Crowd Evacuations: Potentials in modeling and beyond:

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[21],[12],[25], [7], and [5]

- National Institute Disability Research and Rehabilitation (NIDRR)
  - Very little consideration of disabilities in building evacuation plans or built environment
  - Existing modeling of disability results in just a bulk model, slowing the person down
  - Evacuation plans do not include disabilities, or have unused or unknown refuge areas
Motivation II

- No detailed data on social/behavioural interactions of Individuals with Disabilities (IWDs) in crowds, non-IWD behavior, and no evacuation outside of Mass Evacuation Time (MET).
- One basic model includes disabilities in a preliminary stage. No empirical data to use as of yet.
- IwDs cause unknown issues to crowd evacuation
- IwDs: Motor Wheelchair, Manual Wheelchair, Stamina, Visual, Hearing (Outside of Home)
Motivation III

- Faster-is-slower effect:
  - Individual desire to evacuate faster, against the limited exiting capacity of passages

- Heterogeneity even in IDs. Cause more significant influence on crowd evacuation?
  - Wheelchair (Spatial and Speed)
  - Visual (Speed)
  - Stamina (Spatial and Speed)
Is it Fractional? I

[1],[17], [11], and [23]

- Of course it is! But how and in what parts?
- Fractal time series and power laws found and observed in traffic systems
- While most social crowds are complex, humans are by far the most.
- Actions dependent not just on their immediate surroundings, but memory, experience, and long term goals.
- Its complex and therefore FOC, but by how much? In what manners? What are the actual differences and impacts?
- Black Swan: The high impact of 'rare' events.
The many scales of computation I

[16], [25], [13], [4], [25], [2], and [2]

- **Microscopic Model**
  - Newtonian Dynamics
  - Agent-based
  - Individual social behavior (Social Force)
  - Cellular Automaton
  - Computationally complex, slow, individual trajectories/velocities

- **Macroscopic Model**
  - Fluid/Gas theory, Semi-compressible fluid, Identical, orientation-based individuals
The many scales of computation II

- No stress or social behavior induced, homogenous, faster computation.
- Speed/Density, Speed/Flow, and Flow/Density

- Meso-scopic Model
  - Gas-Kinetic Models, Multi-scale Models
  - Some heterogeneity, yet still saves on computation
[26], [14], and [17]

- **Kinetic Model**
  - Large particle system
  - No particle interaction, based on field interaction of collective group
  - Density and flow based on crowd

- **Various models of interaction for the fields**
  - Environmental interaction model
  - Localized interaction model
  - Long range interaction model (F.O long range interactions and memory here?)
Collective behavior can be shown using Boltzmann-like equations for gas.

Heterogeneity can be induced by creating various probability density functions.

Allows for macroscopic-like computational approaches while still leaving in 'some' ability to describe heterogeneity.

Computational complexity can grow high if too many interactions are considered.

Kinetic theory uses ODE/PDE frameworks that are integer order, thus changing to fractional order is possible. What does this provide?
Still a disadvantage, as interactions have to be complex to represent heterogeneity properly, yet still little difference amongst each type, without heavy rules.
Mean Field Games I

[19] and [8]

- Mean Field theory takes a governing set of interaction fields for a given type in the heterogeneous set and creates a 'mean-field' instead.

- Mean Field Games (MFG) is then the combination of this approach with goals set forth in game theory. i.e Nash Equilibrium, fitness, health, etc.

- There is a goal to optimize position in space/time, but the preference is partially driven by the choices and interactions of other agents.
Typically derived as a coupled system of forward and backward equations

- **Fokker-Planck (F-P):** Forward time describing the density change function $M$ of the agents in the system.
- **Hamilton-Jacobi-Bellman (H-J-B):** Backward time describing the desired optimal paths for each agent.
Mean Field Games III

- (HJB) Equations
  - Goal of agent to minimize some $u(t, x(t))$, where $x(t)$ is the desired location to be at. Also with some transportation cost $C(\nu)$.
  - The agents steering ability has some fluctuation added in the form of Brownian Motion. Desired position may be $x_0 + vdt$ at $dt$, but instead goes to $x_0 + vdt + \sigma dB_t$. (Fractional Brownian Motion?)
The resultant cost function is the expectation:

\[ u(t_0, x_0) = E(u(t_0 + dt, x_0 + vdt + \sigma dB_t) + C(v)dt); \]

- Ito’s Formula leads to a H-J-B version.
- Considered a nonlinear backwards heat equation, solving cost backwards in time. Inserts uncertainty into future costs.
Mean Field Games V

- (F-P) equations
  - Consider group of agents as whole, i.e. continuum limit.
  - Normalized density function $M(t, x)$, with velocity field $v$, and initial distribution $M(0, x)$.
  - Describe how distribution evolves through time.
  - Give a test function to test density as function in space. The distribution of density over the test function can be,
    \[ \frac{1}{N} \sum_{i=1}^{N} F(x_i(t)), \]
    where $x_i(t)$ is agent $i$ at time $t$.
  - Expanding as with (H-J-B) and adding Brownian noise again.
    \[ \int M(t+dt, x)F(x)dx \approx \frac{1}{N} \sum_{i=1}^{N} F(x_i(t)+v(t, x_i(t)))dt + \sigma dB_t \]
  - Through the advection equation and some work, the Fokker-Planck Equation is achieved.
In MFG, the H-J-B cost function also has dependence on $M$ for the other agents.

So a transport cost may also factor in not only the velocity, but also the density function $M(t, x)$ for that point space/time.

Thus agents prefer to be away from other agents, a repulsive field effect.

H-J-B, where I want to be. F-P, where we all end up.

Non-trivial to solve, does not include heterogeneity of different types on its own.

The Mexican wave phenomenon, stadium size to allow for a wave is correctly predicted using MFG.
Where do IWDs fit in this mix. They could be represented as moving spatial-temporal obstacles to a gas kinetic or heat advection pde. May also work in larger macroscopic models. If we can successfully argue that they have larger heterogeneic impact to crowd evacuations over the differences in general.
Figure: Spatial/Temporal obstacle with Lattice Gas Diffusion
[7], [6], and [20]

- Bottom-Up Modeling of Mass Pedestrian flows- implications for the Effective Egress of individuals with disabilities.
- Created as a micro-simulation software system based around Cellular Automaton, by the USU Center for Persons with Disabilities (CPD).
- One of the first models to represent IWDs as separate types instead of one bulk type.
- Has options for determined built environments, reenforced learning, and tuning of spatial/temporal characteristics of each group.
Currently no empirical model information outside of MET for IWD crowd evacuation.

Current settings based on, best guess and reasonable proportionality.
Figure: BUMMPEE Software
Each cell has value based on distance to a particular exit and for a particular or 6 IWD types and 1 Non-IWD type. The layout of cells distances to exits determine a Static Floor Field.

There is a separate Static Floor Field for every exit for each type. Very computationally expensive.
Figure: Static Floor Field
BUMMPEE III

- Randomly placed agents run Greedy algorithms to get to exits, first eliminating obstacles, then choosing best 'cell' direction (N,S,E,W) for their particular type. i.e. Wheelchairs can’t go down stairs, etc.

- Agents take up different amount of square cells. 3x3 versus 5x5, at different maximum speeds per type.

- Social force models come into play if only available destination is occupied. Each occupied cell choice is given a permeability or harness factor. i.e how tight can I pack in with that other individual.
There is also a separate friction factor for how fast I can move to an occupied cell, or the agent viscosity.

Elements of injected randomness:

- At each time $T$, after the decision of which cell direction to enter is made, there is a bounded randomly chosen 'time to transport', of wait time before the agent will move. That is, an element of decision making or velocity change for each agent. (CTRW-like). Possible point to replace normal distributions of random with F.O distributions?
- When agents must choose destinations of occupation. The value of 'hardness' is set within a bounded random normal distribution. As maybe one persons density is easier to occupy a cell with over another. Another point of F.O change?
Finally, the time of friction, or viscosity is also randomly given within a bound for the extra added time of transport to represent the velocity encountered when pushing into occupied space. A final place of F.O change?

Initial start positions are also randomized over a normal distribution, excluding obstacles, walls, and occupied space.
Vision Tracking I

[27], [10], [15], and [3]

- Macroscopic level crowd tracking employs the use of optical flow or the herd. FOOF?
- Smaller individual tracking of people still requires optical flow, but requires the recognition of individuals for more detailed velocity field information.
- Recognition requires some form of histogram or segmentation, very difficult.
- Recognition of IWDs in the crowd has not been accomplished. Initial steps of recognizing people on bikes employed already in vehicle systems (Mercedes, BMW, etc)
Vision Tracking II

- Can F.O help here?

Figure: Optical Flow tracking and Segmentation Recognition
Utilize MAS-net work for PDE optimal sensor/actuator placement and boundary control.

Networked Segway Supported Responders (NSSRs).
Evacuation Control II

Figure: NSSR/CPS Crowd Control
Evacuation Control III

- Start with putting control ability into BUMMPEE. Definite issues with real-time prediction due to computation of micro-simulation. Implement MFG along side simulation, for 'real-time' prediction and understanding. F.O control aspects here too?

- Contingency Plans, inclusion of IWDs in plans, each type has needs that one plan may not support. There is a need for adaptive execution of exit egress desires based on crowd composition.
- AFC in Crowd Modeling Simulations
- Explorations of effects of FOC in BUMMPEE
- Study of FOC appearances validations from empirical data
- Both applications of control and FO Control for crowd evacuations impacts, in simulation? Physical?
- Applications of Distributed Order to heterogeneity issues for crowds with IWDs
- Applications of Computer Vision Recognition for IWDs. (Segmentation, Optical Flow, FOOF, etc)
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