Statistical inference links data and theory in network science

10th SINM edition

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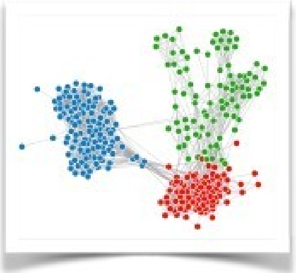
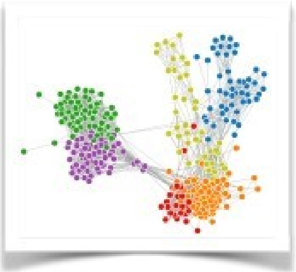
SINM 1st edition

Opportunities:

1. Model selection

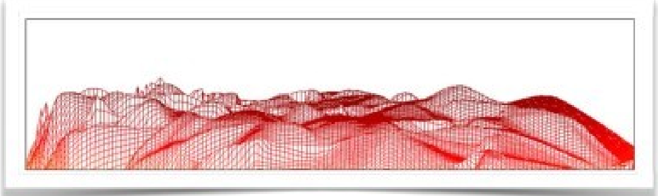




2. Tradeoffs between general and specific models

3. Dynamics

4. Computational challenges



Trade-offs between general and specific models

general ⟷ specific

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More likely to get a “high-impact” paper
Good to raise awareness of Network Science
Doesn’t really solve any actual problems

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general ⟷ specific

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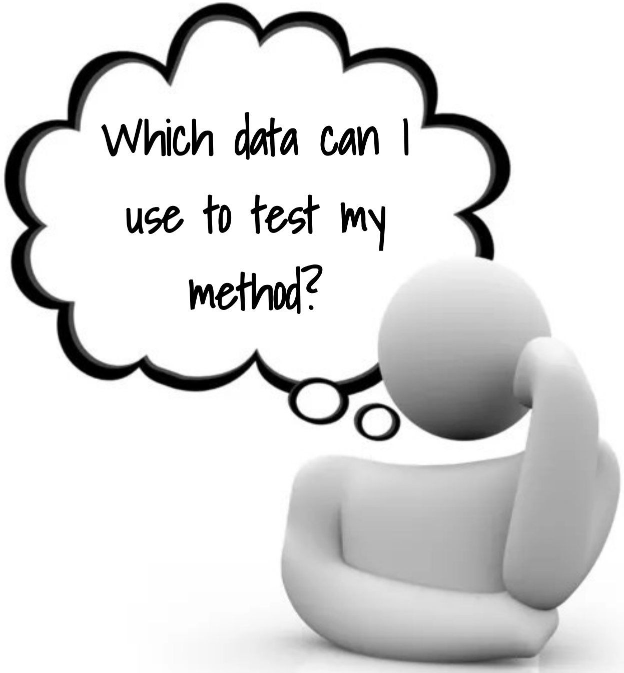
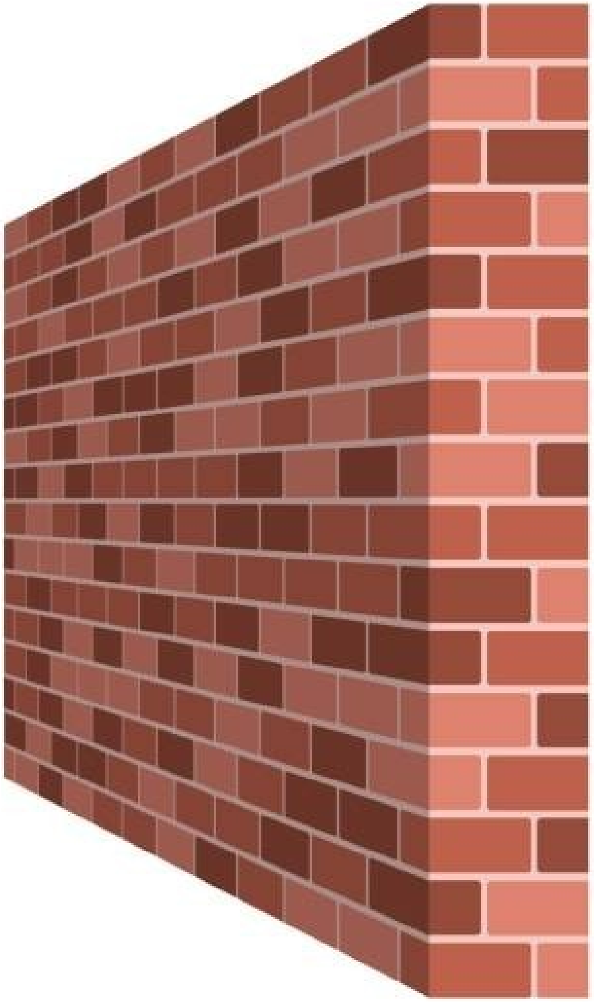
We need to be going more in this direction
This is where the real heroes will be

Network Science

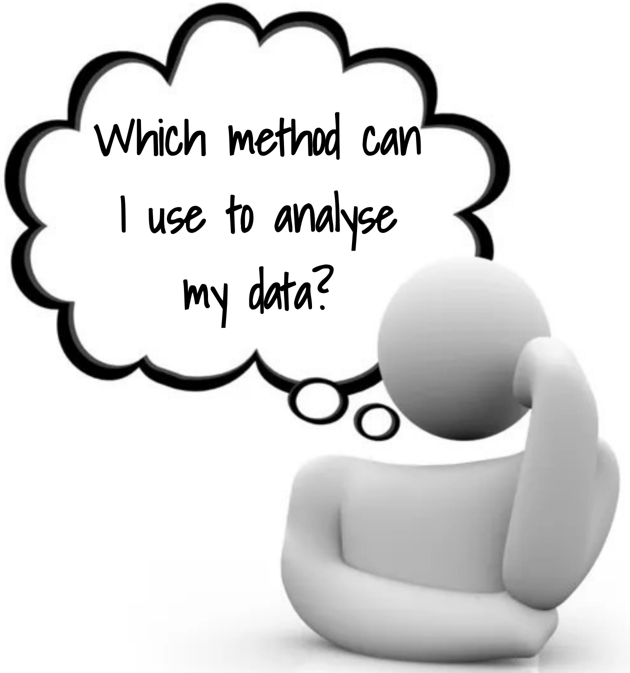
Network science allows us to analyse systems as a whole!

THEORY

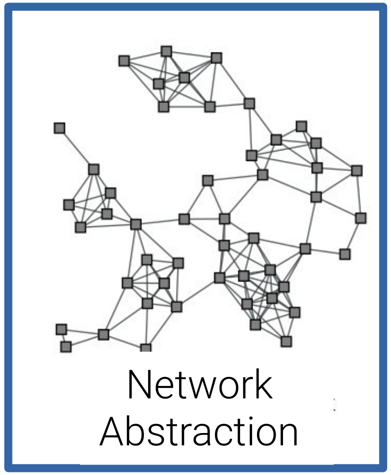




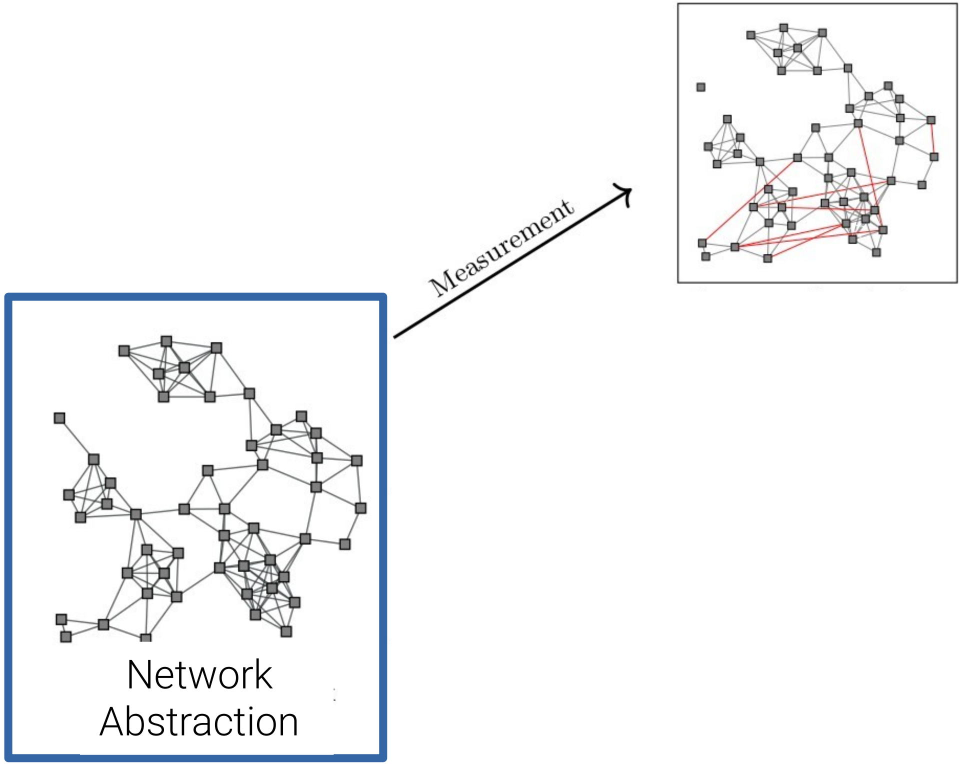
APPLICATION



*Dramatic oversimplification

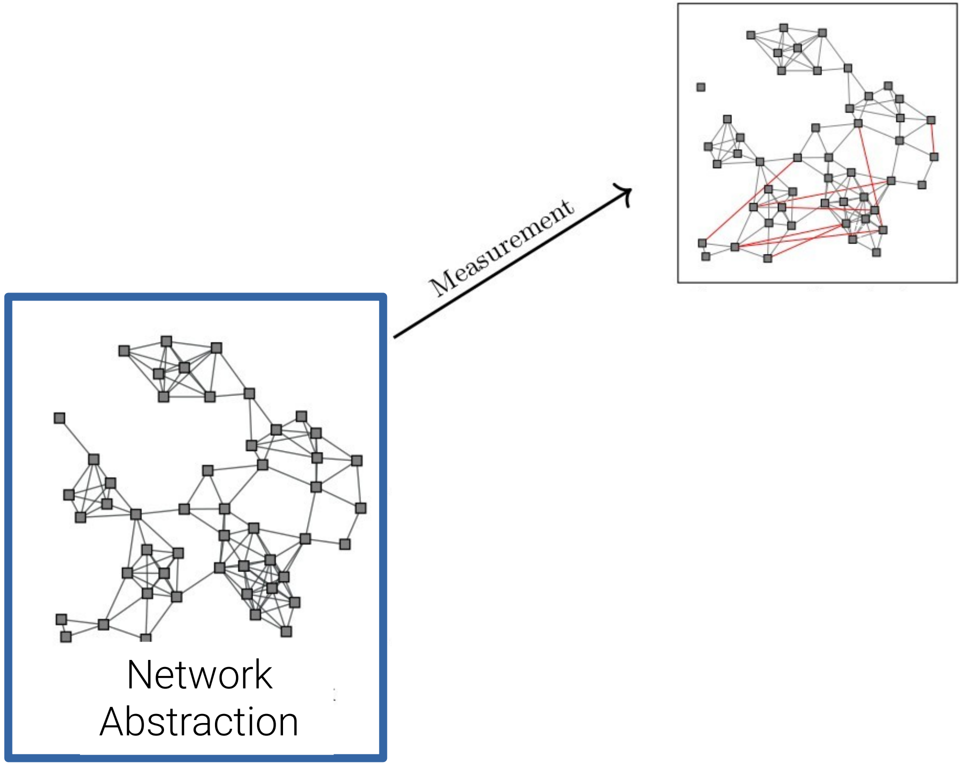


What we'd like to know



What we'd like to know

Errors and Omissions



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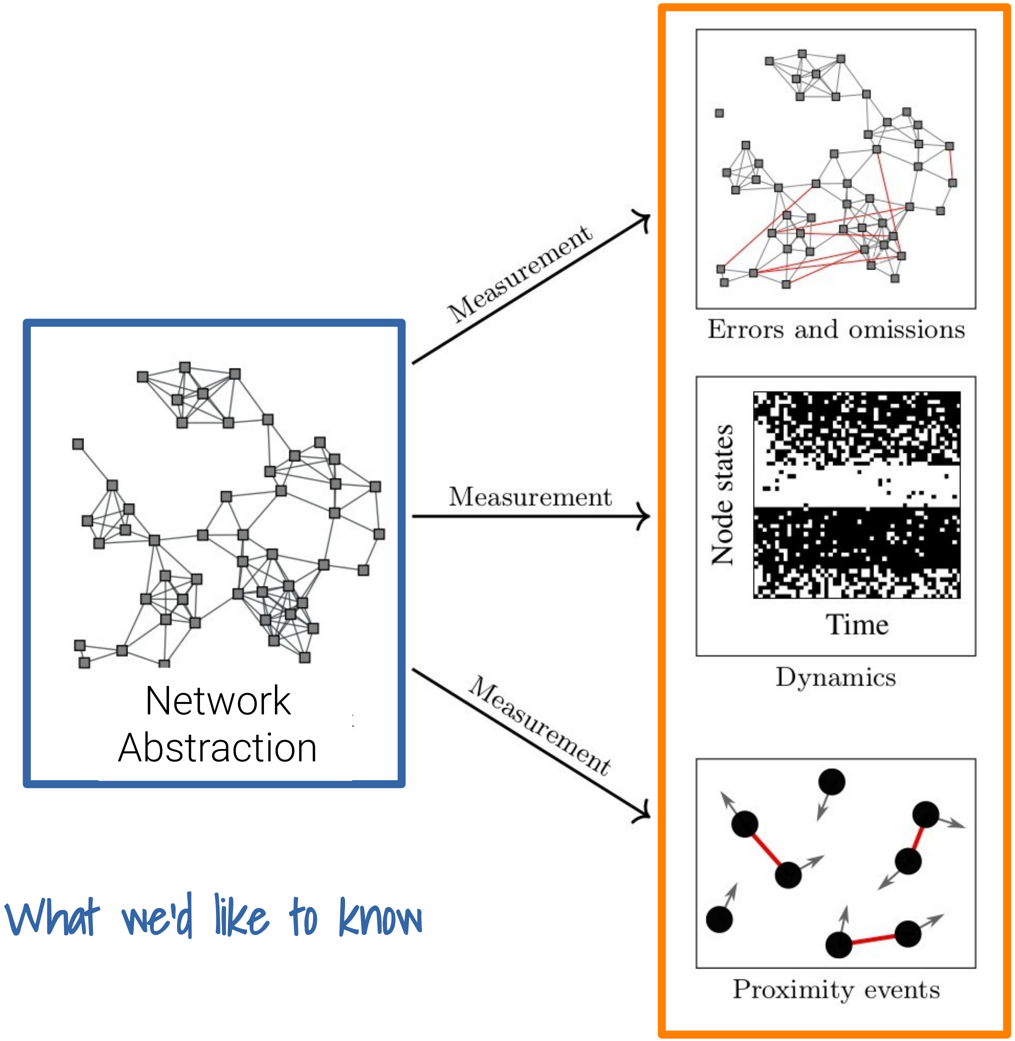


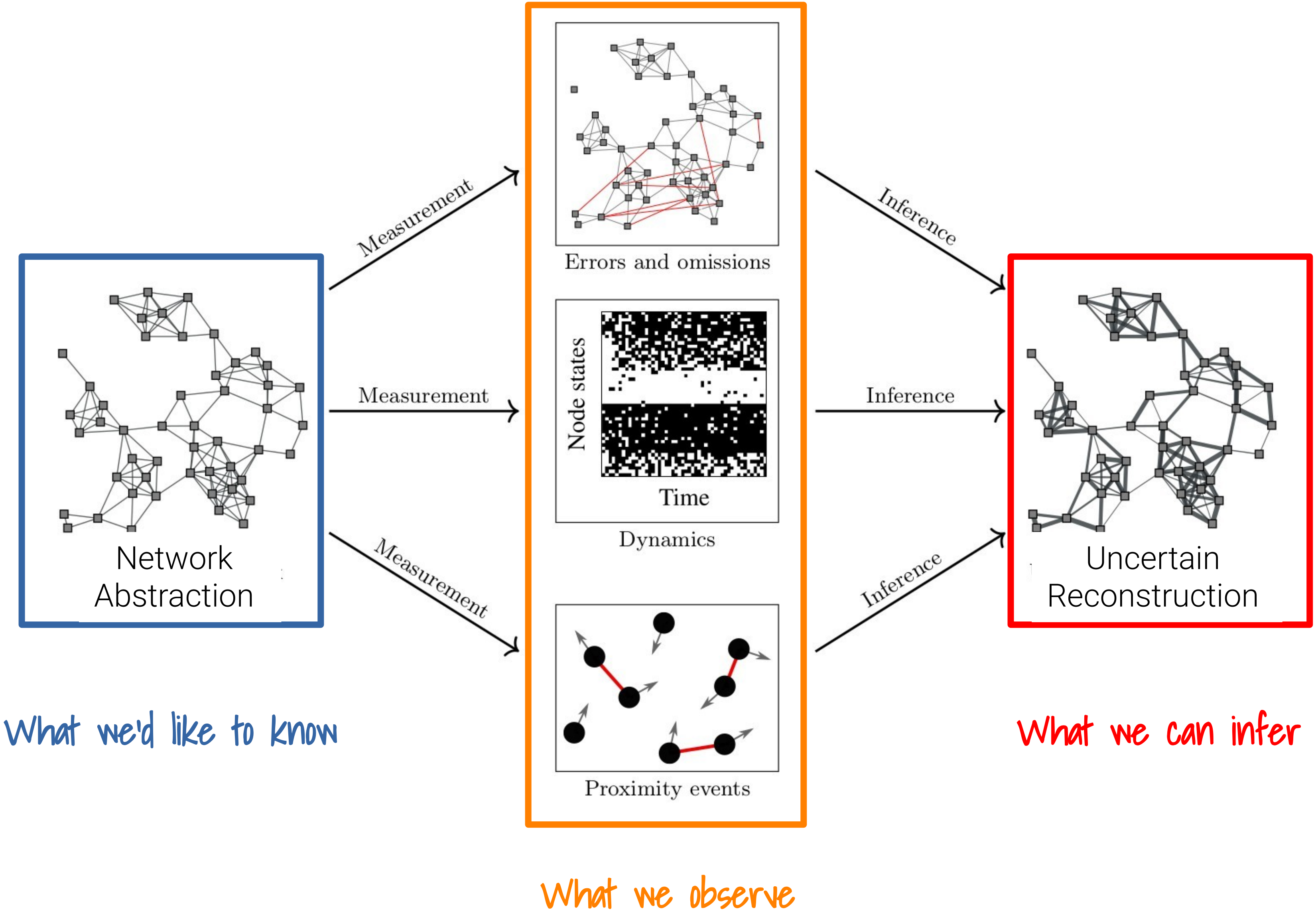
What we'd like to know

What we observe

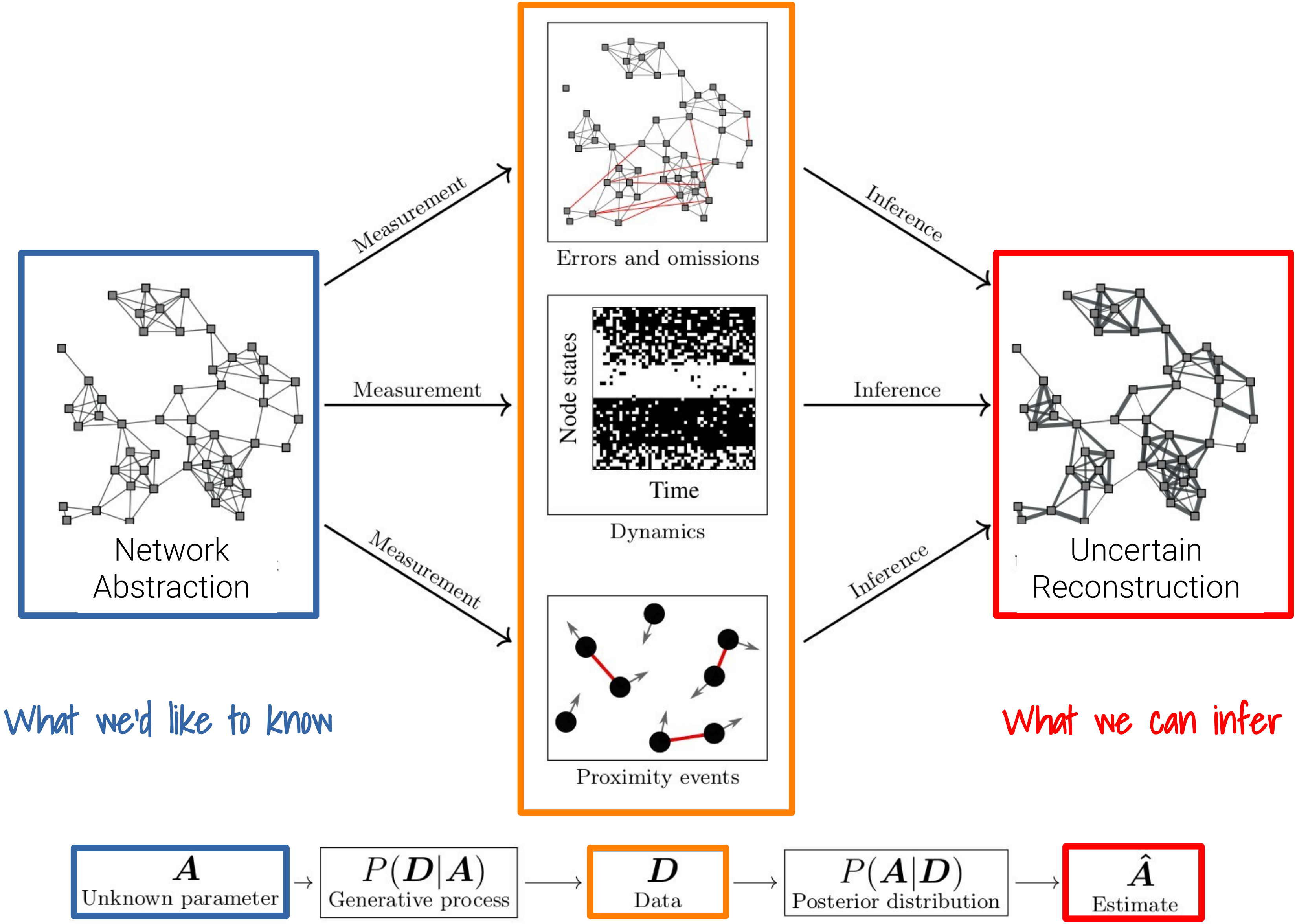
Errors and Omissions

Indirect observations

Thresholds and approximations



Network Abstraction
Measurement
Measurement
Measurement
Errors and omissions
Node states
Time
Dynamics
Proximity events
Inference
Inference
Inference
Uncertain Reconstruction
What we'd like to know
What we observe
What we can infer



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What we'd like to know
What we can infer
$\boldsymbol{A}$
Unknown parameter
$P(\boldsymbol{D}|\boldsymbol{A})$
Generative process
$\boldsymbol{D}$
Data
$P(\boldsymbol{A}|\boldsymbol{D})$
Posterior distribution
$\hat{\boldsymbol{A}}$
Estimate

Three Zachary Karate club club trophy winners enter a Zoom...

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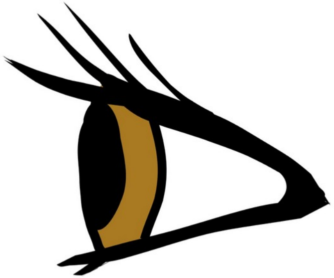
This scene never actually happened, its a reconstruction!

Network science in 3 easy steps...

1. Observations/ measurements



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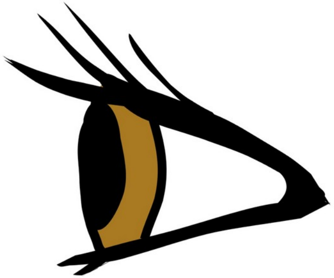

2. Network representation

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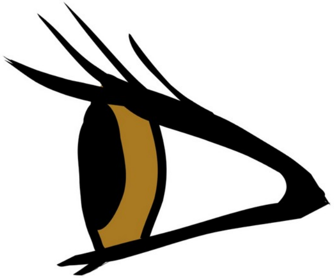
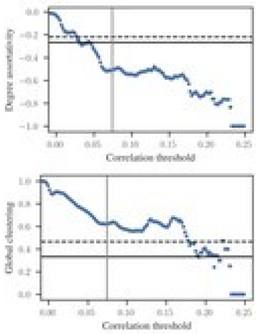
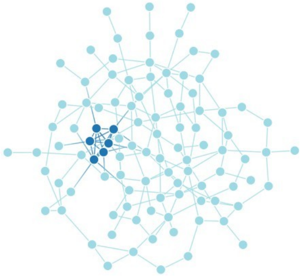


2. Network representation

3. Network analysis





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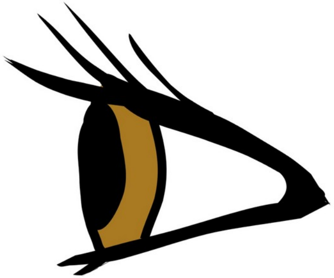
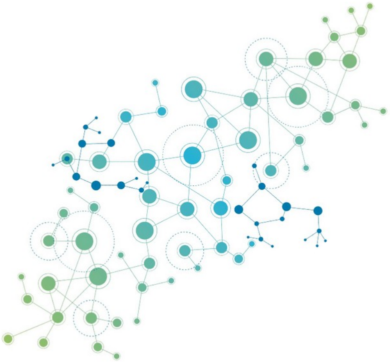
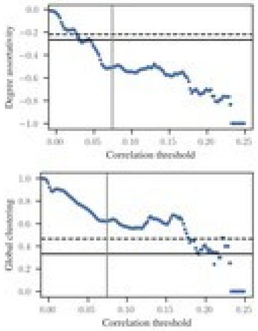
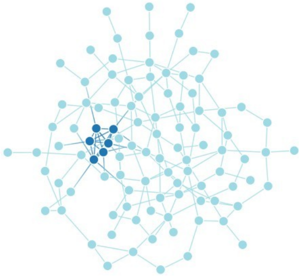


Obscured quality of data







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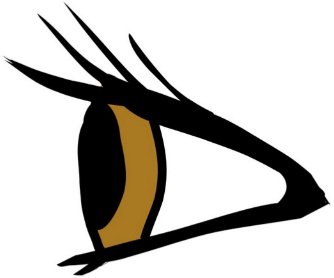

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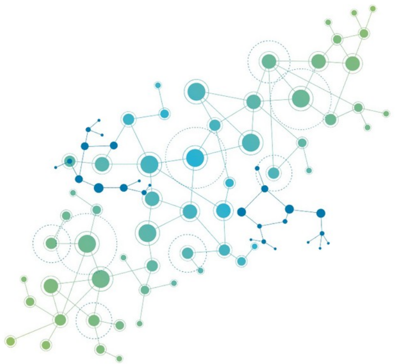
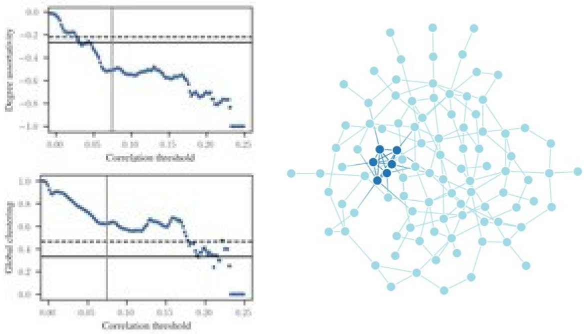


Choice of representation

3. Network analysis



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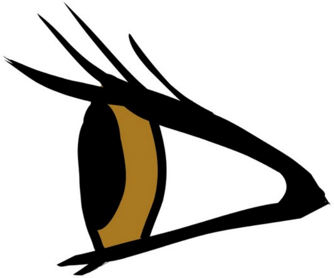

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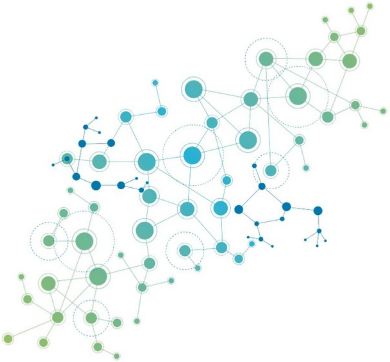

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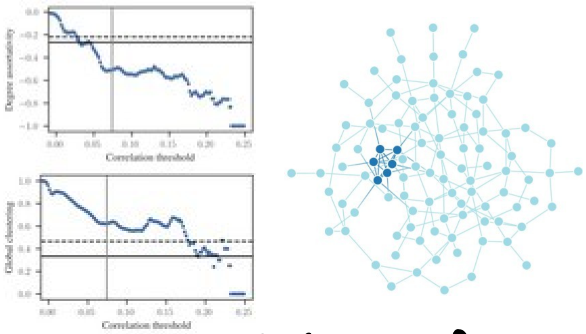
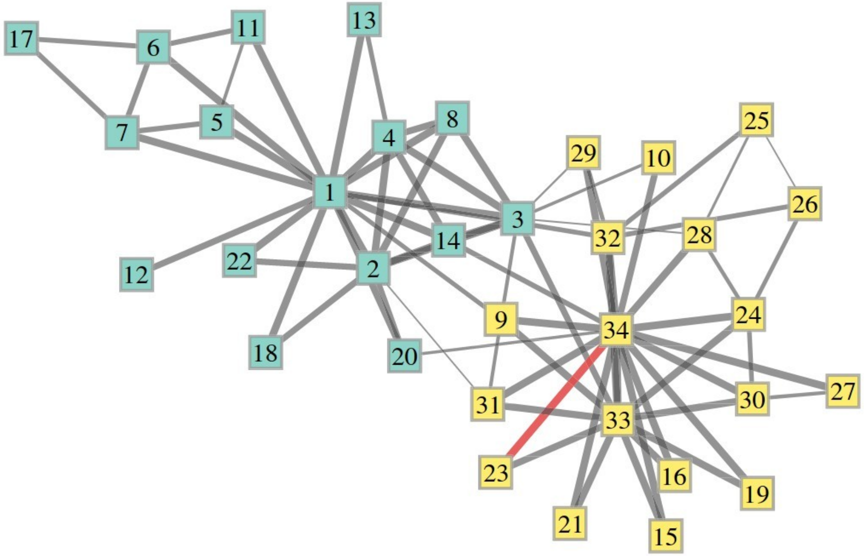


Suitability of the methods

1. Obscured quality of data

Zachary's Karate Club



Zachary, W. W. An Information Flow Model for Conflict and Fission in Small Groups. J. Anthropological Res. 33, 452-473 (1977).

Zachary's Karate Club

Individual Number

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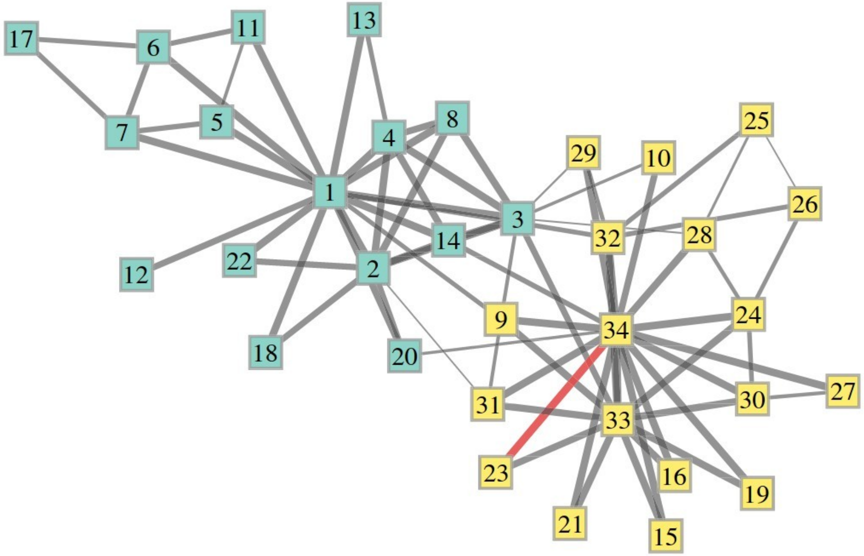

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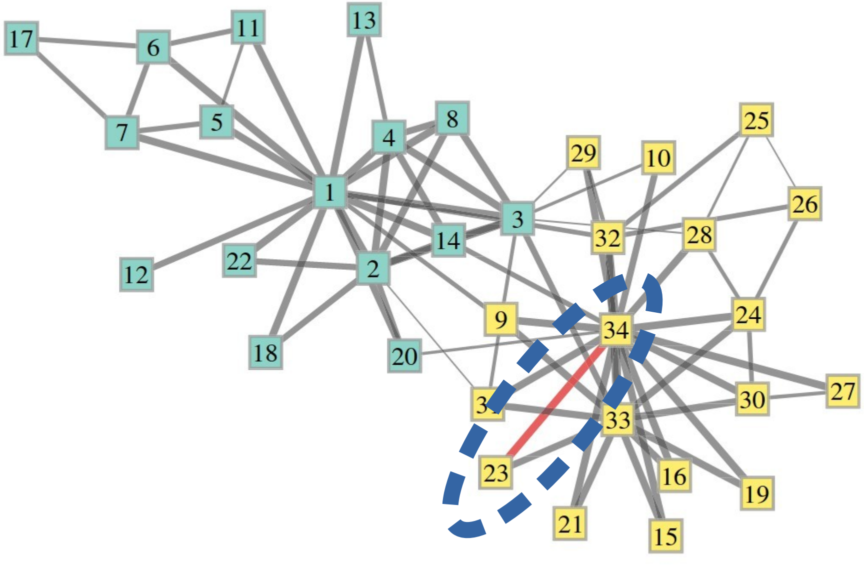
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	4	0	2	0	0	[illegible]	[illegible]
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3	0	0	0	2	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2	0	0	0	0	0	0	7	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	2
28	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3	0	0	0	0	0	0	0	0	4
29	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	4	0	0	0	0	0	3	2
31	0	2	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3
32	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	7	0	0	2	0	0	0	4	4
33	0	0	2	0	0	0	0	0	3	0	0	0	0	0	3	3	0	0	1	0	3	0	2	5	0	0	0	0	0	4	3	4	0	5
34	0	0	0	0	0	0	0	0	4	2	0	0	0	3	2	4	0	0	2	1	1	[illegible]	3	[illegible]	0	0	2	4	2	2	3	4	5	0



Does this edge exist?

Zachary, W. W. An Information Flow Model for Conflict and Fission in Small Groups. J. Anthropological Res. 33, 452-473 (1977).

Assessing experimentally derived interactions in a small world

Debra S. Goldberg and Frederick P. Roth*

Department of Biological Chemistry and Molecular Pharmacology, Harvard Medical School, Boston, MA 02115

Edited by Lawrence A. Shepp, Rutgers, The State University of New Jersey–New Brunswick, Piscataway, NJ, and approved February 10, 2003 (received for review September 27, 2002)

Experimentally determined networks are susceptible to errors, yet important inferences can still be drawn from them. Many real networks have also been shown to have the small-world

negative errors (24, 25). Here we consider in detail a network of protein–protein interactions derived from high-throughput, error-prone yeast two-hybrid (Y2H) studies (26, 27). These data

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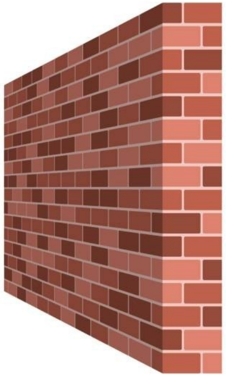
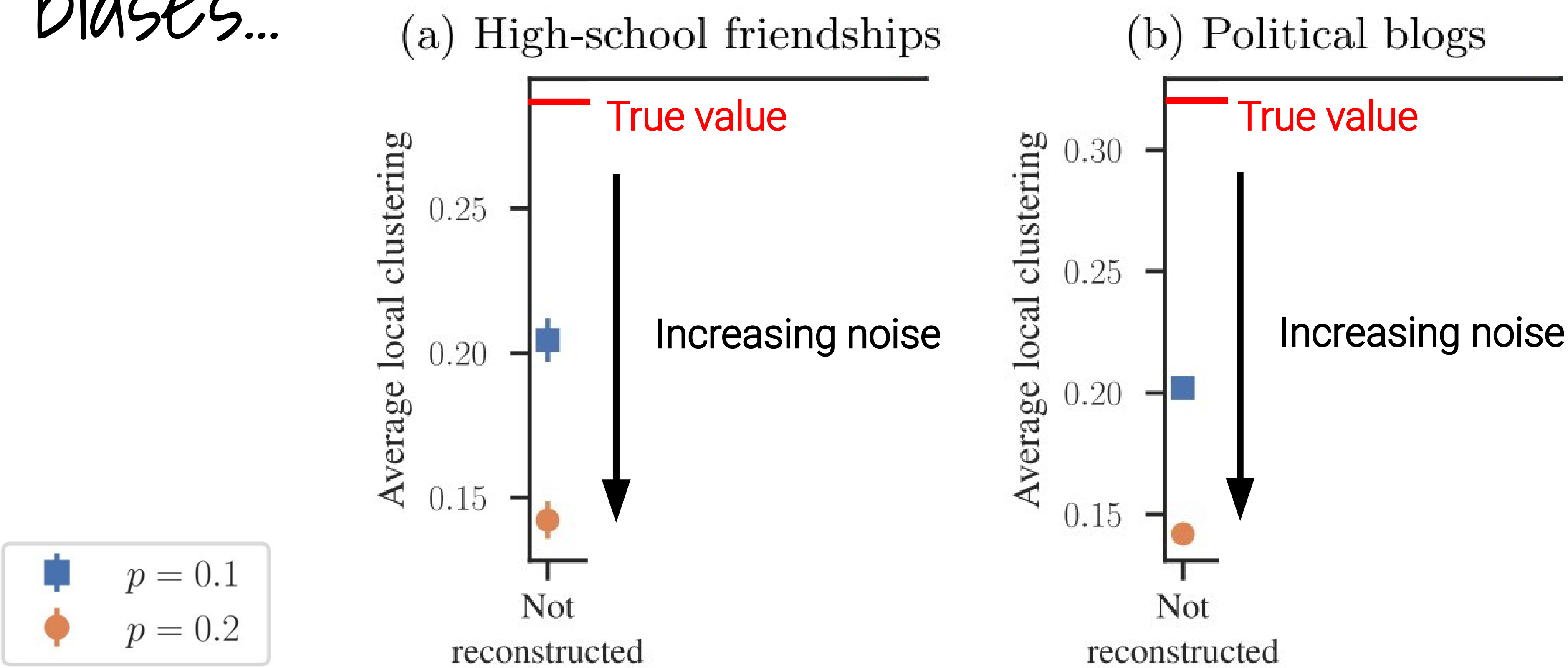
Link prediction

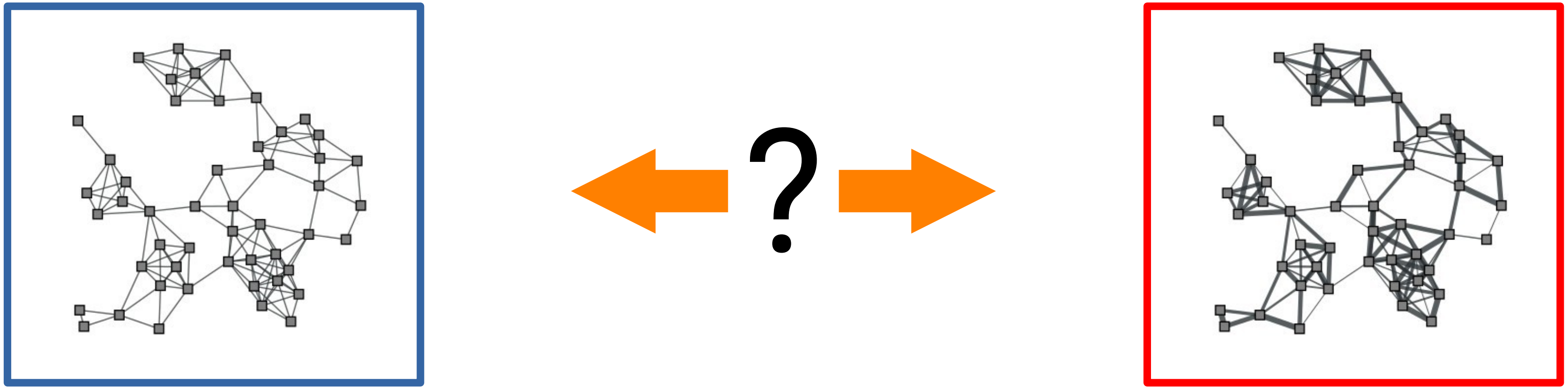


Rest of network science

Errors in network data create systematic biases...

Errors in network data create systematic biases...

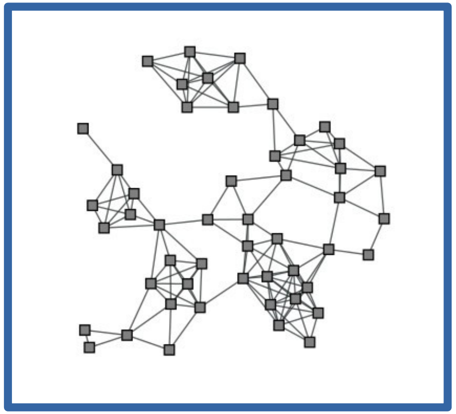




True Network

Reconstructed Network

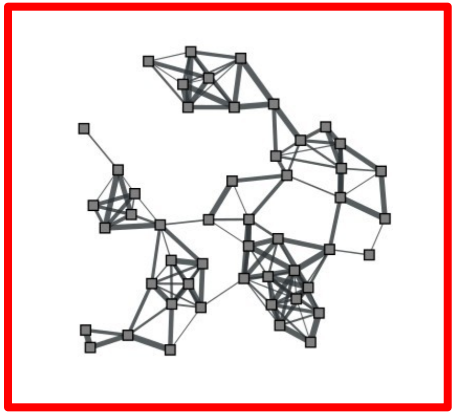
We don't know if the network represents the system



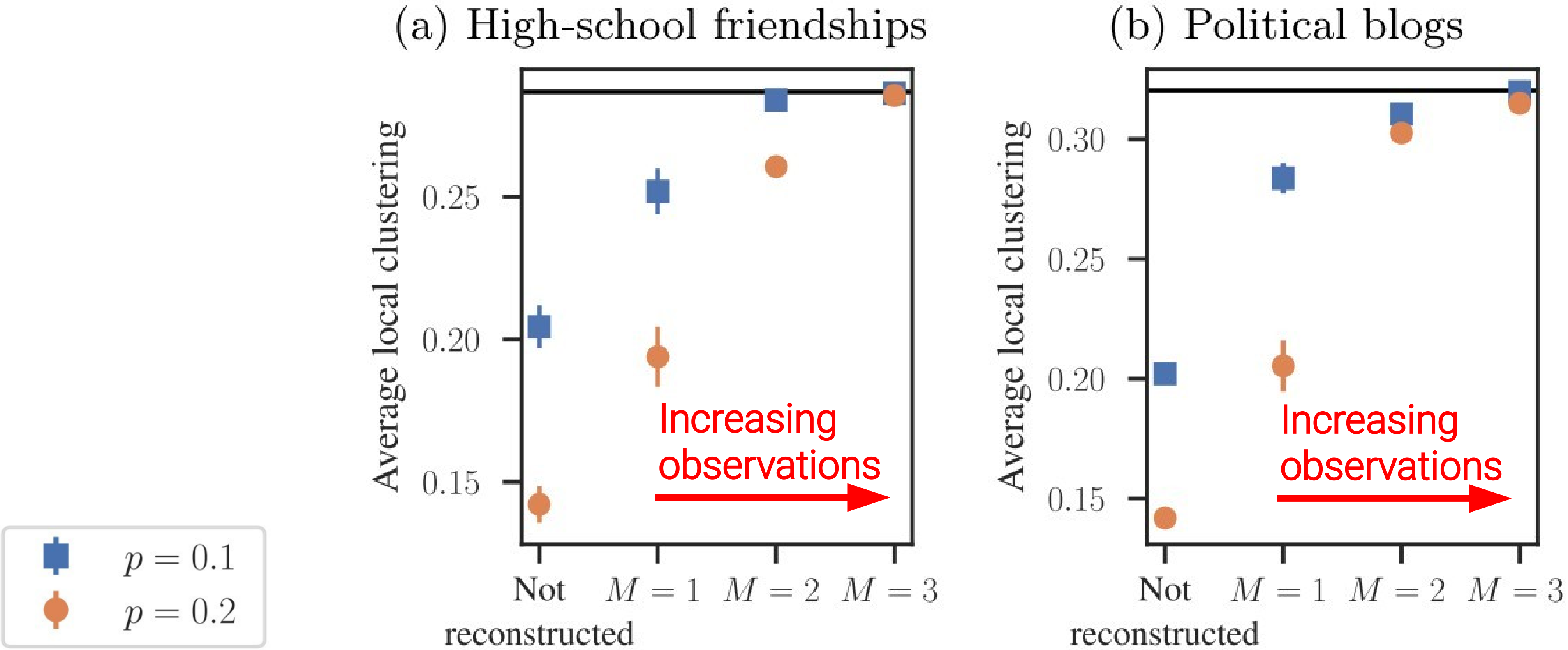
True Network

$$P(\boldsymbol{A}|\boldsymbol{D}) = \frac{P(\boldsymbol{D}|\boldsymbol{A})P(\boldsymbol{A})}{P(\boldsymbol{D})} \ .$$

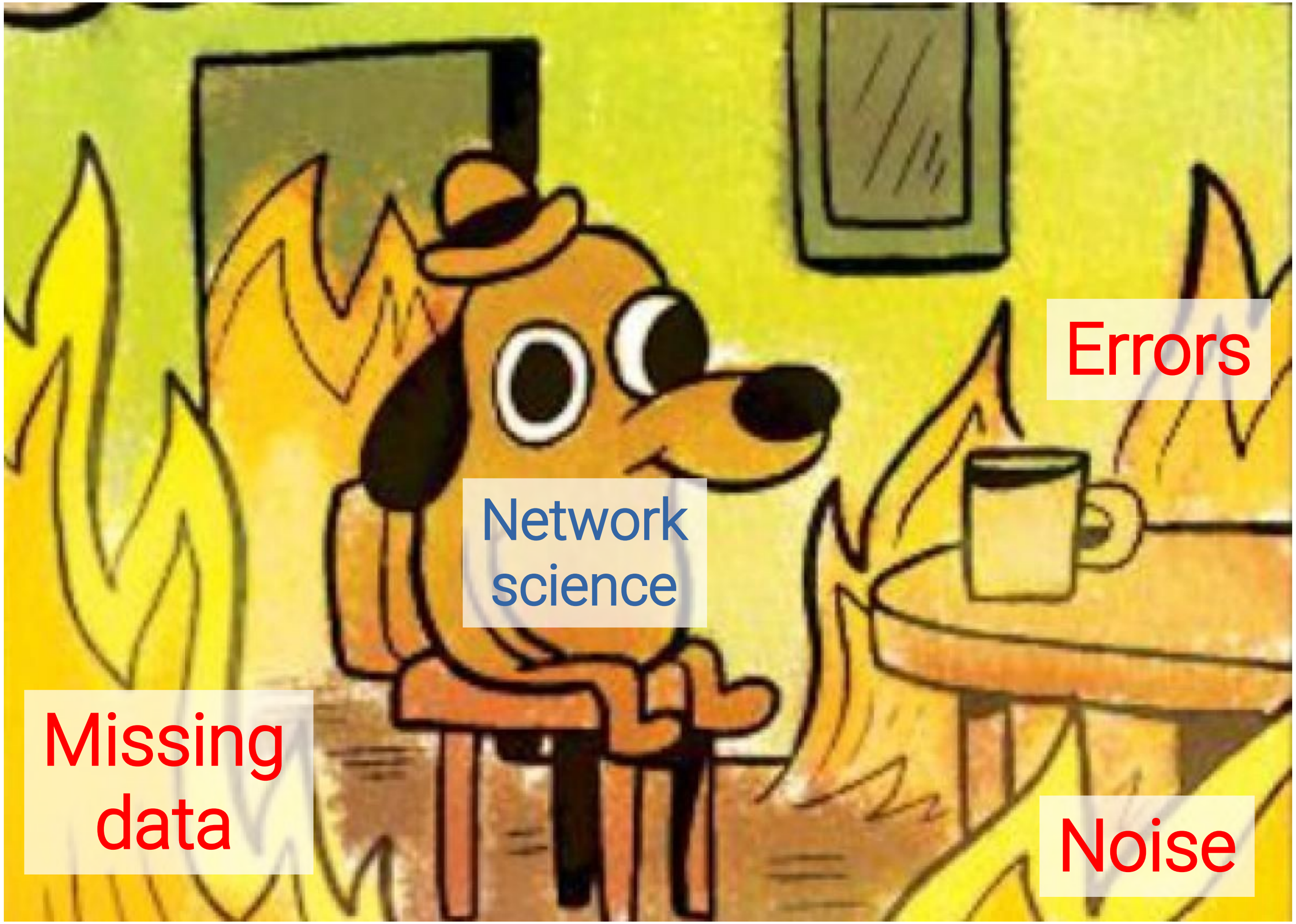
Bayesian inference



Reconstructed Network



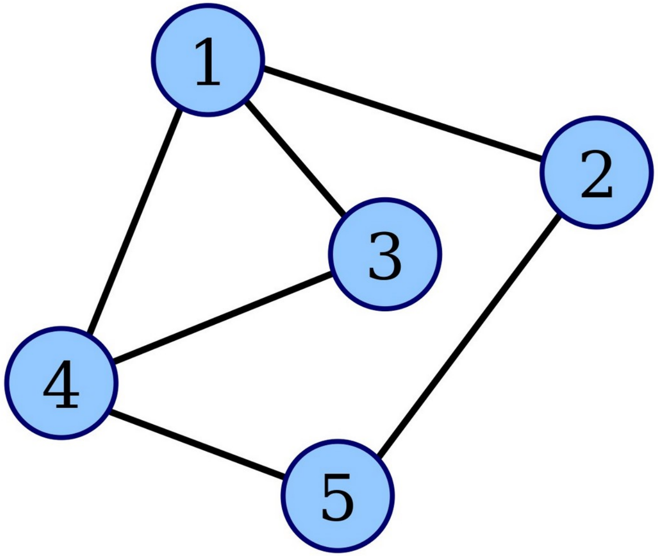
(a) High-school friendships
(b) Political blogs
Average local clustering
0.15
0.20
0.25
0.30
Not reconstructed
M = 1
M = 2
M = 3
Increasing observations
p = 0.1
p = 0.2



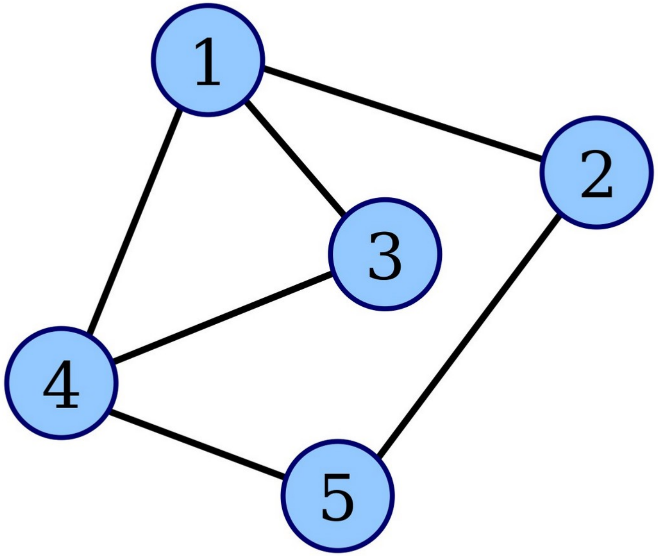
This is NOT fine

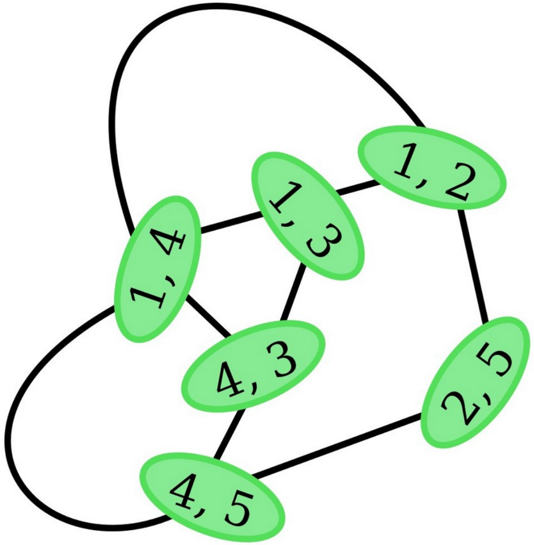
II. Choice of representation

What are the nodes and what are the edges?



What are the nodes and what are the edges?



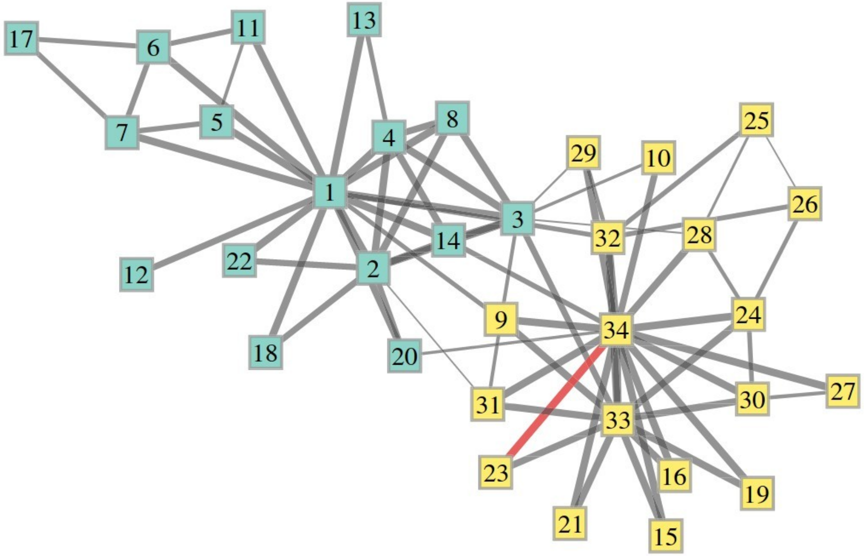


Zachary's Karate Club

Individual Number

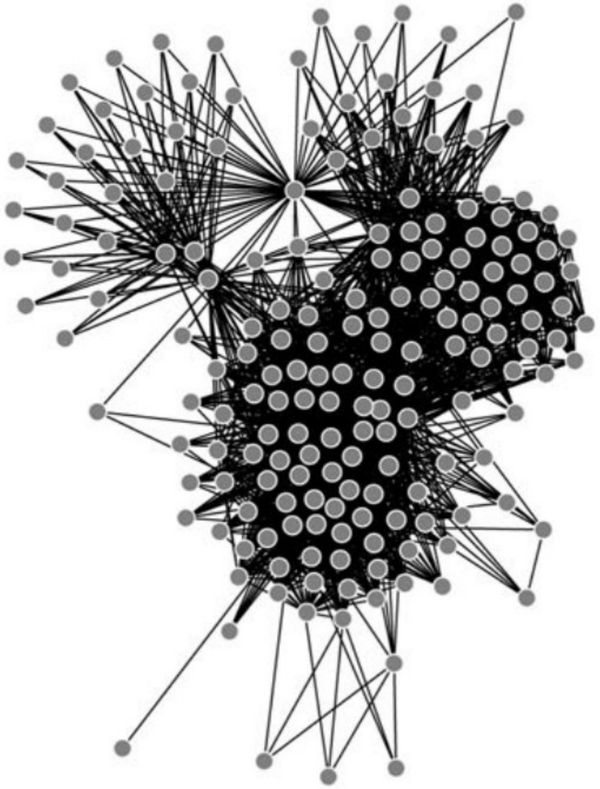
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
1	0	4	5	3	3	3	3	2	2	0	2	3	2	3	0	0	0	2	0	2	0	2	0	0	0	0	0	0	0	0	0	2	0	0
2	4	0	6	3	0	0	0	4	0	0	0	0	0	5	0	0	0	1	0	2	0	2	0	0	0	0	0	0	0	0	2	0	0	0
3	5	6	0	3	0	0	0	4	5	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	3	0
4	3	3	3	0	0	0	0	3	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	3	0	0	0	0	0	2	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	3	0	0	0	0	0	5	0	0	0	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	3	0	0	0	2	5	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	2	4	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	2	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	4	3
10	0	0	1	0																							0	0	0	0	0	0	0	2
11	2	0	0	0																							0	0	0	0	0	0	0	0
12	3	0	0	0																							0	0	0	0	0	0	0	0
13	1	0	0	3																							0	0	0	0	0	0	0	0
14	3	5	3	3																							0	0	0	0	0	0	0	3
15	0	0	0	0																							0	0	0	0	0	0	3	2
16	0	0	0	0																							0	0	0	0	0	0	3	4
17	0	0	0	0																							0	0	0	0	0	0	0	0
18	2	1	0	0																							0	0	0	0	0	0	0	0
19	0	0	0	0																							0	0	0	0	0	0	1	2
20	2	2	0	0																							0	0	0	0	0	0	0	1
21	0	0	0	0																							0	0	0	0	0	0	3	1
22	2	2	0	0																							0	0	0	0	0	0	0	0
23	0	0	0	0																							0	0	0	0	0	0	2	0
24	0	0	0	0																							0	4	0	2	0	0	5	4
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3	0	0	0	2	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2	0	0	0	0	0	0	7	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	2
28	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3	0	0	0	0	0	0	0	0	4
29	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	4	0	0	0	0	0	3	2
31	0	2	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3
32	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	7	0	0	2	0	0	0	4	4
33	0	0	2	0	0	0	0	0	3	0	0	0	0	0	3	3	0	0	1	0	3	0	2	5	0	0	0	0	0	4	3	4	0	5
34	0	0	0	0	0	0	0	0	4	2	0	0	0	3	2	4	0	0	2	1	1	0	3	4	0	0	2	4	2	2	3	4	5	0

What about the raw data?



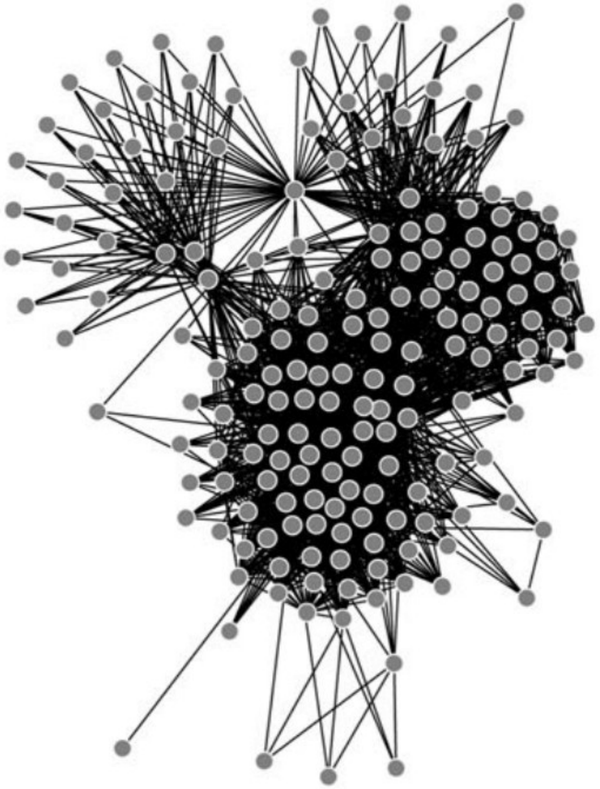
Zachary, W. W. An Information Flow Model for Conflict and Fission in Small Groups. J. Anthropological Res. 33, 452-473 (1977).

How does the network generate data?

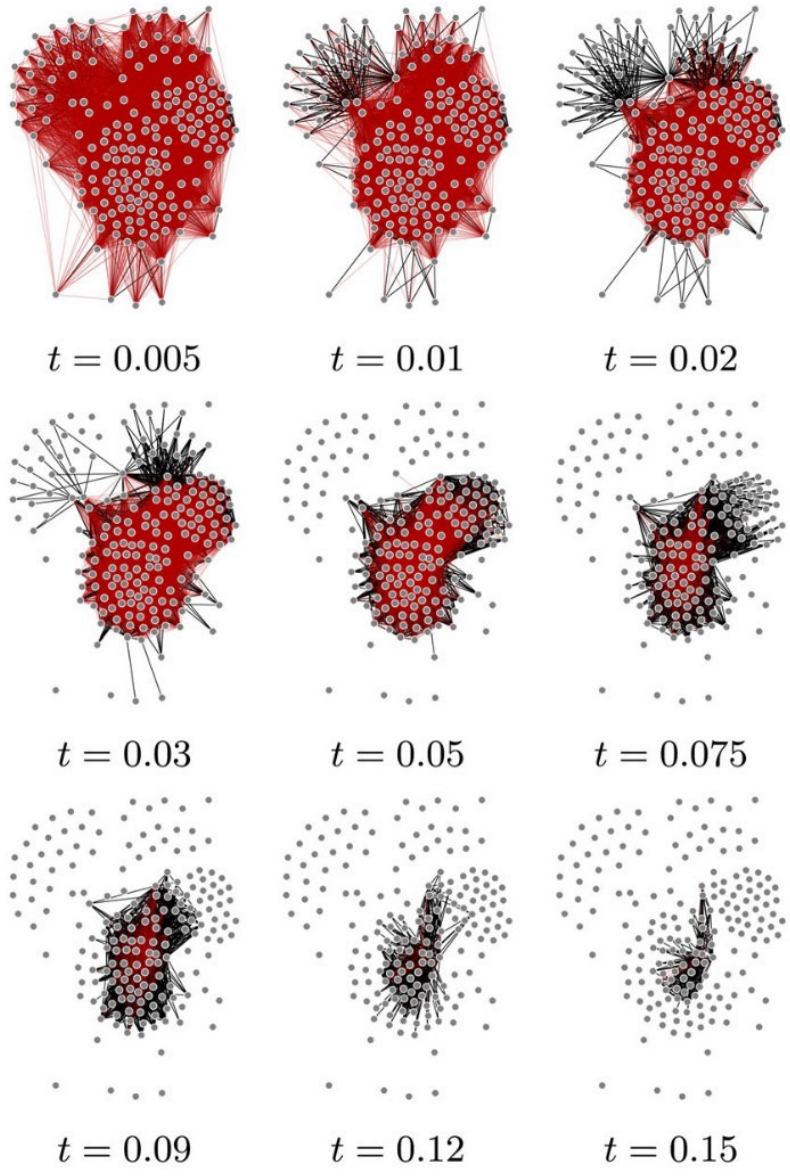


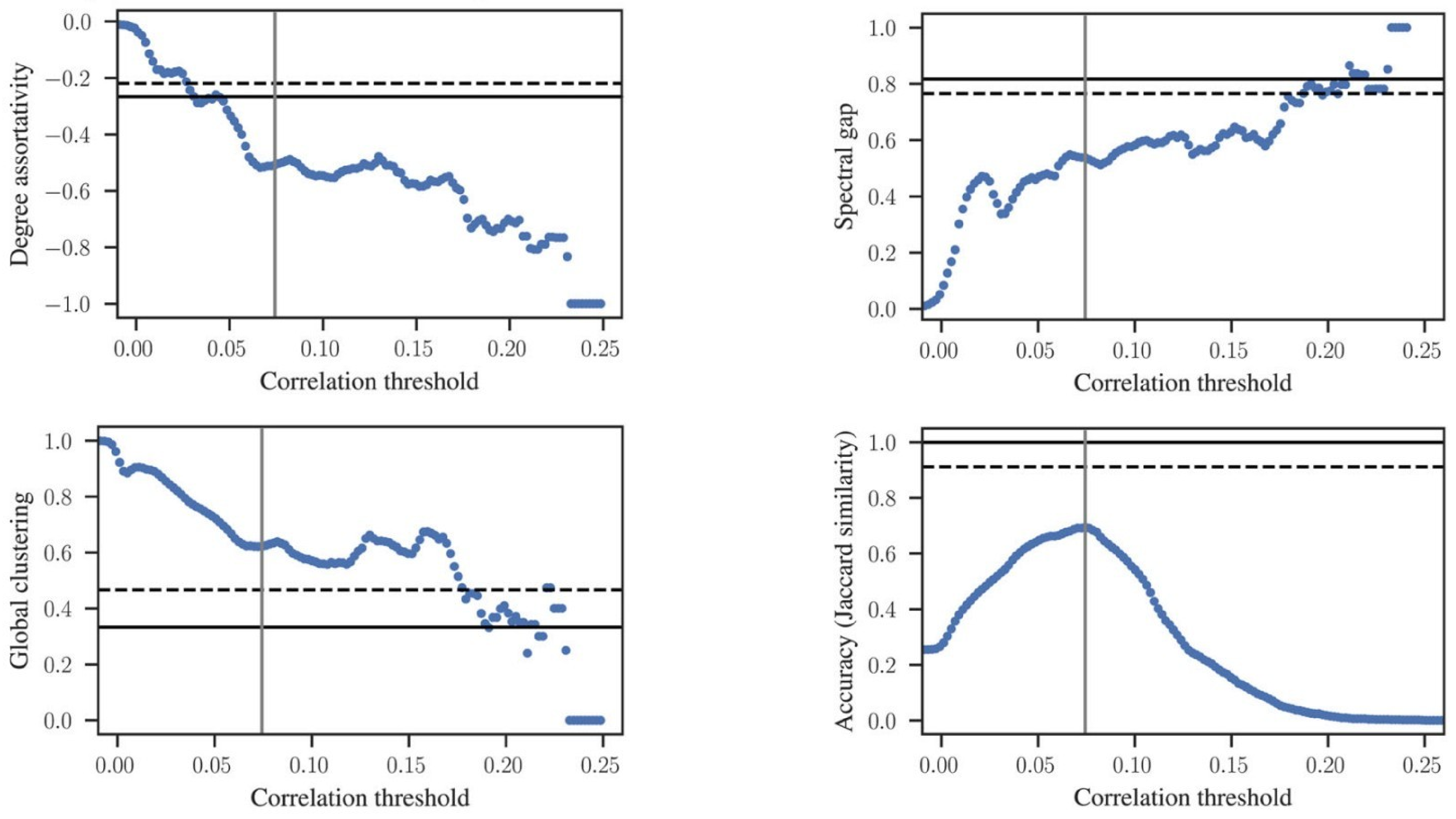
(a) True network

Correlation "networks"

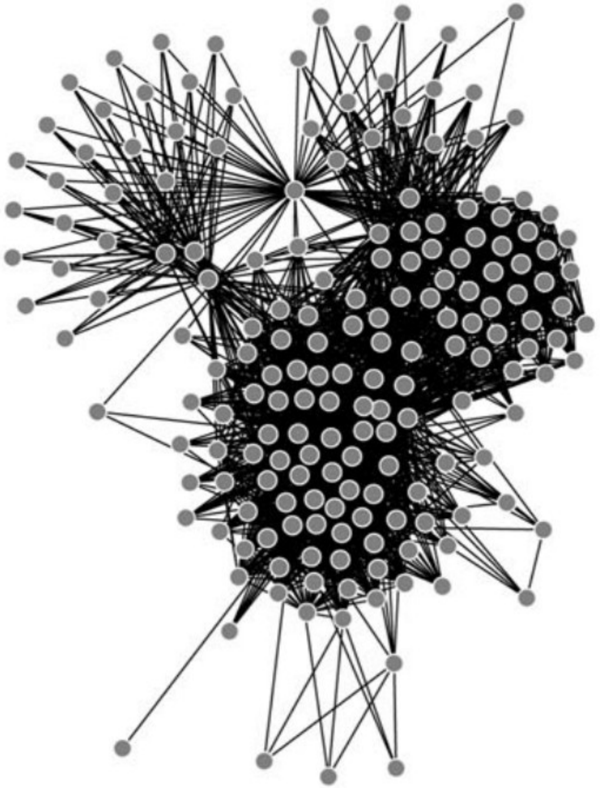


(a) True network




Degree assortativity
Correlation threshold
Spectral gap
Correlation threshold
Global clustering
Correlation threshold
Accuracy (Jaccard similarity)
Correlation threshold

Correlation "networks"

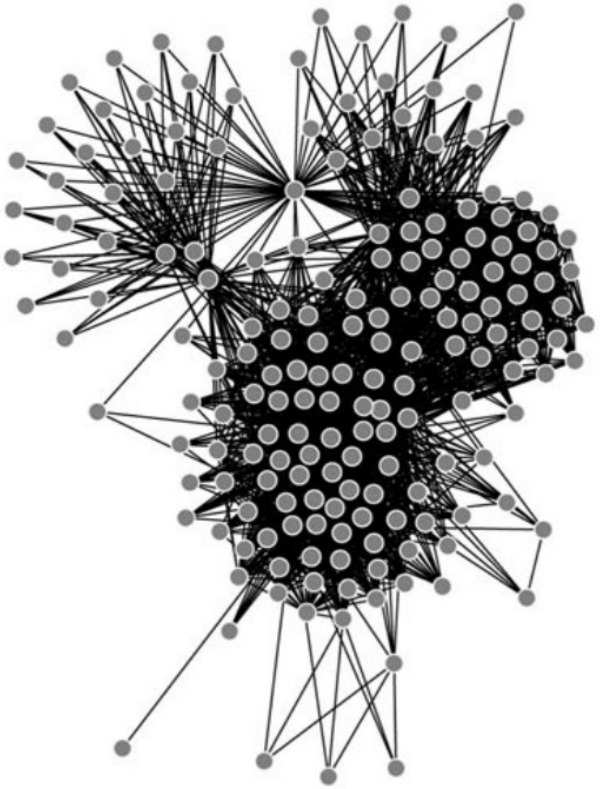


(a) True network

$$\begin{tikzcd} & Z \arrow[dl] \arrow[dr] & \\ Y & & X \end{tikzcd}$$

$$\begin{aligned} X(t) &= Z(t) + \epsilon_1 \\ Y(t) &= Z(t) + \epsilon_2, \end{aligned}$$

Correlation "networks"



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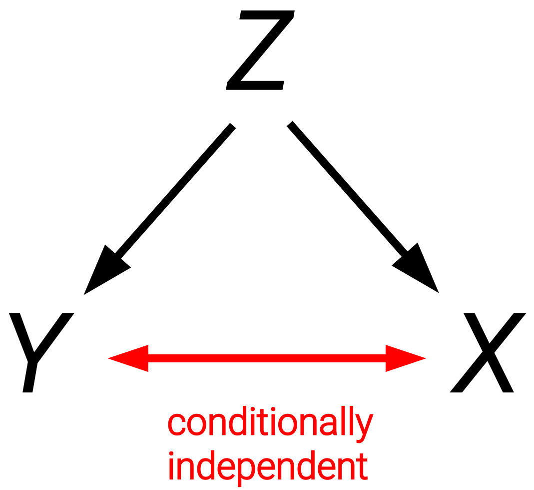
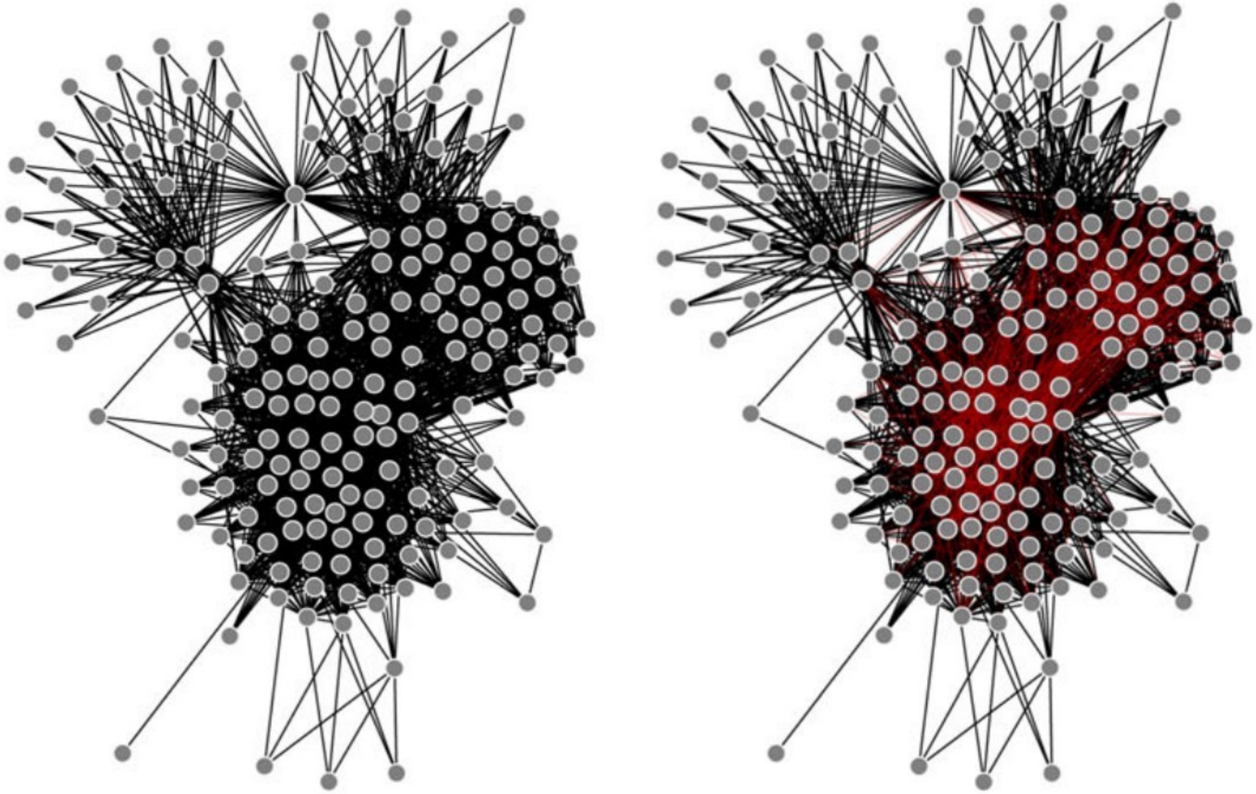


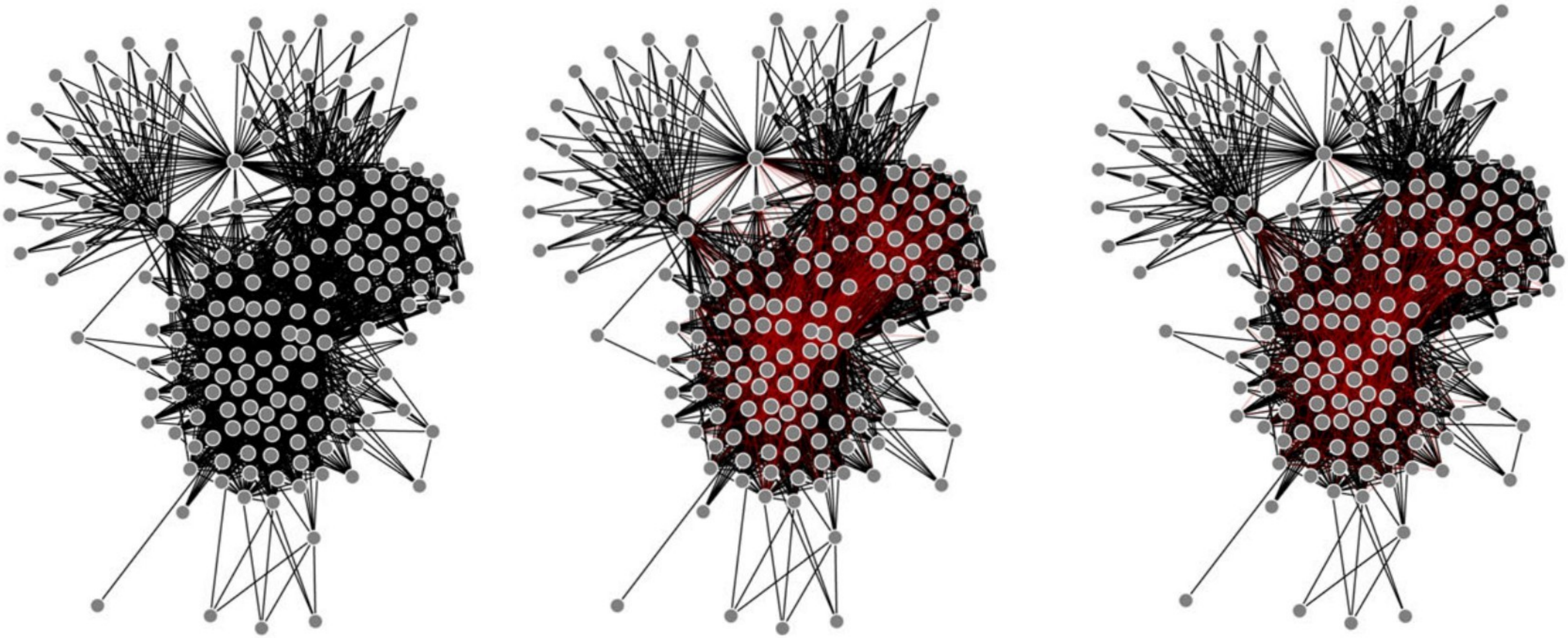
$$X(t) = Z(t) + \epsilon_1$$
$$Y(t) = Z(t) + \epsilon_2,$$

Dempster, A. P. Covariance selection. Biometrics157-175 (1972)



(a) True network (b) Graphical LASSO

Friedman, J., Hastie, T. & Tibshirani, R. Sparse inverse covariance estimation with the graphical lasso. Biostatistics 9, 432-441 (2008).



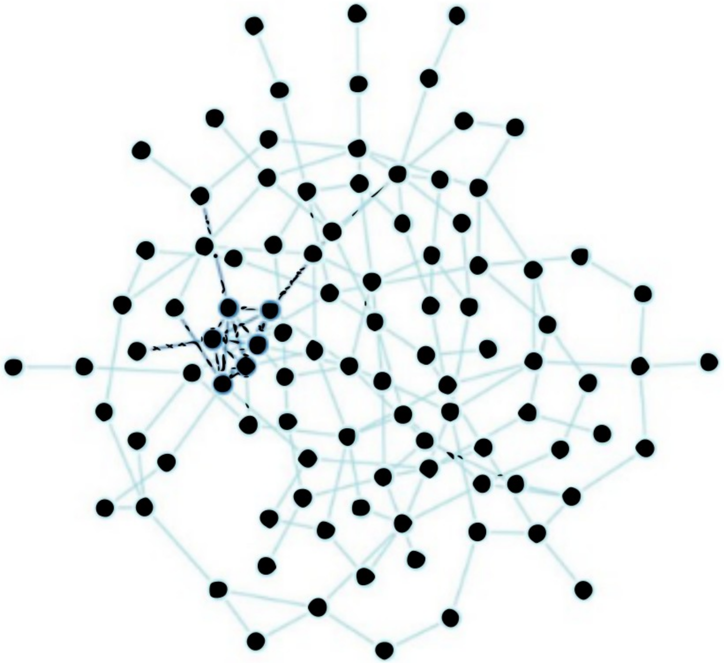
(a) True network (b) Graphical LASSO (c) Bayesian inference

Peixoto, T. P. Network Reconstruction and Community Detection from Dynamics. Phys. Rev. Lett. 123, 128301 (2019).

"I see networks!"

III. Suitability of the methods

Summary descriptors used out of context



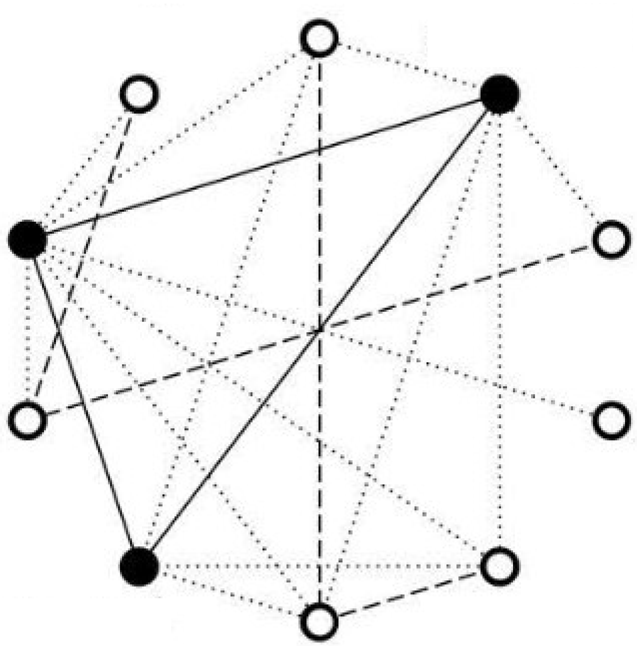
Shortest path of a correlation network?

Maximum modularity of a network?

What to vary, what to keep the same?

What to vary, what to keep the same?

Assortativity of node labels for different null models



Cinelli, M., Peel, L., Iovanella, A. & Delvenne, J.-C. Network constraints on the mixing patterns of binary node metadata. Phys. Rev. E. 102, 062310 (2020).

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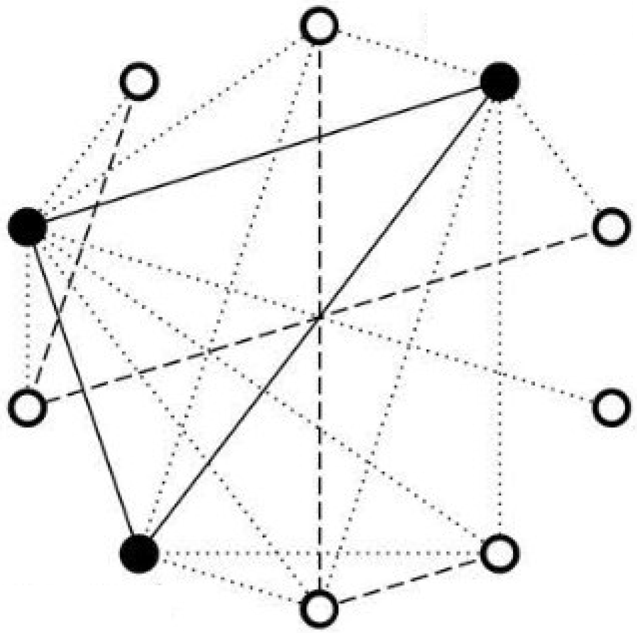

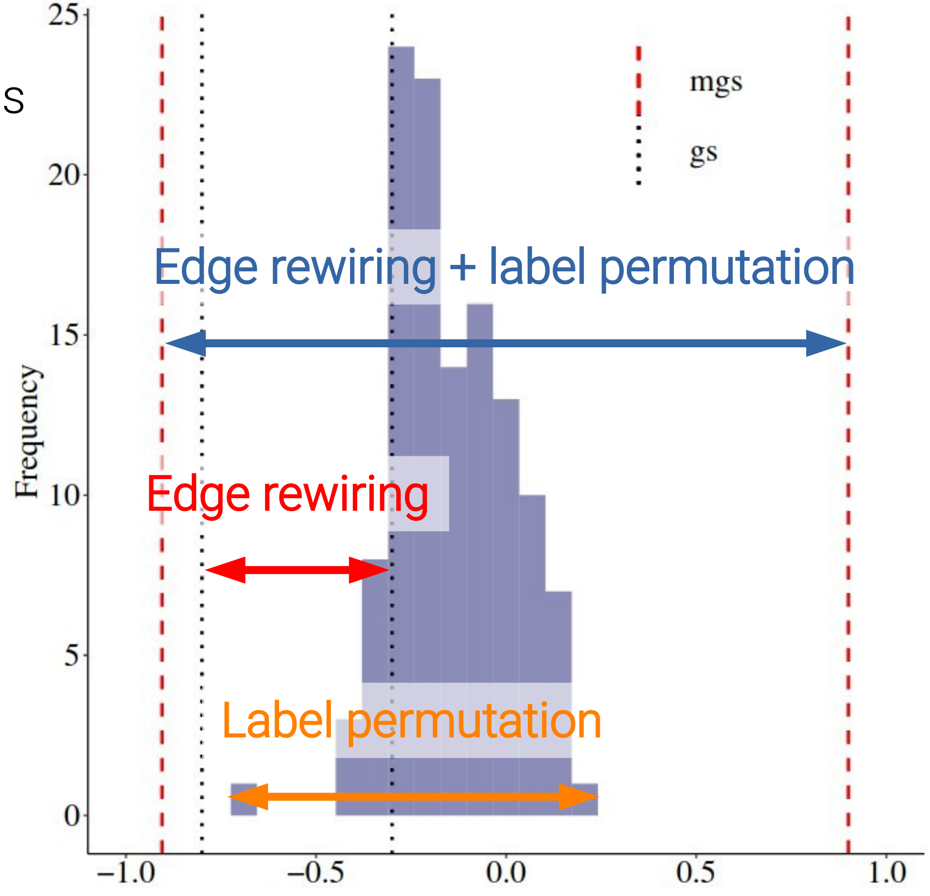

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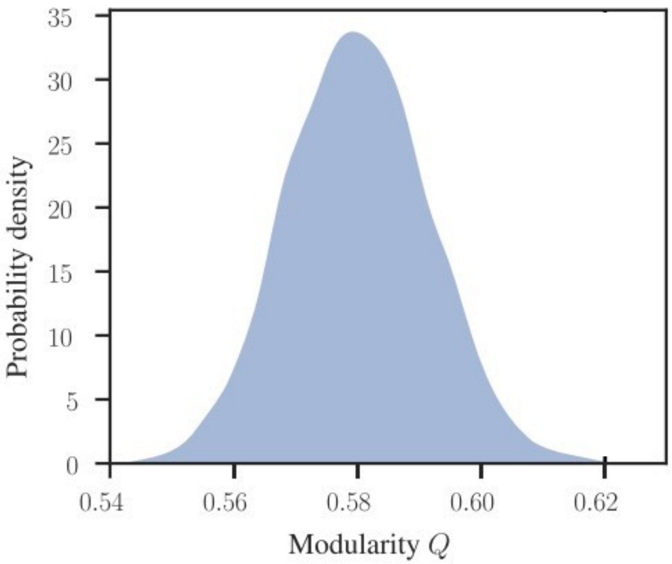
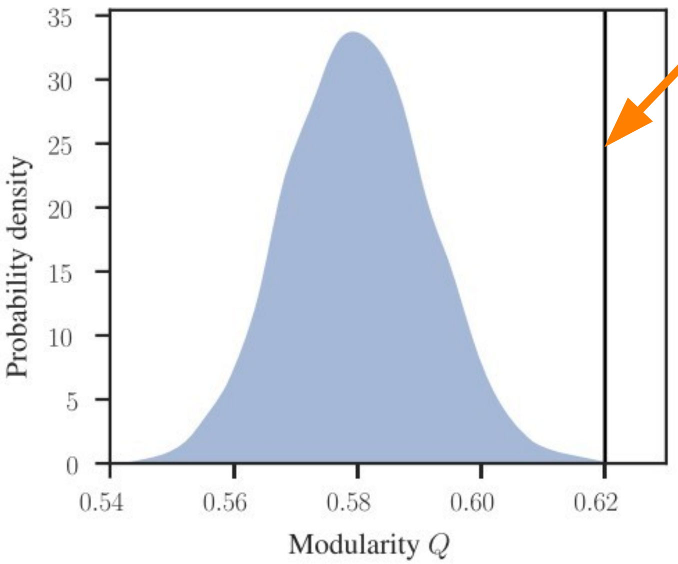
Null models and testing hypotheses

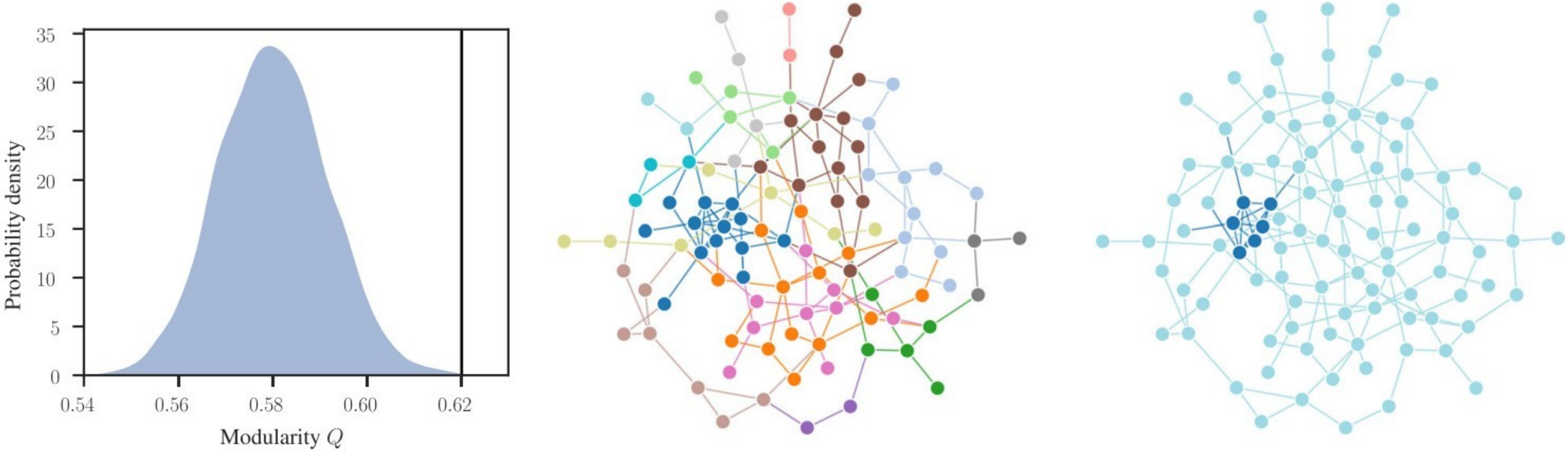


Null models and testing hypotheses

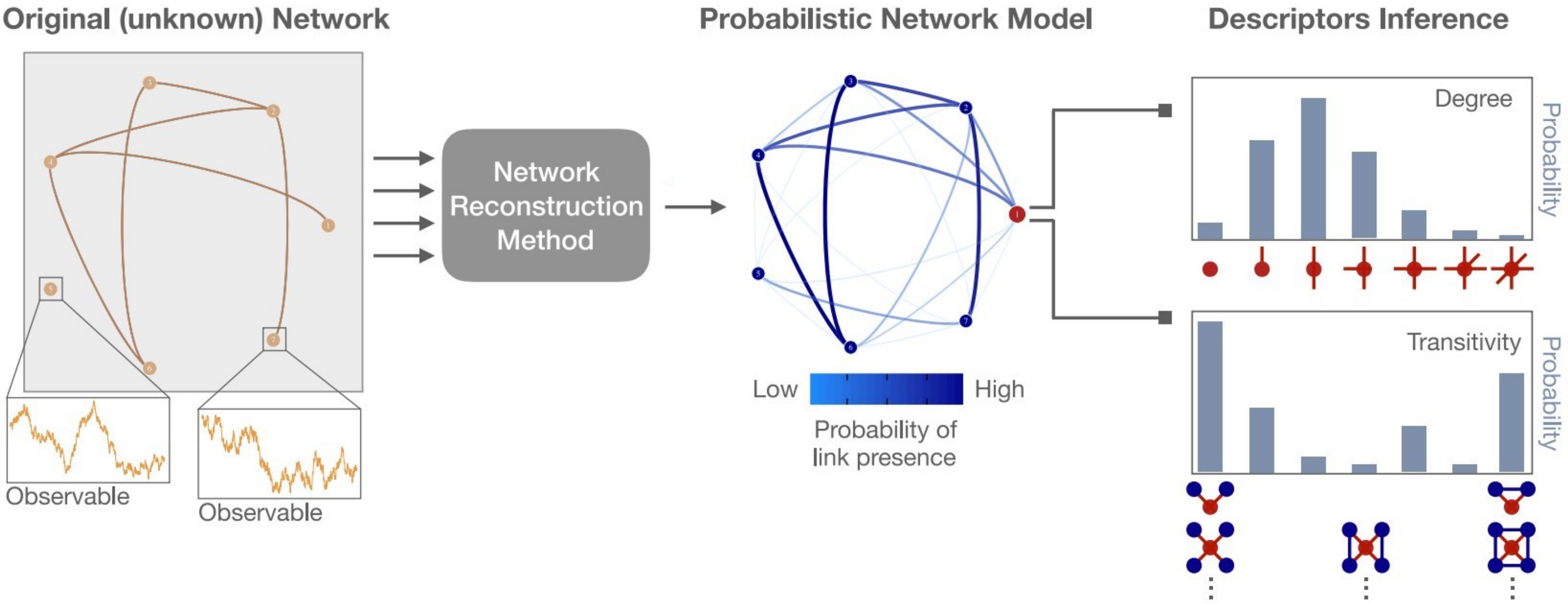
Reject the null hypothesis



Rejecting the null hypothesis does not test the alternative...



Accounting for reconstruction uncertainty




MODEL FREE
IS JUST MODELLING
WITH YOUR EYES CLOSED
imgflip.com

IV. Outlook

Looking forwards...

Looking forwards...

Eat our own dog food. More focus on collaborations, less on individuals

Looking forwards...

Eat our own dog food. More focus on collaborations, less on individuals

Break down walls. Strengthen the link between theory and application.

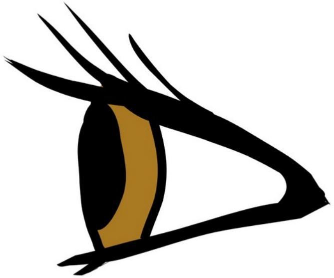
Looking forwards...

Eat our own dog food. More focus on collaborations, less on individuals

Break down walls. Strengthen the link between theory and application.

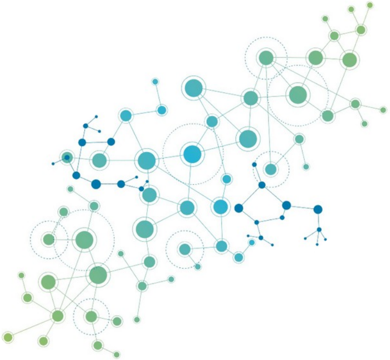
Better modelling. Generative models + statistical inference. Focus on more specific models. Solve real problems.

Observations/
measurements



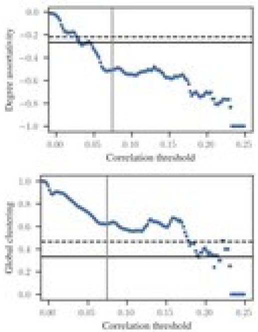
Obscured quality of data

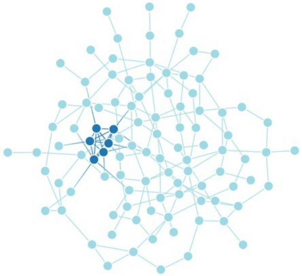
Network representation



Choice of representation

Network analysis

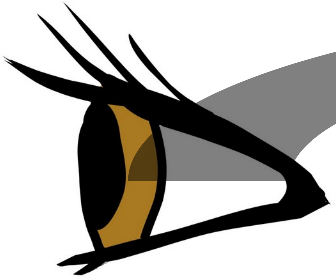




Suitability of the methods

These steps are interdependent

Observations/
measurements

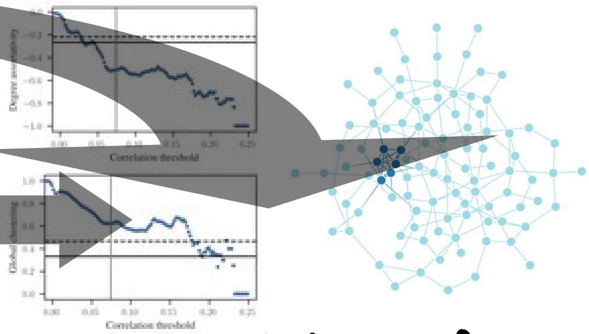


Obscured
quality of data

Network representation

Choice of
representation

Network analysis



Suitability of
the methods

Download the paper!

Peel, L., Peixoto, T.P. & De Domenico, M. Statistical inference links data and theory in network science. *Nat Commun* **13**, 6794 (2022).

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l.peel@maastrichtuniversity.nl