Camera

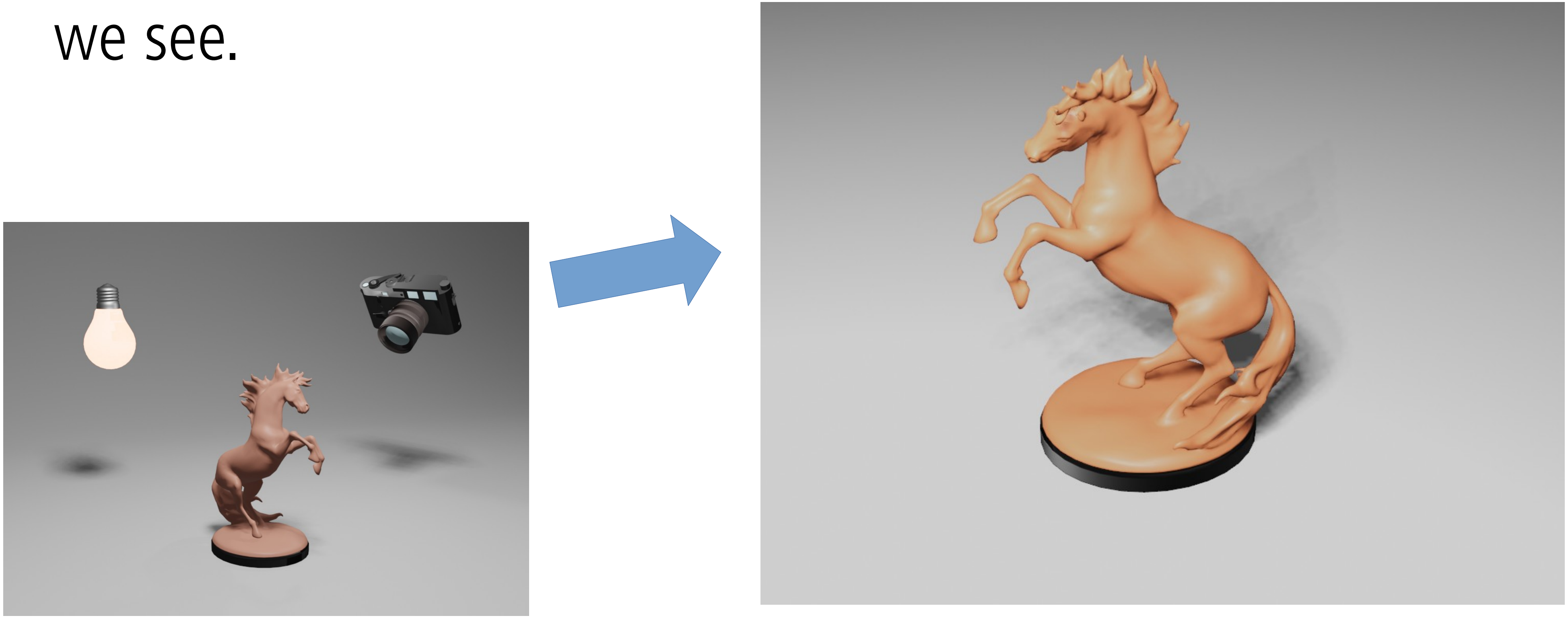
Syllabus

- 3D scene
  - Object
    - Shape
    - Material
      - Scattering
      - **Texture**
  - Camera
  - Light
- Rendering
- Image

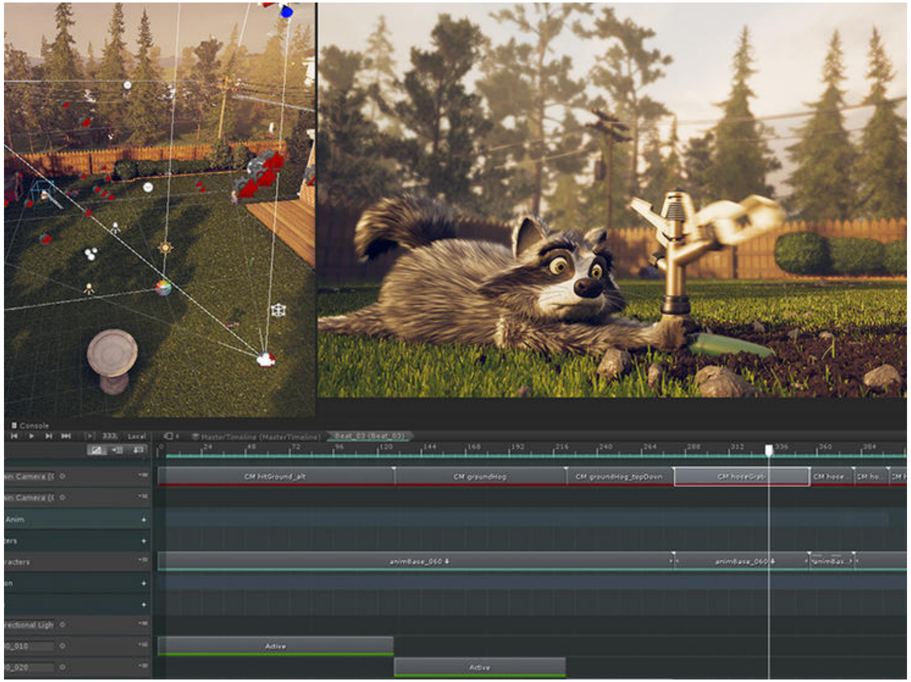
- Camera

Where is camera?

- In rendered images, camera is not seen – it defines what we see.



Where is camera?



https://unity.com/solutions/film-animation-cinematics

https://www.half-life.com/en/alyx/

Camera in rendering

TODO

- In rendering camera model is required to, at least, define a portion of visible sce
  perspective/orthographic projection.
- 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
- Rendering process is calculating radiance (color) 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>

Camera in rendering

TODO

- During rendering, each shading surface point corre
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

Real camera system

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 elements: sensor, aperture, lens>

What camera measures?

TODO

- Images are created when light falls on surface which is sensitive to
- For a film camera, this surface is film or sensor (CCD) for digital camera
- 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

Image formation

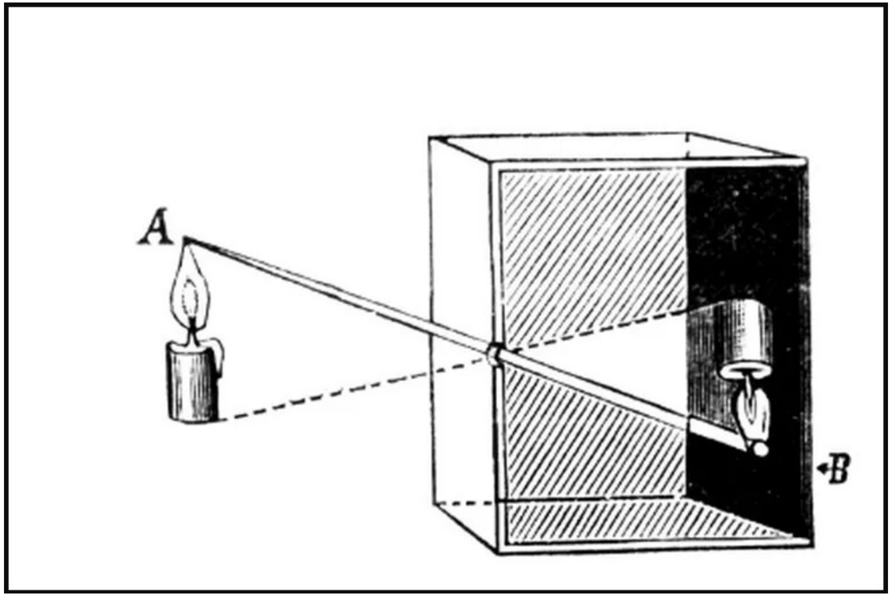
Principle of photography

- Two main processes:
  - **How is image created in camera**
  - How is image stored on film/file*

* Physical support to store an image, thus simulating the photochemical processes used in traditional film photography is out of scope.
Renderer which simulates image storage on film: https://maxwellrender.com/https://maxwellrender.com/

Image formation: camera obscura

- Lightproof box with:
  - black interior (to prevent light reflection)
  - with very small hole – **aperture**
  - light-sensitive film opposite to aperture
- When aperture is opened, film is exposed to light
  - Light passing through the hole forms an inverted image of the external scene on the opposite side of the box
  - Time which aperture must be opened to capture image on film is called **exposure**
- A foundation for modern photographic cameras



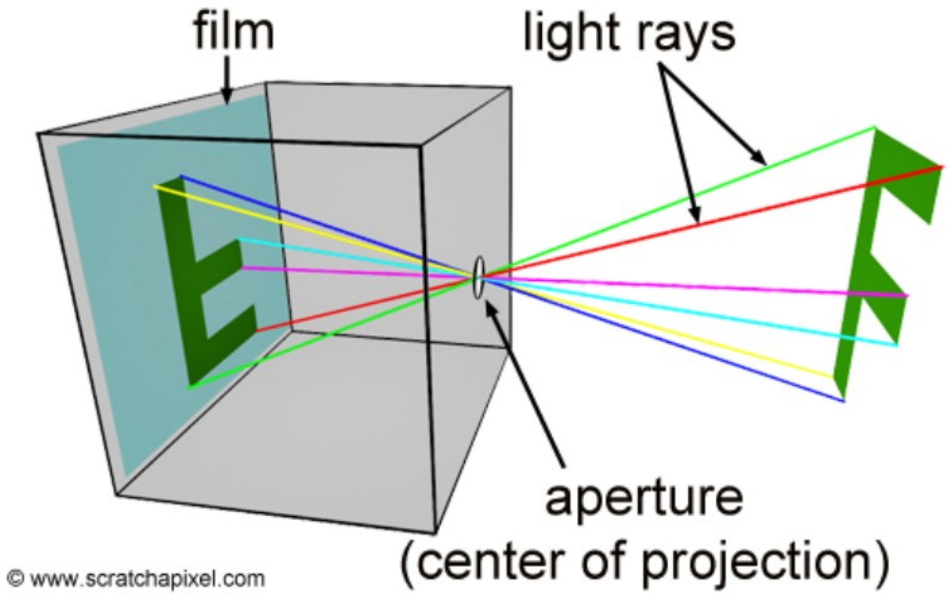
https://www.inquirer.com/philly/entertainment/20160806_Camera_Obscura_at_Fleischer_throws_new_light_on_photography.html

Camera obscura = Dark room

https://www.youtube.com/watch?v=gvzpu0Q9RTU&ab_channel=NationalGeographic

Image formation: pinhole camera

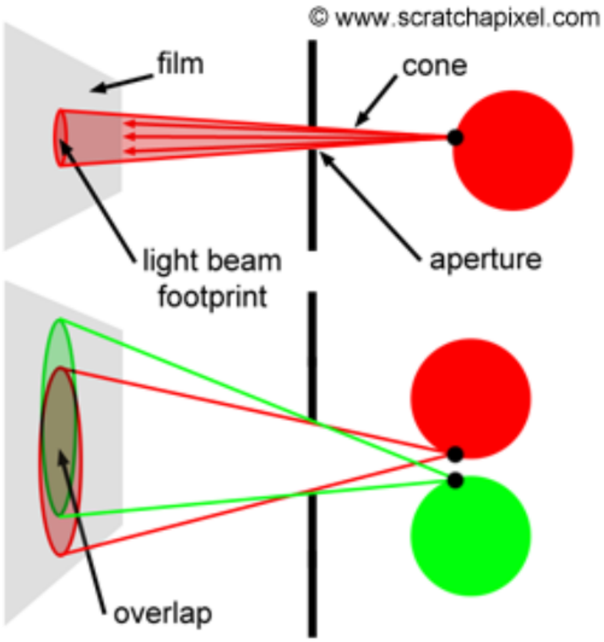
- Simplest type of camera in real world is **pinhole camera (camera obscura)**
- Main elements:
  - **Aperture**: center of projection: all rays entering converge here and diverge from it to the other side
  - **Film**
- Image formation
  - Aperture is opened to expose film to light
  - Aperture must be very small: 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



https://www.scratchapixel.com/lessons/3d-basic-rendering/3d-viewing-pinhole-camera

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 of light
- It is never a single ray that passes the aperture – cone of rays
  - the cone of rays (its angle) is determined by a size of aperture.
  - Smaller cone → sharper image
  - Larger aperture → blurred image



https://polyhaven.com/a/food_pears_asian_01

Cones are overlapping and single point appears multiple times on film → blur (out of focus).

https://www.scratchapixel.com/lessons/3d-basic-rendering/3d-viewing-pinhole-camera

Bokeh

- Out of focus emissive objects are aesthetically pleasing → bokeh effect.

Pinhole camera: exposure

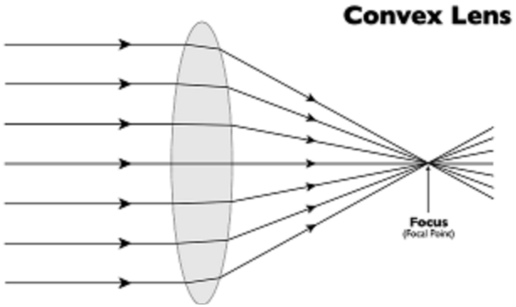
- If aperture is very small, longer time is needed for image to form on a film.
- Time of which the aperture is open is called **exposure** time
  - In real cameras, longer exposure can produce blurred image if camera or objects in the scene are moving (not perfectly still)
  - Simulated camera do not 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, although simulation of motion blur is aesthetically pleasing

Earth rotation causes motion blur in long-exposure photos

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

Aperture and Lens camera

- Aperture trade-offs:
  - Very small aperture requires long exposure times to form an image: motion blur
  - Large aperture causes blurred images
- Solution is to use lens in front of aperture
  - Rays entering camera are gathered (converged) and focused them to one point on a film plane
  - Aperture can now be larger enabling smaller exposure time while lenses canceling blur



https://photo.stackexchange.com/questions/95113/do-convex-lenses-make-light-from-different-points-converge-to-different-points

Depth of field

- Lens camera introduce distance between nearest and the farthest object from the scene that appears sharp in the formed image – **depth of field**
- Pinhole cameras have infinite depth of field
  - Because of this, images rendered with pinhole cameras are completely sharp and thus look artificial

https://www.adobe.com/uk/creativecloud/photography/discover/bokeh-effect.html

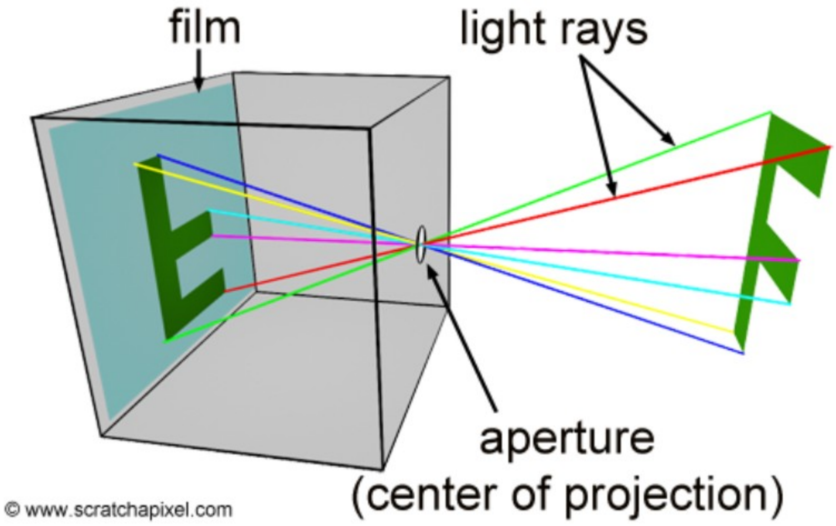
Camera model

Camera model

- Now, we will model 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:
  - photo-realistic rendering which may be combined with live action footage
  - 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
- We start with simplest camera model: **pinhole camera**
  - Much easier way to reproduce images, therefore used in most 3D applications and games
- Main elements:
  - Film (image plane)
  - Aperture (small opening)

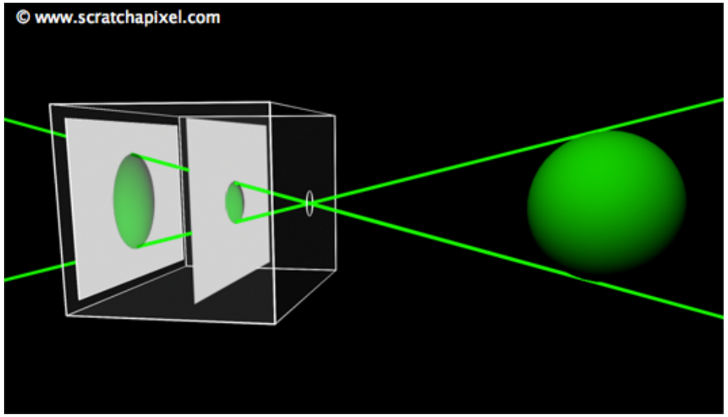


Pinhole camera parameters

- Film and aperture elements form several parameters:
  - Focal length/focal distance, angle of view/field of view
  - Film size

Focal length

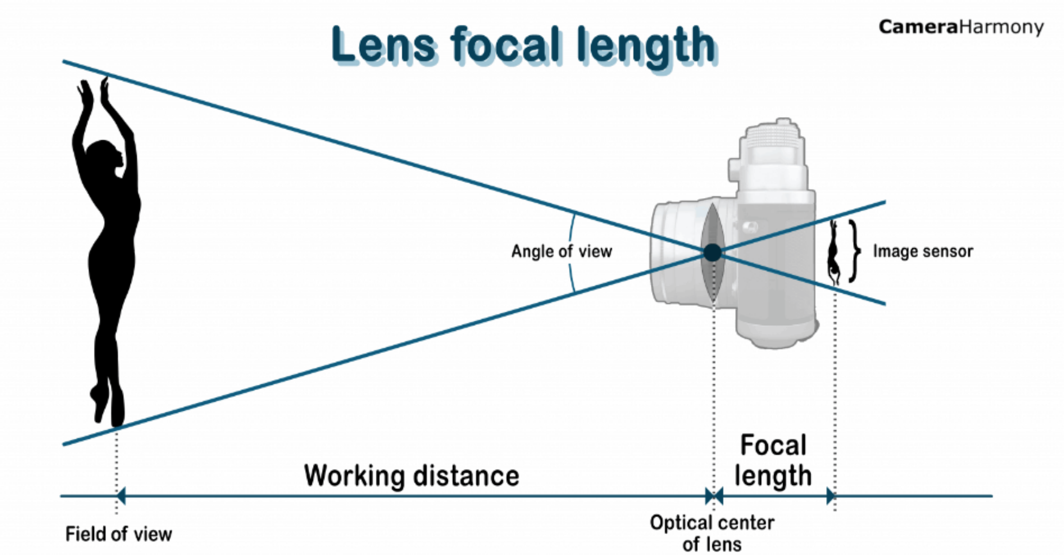
- Distance of film plane from aperture defines amount of scene that we see
  - Moving image plane (film plane) closer to aperture effectively performs **zoom out**
  - Moving film plane away from aperture effectively performs **zooming in**
- This parameter is called **focal length** or **focal distance**



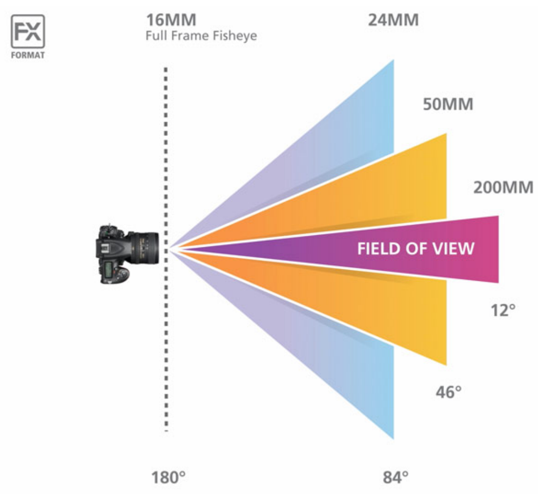
https://www.nikonusa.com/en/learn-and-explore/a/tips-and-techniques/understanding-focal-length.html

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



https://cameraharmony.com/focal-length-explained/



https://www.nikonusa.com/en/learn-and-explore/a/tips-and-techniques/understanding-focal-length.html

Focal length and angle of view

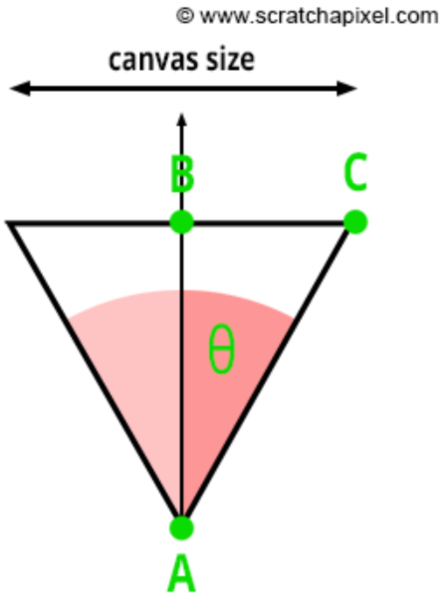
- Relation between focal length and angle of view

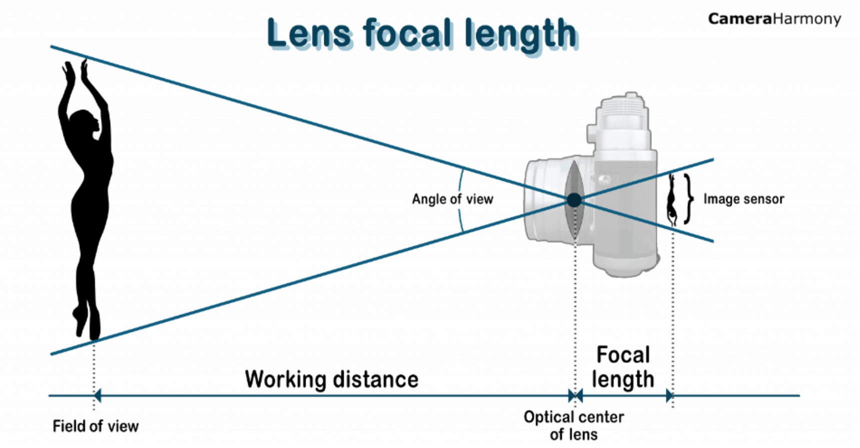
$$\tan(\theta) = \frac{BC}{AB}$$

$$BC = \tan(\theta) * AB$$

$$\text{Canvas Size } = 2 * \tan(\theta) * AB$$

$$\text{Canvas Size } = 2 * \tan(\theta) * \text{ Distance to Canvas}.$$





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: 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.

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

Pinhole camera in computer

TODO

- Continuation of lines from film edges to aperture and
- This representation of pinhole camera model is used for simulation
- https://www.scratchapixel.com/lessons/3d-basic-rendering/3d-viewing-pinhole-camera/virtual-pinhole-camera-model

From camera to the scene

TODO

- As camera creates image based on light falls on sensor, we can compute only that portion of light – now the light in the whole scene
- Tracing rays from camera

To remember

- Field of view → sensor size, focal length
- Depth of field → aperture, focal length, object distance
- Exposure → aperture, shutter, ISO
- Motion blur → shutter
- Grain/noise: ISO

Acknowledgements

- Large part of this lecture is based on ScrachAPixel lession: https://www.scratchapixel.com/lessons/3d-basic-rendering/3d-viewing-pinhole-camera

Literature

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