Camera

Where is camera?

- As viewers of rendered images, camera is not seen – it defines what we see.
- Examples:
  - FP games
  - Isometric games
  - Animation
  - Digital twin exploration

Cameras introduction

- In rendering camera model is required to, at least, define a portion of visible scene and perspective/orthographic projection.
- Rendering process is calculating radiance from shaded surface point to camera position.
  - This simulates simplified model of an imaging system such as film/digital camera or human eye
  - <image: object, camera>

Real camera systems

- Camera systems contain many small discrete **sensors**: cones in the eye, photodiodes in digital camera or dye particles in film camera
- Each of these sensors measures incoming **radiance** values and converts it to **color** signal
- Exposing sensor to radiance will not produce image without **light-proof enclosure** with small opening – **aperture**.
  - Such setup restricts light where light can enter and strike sensor
- **Lens** is placed at the aperture to focus the light so each sensor receives light from only a small set of incoming directions
  - Lens with aperture average light over small area and small set of incoming directions
- <image: camera system, objects and light>

What camera measures?

- Sensors measure average radiance which quantifies the brightness and color of single ray of light
- This is motivation why in computer graphics we only care about light rays which are coming to camera and from them, how are they generated in the scene
  - We will extend this idea in rendering chapters

- Now, we will understand how cameras work and how to simulate a real world camera.
  - Such camera model is similar to ones used in production software (e.g., Blender, Maya, 3DSMax, Houdini)
- Simulating real world camera is important for photo-realistic rendering which may be combined with live action footage. Also, camera effects enable certain expressive and artistic possibilities.

Camera model

- Image generation with real world camera is governed by optical laws → very costly to simulate
- Thus, we start with simplest camera model: **pinhole camera**
  - Much easier way to reproduce images, therefore used in most 3D applications and games
- Pinhole camera can be realized in a real world: small box with hole on one side and photographic film on opposite side.

<IMAGE OF PINHOLE CAMERA AND ITS RESULT>

- To simulate creation of image in a camera depends on:
  - Light traveling in space and its interaction with objects (matter) → determined by law of optics
  - Light which is entering the camera
- Once light enters camera, two main processes are important:
  - How image is stored on film → can be simulated (e.g., https://maxwellrender.com/) but out of scope
  - How image is formed in the camera

Image forming basics

<IMAGE OF BASIC PRINCIPLE OF IMAGE CREATION>

- Light rays from the world pass through the small hole and form an (inverted) image on plane (film) opposite to the hole.
  - Camera obscura is real-world realization of the described process without film

Pinhole Camera

- Real world realization: lightproof box with very small hole – aperture, and light-sensitive film on the opposite side.
  - To take an image, open aperture to expose the film to light
  - Aperture is small so that only one ray reflected from the world in point P enters the camera and intersects film in one point – each point in the visible portion of the scene corresponds to a single point on the film (note that in real world such hole must be very small)
  - Geometrically, pinhole is called center of projection – all rays entering the camera converging at this point and diverging on the other size

<IMAGE OF PINHOLE CAMERA and its result>

Pinhole camera: aperture size

- Formed image is sharp if each point of the object maps to the one point of the film
- Ideal pinhole: aperture is so small that only one ray passes through it
  - Not possible in a real world because of diffraction
- It is never a single ray that passes the aperture – the cone of rays (its angle) is determined by a size of aperture. Smaller cone → sharper image
  - Example: solid angle

<IMAGES COMPARING LARGE AND SMALL APERTURE SIZE (blur, circle of confusion)>

Pinhole camera: exposure

- If aperture is very small, longer time is needed for image to form on a film.
- Time of which the aperture is open is called exposure time (or just exposure)
  - In real cameras, longer exposure can produce blurred image if camera or objects in the scene are moving
  - Simulated camera do not have problem with this since simulated light transport is considered instant, therefore, simulation of motion blur requires additional simulation
- Therefore, generally, shorter exposure time is better

<IMAGE OF MOTION BLUR>

Pinhole camera vs lens camera

- Since very small aperture requires long exposure times to form an image, it is not possible to obtain sharp images easily (e.g., if camera or objects are not perfectly still)
- Large aperture is again not a solution since blurred images will always be formed
- Solution is to use lens in front of aperture so that rays entering camera are gathered (converged) and focused them to one point on a film plane
- With lenses, aperture can be larger enabling smaller exposure time with sharp images as result

<IMAGE OF LENS CAMERA>

- Introduction of lenses also introduces the depth of field – distance between nearest and the farthest object from the scene that appears sharp in the formed image

<DEPTH OF FIELD IMAGE>

- Pinhole cameras have infinite depth of field
  - Therefore, computer generated images will be sharp. Additional simulation is needed to produce depth of field.

Pinhole camera parameters

- Now when we understand the elements of pinhole camera, we will discuss parameters controlling those elements

Pinhole camera parameters: Focal length

- Moving image plane (film plane) closer to aperture effectively performs zoom out
- Moving film plane away from aperture effectively performs zooming in
- Therefore, distance of film plane from aperture defines amount of scene that we see
- This parameter is called focal length or focal distance

<IMAGE OF PINHOLE CAMERA WITH VARYING FOCAL DISTANCE AND RESULT>

Pinhole camera parameters: angle of view

- Zooming in and zooming out described by Focal length (focal distance) can be also described by angle of the apex of triangle defined with aperture and film edges
- This angle is called angle of view or field of view
- In 3D, this triangle is actually a pyramid and we distinguish horizontal and vertical FOV

<IMAGE OF PINHOLE CAMERA WITH VARYING FOV AND RESULTING IMAGES>

Observation - Pinhole camera: alternative representation

- Triangle introduced in FOV defines how much of the scene is visible
- This triangle can also be viewed as continuation of lines from film edges to aperture and to a scene
- This representation of pinhole camera model is used for simulation

<IMAGE COMPARING TWO REPRESENTATIONS OF PINHOLE CAMERA>

Pinhole camera parameters: film size

- Amount of scene that is captured also depends on film size (image sensor)
  - Film parameters are horizontal and vertical direction
- Smaller surface of film size implies smaller angle of view
- Larger film formats were developed for more details and better image quality
- Capturing the same extent of the scene with larger film requires adjusting focal length

<IMAGE SHOWING DIFFERENT FILM SIZES>

Pinhole camera parameters: quick recap

- Focal length (focal distance)
- Angle of view (field of view)
- Film size
- All three parameters are interconnected, knowing two we can infer the third.
- Angle of view is parameter we usually need for rendering and expose focal length and film size to the user

Pinhole camera parameters: image resolution and aspect ratio

- As discussed, size of film (image sensor) has an effect on angle of view
- Number of pixels (resolution of image) placed on image sensor doesn't have influence on angle of view
- Image quality depends both on image sensor size and number of pixels on it (resolution)
  - Higher resolution images will have more details
- Resolution is determined by width and height which defines number of pixels
- Image aspect ratio can be computed using width and height of resolution, e.g., 4:3, 5:3, 16:9

Camera in rendering

- During rendering, each shading surface point corresponds to single ray and thus to sample point on the sensor surface
  - example
- In chapter about image, we will discuss reconstructing image (signal) over each discrete sensor surface – reconstruction of continuous image signal from discrete samples

Literature

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