Virtual Humans Animation in Informed Urban Environments

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Abstract

In order to populate virtual cities, it is necessary to specify the behaviour of dynamic entities such as pedestrians or car drivers. Since it is not possible to construct in real time a complete mental model only from vision and image processing, we have to add higher levels of information than the geometrical one in the model of the virtual environment. In this article, a pedestrian behavioural model which exploit the information produced by VUEMS, our city modeller, is presented.

1 Introduction

Using 3D modelling systems allow the generation of realistic geometrical models in which walk through is possible in real time. As this modelling operation is still a long, complex and costly task, a lot of work has been done to partially automate the rebuilding process. All these techniques are very useful for the visual realism of virtual urban environments but they are not sufficient due to the lack of life of these digital mock-ups. Walking through these virtual city models do not provide a real life feeling as they are uninhabited. In order to populate these virtual environments, we have to specify the behaviour of dynamic entities such as pedestrians, car drivers or public transportation systems. Behavioural animation consists of a high level closed control loop [12, 18, 6, 5], which offers the ability to simulate autonomous entities [2, 23]. Such actors are able to perceive their environment, to communicate with others [4] and to execute some actions, such as walking in the street or grasping an object, according to the nature of the environment and with their intentions. In order to reproduce more complex behaviour than obstacle avoidance it is necessary to provide additional data such as mereotopological and semantic information (Mereology concerns the part-hood relationships, while topology concerns connection relationships).

The issue of this paper is to present how it is possible to produce more realistic behaviours by using a city model *affordant* to autonomous actors. The term *affordance* that has been introduced by J.J. Gibson [13] will be explained in the core of the article. In this paper, we focus in the first part on the nature of data that are requested to simulate behavioural entities from a psychological point of view and in a second part on the pedestrian behavioural model. Our modelling tools such as VUEMS for the modelling of urban environments [8, 24] and HPTS for the behavioural modelling [19] are not addressed in this paper, but during the description of the human character capabilities, information on the environment used by each behaviour will be presented.

2 Behavioural Animation Requirements

Realistic behaviours of autonomous actors evolving in complex and structured environments can be obtained if and only if the relationship between the actor and its surrounding environment can be simulated. Information that must be extracted or interpreted from environment depends on the abstraction level of the reasoning performed by autonomous actors. An autonomous actor whose main action is obstacle avoidance in an unstructured environment does not need other knowledge than the geometrical one. In order to simulate more sophisticated behaviours, other kind of information must be manipulated. The simplest behaviour, for a pedestrian walking in a street, consists in minimizing possible interactions, which mean avoiding static and dynamic obstacles. But, even in this simple walking activity, one needs to know the nature of objects he will interact with. For example, a public phone is considered as an obstacle to avoid for most people, but some of them will be interested by its functionality and will use it. For the crossing of a street, one activity consists in reading the signals, which mean that it is necessary to associate semantic information to geometric objects in the scene, and to update it during the simulation. In the realm of behavioural psychology, there have been a few studies on visual perception, mainly based on Gibson's theory of affordances [13]. The theory of affordances is based on what an object of the envi-

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ronment *affords* to an animal. Gibson claims that the direct perception of these affordances is possible. Affordances are relations between space, time and action, which work for the organism. What the world is to the organism depends on what the organism is doing and might do next. For computer scientists, Gibson theory is really attractive because it assigns to each object some behavioural semantic, i.e. what the human being is likely to do with a given object. Associating symbolical information to objects, Widyanto experienced the Gibson's theory of "affordances" [26]. A visual system captures the layout of the environment by scattering a number of line rays within the field of view, and is able to find occluding edges, to detect collision and to determine the affordances of the environment. M. Kallmann [16] introduces smart objects, in which all interesting features of objects are defined during the modelling phase. He defines four classes of different interaction features: intrinsic object properties, interaction information, object behaviours and expected agent behaviours.

In the field of psycho-sociology, M. Relieu [22] has defined the notion of positive and negative affordances for a pedestrian. A positive affordance specifies the fact that the extrapolated trajectory of the corresponding pedestrian is not supposed to intersect the planned trajectory of the other one, while a negative affordance points out that they may collide. M. Relieu says also that a mobile entity uses the urban discrimination [1] to focus his attention, to select pertinent information for his actions inside the current region, while he maintains a secondary task to observe what is happening in regions close to its circulation area. Those observation behaviours have been introduced in behavioural animation by S. Chopra [7], but are not guided by spatial analysis. S. Chopra has integrated in a virtual human character three kinds of visual attention: endogenous (deliberate capture of information in the region of attention), exogenous (involuntary perception of peripheral motion) and idling (spontaneous looking). Synthetic actors should exhibit the appropriate looking or attending behaviours relevant to the activities they are engaged in [1]. In this paper, spatial organization is taken into account for the pedestrian attending behaviour.

Information needed to describe the behaviour of an entity, depends on the nature of this entity. No theory exist for determining either the necessary or sufficient structures needed to support particular capabilities and certainly not to support general intelligence. As direction and inspiration towards the development of such theory, Newell [21] posits that one way to approach sufficiency is by modelling human cognition in computational layers or bands. He suggests that these computational layers emerge from the natural hierarchy of information processing. Lord [17] introduces several paradigms about the way the brain works and controls the remainder of the human body. He explains that human behaviour is naturally hierarchical, that cognitive functions of the brain are run in parallel. Moreover cognitive functions are different in nature: some are purely reactive, while the others require more time. Newell asserts that these levels are linked by transferring information across hierarchical levels, and that each of them operate without having any detailed knowledge of the inner workings of processes at other levels. All that is required is a transfer function that transforms the information produced by one level into a form that can be used by another. Particularly important is the notion that symbolic activities occur locally based on problem spaces constructed on a moment-to-moment basis. In accordance with Gibson's ecological theory, components of the virtual urban environment should be informed. N. Farenc [10] has proposed to use an informed environment, dedicated to urban life simulation, which is based on a hierarchical decomposition of a urban scene into environment entities providing geometrical information as well as semantic notions. S. Raupp Musse [20] has used this informed environment to animate human crowds by using a hierarchical control: a virtual human agent belongs to a group that belongs to a crowd, and an agent applies the general behaviours defined at the group level. The knowledge on the virtual environment used by the crowd is composed of a set of obstacles (bounding box information of each obstacle to be avoided), a list of interest points (locations that the crowd should pass through and their associated regions) and a list of action points (regions where agents can perform actions).

Our aim is to be able to offer virtual humans all the information required to perform realistic actions according to their intention. Due to the complexity of the urban structure we have to deal with both the efficiency of the access to information and the quantity of data to store. The use of a mereotopological structure makes it possible to have an efficient access to information. As far as we know there is no normalization for the design of urban elements such as a roundabout or a crossroads. Each element of the public thoroughfare in an urban environment is unique, but it is possible to classify them in a little number of category [8]. Concerning pedestrians, it is not possible to restrict the environment to a subpart of the city, like the thoroughfare for vehicles as, unlike car or tram drivers, they can wander about everywhere in the city. The autonomous actors presented in this paper are pedestrian navigating in a virtual city; urban organisation and social rules guide their behaviours.

3 The synthetic pedestrian

3.1 Introduction

Gibson [13] states that *animals perceive the environment in terms of what they can do with and in it* (theory of affor-

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[1] A street is composed of connected lanes devoted to distinct mobile entities such as cars and pedestrians

dance). The **what ... with** has been addressed by Becheiraz and Kallmann [3, 16] with the notion of *smart objects*. Here we are interested in the simulation of pedestrians acting **in** a virtual urban environment. As introduced before, it is necessary to inform the environment. The complete city model and the modelling tool we implemented is described in [24]. The purpose of this paper is not to present in detail the urban database but to present the synthetic pedestrian model and what information are used for each of his behaviours.

3.2 The pedestrian model

The synthetic pedestrian model is based on the traditional perception / decision / action loop used to define autonomous actors. Autonomous actors are endowed with intentions; to achieve those intentions, they take decisions in accordance with their perception of the environment and their temperament. Up to now, the pedestrian's intentions are reduced to specific locations he should pass through. Its temperament is characterized by a desired speed and a caution factor. Two attributes representing the oval security zone introduced by Goffman [14] are also associated to pedestrians. The front distance represents an anticipation zone and the lateral distance is the accepted gap to pass beside an other actor, a building or an object. Social variety can be reproduced thanks to the notion of temperament and the parameterization of the Goffman's oval security zone.
Three main activities characterize the pedestrian behaviour:

1. Navigation: path planning is guided by the pedestrian caution.
2. Circulation in urban spaces: to follow a sidewalk or to cross a street for example. Cautious pedestrian will perform those actions in respect with social rules and obeying signals.
3. Obstacle avoidance: concerns the avoidance of objects and actors. Interactions between actors are based on social rules.

Pedestrian's behaviour depends on its urban knowledge and on its perception of the environment. Figure 1 shows that in correlation with the three behaviour levels of the pedestrian (to navigate, to circulate, to avoid obstacles), three levels of data constitute the urban database (hierarchical and topological structures, space representation and lists of objects and actors associated to spaces).

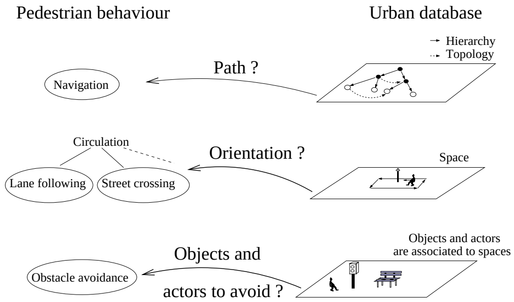


Figure 1. Pedestrian's activities.

1. The navigation behaviour is possible if the pedestrian *knows* the accessibility relations between spaces; the topological structure contains all urban spaces connected through their adjacent borders. A border is a component of a space outline; this border can be immaterial but also a building wall or a barrier along a side-walk for example. Because planning behaviour can take place at distinct hierarchical levels of the city (between two suburbs for example), the database contains a hierarchical description of the city that could be exploited to simulate the mental map of a pedestrian. An example of hierarchical relation is that a road section is composed of lanes and crosswalks.
2. Pedestrian trajectories through spaces depends on the space type (lane, intersection, square) and on the circulation action (to turn, to follow, to cross). We have proposed space structures that help pedestrians in performing those circulation actions.
3. The last behavioural level is obstacle avoidance. A list of objects is associated to each space and a list of actors is updated at each simulation step. Objects and actors have symbolical and procedural attributes which are useful for pedestrian decisions.

The relationship between the pedestrian and its environment is implemented through perception which is not based on a vision cone but on access methods to the database. These methods extract visible objects in an attending zone. A social study of pedestrians following side-walks corroborate our choice of attending behaviour [22]. The attending zone is defined when the pedestrian looks for "spatial affordances"; the zone depends on the circulation space and on the pedestrian activity. When the pedestrian follows a side-walk he looks straight ahead, whereas when he is on the point to cross a street he looks on both sides.

3.3 Navigation

To specify the journey of a pedestrian, the user has to give a set of positions in the city that should be reached. From this set, the pedestrian constructs a path to follow. Its navigation behaviour is based on the hierarchical and topological structure of the urban environment. Although if the first path planning algorithm we implemented is trivial, the hierarchical and topological structure is adapted to many planning algorithms. The pedestrian's caution guides the choice of its path. Figure 2 shows an urban area composed of three crossroads. In this simulation, the user specified two points **A** and **B**. From those points, two paths have been generated; one by a cautious pedestrian and the other by a careless one.

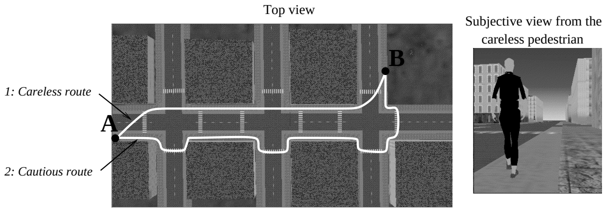


Figure 2. Route choice depends on caution.

The difference between the two paths drawn on figure 2 is a consequence of the choice of spaces to cross made by the pedestrians:

1. Careless pedestrian tries to take the shortest path. The resulting path is a succession of wild crosses inside each road section.
2. Cautious pedestrian goes only through spaces dedicated to pedestrian circulation (sidewalk and crosswalks in this example).

To resume, the first path that the pedestrian generates from the hierarchical and topological structures is a list of spaces. The next step of the pedestrian behaviour is to walk through each space knowing the entrance and exit borders of each space. The pedestrian behaviour through regions is described in next sections.

3.4 Circulating through lanes

Following a lane is a very usual behaviour for a pedestrian; his main goal during this activity is to avoid static and dynamic obstacles. The structure associated to lanes simplifies this pedestrian behaviour.

3.4.1 Lane structure

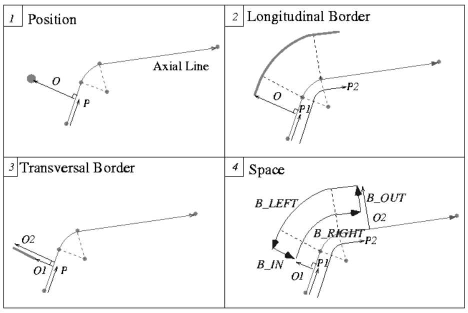


Figure 3. From position to space.

A lane is characterized by a main direction of circulation (called skeleton or axial line) and a width. In the urban model exploited by the autonomous pedestrian a lane is a space defined by four oriented borders geometrically indexed on the skeleton of the road (the axial line). Figure 3 shows the reference system relative to the axial line. In this system a position is defined by a parameter **P** and an offset **O** to the axial line (see picture 1 on figure 3). The fourth picture represents a space which is a lane composed of two longitudinal (**B_LEFT** and **B_RIGHT**) and two transversal (**B_IN** and **B_OUT**) borders. Given an entity with a relative position (**O**, **P**), the lane configuration (see picture 4 in figure 3) easily allows to:

- *test inclusion*: a pedestrian is included in the space if its parameter is between $\mathbf{P}_1$ and $\mathbf{P}_2$, and its offset between $\mathbf{O}_1$ and $\mathbf{O}_2$.
- *follow a lane*: the orientation is tangent to the axial line at parameter **P**; offset is constant.

Before circulating through a lane, the pedestrian knows the entrance and the exit border (it is a result of the navigation behaviour described in previous section). Depending on those borders, resulting circulation actions are: to follow (with the same orientation than the axial line FOLLOW+ or opposite one FOLLOW-), to turn (LEFT or RIGHT) and to cross (from left to right CROSS+ or from right to left CROSS-). Procedural and geometrical information necessary for pedestrian circulation through a lane is obtained from the lane structure:

- procedural information: circulation action depends on entrance and exit borders and is calculated using the routing matrix showed in figure 4.

EXIT ENTRANCE	B_IN (1)	B_RIGHT (2)	B_OUT (3)	B_LEFT (4)
B_IN (1)		RIGHT	FOLLOW+	LEFT
B_RIGHT (2)	LEFT		RIGHT	CROSS-
B_OUT (3)	FOLLOW-	LEFT		RIGHT
B_LEFT (4)	RIGHT	CROSS +	LEFT	

Figure 4. Actions matrix.

- trajectory depends on action:
  - to follow: orientation is the tangent (or opposite) at the axial line.
  - to cross: orientation is perpendicular to the axial line.
  - to turn: the pedestrian calculates a Bezier curve.

3.4.2 Obstacle avoidance

A list of objects is associated to each lane. Objects are positioned relatively to the axial line; this allows to perform an efficient obstacle avoidance. Figure 5 illustrates a situation of obstacle avoidance for a pedestrian.

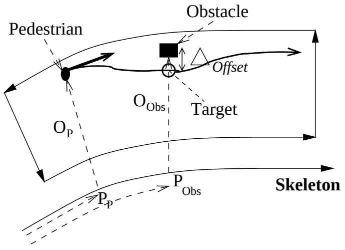


Figure 5. Obstacle avoidance.

When an obstacle ($\mathbf{O}_{Obs}, \mathbf{P}_{Obs}$) is on the path of the pedestrian ($\mathbf{O}_P, \mathbf{P}_P$), a target position ($\mathbf{O}_{Obs} + \Delta_{Offset}, \mathbf{P}_{Obs}$) is computed to bypass the obstacle. An obstacle is on the path of the pedestrian if $\mid O_P - O_{Obs} \mid < Epsilon_1$ and $\mathcal{D}(P_P, P_{Obs}) < Epsilon_2$. $Epsilon_1$ and $Epsilon_2$ are the pedestrian attributes inspired from Goffman's oval model [14]. The reality is more complex than avoiding a single obstacle. To complete the behaviour of entities through lanes, a study of dynamic interactions has been done.

3.4.3 Pedestrians avoidance

Our objective is to obtain realistic pedestrian flows on lanes; pedestrians decisional part is therefore coherent with driving rules and the law of minimum changes introduced by Goffman [14]. Three interaction configurations exist; there are graphically illustrated at the top of the figure 6:

1. confrontation: two pedestrians are face to face and mutually block their ways.
2. blockage: a pedestrian blocks another pedestrian way because he goes in the same direction but walks slower.
3. perpendicular: a pedestrian tries to cross the lane while an other near him is following the lane.

Depending on the configuration, several adjustment decisions are possible for confrontation and blockage configurations (see figure 6). The choice between "driving rules" and "minimum changes" depends on adjustment distance. If distance between pedestrians is more than 10 meters, "driving rules" is chosen; this choice ensures the minimum number of interactions between pedestrians. When distance between pedestrians is low, "minimum changes" are chosen in order to avoid collisions. When pedestrian current action is to turn (**LEFT** or **RIGHT**) a prediction is realised on the consequence of the direction change. This prediction illustrated in figure 7 brings the situation back to configurations of the figure 6.

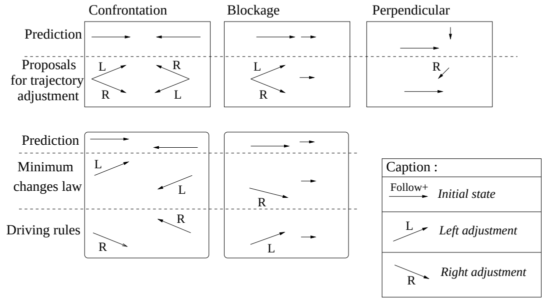


Figure 6. Interaction configurations.

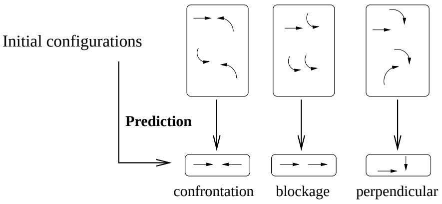


Figure 7. Prediction on pedestrians who are changing direction.

Figure 8 shows a simple example of a pedestrian **A** following a lane looking for its *spatial affordance*. When a pedestrian follows a lane, its attending zone is straight ahead. Based on this attending zone, pedestrians and objects are extracted from the database. For each lane in the urban environment, a sorted list of pedestrians and cars present in this lane is maintained. The output of the perception filtering on the database is a list of pedestrians and actors present in the attending zone. Information associated to each pedestrian is: relative position, speed and action (**FOLLOW+**, **FOLLOW-**, **LEFT**, **RIGHT**, **CROSS+**, **CROSS-**). The search algorithm of the opening works as follow: pedestrians and objects present in the attending zone are successively considered; the search stops if an opening is found or if the limit of the attending zone is reached. When no opening is found, the pedestrian goes behind the nearest pedestrian which block its way if it exists, adjusting its speed, and if nobody blocks its way, he slows down. This algorithm works fast due to the relative positioning system in lanes. Indeed the comparison between pedestrian's positions is low cost; it corresponds to two comparisons between the offset and the parameter values. In the configuration shown in figure 8 two pedestrians (**B** and **C**) responsible of a negative affordance [22] for **A** are extracted from the database. After the search algorithm, no opening is found by pedestrian **A**; its decision is to go behind pedestrian **B**.

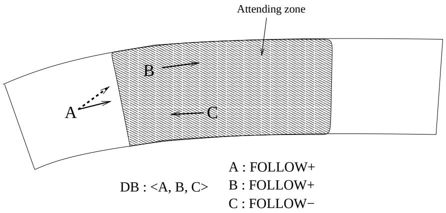
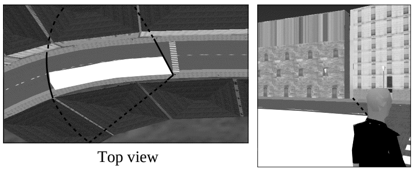


Figure 8. Looking for spatial affordance.

3.5 Crossing streets

Many psychological studies deal with risky pedestrian crossing behaviours. Firth [11] observed a variety of pre-crossing behaviours based on the selection of the moment and of the location for crossing. His study revealed a variety of behaviours between children, adults and elderly pedestrians. Wagner [25] also recorded observations on pedestrians pre-crossing behaviour; he observed a role differentiation among pedestrians waiting to cross a busy street. Some read signals, some watched for cars, and others simply watched those who stood in front of them. We plan to simulate those configurations using our environment and behaviour modelling tools. Figure 9 illustrates the pre-cross state of a pedestrian. In order to take its crossing decision, the pedestrian observes the environment. The attending behaviour depends on the street configuration: the presence or not of crosswalks and pedestrian traffic lights. In figure 9 there is a cross-walk; the pedestrian chooses to cross on it (chooses its place) and wait for the clean field before crossing.


Top view

Subjective view

Figure 9. Cross behaviour decision process.

The topological structure of a road section contains adjacency relations between lanes that guide the definition of the attending zone (outlined in white in figure 9). A nature (car lane, sidewalk) and a logical information (direct or indirect circulation) are also associated to each lane; using this information, the pedestrian **knows** the kind of entities that can block his way and their arrival direction. In the cross situation shown in figure 9, the first attending zone is in the sub-part of the car-lane near the sidewalk where the pedestrian is. From perception (performed with a filter on the database), a list of cars and their associated speed and distance is extracted from the database. From this list, the pedestrian calculates the crossing gap. If no spatial affordance is found (e.g. the gap is too short) the pedestrian goes on looking after the traffic; otherwise, he crosses.

The gap calculus is based on pedestrian assessment on cars speed and distance and on its potential walk speed. All pedestrians do not have the same assessments capabilities neither potential speed. In this way, behaviours variety comes from variations in the gap acceptance; this is conform to sociological studies [15]. A pedestrian can safely cross when the road section contains a crosswalk associated with a pedestrian traffic light. In this configuration, the attending zone of a pedestrian which respect driving rules is on the opposite sidewalk where the object of interest is the traffic light. This scenario simply illustrates the endogenous attending behaviour. The pedestrian can easily orient his gaze toward the traffic light due to its **knowledge** of the street configuration represented in the database.

4 Simulations

Up to now, driving simulations are commonly limited to cars and trucks interactions on highways. Urban traffic has a higher degree of complexity, as it requires interactions on the same thoroughfare between not only cars, trucks, cyclists and pedestrians, but also public transportation systems such as busses and trams. As our approach is modular, we have started to integrate all these transportation modes into GASP, our simulation platform [9]. Mechanical models of tram, trucks and cars are available, as well as a biomechanical model of pedestrians (see figure 10). Each simulation is composed of several modules working at their own frequency. The kernel of the simulation platform manages the data-flow and event based communication between modules and their synchronization. Modules are organized in a simulation tree and for example an autonomous pedestrian entity is composed of a visual sensor module, a behavioural module and a biomechanical module. The user can also control the motion of one pedestrian by using a joystick with force feedback.

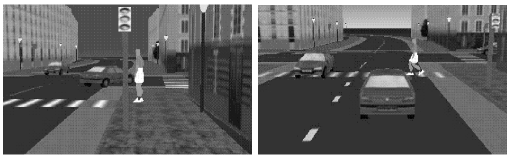


Figure 10. Pedestrians and cars interaction.

A set of tools has been developped to produce these models (see in Figure 11). Hierarchical Parallel Transition Systems, or HPTS is a formalism proposed to specify the decisional part of an autonomous entity. A language has been proposed to describe both the hierarchical parallel state machines and their associated data-flows [19]. Afterwards, C++ code for GASP is generated. The emphasis in the code generation phase is put on efficiency and connectivity to existing C++ code. The mechanical aspect of the car is modelled with DREAM, our rigid and deformable bodies modelling system which generates numerical C++ simulation code for GASP. VUEMS is the acronym for Virtual Urban Environment Modelling System, and its main aim is to build a realistic virtual copy of urban environments in which we would perform behavioural simulations. VUEMS produces two complementary outputs: the 3D geometric representation of the scene and its symbolic representation used by sensors and behavioural entities. The scene produced by VUEMS is loaded and is then available for use by all autonomous entities. First, sensors can determine visible objects in their environment and then the behavioural module can have access to the information on these visible objects.

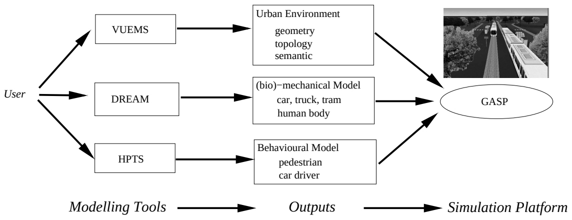


Figure 11. A set of modelling tools.

Figure 12 illustrates the variety of trajectories taken by pedestrians on the same sidewalk[2]. The sequence of the figure 13 illustrates the navigation task of a pedestrian evolving in a city, using for that the topological structure of the virtual environment and passing through connected regions. The twelve pictures of the figure 14 illustrate the crossing of two pedestrian crowds on a sidewalk. The camera viewpoint corresponds to the subjective view of one of the fifty pedestrians, which explain why pedestrians arriving on the opposite direction change their trajectory. The behavioural model of pedestrians includes social and driving rules of interaction (minimize the interaction and choose in priority the left side to overtake), as explained in this paper. Videos of simulation sequences can be viewed at the following address: **http://www.irisa.fr/prive/donikian/**.

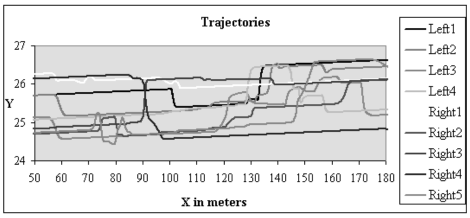


Figure 12. Pedestrian's trajectories on a sidewalk.

5 Conclusion and perspectives

In this paper we have presented the behavioural model of an autonomous human agent, which is able to navigate through informed urban environments automatically generated by VUEMS, our Virtual Urban Environment Modelling System. The simulation we realised shows how the attachment of information and structures to the environment helps for the simulation of complex and realistic behaviours. The enrichment of the environment is possible thanks to the modelling tool we developed. We think that this approach of modelling tools dedicated to behavioural animation is promising. First results concerning multi-modal interaction has been obtained, but more work should be performed on behavioural models. Up to now we have focused our attention on the nature of the interaction of human agents with their environment, an obvious extension concerns what actors can do with objects in it.

A perspective concerns the simulation of autonomous actors inside buildings, as concepts used for urban environments can be easily transposed to the internal structure of buildings. Another perspective is to improve the cognitive aspect of pedestrians. The main aim of this paper was to show benefits obtained in the realism of behaviour by informing the environment and by using it in perception and decisional mechanisms.

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[2] Left indicates that the pedestrian come from the left side.

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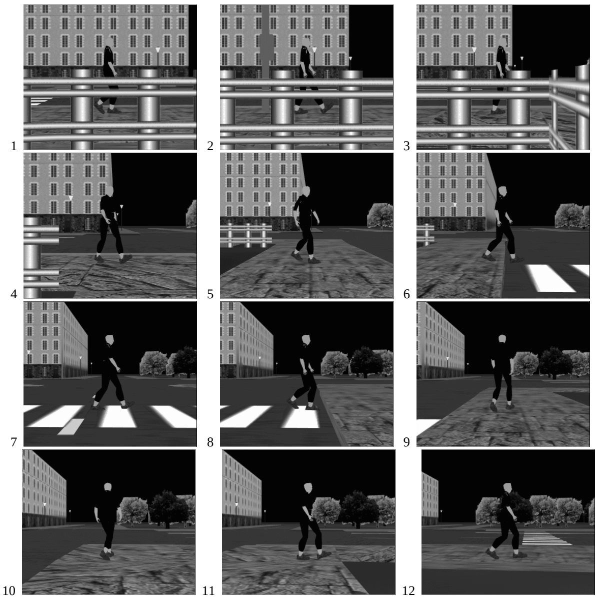

Figure 13. Navigating in the city.

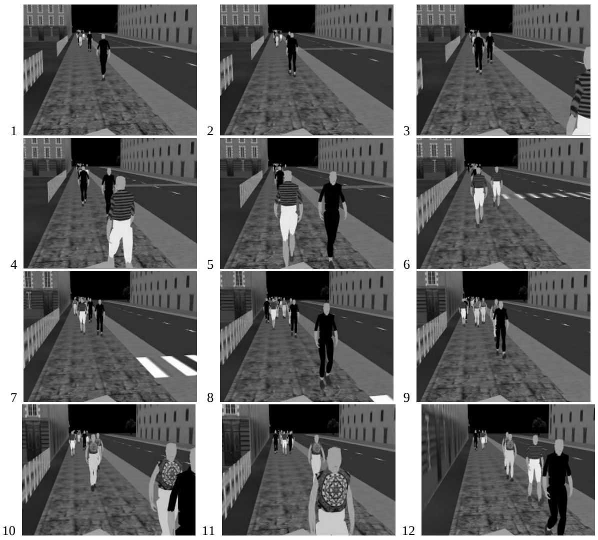

Figure 14. Pedestrians on a sidewalk.