Information on the oral exam from the Computer Graphics III course (NPGR010)

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General information

The exam is oral and consists of three questions. Two of them concern the material covered in the classes and will be selected from the list given below. In the third question, the student will be asked to concisely and clearly explain the contents of one of three scientific papers previously chosen by the student and approved by the lecturer.

The exam starts by the student drawing the two questions and the examiner selecting one of the three papers. The student then has 30 minutes for preparation, which is then followed by the oral exam itself.

The following two points are essential to succeeds at the exam:

- A true understanding of the material from the lectures (as opposed to repeating buzzwords and formulas)
- The ability to clearly explain the contents of the selected paper in a short time period. This latter point should not be taken lightly. Not only is it important to explain the „how", but also the "what" and "why" of the paper. Of course, results of the work need to be presented too. The students should be able to critically assess the quality of the paper.

Questions:

1. **Radiometry & photometry.** Relation between radiometric and photometric quantities. Spectral efficiency curve. Model of light for the purpose of radiometry. Radiant energy. Spectral vs. integrated radiometric quantities. Overview of radiometric and photometric quantities.

2. **Radiometric and photometric quantities.** Radiant and luminous energy, radiant and luminous flux, irradiance/illuminance, Lambert cosine law, radiant and luminous intensity. Radiance/luminance and its properties. Incoming and outgoing radiance. Significance of the cosine factor in the radiance definition.

3. **Light sources and their description.** Point source, area source and their description by radiometric quantities. Environment map. Relation between the radiant intensity and total flux for some basic point sources. Relation between emitted radiance and flux for area light sources. Irradiance on a plane due to a point source. Projected solid angle.

4. **BRDF.** Definition, properties, meaning. Hemispherical-hemispherical and hemispherical-directional reflectance. BRDF types. Different approaches to modeling surface reflectance. BTDF, BSDF, SVBRDF, BTF, BSSRDF.

5. **Basic BRDF models.** Diffuse BRDF (reflectance, energy conservation conditions). Reflection and refraction at a smooth interface, Fresnel equations, Snell's law, total internal reflection. BRDF for physically-plausible Phong model, its reciprocity and energy conservation.

6. **Local reflection equation** (OVTIGRE). Derivation from the BRDF definition, its meaning, description of the radiometric quantities involved.

7. **Rendering equation.** Derivation from the local reflection equation. Difference between the local reflection equation and the rendering equation. Angular and area form of the rendering equation. Sketch of the derivation of the radiosity method from the rendering equation.

8. **Solving the rendering equation.** Formulation of the rendering equations in the operator form. Transformation into an infinite-dimensional integral: Neumann series and its convergence conditions. Meaning of the Neumann series terms.

9. **Monte Carlo quadrature.** Estimation of a definite integral using the Monte Carlo method. Primary and secondary estimator. Derivation of the unbiasedness and the variance of the primary and secondary estimators. Difference between an estimator and its realization. Comparison to deterministic quadrature formulas (convergence speed). Examples of estimators for simple integrals in illumination calculation.

10. **Properties of Monte Carlo estimators.** Unbiased and consistent estimator. Mean squared error (MSE), efficiency. Examples of unbiased, consistent and biased/non-consistent estimators of the rendering equation.

11. **Combination of MC estimators.** Multiple importance sampling in a general form. Conditions on the unbiasedness of the combined estimator. Balance, power and maximum heuristic. What is the intuition behind the MIS working so well? When does it not work well? Briefly mention example uses in rendering.

12. **Multiple importance sampling in image-based lighting**. Explain the principle of multiple importance sampling on the example of image-based lighting. What sampling strategies can be used here? Use this example to highlight the difference between the balance and the maximum heuristic. What could be the benefit of the maxim heuristic in this case?

13. **Variance reduction in MC.** Control variates, importance sampling, stratified sampling (jittering), quasi-Monte Carlo methods. Definition of discrepancy and its relation to the estimation error. Basic low-discrepancy sequences.

14. **Generating samples from 1D and 2D probability distributions.** Sampling from discrete distributions. Example uses in rendering. Sampling from a 1D continuous distribution – transformation method, rejection sampling. Sampling from a multi-dimensional continuous distribution.

15. **Path tracing.** Explanation of the algorithm as a recursive solution of the rendering equation and as a method for path space sampling. Pseudocode.

16. **Optimizing path tracing**. Various methods for path termination and their consequences. Russian roulette and its unbiasedness. Scattering direction sampling for Phong BRDF. Use of multiple importance sampling for direct illumination calculation.

17. **Importance and duality in light transport**. Measurement equation. Emitted importance. Transport of importance. Duality of importance and radiance. Light tracing algorithm as a recursive solution of importance transport.

18. **Path integral formulation of light transport**. Path space, path contribution function, path integral, path sampling techniques, path pdf. Path tracing and light tracing as MC estimators of the path integral.

19. **Bidirectional path tracing**. Various path sampling strategies and their combination through MIS. Naive BDPT implementation. Practical BDPT implementation. Combination with path tracing, light tracing and photon mapping in terms of efficiency at rendering various illumination features.

20. **Photon mapping algorithm**. Purpose and how it's achieved, illumination effects that can and cannot be easily rendered with PM. Comparison to path tracing, light trancing and bidirectional path tracing (in terms of biasedness/consistency; illumination features that can/cannot be easily rendered). Overall structure of the algorithm with the focus on the rendering phase of classic photon mapping (rendering of caustics, final gathering). Progressive photon mapping. Basic idea of Vertex Connection and Merging.

21. **Photon mapping details**. Photon tracing, rules for photon emission, scattering and termination. Caustic and global photon map. Photon map data structure: construction and query. Radiance estimate.

22. **Irradiance caching**. Purpose and general overview of the algorithm, advantages and disadvantages. Individual algorithm steps, data structure, translation and rotation gradients. Combination with final gathering in photon mapping?

23. **Interaction of light with optically participating media**. The four types of light-medium interactions. Optical properties of a medium. Explain: single-scattering albedo, phase function, homogeneous/heterogeneous medium, isotropic/anisotropic scattering. What parameter value ranges correspond to what medium appearance? (Give some examples: clear and turbid water, wine, milk, human skin, clouds, etc.) Attenuation of light in a medium, transmittance, Beer-Lamber law.

24. **Methods for rendering participating media**. Volume rendering equation in the integral form. Explain: Single scattering approximation and multiple scattering. Ray marching. Explain the difference between surface-only path tracing and path tracing that can handle media. Outline of a volumetric path tracer for homogeneous media.

25. **Volumetric path tracing**. Explain the difference between surface-only path tracing and path tracing that can handle media. Sampling of interaction distances in media. Derive the distance-sampling procedure for a homogeneous medium (for transmittance-proportional sampling). Distance sampling in a heterogeneous medium: the inversion method (i.e. ray marching), Woodcock tracking (discuss also the relative efficiency of the two methods).

26. **Advanced volume rendering methods**. Volumetric photon mapping (how exactly does the radiance estimate differ on surfaces and in a medium?). Beam-radiance estimate (write out the radiance estimate formula, explain). Photon beams, virtual point lights (explain the high-level idea).