CSCU9YM: Modelling for Complex Systems

Lecture 4: Doing experiments with Agent-Based Models

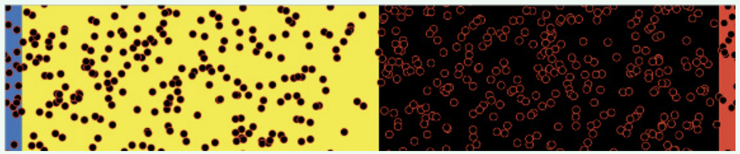
Studying Simulations

"A simulation study is an experiment that needs to be designed" – David Kelton

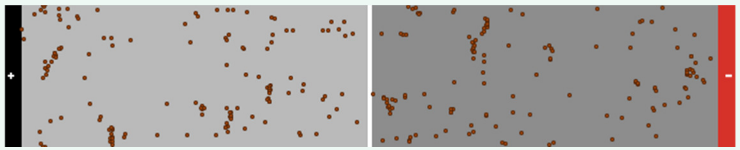
- Today we look at the theory of experimental design and how to apply this to the study of simulations. Topics include:
  - Initial explorations of a model (ten heuristics to use for this)
  - Formulating experimental hypotheses
  - Designing experiments
  - Reporting results (data visualization and simple statistics)
  - Dealing with multiple parameters (the problem of dimensionality)
  - Sensitivity analysis
- Reference: Chapters 21-23 of Railsback and Grimm ("Model Analysis"), see also papers in "Resources" section of website.

Aside: Good and bad visualization

- Models library/Curricular Models/NIELS/Series Circuit



Initial design



Final design

Kornhauser, Wilensky and Rand, Design Guidelines for Agent Based Model Visualization, http://jasss.soc.surrey.ac.uk/12/2/1.html (highly recommended)

Why do experiments?

- The purpose of creating a simulation is to find a useful, simple model of a complex system.
- We perform experiments in order to answer questions about that system:
  - Why do certain results emerge? Which factors are important for influencing the results and which are less important?
  - Can the model be used to predict how the real world system responds to certain controllable factors?
  - Optimization: can we find the "best" or optimal configuration of controllable factors? And how is "best" defined?
  - Robustness: can we find stable configurations of the controllable factors, that are not sensitive to changes in the less controllable factors.

The segregation model

- Based on a model Thomas Schelling (1971) of how social segregation of households might arise in a city.
- Turtles represent households, patches represent houses, arranged in a 51x51 grid.
- Households are of two types, red and green.
- Households have a state variable happy? which is set to false if the household has more unlike neighbours than it tolerates.
- A parameter %-similar-wanted represents the minimum percentage of like neighbours a household must have in order to be happy.
- One time step represents the time in which a household decides to move.
- At each time step, households that are not happy move to a randomly chosen empty patch.
- The model stops when all households are happy.

Exploring a model

- Ten heuristics to use when exploring a model:
  1. Analyze from the bottom up
  2. Try several "currencies" for evaluating results
  3. Try different "views" (visual outputs)
  4. Run the model step-by-step
  5. Analyze simplified versions of the model
  6. Try extreme values of parameters
  7. Look for striking or strange patterns in the model output
  8. Find tipping points in model behaviour
  9. From an interesting point in parameter space, keep the controlling parameter constant and vary other parameters
  10. Explore unrealistic scenarios

Formulating hypotheses

- Exploration (using the ten heuristics) can be enough to give a good understanding of a simple model like the Segregation model.
- For more complex models, it will be necessary to carry out systematic experiments to understand the model.
- The initial exploration can help us to identify hypotheses:
  - **Hypothesis**: a testable statement about the relationship between the model parameters and the simulation results
- Can you suggest any hypotheses about the Segregation model?

Experiment example

- Manual exploration is ok for understanding very simple models, but to study a model systematically you need to do experiments.
- A typical experiment:
  - Hypothesis: As the level of intolerance goes up, the time taken for all households to become happy also increases.
  - Experimental design:
    - » Vary the intolerance parameter systematically from 0 – 100% (this is called ***parameter sweeping***).
    - » Run the model for each parameter value.
    - » Measure how many time steps it takes before %unhappy becomes zero.
    - » From our explorations, we know that this number may be infinite, so we will need to terminate the experiment when some cutoff is reached. (How can we choose a suitable cutoff value?)
    - » Is it enough to run the model just once for each parameter value?

Designing experiments

- A simple approach to experimental design is to try to simulate all possible combinations of the input parameters (or ***factors***).
  - However, unless the model is very simple, this can be highly inefficient!
  - A better approach is to use the initial exploration to identify interesting portions of the full parameter space to explore further.
- Other things to consider:
  - **Stopping criteria**. Is there a terminal state, a steady state, or do we need to impose a cutoff time?)
  - **Model outputs (*responses*)**. If in doubt about whether some particular output is interesting, include it. It is easier to ignore an unneeded output than to redo experiments to record an output that was not included.
  - **Role of randomness**. Deterministic models need only be run once, but models with random behaviour should be run multiple times (called ***replicates***).

Experiment example

- NetLogo includes a tool called BehaviorSpace which makes it easy to set up parameter-sweeping experiments and record the results.
- The results are stored in a .csv file and can be analyzed with other software.
  - In this module we shall use Excel to do simple analyses and graphs
  - More sophisticated analyses can be done with tools like Mathematica and R, but these are outside the scope of this course.
- We shall set up experiments to do the following:
  1. Explore how the model evolves through time for a single run with fixed parameters.
  2. Same as above, but with multiple runs so that we can explore how variable the run lengths are.
  3. Test our hypothesis: that increasing intolerance makes it take longer for households to become happy.

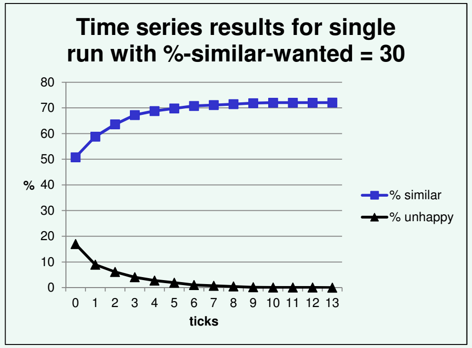
Visualizing and Reporting Results

We use simple statistical techniques for reporting results. These include:

- Histograms. Shows the shape of the distribution of the results.
- Time series graph. Shows temporal behaviour of model – how outputs change as time goes on.
- Means and standard deviations. Used to summarise results from multiple simulation runs.
- We look at some results from experiments on the segregation model

Single run with fixed parameters

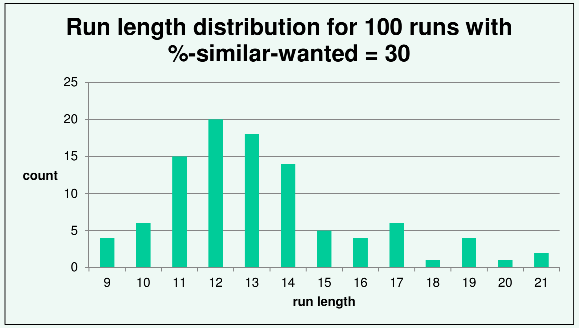
- Our first experiment explored how the system evolves through time for a fixed parameter configuration.
- The results are shown in a time series plot:



- The chart was created in Excel.

Multiple runs with fixed parameters

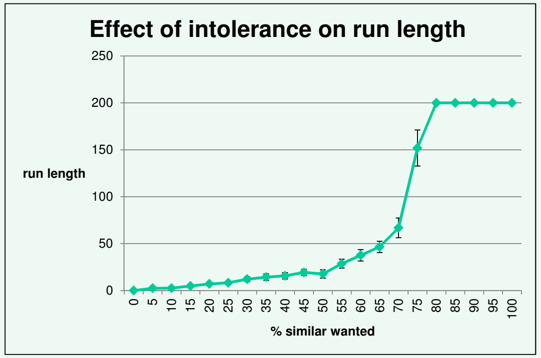
- The second experiment used 100 runs with %-similar-wanted = 30.
- Results: Mean run length = 13.28 ticks, st dev = 2.663



- The histogram was made using a ***PivotChart*** in Excel. Find out how in the practical.

Effect of intolerance on run length

- The third experiment looked at how varying %-similar-wanted affects the time it takes for all households to become happy.
- Results:



- (Remember that runs are stopped at 200 time steps.)
- Our hypothesis seems to be correct. What else can you observe?

Dealing with multiple parameters

- If you have k parameters, each of which can take one of n different values, then the total number of parameter combinations is n^k
  - This could be a very big number!
- A full-factorial experiment is one which considers all n^k scenarios.
  - Could be time consuming and data analysis is tricky, as it is very hard to visualize multi-dimensional data.
- A fractional-factorial experiment is one in which the number of scenarios is reduced by imposing some restrictions.
  - For example, keeping some parameters constant while varying others, or imposing some relationship between certain parameters
  - Can be much more efficient.

Sensitivity analysis

- Objective: to understand how sensitive the model is to the value of each individual parameter. We use a simple method called ***local sensitivity analysis***:
  - Consider each parameter one at a time
  - Holding all other parameters constant, run the model with the parameter of interest set to some chosen value p_1. Record the model output o_1.
  - Then run the model again with a slightly different value p_2. (This is called perturbing the parameter). Record the new output o_2.
  - Calculate the difference quotient $(o_2 - o_1) / (p_2 - p_1)$. This is a measure of how sensitive the output o is to the parameter p.
  - By repeating this for all parameters you can compare how greatly the model is affected by each parameter.
  - Care needs to be taken in choosing the parameter values and interpreting the results.

Further reading

- Kelton, W David. (1999) "Designing simulation experiments". In (Eds.) Proceedings of the 31st conference on Winter simulation: Simulation - a bridge to the future - Volume 1, Phoenix, Arizona, United States: ACM.
- Kleijnen, Jack P C, Susan M Sanchez, and Thomas W Lucas and Thomas M Cioppa. 2005. A User's Guide to the Brave New World of Designing Simulation Experiments. INFORMS Journal on Computing 17, 263--289.
- Part IV of Railsback and Grimm (Model analysis)
- notes from Alan G Isaac (American University) at https://subversion.american.edu/aisaac/notes/experimental-design.xhtml
- Wilensky, Uri, and William Rand. 2007. Making Models Match: Replicating an Agent-Based Model. Journal of Artificial Societies and Social Simulation 10, Article 2. http://jasss.soc.surrey.ac.uk/10/4/2.html

End of lecture