CS F681 Advanced Computer Graphics Rendering

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University of Alaska Fairbanks

Course Number	CS F681
Credits	3
Prerequisites	CS F202 and MATH F253X
Location	UAF Campus in DUCK 535
Meeting Time	Tuesday 9:45am to 11:15am
Final	8-10 a.m., Tuesday, April 30
Method	Lecture and Distance
Reading Materials	None required
Optional Reading	Realtime Rendering 4th edition by Tomas Akenine-Möller et. al. ISBN: 978-1138627000
Optional Reading	Ray Tracing in One Weekend by Peter Shirley (`https://github.com/petershirley/raytracinginoneweekend/releases/`)

1. INTRODUCTION

Catalog Description. Designing graphics engines for realtime rendering of computer generated imagery; physically based approaches to shading and shadows; artistic approaches to shading and nonphotorealistic rendering; algorithms for rendering an image including ray tracing, deferred rendering, and global illumination; image space algorithms for simulation of camera effects.

1.1. Welcome

In this class, we are going to investigate computer graphics rendering. Specifically, we will be learning how to produce high quality rendered graphics using techniques drawn from Ray Tracing, Real-time Rendering, and Physically Based Rendering. We want to focus on how to understand the rendering equation

$$L_o(\omega_i \rightarrow \mathbf{x}) = L_e(\mathbf{x} \rightarrow \omega_o) + \int_\Omega f_r(\omega_i, \omega_o)\, L_i(\omega_i \rightarrow \mathbf{x})\, \langle \omega_i, \omega_g \rangle \, d\omega \,,$$

and how to implement algorithms that solve each part.

Graduate students, let me welcome you to the wonderful area of active research in computer graphics. You may be expecting more work than the undergraduate class. So let me take a moment and quickly highlight the main differences. First, you will notice that your research project requires additional effort with more emphasis placed on working to show how your research presents a *novel* idea. Second, there are additional homework projects to work on because *proficiency* is especially important. Thirdly, every week there is additional work on your part in learning the course material and working through additional activities covering more advanced topics. Lastly, there will be additional presentations where you highlight the results of a research paper with a focus on helping the class understand how it works.

1.2. Hybrid Topics

This is a hybrid course. This means that on Tuesday, we will meet in class and a special activity will be assigned for the Thursday class session. This special activity may combine video, reading assignments, and interactive presentations to help you learn. Some of these activities include

1. Computer Graphics Crash Course
2. Using the ray tracing algorithm
3. Using signed distance functions and constructive solid geometry to create 3D models
4. Using physically based sky models such as the Hosek-Wilkie model
5. Creating a rendering with the *Corona Renderer* and studying changes in material properties
6. Comparing a variety of physically based *bidirectional reflectance distribution functions* (BRDFs)
7. Comparing performance of Monte Carlo methods
8. Using bounding volume hierarchies to accelerate ray tracing
9. Examining the architecture of a web based graphics rendering system
10. Comparing different shadow mapping algorithms such as percentage closer filtering (PCF) or cascaded shadow maps (CSM)
11. Examining different post processing methods
12. Using creative synthesis and procedural generation to create textures
13. Some miscellaneous topics as chosen by the students

2. COURSE OUTCOMES

In this section, we cover the list of course outcomes. This is what you should expect to be able to do when the course is completed.

- Given a g-buffer shader, implement a physically based shader using a *bidirectional reflectance distribution function*. **Graduate students, given an anisotropic BRDF equation, implement a version to simulate cloth or another anisotropic microsurface.**
- Given a multi-pass rendering pipeline, implement an image based effect using a shader. **Graduate students, be able to describe the effects and solutions of temporal aliasing in post processing.**
- Given a multi-pass rendering pipeline, implement the shadow mapping algorithm. **Graduate students, given a basic shadow mapping shader, understand how to convert it to use the percentage closer filtering algorithm.**
- Given a full-screen shader system, implement a ray tracer with spheres. **Graduate students, given a basic sky miss shader, describe the process of incorporating a physically based sky model.**
- Given a basic ray tracer, create a complicated scene using signed distance functions. **Graduate students, given a chart of signed distance functions, illustrate a diagram of the set operations *union*, *intersection*, and *subtraction* for constructive solid geometry.**
- Given a basic ray tracer, implement importance sampling to improve convergence. **Graduate students, understand how using the Fresnel function affects the performance of reflection and refraction.**
- Given a list of shadow algorithms, compare and contrast shadow mapping and shadow volumes. **Graduate students, illustrate a diagram demonstrating the shadow volume method.**
- Given a list of lighting algorithms, compare and contrast different global illumination approaches. **Graduate students, illustrate a diagram demonstrating the instant radiosity method.**
- Given the rendering equation, explain its six parts and how each one is implemented. **Graduate students, using a real-time rendering engine, use a texture map to simulate the effects of using $L_e(\mathbf{x} \rightarrow \omega_o)$.**
- Graduate students, given rasterization and ray tracing images of the same scene, understand the differences of images produced with either. **Graduate students, given a scene description, produce a difference image comparing your renderer to a commercial or open-source renderer.**

3. GRADING & COURSE POLICIES

The course load consists of two exams, several homework assignments, and a research project. The midterm exam and final exam are both worth 20% of your final grade. Your research project will be worth 15% of your final grade. The homework assignments will be worth 40% of your final grade. The lowest homework grade will be replaced by the average grade of the remaining homework grades, but ALL homework must be completed. We use *Slack* as an online collaboration platform and 5% of your grade comes from participating. The exams are primarily based on the content of the assigned readings or videos. This is summarized in the table below.

IMPORTANT! Homework and Projects are due by midnight. Late homework gets penalized one whole letter grade each day that it is late starting at 12:00am. Late homework after 3 days receives no credit.

%	Type
20%	Midterm Examination
20%	Final Examination
40%	Homeworks
15%	Research Project
5%	Class participation on Slack

Students are expected to be at every class meeting on time, and are responsible for all class content, whether present or not. If absence from class is necessary, in-class work (other than quizzes) and homework may be made up only if the instructor is notified as soon as possible; in particular, absences due to scheduled events must be arranged ahead of time. Academic dishonesty will not be tolerated, and will be dealt with according to UAF procedures. Students in this class must pay the CS lab fee. Payment allows access to the computing lab.

- UAF academic policies `http://www.uaf.edu/catalog/current/academics`
- CS Department policies `http://www.cs.uaf.edu/departmental-policies`

3.1. Homework Grades

For homework assignments, graduate students are expected to complete the four required homeworks and must choose **four** from the remaining available topics. A list of these is presented a little later in the syllabus. The homeworks are graded with the following scheme. Several items are pass/fail for the entire homework assignment. In other words, they must be completed or no credit at all is given regardless of the completion of the other items. Graduate students will be graded according to the following scheme.

- (Pass/Fail) Program runs
- (Pass/Fail) Program source code and screenshot
- (Pass/Fail) Project page includes description

- (100 pts) Program *Interaction*
- (200 pts) Program *Correctedness*
- (200 pts) Program *Novelty*

Interaction refers to the ability to allow the user to control the application in some way. *Correctness* refers to how well the program implements the technique or algorithm. *Novelty* refers to the way that the program presents a new idea.

3.2. Research Project Grades

Research projects are topics chosen by the student related to the course content. Students will give a one minute pitch to announce their project about the third week of the class. Eight weeks into the class, students will give a five minute presentation talking about the background of their project. Lastly, the week before finals, students will demonstrate their projects and give a seven to ten minute presentation summarizing their results. Times may be adjusted according to class size. Graduate students, be aware that *novelty* is especially important in research and must be justified in your final paper. Graduate students will be graded with the following scheme.

- (100 pts) 6.5 pages in length, written in LaTeX, submitted as a PDF
- (100 pts) 8 journal or conference citations
- (100 pts) 3 journal or conference citations within last 3 years
- (200 pts) **Novelty**: **Graduate students, please justify why your idea is new**.
- (50 pts) Introduction section
- (50 pts) Previous work section
- (50 pts) Problem description section
- (50 pts) Method of solution section
- (50 pts) Results and analysis section
- (50 pts) Conclusion and Future Work section
- (200 pts) Research Project Pitch (one minute presentation)
- (300 pts) Midterm project report presentation (five minute presentation)
- (400 pts) Final project presentation (seven minute presentation)

3.3. Class Participation

We will use Slack to talk about class subjects through the week. Graduate students are expected to post at least **four** times to the Slack channel. It is highly encouraged for students to talk about their experiences and challenges with the course material.

Every week, one graduate student will present the results or method of a research paper in a short presentation (5 to 10 minutes). We will go round robin until all students has presented at least two different research papers.

4. HOMEWORK ASSIGNMENTS

In this section, the basic homework assignments are described. The first set are core homeworks required to be completed by all students. The second set are Student's Choice assignments where the student may select relevant topics suited to their interests. Lastly, the Game / Demoscene compo is a fun assignment to demonstrate the skills they learned in class.

4.1. Required Homework Assignments

- Ray tracer
- Real-time renderer
- Shadow maps
- Post processing

4.2. Student's Choice Homework Assignments

Graduate students, please choose four of the following. Homework details will be presented as separate handouts.

- Video documentary of a rendering technique (may be repeated once)
- Creative synthesis
- Debug tools
- Stencil shadows
- Global illumination
- Video game based on approved theme (may be repeated once)

4.3. Game / Demoscene Compo

One popular way of demonstrating graphics skills is by creating video games or demoscene applications. Many competitions (also called *compos*) are held every year. Our last homework is specifically set aside to create the most awesome computer game or demoscene application. Rules will be specified in class.

5. SCHEDULE

Week	Topics	Other
1	Computer graphics crash course	
2	Ray tracing	
3	Signed distance functions	Project pitch
4	Shading models	Homework 1
5	Monte Carlo methods	Homework 2
6	Global illumination	Homework 3
7	Bounding volume hierarchies	Homework 4
8	Motion blur and anti-aliasing	Midterm review
9	Spring break	
10	Scene Graphs	Midterm due
11	Deferred Rendering and Modern Pipelines	Project updates
12	Shadow Mapping and Shadow Volumes	Homework 5
13	Image Processing and post processing	Homework 6
14	Creative Synthesis	Homework 7
15	Final Presentations and Final Review	Homework 8

6. POLICIES

- Disabilities Services: The Office of Disability Services implements the Americans with Disabilities Act (ADA), and ensures that UAF students have equal access to the campus and course materials. I will work with the Office of Disabilities Services (208 Whitaker, (907) 474-5655) to provide reasonable accommodation to students with disabilities uaf.edu/disability/

- University of Alaska Board of Regents have clearly stated in BOR Policy that discrimination, harassment and violence will not be tolerated on any campus of the University of Alaska. If you believe you are experiencing discrimination or any form of harassment including sexual harassment/misconduct/assault, you are encouraged to report that behavior. If you report to a faculty member or any university employee, they must notify the UAF Title IX Coordinator about the basic facts of the incident. Your choices for reporting include: 1) You may access confidential counseling by contacting the UAF Health & Counseling Center at (907) 474-7043; 2) You may access support and file a Title IX report by contacting the UAF Title IX Coordinator at (907) 474- 6600; 3) You may file a criminal complaint by contacting the University Police Department at (907) 474-7721. uaf.edu/oeo/civil-rights/aa-eo/

- Any UAF employee or volunteer who reasonably suspects or observes Minor abuse or maltreatment is required to report the incident. Reporting procedures are available on the UAF Protection of Minors. Violation of this policy by employees shall be reported as well.

- UA is an AA/EO employer and educational institution and prohibits illegal discrimination against any individual: alaska.edu/nondiscrimination.
- Your instructor follows the University of Alaska Fairbanks Incomplete Grade Policy: "The letter "I" (Incomplete) is a temporary grade used to indicate that the student has satisfactorily completed (C or better) the majority of work in a course but for personal reasons beyond the student's control, such as sickness, he or she has not been able to complete the course during the regular semester. Negligence or indifference are not acceptable reasons for an "I" grade."
- C- (1.7) is the minimum acceptable grade that undergraduate students may receive for courses to count toward the major or minor degree requirements, or as a prerequisite for another course. A minimum grade of C (2.0), however, MAY be required by specific programs for prerequisite and / or major / minor courses. Please consult specific program listings in the UAF Catalog.
- Contact the Elmer E. Rasmuson Library at UAF reference desk for help with research. library.uaf.edu or (907) 474-7481
- The Student Support Services (SSS) program, located in 514 Gruening Building, provides opportunities for academic development, assists students with college requirements, and serves to motivate students towards successful completion of their degree program. Students have access to services if they meet any of the three eligibility requirements: a) limited income, b) documented disability, or c) first generation college student. Students receive intensive advising, one- one-one tutoring, technology check-outs, free printing and copying, computer lab space, and many other services. Additional information is at www.uaf.edu/sss, or contact them directly at (907) 474-6844.
- UAF Help Desk. Go to www.alaska.edu/oit/ to see about current network outages and news. Reach the Help Desk at: helpdesk@alaska.edu or (907) 450-8300 (in the Fairbanks area) or 1-800-478-8226 (outside of Fairbanks)
- UAF eLearning Student Services helps students with registration and course schedules, provides information about lessons and student records, assists with the examination process, and answers general questions. Our Academic Advisor can help students communicate with instructors, locate helpful resources, and maximize their distance learning experience. Contact the UAF eLearning Student Services staff at (907) 479-3444 (toll free 1-800-277-8060) or contact staff directly – for directory listing see: elearning.uaf.edu/contact
- Effective communication: Students who have difficulties with oral presentations and/or writing are strongly encouraged to get help from the UAF Department of Communication's Speaking Center (907) 474-5470, speak@uaf.edu) and the UAF English's Department's Writing Center ((907) 474-5314, Gruening 8th floor), and or CTC's Learning Center (604 Barnette st, (907) 455-2860).
- Veteran and Military Support Services: UAF is committed to all veterans and military students—active duty, reserve, guard, separated and retired—as well as

their dependents who are exploring UAFś academic opportunities. Staff members in Financial Aid, Admissions, Career Services, VeteransŚervices and the Veterans' Resource Center are here to help you with any challenges you encounter while working while in or transitioning from a military to an academic environment.Please contact the Veterans Resources Center, (907) 474-2475, uaf.edu/veterans/ in room 111 in the Eielson Building.

- Rural Student Services: Responding to student needs by providing quality services to Native and rural students who expend positive effort in the pursuit of higher education and its opportunities. Please see: uaf.edu/ruralss/.
- Additional student support services can be found here: `https://www.uaf.edu/ruralss/tutoring-services/`