Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Lecture with Computer Exercises:
Modelling and Simulating Social Systems with MATLAB

Project Report

# Emegency Evacuation

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Waldburger Dominik Zehnder Matthias

# Contents

# 1 Individual contributions

At the beginning of our project we worked a lot together to bring our ideas down to a model. We defined in detail how our model should work and simulate our problem. We defined our parameters which we wanted to investigate in detail.

In the further working Dominik Waldburger was responsible for the implementation. Especally he took care that the interfaces between the different functions were functionable. We both worked on the different functions.

Matthias Zehnder was at the end of the project responsible for the report. Dominik Waldburger contributed the part of the implementation.

# 2 Introduction and Motivations

Emergency evacuation in a building like the ETH Hauptegebäude is a very important topic. We all hope that there will never be a situation where an emergency evacuation is necessary.

We wanted to investigate the dynamics of students in case of an emergency, when they have to leave the auditorium in a hurry. We wanted to analyze the influence of different arrangements of seats, doors and escape routes.

For us it was interesting to discuss how a model could evaluate the fastest way to the exit. Also in this problem we asked us how the model can determine if a detour is better than the direct way out. We placed special emphasis on modeling this decision making process in cases where more than one person is demanding the same empty space on the evacuation route or in cases where a detour would be faster than the direct way out.

Various parameters have been investigated like the width of the aisles, the placements of the exits and a seat arrangement other than straight rows. A special safety aspect we looked into was the pressure behind exiting people build up by the length of the queue.

A further aspect we considered was optimizing the time discretisation by elimination of the influence of the implementation itself.

We always have been fully aware of the fact that the model would never be able to represent the reality. We tried to brake down our model to a level detailed enough to allow us to transfer the conclusions into real world. We especially tried to further develop the approach shown in the lecture to get e better understanding in modeling such problems.

# 3 Description of the Model

## 3.1 Introduction

Basically, for our model we take the idea of a Cellular Automata like the one we discussed in the lecture. However, unlike in the lecture, where the decision was based solely on the neighbor cells, in our model, it is based on the empty spaces, the demands for them and the pressure for the demands as well as the benefit to move to a particular space.

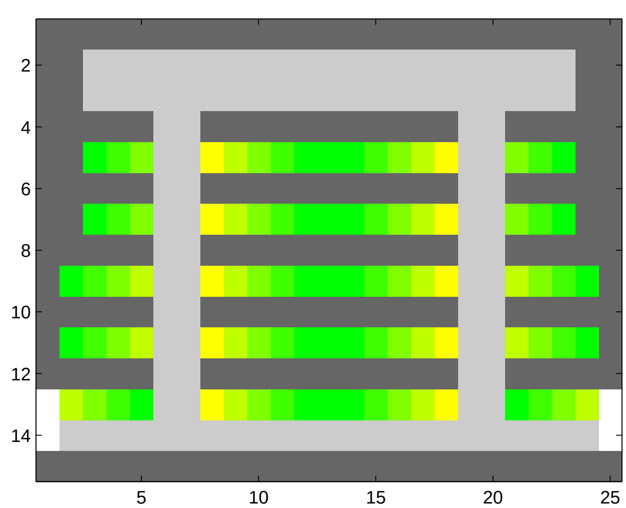
## 3.2 The auditoriums

The auditoriums in our Model are two dimensional matrices, where each point in the matrix describes either a person, a desk, a wall, an exit or a free space. We do not distinguish between walls and desks, so it is not possible to climb desks. Allowed exit routes lead only through free spaces. To be able to compare various room layouts, we always choose the same room area, meaning the same matrix dimensions. This means that the number of people vary from room to room. Basic layouts of the model rooms derives from the auditoriums in the HPH and in the HG.

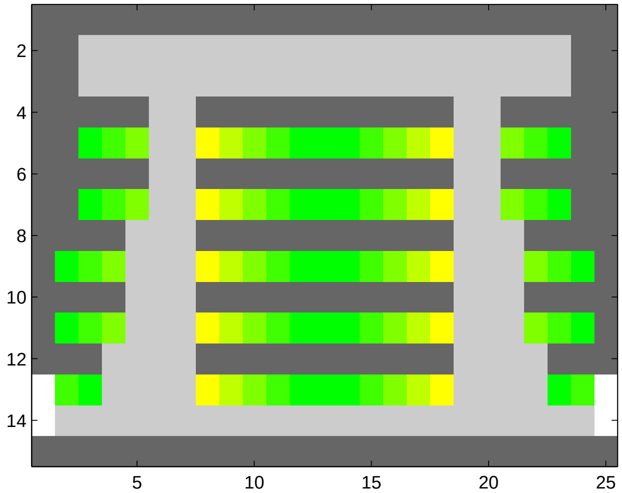
### 3.2.1 Our auditoriums

Legend: grey = wall     white = door     green to yellow = people w. dif. pressures

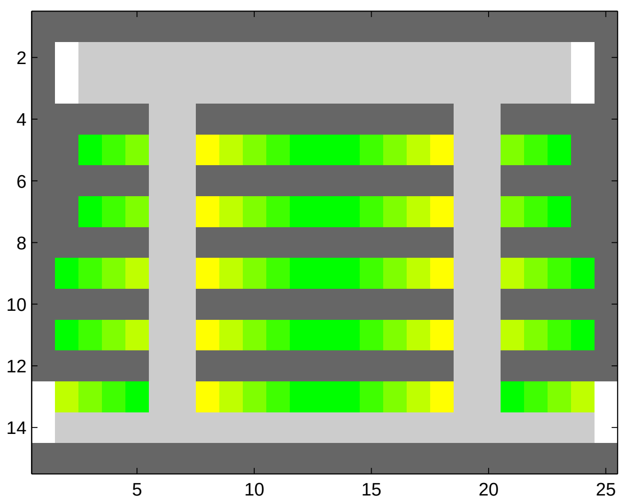
Auditorium one:



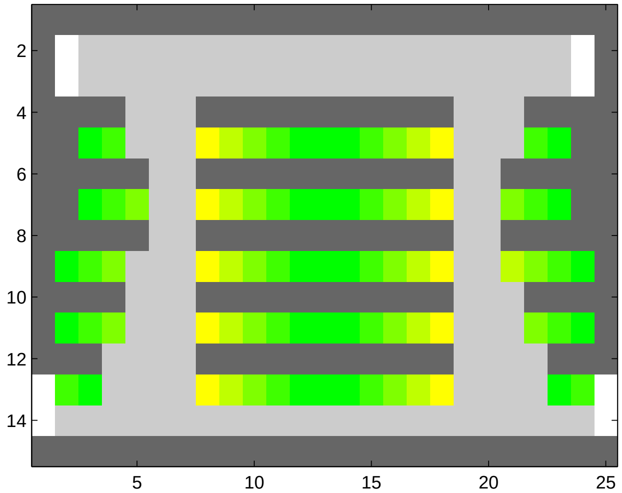
Auditorium two:



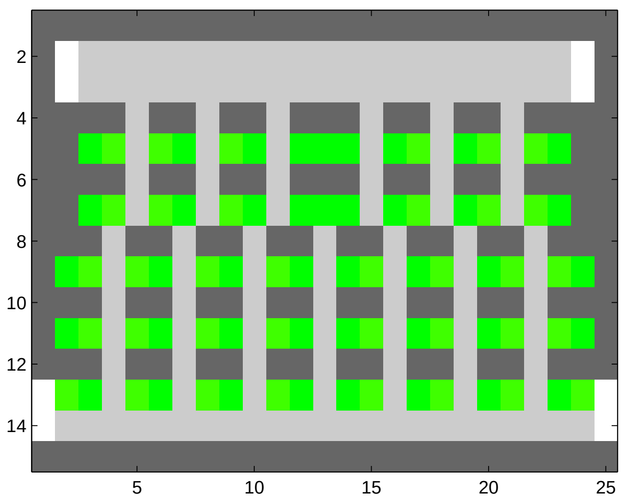

Auditorium three:



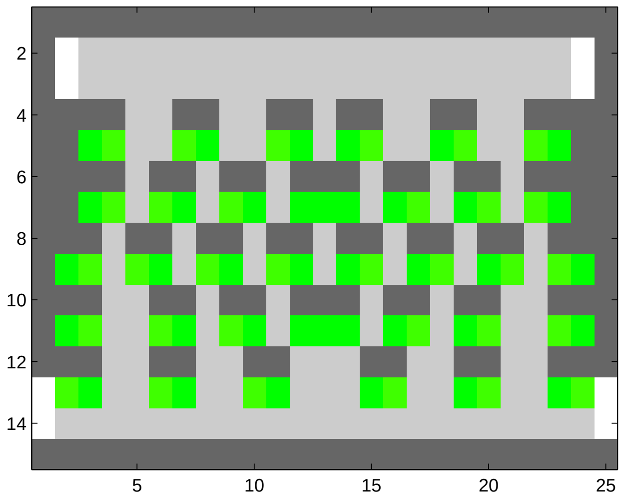
Auditorium four:




Auditorium five:



Auditorium six:




### 3.3 Time descretisation

In order to avoid influence of the implementation on the time discretisation we prohibit that the checking order influences the decision of the people. The model fulfills that by comparing the demand weights for multiple allocations for a free space. Furthermore, the steps are taken only after all comparisons have been done and the priorities have been set.

### 3.4 The decision pyramid

Where is the nearest exit? Which one is the shortest way? Would a detour be faster? Do I have a free space to move to?

The decision for the next move of a person is based on these aspects. To take this decision our model works in three steps. In the first step the decision is sought based on free spaces, the closeness to the exit, demands and the pressure of others. If no clear decision can be taken in a a second step the model takes a random decision. In a third step the model checks for blocked people which could benefit from a detour. Our model also takes care of the possibility that a person can stumble in which case a possible move cannot be taken.

### 3.5 Step one

In the first step a person looks at the four places around him. He checks if the places are free and wether they bring him closer to the exit. If a place fulfills these requirements, it checks if there are others demanding the same free space. If there is no such demand it reserves this space. If there are other demands on a particular free space the model compares the pressure, that is the queue length behind the people, and makes the reservation based on the highest pressure. If no clear decision can be taken no one gets the space in step one.

### 3.6 Step two

In the second step the model decides among the candidates with the same pressure which one gets the reservation. In our model we use a random generator for this decision.

### 3.7 Step three

For all people with adjacent free spaces but without reservations the model checks the availability and the benefit of a possible detour. To do that the model checks whether the person is already on a detour or not.

If not he looks for a detour and the benefit of taking it, based on the increasing length of the way and the projected time on the direct way. If there is a positive match it makes the reservation.

If he is on a detour it checks whether the detour is still available and still would be a benefit, then he remains on the detour, if not he goes back to the direct way.

# 4 Implementation

## 4.1 Introduction

In this chapter we describe the implementation of our model in MATLAB illustrated by some selected parts of the code. The full code can be found in the chapter Code.

## 4.2 No subdiscretization

As mentioned we like to avoid a subdiscretization. That's why we can't save just the position of all students in the room. For each student we have to save the actual position and the position he'd like to go in the next step. To implement this in MATLAB we save the information in an s (s = number of students) x 2 or s x 4 matrices with alternate access:

t = the global discretization time variable

| Function | t=1 | t=2 | t=3 | t=4 | t=odd | t=even |
|---|---|---|---|---|---|---|
| mod(t+1,2)+1 | 1 | 2 | 1 | 2 | 1 | 2 |
| mod(t,2)+1 | 2 | 1 | 2 | 1 | 2 | 1 |
| 2*mod(t+1,2)+1 | 1 | 3 | 1 | 3 | 1 | 3 |
| mod(t+1,2)+2 | 2 | 4 | 2 | 4 | 2 | 4 |

## 4.3 Input

The input for the simultion is an n x m integer-matrix of a room with the information about the walls (= -1), the exits (= 1) and the places of the students (= 2). The border-cells have to be a wall or an exit and for every student there have to be a way to an exit. For better handling the room-matrix get split in two matrices waym and studm and the students get numbered.

For example:

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| -1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | -1 |
| -1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | -1 |
| -1 | -1 | -1 | -1 | -1 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 0 | 0 | -1 | -1 | -1 | -1 | -1 |
| -1 | -1 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | -1 | -1 |
| -1 | -1 | -1 | -1 | -1 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 0 | 0 | -1 | -1 | -1 | -1 | -1 |
| -1 | -1 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | -1 | -1 |
| -1 | -1 | -1 | -1 | -1 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 0 | 0 | -1 | -1 | -1 | -1 | -1 |
| -1 | 2 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | -1 |
| -1 | -1 | -1 | -1 | -1 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 0 | 0 | -1 | -1 | -1 | -1 | -1 |
| -1 | 2 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | -1 |
| -1 | -1 | -1 | -1 | -1 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 0 | 0 | -1 | -1 | -1 | -1 | -1 |
| 1 | 2 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 1 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |

### 4.4 Ground structure

The ground structure is provided by the four files: waym, studm, studc, studl

#### 4.4.1 waym

Waym stands for way-map. It's an n x m integer-matrix with the same dimension as the given room. It contains the information about walls (= -1) and exits (= 1). In the other cells, the floor cells, is the number of steps written for the shortest way to an exit. This allows a fast request if a field is on the way to the nearest exit.

An example of a waym-matrix:

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| -1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | -1 |
| -1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | -1 |
| -1 | -1 | -1 | -1 | -1 | 6 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 7 | 6 | -1 | -1 | -1 | -1 | -1 |
| -1 | -1 | 10 | 9 | 8 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 8 | 9 | 10 | -1 | -1 |
| -1 | -1 | -1 | -1 | -1 | 8 | 9 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 9 | 8 | -1 | -1 | -1 | -1 | -1 |
| -1 | -1 | 12 | 11 | 10 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 10 | 11 | 12 | -1 | -1 |
| -1 | -1 | -1 | -1 | -1 | 10 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 11 | 10 | -1 | -1 | -1 | -1 | -1 |
| -1 | 14 | 13 | 12 | 11 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 11 | 12 | 13 | 14 | -1 |
| -1 | -1 | -1 | -1 | -1 | 9 | 10 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 10 | 9 | -1 | -1 | -1 | -1 | -1 |
| -1 | 12 | 11 | 10 | 9 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 9 | 10 | 11 | 12 | -1 |
| -1 | -1 | -1 | -1 | -1 | 7 | 8 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 8 | 7 | -1 | -1 | -1 | -1 | -1 |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |

### 4.4.2 studm

Studm stands for student-map. It's a n x m integer-matrix with the same dimansion as waym. The position of each student is saved and reserved by his number in the corresponding cell. So fast answers to the questions if there's a student on this field or which student is on this field is provided without searching the coordinates of all students.

An example of a studm-matrix:

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 2 | 3 | 0 | 0 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 0 | 0 | 15 | 16 | 17 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 18 | 19 | 20 | 0 | 0 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 0 | 0 | 32 | 33 | 34 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 35 | 36 | 37 | 38 | 0 | 0 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 0 | 0 | 50 | 51 | 52 | 53 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 54 | 55 | 56 | 57 | 0 | 0 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 0 | 0 | 69 | 70 | 71 | 72 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 73 | 74 | 75 | 76 | 0 | 0 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 0 | 0 | 88 | 89 | 90 | 91 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

#### 4.4.3 studc

Studc stands for student-coordinates. It's an s x 4 integer-matrix with the actual coordinates and the last or next coordinates of all students saved.
studc(i, 2*mod(t+1,2)+1) = actual x-coordinate of the i-th student
studc(i, 2*mod(t+1,2)+2) = actual y-coordinate of the i-th student
studc(i, 2*mod(t,2)+1) = last or next x-coordinate of the i-th student
studc(i, 2*mod(t,2)+2) = last or next x-coordinate of the i-th student

#### 4.4.4 studl

Studl stands for student left in the room. It's an s x 2 boolean-matrix and saves the information if a student is still in the room and if he had already chosen his next step.
studl(i, mod(t+1,2)+1) = 1
  i-th student is in the room and doesn't have chosen his next step
studl(i, mod(t+1,2)+1) = 0
studl(i, mod(t,2)+1) = 1
  i-th student is in the room and has chosen his next step
studl(i, mod(t+1,2)+1) = 0
studl(i, mod(t,2)+1) = 0
  i-th student left the room

### 4.5 Stumble and decision making

To simulate different running speeds or accidents we let the students randomly waiting for some rounds. For the decision-making-process we must be aware of the pressure on the student and the possibility of a faster detour for every student in the room. This information is saved in the variables: studt, studp and wayt

#### 4.5.1 studt

Studt stands for student-time. Its is a s x 3 integer-matrix saving the time the student hase to wait because of stumbling, the time the student has waited and if the student is on an alternative way.

studt(i, 1) = time to wait of the i-th student
studt(i, 2) = time waited of the i-th student
studt(i, 3) = 1 i-th student is on alternative way (detour)
studt(i, 3) = 0 i-th student is not on alternative way (detour)

#### 4.5.2 studp

Stutp stands for student-pressure. The pressure from up, down, right, left on the student is saved in a s x 4 double-matrix.

studp(i, 1) = the pressure on the i-th student from up
studp(i, 2) = the pressure on the i-th student from down
studp(i, 3) = the pressure on the i-th student from right
studp(i, 4) = the pressure on the i-th student from left

#### 4.5.3 wayt

Wayt stands for way-time. It's a s x 6 double-matrix saving the shortest way-time on a direct and an alternative way. For the shortest way-time on the direct way it sums up the time the students on the direct way to the exit have to wait. For the shortest alternative way-time it sums up the time the students on the alternative way have to wait and adds the step backwards which must be taken.

wayt(i, 1) = the shortest way-time for the i-th student on a direct way to the exit
wayt(i, 2) = the shortest way-time for the i-th student on a alternative way to the exit
wayt(i, 2) = -1 there exists no alternative way for the i-th student
wayt(i, 3:6) = 1 there's a free field up, down, right, left on the way of the shortest alternative way
wayt(i, 3:6) = 0 there's no free field

### 4.6 Visualisation and statistics

For the visualisation and the statistics we save the current situation in the variables: p and stats

#### 4.6.1 p

P stands for picture. It's an n x m x t (t number of discretization steps) 3-dimensional-double-matrix.

p(:, :, t) = a picture of the actual situation of the room
p(i, j, t) = 1 wall
p(i, j, t) = 2 floor
p(i, j, t) = 3 exit
p(i, j, t) = 4+ student plus his pressure

#### 4.6.2 stats

Stats stands for statistics and is a s x 2 x t 3-dimensional-double-matrix.

stats(i, 1, t) = pressure of the i-th student to the time t
stats(i, 2, t) = time to wait of the i-th student to the time t
stats(i, :, t) = [-1 -1] i-th student left the room

### 4.7 Simulation.m

The Simulation.m is the main m-file which coordinates the different functions. First it deletes all potentially existing variables which could disturb the simulation and runs the preperation.m function.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Simulate an emergency evacuation %
% choose a map 0-6                 %
mapn = 1;                          %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% clears possible existing files
clear waym wayt studm studc studt studl studp p bool t stats

% preperation
[waym,studm,studc,studt,studl] = preperation(maps(mapn));
    % waym = map with the shortestway to the doors
    % studm = who is where
    % studc = coordiates of each student
    % studp = pressure of each student from up, down, right, left
    % studt = time the student have to wait
    % studl = which students are left in the room
    % stats = pressure, time to wait for every student over time
```

Now the decision-making, stumble, visualisation and statistic variables get computed and the students walk as long as every student has left the room. In the end uninteresting variables get deleted.

```
bool = true; % Loop until nobody restes in the room
t = 1;
while(bool)
    % pressure
    studp = pressure(waym, studm, studc, studl, t);
    % picture
    p(:,:,t) = picture(waym,studm,studp);
    % stolpern
    studt = stumble(studp, studt, studl, t);
    % waytime
    wayt = waytime(waym,studm,studc,studt,studl,t);
    % statistic
    stats(:,:,t) = statistic(studp,studt,studl,t);


    % step 1
    [studm,studc,studt,studl] = step1(waym,studm,studc,studp,studt,studl,t);
    % step2
    [studm,studc,studt,studl] = step2(waym,studm,studc,studt,studl,t);
    % step umweg?
    [studm,studc,studt,studl] = step3(wayt,studm,studc,studt,studl,t);
    % make final step: restlicher twaited +1, ttowait -1, ausgang löschen
    [studm,studc,studt,studl] = laststep(waym,studm,studc,studt,studl,t);

    t=t+1;
    % noch wer da?
    bool = sum(studl(:,mod(t+1,2)+1));
end
% stats auswerten
stats(:,:,t) = statistic(studp,studt,studl,t);

clear i t bool mapn
```

### 4.8 preperation.m

The preperation.m splits the rawmap into the waym and the studm. For every free field of the waym it computes the number of steps for the shortest way to an exit and the students in the studm get numbered. For every student it reserves a line in studc, studt and studl.

### 4.9 pressure.m

For all students in the room and for all directions (up down left right),

```
function[studp] = pressure(waym, studm, studc, studl, t)
quant = size(studl); % quantity of students
studp = zeros(quant(1,1),4); % set p to 0

for s = 1:quant(1,1) % for all students
    if studl(s, mod(t+1,2)+1) % t ungerade 1; gerad 2 % for all students left
        for i = 1:4 % for all directions
            x = studc(s,2*mod(t+1,2)+1); % t ungerade 1; gerade 3
            y = studc(s,2*mod(t+1,2)+2); % t ungerade 2; gerade 4
            [dx,dy] = udrl(i); % up down right left
            bool = true;
```

it looks field per field. Is there a student for which the field in my direction is on the direct way? On direct way means that the number of the field in waym is smaller than the number of the actual position.

Yes: It adds 1 divided by the number of field on the way of the other student to the pressure in this direction

No: It stops.

```
            while(bool) % until there's nobody in this direction
                if waym(x+dx,y+dy) == -1 % wall: break
                    bool = false;
                    break
                elseif not(studm(x+dx,y+dy)) % no person: break
                    bool = false;
                    break
                elseif (waym(x,y) - waym(x+dx,y+dy)) >= 0% student doesn't want to go to this field
                    bool = false;
                    break
                else
                    n = 0;
                    for j = 1:4 % number of field student could go
                        [ddx,ddy] = udrl(j);
                        if waym(x+dx+ddx,y+dy+ddy) ~= -1 %keine Wand
                            n = n+(waym(x+dx,y+dy)-(waym(x+dx+ddx,y+dy+ddy)) > 0);
                        end
                    end
                    studp(s,i) = studp(s,i)+1/n;
                end
                x = x+dx;
                y = y+dy;
            end
        end
    end
end
end
```

### 4.10 border.m

A simple function which returns if (x, y) is in the matrix.

### 4.11 dulr.m udrl.m

Two short functions containing two polynomials to have access to the neighbour fields in a for-loop.

### 4.12 picture.m

This function makes a picture of the actual situation as described in chapter 4.6.1.

### 4.13 stumble.m

Every student who hasn't to wait gets randomly a time to wait. The probability of stumble is:

$$\frac{e^{\frac{pressure - time\,waited}{20}}}{e}$$

The intensity of stumble is a random number between 1 and min($\frac{pressure}{2}$ + 1, 20)

### 4.14 waytime.m

For every student it computes with the functions directway.m and alternivway.m the direct way-time and the alternative-way-time with the connected direction.

### 4.15 directway.m

Directway.m is a recursive function which sums up the students and their time to wait on the direct way to the exit and returns the shortest way.

### 4.16 alternivway.m

Alternivway.m is also a recursive function similar to directway.m but now it looks through the alternatives ways and add additionally the step backwards which must be taken.

### 4.17 statistic.m

This creates the stats variable.

### 4.18 step1.m

Step1.m checks for every not waiting student if there's a free adjacent field on the direct way without flip and checks the neighbour fields of the adjacent field for the possible combatant. Flip means that the student flips between the actual an the last position.

```
function[studm,studc,studt,studl] = step1(waym,studm,studc,studp,studt,studl,t)
quant = size(studl); % Anzahl Studenten

for steps = 1:4
    for s= 1:quant(1,1)
        if studl(s,mod(t+1,2)+1) && not(studt(s,1)) % Stud im Raum, nicht wartend
            x = studc(s,2*mod(t+1,2)+1); % t ungerade 1; gerade 3
            y = studc(s,2*mod(t+1,2)+2); % t ungerade 2; gerade 4
            field = zeros(1,4); % mögliche Felder down up left right
            field2 = zeros(4,4); % mögliche Mitbesteiter down up left right
            for i = 1:4
                [dx,dy] = dulr(i); % down up left right
                if not(studm(x+dx,y+dy)) && waym(x+dx,y+dy) ...
                        < waym(x,y) && waym(x+dx,y+dy) ~= -1 && not(x+dx...
                        == studc(s,2*mod(t,2)+1) && y+dy == ...
                        studc(s,2*mod(t,2)+2))
                    % gibt es Felder frei, auf Weg, kein Flip
                    field(1,i) = 1;
                    for j = 1:4
                        [ddx,ddy] = udrl(j); % down up left right
                        if i ~= j && border(x+dx+ddx,y+dy+ddy,size(waym))
                            % nicht ausgehendes Feld, noch im Raum
                            if studm(x+dx+ddx,y+dy+ddy) &&  studl(studm(x+dx+ddx,y+dy+ddy),...
                                    mod(t+1,2)+1) && not(studt(studm(x+dx+ddx,y+dy+ddy),1)) &&...
                                    waym(x+dx,y+dy)<waym(x+dx+ddx,y+dy+ddy)
                                % Mitstudent?, nochnicht gelaufen, nicht wartend, auf Weg
                                field2(i,j) = 1;
                            end
                        end
                    end
                end
            end
```

Are there adjacent fields without combatants?

```
            if sum(field) % gibt es freie Felder
                for i = 1:4 % Gibt es Felder ohne Konkurenz
                    if field(1,i) % Feld frei?
                        if sum(field2(i,:)) % there are other students
                            field(1,i) = 0;
                        end
                    end
                end
```

Yes: Reserve the field, if there are multiple choose randomly.

```
if sum(field) % es gibt solche Felder ohne Konkurenz
    choosen = round(sum(field)*rand(1)+0.5); % random auswahl
    i = 1;
    while(choosen)
        if field(1,i)
            if choosen == 1
                [dx,dy] = dulr(i);
                studt(s,2) = 0;
                studt(s,3) = 0;
                studc(s,2*mod(t,2)+1) = x+dx;
                studc(s,2*mod(t,2)+2) = y+dy;
                studl(s,mod(t+1,2)+1) = 0;
                studl(s,mod(t,2)+1) = 1;
                studm(studc(s,1),studc(s,2)) = s;
                studm(studc(s,3),studc(s,4)) = s;
                choosen = choosen-1;
            else
                choosen = choosen-1;
            end
        end
        i = i+1;
    end
```

No: Does the student have the higher pressure then the combatant to a field?

```
else % gibt es Felder wo grösster Druck?
    field(1,:) = (sum((field2')) > 0); % freies Feld
    for i = 1:4 % grösserer Druck?
        if field(1,i)
            [dx,dy] = dulr(i);
            for j = 1:4
                if field2(i,j) % steht da jemand
                    [ddx,ddy] = udrl(j);
                    field(1,i) = field(1,i)*(studp(s,i) >...
                        studp(studm(x+dx+ddx,y+dy+ddy),j));
                    % = 0, wenn nicht grösserer Druck als alle andern
                end
            end
        end
    end
```

If yes reserve the field.
This runs four times. So it's sure that no student has longer any pressure advantage to a field.

### 4.19 step2.m

Step2 is similar to step1, but now no student has longer any pressure advantage. So the student now is allowed to reserve a field is randomly chosen.

```
else % wer darf ziehen?
    field(1,:) = (sum((field2')) > 0); % freies Feld
    for i=1:4
        if field(1,i)
            field(1,i) = (round((sum(field2(i,:))+1)*rand(1)+0.5) == 1);
        end
    end
```

This runs as long as every student who could walk has done his reservation.

## 4.20 step3.m

In step3.m the students on direct way and on alternative way are handled differently. First it checks if the first field of the alternative way fields from wayt are still free.

```
function[studm,studc,studt,studl] = step3(wayt,studm,studc,studt,studl,t)
quant = size(studl);

for s = 1:quant(1,1)
    if studl(s,mod(t+1,2)+1) && not(studt(s,1)) % im Raum, nicht wartend
        x = studc(s,2*mod(t+1,2)+1); % t ungerade 1; gerade 3
        y = studc(s,2*mod(t+1,2)+2); % t ungerade 2; gerade 4
        for i = 1:4 % Felder immer noch frei?
            if wayt(s,2+i)
                [dx,dy] = dulr(i);
                wayt(s,2+i) = not(studm(x+dx,y+dy));
            end
        end
```

For the students on the alternative way it checks if the detour still exists and if it's still profitable. So he walks or wait or he goes back on the direct way and if the last field is free he returns to it.

```matlab
if studt(s,3) % schon auf Umweg
    if sum(wayt(s,3:6)) % es gibt Umweg, erstes Feld frei
        choosen = round(sum(wayt(s,3:6))*rand(1)+0.5); % random auswahl
        i = 1;
        while(choosen)
            if wayt(s,2+i)
                if choosen == 1
                    [dx,dy] = dulr(i);
                    studt(s,3) = 1; studc(s,2*mod(t,2)+1) = x+dx;
                    studc(s,2*mod(t,2)+2) = y+dy;
                    studl(s,mod(t+1,2)+1) = 0; studl(s,mod(t,2)+1) = 1;
                    studm(studc(s,1),studc(s,2)) = s;
                    studm(studc(s,3),studc(s,4)) = s; choosen = choosen-1;
                else
                    choosen = choosen-1;
                end
            end
            i = i+1;
        end
    else
        if wayt(s,2) == -1 || (wayt(s,1)+studt(s,2)) <= wayt(s,2)
            % Umweg gibt es nicht mehr, Umweg lohnt sich nicht mehr
            studt(s,3) = 0;
            if not(studm(studc(s,2*mod(t,2)+1),studc(s,2*mod(t,2)+2)))
                % letzte Position noch frei
                studt(s,2) = 0;
                studl(s,mod(t+1,2)+1) = 0; studl(s,mod(t,2)+1) = 1;
                studm(studc(s,1),studc(s,2)) = s;
                studm(studc(s,3),studc(s,4)) = s;
            end
        end
    end
```

For the students on direct way it checks wayt for an existing profitable detour. If one exists he reserves it, otherwise he waits.

```
        else % noch nicht auf Umweg
            if sum(wayt(s,3:6)) && (wayt(s,1)+studt(s,2)) > wayt(s,2)
                % es gibt Umweg, erstes Feld frei, Umweg lohnt sich
                choosen = round(sum(wayt(s,3:6))*rand(1)+0.5); % random auswahl
                i = 1;
                while(choosen)
                    if wayt(s,2+i)
                        if choosen == 1
                            [dx,dy] = dulr(i);
                            studt(s,3) = 1;
                            studc(s,2*mod(t,2)+1) = x+dx;
                            studc(s,2*mod(t,2)+2) = y+dy;
                            studl(s,mod(t+1,2)+1) = 0;
                            studl(s,mod(t,2)+1) = 1;
                            studm(studc(s,1),studc(s,2)) = s;
                            studm(studc(s,3),studc(s,4)) = s;
                            choosen = choosen-1;
                        else
                            choosen = choosen-1;
                        end
                    end
                    i = i+1;
                end
            end
        end
    end
```

### 4.21 laststep.m

The function laststep.m handles all students which couldn't walk in this turn. For the students on the alternativway (studt(s, 3) = 1) it exchanges the old and new coordinates with the effect, that they can't walk on the direct way in the next turn because of the no flip in step1.m and step2.m. The other still standing students take the old coordinates as new ones. And all students get set moved.

```
function[studm,studc,studt,studl] = laststep(waym,studm,studc,studt,studl,t)
quant = size(studl);
for s = 1:quant(1,1)% alle nicht bewegten wartend setzen
    if studl(s,mod(t+1,2)+1) % kein Schritt gemacht
        if studt(s,3)
            ax = studc(s,2*mod(t,2)+1); % Koordinaten wechseln
            ay = studc(s,2*mod(t,2)+2);
            studc(s,2*mod(t,2)+1) = studc(s,2*mod(t+1,2)+1);
            studc(s,2*mod(t,2)+2) = studc(s,2*mod(t+1,2)+2);
            studc(s,2*mod(t+1,2)+1) = ax;
            studc(s,2*mod(t+1,2)+2) = ay;
        else
            studc(s,2*mod(t,2)+1) = studc(s,2*mod(t+1,2)+1); % Koordinaten übernehmen
            studc(s,2*mod(t,2)+2) = studc(s,2*mod(t+1,2)+2);
            studt(s,2) = studt(s,2)+1; % Warten =+1
        end
        studl(s,mod(t+1,2)+1) = 0; % gezogen
        studl(s,mod(t,2)+1) = 1; % noch im Raum
    end
end
```

In the second part the function redraws the map and clears the student on the exit from studl.

```
studm = zeros(size(studm)); % studm neu einzeichnen
for s = 1:quant(1,1)
    if studl(s,mod(t,2)+1) % noch im Raum
        if waym(studc(s,2*mod(t,2)+1),studc(s,2*mod(t,2)+2)) == 1 % Exit
            studl(s,:) = [0,0]; studt(s,:) = [-1,t,0];  % Stud verlässt Raum
        else % nicht auf Ausgang
            if studt(s,1) % time to wait -1
                studt(s,1) = studt(s,1)-1;
            end
            studm(studc(s,2*mod(t,2)+1),studc(s,2*mod(t,2)+2)) = s; % einzeichnen
        end
    end
end
```

## 4.22 pictureshow.m

This function sets the colormap to our costume colormap and animates the pictures saved in p to a movie.

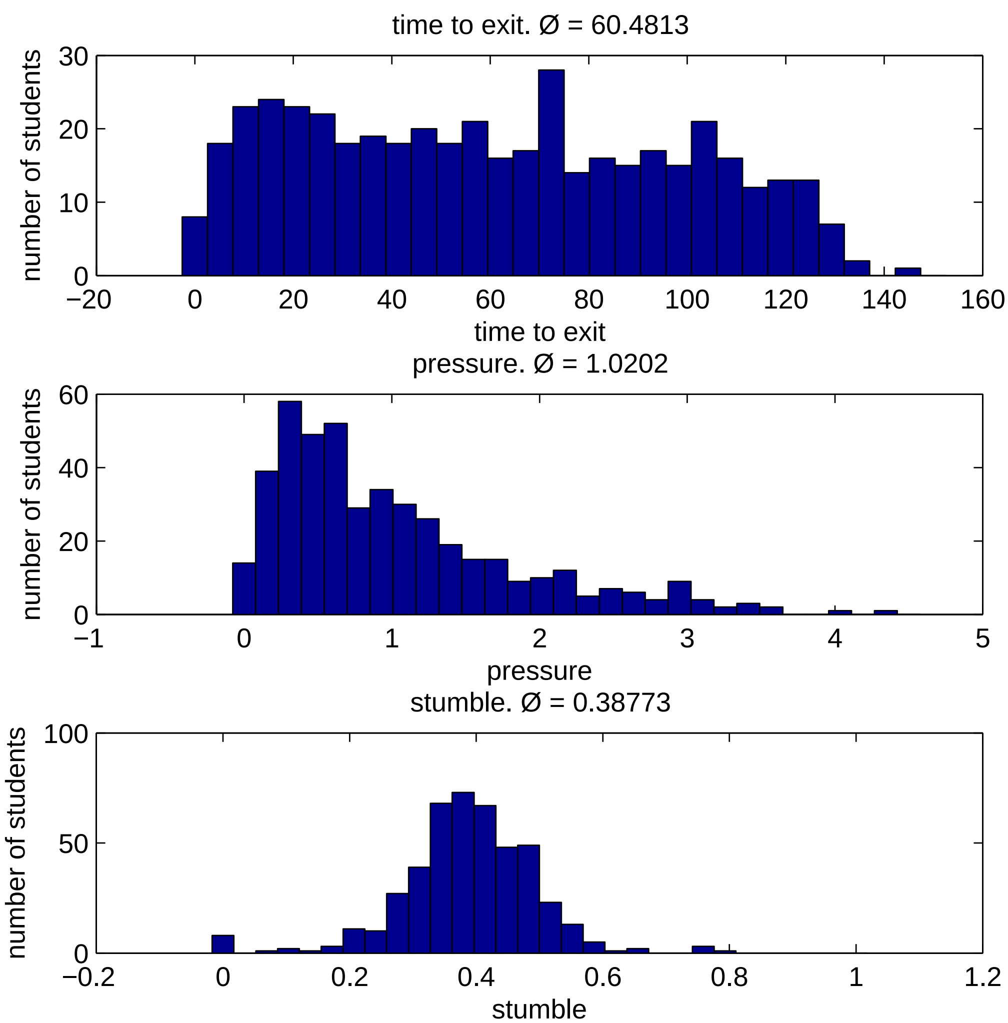
# 5 Simulation Results and Discussion

## 5.1 Results

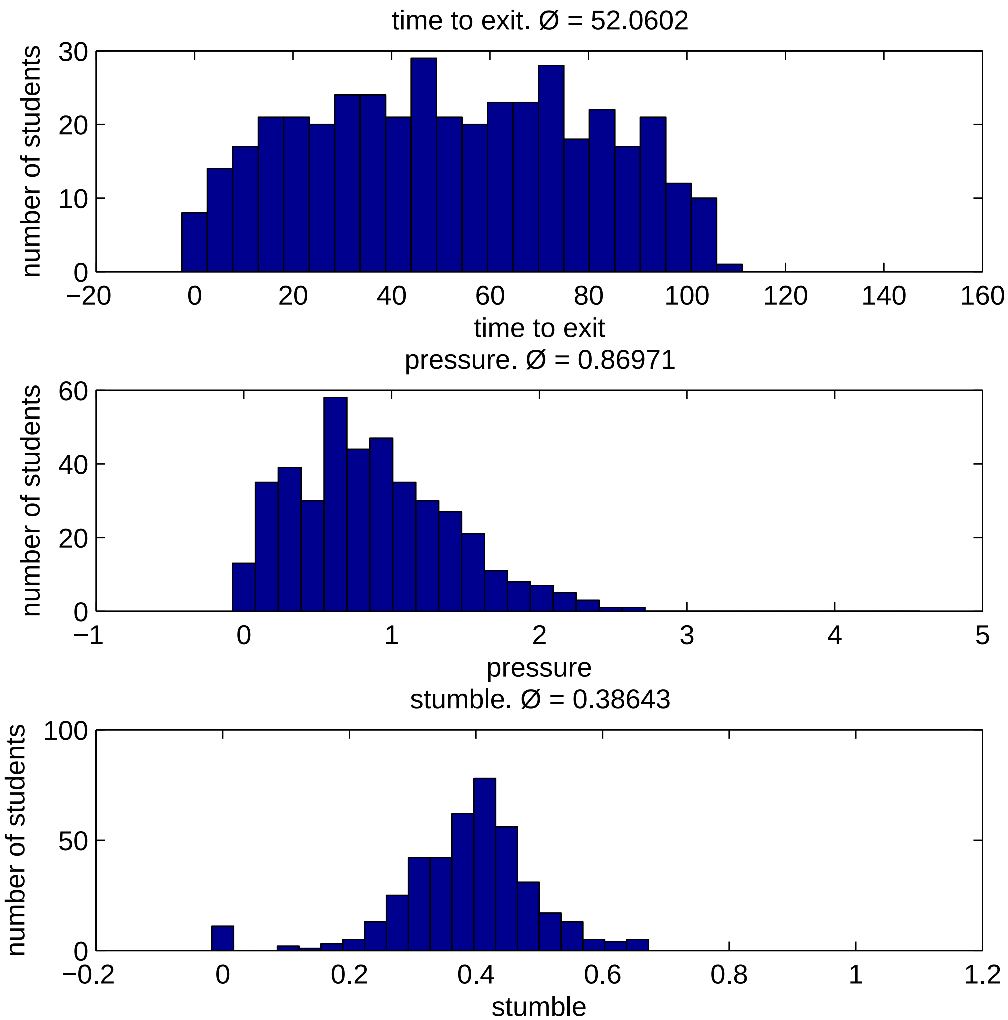
In the simulations three parameters have been evaluated in the six different auditoriums:

- Time to leave the room for each person
- Medium pressure on each person during exiting
- Medium risk for stumbling

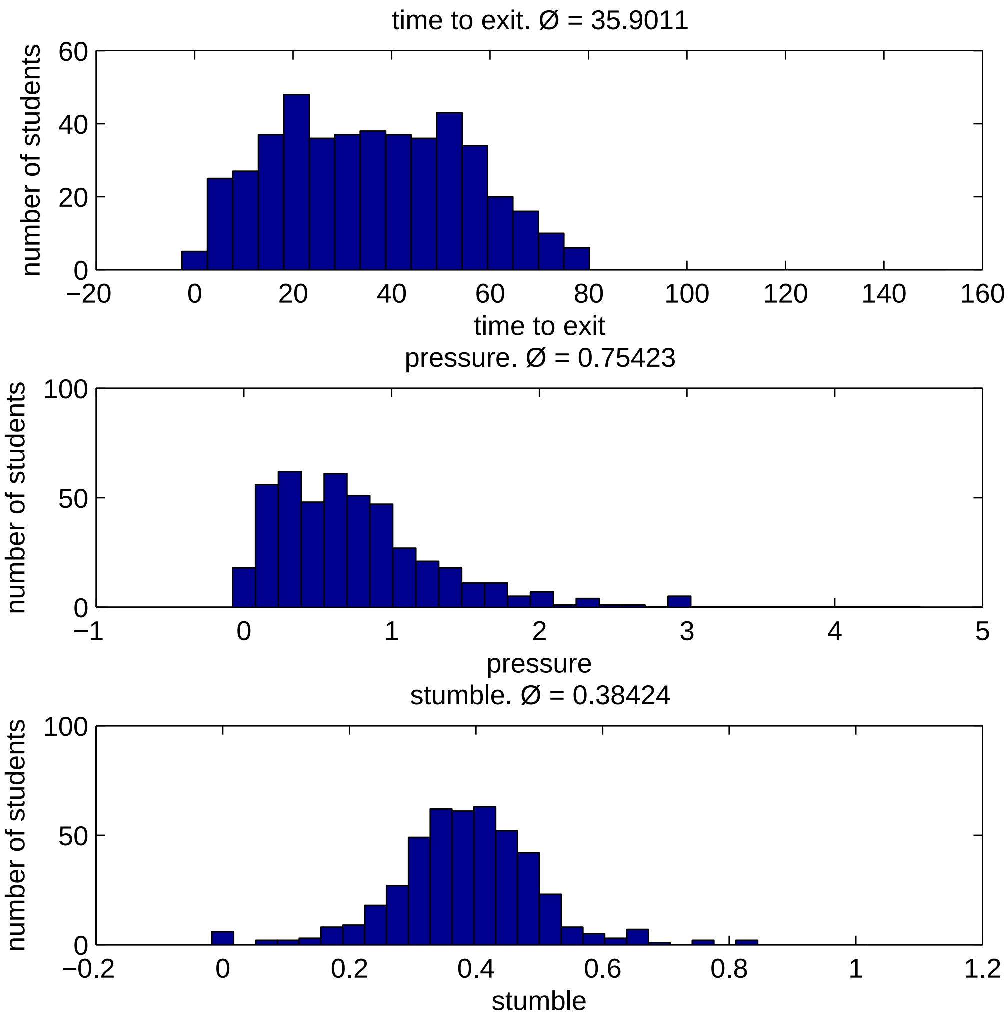
Auditorium one:



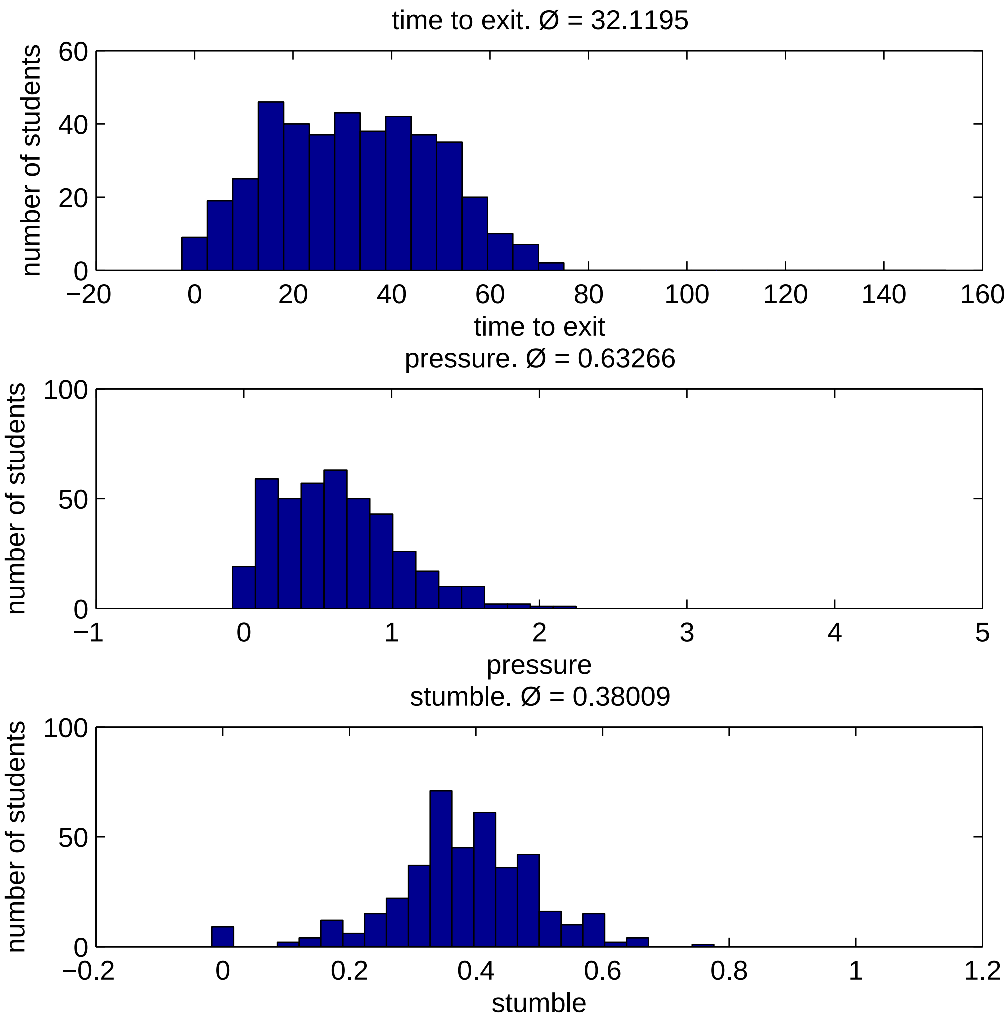
Auditorium two:



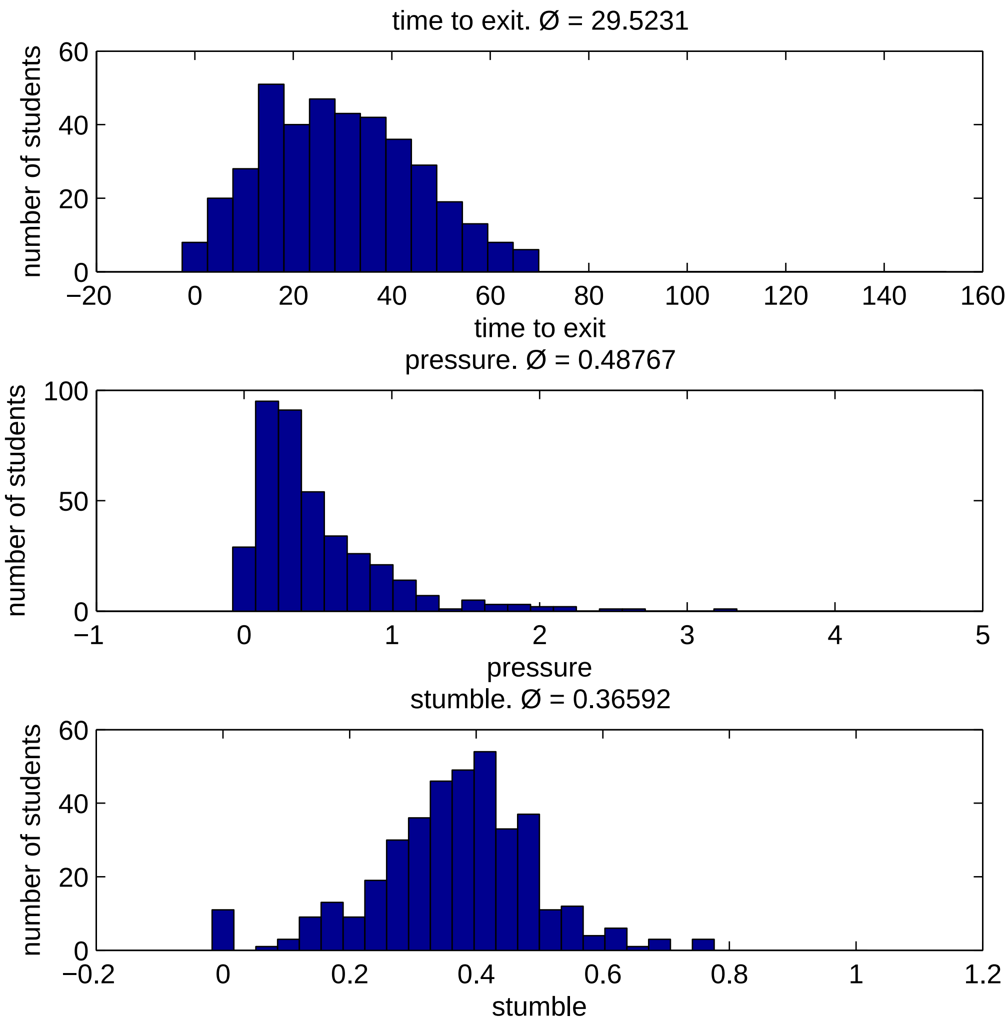
Auditorium three:



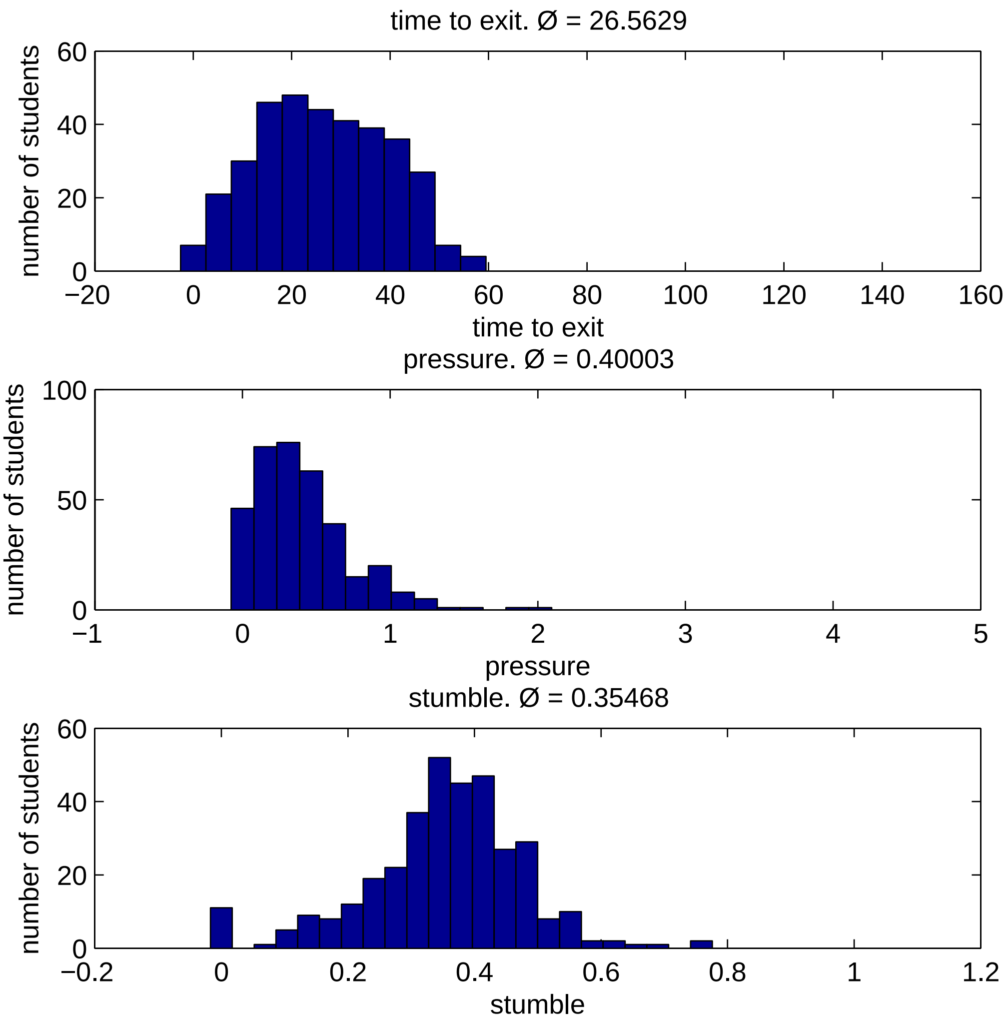
Auditorium four:



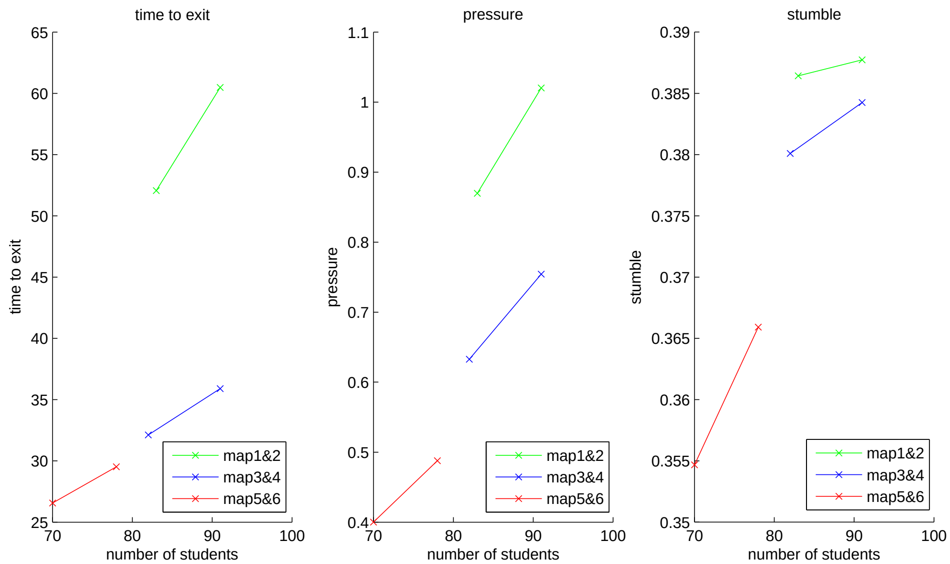
Auditorium five:



Auditorium six:



Comparison of the differnt auditoriums:




## 5.2 Discussion

### 5.2.1 Influence of exit door distribution

The comparison between rooms with doors in the back only and with rooms with doors in the back and in the front shows that the evacuation time can be drastically reduced by a wider distribution of exit doors. We can see that the average exit time drops from room one (two doors) to room three (four doors) from 60 to 36 time units. The same result we can see in the rooms two (two doors) and four (four doors) with exit time 52 time units to 32 respectively.

Conclusion: This outcome was more or less expected, but it shows, that it is essential that all doors are accessible and operational for a fast evacuation. Since the model is assuming that everyone knows the nearest exit. It is imperative that also in reality everyone is familiar with all possible exit routes. During the discussion of this result we recognized that both of us are not yet familiar with the exit routes in our lecture rooms.

### 5.2.2 Influence of Aisle width

Our simulations show that by increasing the aisle width by taking out 10 percent of all seats the exiting time over proportionally was reduced by 13.5 percent. Our model is not taking in to account that the increase of the aisle width by one chair will free more space than for one exiting person. Therefore in reality the gain would be even higher.

Conclusion: The contrary of increasing the aisle width would be an overload of the auditorium with more people than available seats. In this case we would expect a drastic increase of the exiting time. It might be worthwhile to consider weather in some auditoriums a couple of seats could be abandoned without loosing much capacity.

### 5.2.3 Influence of different room layouts

In our simulation of the auditorium number five and six we can see that a larger number narrower exiting roots reduces the exiting time distinctly. But we also see that this reduces also the capacity significantly.

Conclusion: For the design of new auditoriums omitting seat rows would be of interest but the reduced capacity might turn out problematically.

### 5.2.4 Model weaknesses

We are fully aware of the fact that our model is not depicting the reality. For example we assigned in model the same space for a seat as for an exiting person. In reality the density of people in the aisles is much higher than the density of seated people. Furthermore in reality people act more egoistically than in our model. We assumed that people with higher pressure would get priority independent of there personalities. An other weakness in our model is stumbling of exiting people. The model implies that a stumbling person gets up again, where in reality a stumbling person might gets furthers to stumble or could even couse panic. Despite the weaknesses of the model we believe that the drawn conclusions held some value.

# 6 Summary and Outlook

We explored with a model implemented in Matlab the emergency evacuation of an auditorium. It showed us the influences of different room layouts, exit door distributions, and aisle width for the evacuation. It is important that an auditorium has enough and distributed exit doors for an evacuation to be fast and safe. With a slight reduction in seat numbers leading to wider aisles the evacuation time can be reduced overproportionally. Increasing the number of exit ways while reducing their width is also reducing the evacuation time but reduces the capacity significantly.

To improve our model one could think of implementing also different person densities and different behaviors (personalities) of exiting people.

# 7 References

http://www.ti.inf.ethz.ch/ew/courses/Info1_09/script/notes.pdf page 155-164

# 8 Code

## 8.1 Simulation.m

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Simulate an emergency evacuation %
% choose a map 0-6                 %
mapn = 1;                          %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% clears possible existing files
clear waym wayt studm studc studt studl studp p bool t stats

% preperation
[waym,studm,studc,studt,studl] = preperation(maps(mapn));
    % waym = map with the shortestway to the doors
    % studm = who is where
    % studc = coordiates of each student
    % studp = pressure of each student from up, down, right, left
    % studt = time the student have to wait
    % studl = which students are left in the room
    % stats = pressure, time to wait for every student over time

% Loop until nobody restes in the room
bool = true;
t = 1;
while(bool)
    % pressure
    studp = pressure(waym, studm, studc, studl, t);
    % picture
    p(:,:,t) = picture(waym,studm,studp);
    % stolpern
    studt = stumble(studp, studt, studl, t);
    % waytime
    wayt = waytime(waym,studm,studc,studt,studl,t);
    % statistic
    stats(:,:,t) = statistic(studp,studt,studl,t);
```

```
    % step 1
    [studm,studc,studt,studl] = step1(waym,studm,studc,studp,studt,studl,t);
    % step2
    [studm,studc,studt,studl] = step2(waym,studm,studc,studt,studl,t);
    % step umweg?
    [studm,studc,studt,studl] = step3(wayt,studm,studc,studt,studl,t);
    % make final step: restlicher twaited +1, ttowait -1, ausgang löschen
    [studm,studc,studt,studl] = laststep(waym,studm,studc,studt,studl,t);

    t=t+1;
    % noch wer da?
    bool = sum(studl(:,mod(t+1,2)+1));
end
% stats auswerten
stats(:,:,t) = statistic(studp,studt,studl,t);

clear i t bool mapn
```

## 8.2 preperation.m

```
function[waym,studm,studc,studt,studl] = preperation(rawmap)
% seperate the waymap and the studmap infomations
waym = mod(rawmap,2).*rawmap;
studm = (rawmap-waym)./2;

% finds the shortesway to a exit
i = 1;
bool = true;
dim = size(waym);

while bool
    for l = 1:dim(1,1)
        for r = 1:dim(1,2)
            if waym(l,r) == i
                if border(l-1,r,dim) && waym(l-1,r) == 0 % auf der Karte und gleich 0
                    waym(l-1,r) = i+1;
                    bool = false;
                end
                if border(l+1,r,dim) && waym(l+1,r) == 0
                    waym(l+1,r) = i+1;
                    bool = false;
                end
                if border(l,r-1,dim) && waym(l,r-1) == 0
                    waym(l,r-1) = i+1;
                    bool = false;
                end
                if border(l,r+1,dim) && waym(l,r+1) == 0
                    waym(l,r+1) = i+1;
                    bool = false;
                end
            end
        end
    end
```

```
    i = i+1;
    bool = not(bool);
end

% numbering the students
i = 1;
quant = sum(sum(studm));
studc = zeros(quant,4);
for l = 1:dim(1,1)
    for r = 1:dim(1,2)
        if studm(l,r) ~= 0
            studm(l,r) = i;
            studc(i,1:2) = [l r];
            i = i+1;
        end
    end
end

studt = zeros(quant,3);
studl(:,1) = ones(quant,1);
studl(:,2) = zeros(quant,1);
```

## 8.3 step1.m

```
function[studm,studc,studt,studl] = step1(waym,studm,studc,studp,studt,studl,t)
quant = size(studl); % Anzahl Studenten

for steps = 1:4
    for s= 1:quant(1,1)
        if studl(s,mod(t+1,2)+1) && not(studt(s,1)) % Stud im Raum, nicht wartend
            x = studc(s,2*mod(t+1,2)+1); % t ungerade 1; gerade 3
            y = studc(s,2*mod(t+1,2)+2); % t ungerade 2; gerade 4
            field = zeros(1,4); % mögliche Felder down up left right
            field2 = zeros(4,4); % mögliche Mitbesteiter down up left right
            for i = 1:4
                [dx,dy] = dulr(i); % down up left right
                if not(studm(x+dx,y+dy)) && waym(x+dx,y+dy) ...
                        < waym(x,y) && waym(x+dx,y+dy) ~= -1 && not(x+dx...
                        == studc(s,2*mod(t,2)+1) && y+dy == ...
                        studc(s,2*mod(t,2)+2))
                    % gibt es Felder frei, auf Weg, kein Flip
                    field(1,i) = 1;
                    for j = 1:4
                        [ddx,ddy] = udrl(j); % down up left right
                        if i ~= j && border(x+dx+ddx,y+dy+ddy,size(waym))
                            % nicht ausgehendes Feld, noch im Raum
                            if studm(x+dx+ddx,y+dy+ddy) && studl(studm(x+dx+ddx,y+dy+ddy),...
                                    mod(t+1,2)+1) && not(studt(studm(x+dx+ddx,y+dy+ddy),1)) &&...
                                    waym(x+dx,y+dy)<waym(x+dx+ddx,y+dy+ddy)
                                % Mitstudent?, nochnicht gelaufen, nicht wartend, auf Weg
                                field2(i,j) = 1;
                            end
                        end
                    end
                end
            end
```

```
        end
        if sum(field) % gibt es freie Felder
            for i = 1:4 % Gibt es Felder ohne Konkurenz
                if field(1,i) % Feld frei?
                    if sum(field2(i,:)) % there are other students
                        field(1,i) = 0;
                    end
                end
            end
            if sum(field) % es gibt solche Felder ohne Konkurenz
                choosen = round(sum(field)*rand(1)+0.5); % random auswahl
                i = 1;
                while(choosen)
                    if field(1,i)
                        if choosen == 1
                            [dx,dy] = dulr(i);
                            studt(s,2) = 0;
                            studt(s,3) = 0;
                            studc(s,2*mod(t,2)+1) = x+dx;
                            studc(s,2*mod(t,2)+2) = y+dy;
                            studl(s,mod(t+1,2)+1) = 0;
                            studl(s,mod(t,2)+1) = 1;
                            studm(studc(s,1),studc(s,2)) = s;
                            studm(studc(s,3),studc(s,4)) = s;
                            choosen = choosen-1;
                        else
                            choosen = choosen-1;
                        end
                    end
                    i = i+1;
                end
            else % gibt es Felder wo grösster Druck?
```

```
                    field(1,:) = (sum((field2')) > 0); % freies Feld
                    for i = 1:4 % grösserer Druck?
                        if field(1,i)
                            [dx,dy] = dulr(i);
                            for j = 1:4
                                if field2(i,j) % steht da jemand
                                    [ddx,ddy] = udrl(j);
                                    field(1,i) = field(1,i)*(studp(s,i) >...
                                        studp(studm(x+dx+ddx,y+dy+ddy),j));
                                    % = 0, wenn nicht grösserer Druck als alle andern
                                end
                            end
                        end
                    end
                    if sum(field) % es gibt ein solches Feld
                        choosen = round(sum(field)*rand(1)+0.5); % random auswahl
                        i = 1;
                        while(choosen)
                            if field(1,i)
                                if choosen == 1
                                    [dx,dy] = dulr(i);
                                    studt(s,2) = 0;
                                    studt(s,3) = 0;
                                    studc(s,2*mod(t,2)+1) = x+dx;
                                    studc(s,2*mod(t,2)+2) = y+dy;
                                    studl(s,mod(t+1,2)+1) = 0;
                                    studl(s,mod(t,2)+1) = 1;
                                    studm(studc(s,1),studc(s,2)) = s;
                                    studm(studc(s,3),studc(s,4)) = s;
                                    choosen = choosen-1;
                                else
                                    choosen = choosen-1;
                                end
                            end
                            i = i+1;
                        end
                    end
                end
            end
        end
    end
end
end
```

## 8.4 step2.m

```matlab
function[studm,studc,studt,studl] = step2(waym,studm,studc,studt,studl,t)
quant = size(studl);

bool = true;
while(bool)
    for s = 1:quant(1,1)
        if studl(s,mod(t+1,2)+1) && not(studt(s,1)) % im Raum, nicht wartend
            x = studc(s,2*mod(t+1,2)+1); % t ungerade 1; gerade 3
            y = studc(s,2*mod(t+1,2)+2); % t ungerade 2; gerade 4
            field = zeros(1,4); % mögliche Felder down up left right
            field2 = zeros(4,4); % mögliche Mitbesteiter down up left right
            for i = 1:4
                [dx,dy] = dulr(i); % down up left right
                if not(studm(x+dx,y+dy)) && waym(x+dx,y+dy) < waym(x,y) &&...
                        waym(x+dx,y+dy) ~= -1 && not(x+dx == studc(s,2*mod(t,2)+1)...
                        && y+dy == studc(s,2*mod(t,2)+2))
                    % gibt es Felder frei, auf Weg, kein Flip
                    field(1,i) = 1;
                    bool = false; % es gibt noch einer mit möglichem freien  Feld
                    for j = 1:4
                        [ddx,ddy] = udrl(j); % down up left right
                        if i ~= j && border(x+dx+ddx,y+dy+ddy,size(waym))
                            % nicht ausgehendes Feld, noch im Raum
                            if studm(x+dx+ddx,y+dy+ddy) && ...
                                    studl(studm(x+dx+ddx,y+dy+ddy), ...
                                    mod(t+1,2)+1) && not(studt(studm(x+dx+ddx,y+dy+ddy),1)) ...
                                    && waym(x+dx,y+dy)<waym(x+dx+ddx,y+dy+ddy)
                                % Mitstudent?, nochnicht gelaufen, nicht wartend, auf Weg
                                field2(i,j) = 1; % anderer
                            end
                        end
                    end
                end
            end
            if sum(field) % es gibt ein freies Feld
                for i = 1:4 % Gibt es Felder ohne Konkurenz
                    if field(1,i) % Feld frei?
                        if sum(field2(i,:)); % there are other students
                            field(1,i) = 0;
                        end
                    end
                end
                if sum(field) % es gibt solche Felder ohne Konkurenz
                    choosen = round(sum(field)*rand(1)+0.5); % random auswahl
                    i = 1;
                    while(choosen)
                        if field(1,i)
                            if choosen == 1
                                [dx,dy] = dulr(i);
                                studt(s,2) = 0;
                                studt(s,3) = 0;
                                studc(s,2*mod(t,2)+1) = x+dx;
                                studc(s,2*mod(t,2)+2) = y+dy;
                                studl(s,mod(t+1,2)+1) = 0;
                                studl(s,mod(t,2)+1) = 1;
                                studm(studc(s,1),studc(s,2)) = s;
                                studm(studc(s,3),studc(s,4)) = s;
```

```
                                choosen = choosen-1;
                            else
                                choosen = choosen-1;
                            end
                        end
                        i = i+1;
                    end
                else % wer darf ziehen?
                    field(1,:) = (sum((field2')) > 0); % freies Feld
                    for i=1:4
                        if field(1,i)
                            field(1,i) = (round((sum(field2(i,:))+1)*rand(1)+0.5) == 1);
                        end
                    end
                    if sum(field) % es gibt ein solches Feld
                        choosen = round(sum(field)*rand(1)+0.5); % random auswahl
                        i = 1;
                        while(choosen)
                            if field(1,i)
                                if choosen == 1
                                    [dx,dy] = dulr(i);
                                    studt(s,2) = 0;
                                    studt(s,3) = 0;
                                    studc(s,2*mod(t,2)+1) = x+dx;
                                    studc(s,2*mod(t,2)+2) = y+dy;
                                    studl(s,mod(t+1,2)+1) = 0;
                                    studl(s,mod(t,2)+1) = 1;
                                    studm(studc(s,1),studc(s,2))=s;
                                    studm(studc(s,3),studc(s,4))=s;
                                    choosen = choosen-1;
                                else
                                    choosen = choosen-1;
                                end
                            end
                            i = i+1;
                        end
                    end
                end
            end
        end
    end
    bool = not(bool);
end
end
```

## 8.5 step3.m

```
function[studm,studc,studt,studl] = step3(wayt,studm,studc,studt,studl,t)
quant = size(studl);

for s = 1:quant(1,1)
    if studl(s,mod(t+1,2)+1) && not(studt(s,1)) % im Raum, nicht wartend
        x = studc(s,2*mod(t+1,2)+1); % t ungerade 1; gerade 3
        y = studc(s,2*mod(t+1,2)+2); % t ungerade 2; gerade 4
        for i = 1:4 % Felder immer noch frei?
            if wayt(s,2+i)
                [dx,dy] = dulr(i);
                wayt(s,2+i) = not(studm(x+dx,y+dy));
            end
        end
        if studt(s,3) % schon auf Umweg
            if sum(wayt(s,3:6)) % es gibt Umweg, erstes Feld frei
                choosen = round(sum(wayt(s,3:6))*rand(1)+0.5); % random auswahl
                i = 1;
                while(choosen)
                    if wayt(s,2+i)
                        if choosen == 1
                            [dx,dy] = dulr(i);
                            studt(s,3) = 1;
                            studc(s,2*mod(t,2)+1) = x+dx;
                            studc(s,2*mod(t,2)+2) = y+dy;
                            studl(s,mod(t+1,2)+1) = 0;
                            studl(s,mod(t,2)+1) = 1;
                            studm(studc(s,1),studc(s,2)) = s;
                            studm(studc(s,3),studc(s,4)) = s;
                            choosen = choosen-1;
                        else
                            choosen = choosen-1;
                        end
                    end
                    i = i+1;
                end
            else
                if wayt(s,2) == -1 || (wayt(s,1)+studt(s,2)) <= wayt(s,2)
                    % Umweg gibt es nicht mehr, Umweg lohnt sich nicht mehr
                    studt(s,3) = 0;
                    if not(studm(studc(s,2*mod(t,2)+1),studc(s,2*mod(t,2)+2)))
                        % letzte Position noch frei
                        studt(s,2) = 0;
                        studl(s,mod(t+1,2)+1) = 0;
                        studl(s,mod(t,2)+1) = 1;
                        studm(studc(s,1),studc(s,2)) = s;
                        studm(studc(s,3),studc(s,4)) = s;
                    end
                end
```

```
                end
            else % noch nicht auf Umweg
                if sum(wayt(s,3:6)) && (wayt(s,1)+studt(s,2)) > wayt(s,2)
                    % es gibt Umweg, erstes Feld frei, Umweg lohnt sich
                    choosen = round(sum(wayt(s,3:6))*rand(1)+0.5); % random auswahl
                    i = 1;
                    while(choosen)
                        if wayt(s,2+i)
                            if choosen == 1
                                [dx,dy] = dulr(i);
                                studt(s,3) = 1;
                                studc(s,2*mod(t,2)+1) = x+dx;
                                studc(s,2*mod(t,2)+2) = y+dy;
                                studl(s,mod(t+1,2)+1) = 0;
                                studl(s,mod(t,2)+1) = 1;
                                studm(studc(s,1),studc(s,2)) = s;
                                studm(studc(s,3),studc(s,4)) = s;
                                choosen = choosen-1;
                            else
                                choosen = choosen-1;
                            end
                        end
                        i = i+1;
                    end
                end
            end
        end
    end
end
```

## 8.6 alternivway.m

```
function[tmin,nw] = alternivway(x,y,j,waym,studm,studt)
% ungefährezeit auf einem kürzesten alternativen weg
tmin = -1;
nw = 0; % 0 kein Weg
field = (-1)*ones(1,4);

for i = 1:4
    [dx,dy] = udrl(i);
    if border(x+dx,y+dy,size(waym)) && waym(x+dx,y+dy) ~= -1 && i ~= j
        % im Raum keine Wand und kein Flip
        if waym(x,y) <= waym(x+dx,y+dy) % auf Umweg
            [t,nnw] = alternivway(x+dx,y+dy,round(i/2)*2-mod(i+1,2),waym,studm,studt);
            % Permutation 1<->2,3<->4
            if nnw && (not(studm(x+dx,y+dy)) || studt(studm(x+dx, y+dy),3))
                %keine Sackgasse, kein Student der nicht auf Umweg
                nw = 1;
                if studm(x+dx,y+dy) && studt(studm(x+dx,y+dy),3) % Student auf umweg
                    field(1,i) = 1+studt(studm(x+dx,y+dy),1)+waym(x+dx,y+dy)-waym(x,y)+t;
                    tmin = field(1,i);
                else
                    field(1,i) = waym(x+dx,y+dy)-waym(x,y)+t;
                    tmin = field(1,i);
                end
            end
        else
            tmin = 0;  % Umweg beendet, es ist keine Sackgasse
            nw = 1;
            return
        end
    end
end
if tmin ~= -1
    for i = 1:4 % kleinstes t
        if field(1,i) ~= -1
            if field(1,i) < tmin
                tmin = field(1,i);
            end
        end
    end
end
end
```

## 8.7 border.m

```
function[bool] = border(x, y, dim)
% x,y in the matrix -> true
% else              -> false
bool = true;
if x < 1 || x > dim(1,1) || y < 1 || y > dim(1,2)
    bool = false;
end
```

## 8.8 dulr.m

```
function[dx,dy] = dulr(i)
% down up left right
dx = -2/3*i^3+11/2*i^2-83/6*i+10;
dy = 2/3*i^3-9/2*i^2+53/6*i-5;
end
```

## 8.9 udrl.m

```
function[dx,dy] = udrl(i)
% up down right left
dx = 2/3*i^3-11/2*i^2+83/6*i-10;
dy = -2/3*i^3+9/2*i^2-53/6*i+5;
end
```

## 8.10 stumble.m

```
function[studt] = stumble(studp,studt,studl,t)
quant = size(studl);

for s = 1:quant(1,1) % all students
    if studl(s,mod(t+1,2)+1) % noch im Raum
        if not(studt(s,1)) % nicht wartend
            if sum(studp(s,:))>39
                smax = 20;
            else
                smax = sum(studp(s,:))/2+1;
            end
            studt(s,1) = round(smax*rand(1)+.5)*(rand(1) <= exp((sum(studp(s,:))-studt(s,2))/20)/exp(1));
            % random(studp,studt(i,2))
        end
    end
end
end
```

## 8.11 picture.m

```
function[p] = picture(waym,studm,studp)
dim = size(waym);
p = zeros(dim);
for l = 1:dim(1,1)
    for r = 1:dim(1,2)
        if abs(waym(l,r)) == 1 % Wand oder Ausgang
            p(l,r) = waym(l,r);
        elseif studm(l,r) ~= 0; % Student
            p(l,r) = 2+sum(studp(studm(l,r),:));
        end
    end
end
p = p+2; % 1 Wand, 2 Boden , 3 Türe, 4-? Studentenpressure
end
```

## 8.12 statistic.m

```
function[stats] = statistic(studp,studt,studl,t)
quant = size(studl); % Anzahl Studenten
stats = zeros(quant);

for s = 1:quant(1,1)
    if not(studl(s,mod(t+1,2)+1)) % nicht mehr im Raum
        stats(s,:) = [-1 -1];
    else
        stats(s,1) = sum(studp(s,:));
        stats(s,2) = studt(s,1);
    end
end
end
```

## 8.13 directway.m

```
function[tmin] = directway(x,y,waym,studm,studt) % ungefähre Zeit auf direktem Weg
tmin = -1;
if waym(x,y)==1
    tmin = 0;
    return
end
field = (-1)*ones(1,4);
for i = 1:4
    [dx,dy] = dulr(i);
    if waym(x+dx,y+dy) < waym(x,y) && waym(x+dx,y+dy) ~= -1% auf Weg
        field(1,i)=0;
    end
end
for i = 1:4
    [dx,dy] = dulr(i);
    if not(field(1,i)) % auf Weg
        if studm(x+dx,y+dy)
            field(1,i) = (studt(studm(x+dx,y+dy),1)+1+directway(x+dx,y+dy,waym,studm,studt));
            tmin = field(1,i);
        else
            field(1,i) = directway(x+dx,y+dy,waym,studm,studt); tmin = field(1,i);
        end
    end
end
for i = 1:4 % kürzester Weg
    if field(1,i) ~= -1
        if tmin > field(1,i);
            tmin = field(1,i);
        end
    end
end
end
```

## 8.14 laststep.m

```
function[studm,studc,studt,studl] = laststep(waym,studm,studc,studt,studl,t)
quant = size(studl);
for s = 1:quant(1,1)% alle nicht bewegten wartend setzen
    if studl(s,mod(t+1,2)+1) % kein Schritt gemacht
        if studt(s,3)
            ax = studc(s,2*mod(t,2)+1); % Koordinaten wechseln
            ay = studc(s,2*mod(t,2)+2);
            studc(s,2*mod(t,2)+1) = studc(s,2*mod(t+1,2)+1);
            studc(s,2*mod(t,2)+2) = studc(s,2*mod(t+1,2)+2);
            studc(s,2*mod(t+1,2)+1) = ax;
            studc(s,2*mod(t+1,2)+2) = ay;
        else
            studc(s,2*mod(t,2)+1) = studc(s,2*mod(t+1,2)+1); % Koordinaten übernehmen
            studc(s,2*mod(t,2)+2) = studc(s,2*mod(t+1,2)+2);
            studt(s,2) = studt(s,2)+1; % Warten =+1
        end
        studl(s,mod(t+1,2)+1) = 0; % gezogen
        studl(s,mod(t,2)+1) = 1; % noch im Raum
    end
end
studm = zeros(size(studm)); % studm neu einzeichnen
for s = 1:quant(1,1)
    if studl(s,mod(t,2)+1) % noch im Raum
        if waym(studc(s,2*mod(t,2)+1),studc(s,2*mod(t,2)+2)) == 1 % Exit
            studl(s,:) = [0,0]; studt(s,:) = [-1,t,0];  % Stud verlässt Raum
        else % nicht auf Ausgang
            if studt(s,1) % time to wait -1
                studt(s,1) = studt(s,1)-1;
            end
            studm(studc(s,2*mod(t,2)+1),studc(s,2*mod(t,2)+2)) = s; % einzeichnen
        end
    end
end
```

## 8.15 pressure.m

```
function[studp] = pressure(waym, studm, studc, studl, t)
quant = size(studl); % quantity of students
studp = zeros(quant(1,1),4); % set p to 0

for s = 1:quant(1,1) % for all students
    if studl(s, mod(t+1,2)+1) % t ungerade 1; gerad 2 % for all students left
        for i = 1:4 % for all directions
            x = studc(s,2*mod(t+1,2)+1); % t ungerade 1; gerade 3
            y = studc(s,2*mod(t+1,2)+2); % t ungerade 2; gerade 4
            [dx,dy] = udrl(i); % up down right left
            bool = true;
            while(bool) % until there's nobody in this direction
                if waym(x+dx,y+dy) == -1 % wall: break
                    bool = false;
                    break
                elseif not(studm(x+dx,y+dy)) % no person: break
                    bool = false;
                    break
                elseif  (waym(x,y) - waym(x+dx,y+dy)) >= 0% student doesn't want to go to this field
                    bool = false;
                    break
                else
                    n = 0;
                    for j = 1:4 % number of field student could go
                        [ddx,ddy] = udrl(j);
                        if waym(x+dx+ddx,y+dy+ddy) ~= -1 %keine Wand
                            n = n+(waym(x+dx,y+dy)-(waym(x+dx+ddx,y+dy+ddy)) > 0);
                        end
                    end
                    studp(s,i) = studp(s,i)+1/n;
                end
                x = x+dx;
                y = y+dy;
            end
        end
    end
end
end
```

## 8.16 pictureshow.m

```
function[] = pictureshow(p)
steps = size(p);
%steps = steps(1,3);
steps=1;
i = 1;
axis off;
grid off;
cmap = zeros(64,3);
cmap(1:29,:) = [0.4000    0.4000    0.4000;
                0.8000    0.8000    0.8000;
                1.0000    1.0000    1.0000;
                     0    1.0000         0;
                0.2500    1.0000         0;
                0.5000    1.0000         0;
                0.7500    1.0000         0;
                1.0000    1.0000         0;
                1.0000    0.8500         0;
                1.0000    0.7000         0;
                1.0000    0.5500         0;
                1.0000    0.4000         0;
                1.0000    0.3000         0;
                1.0000    0.2000         0;
                1.0000    0.1000         0;
                1.0000         0         0;
                0.9000         0         0;
                0.8000         0         0;
                0.7000         0         0;
                0.6000         0         0;
                0.5400         0         0;
                0.4800         0         0;
                0.4200         0         0;
                0.3600         0         0;
                0.3000         0         0;
                0.2400         0         0;
                0.1800         0         0;
                0.1200         0         0;
                0.0600         0         0;];
colormap(cmap);
while(true)
    image(p(:,:,mod(i,steps)+1))
    i = i+1;
    pause(.2);
end
end
```

### 8.17 maps.m

```
function[map] = maps(n)

if n == 1
    map = % map as a matrix
elseif n == 2
    map = % map as a matrix
elseif n == 3
    map = % map as a matrix
elseif n == 4
    map = % map as a matrix
elseif n == 5
    map = % map as a matrix
elseif n == 6
    map = % map as a matrix
end
end
```

We disclaim here to plot the map matrices. In the chapter 4.3 you can see how we implemented the different maps.