JÜLICH
FORSCHUNGSZENTRUM

Review about fundamental diagrams of pedestrian streams

Oct. 2nd 2015

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University of Wuppertal
and
Forschungszentrum Jülich GmbH

Overview

Motivation

Experiments and measurement methods

Unidirectional streams

- Common consent
  - Trends
  - Specific flow
- Transitions
- External influences

Comparison of pedestrians, bicycles and cars in a 1d-system

Motivation

Chowpatty-beach, Mumbai, Indien

Foto: J. Sorabjee, Urban Design Res. Inst.

Motivation

Utrecht Central Station, Netherlands *Foto: Jeroen van den Heuvel, Railway Netherlands*

Cologne Central Station, Germany *Foto: unknown*

Motivation

Viewpoint of an engineer

Aims

- Transport infrastructures (stations, airports, trains, …)
- Design of escape routes (stadiums, theater, schools, …)
- Safety at big events
- …

Tools and methods

- Legal regulations
- Guidelines and handbooks
- Computer simulations

Quantitative description of crowd movement necessary!

Motivation

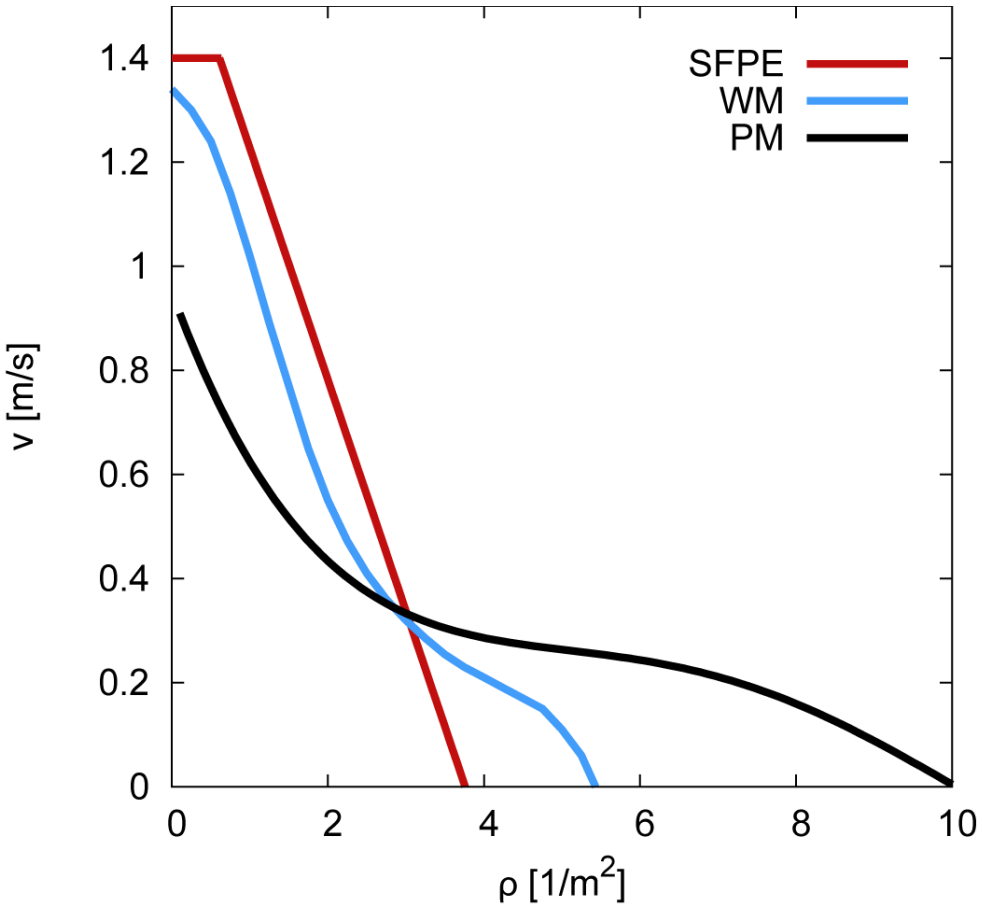
General aim: Prevent congestions for movement under orderly conditions!

How to describe the movement of ‘many’ pedestrians?

- If many people are involved density, speed and flow are useful concepts
- Speed, density and flow are helpful to rate e. g.
  - Performance of pedestrian facilities (flow)
  - Level of service (density)
  - Travel or waiting times (speed)
- Speed, density and flow are related (Fundamental diagram)

Photo: Sebastião Salgado

Motivation



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

Motivation

Research groups studying systems with ‘many’ pedestrian (>20) by laboratory experiments and with determination of trajectories

- Univ. Milano-Bicocca, Italy: Vizari, Bandini et al.
- University of Tokio, Japan: Nishinari, Yanagisawa, Tadaki, et al.
- TU Delft, Netherlands: W. Daamen, S. Hoogendoorn, et al.
- PEDIGREE project, France: Jelić, Appert-Rolland, Pettré, et al.
- TU Berlin, Germany: Plaue, Baerwolf, et al.
- University of Hefei, China: W. Song, J. Ma, et al.
- Monash University, Australia: M. Sarvi, et al.
- TU Denmark, Denmark: J. Starke, et al.
- SL Rasch, Germany, R. Löhner, et al.
- University of Pamplona, Spain: A. Garcimartin, I. Zurigel et al.
- …
- Univ. Cologne, Univ. Wuppertal and Research Centre Jülich, A. Schadschneider, M. Boltes, J. Zhang, …

Experiments

Date	Place	# Pers.	Capturing	Aim
Mar. 2005	Jülich	34	manual	v(ρ) corridor
Nov. 2005	Jülich	60	manual	bottleneck width J(b)
Nov. 2006	Bergische Kaserne D-dorf	200	autom.	- v(ρ) corridor - bottleneck width J(b) - bottleneck length J(l), …
Feb. 2008	Indien	64	manual	v(ρ) corridor
July 2008	Wuppertal	50	manual	v(ρ) corridor, motivation
Apr. 2009	ESPRIT Arena /	400	autom.	- stands (exits, stairs), stairs, … - corridor, corners, junctions, … - field studies on stairs J(ρ)
June 2013	Messe Düsseldorf	1000	autom.	development of congestions
Jan. 2015	Schools	200	Autom.	- v(ρ) corridor, heterogeneity - bottlenecks, groups

Video streams, trajectories,…. http://www.fz-juelich.de/ias/jsc/cst

Experiments

BaSiGo experiments

- Founded by the BMBF
- Fairground Düsseldorf, Hall 14

Messe Düsseldorf

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- Cooperation:
  - Univ. Siegen
  - IBIT GmbH
  - University of Essex (Talk N. Bode)
- Around 50 staff and supporters

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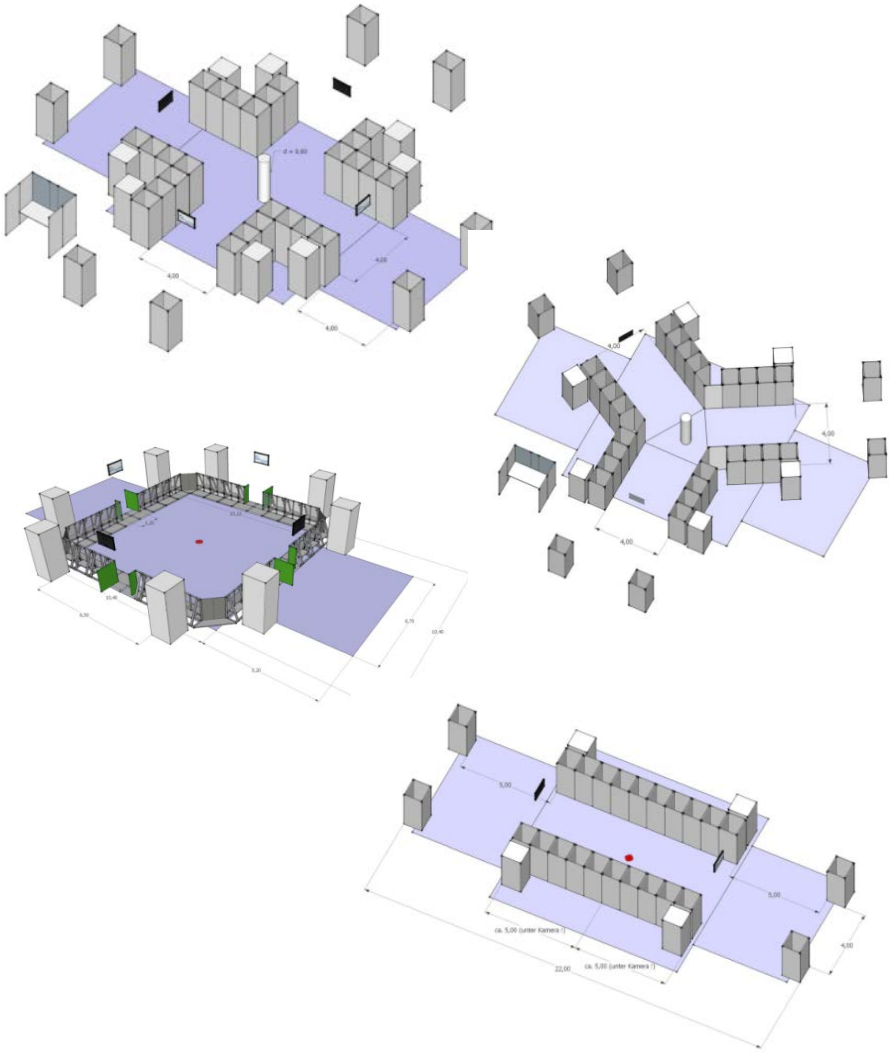

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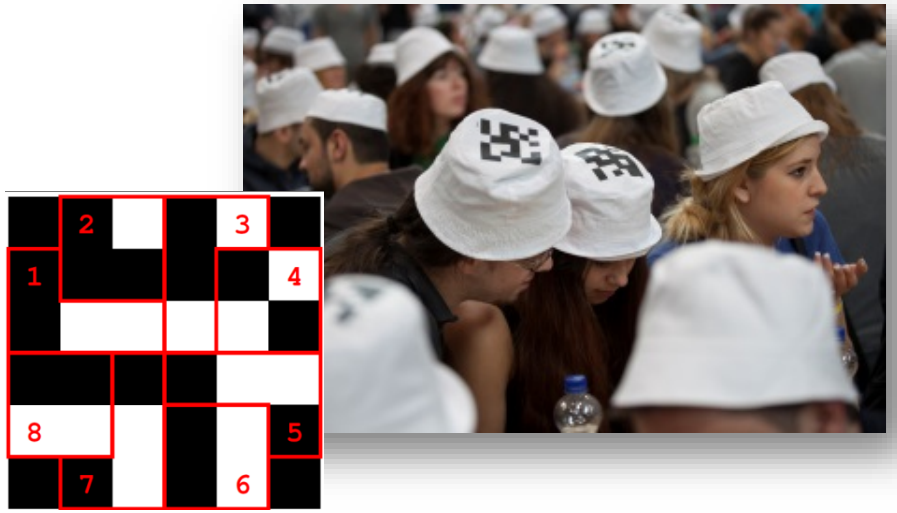
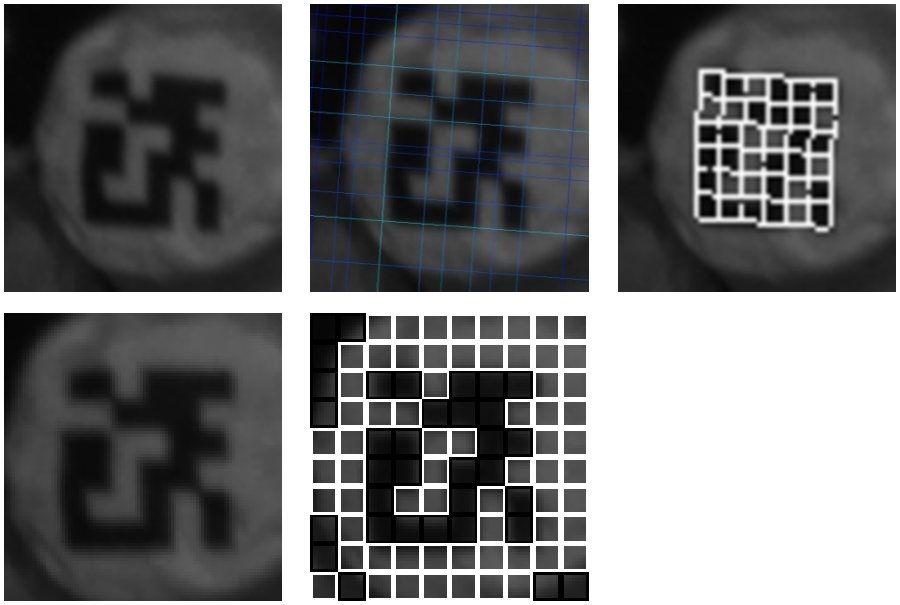
- Individual tracking





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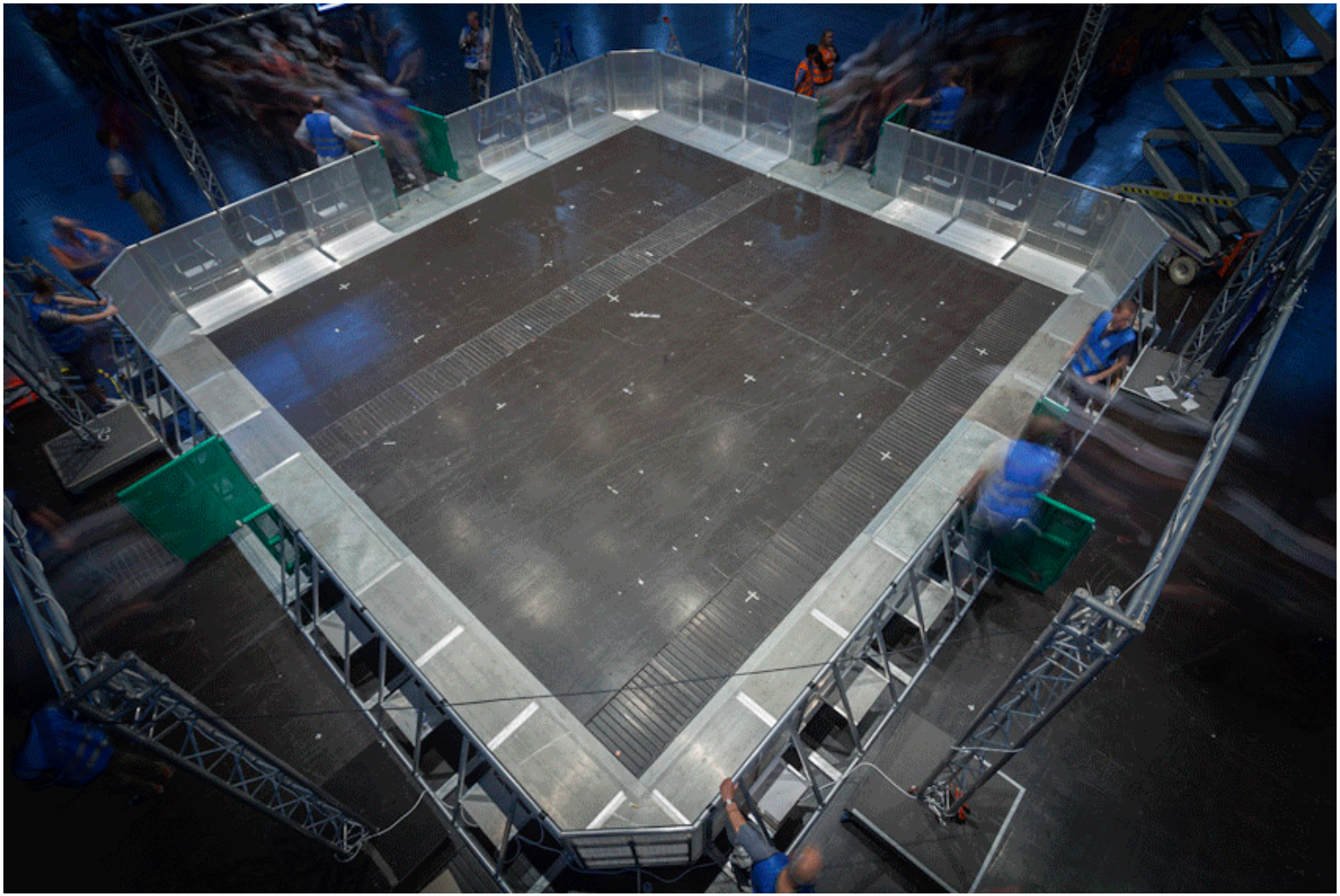
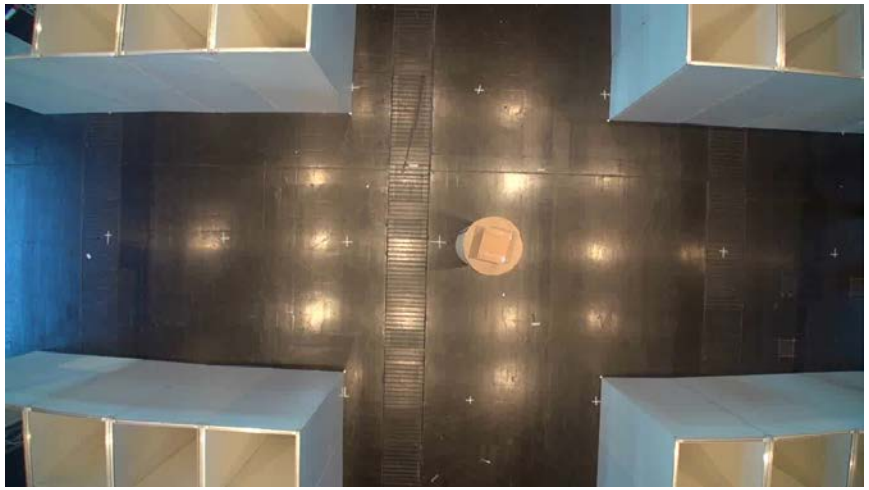
- Around 50 staff and supporters
- 5 days, 31 experiments, 200 runs
- Grid with 28 industrial cameras, additional HD-, Stereo-, GoPro and spectacle cameras
- Individual tracking
- 2200 participants in total, max. 950 on one day

Experiments BaSiGo



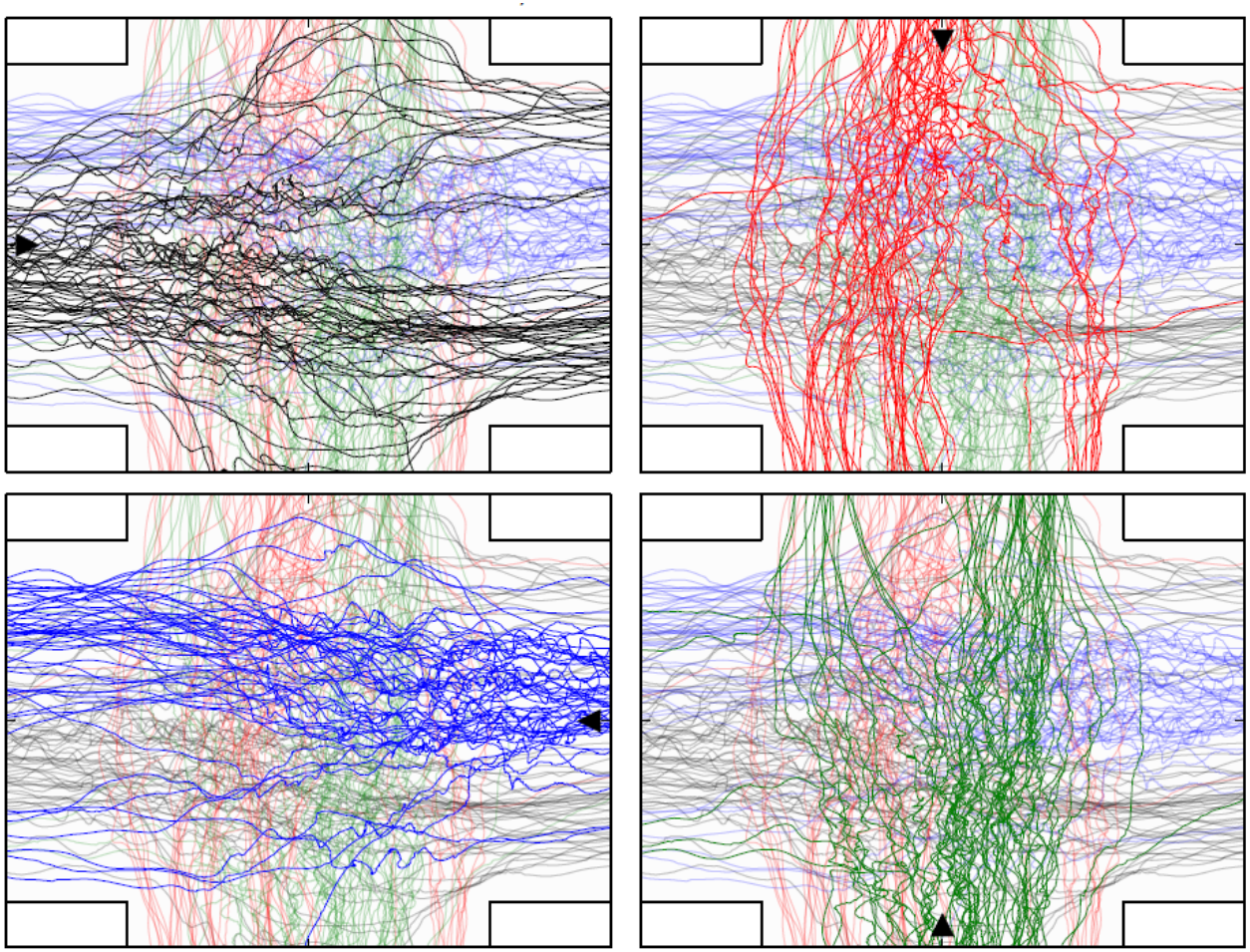
Experiments BaSiGo: Crossing streams



Experiments BaSiGo: Crossing streams

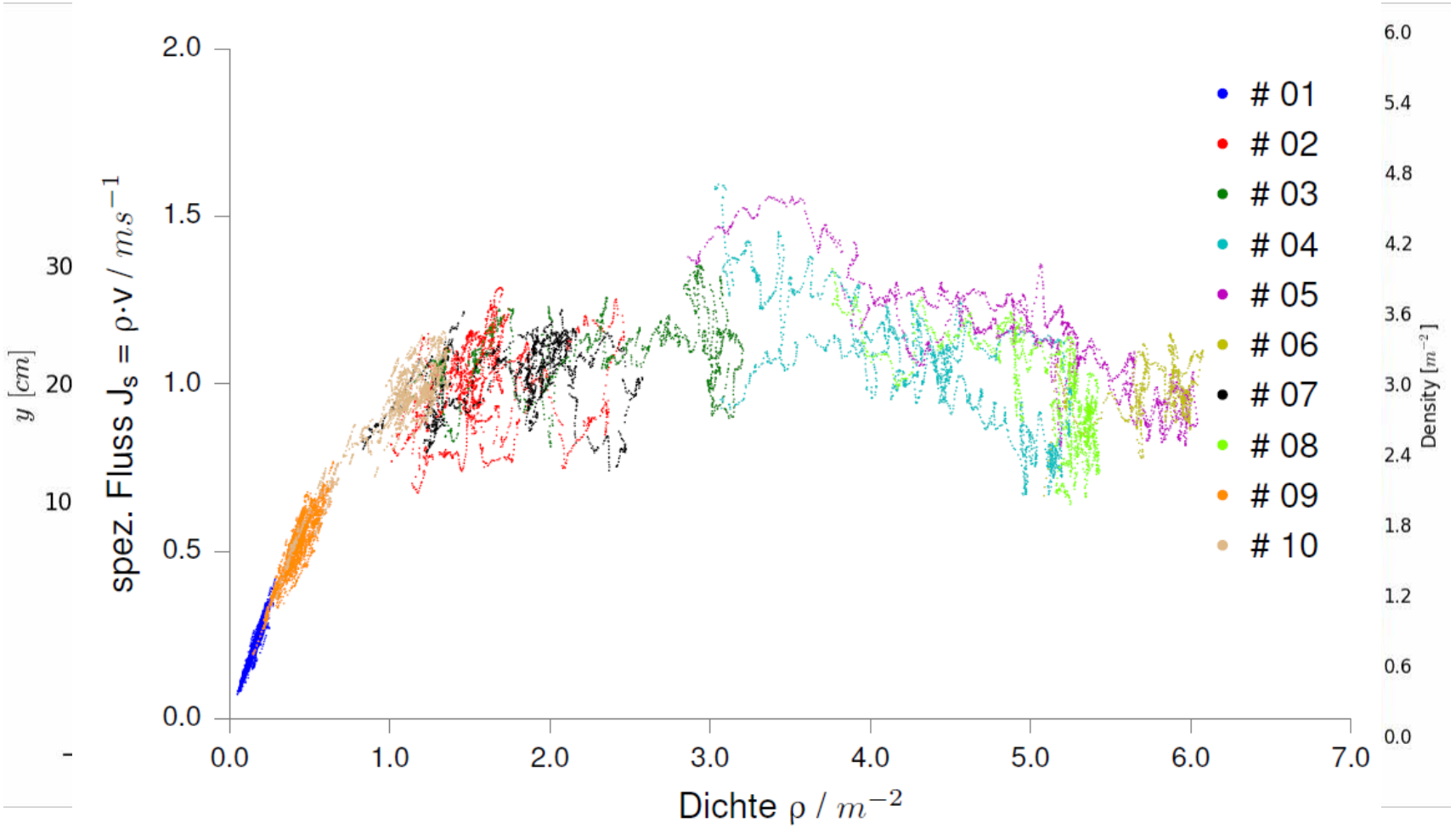
Experiments BaSiGo: Crossing streams

Trajektories*



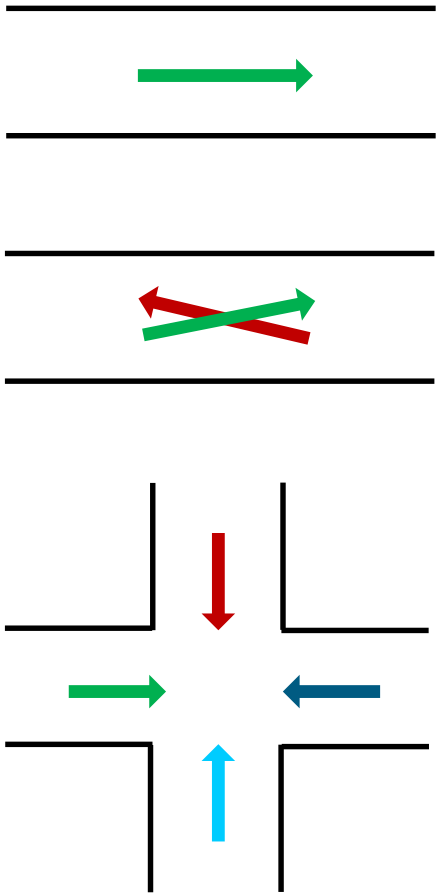
* Masterthesis, David Bodenstein, Mai 2015

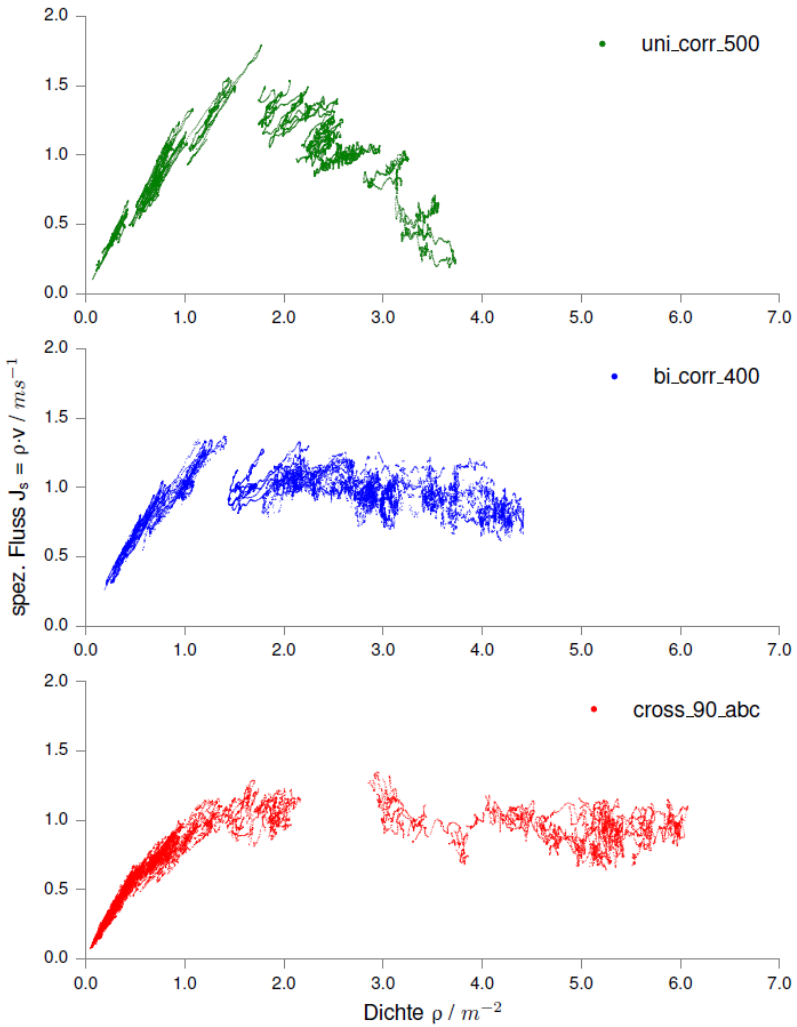
Experiments BaSiGo: Crossing streams



Experiments BaSiGo: Crossing streams

Fundamental diagrams





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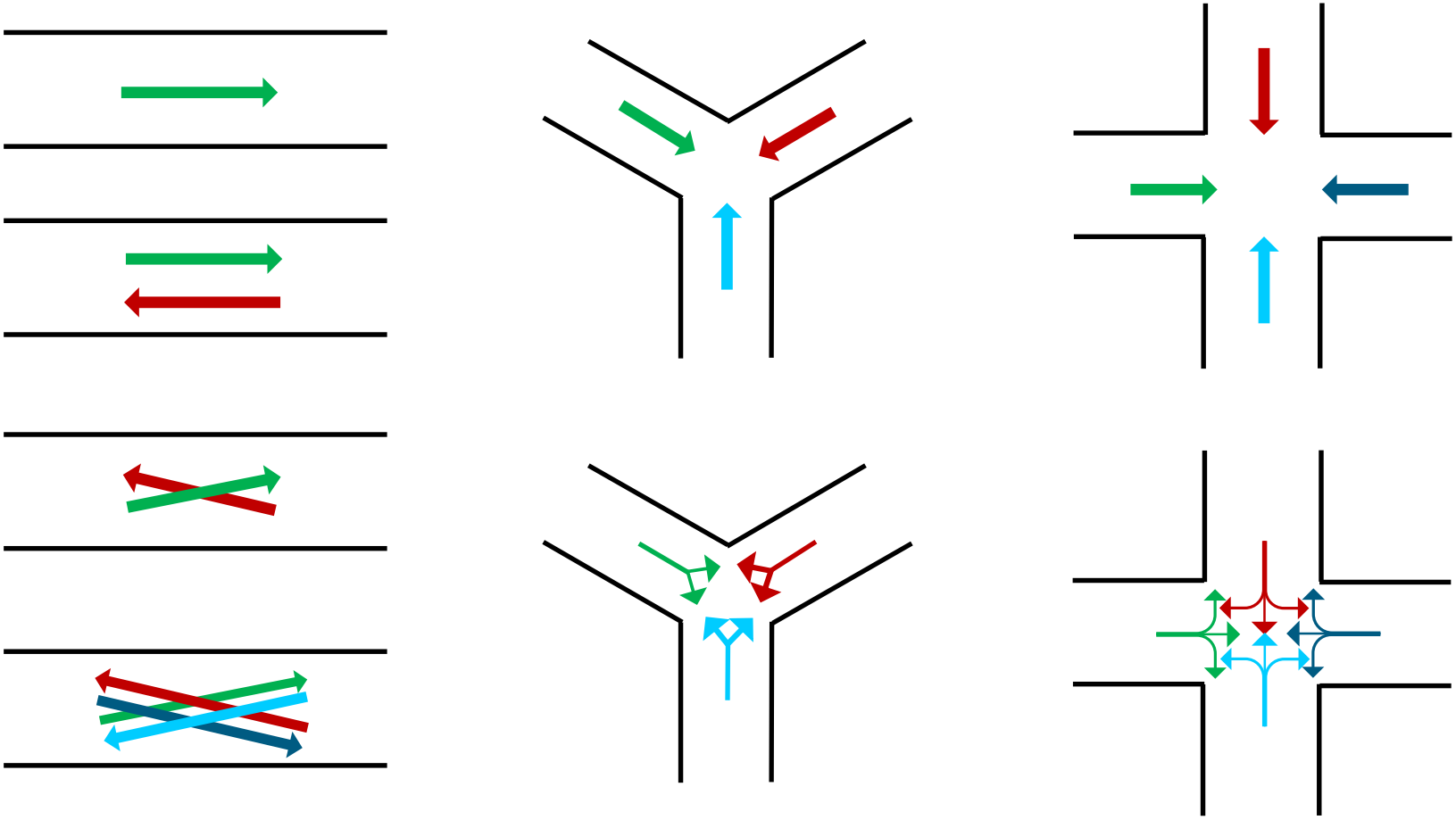
Introduction

Uni- and multidirectional streams at different types of facilities

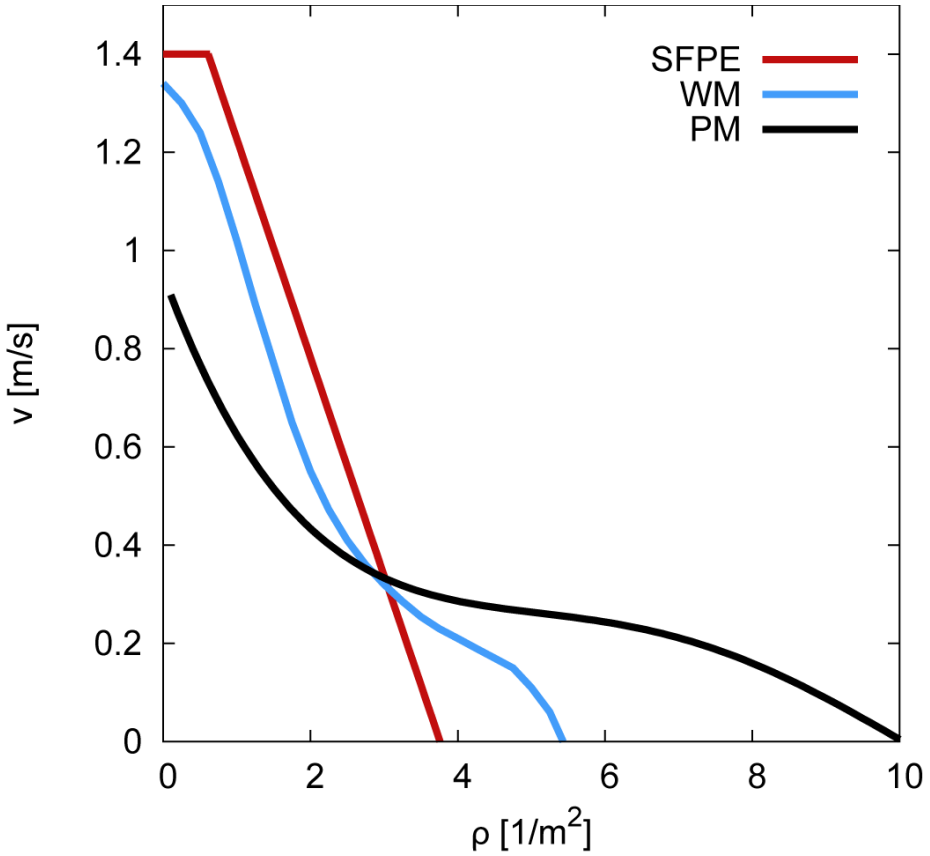


NOT INCLUDED: Bottlenecks, doors, ramps, stairs or mixtures

Unidirectional flow - Common consent

Now:

Unidirectional flow - Common consent



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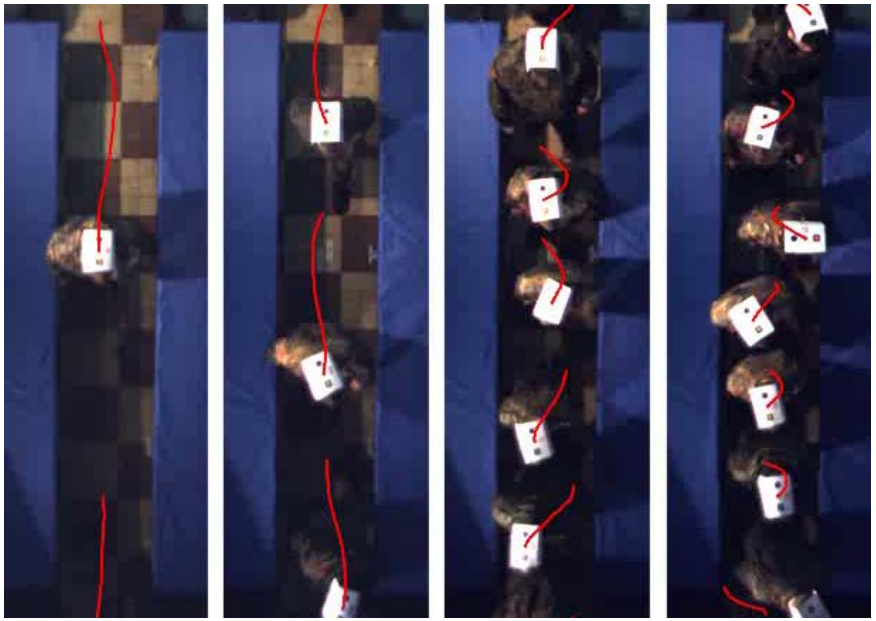

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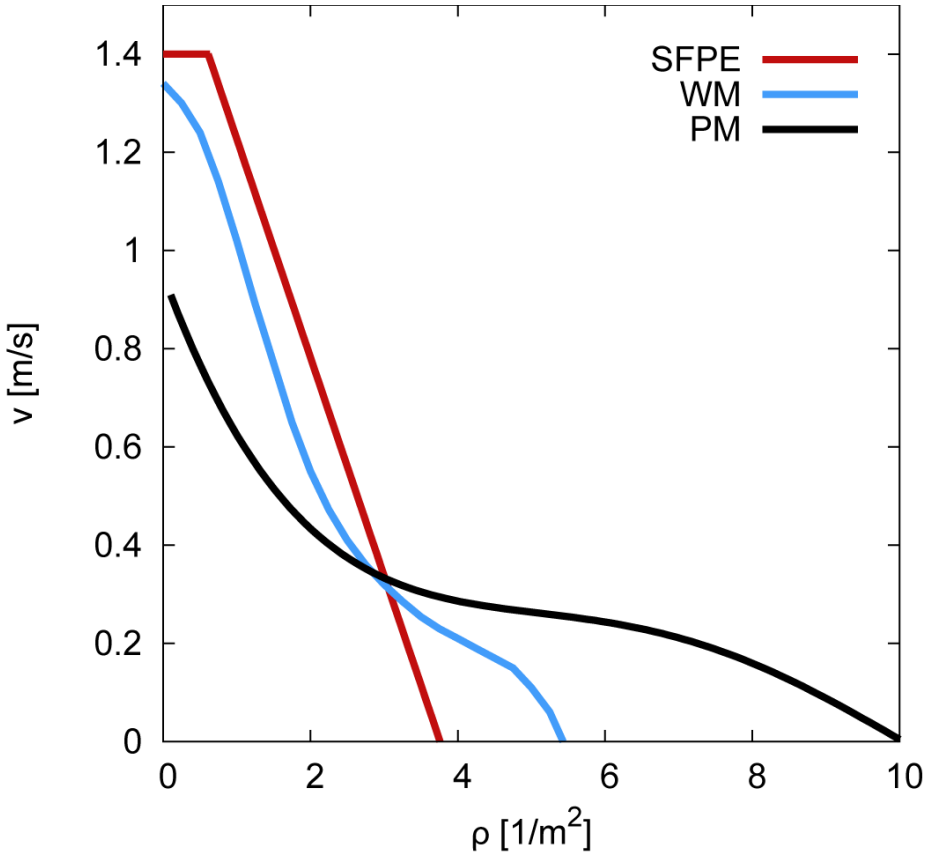

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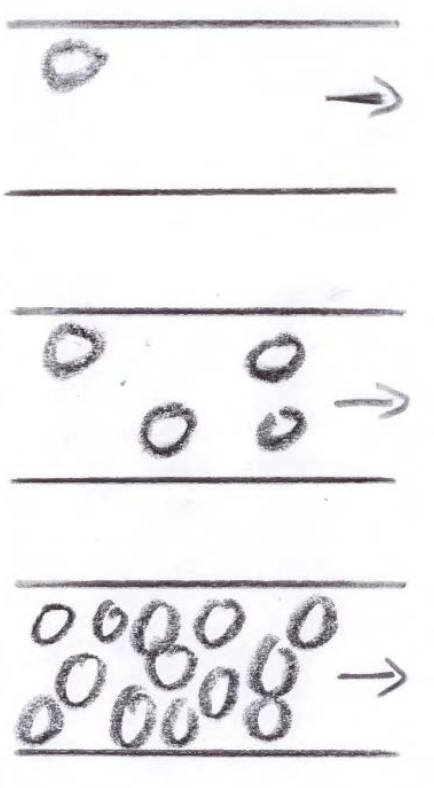
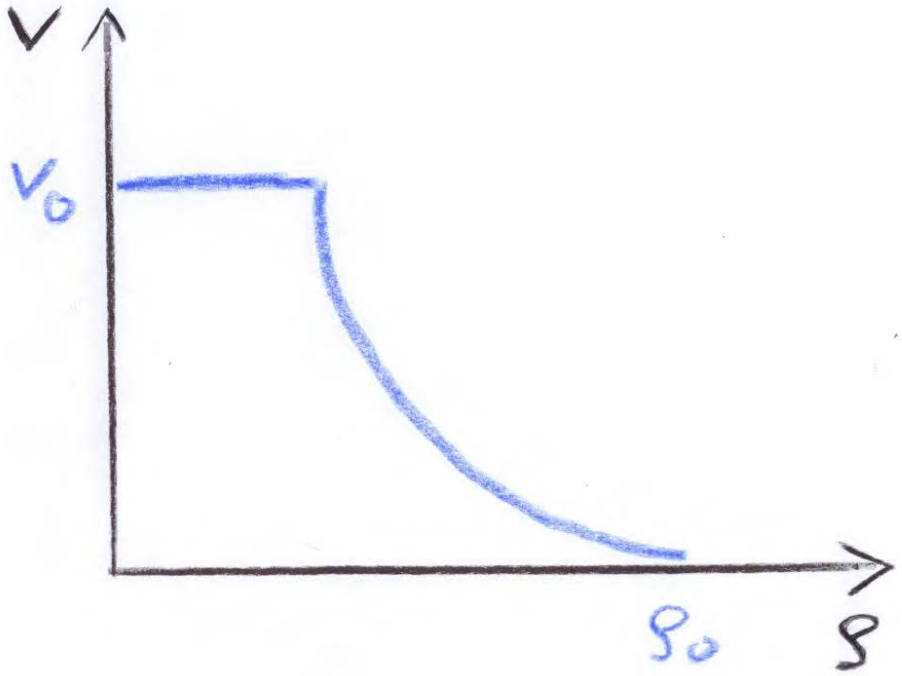


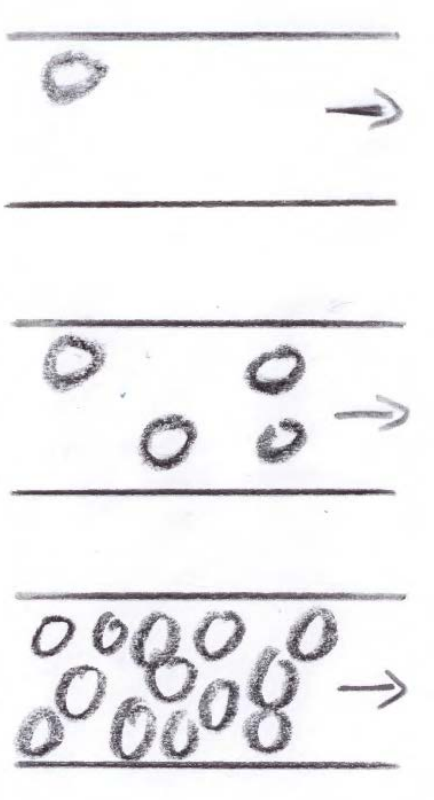


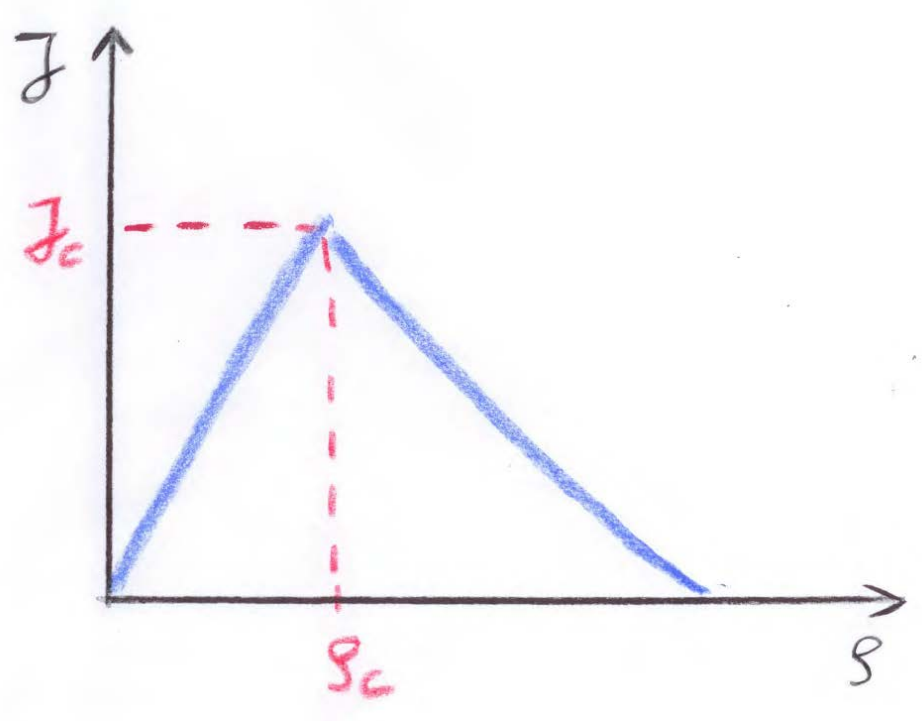
ρ small $\rightarrow v_0$ free flow speed

ρ high $\rightarrow v$ decreases

ρ_0 $\rightarrow v = 0$ (jamming)

Unidirectional flow - Common consent



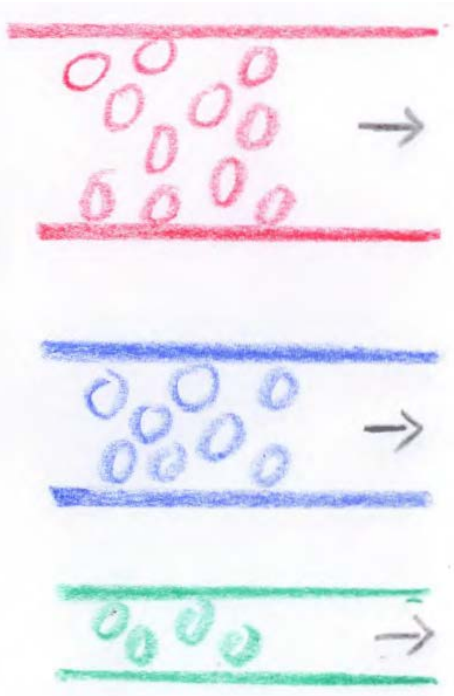


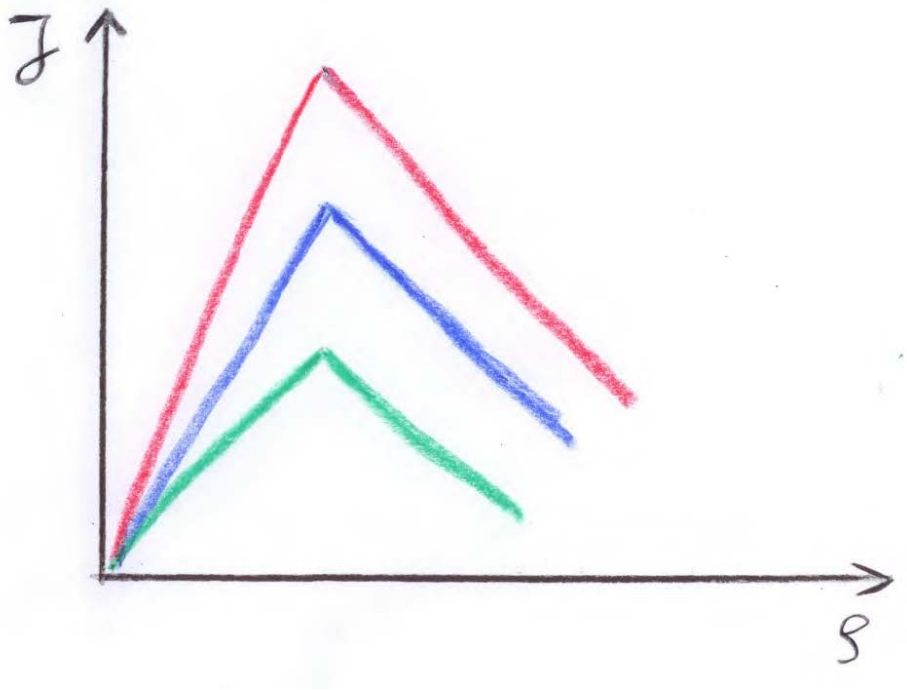
$\rho < \rho_C$ → J increases: Free flow state

$\rho = \rho_C$ → J_C maximum: Capacity

$\rho > \rho_C$ → J decreases: Congested state

Unidirectional flow – Specific flow

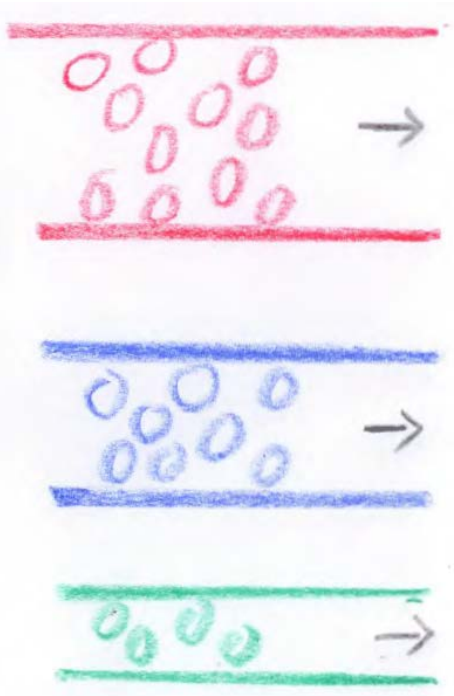




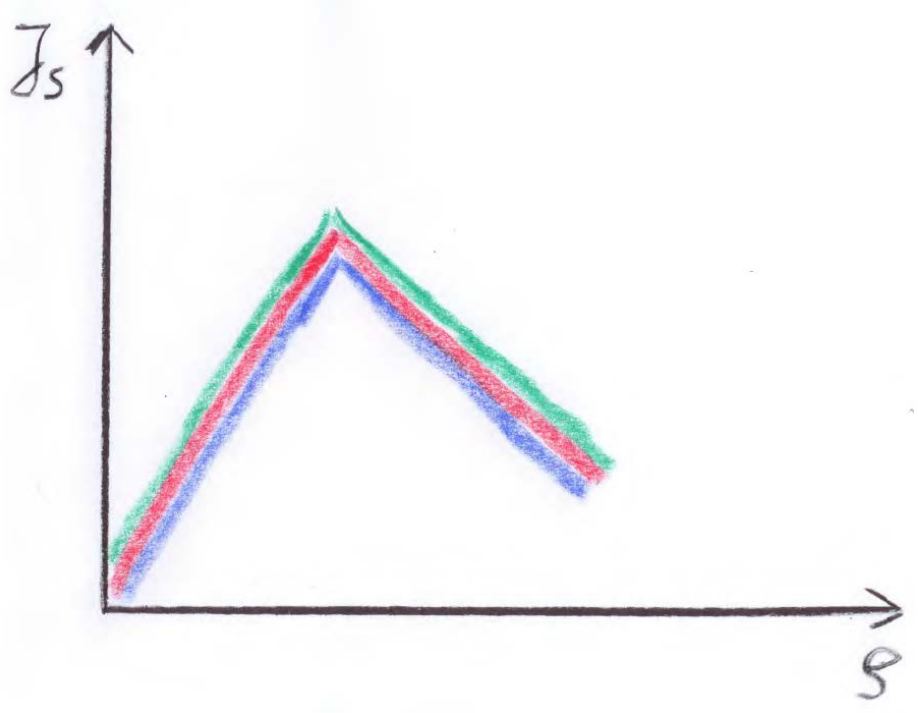
$b_1 > b_2 > b_3$ width increases → flow increases

Zhang et al., 2011, Transitions in pedestrian fundamental diagrams of straight corridors and T-junctions, J Stat Mech, P06004

Unidirectional flow – Specific flow



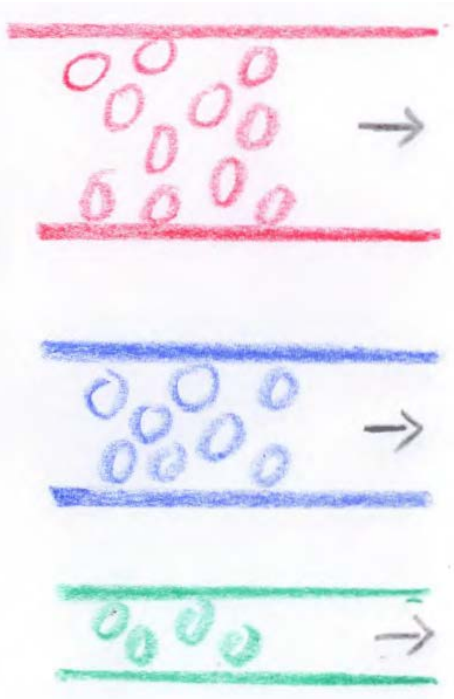
$J_s = J/b$

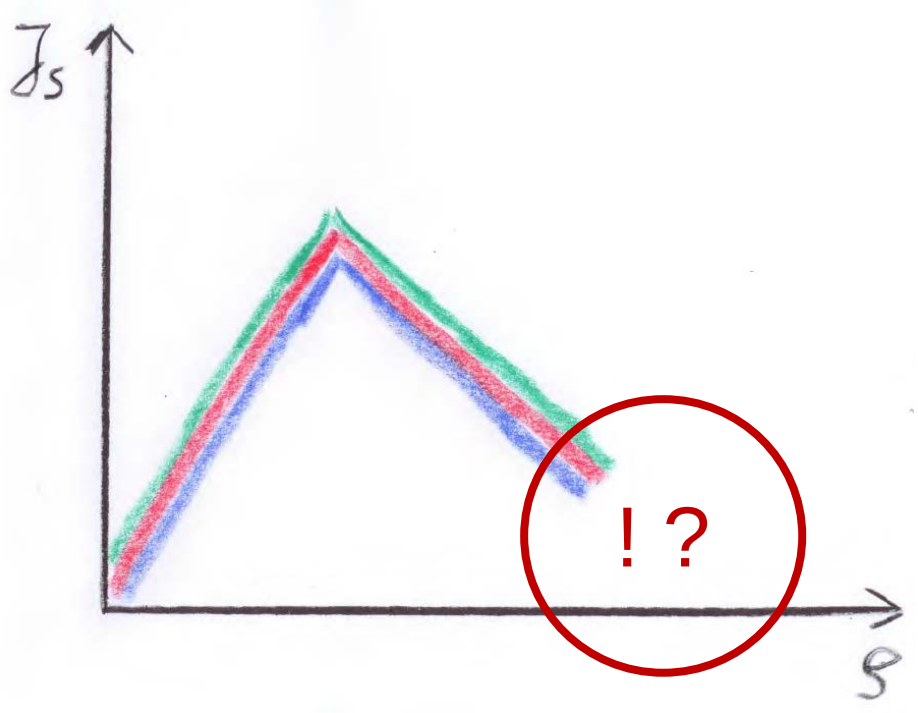


J_s: Fd's for **b_1**, **b_2**, **b_3** lie upon each other

Zhang et al., 2011, Transitions in pedestrian fundamental diagrams of straight corridors and T-junctions, J Stat Mech, P06004

Unidirectional flow – Specific flow

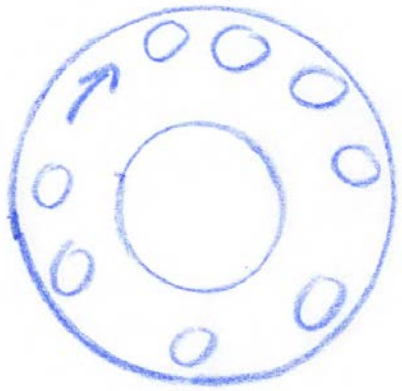




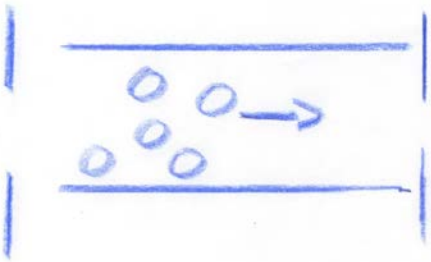
No data for high densities!

Zhang et al., 2011, Transitions in pedestrian fundamental diagrams of straight corridors and T-junctions, J Stat Mech, P06004

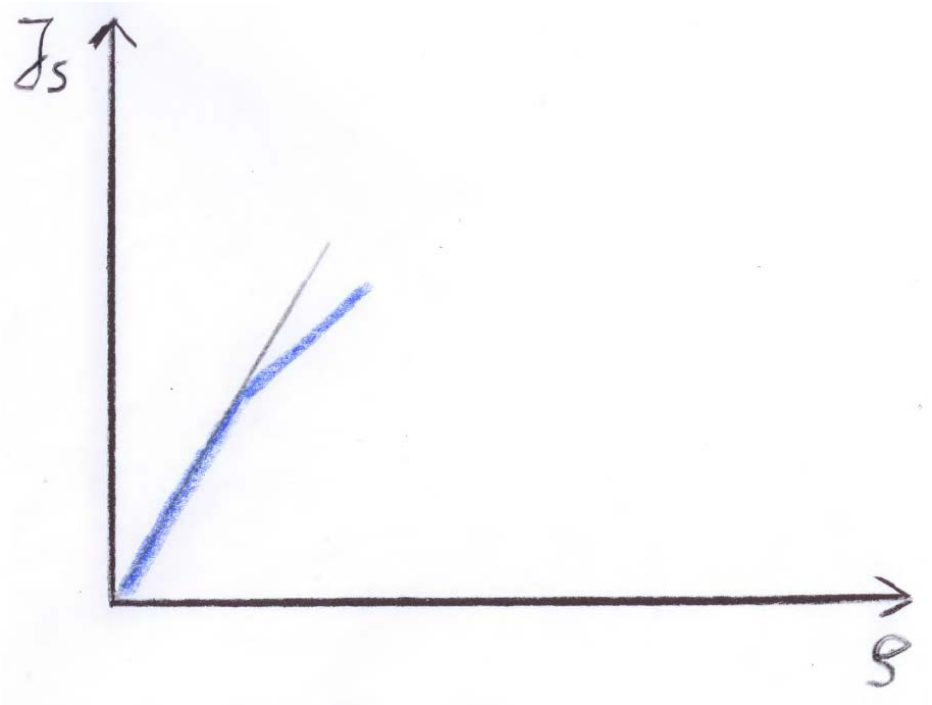
Fd: Transitions (free flow regime)



1)



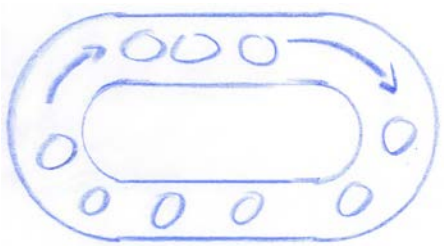
2)

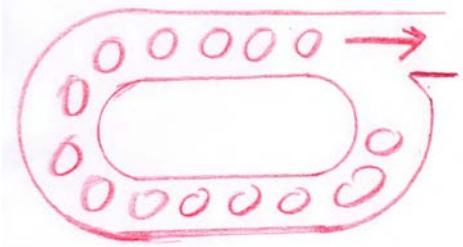


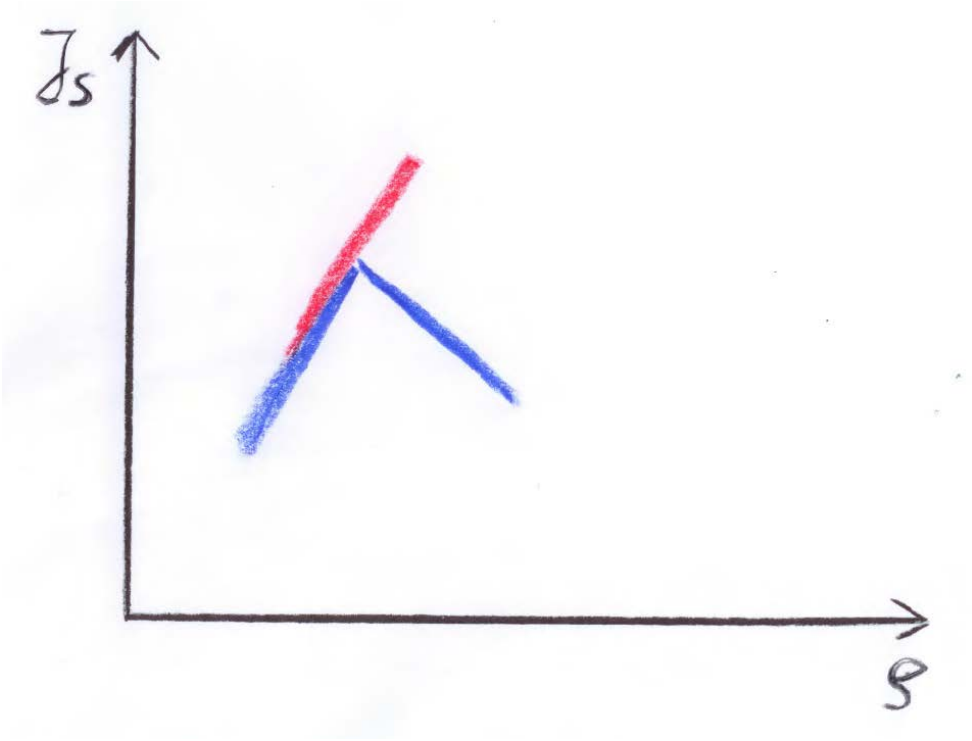
1) Jelic et al., 2012, Properties of pedestrians walking in line: Fundamental diagrams, Phys Rev E 85, 036111

2) Zhang et al., 2011, Transitions in pedestrian fundamental diagrams of straight corridors and T-junctions, J Stat Mech, P06004

Fd: Transitions (at the capacity)

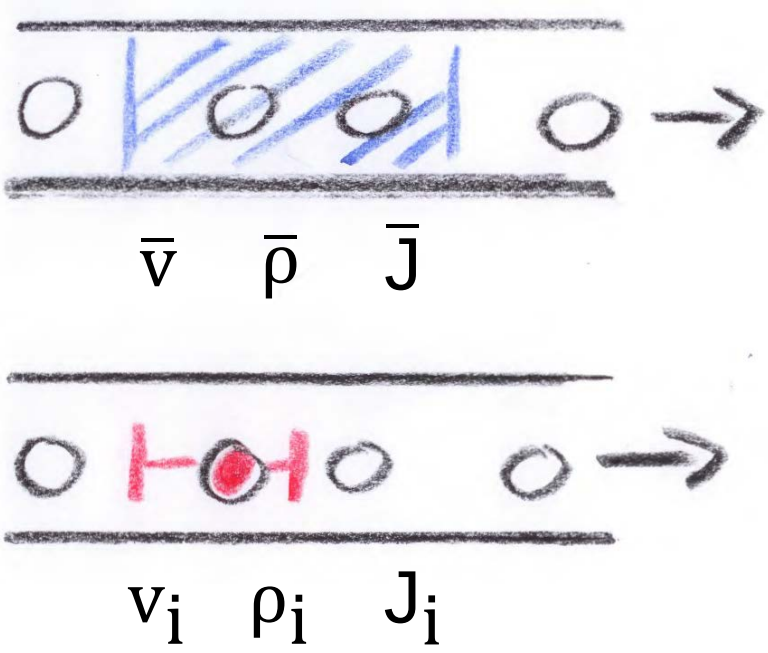


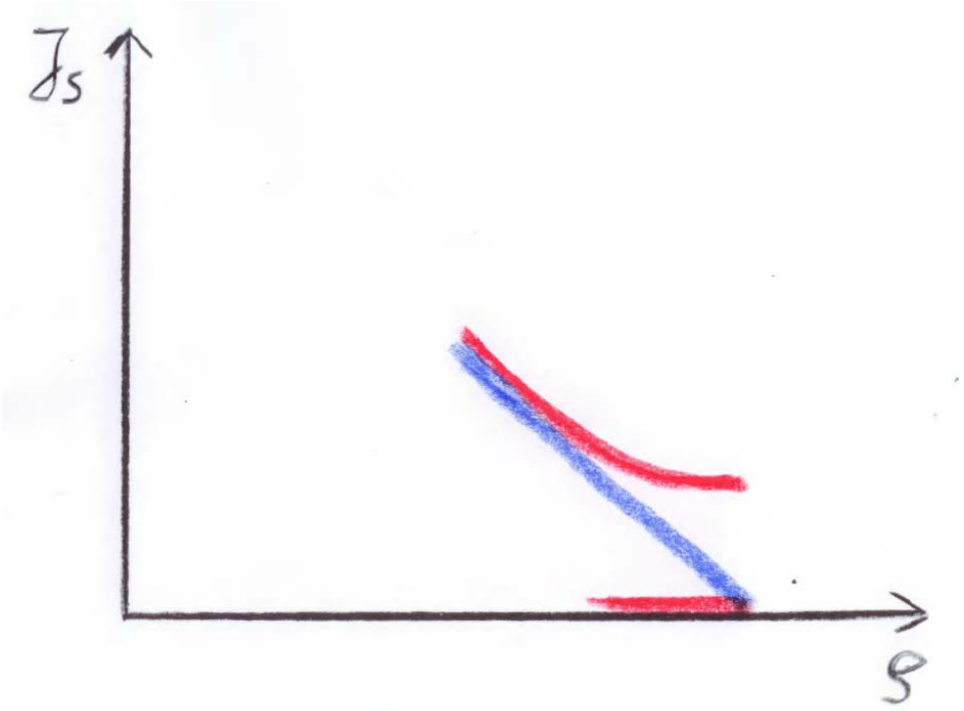




Zhang et al., 2014, Effects of Boundary Conditions on Single-File Pedestrian Flow, ACRI, Lecture Notes in Computer Science (LNCS), to appear

Fd: Transitions (stop and go waves)



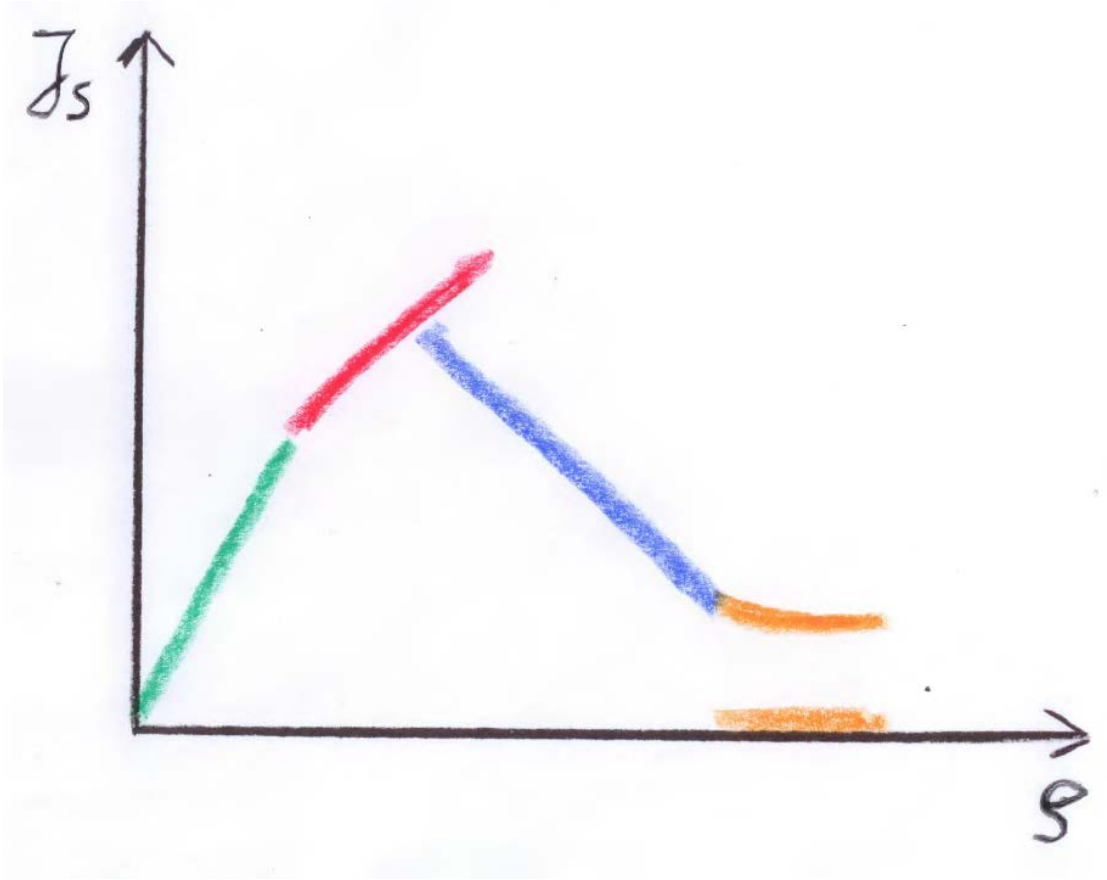


Portz, A. et al. (2011) Analyzing Stop-and-Go Waves by Experiment and Modeling Pedestrian and Evacuation Dynamics 2010, Springer, S. 577-586

Fundamental diagram: Summary

Regimes of the Fd

- Free flow regime 1
- Free flow regime 2
- Congested state 1
- Congested state 2 with STOP and GO



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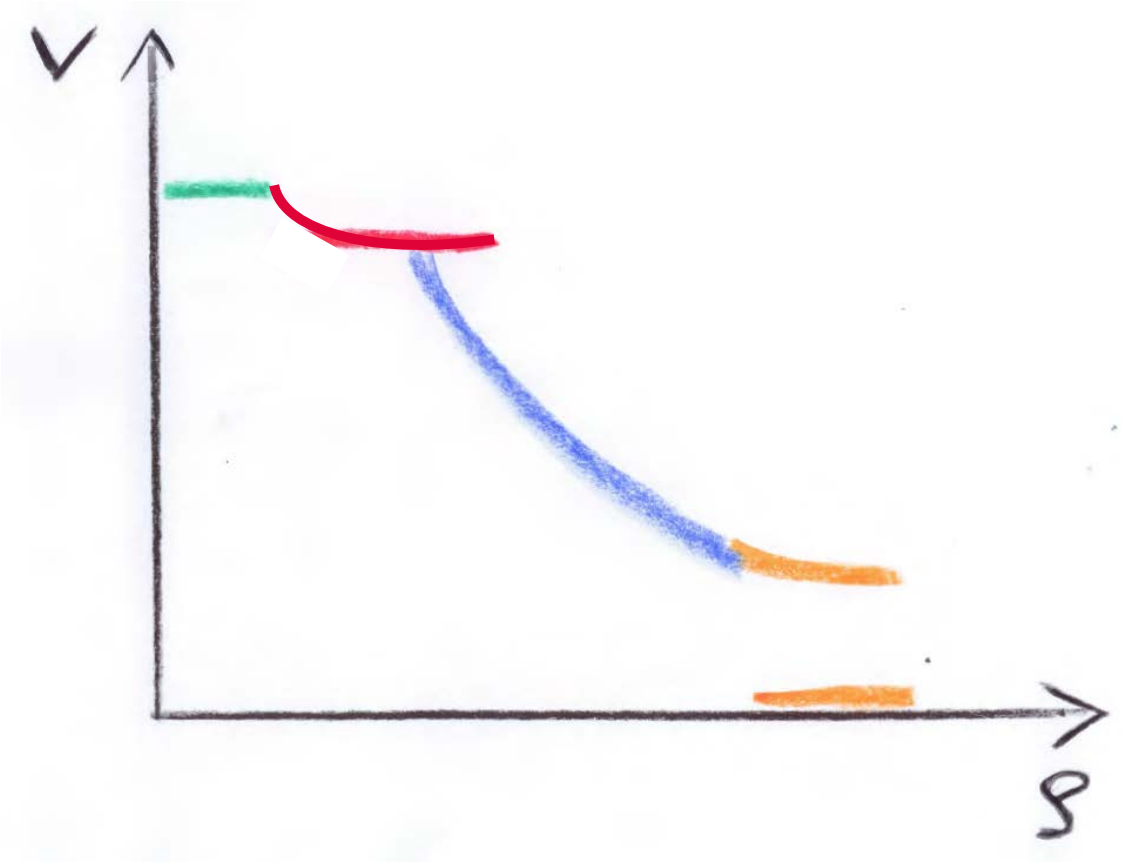

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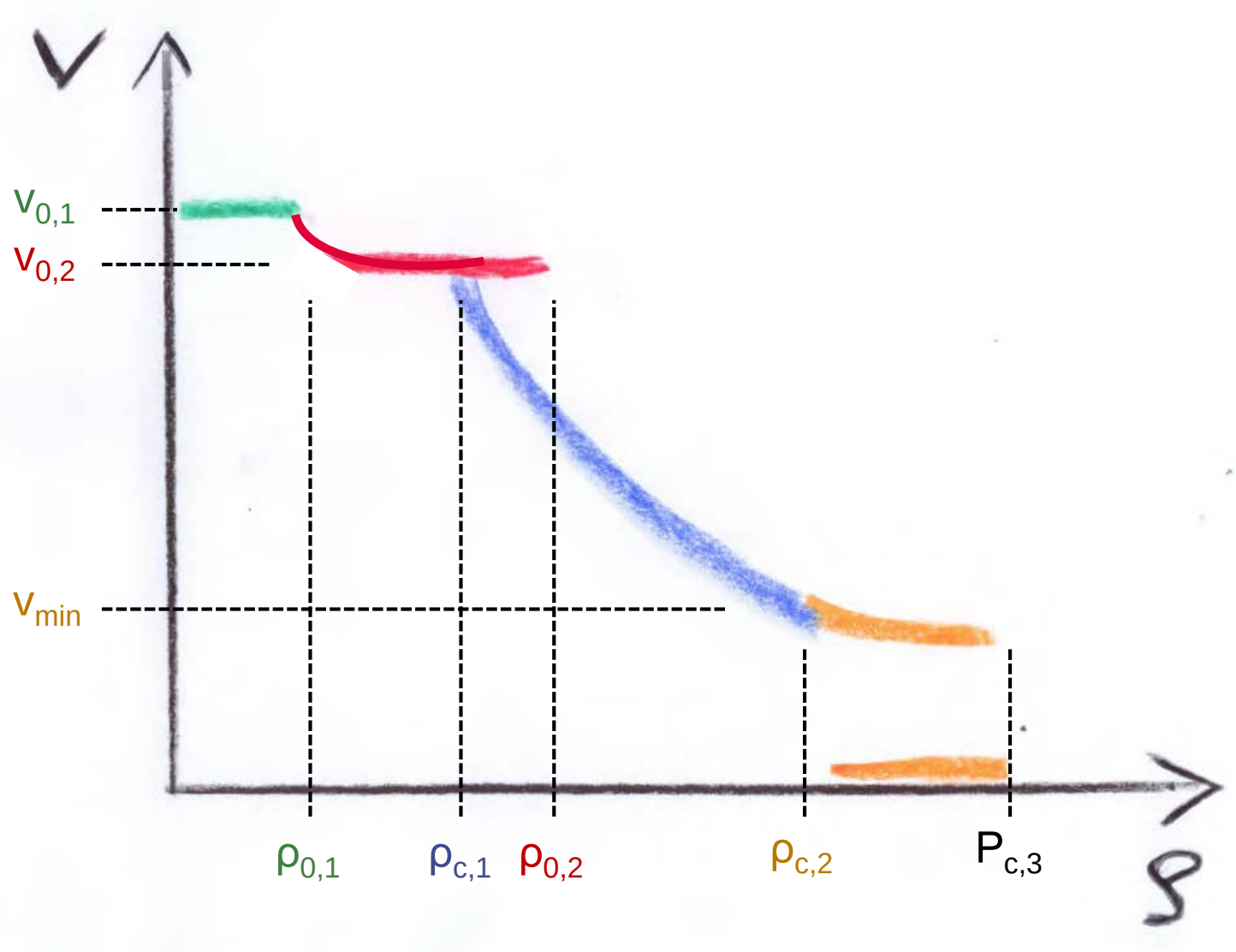


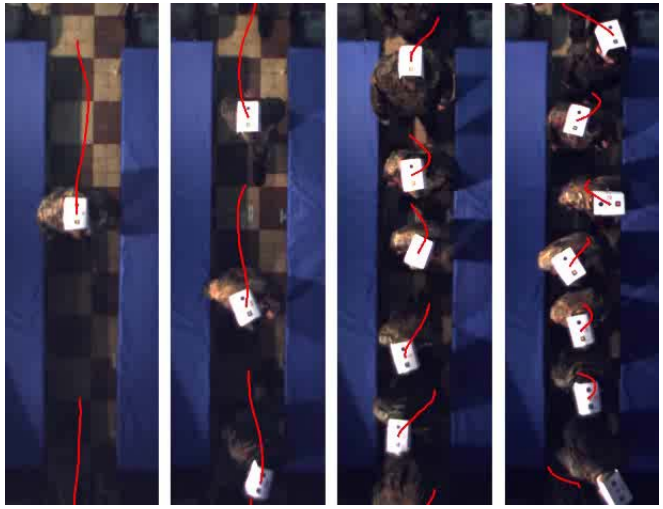
Comparison of 1d-FD for different pedestrians and enviroments

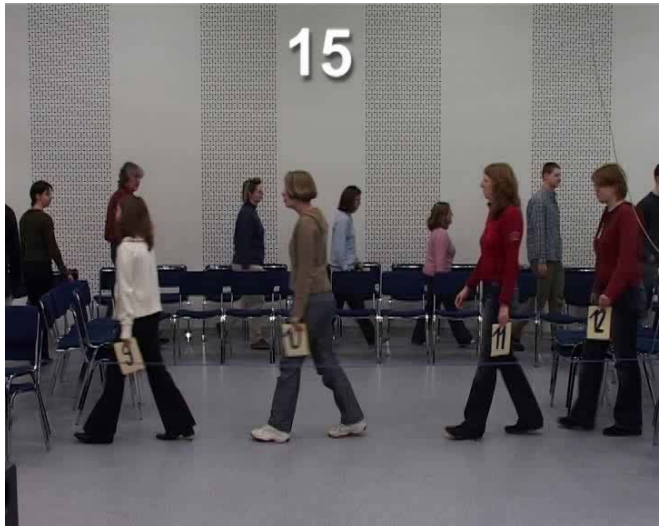
Yanagisawa, D.; Tomoeda, A. & Nishinari, K.,*Improvement of pedestrian flow by slow rhythm*, Phys. Rev. E, American Physical Society, 2012, 85, 016111

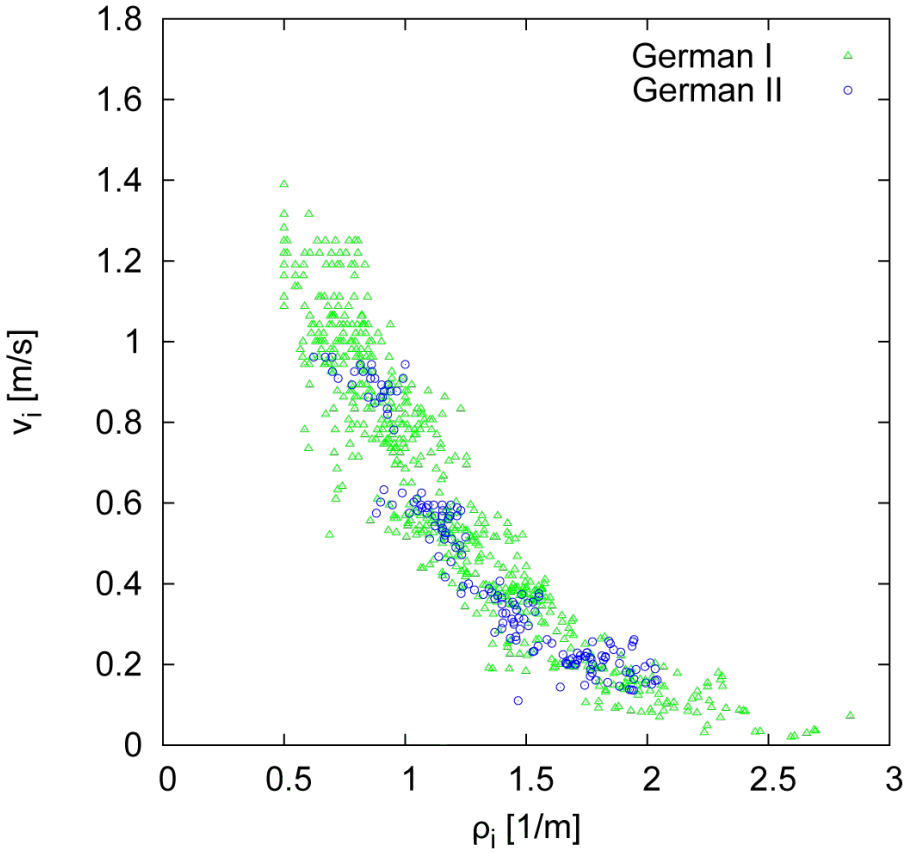
U. Chattaraj et al., Advances in Complex Systems 12(3), 393-405, 2009

J. Lukowski, Masterthesis, Univ. Wuppertal (2009)

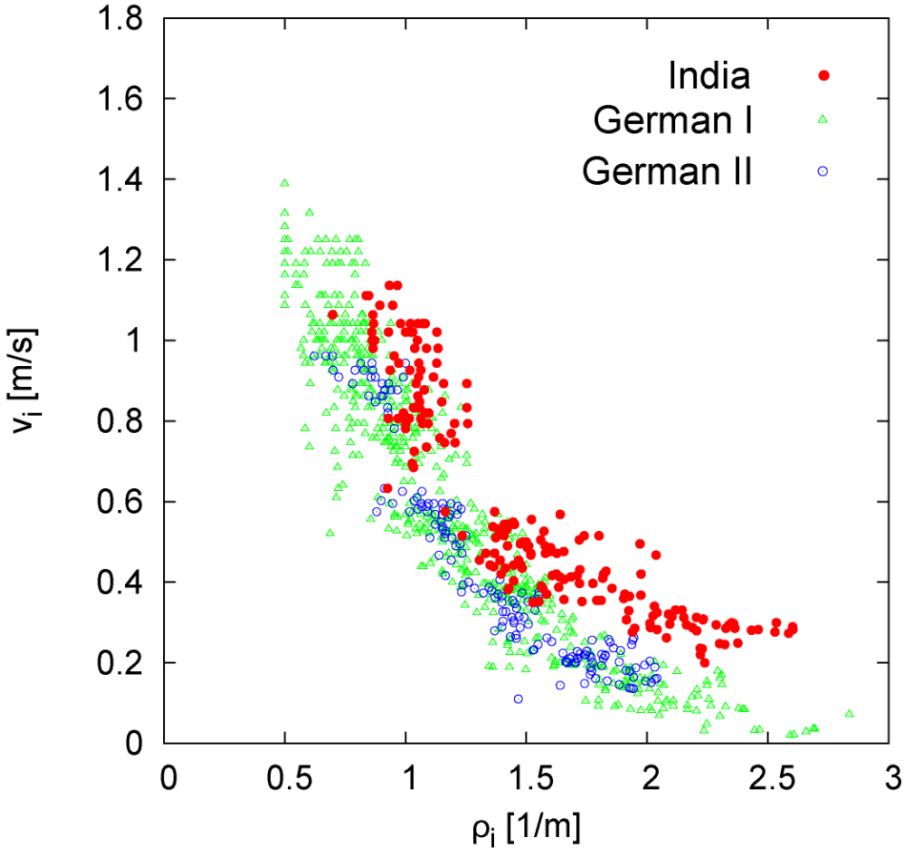
Soldiers versus students





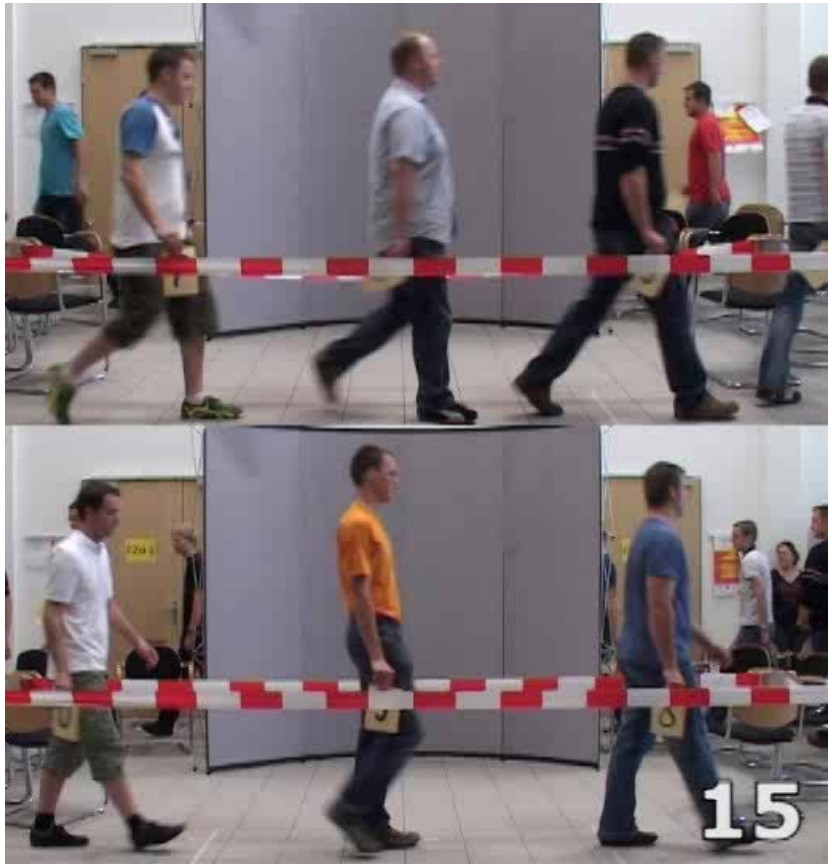


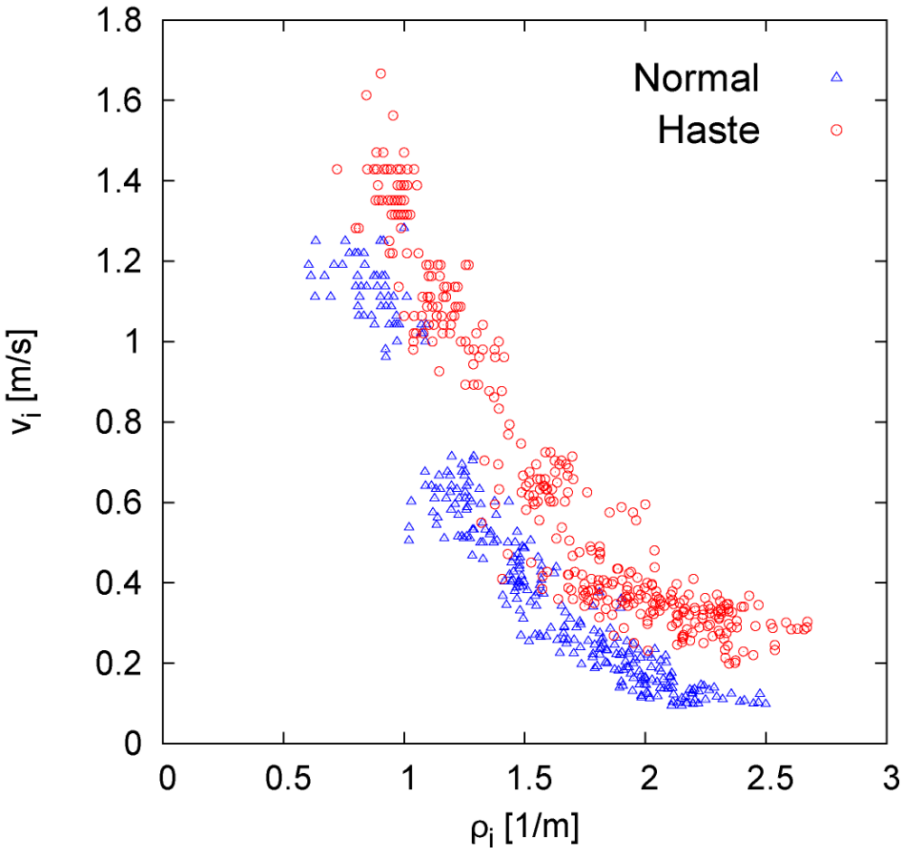
India (male) versus German I and II



*U. Chattaraj et al., Advances in Complex Systems 12(3), 393-405, 2009

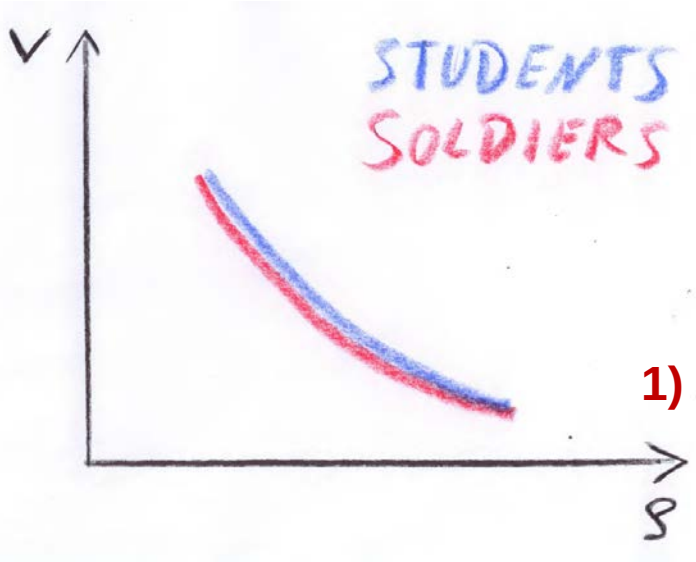
Influence of motivation*

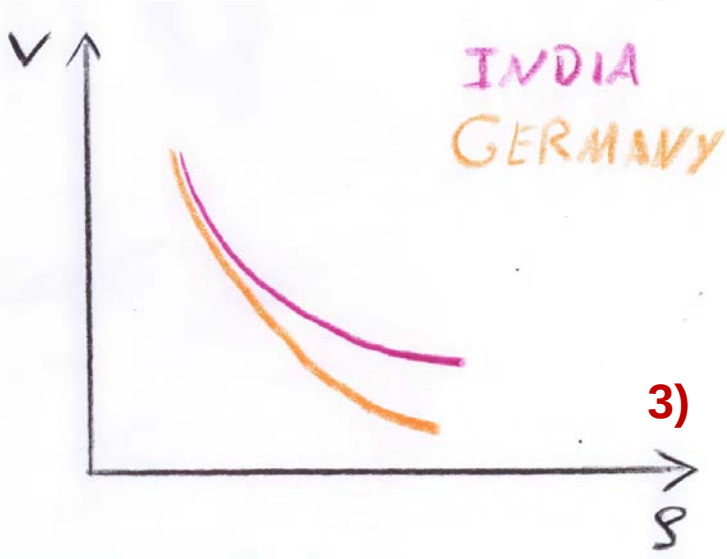




*J. Lukowski, Masterthesis, Univ. Wuppertal (2009)

FD: Potential influences



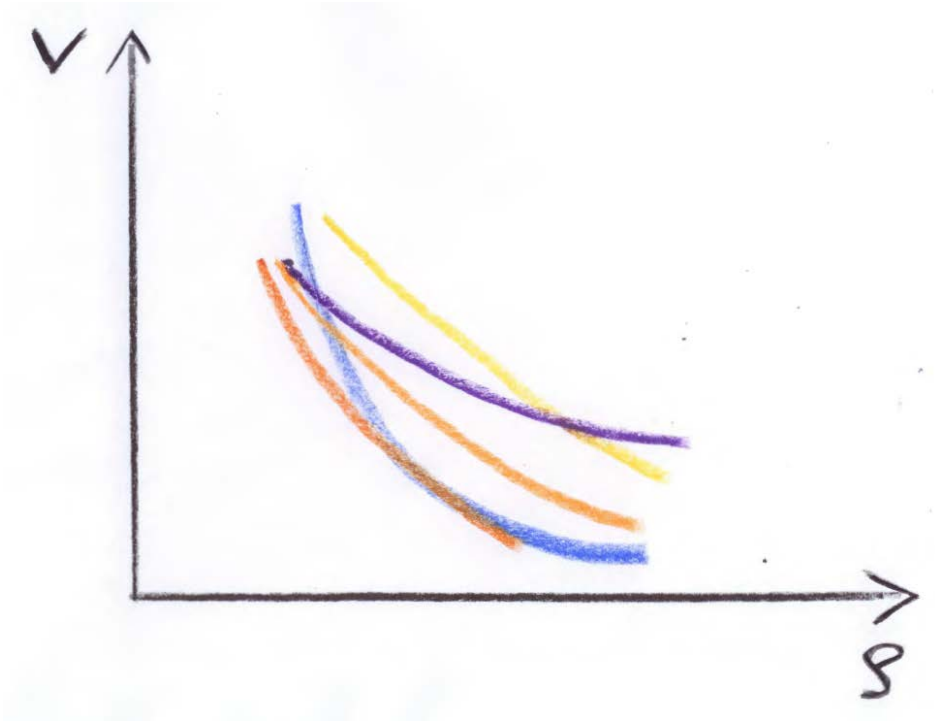


1) Portz, et al. (2011) PED 2010
2) Lukovski (2008) Masterthesis Wuppertal
3) Chattaraj (2009) Adv Comp Sys 12(3), 393
4) Nishinari, Tokyo, Japan
5) Delft
6) Hefei
7) SL-Rasch, …

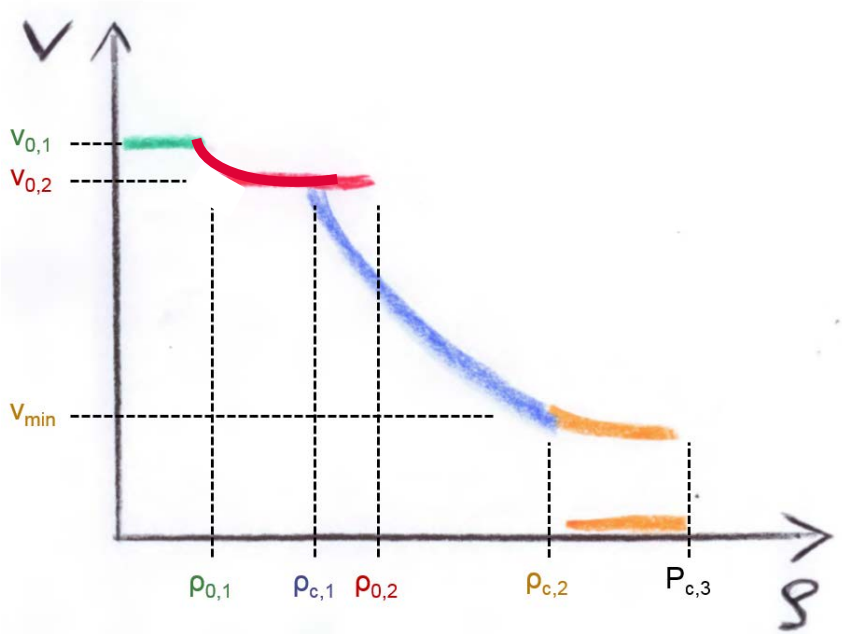
FD: Potential influences

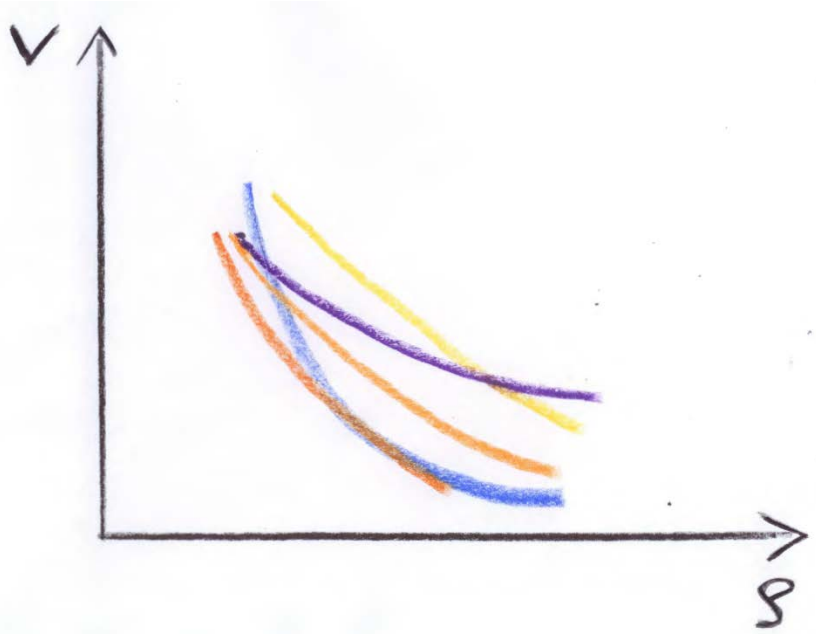
Other potential influences

- Age
- Gender
- Social relations (groups)
- Fitness
- Size
- Weight
- Weather
- Motivation
- Attention
- Trip purpose
- Lighting
- Season
- Ground
- Indoor or outdoor
- Daytime
- Living space
- Distractions, …



Fundamental diagram: summary





Regimes of the Fd

- Free flow regime I ($\rho_{0,1}$,$v_{0,1}$)
- Free flow regime II ($\rho_{0,2}$,$v_{0,2}$)
- Congested state I ($\rho_{c,1}$,$v_{0,2}$)
- Congested state II ($\rho_{c,2}$,v_{min} $\rho_{c,3}$) with STOP and GO

Potential influences on $\rho_{i,j}$,$v_{i,j}$

- Age
- Gender
- Training
- Weather
- Motivation
- Attention
- Lighting, …

Comparison of 1d-FD of cars, bicycles and pedestrians

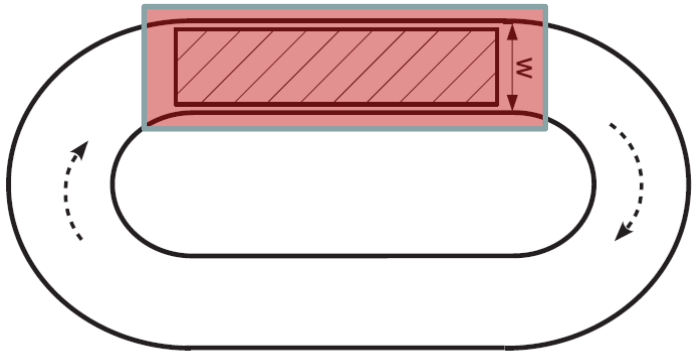
Zhang, Mehner, Holl, Boltes, Andresen, Schadschneider and Seyfried
Universal flow-density relation of single-file bicycle, pedestrian and car motion
Physics Letters A 378 (2014) 3274–3277

Pedestrians

Setup details

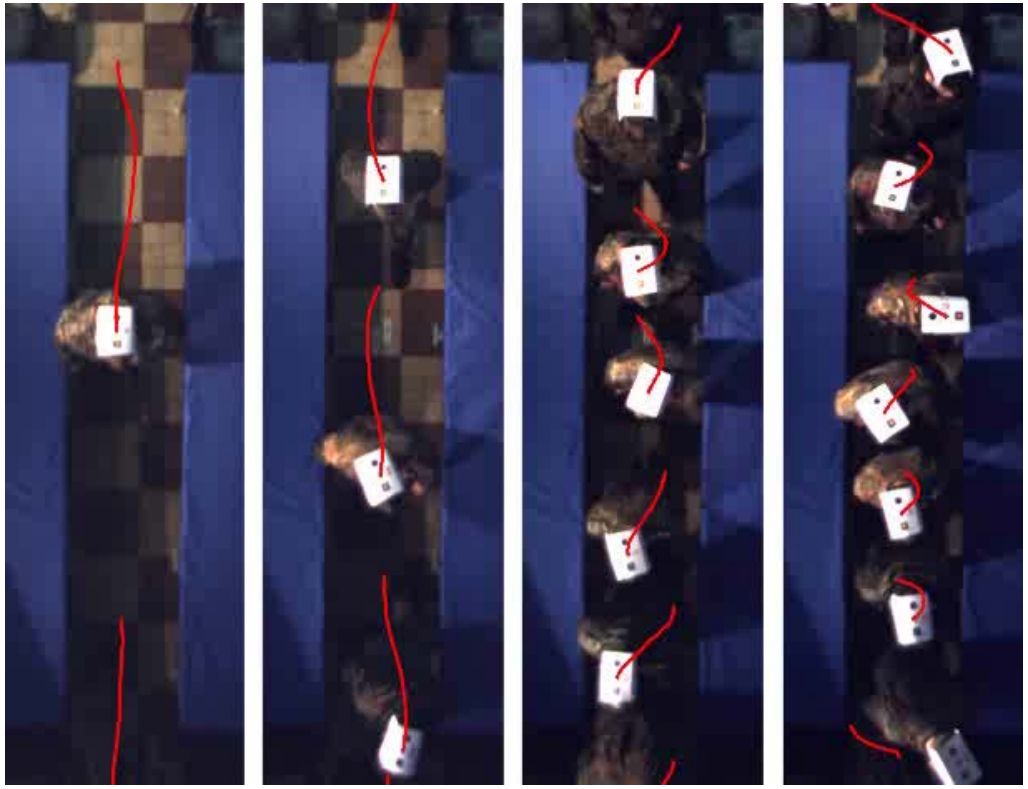
- Closed system
- Oval shape circuit with length

L = 26 m



- Number of pedestrians

N = 14, 17, 20, 22,
25, 28, 34, 39,
45, 54, 62, 70



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

Seyfried et al., 2010, PED 2008

Bicycles

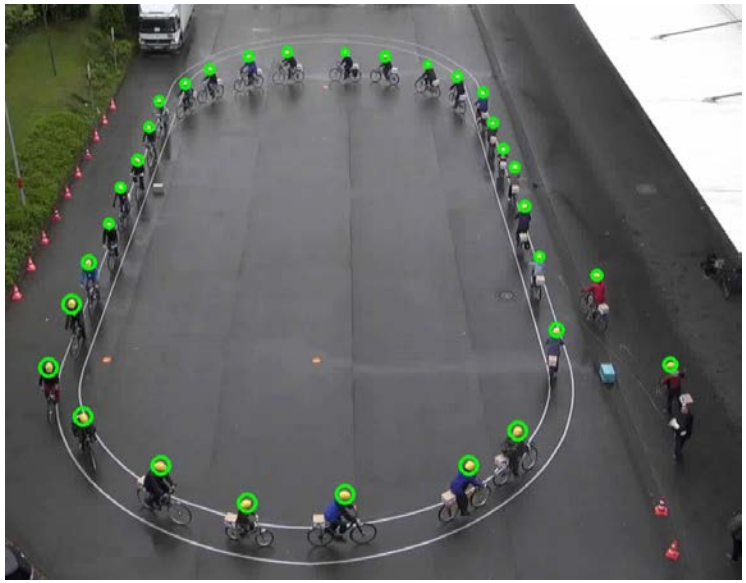
Setup details

- Oval shape circuit with length

  L = 86 m

- 6 runs with number of bicycles

  N = 5, 10, 15,
  18, 20, 33



Andresen et al. 2013 1st SUMO user conference 2013, LNCS, to appear

Cars

Setup details

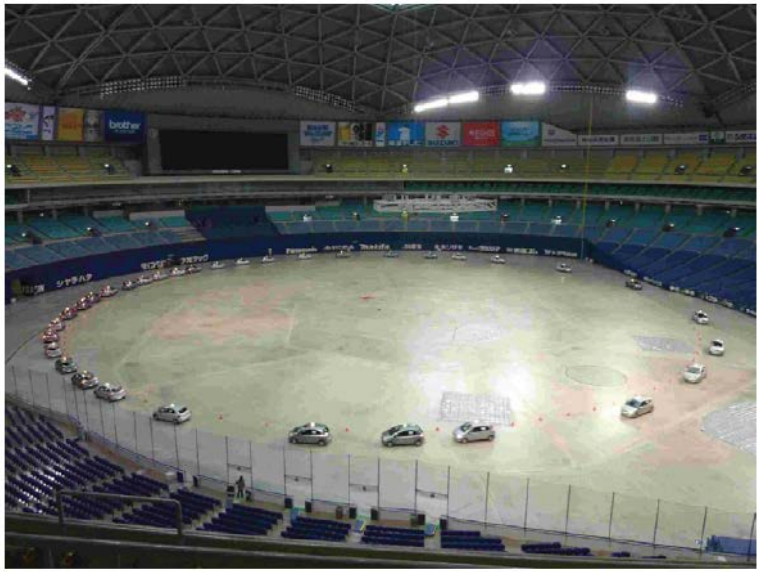
- Circuit shape of length

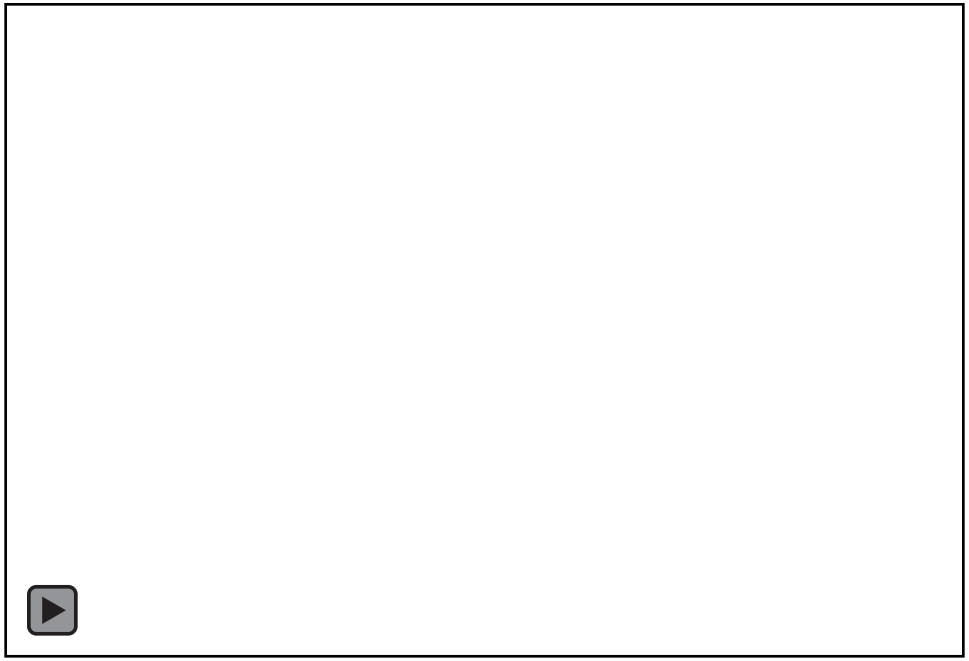
  L = 230 m and 312 m

- 21 runs with numbers

  N_{230} = 22, 23

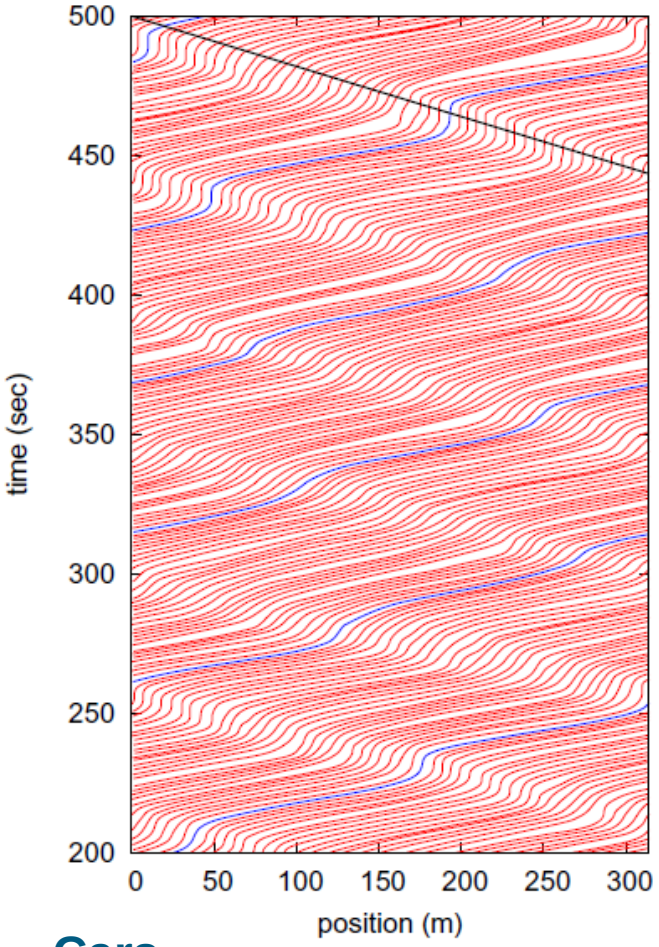
  N_{312} = 10 - 40 (19 runs)



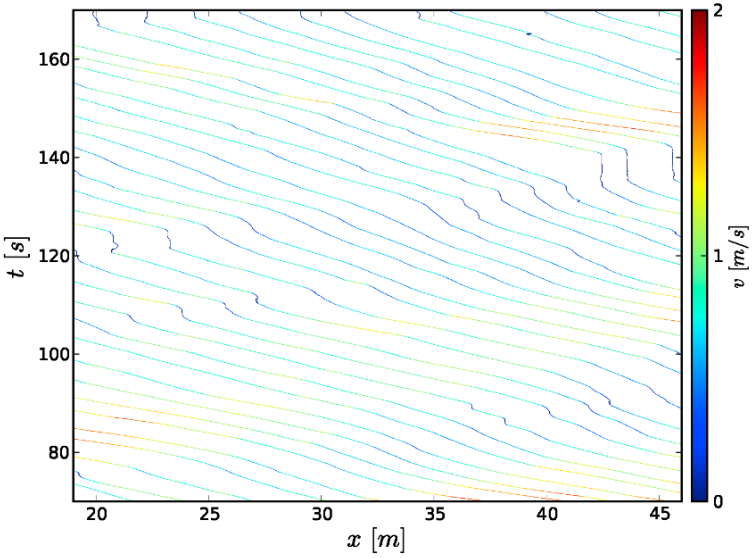


Sugiyama et al., 2008, *New Jour. Phys.* **10**, 1-7
Tadaki et al. 2013, *New Jour. Phys.* **15**, 103034

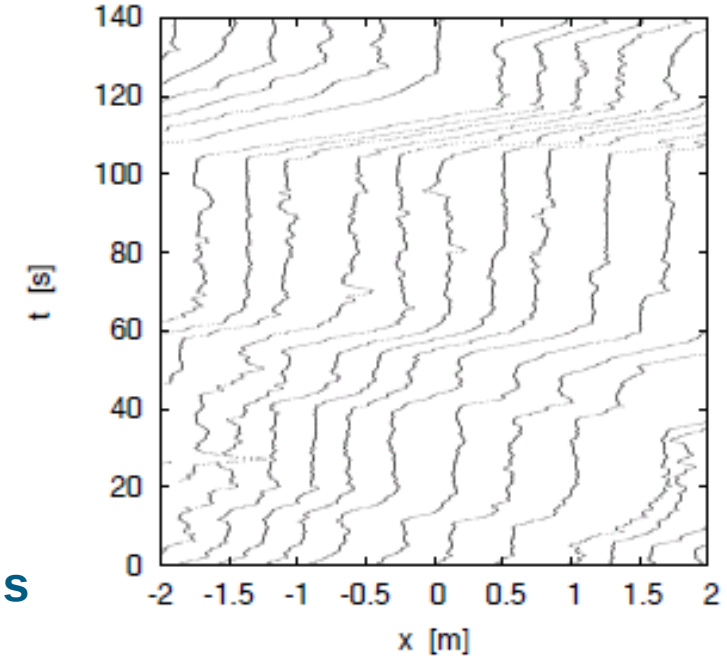
Instabilities (stop and go waves)



Cars

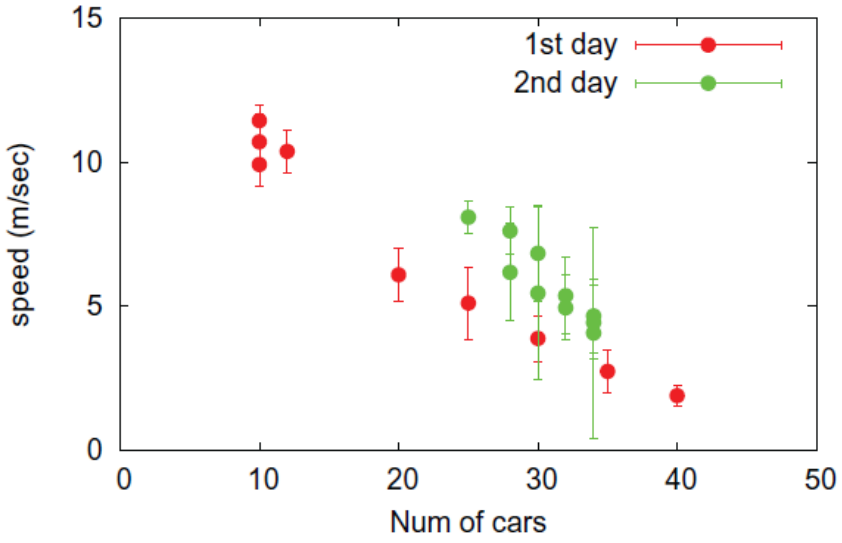


Bicycles



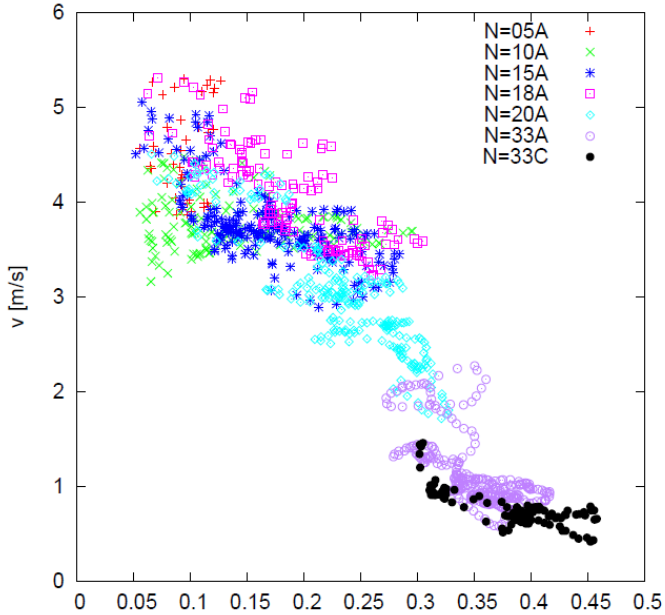
Pedestrians

Speed-density relations

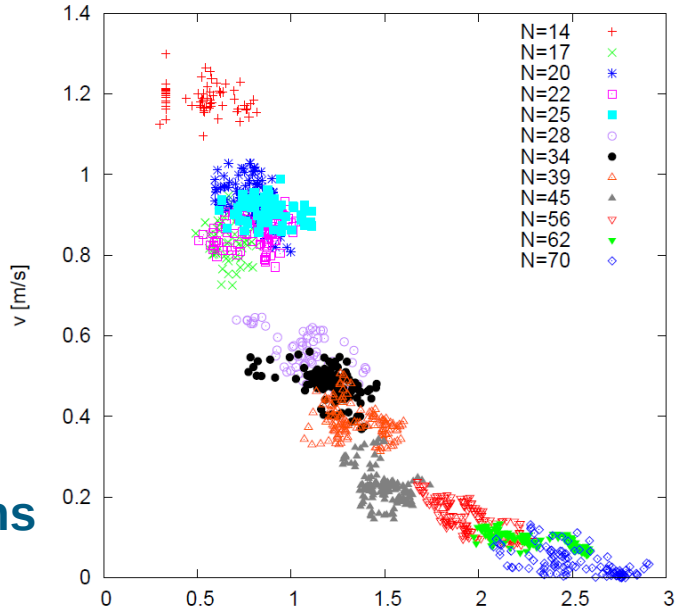


Cars

Bicycles



Pedestrians



Comparison and scaling

Scaling factors

Density $\rho \rightarrow {}^{\rho}/_{\rho_0} = \rho L_0$

Ped: L_0 = 0,40 m

Bicy: L_0 = 1,73 m

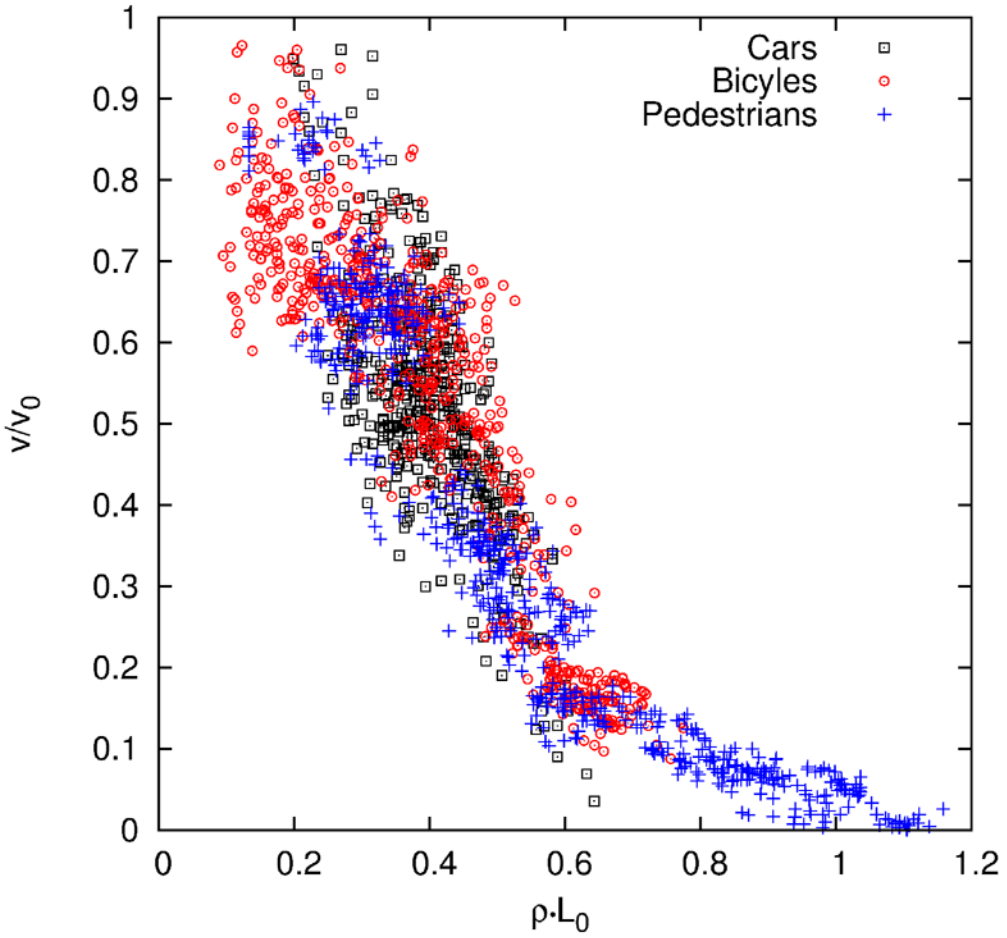
Cars: L_0 = 3,90 m

Speed $v \rightarrow {}^{v}/_{v_0}$

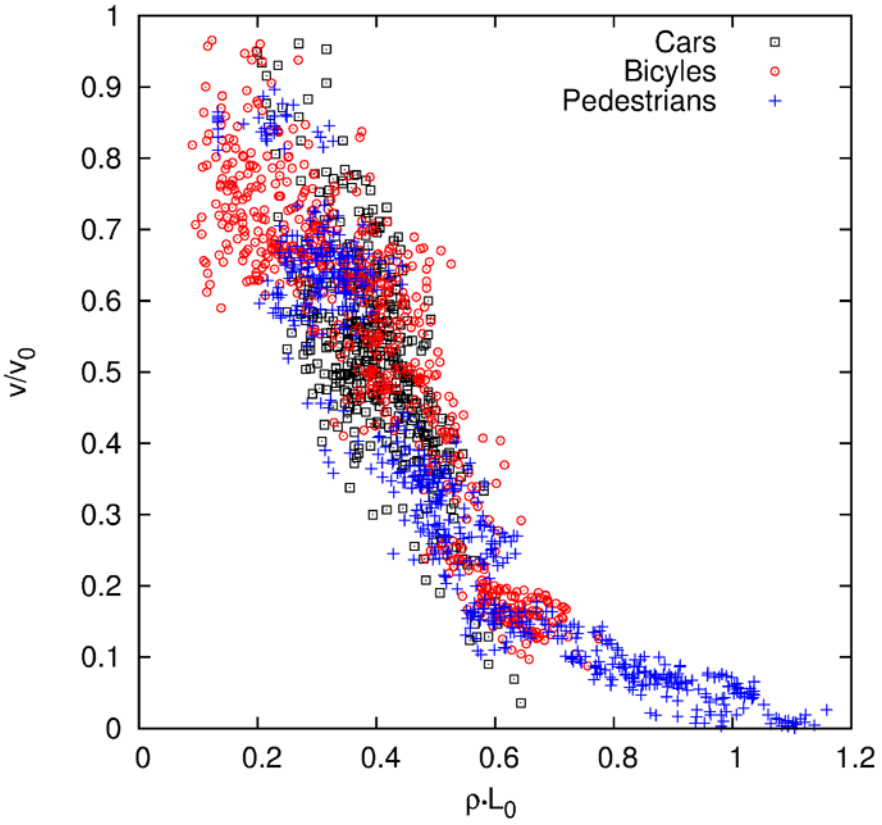
Ped: v_0 = 1.4 m/s

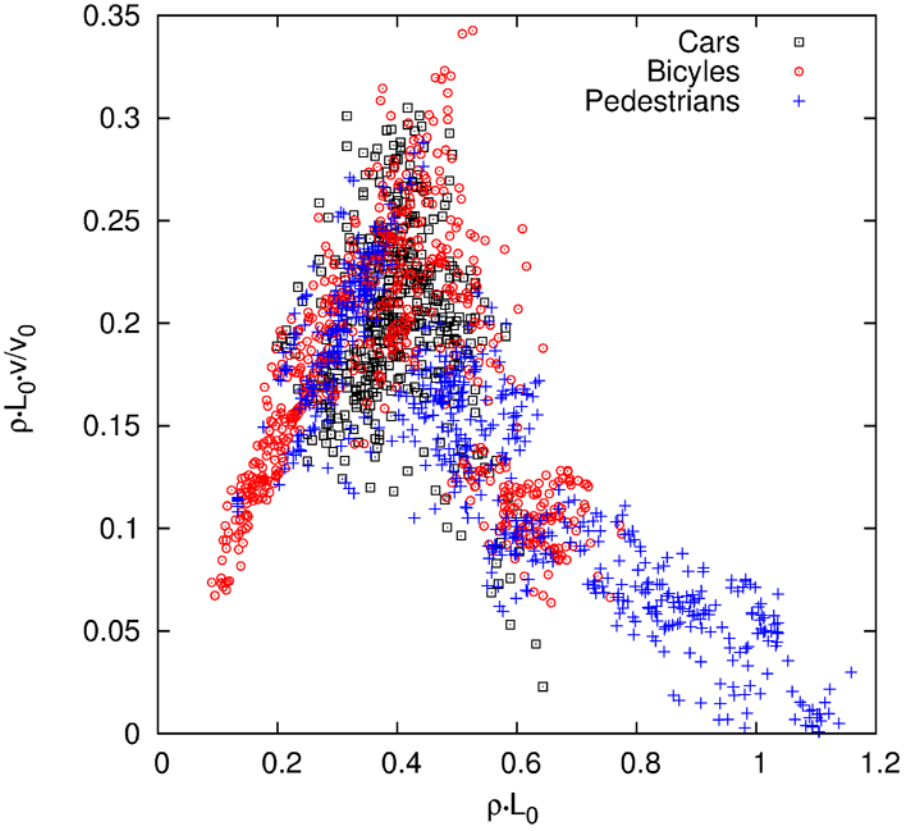
Bicy: v_0 = 5.5 m/s

Cars: v_0 = 11.1 m/s



Comparison of scaled relations

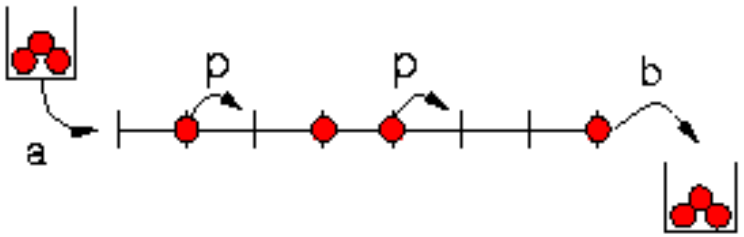




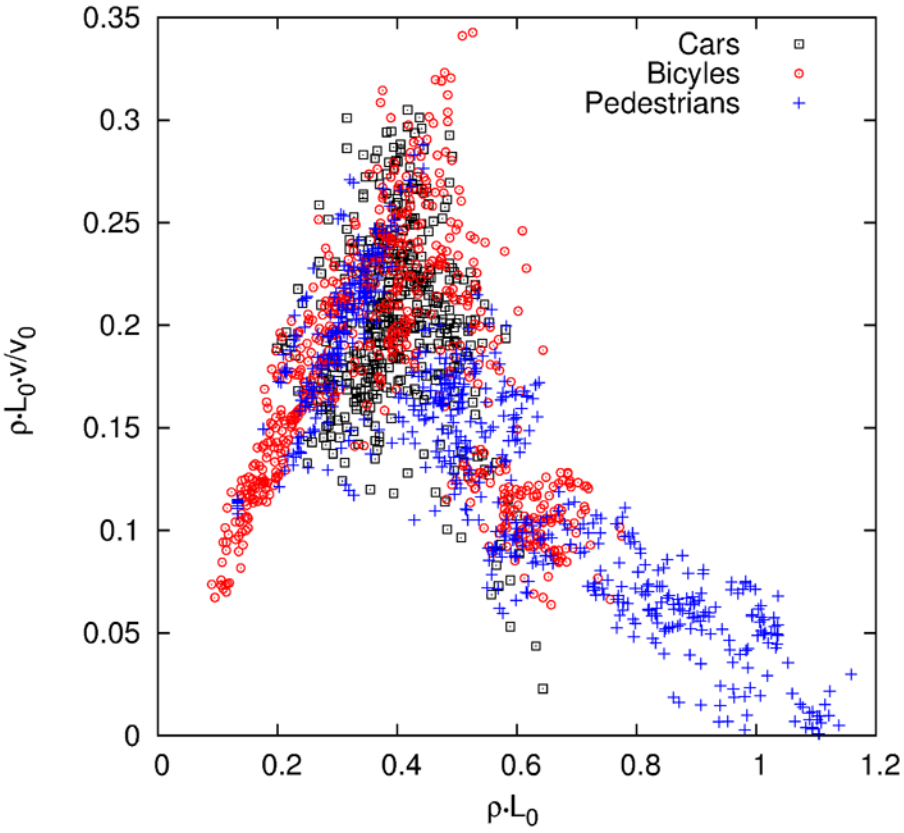
Massage

Simplest model reproducing such a shape?

Asymmetric exclusion process



- Particles hoping with a probability p from cell to cell



Ingredients

- Particles prefer a direction
- **Volume exclusion** (Two particles in one cell are forbidden)

Summary

Experiments

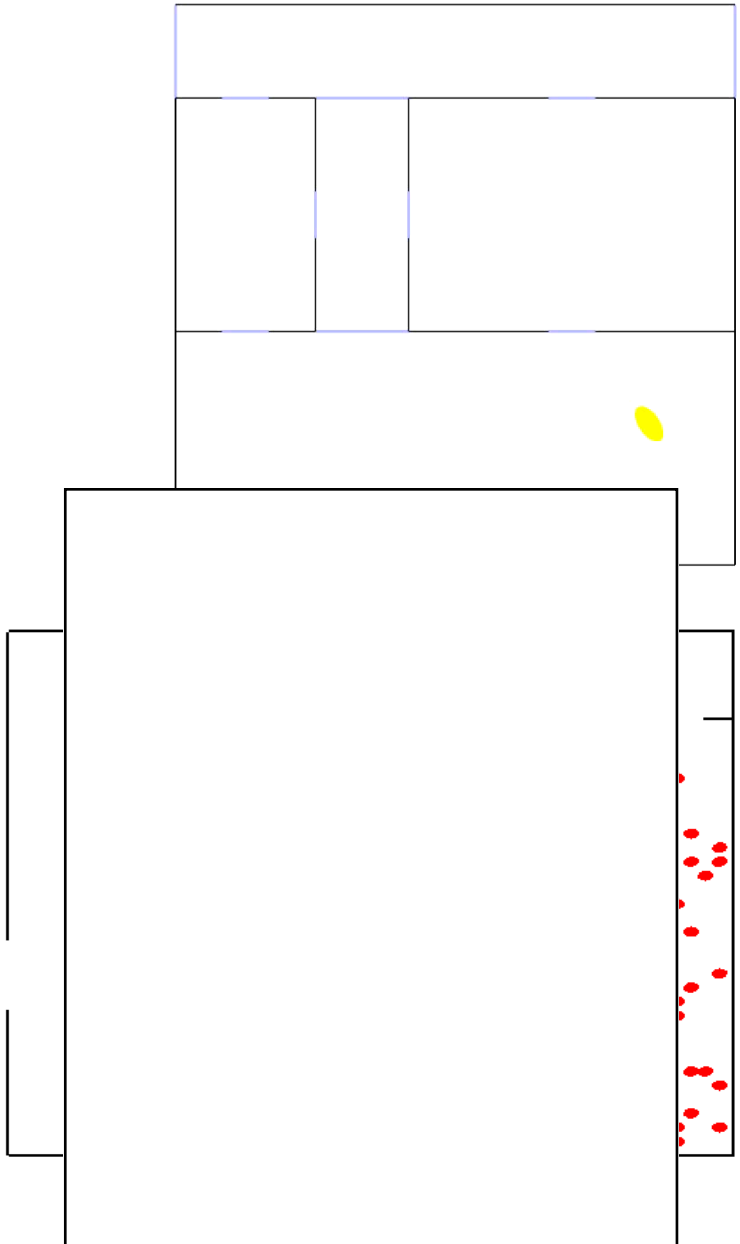
- Open source database including video recordings, trajectories, …

  http://www.fz-juelich.de/ias/jsc/cst

Modeling – Open source project

JuPedSim

- JPScore: computing trajectories
- JPSvis: visualizing trajectories.
- JPSreport: analyzing trajectories and validating the model
- JPSed: editing geometry and model parameters



Thank you

Density measurement with Voronoi-diagrams

Steffen, B. und Seyfried, A.
Methods for measuring pedestrian density, flow, speed and direction with minimal scatter
Physica A, 2010, 389, 1902-1910

Definitions for the density

Different definitions

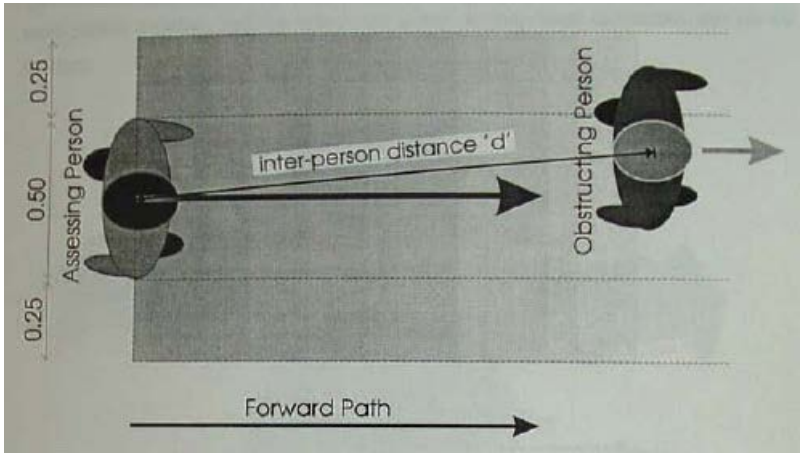
- Classical

$$\rho_{class} = \frac{N}{|A|}$$

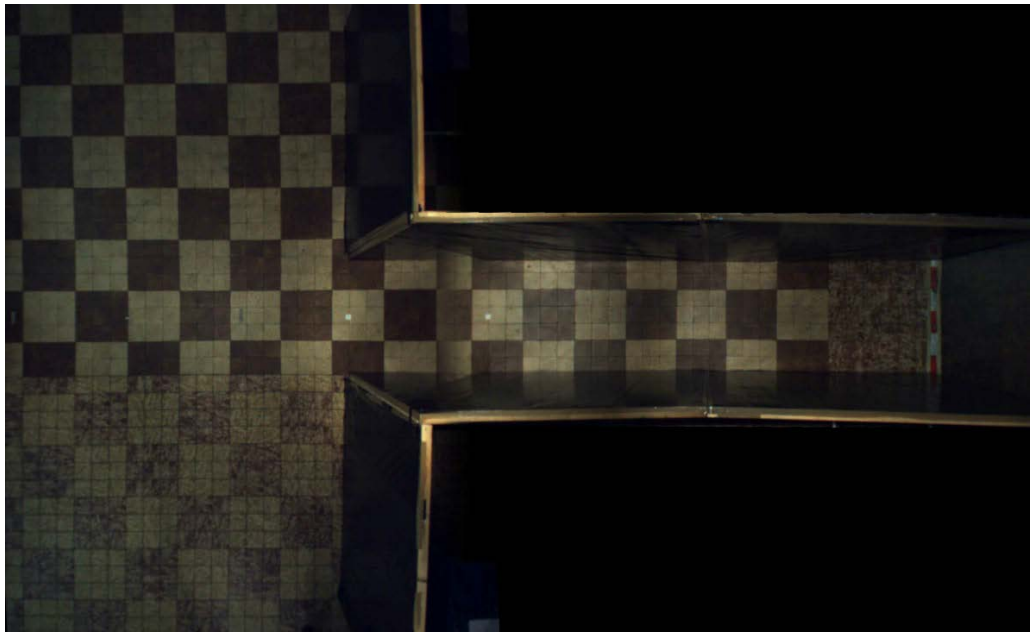
- Pedestrian area module M (Fruin)
  - computed by the classical density

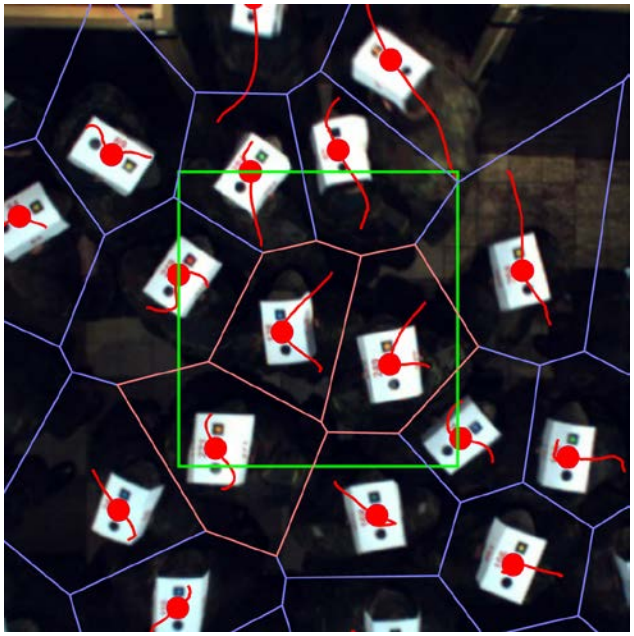
$$M = \frac{1}{\rho_{class}}$$

- Interperson distance (Thompson)
  - not unique
  - …



Problems of the classical density definition



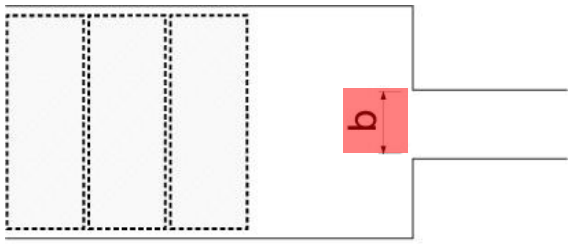


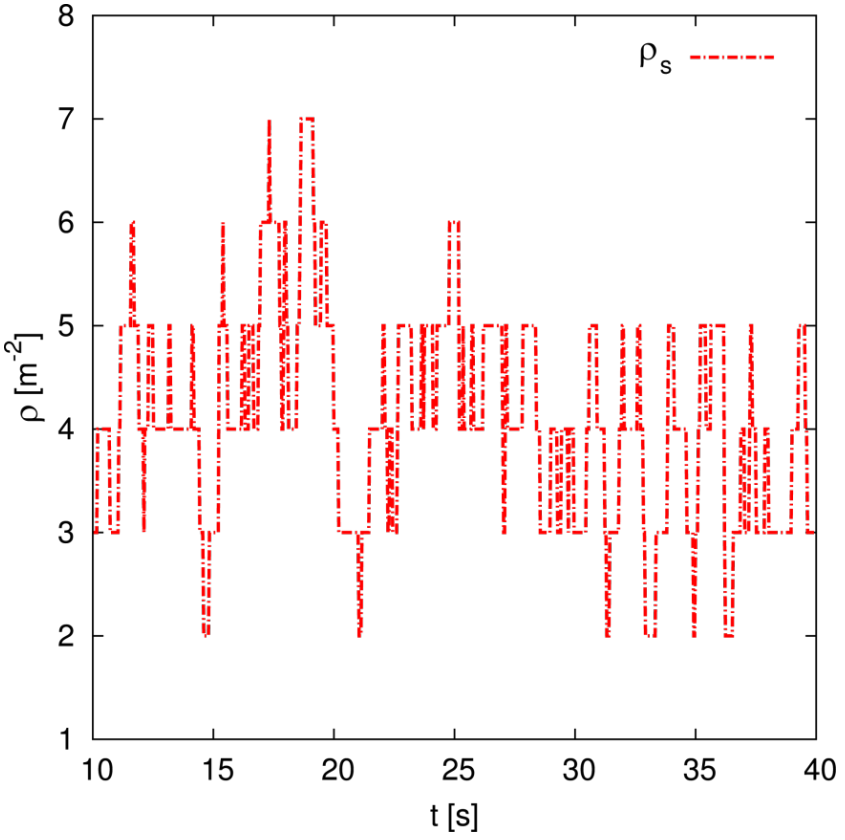
Problems

- Size of facilities normally restricted to 1 -10 m
- Number of pedestrians in the measurement area is small
- Mean value and fluctuations have same order of magnitude
- Proportion between of particle number and measurement area problematic

Problems of the classical density definition

Local density in front of the bottleneck





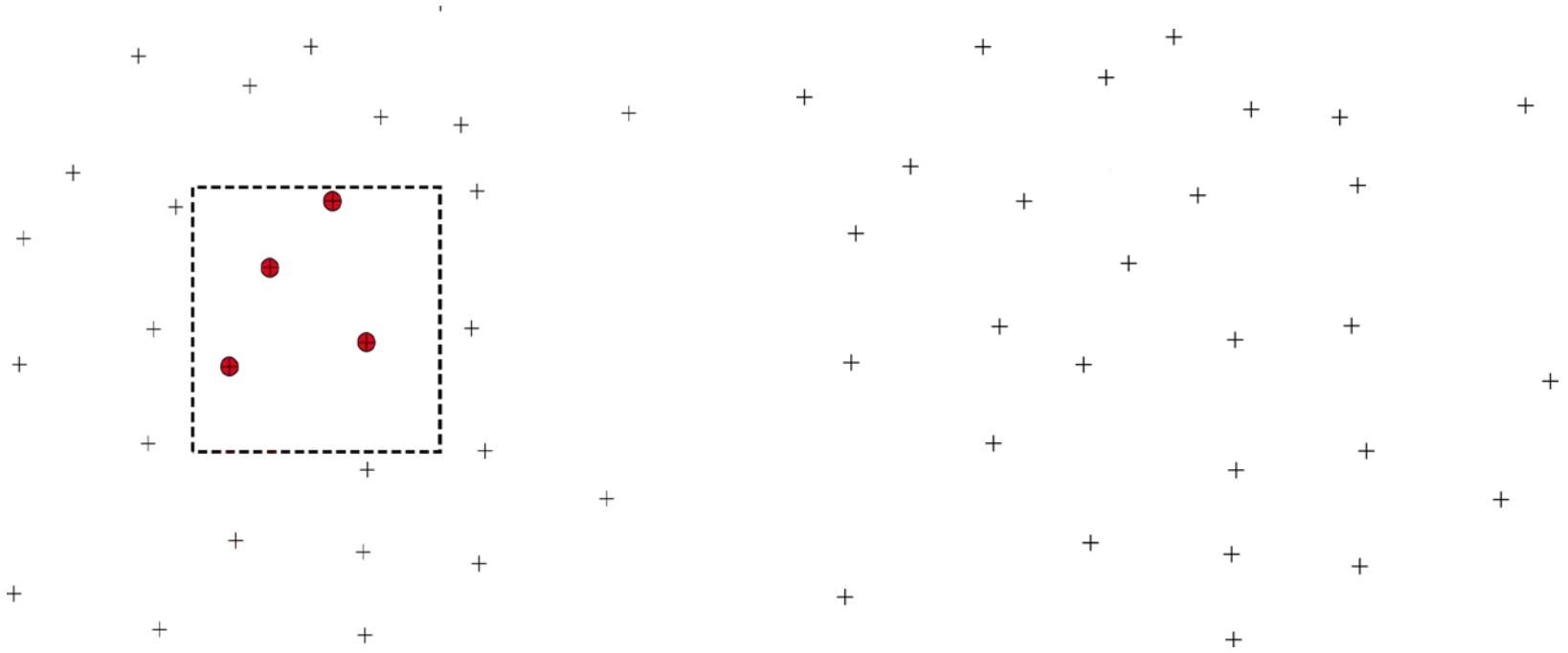
- Large fluctuations

  $\rho_{min}=2\ m^{-2}$ to $\rho_{max}=7\ m^{-2}$

- Stationary state?
- Mean value?

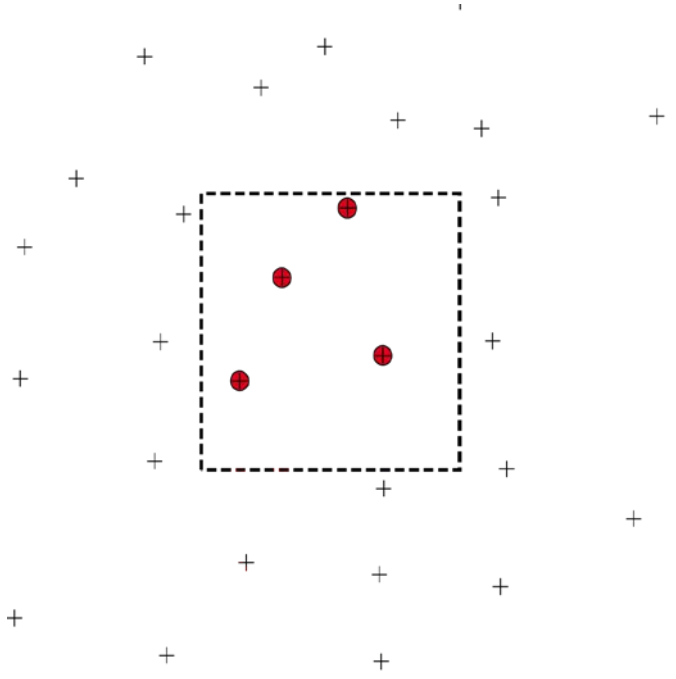
Voronoi - Density

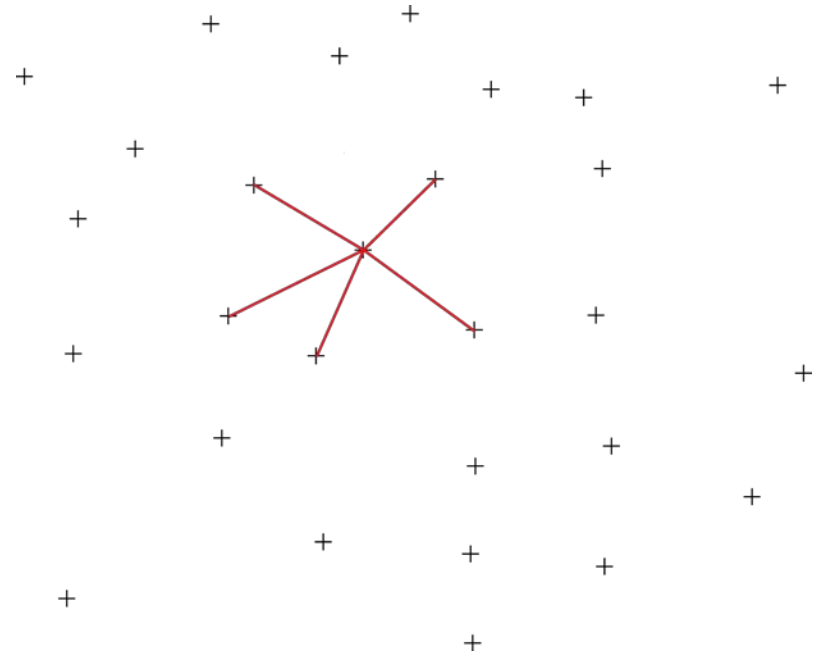
$$\rho_{class} = \frac{N}{|A|}$$



Voronoi - Density

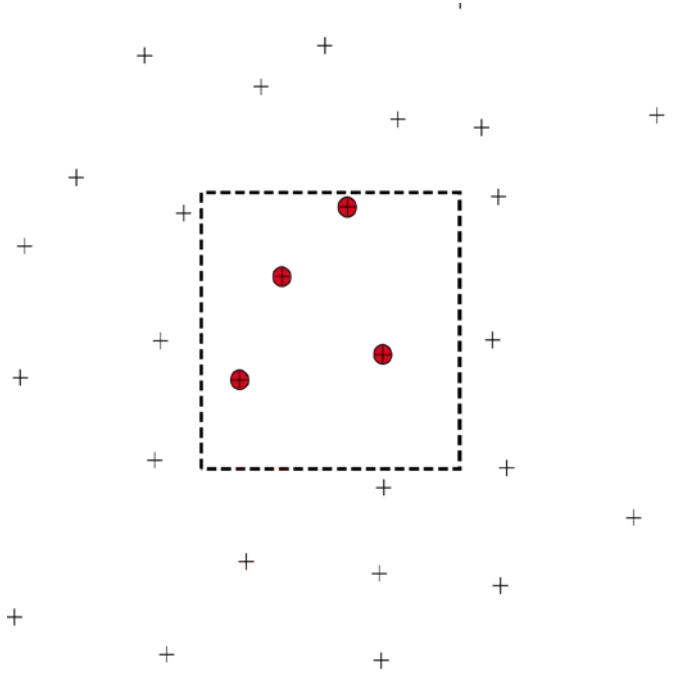
$$\rho_{class} = \frac{N}{|A|}$$

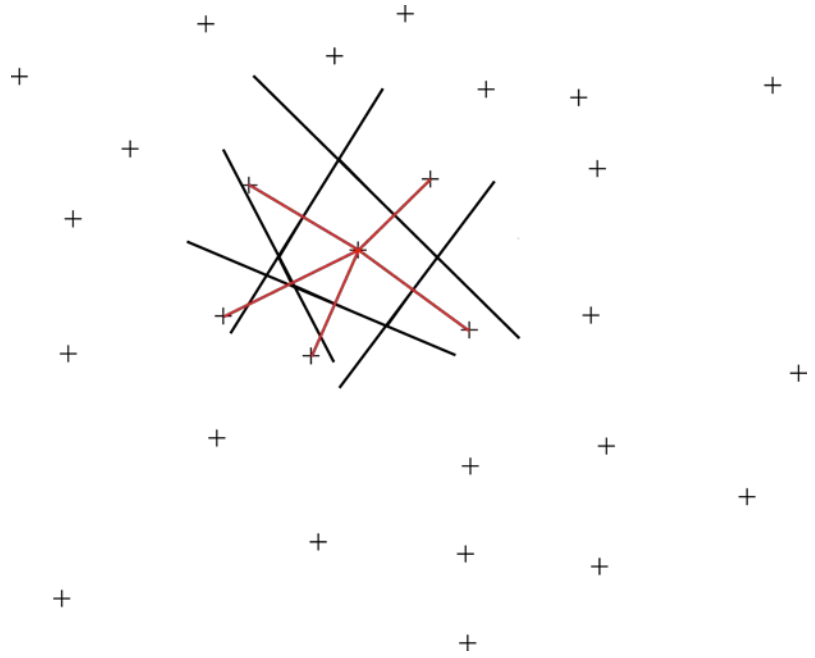




Voronoi - Density

$$\rho_{class} = \frac{N}{|A|}$$

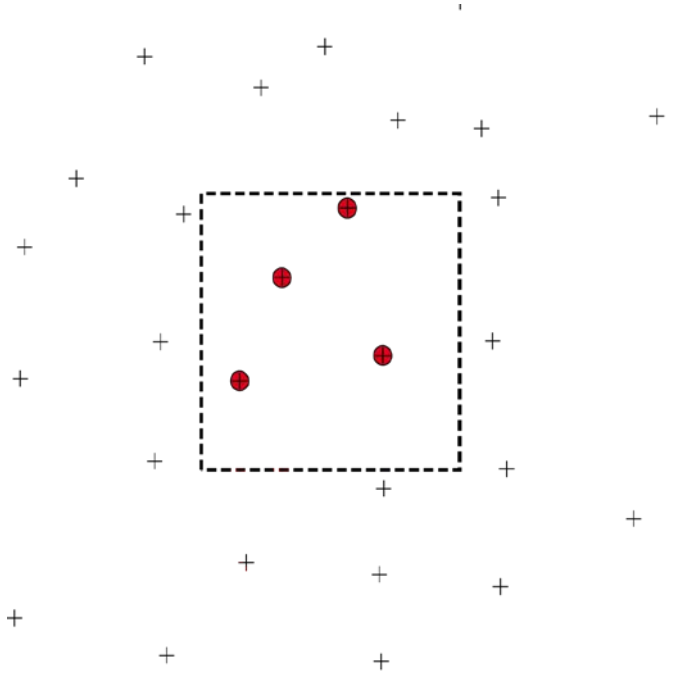


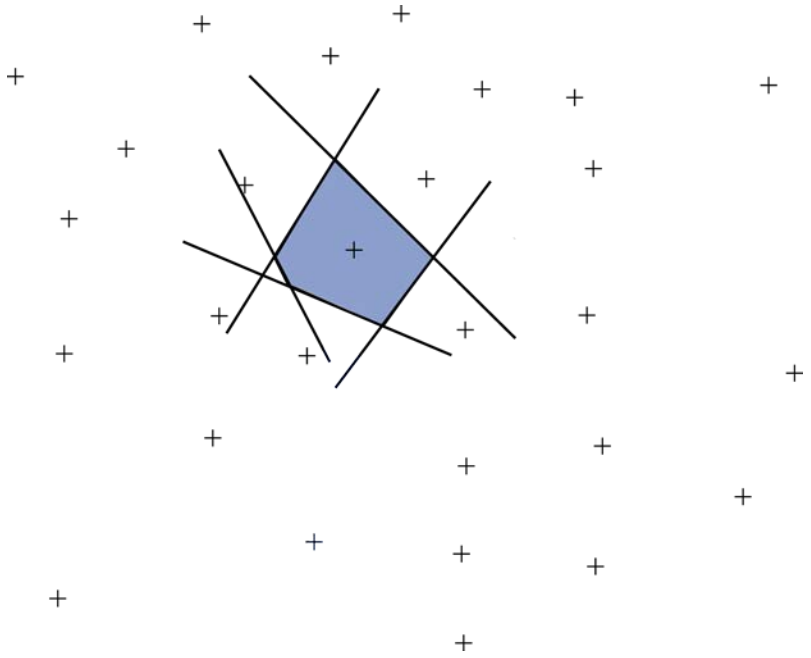


Voronoi - Density

$$\rho_{class} = \frac{N}{|A|}$$

Voronoi - Cell: A_i

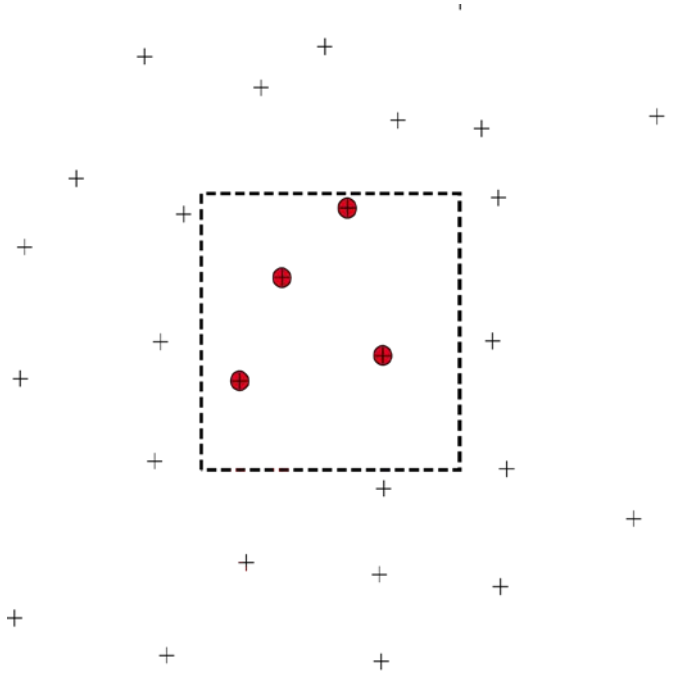


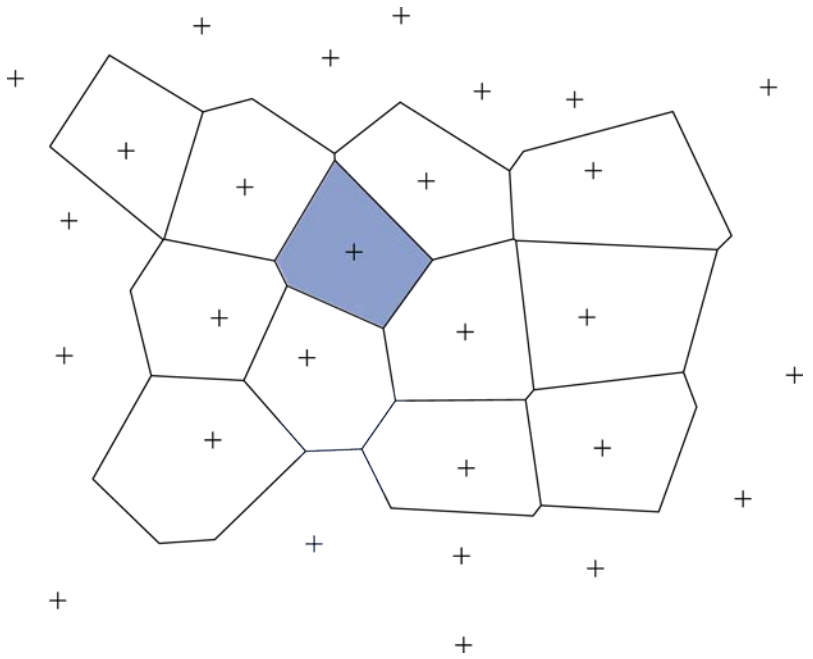


Voronoi - Density

$$\rho_{class} = \frac{N}{|A|}$$

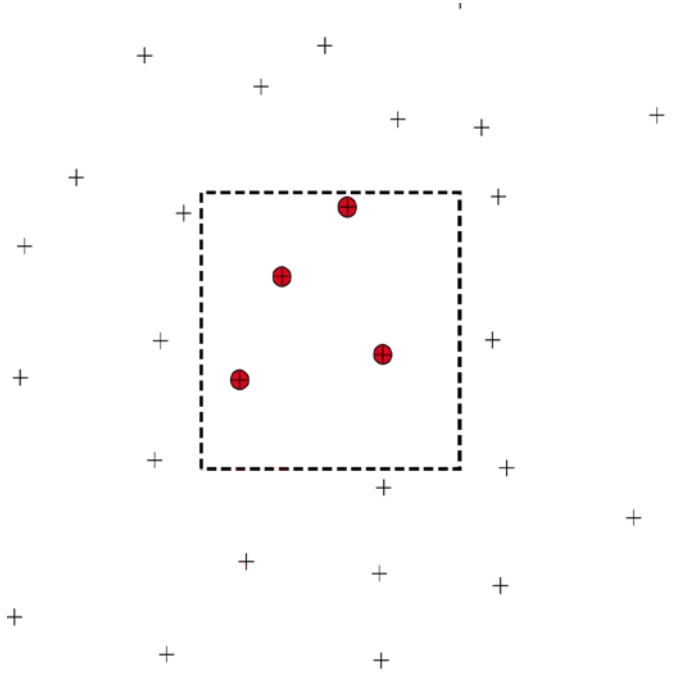
$$p(\vec{x}) = \begin{cases} 1/A_i & : \vec{x} \in A_i \\ 0 & : \text{else} \end{cases}$$

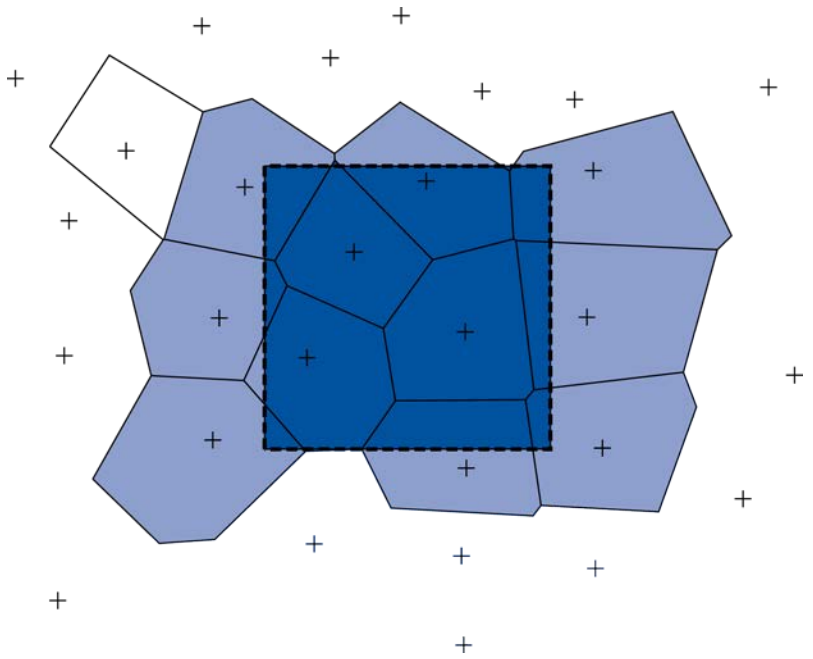




Voronoi - Density

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

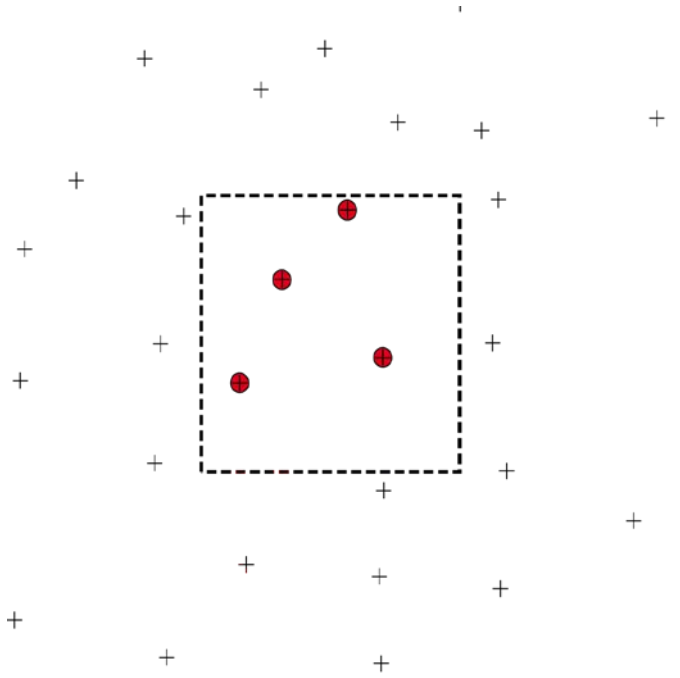


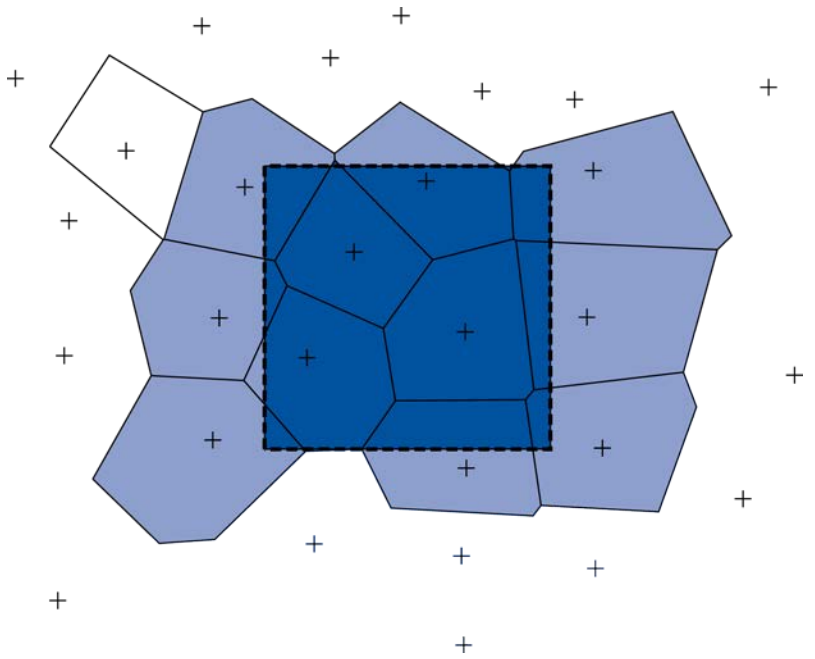


Voronoi - Density

$$\rho_{Class} = \frac{N}{|A|}$$

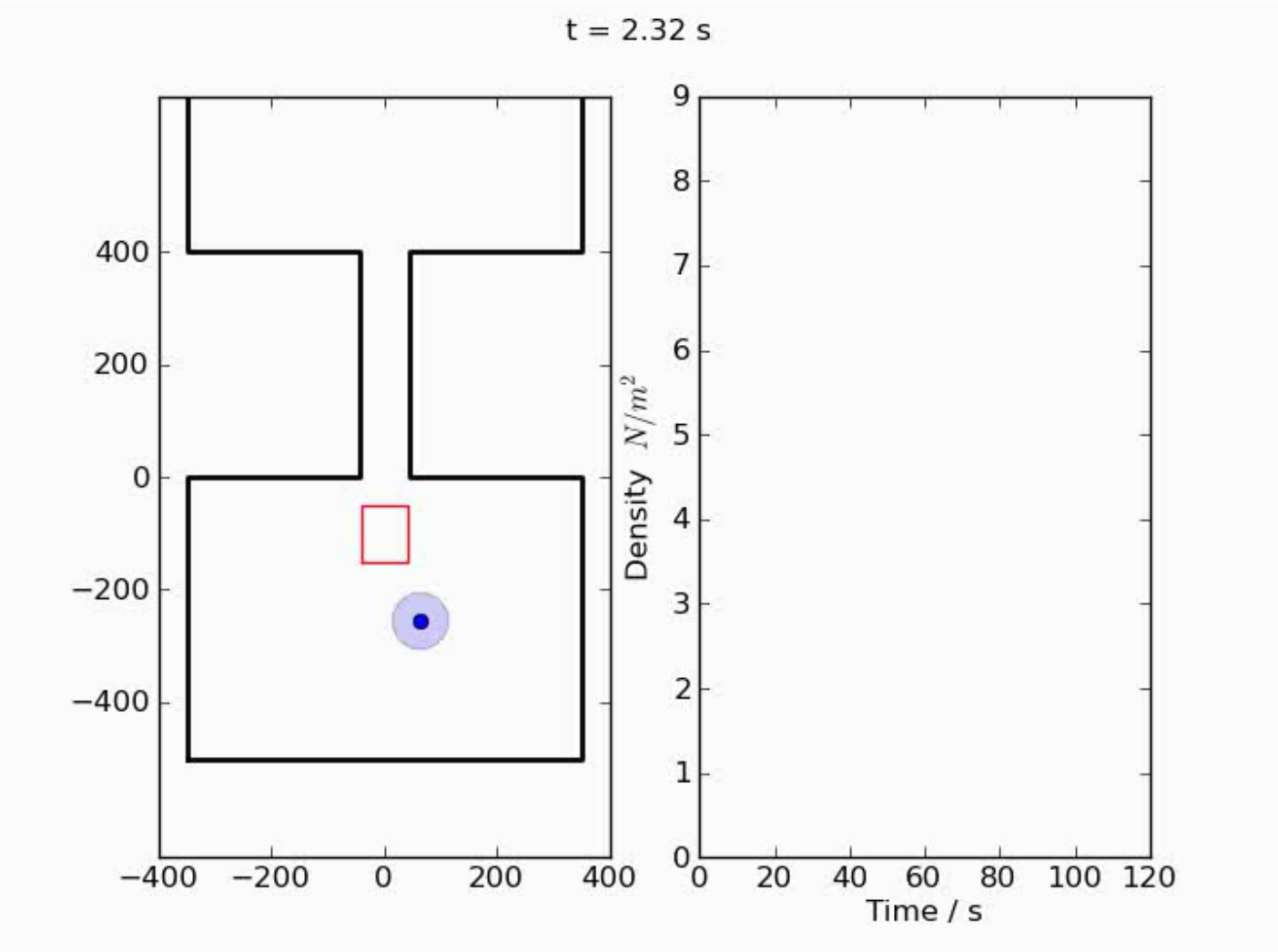
$$\rho_{Voronoi} = \frac{\int_A p(\vec{x})\, d\vec{x}}{|A|}, \quad p(\vec{x}) = \begin{cases} 1/A_i & : \vec{x} \in A_i \\ 0 & : \text{else} \end{cases}$$





[1]B. Steffen and A. Seyfried, *Physica A,* **2010**, *389*, 1902-1910

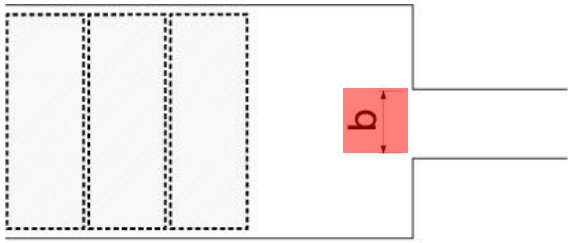
Voronoi - Density



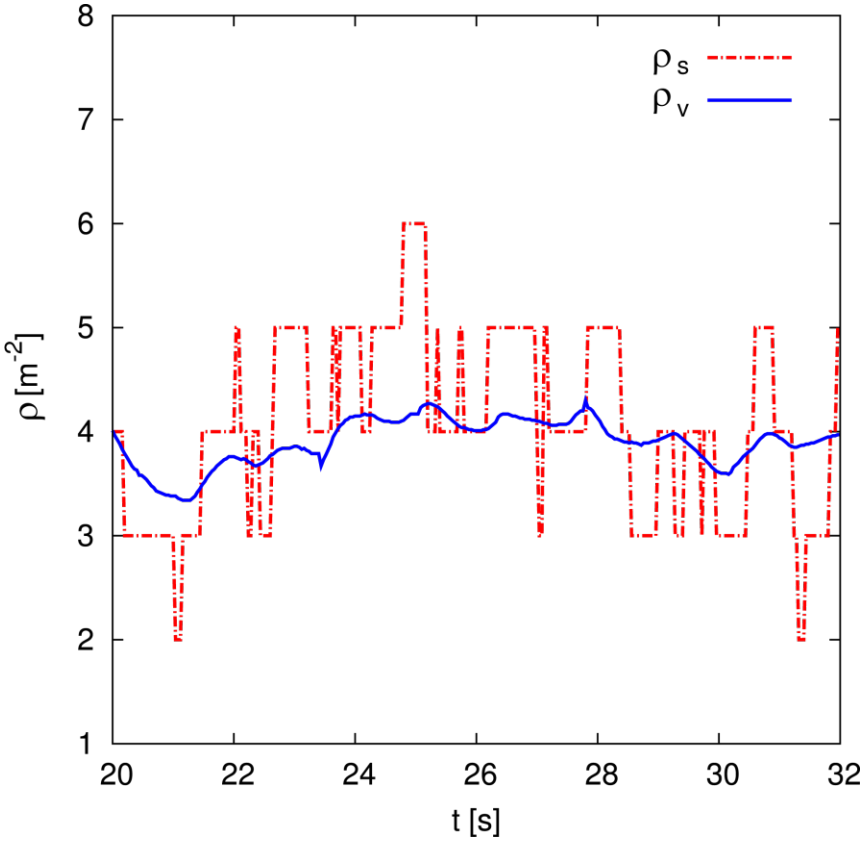
Credits: J. Liddle

Voronoi - Density

Comparison

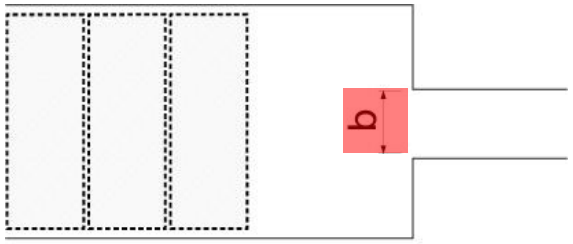


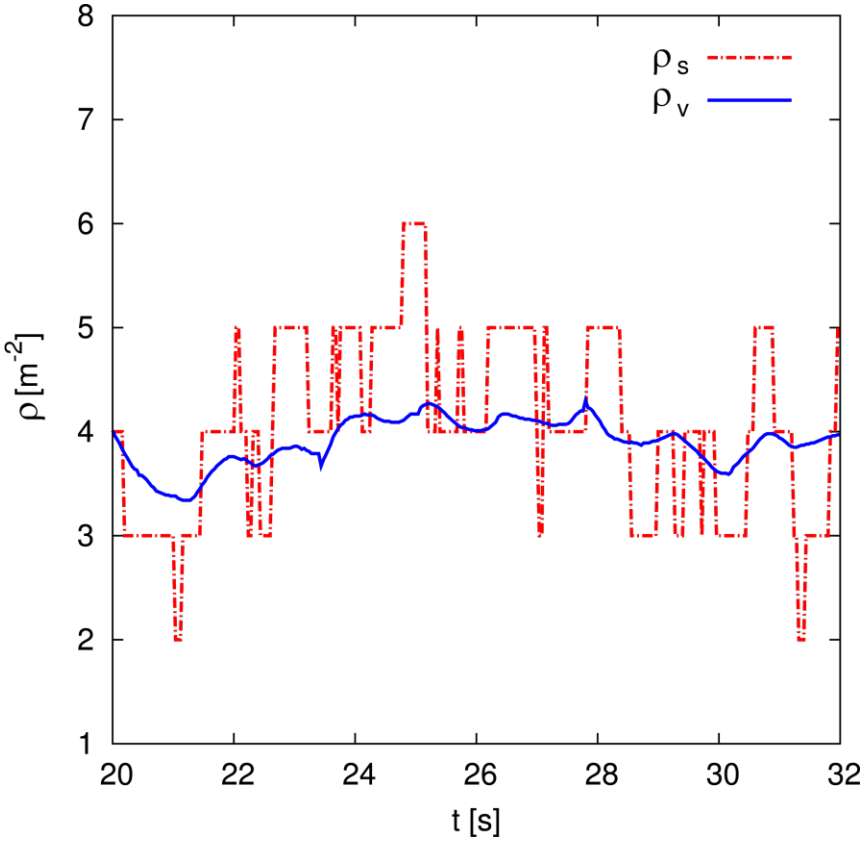
Typ	Mean [1/m²]	Std. dev. [1/m²]
ρ_{Class}	4.06	0.88
$\rho_{Voronoi}$	3.90	0.23



Voronoi - Dichte

Vergleich

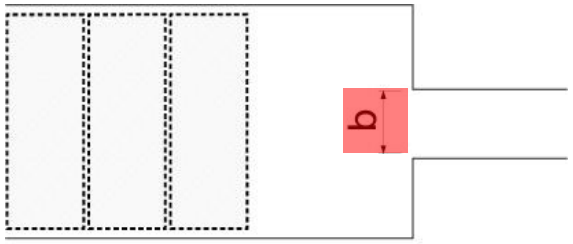


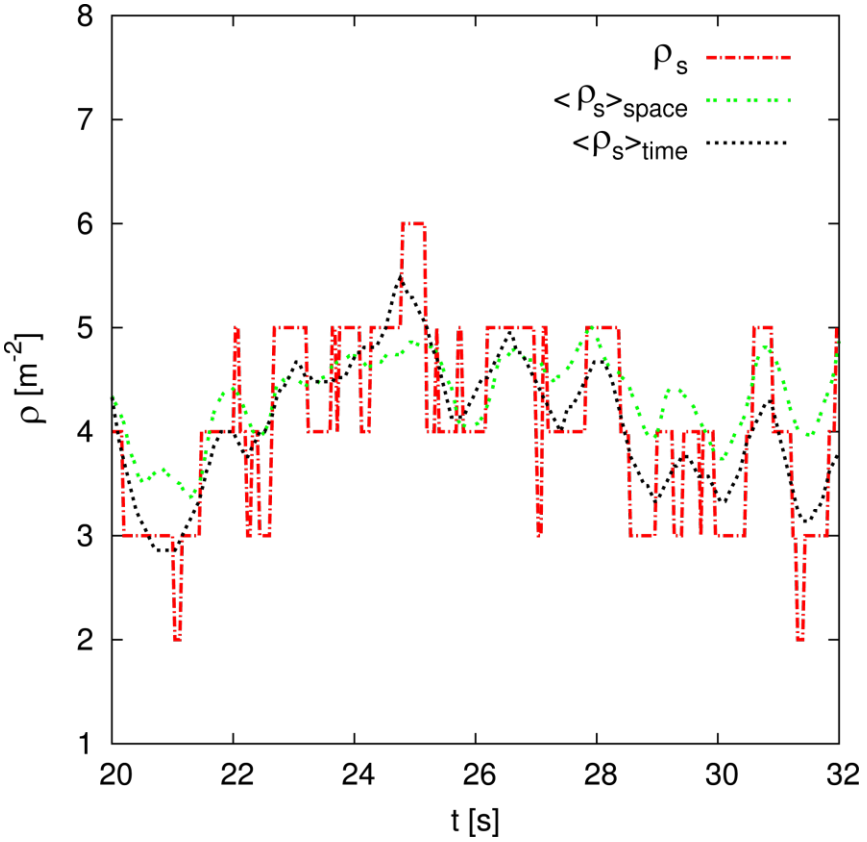


Typ	Mean [1/m²]	Std. dev. [1/m²]
ρ_{Class}	4.06	0.88
$\langle\rho\rangle_{Space}$	4.33	0.40
$\langle\rho\rangle_{Time}$	4.07	0.62
$\rho_{Voronoi}$	3.90	0.23

Voronoi - Dichte

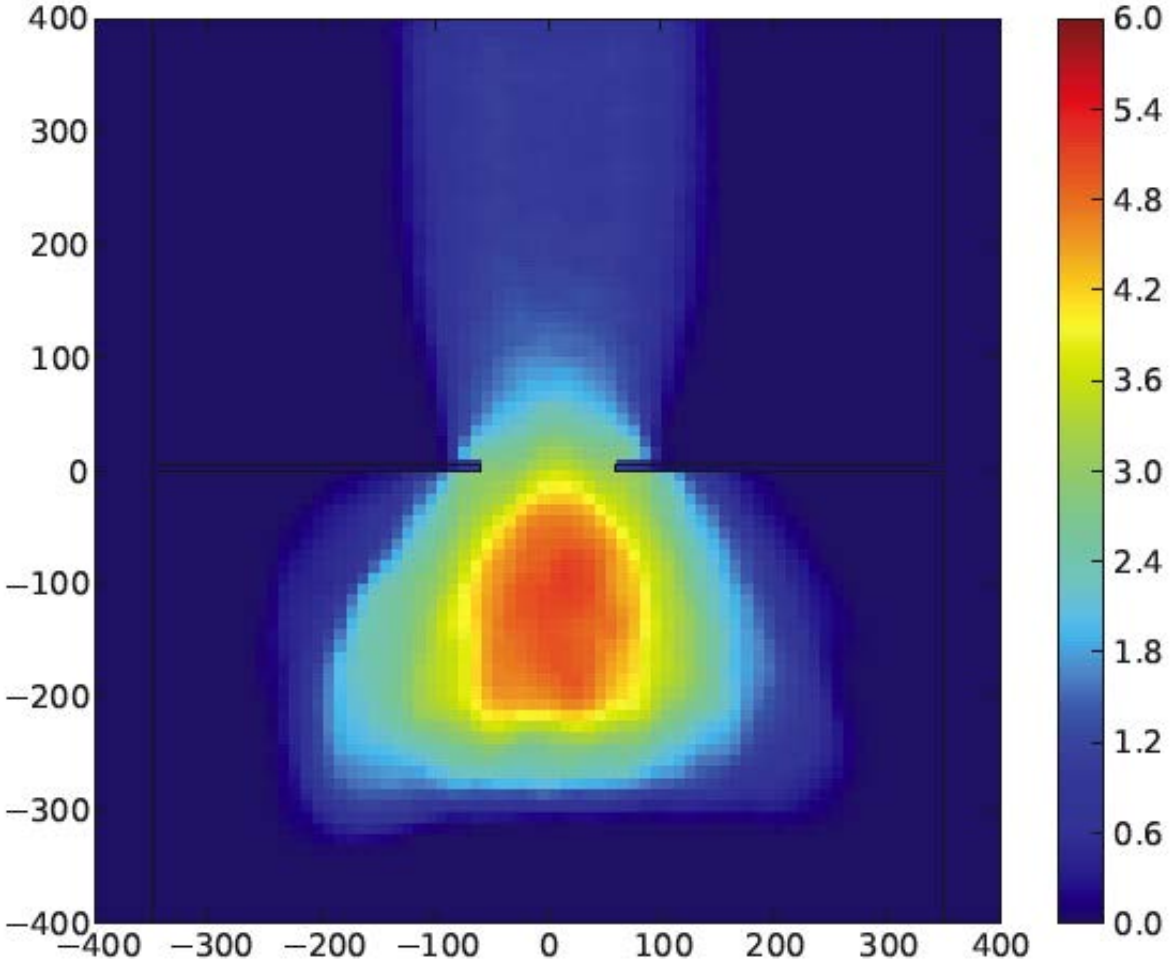
Vergleich





Typ	Mean [1/m²]	Std. dev. [1/m²]
ρ_{Class}	4.06	0.88
$\langle\rho\rangle_{Space}$	4.33	0.40
$\langle\rho\rangle_{Time}$	4.07	0.62
$\rho_{Voronoi}$	3.90	0.23

Voronoi - Density



J. Liddle, et al., *arXiv:1105.1532*

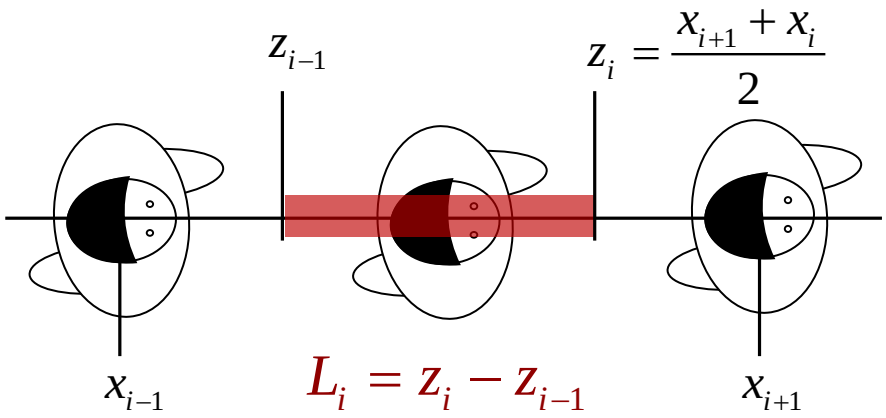
Fundamental diagram for single file movement

-Microscopic measurement and phase separation -

Seyfried, A.; Portz, A. & Schadschneider, A.
Phase Coexistence in Congested States of Pedestrian Dynamics
Cellular Automata, Springer, **2010**, 6350, 496-505

‘Microscopic’ Measurement

Density measurement with Voronoi diagrams[1].



$$\rho_i(x) = \begin{cases} \dfrac{1}{L_i}, & x \in [z_{i-1}, z_i[\\ 0, & \text{otherwise} \end{cases}.$$

[1]B. Steffen and A. Seyfried, *Physica A,* **2010**, *389*, 1902-1910

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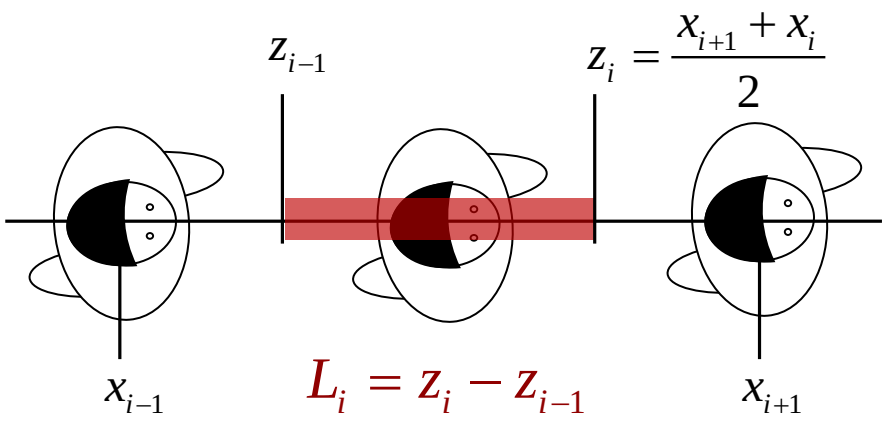

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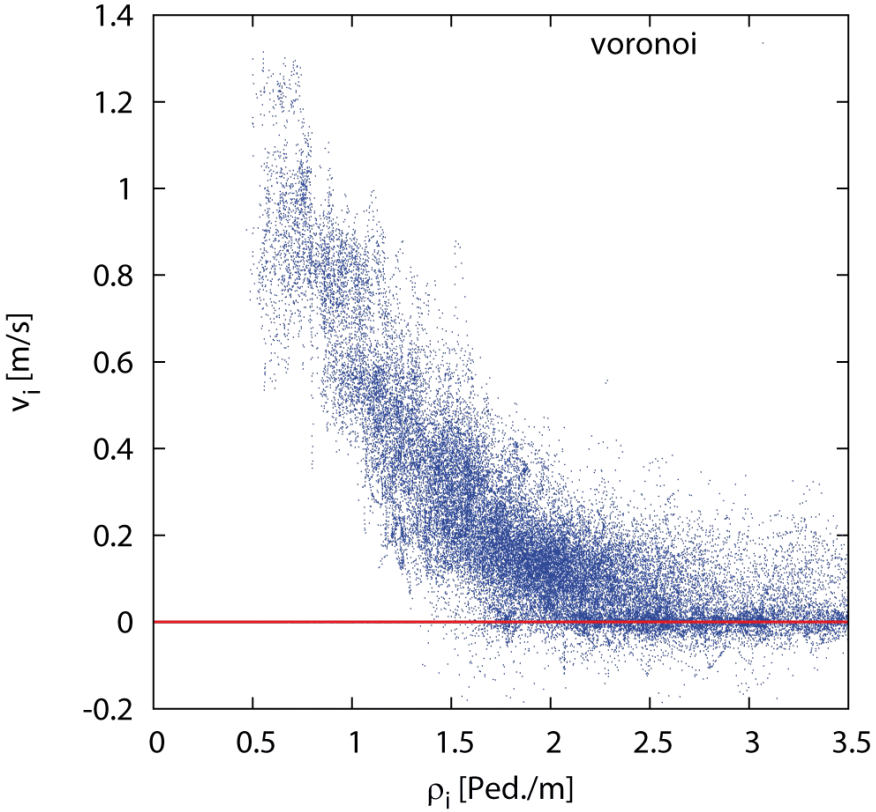

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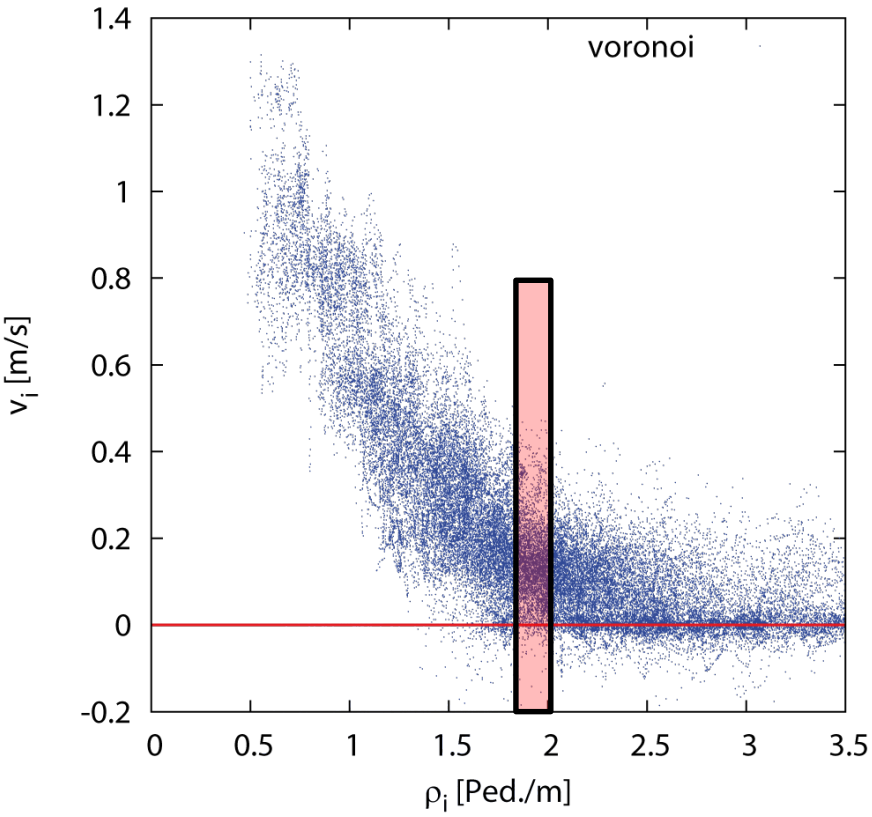
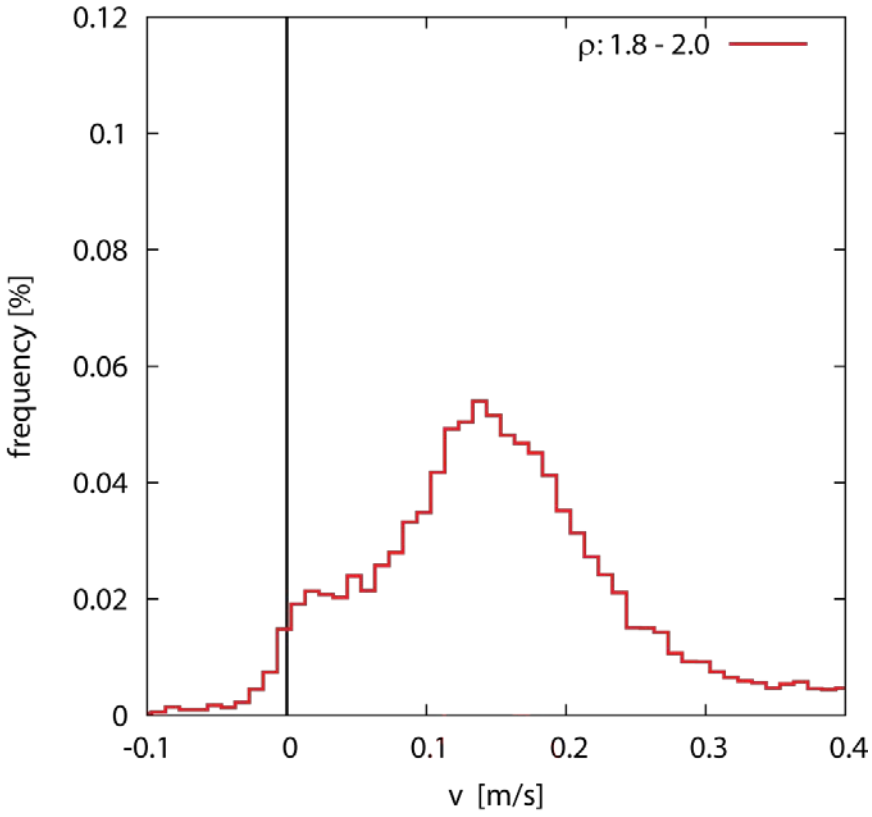
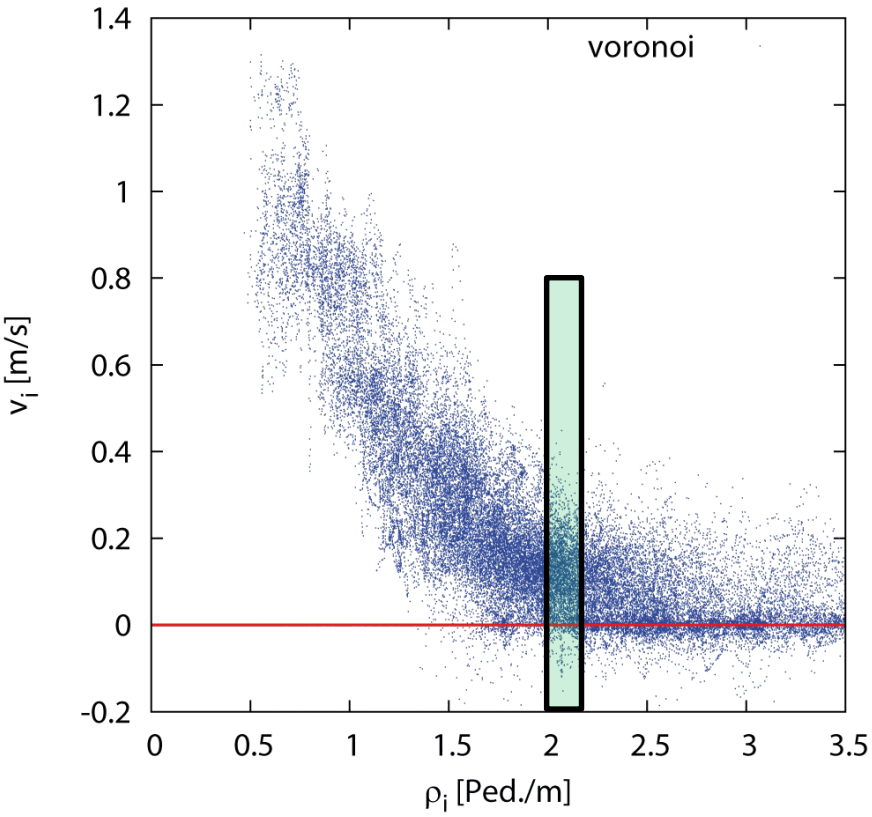
Velocity distribution

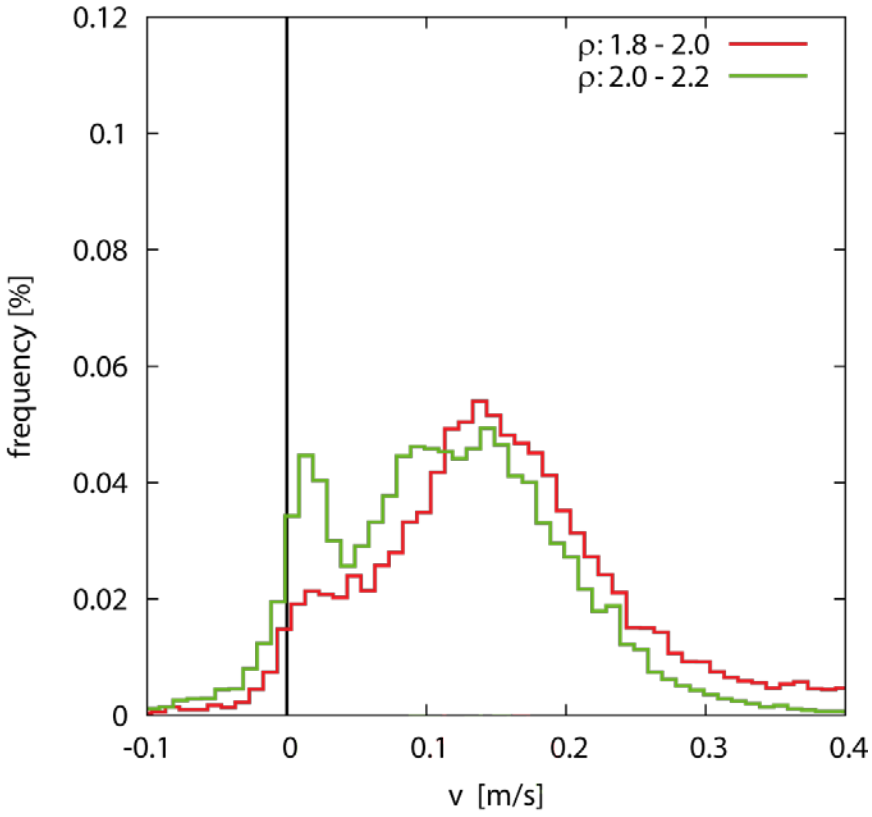




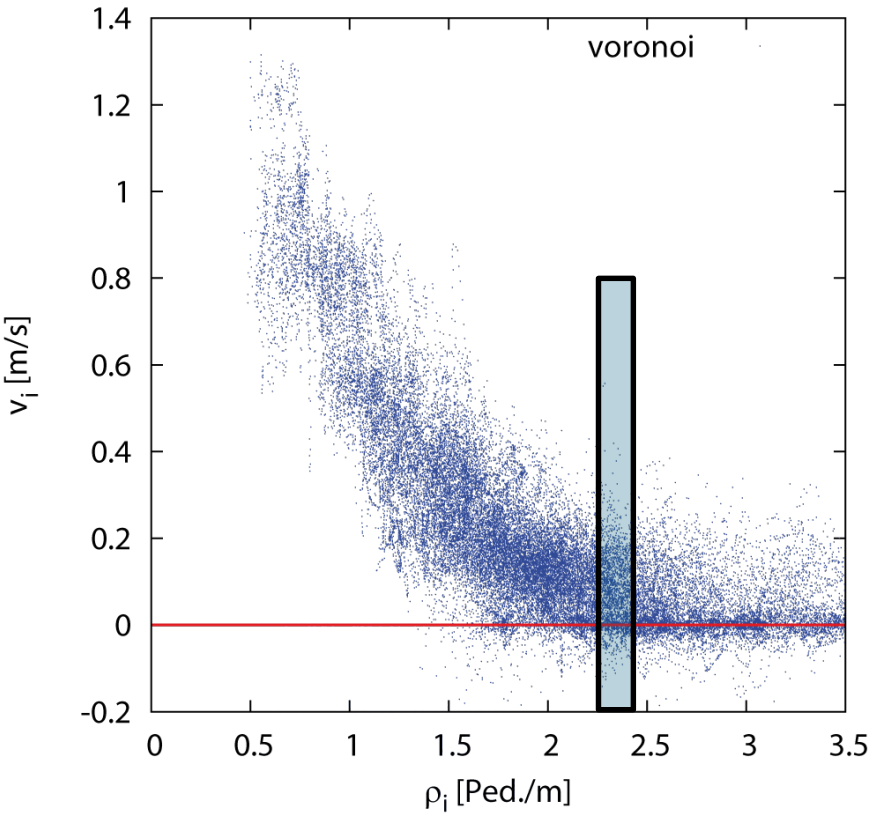
[1]A. Portz and A. Seyfried, Pedestrian and Evacuation Dynamics 2010

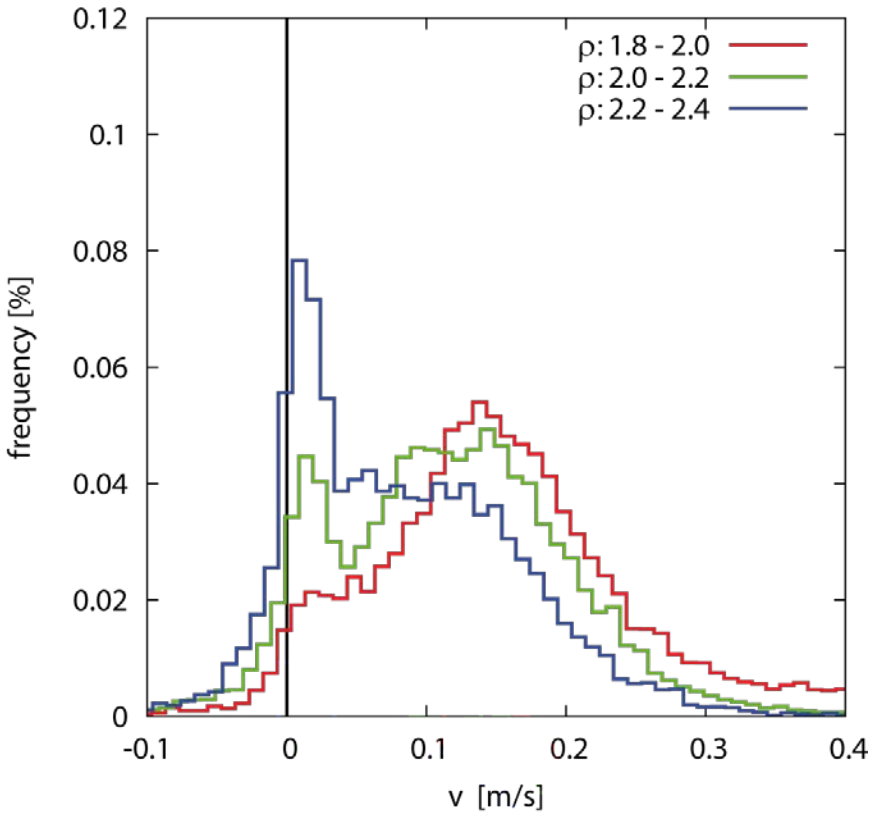
Velocity distribution



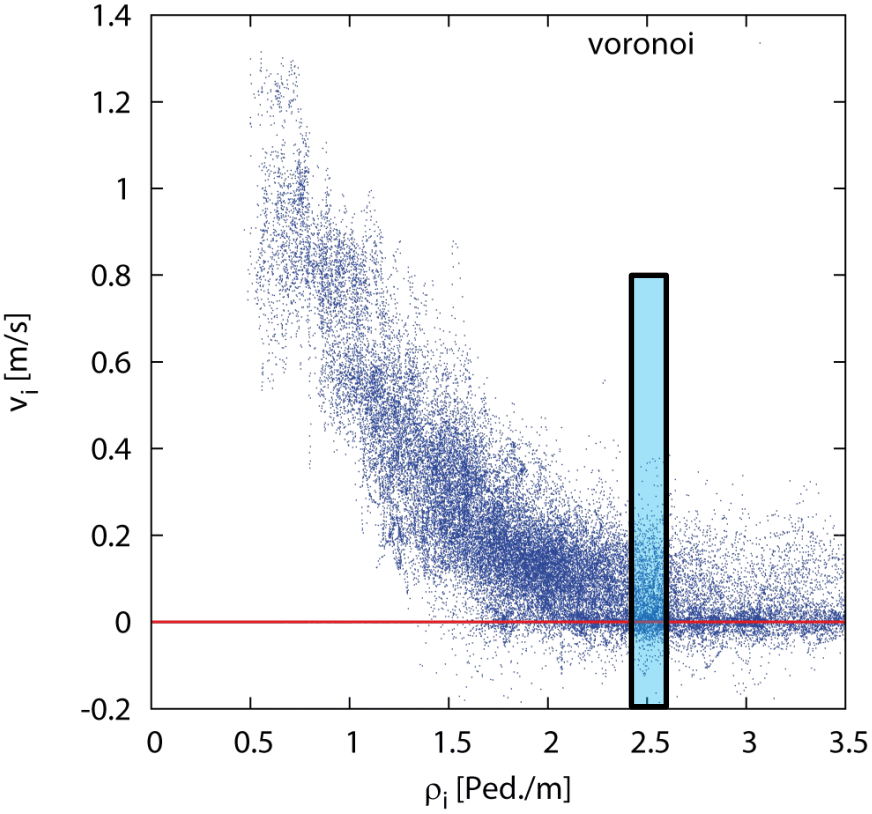


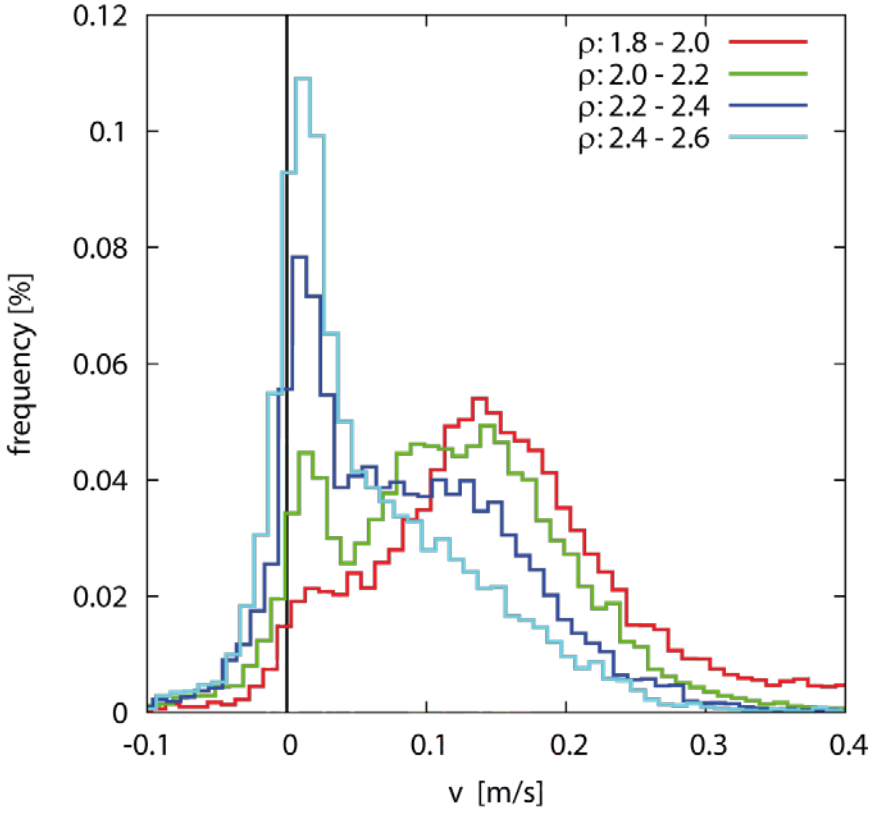
Velocity distribution





Velocity distribution





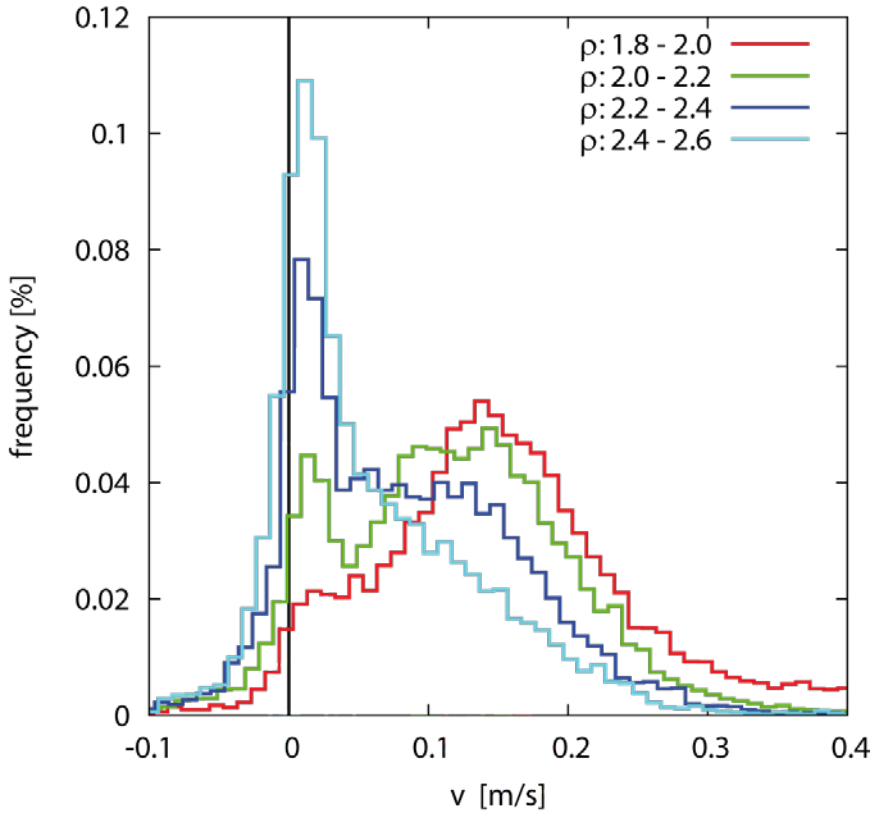
Velocity distribution

Coexistence of two states at one density

Continuous transition from Go to Stop - phase

First peak at v = 0 m/s

Second peak at v = 0.15 m/s



Thank you