Infra-slow brain dynamics as a marker for cognitive function and decline

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Brain activity: Many scales

Sejnowski, Churchland and Movshson, 2014, Nature Neuroscience
How relevant are slow (<1 Hz) and infra-slow (<0.1 Hz) fMRI brain dynamics for human cognition and behavior?
Gaussian Process Factor Analysis (GPFA)

Technique for simultaneously denoising and extracting smooth, low-dimensional dynamics at characteristic timescales


\[
y_{:,t} \in \mathbb{R}^{q \times 1} \quad \text{high-dimensional fMRI data}
\]
\[
x_{:,t} \in \mathbb{R}^{p \times 1} \quad \text{low-dimensional GPFA latent components (p < q)}
\]
\[
y_{:,t} | x_{:,t} \sim \mathcal{N}(Cx_{:,t} + d, R) \quad \text{linear-Gaussian relationship}
\]
where \( C \) weight matrix
\[
d \in \mathbb{R}^{q \times 1} \quad \text{mean of each fMRI series}
\]
and \( R \in \mathbb{R}^{q \times q} \quad \text{independent variances}

\[
x_{t:} \sim \mathcal{N}(0, K_i) \quad \text{GPFA latent dimensions, with}
\]
\[
K_i \in \mathbb{R}^{T \times T} \quad \text{temporal covariance being a squared exponential function}
\]
\[
K_i(t_1, t_2) \propto \exp\left(-\frac{(t_1-t_2)^2}{2\tau_i^2}\right)
\]

\[
\theta = \{C, d, R, \tau_1, ..., \tau_p\} \quad \text{GPFA parameters learnt via Expectation Maximization [4]}
\]
GPFA Latents: Slow dynamics and Spatial modes

N=8000 fMRI scans from HCP database
Slow trajectories characterize cognitive states

Language

GP trajectories

GP spectra

IRASA oscillations

fractal

\( \tau_1 = 8329 \text{ ms} \)

\( \tau_2 = 3798 \text{ ms} \)
Slow latents predict cognitive score variations
Slow latents mark cognitive decline

Data source: ADNI
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