Light

Light makes it right

Light frequency and color

- Light is electromagnetic radiation visible by eye
  - Wavelenght: 400 – 700 nm.
  - Different wavelengths (frequencies) are perceived as color - color is **perceptual** phenomena rather than **physical** one.
- Light can be described both on:
  - Microscopic scale: wave optics
  - Macroscopic scale: **geometric optics**
- Light is measured both using:
  - **Radiometry** – measurement of radiation (more physics involved)
  - **Photometry** – measurement related to human visual system (more perceptual)
    - Summary measures: computed from radiometic quantities.

Light: microscopic level

- Light is quantized – it comes in individual and indivisible packets called **photons**
- At same time light is **wavelike** – radiometric radiation with frequency
  - Light on microscopic level explains color and perception of light <spectrum image>
- Microscopic level is important to mentions since some effects of light-matter interaction can be only explained (and thus modeled*) using wave optics:
  - Interference
  - polarization
  - Diffraction
  - Iridescence
  - Pleochroism and birefringent
  - examples
- Also, knowing microscopic background often helps in getting intuition for some shading and light transport methods**

* It is important to note that complexity of model level depends on application. Often, in computer graphics wave effects can be "faked" to achieve desired apperance: https://developer.nvidia.com/gpugems/gpugems/part-i-natural-effects/chapter-8-simulating-diffraction. On the other hand, physically based methods for achieving wave-effects is actively researched area: https://sites.cs.ucsb.edu/~lingqi/publications/202203_practical_plt_paper_lowres.pdf
** For example photon mapping: http://web.cs.wpi.edu/~emmanuel/courses/cs563/write_ups/zackw/photon_mapping/PhotonMapping.html

Light: macroscopic level

- Light in computer graphics is often modeled at macroscopic level.
- **Energy** that flows uninterrupted through empty space in **straight line**.
- It **absorbs** and **reflects** from surfaces it meets.

Light interaction with medium

- Light passing from one to another medium changes speed.
- **Index of refraction*** is characteristics of medium which states the ratio of speed of light in vacuum to the speed of light in that medium
  - This parameter is approximating microscopic level of light behavior – its interaction with medium, used in geometric optics.
- Difference in refractive index in different media causes light rays to be **bend**
  - **Snell's law** – angle of reflection and refraction example
  - Important for physically based rendering of transparent objects. Important information for light transport since it determines angle of refraction/reflection on optically flat interface. <example>
- Amount of reflected and refracted light is calculated using **Fresnel equations**.
  - TODO

* IOR is dependent on light wavelength. Therefore, light of different wavelengths gets bent by different amounts. This can be seen by white light passing through prism creating rainbow. Also, this causes chromatic aberration – effect of camera lenses.

Light as continuous flow

- CG practices and principles 26.6

Light: angles and solid angles

- CG practices and principles 26.6.3

Radiometric quantities

- Radiance
- Irradiance
- Radiant flux
- CG practices and principles 26.6

Light color and intensity

- We have seen that light has physical but also perceptual properties
- Photometry deals with human perception of light
- We have seen that **color** is due to frequency
- Discussion on radiometry was needed to understand light **intensity** – proxy for radiance
- Color and intensity are two main parameters of light that we need for modeling.

Sources of light

- In a real world, every light source has a physical shape and size, e.g., **Sun** or very hot objects.
- Motion of atomic particles that hold electrical charge causes objects to emit electromagnetic radiation over a range of wavelengths (Maxwell's equations)
- Different way how energy is converted into electromagnetic radiation:
  - **Incandescent (tungsten) lamps**: flow of electricity through tungsten filament heats is up and causes to emit electromagnetic radiation with distribution of wavelengths depending on filament temperature. A frosted glass enclosure is often present to absorb some of the wavelengths.
  - **Halogen lamps**: tungsten filament is enclosed in halogen gas. Part of the filament in an incandescent light evaporates when it's heated. Halogen causes evaporated tungsten to return to filament
  - **Gas-discharge lamps**: passing electrical current through hydrogen, neon, argon, or vaporized metal gas, causes light to be emitted at specific wavelengths that depend on the particular atom in the gas. Fluorescent coating on the bulb's interior is often used to transform the emitted frequencies to a wider range.
  - **LED lights** are based on electroluminescence: they use materials that emit photons due to electrical current passing through them.

Foundations of light modeling

- Reminder: when we discussed the material of 3D models, we mentioned **shading process** which uses material information and light information to calculate appearance of the object surface.
- **Light is emitted from a light source**, bounces around the scene, interacting with object and some (very small!) portion enters eye or camera enabling us to see objects in the scene
  - Without light in a 3D scene (or real world) we wouldn’t see anything. Resulting image would be completely black.
- Light sources define position and distribution of light

Light models

- Discussion before showed that lights have shape, size and certain light distribution.
- Representation and modeling of light physically: with shape and size is very computationally expensive. Such lights are called **geometric area light or physical lights***
  - Interaction of physical lights with the scene can not be computed in closed form. Advanced, approximation-based methods such as Monte Carlo integration must be used
- Simplification are lights with no physical size, thus called **delta or non-physical lights**
  - enable us to control light fall-off with distance, which objects are illuminated, which objects cast shadows and so on.

* When we discussed surface material we mentioned scattering and absorption. Also, materials are able of emission. Therefore, physical lights have 3D shape and material which is emissive. Emissive material is modeled as black body meaning that is absorbs all light falling on it.

Physical lights

Physical lights

- Geometry with emissive material
- TODO:
  - Examples
  - Hint that it will be discussed later

Non-physical lights

Non-Physical lights

- Directional (distant) lights
- Point (spherical, omnidirectional) lights
- For physically-based rendering, non-physical light should be avoided
  - Example: size of reflection of object by glossy or mirror-like surface depends on its size and distance to reflective surface. If light source has no shape nor size how reflection should look like? Hack: size parameter which is only used during shading.

Directional lights

- Directional lights are also called distance because they are considered so far from the objects in a 3D scene that they can be represented by parallel rays. As such, we only care of the direction of those parallel rays.
  - Best example of directional light is Sun light on Earth. Sun has spherical shape, but it is so far and Earth is so small compared to it that light rays reaching Earth can be considered parallel (small cone of directions – solid angle).
  - For scenes that cover small area of Earth's surface, Sun light can be assumed parallel.
  - General note: this is another example showing that it is always important to assess the application of Computer graphics and see what is really important to model.

<IMAGE: EXAMPLE OF DISTANT LIGHT>

<IMAGE: EXAMPLE OF DIRECTIONAL LIGHT VECTORS IN THE SCENE>

Point lights

- Most common light sources in nature and around us are spherical (e.g., light bulbs or candle flame) or can be approximated as a collection of spherical light sources.
- As opposed to directional lights:
  - Point light position is important parameter, it is considered infinitesimally small in size
  - Light is emitted in all directions (omnidirectional, isotropic) therefore, no “direction” parameter
- Point light position determines:
  - Direction of incoming light ray for each surface position for each object in the scene
  - Distance to the each surface position for each object in the scene – light falloff

Light intensity and color

- For each light source (physical or non-physical) next to shape, size, position and direction we need to define:
  - Intensity – float value in [0, inf]
  - Color – RGB value in [0,1]

Point lights: light direction and falloff

- Point lights emit radially
- Direction and distance of point light to point on the surface is obtained by tracing ray between these two points.
- Distance of point light to each point of surface of each object in the scene defined how much is that point illuminated
- Energy emitted from point light is distributed across the space as sphere. As the sphere keeps expanding in the space, energy becomes spread across much larger area → more distant objects in the scene receive less light – light falloff. <INVERSE SQUARE LAW FORMULA>

<IMAGE OF POINT LIGHT, ILLUMINATED OBJECTS, SOLID ANGLE>

Point lights: other derivations

- Interesting light sources can be derived by angularly varying distribution of outgoing light:
  - **Spotlights** - emit light in a cone of directions from their position
  - **Textured projections**
  - **Goniophotometric diagram** describes the angular distribution of luminance from a point light source; it is widely used in illumination engineering to characterize lights

Shadows

Light and shadow

- Light falling on object causes object to cast shadow – blocking light to fall on another surface

<IMAGE WITH AND WITHOUT SHADOW>

- Shadows are important for:
  - Understanding relation of objects to one another
  - Realistic image synthesis
- Simulating shadow depends on rendering algorithm (more specifically, algorithm for solving the visibility problem)
  - As we will see, in rasterization-based rendering shadows will not be inherently present. Advanced, multi-pass rendering is required to obtain visibility of objects looking from the position of light. This way, shadow map is generated and used for rendering.
  - In ray-tracing based rendering, shadows are inherently present due to way incoming light on surface is calculated

Intuition: calculating light and shadow

- How to know if point of surface will be under shadow or not?
- Generate ray from that point in light direction and if no intersections are found, shadow won't be present.
  - For point lights, we need to take in the account their maximum influence!
  - Shadow-acne problem → Later!

Sharp vs smooth shadows

- Size of light determines smoothness of shadows

Light and Shadow: Tips and Tricks

- Non-physical light sources as well as shadows they cause can be simulated efficiently
- For real-time rendering, full physically based simulation of light transport might not be feasible
- When creating 3D scene, (environment) artists understand the how the scene should be illuminated given some main sources of light. Using this knowledge they place non-physical light to fake actual light flow through the scene
- https://80.lv/articles/dishonored-interiors-lighting-props/

Literature

- https://github.com/lorentzo/IntroductionToComputerGraphics/wiki/Foundations-of-3D-scene-modeling