Final Project: Evacuation

Modelling and simulation of complex systems

Simulation Goals

- This project addresses a research question: How information spread and evacuation behavior impact community safety during flooding events?

- The model focuses on modeling evacuation by different strategy to minimize time wasting on traffic jam and maximize survival rates.

Preparation

Preparation

Initialization (using example models):

- Loading shape files

- Create city's agents: **building**, **road**, **rivers**

- Assign highest building to be a shelter

```
create building from: shapefile_buildings with:[height::int(read("height"))];
// Find the largest building to be the shelter
shelter <- building with_max_of(each.shape.area);
```

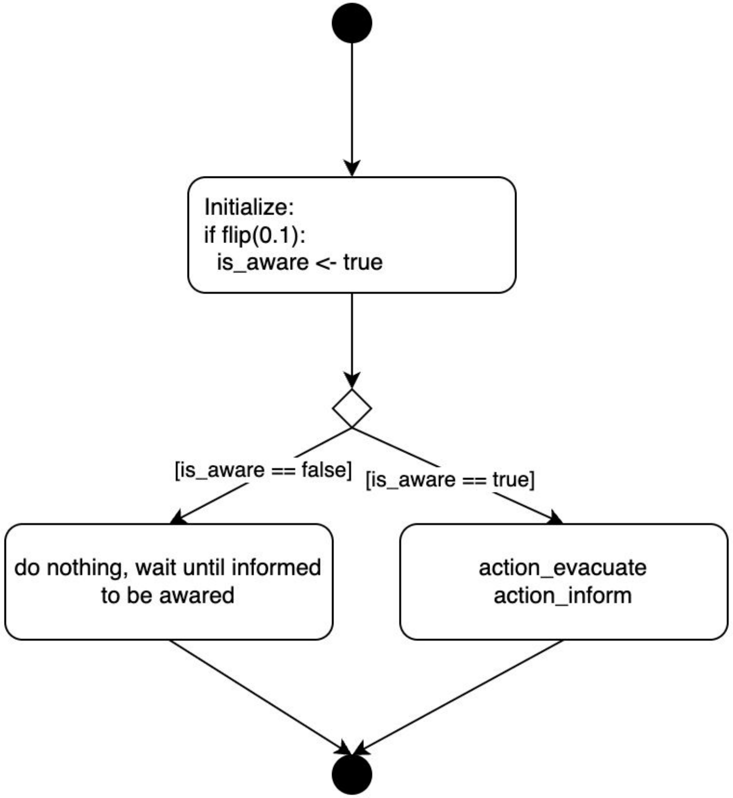
- Residential move across building on road network

Simulation Model - Base

Simulation Model - Base

Information spreading:

- Initially, 10% of residents are informed of evacuation (Picked randomly).
- When informed, 100% of resident know the evacuation
- Information spreads when people observe others evacuating (within 10m radius, 0.1 probability)
- Simulation finished when all informed people had evacuated



Simulation Model - Base

Inhabitant Species:
- Active agents with movement capabilities (inherits 'moving' skill)
- State attributes:

  - is_aware: Knowledge of evacuation
  - is_evacuated: Evacuation status
  - home: Starting location
  - speed: Movement rate

- Actions:

  - evacuate: Movement towards shelter
  - inform: spread awareness to nearby agents with 10% success

In Global

```
init {

    create inhabitant number: 1000 {
        home <- any_location_in(one_of(building));
        location <- home;
        // Only 10% of the population will be aware of the evacuation
        is_aware <- flip(0.1);
    }

}
```

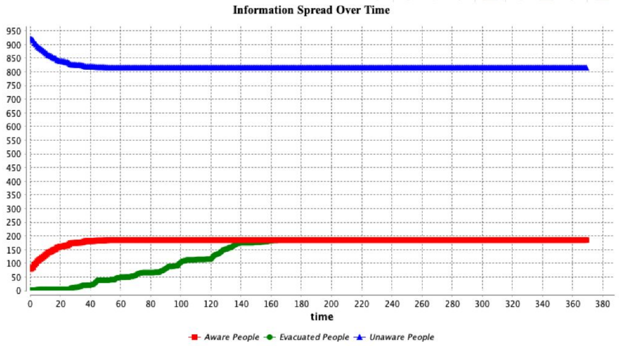
In Inhabitant Species:

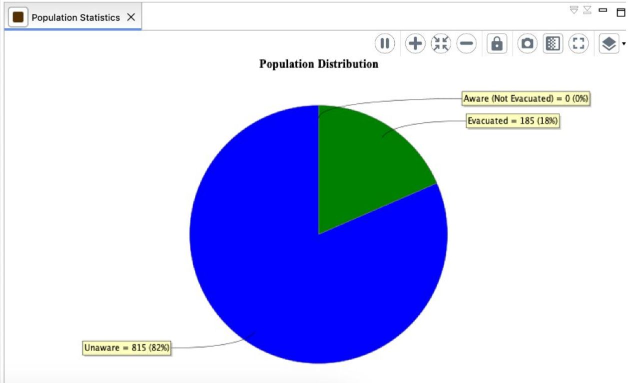
```
reflex evacuate when: is_aware and !is_evacuated {
    do goto target: shelter.location on: road_network;

    // Check if reached shelter
    if location distance_to shelter.location < 2.0 {
        is_evacuated <- true;
        nb_evacuee <- nb_evacuee + 1;
        location <- any_location_in(shelter);
    }

    // Inform nearby people at a distance of 10 meters
    ask inhabitant at_distance 10.0 {
        if !self.is_aware and flip(0.1) {
            self.is_aware <- true;
        }
    }
}
```

Simulation Model - Base





Monitors

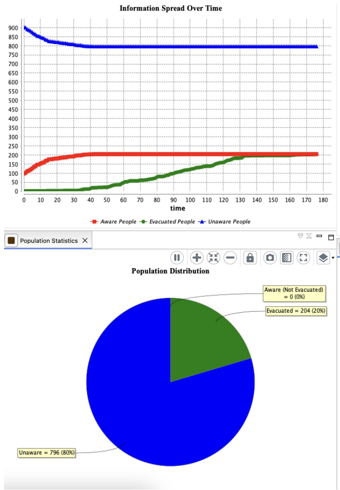
Evacuated people: 185

Number of evacuees: 185

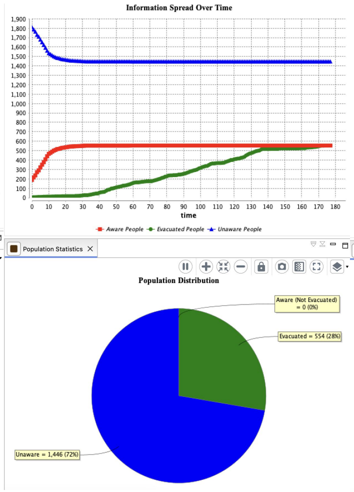
Aware people: 185

Batch experiment: Information spreading capacity

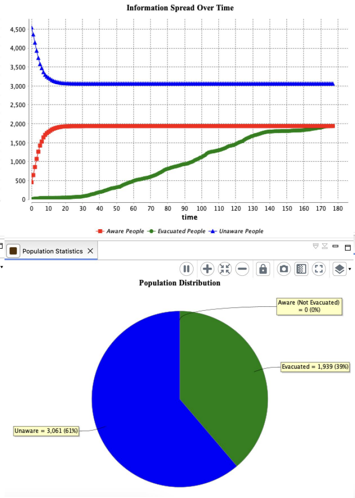
- Number of people: [1000, 2000, 5000, 10000, 20000]
- Each runs 3 times



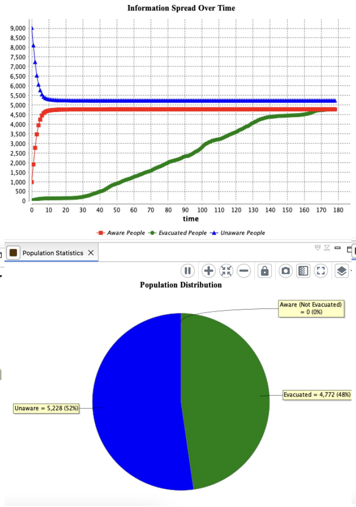
Number: 1000
Time: 173 cycle
Evacuate: 20%



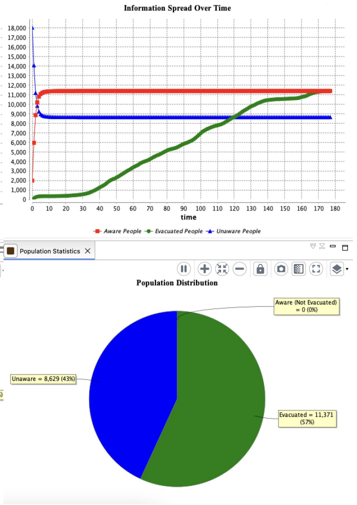
Number: 2000
Time: 174 cycle
Evacuate: 28%



Number: 5000
Time: 174 cycle
Evacuate: 39%



Number: 10000
Time: 176 cycle
Evacuate: 48%

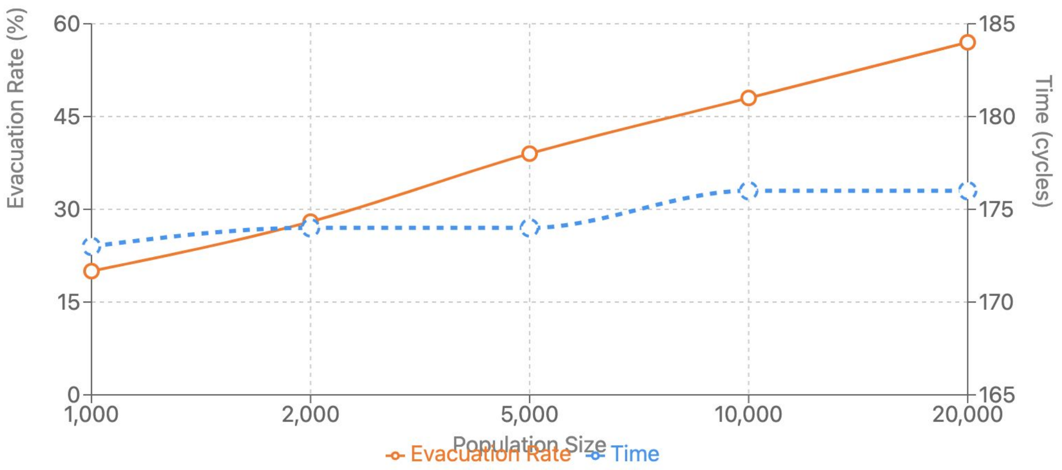


Number: 20000
Time: 176 cycle
Evacuate: 57%

* 1 cycle = 10s

Batch experiment: Information spreading capacity

- Number of people: [1000, 2000, 5000, 10000, 20000]
- Each runs 3 times



evacuation_rate = f(aware_rate, spreading_rate, total_citizen)

Observation:

- The more people in the city -> The higher the evacuation rate
- Evacuation rate shown to be a product of initial condition (rate of aware + spreading rate + number of citizen) -> This suggest a “golden rate” of awareness so evacuation can be close to 100%.
- Change in total time of complete evacuation remains steadily -> This suggests a “golden period” of evacuation for a specific city.

(Here is averagely 175 cycle ~ 29 minutes)

** 1 cycle = 10s*

Extension 1

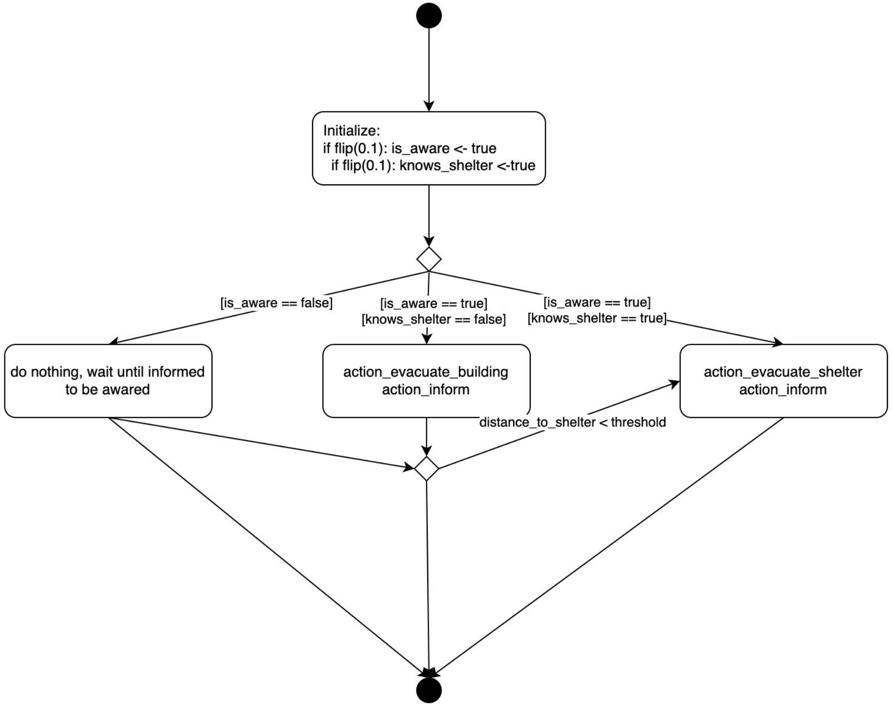
Simulation Model - Extension 1

Evacuation behaviour:

- Only 10% of 10% aware resident know the location of shelter and move directly there.

- The rest move to random building to find shelter

- If distance to shelter is <20m, they go directly to shelter



Simulation Model - Extension 1

Inhabitant Species:

Inhabitant
is_aware: bool
knows_shelter: bool
is_evacuated: bool
current_building: [Building]
target: [Point]
distance_to_shelter: float
reflex update_distance
reflex evacuate
+ action evacuate_shelter
+ action evacuate_building
+ action inform

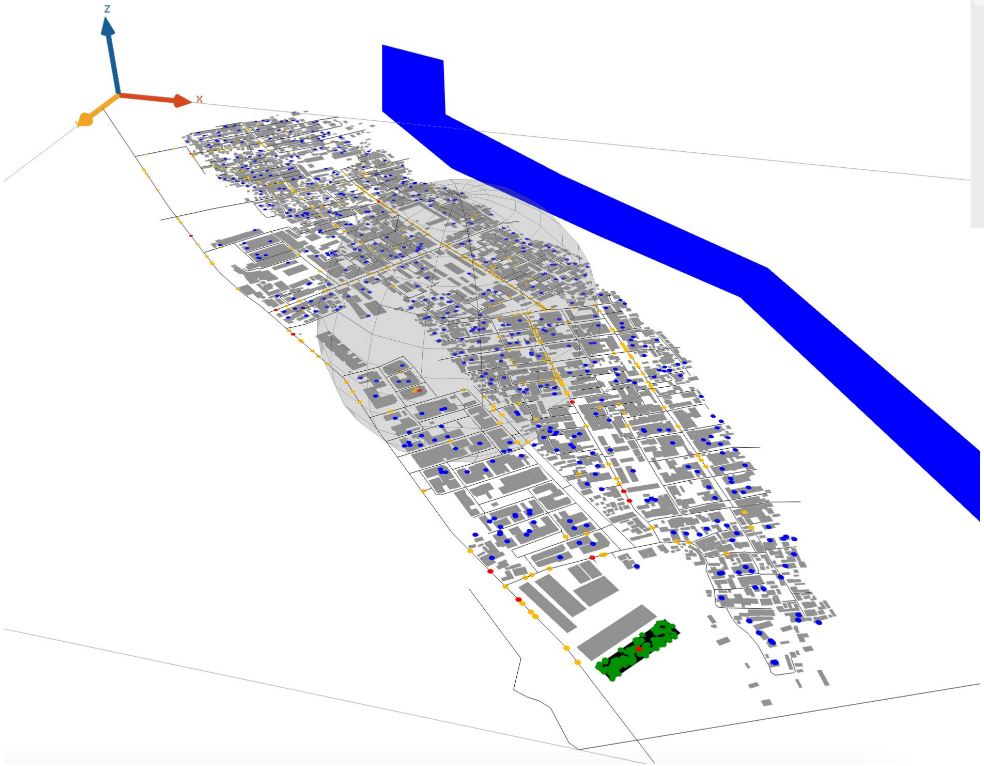
```
reflex update_distance when: !is_evacuated {
    distance_to_shelter <- location distance_to shelter.location;
}
```

```
reflex evacuate when: is_aware and !is_evacuated {
    // If knows shelter location or close to it, go directly there
    // For this map, 20m is too small, I increased to 200m
    if knows_shelter_location or (distance_to_shelter < 200.0) {
        do goto target: shelter.location on: road_network;

        // Check if reached shelter
        if distance_to_shelter < 2.0 {
            is_evacuated <- true;
            nb_evacuee <- nb_evacuee + 1;
            location <- any_location_in(shelter);
        }
    }
    // Otherwise, search randomly through buildings
    else {
        do goto target: target on: road_network;
        // If reached current target building, choose a new one
        if location distance_to target < 2.0 {
            current_building <- one_of(building where (each != shelter and each != current_building));
            target <- any_location_in(current_building);
        }
    }

    // Inform nearby people at a distance of 10 meters
    ask inhabitant at_distance 10.0 {
        if !self.is_aware and flip(0.1) {
            self.is_aware <- true;
            // 10% chance to also learn shelter location from informed person
            self.knows_shelter_location <- flip(0.1);
        }
    }
}
```

Simulation Model - Extension 1



Monitors

Aware people: 491

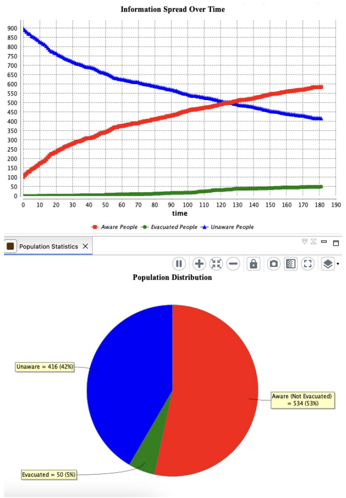
People knowing shelter: 56

Evacuated people: 117

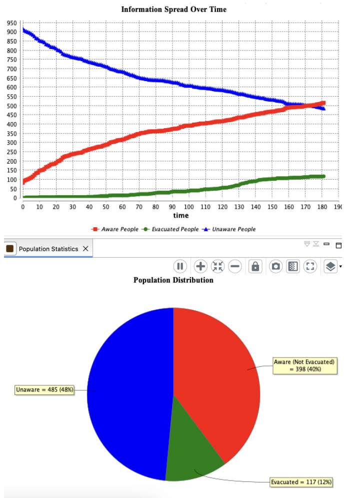
Number of evacuees: 117

Batch experiment: How limited knowledge of shelter location affects evacuation efficiency?

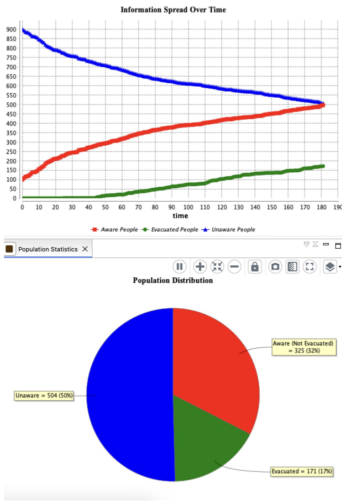
- Number of citizens: 1000; limited evacuation time: 30 min = 1800s = 180 cycles
- Shelter knowledge ratio: 0.1, 0.3, 0.5, 0.7, 1



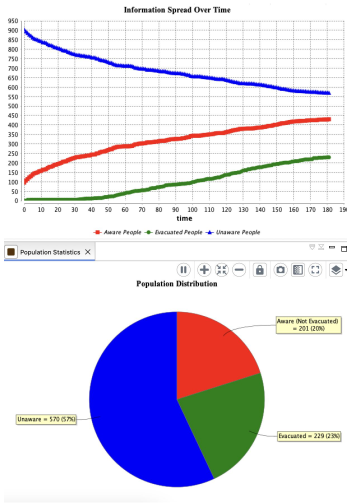
Aware (Not Evacuated): 53%
Evacuate: 5%
Possible to save: 58%



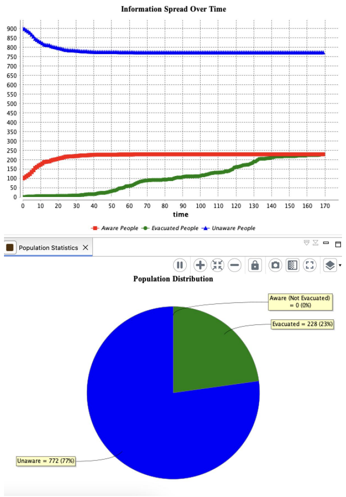
Aware (Not Evacuated): 40%
Evacuate: 12%
Possible to save: 52%



Aware (Not Evacuated): 32%
Evacuate: 17%
Possible to save: 54%



Aware (Not Evacuated): 20%
Evacuate: 23%
Possible to save: 54%

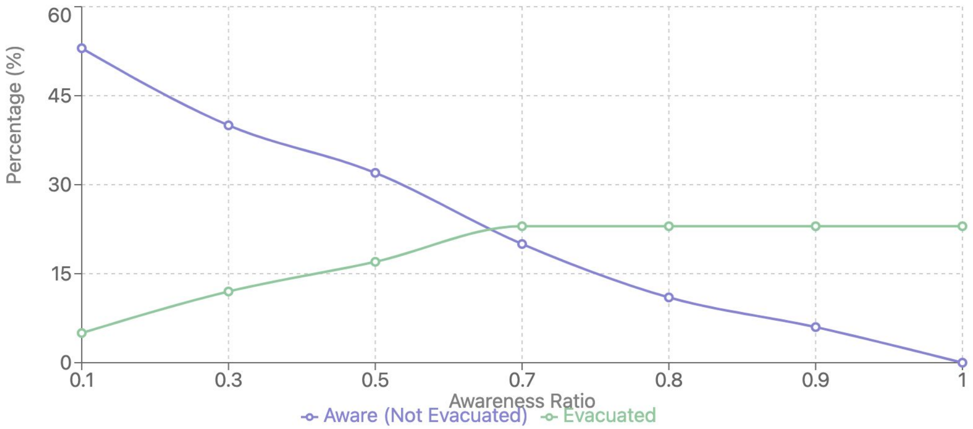


Aware (Not Evacuated): 0%
Evacuate: 23%
Possible to save: 16%

** 1 cycle = 10s*

Batch experiment: How limited knowledge of shelter location affects evacuation efficiency?

- Number of citizens: 1000; limited evacuation time: 30 min = 1800s = 180 cycles
- Shelter knowledge ratio: 0.1, 0.3, 0.5, 0.7, 1



Observation:

- Higher shelter knowledge rate ratio = higher evacuate rate + smaller Aware (Not Evacuated)
- Evacuate rate is saturated when knowledge rate > 0.7 -> indicate a “good knowledge ratio” when number of evacuated reach maximum and we still get to spread the information

- Better than knowledge rate = 1? As for people who is aware but can not evacuated to shelter, they might be able to find personal solutions -> increase saved rate.

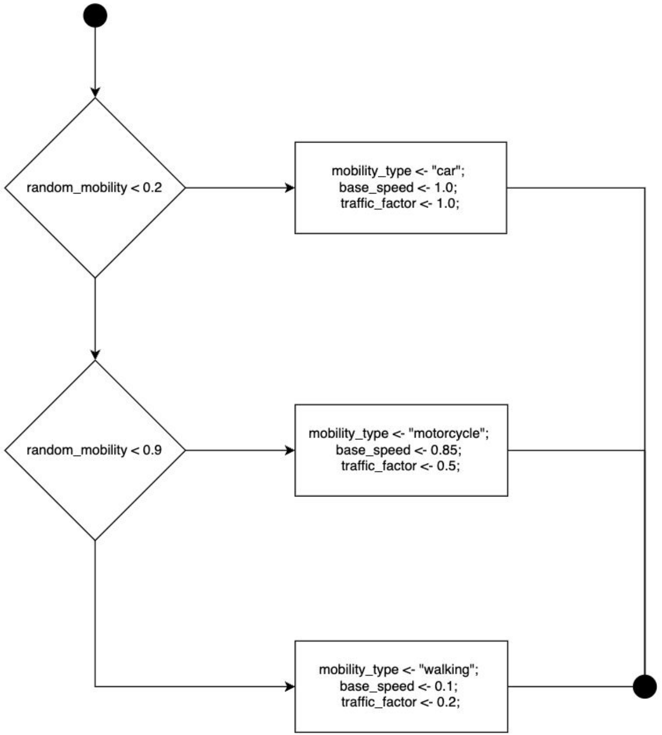
** 1 cycle = 10s*

Extension 2

Simulation Model - Extension 2

Transportation Model Effects - Residents have different type of mobility:

- Cars (20% of population): Fastest but most affected by congestion (1 factor)
- Motorcycles (70% of population): Slightly slower (0.85) but more resilient to traffic (0.5 factor)
- Walking: Slowest (0.1) but least affected by congestion (0.2 factor)



Simulation Model - Extension 2

Inhabitant Species:

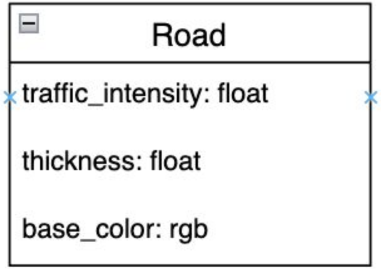
Inhabitant
is_aware: bool knows_shelter: bool is_evacuated: bool current_building: [Building] target: [Point] distance_to_shelter: float mobility_type: string base_speed: float traffic_factor: float
reflex update_distance reflex evacuate + action evacuate_shelter + action evacuate_building + action inform

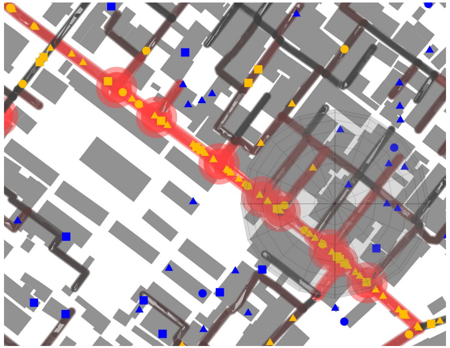
Introduce:

```
string mobility_type;
float base_speed;
float traffic_factor;
```

Simulation Model - Extension 2

Inhabitant Roads:





In Global

```
// Update traffic density every step
// Trafic density: 0% to 100%
reflex update_traffic {
    traffic_density <- road as_map (each::0.0);
    ask road {
        // Normalize traffic density to be between 0 and 1
        float raw_density <- length(inhabitant at_distance 5.0) / shape.perimeter;
        traffic_density[self] <- min(1.0, raw_density / 2.0);  // Assuming max realistic density is ~ 2 agents per meter
    }
}
```

In Road Species:

```
species road {
    aspect default {
        float traffic_intensity <- traffic_density[self];
        float thickness <- 1 + (traffic_intensity * 4);
        rgb base_color <- rgb(55 + min(200, int(255 * traffic_intensity * 4)), 55, 55, 100);

        draw shape + thickness color: base_color;
        draw shape + (thickness * 1.5) color: rgb(base_color.red, base_color.green, base_color.blue, 200); //Opacity 0.5
        draw shape + (thickness * 2) color: rgb(base_color.red, base_color.green, base_color.blue, 128); //Opacity 0.2
    }
}
```

Simulation Model - Extension 2

Potential traffic bottlenecks indicated:

- Intersection
- Road in the centre area

Extension 3

Simulation Model - Extension 3

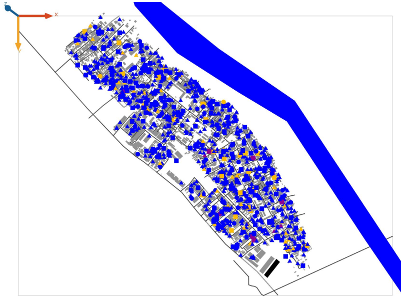
Strategies to choose 10% of the population who aware of the situation:

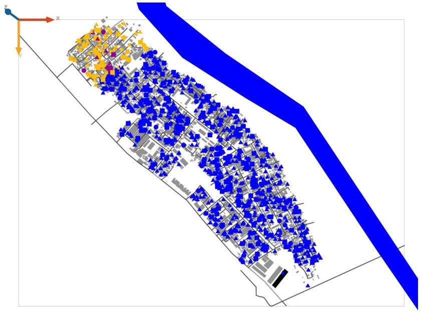
- Random: randomly chosen among the map
- Furthest: to the shelter
- Closest: to the shelter

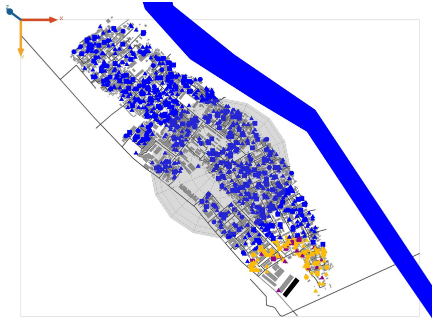
Measure efficiency:

efficiency = time for the total evacuation/time spent on the roads

Higher efficiency = better







Simulation Model - Extension 3

Initialization:

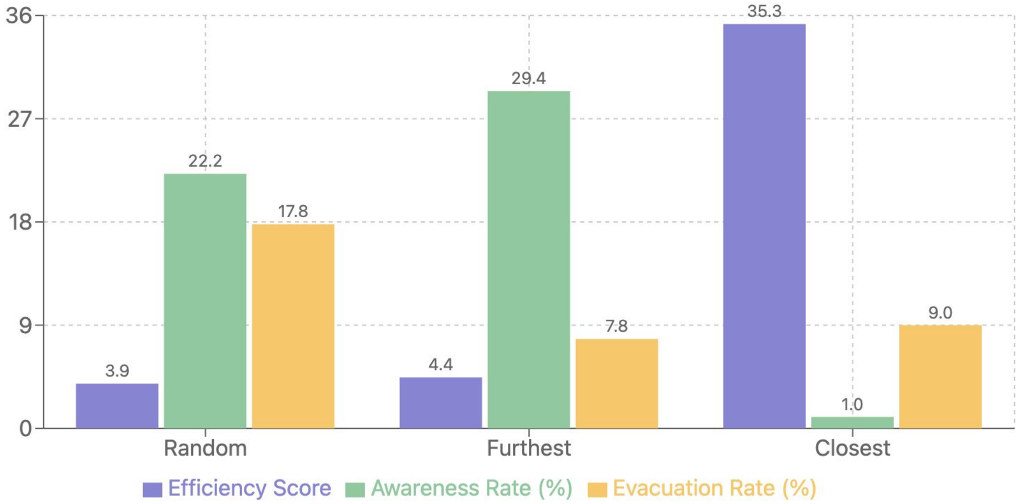
```
// Apply awareness strategy
list<inhabitant> sorted_inhabitants;
switch awareness_strategy {
    match "random" {
        ask (initial_population * 0.1) among inhabitant {
            is_aware <- true;
            knows_shelter_location <- flip(0.1);
        }
    }
    match "furthest" {
        sorted_inhabitants <- inhabitant sort_by (each.distance_to_shelter);
        ask last(int(initial_population * 0.1), sorted_inhabitants)  {
            is_aware <- true;
            knows_shelter_location <- flip(0.1);
        }
    }
    match "closest" {
        sorted_inhabitants <- inhabitant sort_by (each.distance_to_shelter);
        ask first((initial_population * 0.1), sorted_inhabitants) {
            is_aware <- true;
            knows_shelter_location <- flip(0.1);
        }
    }
}
```

Efficiency:

```
total_evacuation_time <- cycle * step;
total_road_time <- mean(inhabitant collect each.road_time);
write "Efficiency: " + total_evacuation_time/total_road_time;
```

Batch experiment (5 times each): Examine which strategy is the most efficient?

- Number of initial people: 1000
- Alert time = limited evacuation time: 30 min = 1800s = 180 cycles



Key finding:

- The 'Closest' strategy shows significantly higher efficiency. However, it has the lowest awareness rate (1.0%)
- 'Furthest' strategy shows highest awareness rate but slightly lower evacuation rate (7.8%)
- 'Random' strategy maintains more balanced awareness and evacuation rates.

** 1 cycle = 10s*

Conclusion

Conclusion

- It is possible to propose a “golden period” for a evacuation of a city. The evacuation rate reaches maximum during this golden period.
- As we can conduct measurement metrics (evacuation rate, efficiency) to be a function of given initial parameter, it’s possible to optimize for the best parameter (scenario of best known_shelter_location_rate)
- During the simulation, we detect some potential traffic bottlenecks, this is useful for traffic management during evacuation.
- Strategies of spreading initial evacuation information using time efficiency is important to make decision of evacuation (focusing on information spreading, minimizing time on roads or utilize evacuation rate).