Pedestrian Dynamics

Universität zu Köln

Introduction

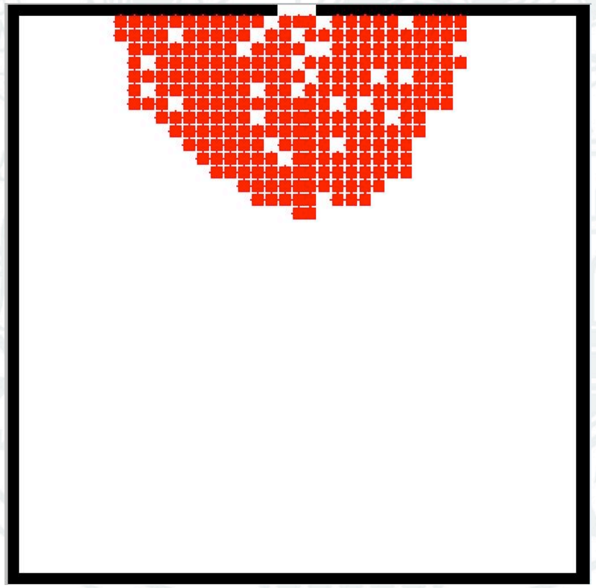
Pedestrian dynamics more complex than vehicular traffic:

- **motion is 2-dimensional**
- **counterflow**
- **interactions “longer-ranged”**

Empirics

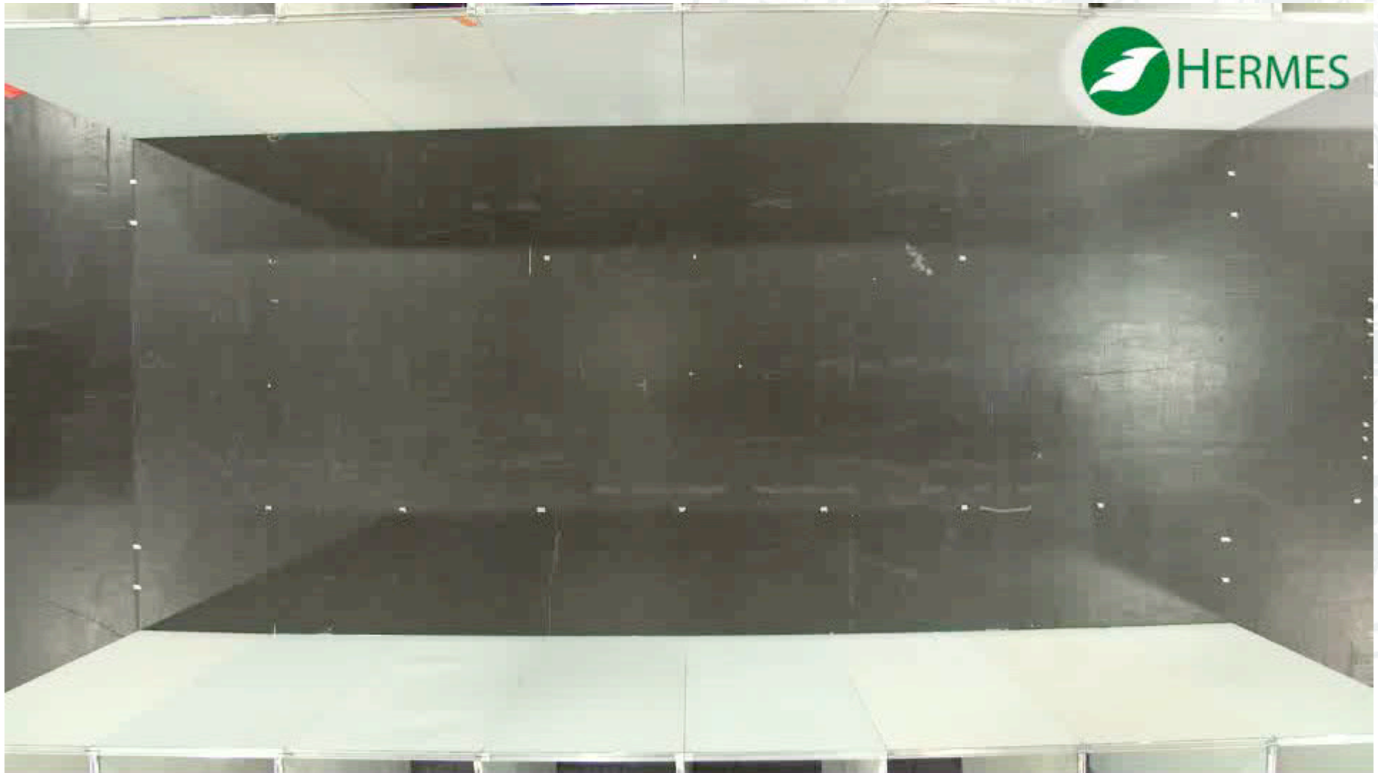
Collective phenomena

jamming or clogging
(e.g. at exits)

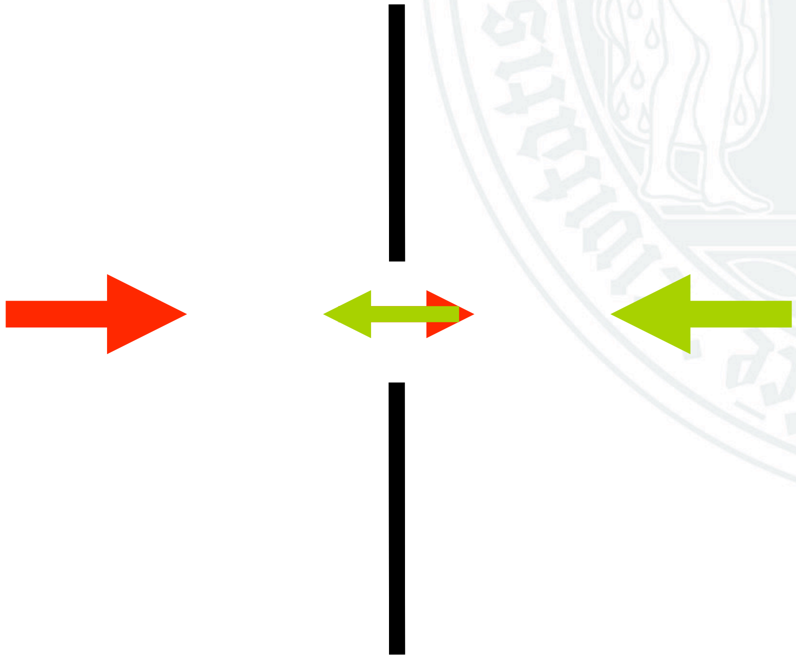


no real challenge for modelling!

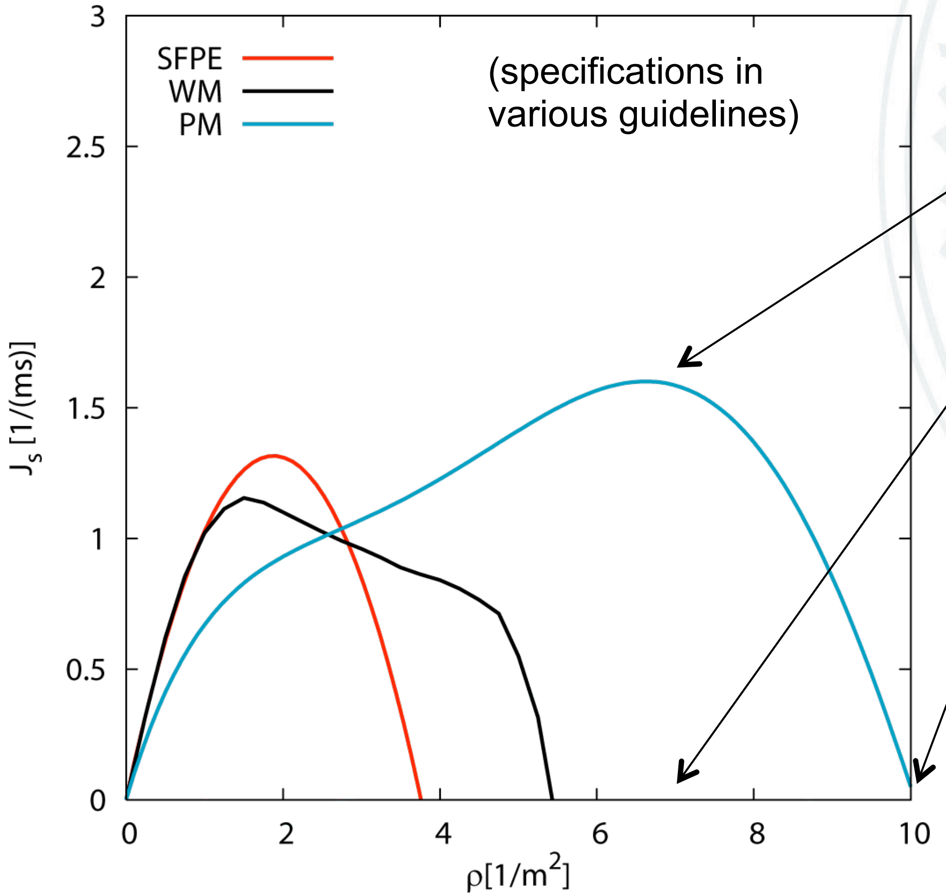
Lane Formation in Counterflow



Oscillations of flow direction



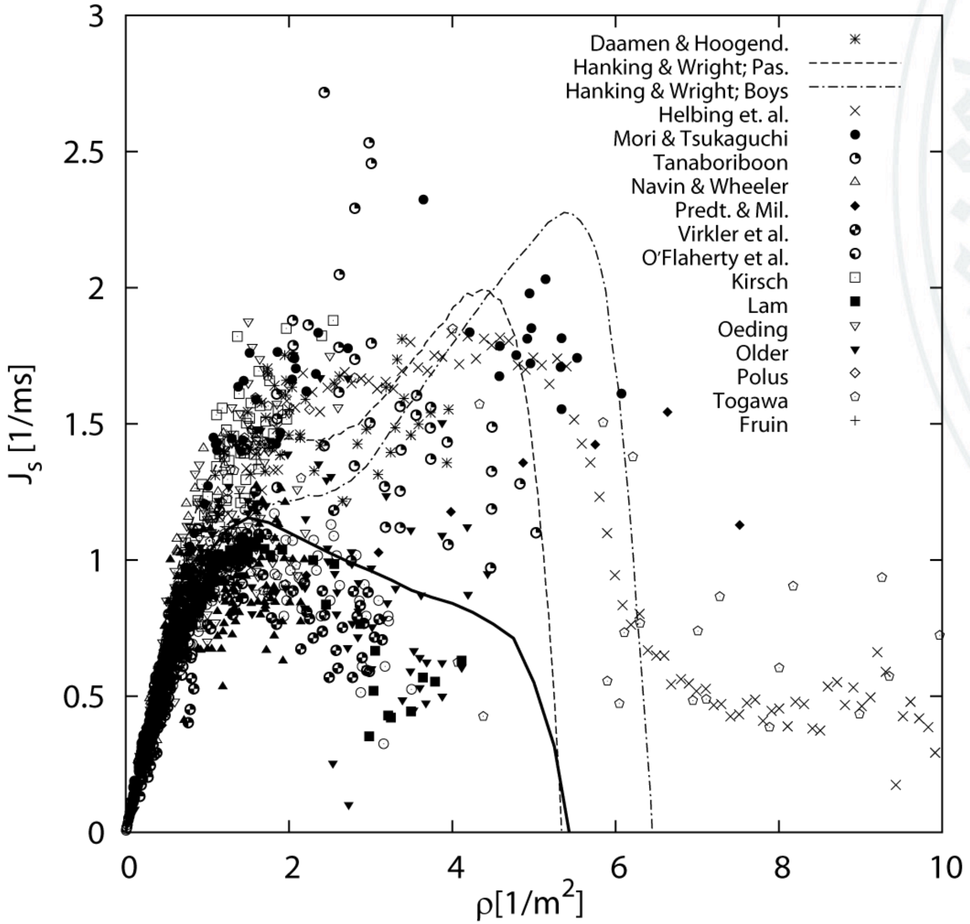
Fundamental diagram: Guidelines



- **Different shapes**
- **Capacity value C_s**
  C_s = 1.2 – 1.6 $(ms)^{-1}$
- **Location of the maximum**
  ρ_C = 1.8 – 7 m^{-2}
- **Density of flow breakdown**
  ρ_0 = 3.8 – 10 m^{-2}

➙ **large discrepancies!**

Fundamental diagram: Empirical results



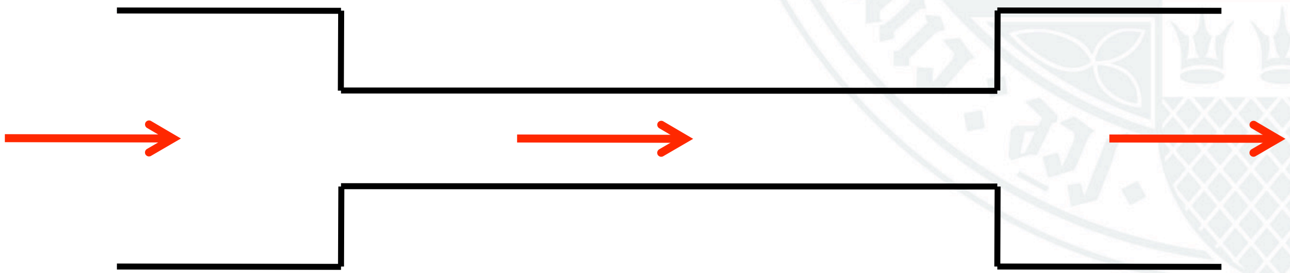
Possible explanation for the large discrepancies:

- uni- vs. bidirectional flow
- measurement techniques, density definition
- fluctuations
- cultural influence
- demographics of test group
- psychological factors

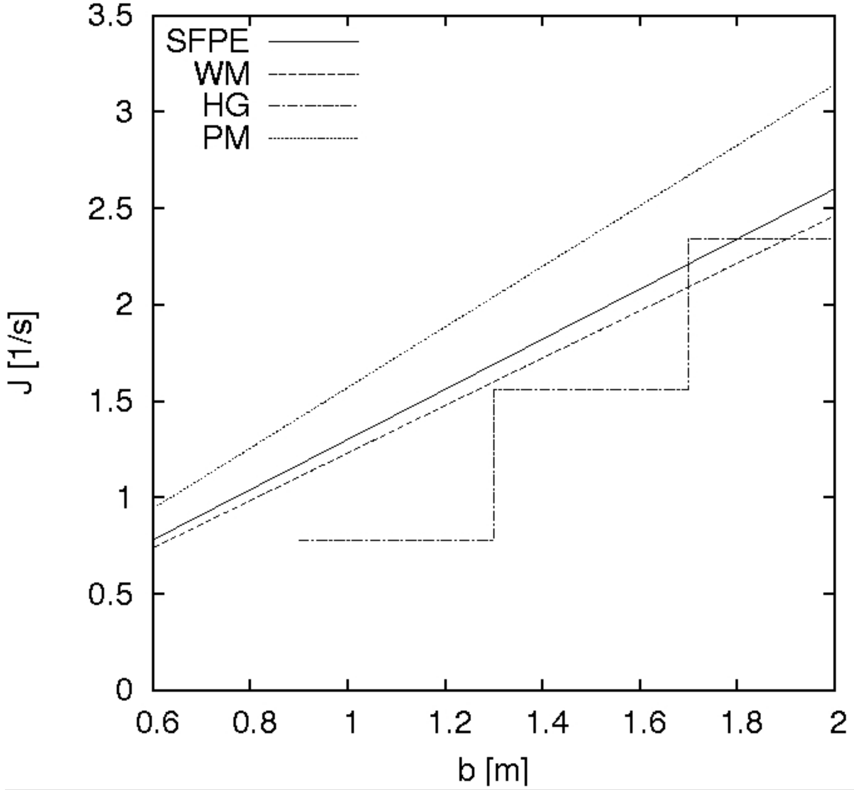
Bottleneck scenario

bottlenecks = flow limitations

(e.g. doors, narrow corridors, stairs)



Bottleneck flow

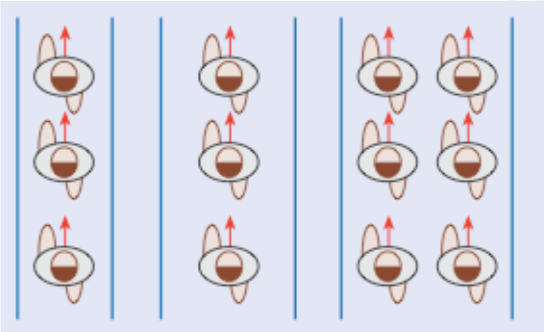


dependence of bottleneck capacity on width:

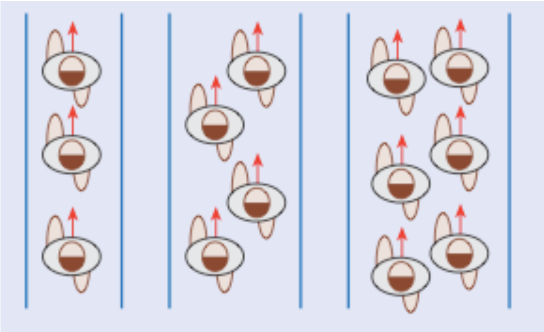
linear or stepwise??

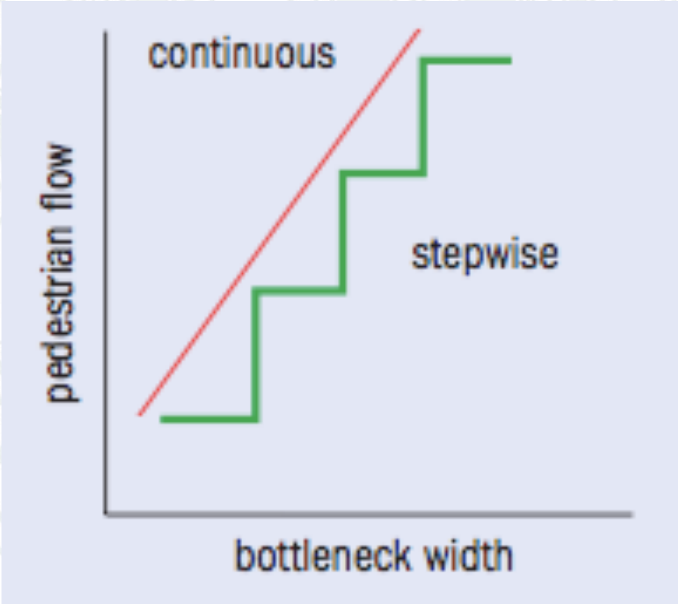
Bottleneck flow

stepwise:



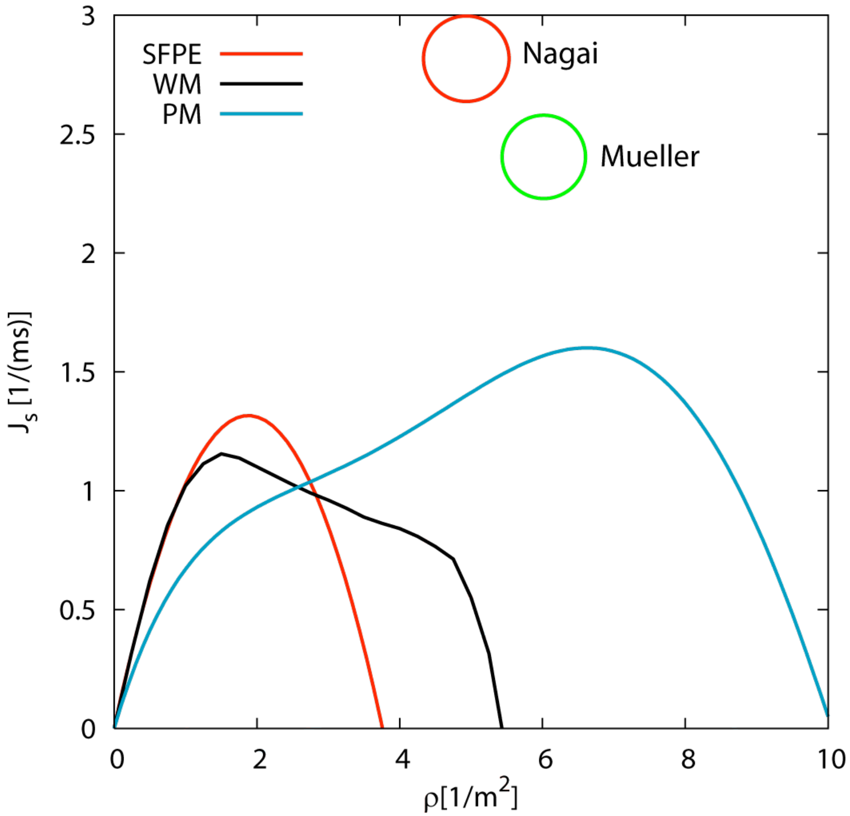
linear:





„zipper effect“

Bottleneck flow



Bottleneck flows significantly larger than maximum of fundamental diagram !!

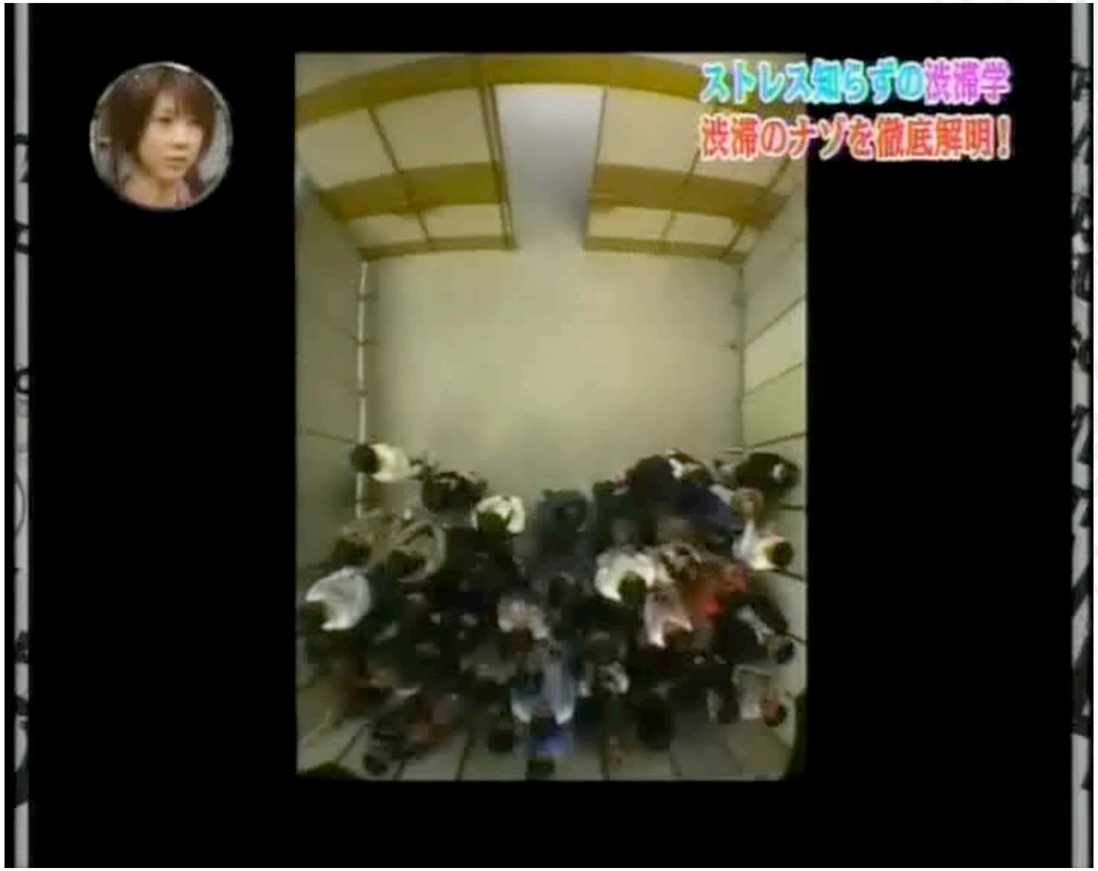
➞ "contradiction" with physics !!

Origin of this surprising result?

- **finite-size effects**
- **fluctuations**
- **non-stationary flow**
- **psychology**

Mueller K. Dissertation (1981)
Nagai et al. (2006)

Evacuation and motivation



(K. Nishinari)

evacuation times for different

- motivation levels (cooperative vs. competitive)
- exit widths

surprising result:
for narrow exits
cooperation is better!!!

Modeling

Modeling approaches

Classification of models:

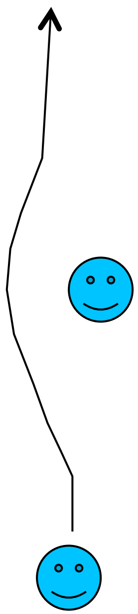
- **description**: microscopic ↔ macroscopic
- **dynamics**: stochastic ↔ deterministic
- **variables**: discrete ↔ continuous
- **interactions**: rule-based ↔ force-based
- **fidelity**: high ↔ low
- **concept**: heuristic ↔ first principles

Rule-based vs. force-based

rule-based dynamics:

- pedestrians make decisions on basis of current state (in some neighbourhood)
- intuitive consideration of psychological effects
- often stochastic

Rule-based vs. force-based



presence of other persons leads to changes in direction of motion (acceleration) → forces

- social forces $f_{jk}^{(soc)}$
  - repulsive ("private sphere")
  - violate Newton's 3. law ("actio = reactio")
- physical forces $f_{jk}^{(phys)}$
  - friction
  - elastic forces

Rule-based vs. force-based

- Social-force model: continuous (Helbing/Molnar, 1995)
- Newtonian equations of motion with

$$f_{jk} = f_{jk}^{(soc)} + f_{jk}^{(phys)}$$

- social forces: $f_{jk}^{(soc)} \propto \exp(-r_{jk}/\xi)$
- $O(N^2)$ interactions ("molecular dynamics")
- forces often „cut off“

Hydrodynamic models

analogy with streamlines

"exotic fluid"

macroscopic model

Navier-Stokes-type equations with driving term $\frac{v_0 - v}{\tau}$

relaxation towards "desired velocity"

Cellular automata models

- Cellular automata: discrete in space, time, state variable
- generically: stochastic, rule-based dynamics

- Space divided into cells (40*40 cm^2)
- Exclusion principle: at most one pedestrian per cell

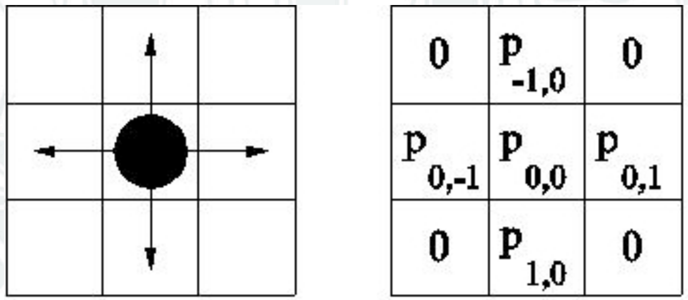
- Discrete time: parallel (synchronous) dynamics
  - natural timescale
  - calibration and quantitative predications possible!!

Transition probabilities

stochastic dynamics:

transition probability p_{ij} in direction (i,j)

depend on the occupation of neighbouring cells



Types of interactions

Behaviour of pedestrians determined by

- **route choice**
- **person – person interactions**
- **person – infrastructure interactions**

incorporate all interactions in unified way ?

Floor Field Cellular Automaton

- **Floor field CA: stochastic model, defined by transition probabilities, only local interactions**
- **reproduces collective effects (e.g. lane formation)**

Interaction: virtual chemotaxis (not measurable!)

dynamic + static floor fields

interaction with pedestrians and infrastructure

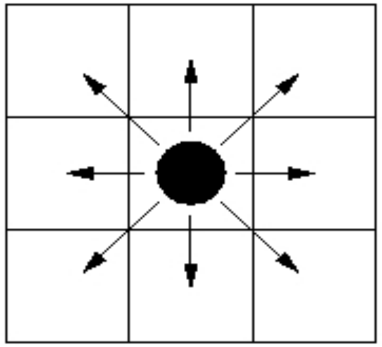
Floor Field Model

Burstedde, Klauck, Schadschneider, Zittartz 2001; Schadschneider 2001

- **Free motion: specified by average velocity v**
- **Floor field = virtual field, modifies transition probabilities**
- **2 types:**
  - **Dynamic floor field: motion of pedestrians creates "pheromone trace")**
  - **Static floor field: determined by infrastructure**

General principle: motion into direction of larger fields is preferred

Matrix of Preferences



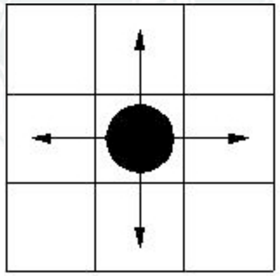
$M_{-1,-1}$	$M_{-1,0}$	$M_{-1,1}$
$M_{0,-1}$	$M_{0,0}$	$M_{0,1}$
$M_{1,-1}$	$M_{1,0}$	$M_{1,1}$

- M_{ij} = probability for motion in direction (i,j)

- can be expressed by measurable quantities:
  - Average velocity: $\langle \vec{v}_i \rangle$
  - Variance: $\sigma^2 = \langle (\vec{\mathbf{v}}_i)^2 \rangle - \langle \vec{\mathbf{v}}_i \rangle^2$

Transition probabilities

Transition probability p_{ij} in direction (i,j):



0	$p_{-1,0}$	0
$p_{0,-1}$	$p_{0,0}$	$p_{0,1}$
0	$p_{1,0}$	0

$$p_{ij} = N \cdot M_{ij} \exp(k_D D_{ij}) \exp(k_S S_{ij})(1-n_{ij})$$

- M_{ij} = matrix of preferences (route choice, desired velocity)
- D_{ij} = dynamic floor field (interaction between pedestrians)
- S_{ij} = static floor field (interaction with geometry)
- k_D, k_S = coupling strength
- N = normalization ($\sum p_{ij} = 1$)

Dynamic Floor Field

- Motion increases field strength in starting cell
- pedestrians change dynamic field
- motion creates a trace

- Dynamic floor field has dynamics:

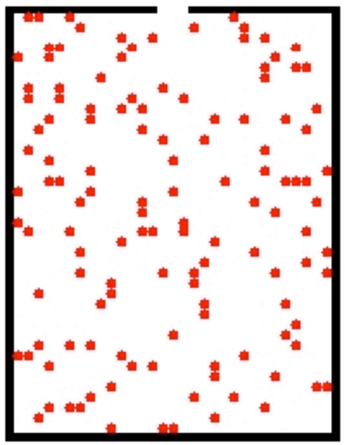
  diffusion + decay

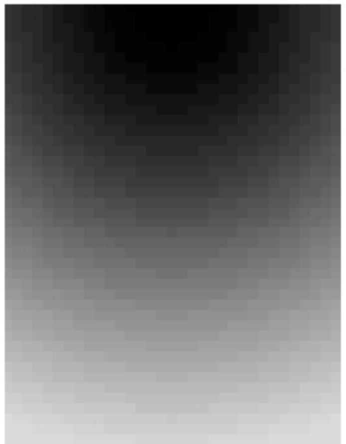
- → broadening and dilution of trace

Static Floor Field

- Not influenced by pedestrians
- no dynamics (constant in time)
- modelling of influence of infrastructure

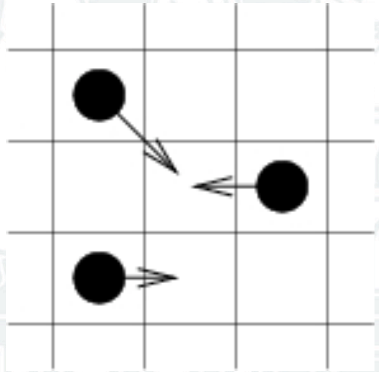
- Example: Ballroom with one exit





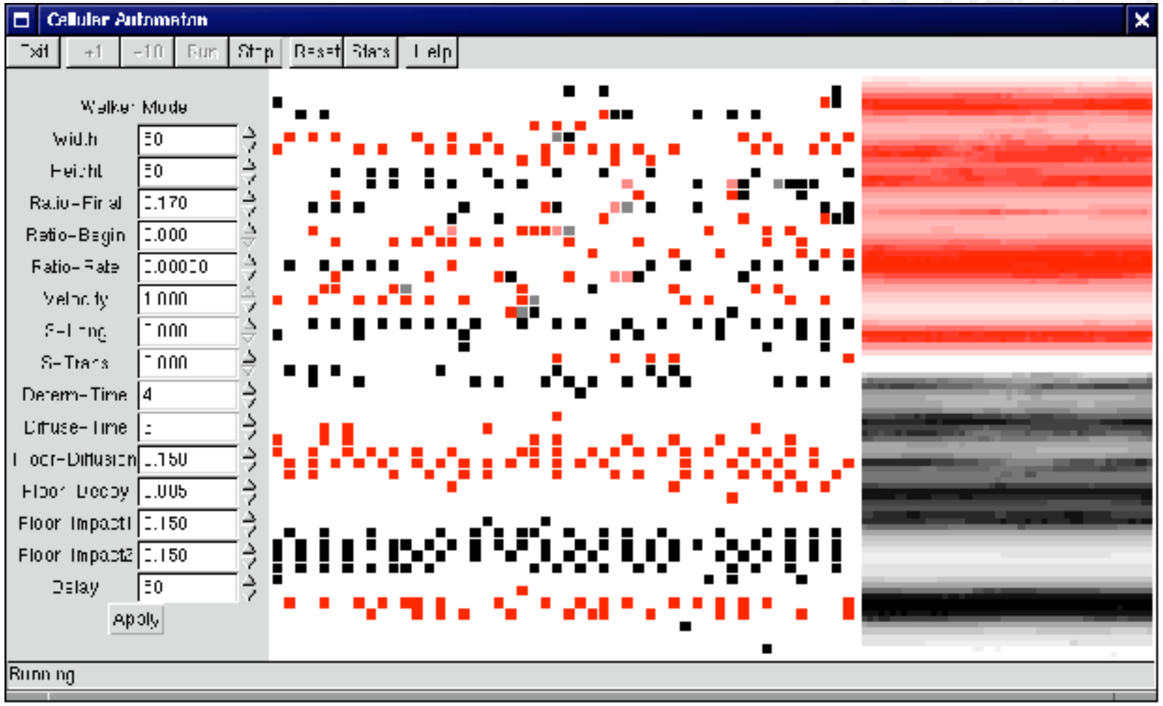
Conflicts

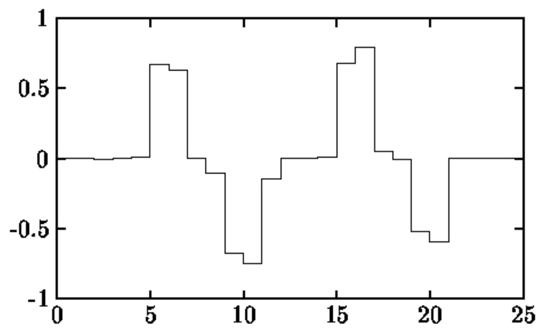
Conflict: 2 or more pedestrians choose the same target cell



- Consequence of discreteness in space and time!!
- Conflicts have to be **resolved** in some way

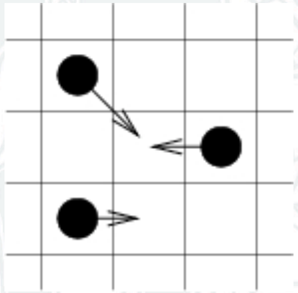
Lane formation in FF model





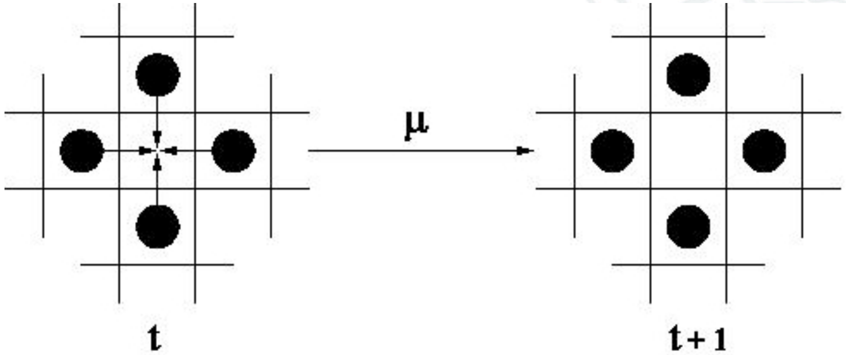
velocity profile

Friction



Conflict: 2 or more pedestrians choose the same target cell

Friction: not all conflicts are resolved!



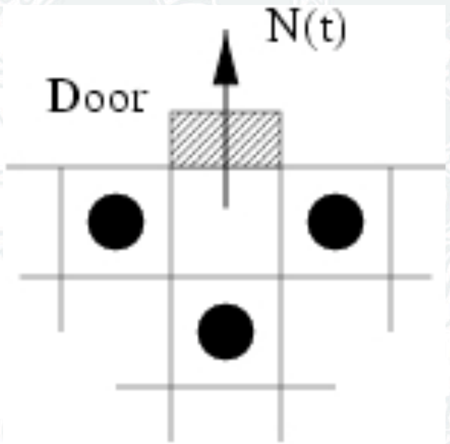
friction constant μ = probability that no one moves

Artefact or Real Effect ?

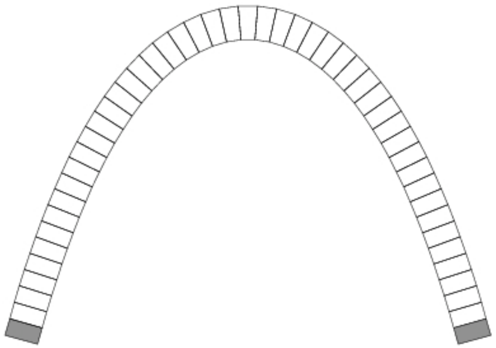
- conflicts reduce efficiency of simulations
- sometimes avoided by special update choice
- However: Conflicts and friction correspond to real effects, e.g. physical contact, moment of hesitation

Friction at Exits

"Friction" at exits increases evacuation times by reducing the outflow



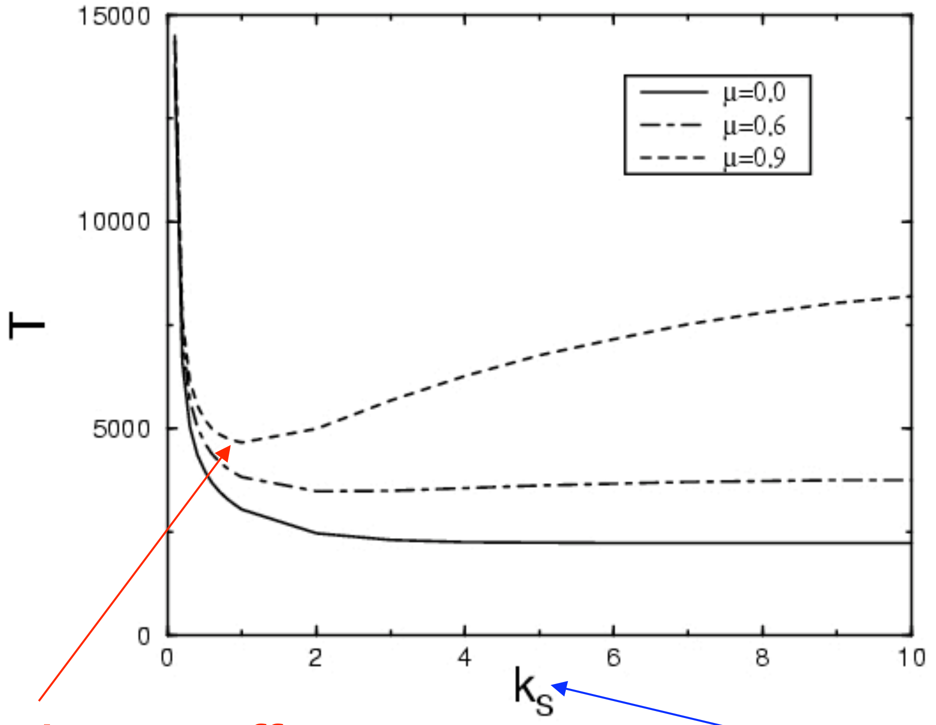
Granular materials:
Arching



Evacuation Scenario With Friction Effects

(Kirchner, Nishinari, Schadschneider 2003)

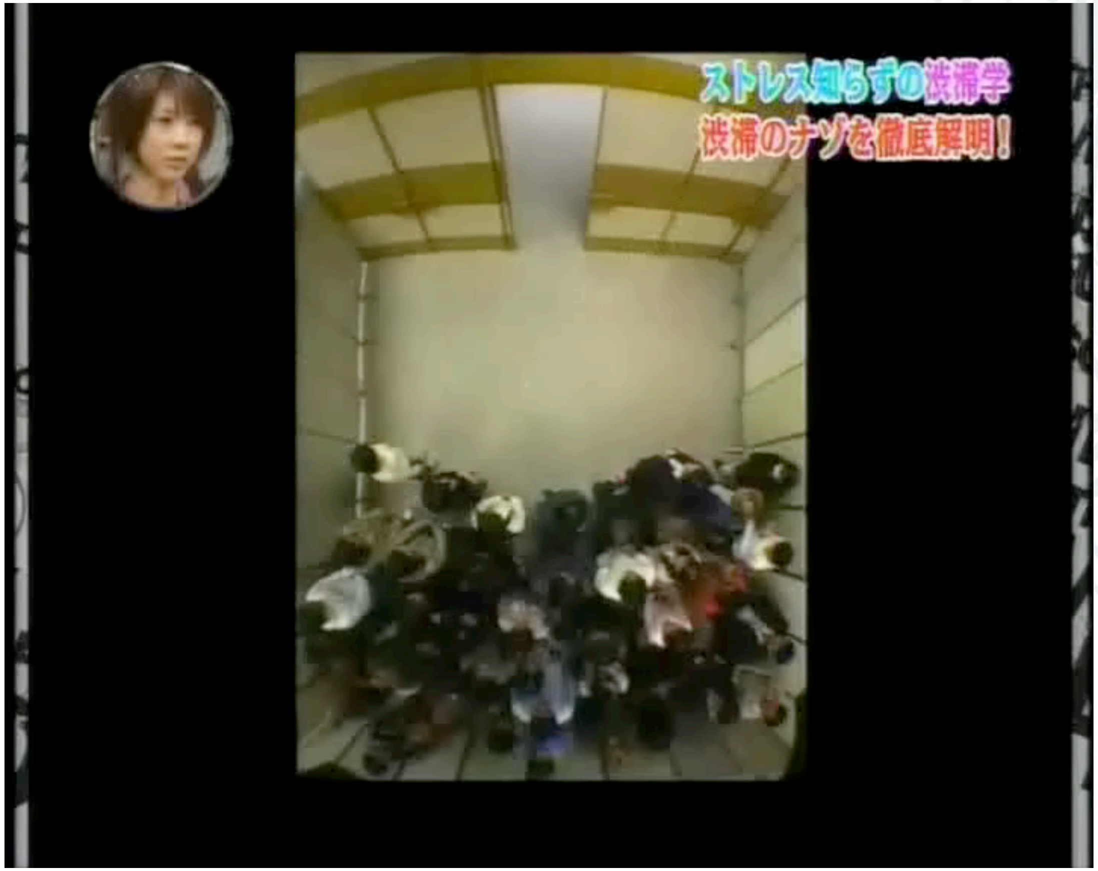
evacuation time



effective velocity

Faster-is-slower effect

Evacuation and motivation



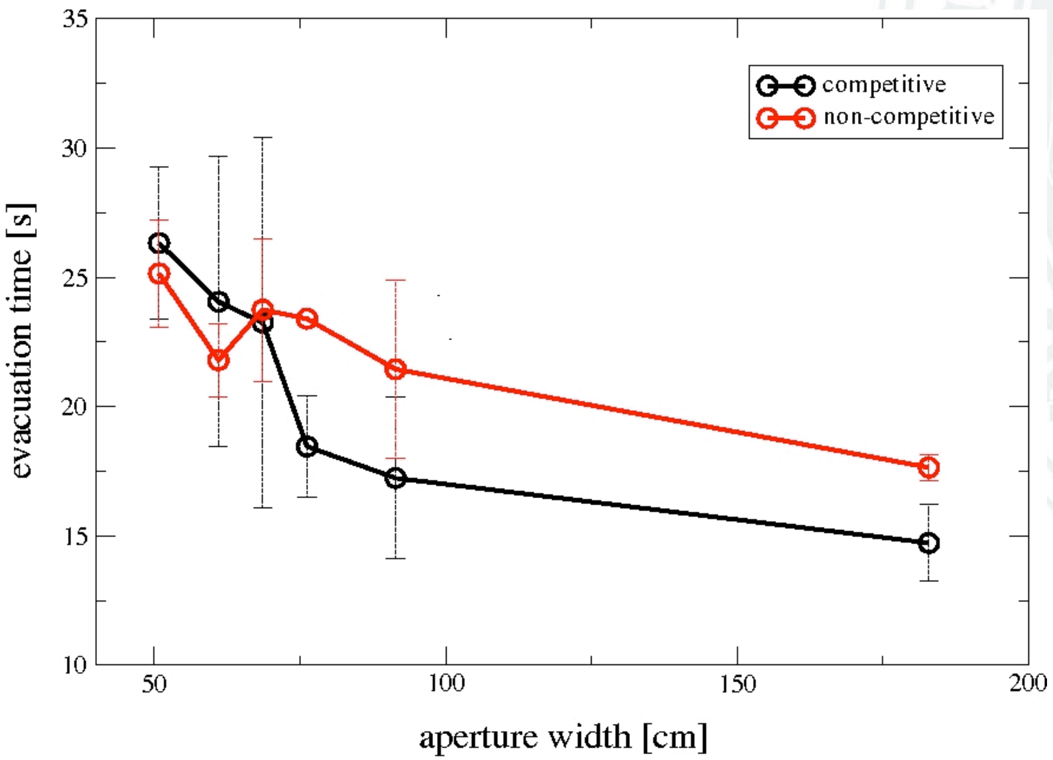
(K. Nishinari)

evacuation times for different

- motivation levels (cooperative vs. competitive)
- exit widths

surprising result:
for narrow exits
cooperation is better!!!

Experiments: Egress from airplane

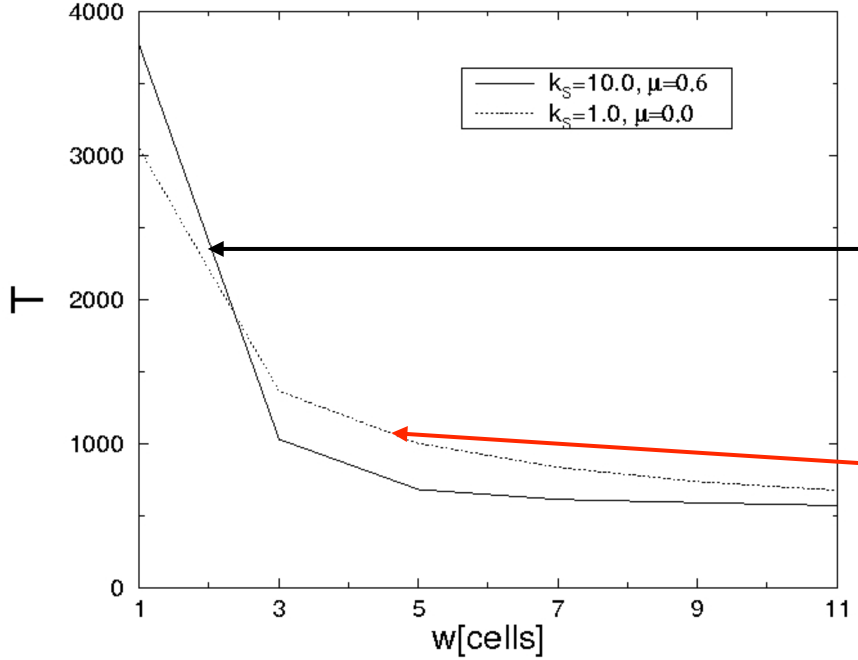


(Muir/Bottomley,/Marisson, 1996)

$T_{comp} > T_{coop}$ for $w < w_c$

$T_{comp} < T_{coop}$ for $w > w_c$

Model Approach



•**Competitive behaviour:**

•**large k_S + large friction μ**

•**Cooperative behaviour:**

•**small k_S + no friction $\mu=0$**

(Kirchner, Klüpfel, Nishinari, Schadschneider, Schreckenberg 2003)

Empirics II

Experiments

status of empirical results unsatisfactory

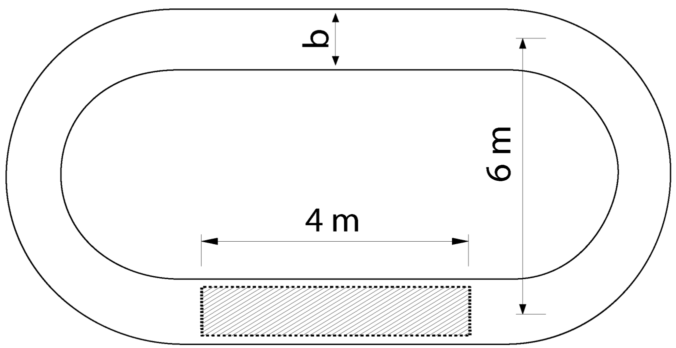
large-scale laboratory experiments (more than 300 persons) performed at

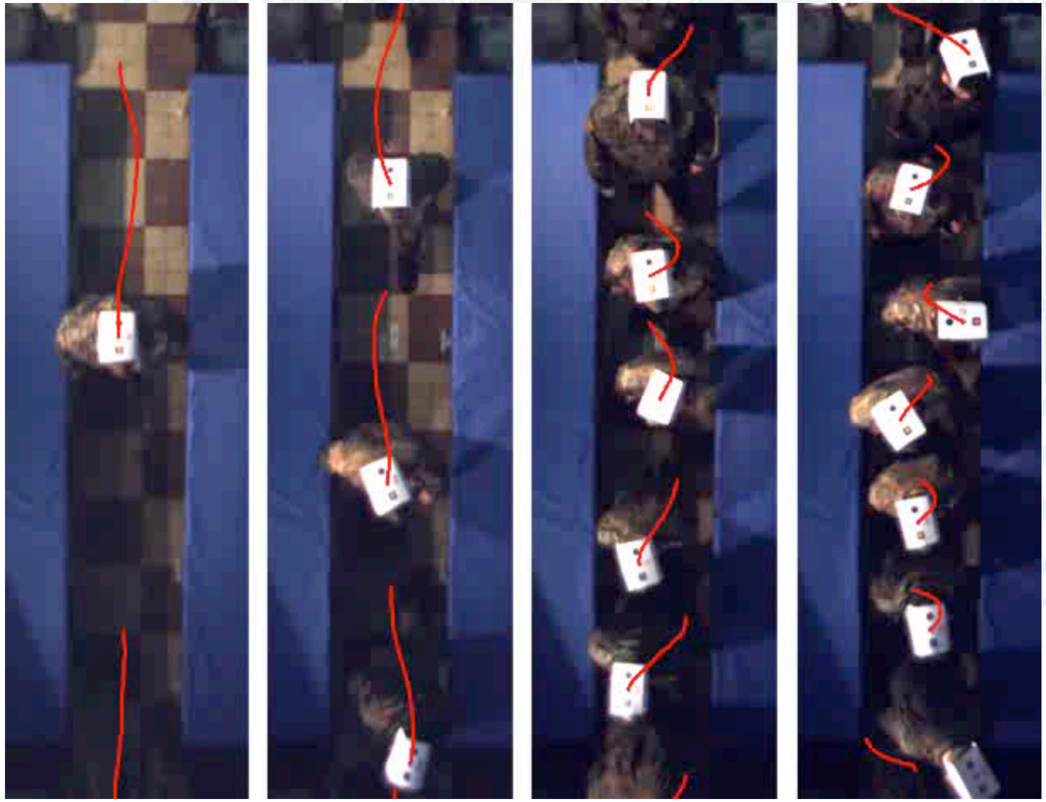
- Bergische Kaserne Düsseldorf
- Düsseldorf exhibition center
- Esprit Arena Düsseldorf

organized by FZ Jülich and Wuppertal University

Experiments: Fundamental diagram

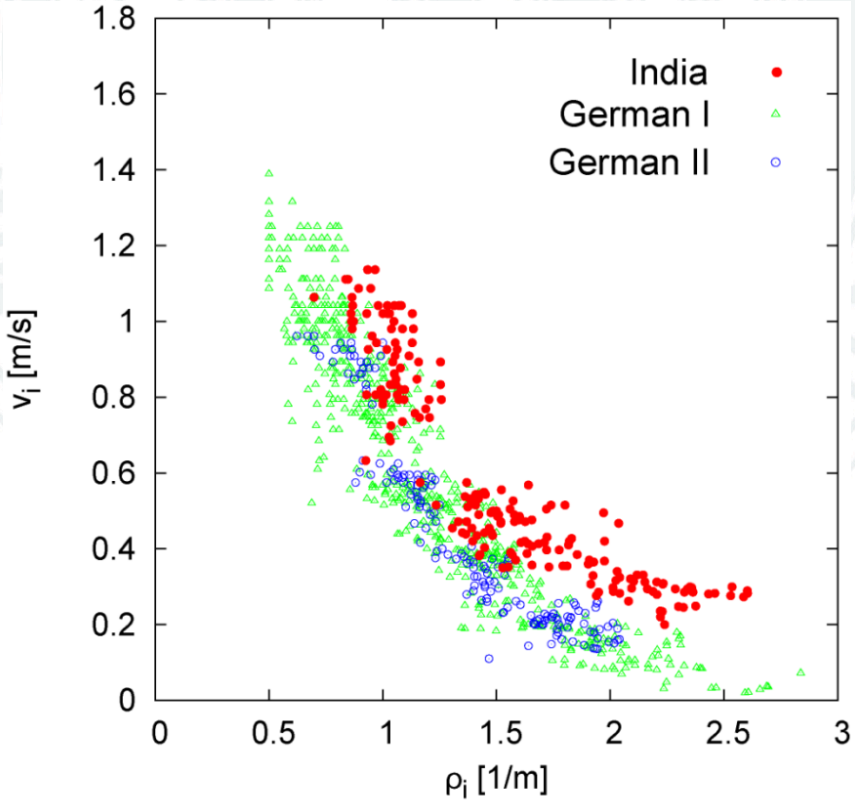
corridor, periodic





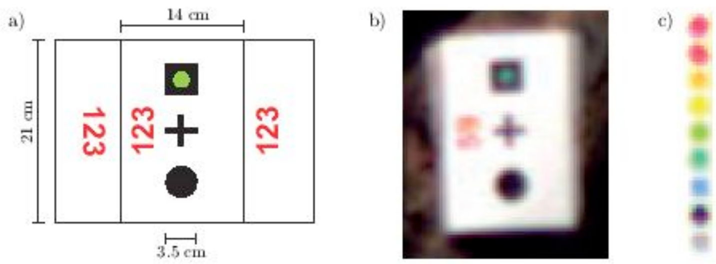
Influence of culture

India vs. Germany

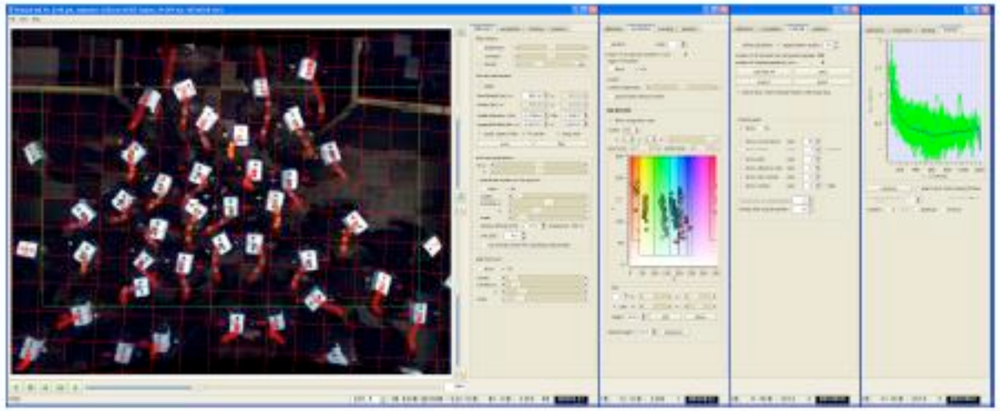


Automated video analysis

automated determination of trajectories from video

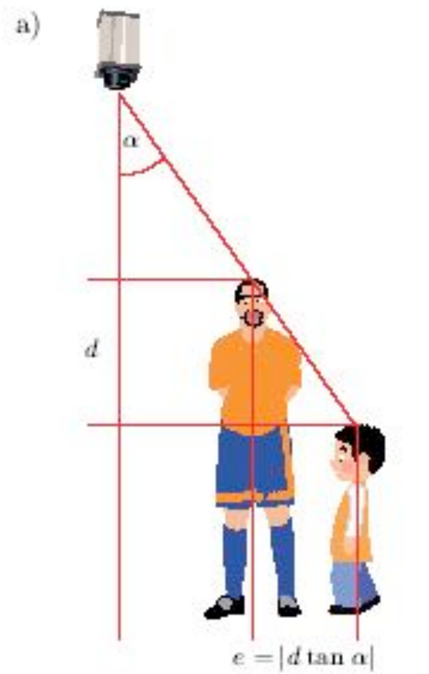


pasteboard for detection and height correction

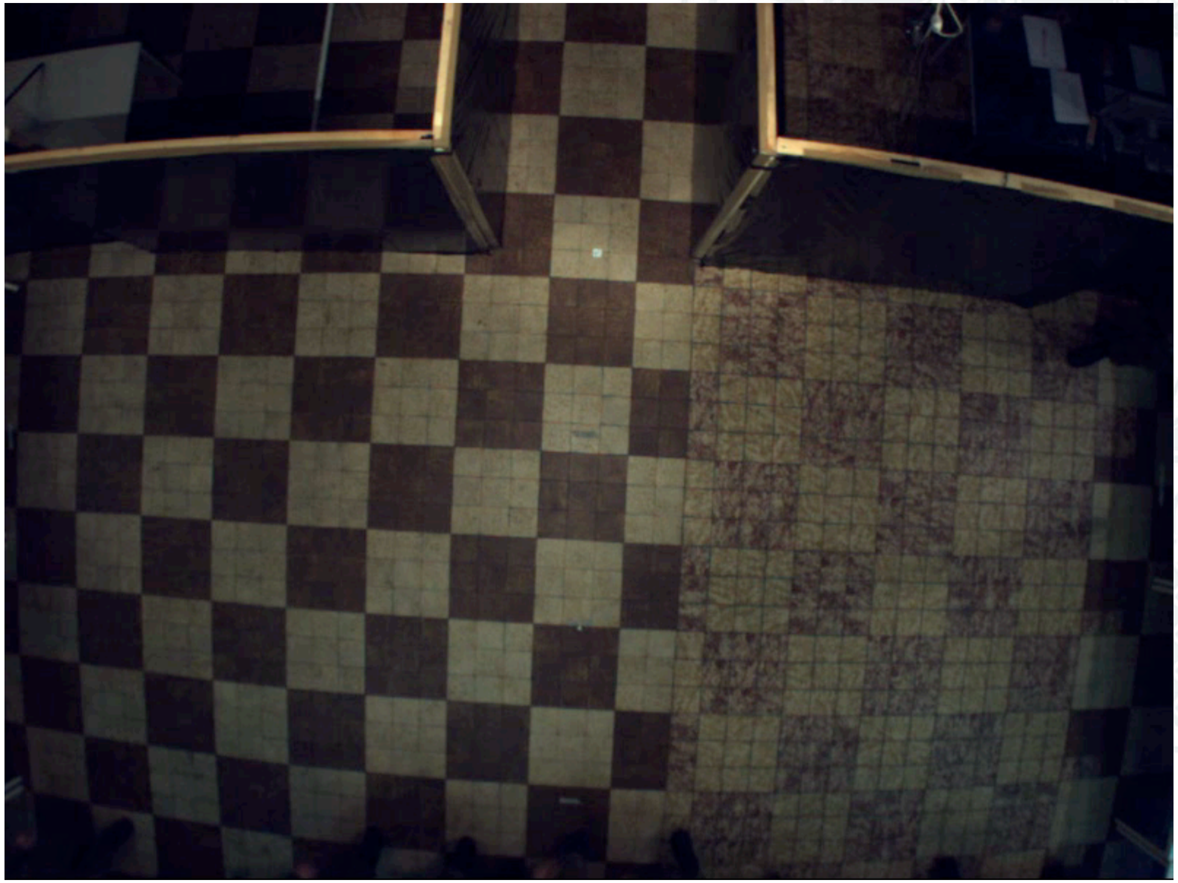


PeTrack: software tool for video analysis (M. Boltes, FZ Jülich)

Automated video analysis



Bottlenecks



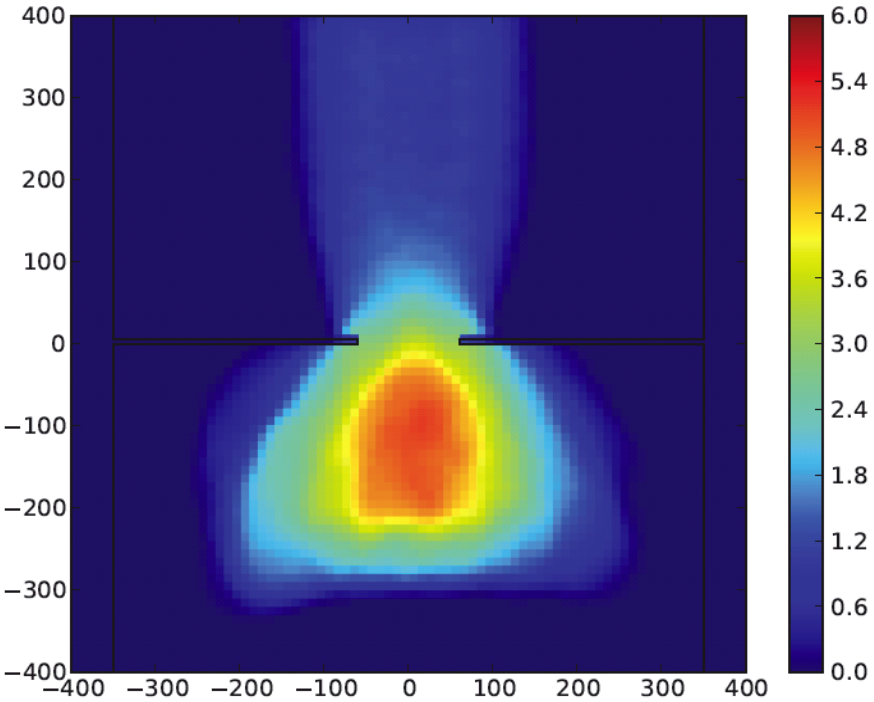
(University Wuppertal, FZ Jülich)

Bottleneck

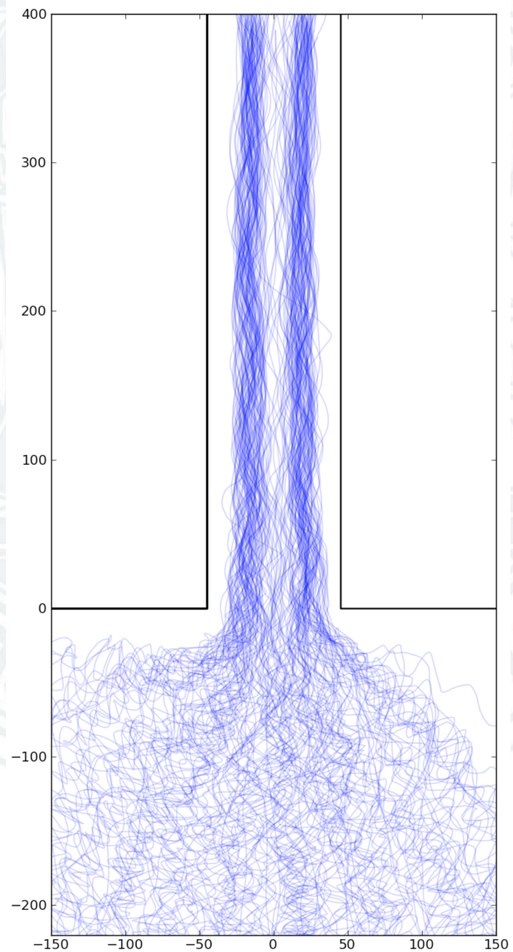
Densities via Voronoi diagram

$$\rho_{Voronoi} = \frac{\int_A p(\vec{x})\, d\vec{x}}{|A|} \quad \text{mit} \quad p(\vec{x}) = \begin{cases} 1/A_i & : \vec{x} \in A_i \\ 0 & : \text{else} \end{cases}$$

Bottleneck



400
300
200
100
0
−100
−200
−300
−400
−400 −300 −200 −100 0 100 200 300 400
6.0
5.4
4.8
4.2
3.6
3.0
2.4
1.8
1.2
0.6
0.0



400
300
200
100
0
−100
−200
−150 −100 −50 0 50 100 150

HERMES

Hermes project

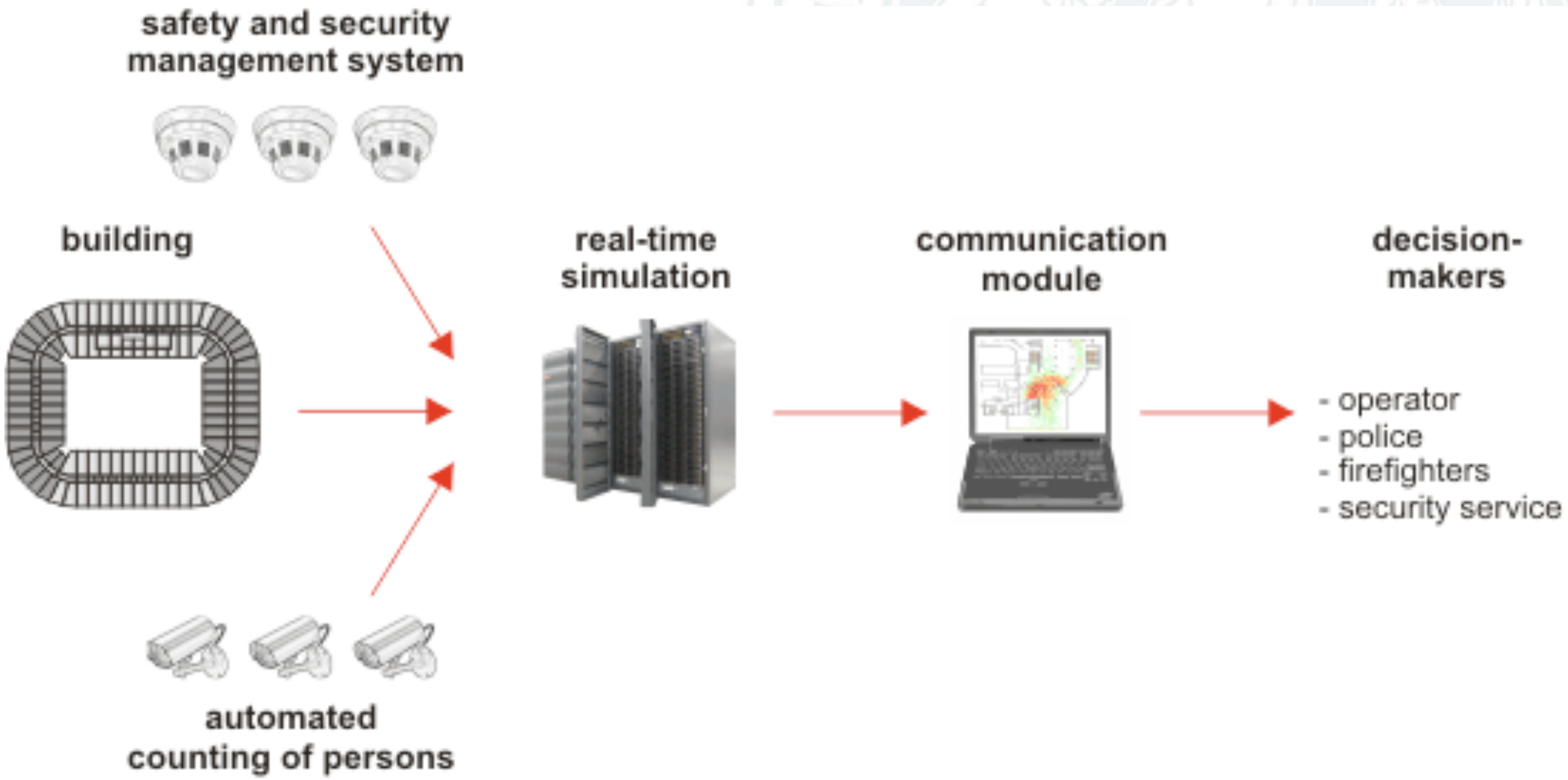
cooperation between

- police and fire department Düsseldorf
- Esprit Arena Düsseldorf
- University of Cologne, Bonn and Wuppertal
- Jülich Supercomputing Centre
- several industrial partners
- sponsored by BMBF

Esprit Arena, Düsseldorf

multifunctional arena (66 000 spectators)
site of Eurovision Song Contest 2011

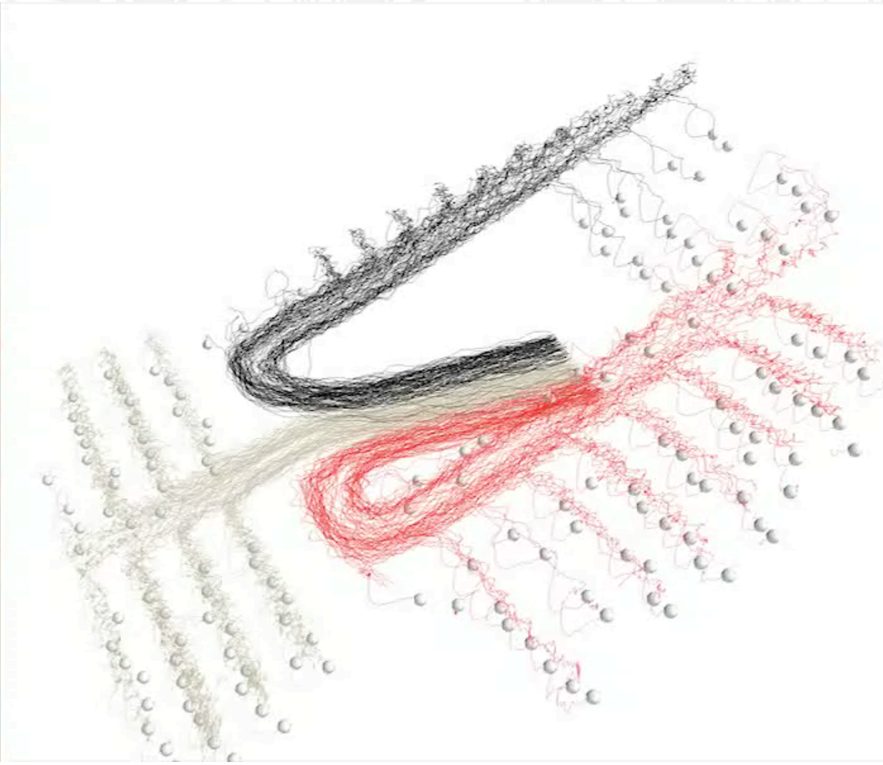
Evacuation assistent



Hermes Evacuation Assistent

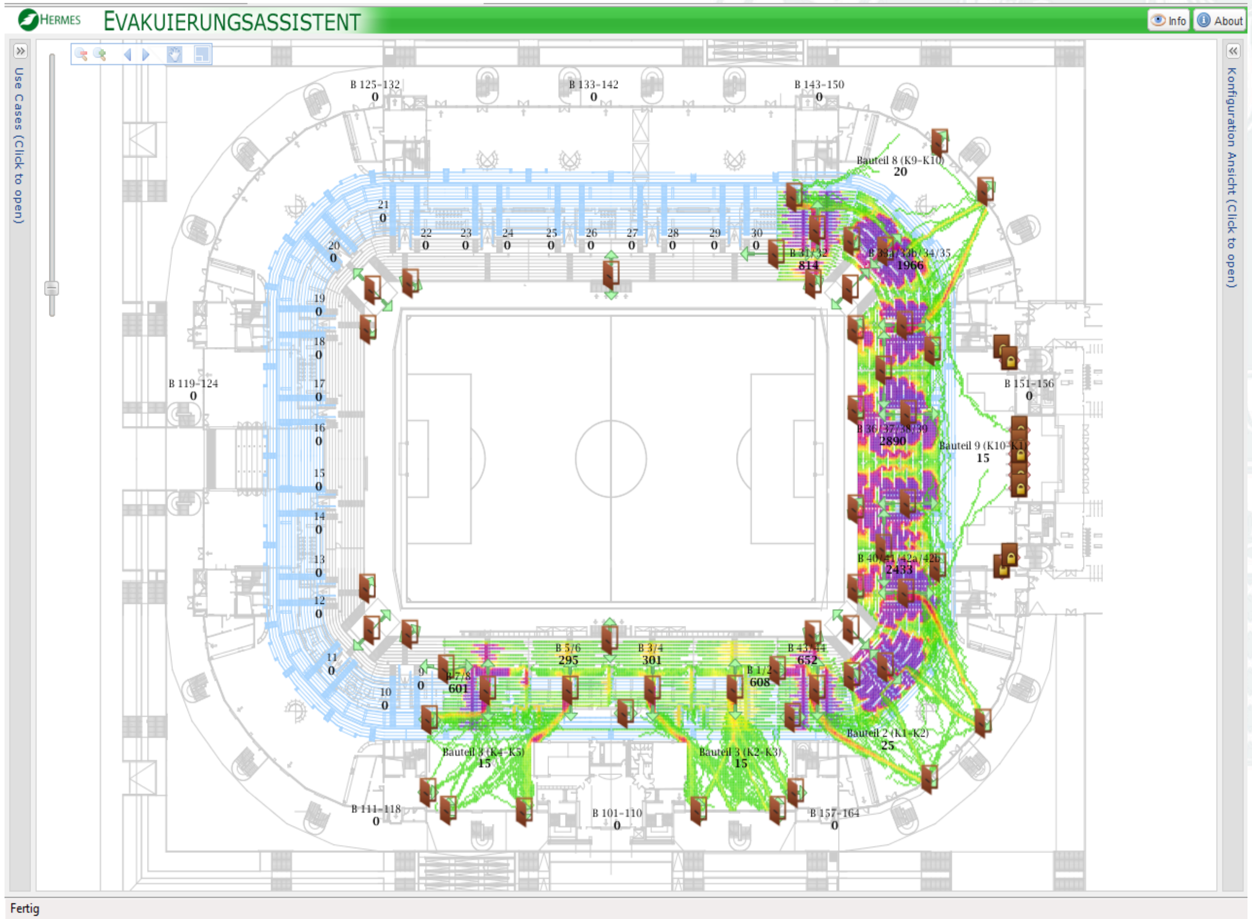
cameras for counting
provide "initial condition"
for simulation

Esprit Arena: Experiment



(M. Boltes)

Communication Modul



The deterministic limit of pedestrian dynamics!