Enhanced Robustness of Evolving Open Systems by Bipartite Network Topology

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Many natural and man-made systems have bipartite network topology, such as plant-pollinator systems, the editor-article relationship in Wikipedia community, and the country-product network in world trades. All these systems evolve under successive introductions of new elements and deletions of resident ones. Systems sometimes can grow against such a big disturbance triggered by the introduction of new element, but some other times they go extinct. In the previous studies, it has been shown that the essential features of the stability of these evolving open systems can be well captured using a simple graph dynamics model [1, 2].

In this study, we report the reinforcement effect of bipartite network topology on the robustness of evolving open systems using a model with bipartite topology in which the species are grouped into two groups, α or β (Fig. 1A). When a new species i is introduced into the system, we randomly assign its type χ (i.e., α or β). Then we create m_χ new interactions with species randomly chosen from the other group. These interactions are represented by directed and weighted links. In this system, the survival of each species i is determined by its fitness f_i, calculated as the sum of the weights of its incoming links, defined as

$$f_i = \sum_{j}^{in} a_{ij}. \tag{1}$$

If species i has positive fitness $f_i > 0$, it survives in the system. On the other hand if $f_i \leq 0$, the species i and all interactions from and to it are removed. After removal, the fitness of other species is recalculated. This extinction process is repeated until all species have positive fitness. When the system reaches such a stable state, we introduce a new species and the extinction process continues. In this model, the growth behavior is determined by the initial degrees m_α and m_β. The system size of both the α and β groups can sometimes diverge (growing phase) and some other times they fluctuate within a finite range (finite phase), as shown in Fig. 1B.

We summarize the simulation results as a phase diagram in Fig. 1C. For the symmetric case ($m_\alpha = m_\beta = m$), the system can grow only within $5 \leq m \leq 18$ (along the diagonal in Fig. 1C). This result is consistent with that of the original non-structured model and confirms the mean-field prediction. For the asymmetric case $m_\alpha \neq m_\beta$, the mean-field argument yields that the bipartite system is more robust than the symmetric system and the non-bipartite system. As shown in Fig. 1C, the growing phase can be observed in the wider parameter range above $\frac{m_\alpha + m_\beta}{2} \geq m_c$, where $m_c (= 18.5)$ denotes the critical point in the symmetric system and the original non-structured model. Moreover, the system can grow even in the densely connected regions that exceed the upper limit for the reinforcement of asymmetry, $\min(m_\alpha, m_\beta) \leq m_c$, as predicted by the mean-field argument.

In this talk, we will discuss the origin and the basic mechanisms of the reinforcement effect of bipartite network topology on the robustness.

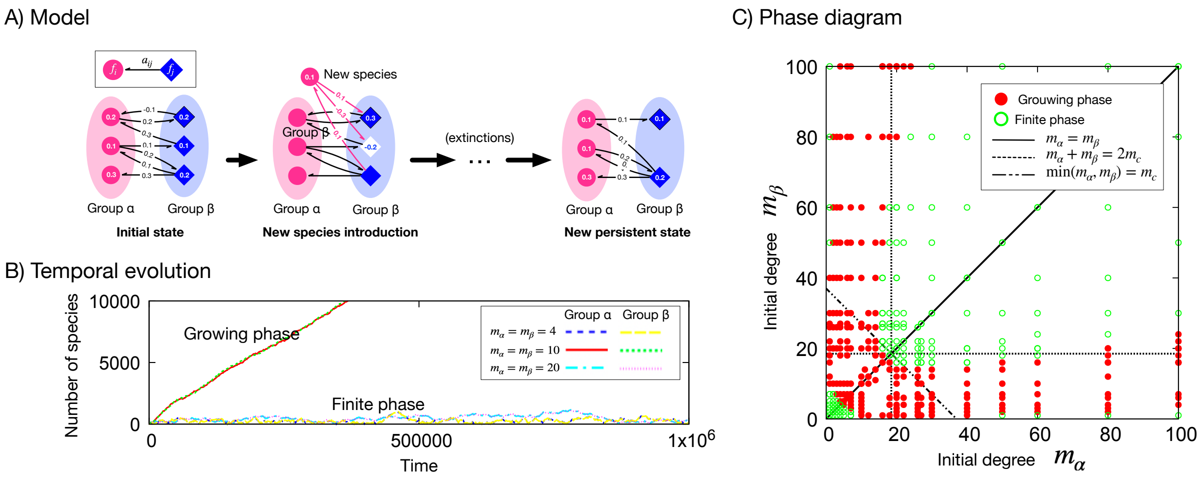

Figure 1: **Evolving open system with bipartite network topology.** (A) Temporal evolution of the bipartite model. (B) Temporal evolutions of total number of species in Group α and Group β. (C) Phase diagram as a function of the initial degrees of each group, m_α and m_β. Dotted and double-dotted lines are the upper and lower boundary estimate from the mean-field argument.

References

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