

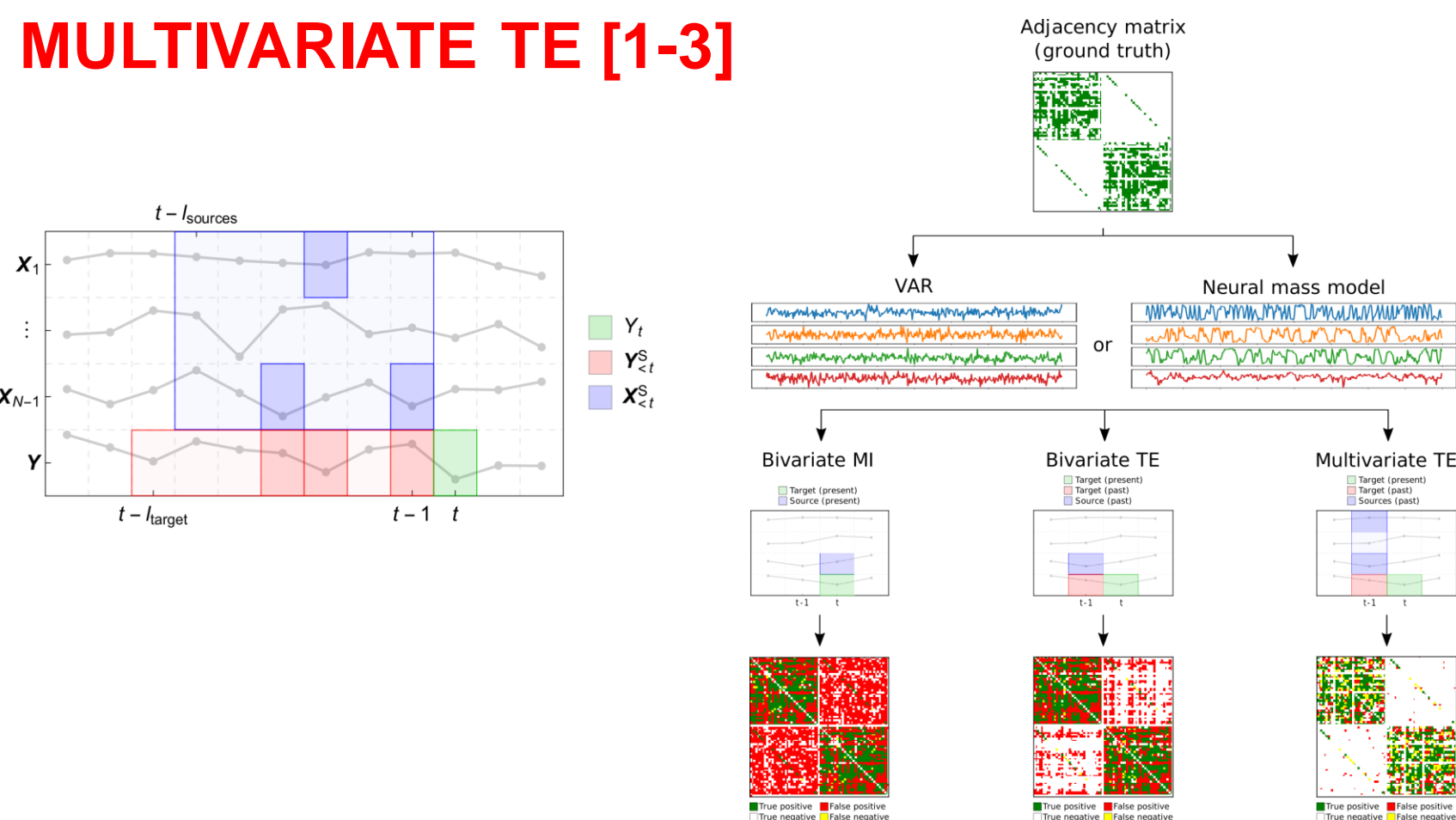


1. MOTIVATION

Infer effective network structure in spiking data using multivariate transfer entropy (TE)

- Effective network inference with a greedy algorithm via multivariate TE validated to work well with continuous-valued activity, e.g. MEG, fMRI, via IDTxI [1-3].
- But until recently we did not have an accurate, data-efficient estimation algorithm for TE in spike trains [4-6]
- Let's bring the two together and get this done!

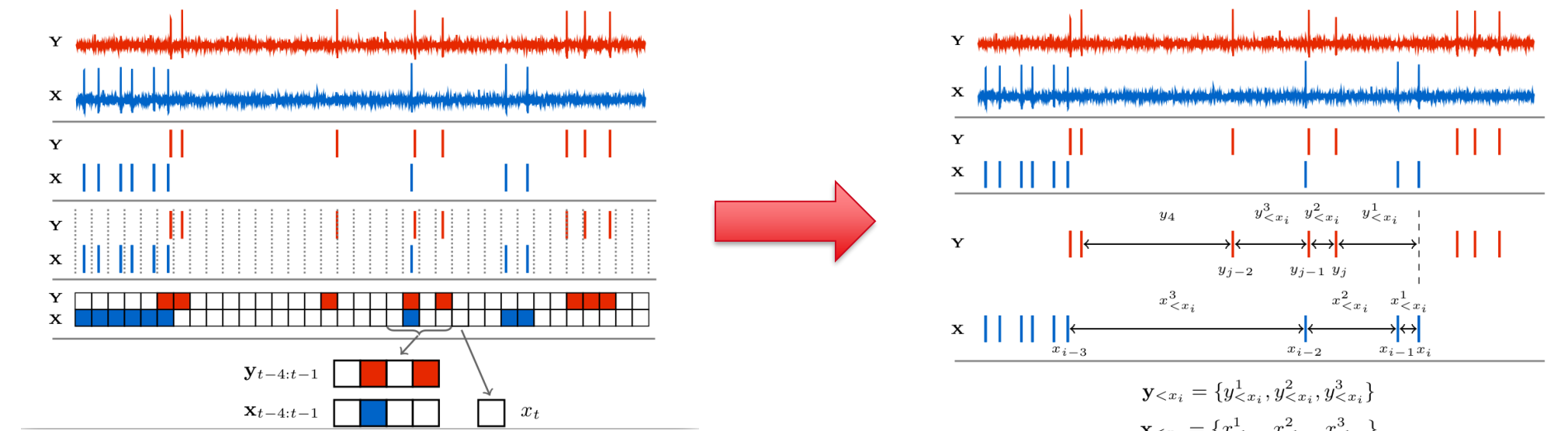
2. EFFECTIVE NETWORK INFERENCE WITH MULTIVARIATE TE [1-3]



3. TE FOR SPIKE TRAINS

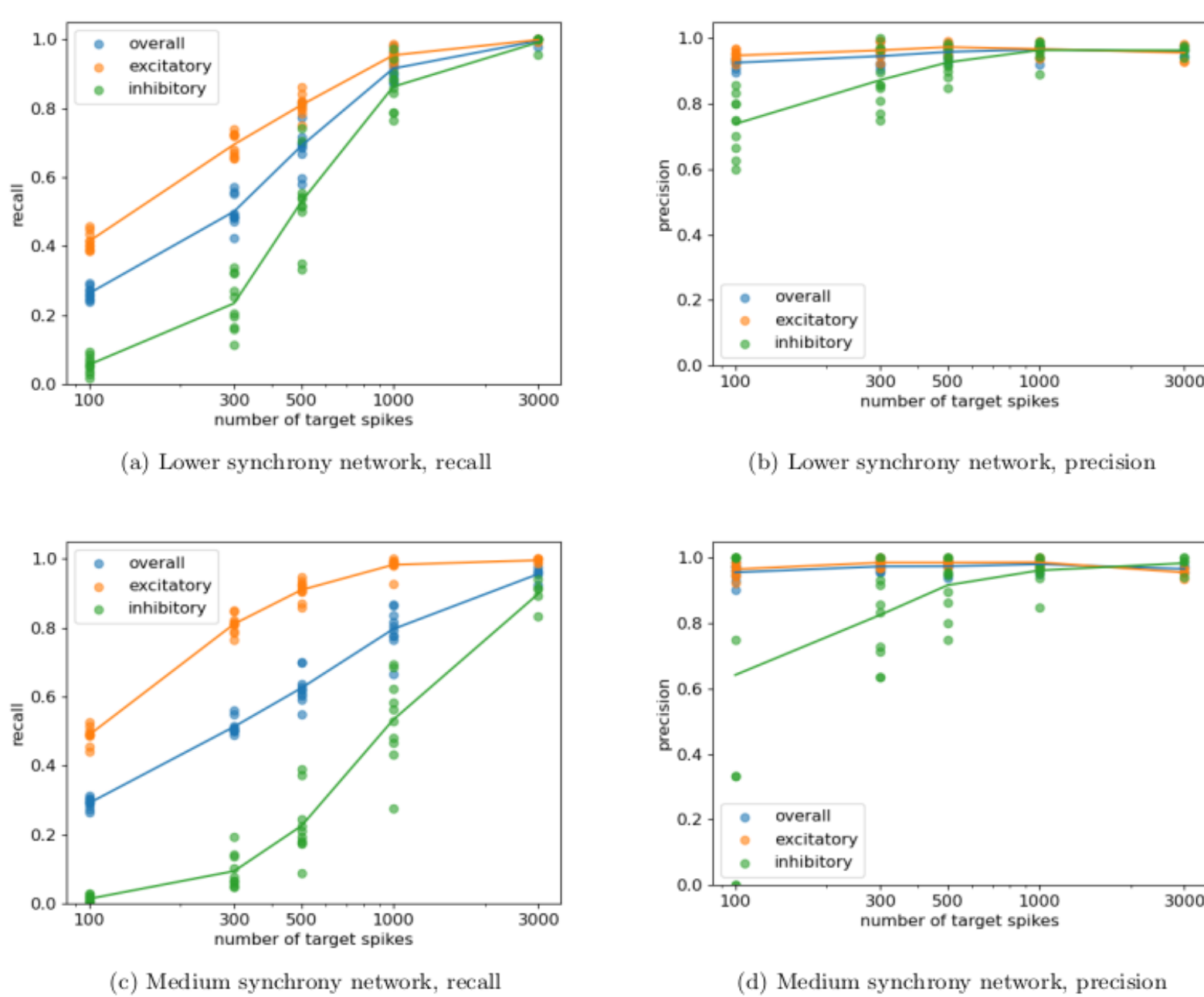
- Properly mathematically formulated [4]
- New estimator developed [5]

$$\hat{T}_{Y \rightarrow X} = \lim_{\tau \rightarrow \infty} \frac{1}{\tau} \sum_{i=1}^{N_X} \ln \frac{\lambda_{X|X_{<t}, Y_{<t}} [X_{<x_i}, Y_{<x_i}]}{\lambda_{X|X_{<t}} [X_{<x_i}]}$$



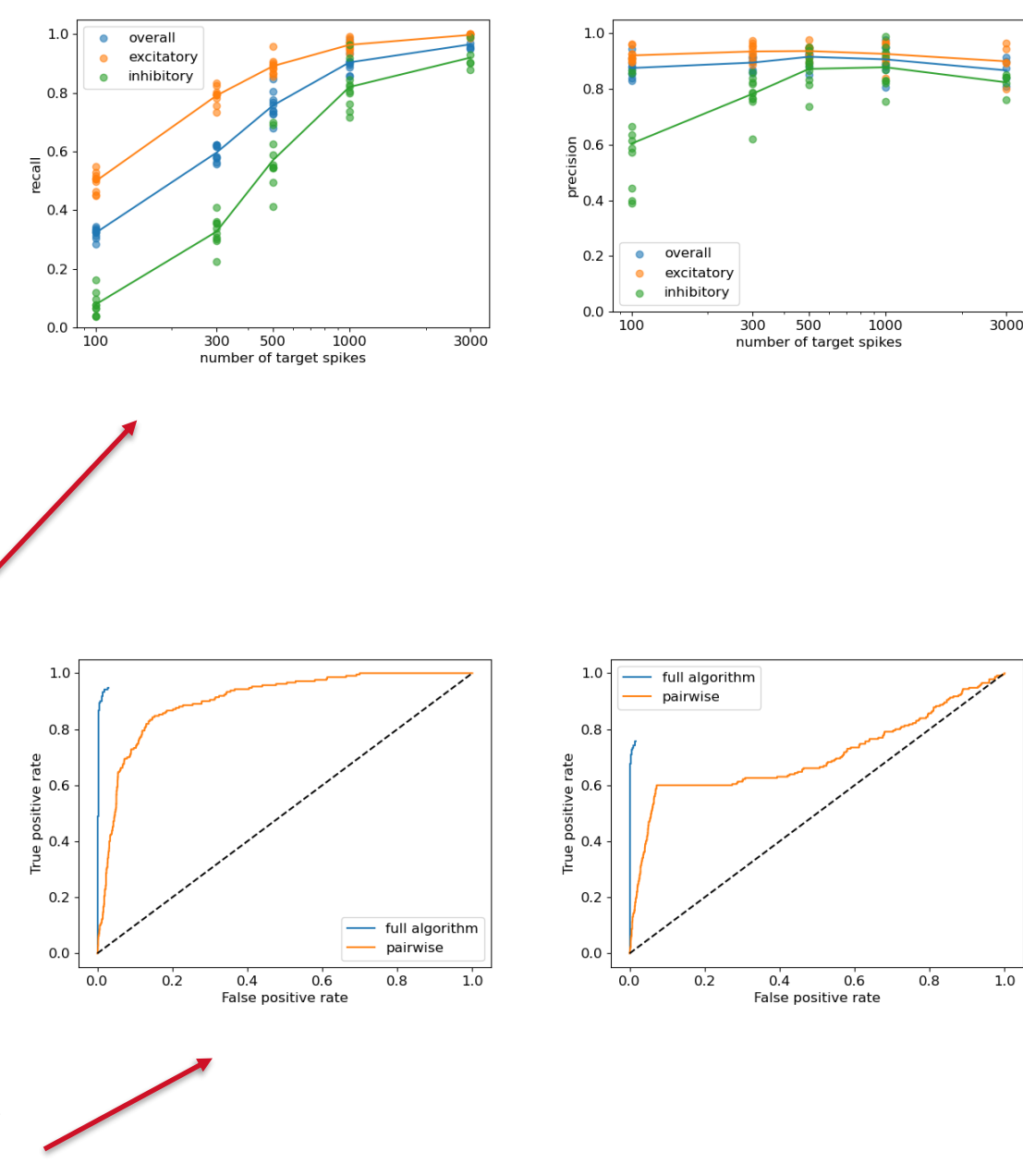
- Demonstrated to show lock-ins of directed functional networks in developing neural cultures [6]

4. INFERENCE ON SYNTHETIC LIF NETWORKS UNDER VARIOUS LEVELS OF SYNCHRONY



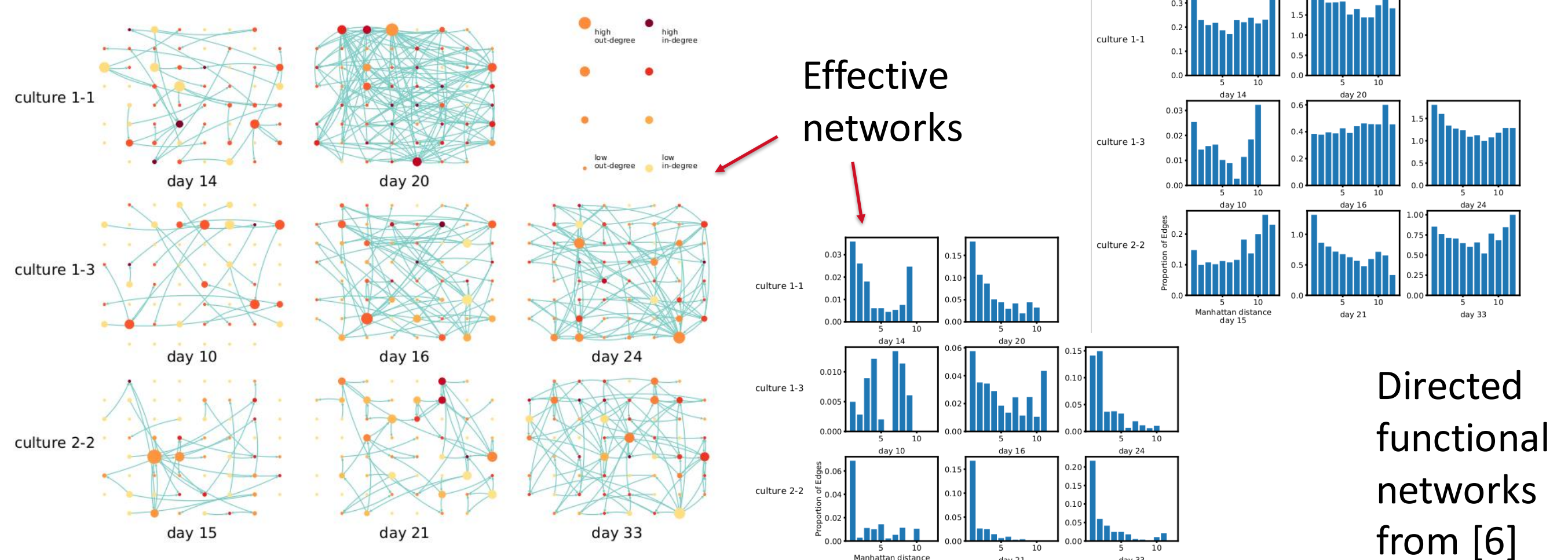
LIF random network of 50 neurons (30 ex, 20 inh), 5 sources per target, varying ex/inh ratio controls synchrony:

- High precision of greedy algorithm maintained
- Recall converges to 100% with sample time (consistent)
- Increased synchrony has little impact, except
- Inhibitory sources are more difficult to infer higher synchrony, but precision remains high
- Greedy algorithm with multivariate TE outperforms
 - CoNECT (low recall)
 - GLM (low precision)
- Regularity of stimulus handled well – algorithm handles levels of determinism or unobserved noise
- ROC curve demonstrates efficacy of multivariate effective network inference over directed functional with TE



5. INFERENCE ON DEVELOPING NEURAL CULTURES

- Studied 3 cultures with multiple overnight recordings from the Wagenaar data set [7,8]
- Early lock-in of directed relationships maintained here in effective networks, like in directed functional networks [6]
- But many redundant relationships are removed in the effective network models
- A preference for shorter connections from sources to targets are far more apparent in the effective network model than in the directed functional networks in [6].



6. CONCLUSION

Multivariate TE greedy algorithm for effective network inference adapted for TE spike train estimator

- Validated to perform well on synthetic data sets, and handle adverse conditions.
- Outperforms other known techniques
- Provides interesting insights regarding early lock in and local connectivity in developing neural cultures
- Will be included in the IDTxI/JIDT open source toolkits [1,9]

REFERENCES

- P. Wollstadt, J.T. Lizier, R. Vicente, C. Finn, M. Martínez-Zarzuela, P. Mediano, M. Wibral, "IDTxI: The Information Dynamics Toolkit xl: A Python package for the efficient analysis of multivariate information dynamics in networks", Journal of Open Source Software, 4(34), 1081 (2019)
- L. Novelli, P. Wollstadt, P. Mediano, M. Wibral, and J. T. Lizier, Large-scale directed network inference with multivariate transfer entropy and hierarchical statistical testing, Network Neuroscience 3, 827 (2019).
- L. Novelli and J. T. Lizier, Inferring network properties from time series using transfer entropy and mutual information: validation of multivariate versus bivariate approaches, Network Neuroscience 5, 373 (2021).
- R. E. Spinney, M. Prokopenko, and J. T. Lizier, Transfer entropy in continuous time, with applications to jump and neural spiking processes, Physical Review E 95, 032319 (2017)
- D. P. Shorten, R. E. Spinney, and J. T. Lizier, Estimating transfer entropy in continuous time between neural spike trains or other event-based data, PLoS Computational Biology 17, e1008054 (2021)
- D. P. Shorten, V. Priesemann, M. Wibral, and J. T. Lizier, Early lock-in of structured and specialised information flows during neural development, Elife 11, e74651 (2022)
- D. A. Wagenaar, J. Pine, and S. M. Potter, An extremely rich repertoire of bursting patterns during the development of cortical cultures, BMC Neuroscience 7, 1 (2006).
- Network activity of developing cortical cultures in vitro, <http://neurodatasharing.bme.gatech.edu/development-data/html/index.html>
- J.T. Lizier, JIDT: An information-theoretic toolkit for studying the dynamics of complex systems. Frontiers in Robotics and AI, 1, 11 (2014)
- Schreiber T: Measuring information transfer. Phys Rev Lett 2000, 85:461-464.
- Bossomaier T, Barnett L, Harré M, Lizier JT: An introduction to transfer entropy: information flow in complex systems. Springer, 2016