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

- 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)
- Tecchia et. al. Cellular automata model (2001)
Architecture Overview

High-Level Module
Navigation, Communication, Decision-making

Next Attractor

Bottlenecks and door changes

Attractor reached

Supervise & modify Low level

Motion

Next position
density, speeds, angles, positions

Perception

Low-Level Module

Agent’s Psychological and Physiological State

Supervise & modify High level

Contribution
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:

\[
F_{i}^{To}[n] = F_{i}^{To}[n-1] + F_{i}^{At}[n]w_{i}^{At} + \sum_{w} F_{wi}^{Wa}[n]w_{i}^{Wa} + \sum_{k} F_{ki}^{Ob}[n]w_{i}^{Ob} + \sum_{j(\neq i)} F_{ji}^{Ot}[n]w_{i}^{Ot}
\]

- Desired new position:

\[
p_{i}[n+1] = p_{i}[n] + a_{i}[n]v_{i}[n] \left((1 - \beta_{i}[n])f_{i}^{To}[n] + \beta_{i}[n]F_{i}^{Fa}[n]\right)T + r_{i}[n]
\]
Avoidance forces (I)

- Distance ($d_{ji}$) and angle ($\theta_j$) establish 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:

$$ F_{ji}^{Ot} = t_j w_i^d w_i^o $$

- $w_i^d$ Increases as the distance between agents becomes smaller
- $w_i^o$ Depends on relative orientation
Repulsion forces

- When overlapping occurs, repulsion forces are calculated

\[
\mathbf{r}_i[n] = \sum_w \mathbf{F}^R_{wi} \cdot \mathbf{Wd}[n] + \sum_k \mathbf{F}^R_{ki} \cdot \mathbf{Ob}[n] + \lambda \sum_{j(\neq i)} \mathbf{F}^R_{ji} \cdot \mathbf{Ot}[n]
\]

- \(\lambda\) 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 \( (v_j \cdot F^R_i - O_t[n]) < 0 \) \( \land \) \( \neg panic \) 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 ($\varepsilon$)
  \[
  F_{ji}^{R \rightarrow O_t}[n] = \frac{(p_i[n] - p_j[n])(r_i + \varepsilon_i + r_j - d_{ji}[n])}{d_{ji}[n]}
  \]

- 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

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

Welcome to SCA07

people waiting to go through the door.
Questions?

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URLs:

- HMS Center:  
  http://hms.upenn.edu
  HiDAC videos:  
  http://hms.upenn.edu/people/pelechano