Conference Stochastic Models, Statistics and their Application 2019

Session : *Big data and the calibration of mobility simulations*

Artificial neural networks predicting pedestrian dynamics in complex buildings

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— SMSA2019, March 6th to 8th, 2019, TU Dresden, Germany —

Overview

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Simulation of pedestrian dynamics

Artificial neural networks

Corridor and bottleneck experiments

Prediction for the speed

Summary

Simulation of pedestrian dynamics

- Control of crowd and pedestrian flows in term of safety and performance
  - Large infrastructures (train station, shopping malls) or large events (sport events, festivals)
- Pedestrian dynamics are not straightforward to predict
  - Complex human behaviors including learning and anticipation / Complex multi-agent systems

Simulation of pedestrian dynamics

- Control of crowd and pedestrian flows in term of safety and performance
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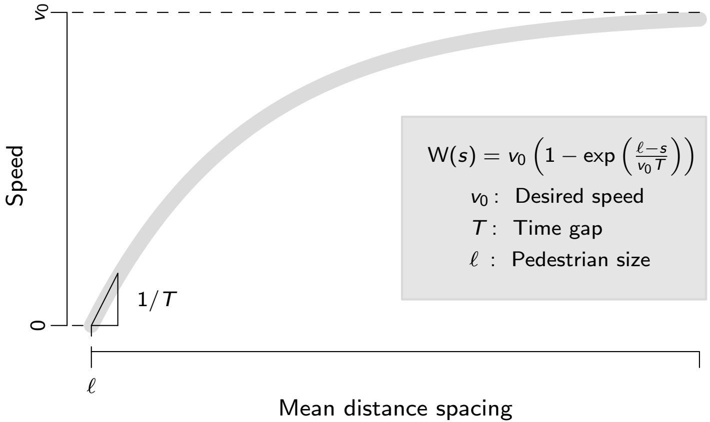
  - Complex human behaviors including learning and anticipation / Complex multi-agent systems

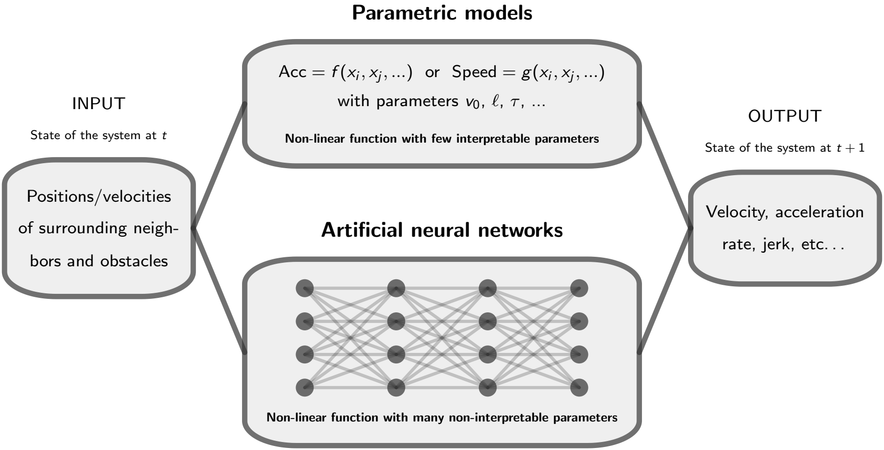
- Management and control thanks to simulation tools
  - Microscopic models inspired from physical, social, psychological or proxemics concepts / Examples are force-based (social force), velocity-based or rule-based
  - Models based on few interpretable parameters (desired speed, pedestrian size, ...)
- Fundamental diagram
  - Phenomenological relationship between the speed (or the flow rate) and the density (or the mean distance spacing)
  - Weidmann's model (1992) $$\mathrm{W}(\bar{s}, v_0, T, \ell) = v_0\left(1 - \exp\left(\frac{\ell - \bar{s}}{v_0 T}\right)\right)$$

Speed/Spacing relationship for the Weidmann's model (1992)



Overview

Models for understanding *versus* Models for prediction[1]



[1] See e.g. Saporta, *COMPSTAT 2008*, pp 315-322 (2008)

Artificial neural networks

- Data-based machine learning approaches for the motion prediction
  - For autonomous driving, motion of robots in crowded environments or pedestrian dynamics in complex geometries[2]
  - Artificial neural networks (convolutional, LSTM, deep learning, ...)

[2] See e.g. Alahi et al., 2016; Chen et al., 2017; Das et al., 2015; Ma et al., 2016

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- Feed-forward neural networks for speed prediction according to the positions of the K nearest neighbors
  1. Inputs are the relative positions to the K nearest neighbours ($2K$ inputs)

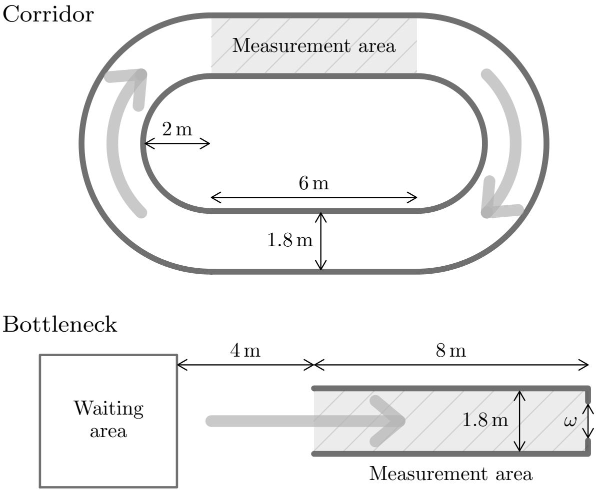
  $$\mathrm{NN}_1 = \mathrm{NN}_1\big(x_i - x, y_i - y, 1 \leq i \leq K\big).$$

  2. Speed prediction according to the relative positions and the mean distance spacing $\bar{s}_K$ to the K nearest neighbours ($2K + 1$ inputs)

  $$\mathrm{NN}_2 = \mathrm{NN}_2\big(\bar{s}_K, (x_i - x, y_i - y, 1 \leq i \leq K)\big).$$

[2] See e.g. Alahi et al., 2016; Chen et al., 2017; Das et al., 2015; Ma et al., 2016

Corridor and bottleneck experiments

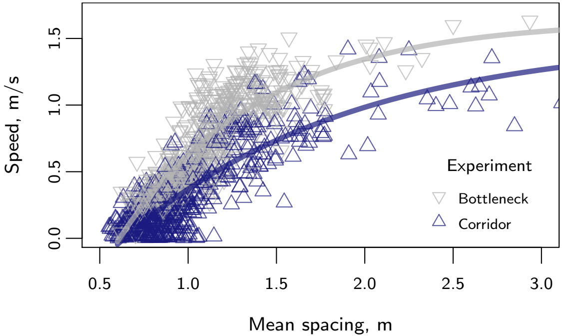


Corridor and bottleneck experiments

Corridor

Bottleneck

Speed/Spacing relationship



Experiment	Spacing (m)	Speed (m/s)	ℓ (m)	T (s)	V_0 (m/s)
Corridor	1.03 ± 0.40	0.35 ± 0.33	0.64	0.85	1.50
Bottleneck	1.14 ± 0.37	0.72 ± 0.34	0.61	0.49	1.64

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Setting the network structures

- Fully connected neurons spread in hidden layers
- Setting the network structures: Optimal number of layers and neurons
  - $\rightarrow$ Tested structures (1)[3], (2), (3), (4,2), (5,2), (5,3), (6,3) and (10,4)[4]
- Cross-Validation: Split of the data in training and testing homogeneous datasets

- Training thanks to back-propagation algorithm, minimising the mean squared error

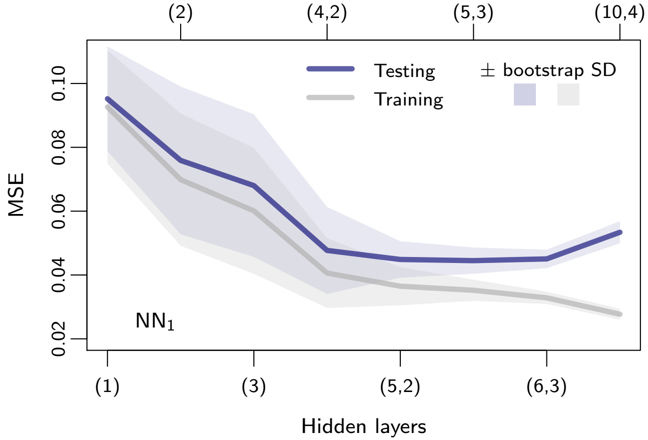
$$\mathrm{MSE} = \frac{1}{N}\sum_{i=1}^{N}\left(v_i - \tilde{v}_i\right)^2.$$

- Training and testing in bootstrap loops (50 subsamples) to evaluate the precision of estimation

[3] One hidden layer with 1 neuron

[4] Two hidden layers with respectivelly 10 and 4 neurons

Network NN_1 based on the relative positions



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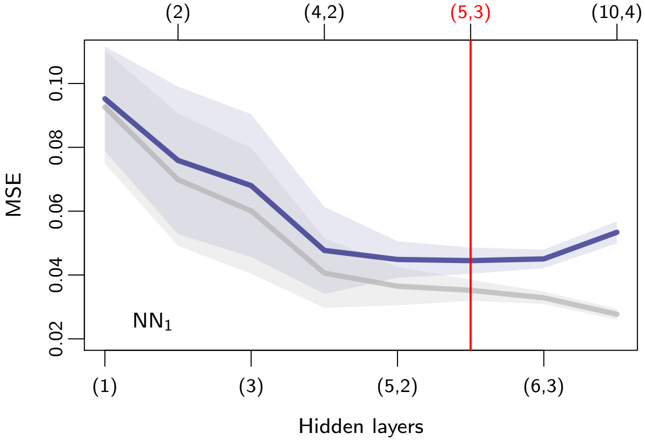
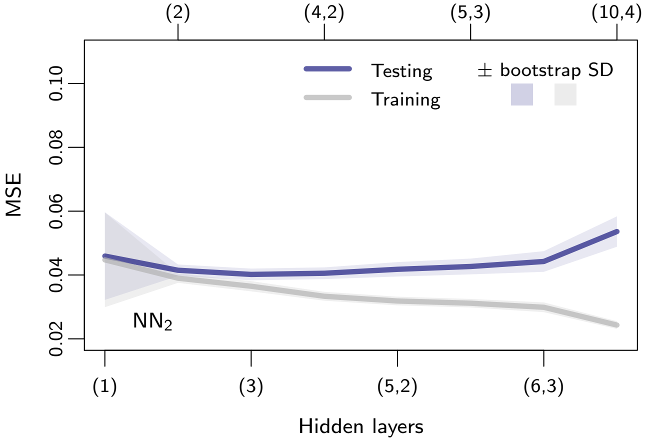


Network NN_2 based on the relative positions and mean spacing



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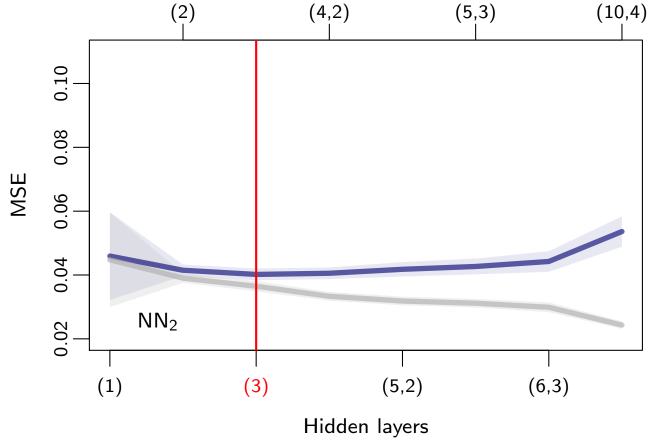


Prediction for the speed

- Analyse of several combinations of training and testing sets to evaluate the precision and robustness of the predictions
- Tested scenario

  Notation :

  `Training set / Testing set`

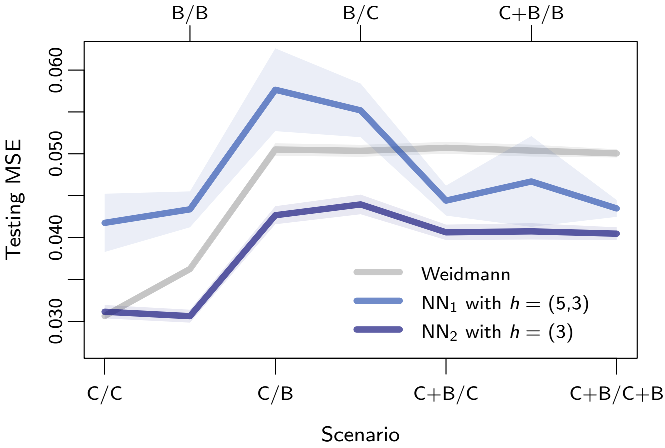
  C: Corrridor experiment

  B: Bottleneck experiment

  - B/B and C/C.
    Single dataset is used for both training and testing
  - B/C and C/B.
    Prediction ability in new situations
  - C+B/B, C+B/C and C+B/C+B.
    Prediction in heterogeneous situations
- Weidmann speed model used as benchmark

Mean squared error

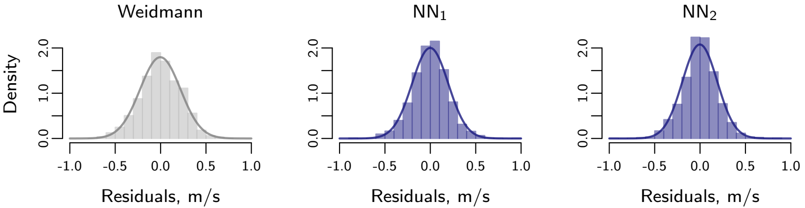
NN$_1$: based on relative positions — NN$_2$: based furthermore on mean distance spacing



Quality of the fit

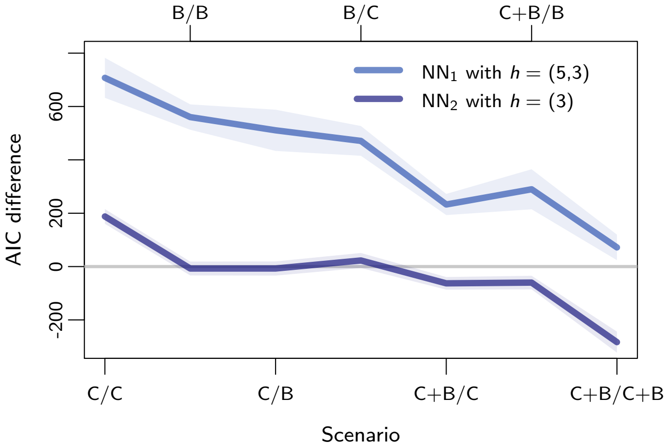
- Weidmann's model based on $k_0 = 3$ parameters
- Artificial neural networks NN_1 and NN_2 based on $k_1 = 189$ and $k_2 = 88$
- Akaike Information Criterion for the quality of the fit (normal residuals)

$$\mathrm{AIC} = 2k + n\ln(\mathrm{MSE}) + n\big(1 + \ln(2\pi)\big)$$



AIC difference

NN_1: based on relative positions — NN_2: based furthermore on mean distance spacing



Summary

- Significant prediction improvement of pedestrian dynamics (MSE and AIC) with artificial neural networks in cases of heterogeneous scenarios
- First steps for the modelling of pedestrians behaviors in complex infrastructures/buildings
- Data-based approach for the prediction – No modelling of mechanisms governing the pedestrian motion
- Use of mean spacing as input, even if based on pedestrian relative positions already provided, allows improving the prediction and reducing the network complexity

- Training, testing and setting of the network complexity with large experimental datasets[5]
- Prediction of full trajectories in two dimensions and coupling to strategical routing models for simulation in complex scenarios
- Comparison to other parametric models (force-based models) and multi-agent systems

[5] ped.fz-juelich.de/database

Source: Cartoonstock.com

Many thanks for your attention!