










1 XGI: A Python package for higher-order interaction 2 networks

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Software

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9 Summary

10 **Complex Group Interactions (XGI)** is a library for higher-order networks, which model interac-
11 tions of arbitrary size between entities in a complex system. This library provides methods for
12 building hypergraphs and simplicial complexes; algorithms to analyze their structure, visualize
13 them, and simulate dynamical processes on them; and a collection of higher-order datasets.
14 XGI is implemented in pure Python and integrates with the rest of the Python scientific stack.
15 XGI is designed and developed by network scientists with the needs of network scientists in
16 mind.

Statement of need

17 The field of network science bridges across many different disciplines, bringing together theorists,
18 computational scientists, social scientists, and many others. To facilitate cross-disciplinary
19 collaboration, a common tool kit is crucial. Existing packages like NetworkX ([Hagberg et al.,
20 2008](#)), graph-tool ([Peixoto, 2014](#)), and igraph ([Csardi & Nepusz, 2006](#)) have been successful in
21 facilitating collaboration for traditional networks, restricted to pairwise interactions. However,
22 the rapidly growing subfield of higher-order network science ([Battiston et al., 2020](#)), which
23 models interactions between any number of entities, requires a different approach. Higher-order
24 interaction networks promotes rich dynamical behavior ([Hickok et al., 2022](#); [Iacopini et al., 2019](#);
25 [Neuhäuser et al., 2020](#); [Skardal & Arenas, 2019](#)), and can model some empirical interaction
26 patterns more accurately than pairwise networks ([Chodrow, 2020](#)). We anticipate that this
27 field will have lasting impacts on various research areas such as infectious diseases, dynamical
28 systems, and behavioral science. To support the higher-order network science community, we
29 have developed the **Complex Group Interactions (XGI)**—an open-source solution in Python.
30

31 Related Software

32 There are several existing packages to represent and analyze higher-order networks:
33 HyperNetX ([Praggastis et al., n.d.](#)) and Reticula ([Badie-Modiri & Kivelä, 2023](#)) in Python,
34 SimpleHypergraphs.jl ([Spagnuolo et al., 2020](#)) and HyperGraphs.jl ([Diaz & Stumpf, 2022](#))
35 in Julia, and hyperG in R. XGI is a valuable addition to the network science practitioner's
36 toolbox for several reasons. First, XGI is implemented in pure Python, ensuring interoperability
37 and easy installation across operating systems. Second, like several of the packages listed, XGI
38 has a well-documented codebase and tutorials designed to make the learning process intuitive.
39 Third, in contrast to existing packages, XGI contains a stats module enabling researchers

40 to easily access established nodal and edge quantities, and even define custom quantities.
 41 Fourth, XGI offers data structures for hypergraphs and simplicial complexes, which allows
 42 users to explore a wider range of interaction models than comparable packages. Lastly, XGI
 43 integrates higher-order datasets with its interface, providing a standard format in which to
 44 store hypergraphs with attributes and a data repository with corresponding functions to load
 45 these datasets.

46 Overview

47 The two core classes of the library are those representing hypergraphs and simplicial complexes.
 48 The data structure (seen in Figure 1) employed by XGI for both is a bipartite graph with
 49 entities represented by one node type and relationships among entities (i.e., hyperedges or
 50 simplices) represented by a second node type.

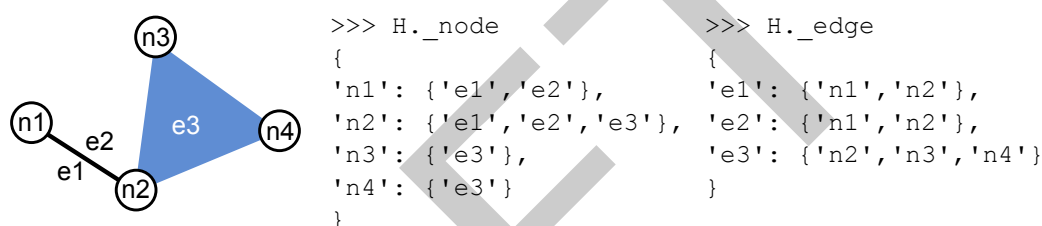


Figure 1: A hypergraph is internally represented as a bipartite network stored as two dictionaries, where keys are node IDs and sets specify the edges to which they belong, and vice-versa. Unique identifiers allow for multi-edges, as can be seen for edge IDs 1 and 2.

51 XGI provides several ways to create hypergraphs and simplicial complexes. First, by adding
 52 or removing nodes or hyperedges (or simplices). Second, by creating generative models,
 53 which can produce datasets with desired structural characteristics. Third, by loading existing
 54 datasets. XGI allows easy and unified access to many hypergraph datasets currently existing in
 55 diverse formats (A. Benson, 2021; Clauset et al., 2016; Peixoto, 2021) in three ways: first, by
 56 implementing a standard for hypergraph data in JSON format; second, by storing datasets in
 57 this format in a single repository, XGI-DATA (Landry et al., 2023); and third, by providing
 58 file I/O for common formats. Each dataset in XGI-DATA can be easily accessed through the
 59 library's API and the repository provides a description of it.

60 XGI provides many standard and state-of-the-art measures such as assortativity, centralities,
 61 connectedness, and clustering. A strength of XGI is its stats package: it provides a convenient
 62 and unified interface for computing statistics of nodes and edges, such as degree centrality or
 63 edge order. Any measure that is a node/edge-to-quantity mapping uses the same interface.
 64 Stats can be used to filter nodes and edges and multiple stats filters can be combined. XGI
 65 provides convenient visualization functions, as illustrated in Figure 2. We support multiple
 66 layouts and allow users to control many of the drawing parameters. Finally, XGI provides
 67 functions to simulate synchronization models on hypergraphs and simplicial complexes (Adhikari
 68 et al., 2022; Arnaudon et al., 2022; Lucas et al., 2020; Millán et al., 2020).

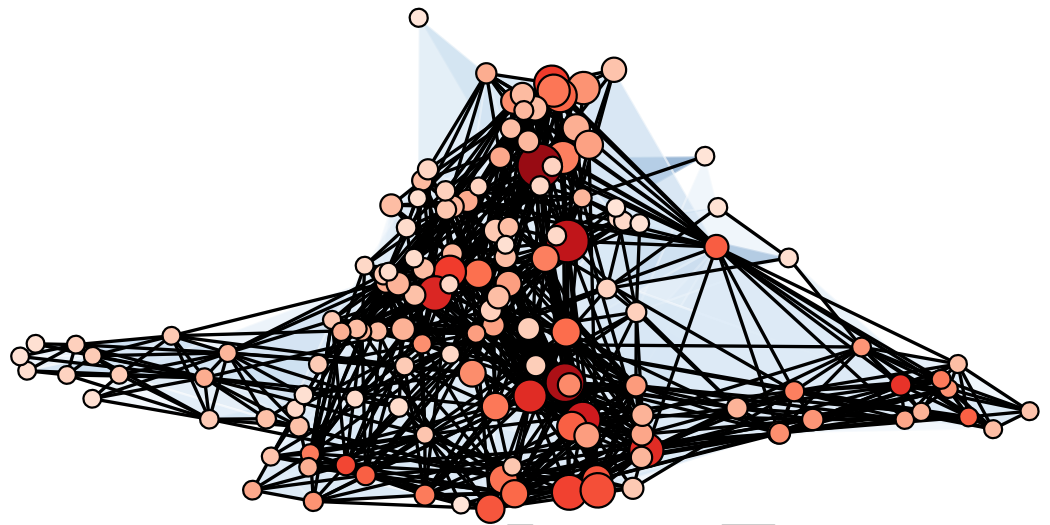


Figure 2: A visualization of the email-enron dataset (A. Benson, 2021; Landry et al., 2023) with hyperedges of sizes 2 and 3 (all isolated nodes removed). The nodes are colored by their degree and their size proportional to the Clique motif Eigenvector Centrality (A. R. Benson, 2019).

69 Projects using XGI

70 XGI has proved to be an invaluable resource for research projects (Zhang et al., 2022) on
71 higher-order networks as well as other software projects (Landry & Miller, 2022). We expect
72 that as this library matures, it will become a more essential part of the higher-order network
73 science community.

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