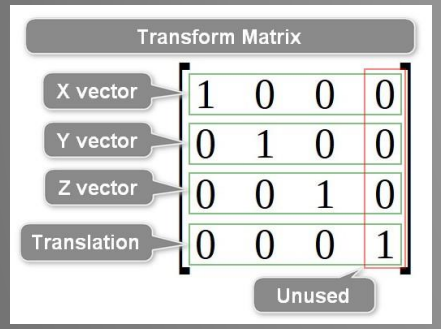
Basics of computer graphics

Transformations

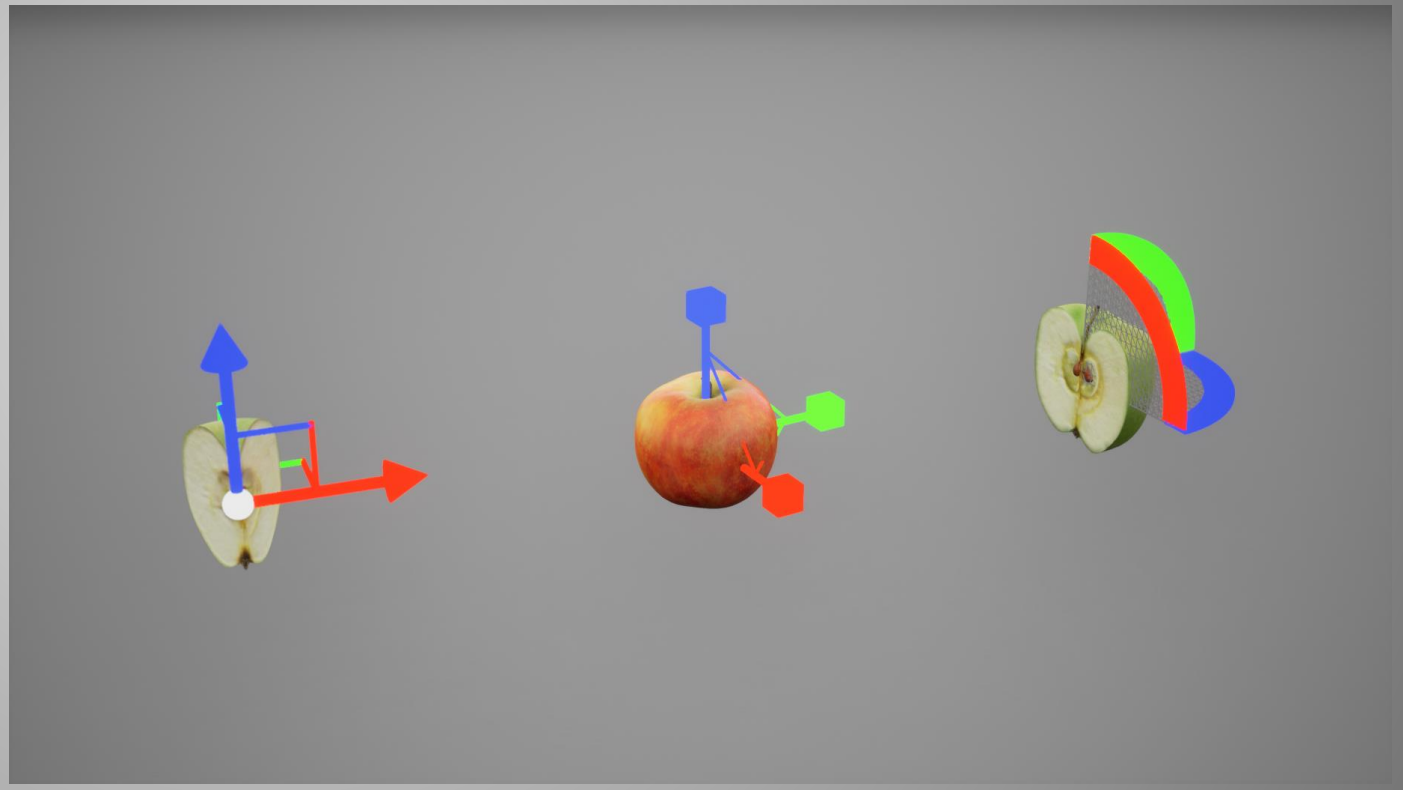
Under the term transformation, we mean a way of describing the position, size, and orientation of a virtual object in space.Transformations are expressed in the form of matrices:



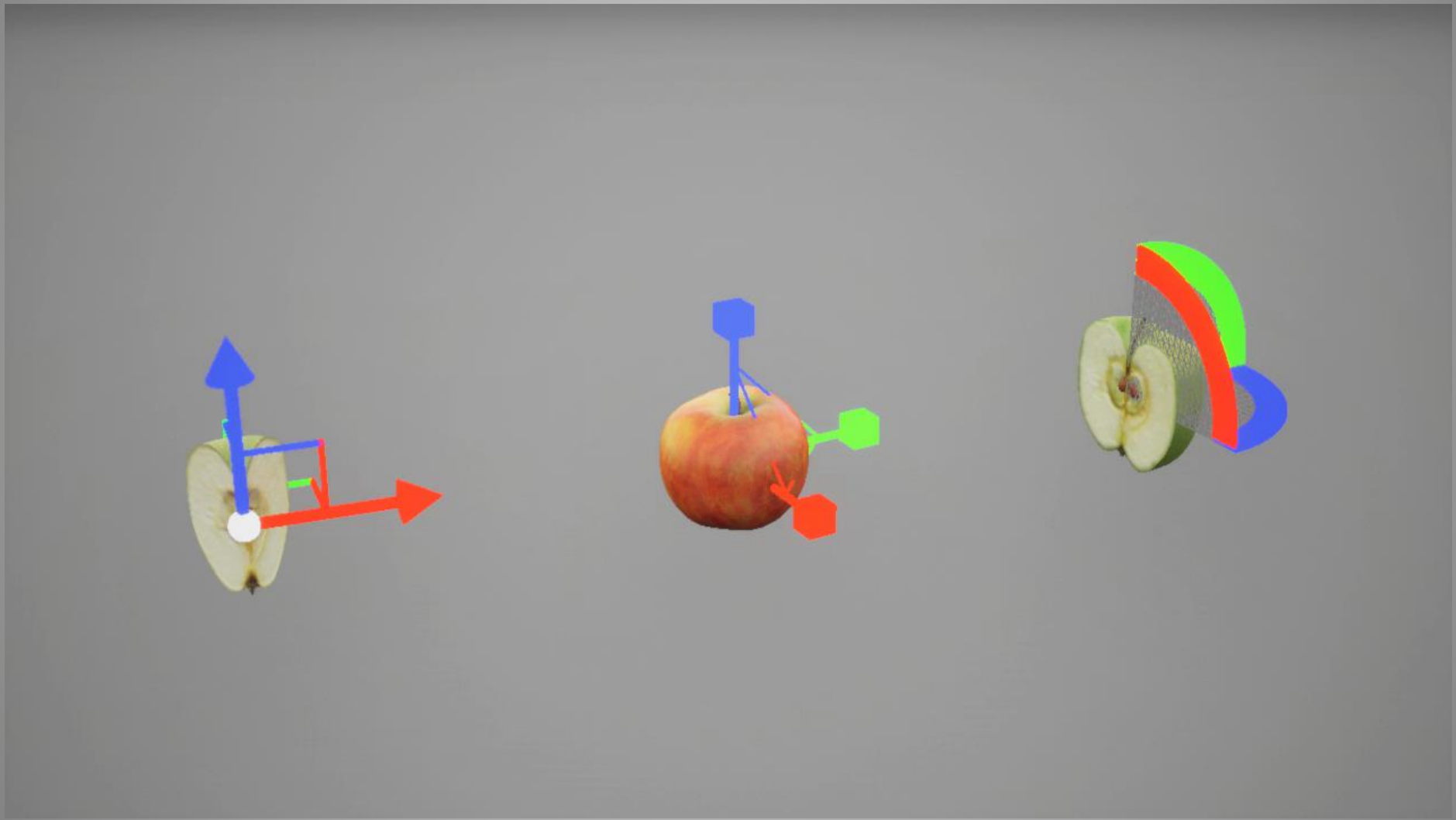
Where rotation and scaling are combined and interconnected.

Three ways to control 3D objects in space

Position, scaling, and rotation

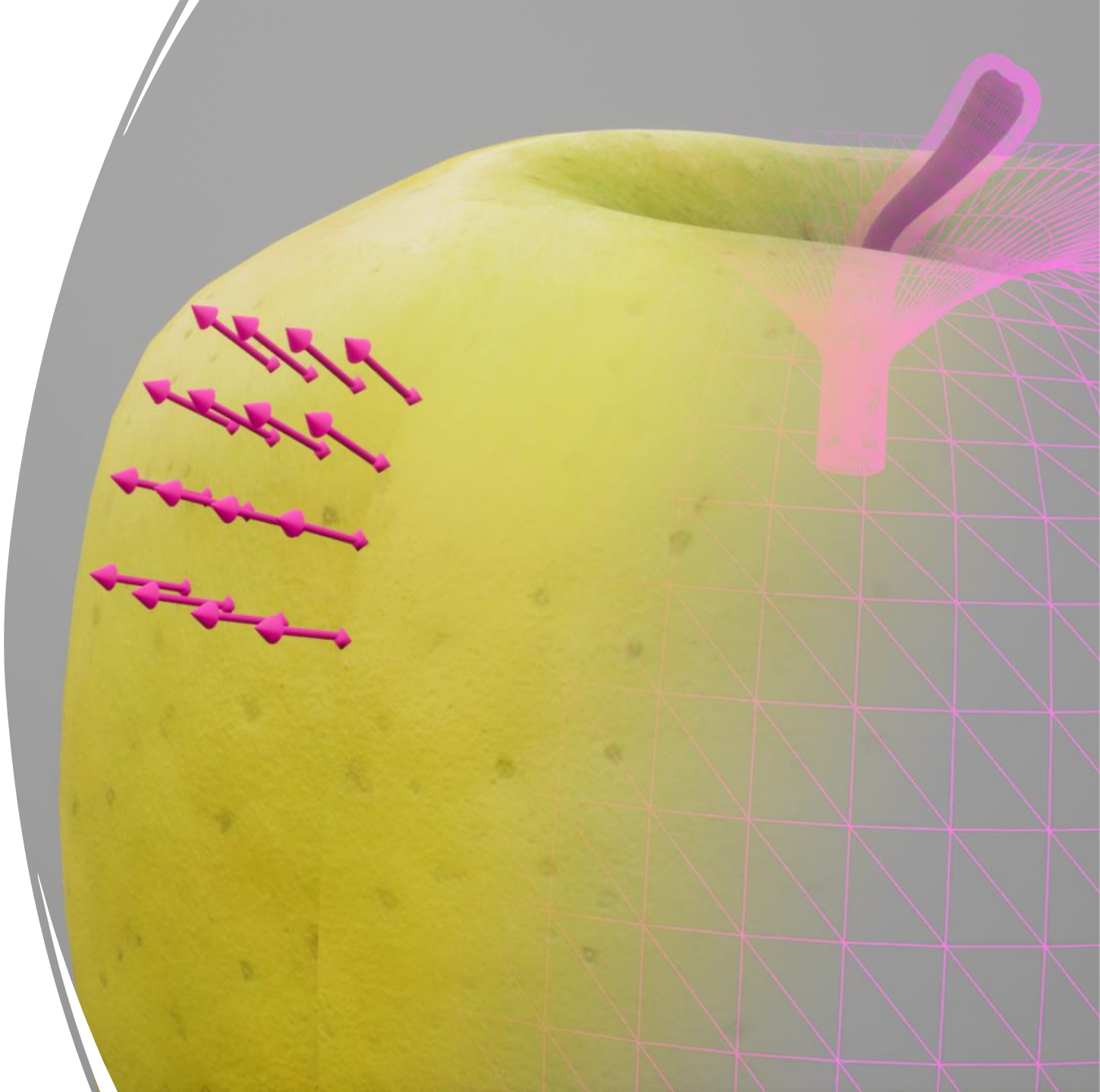


Animations of transformations



Elements of a 3D model

- Every 3D model in virtual space contains certain elements through which the model is described.
- Each 3D model has the following elements:
- Vertices
- Edges (lines between vertices) that form
- Polygons (or triangles)
- Normals at vertices and interpolated normals per pixel
- UV mapping
- Materialization and shaders
- Textures used by shaders



Poligons and triangles

Triangles are the smallest unit of surface from which a model can consist.

Modeling objects is mainly done using polygons, or planes with four sides.

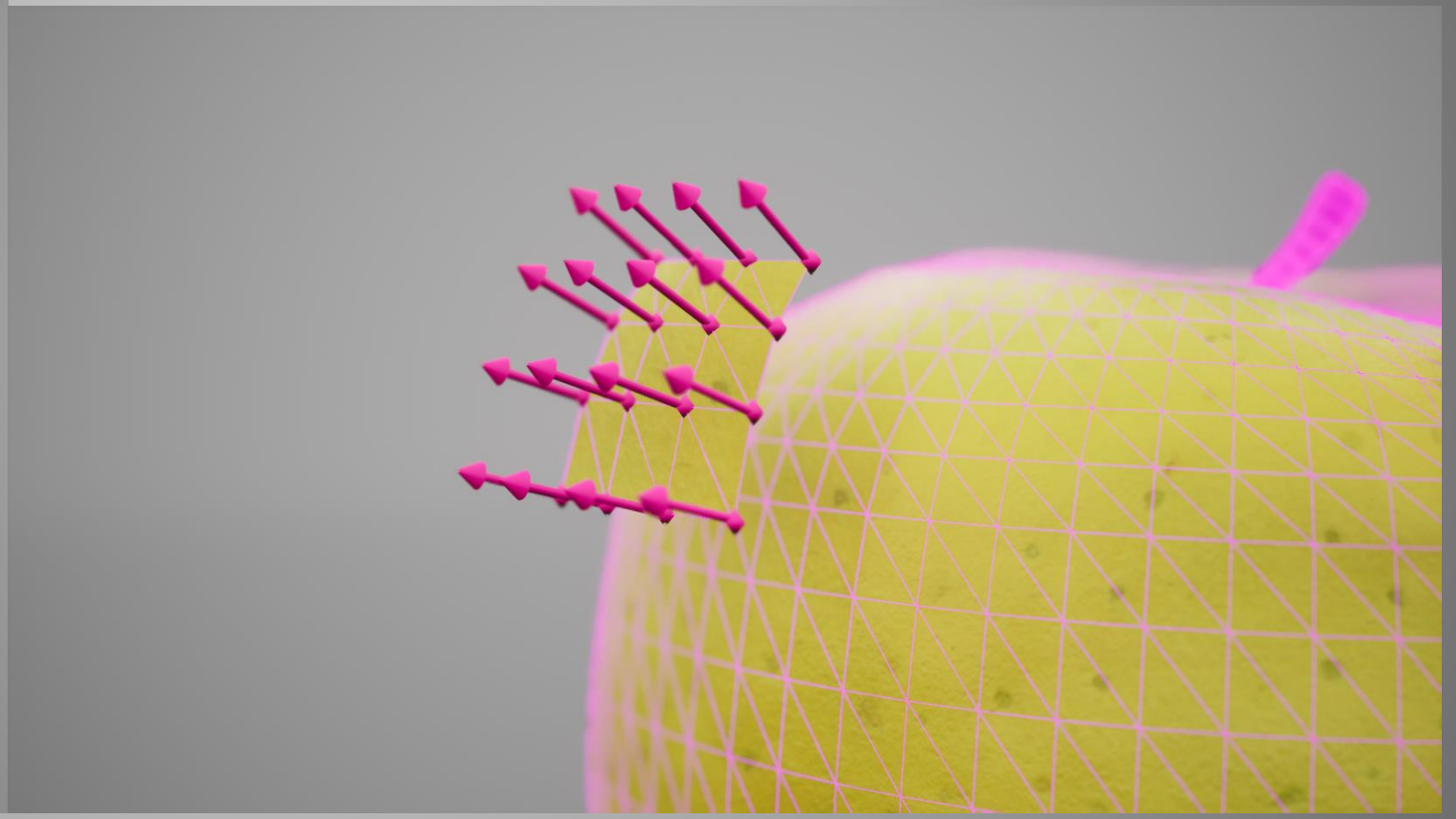
However, the graphics card always converts each 3D model into triangles.

Video games also treat all 3D models as triangles.

Normals describe the direction on the surface of the object in the form of a vector (arrows in the image on the right).

Normals are used in shader calculations (lighting and materialization).

Tirangles, poligons, vertices and normals.



Materialization and lighting

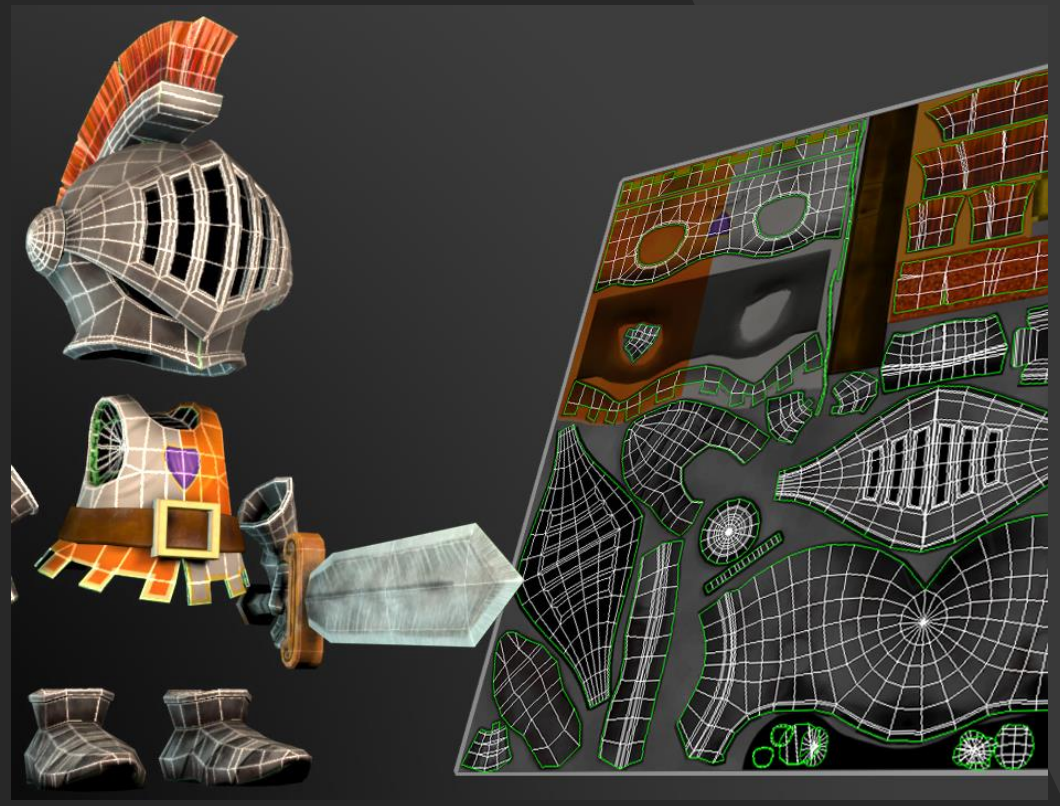
- To obtain the final image of a 3D model, it is necessary to apply materialization and lighting in 3D space.
- The way this is done is through shaders.
- Shaders combine information about the material and information about lighting and render the final pixels.
- In other words, shaders fill in pixels within polygons.

What is a shader

- A shader is a small program that is called in the graphics card when determining the color of each pixel.
- Shaders define the following:
  - Which textures are used
  - How these textures affect the color of pixels
  - How the combination of textures affects the lighting of the object.
  - What reflections on the object look like
  - Whether the object is transparent or not, etc.
- There are many types of shaders, because the way of determining the color of pixels is unlimited. There is some kind of standardization of shaders by following the physical laws of interaction of light and objects in the real world.

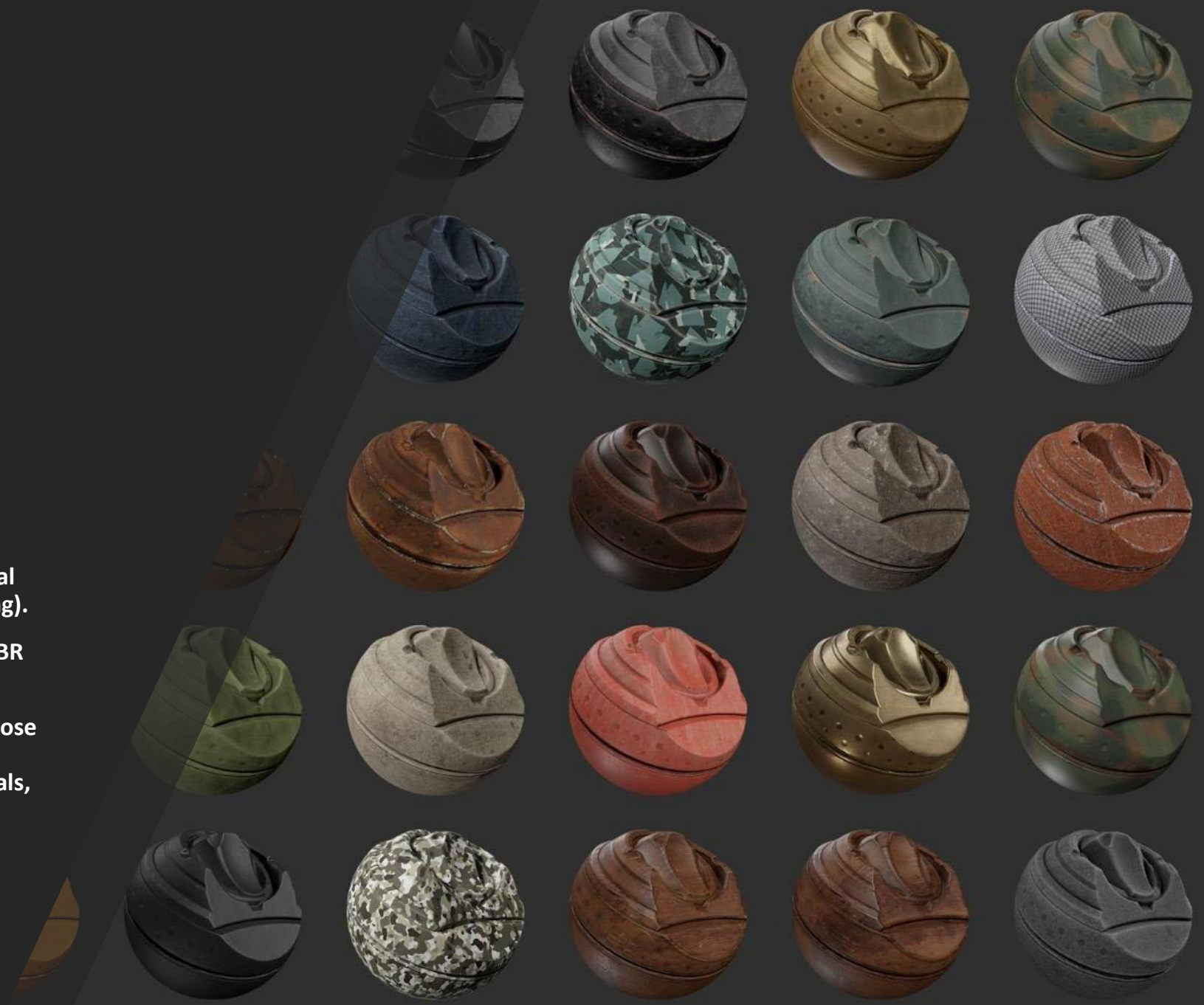
UV mapping process

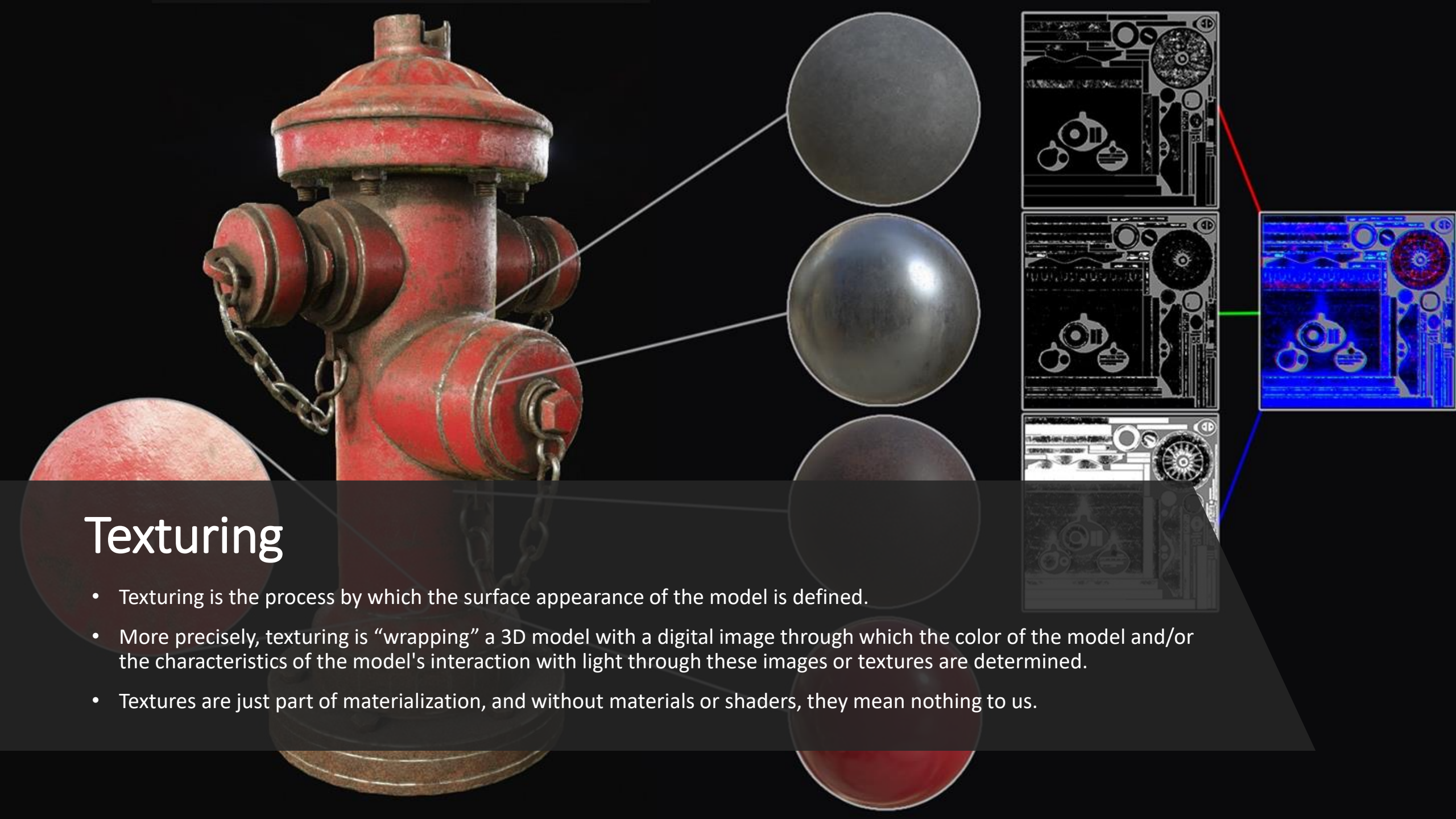
- Since models are three-dimensional, we need a way to wrap a two-dimensional image over a three-dimensional object.
- The reason for UV mapping is that rendering the surface of an object is first done by determining which triangles are visible and which are not, and then determining the color of those triangles, i.e., filling in the pixels that the triangle edges occupy.
- If we didn't use textures, then these triangles would have to be constantly the size of one pixel in relation to the screen and the camera position.
- This is impractical, so instead, it is determined which triangle occupies which part of the two-dimensional image (texture), and when filling in the pixels inside the triangle, they are filled using the colors from the textures.
- UV mapping, simply put, is the cutting of the model and the unfolding of the 3D model into a two-dimensional surface.



Materials

- Materialization is the process by which it is defined how the model interacts with light.
- Materialization has several phases:
  - UV mapping (UV mapping, Texture mapping)
  - Texturing
  - Shading
- Materials can be realistic or stylized.
- Realistic materials today are based on a special process called PBR (Physically Based Rendering).
- Even if a stylized rendering method is used, PBR can be used for these purposes.
- There are specific shaders that serve the purpose of rendering special materials that are very complex. E.g. human skin, translucent materials, layered materials, etc.





Texturing

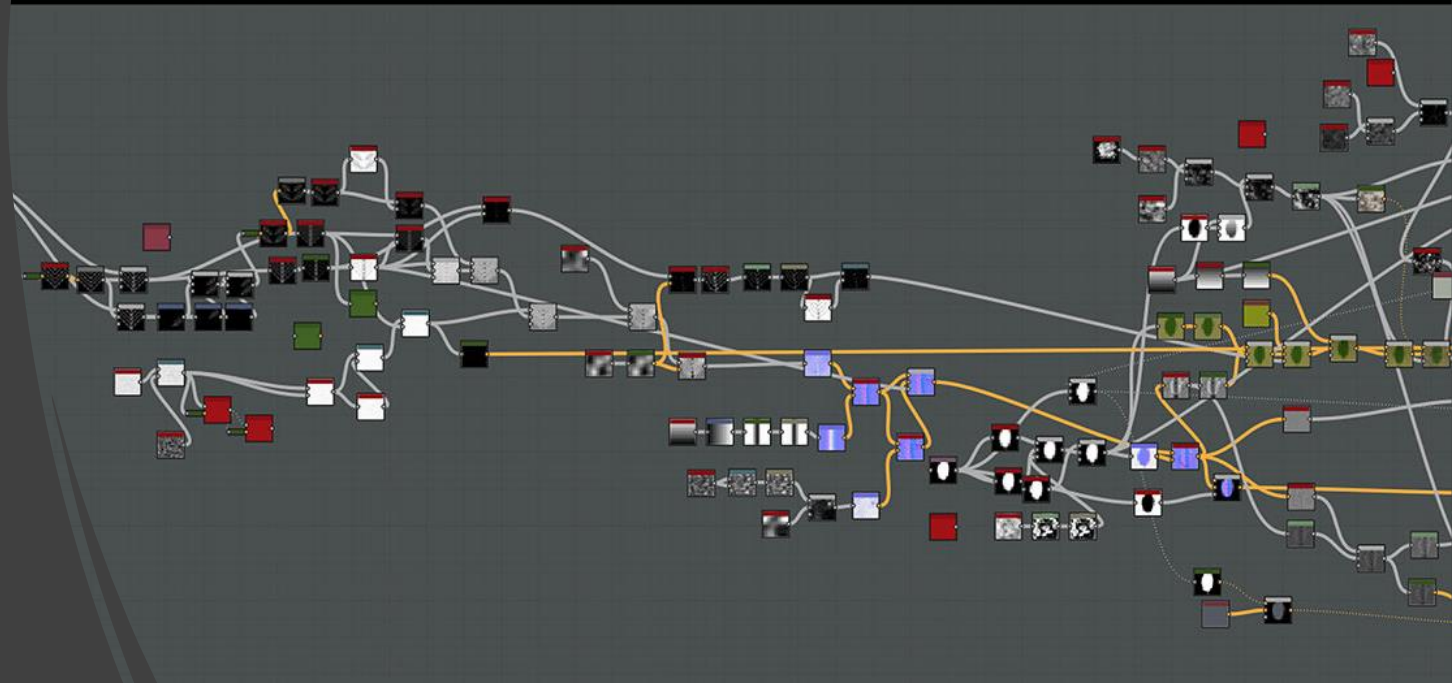
- Texturing is the process by which the surface appearance of the model is defined.
- More precisely, texturing is “wrapping” a 3D model with a digital image through which the color of the model and/or the characteristics of the model's interaction with light through these images or textures are determined.
- Textures are just part of materialization, and without materials or shaders, they mean nothing to us.

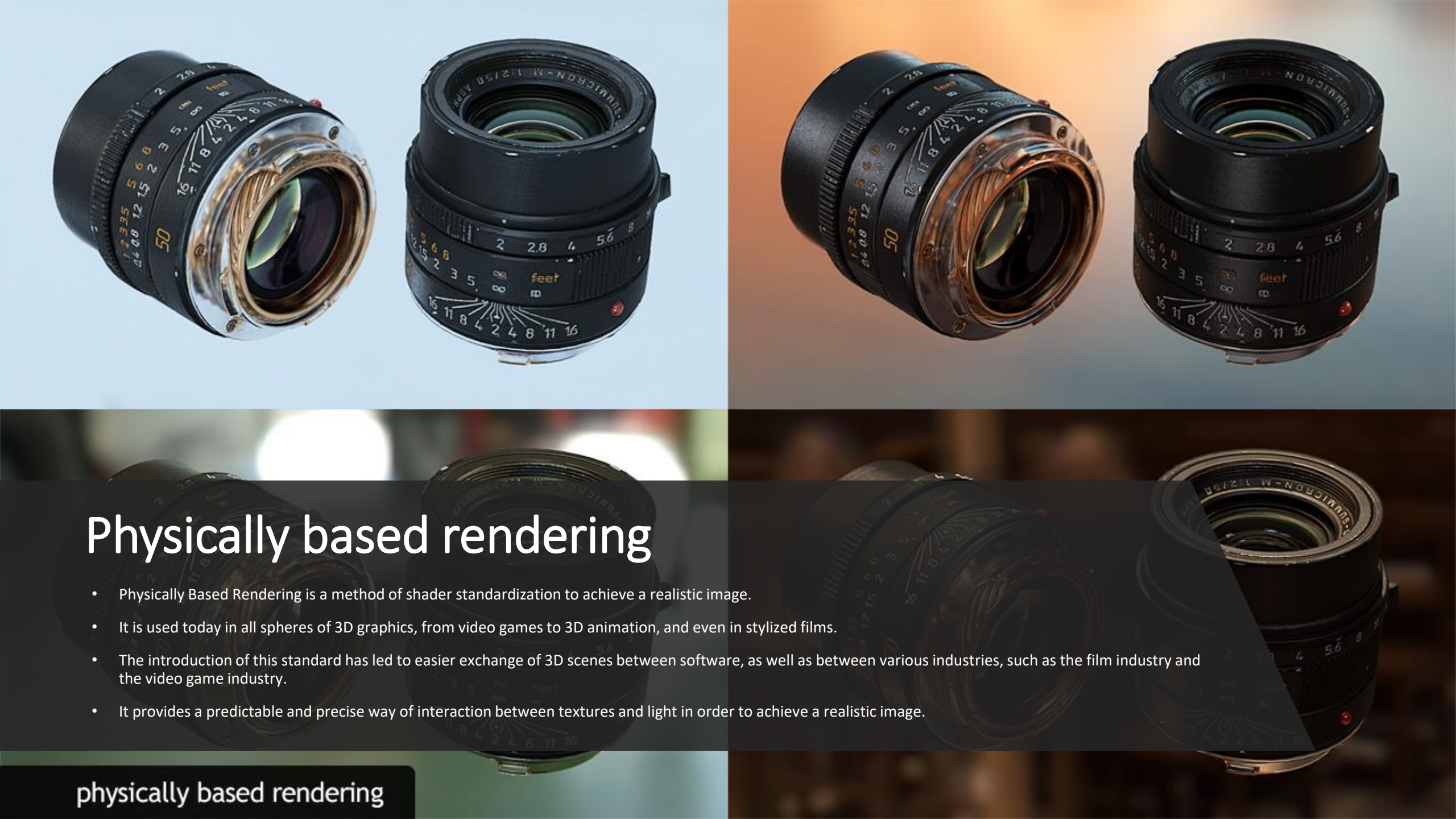
Methods of texturing

- Today, texturing is done using specialized software. However, any 2D digital image can serve as a texture.
- Since materials use several textures, each of which has its own special function, synchronization of these textures is necessary in terms of their features. For example, if there is a screw in the wood in a texture obtained from a photograph, that screw must be exactly in the pixel in the same place in other textures.
- These other textures can describe information that the screw is made of metal (metallic texture), or that it is highly reflective (roughness texture), or that it is protruding (normal texture or displacement texture).
- Therefore, texturing software automatically controls all these channels, so it is possible to paint materials on a 3D object with digital brushes, and that software will simultaneously convert our strokes on the 3D object into a 2D texture, and paint all the necessary textures that define the material at the same time.
- That's why Photoshop as a texturing tool is outdated. Standard texturing software includes Substance Painter, Quixel Mixer, and Mari.

Three ways of texturing

- Texturing can be done so that textures are specific only to one model.
- Another way of texturing is to use textures that can be repeated infinitely (tiling). This allows us to have a higher texture resolution (we can get closer to the model with the camera without seeing individual pixels of the texture, but repetition of textures becomes very noticeable).
- Another method of texturing is procedural texturing, where textures are generated using program code.
- One software for generating such textures is Substance Designer.
- This method of texturing is rarely used in video games.





Physically based rendering

- Physically Based Rendering is a method of shader standardization to achieve a realistic image.
- It is used today in all spheres of 3D graphics, from video games to 3D animation, and even in stylized films.
- The introduction of this standard has led to easier exchange of 3D scenes between software, as well as between various industries, such as the film industry and the video game industry.
- It provides a predictable and precise way of interaction between textures and light in order to achieve a realistic image.

physically based rendering

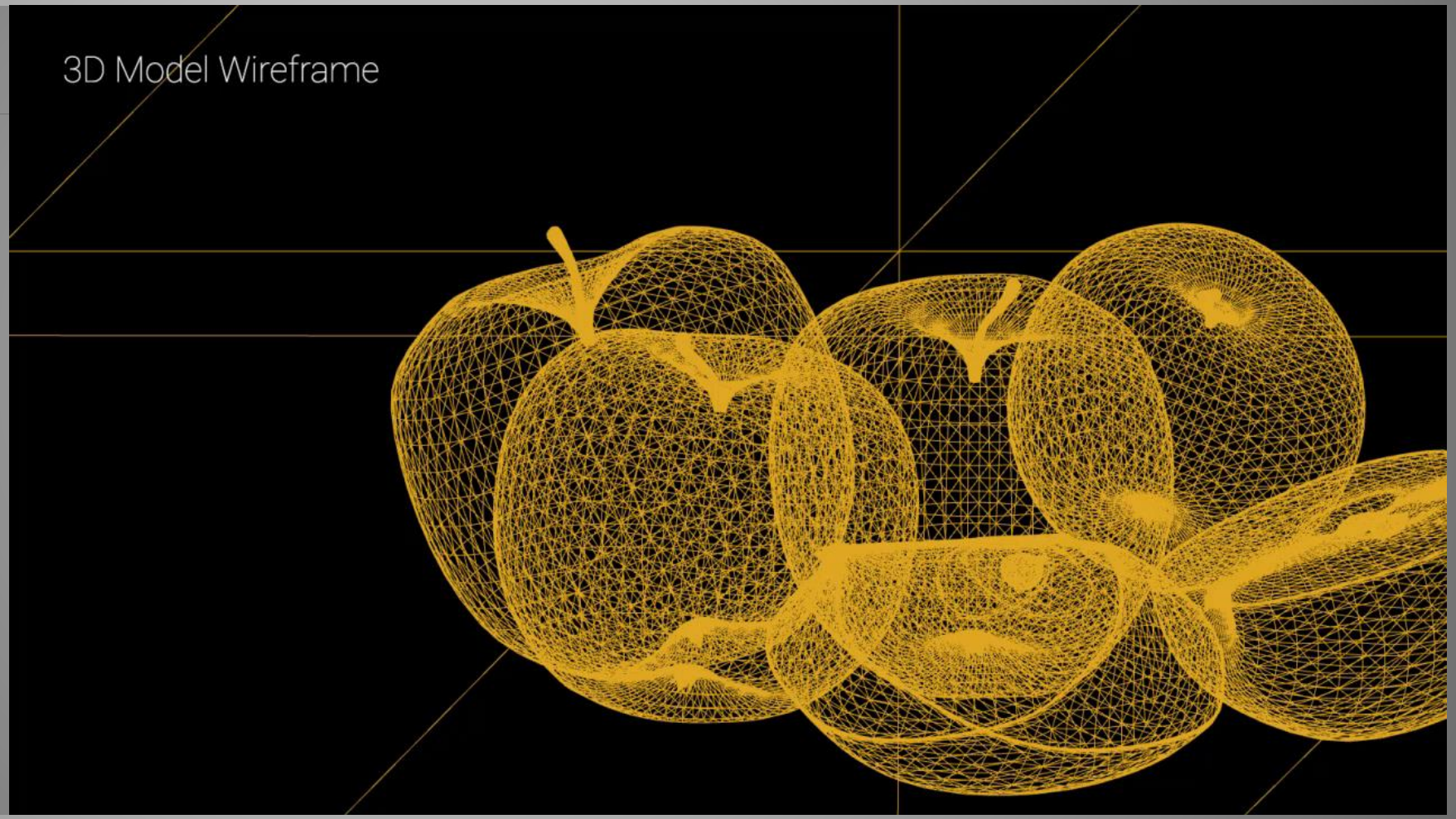
Applying textures and phases of shading

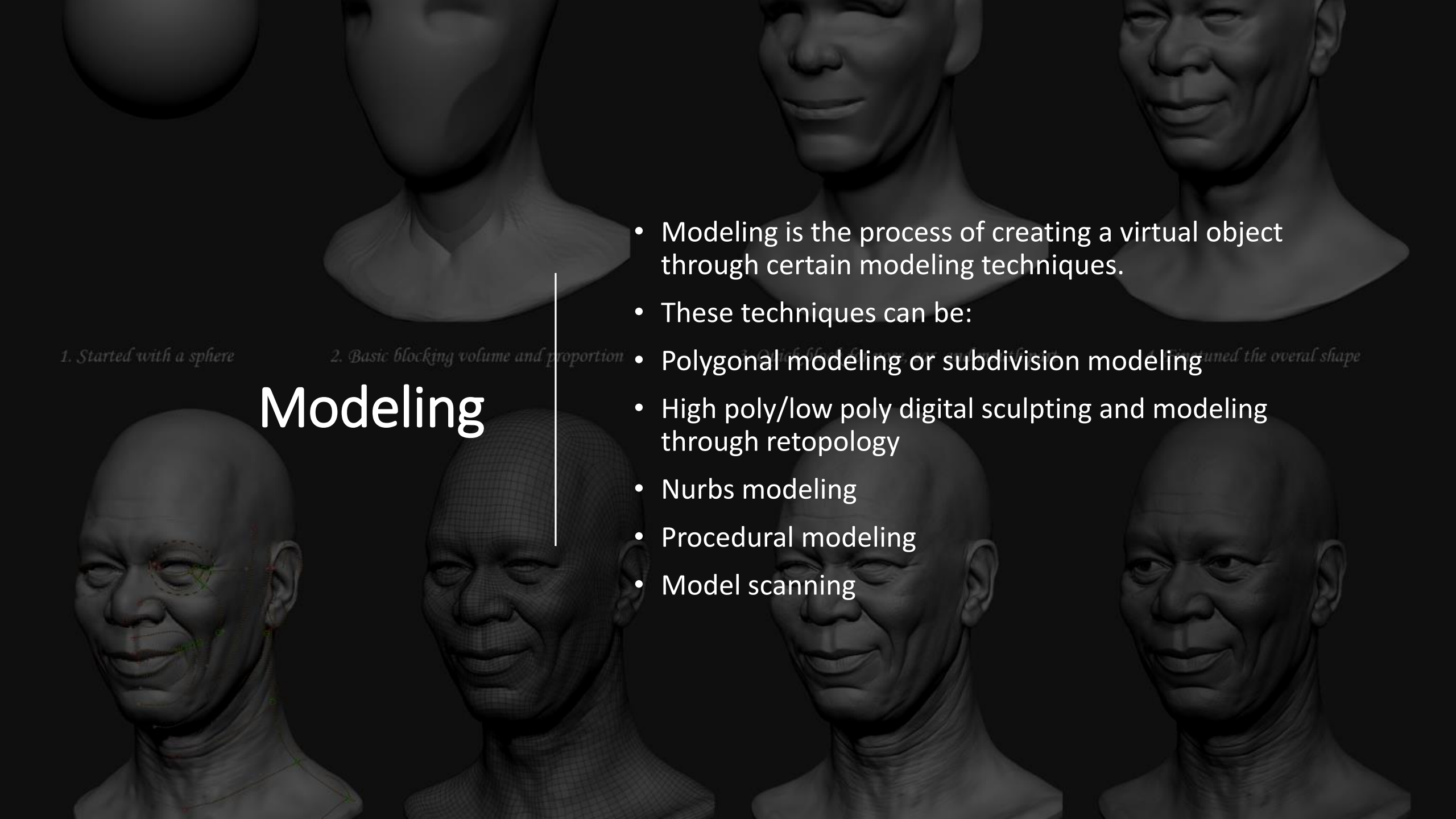
Rendering

The term rendering refers to the process by which all these calculations are performed to determine the final pixel that you see as a result of all these operations.

In the animation on the right, you can see a rough representation of how elements are assembled in a shader to obtain the final image.

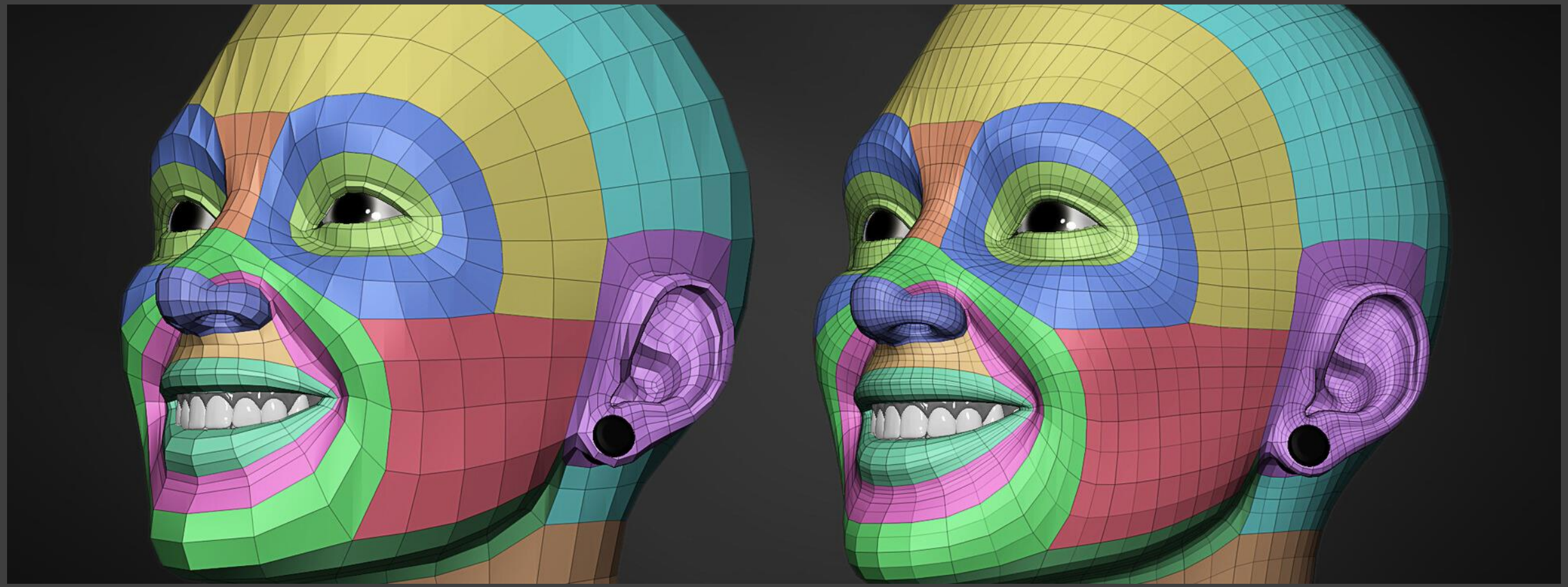
Of course, the process is much more complex and intricate in reality, but this way, you can see a rough insight into what is needed to display a 3D space.





Modeling

- Modeling is the process of creating a virtual object through certain modeling techniques.
- These techniques can be:
- Polygonal modeling or subdivision modeling
- High poly/low poly digital sculpting and modeling through retopology
- Nurbs modeling
- Procedural modeling
- Model scanning

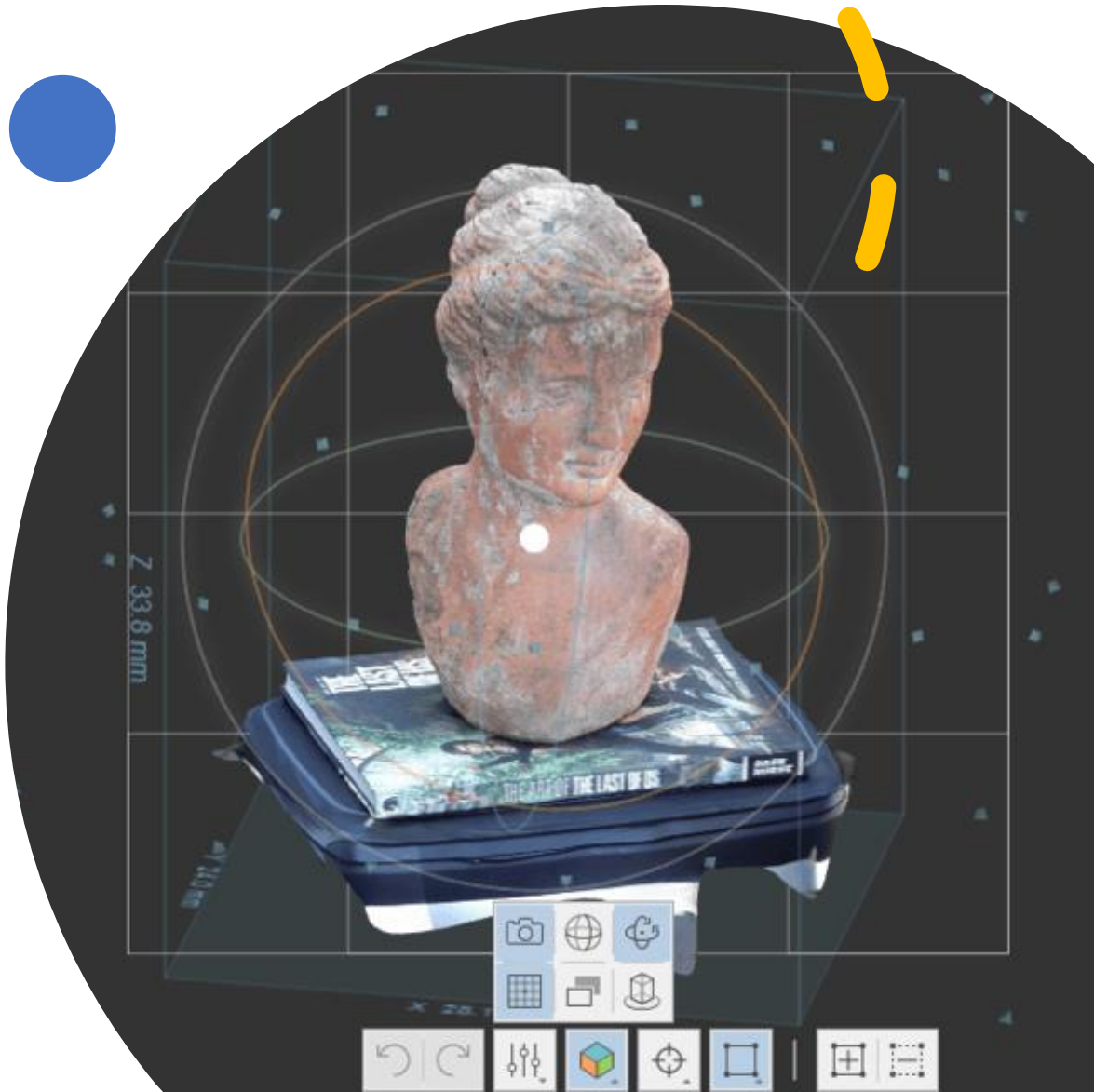


What is topology?

- Topology is a three-dimensional arrangement of polygon edges and vertices.
- It is a very important aspect of a 3D model because the topology determines how the model will look after applying the subdivision technique.
- Also, animation requires a certain topology for the correct deformation of the model after the rigging process.
- Essentially, the same model can be represented through an infinite number of topology variations, all that is needed is for the vertices to describe the surface of the model.
- The way these vertices are arranged is called topology.

Scanning models

- **Model scanning is a process by which an object from reality is transferred into the form of a 3D model described by polygons and triangles, and this process is called photogrammetry.**
- **The model is photographed from many different angles, after which specialized software calculates the position of each vertex by comparing each angle, and calculating the position of almost every pixel from the model into a 3D coordinate through trigonometry.**
- **This workflow is then overlapped with High poly modeling, where the scanned object is cleaned of irregularities, and then retopology is performed.**
- **One of the well-known software for scanning is Agisoft Metashape and Reality Capture.**
- **Certain companies specialize only in scanning 3D models, such as Quixel, whose models are available for free to all users of Unreal Engine software, within projects that are done in the same.**

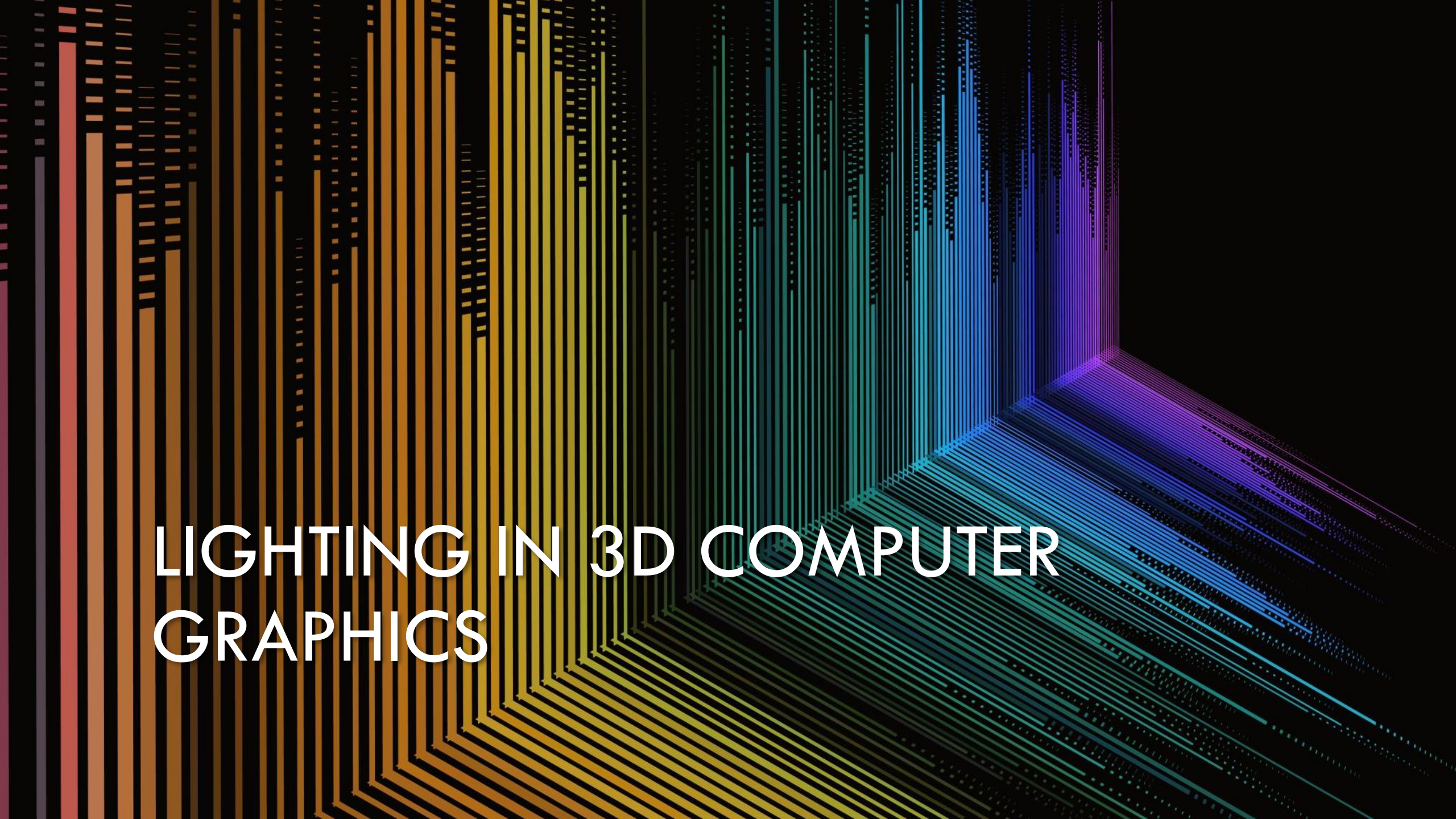


Specialized software

- There are softwares like SpeedTree that are specialized for different types of 3D models.
- For example, the recently created software Metahuman is specialized for easy and fast creation of photorealistic humans for use in Unreal Engine software.
- Another popular software is Character Creator 3, which offers you even more detailed options for creating 3D characters, both realistic and stylized.
- There are also specialized software for creating landscapes and terrains. Terragen, World Creator, World Machine, Gaea, Vue, TerreSculptor, etc.
- For fast architecture creation, ArchiCad, Sketchup, Revit, etc. are also used.
- Clothing creation is done through the simulation process of sewing in software like Marvelous Designer.
- Lately, experiments are being made with the application of Artificial Intelligence for a type of procedural modeling.
- Software for retopology that are industry standards are Wrap3, Topogun, 3D Coat. ZBrush has tools for automatic retopology.

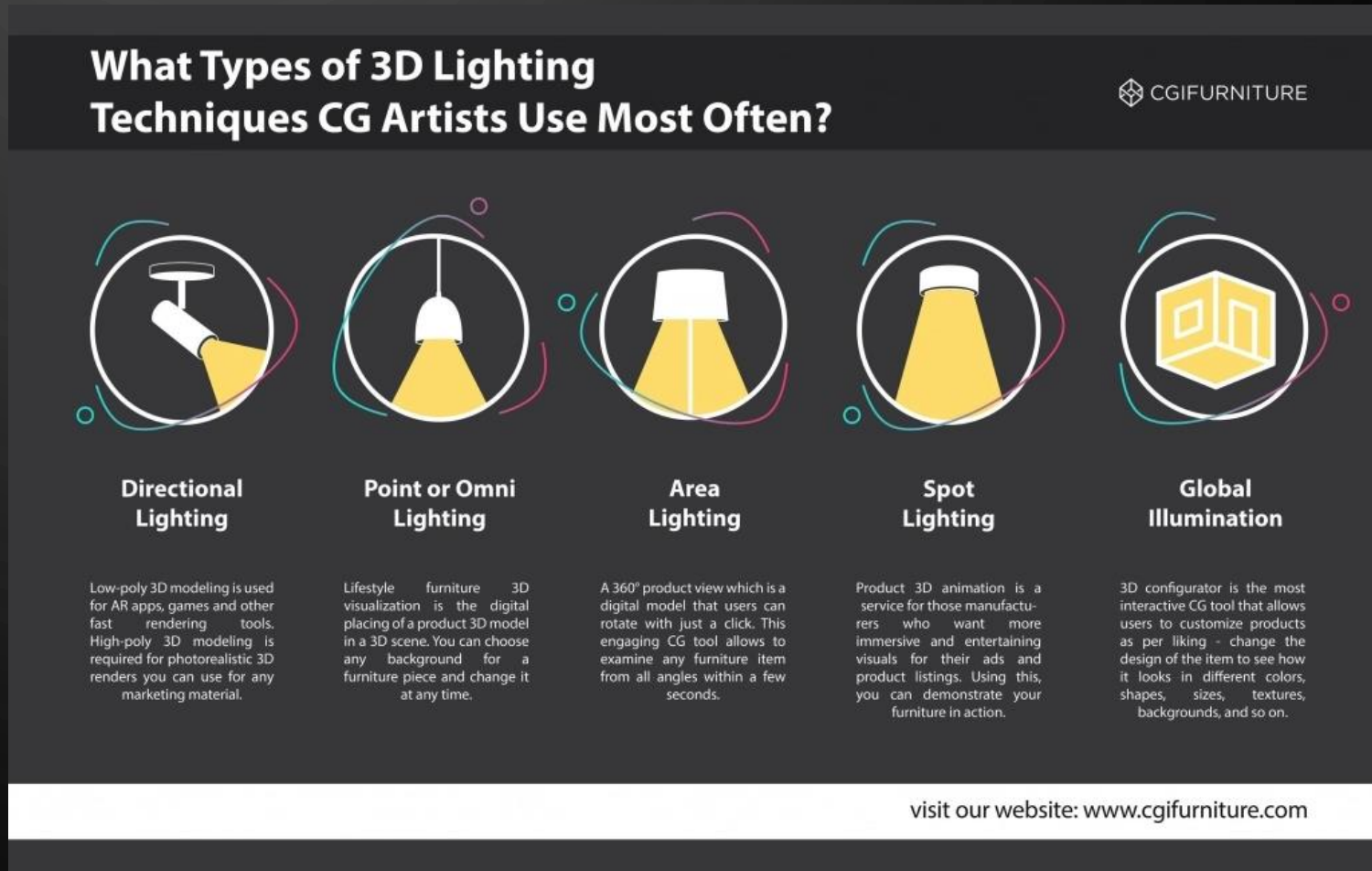
Animation and rigging

- After the modeling process is completed, before animating those models, the rigging phase must follow.
- For example, for a character in an animated movie to be able to move and deform, it is necessary to go through the rigging process, which contains several phases that we will talk about in more detail later.
  - Phase 1: Setting bones
  - Phase 2: Binding vertices of the model to these bones
  - Phase 3: Creating controls for the animator to use
  - Phase 4: Connecting controls and bones
  - Phase 5: Making face deformations and corrective deformations.
- Animation is done after rigging and has the following phases:
  - Phase 1: Recording references
  - Phase 2: Blockout
  - Phase 3: Working with curves
  - Phase 4: Refining details


LIGHTING IN 3D COMPUTER GRAPHICS

BASIC TYPES OF LIGHTS IN 3D SOFTWARES

- Point Light Sources (Point light, Omni light)
- Spot Directional Lights (Spotlight)
- Surface Light (Diffuse light, Area light, Rectangular light)
- Directional Lighting (A very distant light source, like the Sun, where the light rays are practically parallel when they reach the Earth) (Directional light)
- Ambient Light
- Sky as a Light Source (Skylight, Dome light)
- HDRI as a Light Source
- GI (Global illumination)



BASIC LIGHT SETUP