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# ENGINEERING GEOMETRY, COMPUTER GRAPHICS, AND AUDIO AND VIDEO TECHNOLOGIES

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**Abstract.** This article analyzes the interrelationship between engineering geometry, computer graphics, and audio and video technologies from a scientific perspective. It examines the mathematical foundations of geometric modeling (projection, affine transformations, curves and surfaces), the stages of forming graphic images, and methods of digitizing, compressing, and synthesizing digital audio and video. Using modern directions as examples (neural radiance fields, Gaussian splatting, spatial audio, and high-efficiency video codecs), it shows development trends in multimedia systems. The results of the research can be applied in engineering education, design systems (CAD), and virtual and augmented reality.

**Keywords:** engineering geometry, computer graphics, geometric modeling, projection, NURBS, rendering, digital audio, video codecs, multimedia, virtual reality.

## Introduction

In recent decades, information technology has become an inseparable part of engineering activity. Designing products and structures, predicting their appearance, and delivering the result to the user are now carried out mainly in a digital environment. The foundation of this process is engineering geometry: it provides the rules for representing spatial forms on a plane, determining their mutual positions, and studying their metric properties. Computer graphics, in turn, implements these rules in the form of algorithms and software, turning geometric data into a visible image. The modern information environment is not limited to images alone. Virtual environments, simulators, educational multimedia, and the film industry also require sound and moving images. For this reason, audio and video technologies are considered together with graphics systems as a single multimedia complex. The aim of this article is to summarize the theoretical foundations of these three areas and to show how they are related.

## 1. The Role of Engineering Geometry in Computer Graphics

The classical foundation of engineering geometry is the methods of projection. In central projection, a spatial point is mapped onto the image plane by a straight line passing through the center of projection; in parallel projection (orthogonal and axonometric), all projecting rays are parallel to one another. These same concepts are used in computer graphics as perspective and orthographic cameras [1, 6]. The Monge diagram of technical drawing corresponds to view matrices in 3D modeling, and axonometry corresponds to isometric views. In computer graphics, geometric transformations are specified using homogeneous coordinates and 4×4 matrices. Translation, rotation, and scaling are expressed as matrix products, which makes it possible to combine complex transformations into a single matrix. For a point $P = (x, y, z, 1)^T$, the transformation is performed as $P'$

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= M·P, where M is the product of the matrices of the successive transformations. Perspective projection is carried out by dividing by the last component of the homogeneous coordinates.

Several models exist for representing geometric objects. Polygonal meshes (collections of triangles) are widespread in real-time systems because of their simplicity and fast processing on graphics processors. In engineering design systems (CAD), where smooth surfaces must be specified precisely, Bézier curves, B-splines, and NURBS (non-uniform rational B-splines) are used [4, 5]. NURBS can represent conic sections (circles, ellipses) exactly, which is why it has become an industry standard. In addition, constructive solid geometry (CSG), voxels, and point clouds are also used. A Bézier curve is constructed using Bernstein polynomials of degree n: $C(t) = \Sigma B_{i,n}(t) \cdot P_i$, $t \in [0, 1]$, where $P_i$ are the control points. The curve lies within the convex hull of the control points, and its shape is controlled intuitively by moving the points [4]. This property allows a design engineer to specify a complex profile (for example, a car body or an aircraft wing cross-section) with just a few parameters.

**2. Computer Graphics: Stages of Image Formation**

In real-time graphics, an image is produced through the graphics pipeline. The pipeline consists of several stages: processing the vertices of the model (vertex processing), transforming them into camera space and clip space, assembling and clipping primitives, rasterization, and coloring pixels (fragment processing). In the last stage, hidden surfaces are removed using a depth buffer (z-buffer) [6]. Graphics processors (GPUs) perform these operations in parallel across hundreds of thousands of threads, which makes it possible to produce dozens of frames per second. The realism of an image depends on lighting models. The Lambert diffuse model takes surface brightness to be proportional to the cosine of the angle between the surface normal and the light direction; the Phong and Blinn–Phong models add specular highlights. Today, physically based rendering (PBR) is widely used; it relies on energy conservation and microfacet theory [7]. Ray tracing and path tracing compute global illumination (shadows, reflections, and refractions) with high accuracy. Hardware-accelerated ray tracing has recently entered real-time systems as well [6]. In recent years, approaches based on machine learning have appeared in graphics. Neural radiance fields (NeRF) reconstruct a scene from several photographs using a neural network and synthesize views from any new viewpoint [13]. The 3D Gaussian splatting method represents a scene as many anisotropic Gaussian particles, combining high quality with real-time speed [14]. These methods are promising for photogrammetry and for digitizing engineering objects (documenting architectural monuments, industrial inspection).

**3. Audio Technologies**

Sound is a mechanical vibration of air, and to process it on a computer the continuous signal is digitized. Digitization consists of two operations: sampling (in time) and quantization (in amplitude). According to the Kotelnikov–Nyquist theorem, for a signal to be reconstructed without loss, the sampling frequency must be at least twice the highest frequency in the signal. Since the human hearing range is approximately 20 Hz–20 kHz, 44.1 kHz and 16 bits were chosen for audio CDs, while 48–192 kHz and 24 bits are used in professional recordings [8]. The Fourier transform plays a central role in digital signal processing. The Fast Fourier Transform (FFT) converts a signal to the frequency domain, enabling operations such as filtering, equalization, noise reduction, and spectral analysis [9]. Effects such as reverberation, compression, and delay are also implemented using digital filters and delay lines. There are two groups of methods for compressing audio data. Lossless compression (FLAC, ALAC) fully restores the original signal. Lossy compression (MP3, AAC, Opus) relies on the

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psychoacoustic model: the human ear does not hear a quiet sound next to a loud one (the masking effect), so such components are discarded and the file size is reduced several times over [8]. In spatial audio, binaural sound, ambisonics, and object-based formats (for example, Dolby Atmos) simulate the 3D positions of sound sources. Here the head-related transfer function (HRTF) models the differences in arrival time and intensity of sound at the ears. The direct connection with engineering geometry is evident here: the spatial positions of the sound source and the listener are computed geometrically, and room acoustics is estimated using methods similar to ray tracing.

**4. Video Technologies**

Video is a stream of sequential frames, and each frame is stored as a matrix of pixels. Uncompressed video is very large: for example, 1920×1080 video with 24-bit color at 30 frames/s produces a stream of about 1.5 Gbit/s. For this reason, video codecs (H.264/AVC, H.265/HEVC, VP9, AV1) are used [10–12]. Their main idea is the removal of redundancy: exploiting similarity within a frame (spatial) and between frames (temporal).

Within a frame, pixels are divided into blocks and the discrete cosine transform (or its integer analog) is applied; the coefficients are then quantized and entropy coded. Between frames, motion estimation and compensation are performed: the matching block in a previous frame is found, and only the motion vector and the difference (residual) are transmitted. Experiments have shown that HEVC requires about half the bitrate of H.264 at equal quality [12]. Frames are divided into I (intra-coded), P (predicted), and B (bidirectionally predicted) types, and they form a group of pictures (GOP) [10, 11].

Video quality is assessed by subjective methods (expert ratings) and by objective metrics: PSNR, SSIM, and VMAF. PSNR is measured in dB and is found by the formula $PSNR = 10 \cdot \lg(MAX^2/MSE)$. High-resolution (4K, 8K), high-dynamic-range (HDR), and 360° video, as well as real-time streaming (adaptive bitrate), place new demands on network and computing resources. The intersection of video and graphics is clearly seen in computer vision, frame interpolation, virtual studios, and augmented reality.

**5. Integration of the Three Areas and Fields of Application**

In practice, engineering geometry, computer graphics, and audio-video technologies form a single chain. First, a geometric model of a product is created in a CAD system; then it is rendered and presented as an image or animation (video), and its operation is enriched with voice commentary or simulation sound. In virtual and augmented reality systems, these three components must work synchronously in real time: the image is rebuilt according to the user's head movement, the directions of sound sources are updated, and the video stream is transmitted over the network. In education, when teaching descriptive geometry and engineering graphics, 3D models, interactive animations, and video lessons develop students' spatial imagination. In industry, digital twins, virtual testing, and assembly trainers reduce costs. In architecture and cultural heritage preservation, technologies such as laser scanning, photogrammetry, and NeRF create accurate digital copies of monuments. These technologies are also widely used in medicine, film, computer games, and remote communication. The existing problems include the computational complexity of high-quality rendering and video encoding, network latency, incompatibility of formats across platforms, and loss of accuracy when converting geometric data (CAD) into mesh and other graphic formats. In the future, automatic modeling based on artificial intelligence, generative synthesis of images and sound, neural methods in codecs, and energy-efficient computing will remain the main directions.

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**Conclusion**

The analysis showed that engineering geometry is the theoretical foundation of computer graphics, and that projection, transformations, and the theory of curves and surfaces are used at all stages of graphics systems. Audio and video technologies complete the multimedia product with methods of digitization, spectral analysis, compression, and synchronization. Modern trends (physically based rendering, neural scene representation, spatial audio, and efficient video codecs) show that these three fields are drawing even closer together. In training specialists, it is recommended to teach geometric, graphic, and multimedia knowledge as a unified whole.

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