Abstract
The German Federal Office of Civil Protection and Disaster Assistance categorises potential hazards, which could arise for inhabitants of Germany (BBK, 2006). They share a common trait: a huge number of persons would be affected by the concrete situation. The responsible management organisations would have an urgent need for better forecasts of human behaviour and dynamics to better supply people with, e.g. food and water. The dispatch of rescue teams as well as the management of self-help for persons affected by the disaster could be managed more efficiently by using the outcome of computer simulation studies. The project WALK is placed into this context suggesting a framework and methodology to build a reliable multi-agent model for computer prediction of human behaviour in critical situations that includes emotional stress and complex interaction between individuals. This paper is aimed at giving a brief overview about the specific requirements, which WALK is dealing with.

1 Introduction
Leaving a building in a hurry due to fire or other disastrous influences is always combined with heavy emotional stress. It is therefore attractive to integrate emotional aspects in simulating models, which aim to provide decision support for security organisations and planners. This paper is meant as a brief introduction into the project WALK that is currently under development in a joint research effort between the Universities of Applied Sciences in Hamburg and Munich. We would like to recommend to Baldowski (2011), Thiel (2011), and Roiss (2011) for further reading about WALK.

This paper breaks down as follows: in this section we describe a basic every-day scenario to motivate the concept of agents with goals and dynamically arising sub-goals that lead to actions. The current state of the art on pedestrian and crowd models is given in the second section. The next one covers three important topics for the development of WALK: 1) To achieve high quality software in a sustainable way WALK will be developed following modern software engineering best practices. 2) Credibility is an essential factor for those software tools. Therefore, some first
validation aspects are named. 3) We build Walk on top of a strong mathematical foundation. Some key elements are delineated here. Conclusions and future developments will close the paper.

1.1 Scenario

Let us start with an example scenario as shown in Figure 1. It holds a T-junction subway corridor and a centred food stand, which sells breakfast bagels.

Figure 1: Subway scenario

A single agent wants to reach his subway train. It is morning and he is on his way to his office. The following list gives an incomprehensive view to the things that might happen next:

- He knows the area and moves quickly to the left exit.
- He stops at the food stand because he has not had breakfast yet.
- He meets a former colleague, stops, and chats.
- He starts running because there is a schedule display that tells him to hurry to catch his train.
- He reduces speed because the same display tells him his train just left, the next one due in 5 minutes.
- It is his first day using the subway and he has to familiarize himself with the surroundings.
• He turns left because the signage is obvious and clear (and he recognizes them).

• He turns right to the exit because the signs are hidden, unclear or invisible due to other circumstances (or he missed them).

Obviously, we have a hierarchy of goals (e.g. 'get specific train'), sub-goals (e.g. 'get breakfast'), and actions (e.g. 'move left'). It is also observable that sub-goals arise dynamically ('see a person you know') and they will be nested into the hierarchy of goals.

In the next modelling step we crowd the corridor with many other moving agents – with different goals and sub-goals. Everyone has his or her own velocity, i.e. a vector of movement of which its length correspond with the speed. We now may enhance our list above by:

• Avoidance of collisions with other agents.

• Increase and reduce speed because of blocks and gaps in the crowd.

The complexity of this example might be enhanced by the fact that people often move in small groups (e.g. pairs, parents with children).

1.2 State-of-the-art

There is a long tradition of research in pedestrian movement and dynamics. Evacmod (2011) lists an incomplete number of 65 different models alone. This means a staggering increase by 43 models since 1999 (Gwynne et al., 1999). Among the most successful in terms of simulation speed and correct reproduction of observable phenomena are cellular automata (Schadschneider et al., 2009; Köster, 2010) and social force models (Helbing, 1998).

However, especially the latter, which are based on solving differential equations motivated by an analogy to electrodynamics, do not lend themselves naturally to enhancements that allow to incorporate individual behaviour. The movement of each virtual person is governed by the same set of rules. This allows investigating interaction between individuals on a more abstract level, but excludes exceptions to the postulated physical laws.

This situation is very similar to the discussion within the community of ecosystem modellers (Clemen, 1999; Breckling et al., 1994). One of the main disadvantages of differential equations approaches was and is the fact, that only symptomatic behaviour is modelled. In our context this means to give up the search for understanding the human motivation and replace it by a mathematical system, which reproduces certain statistical or macroscopic phenomena instead.

This approach has produced very useful insight on evacuation dynamics. But is our movement really governed by mechanical laws to such an extreme extent? We believe that the risk to neglect crucial aspects is high. The following list shows some issues, that we believe can influence simulation outcome quality in a critical manner:
For example, we consider a family of two adults and two children instead of a single agent. They act as a group and not as individuals. What happens if a child is separated from his or her parents? Will the parents wait? Will they turn and move toward the lost child? We think they will – and that this tendency has large impact on pedestrian flow at bottlenecks.

Group cohesion and group behaviour is something that can be solved within the frame of social force models (Moussaid et al., 2010) and cellular automata (Köster et al., 2011) at least to some extent. In the latter case this is best achieved by enhancing cellular automata with functionality that is taken from software agents, originally. This is a strong motivation to base the WALK project on a true agent-based model right from the start.

Our group started to target the influence of emotions by simulating the crowd dynamics at an African market (Thiel-Clemen et al., 2010). It became evident that emotions have a major impact on the simulation results. Obviously, emotions are an important factor to self-organizing of crowds, which could be observed by emergent behaviour.

In WALK we aim to include different personalities and moods of the agents. Aggressive behaviour, e.g. noticeable by nudging between persons, effects evacuation times substantially. Indeed, experimental work by (Chattaraj et al., 2009) comparing walking behaviour of German and Indian test persons suggests that there is a significant impact.

2 WALK

The WALK project actually conglomerates various research tasks. To conduct fundamental research on the impact of emotions on crowd dynamics a simulation tool is necessary. In turn, building up the software as well as the underlying models means to bring together various aspects of interdisciplinary research.

As mentioned above, there are three papers in this volume which are detailing the Walk simulation system, i.e. the GIS component (Baldowski, 2011), the multi-agent system (Thiel, 2011), and the modelling of agents interior (Roiss, 2011). This work complements these topics by some software engineering issues, ideas for validation, and some considerations about scales.

2.1 Architectural Design

In WALK we strictly follow modern software engineering principles, like component-orientation, loose coupling and usage of coding guidelines (Martin, 2008), while designing the software architecture of our simulation environment. This should aid in keeping the system scalable, understandable, and evolvable, which is especially important, as many developers will take part in the project over a long period of time.

A rough outline of our current component-architecture is shown in Figure 2.
The responsibilities of the various components are as follows:

- The **GIS**-component will provide spatial data as landscapes, terrain, and buildings.

- Individual emotional agents will be simulated by the **Agent**-component; agents are built and coordinated by the **Agent Factory and Manager**.

- Distribution among different computers will be controlled by a component named **Distribution Manager**. Distribution is incorporated to support scalability of our simulation environment.

- Scenarios will be defined using the **Simulation Manager**. A scenario describes a concrete configuration of an environment, a number of agents, their initial state, and events to occur during the simulation run. Such events could be the outbreak of a fire or collapse of a wall.

- A graphical user interface will be used for defining scenarios (**Scenario Editor**), for initializing and controlling the simulation run (**Simulation Controller**), and for visualizing the simulation (**Visualization-Component**).

- Most components will communicate by using a message bus (**Enterprise Service Bus**). Messaging is used to support loose coupling and aid distribution of the components among different computers.

- A **Logging Manager** will be used to be able to track the simulation runs.
The GIS- and Agent-Components are described in detail in (Baldowski, 2011; Thiel, 2011).

2.2 Validation

Validation, in our context, is the systematic attempt to establish that the model reproduces reality with sufficient accuracy. This definition of validation is not only valid for agent-based pedestrian models but whenever phenomena from real life are observed and modelled (Sargent, 2005). In contrast, the term ‘verification’ means to ensure that the implementation is correct.

The outcome of events must be predicted correctly so that decisions can be based on the simulation results. This is a very difficult task, in particular with regard to the large number of parameters a detailed agent-based model comprises, usually. Validation falls into two classes: Qualitative and quantitative tests.

Qualitative tests provide scenarios where scientists and users agree that certain behaviour must be observed. A very basic requirement is that a person should walk along a corridor in a straight line. Or that he or she shall be capable of navigating around a U-shaped obstacle even if the person’s target is exactly behind the obstacle.

In force-based models pedestrians often get trapped in the cul-de-sac unless graph-based path finding or a floor field is introduced. Another, more complex requirement is that people in small interacting groups walk side by side if possible (Köster et al., 2011). In an agent-based model one may deliberately wish to deviate from such a requirement to reproduce individualized behaviour. However, default parameters should be available to qualitatively reproduce ‘standard behaviour’.

Quantitative tests are more difficult to construct because very little reliable empirical data is available to the public. Additionally, it is not trivial to define a meaningful measure based on such observational data to which simulation results can be compared. One widely accepted concept is the relationship between the density of a crowd and its flow. Several so-called fundamental diagrams describing this relationship can be found in PedNet (2011).

The most widely used diagram is the one provided by (Weidmann, 1992). It is also suggested in test 4 by the RiMEA organisation (RiMEA, 2009), which is a joint initiative by scientists and companies working in the field of pedestrian stream simulators. This test requires that a suitable simulation tool shall be capable of reproducing the fact that the crowd slows down with increasing density. We go one step beyond. Fundamental diagrams may differ widely depending e.g. on the culture or simply the composition of a crowd. Rush hour passenger traffic at a train station is much more efficient than the leisure time passenger traffic perhaps only 30 minutes later. So we demand that the tool shall be able to calibrate parameters such that any measured diagram can be faithfully reproduced (Davidich et al., 2010).
We will follow the suggestions by RiMEA to validate WALK, which insures a common standard of quality.

2.3 Transition function and scales

A human who is observing a dynamic system may choose between different scales of cognition. One example of a complex dynamic system is the scenario depicted in subsection 1.1. The observer may either follow one specific pedestrian by his way through the subway floors or abstract from individual behaviour by watching the flow dynamics that occur. Thus, the overall dynamic results from various processes with other sub-processes nested into. A hierarchy of processes unfolds.

The core ‘behaviour’ of a software agent can be essentially described by the following function:

\[ \delta_k : S \times T \times I \rightarrow S \times O \]

with

- \( S \) : current state of agent \( k \) (e.g. position, emotional state),
- \( T \) : current timestamp,
- \( I \) : sensory input, and
- \( O \) : sensory output.

Any behaviour of the agents is basically describable by this non-deterministic transition function with current state and influences of the sensory inputs from the immediate environment as main parameters (see Roiss (2011) and Thiel (2011) for more details). In WALK, the description of set \( S \) is of particular interest. Apart from usual state variables like geographical position, heading, and so on, we cover individual details of physiological and psychological by parts of \( S \).

The output characteristic of every function \( \delta_k \) is a composite of signals over time. Obviously, the above hierarchy of processes will leave a trace of its enlisted scales in each of the output signals (Clemen, 2000). In many dynamic systems processes and sub-processes work on different scales in respect to their time extension, frequency, and spatial impact. We assume that these could also be true for evacuation dynamics.

3 Conclusions

Have evacuation models reached their functional optimum by using the multi-agent paradigm? From our perspective choosing the ‘right’ modelling paradigm for pedestrian dynamics depends on the temporal and spatial scale of the scenario. The following table shows usual paradigms in comparison to their scales:
<table>
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Table 1: Scales vs. Paradigms

Network flow models and models based on fluid dynamics are known as macro models and determine aggregated parameters such as flow or density without considering individual behaviour. Microscopic models treat individual movement and interactions by rules (cellular automata) or differential equations (social force models). In both cases all individuals obey the same rules or laws. Thus, individual behaviour is modelled in a somewhat static and centralized mode.

In this hierarchy, multi-agent models represent the ‘Nano’-scale, a term that we introduce here. Every agent object keeps its own facts and belonging methods to work with them. Whereas microscopic models ‘control’ the performance of individuals from ‘outwards to the centre’, true agent models works in a reversed manner.

We believe that successful application of a model depends on the appropriate choice of the scale for the application scenario. Are we interested in getting a lower bound for evacuation times of whole regions? In that case, using a network flow gives useful information in appropriate time (Hamacher et al., 2010). Do we need to include the effects of, e.g., individual speeds, bottlenecks, obstacles or crowd densities, when we wish to plan the exit routes from a football stadium? In that case a microscopic model is necessary and - when well implemented - will give reliable results for thousands of individuals in real time and on off-the-shelf hardware.

However, a multi-agent-model becomes indispensable in our attempt to model complex individual perception and decision processes as well as interaction between individuals. The interdependencies between the multitudes of parameter and agent behaviour and emerging crowd phenomena, respectively, makes this very challenging. This is aggravated by the fact that some of the psychological and physiological topics that we are aiming to utilize are still under discussion in their respective special fields. We hope that WALK will help to clarify some of these points in the future.
4 References


Davidich, M., Köster, G. (2010): Towards automatic and robust adjustment of human behavioural parameters in a pedestrian stream model to measured data. Fifth International Conference on Pedestrian and Evacuation Dynamics, Gaithersburg, MD USA 8-10 March 2010.


