

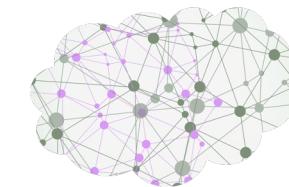
Connector and Provincial Hub Dichotomy in Scientific Collaborations Identified by Reinforcement Learning Algorithm

Taking the field of physics as an example



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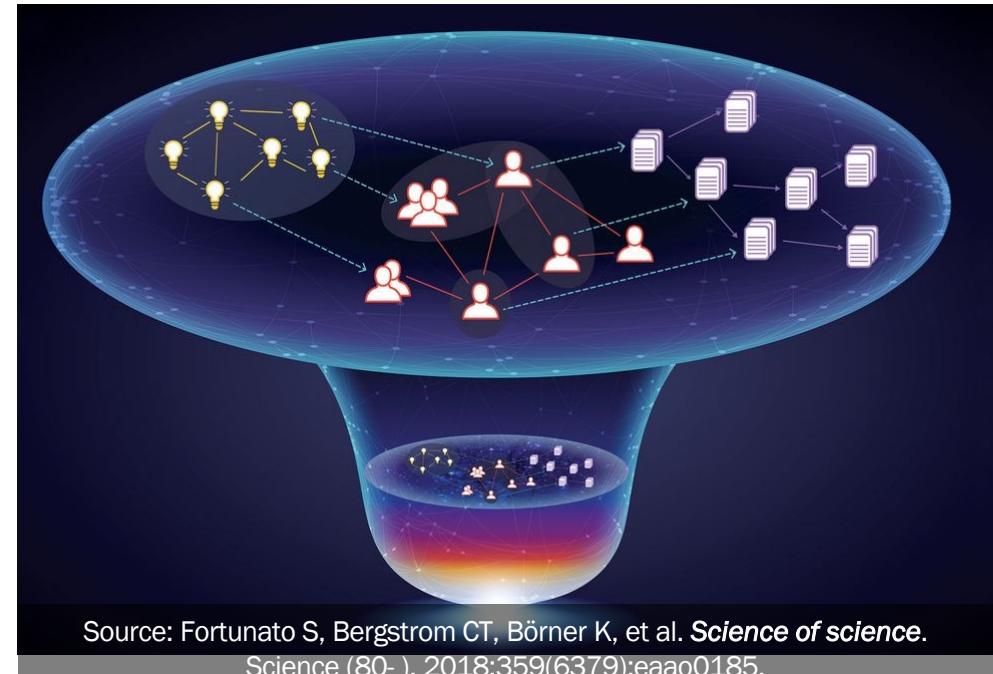


Joint Workshop of the 5th Extraction and Evaluation of Knowledge Entities from Scientific Documents and the 4th AI + Informetrics (EEKE-AII2024)

April 23-24, 2024, Changchun, China

Research background

- Science as a large-scale complex adaptive system
- The *scientific collaboration network* constitutes a fundamental component of the overall innovation framework, embodying the interactive and cooperative dynamics among researchers.



Research problem

- Science as a large-scale complex adaptive system
- How researchers with varying levels of social capital or differing types of social linkages contribute to the social division of cognitive labor in scientific communities?



Science as a massive social innovation activity

Dataset

- We use the scientific publications in the journals of the American Physical Society (APS) from the period 1985 to 2009.
- After the necessary pre-processing procedure, the dataset finally contains 104,484 individual researchers, 848,231 edges.

The screenshot shows the homepage of the PHYSICAL REVIEW JOURNALS website, published by the American Physical Society. The top navigation bar includes links for Journals, Authors, Referees, Collections, Browse, Search, Press, and a magnifying glass icon. Below the navigation, there are several sections for different journals:

- Physical Review Letters**: Described as the premier APS journal for current research, providing rapid publication of short reports of important fundamental research in all fields of physics. Includes a "View Phys. Rev. Lett." button.
- Physical Review X**: An online-only, fully open access, peer-reviewed journal that aims to publish, as timely as possible, exceptional original research papers from all areas of pure, applied, and interdisciplinary physics. Includes a "View Phys. Rev. X" button.
- PRX Energy**: A highly selective, open access journal featuring energy science and technology research with an emphasis on impact and lasting impact. The journal expands on the excellence and innovation of Physical Review X (PRX). Includes a "View PRX Energy" button.
- PRX Quantum**: A highly selective, open access journal featuring quantum information science and technology research with an emphasis on outstanding and lasting impact. The journal expands on the excellence and innovation of Physical Review X (PRX). Includes a "View PRX Quantum" button.
- Reviews of Modern Physics**: Described as the broad fundamental physics literature in established topical areas together and places it within the context of current trends in research and applications. Its in-depth review articles and shorter Colloquia serve students, engineers, and physics researchers in a range of fields. Includes a "View Rev. Mod. Phys." button.
- Physical Review A**: Covering atomic, molecular, and optical physics and condensed matter physics. Includes a "View Phys. Rev. A" button.
- Physical Review B**: Covering condensed matter and materials physics. Includes a "View Phys. Rev. B" button.
- Physical Review C**: Covering nuclear physics. Includes a "View Phys. Rev. C" button.
- Physical Review D**: Covering particle, field, gravitation, and cosmology. Includes a "View Phys. Rev. D" button.
- Physical Review E**: Covering statistical, nonlinear, biological, and soft matter physics. Includes a "View Phys. Rev. E" button.
- Physical Review Research**: A peer-reviewed international, multidisciplinary, open access journal covering all research topics of interest to the physics community. Includes a "View Phys. Rev. Research" button.
- Physical Review Accelerators and Beams**: A peer-reviewed, online-only open access journal funded by contributions from national and international laboratories and other partners. It covers the full range of accelerator science and technology. Includes a "View Phys. Rev. Accelerators and Beams" button.

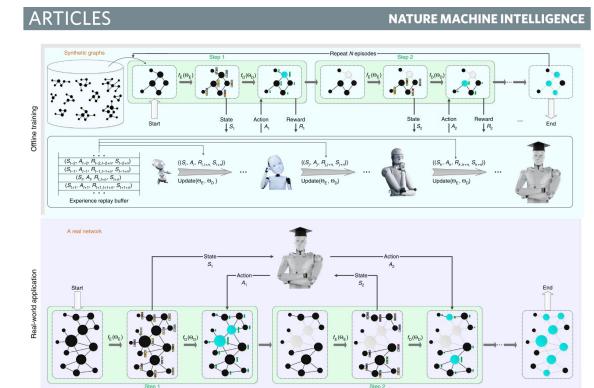
Method

- Complex network analysis metrics
 - Participation coefficient, z-score of node degree value within the community, clubness, modularity .etc
- Graph Representation Learning and Deep Reinforcement Learning
 - Node2Vec
 - Reinforcement learning algorithms
- Susceptible-Infected (SI) model
 - Modelling knowledge diffusion process

- Guimerà, R., & Amaral, L. A. N. (2005). Functional cartography of complex metabolic networks. *Nature*, 433(7028), 895–900. <https://doi.org/10.1038/nature03288>
- Fan, C., Zeng, L., Sun, Y., & Liu, Y. Y. (2020). Finding key players in complex networks through deep reinforcement learning. *Nature Machine Intelligence*, 2(6), 317–324. <https://doi.org/10.1038/s42256-020-0177-2>

$$Pc_i = 1 - \sum_{s=1}^{N_M} \left(\frac{\kappa_{is}}{\kappa_i} \right)^2$$

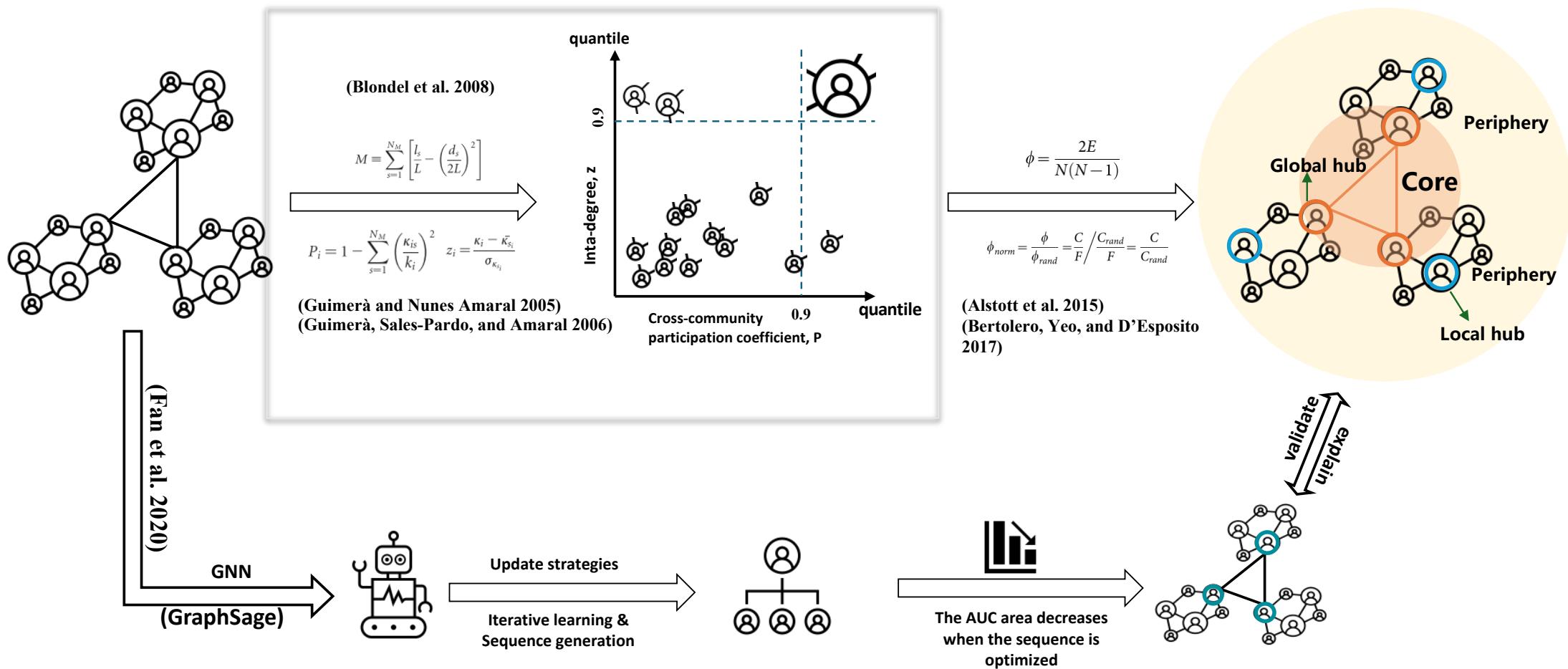
$$z_i = \frac{\kappa_i - \bar{\kappa}_{s_i}}{\sigma_{\kappa_{s_i}}}$$



$$\frac{dS}{dt} = -\frac{\beta \cdot S \cdot I}{N}$$

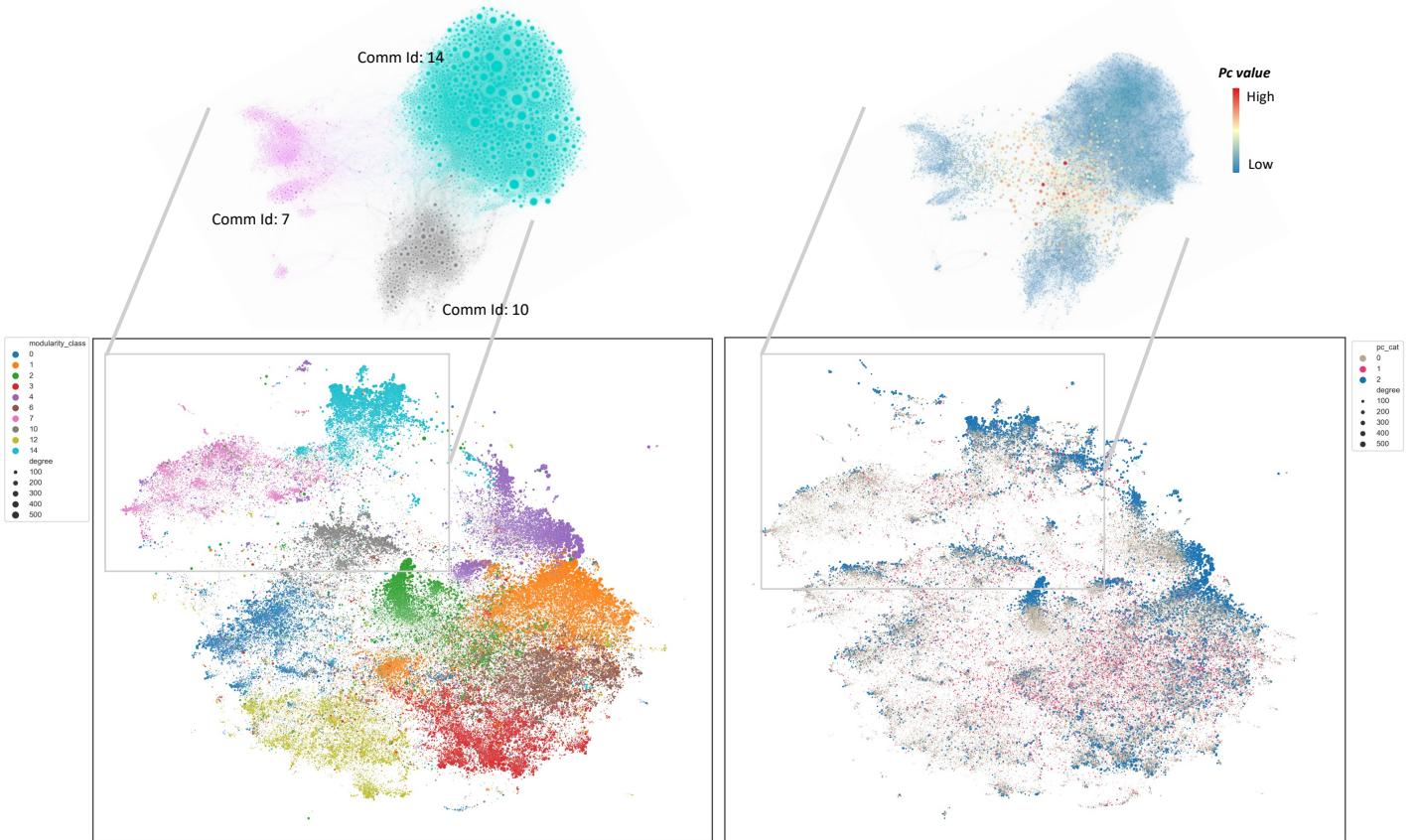
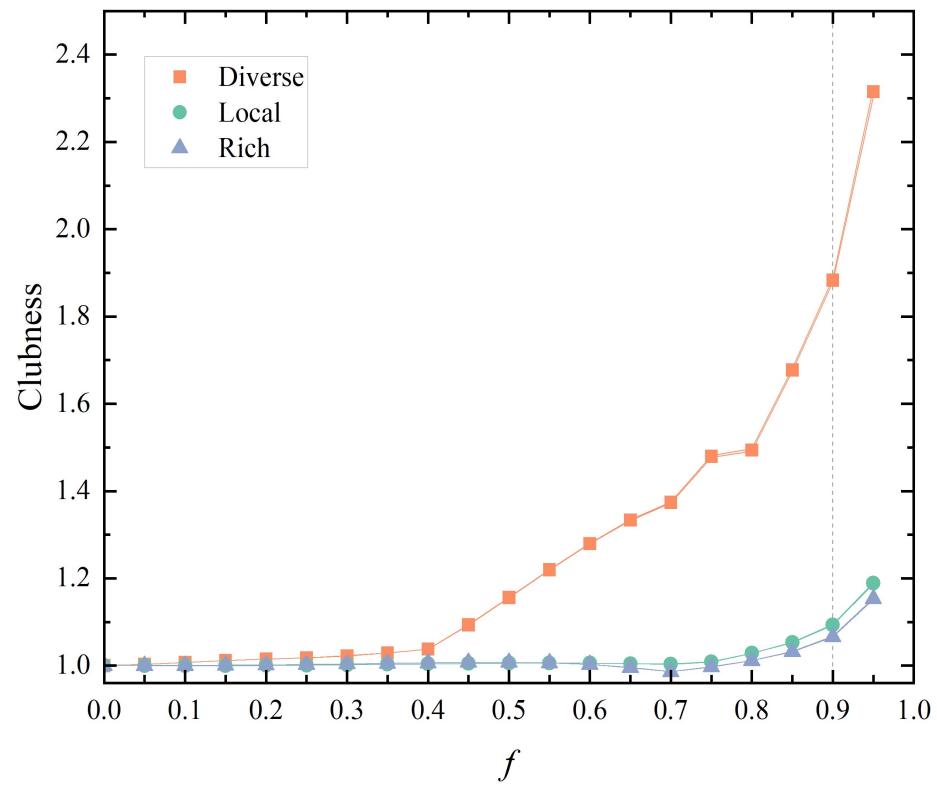
$$\frac{dI}{dt} = \frac{\beta \cdot S \cdot I}{N} = \beta I \left(1 - \frac{I}{N}\right)$$

- The technological route illustration of core structure detection in the complex network by integrating the deep reinforcement learning algorithm and the hub-connected roles algorithm and the hub-connected roles

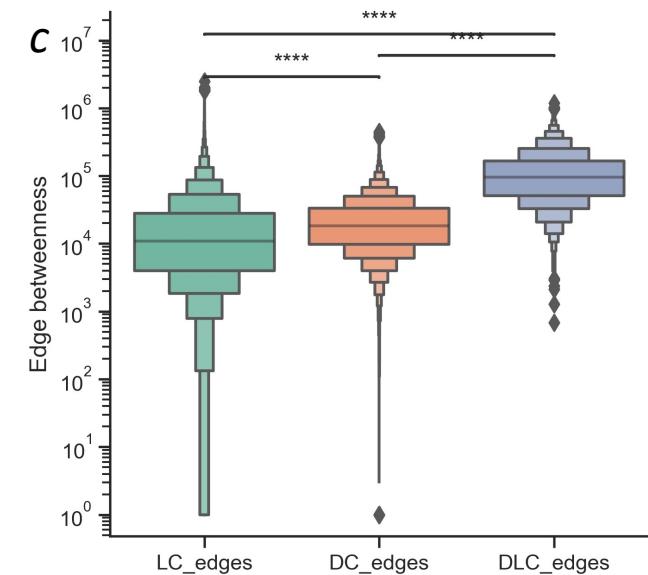
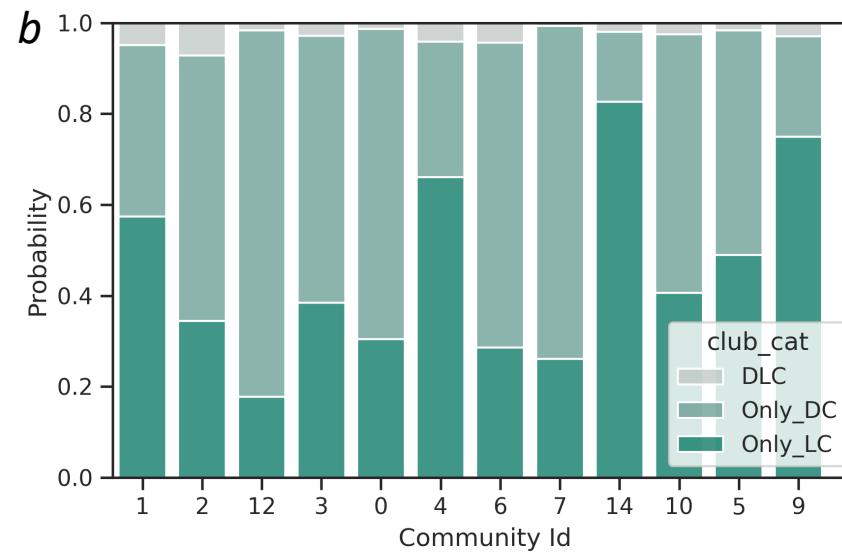
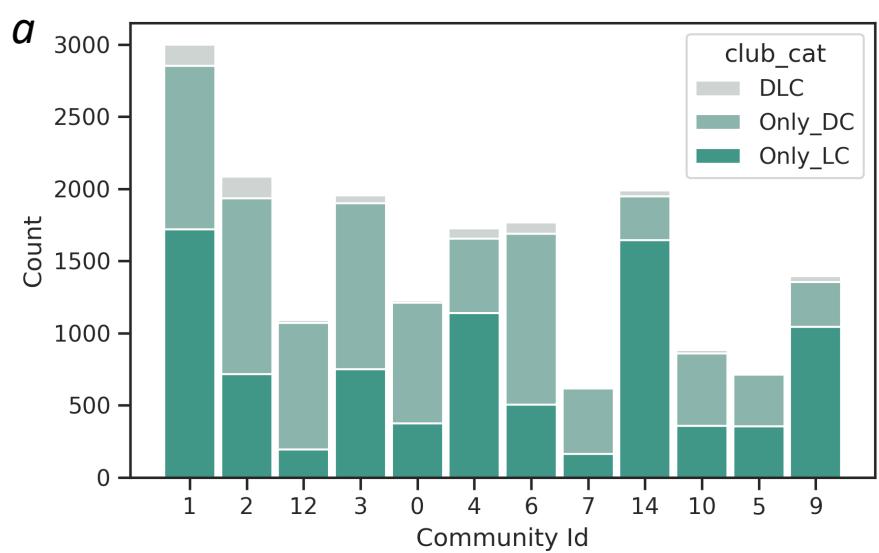


Result

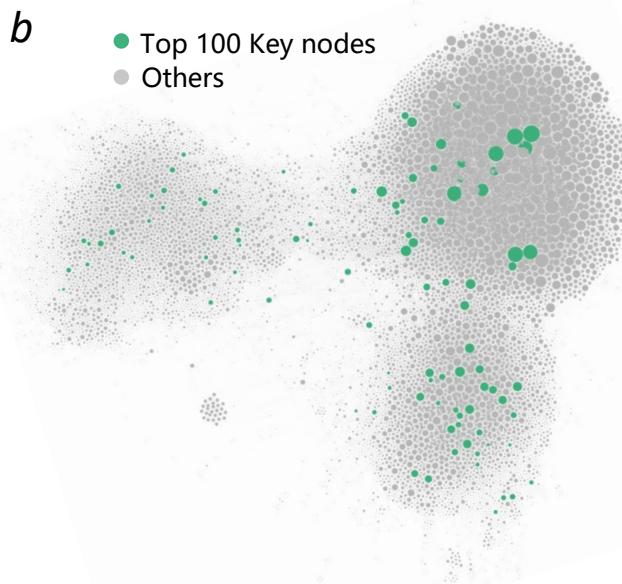
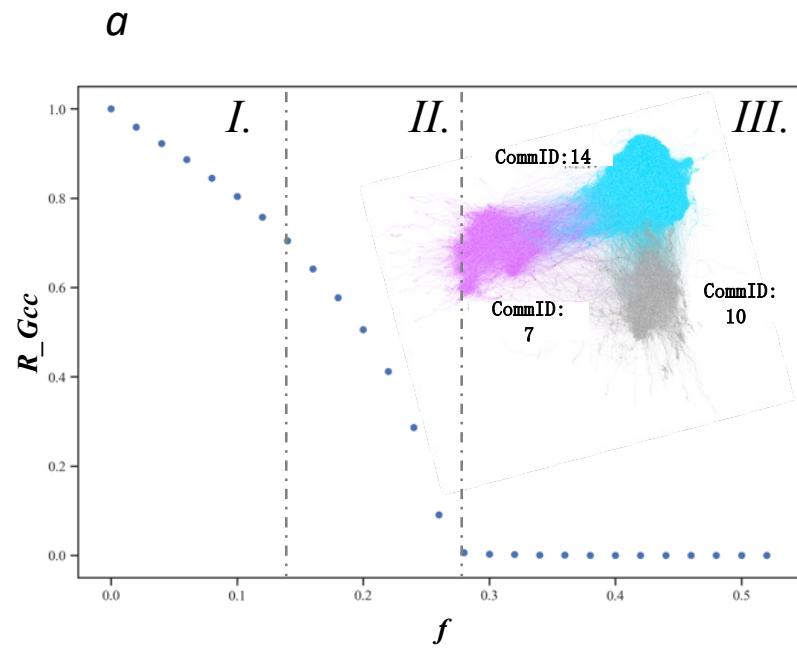
- I. Network features between the global hub and the local hub club members
- II. Results of robustness experiments of the key players in the scientific collaborative network detected by deep reinforcement learning algorithm
- III. The matching distribution of the key players and the identified hub-connected club members
- IV. The distribution of club members in the collaborative network across communities and their corresponding edge betweenness centrality
- V. The results of SI-model-based knowledge diffusion experiment among various types of club members



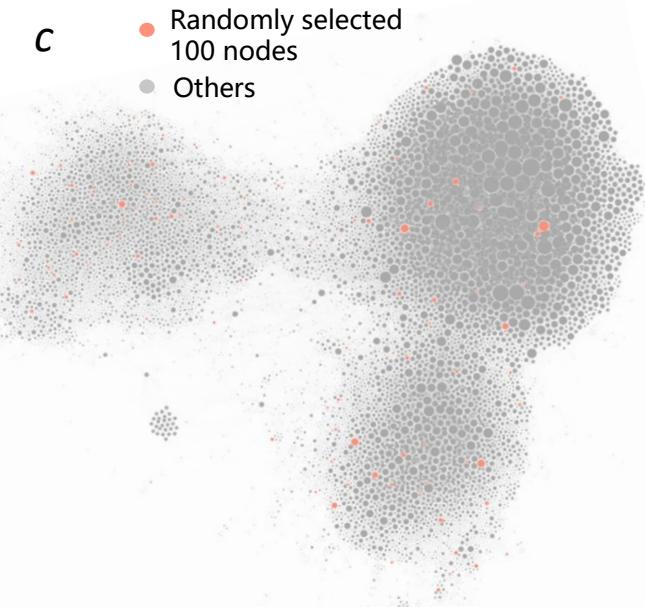
The Embedded Landscape of Scientific Collaborative Network in Physics



Network features between the global hub and the local hub club members



Number of connected subgraphs after removing key nodes: 209



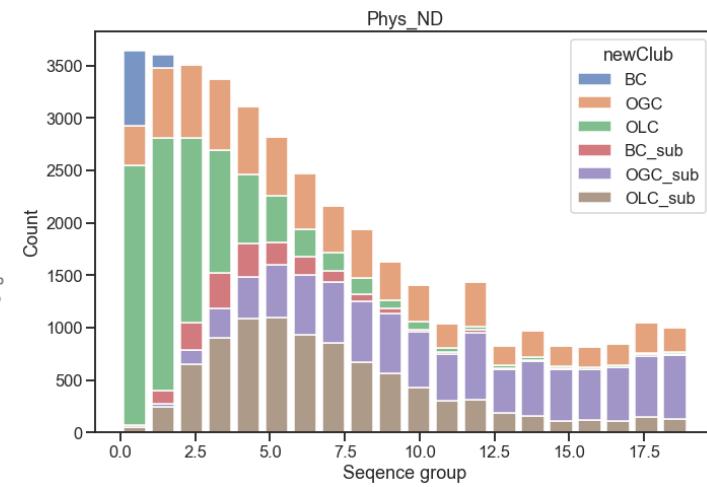
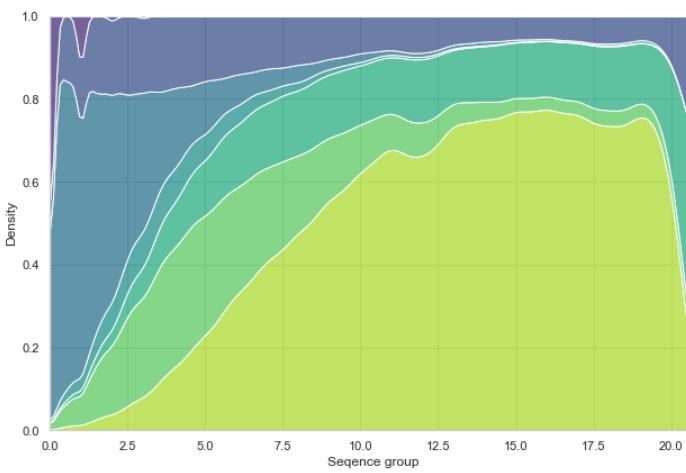
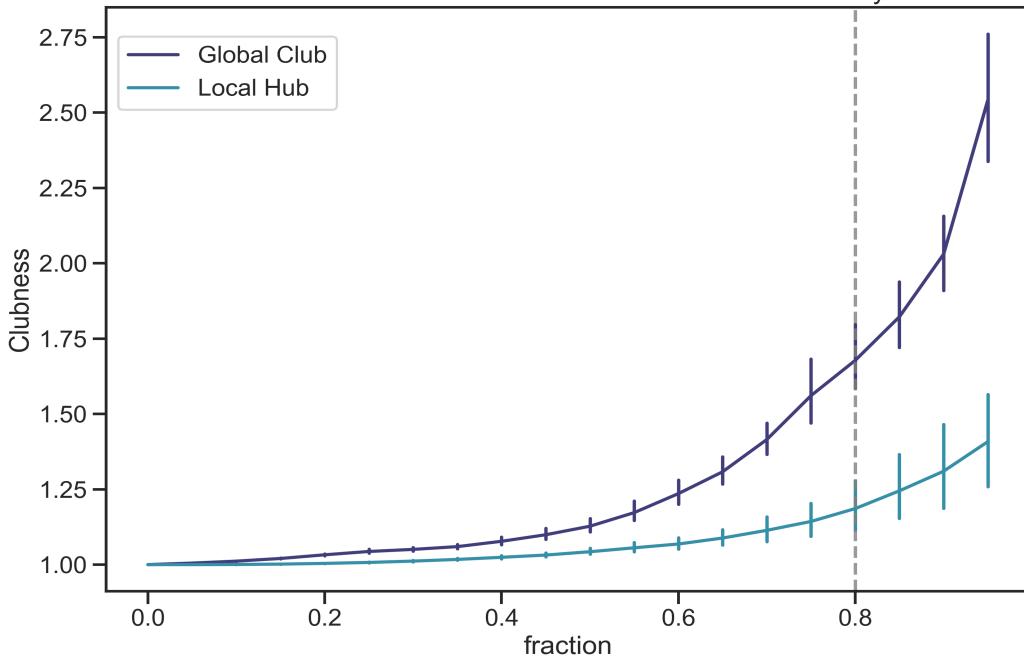
Number of connected subgraphs after removing key nodes : 14

The results of robustness experiments of the key players in the scientific collaborative network detected by deep reinforcement learning algorithm

The mixing patterns of the key players and the hub-connected club members

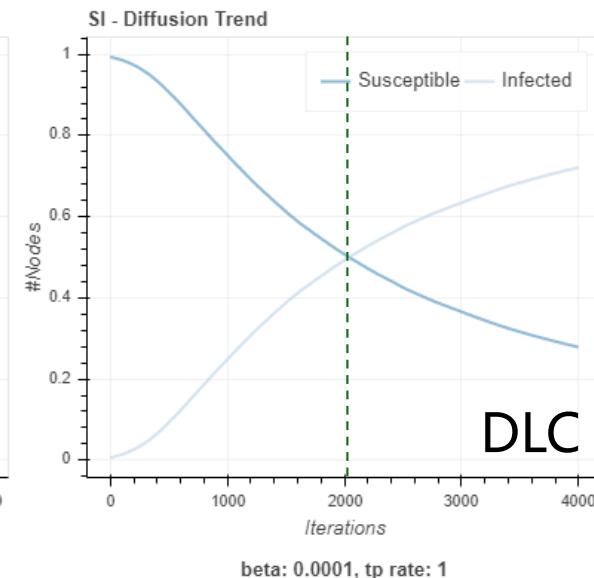
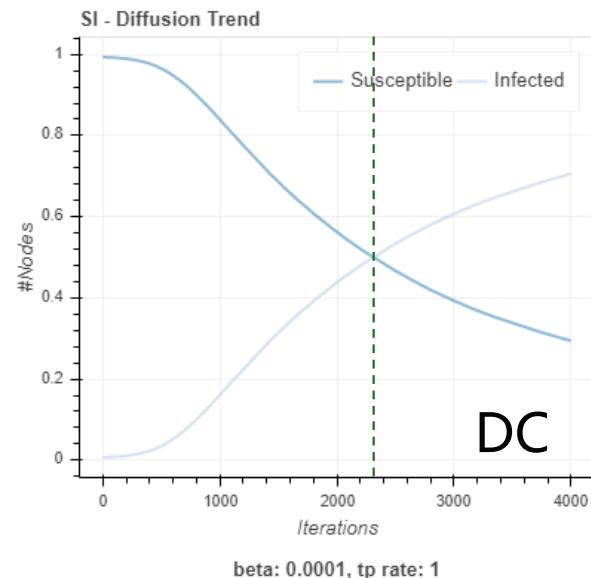
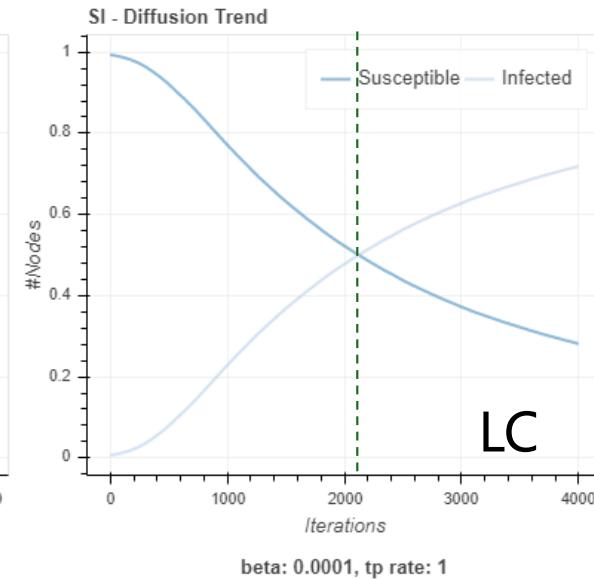
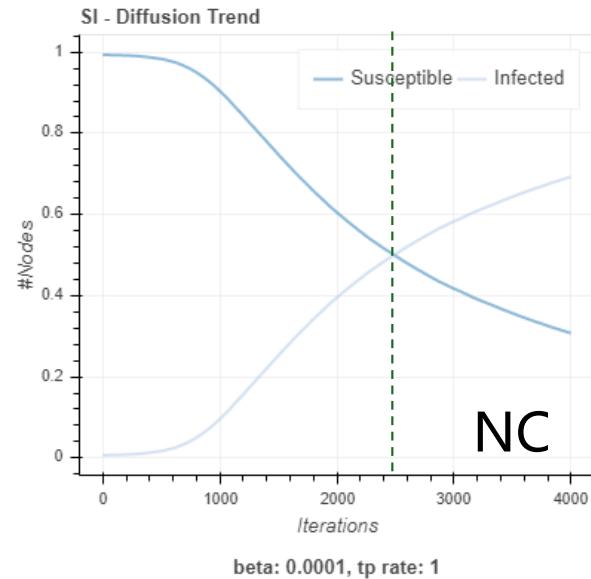
$$\theta_{norm} = \frac{\theta}{\theta_{rand}} = \frac{2C/N(N-1)}{2C_{rand}/N(N-1)} = \frac{C}{C_{rand}}$$

Clubness of 20 collaborative sub-communities in Phys.



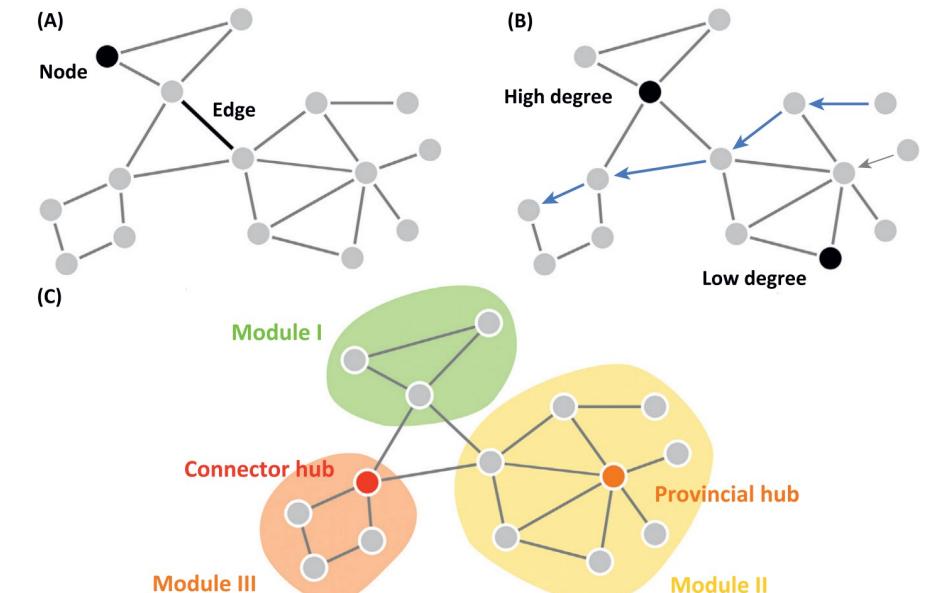
SI-model-based knowledge diffusion experiment among various types of club members

- Reflecting the facilitating effect of provincial or connector hub structure on knowledge exchange and diffusion



Conclusion and future work

- Hubs and multi-cores
 - provincial hub scientists
 - Central role within their communities
 - connector hub scientists
 - who bridge different communities.
- The spontaneous formation of "local centrality and global decentrality" in the scientific collaboration system.
- It makes the knowledge creation system economical at the structural level and efficient in the functions of global collaboration and knowledge diffusion.



TRENDS in Cognitive Sciences

Provincial Hub and Connector hub in SCN

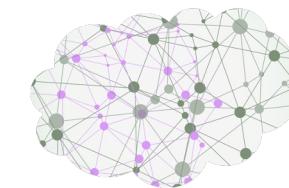
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