POLITECNICO
MILANO 1863

SCUOLA DI INGEGNERIA INDUSTRIALE
E DELL'INFORMAZIONE

Formal Analysis of Search-and-Rescue Scenarios

Project for Formal Methods for Concurrent and Realtime Systems course

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Academic Year: 2023-24

Abstract

This document presents a formal model implemented with Uppaal of search-and-rescue scenarios. Inside a rectangular map of arbitrary size, civilians have to be brought to safety by either reaching an exit or being assisted by first-responders. Drones surveys the area and coordinate the rescue efforts by instructing civilians on what to do. The model then undergoes formal verification to highlight key behavioral aspects and identify optimal configurations for maximizing civilian safety.

1 High Level Model Description

The model adopted for the search-and-rescue mission involves 3 different types of agents: Civilians, First-responders and Drones. They are placed in different numbers inside a rectangular map, where exits (i.e. safe zones reached by civilians to get to safety) and fires are fixed in placed from the beginning of the scenario.

The key characteristics of the agents are these:

- **Civilians**: Can be in 3 different states, depending whether they find themselves near a fire or if they are following instructions
  - **In-need** (i.e. near a fire): They cannot move and needs to be assisted. After T_v time units near a fire, they became a casualty
  - **Busy**: The civilian is following an instructions and can be either assisting directly or contacting a *first-responder* to get help
  - **Moving**: When civilians are not near a fire or busy enacting some instruction, they can move towards an exit to get to safety following a some *moving policy*
- **First-responders**:
  - **Assisting**: When a civilian *in-need* is within a 1-cell range, the *first-responder* will assist them for T_{fr} time units. After that, the assisted civilian is considered safe
  - **Moving**: When free from other tasks, the *first-responder* can move following some *moving policy*
- **Drones**: They survey their surroundings, limited by the field of view N_v of the sensors, and follow a pre-determined path moving 1 cell at each time step. When two civilians, one *in_need* and one free, are detected the drone can instruct the free civilian to assist the *in_need* directly or to contact a *first-responder*

1.1 Model Assumptions

To simplify the model described in the assignment the following assumptions have been made:

- The map is a 2D grid with a fixed number of rows and columns, and fires and exits are static (i.e. they won't change during simulation);
- The distance between 2 cells is considered as the number of step needed to move from one cell to the other allowing diagonal movement, not the Euclidean distance;
- When a *civilian* need to move towards someone *in_need* or a *first-responder*, the model consider it moving for the whole duration of the movement and considering it safe at the end, without modeling the actual movement of the *civilian*;
- Drones know the global position of all the *first-responders* and their status, at any given time;
- All *civilians* know the location of the exits and can determine the nearest one;
- *survivors* cannot start the simulation inside a fire cell.

2 Model Description and Design Choices

2.1 Map Representation

The map is represented as a 2D grid of cells N_COLS x N_ROWS, each cell can be in one of the following states:

- `CELL_EMPTY`: The cell is empty and can be traversed by agents
- `CELL_FIRE`: The cell is on fire and cannot be traversed by agents
- `CELL_EXIT`: The cell is an exit and can be reached by civilians to get to safety
- `CELL_FIRST_RESP`: The cell is occupied by a first-responder
- `CELL_SURVIVOR`: The cell is occupied by a civilian in a safe state
- `CELL_ZERO_RESP`: The cell is occupied by a
- civilian following a drone instruction
- `CELL_IN_NEED`: The cell is occupied by a civilian in need of assistance
- `CELL_ASSISTED`: The cell is occupied by a civilian *in_need* that is being assisted
- `CELL_ASSISTING`: The cell is occupied by a first-responder assisting a civilian

```
// Map cell status enumeration
const int CELL_EMPTY =      0;
const int CELL_FIRE =       1;
const int CELL_EXIT =       2;
const int CELL_FIRST_RESP = 3;
const int CELL_SURVIVOR =   4;
const int CELL_ZERO_RESP =  5;
const int CELL_IN_NEED =    6;
const int CELL_ASSISTED =   7;
const int CELL_ASSISTING =  8;

typedef int[0, 8] cell_t;

// Map array
cell_t map[N_COLS][N_ROWS];
```

The map is populated by the actors described in the following sections.

2.2 Civilian

The civilian agent is the actor in danger that needs to get to safety.

At the beginning of the simulation the civilians position themselves in the map; if they are near a fire they become *in_need* otherwise they are considered *survivors*.

1. *in_need*: The civilian cannot move and needs to be assisted. After T_v time units near a fire, they became a casualty, if assisted in time they are considered safe. In both cases they leave the simulation freeing the map cell they were occupying.
2. *survivors*: The civilian moves towards an exit following a *moving policy*. If they are within a 1-cell range from an exit they are considered safe and leave the simulation freeing the map cell they were occupying. In this state they can receive instructions from the drone to either assist a *in_need* civilian or to contact a *first-responder* to get help.
   - Assisting a *in_need* civilian: The civilian "moves" towards the *in_need* civilian by staying in the same cell for the time needed to reach the *in_need* (the distance between the two). The Civilian "assist" the *in_need* by waiting T_{zr}. After that the civilian is considered safe and leaves the simulation.
   - Calling a First responder: The civilian "moves" towards the *first-responder* by staying in the same cell for the time needed to reach the *first-responder* (the distance between the two). The Civilian "calls" the *first-responder* that will assist the *in_need* civilian. When the *first-responder* ends the assist the civilian is considered safe and leaves the simulation.

At the end of the simulation all civilians are either safe or casualties.

2.3 First-responder

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2.4 Drone

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2.5 Initializer

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2.6 Design Choices

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3 Properties

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4 Conclusion

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