LINC

Learning about Interacting Networks in Climate

Marie Curie Initial Training Networks (ITN)

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WorkPackage WP2: *Interacting Networks*

Deliverable D2.2

A computer algorithm developed that generates interacting climate networks for the ITN

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EXECUTIVE SUMMARY

The main objective of this deliverable is to produce a Monte Carlo simulation of coupled networks. This means that different runs of the computer program with the same parameters but different initial seed number yield a coupled network data structure as an outcome.

Since the main theme of LINC is “learning about interacting networks in climate”, a simulation of interacting networks is obviously essential for the entire research in all groups.

In particular, WP1 deals with network construction based on real climate data and climate simulations. These are expected to resemble the theoretical predictions that our algorithm supplies. WP2 is about investigating interacting network. This aim stands on two implementation feet – one is mathematical theory, and the other is the current delivered computer algorithm. WP3 deals with natural variability of the climate, as reflected by the climate network. This is modelled by our Monte Carlo simulation as different realizations based on the same sets of parameters. WP4 deals with climate changes. This is modelled by our Monte Carlo simulation as different realizations based on different sets of parameters. WP5 deals with identification of early signatures of climate changes (i.e. tipping points). These can be simulated as an external loop that calls our program with the same seed number and gradual changes of a parameter.

Our computer algorithm can produce coupled networks of the kinds: 1. Erdos Renyi 2. Scale free 3. Random Regular. 4. Any other general distribution of links. The networks can be either directed or non-directed. The coupling is done by attaching a fraction of the nodes of the several networks to each other.

The main research results which were obtained by this program indicates that the critical point for a cascading failure of all nodes of the network is fluctuating. This result is a new theoretical achievement in the research field of interacting networks (WP2) and has an analogy to the natural variability discussed in WP3. As a follow-up we intend to include a new generalization of interaction between networks in our analysis, based on ideas from F. Radicchi et. al., in [2].

DELIVERABLE IDENTIFICATION SHEET

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Abstract (for dissemination)	The deliverable describes a Monte Carlo simulation of coupled networks. Different runs of the computer program with the same parameters were run but different initial seed number in order to yield a coupled network data structure as an outcome.	
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Issue Date	**Rev No.**	**Author**	**Change(s)**
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1 Introduction

In a system of interdependent networks, an initial failure of nodes invokes a cascade of iterative failures that may lead to a total collapse of the whole system in a form of a first order transition. When the fraction of initial failed nodes 1-p is at criticality, $p=p_c$, the number of iterations in the cascade, τ, diverges. Here, we find that, while the value of the critical threshold p_c is accurately evaluated by mean-field equations, the critical dynamical process of cascading failures is governed by random fluctuations, which are simulated by a computer program, and validated by an analytic work which is explained in a separate deliverable. The difference between the dynamical process of different single realizations becomes larger as N increases and the standard deviation of τ diverges as $N^{1/3}$. Our computer program is able to generate interacting networks and follow this process, reproducing the analytical results.

2 Results

The basic model of interdependent networks has been first introduced in 2010 [1]. Figure 2-1 shows an example of interdependent networks. The program uses C++ for the core of Monte Carlo calculations, in order to optimize for speed. Three classes "system", "network" and "node" are defined to describe three levels of objects and their corresponding member functions and parameters. Each "node" object has a list of connectivity neighbours, as well as a list of dependency counterparts. In this way, the interdependency links are realized. The data structure I use for the networks is a vector, defined in the standard template library (STL). Simulation results are output in txt files, which are then further analysed and visualized using MATLAB.

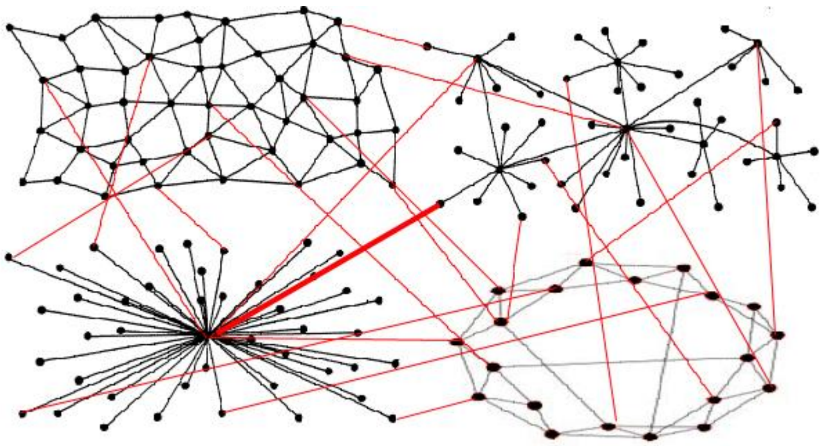

Figure 2-1: An example of interdependent networks

Our computer algorithm can produce coupled networks of the kinds: 1. Erdos Renyi 2. Scale free 3. Random Regular. 4. Any other general distribution of links. The networks can be either directed or non-directed. The coupling is done by attaching a fraction of the nodes of the several networks to each other. The dynamics simulated after the generation of the network is an initial failure in one of the networks which causes a cascade of failures in the other networks. The parameters which can be changed are: 1. The number of networks. 2. The possibility for an initial failure of a node. 3. The degree distribution. 4. The size of the system. 5. The number of realizations. 6. The coupling strength.

The main results which were obtained by this program is that the critical point for a cascading failure of all nodes of the network is fluctuating. This result is a new theoretical achievement in the research field of interacting networks (WP2) and has an analogy to the natural variability discussed in WP3.

3 NEXT STEPS

As a follow-up we intend to include a new generalization of interaction between networks in our analysis, based on ideas from *Abrupt transition in the structural formation of interconnected networks*, F. Radicchi et. al.,[2]. This generalization of interactions which will be included in a separate computer program, seem to be directly applicable to climate networks. We are now testing this idea.

4 SUMMARY

A C++ core Monte Carlo simulation, as well as external MATLAB utilities for visualisation were produced.

The program was validated against accurate mathematical analysis. It was used as a part of a study of the phase transition of the system under random attacks, and dynamical processes of failures. This implementation is of direct relevance to LINC work, and can be used to support research in other work packages.

5 REFERENCES

[1] Buldyrev, S. V, Parshani, R., Paul, G., Stanley, H. E., & Havlin, S. *Catastrophic cascade of failures in interdependent networks*. Presence: Nature, 464(7291), 1025–8, 2010. Doi:10.1038/nature08932.

[2] Radicci, F., Arenas A., *Abrupt transition in the structural formation of interconnected networks.* In arXiv.org > physics > arXiv:1307.4544