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Introducing social influence in pedestrian street crossing simulations

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Abstract - To drive automated vehicles rises the challenge of producing vehicles behaviors similar to those produced by human drivers. Therefore, the automated vehicles could be accepted more easily. Among the many different behaviors to be simulated, one is particularly important from a road safety point of view: the interaction between automated vehicles and pedestrians during a street crossing. More particularly, pedestrians non-normative and unexpected behaviors should be taken into account by automated vehicles. This article aims to develop a new model of pedestrian street crossing at a red light. This model will allow virtual pedestrians to cross the street illegally, and to influence other pedestrians to follow them. Thus, some among the waiting pedestrians will also illegally cross the street. The model is able to manage in a very simple manner a group of pedestrians with only few parameters. These parameters allow to coordinate the pedestrians in the group for street crossing, and experimenters will keep the control on their studies in *ceteris paribus* conditions. The model is based on three hypotheses. The first one concerns the time that each pedestrian accepts to spend at the red light. The second and third hypotheses are related to social influence: the actions made by others influence the pedestrian street crossing decisions. Based on the works of Rosenbloom (2009), we assume that: i) waiting pedestrians encourage the others to wait too, and: ii) crossing pedestrians at a red light shows the others there is an opportunity to cross, and thus encourages them to cross. The simulation results illustrate our method and show different pedestrians group behaviour of street crossings. Our method allows the experimenter to coordinate the pedestrians in the group with only three parameters.

Keywords: Pedestrian simulation, street crossing, neighbor's influence, group behavior

Introduction

The complexity and diversity of pedestrian behaviors are a challenge for automated vehicles (AVs). To be accepted in cities, AVs should behave as close as possible to real drivers. That implies, an acceptable interaction with pedestrians. Moreover, most AVs are only implemented on highways, where there are few interactions with pedestrians. Thus, improving our knowledge on interactions between AVs and pedestrians is a major stake.

Pedestrians are the most vulnerable road users. They have no car body, airbag, belt or helmet to protect themselves in a case of collision. They are less restricted by rules, and do not always follow the rules; moreover, they are less checked by the police than drivers (Lavalette, et al., 2009). About 20 to 25% of the pedestrians in Paris, Brussels and Hamburg violate the traffic rules when crossing a street (Diependaele, 2019). Furthermore, the pedestrian's behavior is more flexible than other road user's behavior, as they can quickly switch from one state to another (walking, running, stepping back, stopping, etc.). Also, pedestrians can change suddenly their direction (Schmidt and Faerber, 2009), and they do not have a flashing lights or horn to warn other road users. This diversity may lead to unexpected behavior, as viewed from the drivers of an automated vehicle, and thus to an accident.

Road crossings are the places where pedestrians

and other road users interact most; police reports reveal that most pedestrians accidents occur at intersections, during the street crossing (King, Soole, and Ghafourian, 2009). Street crossing exposes pedestrians to other road users. In fact, pedestrian's behaviour shows much variability, in terms of speed, trajectory, and decision to cross the street. Not all pedestrians are compliant with the traffic rules. They spend some time waiting at the curb and have to make a quick decision (cross/wait). Some of them just rely on others and reproduce their behavior. According to psychology as well and neuroscience studies (Iacoboni, 2009), imitation includes an automatic process that involves mirror neurons. Social influence includes some level of imitation, and people may be influenced by the other's decisions to cross or not. Indeed, according to (Rosenbloom, 2009), while the pedestrian's light is red, seeing someone crossing encourages the others to cross, and seeing someone waiting encourages the others to wait. A reason why pedestrians may follow someone crossing is that they think the gap with an approaching car is still enough (Faria, Krause, and Krause, 2010; Yang, et al., 2006).

The goal of this paper is to propose a simple way to manage pedestrians group crossings in order to experiment with non-normative pedestrian behaviours in virtual reality environments. To achieve that, we build a pedestrian street crossing simulation model, where pedestrians cross against the traffic lights. In the model, the pedestrian's crossing decision is in-

fluenced by his neighbour's decision. Using only few parameters, it is possible to coordinate the crossing decision of the entire group of pedestrians in a reproducible way. This method makes it relevant for experimental psychology experiments in virtual reality settings, where one wishes to reproduce controlled scenarios. Indeed, our pedestrians' group is composed of one pedestrian bot, and a limited number of pedestrian non player characters (NPC). The first (leader) is controlled by the experimenter, and the NPCs are autonomous. In this work, we focus on the street crossing decision of the NPC's agent. For the pedestrians' motion, navigation and collision avoidance, there exist several models. The most popular ones are the Social Force Model (SFM) (Helbing and Molnar, 1995), the boids model (Reynolds, 1987) and the ORCA model (Optimal Reciprocal Collision Avoidance) (Van Den Berg, et al., 2010). We have used the ORCA model, to which we added a street crossing decision function. The decision model includes social information from the pedestrian's neighbors to take the crossing decision.

This contribution is organized as follows: the next section describes the pedestrian agent and its crossing decision function. In the third section, the way to manage the pedestrian group is provided. In section 4, simulation results are given in order to illustrate different group behaviour when groups cross the street. At last, we will discuss the limits of our model and on the perspective of our works.

Street crossing decision model

In order to simulate non-normative pedestrian behaviors in a group, we need to develop a crossing decision model at the individual level, e.g. for each NPC pedestrian. An NPC is an autonomous agent, which can perceive its neighbor's decision (cross/wait). The model is based on three hypotheses; all of them are identified from the literature, take place in the context of crossings at the red light.

In our context, we suppose that our NPCs do not interact with cars. Thus, the NPC pedestrian acts as a full-scripted pedestrian. Nevertheless, this behavior is plausible according to (Faria, Krause, and Krause, 2010; Yang, et al., 2006). Indeed, the willingness to cross is greater than the perceived risk from the approaching cars. We assumed that the perceived risk from an approaching car decreases when someone is already crossing; a pedestrian might think there is enough gap for crossing.

Agent definition

Each pedestrian has his own specific characteristics: firstly, a pedestrian i cannot walk faster than its maximal speed V_0^i . Pedestrians perceive the position, speed and crossing decision of their neighbours; they know, at each time step, the number of waiting $N_W^i(t)$ and number of crossing pedestrians $N_C^i(t)$ at the crossing location. Each pedestrian is described by an Individual Patience parameter $IP^i(t)$, which can change during the waiting phase before the street crossing (see hypothesis H1 below). The time spent waiting at the curb $WT^i(t)$ is recorded for each pedestrian i .

Crossing decision: hypotheses

Our model is based on three hypotheses: the first hypothesis H1 is about the individual characteristics of pedestrians. The hypotheses H2 and H3 refer to the social influence of neighbours.

- (H1:) Pedestrians have limited patience when waiting at the curb. When the amount of time associated with this individual patience is elapsed, the pedestrian crosses the road, even if the light is red.
- (H2:) The presence of waiting pedestrians around increases the patience of a given pedestrian (Rosenbloom, 2009).
- (H3:) The presence of crossing pedestrians decrease the patience of a given pedestrian (Rosenbloom, 2009).

Crossing decision: implementation

The proposed model modifies, at each time step, the individual parameter $IP^i(t)$ of each pedestrian, depending on the status (waiting or crossing) of the neighbours he perceives. This parameter is initialized at the beginning of the scenario (corresponding to the situation of a pedestrian arriving at the curb).

Each NPC pedestrian perceives its neighbours and associates a status (Waiting or Crossing) to each one. Then, the number of waiting ($N_W^i(t)$) and crossing neighbors ($N_C^i(t)$) can be computed at each time step by each NPC pedestrian i .

Waiting pedestrians tend to influence the pedestrian not to cross (Hypothesis H2), while crossing pedestrians tend to influence the NPC to cross (Hypothesis H3). In order to take into account simultaneously the twice hypothesis H2 and H3, we define a social influence variable, which is a linear combination of $N_W^i(t)$ and $N_C^i(t)$; each variable is weighted. The resulted variable is called $\Delta^i(t)$, and that is used to modify the individual patience $IP^i(t)$. Thus this social influence variable includes two parameters: the weight p_W associated with the influence of Waiting pedestrians and the weight p_C associated with the influence of Crossing pedestrians.

The social influence $\Delta^i(t)$, applied to a NPC pedestrian i , is computed at each time step as follows (equation 1):

$$\Delta^i(t) = p_W \times N_W^i(t) - p_C \times N_C^i(t) \quad (1)$$

The individual patience $IP^i(t + TS)$ is updated at each time step; according to the TS is the simulation time step, the last individual patience $IP^i(t)$, the social influence value and $\Delta^i(t)$ and the n is a parameter to adjust the decrease of the IP^i . In this contribution $n = 7$:

$$IP^i(t + TS) = IP^i(t) \times e^{\left(\frac{\Delta^i(t) \times TS}{n}\right)} \quad (2)$$

If $\Delta^i(t)$ is positive, the NPC pedestrian is influence to wait more since the IP^i increases, and for $\Delta^i(t)$ negative, the desire to cross of NPC increases.

The waiting time of a NPC pedestrian i is updated as follows:

$$WT^i(t + TS) = WT^i(t) + TS \quad (3)$$

Finally, the NPC pedestrian i decides to cross when its individual patience IP^i is smaller than its waiting time WT^i .

At each time t , NPC^i crosses if and only if:

$$IP^i(t) - WT^i(t) \leq 0 \quad (4)$$

In the real world, it is usual to have more pedestrians who wait than those who cross at the red light, it means that in (equation 1) $p_W < p_C$. In the following, we use $p_W = 0.1$ and $p_C = 0.9$. As in the real world, patience cannot increase too above a threshold. It means that when the individual patience reaches this threshold, the pedestrian i could when (equation 4) is satisfied. In our case, the threshold is set to 110% of the initial individual patience of the pedestrian i . At last, the influence of a crossing pedestrian disappears when the pedestrian reaches the final curb.

Therefore, we are able to simulate scenarios where some pedestrians cross the street earlier or later than what would have happened due to the initial individual patience by considering the social influence of the neighbors.

Group modeling

The pedestrian group is composed of one pedestrian bot (leader) and several NPC pedestrians. The leader is called a "bot" since it is controlled by the experimenter. It is the experimenter who decides when the leader starts crossing the street at time t_0 . After that, the other NPC pedestrians begin waiting, meaning that their Individual Patience and their Waiting Time evolve, and no instruction is needed from the experimenter. The rest of the pedestrians on the group will cross the street depending on the initial conditions chosen by the experimenter. One constraint of our model is that all NPCs have a perception function allowing them to detect the pedestrians who cross and those who wait (this will allow the computation of N_W and N_C , see Eq. 1).

To manage the pedestrian group, the experimenter has to set up the appropriate initial conditions. All NPCs have an initial patience IP_0^i . In order to link the NPC's behaviour, we assume that their initial individual patience is defined as follows (equation 5):

$$\begin{aligned} IP_0^1 &= \psi \\ IP_0^2 &= IP_0^1 + \alpha \\ IP_0^N &= IP_0^{N-1} + \alpha \end{aligned} \quad (5)$$

N is the number of pedestrians in the group. We called the pedestrian bot as well P^0 , while P^1 is the first NPC who will follow P^0 until P^N . In our case, we assume that $N \leq 9$. The individual patience of P^1 is ψ ; the other individual patience follows an arithmetic progression of α .

Due to our decision model, it is obvious that the choice of ψ and α should depend on the road width and on the pedestrians' speed (for the bot and the NPCs). Indeed, the decrease of each individual patience depends on the time within the former pedestrians cross. Roughly speaking, the definition of the individual patience of P^1 ψ strongly depends on the crossing time of P^0 , to be sure that P^0 sufficiently influences P^1 .

Results

Scenarios

At the start of a simulation, a group of pedestrians is placed on the curb waiting to cross, one bot and 8 NPC pedestrians. In the following simulations, the width of the street is fixed to $7m$ corresponding to a 2-lanes street. All pedestrians have the same speed $V = 1.2m/s$, leading to a crossing time of $5.83s$. We recall that the social influence model is effective if the initial patience of the first NPC pedestrian is smaller than the crossing time ($IP_0^1 = \psi < 5.83s$). The simulation starts when the leader (bot) starts its crossing (which is determined by the experimenter). In our illustrations, the bot starts at $t = 0$.

Robustness assessment

First, we want to verify if our model works whatever the value of the time step. In this way, the model will works also in real-time. To achieve that, a series of simulations have been conducted with different time steps TS .

Figure 1 shows the evolution during the simulation of the number of NPC pedestrians who are crossing or waiting, for two time steps ($1/100s$ and $1/50s$). We can observe very small differences due to the discretization of time, but none of them can be perceived. At the beginning of the simulation, 8 pedestrians wait on the curb, and the scripted pedestrian starts its crossing. The second pedestrian starts crossing approximately $4.5s$ after the first one, and the number of waiting pedestrians decreases to 7. At $5.8s$, the bot pedestrian reaches the other side of the road and stop influencing the others. Then, the number of crossings is decreasing to 1. At $6.8s$, the third pedestrian starts crossing, and so on. After $9.4s$, no pedestrian are left on the kerb.

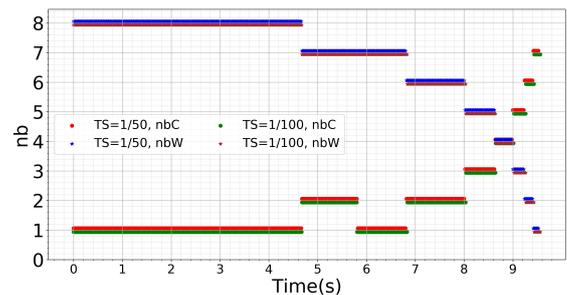


Figure 1: Evolution of number of crossing and waiting pedestrians for two values of the time step ($1/100s$ and $1/50s$).

The evolution of $IP(t) - WT(t)$ in Eq. 4 is illustrated in Figure 2, in which we can observe these of two pedestrians, the second NPC (P_2) and the last one (P_8) in the simulation of a group with 9 pedestrians. We used two different time steps ($1/100s$ and $1/50s$). We can observe that there are no significant differences between the two simulations.

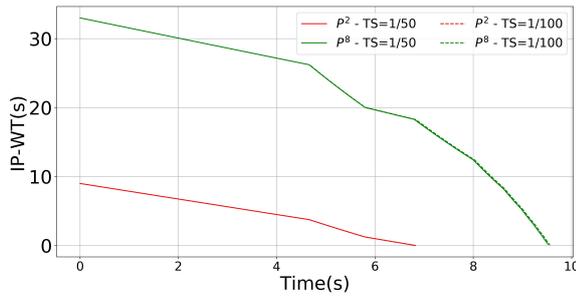


Figure 2: Evolution of the difference between the Individual Patience $IP(t)$ and the Waiting Time $WT(t)$ of two NPC pedestrians, the second NPC (P^2) and the last (P^8) in the 9-pedestrians group, with two different time steps ($1/100s$ and $1/50s$).

In the beginning, when the bot starts crossing, the Waiting Time of each pedestrian is equal to 0, and the number of crossing pedestrians is equal to 1. Thus, the patience of the waiting pedestrians decreases slowly. At each new decision to cross, if one or more pedestrians are already crossing, the social influence increases and the desire to cross too for the remaining pedestrians, meaning that the difference between the individual patience and the waiting time of each NPC waiting pedestrian decreases stronger than at the beginning. When $IP(t) - WT(t)$ is equal to 0 or negative, it means that the NPC pedestrian starts to cross. In our case, we can observe that the difference of the initial individual patience between NPC pedestrian P^3 and P^8 is greater than $20s$, but P^8 really starts its crossing after P^3 in less than $4s$.

We have assessed the robustness of our model in order to be sure that it will work in real-time. The simulations showed that the pedestrian's behavior does not depend on the time step. Therefore, in the following simulations, the time step is set to $1/50s$.

Group behaviour

The goal of this paper is to simulate a non-normative group of pedestrian behaviors. More specifically, the crossing time difference between pedestrians of the group is controlled by a social influence model. In this paper, the experimenter need only to choose the initial patience IP_0^2 of the second pedestrian (setting ψ), the inter-time patience α between two pedestrians, and the number of pedestrians N composing the group.

Several scenarios are illustrated in Table 1. Each scenario corresponds to one parameters set (N, α, ψ) and shows the time $\delta(i, i+1)$ between two starts of two successive pedestrian crossings (for pedestrian i and pedestrian $i+1$). These times illustrate the group behaviour, showing if the NPC pedestrians cross one by one, or if two or more start to cross almost simultaneously.

ψ	α	N	$\delta(0,1)$	$\delta(1,2)$	$\delta(2,3)$	$\delta(3,4)$	$\delta(4,5)$	$\delta(5,6)$	$\delta(6,7)$	$\delta(7,8)$
5	2	5	3.78	0.67	0.4	0.28				
5	4	5	3.8	1.34	0.68	0.5				
5	2	7	4.16	0.84	0.48	0.3	0.26	0.18		
5	4	7	4.16	1.5	0.92	0.5	0.28	0.2		
5	2	9	4.66	0.94	0.68	0.42	0.28	0.18	0.14	0.12
5	4	9	4.66	2.14	1.2	0.62	0.36	0.24	0.18	0.12

Table 1: The time between two starts of two successive pedestrian crossings for different scenarios illustrating different group behaviours.

These results show that the experimenter can decide when one or more pedestrians will cross and define the group behavior by reproducing different real behaviours. For example, the last row ($N = 9, \alpha = 4$) shows that the three first NPC pedestrians start their crossing with more 1 second between them. If we consider that the human reaction time is close to 1 second, it may be considered that the 3 first pedestrians are alone and follow each other. And the remaining start to cross more or less together like a group.

Figures 3 and 4 allow to explain differently the pedestrians group behaviour.

Figure 3 show how our model works to manage pedestrian group. With these six scenarios, we can see that our model tends to homogeneous the behaviours of the last NPCs in the group. It means that, like in the real world, when some pedestrians cross, followed by some others, the other waiting pedestrians will cross whatever the situation.

Figures 4 shows the X/Time diagram of each pedestrians. The pedestrian bot starts first at time $t = 0$ (blue plot), then the NPCs follow (red plots). There is four scenarios $(9, 5, 2)$, $(5, 5, 2)$, $(9, 5, 4)$ and $(5, 5, 4)$ corresponding to a group of 5 and 9 pedestrians respectively, with two $\alpha = 2$ and 4, ψ is equal to 5 for these 4 scenarios. The results show that the number of pedestrian influence the time at which the first NPC starts to cross. We can see that α influences the time gap between two successive crossings. The time interval between two successive crossings increases with α . At last, we note with a small number of pedestrians; it is easier to obtain than the last NCP starts to cross more or less before the end of the crossing of the pedestrian bot.

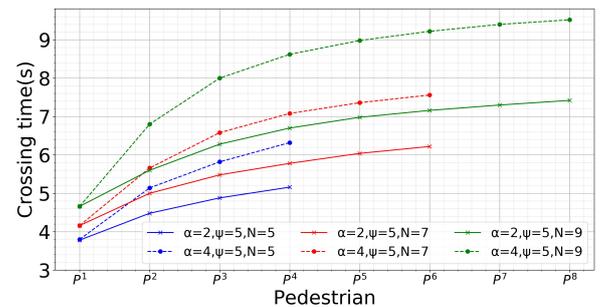


Figure 3: Time of the crossing start for each NPC pedestrian

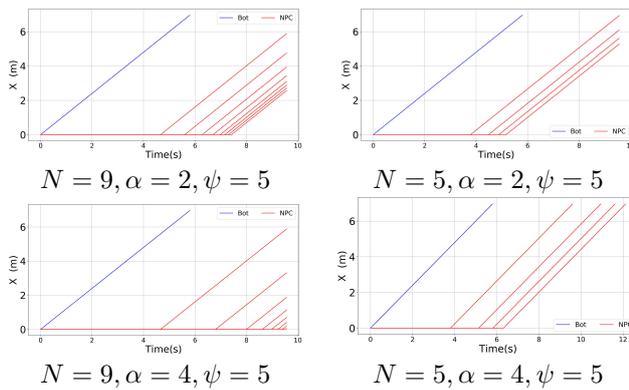


Figure 4: X/Time Diagrams in various simulated conditions.

Finally, we can observe that with more 5 NPC pedestrians we can simulate two different group behaviours: (1) bot crosses, P^2 crosses and the rest of the group cross together, (2) they cross more or less one by one.

Discussion

Controlling a pedestrian group is also possible using the flocking leadership algorithm (Hartman and Benes, 2006) based on the boids model (Reynolds, 1987). In this model, a flock leader is added, and every other boids follow him. Every pedestrian in the flock has to follow the boids' rules, in order to maintain the cohesion of the group. In our model, there are no specific interaction rules between the pedestrians. All of them are independent and autonomous. Furthermore, in our opinion, it would be more difficult to control the group behavior as in our model, where three parameters are enough to simulate different groups crossing.

In the proposed model of non normative crossing decision, the neighbor's influence is limited to the crossing decision. Also, each pedestrian has the same influence on the others, whereas in real life, some individual factors tend to modulate the strength of this social influence. This is the case, for instance, when someone has a high social status (Guéguen and Pichot, 2001; Lefkowitz, Blake, and Mouton, 1955). The spatial configuration also should be taken into account: closer neighbors have more significant influence than further ones (Faria, Krause, and Krause, 2010).

Conclusion

This work provides a real-time simulation method to allow non-normative pedestrian groups in street crossing situations. We show that it is possible to coordinate the crossing decision of a group of pedestrians by only manipulating 3 parameters (N , ψ and α). As the model does not use any stochastic process, all behaviors can be precisely reproduced, for instance, for each participant in a driving simulation behavioral study. This may help the experimenter implementing virtual reality experiments with non-normative pedestrians in order to study drivers or passengers of automated vehicles face to non-normative and non-expected pedestrians crossings.

Furthermore, it might help to improve driver assistants (Schmidt and Faerber, 2009) for better anticipation of the pedestrian crossing decision.

Our crossing decision model for an NPC agent was built in the context of red-light violations. After careful reading, it will be obvious that our method can be applied to any street crossing situations, with or without traffic lights. One possible application concerns the study of pedestrian behavior in a walking simulator. In this case, the proposed model of virtual pedestrian used as NPC can influence the participant or can be influenced by the participant. Thus, it will improve our knowledge of how and why pedestrians cross at red lights.

Finally, in most existing pedestrian simulation models, only cognitive features are sometime modelled. Very few takes into account social interactions among pedestrians. Our model includes social influence and can be integrated in pedestrian simulation model.

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