SURVEY OF AGENT-BASED PEDESTRIAN CROWD SIMULATION MODELS

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CROWD SIMULATION - OVERVIEW

- What is it?
  - Crowd simulation is the process of simulating the movement of a large number of entities or characters

- Why do we need it?
  - Simulation helps in understanding human behavioral pattern
  - Gives an insight to certain situations via simulation before practical implementation
MAJOR CATEGORIES IN CROWD SIMULATION

A general classification would be as follows:

- Motion based simulations
- Psychology or Social theory based simulations
- AI based simulations
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Motion Based Simulations

- Emphasis in the simulation is more on the motion of the entities
- Motion is usually inspired from certain biological phenomenon
- Practical applications for these simulations are not only in human movement study but also in traffic, or multi-robot movement
**Reciprocal n-body Collision Avoidance**

- Motion based simulation inspired by robot navigation algorithms
- Main emphasis is on collision avoidance between the participating entities
- Capable with dealing collision between n number of entities simultaneously
ALGORITHM AND THE GENERAL IDEA

$ORCA_{A|B}^\tau = \{ v \mid (v - (v_A^{opt} + \frac{1}{2}u)) \cdot n \geq 0 \}.$

ORCA defines the collision avoidance velocity for agent A w.r.t. agent B over a time window of $\tau$.

$u$: smallest change required in relative velocity of A and B to avoid collision in time $\tau$. 
SIMULATION SNAPSHOT -I

Snapshot of 1000 agents moving through the center of the circle to the antipodal positions
Simulation snapshot - II

Snapshot of 1000 agents evacuating an office
Simulation Results

Performance Scaling - Office Demo

Running Time vs. Num. Agents (8 Cores)
SUMMARY

- The algorithm is mathematically sound and effectively avoids collision.
- It does not however take into account the intricacies of human movement to be implemented as pedestrian collision.
- The algorithm runs in O(n) time and the simulation result show close to linear scaling. (?)
COLLISION AVOIDANCE FOR VIRTUAL HUMANS

- Extends the n-body collision avoidance scheme for virtual human agents
- Main emphasis is on collision avoidance between virtual humans
ALGORITHM AND GENERAL IDEA

Algorithm 1: The RCAP Algorithm

Input: Agent $A$, List of neighbors $\mathcal{B}$
Output: $v_{new}$ - A new velocity for $A$

1. $ORCA^T_A \leftarrow \emptyset$;
2. foreach $B \in \mathcal{B}$ do
3.  \begin{align*}
   & \text{if } T > T_{sight}^B + T_{obs} \text{ then} \\
   & ORCA^T_A \leftarrow ORCA^T_A \cap ORCA^T_{A|B}
\end{align*}
4. $v_{computed} \leftarrow \text{LinearProgramming}(v_{pref}, ORCA^T_A)$;
5. $v_{new} \leftarrow \text{ ClampVelocity}(v_{computed}, v_{old}, a_{\text{max}})$

- Idea of this algorithm is to generate a velocity that is permissible within the range of velocities available to agent $A$.
- The algorithm also takes into account the limited perception field of agent $A$ and models it as a time frame where they will see each other (agent $B$).
TERMINOLOGIES AND BASIC ELEMENTS

- Response and observation time: $T > T_{sight} + T_{obs}$
- Kinodynamic constraints
- Personal space

$$v_{new} = v_{old} + a_{\text{max}} \Delta T \frac{\Delta v}{\|\Delta v\|}$$

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**Simulation Snapshots**

Superimposing the path of virtual agents with the actual human path.

Simulation of the RCAP algorithm for the office evacuation simulation using 1000 agents.
SIMULATION RESULTS

Simulation results of the RCAP algorithm for a sample run
SUMMARY

- The RCAP algorithm overcomes the problem of the previous paper using many real life pedestrian constraints.
- Closely models real humans path as demonstrated in the experimental data.
- RCAP extends ORCA algorithm but adds no overhead cost.
PLEdEstrians – A Least-Effort Approach to Crowd Simulation

- Inspired by the human behavior of spending least effort (PLE)
- Navigates agents along short routes to the goal while simultaneously avoiding congestion
- Closely mimics human behavior while staying within the human constraint of movement
**MAJOR COMPONENTS**

- The GPC module computes the short term path for the agent with inputs from a final goal from the GS module.
- The VC module accepts this path and feeds to the actuator while also doing collision avoidance.
- The road map module is a graph that has each edge as the distance to travel and has an associated weight that is computed which is the average velocity.
- The GPC module calculates the trajectory based on the selected goal.
- The updated road map is a graph with a weighted edge that decided the effort needed and hence updates the effort function.
Simulation snapshot showing virtual agents in a long corridor and a narrow space using PLE algorithm
SIMULATION RESULTS

- The data obtained is compared with the data collected by Fruin at bus terminals and transit stations in various cities.
- Nelson and Maclennah in their paper defines a different equation for speed $S$ with varying constants as parameters.
SUMMARY

- Computation complexity is $O(N^*n)$ and the value of $n$ is bounded by total number of agents $N$. This is further reduced to $O(N\log N)$.
- Quantification of a bio-mechanically energy efficient trajectory algorithm that is closer to the real world simulation.
- Simulation results closely corresponds to the empirical data.
MAJOR CATEGORIES OF CROWD SIMULATION

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- Motion based simulations
- Psychology or Social theory based simulations
- AI based simulations
Psychology or Social Theory Based Simulations

- Agents behave on the basis of some psychological or social theory
- Emphasis is more on the human behavior of interaction rather than only movement
- A macroscopic study is usually made rather than an individualistic study of the agents
COGNITIVE MODEL OF CROWD BEHAVIOR BASED ON SOCIAL COMPARISON THEORY

- Based on Social Comparison Theory (SCT) [Festinger, 1954]
  - When lacking objective means for appraisal of their opinion and capabilities, people compare their opinions and capabilities to other who are similar to them.
ALGORITHM AND GENERAL IDEA

1. For each known agent \( x \) calculate similarity \( s(x) \)
2. \( c \leftarrow \text{argmax } s(x) \), such that \( S_{\text{min}} < s(c) < S_{\text{max}} \)
3. \( D \leftarrow \text{differences between me and agent } c \)
4. Apply actions to minimize differences in \( D \).

The similarity variable \( s(x) \) is denoted as the weighted sum of the features.

\[
s(x) = \sum_{i=0}^{k} w_i f_i
\]

The features proposed in the paper are color, walking direction and position.
TERMINOLOGY AND BASIC ELEMENTS

- The features suggested in the paper and their weights are as follows:
  - Color weight: 3
  - Walking Direction weight: 2
  - Position weight: 1
- A gain function is also implemented that defines the amount of power and energy devoted by the agent for action $o$.

$$g(o) = \frac{S_{max} - S_{min}}{S_{max} - s(c)}$$
**Simulation Snapshots**

A simulation showing the grouping of the agent in conformity to the Festinger rule.

Simulation snapshot showing agents walking across obstacles with lane formation and grouping phenomena.
SIMULATION RESULTS

![Graph 1: Lane Changes vs Density](image1)

![Graph 2: Flow vs Density](image2)
SUMMARY

- This model incorporates a common psychological phenomenon with their simulation.
- The simulation results agree well with the real world scenarios in most of the different experiments be it bi-directional movement, grouping or obstacle avoidance.
INTERACTIVE SIMULATION OF DYNAMIC CROWD BEHAVIORS USING GENERAL ADAPTATION SYNDROME THEORY

- Inspired by the psychological theory of stressors and its effect on humans
- Follows the General Adaptation Syndrome (GAS) proposed by Hans Selye
- 3 stages of the GAS model:
  - Alarm
  - Resistance
  - Exhaustion
**Algorithm and General Idea**

- Stress quantification
  - Given by Steven's psychological power law as $\psi(I)=kI^n$ where $I$ is the magnitude of the perceived stressor

Types of stressors considered:
- Time pressure
- Area stressor
- Positional stressor
- Interpersonal stressor

$\alpha = \text{Maximum rate of stress response}$

$\beta = \text{Maximum amount of stress response}$
INCORPORATING BEHAVIOR AND STRESS

- There are two parameters that has been associated with human behavior:
  - PC1-correlates to an increased level of “extraverted” or more “intense” behavior.
  - PC2-correlates with an increasing behavior.
- $B_{\text{stress}} = (PC1 \ PC2) \ast (0.95 - 0.3)^T$ stress behavior vector
- Incorporating stress with normal behavior
  
  $\text{SimParams} = S \ A_{pc} \ B_{\text{stress}} + A_{adj} \ P$
SIMULATION SNAPSHOT - I

Opposing group scenario
Simulation snapshot - II

Evacuation scenario in an office building
**Simulation Results**

The first result is that of traffic signal stressor. The second is accordance with the Yerkes-Dodson law that says stress and performance may match only to a certain time.
SUMMARY

- This model accounts for the behavioral change in people under certain stress which is closer to the real world scenario.
- This paper has a wide range of application domain like evacuation scenarios or likes of Shibuya crossing.
- Simulation results of real world simulation show match with empirically collected data.
MULTI-AGENT SIMULATION MODEL OF PEDESTRIAN CROWD BASED ON PSYCHOLOGICAL THEORIES

- Proposes such a model called the HuNAC (Human Nature of Autonomous Crowds)
- Psychological factors considered:
  - Psychophysical: Perception, movement
  - Psychosocial: Grouping, comparison with others

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ALGORITHM AND GENERAL IDEA

● The pedestrian agent is divided into 3 phases:
  1. **Strategic** - defines the global plan of the agent. Fixed in the beginning and remains unchanged.
  2. **Tactical** - represents decision taken by the agent to avoid people and obstacles
  3. **Operational** - determination of the direction and speed suited to reach chosen lane for the previous phase
**TERMINOLOGY AND BASIC ELEMENTS**

\[ S_{(P,L(i,l))} = \sum_i Normalisation(f(A_i)) \times W_i \times F_i \]

S refers to a score that drives the agents to choose a least effort, least change state

A\(_i\) is the attribute

W is the weight

F\(_i\) is -1 in case of penalty and +1 in case of a recompense.

P: pedestrian

L(i,l): indicates that the pedestrian is at the i\(^{th}\) lane.

**Attributes used are:**

Speed: Slowest speed of any agent in the given lane

Density: Equal to the number of pedestrians in the lane

Direction: Equal to the direction of the majority of the pedestrians in the lane
Formation of lanes in conformity of the psychological theories where a person always finds the most easier and comfortable route to its home.
Oscillation phenomenon
SIMULATION RESULTS
SUMMARY

- This paper attempts at incorporating many physical as well as psychological constraints into their simulation.
- The simulation graphs as well as the simulation snapshots have close similarity to empirically collected data and real life scenarios.
- This paper only considers the normal behavior of the pedestrian that may not be the case in a real world domain.
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Multi-agent Reinforcement Learning for Simulating Pedestrian Navigation

- **Main idea:** Pedestrians can use machine learning techniques to make their movement more efficient.
- Each agent’s state represented as a set of features:
  - Angle of velocity vector w.r.t. reference line
  - Distance to goal
  - Distance and angle to nearest neighbor
  - Distance and angle to nearest obstacle (wall)
- Uses a technique called **Vector Quantization Q-learning (VQQL)** to learn features.
  - Two variants proposed:
    - **Iterative VQQL (IT-VQQL):** Learns from scratch for every new setting (population size).
    - **Incremental VQQL (IN-VQQL):** Uses transfer learning to reuse ‘good’ actions from previous ‘similar’ cases.
SIMULATION RESULTS

- Agents placed within 0.4 m from center of a 60 X 100 rectangle that has a narrow aperture at center
  - Goal is to pass through aperture and reach other side
  - Up to 20 agents
  - Agents get penalized for crashing with other agents (a little) and walls (a lot); rewarded for reaching goal

- IT-VQQL learning proceeds slowly and gives lower success percentage than IN-VQQL

- Two macro-level experiments
  - Adapting speed of agents with perceived density: Both VQQL strategies successful; IN-VQQL does better
  - Adjusting flow with perceived density: Both VQQL strategies successful, but max flow is not reached

- Future work: Increase no. of agents to 40, 80; combine two VQQL strategies
CONCLUSIONS AND FUTURE DIRECTIONS

- Reactive systems are the state-of-the-art in pedestrian crowd simulation
  - Social laws mainly used to design reactive rules
  - Other approaches: robotic path planning, AI-based machine learning

- Issues:
  - How do pedestrians move in more complex environments with many obstacles?
  - What is the effect of attractors, sudden changes in environment on pedestrian movement?
  - What are the cognitive model(s) (other than reactive) that pedestrians use to move?
THANK YOU!
REFERENCES


- Stephen J. Guy, Ming Lin, and Dinesh Manocha, “Collision avoidance for Virtual Humans”, *AAMAS* 2010.


