Modelling plant architecture to determine biocontrol strategies

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Introduction

Due to pressure to reduce pesticide inputs, and the move to increasing the biodiversity of agroecosystems in the UK, there is greater interest in the use of biological control of pests. Biological control has been used successfully on protected edibles in the UK (Hussey, Parr & Gould 1965, Nachman 1981, Kropczynska and Tomczyk, 1996). There are however, difficulties in transferring this approach to both protected ornamental crops, which have a low tolerance to pest damage, and to outdoor crops, where environmental factors have a profound influence on biological control.

In order to understand how biological control can be effectively used within protected ornamental crops and outdoors, it is necessary to understand the searching behaviour of the predators within plant canopies. Previous modelling work has identified the movement of natural enemies as a crucial factor in determining the success of a prophylactic release programme for biological control in ornamental crops (Skirvin *et al.* 2002). Experimental work on movement of the predatory mite *Phytoseiulus persimilis* on *Choisya ternata* (Skirvin & Fenlon, 2003) has shown that the number of connections between plants has a significant impact on the dispersal of these natural enemies, which is in agreement with the work of Zemek and Nachman (1998, 1999).

Previous work with modelling biological control in virtual plant canopies (Skirvin, 2004) demonstrated the usefulness of using virtual plant canopies to model the movement of predators, but the modelling was very involved, and it was felt that a more parsimonious model could be created. The modelling approach needed to collapse the three dimensional problem to a one or two dimensional problem, but preserve the three dimensional information, in terms of the spatial relationships between parts of all; plants within the canopy.

This abstract describes ongoing work on the application of finite graph modelling to capture the 3D structure and connectedness of the plant canopy. The movement of insects within this structure will be simulated to aid the selection of introduction strategies for biological control.

Using a finite graph model for three dimensional plant canopies

The first step in creating the finite graph model of the canopy is to export the following information about the canopy from an L-system model:

- The types of canopy components
  (stem node & leaf node)
- The relative positions of the components
  (stored as e.g. plant 1, node 1, leaf 2 for the second leaf on the first node of plant 1)
- The spatial position of each component of the canopy
  (stored as x, y and z data)
- The connections between components
  (a list of the components that are connected to each other e.g. leaf 1 on plant 1 is connected to node 1 on plant 1 and leaf 3 on plant 4)

Once this information has been stored it can be used to generate the finite graph representation of the canopy. The finite graph is represented as a list of node objects that store the type, spatial position and connectivity of the canopy components. From this class we can extract connectivity, distance and decision weighting (used for directed searching) matrices that act as a quick reference for the insects to look up information about the canopy.

The insects are simulated as a traversing object, which queries the matrices for information, which is then used to determine its movement within the plant canopy.

The simulation experiments

We aim to simulate two types of predators moving within the canopy that are described below.

Randomly searching predators

These predators represent the generalist predators, who generally do not use chemical cues to locate prey. Their decisions are made on a purely random basis, so that at any decision point in a network, each potential direction has an equal probability of being chosen.

Directed searching predators

These predators are representative of the specialist predators that are able to use volatile chemical cues emitted by plants to direct their movement within the canopy. To direct movement, we use a weighting matrix. The assumption is that a graph node containing a prey item emits a volatile cue, which can be detected by the predator. The strength of the cue is determined by the distance of a graph node from the emitting graph node (assuming equal distribution of cue in all directions) and the strength can either decrease monotonically or exponentially with distance to give different detection ranges. The weightings are calculated according to rate of change of signal strength along the direction between nodes, (effectively calculated as strength at destination node minus strength at current node divided by distance between the nodes) and stored in a weighting matrix. For a given node containing a predator, the probability of choosing a particular connection is calculated as the weighting for that connection divided by the sum of weightings for all connections (where a node has both positive and negative weightings, the negative weightings are ignored). Therefore, when a predator detects a cue, the decisions about which direction to take are biased by the weightings, increasing the likelihood of the predator moving in a direction towards the prey.

For example, using the finite graph example shown in Fig. 1: if we assume that the predator is on node 1 which has a signal strength of 70%, it has the choice of moving to node 2 (with a signal strength of 80% and a distance of 8 units) or to node 3 (with a signal strength of 85, but a distance of 15 units). Therefore the perceived rate of change of signal for the predator when moving to node 2 is 1.25, and to node 3 is 1.0, Therefore the probability of movement to node 2 is 1.25 / (1.25 + 1.0) which is 0.56, whilst the probability of moving to node 3 is 0.44.

When a predator cannot detect a cue, it follows a random search pattern, as described previously.

Simulating introduction strategies

Using the two types of predator searching, we are assessing a range of introduction strategies for the predators, based on a range of prey distributions within the canopy network. The model outputs the time taken to locate they prey items, and the minimum possible time that could be taken to locate the prey items. From this we can determine the efficiency of the different introduction strategies.

Future directions

This work is still in an early stage, and is providing baseline information about the efficacy of predator introduction strategies in plant canopies. Future work will focus on determining how predator introduction strategies will need to be adapted according to plant canopy structure and connectedness. From this information, and our work on lacunarity as a measure for distinguishing canopy structure types, we hope to be able to determine the most efficient predator introduction strategies for particular canopy types. This would have a major benefit for improving the robustness of biological control within horticultural and agricultural crops.

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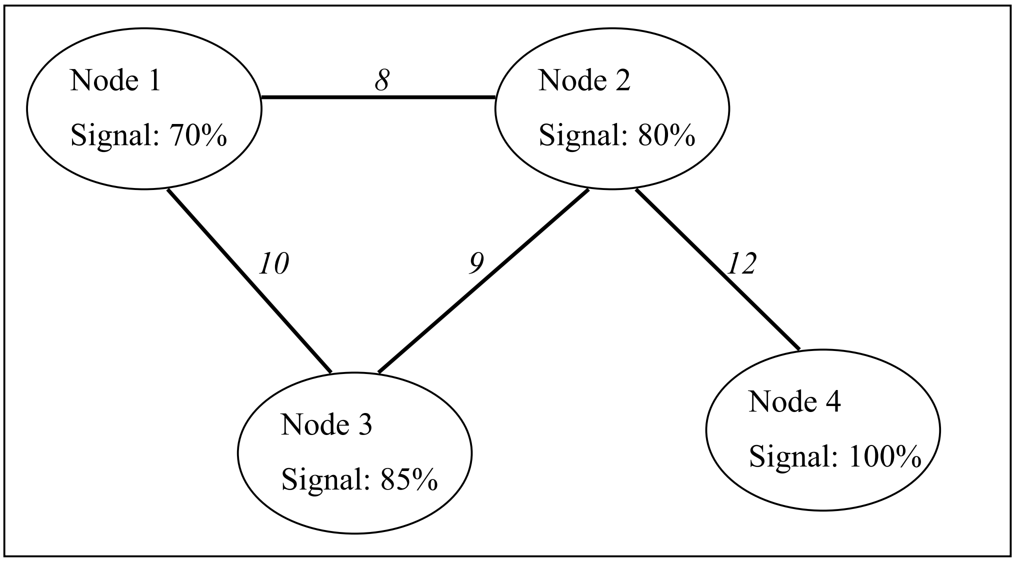

Fig. 1: Example finite graph network showing nodes and the strength of signal at each node based on distance from the emitting node (Node 4). Numbers in italics represent distances between nodes.