Universities of Minho, Aveiro and Porto

Doctoral Program in Informatics

"Computer Graphics"

(Proposal for a Course)

April 2009

Contents

A. Program

1. Purpose and Justification

This document proposes and describes a Unit Course on technologies, for the MAP-I Doctoral Program. This Unit Course is entitled "Computer Graphics" and will address three major and inter-related areas within the field, namely, modeling, rendering and visualization.

Currently, Computer Graphics is ubiquitous in everyday life and constitutes a major field of research in both industry and academia. Applications of Computer Graphics (CG) range from machine interfaces, electronic games, edutainement, digital photography and video to CAD systems, computer vision based control of processes, urban planning, culture heritage research and scientific visualization, to cite only a few. In fact, CG applications seem to be limited by imagination only, therefore yet more developments and innovative applications are to be expected in the near future. All these applications create a huge market and, consequently, a constant need of experts in CG. Hence it is fundamental to ensure that University Graduation Courses in general, and Doctoral Programs in particular, address this theme, either as a self-contained area or connected to other areas of knowledge.

This course will contribute to prepare experts in Computer Graphics, able to design and develop new approaches and systems to solve problems related to CG. These experts will, hopefully, contribute to foster this field development in Portugal, where CG industry is growing slowly, but steadily.

The proposed course is aimed at methodologies and techniques related to modeling, rendering and scientific visualization. The theoretical foundations that support these fields will be introduced, followed by state-of-the-art approaches to solve practical problems. Emphasis will be put on discussing current and possible applications. In fact, it is a major goal to stimulate students to explore new application spaces and alternative approaches to CG-related problem solving techniques.

Examples of courses similar to this one can be found in several universities, such as:

- Carnegie-Mellon University:
    - course 15-642: Computer Graphics
    - course 15-864: Advanced Computer Graphics

  which together cover fundamental and advanced topics on modeling, rendering and computer animation.

- Princeton University:
    - cos 426: Computer Graphics
    - cs 526: Advanced Computer Graphics

  which, besides modeling, rendering and animation, also include some topics on image processing.

The main difference with respect to the above cited courses is the explicit inclusion of scientific visualization as a topic. This is justified by the continuous improvements that data visualization has experienced over the last few years and by a growing need for effective visualization techniques and experts, due to the ever increasing volume of data being generated by scientific, engineering and industrial simulations.

2. Goals

These course main goals are to give students a thorough understanding of Computer Graphics theoretical foundations/techniques and to empower them with the ability to imagine new application areas and design the respective logical support.

These goals are achieved by presenting current state of the art on three main areas (modeling, rendering and visualization) and by stimulating discussion of both alternative approaches and new applications. These discussions will be encouraged during lectures and during the students' public presentations of their respective monographs, whose themes will mostly address new and emerging application areas.

Modeling will allow students to understand the principles underlying representation, storage and manipulation of curves, surfaces, solids and volumes, through static or time-varying models, using appropriate mathematical formulations and computational data structures. Such models are essential for defining a 3D scene to be rendered through a scene-graph (Computer Graphics) or for representing medical or physical voxel data to be interactively analyzed by expert users (Data Visualization) in a collaborative environment.

The **Rendering** component main goal is to introduce different lighting models, algorithms and technologies. Two different approaches to rendering will be explored: the rasterization model and the physically based approach. Students will be able to select the most appropriate combination of both hardware and rendering technique, given the requisites of the intended application (both functional and performance).

Advances in computer science and technology have produced extraordinary improvements in scientific, biomedical, and engineering research, as well as industrial innovation. Continuing these advancements will require the comprehension of vast amounts of data. **Visualization** helps people explore and understand data through adequate visual representations, will be important in achieving that goal. Designing effective visualizations is a complex process that requires understanding of human information processing capabilities and a solid foundation in the visualization body of knowledge. This module intends to introduce the main issues, application areas, and challenges of this scientific discipline.

3. Learning Outcomes

Upon successful conclusion of this unit course students will be able to:

- identify, for a certain problem, the more adequate modeling techniques;
- relate rendering algorithms with the general model supported by the rendering equation, identifying the functional and performance limitations of each algorithm;

- design, implement and evaluate rendering systems, given the available resources and functional/performance requirements;
- describe the main techniques, algorithms and architectures associated to data visualization and to select them according to a certain application requirements.

4. Detailed Program

1. **3D Modeling**
    a. Overview of Generic 3D Representations
        i. Polygonal, and Tetrahedral meshes
        ii. Voxel-based representations
        iii. Explicit (functional) representations
    b. Current representation techniques
        i. Multi-resolution and view-dependent meshes
        ii. Constructive Volume Geometry for volume data sets
    c. Procedural Modeling
        i. Definition
        ii. Procedural modeling techniques
        iii. Procedural modeling of plants and urban environments
2. **Rendering**
    a. Visibility, Textures, Local Illumination
    b. Rendering Pipeline and Graphics Hardware
        i. Acceleration Techniques for the Rendering Pipeline
        ii. Modern use of GPU - Graphics Processor Units
            1. The architecture of the GPU
            2. GPU Programming
            3. Geometry, vertex and fragment shaders
            4. GPU capacities and limitations
    c. Physically Based Rendering (PBR)
        i. The BRDF and the Rendering Equation (RE)
        ii. Numerical Solutions for the RE
            1. Monte Carlo Ray Tracing
            2. Radiosity
3. **Data Visualization**
    a. Definition and goals
    b. Overview of main applications;
    c. Data characteristics;
    d. Taxonomy of techniques;
    e. Algorithms
    f. S/W for Visualization;
    g. Case studies;
    h. Open issues and challenges.
4. **Applications**
    a. 3D Animation

b. Cultural Heritage
c. Electronic Games
d. Medicine

5. *Teaching Methodology*

The course will include theoretic classes that will be taught by professors from the three universities involved, and will be complemented by tutorial meetings between students and professors/researchers, mainly for the advisory related to practical works. The material used by the professors to lecture and support the theoretical classes (slides, videos, notes, etc.) will be made available to the students on the course site.

Practical assignments will be defined at the end of each module and may require either development of simple applications, or writing a report about a given theme with associated bibliographic research. These manuscripts, with a format close to scientific papers, will also serve for their assessment. These can be defined as state-of-the-art reports, position papers, or discussion of publications. It is expected that students make a serious research in this context, using the internationally accepted scientific data bases. Dedicated workshops can also be organized for presentation, in forum environment, of the work done by the students.

Seminal and fundamental papers will be suggested to students as important reading material and some of them will be presented in class, during theoretical presentations, and discussed in tutorial orientation meetings.

The whole course will be supported by video-conference technologies that have already been used in the past by this same team of professors.

Application areas will be presented and discussed. Besides constituting examples of theory usage and allowing the sedimentation of the acquired knowledge as a whole, this is intended as an opportunity for students to exercise their critical abilities and imagine/propose new application spaces.

6. *Assessment*

Student assessment will be achieved in two main components, project assignments and monograph writing, each one with a weight of 50%.

At the end of each main topic, a small project assignment will be given. Depending on the topic, the project can be in the form of a software development that aggregates various theoretical components visited or a text that performs critical analysis to a chosen technique, algorithm, application area, etc.

The monograph takes the form of a survey and will be oriented for a deeper discussion of several solutions of the elected problem.

Students that fail to perform on any of the above assignment/tasks shall not be considered for final assessment.

7. Bibliographic References

Hansen, C., C. Jonhson (ed.), The Visualization Handbook, Elsevier, 2005

Schroeder, W., K. Martin, B. Lorensen, The Visulization Toolkit- An Object Oriented Approach to 3D Graphics, 2nd ed., Prentice Hall, 1998

Pharr, Matt, Humphreys, G. “Physically Based Rendering: from Theory to Implementation”. Morgan Kaufmann, 2004

Dutré, P., P. Bekaert, and K. Bala. *“*Advanced Global Illumination”*.* Natick, Massachusetts: A. K. Peters. 2003

B. Team

1. *Team presentation*

The following four professors, belonging to the three participant universities (CVs following), will be responsible for the course:

1. António F. Coelho (AFC, UP)
2. António Ramires Fernandes (ARF, UM)
3. Beatriz Sousa Santos (BSS, UA)
4. Luís Paulo Santos (LPS, UM)

Two other professors will eventually cooperate (e.g., through one invited lecture each) in the course:

1. A. Augusto de Sousa (AAS, UP)
2. Joaquim Silvestre Madeira (JSM, UA)

All the team members have a PhD and have a large experience in teaching and research in Computer Graphics related themes. The relationship between their expertise and course specific areas is described below.

Modeling is the area of expertise of BSS and JSM. AFC has a deep knowledge in L-Systems that complements the topic. BSS and JSM have several publications on polygonal meshes simplification and comparison; AFC published a few papers on using L-systems to expeditiously prototype urban environments.

ARF has a produced important work in the area of graphics boards and their programming to obtain fast special rendering effects and to explore parallelization between them and the CPU. AAS and LPS complement this knowledge with advanced rendering, namely high fidelity physically based approaches, including parallel and interactive systems.

Finally, BSS and JSM have done much research work on Data and Scientific Visualization, in particular Medical Data Visualization.

The collaboration of other professors/researchers is also possible, according to their skills and to the course needs.

2. *UC Coordinator*

This Unit coordinator will be Professor Beatriz Sousa Santos, from the University of Aveiro.