Relationship between topology and geometry in the 3d mouse brain connectivity network

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Introduction

- Understanding the functions of the brain requires a comprehensive knowledge of its *structural connectome*: the network of physical connections among neurons or brain regions.
- This network arises from complex developmental processes, some deterministic and some random.
- Its structure and function are very different at the multiple levels of organization, suggesting that the properties and principles underlying brain wiring may differ at each different scale.
- The connectome is embedded in three-dimensional space. The structural connectome must adhere to mechanical and physical constraints.
- The understanding of the interplay of its topological *and* geometrical properties is essential to comprehend the brain network organization.
- We consider the mesoscopic mouse connectome generated by the Allen Institute for Brain Science[1], and present an analysis of the interplay of its topological and geometrical properties.
- This data has been investigated from geometrical and topological perspectives[1,2] , including the proposal of a generative model for its connectome[3] and the correlation with the mouse transcriptome[4].

Objectives

To investigate the interplay of the topological and geometrical properties of the structural mouse connectome:

1. Can we characterize brain regions in terms of topological and geometrical properties?
2. How the geometry correlates with the topological brain organization?

Methodology

Data:
Our analysis is based on mesoscale connectome of axonal bundles identified by experiment. We consider a 295-structure parcellation, and a macroscale parcellation with only the 13 major brain regions[1]: *Isocortex, Olfactory areas, Hippocampal formation, Cortical subplate, Striatum, Pallidum, Thalamus, Hypothalamus, Midbrain, Pons, Medulla, Cerebellar Cortex and Cerebellar Nuclei.*

Clustering:
We use clustering based methods to generate descriptive networks, utilizing the clustering package Quick Bundles [5]. The weight of the bundles is equal to the number of clustered lines.

We consider the following geometric properties:

- Total length, Euclidean distance, curvature,

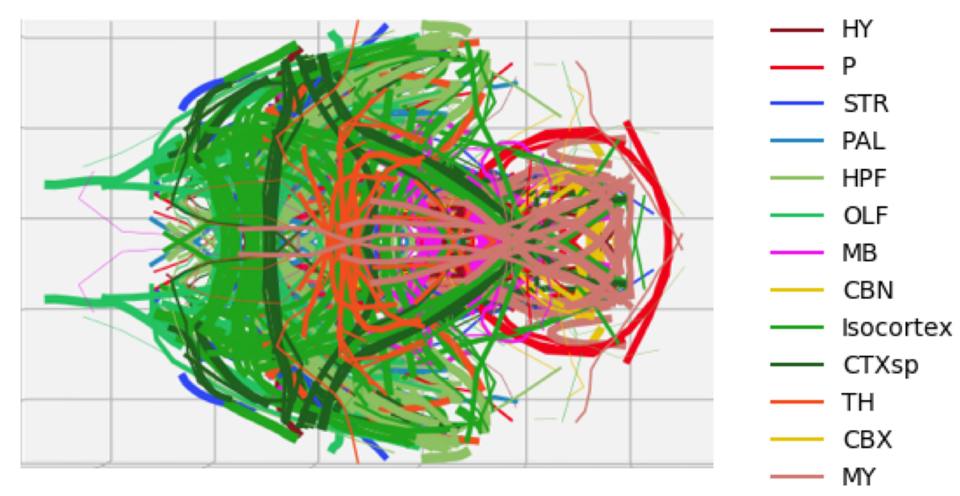
…and topological properties:

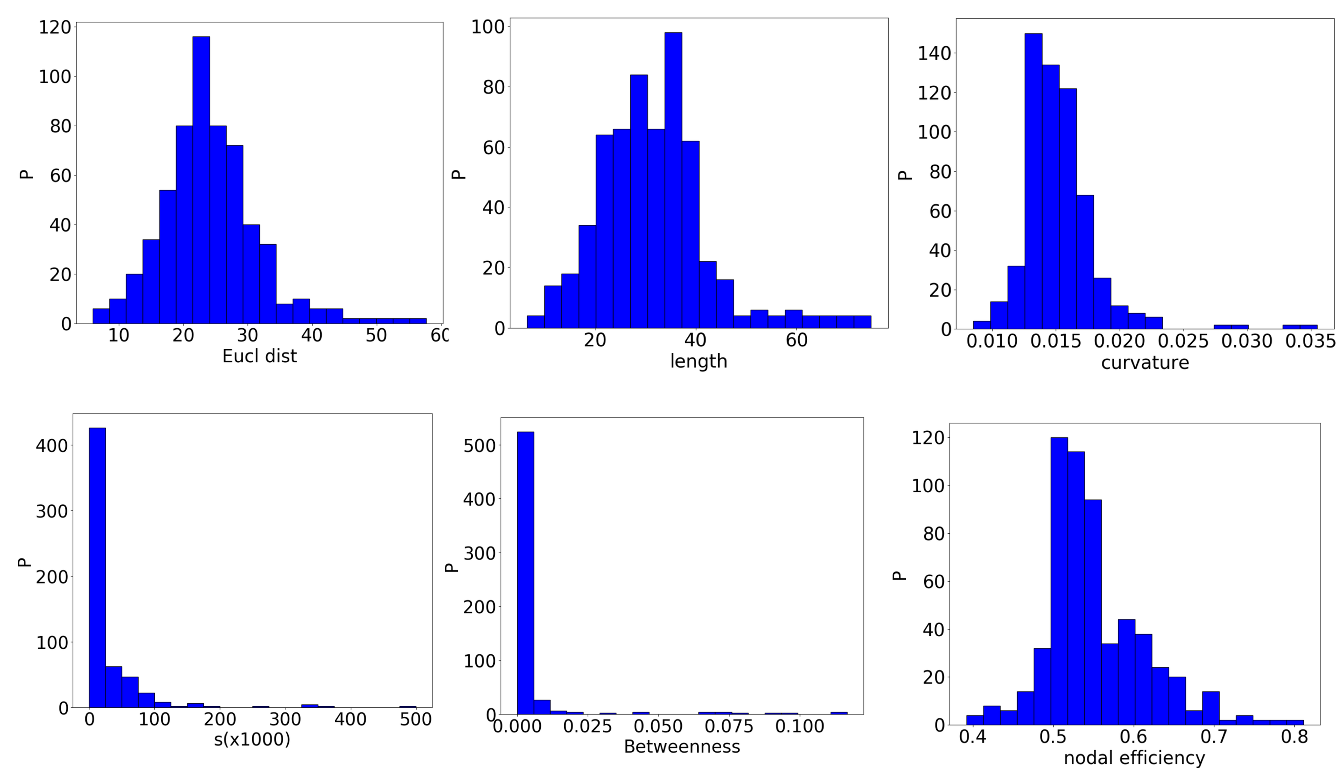
- Betweenness-centrality, clustering, efficiency, partition coefficient (modules = 13 regions).

Analysis: We will analyze the correlation of geometrical and topological properties of axonal bundle connections at the level of averages at the nodes.

Results

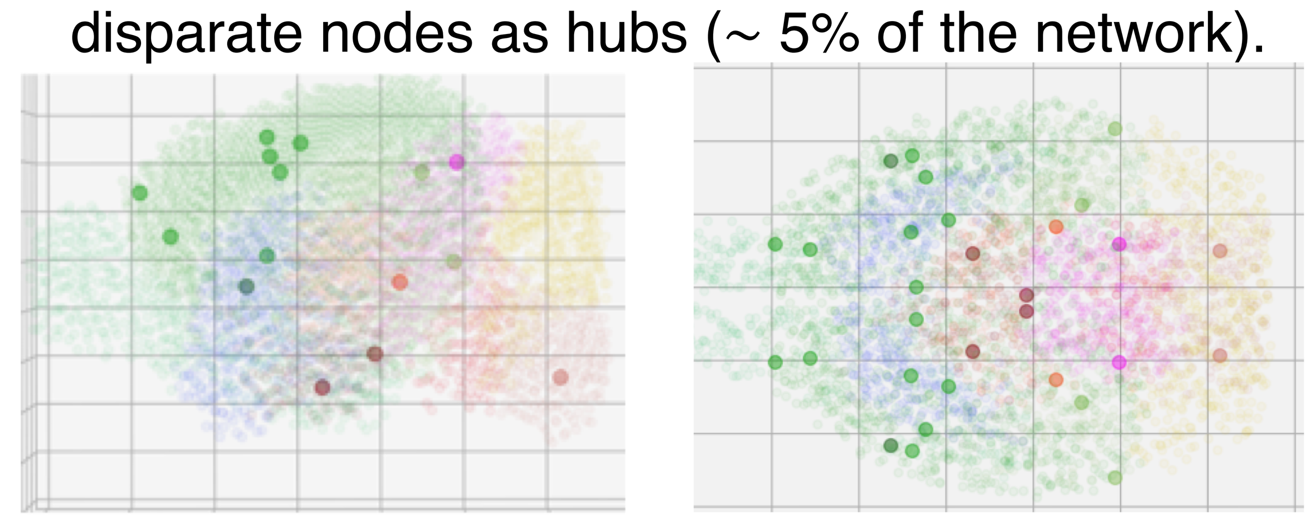
3d visualization of bundles between the 13 macro brain regions





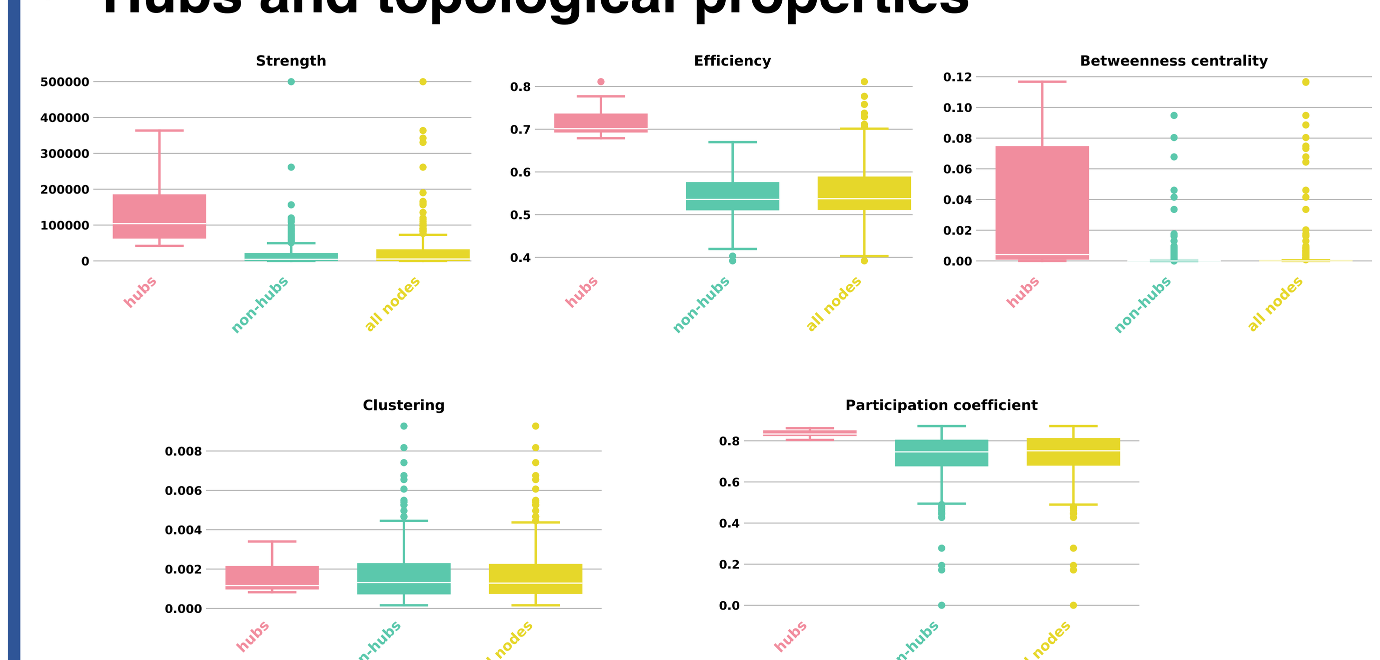
Distribution of nodes average values of geometrical and topological properties for the 295 regions

- **Hubs** are defined as nodes of degree *k* with a z-score greater than 2. This identifies 30 spatially disparate nodes as hubs (~ 5% of the network).

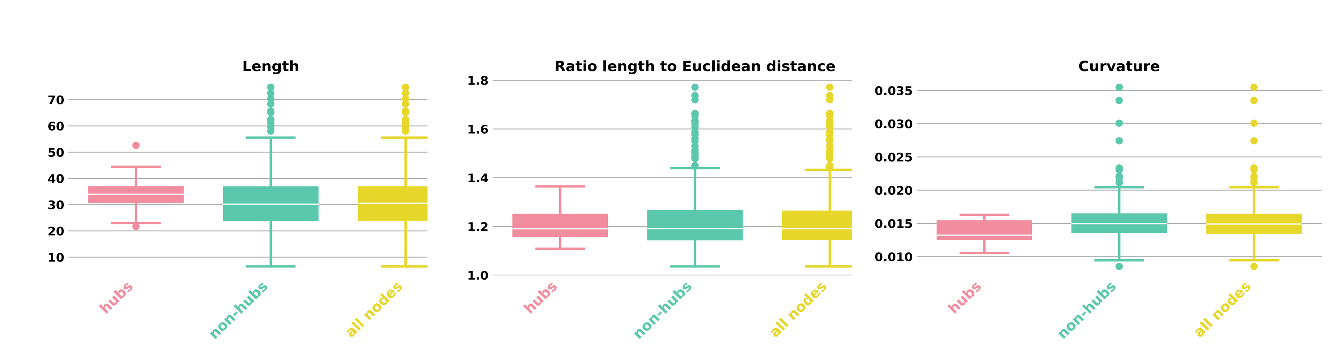


Side view Top-down view
Hubs are shown in the brain (darker colors)

- **Hubs and topological properties**



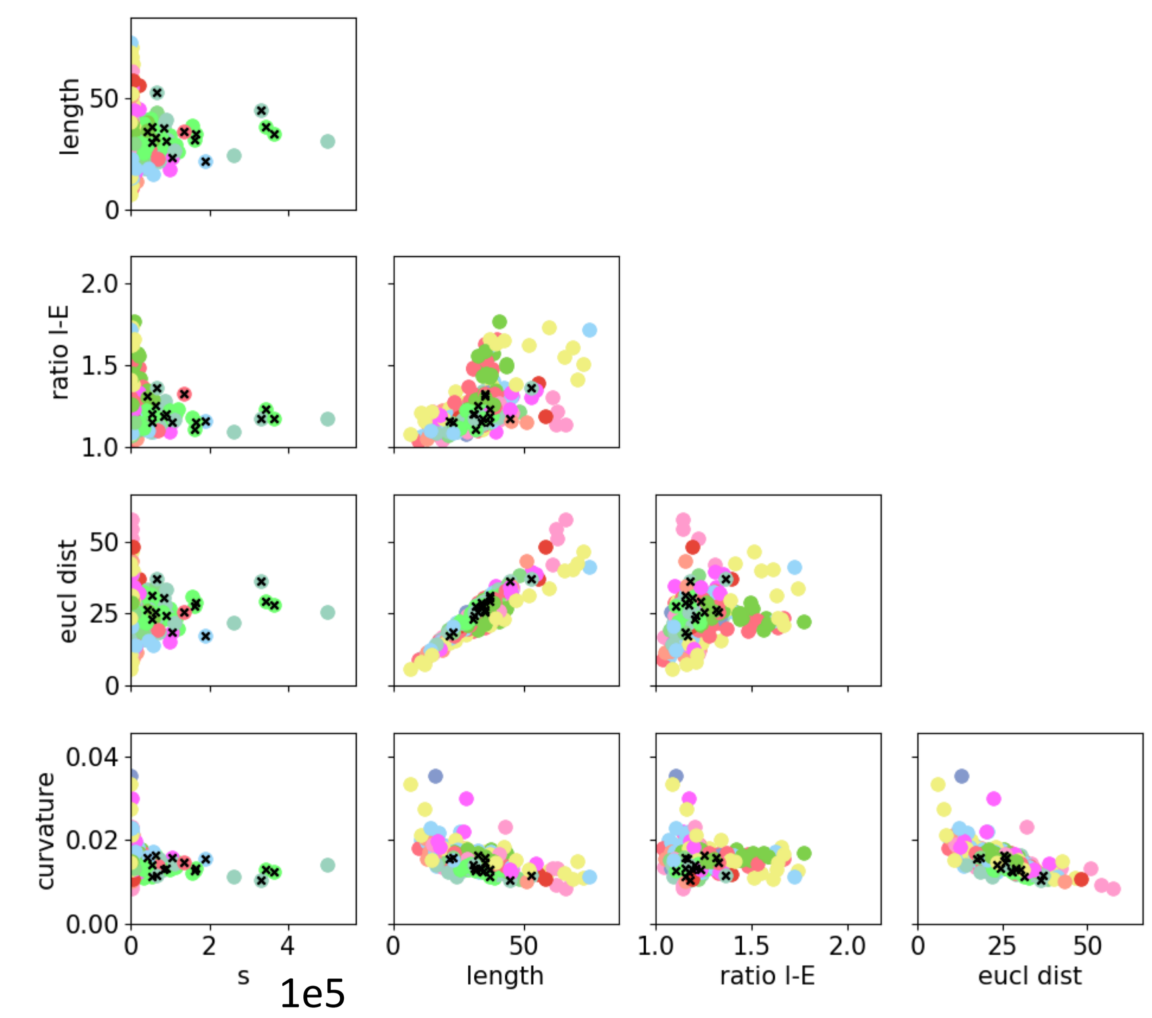
- **Hubs and geometrical properties**



Results (cont.)

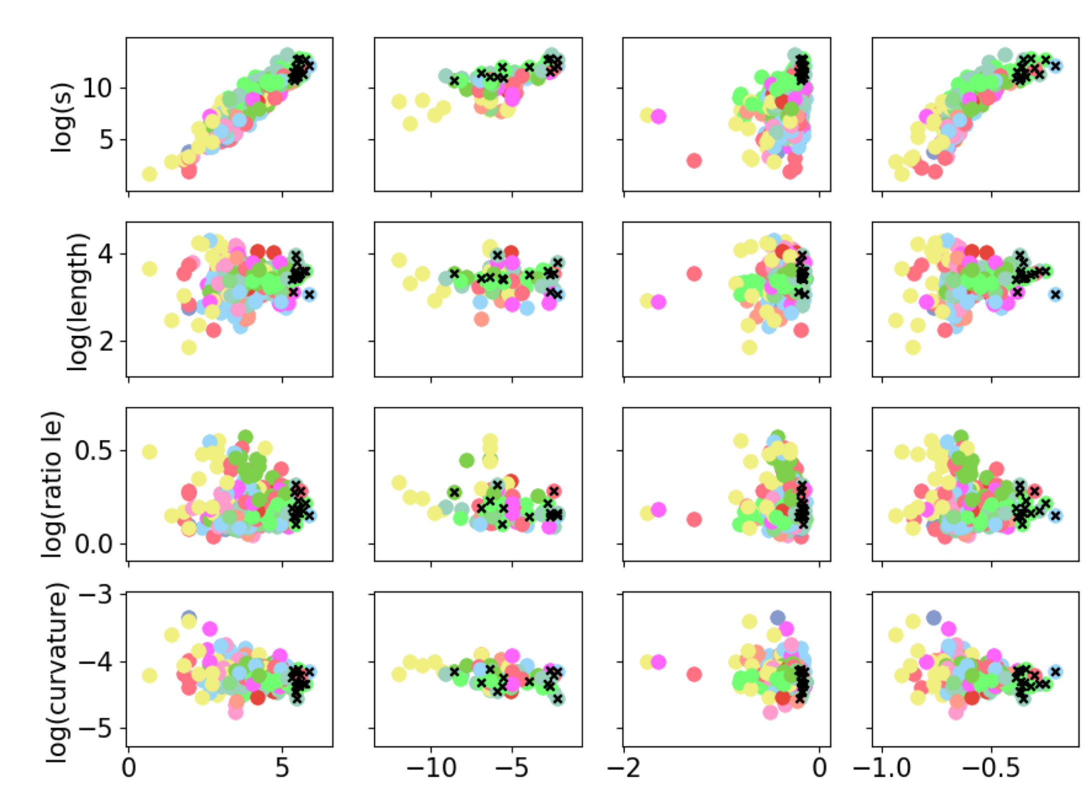
- Topologically, the hubs nodes have higher efficiency and betweenness in comparison to the rest of the network, and lower clustering.
- Geometrically, however, they do not show significant variation compared to the network as a whole.

Geometrical Correlations
Hubs nodes as black crosses



- Geometrical properties are strongly interrelated.
- Hubs show curvature and length at mid-values.

Geometrical and Topological Correlations



- Higher curvature is correlated with lower values of topological properties in general. (Less related to partition coefficient.)
- Higher values of topological properties often come with greater lengths of connections.

References

[1]S.W. Oh et al., Nature **508**, 207 (2014).
[2] M. Rubinov et al., PNAS **112**, 10032 (2015).
[3] S. Henriksen at al., eLife **5**, e12366 (2016).
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[5] E. Garyfallidis et al., Frontiers of Neuroscience **6**, 175 (2012).

Acknowledgements

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