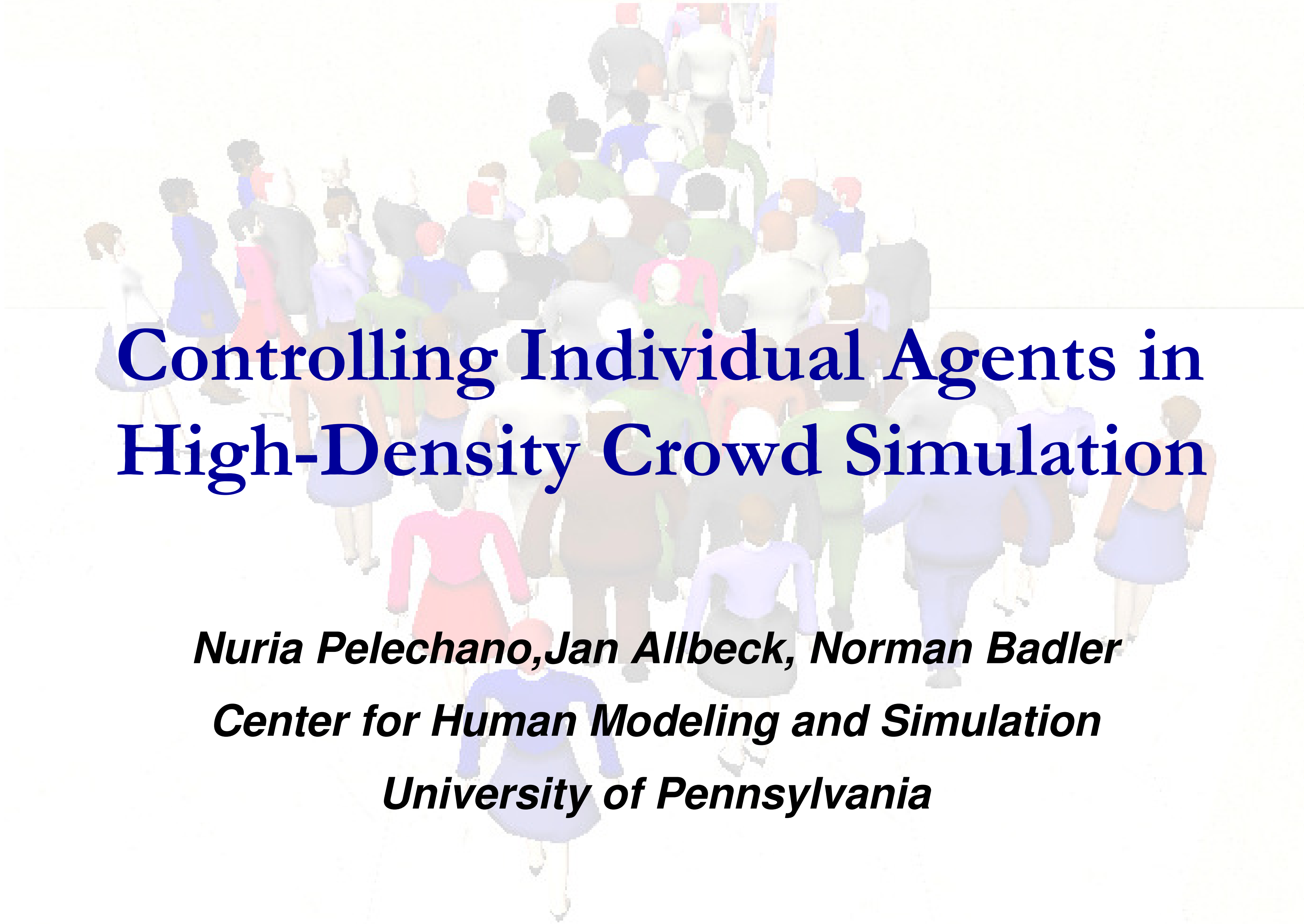

Controlling Individual Agents in High-Density Crowd Simulation

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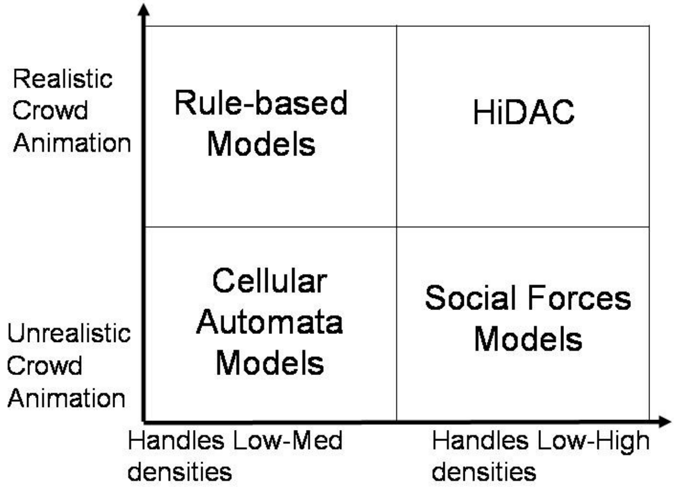
Introduction: Challenge of simulating high density crowds.

Problems in current approaches:

- **Rule Based**: lack collision response or stopping to avoid overlapping.
- **Social Forces**: continuous vibration problem.
- **Cellular Automata**: checkerboard.

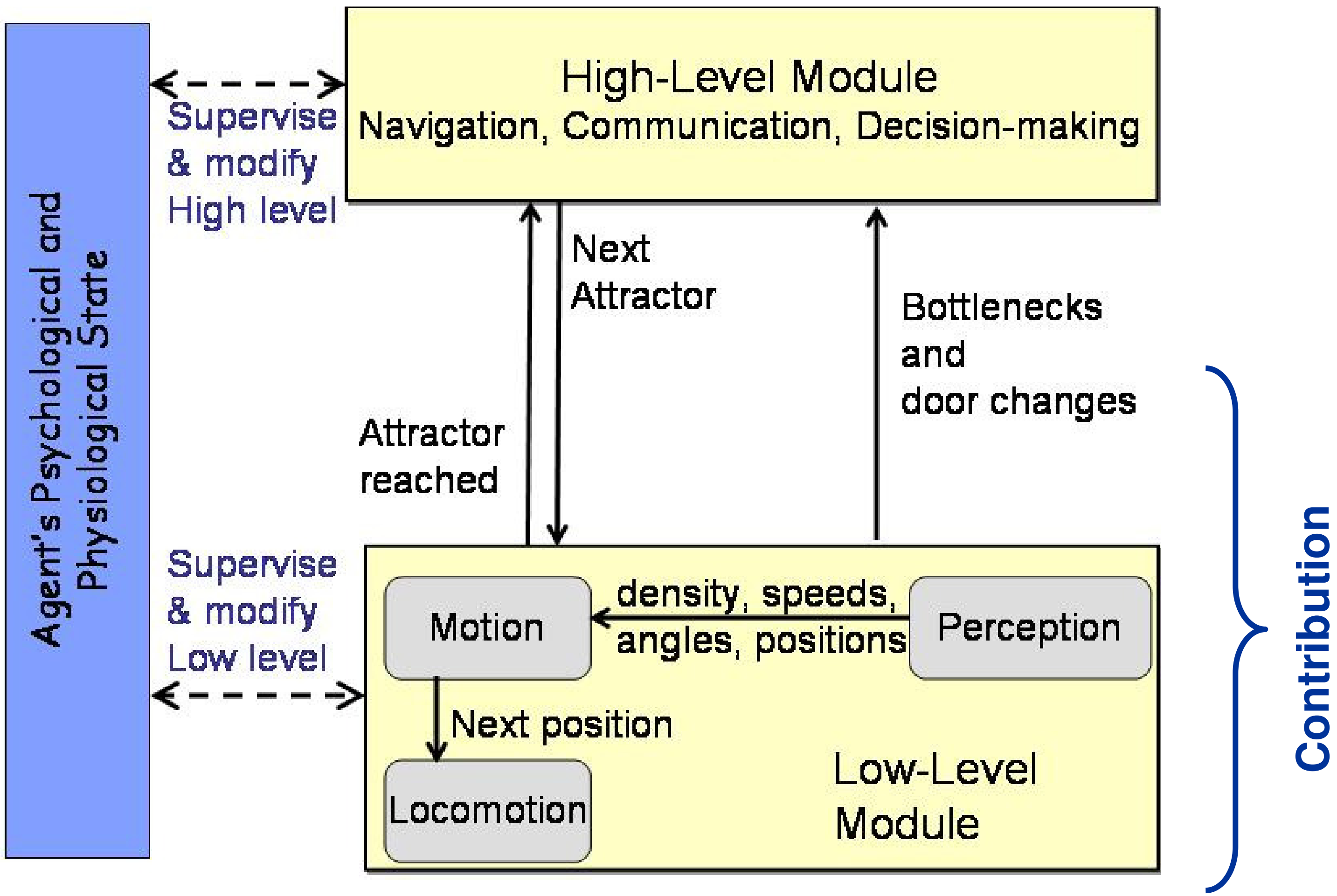


- **HiDAC** (High-Density Autonomous Crowds) Combines geometrical and psychological rules with a social forces model. Exhibits a wide variety of emergent behaviors relative to the current situation, personalities of the individuals and perceived social density.

Related Work

- Helbing: social forces models (2000).
- Brogan et. al.: particle systems with dynamics (1997)
- Braun et. al.: social forces+individualism (2003)
- Lakoba et. al.: extended Helbing's model. No real time (2005)
- Treullie et. al.: continuum crowds (2006)
- Reynolds: rule based models (1987,1999)
- Shao and Terzopoulos: cognitive models with rules (2005)
- Chenney: Flow tiles (2004)
- Tecchia et. al. Cellular automata model (2001)

Architecture Overview



Low-level: Local motion

- HiDAC uses psychological attributes (panic, impatience) and geometrical rules (distance, areas of influence, relative angles) to eliminate unrealistic artifacts and to allow new behaviors:
  - Preventing agents from appearing to vibrate
  - Creating natural bi-directional flow rates
  - Queuing and other organized behavior
  - Pushing through a crowd
  - Agents falling and becoming obstacles
  - Propagating panic
  - Exhibiting impatience
  - Reacting in real time to changes in the environment

The HiDAC model

- Direction of movement:

$$\mathbf{F}_i^{To}[n] = \mathbf{F}_i^{To}[n-1] + \mathbf{F}_i^{At}[n]w_i^{At} + \sum_{w}\mathbf{F}_{wi}^{Wa}[n]w_i^{Wa} + \sum_{k}\mathbf{F}_{ki}^{Ob}[n]w_i^{Ob} + \sum_{j(\neq i)}\mathbf{F}_{ji}^{Ot}[n]w_i^{Ot}$$

Current direction | Attractor | Walls | Obstacles | Other Agents

- Desired new position:

Shakiness & Queuing

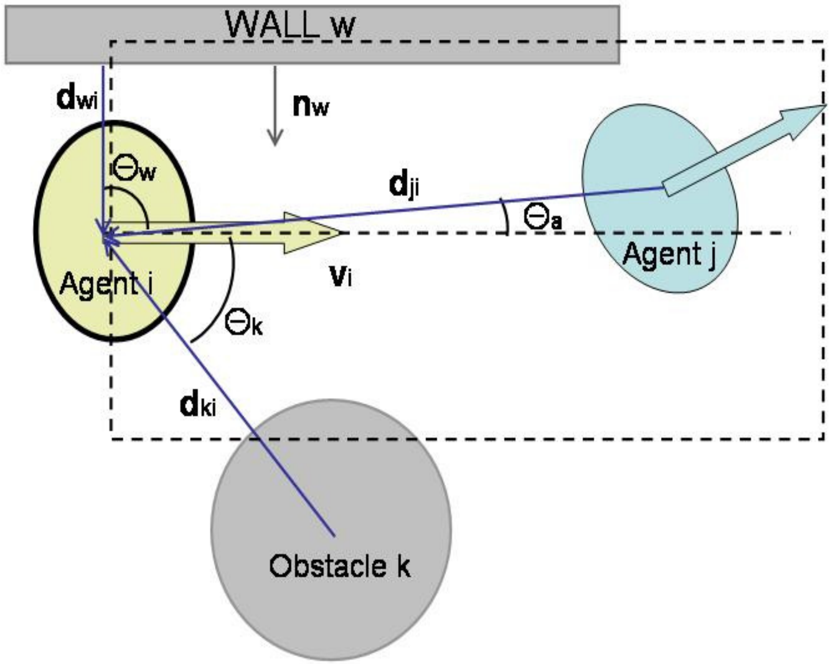
Fallen agents: Priority, Avoidance

$$\mathbf{p}_i[n+1] = \mathbf{p}_i[n] + \alpha_i[n]v_i[n]\left(\left(1-\beta_i[n]\right)\mathbf{f}_i^{To}[n] + \beta_i[n]\mathbf{F}_i^{Fa}[n]\right)T + \mathbf{r}_i[n]$$

Previous position | Velocity | Normalized direction of movement | Repulsion

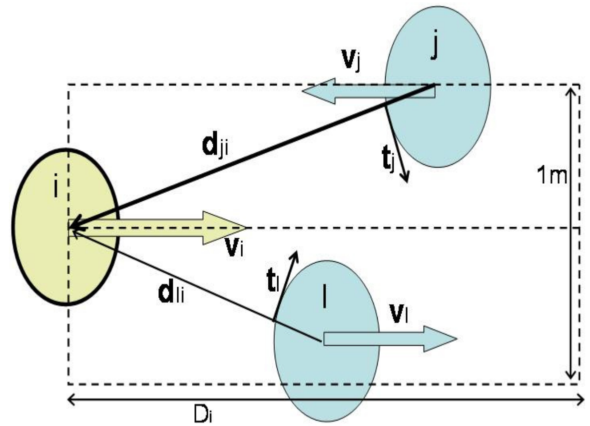
Avoidance forces (I)

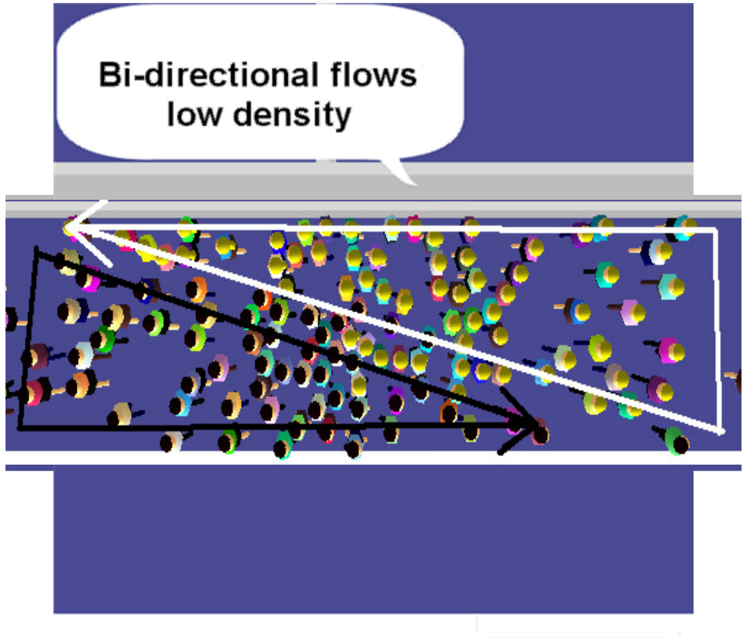
- Distance (d_{ji}) and angle (θ_j) establishes the relevance of the obstacle in the agent's trajectory.
- Agents update their perceived density as they navigate



Avoidance forces (II) Other agents

- Overtaking and bi-directional flow
- Avoidance forces for other agents affected by:
  - Distance to obstacles.
  - Direction of other agents relative to agent *i*'s direction of movement.
  - Density of the crowd.
  - Right preference.





Avoidance force: $\mathbf{F}_{ji}^{Ot} = \mathbf{t}_j w_i^d w_i^o$

w_i^d Increases as the distance between agents becomes smaller

w_i^o Depends on relative orientation

Repulsion forces

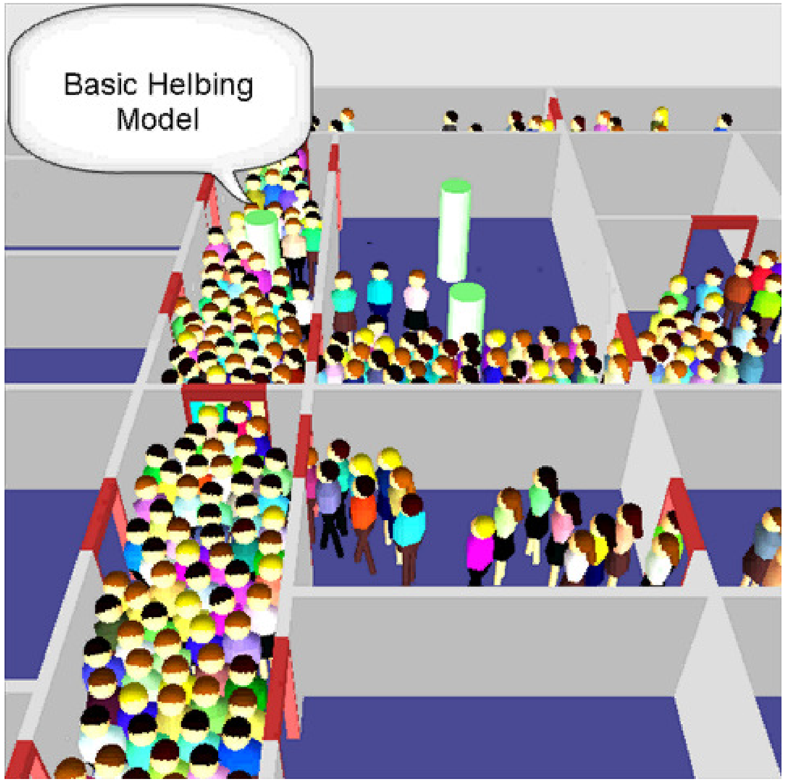
- When overlapping occurs, repulsion forces are calculated

$$\mathbf{r}_i[n] = \sum_w \mathbf{F}_{wi}^{R\_Wa}[n] + \sum_k \mathbf{F}_{ki}^{R\_Ob}[n] + \lambda \sum_{j(\neq i)} \mathbf{F}_{ji}^{R\_Ot}[n]$$

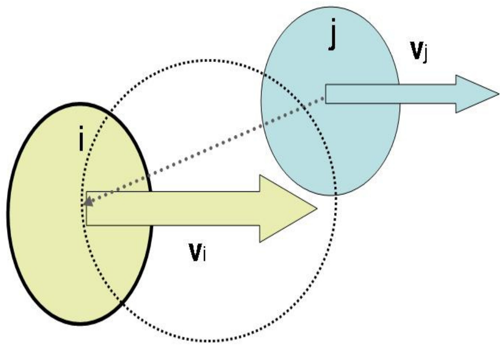
- λ is used to set priorities between agents (that can be pushed) and walls or obstacles (that cannot be pushed away)

Solution to "shaking" problem

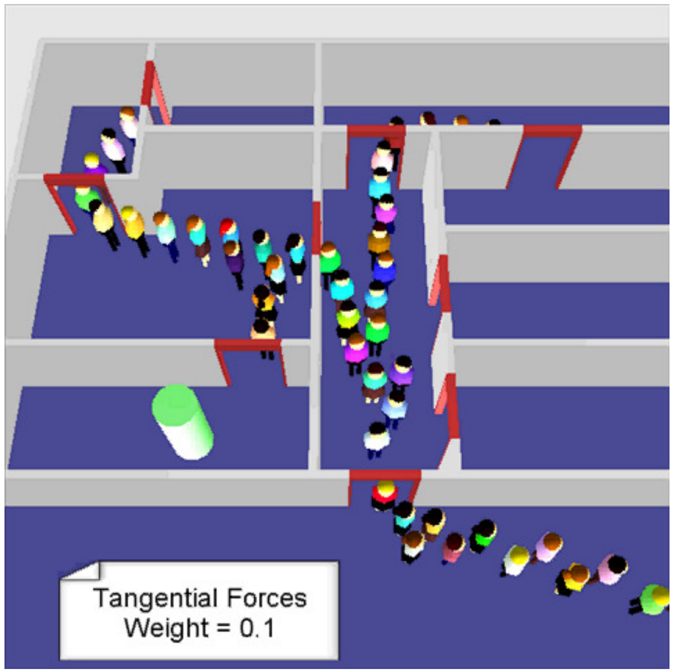
- When repulsion forces from other agents appear against the agent's desired direction of movement, and the agent is not in panic state, then the stopping rule applies:
- If $\left(\left(\mathbf{v}_j \cdot \mathbf{F}_i^{R-Ot}[n]\right) < 0\right) \wedge (\neg panic)$ then
  StoppingRule=TRUE
- If *StoppingRule=TRUE* then the agent will not attempt to move, but it could still be pushed by others



Queuing



- No panic : people respect lines and wait
- Influence disks drive waiting behavior.

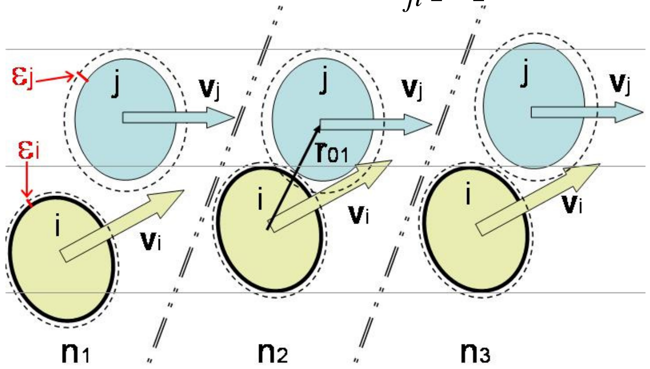


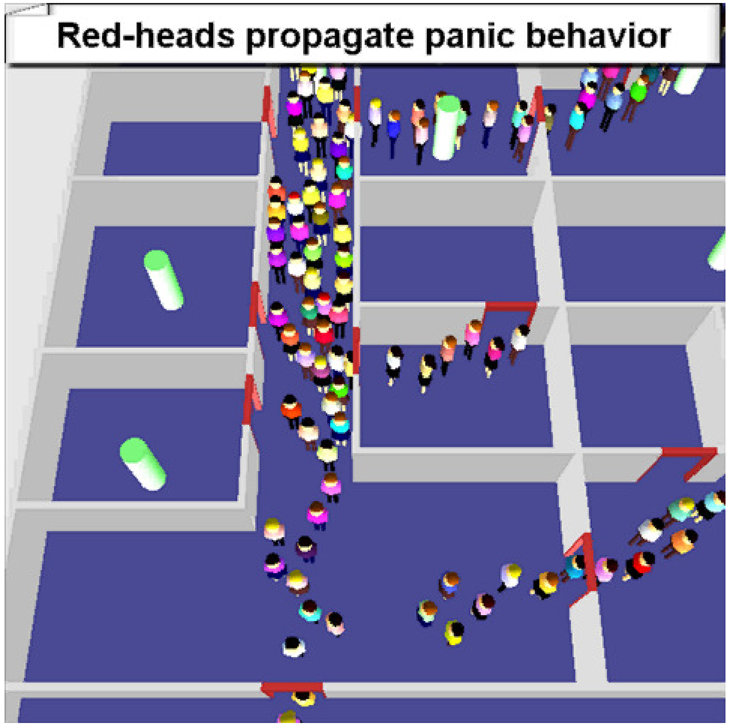
- The radius of the influence disks depend on personality and type of behavior desired (panic vs. normal)
- The strength of the tangential forces leads to different queue widths, and is specified by the user (min,med,max)

Pushing

- Pushing achieved through collision response and different personal space thresholds (ε)

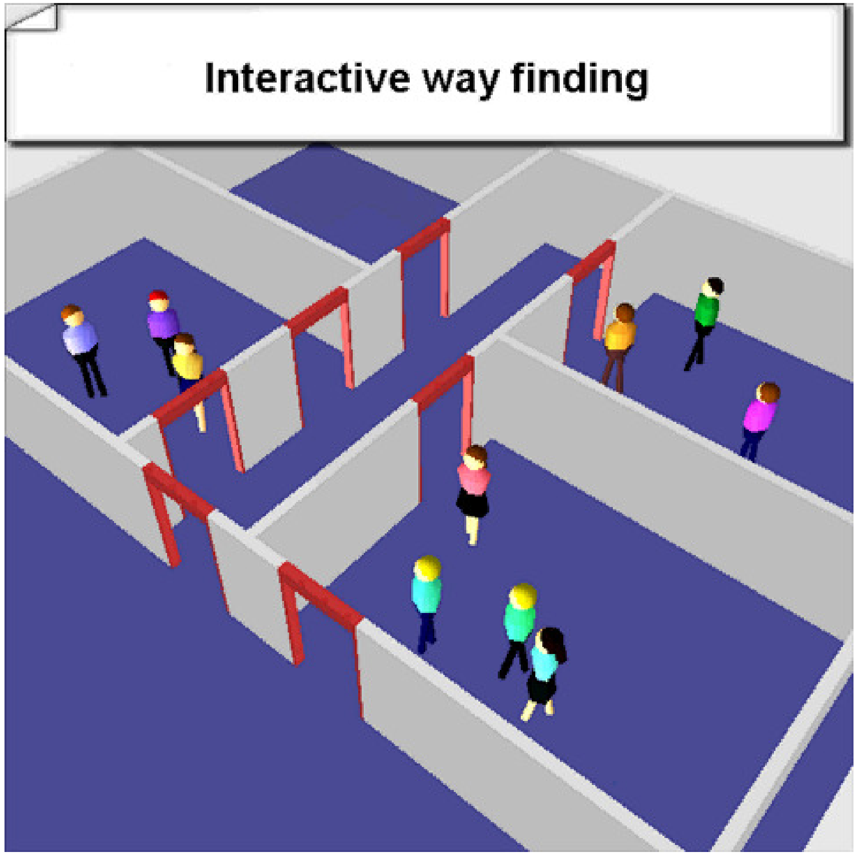
$$\mathbf{F}_{ji}^{R\_Ot}[n] = \frac{(\mathbf{p}_i[n] - \mathbf{p}_j[n])(r_i + \varepsilon_i + r_j - d_{ji}[n])}{d_{ji}[n]}$$





- Panic can be propagated through the crowd by deactivating waiting behavior and modifying pushing thresholds.
- Pushing can also make some agents fall and become new obstacles, which will be avoided but will not apply response.

Avoiding bottlenecks and interactive changes in the environment



- Agents can interactively react to doors being locked/unlocked. If an alternative route is known they will follow it, otherwise they can explore the environment searching for alternatives.
- Likewise impatient agents can react to a bottleneck by modifying their route if an alternative route is known.

Results

Goal	*Method*
Fast perception of environment	Influence rectangles, distances, angles and directions of movement are used to prioritize obstacles.
Eliminate shaking behavior	Apply stopping rules to forces model.
Natural bi-directional flow	Variable length influence rectangles and different 'right' preferences.
Queuing behavior	Influence discs triggering waiting behavior based on agents' direction.
Pushing behavior	Collision response based on variable 'personal space thresholds'.
Falling agents becoming new obstacles	Apply tangential forces for obstacle avoidance but not repulsion forces.
Panic propagation	Modify agent behavior based on personality and perception of other agents' level of panic.
Crowd impatience	Dynamically modifying route selection based on environmental changes.

Conclusions

- HiDAC can be tuned to simulate different types of crowds (from fire evacuation to normal conditions)
- Heterogeneous crowd where different behaviors can be exhibited simultaneously
- Unlike CA and rule-based models, HiDAC can simulate an individual pushing its way through a crowd.
- Unlike social forces models, our agents can exhibit more respectful queuing behavior.
- Shakiness avoidance achieved without increasing computational time, and impatience avoids sheep-like behavior observed in many crowd simulation models.
- Real time simulation achieved for up to 600 agents (with crayon figures) and 1800 (2D rendering)

Conclusions

Questions?

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- URLs:
  - HMS Center:

    http://hms.upenn.edu

    HiDAC videos:

    http://hms.upenn.edu/people/pelechano