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Peer Review

Review of: "Modeling and Simulating Agent-Based City Migration Using Conway's Game of Life"

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This study aims to use Conway's Game of Life (GoL) as a model for city migration.

Although I welcome and encourage all forms of experimenting when it comes to modelling, I would not recommend this publication in its current form for various reasons. Excluding the abstract, I will start by pointing out some issues I have with the current version.

Introduction

"One such complex phenomenon is the ***evolution of population centers*** *like cities using the kinds of simple and 'local' rules that serve as a good probabilistic representation of migration-related and economic phenomena like* ***out-migration*** *due to extreme densification and* ***sparsification****"*

After reading your work, I could not find any metric or measure to try and quantify, or at least identify, these phenomena, which I take from your introduction are the desired phenomena to recreate.

"We say tendency because our goal is to ***model and understand the macroscopic effects of such preferences*** *(expressed probabilistically) at a larger scale* ***using the simple rules of GoL****"*

Although hinting at some exploration of the local rules of GoL that induce some other macroscopic regime and/or recreate phenomena relevant to the desired setting, I cannot find in your work this exploration.

"In the literature, there is precedent for such tendencies through a slew of findings. For example, Del Faro-Odi et al.[11] show how ***GoL can be used to reproduce the statistical properties of wealth distributions*** *(which*

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tend to obey power law-like distributions) observed in real economic data."

I cannot say I agree with using this reference to support your claims of the adequacy of using GoL to study migration, even with the added intent of "*(...) to model and understand the macroscopic effects of such preferences"*. In reference [11], they collapse all spatial information of the system in order to only collect re-activation counts of cells, which generate frequency distributions with certain properties. I don't think one can easily think of migration without a spatial component, and no explanation, method, or metric was produced after these claims to clarify this point. *Macroscopic* does not imply a-spatial.

Also, I was surprised there were no references to any other attempt at explaining urban phenomena using cellular automata. For example, and only picking one author, Michael Batty has many, many works on this topic, creating simple yet meaningful and testable models for this particular setting. In his article *Batty, M., & Xie, Y. (1994). From Cells to Cities. Environment and Planning B: Planning and Design, 21(7), S31-S48. https://doi.org/10.1068/b21S031* they start by explaining Conway's GoL as an introduction to an urban and suburban growth model. It does not focus particularly on migration, but there are also many others focused on this phenomenon, and it was surprising to not see any referenced.

"With this motivation in mind, we implement and simulate a simple, yet ***scale-invariant, agent-based city migration framework****, based on the rules of GoL"*

Scale invariance is claimed to be integrated into the model in some way... As far as my understanding goes, Conway's GoL isn't scale invariant, as structures such as gliders only appear at the grid's scale. Any aggregation or coarse-graining of structures would not lead to the same phenomena and structures as in the non-coarse grained structure. Is it through the "grid-within-a-grid" approach later described? Scale invariance cannot always be achieved by simply replicating a system of cells into the cells of a similar system.

Furthermore, how is the model agent-based? Citing *M. Batty (2009) Urban Modelling, International Encyclopedia of Human geography, Elsevier, Oxford, UK, pp. 51-58*

"Agent-Based Models (ABMs) *A class of models developed since the 1980s which are based on representing objects and populations at an elemental or individualistic level which reflects behaviors of those objects through space and time.*

Cellular Automata (CA) A class of spatially disaggregate models, often pictured as being formed on a two-dimensional lattice of cells, where each cell represents a land use and embodying processes of change in the cellular state are determined in the local neighborhood of any and every cell."

In agent-based modelling, one usually defines the population of agents, an environment, and then the rules that govern the evolution and interactions amongst and between those classes. GoL is purely a cellular automata, which I believe your model does not deviate from at all except for the introduction of a "grid-within-a-grid" approach. I do not know if by the "grid-within-a-grid" approach you are trying to compare this model to an agent-based model (as in each cell with GoL is an agent?). This ties in with a later point, which is clarity in the explanation of the model.

*"We use the framework to **quantify macroscopic and emergent properties** that are **consistently observed** after the simulation has had time to converge, or otherwise been executed for sufficiently long time horizons"*

I could not find a metric or reasonable quantification of any result presented, except for unclear realisation plots and simulation snapshots. I cannot attest to "consistent observation" either, as no statistics of the results were given.

*"We show that even with simplistic rules and a **reasonable ring-based model where GoL grids are 'nested' within an outer grid**, agent-based simulations can effectively capture and model the **complex interplay of individual decisions** and **environmental constraints** on a city's growth and structure"*

I don't think a "ring-based" model is reasonable in a model where growth, stabilisation, and re-distribution of population are expected to emerge. I would like to see that as a consequence of the model, not imposed beforehand. Also, it seems this imposition, derived from empirical knowledge, isn't even maintained by your model, as it simply goes into a GoL-like state in the snapshots included, which does not resemble how population is usually distributed. We also lack a comparison to models that address single-center, polycenter, and merging cities, which in your case should be a relevant comparison.

The model is said to "effectively capture and model complex interplay of individual decisions" yet no validation or comparison is offered. You could argue the model has purely phenomenological interest,

yet in the results presented, I cannot clearly understand or observe via the figures presented any of this.

Addressing the claims of capturing "*a city's growth and structure"* I cannot see how the stationary state reached in results, very similar if not identical to GoL-like states, is representative of a city's growth and structure. Cities can be modelled as growing exponentially, diffusing their borders according to environmental constraints, and then merging or even becoming polycentric when encountering other populated areas. In the snapshots provided, we see GoL-like structures with recognisable hollow centers in the middle. This is not what I would expect when cities "collide".

Experimental setup

When specifying the rules of GoL, do define more rigorously key aspects of the model, such as the neighbourhood, which is usually considered a Moore or a Von Neumann neighbourhood.

As some other reviewers have pointed out, the choice between synchronous and asynchronous updates should be discussed and referenced, as these kinds of models can be highly susceptible to these choices, and this choice can also be relevant for the topic being studied.

I don't think the "pilot experiment" on a 10x10 grid gives any valuable insight. First of all, such a small grid conditions 36 out of the 100 cells available to be affected by finite-size/boundary effects. Afterwards, you derive some insight on a small number of trials (<15) for which no statistics or errors are given. Additionally, the information extracted on convergence times isn't used or referenced later. If one later introduces the ring-based city initial conditions and has some information on what this model does to overpopulation, is it appropriate to include this ring-based city structure?

Ring Agent-Based City Migration Model

I cannot understand the structure of this model. It needs a diagram or some sort of clarification urgently, as after several reads, I still do not understand what is being done here. Also, as I have already mentioned, the concentric, varying density initial conditions are not reasonable to me. This should be something expected from a model with emergent phenomena, not imposed from the start, which later seems to also be completely wiped from the system due to the GoL properties.

Results

In my opinion, the snapshots and plots of realizations provided do not illustrate well any insight gathered from this model, nor do they support the claims of the work presented. No metrics, clear results, or statistics of the simulations are provided. No comparison to the desired phenomena, either from reality or from another model, is presented or mentioned via reference. It seems from the interpretation provided that even when introducing a concentric initial condition, your model wipes all traces of this initial condition and returns the system to a GoL-like state. Is this not a detriment to your claims? You are already starting with a reality-like scenario of city structure, and your model cannot even retain this.

Conclusion

I find the conclusion to be a reiteration of what was claimed in the introduction, with no support or mention of the presented results, their implications, their comparison to other models or reality, an analysis of the advantages and disadvantages of the model presented, amongst other things.

I can be mistaken in any of my claims, and I'm open and glad to be corrected if you disagree with any of them. Please do take all of my criticisms and suggestions as constructive.

Declarations

Potential competing interests: No potential competing interests to declare.