THE INTERPLAY OF MULTIPLE SCALES IN TRAFFIC FLOW: COUPLING OF MICROSCOPIC, MESOSCOPIC, AND MACROSCOPIC SIMULATION

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SUMMARY

Key ITS applications require *simultaneous*, *accurate* simulation of the interplay of complex phenomena occurring at multiple scales in traffic flow. The scales involved range from individual vehicles through collective effects and up to the network level. A promising approach to this problem is the *coupling* of different traffic modeling paradigms capable of handling a wide range of phenomena. This paper describes the design and progress in implementation of a new simulation environment for coupling of simulation techniques describing traffic flow in different degrees of detail. These techniques utilize macroscopic, mesoscopic, and microscopic models. Potential applications include challenging fundamental questions in traffic modeling such as self-organization of traffic structures, traffic prediction, collective and individual route guidance, incident management, the impact of new assistance systems on highway performance and traffic safety, and optimal integration of floating car data into a simulation environment.

INTRODUCTION

The dynamics of traffic flow are affected by phenomena occurring and interacting on a wide range of spatial scales. The interplay of processes on different scales introduces a considerable degree of complexity into the dynamics and poses both theoretical and practical challenges for accurate modeling. Microscopic (here meaning "individual") effects may have macroscopic consequences that are not captured by simple heuristics (see Fig. 1). For example, the microscopic process of lane changing reduces the highway capacity in weaving sections in a context dependent way.

On the other hand, individual reactions are influenced not only by the behavior of the leading vehicle, but also by the surrounding traffic density and flow characteristics on "mesoscopic" scales [3]. Moreover, there is considerable evidence that the individual process of speed adjustment to the flow several hundred meters downstream provides an important contribution to traffic safety on highways by smoothing potential speed drops (a collective process). Here, there is an interaction of mesoscopic and microscopic scales with important consequences for many applications.

Individual behavior is of course also directly influenced by large-scale (macroscopic) conditions. For example, the statistical distributions of typical microscopic traffic safety indicators such as time gaps or times-to-collision depend on the macroscopic context (volume and speed level at least). The surrounding traffic conditions must thus be included as a concomitant factor in any serious study of microscopic vehicle dynamics and certainly in any safety analysis.

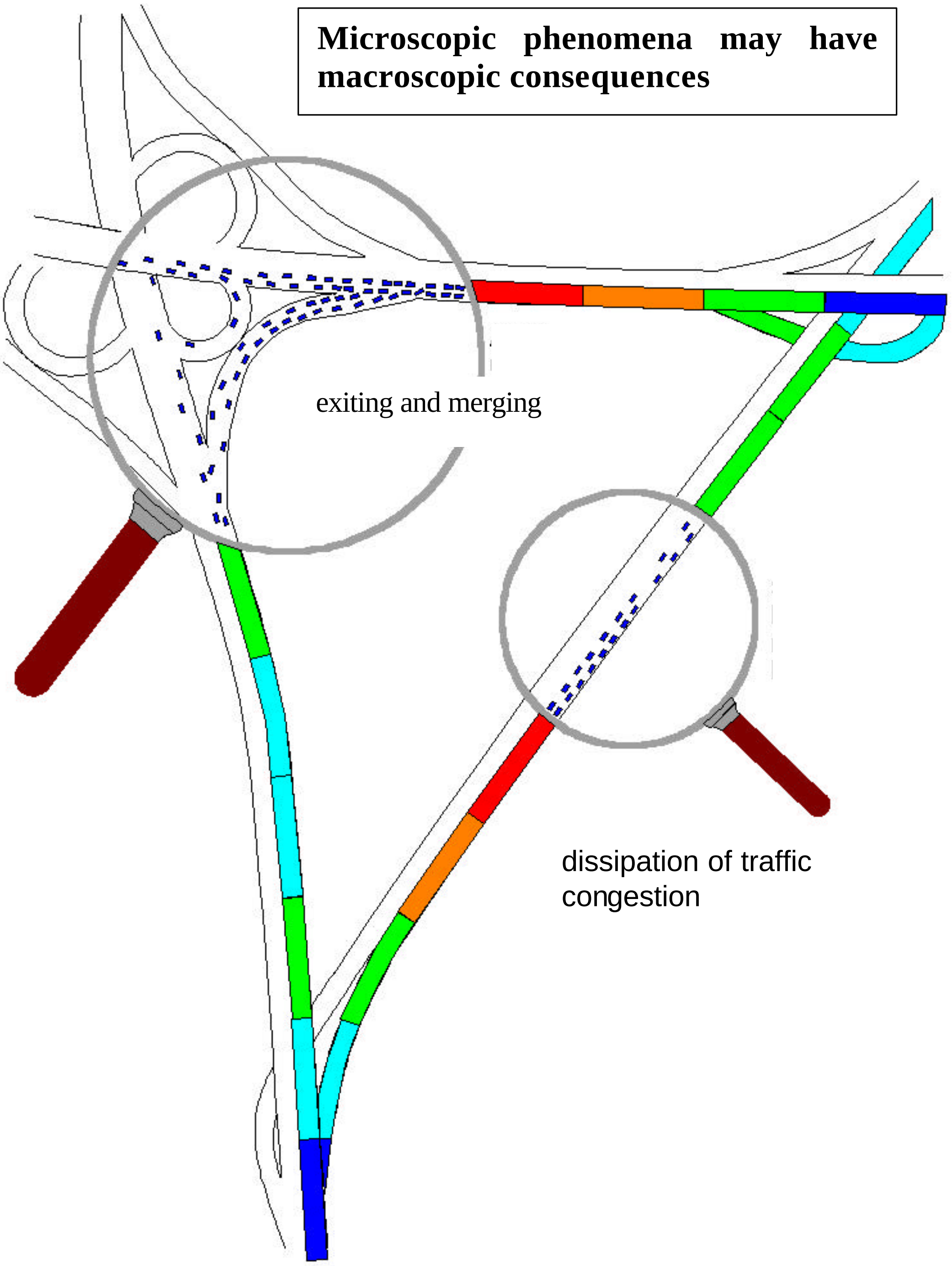

Fig. 1: Examples of scale interactions and their representation by model coupling

The interaction of different scales in traffic has implications not only for researchers, but also for manufacturers, planners, and policy makers. Proper modeling will have an impact on diverse traffic management applications (demand monitoring and forecasting, multi-modal transport, route choice, warning systems). Of particular interest in the automotive industry has been the interaction of *vehicle management* (assistance, guidance, and control systems) with *traffic management* (including traffic safety).

A very strong recent impetus for strengthening our understanding of multiple-scale interactions in traffic flow is the advent of *floating car data* and services that will be enhanced by this data. In order to understand the impact of these services on traffic, one will need to simulate an interacting system with feedback processes linking all dynamic scales. The linkage is in fact bi-directional, because individual cars not only act as probes of the macroscopic flow, but they may be influenced by some services in such a way as to modify the flow to achieve traffic management objectives.

APPROACHES TO TRAFFIC SIMULATION VALID FOR A RANGE OF CONTEXTS AND SCALES

Traffic simulation is a broad area encompassing distinct objectives, which are in turn important in defining the tools required. Simplifying assumptions in traffic models that may be appropriate for one road category (i.e., urban, rural, highway) may lead to severe errors for a different road type. Even within one category there may be subtleties requiring a refinement or modification of the simulation. The appropriate degree of modeling detail and resolution in space and time depends on the problem. For example, geometrical transitions such as highway interchanges, weaving sections generally require a finer resolution than homogeneous sections. Finally, individual vehicle control and assistance systems (individual route guidance, ACC, ABS, brake assist, etc.) obviously require microscopic modeling.

The above discussion implies that microscopic simulation must at least be *included* in a simulation environment appropriate for the finest scales. One conceivable and presumably feasible approach is simply to use a microscopic model for the *entire network*. An enormous computational effort is required for microscopic simulation on a network, so that as a practical matter at present one must live with either small networks, reduced complexity of the microscopic representation, or slower than real-time simulation. Indeed, for traffic prediction it is important to simulate even faster than real-time.

A more fundamental issue regards the nature of traffic modeling: Some applications require not only microscopic details, but also *reconstruction* of a traffic flow state according to measured or prescribed boundary conditions. The reconstruction problem including multiple, possibly “redundant” data sources lends itself to a macroscopic or mesoscopic representation of traffic. An important issue is that available data sources are often *aggregated, incomplete or subject to uncertainties*. Microscopic traffic models by their nature usually contain a larger number of calibration constants than less-detailed models. Hence, control and optimization procedures are more difficult to implement, because there are many “knobs to turn” (over-modeling problem).

MODEL-COUPLING IMPLEMENTATION

As a way of combining the best features of macroscopic, mesoscopic, and microscopic simulation tools, we have developed and implemented a model coupling environment as illustrated in Fig. 1. The macroscopically simulated “collective” flow speeds are color coded (red is slow, blue is fast). Exiting and merging in the interchange as well as the details of congestion dissipation are simulated microscopically, since here microscopic processes have a strong impact on the correctness of the simulation.

The simulation programs are matched at the boundaries by dynamic interfaces. These interfaces regulate both technical and algorithmic coupling of the traffic flow models. The technical implementation as a “client-server” structure is sketched in Fig. 2. The programs communicate via Unix sockets.

Technical realization

A realization of model coupling using the microscopic simulator PELOPS [1] and the macroscopic simulator SIMONE [2] has been realized and will be described along with several selected applications presented in another contribution.

Disaggregation

An important aspect of model coupling is the development of an appropriate statistical model for generating individual vehicle speeds and separations from macroscopic information. The distributions of gaps, times to collision, and velocity correlation statistics provided by the disaggregator correspond to those of real data. Incorrect distributions could cause errors in the representation of microscopic phenomena depending on these distributions such as merging and passing. To this end, a disaggregator was developed that combines aggregated (or macroscopic) data with microscopic *historical* information to produce realistic vehicle time series directly at the simulation model interfaces.

APPLICATIONS AND ILLUSTRATION

In Fig. 2, the coupling of a macroscopic model (SIMONE) upstream and a microscopic model PELOPS (downstream) is illustrated. The simulated scenario represents traffic merging from two freeways of two lanes each into one 4-lane stretch in an interchange north of Munich. After about 300 meters, the right lane ends. This intersection is of considerable interest because it is notorious for developing congestion that can back traffic up for several kilometers -- especially during peaks of (returning) holiday traffic.

Potential applications of the model coupling environment include

- The impact of driver assistance systems such as ACC on congestion.
- Mechanisms for safety enhancement provided by roadside warning systems such as COMPANION [4] (developed by BMW).
- Automatic incident detection and localization
- Traffic guidance systems
- Simulation of floating car data (FCD) generation
- Reconstruction of traffic flow using FCD as input
- Simulation of the back reaction on networks due to FCD services

CONCLUSIONS

The model coupling environment reported here is a promising technique for combining the best features of macroscopic, mesoscopic, and microscopic simulation tools. Although additional refinement is necessary to improve the representation of traffic information flow through the interfaces, the implementation of a model coupling environment represents a key step toward understanding the interplay of multiple scales in traffic flow.

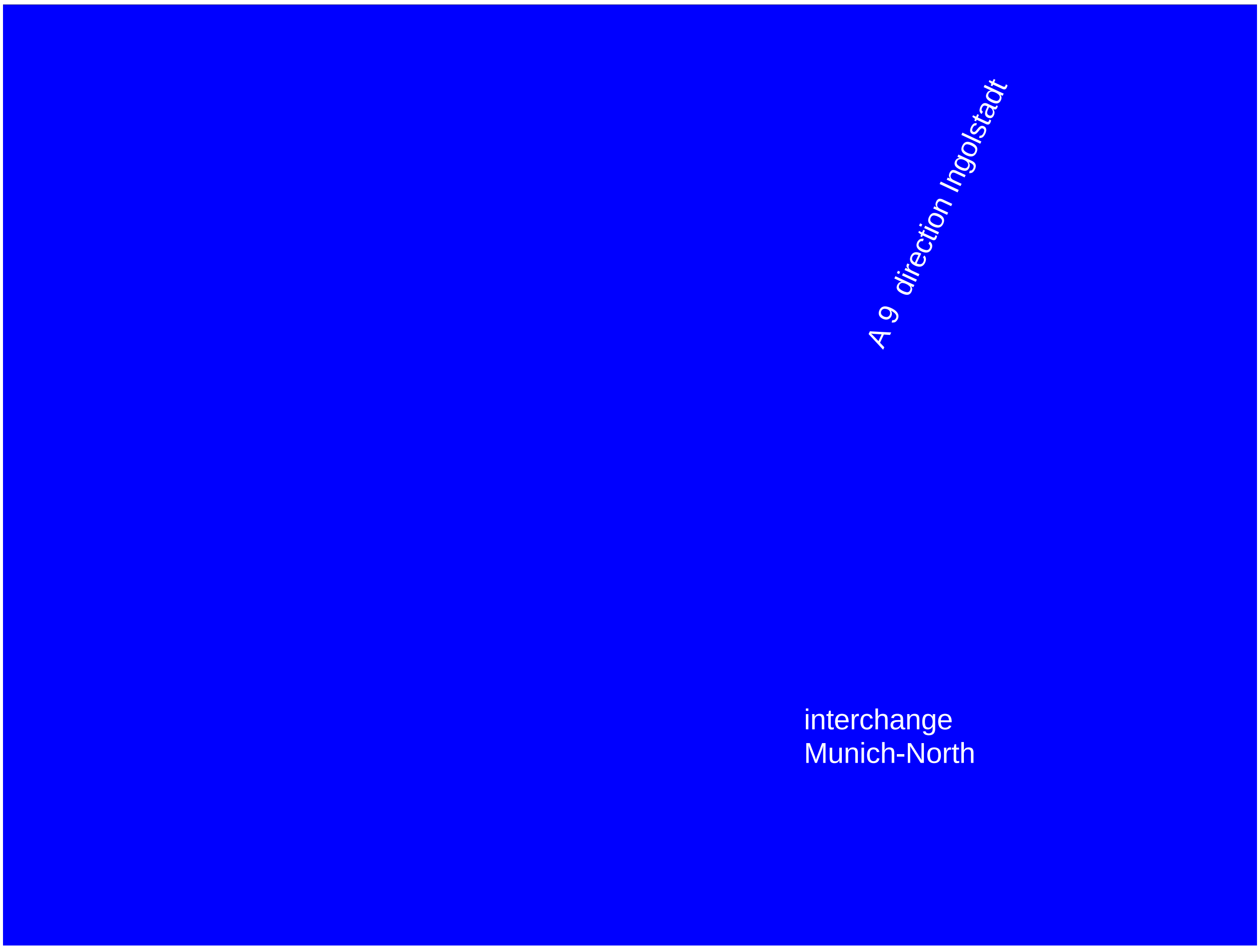

Fig. 2: Holiday congestion

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