Vulnerability Detection for Episimmer

If this problem peaks your interest please contact us and we can discuss further. Here is a short introduction and brief.

Episimmer is an open source epidemic simulation framework built to provide decision support to closed systems like university campuses, industrial areas and residential communities. A major part of decision support is detecting vulnerabilities in the ecosystem and taking appropriate actions through policy implementation.
In simple terms, vulnerabilities can be classified as the weakest links in the ecosystem that on removal improve the epidemic situation and reduce risk of further spread. These vulnerabilities can arise from agents, locations, events and interactions. This can be viewed as disconnecting parts of the system to stop spread of a disease. We shall specifically focus on agent based vulnerabilities.

Agent based vulnerabilities can be broadly classified into two groups

- Vulnerable agents : Agents who are most likely to reach a certain disease state. For example 'agents most likely to die' or 'agents most likely to get infected' or 'agents most likely to be hospitalised'.
- Agent vulnerability : Agents on removal or constrained for a duration of time from the ecosystem, lead to the largest reduction in risk or size of the epidemic. This is an optimization problem using a cost function that can encode priorities.

We focus on the second type called Agent vulnerability and elaborate further.

We define a vulnerability set of size k as a set of k nodes which on removal minimizes the cost function.

Problem statement
Find an efficient heuristic or approximate algorithm that can find a vulnerability set that minimizes the cost function in the given ecosystem. It is important to note that the system is not deterministic due to innate randomness in epidemic spread.

Ecosystem
In the simplest terms an ecosystem consists of a static interaction graph among homogenous agents. Since our focus is on determining vulnerabilities in real systems, we consider a dynamic interaction graph that changes over time, and heterogeneous agents with varying susceptibility and recovery from the disease. Finally, we consider existing policies that are already in implementation. It can be noted that the dynamic interaction network is sparse. Note that the situation with dynamic interaction networks is much more complex where the incubation period of the disease plays a very important role, thus hampering a direct condensation to a static graph.

Cost Function

We encode the degree of risk a vulnerability poses as a cost function that we want to optimize. Consider an example cost function as the total number of infections in a period of 30 days. Then we want to find a vulnerability set of agents who on removal reduce the infections the most. The cost function can also encode the safety of vulnerable agents in addition to freedom, health and economic loss.

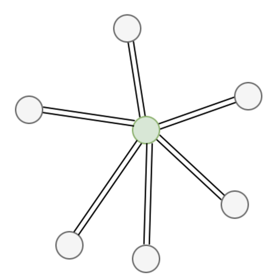
Ideas

- Encoding the dynamic heterogeneous graph with disease dynamics into a weighted static graph. Simultaneously reducing the original cost function to a new cost function on this weighted static graph.
- Pruning the original set of agents by the use of Monte-Carlo simulations.
- Using the graph laplacian matrix
- Treating each agent as a bandit in a multi armed bandit problem
- Graph Neural networks with Reinforcement learning

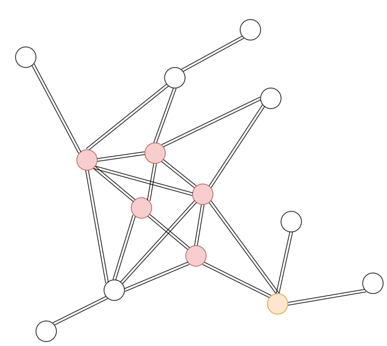
Examples

We shall look at some simple examples to illustrate this better.

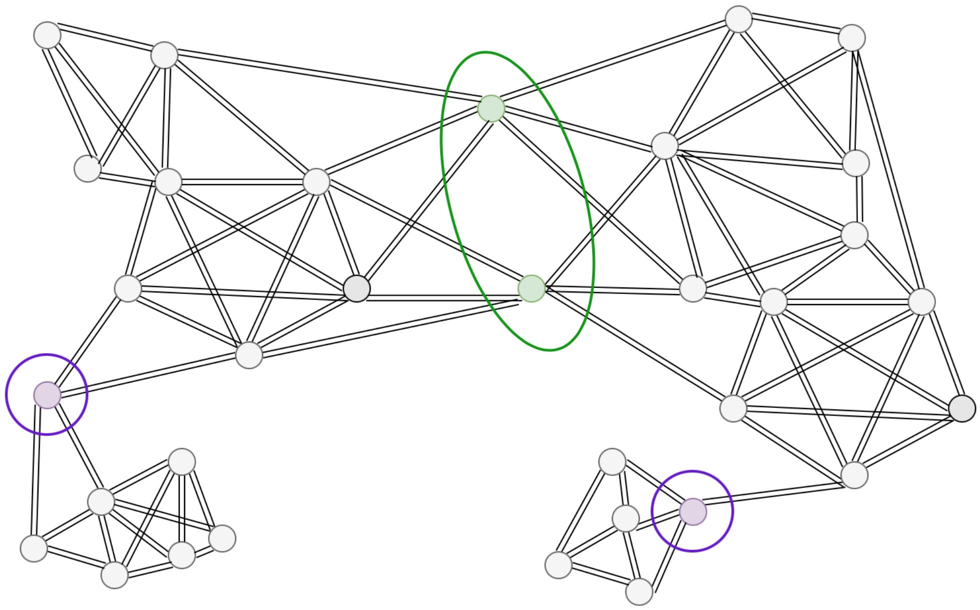
1. In a simple star graph it is evidently clear that the central node is the largest vulnerability which on removal completely slows the spread.



2. As seen in Example 1, it does not imply that a central node is most likely a vulnerability. In the below figure removal of any of the central red nodes does not perform as well as removing the orange node.



3. Below is a more complex graph where the two largest vulnerability sets of size 1(purple) pale in comparison to the vulnerability set of size 2(green).



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