Why are we studying crowds?

Real Crowds

- Design, dimensions of public building
  - Normal usage
  - Emergency evacuation

Why are we studying crowds?

Virtual Crowds

- Video games
- Movies, ads
- Participative democracy

Le Seigneur des Anneaux

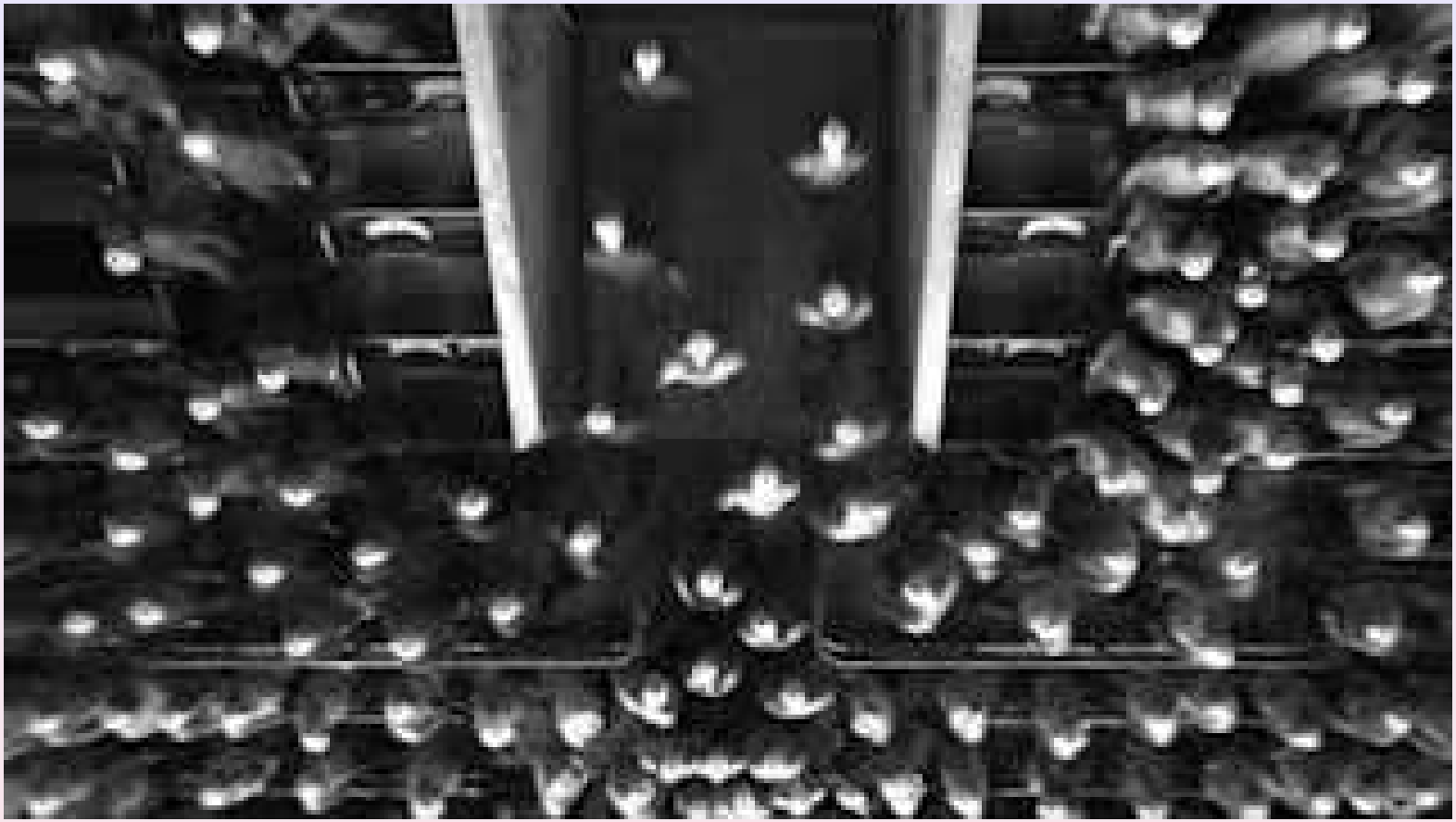
- Crowd simulation software

Avatar

Data

- `https://ped.fz-juelich.de/db`
  - Collection of data from experiments involving the Forschungszentrum Jülich
    Includes large scale experiment of stadium evacuation
  - Links to other experimental data obtained all over the world

Experiment in a stadium

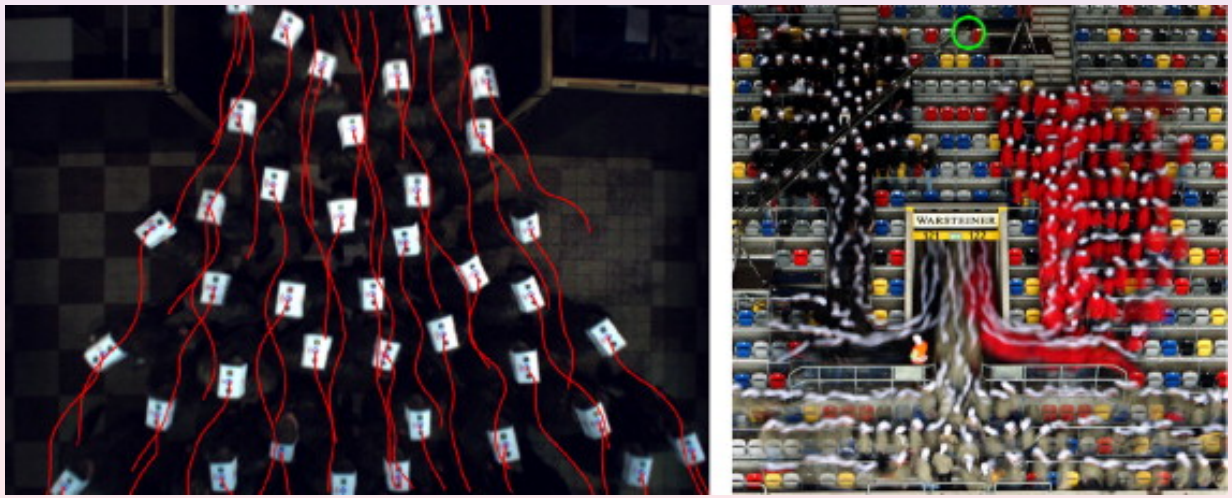


Project HERMES,
cf [Burghardt, Seyfried, Klingsch, Transp. research Part C 37, 268 (2013)]

Pedestrian experiments: tracking

From Videos

- Easier if pedestrians wear a special hat
- Use of some tracking software
  - Example : Open Software PeTrack (`https://www.fz-juelich.de/en/ias/ias-7/services/software/petrack`)



From [Boltes et al, Neurocomput. (2013)]

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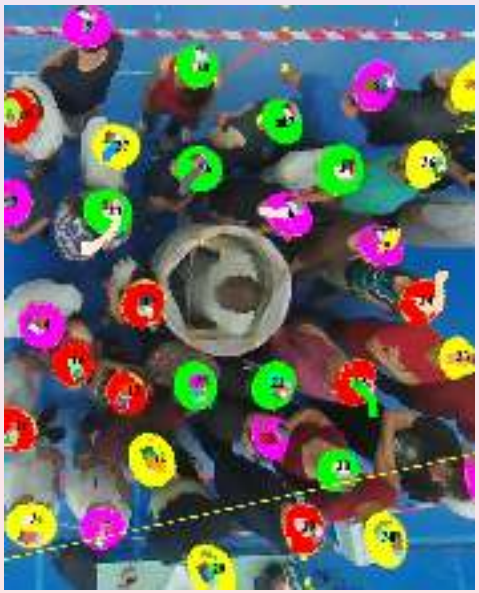
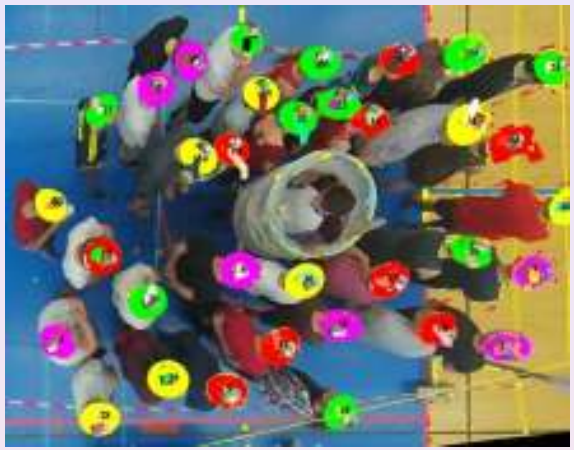
Exp. of [Nicolas & al, Sci. Rep. (2019)]



Pedestrian experiments: tracking



From Depth-Field movies

- Preserves more anonymity
- Kinect (Easy, narrow field of view, works only inside)
- Double cameras (Synchronization needed)

High precision motion capture (VICON)

- Markers detected by infrared cameras
- Used for virtual production, in virtual reality, etc

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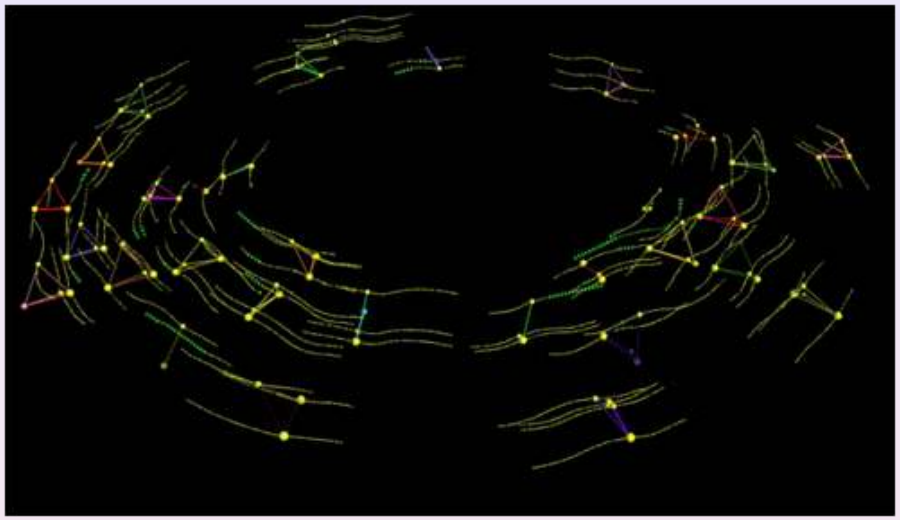
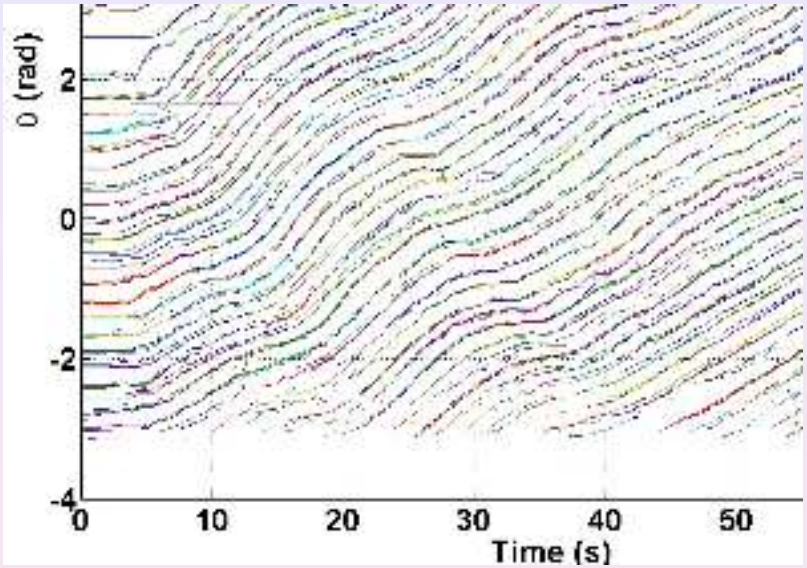
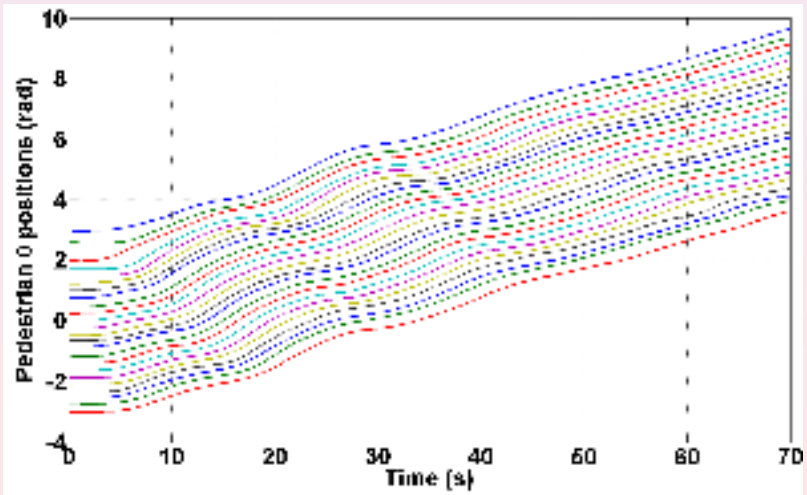
From the PEDIGREE Project

Reconstruction of trajectories



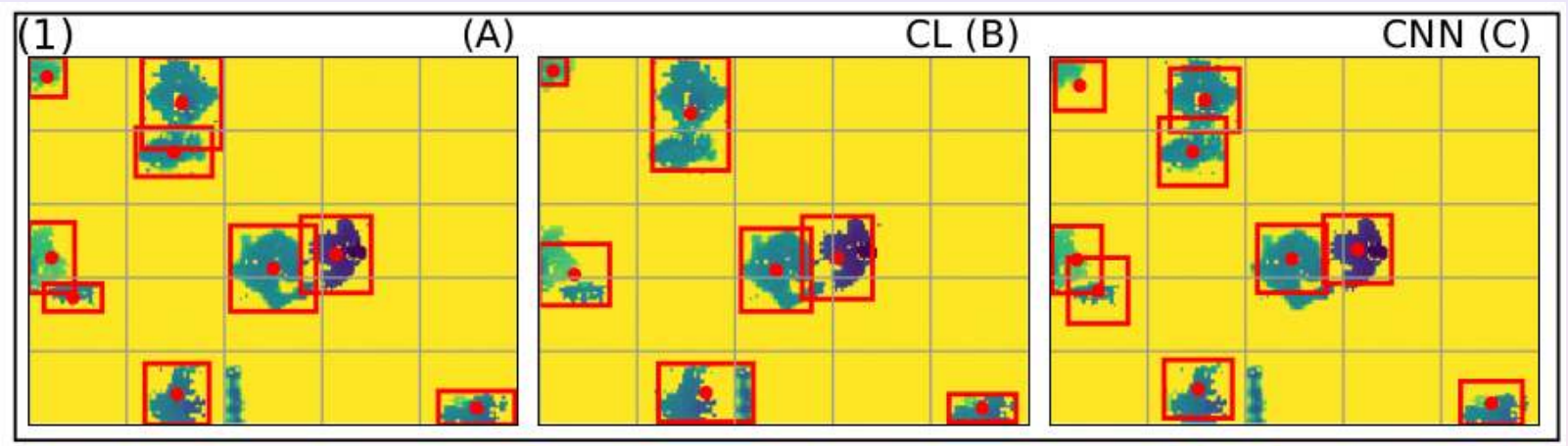




- From raw data to 3D markers' trajectories
- From markers to pedestrians
- Interpolating for missing data

Deep learning

Example with depth field measurements

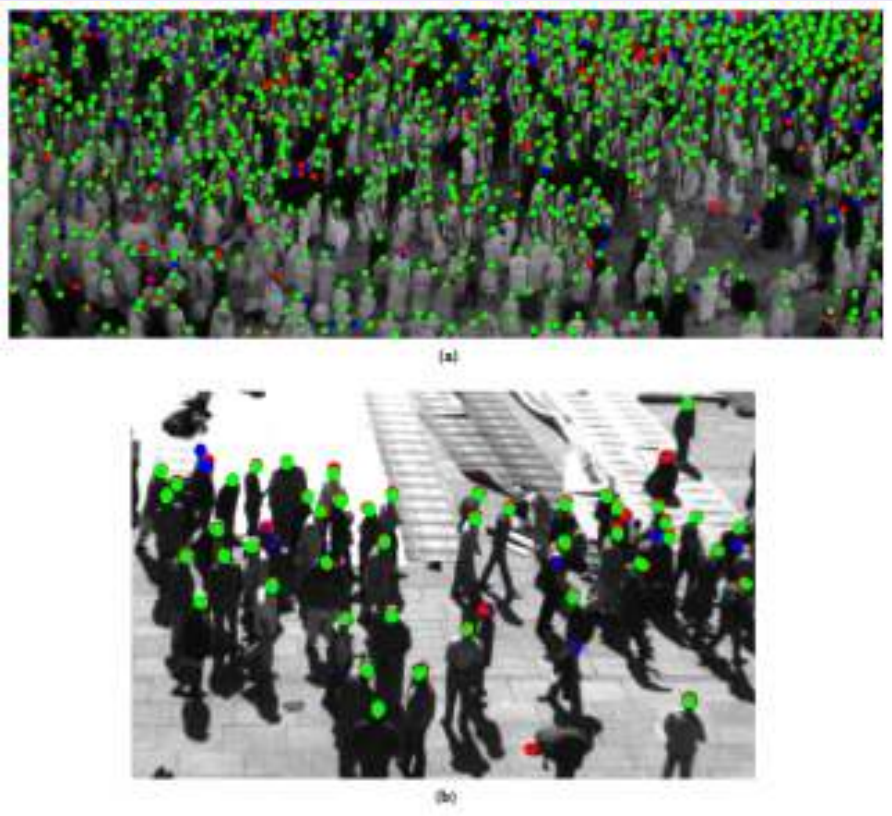


From [Corbetta et al, AVSS 2017]

- (A) = synthetic data (ground truth)
- (B) = CL = Clustering Approach
- (C) = CNN = Deep Convolution Neural Network

Deep learning

Intermediate and high densities



(a) Makkah Dataset

(b) Regent's Park Dataset

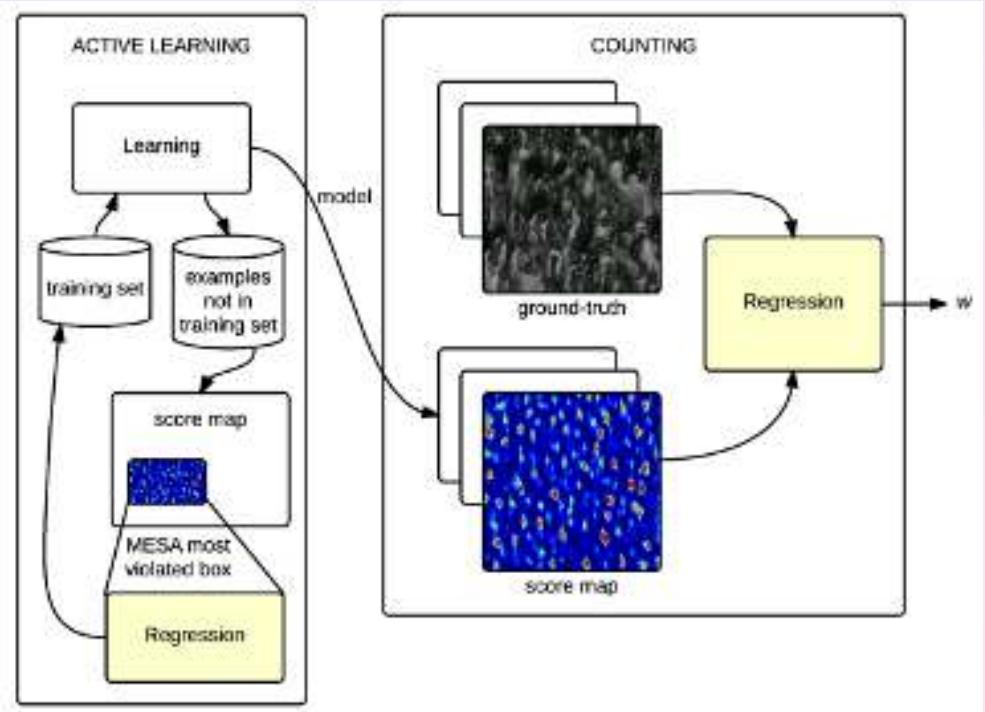
- Red blobs = ground-truth heads
- Green blobs = True positive
- Blue blobs = False positive

From [J. Vandoni, PhD Thesis, SATIE, Univ. Paris Saclay (2019)]

Deep learning

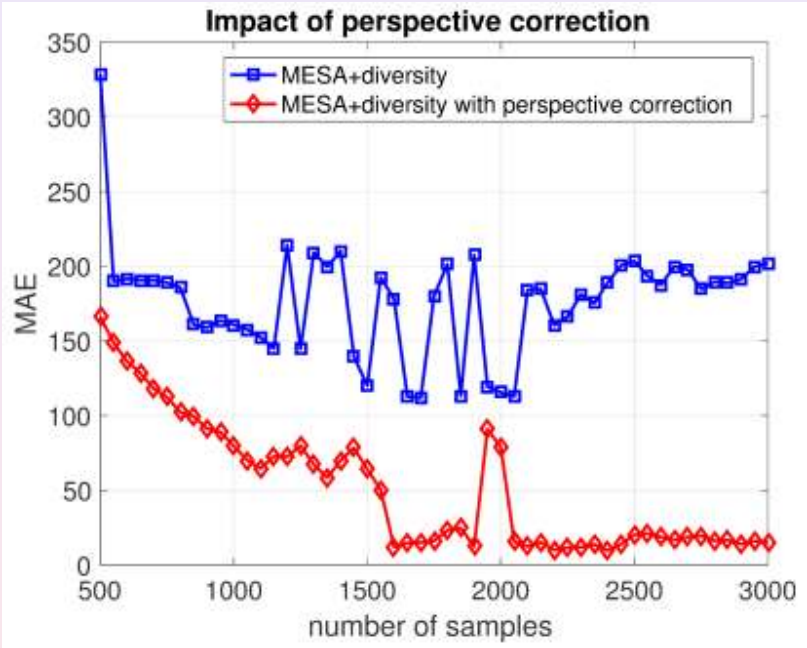
Learning to estimate density without individual tracking

- Learning principle



From [J. Vandoni, PhD Thesis, Univ. Paris Saclay (2019)]

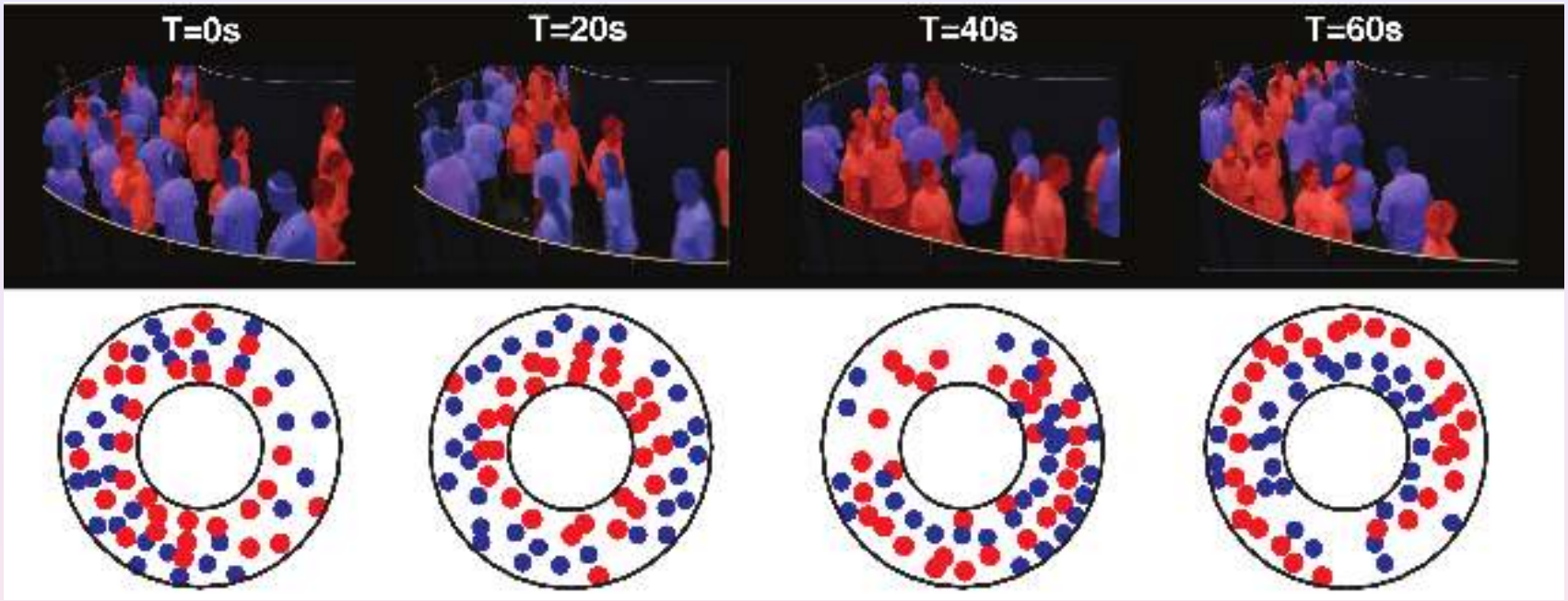
- Perspective correction



MAE = Mean Absolute Error (compared to ground truth)

Ring

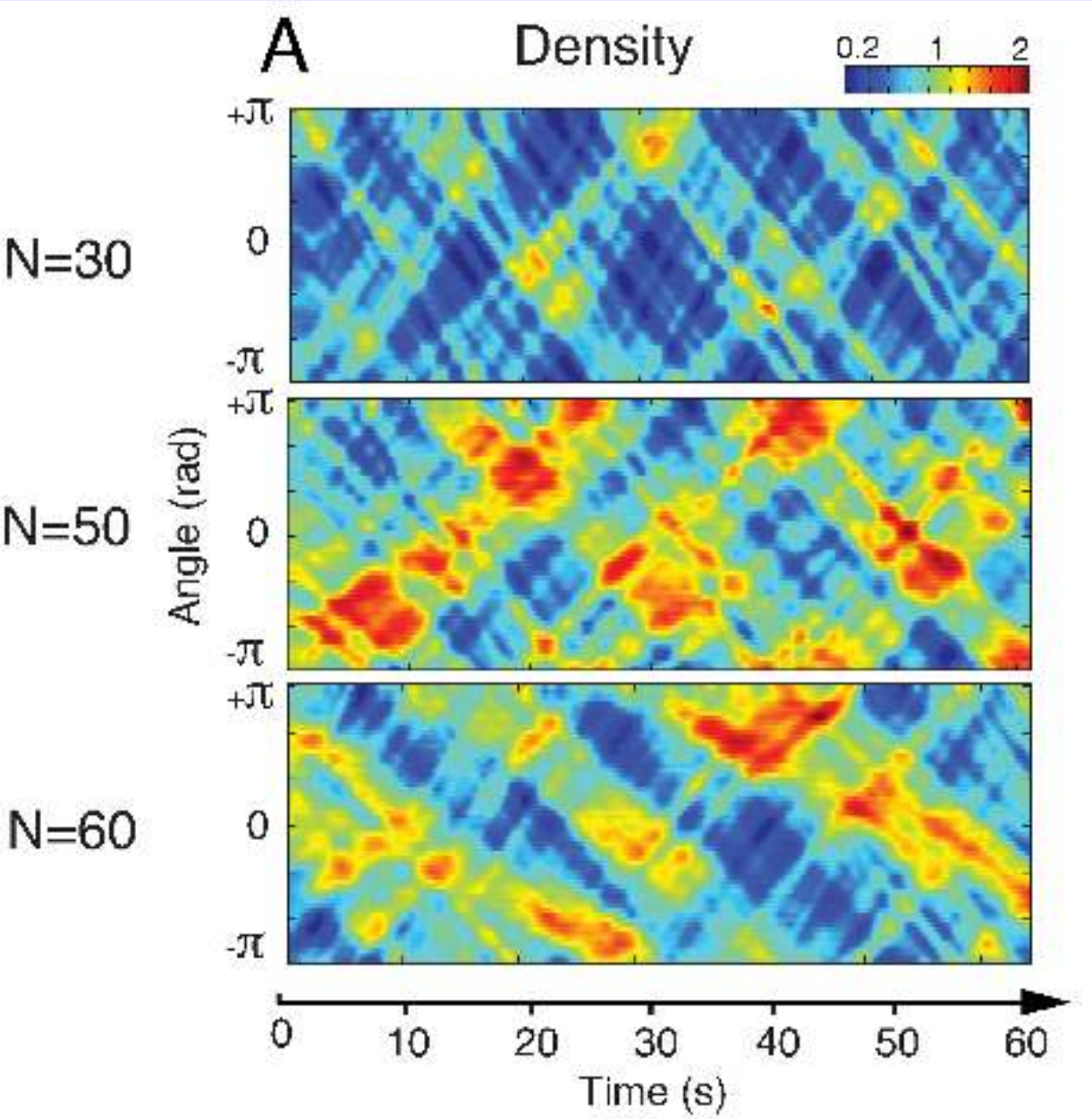
Ring



[M. Moussaïd, E. Guillot, M. Moreau, J. Fehrenbach, O. Chabiron, S. Lemercier, J. Pettré, C. Appert-Rolland, P. Degond and G. Theraulaz, *Traffic Instabilities in Self-organized Pedestrian Crowds*, PLoS Computational Biology (2012)]

Can we model pedestrian flows as fluids?

Ring : Experimental density fields



global density

0.59,

0.98 ped/m^2

1.18

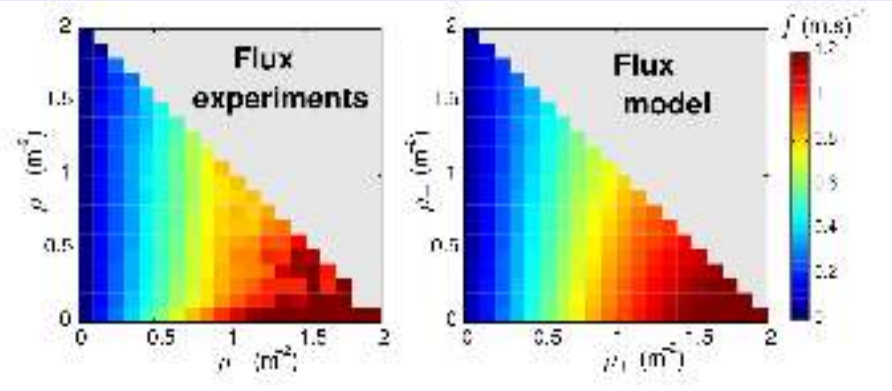
Macroscopic models for pedestrians

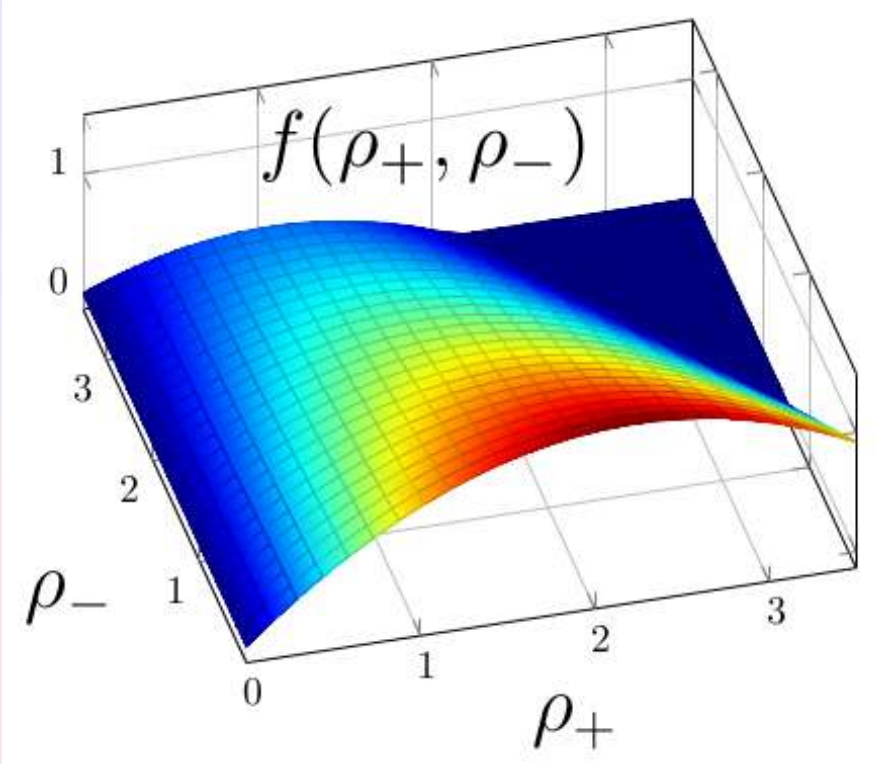
- 2 densities ρ_+ and ρ_-
- 2 velocities u_+ and u_-

- Possible to develop 1st or 2nd order macroscopic models, but with double number of equations.

1st order macroscopic model for pedestrians

[S. Motsch et al,Math. Biosci. Eng. **15** (2018) 1271]



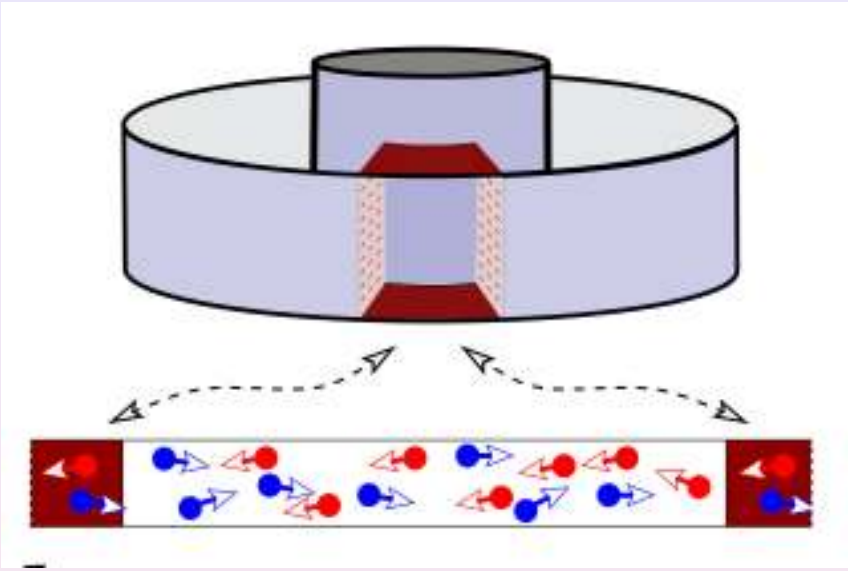


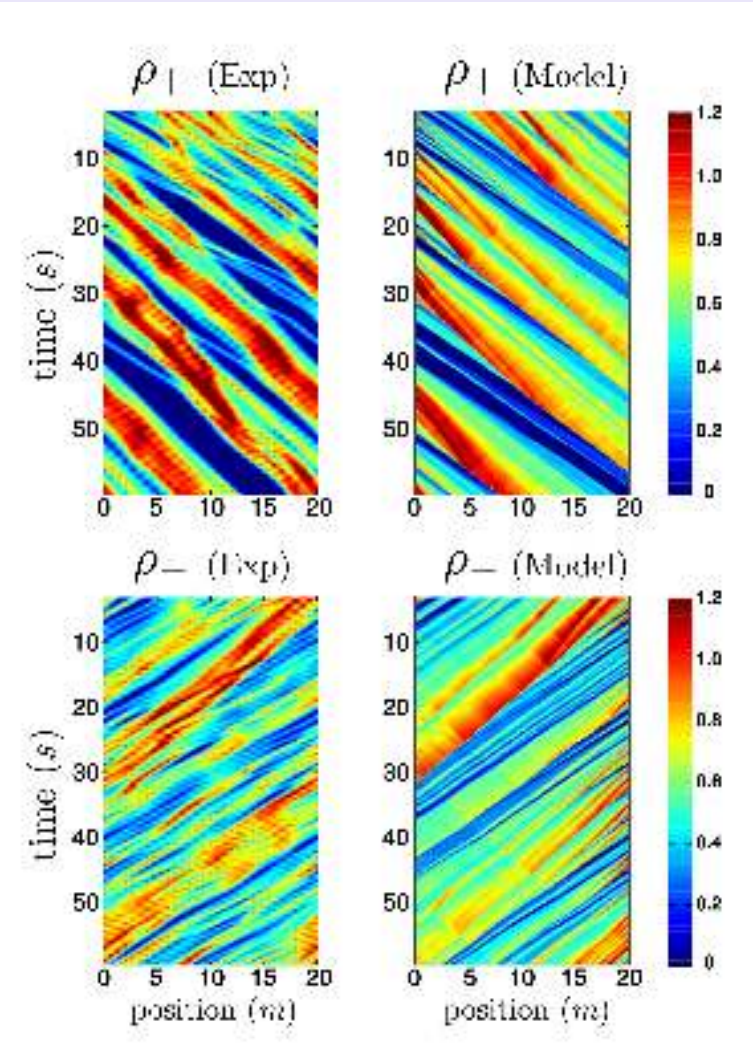
$$f(\rho_+, \rho_-) = a\rho_+ (1 - b\rho_+ - c\rho_-)$$

Sample set	a	b	c	R^2
$50\% - 50\%$	1.218	0.273	0.181	0.944
$75\% - 25\%$	1.216	0.087	0.203	0.972
$100\% - 0\%$	1.269	0.077	0	0.982

- a $\sim$ free average velocity
- b $\sim$ friction with co-moving pedestrians
- c $\sim$ friction with counter-moving pedestrians

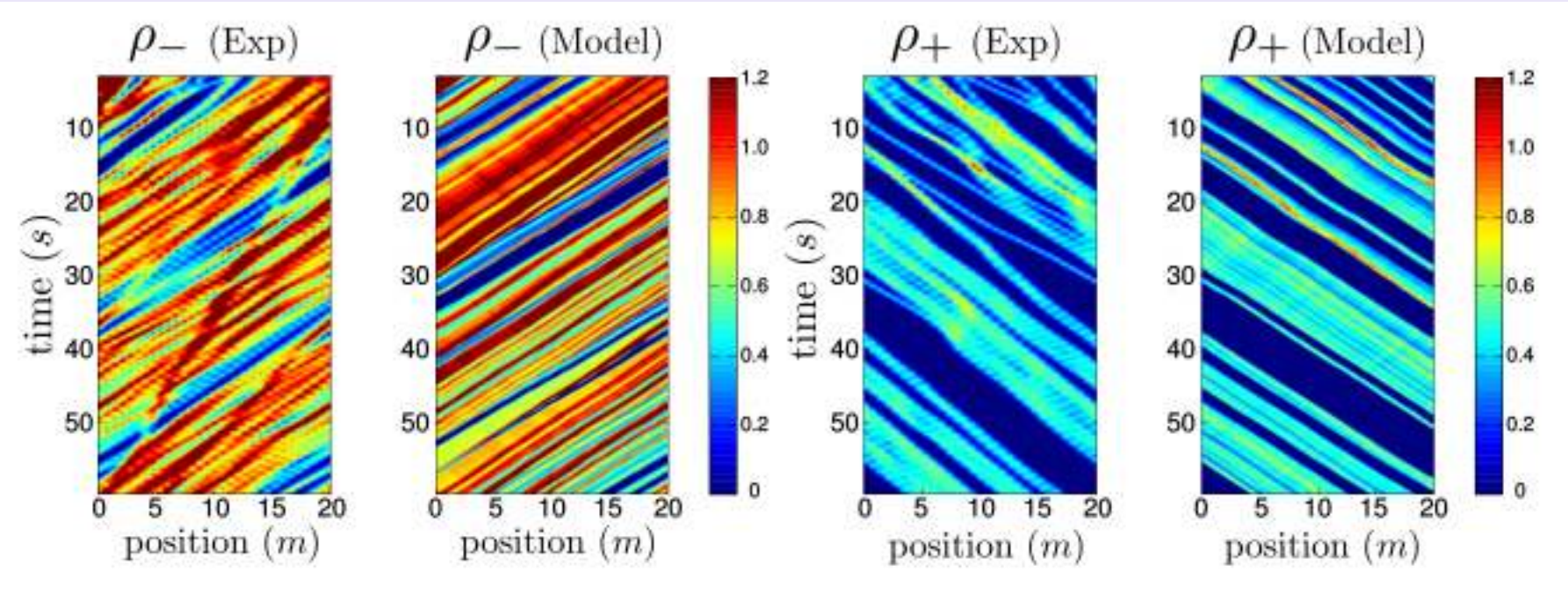
Comparison Model/Experiment





50% – 50%

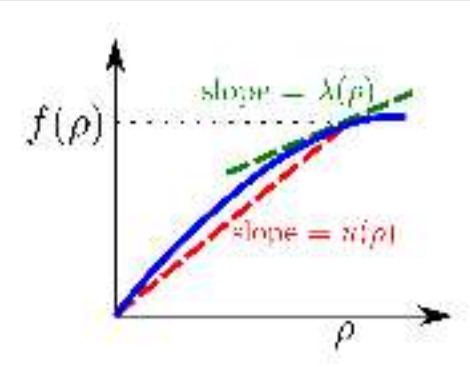
Comparison Model/Experiment

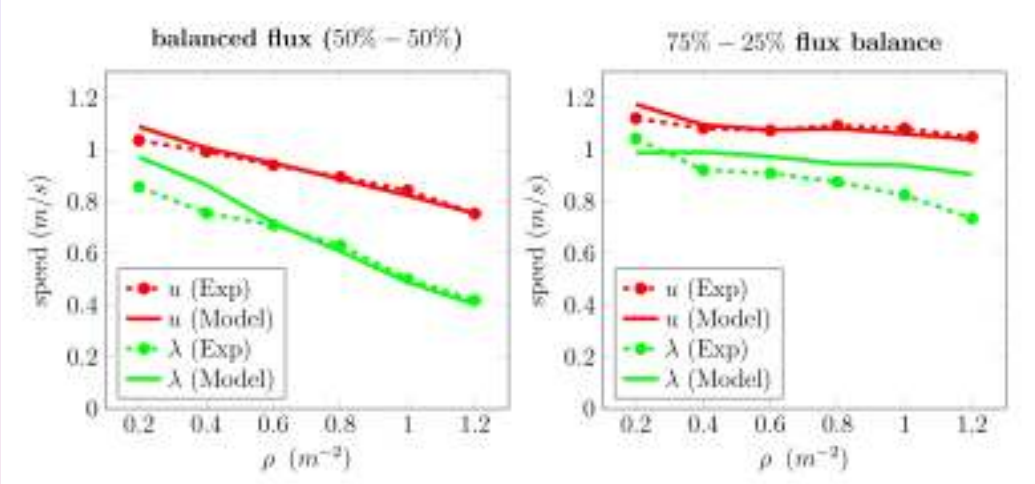


75% – 25%

From [Motsch et al, Math. Biosci. Eng. **15** (2018) 1271]

Comparison Model/Experiment



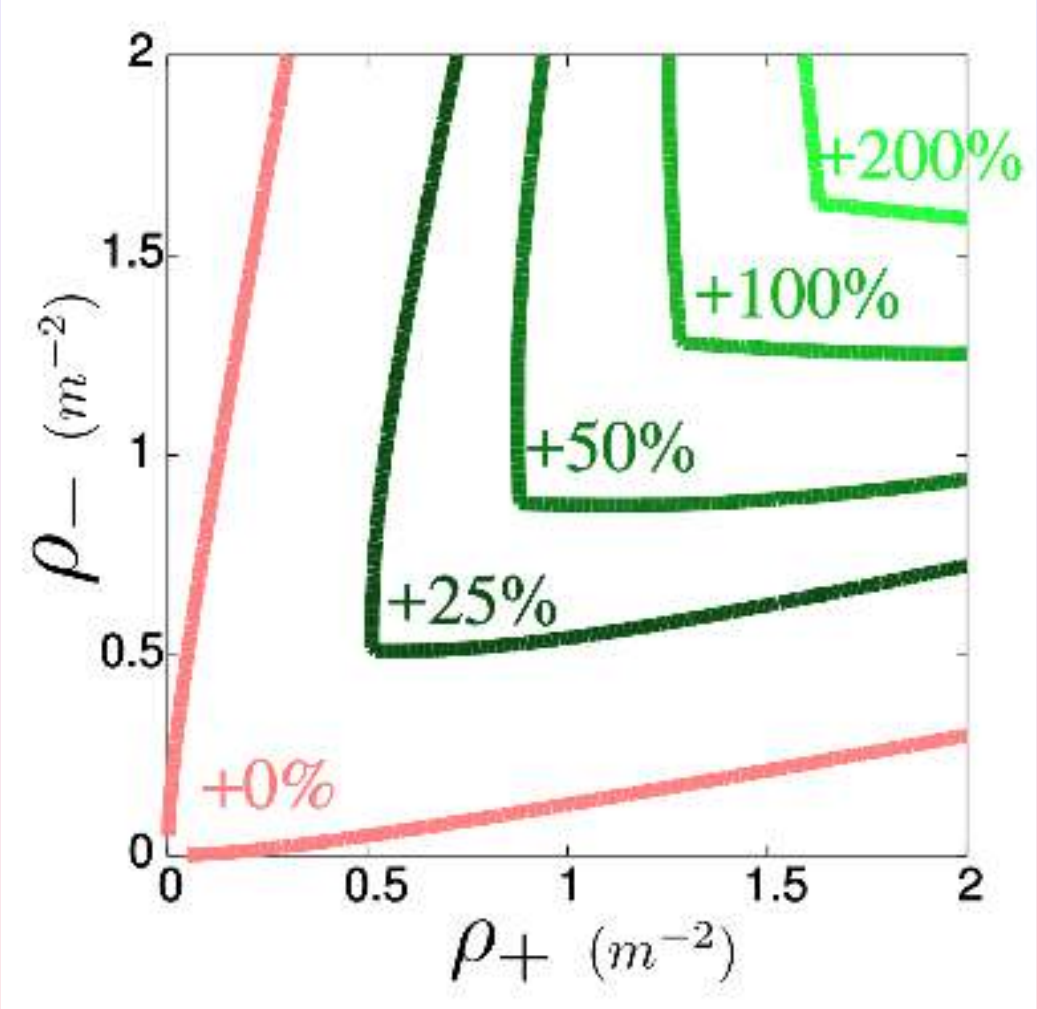


Velocity $u(\rho) = f(\rho)/\rho$
Cluster velocity $\lambda(\rho) = f'(\rho)$

From [Motsch et al, Math. Biosci. Eng. **15** (2018) 1271]

Model prediction

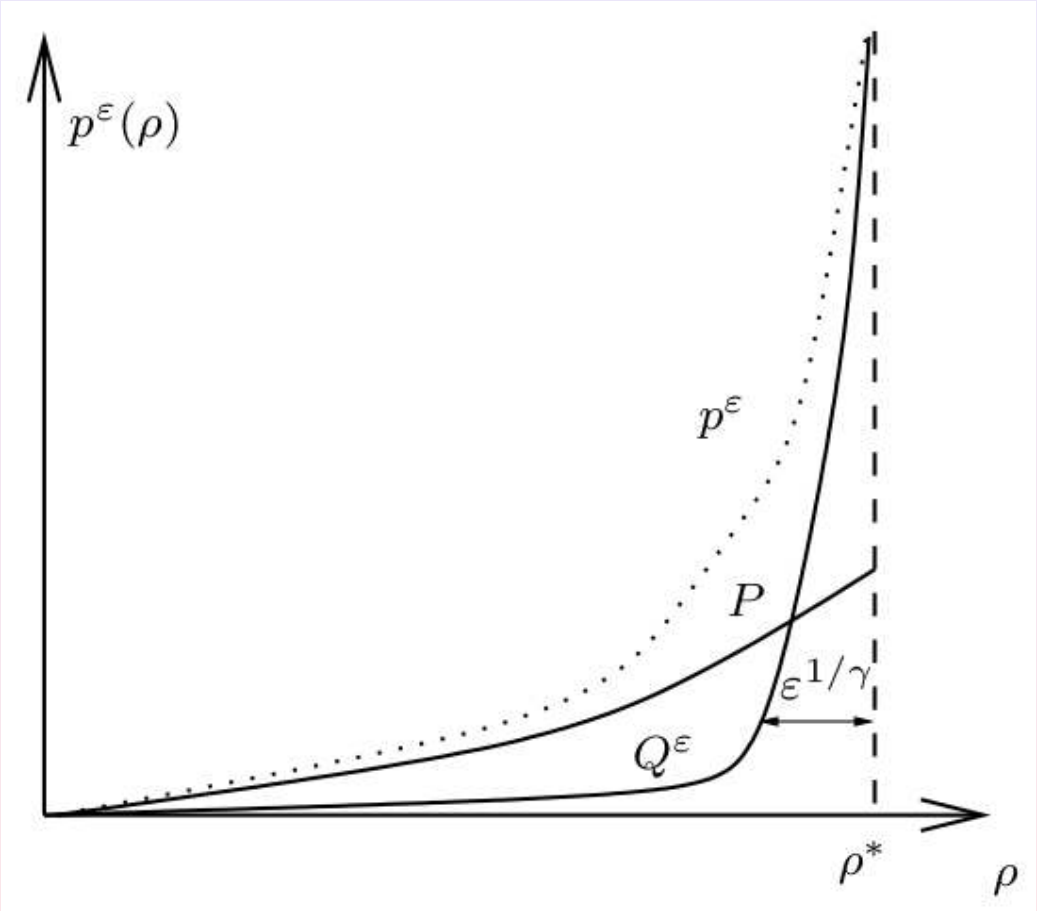
Relative gain using the segregation strategy



From [Motsch et al, Math. Biosci. Eng. **15** (2018) 1271]

Pressure divergence

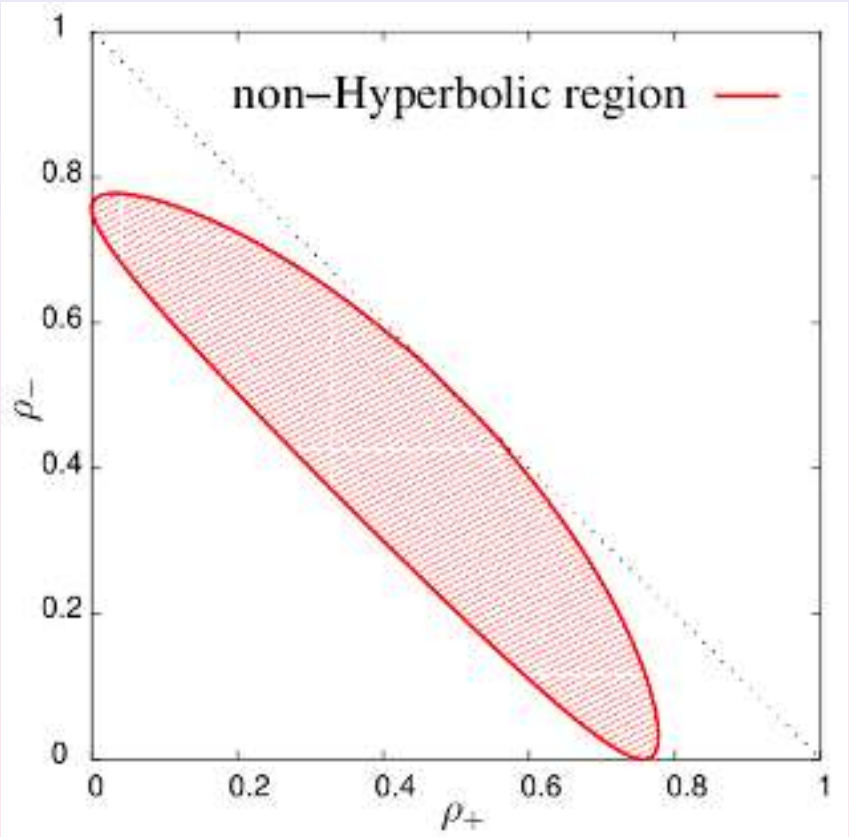
Pressure term diverging at maximum density



From [Appert-Rolland, Degond, Motsch (2011)]

Two-Ways Aw-Rascle model

Contrarily to the One-Way Aw-Rascle model, the Two-Ways Aw-Rascle model is not always hyperbolic.

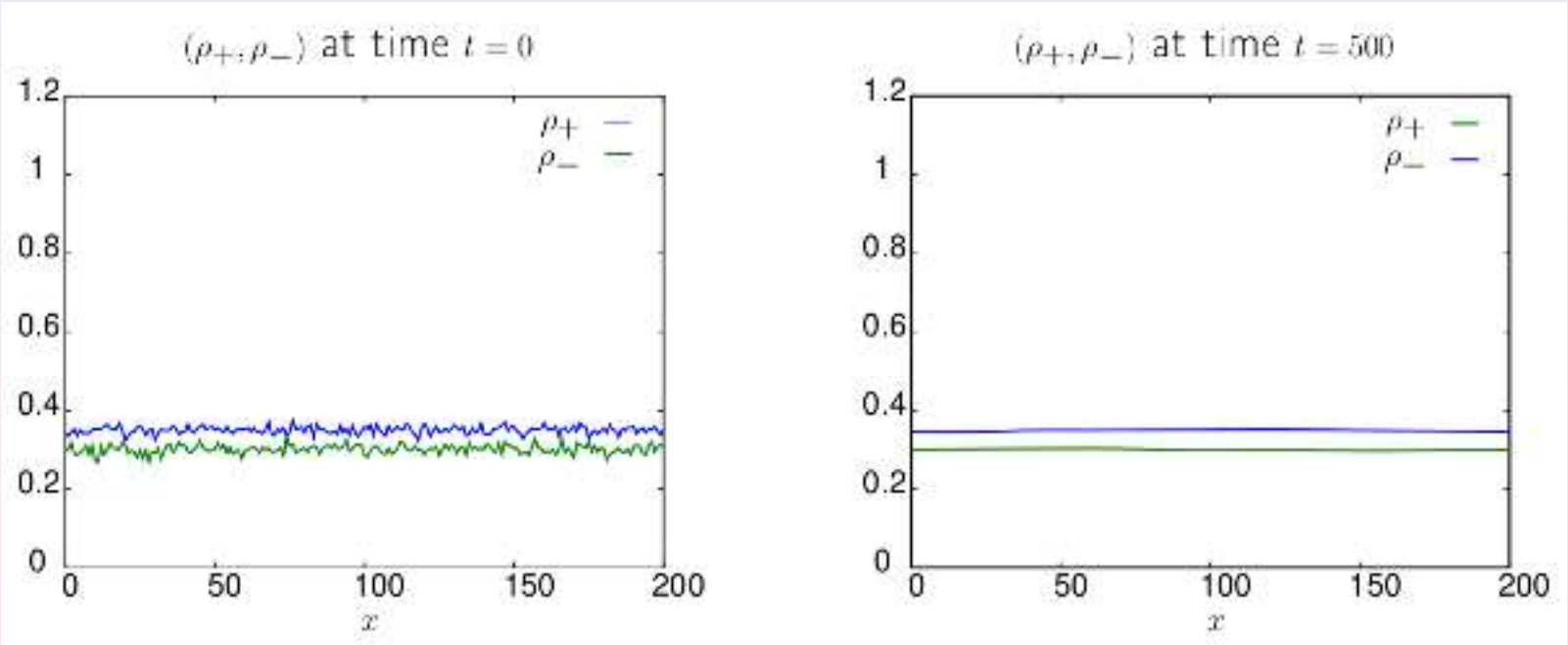


From [Appert-Rolland, Degond, Motsch (2011)]

Example for one particular choice of $p(\rho_+, \rho_-)$.

Numerical simulations of the Two-ways Aw-Rascle model

Initial condition in the hyperbolic region:



From [Appert-Rolland, Degond, Motsch (2011)]

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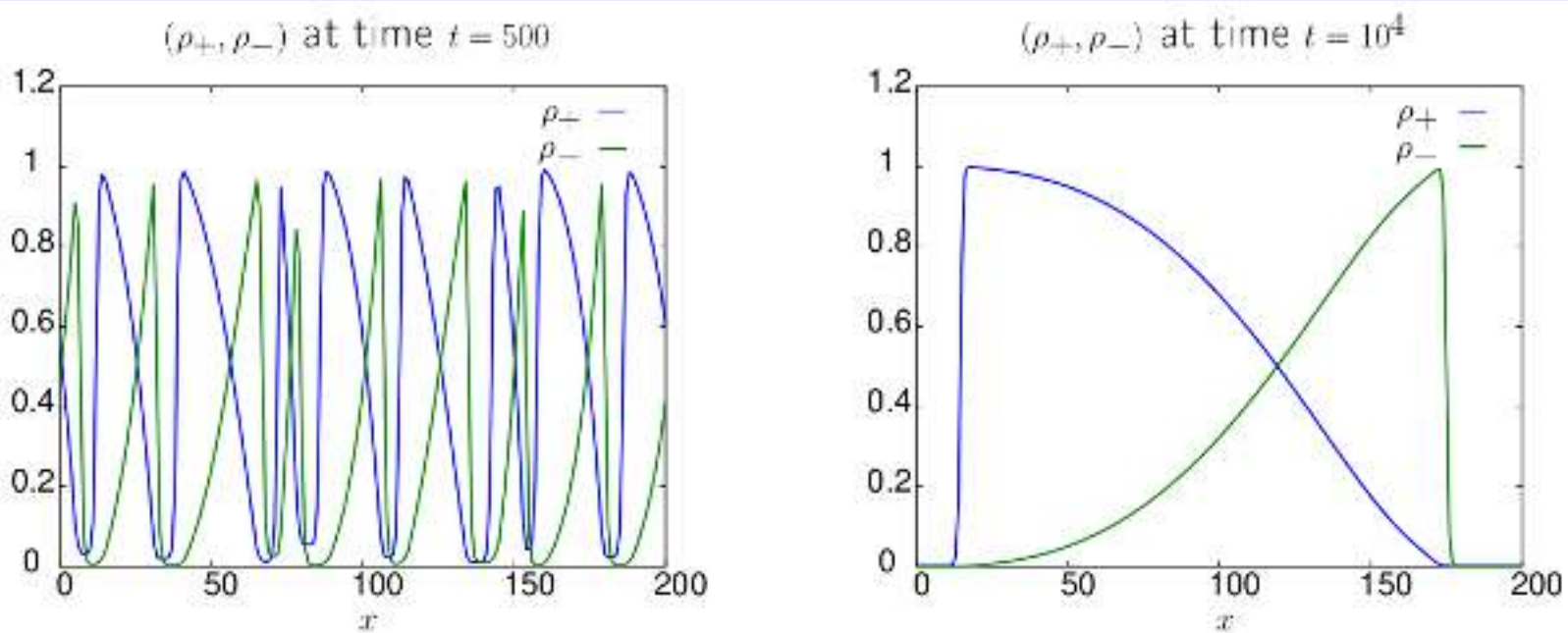
Initial condition outside of the hyperbolic region:



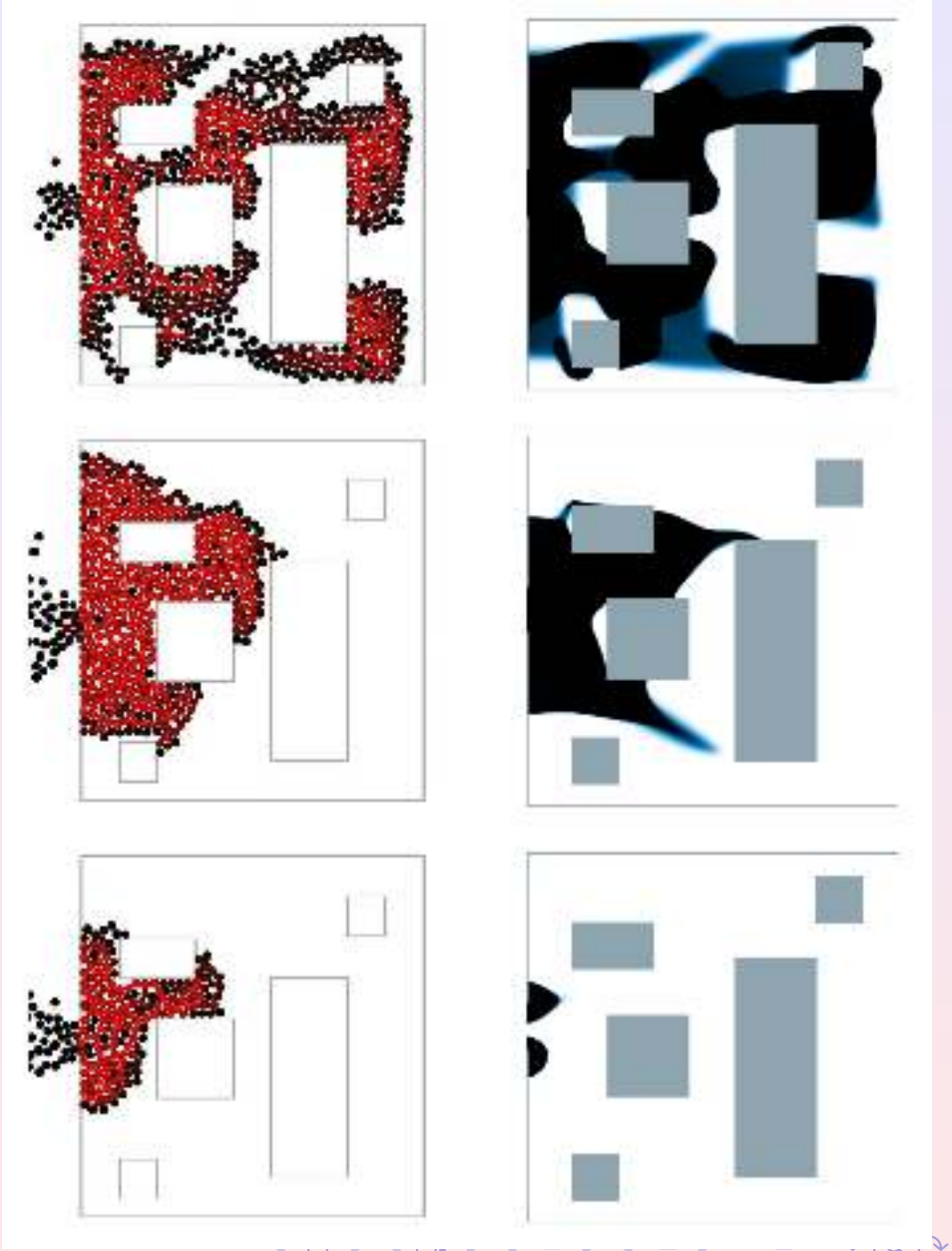
From [Appert-Rolland, Degond, Motsch (2011)]

First many clusters; after longer time, only one cluster remains.

PbI Macroscopic models

Properties of pedestrians:

- Incompressible at high density
- Undeformable



PhD thesis Aude Roudneff-Chupin
(LMO, Orsay, 2011)

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