Transient polysynaptic resting-state components map to known functional systems

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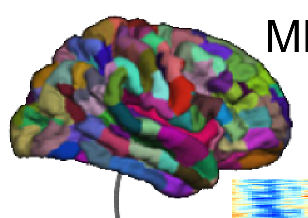
Brain CONNECTIVITY, DYNAMICS and COMMUNICATION

- A growing body of literature highlights the non-stationary nature of **resting-state fMRI** signals and non-trivial **brain dynamics** (*Hutchison2013*)
- **Time-average functional correlations** are partially predicted by different aspects of the brain **structural architecture** (*Goñi2014*), but there is **no one-to-one correspondence** between structural and time-average functional links
- **Jointly considering non-stationarities of the resting-state interactions** and the **underlying structural network** is fundamental to understand **how information is exchanged between different brain regions**

✔ We integrate DSI-derived structural connectivity (*SC*) and fMRI dynamics into a single **multilayer network *M*** (*Kivela2014*) to investigate **transient assemblies of spatio-temporal coherence** and viable pathways for communication

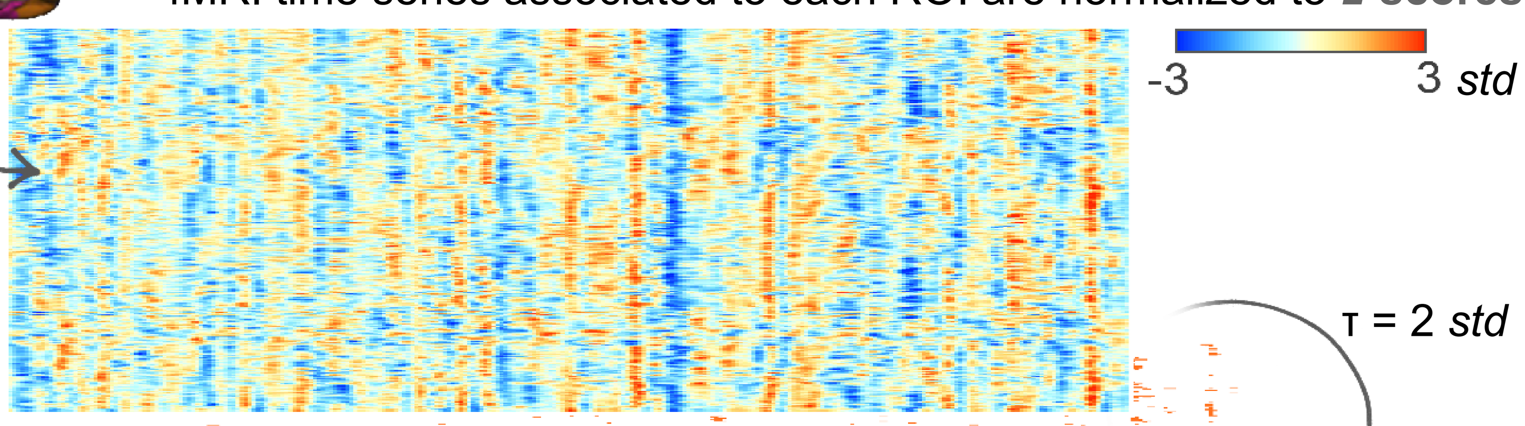
Methods: SPATIO-TEMPORAL BRAIN NETWORKS

71 healthy subjects (29±9yo, 28F): **MPARGE**, **DSI**, **resting-state fMRI**

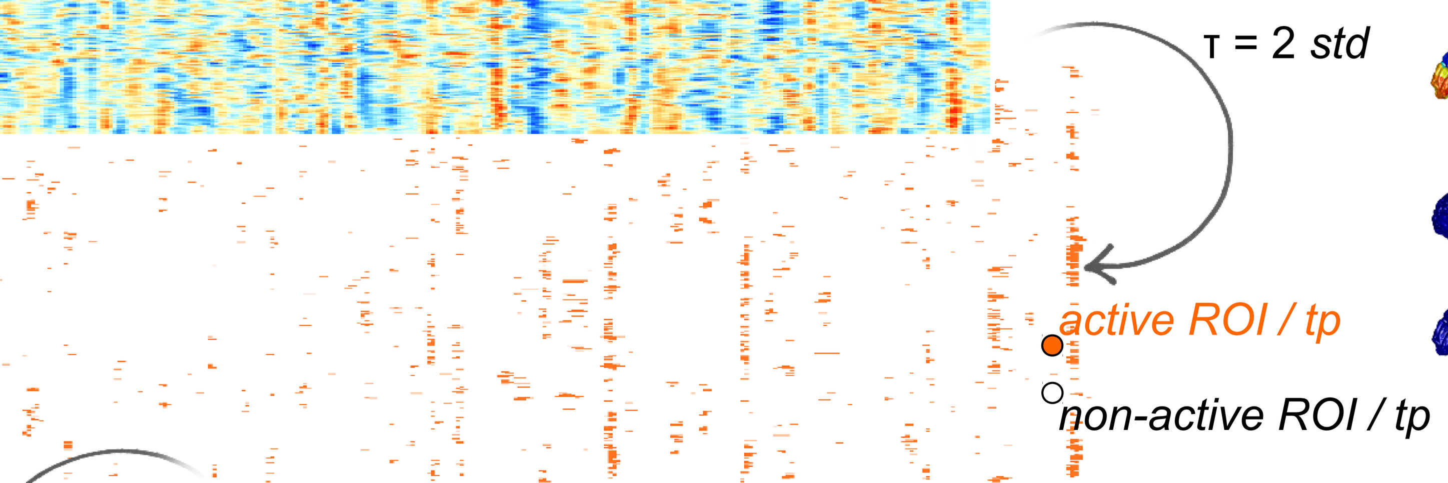


MPRAGE is segmented into **448 cortical ROIs**

fMRI time series associated to each ROI are normalized to ***z*-scores**

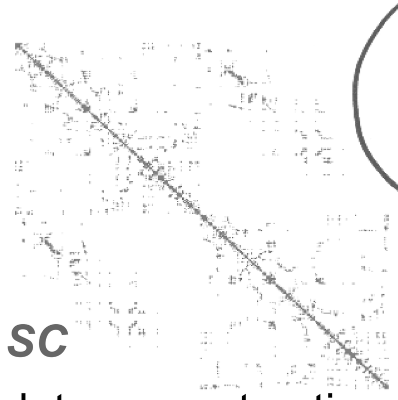


fMRI
TR = 1920 ms
TA = 9 min
276 time points (*tp*)

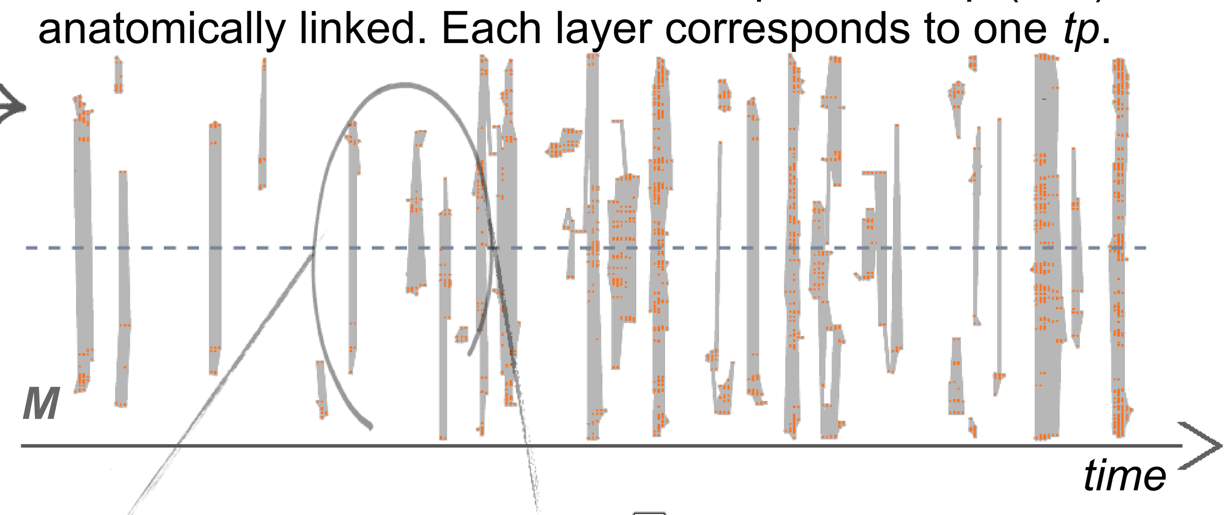


fMRI *z*-scores are thresholded to identify active and non-active time (**point-process data compression**, *Tagliazucchi2012*)

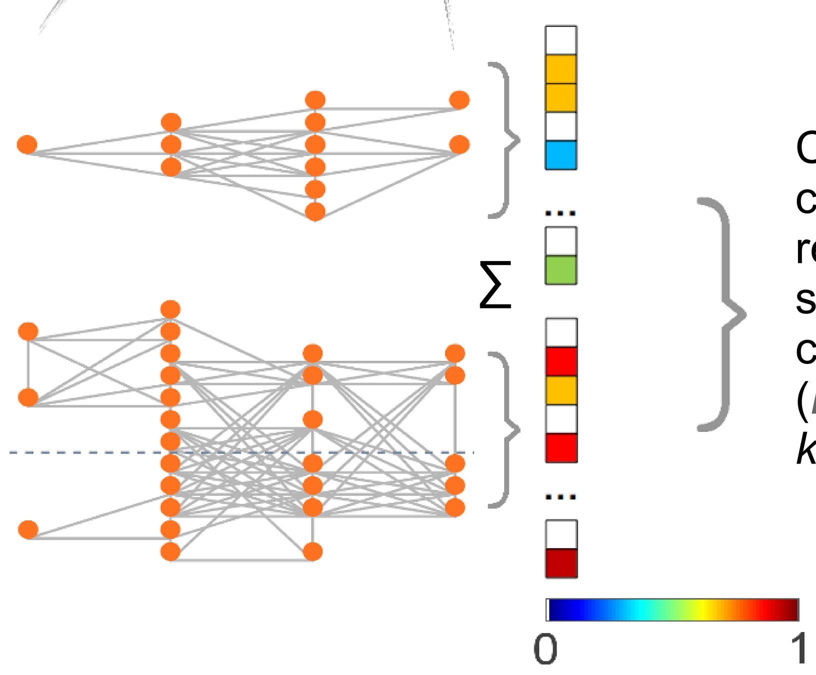
In the **multilayer network *M*** two nodes are connected if they are co-active at the same or one-step forward *tp* (~2s) AND anatomically linked. Each layer corresponds to one *tp*.



DSI data reconstruction and deterministic tractography estimate a **group-representative structural connectivity network** (*SC*)



The **connected components** (*CCs*) of *M* represent **transient assemblies of coherent activity propagated among anatomically wired brain regions**



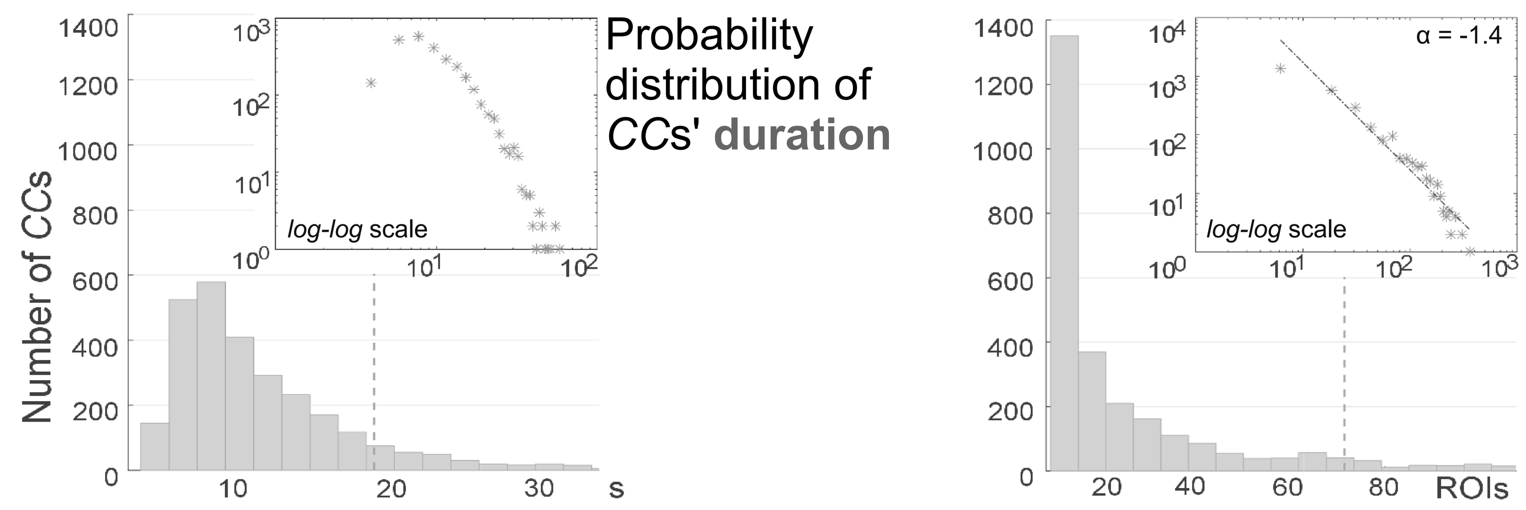
CCs of M are clusterd to identify recurrent patterns of spatio-temporal coherence (***k*-means** clustering, *k* = 12)

Each *CC* can be reduced to a feature vector that describes its spatial pattern of temporal activation

Results

I. The transient assemblies are spatially and temporally heterogeneous and show non-trivial power-law probability distributions, thus suggesting the presence of a critical regime

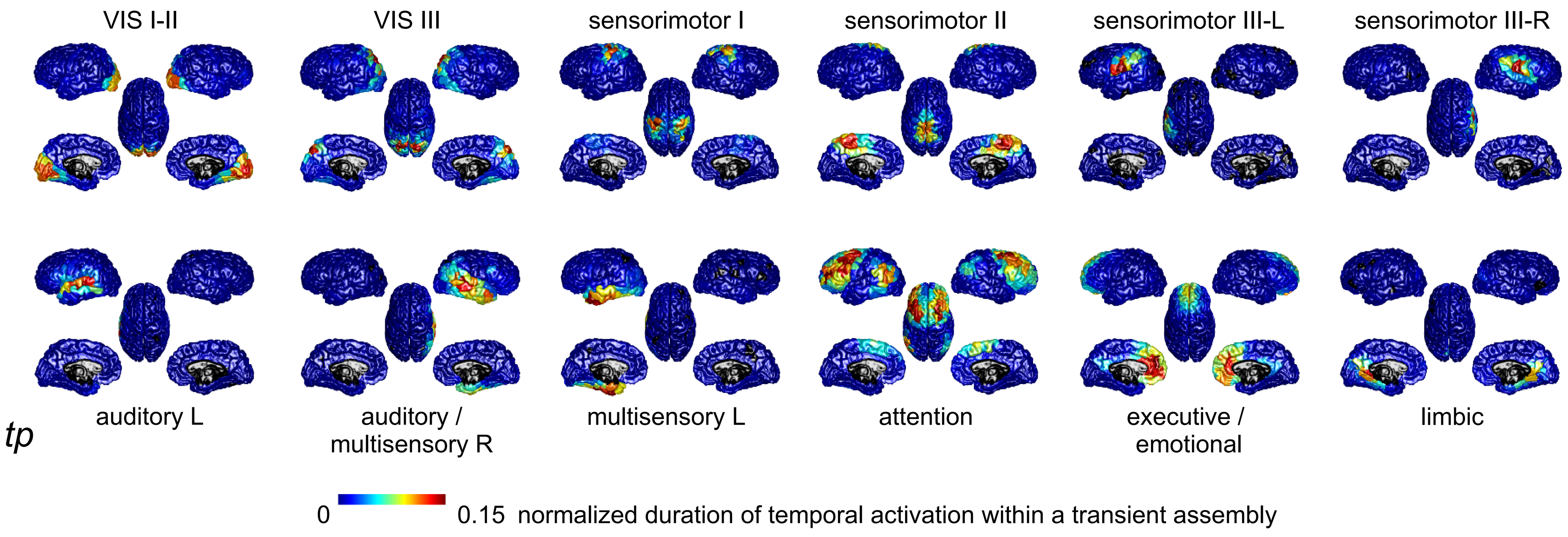
70 multilayer networks, 40 *CCs* per subject on average, 30% of temporal overlap between *CCs*



Statistics drawn from 2'789 transient assemblies (*CCs*)

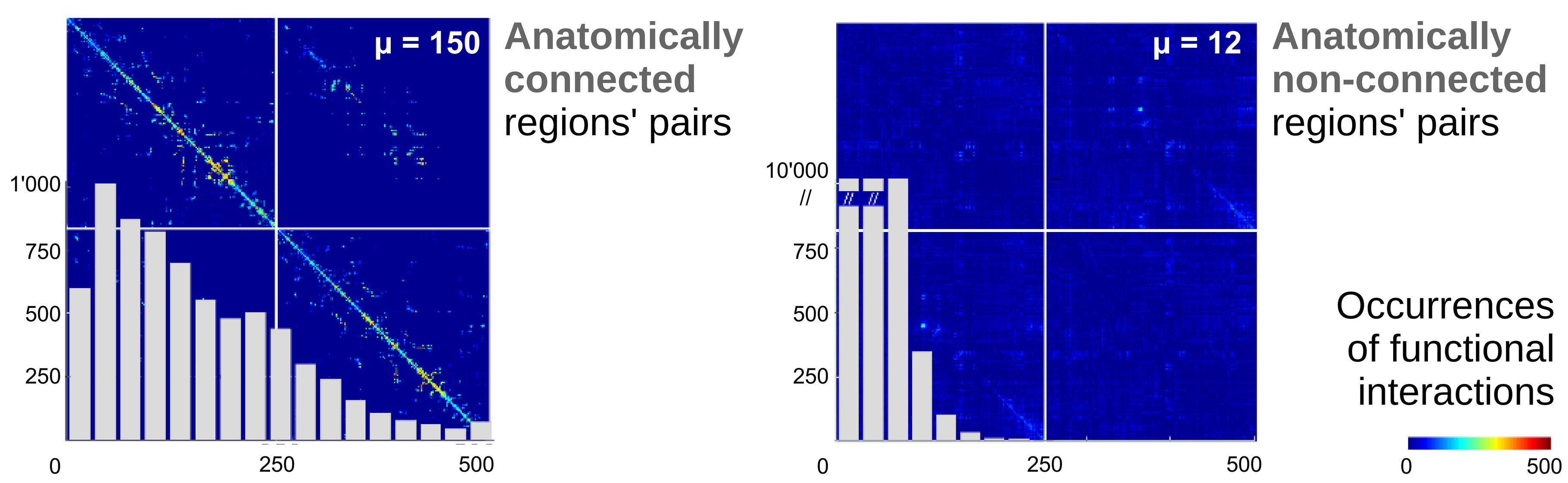
II. The average spatial patterns of the transient assemblies map to known functional systems. Accordingly, classical resting-state networks would be the time-average expression of complex interactions between anatomically wired neural units

Centroids of the 12 clusters that group the transient assemblies of spatio-temporal coherence



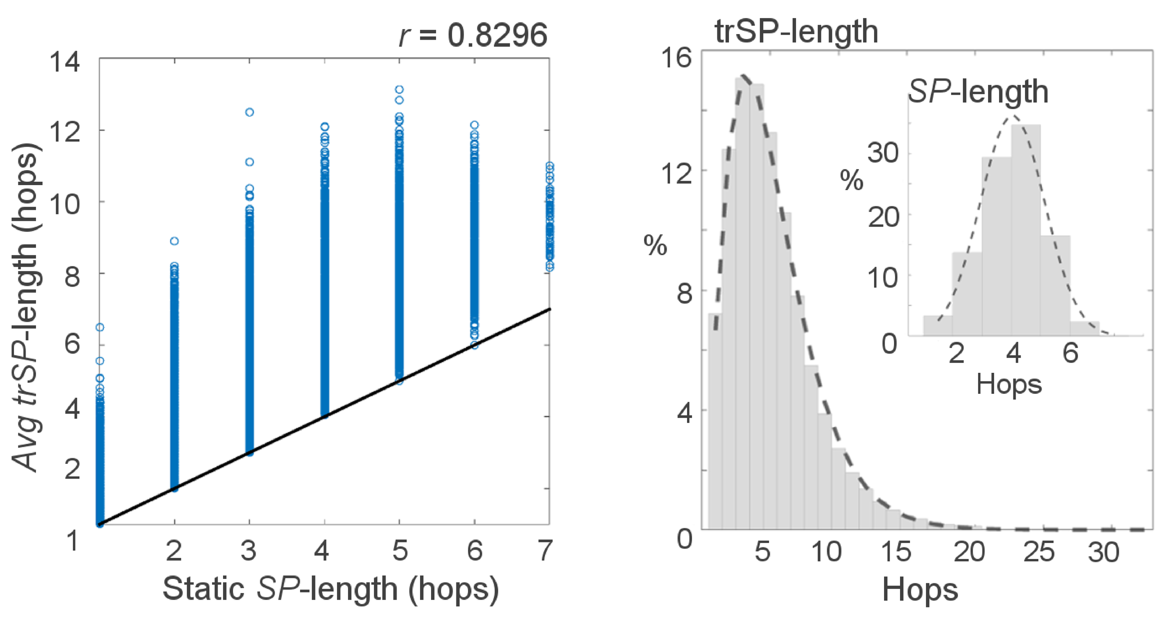
III. The probability of functional interactions, occurring at the temporal scale of 2 seconds between anatomically connected brain regions, outclasses the probability of functional interactions in absence of a direct anatomical link

Matrices representing the recurrence, across recording time and subjects, of functional interactions between brain regions, and relative histograms. The matrices are asymmetric.



IV. Within the transient assemblies, information propagates between brain regions separated by long structural paths. The time-respecting shortest paths (*trSP*) are significantly longer than the shortest paths (*SP*) on the structural network, and their length better predicts time-average functional correlations evaluated on an independent sample

The length distribution of (i) the time-respecting shortest paths computed within the transient assemblies and (ii) the structural shortest paths computed on *SC* are compared.



Capacity of prediction of time-average functional correlations (evaluated on an independent dataset):

$r_{static\ SP\text{-}lenght} = -0.311$

$r_{time\text{-}respecting\ SP\text{-}lenght} = -0.486$

Conclusions

The proposed multilayer framework reveals a rich dictionary of resting-state dynamics spatially related to known functional systems, and it selects transient sets of anatomical channels for activity propagation.

While predominant time-resolved functional interactions happen through direct anatomical connections, transient functional assemblies span several time points and include polysynaptic paths significantly longer than shortest paths of the structural network, this suggesting that routing strategies, other than static shortest paths, might underpin communication principles of the human brain.

Further characterization of structural-functional patterns may elucidate key aspects of brain communication mechanisms and neural channels selection for information transmission and processing.

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References: **Goñi, J (2014)** 'Resting-brain functional connectivity predicted by analytic measures of network communication', PNAS 111(2):833-838. **Hutchison, RM (2013)** 'Dynamic functional connectivity: Promise, issues, and interpretations', NeuroImage 80:360-378. **Kivelä, M (2014)** 'Multilayer networks', Journal of Complex Networks 2(3):203-271. **Tagliazucchi, E (2012)** 'Criticality in large-scale brain fMRI dynamics unveiled by a novel point process analysis', Frontiers in Physiology, 3(15).