ETH zürich

Resilience of complex systems: a complex network approach

Giona Casiraghi
Chair of Systems Design, ETH Zürich
gcasiraghi@ethz.ch

in collaboration with:
Prof. Dr. Dr. F. Schweitzer, Dr. A. Garas, Dr. Ingo Scholtes, V. Nanumyan

1 Introduction

Resilience quantifies the capacity of a system to *withstand shocks* and its ability to *recover from them*. Here we concentrate on the structural component of resilience: ***robustness***. We propose a methodology to identify relevant structures, and we further show that the coupling of these components is relevant for measuring resilience.

2 Multilayer Perspective

Many different types of relations between system elements possibly exist. But what are those that matter when studying its resilience? We address the problem of finding **resilience factors** in the framework of *multilayer networks.*

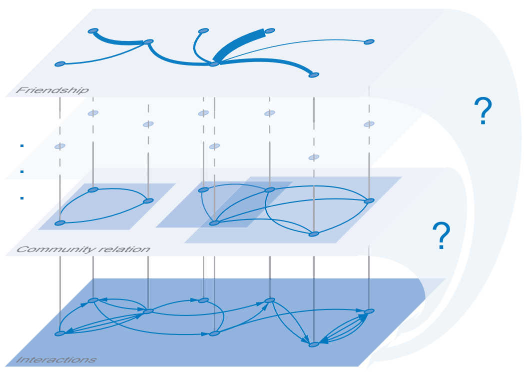

Fig. 1. *Multiplex network* representation of a system, where different types of ***relation layers*** governs the interactions between system elements. But how do relations drive interactions?

Furthermore, the influence of ***coupling, interdependent multilayer networks*** is of utmost importance, in particular in the study of percolation, diffusion dynamics, and systemic risk. In ecology, network approaches have been restricted to mutualistic, bipartite networks. We show that embedding them in multilayer networks provides a new perspective in the study of the resilience of complex systems.

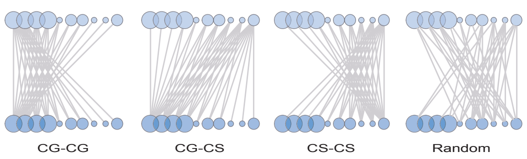

Fig. 2. How important is the coupling between network layers? Resilient bipartite networks (e.g. mutualistic networks) have been found to be *nested*. However, the effect of their embedding in a broader multilayer network has often been neglected.

3 Resilience: the Influence of Layer Coupling

In mutualistic networks in ecology and in cooperative networks in economy is known that ***nestedness*** plays a relevant role in the resilience of such networks. Here we investigate the effect of adding information about the *within-layer* topology, when the *between-layers* structure is perfectly nested. In other words, we study the importance of multilayer embedding by means of simple examples.

What is the effect of different couplings between layers?
We find that introducing within-layer links does not necessarily reduce the measured resilience of the system against elements removal, as expected from naîve intuition. Moreover, even though the between-layers structure is kept constant, there are significant variation in the resilience profiles when considering different couplings.[1]

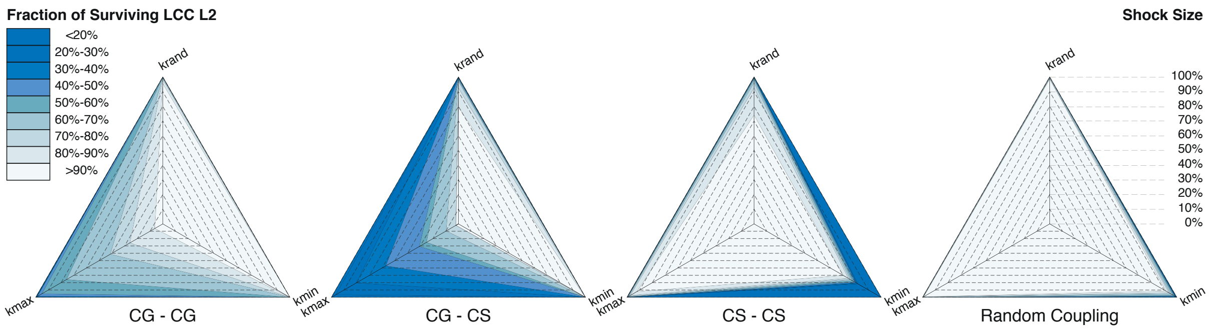

Fig. 3. Resilience profiles for 3 different couplings between a nested interlayer and 2 layers with a core-periphery structure. Different coupling provide radically different profiles. We can conclude that ignoring the multilayer pespective gives an incomplete view on the resilience of a system. As benchmark, we use radom coupling profile.

4 Network Regression

We propose to identify the resilience factors of systems studying their network representation. We introduce a methodology to perform *network regression,* to identify which layers drive the observed interactions in a multilayer network representation.[2]

To do so, we develop a novel statistical ensemble of complex networks. The ***generalised hypergeometric ensemble*** allows to statistically test hypothesis about complex network models of observed systems. It specifies the probability to observe a network given some model hypotheses.[3]

5 Conclusion

We present a preliminary framework to study of the resilience of complex systems, focusing on multilayer network representations. In particular, we show how to identify resilience factors and that considering multiple layers instead of simple bipartite networks is important for a correct evaluation of resilience.

The analysis of resilience needs to be further extended with respect to its dynamic component ***adaptation***, i.e. the ability of a system to *respond* to shocks. We foresee that measuring adaptation involves comparing the changes of a system against suitable null-models.

6 References

1. Garas, A., Casiraghi, G. & Schweitzer, F. Robustness of Multilayer Networks. Manuscr. Prep. (2017).
2. Casiraghi, G. Multiplex Network Regression: How do relations drive interactions? arXiv Prepr. arXiv1702.02048 (2017)
3. Casiraghi, G., Nanumyan, V., Scholtes, I. & Schweitzer, F. Generalized Hypergeometric Ensembles: Statistical Hypothesis Testing in Complex Networks. arXiv Prepr. arXiv1607.02441 (2016)