Short Communication

Some thoughts on the control of network systems

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Abstract
The controllability of network-like systems is becoming a trendy key-issue in many disciplines, including ecology and biology. To control a biological, ecological or economic system is to make it behave according to our wishes, at the least possible cost. In this paper, I propose some ideas on networks control that do not precisely follow recent papers on the argument. By the way, since this scientific topic is still in open evolution, discordant thoughts might be helpful to the debate.

Keywords: network control; driver nodes; driver links; external control; networks taxonomy.

1 Introduction

Back in 1955, John Von Neumann (Von Neumann, 1963) observed that one could achieve great changes in global climate by changing the albedo on large portions of the ice caps. In other terms, if we observe some displeasing changes in the climate of our planet, John Von Neumann stated that we can control the climatic system and return to a solution that we like better.

Network controllability is in fact the ability to guide a system's behaviour towards the desired state through the appropriate handling of a few input variables (Luenberger, 1979; Slotine and Li, 1991). The controllability of network-like systems is becoming a trendy key-issue in many disciplines, including ecology (Caldarelli, 2007) and biology (Dorogovtsev and Mendes, 2003; Kim and Motter, 2009; Marucci et al., 2009).

In nature, there are many situations where the control of a very large complex network is an important functional requirement; for instance, this is the case of some bodily functions such as the contemporaneous beats of the heart cells (Peskin, 1977), or the synchronous behaviors of the cells of the suprachiasmatic nucleus in the brain, which sets the clock of the circadian bodily rhythms (Yamaguchi et al., 2003). Other examples can be easily found in social networks, where the formation of mass-opinions and the emergence of collective behaviors are frequently observed.

Recently, in Nature Liu et al. (2011) have proposed analytical tools for the controllability of complex networks, identifying the set of driver nodes that can guide the system's dynamics. Their way to the controllability of networks is based on the identification of the set of driver nodes that can guide the system's dynamics, in other words on the choice of a subset of nodes that are selected to be permanently controlled. This assumption seems motivated by real-world networks observation, where a decentralized control action is often applied only to part of the nodes.

I remark here the need for five key-improvements to this usual approach in networks controllability, using the paper by Liu et al. (2011) as a scientific benchmark.

2 Five Unconventional Thoughts on Networks Control

First, Liu et al. (2011) focussed on the control of nodes, neglecting to enlarge their approach to edges as well. They claim that, for most real networks, weights of links are either unknown or known only approximately, and that, even if all weights are known, the control based on a brute-force algorithm would be computationally prohibitive for large networks.

Although a *n*-node network could bear up to *n*(n-1)* links (or *n*n* if we also consider self-links) among nodes, this could be conceived as a better chance of network control, not just like a computational difficulty. The higher the number of switches on which one can act, the higher the chance to commute the actual network into the desired one. Several tools, like genetic and particle swarm optimization, can reasonably lower the seemingly intractable problem of edge control. Furthermore, the control of one edge leads to directly influence both the two nodes connected by the edge itself, hence network control based on edge ascendancy could be more parsimonious than expected.

Second, I observe that, while nodes are time-dependent by definition, edges are not time-dependent by necessity in many types of network. It's well-known that many stock-and-flows networks in ecology (Cohen et al., 1990), geography (Chorley and Kennedy, 1973) and socio-economic dynamics (Forrester, 1971; Leontief, 1966) have almost constant links, at least on short and mid-time intervals, and are hence expressed on a yearly basis. The controllability of complex networks through discrete-time edge control could result more parsimonious than a continuos-time node control in many situations.

Third, I remark that the concept of driver nodes employed by Liu et al. (2011) could be translated to edges too. One could think of the control of edges which connect driver nodes as complementary to the control of just driver nodes. Because of the distributed nature of complex networks, whose dynamics are mainly decentralized, it is feasible to control them by acting locally on permanently-selected driver links, which could play the role of network pacemakers, and by exploiting the coupling effects between these and the rest of the network.

Fourth, I observe that while the control of driver nodes has just one time-dependent solution to get the desired final state, the control of edges makes many solutions available to the controller due to the indirect effects that can derive higher-level properties of the system. The wider the network, the higher the number of solutions to the problem of controlling it by mastering its edges. Because one solution is enough to the purposed goal, the controller is not requested to find all the solutions available to get the desired final configuration, which would be truly prohibitive.

Fifth, Liu et al. (2011) do not mention the chance to employ a node exogenous to the network (Almendral et al., 2009). Nodes in the network might behave as slave systems of the external node, and could be coupled to it through *n* links. In this way, the problem of network controllability could be translated into the control of just *n* links, instead of *n*(n-1)*. If one external node is not enough, further nodes can be added up to satisfaction.

3 Conclusions

The controllability of complex networks through edge control is more promising than Liu et al. (2011) affirm, and a precise taxonomy of network properties (discrete vs. continuous time; directed vs. undirected; diameter, openness, self-organization, robustness; levels of clustering, assortativity-dissortativity and degree distribution) (e.g., Albert et al., 1999; Strogatz, 2001) should precede the choice of which switches (nodes, a subset of nodes, edges, a subset of edges, nodes and edges, a subset of edges and nodes, external nodes) to act on in order to tame them.

References

Albert R, Jeong H, Barabási AL. 1999. Diameter of the world-wide web. Nature, 401: 130-131

Almendral JA, Sendiña-Nadal I, Yu D, et al. 2009. Regulating synchronous states of complex networks by pinning interaction with an external node. Physical Review E, 80: 066111

Caldarelli G. 2007. Scale-Free Networks: Complex Webs in Nature and Technology. Oxford University Press, UK

Chorley RJ, Kennedy BA. 1971. Physical Geography: A Systems Approach. Prentice-Hall Press, USA

Cohen JE, Briand F, Newman CM. 1990. Community Food Webs: Data and Theory. Springer-Verlag, Germany

Dorogovtsev SN, Mendes JFF. 2003. Evolution of Networks: From Biological Nets to the Internet and WWW. Oxford University Press, UK

Forrester JW. 1971. World Dynamics. Wright-Allen Press, USA

Kim DH, Motter AE. 2009. Slave nodes and the controllability of metabolic networks. New Journal of Physics, 11: 113047

Leontief WW. 1966. Input-Output Economics. Oxford University Press, UK

Liu YY, Slotine JJ, Barabasi AL. 2011. Controllability of complex networks. Nature, 473:167-173

Luenberger D.G. 1979. Introduction to Dynamic Systems: Theory, Models, & Applications. Wiley, USA

Marucci L, Santini S, di Bernardo M. 2009. How to turn a genetic circuit into a synthetic tunable oscillator, or a bistable switch. PLoS ONE, 4: e8083

Peskin C. 1977. Mathematical Aspects of Heart Physiology. Courant Institute of Mathematical Sciences, New York, USA

Slotine JJ, Li W. 1991. Applied Nonlinear Control. Prentice-Hall, USA

Strogatz SH. 2001. Exploring complex networks. Nature, 410: 268-276

Von Neumann J. 1963. Collected Works. Pergamon, Oxford, UK

Yamaguchi S, Isejima H, Matsuo T, et al. 2003. Synchronization of cellular clocks in the suprachiasmatic nucleus. Science, 302: 1408-1412