Comfort driven navigation of individuals in a crowd simulation

Patrick Sterlin
SPIROPS R&D
patrick.sterlin@spirops.com

Florian Deconinck
SPIROPS R&D
florian.deconinck@spirops.com

Tojo Rakotoarison Raobelina
SPIROPS R&D
tojo.rakotoarison@gmail.com

Axel Buendia
SPIROPS CEO
axel.buendia@spirops.com

Abstract

SPIROPS crowd simulation framework developed with Walt Disney Imagineering Research & Development, simulates large crowds at the scale of every single character. A three layers navigation system is used for the characters to navigate through any environment (navigation graph, Platter Lift algorithm and local avoidances of other pedestrians and obstacles). In this article we will focus on the lowest layer. Simple avoidance behaviors are implemented using the SPIROPS AI engine.

We use the concept of personal space inspired from experimental studies and crowd simulation literature to design comfort driven techniques, and obtain a more realistic space distribution and more believable pedestrians trajectories.

Keywords: crowd simulation, avoidance, artificial intelligence, personal space

1 Introduction

The first step to simulate natural looking crowds is to design collision avoidance behaviors. However, this system alone is insufficient: characters brush against each other (avoid each other by nearly touching), and their trajectories do not look natural. In real life, people keep - or at least try to keep - a clear personal space around them. The size of this space depends on multiple parameters: social relations (friends, strangers, *etc.*), being in a hurry, the density of the crowd, *etc.* In the following sections we will explain how to simulate this notion of personal space to obtain more natural looking characters navigation and repartition in space.

2 Three layers navigation system

The navigation is based on a three layers top-down strategy. A navigation graph is computed offline by the SPIROPS PathGenerator. It automatically determines which areas are accessible and how they are connected. The highest level navigation layer chooses a path with an A* algorithm within this navigation graph.

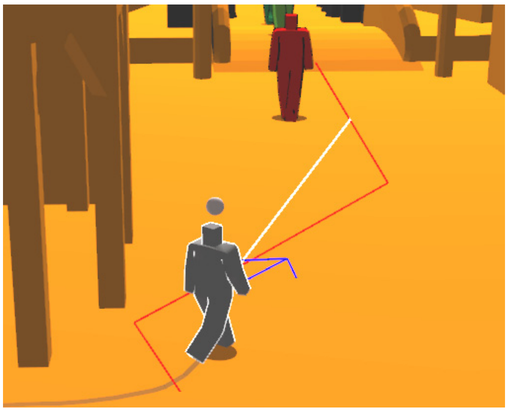

Figure 1: *The three layers navigation system: A* path (red lines), Platter Lift (white bar) and local avoidances (blue arrow).*

The middle level is our Platter Lift algorithm: the character follows a variable length bar connected directly to the links selected by the A*. The Platter Lift smoothes the path followed by the character in a straightforward way. The lowest level is driven by behaviors designed in the SPIROPS AI editor. It deals with the avoidance of local obstacles, including the other characters. The latest improvements in this layer will be discussed in this paper.

3 Local avoidance

3.1 *The Drive oriented paradigm*

SPIROPS AI system [1] allows to design straightforward and independent behaviors called Drives, that react to a specific type of target (static obstacle, other character, *etc.*). Characters think at a predefined frequency (*e.g.* 10Hz). At each thinking cycle, a character evaluates each one of its Drives, first by taking into account its own motivation (*e.g.* ”Am I tired?”, ”Am I in a rush?”), then by considering each perceived target (*e.g.* ”Is this particular character going to intersect my trajectory?”). Then the system can determine which behavior(s) are chosen, and on which target they will apply.

The strong point of this system is to remain straightforward in terms of conception (as each Drive can be designed independently from the others), as well as in terms of computation time.

In addition SPIROPS uses fuzzy logic principles: each Drive evaluates its adequacy with the current context by computing a fuzzy value, its interest. That leads to continuous, weighted and, therefore, rich decisions.

In the rest of this paper, A will be the thinking character, and B the one perceived in a Drive.

3.2 *Collision avoidance*

First of all we keep only problematic characters: in a close area, we compute trajectories of the surrounding neighbors and extract those who might collide with A, assuming they will keep their speed and direction. Once this filtering is done, the impact time of each filtered pedestrian is computed and permits the avoidance of the most imminent one.

Several behaviors are designed to keep characters from walking into each other. The goal is to anticipate B’s trajectory to avoid it with the smallest deviation from A’s own trajectory. As a result, A and B will brush against each other. These Drives change the speed and/or direction according to different strategies (*e.g. wait for B to pass by*, *pass before B*, *make a detour by left/right*).

These Drives are essential, as they allow to interpolate the avoided character trajectory (based on its immediate position and speed vector), so the characters pass each other without colliding. However, this set of Drives does not succeed in creating realistic crowd behaviors: characters only avoid collision with each other and do not consider any notion of ”walking in comfort” (*e.g. free their line of view*, *not walking close to unknown people*).

3.3 *Comfort driven avoidance*

3.3.1 Personal Space

In his book ”The hidden dimension”, Edward Hall [2] defines personal space as an invisible zone in which other people are not welcome to enter. If someone enters his personnal space, a pedestrian will feel uncomfortable and try to move until he is at a reasonable distance from all his neighbors. This zone is influenced by many parameters such as the density around the pedestrian, his wanted speed, his acquaintances with his neighbors (social relations, familiarity, *etc.*), *etc.* Edward Hall distinguishes four zones (see also Figure 2):

(a) the intimate zone (from 0 to 45 cm) where the presence of another pedestrian is highly disturbing,

(b) the personal zone (from 45 to 120 cm) is the distance that every individual tries to maintain between him and another pedestrian (whoever that is),

(c) the social zone (from 120 to 360cm) in which the presence is allowed with special conditions (high density, acquaintance with the character, avoiding an obstacle, social situations, *etc.*),

(d) the public zone (360cm and beyond) where other pedstrians are seen but not taken into account while navigating.

3.3.2 Perceptions

In order to take the right decisions the character needs a good perception of its environment. In our research we determined a zone of perception in which neighboring pedestrians are sensed. This zone is a combination of human vision perception and the personal space described above. Humans perceive objects situated in their field of view. But this perception decreases on the edges. In addition we take the hypothesis that humans can sense everything in a really close area, even behind them. To simulate this vision we used the parabola of equation:

$$p(x) = i\left(\frac{x^2}{s^2} - 1\right) \quad (1)$$

where *i* is the highest boundary of the intimate zone and *s* is the distance at which a character can sense an object on its sides.

We combined this vision perception with Edward Hall's zones to get different levels of responses in our behaviors as shown in Figure 2:

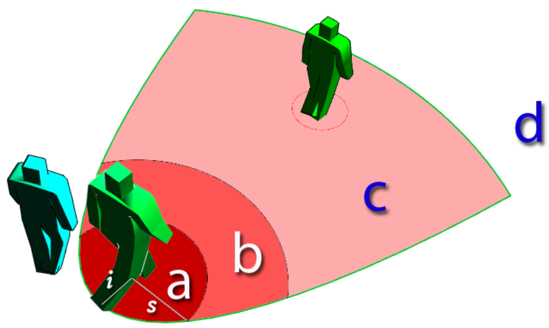

Figure 2: *The personal space*

Concerning static obstacles, we just detect the closest one. This is done quickly thanks to a subdivision of the environment into vectorial zones, preprocessed by the SpirOps PathGenerator. Once the closest obstacle is detected, we compute the width of the passage in the direction of the normal vector of its surface, looking for another obstacle. This technique determines if the character is in a passage, and computes its width.

3.3.3 The three main comfort Drives

In this section we will present the three central Drives of the system. Some of these Drives are inspired by the work of Demetri Terzopoulos and Shao Wei [3].

Clear personal space by turning left/right

The idea behind this Drive is to clear A's personal space as much as possible . This behavior has been divided into two seperate Drives: *clear by moving towards my left*, and *clear by moving towards my right*. Even if the behaviors and the parameters computations are similar, this design allows us to choose the best angle for each strategy and for every perceived pedestrian, before electing the best fitting strategy.

The decision takes into account multiple factors:

- B will annoy A: if B is walking towards A or if B is walking way too slow in front of A.
- The more B is at A's right, the more A will prefer to avoid B by its left.
- The closest the character is, the more A turns to clear its personal space. The turning angle stays in a reasonable range (we are not here in a critical collision avoidance). This factor depends on A's speed: if A is walking too slowly due to the density of the crowd, it will less try to stay away from its neighbors. This factor also depends on the relationship between A and B: if B is a friend, A will be less tolerant than if it is a complete stranger.
- Is there enough space between B and any obstacle?
- Is A's side obstructed by other characters or static obstacles?
- Is B trying to avoid A with a different strategy? This factor simulates non verbal signals that pedestrians use to express their avoiding strategy.
- Is there another character coming towards A? In this case, this Drive is inhibited for characters going the same way: A won't try to pass B if there is another character coming towards it.

Even though the goal of this behavior is not to avoid a character, the results show that it induces smooth and comfortable avoidances, as the characters keep a reasonable distance between them.

Avoid Static Obstacle

This Drive aims to maintain a certain distance from static obstacles (basically walls), depending on the density of the crowd and the width of the area: in a wide area, characters try to remain far from borders, whereas they will be more tolerant of being close to walls in a narrow alley. Likewise, characters will accept being close to walls when the place is crowded.

Moreover, we used the observations of David Brogan and Nicholas Johnson [4] which show that characters decrease their speed when they avoid an obstacle. They showed that pedestrians walk at 80% of their wanted speed when the distance to an obstacle is below 81 centimeters. We also used their general wanted speed repartition on all pedestrians (average: 1.36 m/s, standard deviation: 0.162 m/s) which gives pretty good looking results.

Decelerate When Pedestrian In Front

This Drive keeps characters from getting too close to those who precede them by adjusting their speed. If A is behind B and goes faster, it will decelerate to B's speed, the more:

- B is in front of A (and therefore will likely annoy A),
- B is going in the same way,
- B is close,
- they are in a very narrow passage (no place to pass B),
- they are in a passage and there is another character coming towards A (which gets avoidance priority).

Moreover, if A's speed exceeds B's with more than a given threshold (depending on its mood, rush, *etc.*), it will not decelerate and it will try to pass B. In other words, A will accept to decelerate to reach B's speed only if their speeds are in the same range.

Although these three behaviors are the heart of our system, we designed other ones to refine the results and handle specific situations (*e.g. strafing sideways when we get stuck against another character*). Nevertheless, the "emergency" avoidances will always be chosen preferentially if a collision is imminent.

4 Results and development perspectives

Applying the notion of personal space within the SpirOps framework allowed us to split the navigation into simple behaviors. The comfort Drives are easily implemented in our three layers navigation system, as they only affect the local trajectory and speed, without modifying the layers on top of it. Trajectories and decisions taken by the characters are heterogeneous and diversified enough to be believable. The system works either for the solitary navigation (*e.g.* position in a passage, path while taking into account the obstacles) or the inter-characters multiple interactions in a dense crowd (like crossroads, narrow passages with character walking both ways, *etc.*). Natural looking crowd spatial repartition is emergent. The performance of our system remains acceptable since we are able to simulate up to 1000 characters at the same time with a thinking frequency of 10 times per second.

However, groups and social relations handling can be greatly improved (politeness, courtesy, *etc.*). Our future work will be mainly focused on detecting and avoiding groups, which requires specific treatments.

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