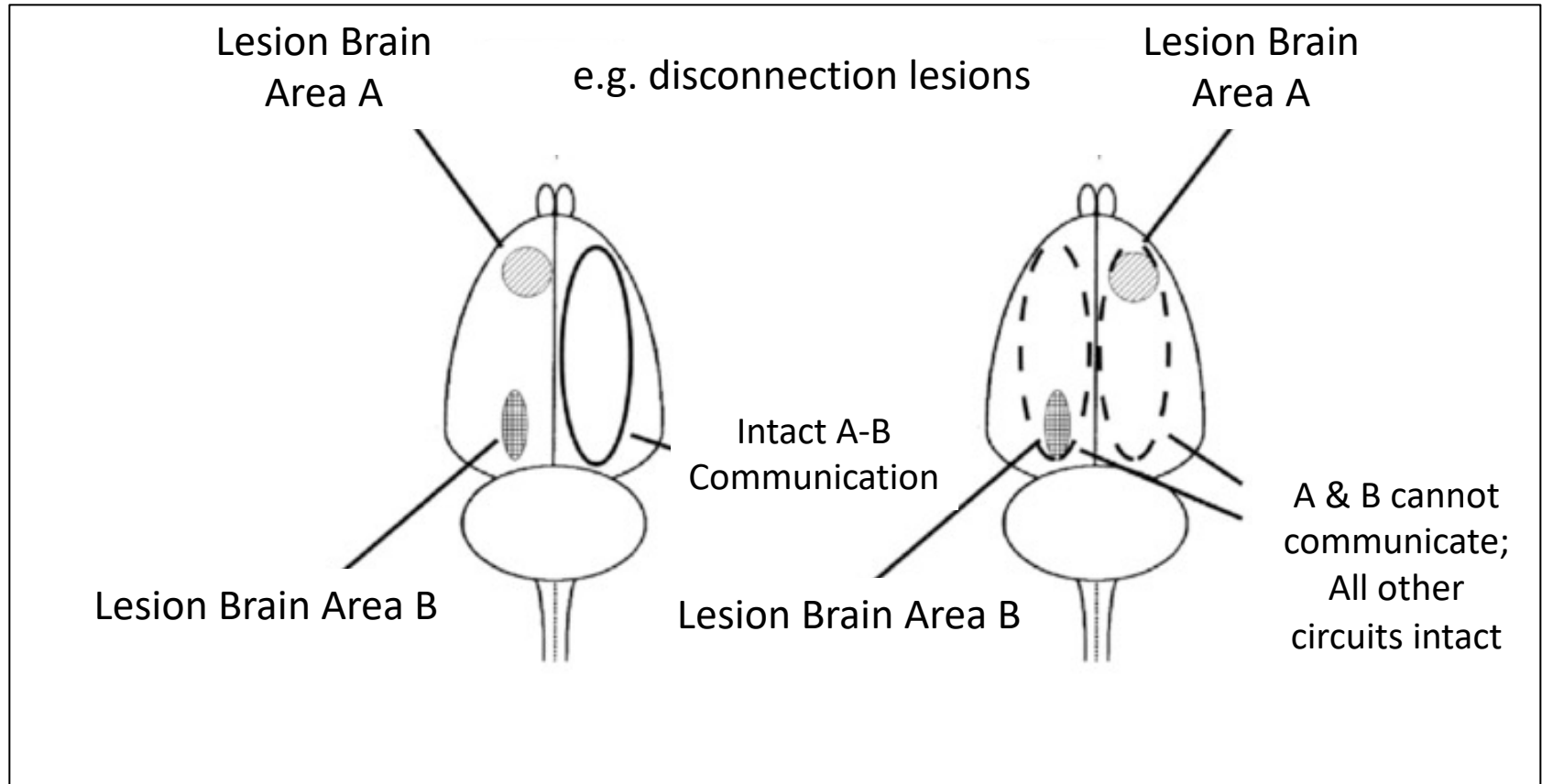


Functional connectivity

What is functional connectivity?



We know interactions between brain regions are important...



We know interactions between brain regions are important...

“Functional connectivity” = the physiological basis of these interactions

*** We don't know what mechanisms underlie these interactions***

- Potentially many different mechanisms & measures

Coherence (LFP-LFP, spike-phase)

fMRI co-activations

LFP amplitude correlations

Spike correlations

Cross-frequency coupling

Mutual information

Granger Causality

Partial directed coherence

Transfer entropy...



Wang et al. (Front Neurosci 2014) explores 42 different measures

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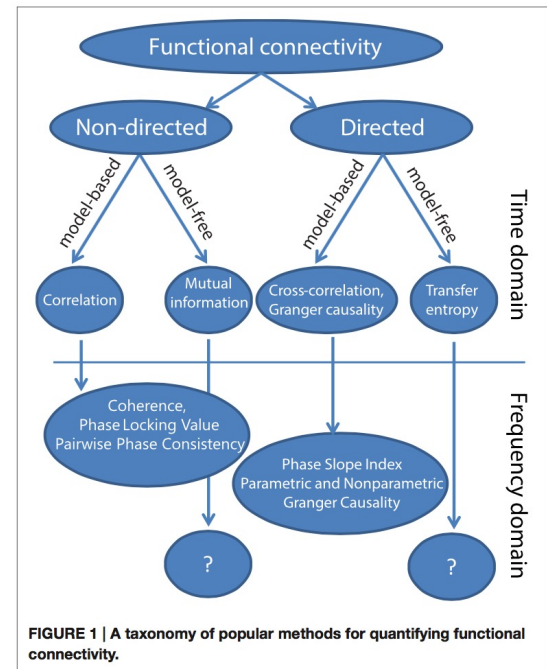
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We know interactions between brain regions are important...

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- Potentially many different mechanisms & measures
- Investigations involve documenting statistical regularities (e.g. correlated activity, predictive relationships) between two time series that
 - a. can't be explained by non-specific effects (e.g. to an external event)
 - b. Predict something behaviorally or cognitively relevant
- Statistical regularities should therefore occur over small time scales

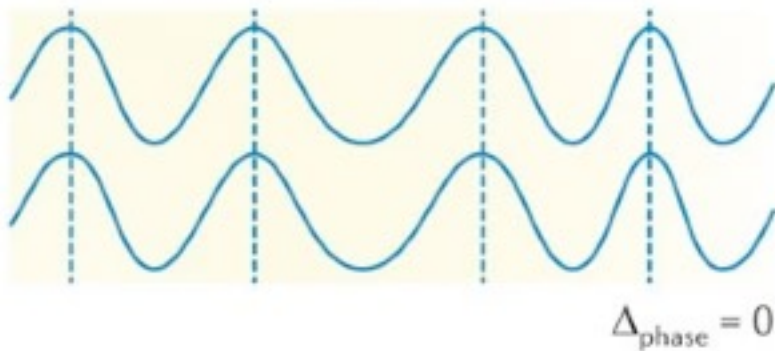
Types of functional connectivity:

Coherence

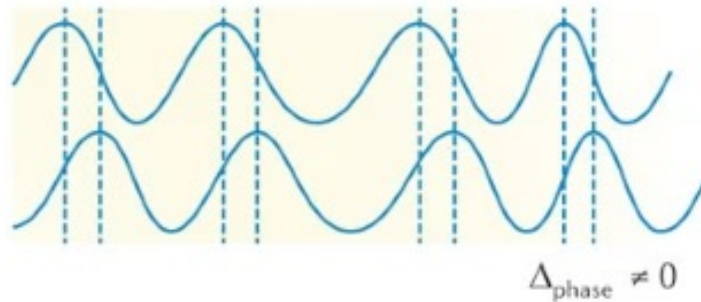
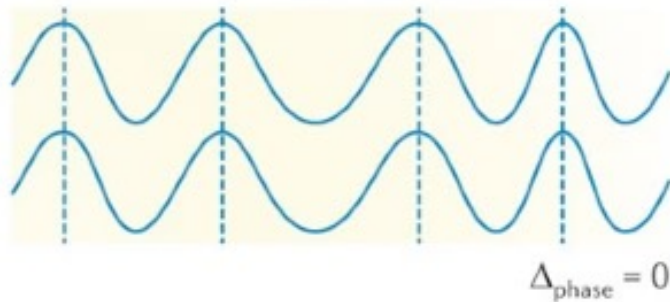
Coherence = phasic coordination (synchronization) of two oscillating signals
- *correlation* of two oscillating signals

Hypothesized that rhythmic coordination of oscillations could be a mechanism enhancing communication between brain areas – “Communication through coherence” (Fries 2005)

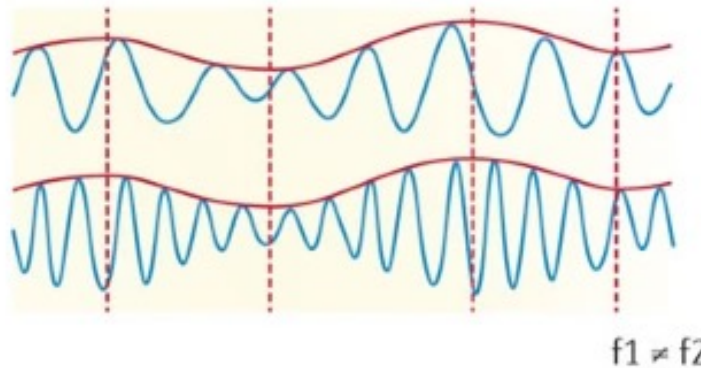
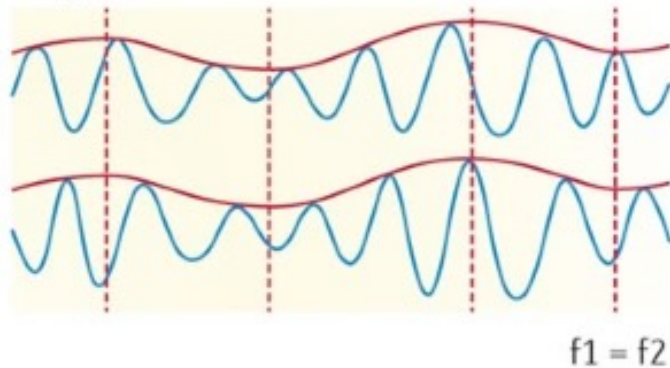
a Phase coherence



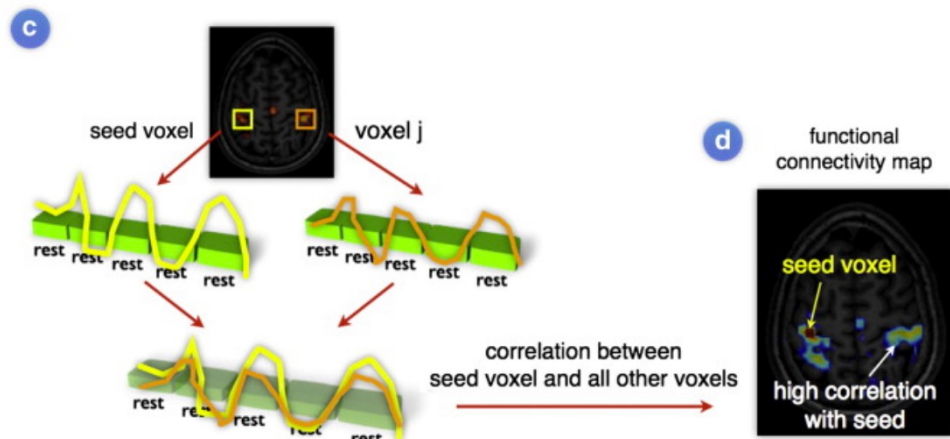
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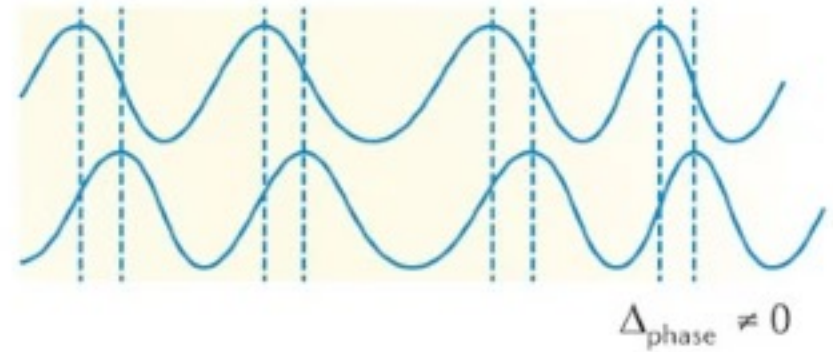
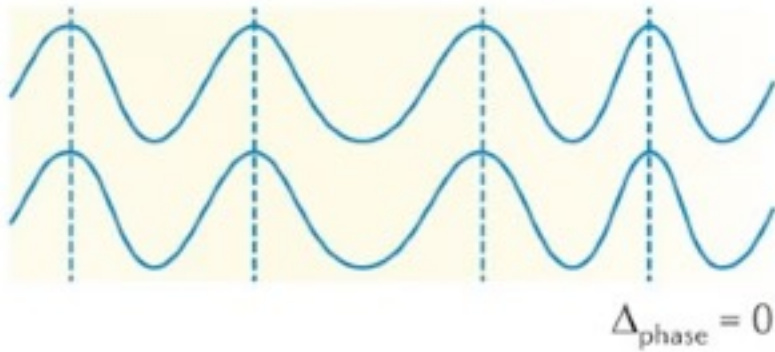
b Amplitude correlation



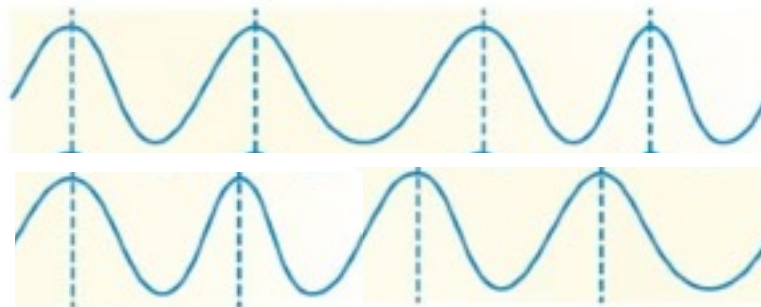
Amplitude correlations are similar to methods used to determine functional connectivity by fMRI



a Phase coherence



No phase coherence



Types of functional connectivity: Coherence

Coherence between signals x and y

“Cross-spectral Density”

$$C_{xy}(f) = \frac{|G_{xy}(f)|^2}{G_{xx}(f)G_{yy}(f)}$$

“Autospectral Densities”

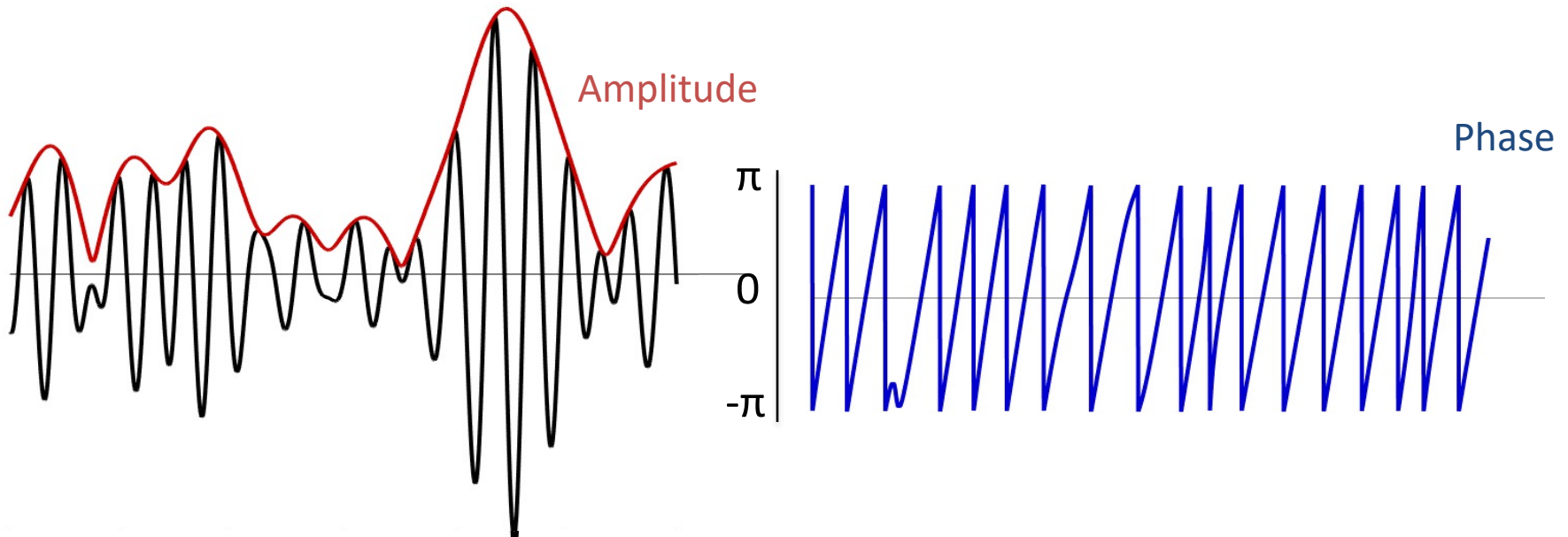
The diagram shows the coherence formula $C_{xy}(f) = \frac{|G_{xy}(f)|^2}{G_{xx}(f)G_{yy}(f)}$ enclosed in a rectangular box. Three arrows point from text labels to parts of the formula: one from 'Coherence between signals x and y' to the left side $C_{xy}(f)$, one from '“Cross-spectral Density”' to the numerator $|G_{xy}(f)|^2$, and one from '“Autospectral Densities”' to the denominator $G_{xx}(f)G_{yy}(f)$.

- Coherence is *non-directional*
- Phase coherence can be contaminated by amplitude measures

Types of functional connectivity: Coherence

Coherence = phasic coordination (synchronization) of two oscillating signals
- *correlation* of two oscillating signals

Phase Locking Value (PLV) (and PLI) – based on Hilbert transformed, bandpassed signal



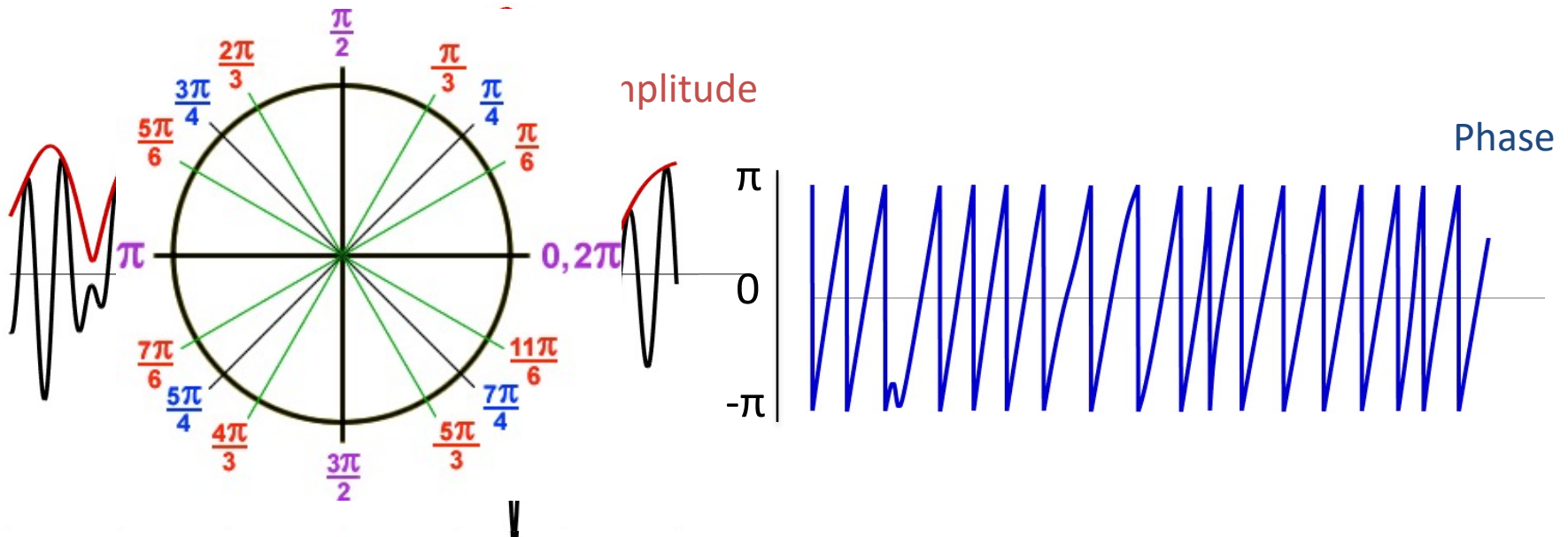
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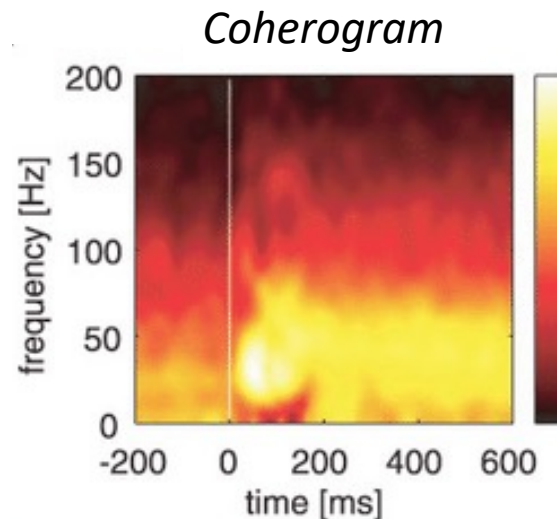
Types of functional connectivity:

Coherence

Frequency domain

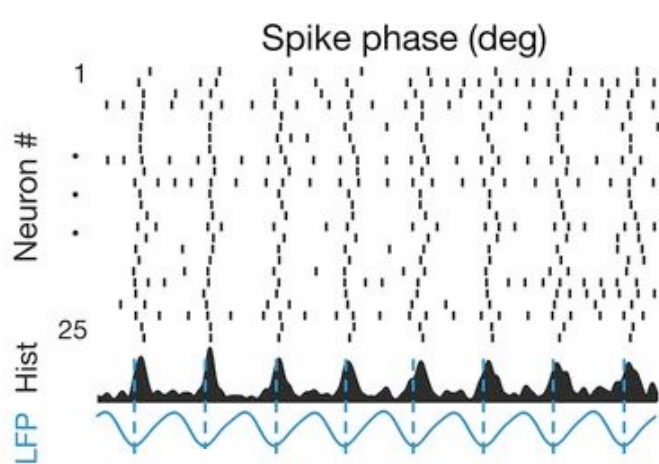
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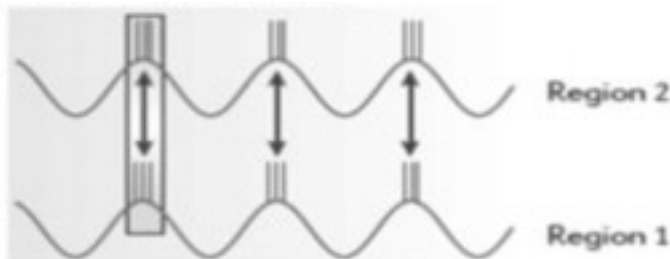
Types of functional connectivity: Coherence

Hypothesized that rhythmic coordination of oscillations could be a mechanism enhancing communication between brain areas – “Communication through coherence” (Fries 2005)



How might this work?

- Local voltage environment can move neurons closer/farther from threshold -> Change postsynaptic response to presynaptic afferents

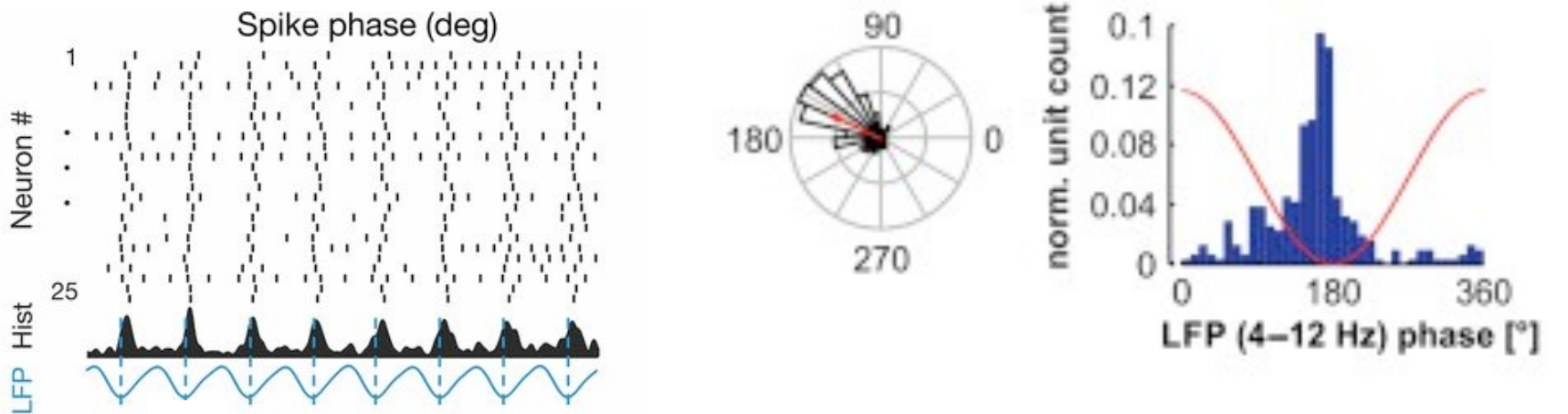


- Coordinate spike *timing* between two regions -> “Binding by synchrony”

Types of functional connectivity:

Spike-field coherence

Directly quantify the LFP phase at which a neuron spikes



Use circular statistics to:

- calculate the direction and magnitude of the resultant vector
- Test against the null hypothesis that spike phases are randomly distributed (Rayleigh test for non-uniformity of circular data)

Is synchronous activity always a good thing?

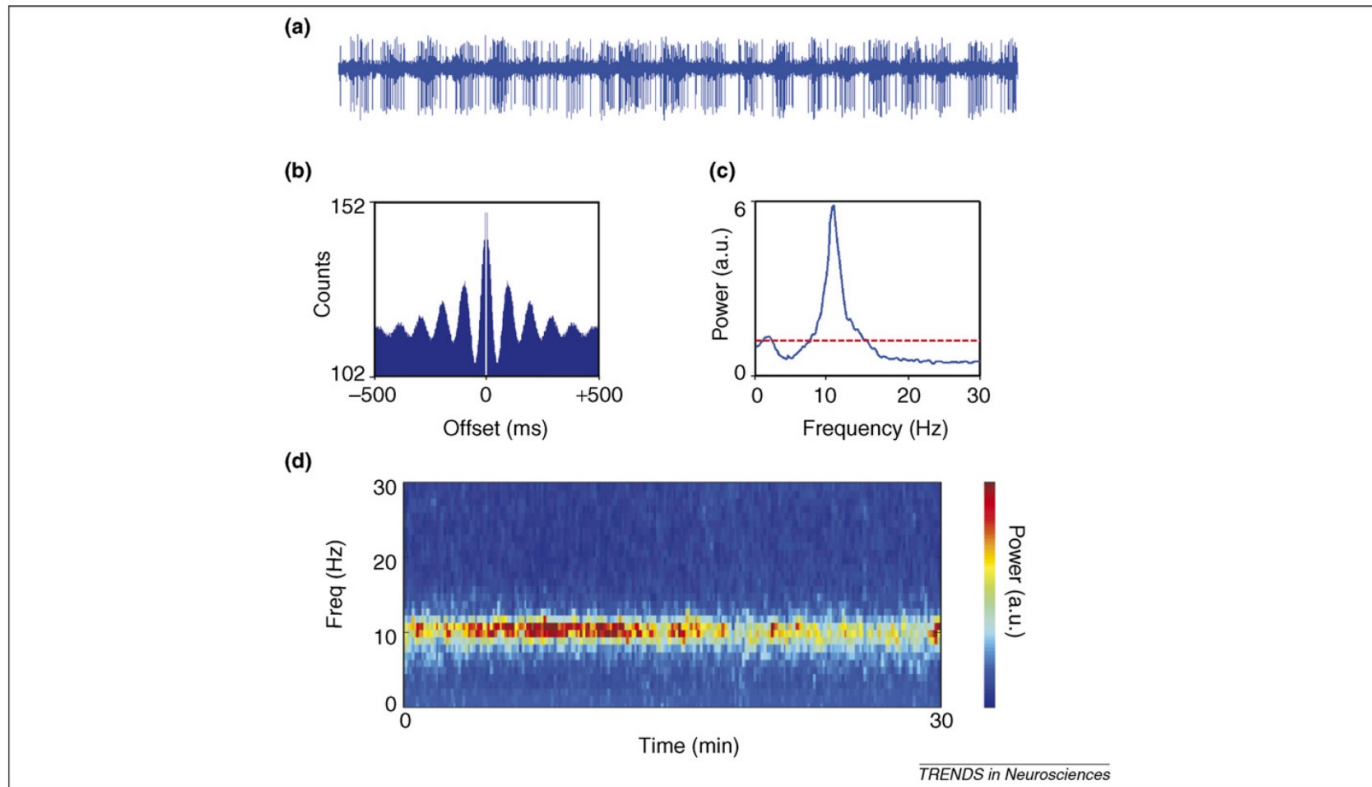


Figure 2. Oscillations (~ 10 Hz) of a single GPI neuron in the MPTP-treated monkey. The neuron was recorded for 30 min. **(a)** An example of two seconds of the raw analogue signal (amplified by 5000 and 300–6000-Hz band-pass filtered). **(b)** Autocorrelation function of the spike trains of this neuron. **(c)** Power spectrum and **(d)** spectrogram of the full period of the discharge of the cell, confirming that the latter is highly oscillatory, with a frequency centred on ~ 10 Hz (H. Bergman *et al.*, unpublished). Abbreviation: a.u., arbitrary units.

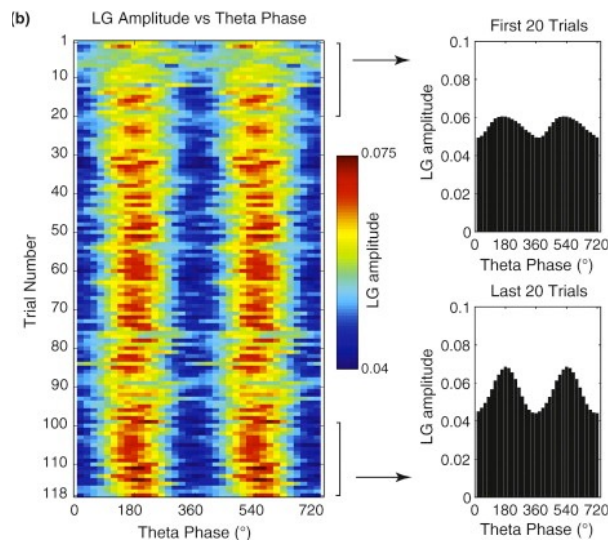
Hammond et al., 2007

Types of functional connectivity:

Cross-Frequency Coupling (CFC)

a.k.a. phase-amplitude coupling

Amplitude of a higher frequency rhythm is modulated by the phase of a lower frequency



- HF activity is believed to reflect more local processing
- LF activity can be synchronized across brain regions

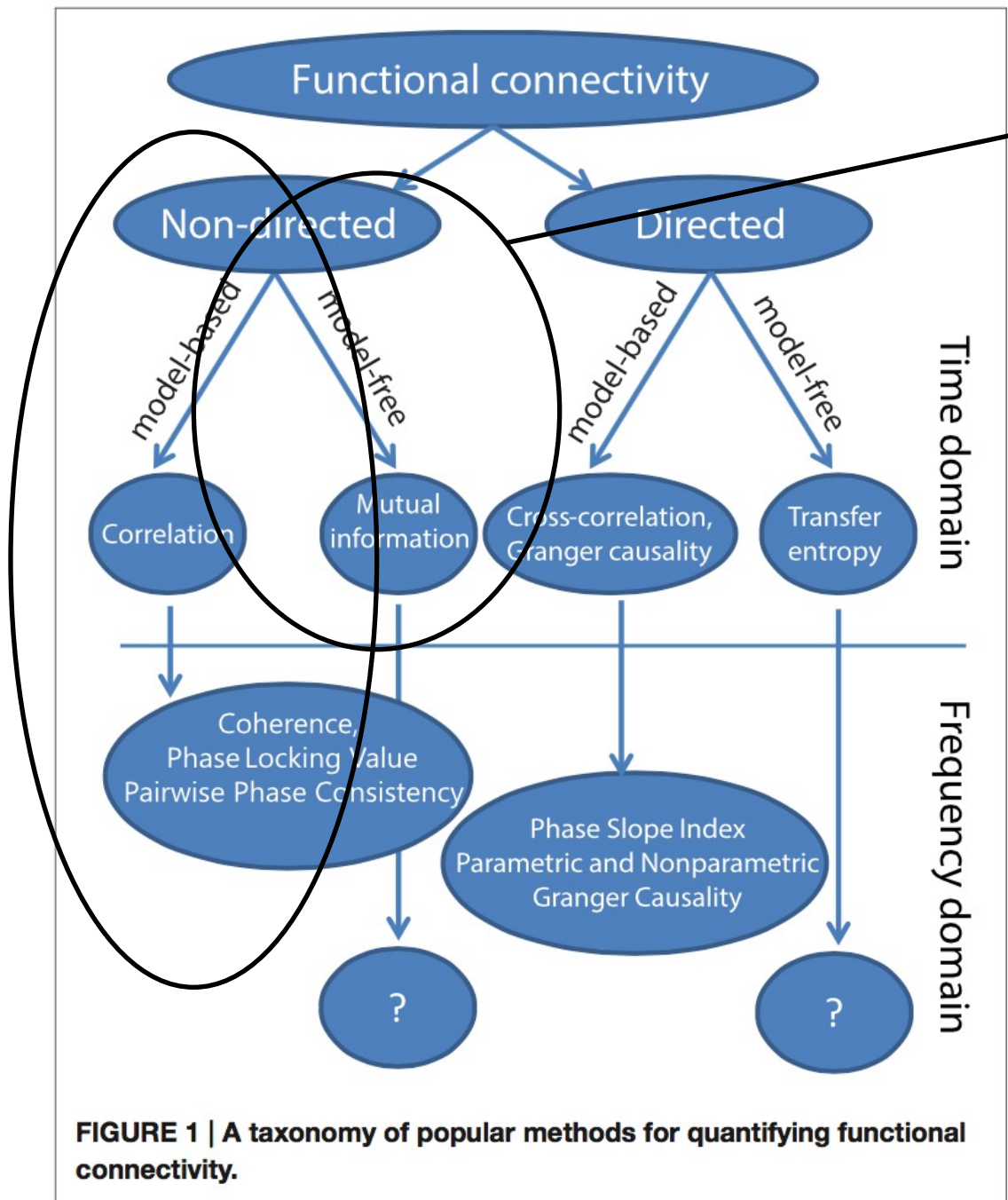


FIGURE 1 | A taxonomy of popular methods for quantifying functional connectivity.

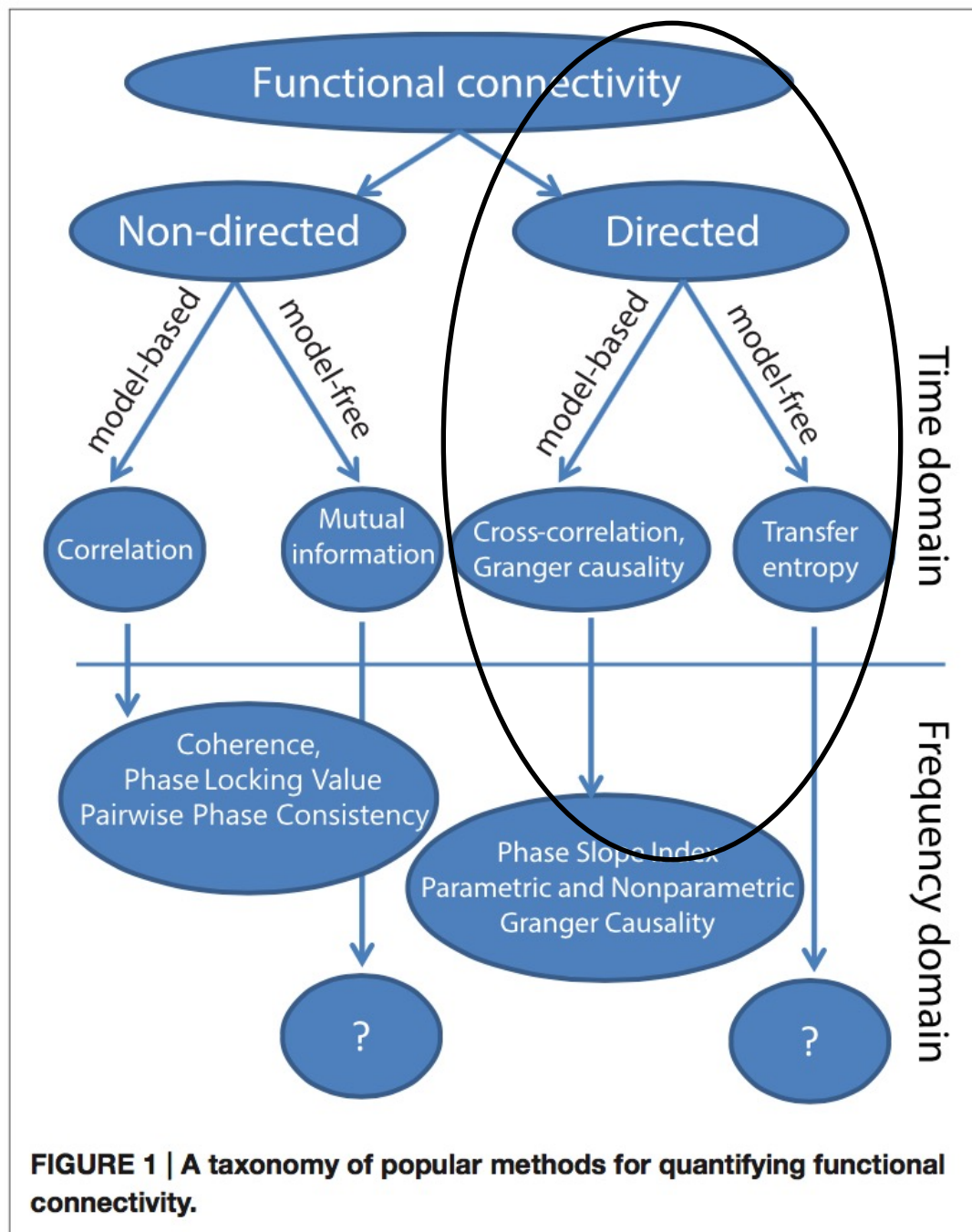
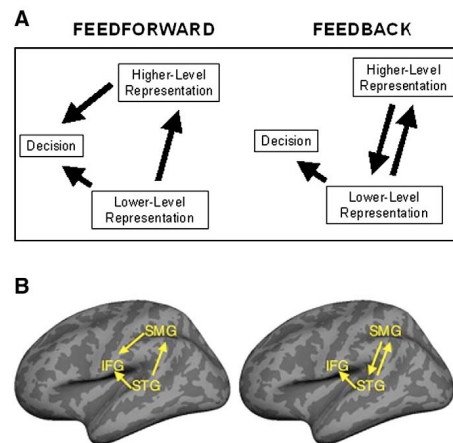


FIGURE 1 | A taxonomy of popular methods for quantifying functional connectivity.

Directed measures of functional connectivity

Attempt to infer the direction of influence between two brain areas (e.g. top-down vs bottom-up)

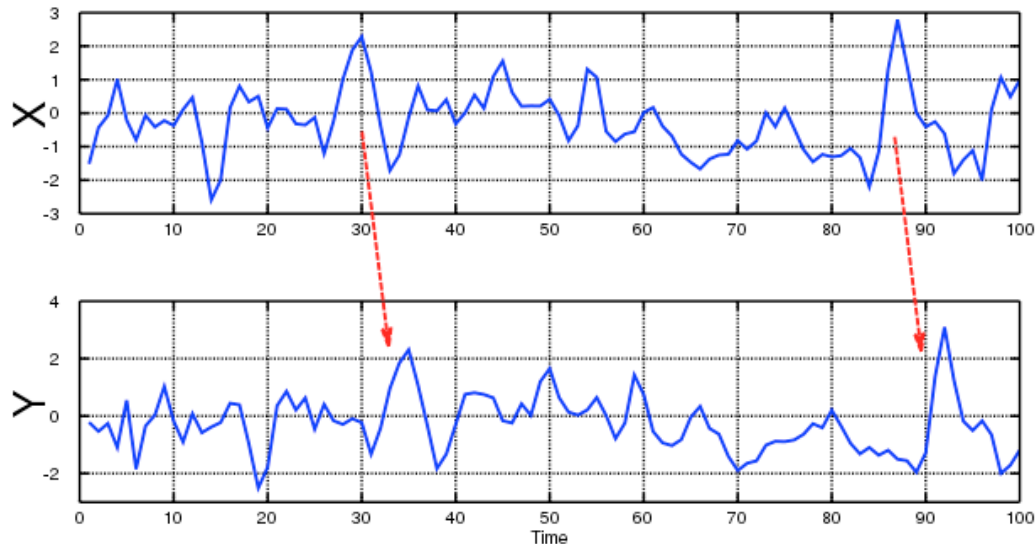


~~True causality is impossible to prove without causal interventions~~

Directed measures of functional connectivity

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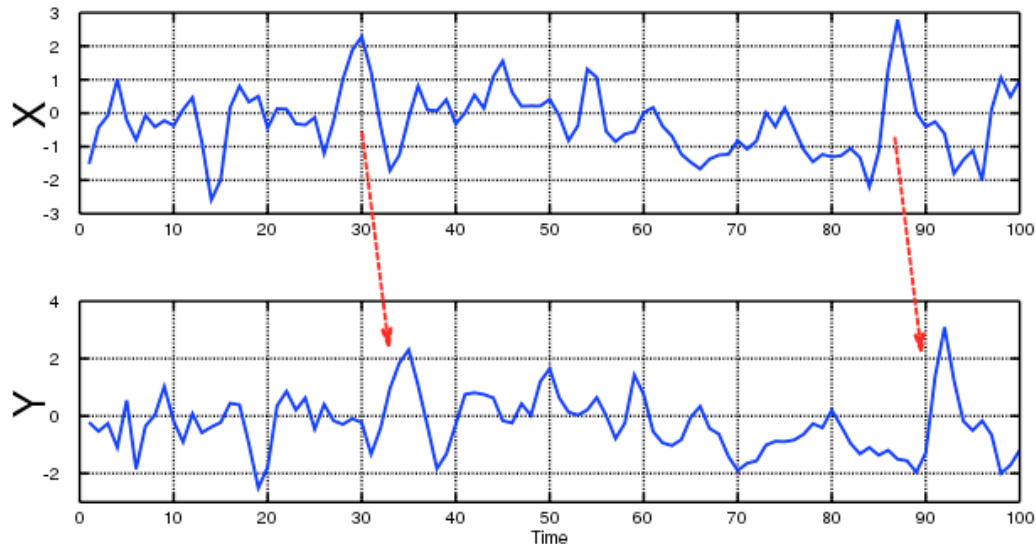
Assess the ability of one time series to predict another



Directed measures of functional connectivity

Granger Causality

Granger: How much does my knowledge of Y improve by knowing the history of X?

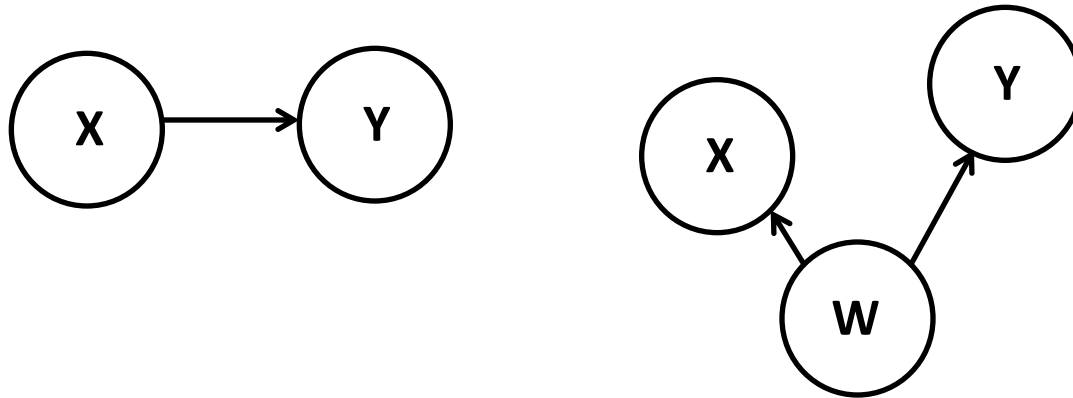


“X Granger-causes Y”

Directed measures of functional connectivity

Granger Causality

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Granger cannot distinguish these possibilities!

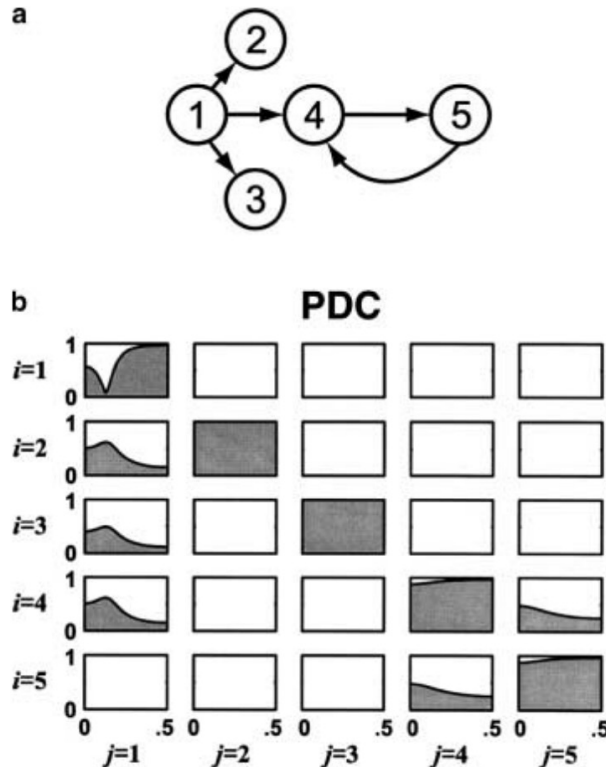
Granger cannot deal with more than 2 nodes at a time

Directed measures of functional connectivity

Partial Directed Coherence (PDC)

Baccala & Sameshima, 2000

- Method for determining directed interactions among multiple nodes
- Uses frequency domain



No Homework!