Building and Describing an ABM

1. Research Question

RQ1: How do individuals in an open space behave and interact during an emergency event?

RQ2: How do factors such as population size, space area, event timing, individual perception and action capabilities affect the evacuation time?

2. ODD Description

2.1 Purpose and patterns

Purpose

This model aims to understand how individuals in an open space behave and interact during an emergency event, and how factors like population size, space area, event timing, perception, and action capabilities affect evacuation time.

Patterns

The model represents individuals moving in a circular open space. When an emergency occurs, nearby individuals panic and attempt to evacuate, interacting by perceiving each other's state and adjusting their behavior.

The model will be evaluated by its ability to reproduce several patterns observed in real-world emergency evacuations:

- Pattern 1: Evacuation time increases non-linearly with population size (Haghani and Sarvi, 2016). The model should show a similar relationship between the number of individuals and the time required for all individuals to reach safety.
- Pattern 2: Herding behavior emerges during evacuation, with individuals tending to follow the actions of nearby individuals (Helbing, Farkas and Vicsek, 2000). The model should exhibit clustering of individuals with similar panic states and movement directions.
- Pattern 3: Individual perception and decision-making affect evacuation dynamics (Moussaïd *et al.*, 2016). Variations in individual perception radius and vision angle in the model should lead to differences in overall evacuation patterns and time.

2.2 Entities, state variables, and scales Entities

The model has two main entities: individuals (turtles) and the environment (patches). The individuals have several state variables, including:

- vision: the radius of an individual's perception
- status: the current state of an individual (normal, panic, injured, dead, or safe)
- direction: the heading of an individual
- speed: the current speed of an individual
- collided?: a flag indicating whether an individual has collided with another

The environment is a circular open space with a radius defined by the global variable arena-radius. Patches have a state variable affected?, indicating whether they are within the effect radius of a dead individual.

The space is a 30x30 grid, each cell representing 1 m^2. The spatial scale of the model is two-dimensional. Time is represented by ticks, with one tick corresponding to one step of the simulation.

Table 1. Individual state variables

Variable	Meaning	Type
vision	Vision radius	Number
status	Individual state	String
direction	Heading direction	Number
speed	Current speed	Number
collided?	If collided	Boolean

Table 2. Global variables

Variable	Meaning	Type
num-turtles	Number of individuals	Number
arena-radius	Radius of the circular space	Number
vision-radius	Individual vision radius	Number
initial-speed	Initial speed	Number
speed-increase	Speed increase percentage during panic state	Number
speed-decrease	Speed decrease percentage during panic state	Number
distance-threshold	Distance threshold between individuals	Number
pause-time	Pause time after collision	Number

event-time	Time when the event occurs	Number
effect-radius	Effect radius of dead individuals	Number
vision-angle	Vision angle size	Number

2.3 Process overview and scheduling

The model proceeds in discrete time steps (ticks). Within each tick, the following processes occur in order, illustrated in Figure 1:

1. Event occurrence: At the specified event-time, an individual randomly selected to become "dead", and the surrounding individuals within the effect-radius are set to "panic" state.
2. Status update: All individuals update their status based on their surroundings and interactions with other individuals.
3. Individuals execute behaviors corresponding to their current status (e.g., moving randomly in the normal state, moving away from the dead individual or towards the nearest exit when in panic).
4. Location update: Individuals update their positions based on their current status, speed and direction.
5. Patch state update: Update patches within the effect-radius of dead individuals.
6. The visualisation of individuals and the environment is updated based on their current states.

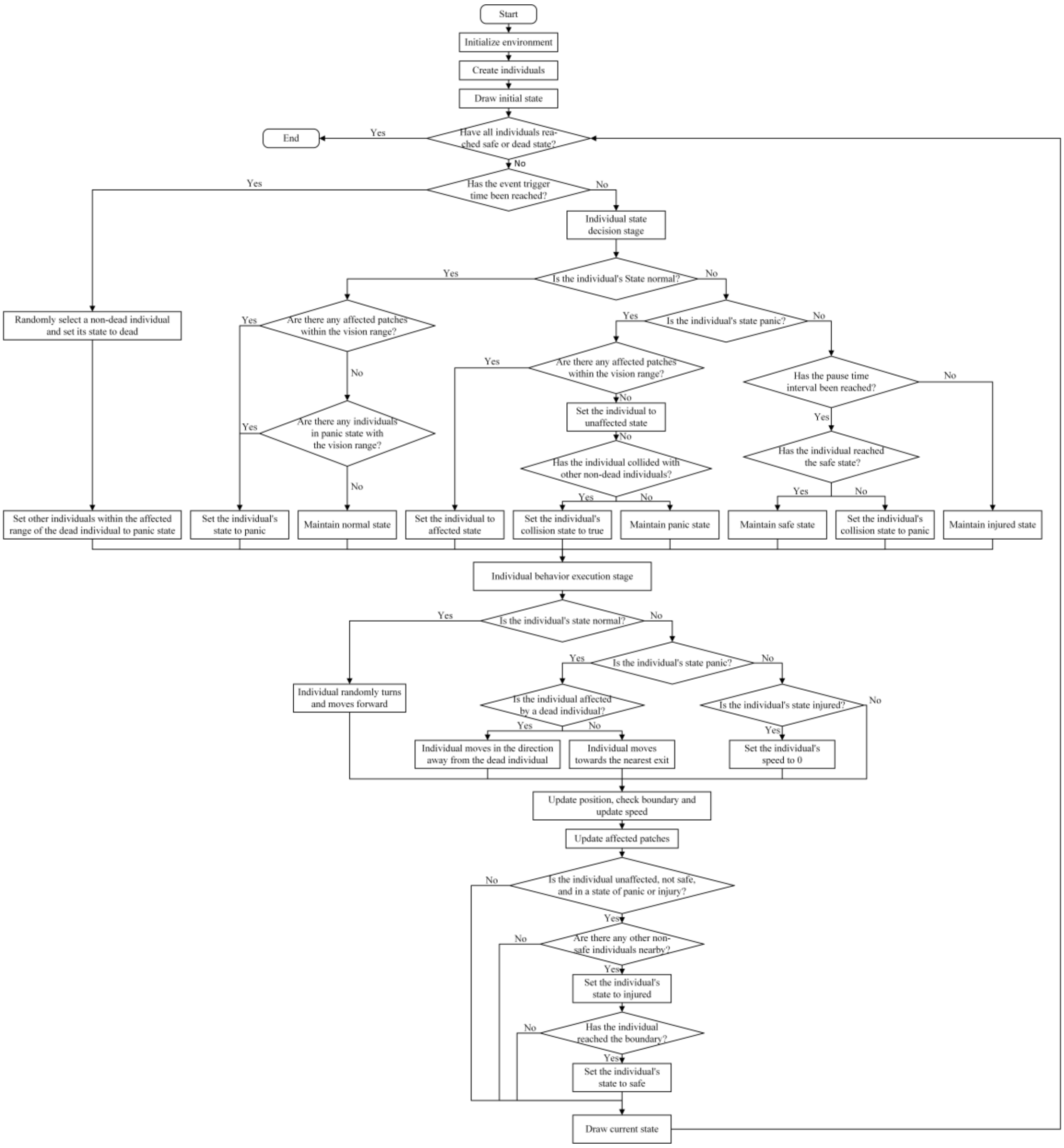

Figure 1. Model execution flow chart.

2.4 Design concepts

Emergence

The key emergent phenomena are the collective evacuation patterns and overall evacuation time, arising from individuals' interactions and behaviors, such as responding to others' panic states, avoiding collisions, and moving towards exits. The model exhibits self-organised patterns of evacuation, where individuals form clusters and display herding behavior, similar to observations in real-world evacuations, resulting from simple rules governing individual behavior and interactions without centralised control (Helbing, Farkas and Vicsek, 2000).

Interaction

Individuals interact with each other and with the environment in several ways. First, individuals respond to the panic state of nearby individuals within their vision radius, entering a panic state themselves if they perceive panicking neighbors. Second, individuals adjust their speed based on the proximity of other individuals to avoid collisions, a behavior observed in real-world crowd dynamics (Parisi and Dorso, 2007). Third, individuals interact with the environment by perceiving and responding to patches affected by dead individuals and by detecting and avoiding the boundaries of the open space. These interactions give rise to the emergent evacuation patterns and contribute to the overall dynamics of the system.

2.5 Initialisation

At the start of the simulation, the circular open space is initialised with a radius defined by arena-radius. The affected? state variable of all patches is set to false. A predetermined number of individuals (num-turtles) are created and randomly placed within the open space. Individuals are initialised with a normal status, a randomly assigned direction, an initial speed (initial-speed), and default values for vision radius (vision-radius) and vision angle (vision-angle). The collided? flag is set to false for all individuals.

2.6 Input data

The model does not use any external input data.

2.7 Submodels

Update-status: Determines an individual's new status based on its current status, surroundings, and interactions. Normal individuals enter the panic state if they perceive affected patches or panicking individuals within their vision radius. Panic individuals become injured if they collide with another individual.

Execute-behavior: Determines an individual's actions based on its current status. Normal individuals move randomly. Panicking individuals move away from dead individuals or towards the nearest exit while adjusting their speed based on the proximity of other individuals. Injured individuals remain stationary for a pause-time.

Nearest-exit: Calculates the direction towards the nearest point on the boundary of the circular open space.

Away-direction: Calculates the direction away from a given dead individual.

Update-speed: Adjusts an individual's speed based on the proximity of other individuals within its vision radius. Speed is reduced if others are within a distance threshold (speed-decrease) and increased otherwise (speed-increase), reflecting the speed-density relationship in pedestrian dynamics (Seyfried *et al.*, 2005).

Check-boundary: Ensures individuals remain within the open space. If normal individuals crosses the boundary, its heading is reversed, and it is moved back inside. Non-normal individuals reaching the boundary are set to the safe state.

3. Brief Methodology

To address the research questions, we will conduct experiments by systematically varying key parameters and measuring their effects on the evacuation process. We will:

1. Vary individual perception parameters (vision radius and angle) and action capability parameters (speed changes), measure evacuation time and qualitatively analyse collective patterns to examine how perception and action affects behavior and outcomes (RQ1, RQ2).
2. Vary population size and arena size, measuring evacuation time to investigate their impact on evacuation efficiency (RQ2).
3. Modify event timing and measure evacuation time to understand how event timing influences evacuation dynamics (RQ2).

Word Count	*998*

Reference

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