Workshop
on
Modelling and Mining Complex Networks
as
Hypergraphs
(May 15–19, 2023)

Host: **Toronto Metropolitan University**
Location: Student Learning Centre, DMZ Sandbox (3rd floor)
341 Yonge Street, Toronto, Ontario, Canada M5B 1S1

Organizers:
– Bogumił Kamiński (bkamins@sgh.waw.pl)
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Sponsors:
– Tutte Institute for Mathematics and Computing (TIMC)
– Faculty of Science, Toronto Metropolitan University

1 Introduction

Hypergraphs have recently emerged as a useful representation for complex networks since they allow capturing more general relations than graphs. Research on the generalization of various graph-based tools and techniques is booming and, in parallel, new software packages are being developed. Having said that, the theory and tools are still not sufficiently developed to allow most problems to be tackled directly within this context.

The main goal of the 5 day workshop is to gather together a small group of experts who specialize on modelling and mining complex networks represented as higher-order structures such as hypergraphs. Long talks (2 x 75 minutes) in the morning will aim to introduce specific problems in this context and explain solutions as well as tools used to solve them. Shorter talks (30 minutes) in the early afternoon will concentrate on open problems and unsolved questions to stimulate collaboration and discussions in the late afternoons and evenings.

There is no registration fee but please let one of us know that you plan to attend (to make sure we have enough space and food). The workshop will include theoreticians interested in developing theory of hypergraphs, practitioners interested in building ML tools for hypergraphs, and economists interested in incorporating such solutions in real-world business applications.

2 Schedule

Monday, May 15, 2023

8:55-9:00 Official Opening

9:00-12:00 **Leland McInnes**, Tutte Institute for Mathematics and Computing
A Whirlwind Introduction to Topological Data Analysis

10:15-10:45 Coffee break

12:00-2:00 Lunch break

2:00-2:30 **Megan Dewar**, Tutte Institute for Mathematics and Computing
Introduction to the Tutte Institute

2:30-3:00 **Helen Jenne**, Pacific Northwest National Laboratory
Hypergraphs and SVD for Explainable AI

3:00-3:30 **Jordan Barrett**, Toronto Metropolitan University
Structural properties of ABCD graphs and h-ABCD hypergraphs

3:30-4:00 Coffee break

4:00- Working in groups

Tuesday, May 16, 2023

9:00-12:00 **Nicholas Landry**, University of Vermont
Part a) Higher-order interaction networks: structure, dynamics, and inference
Part b) XGI: A Python package for higher-order interaction networks

10:15-10:45 Coffee break

12:00-2:00 Lunch break

2:00-3:30 **Yuly Billig**, Carleton University
Dense Clusters in Hypergraphs

3:30-4:00 Coffee break

4:00- Working in groups

Wednesday, May 17, 2023

9:00-12:00 **Cliff Joslyn and Brenda Praggastis**, Pacific Northwest National Laboratory
Hypergraph Modeling and Topological Approaches in HyperNetX

10:15-10:45 Coffee break

12:00-2:00 Lunch break

2:00-3:00 **Valérie Poulin**, Tutte Institute for Mathematics and Computing
Hypergraph exploration via vectorization

3:00-3:30 **Bill Kay**, Pacific Northwest National Laboratory
Interpretations of Homology in Hypergraph Analysis

3:30-4:00 Coffee break

4:00- Working in groups

Thursday, May 18, 2023

9:00-12:00 **François Théberge**, Tutte Institute for Mathematics and Computing
Paweł Prałat, Toronto Metropolitan University
Paweł Misiorek, Poznan University of Technology
Modularity Based Community Detection in Hypergraphs

10:15-10:45 Coffee break

12:00-2:00 Lunch break

2:00-2:30 **Leman Akoglu**, Carnegie Mellon University
Graph-based Anomaly Detection: Problems, Algorithms and Applications

2:30-3:00 **Przemysław Szufel**, SGH Warsaw School of Economics
Modelling hypergraphs in Julia with `SimpleHypgraphs.jl`

3:00-3:30 **Sebastian Zajac**, SGH Warsaw School of Economics
Quantum computing in the context of graphs and hypergraphs

3:30-4:00 Coffee break

4:00- Working in groups

6:00 Dinner

Friday, May 19, 2023

9:00-12:00 **Lasse Leskelä**, Aalto University
Recovery of communities in sparse and dense hypergraph stochastic block models

10:15-10:45 Coffee break

12:00-2:00 Lunch break

2:00-3:00 **Bogumił Kamiński**, SGH Warsaw School of Economics
Panel on "Applications of hypergraphs"

3:00-4:00 Coffee break

4:00- Working in groups

3 Participants

1. **Leman Akoglu**, Carnegie Mellon University, Pittsburgh, US
2. **Jordan Barrett**, Toronto Metropolitan University, Toronto, Canada
3. **Yuly Billig**, Carleton University, Ottawa, Canada
4. **Winfield Chen**, Canoe Financial, Toronto, Canada
5. **Megan Dewar**, Tutte Institute for Mathematics and Computing, Ottawa, Canada
6. **Konstantinos Georgiou**, Toronto Metropolitan University, Toronto, Canada
7. **Sanaz Gholizadeh**, York University, Toronto, Canada
8. **Anatoliy Gruzd**, Toronto Metropolitan University, Toronto, Canada
9. **Reaz Huq**, Toronto Metropolitan University, Toronto, Canada
10. **Helen Jenne**, Pacific Northwest National Laboratory, Seattle, US
11. **Cliff Joslyn**, Pacific Northwest National Laboratory, Seattle, US
12. **Bogumił Kamiński**, SGH Warsaw School of Economics, Warsaw, Poland
13. **Vinay Kumar**, INRIA, France
14. **Bill Kay**, Pacific Northwest National Laboratory, Seattle, US
15. **Nicholas Landry**, University of Vermont, Burlington, US
16. **Lasse Leskelä**, Aalto University, Espoo, Finland
17. **Lidan Liao**, Toronto Metropolitan University, Toronto, Canada
18. **Lukas Lüchtrath**, Weierstrass Institute, Berlin, Germany
19. **Rehan Malik**, Toronto Metropolitan University, Toronto, Canada
20. **Trent Marbach**, Toronto Metropolitan University, Toronto, Canada
21. **Leland McInnes**, Tutte Institute for Mathematics and Computing, Ottawa, Canada
22. **Paweł Misiorek**, Poznan University of Technology, Poznan, Poland
23. **Audun Myers**, Pacific Northwest National Laboratory, Seattle, US
24. **JD Nir**, Toronto Metropolitan University, Toronto, Canada
25. **Valérie Poulin**, Tutte Institute for Mathematics and Computing, Ottawa, Canada
26. **Brenda Praggastis**, Pacific Northwest National Laboratory, Seattle, US
27. **Paweł Prałat**, Toronto Metropolitan University, Toronto, Canada
28. **Rupan Sampanthan**, Toronto Metropolitan University, Toronto, Canada

29. **Omair Shafiq**, Carelton University, Ottawa, Canada
30. **Przemysław Szufel**, SGH Warsaw School of Economics, Warsaw, Poland
31. **François Théberge**, Tutte Institute for Mathematics and Computing, Ottawa, Canada
32. **Sebastian Zajac**, SGH Warsaw School of Economics, Warsaw, Poland
33. **Jingwei Zhang**, Toronto Metropolitan University, Toronto, Canada
34. **Zhiyuan Zhang**, Toronto Metropolitan University, Toronto, Canada

4 Semi-random List of Places for Lunch Near TMU

- Salad King (Thai Cuisine)
- GB Hand-Pulled Noodles (Chinese noodle soup)
- Paramount Fine Foods (Middle Eastern)
- Hokkaido Ramen Santouka (Ramen)
- food court at Eaton Center or 10 Dundas East (Cineplex)
- JOEY Eaton Center
- 3 Brewers
- Blaze Pizza
- ... (ask, say, Google for more)

5 Semi-random List of Places to See in Toronto

- **CN Tower** (`https://www.cntower.ca`) Soar above the city at the iconic CN Tower. Standing 553.3 meters tall, this engineering marvel offers breathtaking views of Toronto's skyline. Don't miss the Glass Floor, SkyPod, and EdgeWalk for an unforgettable experience.
- **Royal Ontario Museum** (`https://www.rom.on.ca`) Delve into art, world culture, and natural history at ROM, Canada's largest museum. Featuring over six million objects, the museum's exhibits span from ancient civilizations to cutting-edge technology. The Michael Lee-Chin Crystal is a sight to behold.
- **Art Gallery of Ontario** (`https://www.ago.ca`) Home to over 95,000 works, AGO showcases an impressive collection of Canadian, Indigenous, European, and contemporary art. Witness the creative genius of renowned artists like the Group of Seven, Vincent van Gogh, and Pablo Picasso.
- **Distillery District** (`https://www.thedistillerydistrict.com`) Step back in time at the Distillery District, a pedestrian-only village adorned with Victorian-era architecture. Boasting art galleries, unique shops, and trendy restaurants, it's an ideal place to unwind and enjoy Toronto's vibrant arts and culture scene.

- **Casa Loma** (https://casaloma.ca) Gothic Revival castle-style mansion and garden in midtown Toronto, Ontario, Canada, that is now a historic house museum and landmark. It was constructed from 1911 to 1914 as a residence for financier Sir Henry Pellatt.
- **City Cruises Toronto** (https://www.citypass.com/toronto/city-cruises-toronto) Take a break from seeing Toronto by land to see it from the harbour! Discover the historic and contemporary sites and nuances of Toronto Harbor during this fun, informative and fully narrated 60-minute Sightseeing Harbour Tour.
- **Toronto Island** (https://www.torontoisland.com) The Toronto Islands - also called the Island, or Toronto Island Park - is located in Lake Ontario, a 13-minute ferry ride from downtown Toronto. Boats to the Island leave from the Jack Layton Ferry Terminal at the foot of Bay St. and Queen's Quay. The Island is actually a group of 15 islands inter-connected by pathways and bridges. You can walk from one end of the Island to the other.
- **Music**
  – Toronto Symphony Orchestra (https://www.tso.ca/)
  – Jazz Bistro (https://jazzbistro.ca/) – Jazz, very close to TMU, more fancy
  – The Rex (https://www.therex.ca/) – Jazz, more casual
- . . . (ask, say, Google for more)

6 Abstracts

6.1 A Whirlwind Introduction to Topological Data Analysis

Speaker: **Leland McInnes**, Tutte Institute for Mathematics and Computing

Abstract
Topological data analysis seeks to bring powerful tools from topology to bear on problems in data science, helping to elucidate the geometry and structure of diverse data sets. This mini-course will offer an introduction to relevant topological ideas and approaches, as well as demonstrating how they can be used in data science to solve real practical problems. Particular focus will be given to problems in unsupervised learning and exploratory data analysis where such tools are most effective.

6.2 Introduction to the Tutte Institute

Speaker: **Megan Dewar**, Tutte Institute for Mathematics and Computing

Abstract
The Tutte Institute for Mathematics and Computing (TIMC) is a government research institute focused on strategic research in mathematics and computer science, as it applies to Communication Security Establishment's (CSE's) mandate. Our mission is to deliver research results having an impact on the most important scientific challenges facing the Canadian and 5-Eyes security and intelligence communities. The TIMC's key research areas are cryptography and data science. TIMC occupies a unique position; acting as an interface between classified and unclassified research organizations linking CSE, second-parties and external research partners (notably, academia and industry). This talk will present an introduction to the organization; including outlining our mission and ways to engage with us. We will also give an overview of our research activities that may be of interest to workshop attendees.

6.3 Hypergraphs and SVD for Explainable AI

Speaker: **Helen Jenne**, Pacific Northwest National Laboratory

Abstract
Convolutional Neural Networks (CNNs) provide powerful tools for image classification but are difficult to interpret. At present there is no definitive methodology for linking the features of an input's domain to a CNN's decision process and classifications. We approach this problem by studying the internal dynamics of the network's convolutional layers using singular value decomposition. The singular vectors of the weights of a layer align with the most important changes to the internal representations of the input data occurring within that layer. Moreover, the natural ordering of the singular values ranks the singular vectors by the importance of the domain-centric features.

The many-to-many relationships between input images and the singular vectors found at each layer poses a problem: how do we interpret this data so that we can study the association between singular vectors and features of the input domain? Our approach uses hypergraphs to model the relationships between singular vectors and images. In this talk, we show that the combinatorial statistics of hypergraphs are invariant to changes in random

initial weights and random batch orderings of stochastic gradient descent. This, combined with other experiments, suggests that feature learning is independent of training run. We conclude by demonstrating how our methodology can be used to isolate discriminative features of the input domain. This is joint work with Davis Brown, Brenda Praggastis, and Madelyn Shapiro.

6.4 Structural properties of ABCD graphs and h-ABCD hypergraphs

Speaker: **Jordan Barrett**, Toronto Metropolitan University

Abstract
The Artificial Benchmark for Community Detection (ABCD) graph is a model for networks with community structure that exhibit power-law in both their degree distribution and community sizes. The bulk of this talk will introduce the ABCD model and discuss some of the intricacies of its construction process. We will then briefly introduce the hypergraph-ABCD (h-ABCD) model and discuss the similarities and differences between the two models. This talk will act as a preliminary to the talk given later that week, where the ABCD and h-ABCD models will be discussed more thoroughly.

6.5 a) Higher-order interaction networks: structure, dynamics, and inference; b) XGI: A Python package for higher-order interaction networks

Speaker: **Nicholas Landry**, University of Vermont

Abstract
Part a) In contrast to the assumption that social interactions only involve two individuals when modeling complex systems, larger interactions often occur in empirical settings. The collection of these group interactions form a higher-order interaction network.

Higher-order networks are often represented with one of two mathematical objects: (i) hypergraphs and (ii) simplicial complexes. Many null models of higher-order networks either do not consider the inclusion structure of group interactions or explicitly assume a simplicial complex. In contrast, empirical datasets do not often exist at either of these extremes, but rather, somewhere in between. We quantify where a dataset lies on this spectrum with a metric we define as "simpliciality". We show that existing null models are inadequate for generating higher-order networks with the same inclusion structure as empirical datasets. In addition, we show that the location of the missing subfaces are extremely important for quantifying the simpliciality of a dataset. We introduce null models aimed at bridging the gap between hypergraph null models and null models of simplicial complexes by specifying the inclusion structure.

Dynamics on higher-order networks can produce rich behavior, even for very simple models of contagion. We present two different contagion models: one representing social contagion and the other describing epidemiological contagion. For the social contagion model, we focus on the interplay between higher-order structure and the resulting contagion dynamics of a hypergraph SIS model; in particular, we describe how degree heterogeneity and community structure can affect the onset and existence of tipping-point behavior and polarization. For the epidemiological model, we describe a reality-inspired model of

environmentally-mediated contagion and present a method to infer network structure and epidemiological parameters from time-series data. We discuss initial work and challenges applying this model to transmission of C. diff in a hospital setting.

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

We demonstrate this library's effectiveness by choosing several higher-order datasets and then analyzing them. We start by extracting basic statistics of these datasets such as its size, degree distribution, and density. We also calculate structural measures such as connectedness, assortativity, and centrality and compute different statistics of these metrics. We show not only how to easily represent higher-order datasets with different data structures, but also how to use statistics to easily filter datasets. Lastly, we visualize these datasets using the visualization capabilities of XGI.

6.6 Dense Clusters in Hypergraphs

Speaker: **Yuly Billig**, Carleton University

Abstract
We solve the problem of finding in a given weighted hypergraph a subhypergraph with a maximum possible density. We introduce the notion of a support matrix and prove that the density of an optimal subgraph is equal to $|A^T A|$ for an optimal support matrix A. Alternatively the maximum density of a subgraph is equal to the solution of a minimax problem for column sums of support matrices. We introduce the spectral decomposition of a hypergraph and show that it is a significant refinement of the Dulmage-Mendelsohn decomposition. Our theoretical results yield an efficient algorithm for finding the maximum density subhypergraph and more generally, the spectral decomposition for a given weighted hypergraph.

6.7 Hypergraph Modeling and Topological Approaches in HyperNetX

Speaker: **Cliff Joslyn** and **Brenda Praggastis**, Pacific Northwest National Laboratory

Abstract
The Pacific Northwest National Laboratory in the United States has been supporting a concerted research effort in complex systems modeling incorporating a distinct perspective on complex networks. Casting complex systems as hypergraphs with an inherent multidimensional topological structure supports multiple missions in analyzing complex information from computational biology, cyber systems, and open-source analytics. In this session we will first relate the mathematical perspective which informs our modeling approach, including the reliance on attributed hypergraphs with edge- and incidence-specific properties, multiple topological representations thereof, and the incorporation of these capabilities into

our HyperNetX (HNX, `https://pnnl.github.io/HyperNetX`) platform. Recent developments additionally include both the requirement, and the opportunity, to understand how to marry such high-order network representations to common property graph data models and engines. With the announcement of HNX 2.0, we will illustrate the methods over a sequence of case studies.

6.8 Hypergraph exploration via vectorization

Speaker: **Valérie Poulin**, Tutte Institute for Mathematics and Computing

Abstract
Text vectorization has undoubtedly become a basic step in natural language processing. One of its particularities is that it allows for joint embedding of words with sentences or paragraphs in a common space yieldind a distance measure between those different objects.

Inspired by this success, we define a joint embedding of vertices and hyperedges. This common space offers a mean to perform vertex/hyperedge clustering/classification and hypergraph exploration in general. We will test our vectorization on some benchmark problems and end this talk with a food for thought question: for which hypergraph problems is vectorization unsuitable?

6.9 Interpretations of Homology in Hypergraph Analysis

Speaker: **Bill Kay**, Pacific Northwest National Laboratory

Abstract
Cyber analysts use a variety of tools to maintain situational awareness, discover patterns of user behavior, and keep their network secure. These tools may be based on known signatures of behavior or use methods from statistical analysis and machine learning. As adversaries evolve more complex patterns of behavior, flexible tools that can make sense of complex changing behavior are needed. Topological Data Analysis is a mathematical method we are exploring to build such tools. Loosely speaking, topology is the study of data distributed over space to provide insight into global structure built out of local observations. Examples of such global structures are loops, voids, and components. With an appropriate space built from cyber data topological analysis can be performed. As the topology of a cyber network changes an analyst can gain insight into the factors that cause these changes. In this talk, we explain various modes of constructing hypergraphs from cyber data and then describe the topological metrics we use to identify interesting substructures within the data. Finally, we will show how these topologically-identified substructures were used to gain insight and draw meaningful conclusions from complex cyber network data.

6.10 Modularity Based Community Detection in Hypergraphs

Speaker: **Paweł Misiorek**, Poznan University of Technology

Abstract
Part a), **François Théberge**: The Artificial Benchmark for Community Detection (ABCD) graph is a recently introduced random graph model with community structure and power-law distribution for both degrees and community sizes. In the first part of the talk, we

introduce a hypergraph counterpart of the ABCD model, h–ABCD.

Part b), **Paweł Prałat**: The modularity for graphs was first introduced by Newman and Girvan, and many popular algorithms for partitioning nodes of large graphs use it and perform very well. In the second part of the talk, we generalize it to hypergraphs.

Part c), **Paweł Misiorek**: The main attraction is a scalable community detection algorithm using hypergraph modularity function. The main obstacle with adjusting the initial stage of the classical Louvain algorithm is dealt via carefully adjusted linear combination of the graph modularity function of the corresponding two-section graph and the desired hypergraph modularity function. Bayesian optimization is used to properly tune the algorithm. Finally, the algorithm needs to adjust the weights in the modularity function (in an unsupervised way), depending on how often nodes in one community share hyperedges with nodes from other communities.

6.11 Graph-based Anomaly Detection: Problems, Algorithms and Applications

Speaker: **Leman Akoglu**, Carnegie Mellon University

Abstract
Graphs provide a powerful abstraction for representing non-iid data, capturing immediate as well as long-range relations between various entities. The study of the structure and dynamics of complex graphs has been a central theme of research across various communities. Graph-based anomaly detection focuses broadly on identifying those 'constructs' that do not 'fit' the expected relational patterns.

This talk will present vignettes from my decade-long research on anomaly detection using graph-based techniques. I will introduce various scenarios in which graphs can be used in a natural way – both to formalize concrete anomaly detection problems and to develop algorithmic solutions that span classical detection methods as well as those leveraging graph neural networks. These will be motivated by real-world applications of anomaly detection including opinion fraud, accounting anomalies, and host-level intrusion.

6.12 Modelling hypergraphs in Julia with SimpleHypgraphs.jl

Speaker: **Przemysław Szufel**, SGH Warsaw School of Economics

Abstract
SimpleHypergraphs.jl is a flexible library for working with hypergraphs written in the Julia programming language. SimpleHypergraphs provides several methods for efficient construction, manipulation, and visualization of hypergraphs. The data is stored in a redundant format (vertices x hyperedges and hyperedges x vertices) for fast access and computation of hypergraph properties. The library also provides "views" of hypergraphs that implement an abstraction mechanism required by the popular Graphs.jl library. As of today, Graphs.jl is one of the fastest graph processing libraries across programming languages. This compatibility makes it possible to run several graph algorithms directly on a bipartite or a two-section representation of a hypergraph without actually copying the underlying data. The library also provides several visualization mechanisms, including its implementation on HTML canvas, support for HyperNetX, as well as GraphPlot.jl available due to Graphs.jl

compatibility. More information along with tutorials can be found on project's website at `https://github.com/pszufe/SimpleHypergraphs.jl`.

6.13 Quantum computing in the context of graphs and hypergraphs

Speaker: **Sebastian Zajac**, SGH Warsaw School of Economics

Abstract
Recent years have seen rapid progress in developing quantum computing (QC) devices. Multiple paradigms have been proposed and implemented in hardware. Still, in the NISQ era (noisy inter-mediate scale quantum) there is an increasing interest in developing algorithm that requires hybrid quantum-classical approaches. Quantum computing is believed to solve several problems faster than classical computing in graphs or hypergraphs and in many optimization problems. For example, the possibility of quantum speedup using the hybrid quantum approximate optimization algorithm (QAOA) for a max-cut problem is a subject of active discussion. I will present a realization of the max-cut problem for some simple graphs that can be computed on quantum simulators and real quantum devices.

6.14 Recovery of communities in sparse and dense hypergraph stochastic block models

Speaker: **Lasse Leskelä**, Aalto University

Abstract
The accuracy of a community recovery algorithm can be evaluated by running it on benchmark data sets for which the latent community structure is known, but such empirical approach is biased by the limited availability of suitable data sets. The hypergraph stochastic block model (HSBM) is a generative model for synthetic hypergraphs associated with an explicit community structure, providing an unbiased benchmark for performance evaluation of community recovery algorithms. In addition to being a simulation workbench, the HSBM also allows to mathematically analyse the expected accuracy of an algorithm using the methods of probability theory and statistical information theory.

In this lecture I will discuss fundamental concepts and recent developments on the statistical analysis of hypergraph stochastic block models. In part (a), the focus is on universal information-theoretic bounds that help to understand requirements on data sparsity and model dimensions, under which consistent learning is possible. In part (b), I discuss algorithms that are proven to be consistent in the information-theoretic feasible parameter regime. Part (c) is devoted to open problems and computational challenges concerning a generalised non-binary HSBM in which interactions can be of arbitrary type, which allows to model temporal hypergraphs with time-correlated interaction patterns as a special case.

6.15 Panel on "Applications of hypergraphs"

Moderator: **Bogumił Kamiński**, SGH Warsaw School of Economics

Panelists (tentative):

1. **Cliff Joslyn**, Pacific Northwest National Laboratory

2. **Nicholas Landry**, University of Vermont

3. **Lasse Leskelä**, Aalto University

4. **Brenda Praggastis**, Pacific Northwest National Laboratory

5. **François Théberge**, Tutte Institute for Mathematics and Computing

Abstract
Hypergraphs are natural generalizations of graphs. Therefore they are attractive objects of theoretical research. At the same time the fact that a hyperedge can join any number of vertices is a property that is often an important feature in applications that should be captured by a proper mathematical model.

The flexibility of hypergraphs means that not all concepts and methods developed for graphs can be easily translated. Researchers and practitioners constantly face novel theoretical and computational problems when studying hypergraphs. This makes this field both interesting and challenging.

The objective of the panel is to discuss current opportunities and challenges of practical applications of hypergraphs. Together with the panelists we will discuss the following topics:

1. What are currently the most interesting areas of applications of hypergraphs and which are expected to be most promising in the future?

2. What algorithms and methods are most important to be the focus of the research community to ensure we have the tools that will be used and useful for practitioners?

3. When doing hypergraph research choosing the right datasets on which the studied methods should be tested can be a challenge. Does the community need a standard set of benchmark hypergraphs (both real-world and synthetic benchmarks)?

4. What hypergraphs are encountered in applications (like: number of nodes, degree distribution, hyperedge size distribution, community structure etc.)?

5. What are the next high-order structures we should look at beyond standard hypergraphs? E.g. directed hypergaphs, simplicial complexes?