Unit 6: Graphics

CS 3570

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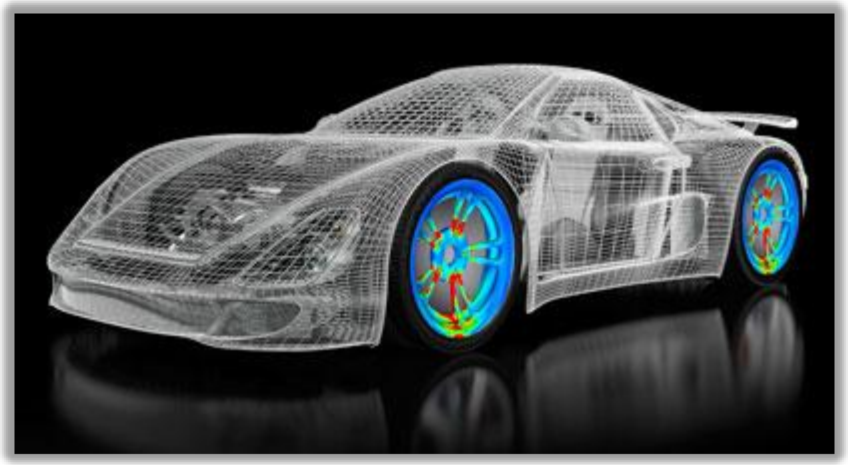
Graphics — Outline

- **Vector graphics**
  - Difference between bitmap and vector graphics
  - To describe a curve – Bézier curve
- **3D Graphics**
  - 3D model
  - Lighting
- **Applications**

Vector Graphics

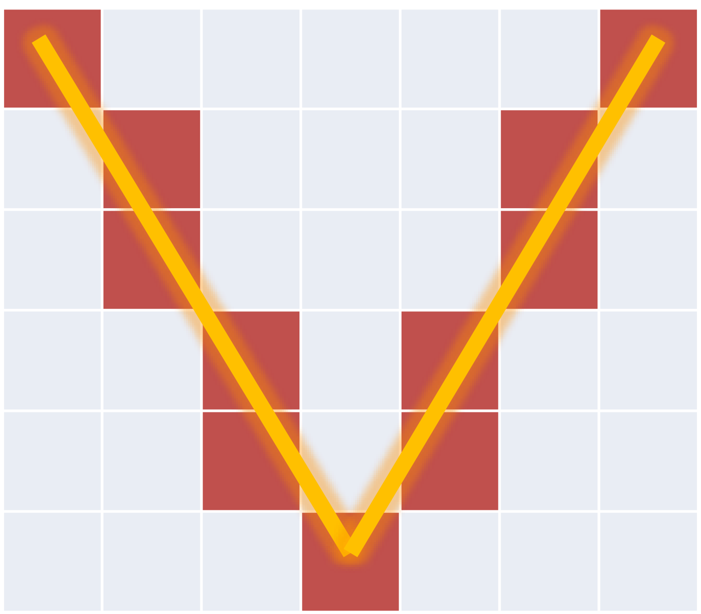
- ***Vector graphics*** is an image file format suitable for pictures with simple components, such as
  - areas of solid
  - clearly separated colors

  It is widely used in
  - animation and games
  - font design
  - architectural design
  - industrial design

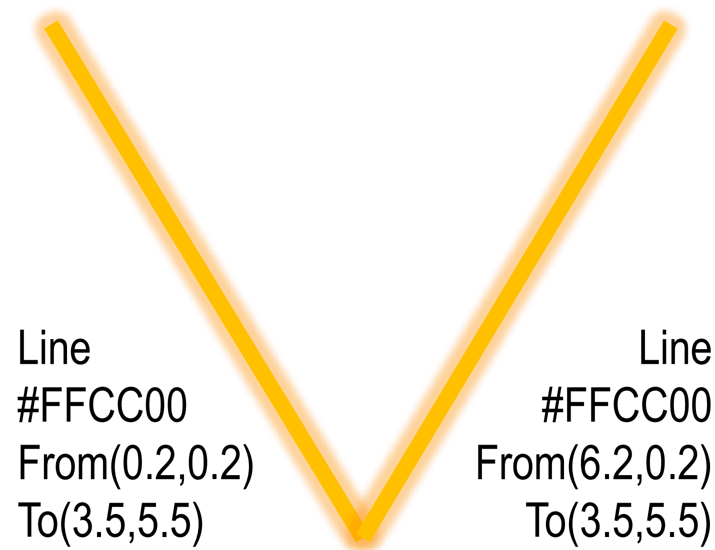


Vector Graphics

- A bitmap saves an image pixel by pixel,
  while a vector graphic describes an object in terms of combination of geometric shapes.



representing a “V” using bitmap

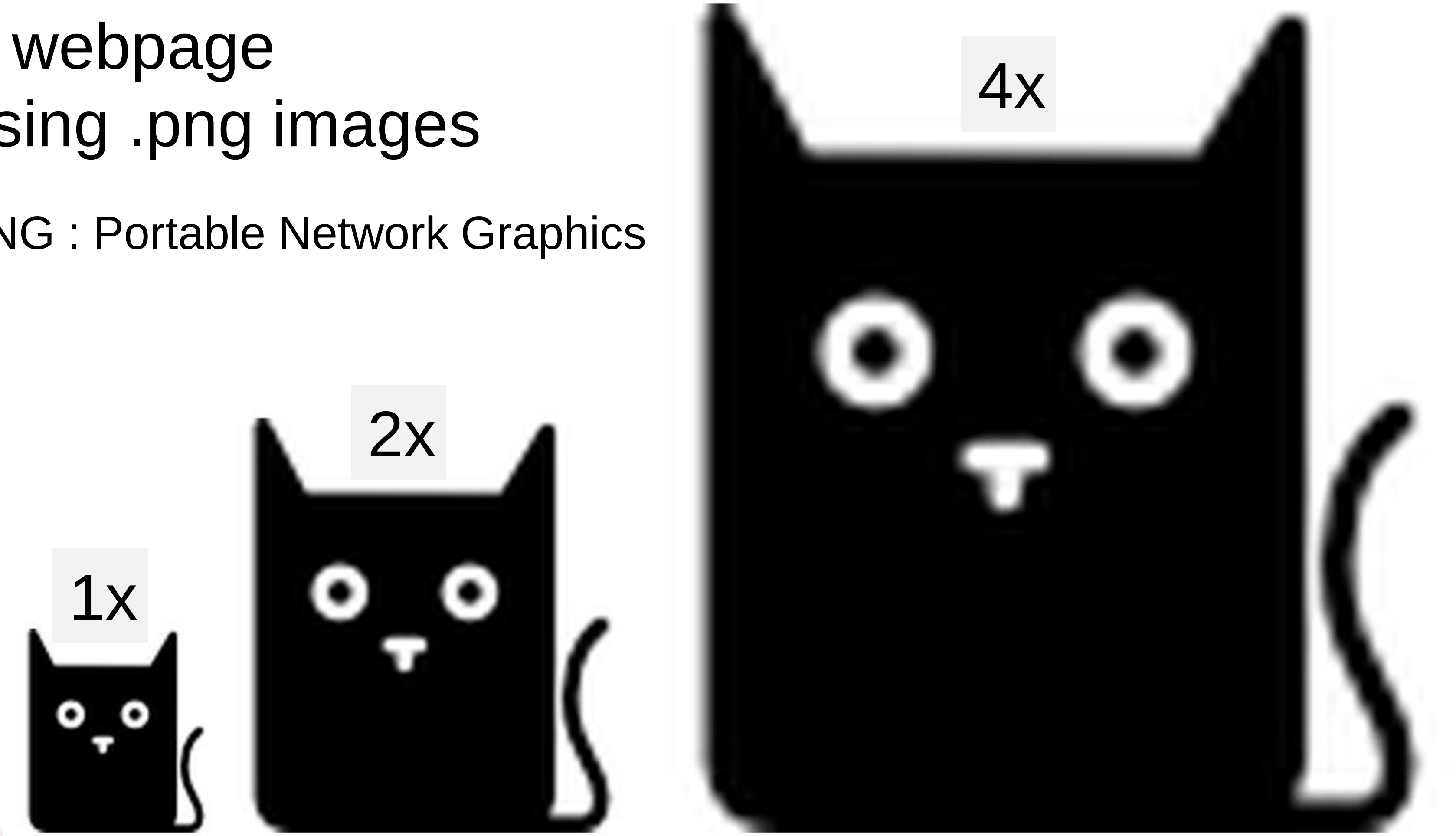


representing a “V” using vector graphic

Vector Graphics

A webpage
using .png images

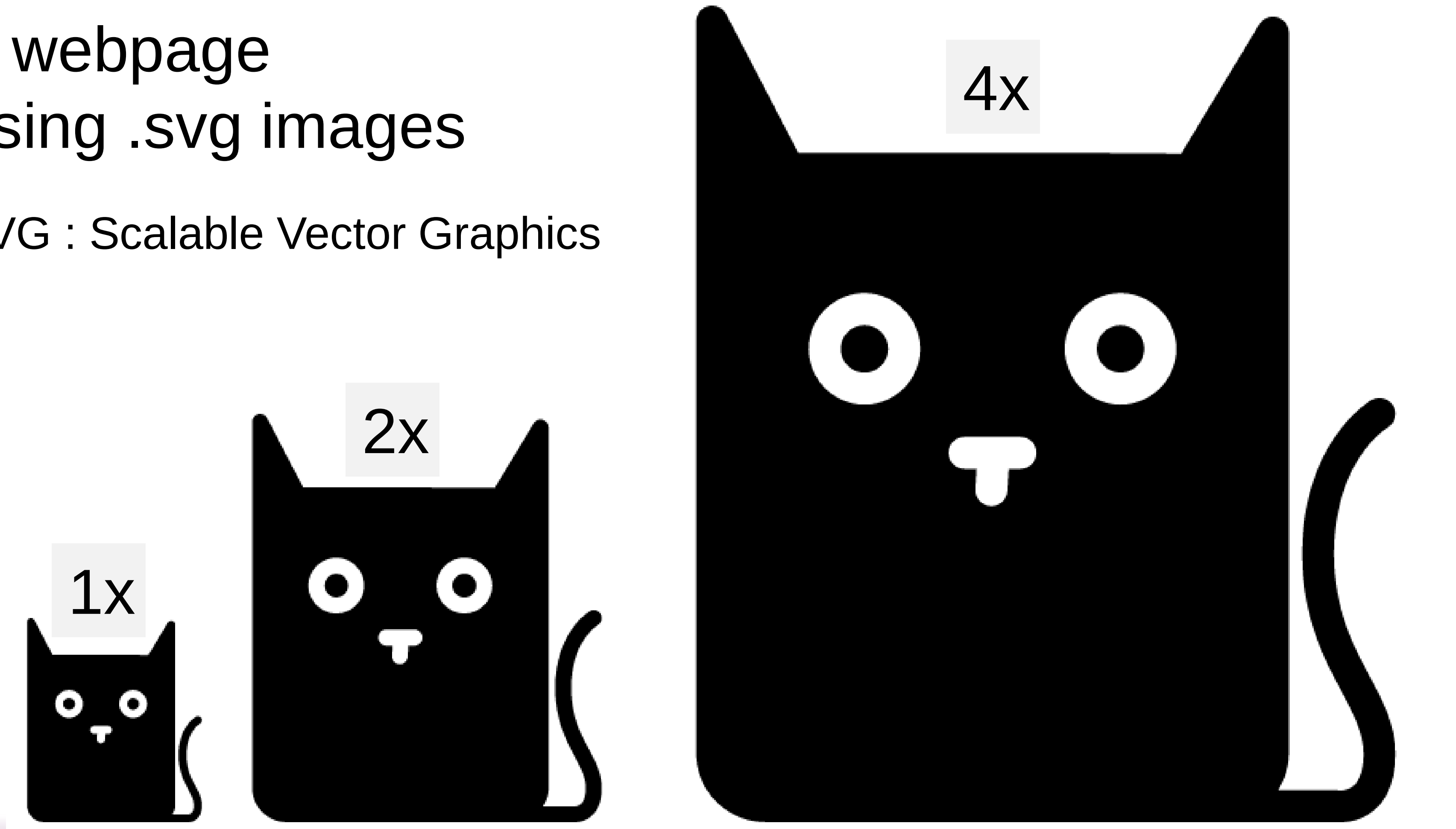
PNG : Portable Network Graphics



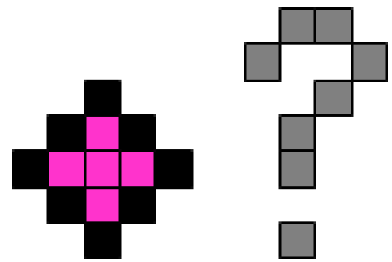
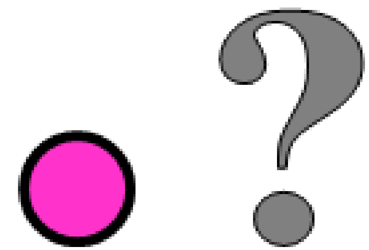
Vector Graphics

A webpage
using .svg images

SVG : Scalable Vector Graphics



Bitmaps vs. Vector graphics

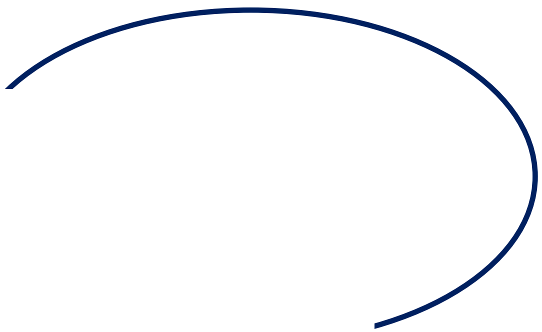
	Pixel	Vector
Example		
Grow and shrink	Bad	Good
Speed	Fast to create. Very hard to edit!	Slow to create. Much faster to edit.
Applications	Painter Photoshop	Power Point Illustrator
File Format	.jpg, .png, .gif, .bmp, .tiff	.svg, .cgm, .odg, .eps,.xml

Specifying curves

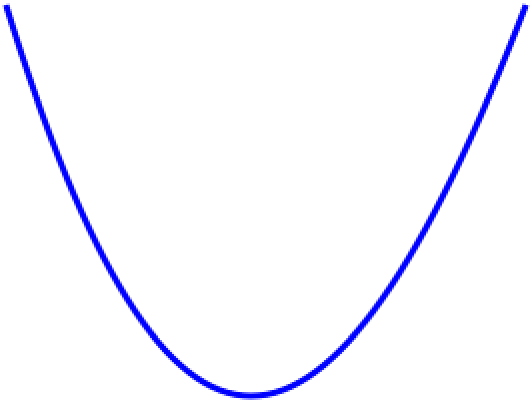
- **Explicit form of a function** $y = f(x)$
  provide a prescription for determining the *output* value of the function *y* in terms of the *input* value *x*
  - E.g. $$y = \sqrt{r^2 - x^2}$$
- **Implicit form of the function** $f(x, y) = 0$
  the value of *y* is obtained from *x* by *solving* an equation of the form
  - E.g. $$x^2 + y^2 - r^2 = 0$$

Specifying curves

- **Straight line** is easy to describe, yet how about a curve ?



Elliptical Arc



Parabola

- More complex curve ?

Parametric Curve

- Parametric representation of a function
  p(t) = (x(t), y(t))

$$x(t) = a_x t^3 + b_x t^2 + c_x t + d_y$$

$$y(t) = a_y t^3 + b_y t^2 + c_y t + d_y$$

$$P(t) = [x(t)y(t)] = \underbrace{\begin{bmatrix} t^3 & t^2 & t & 1 \end{bmatrix}}_{T} \underbrace{\begin{bmatrix} a_x & a_y \\ b_x & b_y \\ c_x & c_y \\ d_x & d_y \end{bmatrix}}_{C} \quad 0 \leq t \leq 1$$

$$P = T\, C$$

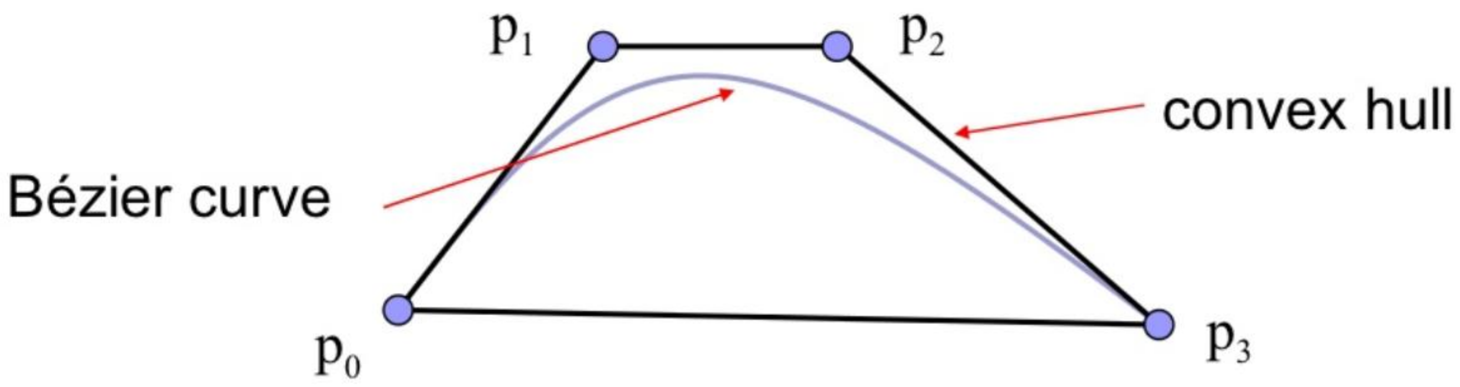
- Curve-generating algorithms can be divided into 2 main categories: interpolation algorithms and approximation algorithms.

Bézier Curves

- A Bézier curve is a parametric curve described by polynomials based on a sequence of control points
  - Degree of polynomials = number of points - 1
  - A Bézier curve passes through its first and last control points, but, in general, no others.

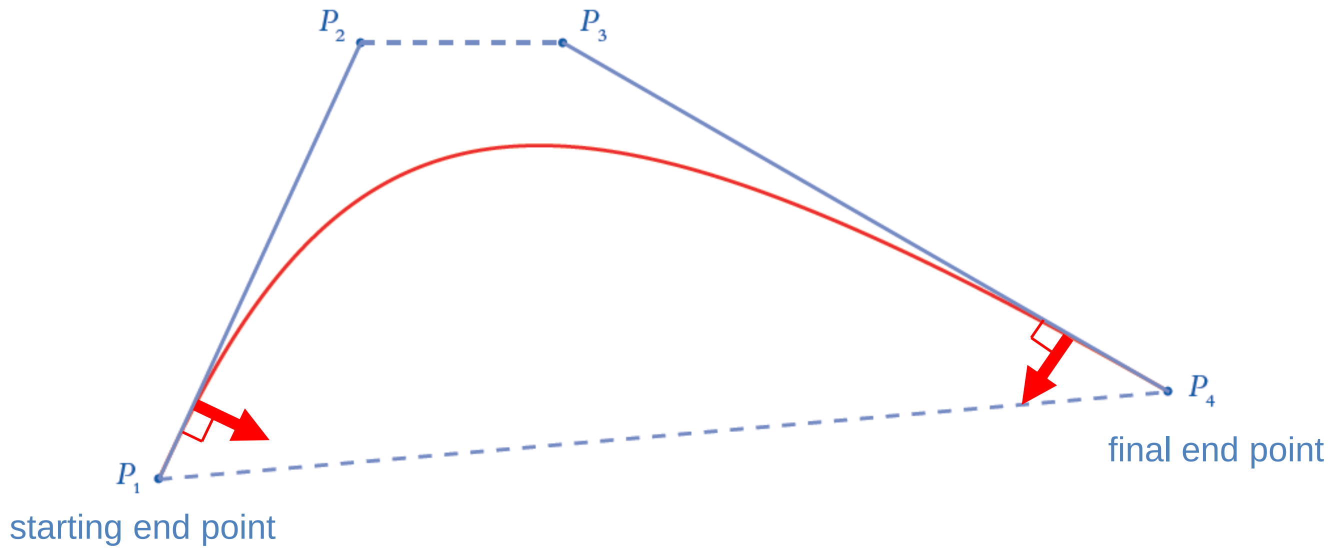
Bézier Curves

- *The entire curve will lie within the polygon constructed by joining the control points with straight lines. This polygon is called the curve's **convex hull.***



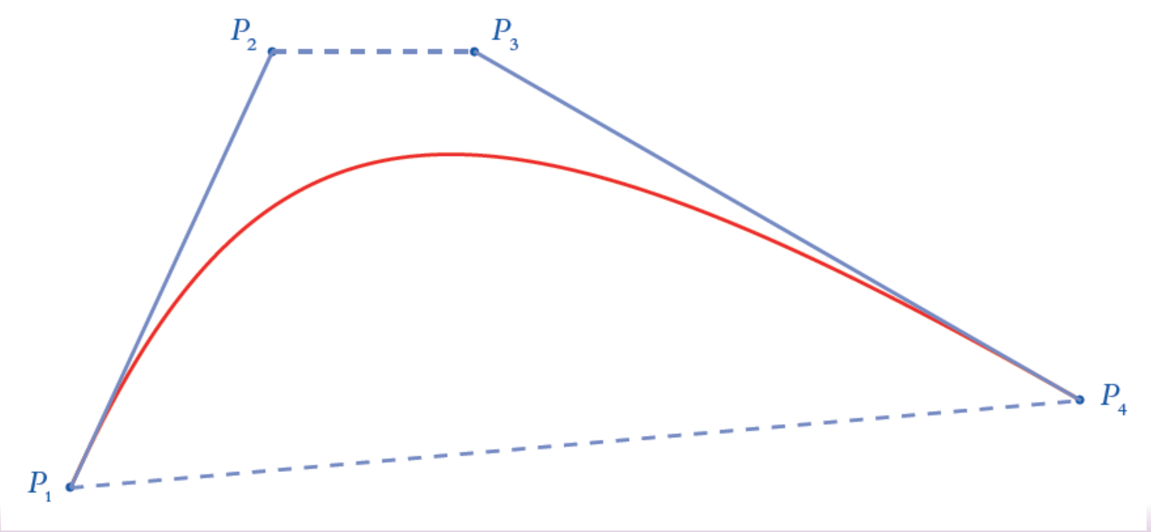
Bézier Curves

- The line between the starting end point and the next control point is tangent to the curve, and so is the line between the final end point and the preceding control point.

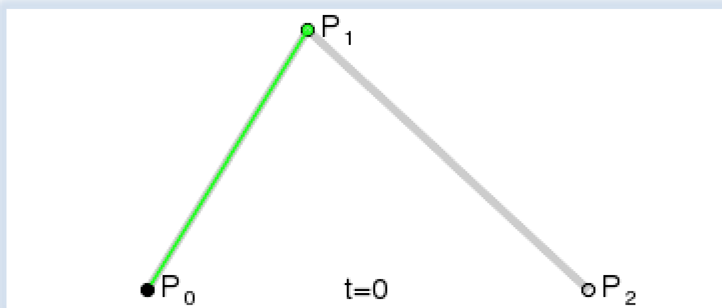


Cubic Bézier Curves

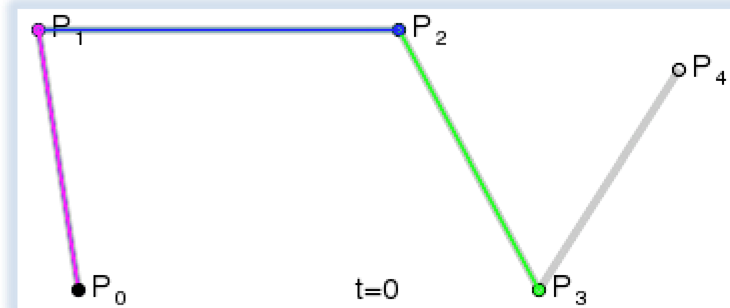
- Bézier curves of degree 3, commonly called "cubic Bézier curves", are most commonly used in vector graphics.
- They have just four control points: two are the **end points**, and the other two are called ***direction points.***



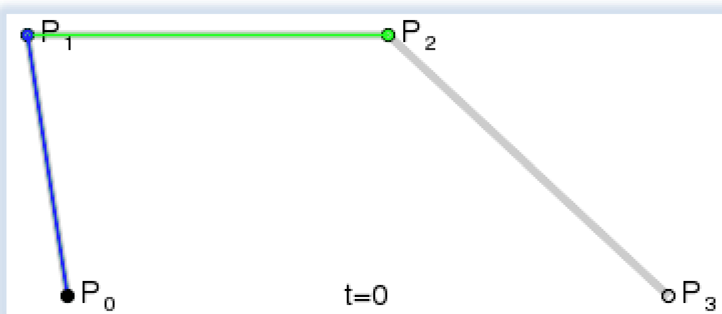
Bézier curves - Examples



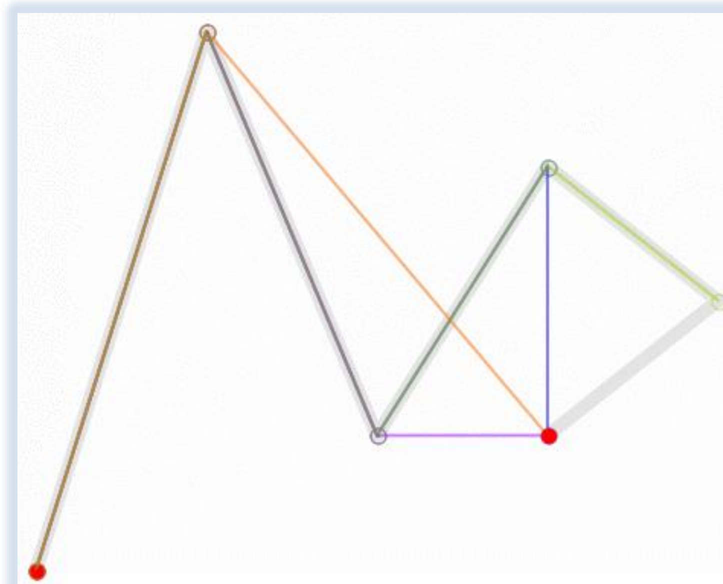
2nd order (quadratic) Bézier curve



4th order (quartic) Bézier curve



3rd order (cubic) Bézier curve



http://en.wikipedia.org/wiki/B%C3%A9zier_curve

Bézier curve

- A Bézier curve is defined by a cubic polynomial equation
- ***P***(***t***) = ***T*** * ***M*** * ***G***
- *T* = $[t^3\ t^2\ t\ 1]$, ***M*** is called the ***basis matrix***. ***G*** is called the ***geometry matrix***.

$$M = \begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 3 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \qquad G = \begin{bmatrix} p_0 \\ p_1 \\ p_2 \\ p_3 \end{bmatrix}$$

- The blending functions are given by *T* * *M*,

$$\boldsymbol{P}(t) = (\boldsymbol{T} * \boldsymbol{M}) * \boldsymbol{G} = (1 - \boldsymbol{t})^3 \boldsymbol{p}_0 + 3t(1-t)^2 p_1 + 3t^2(1-t)p_2 + t^3 p_3$$

Blending Function

- Bézier curves can be described in terms of the blending functions

$$P(t) = \sum_{k=0}^{n} p_k \, blending_{k,n}(t) \quad \text{for} \quad 0 \leq t \leq 1$$

- In the blending functions $blending_{k,n}(t)$, n is the degree of the polynomial and k refers to the "weight" for the kth term in the polynomial.

$$blending_{k,n}(t) = C(n,k)t^k(1-t)^{n-k}$$

$$C(n,k) = \frac{n!}{k!\,(n-k)!}$$

- For cubic polynomials,

$$blending_{0,3} = (1-t)^3, blending_{1,3} = 3t(1-t)^2$$

$$blending_{2,3} = 3t^2(1-t), blending_{3,3} = t^3$$

Bézier curves – advantage & disadvantages

- Advantage
  - Very simple
- Disadvantages
  - Expensive to evaluate the curve at many points.
  - No easy way of knowing how fine to sample points, so maybe sampling rate must vary along a curve.
  - No easy way to adapt.
    In particular, it is hard to measure the deviation of a line segment from the exact curve.

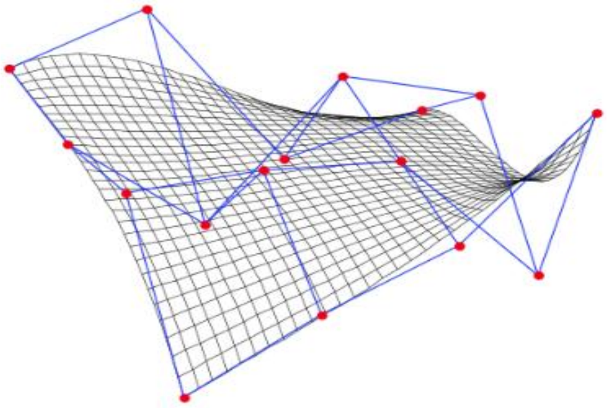
Bézier Surface

- A two-dimensional Bézier surface can be defined as a parametric surface:

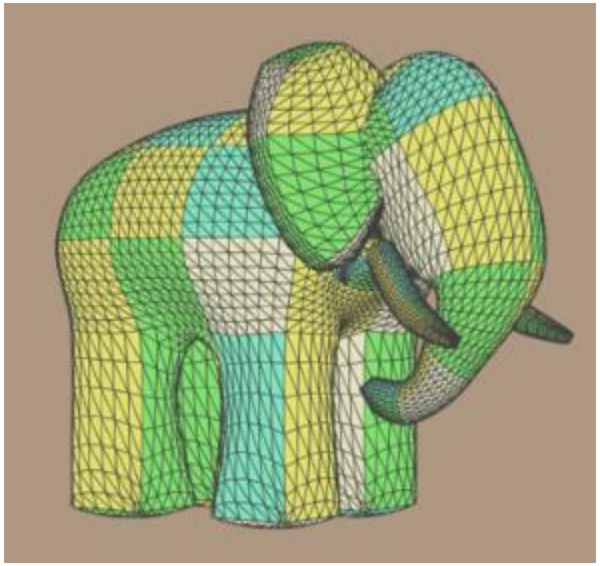
$$\mathbf{p}(u,v) = \sum_{i=0}^{n} \sum_{j=0}^{m} B_i^n(u)\, B_j^m(v)\, \mathbf{k}_{i,j}$$

where

$$B_i^n(u) = \binom{n}{i} u^i (1-u)^{n-i}$$



- **bicubic patches** (*m* = *n* = 3).
- The bicubic patches are typically linked up to form a B-spline surface in a similar way as Bézier curves are linked up to form a B-spline curve.



Upscaling

- Even with some modern algorithms,
  upscaling a bitmap may cause some artifacts

Original Image

Upscaling using Bilinear Interpolation

Upscaling using S-Spline Interpolation

Ground Truth

Curves Fitting

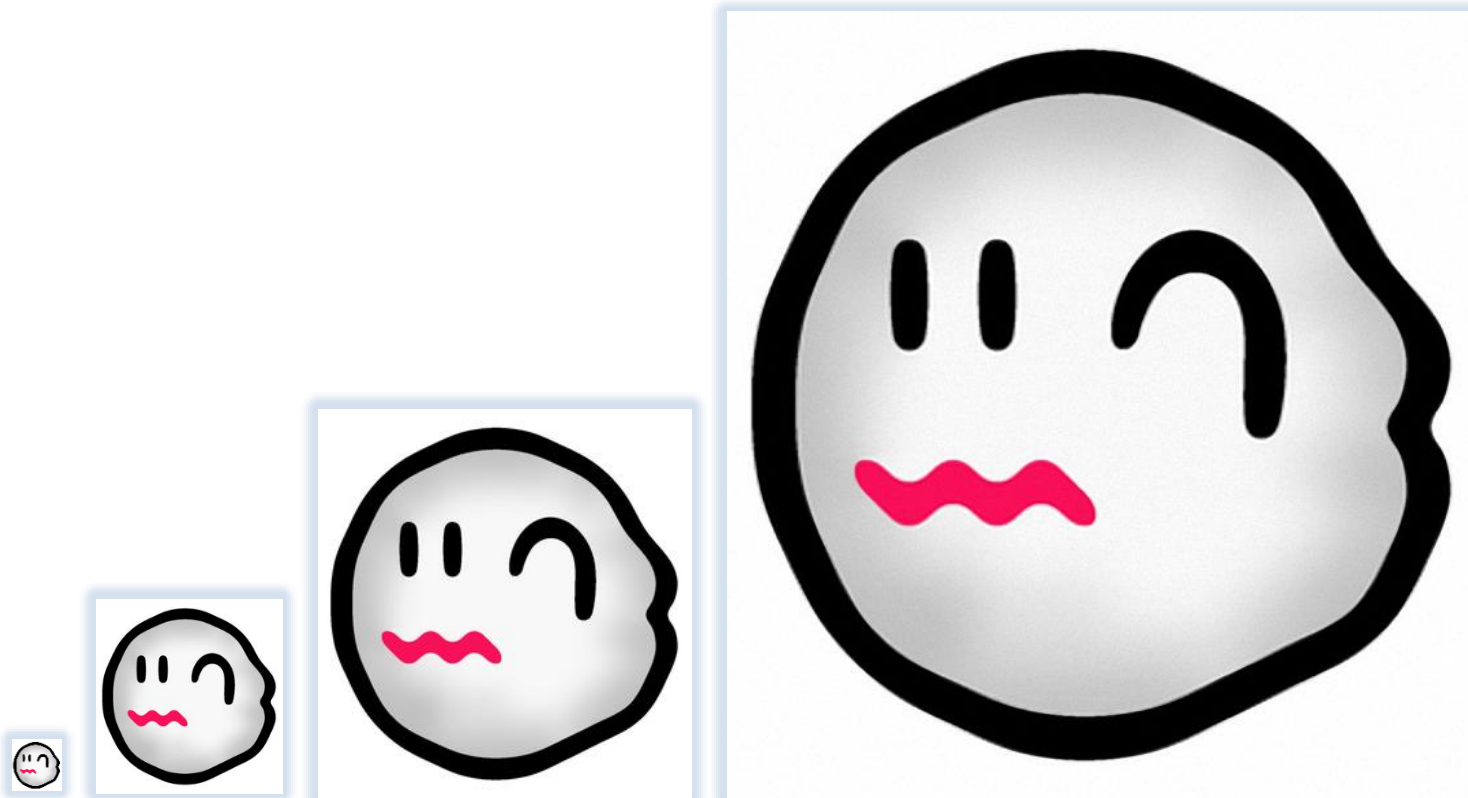
- If we can convert bitmap into vector graphics,
  we can improve the display quality of object resizing.

Input Image

Depixelized

Johannes Kopf, Microsoft Research and Dani Lischinski, The Hebrew University. "Depixelizing Pixel Art", SIGGRAPH 2011

Upscaling a depixelized bitmap



Input Image 4x 8x 16x

3D Graphics

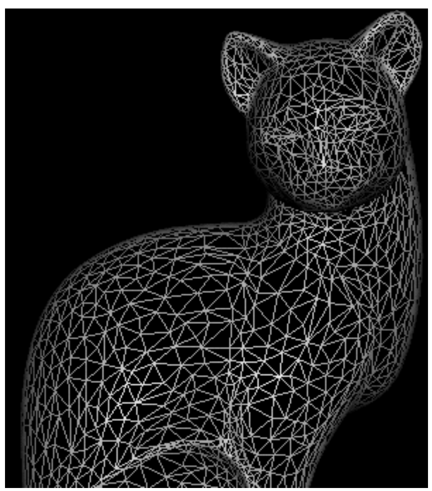
- 3D Graphics Pipeline

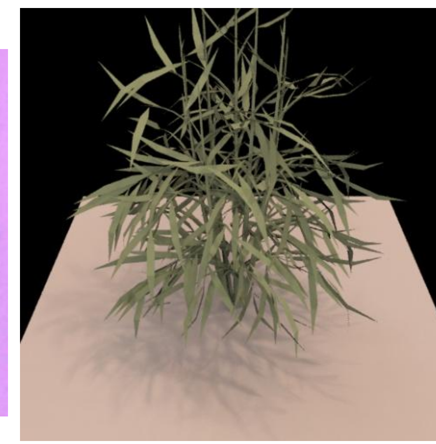
Modeling
(Creating 3D Geometry)

→

Rendering
(Creating, shading images from geometry, lighting, materials)



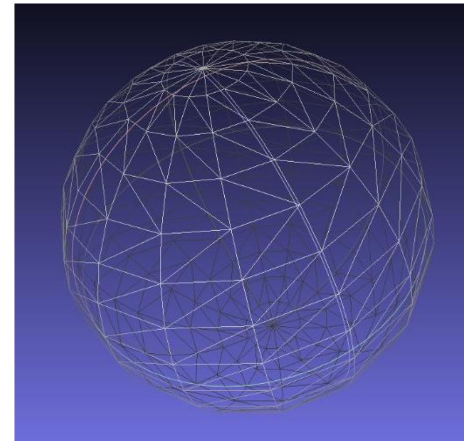


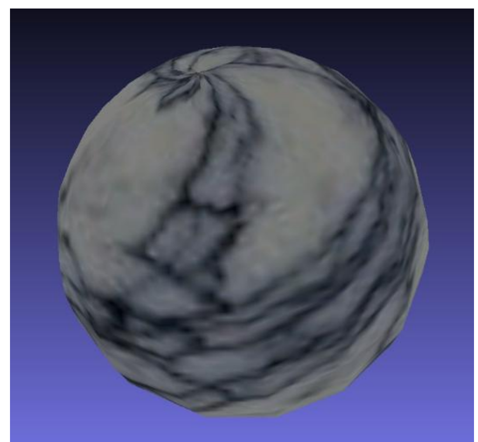


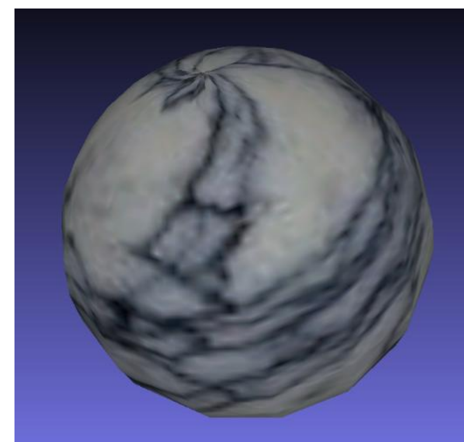
3D Graphics – 3D Model

- Structure
  - Vertices
  - Faces
- Transformation & Projection
- Texture
- Lighting
  - Normal Vectors
  - Material


Vertices

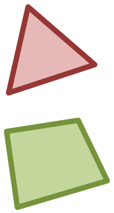

Faces

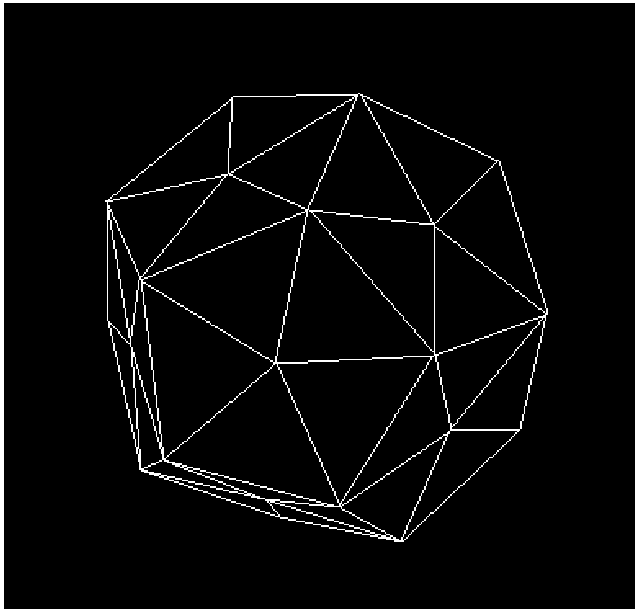

Texture Mapped

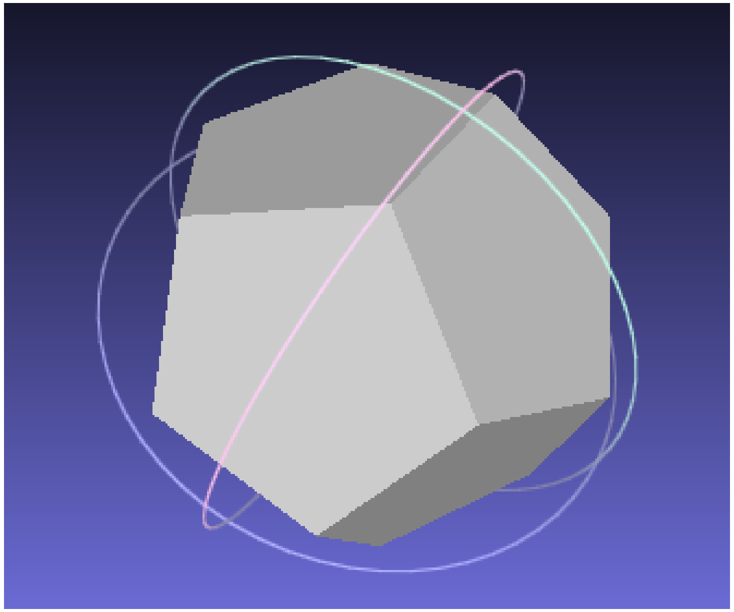

Light on

3D Graphics – 3D Model

- A triangular face consists of 3 vertices
  - While a convex quadrilateral face needs 4
- A mesh model is composed of many faces

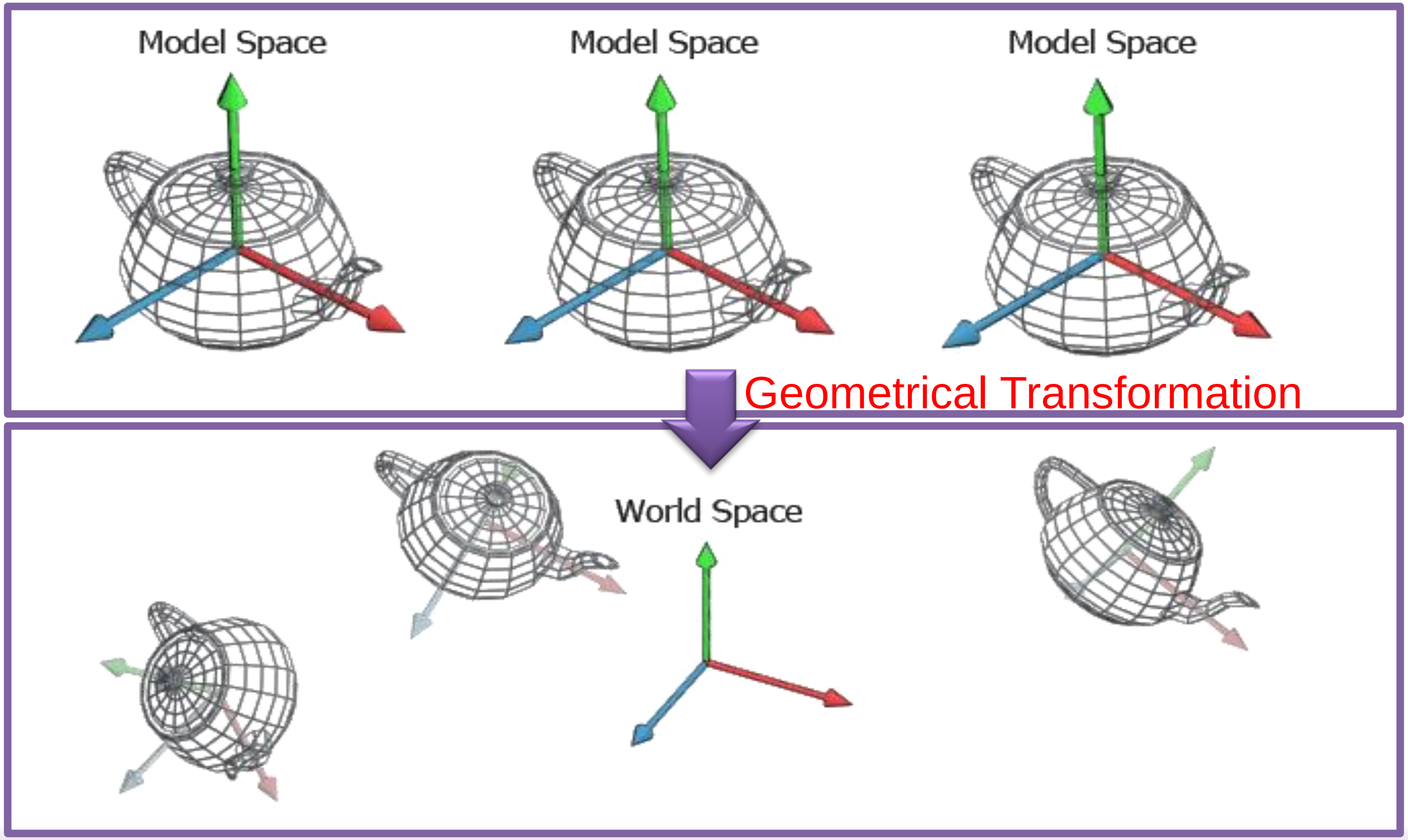






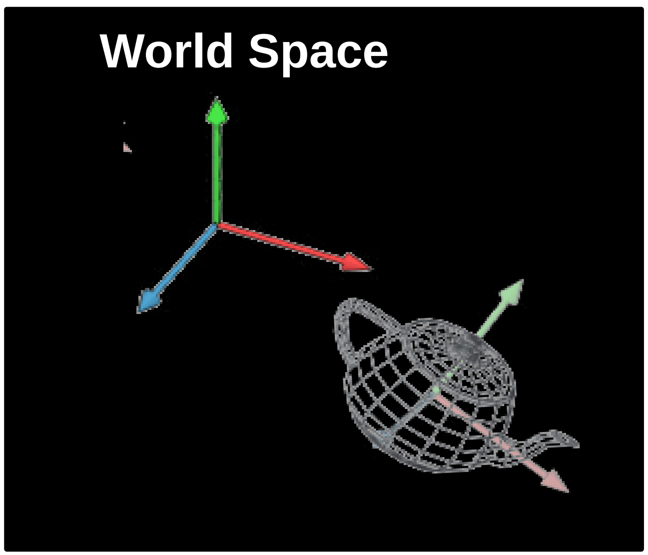
3D Graphics – Transformation

- Geometrical Transformation
  - From Model Space to World Space

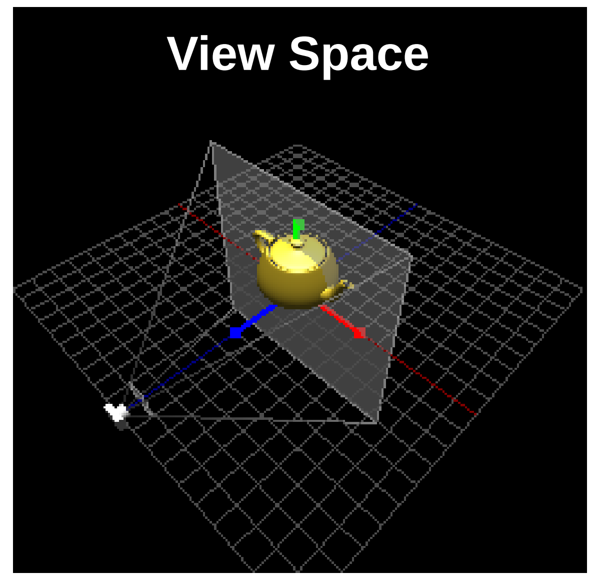


3D Graphics – Transformation

- Viewing Transformation
  - Form World Space to View Space (Eye Space or Camera Space)

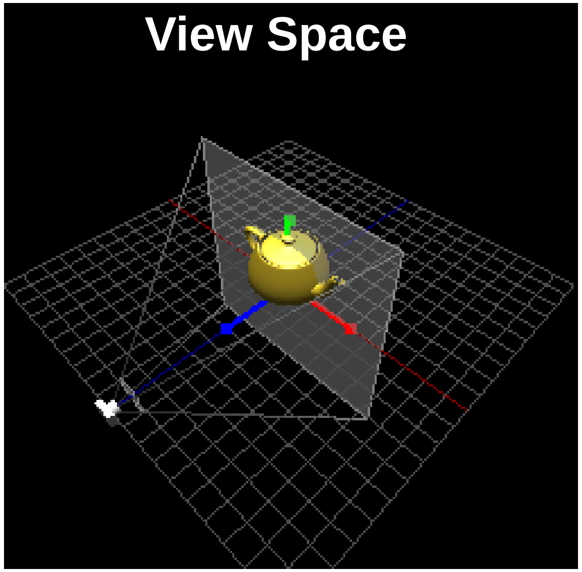


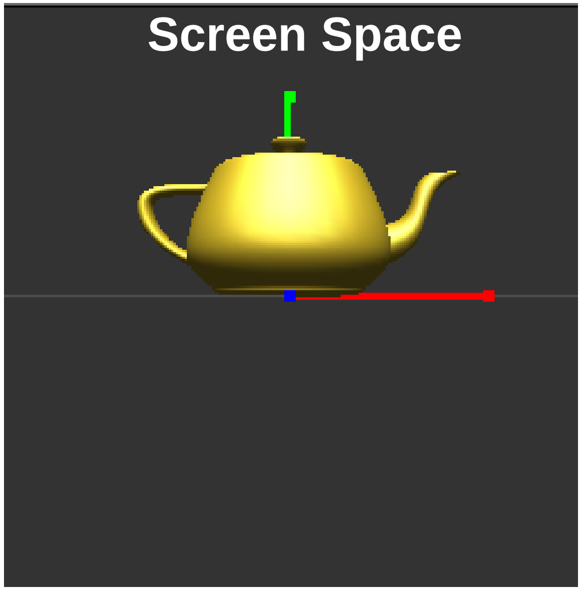
Viewing Transformation



3D Graphics – Transformation

- Projection and Viewport Transformation
  - From View Space to Sceen Space

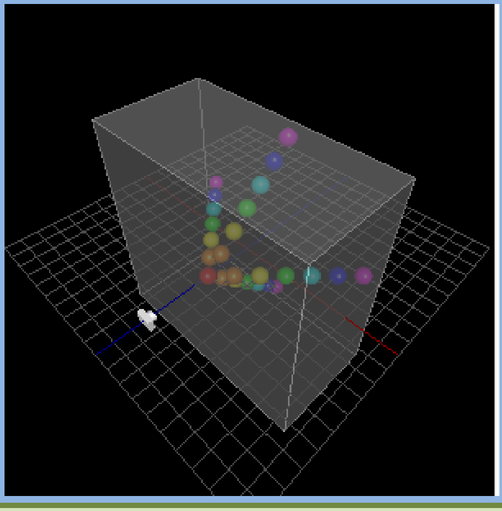


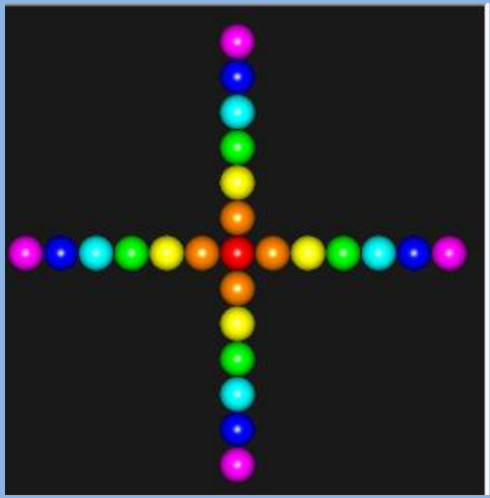


3D Graphics – Projection

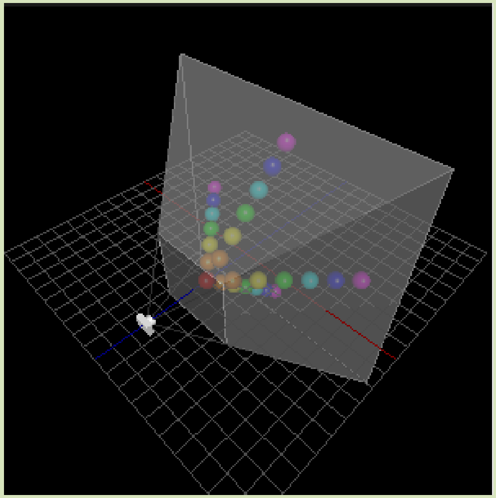
- Parallel projection vs. perspective projection

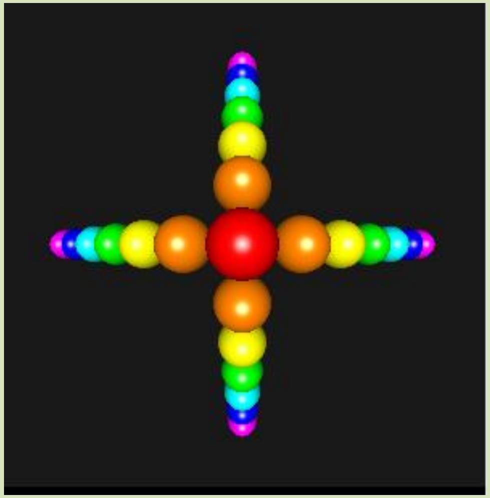
Parallel projection





Perspective projection

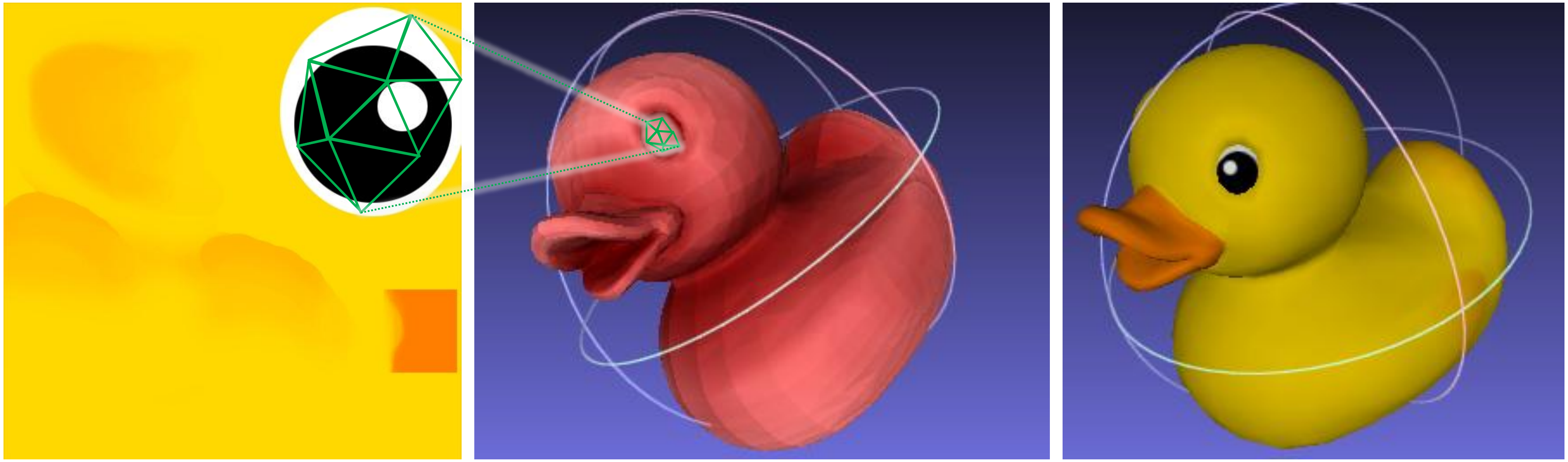




3D Graphics – 3D Model

- Texture mapping

  Each face of the 3-D model is mapped to corresponding triangular piece of the 2-D image.

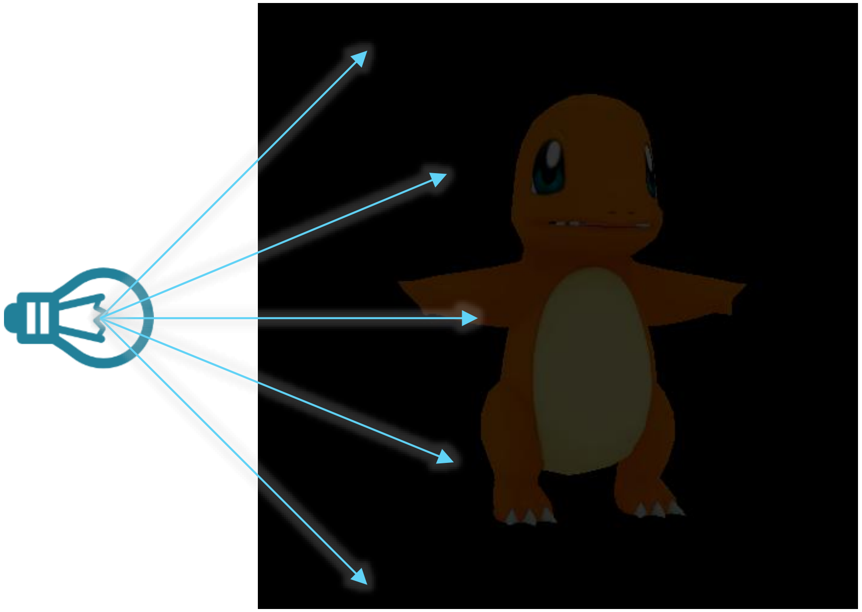


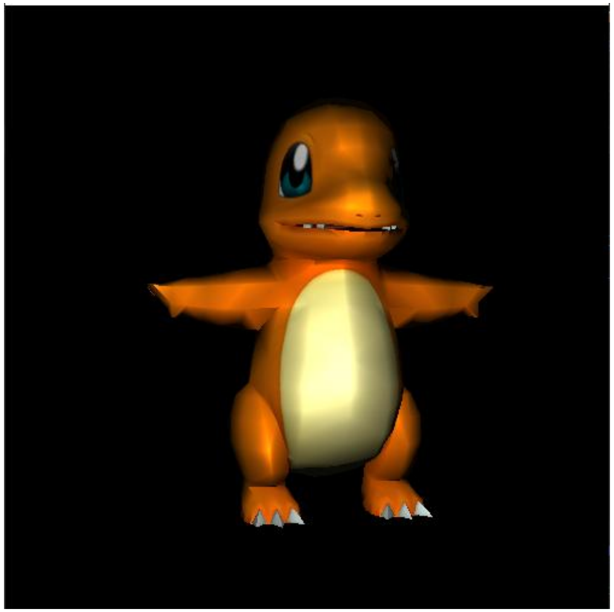
Texture image + Textureless model → Model with texture

How do we do this?

3D Graphics – Light Sources

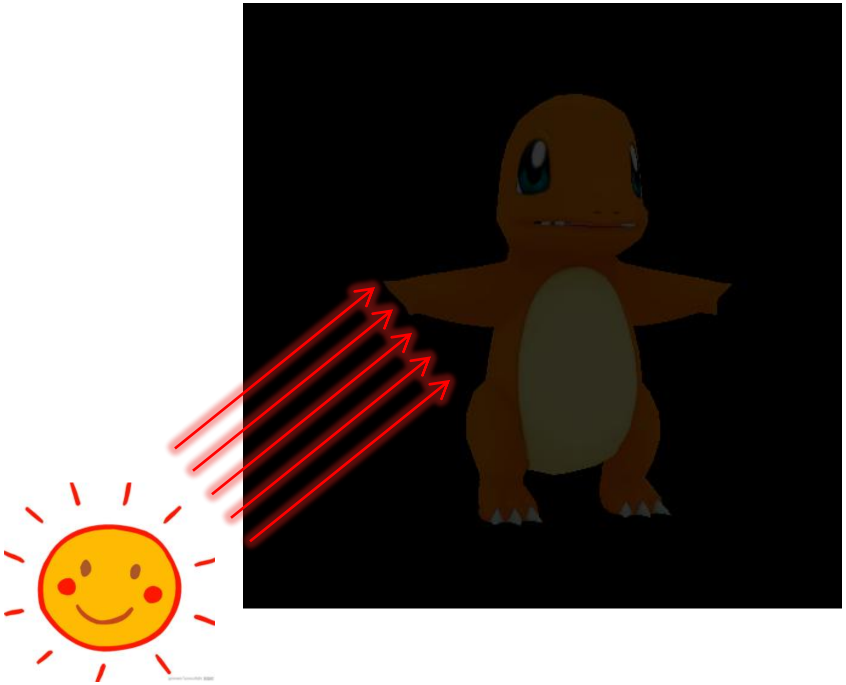
- Positional light(Point Light)
  - Light source located at a specific position

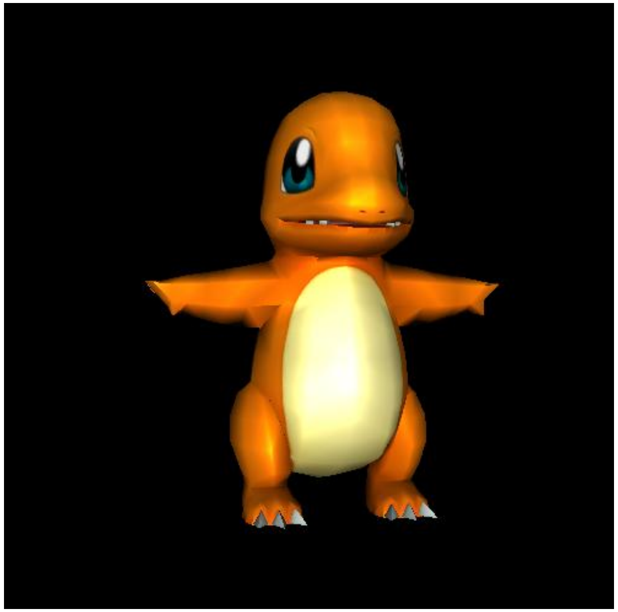




3D Graphics – Light Sources

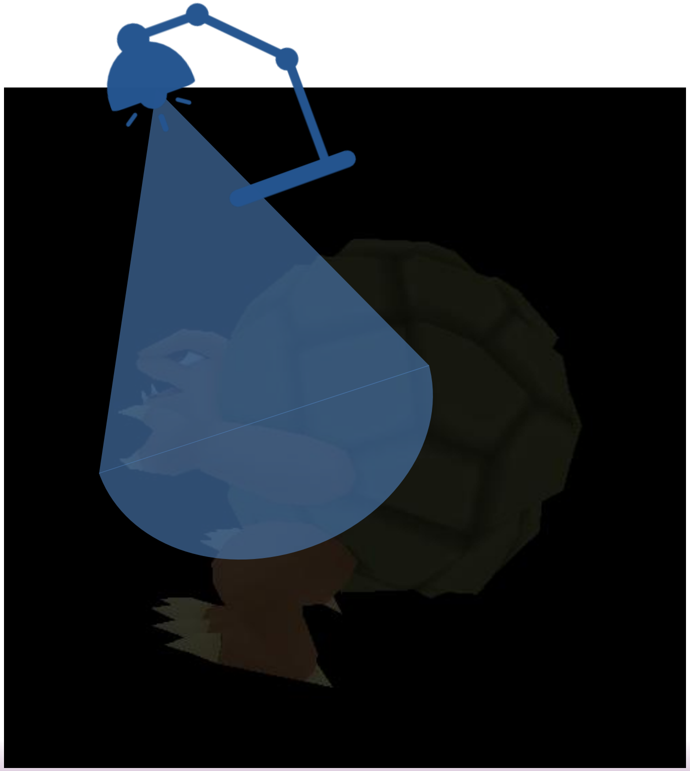
- Directional light (positional light at infinity)
  - Light source located at infinite far away. Such as sun.





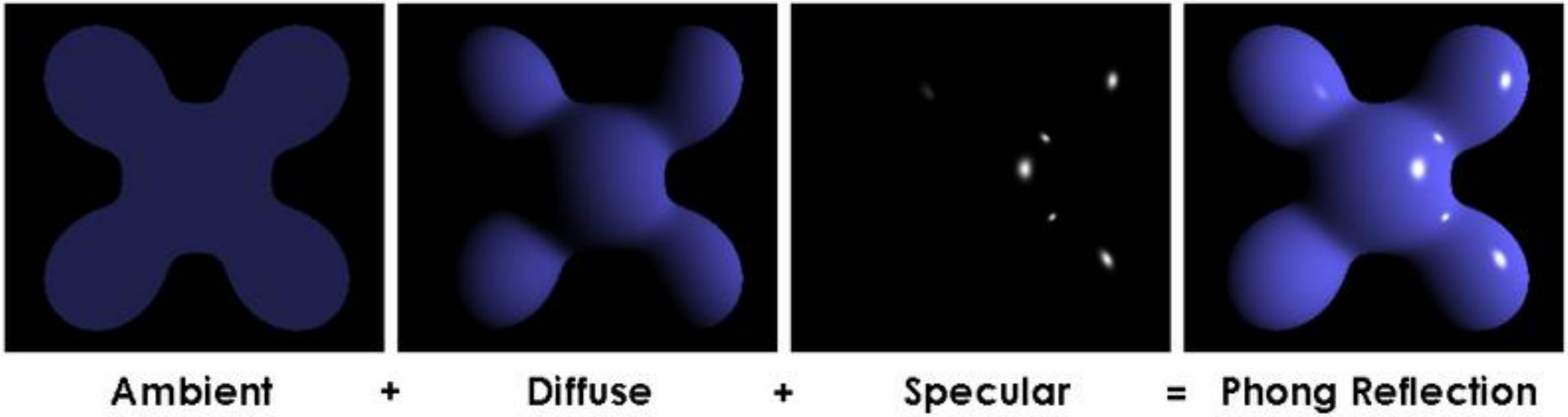
3D Graphics – Light Sources

- Spot light (positional light with angle limitation)
  - Light source located at a specific position with certain cutoff range.



3D Graphics – Lighting Equation

- **Intensity = Ambient + Diffuse + Specular**



3D Graphics – Ambient

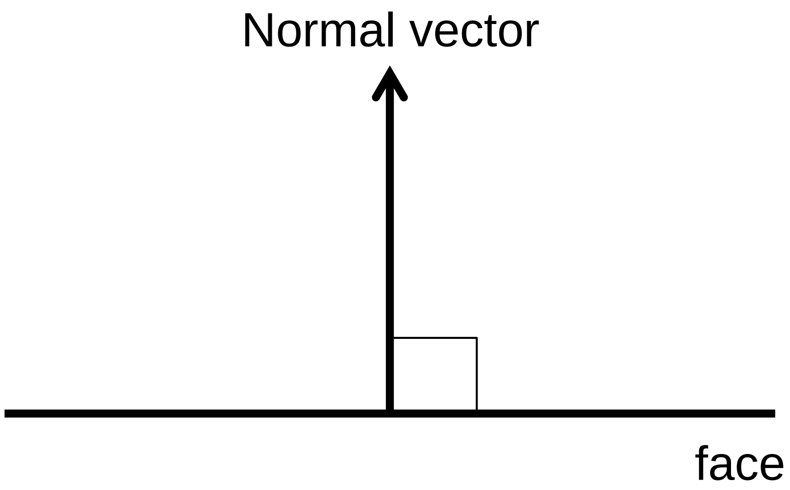
- Ambient
  - Illumination surrounding a scene without providing any specific light source.

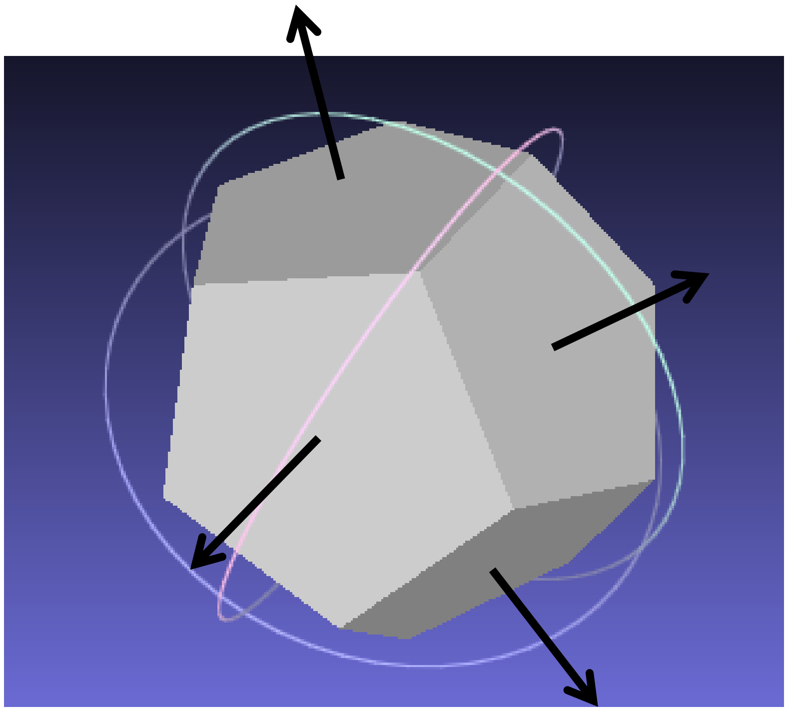
$$I = I_a \times k_a$$

I : resulting intensity
I_a : ambient light intensity
k_a : ambient reflection coefficient

3D Graphics – Surface Normal

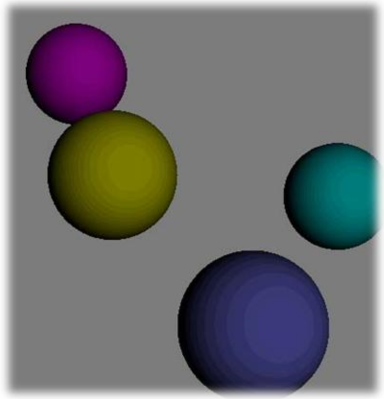
- Each face has a normal vector.



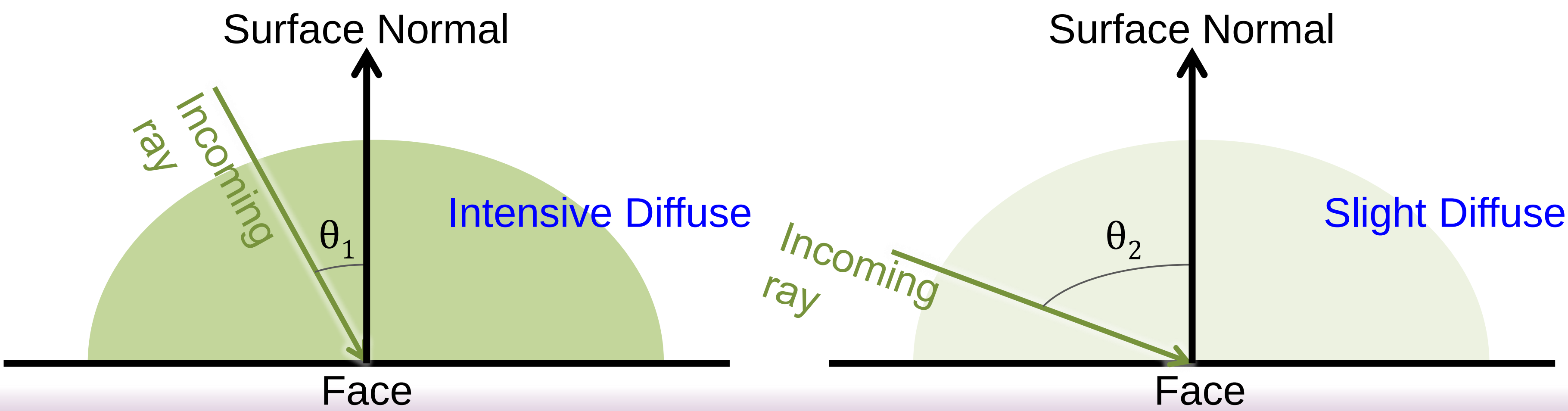


3D Graphics – Diffuse

- Diffuse reflection intensity : $I_p \times k_d \times cos^+ \theta$

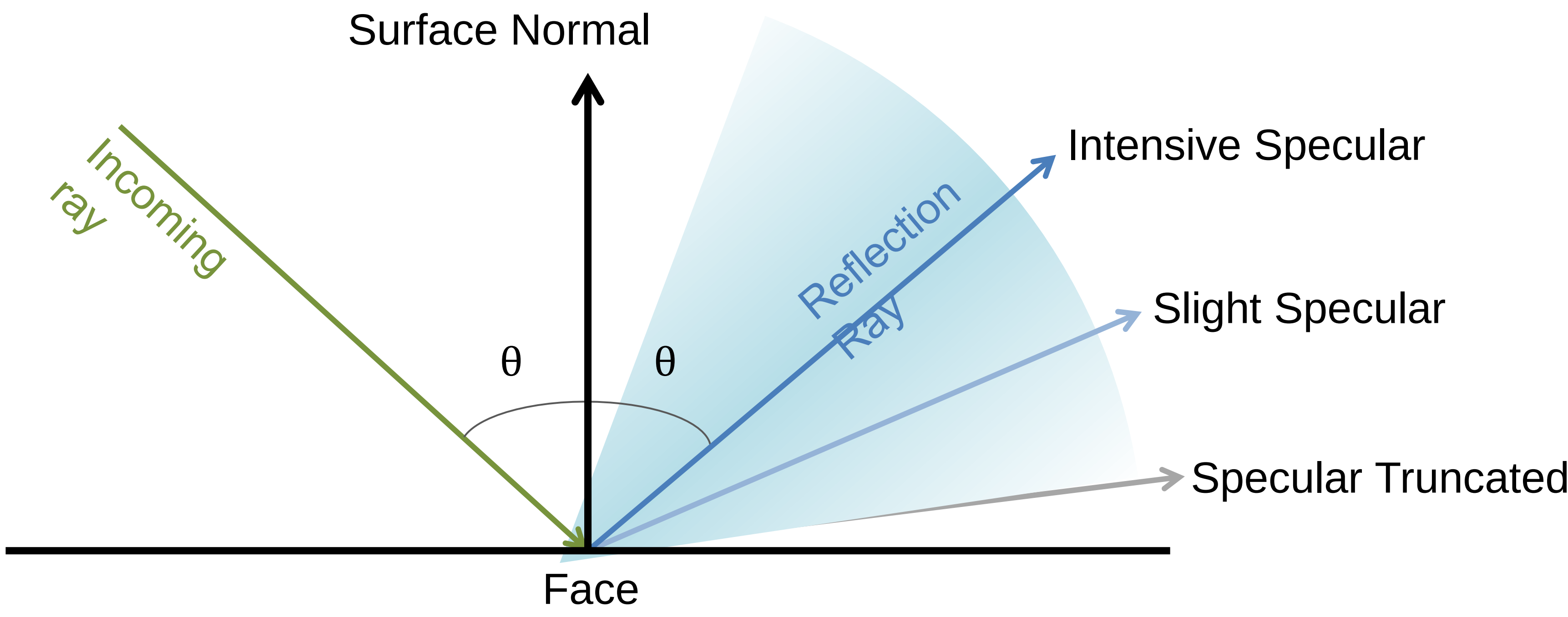


I_p *: point light source intensity*
k_d *: diffuse reflection coefficient*
$cos^+ \theta$ *: max(0,* $\cos\theta$*)*



3D Graphics – Specular

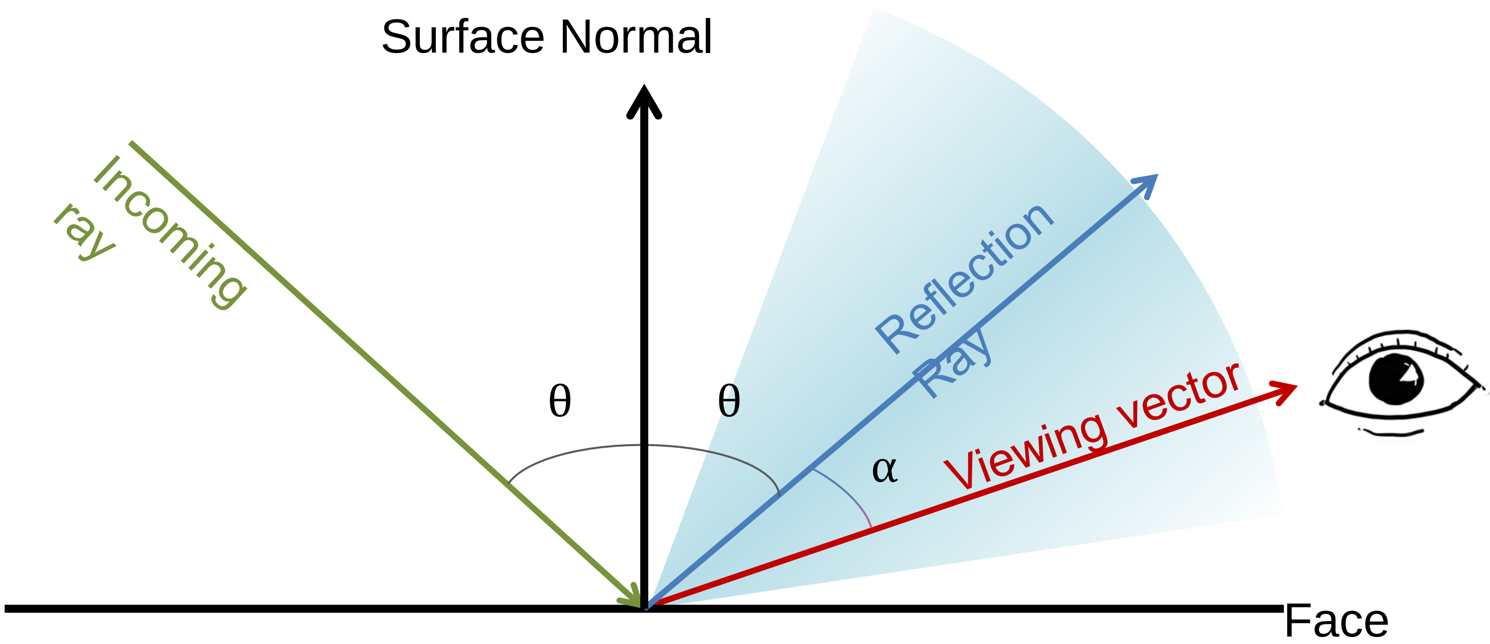
- Specular reflection



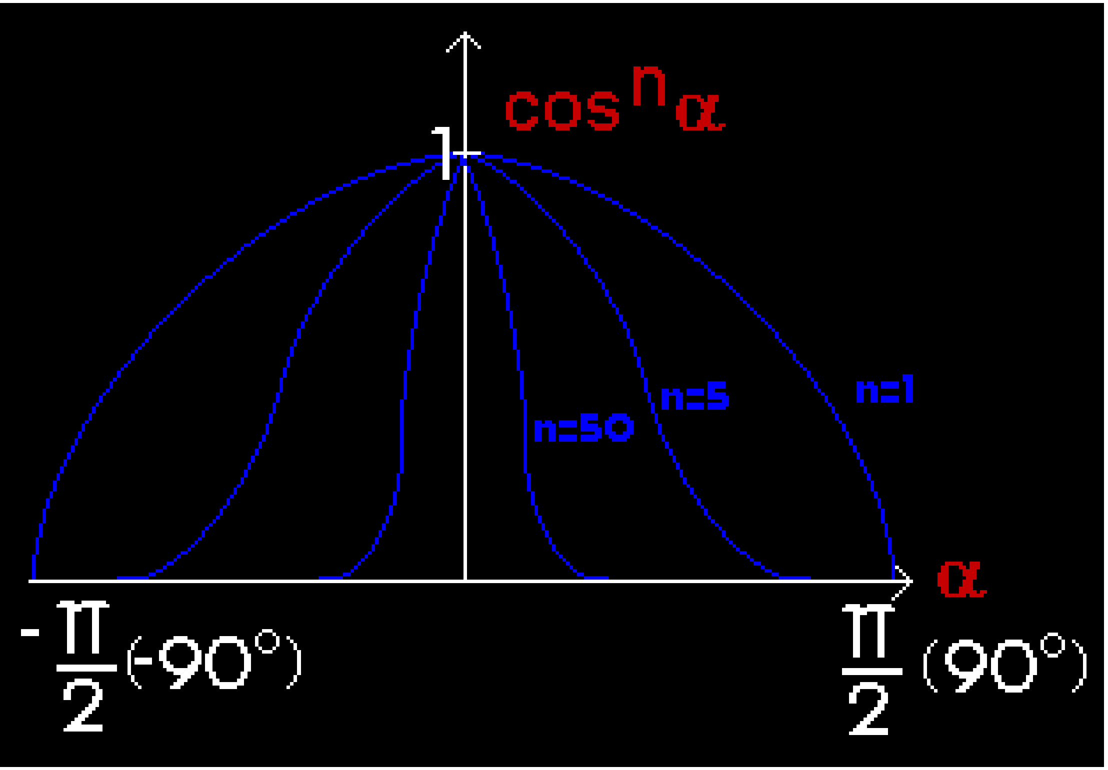
3D Graphics – Specular

You will see the lighting intensity : $I_p \times k_s \times (\cos\alpha)^n$

I_p : Light source specular intensity
k_s : specular reflection coefficient
n : a positive parameter

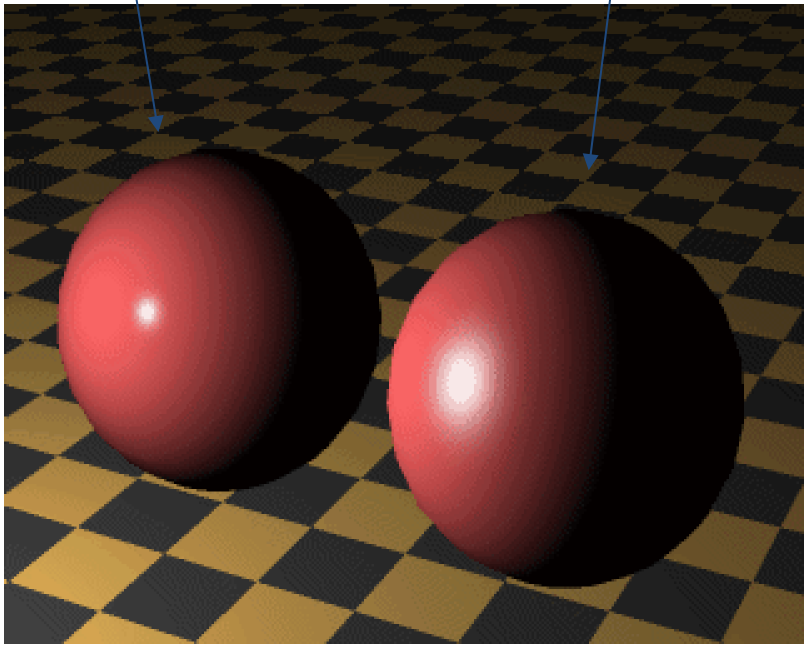


Specular



Small n

Large n



3D Graphics – Specular

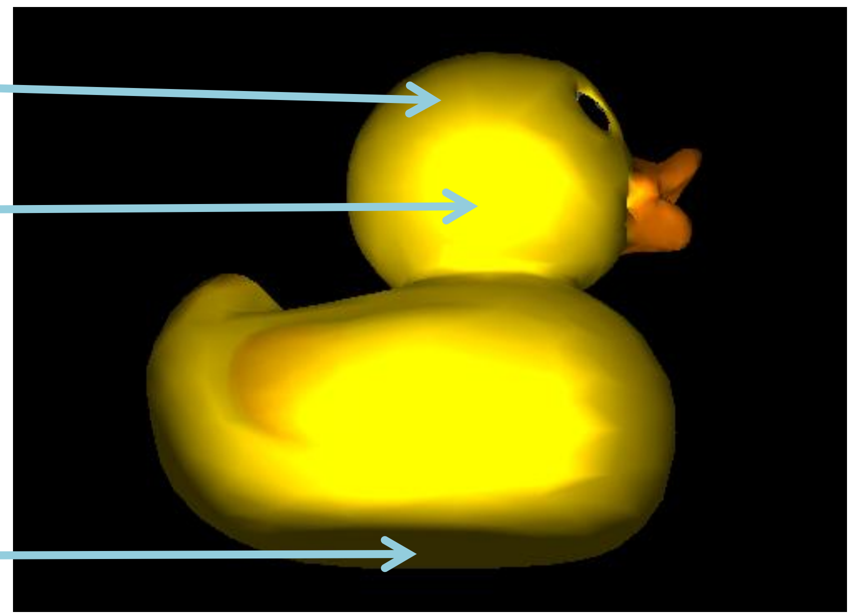
You will see the lighting intensity : $I_p \times k_s \times (\cos\alpha)^n$

The bigger $|\alpha|$, the smaller $I_p \times k_s \times (\cos\alpha)^n$

$|\alpha| > 0$

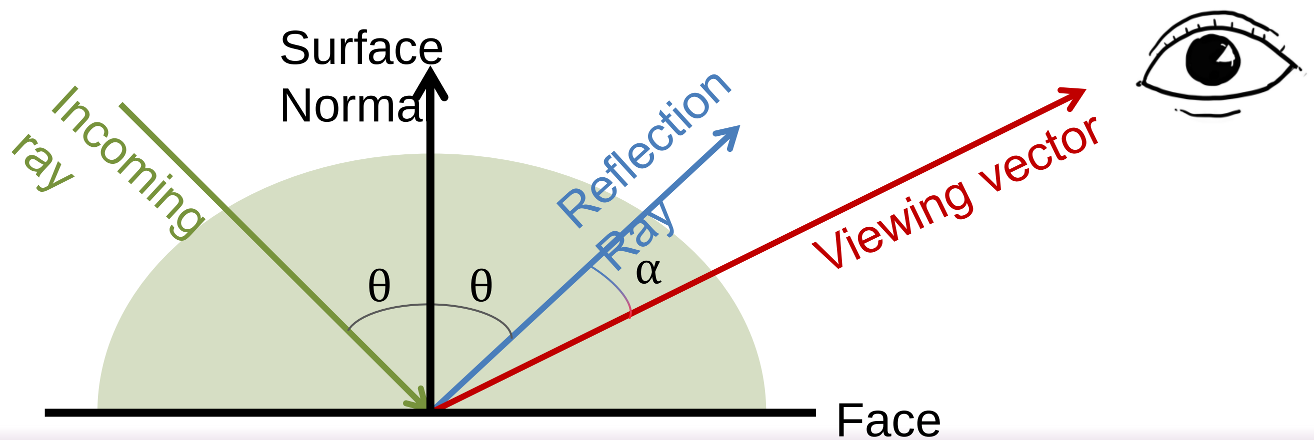
$|\alpha| \fallingdotseq 0$

$|\alpha| >> 0$



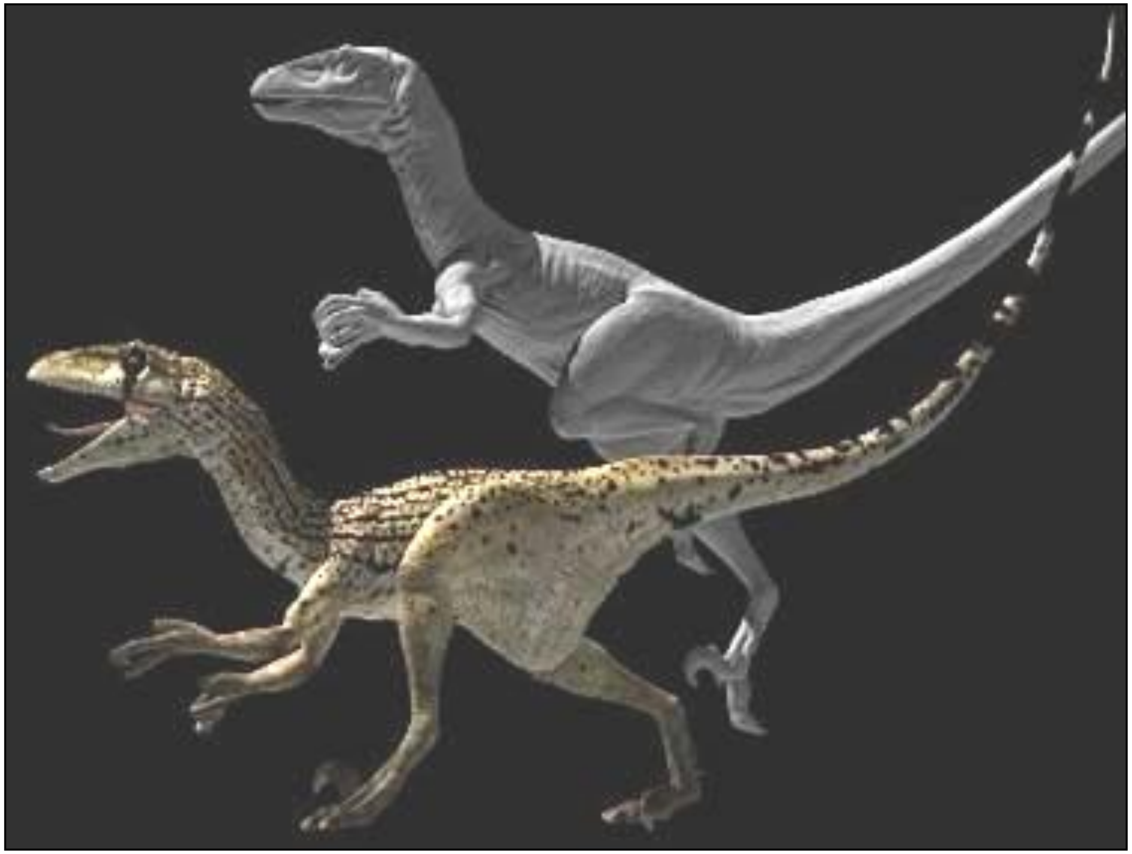
Phong model

- Intensity = Ambient + Diffuse + Specular
- => $\underbrace{(I_a \times k_a)}_{\text{Ambient}} + \underbrace{(I_p \times k_d \times \cos\theta)}_{\text{Diffuse}} + \underbrace{(I_p \times k_s \times (\cos\alpha)^n)}_{\text{Specular}}$

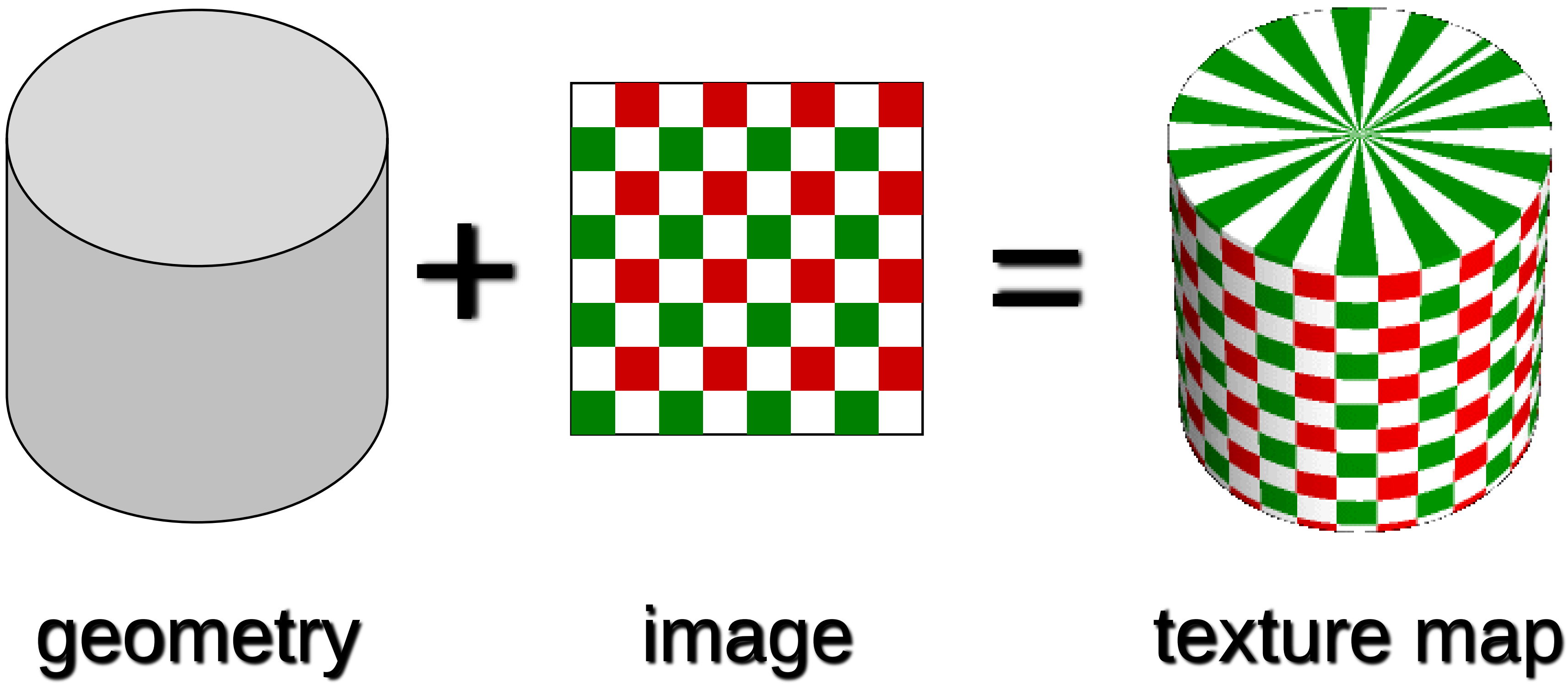


Surface Textures

- Add visual detail to surfaces of 3D objects

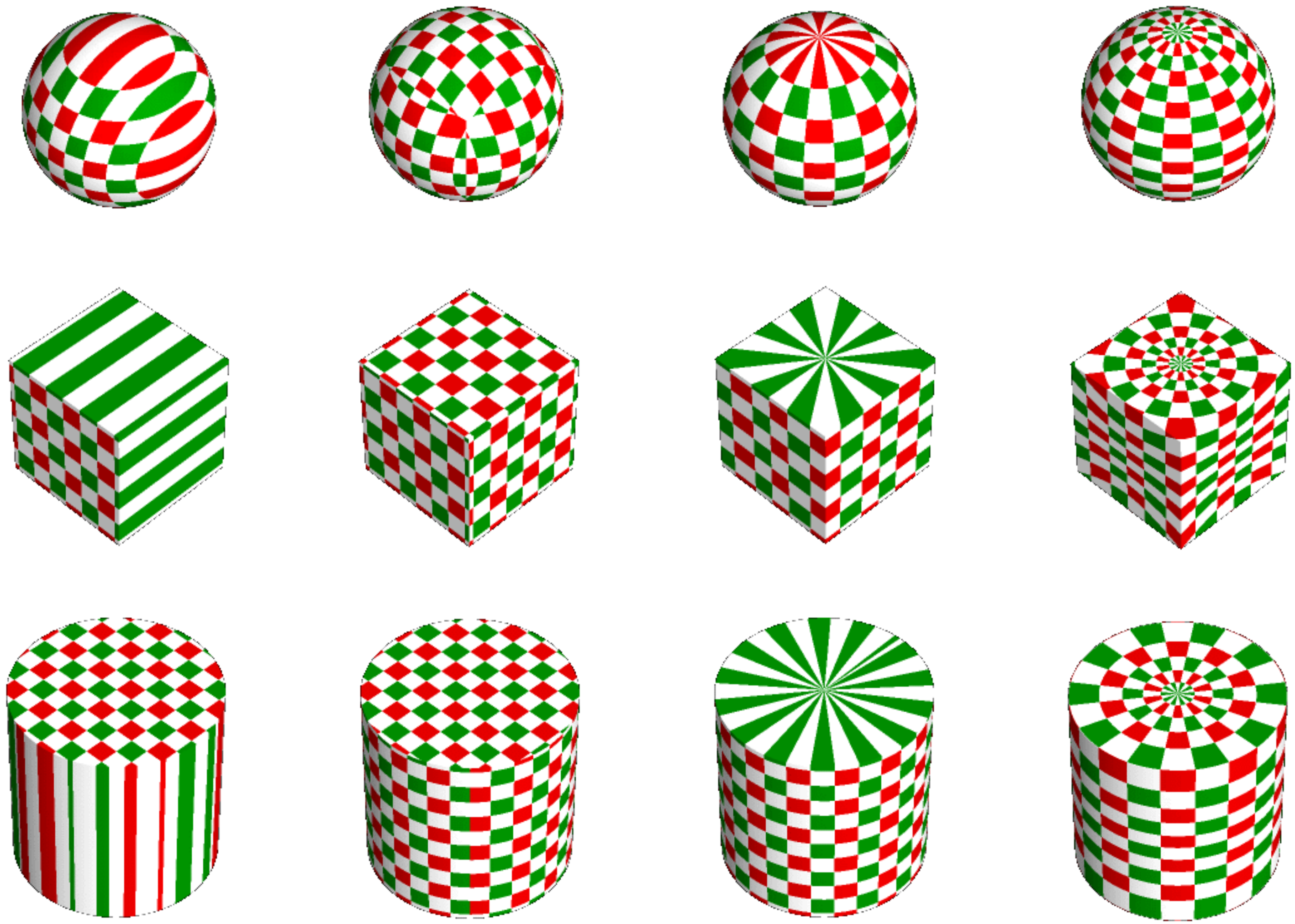


Parameterization



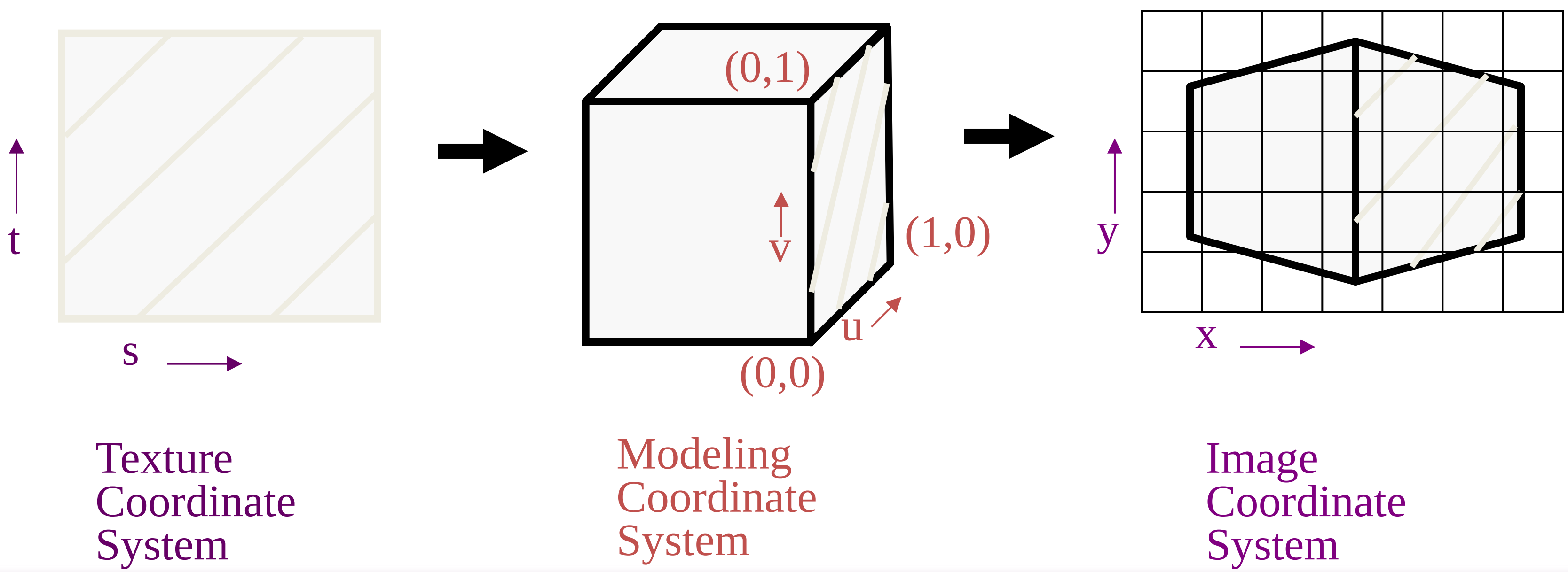
- Q: How do we decide *where* on the geometry each color from the image should go?

Option: Varieties of projections



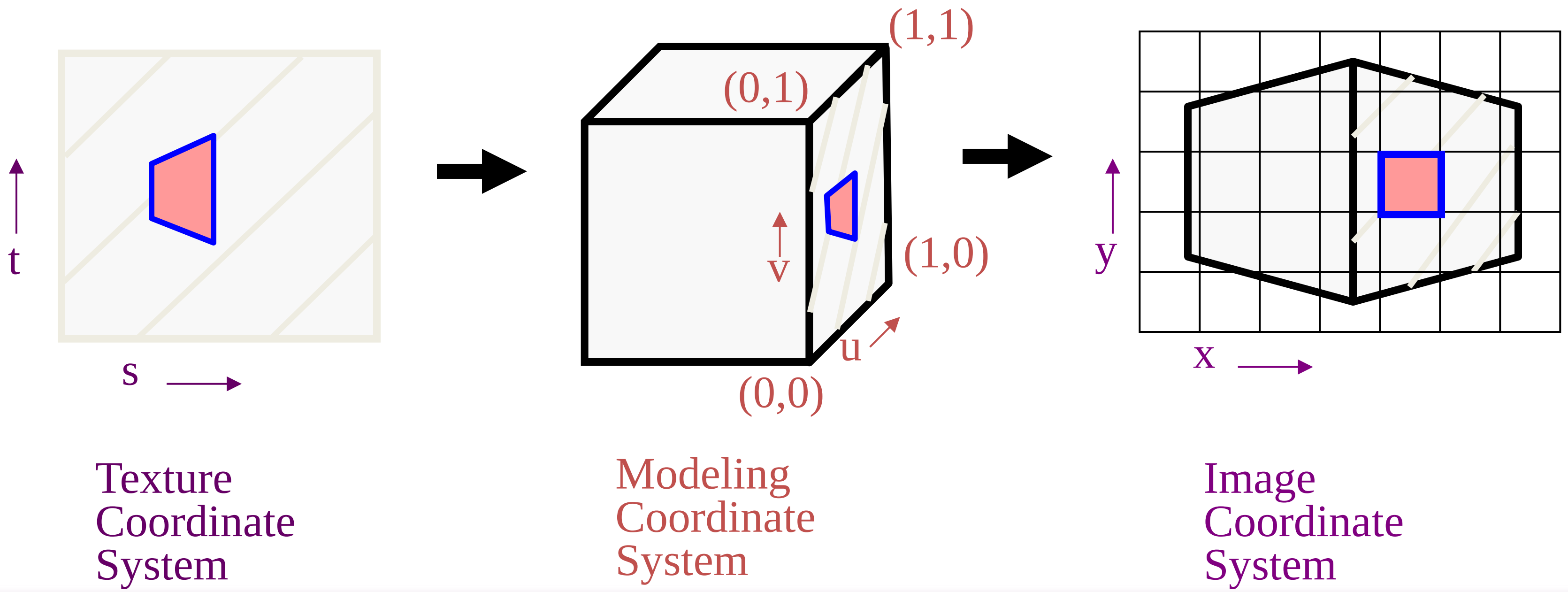
Texture Mapping

- Steps:
  - Define texture
  - Specify mapping from texture to surface
  - Lookup texture values during scan conversion



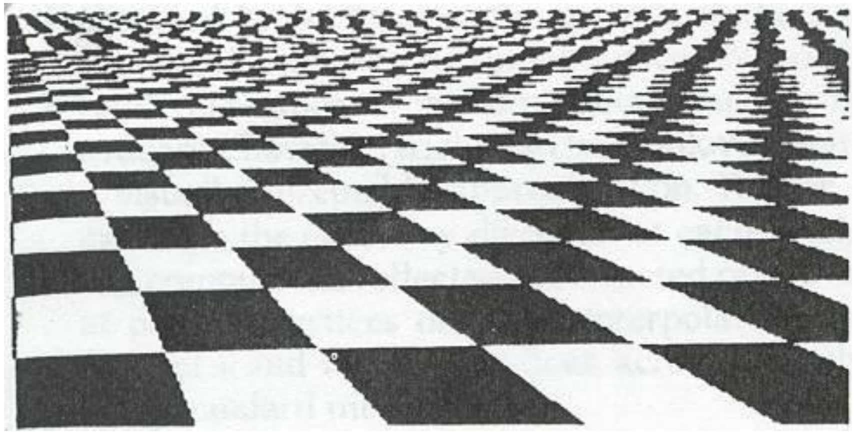
Texture Mapping

- When scan convert, map from …
  - image coordinate system (x,y) to
  - modeling coordinate system (u,v) to
  - texture image (t,s)

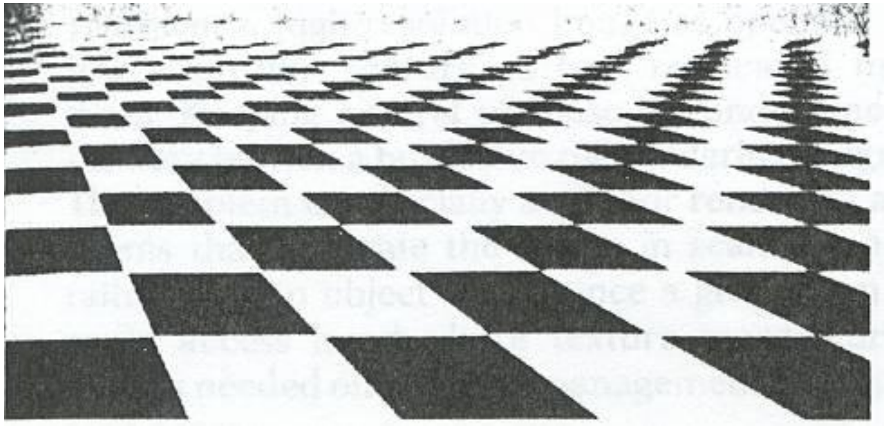


Texture Filtering

- Aliasing is a problem



Point sampling

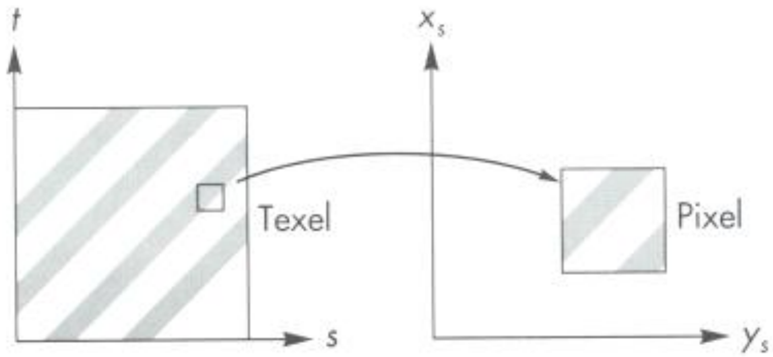


Area filtering

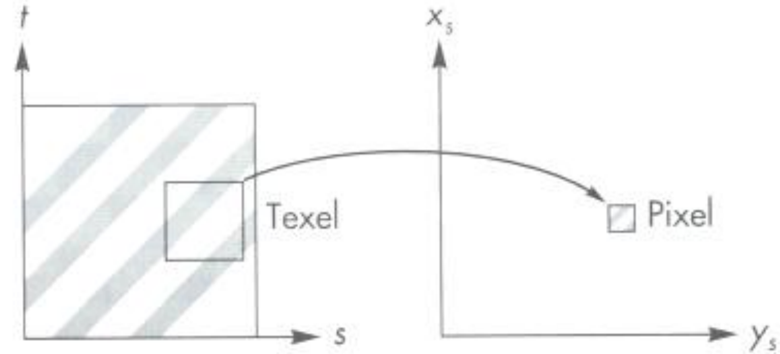
Angel Figure 9.5

Texture Filtering

- Size of filter depends on projective warp
  - Can prefiltering images



Magnification

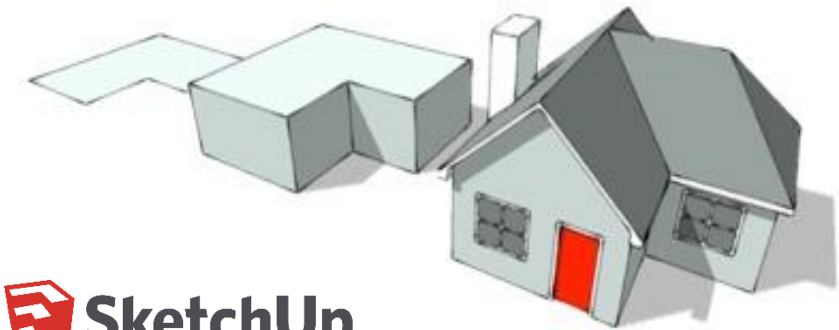


Minification

Angel Figure 9.14

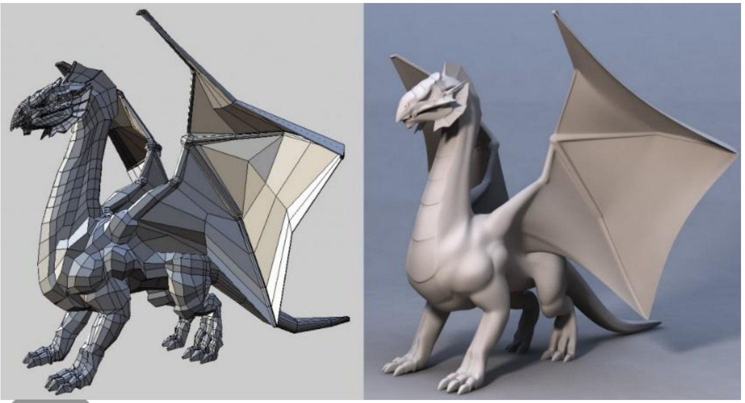
3D Face Modeling Example

CG Tools

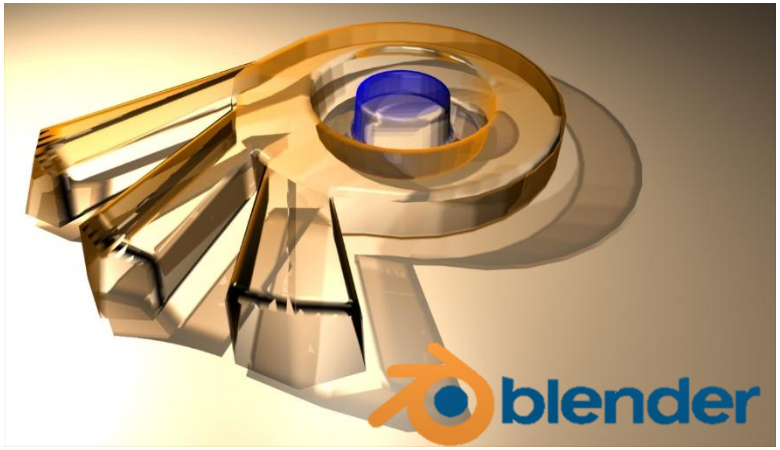


SketchUp

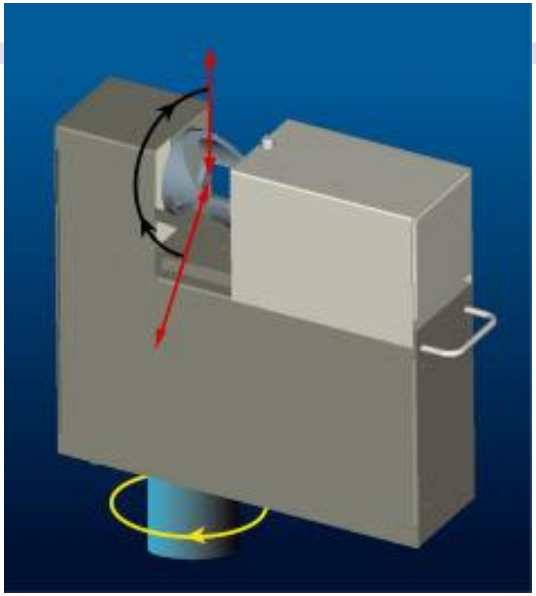
(Free trial) MAYA



WINGS 3D



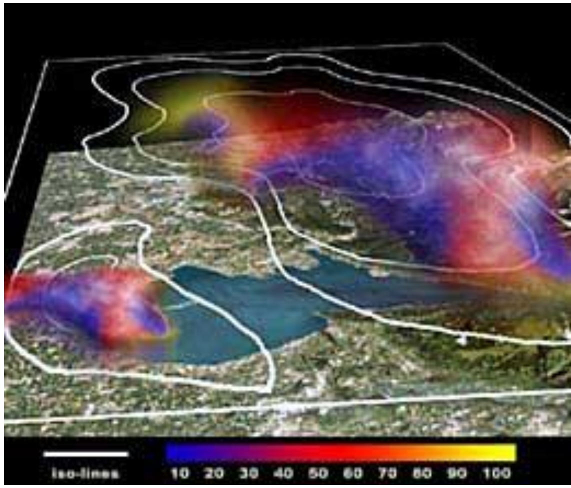
Scanners



- Image Scanners - Flatbed, etc.
  - What type of data is returned? Bitmap
- Laser Scanners - Deltasphere
  - Emits a laser and does time of flight. Returns 3D point
- Camera (image) based
  - Examine camera image(s) and try to figure out vertices from them.

Computer Graphics Applications

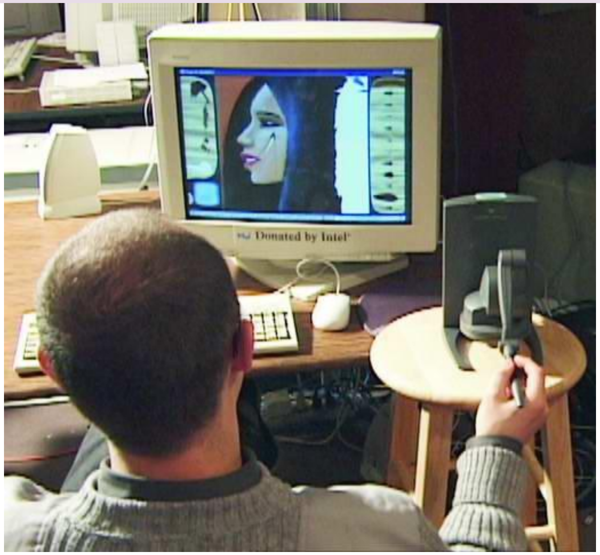
- Data Visualization
  - Scientific, Engineering, Medical data
  - Visualizing millions to billions of data points
  - See trends
  - Different schemes

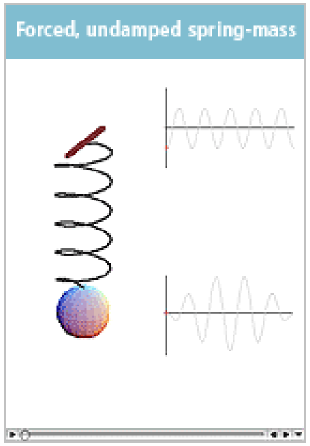


- Virtual Reality
  - VR: User interacts and views with a 3D world using “more natural” means

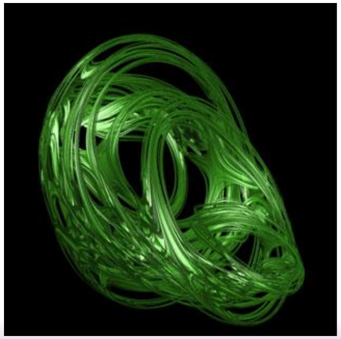
Computer Graphics Applications

- Education and Training
  - Models of physical, financial, social systems
  - Comprehension of complex systems





- Computer Art
  - Fine and commercial art
  - Performance Art
  - Aesthetic Computing
  - SIGGRAPH



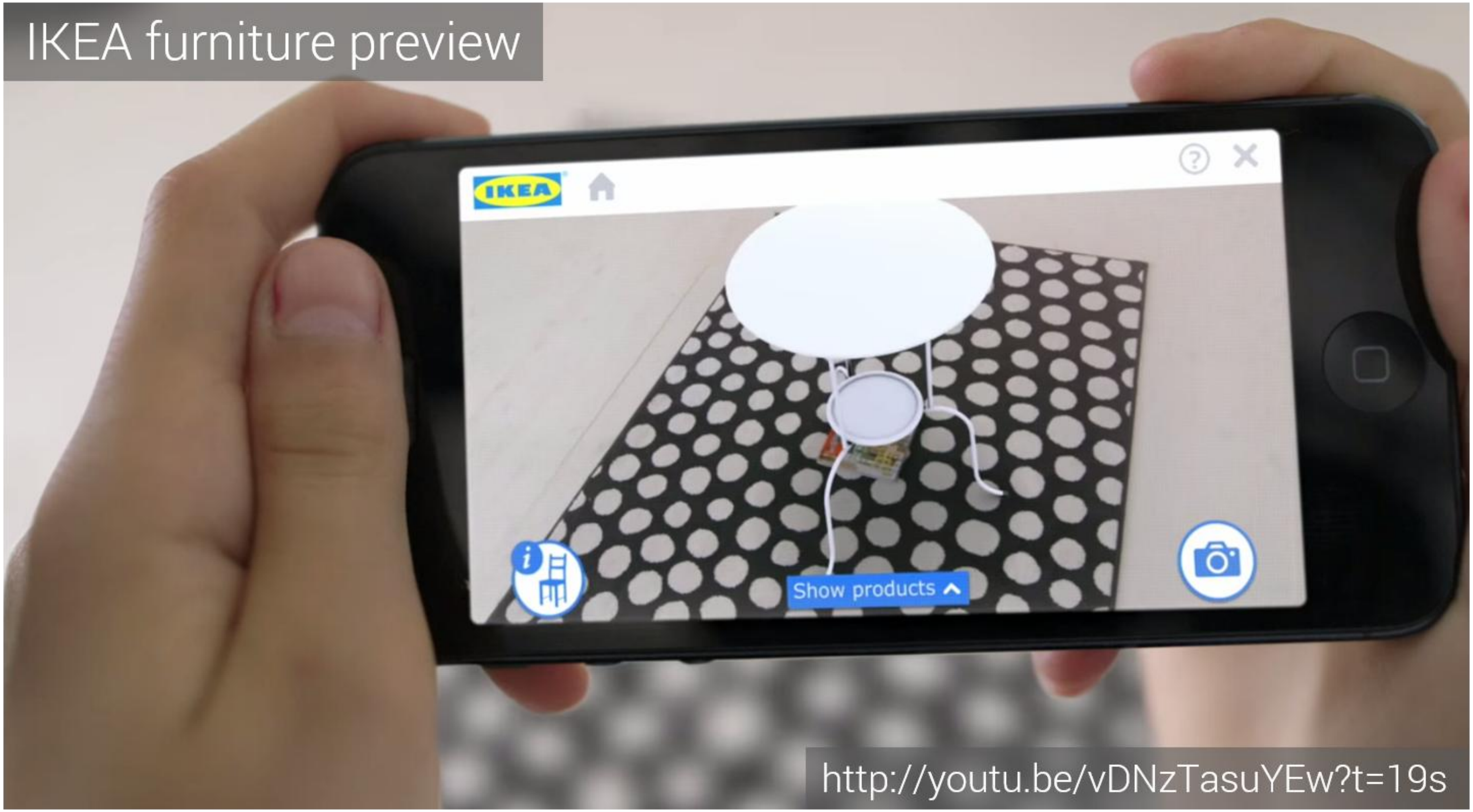
Computer Graphics Applications

- Games/Movies

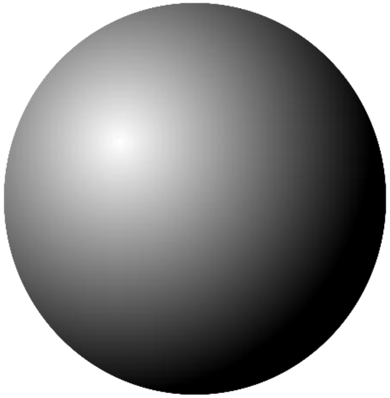
Augmented Reality

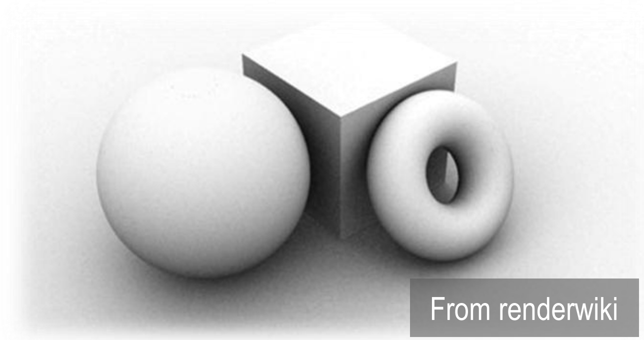
- It's computationally expensive to render a 3-D scene in real-time
- To render these vivid 3D scenes, a high-end gaming PC is necessary
- AR is to render some virtual objects that are mixed in real world

Augmented Reality



3D perception — Depth



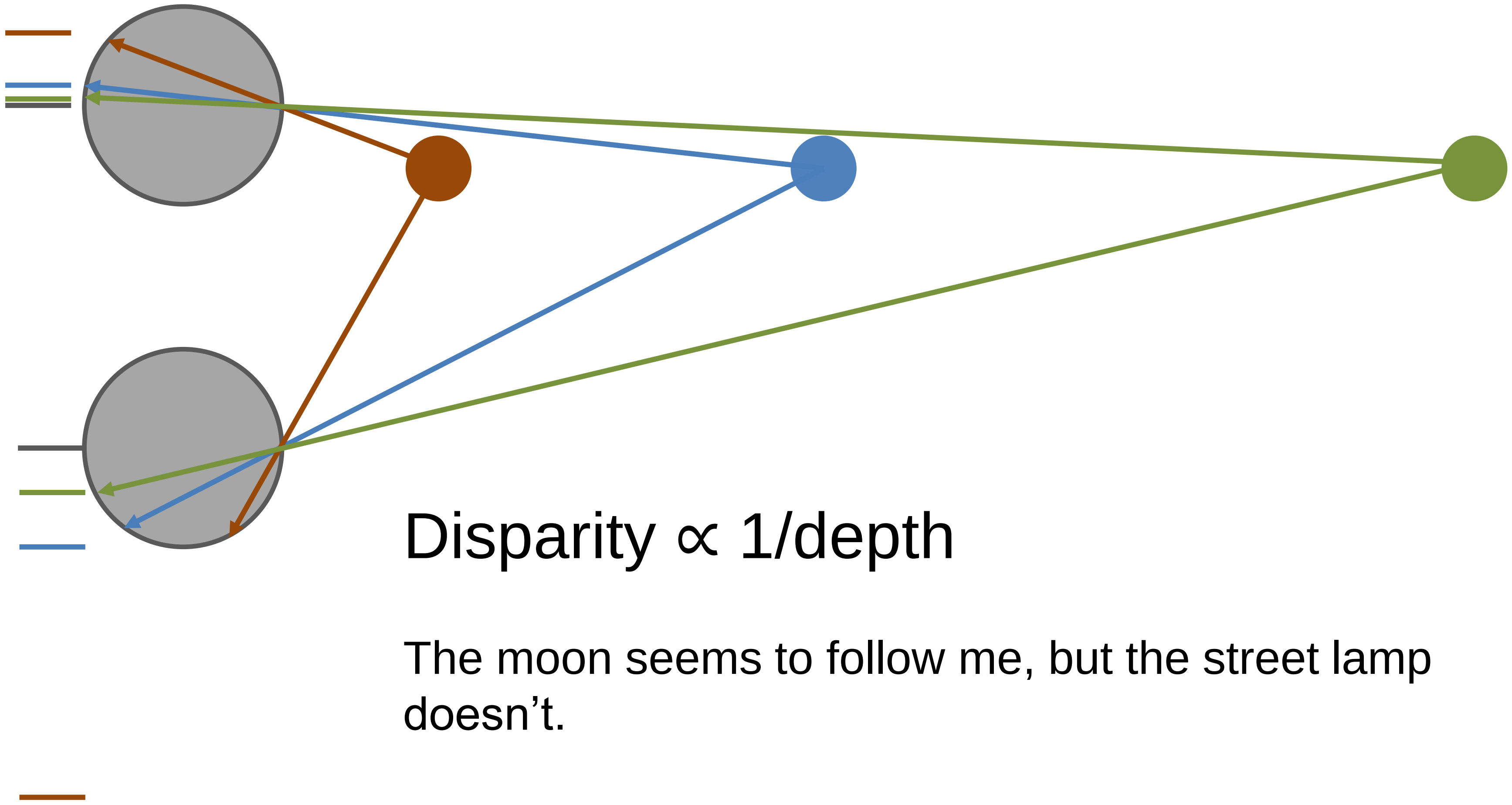


Size and Vanishing point

Light and Shadow

Occlusion

Stereo 3D perception

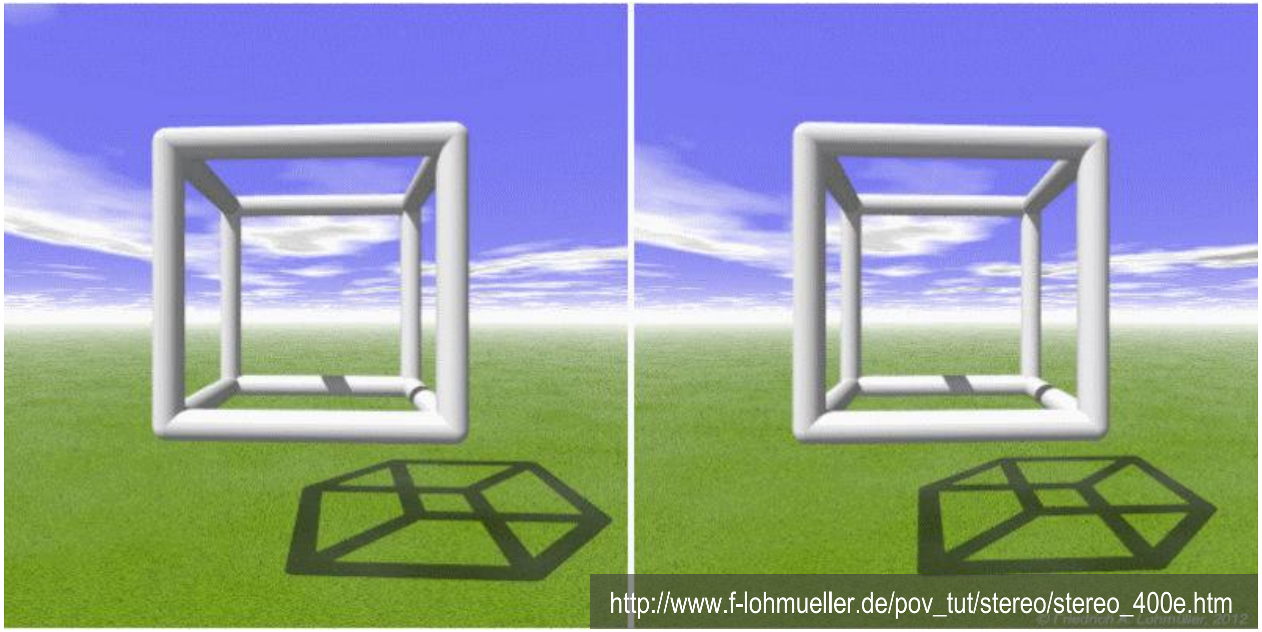


Disparity ∝ 1/depth

The moon seems to follow me, but the street lamp doesn't.

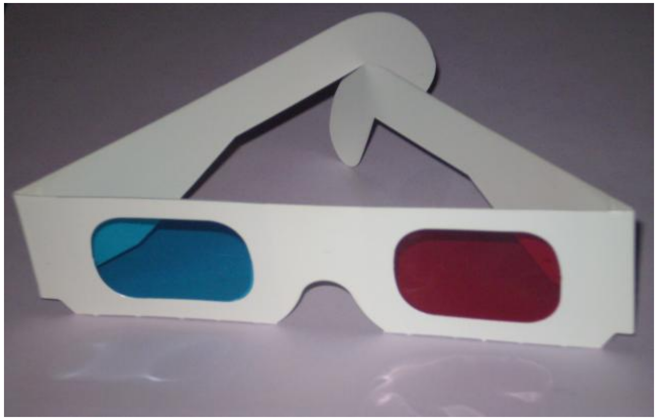
Stereo Camera and Stereo Images

Stereo Camera



Stereo Images

3D movies & 3D TV



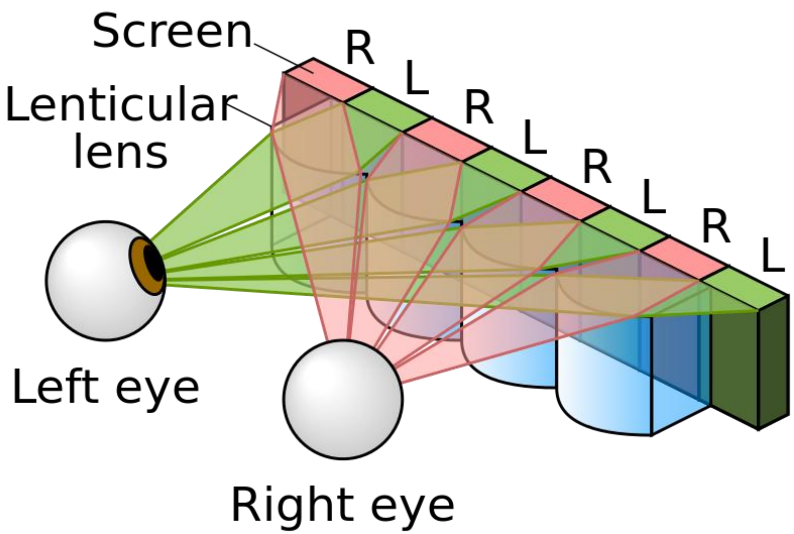
Anaglyph 3D glasses

Polarized glasses

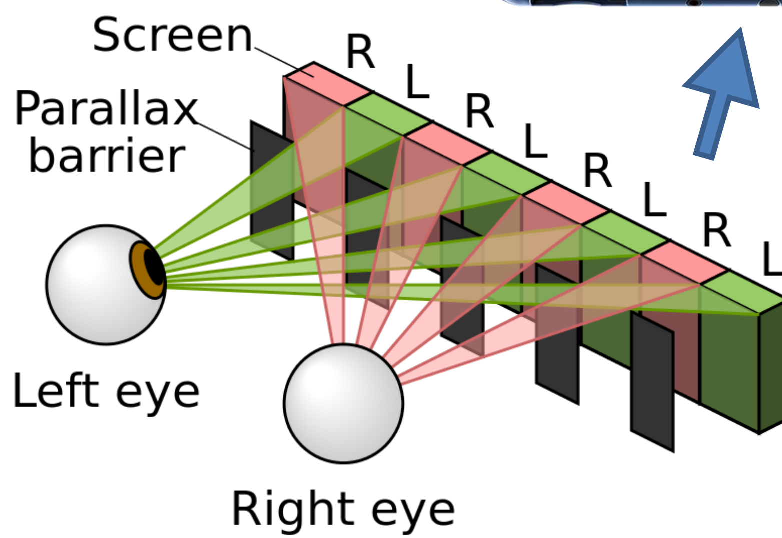
Shutter glasses

Autostereoscopy (Glass-less)

Nintendo 3DS



Lenticular screen



Parallax barrier

Summary

- 2D Vector Graphics
- 3D Graphics
  - 3D modeling
  - Image rendering
- Applications