Simulating crowd phenomena in African markets

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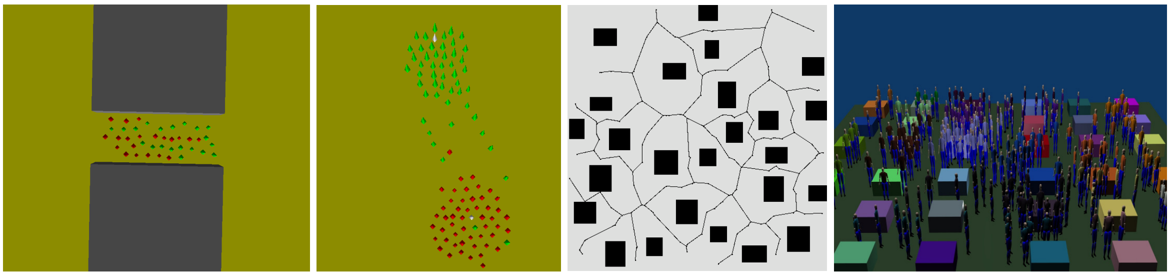

(a) Street flows (b) Street performances (c) Road map of an agent (d) Crowd in an African market

Figure 1: Simulations of crowd phenomena in an African market

Abstract

Crowd simulation is an important feature in the computer graphics field. Typical implementations simulate battle scenes, emergency situations, safety issues or add content to virtual environments. The problem stated in this paper falls in the last category. We present a crowd simulation behavioural model which allows us to simulate identified phenomena in popular local African markets such as narrow street flows and crowd formation around street performances. We propose a three-tier architecture model enable to produce intentions, perform path planning and control movement. We demonstrate that this approach produces the desired behaviour associated with crowds in an African market, which includes navigation, flow formation and circle creation.

CR Categories: I.3.7 [Computer Graphics]: Three-dimensional graphics and realism;1.6.8 [Simulation and modelling]: Type of simulation-Animation

Keywords: crowd simulation, flows, autonomous agents, African market

1 Introduction

Crowd simulation, the procedural animation of large groups of individuals, has applications in areas such as entertainment, urban modelling and safety. In general, these applications require a simulation of crowds under atypical circumstances, such as battle scenes or emergencies. We wish to simulate crowds under non-emergency circumstances, with the aim of achieving "normal" crowd-based phenomena from large numbers of individuals. Our focus is on simulating an African market, which is an example of a densely populated non-emergency environment characterized by high density crowds and narrow navigation areas.

This paper presents an agent-based model that animates a high density crowd in an African market. Each agent consists of an intention generator, path planner and movement controller, and is independent of every other agent in terms of the internal processes for navigating its environment. We investigate whether this agent-based model produces phenomena which we believe to be typical to a high density African market, including flows of agents, and organizational patterns.

This paper is structured as follows: the novelty of our application area (African markets) and motivation for agent design is examined in Section 2. Our simulation model and its implementation is presented in Section 3. We evaluate our model in Section 4 and present conclusions in Section 5.

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2 Related Work

Crowd simulation has become popular in a number of areas, including the creation of films. For example, the MASSIVE system is specially designed for the generation of battle scenes containing thousands of agents (used in the Lord Of Rings III, 2003 [Massive Software Inc 2001]). Crowd simulation is also used for analyzing behaviour in emergency situations with limited navigable areas [Helbing et al. 2000], to assist in the design of safe evacuation strategies. Both these applications are common in that they simulate extraordinary circumstances. In contrast, systems exist for adding content to an existing virtual environment and provide a simulation of a real life crowd phenomena [da Silveira and Musse 2006]. However, these systems tend to assume a Western urban context. Crowd simulation in African markets is still an unexplored subject.

Similar to Tu and Terzopoulos [1994] and Shao and Terzopoulos [2005], we believe that agents in an African market environment are characterized by different types of goals. For instance, an agent that is hungry has the goal of seeking a food stall, while an agent that is bored has the goal of seeking some entertainment. This is

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unlike simulations of emergency or battle environments, where all the agents have an identical goal.

Once a path is defined for navigating to a stall, the agent must follow this path while avoiding collisions with objects in the environment and other agents. We differentiate between two models for agent motion in a virtual environment: social-force and rule-based models. Social-force models represent the interactions between each agent and its neighbourhood using attractive and repulsive forces [Helbing et al. 2000]. These forces are integrated to derive the motion of each agent at each time-step in the simulation. Rule-based models define a finite set of behavioural responses to internal and environmental conditions [Reynolds 1987; Reynolds 1999]. While often appearing realistic, these systems are limited to the set of rules defined and are not transferable to different scenarios. For this reason, our approach to agent basic motion design follows the social force model.

3 Agent design for African markets

African markets have several common characteristics: a high density of people, narrow streets, and public manifestations such as street performances. African markets also contain a large number of obstacles and potential paths from one point to another.

We believe that the navigation decisions taken by a visitor to an African market are not directly influenced by other visitors. As such, we operate at a personal level by individually animating each agent. We use three modules: an intention generator for the agent's global behaviour (specifying goals); a path planner for managing its local behaviour (calculating paths to goals) and a movement controller for basic motion (performing motion and avoiding obstacles).

The structure of these modules and the interactions with the environment are presented in Figure 2.

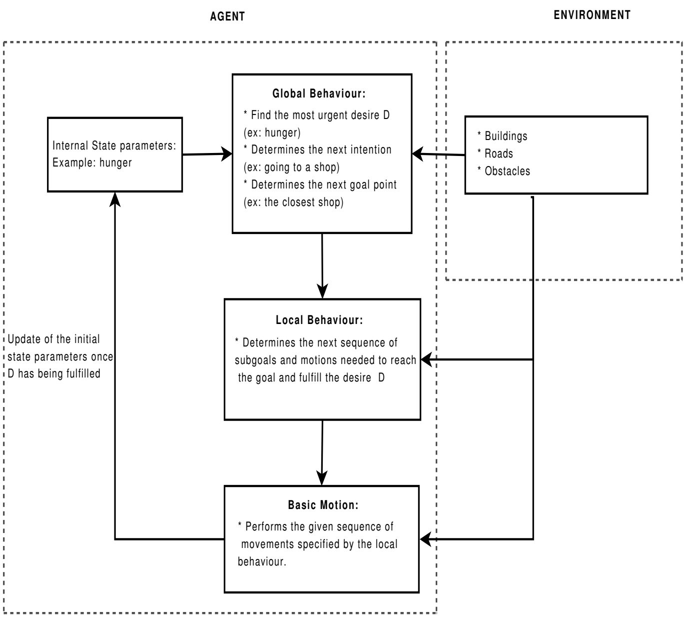


Figure 2: Three components comprising agent structure.

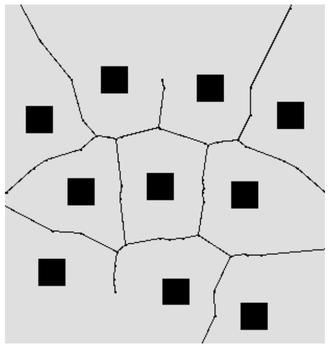


Figure 3: Road map of an agent using Generalized Voronoi diagrams

3.1 Global behaviour

We use a model similar to Tu and Terzopoulos [1994] and Shao and Terzopoulos [2005] for modelling the decision making process for formulating an agent's goals. Decisions are based on sets of rules involving the internal state and the virtual environment. The internal state is represented by a set of predefined parameters representing the agent's desires. The values of these parameters are initialized randomly and updated over time. Influenced by these values and other parameters such as position, the agent will generate an intention (goal) that will satisfy a desire. The ratio of each desire and the distance to the goal (that will satisfy the desire) is calculated, and the greatest is chosen as the goal of the agent. The goal is represented as a coordinate, which is passed to the local behaviour module for formulating a plan to satisfy the desire.

3.2 Local behaviour

The local behaviour component performs collision-free path planning for satisfying a goal generated by the global behaviour component. A path is generated consisting of a sequence of intermediate goals leading to the main target.

Our path planning module is based on probabilistic road maps [Loscos et al. 2003; Overmars 1992]. A graph representing the environment is generated by randomly choosing points in the environment and making connections between these points. Initial nodes are added near each stall and additional random nodes are selected in the environment. An edge is created between two nodes whenever the path from one node to another is collision free. If the agent needs to find a path from its current position to a goal, a sequence of intermediate nodes is produced using the Dijkstra shortest path algorithm [Dijkstra 1959].

An alternative to probabilistic road maps is the concept of generalized Voronoi diagrams (GVD), widely used in path planning [Latombe 1991; Choset and Burdick 1996]. Boundaries of a generalized Voronoi diagrams represent paths of maximal clearance between static obstacles. However practical solutions using GVDs are complex and the complexity increases as the number of agents and stands increases [Sud et al. 2007].

Figure 3 shows the road map of an agent, in an environment containing the footprints of a number of market stands. All the paths in the map are collision free, irrespective of the order or structure with which stands are placed in the environment, and the shortest route choice allows efficient path planning.

Ideally an agent will follow the calculated path directly from its current location to its goal. However, in a multi-agent environment, it is expected that collisions will occur between moving agents. Each intermediate path is passed to the basic motion module, which is responsible for moving the agent in the environment while avoiding collisions.

3.3 Basic motion

Navigation is handled by the basic motion module, based on Helbing's social-forces model [Helbing et al. 2000], which was designed for pedestrian navigation. Once agent i determines the next intermediate goal on its path, its acceleration is defined by:

$$m_i \frac{d\mathbf{v_i}(t)}{dt} = m_i \mathbf{f_{target}} + \sum_{j \neq i} \mathbf{f_{ij}} + \sum_{W} \mathbf{f_{iW}}$$

where $\mathbf{v_i}$ is the agent's current velocity, m_i is its mass, and $\mathbf{f_{target}}$, $\mathbf{f_{ij}}$, $\mathbf{f_{iW}}$ are the following social forces:

- $\mathbf{f_{target}}$ is the attractive force of the intermediate goal defined by:

  $$\mathbf{f_{target}} = \frac{\mathrm{v_i^d}\mathbf{e_i} - \mathbf{v_i}}{\tau_i}$$

  where v_i^d is the desired speed of i (for our experiments we use $v_i^d = 1.5$), $\mathbf{e_i}$ is the unit vector from the target to the position of i and τ_i is a constant time that ensures that agent speed is not too low even after a collision.

- $\mathbf{f_{ij}}$ is a repulsive force from another agent j defined by:

  $$\mathbf{f_{ij}} = \left[A_i \exp(r_{ij}-d_{ij}/B_i) + k g_{ij}\right] \mathbf{n_{ij}} + K g_{ij} \Delta v_{ji} \mathbf{t_{ij}}$$

  where d_{ij} is the distance between i and j, r_{ij} is the sum of their radii, $\mathbf{n_{ij}}$ is the unit vector pointing from j to i and $\mathbf{t_{ij}}$ is the tangential direction. A_i,B_i, K, k are constant values with meanings described in Table 1. The term Δv_{ji} represents a change in velocity $(\mathbf{v_j} - \mathbf{v_i})\mathbf{t_{ij}}$ and:

  $$g_{ij} = \begin{cases} 0 & d_{ij} > r_{ij} \\ r_{ij} - d_{ij} & otherwise \end{cases}$$

- $\mathbf{f_{iW}}$ is a repulsive force from a border of a stall W defined by:

  $$\mathbf{f_{iW}} = [A_i \exp(r_i - d_{iW}/B_i) + k g_{iW}]\, \mathbf{n_{iW}} + K g_{iW}\, (\mathbf{v_i}.\mathbf{t_{iW}})\, \mathbf{t_{iW}}$$

  where d_{iW} is the distance to W, r_i is the the radius of agent i, $\mathbf{n_{iW}}$ is the unit vector perpendicular to the surface of W, $\mathbf{t_{iW}}$ is the tangential direction to W , and:

  $$g_{iW} = \begin{cases} 0 & d_{iW} > r_i \\ r_i - d_{iW} & otherwise \end{cases}$$

A characteristic of the African market is the participation of a large number of people, making the above formulation susceptible to the n-forces problem. This means that each agent must take into account the motion of every other agent, resulting in a complexity of at least $O(n^2)$ for each time-step. To mitigate this problem we perform broad-phase spatial partitioning by dividing the environment into a regular grid [Teschner et al. 2003]. At each time step, cell contents are updated and an agent needs only take into account agents in the same cell and adjacent cells.

We have designed an agent-based model which allows each agent of a crowd to make decisions by choosing a goal that will satisfy their desire, plan a path to that goal and move along the resulting path. The following section determines how well the implementation of this model is able to achieve crowd behaviours exhibited in African markets.

Constant	Description	Value
v_i^d	Desired speed of agent i	1.5
τ_i	Acceleration time of agent i	0.5
A_i	Weight of a repulsive force on agent i	2×10^3
B_i	Fall-off distance of agent i	0.5
k	Pushing weight	1.2×10^5
K	Friction weight	2.4×10^5

Table 1: Description of constant values.

4 Evaluation

We evaluate our crowd simulation model by simulating a market environment, and examining different phenomena that we believe are characteristic of an African market:

- Street flows: We assume passageways between stalls are narrow, making traversal slower as the density of a crowd increases. We believe that in such situations pedestrians tend to form streams in which neighbouring pedestrians line-up and move in the same direction. We investigate if our model produces evidence of these flows.
- Street performances: African markets often contain street performers or unusual events, the result of which is a large crowd surrounding the attraction in a circular fashion. We investigate whether our model is capable of simulating this behaviour.
- Goal-based navigation: We investigate if our model is capable of simulating a crowd in which each individual agent's goals are created and satisfied.

We conduct several experiments discussed below in order to establish the degree to which our system can successfully simulate these phenomena,

4.1 Street Flows

A characteristic of local African markets is narrow passages between stands. We expect a crowd model representing behaviour in such a context to exhibit behaviour associated with these constraints, namely that flows form that allow for faster traversal of agents through a passage.

We examine the rate of two groups of agents passing through a narrow street in opposite directions. In the absence of flows, we expect plentiful collisions and the rate at which the groups pass through the alley should be proportional to the width of the passage i.e. the wider the passage, the faster the crowd passes through. Our expectation is that this will not be the case if flows form, specifically because flows provide for efficient traversal even through narrow passages.

We conduct a simulation with two crowds, each containing 20 agents. Each crowd starts on opposite sides of the passage (where agents are spaced across the full width of the passage). The time taken for both crowds to cross the passage in their entirety is measured for passages of different widths.

The rate t (the reciprocal of the time taken to traverse the passage) is plotted in Figure 4. We observe that the rate is zero or low for very narrow passages, which is expected as the passage is limited

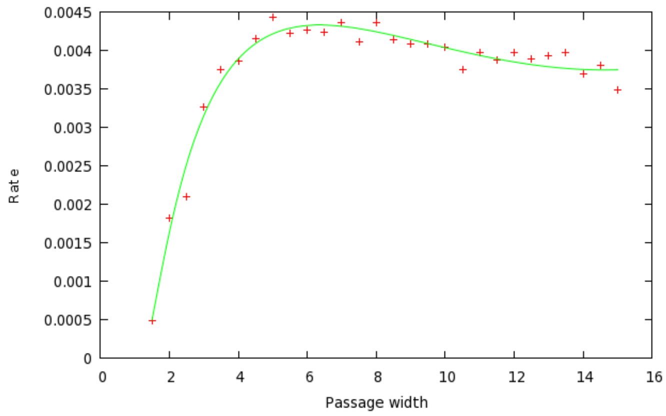


Figure 4: Influence of the width of a passage on the rate.

to only one person at a time. The rate increases rapidly as the passage opens up until it reaches a maximum at which point it decreases slowly with increasing passage width. We attribute this to the formation of flows: narrow passages encourage the formation of streams of individuals in opposite directions which convey both crowds efficiently though the gap. As the passage gets wider, individuals break away from the flow when gaps open up and eventually collide with flows in the opposite direction which reduces the overall rate slightly. This hypothesis is supported by visual observation of simulated agents (illustrated in Figure 1 (a)).

We conducted another simulation of two crowds, fixing the passage width to 3.0 units and increasing the number of agents for each simulation. The rate is plotted in Figure 5. We observe that the rate drops with the increase of the number of agents (as expected) but the rate does not drop as rapidly after the number of agents exceeded 3. We attribute this to the emergence of street flows which can only occur once a sufficient number of agents is present.

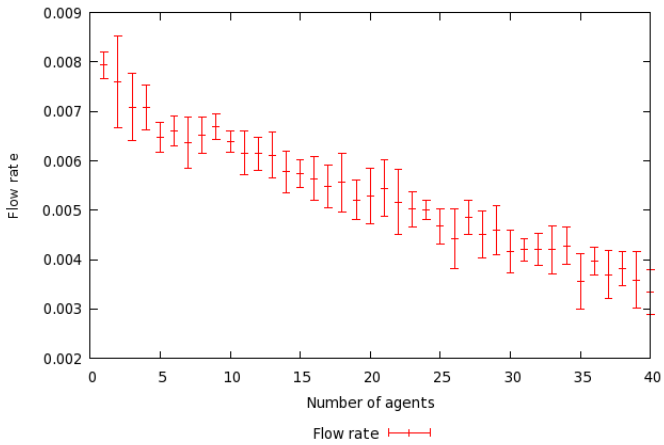


Figure 5: Influence of crowd density on rate.

We introduce a random factor r in the motion of all the agents to further validate the existence of flows. At each time step every agent generates a random value and stops if that value is less than r. The rates observed are plotted in Figure 6, in which the rate drops rapidly as r increases. This rapid drop is explained by the fact that agents are behind another agent that is stopping, and the penalty of the random factor is thus felt on more than a single agent. This means that agents are benefiting from each other i.e. they are not forming paths independently from one another, even though they are designed as autonomous agents.

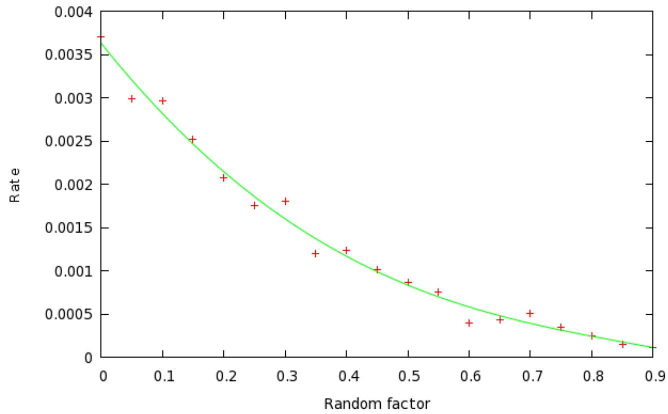


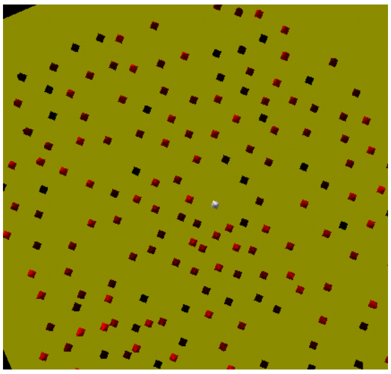
Figure 6: Random factor vs rate

We conclude that our model is capable of producing appropriate street flow behaviour in the context of the narrow passages associated with an African market.

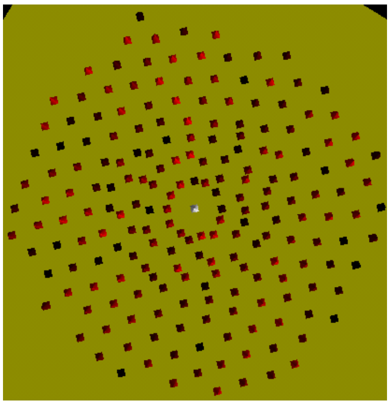
4.2 Street performances

A feature of African market crowds is the attraction to public street performances or unusual events. By adding a curiosity parameter to the internal state of each agent, we allow agents to follow interesting events occurring in the environment and steer towards them. We create a specialist performer agent that exhibits a larger repulsive radius of influence. Agents are initially placed at random locations.

A crowd simulation of 100 agents attracted to an agent named performer is illustrated by Figure 7. We observe that agents are forming a circular pattern around the performer agent, as is typical with such events in an African market. Agents also tend to space themselves evenly in the area beyond the inner ring.

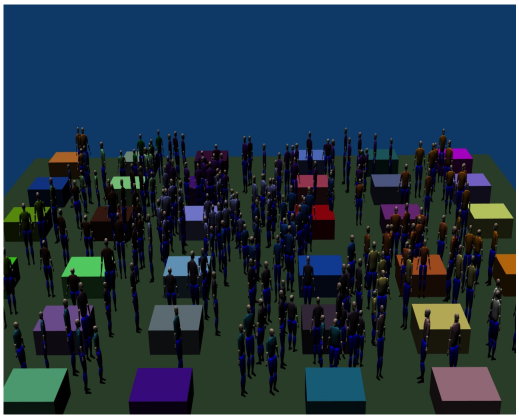


(a) Start

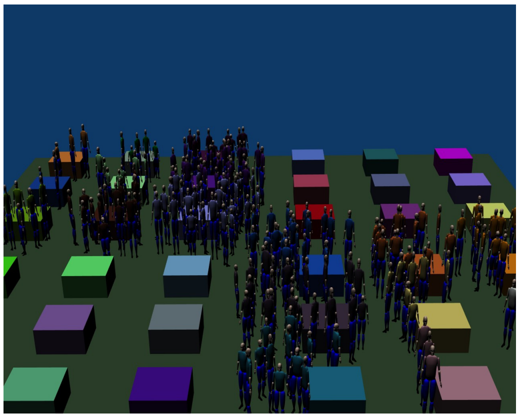


(b) End

Figure 7: Simulation of a crowd attraction to a public street performance.



(a) Start of simulation



(b) End of simulation

Figure 8: Simulation of the virtual market

The significance of this result is the fact that different behaviour is achieved from the crowd as a collective without changing the fundamental design of each agent.

4.3 A local African market

As indicated in Section 2, visitors to an African market are characterized by different desires. We evaluate the path planner and global behaviour components of the crowd model by simulating a marketplace containing 27 stalls and 200 agents (each with individual desires), and observing whether desires are satisfied for each agent.

We classify an agent in a local African market as a buyer or a seller. Sellers can be static or mobile and we assume they specialize in satisfying only one type of desire. 90% of the simulated crowd consists of buyers.

Snap-shots from the simulated output are presented in Figure 8. Agents are textured with the same colour shirts as the goal that they are seeking. We observe that at the beginning of the simulation agents are uniformly distributed in the environment but some stalls become more popular than others of the same type as the simulation executes. This is explained by the strategic positions of some stalls (along the main street) or a specific desire common to the majority of the crowd.

We also observe that the majority of the agents eventually arrive at their goal location. In some instances there are too many agents to reach the stall-front, and groups form that surround the stall. This is another feature that we believe defines a marketplace.

These results demonstrate that the goal formation and path-planning components produce behaviour in which agents are capable of having their own desires, and of having these desires satisfied.

5 Conclusion

We conclude that our agent-based model for simulating crowds in an African market produces behaviours characteristic of real crowds. Our model results in the emergence of flows that form in narrow passages, aiding in efficient traversal. Our model is also capable of creating crowd formations that often occur, such as a circle around a performer. Our agent-based model effectively simulates a non-emergency market scene, where numerous agents have varying goals.

This research contributes to the domain of crowd simulation by providing the first mechanism for simulating a non-emergency situation in an African market. Future work includes simulating further emergent features of market-related crowds, and evaluating the model in more complex environments.

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