

Simulating the Collision Avoidance Behavior of Pedestrians

1. Introduction

For a more efficient and safer design of public facilities, it is important to be able to estimate the behavior of the crowd, to predict heavily used routes or peak flows. For example, a computer simulation of crowd movement can be used to elaborate emergency evacuation plans.

The models available to describe the behavior of the crowd usually deal with macroscopic variables like the average speed or the flow.

Our purpose is to **design an individual-based model of the crowd**, hoping that a more refined simulation might be obtained by considering each pedestrian's behavior.

2. Crowd Models

a. Macroscopic approach

In this approach, the crowd is described with **fluid-like properties**. Usually, some measures are made to find an expression of the speed according to the density (of course, the higher the density is, the more frequent the contacts are, and the lower the speed is). Individually, there are many variations according to one's sex, age, physical shape, motivation... but this model only deals with averages (see boxes 1 and 2).

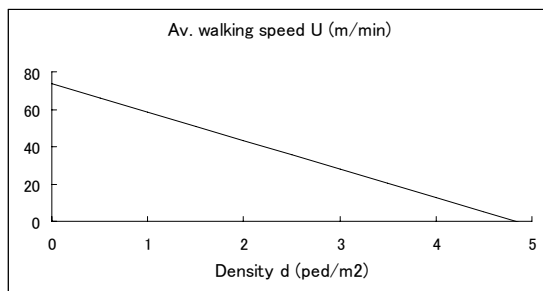
1. Macroscopic description

Variables

- Average walking speed U (in meter per minute)
- Density of pedestrians d (in pedestrians per square meter)
- Flow Q (in pedestrians per minute per meter width), with $Q=U.d$

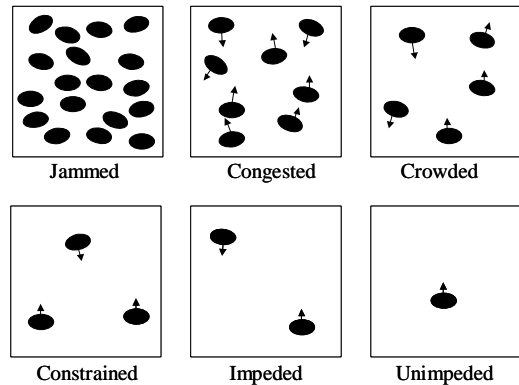
Linear approximation

$$U = A - B.d$$



2. Factors defining the quality of the flow

- Freedom to choose one's desired speed and to overtake
- Ability to cross a stream
- Ability to walk in the direction opposing the major flow



In simulations using the macroscopic approach:

- The environment is modeled by a graph, each edge being a transit place (sidewalk, passageway, stairway, escalator...) with its own capacity (estimated from surveys).
- The pedestrian concentration is propagated across this graph.

These simulations are successfully used for **large-scale estimations**, such as the study of the effect of a modification in the design of a facility (adding a new entrance, a new exit...), or the estimation of the evacuation time of a building.

However, they do not take into consideration behavioral elements, and thus cannot be used at a more precise scale, to study how pedestrians really act.

b. Microscopic approach

i. Individual description

Yielding is the action to change one's own trajectory to allow another pedestrian to pass. It is hard to measure exactly the distance at which one starts yielding. Observations made showed that the yielding distance decreases as the density increases, from 2.1m at low density, to 1.5m in congested

situation:

- When the density is low enough (unimpeded situation), people start detouring much earlier, at about 15~30m from the obstacle.
- At high density, when a simple detour is not possible, the “step-and-slide” movement occurs, starting at a distance of about 1.5 m. It consists in a slight angling of the body, the turning of the shoulders and a side step.

While the people coming ahead are usually briefly glanced at, and then discarded, when a collision is likely to happen, a kind of **communication** occurs, involving:

- The emission of signs to allow the other to discover one’s purpose
- An establishment point, when both parties acknowledge

Of course, misunderstanding is possible in this communication, both parties proposing to take the same option at the same time. They enter in what was called a “reciprocal dance”, which can require a couple of occurrences to break.

ii. *Boids*

This famous model of group movements can simulate flocks of birds, herds of horses, schools of fish... These bird-like agents are called *boids* (for bird-oid).

The model is based on a very simple formulation of **local rules** that any agent in the group must enforce, resulting in a surprisingly harmonious result:

- Separation: avoid collision with nearby flock mates
- Alignment: match velocity with nearby flock mates
- Cohesion: attempt to go towards the center of the flock

When avoiding collisions, a boid only considers the positions of its flock mates, and it chooses its speed relying only on its neighbors’ speed. Therefore, collision-free navigation appears as a side effect.

Boids are cooperative and all share the same goal and preoccupations. In a human crowd, everyone tries to avoid collisions, but the result is very different from a school of fish. This is probably because **few pedestrians have the same objectives**, and because everyone tends to act in a rather selfish way, not enforcing the rules of alignment and cohesion. The difference shall be evident at low densities, when everyone is free to choose his speed.

iii. *Particle systems*

Particle systems are usually used in computer animation for the modeling and the visualization of clouds, water, gases, fires... They consist in some clouds of elementary primitives (particles) with physical attributes (which obey physical laws). One can make the analogy with actual particles in electro-magnetic fields.

This method was used for simulation of crowd movement involving up to 50,000 persons, especially to test emergency evacuation plans. The model is robust enough to allow such large-scale simulations, and can be used to study the apparition of **congestion points** or the spreading of **panic phenomena**.

On the other hand individual behaviors are relatively simple (the agents do not plan their actions).

3. An Algorithm for Collision Avoidance

a. Outline

We adopted the following specifications for our model:

- Each agent is able to **plan a safe trajectory** from the current position, using information on the position and speed of the obstacles to forecast their trajectories.
- Both **detouring** and **speed variations** are possible in the avoidance scheme.
- **(x,y,t) space** is used to represent the collision avoidance problem.

b. *(x,y,t) space*

The future position of all visible obstacles is predicted and represented in a three-dimensional (x,y,t) space. In such a space, all objects are static, and the problem becomes one of path planning (box 3, top).

By introducing the **disk of admissible displacements**, we simplified the search of a path in a three-dimensional space to a search of a point in a limited two-dimensional domain (box 3, bottom).

Our goal is to select a good point in the disk for the next movement, “good” meaning collision-free and optimal in relation to speed variation and detouring

To characterize a point P in the disk, we consider the trajectory T_P obtained by adopting the speed corresponding to P (therefore T_P is a straight line). We showed that points corresponding to a collision are on a segment AZ (box 4, top).

Then, taking a point P not on AZ , we calculated the minimal horizontal distance d_{min} between T_P and the line to avoid (the

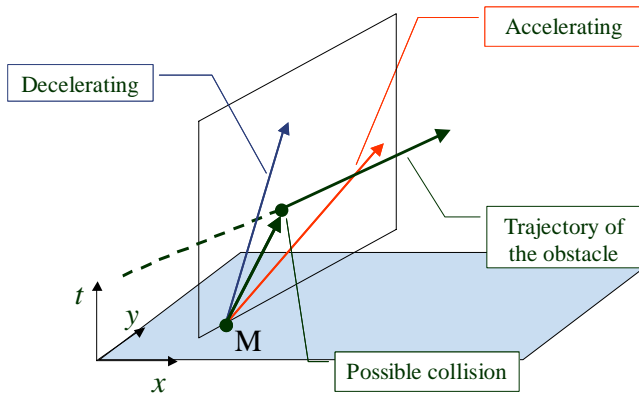
velocity of the obstacle is supposed to be constant).

If the pedestrian discards all movements that correspond to a d_{min} inferior to a fixed limit, it creates a **triangular shaped forbidden area having Z for vertex** (see box 4, bottom).

3. (x,y,t) space

When avoiding a collision point in (x,y,t) space :

- Passing under it means passing earlier, thus accelerating
- Passing above it means passing later, thus decelerating

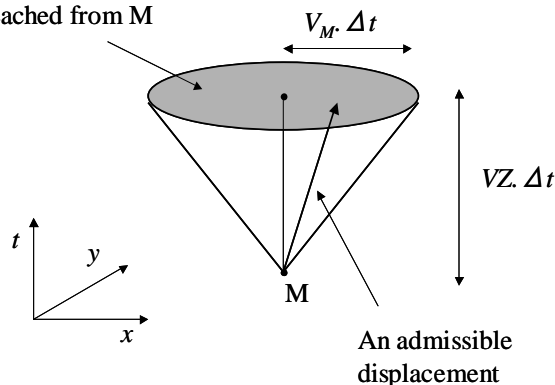


Admissible displacements

The main constraint on the trajectory is that time is not reversible. Since $z=VZ.t$, where VZ is an arbitrarily fixed constant, all admissible displacement vector for the time interval t must have $VZ.t$ for third coordinates.

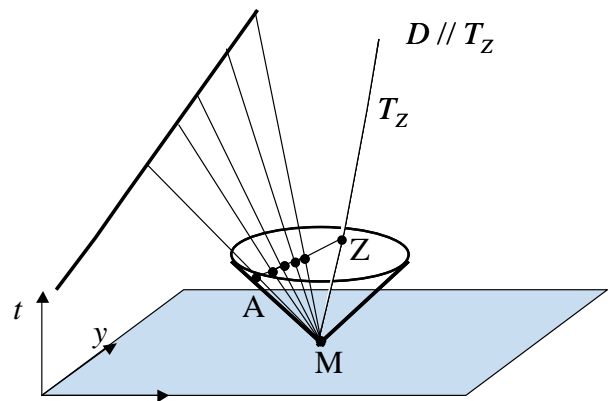
Hence, the points that can be reached after t are on a disk $VZ.t$ above the current position, which radius is $V_M.t$, V_M being the maximum speed for the pedestrian.

Points that can be reached from M

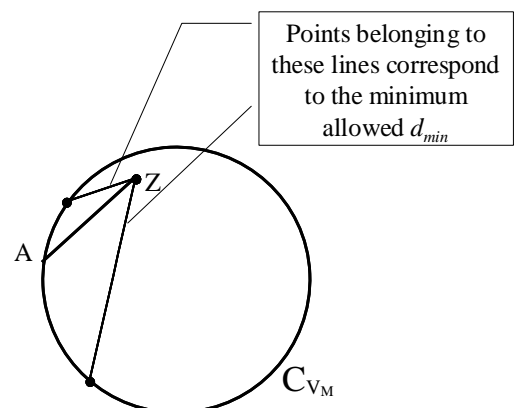


4. Geometrical properties

Property 1: If the trajectory to avoid is a line in (x,y,t) space, then the set of points that would lead to a collision is a segment AZ in the disk of admissible displacements



Property 2: The points on a same line from Z correspond to a same d_{min} . Intuitively, it means that the closer P is to Z , the further the collision point is, and the less deviation is required.



5. Cost of a point P

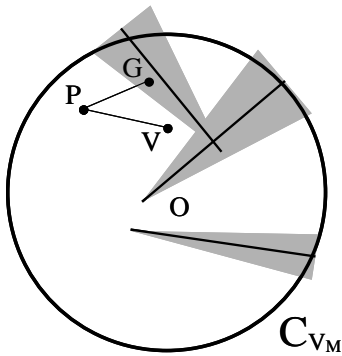
The cost of P is defined by the function:

$$C_P = K_1 \frac{GP}{2r_M} + K_2 \frac{\text{angle}(\mathbf{OV}, \mathbf{OP})}{180} + K_i \frac{|OP - OV|}{2r_M}$$

$$\text{with } i = \begin{cases} 3 & \text{if } OP \geq OV \\ 4 & \text{if } OP < OV \end{cases} \quad \text{and } r_M = \text{radius}(C_{V_M})$$

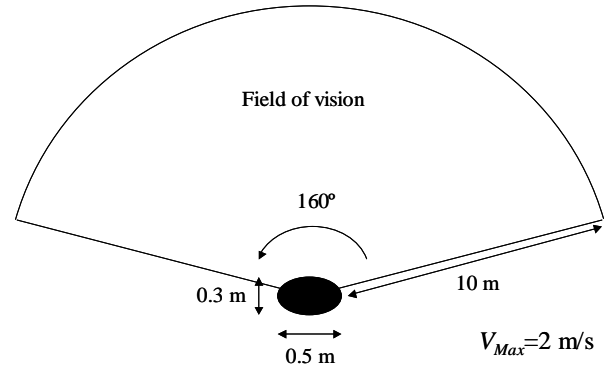
K parameters are constants, with the following signification:

- K_1 : cost of moving away from the goal
- K_2 : cost of changing direction
- K_3 : cost of acceleration
- K_4 : cost of deceleration



6. Physical characteristics

- Speed limited by $V_{Max}=2m/s$
- Unlimited acceleration
- Unlimited rate of rotation
- Obstacles outside the field of vision are not considered



4. Implementation

We implemented both a graphical version (for test purposes) and a non-graphical version of the simulation.

The characteristics of the agents are summarized in box 6.

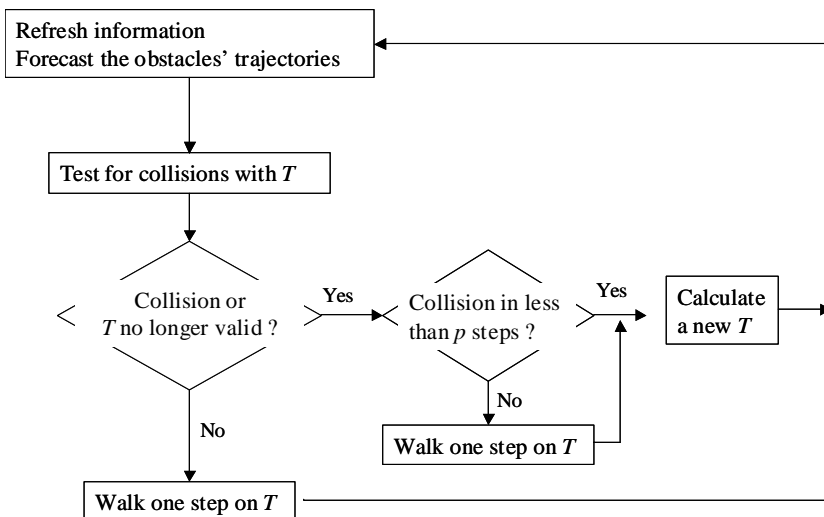
We also give a screenshot of the graphical version: the situation involves three pedestrians. A first window shows the real scene, a second window shows the planned trajectories in (x,y,t) space. A last window gives a representation of the disk of admissible displacements for the current position of the considered agent.

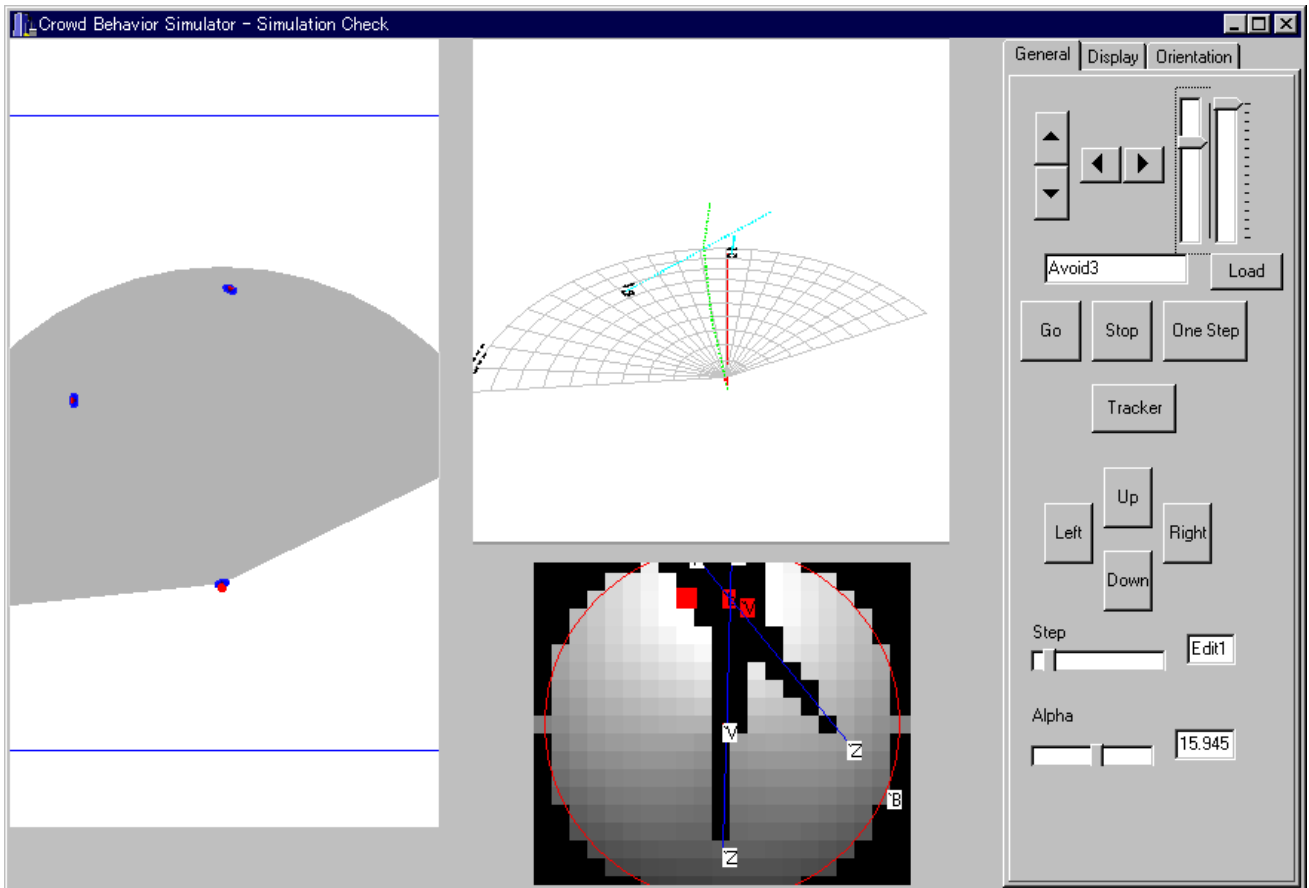
c. Finding the best movement

To choose among the points outside the forbidden area, we defined a **cost function** over the disk. In box 5, the forbidden zone created by three obstacles is represented. Points V represent the pedestrian's current speed, and the point leading to the goal at his favorite speed is G .

d. Planning and following the trajectory

By iterating n times the process, a n -step trajectory can be planned from the current position, as shown in the following chart:





5. Evaluation

a. Real data

Experimental data was obtained by filming outdoor scenes with a video camera, but we faced two problems.

First, **the coordinates of the pedestrians must be pointed at manually**. It would have been interesting to make the whole process automatic, however, useful scenes involve many pedestrians. In such cases, it is difficult to apply object tracking methods since the environment is complex and many occlusions occur.

Next, **the behavior of the pedestrians is difficult to analyze**. We were able to obtain trajectories and velocity profiles; and we observed some variation according to the age (elder people walk more slowly) and the motivation (people in a hurry often rush when crossing the street). From these observations, we found that an average value for v_{fav} can be 1.5 m/s.

b. Test situations

i. *Frontal avoidance*

In this situation, the two agents walk from opposite directions and must deviate to avoid a collision. The amount of deviations depends on the value of d_{min} , and the value of the K parameters does not influence the movement (the points on the limit of the forbidden area have the lowest cost). The trajectories of the pedestrians for different values of d_{min} are represented in box 7 (top).

ii. *Lateral avoidance*

In this situation, the pedestrians come from orthogonal directions. Collision avoidance is possible both by changing speed and by detouring. This choice depends on the values of the K parameters.

- In the first case, the cost of deceleration is lower than the cost of acceleration for pedestrian 0 (in green)
- In the second case, the cost of acceleration is higher
- In the third case, the attraction to the goal is stronger, so that he does not

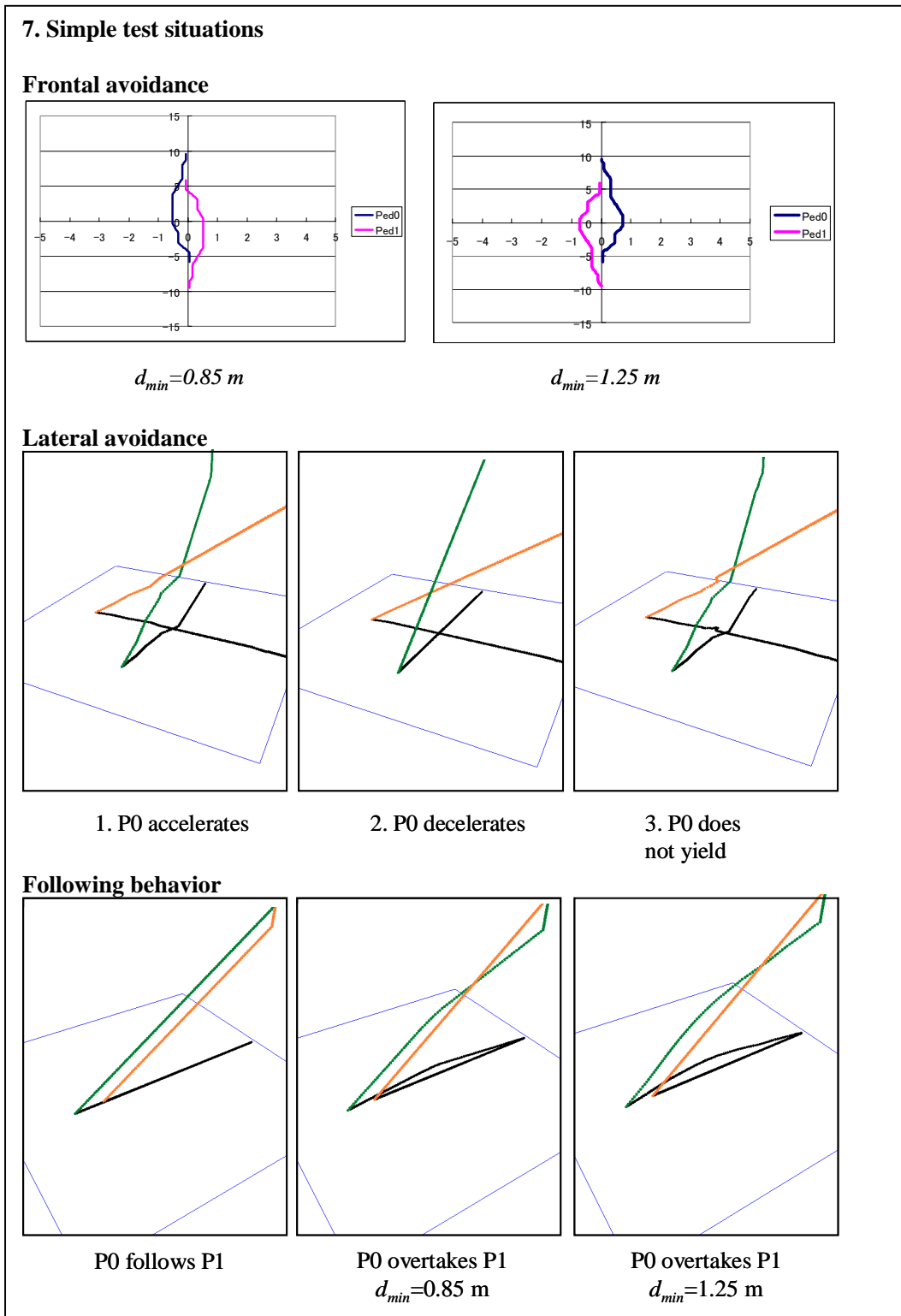
yield and force pedestrian 1 (in orange) to make a detour.

The trajectories in (x,y,t) space of the two pedestrian are represented in box 7 (middle).

iii. Following behavior

In this situation, pedestrian 0 (in green) is placed 2m behind pedestrian 1 (in orange). According to his “favorite speed”, he will

either stay behind or overtake. In the first case, both have the save value for V_{fav} (1.5m/s). In the second case, V_{fav} is set to 1.9m/s for P0 and 1.3m/s for P1. In the third case, the values are the same as for the second one, except that the value of d_{min} is 1.25m instead of 0.85m, so that P0 makes a greater detour to overtake (box 7, bottom).



iv. Twelve agents with converging trajectories

In this situation, 12 pedestrians arrive from different directions and converge to a same central point. We used this experiment to see the effect of d_{min} and n of the general aspect of the trajectories (an energy value was used as a measure of the smoothness of the trajectories), see box 8.

From this experiment, we set the standard values to 20 for n (the trajectory is planned for the next 2s, that is for a distance of about 3m) and to 0.85m for d_{min} .

c. Limitations

First, **the disk might be saturated** when many pedestrians are to be avoided at the same time. A solution is to define a priority level (related to the actual distance or the distance in (x,y,t) space between the current position and the obstacle) and to consider only the pedestrians with the highest priority.

Second, **oscillatory situations** can appear when two pedestrians enter in a loop pattern. Of course, this pattern is observed in reality (“reciprocal dance”), but it is usually prevented by the continuous perception of the environment that people have: the

probability to take similar actions at the very same moment is much lower. Moreover, even in this case, the loop is broken after a few occurrences, because people can detect it and react to it. This kind of higher lever supervising mechanism should also be implemented in the simulation.

6. Conclusion and possible enhancements

We presented an efficient collision avoidance algorithm that was used in a simulation of crowd behavior, involving up to 12 pedestrians with conflicting goals.

Our model is based on a representation of the situation in a (x,y,t) space, which makes it possible to consider both detouring and speed modifications in the avoidance patterns.

Among the enhancements that are to be implemented before our model can realistically describe crowd behavior:

- In the description of the environment: implement sources and sinks of pedestrians (doorways in reality) to generate large numbers of agents
- In the description of the agents: improve the mechanical model (limited acceleration and rate of turn), implement specific behaviors (step-and-slide movement, group behavior), and improve the method used to forecast the trajectories to be avoided.

8. Avoidance with 12 agents

Influence of d_{min}

- Too small ($d_{min} < 0.8m$): the resulting trajectories are no longer collision-free.
- Too large: unnecessary detours are made.

Influence of n

- Too small ($n < 4$): the agents constantly re-plan their trajectory, so that it becomes difficult to accurately forecast their behavior, resulting in unstable situations.
- Too large: the last part of the planned trajectory corresponds to unrealistic forecasting.

