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Why Human Brain Networks are Hyperbolic?

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Abstract:
Recently, the study of graphs representing various complex systems has been extended beyond the standard graph-theoretic measures. The use of methods of algebraic topology enabled revealing the higher organized structures and related hidden geometries that can appear in the graph. More specifically, the Q-analysis based on the algebraic topology of graphs identifies elementary geometric shapes or simplexes (triangles, tetrahedrons and higher order cliques) and how they connect to make more substantial structures or simplicial complexes. The original composition of these basic geometry descriptors is unique for a particular network; furthermore, it can induce emergent hyperbolicity or *negative curvature*, a measure of nodes proximity in the graph-metric space, which often associates with an improved function of the network. However, how the hyperbolic geometry evolves [T3] to support the network's capacity remains a challenging issue, depending on the nature of the complex system in question. In this lecture, we discuss such hidden structures in conjunction with the functional properties of different types of human brain networks. More specifically, we consider the network structures that are originating from the aggregated fNMR imaging data recently described in [C1,C2], and the graphs mapping the brain activity patterns during social communications recorded by EEG [E1,T1,T2]. Using the generalized 4-point Gromov hyperbolicity criterion for graphs, we demonstrate that these brain networks are hyperbolic, and by performing Q-analysis, we determine the structure of underlying simplicial complexes in them. By comparing brain networks obtained from selected sets of data in conjunction with various resolution, female/male participants, and the level of cross-brain coordination, we attempt to find out how these hidden geometries vary, which may suggest the potential neuro-dynamical origin of the observed negative curvature.

Keywords:
brain imaging data, brain networks, simplicial complexes, gromov hyperbolicity

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