Title:	Resilience of networks of multi-stable chaotic systems to targetted attacks
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Abstract:	Abstract: Predictions of the resilience of dynamical networks is a fundamental challenge in physical, biological, environmental, and social sciences. The resilience of the network depends crucially on both network properties, as well as the dynamical behaviour of the interactive elements. While it is expected that nodes of the highest centrality will play an essential role in maintaining the robustness of the network, we still do not have a universal result that can explain how the interplay of nodal dynamics and connection properties affect network resilience. So to understand this aspect we examine the collective dynamics of multi-stable Duffing oscillators coupled in a variety of network topologies, in response to different classes of strong localized perturbations. Our investigations span both ring networks where all nodes have same features, as well as star networks where the hub and peripheral nodes have markedly different centrality measures. Further we also consider heterogeneous scale-free networks which bridge these two contrasting scenarios with nodes having different distributions of different centrality properties. The multi-stable Duffing oscillator offers a particularly fertile test-bed as it has co-existing chaotic and limit cycle attractors, marked by complex basin boundaries. In order to assess the robustness of this network comprised of complex multi-stable dynamical elements, we use a variant of multi-node Basin Stability, where a large perturbation is given to a specified set of nodes, chosen randomly or preferentially according to the network properties. We find that the robustness of the network depends on the centrality of the perturbed node, with betweenness centrality being more important than degree or closeness centrality in determining resilience. Further, we demonstrate that ring and star networks of multi-stable limit cycles are more robust than networks of multi-stable chaotic attractors. However, counter-intuitively we find that scale-free networks of multi-stable limit cycle oscillators are less robust than networks of multi-stable chaotic attractors, under certain classes of perturbations. Thus we demonstrate that, in addition to connection properties, the non-trivial interplay of nodal dynamics and type of perturbation is also crucial for assessing the tolerance of different types of complex dynamical networks to diverse kinds of strong targetted attacks.
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