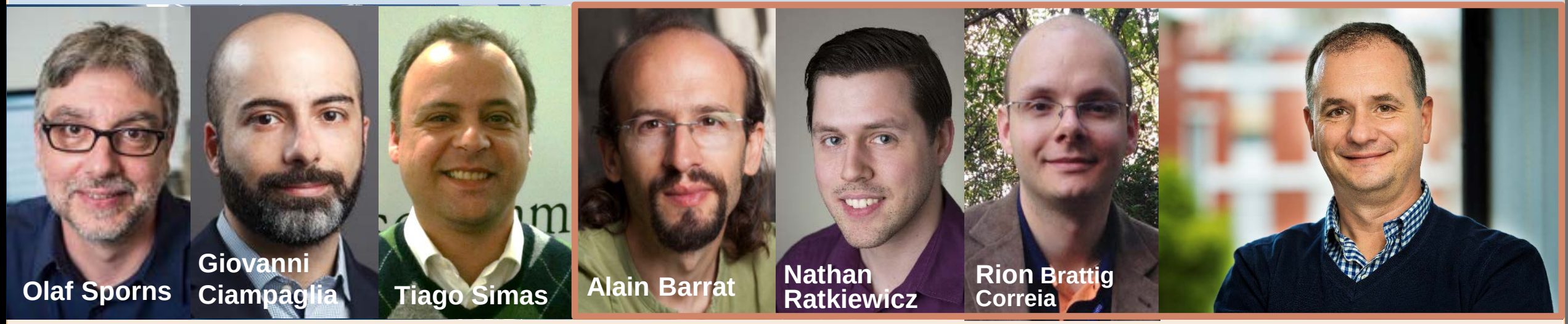
the metric backbone of contact networks in Epidemic Spread Models



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Instituto Gulbenkian de Ciência

Indiana University
Network Science Institute

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cnrs dépasser les frontières

NSF

NIH NLM

FULBRIGHT

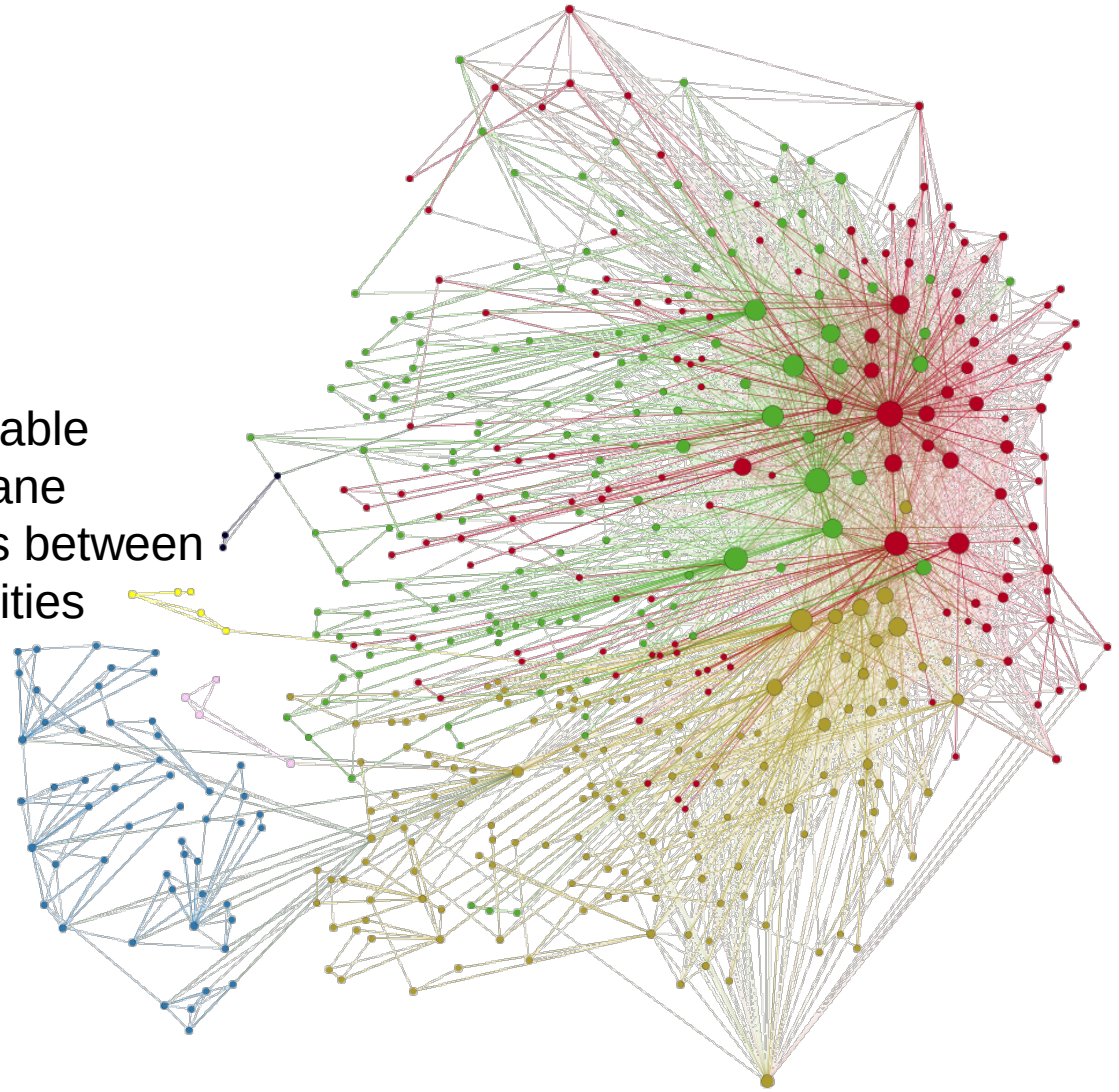
PERSISTENT

metric backbone

of distance networks (weighted graphs)

d

Available airplane seats between US cities



Colizza,, Pastor-Satorras,, Vespignani [2007]. *Nature Physics* **3**, 276-282.;

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metric backbone

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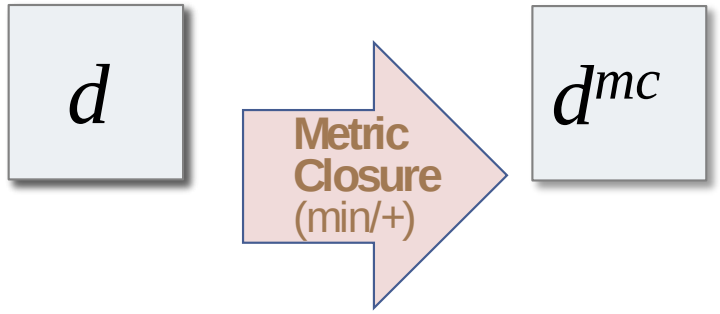
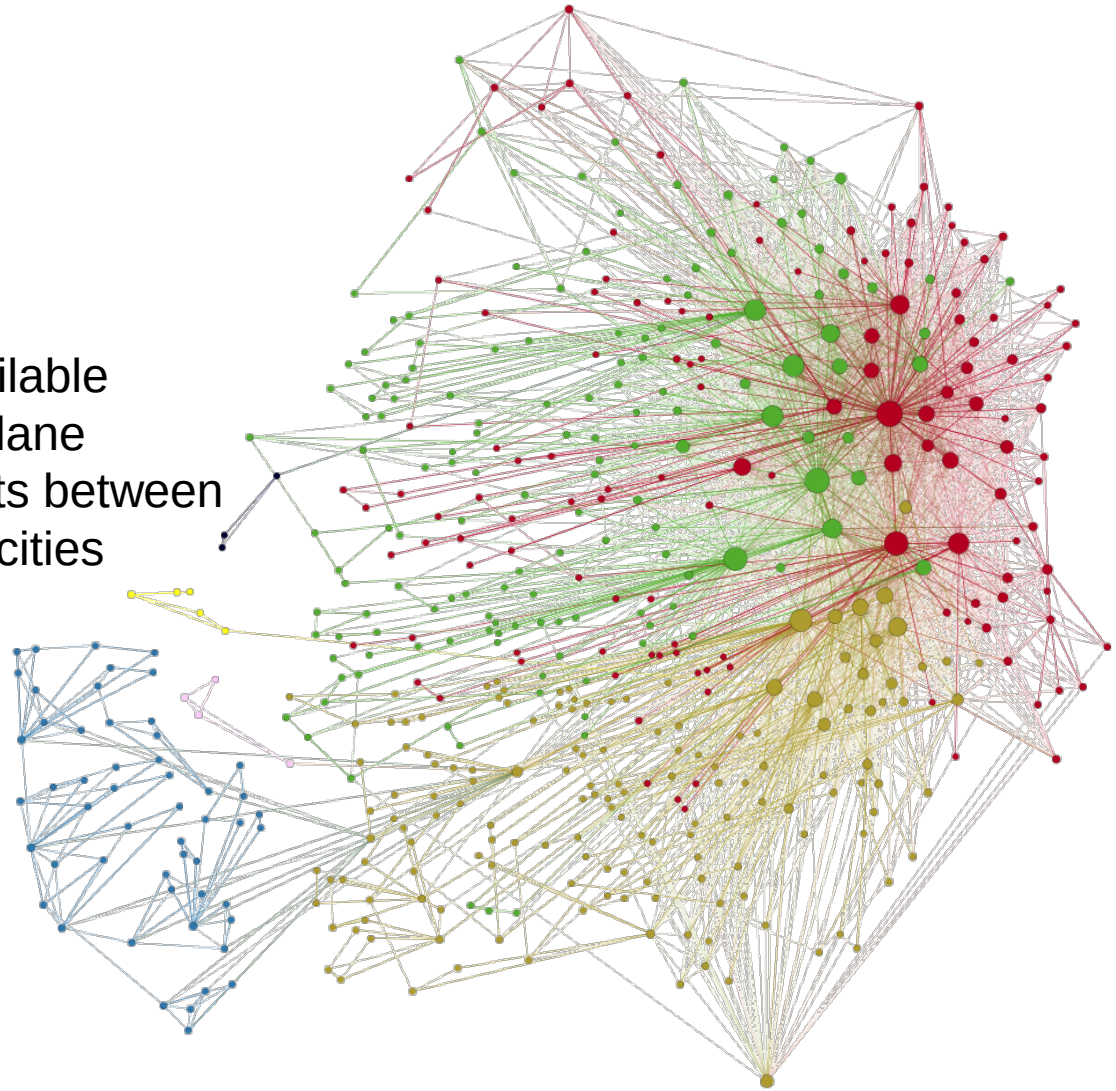


all pairs ***shortest paths*** problem (APSP) on distance graphs

Available airplane seats between US cities



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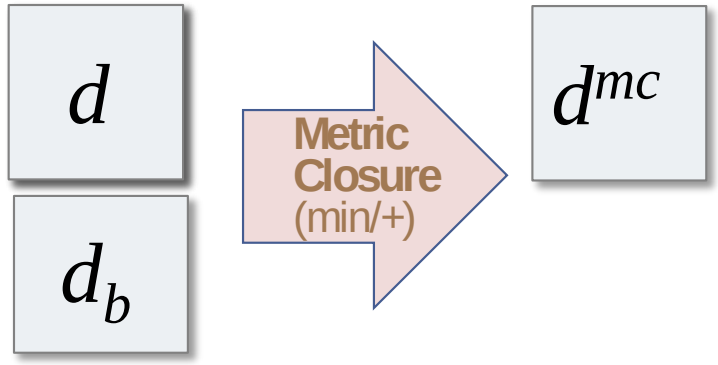
of distance networks (weighted graphs)

Metric (distance) Backbone: minimum sub-graph for which all shortest paths are preserved.

Invariant subgraph under metric closure (or APSP)



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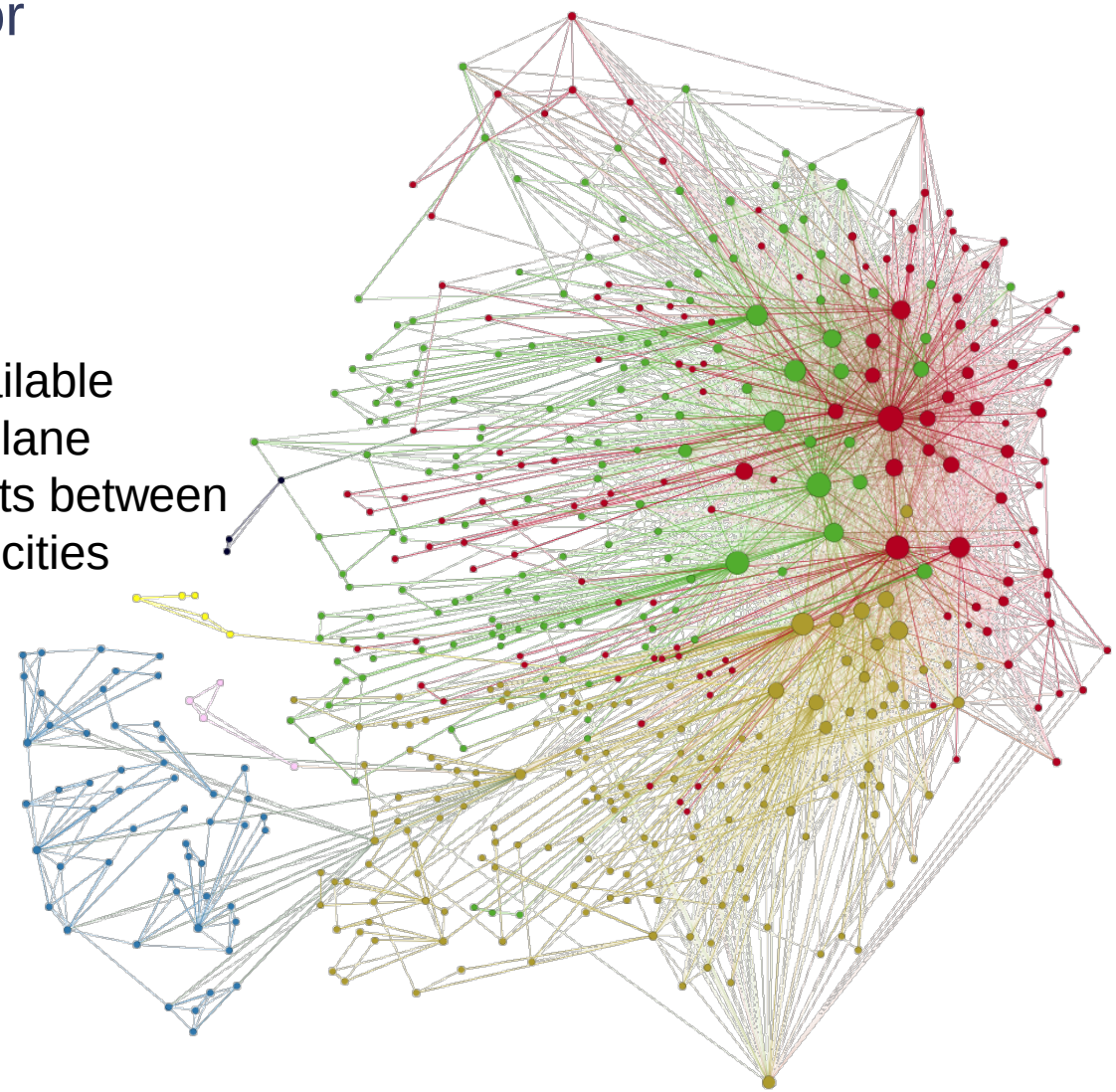
Available airplane seats between US cities



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of distance networks (weighted graphs)

Metric (distance) Backbone: minimum sub-graph for which all shortest paths are preserved.

Invariant subgraph under metric closure (or APSP)

75% of edges are ***semi-metric*** and removed from metric backbone

d

d_b

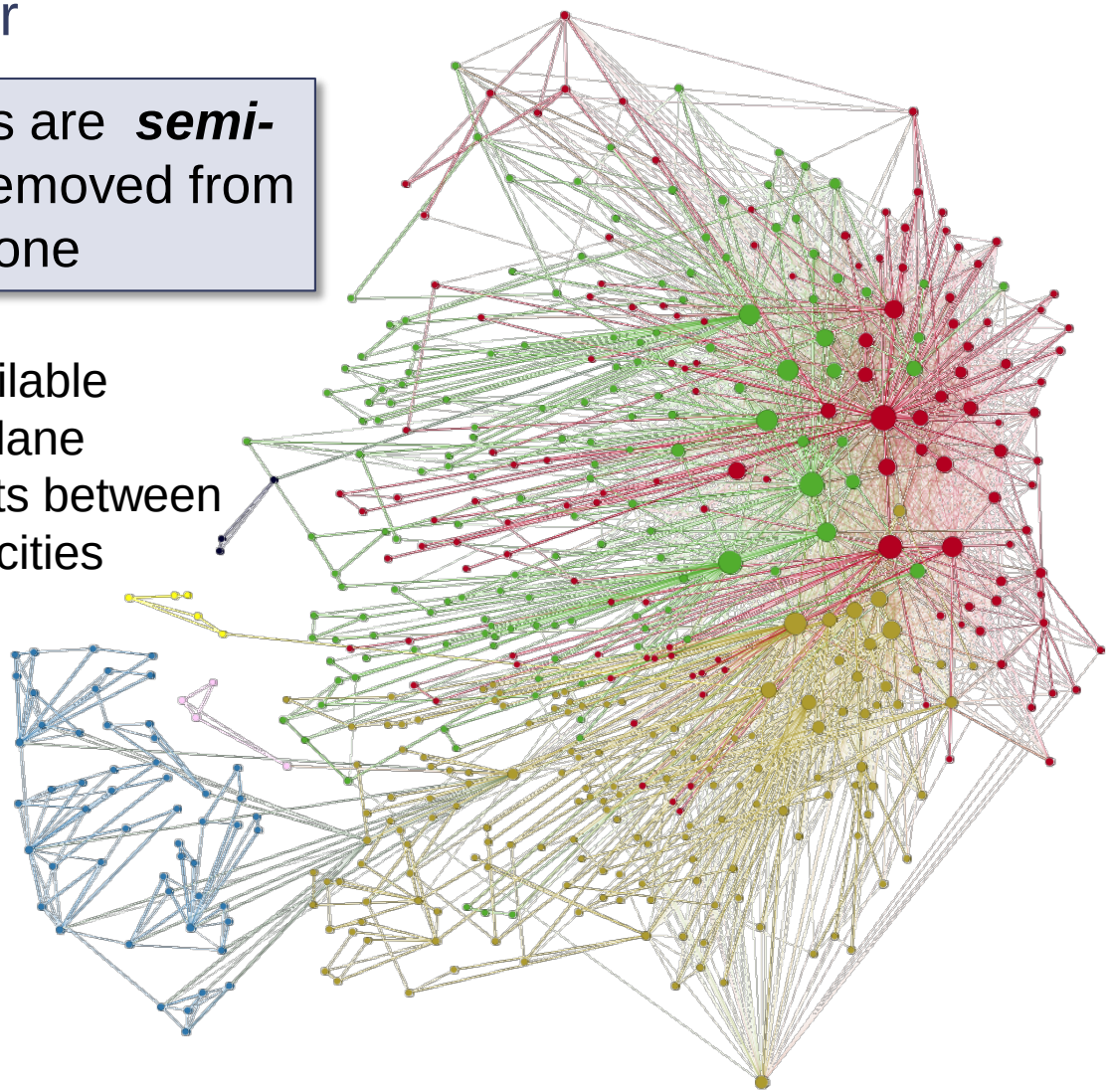
Metric Closure (min/+)

d^{mc}

$$s_{i,j} = \frac{d_{i,j}}{d_{i,j}}$$

all pairs ***shortest paths*** problem (APSP) on distance graphs

Available airplane seats between US cities



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of distance networks (weighted graphs)

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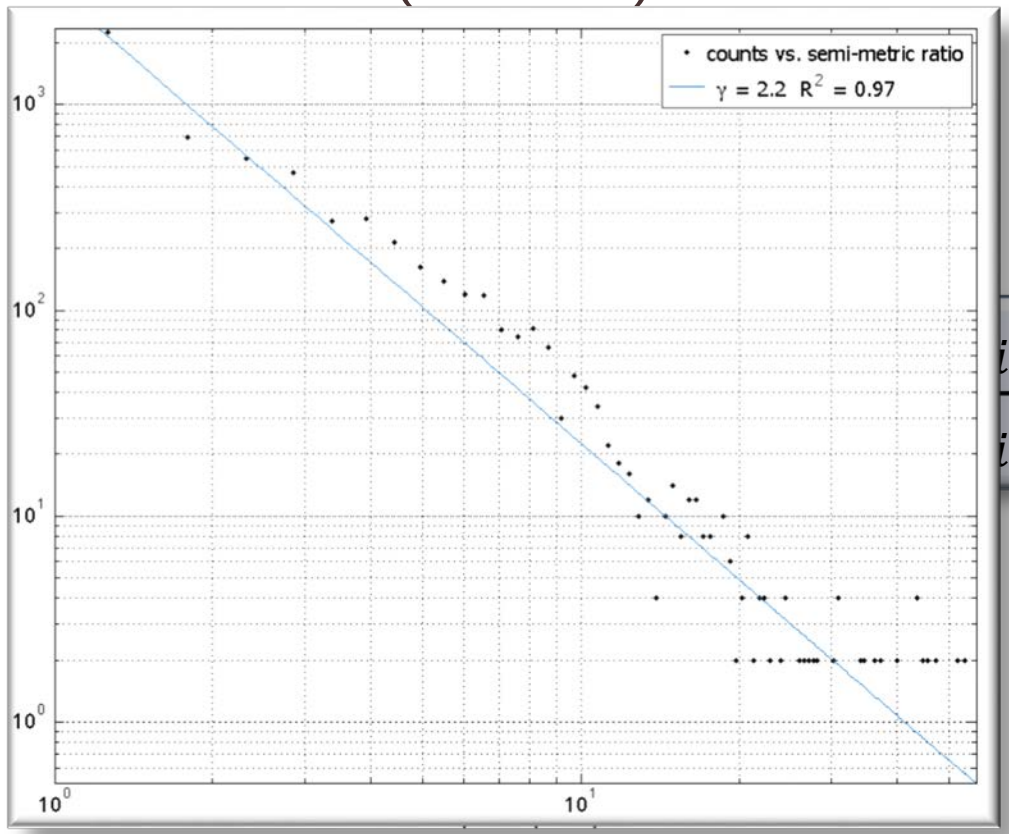
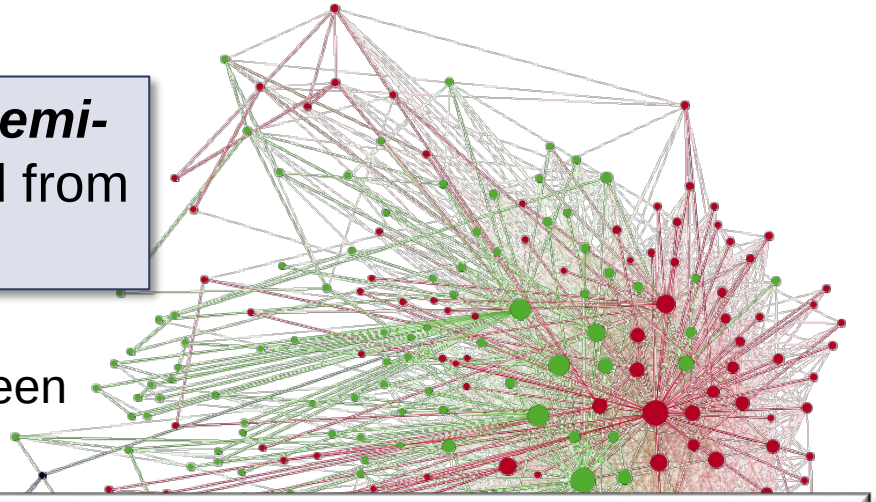


75% of edges are ***semi-metric*** and removed from metric backbone



airplane seats between US cities

- **Semi-metric (semi-triangular) edges**:
  - Redundant for shortest-path computation (distance closure)
  - Null edge betweeness centrality
  - Varying *semi-metric distortion*
  - Participate in Clustering coefficient, Degree, Modularity
  - Do not form bridges
- **Metric (triangular) Edges**:
  - Participate in shortest path, Efficiency, betweenness
  - All bridges in metric backbone
- **Networks**
  - more semi-metric (redundant) early in evolution
  - semimetric networks robust to random node removal

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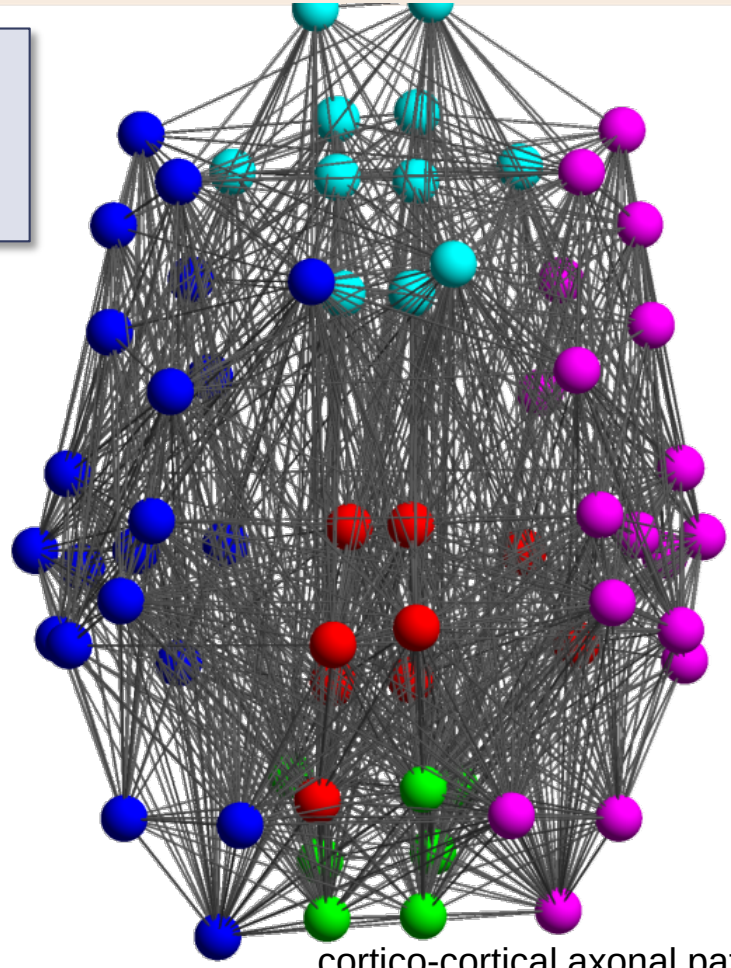
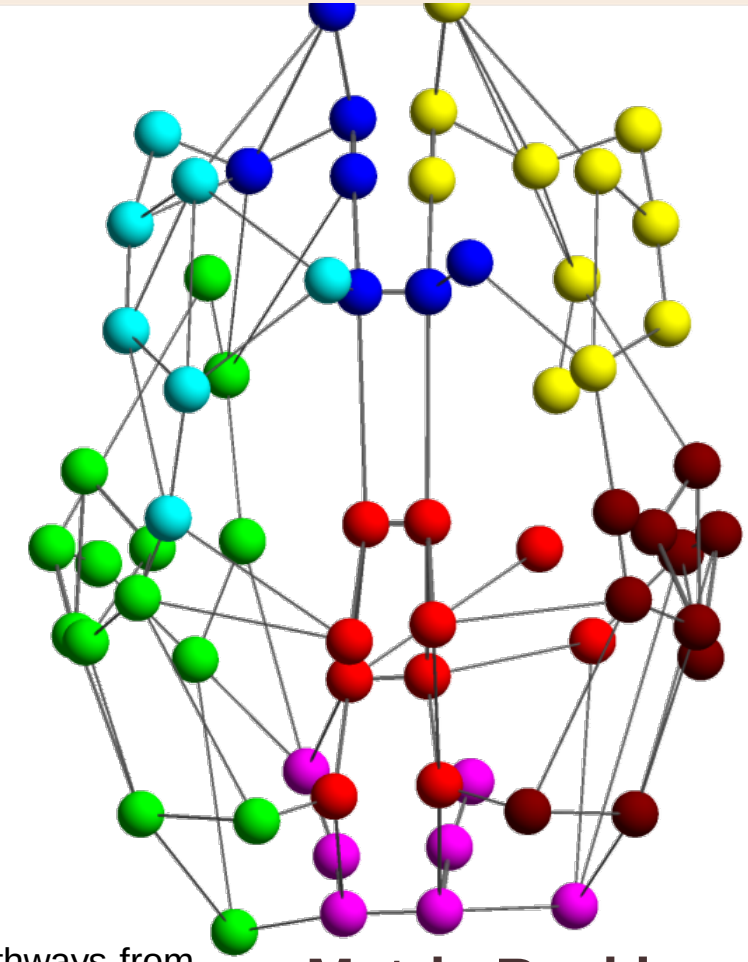
In brain, bio, and socio-technical distance networks

91% of edges are semi-metric (removed from backbone)

#id	Network	# Nodes	SM
1	USN	500	75%
2	HCN	66	91%
3	HBFN	116	85%
4	C-Elegans	297	31%
5	BKF	58	85%
6	ARP-IPP	1,702	71%
7	ARP-PIP	382	73%
8	ARP-Keywords	500	96%
9	WordNet	150	85%
10	SCN	12,722	9%
11	APN	14,845	20%
12	HEN	5,835	13%





cortico-cortical axonal pathways from diffusion spectrum Imaging (DSI)
Hagmann et al. [2008]. *PLoS Biol* **6**(7): e159.

Metric Backbone

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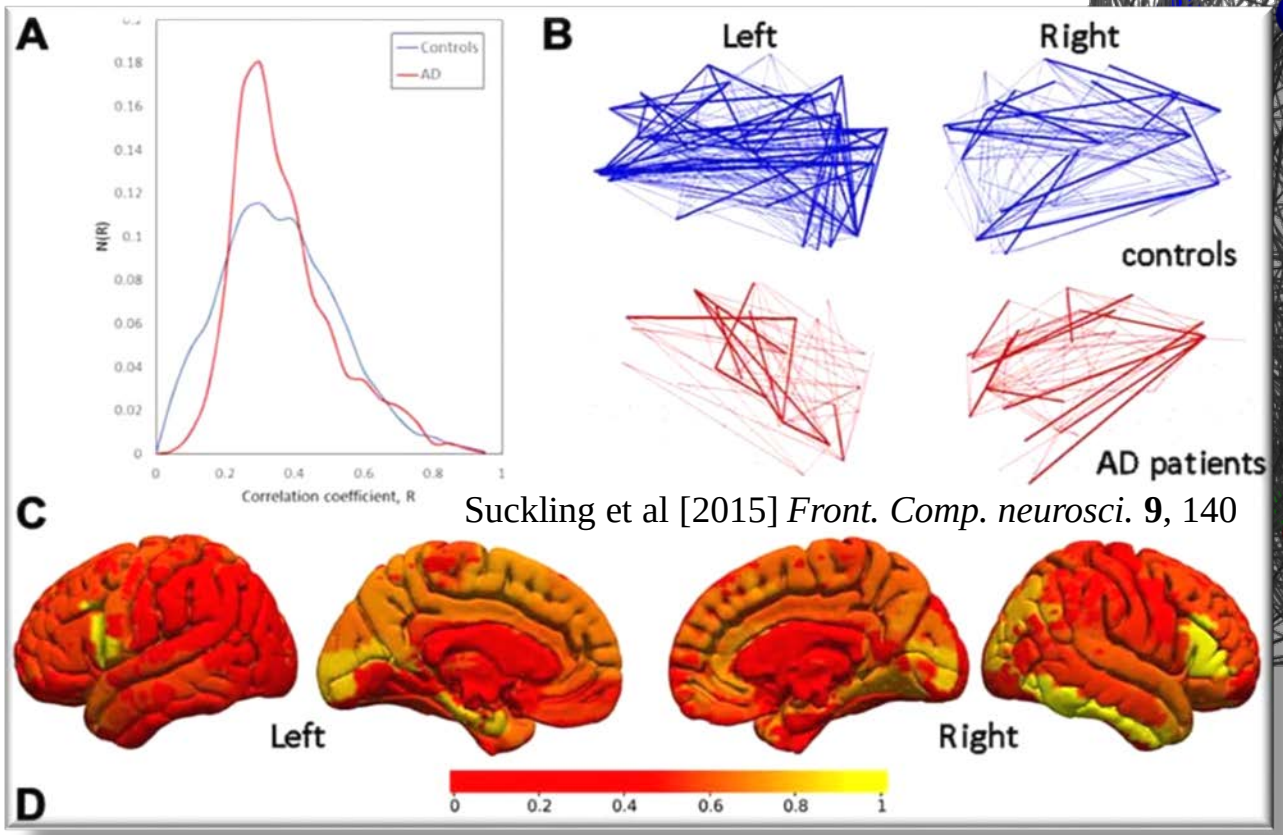
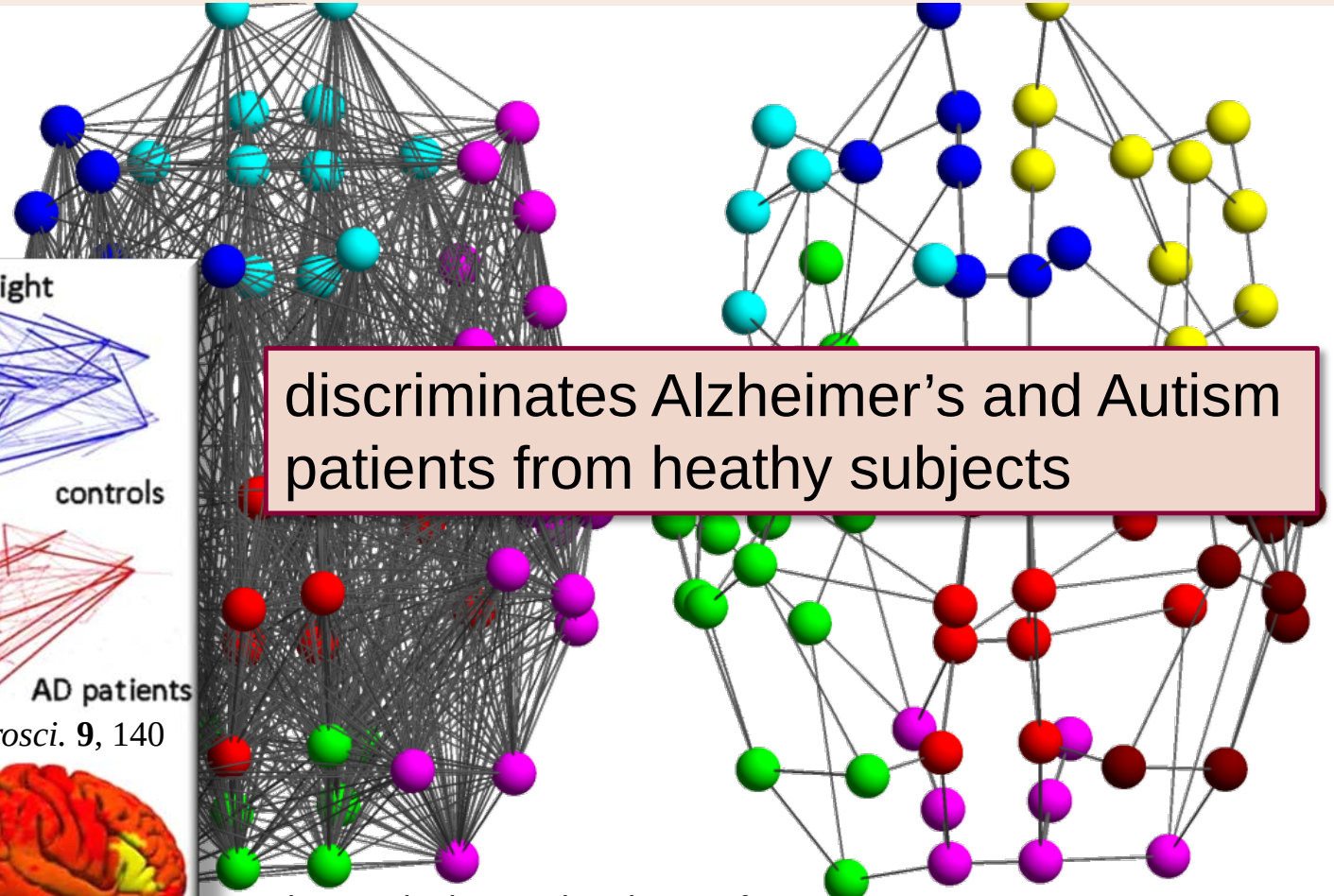


Suckling et al [2015] *Front. Comp. neurosci.* **9**, 140



discriminates Alzheimer's and Autism patients from heathy subjects

cortico-cortical axonal pathways from diffusion spectrum Imaging (DSI)
Hagmann et al. [2008]. *PLoS Biol* **6**(7): e159.

Metric Backbone

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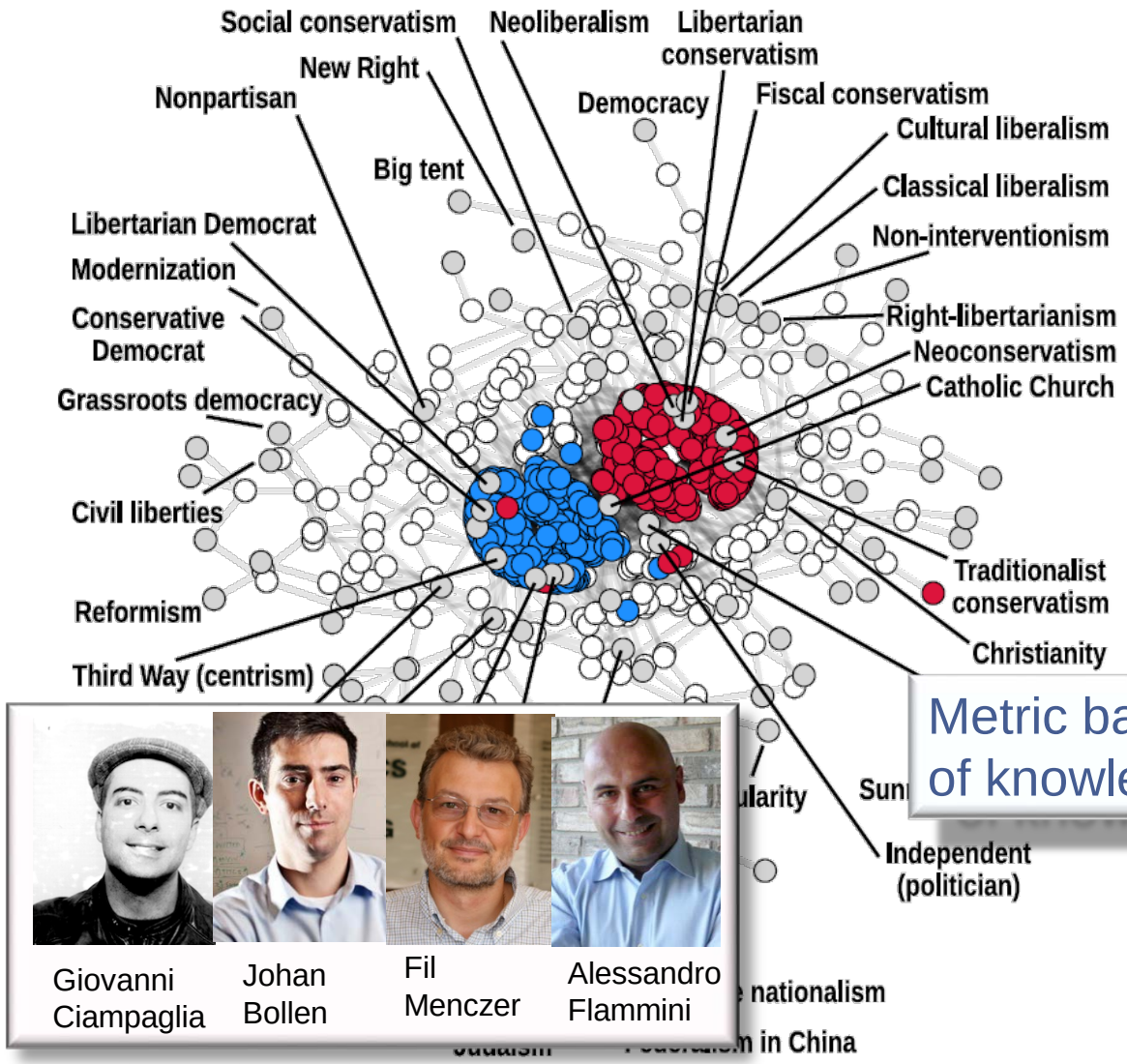
from data in Wikipedia

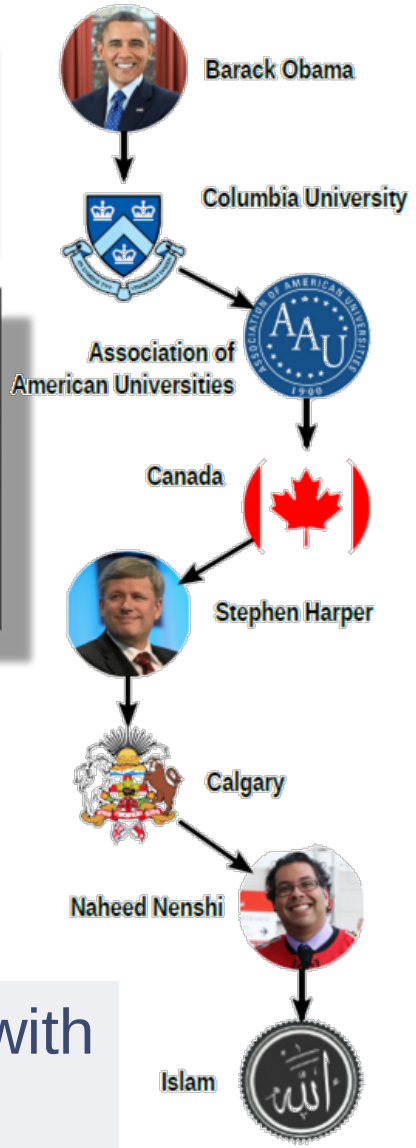


Giovanni Ciampaglia | Johan Bollen | Fil Menczer | Alessandro Flammini

Massive distance graph
3.14 Million nodes
23 Million edges

Fact-Checking
Associative inference via shortest paths (metric backbone) of maximum Information content distance/knowledge graph

Metric backbone is **2%** of knowledge graph



DBpedia

4.0 million “things” with 470 million “facts”.

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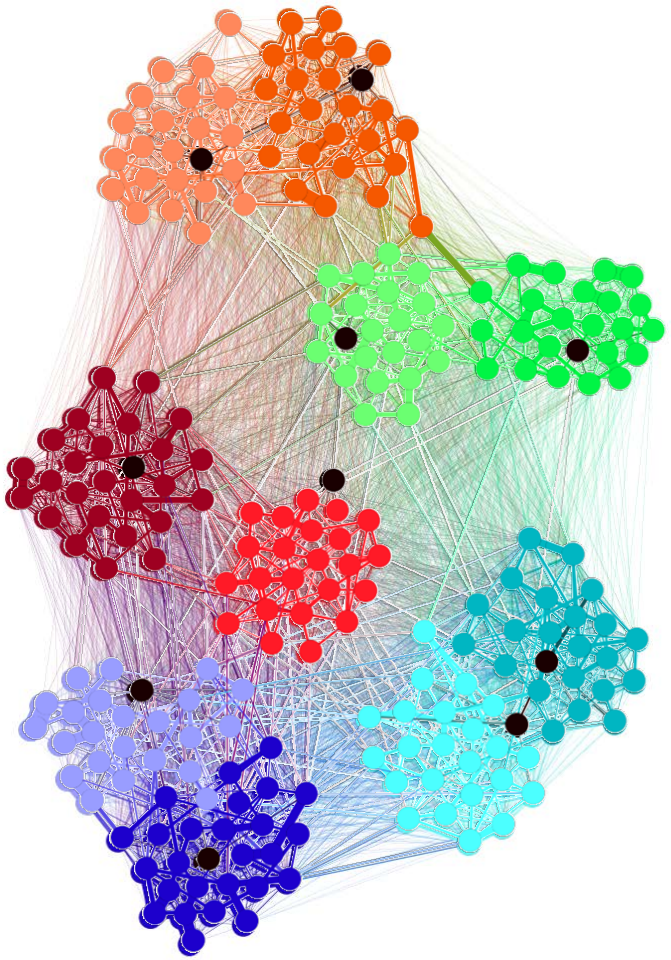
Ciampaglia et al [2015]. *PLoS ONE* **10**(6): e0128193.

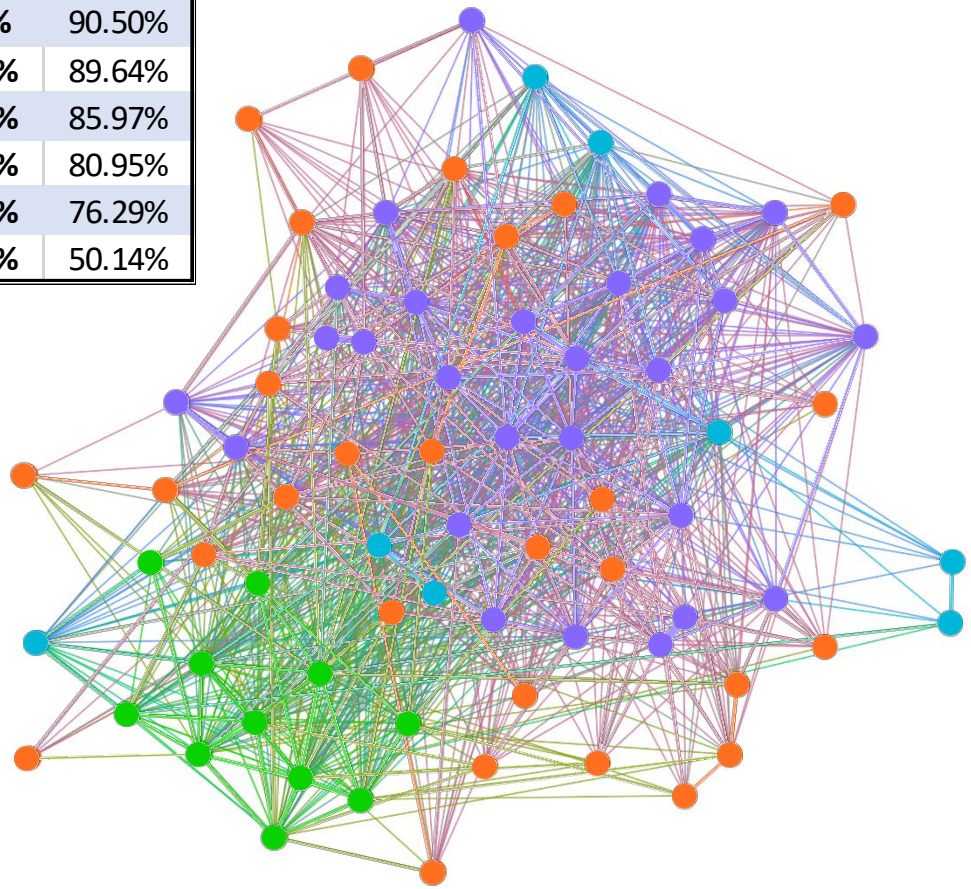
on social contact distance networks



Network	N	E	Con	MB	SM
Primary School	242	8317	28.52%	**9.50%**	90.50%
High School	327	5818	10.92%	**10.36%**	89.64%
Conference	113	2196	34.70%	**14.03%**	85.97%
Hospital	75	1139	41.05%	**19.05%**	80.95%
workplace	92	755	18.04%	**23.71%**	76.29%
Museum	200	714	3.59%	**49.86%**	50.14%

metric backbone sufficient to compute all shortest paths

Does it preserve social organization in SocioPatterns datasets?



SocioPatterns

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Correia, Ratkiewicz, Barrat & Rocha [2018]. In Preparation.

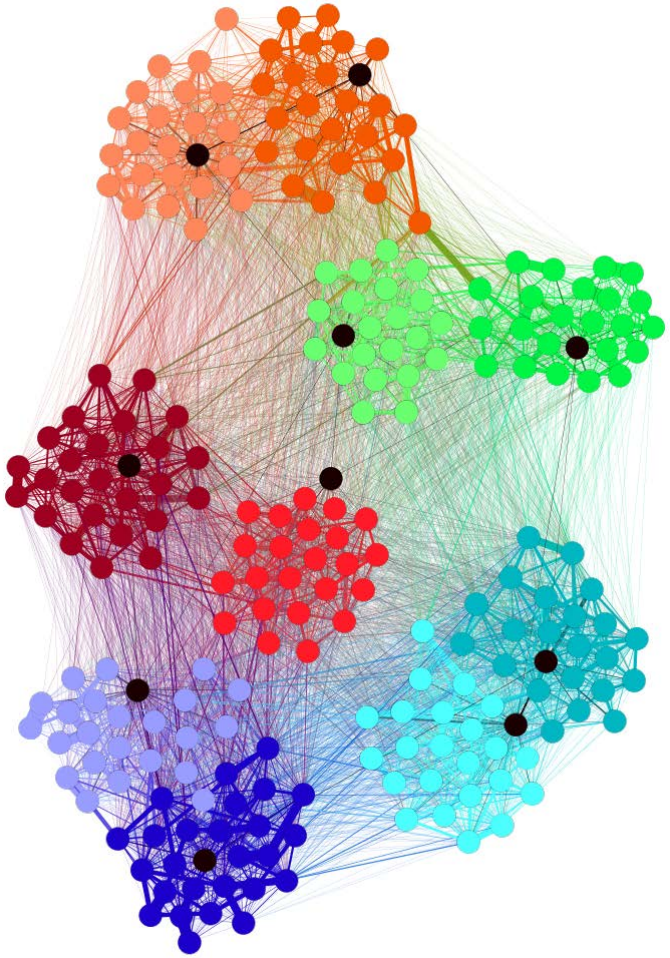
R. Mastrandrea, J. Fournet, A. Barrat, *PLoS ONE* **10**(9):e0136497 (2015)

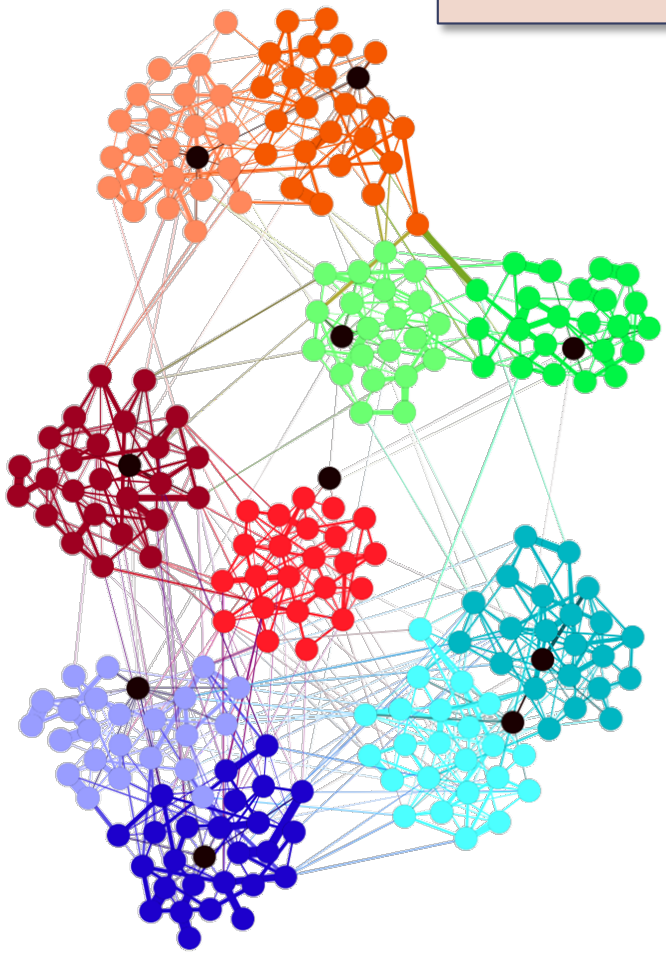
social organization in primary school contact network

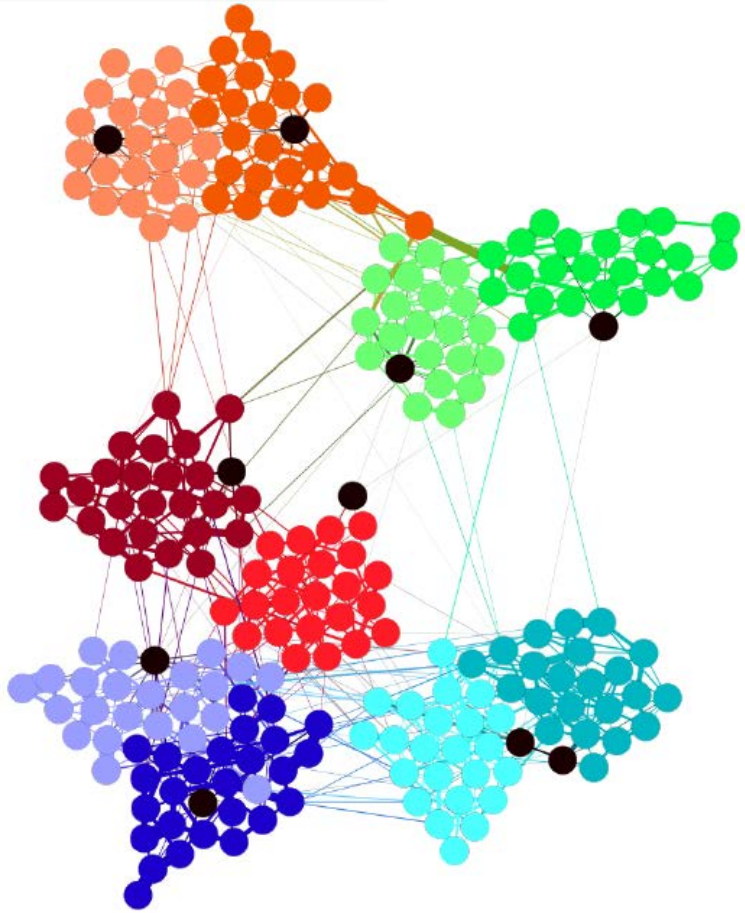
is preserved in metric backbone

Network	N	E	Con	MB	SM
Primary School	242	8317	28.52%	**9.50%**	90.50%

Original class labels remain as communities in metric backbone subgraph







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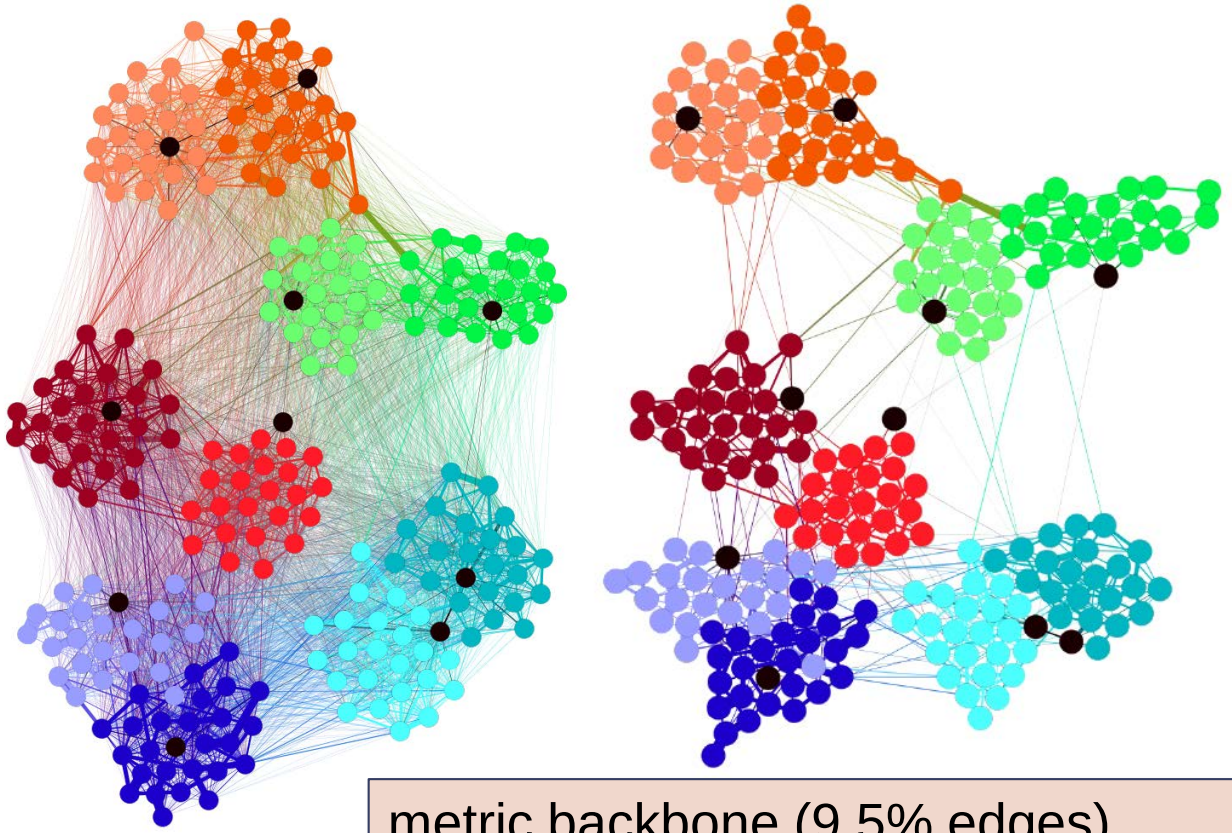
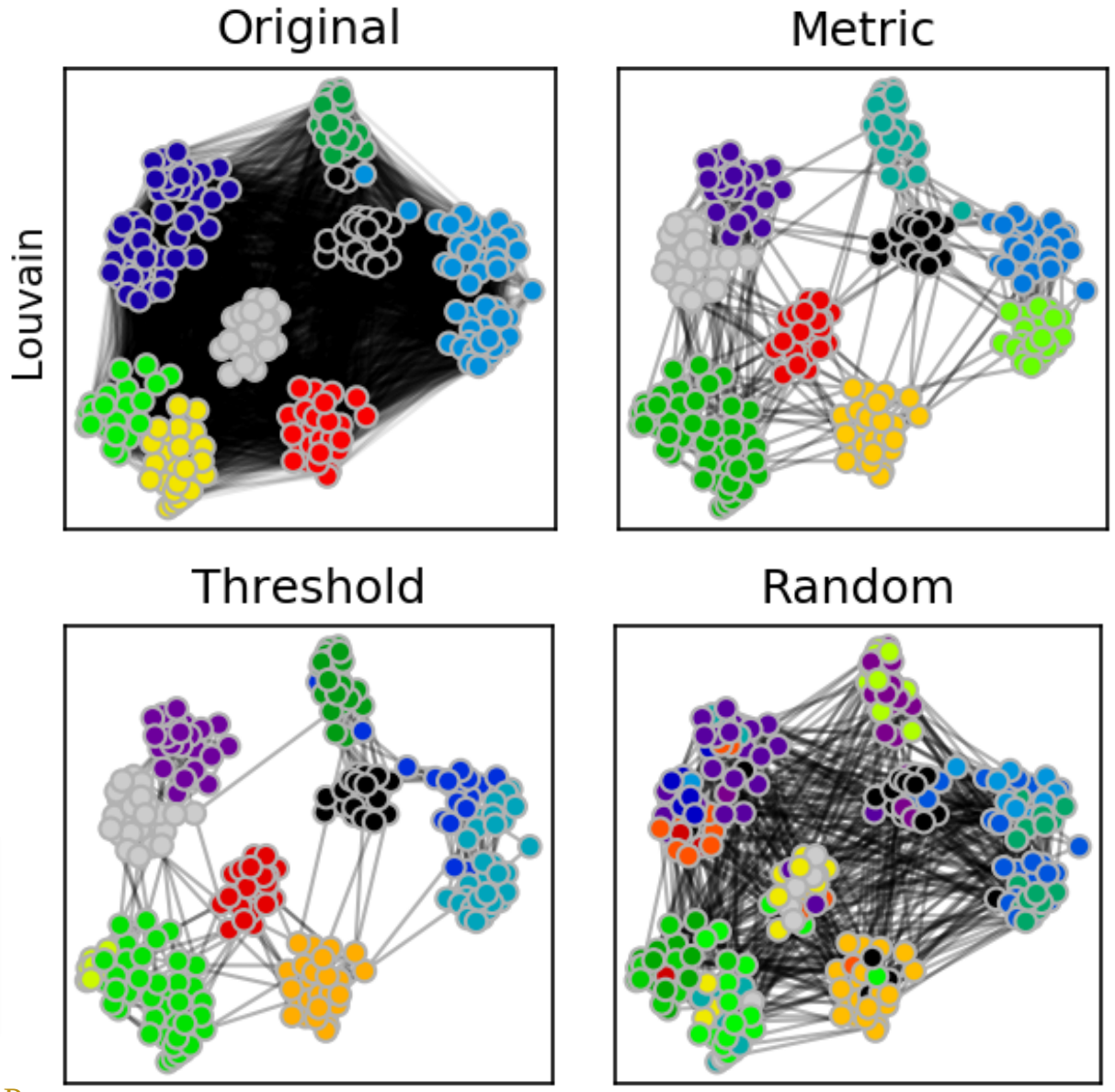
metric backbone vs. distance threshold and random deletion “backbones” of same size

Network	N	E	Con	MB	SM
Primary School	242	8317	28.52%	**9.50%**	90.50%



metric backbone (9.5% edges) sufficient to compute all shortest paths unlike other “backbones”



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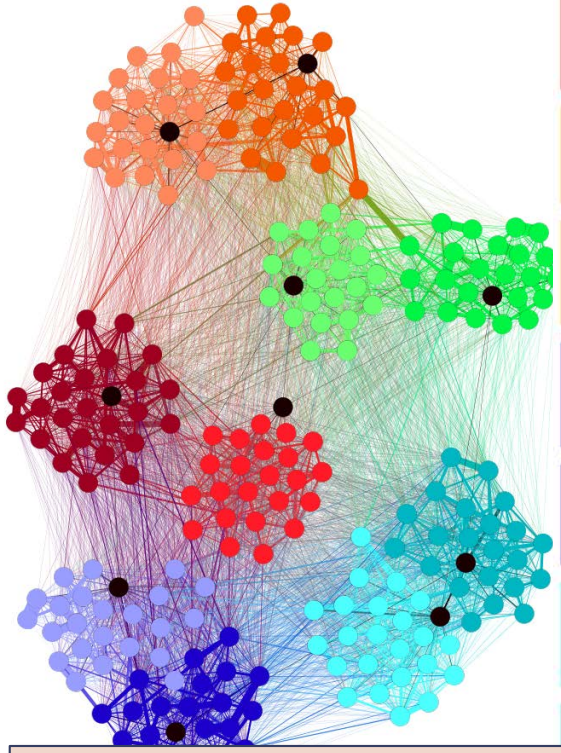
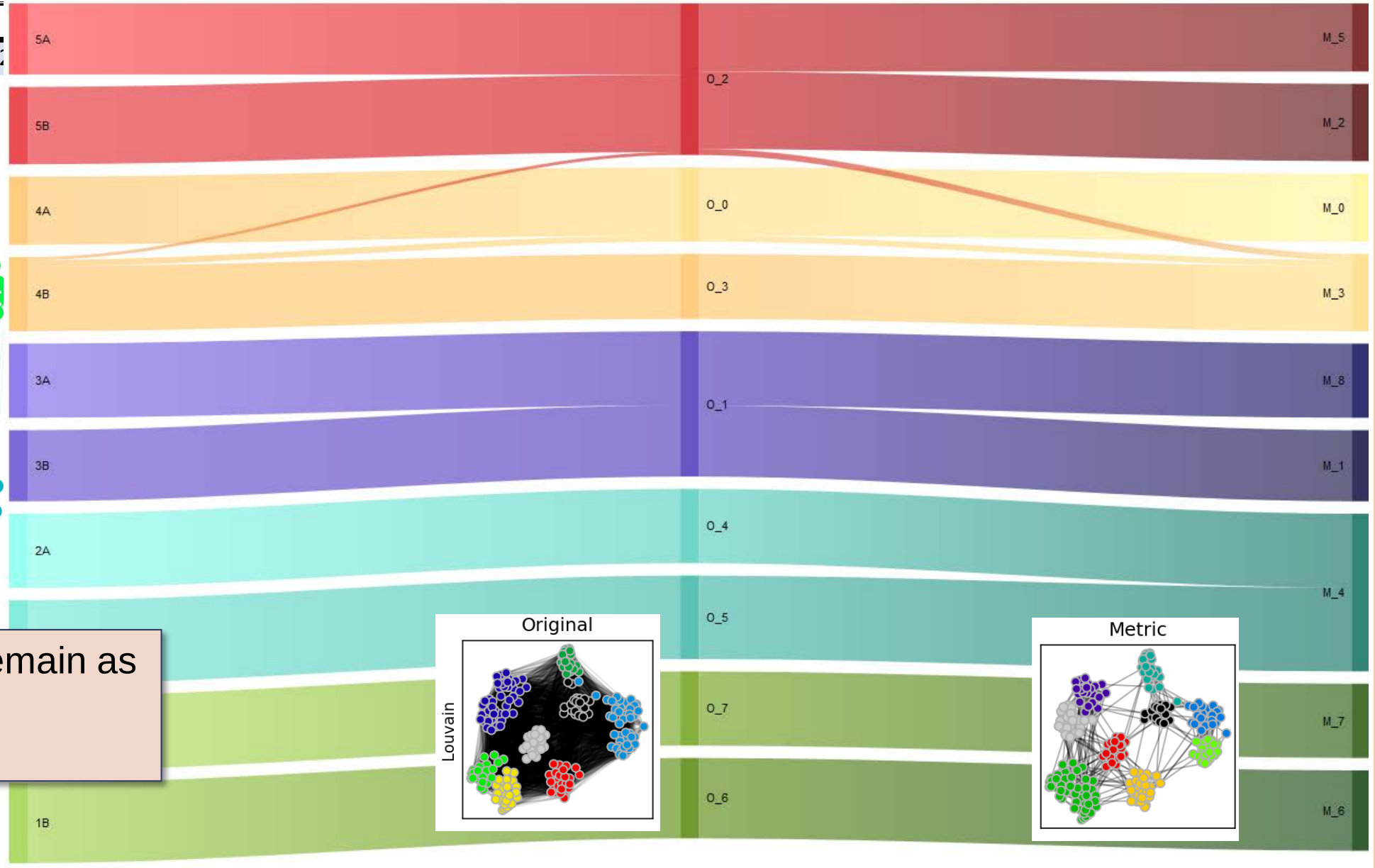
community structure of primary school contact network

metric backbone vs. distance threshold and random deletion “backbones” of same size

Network	N	E
Primary School	242	8317



original class labels remain as communities in metric backbone subgraph



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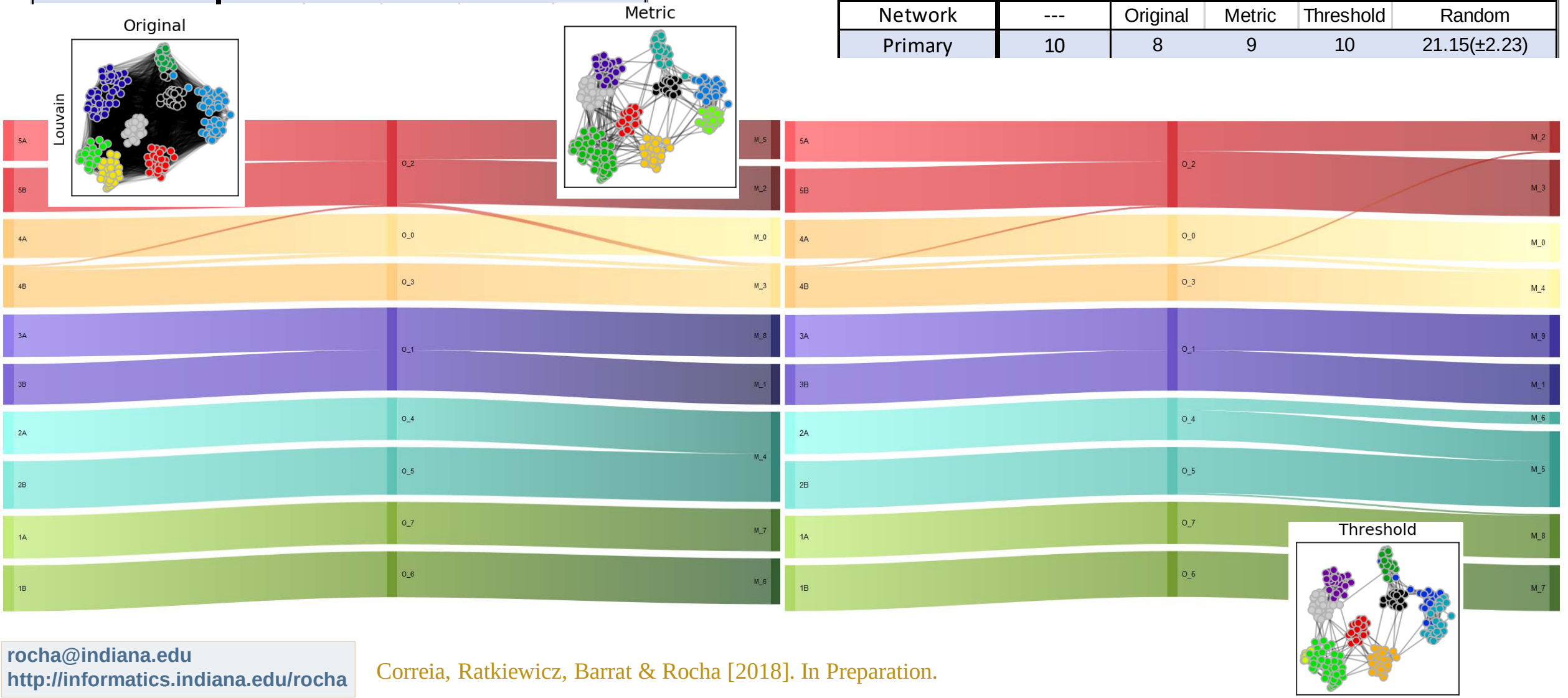
community structure of primary school contact network

metric backbone vs. distance threshold and random deletion “backbones” of same size

Network	N	E	Con	MB	SM
Primary School	242	8317	28.52%	**9.50%**	90.50%

	Communities				
	metalabels	Louvain			
Network	---	Original	Metric	Threshold	Random
Primary	10	8	9	10	21.15(±2.23)



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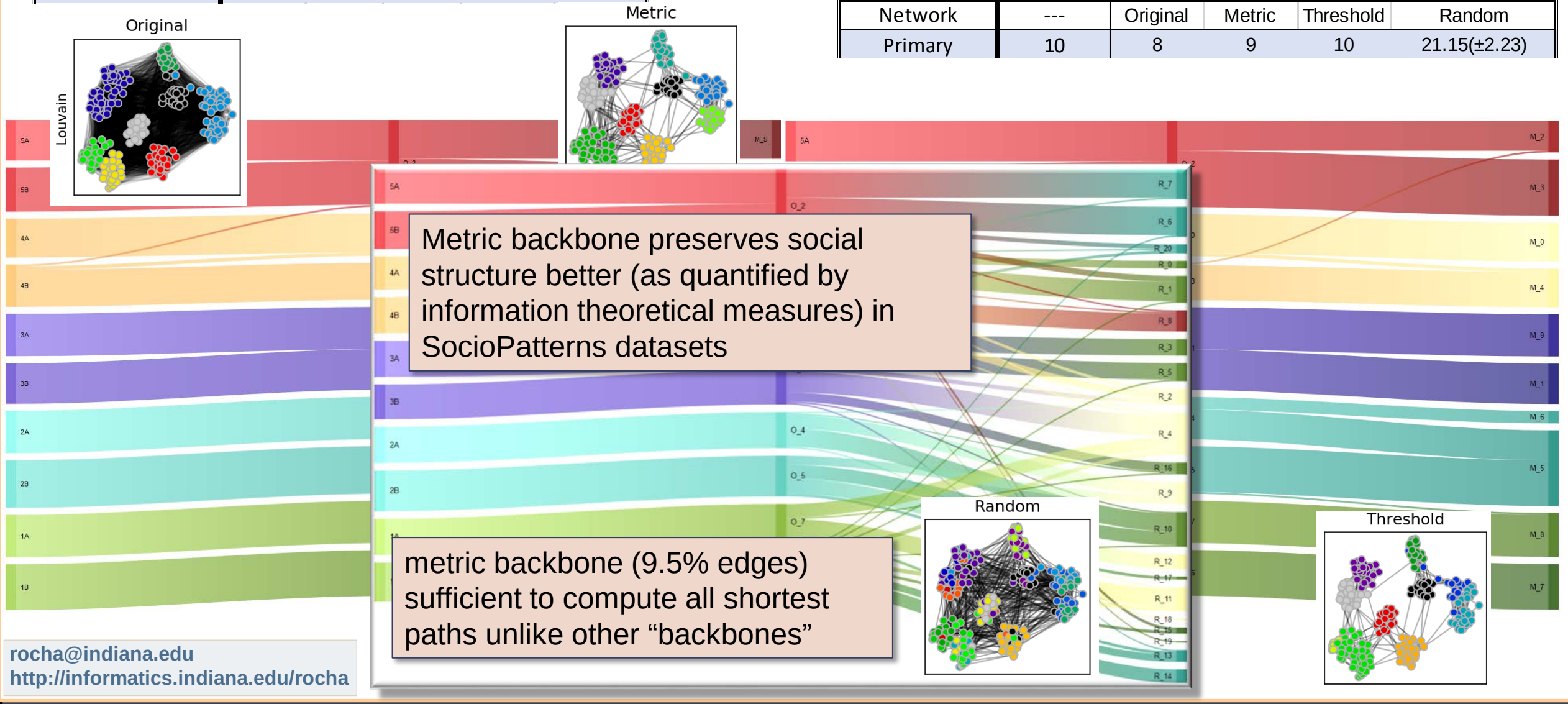

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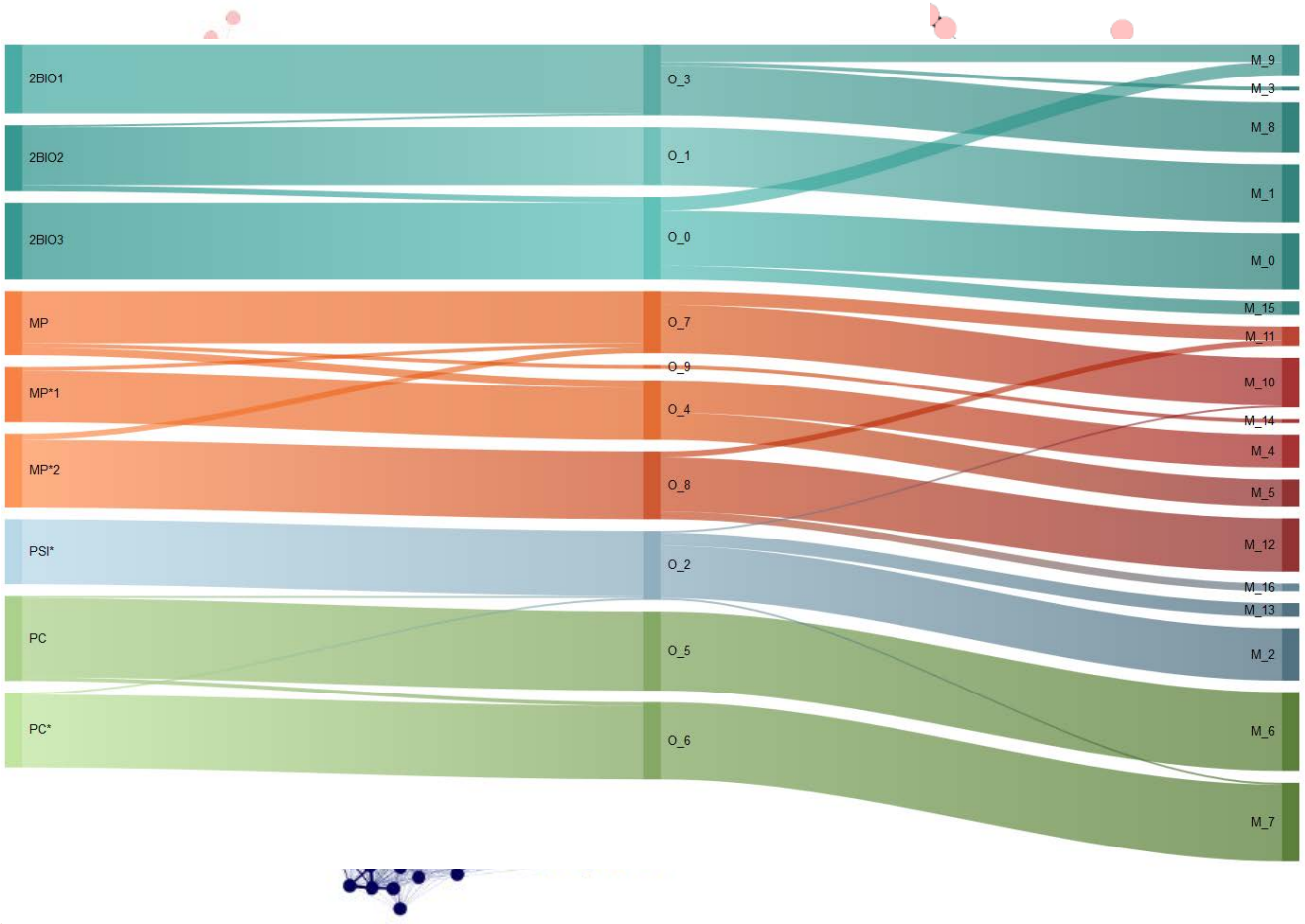
community structure of high school contact network

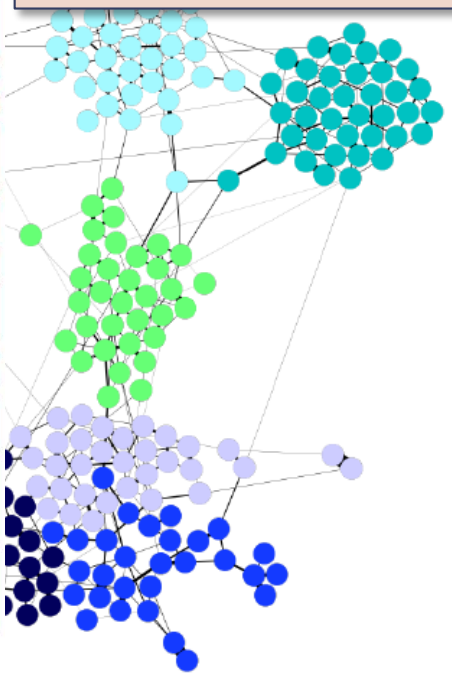
metric backbone vs. distance threshold and random deletion "backbones" of same size

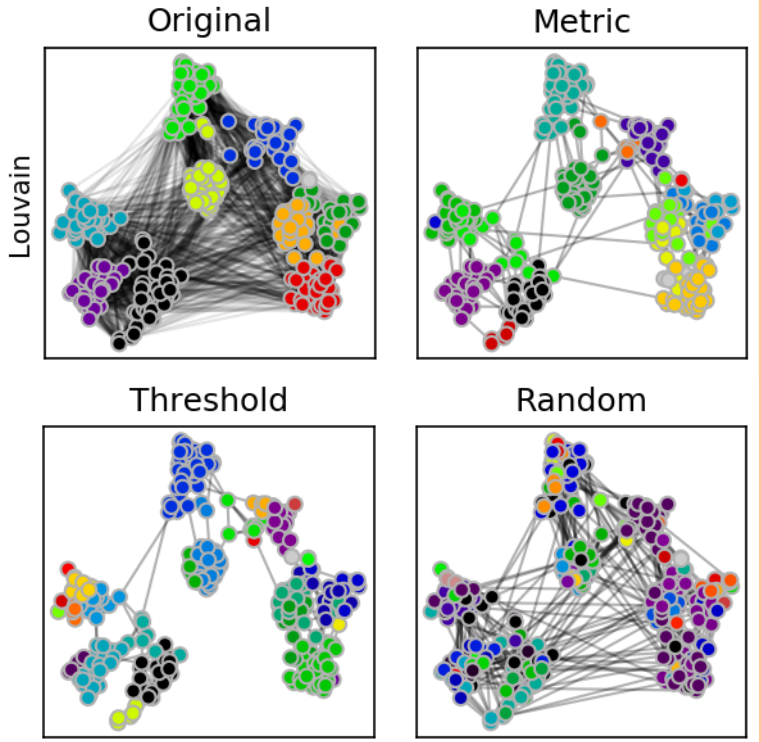
Network	N	E	Con	MB	SM
Primary School	242	8317	28.52%	**9.50%**	90.50%
High School	327	5818	10.92%	**10.36%**	89.64%

	Communities				
	metalabels	Louvain			
Network	---	Original	Metric	Threshold	Random
Primary	10	8	9	10	21.15(±2.23)
High School	9	10	17	28	47.19(±3.79)



Original class labels and community structure remain as communities in metric backbone subgraph despite appearance of a few smaller, nested communities





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community structure of high school contact network

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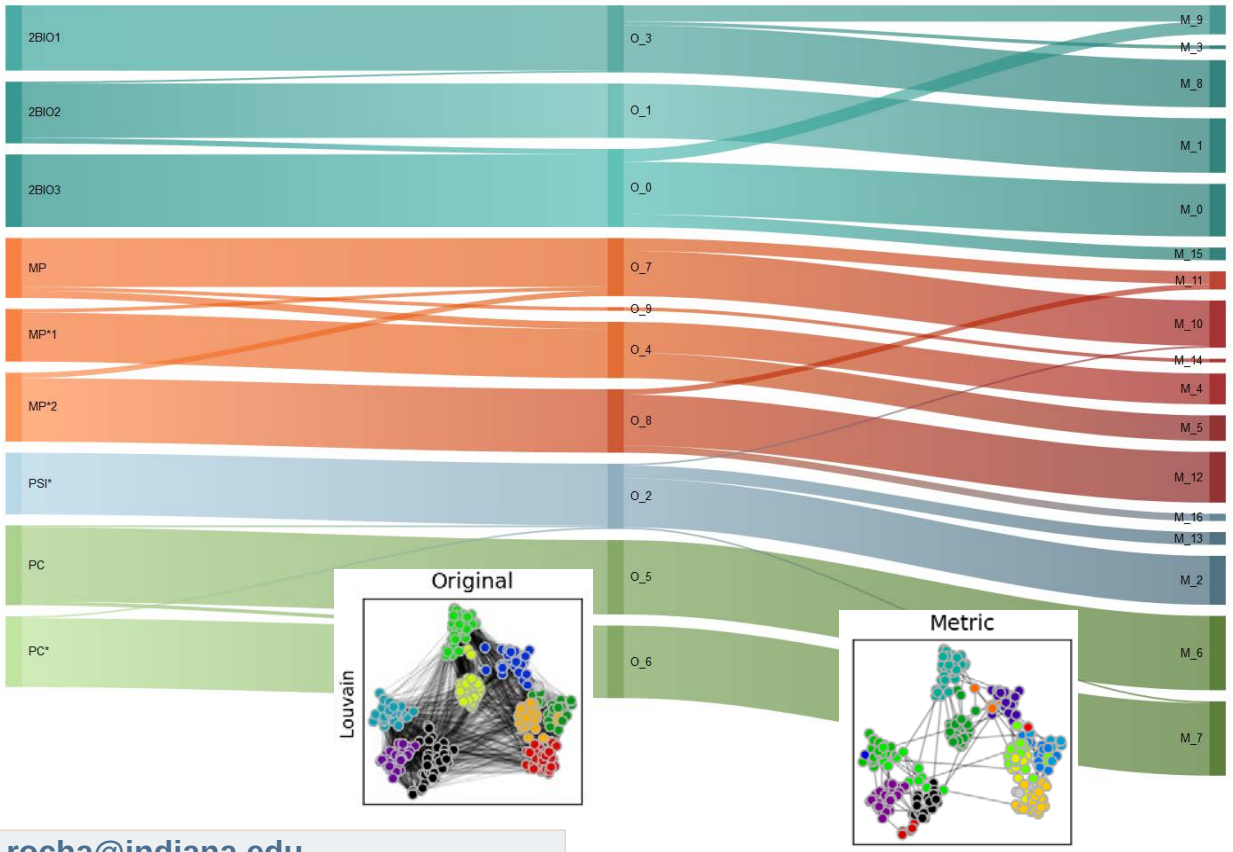

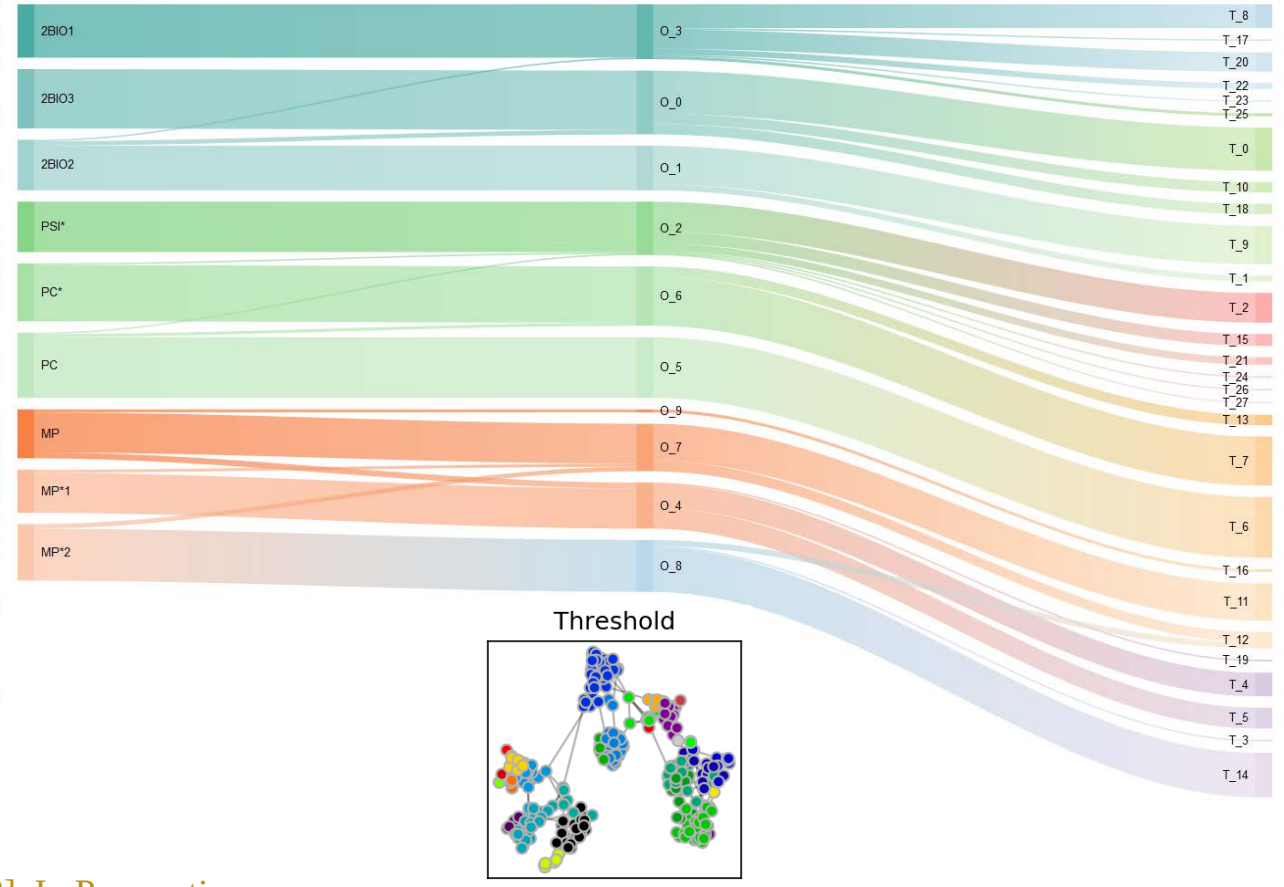

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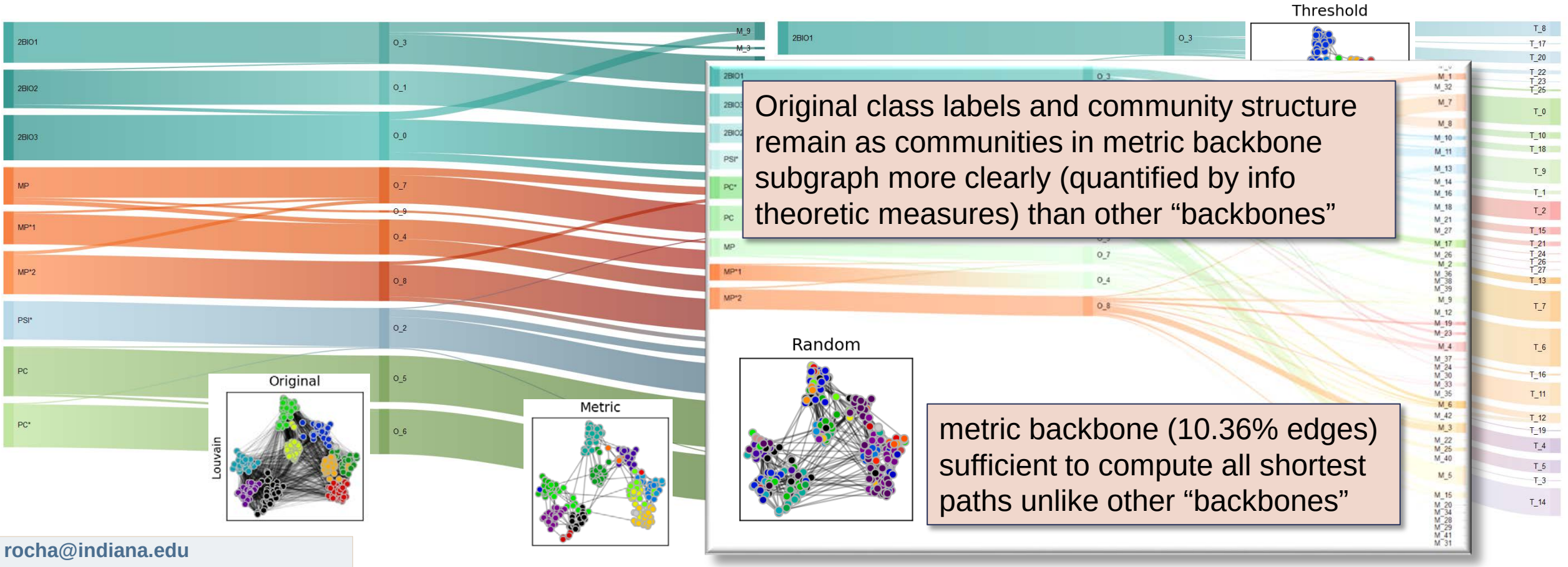

Original class labels and community structure remain as communities in metric backbone subgraph more clearly (quantified by info theoretic measures) than other "backbones"

metric backbone (10.36% edges) sufficient to compute all shortest paths unlike other "backbones"

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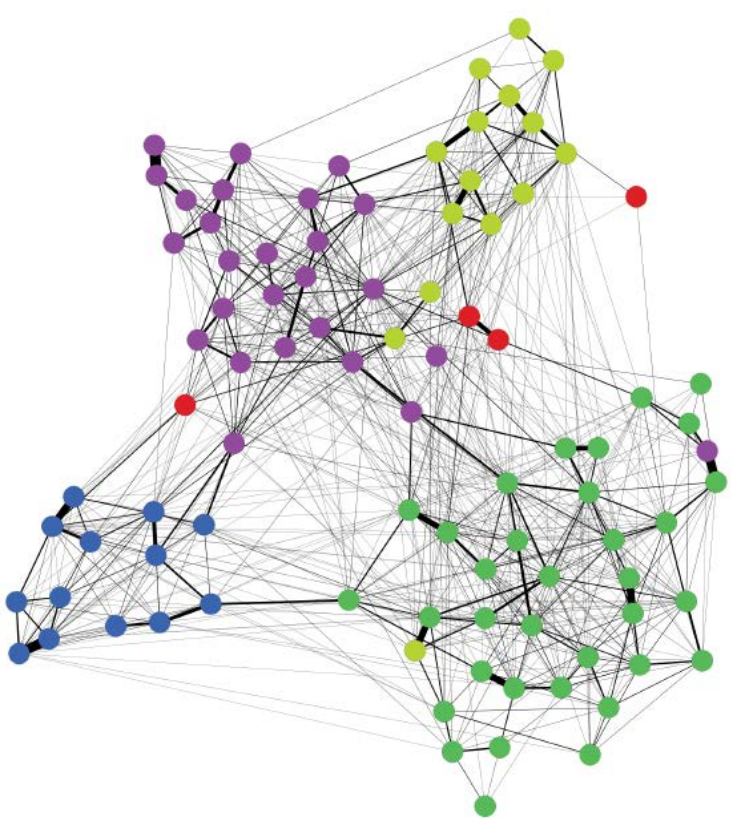
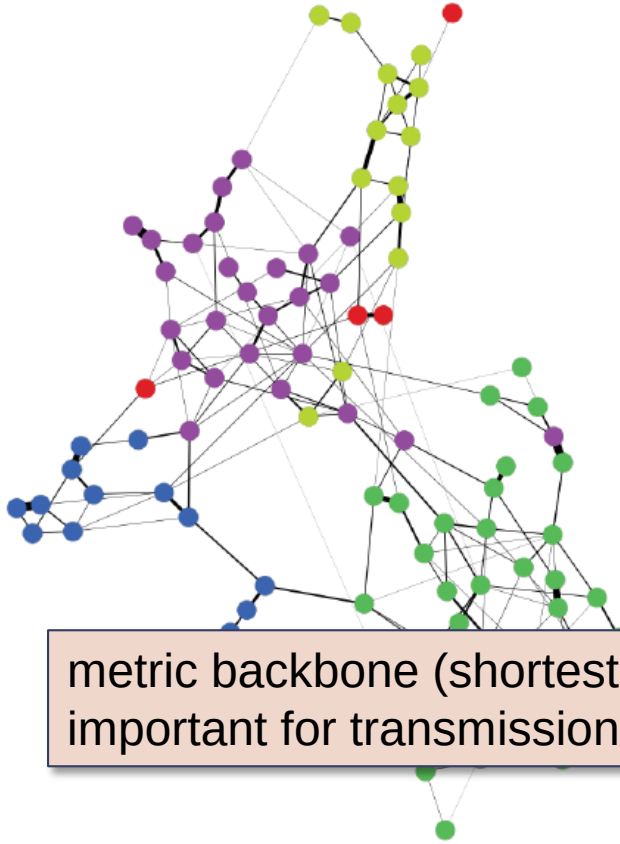
epidemic spread on metric backbone

preliminary results





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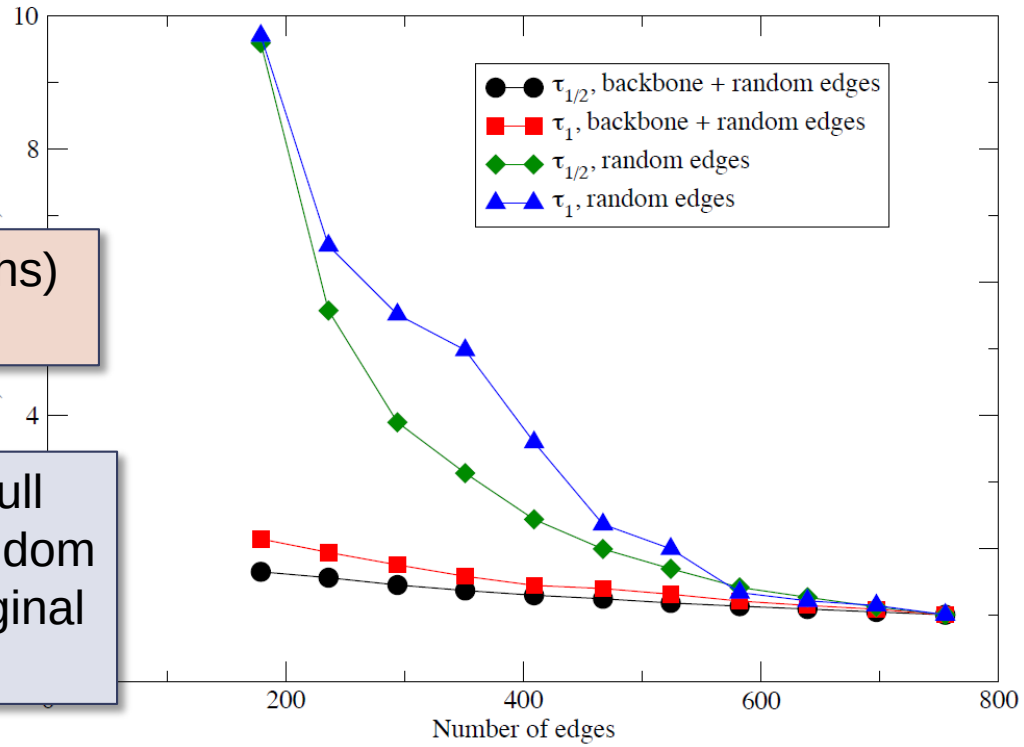
workplace	92	755	18.04%	**23.71%**	76.29%
Museum	200	714	3.59%	**49.86%**	50.14%

metric backbone (shortest paths) important for transmission

SI processes. Time to ½ and full infection on backbone and random "backbone" as edges from original network are added



SocioPatterns

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Correia, Ratkiewicz, Barrat & Rocha [2018]. In Preparation.

http://bit.ly/SMNets

MERCI!
THANK YOU!
OBRIGADO!

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