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COMBINED USAGE OF PHONG SHADING AND RAY TRACING

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Photorealistic rendering [1] is one of the central directions of computer graphics, as it provides the formation of images, the quality of which is comparable to real photos. Photorealistic rendering is widely used in the development of animated films, feature films, computer games, augmented and virtual reality systems, and in the architectural and scientific modeling. A high level of realism not only provides a more

aesthetic perception of a graphic scene, but also allows people to more accurately convey basic information about it. In particular, physical processes, such as the reflection of light from a certain material, are more accurately represented. Thanks to the use of photorealistic rendering in games and simulators, users interact with the virtual environment more effectively, and developers achieve greater trust among users. In general, with the help of special algorithms for modeling the reflection of light from materials, graphic scenes achieve a level of realism that was previously only available using traditional photography.

Another equally important area of computer graphics is high-performance rendering, which provides fast generation of images of acceptable quality under the condition of limited computing resources. This is crucial for real-time systems, such as video games and interactive simulations. The main goal of high-performance rendering is to ensure visual plausibility of images without significant time costs, which is important when the user interacts with the scene. The compromise between speed and quality of visualization is achieved by using high-performance methods of object shading, optimized lighting models, pre-calculations and the use of hardware acceleration of calculations.

The two main classical directions of forming three-dimensional images are rasterization and ray tracing, which are respectively used for high-performance and highly realistic image formation.

Rasterization is the process of projecting a three-dimensional scene to two-dimensional screen space. The 3D coordinates of the vertices of the triangles of polygonal models are converted to 2D coordinates in the camera coordinate system. At the same time, the z-coordinates of the vertices are stored for further clipping of invisible surfaces. For each projected triangle, it is determined which pixels of the image belong to it. After that, the color intensity is determined for each pixel inside the triangle. This stage is called shading and is carried out using various methods.

The well-known Phong shading method [2, 3], proposed by Bui Tuong Phong in the 1970s, is based on one of the first empirical models of light reflection from a material surface, which allows creating fairly realistic images at moderate computational costs. The emergence of the method was due to the need to increase the accuracy of visualization of three-dimensional objects, in particular to ensure more accurate reproduction of specular reflections.

An important feature of the Phong method is the use of normal interpolation (as opposed to color intensity interpolation in the Gouraud method). First, normals are calculated at the vertices of the triangles of the polygonal model, and then interpolated inside the surfaces of the triangles. Next, for each point of the triangle, the color intensity is calculated based on the corresponding interpolated normal. For this, the Phong light reflection model is used.

The basis of the Phong reflection model used in the method is the division of lighting into three components: ambient, diffuse and specular. Ambient lighting is a background light evenly distributed over the scene. Diffuse lighting is responsible for the visibility of the object and depends on the angle between the direction to the light source and the normal to the surface point. Specular lighting is associated with the

modeling of specular highlights on the surfaces of objects and depends on the direction to the observer and the direction of mirror reflection of light.

Due to its high performance, the method has been widely used in graphics engines, computer-aided design systems, and computer games. However, the method has a number of limitations. Global illumination is not taken into account, all calculations are performed only locally - at the point of contact of the beam with the object surface. This limits the realism of image formation, especially in cases of complex lighting or materials with complex optical properties.

Ray tracing [2] is one of the most accurate methods for generating highly realistic images in computer graphics. The basic idea of ray tracing is to direct a ray from the camera (or the observer's eye) through each pixel of the image and find the intersection of the ray with the objects of the scene. At the point of intersection of the ray with the object of the scene, the intensity of the pixel color is calculated, taking into account the normal to the surface, vectors to the observer and to the light source, and the optical properties of the material. Additional rays of reflection and refraction of light are often generated. The process is repeated recursively, with the value of the pixel color intensity updated at each iteration. Ray tracing is terminated in the following cases: the secondary ray reaches the light source, the maximum recursion depth is reached, the contribution of the secondary light reflection to the pixel color intensity is too small. The method allows users to model a wide range of optical effects, including shadows, specular reflections, light refraction, and caustics (concentrated light when interacting with a curved surface, like water).

Unlike simpler rasterization-based image generation methods, it takes into account the global interaction of light in the scene, which provides a high level of image realism. As a result, the method is widely used in cinematography and scientific visualization, where rendering quality is important.

The main disadvantage of ray tracing is its computational complexity. In the most complex case, for each pixel of the image, it is necessary to trace the path of the ray, including its multiple reflections and refraction. As a result, the method is time-consuming and slower compared to the rasterization method. Modern GPUs with hardware support for ray tracing (for example, Nvidia RTX) significantly accelerate the speed of the method, but the formation of complex scenes can still take a long time.

Therefore, hybrid rendering methods are used, where ray tracing is combined with simple shading methods to achieve a compromise between quality and performance.

In particular, the combination of ray tracing and the Phong shading method is promising. The combination of these methods is applied to combine their advantages and minimize limitations. Each of the methods is characterized by a set of advantages, but is not able to independently provide sufficiently high realism and sufficiently high performance of image formation at the same time.

The Phong method is effective for fast modeling of local lighting, but does not take into account complex cases of light interaction between objects, such as indirect lighting, caustics. On the other hand, ray tracing provides a high level of photorealism, providing accurate modeling of the passage of light through the scene. However, this method is resource-intensive, especially with a significant number of secondary rays.

In complex 3D scenes containing a significant number of objects and materials, it is impractical to trace all lighting interactions. Simple lighting effects can be generated based on the Phong method, while more complex lighting effects can be further calculated using ray tracing.

The main directions of combining the Phong method and ray tracing involve dividing the tasks between the methods according to their advantages.

The first direction of combining methods is that the base image is created based on the rasterization algorithm using the Phong shading method. At this stage, the effects of local (direct) lighting are simulated. Next, the individual groups of pixels corresponding to complex optical effects and phenomena, such as indirect lighting, shadows from complex light sources, caustics, are refined using ray tracing.

When analyzing pixels to which ray tracing is required, the type of material and the distance of the object from the camera are taken into account. In particular, ray tracing is desirable for transparent materials (glass, liquid), which are characterized by light refraction and caustics, as well as for polished metals. For matte surfaces and plastics, rasterization with simple shading methods is sufficient. In addition, objects closer to the camera are reproduced highly realistically. For distant objects, users can use the Phong method or an even simpler shading method, for example, Gouraud.

This reduces the number of rays being traced, reducing the overall computational load, while maintaining image quality in important areas.

An example is the rendering of an interior scene with shiny furniture. Phong shading is used to reproduce reflections on wooden surfaces, while ray tracing allows users to recreate reflections in mirrors, transparent windows, or light coming through curtains.

A similar direction of hybrid rendering is the use of rasterization and Phong method to model the primary reflection of light (from the surface to the observer) and ray tracing to model the secondary rays (reflected between objects, refracted rays). As a result, ray tracing is used incompletely (as a supplement to the rasterization algorithm) and only for certain areas of the image.

The next direction is to use ray tracing to generate lighting maps at the scene preprocessing stage. The generated lighting maps are used during rendering based on the Phong method. This allows users to recreate global illumination effects without using ray tracing during each frame generation.

Another direction is that ray tracing is used only to determine the visibility of a light source relative to a point on the surface. If the point on the surface is visible, the color intensity is calculated for the corresponding pixel according to the Phong model. Otherwise, the point is in shadow. This ensures accurate reproduction of both hard (with clear boundaries) and soft (with penumbra) shadows without using full ray tracing. As a result, much higher performance is provided.

An important area of research in the field of hybrid rendering is ensuring the optimal selection of scene objects for ray tracing. For example, F. Sabino et al. [4] proposed a hybrid rendering method using a G-buffer and heuristic selection of objects for ray tracing. The basis of the image is formed using the deferred rendering. This type of rendering lies in pre-saving the geometric data of the scene in the G-buffer,

which is used for further calculation of lighting. The Phong method can be used at both stages of deferred rendering - respectively for normal interpolation and calculation of pixel color intensity. Next, the image is enhanced by applying ray tracing. The G-buffer additionally stores data on the optical properties of materials, so rays are directed only to surfaces that reflect or refract light. To select scene objects for ray tracing, the available amount of time, the rendering cost parameter (based on the visibility of the object and the required number of rays to simulate lighting effects), and the object relevance parameter (whether the object has been selected before) are taken into account.

A promising approach is to implement hybrid rendering at the hardware level (e.g., using hardware cores in Nvidia RTX). Special hybrid pipelines are being implemented, where rasterization provides the main rendering of the scene, and hardware-optimized ray tracing adds global illumination effects. Such pipelines are actively used in modern games and virtual reality applications.

The use of hybrid rendering methods in modern rendering software is widespread.

In particular, the 3D tool Blender allows users to use two renderers: Cycles and Eevee. Cycles provides physically realistic rendering of images using the ray tracing method. Eevee involves the use of a real-time rasterization algorithm with normal interpolation during shading (Smooth Shading). Blender allows users to combine both renderers using the Compositing function.

In addition, the Unreal Engine game engine is characterized by the ability to use the Hybrid Ray Tracer mode. The basis of the image is formed based on the rasterization algorithm, special effects are reproduced using ray tracing, which provides real-time rendering.

In general, the combination of ray tracing and the Phong method has a number of advantages. The rendering process is significantly accelerated compared to traditional ray tracing, which is extremely time-consuming. Due to the use of the Phong method, an acceptable quality of direct lighting modeling is maintained. Simplifying the process of modeling global lighting and the number of rays traced allows users to reduce the level of image noise, which is important for interactive rendering systems.

However, the combined use of ray tracing and the Phong method is characterized by a number of shortcomings. One of the main shortcomings is that ray tracing is a direction of physically realistic rendering, and the Phong method is an empirical method. In particular, the lighting model used in the method is not energy-correct. Accordingly, for the surface of the material, the amount of reflected light may be overestimated or underestimated. As a result, the consistency between the different components of the image formed on the basis of different methods is lost. One way to solve this drawback is to use the energy-correct Phong model in the method.

Conclusion: The combination of ray tracing and the Phong method allows for high-quality rendering of the main objects of the scene and high performance of rendering the entire scene.

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CHRONICLE OF DEEPPFAKE RESEARCH: PUBLICATION TRENDS, DETECTION METHODS, AND KEY DATASETS

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This work provides a systematic overview of deepfake detection research from 2015 to 2025, analyzing how advances in generation technology have driven detection methods and research trends. We survey major detection approaches, key benchmark datasets, and publication growth trajectory, drawing on over 45,000 publications to quantify research interest surge and periodize the field's development.

Deepfakes—hyper-realistic fake videos or audio generated by AI—emerged as a prominent phenomenon in the late 2010s. While having potential applications in entertainment and education, they pose serious risks: manipulation, fraud, identity theft, and disinformation. The term "deepfake" gained public attention around 2017, when a Reddit user posted face-swapped celebrity videos. By 2018, the first academic papers on deepfake detection appeared, initially exploring basic detection cues such as unnatural eye-blinking [2]. This rapid rise of generative capabilities has continually challenged defenders and stimulated new detection techniques development.

Early academic efforts (2018-2019) focused on identifying visible artifacts left by nascent generation methods. Researchers found early deepfake videos exhibited abnormally low eye-blink rates, leading to blink-detection as one of the first automated detectors [1]. Other works examined facial warping artifacts or pixel-level noise patterns as tell-tale signs of manipulation. Various machine learning architectures were proposed to improve detection: compact CNNs like MesoNet appeared in 2018 to detect face forgeries by analyzing mesoscopic image features [2]. Some approaches combined CNNs with recurrent networks to capture temporal inconsistencies in video sequences [3].

With the research boom after 2018, detection methods grew more sophisticated. Standard deep CNN models became prevalent for real vs fake classification, often