1
Introduction

1.1
Motivation

Since computer games started to be commercialized in the 70s, their popularity has not yet stopped growing. Today, the gaming industry has grown into an industry worth staggering USD$65 billion in revenues (Reuters 2011), reaching the level of other well established entertainment industries such as music and movies.

All this growth has brought huge investments to the development of new computer technologies, particularly those devoted to increasing realism in audiovisual media. Specialized hardware for graphics acceleration has been one of the main focuses of innovation in the gaming industry. More recently, game physics (Eberly 2003) has also become one of the main disciplines in game development. The performance required to achieve this kind of realism also requires fast algorithms to run the game logic. For this purpose, game AI has also become one of the main research fields in computer games (Nareyek 2004). More recently, with the internet and the increasing adoption of network multi-player games, much of the research turned to reducing the impact of network delays in player experience (Smed et al. 2002; Pantel and Wolf 2002). One interesting side effect of the evolution of graphic cards is that they have become so powerful that there is currently a research field trying to apply that potential for generic parallel programming, including complex simulations (Owens et al. 2007).

The interactive aspect of computer games is capable of providing the players with the most joyful experiences, allowing them to be someone they could never be, do things they could never do and go to places where they could never be (Sheldon 2004). This kind of experience that entertainment games provide is certainly appealing and sometimes dangerously addictive. On the other hand, such kind of immersive experience can also be used for purposes other than mere entertainment, such as learning and training.

The so-called *serious games* (Susi et al. 2007) attempt to show that computer games may have purposes other than mere entertainment. In this kind of game, it may not be so important to achieve fun in the game experience itself, but to learn and improve important skills during and after game play. Areas such as military, medicine, architecture, education, urban planning, and government can in fact draw many benefits from computer games technology (Smith 2007; Susi et al. 2007). The class of serious games includes all those designed for non-entertainment purposes.

Some of the earliest serious games consisted of simulators for military operations and aircraft flights. They grew in parallel with the entertainment gaming industry, also receiving considerable amounts of investments. These kinds of games are technically very similar to computer games, sharing with them requirements for realism in audiovisual media. However, they are considerably different with respect to *simulational realism* requirements. The term simulational realism denotes the degree of correctness of simulation methods used behind the games, in the sense that they correctly simulate real world phenomena. While it is common practice in entertainment games to sacrifice simulational realism for better playing experience, the correctness of the simulations is often more important in serious game design (Michael and Chen 2005). Henceforth, simulational realism shall be referred to simply as realism throughout the rest of the text.

While computer games used for entertainment usually create their own reality, simulators must represent realistic situations. This might be the main reason why computer games have been viewed slightly as a non-serious research subject by most of the scientific community until recently. In fact, computer games have been traditionally one of the most informal areas of computer science. In addition, since the gaming industry is so competitive, top technologies are often developed in secret and are only published after becoming relatively obsolete. Until recently, it was hard to find game research literature with the same level of depth and formalism as other more traditional Computer Science areas.

This thesis focuses on one specific type of serious games, namely those which require the simulation of realistic situations. In the scope of this thesis, training is the process of improving decision making capabilities of some set of humans through the simulation of realistic situations, and serious games are often designed to assist in that learning process. For simplicity, computer games shall be referred to simply as games.

In psychology, a number of sophisticated models for understanding the learning process have been developed. According to Piaget (1972), people learn by assimilating knowledge obtained in a new experience to their existing schemas. Learners build new cognitive structures in this process of assimilation where previously existing structures are adjusted to incorporate new knowledge. Also useful here is Kolb's model for experimental learning (Kolb 1984). It sees learning as a cyclic process of experience and reflection. Experience generates observations, which feed a process of reflection, where new mental models are formed. These new models are then tested through experience again. The main benefit of serious games to that process is that they can serve as a source of simulated experiences with possibly much lower costs than real experiences. Just consider as an example the case of disaster management, where field exercises often demand lots of people, resources and time. Besides that, the use of simulated situations allows one to control factors that would otherwise be uncontrollable, such as weather conditions.

In general, games can always be thought of as simulations where the player(s) take active roles and interfere with the simulation progress during its execution. Therefore, the notion of *interactive simulation* comprises the notion of game. Interactive simulators may have different objectives, such as studying and predicting the behavior of real dynamic systems. What characterizes an interactive simulation as a game is the notion of a goal that should be pursuit by the player(s).

Since this thesis focuses on serious games thatsimulate realistic situations, it will take into consideration previous work developed in the area of simulation and other correlated areas to try to integrate these existing techniques in a framework for serious games. The following sections provide an overview of these correlated areas and a list of requirements that will be addressed in chapters 3 and 4.

1.2 Simulation Overview

This section briefly overviews the areas of Modeling and Simulation, Agent-Oriented Simulation and Geographic Information Systems. These

Computer Science areas provide simulation techniques that can help achieving simulational realism in serious games.

1.2.1
Modeling and Simulation

Modeling and Simulation is an active research area almost as old as Computer Science itself. In this context, simulation is not just a tool but a scientific discipline whose purpose is to study real systems through the construction of computational models for these systems (Michel et al. 2009). Such models can then be used either for understanding the behavior of a real system or helping in the design of a new one. Modeling and Simulation techniques have been successfully adopted in fields such as military applications, health care, logistics, construction engineering, supply chain management, electronic circuits manufacturing, business process modeling, biological sciences and emergency response, among others. Active research fields in simulation include:

- **Modeling formalisms, languages and processes.** Specific application domains usually adopt modeling formalisms, languages and processes in which clear and correct models become simpler to define (Sánchez 2006; Robinson 2006).

- **Model validation.** Models need to be properly validated with formal methods so that their results can be trusted (Sargent 2009; Coyne et al. 2008).

- **Simulation algorithms and distributed simulation.** As the complexity of simulation models grows, more powerful simulation platforms are required. This is achieved by making simulation algorithms more efficient or by parallelizing the execution (Perumalla 2006).

- **Reuse and integration of simulation models and systems.** From the software engineering point of view, the challenges are at multiple levels: the reuse of simulation models (or parts of models) defined in the same formalisms (Balci et al. 2008; Röhl and Uhrmacher 2008), the integration of models defined in different formalisms (Eker et al. 2003; Lee and Zheng 2005; Sarjoughian et al. 2008) and, more broadly, the integration of different simulation systems (IEEE 2000; Benjamin and Akella 2009).

Traditionally, Modeling and Simulation is more focused on fully automated simulations than on interactive simulations. Interactive simulations are those in which one or more human users take part in the simulation dynamics. The addition of human elements brings some interesting challenges. From the simulation point of view, it is necessary to: (1) provide communication between humans and other fully automated simulation elements; (2) find ways to properly synchronize the actions of these two inherently asynchronous kinds of elements. Indeed, one of the current topics in the integration of heterogeneous simulation models is the integration of asynchronous models (Eker et al. 2003). If simulation techniques are to be integrated with computer games, this is certainly one of the main issues to work on.

1.2.2 Agent-Oriented Simulation

Agent-Oriented Simulation (AOS) (Uhrmacher and Swartout 2003), or Agent-Based Modeling and Simulation (ABMS) is in the intersection of the multi-agent systems (MAS) and the simulation fields. It is a paradigm that represents not only a specific kind of dynamic systems but essentially a new approach to modeling these systems by thinking about and designing them as societies of autonomous agents. Its benefits appear mainly in the simulation of complex systems (i.e. systems composed of many interacting and autonomous entities) such as agent-based social simulations (ABSS). More than just simulating the evolution of a system from a given input set, MAS work as artificial worlds where experiments can be made. One of the main qualities of AOS is its capacity of integrating quantitative variables, differential equations and behaviors based on symbolic rules systems, all in the same model (Michel et al. 2009).

Current challenges in AOS include combining MAS techniques for modeling cognitive behavior such as the BDI architecture (Rao and Georgeff 1992) and simulation platforms (Bordini and Hübner 2009). Moreover, all the formalism developed in the simulation field is relatively underdeveloped in MAS. Ways of creating well-defined MAS models that are platform-independent, model reuse and formal methods of verification must still evolve (Michel et al. 2009). Other interesting problem typically found in ABSS is how to model causal relations among different abstraction levels (Troitzsch 2009).

There is some tendency in the MAS field of anthropomorphizing agents, giving them human qualities such as intelligence, cooperation and rationality (Uhrmacher and Swartout 2003). The techniques developed in that direction could be of great use in serious games. Therefore, the effort to incorporate them into the dynamic models of serious games is perfectly justifiable.

1.2.3 Simulation in Geographic Information Systems (GIS)

Geographic Information Systems (GIS) is also a long-lived field in Computer Science. Traditionally, most of the work in the field is devoted to storing, querying, processing, analyzing and mining geographical data. In the field of serious games, GIS are expected to play a major role. Since one of the main focus of serious games is simulational realism rather than realism in audiovisual media, their simulations tend to take place on realistic rather than on imaginary scenarios. In this situation, GIS can contribute to serious games in different ways (Gonçalves et al. 2004):

- **Access to GIS Databases.** By providing efficient access to repositories of geo-referenced spatial data (Güting 1994), GIS helps building realistic scenarios for games.

- **Spatial Operators.** Spatial querying, distance and topological operators (Egenhofer 1991) may be used in the simulation logic of serious games.

- **Simulation Models.** Dynamic models of anthropic and natural phenomena, such as land use change (Carneiro 2006), traffic control (Kesting et al. 2009) and socio-economic dynamics (Batty 2001) have been extensively studied in the GIS field (van Deursen 1995). They may be quite useful, depending on the game domain.

- **Visualization.** Although GIS visualization tools do not provide top-quality graphics and interaction as modern games do, some of them provide interesting ways of visualizing relevant information (Dykes et al. 2005). They may be used by serious games that do not require state of art graphics. Some specific techniques were developed for rendering GIS data in 3D (Schneider et al. 2005).

- **Real-Time Monitoring.** The *Global Positioning System* (GPS) and *sensor networks* provide techniques for monitoring entities in real time (Akyildiz et al. 2002). These techniques could be useful in serious games in which computer simulation is mixed with real dynamics.

As a last remark, all the standardization efforts in GIS, such as those promoted by the Open Geospatial Consortium (OGC) (Percivall 2003), help making serious game applications interact with multiple Spatial Data Infrastructures (SDI's) and, more generally, with any GIS that follow the standards.

1.3 Selected Requirements for Serious Games

Naturally, the requirements for serious games may differ from game to game. For example, while some may demand realism in audiovisual media, other may devote their resources to ensuring correct simulations. However, that does not mean that the requirements for this kind of games cannot be studied from a generic point of view. This section aims at selecting interesting requirements for serious games that are focused on the simulation of realistic situations. Most of these requirements are not among the priorities of most entertainment games. Even though these general requirements will not be present in every serious game, it is expected that they will appear frequently. The following requirements were selected:

- **Simulational Realism**: If a serious game is able to simulate a realistic situation, it can help improving human decision making capabilities in the real world. A realistic simulated situation is one in which the outcome of the players' actions is similar to a real situation. Serious games focused on training must provide that in order to fulfill their objectives.

- **Game-Like User Experience**: It should be possible to integrate the simulation models with game engines capable of deploying current audiovisual gaming technology.

- **Dynamically Change the Game Speed**: Sometimes, when simulating a real situation, it is convenient to speed up the game simulation to help players focus on what is really important in the simulation (Michael and Chen 2005). Since the focus is on decision making, the player should be able to fast-forward periods that do not require decision making, thus saving time and avoid boredom.

- **Scenario Composition Capabilities**: An important requirement for serious games with simulational realism that should not pass unnoticed is their ability to serve as a testing environment for new ideas. This may require that the game dynamics be applicable to a variety of scenarios. Particularly important is to be able to run the game on scenarios composed by end users to test their new ideas and decision procedures, as well as to test their existing decision procedures on different scenarios. Even though scenario composition is a well known feature of a number of entertainment games, it is usually limited to setting the state of physical objects at the beginning of the game. Serious games may require more sophisticated composition mechanisms capable of setting the main storyline and other dynamic aspects of the game. Needless to say, simulation modularity is mandatory in this case.

- **Integration with Existing Systems and Databases**: Corporative simulators may require interaction with other previously existing systems and databases, such as those of GIS. The integration can work in both ways, either for reading data as input or sending the simulation outputs to them. This requirement may also require a certain level of simulation modularity so that simulation models can be defined independently of any external data source.

- **Simulation Reuse by Different Systems or with Different Player Configurations**: Multiple systems can benefit from sharing the same underlying simulation. For example, a simulation-based single user planning system may use the same simulation as a multi-player training game. Moreover, the same application may require certain flexibility on its simulation elements. For example, a multi-player training game may be played with different sets of players, with fully automated non-playing characters (NPC) taking the roles for which there are no human players. Simulation modularity is important to allow this flexibility in simulation use.

The last three requirements mention modularity as a desirable property of serious games. Indeed, this kind of software is likely to be used by corporations with specific needs. It is unlikely that all necessary simulation elements will be available in some sort of generic third-party simulation package. Most of the time, some specific customization is needed. Moreover, corporations usually have needs that change over time. Therefore, unlike the case of most entertainment games, there is a need for some sort of continuous development. For those reasons, designing simulators in a modular way is mandatory for the sake of software engineering.

In the simulation area, modular design has been a concern for a long time. Simulation formalisms such as DEVS (Zeigler 2000) and System Dynamics (Forrester 1972) are good examples of how to achieve modularity in simulation models. Modularity has helped to achieve three main goals in simulation. First, it allows easier model reuse. Second, it makes the dynamic models more intelligible and easier to change. Finally, it allows one to build more flexible simulation software where the users can compose their simulations out of small components.

Probably, the best examples of reuse of software components in computer games are the so-called *game engines*. However, they are usually focused on specific kinds of games and the simulation capabilities they offer, if any, are also focused on specific kinds of processes, such as physical simulation of mechanics, collision detection, character movement and animation interpolation. Usually, they do not offer a formal simulation framework flexible enough to embrace other interesting simulation formalisms found in other Computer Science fields.

1.4 Objectives and Contributions

This thesis aims primarily at investigating the requirements and proposing solutions for modeling and simulation in serious games that attempt to simulate realistic situations, with a specific focus on the requirements listed in section 1.3. Since most of these requirements are usually not emphasized in entertainment games, this work will contribute to the current expansion of the use computer games in application fields other than entertainment.

It is also an objective of this thesis to contribute to the increase of the level of formalism in the design of game dynamics by discussing modeling and simulation paradigms. It is expected that the findings of this discussion will be useful to provide a more solid foundation both for serious and entertainment games, even though it is more focused on serious.

More concretely, this thesis presents a formal modeling and simulation framework that facilitates the integration of games with simulation technologies developed in other relevant areas of Computer Science, such as modeling and simulation, multi-agent systems, geographic information systems and knowledge representation. This integration aims at fulfilling most of the serious games modeling and simulation requirements by importing well-grounded solutions from these areas.

Finally, this thesis presents a concrete game for disaster simulation to demonstrate how the proposed framework can be applied to a real problem. This game is part of the InfoPAE system (Carvalho et al. 2001), which is a system designed for helping managing emergency situations.

In short, the objectives of this thesis are:

- Discuss in depth the general requirements for modeling and simulation in serious games that attempt to simulate realistic situations

- Investigate which techniques already developed in other areas of Computer Science would help fulfilling these requirements

- Elaborate a conceptual framework to integrate these techniques and point out the restrictions that should be obeyed

- Develop new techniques to fulfill the remaining requirements

- Implement a real serious game to test the proposed solutions

The major expected contributions are:

- Provide a formal discussion on modeling and simulation paradigms for computer games, thereby contributing to increase the level of formalism in the area

- Define a detailed framework for designing the dynamics of serious games, in which it is possible to integrate simulation techniques from other areas of Computer Science and achieve a high level of modularity and reuse

- Implement a real training game for the InfoPAE system (Carvalho et al. 2001) based on the proposed solutions

The rest of this thesis is organized as follows. Chapter 2 lists representative research in other areas that helps fulfilling the requirements, as well as similar frameworks used as the basis for designing the proposed framework. Chapter 3 discusses in depth the principles of modeling and simulation in serious games and formally defines the proposed framework. Chapter 4 shows how to integrate some existing formalisms with the proposed framework. Chapter 5 presents a concrete implementation of a training game for managing disaster situations. Finally, Chapter 6 draws the conclusions of the thesis and contains suggestions for future work.