COM3001/6009 Modelling and Simulation of Natural Systems Assignment 1.

Lecturer: Dr D Walker (d.c.walker@sheffield.ac.uk)
Spring Semester 2021

Assignment 1 (COM3001- 40%, COM6009 – 30%)
Exploring Natural Systems using Agent-based Models – a Case Study

Aim of the Assignment

The objective of this group-based assignment is to
i) **design** an individual- (agent-) based model to represent a simplistic version of a natural system
ii) **explore** how such a model can be used to investigate a real-world natural system by carrying out virtual experiments in order to address a specific research question(s).
iii) **effectively communicate** details of an ABM your team has developed
iv) **critically discuss** examples of ABMs published in the scientific literature.

Time allocated to project
You will be working on this project with your group in the next few weeks. Demonstrators and teaching staff will be available to help during the scheduled live slots for this session 10:00 – 12:00 on Wednesdays in weeks 4 and 5, with the possibility of requesting additional slots after this. However, you should meet with your group regularly and put in additional hours outside these allocated slots.

Allocation of marks:
A mark will be allocated ***to your group*** according to the quality of a single written report to be submitted by **3pm on Friday 26th March**. One copy PER GROUP should be uploaded to BLACKBOARD.

The intention is that an opportunity will be provided for students to complete a Peer Assessment Survey in order to provide input on the overall contribution of each group member (details to be supplied at a later date). This will allow the group mark to be moderated to provide a mark for each ***individual student***.

In order to provide evidence of progress within each group, you will be assigned a Google folder where you will be asked to regularly update a *Schedule of Activities* recording the tasks assigned to and completed by each student.

Instructions

You will be working in teams of 3-4 students to design, develop and execute an ABM of a natural system (please see suggested subject areas provided at the end of this document). Each team will contain **either** undergraduate or postgraduate students, potentially from different degree programmes.

Irrespective of which subject area your team selects, you will need to undertake the following process in order to complete this assignment. It is not expected that every member of your team will be directly involved in every part of this process – how you choose to allocate tasks is entirely up to you as a team.

Your team should tackle this assignment using the following process (note it is expected that work on parts A and B will happen in parallel after the initial planning stages):

Stage 1 Planning phase (to be completed by end of live session on week 4)

1.1 Identify a natural system of interest to you that fits one of the following areas

i. Foraging
ii. Flocking/Swarming
iii. Interactions in Cellular Systems
iv. Host-parasite interactions
v. Competition between species
vi. Disease spread and control in animal populations

A brief description of each area and some potentially useful references of existing models in each area are listed at the end of this document.

1.2 define a research question regarding *emergent* behaviour of this system, and how it may be influenced by the behaviour of the individual entities (agents) present in this system, or their interactions with one another or their environment.

An example of a suitable research question (for the foraging example) would be something along the lines of:

Does more effective communication between scout and worker ants in a colony lead to more efficient foraging?

An example of a research question focussed on the environment would be:

Does the distribution of food sources in the environment alter the efficiency of a colony to forage effectively?

1.3 Do some preliminary reading about the natural system of your choice and in order to address your research question, identify:

i) which individuals/entities in the system should be explicitly represented by agents and where appropriate, classes of agents
ii) what properties/states should be associated with the above?
iii) the type of behaviour that these agents will perform
iv) the representation of the model environment e.g. will it vary spatially? What kind of resources, features will it include? Will it vary dynamically as the simulation progresses?

v) the time and length scales represented in your model
vi) the emergent (system-level) behaviour that your model will generate and how this will be presented and analysed

Generate a brief overview of your model design (maximum 1-2 pages). Include flowcharts showing how rules (behaviour) will be applied to each agent type and the overall execution strategy for your model. This stage should be completed by the end of the session on 3rd March (**week 4**) and placed in your Google folder for **feedback**, which will be provided by email or by myself or a demonstrator in a breakout room during the session.

You will then proceed to stage 2 of the project. Note that 2A and 2B should be tackled in parallel.

Part 2A Computational model design, implementation, simulation and testing.

<u>Development</u>
Develop the code necessary to run the model you have designed above (taking into account any feedback given). You are advised to use the *Ecolab* predator/prey model used during the training session as a starting point. Note that your final code, properly commented and documented, should be zipped and submitted at the same time as your group report.

<u>Testing</u>
You will debug your model for coding errors as you proceed. However, it is advisable to design a small number of basic tests to demonstrate that your system is working as you expect under some simple conditions e.g. what would you expect to happen if you removed all food sources in an ecological model? Does your model comply with this expectation? If not, why not? If there is not sufficient space in your main report, you could add a summary of these tests to the appendix.

<u>Experimentation</u>
Design and run simulations in order to explore/answer the research question you first identified. Remember that if your model includes stochastic (probability-based) behaviour, you will have to run more than one simulation for each set of conditions. Are there one or more parameters or rules in the system that dominate the emergent behaviour predicted by your model?

<u>Discussion and Analysis</u>
What results did your simulations produce? Were they as you expected – if not, why not? Are the rules/behaviour in your model realistic, or could they be over-simplified? If you had longer to work on this model, how would you adapt it? Would it be easy to validate your model results against real data?

<u>Computational efficiency review and optimisation</u>
Run some tests to investigate how your model efficiency scales with number of agents. Are there any possible ways that you could reduce the execution time of your model? (Note that it is not necessarily expected that you implement these, but a discussion of possible methods will earn you credit).

Part 2B Literature review (Note this will be a maximum of two pages and will be presented primarily within the Introduction of your report, as described in the *Report Presentation* section below)**.** This should include:

i) A brief overview of a selection of published ABMs relevant to your chosen area. What features of the system were investigated and what did the results show?

ii) Select one paper that ideally focuses on the behaviour/phenomena investigated by your group's model (or related behaviour otherwise). Carry out a more detailed review, aiming to address the following points:

- What are the questions that the model is trying to answer, or what particular features of the system does it aim to provide insight into?
- What entities and behaviours are explicitly represented in the model?
- What assumptions and simplifications were made in building the model?
- What are the time and length scales reflected in the model?
- What are the parameters that are included in the model and from where are they derived? Is the choice of parameters justified by the authors?
- How were the predictions of the model validated against the real natural system? If this is not discussed in the paper, do you have any ideas about how this could be done in the future?
- Do you think that this model provided any useful insight into the behaviour of the natural system? Has it led on to other modelling work? Could this system have been modelled more effectively using a different approach?

Note that while a literature review is an integral part of this project, it is NOT intended that you should attempt to implement a model from the literature. Your model design should be based on your understanding of the system in question (which is not expected to be in any great depth), and you may use the literature and any general websites (e.g. Wikipedia) for inspiration. An important part of this exercise is to demonstrate that you can critically compare your model with published examples, which will almost certainly be of greater complexity.

Note on literature sources

Your main publication discussed in ii) above should be a **journal paper** (non-peer reviewed material such as PhD/Masters theses should be avoided).
Possible starting points for doing this are a search on Google Scholar
http://scholar.google.co.uk/
or for medicine- or biology-related papers, Pubmed:
http://www.ncbi.nlm.nih.gov/pubmed/
Examples of papers that may be of interest or provide starting points for a search are provided at the end of the document.

The review should be written **IN YOUR OWN WORDS**. Do not copy or make minimal changes to the original text – this is considered plagiarism, which the university takes extremely seriously (see below for further information). Make sure you clearly reference the selected papers in a bibliography at the end of your report (please ask myself or a demonstrator if you are not clear how to do this).

Stage 3 - Report write-up

Your report should be written in the style of a scientific paper, as outlined in the template provided.

There is a strict 8 page (~4000 word limit) for this report, not including appendices.
Please see Blackboard for more detailed guidelines for the report structure, as well as the template.

Marking criteria
Please see the accompanying documents on Blackboard for marking criteria.

Deadline
The deadline for uploading a SINGLE copy of your report via MOLE is **3pm on Friday 26th March 2021.**
Please note that your submission will be automatically evaluated for plagiarised material using Turnitin.

Plagiarism
Credit will not be given to material that is copied (either unchanged or minimally modified) from published sources, including web sites. Any references that you use should be cited fully. Please refer to the guidance on "Collaborative work, plagiarism and collusion" in the Undergraduate or MSc Handbook.

Introduction to possible project areas

1. Foraging behaviour

Many animal species, and insects in particular, form highly organised societies which are extremely effective in identifying food sources within their local environment, and communicating information relating to these sources to other individuals in the colony. Details of both the searching and communication behaviour of individuals within the colony, as well as the quality and distribution of food sources, are likely to influence the effectiveness of the colony in sourcing food, and hence it's sustainability.

Useful references:

- de Vries, H. and Biesmeijer, J.C., Modelling collective foraging by means of individual behaviour rules in honey-bees. Behavioral Ecology and Sociobiology, 1998. 44(2): p. 109-124.
- Dornhaus, A., Klugl, F., Oechslein, C., Puppe, F. and Chittka, L., Benefits of recruitment in honey bees: effects of ecology and colony size in an individual-based model. Behavioral Ecology, 2006. 17(3): p. 336-344.
- Jackson D, Holcombe M, Ratnieks F, Coupled computational simulation and empirical research into the foraging system of Pharaoh's ant (Monomorium pharaonis) Biosystems, 76(1-3):101-12.

2. Flocking/Swarm behaviour

Several animal species exhibit different types of collective motion. These include birds (flocking) fish (shoaling), insects (swarming) and large land mammals (herding). With the possible exception of the latter (e.g. in the case of livestock control), there is no concept of external or centralised control– the emergent behaviour arises solely due to local interactions of the individuals within the group. Understanding the rules that govern this behaviour may have applications in the field of robotics, or implications for understanding crowd behaviour in humans.

Useful references:

- Vabo, R. and Nottestad, L., An individual based model of fish school reactions: predicting antipredator behaviour as observed in nature. Fisheries Oceanography, 1997. 6(3): p. 155-171.
- E. A. Codling, J. W. Pitchford, S. D. Simpson, Group navigation and the ''Many-wrongs principle'' in models of animal movement. Ecology, 88(7), 2007, pp. 1864–1870.
- R Jeanson, C Rivault, JL Deneubourg, S Blanco....Self-organized aggregation in cockroaches. Animal Behaviour 69, (1), 2005, pp169-180

3. Interactions in cellular systems

Biological cells are autonomous individuals – they can grow, divide, migrate and even die in response to the nature of their local environment and individual interactions. Emergent behaviours arising from these interactions include normal tissue growth and development, the expansion of tumours and the growth of bacterial/microbial colonies. Cellular-based processes such as inflammation and the operation of the immune system have also been modelled using agent-based processes.

<u>Useful references:</u>

- Walker, D., Southgate, J., Hill G, Holcombe, M., Hose, D., Wood, S., Macneil, S. and Smallwood, R., The Epitheliome: modelling the social behaviour of cells. Biosystems, 2004. 76(1-3): pp. 89-100.
- Krawczyk, K; Dzwinel, W; Yuen, D. A. Nonlinear Development of Bacterial Colony Modeled with Cellular Automata and Agent Objects. International Journal of Modern Physics C, 14, (10), pp. 1385-1404. (Note: this is a hybrid agent: cellular automata model).
- Folcik, V.A., An, G.C. and Orosz, C.G., The Basic Immune Simulator: an agent-based model to study the interactions between innate and adaptive immunity. Theor Biol Med Model, 2007. 4: p. 39.

4. Host-parasite interactions

Although many pathogens harm or even kill their hosts, there are also a group of organisms known as *parasites* which can remain associated with the host for extended periods, without necessarily causing direct harm. These systems can be explored using agent-based models.

<u>Useful references:</u>

- Jeltsch F, Muller MS, Grimm V, Wissel C, Brandl R. 1997. Pattern formation triggered by rare events: lessons from the spread of rabies. Proc. R. Soc. London Ser. B 264:495-503.
- Bonnella T, Sengupta R, Chapmanb C,Goldberg T (2010) An agent-based model of red colobus resources and disease dynamics implicates key resource sites as hot spots of disease transmission. Ecological Modelling. 221. pp 2491-2500.
- van Roermund H, van Lenteren J, Rabbinge R (1997). Biological Control of Greenhouse Whitefly with the Parasitoid Encarsia formosa on Tomato: An Individual-Based Simulation Approach. Biological control 9, 25–47.

5. Competition between species

In the natural world, many species of plants, animals or even microbes compete to survive in an environment that has limited resources. Examples of this behaviour include the competition between native and introduced sub-species, such as red and grey squirrels in the UK, northern cardinals with other related bird species in the US or coyotes intimidating carrion birds attempting to feed on dead prey. Competition can take a number of forms of behaviour including straightforward aggression between species, domination of food sources or be more indirect, e.g. a species modifying the local environment so it is less favourable for its' competitor to thrive.

<u>Useful references</u>

- Karsai, I., Montano, E., & Schmickl, T. (2016). Bottom-up ecology: an agent-based model on the interactions between competition and predation. *Letters in Biomathematics*, *3*(1), 161-180.
- Xiao, S., Zobel, M., Szava-Kovats, R., & Pärtel, M. (2010). The effects of species pool, dispersal and competition on the diversity–productivity relationship. *Global Ecology and Biogeography*, *19*(3), 343-351.
- Portell, X., Pot, V., Garnier, P., Otten, W., & Baveye, P. C. (2018). Microscale heterogeneity of the spatial distribution of organic matter can promote bacterial biodiversity in soils: insights from computer simulations. *Frontiers in microbiology*, *9*, 1583.

6. Disease spread and control in animal populations

As for human populations, contagious disease is a constant threat to many species both in the wild and also in managed livestock populations. Examples of the former include Ebola, which is a threat to ape populations as well as humans, West Nile encephalitis, which is spread by mosquitoes and has affected populations of urban birds in the US and anthrax, which can affect many animal species as well as humans. The introduction of new species, and changes in environment can have an impact on the spread and impact of disease in animal populations. In managed livestock, it is possible that interventions such as vaccination or selective culling can have a positive impact in limiting disease spread.

Useful References

- Ramsey, D. S., & Efford, M. G. (2010). Management of bovine tuberculosis in brushtail possums in New Zealand: predictions from a spatially explicit, individual-based model. *Journal of Applied Ecology*, *47*(4), 911-919.
- Fa, J. E., Sharples, C. M., Bell, D. J., & DeAngelis, D. (2001). An individual-based model of rabbit viral haemorrhagic disease in European wild rabbits (Oryctolagus cuniculus). *Ecological Modelling*, *144*(2-3), 121-138.
- Ivan, L. N., Brenden, T. O., Standish, I. F., & Faisal, M. (2018). Individual-based model evaluation of using vaccinated hatchery fish to minimize disease spread in wild fish populations. *Ecosphere*, *9*(2), e02116.