ROKE

Agent Based Modelling

What is it and how can you use it for Military OR?

15/07/2025

Agenda

Introductions

- Mark Gould
  - Nearly 20 years experience of OR in the civil nuclear industry and defence
  - 9 years at Dstl where I was responsible for a variety of different combat modelling tasks and tools including CAEn and ATLAS
- Lots of experience with general OR but in particular combat modelling and wargaming
- Why am I talking to you?
  - I've written lots of agent based models of combat
  - I've written lots of models which didn't work!
  - I was the Dstl technical lead for the creation of RET

Roke - Defence

MILITARY CAPABILITY

Our product portfolio optimised to deliver operational advantage in the Electromagnetic Spectrum.

DECISION ADVANTAGE

Advice consultancy and engineering services on how to operate within the Electromagnetic Spectrum to enhance; Lethality, Survivability and Interoperability to deliver Multi-Domain Integration.

SCIENCE & INNOVATION

Within 6 core areas; Electronic Warfare, Survivability, Resilient Position Navigation & Timing, Integrated ISTAR, Digital Battlespace, AI & Analytics.

Caveats and Further Information

- Agent Based Modelling is no different to any other OR technique
  - There are some studies where it is more suitable than others
  - Other techniques may work just as well (or better!)
- I'm not claiming to be an expert on Agent Based Modelling
  - I've got lots of experience in using it, but I am a practitioner not an academic

If you want to know more about Agent Based Modelling after this, I would recommend the following resources:

- OR Society Website and JORS
  - Operational Research: methods and applications (JORS 75 (3): 423-617
- Books
  - An Introduction to Agent-Based Modeling (Uri Wilensky and William Rand)
  - Complex Adaptive Systems (John H. Miller and Scott E. Page)
- Case studies
  - Read pretty much anything by Joshua Epstein
- Try it!
  - Mesa and NetLogo example models are well documented and often reference real studies from which the examples are drawn
  - AnyLogic has some great introductory videos which show ABMs being built (in AnyLogic) and has a library of models which are already built and available online

What is Agent Based Modelling?

From the OR Society website:

> *Agent-based modelling is a computational modelling technique used to simulate complex systems by representing individual agents and their interactions within a dynamic environment.*

• Agents are autonomous	Agents are free to do whatever they want within the confines of the world you build for them
• Predefined characteristics	You tell them what they are…
• Predefined behaviours	How they should do things…
• Decision making rules	And why they should do things
• Agents interact with each other and the environment based on the characteristics, behaviours and rules you have set	Microscopic behaviours are defined, but macroscopic behaviours are emergent

You define the system against your best understanding and then let the agents within that system act according to their perception of their local environment. The individual agent behaviours are just what you set and are often simple abstracted rules, but the system behaviour can be complex and rich even with these simple rules

Key Points – When should I use ABM?

- Agent Based Modelling is a bottom up approach for looking at complex systems
  - If your study is about too simple a system, or if you will find it easier to go from a top down perspective when looking at the system then ABM may not be the right choice
  - If you can describe the components of your system but want to explore how they combine and interact to produce system level outcomes, then ABM may be a good choice
- ABMs consider the decisions that get made and the consequences of those decisions
  - They are not usually a great choice for studies where you are looking in detail at one characteristic or behaviour
  - They are generally good for considering 'operations' where you need to represent dynamic systems which respond to changes in the environment (and where the environment responds to those decisions)
- ABMs are all about interaction
  - If you have lots of systems which only interact in a linear fashion or which have limited interactivity, ABMs might not show you interesting outcomes
  - Where your system is complex in its interactions, ABMs may be a good choice (if you can articulate the rules of those interactions!)
- Agents are built around rational rules
  - If you can't articulate rational rules for decision making, and express these in software then ABMs will not work – consider starting with a wargame to get after these rules
  - If you can express these rules, then ABMs provide an artificial world in which you can explore the consequences of changes (to the rules, to the characteristics or to the behaviours) in a rigorous manner

Agency

Agents in an ABM are autonomous – they decide what they are going to do and when based on the characteristics, rules and behaviours we give them. Agency is then the freedom to act within those rules etc. to achieve a goal. Agents can decide to stop what they are currently doing when their perception of the world changes and can reevaluate and determine a new course of action as needed.

Scheduling

With many agents all interacting, we use scheduling to control how time is handled in our model to ensure that agent interactions are representative of the real world system it is based on. Often also referred to as activation.

From a psychological perspective, agency is the ability of an entity to initiate and control their actions

> *In behavioural psychology, agents are goal-directed entities that can monitor their environment to select and perform efficient means-end actions that are available in a given situation to achieve an intended goal. Behavioural agency, therefore, implies the ability to perceive and change the environment of the agent.*

From Wikipedia – Agency (psychology)

- An agent can perceive its environment and based on that perception determine what actions to take to achieve some goal
- Truly autonomous agents should not be told what do, they should be directed what to achieve and given a set of actions they can perform and then set free to determine their own plan
- When the situation changes, so might the plan
- Not all agents need to be completely autonomous in every study…

Agency – in the context of Agent Based Modelling

Three pillars – perception, determination, action / interaction

Perception

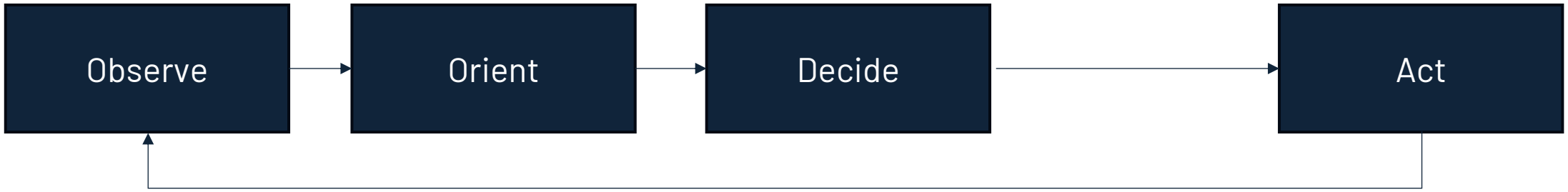
- An agent's knowledge of its environment should be derived from some form of sensing
- They shouldn't act on what they don't know, and they should only know what they can 'sense'

Determination

- An agent's plan should be derived from their perception
- In most situations they will have access to pre-determined strategies, plans or courses of action which can be selected and adapted but determining which course of action to follow must be up to the agent

Action / interaction

- The activities undertaken by the agent should have consequences on their environment and other agents
- This changes the simulation state and that state change might be observed, leading to a new perception…



Scheduling

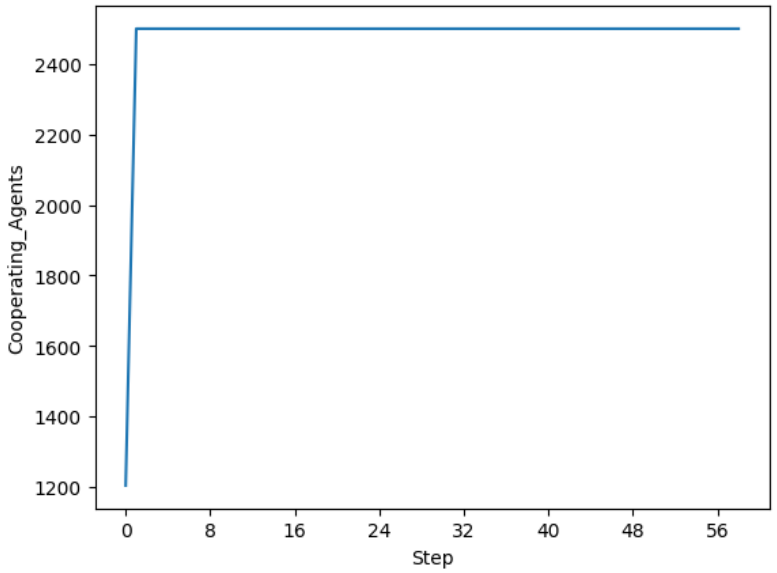
With many agents all interacting, there needs to be some means of controlling when those agents act in relation to one another - this is scheduling. Agent Based Models are almost always time stepped rather than event driven so scheduling concerns how we decide what order to consider the agents in within a timestep.

In general there are three main approaches:

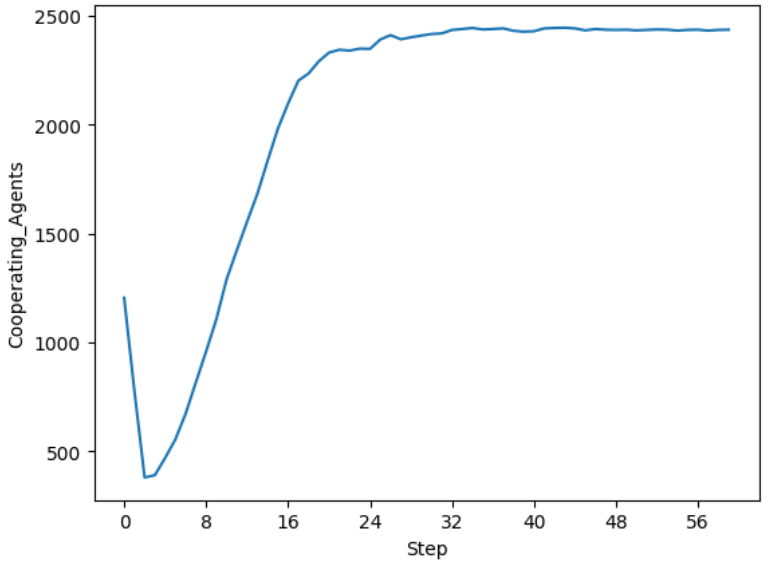
- Ordered or Sequential scheduling
  - Agents are placed into an order and they are considered in that order at every timestep and in every replication
  - Pros: Highly controlled and repeatable, easy to understand and explain
  - Cons: The agent which goes first might get an advantage in interactions for competitive simulations
- Random or Shuffled scheduling
  - Agents are placed into a random order every timestep and then considered in that order for this timestep in this replication. A new order for the agents is created for every timestep in every replication
  - Pros: Removes the advantage from going first **on average**
  - Cons: Introduces a potential interaction between the replication and the outcome even for simple models
- Simultaneous scheduling
  - Agents can be placed in any order. They all determine what they are going to do and the outcome of those actions, but don't apply those outcomes.
  - Once every agent has determined what will happen, the outcomes are applied creating an approximation of simultaneous action.
  - Pros: Controlled and repeatable, removes the interaction of schedule ordering on outcomes
  - Cons: More complex to create, can create odd effects

Sensitivity to Schedule Approaches

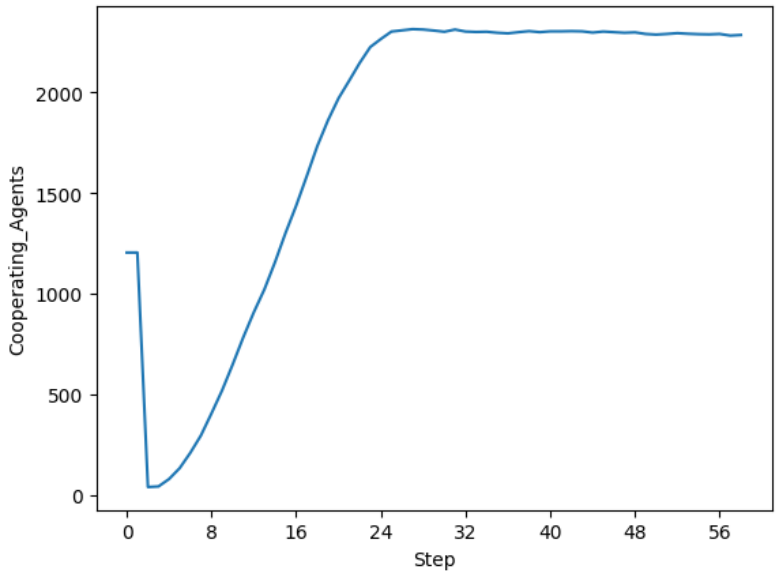
A model can be sensitive to the scheduling regime you choose. Think carefully about what kind of scheduling approach you use and explore options. Example – the Demographic Prisoner's Dilemma (Epstein, J. Zones of Cooperation in Demographic Prisoner's Dilemma. 1998)



Sequential schedule



Random schedule



Simultaneous schedule

These charts were created using Python's Mesa package (ter Hoeven, E., Kwakkel, J., Hess, V., Pike, T., Wang, B., rht, & Kazil, J. (2025). Mesa 3: Agent-based modeling with Python in 2025. Journal of Open Source Software, 10(107), 7668. https://doi.org/10.21105/joss.07668

The example can be accessed from Mesa's built in examples – instructions available at https://mesa.readthedocs.io/latest/examples/advanced/pd_grid.html

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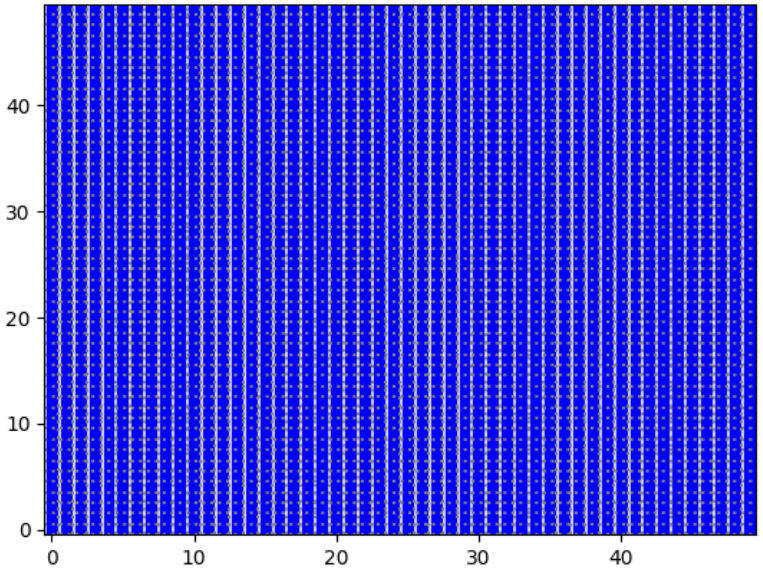
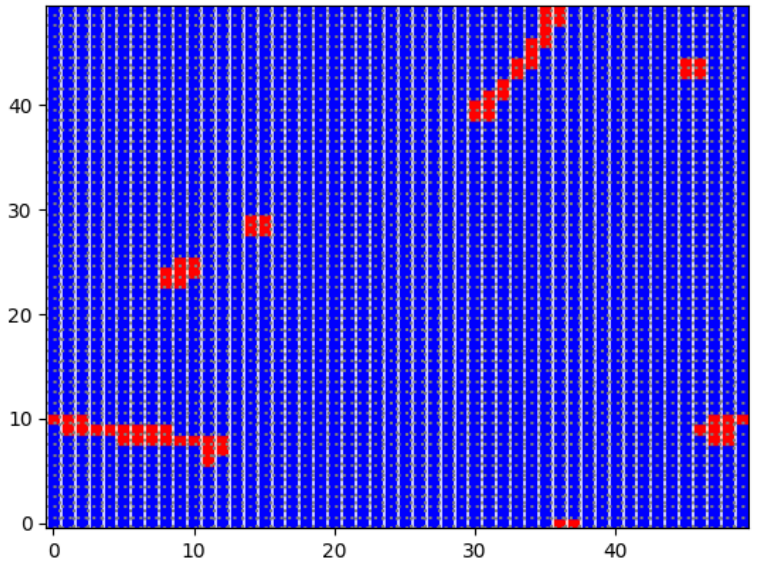
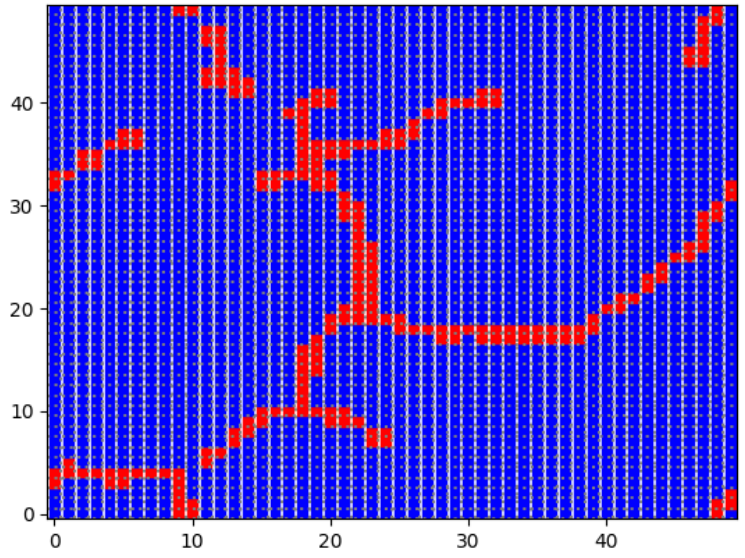


Sequential schedule



Random schedule



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How does Agent Based Modelling relate to other analytical techniques?

- Works well with system dynamics models
  - Many of the tools we will look at in a minute enable you to use both techniques interchangeably within a single model
  - A model of a complex system might well contain additional complex systems which are best represented by a different kind of model.
  - Both tools are most often time stepped so they can work well together without significant difficulty
- A great follow up to wargaming in a Military OR context
  - Wargames are amazing for identifying what decisions get made and articulating why, but limitations on the ability to replicate games can cause issues. 'What if' analysis via a wargame can be limited and expensive.
  - ABMs can be replicated easily and are brilliant for what if analysis through batch processing but require the decision making rules to be articulated first.
  - Combined approach – wargame to get the decision making rules and explore narrow scenarios in depth, then ABM to explore what ifs and do a shallow search across a broad problem space, then wargame to explore the depths of the most interesting what if scenarios…
- Soft OR and system understanding
  - ABMs, like any model, need to represent a system and the analyst creating that simulation needs to understand what that system is, how it works and what it does so that the abstractions are appropriate and resulting model fit for purpose
  - ABMs strongly benefit from some form of Soft OR in advance of creating a model to ensure the system understanding is complete

Tooling

There are a variety of high quality tools available to help you build analytical Agent Based Models, but here are three we'll focus on:

AnyLogic

- Dedicated modelling system combining ABM, Discrete Event Simulations and System Dynamics models
- Pros:
  - UI based and user friendly – easy to use for beginners
  - All in one solution including model, visualisation and analysis
- Cons:
  - Reduced flexibility compared to other options
  - Expensive licence

NetLogo

- Dedicated modelling system combining ABM and System Dynamics models
- Pros:
  - Free software
  - Large user community (mostly academic) and library of example models
  - Strong modelling component with significant flexibility
  - Includes basic visualisation and analysis
- Cons:
  - Uses a variant of Logo language for writing models which is uncommon

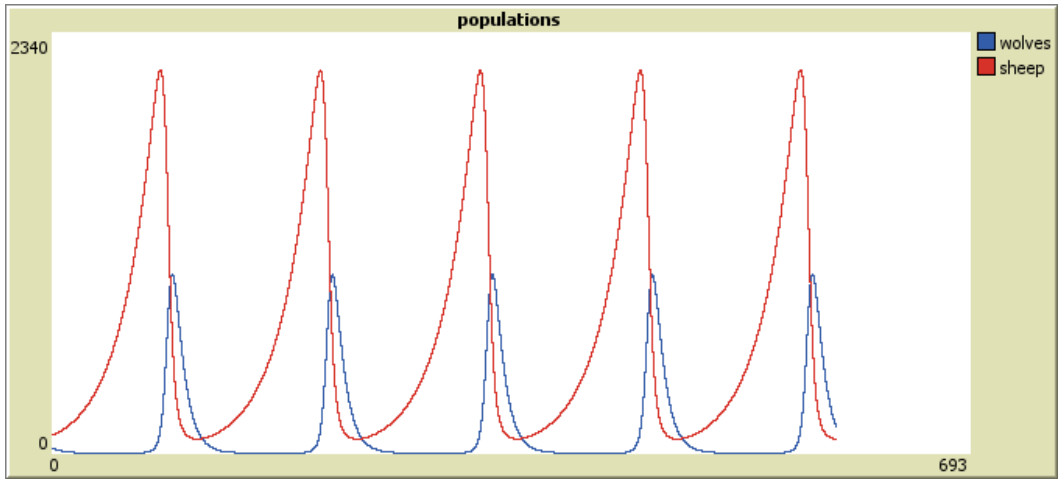
Python Mesa

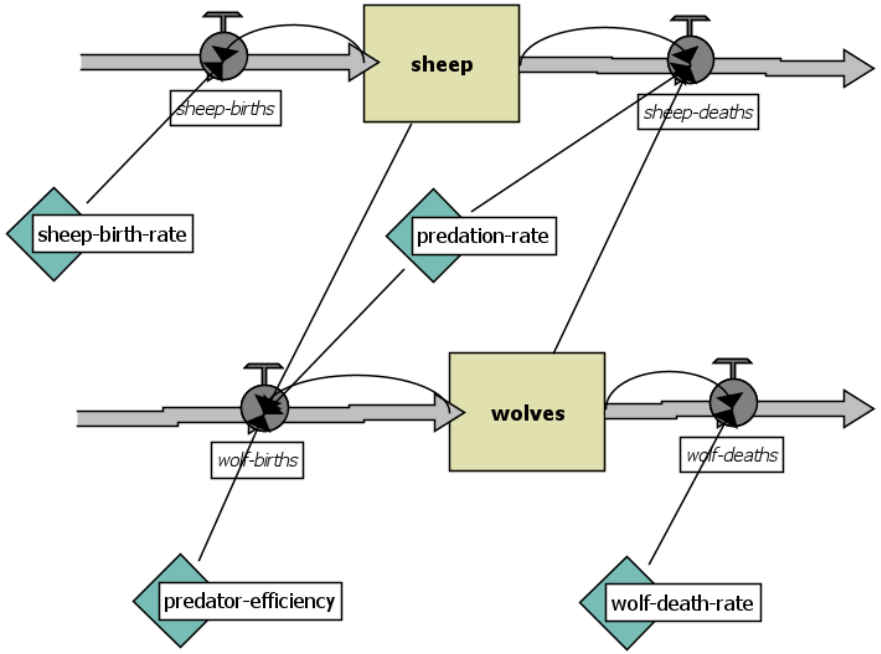
- Python module for building ABM
- Pros:
  - Free and open source
  - Highly flexible and extensible
  - Works well with the broader Python ecosystem of data analysis and AI tools
  - Easily shareable
- Cons:
  - Steeper learning curve (basic Python coding + Mesa specifics)
  - Inbuilt visualisation is limited

How can tooling support a study life cycle?

- Documentation
  - Code can capture what a model does, but good documentation captures why it was done that way - models become easier for new users to pick up and more transparent for decision makers
  - These tools all support 'in situ' documentation which helps ensure that all users have access to the information and that changes to the model can be carried out concurrently to changes to the documentation (but you still have to remember to do it!)
- Analysis
  - All modern tools support analysis directly, albeit to different levels – in place data visualisation is supported
  - Data can be captured in common formats for analysis in different tools or comparison with other experiments
- Assumptions capture
  - Modern IDEs enable 'tagging' of code so assumptions in models can be captured as they are built
- Version Control
  - All the tools mentioned support full version control in systems like Git which helps keep track of model development
  - Branching can be a useful way of managing some aspects of experimentation
- Verification and Validation
  - By capturing good documentation, assumptions and keeping track of how inputs and outputs relate through testing and analytical use of a model, confidence can be built
  - Compared to previous tools, models built using the above tools these can be run very fast and with high quality visualisations enabling live experimentation with subject matter experts to support validation

Predator-Prey Modelling in NetLogo using System Dynamics





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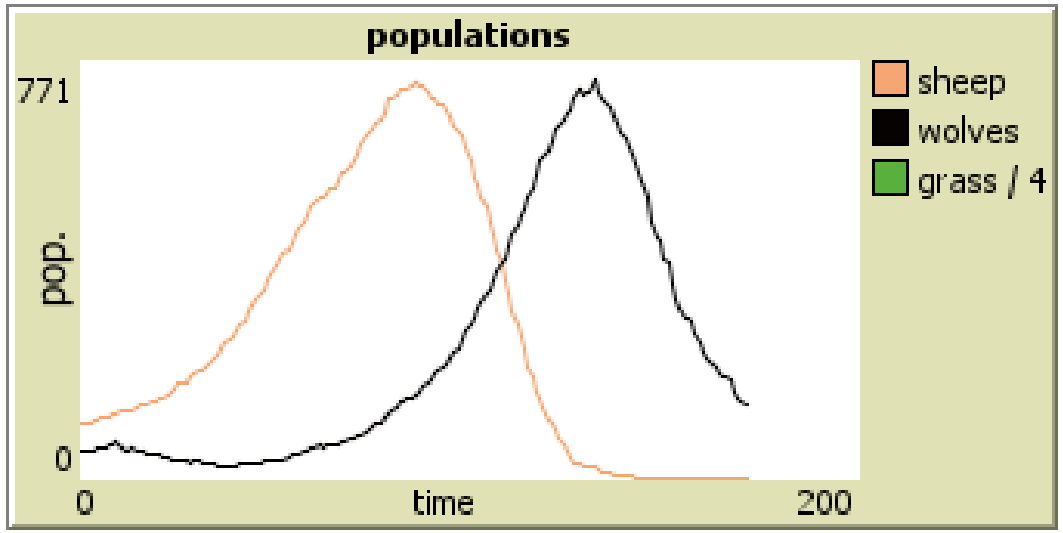
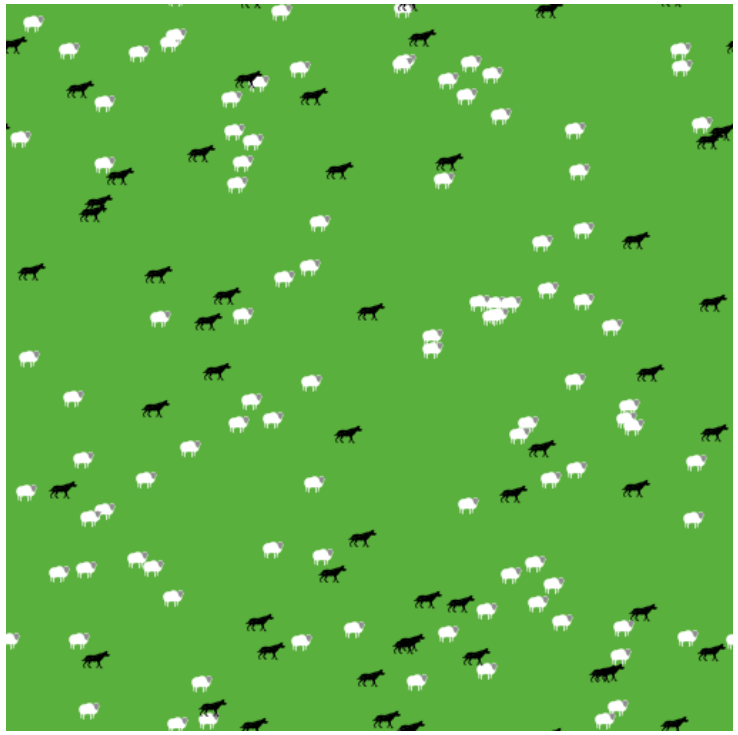
Basic examples

Predator-Prey Modelling in NetLogo using Agent Based Modelling





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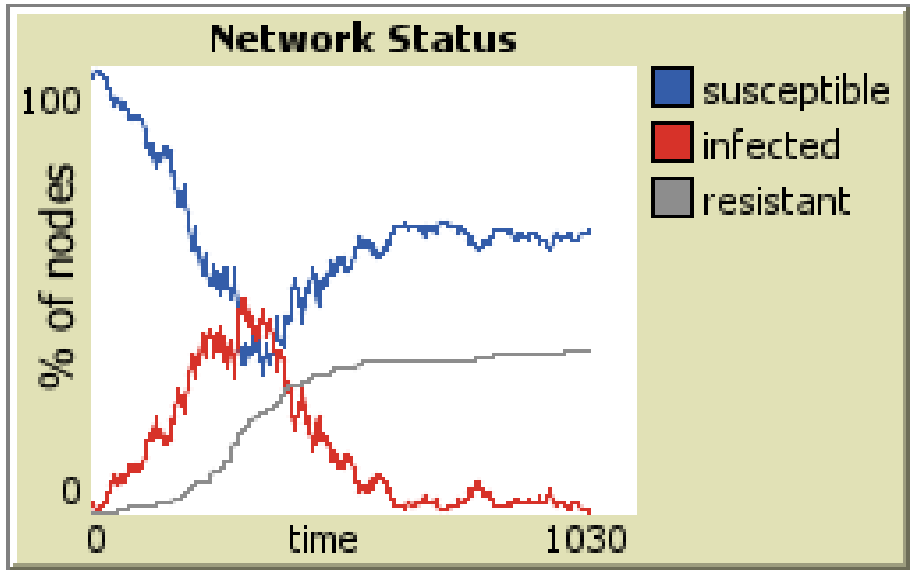
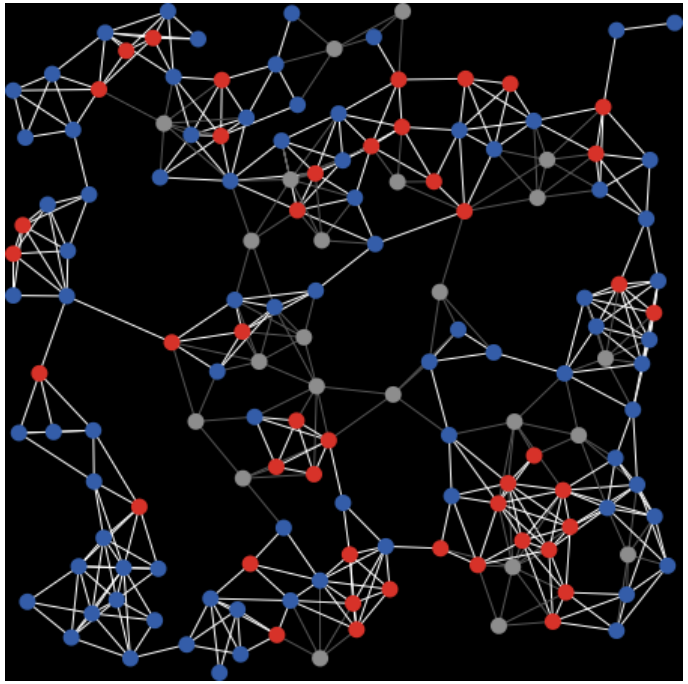
Basic examples

Virus propagating on a network in NetLogo – use of a network space rather than a grid





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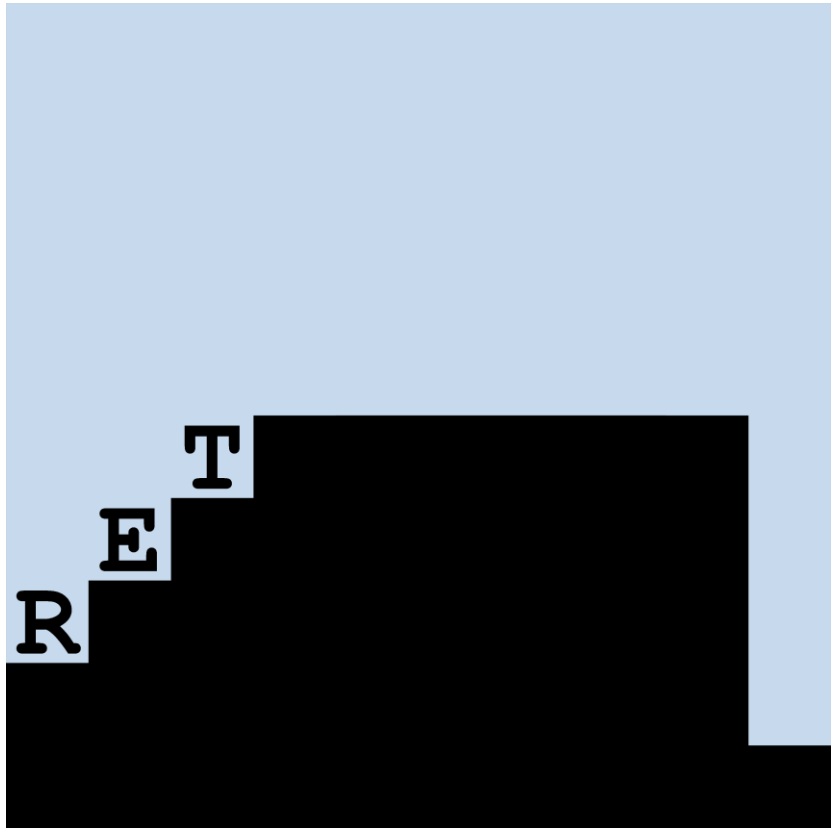
Agent Based Modelling - use in Military OR

- Many similarities between the concept of Agency in ABM and an OODA loop in a military operation
  - Agent based models are very well suited to representing C2 problems where complex decisions need to be made based on incomplete information
- There are many combat models which are agent-like, but very few true agent based models - Why?
  - Agent based models are best used as part of multimethod studies which aren't always possible with constrained funding
  - Building them was hard and expensive when you have to start from scratch every time – easier to stick with the large models which do a bit of everything
  - They can consume lots of compute resources making them hard to run on readily available hardware in a classified environment
- With new tools available and more OR practitioners and analysts having a good grounding in programming it is now possible for ABMs to be built quickly and reliably to support military OR studies
- Caveats:
  - You still need system understanding before you can build a model, being able to build quickly doesn't mean being able to build well
  - You still need good data or at least to explore your uncertainty, garbage in garbage out still applies
  - Validating the outcomes in general and the decision making rules specifically is non-trivial but is still an absolute requirement if your model is to inform any kind of decision

Rapid Exploratory modelling Toolset (RET)



- Developed and open-sourced by Dstl
- A toolset for building agent based models of military operations with a focus on exploring uncertain input data
- Contains a variety of 'boiler plate' capabilities which make it quicker and easier to build ABMs of military operations
  - Agents with weapons and sensors which are used to generate a perception of the world and interact with other agents
  - Systems for building decision trees or simply scripting the behaviour of agents
  - Systems for generating new orders and disseminating them to subordinates over a communications network
- Used successfully as part of a hybrid wargaming and simulation study recently

Conclusions

- Agent Based Modelling is a powerful technique which is now accessible to almost all OR practitioners
- It is well placed to support studies where you are interested in the impact of different decision-making processes
- It works well as part of multimethod approaches where its strengths can overcome deficiencies in other approaches and vice versa
- Simple rules can create complex outcomes…
- …But don't read too much into them, especially in the details!

ROKE

Thank You

If you have any questions, please email me at:
mark.gould@roke.co.uk