On metrics and models for multiplex networks
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Concluding remarks

In this thesis, we have focused on multi-layer complex networks, developing various maximum-entropy models and showing their application in the extraction of relevant patterns of several real systems. We have therefore exploited concepts stemming from theoretical and statistical physics, such as entropy and partition functions, to design null models for networked systems as canonical ensembles with specified constraints.

The definition of random benchmarks in terms of canonical ensembles is by no means new, as it has already been introduced at the beginning of the 21th century for single-layer networks and extended to the multiplex case a few years later. Our main contribution, clearly illustrated in this work, consisted in the fit of such maximum-entropy models to real-world systems via the so-called maximum-likelihood method. This allowed us to deeply analyze systems composed by a large number of layers without incurring into significant computational limitations.

We have pointed out that the aforementioned models can be employed for different - and sometimes even opposite - purposes, ranging from the phenomenological modelling of observed networks to the statistical inference and data filtration. In this context, we have indeed shown that they are able to inform us about the genuine correlations between layers of a multiplex; the flexibility of these models was also exhibited by their application to directed and weighted graphs, as illustrated in Chapters 1 and 2. Furthermore, in Chapter 3 we have pointed out that such metrics can overcome the problem of limitedness of topological information, leading to the design of new multiplex reconstruction methods able to infer the inter-layer topology from partial information. We have then highlighted that, strikingly, the same models that can be used for the previous inference problems may also be employed for the opposite task, namely the data filtration. This observation led us to the development of an original and successful graph pruning method (Chapter 4). In conclusion, we have also focused on a scientific publications system, thanks to the collaboration with the ScienceWISE platform, that allowed us to connect scientific manuscripts based on their content. In Chapter 5 we have shown that this system can be effectively tackled in the network theory framework; a better comprehension of this system, involving the whole scientific community, may come from the inclusion of other layers of interactions, such as adding the information about the citations between articles. These analyses can therefore provide insights into the global scientific landscape.

As previously stated, one of the cornerstones of the thesis was the focus on real-world systems. Indeed, we have tested all our new metrics and models to observed networks, ranging from the economic sector to the infrastructural one. Moreover, we have highlighted that a better understanding of some of these systems is strictly connected to the use of the multiplex approach, as clearly shown for instance in the case of the World Trade Network. This approach can therefore provide a significant added value to the usual "monoplex" network theory.

Our findings point out once more the power of the maximum-entropy method, especially when coupled to the maximum-likelihood approach, and show their relevance with respect to various fields. These results can therefore be considered as the building blocks of further research in the direction of more advanced maximum-entropy network models, for instance with the introduction of inter-layer correlation within the benchmarks and the applications of similar reference models to different fields, ranging from the financial sector to the biological systems.