Spatial conflicts resolution in pedestrians: a social choice theory approach

Chanattan Sok - ENS Rennes

Chanattan Sok
chanattan.sok@ens-rennes.fr

Supervised by Olivier Simonin

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INSA Lyon - Inria
France

Times Square: a great stress zone

Social Force Model (SFM)

Figure 1: Social Force Model for Pedestrian Dynamics - Helbing, Molnar (1998)

A little perspective

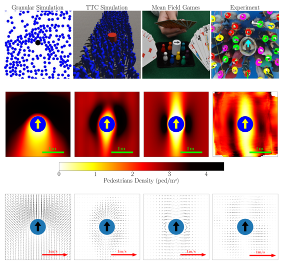


Figure 2: Physics model for crowd study with prediction (dynamics)

Pedestrians in static crowds are not grains, but game players (Bonnemain, Bonnet, Echeverria, Nicolas & al.)

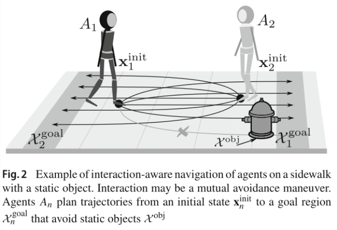


Figure 3: Realistic local motion planner (game-theory)

Human-Like Motion Planning Based on Game Theoretic Decision-Making (Turnward & Wollher)

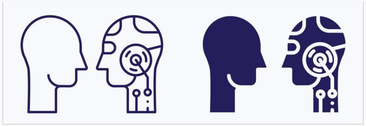
Our focus

Interest on spatial conflict resolution rather than realistic motion planner while having relevant pedestrian modelling

Pedestrians' motions in complex situation

Pedestrians, and not robots, in complex scenarios present conflicts...
How do we solve them *relevantly*?

Pedestrians $\neq$ robots $\implies$ **a different approach in modelling**



$\rightarrow$ Can we try to model and simulate pedestrians in such situations with a **cognition process** to solve spatial conflicts?

Pedestrians: an agent-based modelling

ABM: what are relevant traits to pedestrians?

- **position**: coordinates
- **speed**: a direction vector
- **motivation**: definition of the opposite of fatigue, the will of a pedestrian to adapt translated in motion
- **attention**: which agents does one consider?

Spatial conflicts

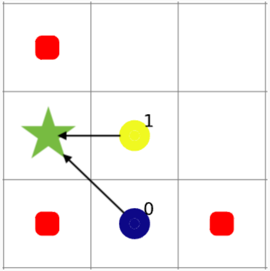
Choice: Everything discrete

- **Discrete motion**: 8 moves (Moore neighborhood)
- **Discrete time**: iterations as steps

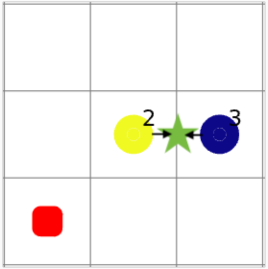
Definition: Spatial conflict

Given a grid and a time step t, a blocking situation happens between at least two agents where at $t+1$ one cannot move to an area because of the other.

Two cases of spatial conflicts



(a) case 1: virtual obstacle in a desired area



(b) case 2: inter-blocking situation

These conflicts (green stars) are complicated to handle in complex scenarios (obstacles and numerous agents)

→ relevant pedestrian simulation with a conflict solver

Objectives

Main objective

Proposal of a model (simulation and algorithm) with pedestrians solving spatial conflicts with an innovative approach.

Sub-objectives:

1. Integration with a physics model for realistic motion
2. Application in advanced simulations / real case scenarios
3. Exportation to robots?

Social choice: an innovative approach?

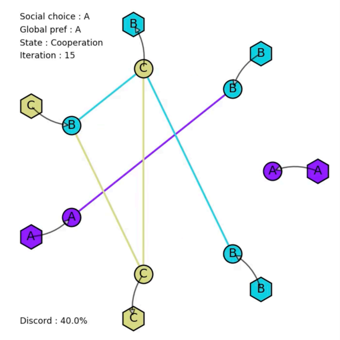


Figure 5: A social choice application: negotiations and vote between states among 3 choices

Social choice theory
Aggregation of diverse preferences to find a suitable compromise for each: maximize global welfare

→ *Application in economy (e.g., fair allocation), social sciences (e.g., political bargaining, vote), ...*

Social force model ⟷ Social choice

How do we take inspiration / make use of this for spatial conflicts?

Map

A map is a given setup with a fixed number of agents, a grid with obstacles and objectives.

An agent a_i has the following initial traits:

- a 2D **position** $\boxed{pos(a_i)}$ bounded by the grid's borders
- a **speed** generated at random $\boxed{0 \leq v(a_i) \leq 2}$ (TBR)
- a **motivation** generated at random $\boxed{0 \leq mot(a_i) \leq 1}$
- an **attention** generated at random $\boxed{0 \leq att(a_i) \leq 1}$ (TBR)

Motion: a_i has a **path** computed (A* now) at each iteration towards its objective.

NB: both motivation and attention may later evolve over time automatically. The motivation changes through negotiations otherwise.

Hypotheses and events

HYP. 1: Capacities

Agents have sufficient logical capacities to estimate the trajectory of another.

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Agents aim ultimately to reach their objective with no collision.

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Agents can adapt their trajectory with a certain tolerance to the profit of another.

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Collision event

During motion, agents anticipate conflict and communicate to avoid it together

$\rightarrow$ Self-interest cooperative game

How do we solve conflicts?

Inspiration from social choice theory

1. Aggregate agents' preferences
   $\rightarrow$ **cost function**
2. Communicate and decide $\rightarrow$ **vote**
3. Influence others $\rightarrow$ **negotiate**

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$$\boxed{C_T(a_i) = \frac{K_1 \cdot size(T)}{dist(pos(a_i), goal(a_i))} + K_2 \cdot v(a_i) + \frac{K_3}{mot(a_i)} + \eta}$$

Figure 6: A proposal for the cost function

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Algorithm 4 Global simulation algorithm

for $a_i \in AGENTS\_SCHEDULER$ **do**
  $move(a_i)$ ▷ Agents thought at initialization
  $think(a_i)$ ▷ Compute alts, select path and direction
end for
for $a_i \in AGENTS\_SCHEDULER$ **do**
  $neighs \leftarrow filter(NOT\_NEGOTIATING,$
    $neighbors(a_i, DELTA) + \{a_i\})$
  if $len(neighs) > 1$ **then**
    $VOTE(neighs)$ ▷ Nested scheduler
  end if
end for

Figure 7: Global simulation dynamic, schedulers execute in random order

Vote

Voting algorithm (simplified)

1. **Check collisions** between voting agents
2. **If no collision $\rightarrow$ vote ends**
   (later, negotiations may exist with no collision)
3. **For each collision** the pair of **agents propose their trajectory and negotiate** (random order) mutually.
   Success in negotiation increases motivation of the negotiator.
4. **Loop back** to **1.** Γ times
5. **For each remaining collision** (unsuccessful negotiation) the most **motivated agent waits if imminent collision** (at $t+1$)

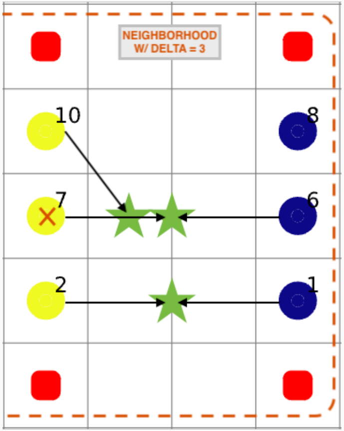


Figure 8: A voting situation with 7 at its center and potential collisions

Negotiation

Negotiation algorithm (simplified)

1. a_2 **computes** its best **collision-free (CF) trajectory** w.r.t. a_1's communicated path
2. **If not found,** a_2 **computes one with neighbor obstacles**
   2.1 **If there is no existing** CF alternative, a_2 **seeks its best alternative with a tolerance** matching a_1's cost
3. **If computed path** is already **taken**, the **negotiation ends positively**
4. **Else**, a_2 **reconsiders the alternative** only **if it is worth** w.r.t. its motivation
5. **If worth, negotiation ends positively, negatively otherwise**

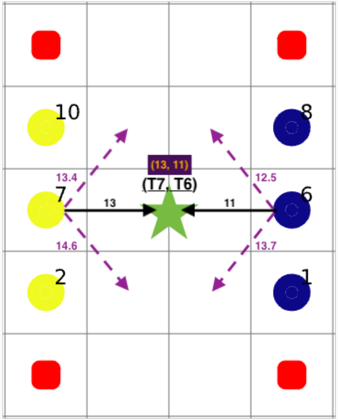
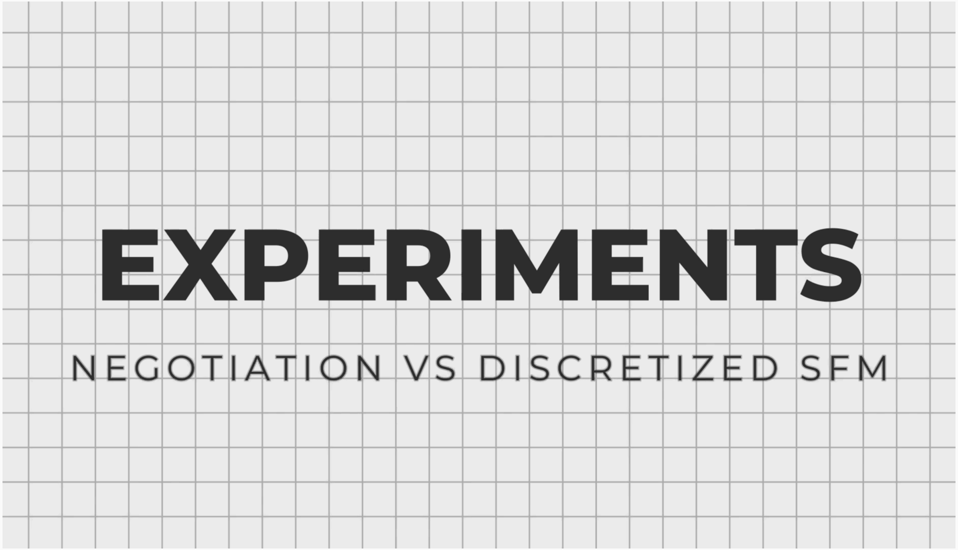


Figure 9: A conflict resolution attempt between agents 7 and 6

Experiments and comparisons



A few empirical lessons...

1. **Pedestrians can be smart**er than expected → simple modelling
2. **The freest** (flexible) agents are mostly the ones to **unblock complex situations** → gained insights from model
3. **Communication is key**: information propagation helps to streamline crowds → refine & study local groups interactions and cost semantics

Ongoing research and comments

Ongoing research

1. **Elaborate N-negotiations**: priority - attention, successive/simultaneous negotiations
2. **Updating traits**: attention & motivation change automatically
3. **Negotiation ignorance**: self acclimation, ...
4. **Refined cost function**: inertia & desires combined to reflect with the right cost of an agent
5. **Local welfare research**: creation of groups, influence over other groups to reach high welfare (situation propagation: awareness)

Ongoing research and comments (2)

Research horizons

7. **Voting objects**: subset of alternatives, other's trajectory offer / negotiation over cell allocation
8. **Refined discrete motion**: freedom enhances possibilities
9. **Refined computed set of alternatives**: sub-objectives for relevant trajectories, ...
10. **Refined pedestrians**: limited waiting, strategies (e.g., lies), speed variation - motivation (energy)
11. **Empirical study & focus on theory**