

Universities of Minho, Aveiro and Porto

Doctoral Program in Informatics

"Computer Graphics"

(Proposal for a UCT Course)

April 2008

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A. Program

1. Purpose and Justification

This document proposes and describes a Unit Course on Technologies (UCT), 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, edutainment, digital photography and video to CAD systems, computer vision-based control of processes, urban planning, cultural 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. 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.

Some of the above applications of CG are also fundamental issues for today’s increasingly Web-based Information Systems, namely, appropriate user interaction, object rendering and data visualization techniques. Such issues are clearly identified for particular applications areas, e.g., for Geographical Information Systems (GIS).

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.

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, in particular, regarding today's main application and research areas: modeling, rendering and visualization.

These goals are achieved by presenting current state of the art on three main areas 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).

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 science and technology require the understanding of vast amounts of data and information produced from a multitude of sources. Helping people explore or explain data through visualization systems is a critical issue. Well-designed visualizations have the power to help people, and naive attempts often result in poor visualizations that are ineffective or misleading. Designing effective visualizations is a complex process that requires understanding the human information processing capabilities and a solid foundation in the body of knowledge of the visualization field. Students will be introduced to the main issues, application areas, and challenges of Data Visualization.

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

- Overview of Generic 3D Representations
 - Parametric representations for free-form curves and surfaces
 - Polygonal and Tetrahedral meshes
 - Voxel-based representations
- Current representation techniques
 - Multi-resolution and view-dependent meshes
 - Constructive Volume Geometry for volume data sets
- L-Systems
 - Definition
 - Modeling plants
 - Modeling other structures

2. Rendering

- Visibility, Textures, Local Illumination
- Rendering Pipeline and Graphics Hardware
 - Acceleration Techniques for the Rendering Pipeline
 - Modern use of GPU — Graphics Processor Units
 - The architecture of the GPU
 - GPU Programming
 - Geometry, vertex and fragment shaders
 - GPU capacities and limitations
- Physically Based Rendering (PBR)
 - The BRDF and the Rendering Equation (RE)
 - Numerical Solutions for the RE
 - Monte Carlo Ray Tracing
 - Photon Mapping
 - Radiosity

3. Data Visualization

- Fundamentals
 - Definition and goals
 - Overview of main applications
 - Data characteristics
 - Taxonomy of techniques
 - Open issues and challenges
- Visualization algorithms
- S/W for Visualization
- Case studies

4. Applications

- Medical Imaging and Visualization

- b. Geographical Information Systems
- c. Cultural Heritage
- d. Computer Games

5. Teaching Methodology

The course will include lectures 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 supervision of assignments. The material used by the professors to lecture (slides, videos, notes, etc.) will be made available to the students on the course site.

Assignments will be defined at the end of each main topic and may require either development of simple applications, or writing a report about a given theme with associated bibliographic research. Such manuscripts, with a format close to scientific papers, will also serve for student assessment. These can be defined as state-of-the-art reports, position papers, or discussion of publications. It is expected that students undertake 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 during lectures, and discussed in tutorial orientation meetings.

Application areas will be presented and discussed. Besides providing application examples and allowing the sedimentation of the acquired knowledge as a whole, they will provide an opportunity for students to exercise their critical abilities and imagine/propose new application spaces.

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

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 software development, allowing the application of fundamental knowledge presented during the lectures, or a written report presenting a critical analysis for a chosen technique, algorithm, application area, etc.

The final 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

Mortenson, M., *Geometric Modeling*, 3rd Ed., Industrial Press, 2006

Farin, G., J. Hoschek, M.- S.Kim, *Handbook of Computer-Aided Geometric Design*, Elsevier, 2002

Farin, G., *Curves and Surfaces for CAGD: A Practical Guide*, 5th Ed., Morgan Kaufmann, 2001

Pharr, M., and G. Humphreys. *Physically Based Rendering: from Theory to Implementation*. Morgan Kaufmann, 2004

Dutr  , P., P. Bekaert, and K. Bala. *Advanced Global Illumination*. Natick, Massachusetts: A. K. Peters. 2003

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

B. Team

1. Team presentation

The team will be composed by the following professors belonging to the three participant universities (CVs following):

1. A. Augusto de Sousa (AAS, UP)
2. António F. Coelho (AFC, UP)
3. António Ramires Fernandes (ARF, UM)
4. Beatriz Sousa Santos (BSS, UA)
5. Joaquim Silvestre Madeira (JSM, UA)
6. Luis Paulo Santos (LPS, UM)

All the team members have a PhD and have a large experience in teaching and research in Computer Graphics related themes. Among other courses, they are currently teaching the Distributed Computer Graphics course for the MAP-I doctoral program. 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 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 has 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 the course needs.

2. UC Coordinator

This Unit coordinator will be Professor Luís Paulo Peixoto dos Santos, from Escola de Engenharia, Universidade do Minho.

3. Curricula Vitae

A. Augusto de Sousa

A. Augusto de Sousa is an Associate Professor at Faculty of Engineering of University of Porto (FEUP), Portugal. He got his PhD in 1996 at FEUP, in the area of Computer Graphics/Image Synthesis and Parallel Computing. He has been teaching in the same Faculty since 1983, in areas related to Computer Architectures and Computer Graphics. He was member of Board of Directors of the Graduation on Journalism and Communications Sciences (University of Porto) during its installation phase (2000-2003) and is now Director of the Integrated Master on Informatics Engineering and Computing of FEUP.

He has also been researcher in INESC/INESC Porto in the same areas, since 1985 and was the Coordinator of the Information Systems and Computer Graphics Unit of that institution. Currently he integrates the Telecommunications and Multimedia Unit.

His expertise is concentrated in the area of Computer Graphics, namely Image Synthesis, Illumination Design and Virtual Reality, and in the area of Parallel Computing. He co-advised three PhD theses, under the scope of Computer Graphics and Virtual Reality, as well as several MSc theses. He is currently advising three new PhD theses in Virtual and Augmented Reality, Spacio-temporal databases and visualization, and Rendering.

He is a member of the European Association for Computer Graphics EUROGRAPHICS and of the ACM SIGGRAPH. He was the chairman of the EUROGRAPHICS Portuguese Chapter since 1998 to 2000.

Publications

Expeditious modeling of virtual urban environments with geospatial L-systems; COELHO, António; BESSA, Maximino; SOUSA, A. Augusto; FERREIRA F. Nunes; Journal Computer Graphics Forum Vol. 26, N. 4, 769–782, 2007.

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3D Modelling of Large Urban Scenes from Diverse Sources of Information; COELHO, António Fernando; SOUSA, A. Augusto; FERREIRA, Fernando Nunes; ELPU2003-Seventh International Conference on Electronic Publishing, Guimarães, Portugal, 25-28 de Junho de 2003.

A new technique for Spherical Radiance Calculation; COSTA, Antonio; SOUSA, A. Augusto; PARRACHO, Helder; CRUZ, Pedro; Simpósio Ibero-Americano de Computação Gráfica, Guimarães, 2 a 5 de Julho de 2002.

Projects

URBIS: Efficient Management and Visualization of Spatio-Temporal Urban Data (FCT fin., responsible researcher).

3DLBMS: 3D for Location Based Mobile Systems, Projecto FCT POSI/CHS/48220/2002 (responsible researcher).

IOPGIS: Interoperabilidade em GIS, Projecto PRAXIS XXI/EEI/98 (investigador responsável).

CASSILDE: Computer Assisted Illumination Design, Project PRAXIS XXI/EEI/98 (responsible researcher).

Graphical Interface for the Data Input Module of the "ValorAgua" model of the portuguese electrical energy enterprise.

ASI: Image Analysis and Synthesis in Real and Virtual Road Environments.

ScateX: Automation and Telecontrol System for EFACEC.

NEC FA-1201 Testing: Emulation and Test System of Digital Commutation Systems (graphical interface).

IIRRA: Rendering with increasing level of Realism (JNICT fin.).

ShoeCad: CAD System for the Shoemaking Industry (SFS-NATO fin.)

António F. Coelho

António Fernando Vasconcelos Cunha Castro Coelho is Auxiliary Professor at the Informatics Engineering Department of the Faculty of Engineering of University of Porto where he teaches in the areas of Computer Graphics and Programming. Previously, he has been Assistant Lecturer for ten years at the University of Trás-os-Montes e Alto Douro, Portugal.

António Coelho got his PhD in 2006 in the Faculty of Engineering of University of Porto, in the area of Computer Graphics. His research interests are focused in the areas of Computer Graphics and Geographic Information Systems, has participated in several research projects, is the author of 24 publications and has been president of the organizing committee of the Portuguese Conference in Computer Graphics.

Publications

Expeditious modeling of virtual urban environments with geospatial L-systems; COELHO, António; BESSA, Maximino; SOUSA, A. Augusto; FERREIRA F. Nunes; Computer Graphics Forum Vol. 26, N. 4, 769–782, 2007.

Expeditious Modelling of Urban Environments Based on Interoperability and Geospatial Awareness; COELHO, António; PhD Thesis, Faculty of Engineering of University of Porto, 2006. (in Portuguese)

Selective presentation of perceptually important information to aid rapid orientation and navigation in an urban environment; BESSA, Maximino; COELHO, António; BULAS-CRUZ, José; CHALMERS, Alan; Special Issue of IJPRAI (International Journal of Pattern Recognition and Artificial Intelligence) "Intelligent Mobile and Embedded Systems", Vol.20 nº 4, pp.467-482, 2006.

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3D Modelling of Large Urban Scenes from Diverse Sources of Information; COELHO, António; SOUSA, A. Augusto; FERREIRA F. Nunes; Proceedings of the 7th International Conference on Electronic Publishing, Univ. Minho, Guimaraes, Portugal, pp. 278-287, 2003.

Projects

Project “3D4LBMS – Three Dimensional Modelling of Urban Environments for Location Based Mobile Services” (POSI/CHS/48220/2002), initiated in November 2003 and concluded in July 2006.

Project *Digital Trás-os-Montes / SCETAD (Cooperative Extension Service in Trás-os-Montes e Alto Douro)* (Digital Cities Program), started in 1999 and finished in 2002.

Project “*Image Analysis and Synthesis*” (PRAXIS XXI), initiated in 1996 and finished in 2000.

António Ramires Fernandes

António Ramires Fernandes is an Auxiliary Professor at the Dept. of Informatics, Universidade do Minho, since 1997, when he finished his PhD from the University of St.Andrews, Scotland. His research activity has been focused on Real Time CGs and HCI and he has published several papers on international conferences. He has supervised a PhD in image based 3D reconstruction and several MSc in is areas of interest. He currently supervises 6 postgrads, all in Computer Graphics. He has been a Conference Chair of International Conferences and has published papers in a number of international conferences.

He is the head of the Executive Committee of the Master Course on Computer Graphics and Virtual Environments, Universidade do Minho, where he also lectures “Fundamentals of Computer Graphics”, and “Procedural and Graphical Modelling”.

Publications

Efficient Conservative Collision Detection for Populated Virtual Worlds; Ramires Fernandes, A., Deusdado, L. SIACG - Ibero American Symposium in Computer Graphics, Jul. 2006

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Rui Rodrigues, António Ramires Fernandes, Kees van Overveld & Fabian Ernst; *Reconstructing Depth from Spatiotemporal Curves*. In D.D. Gorodnichy and H. Zhang, editor(s), 15th International Conference on Vision Interface, pp 252-259, Calgary, Canada, May 2002. (Best Paper Award)

Projects

Project Leader “Ponte de Lima: Terra Rica da Humanidade - A Large Scale 3D Model”, 48000 Euros, 2006.

Member of the research team, “ViAr - Affordable Interactive Virtual Archaeology with Adaptive Cluster Computing”; POSI/CHS/42041/2001; 68.000 euros; 2002-2004

Beatriz Sousa Santos

Beatriz Sousa Santos is Associate Professor at the Department of Electronics, Telecommunications and Informatics of the University of Aveiro. She graduated in Electrical Engineering in 1980 and received a PhD degree, from the University of Aveiro, Portugal. Her current research interests are in the area of Data Visualization, in particular in Medical Imaging. In recent years she has been teaching in the areas of Computer Graphics, Visualization and Human-Computer Interaction, both at graduate and at M.Sc. level. She has supervised several PhD. and M.Sc. students in her areas of interest, and currently supervises 4 post-graduation students in the areas of Visualization, Human-Computer Interaction and Information Systems.

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Joaquim Silvestre Madeira

Joaquim Silvestre Madeira is "Professor Auxiliar" at the Department of Electronics, Telecommunications and Informatics of the University of Aveiro, since February 2003. He

graduated in Electrical Engineering in 1986 and earned a M.Sc. degree in Computer Science in 1991, both at the University of Coimbra, Portugal; in 1998 he earned a Dr.-Ing. degree in Computer Science at the Technical University of Darmstadt, Germany. He has been lecturing in the Computer Graphics and Geometric Modeling areas since 1989 (prior to 2003, at the University of Coimbra, Portugal), and has recently taught Computer Graphics and Geometric Modeling courses for M.Sc. level. His current main research area is Geometric Modeling using polygonal meshes. He currently co-supervises one Ph.D. student in the areas of Geometric Modeling and Visualization.

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J. S. Silva, B. Sousa Santos, A. Silva and J. Madeira. A Level-Set Based Volumetric CT Segmentation Technique: A Case Study with Pulmonary Air Bubbles. In *Proc. Int. Conf. Image Analysis and Recognition (ICIAR 2004)*, Part II, pp. 68-75, Porto, Portugal, Sept./Oct. 2004. Pub. by Springer as LNCS 3212.

Luís Paulo Peixoto dos Santos

Luís Paulo Peixoto dos Santos is an Auxiliar Professor at the Dept. of Informatics, Universidade do Minho, since 2001, when he finished his PhD on "Scheduling on Parallel Systems". His research activity has been focused on Physically Based Parallel Rendering and he has published several papers on international conferences. He organized and edited the proceedings of the 2006 Eurographics Symposium on Parallel Graphics and Visualization; he was the program co-chair for the 2007 event of the same series. He was also program chair of the topic "Scheduling and Load Balancing" of EuroPar'2004 and program chair for short papers of Graphite'2006. He was guest editor of two special issues on Parallel Graphics and Visualization from the following journals: "Parallel Computing" and "Computers & Graphics". He lectures "Physically Based Rendering" to MSc courses at Universidade do Minho since 2003.

Publications

Chalmers, Alan and Debattista, Kurt and Mastoropoulou, Georgia and Santos, Luís Paulo; "*There-Reality: Selective Rendering in High Fidelity Virtual Environments*"; Int. Journal of Virtual Reality, Vol. 6(1), IPI Press, March, 2007 (<http://www.ijvr.org/issues/issue1-2007/1.pdf>)

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Santos, Luís Paulo and Proença, Alberto; "*Scheduling Under Conditions of Uncertainty: a Bayesian Approach*"; EuroPar'2004: Parallel Processing, Lecture Notes in Computer Science

3149, Springer-Verlag, , Italy, September, 2004 (Springer Online: <http://www.springerlink.com/content/x1j8txntc7y8/>)

Projects

Project Leader of "IGIDE: Interactive Global Illumination on Dynamic Environments"; PTDC/EIA/65965/2006; 101.000,00 euros; 2007-2010

Portuguese Leader of "*High Fidelity Interactive Rendering*", in conjunction with the University of Bristol, supported by the "Treaty of Windsor", CRUP and British Council, 1.450 Euros, 2006;

Project Leader by Universidade do Minho on "*SIGMA – Image Aided Mobile GeoReferencing System*", in cooperation with GEONAV, supported by "Agência de Inovação", POCTI 2.3 e POSI 1.3; 165.268,37 euros; 2003- 2005

Member of the research team "*RoD - Rendering on Demand*"; Dept. of Computer Science, University of Bristol, Bristol, United Kingdom; 2003

Member of the research team, "*ViAr - Affordable Interactive Virtual Archaeology with Adaptive Cluster Computing*"; POSI/CHS/42041/2001; 68.000 euros; 2002-2004