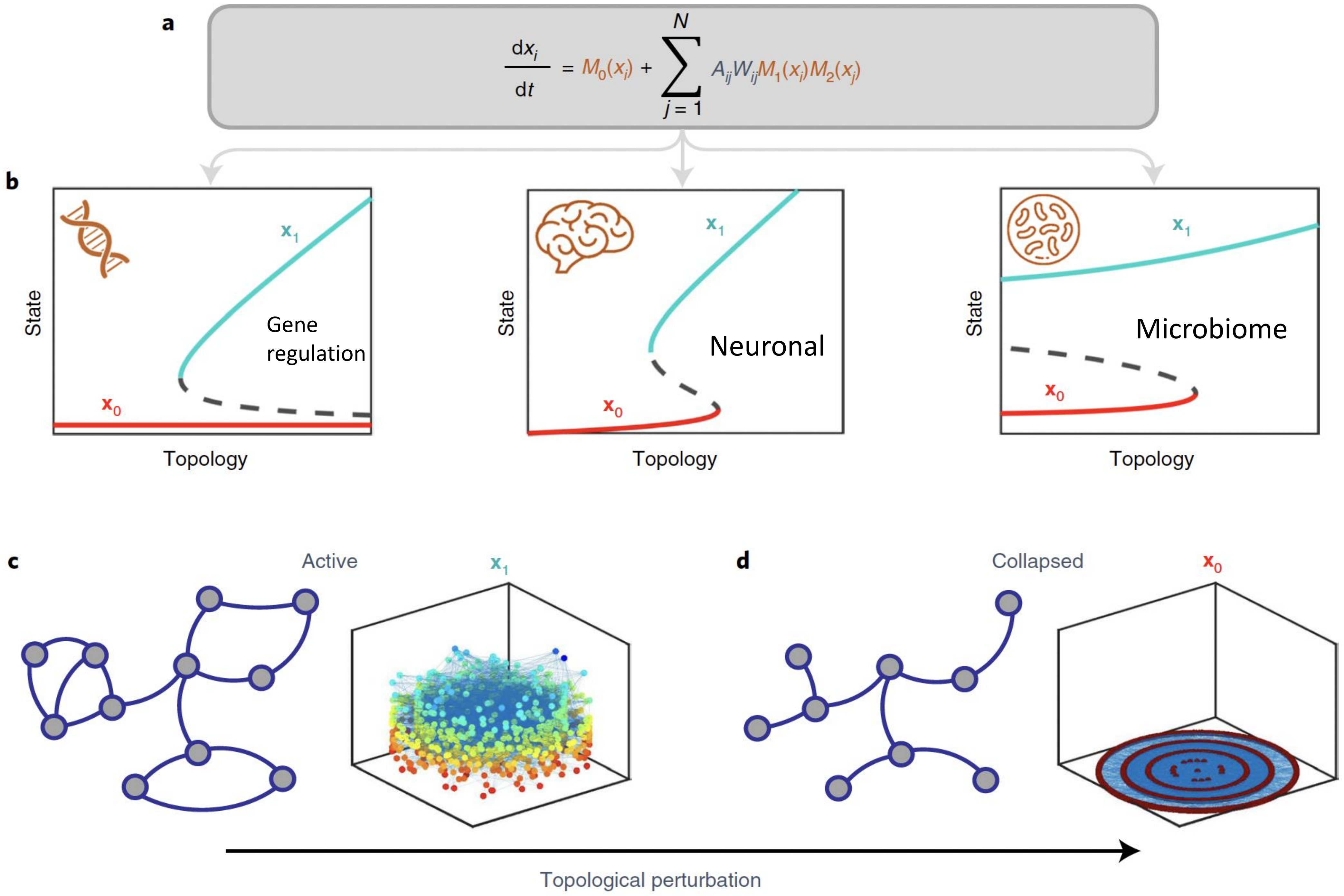
Network applications in physiology and biology

Shlomo Havlin
Bar-Ilan University
Usrael

[1] Reviving a failed network through microscopic interventions
Sanhedrai, J Gao, A Bashan, M Schwartz, S Havlin, B Barzel
Nature Physics 18 (3), 338-349 (2022)
[2] Sustaining a network by controlling a fraction of nodes. H Sanhedrai, S Havlin
arXiv preprint arXiv:2205.13377 (2022)
[3] Connectivity of EEG synchronization networks increases for Parkinson's disease patients with freezing of gait
E. Asher, R. Bartcsh, S. Havlin et al
Communications Biology 4 (1), 1-10 (2022)—By Ronny Bartsch on Tuesday
[4] Brain dynamic network during rest and personal performance
Shu Guo et al, In preparation, 2022

Reviving a failed network

Sanhedrai et al Nature Physics, 18, 338 (2022)


a
$$\frac{dx_i}{dt} = M_0(x_i) + \sum_{j=1}^{N} A_{ij} W_{ij} M_1(x_i) M_2(x_j)$$
b
State
Topology
x_1
x_0
Gene regulation
Neuronal
Microbiome
c
Active
d
Collapsed
Topological perturbation

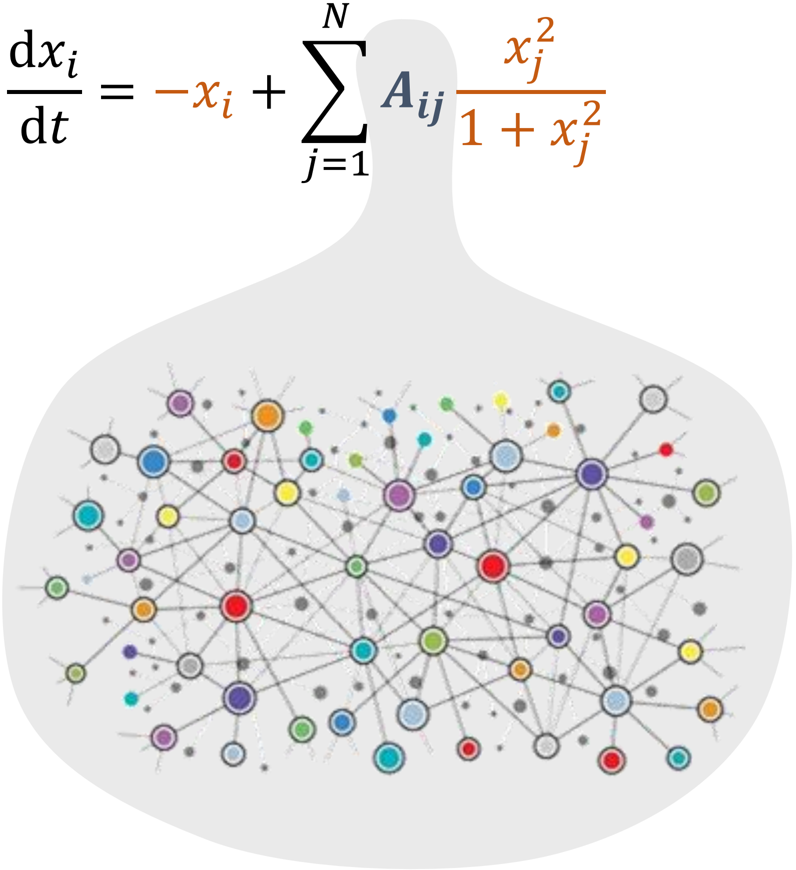
Example: Gene regulation

Michaelis-Menten (MM) Model for subcellular dynamics

$$\frac{\mathrm{d}x_i}{\mathrm{d}t} = -x_i + \sum_{j=1}^{N} A_{ij} \frac{x_j^2}{1 + x_j^2}$$

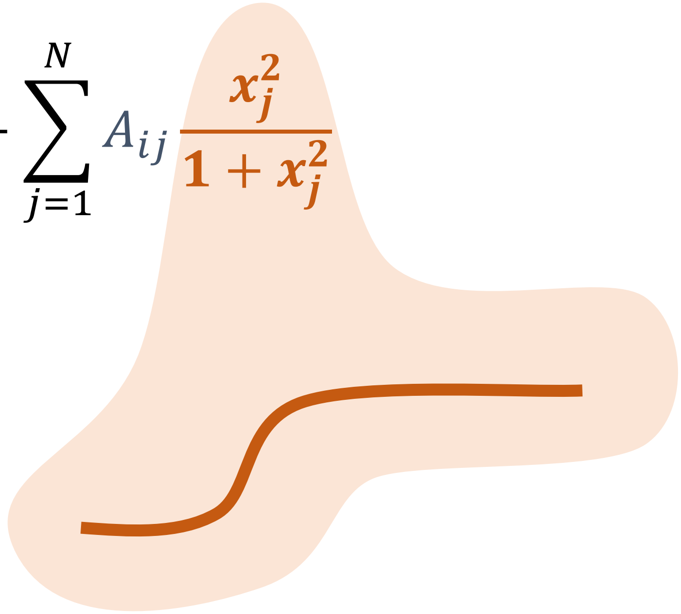
Example: Gene regulation

$$\frac{\mathrm{d}x_i}{\mathrm{d}t} = -x_i + \sum_{j=1}^{N} A_{ij} \frac{x_j^2}{1 + x_j^2}$$



Example: Gene regulation

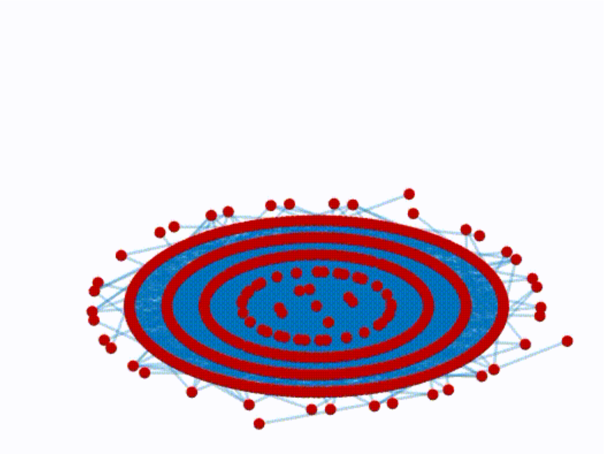
$$\frac{\mathrm{d}x_i}{\mathrm{d}t} = -x_i + \sum_{j=1}^{N} A_{ij} \frac{\boldsymbol{x_j^2}}{\boldsymbol{1 + x_j^2}}$$



Example: Gene regulation

$$\frac{\mathrm{d}x_i}{\mathrm{d}t} = -x_i + \sum_{j=1}^{N} A_{ij} \frac{x_j^2}{1 + x_j^2}$$

High initial conditions



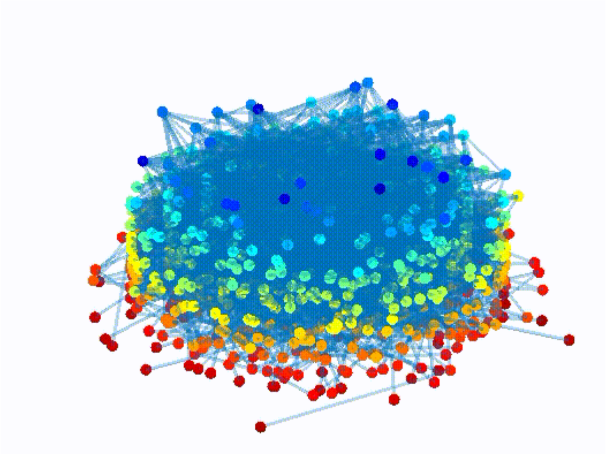
Low initial conditions

Bi-stability

Example: Gene regulation

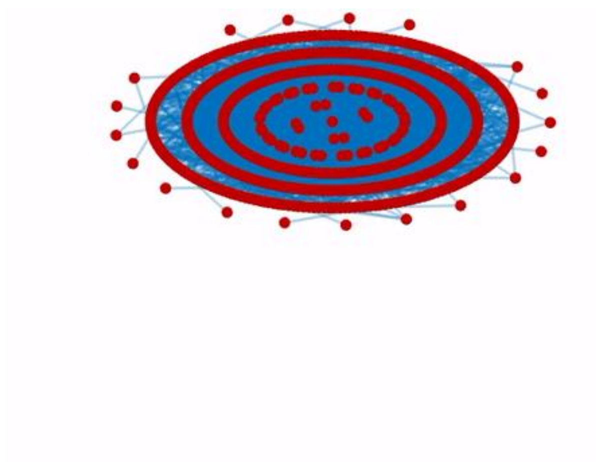
$$\frac{\mathrm{d}x_i}{\mathrm{d}t} = -x_i + \sum_{j=1}^{N} A_{ij} \frac{x_j^2}{1 + x_j^2}$$

High initial conditions



Bi-stability

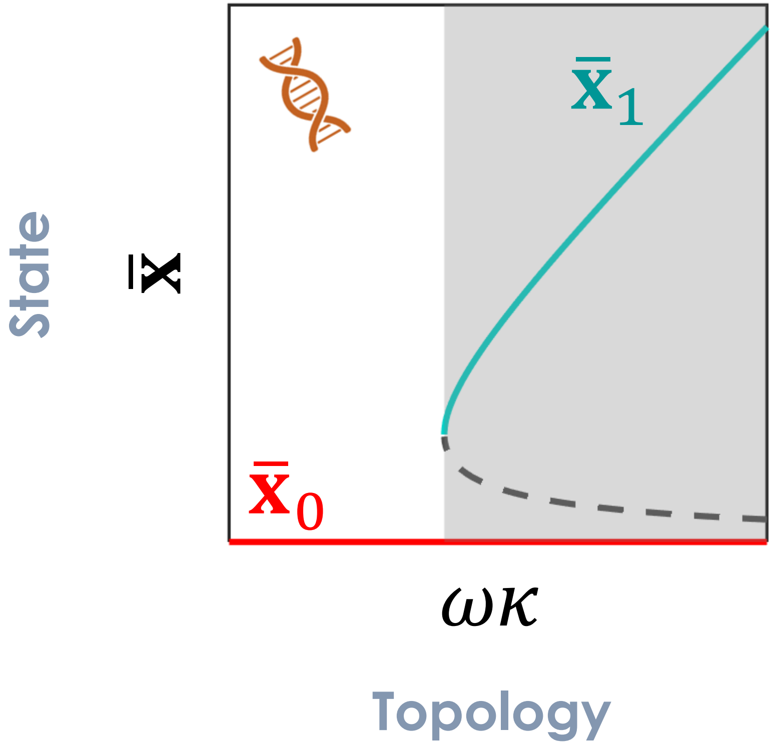
Low initial conditions

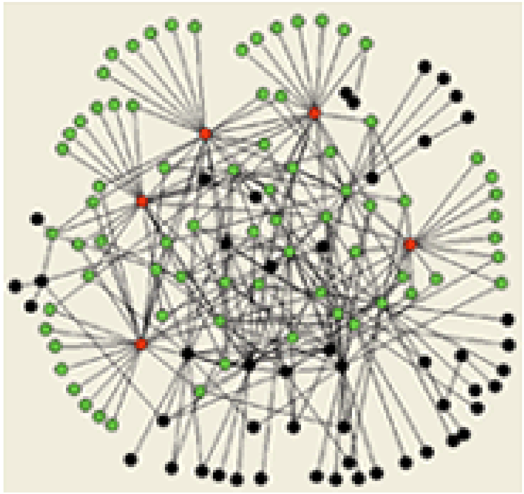


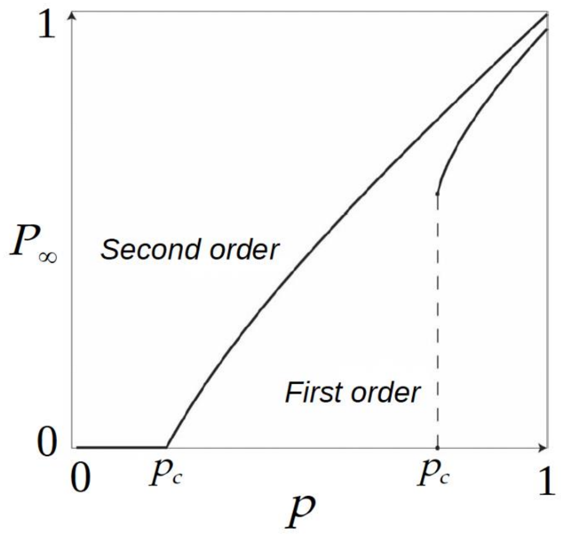
Dynamic phase diagram

$$A_{ij} = \omega$$

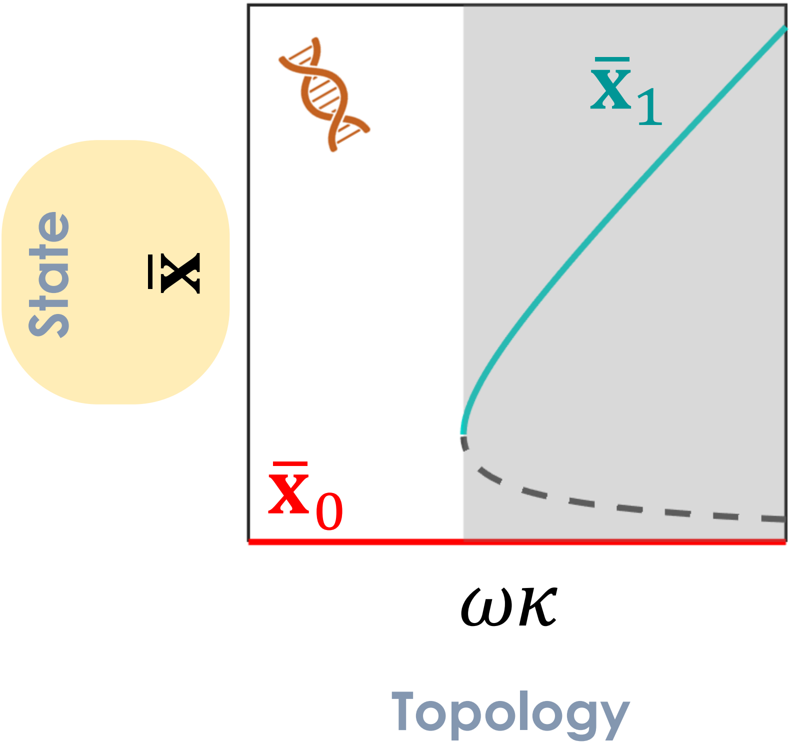
κ=<k^2>/<k>-1



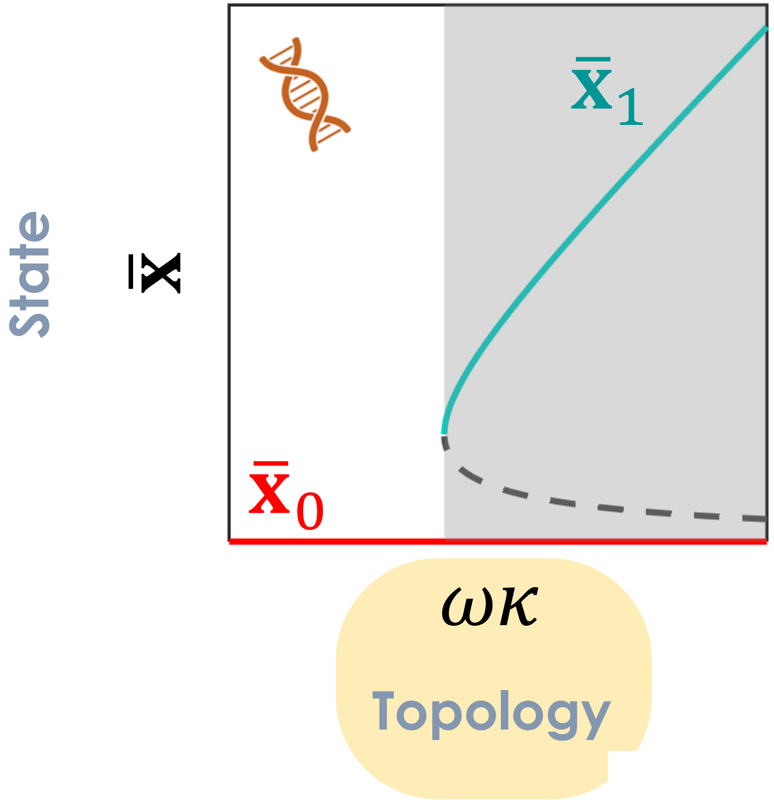




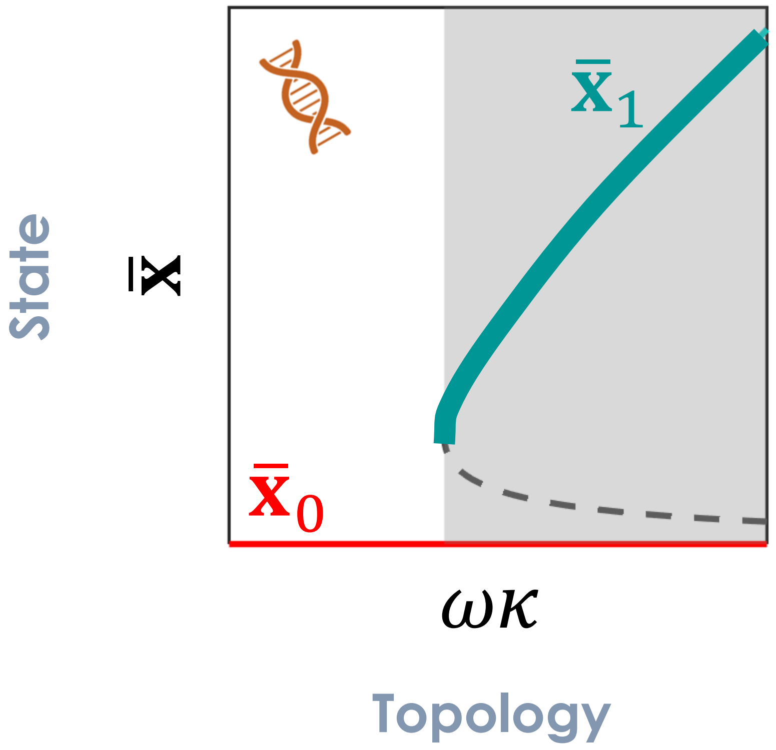
Dynamic phase diagram



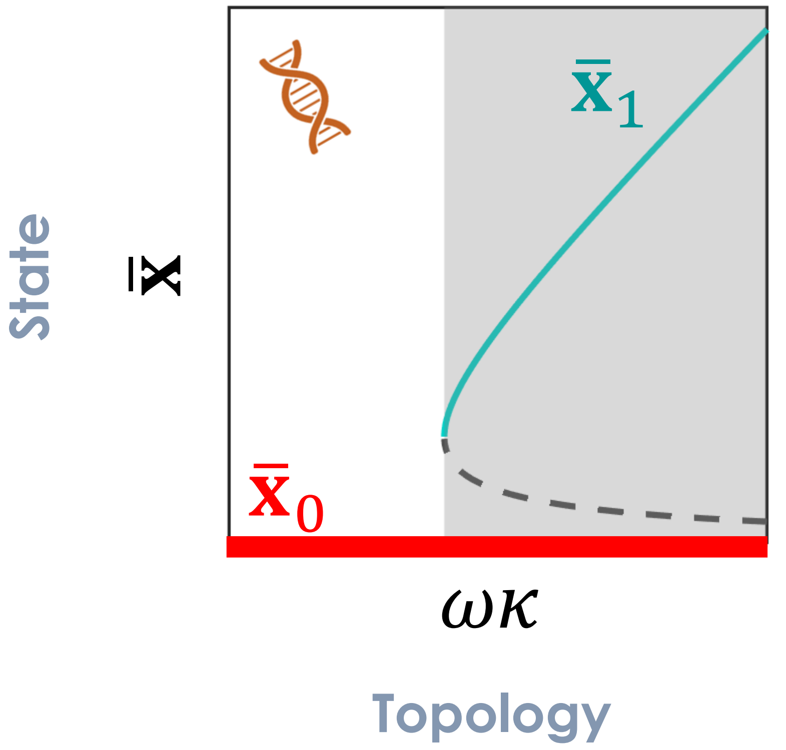
Dynamic phase diagram



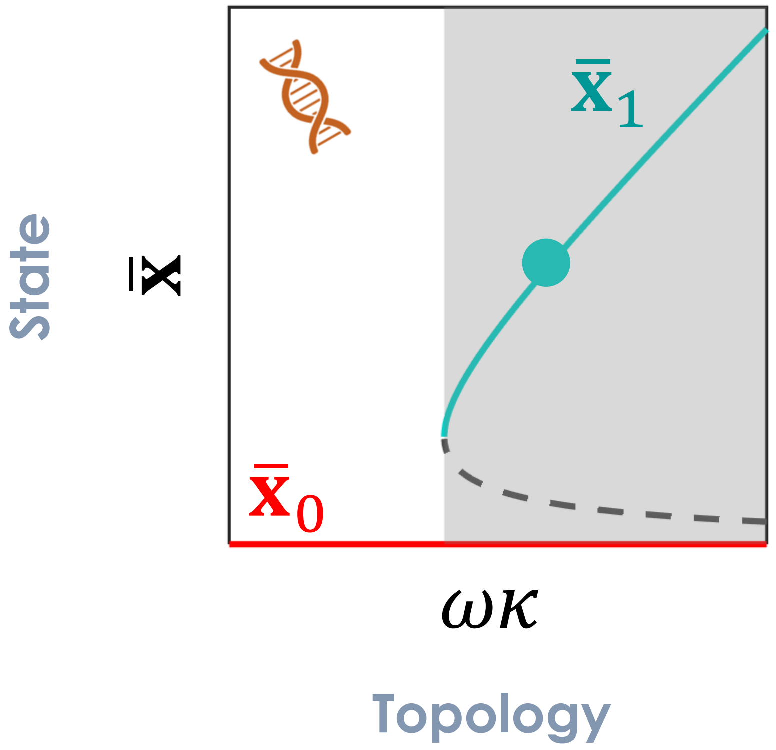
Dynamic phase diagram

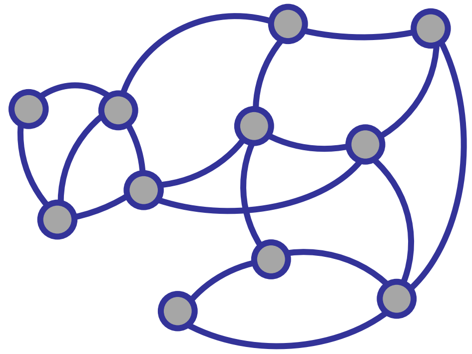


Dynamic phase diagram



Failure of a network





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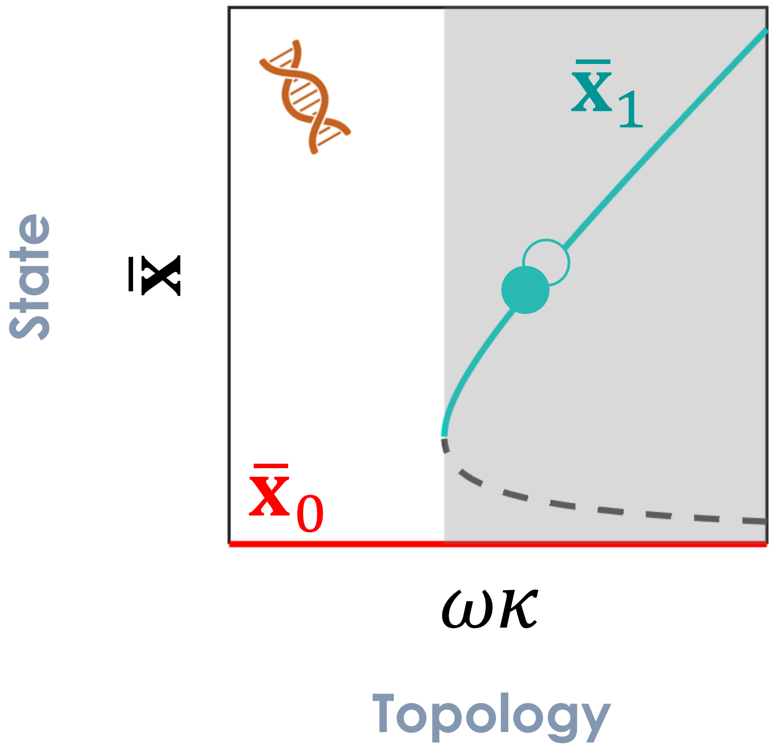

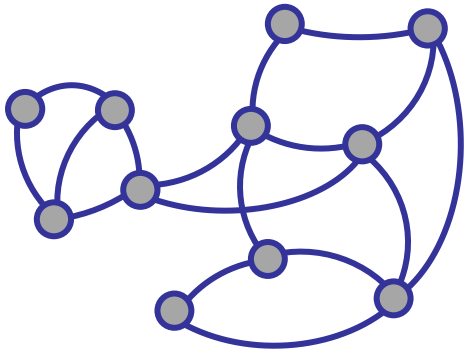

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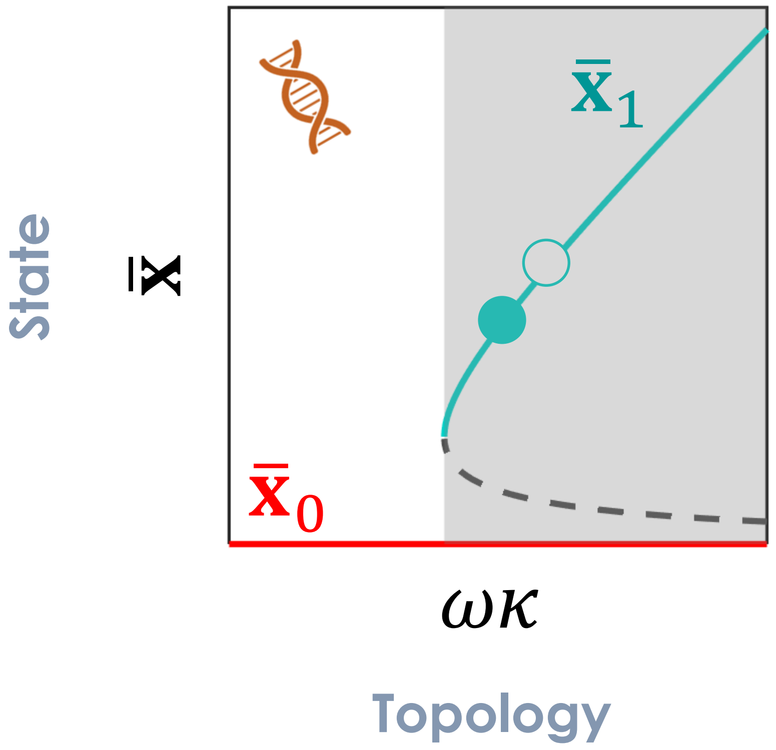

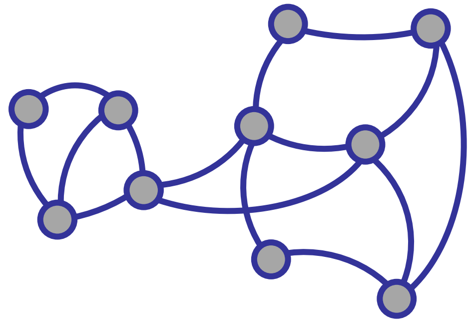

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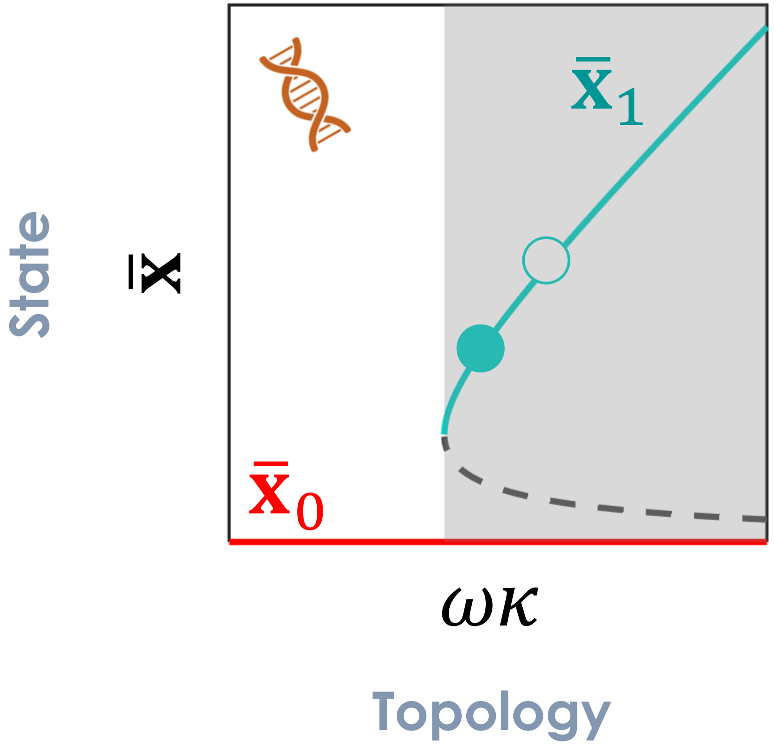

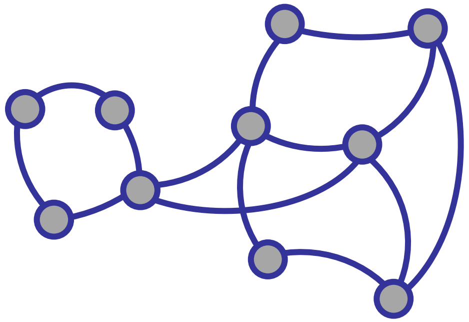

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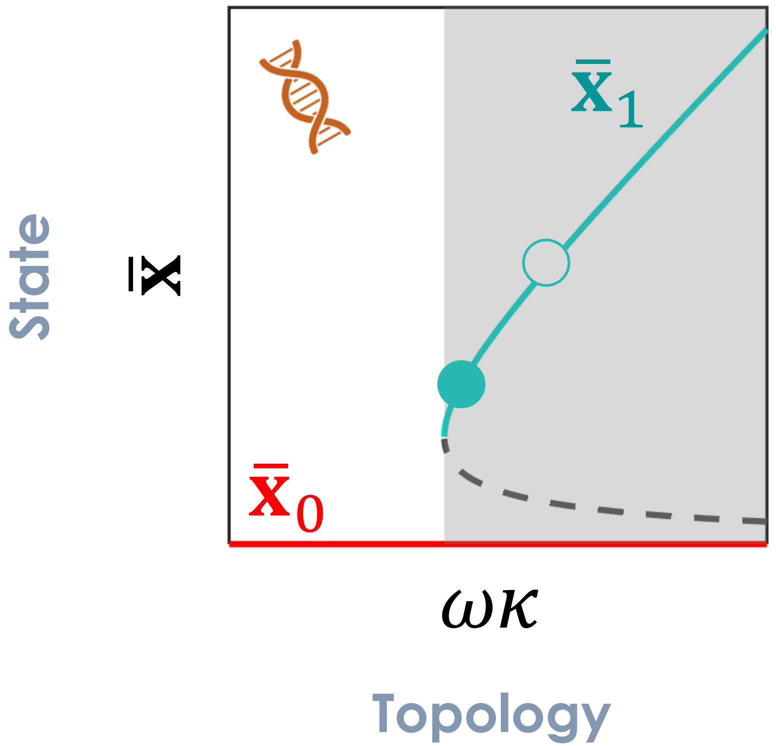

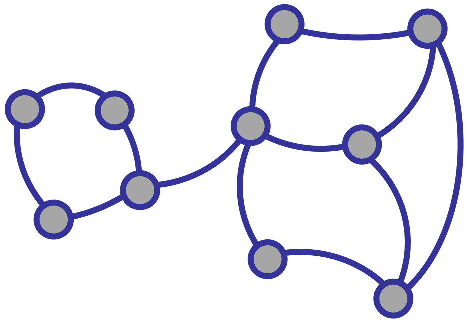

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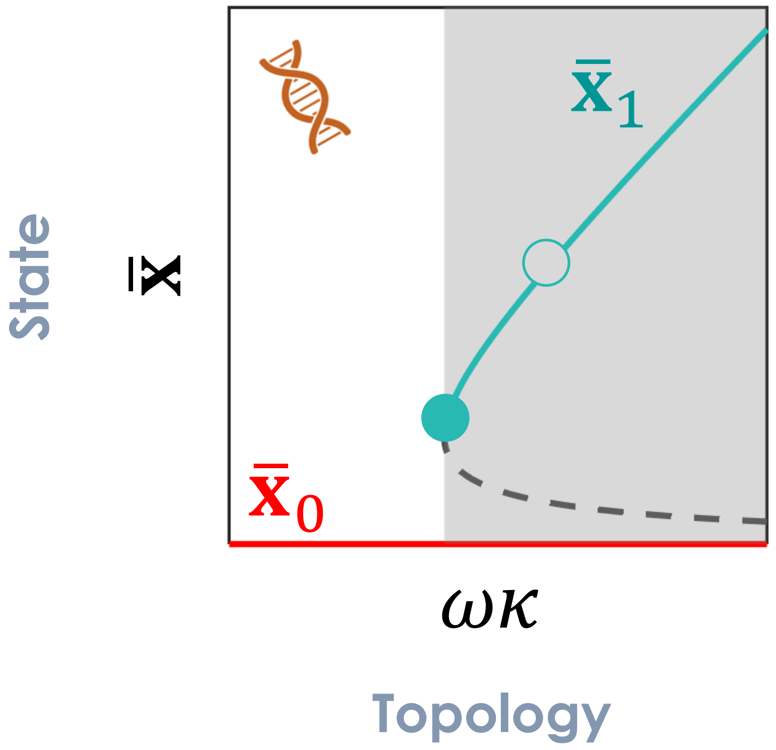

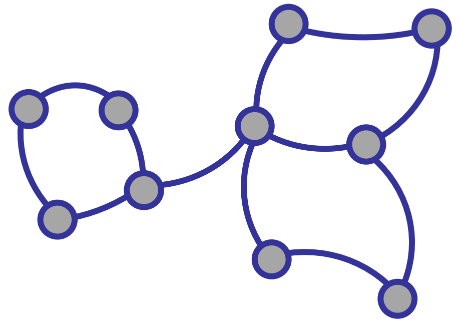

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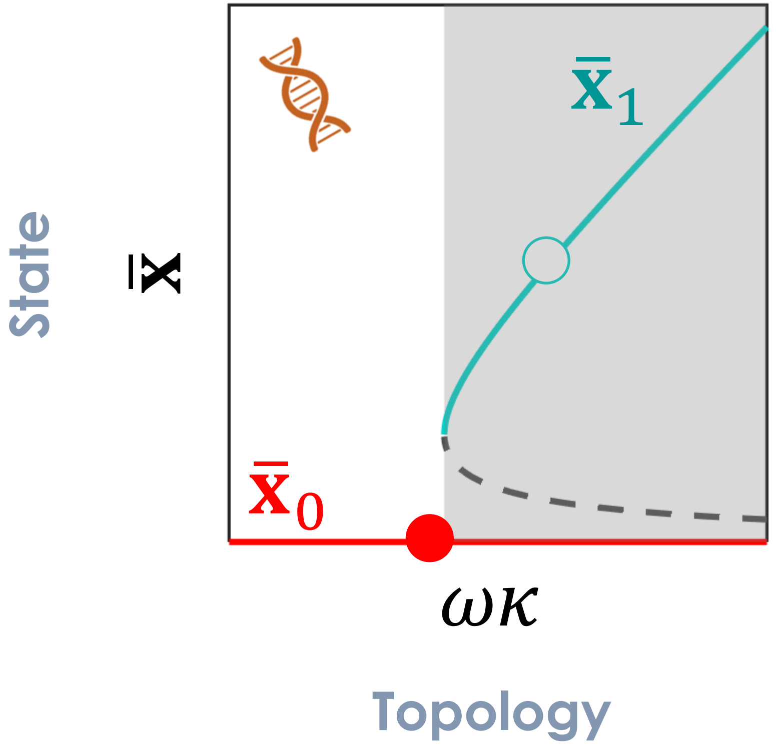

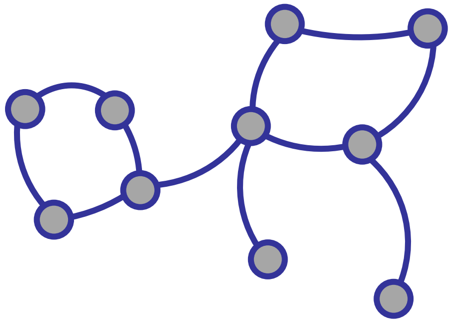

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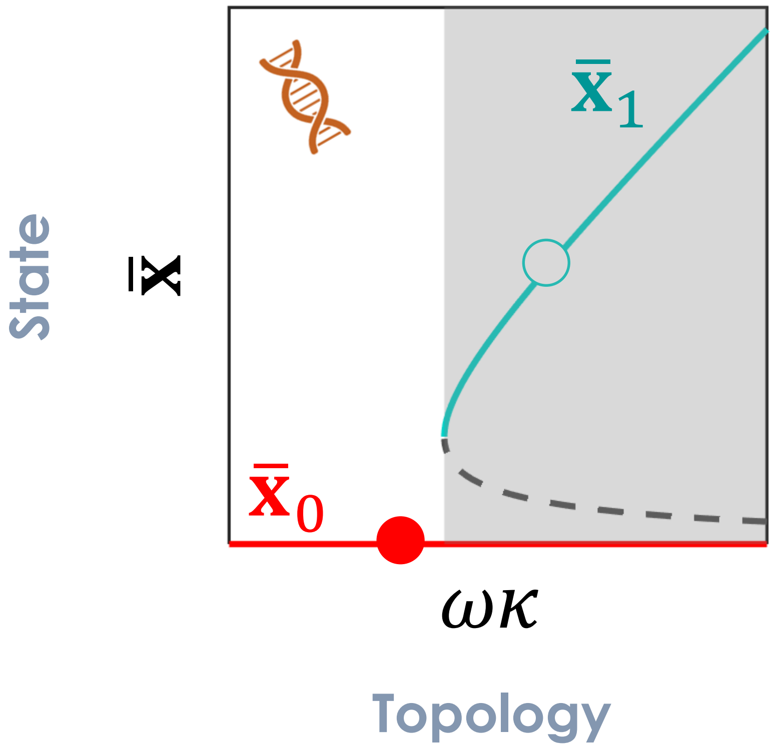

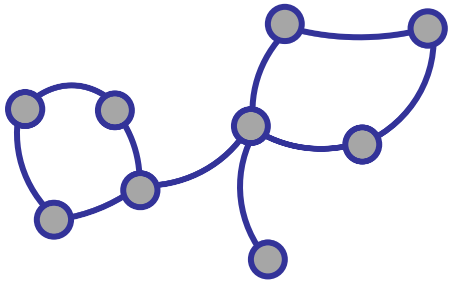

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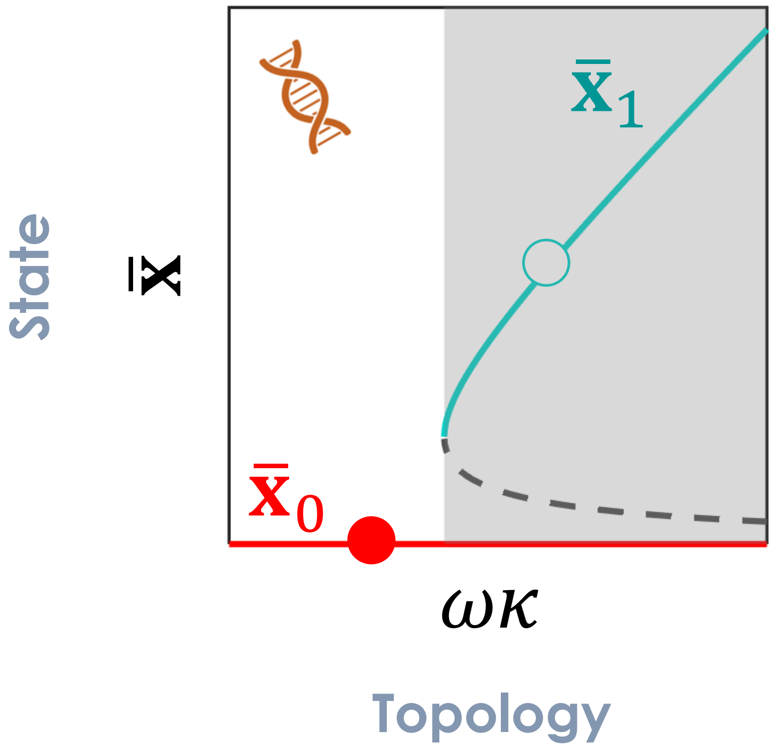
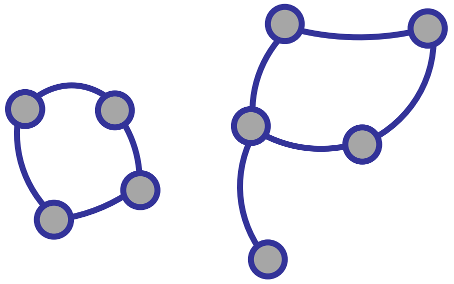
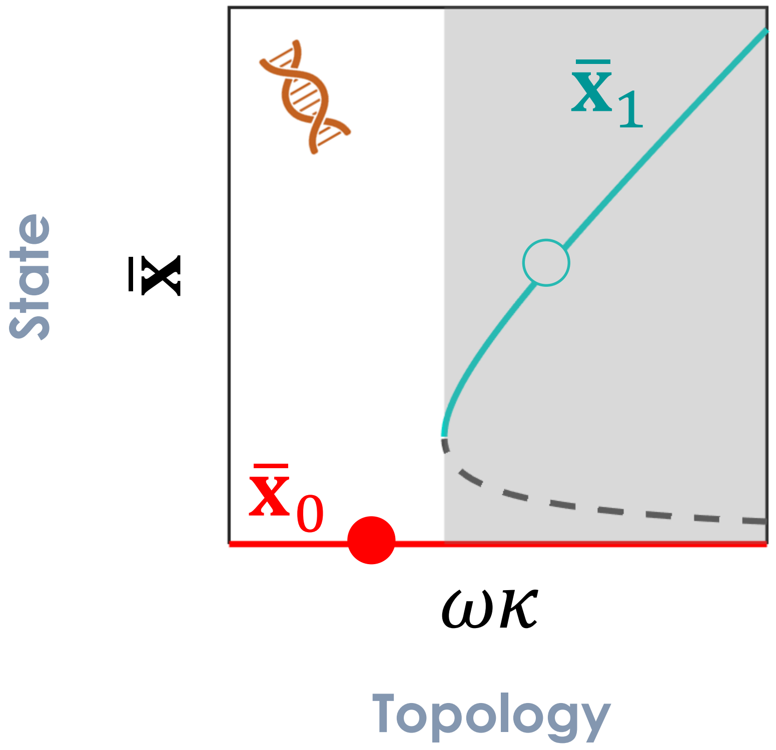
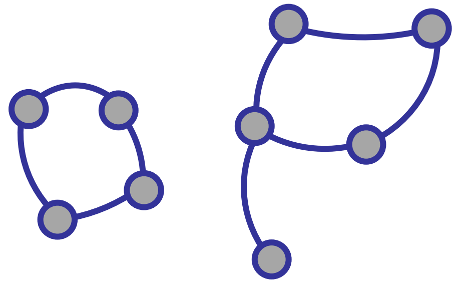




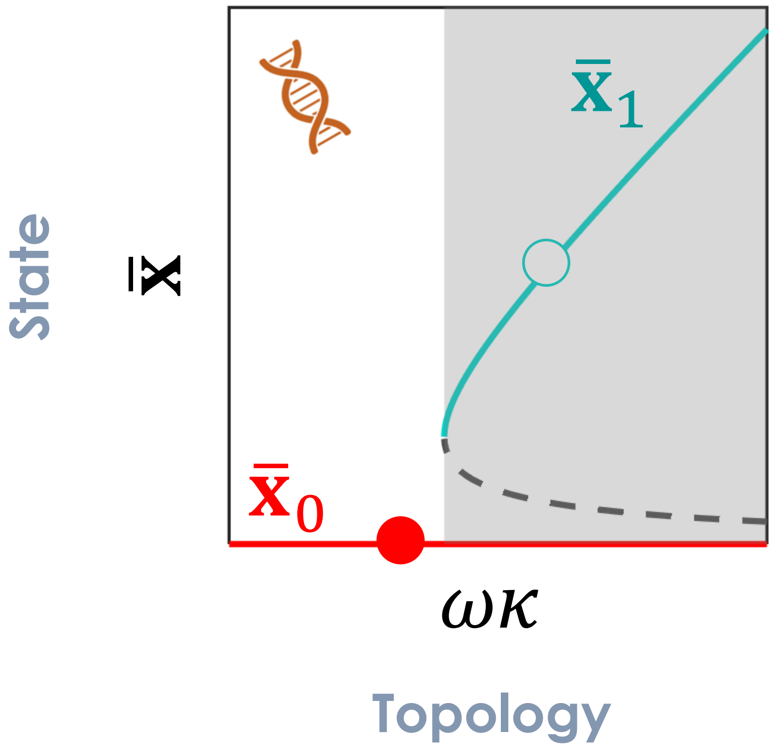
Failure of a network

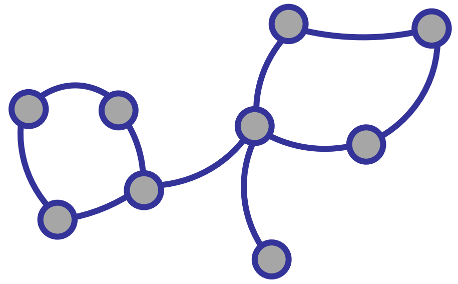
How can we revive it?





Restructuring the network





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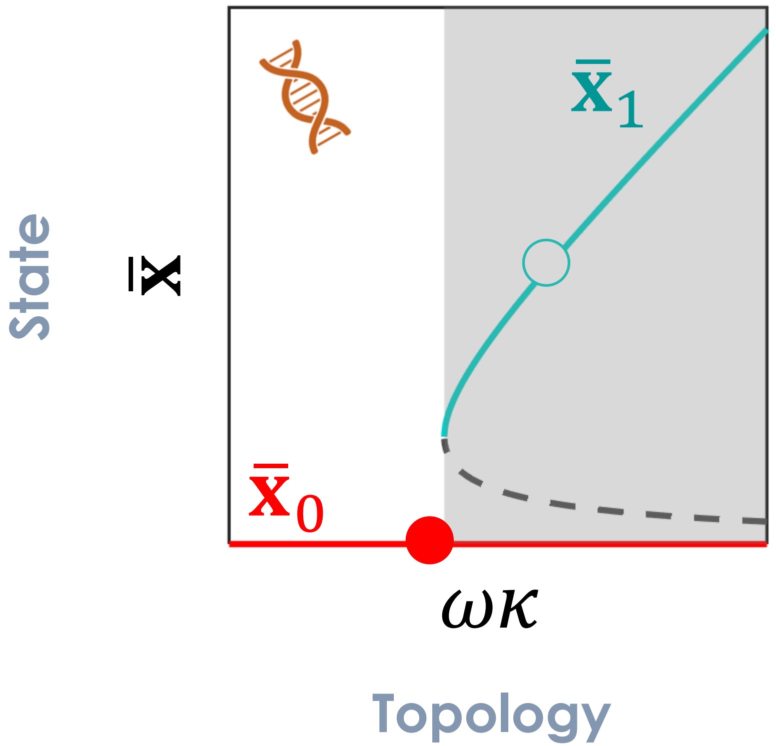

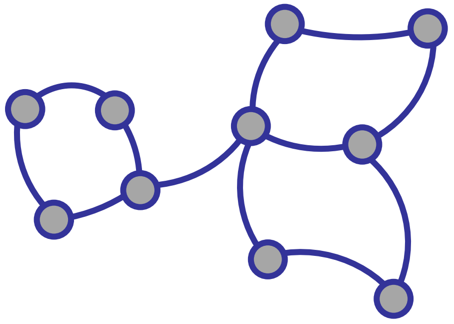

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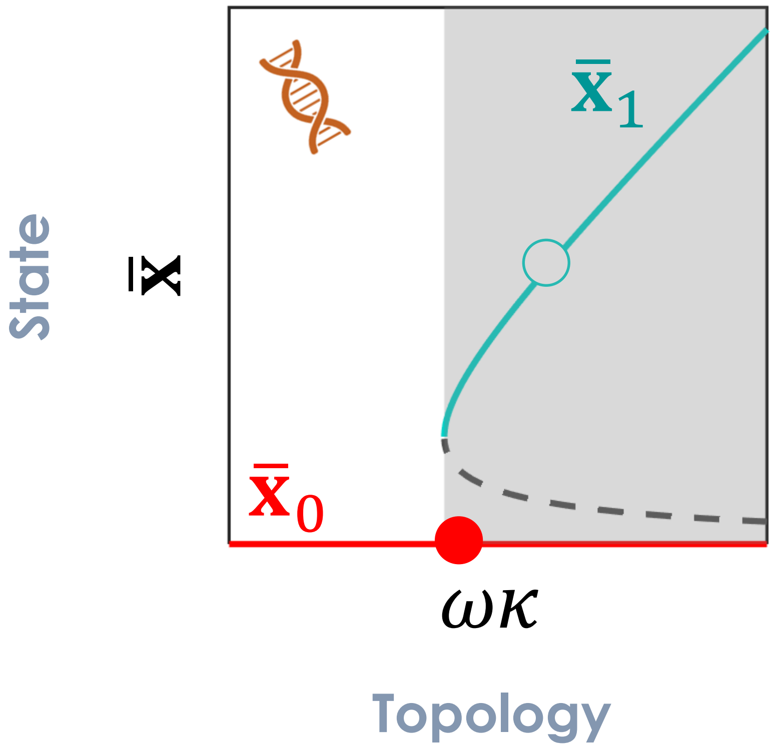

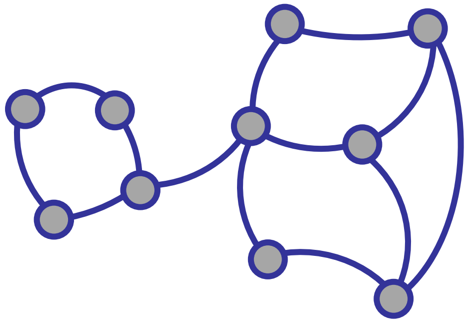

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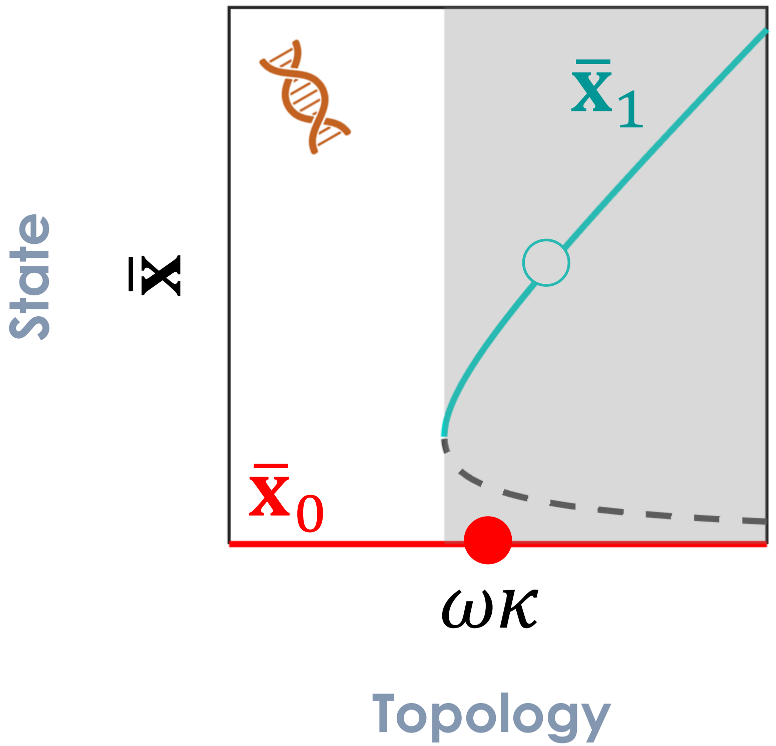

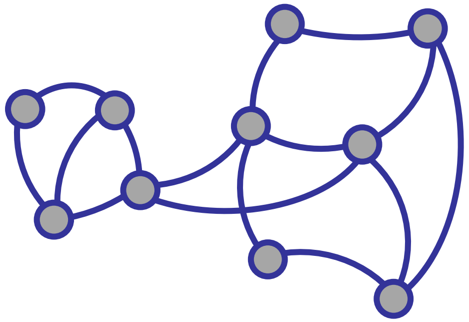

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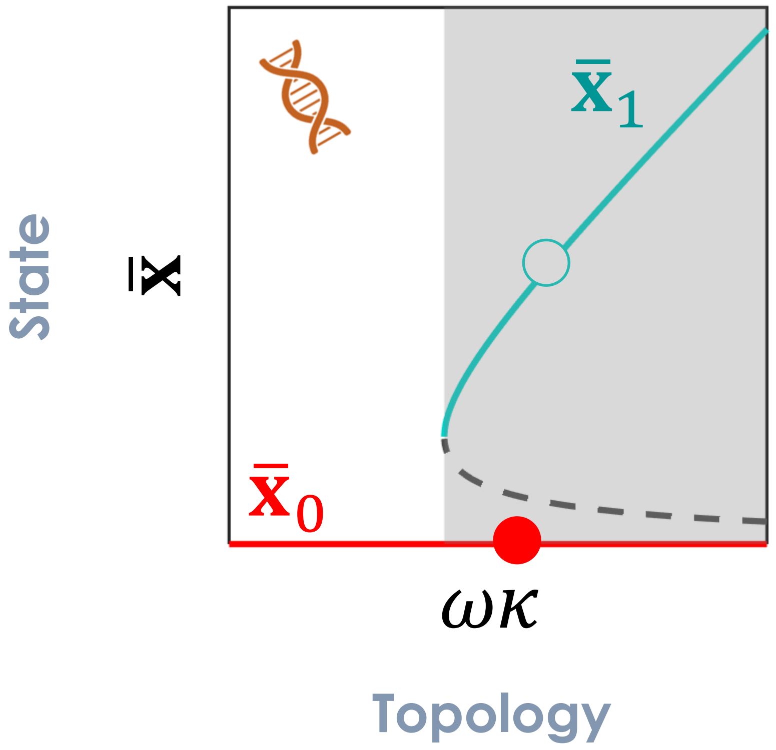

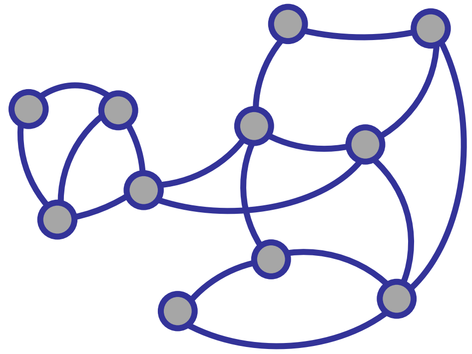

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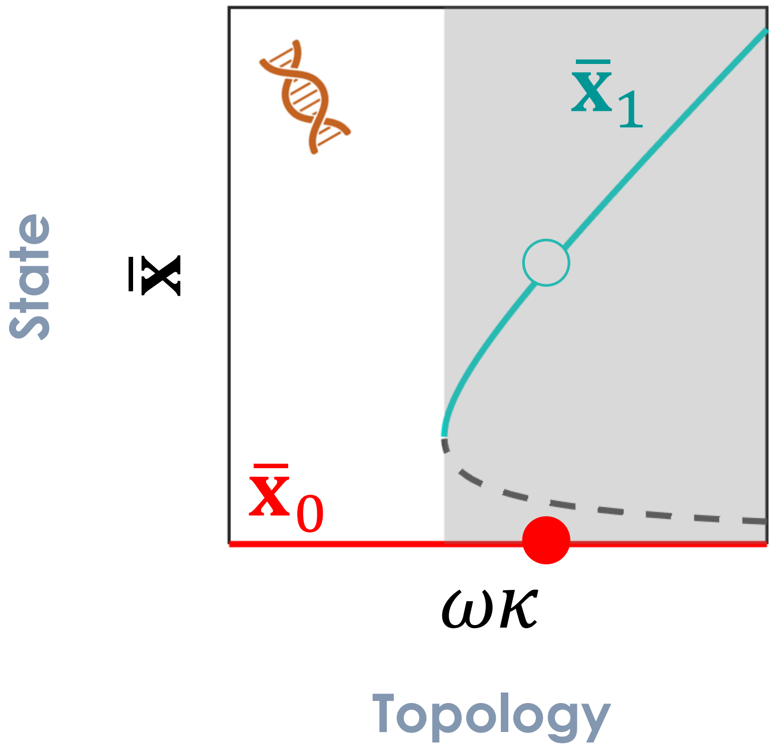
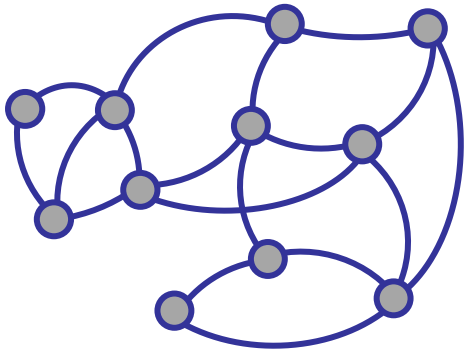
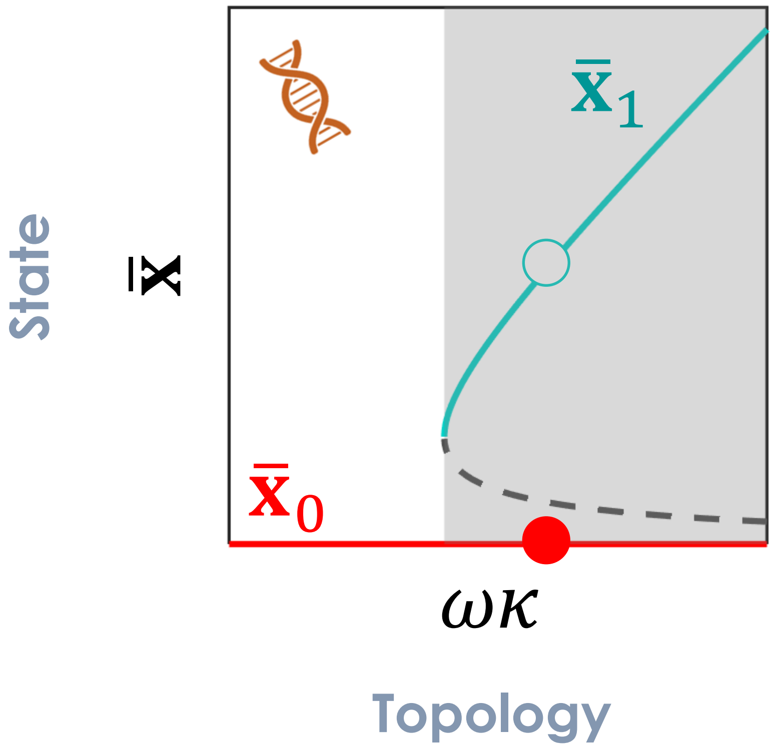
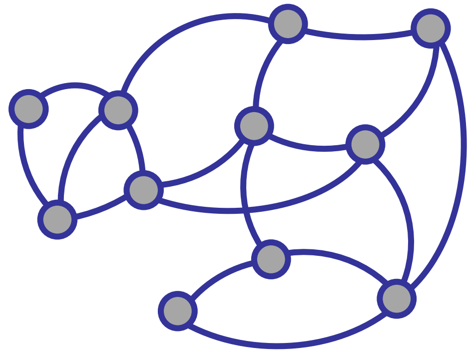




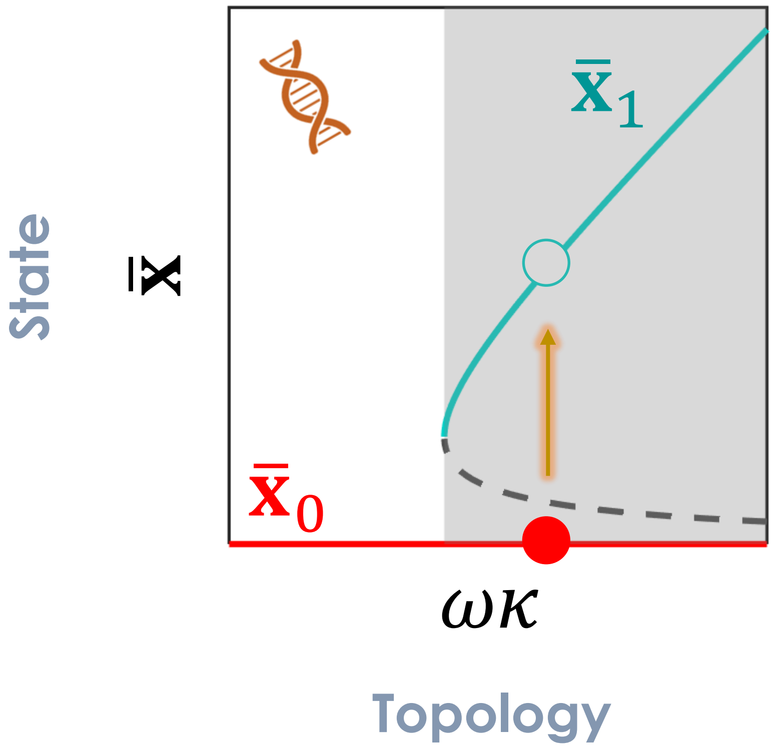
Restructuring the network

How can we revive it?



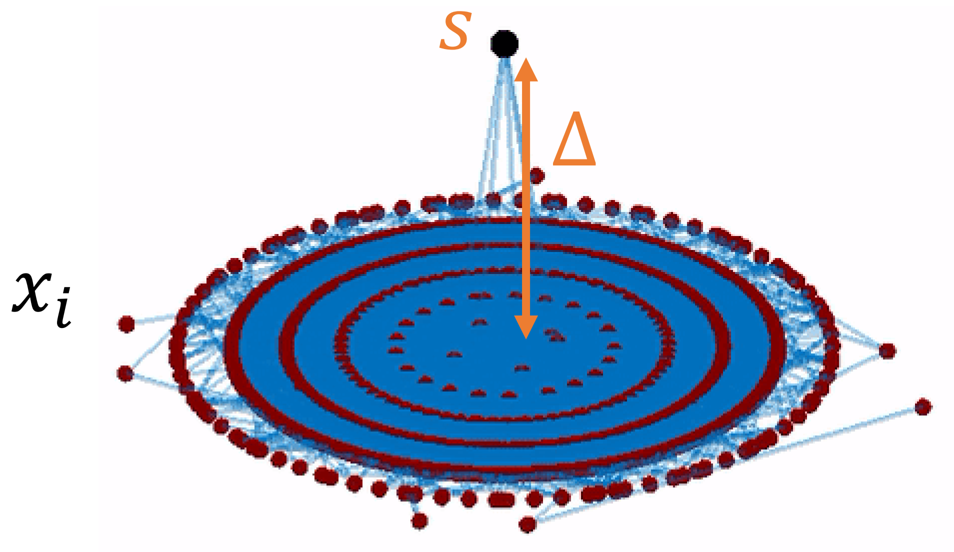


Reigniting the dynamics



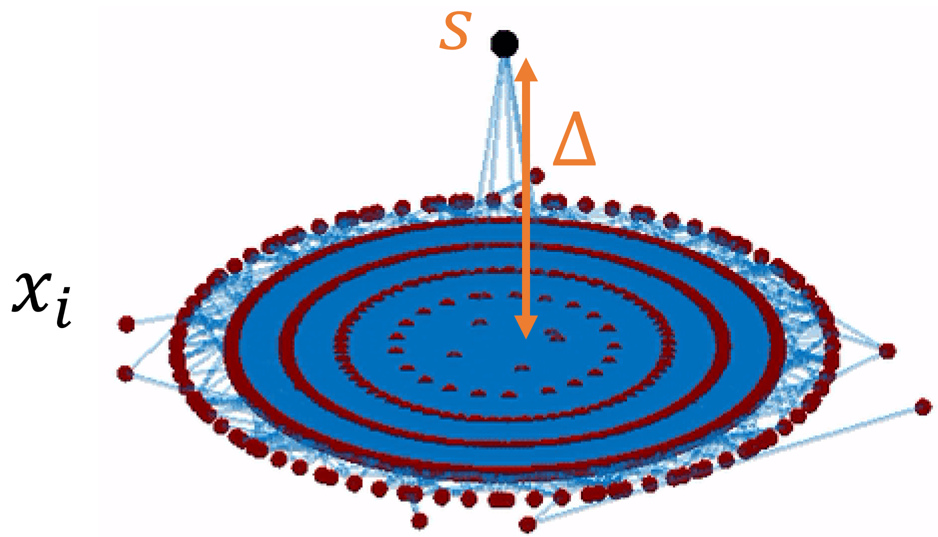
Can we revive the system by controlling just a single node?

Single-node reigniting

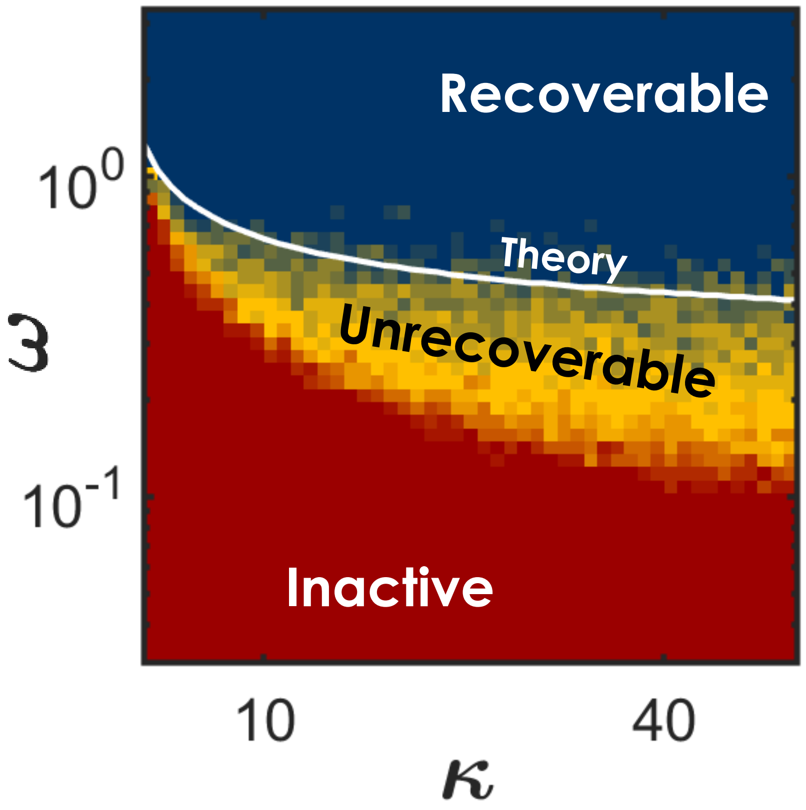


Single-node reigniting

$$\begin{cases} x_s(t) = \Delta \\ \dfrac{\mathrm{d}x_i}{\mathrm{d}t} = -x_i + \displaystyle\sum_{j=1}^{N} A_{ij} \frac{x_j^2}{1 + x_j^2}, \qquad i \neq s \end{cases}$$

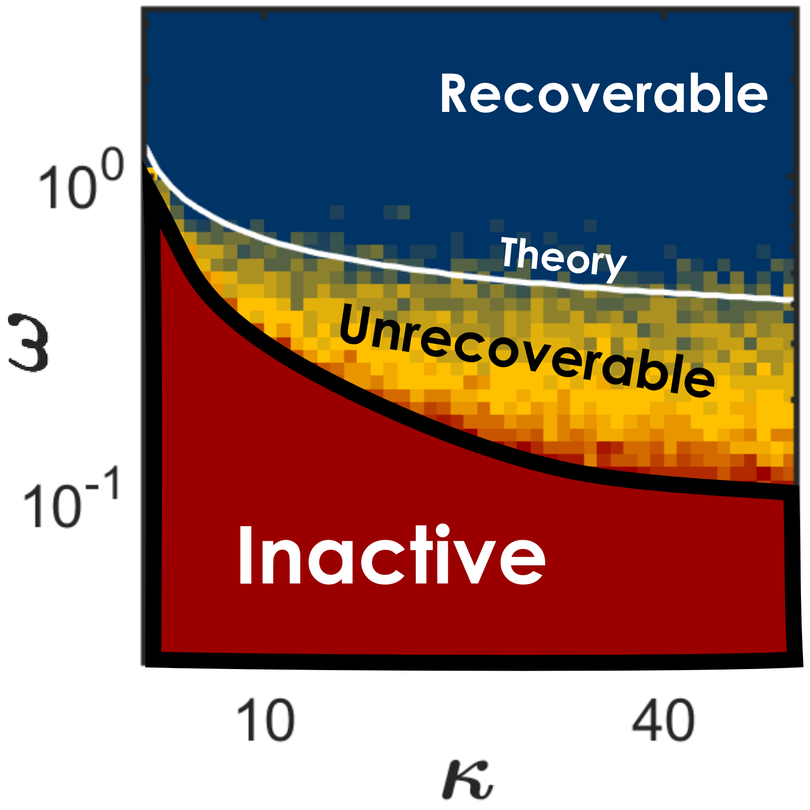


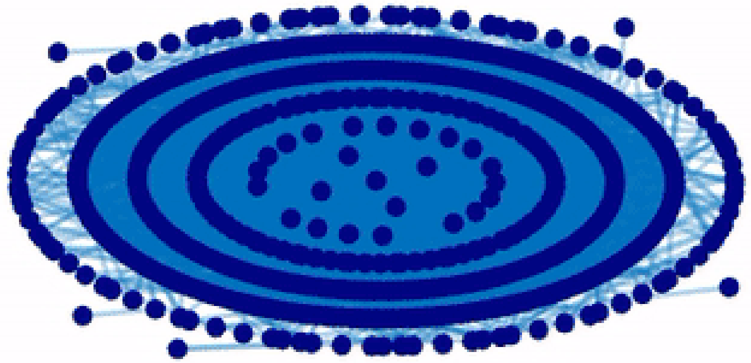
Recoverability phase diagram



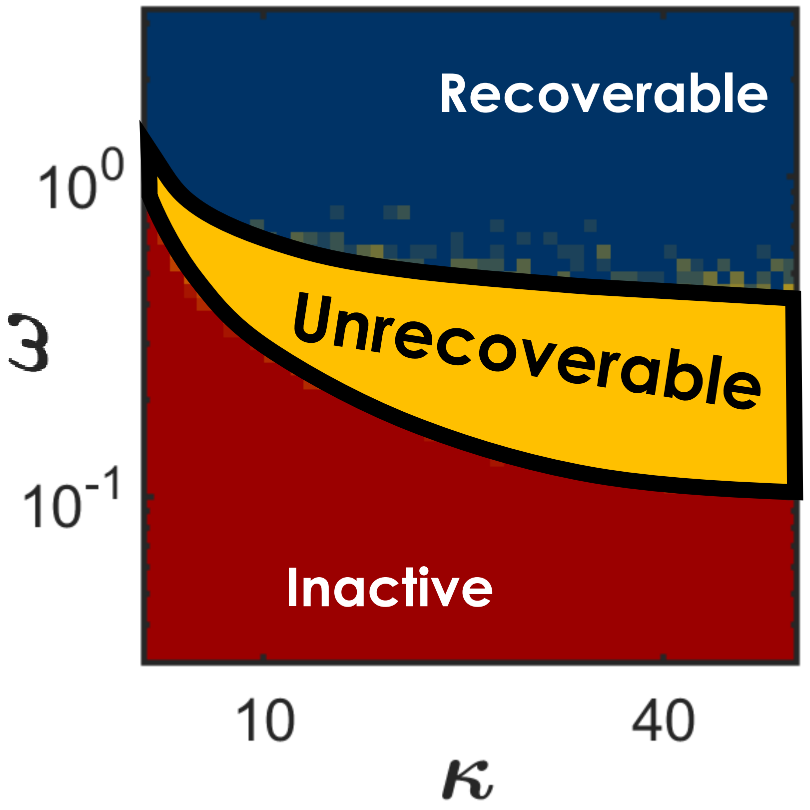
$A_{ij} = \omega$ κ=<k^2>/<k>-1

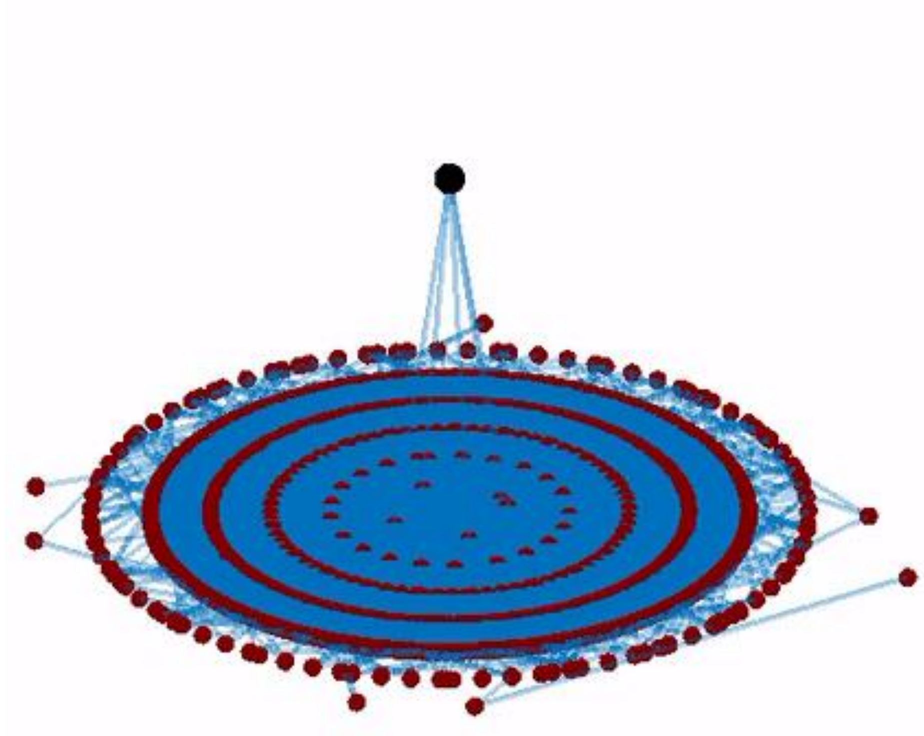
Recoverability phase diagram



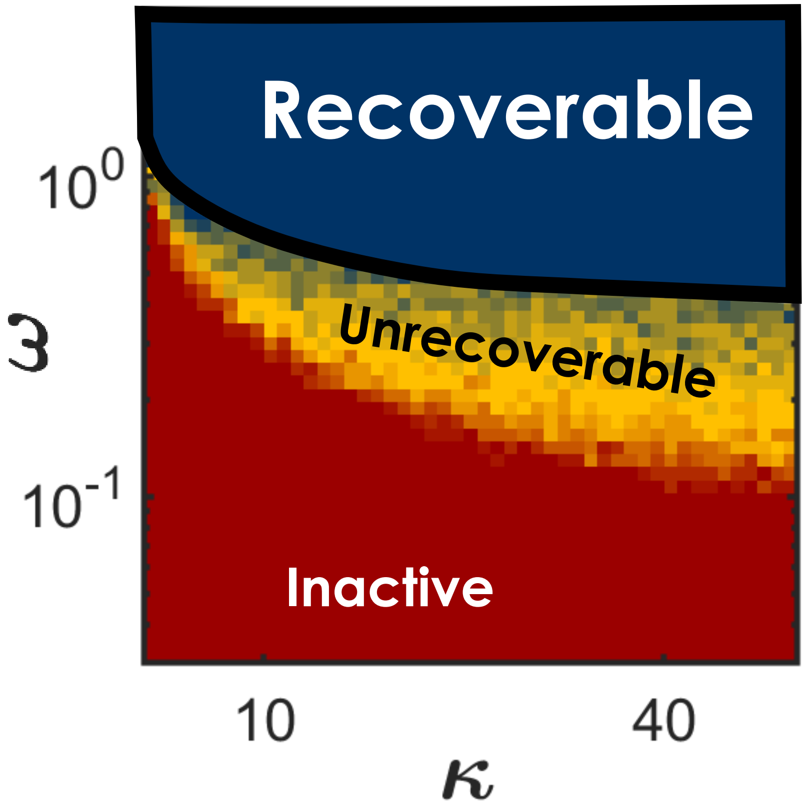


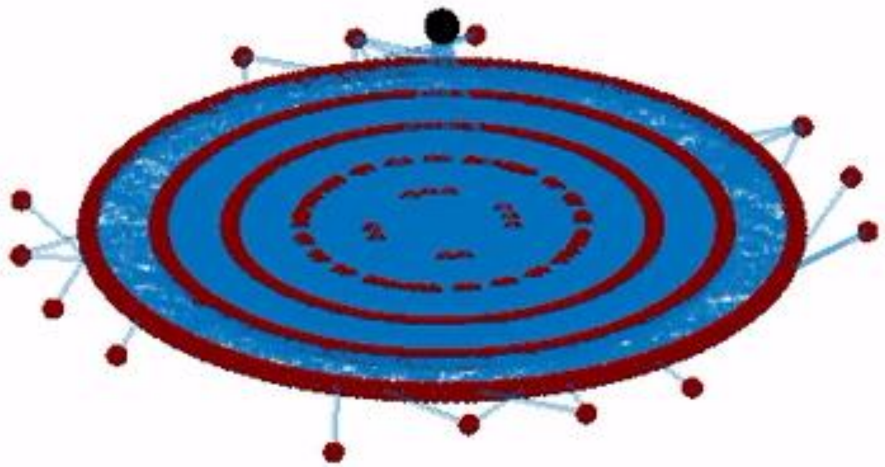
Recoverability phase diagram



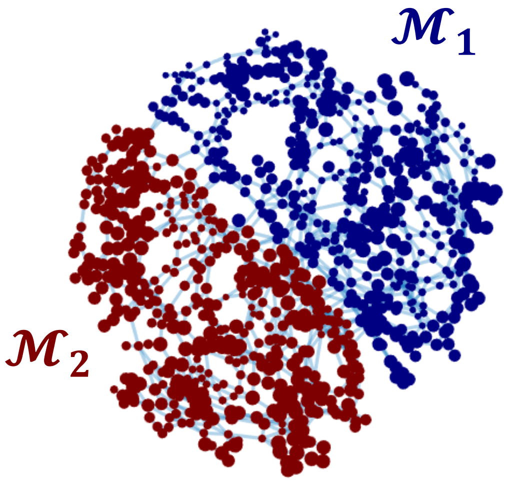


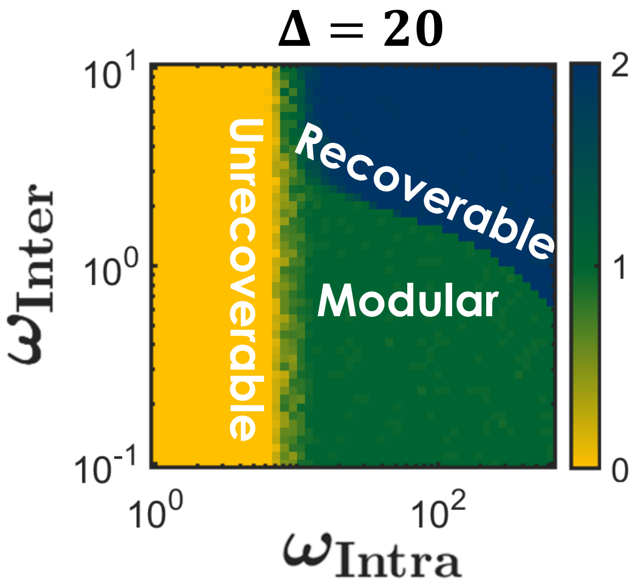
Recoverability phase diagram





Modular networks - Brain





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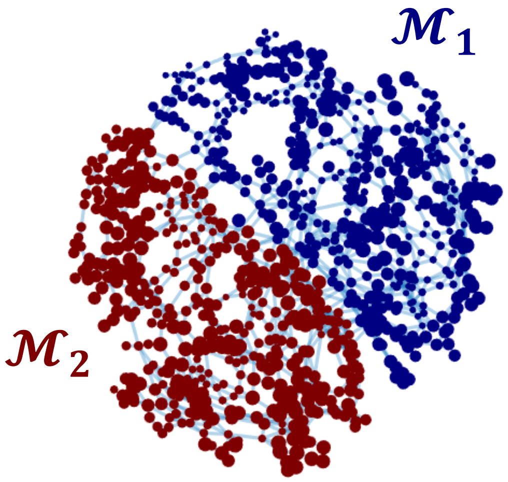
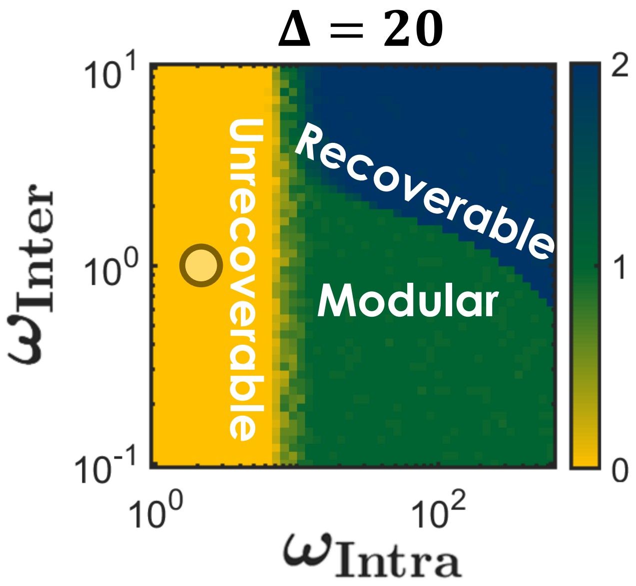
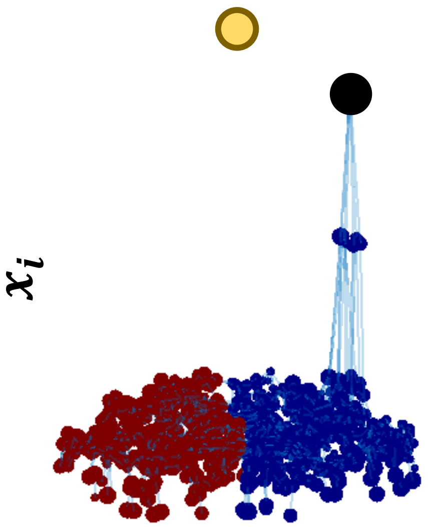






Gut-microbiome

We suggest which species are good candidates to revive the whole gut-microbiome system through probiotics

nature physics

ARTICLES

https://doi.org/10.1038/s41567-021-01474-y

Check for updates

Reviving a failed network through microscopic interventions

Hillel Sanhedrai[1], Jianxi Gao[2,3], Amir Bashan[1], Moshe Schwartz[4], Shlomo Havlin[1] and Baruch Barzel[5,6] ✉

From mass extinction to cell death, complex networked systems often exhibit abrupt dynamic transitions between desirable and undesirable states. These transitions are often caused by topological perturbations (such as node or link removal, or decreasing link strengths). The problem is that reversing the topological damage, namely, retrieving lost nodes or links or reinforcing weakened interactions, does not guarantee spontaneous recovery to the desired functional state. Indeed, many of the relevant systems exhibit a hysteresis phenomenon, remaining in the dysfunctional state, despite reconstructing their damaged topology. To address this challenge, we develop a two-step recovery scheme: first, topological reconstruction to the point where the system can be revived and then dynamic interventions to reignite the system's lost functionality. By applying this method to a

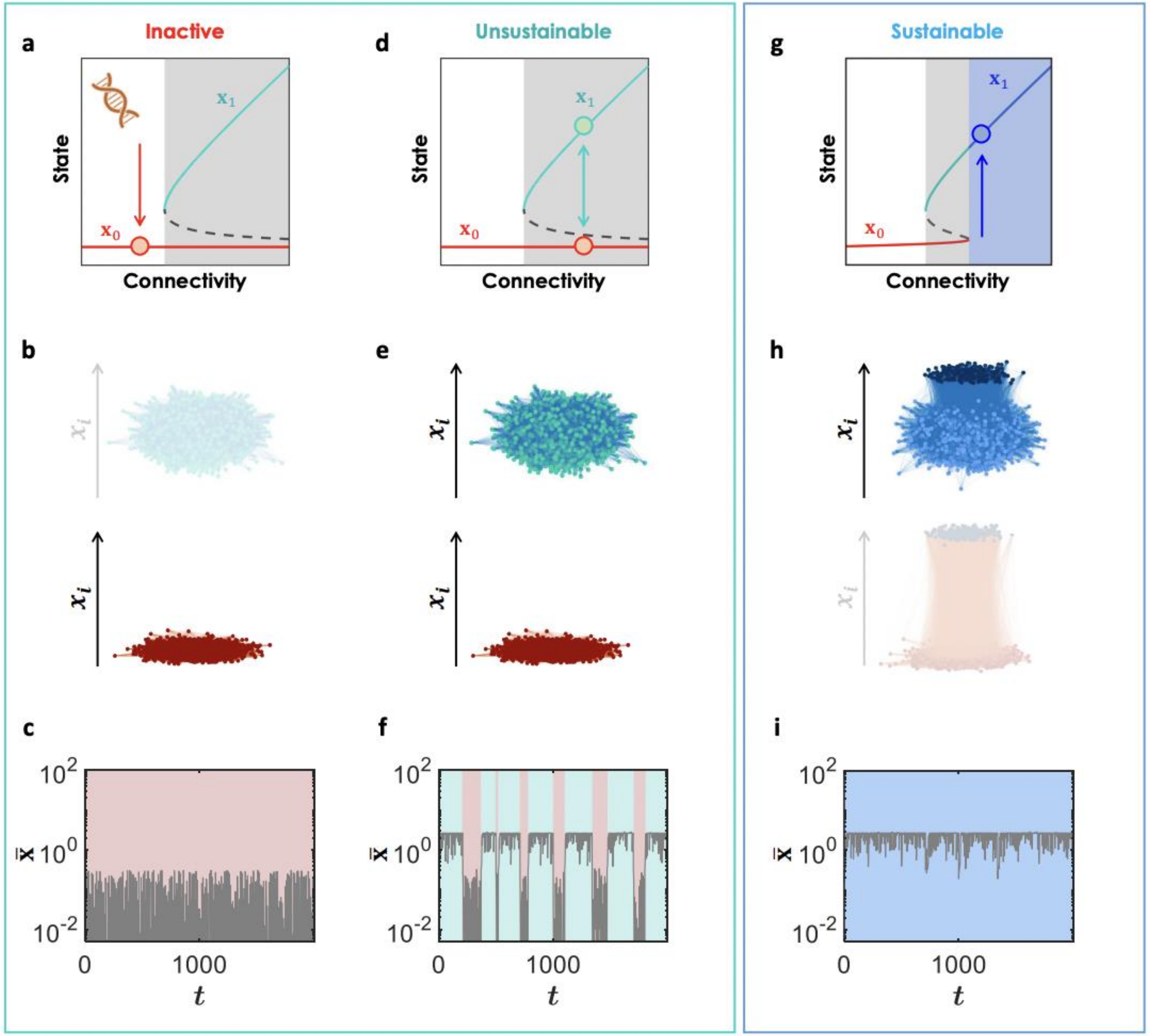
Sustaining **a network by controlling a fraction of nodes**

Sanhedrai et al arXiv:2205.13377 (2022)

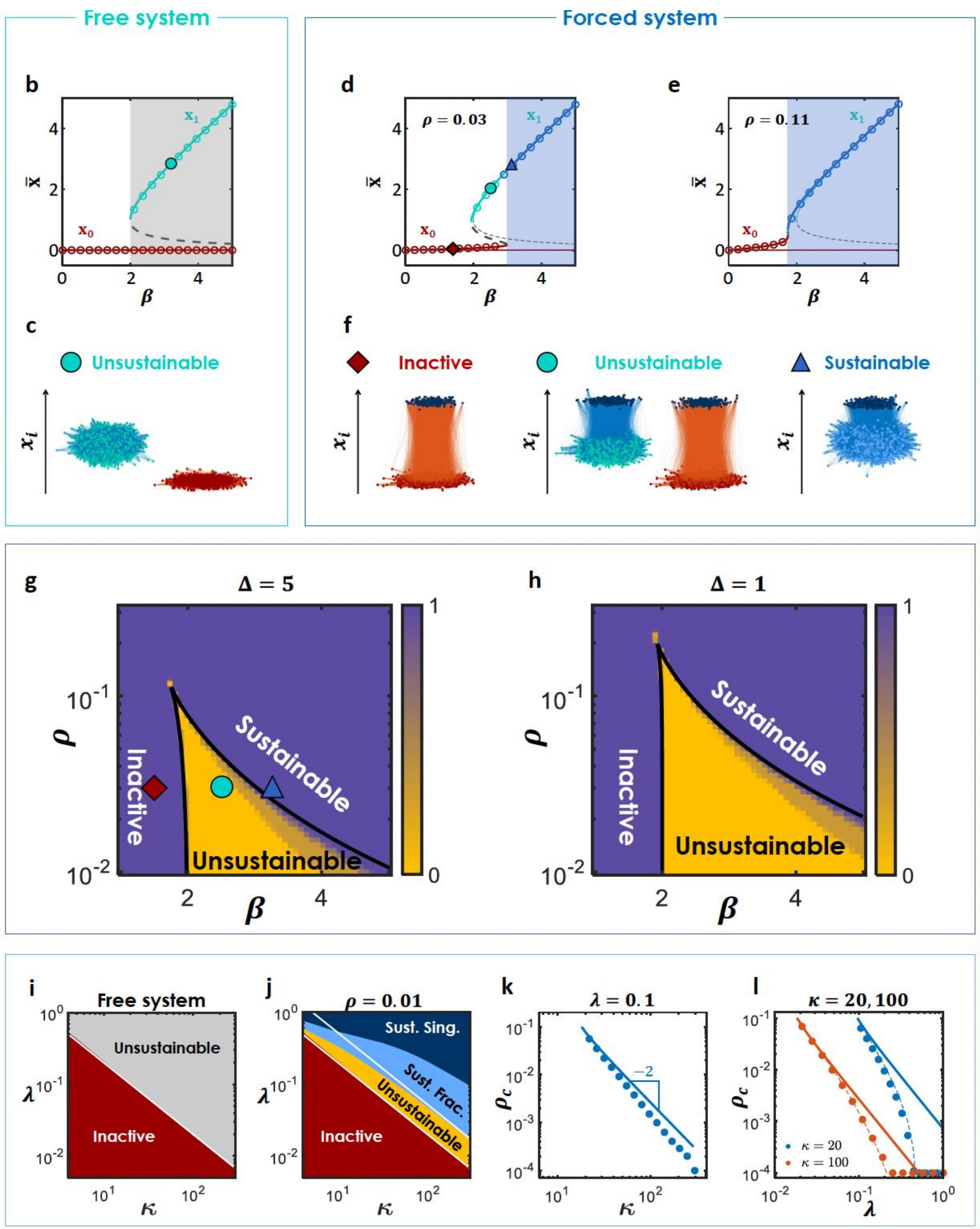
Sustaining Dynamics on Networks

$$\frac{\mathrm{d}x_i}{\mathrm{d}t} = M_0(x_i) + \lambda \sum_{j=1}^{N} A_{ij} M_1(x_i) M_2(x_j)$$

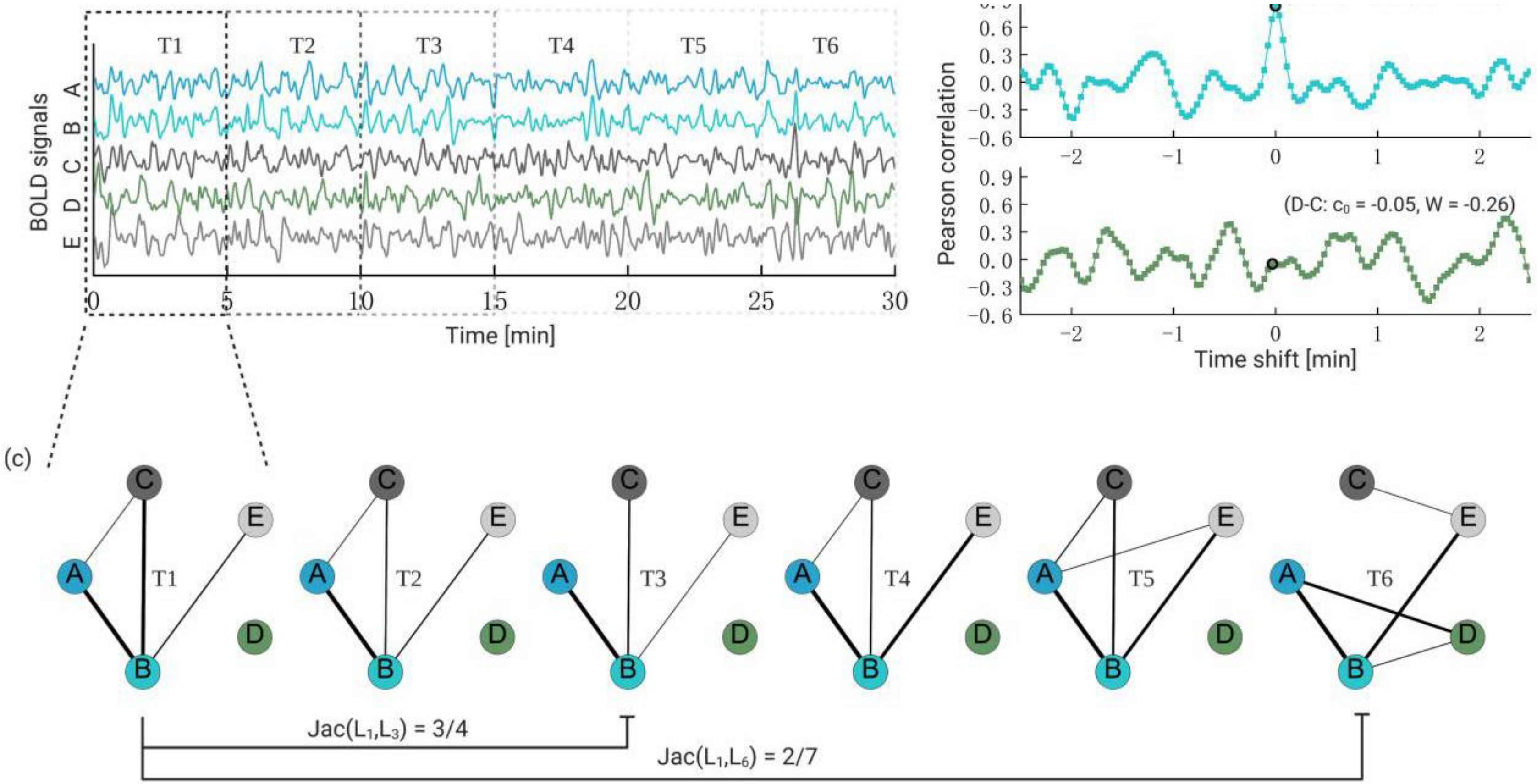
$$\begin{cases} x_i = \Delta & i \in \mathcal{F} \\ \dfrac{\mathrm{d}x_i}{\mathrm{d}t} = M_0(x_i) + \lambda \sum_{j=1}^{N} A_{ij} M_1(x_i) M_2(x_j) & i \in \mathcal{D} \end{cases}$$

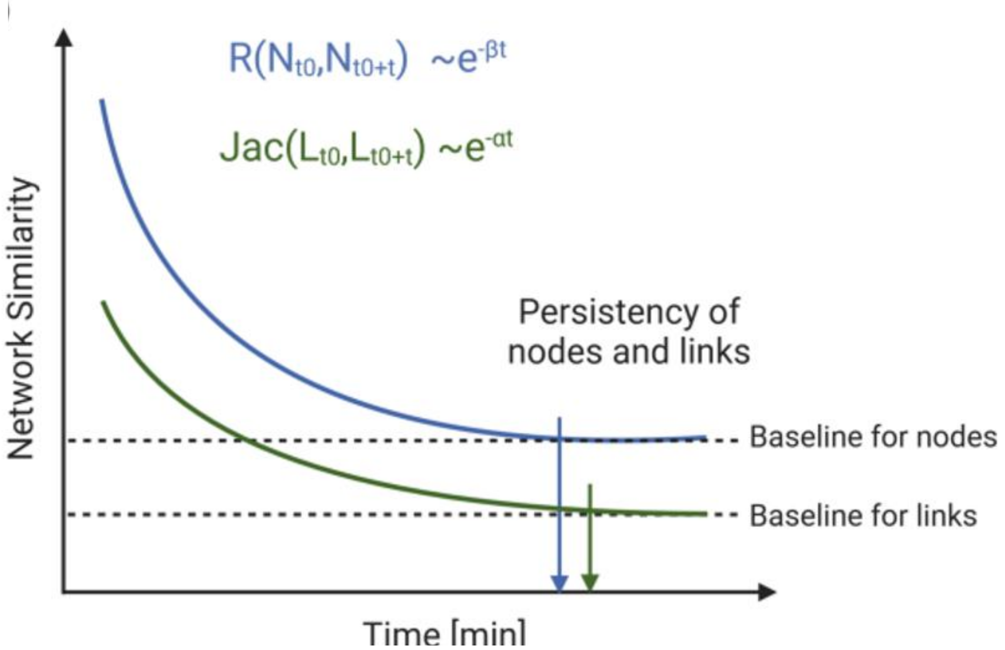


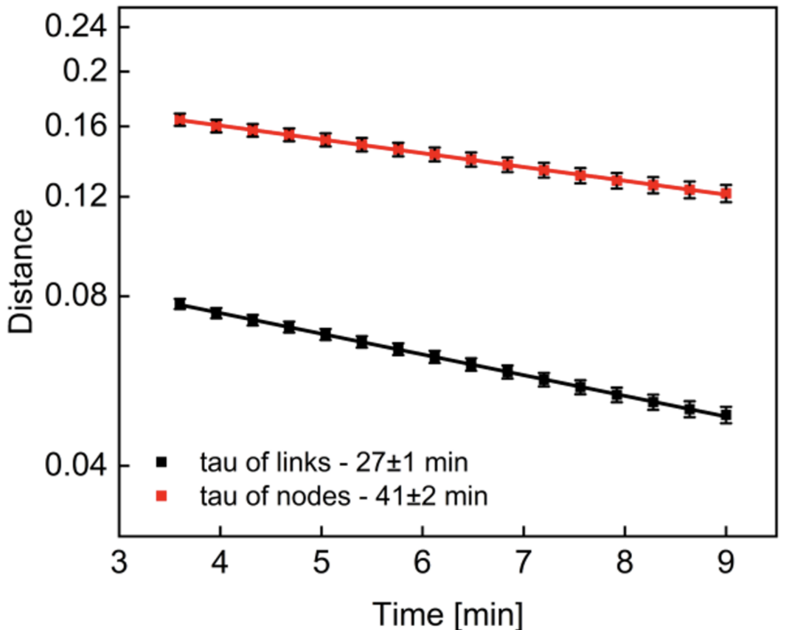
Cellular $\quad \dfrac{\mathrm{d}x_i}{\mathrm{d}t} = -Bx_i^a + \lambda \sum_{j=1}^{N} A_{ij} \dfrac{x_j^h}{1 + x_j^h}$

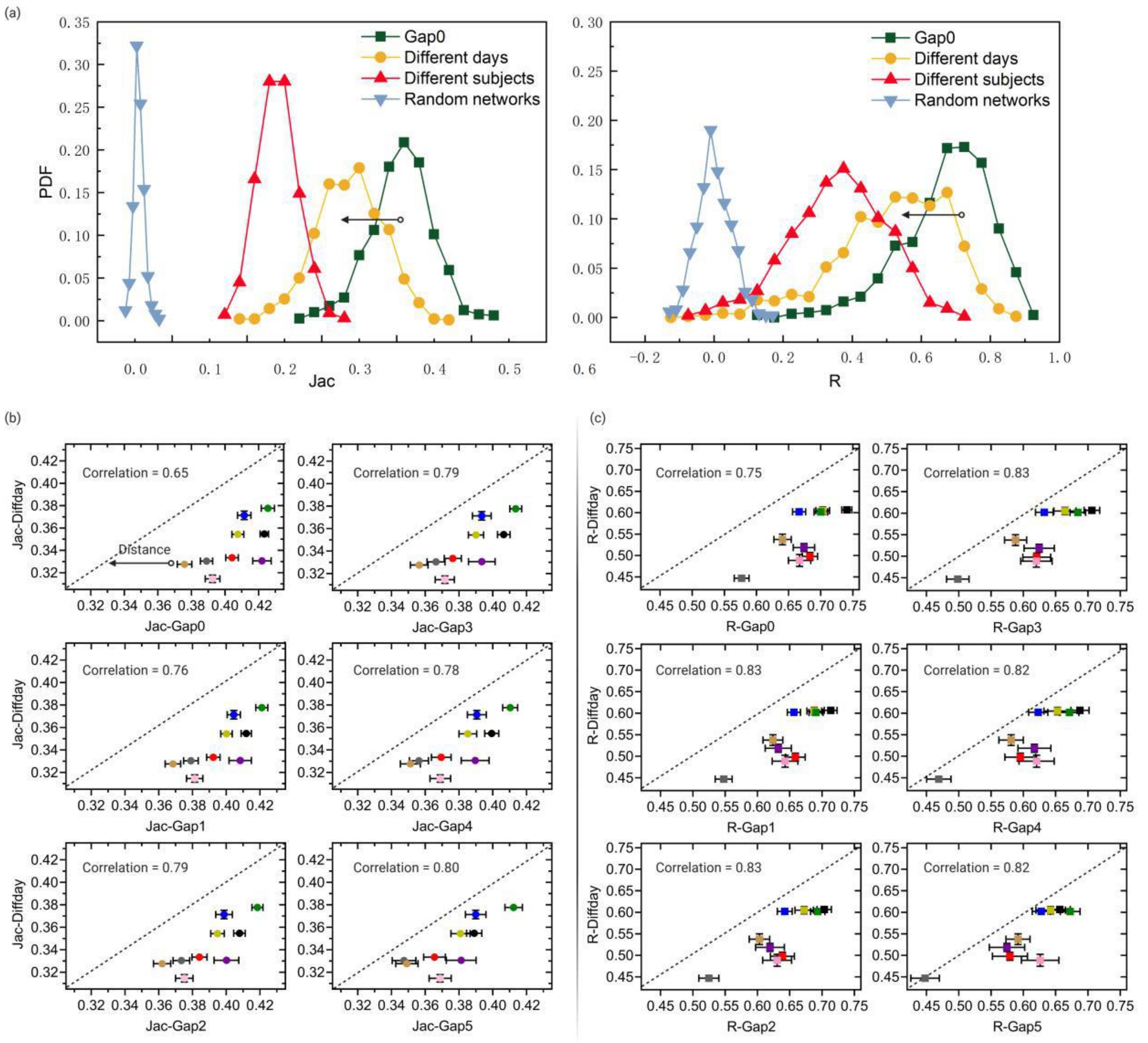


Evolving Brain Networks (Shu et al, preprint 2022)

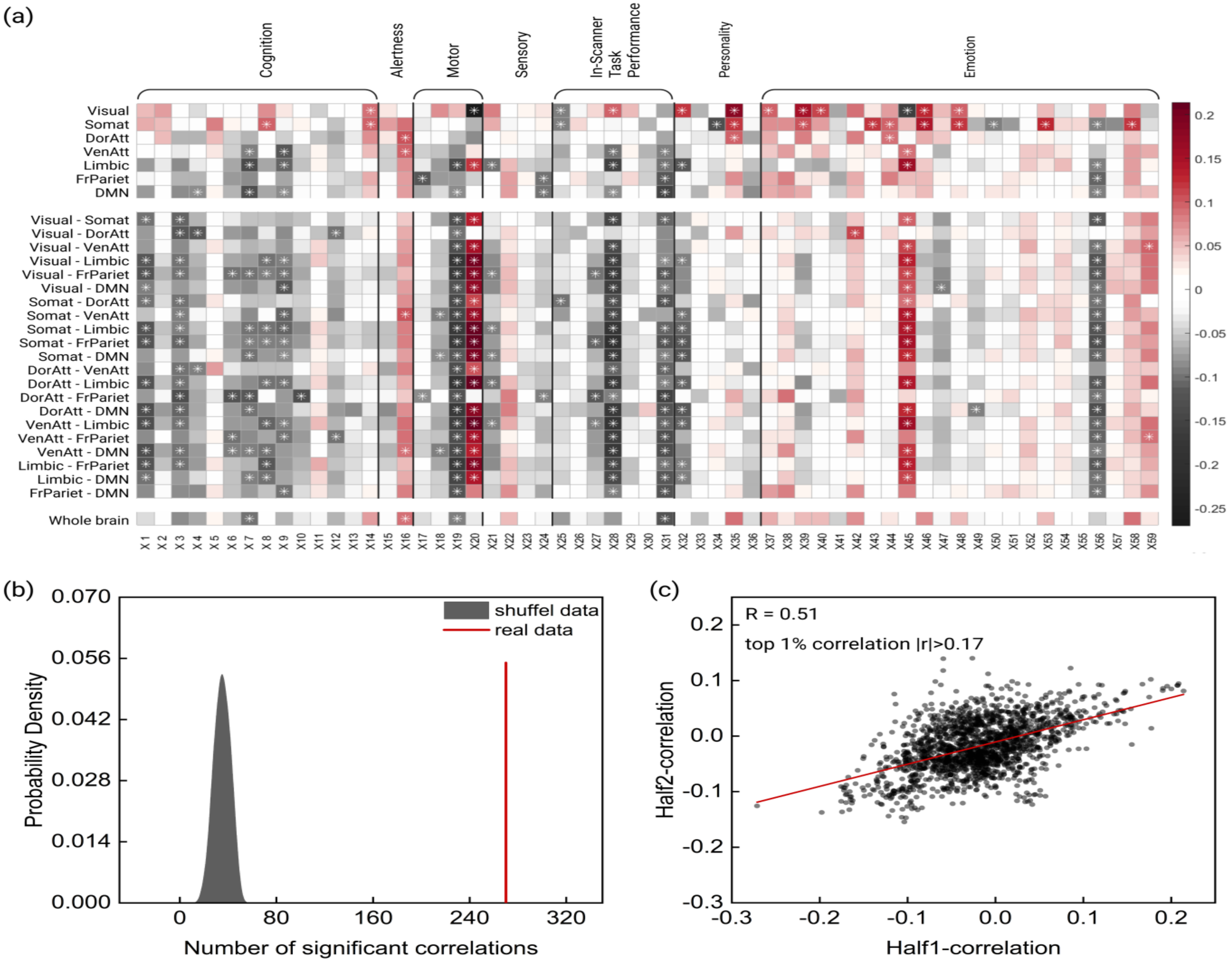



$R(N_{t0},N_{t0+t}) \sim e^{-\beta t}$
$Jac(L_{t0},L_{t0+t}) \sim e^{-\alpha t}$
Network Similarity
Persistency of nodes and links
Baseline for nodes
Baseline for links
Time [min]


Distance
Time [min]
tau of links - 27±1 min
tau of nodes - 41±2 min

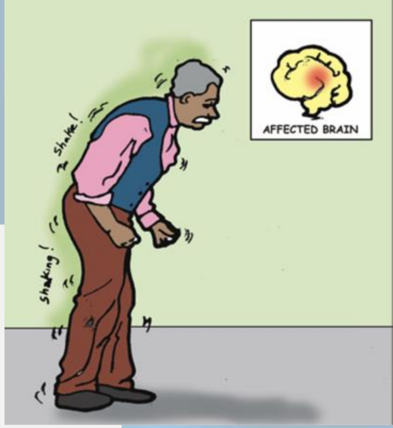

(a)
PDF
Jac
R
Gap0
Different days
Different subjects
Random networks
(b)
Distance
Correlation = 0.65
Correlation = 0.79
Correlation = 0.76
Correlation = 0.78
Correlation = 0.79
Correlation = 0.80
Jac-Diffday
Jac-Gap0
Jac-Gap3
Jac-Gap1
Jac-Gap4
Jac-Gap2
Jac-Gap5
(c)
Correlation = 0.75
Correlation = 0.83
Correlation = 0.83
Correlation = 0.82
Correlation = 0.83
Correlation = 0.82
R-Diffday
R-Gap0
R-Gap3
R-Gap1
R-Gap4
R-Gap2
R-Gap5

Network persistency of different brain regions in REST is associated with performance



Connectivity of EEG synchronization networks increases with severity of Parkinson’s disease and freezing of gait

E. Asher, R. Bartcsh et al
Comm. Physics 4, 1017 (2021)



Data consists of EEG recordings of 4 groups, according to disease severity.

1. $Elderly\ Control$
2. $PD - FoG$
3. $PD + FoG^{-}$
4. $PD + \ FoG^{+}$

Summary:

Network applications in physiology and biology

[1] Reviving a failed network through microscopic interventions
Sanhedrai, J Gao, A Bashan, M Schwartz, S Havlin, B Barzel
Nature Physics 18 (3), 338-349 (2022)
[2] Sustaining a network by controlling a fraction of nodes. H Sanhedrai, S Havlin
arXiv preprint arXiv:2205.13377 (2022)
[3] Connectivity of EEG synchronization networks increases for Parkinson’s disease patients with freezing of gait
E. Asher, R. Bartcsh, S. Havlin et al
Communications Biology 4 (1), 1-10 (2021)—By Ronny Bartsch this afternoon
[4] Brain dynamic network during rest and personal performance
Shu Guo et al, In preparation, 2022