PROFESSOR TAMIKI KOMATSUZAKI
Molecule & Life Nonlinear Sciences Laboratory
Research Institute for Electronic Science
Hokkaido University
Kita 20 Nishi 10, Kita-ku, Sapporo 001-0020, Japan

TEL&FAX +81(11) 706-9434
Email: tamiki@es.hokudai.ac.jp
URL: http://mlns.es.hokudai.ac.jp

Dear Editor:

Please find the enclosed manuscript titled "*Detecting existence of a hidden mediator between a pair of individual time series*" by M. Mohiuddin, Udoy S. Basak, Md. Motaleb Hossain, Sulimon Sattari, Mikito Toda, and Tamiki Komatsuzaki. We would like to submit the manuscript to *Scientific Reports*.

Complex self-organizational systems consist of many interacting parts. The influence of an agent on another may be direct or indirect through another intermediary agent. *How then, can one determine how an agent influences others in the group, while accounting for confounding variables?* This presents a significant challenge in the study of emergent behaviors in complex systems such as flocking in birds, schooling in fish, swarming in insects, and bacterial or cell communities.

Our research addresses this issue using information-theory for pairwise time series data to distinguish between direct and indirect interactions among agents. Causation entropy may also be another measure to infer causal inference from a third variable to intermediate a pair of agents when one could list all the candidates of the third variable. However, when the total number of agents increases, the total number of combinations increases exponentially, which prevents us from inferring direct or indirect interactions among agents *in practice*. In this article, we develop an information theoretic scheme to enable us to infer and differentiate direct and indirect interactions using modified transfer entropy and delay time dependency where the support in quantifying the information amount to be transferred is delay-time-independent in contrast to the original transfer entropy does depend on the delay time. We observed distinct patterns as the delay time increases: agents in direct interactions show a monotonically decreasing trend in modified transfer entropy, while those in indirect interactions exhibit an opposite trend. These observations provide a clear differentiation of the direct and indirect interactions without listing the candidates of the third agents to mediate any of two agents.

To validate our approach, we applied it to two models such as the modified Vicsek model and underdamped Langevin dynamics. Our research contributes to a deeper understanding of emergent behaviors in self-organizational systems, potentially enabling predictive and control strategies.

We believe our research provides an important contribution to *Scientific Reports* by introducing a new information-theoretic technique for analyzing self-organizational systems. Our findings are relevant to a broad audience, including researchers in information theory, physical sciences, computer science, and other disciplines.

1. Niizato, T., Sakamoto, K., Mototake, Y.-i., Murakami, H. & Tomaru, T. Information structure of heterogeneous criticality in a fish school. *Sci. Rep.* **14**, 29758 (2024).
2. Singh, M. S., Pasumarthy, R., Vaidya, U. & Leonhardt, S. On quantification and maximization of information transfer in network dynamical systems. *Sci. Rep.* **13**, 5588 (2023).
3. Brown, J., Bossomaier, T. & Barnett, L. Information flow in finite flocks. *Sci. Rep.* **10**, 3837 (2020).
4. Takamizawa, K. & Kawasaki, M. Transfer entropy for synchronized behavior estimation of

interpersonal relationships in human communication: identifying leaders or followers. *Sci. Rep.* **9**, 10960 (2019).
5. Prokopenko, M. & Lizier, J. T. Transfer entropy and transient limits of computation. *Sci. Rep.* **4**, 5394 (2014).

We would be grateful if the manuscript can be reviewed in depth and considered for the publication in *Scientific Reports*.

Tamiki Komatsuzaki

Suggested Reviewers:

Prof. Jean-Paul Rieu
Professor of Physics
Institut Lumière Matière (Institute of Light and Matter, ILM, UMR 5306)
Université Claude Bernard Lyon 1
Phone: +33 (0)4 72 43 11 42
Email: jean-paul.rieu@univ-lyon1.fr

Prof. Masaki Sano
Department of Physics, Graduate School of Science
University of Tokyo
7-3-1 Hongo, Bunkyo-ku,Tokyo 113-0033
Phone:+81-3-5841-4188
Email: sano@phys.s.u-tokyo.ac.jp

Prof. Jason Green
University of Massachusetts Boston
Department of Chemistry, College of Science and Mathematics
Phone: +1-617-287-6136
Email: jason.green@umb.edu

Prof. Jim Crutchfield
Complexity Sciences Center, Director
Distinguished Professor of Physics
Physics Department
University of California, Davis
Davis, CA 95616-8572
Phone: +1-530-752-0600
Email: chaos@ucdavis.edu

Prof. Jinsong Zhao
Institute of Process System Engineering
Department of Chemical Engineering
Tsinghua University
Office Phone: 010-62783109
Email: jinsongzhao@tsinghua.edu.cn