GESIS Leibniz Institute for the Social Sciences

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GESIS Fall Seminar in Computational Social Science 2025
"Agent-Based Modelling & Simulation"

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About the Lecturer

Daniel Mayerhoffer is an Assistant Professor at the University of Amsterdam. There, he teaches in the Bachelor Program "Computational Social Science", is a member of the "Institutions, Inequalities, and Life courses" research group in Sociology, and an affiliate of the Data Science Centre. Daniel uses agent-based simulation, among and in combination with other methods, to explain and predict complex socio-technical systems to enhance their governance. He applies Computational Models mainly to questions in Economic Sociology, Collective Behaviour, and Political Epistemology. Namely, he studies the perception of (economic) inequalities in homophilic networks, and the resulting individual and collective actions. Furthermore, Daniel evaluates these models from an analytical and Philosophy of Science perspective.

Course Description

Agent-based models (ABMs) are becoming increasingly attractive in the social sciences. Examples could be given from virtually all subfields, cf. the additional recommended literature; famous ABMs describe the formation of values and political beliefs as well as polarisation in different social environments, transmission of disease (this has received some attention during the CoViD-19 pandemic), diffusion of innovation in households and firms, or the formation of street protests. BMs are used to simulate the emergence of complex macro phenomena based on individual actions. Such simulation can be integrated into the pipeline of data-driven research in various ways.
Before data collection or analysis, ABMs can help operationalise theory and explore candidate explanations in preparation of subsequent empirical work; furthermore, simulation can identify key actors to further investigate with quantitative as well as qualitative designs. After data analysis, simulation can help fill gaps or detail the causal inferences identified in the analysis. On some occasions, simulation may be the only way to retrieve data (in an ethically acceptable way) at all.
Because researchers have full control over their ABM, they can monitor all cognitive processes of their agents and social interactions they deem interesting in arbitrary granularity, while at the same time running virtually unlimited repetitions and parameter settings. Consequently, data from ABMs combines advantages of quantitative (large N) and qualitative (rich, detailed) data. However, simulation output is only meaningful if the simulated social system resembles the real world in the relevant respects. Thus, appropriate calibration and validation is key to successful research using ABMs.

The aim of this course is to provide an epistemic and methodological background on agent-based modelling and guide participants through the conceptual development of ABMs as well as their implementation using the free software NetLogo . Its programming language is intuitively accessible even without previous programming or computer science knowledge. Therefore, the tool is ideally suited for social scientists who aspire to use simulated data from ABMs to pilot or complement empirical data.
As a complement to NetLogo, we will discuss the implementation of ABMs in other programming languages such as Python, Julia, R, or C++. Moreover, we will experiment with using Large Language Models to conceptualise and implement ABMs. With that, participants can integrate ABMs into their individual research pipelines.

Organizational Structure of the Course

The course will consist of a basic unit (day 1-3), an intensification module (days 2-4), and a hackathon phase (days 2-5) that will allow participants to kickstart their own research project either individually or in collaboration with other participants. This design will allow participants without prior knowledge to get from the basics to productive application during the course, while those who have some experience have a chance to take shortcuts and progress faster.

The basic unit introduces participants to the fundamentals of agent-based modelling using three exemplary models, showcasing potential application scenarios in the Social Sciences as well as discussing underlying concepts and methodological considerations. The practical programming will follow an intensively guided hands-on approach covering movement in space and strategic interaction, simulating network generation, and diffusion processes. The background topics will be integrated with these practical exercises to show their importance for ABM research practice.

The intensification module will practice the development of a larger model (the so-called Hegselmann Krause Model of bounded confidence opinion dynamics) in multiple steps and with various extensions based on the participants' preferences. Thereby, participants can apply what they have learned in the basic unit and try out individual solutions while still receiving guidance and feedback.

The hackathon or research incubator phase is meant to support participants in developing an ABM to answer their own research question. Participants can bring an existing research question but we will also allocate time during the course for developing an appropriate one based on participants' research interests. If participants want, they may collaborate with other participants on this project. In the hackathon, the lecturer will act as coach to guide participants through the modelling cycle of conceptualisation, technical implementation, analysis, potential refinements and communication of results. By the end of the week, participants will have a first version of their own ABM and ideally already some insights to be used in a paper.

Keywords

Simulation, networks, analytical sociology, agent-based modelling (ABM)

Target Group

You will find the course useful if:

- …you are an empirical (social) scientist but frequently encounter research puzzles that you cannot solve based on available or easy-to-collect data, or want to explore which data is worth collecting.
- …you are a (social) theorist but want to see whether the theories that you come up with can indeed explain a certain phenomenon.
- …you are a decision-maker or (social) researcher who studies these decision makers but do not know beforehand which outcomes certain decisions might entail and hence want to explore counterfactual scenarios.
- …you enjoy playing God and controlling whole societies or individuals but seek a way for doing so that is less harmful to others than becoming a dictator. ;-)
- …you are a novice in coding or an experienced coder: For many parts of the course, you will be able to adjust your speed of learning individually so that you will not feel overwhelmed without prior experience, nor bored if you find the technical aspects of the course to be easy.

Course and Learning Objectives

By the end of the course, you will:

- …be able to conceptualise common types of ABMs and implement them in NetLogo.
- …understand and apply all major NetLogo commands.
- …know the fundamentals of implementing ABMs independent of programming language.

- …use Large Language Models as "collaborators" for defining and refining ABM concepts and implement these concepts in the programming language of your choice.
- …critically evaluate your own and others' ABMs in terms of internal and external validity.
- …identify potential use-cases of ABMs in your research settings.
- …have a first version of your own ABM ready to be analysed for a future research paper.

Course Prerequisites

Fundamentals acquired in any academic degree (such as how to formulate a research question/puzzle), basic descriptive statistics. middle-school level math.

Software and Hardware Requirements

Participants should bring their own laptops for use in the course and have the latest version of NetLogo installed (available for Windows, Linux, and MacOS). Participants should also have admin rights on their device so that they can install additional software during the course if required.
If you have experience in programming (e.g., Python, Julia, C++, Java, but also R or Mathematica), it might also be good to have your favourite setup for this prepared on your machine.
An account for the LLM service of your choice, premium subscriptions are nice to have but free versions are typically fine. No API access required, using a chat interface will fully suffice for our purposes.

Course Contents

- Conceptualisation of agent-based models (ABMs) based on their intended use.
- Implementation of ABMs in NetLogo (in detail) and independent of language (basic concepts).
- Utilising LLMs in the modelling process.
- Epistemic status of ABMs, their calibration and validation.
- Development of one's own ABM.

Recommended Literature to Look at in Advance

NA

Day-to-day Schedule and Literature

Day 1:

- *Introduction*: Why Agent-Based Modelling and how to use it for explanations in the social sciences?
- *Basic unit*: Build your first models, learn about fundamental modelling paradigms

Suggested Readings:

Grüne-Yanoff, T., & Verreault-Julien, P. (2021). How-possibly explanations in economics: anything goes? *Journal of economic methodology*, *28*(1), 114-123. https://doi.org/10.1080/1350178X.2020.1868779

Reutlinger, A., Hangleiter, D., & Hartmann, S. (2018). Understanding (with) toy models. *The British Journal for the Philosophy of Science, 69*(4), 1069-1099. https://doi.org/10.1093/bjps/axx005

Hedström, P., & Swedberg, R. (1996). Social mechanisms. *Acta sociologica*, *39*(3), 281-308. https://doi.org/10.1177/000169939603900302

Day 2:

- *Basic unit*: Another introductory model; good simulation practice; how to analyse model output; basics of model documentation
- *Intensification module*: The Hegselmann-Krause Model and its implementation, floating-point errors in ABMs
- *Hackathon phase*: Finding a research question, group formation, specifying a model idea

Suggested Readings:

Grimm, V., Railsback, S. F., Vincenot, C. E., Berger, U., Gallagher, C., DeAngelis, D. L., ... & Ayllón, D. (2020). The ODD protocol for describing agent-based and other simulation models: A second update to improve clarity, replication, and structural realism. *Journal of Artificial Societies and Social Simulation*, *23*(2), 7. https://doi.org/10.18564/jasss.4259

Rainer, H., & Krause, U. (2002). Opinion dynamics and bounded confidence: models, analysis and simulation. *Journal of Artifical Societies and Social Simulation, 5*(3), 2. https://jasss.org/5/3/2.html

Kurz, S., & Rambau, J. (2011). On the Hegselmann–Krause conjecture in opinion dynamics. *Journal of Difference Equations and Applications, 17*(6), 859-876. https://doi.org/10.1080/10236190903443129

Day 3:

- *Basic Unit*: Modelling beyond NetLogo and how Large Language Models can help
- *Intensification module*: Model calibration and validation
- *Hackathon phase*: Define the first basic concept of your model and implement it

Suggested Readings:

Fagiolo, G., Guerini, M., Lamperti, F., Moneta, A., & Roventini, A. (2019). Validation of agent-based models in economics and finance. In Beisbart, C., & Saam, N. J. eds. *Computer simulation validation: fundamental concepts, methodological frameworks, and philosophical perspectives*, 763-787. https://doi.org/10.1007/978-3-319-70766-2_31

Yang, L., & Gilbert, N. (2008). Getting away from numbers: Using qualitative observation for agent-based modeling. *Advances in complex systems*, *11*(02), 175-185. https://doi.org/10.1142/S0219525908001556

Day 4:

- *Intensification module*: Extensions of the Hegselmann Krause Model
- *Hackathon phase*: Analyse first mock results, refine your model

Suggested Readings:

Hegselmann, R., & Krause, U. (2009). Deliberative exchange, truth, and cognitive division of labour: A low-resolution modeling approach. *Episteme*, *6*(2), 130-144. https://doi.org/10.3366/E1742360009000604

Hegselmann, R., & Krause, U. (2015). Opinion dynamics under the influence of radical groups, charismatic leaders, and other constant signals: A simple unifying model. *Networks and Heterogeneous Media*, *10*(3), 477-509. https://doi.org/10.3934/nhm.2015.10.477

Riegler, A., & Douven, I. (2009). Extending the Hegselmann–Krause model III: From single beliefs to complex belief states. *Episteme*, *6*(2), 145-163. https://doi.org/10.3366/E1742360009000616

Day 5:

- *Hackathon phase*: Retrieve and analyse simulation results, document your model, lightning presentations of model outcomes
- *Beyond this course*: Strategic considerations for agent-based modellers, plan how to continue with your model

Additional Recommended Literature

Introductory textbooks that I personally find helpful:

Gilbert, N. (2019). *Agent-based models*. Sage Publications. https://doi.org/10.4135/9781506355580

Railsback, S. F., & Grimm, V. (2019). *Agent-based and individual-based modeling: a practical introduction*. Princeton University Press. https://press.princeton.edu/books/ebook/9780691190044/agent-based-and-individual-based-modeling-pdf

Squazzoni, F. (2012). *Agent-based computational sociology*. John Wiley & Sons. https://doi.org/10.1002/9781119954200

Wilensky, U., & Rand, W. (2015). *An introduction to agent-based modeling: modeling natural, social, and engineered complex systems with NetLogo*. MIT Press. https://www.jstor.org/stable/j.ctt17kk851

Discussion of Agent-Based Modelling in the Philosophy of Science

Hedström, P., & Ylikoski, P. (2010). Causal mechanisms in the social sciences. *Annual review of sociology*, *36*(1), 49-67. https://doi.org/10.1146/annurev.soc.012809.102632
Mäki, U. (2009). MISSing the world. Models as isolations and credible surrogate systems. *Erkenntnis*, *70*, 29-43. https://doi.org/10.1007/s10670-008-9135-9
Sugden, R. (2009). Credible worlds, capacities and mechanisms. *Erkenntnis*, *70*, 3-27. https://doi.org/10.1007/s10670-008-9134-x

Sources for good-practice examples of Agent-Based Models:

Special Issue *Agent-based modeling in social sciences* in the *Journal of Business Economics*, 9 (2021), edited by Fischbach, K., Marx, J. & Weitzel, T. https://link.springer.com/journal/11573/volumes-and-issues/91-9
Special Issue *Agent-based modeling in social science, history, and philosophy* in *Historical Social Research/Historische Sozialforschung*, *43*(1) (2018), edited by Klein, D., Marx, J., & Fischbach, K. https://www.gesis.org/en/hsr/full-text-archive/2018/431-agent-based-modeling-in-social-science-history-and-philosophy
The *Journal of Artificial Societies and Social Simulation (JASSS)*, focussed entirely on (agent-based) simulation models. https://www.jasss.org/JASSS.html