Coupling of smoke and pedestrian simulation: triggering of crowds by perception of smoke

PhD Students' Seminar on Fire Safety Science 2019
Braunschweig, Germany

Ben Hein

JÜLICH Forschungszentrum

BERGISCHE UNIVERSITÄT WUPPERTAL

Outline

1. Introduction
2. Underlying experiments and coupling Ansatz
3. Visibility framework
4. Motivation framework
5. Future steps

Introduction

BERGISCHE
UNIVERSITÄT
WUPPERTAL

"Toxic gases and/or depletion of oxygen in fire smoke are the final causes of death of those victims. However, many evacuees are trapped in an **early stage** of fire by relatively thin smoke, and **loss of visibility** is an indirect but fatal cause of death."

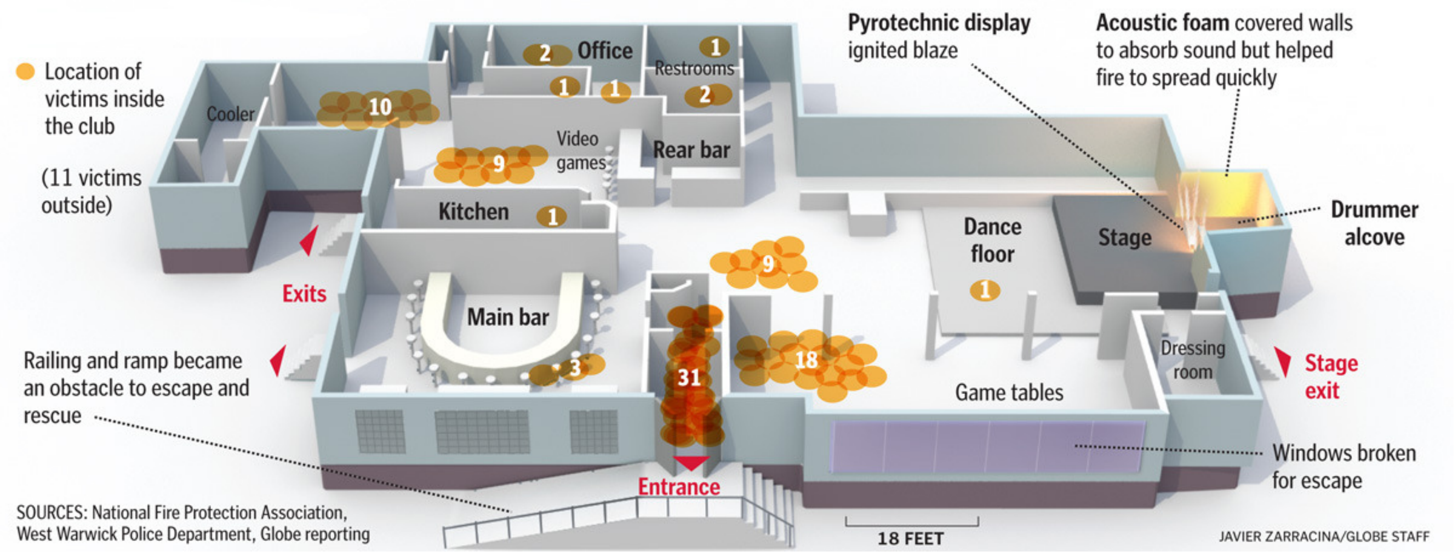
SFPE Handbook of Fire Protection Engineering, 2016

Smoke control systems

- big volume buildings (airports, carparks, malls)
  - smoke easily rises
  - smoke exhaustion system fit possible
  - → „smoke-free“ evacuation

- casual buildings (hotels, offices, hospitals, clubs)
  - corridors and small compartmentation
  - smoke exhaustion system fit difficult
  - even when in place, not that effective
  - → smoke conditions during evacuation

- crowd in a competitive behaviour due to a fire scenario



Potential for improvement through coupling

"Traditional **ASET/RSET** analysis does not couple the fire analysis to the evacuation analysis [...] (but) fire hazards may have a significant impact on the progress of the evacuation (and) this omission may produce significantly optimistic conclusions […]"

E. Galea, Coupled Fire/Evacuation Analysis of the Station Nightclub Fire, 2009

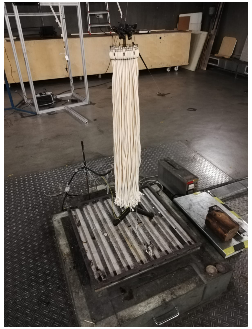
- fire related factors substantially **affect** the evacuation dynamics
- new implementations would **improve** current evacuation models
- preference for integration of **propagating smoke** and **agent motivation**
- application: more extensive analysis of **route choice** with phenomena like **crowding** and congestion in front of exits

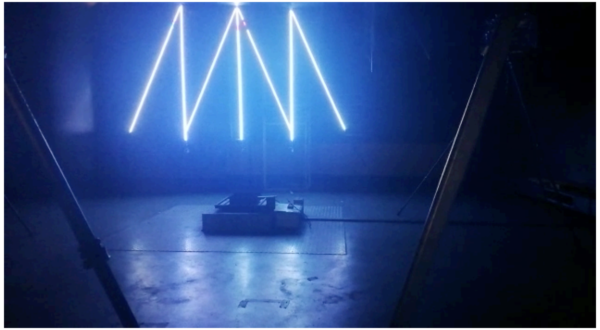
Underlying experiments

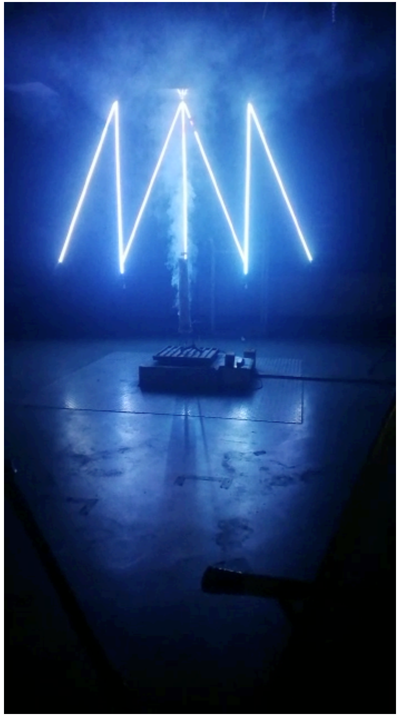
BERGISCHE
UNIVERSITÄT
WUPPERTAL

Experiments on light extinction

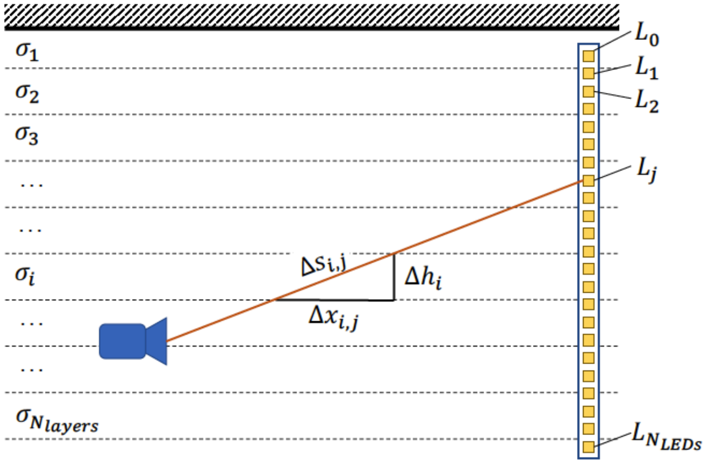
- cooperation with university Duisburg-Essen
- new **measurement technique** for light extinction in space
- goal: numerical **modelling of visibility and** analyse impact of type of smoke on visibility

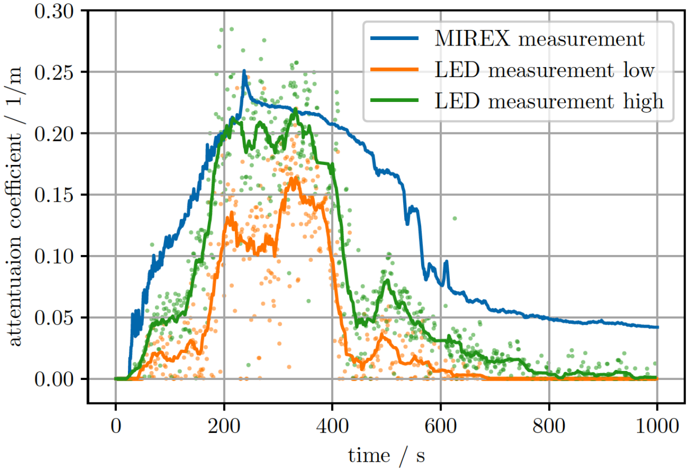






- results for **TF5** with new measurement technique:

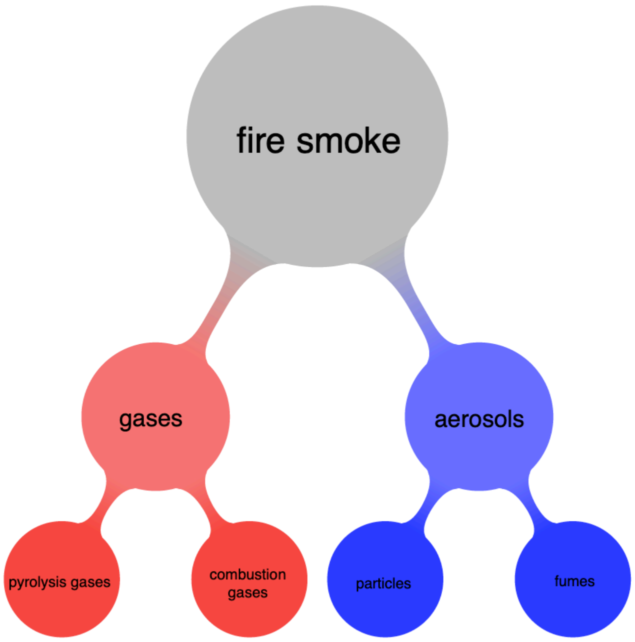




Arnold et al., Spatiotemporal measurement of light extinction coefficients in compartment fires, 2019

"On the other hand, the characteristics of fire smoke, that is, **composition, shape, and size of the particles**, depend on the combustible materials involved and the conditions of combustion. These characteristics are also highly **dependent on** surrounding **flow** and **temperature** fields and **vary with time.**"

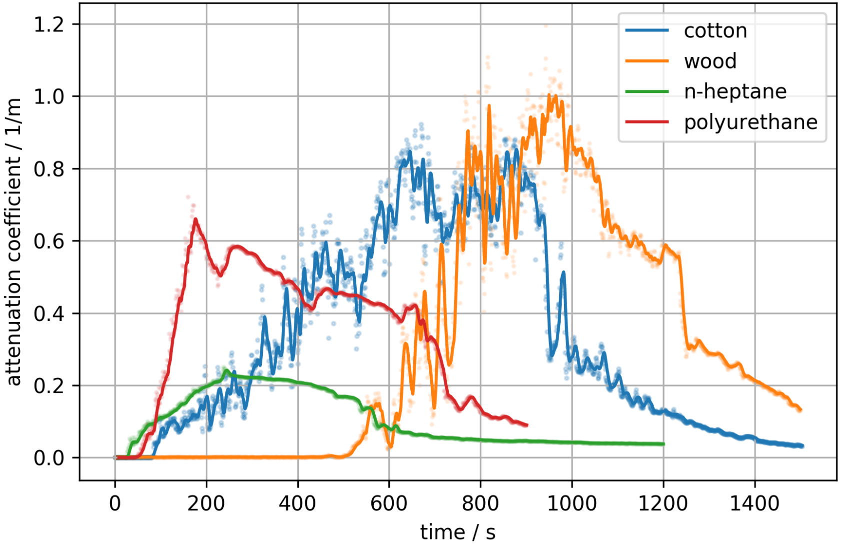
SFPE Handbook of Fire Protection Engineering, 2016



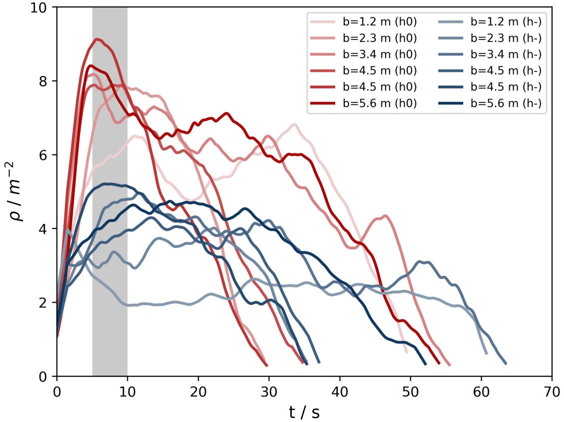
N. Montreal, Numerische und experimentelle Untersuchung von Brandrauch unter Berücksichtigung von flammenden und nicht-flammenden Verbrennungsvorgängen, 2018

- **local** MIREX measurements during **experiments** in Duisburg

- TF2 (wood): smouldering fire with bright, strong scattering smoke
- TF3 (cotton): smouldering fire with bright, strong scattering smoke
- TF4 (PU): plastic fire with very dark smoke
- TF5 (n-heptane): pool fire with very dark smoke



- variation of corridor width and participants' motivation
- impact on density in front of the exit and queuing or crowding behaviour

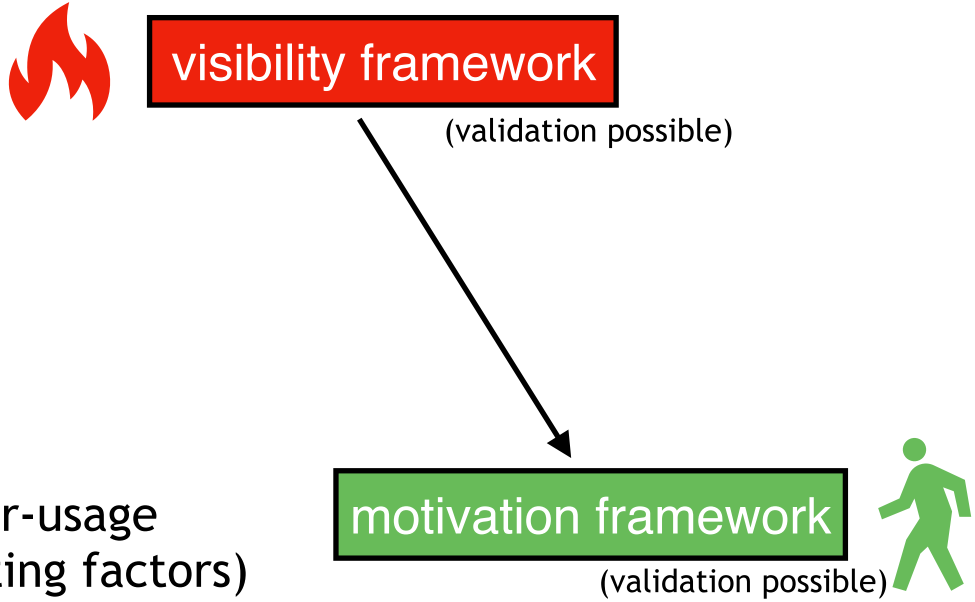


J. Adriane et al, Crowding and Queuing in Entrance Scenarios: Influence of Corridor Width in Front of Bottlenecks, 2018

1. reduced visibility of exit signs

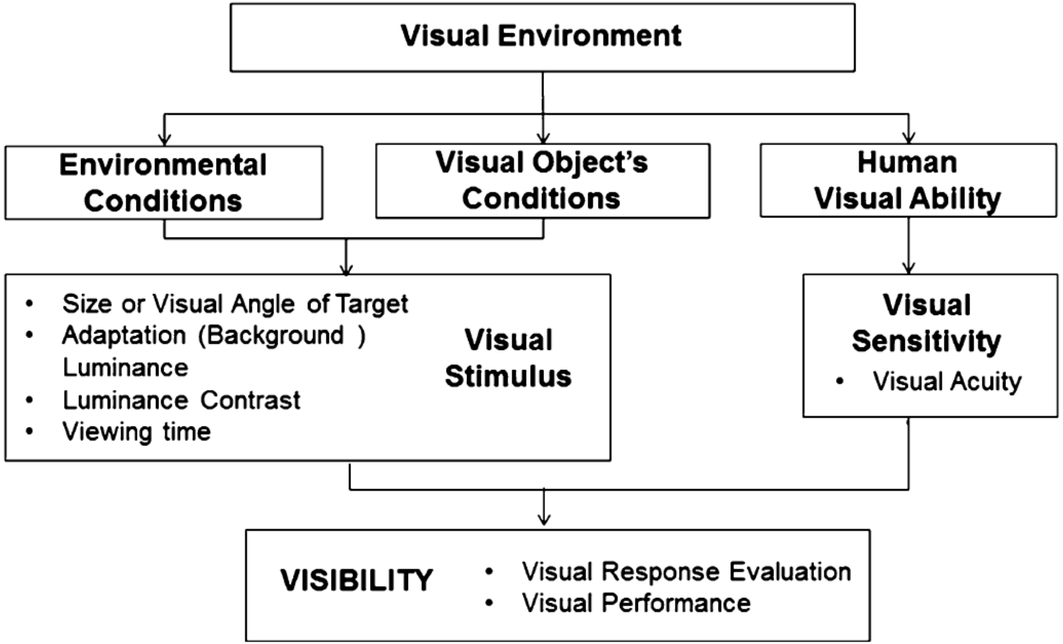
2. rerouting consequences:
- herding
- familiarity behaviour
- orientation using walls

3. irregular usage of exits
- occurrence of crowding due to over-usage
- motivational change (stress, irritating factors)



Visibility framework

Visual environment



SFPE Handbook of Fire Protection Engineering, 2016

- simplified version of a mathematical visibility model developed by Jin:

$$V = \frac{E}{\sigma}$$

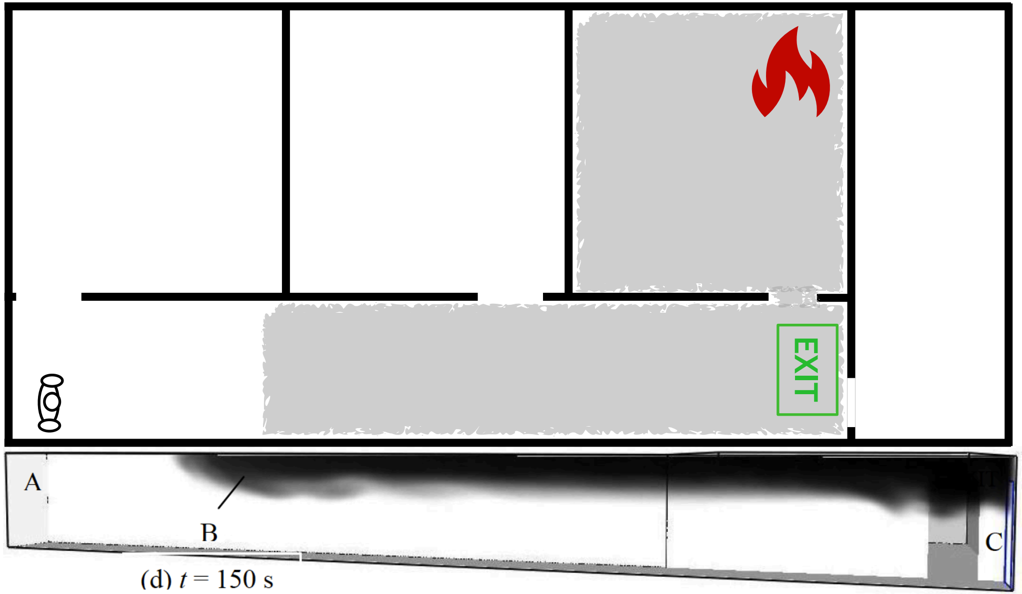
- strong simplification in visibility factor E: $E = \ln\left(\frac{L_t}{\delta_c \alpha E/\pi}\right)$

- homogeneous smoke conditions: $\sigma = -\frac{1}{\Delta s}\ln\left(\frac{I}{I_0}\right)$

- visibility not direction-dependent

Problem with local visibility

- local approach indicates high visibility in this case (zone-model approach)



Y. He, Evaluating Visibility Using FDS Modelling Result, 2009

- **K. Kang**: visibility on line of sight in 3D
  but: Δs constant and interpolation, smoke obscuration level (graphical approach), no specific targets

  K. Kang, A smoke model and its application for smoke management, 2007

- **Y. He**: virtual visibility of exit signs
  variable extinction coefficients as a constant average extinction coefficient -> homogeneous assumption

  Y. He, Evaluating Visibility Using FDS Modelling Result, 2009

- **B. Schröder**: semi-quantitative approach with smoke factors
  but: no visibility, 2D (constant extraction height)

  B. Schröder et al., Knowledge- and perception-baed route choice in case of fire, 2015

Intensity reduction in 3D

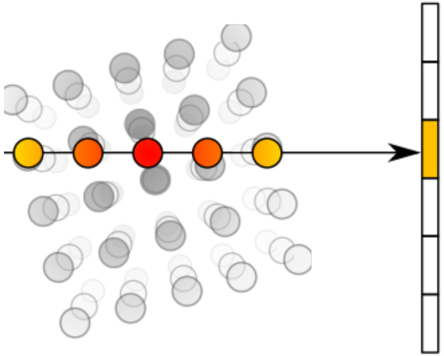
- new Ansatz: inhomogeneous smoke conditions

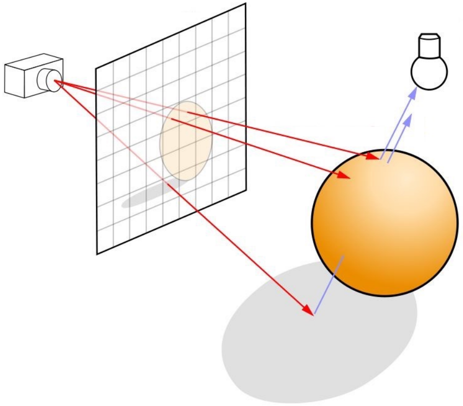
$$T = \frac{I}{I_0} = \exp(-\tau_\lambda) = \exp(-\sigma \cdot \Delta s)$$

$$T = \frac{I}{I_0} = \exp\left(-\int_s \sigma(s)\mathrm{d}s\right) = \exp\left(-\sum_{i=0}^{n_{voxels}} \sigma_i \Delta s_i\right)$$

- light attenuation for exit signs for all room positions, agent height and time steps -> grid traversal algorithm needed

- ray **tracing**: processes surface data
- ray **casting**: processes volume data (used in game development, AI, collision detection)

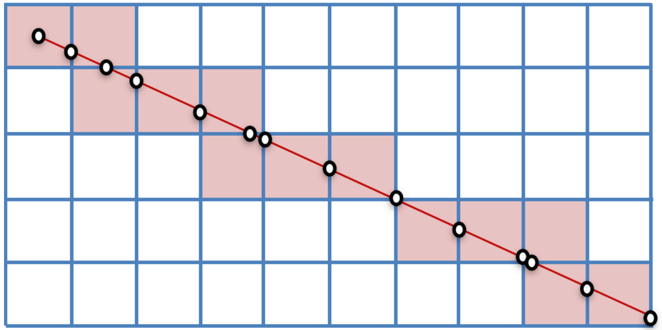




	ray tracing	volume ray casting
output	graphic games	volume visualization
goal	realism	visualize features
rays	N	1

Sampling methods for ray casting

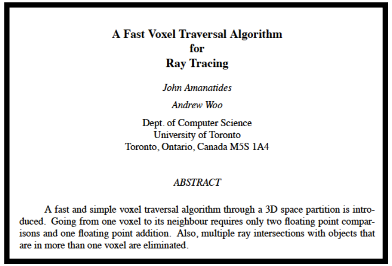
- **line rasterization methods:** Bresenham, digital differential analyser (DDA)
- **regular sampling:** uniform steps along ray with Nyquist criteria
- **voxel intersection (exact ray casting):** all cells with intersection points



BERGISCHE UNIVERSITÄT WUPPERTAL

Fast voxel traversal algorithm

- **implementation** of fast voxel traversal algorithm (by J. Amanatides)
- **illustration** for one calculation:



A Fast Voxel Traversal Algorithm
for
Ray Tracing

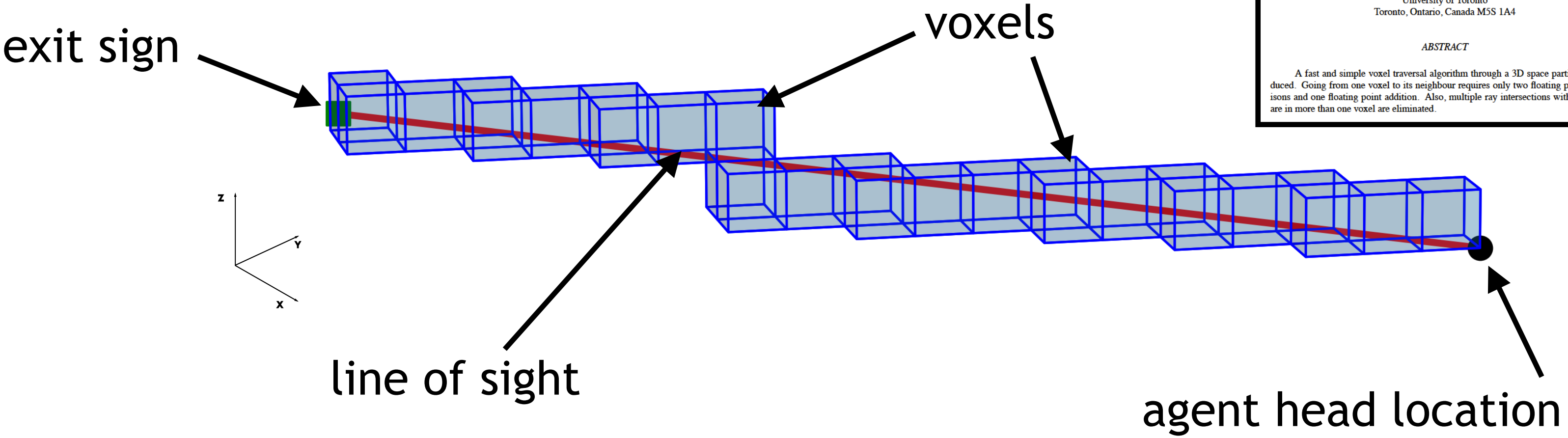
John Amanatides

Andrew Woo

Dept. of Computer Science
University of Toronto
Toronto, Ontario, Canada M5S 1A4

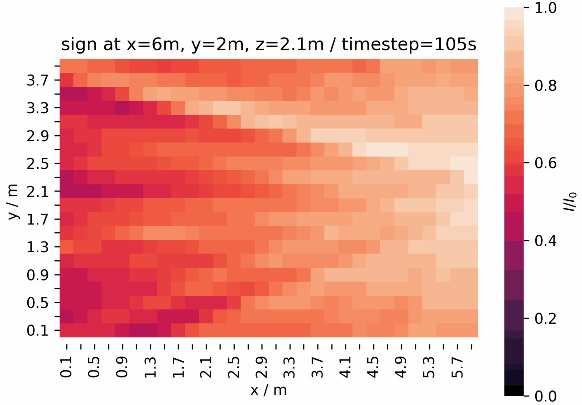
ABSTRACT

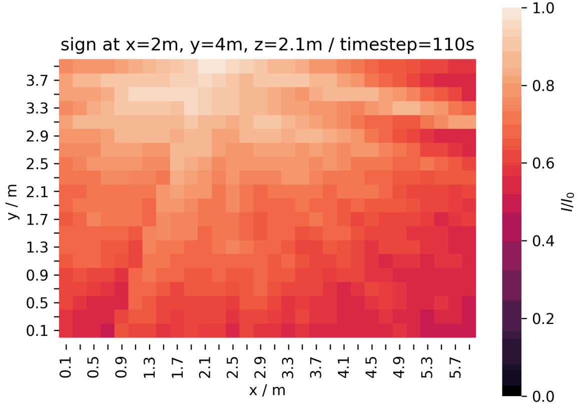
A fast and simple voxel traversal algorithm through a 3D space partition is introduced. Going from one voxel to its neighbour requires only two floating point comparisons and one floating point addition. Also, multiple ray intersections with objects that are in more than one voxel are eliminated.



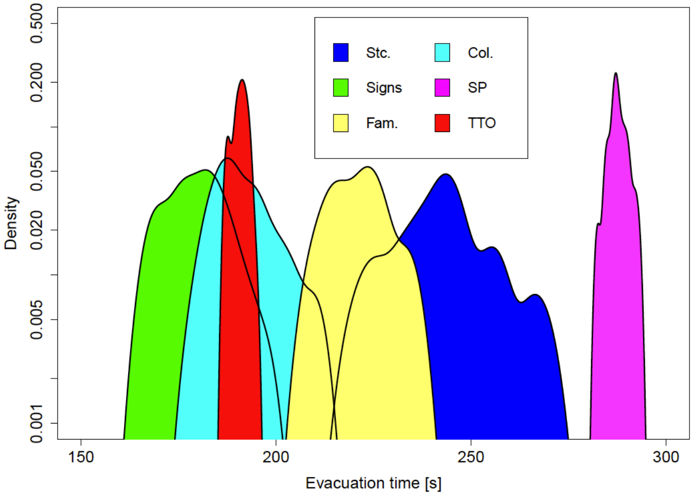
Light attenuation maps

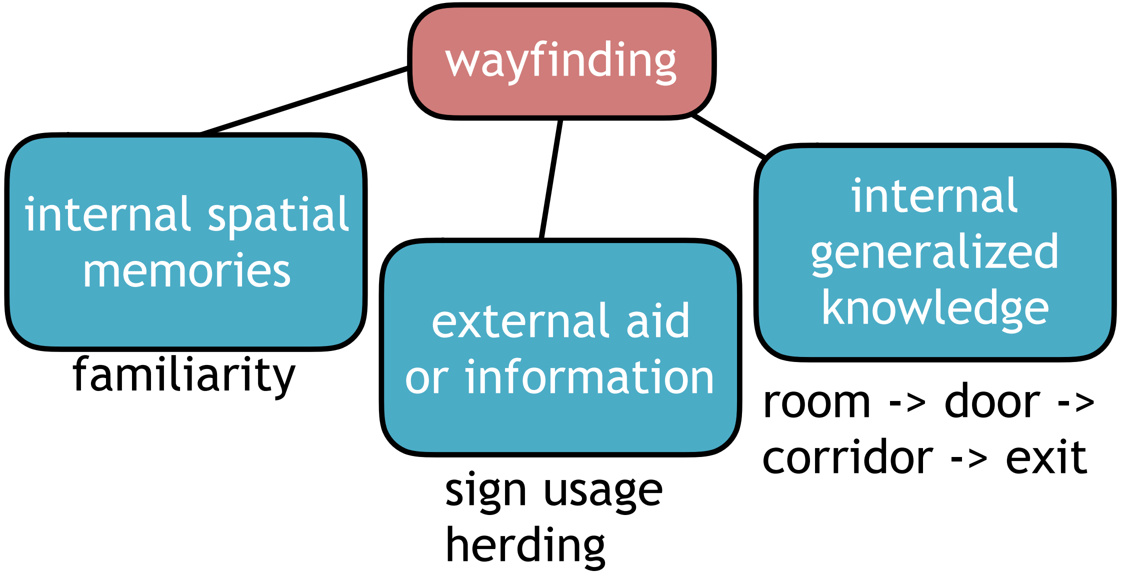
- output as light attenuation **maps**
- in function of exit **sign** and **height** of agent
- threshold values? -> visibility





fds sim
↓
postprocessing of .q files
↓
volume ray casting
↓
3D light attenuation in domain





E. Andresen, Wayfinding and Perception Abilities for Pedestrian Simulations, 2018

FDS+evac

"The smoke concentration affects the exit door selection algorithm. The user gives a threshold visibility value for a door to be considered as a “smoke free” door. A door is usable as long as the visibility is larger than half the distance to the door, where local visibility = 3/extinction coefficient."

Fire Dynamics Simulator with Evacuation: FDS+Evac Technical Reference and User’s Guide, 2017

Preference	Visible	Familiar	Disturbing conditions	
1	yes	yes	no	black
2	no	yes	no	yellow
3	yes	no	no	blue
4a	yes	yes	yes	red
4b	no	yes	yes	green
4c	yes	no	yes	magenta
No preference	no	no	no	cyan
No preference	no	no	yes	cyan

?

Motivation framework

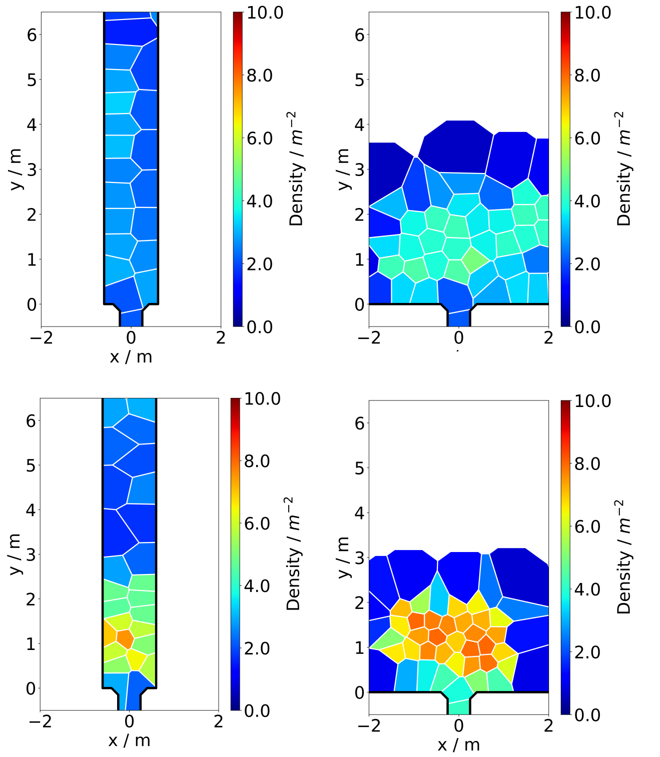
BERGISCHE
UNIVERSITÄT
WUPPERTAL

Modelling approach for motivation framework

- simplified **velocity-based** model
- influence of corridor width modelled by **desired direction**
- motivation variation in function of **agent size** and **time gap** (contraction time scale)

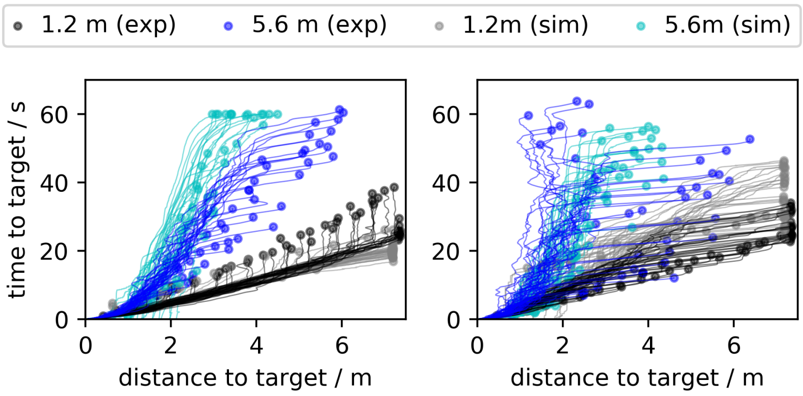
$$\dot{\mathbf{x}}_\mathbf{i} = V\Big(s_i\big(\mathbf{x}_i, \mathbf{x}_j, \dots\big)\Big) \times \mathbf{e}_i \qquad \mathbf{e}_i = \frac{\mathbf{e}_0 + \xi}{N}$$

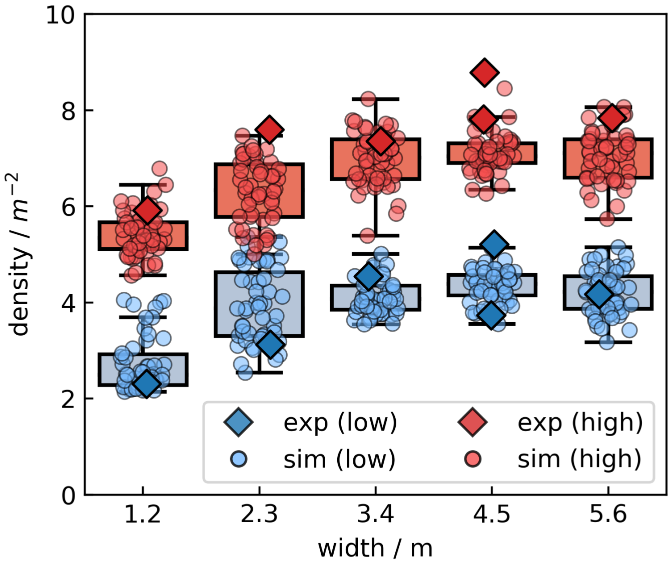
$$V\left(s_i\right) = \min\left\{v_0, \max\left\{0, \left(s_i - l\right)/T\right\}\right\}$$



- larger corridor widths and higher motivation lead to **higher** densities
- comparable **time/distance** plots

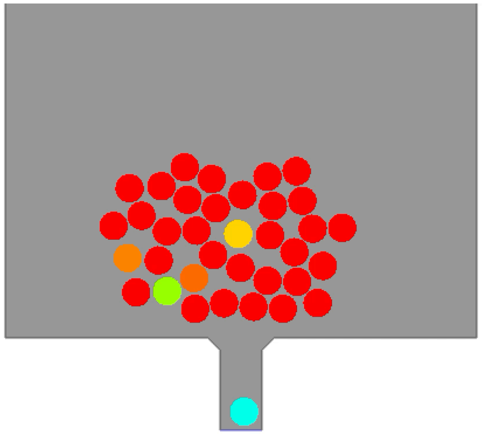
✓ agreement with **experimental** data

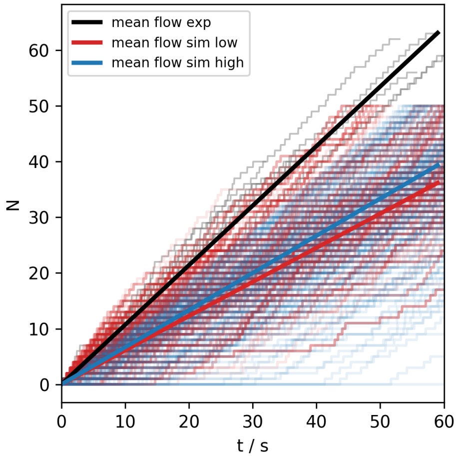


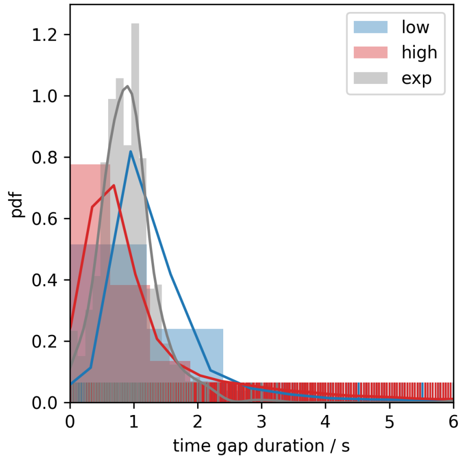


Flow validation fails

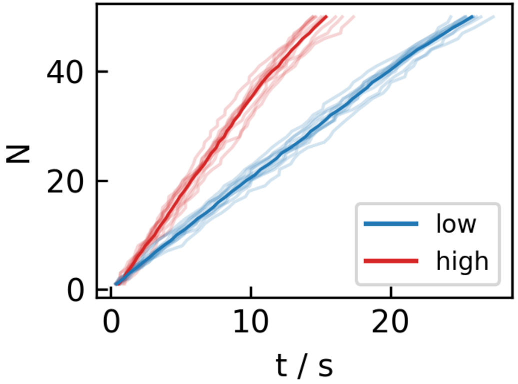
- **flow** validation not possible
- related to **clogs** which occur in the specific validation case

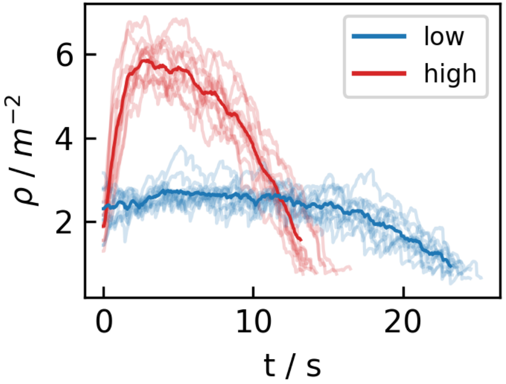


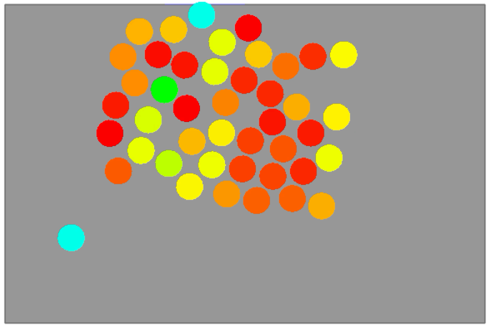


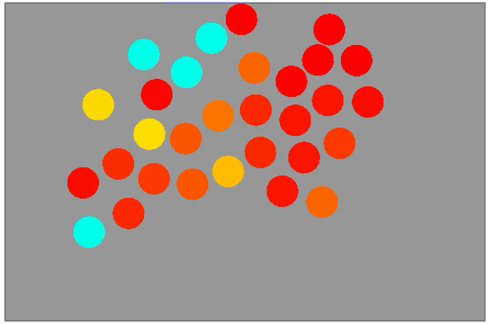


- higher **density** for higher motivation
- higher **flow** for higher motivation
- averaged **results** for 10 runs:









Next steps

BERGISCHE
UNIVERSITÄT
WUPPERTAL

Next steps

- provide a clear coupling **routine** between both frameworks
- analyse **variations** in dynamics (route choice analysis)
- change exit **capacities** by **adapting** signs (placement, size, etc.)
- analyse safety **thresholds** such as density in front of exits, FED, etc.

Discussion