JÜLICH
FORSCHUNGSZENTRUM

9th February 2017

High statistics measurements of pedestrian dynamics & modeling

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NWO
Netherlands Organisation for Scientific Research

TU/e Technische Universiteit Eindhoven University of Technology

High statistics measurements of pedestrian dynamics & modeling

Content from:

2016-now

TU/e NWO

Post-doc

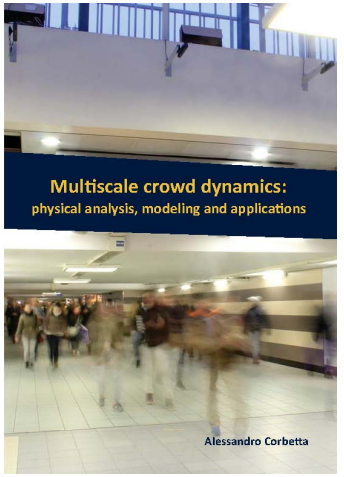
"Vision driven visitor behaviour analysis and crowd management"

2013-2015

POLITECNICO DI TORINO TU/e

Ph.D.

"Multiscale pedestrian dynamics: physical analysis, modeling and applications"



& In collaboration with:

J. Meeusen (Eindhoven)

C-M. Lee (CSU Long Beach)

R. Benzi (Rome)

A. Muntean (Karlstad)

F. Toschi (Eindhoven, CNR-IAC)

A. Holten, G. Oerlemans

Introduction & Motivation

- Walking pedestrians:
  - *Rich dynamics with intriguing physics*
  - Reliable models: relevant in science & technology
    - Safety/serviceability of structures, evacuations…

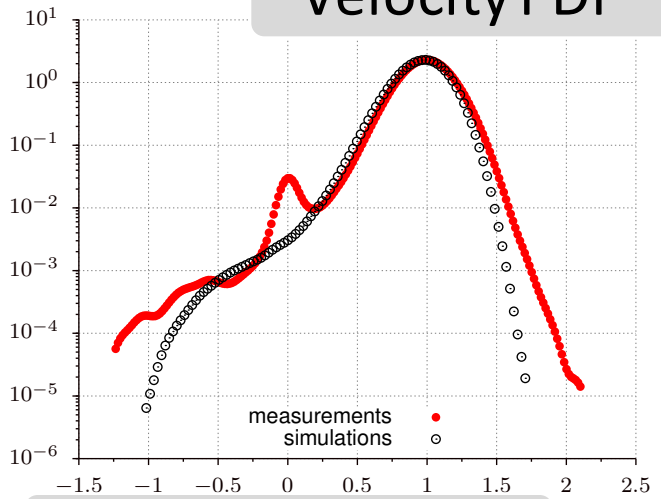
- Stochastic, nearly unpredictable motion
  - *Quantitative*-(statistical) *assessment of fluctuations?*
    - Measurements?
    - Rare behaviors?
    - Modeling?

Introduction & Motivation

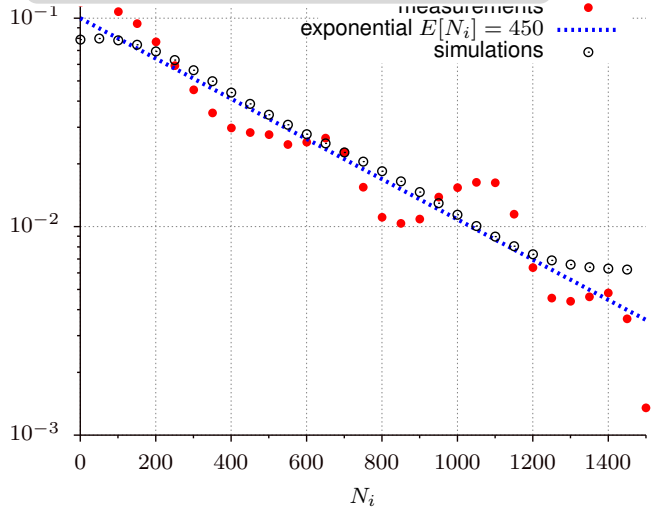
- We want **models** to exhibit same **statistic** signatures of **real-life**

- Challenge: **measure** such statistic signature
  - Real-life data
  - High quality in space-time
  - High statistic resolution
    - In a sense: repeat the same experiment**(s)** over and over
    - **Note:** real-life is also a "technical necessity"
  - Privacy?

"Velocity PDF"



"Rare event PDF"

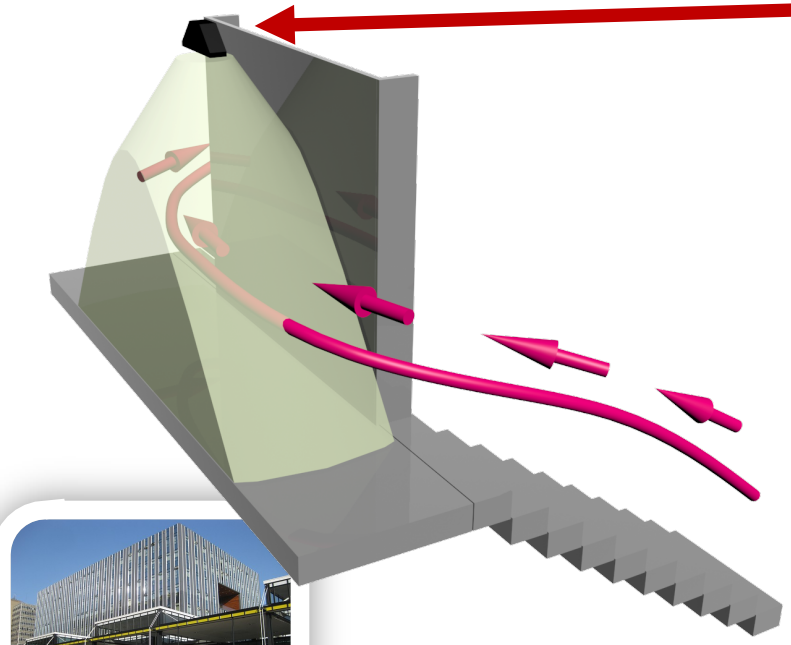


Outline of the talk

1. High statistics crowd measurements in real-life
    - *Measurements via overhead Kinects*
    - *Macroscopic overview of the data*
2. Data classification problem
3. Langevin-like modeling
    - *Diluted behavior*
    - *Pair-wise interactions*
4. Outlook

Crowd measurements in real-life

Continuous, 24/7, measurement



Metaforum @ TU/e *Sept. 13 – Sept. 14*

2.2K trajs/day => 220K trajs in total

Eindhoven Train Station

Sept. 14 – Mar. 15

80K trajs/day => 5M trajs in total

[Corbetta et al. 14,15,16,16,17,17] + Phd thesis

Crowd measurements in real-life

TU/e Technische Universiteit Eindhoven University of Technology

Intelligent Lighting Institute

4x3 grid

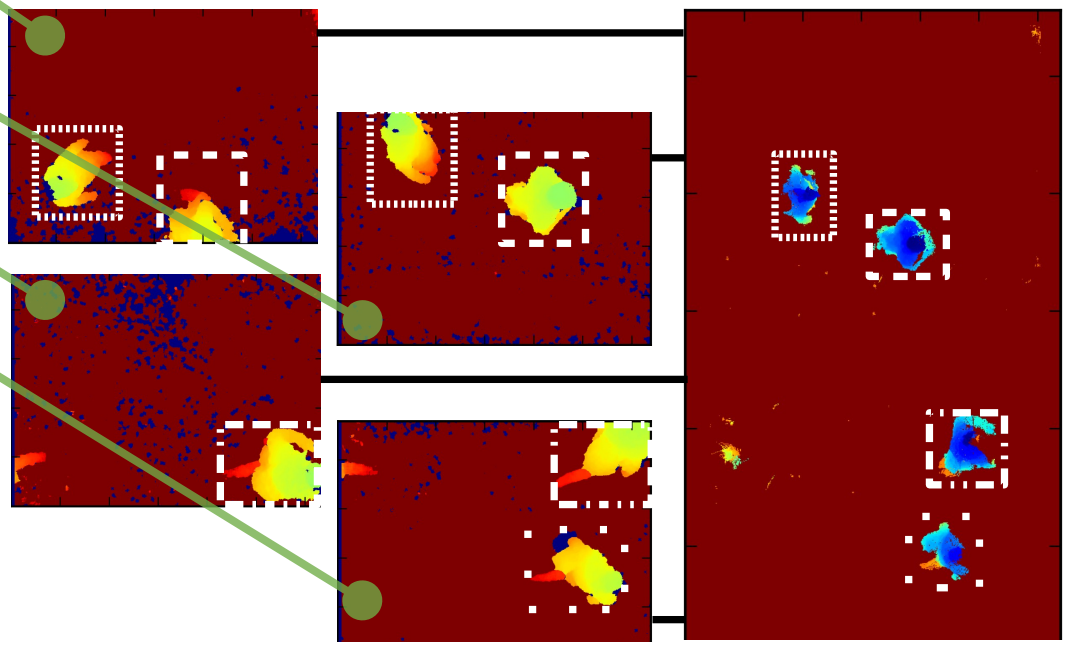
Naturalis Biodiversity Center

EINDHOVEN

(Also Real-time)

Data acquisition

- Overhead depth-maps:
  - Distance(pixel <-> camera plane)
  - h: 3.5-5 m
  - 7.5 – 15 Hz
- Arrays or grids of sensor for larger coverage
- Axonometric transformation: “high-school” geometry problem



[Corbetta et al. Ped16]

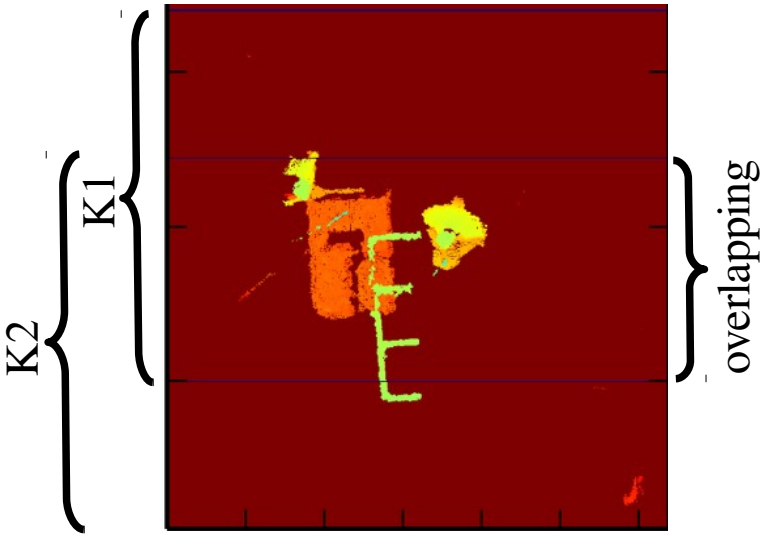
Data acquisition - Eindhoven station

80-100K ped./day

0-1.8 ped./m^2

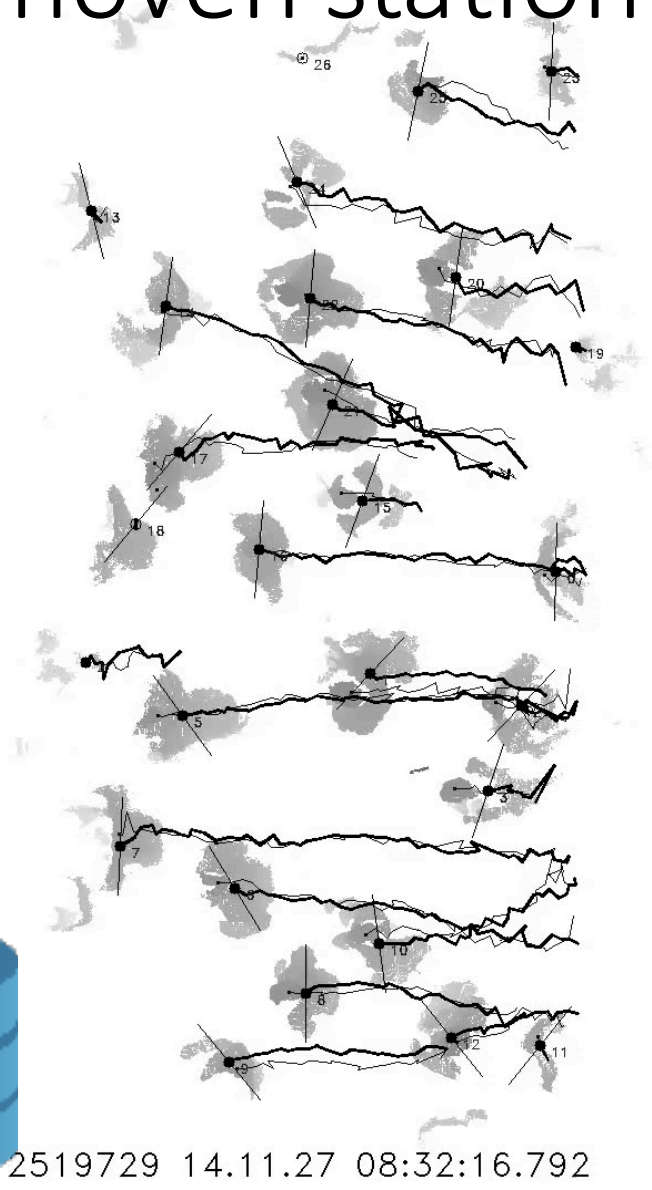
100GB/day

1. Registration/Calibr.



2. Detection

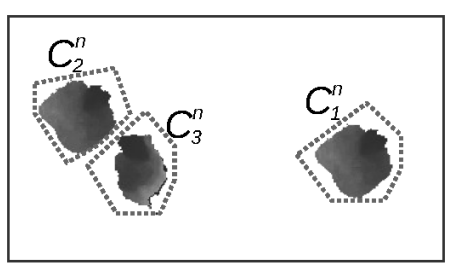
3. Tracking

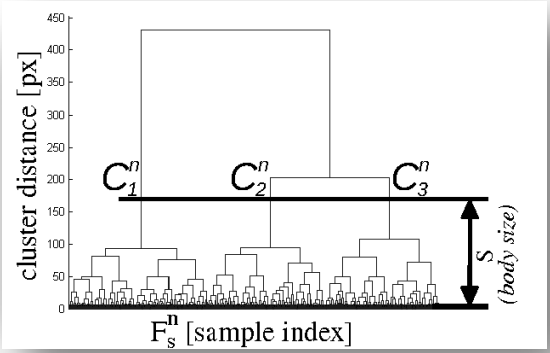


[Corbetta et al. Ped16]

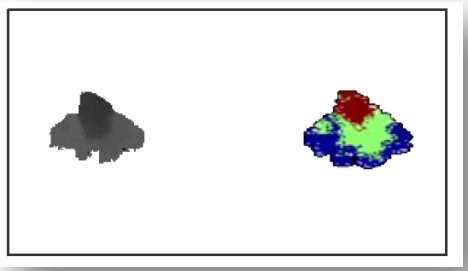
Offline detection & tracking

- **2 Heads detection**
  - Overhead, 3d view
    - Depthmap-based, Via Microsoft Kinect
    - Complete-linkage clustering of “depth-cloud” (Seer et al. 14, Corbetta et al. 14, 15)
    - 15Hz sampling
    - “redundant” detection policy (to submit)





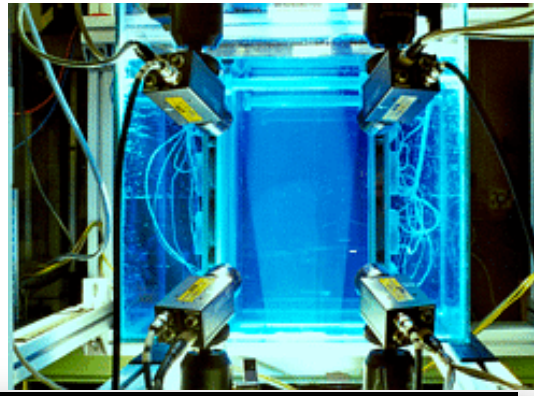
Clusterization tree cut at “body scale”



Heads = low depth percentiles (closest)

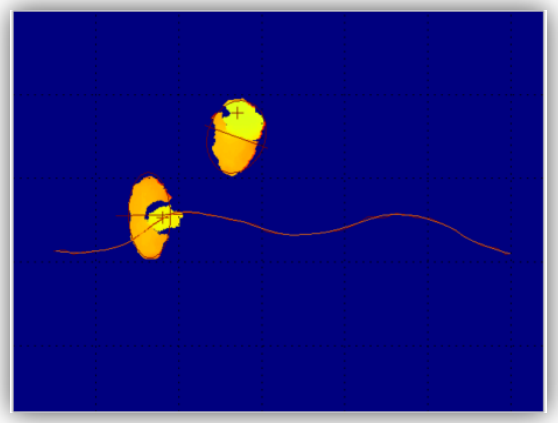
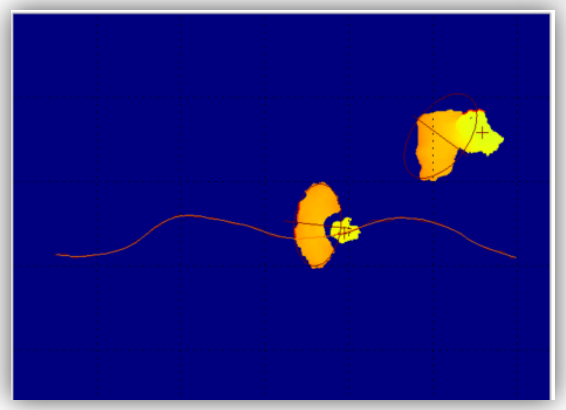
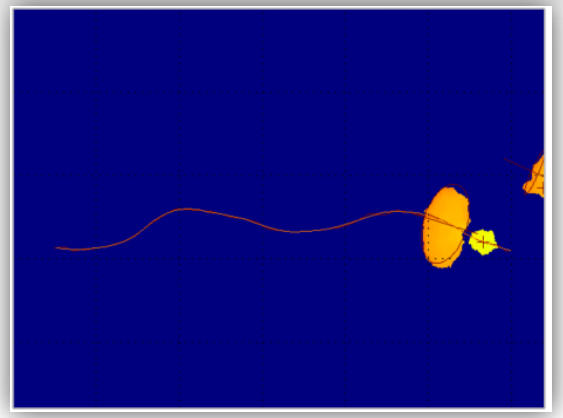
Pedestrian tracking

- **3. Head tracking**
  - Head Spatio-Temporal matching via 3DPTV
    - from experimental fluid mechanics
      (Willneff et Al. 2002, Willneff 2003)
    - Nearest search + velocity prediction



- Implementation:
  - OpenPTV (Open source, 2012-)

OpenPTV
open source particle tracking velocimetry

Acknowledgment: Alex Liberzon (TAU)

Offline processing

lan

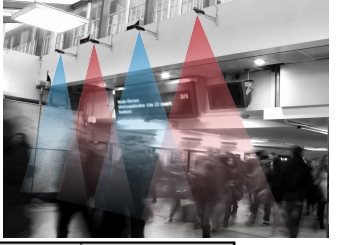
100GB/day

~20 min to process 1 day
~100K trajs
O(400) CPUs
~HDF5 RDBMS

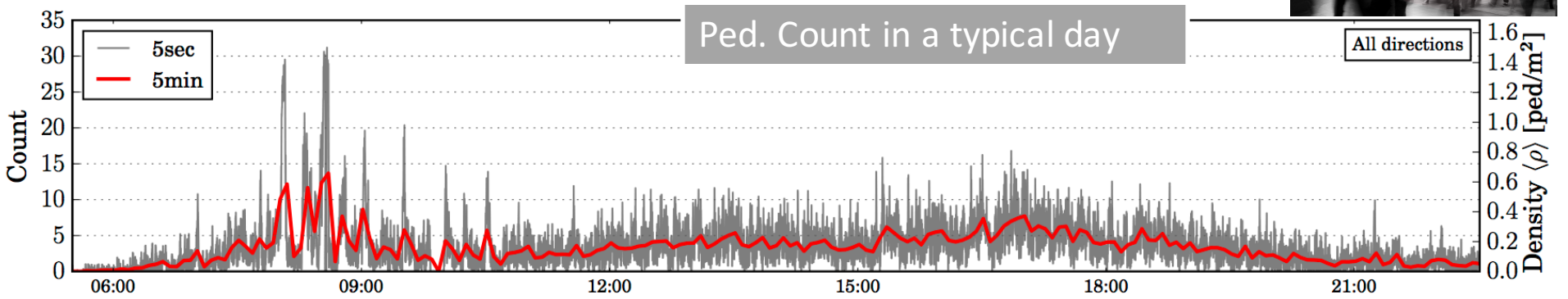
NTP – based time sync (~2ms error)
+ frame matching: closest in time (33ms error)

TU/e Technische Universiteit Eindhoven University of Technology

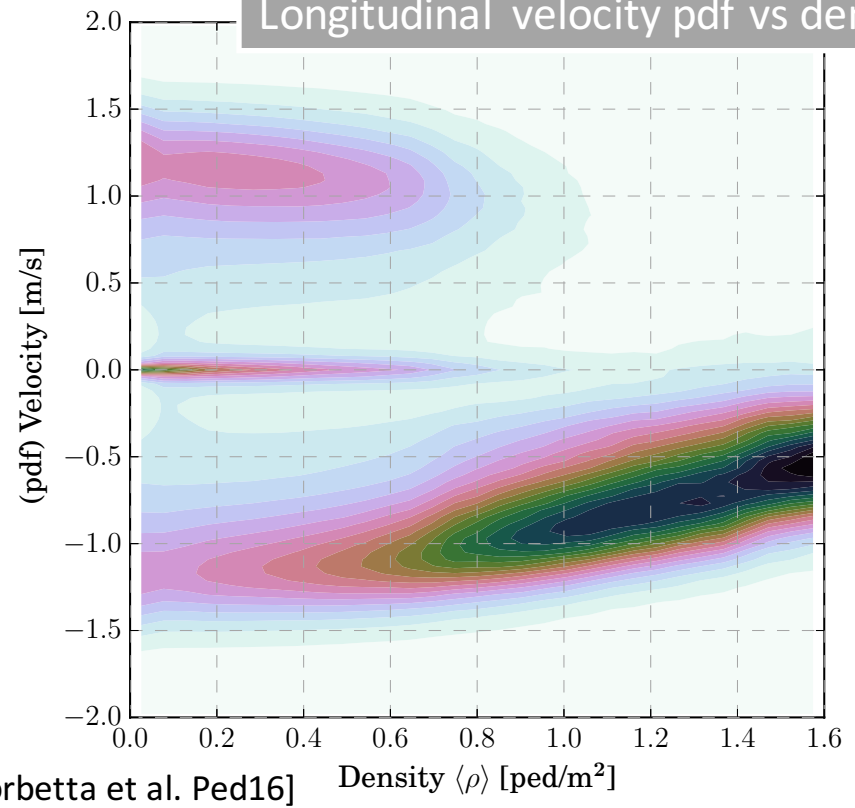
Macroscopic features from high statistics measurements (station)



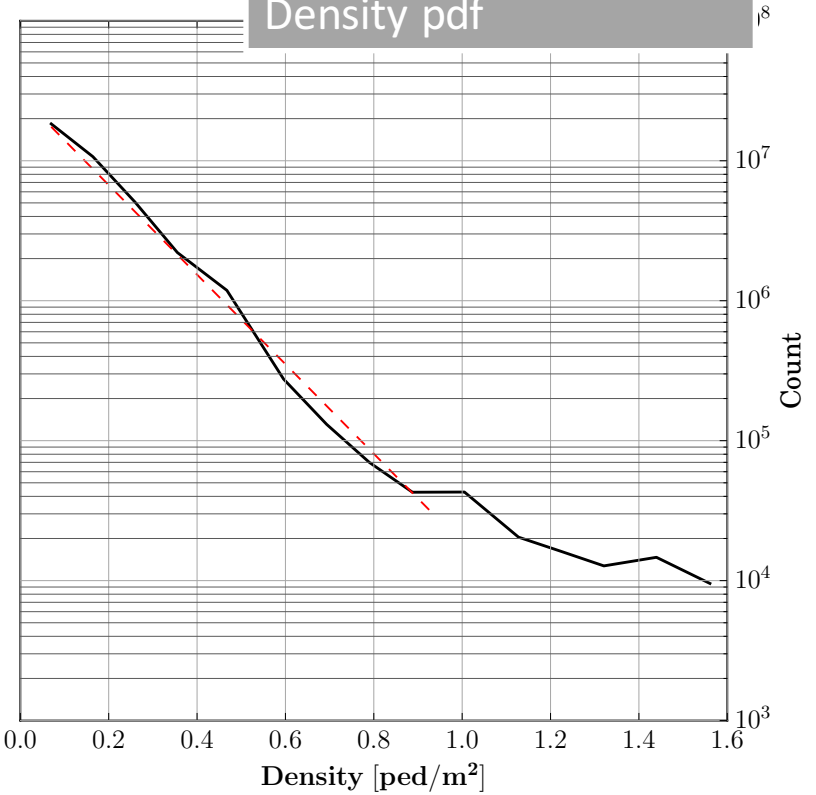
Ped. Count in a typical day



Longitudinal velocity pdf vs density

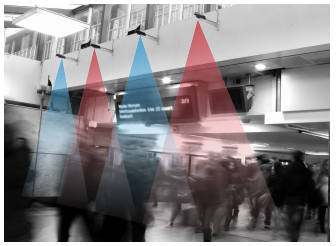


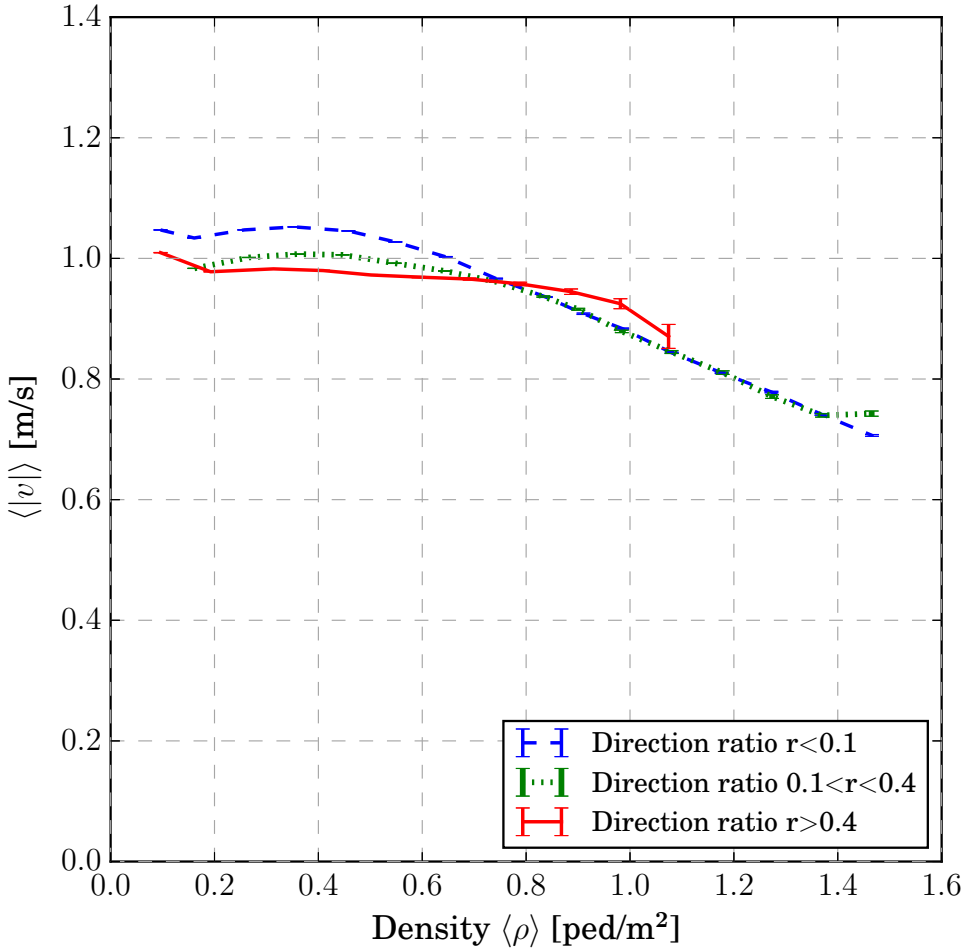
Density pdf

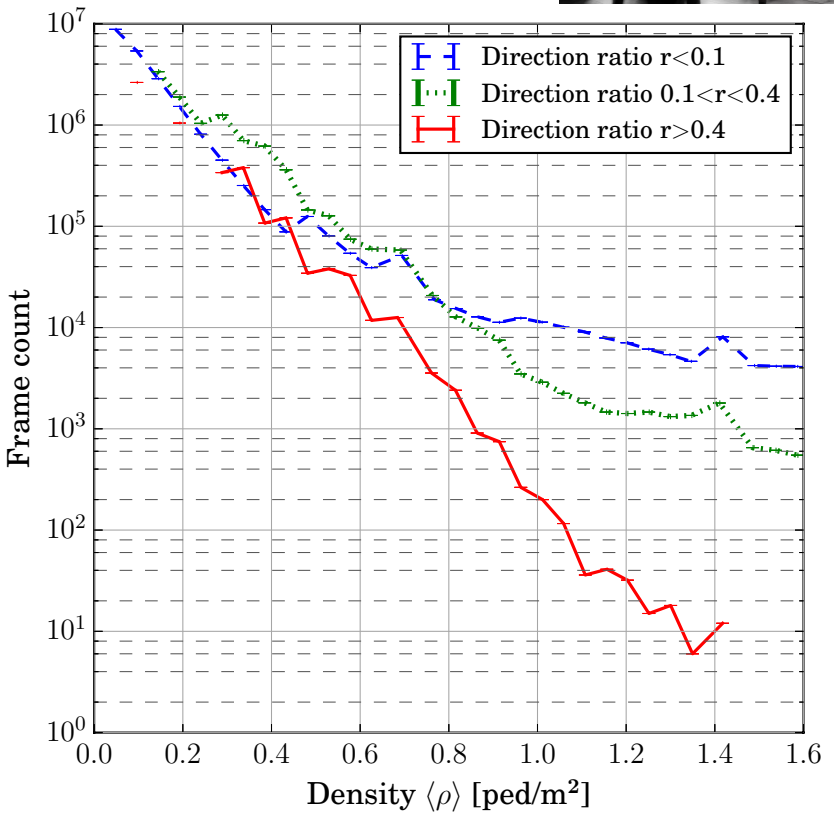


[Corbetta et al. Ped16]

Macroscopic features from high statistics measurements: direction ratio vs. dynamics



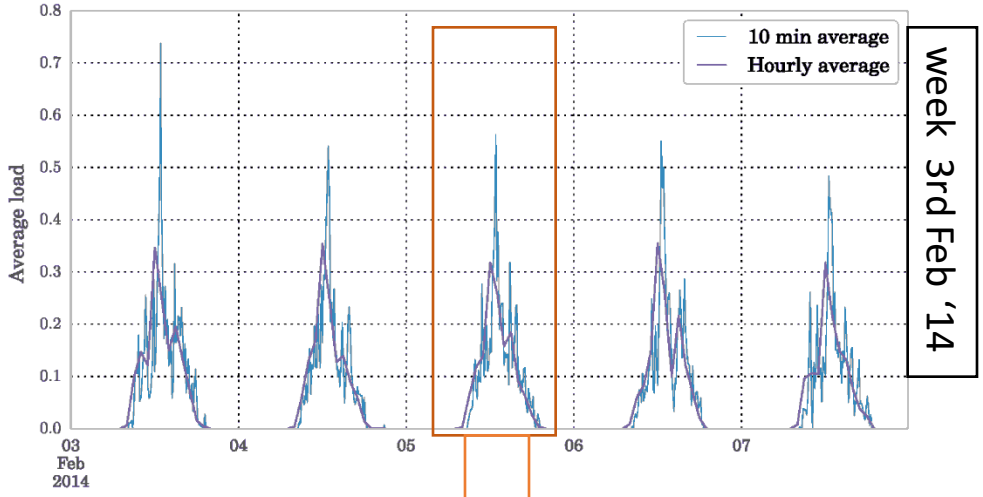




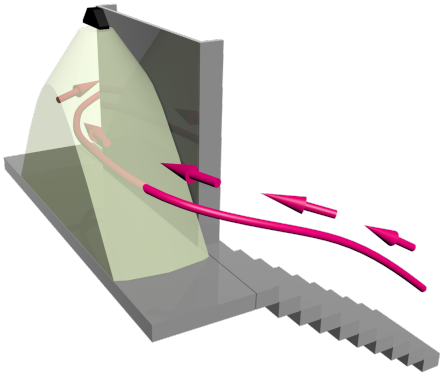
[Corbetta et al. Ped16]

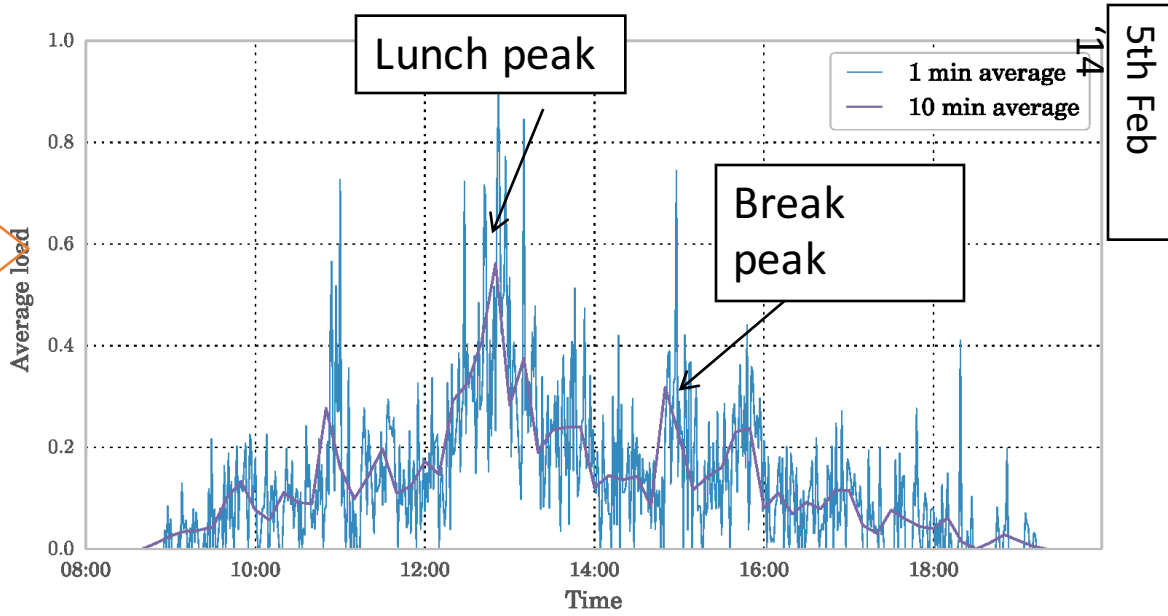
Traffic features (university corridor)

Usage characteristics (ex. 1 week)



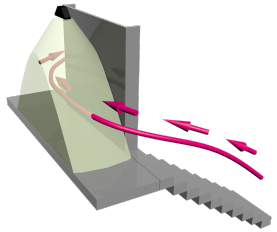
week 3rd Feb '14



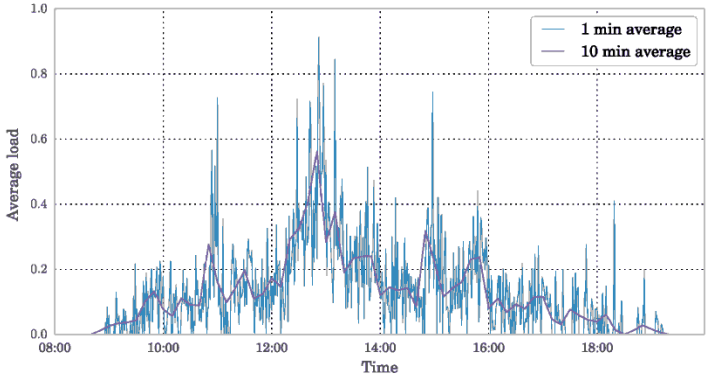


5th Feb '14

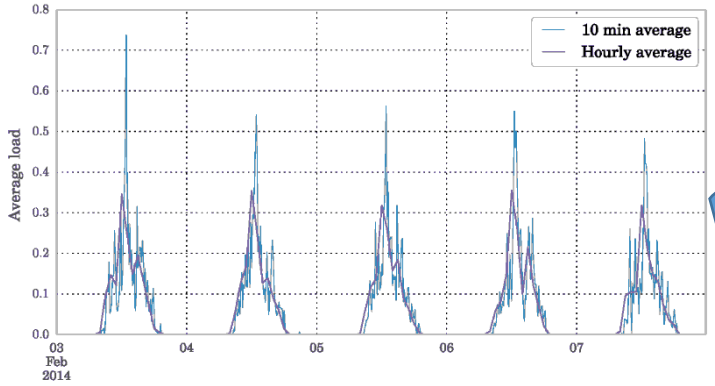
Traffic features (university corridor)

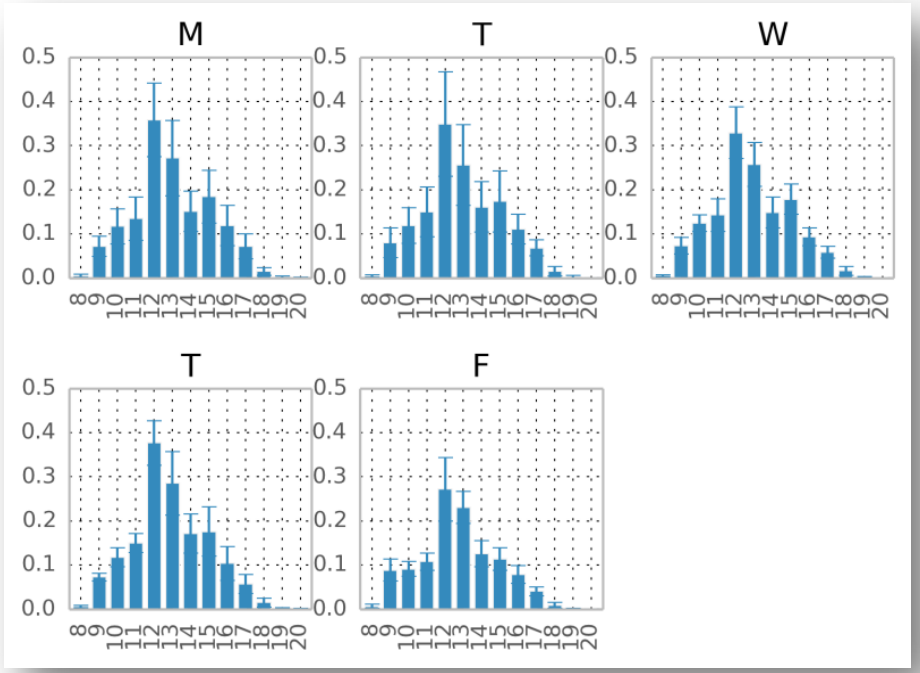


- 50-days averaged load values



Averaging





Hourly-averaged load (50 days)

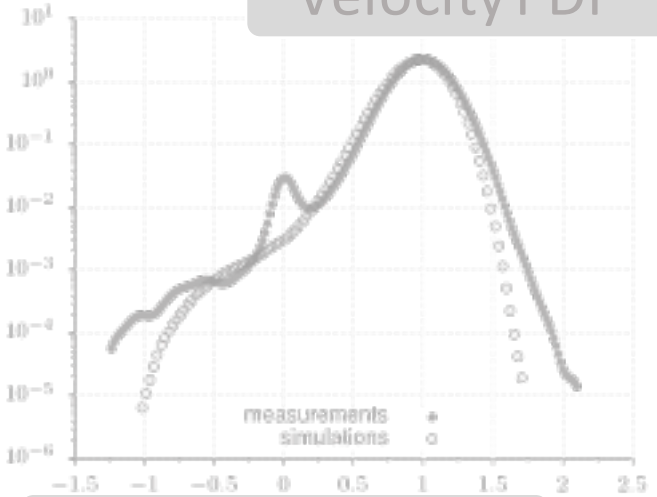
- Most of trajectories from lunch-time where the behavior is expected to be nearly homogeneous

Introduction & Motivation

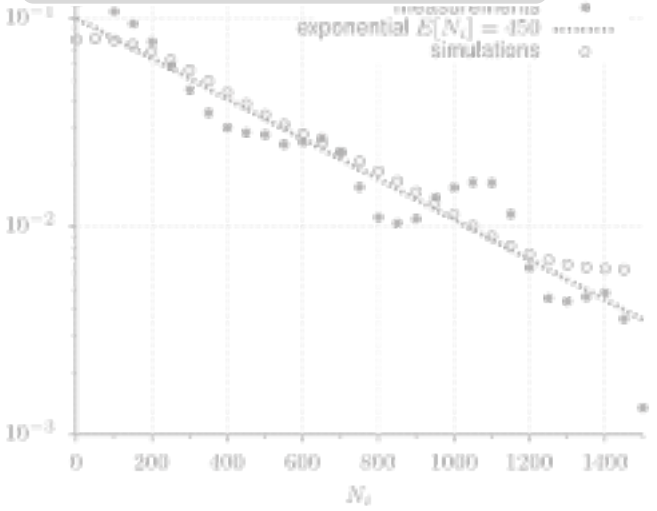
- We want **models** to exhibit same statistic signatures of real-life

- Challenge: **measure** such statistic signature
  - Real-life data ✔
  - High quality in space-time ✔
  - High statistic resolution ✔
    - In a sense: repeat the same experiment**(s)** over and over !
    - **Note:** real-life is also a "technical necessity"
  - Privacy?

"Velocity PDF"



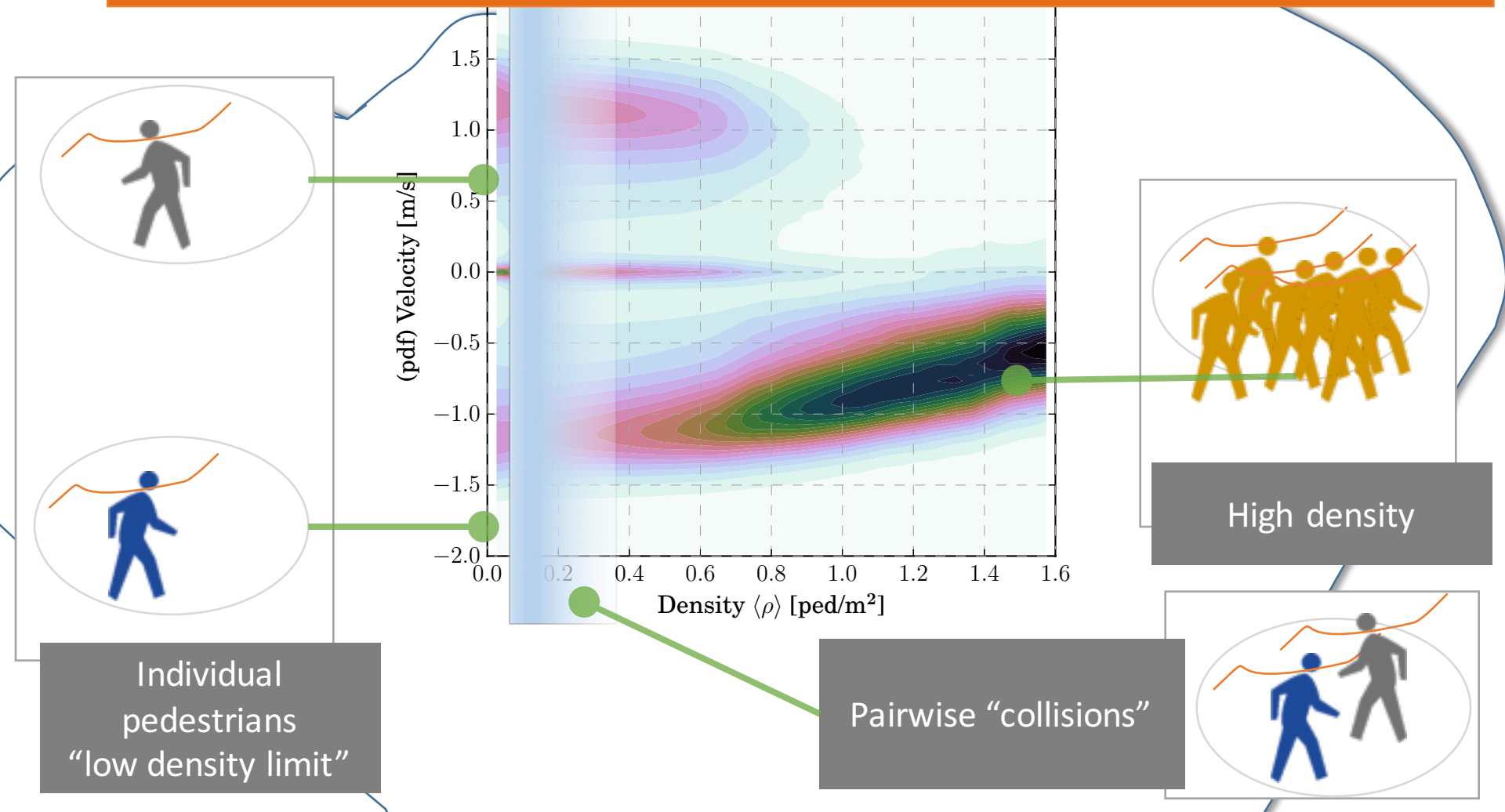
"Rare event PDF"



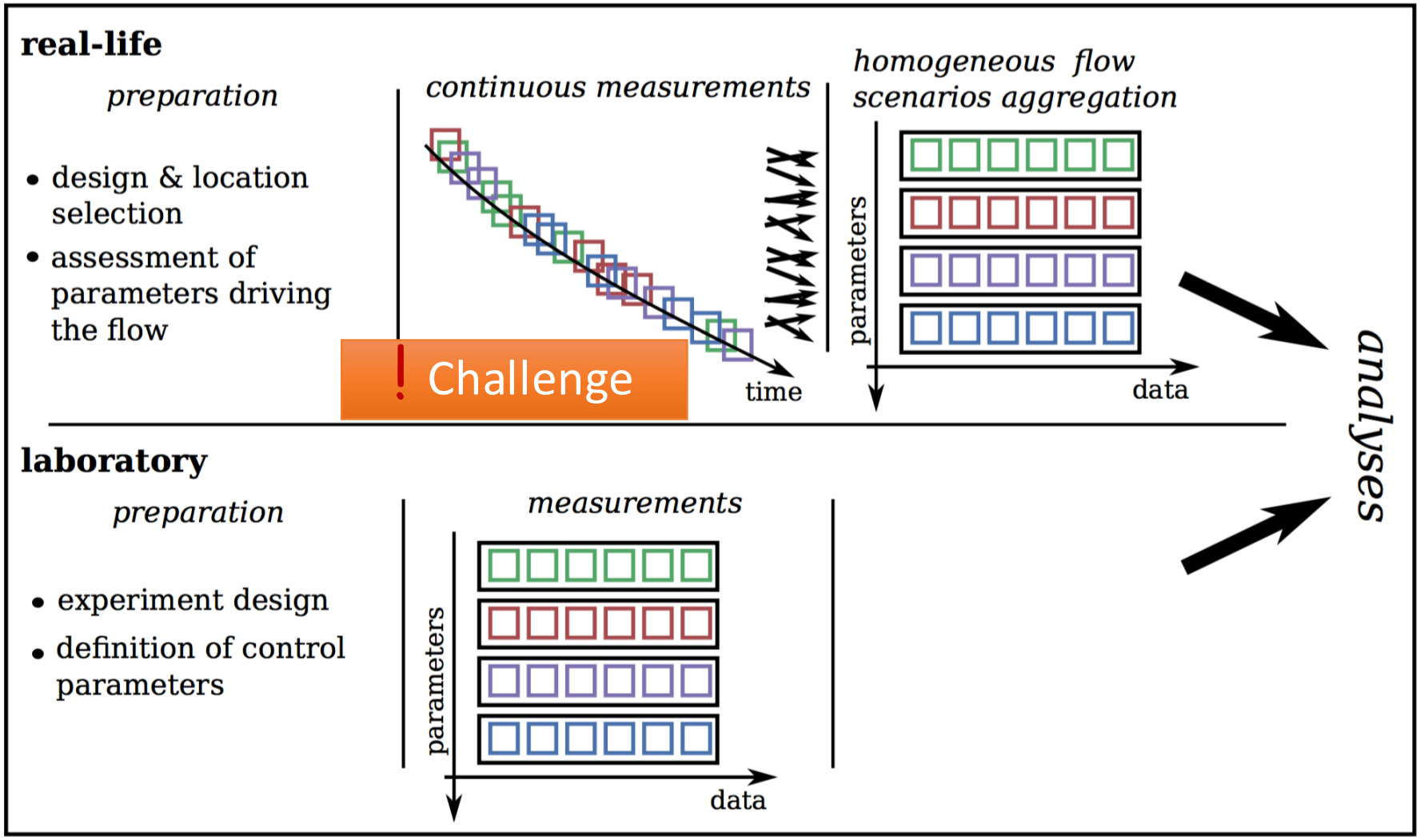
Microscopic dynamics & stochastic modeling

! Challenge: we cannot set the experiment "flow parameters"!

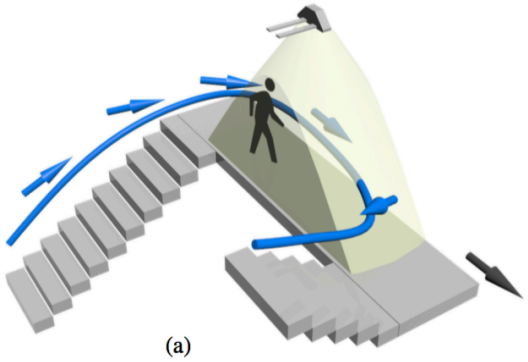
NEED: Automatic classification ("binning") of trajectories for situation-based statistics



Microscopic dynamics & stochastic modeling



Microscopic dynamics & stochastic modeling

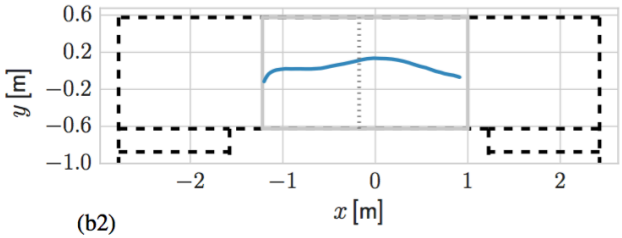


(a)

! Challenge

+ extracting “similar experiments”
+ i.e. automatic dynamics classification *efficiently*

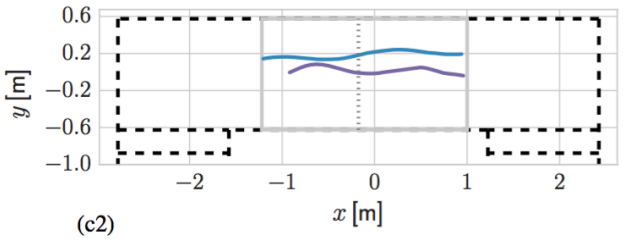
(b1)



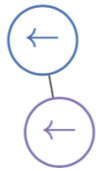
(b2)

(b3)

(c1)

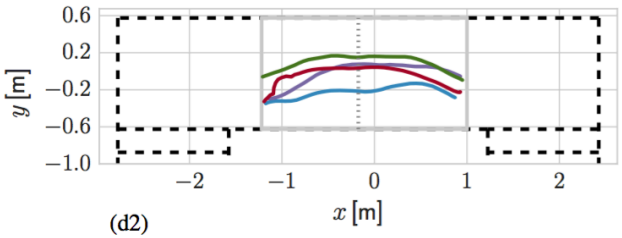


(c2)

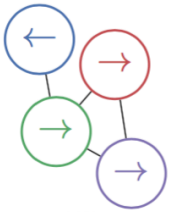


(c3)

(d1)



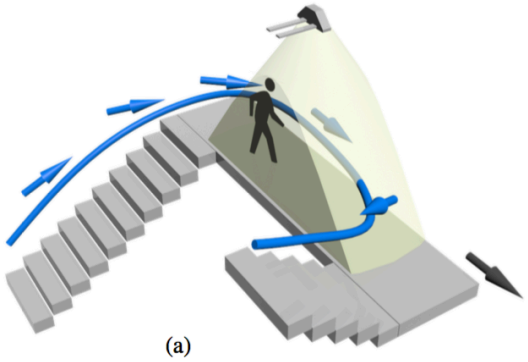
(d2)



(d3)

[Corbetta et al. Collective Dynamics 17]

Microscopic dynamics & stochastic modeling


(a)

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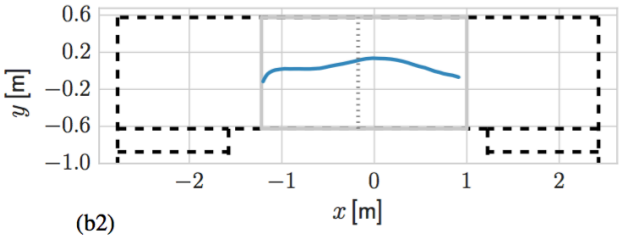
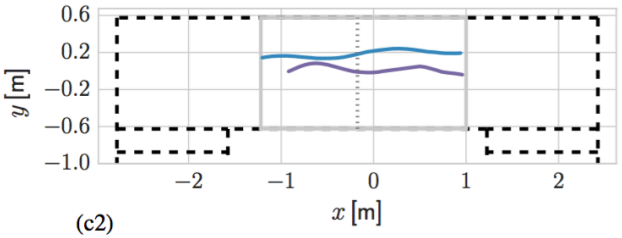


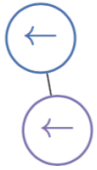
(b2)

(b3)

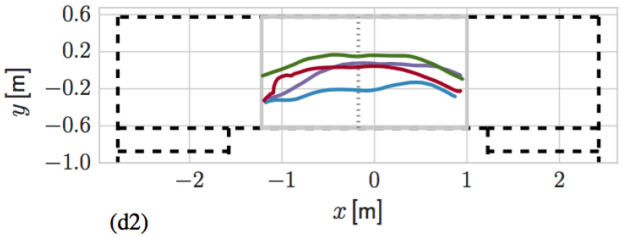
(c1)



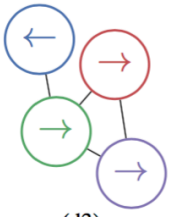
(c2)


(c3)

(d1)



(d2)


(d3)

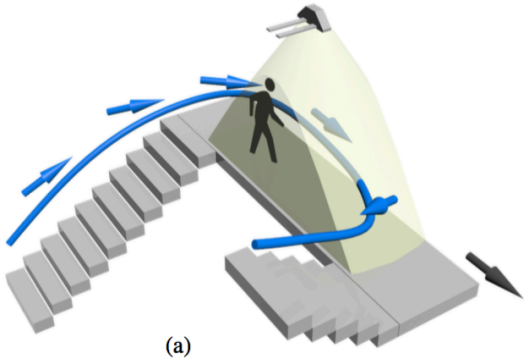
Algorithm

1. Compute interaction network (graph, 1-pass)
   1. 1 ped -> **node**
   2. 2 ped in same frame -> **edge**
2. "similar experiments" = "similar" connected components

Linear in time

[Corbetta et al. Collective Dynamics 17]

Microscopic dynamics & stochastic modeling



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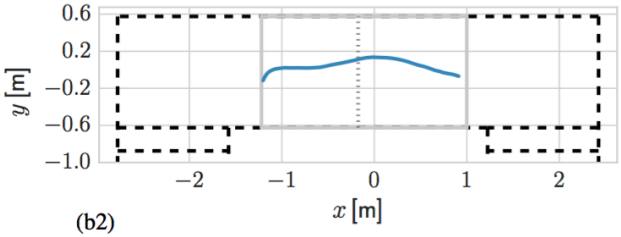
+ i.e. automatic dynamics classification *efficiently*

(b1)

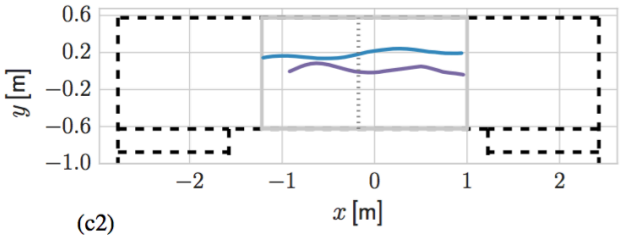


(b2)

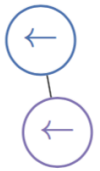
(b3)

"Pedestrians walking alone to the left (diluted limit)"

(c1)



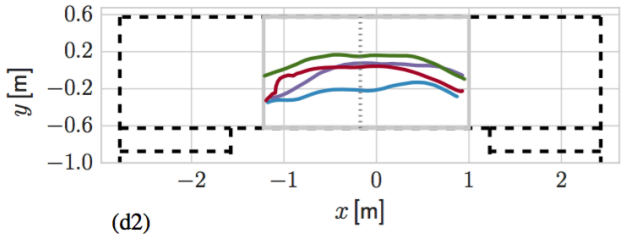
(c2)



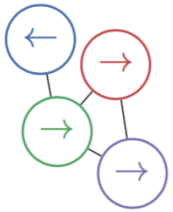
(c3)

"Pairs of pedestrians walking to the right"

(d1)



(d2)

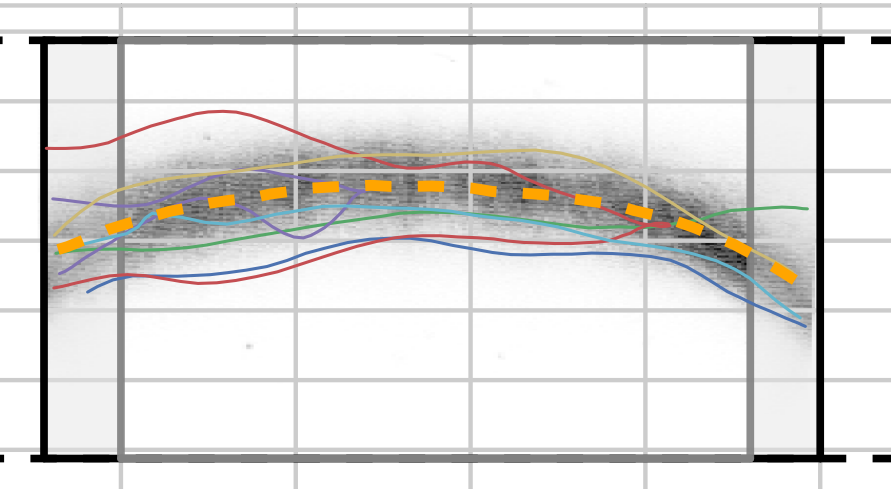


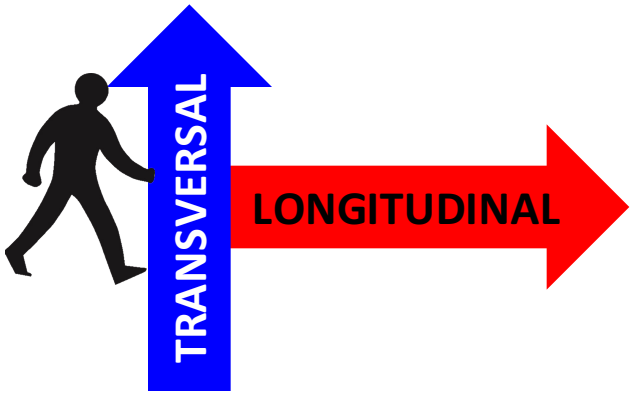
(d3)

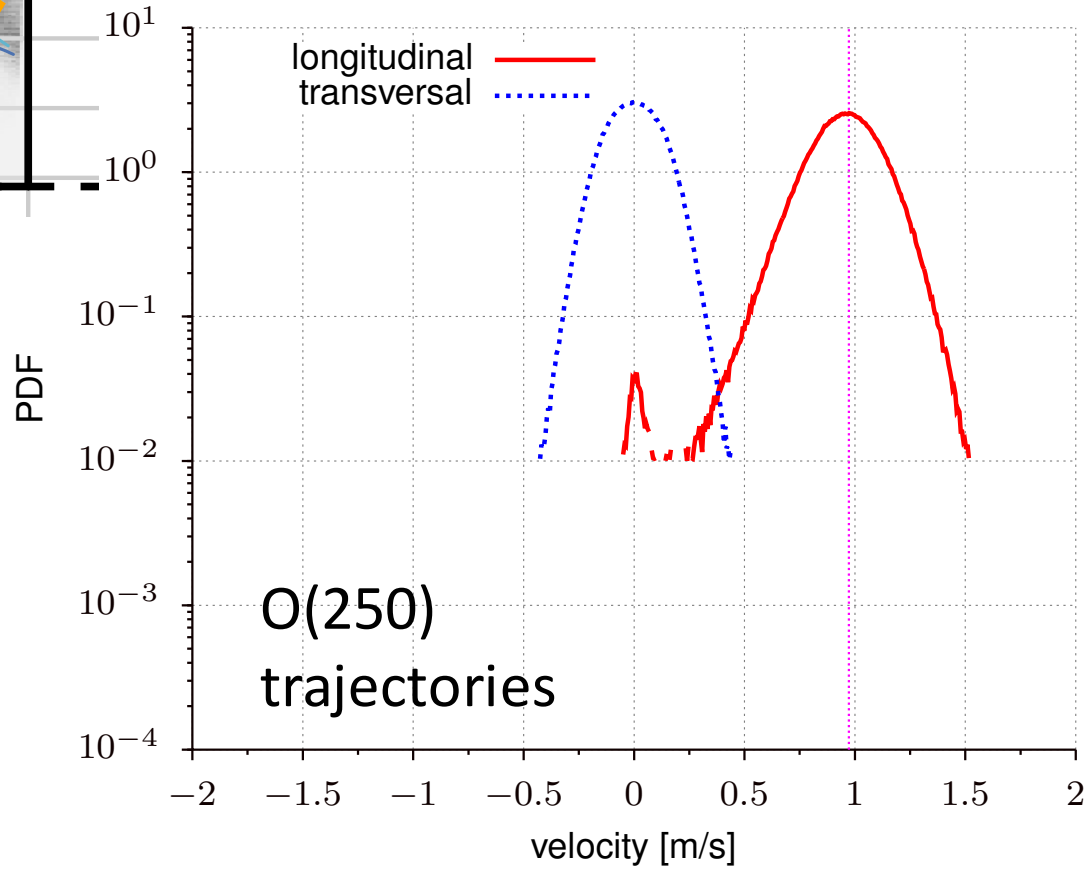
..possible 4-pedestrians scenario..

[Corbetta et al. Collective Dynamics 17]

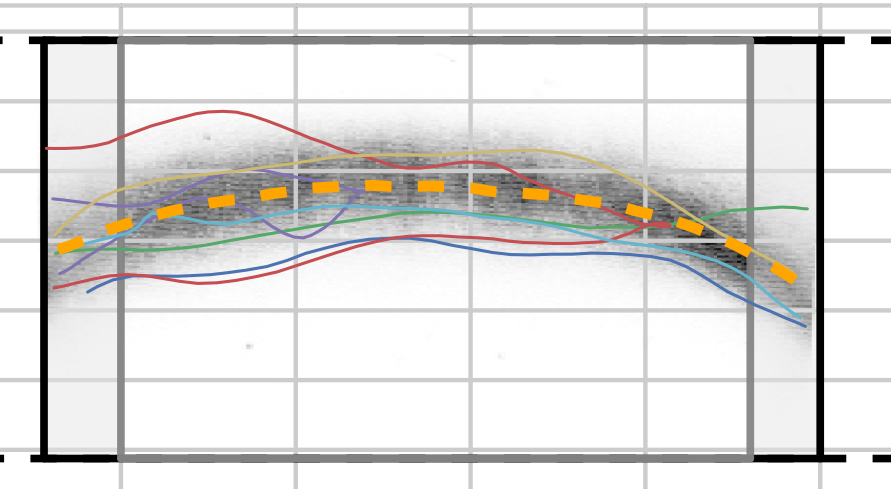
Diluted crowds with high statistics

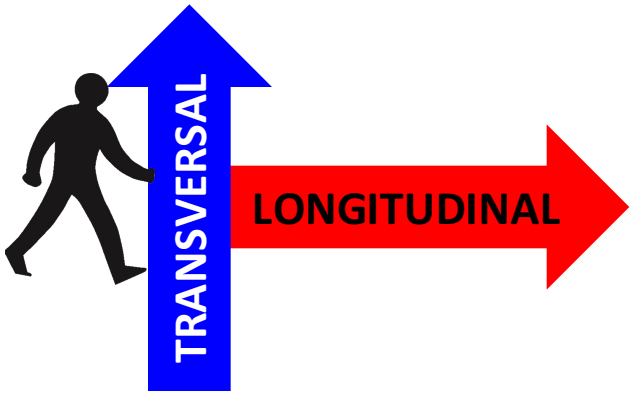




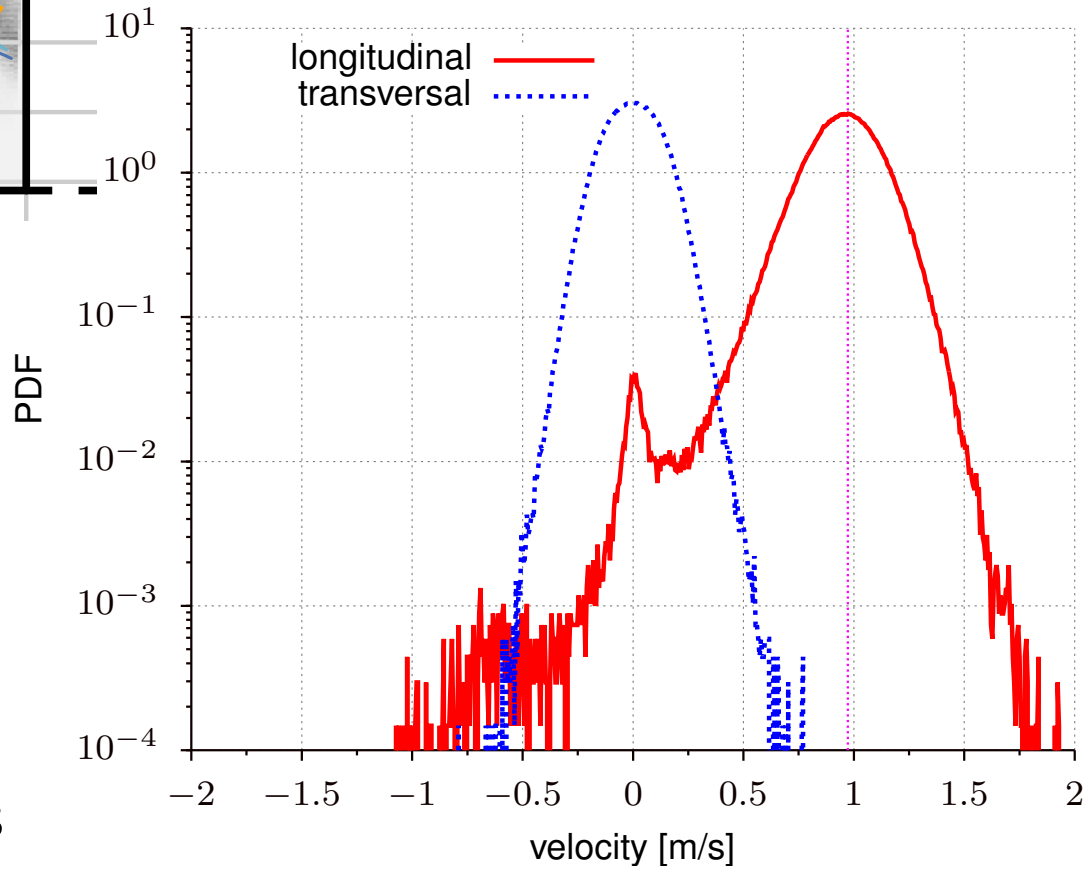


Diluted crowds with high statistics



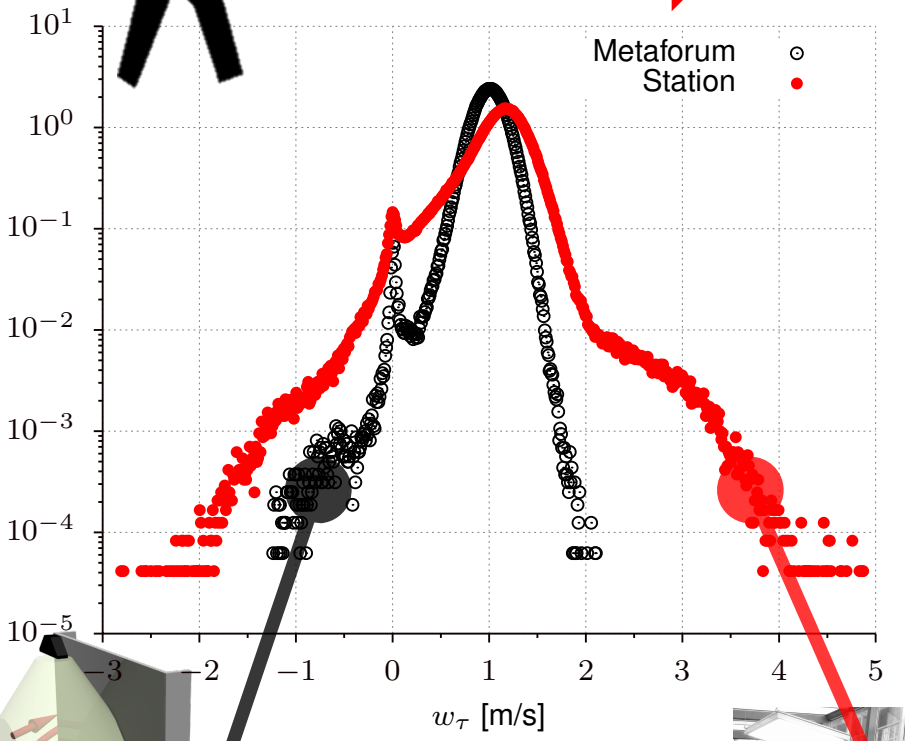


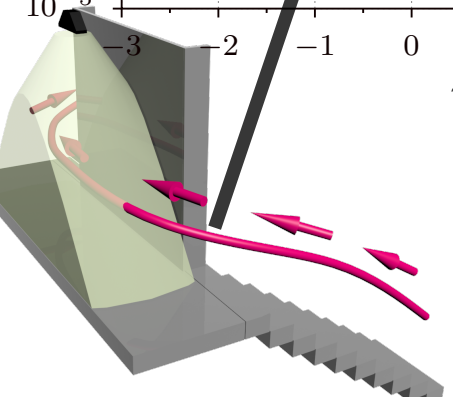
O(250.000) trajectories

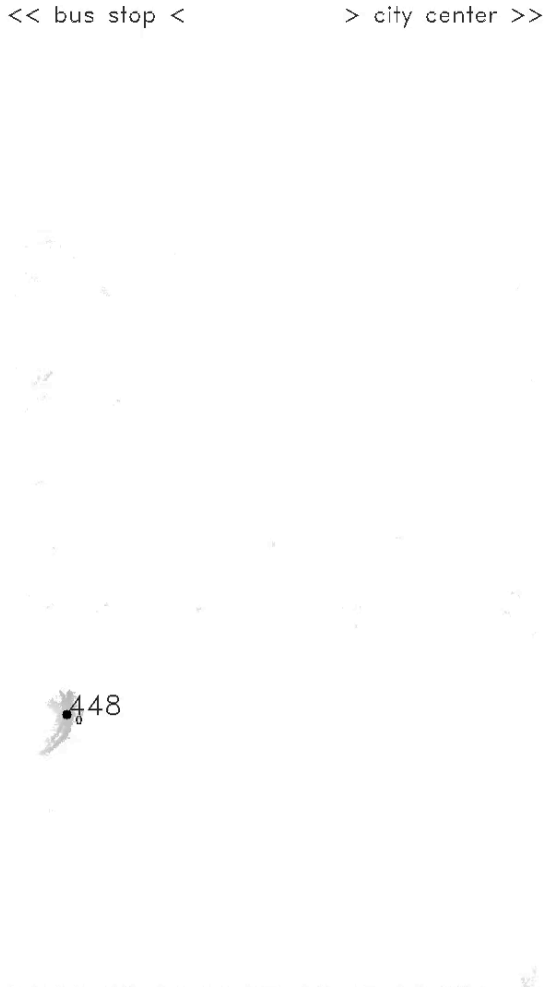


Diluted crowds with high statistics

LONGITUDINAL



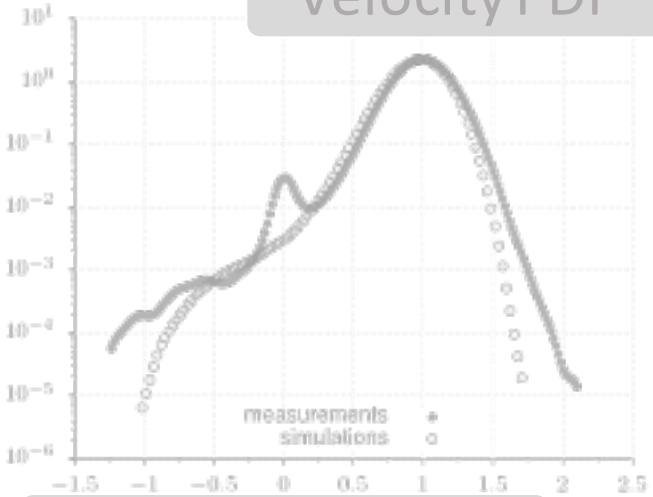




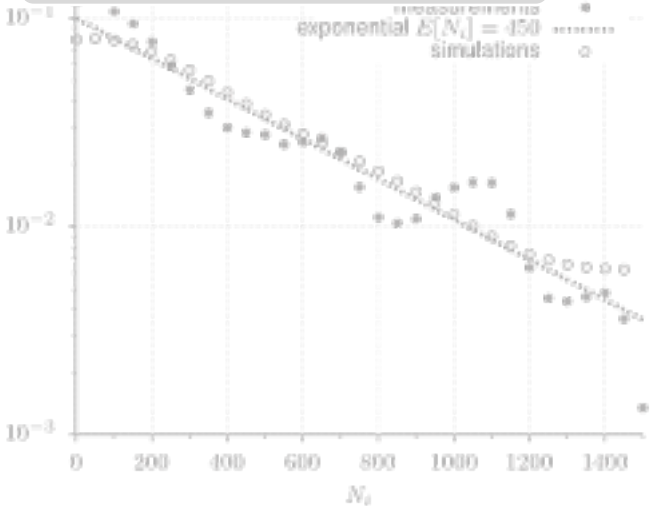
Introduction & Motivation

- We want **models** to exhibit same statistic signatures of real-life !
- Challenge: **measure** such statistic signature
  - Real-life data ✔
  - High quality in space-time ✔
  - High statistic resolution ✔
    - In a sense: repeat the same experiment**(s)** over and over ✔
    - **Note:** real-life is also a "technical necessity"
  - Privacy?

"Velocity PDF"



"Rare event PDF"



Can we reproduce this behavior in statistical sense?

Langevin-like equation

Second order stochastic dynamics:

$$\dot{\mathbf{x}} = \mathbf{v}$$

$$\dot{\mathbf{v}} = -\nabla_{\mathbf{v}} K(\mathbf{v}) - \nabla_{\mathbf{x}} V(\mathbf{x}) + \dot{\mathbf{W}}$$

Activity
(active friction for propulsion)

Spatial confinement

Random external factors

Note: can be seen as a generalization of standard social force

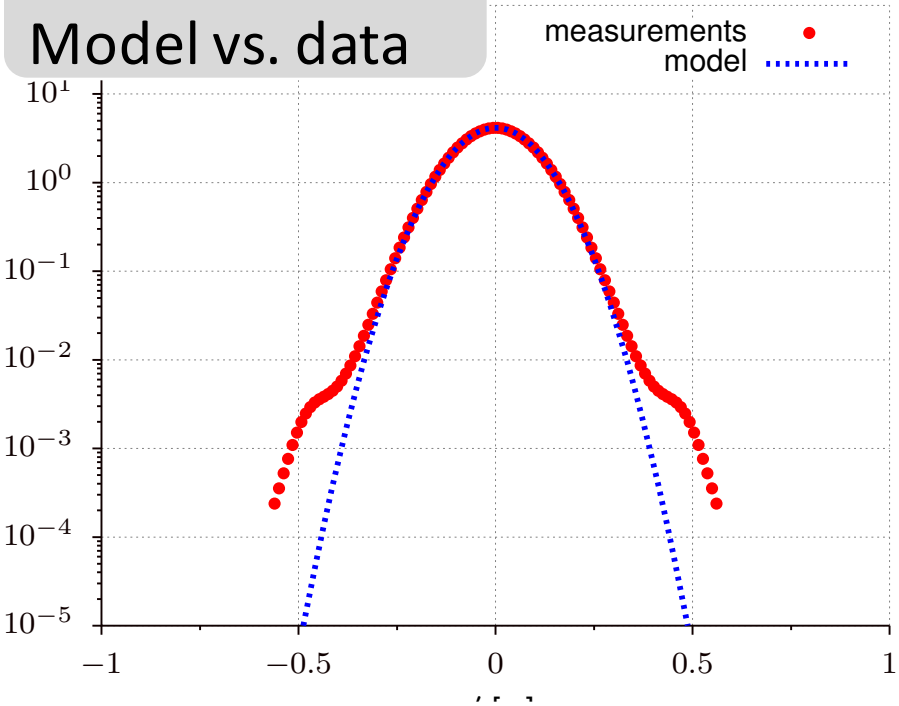
[Corbetta et al. 17, Phys. Rev. E]

Transversal fluctuations

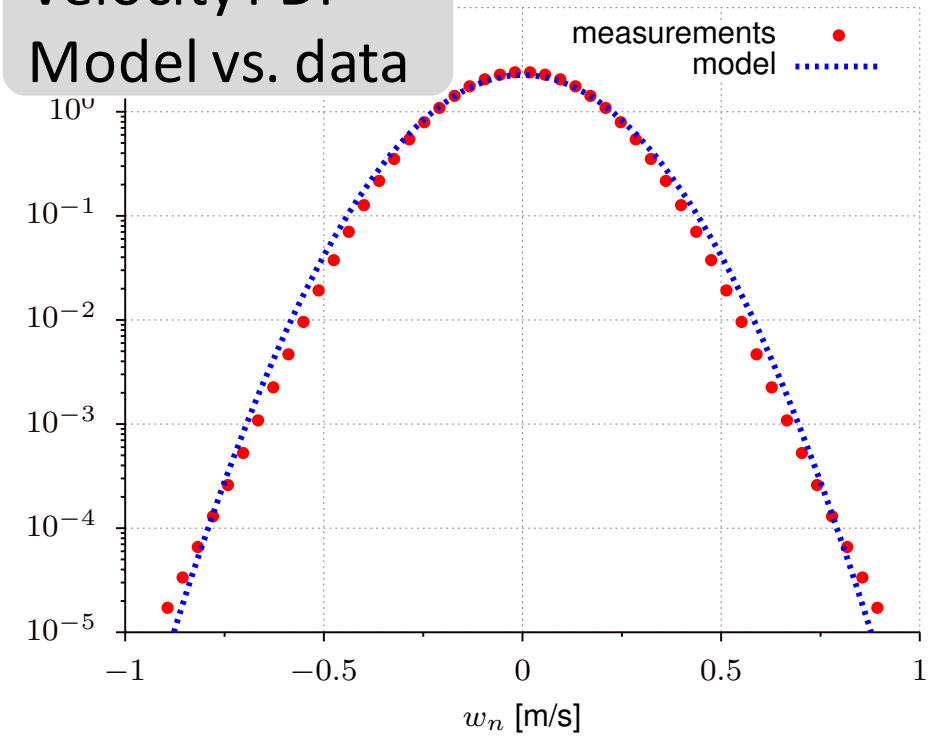
Stochastic motion around preferred path:

Quadratic potential for position (V) and velocity (K)

Position PDF
Model vs. data



Velocity PDF
Model vs. data



Confined Gaussian fluctuation: $\dot{v} = -2\gamma v - 2\beta y + \sigma_y \dot{w}$

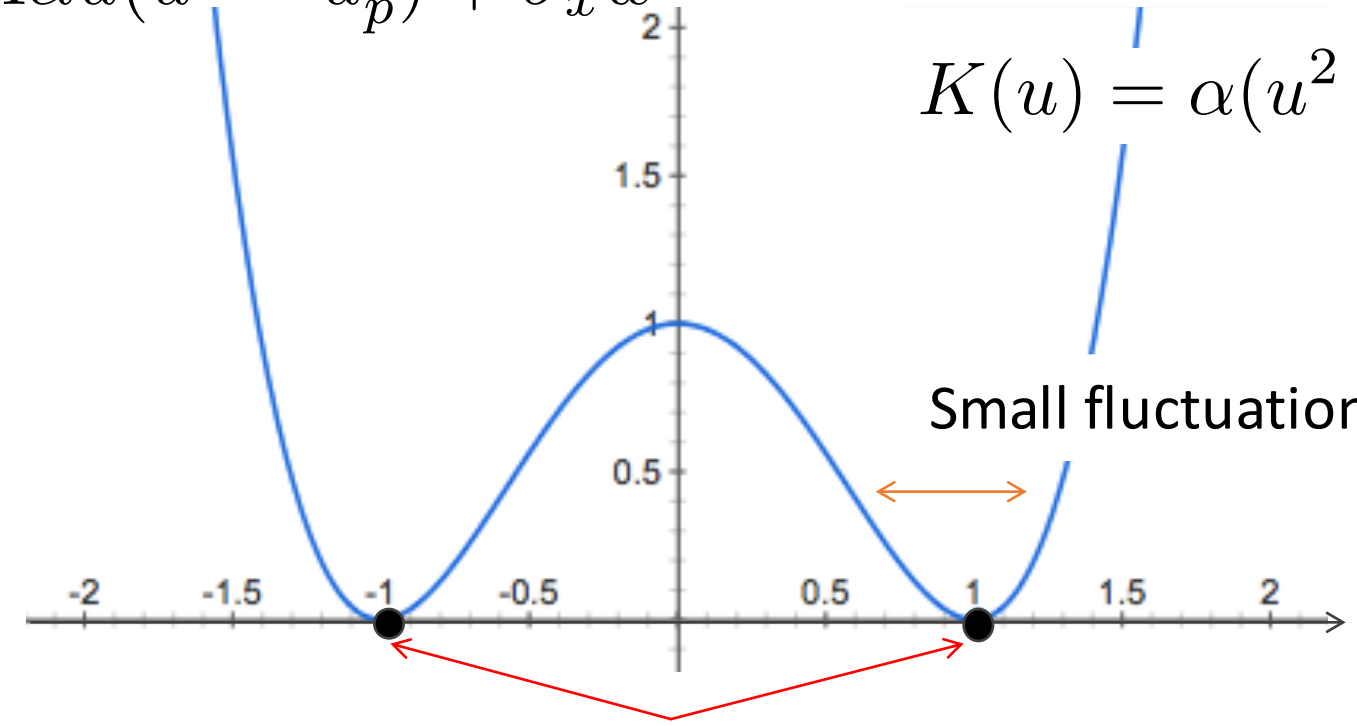
[Corbetta et al. 17, Phys. Rev. E]

Bi-stable longitudinal motion

4th order velocity potential velocity (K)

Simplest bi-stable stochastic velocity dynamics

$$\dot{u} = -4\alpha u(u^2 - u_p^2) + \sigma_x \dot{w}$$



$$K(u) = \alpha(u^2 - u_p^2)^2$$

Small fluctuations

Stable velocity states

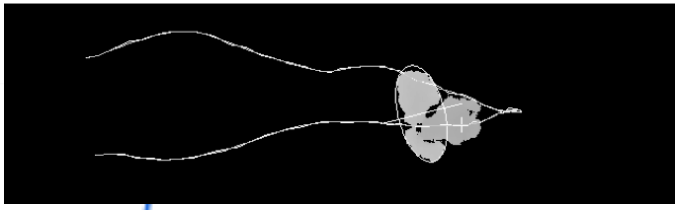
[Corbetta et al. 17, Phys. Rev. E]

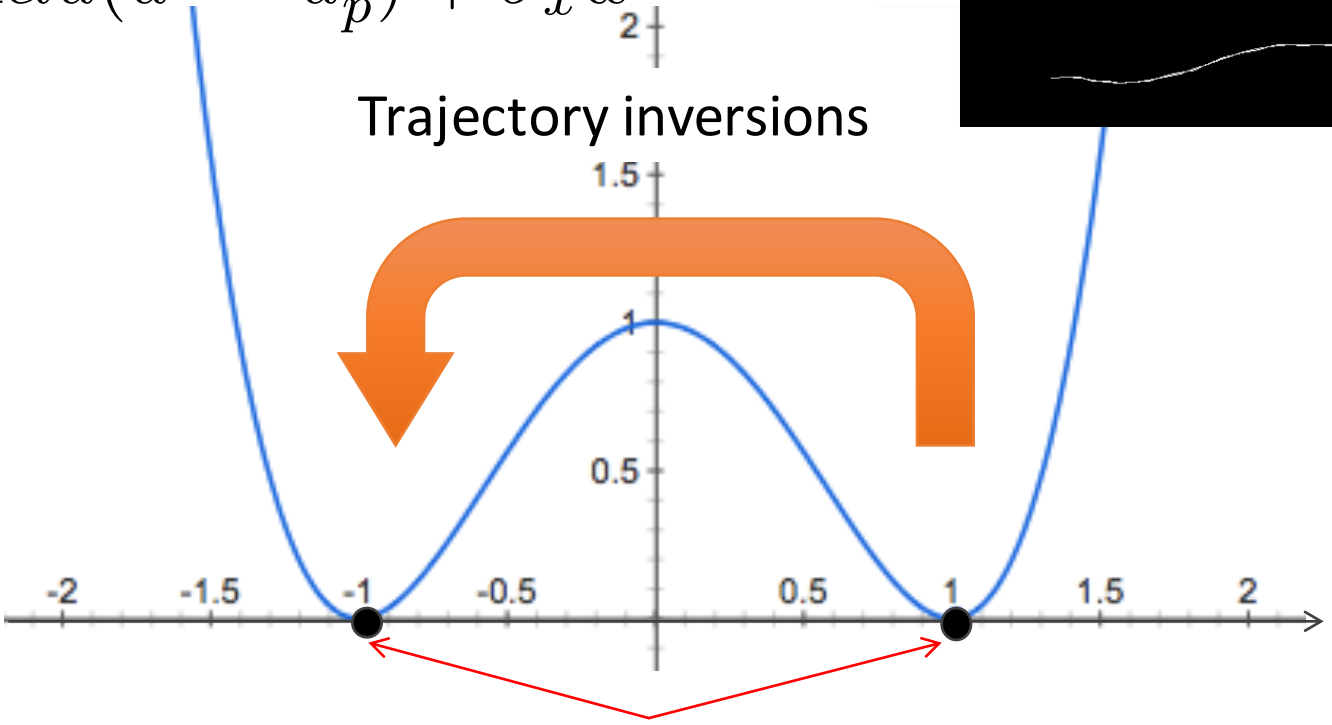
Bi-stable longitudinal motion

4th order velocity potential velocity (K)

Simplest bi-stable stochastic velocity dynamics

$$\dot{u} = -4\alpha u(u^2 - u_p^2) + \sigma_x \dot{w}$$





Trajectory inversions

Stable velocity states

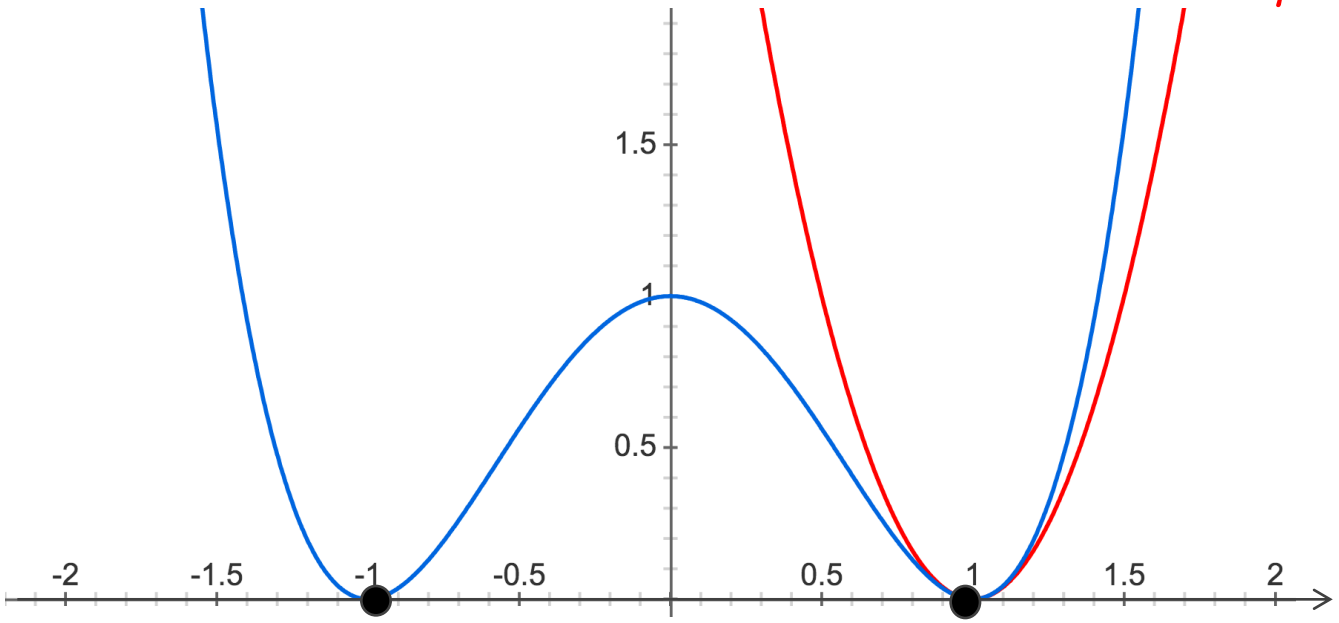
[Corbetta et al. 17, Phys. Rev. E]

Bi-stable longitudinal motion

Note: extension of social force approach for undisturbed motion ≅ Taylor exp. around positive velocity state

$$\dot{u} = -4\alpha u(u^2 - u_p^2) + \sigma_x \dot{w}$$

$$\dot{u} = -\frac{u - u_p}{\tau} + \sigma_x \dot{w}$$

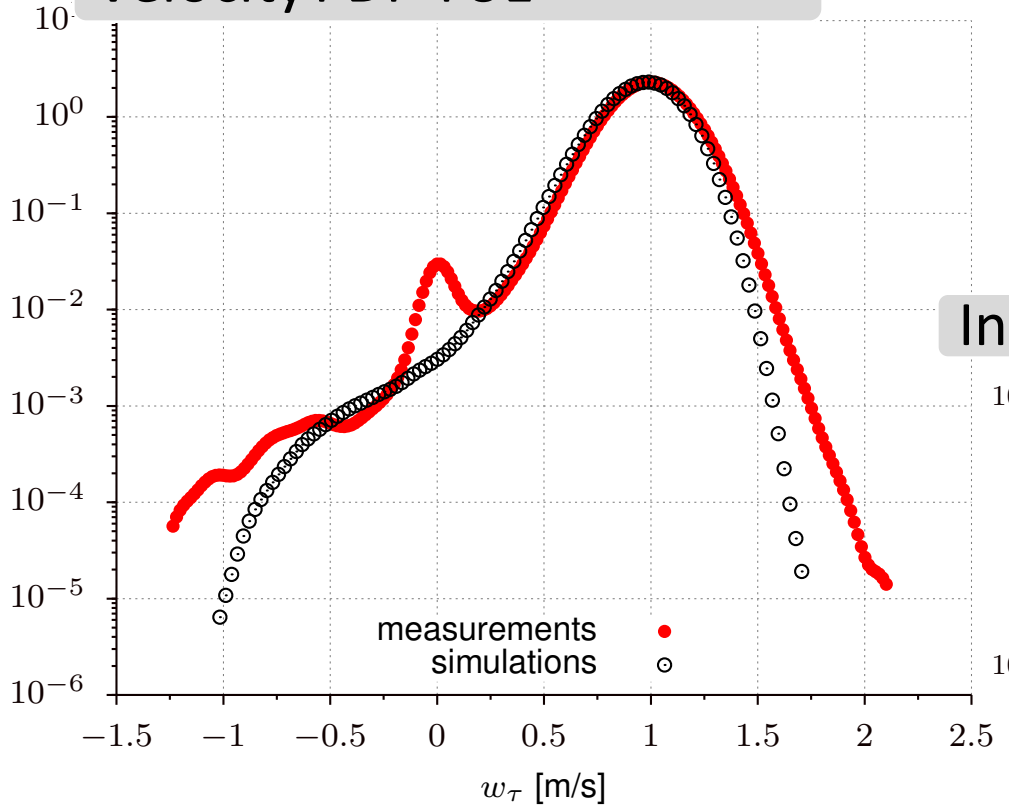


$$K(u) = \alpha(u^2 - u_p^2)^2 \cong K(u) = \frac{(u - u_p)^2}{2\tau} \qquad \tau = \frac{1}{8\alpha u_p^2}$$

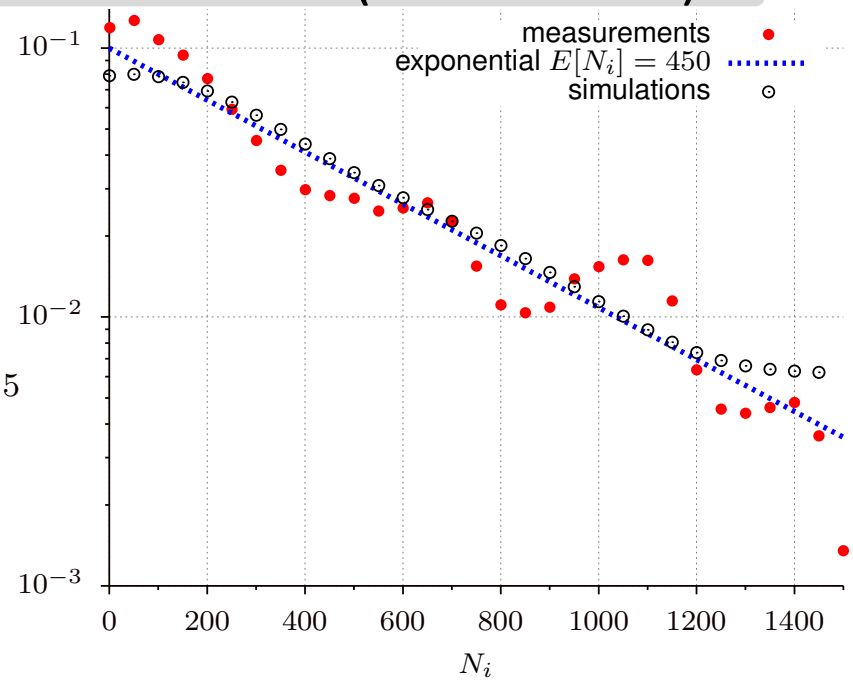
[Corbetta et al. 17, Phys. Rev. E]

Bi-stable longitudinal motion

Velocity PDF TUE



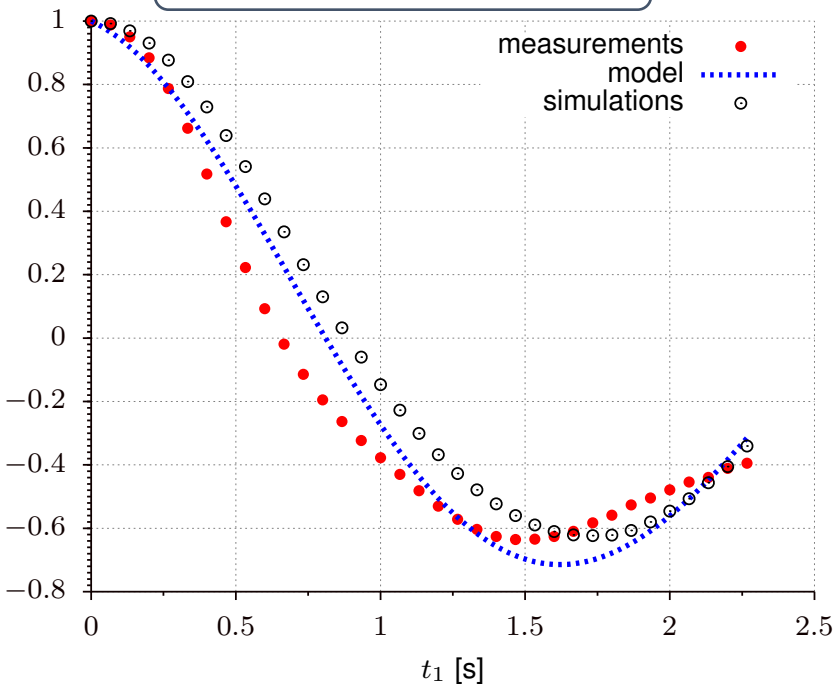
Inversion PDF (Poisson stat)



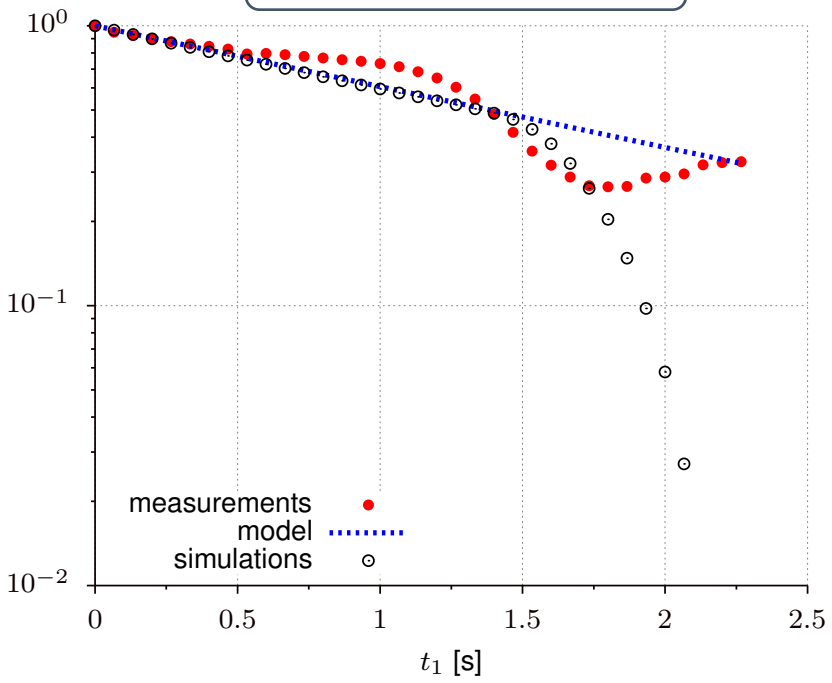
[Corbetta et al. 17, Phys. Rev. E]

Time-Correlation functions

Transversal displacement



Longitudinal velocity



Furthermore:

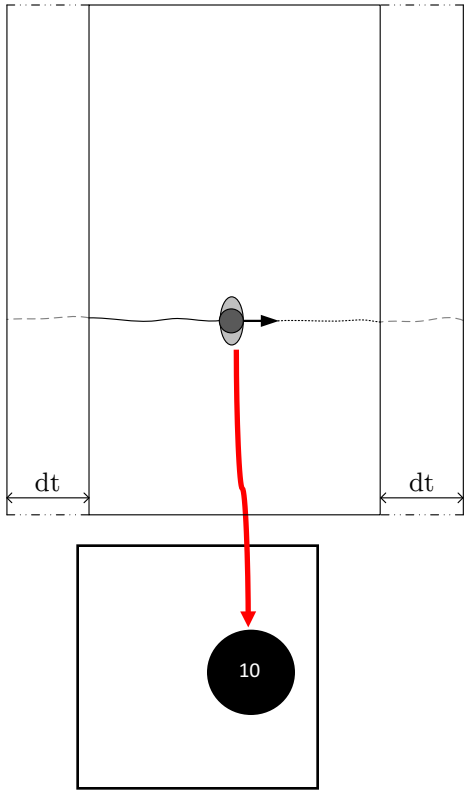
$$\sigma_x \approx \sigma_y$$

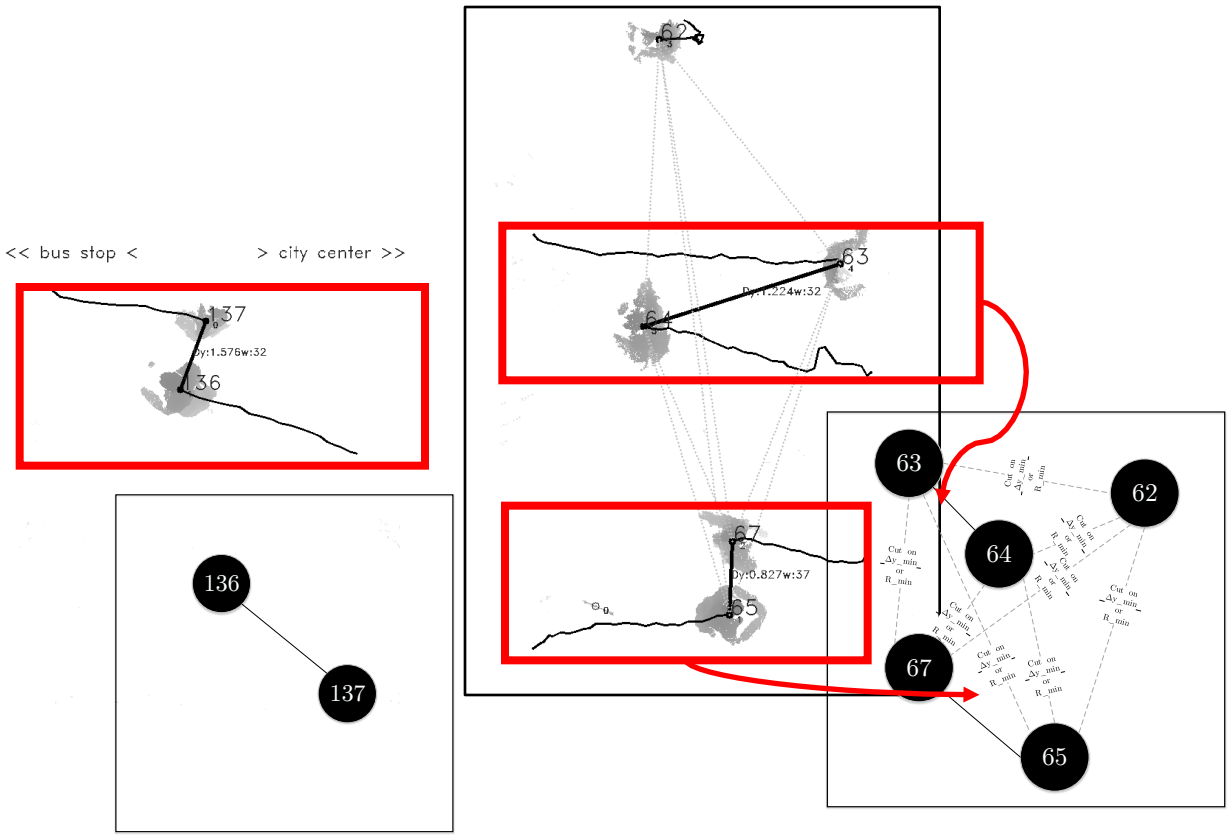
$$T_x = 2s \approx T_y = 2.5s$$

[Corbetta et al. 17, Phys. Rev. E]

Next step: interaction dynamics

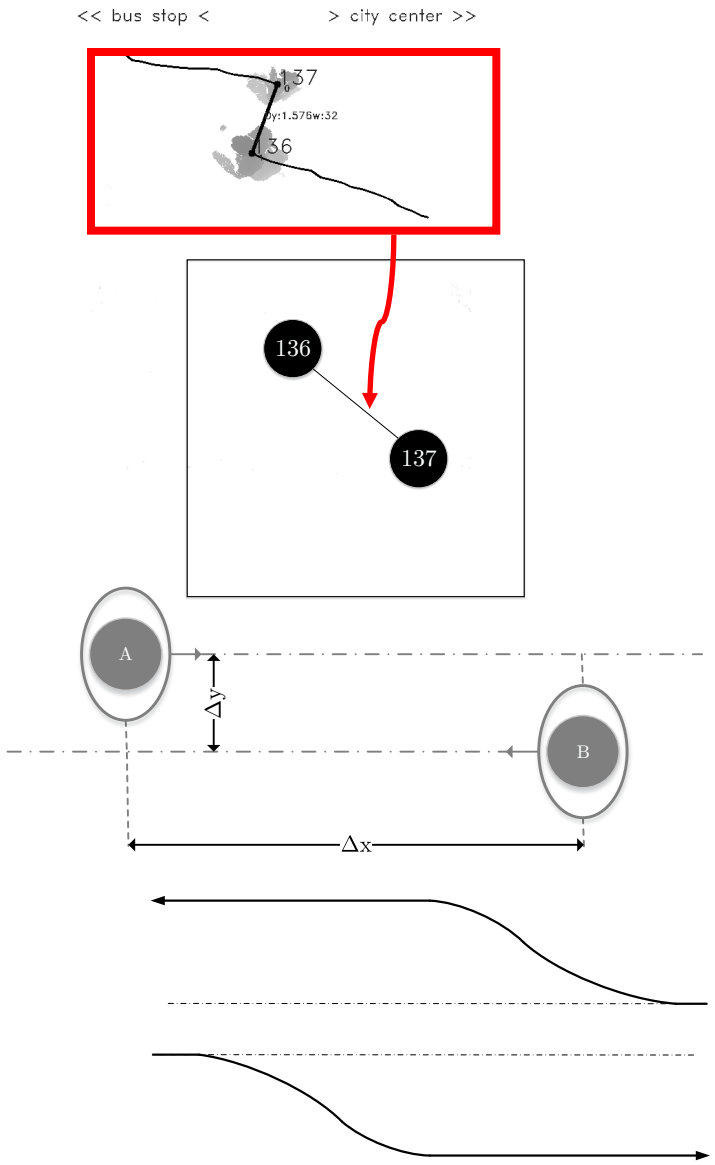
Graph queried for connected components
(interacting subnets)



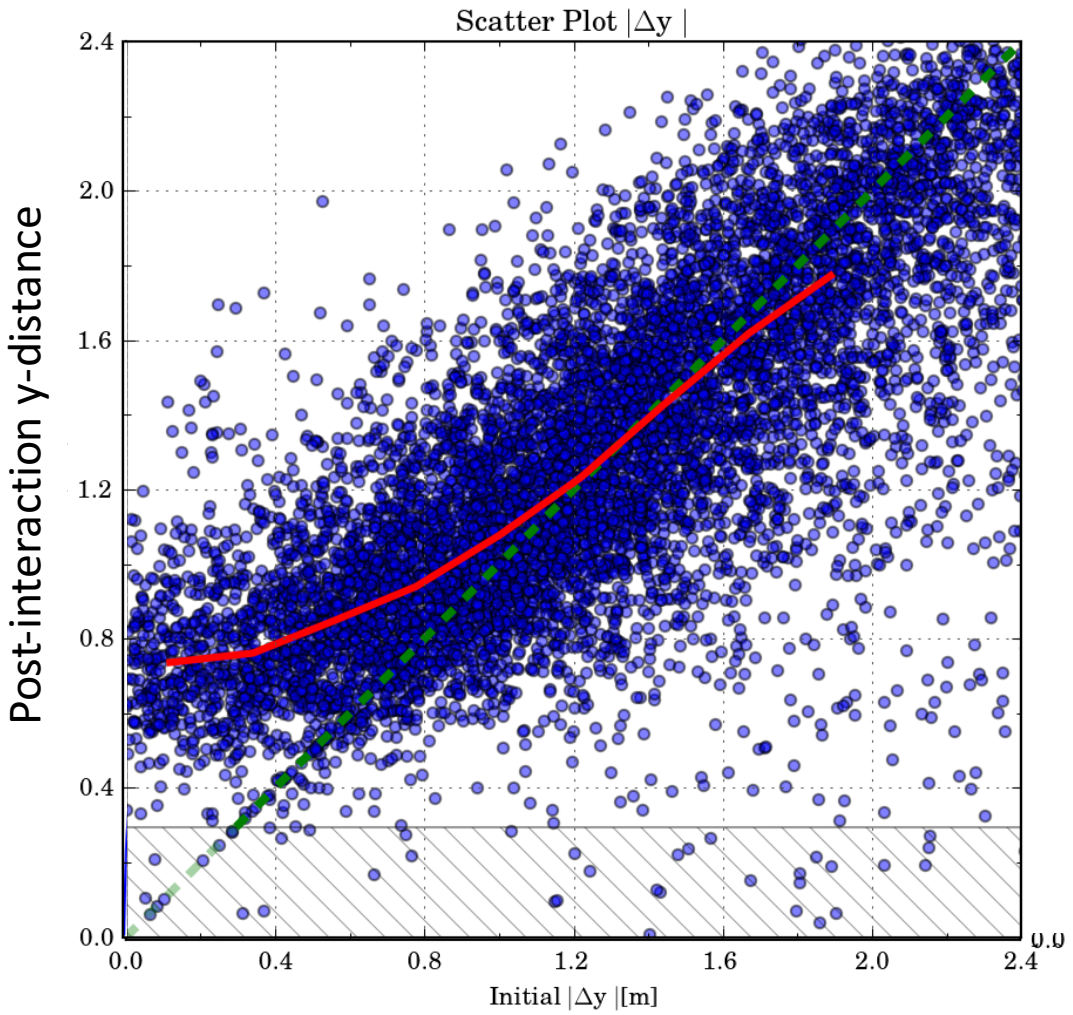


[Corbetta et al. to be subm]

Interaction dynamics: “y offset”



[Corbetta et al. to be subm]



Pre-interaction y-distance

Aligned peds. Infinitely far

Summary & outlook

- Modeling vs. massive statistics
  from long-time real world measurements
- Gathering trajectories is just a part of the measurement effort
- Diluted dynamics ≈ Bistable Langevin

- Next building block:
  Pairwise interactions, denser regimes

- Acknowledgements: Alex Liberzon, Ad Holten, Dutch National Railways, Intelligent Lighting Institute (Eindhoven)

References

1. A. Corbetta, C. Lee, R. Benzi, A. Muntean, F. Toschi, Fluctuations and mean behaviours in diluted pedestrian flows, 2017, Phys. Rev. E, accepted
2. A. Corbetta, C. Lee, A. Muntean, F. Toschi, Frame vs. trajectory analyses of pedestrian dynamics asymmetries in a staircase landing, Collective Dynamics, 2017, accepted
3. A. Corbetta, J.A. Meeusen, C. Lee, F. Toschi, Continuous measurements of real-life bidirectional pedestrian flows on a wide walkway, Proceedings of Pedestrian and Evacuation Dynamics 2016, 18-24, 2016
4. A. Corbetta, C. Lee, A. Muntean, F. Toschi, Asymmetric pedestrian dynamics on a staircase landing from continuous measurements, in W. Daamen & V.L. Knoop (Eds.), Traffic and Granular Flow '15, 2016
5. A. Corbetta, Multiscale pedestrian dynamics: physical analysis, modeling and applications, PhD Thesis, 2016
6. A. Corbetta, A. Muntean, K. Vafayi, F. Toschi, Parameter Estimation of Social Forces in Pedestrian Dynamics models via a Probabilistic Method, 2015, Mathematical Biosciences and Engineering, 12 (2), 337-356
7. A. Corbetta, L. Bruno, A. Muntean, F. Toschi, High Statistic Measurements of Pedestrian Dynamics, 2014, Transportation Research Procedia, 2

8. S. Seer, N. Brandle and C. Ratti, *Kinects and human kinetics: a new approach for studying pedestrian behavior*, Transportation Research Part C: Emerging Technologies, 2014, 48 : 212-228.
9. The OpenPTV initiative, 2012 -, www.openptv.net
10. J. Willneff, A. Gruen, A new Spatio-Temporal Matching Algorithm for 3D-Particle Tracking Velocimetry, The 9th of International Symposium on Transport Phenomena and Rotating Machinery, Honolulu, Hawaii, 2002
11. J. Willneff, A Spatio-Temporal Matching Algorithm for 3D Particle Tracking Velocimetry, PhD Thesis, ETH-Zurich, 2003