Pedestrian Dynamics at Transit Stations: A Hybrid Pedestrian Flow Modeling Approach

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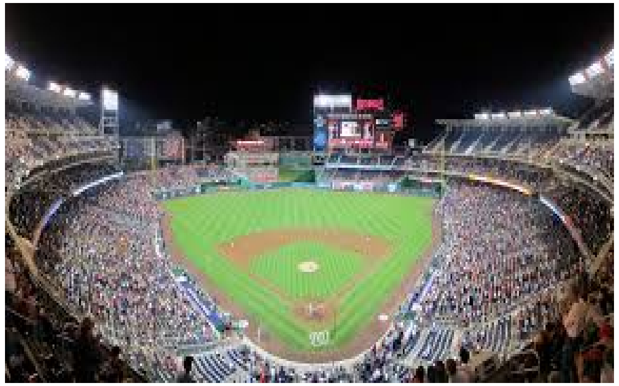
Outline

1. Introduction:
    1. Motivation
    2. Objectives

2. Hybrid Modeling Framework
    1. Social force
    2. Behavioral heuristics
    3. Materials science

3. Numerical Analysis
    1. Experimental Data
    2. Simulation Scenarios

4. Conclusions:
    1. Summary
    2. Future Research

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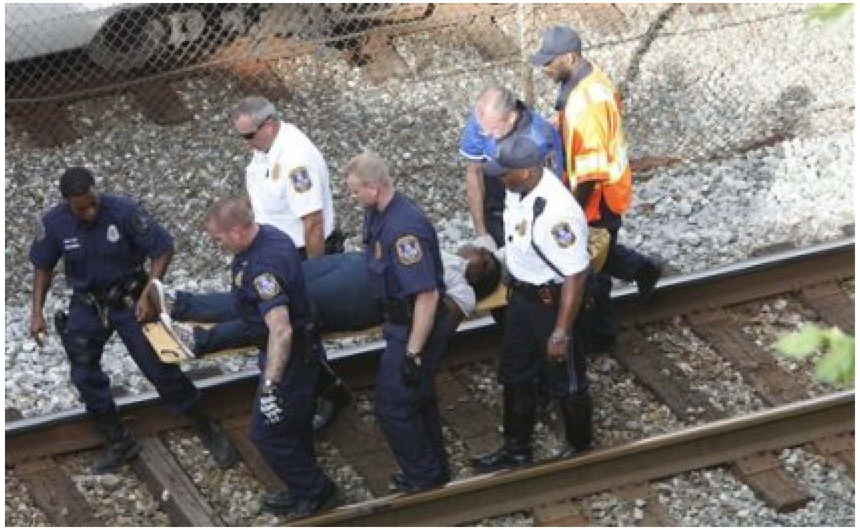

The Washington Post

Transportation

Federal officials will assume responsibility for Metro safety

A | 113

Passengers walk toward a train at the Archives-Navy Memorial-Penn Quarter Metro station. A new plan puts Metro under direct federal supervision. (Nikki Kahn/The Washington Post)

By Lori Aratani and Paul Duggan October 9 Follow @lor Follow @duggar

Metro now is the first U.S. subway system placed under direct federal supervision for safety lapses under a plan announced late Friday by Transportation Secretary Anthony Foxx.

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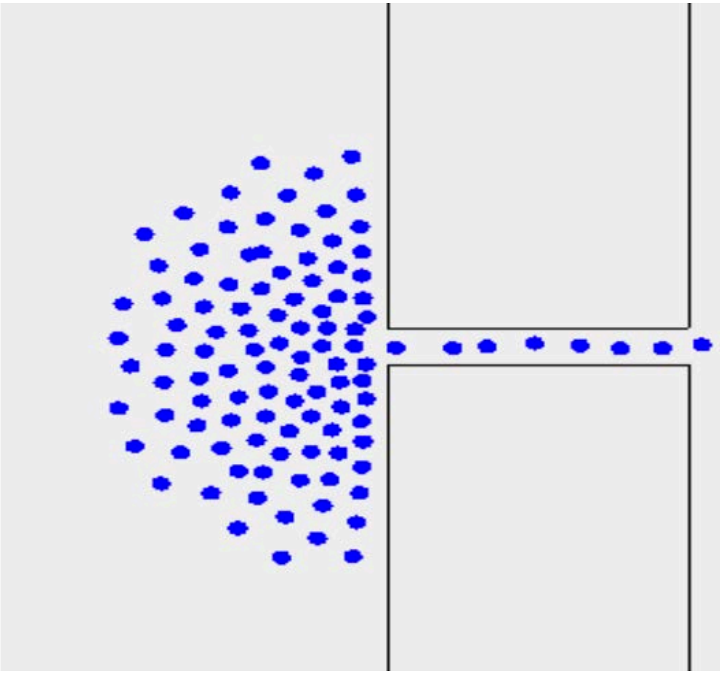

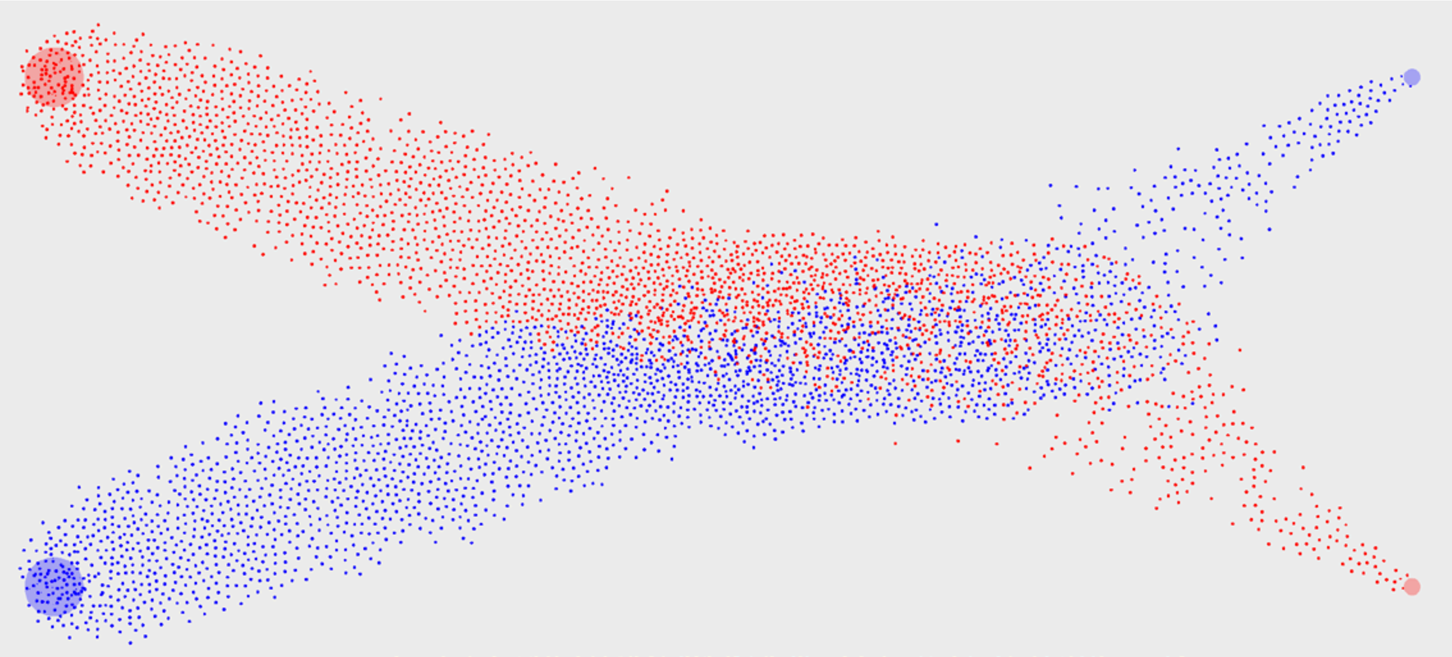

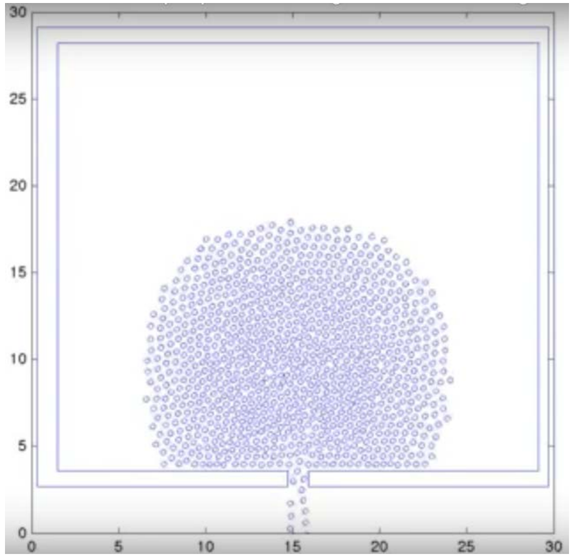
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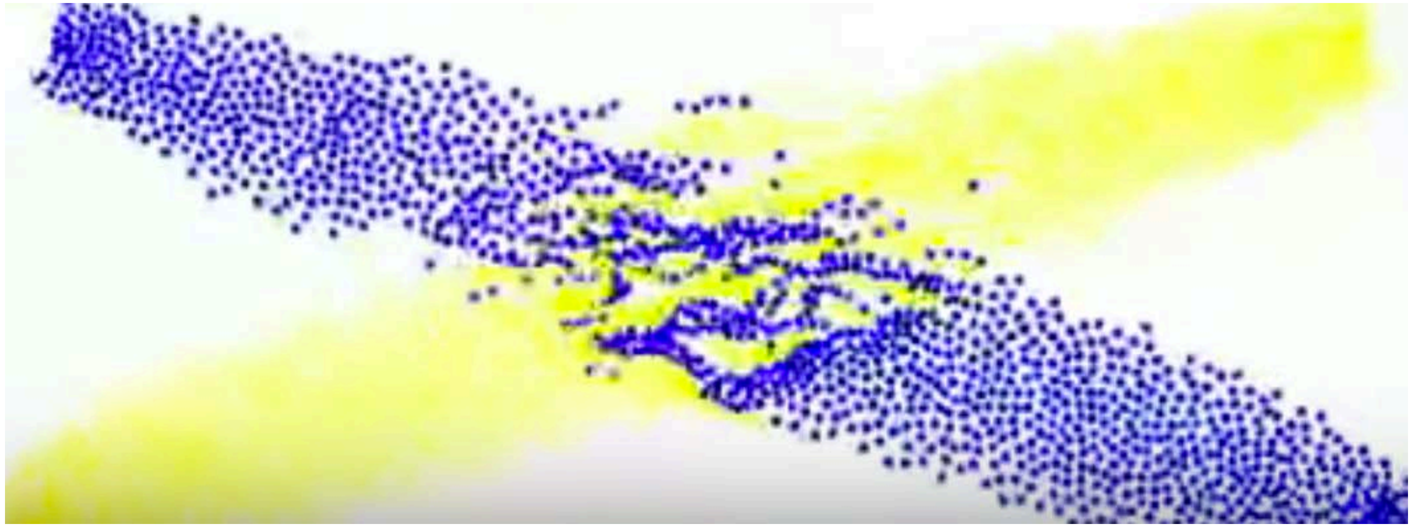
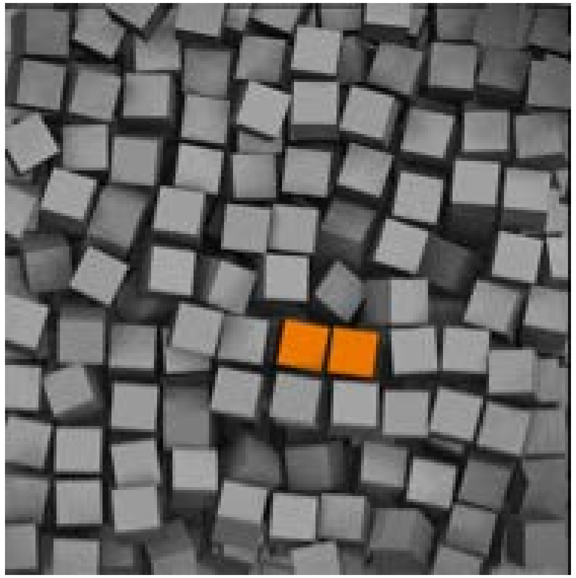


Objectives

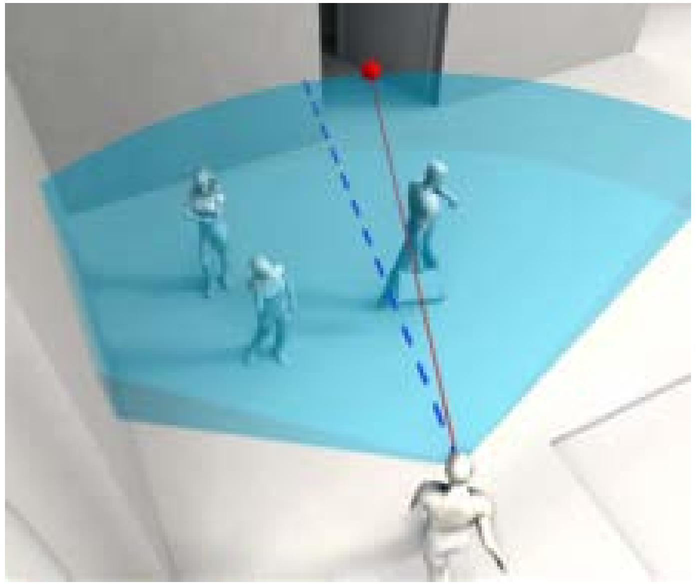
- Consider an integrated modeling approach that captures pedestrian walking behavior in congested and uncongested conditions in transit stations
- Combine concepts from previously existing pedestrian behavior models
- Simulate scenarios that can be compared to real world data
- Explore model results for a transit station application

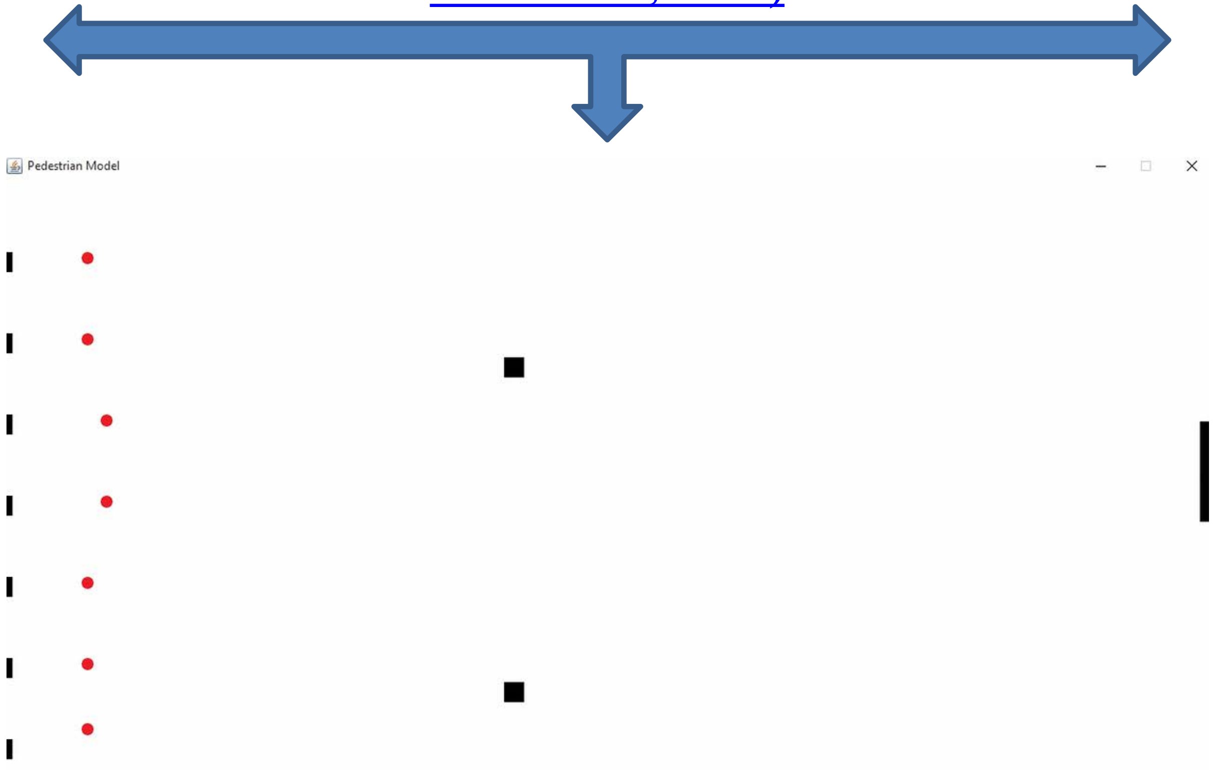
Modeling Framework



Social Force Model:
attractive and repulsive force structure

[(Helbing, Buzna, Johansson and Werner, 2005)]





Materials Science:
multi-body potential molecular interactions

[(Karamouzas, Skinner and Guy; 2014)]

Behavioral Heuristics:
Incorporating cognitive and physiological pedestrians characteristics

[(Moussaïd, Helbing and Theraulaz; 2011)]

Social Force Model

Acceleration

$$\overrightarrow{F_\alpha^0}(\overrightarrow{v_\alpha}, v_\alpha^0\overrightarrow{e_\alpha}) = \frac{1}{\tau_\alpha}(v_\alpha^0\overrightarrow{e_\alpha} - \overrightarrow{v_\alpha})$$

$\overrightarrow{v_\alpha}(t) \equiv$ *actual velocity of pedestrian* α

$\overrightarrow{e_\alpha}(t) \equiv$ *desired direction of pedestrian* α

$\overrightarrow{v_\alpha^0}(t) = v_\alpha^0\,\overrightarrow{e_\alpha} \equiv$ *desired velocity of pedestrian* α

$\tau_\alpha \equiv$ *relaxation time of pedestrian* α

Pedestrian Repulsion

$$\overrightarrow{f_{\alpha\beta}}(\overrightarrow{r_{\alpha\beta}}) = -\nabla_{\overrightarrow{r_{\alpha\beta}}} V_{\alpha\beta}[b(\overrightarrow{r_{\alpha\beta}})]$$

$\overrightarrow{f_{\alpha\beta}} \equiv$ *repulsive effect felt by pedestrain* α *due to pedestrian* β
$\overrightarrow{r_{\alpha\beta}} \equiv$ *distance between pedestrians* α *and* β
$V_{\alpha\beta}[b(\overrightarrow{r_{\alpha\beta}})] \equiv$ *replusive potential (monotonic decreasing function of b)*

Obstacle Repulsion

$$\overrightarrow{f_{\alpha B}}(\overrightarrow{r_{\alpha B}}) = -\nabla_{\overrightarrow{r_{\alpha B}}} U_{\alpha B}(\|\overrightarrow{r_{\alpha B}}\|)$$

$\overrightarrow{f_{\alpha B}} \equiv$ *repulsive effect felt by pedestrain* α *due to obstacle B*
$\overrightarrow{r_{\alpha B}} \equiv$ *distance between pedestrian* α *and obstacle B*
$U_{\alpha B}(\|\overrightarrow{r_{\alpha B}}\|) \equiv$ *replusive potential (monotonic decreasing potential)*

Pedestrian Repulsive Potential

$$V_{\alpha\beta}(b) = V_\alpha^0 e^{-b/\sigma}$$

$$b = 0.5 * \sqrt{\left(\|\overrightarrow{r_{\alpha\beta}}\| + \|\overrightarrow{r_{\alpha\beta}} - v_\beta \Delta t \overrightarrow{e_\beta}\|\right)^2 - (v_\beta \Delta t)^2}$$

$V_{\alpha\beta}^0 \equiv$ *constant parameter*
$\sigma \equiv$ *constant parameter*
$v_\beta \equiv$ *velocity of pedestrian* β
$\overrightarrow{e_\beta} \equiv$ *direction of motion of pedestrian* β
$\Delta t \equiv$ *time change used to determine step width of pedestrian* β

Obstacle Repulsive Potential

$$U_{\alpha B}(\|\overrightarrow{r_{\alpha B}}\|) = U_{\alpha B}^0 e^{-\|\vec{r}_{\alpha B}\|/R}$$

$U_{\alpha B}^0 \equiv$ *constant parameter*
$R \equiv$ *constant parameter*

Behavioral Heuristics

Walking Direction

$$\overrightarrow{e_\alpha}(t) = d_{max}^2 + r(e)^2 - 2d_{max}r(e)\cos(e_0 - e)$$

$\overrightarrow{e_\alpha}(t) \equiv$ *desired direction of pedestrian* α

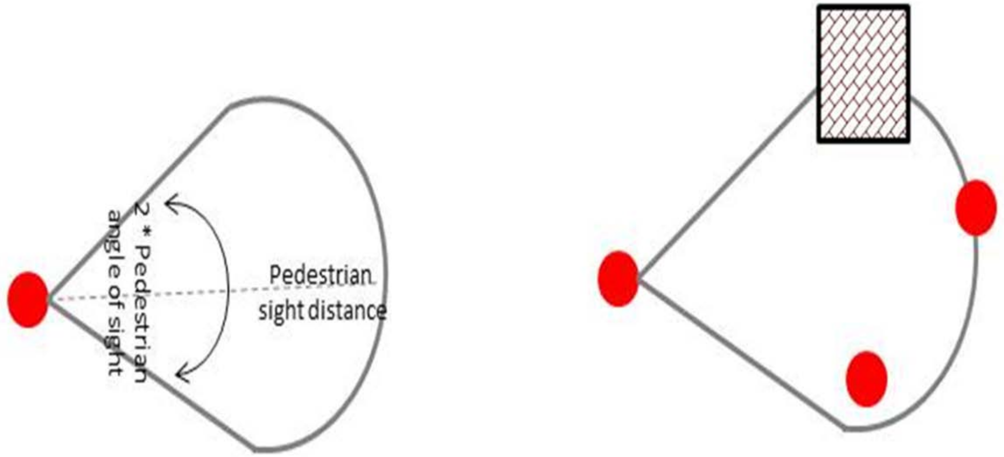
$d_{max} \equiv$ *sight distance of pedestrian* α

$r(e) \equiv$ *distance to first collision*

$e_0 \equiv$ *direction of destination*

$e \equiv$ *direction within field of view considered by pedestrian*

Field of View



Materials Science

Molecular interactions can be modeled by taking into account directly neighboring molecules.

Requires “social force” calculations between multiple bodies within the corresponding field of view.

$$Total\ Force\ Felt\ by\ Pedestrain\ \alpha = \sum_{i=1}^{3} \overrightarrow{F_{\alpha}^{0}}(\overrightarrow{v_{\alpha}}, v_{\alpha}^{0}\overrightarrow{e_{\alpha}}) + \overrightarrow{f_{\alpha\beta_i}}(\overrightarrow{r_{\alpha\beta_i}}) + \overrightarrow{f_{\alpha B_i}}(\overrightarrow{r_{\alpha B_i}})$$

Numerical Analysis

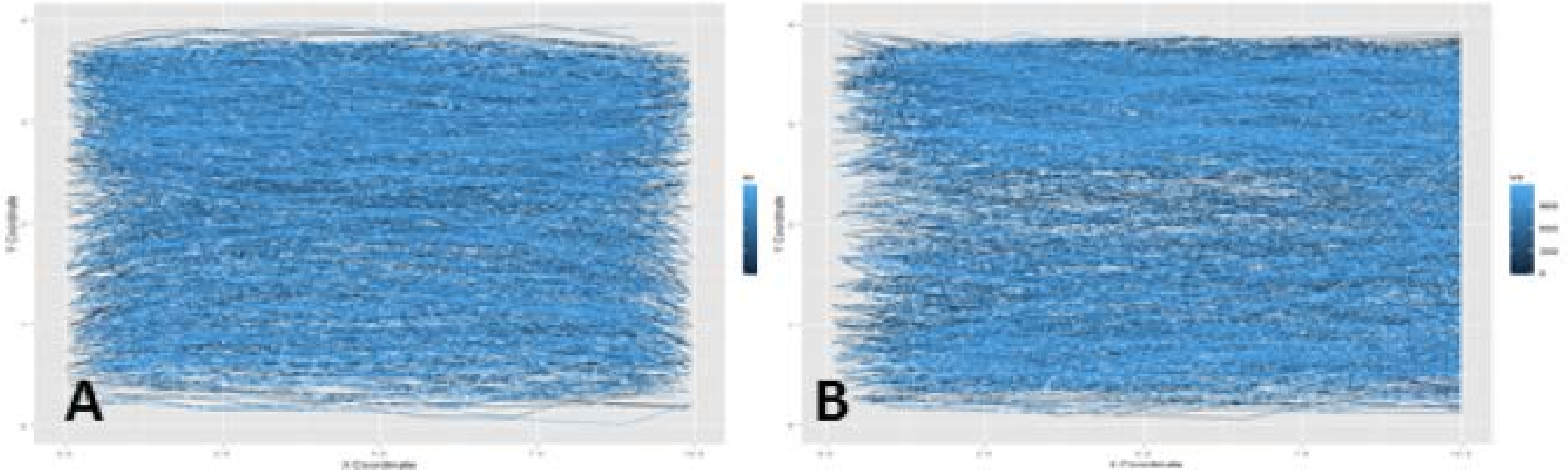
Experimental Results (Courtesy, TU Delft)

- One directional flow
- Two directional flow
- Crossing
- Wide Bottleneck
- Narrow bottleneck

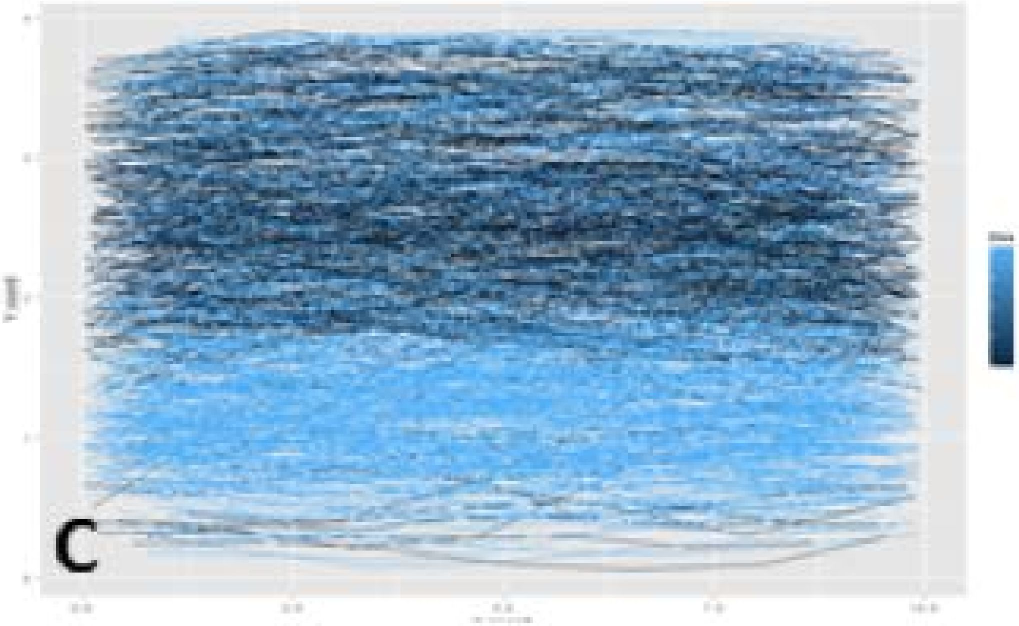
Simulation

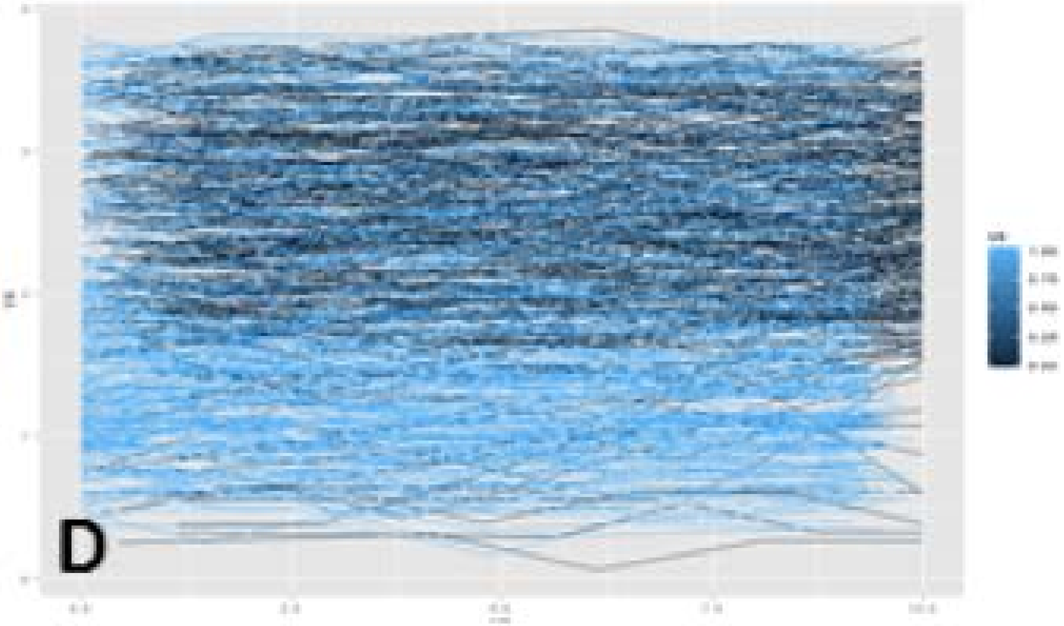
- Alternative Crossing Scenario
- Transit Application

Experimental Results: 1-D Flow (A vs. B)

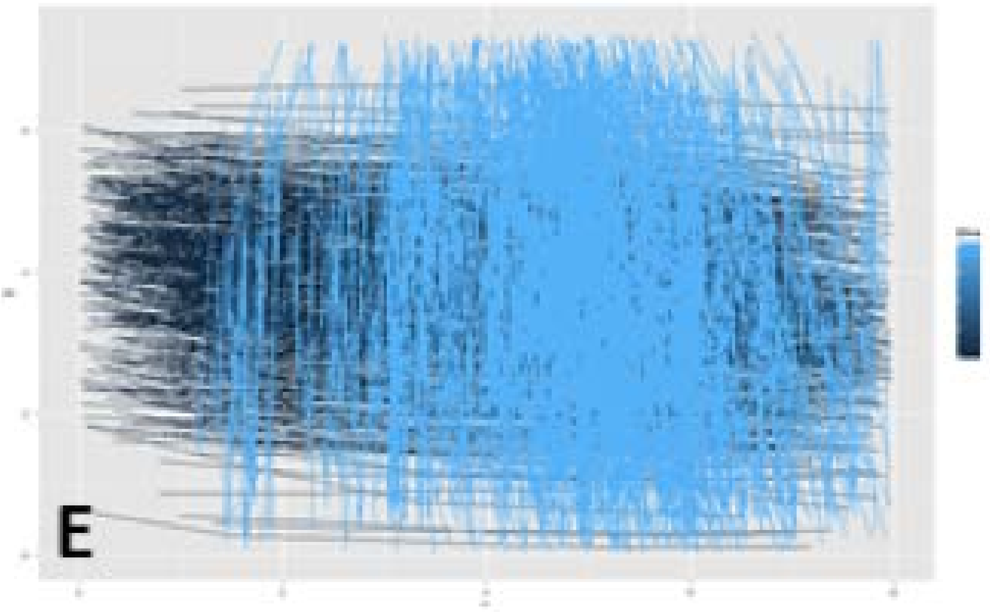


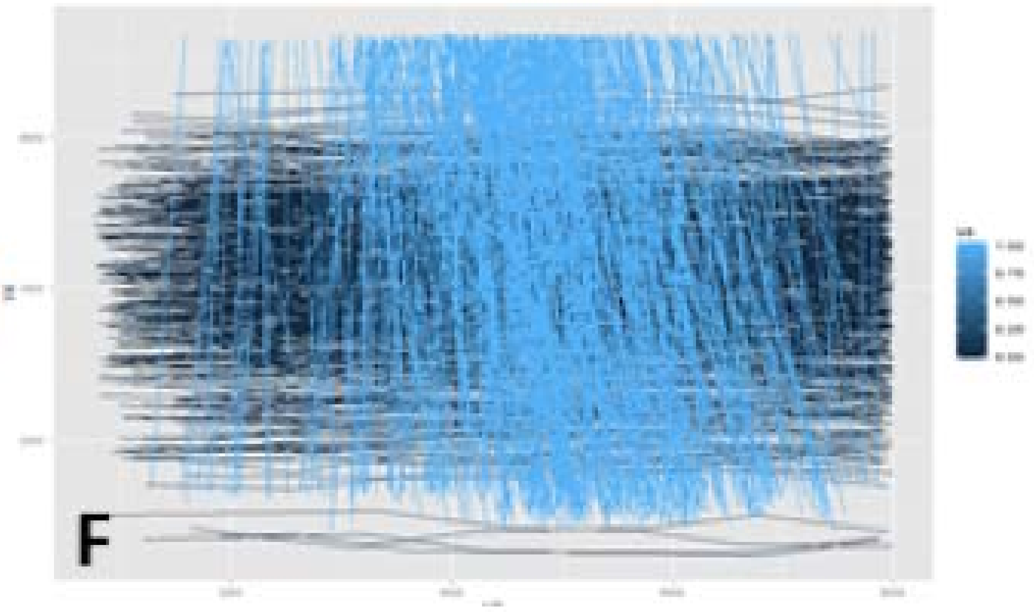
Experimental Results: 2-D Flow (C vs. D)



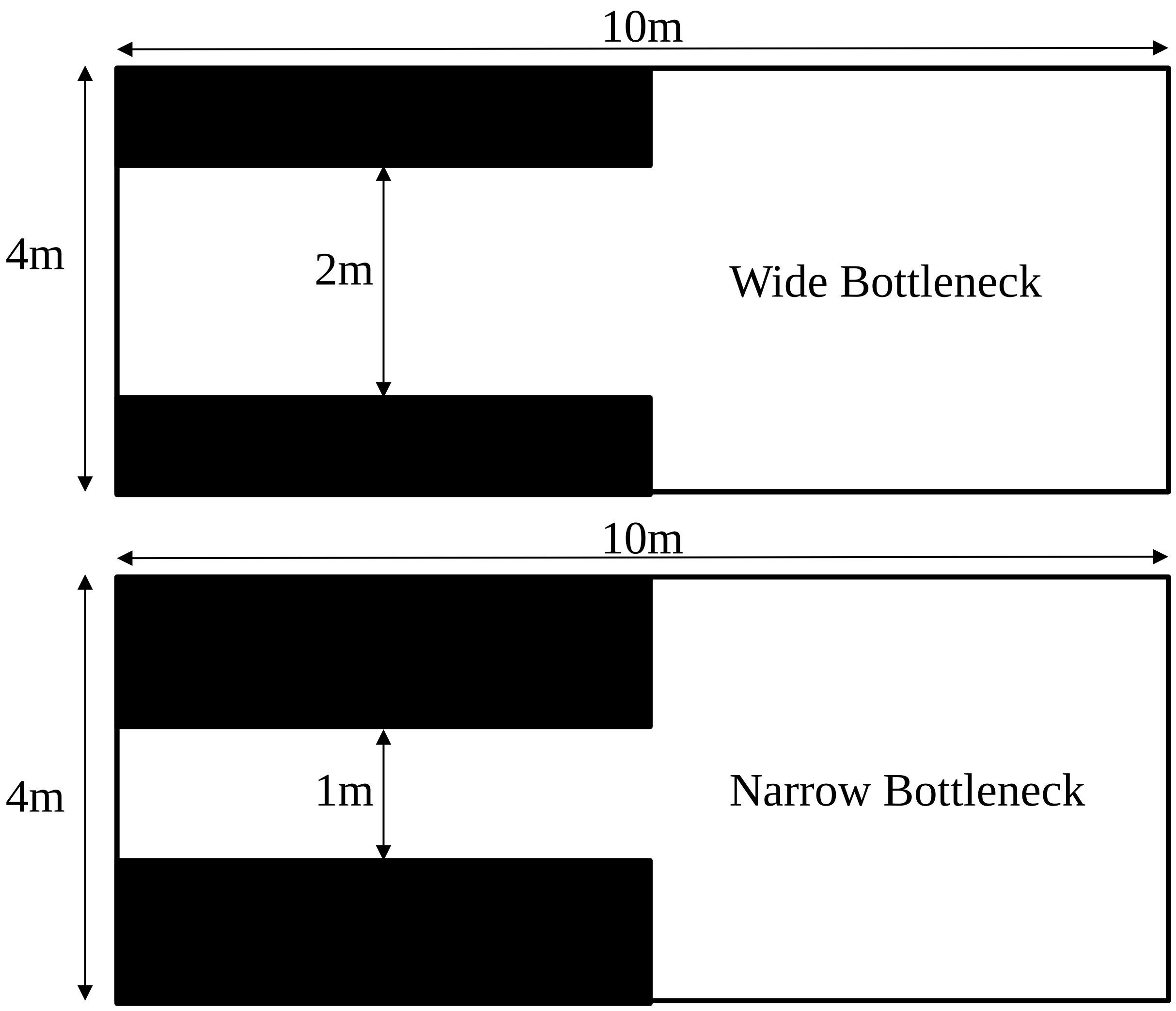


Experimental Results: Crossing (E vs. F)



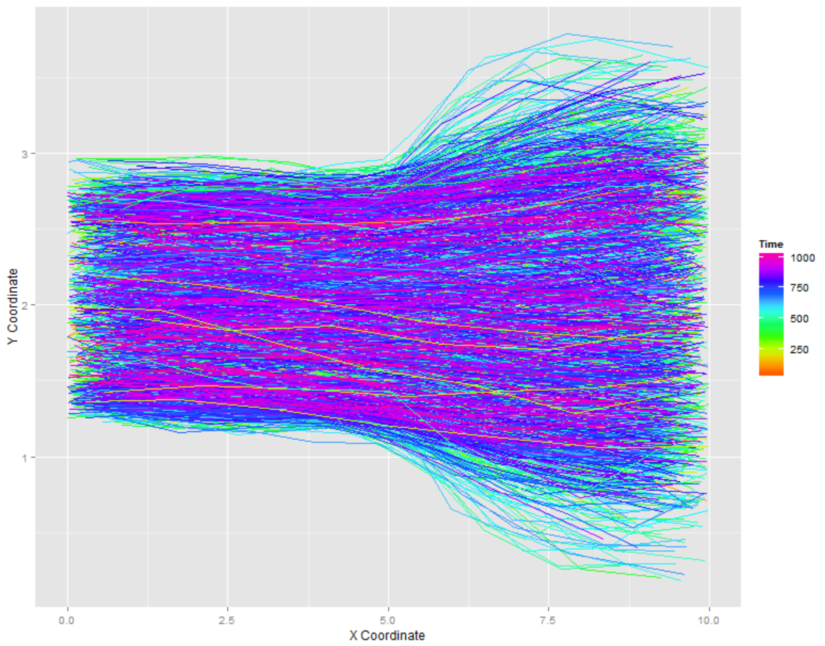


Experimental Results: Wide and Narrow Bottlenecks

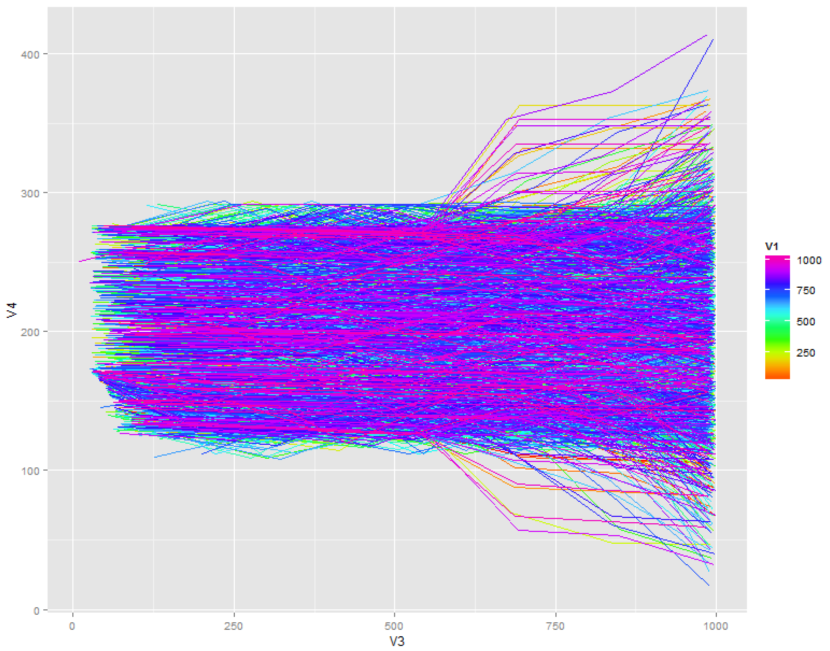


Experimental Results: Wide Bottleneck

Data

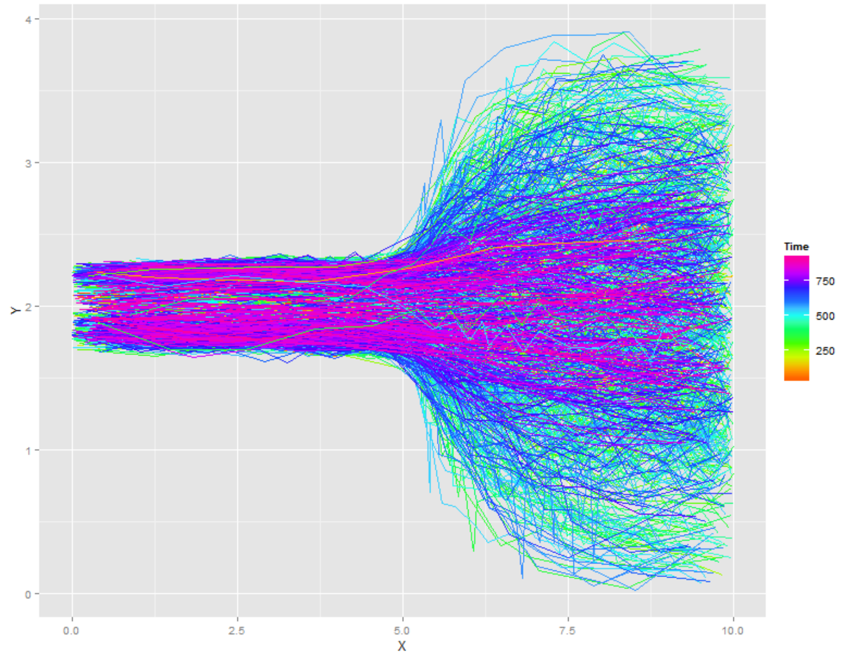


Model

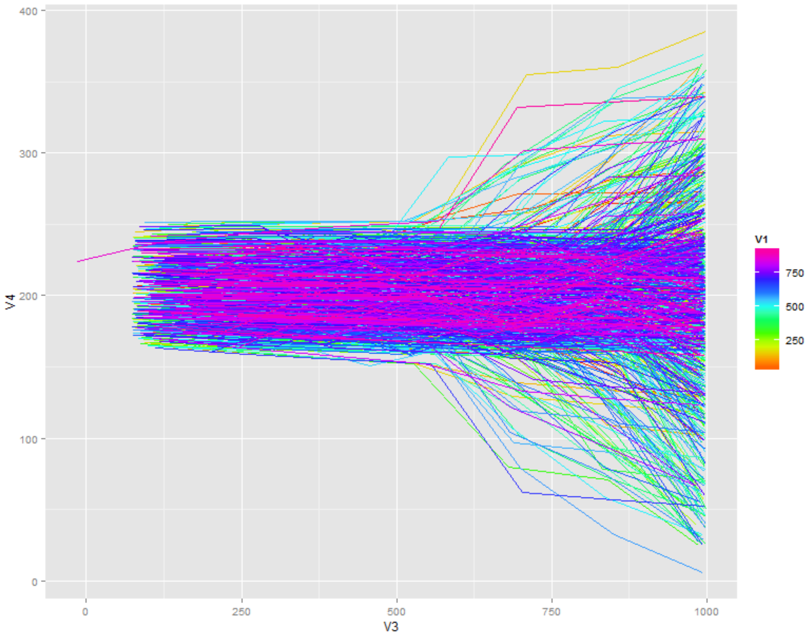


Experimental Results: Narrow Bottleneck

Data



Model



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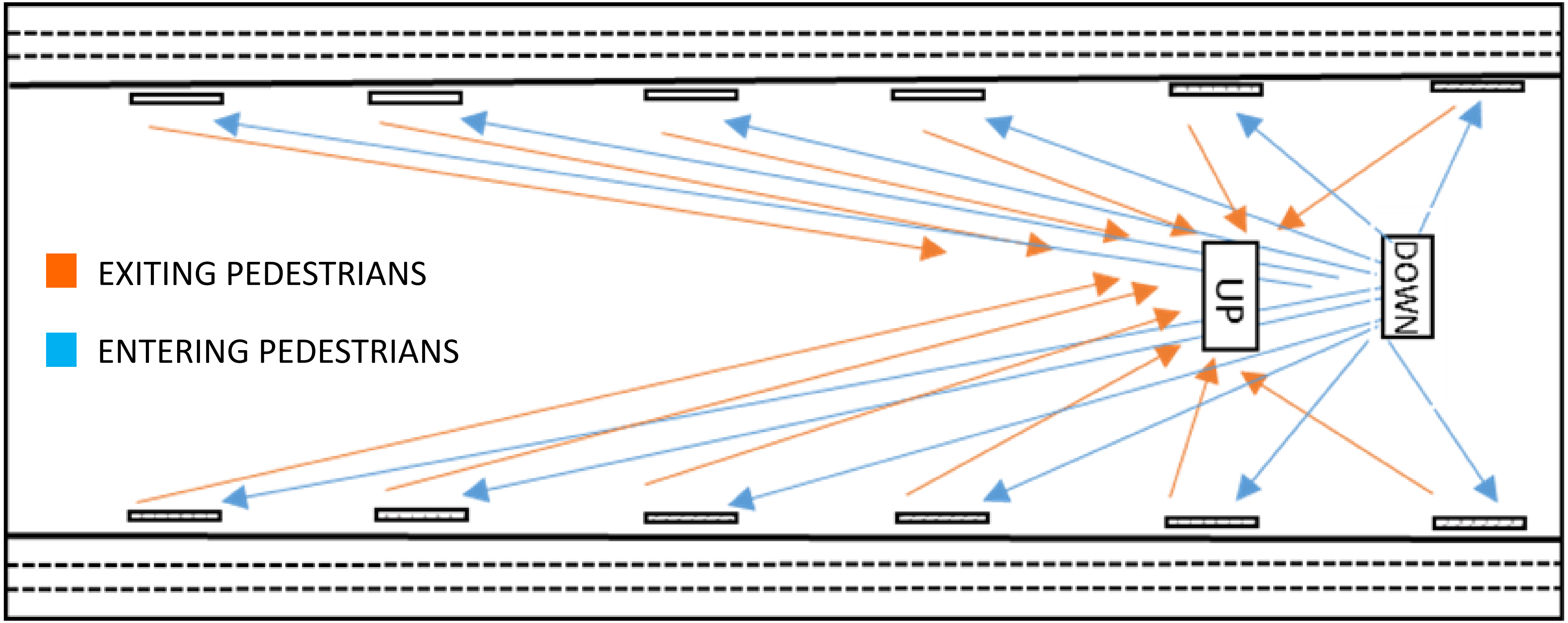
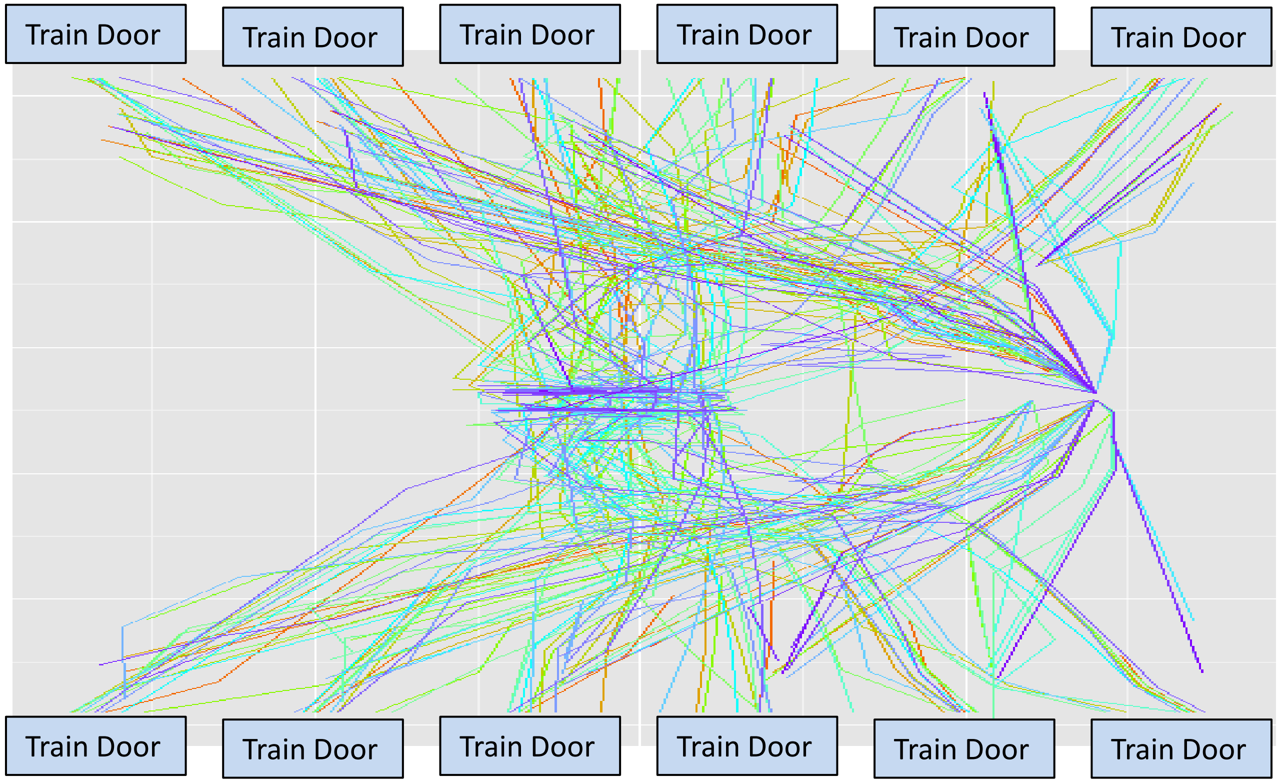
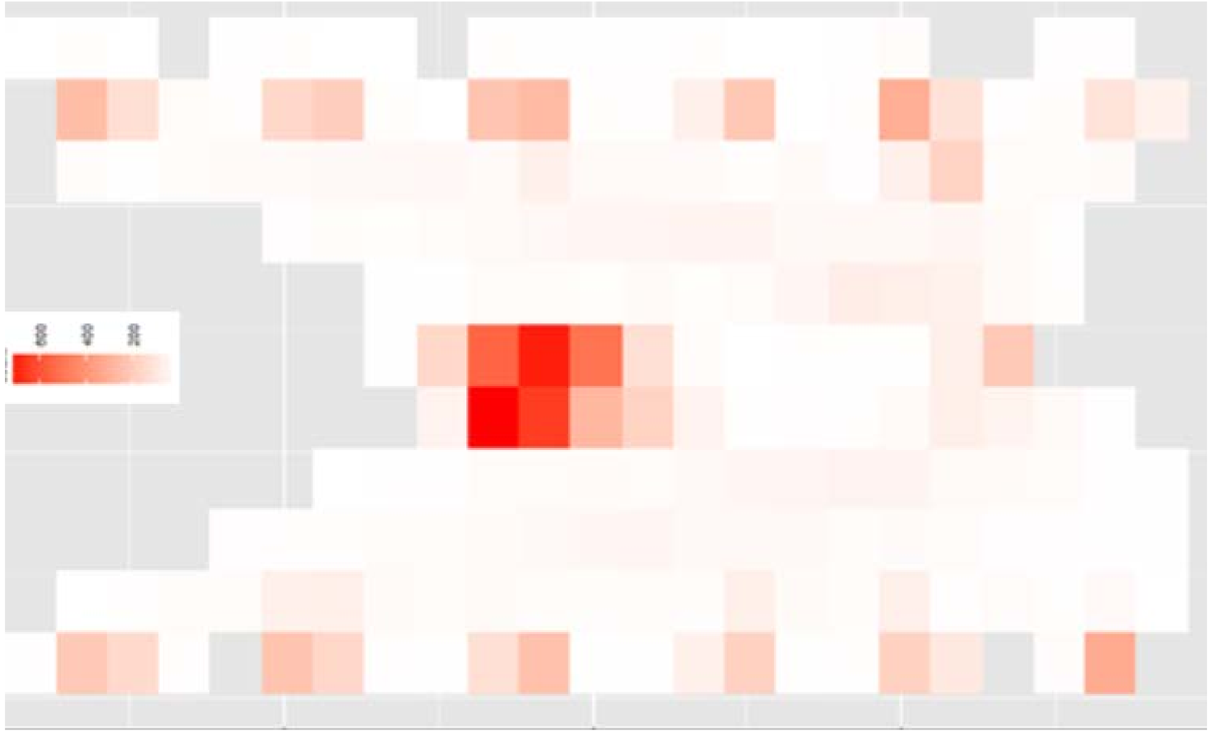
Transit Application
Transit Layout



Transit Trajectories & Space Usage





Conclusions

- Feasible modeling approach: flexible and computationally efficient
- Basic validity analysis (i.e. macro analysis)
- Realistic trajectory patterns

- Next steps:
  - Flow-density analysis → traffic flow theory based study
  - Additional trajectory data specific to transit related pedestrian dynamics
  - Microscopic calibration capturing heterogeneity
  - Real-time application: predictive tool

Acknowledgements

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