Pedestrian Simulation Software
Version 0.0, Model and Documentation
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Simulation Instructions

Upon starting the executable, a map with four exits at its corners is loaded.

People are added to the simulation based on a demographic. To change the demographic, open the "Population Control" dialog. To change the demographic, select one from the "Demographic" list. To restrict the demographic to a certain age or gender, select any restrictions from the "Gender" and "Age" lists.

To add people to the simulation:
1. Click on the map. A random person from the defined demographic is added.
2. To add more than one person at a time, open the "Population Control" dialog. Enter the number of people required in the "Population number" text box, and click the "Populate" button.

The number of people in the simulation is displayed in the status bar.

As the person is added to the simulation their preferred exit is assigned in turn. Therefore if you add a person to one of four groups one at a time, each person in the group will have the same preferred exit. This helps verify that the preferred exit is decided by group interaction.

The behavior dialog indicates which color indicates which state of the simulated person.

To control the simulation, equivalent commands are given in the simulation menu and tool bar:
1. Alarm On/Off: Turn the alarm on and off. The alarm is off by default and the pedestrian will not react unless the alarm is turned on. The alarm status is displayed in the status bar and indicated by the color of the alarm button in the tool bar.
2. Play/Pause: Start and pause the simulation.
3. Step: When in a paused state, step will move the simulation forward one increment.
4. Fast forward: The speed of the simulation can be increased and is displayed in the status bar.
5. Stop: Returns the simulation to its initial state. The same random number generator state is used each time, so rerunning the simulation after stopping it will result in the reenactment of the previous simulation. Any change in the simulation will alter it however and new people can be added.
6. Reset: Removes the population from the simulation and allows you to start over.

Person Definition

The person is defined as a:

1. Physique
2. Personality
3. Health
4. Knowledge
5. Locomotion
6. Behavior

The physique of the person is defined by:

1. Gender
2. Age
3. Height
4. Weight
5. Agility: The relative maximum speed the person can achieve.
6. Reaction time: The physical reaction time of the person to physical stimuli.

The physique of the population of people in the simulation can be derived from a mixture of census and medical data. For this experiment, the 2005 United States census was used to define the relationship between age and gender of the population. Medical charts for the relationship between age, height and weight in the US population are also available and could be used to assign the agility of the person. There are also measurable differences in the age versus height and weight distributions across racial groups in the US population. The proportion of people with physical disabilities is also included in the US census data and can influence the assignment of the physique of the person. However since the social aspects of the emergency situation were the focus of our work, a shallow treatment of physique in the population was performed.

For the personality of the simulated person, the only parameter used was a background anxiety level, which is used to assign an initial stress level to the person. Other personality parameters are planned such as the need for personal space, trust in authority, risk tolerance, independence, self confidence and assertiveness.

Health was not used in the initial simulation but would influence future simulations by defining the physical health of the person and the level of their mobility. Many people have physical disabilities that affect their egress, some minor such as being short sighted, others major such as having limited mobility, and some others that are unpredictable such as suffering from asthma.

The knowledge of the person about their environment and their experience with previous emergency situations of training can significantly effect how they behave in an emergency situation. In this simulation, the person has a mental map of their environment that is build through their experience. They also keep track of the number of previous false alarms and whether or not they have previous experience from an emergency situation.

The locomotion section of a person handles the movement of the person through the environment. It is influenced by the other aspects of the person but does not distinguish the person from any other through parameterizing the pedestrian. It defines the current position, the target position, the maximum speed and the current speed of the person.

The behavior section of the person is the most complex aspect of the simulation and it is described in the next section.

Finite state machine model

To model the behavior of a pedestrian in an emergency situation, a finite state machine model is used where each state is defined by the purpose or goal of the person. Each state does not model every separate conscious or subconscious process undertaken by the pedestrian but the distinct actions taken by the person to fulfill their intention. Therefore transitions between states are mapped to decisions by the person, which can be influenced by external states or events.

For example, the FSM described in Figure 1 was used in the experimental simulation. It describes the objectives of a lone pedestrian during a fire alarm. No direct evidence of an emergency is perceived by the simulated pedestrian. The work also concentrates on the social aspects of the work; therefore many considerations that have been described by other researchers but would influence a more complete simulation such as architecture, crowding etc. have not been implemented as yet.

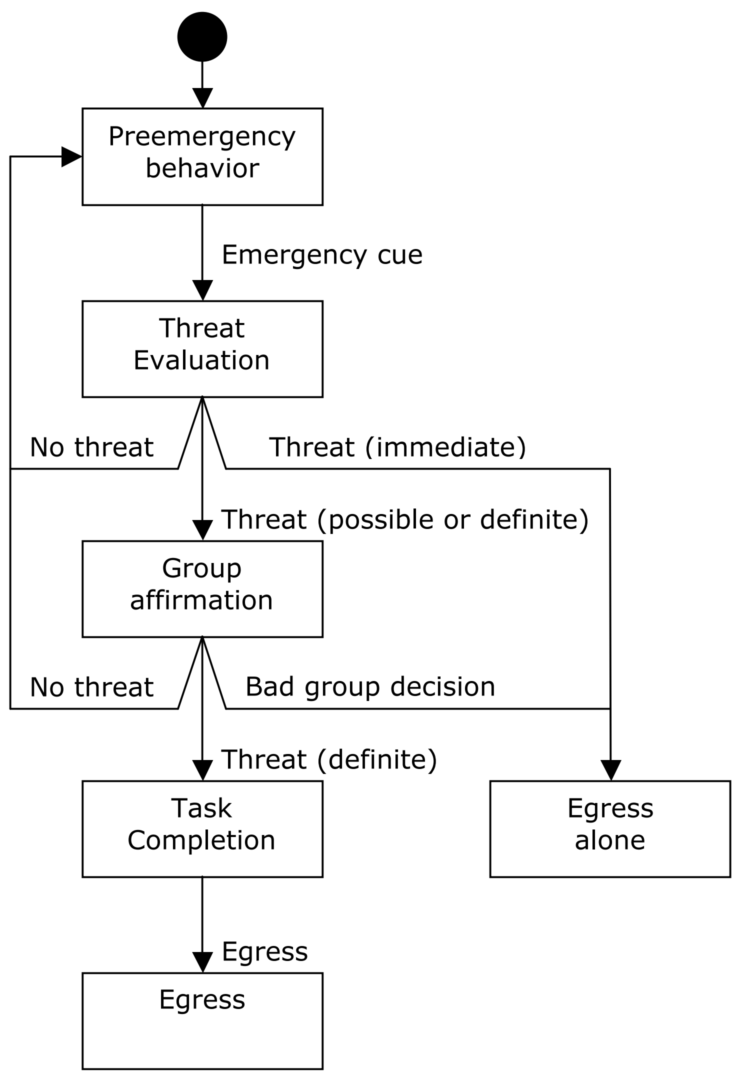

Figure 1: The Finite State Machine describing the objectives of a lone pedestrian during a fire alarm implemented in the simulation. The transition of the alarm being silenced is not represented and simply incurs a return to the pre-emergency behavior state.

Behavior

Each behavioral state defines the goal or intention of the pedestrian, not each conscious or subconscious action of the pedestrian. For example, while a person is in egress they can sense direct emergency cues such as heat, smoke and blasts and respond to them. But their intention is to egress during which they will also respond to the primary, secondary or tertiary groups they belong to. Therefore it is important to model the transition from one goal-based behavior to another. This is modeled as a decision by the person and can be influenced by external events such as an emergency cue.

External Events and Decisions

In the current version of the simulation, the only external events are the sounding and silencing of an alarm. Other emergency cues however can easily be included such as:

Indirect emergency cues:
- An alarm
- A communication or message
- Screams or a commotion

Direct emergency cues:
- Smoke
- Fire
- An explosion
- A gunshot

Each of these external events causes a reaction no matter the current behavior of the pedestrian. In the case of the alarm being silenced, the pedestrian will react by returning to their behavior before the alarm was sounded. Through this mechanism, the pedestrian can react to new external events.

The only other event is the internal Tick event, in which the simulation is updated to the next unit time interval.

The transition between the goal-based behaviors of the pedestrian, the person makes a decision based on their current state and any available evidence. A central parameter in this decision process is the stress parameter.

Stress Level

The transition between behaviors depends mainly on a stress parameter that determines when a person no longer feels comfortable in their current situation and seeks action. Two thresholds are used. The stress tolerance threshold describes when the person will seek action to alleviate their current situation. The critical stress level is the threshold that signals the person perceives immediate peril and acts accordingly.

The stress level is implemented as a normalized real number between the values of 0 and 1. The initial values for the stress related thresholds are tailored for each person:

pre-emergency stress level = 0.
stress tolerance = ~0.75
critical stress level = 0.95

If a pedestrian perceives a threat but does not act upon it, their stress level increases over time. Upon taking action to alleviate the threat, the stress level is reduced. Currently, these values are:

*stress level increment = ~0.10 per sec * anxiety level*
*stress level decrement = ~0.35 per decision * anxiety level*

In future revision, the stress level could be modeled at each point of time, dependent on parameters such as:

- the perceived threat level
- the person's background anxiety level
- the action undertaken

Behavior: Pre-emergency Behavior

In Pre-emergency Behavior the pedestrian is engaged in a task that is interrupted when the alarm is sounded or another emergency cue is received. On the emergency cue, the pedestrian breaks from this task to evaluate the situation and to decide on their course of action. On the removal on the threat, the pedestrian returns to this behavior.

Currently the task is simply performed at a given position and the person returns to this position to continue their task if they ignore the emergency cue or any threat is removed.

Initiation:

// Return to original position if away from position
target position = original position
*speed = normal pace * agility*

// Reset stress level
stress level = pre-emergency stress level

Event::Alarm:

// Decision to change behavior to evaluate threat
Behavior::Threat Evaluation

Behavior: Threat evaluation

On the sounding of the alarm, the pedestrian breaks from their task to evaluate the situation and to decide on their course of action. This state only handles the initial period of time in which the person assesses the situation and is more important for indirect emergency cues than direct emergency cues.

For example, the person evaluates questions such as "Is this a false alarm?", "Is this a drill?", "If there is an emergency, what is the emergency?", "Is their any direct evidence of a threat?", etc. Therefore the intention of the person in the Threat Evaluation state is to determine the immediate level of threat. If there is no perceived threat or they are too preoccupied in their pre-emergency task, they ignore the alarm and return to their previous state. If there is an immediate and perilous threat they act to protect themselves. If they perceive a threat that is not immediately perilous or if they are uncertain, they seek group affirmation.

The decision to ignore the alarm and return to their pre-emergency behavior or to egress is based on two parameters, the task-preoccupation of the person and their stress level.

On initiation of the threat evaluation, the person is assigned an initial stress level that describes how confident the person is of escaping the emergency situation and how anxious the person is.

Ultimately the person's knowledge of the building and emergency, and their prior experience can be built into the calculation.

To trigger an egress decision, the stress level is increased with time as long as the alarm remains on. The decision to egress is based on two critical thresholds. The higher threshold signals the perception of an immediate and perilous threat and the person seeks immediate safety from the threat. At the moment, since we have no direct threats in the simulation, this is modeled as the Egress Alone Behavior and the person seeks to remove themselves immediately from the building. If the task preoccupation level is higher than this critical stress level, we assume the person will ignore the alarm and return to their pre-emergency behavior.

When the stress level breaches the maximum of the second and lower stress tolerance level and the task preoccupation level of the person, they alleviate their current predicament by seeking group affirmation of the situation.

Initiation:

```
// Determine stress level of person
confidence of escape = agility * (1. – anxiety)
stress level = 1. - confidence of escape

// If the person is too preoccupied, they ignore the alarm
if task preoccupation > critical stress level
    Behavior::Pre-emergency behavior
```

Event::Tick:

```
// Build in a physical reaction time
if time elapsed since emergency cue  < physical reaction time
    do nothing

// If the person's stress level is above their critical level,
// they perceive immediate peril and egress alone
if stress level > critical stress level
    Behavior::Egress Alone
else
// If the person has been in an emergency situation before,
// they complete any pre-emergency duties and egress
if person has prior emergency experience
    Behavior::Task Completion
else
// If the stress level felt by the person is:
// - above their stress tolerance, and
// - above their task preoccupation
// they seek group affirmation
if stress level > stress tolerance and task preoccupation
    Behavior::Group Affirmation

// Increase the stress level of the person
stress level = stress level + (stress level increment * anxiety)
```

Event::AlarmOff:

```
Behavior::Pre-emergency Behavior
```

Behavior::Group affirmation

The intention of the Group Affirmation behavior is to gather people into primary, secondary or tertiary groups and to determine a group consensus on the course of action such as whether an emergency exists, whether to egress and if so to which exit. Therefore group affirmation is an important staging point for emergent group behavior.

Primary groups include those to which we have a caring relationship such as family and close friends. Secondary groups include those to which we have a relationship such as colleagues, class mates and acquaintances. Tertiary groups are formed by those immediately around us and are typically constructed from people with no previous relationship. In the current version of the simulation, only tertiary group affirmation and formation is modeled.

If the person has decided to egress, unless they perceive a perilous threat, they seek group affirmation as a precursive step. When they decide to seek affirmation, their stress level is decreased below their stress tolerance level that signals the need to egress. Over time, the stress level is again raised and if it again breaches the stress tolerance level, the person takes the decision to egress with or without consensus from its neighbors. The other path to egress is to find a group of fellow pedestrians and to build a consensus of the group on their intention to egress or remain in the building.

To evaluate a consensus, the person locates their neighbors and moves closer the center of this group of people. The distance to which each person defines their neighborhood depends on the person but in the current version this should not be confused with personal space, which is not implemented. Therefore independent people seek smaller groups than others but composite groups do occur frequently with smaller groups merging.

Each person in a group has a preferred exit, which is typically the one through which they entered the building. The group affirmation stage therefore involves a negotiation as whether to egress and if so to which exit. If each person has a low stress level or want to egress through different exits, they remain in the group affirmation stage and in negotiation. A person leaves this stage under a number of different conditions. Firstly, if the stress level of the person is above their tolerance level, they egress to their preferred exit. Secondly, if the person is significantly stressed, if any neighbor is egressing to their preferred exit, they go with them. Lastly, if a significant majority of the neighbors have agreed to egress to a certain exit, the person goes with them.

If the person does not have neighbors they move towards their preferred exit and continue to seek group affirmation by looking for a group.

Future steps include using the direction of gaze and visibility maps to determine neighborhoods.

Initiation:

// Reduce the stress level of person because of their action
stress level = stress level - stress level decrement

Event::Tick:

// If the person's stress level is above their critical level,
// they perceive immediate peril and egress alone
if stress level > critical stress level
    Behavior: Egress Alone
else
// If the stress level felt by the person is above their stress tolerance,
// they seek group affirmation
if stress level > stress tolerance

```
        Behavior::Egress

    // Gather a list of people in the immediate neighborhood
    neighborhood radius = 1. to 5.m depending on the person
    neighbors = everybody within neighborhood radius

    // If the person has nobody immediately around them
    if no neighbors
        // Go looking for someone
        target position = preferred exit
        speed = slow pace * agility
    else
        // If close to your stress tolerance and somebody is going to your preferred exit,
        // go with them
        if a neighbor is in egress and they have the same preferred exit
            if stress level is within 10% of stress tolerance
                Behavior::Egress
        else
        // Egress if enough of your neighbors are in egress
        if more than a fifth of neighbors are in egress
            if they have the same preferred exit
                Behavior::Egress
            else
                adopt new preferred exit
                Behavior::Egress
        else
            // Move to neighbors (personal distance stops you moving too close)
            target position = center of neighbors
            speed = slow pace * agility

    // Increase the stress level of the person
    stress level = stress level + (stress level increment * anxiety)

Event::AlarmOff:
    Behavior::Pre-emergency Behavior
```

Behavior::Task completion

Upon deciding to egress, the person completes required tasks before starting. The tasks could be official duties such as locking a safe or checking that all doors have been closed and an area evacuated, or a personal duty such as collecting personal items. Therefore, before egress each person goes though the goal-based state of task-completion before proceeding onto egress. However, not all the simulated pedestrians will have a task to complete.

In our initial version, the task is simply modeled as a time-based task at the person's pre-emergency position. About 5% of the pedestrians are assigned a task. Therefore, each pedestrians that has been assigned a task returns to their pre-emergency position to complete the task before starting to egress.

```
Initiation:
    if no task to complete
        Behavior:: Egress
    else
```

target position = original position
*speed = normal pace * agility*

Event::Tick:
if the task is complete
egress
else
work on task

Event::AlarmOff:
Behavior::Pre-emergency Behavior

Behavior::Egress

During egress, the simulated person moves towards their preferred exit with their speed being governed by their level of stress and their agility to ability to move. In a system that includes collision detection and processes for movement of a person through a building, personal space could also be included to help the movement of a group of people appear more realistic. At the moment, a person egressing in a group simply adjusts their speed to try and maintain group coherence if this is possible.

During egress each person is aware of their surroundings. At each stage of the egress, the preferred exit of the person can be changed if a significant majority of their neighbors prefer another exit, similar to the group affirmation stage.

Initiation:
// Reduce the stress level of person because of their action
stress level = stress level - stress level decrement

Event::Tick:
*speed = average speed of neighbors in egress * agility*

Event::AlarmOff:
Behavior::Pre-emergency Behavior

Egress alone

Behavior: The person seeks immediate relief from the situation.

Initiation:
// Reduce the stress level of person because of their action
stress level = stress level - stress level decrement

Event::Tick:
// Head straight for the exit
target position = preferred exit
*speed = normal pace * agility*

Event::AlarmOff:
Behavior::Pre-emergency Behavior

Future Work

1. Building evacuation infrastructure. The first aim of the simulation was to investigate the significance of behavior that's lead to the delay in egress through task-preoccupation and group affirmation. To apply this work to a building evacuation situation, we need to build in existing work on how people egress for various structures.
2. Including an emergency situation in which the simulated people must respond to a direct threat such as fire, smoke, an aggressor, etc.
3. Model the role of the person in the simulation. Roles could include visitor or guest, worker, supervisor, safety officer, emergency worker, etc. The role of the person defines the pre-egress behavior of the person and whether they become an authoritive keynoter.
4. Extended emergency routes. Every person in the simulation has a preferred exit, which from research tends to be the entrance they used if they are not familiar with the space. People who are familiar with the building will have a more extensive mental map of the building and should be able to decide on the closest or safest exit. In laboratories, hotels, and many other work environments, predetermined exit routes are communicated.
5. In the current systems only tertiary groups are modeled. Including primary and secondary groups will significantly alter the behavior of the pedestrians especially when the relationship between people is modeled and groups such as families, friendships, school groups, etc. can be included.