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Emergent Local Control Properties in Particle Hopping Traffic Simulations

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1 Extended abstract

In this study normative driving control logic is identified as an emergent dynamical property of a simple granular traffic simulation. The Nagel-Schreckenberg[1] (N-S) rules (see figure 1 of this document) in a cellular automata (CA) type of simulation of vehicular traffic are shown to generate an emergent representation of a driver that can be viewed as an adaptively compensated derivative feedback control system (see figure 2). Relevant concepts of emergent dynamical hyperstructures[2] and formal properties of simulation and emergence[3] are described and employed. Emergent driving control logic is observed using simulation. We experimentally and theoretically isolate an adaptive control compensation term and various noise terms are added to investigate the emergent controller properties. Certain issues and problems with the N-S rules were made more apparent during this study and are briefly discussed.

We have known for some time that the N-S style granular traffic simulation produces realistic global traffic phenomena such as jams and flow-density relationships in simple roadway settings[3]. We also have results establishing that these effects are visible in continuum, object-actor simulations of more complicated traffic systems, even including signaling at intersections[5]. Also, granular traffic simulations now have an established relationship to traditional traffic flow theory[6]. The assumptions and methods that underlie simulations of this kind are in the spirit of statistical physics and are consistent with the more macroscopic concerns of local interaction influences in urban settlement evolution[7,8]. However, although the relationship of granular simulations to global traffic structures has become clearer, the details of the relationship of the local lattice site transition rules to some kind of driver control model has not. The purpose of these investigations is to begin to correct that gap in knowledge.

Initially, site transition algorithms such as the N-S rules were considered "low fidelity driving models". Issues and problems in applications[9] and research[3,10] has led to a reconsideration of this view. We now view the N-S rules as generator functions that, in interaction with the lattice, the state update algorithm, and in local interaction among themselves, give rise to an intermediate emergent phenomenon that is justifiably called a local vehicle control system. That is, the "driver" emerges between the levels of the generators and the global traffic phenomenology. The driver logic in this sense is a much higher fidelity representation than was previously suspected. This kind of an emergent dynamical hierarchy in simulation is of considerable theoretical and practical interest in its own right and apart from any issue in traffic science[2,3].

The identification of the controller is a non-unique determination. By parsimony arguments and with some semantic understanding of what constitutes a driver, we believe that the noise term in N-S rules are probably best understood as serving to elaborate the controller in the diagram in figure 2, rather than, for example, elaborating a model of the sensory and state estimation errors of the driver. Graphically, the rule transitions on a single simulated vehicle are traced as an input $((dx, v(t))\times$ output $(v(t+1))$ mapping in figure 3. Clearly, we could code such logic explicitly in an encapsulated software actor-object in the object architecture implied by figure 3. Such an object could be considered a driving controller object and, as such, a simulation employing these objects would produce the same global traffic behavior with transparently verifiable driver assumptions. This accessibility would be offset by a decrease in computational efficiency and, depending on the detail of the derived driving logic model, an intractable data collection problem for the validation process of the human-like controller.

The controller is adaptively compensated in that, for a simple gap measurement correction to avoid certain known behavioral problems (e.g., maximum throughput is too low) with N-S rules in high speed traffic, the compensator changes regimes at different traffic densities as can be seen in figure 4(b)[11]. Figure 4(a) is a fundamental diagram generated by the adaptively compensated controller version of the drivers that emerges from the modified N-S rules. For comparison, the usual N-S system flow density relationship is shown in the simulation conditions in figure 5.

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0.  Compute gaps.
1.  Accelerate: If $v < v_{\max} \wedge v < gap$ then $v \leftarrow v + 1$.
2.  If $v > gap$ then $v \leftarrow gap$.
3.  Randomization: if $v > 0$ then $v \leftarrow v - 1$ with probability 0.5.
4.  Move: $x \leftarrow x + v$.

Which can be simplified thus:

0.  Compute gaps.
1.  $v \leftarrow \min(v + 1, v_{\max}, gap)$.
3.  Randomization: if $v > 0$ then $v \leftarrow v - 1$ with probability 0.5.
3.  Move: $x \leftarrow x + v$.
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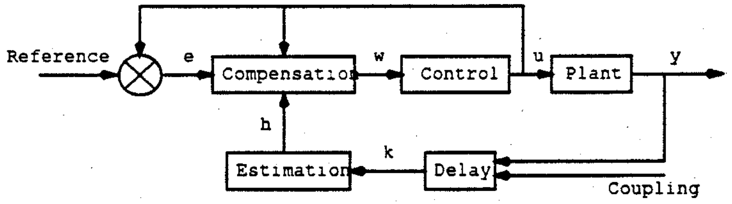
Figure 1: The basic N-S Traffic Generator Rules for a 1-D Lattice.



Reference	$r_i \leftarrow v_m$, v_m is the desired speed.
Error	$e_i \leftarrow r_i - u_i$, u_i is the current speed.
Compensation	$w_i \leftarrow \min(e_i, h_i - u_i)$, h_i is the gap.
Control	$u_i \leftarrow \max(u_i + \min(w_i, 1) + \varepsilon, 0)$, ε is noise.
Plant	$y_i = x_i \leftarrow +u_i$.

Table 1: N-S model rule set rewritten for derivative feedback controller.

note: i is the vehicle index: the vehicle $i + 1$ is ahead of vehicle i in the flow.

Improved	$s \leftarrow \max(\min(v_{i+1} + 1, v_m, h_{i+1}) - 1, 0)$.
Compensation	$w_i \leftarrow \min(e_i, h_i + s - u_i)$.

Table 2: Improved (less conservative) collision-free compensation by lookahead.

Figure 2: Adaptively compensated, derivative feedback control architecture for the N-S rules and a simple modification of those rules.

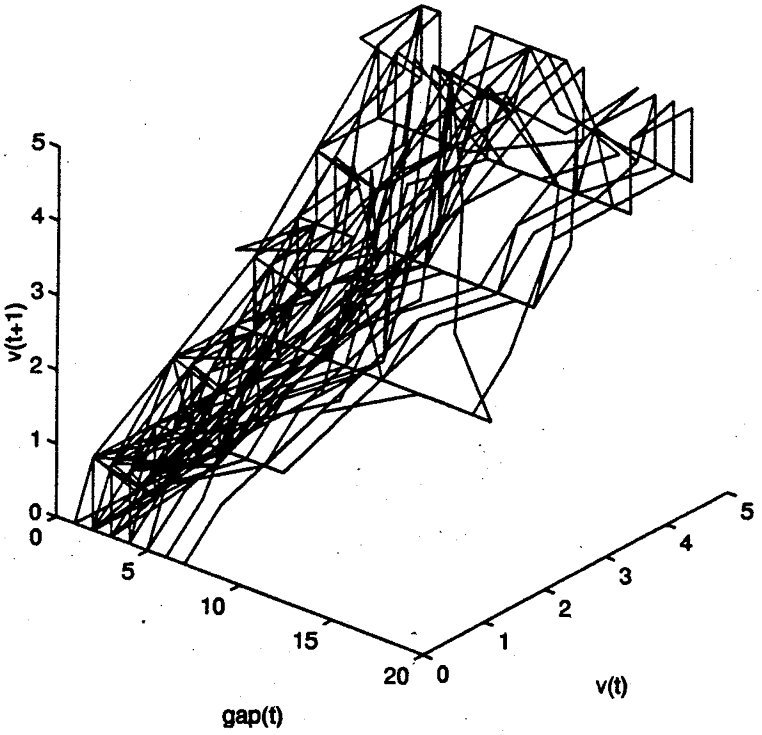


Figure 3: Graphical depiction, as a state space, of the emergent control logic transitions for a single vehicle at a particular point in the flow density regime.

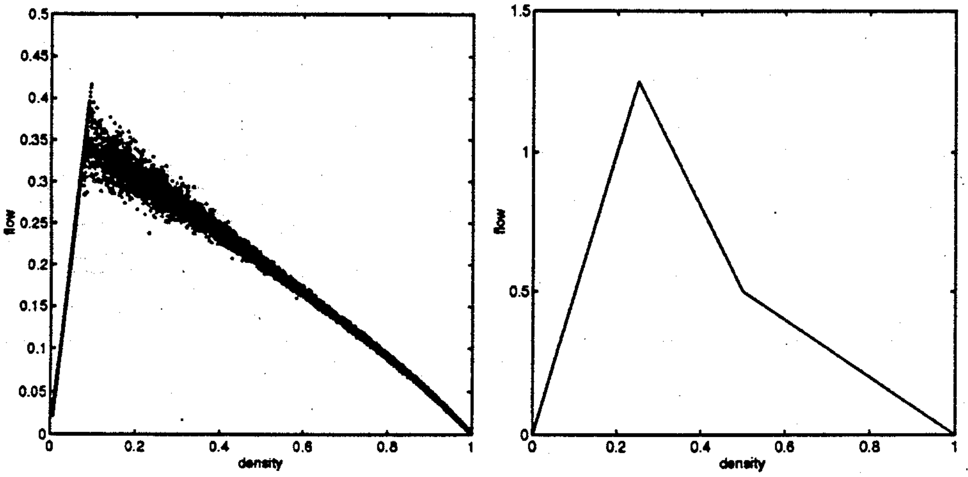


Figure 4: (a) Fundamental diagram for the adaptively compensated N-S system & (b) Graphical depiction of the adaptive compensation regimes as a fundamental diagram.

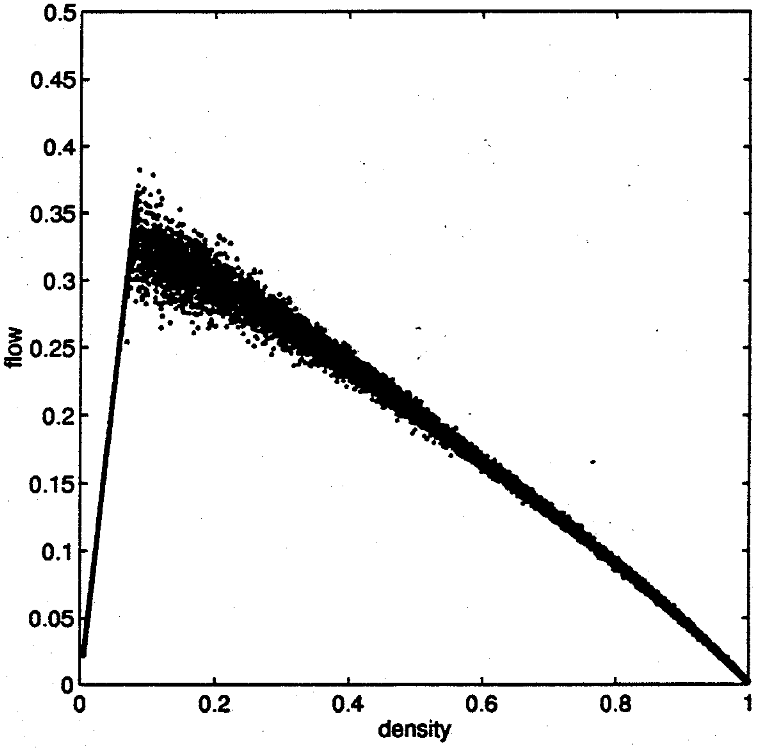


Figure 5: Fundamental diagram for the non-compensated N-S system.

Travel Model Improvement Program

The Department of Transportation, in cooperation with the Environmental Protection Agency, has embarked on a research program to respond to the requirements of the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991. This program addresses the linkage of transportation to air quality, energy, economic growth, land use and the overall quality of life. The program addresses both analytic tools and the integration of these tools into the planning process to better support decision makers. The program has the following objectives:

1. To increase the ability of existing travel forecasting procedures to respond to emerging issues including: environmental concerns, growth managements, and lifestyles along with traditional transportation issues,

2. To redesign the travel forecasting process to reflect changes in behavior, to respond to greater information needs placed on the forecasting process and to take advantage of changes in data collection technology, and

3. To integrate the forecasting techniques into the decision making process, providing better understanding of the effects of transportation improvements and allowing decisionmakers in state governments, local governments, transit agencies, metropolitan planning organizations and environmental agencies the capability of making improved transportation decisions.

This research was funded through the Travel Model Improvement Program.

Further information about the Travel Model Improvement Program may be obtained by writing to:

TMIP Information Request
Metropolitan Planning (HEP-20)
Federal Highway Administration
U.S. Department of Transportation
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Washington, D.C. 20590