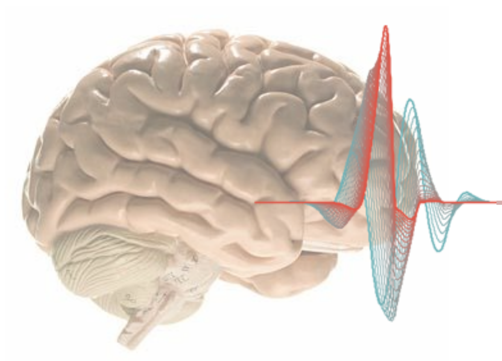

Suspicious of fluctuations?

A signal processing view on dynamic functional connectivity

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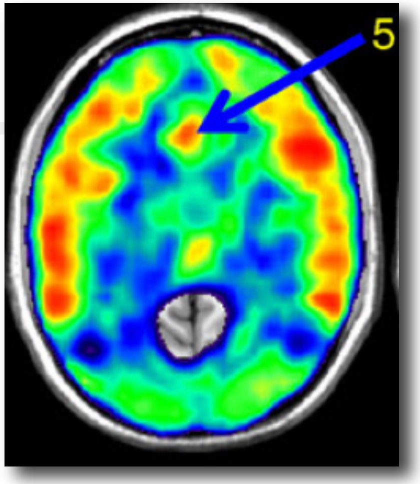
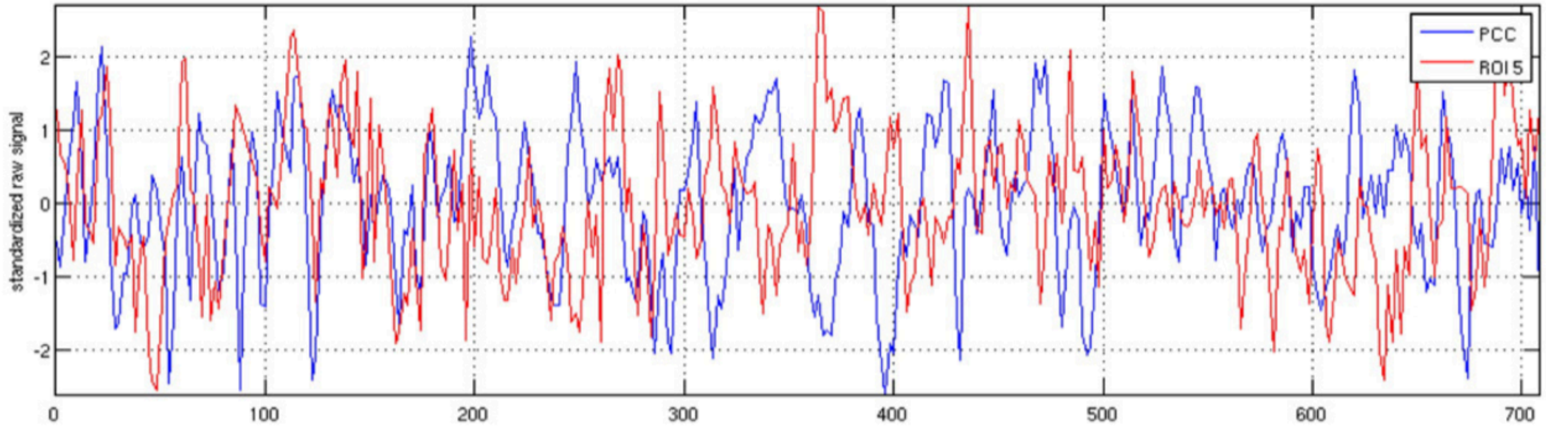
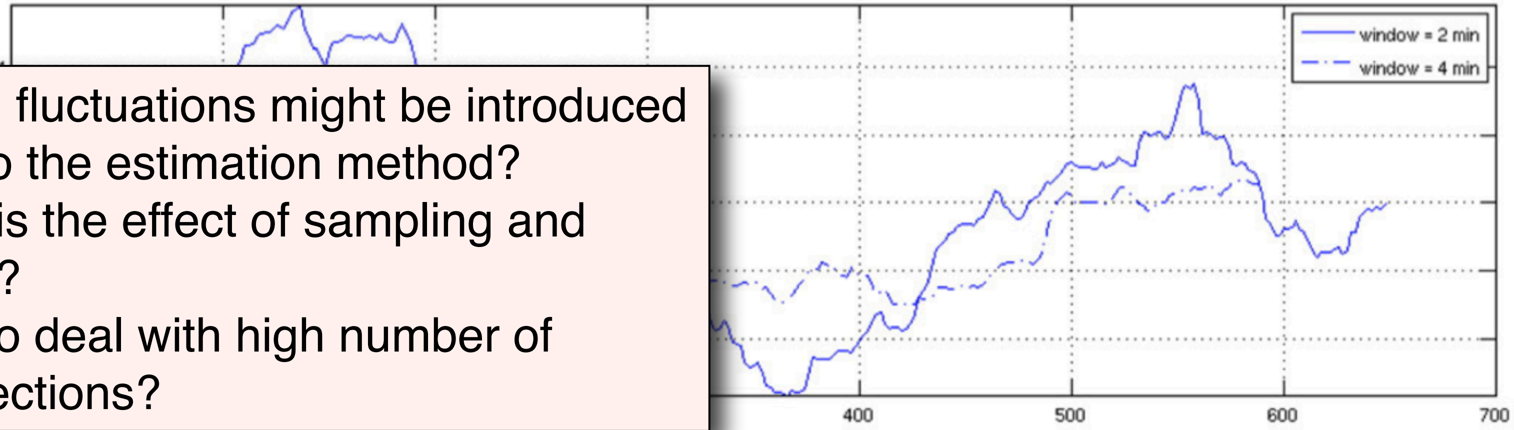
The Dynamic Human Brain, HBM Morning Workshop, June 2014, Hamburg, Germany

Estimating dynamic FC



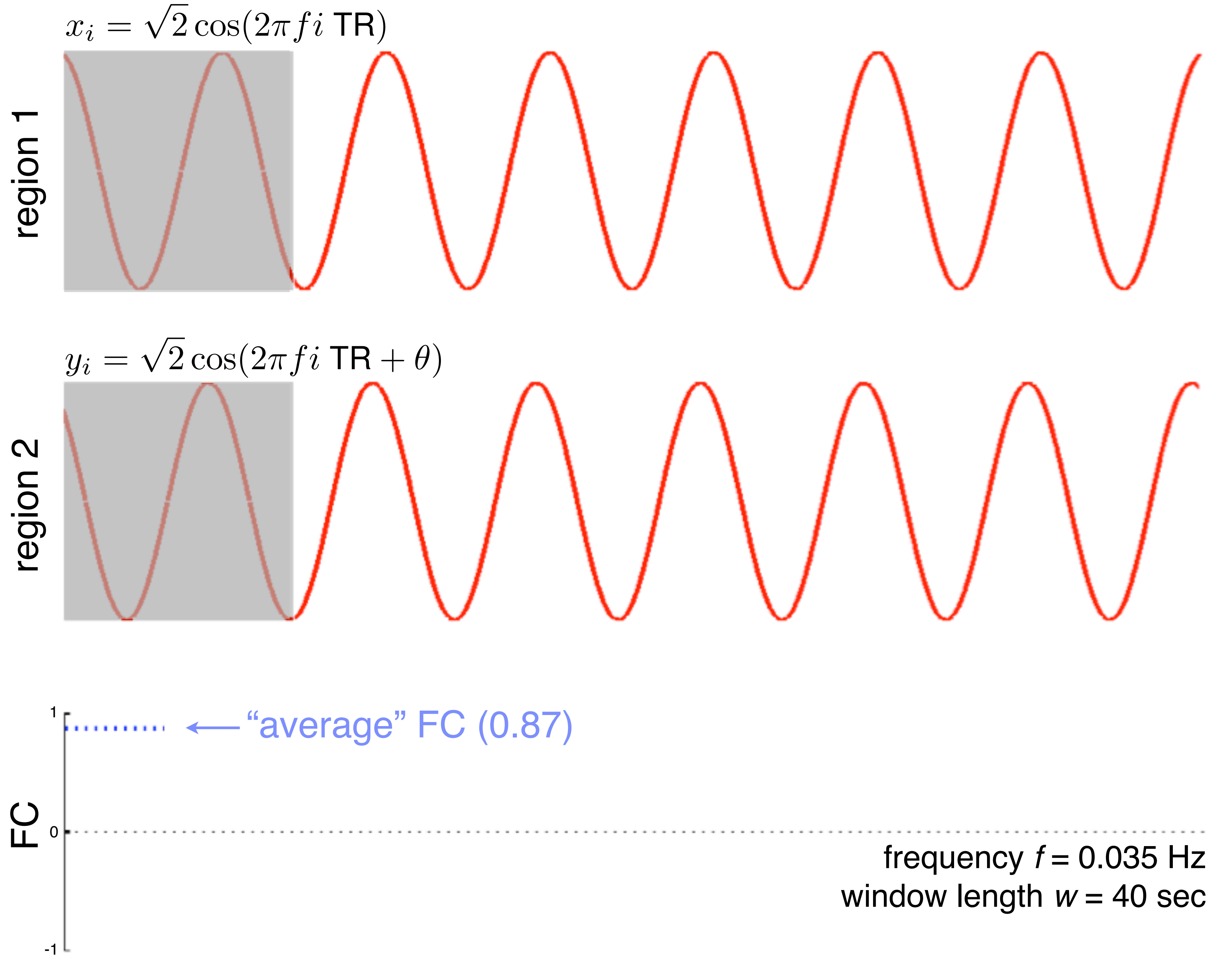
- Look at network dynamics
  - Parcellation can be atlas based or functional
  - Sliding-window pairwise correlations



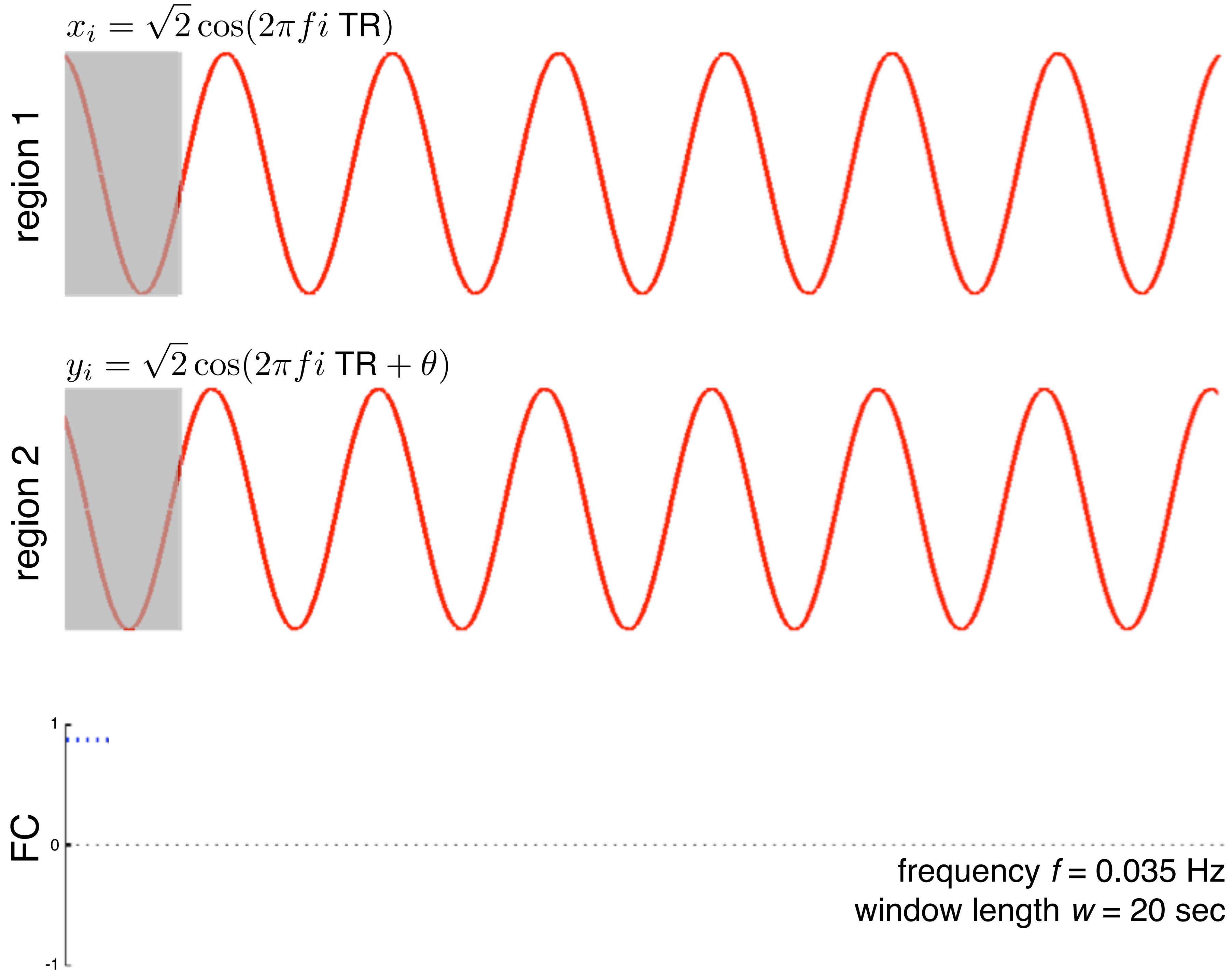


- which fluctuations might be introduced due to the estimation method?
- what is the effect of sampling and noise?
- how to deal with high number of connections?

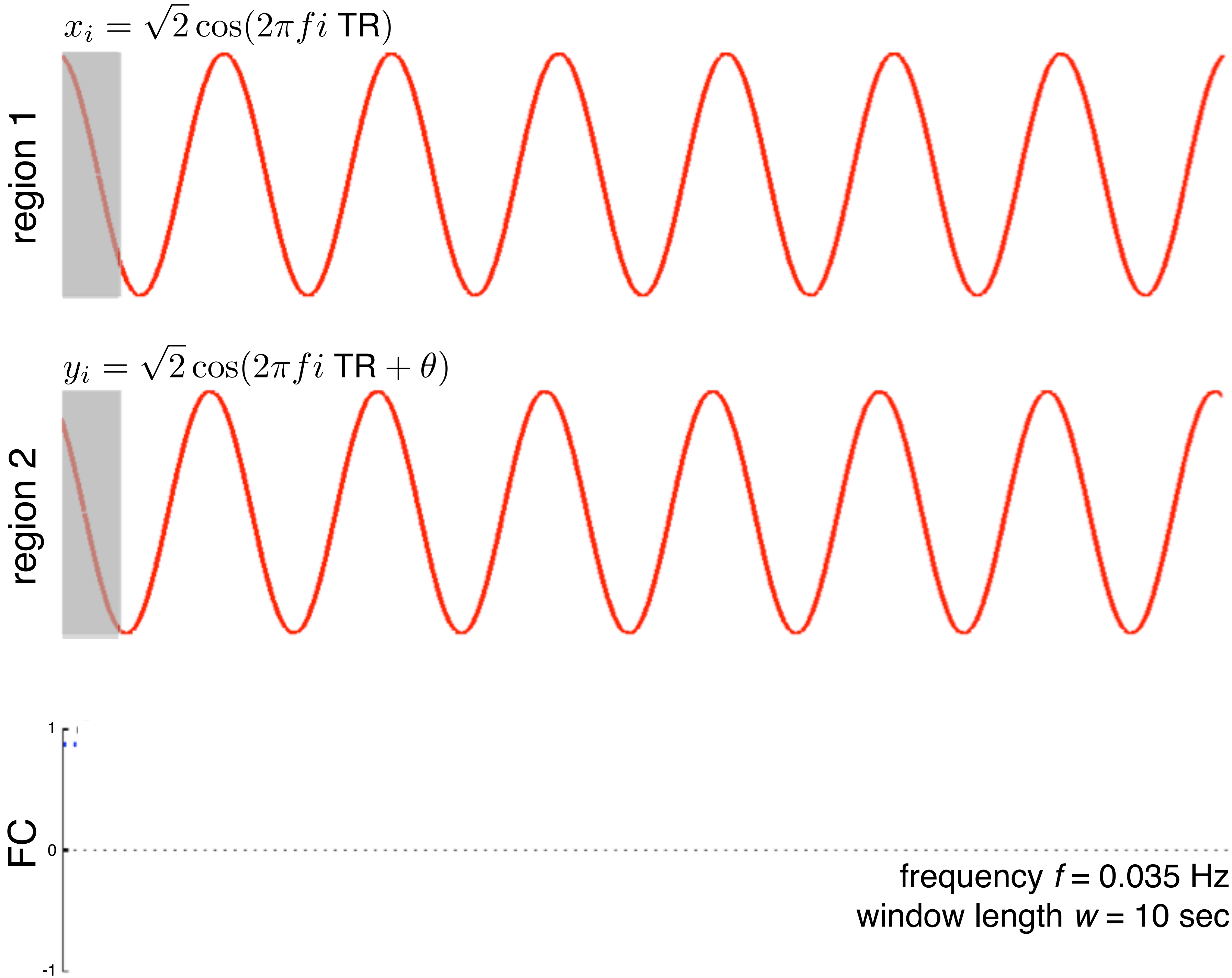
[Chang and Glover, NeuroImage, 2010]



$x_i = \sqrt{2}\cos(2\pi f i \text{ TR})$
region 1
$y_i = \sqrt{2}\cos(2\pi f i \text{ TR} + \theta)$
region 2
1
"average" FC (0.87)
FC
0
-1
frequency f = 0.035 Hz
window length w = 40 sec



$x_i = \sqrt{2}\cos(2\pi f i \text{ TR})$
region 1
$y_i = \sqrt{2}\cos(2\pi f i \text{ TR} + \theta)$
region 2
FC
1
0
-1
frequency f = 0.035 Hz
window length w = 20 sec

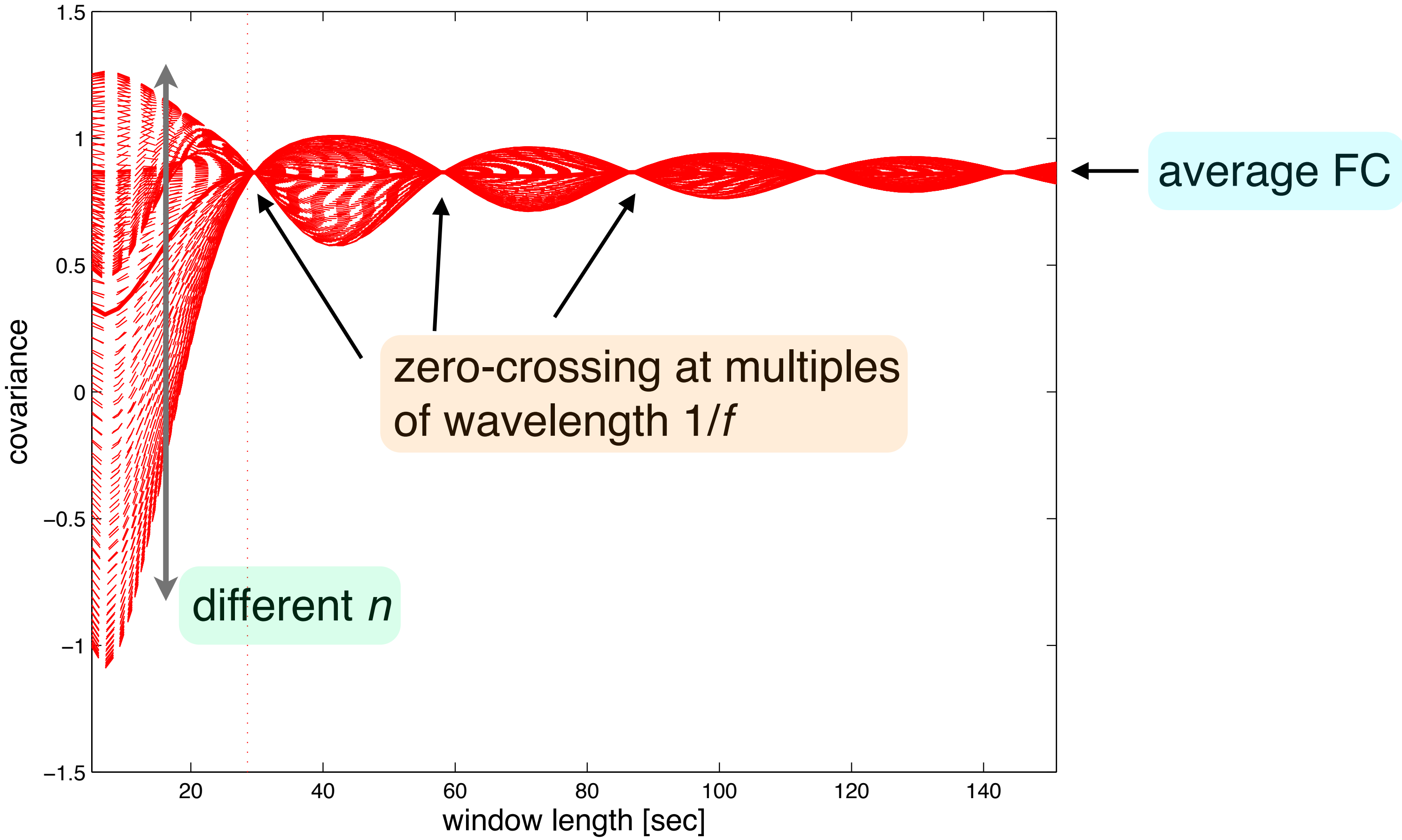


$x_i = \sqrt{2}\cos(2\pi f i\ \mathsf{TR})$
region 1
$y_i = \sqrt{2}\cos(2\pi f i\ \mathsf{TR} + \theta)$
region 2
FC
1
0
-1
frequency f = 0.035 Hz
window length w = 10 sec

Spurious fluctuations of dynFC

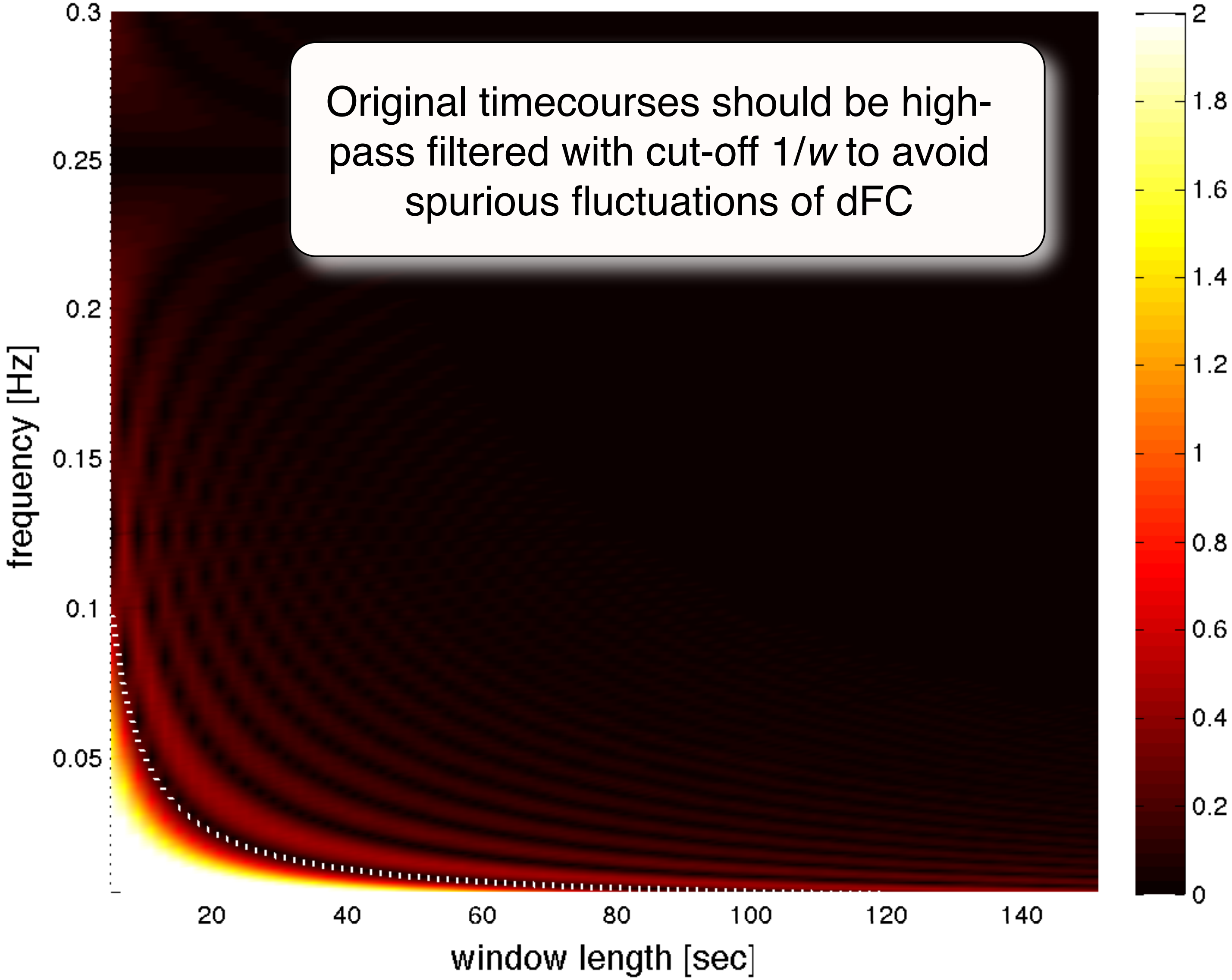
- Sliding-window covariance revisited:

$$c_{xy}[n] = \cos(\theta) + \frac{1}{w\pi f}\cos(2\pi f n\mathrm{TR} + \theta)\sin(\pi f w\mathrm{TR}) - \frac{2}{w^2\pi^2 f^2}\cos(2\pi f n\mathrm{TR})\cos(2\pi f n\mathrm{TR} + \theta)\sin^2(\pi f w\mathrm{TR})$$

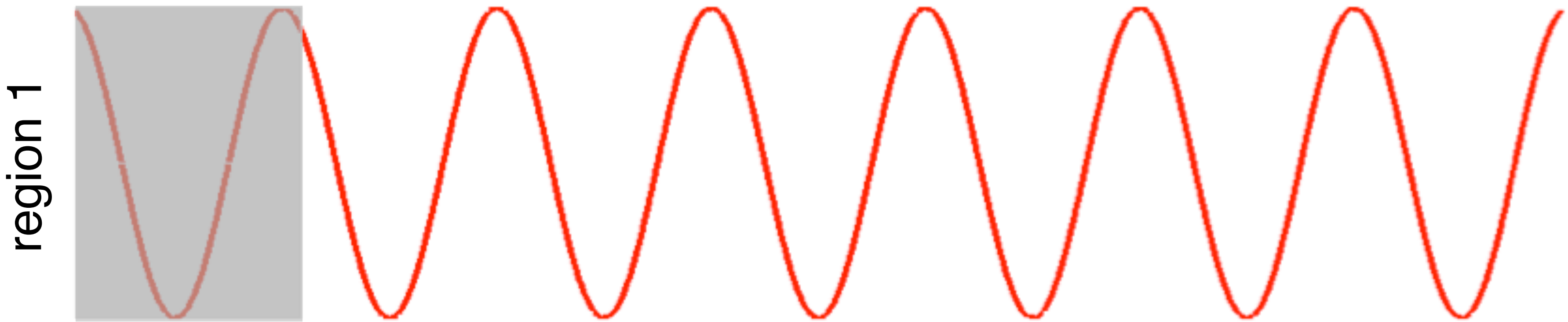


Spurious fluctuations of dynFC

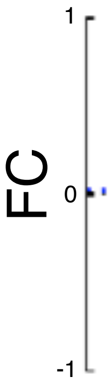
- Max-min for all different window shifts *n*



$x_i = \sqrt{2}\cos(2\pi f i \, \mathsf{TR})$



$y_i = \sqrt{2}\cos(2\pi f i \, \mathsf{TR} + \theta)\cos(2\pi f_0 i \, \mathsf{TR})$



frequency f = 0.035 Hz
window length w = 30 sec
modulation at 0.005 Hz

Real fluctuations of dynFC

- Two deterministic signals:

$$\begin{aligned} x_i &= \sqrt{2}\cos(2\pi f i \,\text{TR}) \\ y_i &= \sqrt{2}\cos(2\pi f i\text{TR})\cos(2\pi f_0 i\text{TR}) \end{aligned}$$

  - modulatory component with frequency $f_0 << f$

- Sliding-window covariance revisited:

$$c_{xy}[n] = \frac{\text{TR}}{w}\frac{\sin(\pi f_0 w)}{\sin(\pi f_0)}\cos(2\pi f_0 n\text{TR}) + \text{harmonics}$$

weighting depends
on low-pass filtering
properties of window:
f_0 below $1/w$
(or equivalent cut-off in case of tapering)

dynFC recovers
modulatory component!

Real fluctuations of dynFC

- Two deterministic signals:

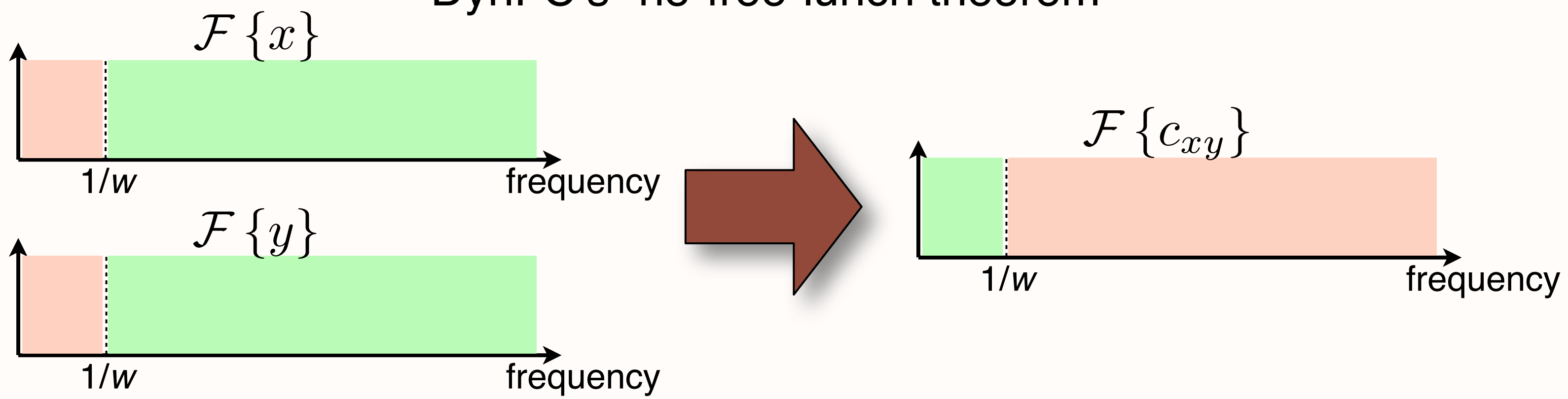
$$
\begin{aligned}
x_i &= \sqrt{2}\cos(2\pi f i\ \mathrm{TR}) \\
y_i &= \sqrt{2}\cos(2\pi f i \mathrm{TR})\cos(2\pi f_0 i \mathrm{TR})
\end{aligned}
$$

  - modulatory component with frequency $f_0 << f$

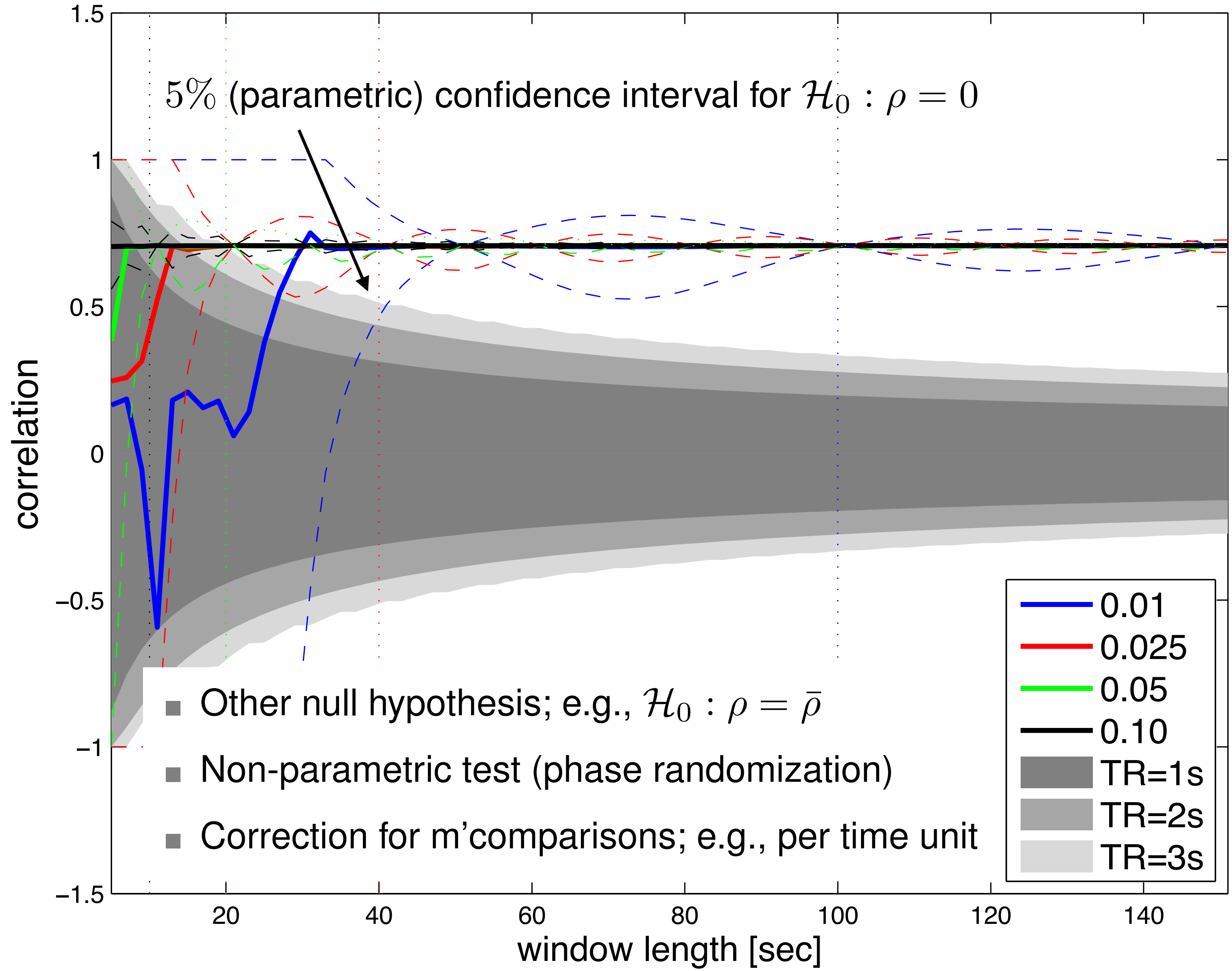
- Sliding-window covariance revisited:

$$
c_{xy}[n] = \frac{\mathrm{TR}}{w}\frac{\sin(\pi f_0 w)}{\sin(\pi f_0)}\cos(2\pi f_0 n \mathrm{TR}) + \text{harmonics}
$$

DynFC's "no-free-lunch theorem"



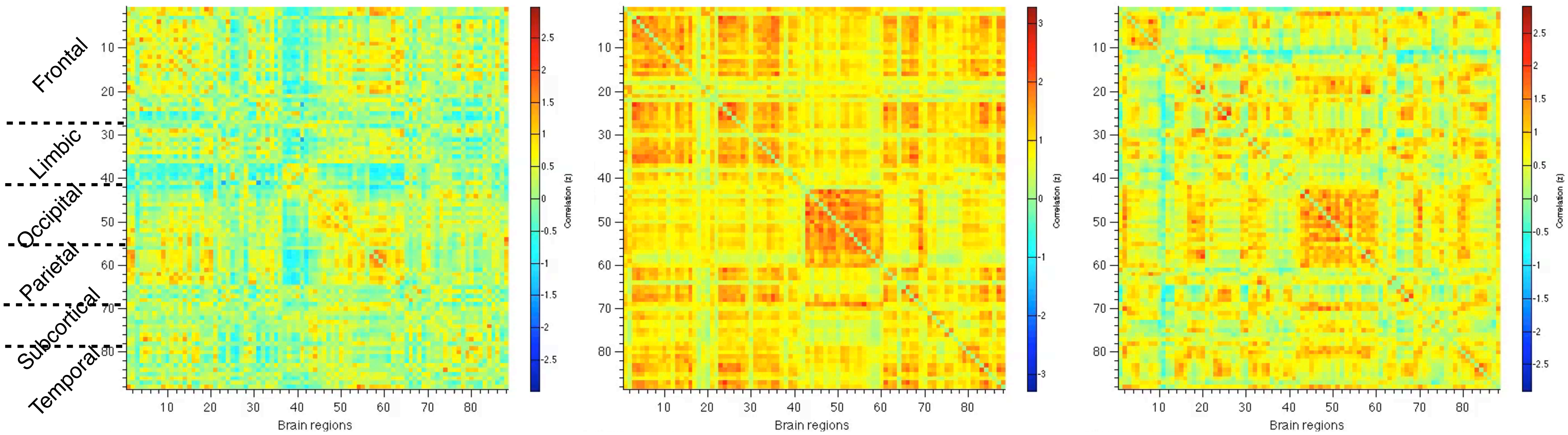
Effect of sampling (TR) and noise



- Other null hypothesis; e.g., $\mathcal{H}_0 : \rho = \bar{\rho}$
- Non-parametric test (phase randomization)
- Correction for m'comparisons; e.g., per time unit

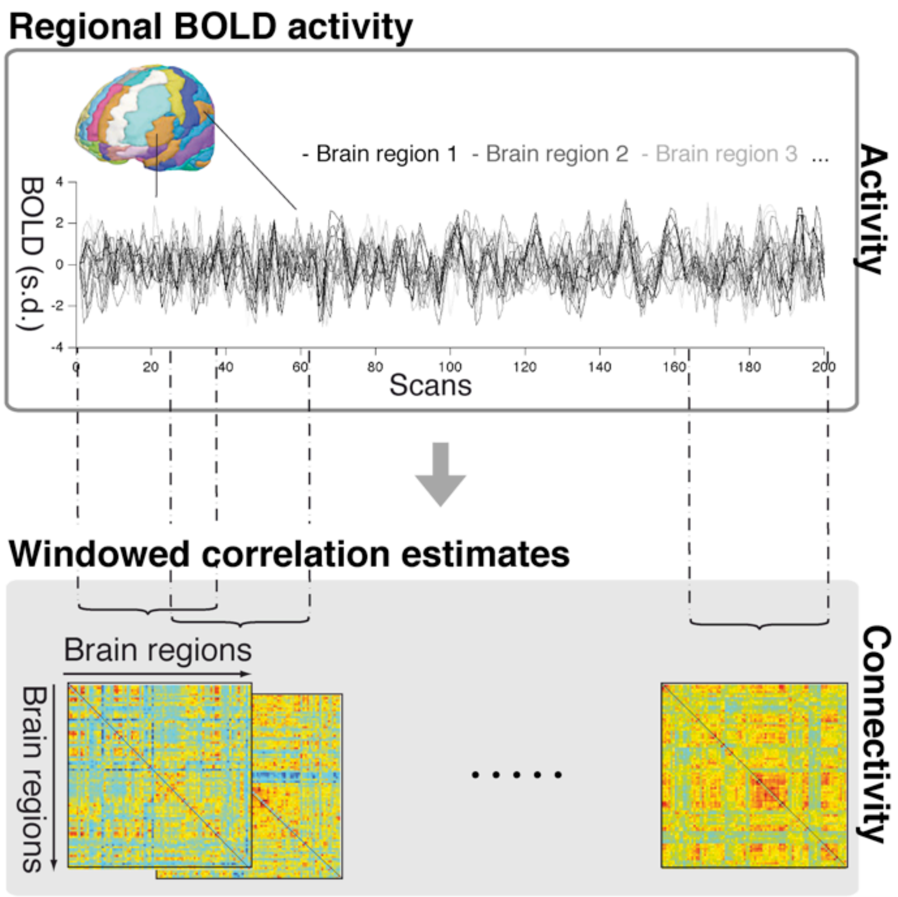
DynFC is not about data reduction

- Sliding window correlation in 3 healthy subjects
  - Window length is 30 TRs, step of 2 TRs, TR=1.1sec

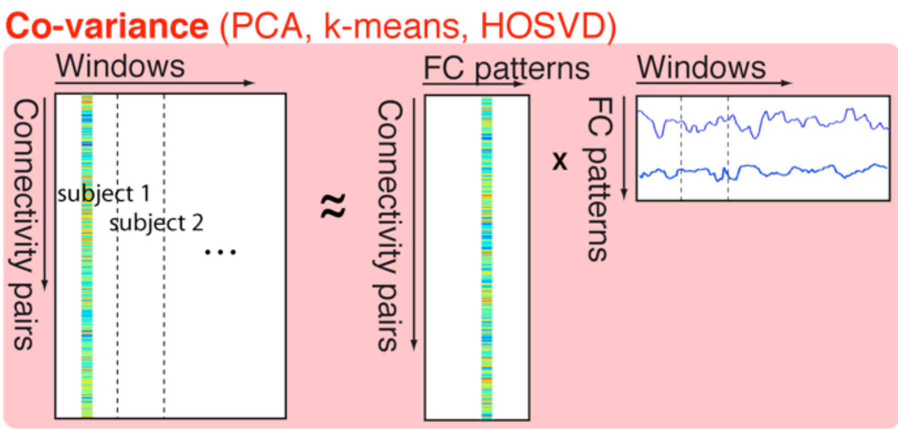


  - Number of connections grows quadratically with #regions
  - Rank of each FC frame is limited by window length (in TRs)

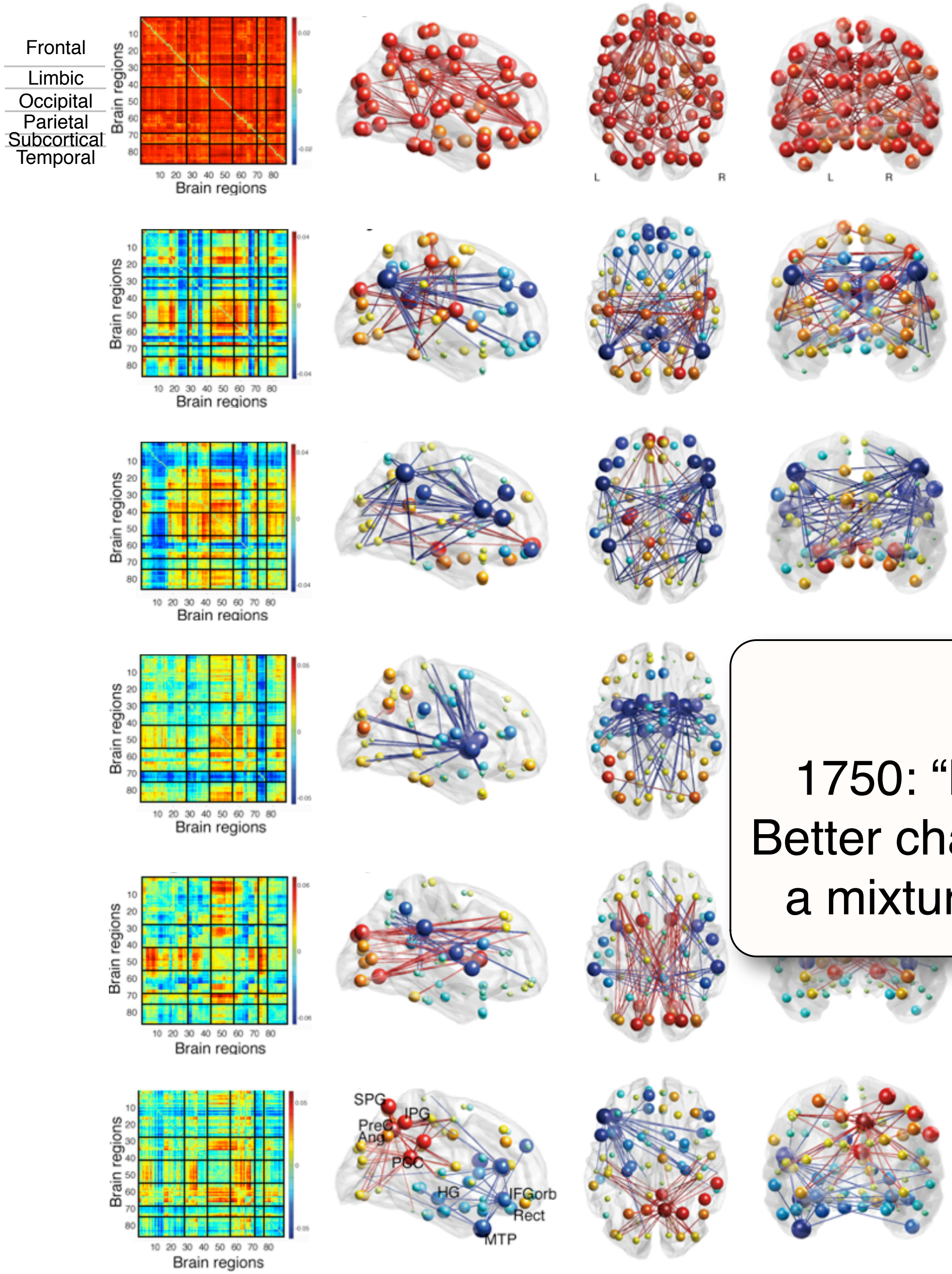
Building blocks of dynFC



- Various types of matrix factorizations are possible
  - k-means
  - PCA
  - sparsity constraints
  - ...
- FC patterns are in common for all subjects



Eigenconnectivities



global fluctuations in FC

cingulate gyri, medial frontal gyri,
precuneus (default-mode network)
primary sensory in red

inferior and middle frontal gyri, inferior
parietal
(fronto-parietal)

presentation O-W2

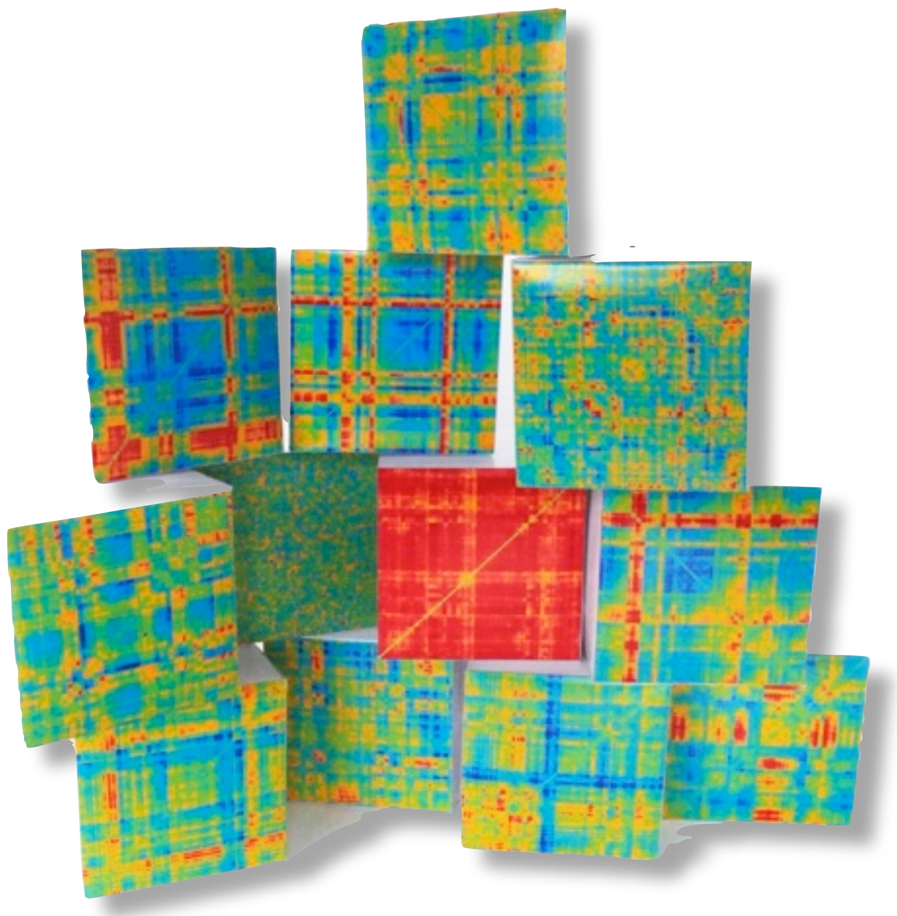
1750: “Dynamic functional connectivity: Better characterized by separated states or a mixture of patterns?” (**Nora Leonardi**)

posterior DMN
temporal and inferior frontal

positive
0
negative

[Leonardi et al, NeuroImage, 2013]

Thank you for the dynamical attention



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