Crowd Health Encoding, for Crowd Simulations Using the Smoothed Particle Hydrodynamics Computational Method

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The story behind this paper

- This paper is based on an MSc dissertation project
- We were interested in modelling dense crowd movement using an alternative approach to the commonly used Social Force Model (SFM)
- We found a paper that uses Smoothed Particle Hydrodynamics Computational Method (SPHCM) for modelling highly dense crowd movement
- We replicated it from scratch and added the notion of "crowd health"

Crowd Dynamics

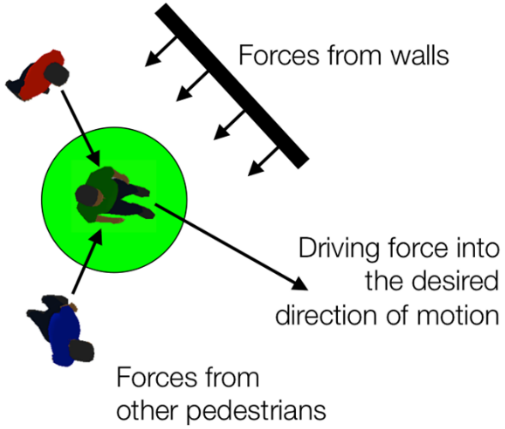
- Flow-based approach (focuses on crowds as a whole rather than its components)
    - SPHCM > Macro (aggregate) level modelling

- Entity-based approach (reactive entities, cannot think for themselves)
    - Standard Social Force Model (SFM) > Micro (individual) level modelling
    - Standard SPHCM + Entities > Macro/Micro level modelling

- Agent-based approach (autonomous, interacting entities, with a degree of intelligence)
    - Extended SFM > Micro (individual) level modelling
    - Standard SPHCM + Agents > Macro/Micro level modelling

Models of crowd movement

- We borrow from Physics
  - Social Force approach (collision avoidance) Helbing 1995
    - Assumes that the acceleration, deceleration and directional changes of pedestrians can be approximated by a sum of different forces, each capturing a different desire or interaction effect
  - Smoothed Particle Hydrodynamics approach (combined flow) van Toll 2020
    - A particle’s contribution to any quantity (such as the density) depends on the distance to particle i



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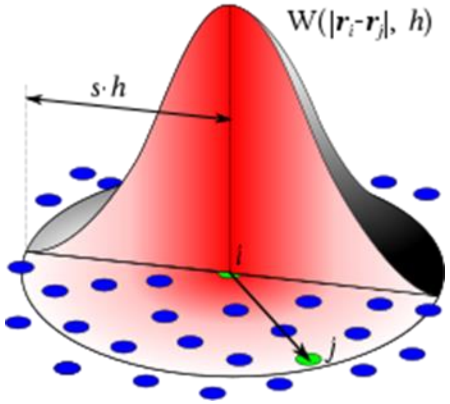


Source: Wikipedia

Aim of the project

- Explore the idea of traits for measuring **crowd health** for Dense Crowd Simulation
  - RQ1: Is **crowd health** currently a suitable application of crowd simulation?
  - RQ2: Is SPHCM effective for simulating **crowd health**?
  - RQ3: What are the suitable metrics involved in measuring, influencing, and ensuring the validity of **health in simulated crowds**?

- Crowd Health
  - Properties involving health of individuals in crowds
    - Individuals can influence, and are affected by other individuals
    - Includes crowd panic and crowd crush
  - Allows the simulation observer to track safety at crowd level

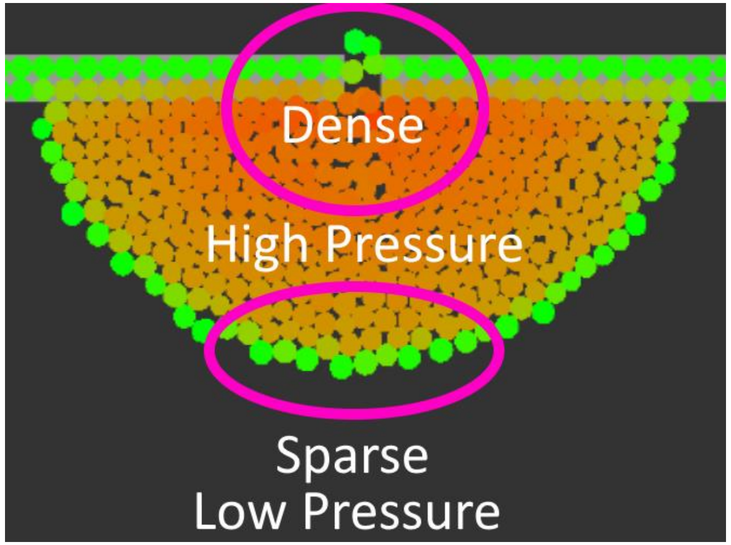
SPHCM Approach (1/2) (after van Toll 2020)

- The idea
  - In SFM an agent's goal is avoid any kind of collisions. In extremely dense crowds this is not meaningful, as collisions are inevitable. SPHCM supports the modelling of these collisions
  - If there is ample physical contact between people, the crowd's motion bears similarities to the motion of fluids, and new types of collective motion such shockwaves may occur
  - Agents can be treated as particles. The forces of SPHCM (for pressure and viscosity) then augment the usual navigation behavior and contact forces per agent

SPHCM Approach (2/2) (after van Toll 2020)

- Features
  - Approximate dense matter from discrete masses
  - Calculate densities of particles using positions and masses
  - Calculate forces using densities, positions and velocities

- Comparison to SFM
  - SPHCM approximates dense fluid body movement
  - SFM gives agents intelligent pathfinding
  - SPHCM smooths dense crowd movements
  - SFM promotes complex emergent interactions
  - They both represent different instinctive behaviours



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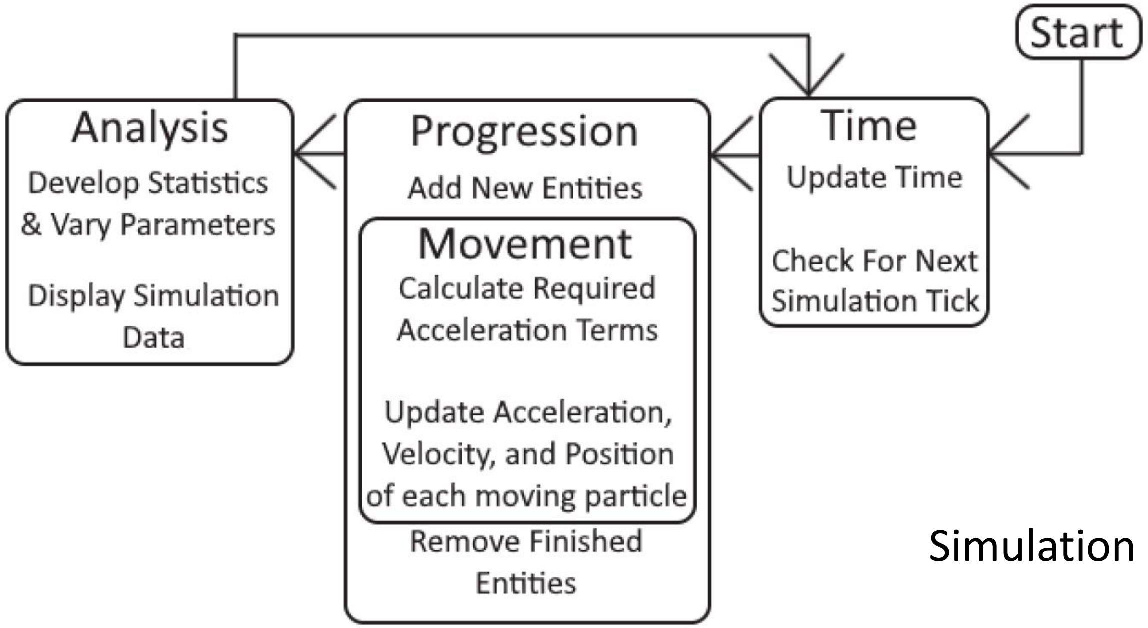
Simulator

- We created a reimplementation of the UMANS (Unified Microscopic Agent Navigation Simulator)
  - Discretised SPHCM/ABM approach (van Toll 2020)



Simulation loop

Simulator

- The method of movement involves accumulating each particle's acceleration, which combines the immediate influence of all chosen social, instinctive and physical behaviours
- The components of this acceleration are delegated to the following techniques
  - **SPHCM** improves crowd-based flow and enables variable pedestrian crowd acclimation
  - **Contact Forces** enforces personal collisions between closely-neighbouring people and avoids obstacle penetration
  - **Navigation Policy** moves people towards their goal
- Calculation of new position (r) of pedestrian
  - Based on velocity and acceleration

$$a_i = minLength\left(a_{max} \cdot \frac{\hat{a}_i}{\|\hat{a}_i\|}, \hat{a}_i\right), \quad \hat{a}_i = a_i^{SPH} + a_i^{cf} + a_i^{goal}$$

$$v_i = minLength\left(s_{max} \cdot \frac{\hat{v}_i}{\|\hat{v}_i\|}, \hat{v}_i\right), \quad \hat{v}_i = v_i + \Delta t_{fine} \cdot a_i$$

$$r_i = r_i + \Delta t_{fine} \cdot v_i$$

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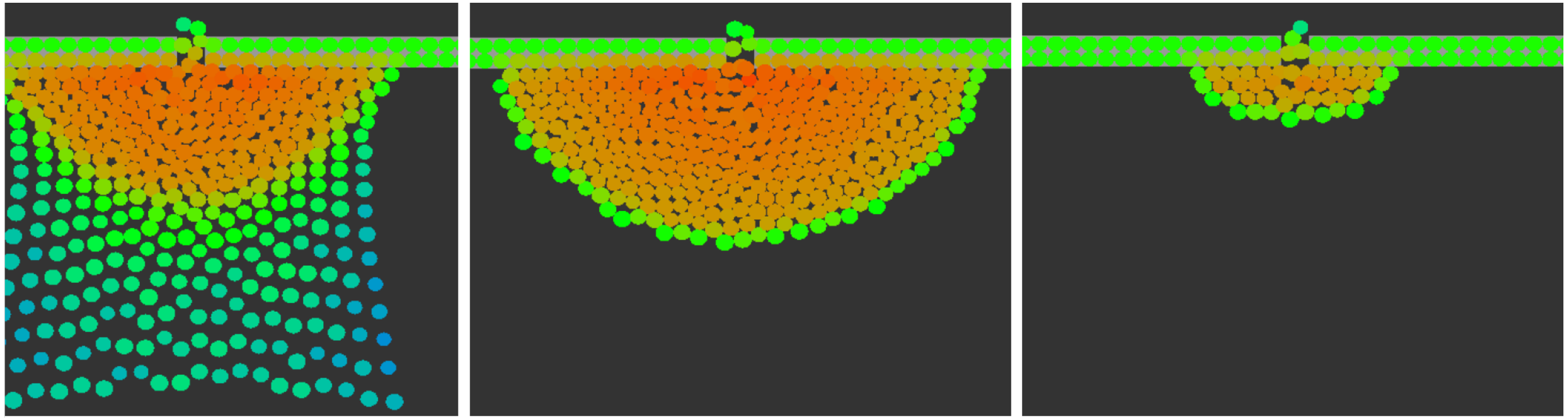
Base Case (1/2)

- Scenario
  - Pedestrians spread across a uniform grid within a 20x20m square room
  - An 80cm wide doorway which is 1m deep is across the room



C++ source code available from https://github.com/RAllcock/CrowdHealthSimulation

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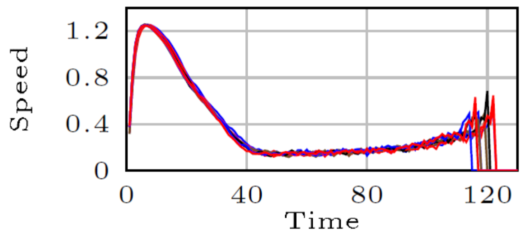
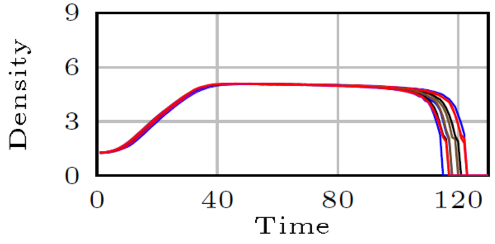
Base Case (2/2)

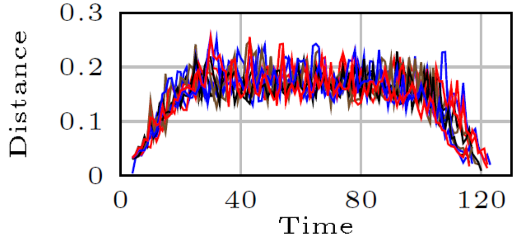
- Outcome



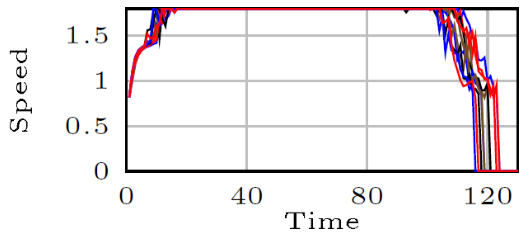
Avg. pedestrian speed



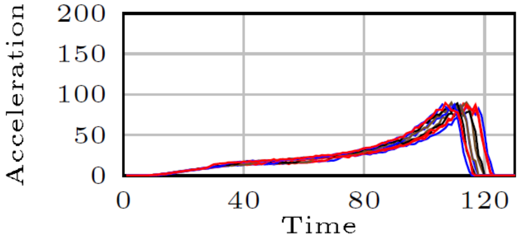
Avg. pedestrian density



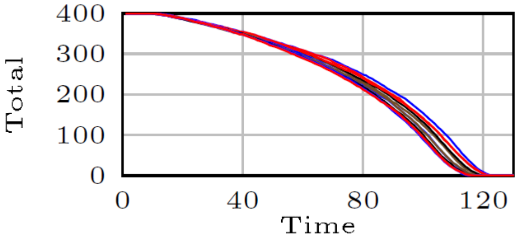
Max. wall penetration



Max. pedestrian speed



Avg. contact acceleration



Pedestrians remaining

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Exploratory Experimentation

Investigations on how changes in certain parameters influence crowd health

- Maximum rest density experiment
  - What it is: Each pedestrian's maximum accepted crowd density before spreading out
  - Setup: Raising maximum rest density (3 to 7 between 40s and 60s)
  - Expectation: Hazardous congestion adjustment
  - Results: Rest density quickly overpowers contact forces

- SPHCM gas constant experiment
  - What it is: Property of particles considered in SPHCM (strength of the SPHCM forces)
  - Setup: Nullifying SPHCM effect (200 to 0 at 40s to 60s)
  - Expectation: Disorder
  - Result: SPHCM prevents violent crowd compressions

Exploratory Experimentation

Investigations on how changes in certain parameters influence crowd health

- Preferred speed experiment
  - What it is: Speed pedestrians try to achieve moving towards the goal
  - Setup: Raising preferred speed (1 to 1.8 at 40s to 60s)
  - Expectation: Larger reactive pushing forces
  - Result: Preferred speed affects the perceived simulation speed

- Goal force strength experiment
  - What it is: Proportional force applied to get to the preferred speed
  - Setup: Raising force towards goal (0.5 to 2.5 at 40s to 60s)
  - Expectation: Drive to escape
  - Result: High goal forces cause otherwise stable pedestrians to oscillate

Answer to the research questions

- RQ1: Is crowd health currently a suitable application of crowd simulation?
  - Considering the complexity of emergent crowd behaviour, originating from the unpredictability of human nature and complex physical interaction, current simulators can begin to properly represent true human crowds by avoiding purely visual success criteria
  - This allows safety-centric data to be obtained from scenarios, especially with more access to real-world data

Answer to the research questions

- RQ2: Is SPHCM effective for simulating crowd health?
  - SPHCM successfully allows nearby pedestrians to smoothly remain apart in crowds, whilst introducing an intuitive density component for affecting perception during panic
  - Other modules can be used to deal with direct pedestrian contacts and behaviours, to achieve more complex and simulation-stable behaviour found in real crowds

Answer to the research questions

- RQ3: What are the suitable metrics involved in measuring, influencing, and ensuring the validity of health in simulated crowds?

  - Measuring: Contact force upon an individual was found to be the most compelling measurement of crush for each person

  - Influencing: For influencing people, affecting desired speed appeared to positively imitate a more panicked behaviour, owing to the resultant rise in erratic forces in the crowd, whilst minimising instability in the force model

  - Ensuring validity: To ensure validity the crowd was observed, both visually and statistically, for anomalies like jittering, unrealistic, or excessive motion. Data outputs, including wall penetration distance, were used to tweak the base case and scenario

Future work

- Full implementation of UMANS
- More scenarios
- Consideration of hybrid SFM/SPHCM approach
- Crowd safety classification, based on "crowd health" indicators

Any Questions?

References

- W. van Toll et al. "Extreme-Density Crowd Simulation: Combining Agents with Smoothed Particle Hydrodynamics". In: MIG ’20: Motion, Interaction and Games. 11. 2020, pp. 1–10. doi: https://doi.org/10.1145/3424636.3426896.
- D. Helbing, I. Farkas, and T. Vicsek. "Simulating dynamical features of escape panic". In: Nature 407 (2000), pp. 487–490. doi: https://doi.org/10.1038/35035023.