Modelling pedestrian behaviour using the BDI architecture

Nicole Ronald and Leon Sterling
Department of Computer Science and Software Engineering
The University of Melbourne
Victoria 3010, Australia
{naron,leon}@cs.mu.oz.au

Abstract

The modelling of pedestrian behaviour in a real-world environment is a complex problem, mainly due to the unpredictable nature of human decision making. Agent-oriented simulation moves away from the traditional all-knowing and “controlling” simulations and towards reality, where pedestrians exhibit different behaviours depending on their knowledge of the environment and other personal characteristics. We explore whether the belief-desire-intention (BDI) architecture is appropriate for this domain using the design methodology Prometheus and programming language JACK Intelligent Agents. Although the BDI architecture is useful for high-level decision making, further work is required in representing and updating the environment.

1. Introduction

There is a need to model pedestrian behaviour for a range of applications including event planning, resource usage, and urban planning. For example, the organisers of a large sporting event require information on what areas are likely to be congested so that management strategies can be developed and tested before the event.

Most of the models developed so far fall in one of two categories: large-scale models producing aggregate results and smaller, disaggregate models. Less work has been done for pedestrian modelling in between these two extremes.

Agent-based simulation appears to have potential for pedestrian modelling. Each pedestrian could be modelled as an autonomous agent with its own knowledge and goals. This representation is closer to reality than traditional simulation methods as it requires less abstraction.

The purpose of our research is to compare different agent-based approaches to modelling pedestrian behaviour, in particular the benefits of disaggregate modelling. The approach we discuss in this paper is based upon belief-desire-intention agents.

2. System properties

The Australian Pedestrian Council defines a pedestrian as “any person wishing to travel by foot, wheelchair or electric scooter, throughout the community” [2]. There are many reasons for walking, and the manner in which we walk changes depending on the purpose.

“Commuters scurry; shoppers meander; bushwalkers trek; power-walkers stride; lovers stroll; tourists promenade; protesters march ... But we all walk.” [2]

Transport systems are constrained, sometimes weakly. For instance, people cannot cross the road whenever they feel like it - they should find a suitable place (such as an intersection) and wait until it is safe. They also should travel on the pedestrian network (eg. designated paths) at all times, however if it becomes too congested, pedestrians may overflow onto the road or surrounding parkland. A stricter constraint is that pedestrians cannot walk through solid objects or on water.

Transport planning is a decision-making process in which the problem is identified, strategies are developed, modelled and evaluated, and the most preferable solution is recommended for implementation [11]. The evaluation of strategies involves examining the effects on stakeholders and the environment and can be undertaken in many ways. Several strategies could be selected for a trial run, however physical tests are not always feasible. For example, it is impractical (not to mention expensive) to build several versions of a pedestrian bridge in order to evaluate the option with the most benefit. In these cases, computers are used to set up an “artificial reality” - a computer model or simulation - which is used to test different strategies.

The inputs to transport models usually include demographic data (age, sex, place of residence, type of work), land use data (assists in determining attractability of certain locations), and demand drivers (what locations are popular, what times are people travelling). This data is sourced from
public data, such as census and land-use data, and data collected specifically for the model, such as the results of an observation or a questionnaire survey. The results of transport models can include economic, environmental and social data.

Most transport modelling techniques have focused on the modelling of cars and vehicles on the road network, as congestion and environmental effects of car travel are pressing problems for cities. The recent interest in environmentally sustainable transport modes however, has led to an interest in providing better infrastructure and facilities for cyclists and pedestrians and therefore a need for improved methods of modelling their behaviour.

3. Previous work

There are many approaches to modelling pedestrian behaviour, which can be divided into two schools. The first school is the “civil engineering” approach. This is concerned with forecasting demand so that decisions can be made about provision of new infrastructure. The main outputs of these models are numbers of people travelling along various routes and the algorithms used are frequently based on traditional vehicle modelling algorithms. They are generally macroscopic or aggregate models, where the smallest detail of a pedestrian’s movement is the locations they visited and the paths they used to get there.

The second school is the “architecture/urban geography” approach. This group is interested in how people move around areas, in particular how design and location of certain attractions influence their movements. These models are usually microscopic, in that they model a pedestrian’s path in more detail, usually in terms of steps or small grid squares. They are usually developed for small areas only, although some have been expanded to cover entire cities. Some models combine both approaches and as a result are very flexible regarding the type of areas they can model.

Mathematical models, such as regression models and Markov models, have also been used to model pedestrian behaviour at aggregate levels [6]. This approach is severely limited due to its simplicity.

Physical models have also been used to model pedestrians. Helbing [7] used the notion of attraction and repulsion to model microscopic behaviour and has developed complex equations to model a range of pedestrian behaviours, commonly referred to as the “social force” model. Hoogendoorn and Bovy [9] have also used this approach for modelling a multi-modal transfer station.

A similar approach is the use of cellular automata (CA), where pedestrians occupy cells on a grid and move according to some simple rules [5, 8, 10]. This has been shown to be useful for disaggregate models with minimal activity choice.

Traditional time-based simulation has also been used in industry. PAXPORT, developed by the consulting firm Halcrow, has been used to model pedestrian movements in airports, train stations, and sporting venues. It provides aggregate measures of flow and level-of-service in a graph-based environment.

4. Modelling Aspects

4.1. Overall Architecture

Transport systems can be broken down into three main concepts: user, vehicle and environment. The user has a perception of attributes of the environment and their vehicle, and needs to guide their vehicle through the environment. The vehicle interacts with and changes the environment. The environment is constantly updated with the new locations of vehicles and provides perceptions to vehicles and users.

For pedestrians, the user and vehicle are essentially the same object: a human. However, most of our walking is done subconsciously and therefore it is permissible to separate these two concepts. We can define the user as the human’s brain and the vehicle as the human’s legs.

4.2. The BDI Architecture

The philosophical component of BDI is based upon practical reasoning. Practical reasoning is defined as reasoning toward actions, as opposed to theoretical reasoning, which is reasoning about beliefs [14].

The key concepts in the BDI architecture are beliefs (what I know or don’t know about the world), desire (what I want to do), and intentions (how I plan to do what I want to do).

BDI fits our problem well, in that:

- People have beliefs about the environment that affect their decisions (eg. “The main street is always crowded at lunchtime - I will take another route.”);

- People have desires to do something or to visit somewhere. If people are wandering “just because”, then that is still a desire;

- People have plans or procedures of deciding where to go first, how to get there, and how to create a path to follow;

- If a route is blocked due to congestion or temporary infrastructure, a new plan can be formulated and a new path taken to reach a location.
4.3. Designing with Prometheus

Prometheus is a methodology developed for specifying agent-oriented software systems. Prometheus was chosen because of its maturity (a book was recently published [12]) and because the concepts used in the methodology tie in with the concepts used in JACK Intelligent Agents, our chosen implementation language. Prometheus consists of three design phases:

- system specification phase: identify functionalities, inputs, outputs and shard data sources;
- architectural design phase: determine agents required and their interaction; and
- detailed design phase: internal design of agents.

The resulting design is a combination of forms and diagrams, which clearly describe the percepts, action, environment, agents, capabilities, and plans in the system. It would not be unfamiliar to those familiar with UML for object-oriented design [13].

The system specification involves identifying system goals and functionalities, developing the interface between system and environment, and developing use case scenarios. An example of a goal diagram is shown in Figure 1, which shows three goals (visit attractions, arrive at the stadium at a reasonable time, move through the environment) and their subgoals using an oval shape. One of the goals is to move through the environment, with the subgoals of satisfying network constraints and taking a reasonable path.

Figure 1. Displaying system goals using Prometheus.

Goals can then be grouped together to create functionalities. Scenarios can also be developed. These consist of steps such as percepts, goals and actions. The system interface involves determining the actions and percepts of the interface to the environment.

The architectural design phase involves grouping the functionalities into similar areas, developing agents to control each area, and specifying the interactions between agents. Also in this phase, communication between agents can also be specified at a high level.

In the detailed design phase, the agent’s capabilities, events, plans and data structures are developed in more detail. An example of a detailed design for the Pedestrian agent is shown in Figure 2. This shows the messages (envelope shape), events (percepts: stars shapes; actions: arrow shapes), capabilities (rounded rectangles), and plans that the agent requires. The arrows signify the incoming and outgoing nature of events.

Figure 2. A detailed design for a Pedestrian agent.

Capabilities are similar to modules in that related plans, events, and data can be combined together in a coherent manner. In this model the pedestrian has a capability for each of its main activities.

Events can be actions (affecting the environment in some way), percepts (knowledge coming from the environment), and messages (to and from other agents). For each of these concepts, several parameters need to be designed including the information carried by the percept/message, the effect of the action, and what to do in case of failure.

Descriptions of data usage are also required. Plans need to specify whether they are reading and/or writing data.

Also in this stage, plans are described at a high level, including their name, the percepts that trigger them, and the actions that occur during the plan. They will be designed in more detail depending on the implementation platform.

The main issue with using an agent-oriented methodology is that it designs the simulation only, i.e. what the agents are doing. It cannot design the core of the simulation, i.e. how the clock will tick over, the graphical user interfaces required to set up the simulation, the methods to collect outputs. Therefore Prometheus needs to be combined with another methodology to design the whole of the simulation.
4.4. Implementation

We constructed a prototype model in JACK Intelligent Agents which involved agents entering a sports precinct and moving towards a stadium. Several “distractions” were located on the way to the stadium, such as food stands and street performers. In our prototype, we attempted to implement the entire model architecture (user-vehicle-environment) in JACK to avoid complex interfacing.

JACK [1] is based on the BDI architecture and was purpose-built for simulations, in particular defence simulations. It is based on Java with a few syntactic extensions, and when compiled compiles to Java code [4].

JACK supports the concepts in the BDI architecture and Prometheus: agents, events, beliefs (data), capabilities, and plans. As the JACK files are compiled into Java before execution, normal Java statements can be embedded in JACK files.

It is straightforward to implement goal-directed behaviour, such as moving towards the stadium. However, it is difficult to represent an environment in detail using JACK beliefsets. Ideally an interface to the environment should be developed and then any environment format (e.g. graph, cells, shapes) could be used behind that.

The decision-making used in BDI and JACK cannot elegantly handle continuous events, such as stepping. It is also difficult to define the subconscious decisions behind walking. Therefore the vehicle model in our architecture would be better suited to an object representation rather than an agent one. JACK has the ability to interface with both Java and C++ code, however we are still experimenting with this interface.

5. Conclusion

In this paper, we explored the need for pedestrian modelling, the nature of pedestrian behaviour and techniques for modelling it. In particular, we investigated using the belief-desire-intention (BDI) architecture to model pedestrian behaviour using the design methodology Prometheus and the agent-oriented language JACK Intelligent Agents.

We found that the user-vehicle-environment architecture is an appropriate separation for transport models, and applies to pedestrian models even though the user and vehicle are physically the same. The BDI architecture is appropriate for the user model only, as that is where the decisions are made. Prometheus is useful for designing the BDI concepts required. For the vehicle and environment model, an object approach is more suitable than using an agent language such as JACK.

The work is continuing as part of a larger project to evaluate approaches and methodologies for modelling pedestrian behaviour. The next stage is to learn from our prototype and use JACK Intelligent Agents to develop a model of the user, following the Prometheus specification, and connecting it to environment and vehicle modules written in Java.

References