MOTORWAY MADNESS II - Cellular Automata

Introduction

As you drive along a motorway, you often find that cars in front of you slow down, then just as inexplicably accelerate a short time later, only to slow again. As you keep adjusting to the speed of the car ahead, you sometimes find a clump of vehicles closely packed in front of and behind you and at other times there are only a few vehicles in sight. Sometimes there is a real reason for this, such as a lane closure, whereas at other times the bunching seems to have no underlying cause.

In some situations, traffic is very similar to granular flow – though without, one hopes, the contacts that characterise the latter. Nevertheless, cellular automata (CA) models have proved to be a useful means to simulate congested city traffic including junctions, and lane-changing. In contrast, the free regime of motorways is unlikely to be well modelled this way, because there is little or no interaction among the vehicles, due to the low density.

Cellular automaton model

The granular theory of traffic encountered a great boost with the introduction of a stochastic (discrete) automaton model by Nagel and Schreckenberg[1]. A road is divided into cells, approximately the size that a car occupies in a jam. Each site may either be empty, or occupied by a vehicle. Each car has an integer velocity with values between 0 and $v_{\max}$. The update of the traffic situation is then based on a fixed number of rules which allow a car to hop to one of the next free cells ahead:

- If the velocity v of the car is lower than $v_{\max}$, and the distance to the next car ahead is larger than $v + 1$, the speed is increased by one.
- If a driver at site i sees the next vehicle at site $i + j$, with $j < v$, she reduces speed to $j - 1$.
- The velocity of each vehicle (if greater than zero) is decreased by one with probability p ('dawdling').
- Each vehicle is advanced by v sites.

Since each vehicle in a CA model hops with some probability, depending on the distance to the car in front, it is a kind of 'car-following model'. Simulations of the model show a transition from smooth flow to start–stop waves with increasing vehicle density, as observed in real motorway traffic. A 'shock wave' can arise from an initial homogenous but unstable flow.

Lane changing

An extension to the model would include several lanes of traffic, most simply treated by allowing vehicles to drive and overtake in any lane. Suitable CA rules for lane changing might consider:

- An incentive: the driver anticipates being able to drive more freely on the new lane
- Safety: not forcing other drivers to brake too hard.

Different types of vehicle

The model may be extended by introducing different types of vehicle, with different maximum speeds. This would be particularly interesting in a multi-lane situation, as one could see whether traffic organised itself into slow and fast lanes.

The project

Set up a computer program to apply a CA model to a series of vehicles: start with a one-lane version. You could have an open system, in which you feed a series of vehicles in at one end at random times selected to give an average traffic density, or you could set up a periodic system (think of it as cars going round in a loop).

Then experiment with different densities of traffic, extend the model to deal with several lanes, try different mixtures of traffic (e.g. a fraction of lorries mixed with cars), and describe the types of behaviour you see. Consider drawing out the distribution of vehicles, and even animating it.

References

[1] K. Nagel and M. Schreckenberg. A cellular automaton model for freeway traffic. *J. Phys. I. France*, 2:2221–2229, 1992.

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