Cellular Automata Models of Pedestrian Dynamics

Andreas Schadschneider

Institute for Theoretical Physics

University of Cologne

Germany

www.thp.uni-koeln.de/~as www.thp.uni-koeln.de/ant-traffic

Overview

Pedestrian dynamics

- interesting collective effects
- simple model ?
- learning from nature?
- similarities with ant trails

unified description of pedestrian dynamics

and ant trails!

Ant trails vs. human trails

ant trail

human trail

Pedestrian Dynamics

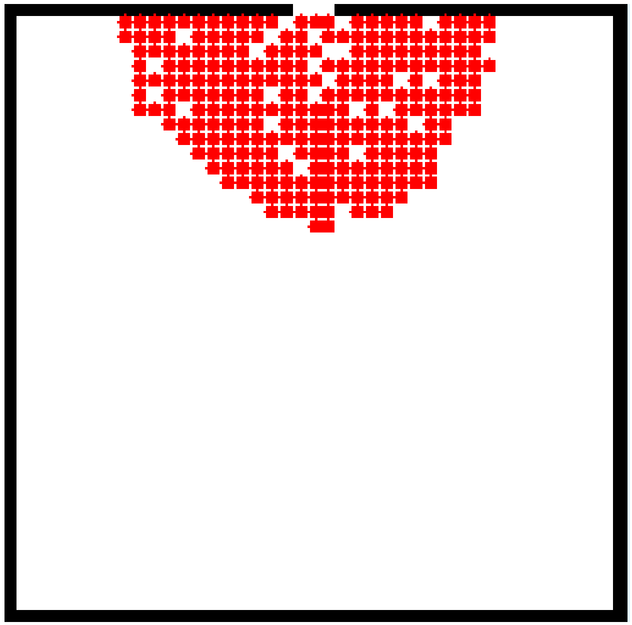
More complex than highway traffic

- motion is 2-dimensional
- counterflow important
- interaction “longer-ranged” (not just nearest-neighbour interactions)

Interesting collective phenomena!

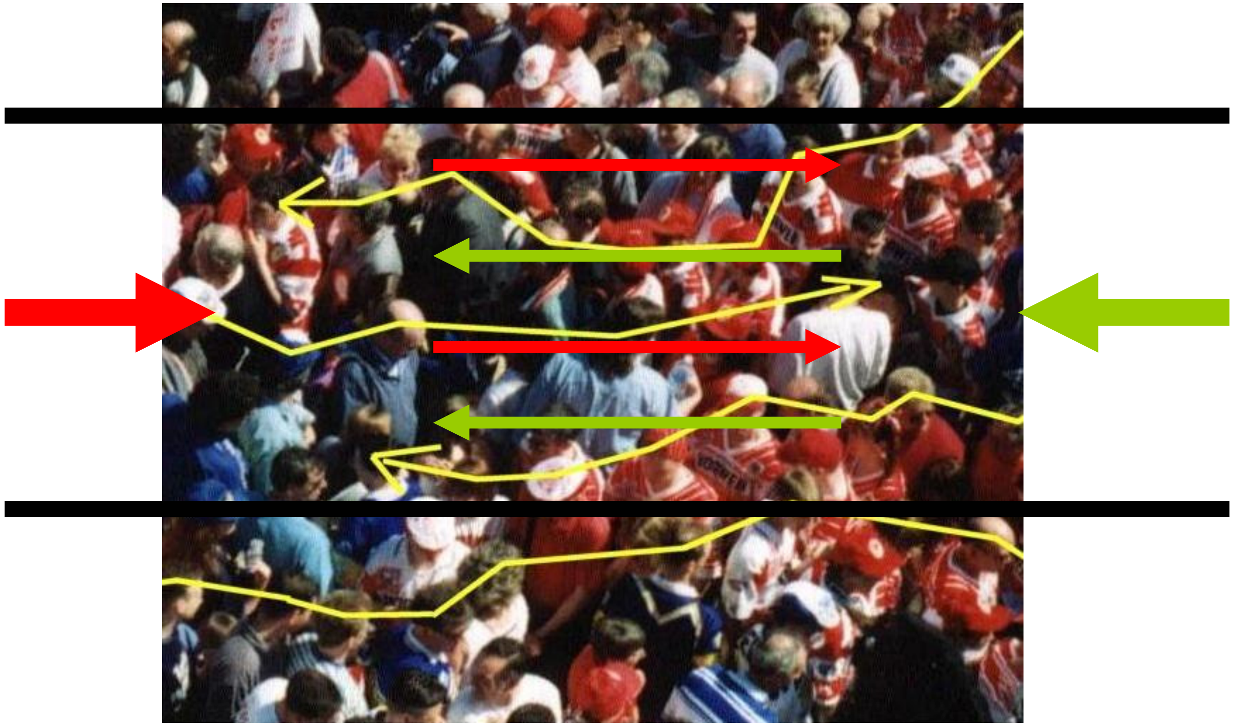
Collective Phenomena

jamming or clogging
(e.g. at exits)



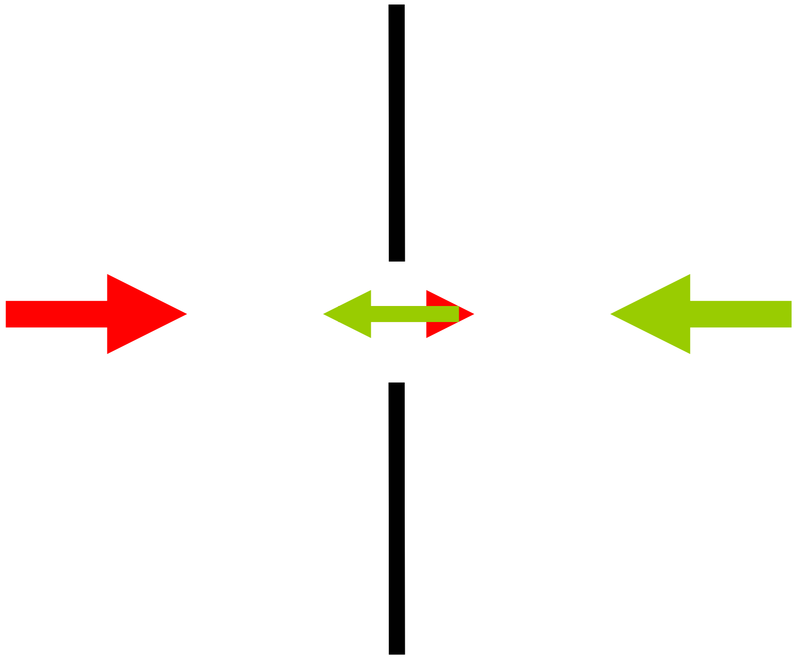
no real challenge for modelling!

Lane Formation in Counterflow



Pedestrian motion

Oscillations of Flow Direction



Empirical Results

- not many quantitative results available
- contradicting results (quantitave, sometimes even qualitative)
- experiments not well documented
- important for calibration of models

→ Experiments with up to 250 soldiers
(in collaboration with FZ Jülich, University of Wuppertal)

Fundamental diagram

Specifications in guidelines

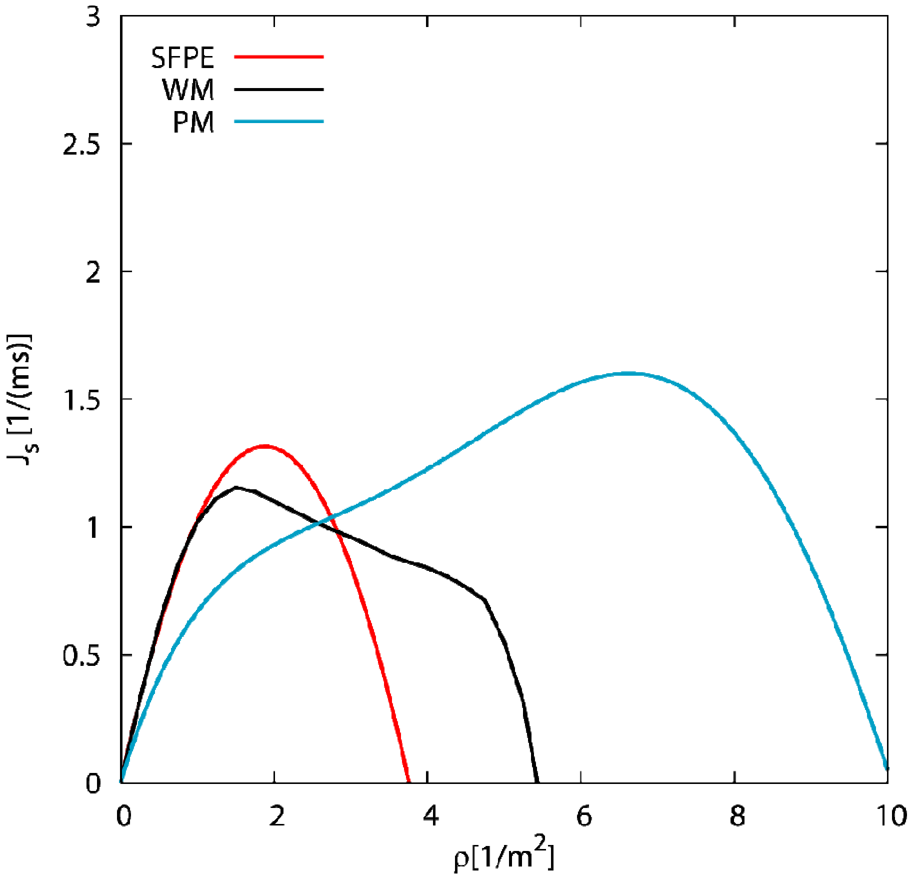
- Different shapes
- Capacity values C_s

  C_s: 1.2 – 1.6 $(ms)^{-1}$
- Location of the maximum

  ρ_C: 1.8 – 7 m^{-2}
- Location of ρ_0

  ρ_0: 3.8 – 10 m^{-2}

Non-negligible differences
In particular for ρ_0



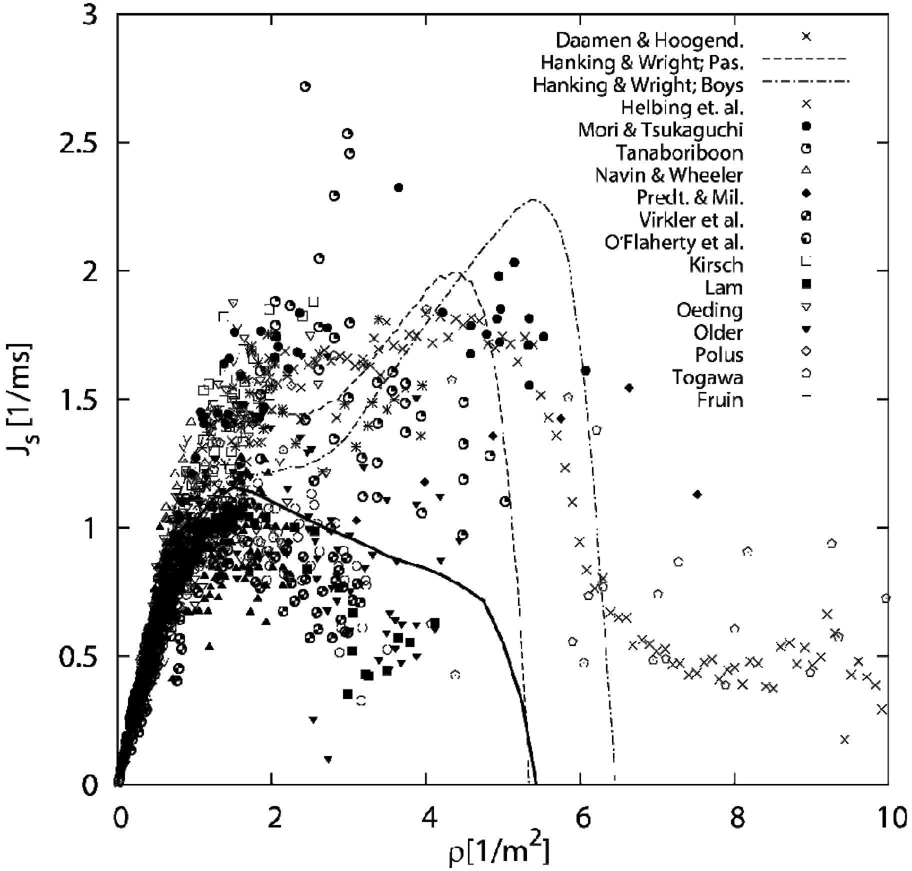
SFPE P. J. DiNenno (2002) *SFPE Handbook …*
PM V. M. Predtechenskii and Milinskii (1978)
WM U. Weidmann (1993) *Transporttechnik …*

Comparison of experimental data

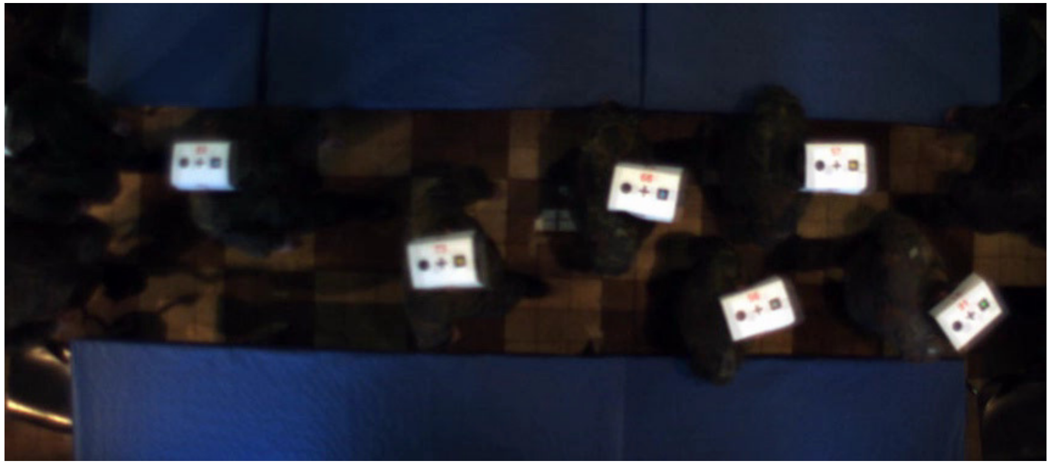
Causes discussed in the literature

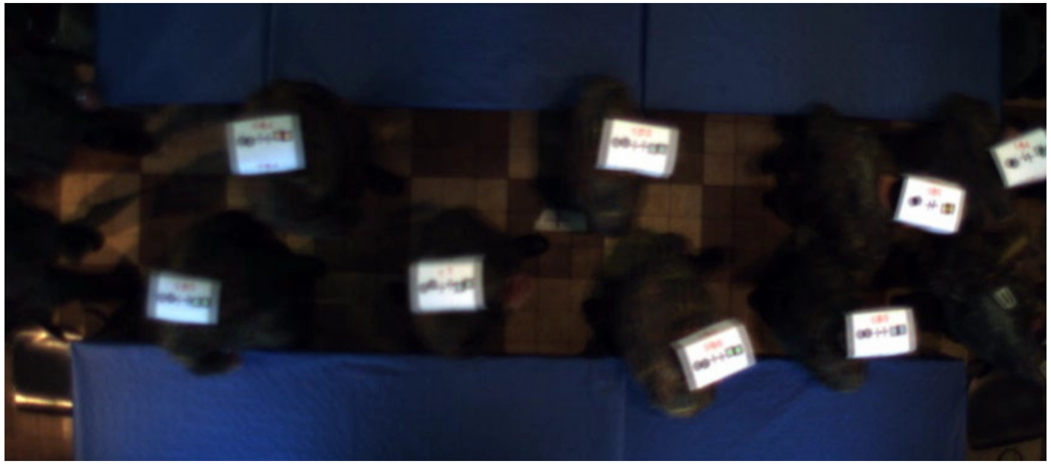
- Uni- and bidirectional
- Way of measurement
- Fluctuations
- Culture and population demographics
- Psychological factors

Unfortunately most authors give not all necessary information!



Flow vs. Density





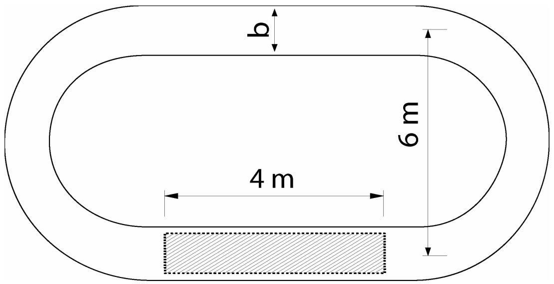
Preliminary results

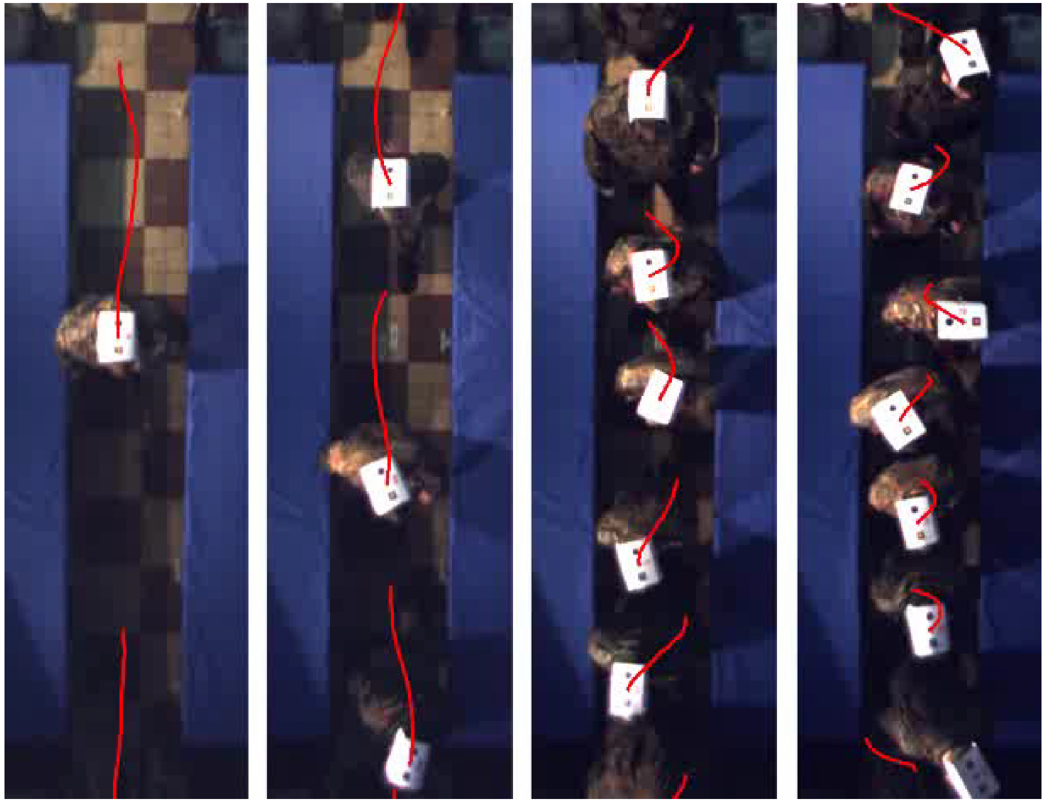
Fundamental diagram

- single file movement
- corridor width

  b = 0.7m
- unidirectional
- closed boundaries
- stationary states
- Number of pedestrians

  N = 17 - 70





N=14 N=25 N=39 N=56

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Bottleneck

Sets of the experiments: Part 2

Bottleneck flow

- Bottleneck width **b**

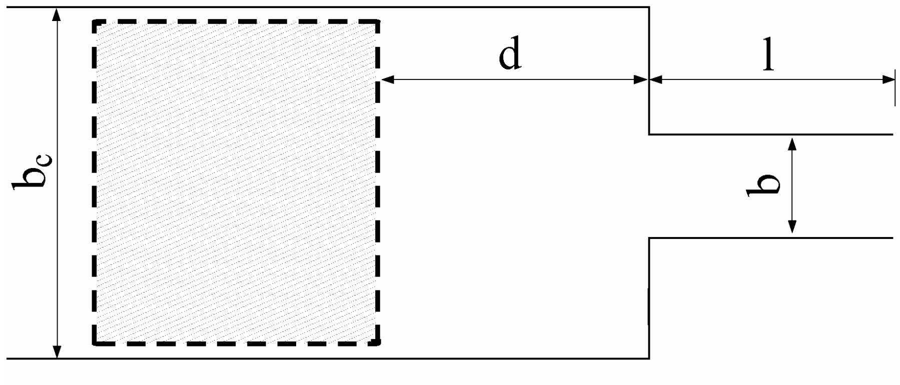
  0.8, 0.9, …, 2.5m
- Bottleneck length **l**

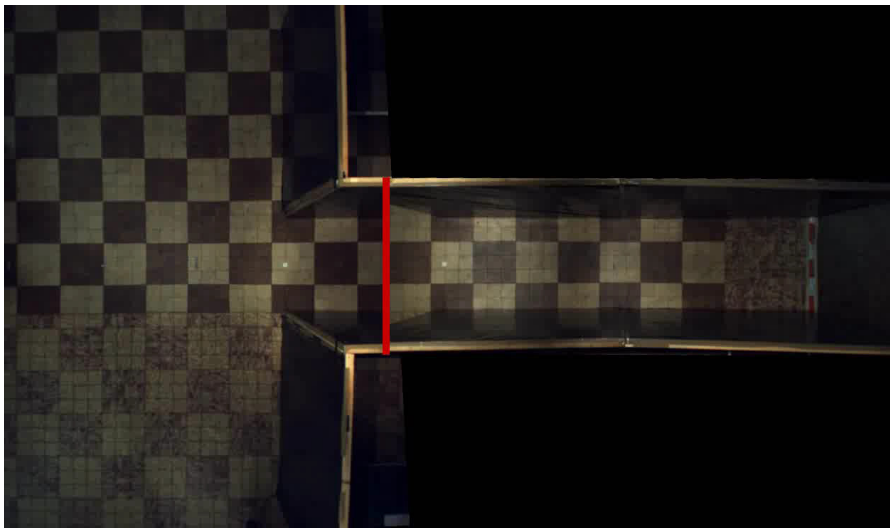
  0.1, 2.0, 4.0m
- Corridor width $\mathbf{b_c}$

  4.0, 5.0, 6.0m
- Number of pedestrians **N**

  50, 100, …, 250
- Distance to the entrance **d**

  1.0, 2.0, 3.0, 4.0m

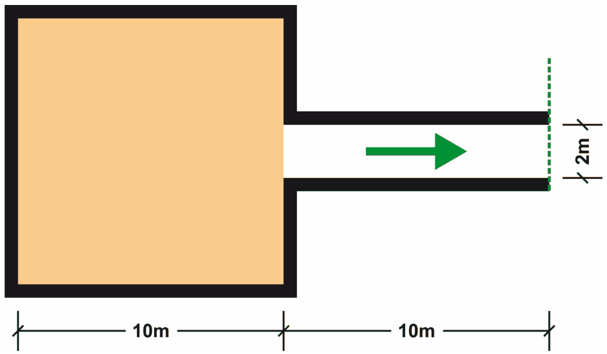


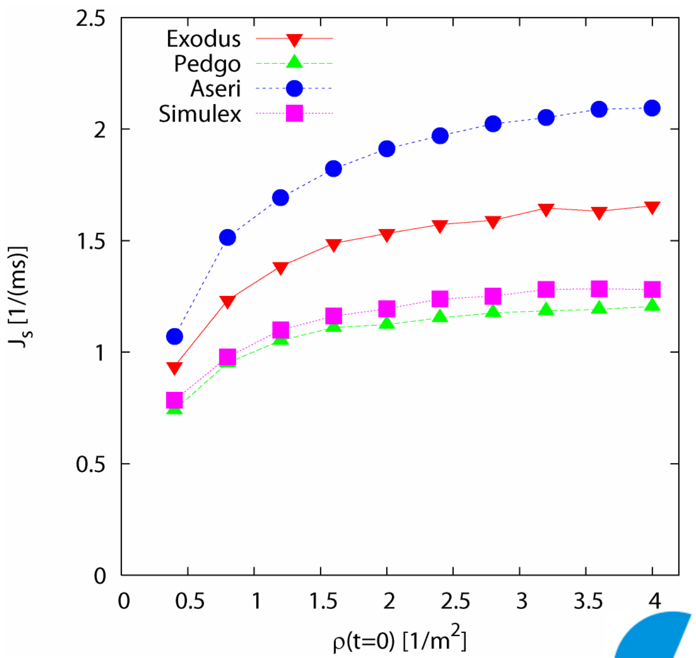


Examples

Calculated egress times (flow rates) of different evacuation simulation tools (Aseri, PedGO, Simulex and BuildingExodus) will differ significantly (factor 2 to 4) (C. Rogsch, PED2005)

In particular for simple geometries





Chemotaxis

Ants can communicate on a chemical basis:

chemotaxis

Ants create a chemical trace of pheromones

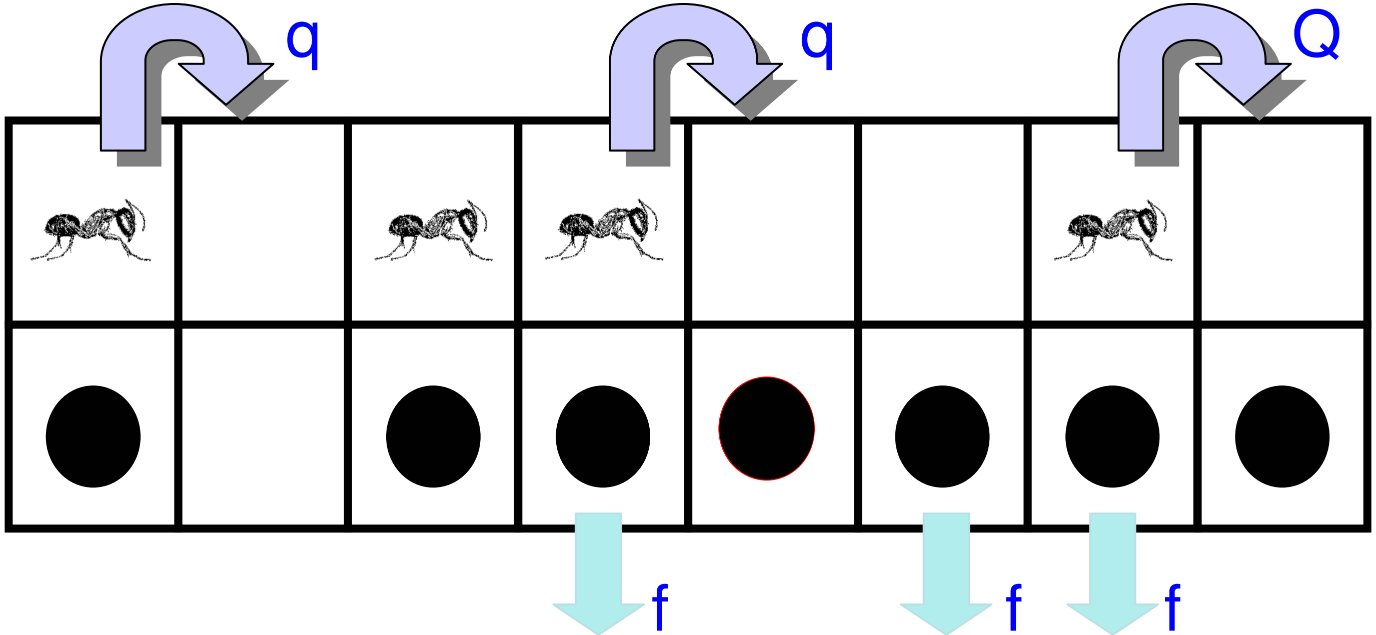
trace can be “smelled” by other ants

follow trace to food source etc.

Ant trail model

Dynamics:

1. motion of ants
2. pheromone update (creation + evaporation)



parameters: $q < Q$, f

Pedestrian model

motion described by stochastic dynamics:

transition probabilities

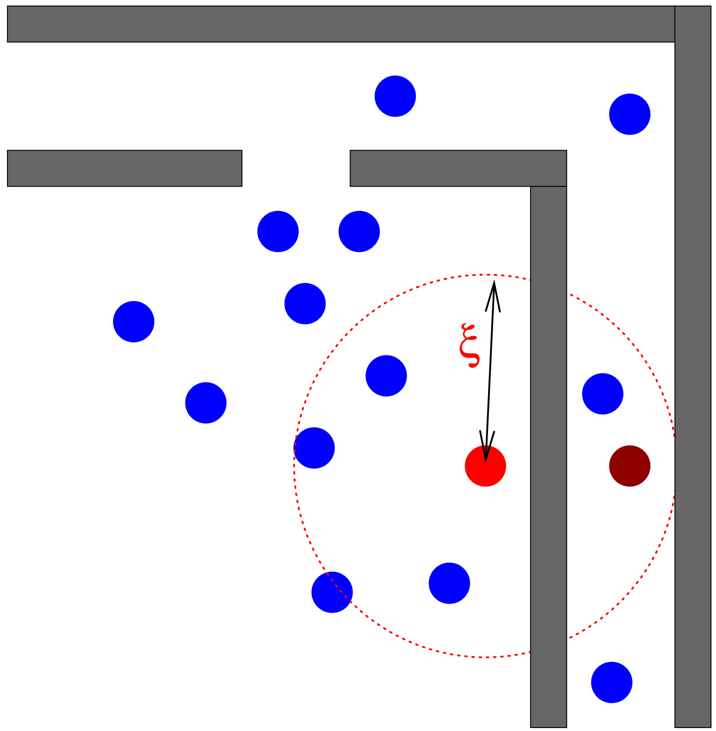
reflects our lack of knowledge

works well for 'large' systems (← physics)

interactions: Virtual chemotaxis

chemical trace: *long-ranged* interactions are translated into *local* interactions with *"memory"*

Long-ranged Interactions



Problems for complex geometries:

Walls ”screen“ interactions

Models with local interactions ???

Floor Field CA: Basics

Cellular automaton model with stochastic dynamics

Space divided into cells (40*40 cm^2)

Exclusion principle: no more than one pedestrian per cell

Discrete time: parallel (synchronous) dynamics

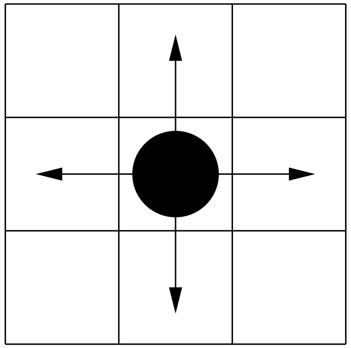
$\longrightarrow$ natural timescale

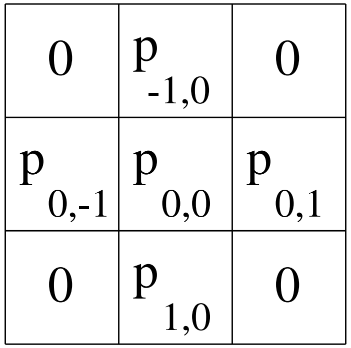
$\longrightarrow$ calibration and quantitative predications possible!!

Motion only to neighbour cells ($v_{max} = 1$)

Transition Probabilities

Stochastic motion, defined by transition probabilities





3 contributions:

- Desired direction of motion
- Reaction to motion of other pedestrians
- Reaction to geometry (walls, exits etc.)

Unified description of these 3 components

Floor Field Model

Free motion: specified by average velocity $\langle \mathbf{v} \rangle$ and variance σ^2

Floor field = virtual field that modifies the transition probabilities

2 types:

- Dynamic floor field: is modified by the motion of the pedestrians (they create a “trace“)
- Static floor field: not influenced by pedestrians; determined by geometry

General principle: motion into direction of larger fields is preferred

Dynamic Floor Field

Motion increases field strength in starting cell
$\Rightarrow$ pedestrians change dynamic field

$\Rightarrow$ motion creates a trace

Dynamic floor field has dynamics:

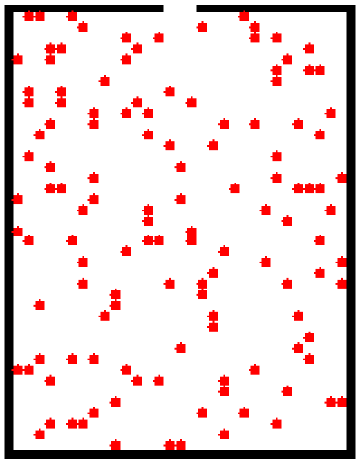
diffusion + decay

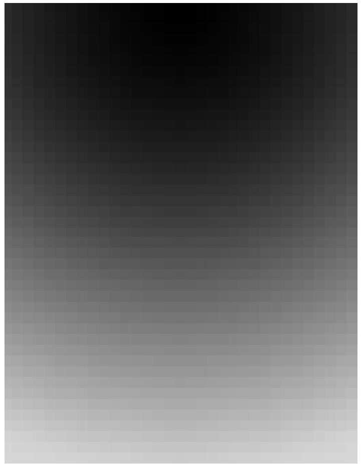
$\Rightarrow$ broadening and dilution of trace

Static Floor Field

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

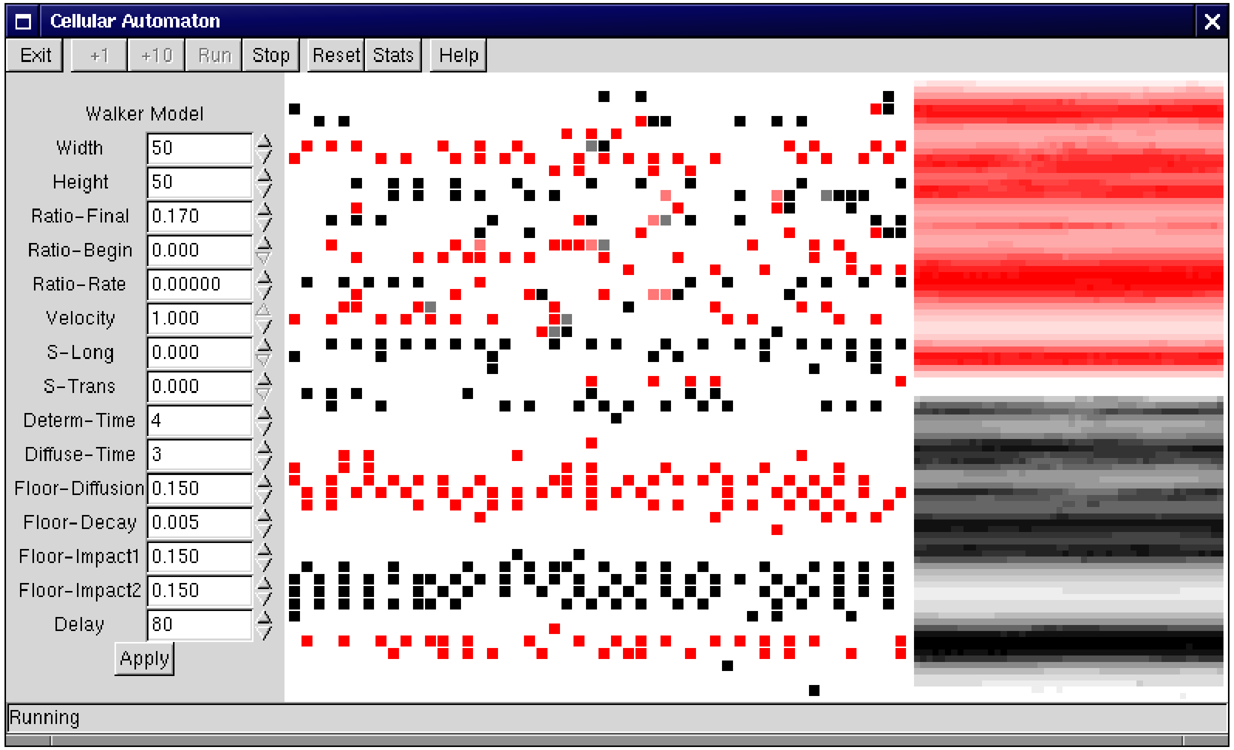
Example: Ballroom with one exit

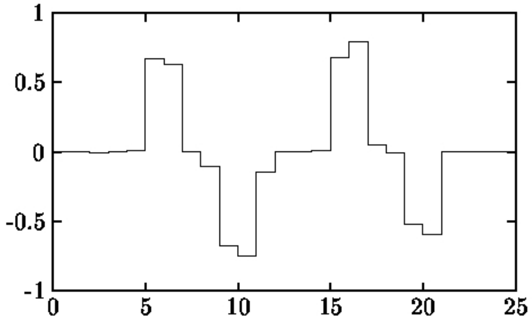




Simulation

Lane Formation





velocity profile

counterflow: left and right mover

Evacuation Simulations

Influence of the different floor fields:

individual behaviour (static) vs. herding (dynamic)

static field dominates: normal situation

full knowledge about infrastructure, e.g. shortest way to the exits

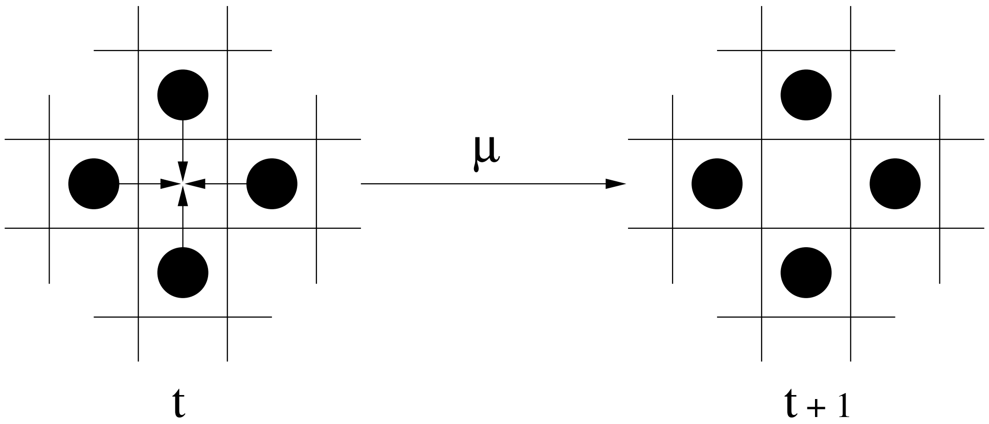
dynamic field dominates: emergency situation ("panic")

herding behaviour

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

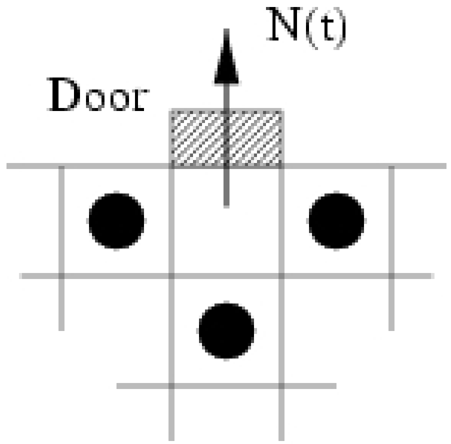
$\longrightarrow$ often avoided by special update choice

However: Conflicts and friction correspond to real effects, e.g.

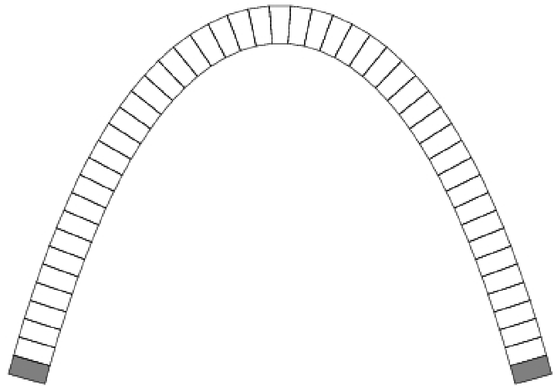
- physical contact
- moment of hesitation

Friction at Exits

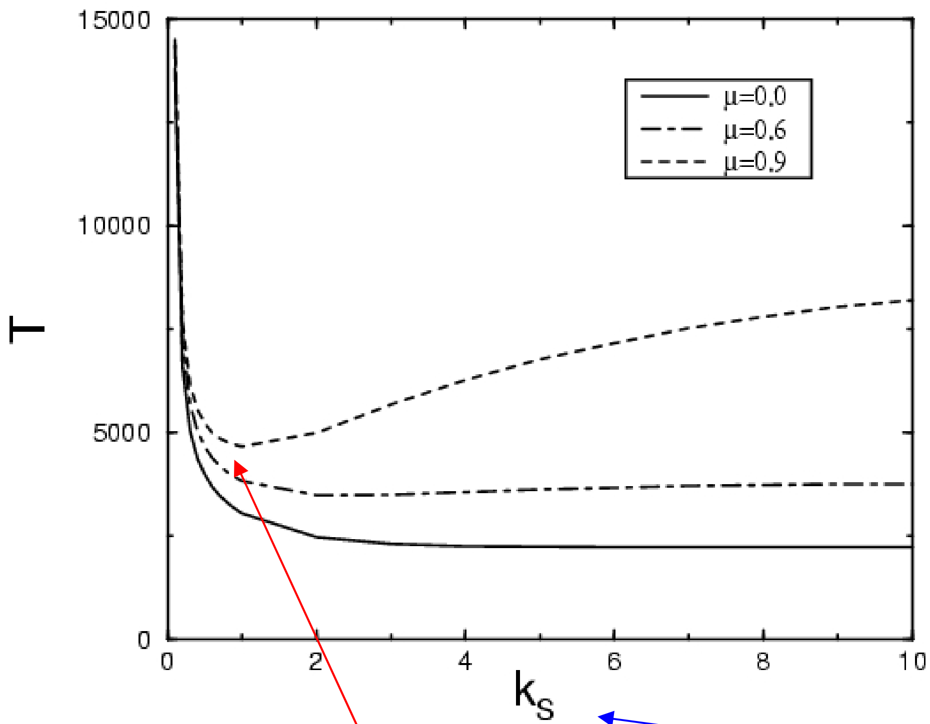
Friction at exits increases evacuation times by reducing the outflow



Granular materials:
Arching



Evacuation Scenario With Friction Effects



(Kirchner, Nishinari, Schadschneider 2003)

evacuation time

effective velocity

Faster-is-slower effect

Friction in Evacuation Processes

Friction most important close to exits and other bottlenecks
$\Rightarrow$ have a direct influence on evacuation times

away from exits it can even have positive effects, e.g.
because jamming at door is suppressed
$\Rightarrow$ Faster-is-slower effect

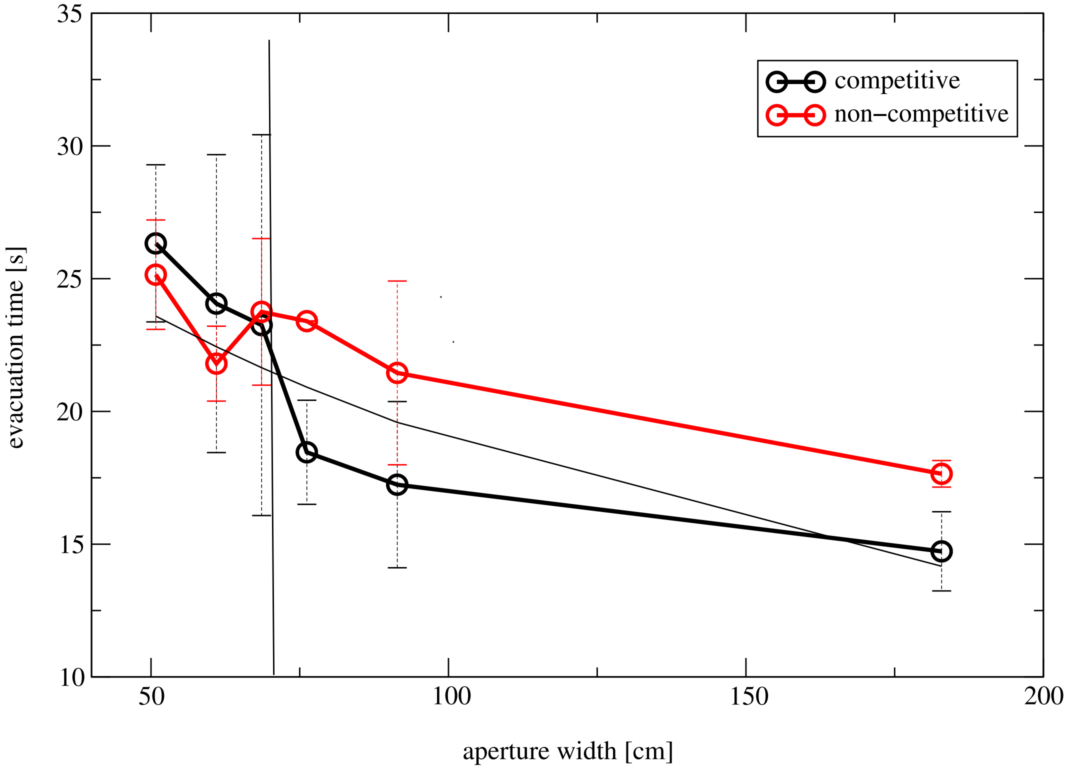
Competitive vs. Cooperative Behaviour

Experiment: egress from aircraft (Muir et al. 1996)

Evacuation times as function of 2 parameters:

- motivation level
  - competitive (T_{comp})
  - cooperative (T_{coop})
- exit width w

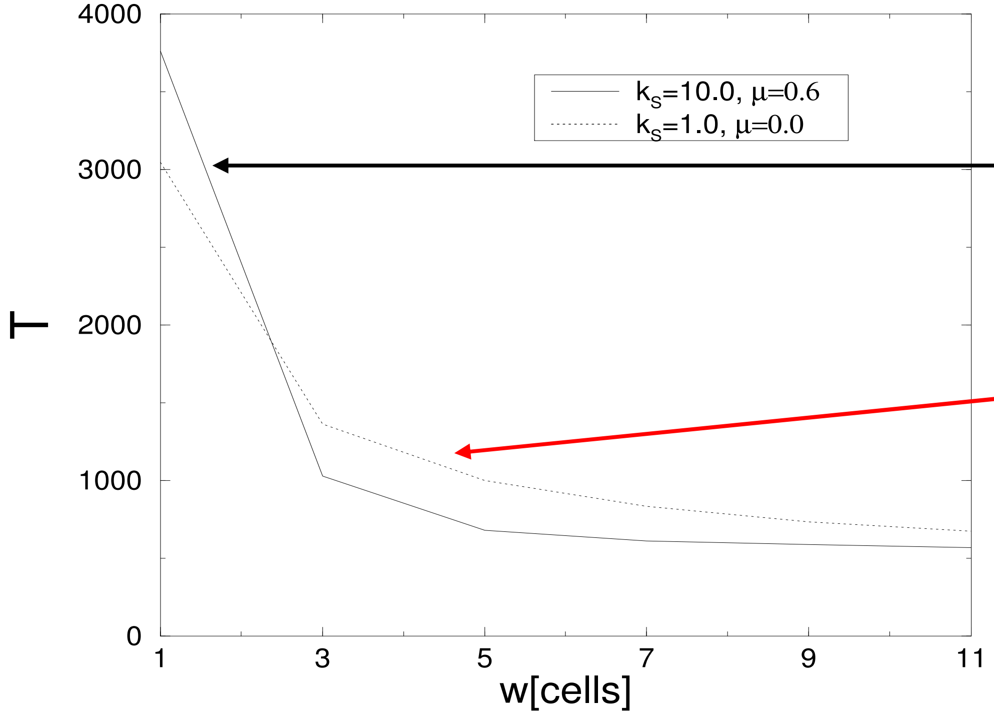
Empirical Egress Times



$T_{comp} > T_{coop}$ 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)

Fundamental diagram

empirically: non-symmetric

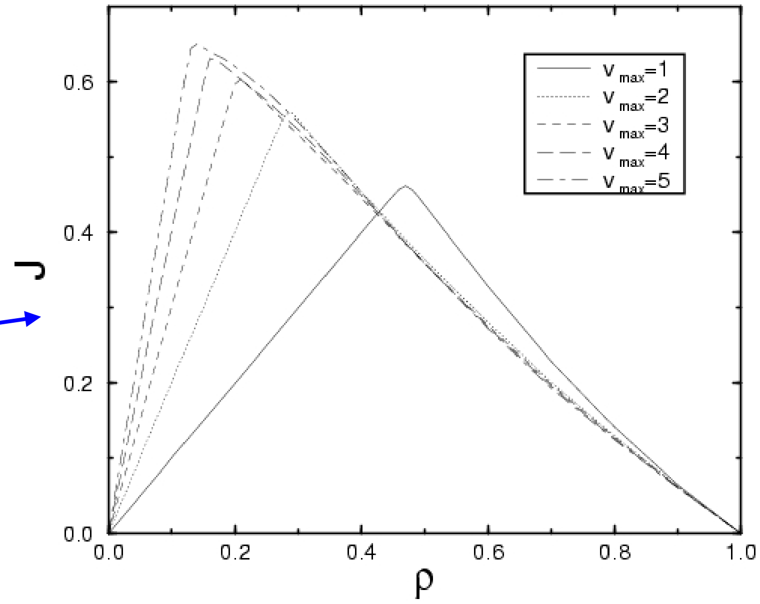
maximal flow at small densities

important: larger space requirement at higher velocities

generalize model to $v_{\max} > 1$

asymmetric fundamental diagram

Dependence on maximal velocity



no non-monotonicity for realistic parameter values !

Summary

Ant traffic on existing trails and pedestrian dynamics can be described by similar models

interactions: local (real/virtual chemotaxis)

ant trails: anomalous fundamental diagrams possible
formation of loose clusters

pedestrian dynamics: no 'intelligence' required
collective effects reproduced (lane formation etc.)
applications to safety analysis