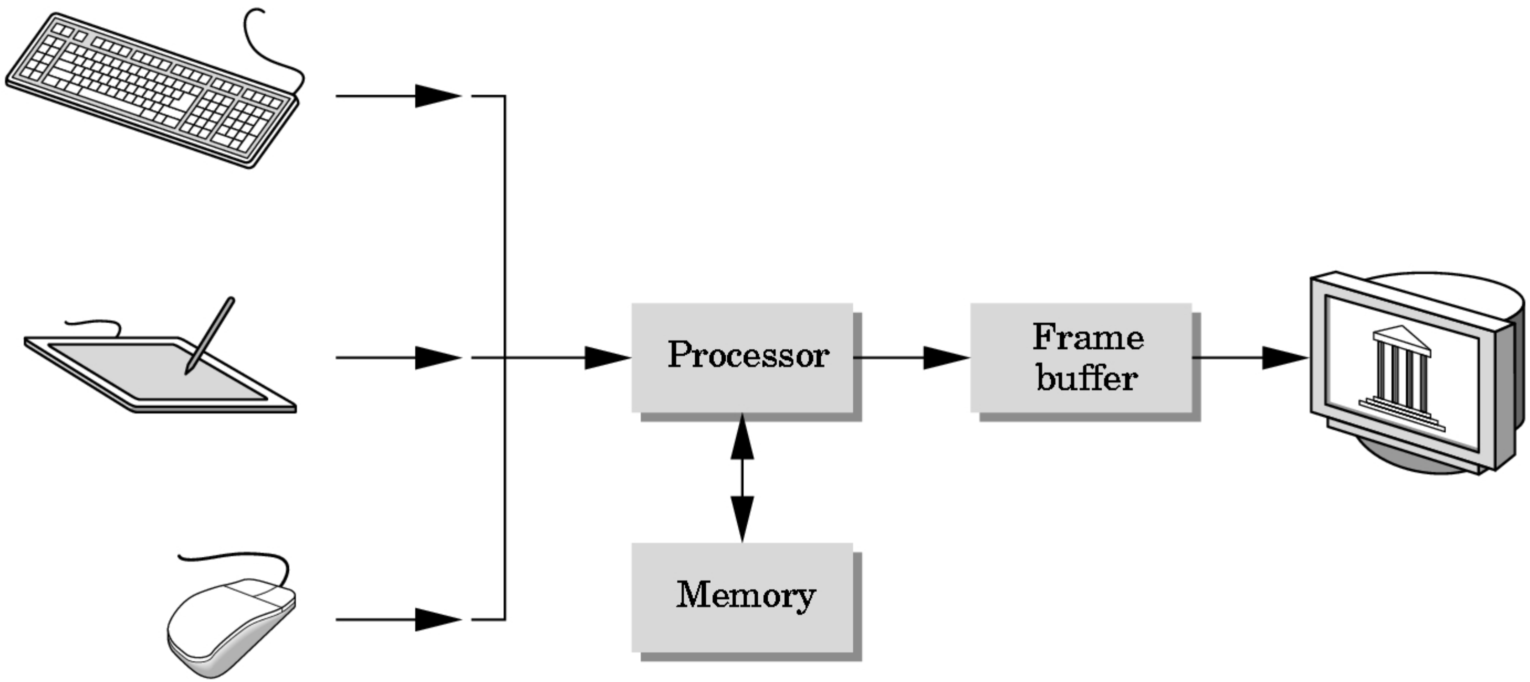
Introduction to Computer Vision & Graphics

Reading: Angel ch.1 or Hill Ch1.

What is Computer Graphics?

‘Synthesis of images’

User → Computer → Image



What are Computer Vision & Graphics?

Graphics: ‘Synthesis of images’

User → Computer → Image

Vision: ‘Analysis of images’

Image → Computer → User

Vision is the inverse problem of Graphics

Graphics goes from a model of the world to images

Vision from images of the world to models

Computer Graphics Applications

2D Display
- Text
- User Interfaces (GUI)
  - web
  - draw/paint programs
- Data Visualisation
  - bar charts/graphs etc.

3D Modelling Shape
- Architecture
- Engineering Design CAD

3D Modelling Shape + Appearance
- VR Simulation
- Video Games
- Film Animation

Computer Vision Applications

2D image analysis:

- text recognition
- industrial inspection (PCB, manufacture)

2D scene analysis from video:

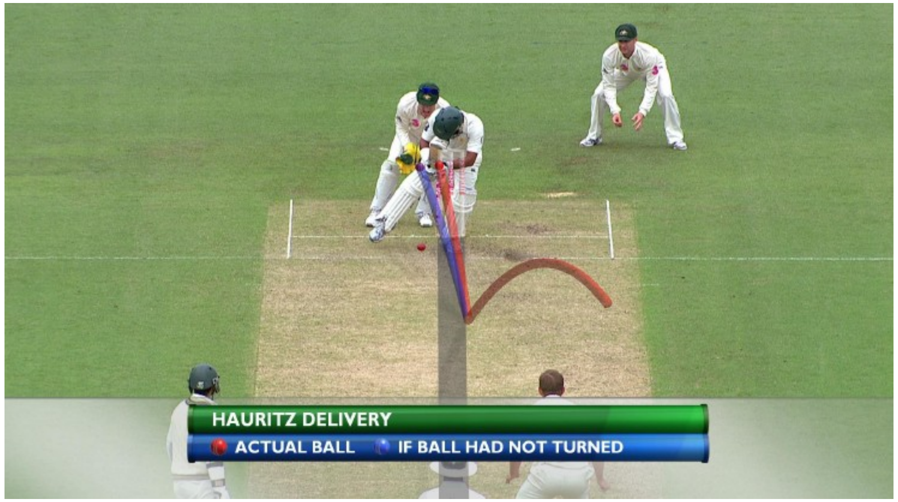
- number plate recognition
- TV sports annotation (Piero,iview)
- surveillance, behavior analysis
- object recognition

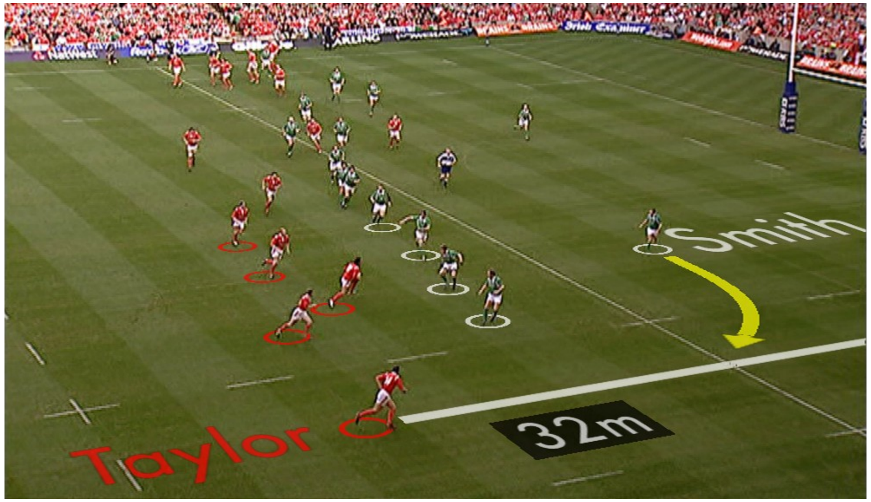
3D scene analysis from video:

- human motion capture (markers)
- camera tracking – film production
- 3D scene reconstruction (objects, building, games)

Analysis, modelling and understanding of real-scenes from images

Computer Vision Applications in Sports





Brief History of Computer Graphics

Whirlwind Computer - MIT 1950

- CRT Display
- SAGE Air Defense mid 50's
  - Whirlwind II used light pen for interaction

Sketchpad - Sutherland 1963

- First interactive graphical system
- Interaction for 'select', 'point', 'draw'
- Data structures for repeating component shapes

Further Development driven by:

Design 60/70's - interactive drawing in 2D/3D

Games/Simulation/Visulisation 70/80's - 3D display

Film Animation 80/90's - Realistic special effects

- Feature length movies

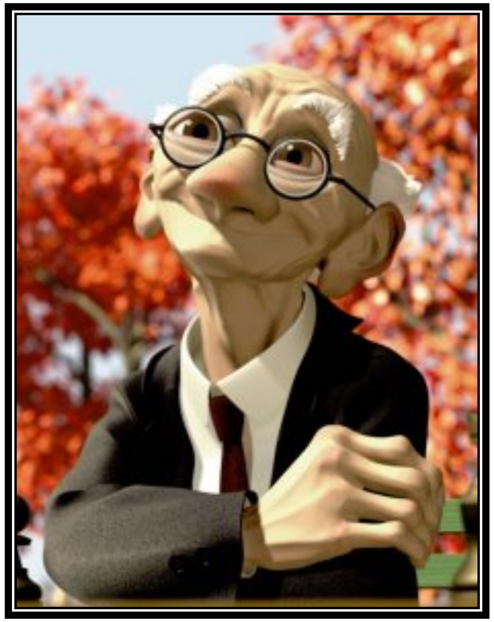
Current CGI State-of-the-art

Low-cost PC/console graphics

- web-based 3D (web3D)
- games
- Real-time user interaction
- real-time data/process visualisation

'Realistic' computer generated characters and effects

- complex physical modelling (water/fire…)
  ie Antz, Bugs Life
- frame-by-frame animation of characters
  ie Toy Story, Shrek(Pixar/Disney)
- photo-realistic faces
  ie Benjamin Button (2009), Beowulf (2007)
- computer generated extras ie Titanic
- integration of synthetic characters & real actors
  ie Star Wars - Episode I

Disney: Gemini Man

Sony: Beowulf

Motion capture

- performance capture with 200 Vicon cameras
- ~200 facial markers
- CG performance of real actors

Sony Image works – Beowulf (2007)

Current Research in Graphics

'Photo-realistic' image synthesis

- synthesis of images which are indistiguishable from the real thing (matrix) (fiat-lux)
- real-time video rate generation

Realistic Modelling of people

- shape, apperance, movement, behaviour
- synthetic actors 'synthespians' & virtual presenters
- digital doubles

Real-time integration of live and computer generated content

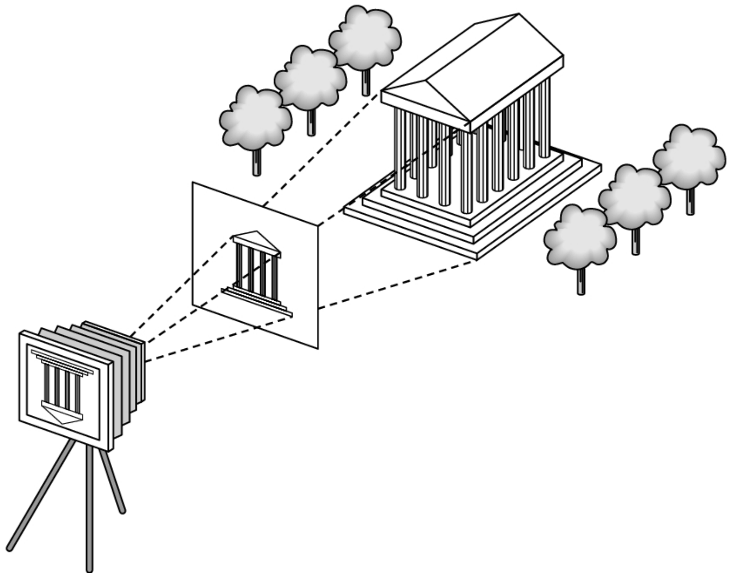
This course will introduce current techniques for computer generated image production (nuts & bolts)


'What is Bullett Time'
(c) 1999 Home Box Office, Time Warner Entertainment

Image Formation

Real camera:

Real scene → Physics of image formation → Image



Computer graphics simulates the physics of real image formation

Synthetic camera:

Graphical model → Synthetic physics of image formation → Synthetic Image

Image Formation

How are real images formed?

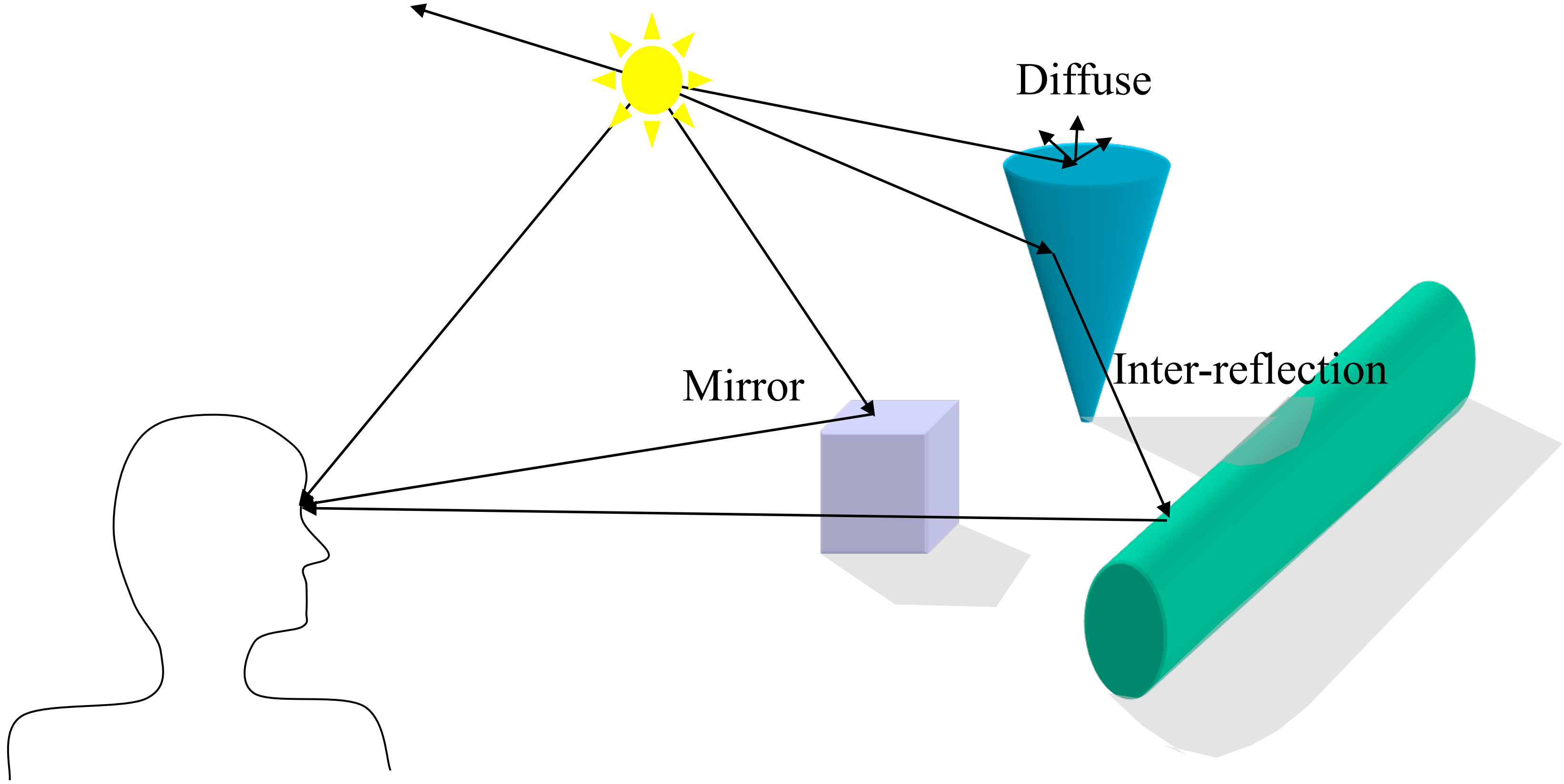
Ray-tracing model of image formation

(1) Lights emit rays of light
(2) Some rays hit objects & illuminate the surface
(3) Some rays are reflected back off objects to the viewer

If we trace the path of all rays in the scene we can model the physical image formation process.

Ray-tracing can be used to simulate complex physical effects and generate highly realistic images

Ray-Tracing



Ray-tracing traces the path of each light-ray in the scene

- highly realistic (physics-based)
- very high computational cost (not real-time)

What Affects Image Formation?

Illumination: - location
- point/area & directional/ambient
- colour

Objects: - surface shape/smoothness
- surface material colour/texture
- surface reflectance (mirror/diffuse)
- surface opacity/transparency

Viewer: - viewpoint/direction
- focal-length/field-of-view
- sensor type (eye/CCD)

A simplified model for image formation

Ray-tracing produces highly realistic images but is **SLOW**

How can we produce 'realistic' images at video rate?

Observation 1: To the viewer a surface illuminated by a light source appears exactly the same as a surface emitting light.

Observation 2: Multiple light rays hitting a surface are additive - there is no such thing as negative light.

Therefore, we can model a scene as a set of objects which emit light:

- fast
- realistic (no shadows/inter-reflections)

Synthetic Image Generation

Three-dimensional computer graphics

Model → **'Renderer'** → Image

Model is a three-dimensional (3D) representation of the scene

Renderer is a synthetic-camera model which generates images from the 3D object model

Image is a two-dimensional digital image of the scene from a particular viewpoint

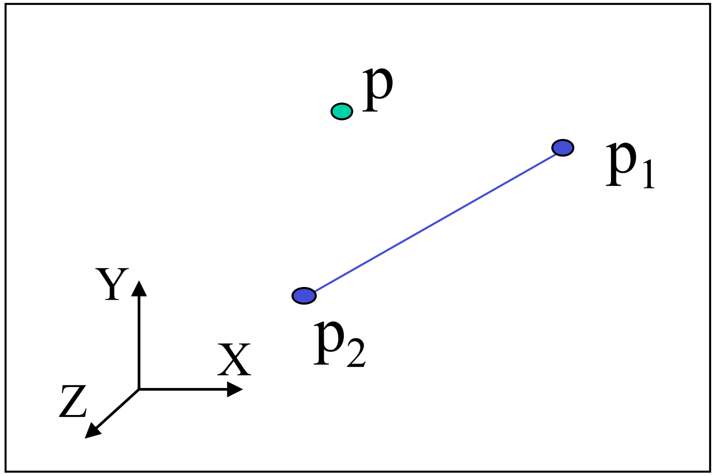
For image generation we must consider each component

Three-Dimensional Modelling

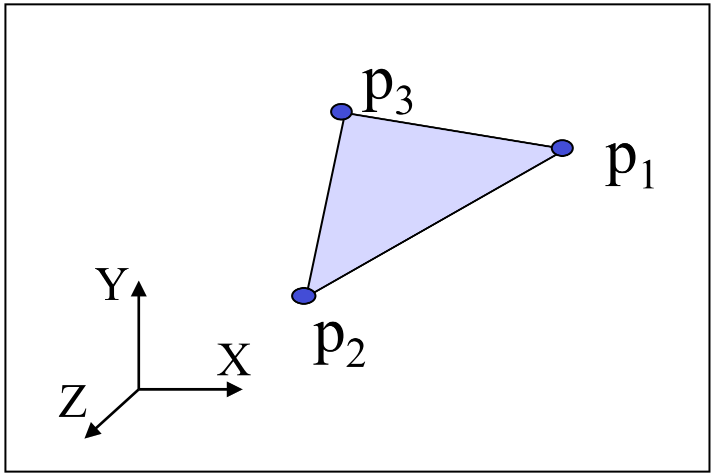
An arbitrary 3D scene can be built from simple primitives: point, lines and polygons.

Point: $p = (x,y,z)$

Line: $l = (p_1,p_2)$



Three-Dimensional Modelling II

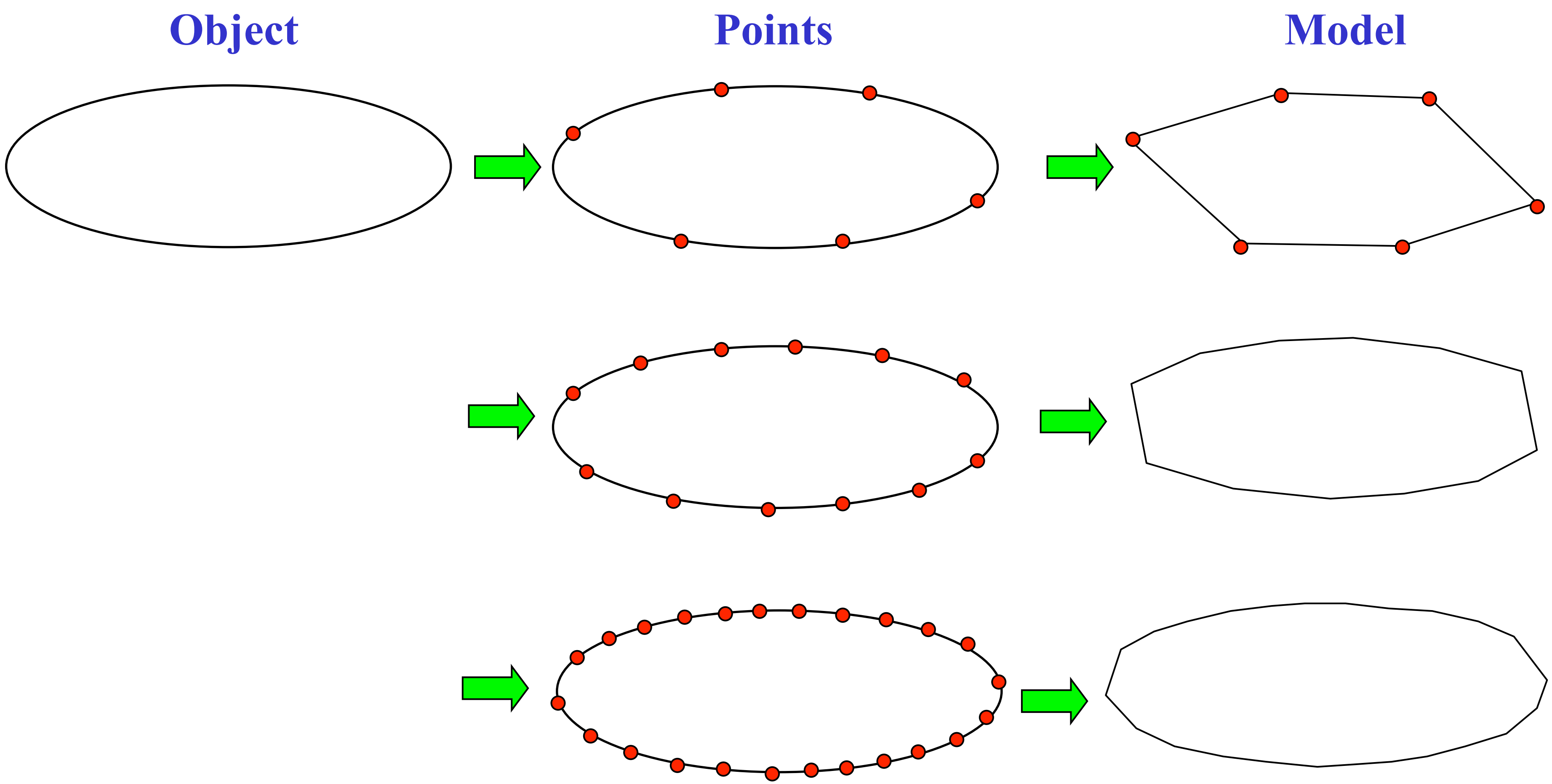


Polygons: Triangle $t = (p_1, p_2, p_3)$
Quadrilateral $q = (p_1, p_2, p_3, p_4)$
N-gon $r = (p_1, \ldots\ldots, p_N)$

- N-gon can be exactly represented by triangulation
- Triangles are the most common primitives in graphics
- Complex surfaces are approximated by thousands of polygons

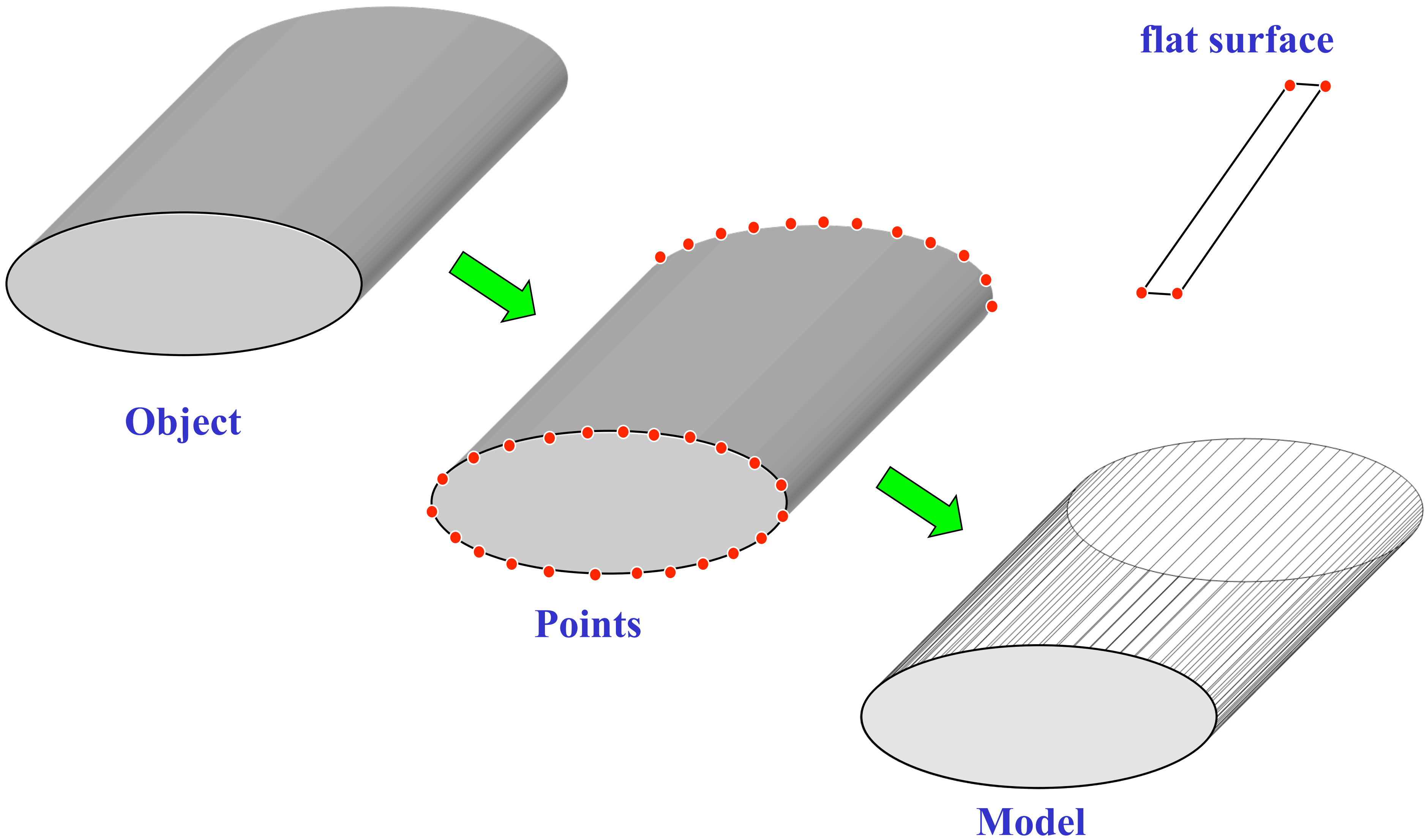
Modelling Object Shape in a Flat World

In a flat world a curved object can be modelled by lines



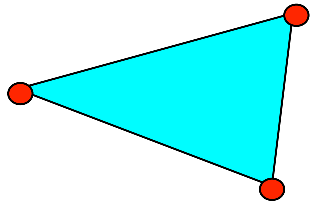
Modelling Object Shape in the Real World

Surface shape can be modelled by small flat surfaces

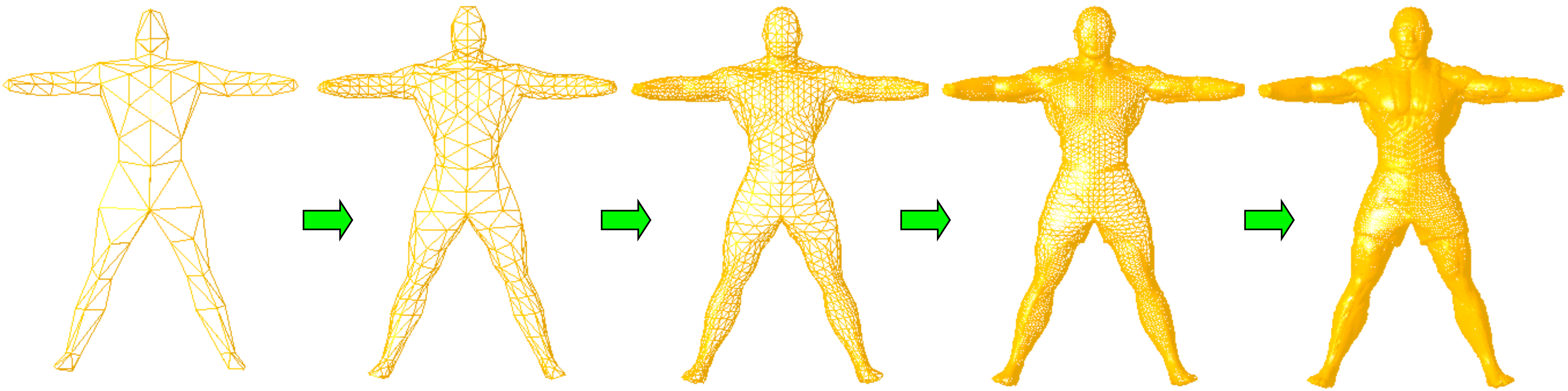


Modelling Surface Shape

A flat surface is defined by 3 points: ‘triangle’



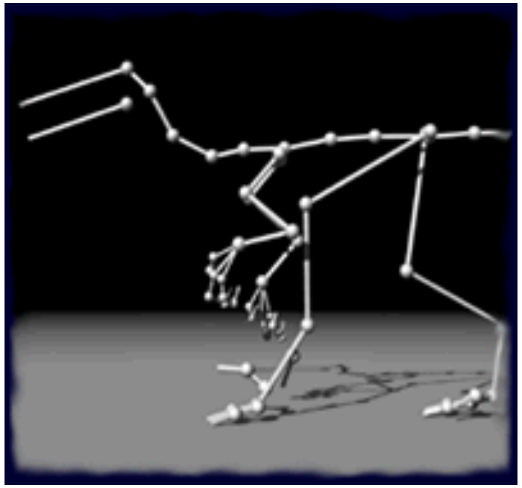
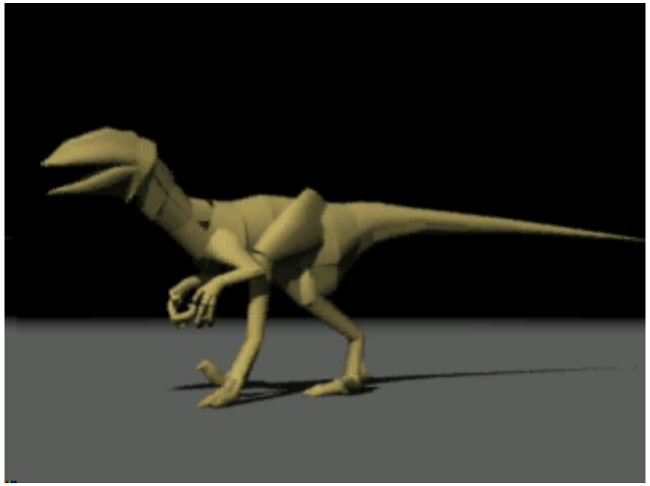
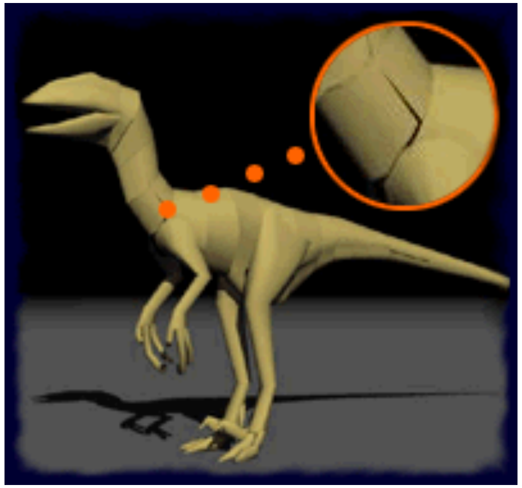
Triangles are joined into ‘meshes’ to model any object surface shape



100 1000 10000 100000 1000000

Example: Animated Models for ‘Walking with Dinosaurs’

(1) Animation Skeleton + Patch Model

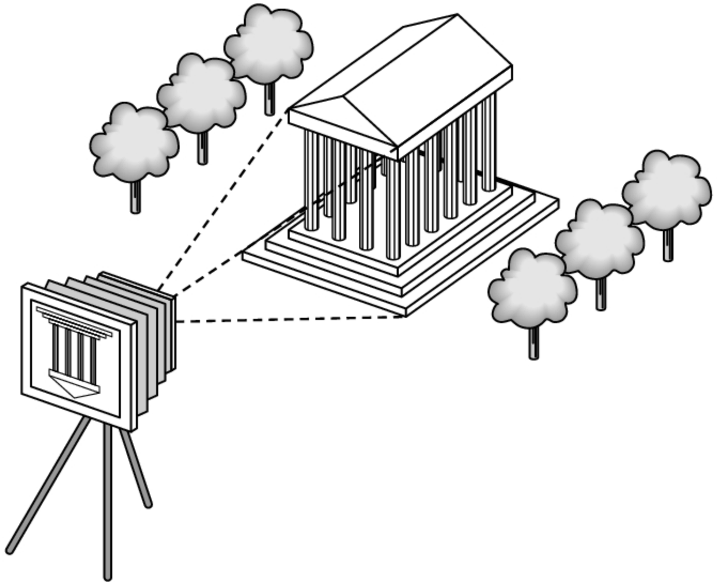
(2) Combine detailed surface mesh model and animation model


(3) Model surface appearance (colour/reflectance)

(4) Illuminate the scene

Synthetic Camera Model

Model the **projection** of the 3D scene onto the **image plane**

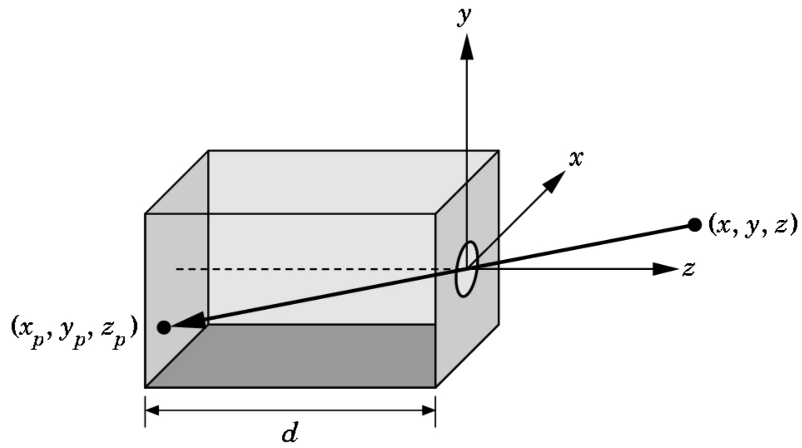


Note: Specification of the 3D scene is independent
of the specification of the viewer.

Pin-hole Camera Model

Pin-hole camera is a box with a small hole on one side.

- A single ray of light passes through the hole and is projected onto the image plane on the opposite side.



If the Z-axis is alligned with the camera **optical axis** then a point p=(x,y,z) is projected to a point $p_p=(x_p,y_p,z_p)$ on the image plane:

$$x_p = -(xd)/z \quad y_p = -(yd)/z \quad z_p = -d$$

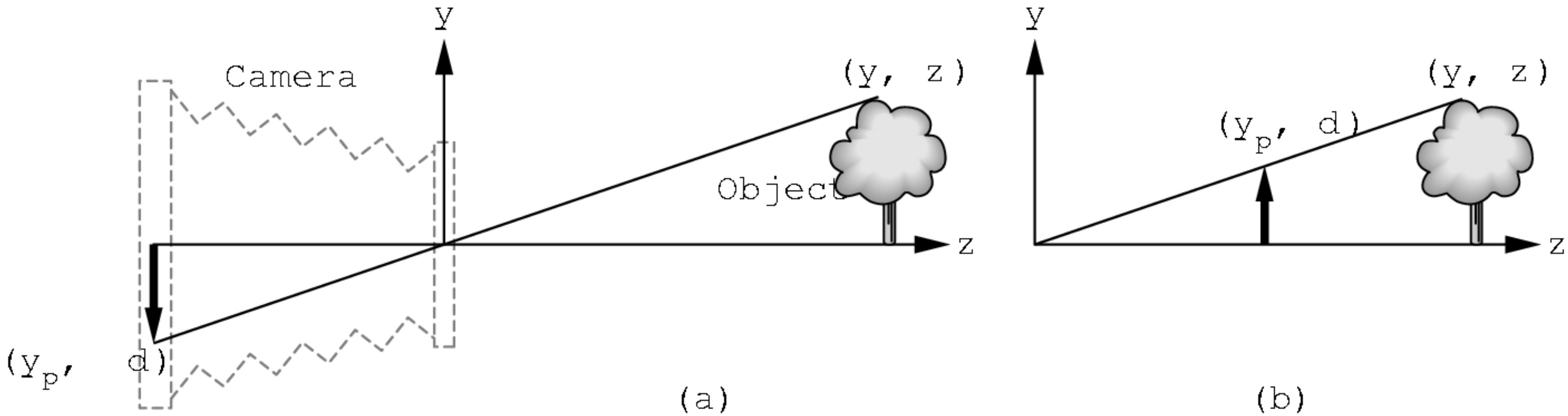
where d is the distance of the image plane from the **centre of projection**

Note: z_p is constant for all p_p ie the depth of the image plane $p_p=(x_p,y_p)$

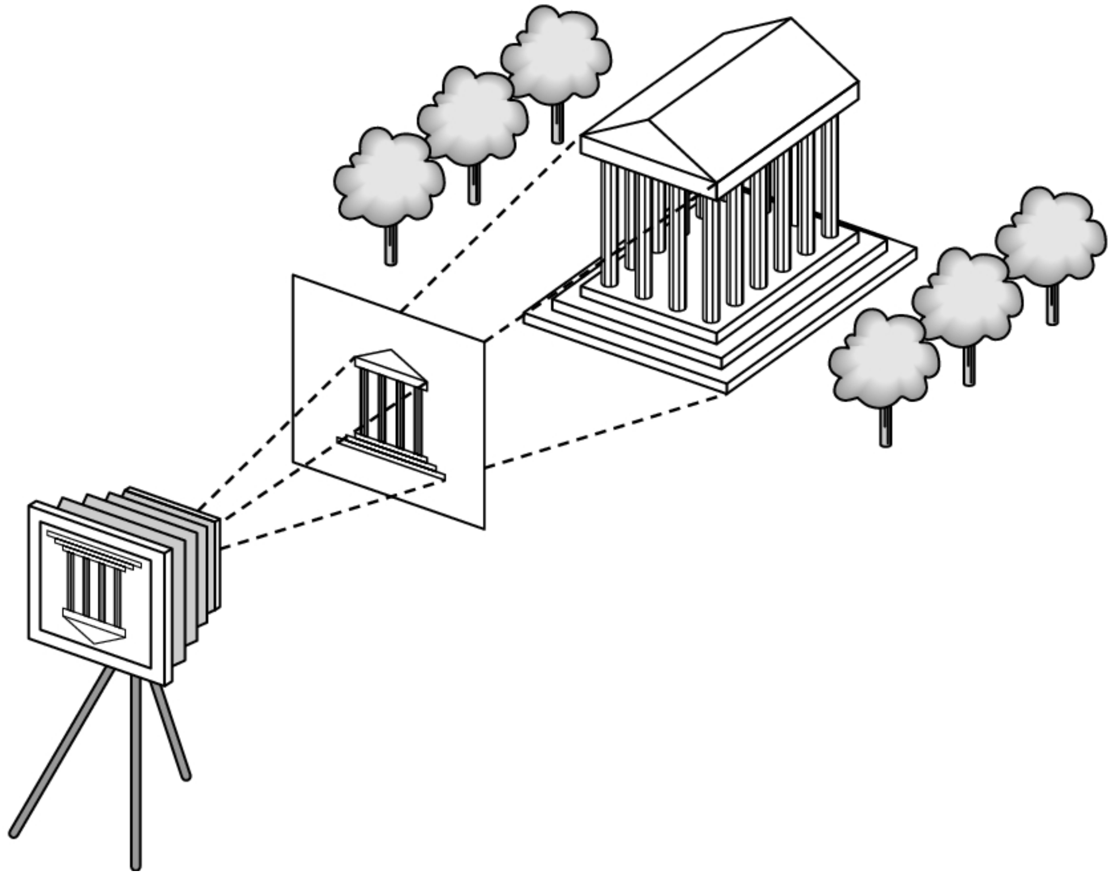
Pin-hole Camera II

An equivalent image is formed if the image plane is placed infront of the camera at distance d:

$x_p = (xd)/z \qquad y_p = (yd)/z \qquad z_p = d$



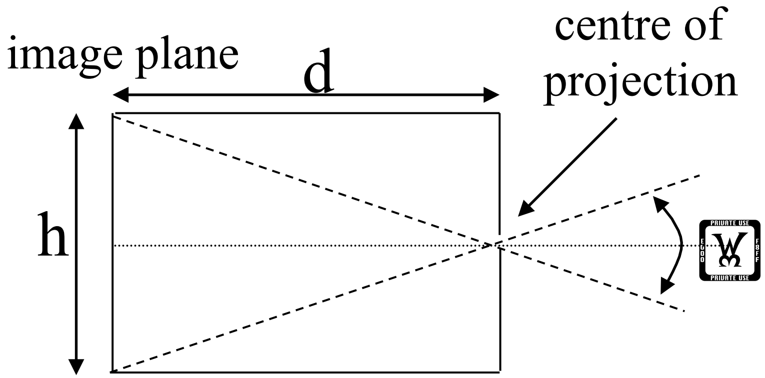
Synthetic camera model: Each point in the 3D model is projected onto the image plane using the pin-hole camera model



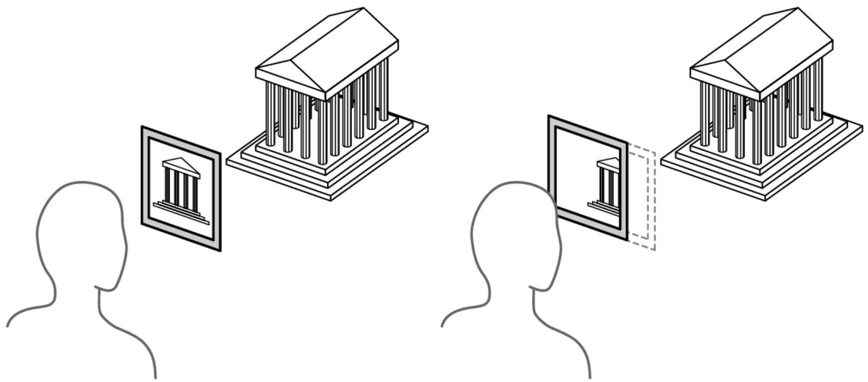
Synthetic Camera - Field-of-view

The field-of-view (fov) for a pin-hole camera is determined by the height of the image plane h and the distance d from the centre of projection:

$$\theta = 2 \tan^{-1} h/(2d)$$



Clipping is performed to eliminate parts of the scene outside the fov



(a) (b)

Modelling Surface Appearance

4 main factors:

Shape Colour Shininess Lighting

Model appearance by:

(1) Colouring triangles

(2) Simulating physics of surface reflection

Synthesize object appearance for each flat surface separately

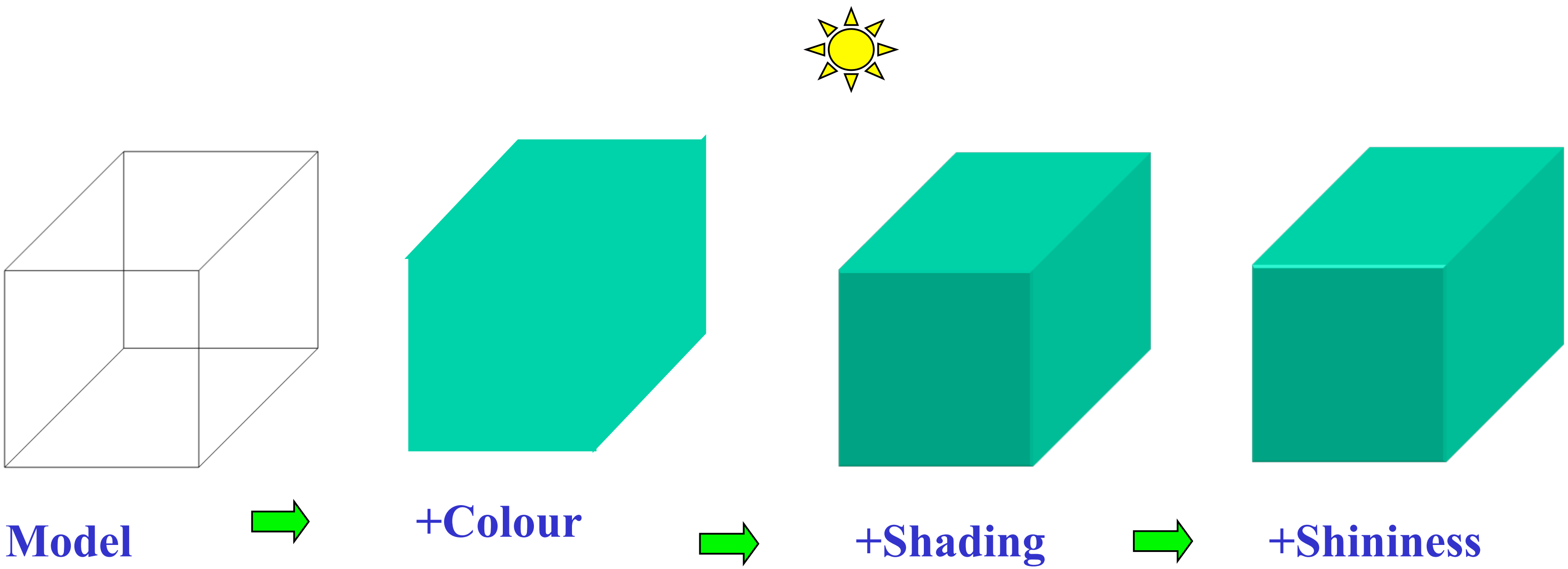
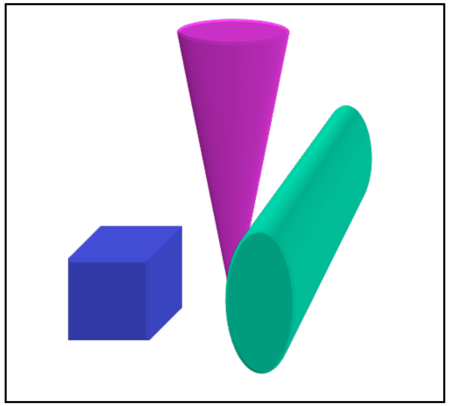
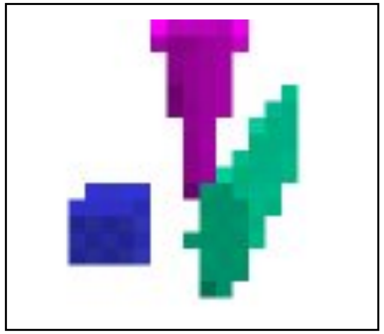


Image Sampling - Rasterisation

Image projection forms a continuous scene projection
in the camera image plane

Rasterisation samples the projection onto a discrete grid of '**pixels**'
in the image plane to generate a digital image
Each pixel stores the colour of the surface
which projects to that pixel.

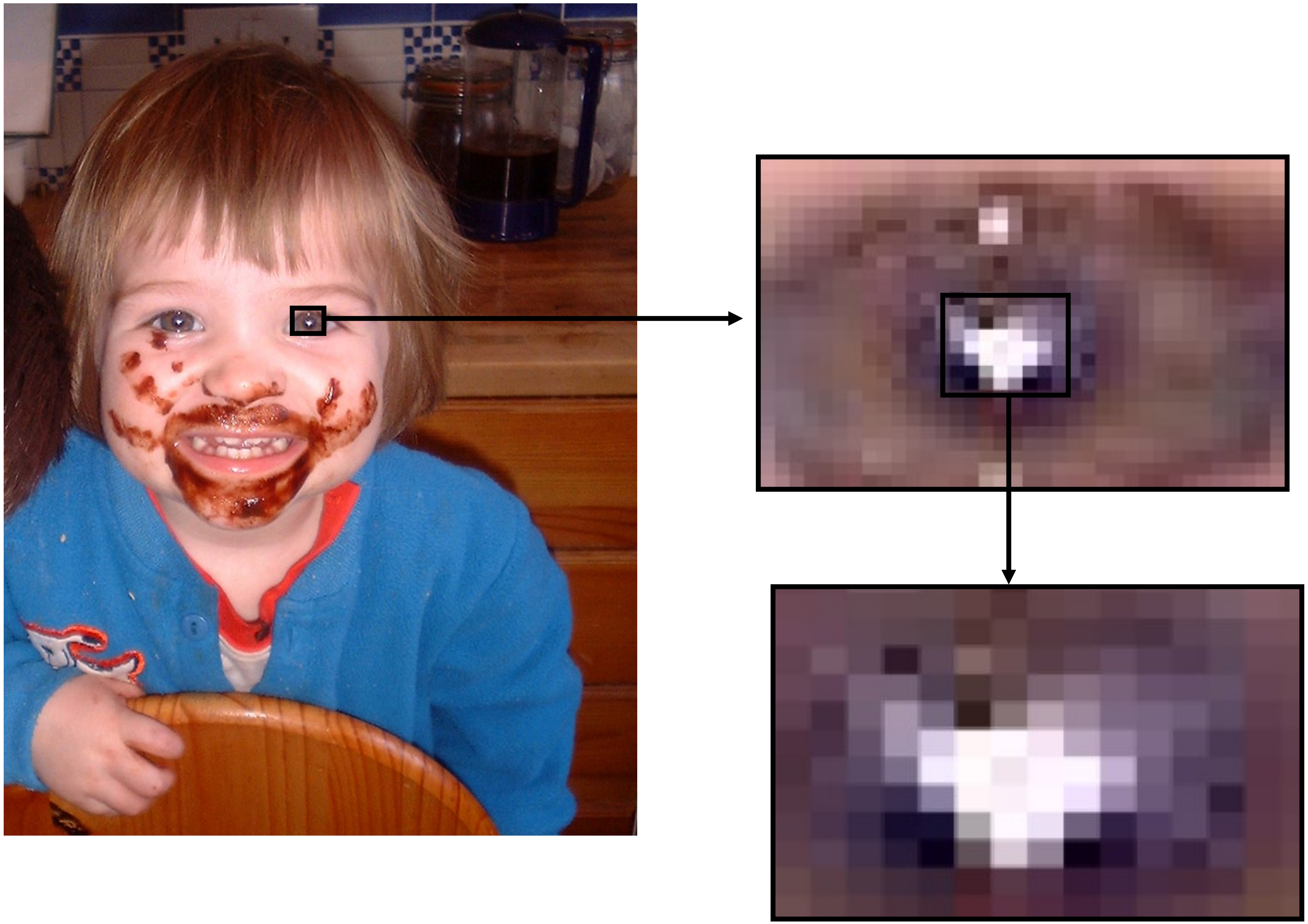




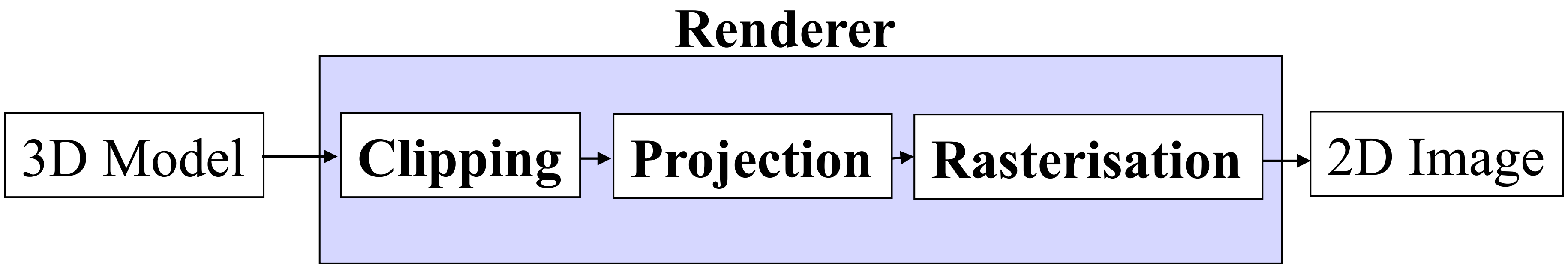
20x20grid

40x40grid

Image Sampling - Digital Camera



Synthetic Image Generation - Graphics Pipeline



Renderer - Synthetic camera model

Clipping - Eliminate parts of the scene outside the field of view

Projection - Project the 3D Scene onto the image plane

Rasterisation - Sample the projection on a discrete image grid