



**POLITECNICO**  
**MILANO 1863**

# **FM24 Homework:** **Formal Analysis of Search-and-Rescue Scenarios**

Formal Methods for Concurrent and Real-Time Systems, A.Y. 23/24

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# 00. Project Goals

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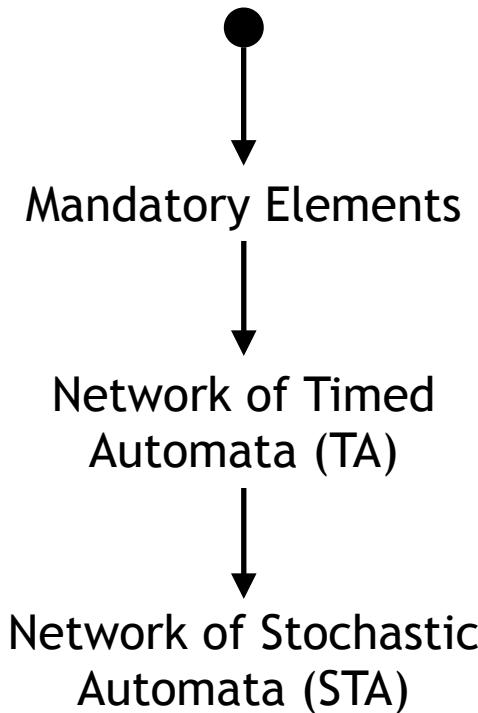
## 3. Practice substantiating your work:

how can you convince your reader/listener that you made the most reasonable and effective choices?

# 00. Project Goals → Deliverables

- 
1. Strengthen your modeling skills → Formal Model
  2. Exploit formal verification to analyze a system → Experimental Results
  3. Practice substantiating your work → Written Report

# 01. Formal Model



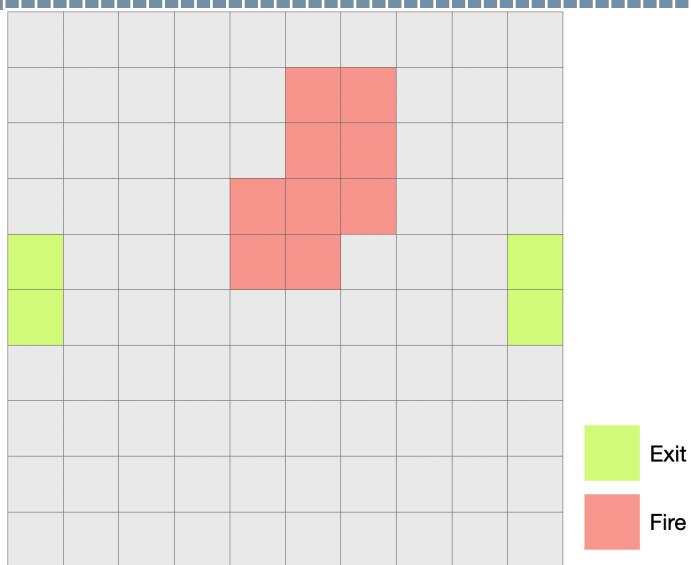
- The main output of the project is the **formal model**.
- Some entities/features (explained in more detail in the upcoming slides) must be **mandatorily** modeled to get a sufficient score.
- The NTA accounts for up to 90% of the total score (i.e.,  $\leq 27/30$ ). Stochastic features are required to get the full score (i.e.,  $> 27/30$ ).

# 01. Formal Model: Context



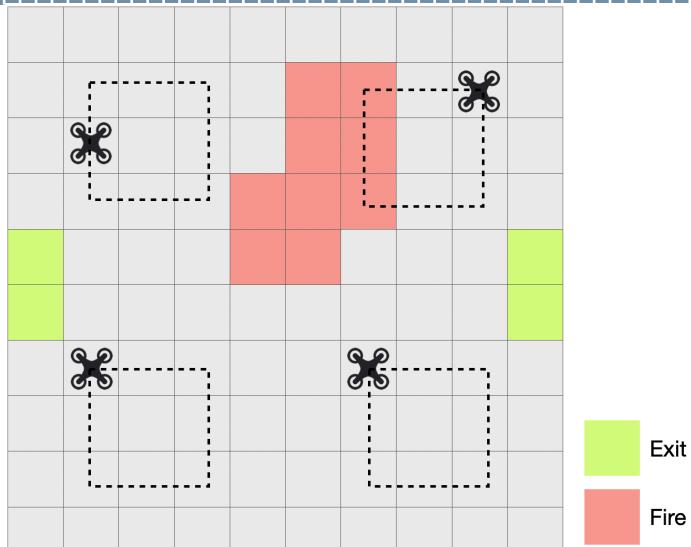
- Autonomous agents (e.g., drones) deployed in search-and-rescue scenarios to support rescue services
- Drones survey the scene and **decide** whether to instruct civilians to help people in need or contact professionals (i.e., firefighters or medical staff)

# 01. Formal Model: Layout



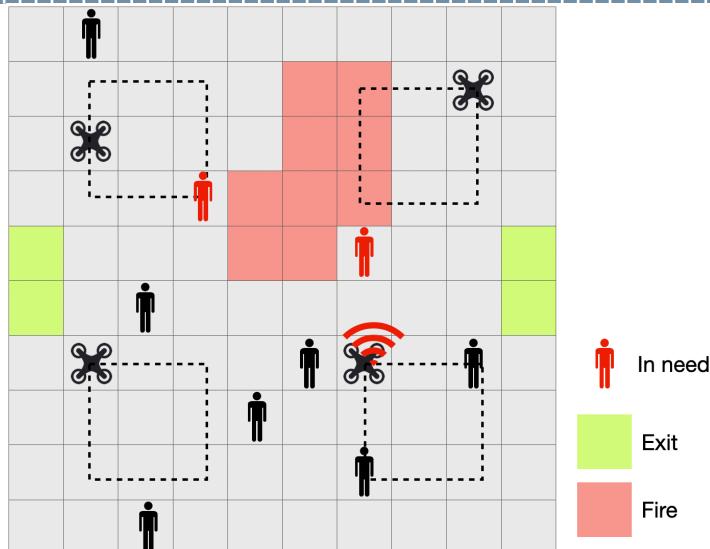
- $m \times n$  grid.
- Emergency exits are placed on the boundary of the layout.
- Fires occupy blocks of adjacent cells
- Agents occupy one cell at a time (drones can hover over cells occupied by a human).
- Agents' positions refresh each time unit (all agents move 1 cell/time unit)

# 01. Formal Model: Drones



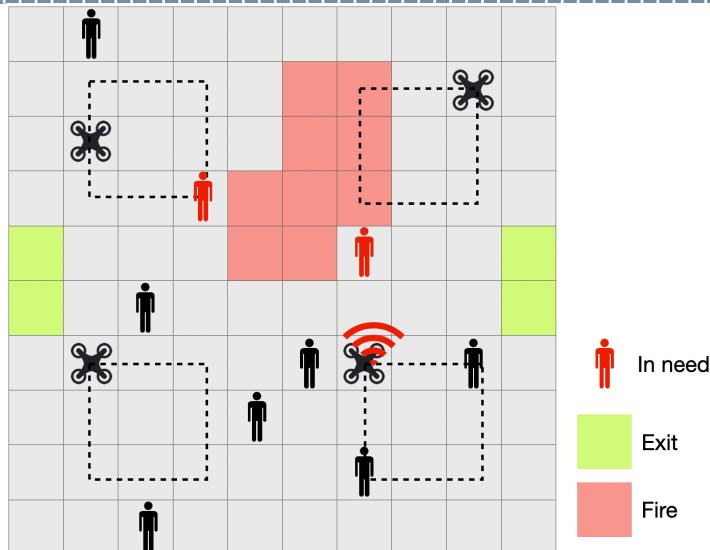
- Drones patrol with a pre-determined movement pattern that you design.
- If  $\text{dist}(\text{drone}, \text{survivor}) \leq N_v$  and  $\text{dist}(\text{drone}, \text{victim}) \leq N_v$  hold  $\rightarrow$  a decision must be made
- You design the **decision-making policy** (i.e., how the drone decides whether the civilian should act as a zero-responder or contact a staff member).

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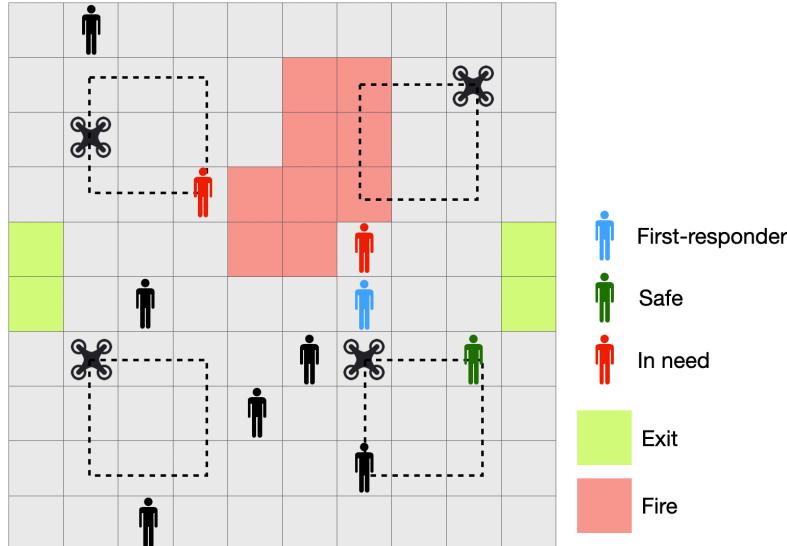
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- You design the **decision-making policy** (i.e., how the drone decides whether the civilian should act as a zero-responder or contact a staff member).
- **Stochastic version:** When in the proximity of a survivor and a victim, the drone detects it with probability  $1 - p_{\text{fail}}$ .

# 01. Formal Model: First-responders



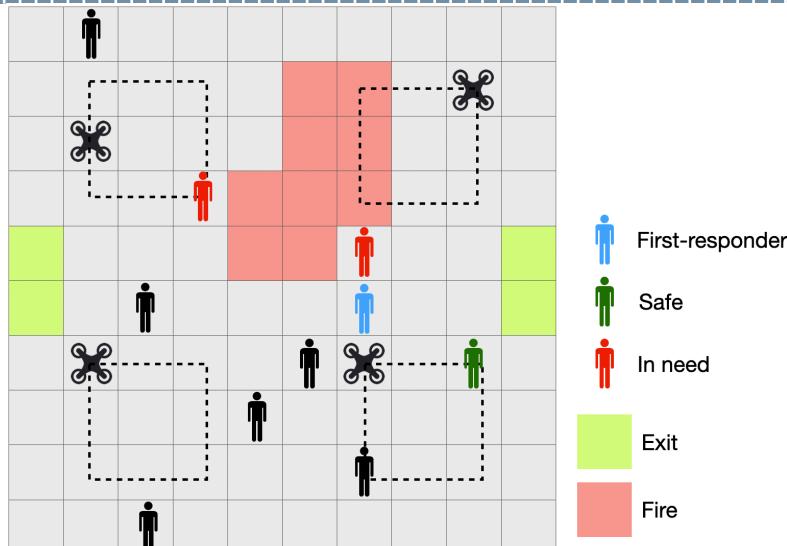
- If a person needing assistance is within a 1-cell range, the first-responder will assist them for  $T_{fr}$  time units.
- Otherwise, the first-responder moves.

# 01. Formal Model: Civilians



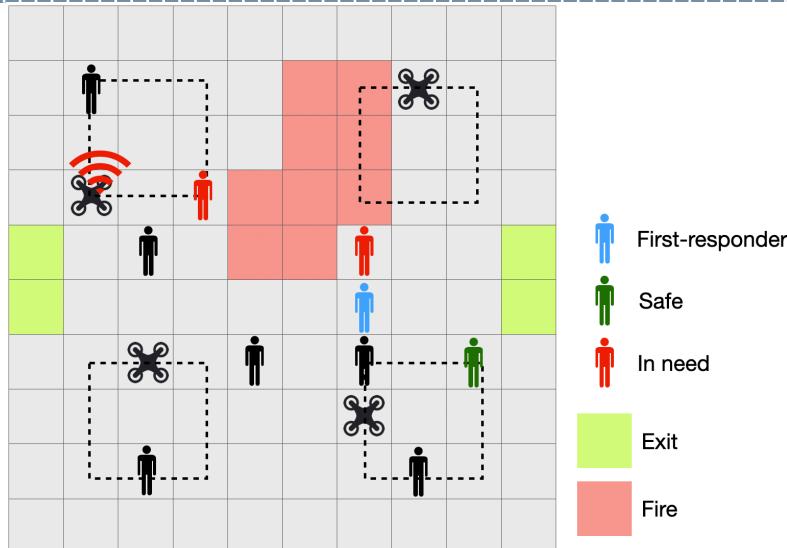
- If an exit is within a 1-cell range, they are considered safe.
- If a tile occupied by a fire is within a 1-cell range, they are considered in need of assistance. They are considered a casualty if not brought to a safe state within  $T_v$  time units.
- If the survivor has been instructed to help, they are busy acting as a zero-responder for  $\text{dist}(\text{survivor}, \text{victim}) + T_{\text{zr}}$  time units.

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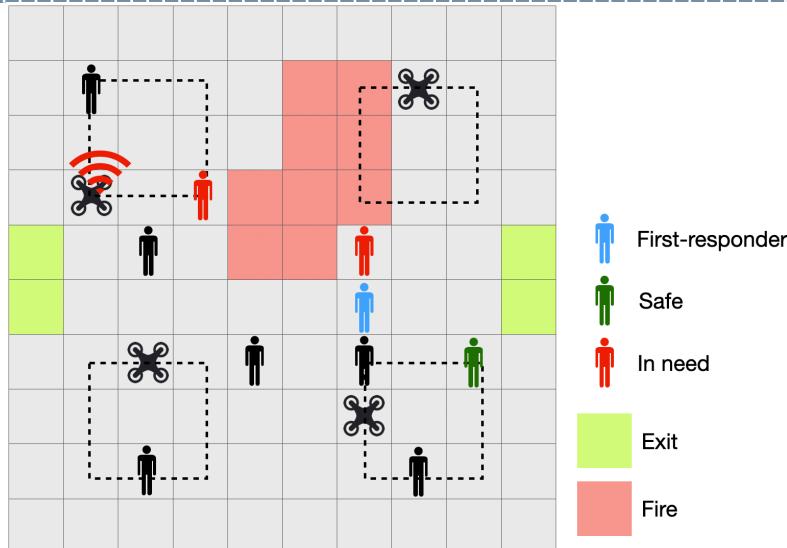
- If the survivor has been instructed to contact the first-responder, they are busy enacting this instruction for  $\text{dist}(\text{survivor}, \text{first-responder}) + \text{dist}(\text{first-responder}, \text{victim}) + T_{fr}$  time units
- If none of the above apply, the survivor moves.

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- If none of the above apply, the survivor moves.
- **Stochastic version:** When instructed by the drone, they acknowledge the instruction and enact with probability  $p_{listen}$  and ignore it (or miss it) with probability  $1 - p_{listen}$ .

## 02. Formal Verification: Properties

- The **mandatory** properties to be verified are:

**P1.** It is **possible** for a percentage  $N\%$  of all civilians to reach a safe state within time  $T_{scs}$ .

**P2.** A percentage  $N\%$  of all civilians is **always** guaranteed to reach a safe state within time  $T_{scs}$ .

## 02. Formal Verification: Properties

- Whether these properties hold or not depends on the **scenario configuration**. Specifically, on the following parameters:
  1. the geometry (i.e., where exits and fires are located);
  2. the number of agents in the scene (i.e., how many drones, civilians, and first-responders are present);
  3. the drones' visibility range  $N_v$ ;
  4. time-related parameters  $T_{fr}$ ,  $T_{zr}$ , and  $T_v$ ;
  5. the drones' decision-making policy;
  6. the drones' and humans' moving policy.
- Present (at least) **three** significant NTA configurations highlighting relevant behavioral aspects of the system.

## 02. Formal Verification: Stochastic Properties

- As for the stochastic version of the model, calculate the **probability** of properties P1-2 holding within a **time bound** (the time bound must also be properly sized).
- The NSTA behavior further depends on the following parameters:
  - the drones' sensor **failure rates**;
  - the civilians' instruction **acknowledgment rates**.
- Present (at least) **three** significant NSTA configurations highlighting relevant behavioral aspects of the system.

## 02. Formal Verification: Tool

- The formal model should be created using the [\*\*Uppaal\*\*](#) tool:
  - ▶ More info during the student presentation session.

## 02. Formal Verification: Tool

- You can find references in the [Getting Started](#) section of the website:
  - Reading the [Tutorial](#) (also for the [SMC extension](#)) is highly recommended!
- When in doubt, the [Documentation](#) is your friend:
  - It contains all the reference for:
    - ▶ GUI of the tool
    - ▶ System Description
    - ▶ Requirement Specification
    - ▶ ...everything you need!

## 03. Written Report

- You must **mandatorily** deliver:
  - Uppaal .xml source file for your model:  
**Beware:** I will re-run the queries you describe in your report, so make sure the model is experiment-ready and queries are saved in the verifier section!

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  - The project report (possibly a .pdf):  
Max 10 pages: front cover, index page, bibliography, appendices [...] do not count.  
No constraints on the template (but you can take this chance to practice with LateX before writing your thesis...).

## 03. Written Report

- Tips for the report:
  - Do not just enumerate variables, locations, clocks [...]: what really matters is your **reasoning** and critical thinking.

For example: “*This feature is modeled as a two-dimensional array of integers.*” ...fine, but **why**? There can be more than one valid motivation, but please provide one.

- I will upload excellent reports from previous years to provide a positive source of inspiration.

## 04. Final Remarks

- Deadline **July 22** (June 26 if you want the grade registered by June).
- It is preferable (for you) to carry out the project in teams of 2/3/4 people.
- My job is to support you and provide directions: please drop an email when you need it.

...I cannot solve bugs for you though :) (that's cheating)

- Do not open up with "*Dear prof, we have problems, can we schedule a meeting?*": please describe your issue, and then I will assess if it can be solved via email or if it requires a meeting.



**Questions? :)**