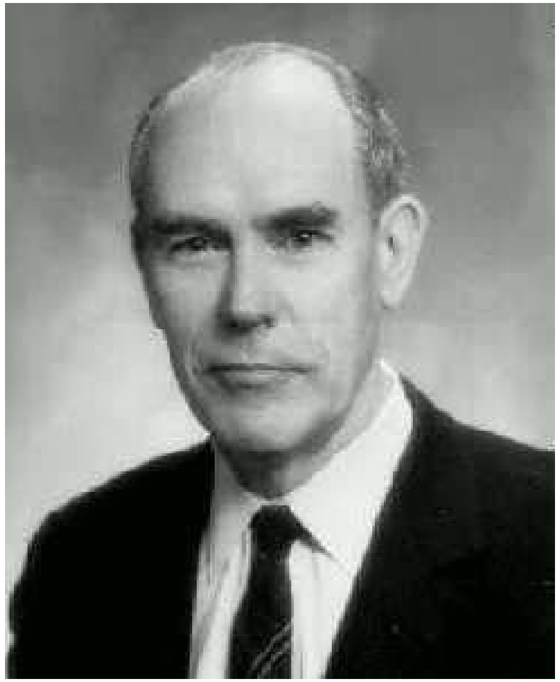
Graphics primitives

Day 3

Agenda

- History of computer graphics
- Graphics pipeline
- Physical and synthetic images
- Ray tracing
- Pinhole Camera
- Synthetic camera

Pioneer: Ivan Sutherland
1963: Sutherland's PhD Thesis："Sketchpad: A Man-machine Graphical Communications System.", MIT,1963



First time used "Computer Graphics". CG started to be a novel and independent scientific branch.

Pioneer： Ivan Sutherland

- First truly interactive graphics system, Sketchpad, pioneered at MIT by Ivan Sutherland for his 1963 Ph.D. thesis

Sketchpad in 1963. Note use of a CRT monitor, light pen and function-key panel.

The History of Computer Graphics

- Poineer: Ivan Sutherland
- 1962: Pierre Bezier put forward “Bezier curve” for the representation of space curve
- 1967: Wylie added lighting effect in objects representation
- 1969: Xerox developed GUI (Graphic User Interface)
- 1973: Richard Shoup invented Raster-Scan Display
- The great improvement of graphic techniques
  - Phong lighting model(1973)； Texture mapping(1974)； Ray tracing(1980)； Radiosity(1984)…

*In **computer graphics**, **ray tracing** is a rendering technique for generating an image by **tracing** the **path** of light as pixels in an image plane and simulating the effects of its encounters with virtual objects.

***Radiosity** is a method of rendering based on an detailed analysis of light

The History of Computer Graphics

- Industry
  - ILM(Industrial Light and Magic): an Academy Award winning motion picture visual effects company, 1975
  - SGI (*Silicon Graphics, Inc*): 1982
  - Pixar 1986
  - AutoDesk, Adobe
- Display card
  - 1994: the first PC display card --- by 3DLabs
  - 1995.11: Voodoo --- by 3DFx
  - 1999: Geforce256, the first GPU --- by nVidia
  - nVidia and ATI
    - Geforce 8800、Radeon HD 2900 XT

ILM

- ILM is one of the largest visual effects vendors in the motion picture industry and has one of the largest render farms (named Death Star). currently available with more than 7500 nodes.
- In 2012, The Walt Disney Company acquired ILM as part of its purchase of Lucasfilm.

- 1975: Resurrected the use of VistaVision; first use of a motion control camera (*Star Wars Episode IV: A New Hope*)
- 1980: First use of Go motion to animate the Tauntaun creatures of *The Empire Strikes Back*
- 1982: First in-house completely computer-generated sequence — the "Genesis sequence" in *Star Trek II: The Wrath of Khan*. (Previous computer graphics in *Star Wars Episode IV: A New Hope* were done outside of ILM.)
- 1985: First completely computer-generated character, the "stained glass man" in *Young Sherlock Holmes*
- 1988: First morphing sequence, in *Willow*
- 1989: First Digital compositing of a full-screen live action image during the final sequence in *Indiana Jones and the Last Crusade*
- 1989: First computer-generated 3-D character to show emotion, the pseudopod creature in *The Abyss*
- 1991: First dimensional matte painting — where a traditional matte painting was mapped onto 3D geometry, allowing for camera parallax, in *Hook*.
- 1991: First partially computer-generated main character, the T-1000 in *Terminator 2: Judgment Day*
- 1992: First time the texture of human skin was computer generated, in *Death Becomes Her*
- 1993: First time digital technology used to create a complete and detailed living creature, the dinosaurs in *Jurassic Park*, which earned ILM its thirteenth Oscar
- 1994: First extensive use of digital manipulation of historical and stock footage to integrate characters in *Forrest Gump*.
- 1995: First fully synthetic speaking computer-generated character, with a distinct personality and emotion, to take a leading role in *Casper*
- 1995: First computer-generated photo-realistic hair and fur (used for the digital lion and monkeys) in *Jumanji*
- 1996: First completely computer-generated main character, Draco in *Dragonheart*
- 1999: First computer generated character to have a full human anatomy, Imhotep in *The Mummy*
- 2000: Creates OpenEXR imaging format.[9]
- 2006: Develops iMocap system, which uses computer vision techniques to track live-action performers on set. Used in the creation of Davy Jones and ship's crew in the film *Pirates of the Caribbean: Dead Man's Chest*
- 2011: First animated feature produced by ILM, *Rango*

Thru ILM Production

2019	*Captain Marvel*[21]	Anna Boden and Ryan Fleck	Walt Disney Studios	$152 million	$1.128 billion
	Us	Jordan Peele	Universal Pictures	$20 million	$254.7 million
	Avengers: Endgame	Anthony and Joe Russo	Walt Disney Studios	$356 million	$2.798 billion
	Aladdin	Guy Ritchie		$183 million	$1.051 billion
	Spider-Man: Far From Home	Jon Watts	Sony Pictures Releasing	$160 million	$1.132 billion
	The Irishman[22]	Martin Scorsese	Netflix	$159 million	N/A
	Terminator: Dark Fate	Tim Miller	Paramount Pictures 20th Century Fox	$186 million	$261.1 million
	Playing with Fire[23]	Andy Fickman	Paramount Pictures	$29.9 million	$64.4 million
	Six Underground	Michael Bay	Netflix	$150 million	N/A
	Star Wars: The Rise of Skywalker	J. J. Abrams	Walt Disney Studios	$275 million[24]	$1.074 billion
Upcoming					
2020	*The SpongeBob Movie: Sponge on the Run*	Tim Hill	Paramount Pictures	$100 million	TBA
	No Time to Die	Cary Joji Fukunaga	Metro-Goldwyn-Mayer Universal Pictures	$250 million	TBA
	Black Widow	Cate Shortland	Walt Disney Studios	TBA	
2021	*Jungle Cruise*[25]	Jaume Collet-Serra		TBA	
	Space Jam: A New Legacy	Malcolm D. Lee	Warner Bros.	$161.9 million	TBA

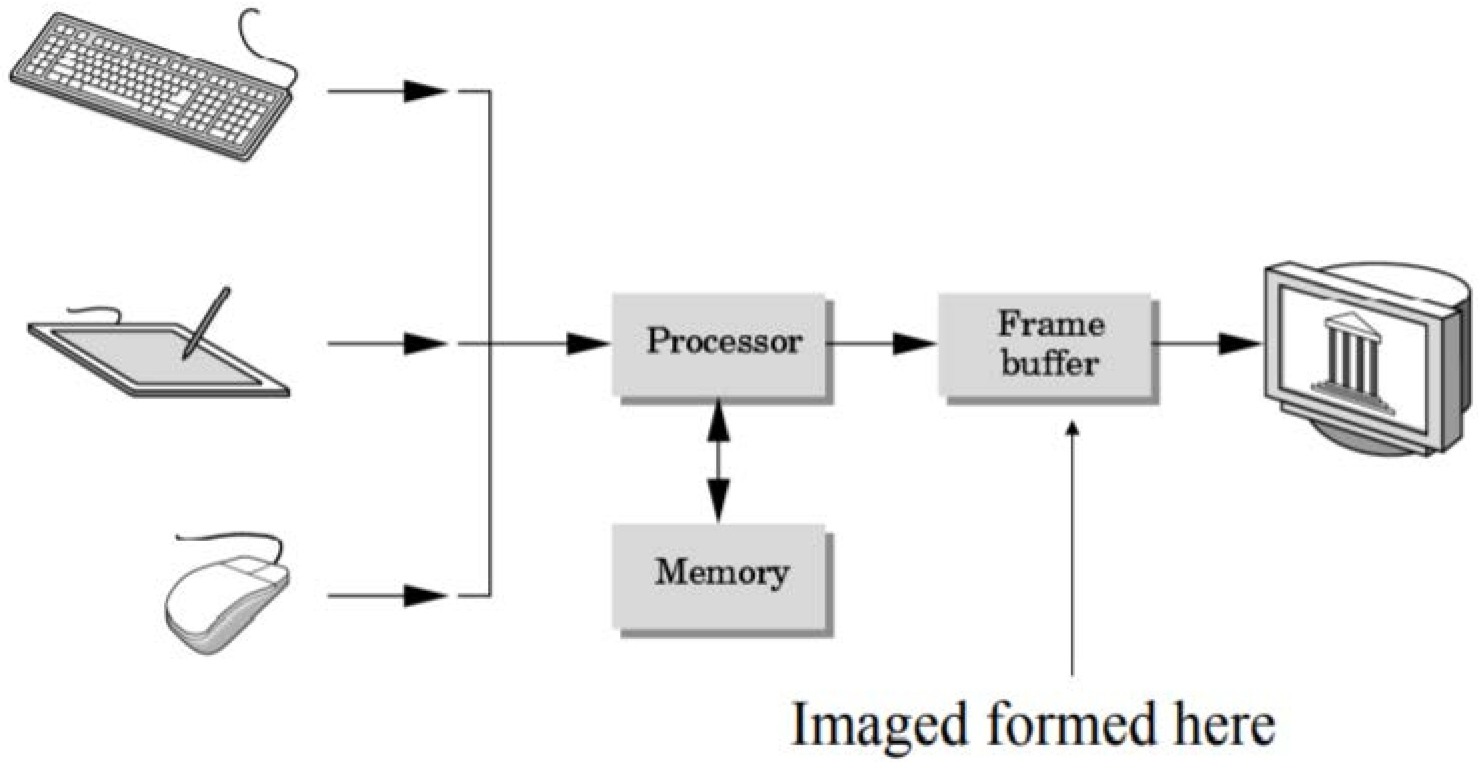
The History of Computer Graphics

- Graphics Standard
  - GKS(Germany, 1970’s); PHIGS(ISO, 1986); GKS-3D(1988)
  - OpenGL(SGI, 1992); DirectX(Microsoft); Java3D(Sun)
- Graphics Application Software
  - 3DS Max, Maya, LightWave 3D
  - Renderman
  - AutoCAD, Solid Work

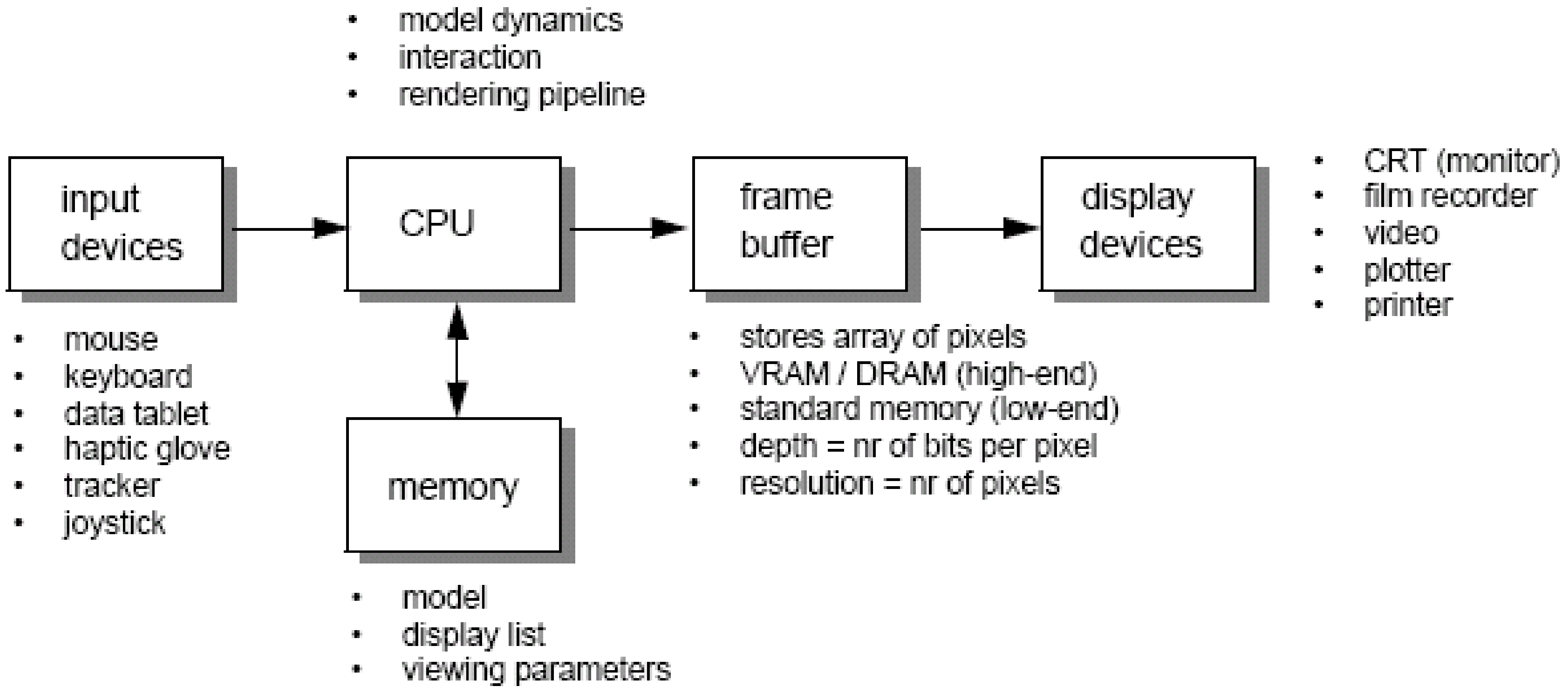
Graphics System

- Store/Create/manipulate different graphical objects such as diagram, pictures.

A Typical Graphics System



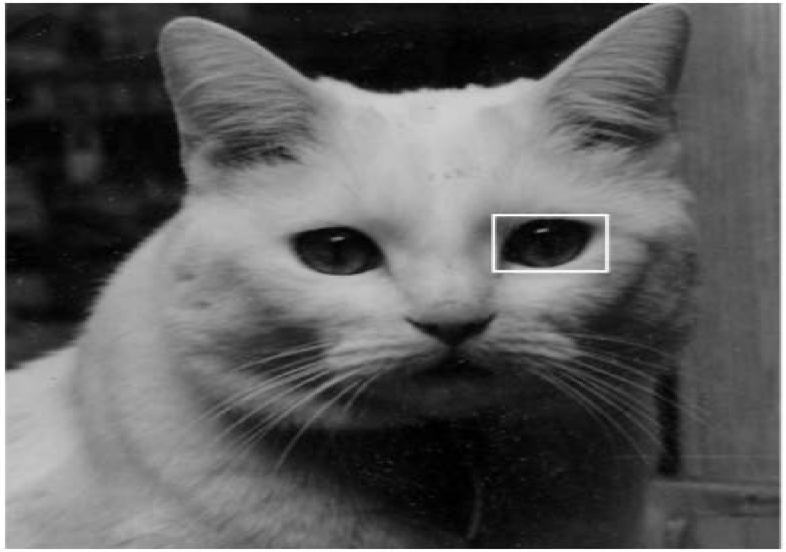
Graphics system



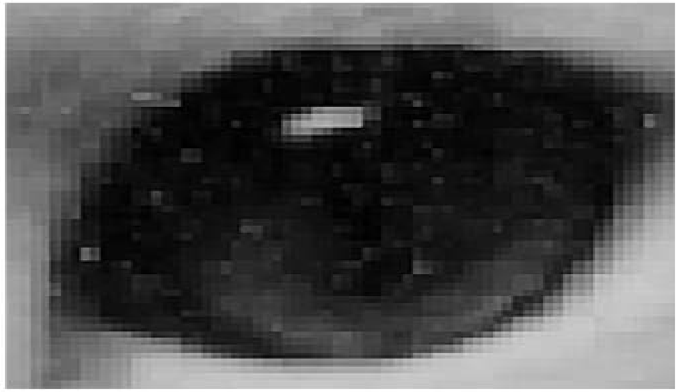
1. Pixels and the Frame Buffer

- All graphics systems are raster-based.
- A picture is produced as an array – the raster – of picture elements, pixels.

Pixels are stored in a part of memory called the **frame buffer**.



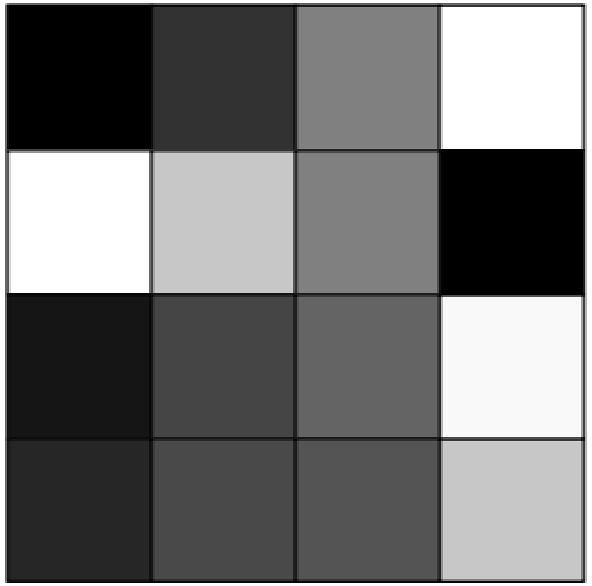
A) Image of Yeti the cat.



B) Detail of area around one eye showing individual pixels.

A sample Image in Pixel_Gray_Map (PGM) Format

```
P2
# test
4 4
255
0     50    127   255
255   200   127   0
10    60    100   250
20    70    80    200
```



This is a 4_by_4 8 bit image, i.e., 255 represents white and 0 represents black, other numbers are used for different shades of gray.

Pixels and the Frame Buffer

- A framebuffer is a portion of *random-access memory containing a bitmap* that drives a video display. It is a memory buffer containing data prepresenting all the pixels in a complete video frame. Modern video cards contain framebuffer circuitry in their cores.

- The depth of the frame buffer, defines the number of bits that are used for each pixel and defines the number of colors.
- The resolution is the number of pixels in the frame buffer and determines the detail that you can see in the image.
- The conversion of geometric entities to pixel assignments in the frame buffer is known as rasterization, or scan conversion.

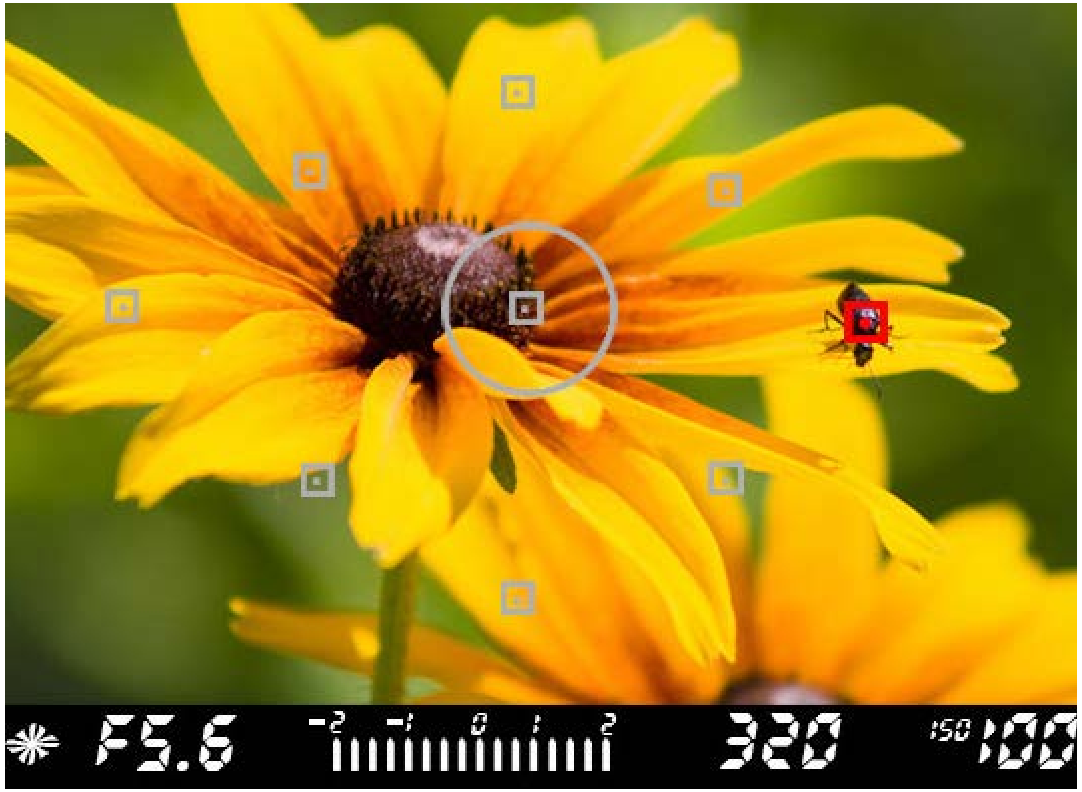
Types of Images

- Physical
- Synthetic image

Physical and Synthetic images

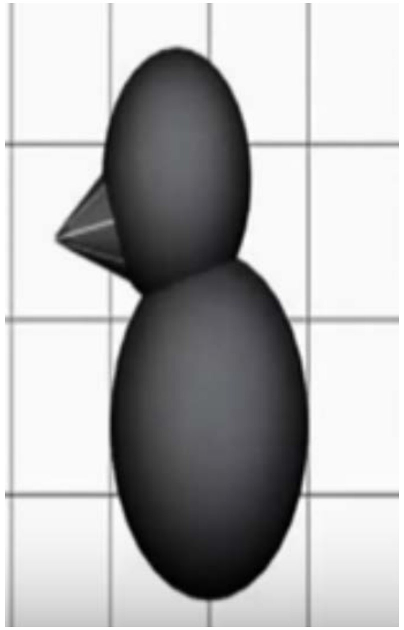
- Physical Image – Exists in real life
- Synthetic image – Artificial image
  - Object
  - Viewer (person, camera or digitizer)
  - Geometric primitives
    - Points, Line, Polygons
  - Light and Exposures
- Image and object are different?

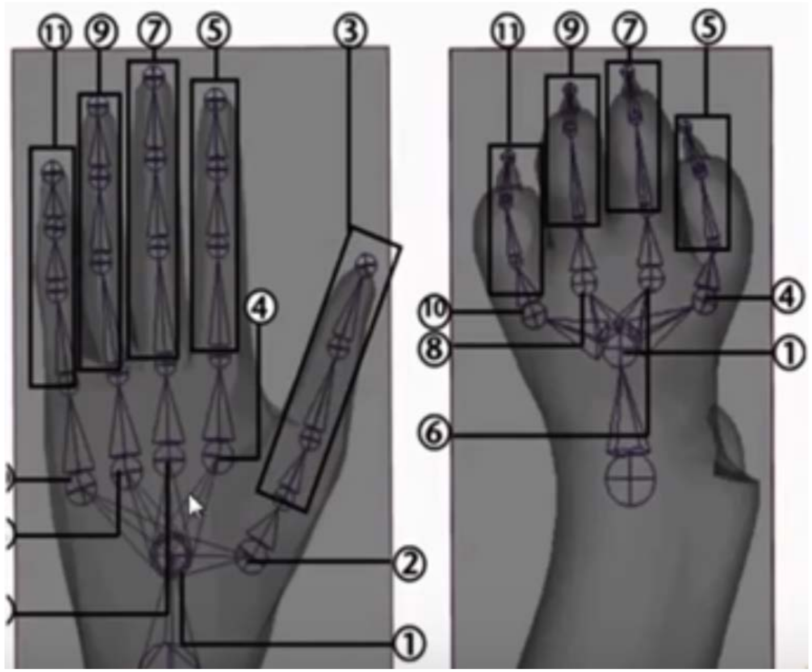
Physical image generation



Synthetic image generation

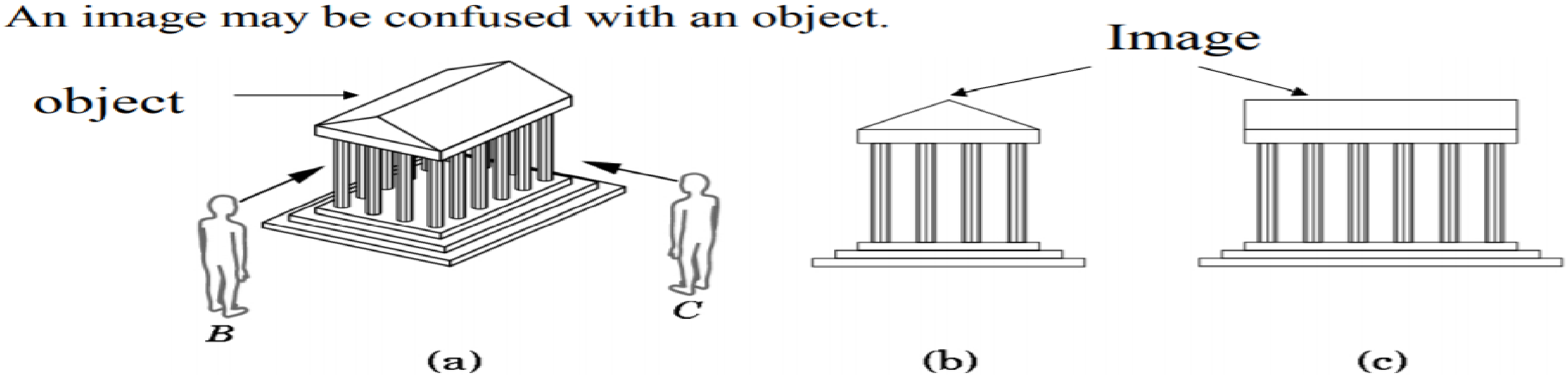
- Object
- Viewer
- Basic shapes/Primitives
- Light/shades/exposure





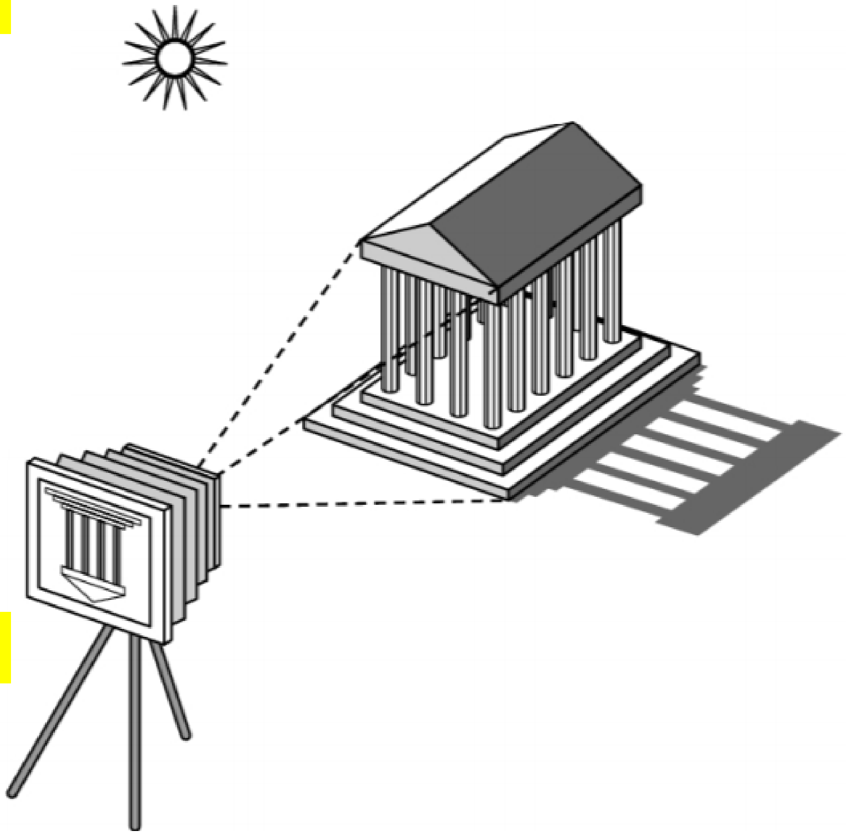
Physical imaging systems

- To form an image, we must have someone, or something, that is viewing our objects, be it a human, a camera, or a digitizer.
- It is the viewer that forms the image of our objects.
- In human visual system, the image is formed on the back of the eye, on the retina. In a camera, the image is formed on the film plane.
- An image may be confused with an object.
- Object and viewer exists in 3d world
- Image is formed by mapping the 3d coordinates of the object into the 2d screen

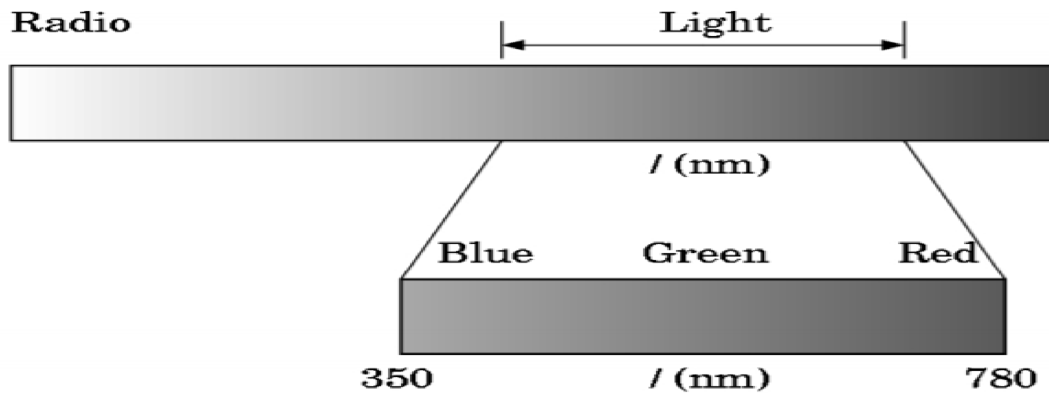


2. Light and Images

- **Light is** electromagnetic radiation that can be detected by the human eye.
- If there is no light source, an object would be dark and there won't be anything visible of the image.
- Light usually strikes various parts of the object and a portion of the reflected light will enter the camera through the lens.
- The details of the interaction between light and the surfaces of the object determine how much light enters the camera.
- Visible light is usually defined as having wavelengths in the range of 400–700 nanometers, or 4.00×10^{-7} to 7.00×10^{-7} m, between the infrared and the ultraviolet.



- The electromagnetic spectrum includes radio waves, infrared (heat), and a portion that causes a response in our visual systems, visible light spectrum.

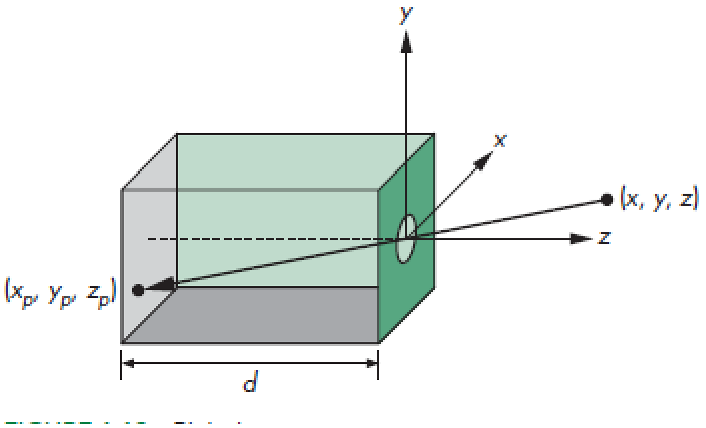


The color of light source is determined by the energy that it emits at various wavelengths.

In graphics, we use the geometric optics which models light sources as emitters of light energy that have a fixed rate or intensity

3. Synthetic Imaging

- Synthetic images are computer-generated image that are similar to forming an image using an optical system.
- This paradigm is known as synthetic-camera model.
- The image is formed on the back of the camera, so we can emulate this process to create artificial images
- We can compute the image using simple trigonometric calculations.(side view calcu.)



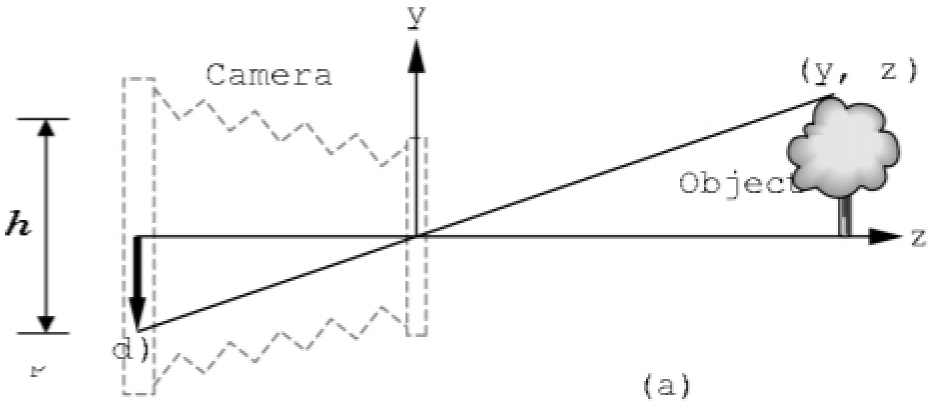
$$\tan(\theta) = \frac{h/2}{d}$$

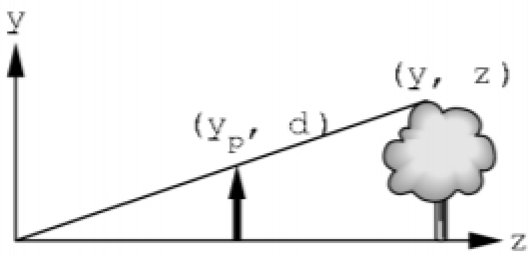
$$\theta = 2\tan^{-1}\frac{h}{2d}$$

$$y_p = -\frac{y}{z/d}.$$

A similar calculation, using a top view, yields

$$x_p = -\frac{x}{z/d}.$$





The Human Visual System

Lights enters the eye through Cornea and Lens.

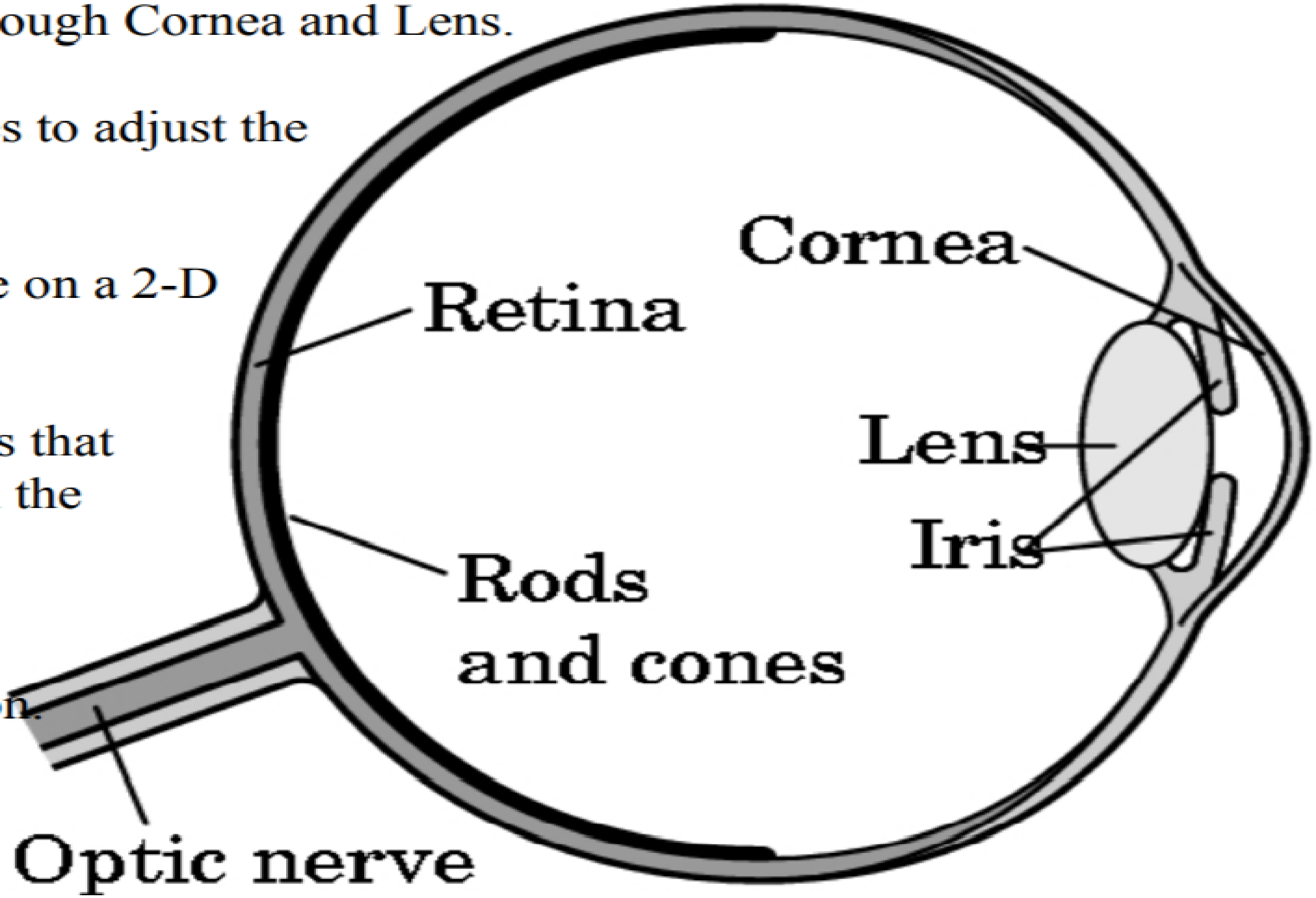
The Iris opens and closes to adjust the amount of light.

The lens forms an image on a 2-D structure called Retina.

There are rods and cones that Act like light sensors on the Retina.

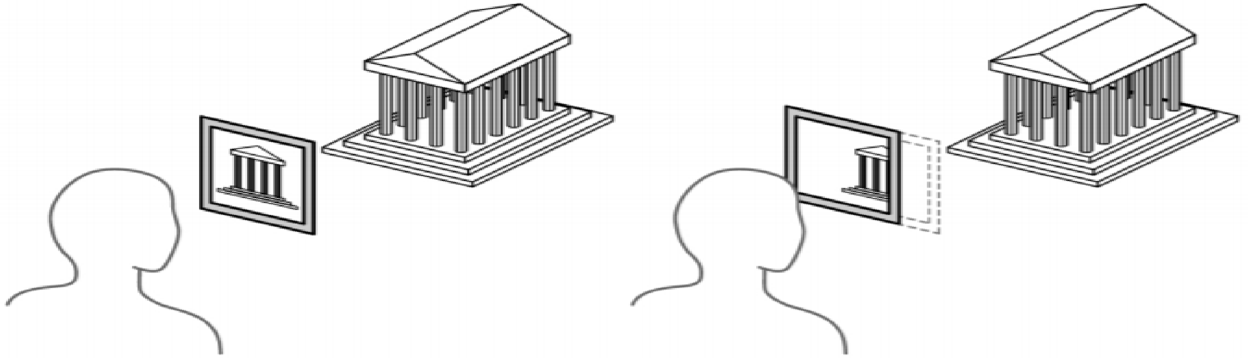
Rods are low-level light sensors, night vision.

Cones are responsible for our day vision.



Synthetic Imaging

- We must consider the limited size of the image. Not all objects can be imaged onto the camera film plane. The angle of view expresses this limitation.
- In our synthetic camera, we place this limitation by placing a clipping rectangle or clipping window in the projection plane.

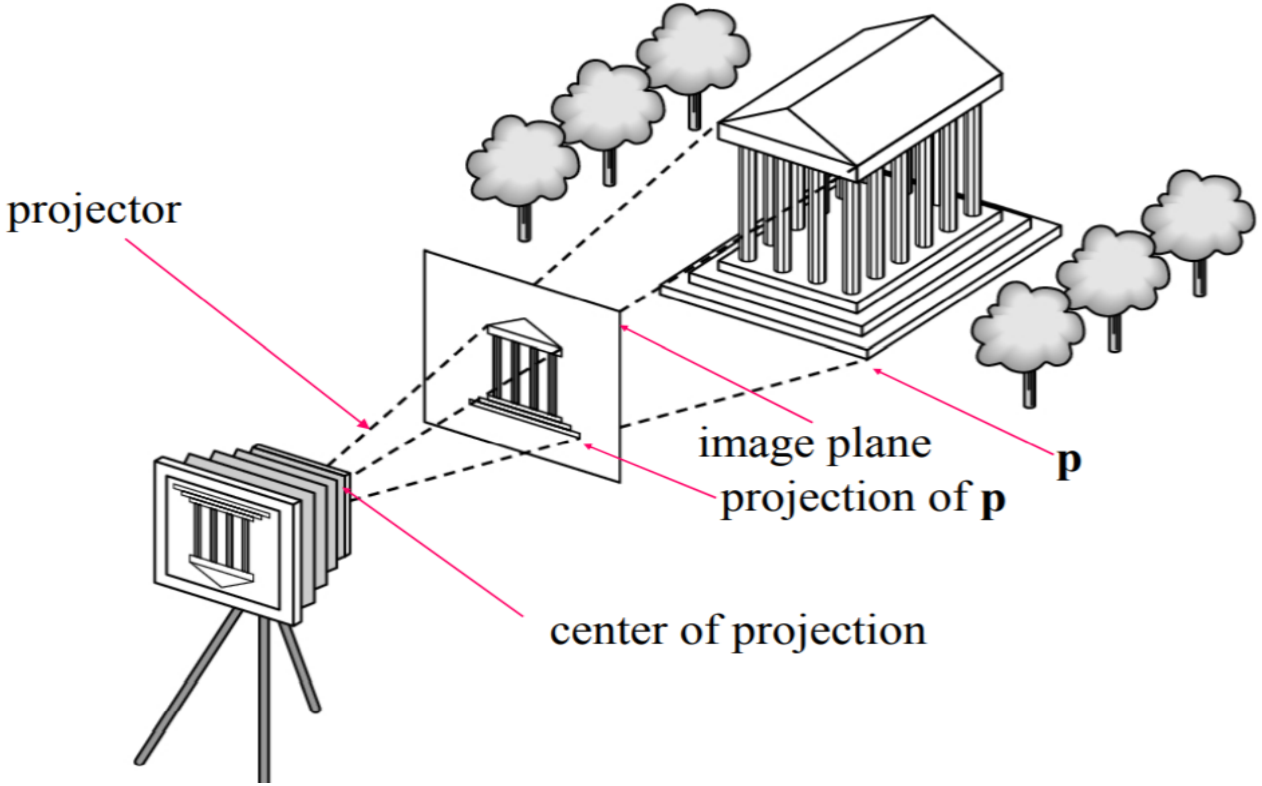


(a) (b)

Given the location of the center of the projection, the location and orientation of the projection plane, and the size of the clipping rectangle, we can determine which objects will appear in the image.

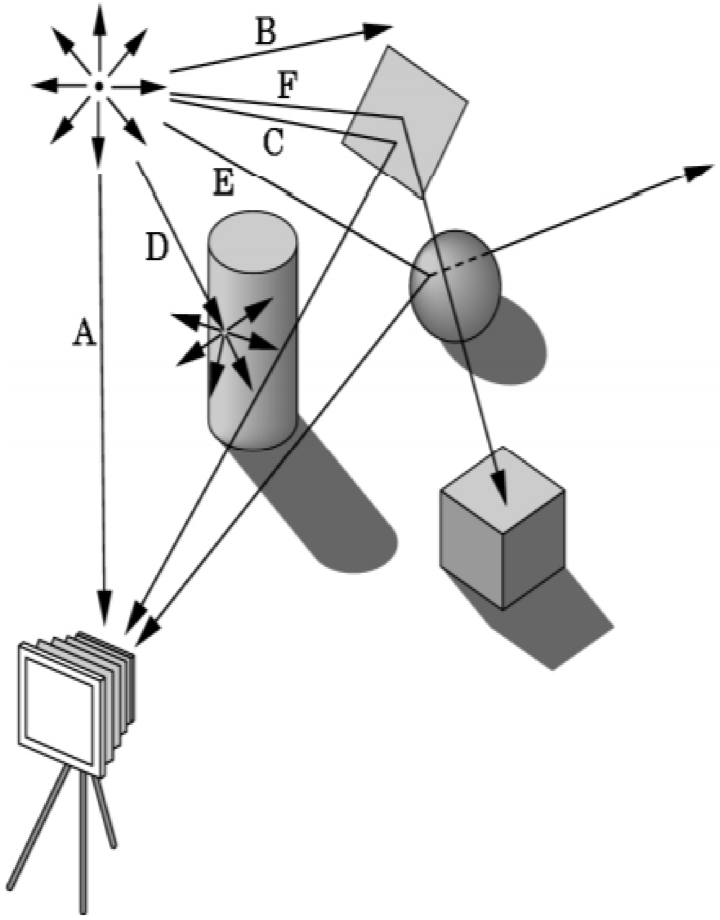
Synthetic Imaging

- We find the image of a point on the object by drawing a line, projector, from the point to the center of the lens, or the center of projection. In our synthetic camera, the film plane is moved in front of the lens and is called Projection plane.



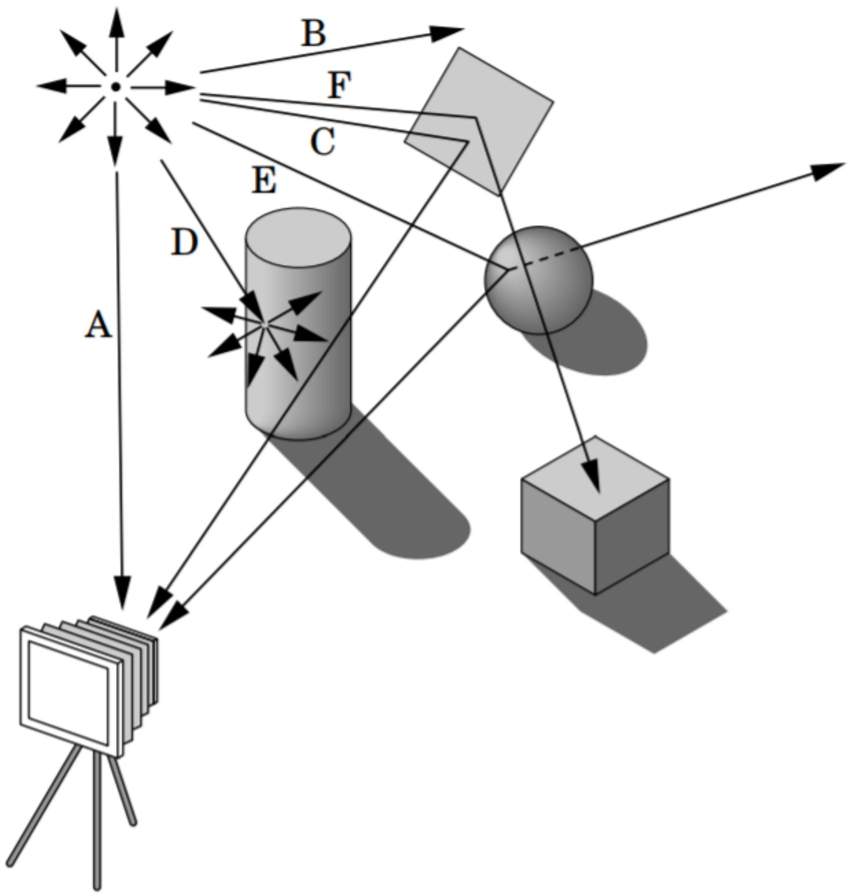
4.Ray tracing

- **ray tracing** is a rendering technique for generating an image by **tracing** the **path** of light as pixels in an image plane and simulating the effects of its encounters with virtual objects.
- We can model an image by following light from a source. The light that reaches the viewer, will determine the image-formation.
- Ray tracing is an image-formation technique used as the basis for producing computer-generated images.
- A ray is a semi-infinite line that comes from a point and travels to infinity in a particular direction.
- Light travels in straight line, thus only a portion the light will get to the viewer.
- The light from the light source can interact with the surface of the object differently, depending on the orientation and the luminosity of the surface.



Light a major source in image formation

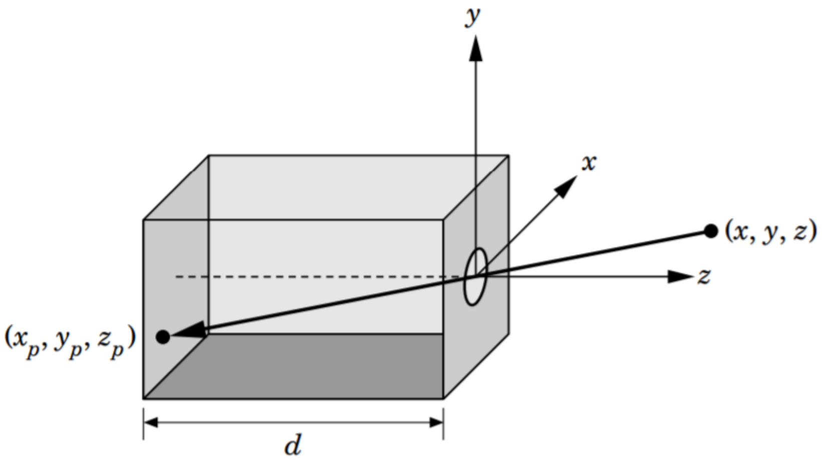
- Ray tracing
  - Exposure
  - Rays
  - Reflection

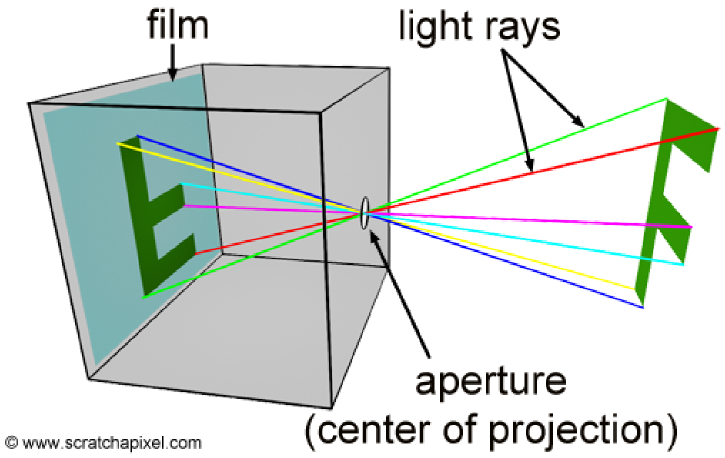


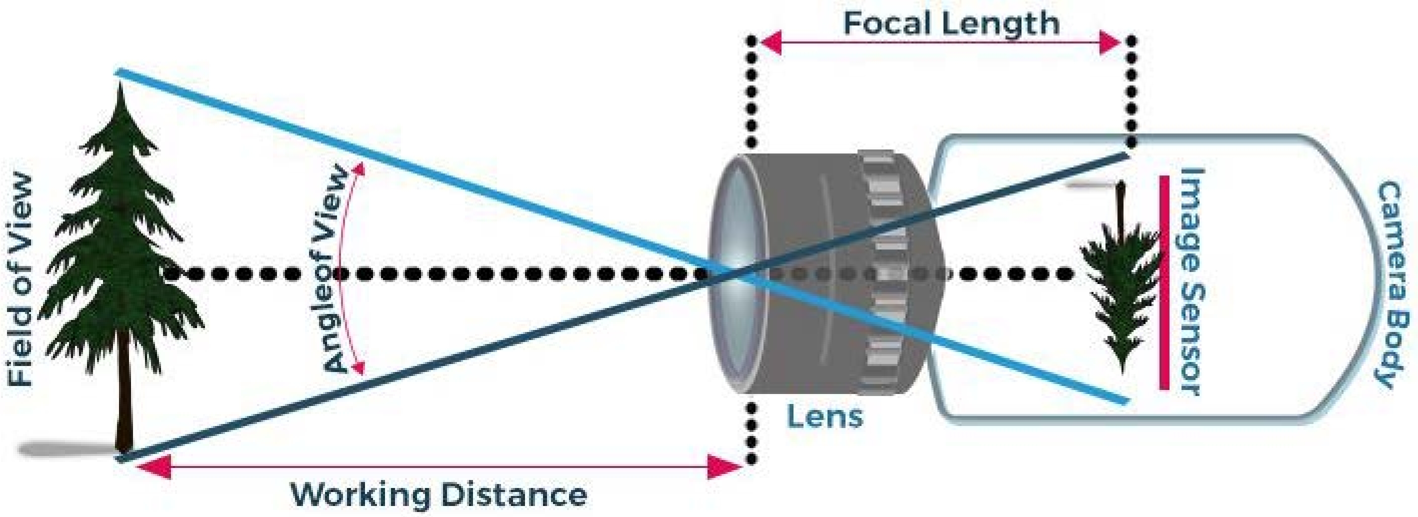
5. Pinhole camera

- A pinhole camera is a simple camera without a lens but with a tiny aperture – effectively a light-proof box with a small hole in one side.
- Light from a scene passes through the aperture and projects an inverted image on the opposite side of the box, which is known as the camera obscura effect.
- Camera calibration technique used in CG to generate synthetic camera models.
- Like pinhole, computer graphics produces images in which all objects are in focus

Pinhole camera





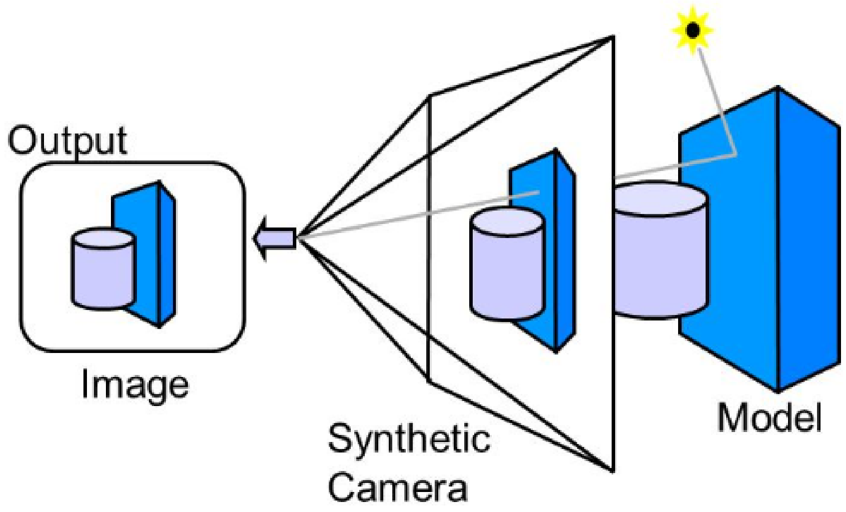


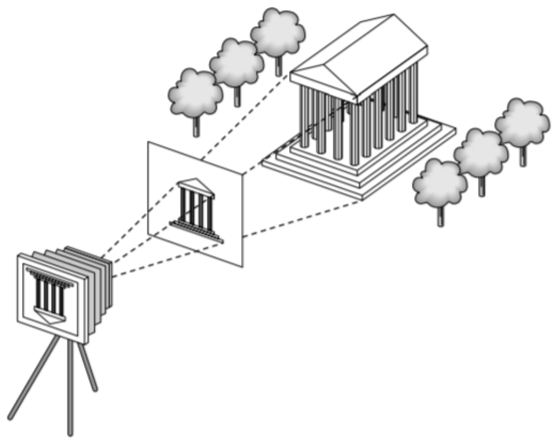
Disadvantages of pinhole camera

- The pinhole camera has an infinite depth of field.
- Too little light gets in
- The angle of view cannot be adjusted.

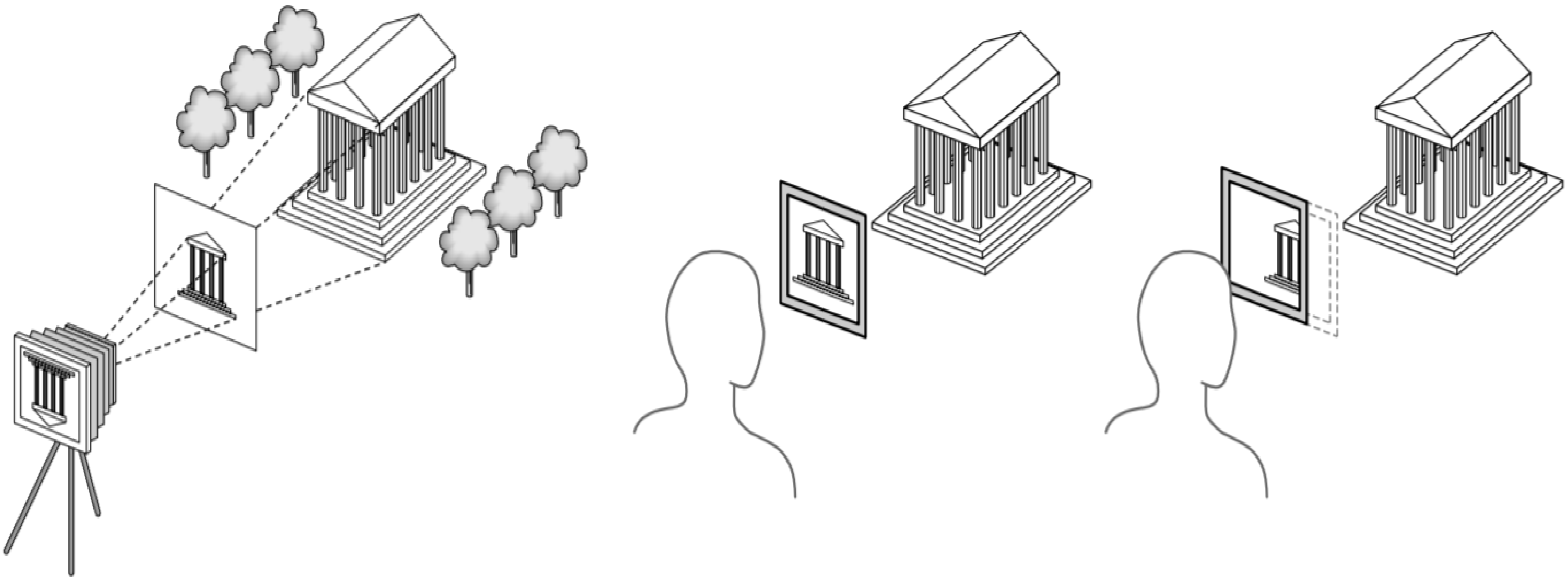
6. Synthetic camera

- In **computer graphics**, **synthetic camera model** is used to **mimic** the Behaviour of a real **camera**.
- In the synthetic camera model we **avoid the inversion** by placing the film plane, called the **projection plane**, in **front of the lens**.





Clipping rectangle or window



Day 4

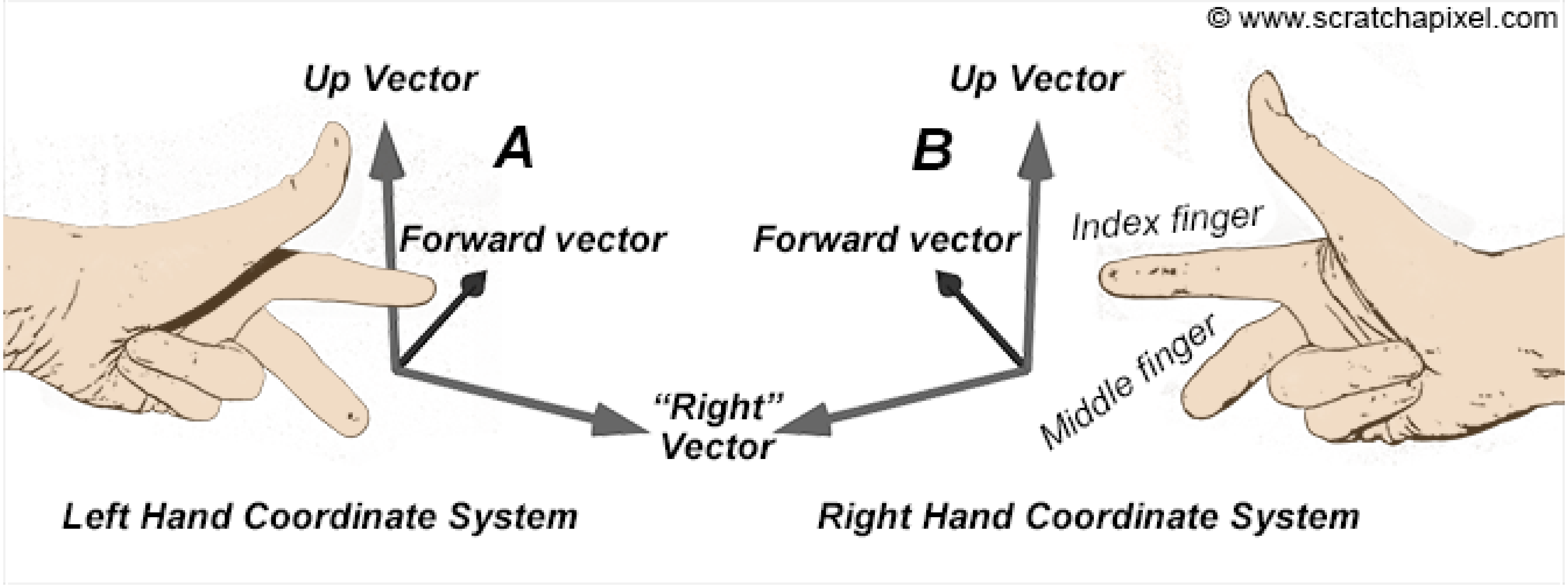
Agenda

- Coordinate System
  - Object Coordinates
  - Model/World/universe coordinates
  - Viewing/eye coordinates
  - Normalized coordinates
  - Device coordinates
- Key frames
- Model to View conversion
  - T-rex Example

What is CS ?

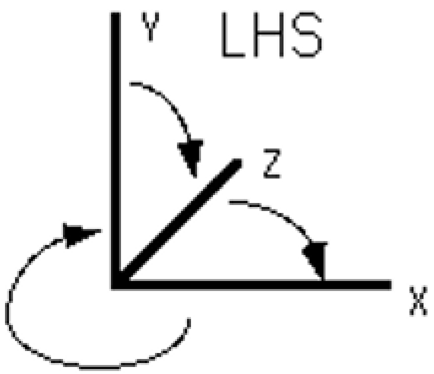
- Coordinate systems play an essential role in the graphics pipeline. They are not complicated; coordinates are one of the first things we learn in school when we study geometry.
- A coordinate system is a way of assigning numbers to points.
- In two dimensions, you need a pair of numbers to specify a point. The coordinates are often referred to as *x* and *y*, although of course, the names are arbitrary.
- Points and objects are real things, but coordinates are just numbers that we assign to them so that we can refer to them easily and work with them mathematically.
- In three dimensions, you need three numbers to specify a point. The third coordinate is often called *z*. The *z*-axis is perpendicular to both the *x*-axis and the *y*-axis.

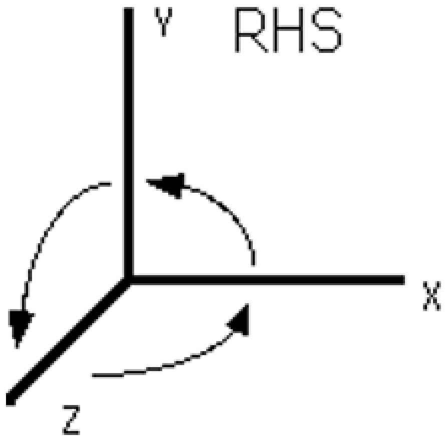
Handedness method(Finger Orientation)



Coordinate System "Handedness"

- In a 2-D coordinate system the X axis generally points from left to right, and the Y axis generally points from bottom to top. (Although some windowing systems will have their Y coordinates going from top to bottom.)
- When we add the third coordinate, Z, we have a choice as to whether the Z-axis points into the screen or out of the screen:



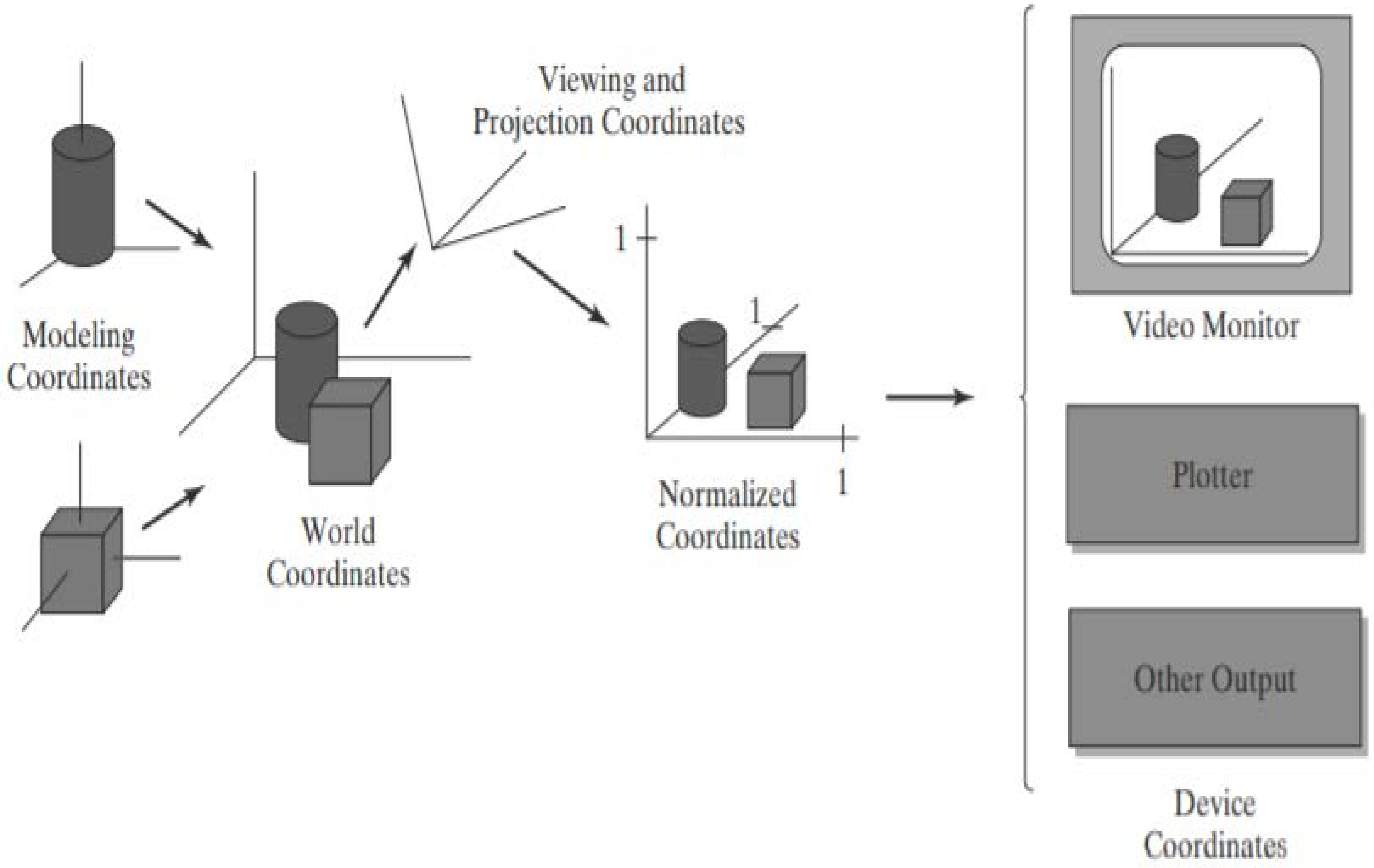


All Coordinates are usually right-handed except few.

- Open GL – RHS
- RenderMan-LHS
- Processing sw-LHS

Multiple Coordinate Systems in a Graphics Program

- Object coordinates
- Model/World coordinates
- Viewing/eye coordinates
- Normalized coordinates
- Device coordinates



1.Object Coordinates

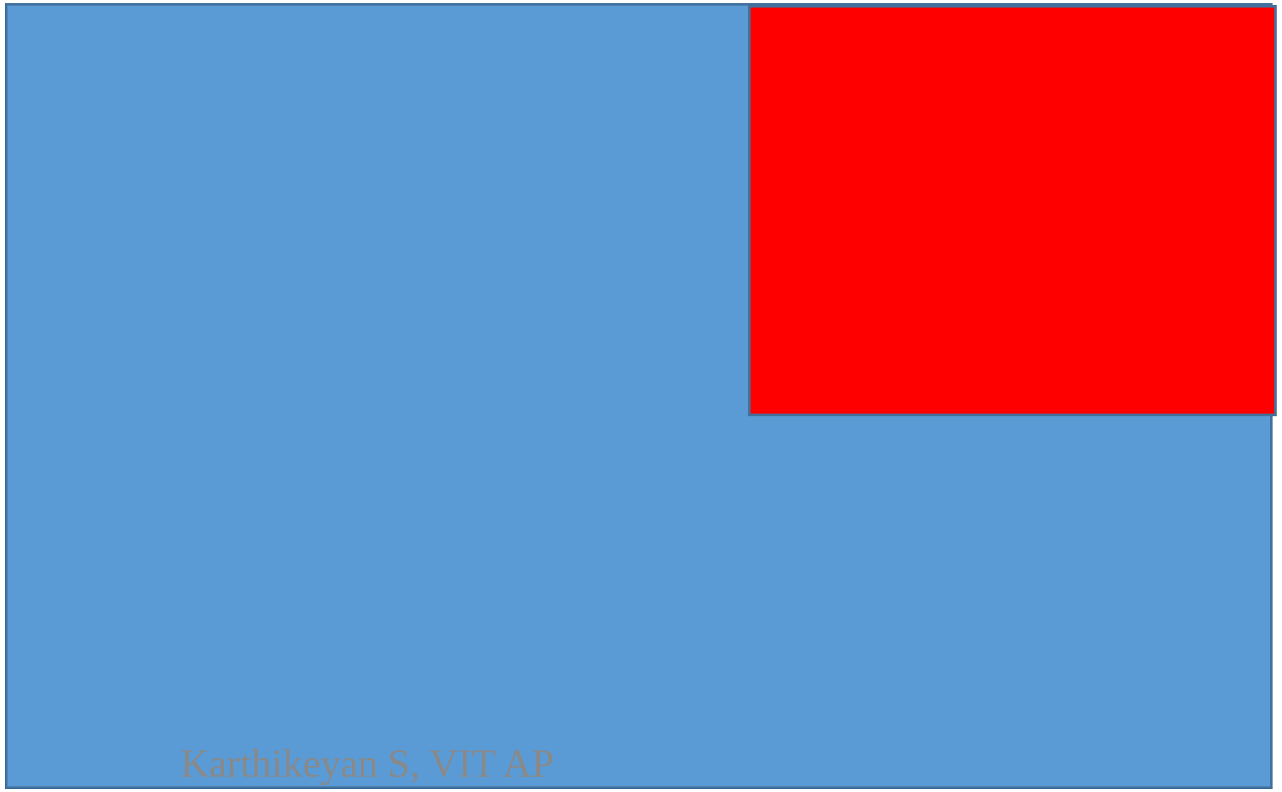
- The coordinates that you actually use for drawing an object are called object coordinates.
- The object coordinate system is chosen to be convenient for the object that is being drawn.
- A modeling transformation can then be applied to set the size, orientation, and position of the object in the overall scene . The modeling transformation is the first that is applied to the vertices of an object.

2. Model/World/universe coordinates

- The coordinates in which you build the complete scene are called world coordinates.
- These are the coordinates for the overall scene, the imaginary 3D world that you are creating. The modeling transformation maps from object coordinates to world coordinates.
- Defines the shapes of individual objects, such as trees or furniture, within a separate reference frame.
- These reference frames are called modeling coordinates, or sometimes local coordinates or master coordinates

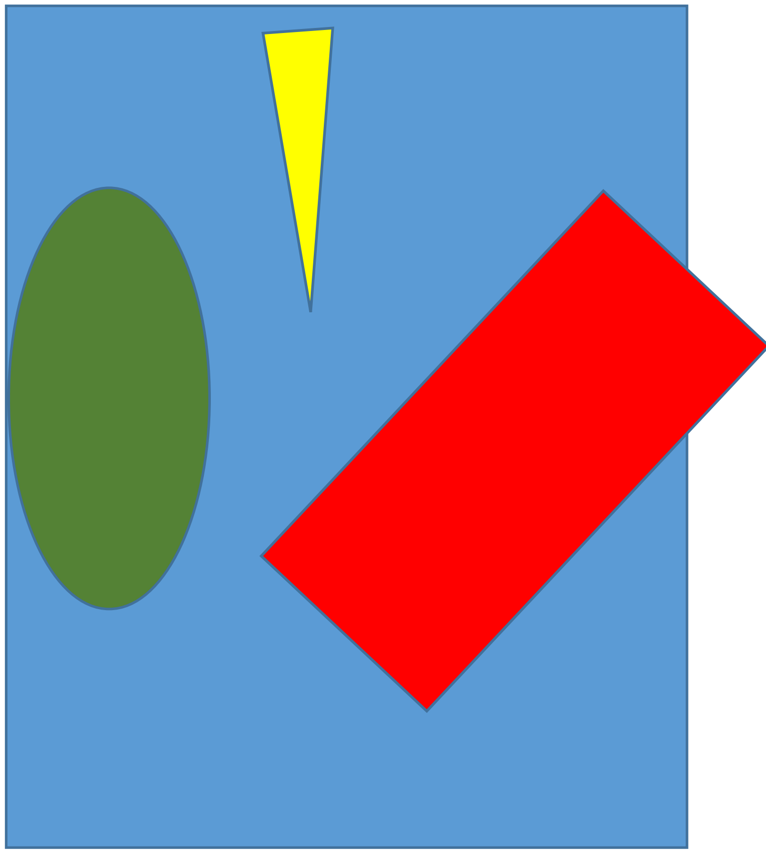
Model

- Object with respect to its own universe.
- The model can be placed in the world.



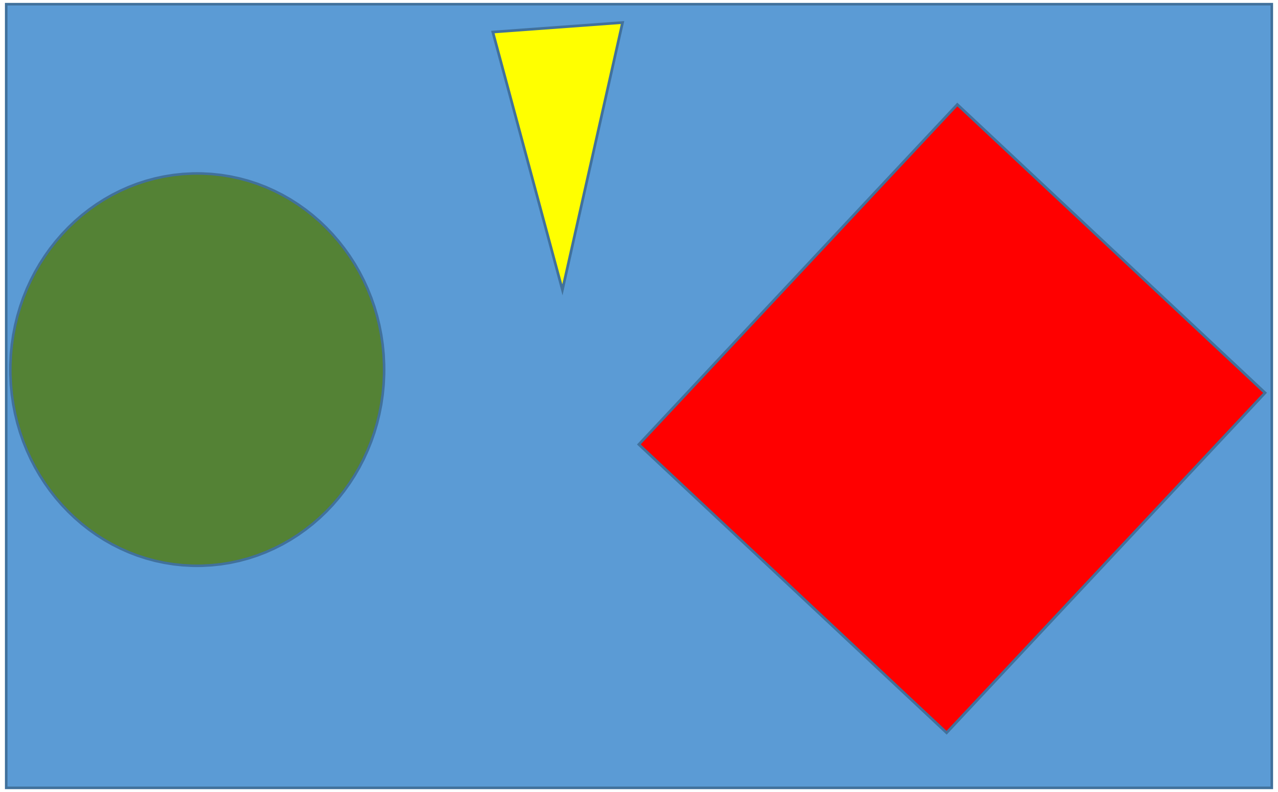
World coordinates

- Once the individual object shapes have been specified a scene is constructed by placing the objects into appropriate locations within a scene reference frame called world coordinates.
- This step involves the transformation of the individual modeling-coordinate frames to specified positions and orientations within the world-coordinate frame.
- For a repeating object only one modelling coordinate is created.
- Translate,rotate,scale..etc



World

- The entire world is populated with multiple models with different positions and scales.



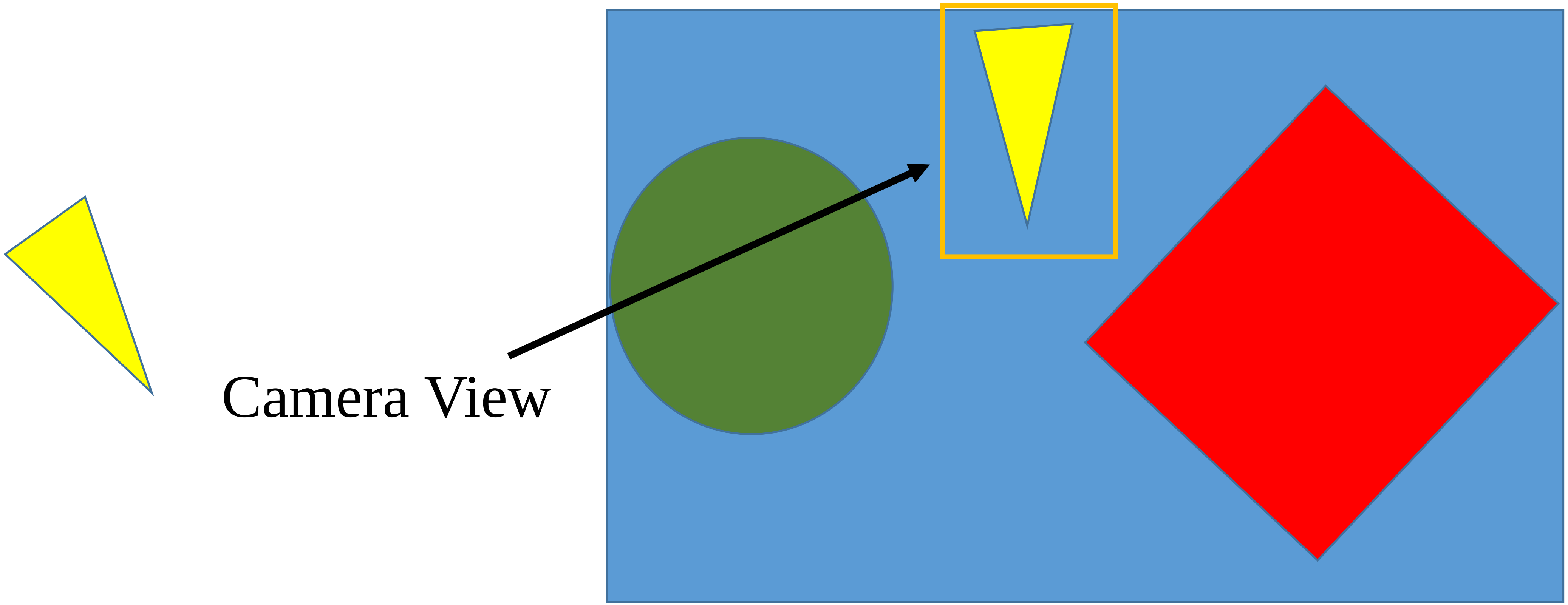
- Scale
- Transform
- Rotate

3.Viewing/Eye/camera Coordinates

- World coordinate positions are first converted to viewing coordinates corresponding to the view we want of a scene, based on the position and orientation of a hypothetical camera.
- Then object locations are transformed to a two-dimensional (2D) projection of the scene, which corresponds to what we will see on the output device.

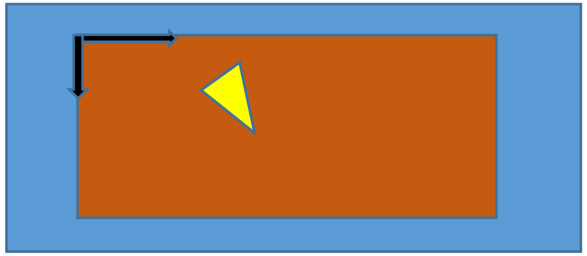
Camera

- In the World we can define the camera. Hence the camera is used for looking or projecting the objects.



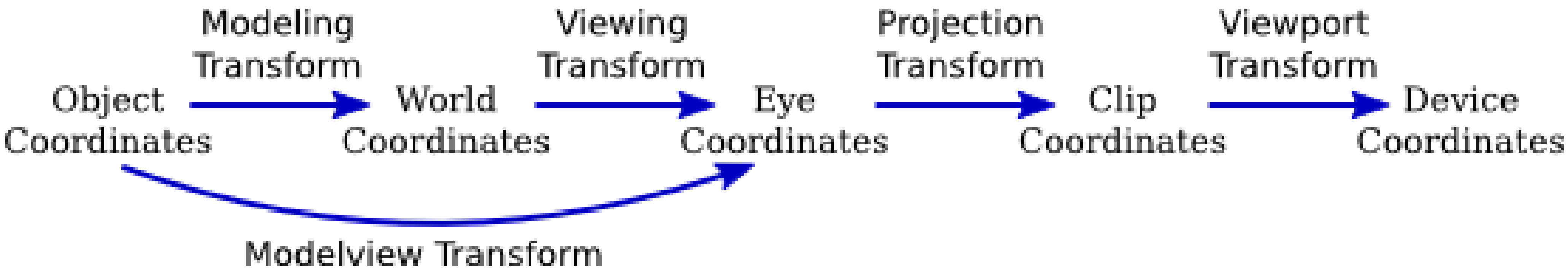
4.Normalized coordinates

- The scene is then stored in normalized coordinates, where each coordinate value is in the range from −1 to 1 or in the range from 0 to 1, depending on the system.
- Normalized coordinates are also referred to as normalized device coordinates, since using this representation makes a graphics package independent of the coordinate range for any specific output device
- We also need to identify visible surfaces and eliminate picture parts outside the bounds for the view we want to show on the display device.



Device coordinates

- Finally, the picture is scan-converted into the refresh buffer of a raster system for display.
- The coordinate systems for display devices are generally called device coordinates, or screen coordinates in the case of a video monitor.
- Let's go through the sequence of transformations one more time. Think of a primitive, such as a line or triangle, that is part of the scene and that might appear in the image that we want to make of the scene.



The primitive goes through the following sequence of operations:

- The points that define the primitive are specified in object coordinates, using methods such as glVertex3f.
- The points are first subjected to the modelview transformation, which is a combination of the modeling transform that places the primitive into the world and the viewing transform that maps the primitive into eye coordinates.
- The projection transformation is then applied to map the view volume that is visible to the viewer onto the clip coordinate cube. If the transformed primitive lies outside that cube, it will not be part of the image, and the processing stops. If part of the primitive lies inside and part outside, the part that lies outside is clipped away and discarded, and only the part that remains is processed further.
- Finally, the viewport transform is applied to produce the device coordinates that will actually be used to draw the primitive on the display device. After that, it's just a matter of deciding how to color the individual pixels that are part of the primitive.
- We need to consider these transforms in more detail and see how to use them in OpenGL 1.1.

Reference: Coordinate System

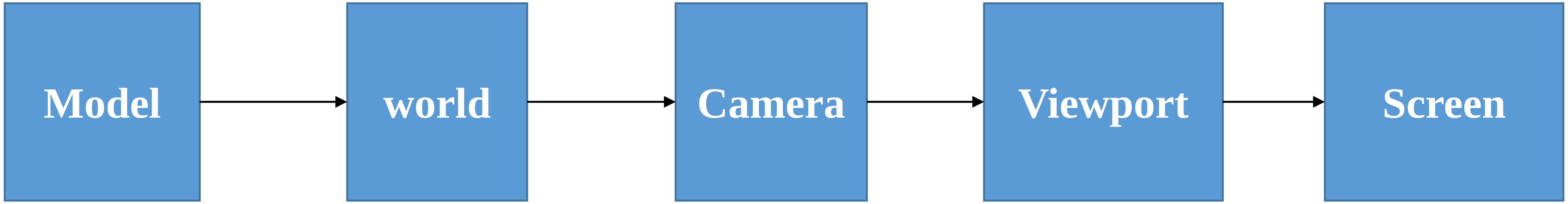
- http://math.hws.edu/graphicsbook/c3/s2.html

- https://www.cs.uic.edu/~jbell/CourseNotes/ComputerGraphics/Coordinates.html#:~:text=Screen%20Coordinate%20System%20%2D%20This%202D,based%20on%20current%20screen%20resolution.&text=Viewport%20Coordinate%20System%20%2D%20This%20coordinate,window%20is%20to%20be%20displayed.

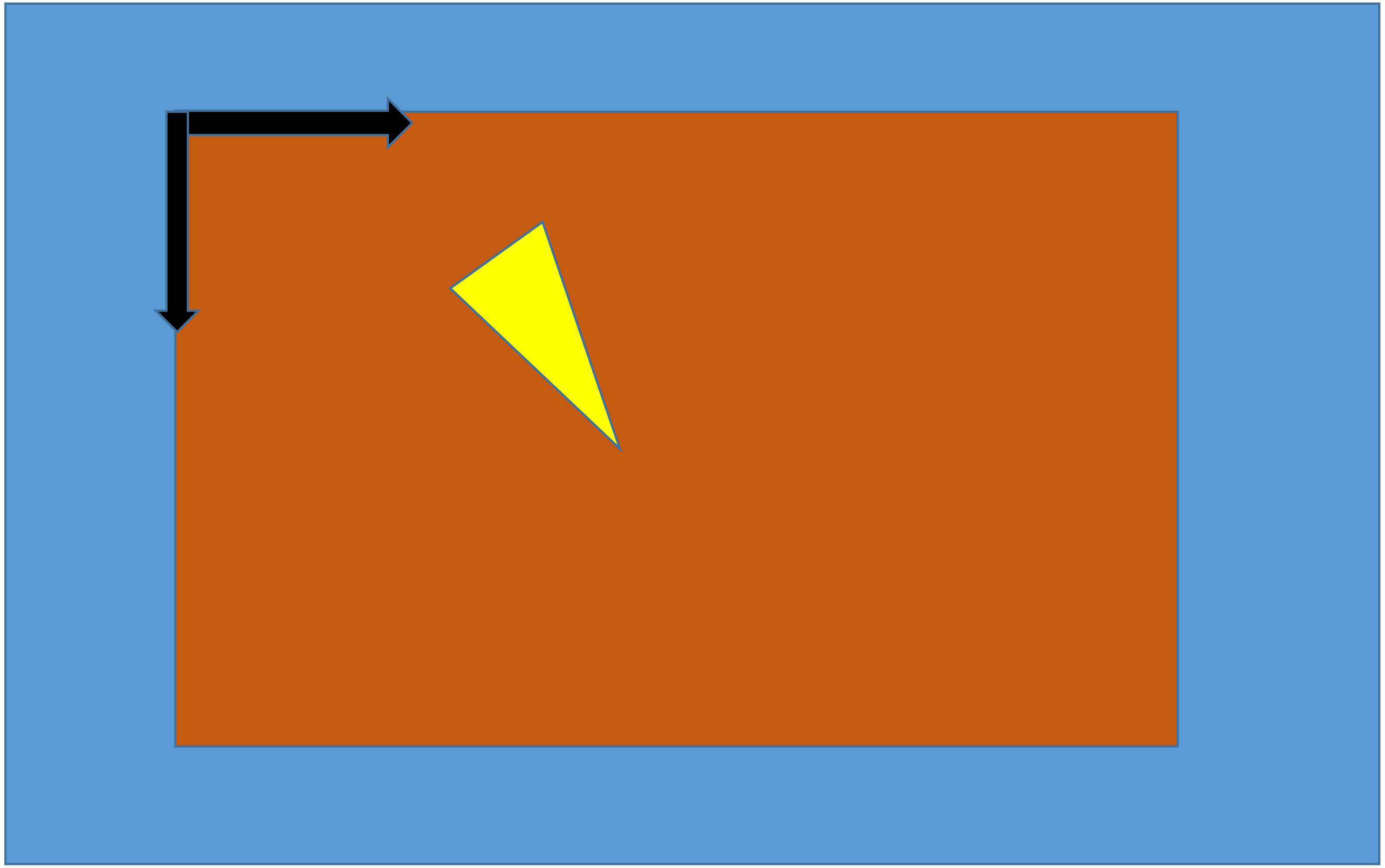
- https://www.scratchapixel.com/lessons/mathematics-physics-for-computer-graphics/geometry/coordinate-systems

Graphics pipeline

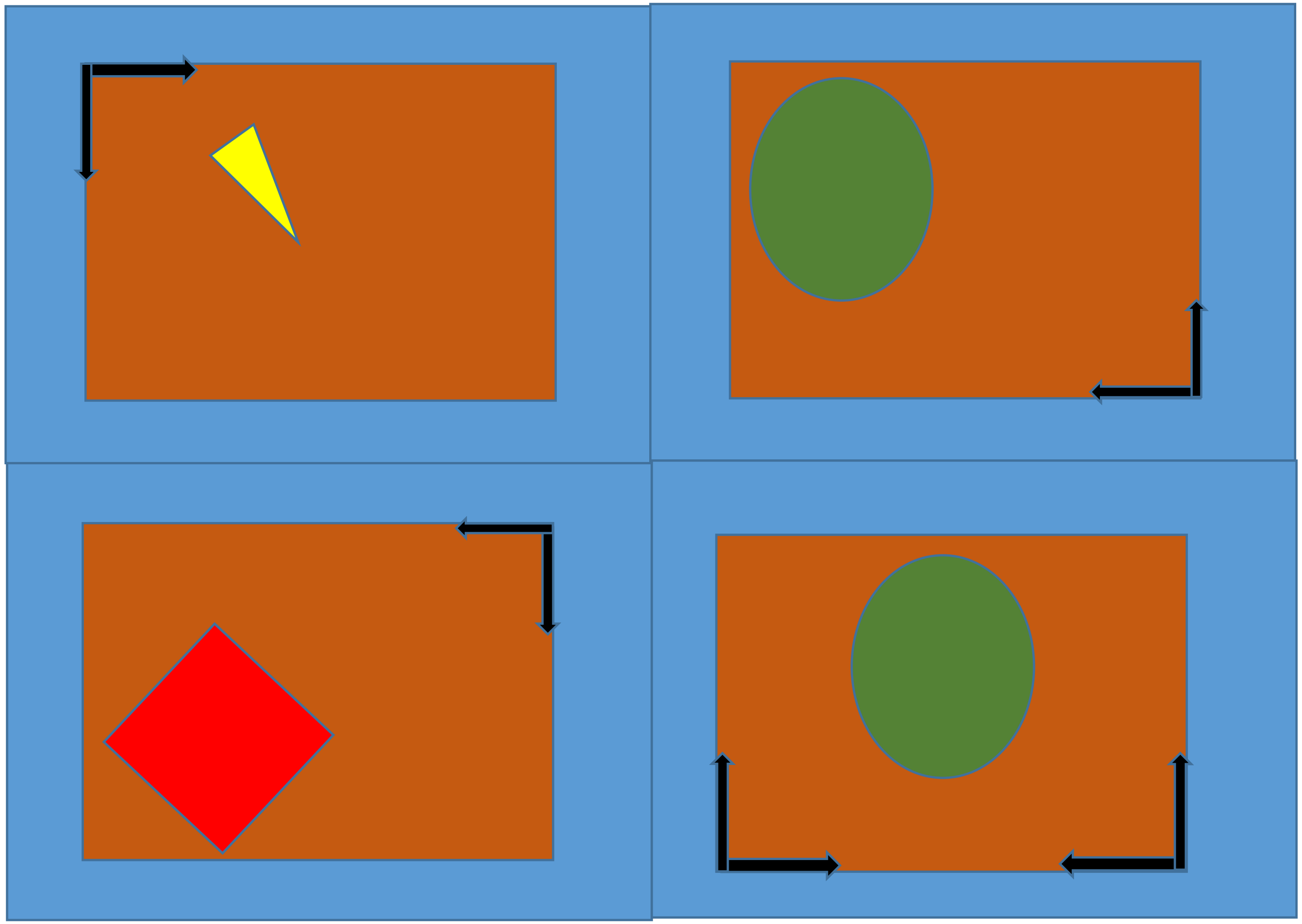
- In **computer graphics**, a **computer graphics pipeline**, **rendering pipeline** or simply **graphics pipeline**, is a conceptual model that describes what steps a **graphics** system needs to perform to render a 2D or 3D scene.



View port



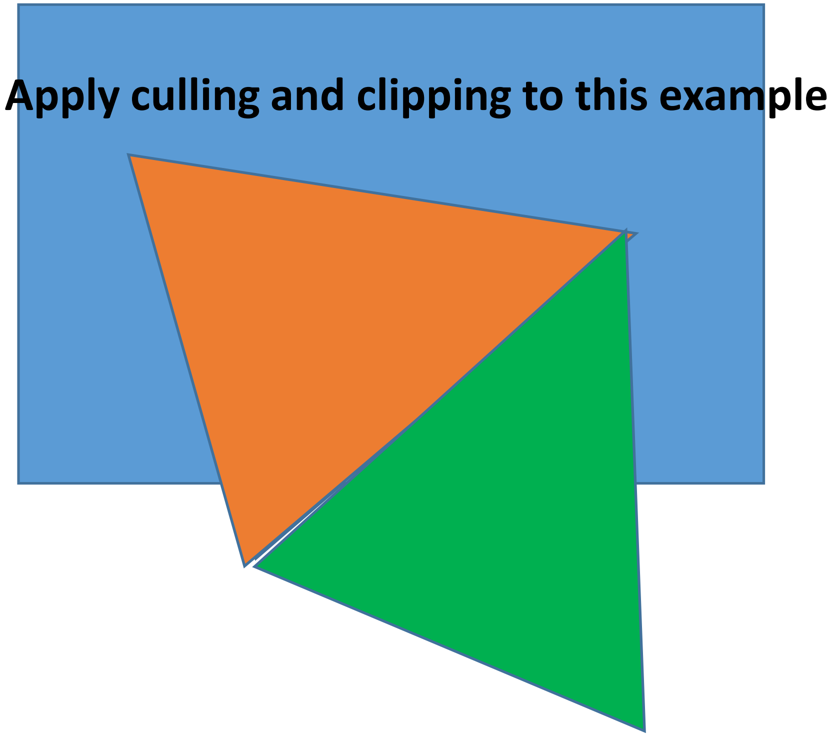
Screen



Common properties

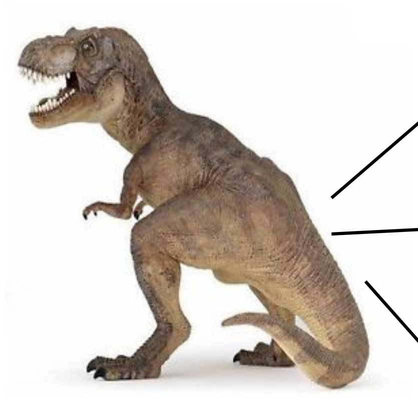
- Multi cameras in the world.
- Multi view ports in the screen space.
- Culling
  - Act of excluding entire object from the pipeline.
- Clipping
  - Act of cutting out a portion of an object.

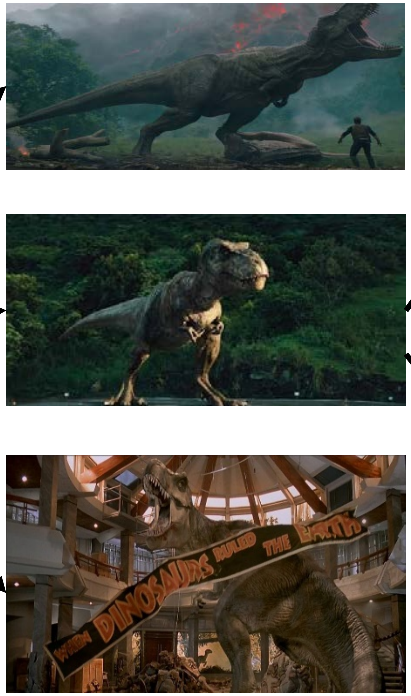
- **Note:**
  - Clipping and culling takes place in world space

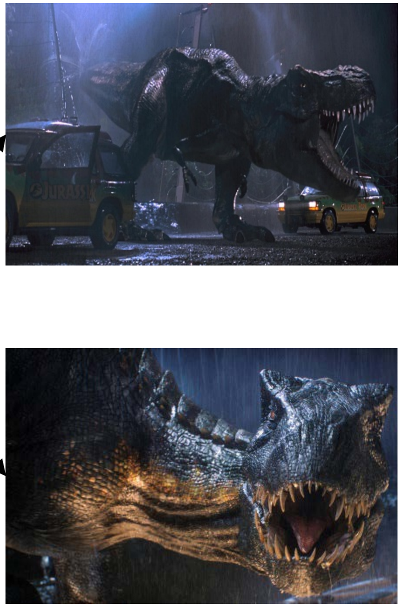


T-rex in Real world

Model → world → Camera → Viewport → Screen





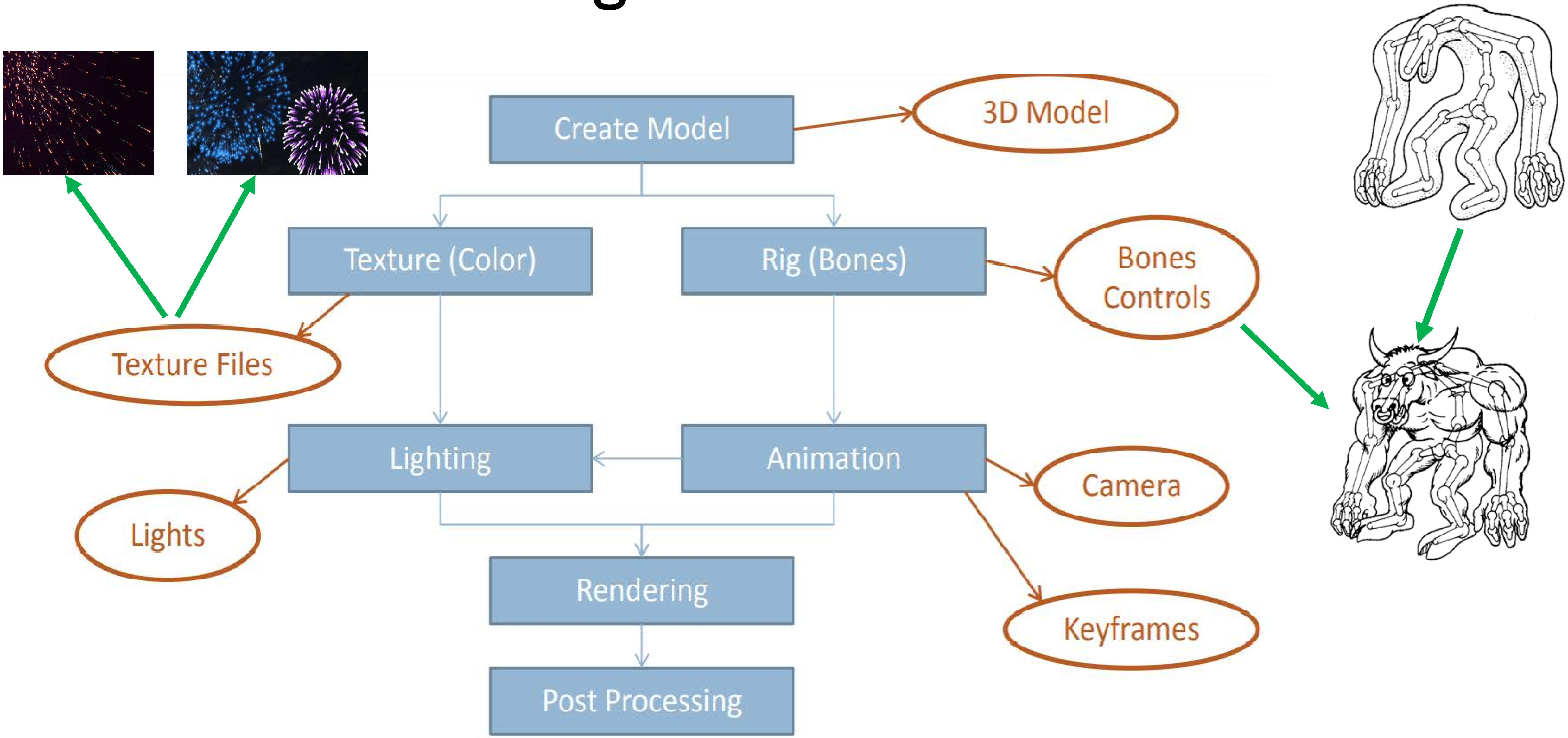


What are the factors which affect the image?

What are the factors which affect the image?

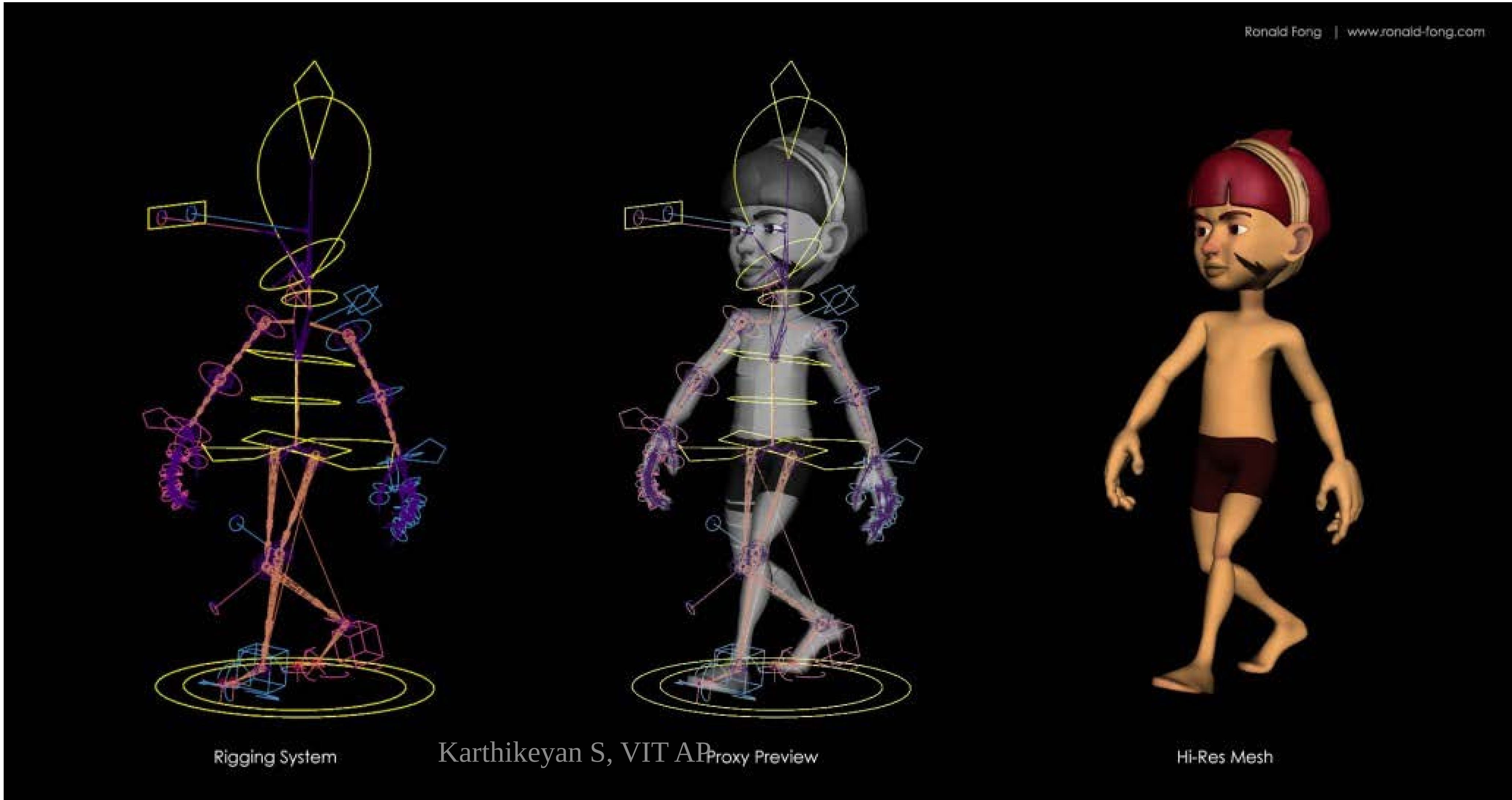
- In creating **photorealistic** images, half of the problem is to correctly reproduce camera properties such as ***field of view***, ***depth of field***, ***exposure***, ***image aspect ratio***; the other half is to correctly reproduce the **physics of light on materials** comprising the objects in the scene.

Character Modelling – 3D



Animation

Day 5



Agenda

- Animation & its types
- Rendering - Factors to be considered
- Computer vision vs Image processing
- Mathematical object models – A review
- Module Summary

Animation

- Animation is a method in which figures are manipulated to appear as moving images.
- traditional animation, images are drawn or painted by hand on transparent celluloid sheets to be photographed and exhibited on film. Today, most animations are made with computer-generated imagery.

- Application
  - Video games
  - Cartoons/movies
  - Mobile applications

Designing animation sequence

- Story board layout
- Object and path definition
- Key frame specification
- Generation of in-between frames

Stages

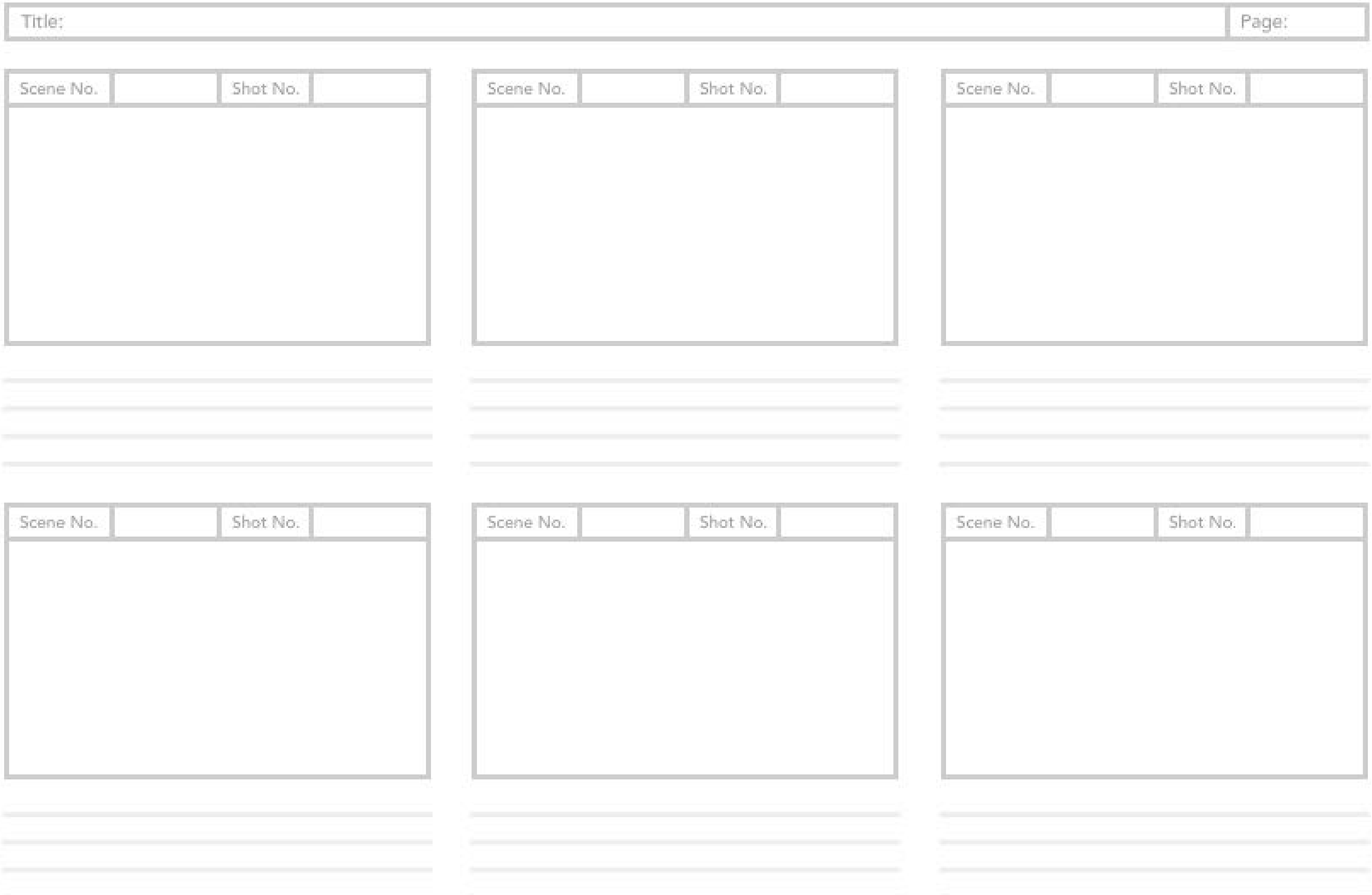
- Pre production
- Production
- Post production

1. Storyboard

- Storyboard is basically the layout of what action is going to happen in the animation.

- Depending on type of animation the storyboard layout may contain images of the objects and also a list of basic motion ideas in the animation sequence.

Storyboard Template



General (Shots & B.. > Shot Lists & Storyboards v0 View Only

Print View

There Will Be Blood

8 SHOTS

Shot 1

MCU · HA · Static · Steadicam

Shot 2

MCU · LA · Static · Hand Held

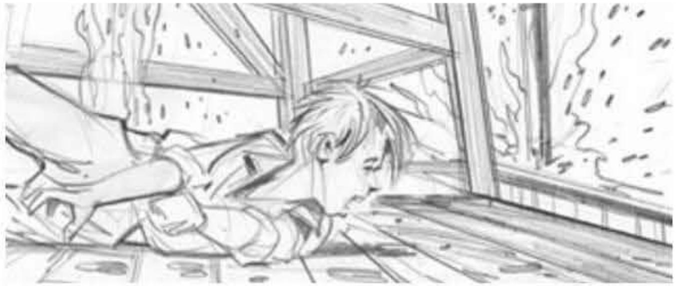
Shot 3

WS · LA · Static · Hand Held

Shot 4

MS · HA · Tracking · Hand Held

Shot 5

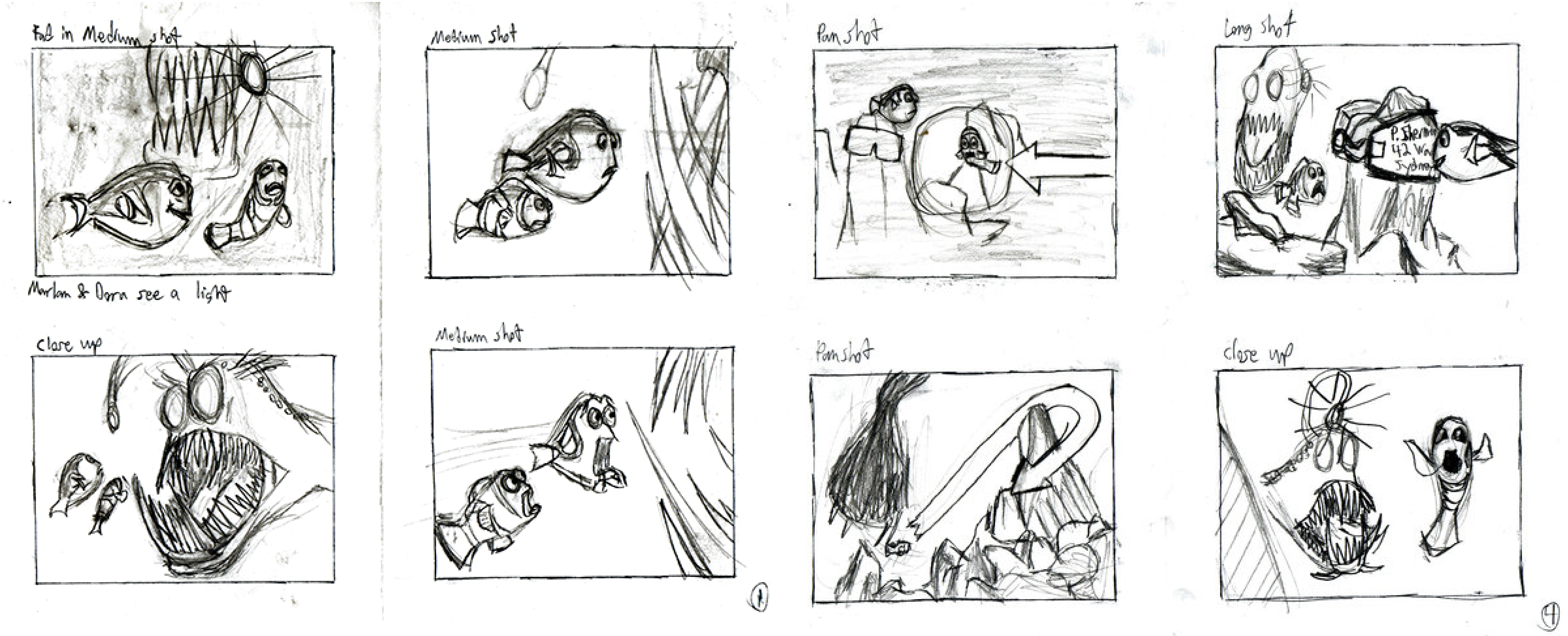


MS · Ground Level · Static · Hand Held

Shot 6

MS · Eye Level · Tracking · Steadicam

Story board

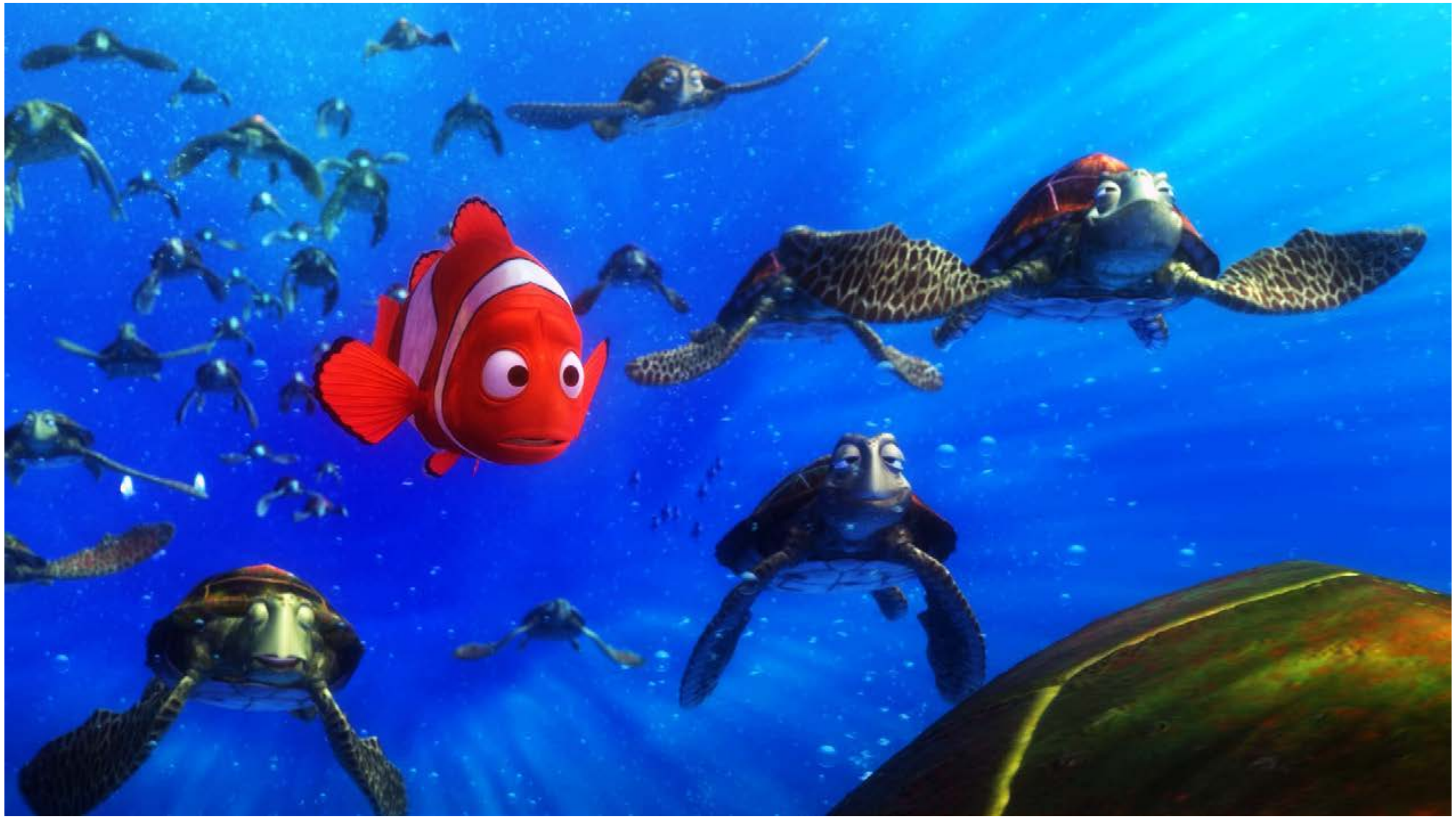

Medium shot
Marlon & Dorn see a light
Close up
Medium shot
Medium shot
Pan shot
Pan shot
Long shot
Close up

2. Object Definition:

- An object definition is given for each participant in the animation. Objects are defined by specifying what type of basic shapes are there in the object, what are properties that is the color or size of the object.

- Also the motion of the objects that is the movements of the objects is also mentioned with the shape.

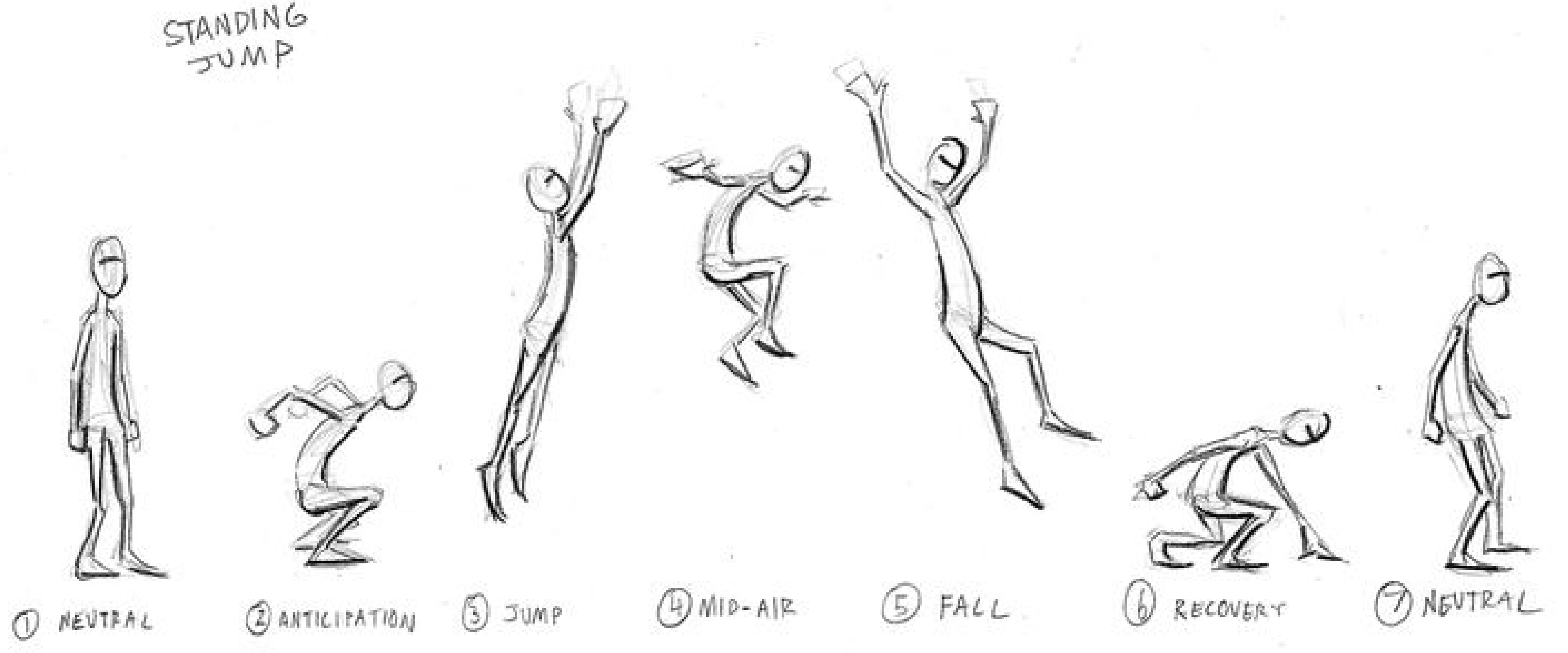
Object and path definition



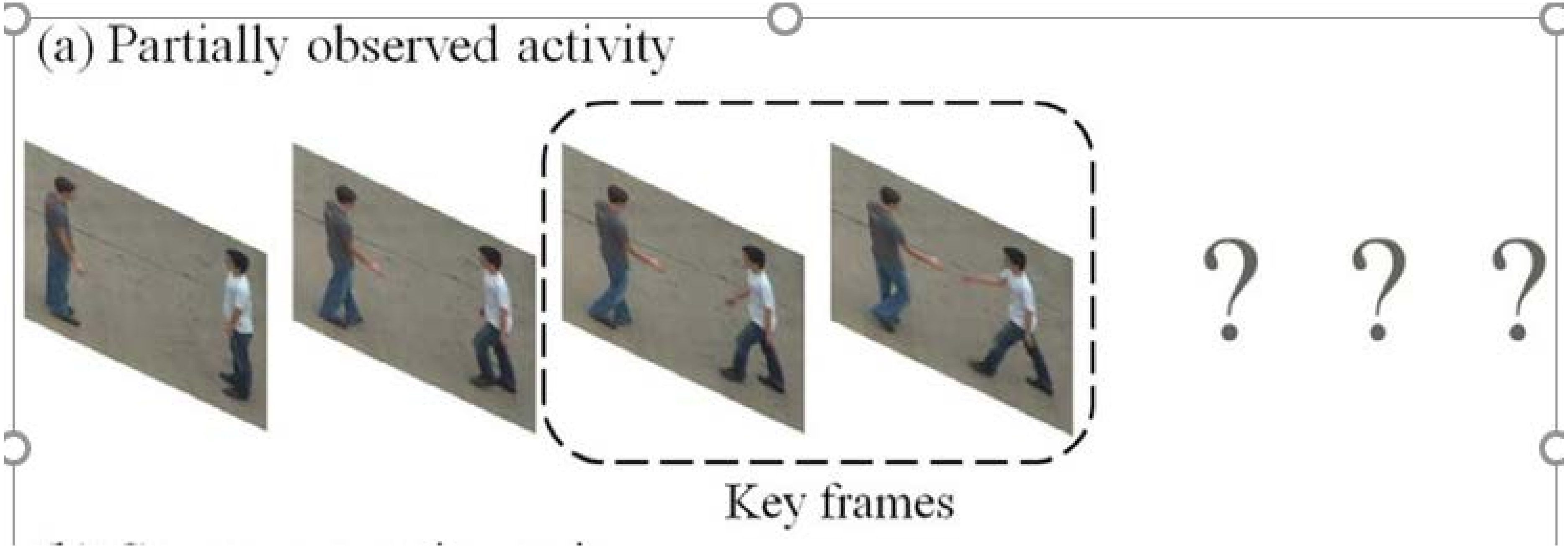
3. Key Frame Specification:

- A key frame is detailed drawing of the scene at a particular moment.
- In each key frame the objects are placed at exact specific position according to specific time in the animation sequence.
- Key frames are spaced at short time intervals so better animation sequence is developed, as it provides more information about position of objects at specific times intervals is available.

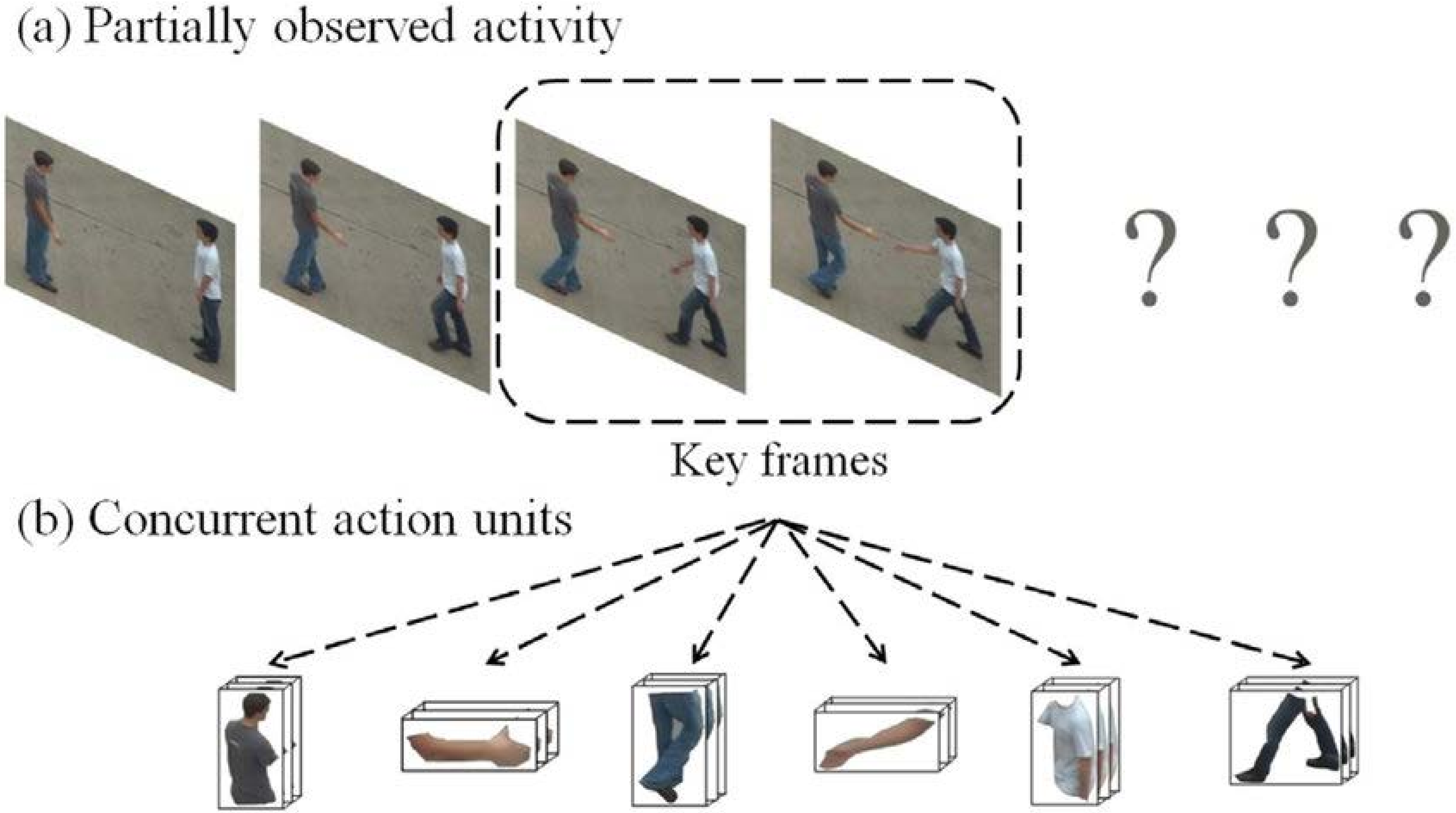
Keyframes are important frames during which an object changes its size, direction, shape or other properties



Can you predict possible keyframes.



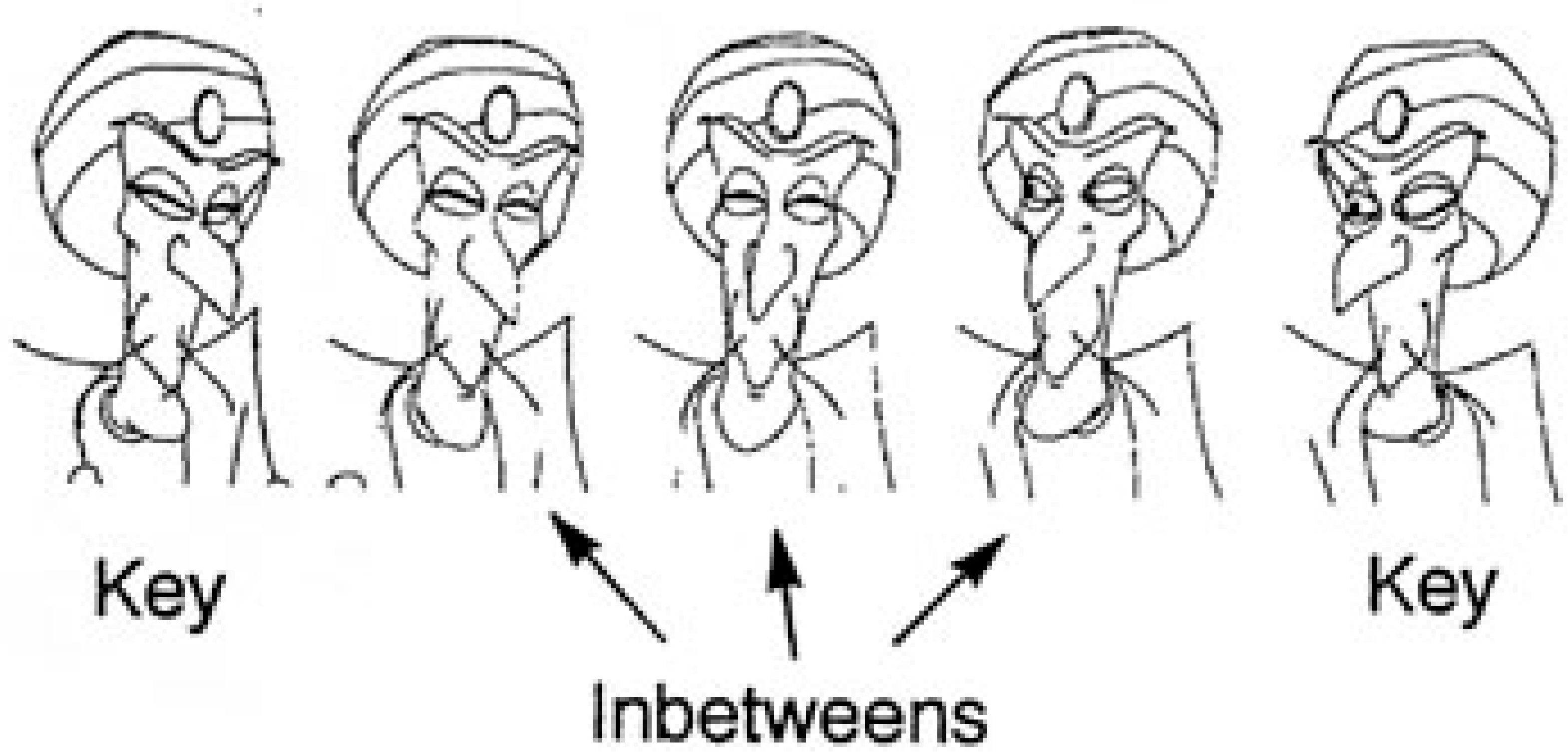
Can you predict possible objects/keyframes.



4. Generation of In-between frames

- In between frames are frames that are in between the key frames. Depending on the medium the number of in between frames differ.
- For example on film there are 24 frames per second and on Television or graphic monitors the frame rate is 30 to 60 frames per second.
- Usually there are 3 to 5 in between frames between 2 Key frames.

4.Key frames and in-between frames generation



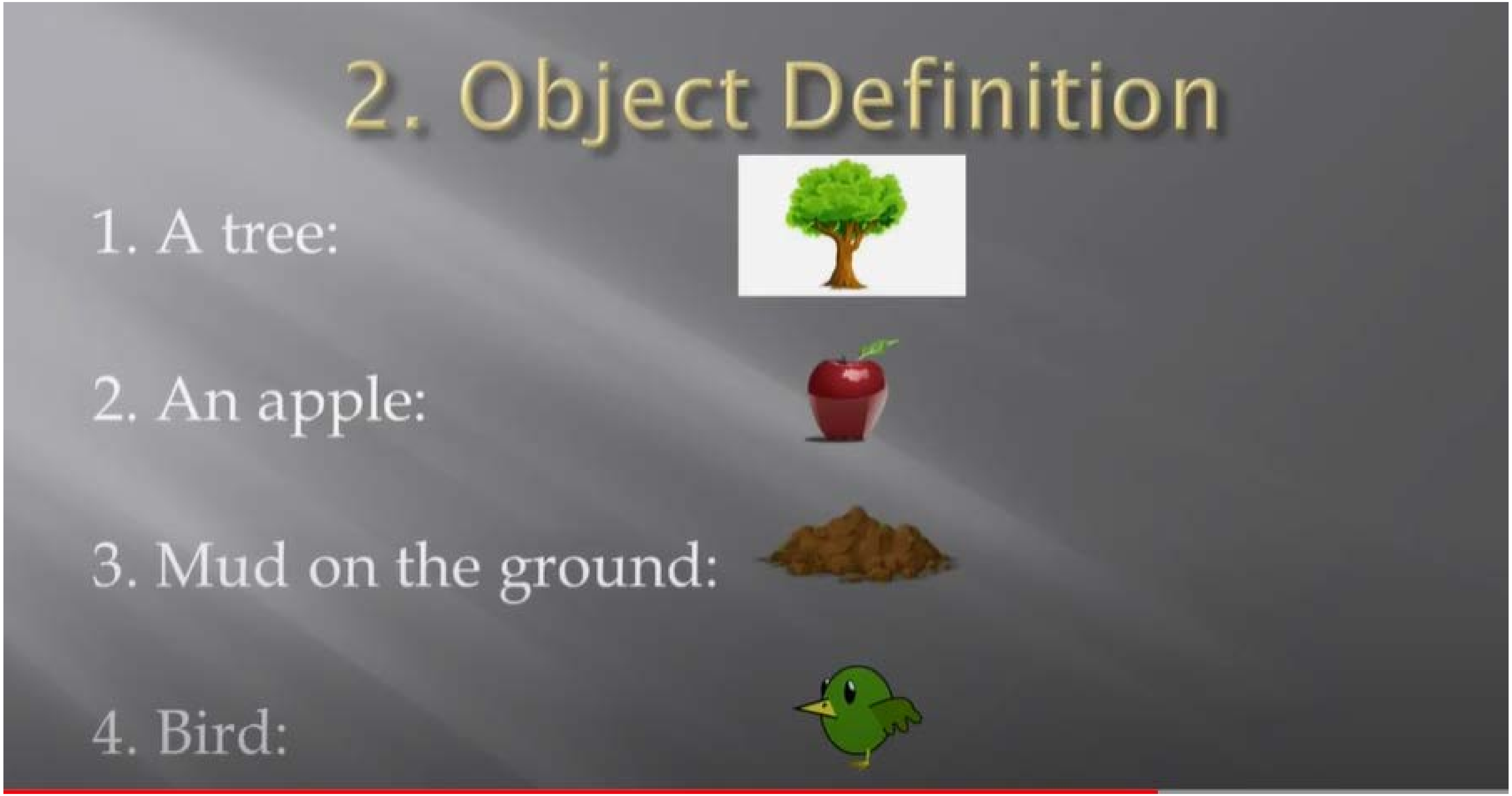
Example

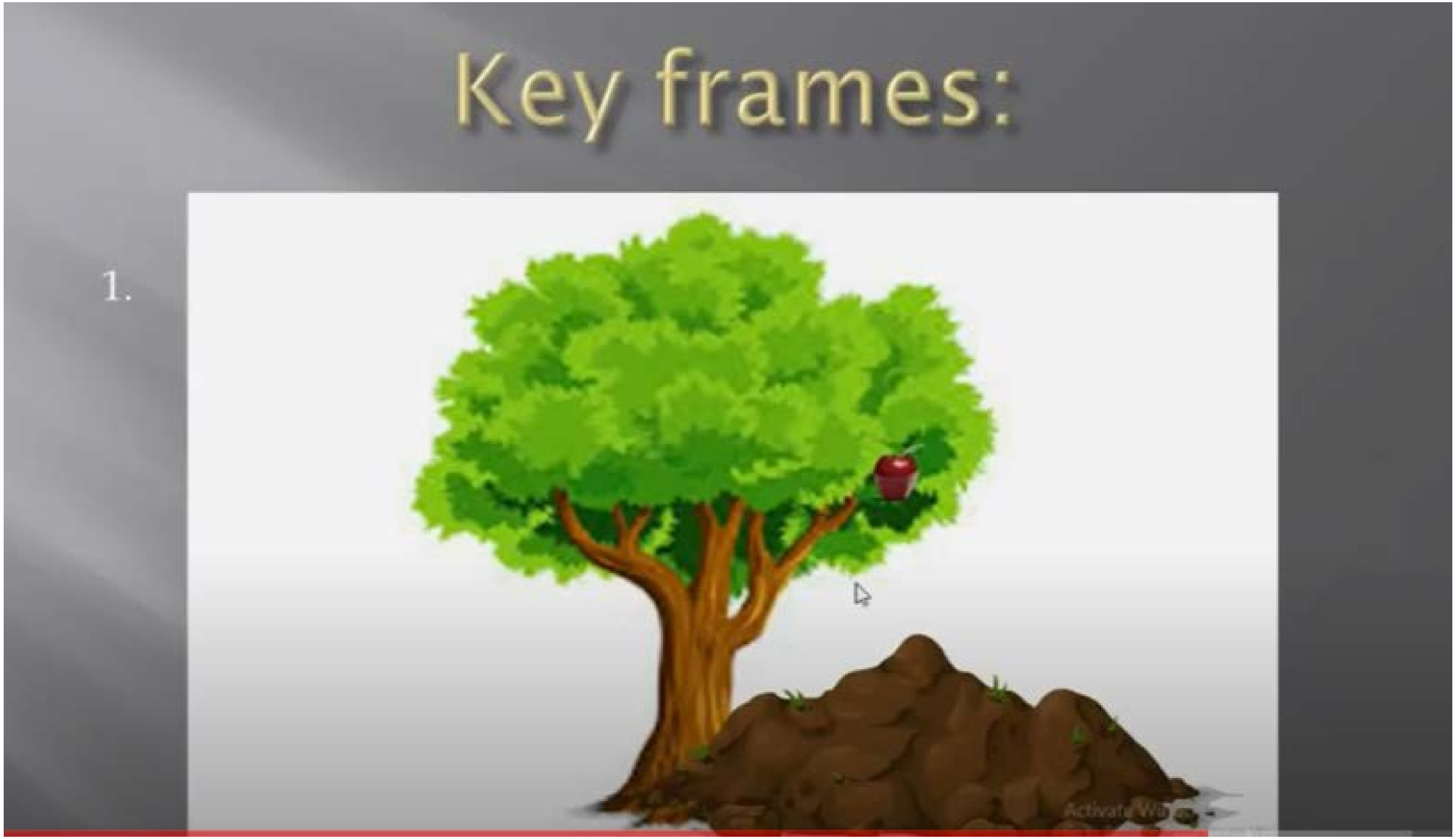
1. Storyboard layout.

a. In our animation one apple falls from a tree and bounces to the ground.

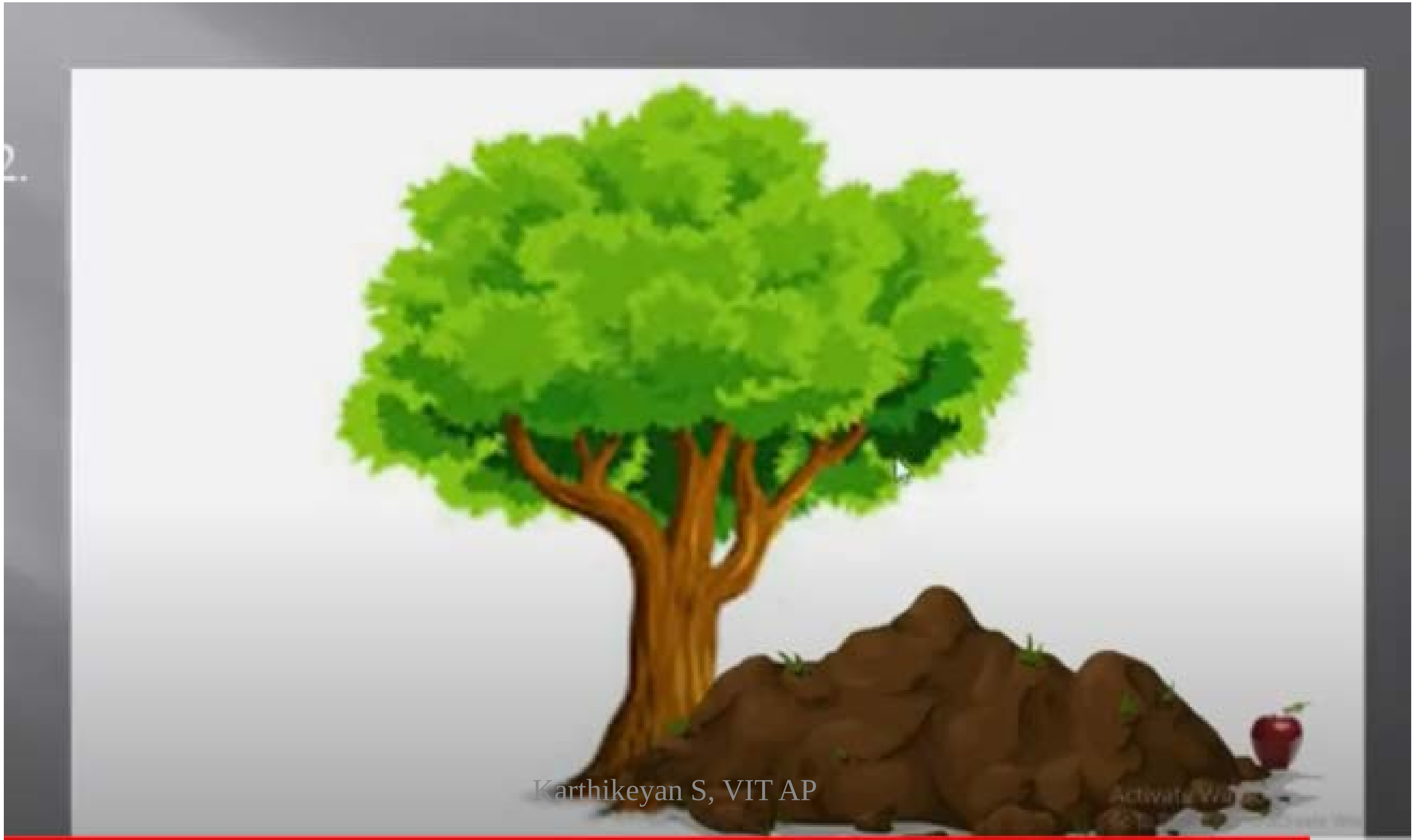
b. Then a bird flies in and swirls around in the air to see if any danger is there.

c. Then it sits on the apple picks it up and flies away.


2. Object Definition
1. A tree:
2. An apple:
3. Mud on the ground:
4. Bird:


Key frames:
1.

In-between key frames(2-9)




3.


4.


5.


6.


7.


8.


9.

General 5 types of animation is

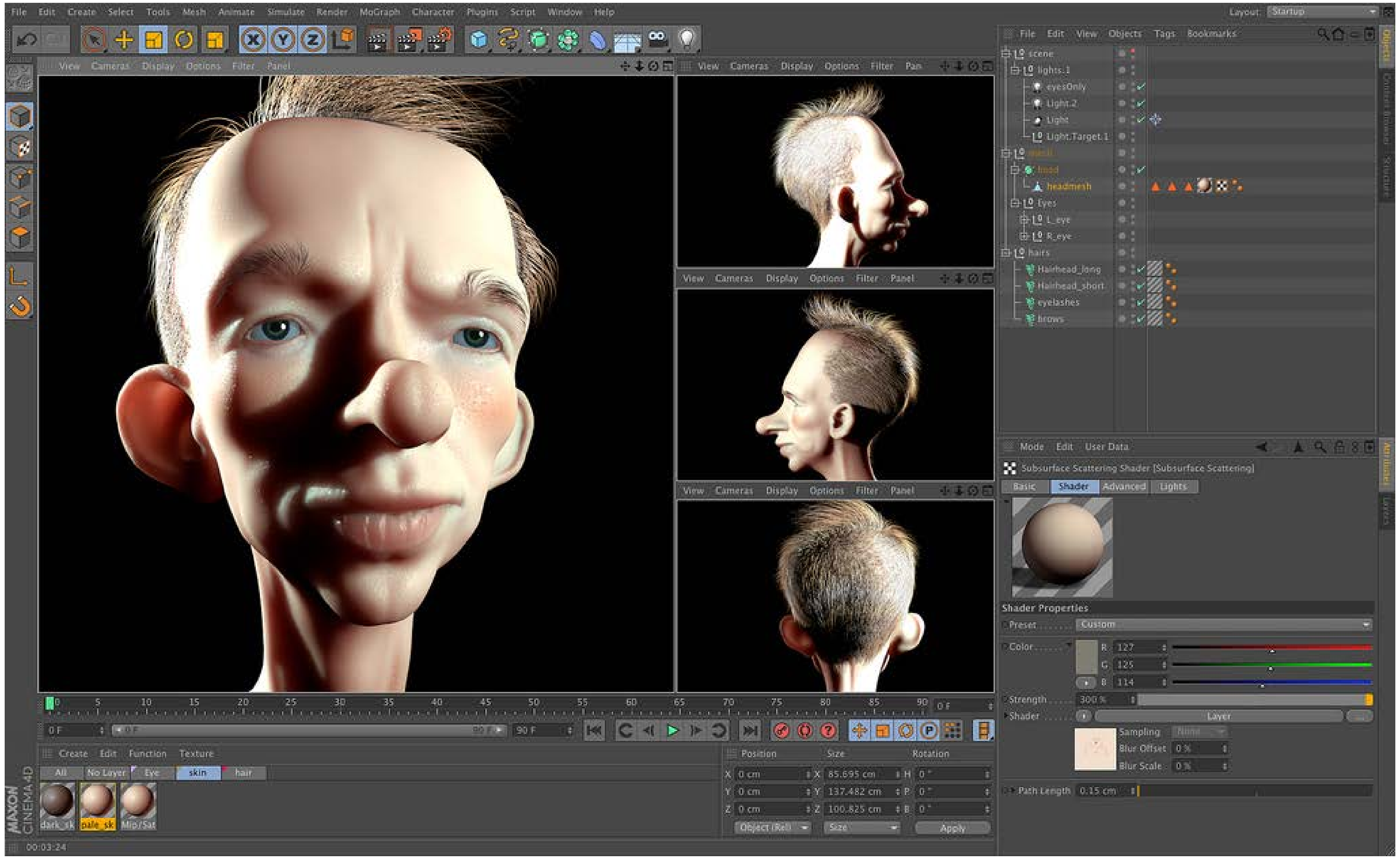
- 1. Cel (Celluloid) Animation
- 2. 2D Animation
- 3. 3D Animation
- 4. Motion Graphics
- 5. Stop Motion

hand-drawn cel animation frame by frame

2D

Antics Scene: C:\Antics\LIBRARY\RABBIT.DAT - 3 Dwgs 26 Cels
File View Scene Odds'n'Sods Help
Replay: RABBIT
1 Foreground
2 Rabbit
3 Shadow
LT Play
Paint Play
Paint It
Clear Off
61
GO
Play Speed: Normal
Slow
Normal
Fast
Frame 61: Repeat 2, Skip 2... Click on list to play animation for a drawing...
Zoom
Position
768 x 576
Screen Pen

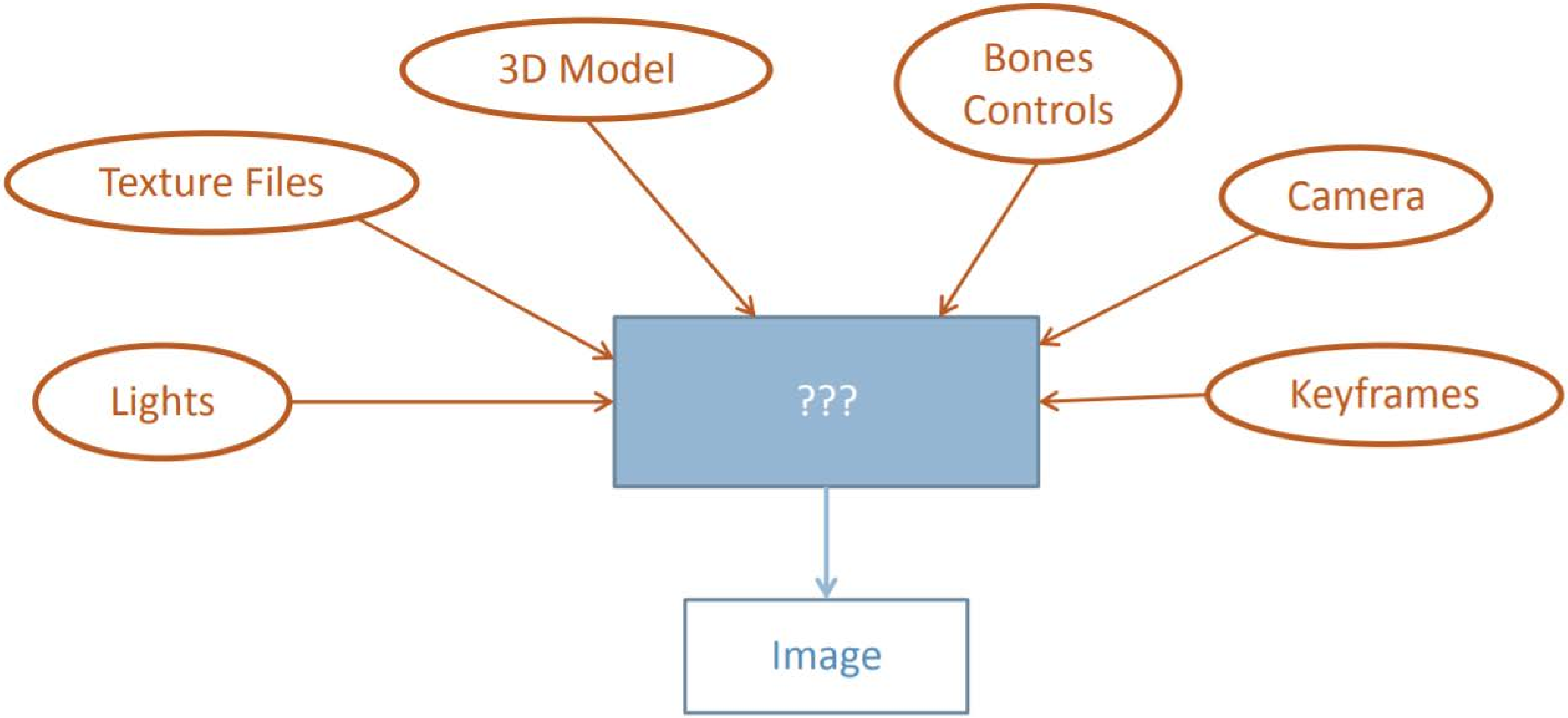
3D


File Edit Create Select Tools Mesh Animate Simulate Render MoGraph Character Plugins Script Window Help

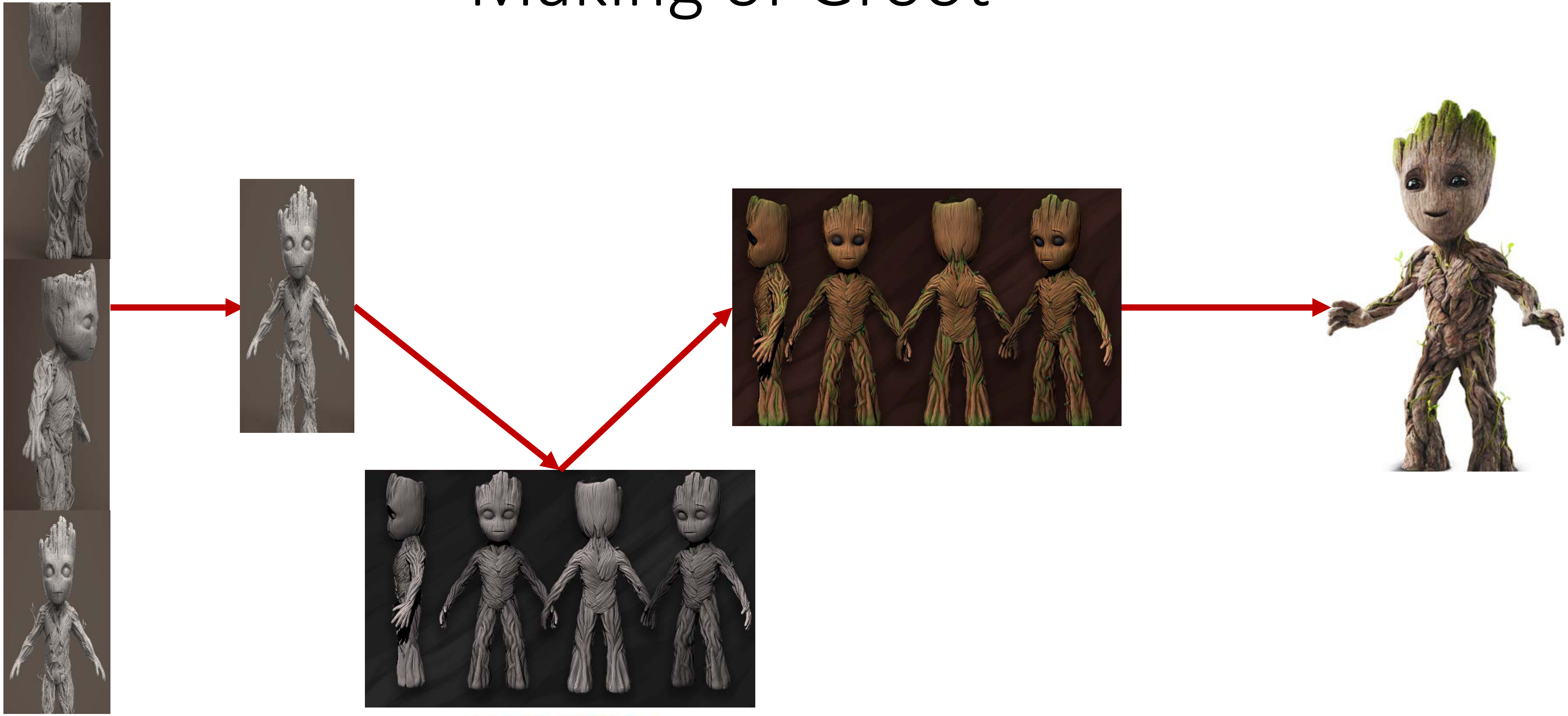
5. Stop Motion

Day 6

Rendering


3D Model
Bones
Controls
Texture Files
Camera
Lights
???
Keyframes
Image

Making of Groot



3D Model + Bones Controls + Keyframes = Geometry

Rendering Groot

2. Rendering - Factors to be considered

- Projection
- Occlusion (technique used to calculate how each point in a scene is exposed to lighting)
- Color / Texture
- Lighting
- Shadows
- Reflections / Refractions (reflected rays/ transmitted rays)
- Indirect illumination (techniques used to add more realistic lighting to 3D scenes)
- Sampling / Antialiasing (technique used to reduce the visual defects that occur when high-resolution images are presented in a lower resolution)

3. Computer vision vs Image processing

- ***Computer Vision:*** Computer vision is an interdisciplinary scientific field that deals with how computers can gain high-level understanding from digital images or videos. From the perspective of engineering, it seeks to understand and automate tasks that the human visual system can do.
- **Input**: Images
  Output: Knowledge of the scene (recognize objects, people, activity happening there, distance of the object from camera and each other, ...)
  Methods: Image processing, machine learning, ...
- ***Image Processing:***
- **Input**: Images
  Output: Images (Might be in different formats, for example compressed images). No knowledge of the scene is given.
  Methods: Different filtering, FFT,

4.Mathematical object models – A review

- **Algebra and Trigonometry (**Vectors and matrix)
- **Linear Algebra (**numerical representations of geometry)
- **Calculus/ Differential Geometry (**smooth curves and surfaces**)**
- **Numerical Methods (**represent and manipulate numbers**)**
- **Sampling Theory and Signal Processing (**Image processing(2D/3D)**)**
- **Physics (**animation/particles/model dynamics**)**
- **Optimization (**gaming**)**

Summary

Module No. 1	Introduction	6 hours
Introduction -What is Computer Graphics? - History of computer graphics, applications, Graphics primitives – graphics pipeline, physical and synthetic images, synthetic camera, modelling, animation, rendering, relation to computer vision and image processing, review of basic mathematical objects		

Quiz -1