Brain Dynamics on the Connectome
Summer School 2021

Lecture 2.2 – Functional Connectivity (FC) and Dynamical FC

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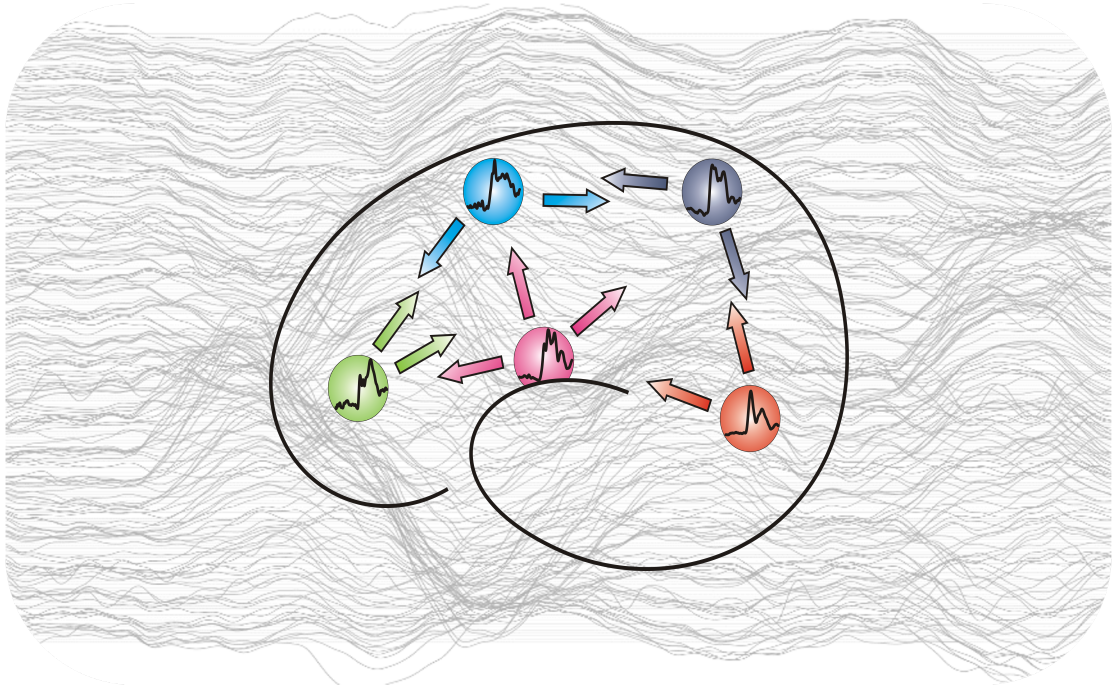
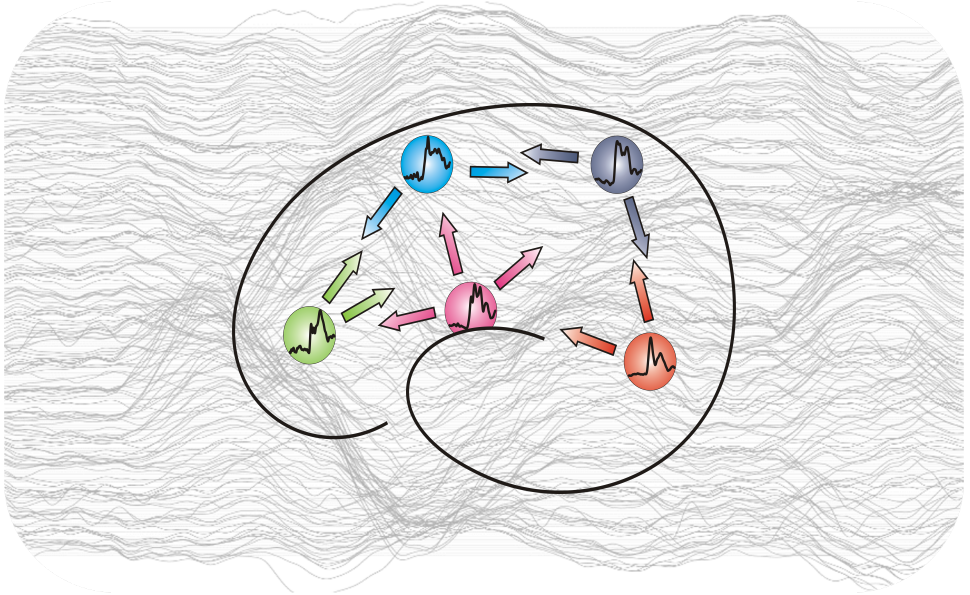
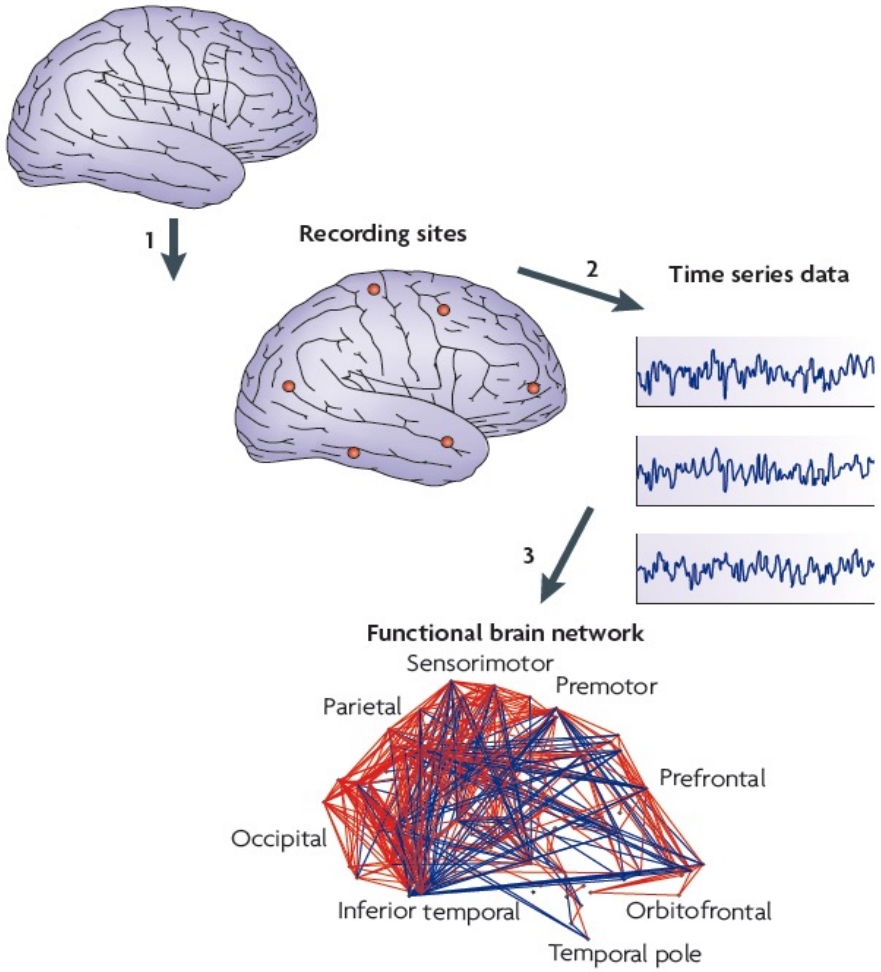


Overview

- What is functional connectivity?
- Functional connectivity and physiology (Rhythms, dynamics, directed interactions)
- Granger causality, partial directed coherence
- Limitations
- Applications



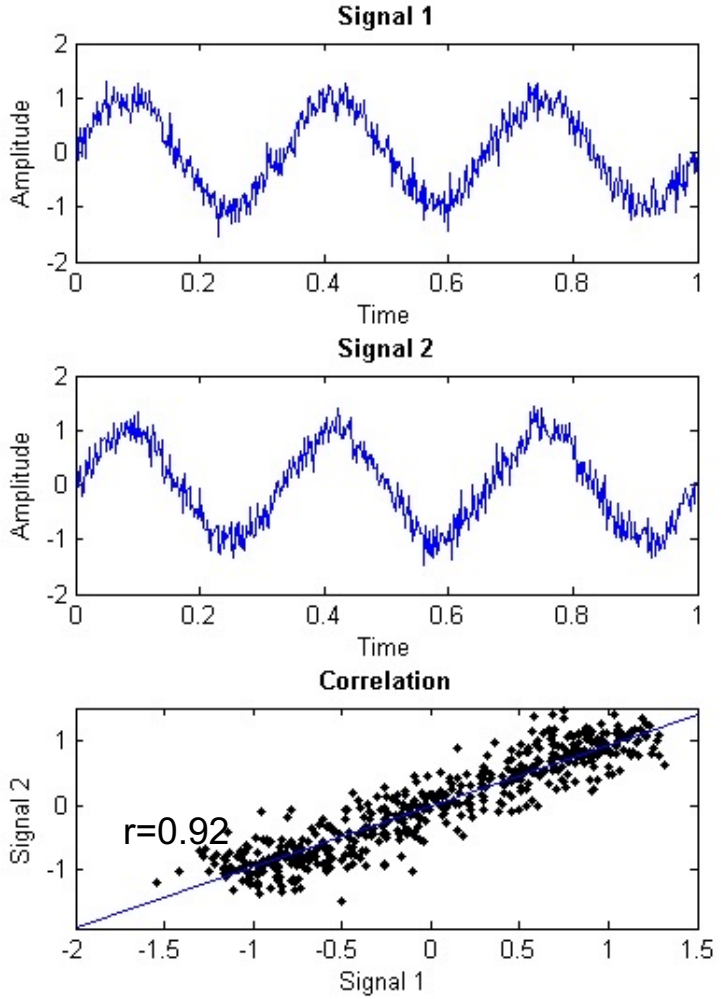
Functional connectivity



Bullmore & Sporns (2009)

- Statistical dependencies between recorded signals
- Indicates how activity in one area relates to activity in another area
- Provide a network view on brain activity

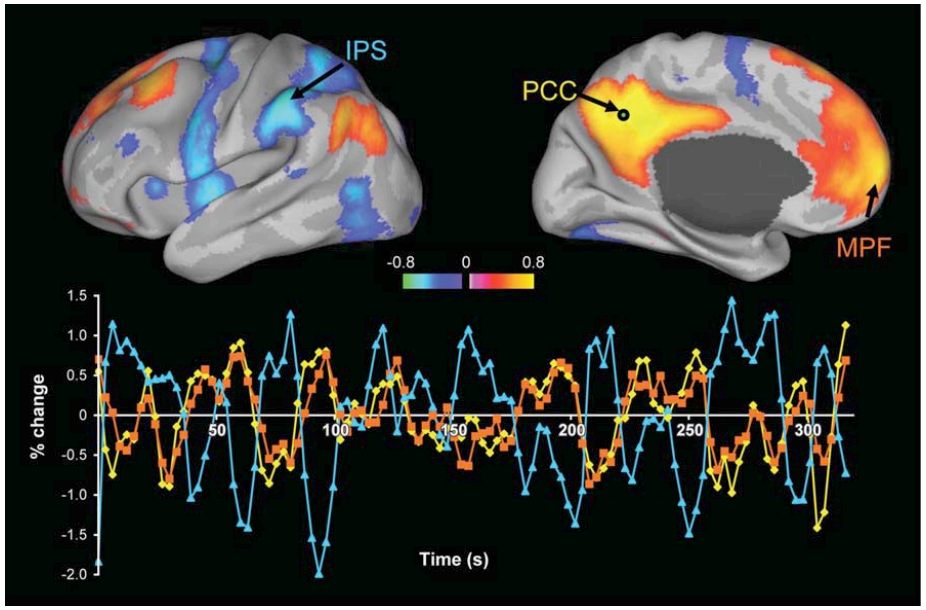
Functional connectivity



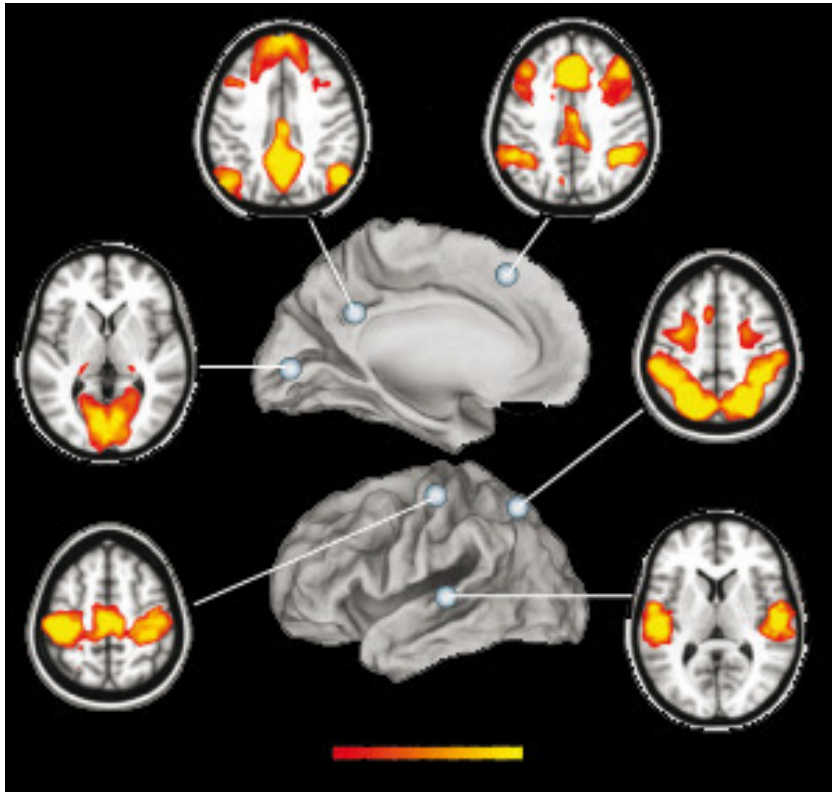
- Correlation coefficient r
  - r=1: perfect match
  - r=0: independent
  - r=-1: inverted signals

Functional connectivity

- Resting-state fMRI
- Correlations with seed-voxels reveal functional networks



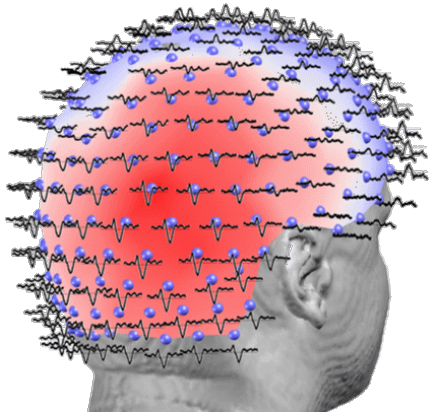
Fox et al., 2005 PNAS

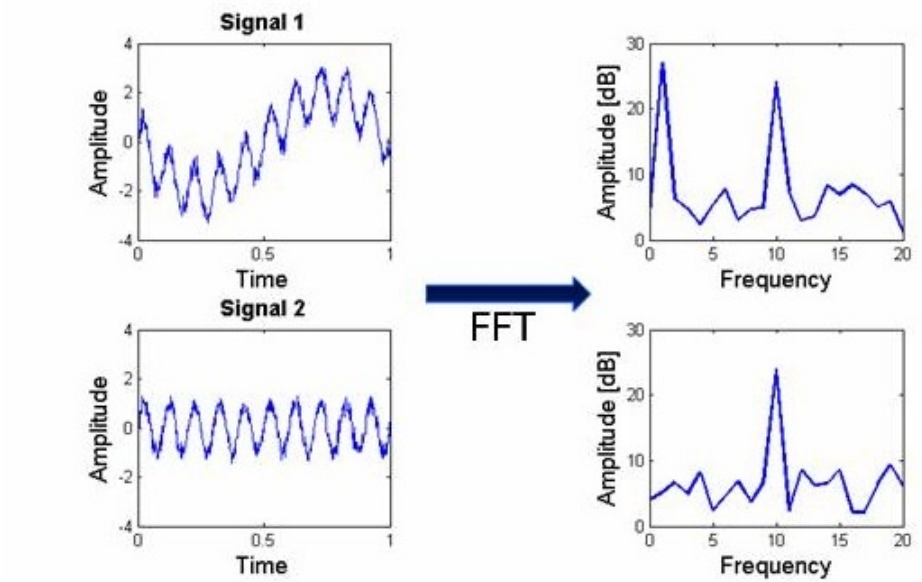


Zhang & Raichle, 2010 Nat Rev Neurol

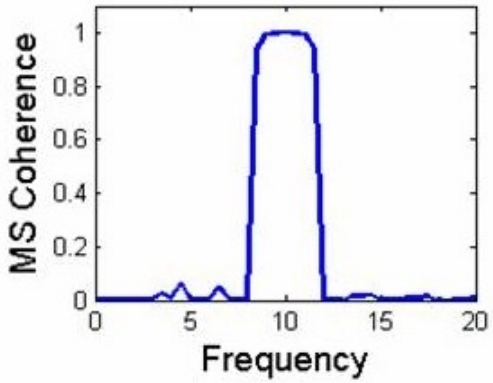
Functional connectivity and M/EEG

EEG or MEG





Coherence



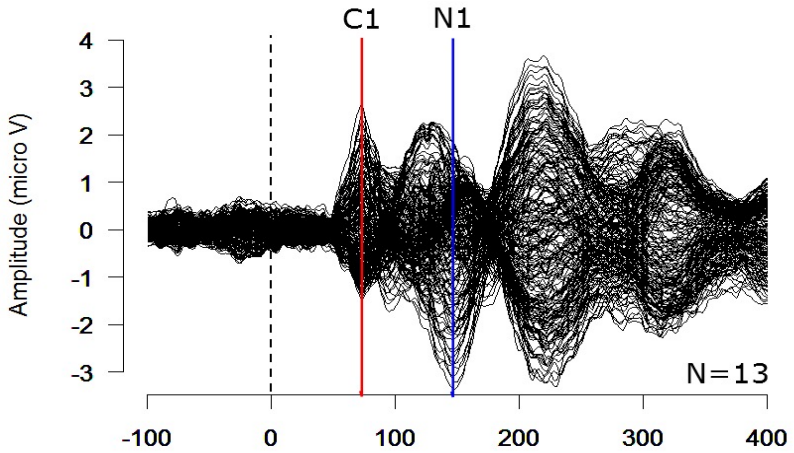
- M/EEG signals show rhythms and oscillations
- Coherence, a correlation value at each temporal frequency
- Standard FC measure for M/EEG studies

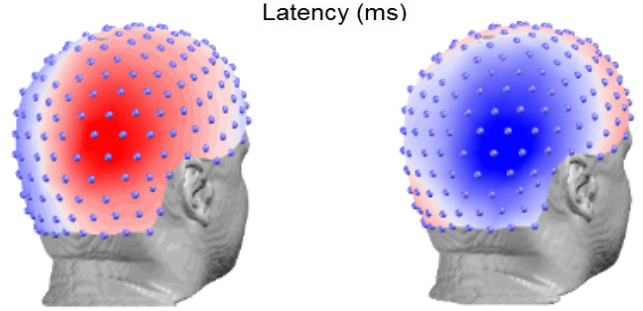
Nunez et al (1997), Wang (2010), He et al. (2019)

Neural dynamics

Brains are fast!

Evoked response potential (ERP)

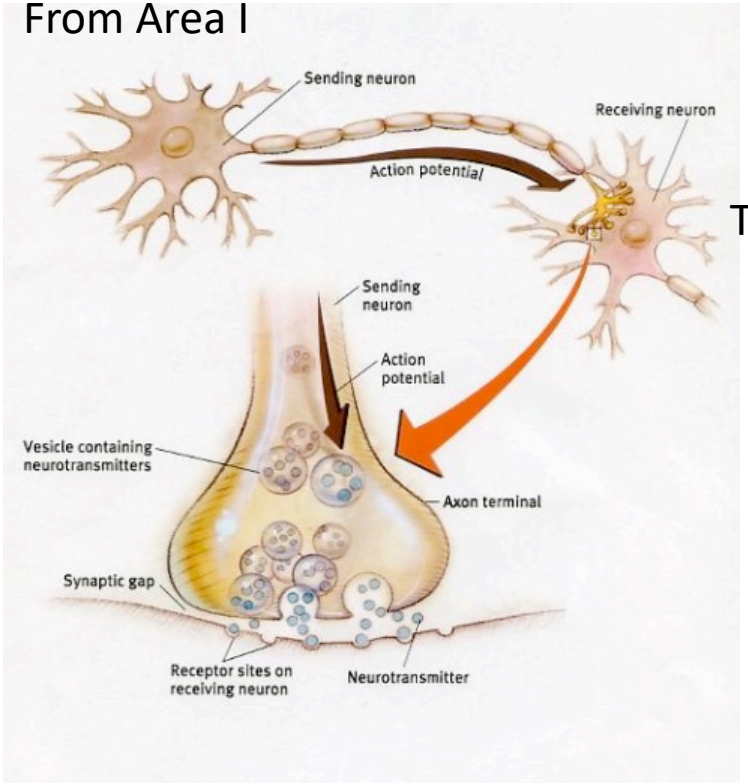




Plomp et al (2015)

FC and physiology

From Area I



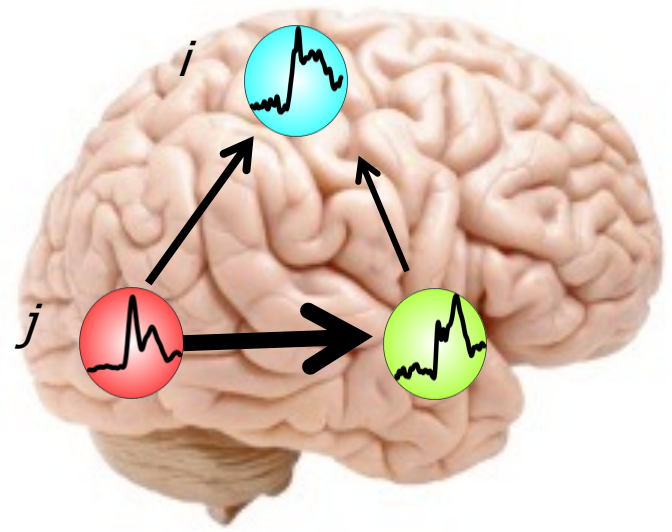
To Area II

- Neural interactions are inherently *directed* interactions

FC and physiology

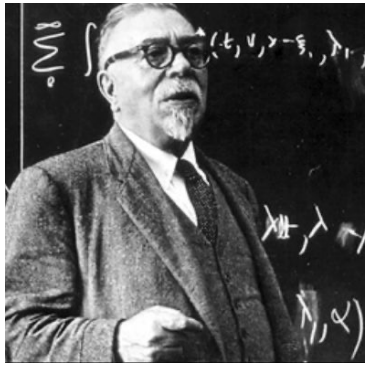
Three key aspects of brain activity:

- Rhythmic, oscillatory
- Fast dynamics
- Directed interactions



FC measures that reflects this, are closer to physiology and better interpretable

Granger causality



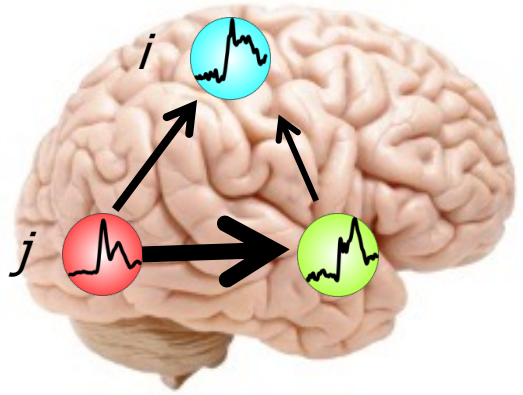
Norbert Wiener

Clive Granger

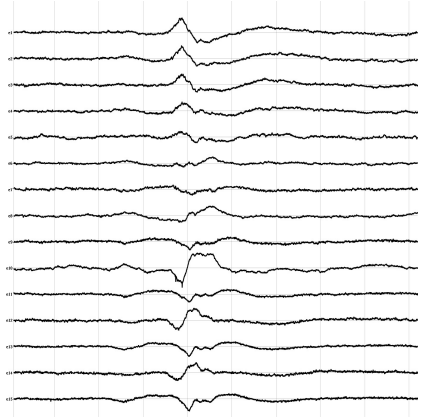
- Granger causality: activity in area *j* predicts activity in *i*, better than that *i* predict it's own activity

- Multivariate autoregressive modeling (MVAR) to estimate the predictability of region *i* from *j*

$$\sum_{k=0}^{p} A_k S(t-k) = E(t)$$

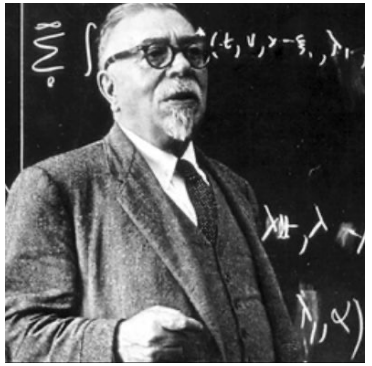


M/EEG signals



Wiener (1956), Granger (1969), Seth et al (2015)

Partial directed coherence

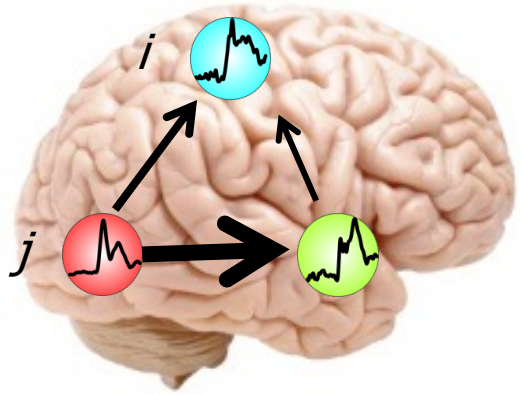


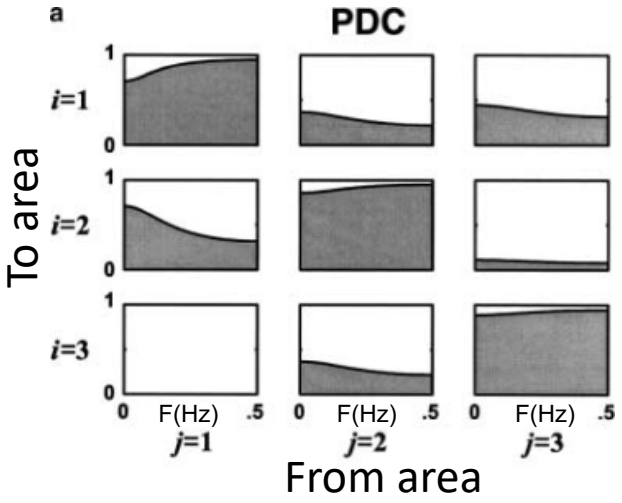
Norbert Wiener

Clive Granger

- Partial directed coherence (PDC) estimates the unique contribution from region *j* to *i*
- Through normalization of the MVAR model

$$sPDC_{ij}(f,t) = \frac{\left|A_{ij}(f,t)\right|^2}{\sum_{m=1}^{N}\left|A_{im}(f,t)\right|^2}$$



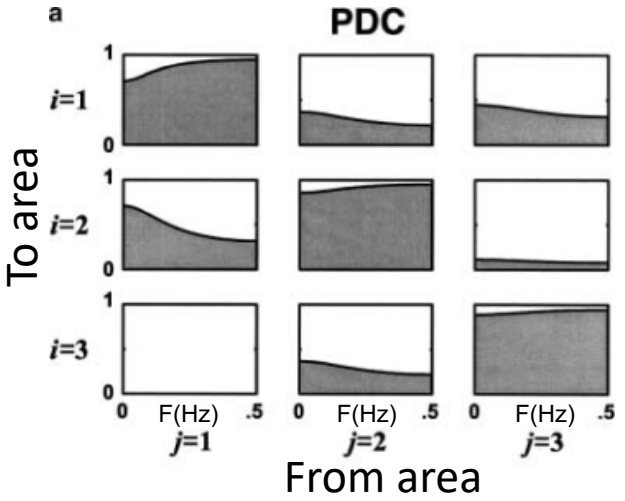


Baccala & Sameshima (2001)

Wiener (1956), Granger (1969)

Partial directed coherence

- A measure in the frequency domain
- Directed interactions
- Dynamic, when based on time-varying MVAR models

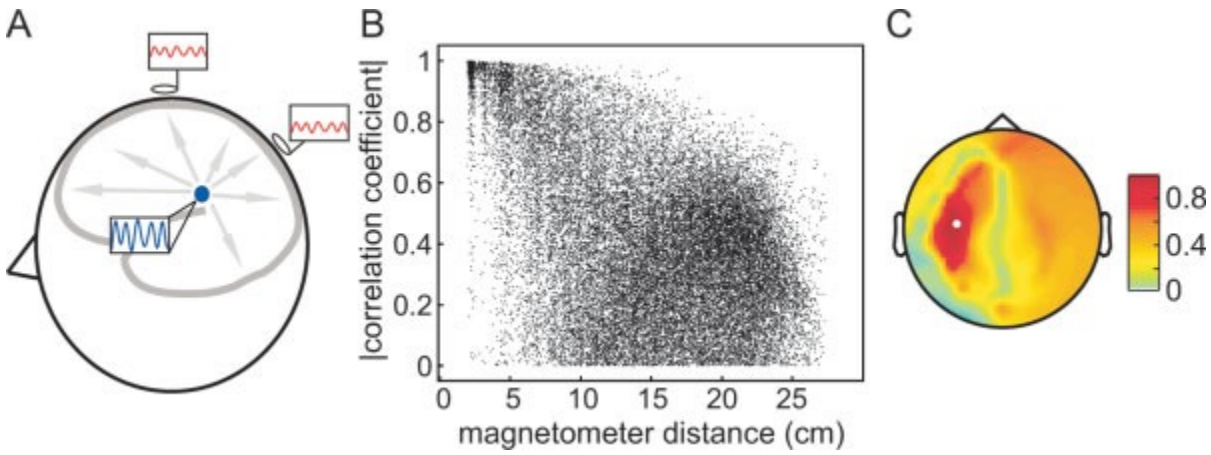


Baccala & Sameshima (2001)

- ➢ Algorithms: Lecture 2.3 by David Pascucci
- ➢ Application: Tutorial 4 by Maria Rubega

Limitations of FC in M/EEG

1. Volume conduction, field spread



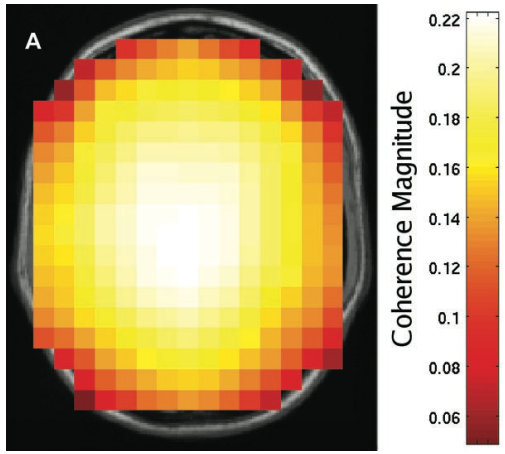
Schoffelen & Gross. Hum Brain Mapp 2009
Srinivasan et al. J Neurosci Meth 2007

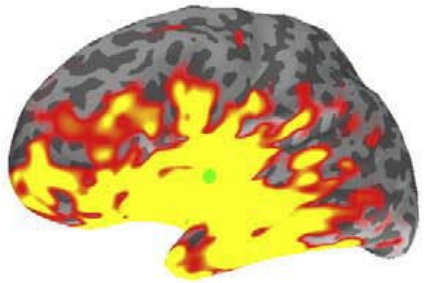
- More than one M/EEG sensor picks up the activity of a given source.
- FC between sensor pairs cannot be attributed to the underlying brain regions.
- Possible solutions: non-instantaneous measure, lagged, imaginary

He et al. (2019), Haufe et al. (2013)

Limitations of FC in M/EEG

1. Volume conduction, field spread





Guggisberg et al. Ann Neurol 2008
Ghuman et al. NeuroImage 2011

- The spatial resolution of inverse solutions is imperfect and inhomogeneous
- Brain areas with low spatial resolution artificially have higher functional connectivity values
- Possible solutions, intracranial recordings

He et al. (2019)

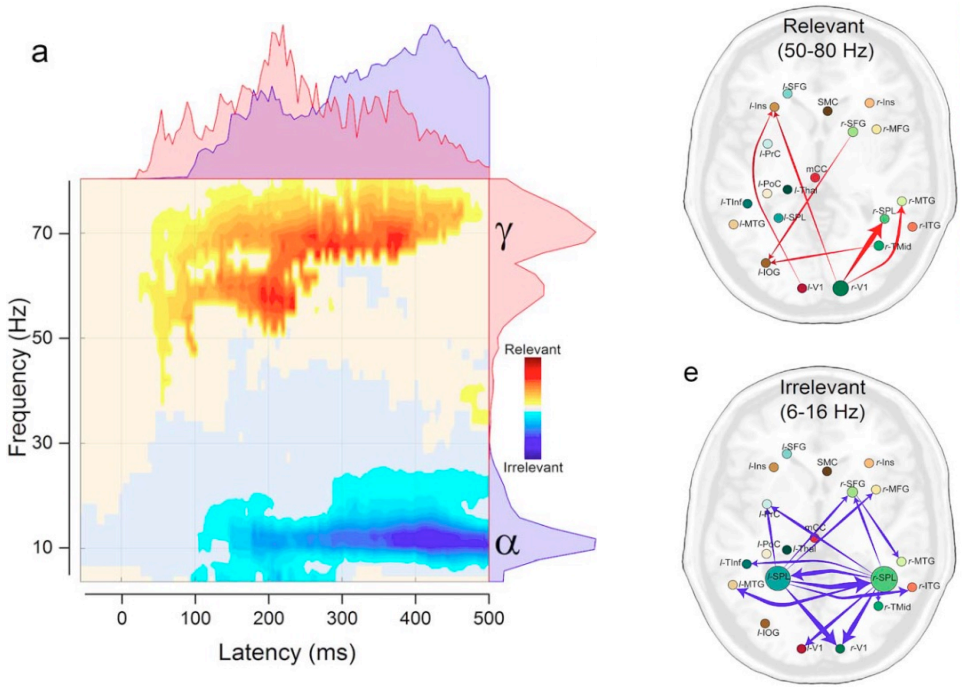
Meaning of models

George E. P. Box

"All models are wrong, but some are useful."

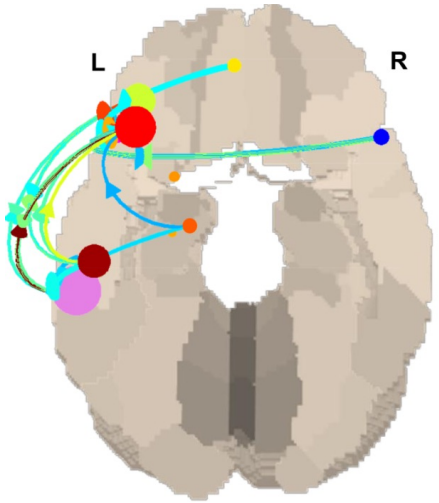
Applications

Selective attention



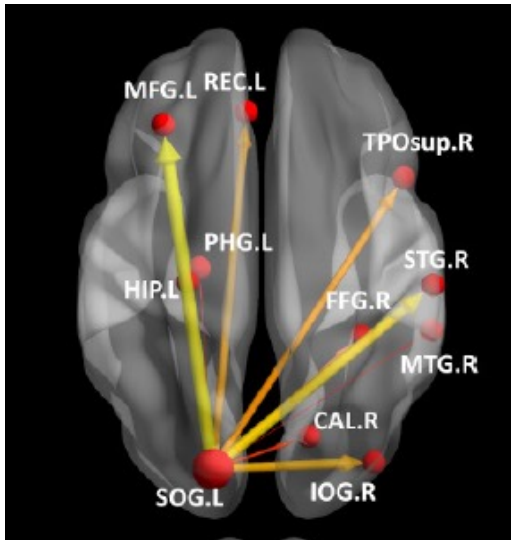
Pascucci et al. (2018), Human Brain Mapping

Epilepsy



Coito et al. (2015, 2016) Epilepsia

Autism



Sperdin et al. (2018) eLife

In sum

Granger causality based on MVAR models reflects key aspects of neural interactions:

- Rhythms
- Dynamics
- Directionality

Limitations, volume conduction and field spread

Applications: for you to imagine!

Key FC references

He, B., Astolfi, L., Valdes-Sosa, P.A., Marinazzo, D., Palva, S., Benar, C.G., Michel, C.M., & Koenig, T. (2019) Electrophysiological Brain Connectivity: Theory and Implementation. *IEEE Transactions on Biomedical Engineering*, 1–1.

Reid, A.T., Headley, D.B., Mill, R.D., Sanchez-Romero, R., Uddin, L.Q., Marinazzo, D., Lurie, D.J., Valdés-Sosa, P.A., Hanson, S.J., Biswal, B.B., Calhoun, V., Poldrack, R.A., & Cole, M.W. (2019) Advancing functional connectivity research from association to causation. *Nat Neurosci*, 1–10.

Seth, A.K., Barrett, A.B., & Barnett, L. (2015) Granger Causality Analysis in Neuroscience and Neuroimaging. *J. Neurosci.*, **35**, 3293–3297.

Wang, X.-J. (2010) Neurophysiological and Computational Principles of Cortical Rhythms in Cognition. *Physiological Reviews*, **90**, 1195–1268.

Thank you

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