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Advanced 3D Graphics for Movies and Games

👤 Lecturer(s): **Tomáš Iser** (<https://tomasiser.com/>)

Code in SIS: **NPGR010**

🔗 (<https://is.cuni.cz/studium/eng/predmety/index.php?do=predmet&kod=NPGR010>)

🕒 Hours per week (lecture/labs), examination type:

2/2 C+Ex

📅 Semester(s): **Winter**



Brief Description

Advanced course in computer graphics with the emphasis on image synthesis. The course covers methods for physically-based realistic rendering used for special effects in movie production, computer animation, architectural and product visualizations etc. Specifically, we start off by briefly covering some of the math and physics behind light transport. We then give a detailed treatment of the industry-standard Monte Carlo methods for light transport simulation, such as path tracing, photon mapping etc. We also cover some of the more advanced techniques such as bidirectional path tracing.

Course information 2025/2026

Lectures:	Wednesdays, 12:20 – 13:50, room S8	Contact: Tomáš Iser (/~tomas)
Practicals:	Tuesdays, 14:00 – 15:30, room SU2	Contact: Tomáš Iser (/~tomas) , Darryl Gouder (https://dargouder.github.io/darryls-pixels/)

Please note: For the 2025/2026 course, we have prepared new content and completely new homeworks. Be cautious when looking at the archived materials from previous years.

Lecture content

Slides and course notes will be updated throughout the semester.

Date	Topic	Slides & Notes
1 October	Introduction to the course Basic explanation of terminology such as rasterization, ray casting, ray tracing, path tracing, ray marching, meshes, solids, surfaces, volumes, signed distance fields, shading, etc.	<u>Slides with notes</u> https://drive.google.com/file/d/1daSipfnQSCKYwZJS2SZ7gWliFp-m7JQW/view?usp=sharing
8 October	Reflection equation and radiometry Photon model and wave model, power (flux), radiant intensity, irradiance, radiance, inverse square law, Lambert's cosine law	<u>Slides with notes</u> https://drive.google.com/file/d/1HiL5NulBj4_VzArr9lv2VXdMma7wecdm/view?usp=sharing
15 October	Numerical integration Numerical quadrature, Monte Carlo, properties of a Monte Carlo estimator, random sampling <i>(more math exercises and proofs during the labs on 14 October)</i>	<u>Slides with notes</u> (https://drive.google.com/file/d/1VPj-bKWVSJrhKUd2dHnBFYnYgqhaAEHS/view?usp=sharing) Blackboard photos: (1) https://drive.google.com/file/d/1hhY1EEff141mOoktvf6qG3xSn2SGdL_C/view?usp=drive_link , (2) https://drive.google.com/file/d/12MM2pKeWp4qwQOgoTFw_i84T7wP-L2GI/view?usp=drive_link

22 October	Monte Carlo in rendering and importance sampling Using Monte Carlo in ray tracing, random sampling, importance sampling; example of importance sampling a diffuse and specular lobe of a BRDF	<u>Slides with notes</u> (https://drive.google.com/file/d/1uYoyqWdfCkGb0R8NCPU1CJODDI9fsmEV/view?usp=sharing).
29 October	Monte Carlo in rendering and importance sampling — continued Importance sampling an environment map and area lights; a bit on control variates and stratification Multiple importance sampling (MIS) Motivation of MIS, formula, balance heuristic, example with BRDF/envmap	<u>MIS slides</u> (https://cgg.mff.cuni.cz/~jirka/teaching/npgr010-2020/slides/06%20-%20npgr010-2020%20-%20MIS.pdf).

5 November	Multiple importance sampling (MIS) — continued Example with BRDF/area lights, examples of other heuristics (cutoff, power, maximum) Building a path tracer Constructing the rendering equation, the operator form, Neumann series, recursion, implementation with a <i>for</i> loop with <i>maxLength</i> (fixed path length → bias)	<u>Slides with notes</u> (https://drive.google.com/file/d/1YTU0ze44yviJbExlaibK9mFTa2E6cKDW/view?usp=sharing).
12 November	<i>canceled</i> (<i>Děkanský sportovní den / Dean's Sports Day</i>)	

19
November

Building a path tracer — continued
Implementation with a *while* loop (using Russian roulette → unbiased), the principles of: 1) adjoint-driven Russian roulette & splitting, 2) path guiding, 3) next event estimation (NEE), NEE with multiple light sources (“many-light methods”)

Slides with notes

(https://drive.google.com/file/d/1QLS5mlYnNC22UVsbnYvMi1_8VRll-xB_/view?usp=sharing).

26
November

**Volumetric light
transport and
participating
media**

Surface vs.
volume
rendering,
examples of
participating
media, Beer-
Lambert law
including
derivation,
volume
rendering
equation (VRE)
including
derivation,
distance
sampling in a
homogeneous
volume
proportional to
transmittance
(including
derivation),
basics of
distance
sampling in
heterogeneous
volumes (main
principles of
regular tracking,
ray marching,
and null-collision
algorithms)

Slides and notes from the SIGGRAPH 2018 course

(<https://cgg.mff.cuni.cz/~jaroslav/papers/2018-mcvolrendering/index.htm>).

Mainly "Introduction", "Fundamentals", and partially "Distance sampling". Other slides are for your information only and will not be examined.

+ Steve Marschner's notes

(<https://www.cs.cornell.edu/courses/cs6630/2012sp/notes/09volpath.pdf>).

Blackboard photos:

(1) (https://drive.google.com/file/d/1pvMY8uPct_5qp1wbai4VRdBe9hdAT-ib/view?usp=drive_link), (2).

(https://drive.google.com/file/d/1UY5CmdGPLKe59bfOef9KiakitjRpcwst/view?usp=drive_link).

3
December

**Bidirectional
path tracing
(BDPT), photon
mapping (PM)**

Only the main
principles
without going
too deep into
technical details

BDPT:

Measurement
equation, duality
of importance
and radiance,
path tracing vs.
light tracing,
path integral
formulation,
constructing
paths in bi-
directional path
tracing and using
MIS (no
derivations)

PM: Problem of
SDS paths,
photon tracing
(including
formulas),
photon maps,
rendering with
photon maps
(caustics vs. final
gathering)

*Any additional
information in the
slides that is not
mentioned above
will not be
examined*

BDPT slides (<https://cgg.mff.cuni.cz/~jirka/teaching/npgr010-2020/slides/11%20-%20npgr010-2020%20-%20BPT.pdf>)

PM slides (<https://cgg.mff.cuni.cz/~jirka/teaching/npgr010-2020/slides/12%20-%20npgr010-2020%20-%20PM.pdf>)

10 December	Inverse and differentiable rendering Only the main principles without going too deep into technical details Inverse problems, various ways to find the optimum, gradient descent, finite differences, automatic differentiation (AD), forward-mode AD, reverse-mode AD, situations that cause problems (ambiguities, discontinuities)	Slides (https://1drv.ms/b/s!AuC8m2CvOUXjhYUhgw_v8gb2NOZbuA?e=nZur7w)
17 December	<i>canceled</i> <i>(conference in Hong Kong)</i>	
7 January	Neural fields and Gaussian splatting Only the main principles without going too deep into technical details	Slides (https://cgg.mff.cuni.cz/wp-content/uploads/2026/01/NPGR010_11.pdf) SIGGRAPH 2023 Course (https://neuralfields.cs.brown.edu/siggraph23.html)

Practicals / labs content

Date	Topic	Slides & Notes
30 September	<i>canceled (before the 1st lecture)</i>	

7 October	Introduction to Blender Homework assignment 1 (10 points + max 3 bonus points) Math exercises (radiometry): solid angle, spherical coordinate system, integrals in spherical coordinates, differential solid angle, differential area	Whiteboard photos: (1) (https://drive.google.com/file/d/1DPNNHAQSlNafipiezZgRnrAhP6cttLTV/view?usp=sharing).
14 October	Introduction to random sampling Math exercises: expected value, variance, probability distribution function, cumulative distribution function, normalization, random sampling in 1D, multidimensional random sampling	Whiteboard photos: (1) (https://drive.google.com/file/d/1j5PP0WVb03p0iEvi1SeKUqksBp_TigtO/view?usp=drive_link), (2) (https://drive.google.com/file/d/1MzXco47cnpLoWHmV0W30ZdDxkzkF5jgu/view?usp=drive_link), (3) (https://drive.google.com/file/d/1tU3P_GhoiQxiav_Au9Zn4gv7AevucGjw/view?usp=drive_link), (4) (https://drive.google.com/file/d/1NC-xkzlx02obFyFTTqsUAaDMsfrZWBrI/view?usp=drive_link), (5) (https://drive.google.com/file/d/1IJoZHNhtfJLMag0vYCexSm5piGrBK6E0/view?usp=drive_link).
21 October	Assignment 1 deadline + student presentations (5 minutes / student)	
28 October	<i>canceled (bank holidays)</i>	

4 November	Homework assignment 2.1 “Monte Carlo Sampling and Ambient Occlusion” (10 points + max 2 bonus points)	
11 November	Online consultation with Darryl	
18 November	Assignment 2.1 deadline Homework assignment 2.2 “Distribution and Whitted-style Ray Tracing” (10 points + max 2 bonus points)	
25 November	Online consultation with Darryl (*time zone difference)	
2 December	Assignment 2.2 deadline Homework assignment 2.3 “Path Tracing, Microfacet Models, and Multiple Importance Sampling” (*time zone difference) (10 points + max 2.5 bonus points)	
9 December	Online consultation with Darryl (*time zone difference)	

16 December	Online consultation with Darryl (*time zone difference)	
6 January	Assignment 2.3 deadline (EXTENDED TO 13 JANUARY)	

Assignment 1 (“Creative exercise”)

Deadline: 21 October 2025 14:00

In this course, we focus on writing algorithms for photorealistic rendering. But what use is it to know an algorithm if you cannot even create your own 3D scene? That is why our first assignment is and has traditionally been to create and render a 3D scene.

If you are not familiar with any 3D editing and rendering software, I recommend to use [Blender](https://www.blender.org/) (<https://www.blender.org/>), which is free and comes with a built-in path tracer called Cycles. Students can use any other 3D editing software (e.g., Autodesk 3ds Max) and any other renderer which uses path tracing (e.g., Autodesk Arnold). Please do not use renderers that are primarily based on rasterization, such as Unreal or Unity.

Your goal is to create and render a 3D scene and satisfy the following requirements:

- The scene must use at least 6 very different materials (e.g., glass, plastic, wood, concrete, liquid, fabric, metal)
- At least one of the materials must have subsurface scattering
- The scene must use at least the following light sources:
 - Environment map / HDRI
 - Area light (e.g., a rectangle)
- You have to render the scene multiple times, split into the following components:
 - Direct vs. indirect illumination
 - Diffuse vs. specular (or glossy) reflections
- You must demonstrate the use of denoising:
 - Render the scene once without denoising, with a very low sample count to get a noisy render
 - Render the scene once without denoising, with a very high sample count to get a smooth, converged render
 - Render the scene once with a very low sample count and with denoising enabled

Prepare a presentation (5 minutes) with the images and describe what we can see on them. Also explain your motivation behind the scene that you modeled.

You can use free resources that you download on the internet, such as textures, environment maps, meshes, and so on. **You cannot download the entire scene** though as the point of the exercise is for you to try to at least insert and transform the objects into a scene, apply materials on them, position a camera, etc.

This is an individual exercise and you should not work in a team.

Assignments 2.1 – 2.3 (“Programming exercises”)

In the set of Assignments 2.1 – 2.3, you will write C++ code to perform Monte Carlo ray tracing and path tracing. With the kind permission of Wenzel Jakob from EPFL in Switzerland, we will use [the Nori framework](https://wjakob.github.io/nori/) (<https://wjakob.github.io/nori/>) and the Nori exercises in our course. That way you will learn how a codebase of a full renderer looks and how a path tracer actually works when implemented in C++.

More details were provided during the practicals and in your GitHub materials.

Archive

Course information for the previous academic years:

- ~~2024/2025~~ (not taught)
- [2023/2024](https://cgg.mff.cuni.cz/wp-content/uploads/2025/09/npgr010_20232024.pdf) (https://cgg.mff.cuni.cz/wp-content/uploads/2025/09/npgr010_20232024.pdf)
- [2022/2023](https://cgg.mff.cuni.cz/wp-content/uploads/2023/10/npgr010_20222023.pdf) (https://cgg.mff.cuni.cz/wp-content/uploads/2023/10/npgr010_20222023.pdf)
- [2021/2022](https://cgg.mff.cuni.cz/wp-content/uploads/2022/09/NPGR010_Archived20212022.pdf) (https://cgg.mff.cuni.cz/wp-content/uploads/2022/09/NPGR010_Archived20212022.pdf)
- [2020/2021](https://cgg.mff.cuni.cz/~jirka/teaching/npgr010-2020/index.html) (<https://cgg.mff.cuni.cz/~jirka/teaching/npgr010-2020/index.html>)
- [2019/2020](https://cgg.mff.cuni.cz/~jaroslav/teaching/2019-npgr010/index.html) (<https://cgg.mff.cuni.cz/~jaroslav/teaching/2019-npgr010/index.html>)

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