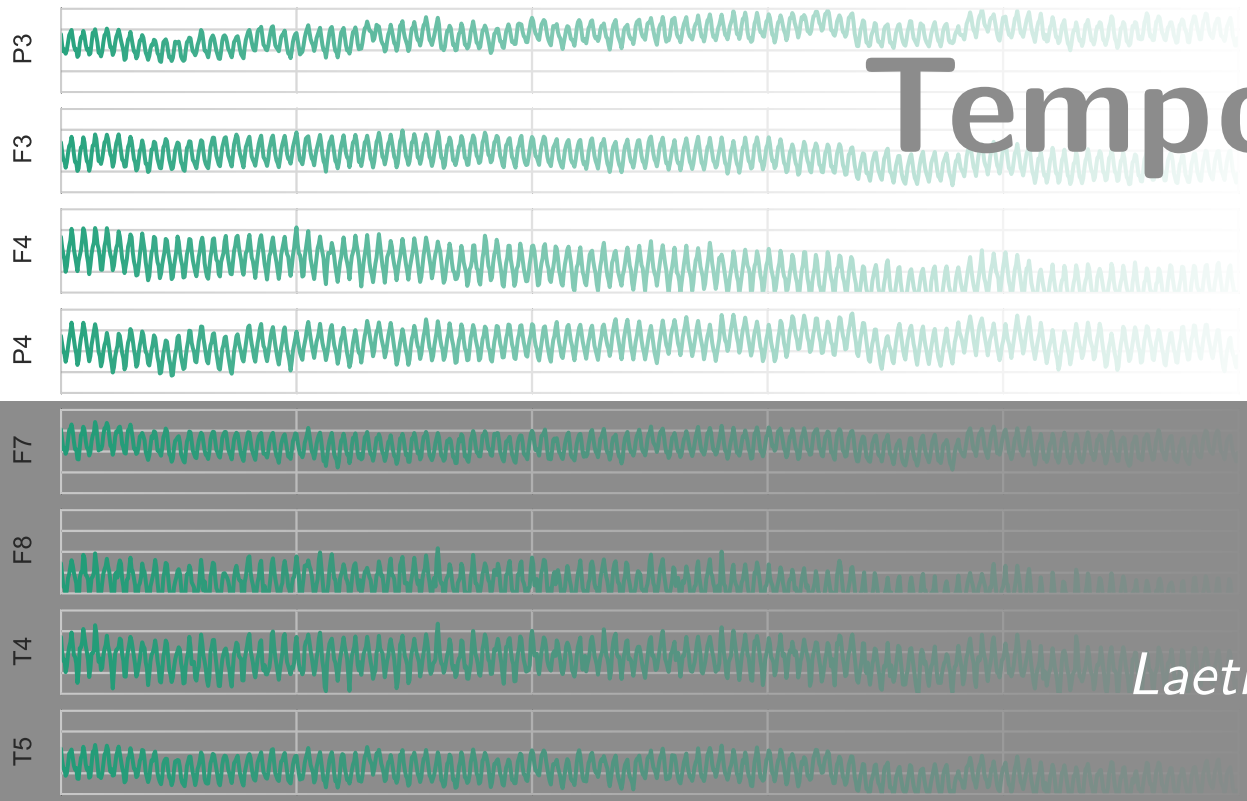
Structural Controllability of EEG Temporal Causal Networks



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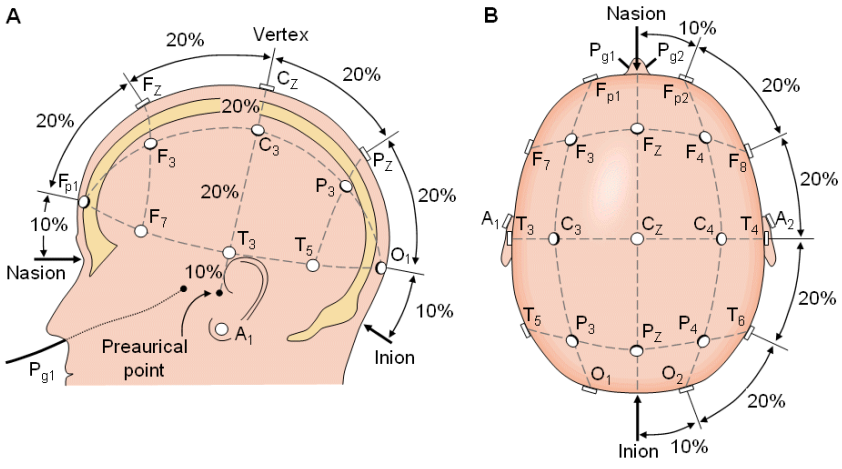
EEG: ElectroEncephaloGram



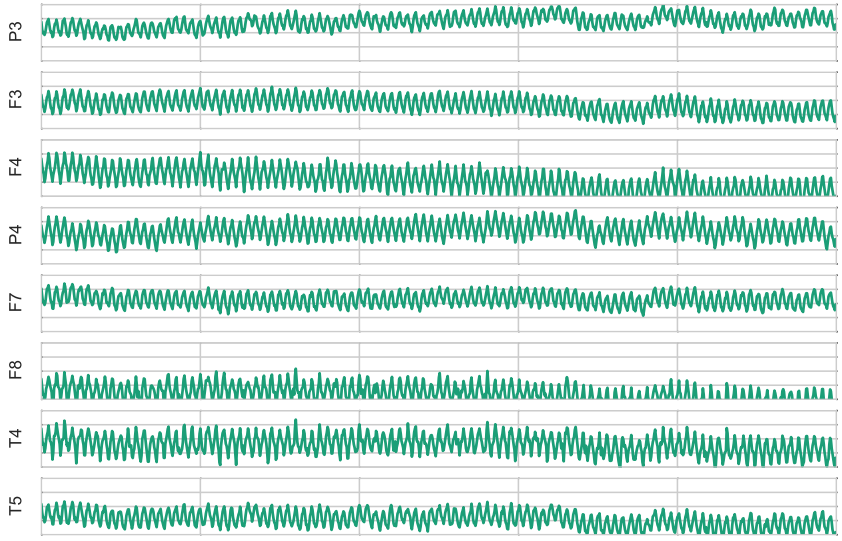
Electrodes measure **local** brain electrical activity.

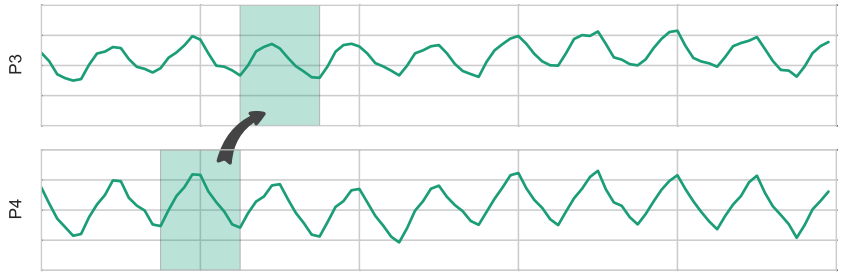
- fixed predetermined positions;
- localized brain activity (electrical fluctuations);

epilepsy, sleep disorders, encephalopathies

Causality

Raw Data





Causality reconstruction

is there a way to reconstruct the causality links between cortical zones?

Approaches:

- Correlation
- Information Dynamics
- Granger Causality

Transer Entropy

Flow of Entropy

- information theory tool
- model-free approach (interactions on neural network can be highly non linear)
- it considers possible information-transfer dalays

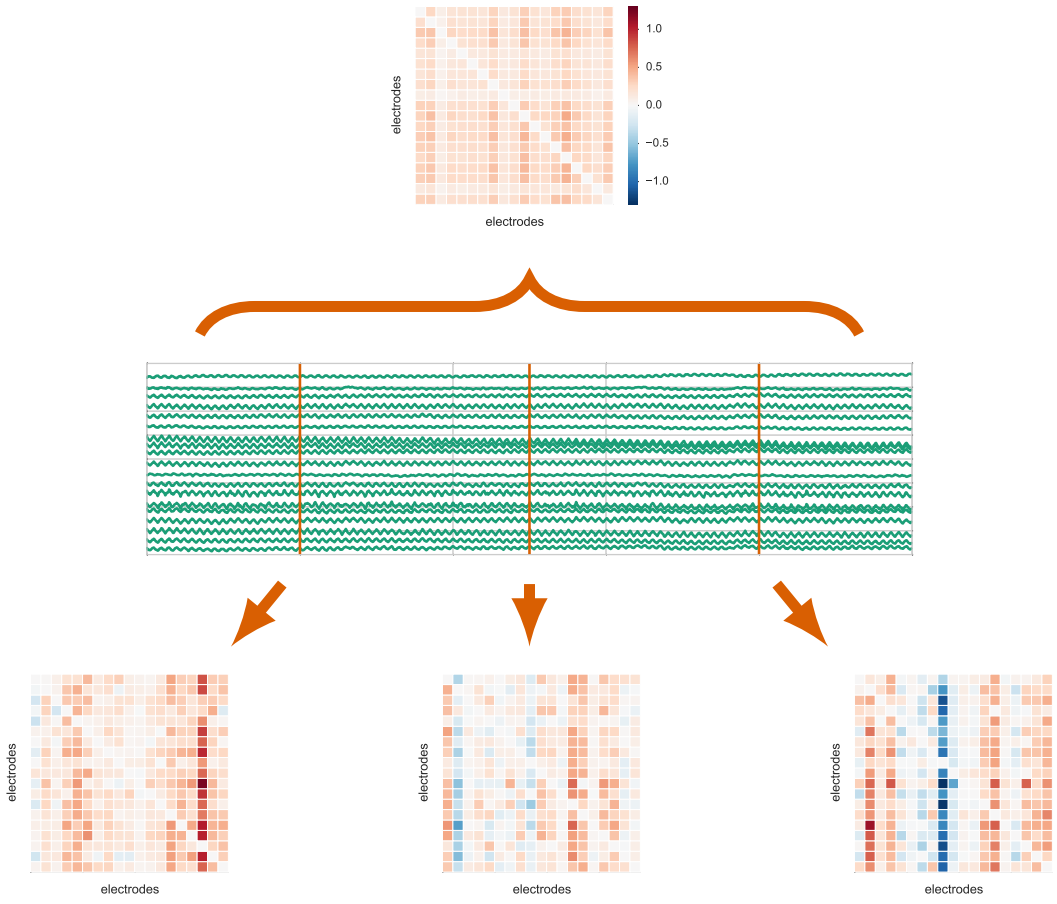
Transfer entropy (TE):

$$\mathrm{TE}_{Y\to X} = H(X_{t+1}|\mathbf{X}_t) - H(X_{t+1}|\mathbf{Y}_t, \mathbf{X}_t)$$

Local Transfer Entropy (LTE):

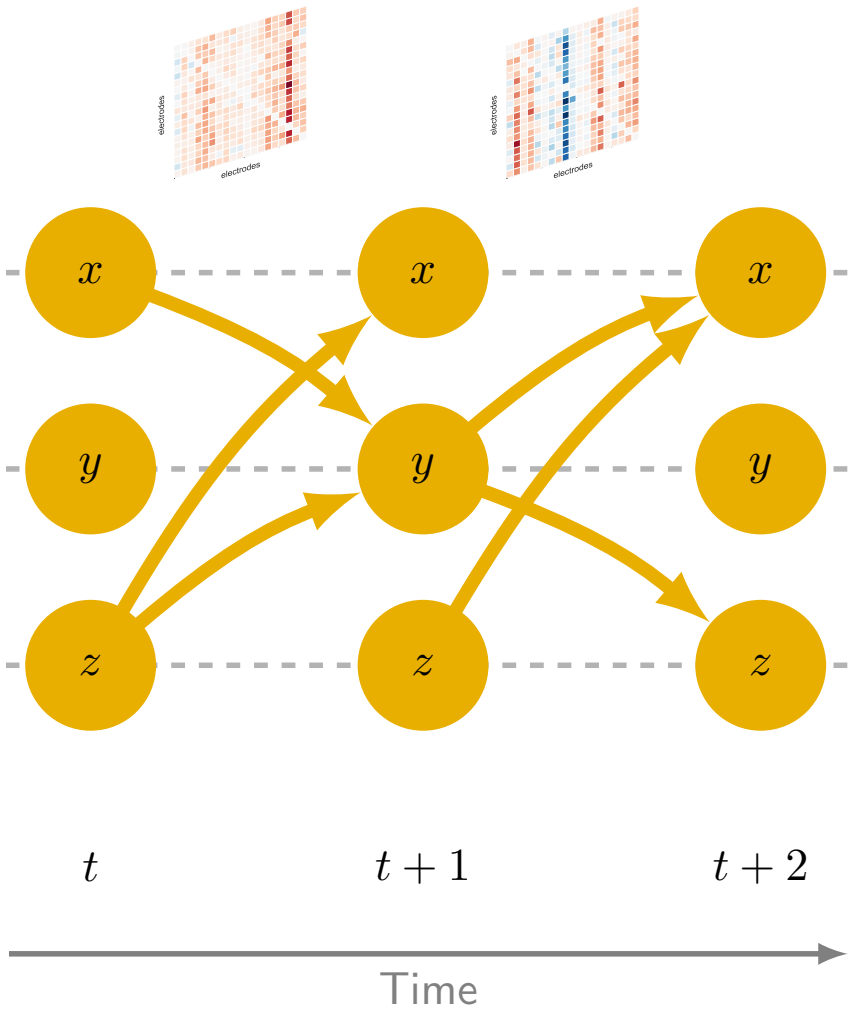
$$\mathrm{te}_{Y\to X}(t+1) = h(x_{t+1}|\mathbf{x}_t) - h(x_{t+1}|\mathbf{y}_t, \mathbf{x}_t)$$

Temporal Causality



Channel to channel causality, computed as average, **wash out** temporal structures.

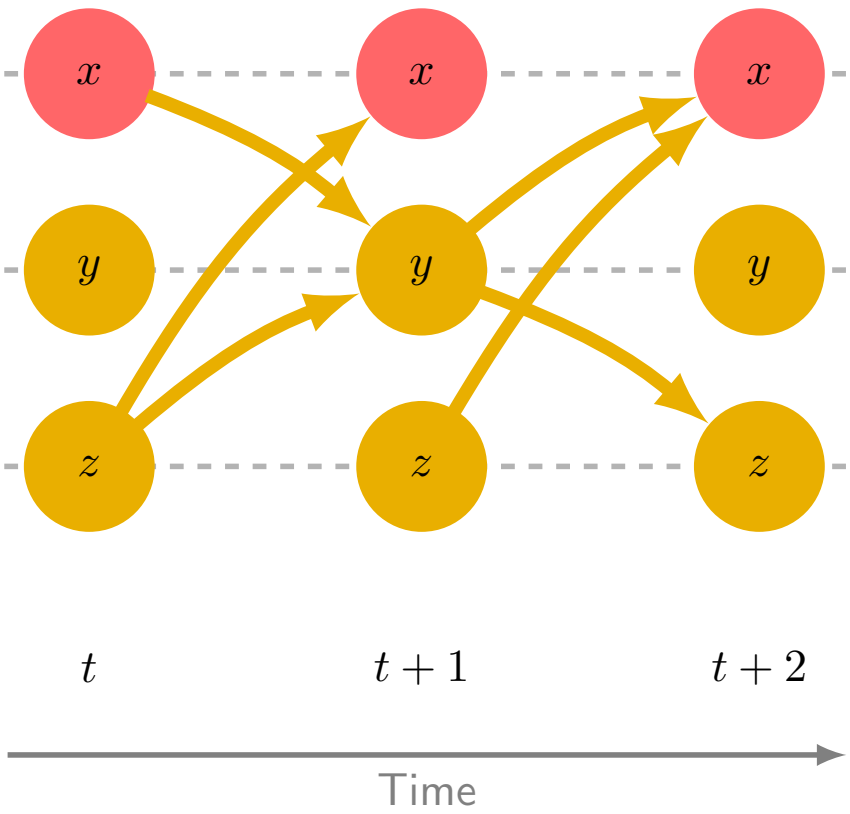
Causality Temporal Network



- local transfer entropy define a causality flow from t to $t+1$;
- causality from x at time t to y at time $t+1$ settles a causality link between them.

Network Control

$$x(t+1) = \mathbf{A}(t)x(t) + \mathbf{B}(t)u(t)$$



How control is performed?

- A single node is controlled for a time range Δt;
- A fraction of the network is indirectly controlled.

Question:

Size of controlled subset from ONE node?

Network Control

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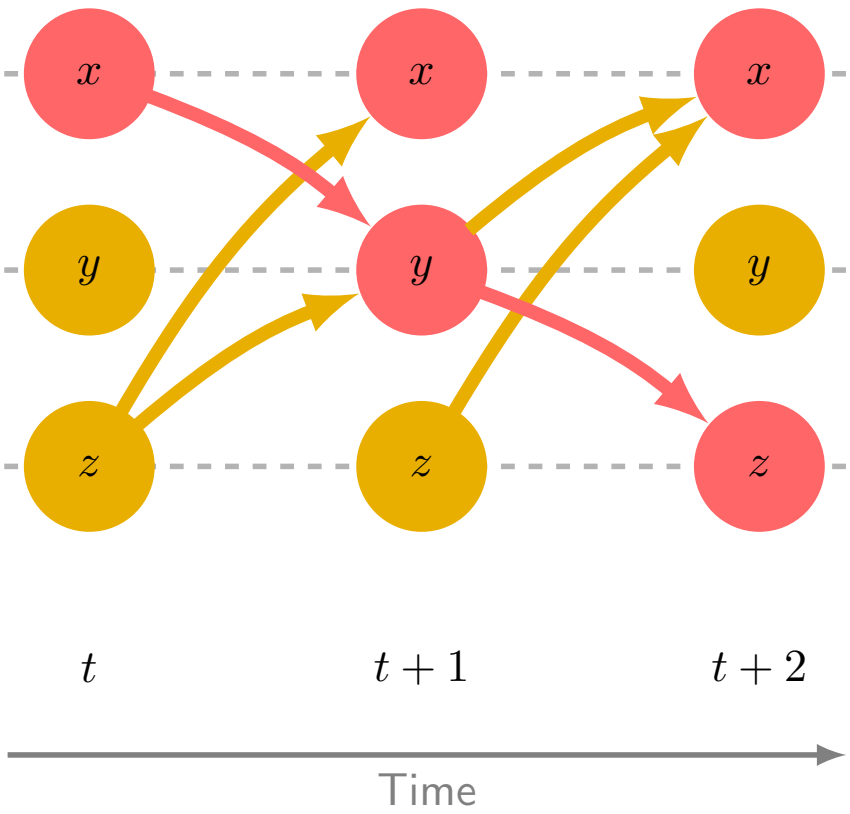

How control is performed?

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Question:

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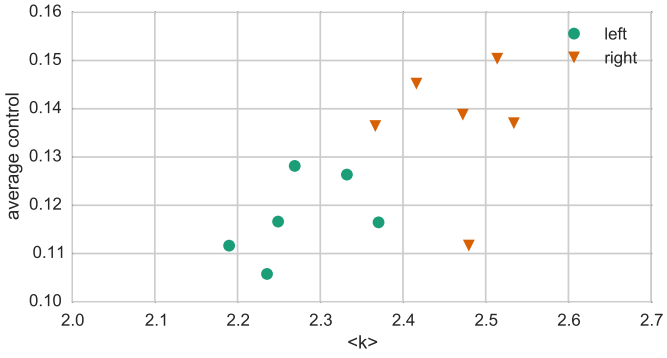
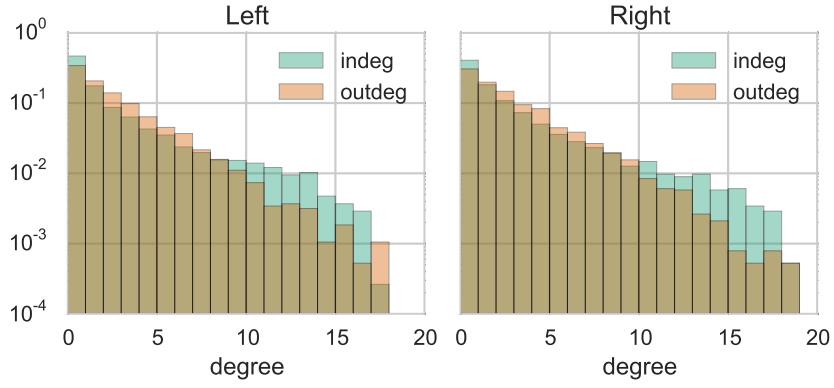
Degree is in control: a first example

Same (right handed) subjects performing tasks with right and left hands

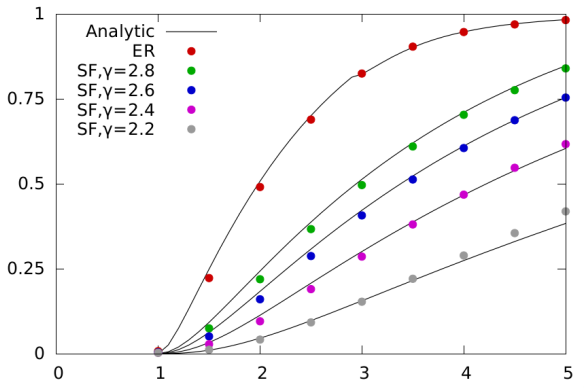




During right-hand movements, the causality network has higher degree, hence higher controllability.

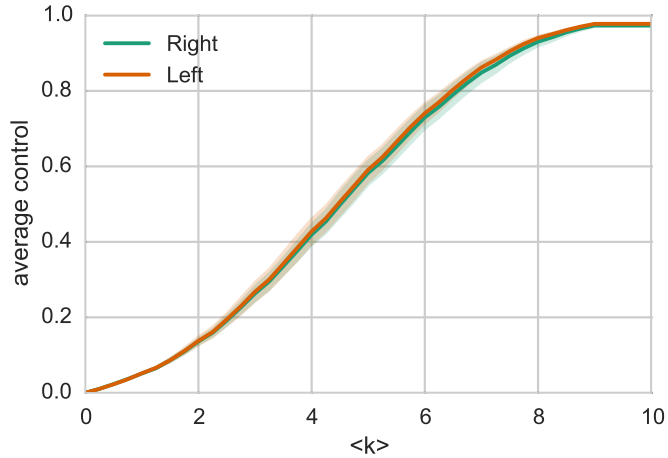
Temporal network reveals degree heterogeneity

Degree is in control: Left/Right



Network control is correlated to the average degree of the network.[1]

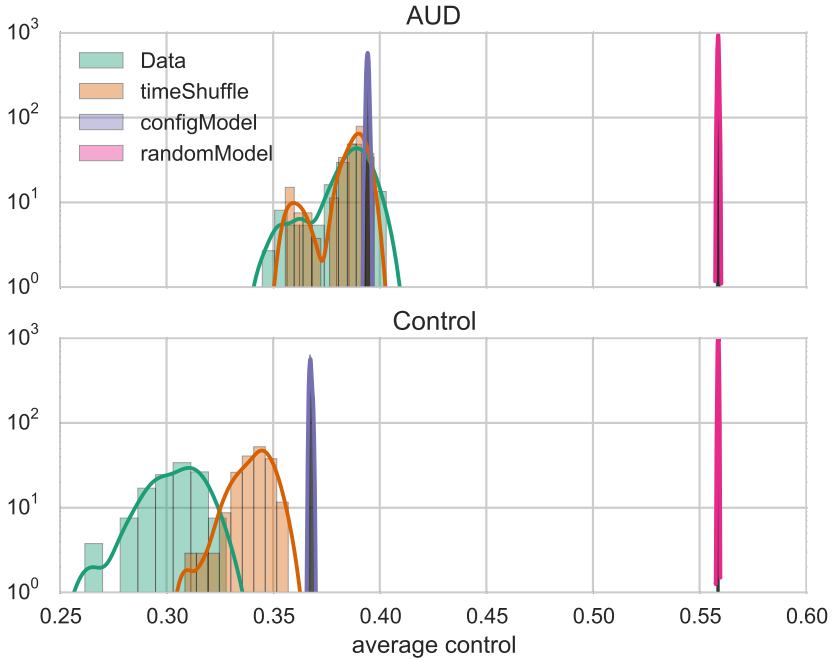
Left and Right forced to have the same average degree

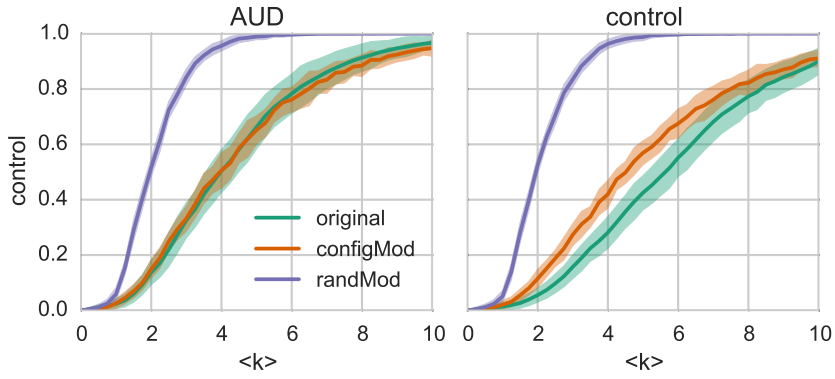


[1] M. Pósfai and P. Hövel. "Phase transition in the controllability of temporal networks". In: *arXiv preprint arXiv:1312.7595* (2013)

Control is bad: AUD

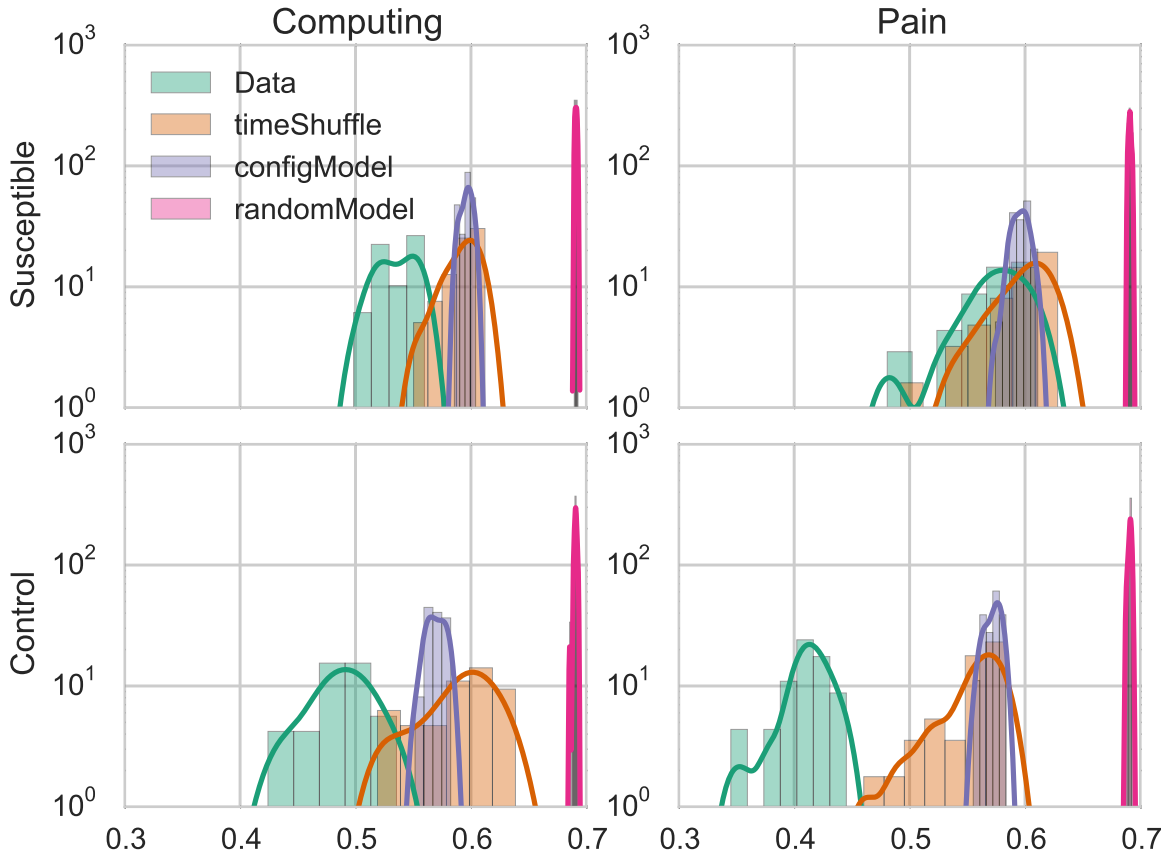
Subjects with alcohol use disorder (AUD) and control subjects.





Control is bad: Hypnosis

Subject susceptible to hypnosis and control subject.



Conclusions and Remarks

- Local Transfer Entropy as structured data
- Brain avoid controllable structures (possibly avoiding unstable states)
- Disorder affected systems show more controllable structures

Thanks to:

- Laetitia Gauvin
- Giovanni Petri