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Runtime Optimization of Force - Based Models within the Hermes Project

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Jülich Supercomputing Centre

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Overview

Motivation

Concept of the evacuation assistant

- Aims and flowchart
- Funding and Partners

Simulation core

- Experiments (calibration and verification)
- Movement model
- Runtime optimization (neighbor list methods)

Outlook

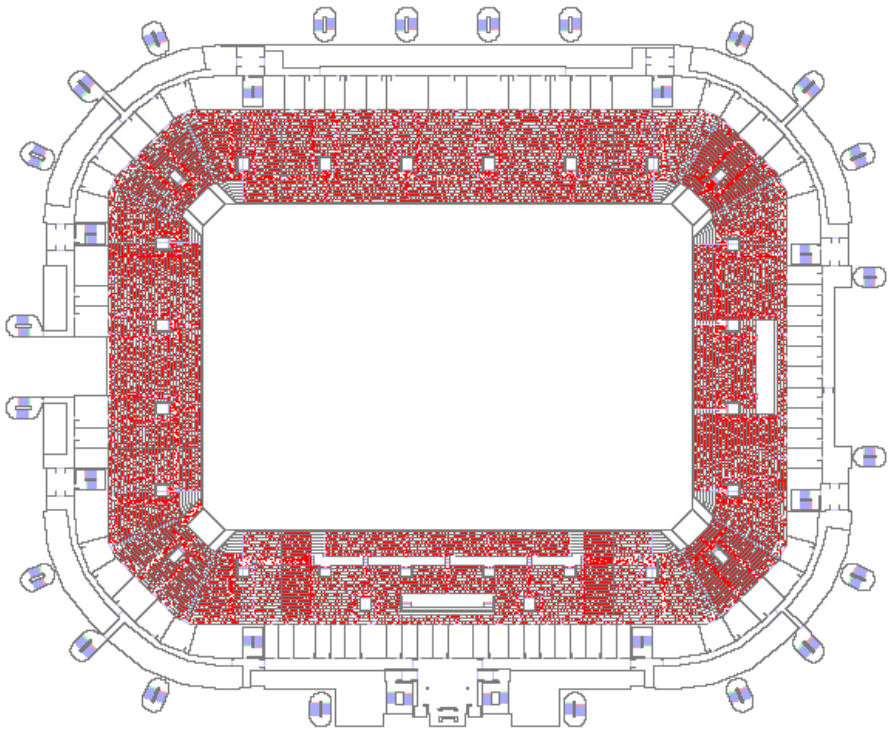
Motivation

Application of evacuation simulation

- Identification of congested areas
- Optimization of egress routes during the planning phase of the building
- Case studies of emergencies

But

In advance only very few case studies can be considered!



Simulation: T. Meyer König, TraffGO HT

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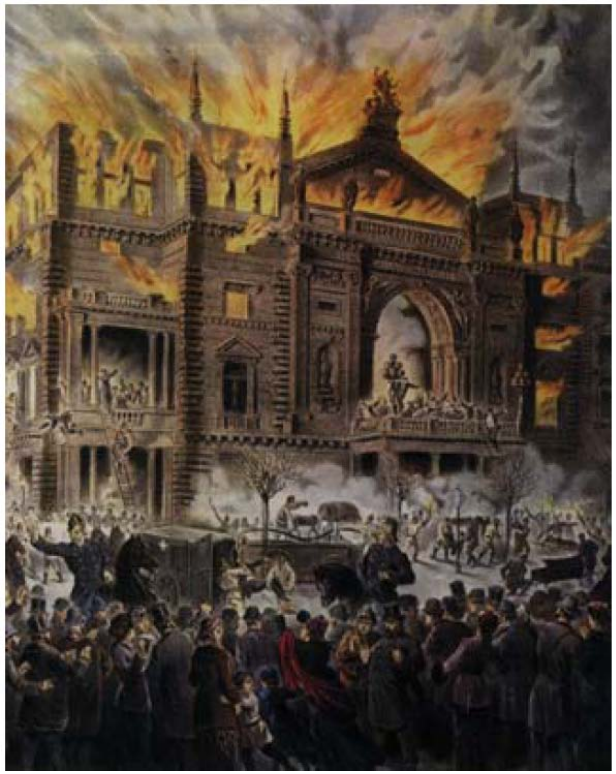
Problem

In case of emergency

- Number and distribution of people unknown
- Failure of escape routes possible

Optimal crowd management needs actual information on-site!

- Number of people in the risk area
- Influence of failed escape routes on the evacuation time
- When and where dangerous congestions will occur



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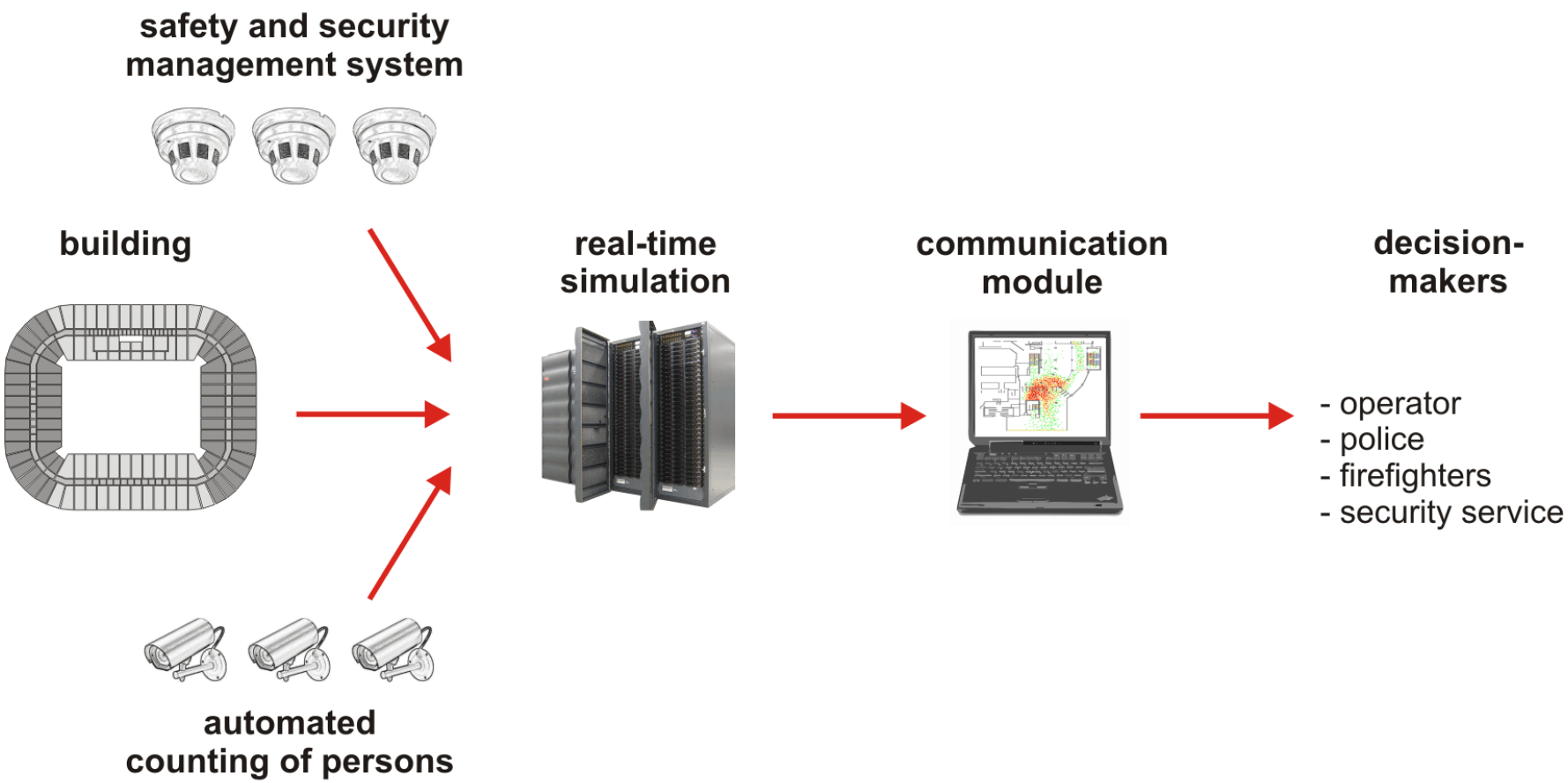
Concept

Layout of the evacuation assistant



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Funding and partners

Study for an evacuation assistant for use in emergencies during large-scale public events - Hermes

funded by the Federal Ministry of Education and Research (BMBF)
Program: Research for Civil Security / Protecting and Saving Human Life

Partners

Research Institutes

- Universität Wuppertal
- Universität zu Köln
- Universität Bonn
- Forschungszentrum Jülich

Companies

- Esprit arena
- TraffGO HT GmbH
- PTV AG
- Vitracom AG
- Imtech GmbH & Co. KG

Operators and Associated Partners

- Düsseldorf Fire Brigade
- North Rhine-Westphalia State Office for Central Police Services
- Special Security Service

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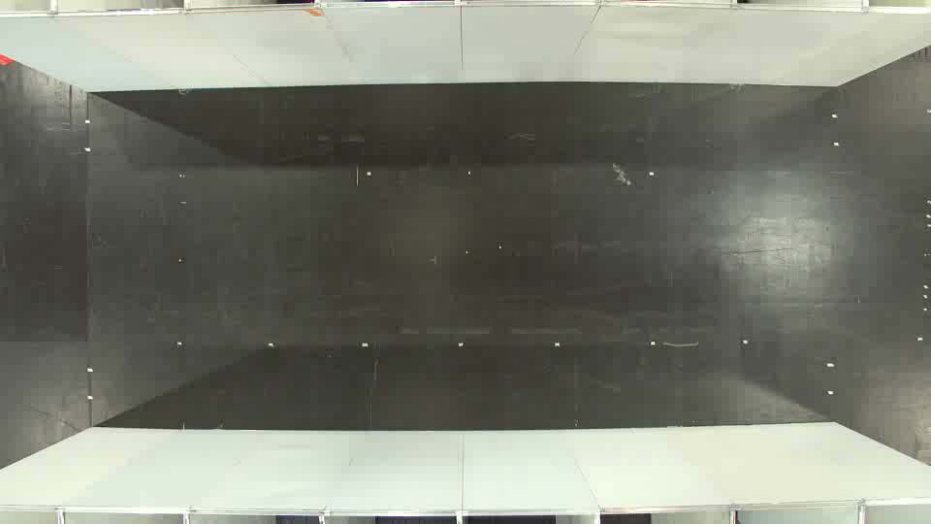
Experiments



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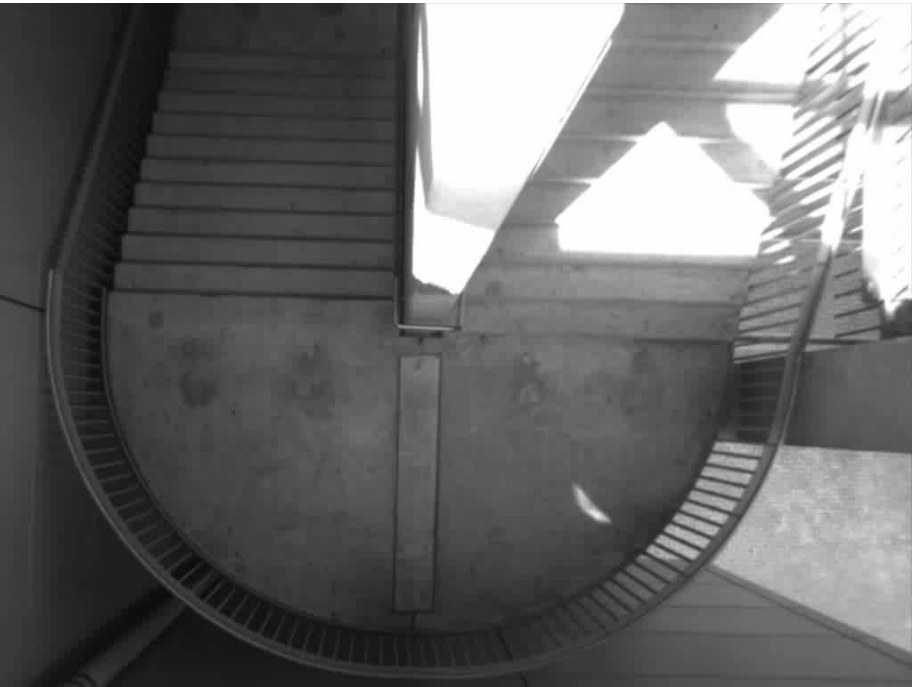

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Trajectories at bottlenecks

see poster of Maik Boltes

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Modeling

Centrifugal Force Model*

Original version

Equation of motion:

$$\overrightarrow{F_i} = \overrightarrow{F_i^{drv}} + \sum_{j \neq i}^{\tilde{N}} \overrightarrow{F_{ij}^{rep}} + \sum_{B} \overrightarrow{F_{iB}^{rep}} = m_i \overrightarrow{a_i}$$

Driving force:

$$\overrightarrow{F_i^{drv}} = m_i \frac{\overrightarrow{v_i^0} - \overrightarrow{V_i}}{\tau}$$

Repulsive force:

$$\overrightarrow{F_{ij}^{rep}} = -m_i K_{ij} \frac{V_{ij}}{\| \overrightarrow{R_{ij}} \|} \overrightarrow{e_{ij}},$$

Yu, W. J. et al. Phys. Rev. E, 2005, 72, 026112

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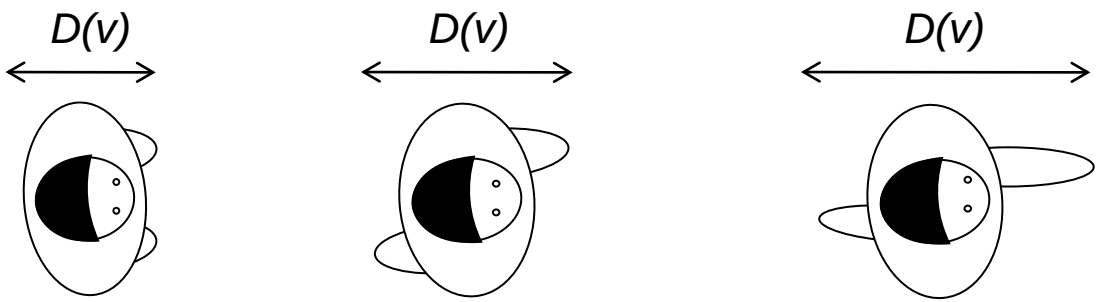
Modified Centrifugal Force Model

Modifications

- space requirement *D* depends on the speed $D_i(\|\vec{V}_i\|)$



- Strength of the force depends on own intended speed $\nu \|\vec{V}_i^0\|$

Modified version: $$\vec{F}_{ij}^{rep} = -m_i K_{ij} \frac{(\nu \|\vec{V}_i^0\| + V_{ij})^2}{\|\vec{R}_{ij}\| - D_i(\|\vec{V}_i\|)} \vec{e}_{ij},$$

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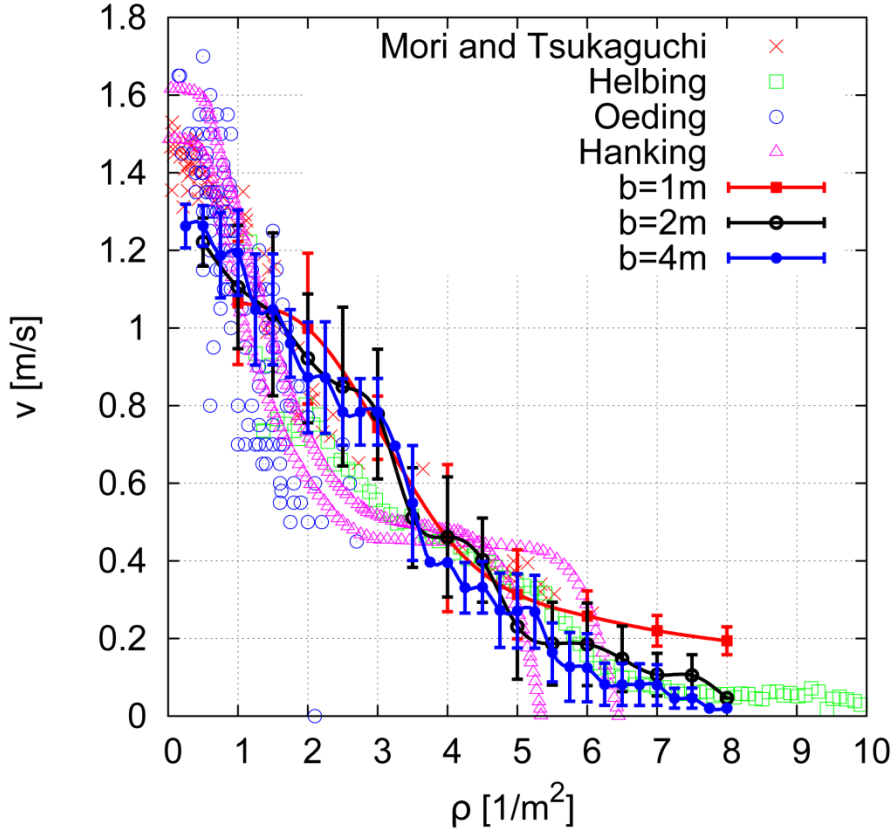
Verification: Velocity-density relation

Modified CFM

- Fundamental diagram in 2d
- different width of corridors
- lines: simulation results



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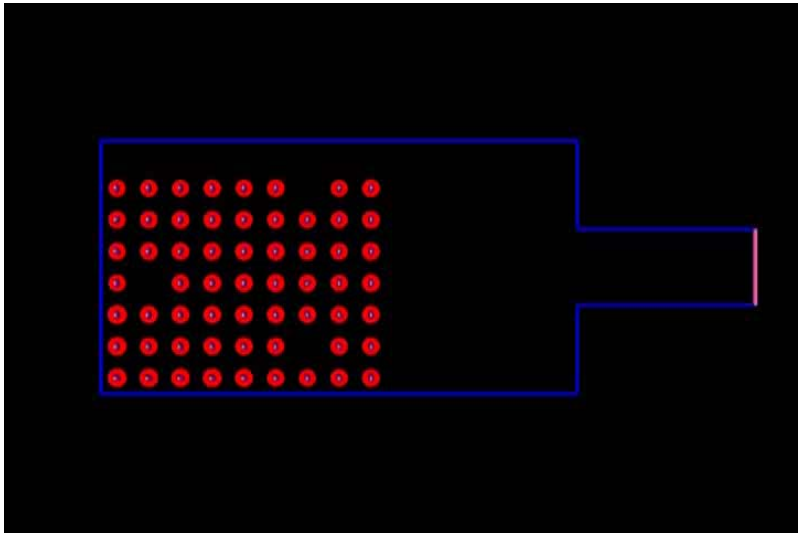
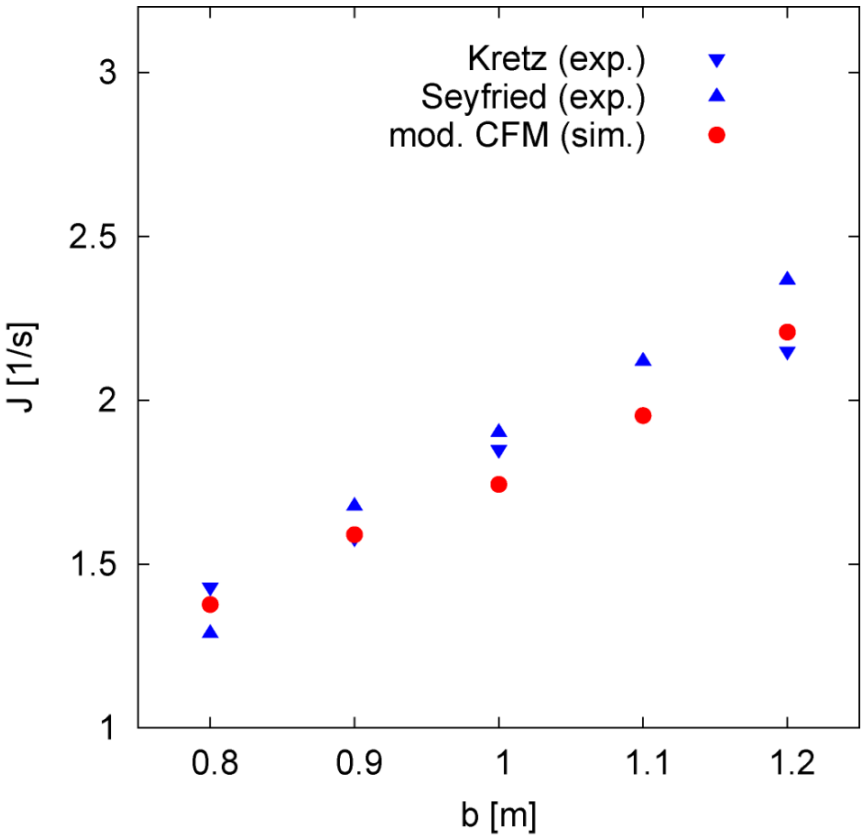
Verification: Bottleneck flow

Modified CFM

- J ~ b
- Density inside and in front of the bottleneck





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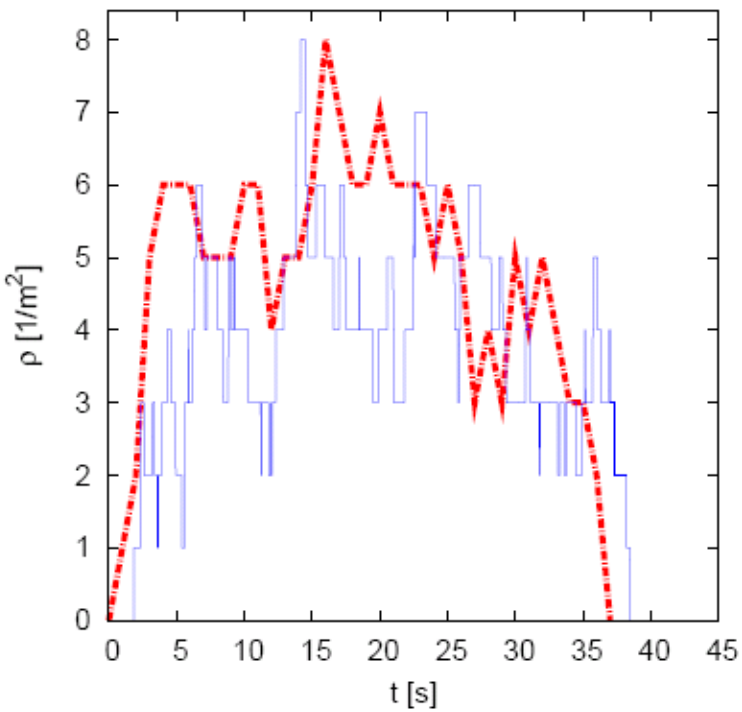
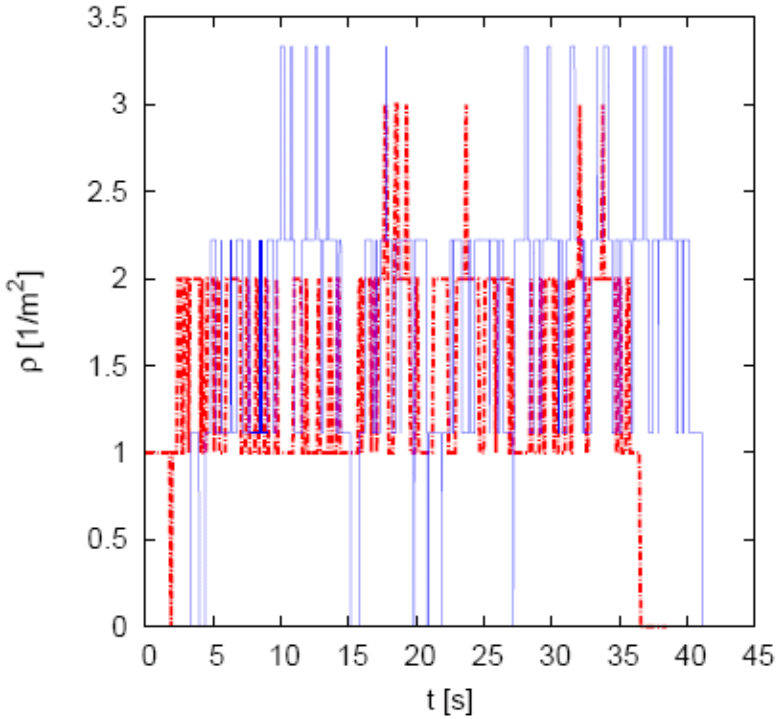
Density in front of and inside the bottleneck



Density in front of the bottleneck



Density inside the bottleneck

Red lines: Experimental data
Blue lines: simulation results

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Runtime optimization

Problem

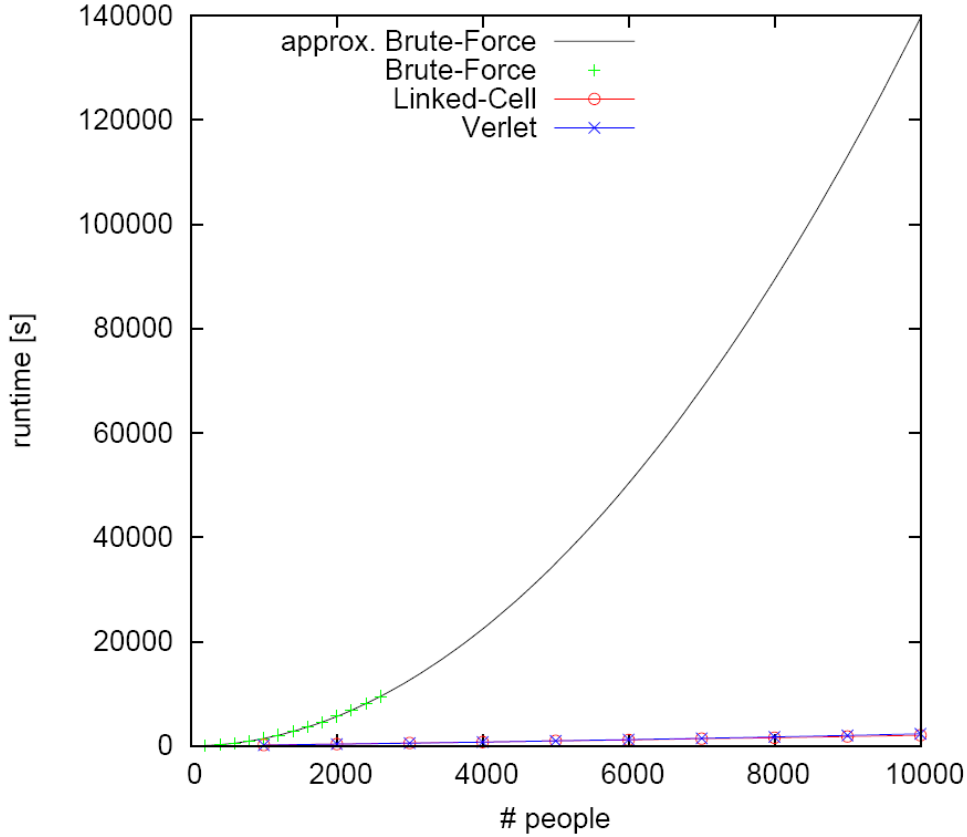
Repulsive force

$$\overrightarrow{F_i} = \ldots + \sum_{j \neq i}^{N} \overrightarrow{F_{ij}^{rep}} + \ldots$$

$$\overrightarrow{F_{ij}^{rep}} \sim \frac{1}{\| \overrightarrow{R_{ij}} \| - D_i(\| \overrightarrow{V_i} \|)}$$

pair interactions $\frac{N(N-1)}{2}$

Brute force implementation leads to an increase of the demand (and compute time) ~ N²



For short range forces neighbor list methods could reduce the demand

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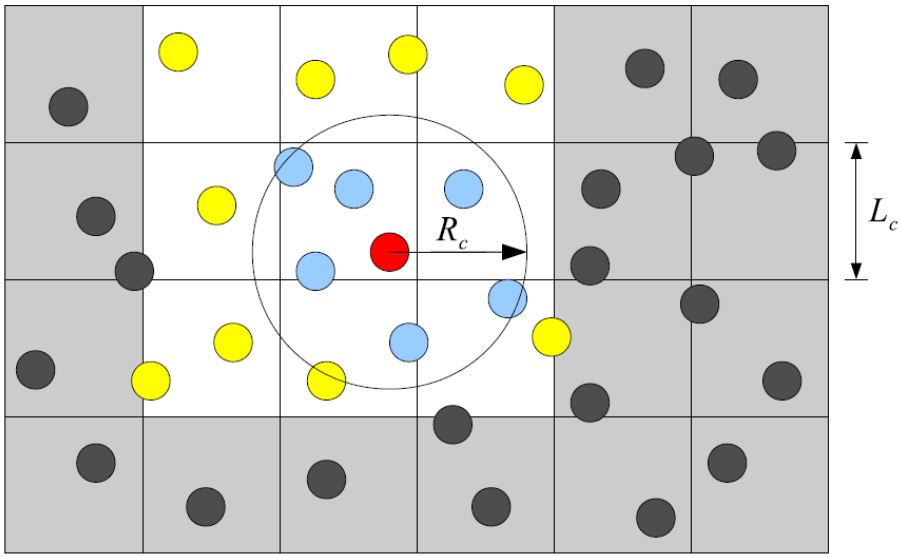
Neighbor list methods

Linked Cell Method*

- Decomposition of space in cells with size $R_c x R_c$
- Only interactions with particles in the same and in adjacent cells have to been considered



**Allen and Tildesley. Computer Simulation of Liquids. Oxford Science (1987)*

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Speedup and efficiency

Speedup

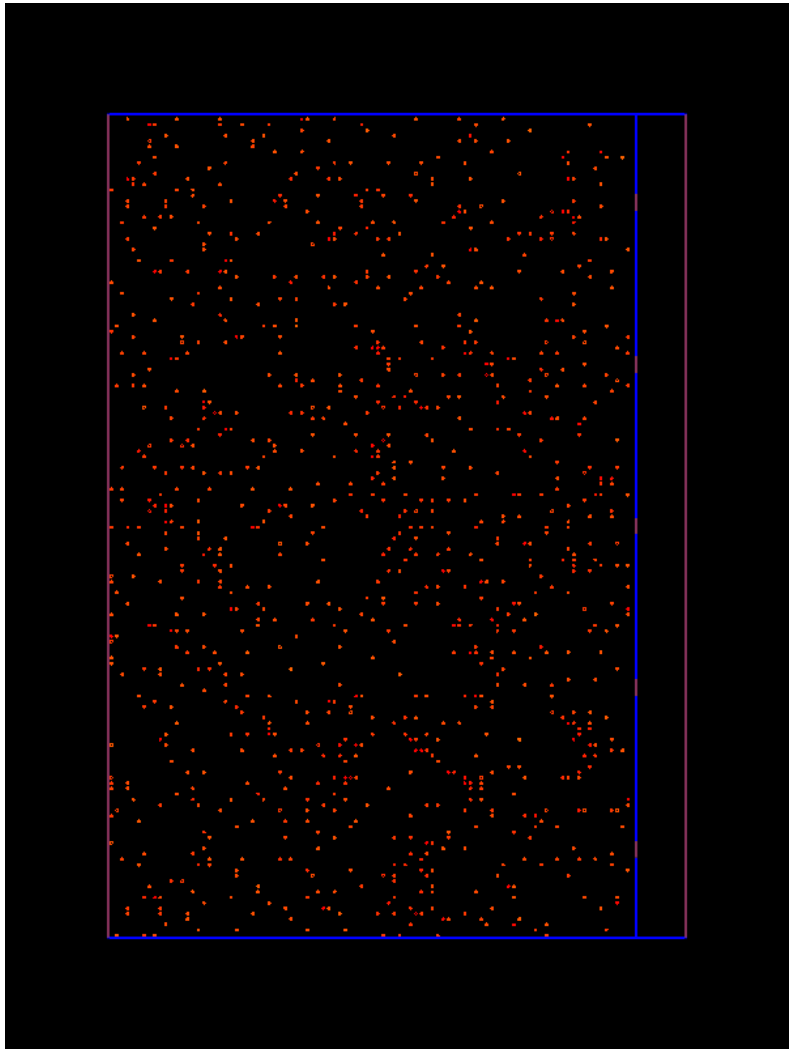
$$\text{speedup} = \frac{t_{BF}}{t_{NL}}$$

t_{BF}: Runtime of brute force method

t_{NL}: Runtime of neighbor list method

Efficiency will depend on

- Range of the force
- Number of pedestrians N
- Density
- Homogeneity of the distribution
- ....



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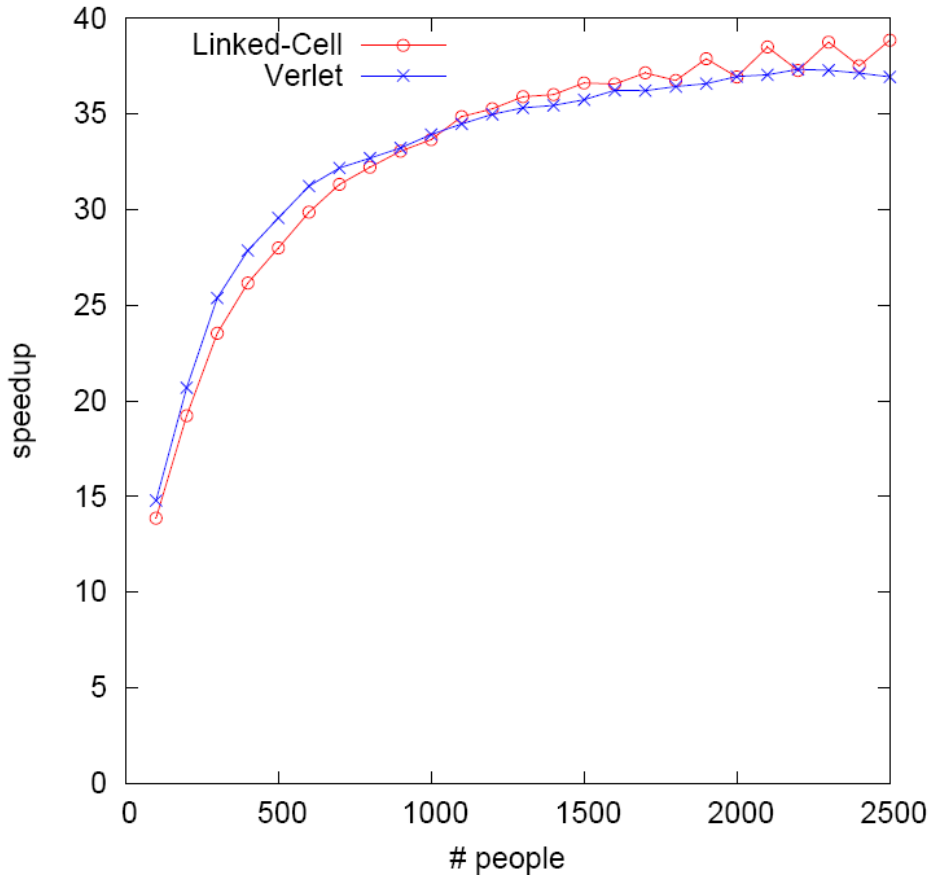
Speedup analysis

Performance tests

- 10000 iteration steps.
- Operating system openSUSE 10.2
- Intel Pentium D Processor with 3.40GHz, a L2-Cache of 2048KB and 2048MB RAM.

Homogeneous test case

- A_{room}=35m x 50m
- Speedup increase with N
- Saturation at high densities
- For a larger room and 10000 pedestrians a speedup of 80 could be reached.



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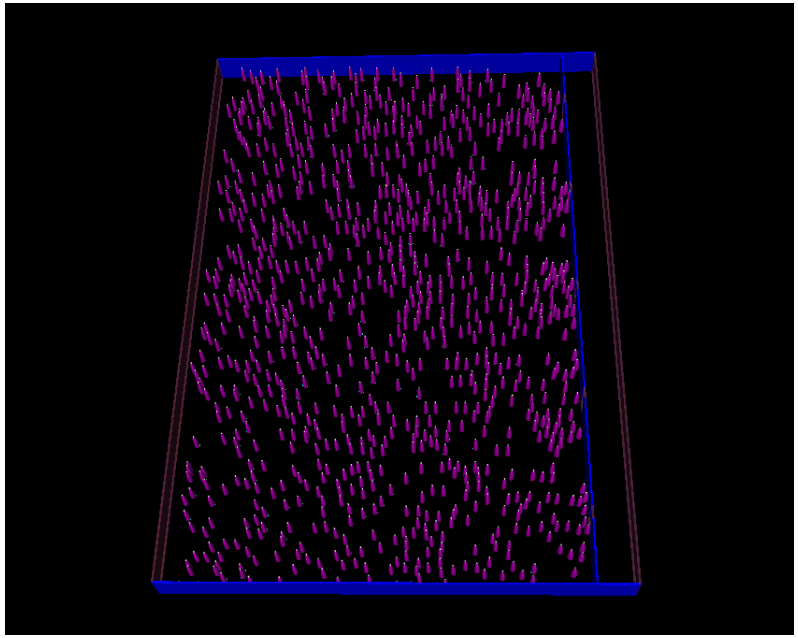
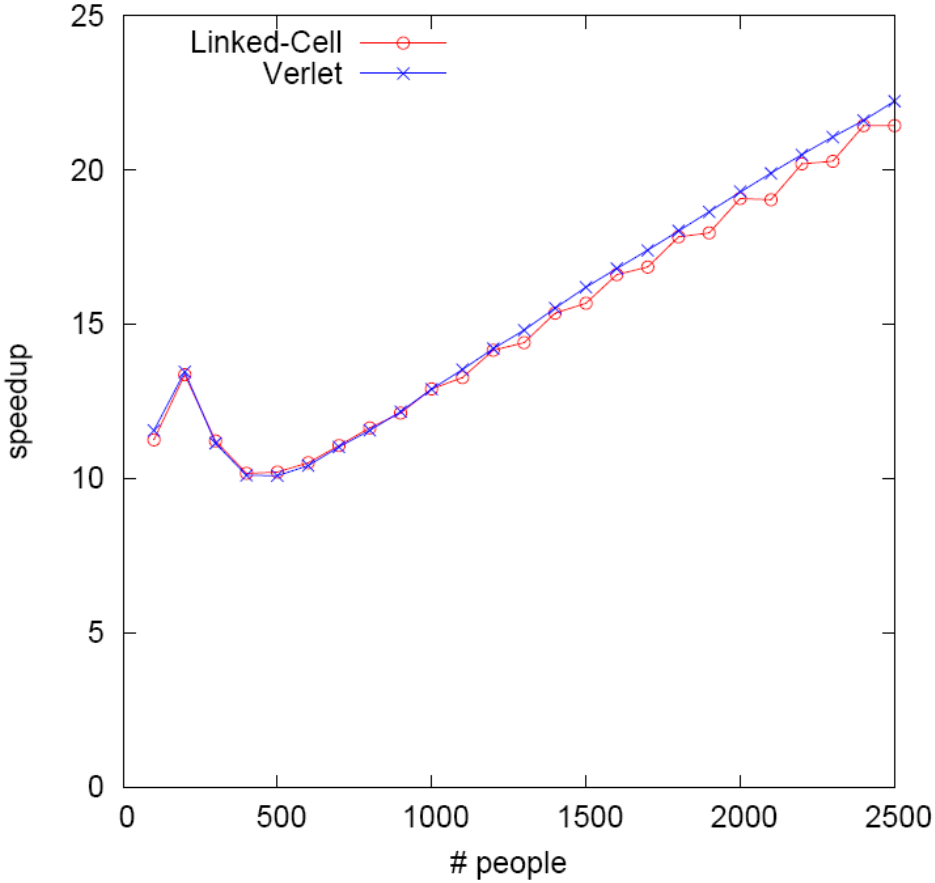
Speedup analysis

Inhomogeneous test case

- A_{room}=35m x 50m
- Speedup increase with N
- Speedup lower then in the homogeneous test case





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Outlook

Outlook

Experiments

- Automated determination of trajectories on stairs
- Analysis of trajectories (Fundamental diagram)

Modeling

- Further verification steps

  Fundamental diagram of single file movement
  Fundamental diagram of bidirectional flow
  Flow at junctions (multidirectional flow)
  Movement at bends (capacity reduction)
  Fundamental diagram of stairs

Runtime optimization

- Parallelization on a cluster

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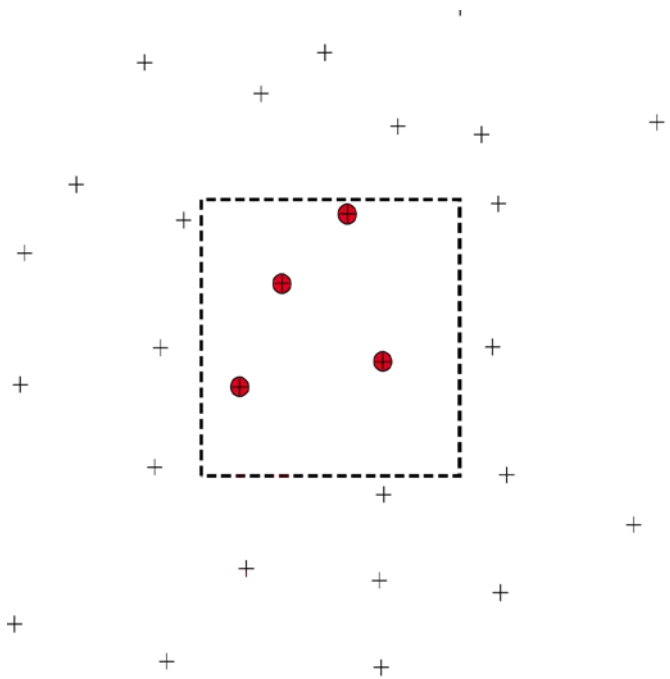
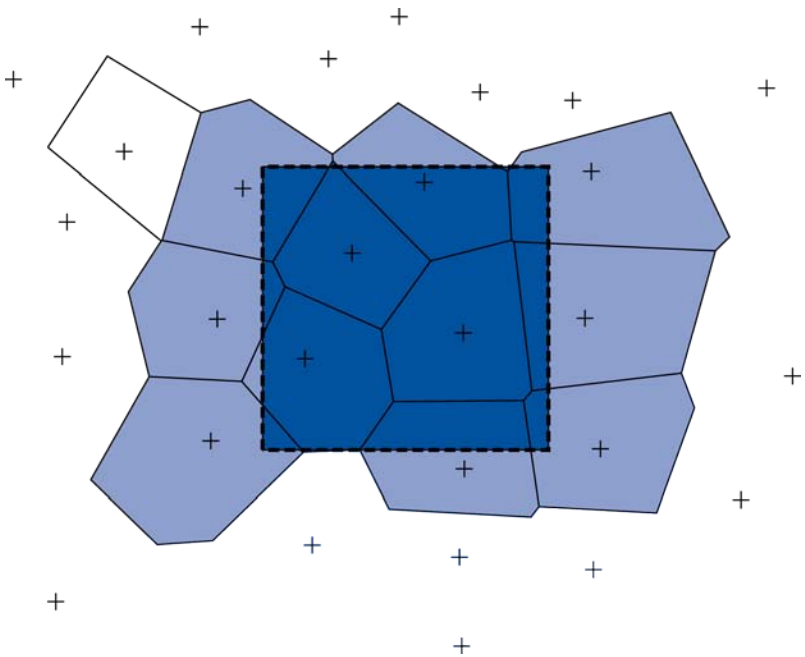
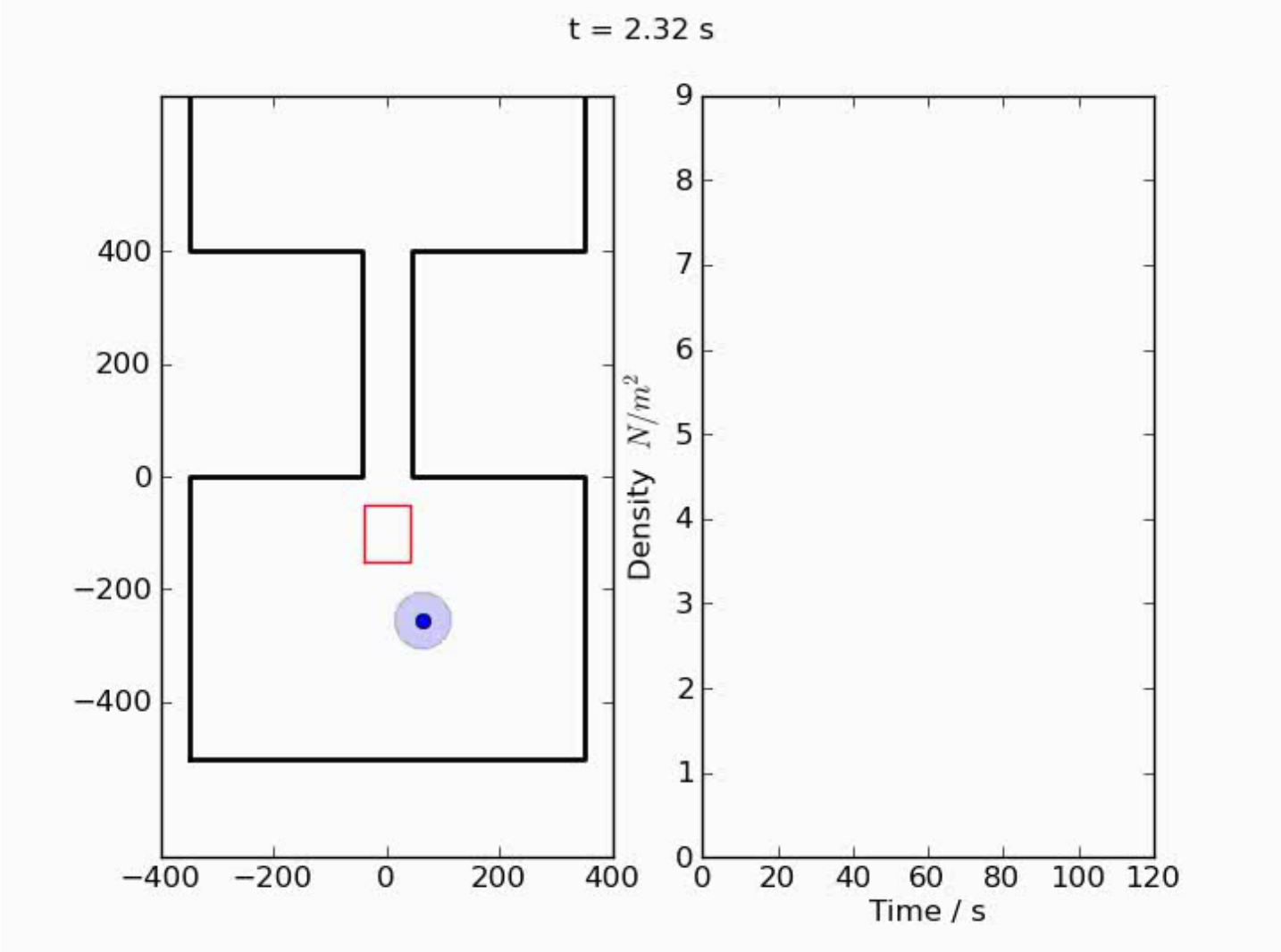
Voronoi - density

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





Voronoi - density



Poster of Jack Liddle

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Thank you for your attention

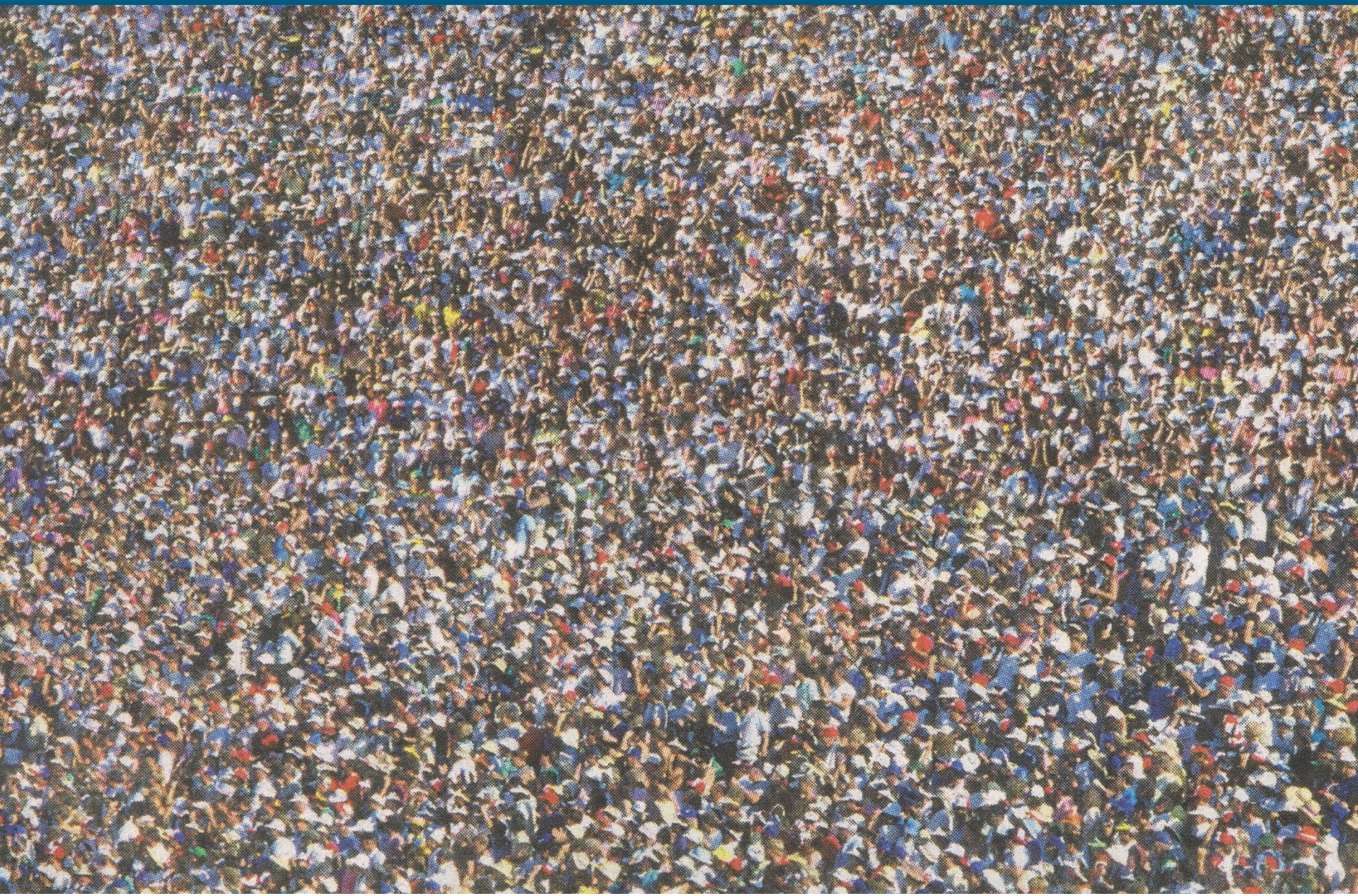

Foto: Bill Ross / Corbis