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

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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 of your choice
ii) **explore** how such a model can be used to investigate a real-world natural system by carrying out virtual experiments
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 during Tuesday computing lab sessions between week 7 and week 10 inclusive. Demonstrators and teaching staff will be present to provide help during 1-2pm. However, it is expected that you will be required to 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 Monday 14th May**. One copy should be uploaded to MOLE.

Each student will be asked to complete a short questionnaire relating to individual group member contributions using a system called WebPA (details to be supplied at a later date) and the group mark will be moderated to provide a mark for each ***individual student***.

<u>Instructions</u>

You will be working in teams of around 4 students to design, develop and execute an ABM of a natural system of your choice (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. It is in your interests to keep records of who was allocated what (and whether it was delivered!).

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.

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):

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

1. Planning phase (to be completed by end of Tuesday session on week 8)

   Identify a natural system of interest to you and define a research question regarding *emergent* behaviour of this system, and how it may be influenced by the individual entities (agents) present in this system, their behaviour and interactions.

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

Write a brief overview of your model design (maximum one page of A4). 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 17th April (**week 8**) and handed in for **feedback**, which will be provided by email or in person by the start of the following week**.**

2) Development phase

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. Copies of code used should be included in an appendix attached to your group report.

3) Testing phase

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?

4) Experimentation phase

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?

5) Analysis phase

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?

6) Computational efficiency review and optimisation phase

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 B 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 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/

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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).

Report presentation

Your report should be written in the style of a scientific paper, as outlined in the template provided. Your report should contain the following sections (figures in brackets represent guideline length unless stated otherwise):

Abstract: A brief summary of what you did and what you found (maximum 200 words).

Introduction and Background including Literature review (around 2 pages) – a brief overview of the natural system you have chosen, why it is appropriate to model with an ABM and the features of the system that you have explored with your model. The rest of this section will consist of the literature review (see Part B above).

Modelling Methodology (1-2 pages) - A short summary of how you have represented your system of interest using an ABM and how your model works. You can also use simple flow or state transition diagrams to support your description. Don't forget to define the time and length scales you are considering.You can also refer to relevant code snippets or pseudocode included in an appendix. State, and where possible, justify any assumptions you have made. You may find the following paper useful in terms of how to present an ABM:

`Volker Grimm, et al, A standard protocol for describing individual-based and agent-based models, Ecological Modelling, Volume 198, Issues 1-2, 15 September 2006, Pages 115-126,`

http://www.sciencedirect.com/science/article/pii/S0304380006002043

Results

1. **Model Predictions (around 2 pages)**

In this section you should describe what simulations you carried out under which conditions (e.g. parameter sets , initial conditions….) and how long the simulations were run for. You should use fully labelled diagrams (e.g. screenshots or where appropriate, line graphs) to display your results and you should also describe your results in text. Additional results can be included in an appendix.

2. **Computational efficiency (up to 1 page)**

The results of your computational efficiency investigation detailed above.
If you have additional figures/tables of results that won't fit here, include the most critical ones and place the others in an appendix.

Discussion of your model and conclusions (around 1 page)
This should discuss the implications, reliability and realism of the results found in your simulation study and also the implications or possible future improvements to computational efficiency. What future improvements could be made? Ideally, you should compare your results with those from at least one published model (e.g. one

described in your literature review) or any published real data (if possible). What are the advantages/disadvantage of using an agent-based approach to model this system?

Conclusion [max 0.5 pages]

Briefly state the main conclusions resulting from your study.

Bibliography

Remember that your **bibliography** should correctly cite any relevant sources or references that you may have identified **(please ask a member of teaching staff/demonstrator for guidance if you're not sure how to do this)**.

Appendix

Please include an appendix containing any additional figures or other material relating to your model (this does **not** count toward the word limit).

The total length of your report <u>should not exceed 8 pages</u> (around 4000 words) which does not include bibliography/appendices).

Marking criteria
Please see the accompanying document on MOLE for marking criteria.

Deadline
The deadline for uploading a SINGLE copy of your report via MOLE is **3pm on Monday 14th May 2018.**
Please note that your submission will be automatically evaluated for plagiarised material using Turnitin.

WebPA survey
After the deadline, you will receive a request to complete a brief WebPA survey on the contribution of yourself and other team members to the project are report on MOLE. Completion of this survey is **COMPULSORY** and students who fail to do so will incur a mark penalty. More information regarding this survey will be provided in lectures/labs. WebPA scores will allow group marks to be converted to marks for each individual student.

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.

Examples of Natural Systems/Behaviour types that could be considered, along with references that may provide useful starting points are listed below. If you are interested in a project area that is not on this list, please check with a member of teaching staff first.

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.

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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.

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 control 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

Growth, development and function 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.

Useful references:

- 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.

Host-pathogen/parasite

Many diseases are spread by individual contact, with the latter highly dependent on a number of factors including the nature of the terrain of the region under consideration, the social and migratory behaviour of the host population and the ability of the host to develop immunity to the pathogen. 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.

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Useful references:

- 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.

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