AN AGENT-BASED SIMULATION OF CROWD MOVEMENT

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Abstract We present a simulation of crowds of people moving around a city, and interacting with each other. The city is represented as a set of squares connected by streets. People are modelled as agents that move from square to square. Interactions between agents, and between agents and the environment, are modelled probabilistically. We find that there are two different modes of long-term behaviour. Either the population of agents distributes itself around the city (in a predictable way) or a large crowd forms spontaneously in one of the squares. The observed behaviour depends on the value of a parameter of the model, and changes mode as that parameter passes a critical threshold.

keywords: crowd movement, simulation, multi-agent system, social interaction, complex system

1 COMPLEX SYSTEMS

"When I stand on a railway platform behind a knot of people trying to get through the door of a crowded commuter train, do I maximise my chances of getting a seat by approaching from behind the centre of the group, or along the sides of the carriage? Are there any specific mathematical rules governing such crowd behaviour?"

This is a question which appeared in the Q&A section of the New Scientist magazine a few months ago [New Scientist, 2002]. It is a typical example of the types of questions the theory of complex systems seeks to answer.

Formally, a complex system is typically defined as "a system which consists of parts interacting in a non-linear way" [Pavard, 2002]. Informally, a complex system is described as "a system which is difficult, if not impossible, to reduce the number of descriptive parameters or variables without losing its essential functional global properties" [Pavard, 2002].

The various theories that have been developed to study complex systems are typically classified in three main, complementary but independent approaches:

• the mathematical theory of non-linear systems

• the AI/neural network approach,

• the theory of distributed or self-organized systems.

The first of these approaches emerged in the beginning of the century out of the pioneering work on developing analytical equations to predict the trajectory of planets. This has been mainly employed for the modeling of physical complex systems.

The neural network approach emerged in the '50s and was mainly used to model the behavior of neurons and explore their classification capabilities.

The theory of distributed or self-organized systems modelling complex systems consisting of entities (humans, technical systems, insects, birds, etc) and where decisions are totally or partially taken collectively by these entities. This approach is viewed as particularly suitable for modelling complex social phenomena, such as trade migration, group formation, battles, interaction with an environment, transmissions of culture, propagation of disease, population dynamics etc and has therefore attracted considerable interest [Epstein, 1996]. The objective here is to identify recognisable macroscopic social patterns while complex behaviours that are typically of interest are, for instance, non-determinism, emergence and self-organization, distributed nature of information etc.

This paradigm includes elements from other related fields and has over time made use of different respective modelling methodologies including connectionist cognitive science, distributed artificial intelligence, genetic algorithms, cellular automata, artificial life, biological modelling etc. [Epstein, 1996].

Recently, there has been considerable interest in modelling such distributed complex systems as agent-based systems.

A multi-agent system consists of a collection of autonomous software and/or hardware components (agents) which are embedded in
an environment and cooperate to perform some task [Wooldridge and Jennings, 1995].

An agent is typically viewed as a self-contained, concurrently executing thread of control. It encapsulates an internal state space and a set of behavioural rules. Some of its state is static and fixed throughout its existence, while some other depends on its interaction with the environment. The behavioural rules dictate the autonomous actions of the agent as well as its reactions in response to the messages it receives from its environment ("agent-environment" rules). An agent can be a simple as a basic java thread, to a complicated AI structure with sensing, planning, inference etc. capabilities [Jennings and Wooldridge, 1998, Bradshaw, 1997].

The environment of an agent encompasses all the entities of the artificial world "inhabited" by the agent. The environment may contain other agents. For any given agent, the other agents of the system will themselves form part of the environment of the agent. The environment itself may encapsulate behavioural rules (e.g. a part of the environment depends on other parts of the environment, "environment-environment" rules).

Thus, the modelling of distributed or self-organized systems using the agent-based approach requires the specification of the agents, the environment, and the rules.

2 CROWD MOVEMENT IN CITIES

A class of complex systems of significant importance for many different fields (from civil engineering and urban planning to psychology and marketing) are pedestrian systems, which study the movement of crowds in cities. The main objective of these studies is to examine the factors and the ways in which they influence the movement of people in an urban setting. Examples of such factors are the configuration of the street network and the location of particular attractions (shops, public building, bars etc.). A chronological overview of the different approaches used to model this problem is provided in [Schelhorn, 1999].

Agent-based systems have been used extensively to study spatial models (e.g. flocking of birds) and several tools have been developed to support the simulation of agent based systems (e.g. Sim-Agent [Sloman, 1996]). The use of agent-based systems in the context of human pedestrian modelling is very limited; three agent-based tools focusing on this latter problem are TRANSIMS [Beckman, 2003], STREETS [Schelhorn, 1999] and LEGION [Still, 2000].

In the city of Granada, Spain, it is customary for young people to wander the streets at night from square to square, meeting their friends, drinking at bars and socialising. Occasionally, when a sufficient number of people gather in the same square, a spontaneous party erupts. It is of interest to be able to predict the conditions under which this happens, so as to be able to prevent such events becoming a public nuisance.

To this end, we simulate the movement of people around a city using an agent-based approach. The city is represented as a graph: there are a number of squares, some of which are connected by streets. Agents wander around from square to square. They interact with each other (by staying to talk) and with the environment (by preferring squares which have a bar). The simulation is controlled by a key parameter: the probability that an agent will stop to chat or drink, as well as being influenced by the topology of the city.

3 THE SIMULATIONS

The old part of the city of Granada is made up of a number of squares, connected by narrow streets. We represent squares as the vertices of a graph. Squares that are directly connected by streets have edges between them. Rather than explicitly modelling Granada, we have looked more abstractly at a number of different topologies and city sizes. Our concern is to understand general principles of crowd movement behaviour, and not just one specific case. The simplest model we have looked at is one in which there are nine squares in a three-by-three grid.

People are modelled as agents which move around the city following simple probabilistic rules. The rules determine how agents interact with each other, and with the environment, and how they move. In the basic model, agents can either stay and chat with each other, or move on. The rules of the basic model are as follows:

**Chatting.** When two agents are in the same square at the same time, then there is the possibility that they will stay for a while to chat. From the point of view of a single agent, we say that for each agent it encounters, there is a probability $c$ that the agent will stay (for one time step) and chat.

**Moving.** If an agent has not found anyone in the square to talk to, then the agent will move to a neighbouring square. The square is chosen uniformly at random from the neighbours of the current square.

Interaction with the environment is added to our model by introducing bars. If there is a bar in a
square, an agent is more likely to stay for a drink. Similarly, an agent is more likely to move to a square containing a bar than to one that does not. These behaviours are summarised in the following alternative rules:

**Chatting.** The probability that two agents stay and chat depends on whether or not there is a bar in the square. If there is a bar, the probability is \( c \). If there is no bar, the probability is \( c/2 \).

**Moving.** When an agent moves to a neighbouring square, those squares which contain a bar are twice as likely to be chosen as squares with no bar.

The main parameters to be set, therefore, are the chatting probability \( c \), the total number of agents \( N \), the topology of the city, and the location of the bars (if any). The model is executed in discrete time steps (or *ticks*). At each tick, an agent is selected at random, and its behaviour is determined using the above rules. Initially, agents are distributed at random around the city.

4 OBSERVED MODES OF BEHAVIOUR

We have conducted a number of experiments with different city topologies, varying the number of agents and their probability of chatting. Our simulation is written in Java, using the RePast libraries\(^1\). We have collected data from many different runs under different parameter settings, in an attempt to understand the characteristics of such systems.

In general, we observe two distinct modes of long-term behaviour. If the chat probability, \( c \), is sufficiently small, then the agents will tend to diffuse around the city. The number of agents that, on average, are in a square depends on the number of streets leading to that square, and whether or not it contains a bar. A square will have a higher long-term population if it is highly connected to other squares, and if it contains a bar. This situation corresponds to a quiet night in the city, where people wander freely. This is illustrated by the results in figure 1. In this example, there are nine squares in a three-by-three grid, with no bars. The population size is 100 and \( c = 0.005 \). The population of each square is shown for a typical run. The effect of adding bar to the central square is shown in figure 2. The population is still distributed about the city but with more people gathered at the bar.

However, if the chat probability, \( c \), is above a critical value, then very quickly all the agents gather together into a single square. This corresponds to the spontaneous self-organisation of a party. This phenomenon occurs even if there are no bars around which such clusters might be expected to form. For example, see the results shown in figure 3, in which we again have a three-by-three city with no bars. The population size is 100 and \( c = 0.1 \). Adding a bar to the central square makes it much more likely that the party will form in that square.

The size of the city, in addition to changing the topology, and therefore the long-term distribution, also affects the short-term, transient, behaviour. This is simply because it takes agents much longer to move around the city. It is also possible, for cities with many squares, that several parties will self-organise in different parts of the city.

5 DISCUSSION

It is clear from the results that we have presented and from many other simulations that the long-term distribution of agents around the city depends critically on the value of the chat probability \( c \) in relation to the population size \( N \). A mathematical analysis shows that, for regular graphs (in which each square has the same number of neighbours), the critical value is \( \frac{\pi}{2} \), where \( n \) is the total number of squares in the city. Of course, in a real-world situation it is hard to measure or estimate the value of this parameter. However, an alternative way of looking at this result is that, given an area of a city with a certain number of squares, there exists a critical population size, above which one can expect spontaneous parties to emerge. Moreover, this critical population size is directly proportional

\[^1\]http://repast.sourceforge.net/
to the number of squares of the area concerned.
In the case where the value of $c$ is lower than the
critical threshold, the crowd disperses itself around
the city. A mathematical analysis of this situation
reveals that the critical factors in this distribution
are:

- whether or not the square has a bar
- the number of neighbours a square has

Obviously our model will tend to make agents
favour staying in squares with bars. However, it is
also interesting that the more connectivity a square
has, the more crowded it is (in the long-term), due
to the fact that there is greater flow through it.
This is because a square with a large number of
neighbouring squares is likely to get more traffic
passing through. If a lot of agents pass through a
square, then it is likely that they will stop and talk
to each other.

We do not claim that we have an accurate model
of how people decide what to do when moving
around a city, nor that we have accurately model-
led the details of any particular city. However, by
running simulations on a more abstract set of mod-
els, we have gone some way towards understanding
the types of behaviours that are exhibited by people
\textit{en masse} and have a good theory as to the primary
factors influencing this behaviour.

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\section*{BIOGRAPHY}

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