Characterisation of individual nodes in the mesoscale of complex networks

14th Mathematics of Networks meeting (MoN14)

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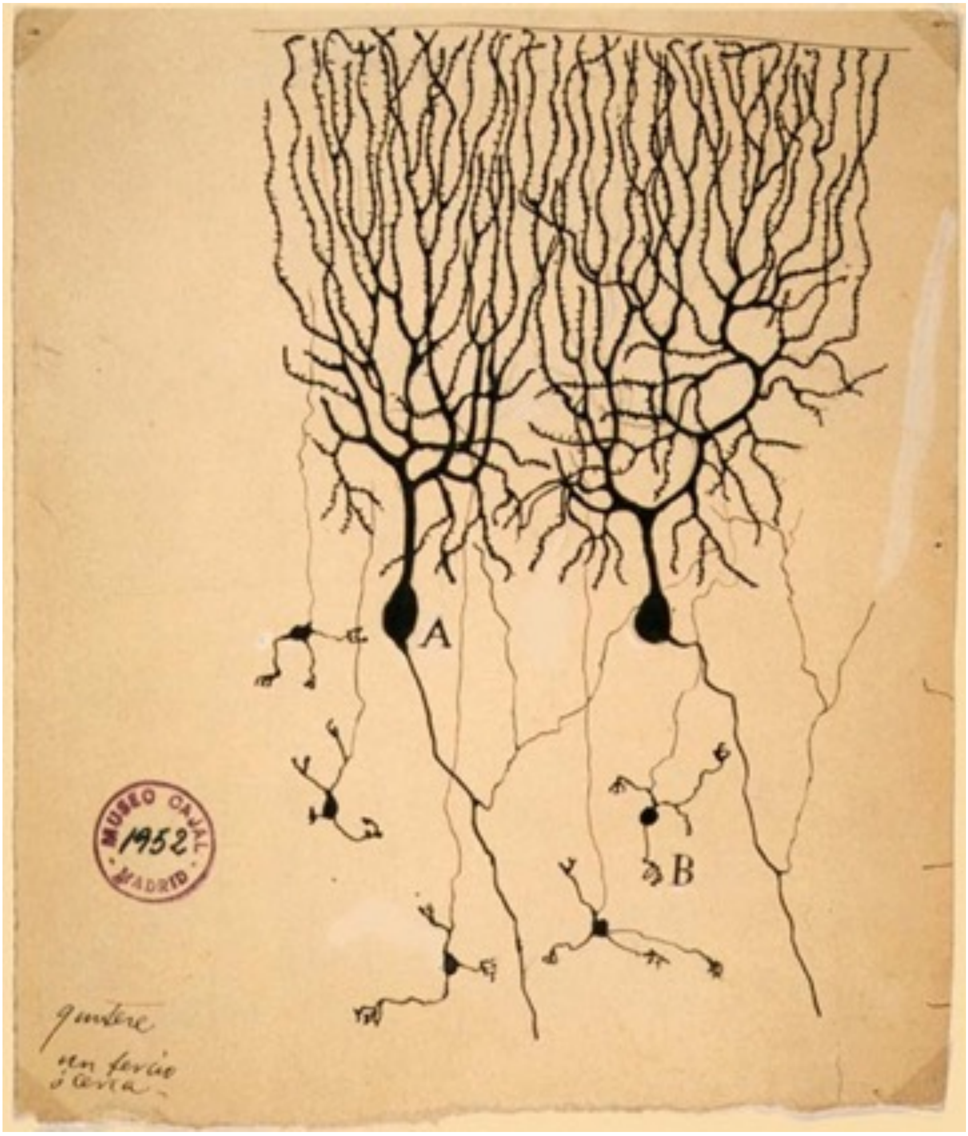
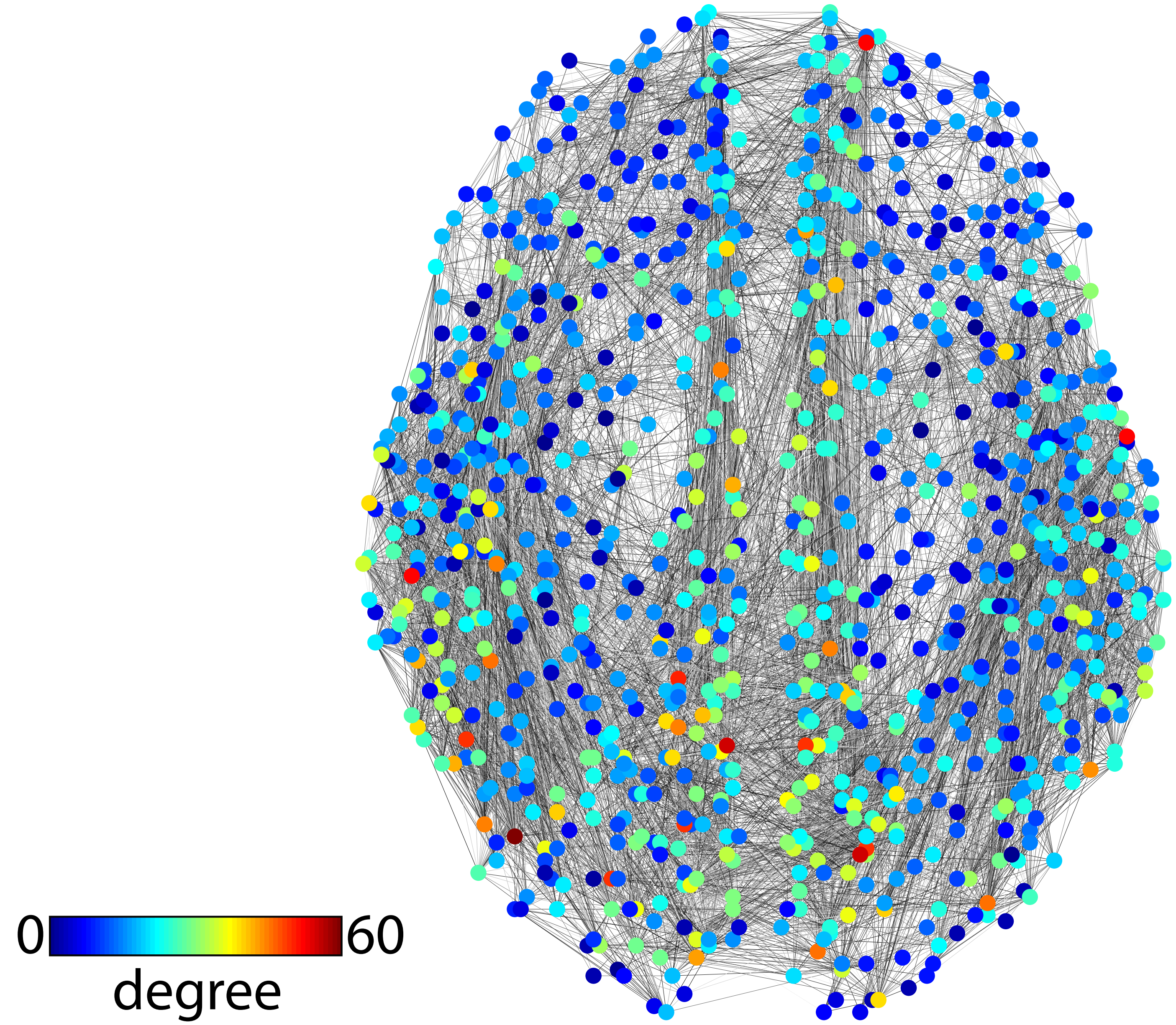
21.9.2015

Structure

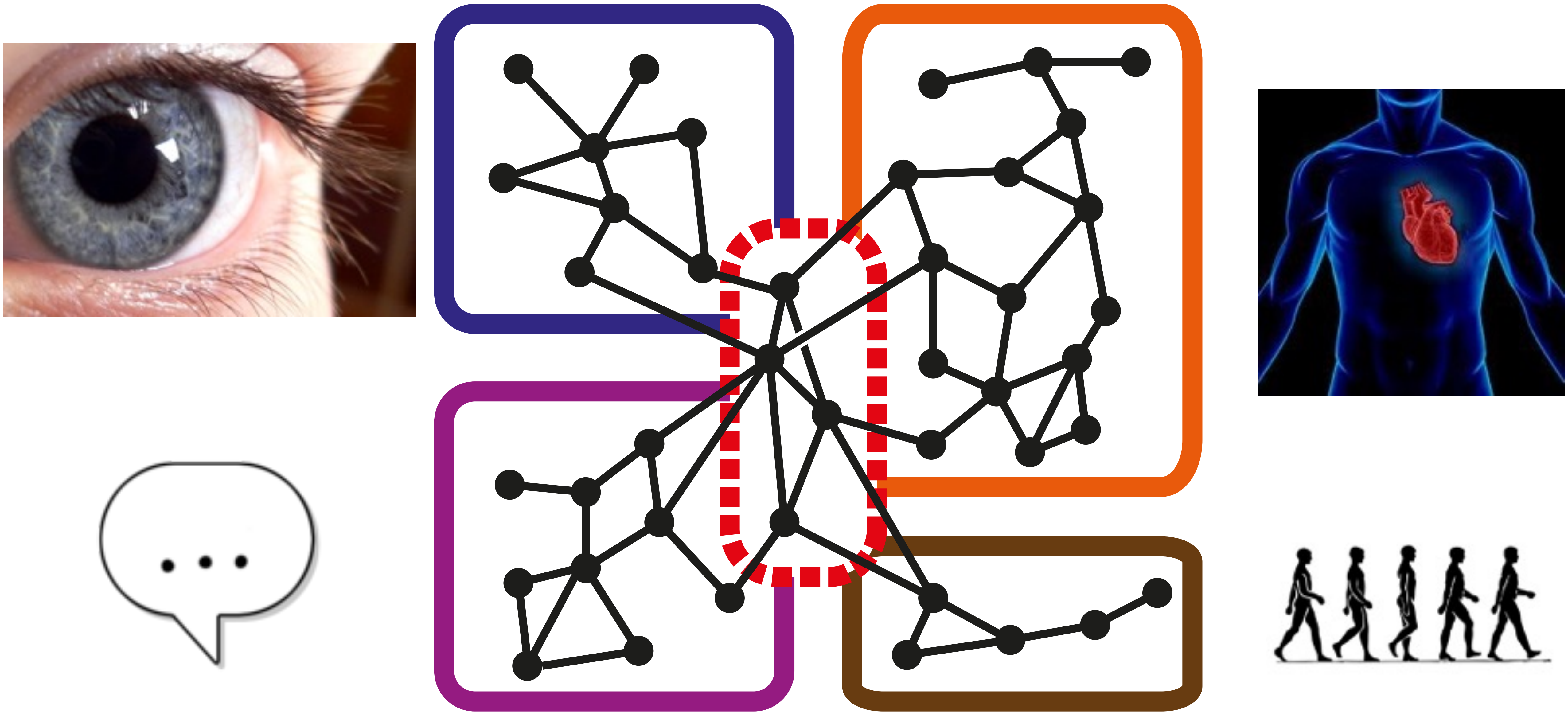
1. Biological neuronal networks
2. Climate networks
3. Multilayer transportation network





Neuronal networks are extremely complex systems

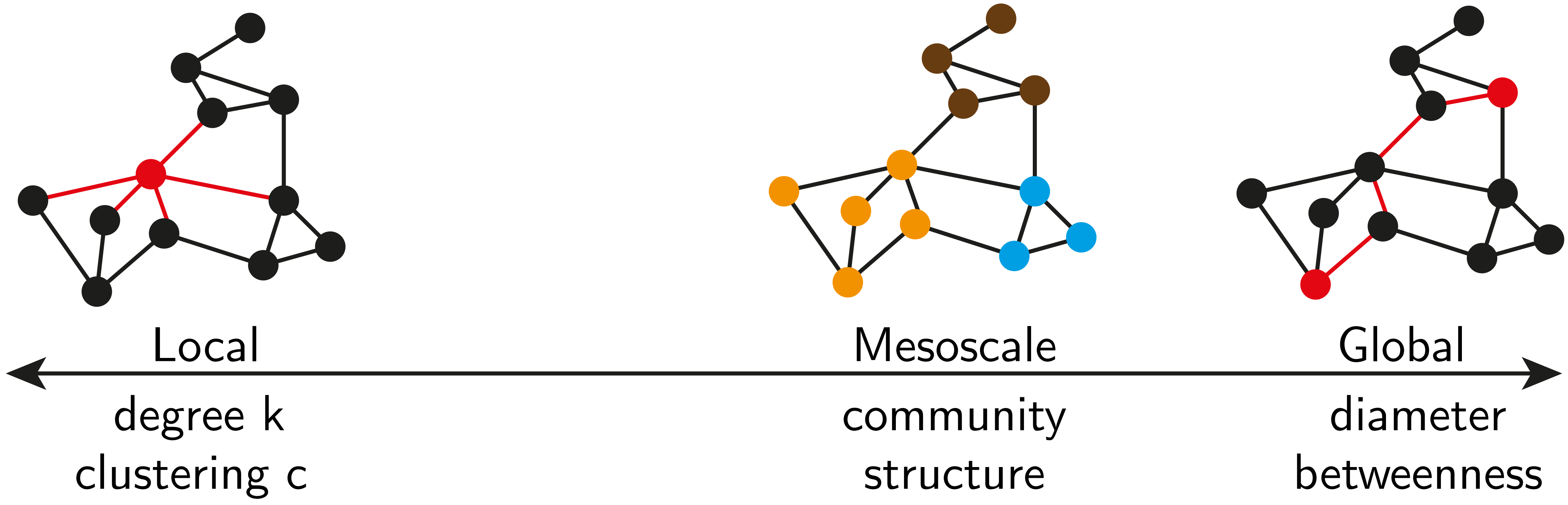
consisting of from 279 to ~86 billion neurons
linked with to 8,000 to 10^15 synapses



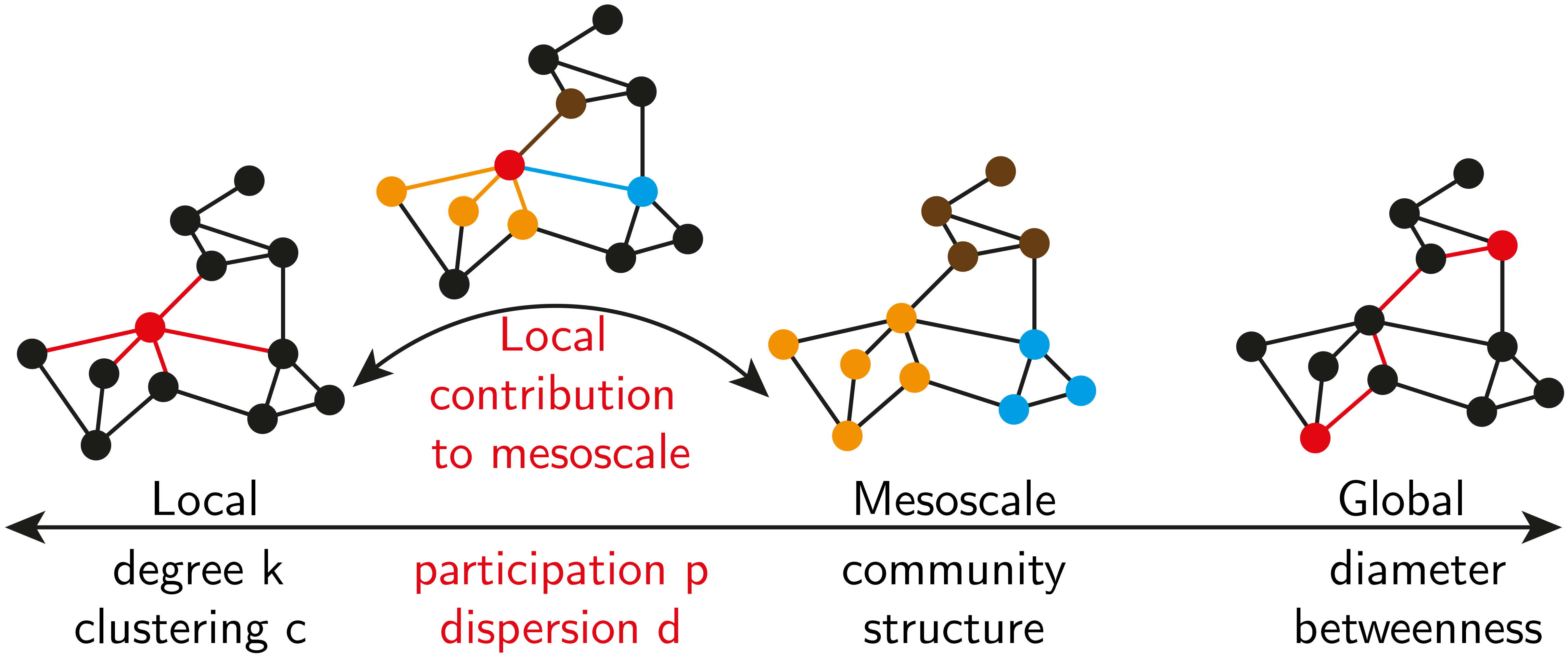
Segregation & Integration

enable parallel information processing

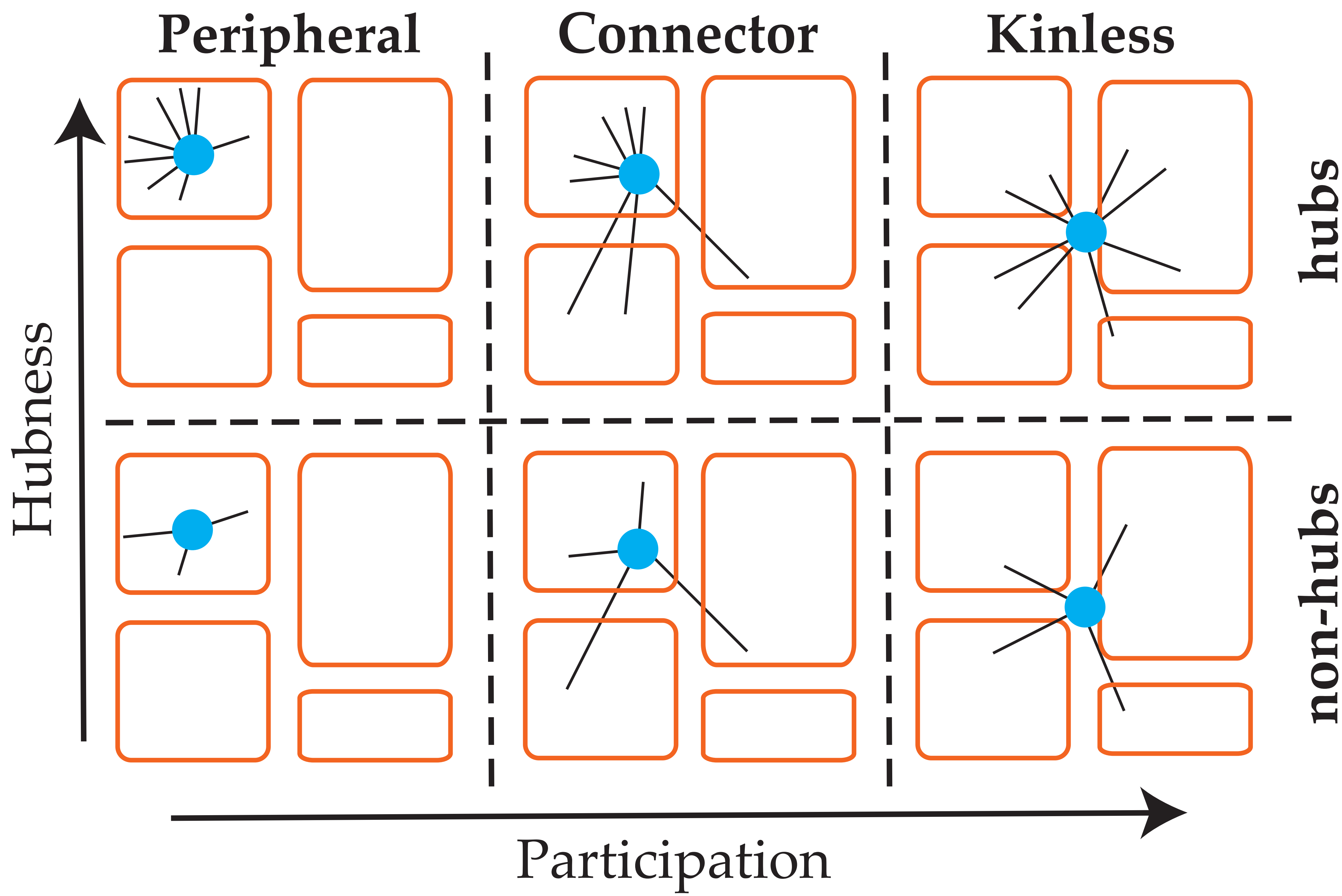
Tononi, G., Sporns, O., & Edelman, G. M. (1994). A measure for brain complexity: relating functional segregation and integration in the nervous system. *Proceedings of the National Academy of Sciences*, *91*(11), 5033-5037.



community detection as mesoscale analysis

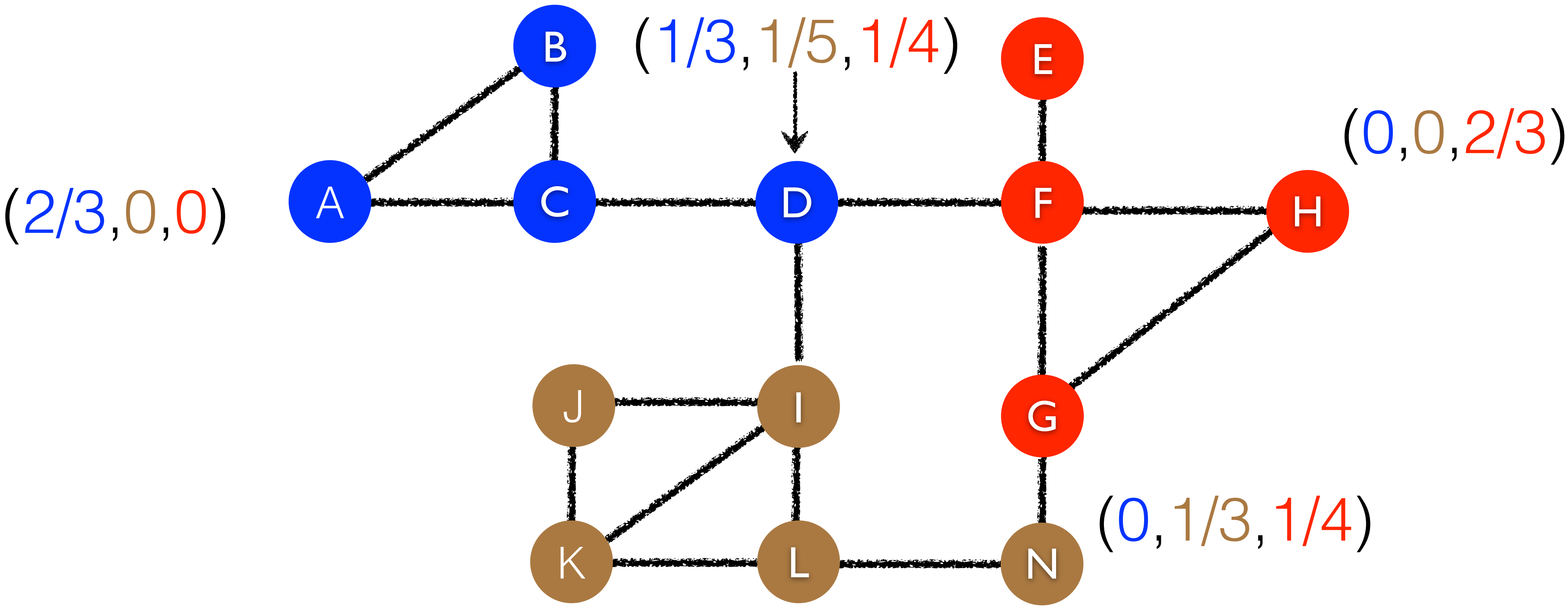


we measure the position of individual nodes in the mesoscale



Measuring segregation and integration in a network
-> role of nodes in the mesoscale

Guimera, R., & Amaral, L. A. N. (2005). Functional cartography of complex metabolic networks. *Nature*, *433*(7028), 895-900.

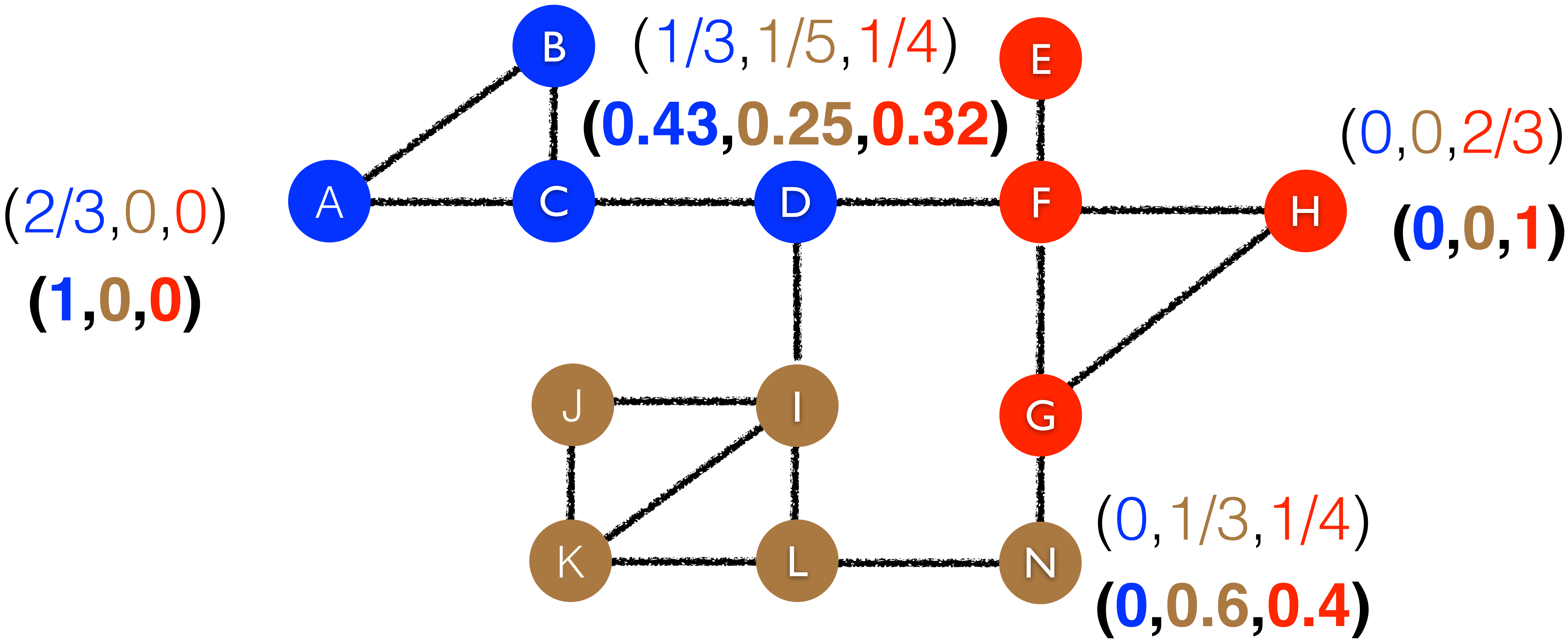


$$P_{im} = \frac{\text{(number of neighbours in this module)}}{\text{(number of potential neighbours in this module)}}$$

participation vector

for each node M elements (= number of modules)

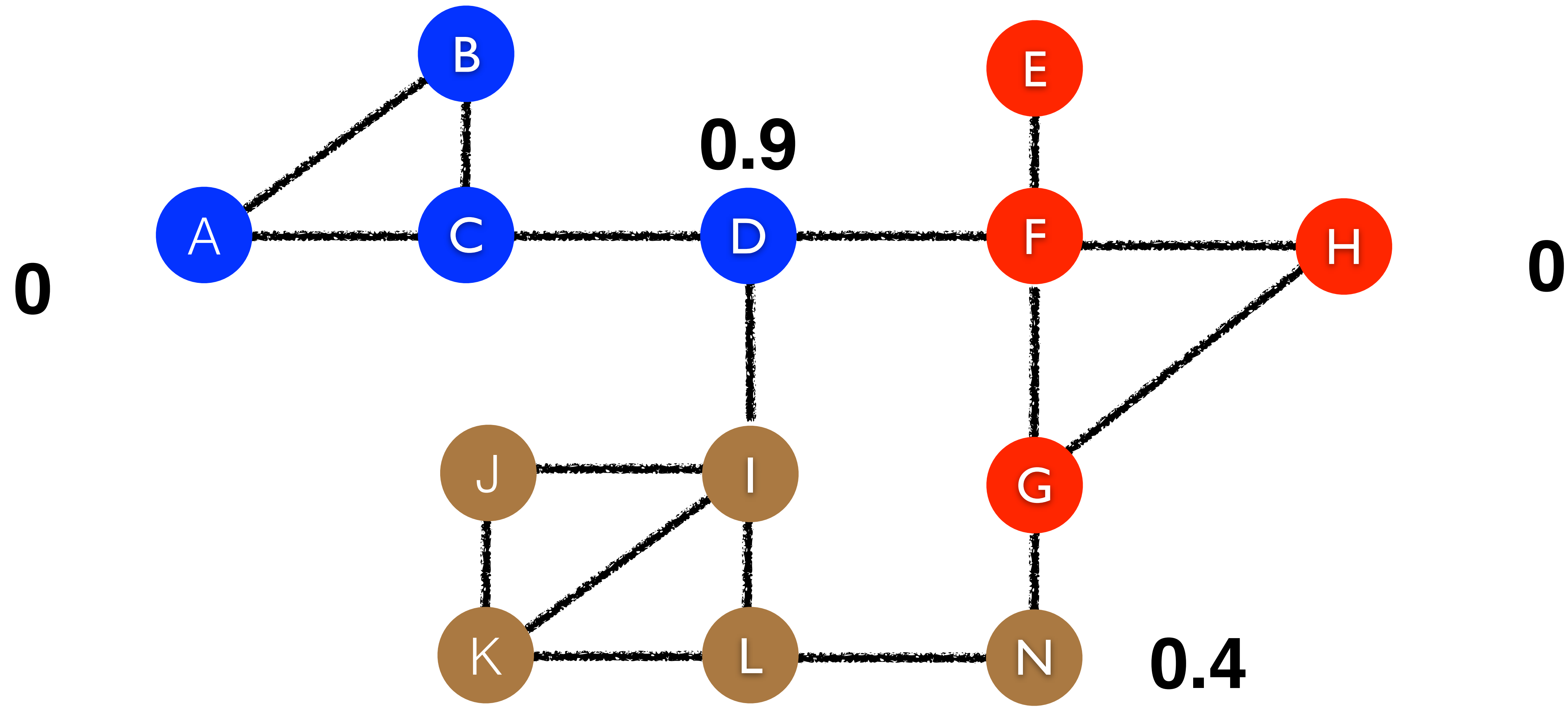
Klimm, F., Borge-Holthoefer, J., Wessel, N., Kurths, J., & Zamora-López, G. (2014). Individual node's contribution to the mesoscale of complex networks. *New Journal of Physics*, *16*(12), 125006.



$$P_{im} = \frac{\text{(number of neighbours in this module)}}{\text{(number of potential neighbours in this module)}}$$

participation vector

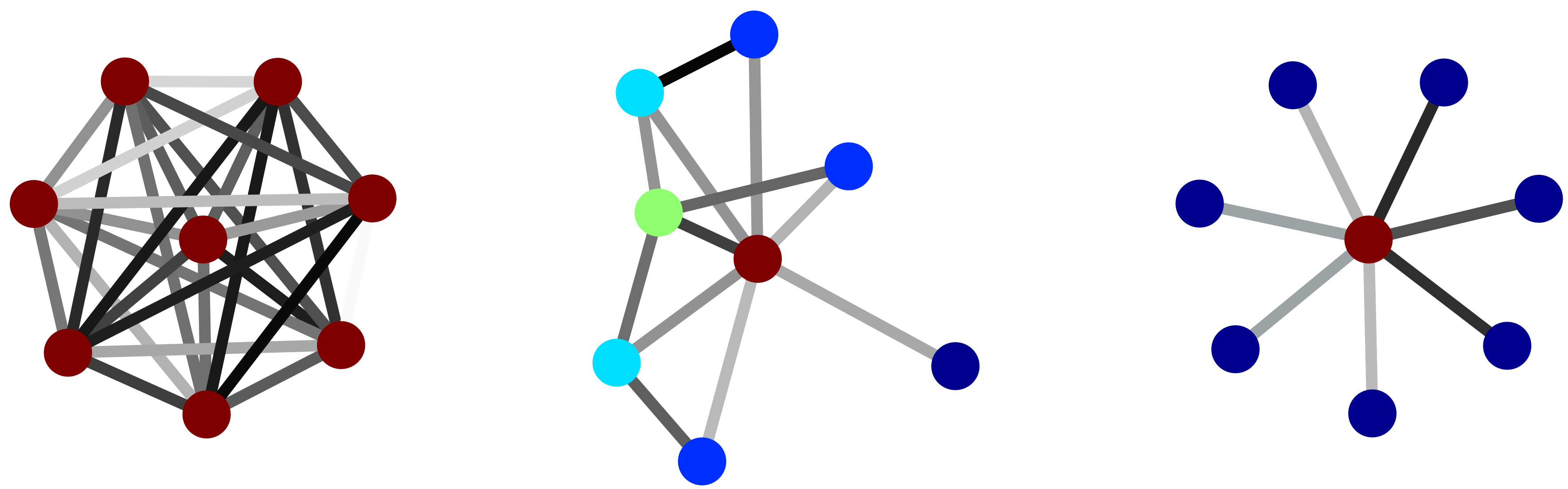
for each node M elements (= number of modules)
normalisation of each vector



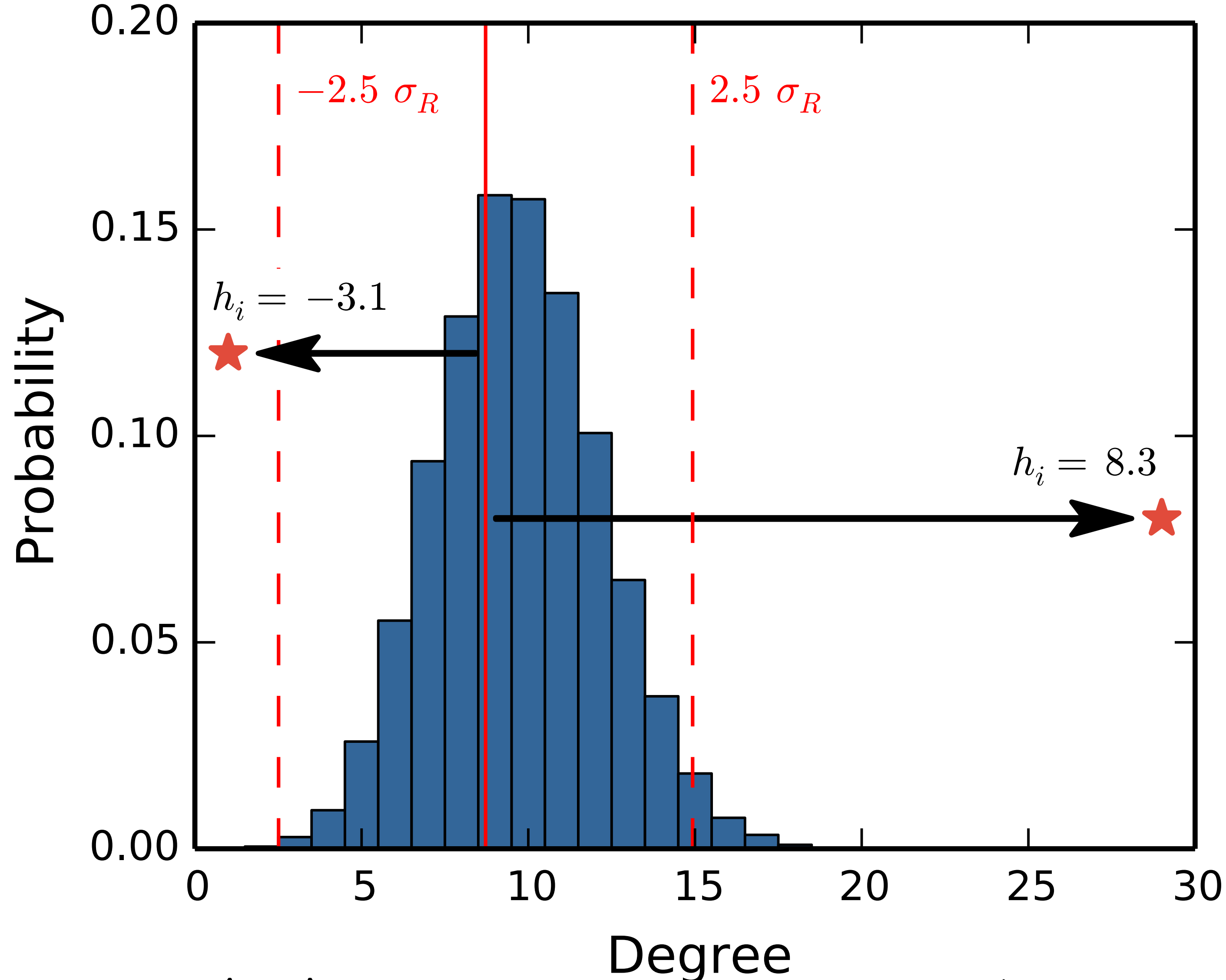
$$p_i = 1 - \frac{M}{\sqrt{M-1}}\,\sigma(\mathbf{P_i})$$

participation index

reduction to scalar value necessary

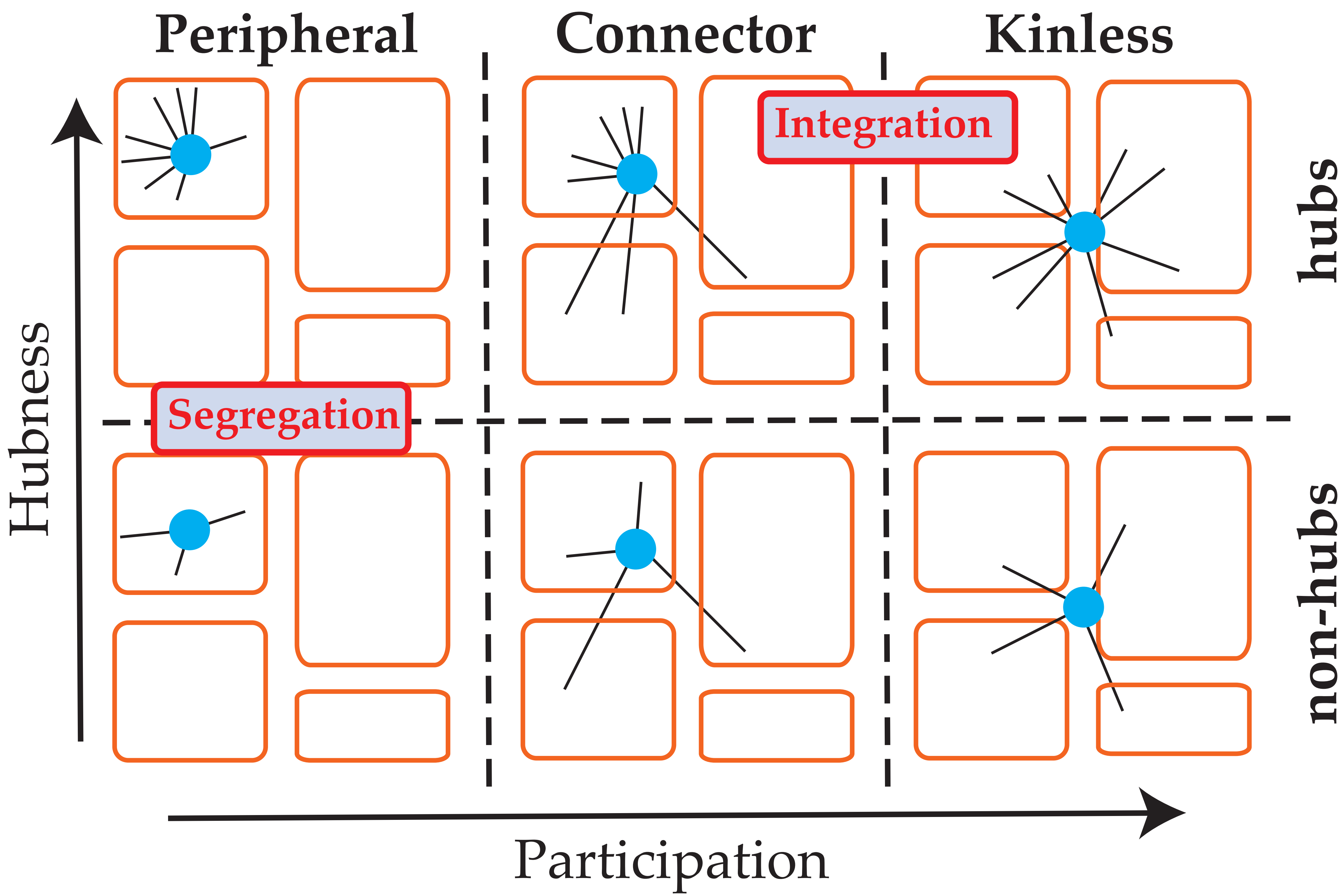


degree is not sufficient to define hubness

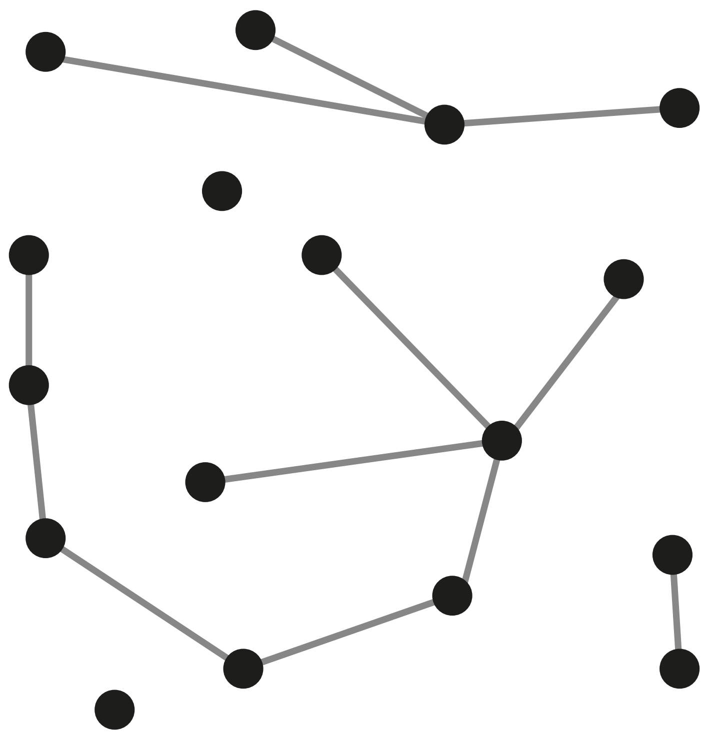


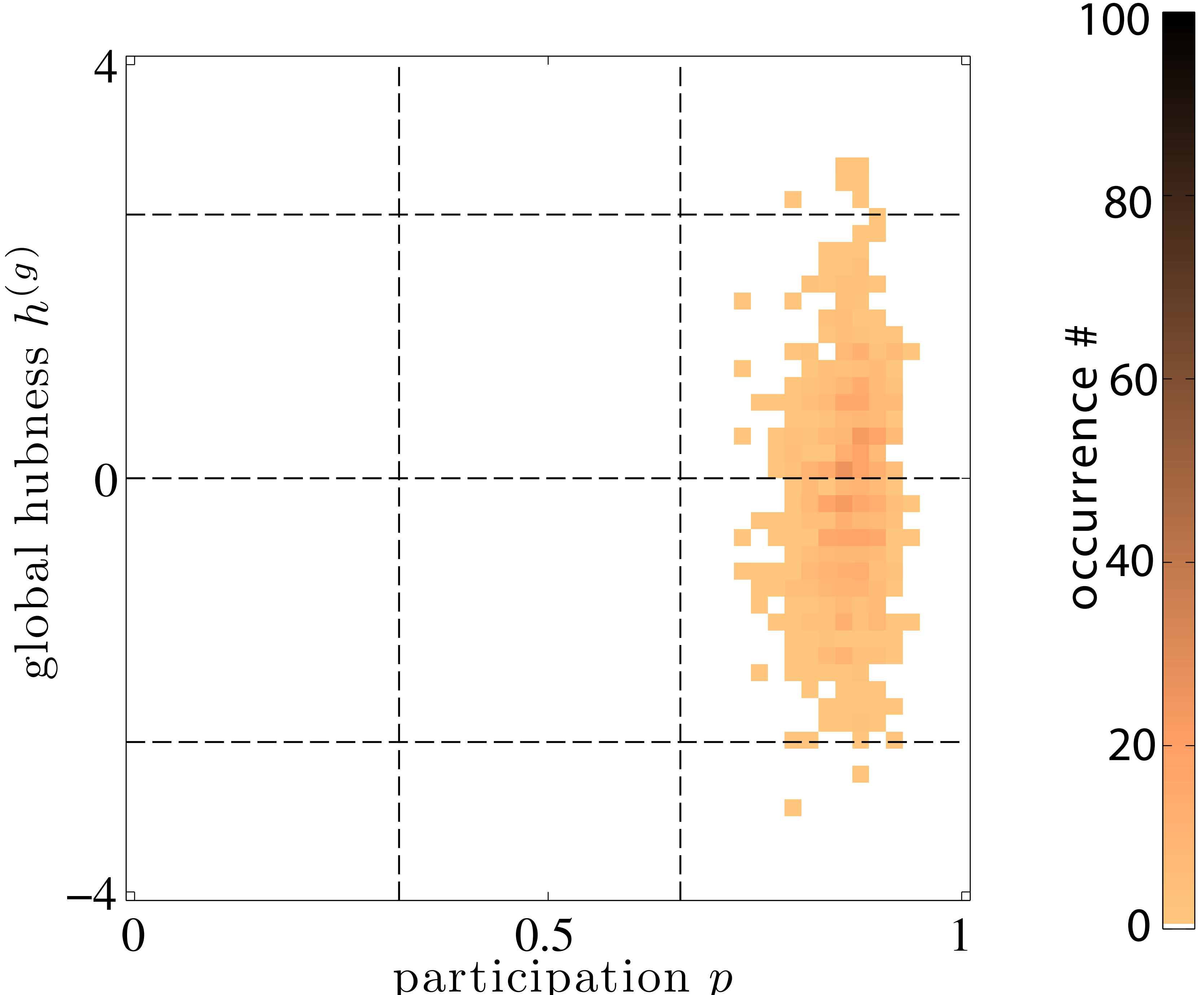
$$h_i = \frac{k_i - \langle k \rangle_R}{\sigma_R} = \frac{k_i - (N-1)\rho}{\sqrt{(N-1)\,\rho\,(1-\rho)}}$$

hubness compares node's degree with a random null model



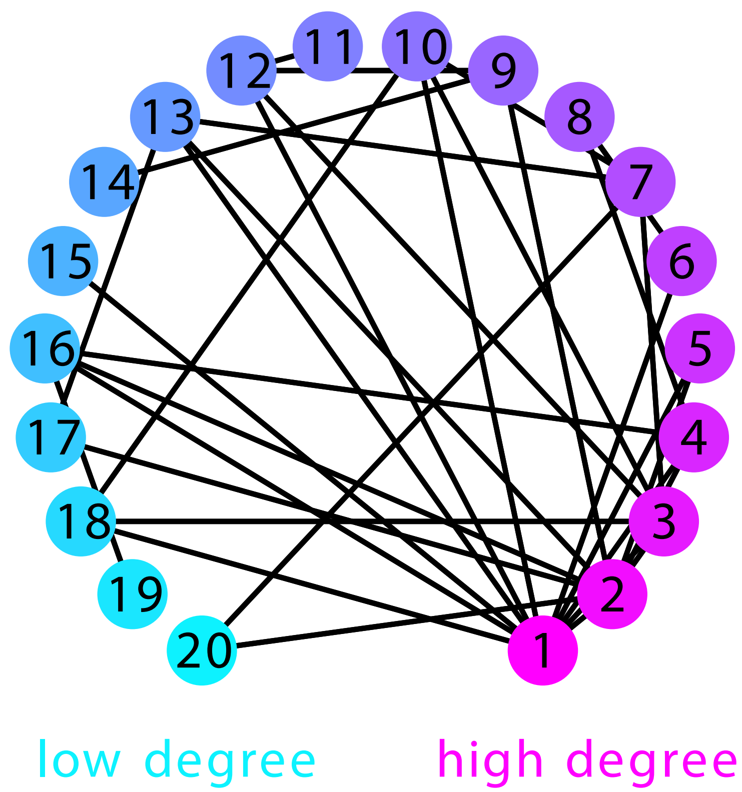
We analyse different networks with this 2-dimensional mapping
-> role of nodes in the mesoscale

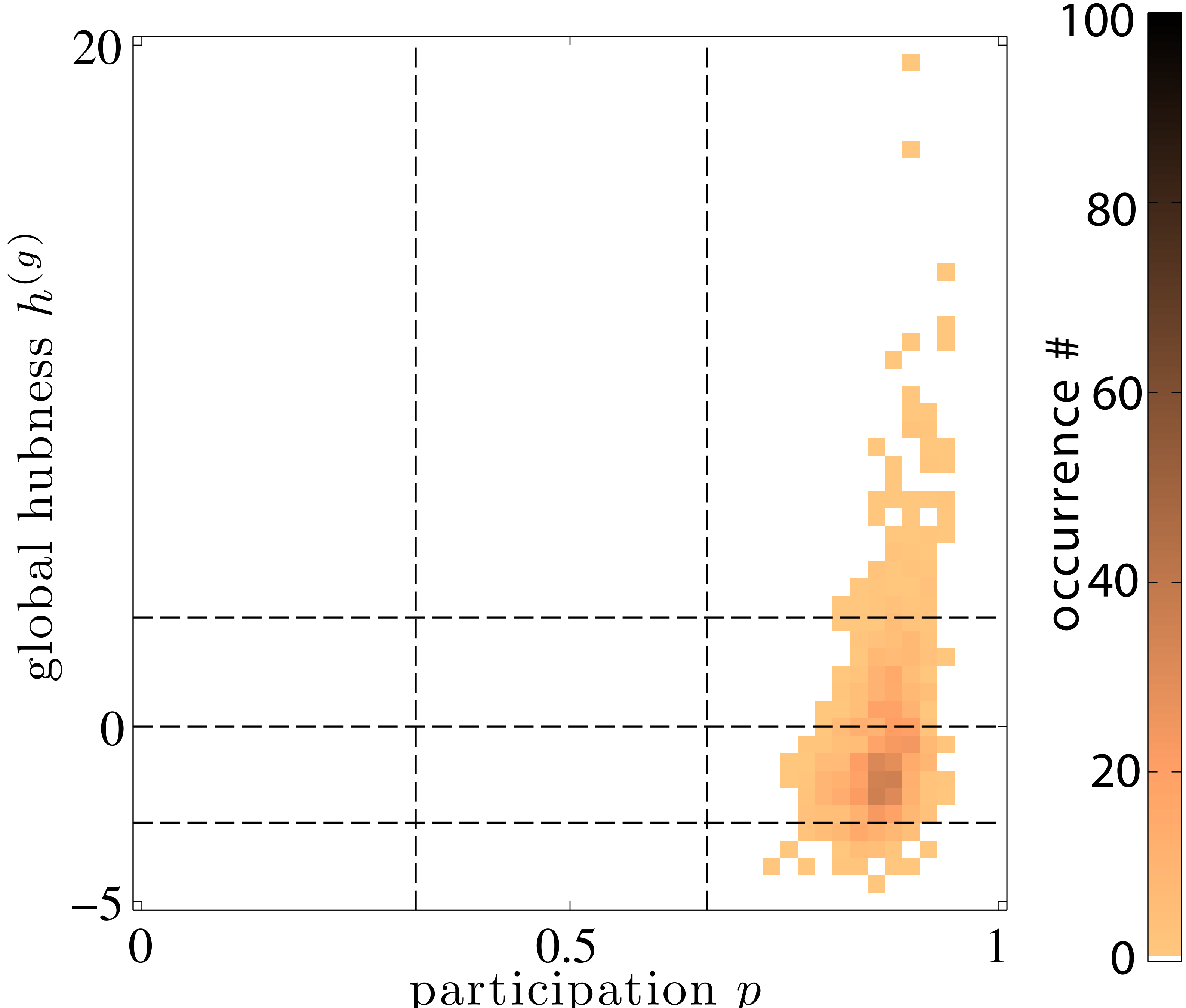




random network

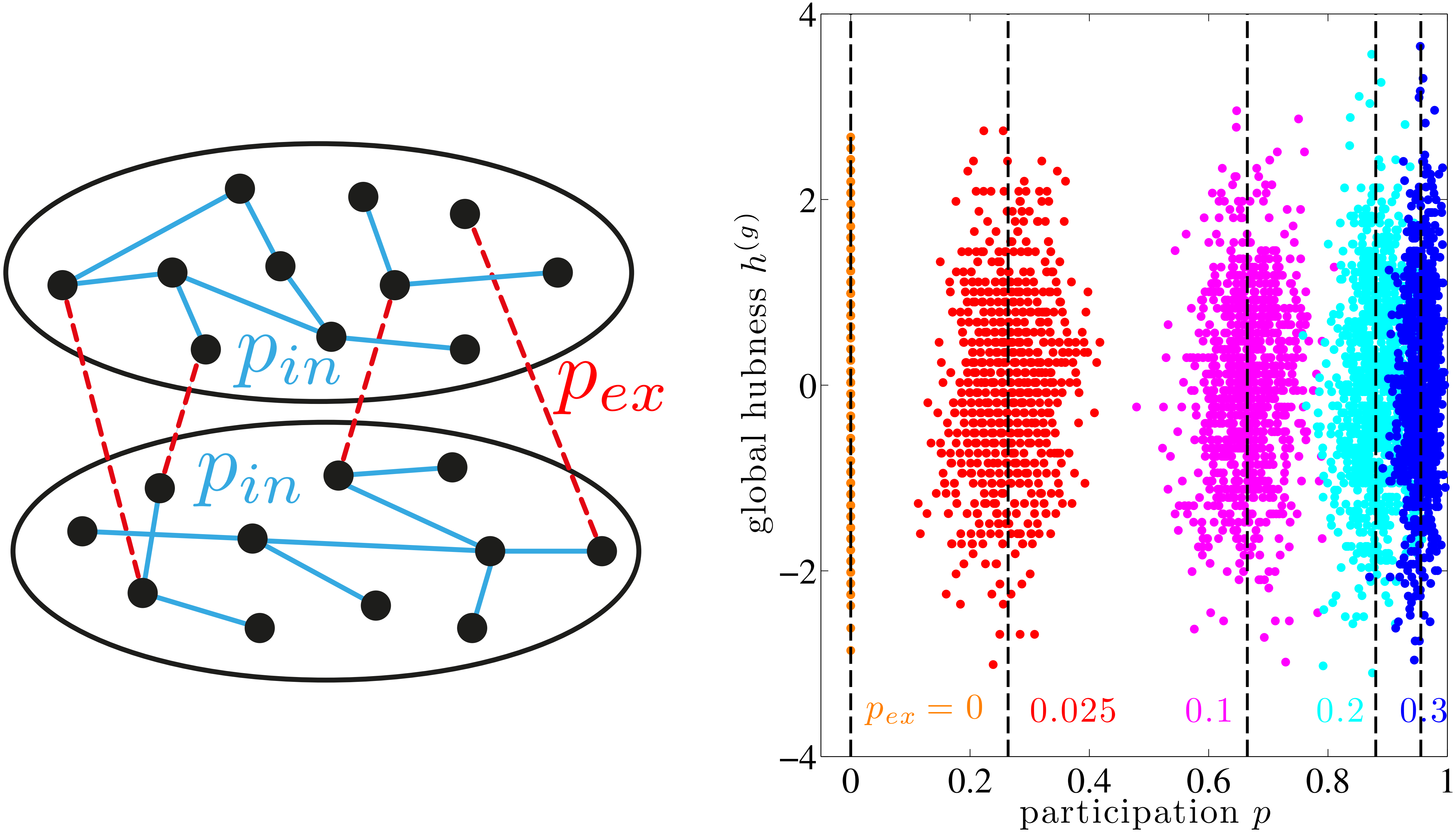
no hubs and no modularity





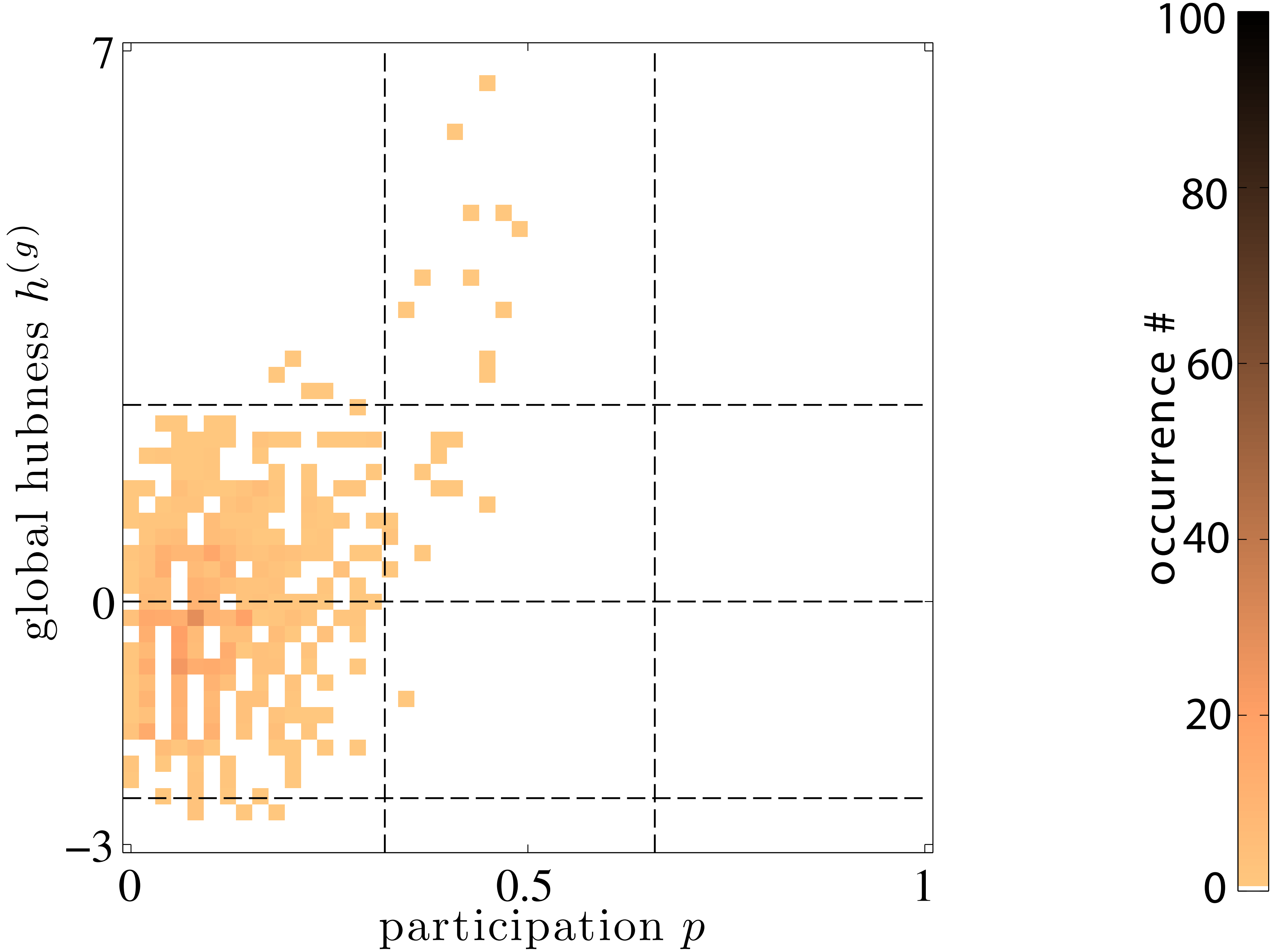
scale-free networks

hubs but still no modularity



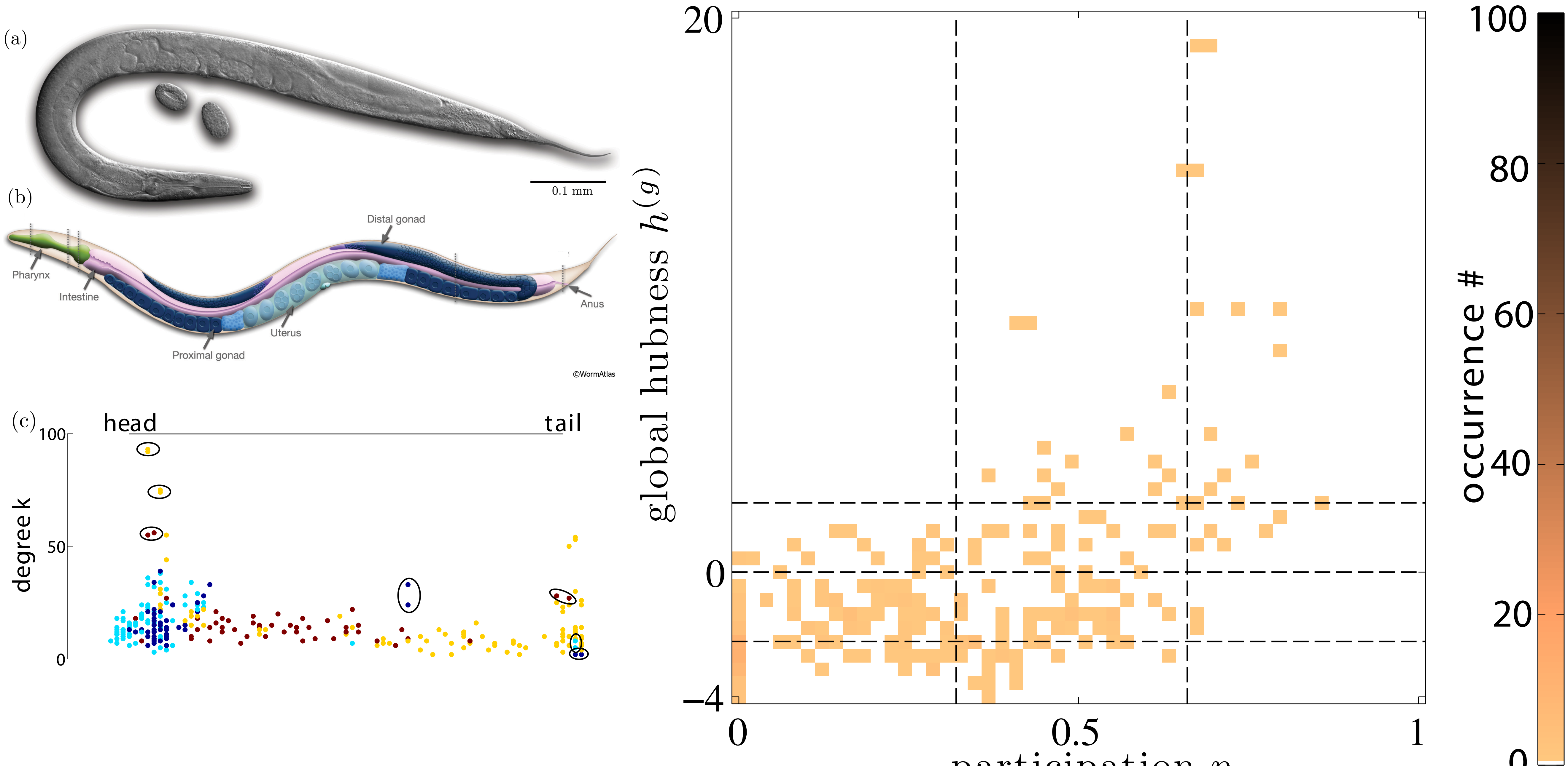
modular networks

modularity is tunebale but no hubs



modular network with SF attachment

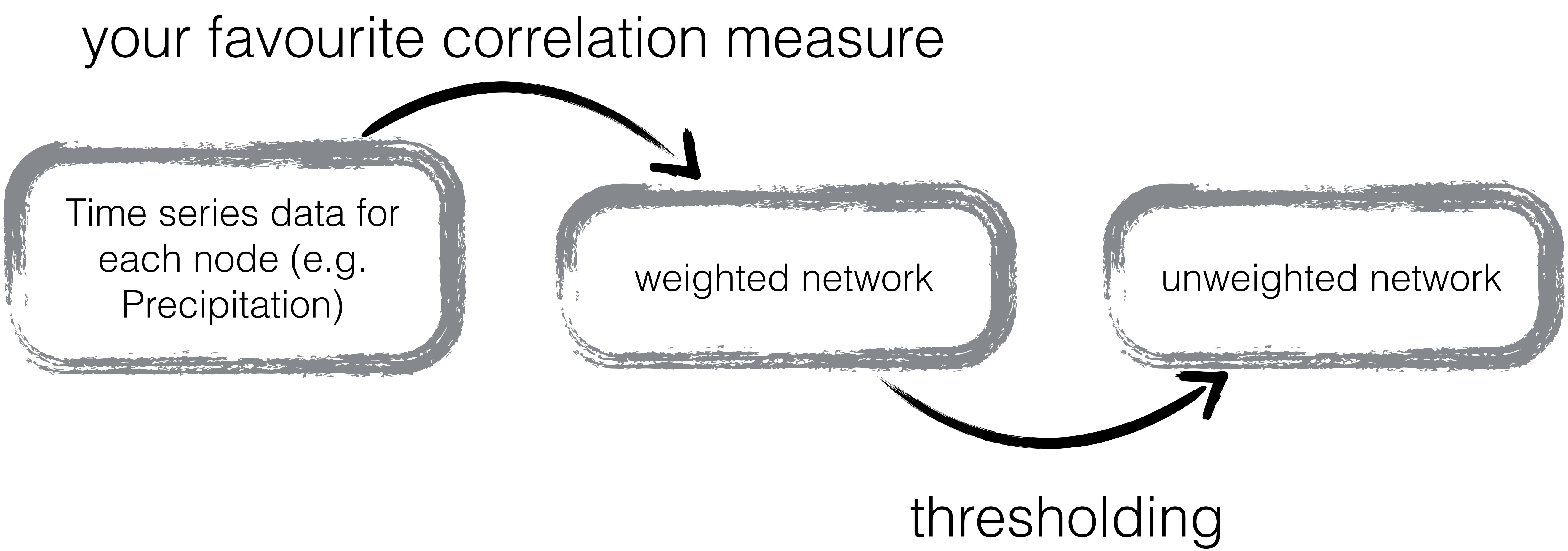
shows segregated modules and connecting hubs



both features coexist in real world neuronal data!

for example in the roundworm *C. elegans*

Climate networks



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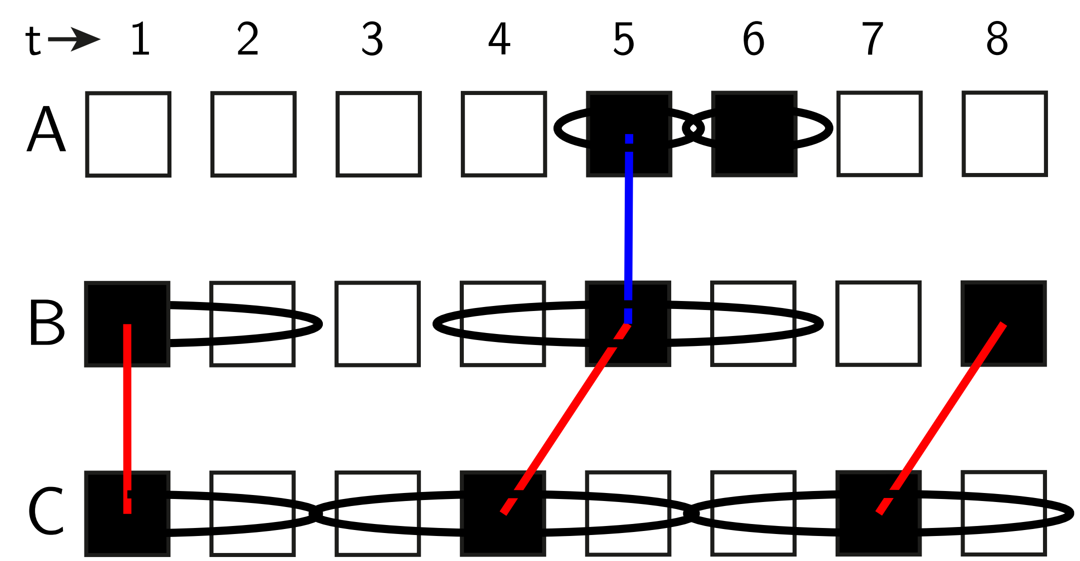
Climate networks



event synchronisation

Time series data for each node (e.g. Precipitation)

weighted network

unweighted network

5% strongest links

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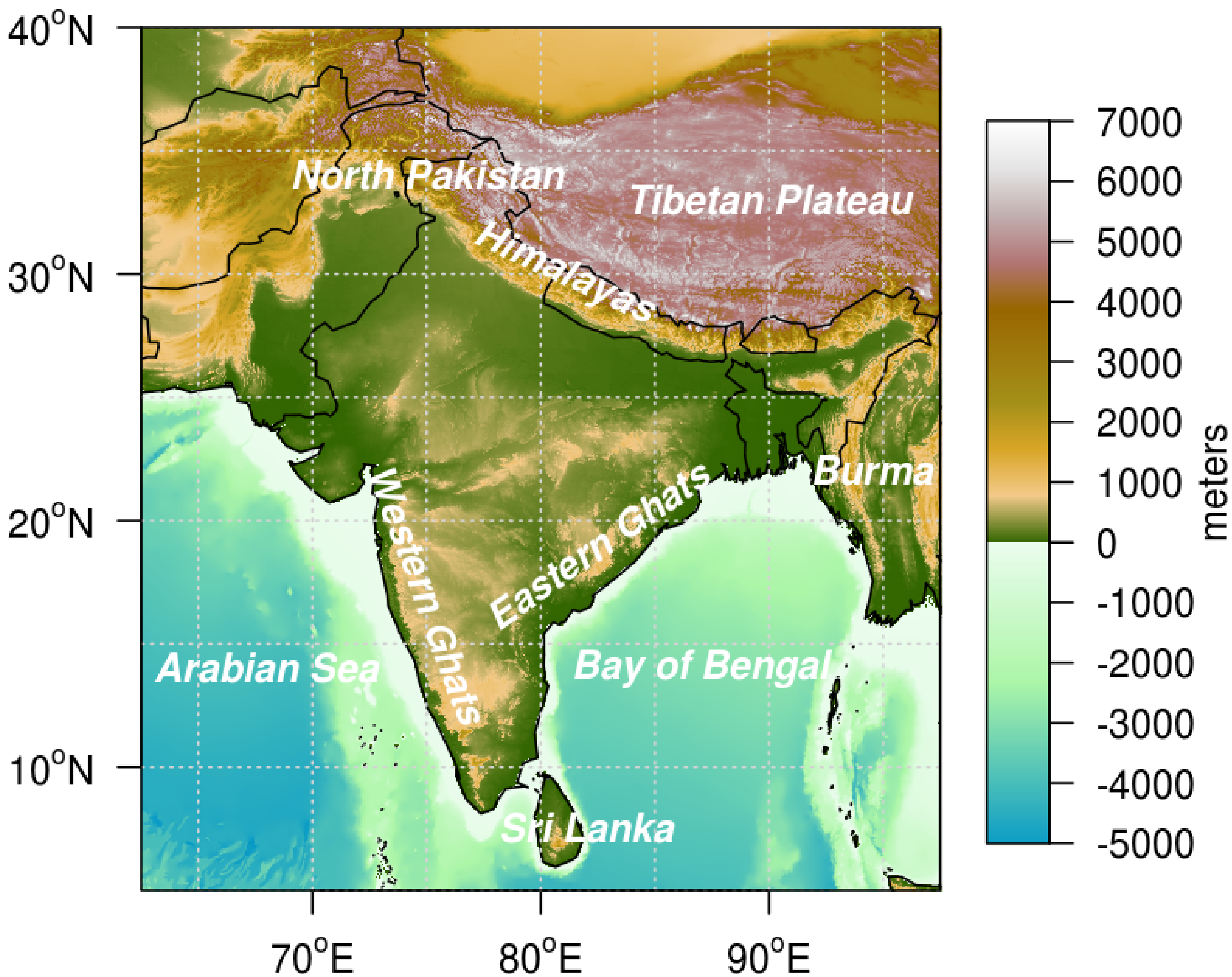
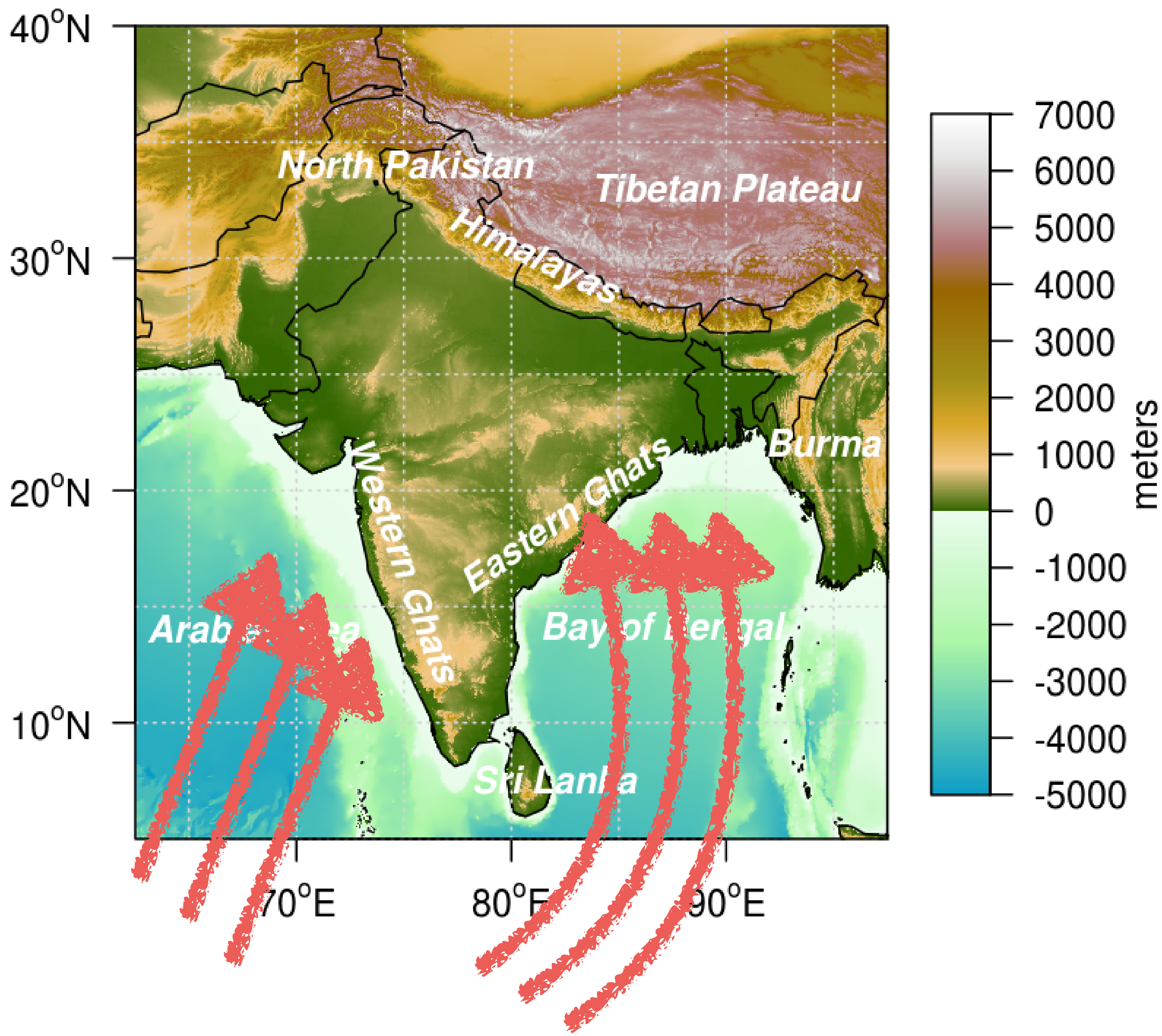
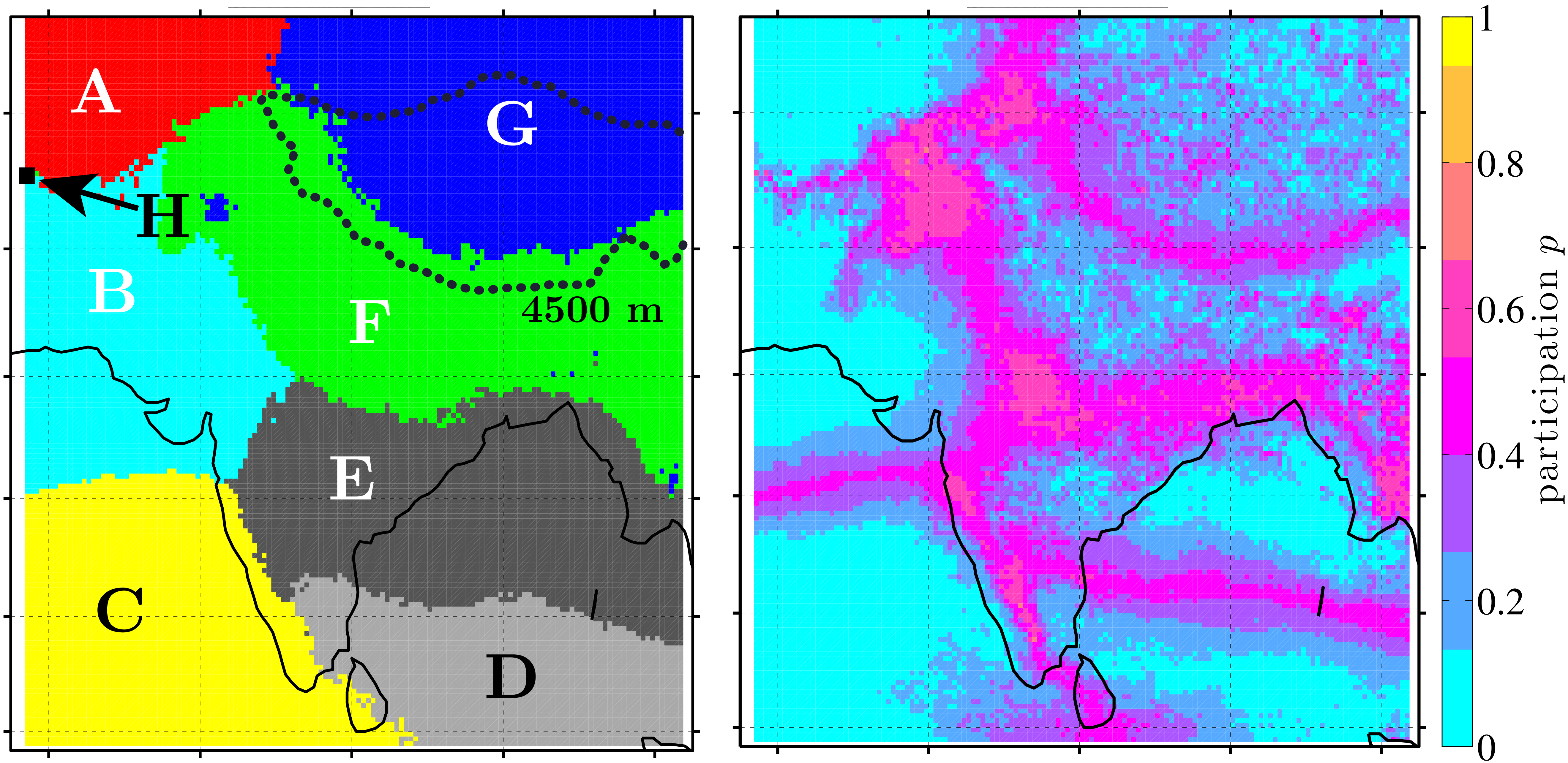
Indian Summer Monsoon



Indian Summer Monsoon



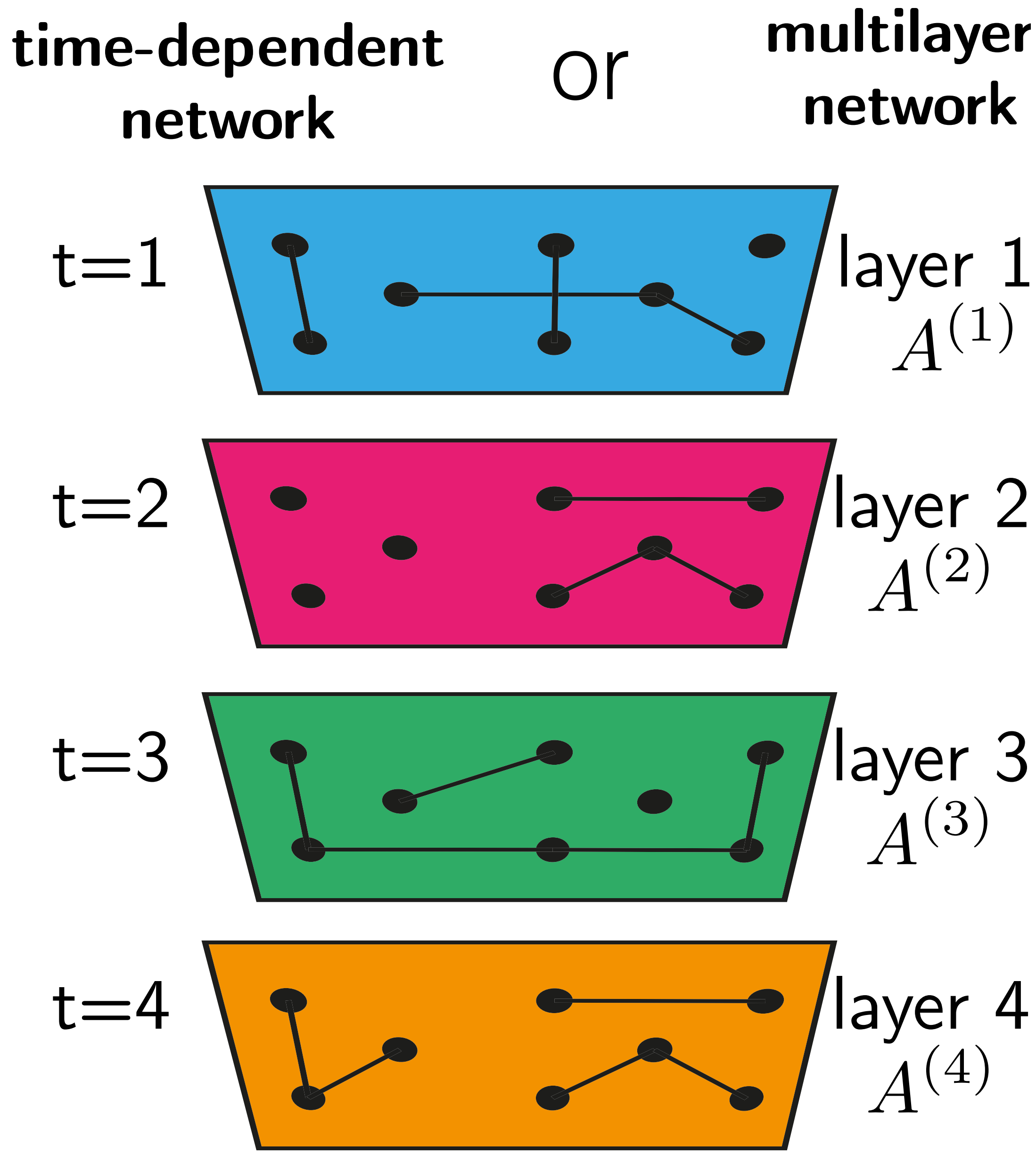


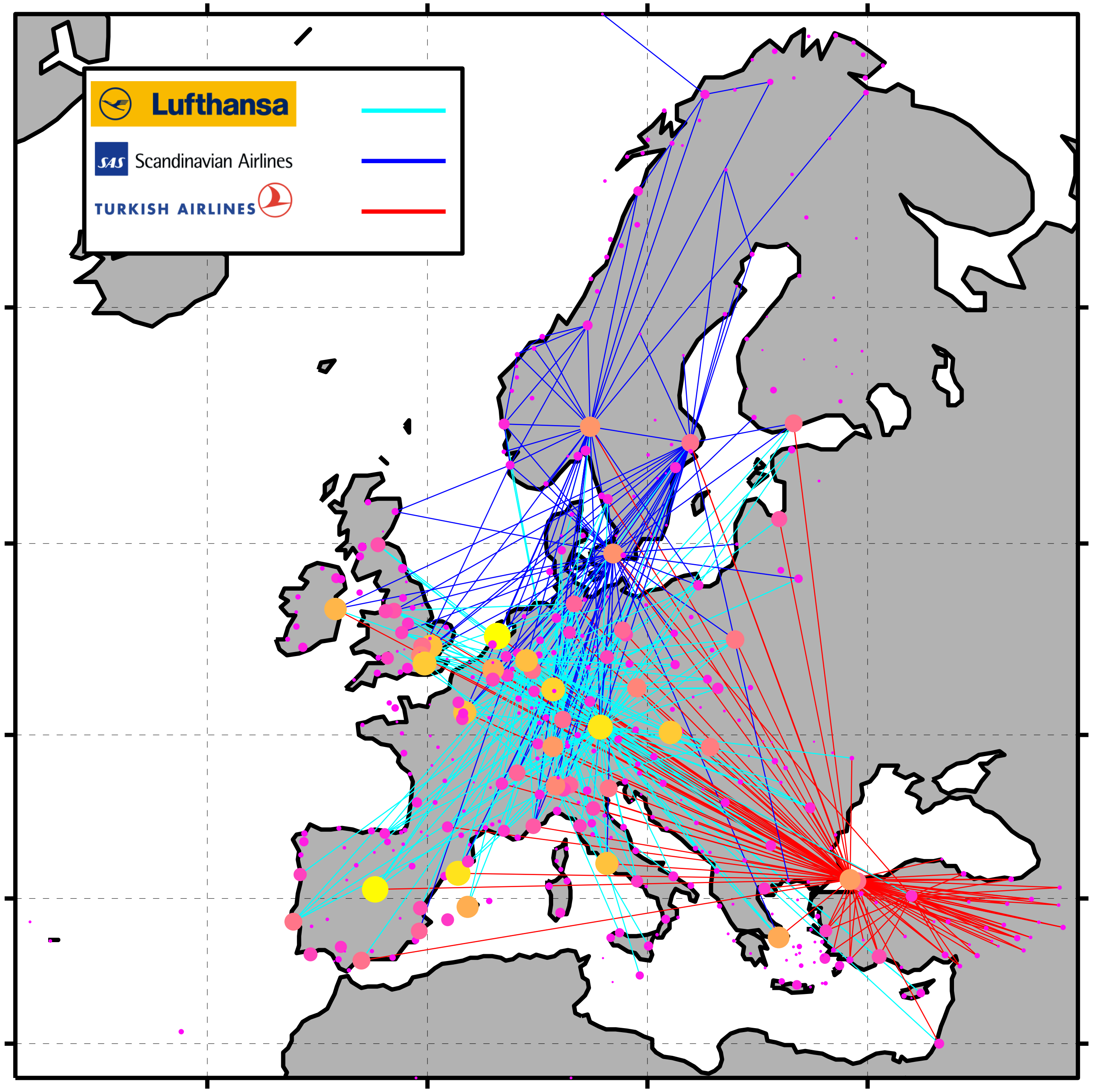
community detection and participation are useful in climate networks

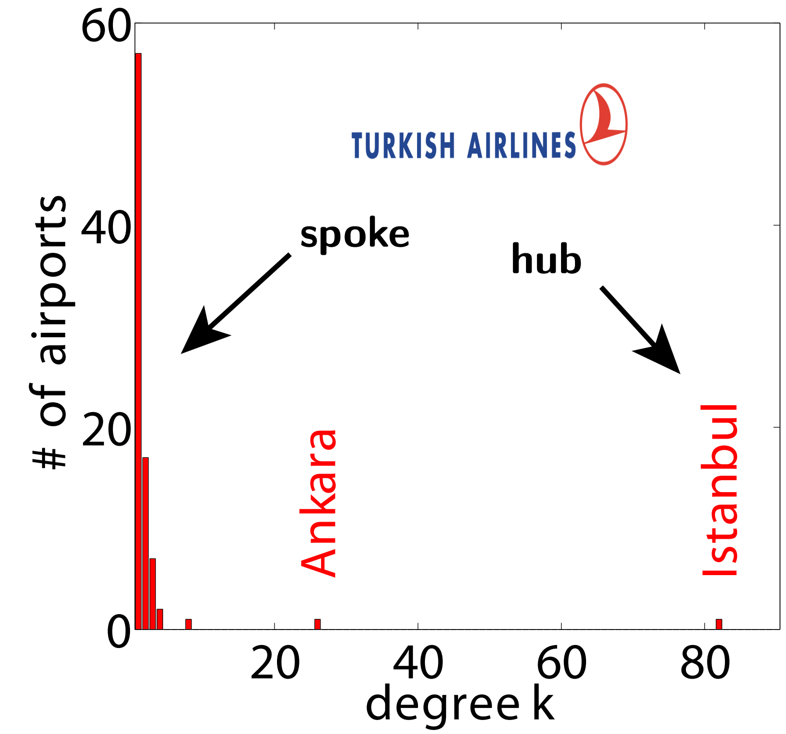
extreme precipitation synchronisation during Indian Summer Monsoon

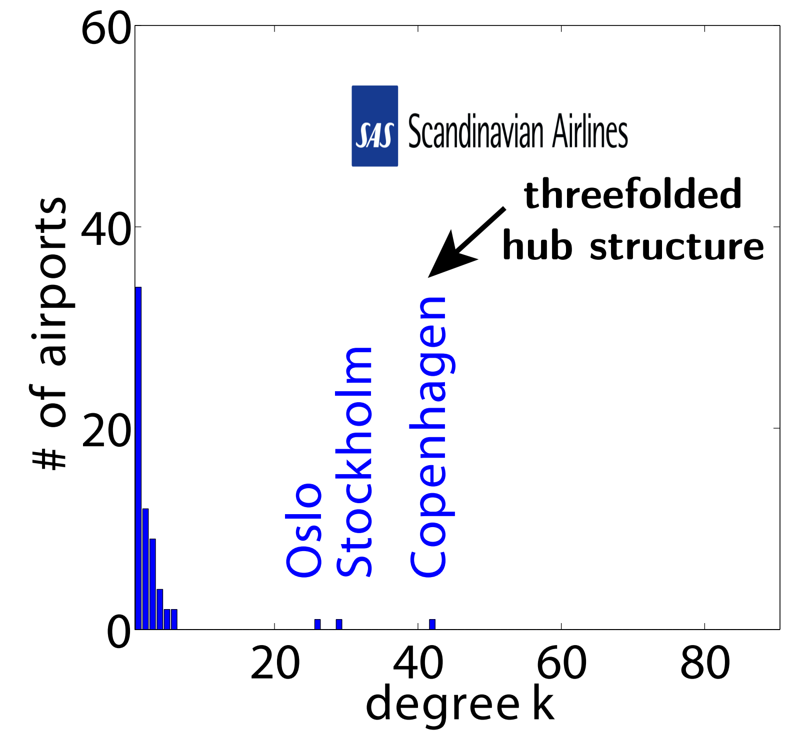
Also applicable to multilayer or time-dependent networks

- multilayer networks consist of different kind of edges (e.g. social interactions or means of transportation)
- time-dependent networks change the adjacency matrix at each time step and can be represented as multilayer networks



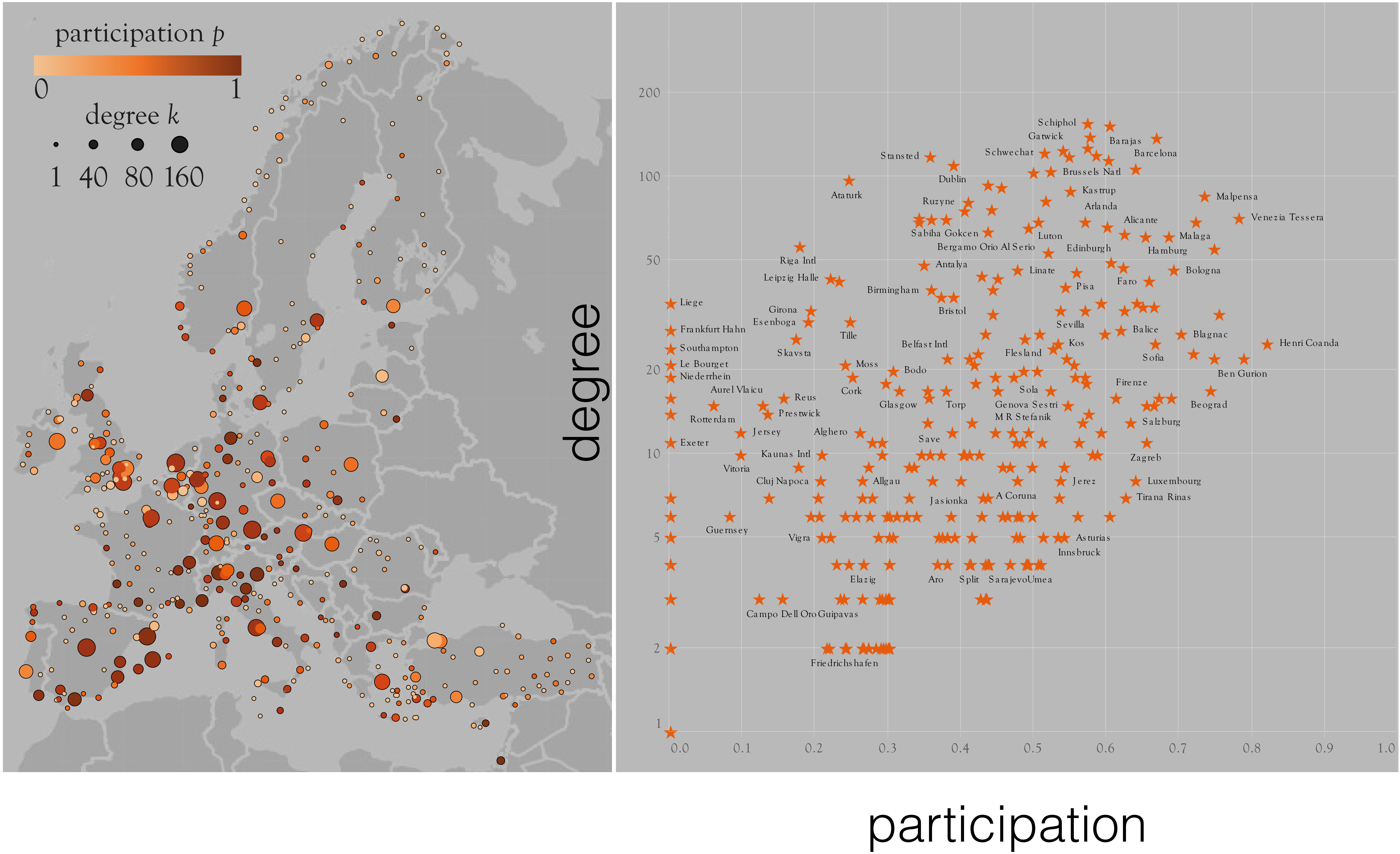






airlines are spatially organised

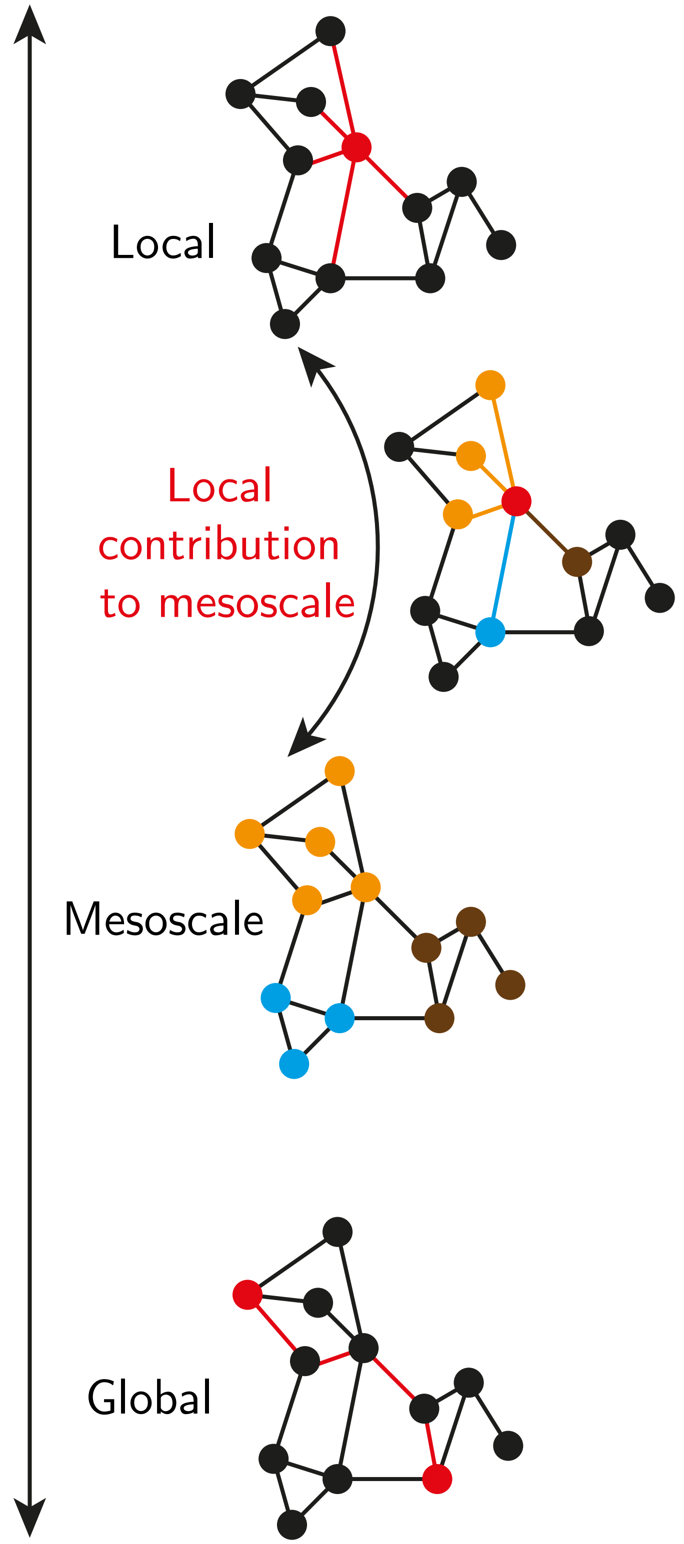
hub and spoke



airports have diverse roles in this multilayer organisation

Conclusion

- nodes have diverse roles in the mesoscale structure of networks
- participation and hubness are **one way** of deciphering those
- structures for segregation and integration are present in neuronal networks
- borders between modules can be investigated
- multilayer variant is applicable



Thank you!

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Klimm, F., Stolbova, V., Kurths, J., & Zamora-López, G. Mesoscale analysis of the network of extreme precipitation during the Indian Summer Monsoon (to be submitted to Nonlinear Processes in Geophysics)
Klimm, F., Kurths, J., & Zamora-López, G. Roles of nodes inside the multilayer structure of networks (in preparation)