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Crisis Responses and Crisis Management: What can we learn from Biological Networks?

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Abstract: The generality of network properties allows the utilization of the 'wisdom' of biological systems surviving crisis events for many millions of years. Yeast protein-protein interaction network shows a decrease in community-overlap (an increase in community cohesion) in stress. Community rearrangement seems to be a cost-efficient, general crisis- management response of complex systems. Inter-community bridges, such as the highly dynamic 'creative nodes' emerge as crucial determinants helping crisis survival.

Keywords: adaptation; cellular networks; communication networks; creative node; crisis management; network; network modules; protein-protein interaction networks; social networks; stress; yeast

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1. Biological networks may provide role models of social behavior

In the last decade the network approach became increasingly popular to study complex systems. Current network representations simplify system complexity to a ‘one-dimensional' scheme, where the interactions are represented as a connection-weight. Network edges are often directed but, colored graphs, multiple edges, hypergraphs and conditional edges are still seldom used. However, the simplicity of network structures has enormous benefits. They not only give us a visual image of complex systems providing an instant recognition of network communities, hubs and other key nodes, but also have a number of general topological properties, which are very similar in biological, social and engineered networks. The small-world character, the existence of hubs, appearance of network communities and hierarchical, nested structures, the stabilizing role of weak links are all general network features (Csermely, 2009). This allows us to use the network description as a conceptual framework to guide our creative associations.

Network-driven transfer of principal findings allows investigator to judge the importance of her discovery by determining whether the finding is applicable to many types of networks of atoms, molecules, cells or organisms, or is valid to only one of these hierarchical levels. Obviously those findings, which have a general descriptive power to all complex systems, such as those mentioned before, are more important than those, which are highly specific to a certain network. Moreover, the network approach provides a powerful solution to circumvent creativity deadlocks. Networks enable us to translate the original problem in a scientifically rigorous manner into the context of another scientific field, where the same problem is embedded to a quite different conceptual and linguistic context. The novel context often sparks unexpected associations, which lead to creative solutions, when translated back to the original context using the same network-driven approach (Farkas et al., 2011). All these require a multidisciplinary research group, which is quite a commonplace in network science.

One of the authors (P.C.) experienced such a surprising system-based transfer of knowledge from one context to another, when he read the seminal review of Scheffer et al (2009) on the “Early warning signals of critical transitions,” where the authors compared the common signs of pre-crisis periods in ecosystems, markets, and climate. In this review, three major warning signals were identified for all systems studied: 1.) the “slower recovery from perturbations”; 2.) the “increased self-similarity of behavior,” and 3.) the “increased variance of fluctuation patterns.” Based on our earlier studies on aging (Kiss et al, 2009; Simko et al., 2009), it was imminently clear that an aging organism shows the very same three signs of change. Thus, aging can be perceived as an early warning signal of a critical transition, where the phase transition is called: death. However, this sobering message also has a positive implication: crisis periods can be slowed down, postponed, or prevented by agents of independent and unpredictable behavior, such as stem cells (in organisms), omnivores or top predators (in ecosystems), or market gurus (in markets) (Farkas et al., 2011). Since biological networks are blueprints of organisms, which survived billions of crisis situations, this above examples highlight their great potential as role models of social behavior.

2. Systems level crisis responses of yeast cells

We performed a network analysis of crisis adaptation on the protein-protein interaction network of yeast cells experiencing a severe stress, such as heat shock using our recently developed method (Kovacs et al, 2010). The overlap between communities of the yeast interactome decreased (their cohesion increased), thus the yeast interactome became partially disintegrated as an initial response to stress. The stress-induced decrease of inter-community interactions was beneficial, since it 1.) allowed a better focusing on vital functions, and thus spared resources; 2.) localized damage to the affected communities; 3.) reduced the propagation of noise; 4.) allowed a larger ‘degree of freedom' of the individual communities to explore different adaptation strategies; and 5.) helped the ‘mediation of inter-community conflicts' during a period of violent changes (Mihalik & Csermely, 2011).

3. Changes in cohesion and association of network communities — as a general mechanism of crisis management and adaptation

Community reorganization emerged as general and novel systems level way of cost-efficient adaptation (Mihalik & Csermely, 2011). Food limitation causes a diversification and specialization of sea otters (Tinker et al., 2009) that greatly resembles to the changes of yeast protein communities in stress. A similar increase of modularization (patchiness) was observed in increasingly arid environments suffering from a larger and larger drought stress (Rietkerk et al., 2004). A partial decoupling of communities was observed, when criminal networks faced increased prosecution (Kenney, 2009). A recent study detected a reorganization of brain network modules during the learning process (Bassett et al., 2011). Stress-induced psychological dissociation (Bob, 2008) may also be perceived as a partial decoupling of psychological modalities. The stress- induced uncoupling/recoupling cycle greatly resembles Dabrowski's psychological development theory of positive disintegration (Mendaglio, 2008), as well as the Schumpeterian concept of “creative destruction” describing socio-economic changes (Schumpeter, 1942). In the model of Estrada & Hatano (2010) community overlaps of socio-economic networks were diminished with the increase of external stress (e.g. by social agitation, or crisis). Crisis-induced changes of telephone communication networks were nicely demonstrated by the recent study of Bagrow et al. (2011). Increased modularity of the banking system was pointed out by Haldane and May (2011) as a very efficient way to prevent the return and extension of the recent crisis in economy. As we summarized recently (Csermely et al., 2012) networks seem to segregate to two basic conformations, the stratus- and cumulus-like network topology, resembling to the interactome structure of normal and stressed yeast cells, respectively.

Inter-community bridges, such as the highly dynamic ‘creative nodes' (Csermely, 2008), determine complex systems' adaptation potential (called evolvability in biological systems). Active centers responsible for the chemical catalysis of enzymes often occupy such a position in protein structure networks (Csermely, 2008). Bridges between communities are reorganized in yeast stress (Mihalik & Csermely, 2011). Inter-community bridges emerge as crucial determinants helping crisis survival.

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Peter Csermely established the LINK network science group in 2004 (www.linkgroup.hu). In 1995 he launched a highly successful initiative, which provided research opportunities for more than 10,000 gifted high school students so far (www.nyex.info). In 2006 he established the Hungarian National Talent Support Council (www.tehetsegpont.hu) running a talent support network involving ~200,000 people and establishing a Europe-wide network of talent support (www.talentday.eu). He wrote and edited 15 books and published over 200 research papers with total independent citations above 5,200. He was the member of the Wise Persons' Council of the Hungarian President, is a vice president of the Hungarian Biochemical Society is the past president of Cell Stress Society International, an Ashoka Fellow, was a Fogarty and Howard Hughes Scholar and received several other national and international honors and awards including the 2004 Descartes Award of the European Union for Science Communication.

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