Gillespie Algorithms for Simulating Spreading Phenomena in Higher Order Networks

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Higher-order dynamics refer to mechanisms where collective mutual/synchronous interactions differs fundamentally from their pairwise counterparts [1], introducing the idea of many-body interactions that scale super linearly with the number of interacting entities. In the context of network science, common pairwise links are generalized to a higher order through the inclusion of hyperedges that represent group interactions of arbitrary sizes. While contagion dynamics on networked systems so far have been assumed to occur exclusively by means of pairwise interactions, many systems operate through group interactions, such as information dissemination on social networks or large gatherings during a viral outbreak. Higher-order dynamics can exhibit phenomena that are absent in simpler pairwise models, such as catastrophic activation, hysteresis, and hybrid transitions. In this work, we propose algorithms that generalize spreading on pairwise networks to higher orders. A bipartite configuration model is adapted to construct higher-order networks of arbitrary interaction and group size distributions. Simulation of contagion dynamics on higher orders is challenging due to the complexity of propagation through hyperedges of any order, often culminating in either slow or imprecise algorithms. To address this issue, an optimized Gillespie algorithm based on [2] is proposed and generalized for higher-order structures. We evaluate alternative implementations of algorithms for the Hyper-SIS model with critical mass threshold [3], a model capable of simulating spreading phenomena on higher-order systems. Optimizations were tested on networks of different sizes, parameters and levels of heterogeneity. We report algorithms that are several orders of magnitude faster than other standard methods. The methods proposed are a gateway to delve deeper into the study of higher-order networks, allowing for the simulation of networks at scales and levels of complexity previously unattainable.
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References

[1] F. Battiston, E. Amico, A. Barrat, G. Bianconi, G. Ferraz de Arruda, B. Franceschiello, I. Iacopini, S. Kéfi, V. Latora, Y. Moreno, et al., "The physics of higher-order interactions in complex systems," Nature Physics, vol. 17, no. 10, pp. 1093–1098, 2021.

[2] W. Cota and S. C. Ferreira, "Optimized gillespie algorithms for the simulation of markovian epidemic processes on large and heterogeneous networks," Computer Physics Communications, vol. 219, pp. 303–312, 2017.

[3] G. Ferraz de Arruda, A. Aleta, and Y. Moreno, "Contagion dynamics on higher-order networks", Nature Reviews Physics 6 (2024).

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