Optimal control of zombie outbreaks on structured grids

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The SIR model of infectious disease represents individuals or agents as either 'susceptible' (S), 'infected' (I) or 'recovered' (R). In its most basic form, the behaviour of the model is governed by two parameters controlling the rate at which susceptible agents can be infected by neighbours, and the rate at which infected agents recover. The model is easily simulated and its behaviour on an infinite square lattice has been well studied [2, 5, 4]. Above a critical infection rate the outbreak can never be contained and all agents are ultimately infected.

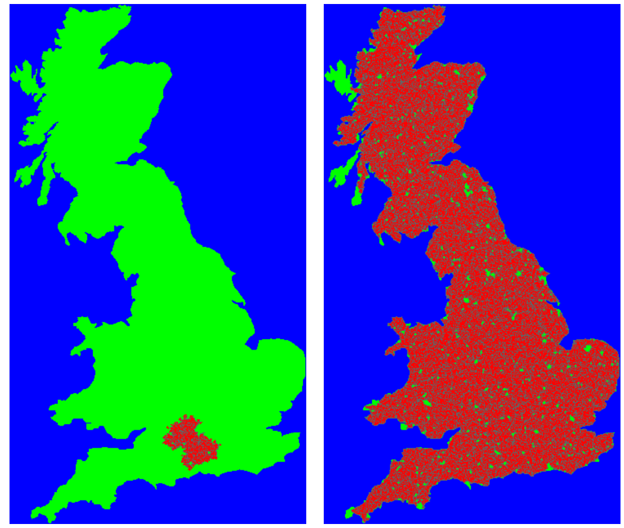
In this mini-project we will explore the behaviour of a modified SIR model, introducing some extensions which represent a 'zombie apocalypse' type outbreak in which the 'R' state represents agents which have starved or been destroyed by neighbouring susceptible pixels, i.e. the population has some capacity to fight the infection. The initial aim of the project will be to devise strategies for optimal control on simple domains, limiting the extent of the outbreak even if the critical infection rate is exceeded. For example, one might define a control radius around outbreak sites and inoculate a ring of individuals, increasing their propensity to fight back. Alternatively one might choose to obliterate all agents within that radius (napalm strike). We will evaluate the effectiveness of alternate control strategies to reduce disease spread in the context of limited resources.

The second part of the project will introduce structured grids. Here we will investigate how the topography of the simulation grid influences the critical infection rate and the optimal choice of control strategy. A simple example would be the use of landscapes with fractal boundaries (e.g. fig 1) and the interplay between the location of the initial outbreak and the optimal strategy for disease control. Structured grids will also allow us to simulate on a domain representing a network of population centres connected by transport links. Here we can investigate optimal control in the context of managing movement of agents between population centres through transport restrictions and destruction of links.

As a result of a project comprising part of PX425/CY901 'High Performance Computing in Physics' we have tested a number of effective optimisation and parallelisation strategies for simulating models of this kind, and are able to rapidly simulate on grids of arbitrary shape/size. Depending on the preference of the student, we can modify existing codes for our purposes or develop a new simulation tool from scratch. There is also scope to compare the simulation results to analytic theories of infection disease spread.

Specific deliverables would include:

- Reproduction of standard results on the unmodified SIR model.
- Quantify the statistical effectiveness of various control strategies on unstructured grids.
- Explore the behaviour of the uncontrolled SIR model on grids constructed from idealised and real geographic data.



(a) initial (b) final

Figure 1: Snapshots of an outbreak simulated on a structured simulation grid. Green pixels indicate susceptible areas, red pixels are infected and grey pixels have recovered. The simulation grid is defined by reading a black and white image file of the UK mainland.

- Establish whether the optimal choice of control strategy is modified by the structure of the simulation grid.

Whilst the specific case of zombies is unlikely to have direct application, models of exactly this kind are used to design control strategies for influenza outbreaks [1], agricultural diseases [3, 6] and other phenomena. There is also some purely theoretical interest in understanding effectiveness of control strategies as an emergent property of the simulation domain, as well as of the model itself.

As such there is scope to extend into a longer PhD project, building grids which realistically represent population structure, mapping the critical behaviour of disease models in terms of order parameters which characterise the grid topology (e.g. fractal dimension) and linking this to optimal strategies for control with comparison to historical disease data. The mini-project would be well suited to a student with good programming/visualisation skills and an interest in the statistical mechanics of disease models.

References

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