Large Scale Microscopic Evacuation Simulation

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Summary. The evacuation of whole cities or even regions is an important problem, as demonstrated by recent events such as evacuation of Houston in the case of Hurricane Rita or the evacuation of coastal cities in the case of Tsunamis. A robust and flexible simulation framework for such large-scale disasters helps to predict the evacuation process. Existing methods are either geared towards smaller problems (e.g. Cellular Automata techniques or methods based on differential equations) or are not microscopic (e.g. methods based on dynamic traffic assignment). This paper presents a technique that is both microscopic and capable to process large problems.

1 Introduction

Disaster and evacuation planning has become an important topic in science and politics. In principle there are two different situations: evacuation of buildings, ships and airplanes or the like on the one hand, or evacuation of whole cities or even regions on the other hand. The former involves normally the evacuation of pedestrians, whereas the latter is often associated with the evacuation by car. Corresponding to the two different types of problems, there are two different basic approaches for simulating the traffic flow:

(1) Methods of dynamic traffic assignment (DTA) have been applied to evacuation simulation on the city or regional scale (e.g. MITSIM [1] or DYNASMART [2]). The DTA approach is based on the analogy between traffic and hydrodynamic characteristics of fluids. That means DTA is a macroscopic approach and reduces the problem of evacuation dynamics to a well known physical problem. However, in DTA it is not straightforward to deal with the inhomogeneity of a population. For this, a microscopic simulation is needed, where all people are simulated as individuals.

(2) Microscopic simulations are often based on Cellular Automata (CA) [3, 4]. In CA models each evacuee is designed as an individual; therefore it is possible to simulate also population structures where people have different speeds or ranges, or more complex behavior. The modeling of complex behavior in evacuation simulation has become important in recent years. People could for example ignore warnings or might not choose the nearest emergency exit, furthermore people tend to follow others (herd behavior) [5, 6]. Agent

oriented research groups have modeled such behavior [7, 8]. In general it is expected that complex behavior leads to longer evacuation times, consequently a simulation that ignores such behavior patterns is probably optimistic.

One possible approach to deal with large-scale scenarios (hundreds of thousands of persons) but to retain persons as individual agents is based up on a modified queuing model [9, 10]. The queuing model simplifies streets to edges and crossings to nodes. This graph-oriented model is defined by lengths/widths, free speed and flow capacity of the edges. This simplification leads to a major speedup of the simulation while keeping results realistic.[1]

2 Simulation framework

The evacuation simulation is based on the MATSim framework (`www.matsim.org`), which is constructed around the notion of agents that make independent decisions about their actions. Each evacuee is modeled as an individual agent that optimizes its personal evacuation route. The objective is a Nash equilibrium, where every agent attempts to find a route that is optimal for the agent. In reality this might be achieved by appropriate training or guidance while maintaining acceptability in the sense that no person could gain by deviating from this solution. The results from the simulation give an estimate of the time it could take to evacuate the endangered area.

The escape routes are encoded in so-called *plans*. Besides the escape route a *plan* also contains the departure time. That means it would also be possible to model an arbitrary variance in the evacuees' response time. However, in the work presented here, it is assumed that all evacuees start to evacuate at the same time. The traffic flow simulation is implemented as a queue simulation, where each street (link) is represented as a FIFO (first-in first-out) queue with three restrictions [9]. First, each agent has to remain for a certain time on the link, corresponding to the free speed travel time. Second, a link flow capacity is defined which limits the outflow from the link. If, in any given time step, that capacity is used up, no more agents can leave the link. Finally, a link storage capacity is defined which limits the number of agents on the link. If it is filled up, no more agents can enter this link. The difference to standard queueing theory is that agents (particles) are not dropped but spill back, causing congestion. An illustration of the queue model is shown in figure 1. The free parameters (i.e. flow capacity, storage capacity and free speed) are chosen to approximate Weidmann's fundamental diagram [12].[2]

The initial escape routes are generated by applying (a time-dependent) Dijkstra's shortest path algorithm [14] assuming free speed is possible on all

[1] For example, the simulation of the whole (motor) traffic of Switzerland (approx. 5 million trips) takes less then 5 minutes for 24h real time [11].

[2] Newer studies [13] imply other fundamental diagrams then those from Weidmann. An adaptation of these values could, in consequence, become necessary in future.

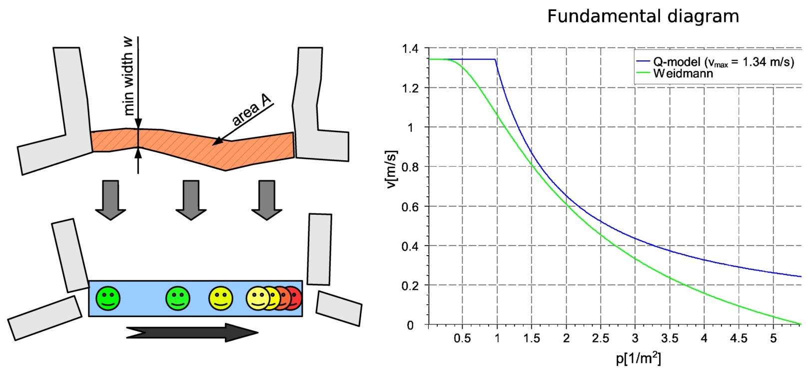

Fig. 1. Illustration of the queue model

links. Dijkstra's algorithm is designed to deal with single-destination problems, but in the case of an evacuation there are many different safe places possible. The standard approach (e.g. [15]) is to transform this multi-destination problem into a single-destination problem by creating a new node as super-sink. All links which lead out of the evacuation area are connected, using virtual zero cost links, to that super-sink (see figure 2 a)). Doing so, Dijkstra's algorithm will find the shortest route from any node inside the evacuation area to this super-sink.

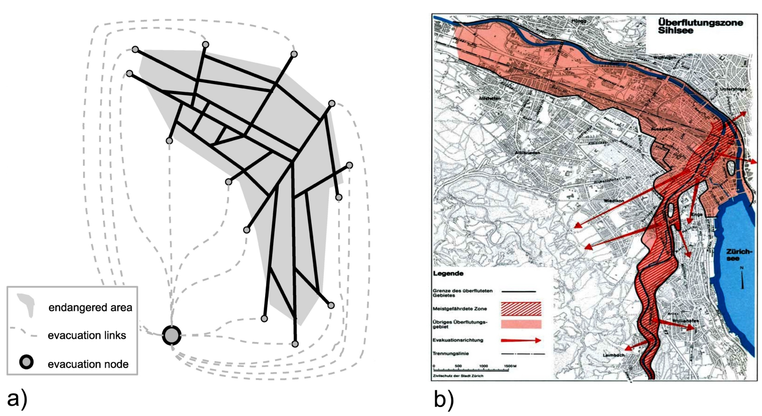

Fig. 2. Inundation map and evacuation network

The outcome of the traffic flow simulation (e.g. congestion) depends on the planning decisions made by agents. It is obvious that simulating the initial escape routes only will not provide a good or realistic solution for the evacuation problem and the results will be far away from Nash equilibrium. To find the Nash equilibrium, the simulation framework runs learning iterations: At the end of each iteration, every agent scores the performed plan. In this study the scoring function is simply the negative of the travel time. This score is then memorized for the plan. After the agents have updated their score, each of them decides with a certain probability to revise its plan. In the re-planning procedure, the Dijkstra router is again applied to find the fastest escape route for each agent. The difference to the initial routing is that the weights for the links are no longer based on free speed travel times but on the experienced travel times from the last iteration. For every agent that has not been chosen for re-planning, a probabilistic discrete-choice model selects a plan out of its memory, where the probabilities of the plans increase with the achieved score. Repeating this iteration cycle, the agent behavior will move towards a Nash equilibrium.

3 Results

A hypothetical event of a dam-break of the Sihlsee dam was chosen as a scenarior. This would lead to an inundation of parts of the city of Zurich. According to the civil defense office there will be an advance warning time of about 110 minutes until the inundation will reach the city center. The civil defense office also provides an instruction sheet with an inundation map of the area at risk (figure 2 b)). A NAVTEQ network (`www.navteq.com`) for Switzerland was chosen as evacuation network and adapted for pedestrian simulation. The affected part of the city of Zurich consists of 3037 nodes and 6120 links. The synthetic population embraces 165571 agents and was extracted from census data and contains all people with their work place within the evacuation area.

The simulation run was performed on a dual core CPU at 2.33 GHz with 2 GB of RAM. The computer runs JAVA jdk1.5_012 on Linux. The evacuation simulation has been stopped after 100 re-planning cycles. The overall runtime was 3 hours and 24 minutes. The simulation consumed up to 1393 MB of RAM. As expected, the evacuation time decreases significantly with the iterations and levels out at approximately 45 minutes (see figure 3 a)). Using a visualizer, some bottlenecks could be detected. This is shown in figure 3 b). These bottlenecks mainly occur at bridges. The snapshot was taken after 100 iterations of learning, consequently there seems to be no better solution for the individual agent than to queue up on these bridges.[3]

4 Conclusions

We introduced a microscopic pedestrian simulation framework for large-scale evacuations. It is implemented as a Multi Agent Simulation, where every

[3] For those who know the area: Since this preliminary study is based on a vehicular traffic network, it ignores links which can be used by pedestrians only. This could be corrected by using different network data.

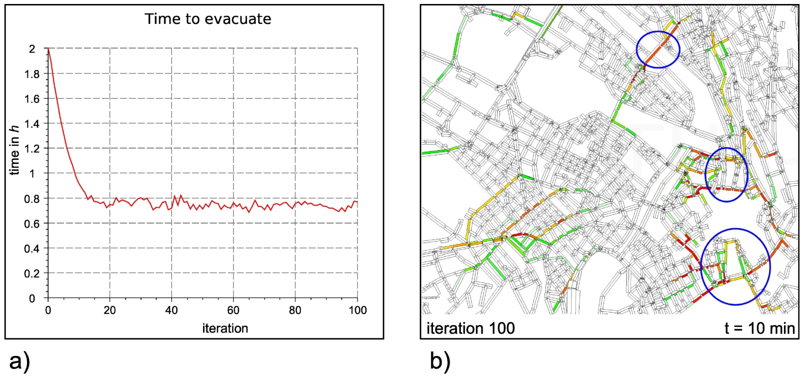

Fig. 3. Results of the simulation

agent tries to optimize its individual evacuation plan in an iterative way. The simulation framework is demonstrated through a case study based on a hypothetical dam-break of the Sihlsee dam near Zurich. Despite the underlying behavioral model being quite simple, the simulation gives plausible results regarding the predicted evacuation time and bottlenecks. The runtime performance shows that this approach is well suited for large scale scenarios. With state of the art hardware it is no problem to simulate much larger scenarios with over one million agents. In future work it is planned to apply this framework to an evacuation simulation in the case of a Tsunami warning for the Indonesian city of Padang. The improvement of the behavioral model (e.g. herd behavior [5] modified for large-scale scenarios [16]) could also be a topic of future work.

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