Modeling and simulating traffic congestion

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For this assignment you can build upon the code that you have developed so far. If you desire you are also free to start from scratch. This assignment document is written in such a way that no existing code is assumed.

Problem statement

It is well-known that traffic flow as function of car density exhibits a phase transition. The first phase is at low density where the cars can freely flow. The second phase is at high density, where the flow stagnates suddenly and dramatically. In Japan this phase transition seems to occur at the **critical density** of about 25 cars per km [1], see Fig. 1. This phenomenon of 'bottleneck-free' congestion on a given stretch of freeway is our **system**. In reality this is a complex phenomenon which is created by a large collection of (diverse) human drivers on a number of traffic lanes; in addition it could be raining, the road condition could be bad, etc. But we would like to gain understanding about this phenomenon by developing a model that exhibits the correct phenomena in the simplest way. If we can find a minimal model which (qualitatively) explains our observed phenomenon, then we have a very strong candidate for the most important mechanism that drives the phenomenon.

Tasks

You are to implement two cellular automata models of traffic flow using Netlogo. The first is an elementary CA ($k = 2$, $N = 3$) with rule number 184. The second is called the Nagel-Schreckenberg model (see 3rd lecture slides and [2]). A template for the Nagel-Schreckenberg code is provided on blackboard (which you can further develop), and for rule 184 you can use your lab 2 code.

Your task is to study the well known phase transition in traffic flow (see Figure 1) using both models. You conduct a self-driven investigation to evaluate the two models explaining how well the capture this real world phenomena. This essentially relates to showing if the models can generate the phase transition, and if so under what conditions (e.g., under what parameters). You should also try to obtain further real world datasets for better model evaluation.

Some guidelines and hints are listed below:

1. Study the behaviour space tool of Netlogo for running many experiments which will enable you to export results into excel. (see `https://ccl.northwestern.edu/netlogo/docs/behaviorspace.html`)
2. Write a function which calculates a 'car flow' value for a given initial state for the CA. We will define it as the number of 1s ('cars') that cross your system boundary on the right-hand side, per unit time. This represents a **measurement** that we can compute on

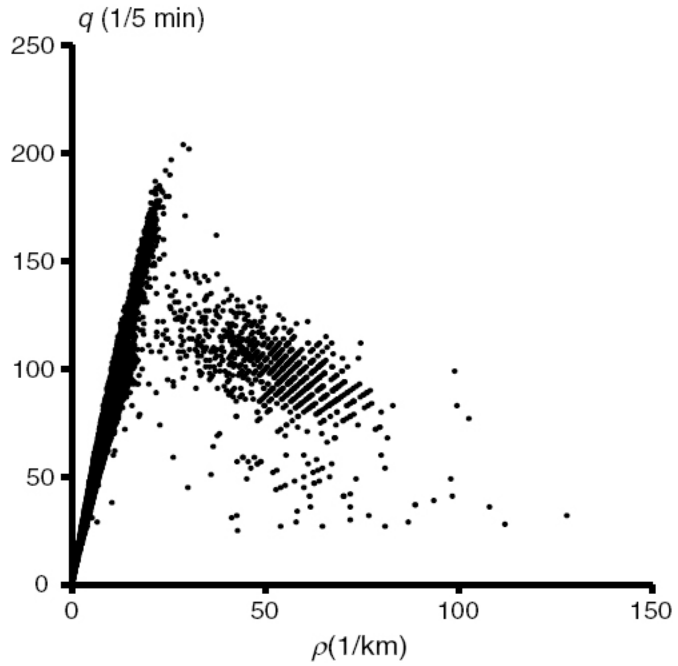

Figure 1: The typical fundamental diagram (the relation between vehicle density ρ and flow rate q) from 1 month of data measured at a point on a freeway. The critical density is nearly 25 (vehicles per km). The data were measured by the Japan Highway Public Cooperation. Copied from Reference [1].

a (simulated) experiment. Use a sufficiently large number of time steps, denoted T, to measure this reliably, e.g., $T \geq 1000$. Pick any $SystemSize \geq 50$.

Plot this car flow as function of the initial density of cars, using at least 20 density values in the range [0.0, 1.0]. For each density value you should generate multiple initial states and plot average the car flow for each initial state. Let us denote the number of initial states that you sample and average over by R. Is there a clear phase transition, and if so, at which density value?

3. Now plot the same graph but for a very low T (e.g., $T = 5$) and a very low number of initial conditions R per density value (e.g., $R = 3$). What is the effect of such 'undersampling'? This effect is very important to consider both in real experiments as well as in simulations. Generally it is unknown how many cells or how many time steps are needed in order to have a reliable measurement. In real experiments it is difficult to be sure that we had a sufficient number of cars driving for a sufficient amount of time: human drivers just want to go home at some point, so you'll have to make due with the data that you gathered – undersampled or not. But in simulation we can measure this.

4. Think about how to demonstrate certainty (or lack of) in your results. How sure are you about the estimate of the critical density made by both models?

Assignment

Please submit to Blackboard a zip file containing:

1. A document in which you describe the two models, your experimental approach, the results and clear conclusions and reflection. (max 1500 words & 4 pages A4)
2. Your code (working and commented)

Grading

- Report document: 80%

  The following should be clear in the report: Introduction, motivation, experimental question, model description(s), experimental results, conclusion.

- Python code: 20%

  Does the code work, is it well-structured, clear comments.

Deadline: Check Blackboard

References

[1] Yuki Sugiyama, Minoru Fukui, Macoto Kikuchi, Katsuya Hasebe, Akihiro Nakayama, Katsuhiro Nishinari, Shin-ichi Tadaki, and Satoshi Yukawa. Traffic jams without bottlenecksexperimental evidence for the physical mechanism of the formation of a jam. *New Journal of Physics*, 10(3):033001, 2008.

[2] Kai Nagel and Michael Schreckenberg. A cellular automaton model for freeway traffic. *Journal de physique I*, 2(12):2221–2229, 1992.