Modeling and Numerical Simulation of Multi-Destination Pedestrian Crowds

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Overview

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Experimental setup

- Two/four groups of participants, 80–150 pedestrians in each group,
- intersecting in a region of about 20 m^2 for approx. one minute,
- recorded by up to seven temporally synchronized surveillance cameras.

Image source: Spiegel Online

Two intersecting pedestrian flows, $\theta = 90^\circ$

Department of Mathematics, TU Berlin (June 2010)

Two intersecting pedestrian flows, $\theta = 180^\circ$

Department of Mathematics, TU Berlin (June 2010)

Four intersecting pedestrian flows

Department of Mathematics, TU Berlin (June 2010)

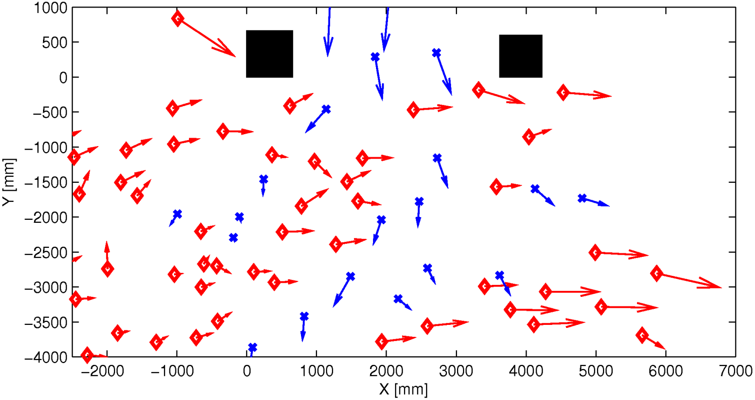
Two intersecting pedestrian flows, $\theta = 90^\circ$

Department of Mathematics, TU Berlin (Dec. 2010)

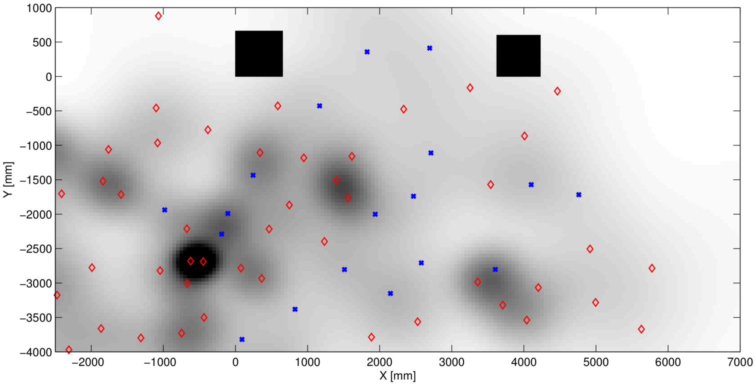
Challenges

- Semi-automatic tracking of the pedestrians: Lucas–Kanade algorithm.
- Extraction of individual spatio-temporal positions from video: world coordinates from image coordinates of head and floor position.
- Computation of smooth trajectories and velocities: cubic B-splines.
- Merging of trajectories from different camera views: matching via the Hungarian algorithm.
- Computation of density and flow fields: kernel estimator with variable bandwidth.

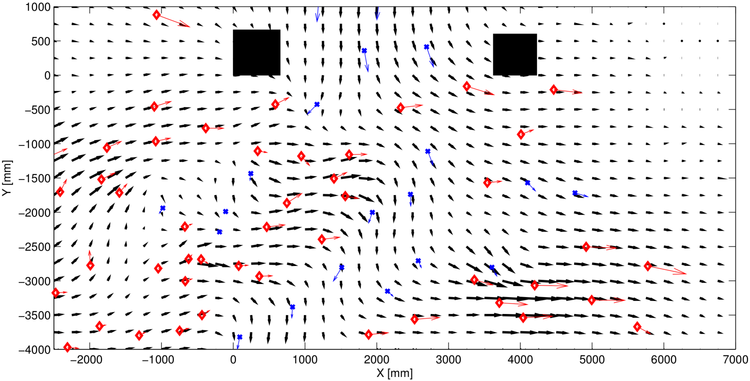
Pedestrian positions and velocities



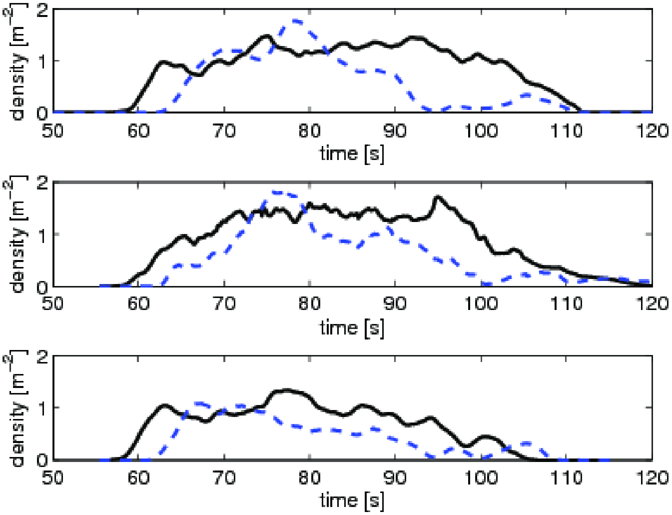
Pedestrian density field



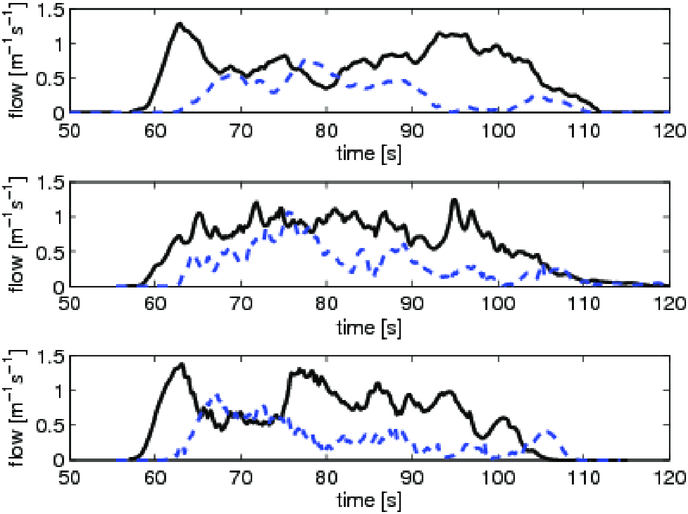
Pedestrian flow field



Spatial/time mean value of density



Spatial/time mean value of flux



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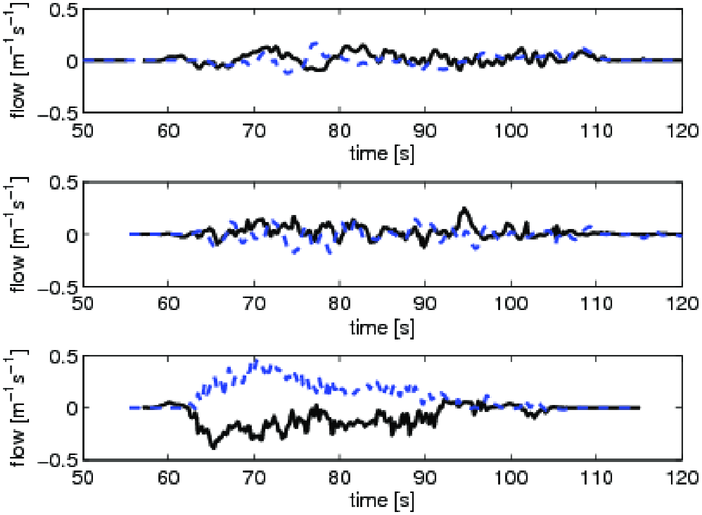
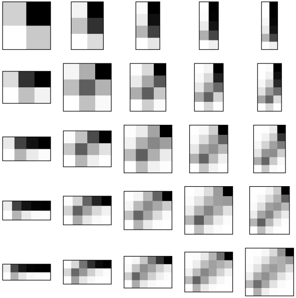


Overview

Simulation of two intersecting pedestrian groups

- The system geometry will be projected onto a two-dimensional regular grid
- The (simulated) pedestrians will be given walking directions toward corresponding destinations
- The pedestrians must consider local collision-avoidance whenever possible
- This is to be guaranteed by the following mechanisms

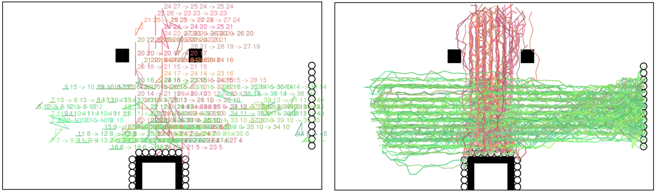


Disintegration of a local step into a series of substeps. The relative occurrence of a position on the route is shown in a gray scale. This ensures that the number of the substeps needed to carry out a certain position change has a mathematical expectation that is equal to the physical length of the step.

```
procedure operational_execution_single begin
input parameter: i
  if destination reached
    mark as ''processed'';
  else
    count successful substeps in the current simulation cycle
      and save this number as a;
    p ⇐ min((v−a)/i, 1);
    calculate and execute a substep with probability p;
  fi
end.
```

```
procedure operational_execution begin
input parameter: a collection of pedestrians
  mark all pedestrians as ''unprocessed'';
  i ⇐ n;
  while i ≥ 1
  do
    process all pedestrians marked ''unprocessed'' by calling
      procedure operational_execution_single sequentially
      with parameter i;
    i ⇐ i − 1;
  enddo
end.
```

Two subroutines for the execution of the local steps (in form of a series of n substeps) of the collected pedestrians. The collision-avoidance is considered in a compensation factor in p for a single pedestrian to carry out a substep whenever possible.



Simulation snapshots

Review

- By construction, this method applies as well to the case of multiple pedestrian groups (at least in a theoretical context)
- To do: Implementation of a navigation module to improve the (multi-position) step choices

  For example, local density information should be included in the decision-making of local step choices (which is, basically also a collision-avoidance problem, but on a larger scale)

Overview

Macroscopic Models (the Being of)

Macroscopic models perceive pedestrian crowds as continuous matter.
The crowd is described by its local density distribution and the temporal change of the latter.

Start with the mass balance equation

ρ_i should be the pedestrian density (of a certain typ) in a certain region.
changing of the pedestrian density (of a certain typ) at a point:

$$\frac{\partial \rho_i}{\partial t} + \nabla \cdot (\rho_i v_i) = 0;$$

key question: what is a good model for v_i in this connection (and what dependencies they have)?

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A generalization

$$\frac{\partial \rho_i}{\partial t} + \nabla \cdot F_i(\rho_1, \ldots \rho_n) + G_i(\rho_1, \ldots, \rho_n) \quad = \quad \epsilon_i \Delta \rho_i$$

with $\rho, \rho_i \in [0, 1]$, species densities;
F_i, fluxfunction (with prescribed direction);
G_i, density-driven flux;
Δ, smooth operator; ϵ_i, small parameter;

flux function (with prescribed direction) and density driven flux term

$$
\begin{aligned}
F_i(\rho_1, \ldots \rho_n) &= a_i \rho_i V(\rho) d_i \\
\rho &= \sum_{i=1}^{n} \rho_i \\
V(\rho) &= 1 - \rho
\end{aligned} \qquad (1)
$$

$V \in [0, 1]$, absolut value of a velocity; a_i constants; d_i species own direction vectors.

$$G(\rho_1, \ldots, \rho_n) := -b_i \nabla \cdot (\rho_i \nabla \rho)$$

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what means a density driven flux term with respect to reality?

the modeled behavior describes the behavior of blind persons with a stick who move to the wanted direction - and - in the case of bigger density the change there direction to skirt places with high densities

some disadvantages left: examples of choosed terms F and G are close to reality - but consider only local effects

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consideration of global information

idea: use of special potential equations:

$$\alpha_j^{(i)} \Delta \phi_j^{(i)}(t) = f_j^{(i)}(t) \tag{2}$$

where α_i is a constant, which weights the globality of information the pedestrian can have, and f_i is the magnitude of influence of enviromental information
challenge: choice of appropriate $\alpha_j^{(i)}$, $f_j^{(i)}$ and boundary values for ϕ_j of (2), that we will get an useful potential $\phi_i = \sum_j \phi_j^{(i)}$.
information, which can be evaluated:

- far field/global information
  - geometry of the considered region
  - ramps, stairs
  - pedestrian congestion
- local information
  - "free" pedestrians

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modeled behavior describes pedestrians

who can spot their local and global environment, and
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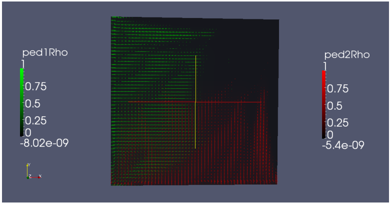

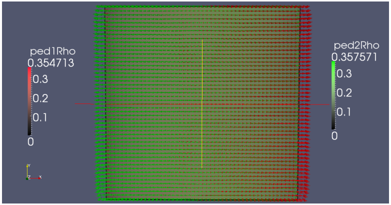

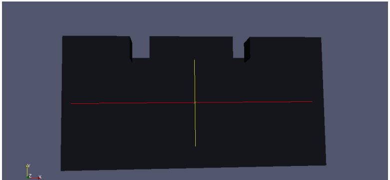

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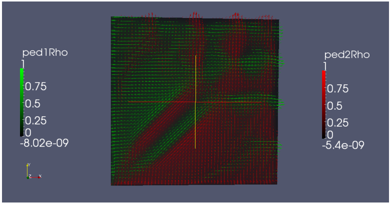

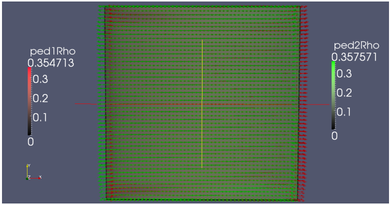

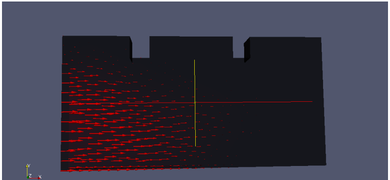

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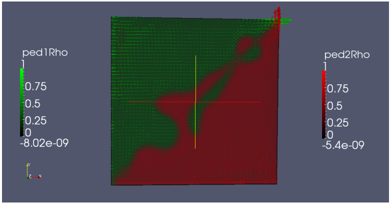

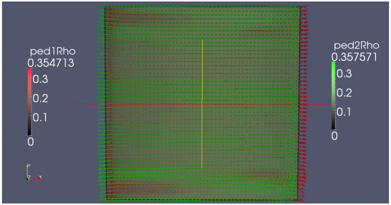

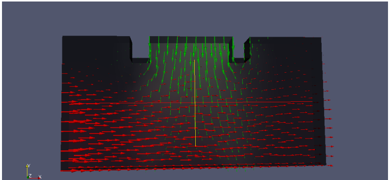

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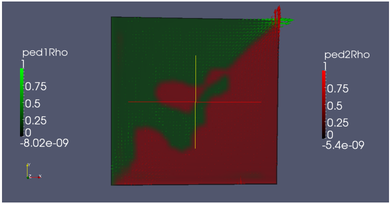

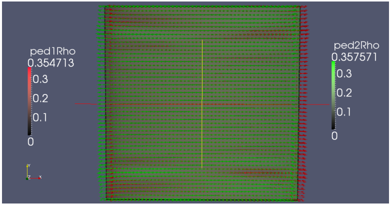

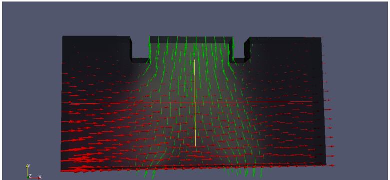

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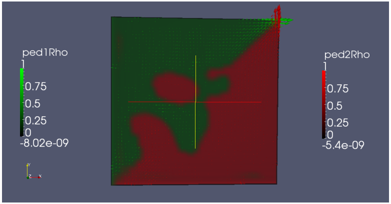

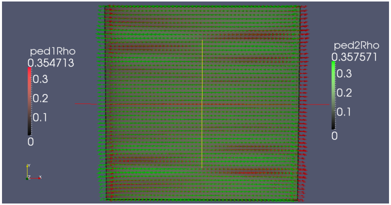

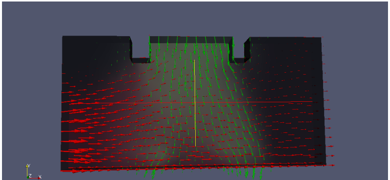

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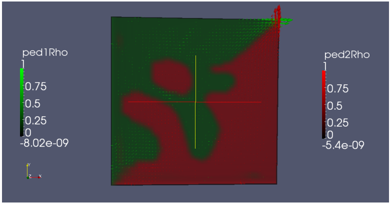

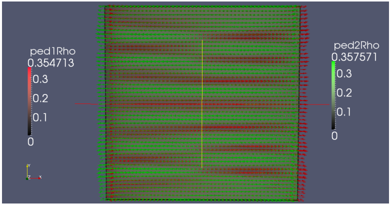

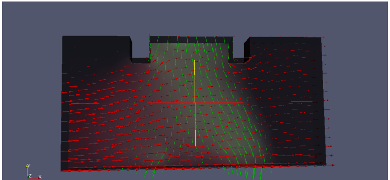

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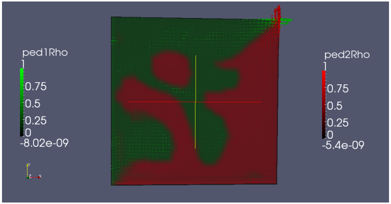

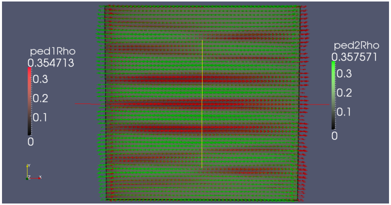

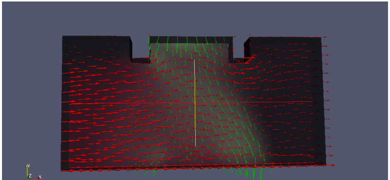

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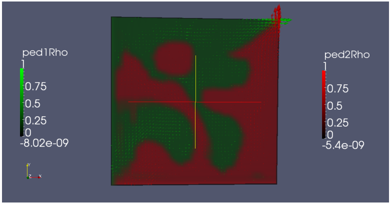

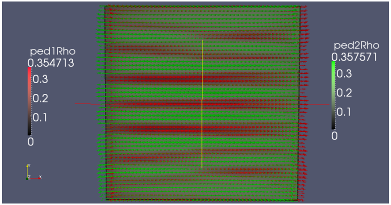

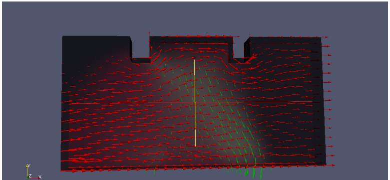

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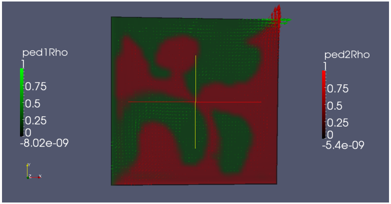

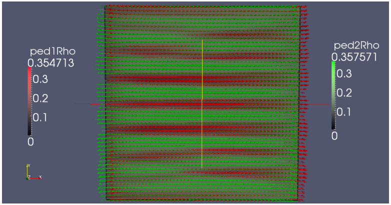

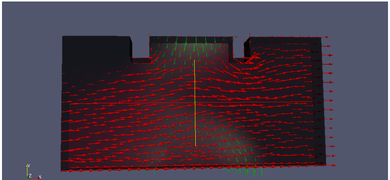

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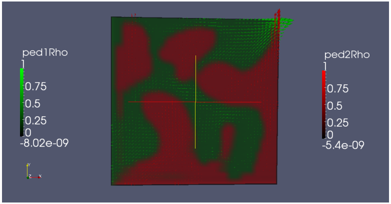
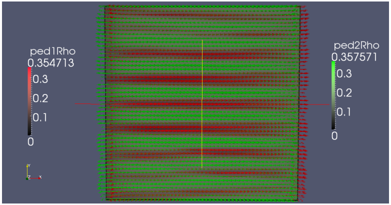
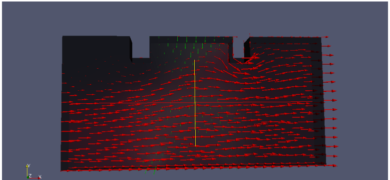
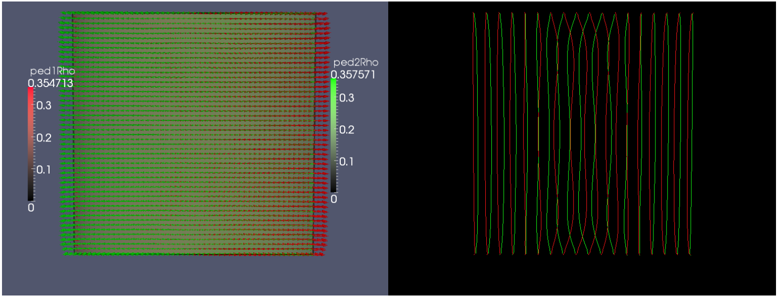






Potential-Applying Simulation (180°)



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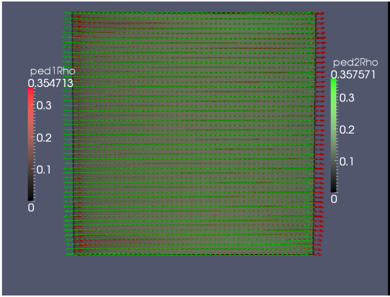

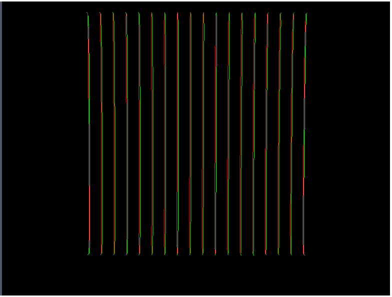

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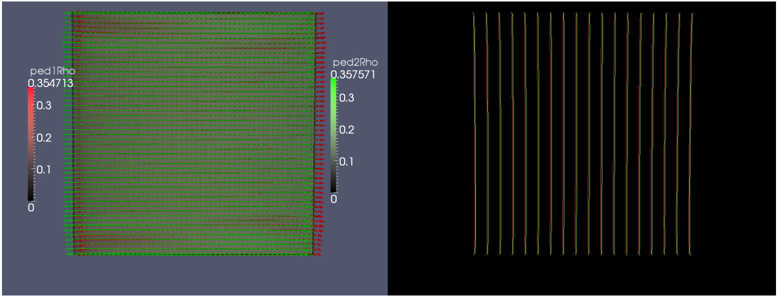

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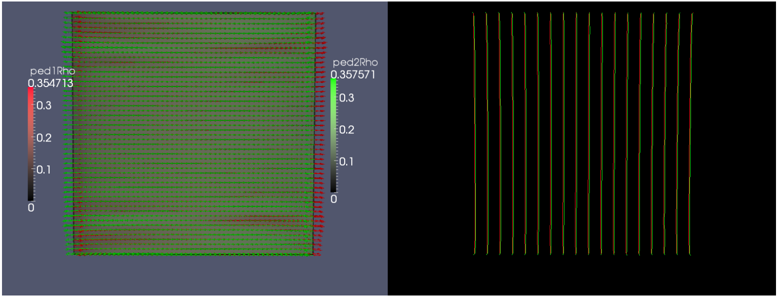

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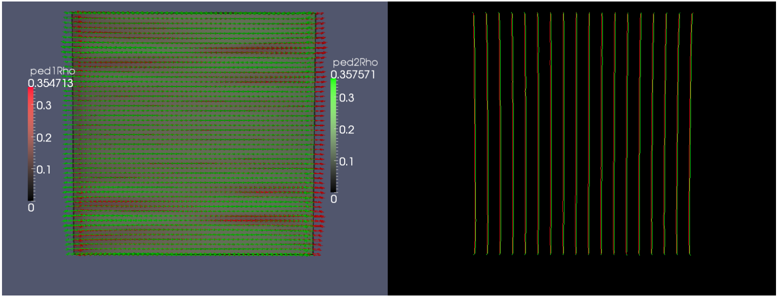

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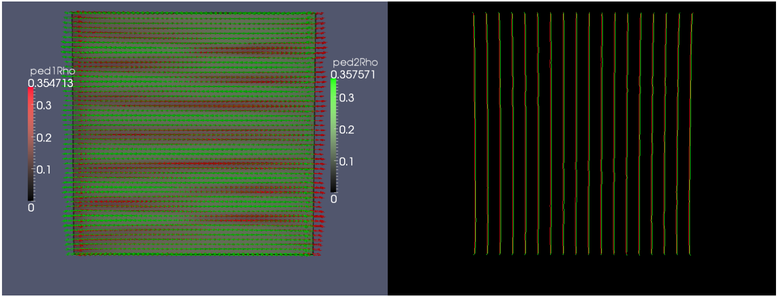

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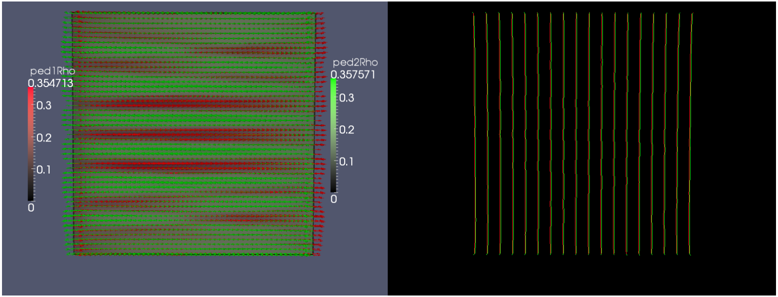

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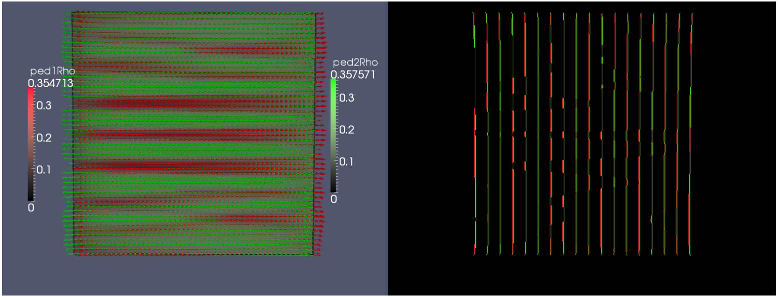

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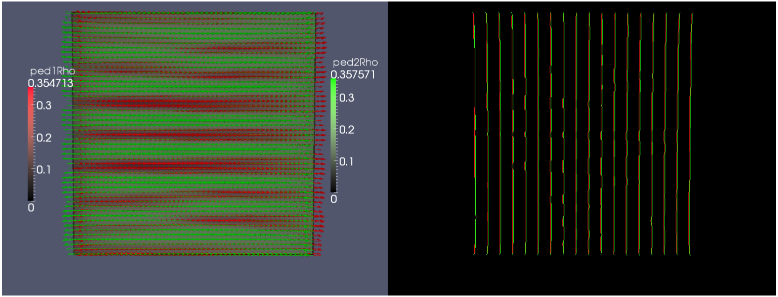

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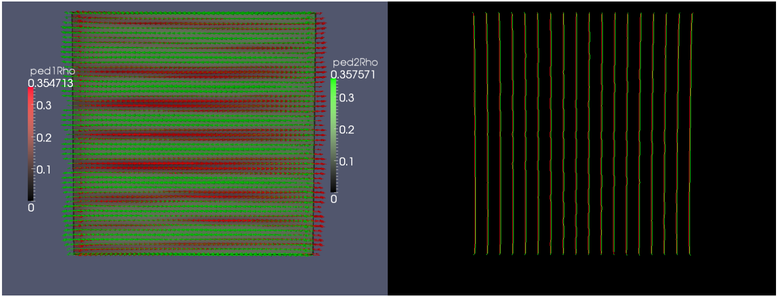
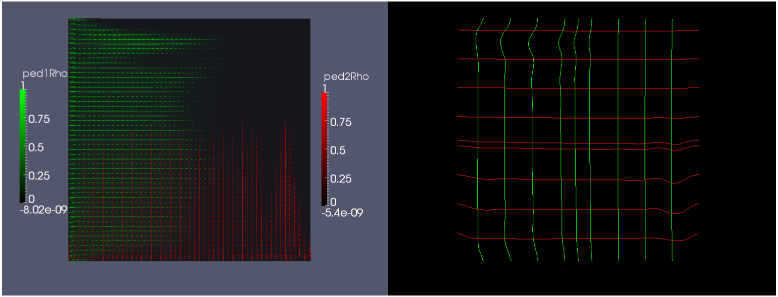


Potential-Applying Simulation (90°)



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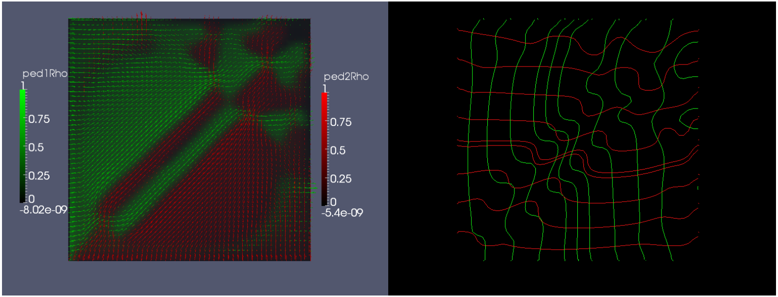

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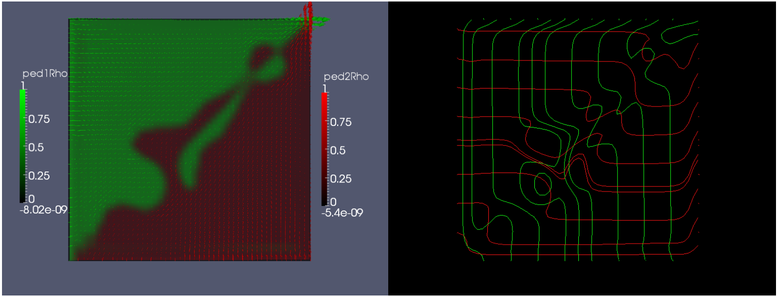

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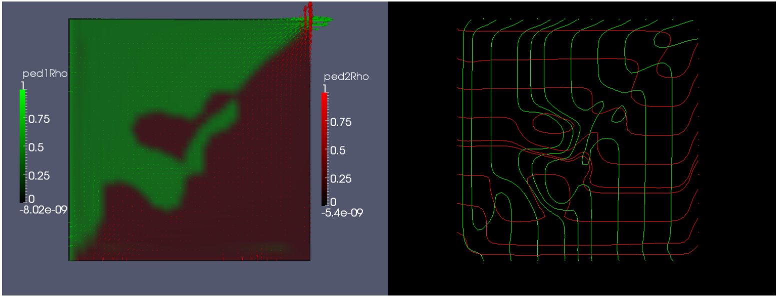

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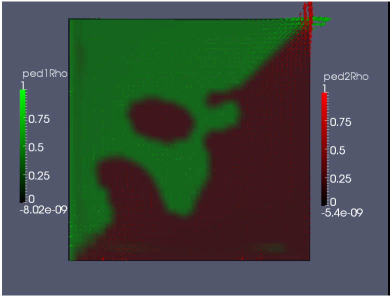

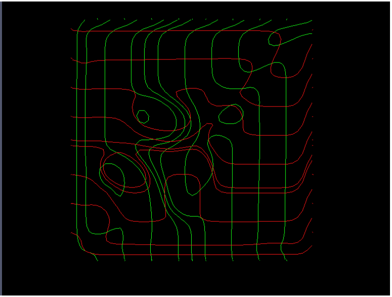

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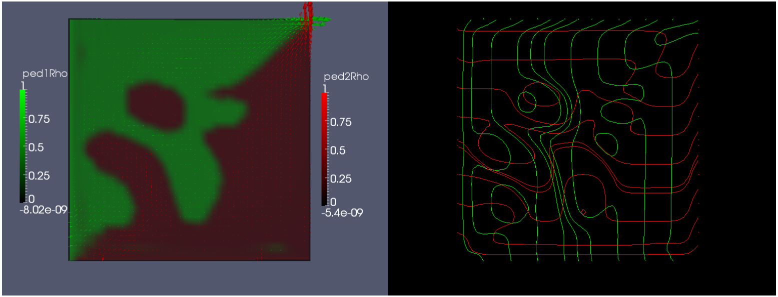

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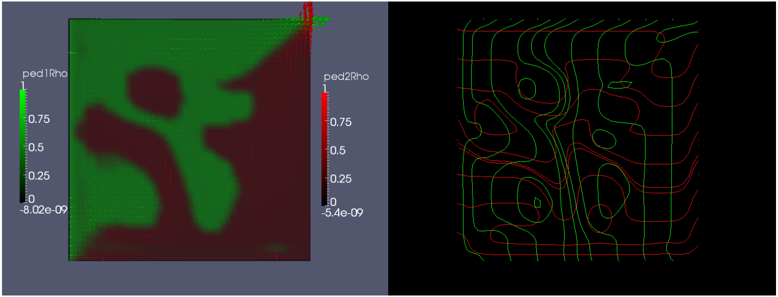

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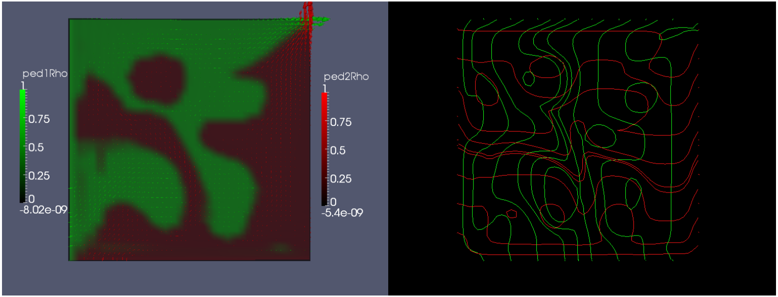

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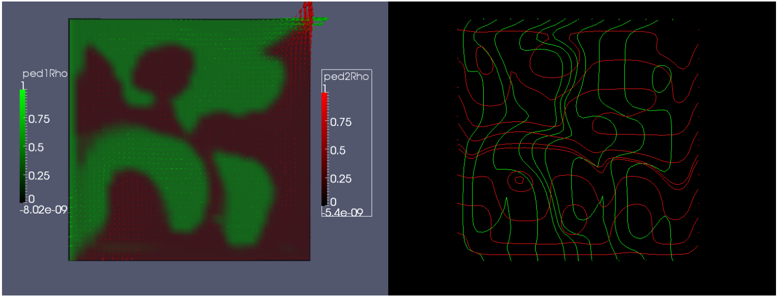

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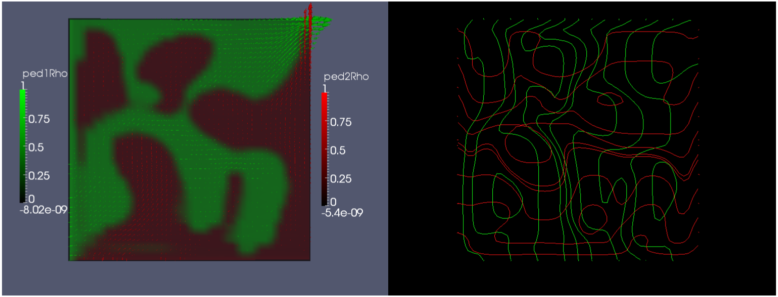
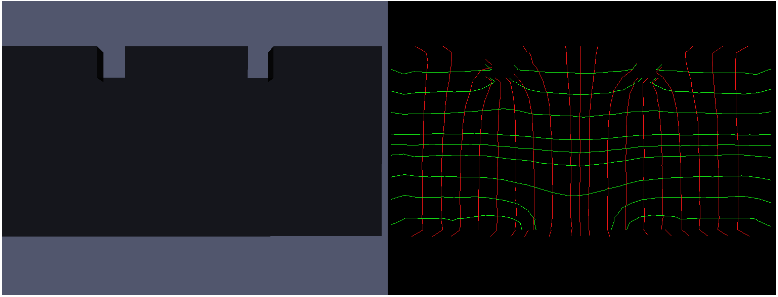


Potential-Applying Math Foyer



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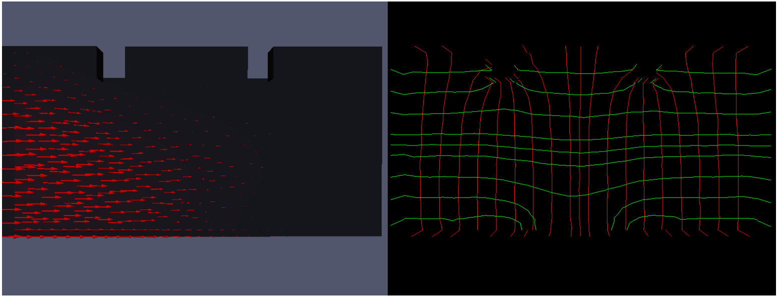

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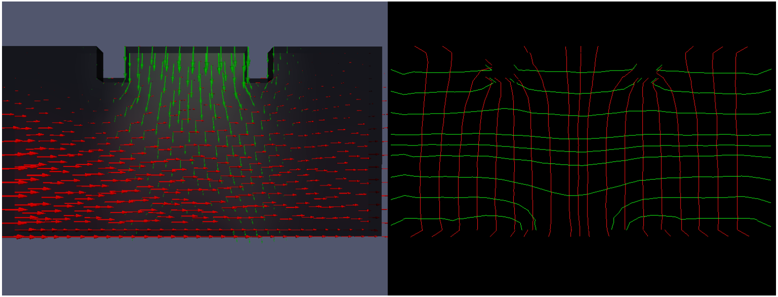

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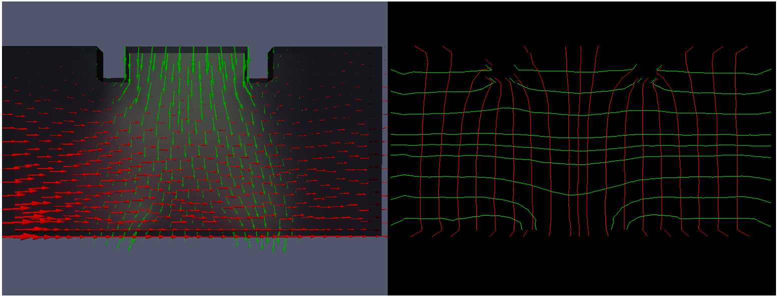

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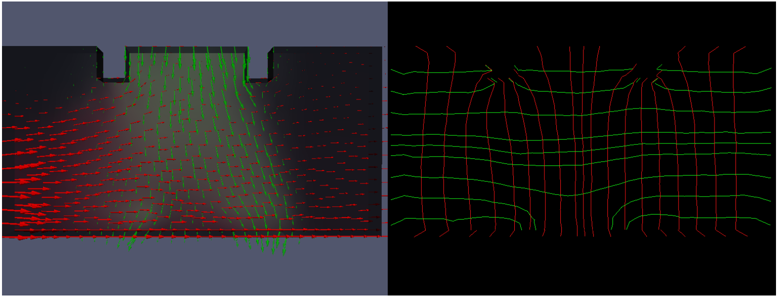

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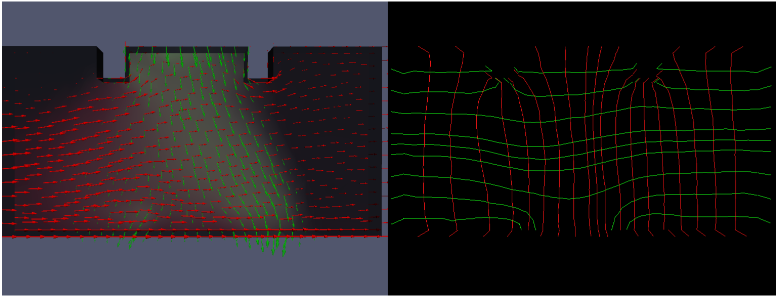

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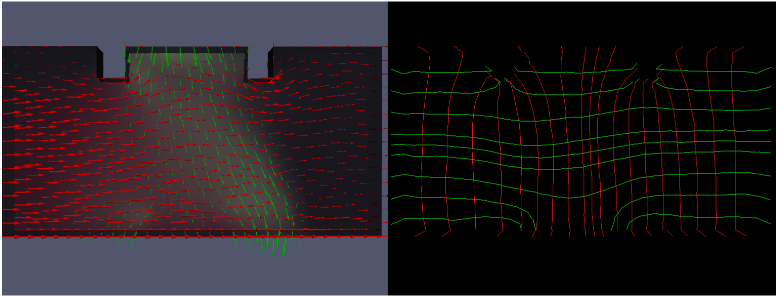

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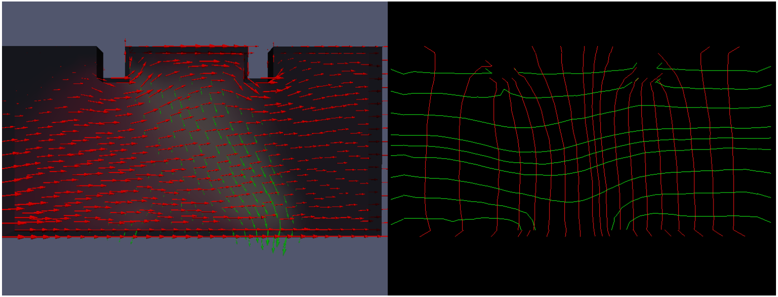

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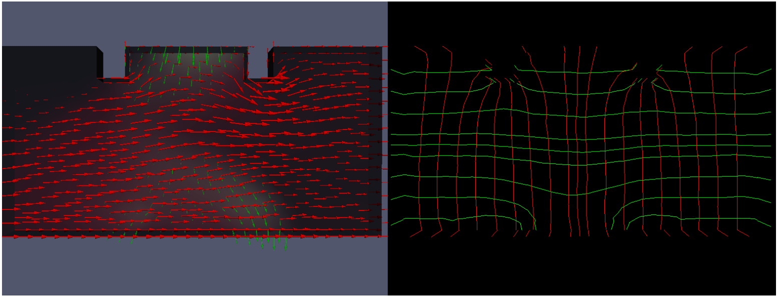

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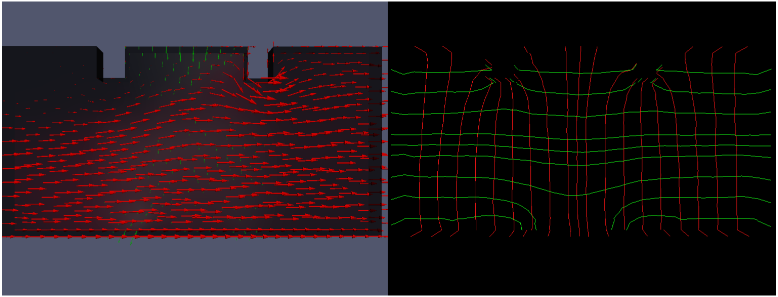

Another approach using the Navier-Stokes equations

We use the non-stationary, incompressible Navier-Stokes equations

$$\rho \frac{\partial \mathbf{v}}{\partial t} + \rho \mathbf{v} \cdot \nabla \otimes \mathbf{v} + \nabla p - \tag{3}$$

$$\nabla \cdot (\mu(\nabla \otimes \mathbf{v}) + \mu(\nabla \otimes \mathbf{v})^T) = \mathbf{f} \tag{4}$$

$$\nabla \cdot \mathbf{v} = \mathbf{0} \tag{5}$$

combined with a volume of fluid (VOF) method as a starting point to simulate $N_p \in \mathbb{N}$ different pedestrian species.

Idea of the incompressible approach

- all pedestrian species are considered as incompressible,
- to model compressions (variable densities) we use an ”empty” species which can diffuse into the third direction
- this mechanism is realized by appropriate different boundary condition for the pedestrian species and for the ”empty” species
- this requires a **3D** approach, but we can use existing tutorials for incompressible multispecies flows

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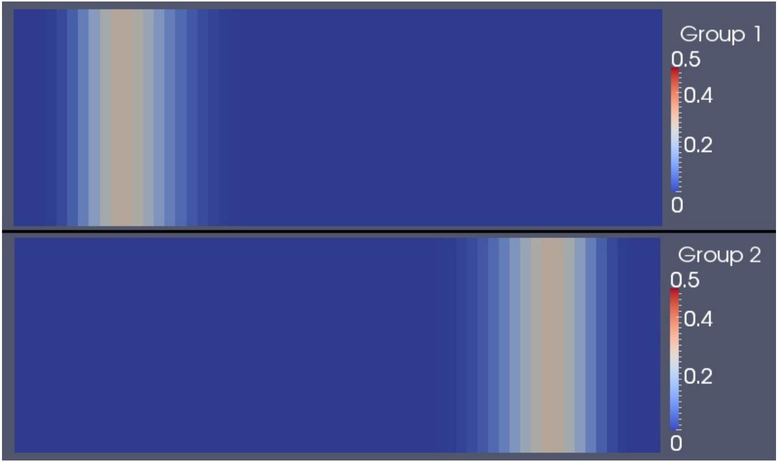

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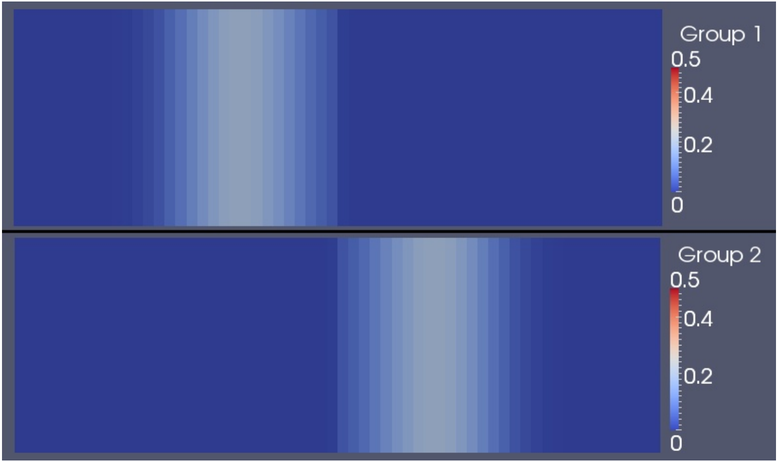

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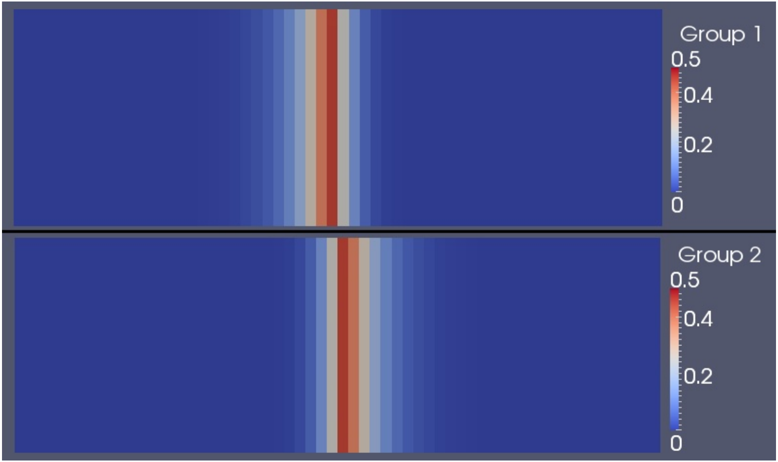

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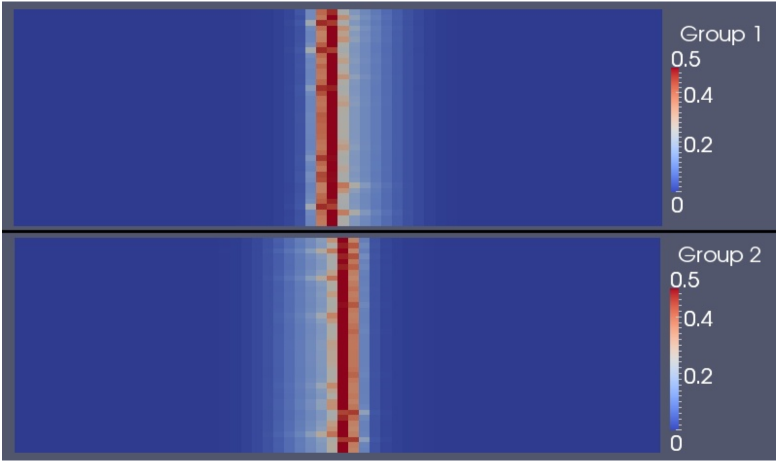

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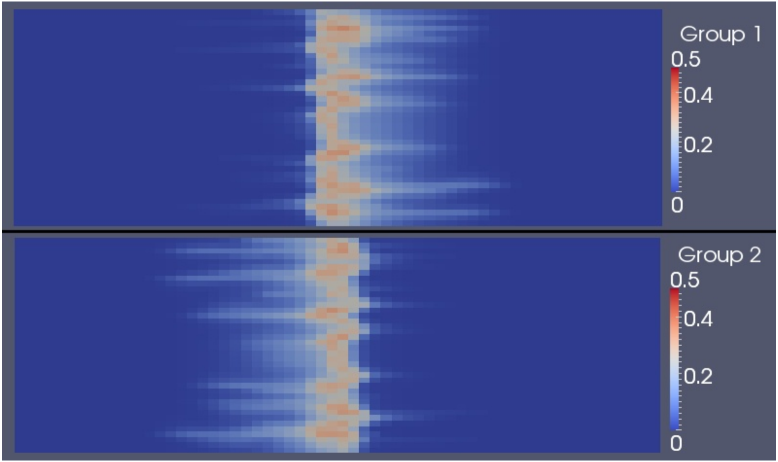

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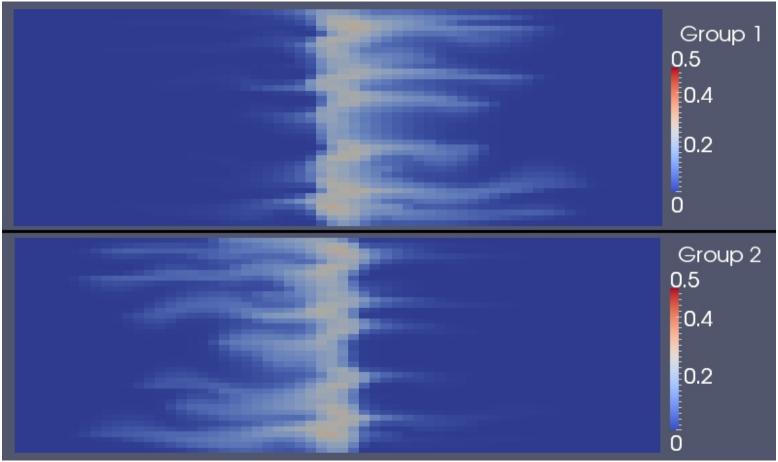

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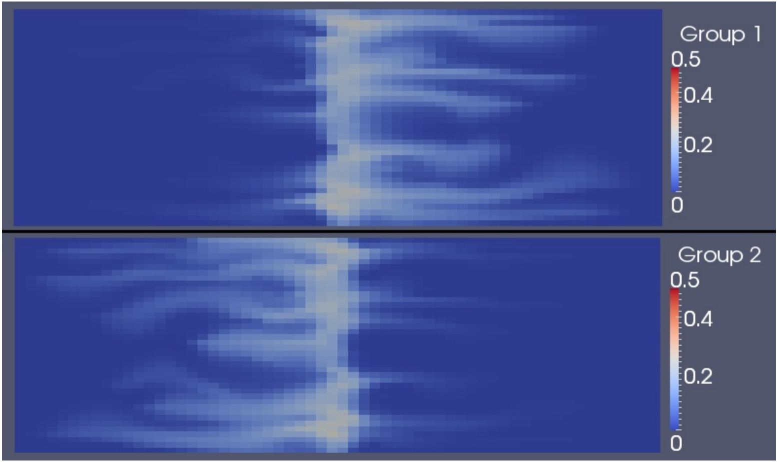

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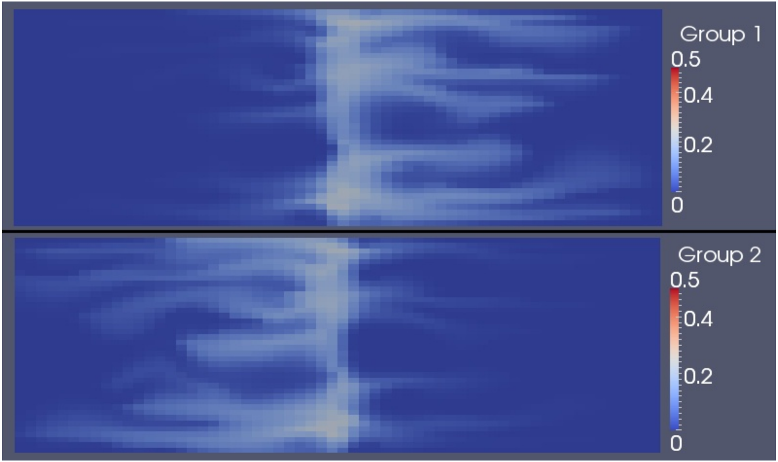

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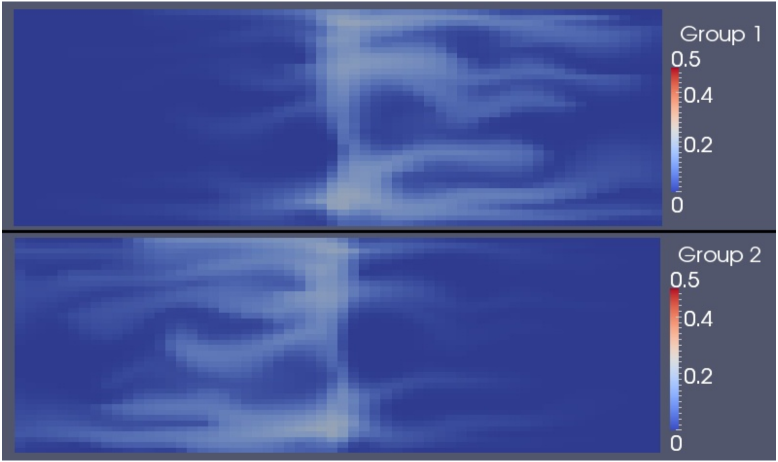

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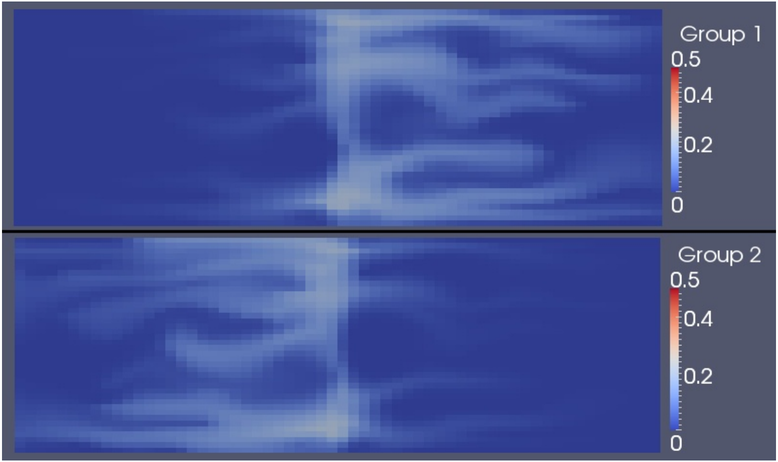

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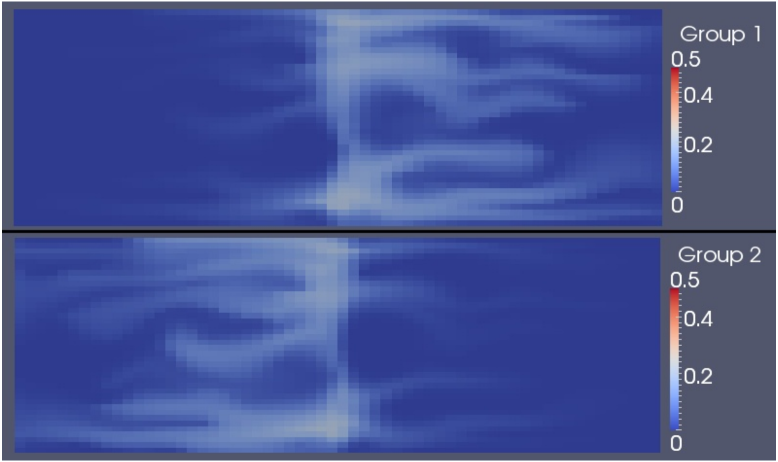

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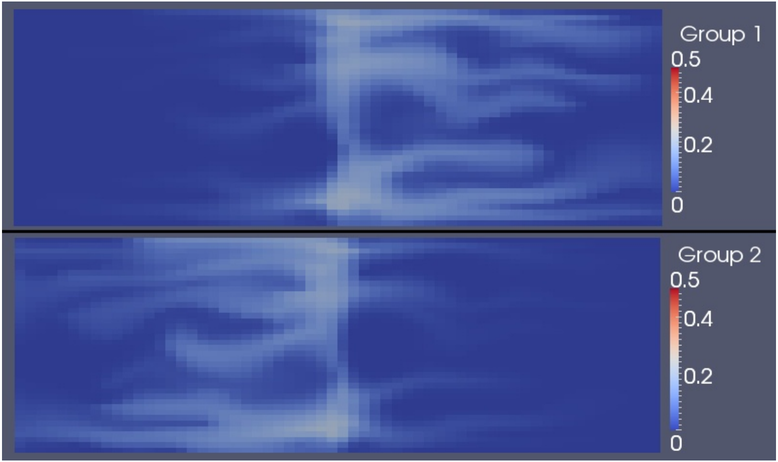

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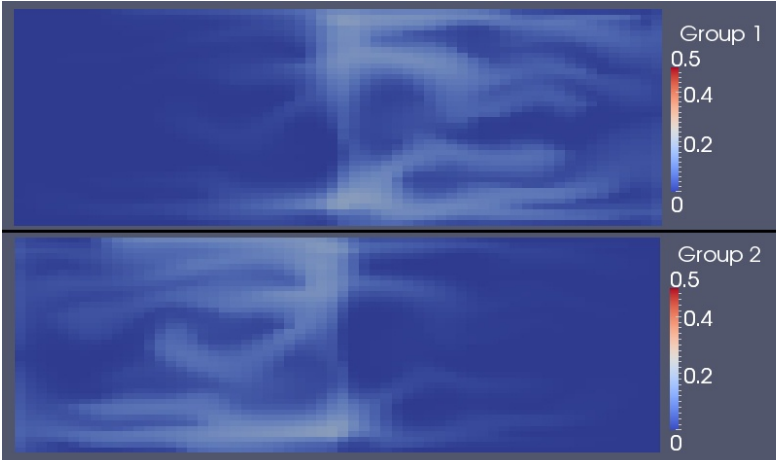

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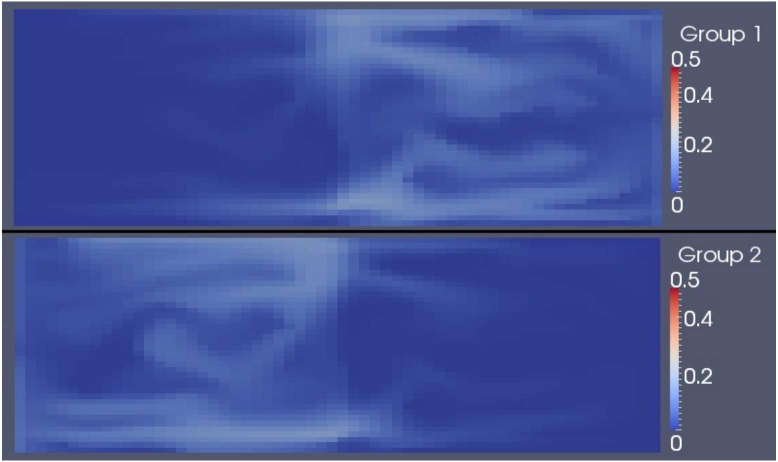

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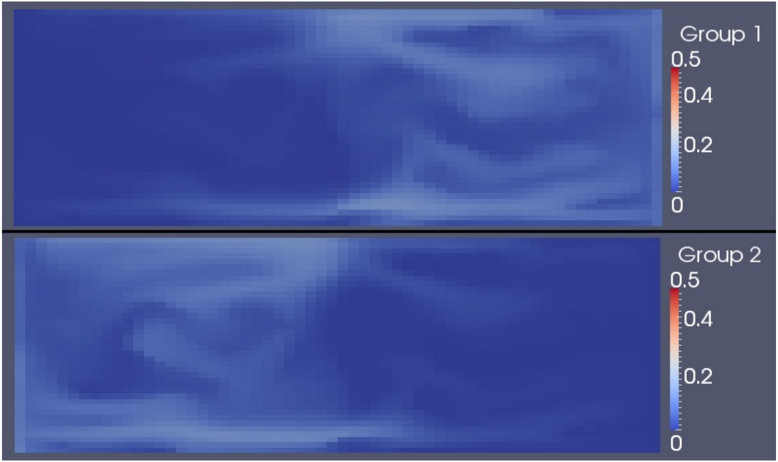

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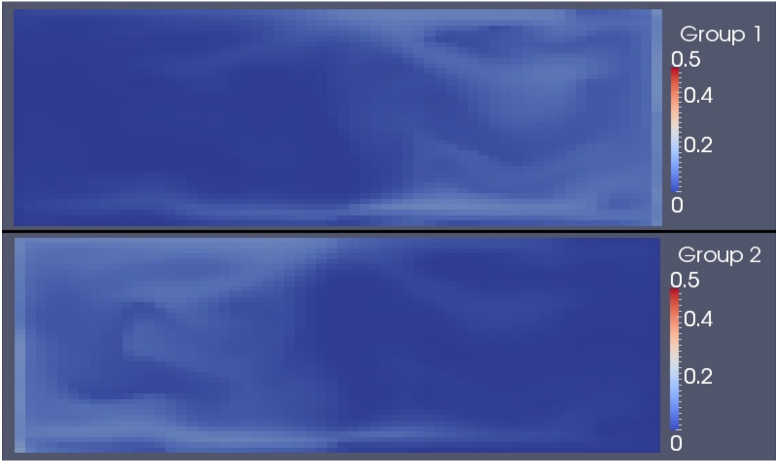

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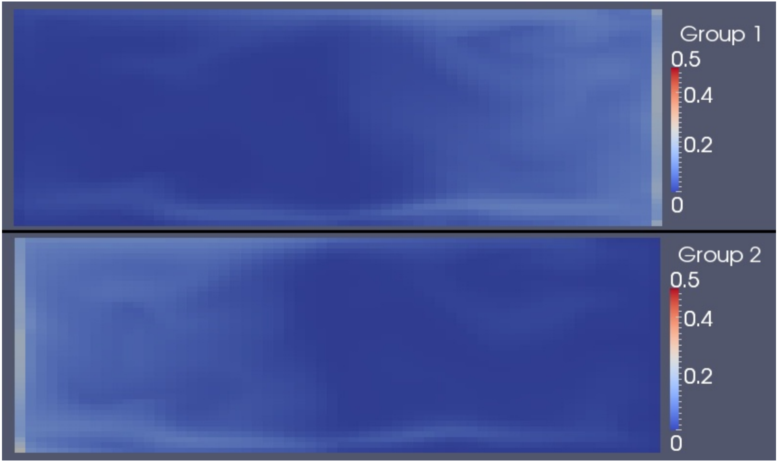

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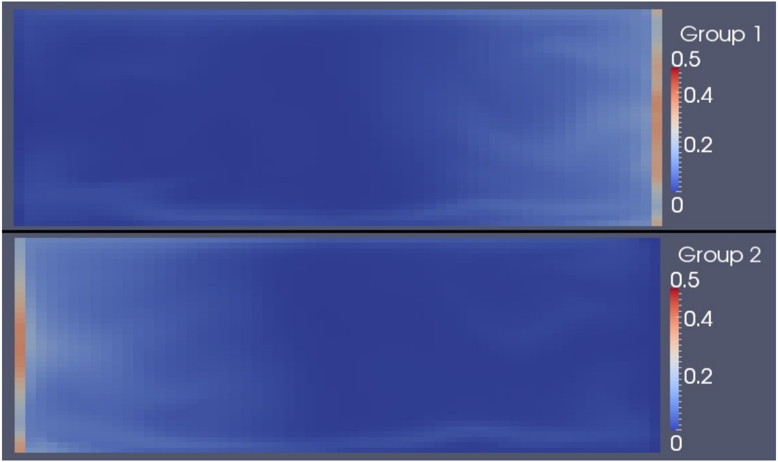

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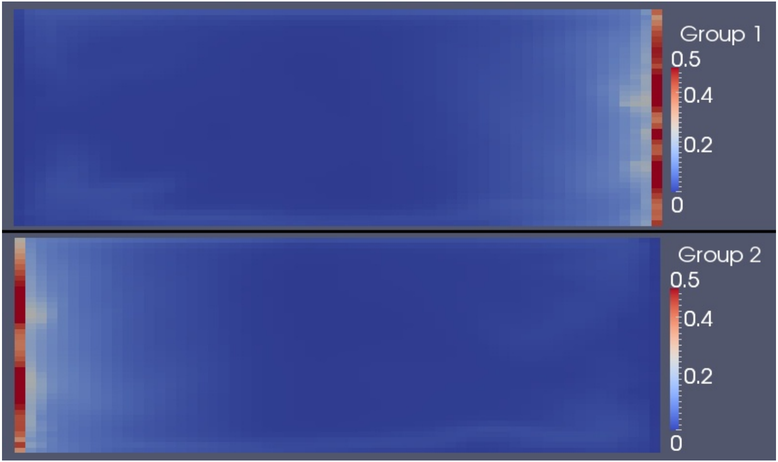

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Overview

Conclusion

- The integration of macroscopic elements into microscopic models, and
- the integration of microscopic elements into macroscopic models, are possibilities to overcome lacks of the models

Conclusion

The developed microscopic and macroscopic models cover the results of the experiments

- density-velocity behavior
- duration of emptying of rooms
- reproduce typical patterns like stripes

Conclusion

next steps

- evaluation of the application domain of the macroscopic models — bounds for densities which can be managed
- realization of interfaces of MATSim and the discussed macroscopic models
- integration of dynamic potential fields into microscopic model by the use of potential gradients as forces which influence the rule set of the microscopic model

Thank you