backbones & *skeletons*

introduction to *network analysis* (*ina*)

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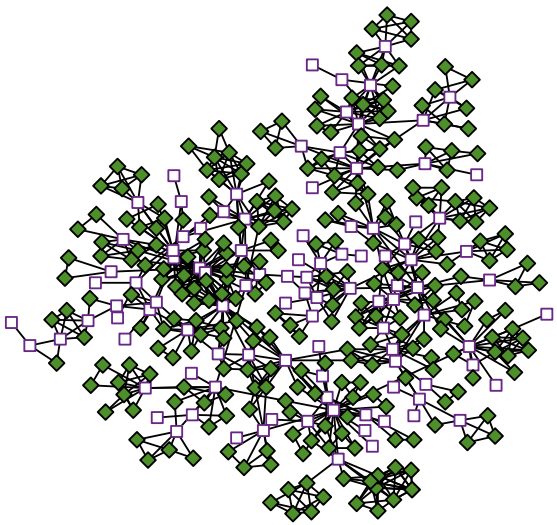
skeletons *overview*

— *network backbone* retains *strongest links/information flow*

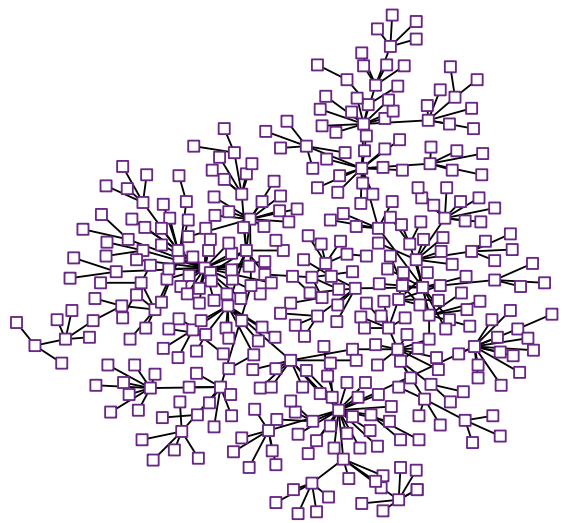
sparsification technique that removes as many links as possible

— *network skeleton* retains *micro/meso/macro structure* [CN17]

simplification technique that retains as many links as possible



coauthorship network

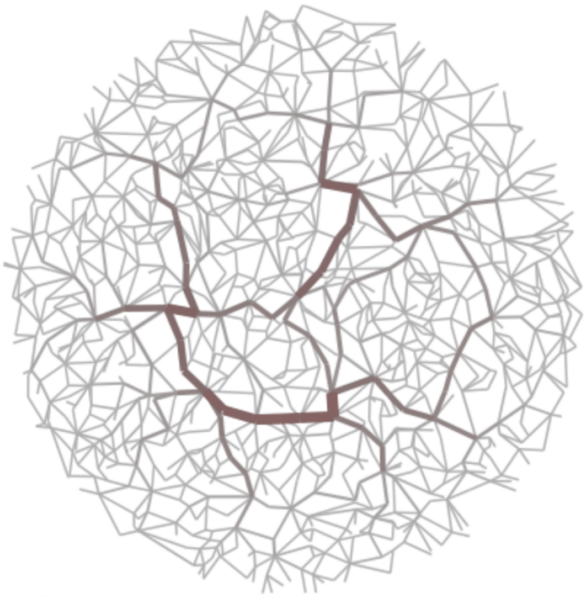


network spanning tree

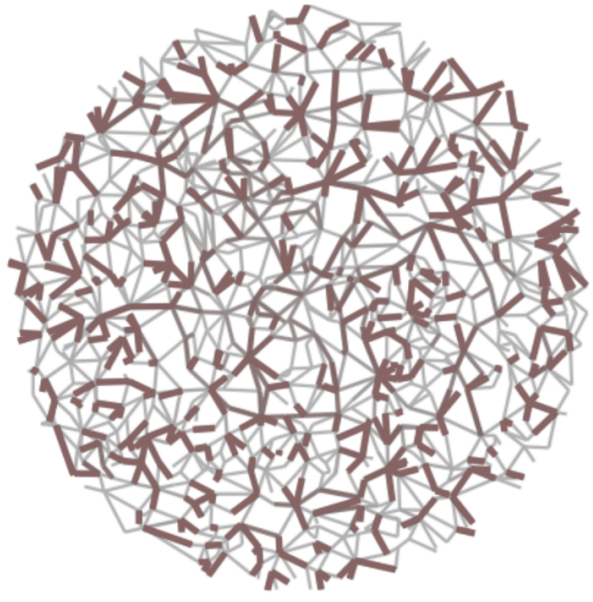
skeletons *geodesics*

— *betweenness/salience skeletons* of *synthetic graph* [GTB12]

betweenness/salience $\sim$ number of geodesics/spanning trees including edge



high-betweenness backbone

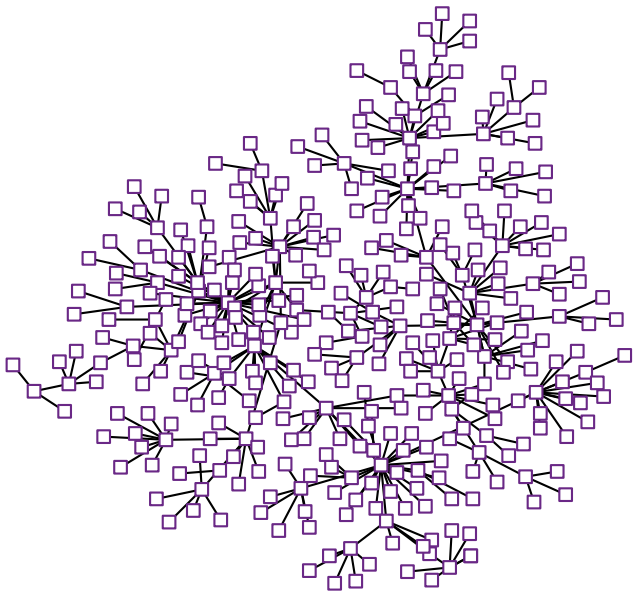


high-salience skeleton

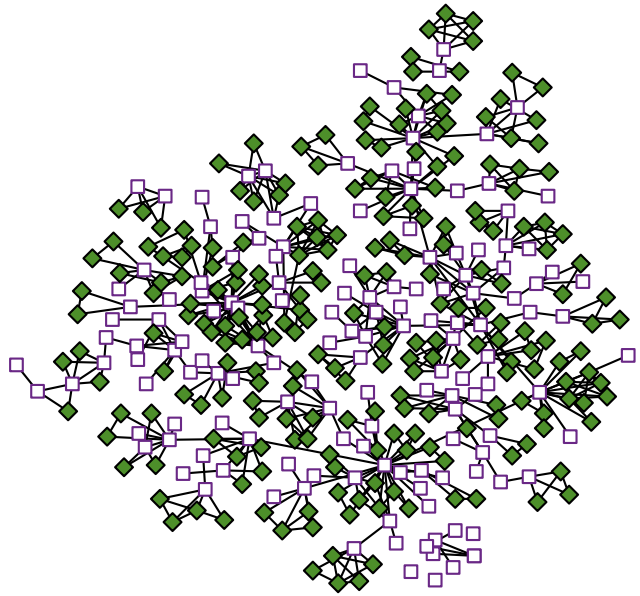
skeletons *convexity*

— *convex skeleton* of famous *network scientists* [MŠ18, Šub18]

largest skeleton where every subgraph includes most geodesics



network spanning tree



convex skeleton $\sim$ tree with cliques

skeletons *statistics*

— *large-scale statistics* of *skeletons of networks* [Šub18]

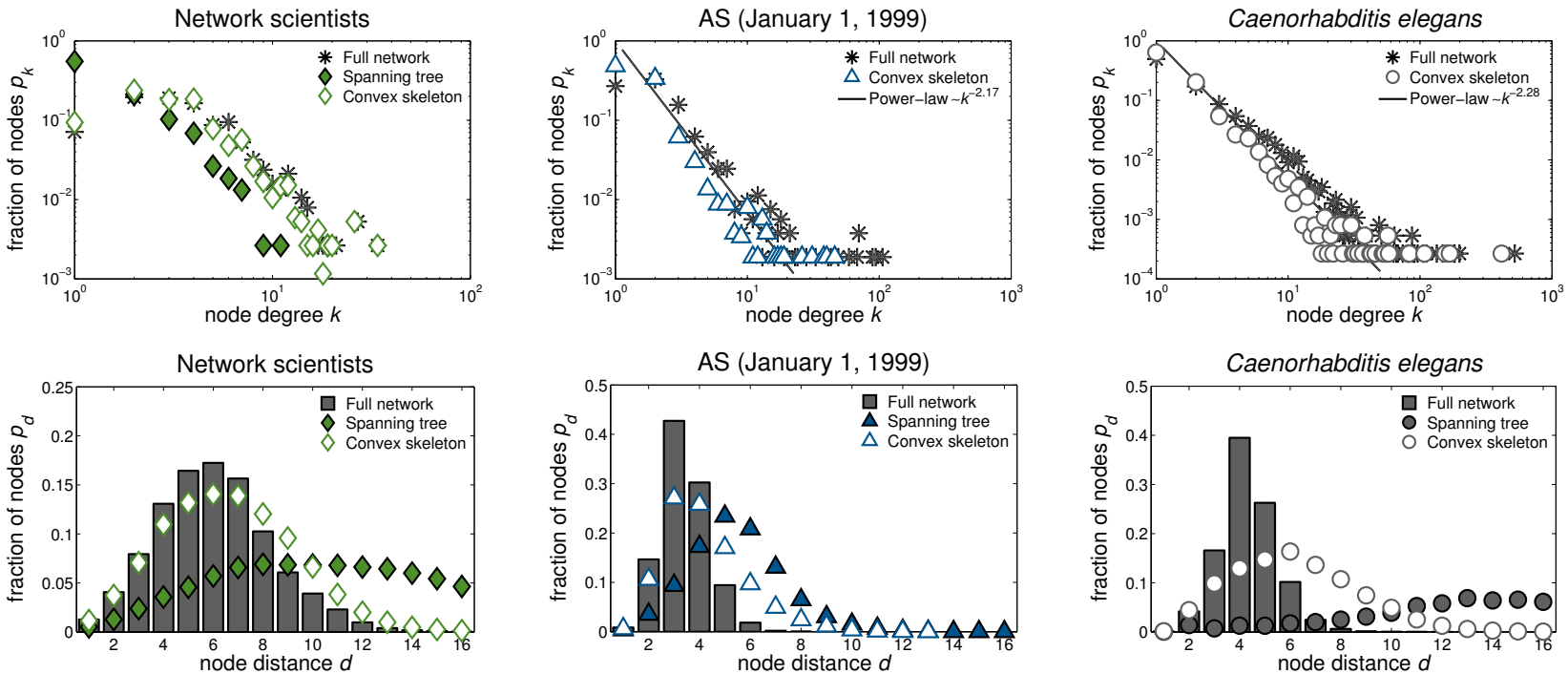
convex skeletons retain connectivity, clustering and geodesics

	clustering $\langle C \rangle$			geodesics $\langle \sigma \rangle$			convexity Xs		
	N	CS	ST	N	CS	ST	N	CS	ST
Jazz musicians	0.62	0.81	0.00	9.71	1.97	1.00	0.12	0.84	1.00
Network scientists	0.74	0.75	0.00	2.66	1.47	1.00	0.85	0.95	1.00
Computer scientists	0.48	0.54	0.00	4.08	1.42	1.00	0.64	0.95	1.00
Plasmodium falciparum	0.02	0.07	0.00	3.71	1.77	1.00	0.43	0.95	1.00
Saccharomyces cerevisiae	0.07	0.10	0.00	2.58	1.19	1.00	0.68	0.88	1.00
Caenorhabditis elegans	0.06	0.12	0.00	6.79	3.03	1.00	0.56	0.85	1.00
AS (January 1, 1998)	0.18	0.21	0.00	3.87	2.32	1.00	0.66	0.91	1.00
AS (January 1, 1999)	0.18	0.27	0.00	3.54	2.05	1.00	0.49	0.95	1.00
AS (January 1, 2000)	0.20	0.25	0.00	4.81	3.07	1.00	0.59	0.90	1.00
Little Rock Lake	0.32	0.69	0.00	22.13	4.32	1.00	0.02	0.82	1.00
Florida Bay (wet)	0.33	0.79	0.00	9.17	1.37	1.00	0.03	0.92	1.00
Florida Bay (dry)	0.33	0.82	0.00	9.37	1.65	1.00	0.03	0.93	1.00

skeletons *distributions*

— *node distributions* of *skeletons of networks* [Šub18]

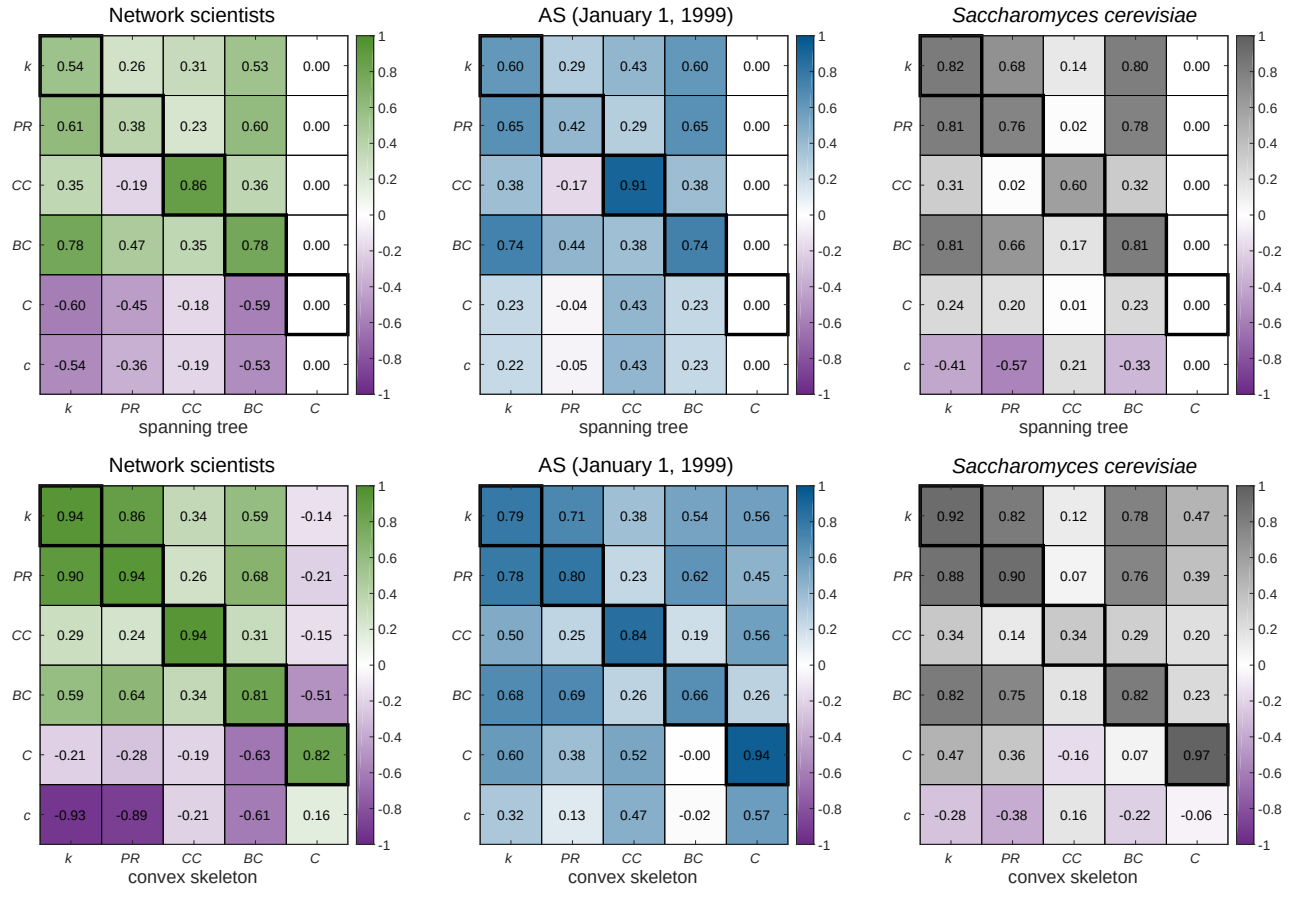
convex skeletons retain node degrees and distances



skeletons *centralities*

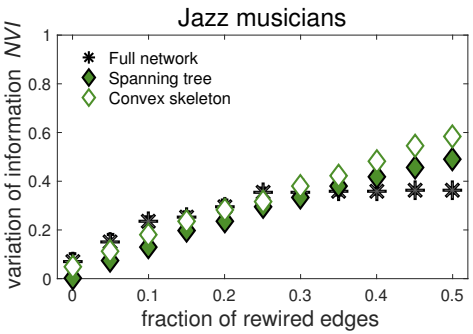
— *node centralities* in *skeletons of networks* [Šub18]

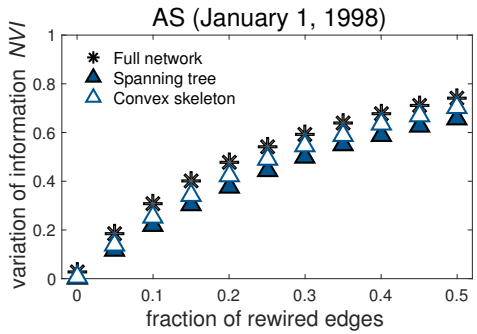
convex skeletons retain node centralities and clustering

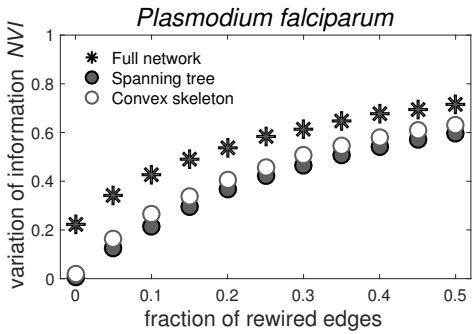


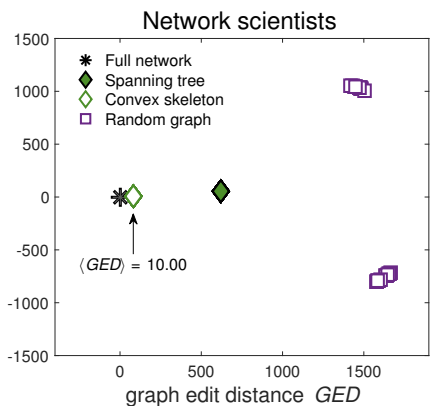
— *communities & robustness* of *skeletons of networks* [Šub18]

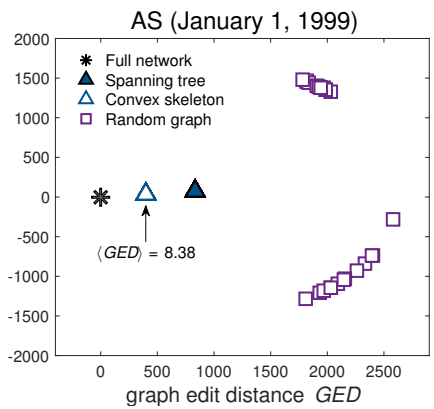
convex skeletons highlight communities with short edit distance

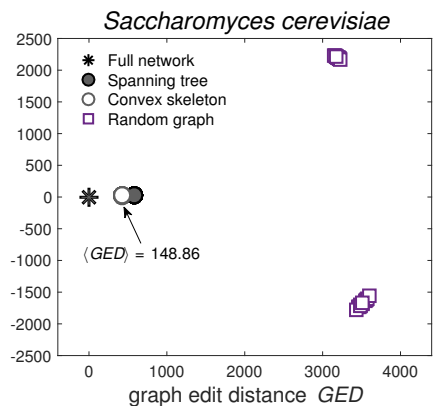








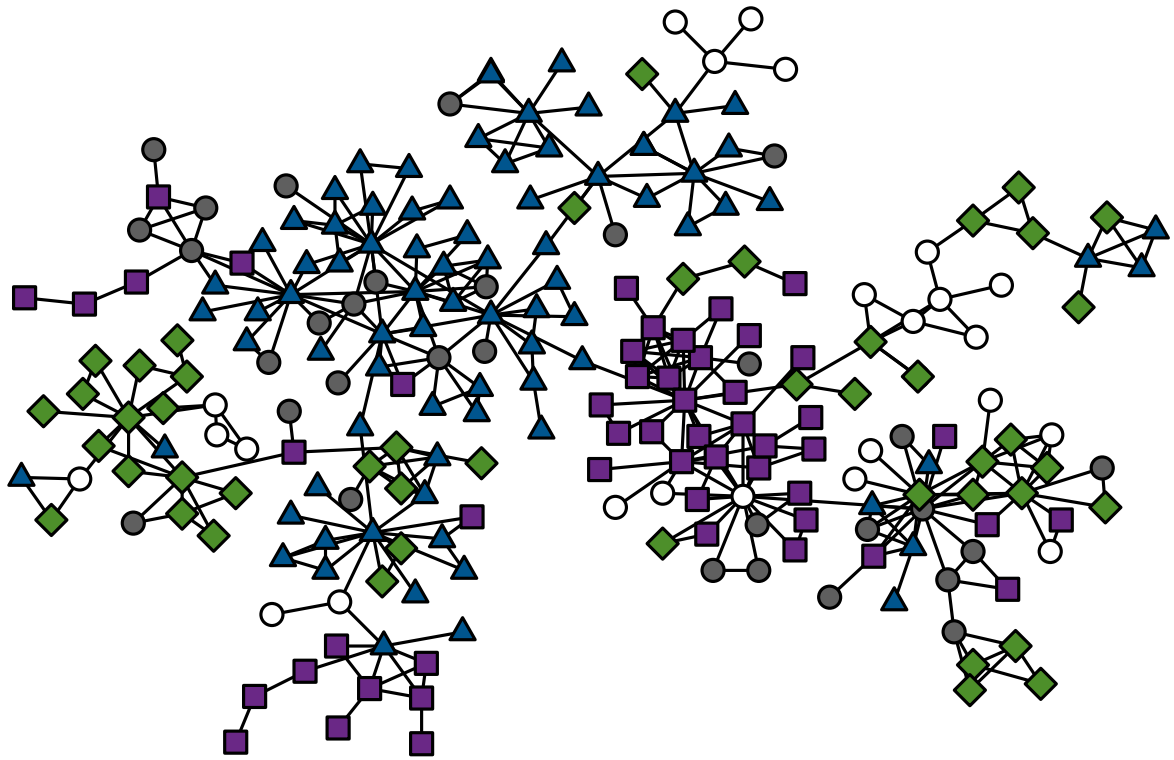




skeletons *coauthorships*

— *convex skeleton* of SI *computer scientists* [Šub18, ŠFCK19]

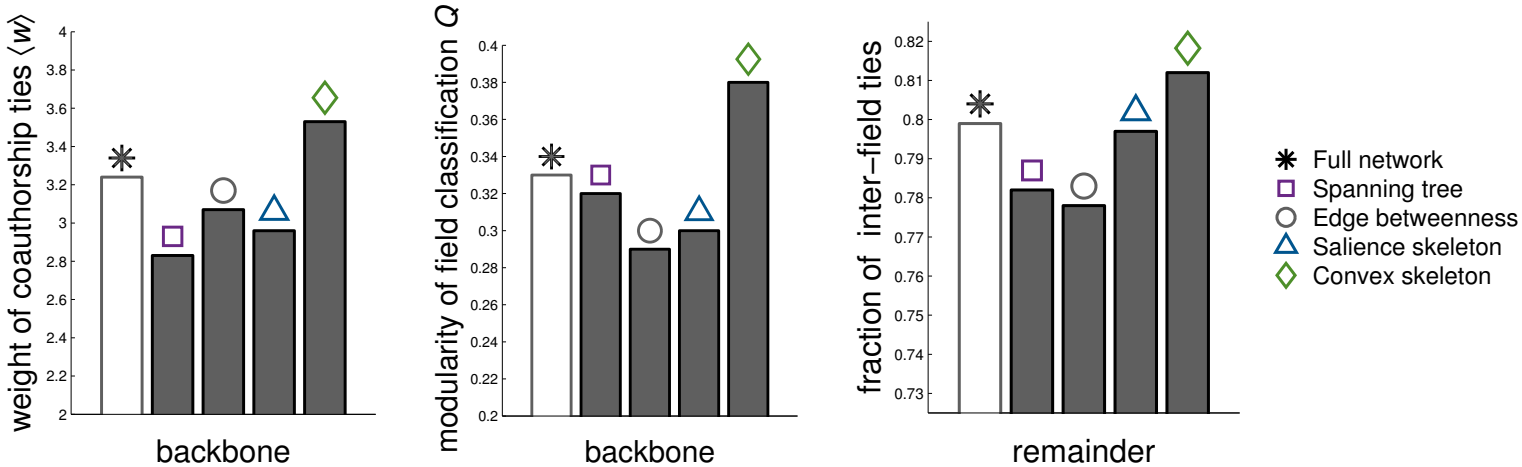
computer theory (◆), information syst. (■), intelligent syst. (▲), programming (○) etc.



skeletons *properties*

— *properties* of *skeletons of coauthorships* [Šub18, ŠFCK19]

convex skeletons retain strong intra-field coauthorships



skeletons *references*

A.-L. Barabási.
Network Science.
Cambridge University Press, Cambridge, 2016.

Michele Coscia and Frank Neffke.
Network backboning with noisy data.
In *Proceedings of the IEEE International Conference on Data Engineering*, pages 425–436, San Diego, CA, USA, 2017.

Wouter de Nooy, Andrej Mrvar, and Vladimir Batagelj.
Exploratory Social Network Analysis with Pajek: Expanded and Revised Second Edition.
Cambridge University Press, Cambridge, 2011.

David Easley and Jon Kleinberg.
Networks, Crowds, and Markets: Reasoning About a Highly Connected World.
Cambridge University Press, Cambridge, 2010.

Ernesto Estrada and Philip A. Knight.
A First Course in Network Theory.
Oxford University Press, 2015.

Daniel Grady, Christian Thiemann, and Dirk Brockmann.
Robust classification of salient links in complex networks.
Nat. Commun., 3:864, 2012.

Martijn P. van den Heuvel, René S. Kahn, Joaquín Goñi, and Olaf Sporns.
High-cost, high-capacity backbone for global brain communication.
P. Natl. Acad. Sci. USA, 109(28):11372–11377, 2012.

Michael Hamann, Gerd Lindner, Henning Meyerhenke, Christian L. Staudt, and Dorothea Wagner.
Structure-preserving sparsification methods for social networks.
Soc. Netw. Anal. Min., 6(1):22, 2016.

skeletons *references*

Tilen Marc and Lovro Šubelj.
Convexity in complex networks.
Netw. Sci., 6(2):176–203, 2018.

Mark E. J. Newman.
Networks.
Oxford University Press, Oxford, 2nd edition, 2018.

Ning Ruan, Ruoming Jin, Guan Wang, and Kun Huang.
Network backbone discovery using edge clustering.
e-print arXiv:12021842v2, 2012.

Lovro Šubelj, Dalibor Fiala, Tadej Ciglarič, and Luka Kronegger.
Convexity in scientific collaboration networks.
J. Infometr., 13(1):10–31, 2019.

Lovro Šubelj.
Convex skeletons of complex networks.
J. R. Soc. Interface, 15(145):20180422, 2018.