Contribution ID: **22** Contribution code: **S12-PSSAP-102** Type: **Oral presentation**

Structure of transmission paths induced by stratified simplicial communities embedded in complex networks

Monday, 29 August 2022 17:00 (15 minutes)

Complex systems display the structural organization of patterns that span over various inherent scales and accordingly affect the functioning of the system. Transcending pairwise interactions in complex networks introduces the study of higher-order structures [Battiston, F., et al. (2020), Physics Reports 874, pp. 1-92.], where the versatility of criteria for aggregation of elements imposes challenges on the reconstruction of organizational patterns. In this context, the focus of the work that will be presented is on the potential mesoscale structures which have the role of building blocks in generalized communities within the simplicial clique complex [Maletić, S. and Rajković, M., (2012) Eur. Phys. J. Special Topics 212, 77–97]. These higher-order structures are considered as embedded in the hierarchical strata of simplicial complex and their relationships are captured by the higher-order combinatorial Laplacian [Goldberg, T. E., Combinatorial Laplacians of Simplicial Complexes, (Annandale-on-Hudson, New York, 2002)]. The discretized Laplacians have already been proven as useful for considerations of topology constraints on flows over the system, such as problems related to the diffusion over complex networks, or Kirchhoff's analysis of electrical networks resulting in the matrix tree theorem, to mention a few. Since the stratified structure of the simplicial complex induces the hierarchy of possible flows, the k-carrying graph is introduced as the structure built by the possible routes of transmission over k-dimensional simplicial clique communities. In other words, the k-carrying graph represents possible paths of the flow over higher-order structures, and its graph Laplacian captures connectivity. The similarity between the structure of clique simplicial communities and the induced k-carrying graph is considered by the mutual information [Cover, T.M., Thomas, J.A., Elements of Information Theory (Wiley ed. 1991)] of the obtained spectra of associated combinatorial Laplacians. As the case studies two real-world networks are considered, and the results reveal new insights into the organizational patterns embedded in networks, in particular the emergence of characteristic similarity k-dimension.

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Session Classification: S12 Physics of Socioeconomic Systems and Applied Physics

Track Classification: Scientific Sections: S12 Physics of Socioeconomic Systems and Applied Physics