Technical University of Denmark

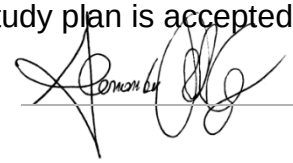
PhD study plan

PhD student: Alessandro Dal Corso

Date of birth: 21st February 1989

[x] This is a revised study plan.
* A letter with a description of all changes must be enclosed as a cover page to the study plan

On 13/10/2014 this study plan is accepted by the following:

PhD student's signature: 

Supervisor's signature: 

Head of PhD school/ Department's signature:

Is the PhD student employed at DTU?

[x] Yes [ ] No

PhD committee

[ ] Chemistry, Biotechnology and Chemical Engineering

[ ] Construction, Production, Civil engineering and Transport

[ ] Electronics, Communication and Space Science

[ ] Life Science

[x] Mathematics, Physics and Informatics

PhD school/ Department: ITMAN

Title of the PhD project: Hybrid Techniques for Interactive Photorealistic Rendering

Date of commencement: 1st October 2014

Date of completion: 31st March 2018

Supervisor: Associate Professor Jeppe Eliot Revall Frisvad, DTU Compute
* Title, name, department

Co-supervisor: Associate Professor Jakob Andreas Bærentzen, DTU Compute
* Title, name, department/company

Technical University of Denmark

PhD study plan

PhD student: Alessandro Dal Corso

Date of birth: 21st February 1989

Project description

Outline

The main research aspect in the PhD project is to bring aspects of movie production quality rendering into interactive applications. The goal is to achieve a photorealistic appearance as close as possible to the real world, with the possibility for the user to interact with the simulation. Interactive rendering applications are often used as a part of

- 3D modeling and printing
- Product Development and visualization
- Digital Prototyping
- Computer Gaming and Animation

Currently, interactive rendering for such purposes cannot achieve the photorealistic image quality that we see in movies. The problem is usually lack of artistic skill (or artist man-hours) and a very limited time budget for computing each image. Our overall strategy is to develop mathematical models of material appearance in place of artistic skill and to modify rendering techniques used in the movie industry so that they can run as a hybrid with real-time techniques on a graphics card (GPU).

The main activities will be related to the synthesis of photorealistic images and the comparison of these with acquired photographs. To achieve this, we will consider different degrees of photorealism that can be obtained with different effects (diffuse illumination, caustics and subsurface scattering). The synthesis of the images will be achieved with the use of fast rendering hybrid techniques developed for a GPU environment. More activities related to the development of such techniques will be performed, such as the investigation of unified CPU-GPU memory models and micro-polygon rendering.

The focus of the project goes towards a more strict integration of 3D printing processes and digital image synthesis as a whole (The Digital-Physical Ecosystem). Our contribution to this ecosystem will allow artists to work interactively on a 3D model while having a realistic overview of the final appearance. This will allow more time for the artists to work faster, reducing production times and waste of printing material.

Technical University of Denmark

PhD study plan

PhD student: Alessandro Dal Corso

Date of birth: 21st February 1989

External Research stay

(DTU strongly recommends that the external research stay takes place abroad)

Two external research stays were performed during the PhD studies:

- NVIDIA Research (November 2015 – May 2016). During the external stay, the student researched on state of the art reconstruction techniques for real-time ray tracing. The collaboration culminated in a paper, *Interactive Stable Ray Tracing*, published in High Performance Graphics in July 2017.
- The University of Tokyo (September 2017 – December 2017). A collaboration meant to explore machine learning techniques for efficient importance sampling of BSSRDF reflectance functions.

Technical University of Denmark

PhD study plan

PhD student: Alessandro Dal Corso

Date of birth: 21st February 1989

Educational requirements

* For DTU courses: Specify course number, title, number of ECTS points and level (e.g. Master or PhD).
* For non-DTU courses: Attach an *official* description including (The URL must be included if it is printed from a homepage): Course content and amount of ECTS points (1 ECTS equals 28 hours), workload in hours, method of examination and course provider. If the official description does not detail this description, an official statement should be obtained from the course provider (not assessed by the PhD student). The total number of ECTS points should be about 30, corresponding to approximately 840 working hours.

* For a definition of the various courses below, go to Course requirements on this home page.

Courses at DTU with course numbers

ECTS no.		Couse no.	PhD/Master's	Course title
5	ECTS	02576	PhD	Physically Based Rendering
3	ECTS	02946	PhD	Image Analysis and Computer Graphics Summer School on Convex & Discrete Optimization
3	ECTS	02943	PhD	Image Analysis and Computer Graphics Summer School on Semi-supervised Learning
2.5	ECTS	88553	PhD	Teaching and Learning
2.5	ECTS	02921	PhD	ITMAN Graduate School Seminars
5	ECTS	02409	MSc	Multivariate Statistics

Specialised courses at DTU (Enclose each course description)

ECTS no.		Course title
5	ECTS	GPU Ray-tracing based subsurface scattering
5	ECTS	A Software Layer for Programmatic Specification of a GPU Pipeline
	ECTS	
	ECTS	
	ECTS	
	ECTS	

External courses (An *official* course description for each course *must* be enclosed)

Technical University of Denmark

PhD study plan

PhD student: Alessandro Dal Corso

Date of birth: 21st February 1989

ECTS no.	PhD/Master's	Course title

Total number of ECTS points at PhD level: 31

Total number of ECTS points at Master's level: 0

* Maximum 15 points at Master's level. Bachelor courses can only be accepted in special cases and are subject to dispensation.

ECTS points in total: 31

Courses taken prior to the start of the PhD studies

Technical University of Denmark

PhD study plan

PhD student: Alessandro Dal Corso

Date of birth: 21st February 1989

Dissemination requirements

(For PhD students employed at DTU the expected dissemination activities and compulsory workload must be stated here)

Institute hours

The three months (12 weeks) of institute hours correspond to 420 hours of work (at 35 hours/week).

The mandatory teaching for courses with more than 40 students will be distributed as follows:

- 02393 – *Programming in C++* (Spring 2015), corresponding to a workload of 65 hours (1.86 weeks)
- 02561 – *Computer Graphics* (Fall 2015, half course), corresponding to a workload of 40 hours (1.14 weeks)
- 02562 – *Rendering - Introduction* (Fall 2015, half course), corresponding to a workload of 45 hours (1.28 weeks)

The remaining institute hours will be distributed as follows:

- Teaching assistance of course *02564 – Real Time Graphics* in Spring 2015. The course requires report assessment and lab assistance, for a total of 100 hours (2.9 weeks)
- Occasional co-supervision of MSc projects (35 hours, 1 week), including *Real-Time Rendering Using Layered Depth Maps* (Frederik Peter Aalund), *A Software Layer for Programmatic Specification of a GPU Pipeline* (Jonas Høiberg Nielsen, Kasper Cato Laursen), *Augmented Reality Sandbox* (Jakub Slupecki) and *Efficient Use of Spatial Data Structures in GPU Shaders* (Peter Bay Bastian).
- Organization of 2 workshops, for a total of 100 hours (2.9 weeks):
  - Exhibition chair at the VisionDay 2015.
  - Co-organizer for the Writing Workshop for the Image Analysis and Computer Graphics section, held in November 2016.
- Preparation of materials for graphics-related courses, with a workload of 35 hours (1 week).

These activities bring the overall total to 420 hours, with 250 hours devoted to teaching.

Dissemination hours

The dissemination activities will be covered in the form of participation to relevant conferences,

Technical University of Denmark

PhD study plan

PhD student Alessandro Dal Corso

Date of birth 21st February 1989

bringing a conference paper or a poster. The student created the following publications, that count towards the fulfilment of the dissemination goals.

- **Dal Corso, A.,** Stets, J. D., Luongo, A., Nielsen, J. B., Frisvad, J. R., and Aanæs, H. 2017. *Virtual Reality inspection and painting with measured BRDFs.* In Proceedings of SA '17 VR Showcase, Bangkok, Thailand, November 27-30, 2017. To appear.
- Stets, J. D., **Dal Corso, A.,** Nielsen, J. B., Lyngby, R. A., Jensen, S. H. N., Wilm, J., Doest, M. B., Gundlach, C., Eiriksson, E. R., Conradsen, K., Dahl, A. B., Bærentzen, J. A., Frisvad, J. R., and Aanæs, H. *Scene reassembly after multimodal digitization and pipeline evaluation using photorealistic rendering.* Applied Optics 56(27):7679-7690, September 2017.
- **Dal Corso, A.,** Salvi, M., Kolb, C., Frisvad, J. R., Lefohn, A., Luebke, D. *Interactive Stable Ray Tracing.* In Proceedings of HPG '17, Los Angeles, CA, USA, July 28-30, 2017.
- **Dal Corso, A.,** Frisvad, J. R., Mosegaard, J., and Bærentzen, J. A. *Interactive directional subsurface scattering and transport of emergent light.* The Visual Computer 33(3), pp. 371-383, March 2017.
- **Dal Corso, A.**, Frisvad, J. R., Kjeldsen, T. K., and Bærentzen, J. A. *Interactive appearance prediction for cloudy beverages.* In Workshop on Material Appearance Modeling (MAM2016), pp. 1-4, The Eurographics Association, June 2016.
- **Dal Corso, A.,** Olsen, M., Steenstrup, K. H., Wilm, J., Jensen, S., Paulsen, R., Eiriksson, E., Nielsen, J., Frisvad, J. R., Einarsson, G., and Kjer, H. M. *VirtualTable: a projection augmented reality game.* In ACM SIGGRAPH Asia 2015 Posters, Article 40, November 2015.
- Aanæs, H., Conradsen, K., **Dal Corso, A.,** Dahl, A. B., Del Bue, A., Doest, M., Frisvad, J. R., Jensen, S. H. N., Nielsen, J. B., Stets, J. D., and Vogiatzis, G. *Our 3D vision data-sets in the making.* CVPR 2015 Workshop: The Future of Datasets in Vision 2015 Posters, June 2015.

Time Schedule

The time schedule for the project is included in Appendix B.

Technical University of Denmark

PhD study plan

PhD student: Alessandro Dal Corso

Date of birth: 21st February 1989

Short description of the extent of the supervision

Throughout the course of the PhD studies, meetings were held approximately every week with the main supervisor, with the occasional participation of the co-supervisor. The main supervisor agreed was available during his working hours for any questions or problems that arisen during the PhD project.

Career options

Regarding the public sector, the skills learned in the process will lead to a possible employment in the academic environment as a postdoctoral fellow or as a researcher, in DTU o into another university. In the private sector, possible career options are in the research and development divisions of companies that have an interest in GPU performance. This companies may include device manufacturers (AMD, NVIDIA, Apple), software developers (Microsoft Research) feature film creators (Pixar, Disney Research, Weta Digital) or computer game developers (Blizzard, Crytek) .

Technical University of Denmark

PhD study plan

PhD student: Alessandro Dal Corso

Date of birth: 21st February 1989

Patents and innovations

Is it expected that there are possibilities for developing any patentable technologies or software in connection with the PhD Project?

[ ] Yes [x] No

If yes: Be aware that the novelty of a patent is not damaged. Please contact the patent responsible at the department regarding disclosure and patent application.

Other matters

* Other matters of importance to the evaluation of the study plan may be stated here.

Abstract for the internet

(Please note! Only if your department needs an abstract of your project for its home page)

Appendix A – Course description

Physically based rendering
From year 2015, the course will be held as a PhD course. The course description can be still found on the DTU Course Database at

http://www.kurser.dtu.dk/2013-2014/02576.aspx?menulanguage=en-gb

GPU Ray-tracing based subsurface scattering
The purpose of this course is to use highly accelerated ray tracing to solve the processing intensive task of rendering the appearance of materials that are translucent due to subsurface scattering of light. Acceleration will be done using spatial data structures and the massively parallel hardware available in the graphics processing unit (GPU). Subsurface scattering will be computed using Monte Carlo integration of the rendering equation (path tracing techniques) in combination with analytical dipole models (Bidirectional Surface-Scattering Reflectance Distribution Functions, BSSRDFs). The NVIDIA OptiX ray tracing engine will be used as a tool. This course will allow the PhD student to construct a framework for ray tracing that will prove very useful in the course of his research activities. The course will be held as a project-based special course under the supervision of Jeppe Revall Frisvad.

Course Responsible: Jeppe Revall Frisvad
Type of assessment: Evaluation of exercises/reports
Evaluation: Pass/fail, Internal assessment
Learning objectives:
A student who has met the objectives of the course will be able to

- Implement ray tracing and path tracing.
- Accelerate ray/path tracing using spatial data structures and graphics cards (GPU).
- Use the NVIDIA OptiX GPU ray tracing engine.
- Explain the properties of the spatial data structures available in OptiX.
- Simulate visual effects that appear in a global illumination context (reflection, refraction, colour bleeding).
- Use analytical BSSRDF dipole models for rendering translucent materials using path tracing.
- Find the nearest neighbours in a point cloud using a spatial data structure.
- Distribute samples evenly across the surface of a triangle mesh using a dart throwing technique.

A Software Layer for Programmatic Specification of a GPU Pipeline
The goal of this project course is to analyze the requirements and the best APIs to use for a software layer that will allow a programmer to author software which runs on both the CPU and the GPU. The goal is further to implement such a layer and to use it for simple proof of concept applications.

In most uses of the GPU for computer graphics, the GPU pipeline is either fixed or specified by various configuration API calls. The proposed novelty in this project is that the GPU pipeline is

not directly specified but simply reflects the structure of the program. The programmer will have at his disposal a number of constructs where the most important are stream buffers, the ability to map a function onto such a buffer in a highly parallel fashion on the GPU, and various API calls implemented by fixed function hardware on the GPU (notably rasterization). Implementing a computer program using these constructs is tantamount to specifying a GPU pipeline. The particular pipelines that are of interest are graphics pipelines. Thus, as proof of concept, very short graphics programs will be implemented on top of the software layer.

Grade: pass/no-pass, internal examiner
Assessment: Report.

Learning objectives
The student will be able to:
- select GPU platforms (OpenGL or CUDA, say) for implementation of higher level software layers.
- implement C/C++ software layer on top of a GPU platform.
- demonstrate basic triangle rasterization in terms of the software layer for GPU programming.
- demonstrate basic ray tracing in terms of the software layer for GPU programming.
- demonstrate combined rasterization and ray tracing in terms of the software layer for GPU programming.
- document the software layer for GPU programming.
- relate the software layer for GPU programming to the literature about graphics APIs and graphics HW.

Appendix B – Time Schedule

Period 1 – 1st October 2014 to 15th February 2015

The goal of the first period is to extend the work done in the Master Thesis in order to publish the work as a scientific paper (published in Period 5). In particular, an accurate reformulation of the sampling technique used in the thesis needs to be done. In this half-year period, there will be some additional work to acquire the general skills in ray tracing and advanced rasterization techniques in order to build the foundation for future research work.

Courses:

- 88553 – Teaching and Learning
- 02921 – ITMAN Graduate School Seminars (2 seminars)
- Special course - GPU Ray-tracing based subsurface scattering

Period 2 – 15th February 2015 to 15th August 2015

In this period, we investigated a new possible API for stream processing and unified memory management of data on GPU, which will constitute the foundation for further research in the topic. In addition, we laid preliminary foundations for a project on Realistic rendering of glass materials.

Publications:

- Aanæs, H., Conradsen, K., **Dal Corso, A.,** Dahl, A. B., Del Bue, A., Doest, M., Frisvad, J. R., Jensen, S. H. N., Nielsen, J. B., Stets, J. D., and Vogiatzis, G. *Our 3D vision data-sets in the making.* CVPR 2015 Workshop: The Future of Datasets in Vision 2015 Posters, June 2015.

Department work:

- 02393 – Programming in C++ - Teaching assistance
- Preparing material for graphics courses
- 02564 – Real-time graphics - Teaching assistance
- Vision Day 2015 organization, as exhibition chair.

Courses:

- 02921 – ITMAN Graduate School Seminars
- 02946 - Image Analysis and Computer Graphics Summer School on Convex & Discrete Optimization
- A Software Layer for Programmatic Specification of a GPU Pipeline

Period 3 – 15th August 2015 to 15th August 2016

In this period, we held the external research stay at NVIDIA Corporation (November to May). Upon return, we produced a preliminary draft on the work of the external stay. We performed some additional work on the project on rendering of realistic glass materials. Finally, we published a small project on realistic rendering of apple juice, *Interactive appearance prediction for cloudy beverages,* at the MAM workshop.

Publications:

- **Dal Corso, A.,** Olsen, M., Steenstrup, K. H., Wilm, J., Jensen, S., Paulsen, R., Eiriksson, E., Nielsen, J., Frisvad, J. R., Einarsson, G., and Kjer, H. M. *VirtualTable: a projection augmented reality game.* In ACM SIGGRAPH Asia 2015 Posters, Article 40, November 2015.

- **Dal Corso, A.**, Frisvad, J. R., Kjeldsen, T. K., and Bærentzen, J. A. *Interactive appearance prediction for cloudy beverages.* In Workshop on Material Appearance Modeling (MAM2016), pp. 1-4, The Eurographics Association, June 2016.

Conferences:

- SIGGRAPH Asia 2015 (Kobe, Japan)
- MAM workshop, High Performance Graphics and European Symposium on Rendering (Dublin, May 2016)

Courses:

- 02576 - Physically Based Rendering
- 02943 - Image Analysis and Computer Graphics Summer School on Semi supervised learning.

Period 5 – 15th August 2016 to 15th February 2017

In this period, we performed additional work on the project for realistic rendering of glass materials, targeting a submission to SIGGRAPH 2017.

Department work:

- Co-organized the writing workshop for the Section for Image Analysis and Computer Graphics.

Period 5 – 15th February 2017 to 15th August 2017

Still some small additional work on the realistic glass project. We completed the external stay work at NVIDIA with a publication in High Performance Graphics in July 2017. We started laying down some preliminary work for the final project in the PhD, a collaboration with the University of Tokyo on rendering of heterogenous scattering materials.

Publications:

- **Dal Corso, A.,** Salvi, M., Kolb, C., Frisvad, J. R., Lefohn, A., Luebke, D. *Interactive Stable Ray Tracing.* In Proceedings of HPG '17, Los Angeles, CA, USA, July 28-30, 2017.
- **Dal Corso, A.,** Frisvad, J. R., Mosegaard, J., and Bærentzen, J. A. *Interactive directional subsurface scattering and transport of emergent light.* The Visual Computer 33(3), pp. 371-383, March 2017.

Conferences:

- High performance Graphics 2017 (Los Angeles, California, July 2017)
- SIGGRAPH 2017 (Los Angeles, California, August 2017)
- Image Analysis and Computer Graphics Summer School on Graphical Models.

Period 6 – 15th August 2017 to 15th February 2018

In this period, the second external stay at the University of Tokyo was performed. The main focus is a project on rendering of heterogenous translucent materials. The realistic glass rendering project was finally published in the journal *Applied Optics*.

Conferences:

- SIGGRAPH Asia 2017 (Bangkok, Thailand)

Articles:

- Stets, J. D., **Dal Corso, A.,** Nielsen, J. B., Lyngby, R. A., Jensen, S. H. N., Wilm, J., Doest, M. B., Gundlach, C., Eiriksson, E. R., Conradsen, K., Dahl, A. B., Bærentzen, J. A., Frisvad, J.

R., and Aanæs, H. *Scene reassembly after multimodal digitization and pipeline evaluation using photorealistic rendering.* Applied Optics 56(27):7679-7690, September 2017.

- **Dal Corso, A.,** Stets, J. D., Luongo, A., Nielsen, J. B., Frisvad, J. R., and Aanæs, H. 2017. *Virtual Reality inspection and painting with measured BRDFs.* In Proceedings of SA '17 VR Showcase, Bangkok, Thailand, November 27-30, 2017. To appear.

Period 7 – 15th February 2018 to 31st March 2018

In this period, we mostly focused on finalizing and completing the PhD Thesis.

Articles:

Dal Corso, A. *Hybrid techniques for interactive photorealistic rendering.* PhD Thesis. To appear, March 2018.