

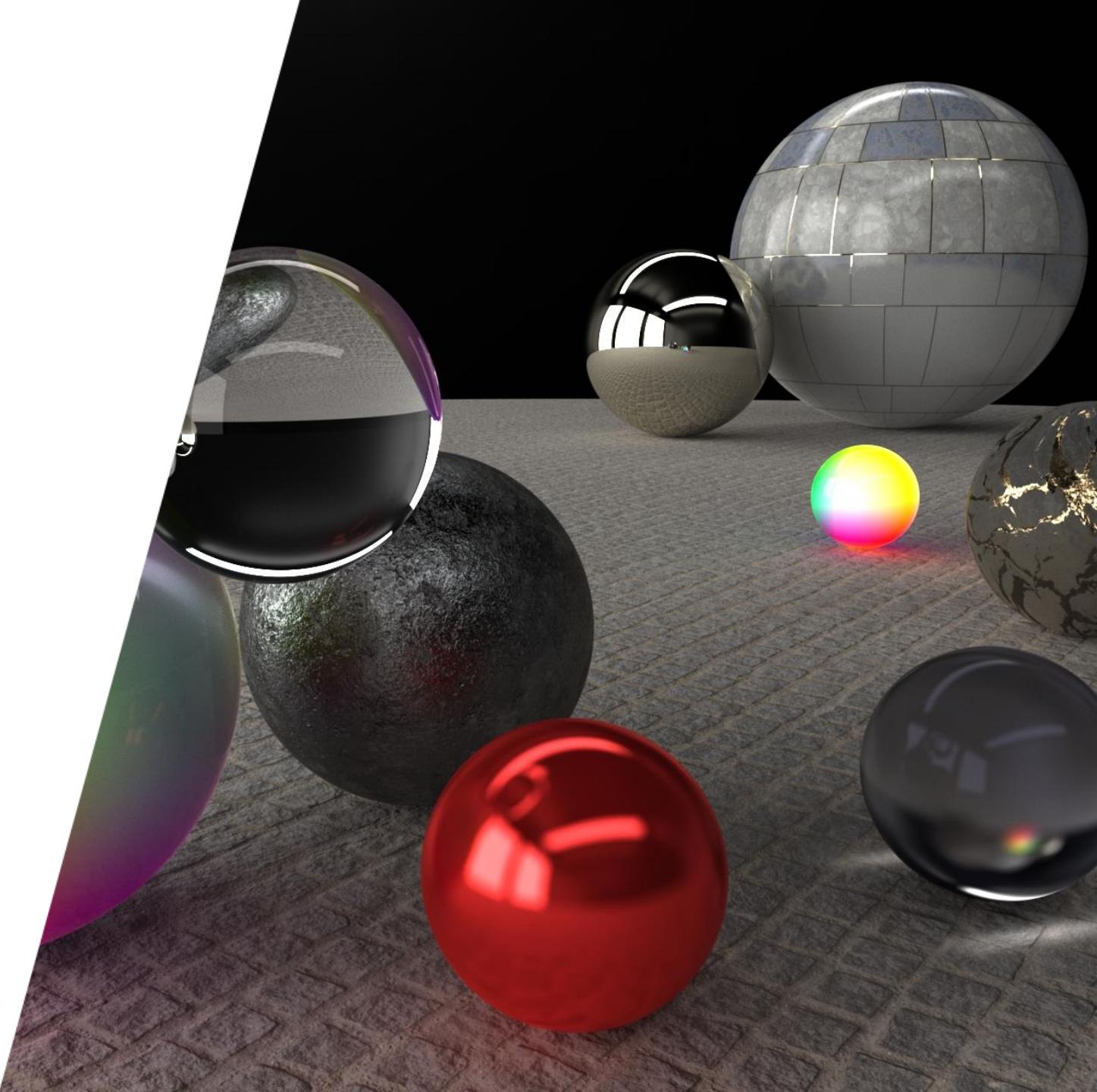
Basics Computer Graphics

Path Tracing

by Benjamin Schiller

STUDIO**42**

Beyond Machines Reasoning.



Intro

Epilogue

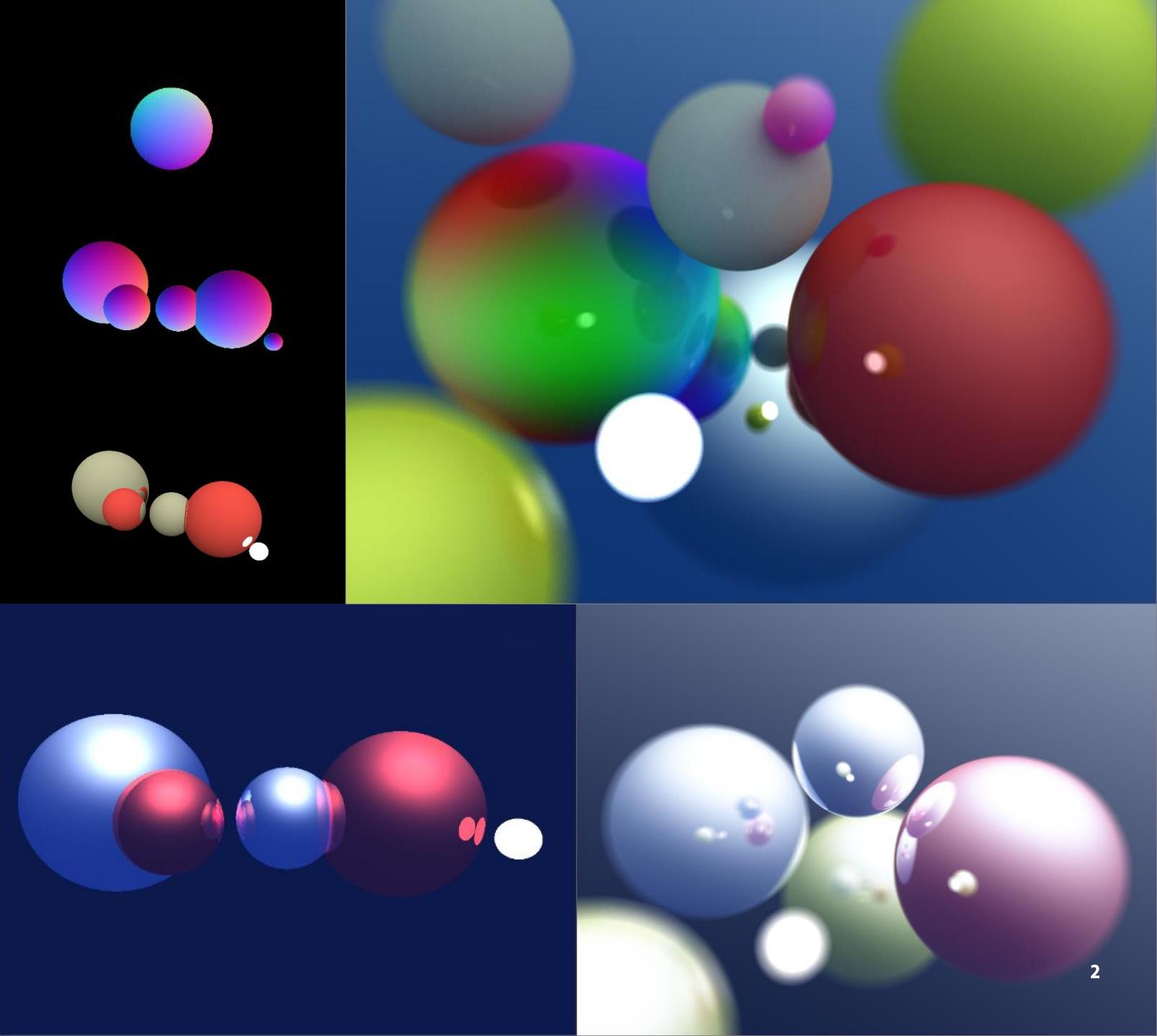
In mid of June 2020 I decided to implement an educative path tracer written 100% in Java (perhaps later with OpenCL etc.).

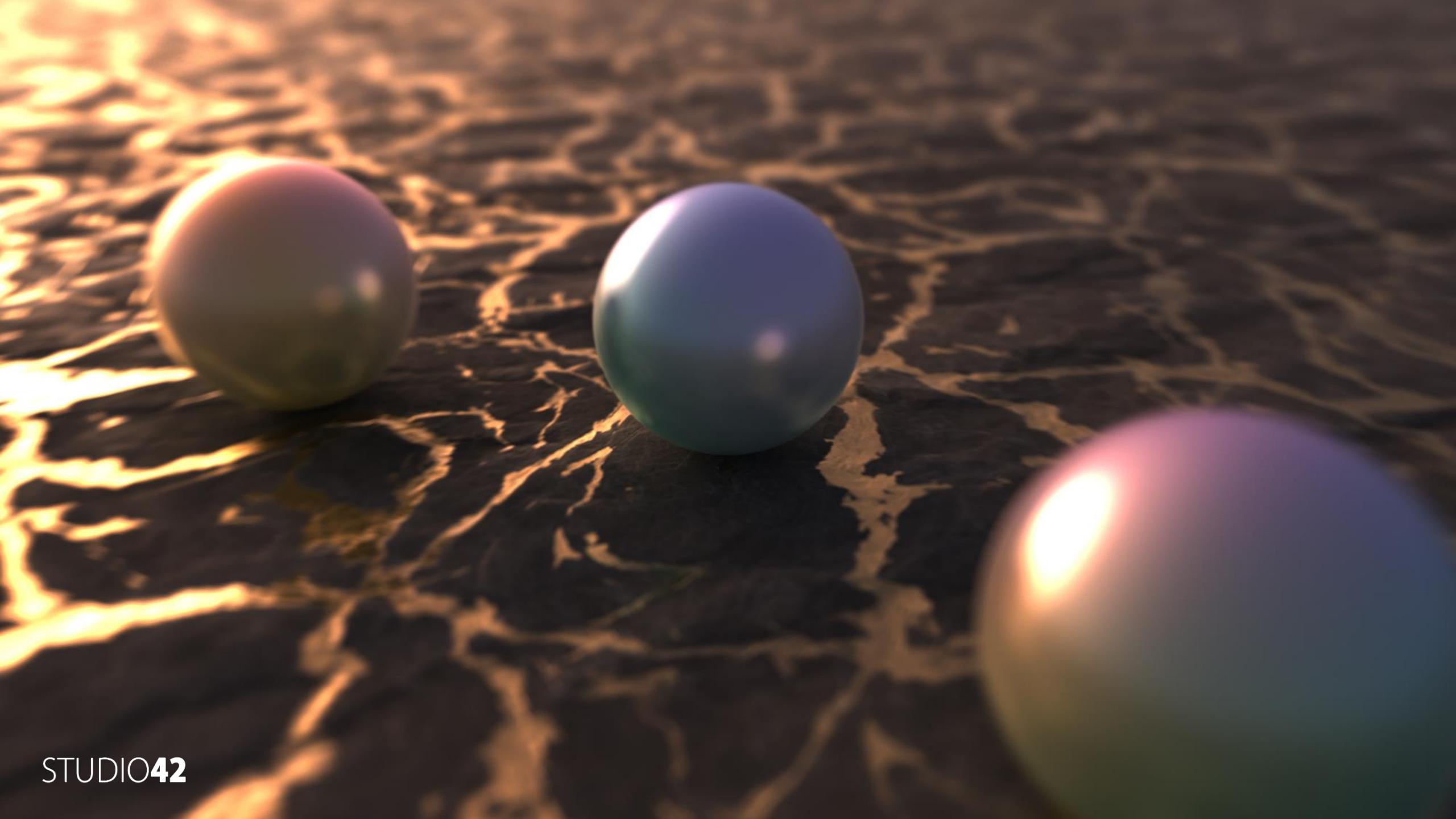
After implementing very basic features in the first days I implemented new features since then.

This workshop shall provide everyone with the possibilities to learn, understand and explore the fundamentals of path tracing and digital 3d graphics in general.

The images on the right show the first tracings on day one and day two.

On the next page you can see the result after a week ...





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Intro

Path Tracing

Path tracing is a computer graphics Monte Carlo method of rendering images of three-dimensional scenes such that the global illumination is faithful to reality. Fundamentally, the algorithm is integrating over all the illuminance arriving to a single point on the surface of an object. This illuminance is then reduced by a surface reflectance function (BRDF) to determine how much of it will go towards the viewpoint camera. This integration procedure is repeated for every pixel in the output image. When combined with physically accurate models of surfaces, accurate models of real light sources (light bulbs), and optically correct cameras, path tracing can produce still images that are indistinguishable from photographs.

https://en.wikipedia.org/wiki/Path_tracing

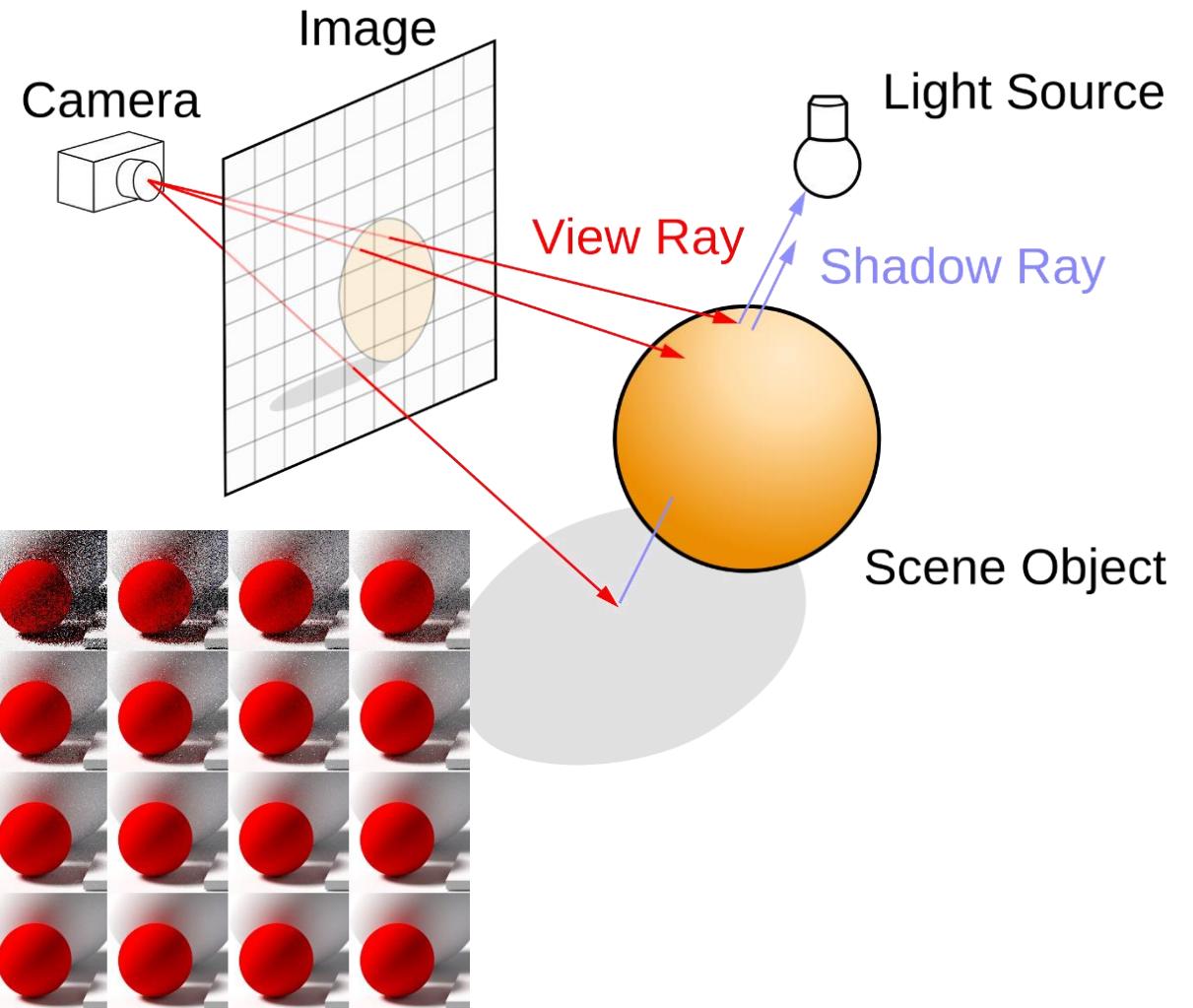
Alternative see:

[https://en.wikipedia.org/wiki/Ray_tracing_\(graphics\)](https://en.wikipedia.org/wiki/Ray_tracing_(graphics))

https://en.wikipedia.org/wiki/Photon_mapping

Global Illumination generally:

https://en.wikipedia.org/wiki/Global_illumination

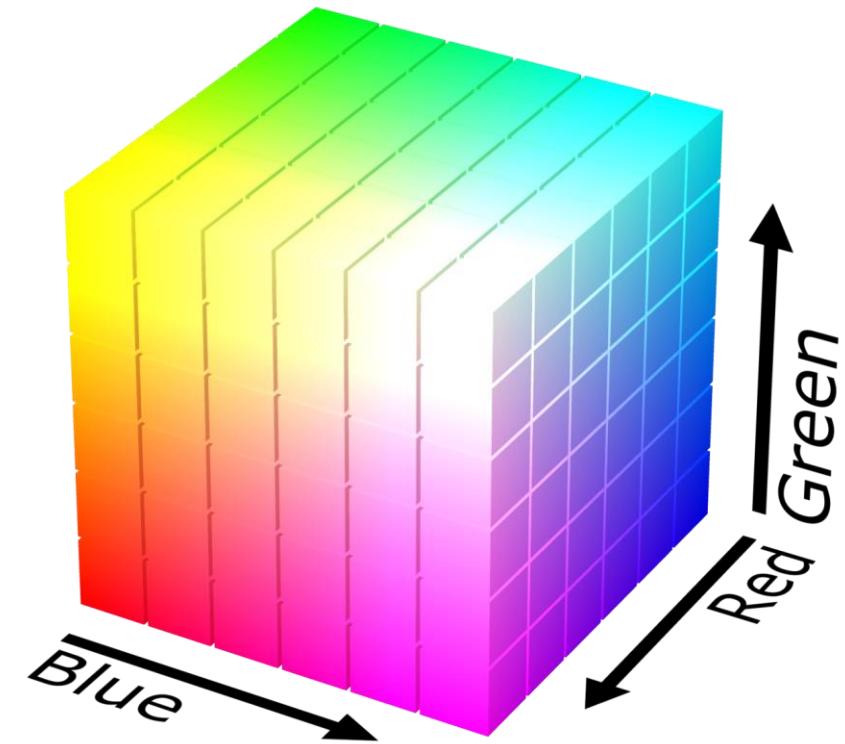


Basics

RGB Color Basics

The **RGB color** model is an additive color model in which red, green, and blue light are added together in various ways to reproduce a broad array of colors. The name of the model comes from the initials of the three additive primary colors, red, green, and blue.

https://en.wikipedia.org/wiki/RGB_color_model

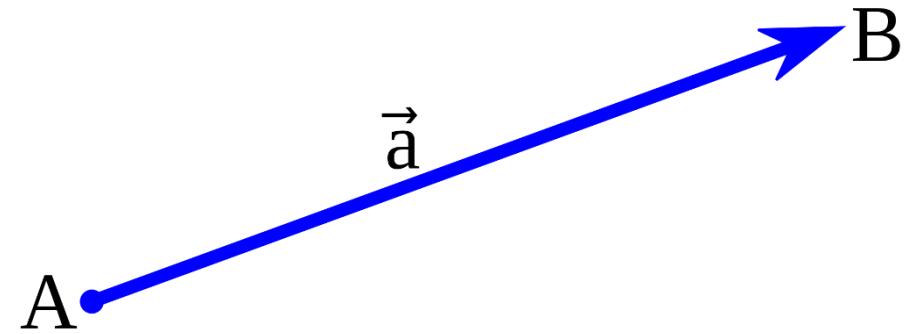


Basics

Vector Basics

In mathematics, physics, and engineering, a Euclidean **vector** (sometimes called a geometric or spatial vector, or—as here—simply a vector) is a geometric object that has magnitude (or length) and direction. Vectors can be added to other vectors according to vector algebra. A Euclidean vector is frequently represented by a line segment with a definite direction, or graphically as an arrow, connecting an initial point A with a terminal point B ...

https://en.wikipedia.org/wiki/Euclidean_vector

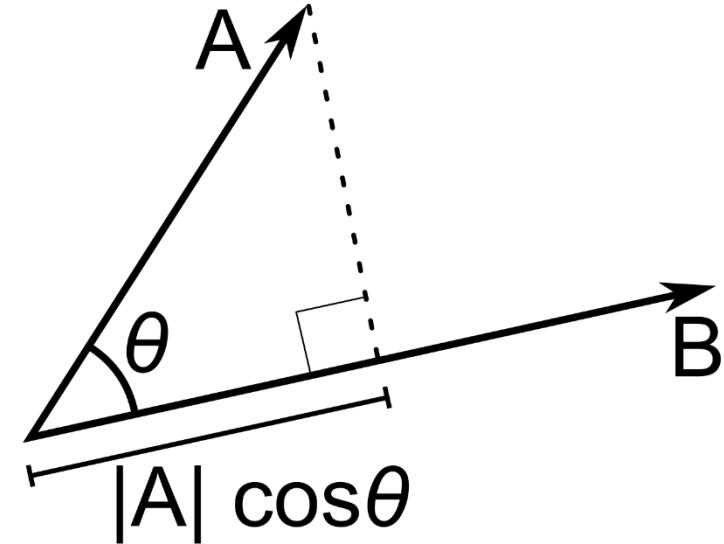


Basics

Dot Product

In mathematics, the **dot product** or scalar product is an algebraic operation that takes two equal-length sequences of numbers (usually coordinate vectors) and returns a single number. In Euclidean geometry, the dot product of the Cartesian coordinates of two vectors is widely used and often called "the" inner product (or rarely projection product) of Euclidean space even though it is not the only inner product that can be defined on Euclidean space; see also inner product space.

https://en.wikipedia.org/wiki/Dot_product

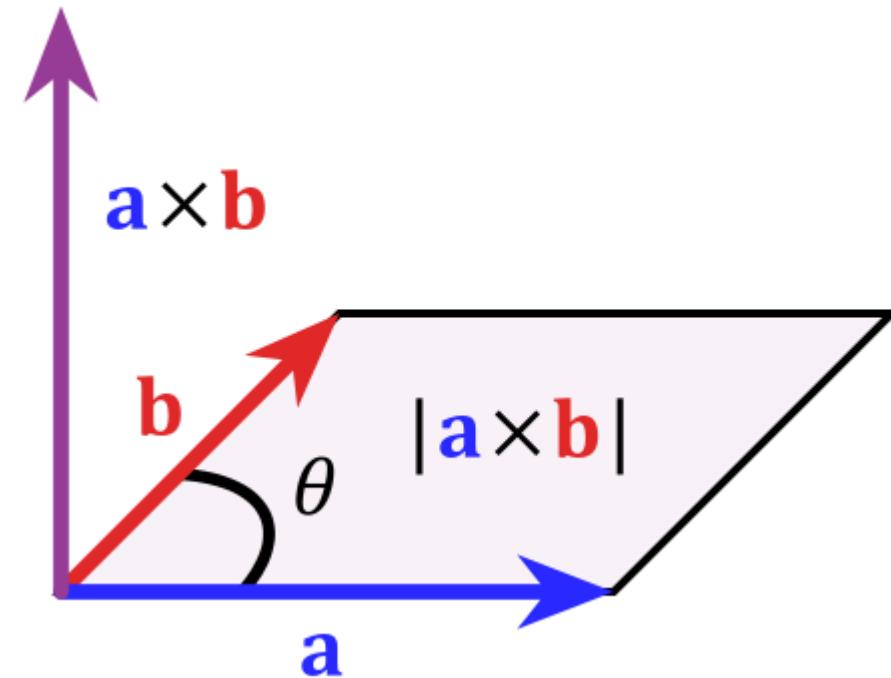


Basics

Cross Product

In mathematics, the **cross product** or vector product (occasionally directed area product to emphasize the geometric significance) is a binary operation on two vectors in three-dimensional space and is denoted by the symbol \times . Given two linearly independent vectors a and b , the cross product, $a \times b$ (read "a cross b"), is a vector that is perpendicular to both a and b and thus normal to the plane containing them. It has many applications in mathematics, physics, engineering, and computer programming. It should not be confused with the dot product (projection product).

https://en.wikipedia.org/wiki/Cross_product



Basics

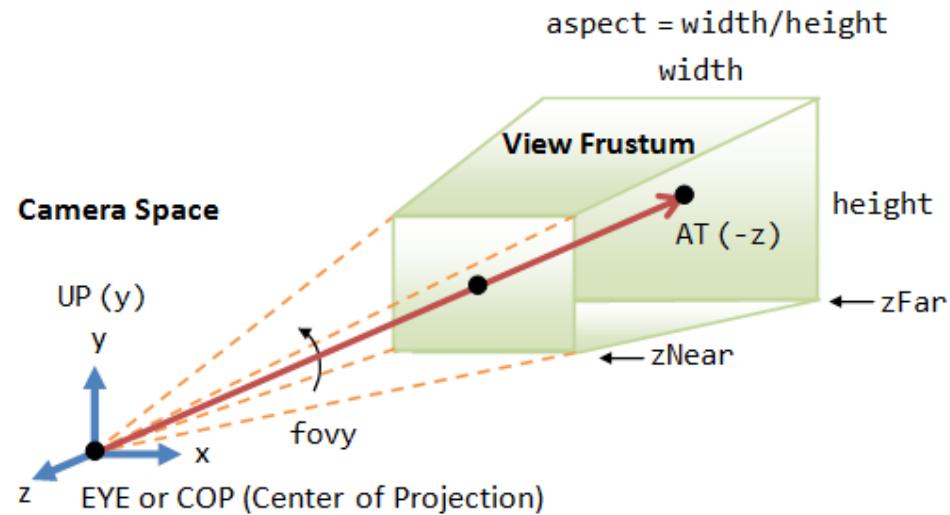
Camera

The **camera** provides the necessary transformations and settings to project the scene onto the 2 dimensional screen plane. Simple straightforward values are therefore the position, the lookat and the field of view.

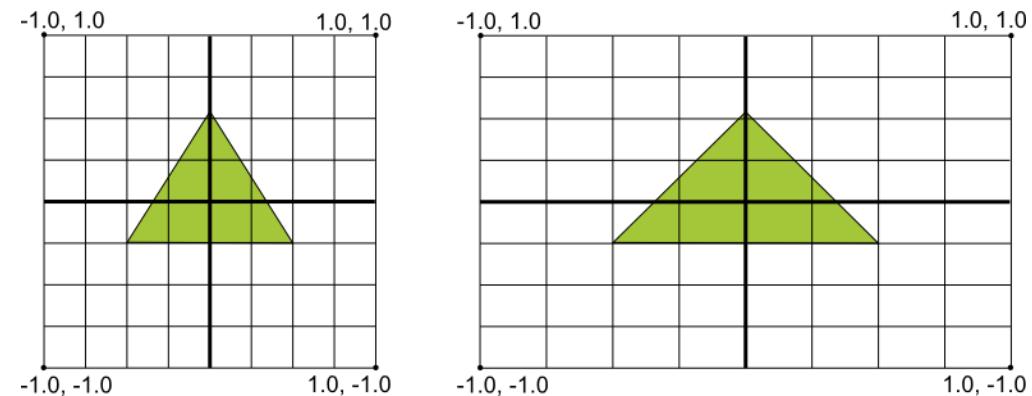
https://en.wikipedia.org/wiki/3D_projection

For further complex reading:

<https://www.sciencedirect.com/topics/engineering/perspective-camera>



Perspective Projection: The camera's view frustum is specified via 4 view parameters: fovy, aspect, zNear and zFar.



Basics

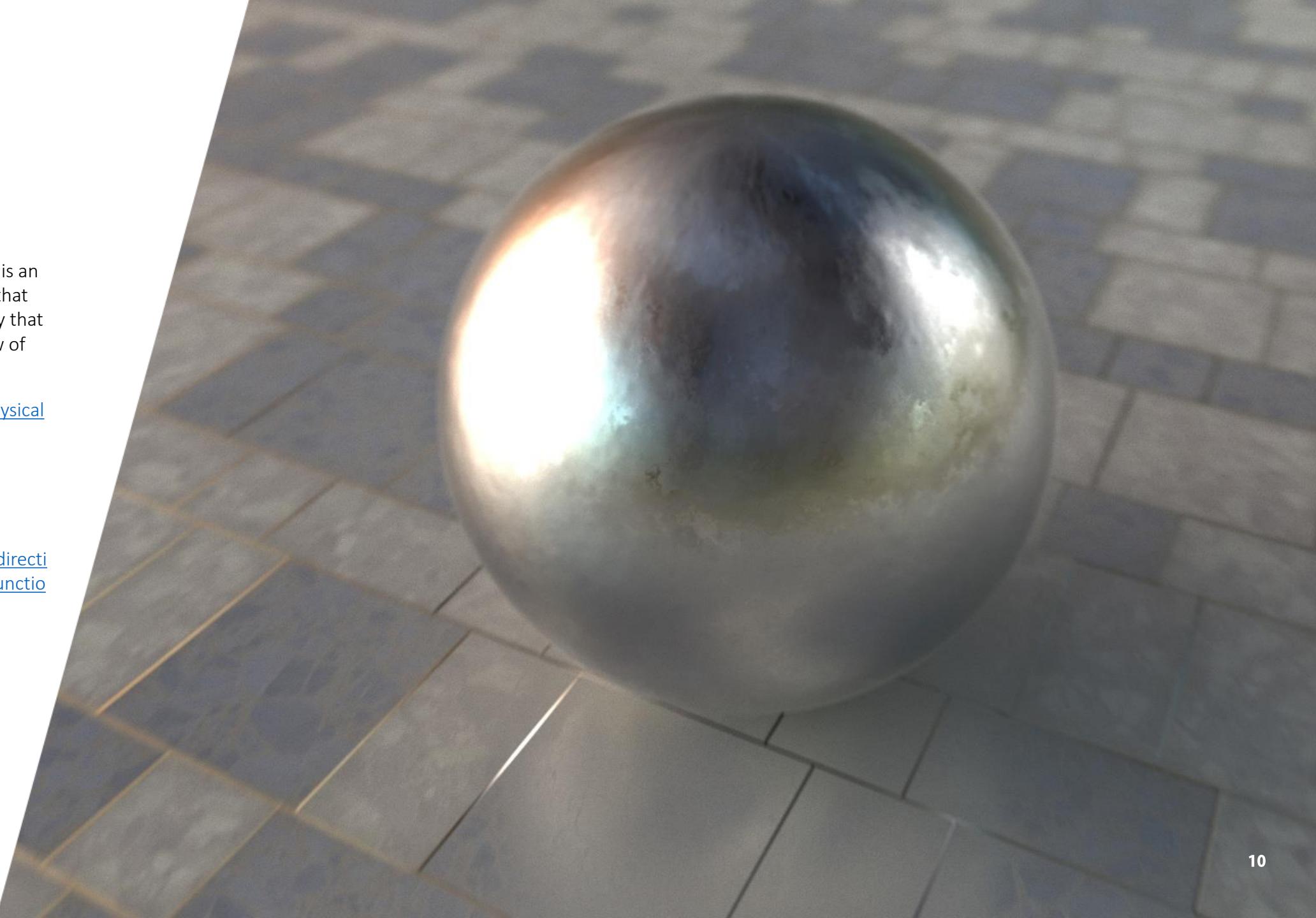
PBR

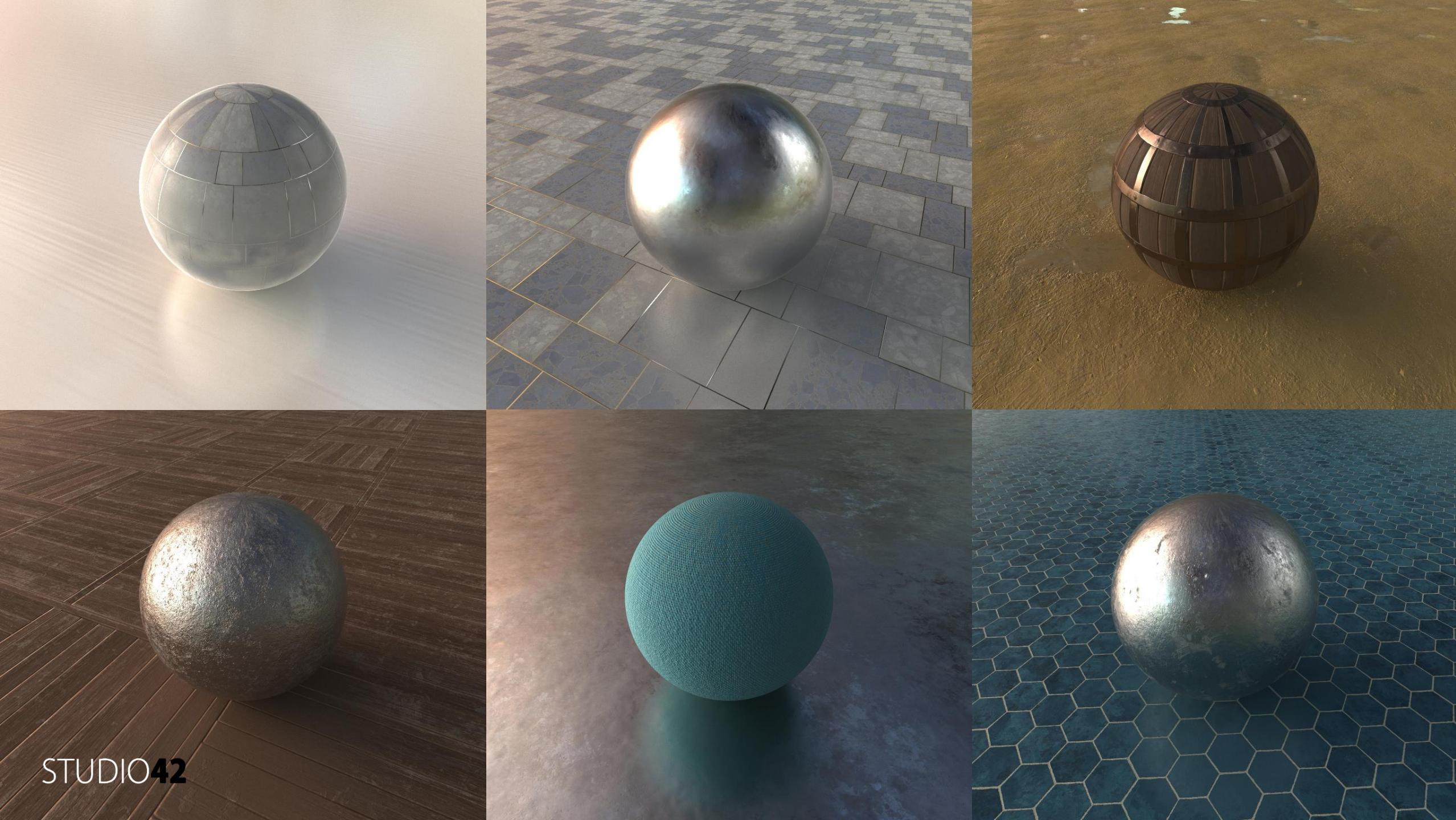
Physically based rendering (PBR) is an approach in computer graphics that seeks to render graphics in a way that more accurately models the flow of light in the real world.

https://en.wikipedia.org/wiki/Physical_based_rendering

Details about the BRDF

https://en.wikipedia.org/wiki/Bidirectional_reflectance_distribution_function





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Hands On

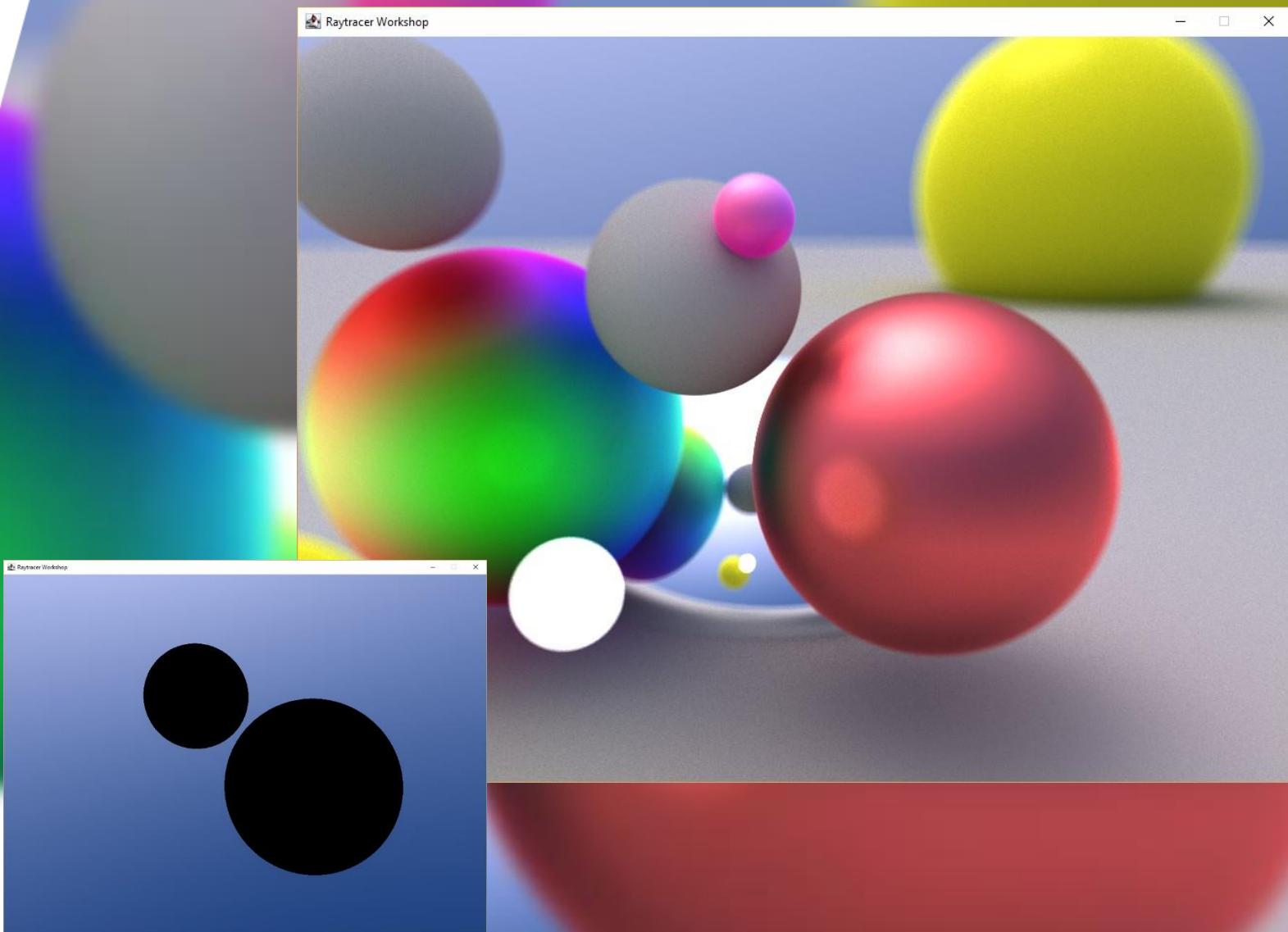
Get Coding

Lets get started with the Netbeans project.

You should be able to just open the project and run it with F6 displaying the rendering of 2 dark circles as seen on the right.

We will play with the Configuration and explore the classes in the project one by one.

In the end your rendering will look like the rendering of the spheres with different colors on the right.



A close-up photograph of a large, metallic sphere, possibly made of steel or iron, resting on a dark, textured surface. The sphere has a rough, pitted texture and is illuminated from the left, creating bright highlights and deep shadows. The background is dark and out of focus, showing some blurred shapes and colors.

Material

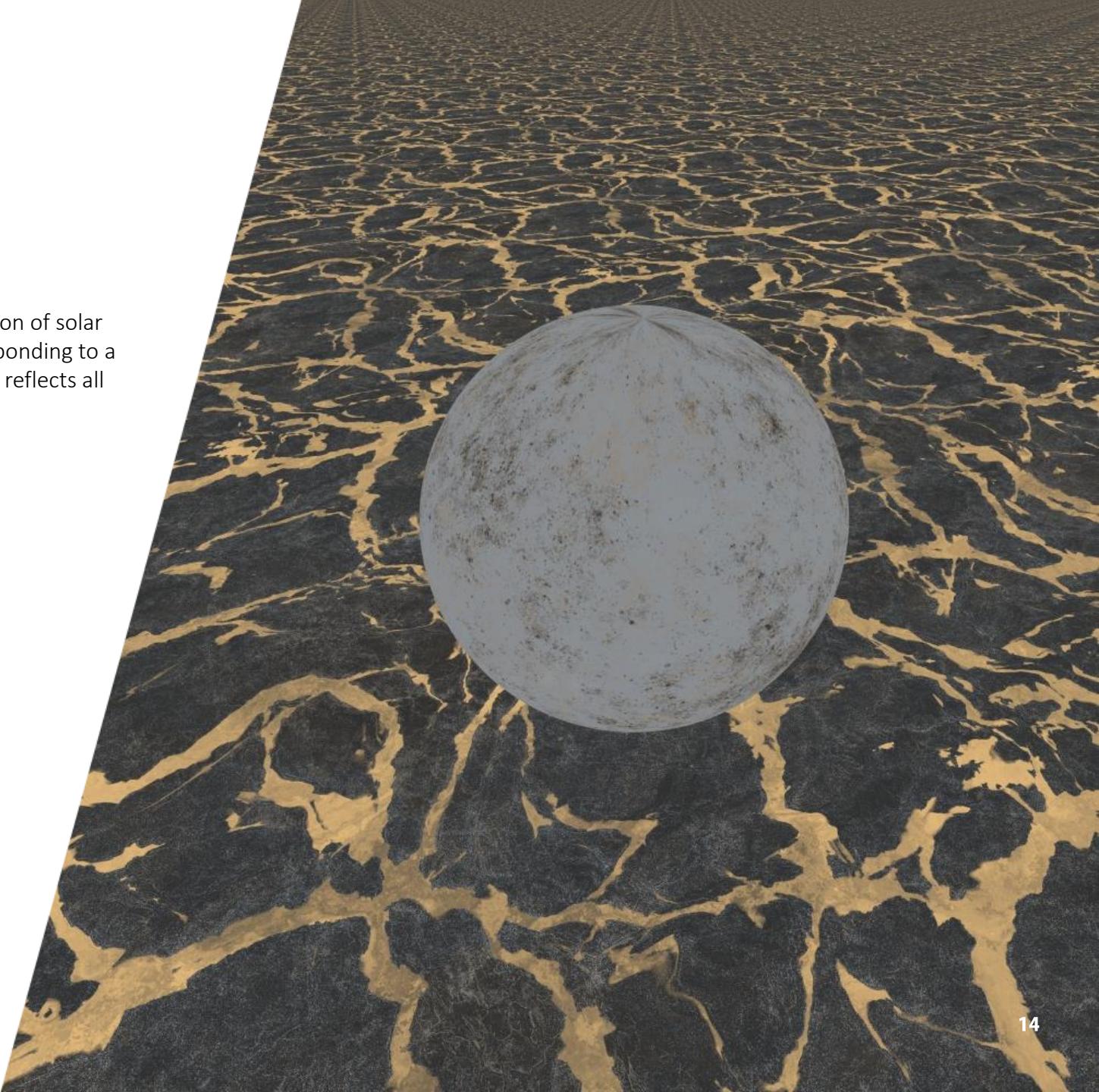
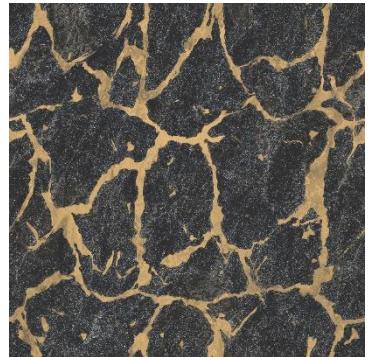
Building Blocks

Material

Albedo

Albedo (Latin: albedo, meaning 'whiteness') is the measure of the diffuse reflection of solar radiation out of the total solar radiation and measured on a scale from 0, corresponding to a black body that absorbs all incident radiation, to 1, corresponding to a body that reflects all incident radiation.

<https://en.wikipedia.org/wiki/Albedo>

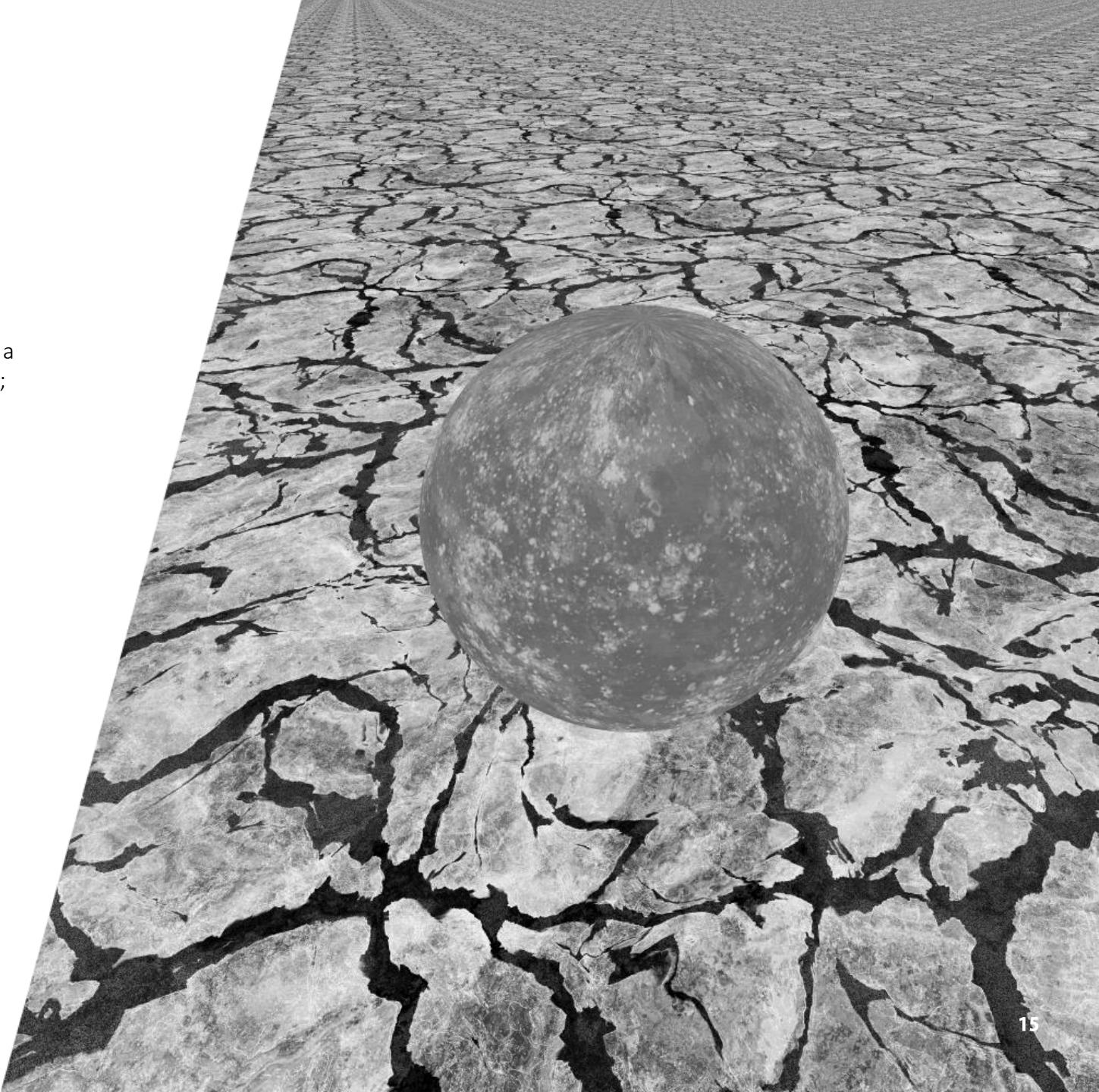
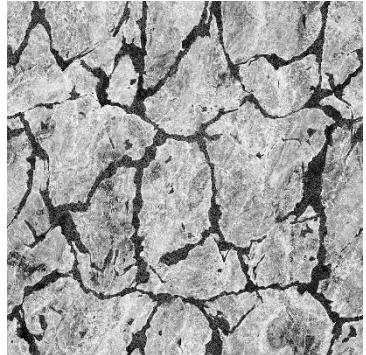


Material

Roughness

Surface roughness often shortened to **roughness**, is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. In surface metrology, roughness is typically considered to be the high-frequency, short-wavelength component of a measured surface. However, in practice it is often necessary to know both the amplitude and frequency to ensure that a surface is fit for a purpose. ...

https://en.wikipedia.org/wiki/Surface_roughness

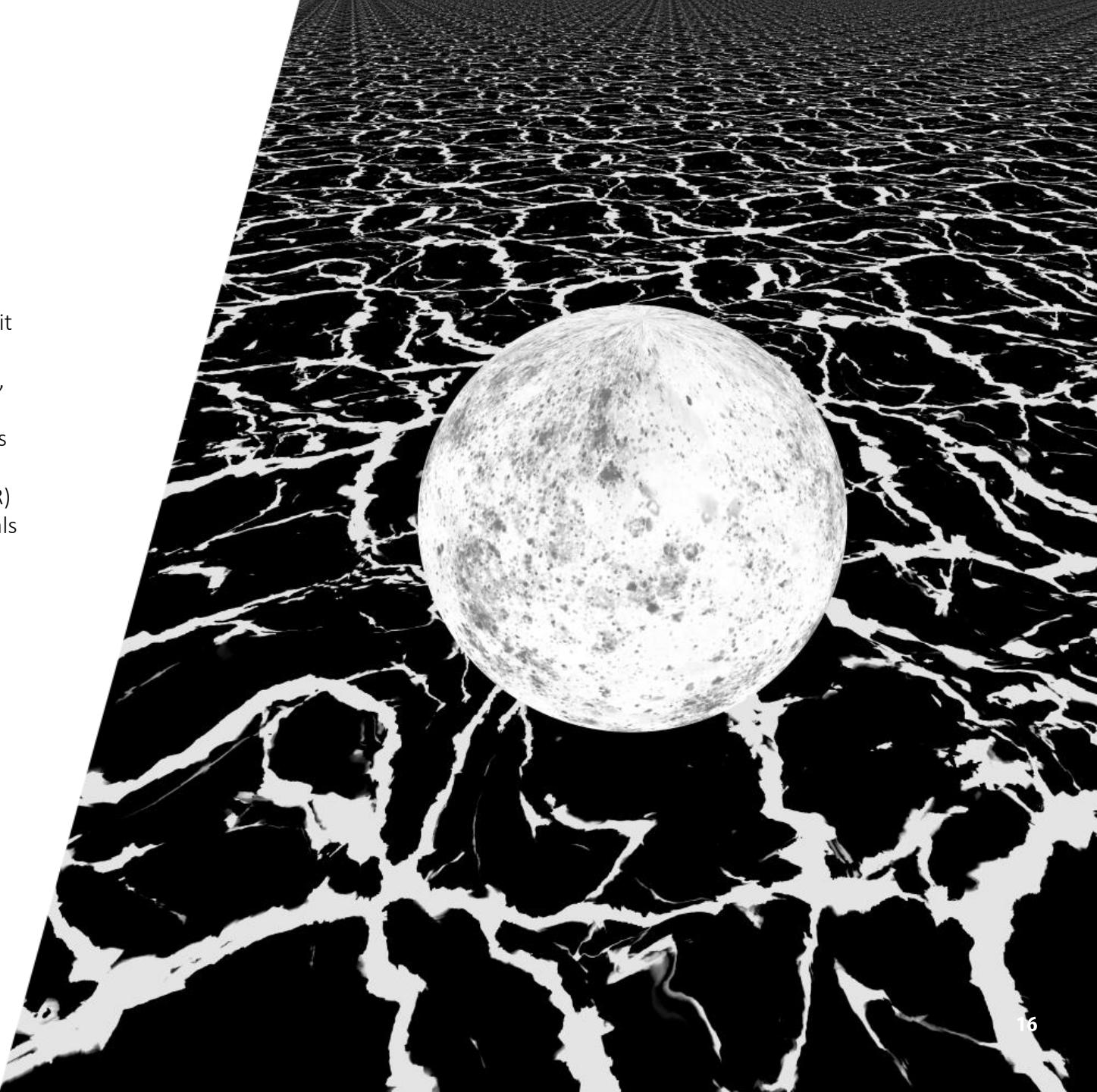
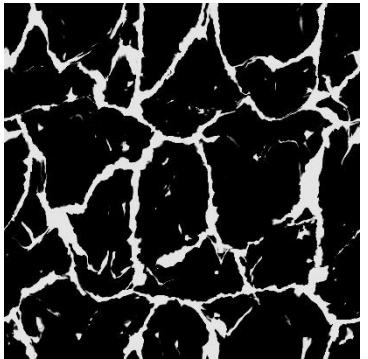


Material

Metalness

When conductive materials are added as an option in the shaders this can make it easier for people to represent metals. What can be confusing is that a material is either dielectric or conductive; there is no in-between state. The term **metalness**, and the fact that it is a variable of 0 to 1 instead of state of 0 or 1, implies that there are different levels of metalness. In the real world, there aren't. Many users of PBR believe that controlling the reflectivity of an object should all be done through metalness values between 0 and 1, and that the Index of Refraction (IOR) value is a constant for all materials; this is physically inaccurate. Different materials have different IOR values and materials are either dielectric or conductive.

<https://www.chaosgroup.com/blog/understanding-metalness>

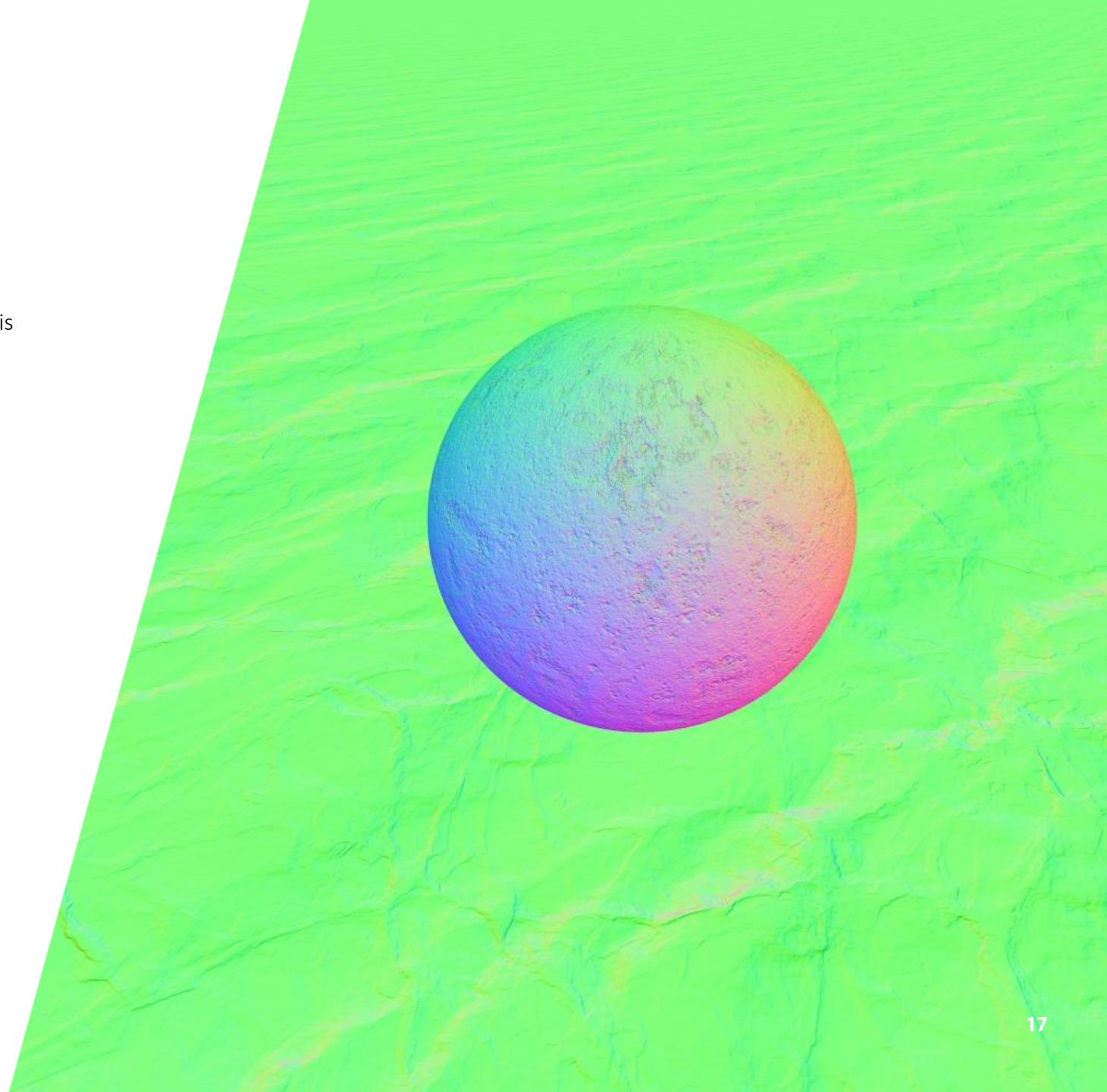
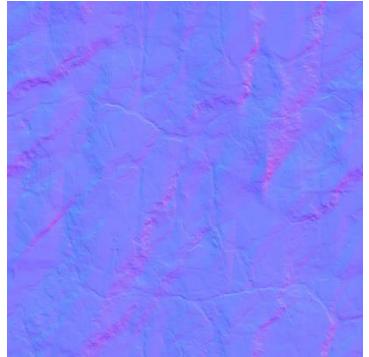


Material

Normals

In three dimensions, a surface **normal**, or simply normal, to a surface at point P is a vector perpendicular to the tangent plane of the surface at P. The word "normal" is also used as an adjective: a line normal to a plane, the normal component of a force, the normal vector, etc. The concept of normality generalizes to orthogonality (right angles).

[https://en.wikipedia.org/wiki/Normal_\(geometry\)](https://en.wikipedia.org/wiki/Normal_(geometry))

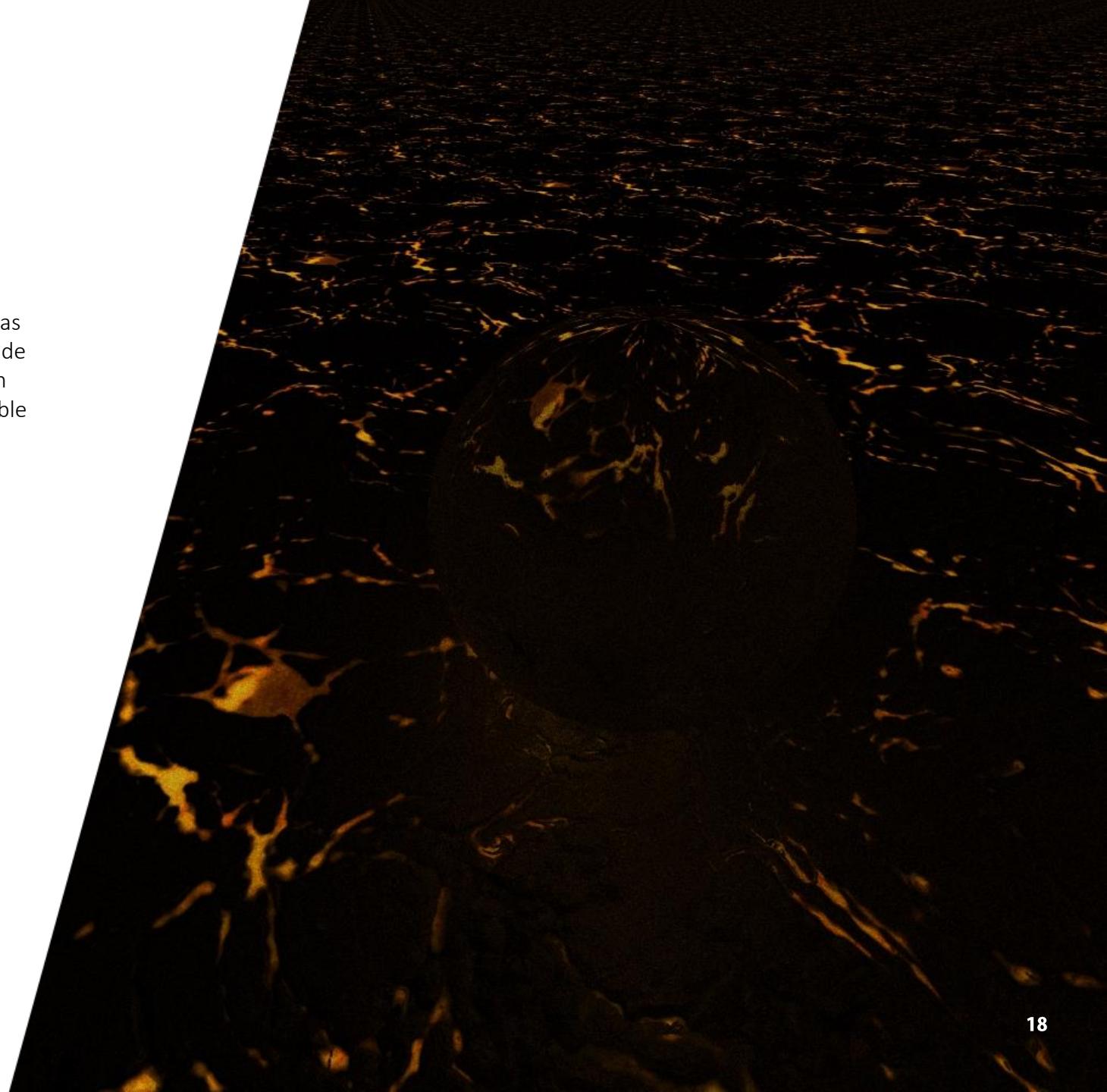
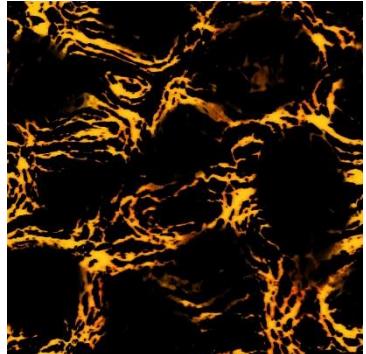


Material

Emissive

The **emissivity** of the surface of a material is its effectiveness in emitting energy as thermal radiation. Thermal radiation is electromagnetic radiation that may include both visible radiation (light) and infrared radiation, which is not visible to human eyes. The thermal radiation from very hot objects (see photograph) is easily visible to the eye. Quantitatively, emissivity is the ratio of the thermal radiation from a surface to the radiation from an ideal black surface at the same temperature as given by the Stefan–Boltzmann law.

<https://en.wikipedia.org/wiki/Emissivity>



Material

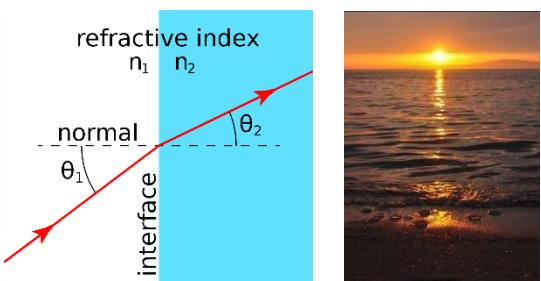
IOR and Fresnel

In optics, the refractive index (also known as refraction index or **index of refraction**) of a material is a dimensionless number that describes how fast light travels through the material. It is defined as

https://en.wikipedia.org/wiki/Refractive_index

The **Fresnel** equations (or Fresnel coefficients) describe the reflection and transmission of light (or electromagnetic radiation in general) when incident on an interface between different optical media. They were deduced by Augustin-Jean Fresnel who was the first to understand that light is a transverse wave, even though no one realized that the "vibrations" of the wave were electric and magnetic fields. For the first time, polarization could be understood quantitatively, as Fresnel's equations correctly predicted the differing behavior of waves of the s and p polarizations incident upon a material interface.

https://en.wikipedia.org/wiki/Fresnel_equations



Material

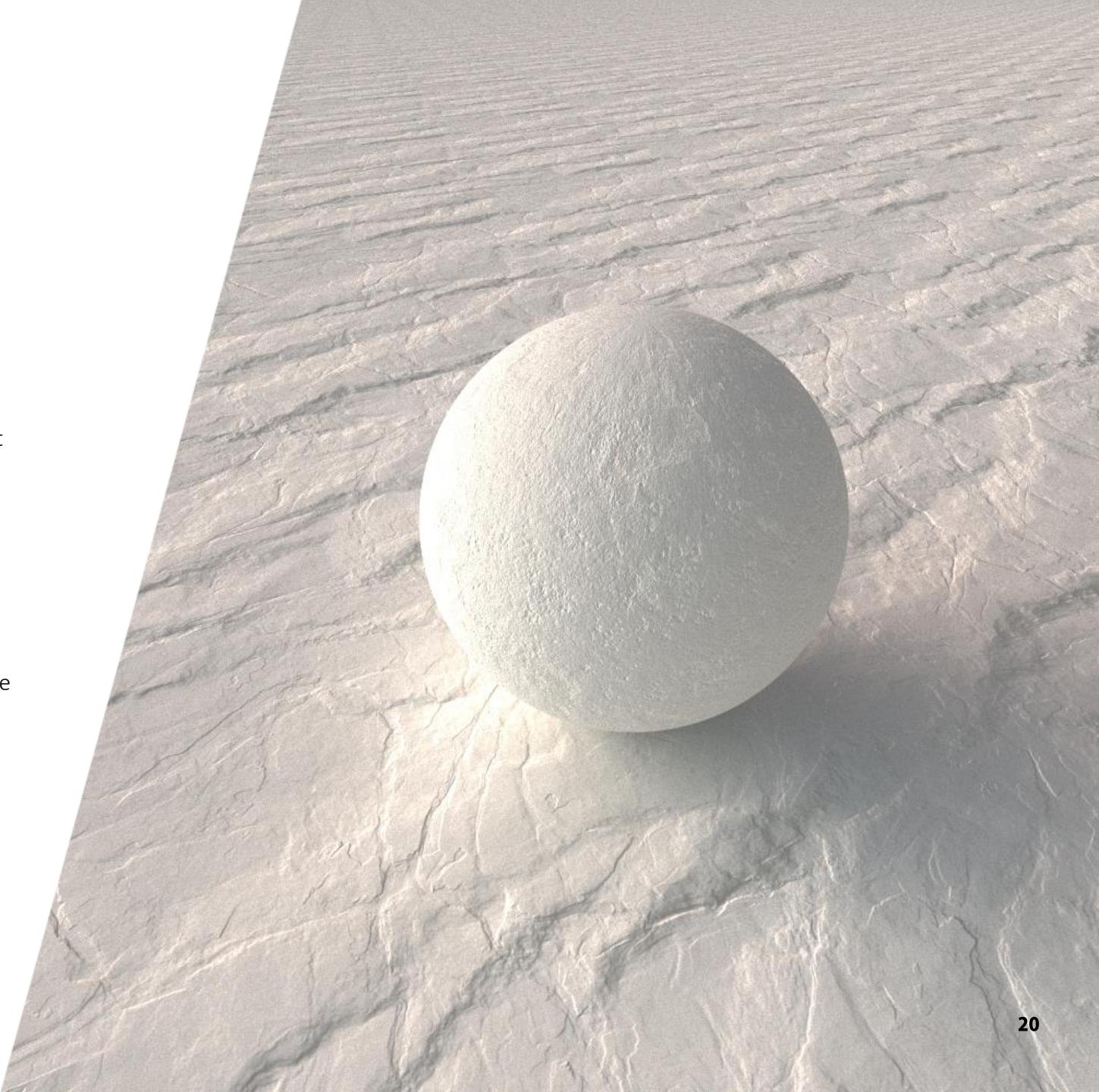
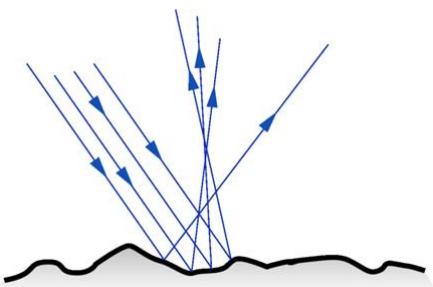
Diffuse

Diffuse reflection is the reflection of light or other waves or particles from a surface such that a ray incident on the surface is scattered at many angles rather than at just one angle as in the case of specular reflection. An ideal diffuse reflecting surface is said to exhibit Lambertian reflection, meaning that there is equal luminance when viewed from all directions lying in the half-space adjacent to the surface.

A surface built from a non-absorbing powder such as plaster, or from fibers such as paper, or from a polycrystalline material such as white marble, reflects light diffusely with great efficiency. Many common materials exhibit a mixture of specular and diffuse reflection.

The visibility of objects, excluding light-emitting ones, is primarily caused by diffuse reflection of light: it is diffusely-scattered light that forms the image of the object in the observer's eye.

https://en.wikipedia.org/wiki/Diffuse_reflection



Material

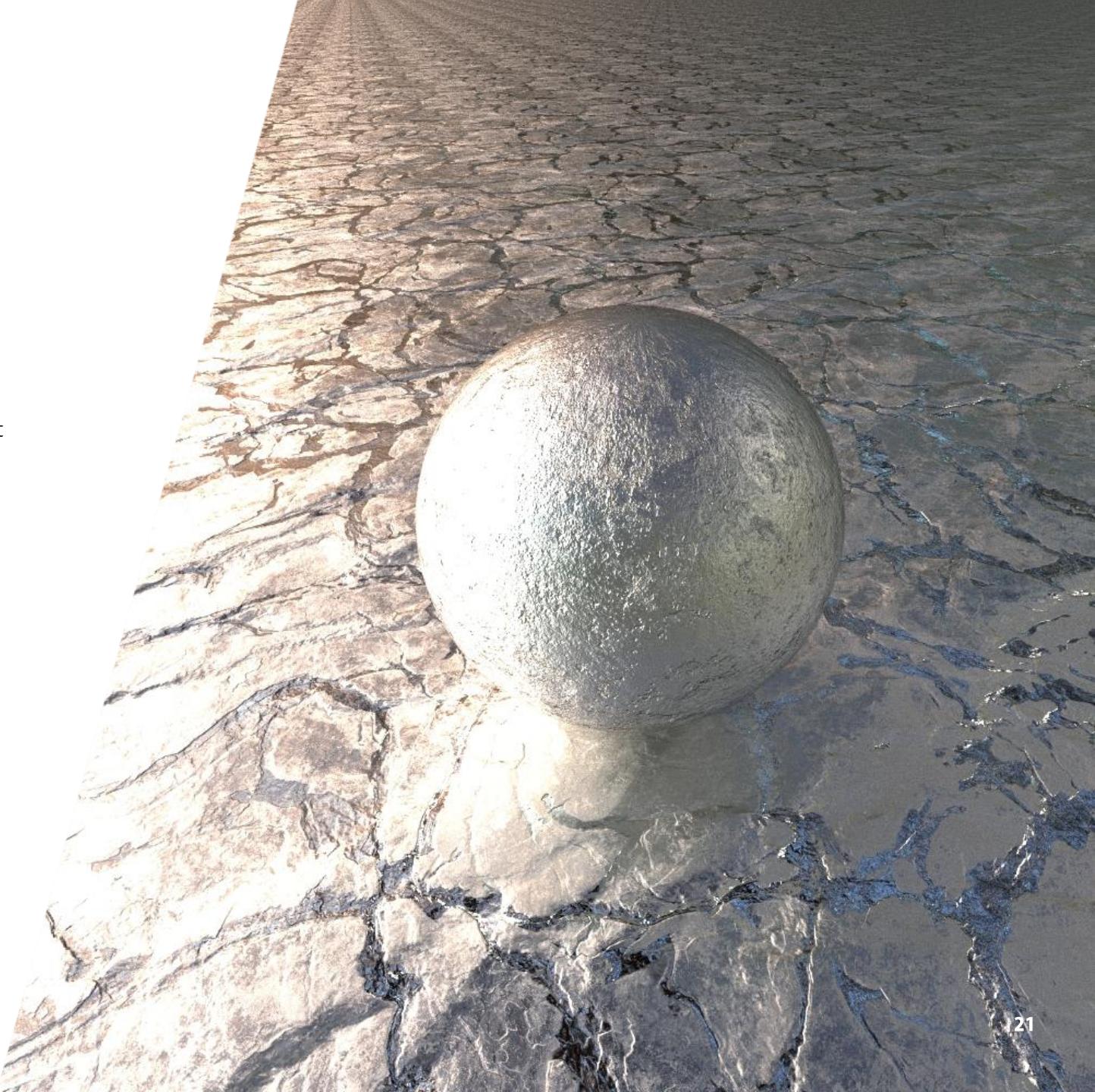
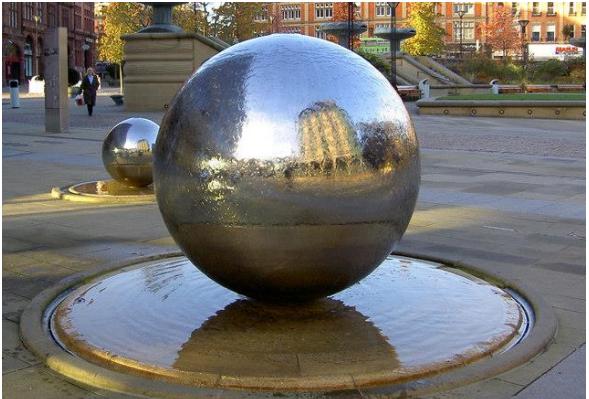
Specular

Specular reflection, or regular reflection, is the mirror-like reflection of waves, such as light, from a surface.

The law of reflection states that a reflected ray of light emerges from the reflecting surface at the same angle to the surface normal as the incident ray, but on the opposing side of the surface normal in the plane formed by the incident and reflected rays. This behavior was first described by Hero of Alexandria (AD c. 10–70).

Specular reflection may be contrasted with diffuse reflection, in which light is scattered away from the surface in a range of directions.

https://en.wikipedia.org/wiki/Specular_reflection

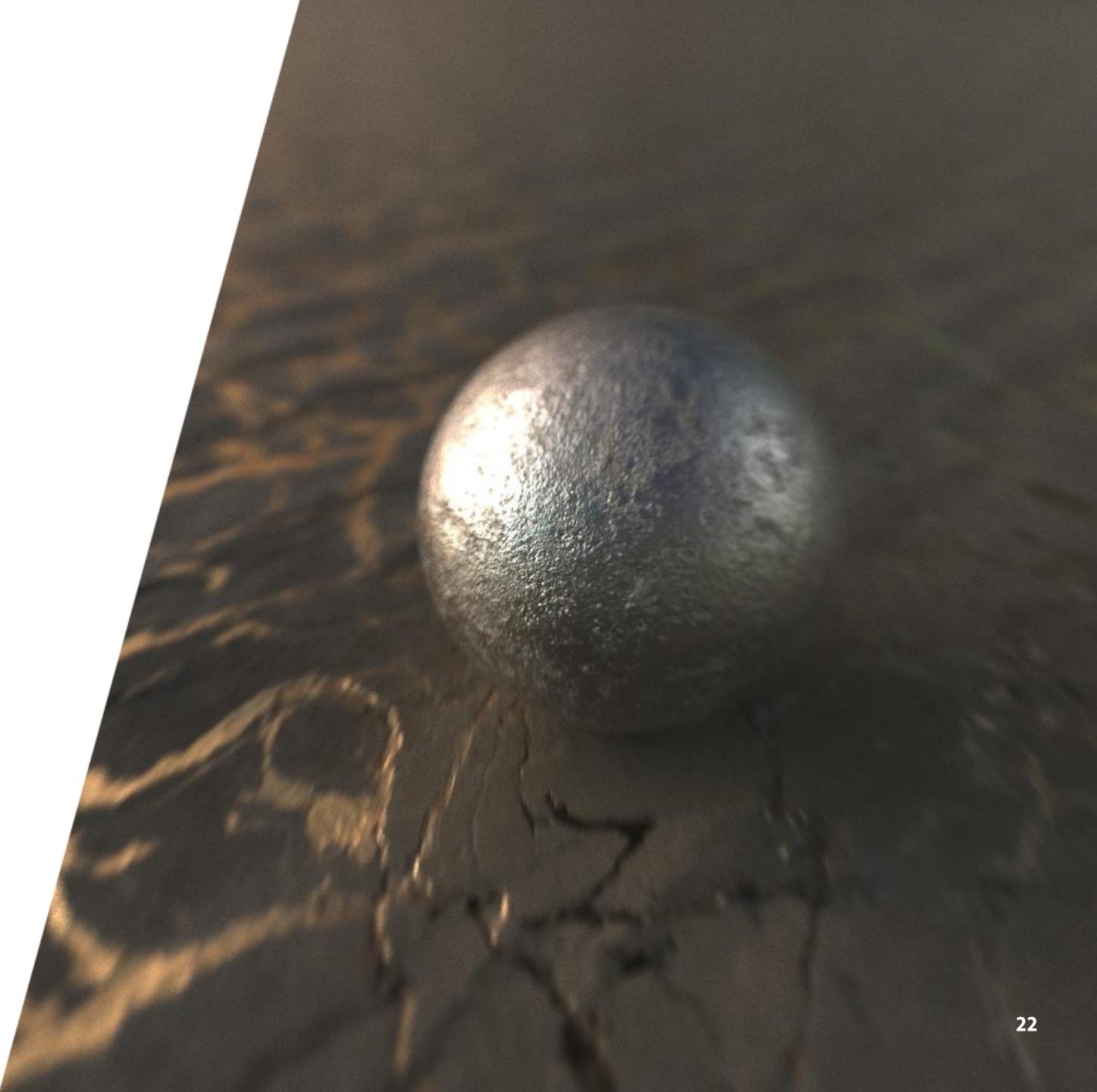


Camera Effect

DOF

For many cameras, depth of field (**DOF**) is the distance between the nearest and the farthest objects that are in acceptably sharp focus in an image. The depth of field can be calculated based on focal length, distance to subject, the acceptable circle of confusion size, and aperture. A particular depth of field may be chosen for technical or artistic purposes. Limitations of depth of field can sometimes be overcome with various techniques/equipment.

https://en.wikipedia.org/wiki/Depth_of_field



Path Tracing

Outlook

There is a lot more of features and methods to explore!

Images like the one on the right are using a plethora of advanced techniques to produce that amazing digital fidelity.

Here are just some images for inspiration:

<https://www.blenderguru.com/articles/24-photorealistic-blender-renders>



Outlook

Transparency

In the field of optics, transparency (also called pellucidity or diaphaneity) is the physical property of allowing light to pass through the material without appreciable scattering of light. On a macroscopic scale (one where the dimensions investigated are much larger than the wavelength of the photons in question), the photons can be said to follow Snell's Law.

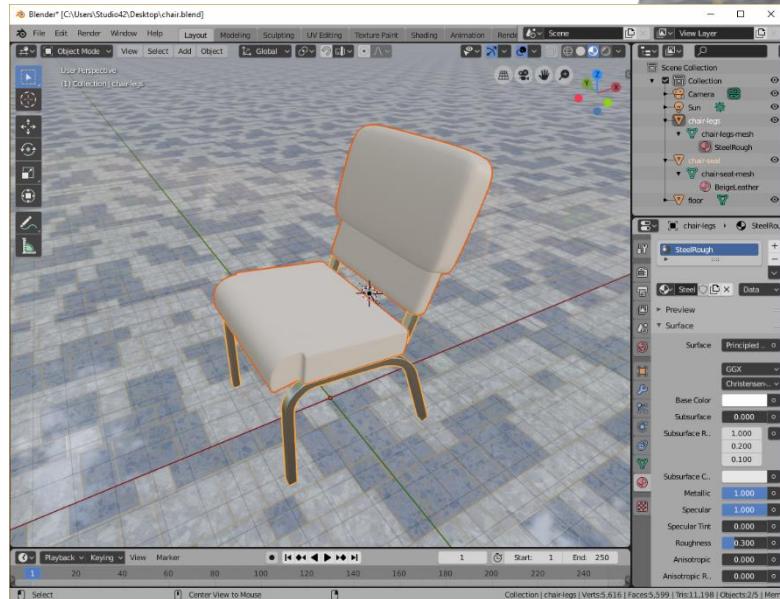
https://en.wikipedia.org/wiki/Transparency_and_translucency



Outlook

Models

Add the possibility to load 3d models from 3d authoring tools like Blender etc.



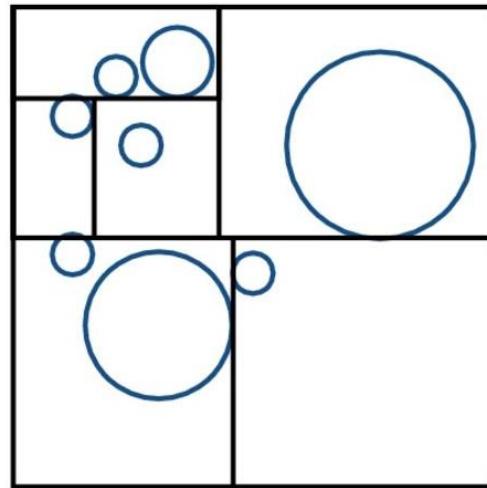
Outlook

Spatial Partitioning

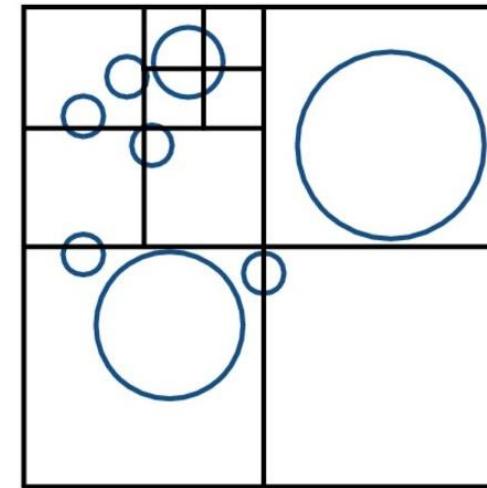
In geometry, **space partitioning** is the process of dividing a space (usually a Euclidean space) into two or more disjoint subsets (see also partition of a set). In other words, space partitioning divides a space into non-overlapping regions. Any point in the space can then be identified to lie in exactly one of the regions.

https://en.wikipedia.org/wiki/Space_partitioning

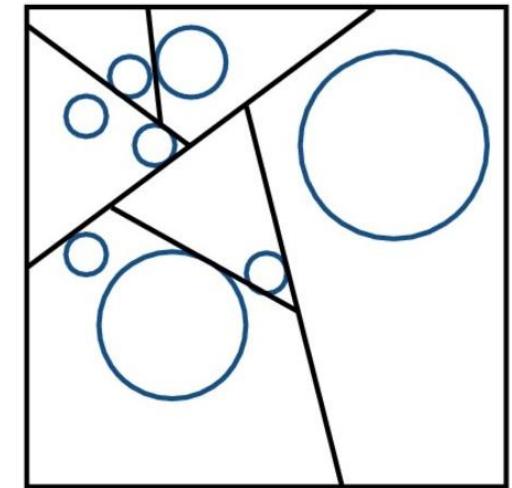
<https://cs184.eecs.berkeley.edu/sp16/lecture/acceleration>



KD-Tree



Oct-Tree



BSP-Tree

Outlook

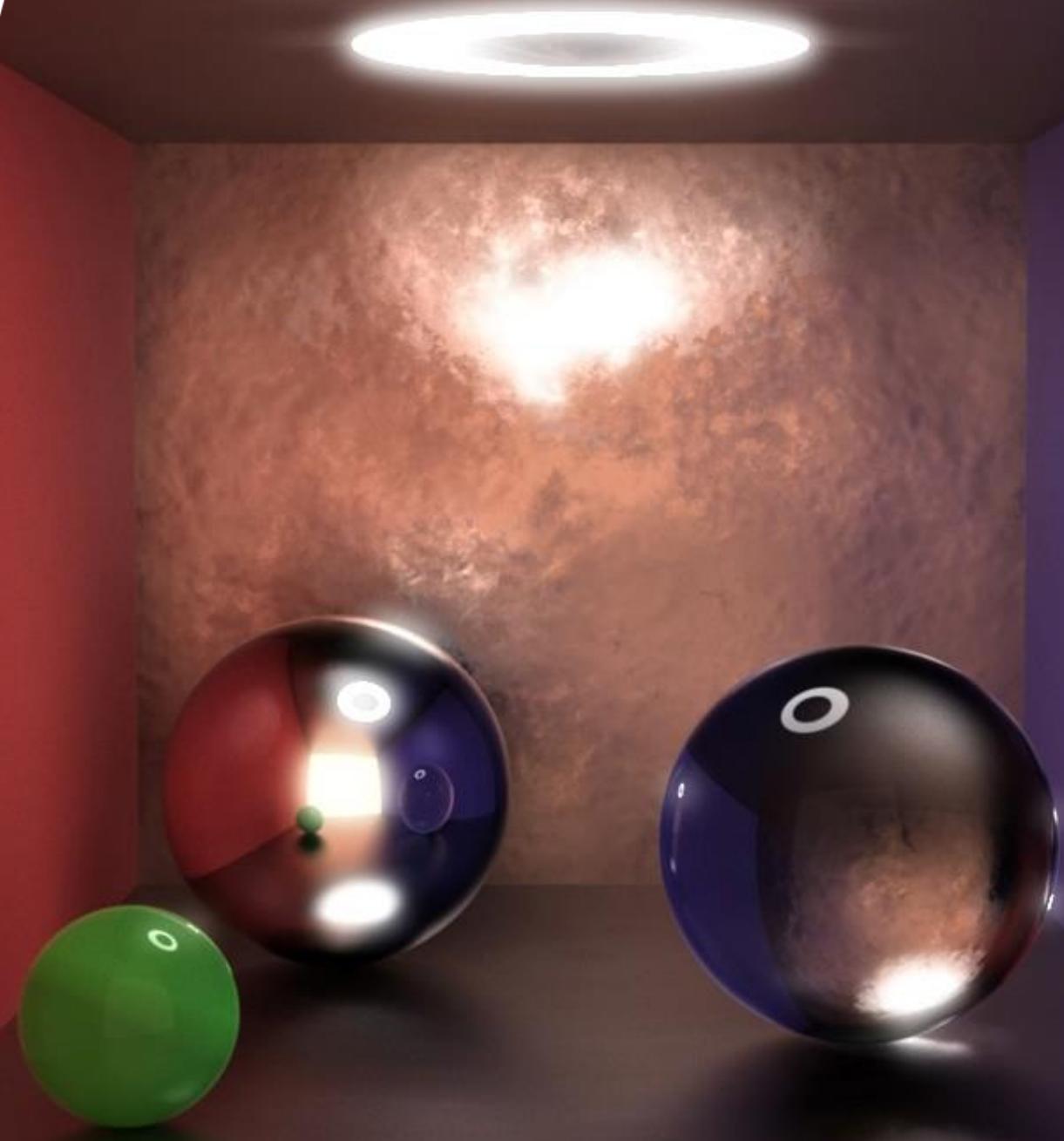
Post FX

There is a lot of methods to improve the image quality and fidelity after rendering either using **post effects** in the render stack or tools like Photoshop.

There are effects like (and many more):

- Bloom
- Lens flare
- Tone mapping
- Chromatic abberation

https://en.wikipedia.org/wiki/Video_post-processing



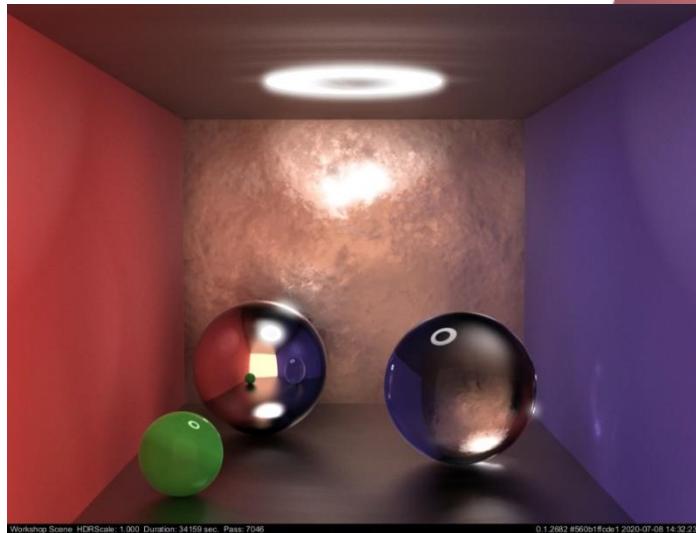
Appendix Reference

SmallIPT

smallpt is a global illumination renderer.
It is 99 lines of C++, is open source, and
renders the above scene using unbiased
Monte Carlo path tracing.

<http://www.kevinbeason.com/smallpt/>

Rendering with Jara based on the scene:



Appendix Tools

Substance Painter

All the tools you need to texture your 3D assets in one application.

Substance Painter has smart materials, smart masks and integrated bakers, and a state of the art real-time viewport.

<https://www.substance3d.com/products/substance-painter/>



Appendix Tools

Blender

Blender is the free and open source 3D creation suite. It supports the entirety of the 3D pipeline—modeling, rigging, animation, simulation, rendering, compositing and motion tracking, video editing and 2D animation pipeline.

<https://www.blender.org/>

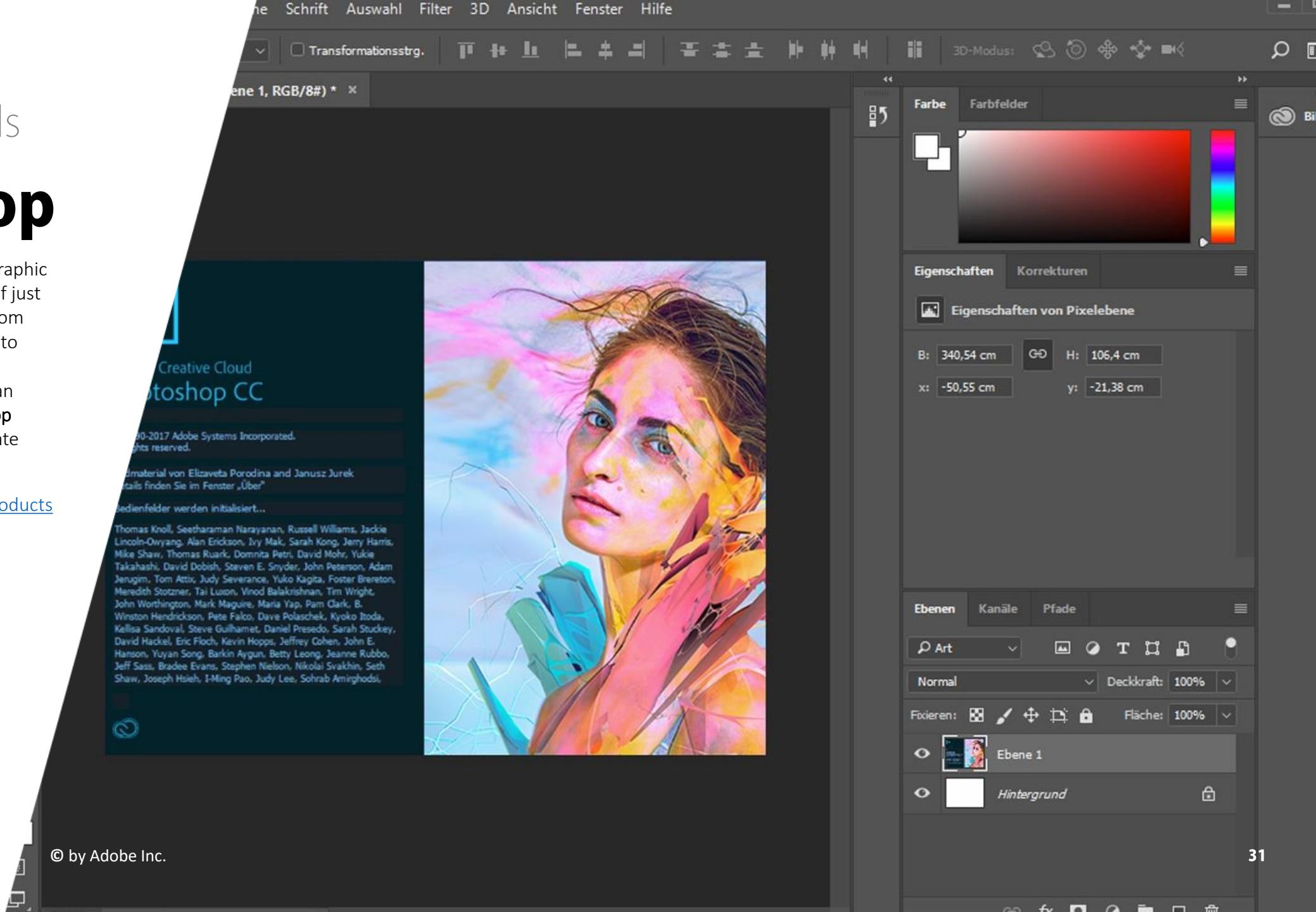


Appendix Tools

Photoshop

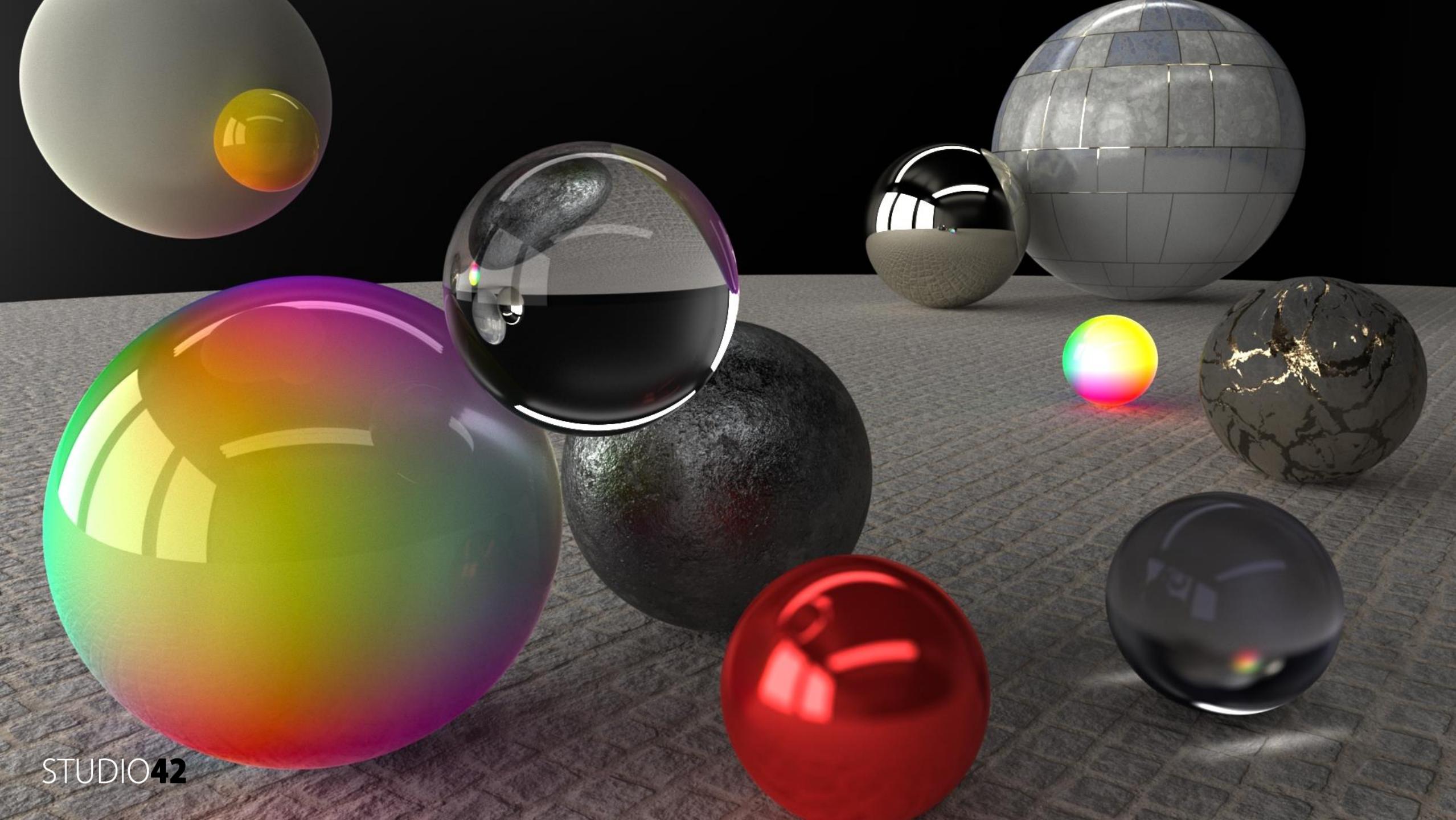
The world's best imaging and graphic design software is at the core of just about every creative project, from photo editing and compositing to digital painting, animation, and graphic design. And now you can harness the power of **Photoshop** across desktop and iPad to create wherever inspiration strikes.

<https://www.adobe.com/de/products/photoshop.html>





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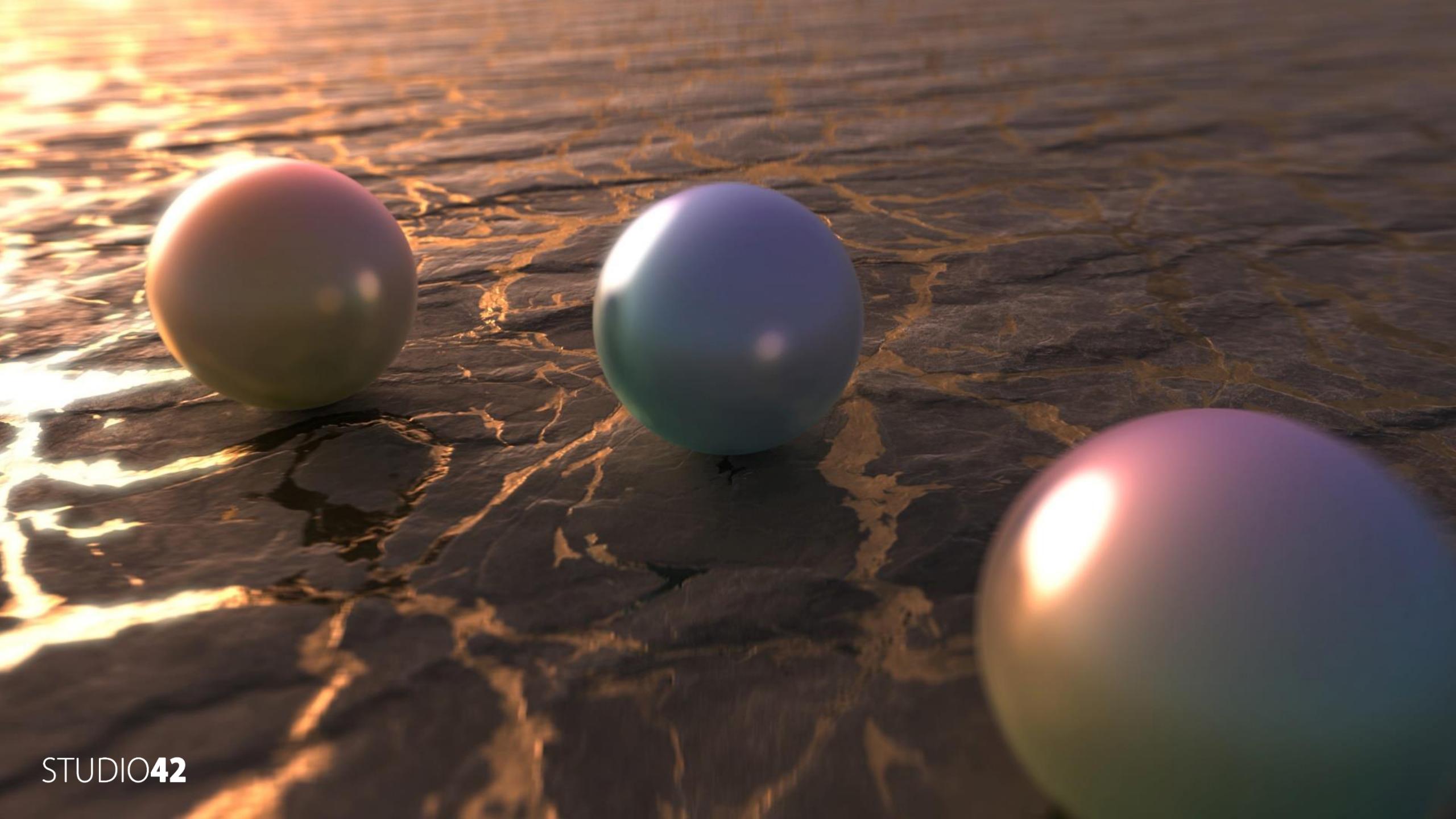
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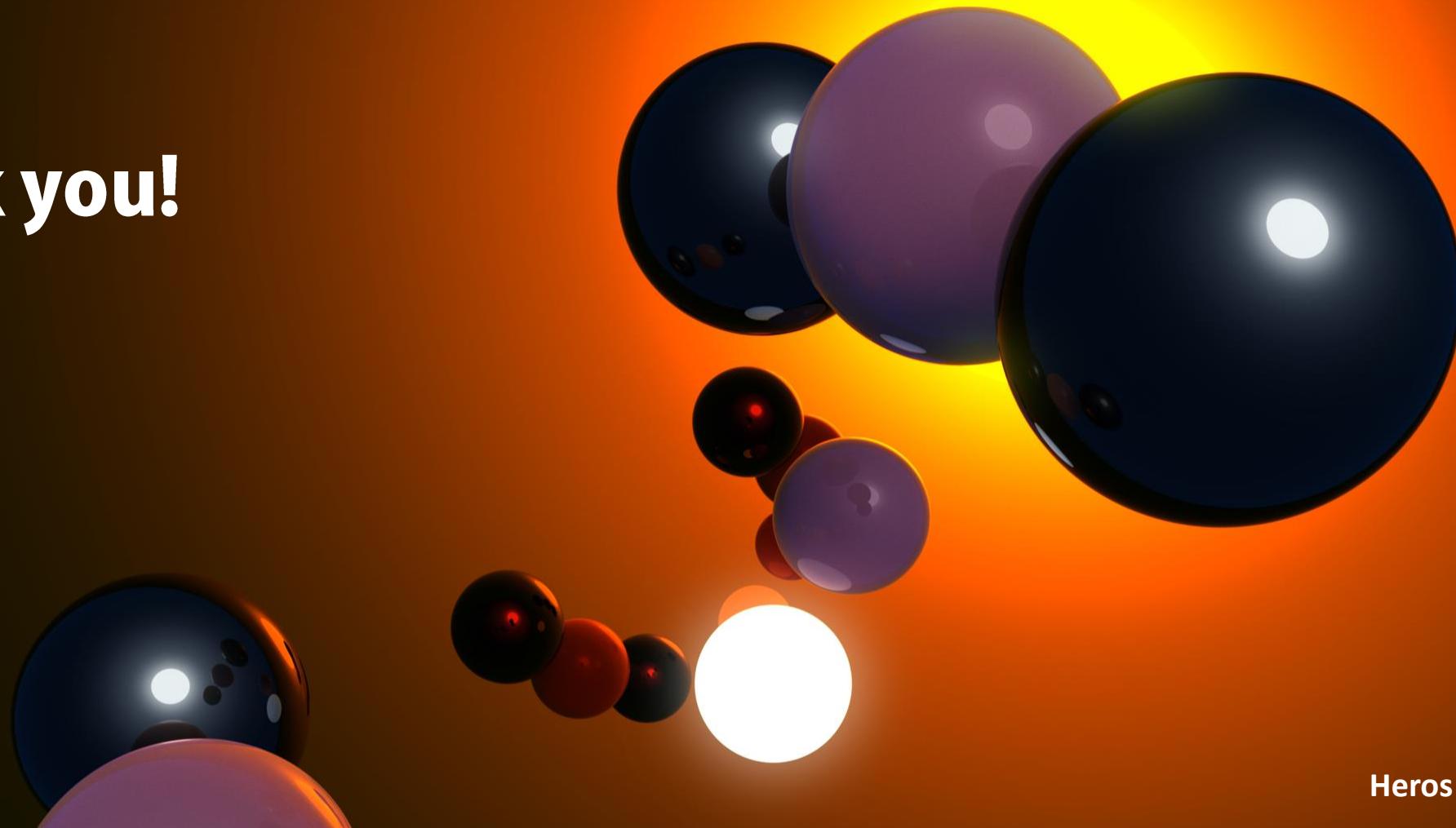


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Thank you!



Heros Substance by Ondrej Wolf

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