Designing a Serious Game of crisis management on top of an Agent-Based Simulation of population evacuation

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Abstract. Serious games have become widely prevalent, manifesting either as board games or role-playing experiences, designed to train individuals to think and respond in intricate scenarios that are often challenging to replicate and control in real life. Concurrently, numerous agent-based simulations, wherein simulated actors exhibit complex behaviors, are being developed to delve into the potential dynamics of intricate systems.
This paper introduces a fusion of these two methodologies, where a serious game built upon an agent-based simulation immerses users in conditions as closely resembling crisis management scenarios as possible. This amalgamation is not without its challenges, as serious games come with specific requirements that may clash with existing simulation frameworks. These include real-time interaction with the simulation, precise replay of given scenarios, an engaging display to captivate players, and the ability to manage multiple users playing different roles simultaneously on the same simulation.
To do so, the ESCAPE-SG serious game is presented. It is crafted on the foundation of ESCAPE, an established agent-based model aimed at simulating mass evacuations of populations from areas facing significant natural or technological hazards. The encountered challenges and the solutions devised to overcome them are outlined. Additionally, a software architecture is proposed to facilitate the connection between an agent-based simulation and a front-end display, serving as an interface for users.

Keywords: Agent-based simulation · Serious Games · Evacuation.

1 Introduction

Institutional actors in charge of inhabited areas may face dangerous phenomena, whether of natural origin (floods, tsunamis, volcanic eruption) or technological (toxic cloud emitted by industrial plant). Decision making during these events is crucial to protect exposed people inside these areas. One way to get ready for these extreme events is to train in advance, what is currently carried out through life-size training courses for the whole crisis management unit [22]. These training sessions often take the appearance of serious games [14] where a predefined scenario is played steps by steps with a careful analysis of results compared to an optimal solution at each step.

The primary goal of serious games, contrary to classical games where the objective is to entertain users, is to teach new knowledge to players through their participation and interaction with the game environment. [9]. This means that even if a serious game looks like a classical game, for example using pen and paper, a set of card or other kinds of pawns, the way it works answers other standards. Most of the serious games take the form of a social simulation or a role-playing game [27]. The game is run by a game master who helps the players make decisions in a believable environment. Then, the consequences of these decisions, which may put the game in a new state, are presented by the game master.At the end of the game, the game master shows and comments the results so that players understand what happened during the scenario they discovered. To increase the reality of the game and the panel of available scenarios, the simulation of the environment may be done through a computer simulation. The main point is that none of the decisions made by players should lead to situations not controlled by the game master or designers; each action must make sense in terms of the training and coaching objectives, and the results of these actions, whether good or bad in terms of the game's objectives, must be, if not known, at least within the range of solutions accepted by the game designers.

Indeed agent-based simulations are a meaningful framework for the study of a large variety of situations where humans interact in a very detailed environment [16]. Just concerning the use case of evacuation, there exists simulations of building evacuation [32], of cities evacuation [11] up to evacuations of regions [2], with various level of decision making complexity for the agents [6]. All these simulations, with their many parameters and random processes, produce a vast amount of data that researchers analyze to establish evolutionary scenarios based on probabilities of occurrence.

ESCAPE is such an agent-based evacuation-oriented simulation framework [11]. It is aimed at researchers whose works focus on the analysis of territorial vulnerabilities and mass population evacuation strategies. It provides intuitive tools for building spatial and social data, as well as libraries in the GAMA modeling platform [29] for fine-tuned modeling of mobility behaviors. Coupled with OpenMole software [24], the ESCAPE suite can be used to explore numerous research hypotheses in "what-if" and "how-to" mode, such as a volcanic eruption [17]. ESCAPE requires the calibration of numerous parameters and exploration of a large number of scenarios to produce territorial diagnosis and implementation of crisis management plan. In this sense, ESCAPE is less a training tool than a support tool to evaluate different strategies, which is a challenge while switching it to a serious-game in respect to the mentionned constraints. ESCAPE-SG [13] is therefore a serious game built on top of ESCAPE, but conceived and designed as a training tool for crisis management. To do so, multiple players have to be able to interact with the running simulation, with various roles and different actions to perform. At the same time, a game manager should be able to run a scenario with external events. Finally, the game should be able to display the useful information in real time as well as ending statistics to measure the performance of the taken decisions and actions. These conditions are not met with the existing frameworks where detailed agent-based simulation of evacuation are implemented.

Section 2 of this articles discusses the previous works done with agent based simulations and serious games, in particular in the context of mass evacuation. Section 3 presents the challenges which come with building a serious game on top of an existing agent based simulation of an evacuation while section 4 details the discussion about the implementation of such method on a specific use case. Finally, section 5 concludes the article.

2 Related Works

Agent based simulations have been widely used to study complex systems involving human decisions and behaviors. They enable to recreate complex situations, for example social or environmental, and test various conditions of evolution of such complex systems. This section focuses on the reviews of agent based simulations and serious games about disaster risk management and population evacuation.

2.1 Simulating evacuation

Evacuation of population under hazardous conditions is a case of social simulations [16] with an importance given to the spatial dimension [12]: an evacuation starts with a situation under normal conditions when something happens (it may be an alert sign or an sudden event) and people switch their normal behavior to abnormal conditions. Many works simulate the evacuation from the inside of a building with hundreds of agents [6] [32]. Indeed a close environment with a fewer number of agents enables to implement a more complex behavior, with cognitive, affective and social dimensions as well as a fine description of architecture and geometries.

There are also city-scale simulations of evacuation. Taillandier *et al.* [29] simulate the evacuation of an urban area under flood. Each agent represents a pedestrian trying to find a shelter from a flood, following advises communicated by institutions. The same type of work may be done on a bigger geographical area with a bushfire as the hazard to evacuate from [2]. Finally, Daude *et al.* [11] proposes ESCAPE, a tool to model and simulate massive population evacuations in territories which can be described by very descriptive land-use data and network transportation system. In ESCAPE, agents which represent individual human may use different types of transport systems, starting as a pedestrian and then driving a car for example, to achieve their goals. ESCAPE offers a powerful Driving-skill pursuit model [26] and the agents have evolving knowledge of their travel environment. They can thus have knowledge of “experienced” traffic conditions, for example by memorizing the time spent by each person in traffic jams, as well as more macroscopic traffic conditions, which allows some agents to benefit from optimized routes. This framework has been used to simulate massive evacuation in the case of volcanic eruption [17] and of flooding [19].

2.2 Serious Games and hazardous situations

Serious games are playful activities which have, by learning, a serious goal on top of entertaining [9]. Learning is based on interactions with the model that simulates the crisis domain and on interactions between participants to collaborate and succeed in solving a certain number of tasks. Marne [21] proposes five common denominators for this type of game. The *challenges* are the problems given to the player; *Significant actions* correspond to the steps taken by the player to resolve these challenges; the *game engine* is the simulator which reacts to the player's actions; the *graphical interface* linked to the engine and the player which makes it possible to give a playful aspect to both the problems and the simulator; finally, a *script* that allows the levels of difficulty offered to evolve according to the desired educational progression.

Serious games have been applied in the field of disaster risk management where they may rise awareness about the consequences of catastrophes. In 2018, 45 serious games about disaster risk management were surveyed [27]. This includes a board game aiming at raising awareness about environmental disaster in the multicultural context of the Caribbean [10] or the "Don't Stop !" video game where users play the role of stakeholders who need to prevent damages before critical situation [15]. This latter video game has been expanded lately on the more specific topic of evacuations in front of a flood [18], proving the subject is still active in the community.

Some serious video games (that is to say serious games that uses video games technique as their core mechanics) rely on agent based simulations and multi-agent systems. Adam *et al.* propose a serious game about urban planning in the context of sustainable transport in cities [1]. In this game, users play the role of a group of people responsible for decisions on the urban landscape and the reaction of the population living in the city is generated through a multi-agent system. This technical design may be found in other works but specifically in the context of risk management and emergency evacuation as with the SPRITE game[28] or LitoSim [4]. The goal is to take actions that will have impact on the future catastrophe, the simulation is not in real time as the game simulate multiple months. With the same principle in mind, Moatty *et al.* developed a serious game about the evacuation of a population during a flood using an existing complex model of evacuation created with a multi agent system [29].

2.3 Synthesis

This section reviewed multiple agent-based simulations of large urban areas and evacuation of their population, and then discussed some existing serious games about disaster risk management. However, only few works combine these two field. From the simulation point of view, integrating game mechanisms would help popularize the results to a broader audience. From the serious game point of view, integrating an agent based simulation would make the result closer to a video game which is now a powerful language to communicate complex ideas to people [5].

One of the problem about using an agent based simulation into a serious "video" game in order to study the evacuation of populations on large urban area comes from the technologies used. Even if there exist multiple platforms to perform this type of simulation [30] [33] [3] [20], each with its own strengths and weaknesses, these tools are not suitable to integrate a complex interface which enables users to input discrete event into the simulation which operates in a continuous time.

3 From Simulations to Serious Games: Challenges

This section discusses the process used to create a serious game [26] about disaster risk management by taking its foundations in an existing evacuation simulation tool [13]. More specificaly, the objective is to create a multiplayer game, where each player has a specific role and may take actions while the simulation is running.

3.1 Simulating evacuation at a city level

The ESCAPE project [11] allows to simulate the evacuation of wide territories confronted to catastrophic events with citizens and civil servants (policemen, firefighters) represented by agents in the system. It's possible to first simulate the dynamics of the territory, such as the flow of vehicles under normal conditions, before injecting an event (e.g. an evacuation order or a volcanic eruption) that is perceived by agents, who will then react by modifying their behavior [8]. More precisely, the ESCAPE project is composed by the following elements :

- **Environment** : the land-use (buildings, forest, river) and road networks of the studied area are modeled. The pedestrian area are included as well as the type of the buildings (school, hospital, residential, etc.). A tool using R-Shiny has been developed to directly produce environment data gathered from OpenStreetMap [23]. All these data are pre-processed before being included in the simulation. Building the environment with open data enables to quickly adapt the project to a new use case about a new area.
- **Agents** : each person is represented by its own agent, and households can be represented as a set of agents. In order to create an agent population at a size coherent with demographic statistics, a sample of real people is reproduced from census data. Generative synthetic population libraries [7] are then applied to this sample in order to generate a population of the correct size, with agents having characteristics as close as possible to the real studied population. There are also vehicles agents which may be used by

people, i.e. cars, trucks, buses, bicycles and motorcycles. The flow dynamics on ordinary days is reproduced using both household travel survey and traffic data measured on the network.
- **Hazard** : hazards and theirs dynamics can be modeled directly or have their geographical footprint uploaded from geographical information system as time-step layers defining their spatial and temporal dynamics. Interactions between agents and hazards dynamics can be modeled to reproduce casualties, or any impact on the environment (e.g. speed reduction) depending on the catastrophe implemented.

ESCAPE is then useful to simulate territorial dynamics, both:

- **Under normal circumstances** : each agent follows its own schedule for the day. This includes going to work, taking care of their children who go to school, going to grocery store or going back to their home among other activities. To perform these activities agents may choose among different mobility modalities depending on their starting and ending point. Once in a vehicle, the shortest path to the destination is followed. Agents may use different types of vehicles to go to their destination target (starting as pedestrian, taking a car, then a bus and maybe ending with a bicycle). The vehicle is chosen based on the household travel survey as well as depending on the lowest estimated time to move from one point to another.
- **Under crisis situation** : when perceiving a hazard (either by seeing it, by hearing an alarm or a message on the radio), agents may change their behavior and give up their normal schedule. Depending on their own characteristics and the received message, they may either choose between evacuating or confining. To do so, each agent may use multiple transportation mode depending on the configuration estimated as the fastest.

Operationalization of crisis management is modeled through different actions taken by authorities such as the trigger of different types of alarms (global such as cell broadcast and local such as siren or mobile alarms set). These alarms may be heard by people which in return will decide or not to follow instructions. This means that not all agents either evacuate or confine shortly after the notification, but may still pursue their activities. This decision making process is fixed by the modeler through the use of different parameters or probabilities functions provided by ESCAPE tools and calibrated upon population surveys [17].

3.2 From ESCAPE to ESCAPE-SG

The ESCAPE project has been extended into the ESCAPE-SG serious game [13] [26]. The main goal of this operation is to create a training tool which is more understandable than a simulation, but provides realistic dynamics and scenarios. The key features of the ESCAPE-SG serious game are then:

- The overall setting is the evacuation of an urban environment, from a part of a town to a few nearby towns. For this, players should be able to interact with the running simulation (ex. to close a road, checking an information such as the number of peoples in a shelter or to select antenas to switch-on alarm system).

– Several players, each with a dedicated role (i.e. mayor, civil servant, road manager), should be able to play together on the same simulation at the same time. They may act on a medium or large scale: evacuate such or such building or area, block a road, intervene on a fire, etc. but the evacuating individuals are ran by the simulation. Likewise, a game manager should be able to trigger events during the game.
– The traffic situation inside the simulation should be displayed according to different temporalities: one in which simulated time is equivalent to real time, and also discrete (x3, x10) or continuous (from 1 to 10) accelerated modes that allows to stay within game durations consistent with the time allowed by players or game managers.
– Taking the fact that each role has its own actions available, players need to have feedback from the game to understand the consequences of their actions.

To integrate all these features, ESCAPE-SG has been implemented by using the SUMO platform [20] for the traffic simulation, and a custom multi-agent system in JAVA which runs the detailed individual interactions between mobile agents, beyond what is possible in SUMO. This MAS acts as an intermediate between SUMO and the Unity game engine [31] which is used for the ESCAPE-SG 3D graphics front-end. Indeed, the ESCAPE simulation is running on the GAMA platform which does not enables to easily act in multiplayer upon a simulation running in continuous time. If GAMA graphical interface allows to display simulation information, it is not meant to manage intensive graphical input from several players at once. It is also not able of synthesizing input from several different graphical interfaces computed on distant networked computers. Finally, GAMA cannot either be interrupted and resumed, or have internal values modified by external programs. It was as a consequence not the right software tool for the back-end.

Figure 1 shows the screen of the game manager watching a particular spot on the road network with ESCAPE-SG. Buildings and vehicles are displayed in three dimensions and the interface shows the various actions which may be taken. Each user watches a similar screen but may focus on an other place of the simulated area. They may access only their available actions. Figure 2 shows a more macroscopic view of the simulated territory, in which traffic conditions can be distinguished, synthesized here by color gradients on the sections.

4 Generalizing the process

Section 3 presented a use case where a serious game is built upon an existing agent based simulation of a city evacuation. This section discusses in a broader way the challenges related to the development of a serious game starting from an existing agent based simulation of an evacuation situation. The goal of this

Fig. 1. View of the manager role in the ESCAPE-SG serious game

Fig. 2. Overview of the simulated area in the city of Rouen

section is to present a general software architecture to ease the development of future serious video games.

4.1 Creating a serious game from a simulation

As mentioned previously, one of the main challenge deals with the fact that players have to perform their actions while the simulation is running; in other words, this means triggering discrete events over a continuous simulation.

Figure 3 shows the software architecture developed to ensure that players could act over a running agent-based simulation. The system may be decomposed in three parts : the back-end where the simulation runs, the front-end which serves as an interface with players and an API which makes the connection between back-end and front-end.

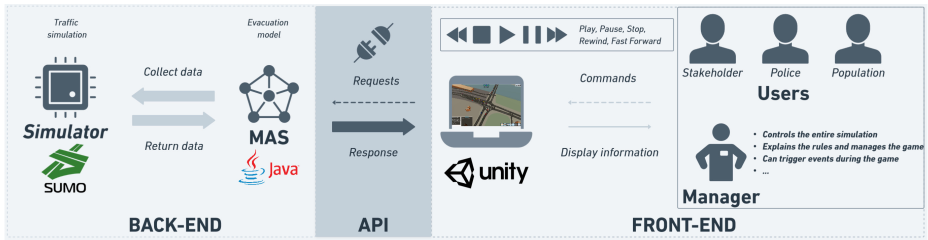

Fig. 3. Global software architecture for the creation of a serious game on top of an agent-based simulation

For ESCAPE-SG, instead of keeping one integrated solution for the back-end as it is the case in ESCAPE, the crisis simulation is performed by two systems communicating together as can be seen on figure 3. The multi-agent system (MAS) models people perception, decision-making and a part of their interactions. The simulator computes the next position of all mobile agents, depending on their current objective, mobility, and interactions with the hazard and other agents. The simulator computes the new location of each agent and sends it to the MAS which forwards it to the REST API for display.

On the front-end side, each user has its own client displaying a graphical interface. Depending on the role of each player, the actions available upon the simulation are different. Each action performed at any time by any player is sent to a REST API as a command. This command is then passed on to the MAS which modifies the environment settings. The set of commands includes closing a road or changing the direction of traffic, opening shelters or triggering alarms for example.

Lastly, the game manager has a dedicated interface. With a dedicated set of actions, the game manager may run a given scenario acting on the environment or the hazardous condition by sending commands to the API. This way, the game manager is seen as a player with a specific role.

4.2 General discussion

To ensure an efficient serious game, in regard to the notions learnt by participants, it is important to put the player as close as possible to the real case situation [27] while having a multiplayer experience [25]. These two principles guided the creation of the software architecture described by figure 3.

Let's take an example of action: closing a road as the mayor during the evacuation. To mimic the real world, the player needs to implement this action by selecting the specific road to close and then close it few minutes after the order was given, simulating the time an employee would take to effectively close the road in real life. Multiple actions follow the same principle: either their effect is differed in time or their consequences will start to have an impact multiple minutes after they were decided.

The same problems arise on the game manager side: the hazard triggered have an effect over the simulation for multiple hours. Hence, the simulation flow of time should be altered in order to have a game covering multiple days around the catastrophe playable in few minutes/hours. With an architecture making a difference between the atomic computation of the next move and the decision making process, it is easier to pause the simulation or fast-forward it; as each part is waiting for the other, a command may be passed to one part which may disconnect until it is executed.

The goal for realism of the game also implies a complex graphical user interface. In the real life, stakeholders have a partial knowledge of the events. By implementing one client per role, each player as access to only partial information from the simulation and needs to communicate with the other players before making a decision. With the same principle, each role only has access to a sample set of all the possible actions, reflecting its real life capacities. All these reasons imply the use of a front-end which is not integrated with the back-end, a modularity that eases a personalized display.

5 Conclusion

This paper presents the challenges coming with the creation of a serious game about disaster risk management crafted on an existing agent-based simulator of mass evacuation. The creation of the serious game ESCAPE-SG [26] from the ESCAPE project [11] is described as an initial use case. This paper uses this particular case to extract a more general discussion on the challenges arising when building a serious game from an existing agent based simulation, especially in the field of disaster risk management.

In the future, the ESCAPE-SG serious game should be tested with crisis managers to assess its capacity to improve the existing training sessions. New scenarios on new areas will be implemented in ESCAPE-SG to demonstrate the generic nature of the project.

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