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Introducing Computer Game Technologies in a Mathematical Modelling and Simulation Course

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Abstract

This paper describes the use of interactive computer graphics and game technologies in a new mathematical modelling and simulation course at KTH Royal Institute of Technology that commenced in January 2015. In order to better engage students in the subject, elements of the course involved real-time physics scenarios using computer game technologies. An important secondary aim in the course was to develop the ability for students to define their own goals in the absence of specific tasks, which culminated in student-led projects. This paper briefly summarises the pedagogical approach, the course structure and presents a sample of student project work.

1. Introduction

The fields of scientific computing and computer graphics share a multitude of models, methods and algorithms, where the main difference often is that while in scientific computing quantitative accuracy is a necessity, in computer graphics, the visual impression and real-time operations are paramount. Models and simulation is becoming increasingly important in science and engineering, used for simulation based experiments, virtual prototyping, forecasts and risk analyses. As computer hardware becomes more powerful, there is a gradual move towards more realistic simulation models. Traditionally, numerical analysis courses are taught using software packages such as Matlab/Octave, with a focus on very simple model problems to illustrate the basic concepts, and with limited capabilities for interactivity and visualisation. While this may be suitable for some groups of students, it may also deter other groups that lose interest in the mathematical abstraction of the models. This is significant at national and international level, where attracting, engaging and retaining students in science, engineering and mathematics has been an issue of growing concern.

A core aim of the course is therefore to exploit numerous relationships between modelling and simulation approaches and computer games technologies (primarily physics simulation and interactive visualisation) in order to stimulate curiosity and provide intuitive knowledge about the underlying numerical methods, algorithms and physics models that are foundational to both entertainment applications and more realistic applications in serious science and engineering.

2. Background

There has been increasing emphasis over the past decade on the importance of engaging students in Science, Technology, Engineering and Mathematics (STEM) subjects. This has been partly due to fears of skills shortages, especially in Europe and the US, and has been reflected by a general decline in retention in computing programmes. For example, in the UK, concerns about abilities of graduates in STEM areas led to the commissioning of Next-Gen, the Livingstone-Hope Skills Review [LH11] recommending major changes to STEM education in secondary and higher education, which is recognised as a serious issue by the UK government [Gov11]. A number of potential solutions have been proposed, including suggestions that degrees should be made ‘more fun’ and offer multi-disciplinary and cross-disciplinary programs [Car06]. With this in mind, pedagogical practitioners have been exploring new ways in which to make STEM subjects more attractive to students. A number of approaches (see [APH*12] and [Kur09] for examples) involve the use of interactive visualisations and game technologies to better engage students in these subjects.

3. Rationale

Game technologies are therefore relevant to pedagogy in a number of ways. For example, interactive experiments featuring mathematical equations and the impact of simulation approaches and results are well-supported by the real-time, advanced graphics technologies underlying modern computer games. Modern engines also provide tools and com-

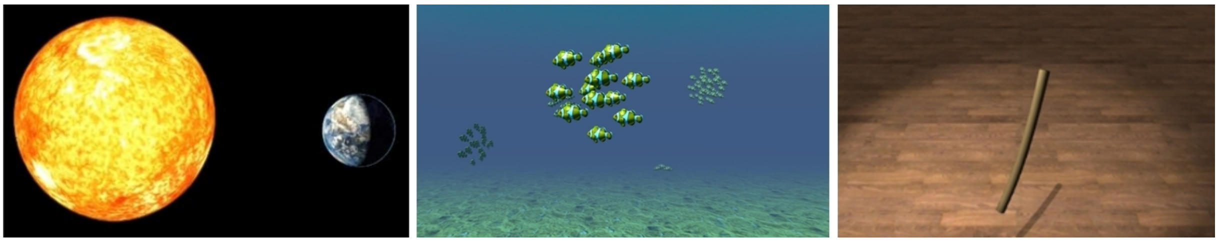

Figure 1: *Screenshots taken from three of the lab assignments: (from left to right) solar system, predator-prey and spring mass scenarios, respectively. Lab assignments were designed to become more open ended as they progressed.*

ponents for supporting the use of GPUs. Beyond these, one of our primary motivations for introducing computer game technologies in the course relates to stimulating student's intellectual curiosity about nature. Game engines supporting modern AAA bestsellers are exceptionally sophisticated and often aim to simulate and synthesise natural environments that appear realistic to viewers, necessitating the development of underlying physical simulation models. A number of previous works have already investigated the use of the video game technologies to teach physics [Pri08] and numerical methods, for example, to undergraduate mechnical engineering students [CS09], in addition to increasing motivation and engagement in computer science subjects [BPCL08]. This paper presents a preliminary summary of our initial course design and experiences with a cohort of 3rd year computer science students in a 6 week time period.

4. Course Details

We aimed to present the students with a set of engaging scenarios featuring themes that clearly connected to specific computer game technologies, especially game physics. Students could also include simple game mechanics in their scenarios, although the focus of the course was on game technology use and development, rather than game design issues.

4.1. Objectives

There were two main course objectives. The first related to developing students' intuitive understanding of simulation methods with a focus on the following concepts:

- Accuracy: The appropriateness of various models and approximations for different application areas.
- Stability: Issues relating to the numerical stability of various approaches.
- Performance: Implications of various simulation techniques and approximations on achieving real-time interactive performance.
- Generalisability: Application of core methods to many different target domains.

The second objective related to engaging students as active learners in the learning process [APH*12]. Since many of the students had not engaged in substantial student-led project work before, i.e projects in which they were fully responsible from the specification phase onwards, the course was split into two phases. The first phase consisted of traditional lecture and lab sessions. Initial lab assignments were designed in order to provide a detailed task decomposition for solving problems. As lab assignments progressed, the questions become less detailed and required students to define their own sub-goals by conducting their own task decomposition. This culminated in the second phase of the course, where students engaged in open ended project work.

4.2. Structure

The course was designed around two sequential phases, a first phase that consisted of a traditional set of lectures and labs, and a second phase that consisted of student-led project work facilitated with feedback from the course team.

4.2.1. Phase 1: Lectures and Labs

The first phase consisted of a four week traditional lecture and lab design. Each week included a single lecture on the theories and methods related to modelling and simulation, in addition to a single lecture related to relevant real-time algorithms from graphics and games. Specifically, theory and methods related to the description of particle models, time-stepping methods, ordinary differential equations, implicit methods, partial differential equations and mesh methods, while the practical lectures focussed on the complementary topics of implementing particle systems, steering algorithms, behavioural animation, and a review of game engines and middleware. There were four lab assignments, each covering the following scenario: solar system, predator-prey, spring-mass system and fluid simulation (see Figure 1).

4.2.2. Phase 2: Projects

The second phase of the course, a further two weeks, consisted of a project. Students could complete the projects in groups of up to three people. Unlike the labs, which had a set structure and questions, students could choose their own project topics. Since the issue of choosing a project topic may be non-trivial for many students, they were asked to

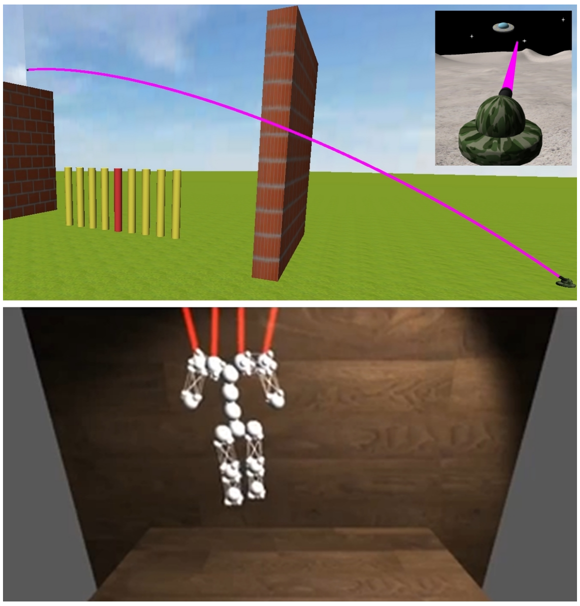

Figure 2: *An example of two of the projects from the course, the first (top) involving an interactive cannon ball simulation and (bottom) real-time ragdoll simulation.*

submit project specifications that received feedback from the course team. The project phase was supported by two weekly activity and project support sessions. A preliminary and final presentation session also took place where students demonstrated their results and received feedback from the course team and from the rest of the cohort.

5. Results

The course team consisted of the two primary lecturers and four Teaching Assistants (a postdoctoral student and three Master-level students). The 2015 student cohort was composed of twenty 3rd year undergraduate students from the computer science and virtual design programmes in KTH Royal Institute of Technology. A total of eight student groups submitted projects at the end of the course. Figure 2 illustrates two examples of projects from the course. The first project, a cannon ball simulator, introduced game mechanics into a physics scenario in which the player needed to judge wind speed and gravity in order to hit targets in the virtual environment. The second project concerned the implementation of a ragdoll system. Students also took part in a written questionnaire session both at the beginning of the course, to establish their skills, and at the end of the course, to describe their experiences and reflect on approaches for problem solving and project specification. The results generally showed that time management in relation to lab and project submission was a central concern in the course and that most students were motivated not only by achieving specific grades, but also by creating demonstrations and deliverables that could be used in their future endeavours. It is interesting to note that mathematics and programming issues were not raised as concerns by this cohort.

6. Future Directions

Feedback from the students suggested a number of improvements for subsequent iterations of the course. Firstly, the course is quite short and is intensive in terms of deliverables. Many students were taking other courses at the same time and in some cases this led to time management problems. We also intend to put a further focus on a set of fundamental mathematical models rather than models specific to particular disciplines, for example, focus on wave propagation and dissipation rather than acoustics, electromagnetics, and so on. Another area of future work involves the further separation of the model from the numerical discretisation method, since this abstraction is very powerful.

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