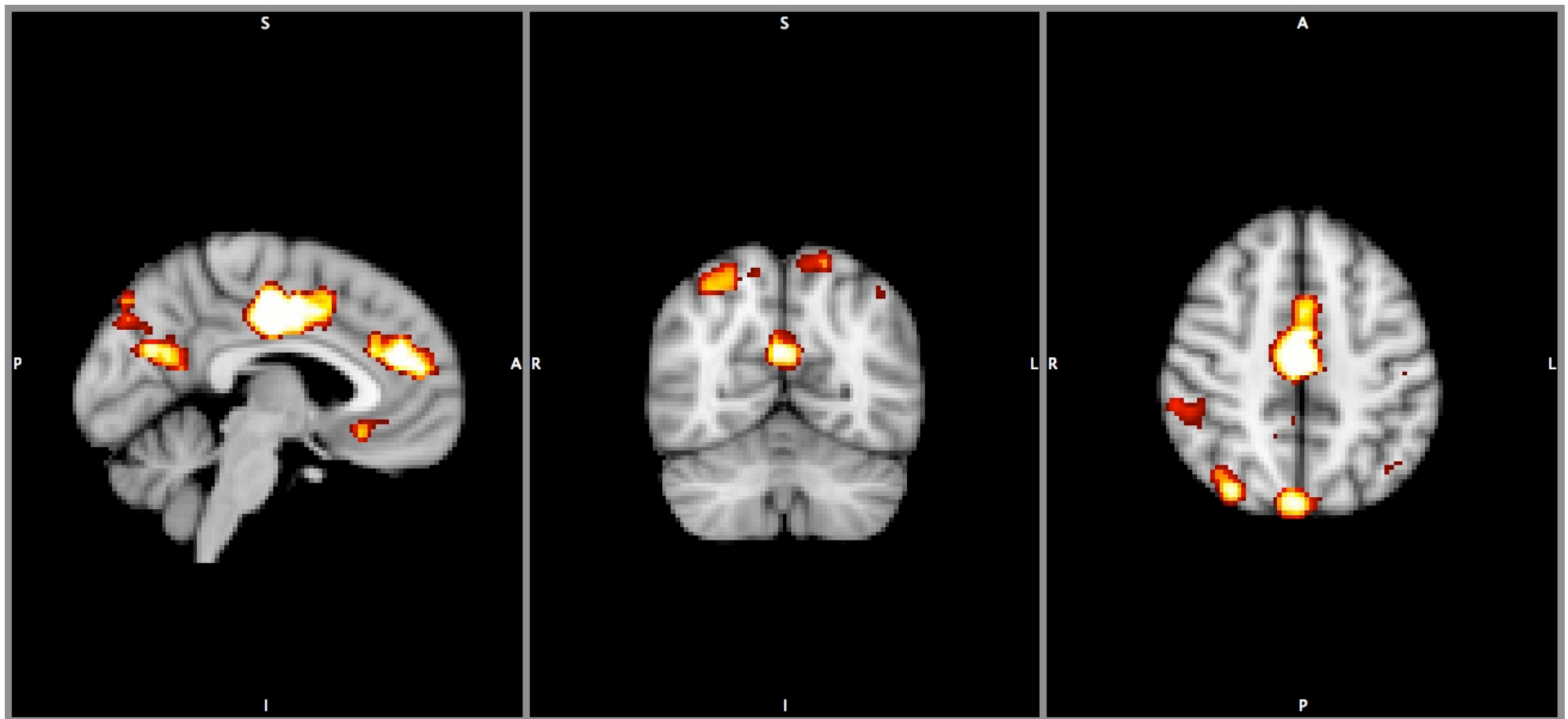
Some *pretty pictures*

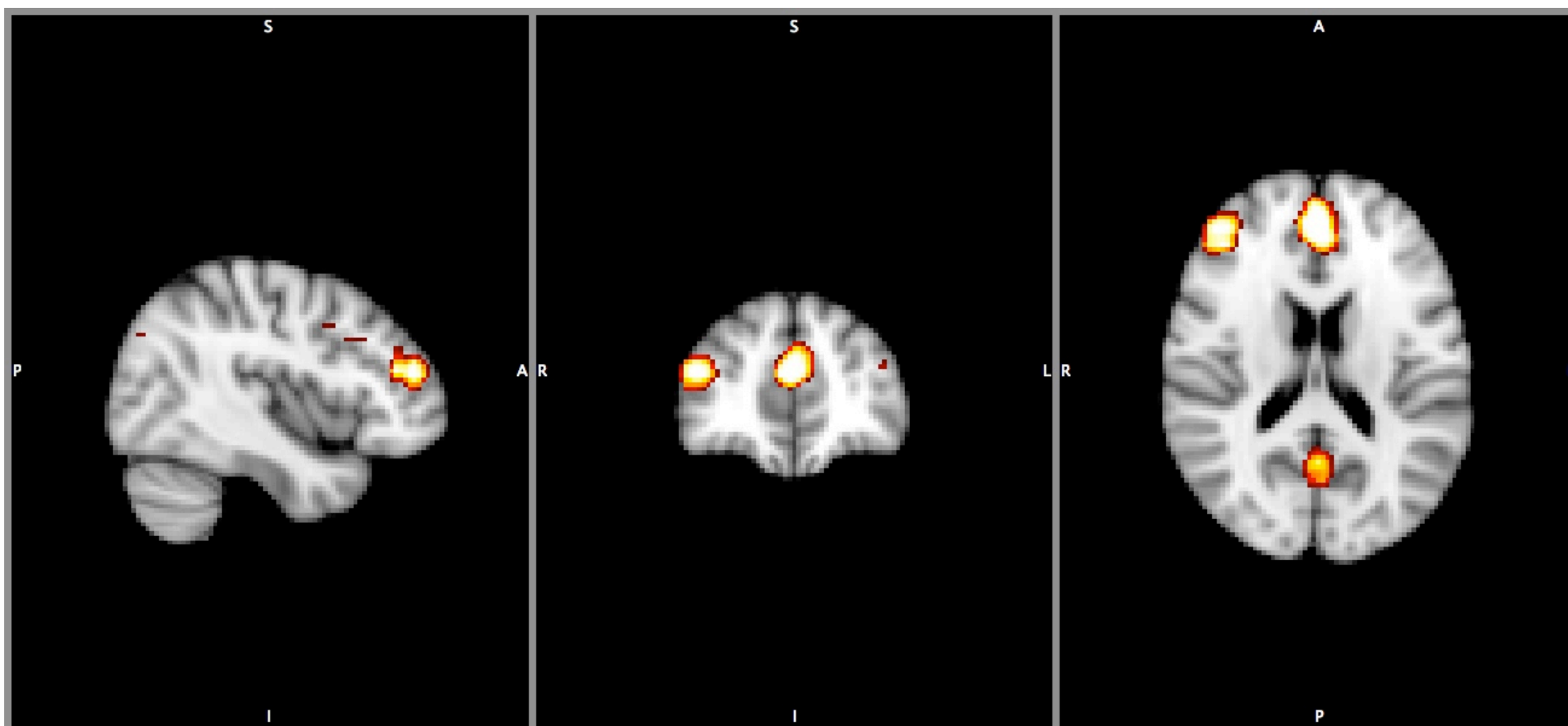


Resting State

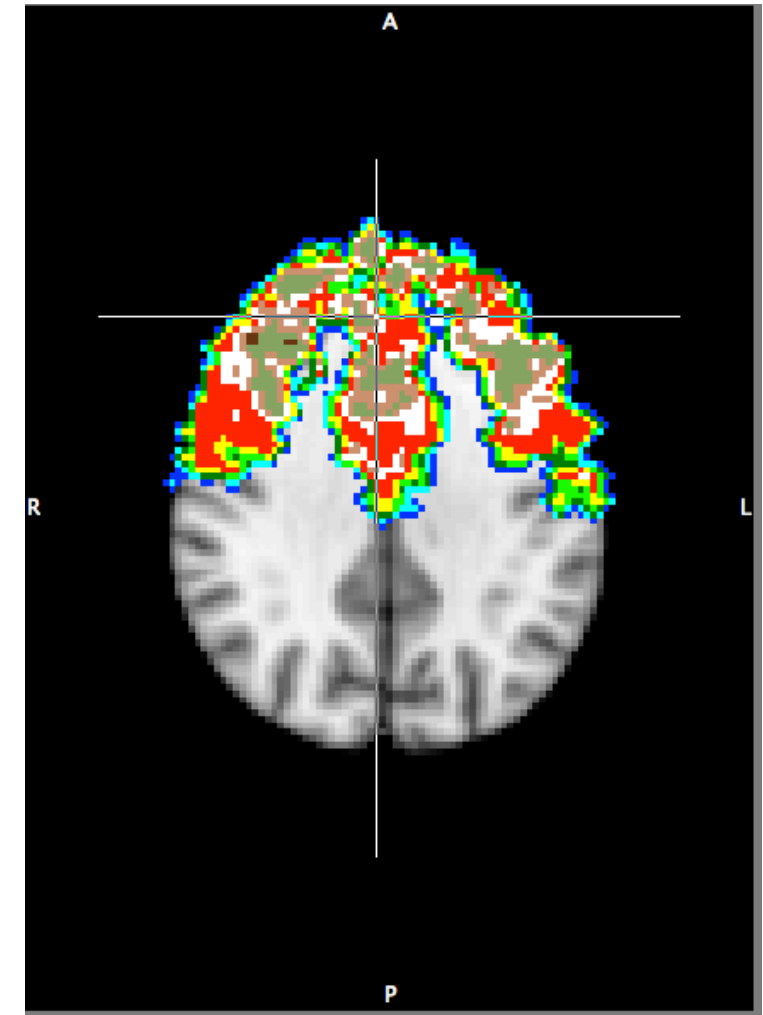
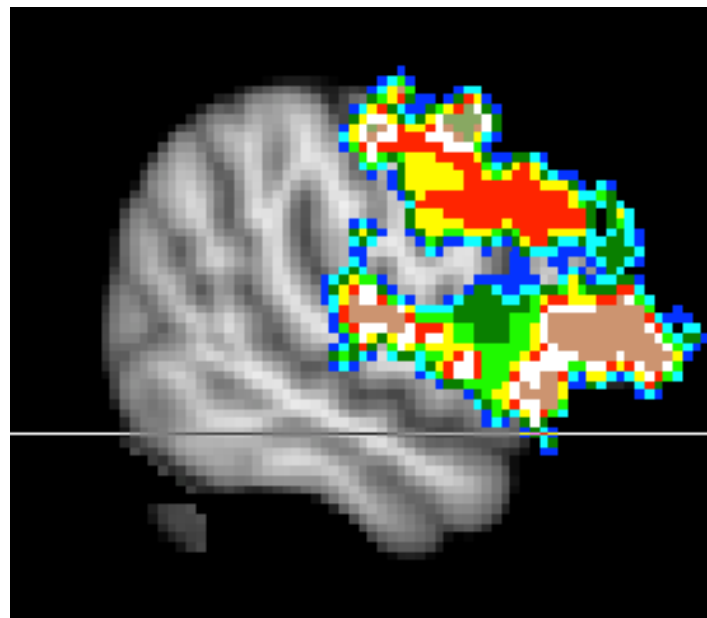
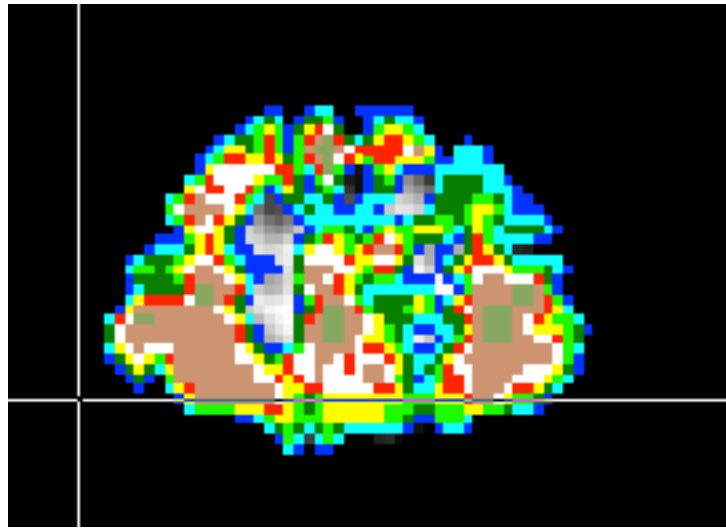
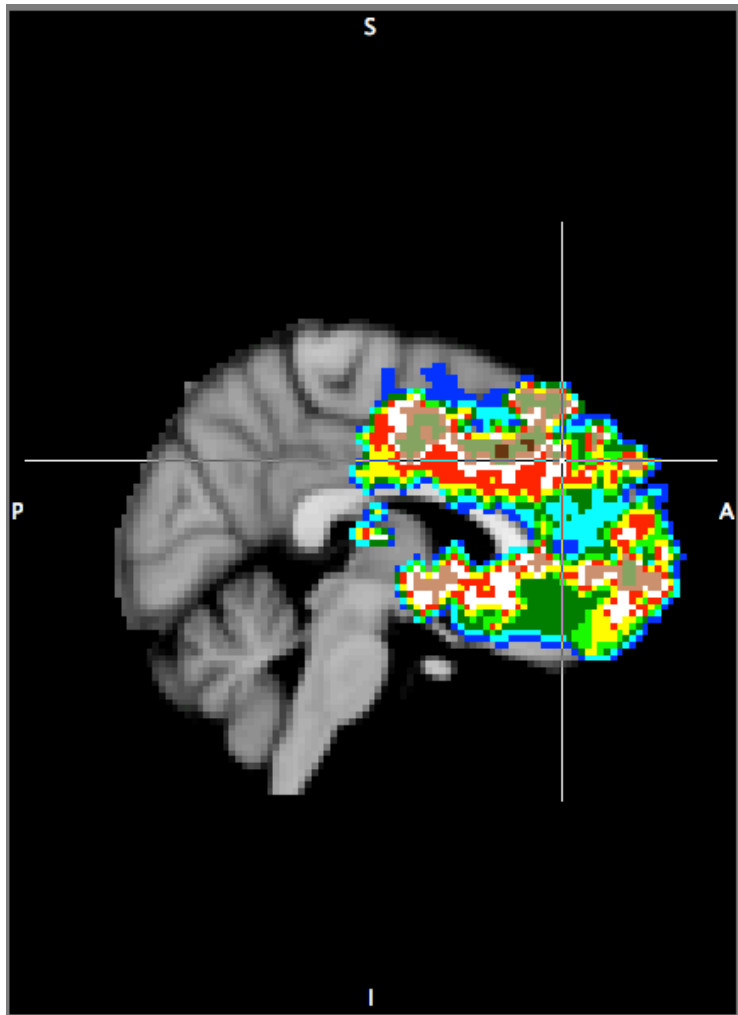


Pagerank

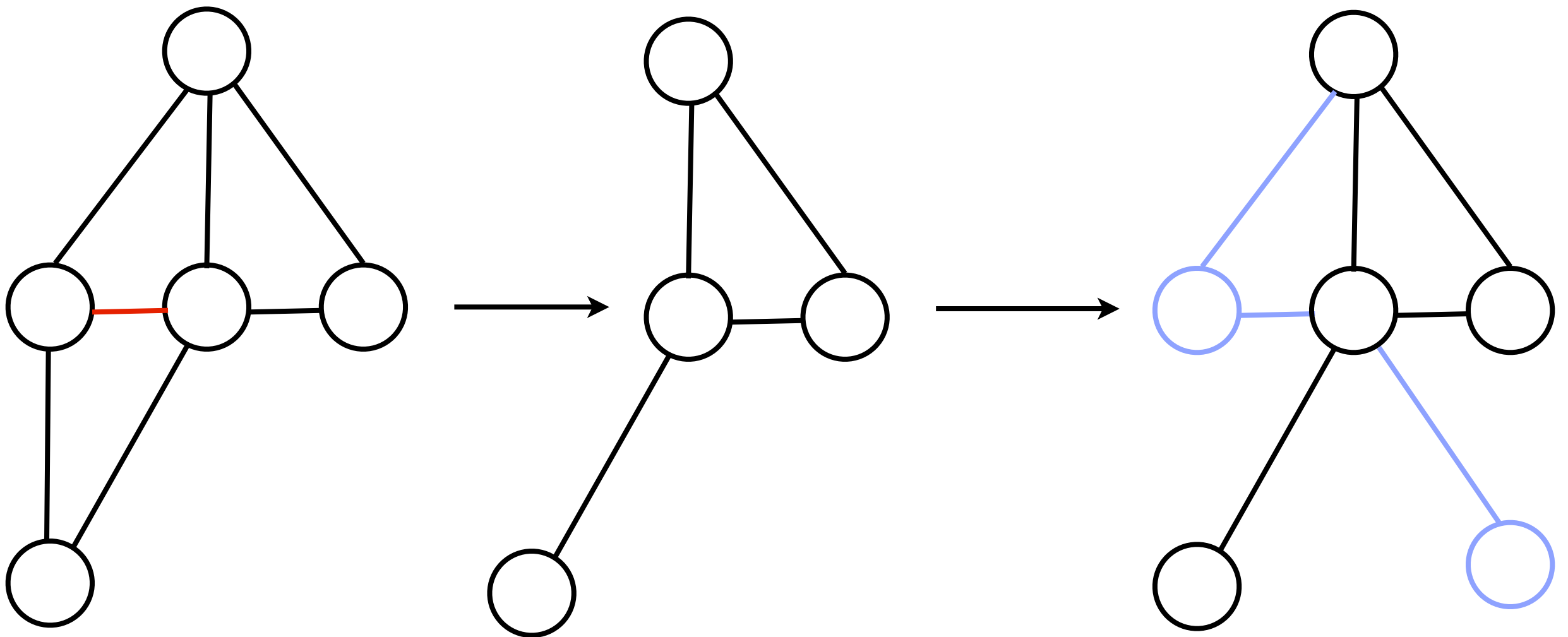




Modules in PFC



Graph transformations





The network is the computation.

Dynamics *of* Graphs

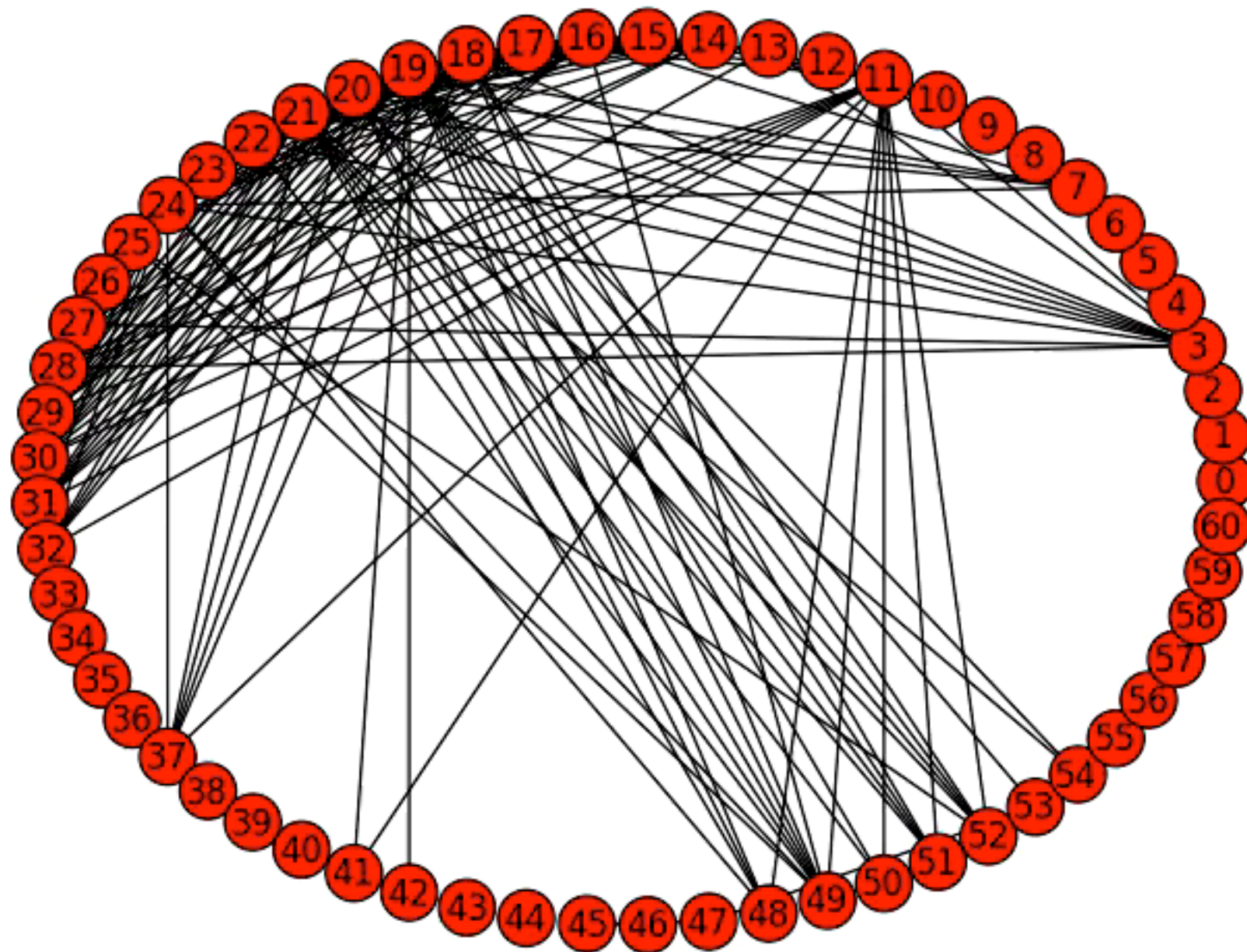
(with Andrew Kope, Casey Wood and Mehrsa Golestaneh)

MEG/EEG

Trade spatial resolution for
temporal resolution.

Trade 0.5 Hz for 500 Hz





$$\left| \frac{1}{N} \sum_{k=0}^{N-1} \text{sign}(\phi_{x_i}(k) - \phi_{x_j}(k)) \right|^a$$

vertex = sensor, edge = thresholded PLI

1800ms trial, 800ms windows, 25ms step

Task: Read a word or listen to a word EEG

Inferring Dynamic Graphs

Smarter people have done this with GLASSO...

Works great... if you only care about covariance

... or approaches like TESLA

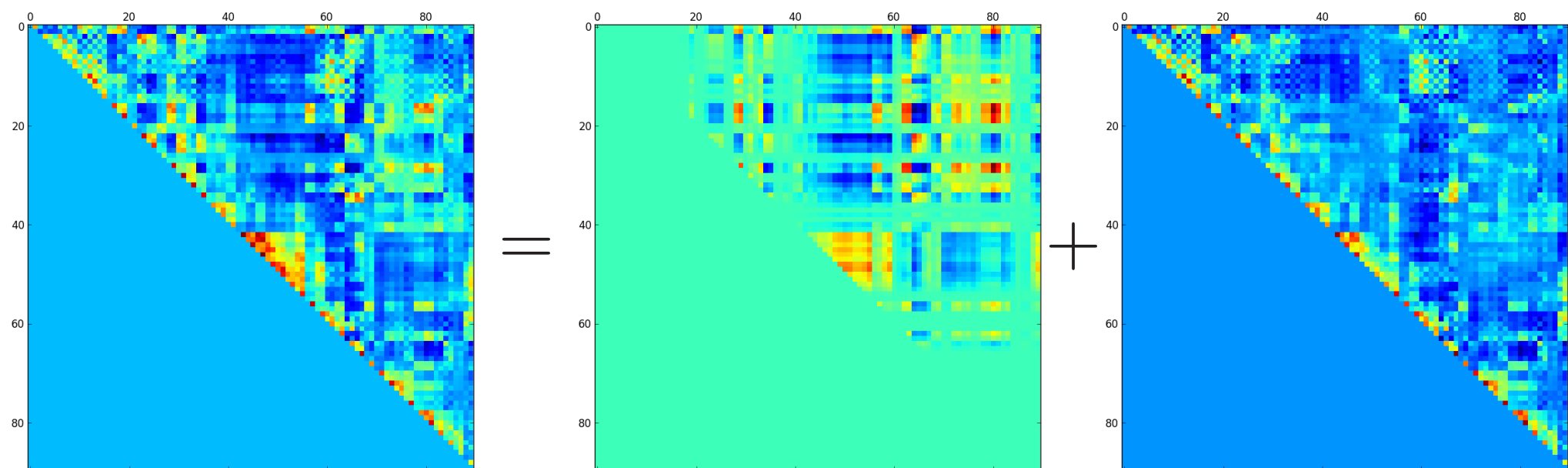
Works great... if your likelihood function is convex

Severely limits the time series
comparison metrics you can use!

So... we're doing it *the dumb way*

Step 1: Build raw sequence of metric matrices

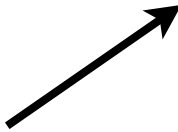
Step 2: Sparse matrix separation



Low rank

Sparse

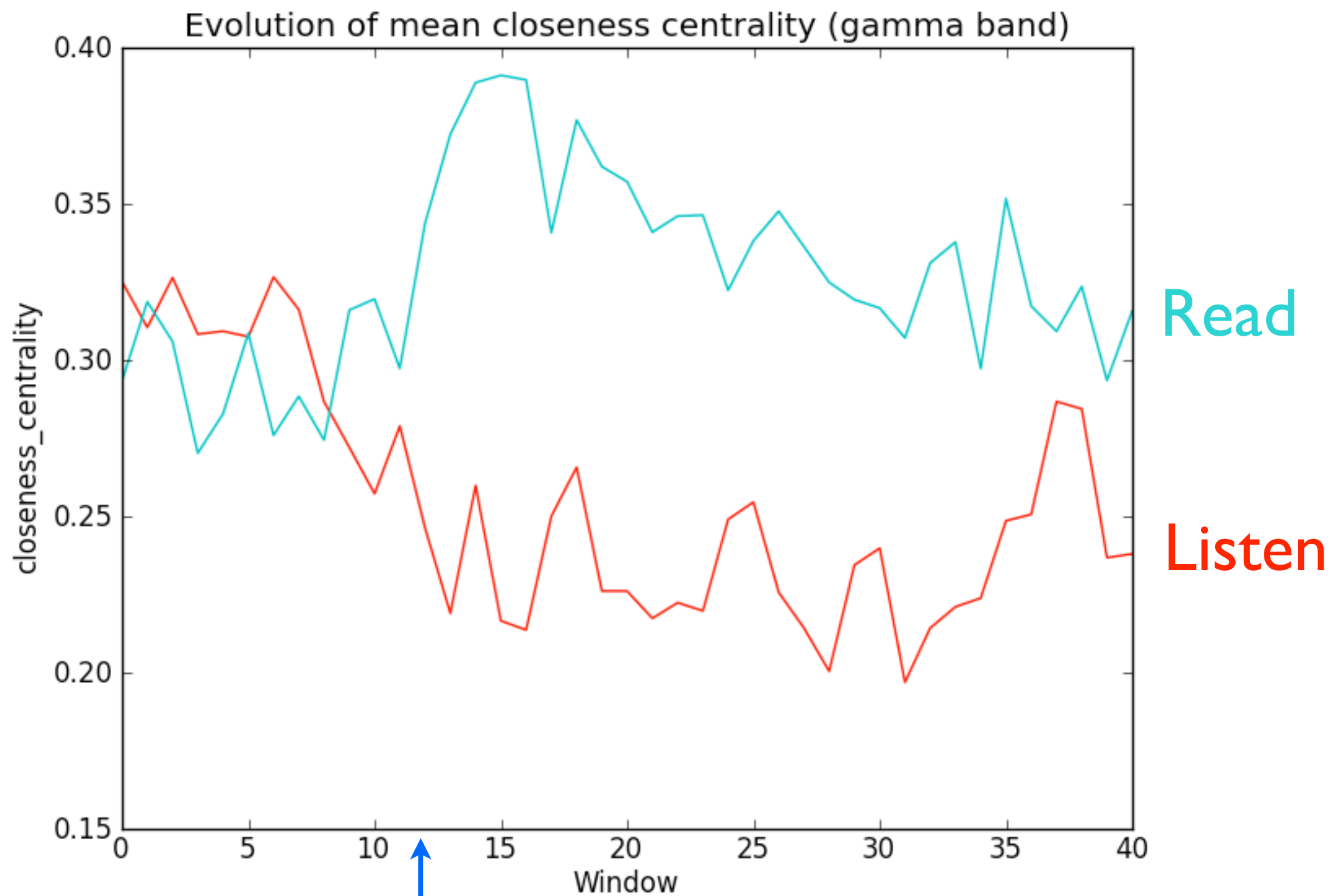
Keep this part



Step 3: Heuristic edge stabilization (temporal smoothing)

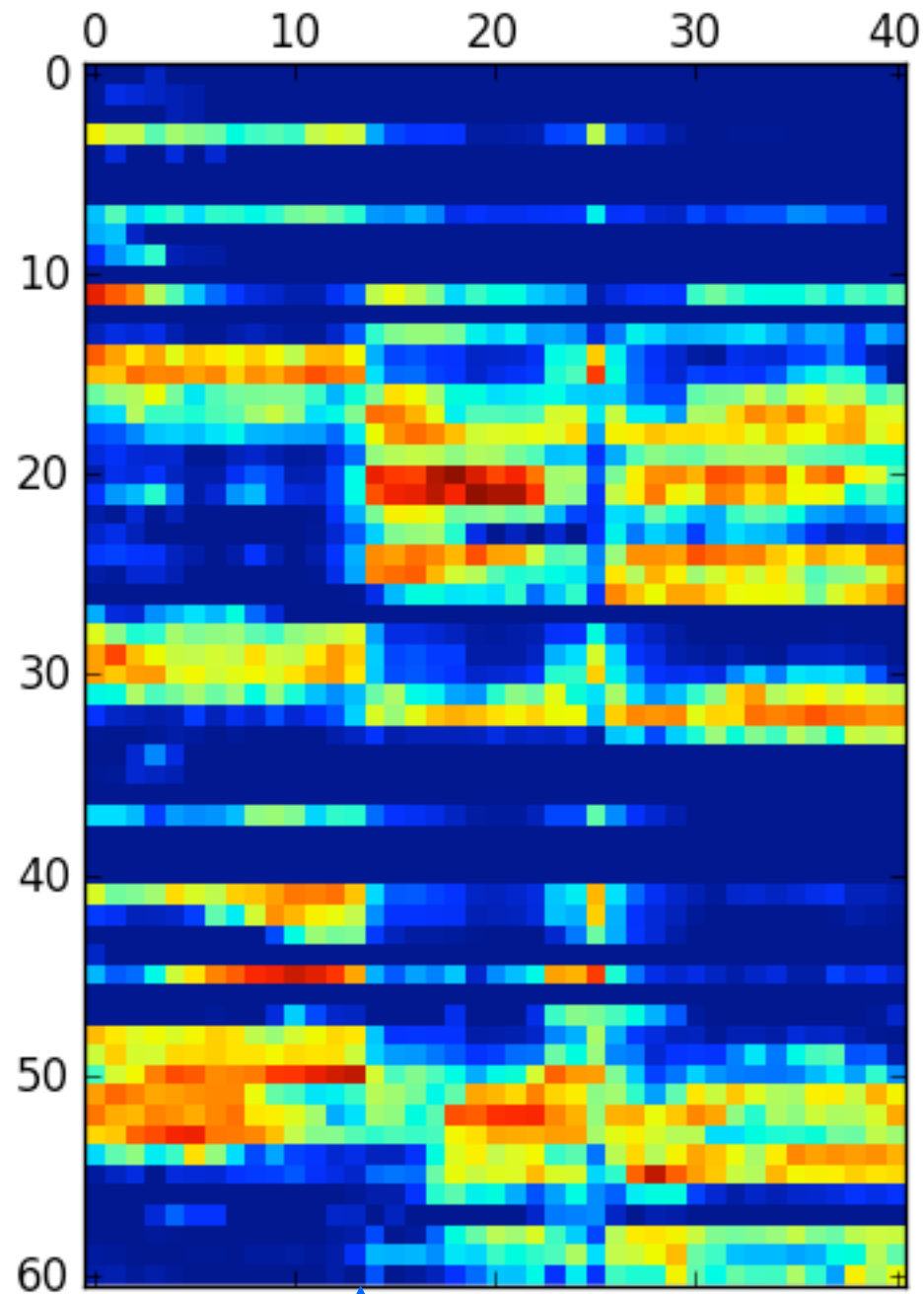
Step 4: Threshold stabilized matrices with RMT

Step 5: Convert matrices to a sequence of graphs

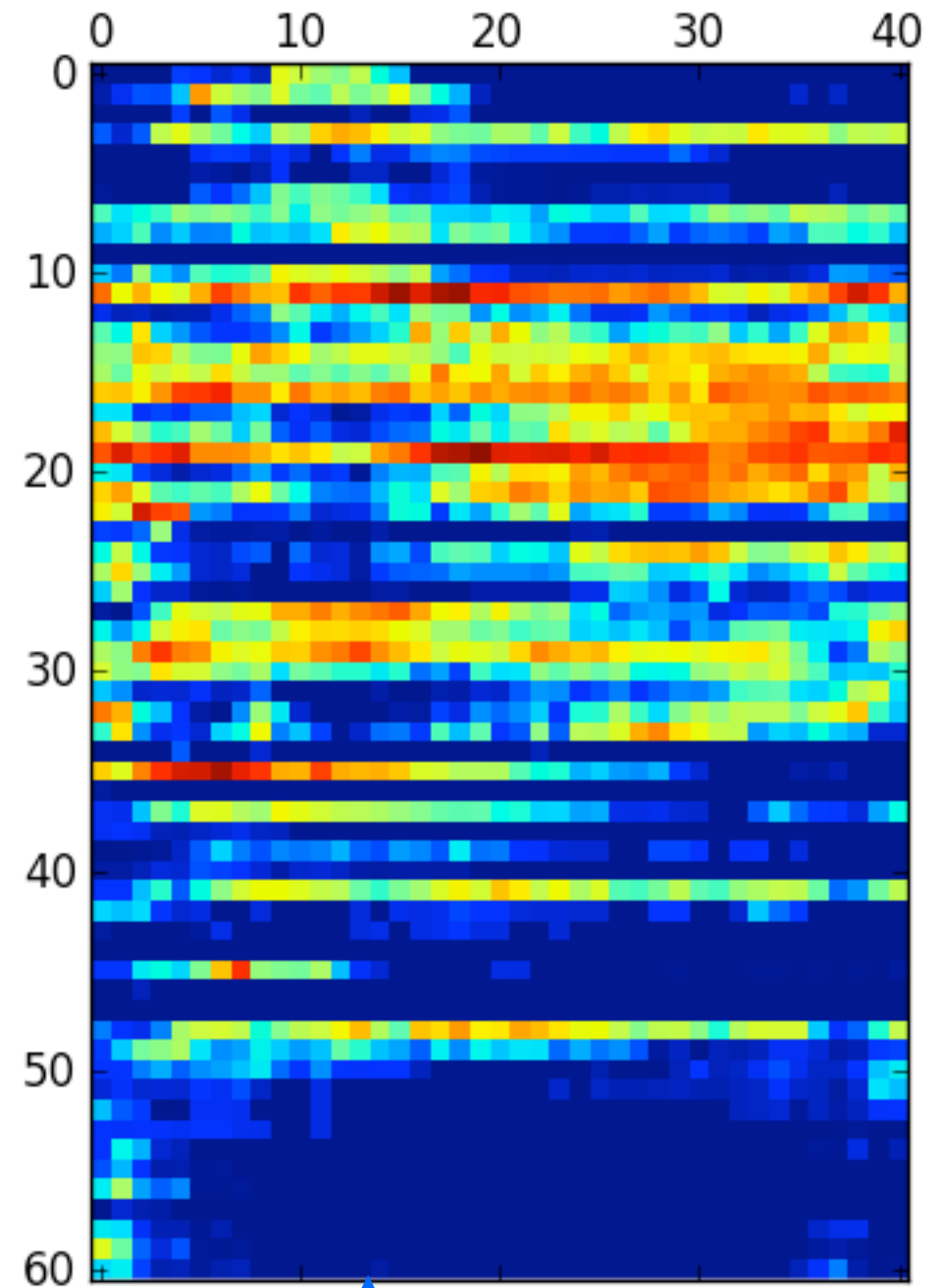


EEG

Per-vertex eigenvector centrality

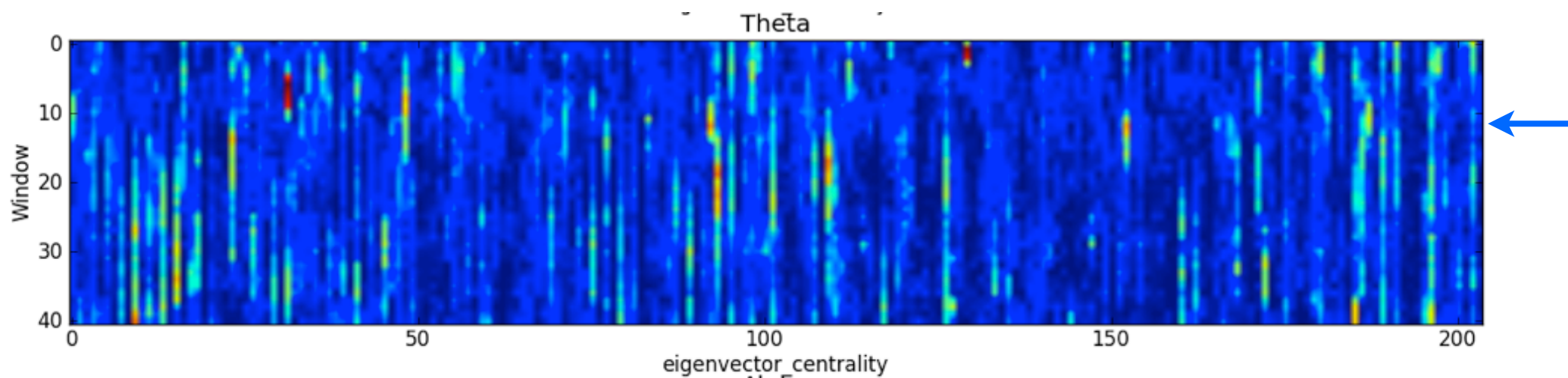
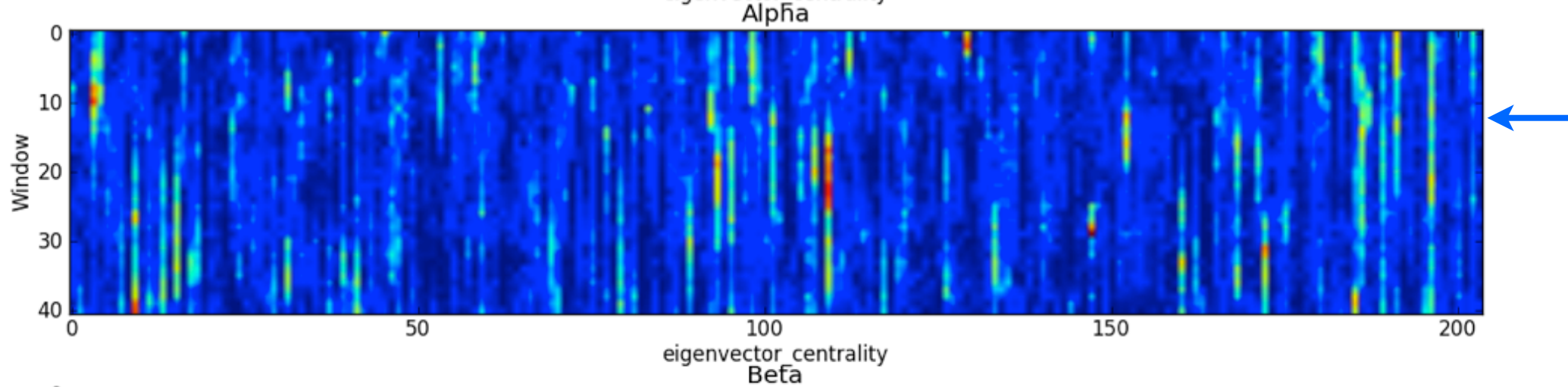
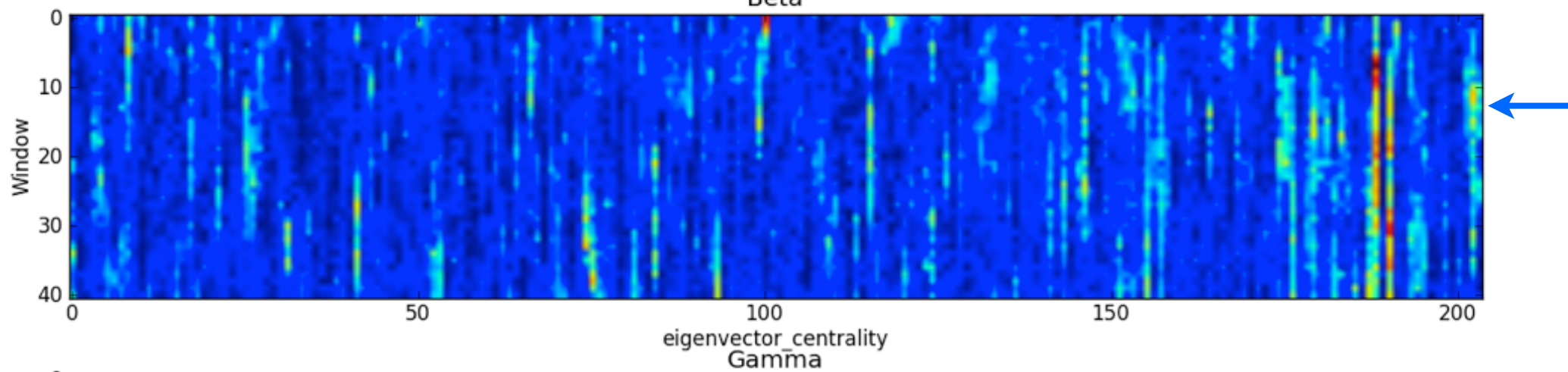
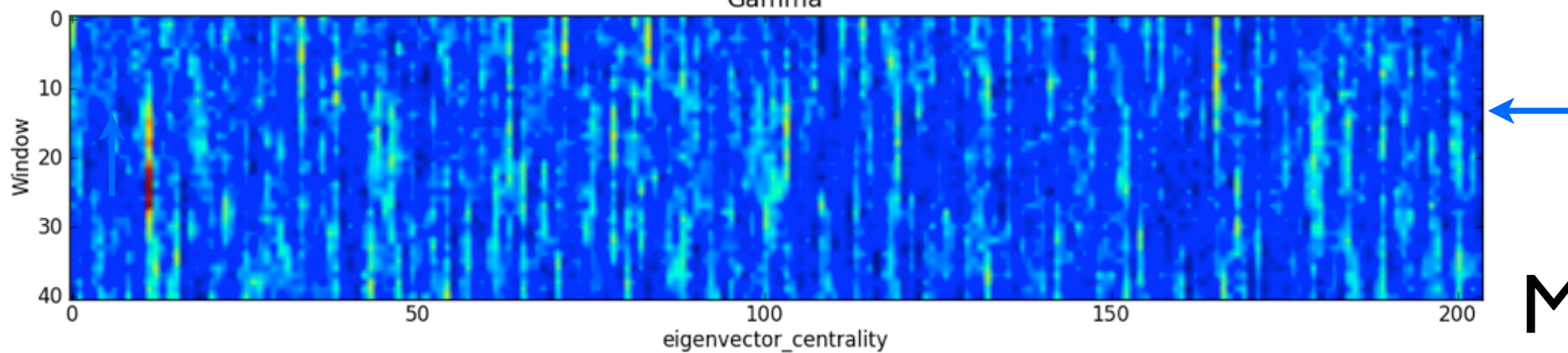


Listen



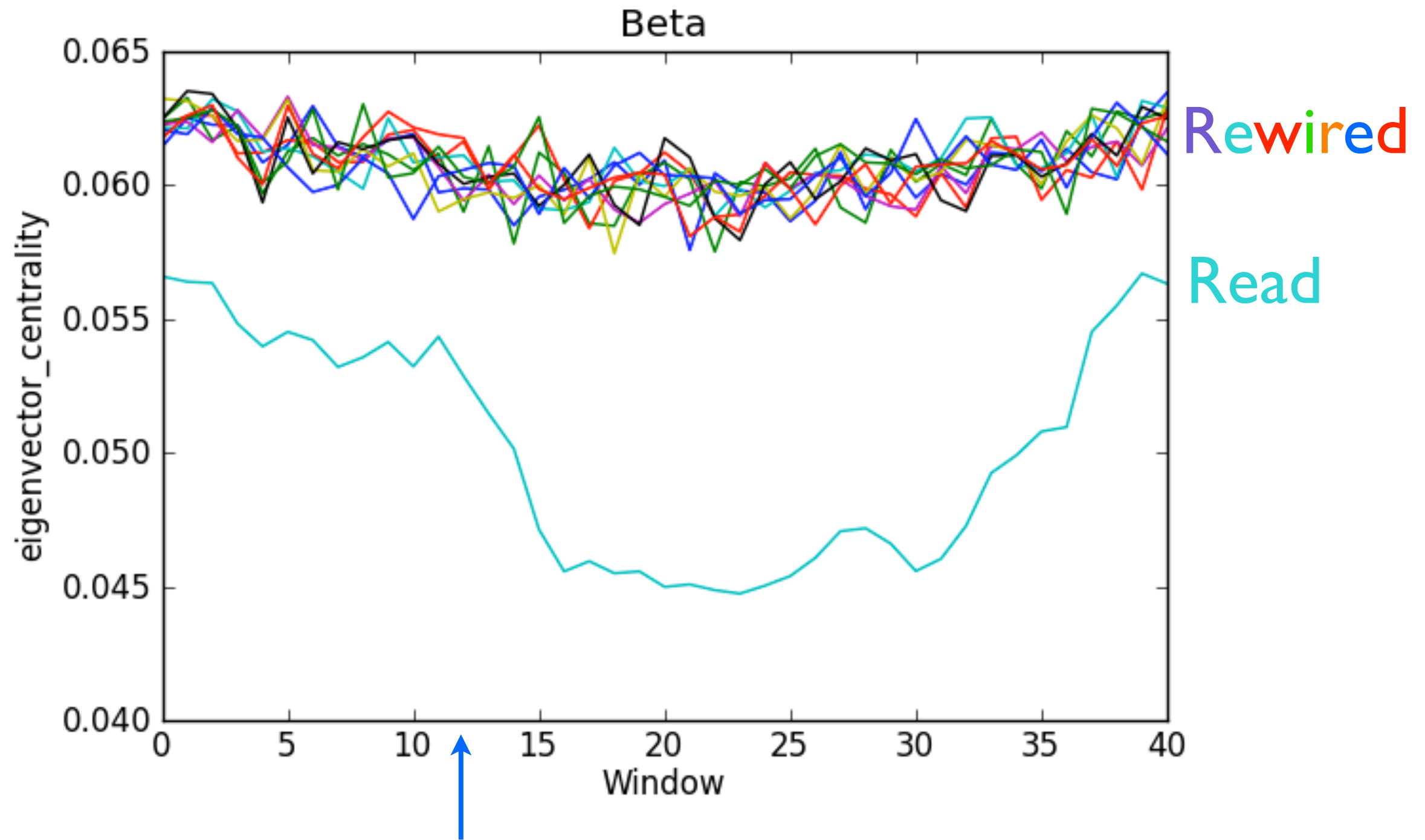
Read

EEG

θ  α  β  γ 

MEG

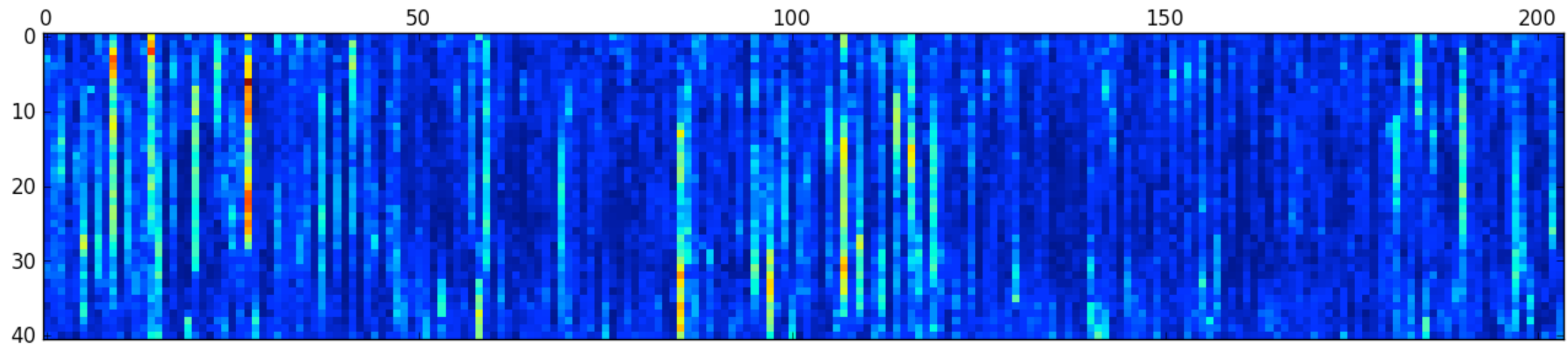
Effect or artifact?



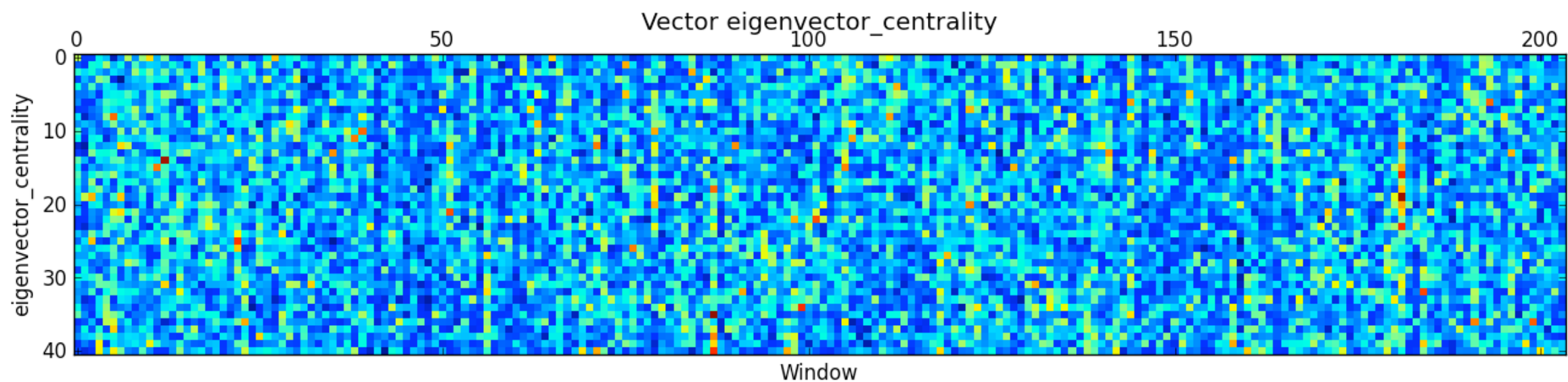
Real graphs vs. rewired graphs

MEG

Per-vertex evolution of MEG data

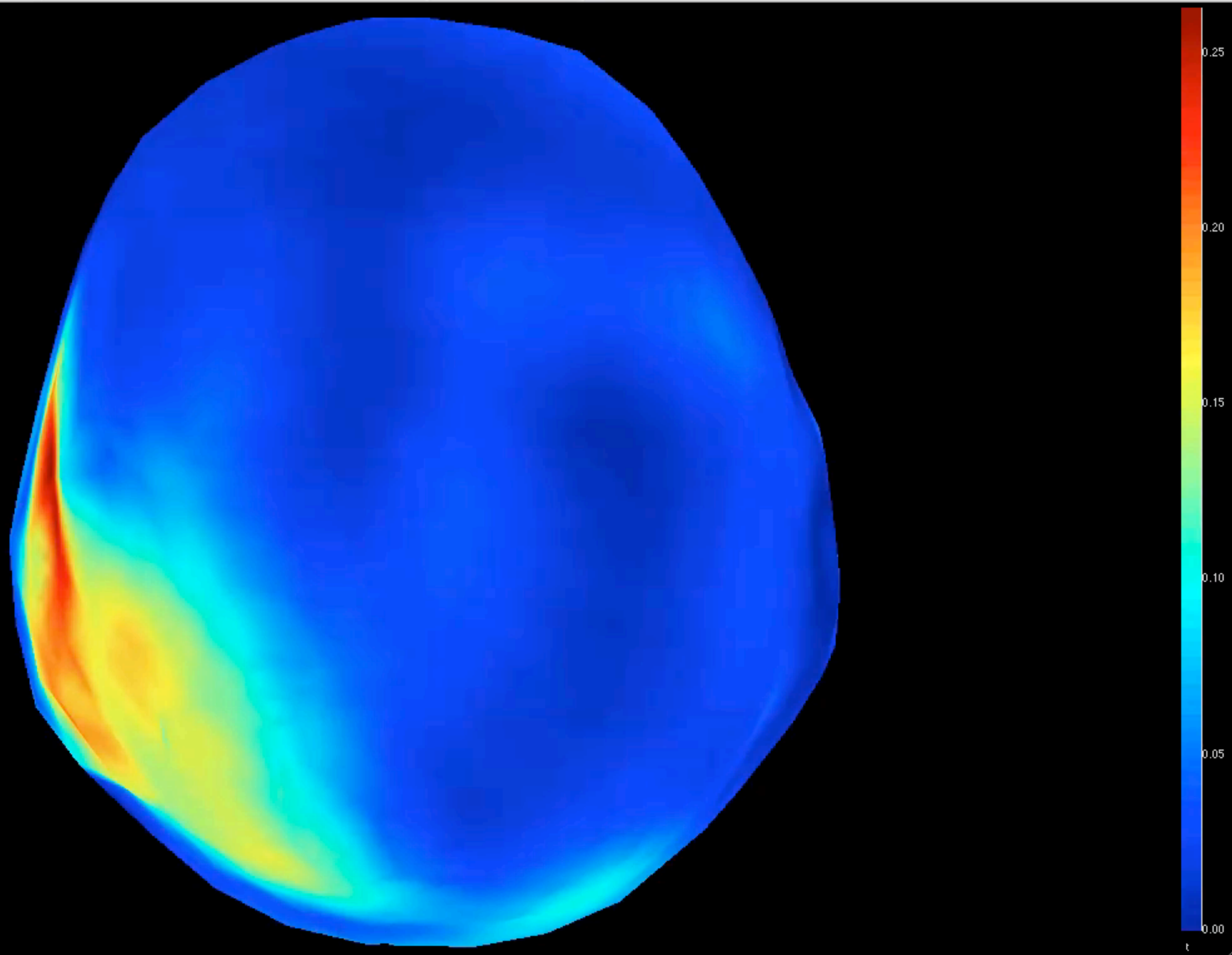


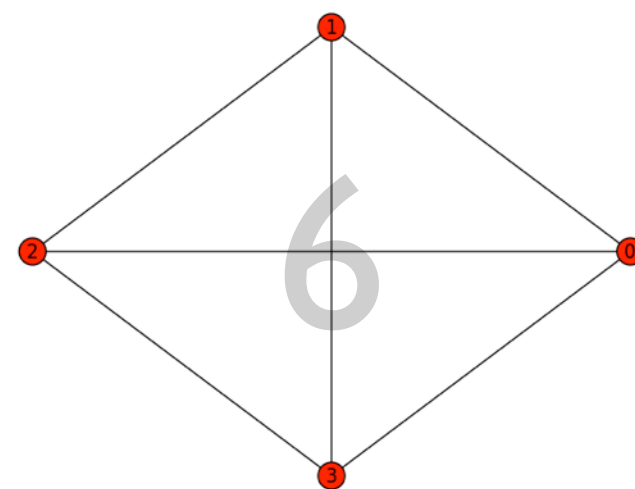
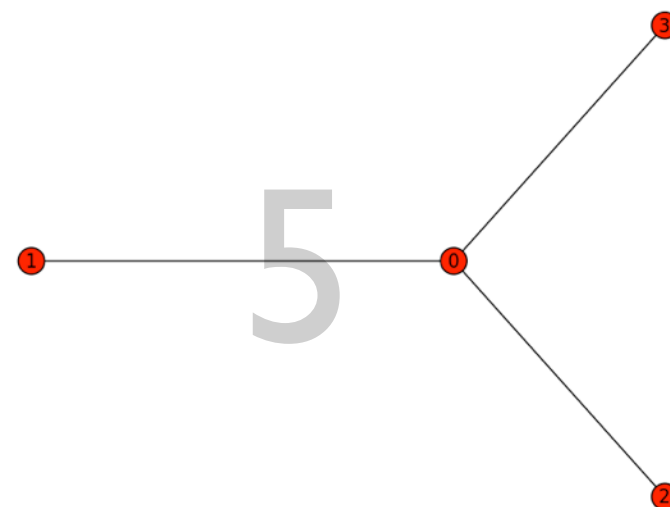
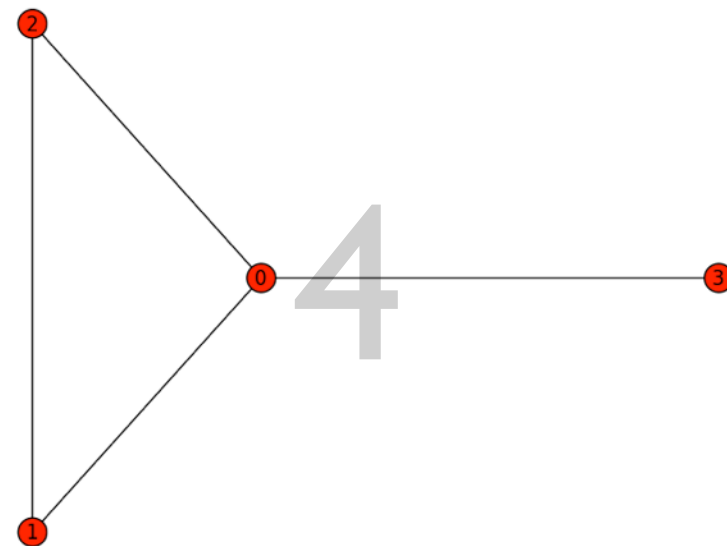
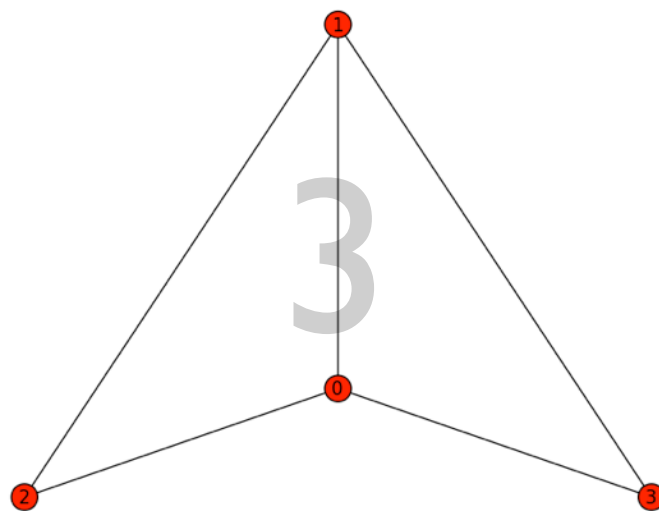
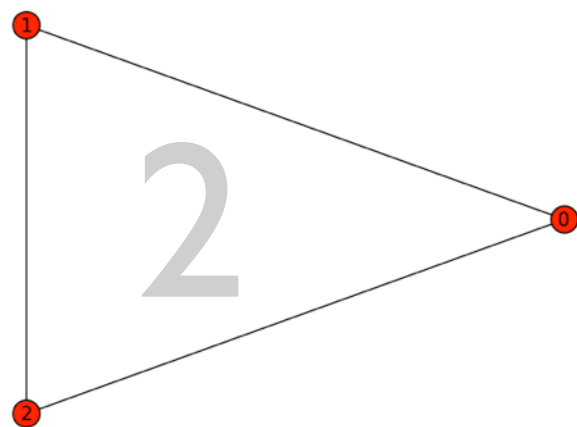
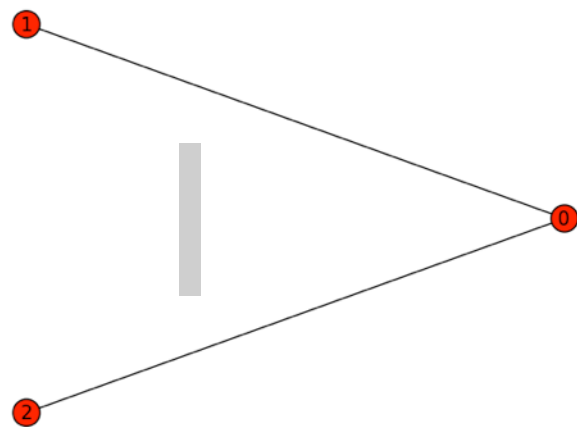
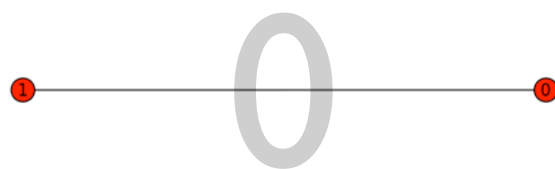
Real



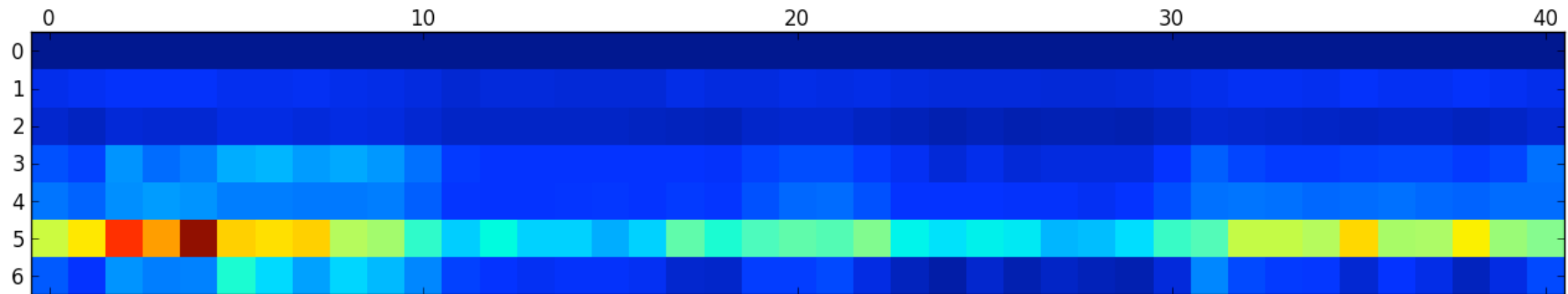
Rewired

MEG

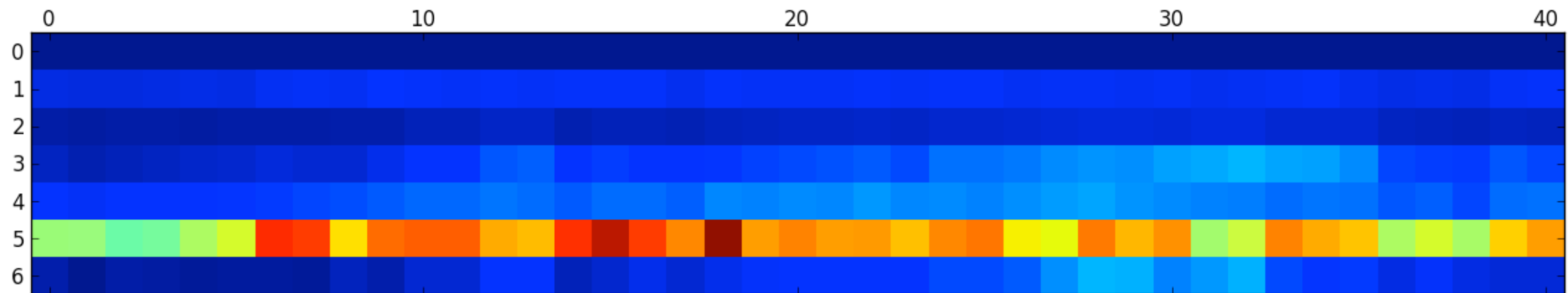




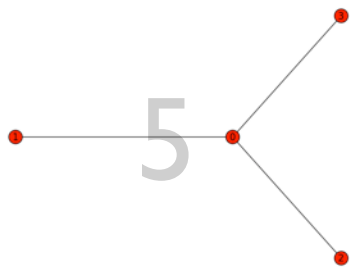
Motif fingerprints



Listen



Look



EEG

Full circle: Back to TCS!

- Gather statistics on graph transformations.
- **What are the properties of a stochastic graph rewriting system with these empirically-derived rules?**

Applications

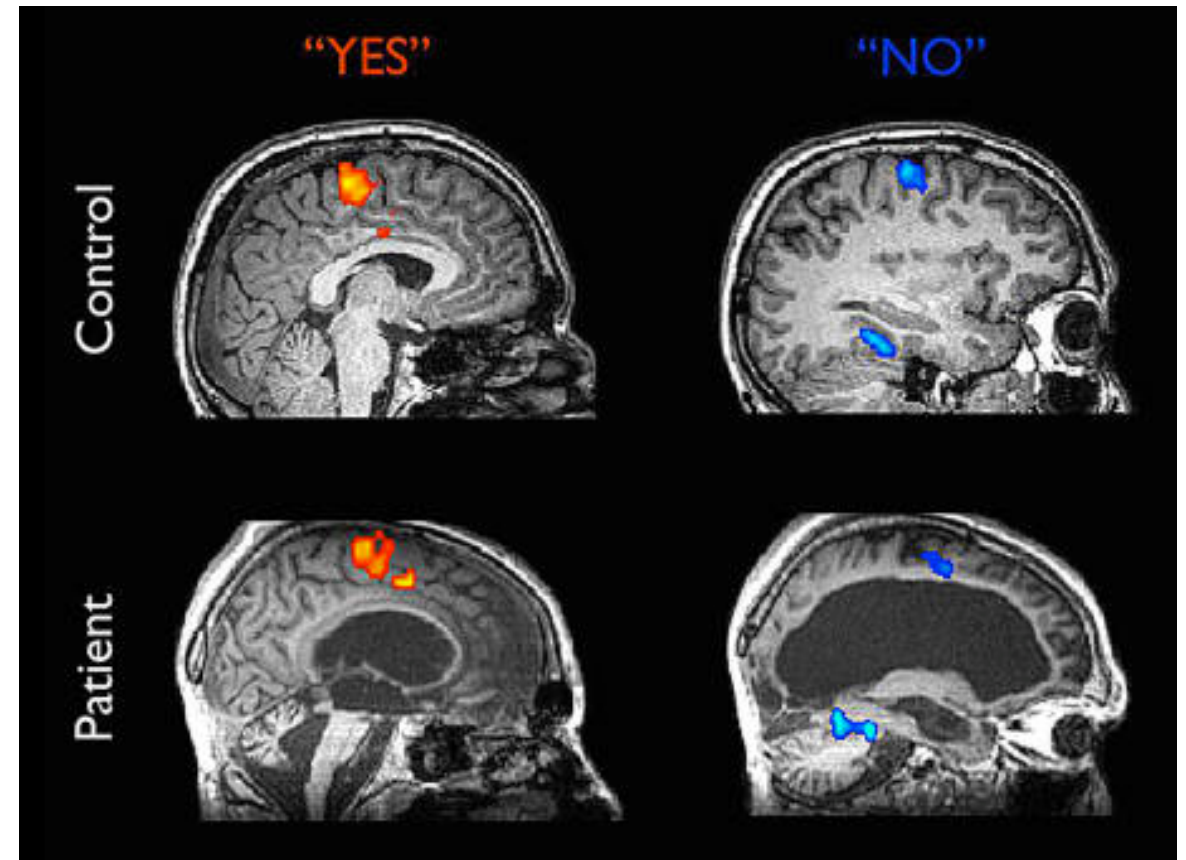


Neonatal Neurological

Assessment
(with R. Cusack)



CIHR IRSC
Canadian Institutes of Health Research
Institut de recherche en santé du Canada

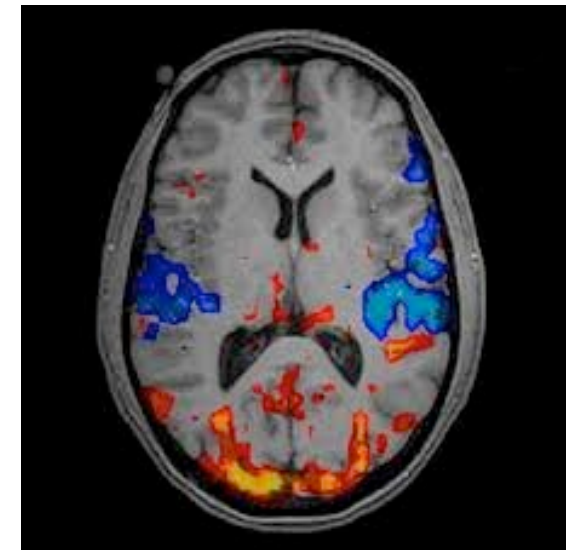


Coma Outcome

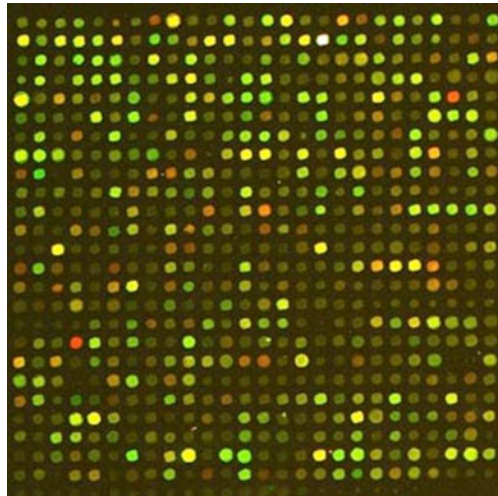
Prediction
(with A. Owen)



Canada Excellence
Research Chairs



Real-time fMRI graphs with FPGAs



Fractionating phenotype from genotype, fMRI and behavioural data.
(with B. Morton)

Thanks

Andrew Kope
Casey Wood
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Rhodri Cusack
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Don Aldridge
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Victor Han
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Randy McIntosh
Bernard Ross
Adam McLean
Shannon O'Connor
Mehrsta Golestaneh

