Introduction to Computer Graphics

Marie-Paule Cani : Cours

Estelle Duveau : CTD OpenGL

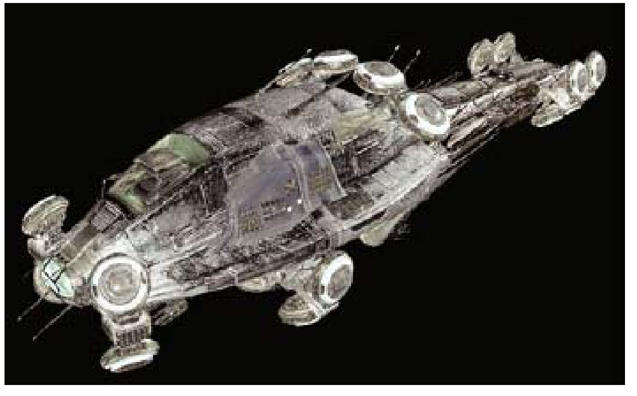
Computer Graphics

- 3D animation
  - « Disney Effects »

(Luxo Jr (1986)
Pixar animation studios
Director: John Lasseter)

Computer Graphics

- Special effects
  - Seam-less mix of real & virtual

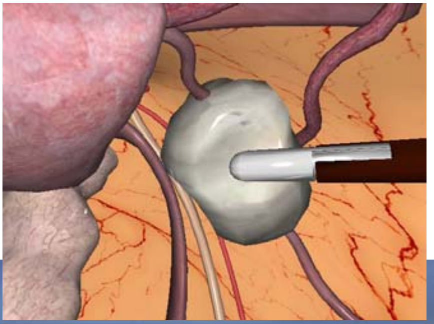


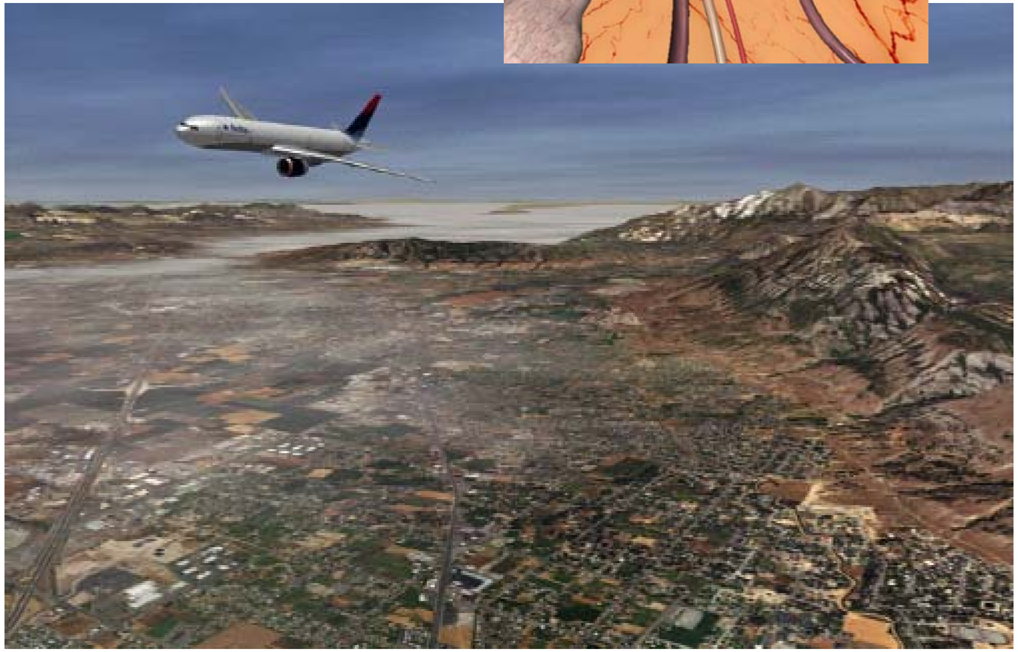
Computer Graphics

- Games
  - Immersion through interaction

Computer Graphics

- Simulation : « serious games »
  - Predictability & interaction





Computer Graphics

- Computer Aided Design (CAD)
  - Virtual prototypes

Computer Graphics

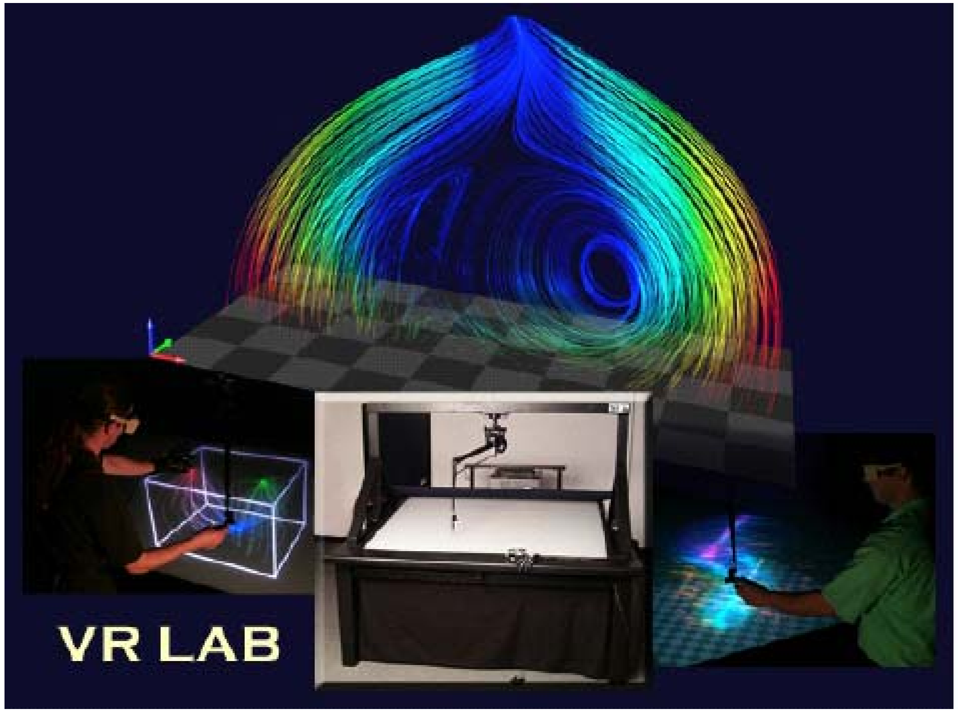
- Architecture
  - Real-time exploration

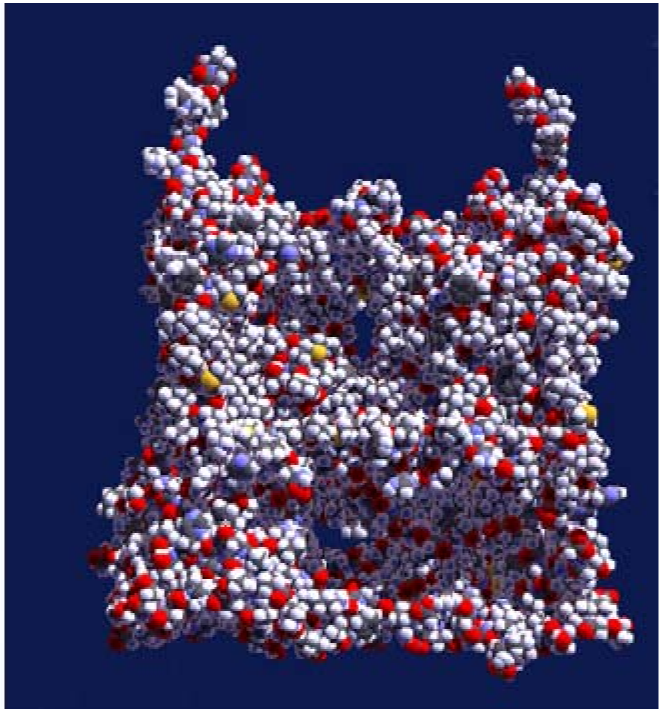
Computer Graphics

- Virtual reality
  - Multi-sensorial immersion
- Augmented reality

Computer Graphics

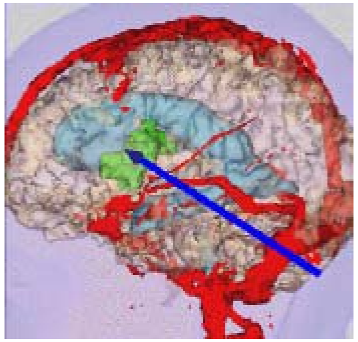
- Visualization
  - Visual exploration of results, interaction

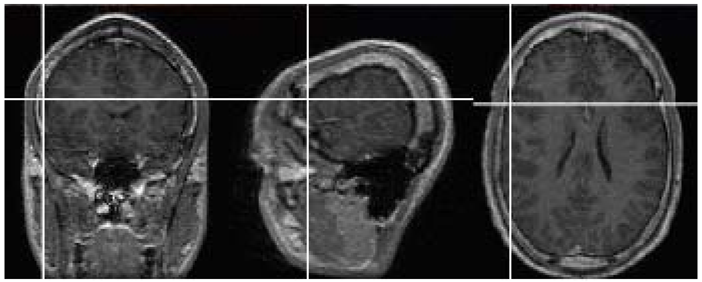


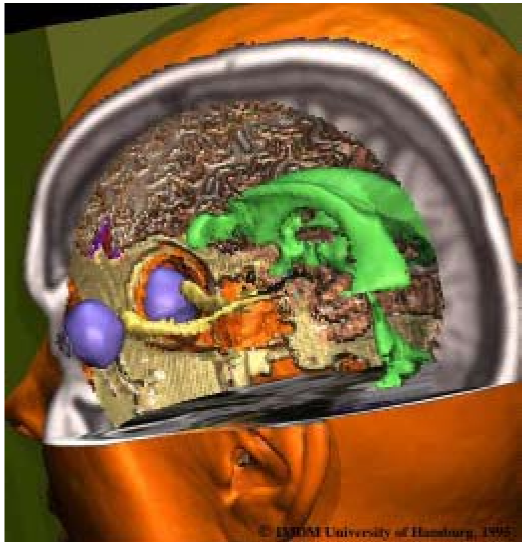


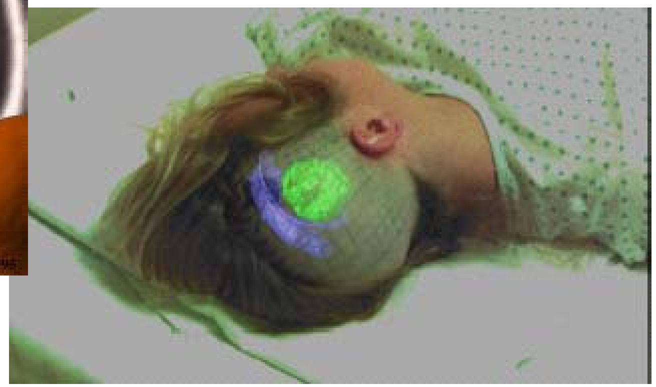
Computer Graphics

- Medical imaging
  - Understanding, planning, on-line monitoring



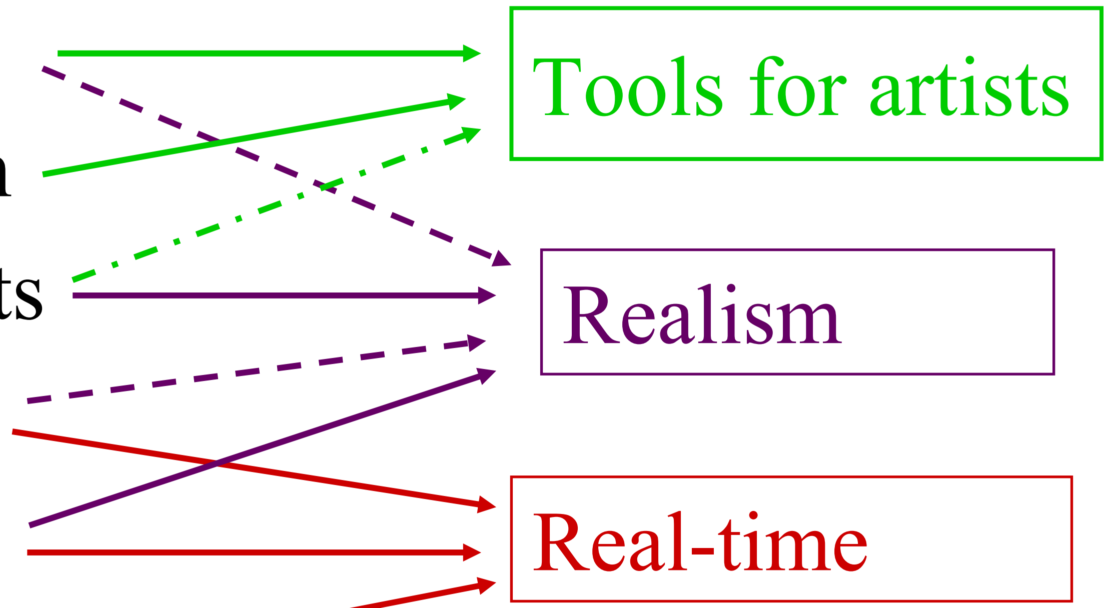






Computer Graphics

- Design
- 3D animation
- Special effects
- Games
- Simulators
- Visualization



Computer Graphics Research

What you will learn

- Overview of Computer Graphics (including vocabulary)
  - Modeling : create 3D geometry
  - Animation : move & deform
  - Rendering : 3D scene → image

- How basic techniques work
- Practice with OpenGL (C++)
- Introduction to research : case studies
  - Choose/combine/extend existing techniques to solve a problem

What you will not learn

- Advanced techniques in detail
- Programming the Graphics Hardware (GPU)
- Artistic skills
- Game design
- Software packages

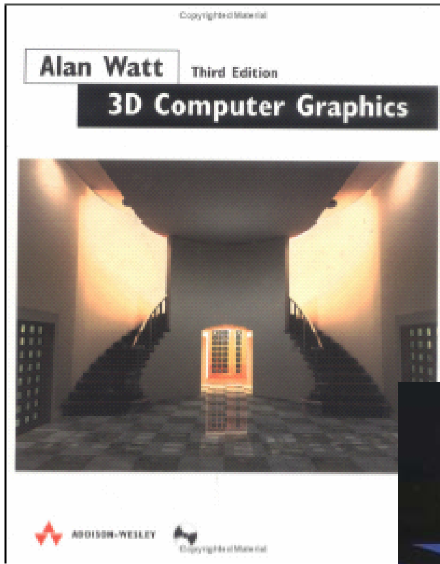
  (CAD-CAM, 3D Studio Max, Maya, Photoshop, etc)

Following up: MOSIG M2 "**GVR**" & ENSIMAG "**IRV**"

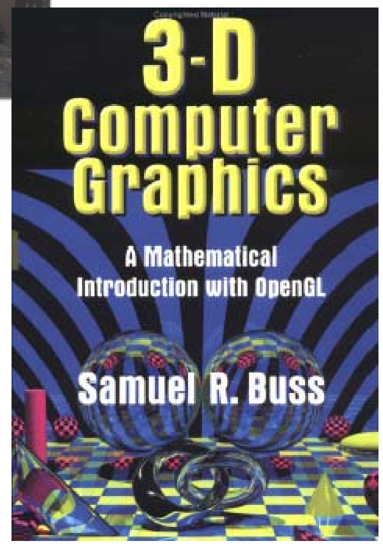
Text books

- No book **required**
- References
  - *3D Computer Graphics*

    Alan H. Watt



  - *3D Computer Graphics: A Mathematical Introduction with OpenGL* (2003) by Buss.



Course schedule (3h a week, A009 or ARV)

Marie-Paule Cani & Estelle Duveau

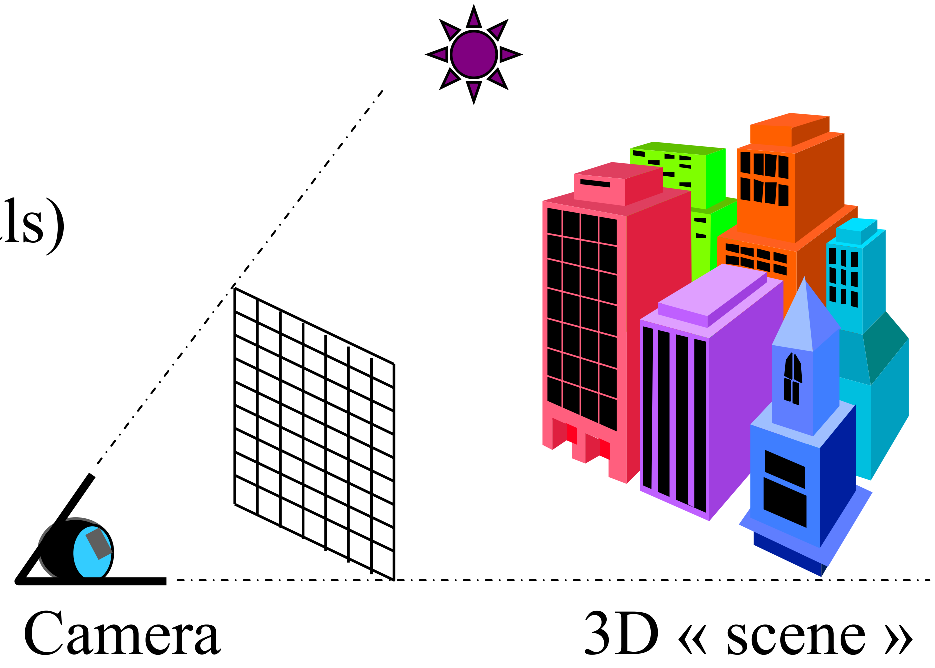
04/02 Introduction + Projective rendering: graphics pipeline, shading
11/02 Parametric modeling : representations + design tools
25/02 Introduction to OpenGL: C + TD
04/03 Implicit surfaces 1 + CTD matrices & hierarchies
11/03 Implicit surfaces 2 + C OpenGL lighting, materials
18/03 Textures, aliasing + TD OpenGL lighting, materials
25/03 Textures in OpenGL: C + TD
01/04 Procedural & kinematic animation + TD procedural anim
08/04 Physics: particle systems + TD physics 1
22/04 Physics: collisions, control + TD physics 2
29/04 Animating complex objects + Realistic rendering
06/05 Talks: results of cases studies

Basic, real-time display?
Projective rendering

Done by the graphics hardware via OpenGL or directX

- Input: Scene
  - 3D models (Faces & normals)

- Goal
  - Image from camera
    Made of pixels



Basic, real-time display?
Projective rendering

2 ingredients:

Graphics pipeline

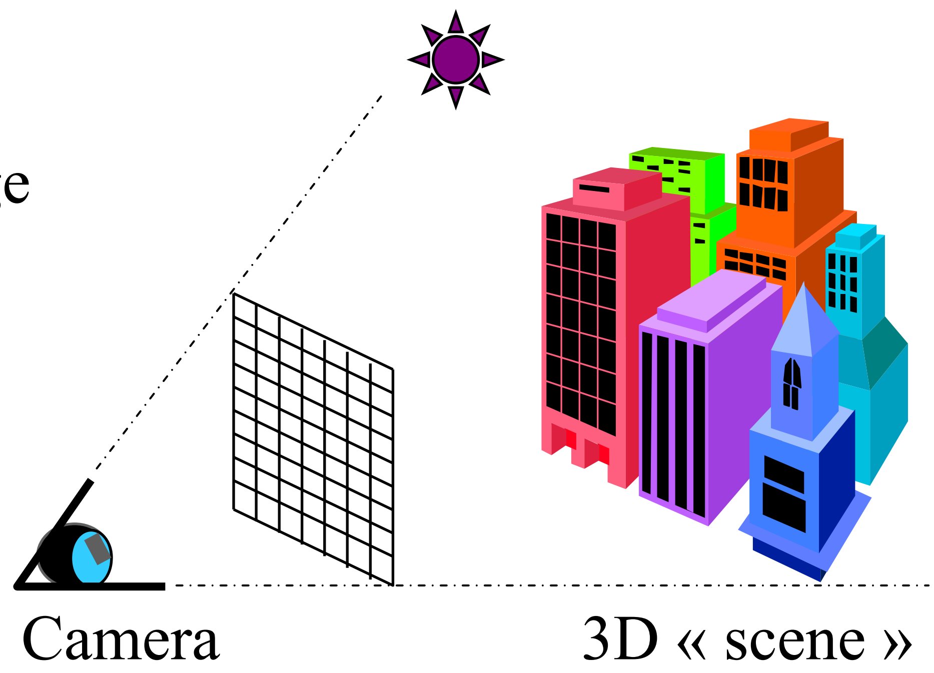
From a 3D scene to a 2D image

- based on geometry

Local illumination

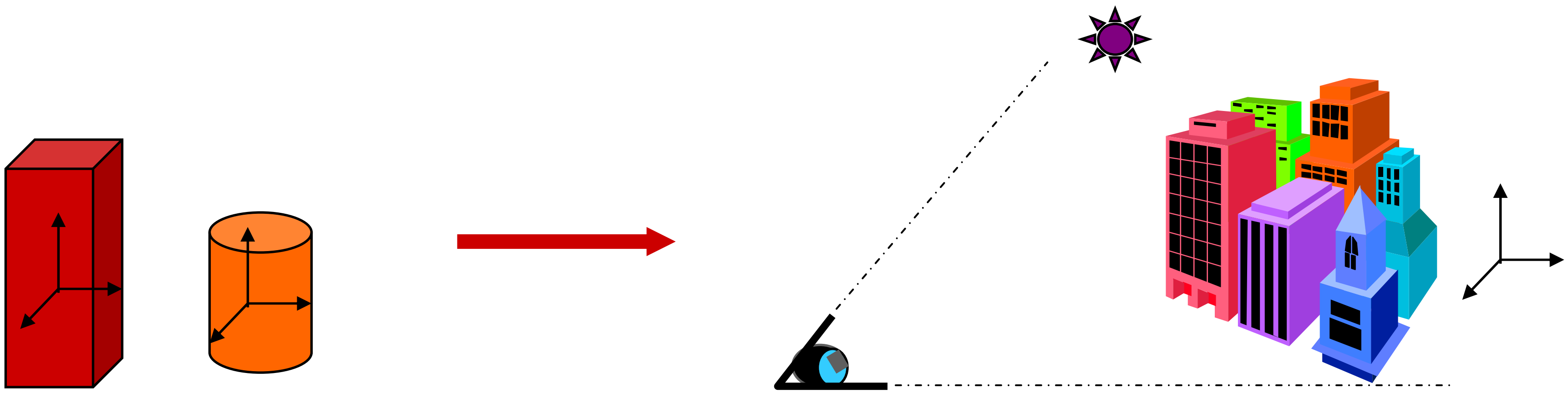
Which color in each pixel?

- based on optics



Graphics pipe-line

1. Create 3D models
   - in local frames, faces = vertices + normals
2. Build the scene
   - place instances of models in the "world frame"
   - add materials, virtual lights, and a camera



Representation of transformations

- From frame to frame (rotate, translate, scale)?
  - Transformations represented by 4x4 matrices

$$\begin{pmatrix} x' \\ y' \\ z' \\ w' \end{pmatrix} = \begin{pmatrix} a & b & c & d \\ e & f & g & h \\ i & j & k & l \\ m & n & o & p \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ w \end{pmatrix}$$

$$p' = M \quad p$$

Why 4x4? Homogeneous coordinates

- w will be used for projective transformations
- Cartesian coordinates: w = 1
- From projective to cartesian: divide by w

$$\begin{pmatrix} x' \\ y' \\ z' \\ 1 \end{pmatrix} = \begin{pmatrix} a & b & c & d \\ e & f & g & h \\ i & j & k & l \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix}$$

Affine transformation

Affine transformations

Translation

$$T = \begin{bmatrix} 1 & 0 & 0 & T_x \\ 0 & 1 & 0 & T_y \\ 0 & 0 & 1 & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

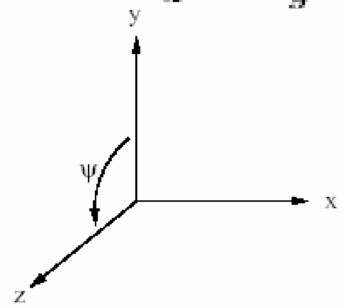
Scale

$$T = \begin{bmatrix} s_x & 0 & 0 & 0 \\ 0 & s_y & 0 & 0 \\ 0 & 0 & s_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

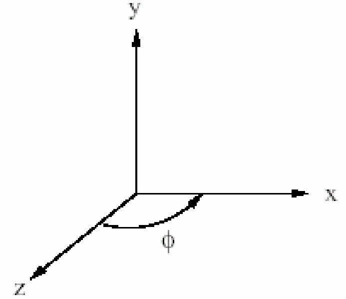
Rotation: Euler angles

$$R = R_z \cdot R_y \cdot R_x,$$

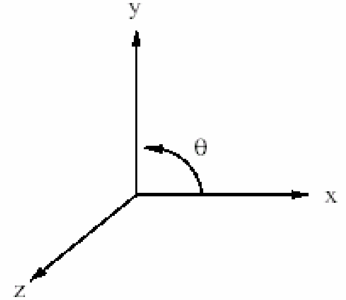
$$R_x = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\psi & -\sin\psi & 0 \\ 0 & \sin\psi & \cos\psi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



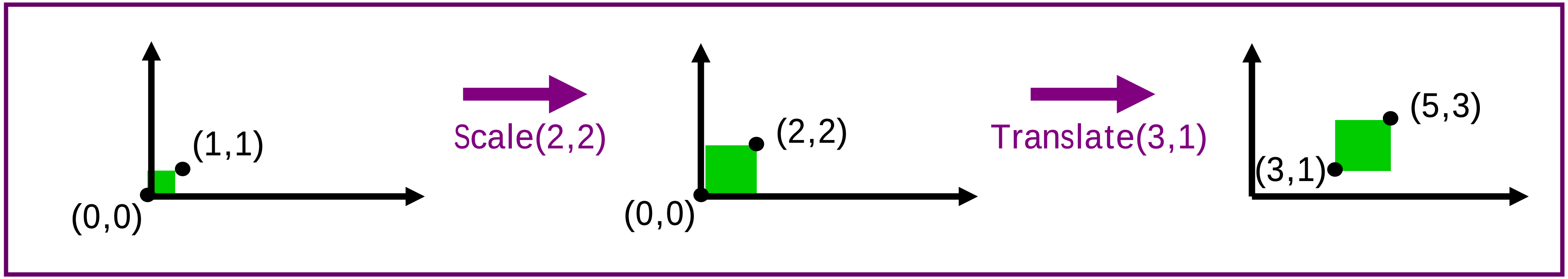
$$R_y = \begin{bmatrix} \cos\phi & 0 & \sin\phi & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\phi & 0 & cos\phi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



$$R_z = \begin{bmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



Composition of transformations

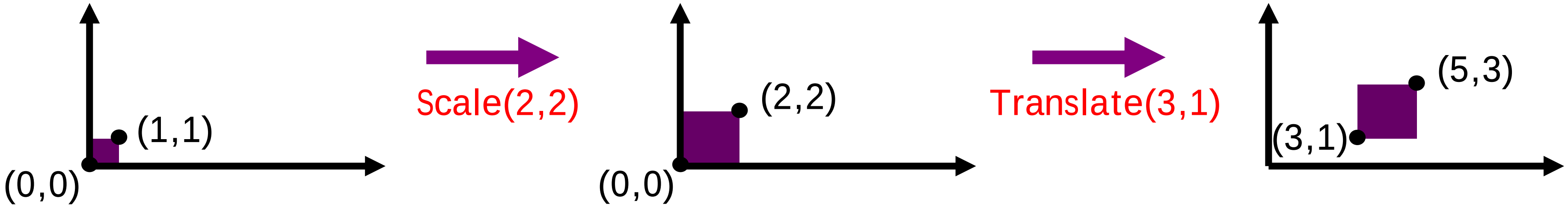


Multiplication of matrices : p' = T (S p) = TS p

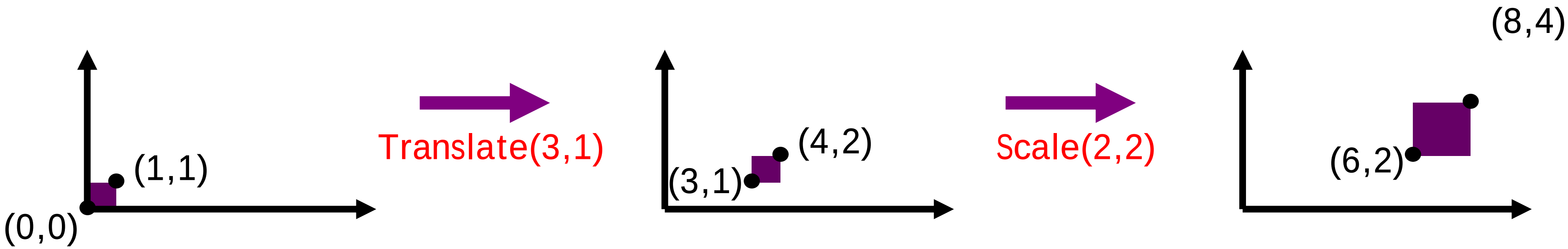
$$TS = \begin{pmatrix} 1 & 0 & 3 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 2 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} 2 & 0 & 3 \\ 0 & 2 & 1 \\ 0 & 0 & 1 \end{pmatrix}$$

Not commutative !!!

Scale then translate : p' = T (S p) = TS p



Translate, then scale : p' = S (T p) = ST p

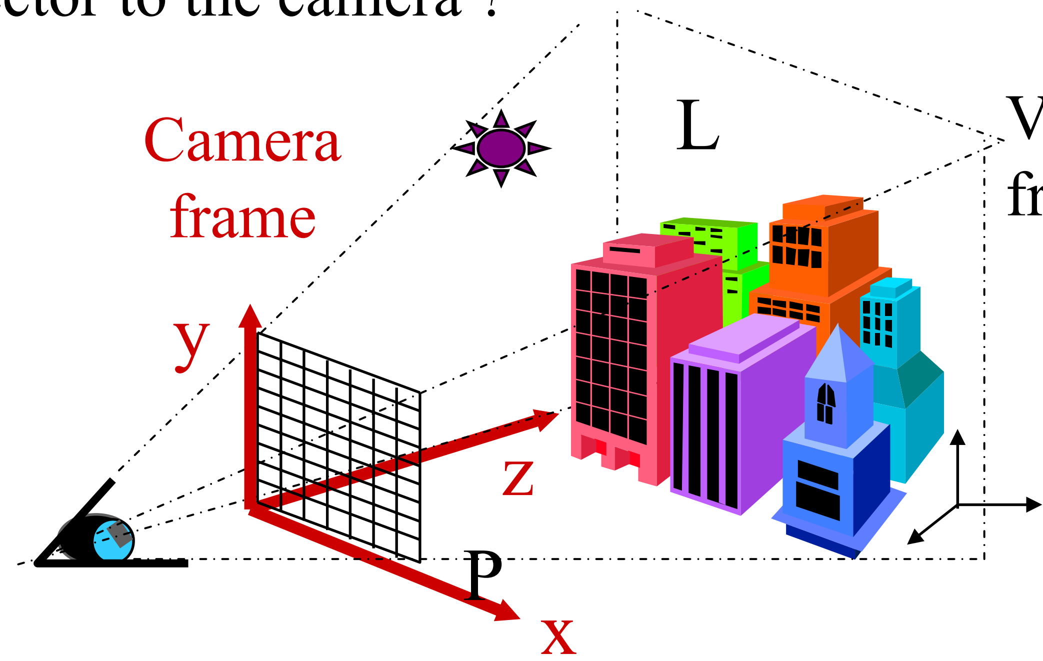


Graphics pipe-line

3. Convert the scene to the camera frame

– « cull » the faces that look in the opposite direction

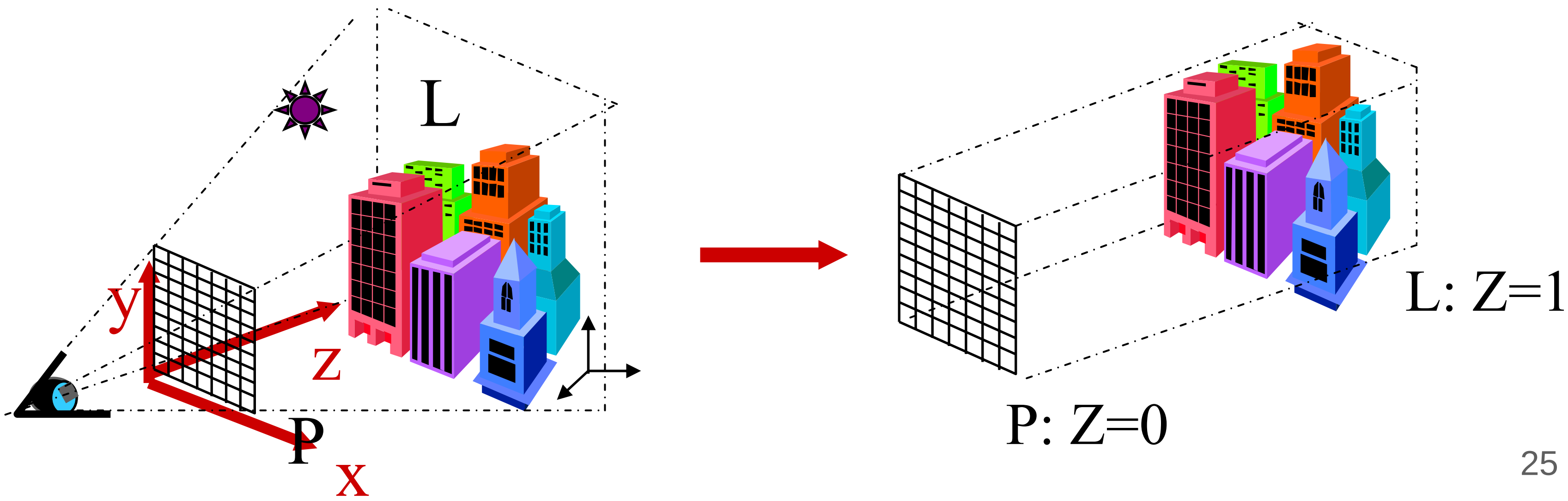
Normal ≈ vector to the caméra ?



Graphics pipe-line

4. Convert to the screen frame (projective transformation!)

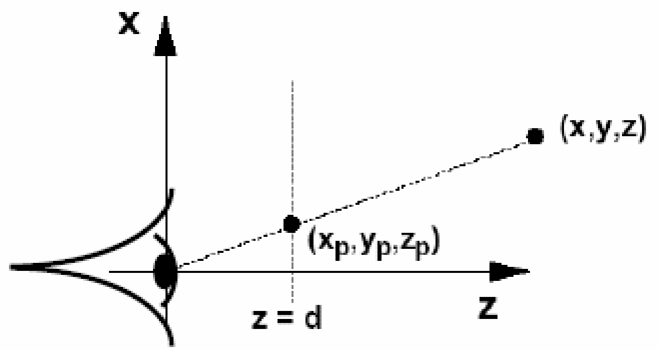
- The viewing frustrum becomes a parallelogram
- « clipping » operations to
  - suppress faces outside the frustrum, cut intersecting ones



Perspective projection to image plane ?

- Project all points to the $z = d$ plane, eyepoint at the origin

$$
\begin{aligned}
x_p &= \frac{d \cdot x}{z} = \frac{x}{z/d} \\
y_p &= \frac{d \cdot y}{z} = \frac{y}{z/d} \\
z_p &= d
\end{aligned}
$$



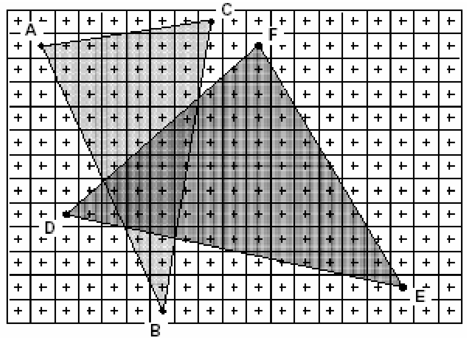
homogenize

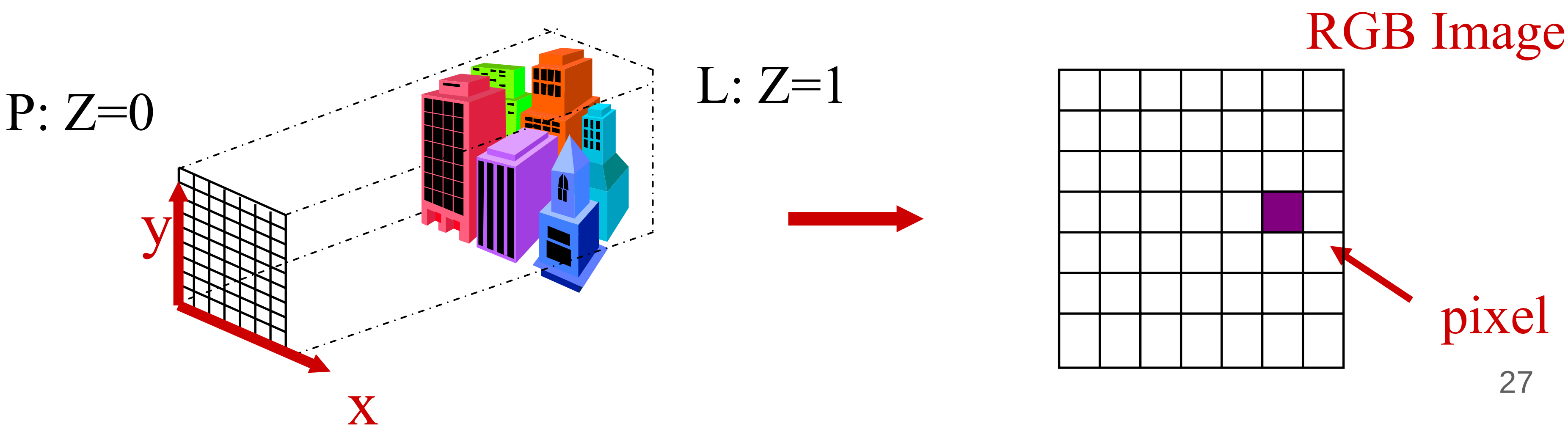
$$
\begin{pmatrix} x * d / z \\ y * d / z \\ d \\ 1 \end{pmatrix} = \begin{pmatrix} x \\ y \\ z \\ z / d \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 1/d & 0 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix}
$$

Graphics pipe-line

5. Compute the image

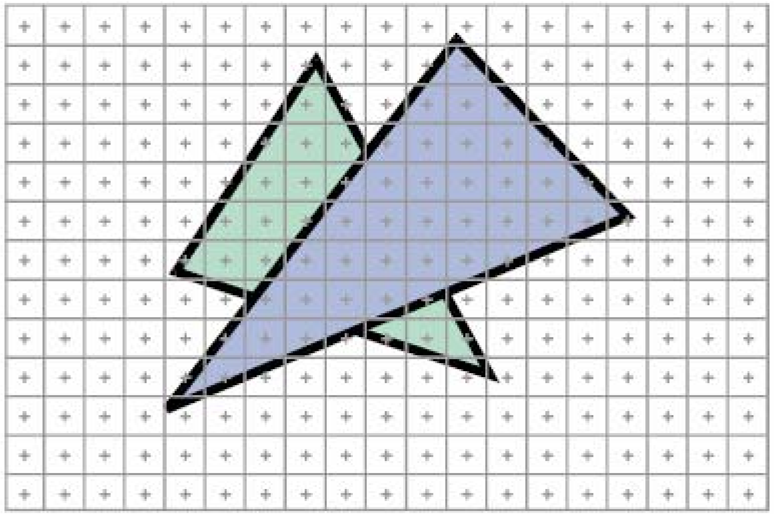
- Rasterize each face into pixels (x,y)
- Suppress hidden parts
- Compute a color for each pixel





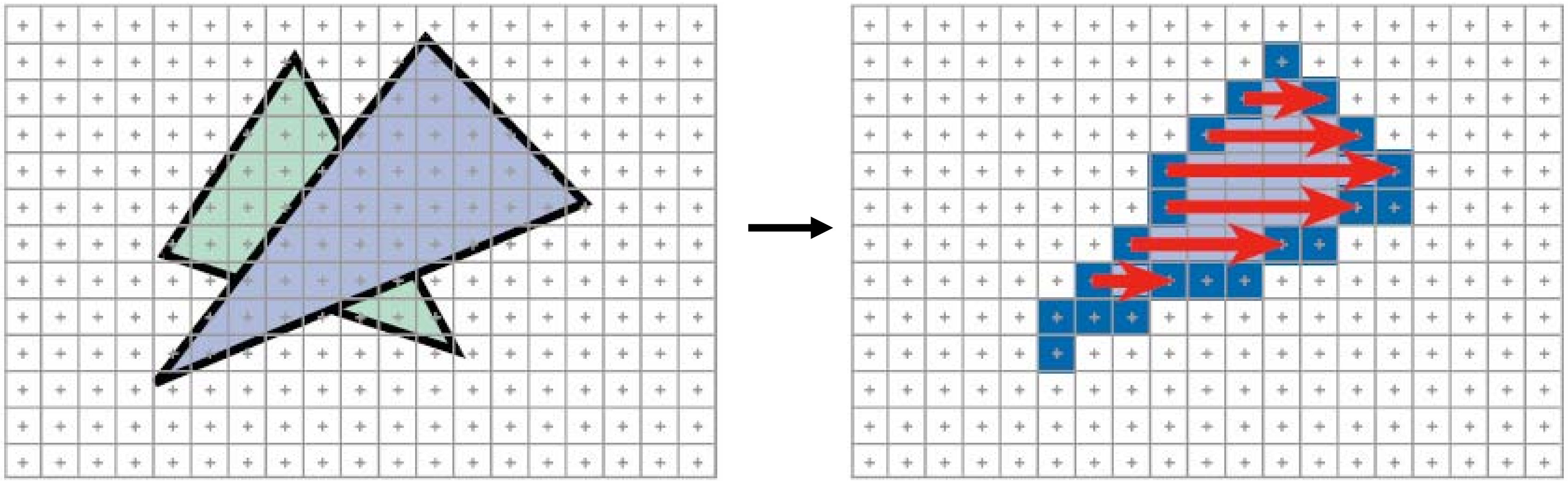
Rasterize faces into pixels?

- Primitives are continuous; screen is discrete
  - triangles are described by a discrete set of vertices
  - but they describe a continuous area on screen



Rasterize faces into pixels?

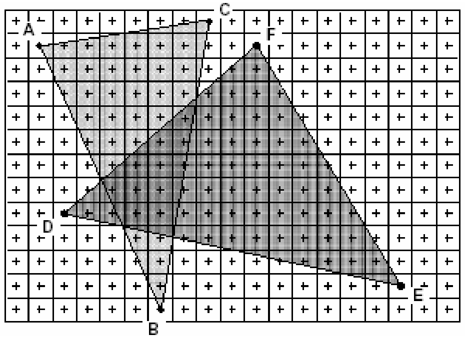
- Scan Conversion: approximation into pixels
  - Check pixels in BB wrt the 3 line equations
  - Scanline rasterization: increment from corner vertices

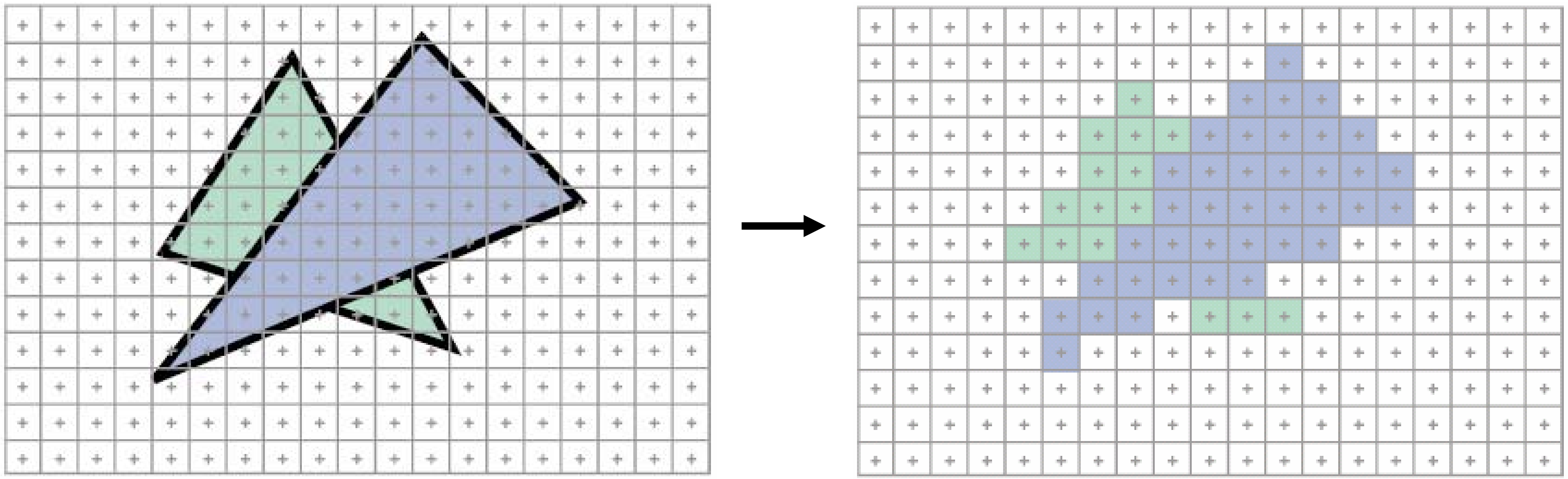


Graphics pipeline

Remove the hidden parts of each triangle?

Else the last one will appear « above »

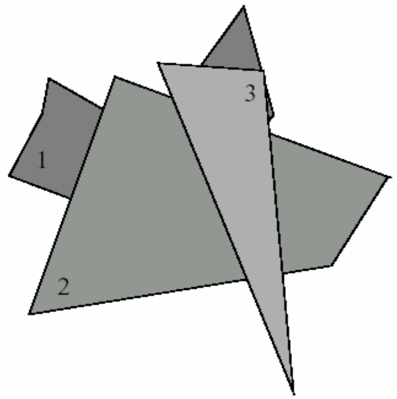




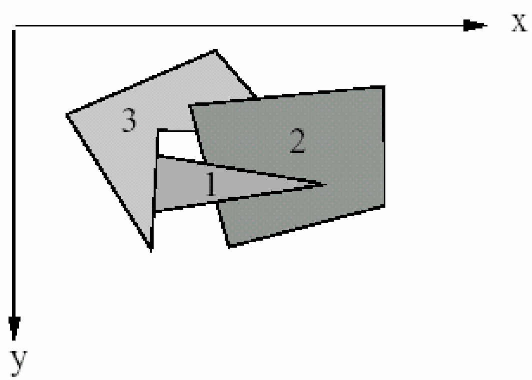
Graphics pipeline

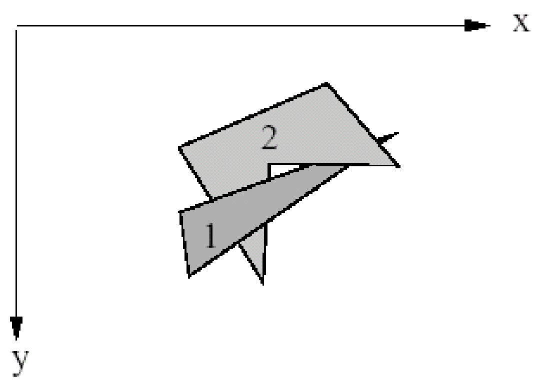
Remove hidden parts of each triangle?

- First method: the painter's algorithm
  - Sort the faces
  - Display triangles starting with the farthest



- Cost *n(logn)*
- Problems!



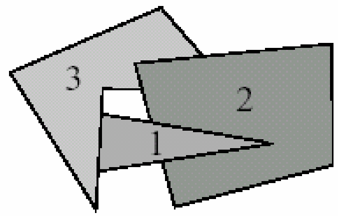


Graphics pipeline

Remonve hidden parts?

- Use a « Z-buffer »   (available thanks to memory)
  – A second array, as large as the image
  – Stores the current z value at each pixel
    (the associated color being in the image buffer)

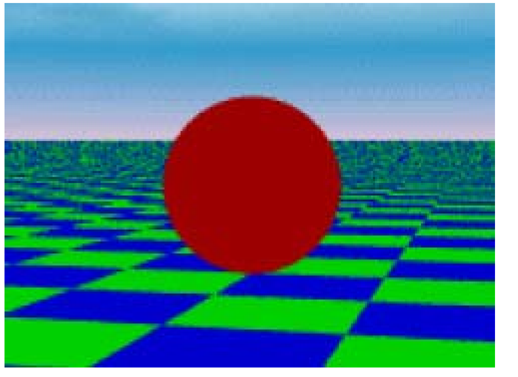
Algo

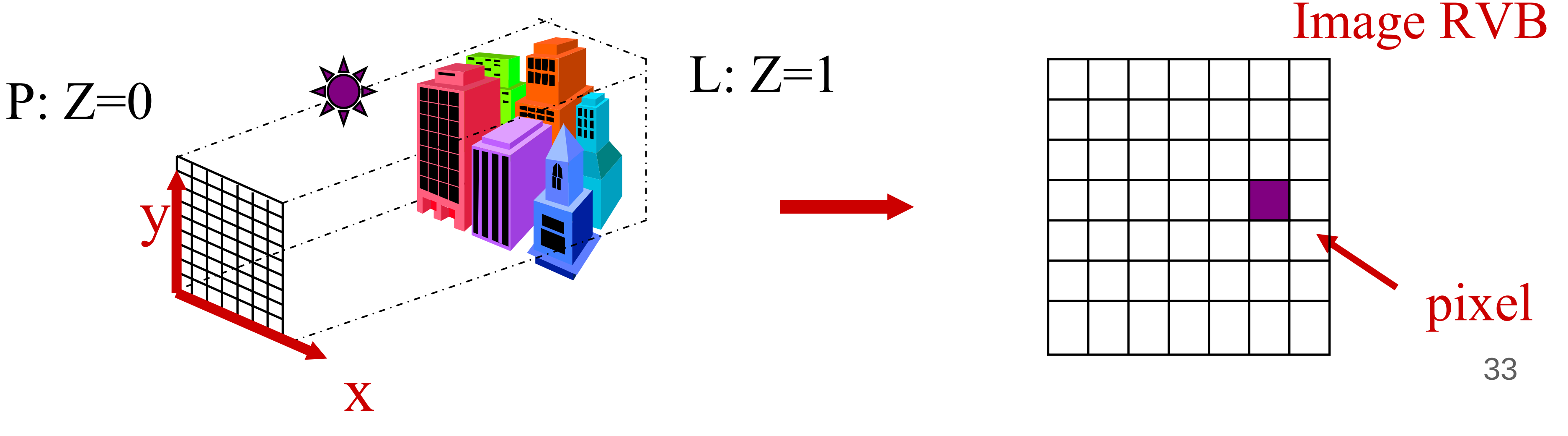


– Init with all pixel at max distance
– For each face, for each pixel P
  - update color and z-value iff (z < current z-value(P))

Graphics pipeline

- Which color should be displayed?
  - Uniform colors would not work!
  - Given by a « local illumination » model





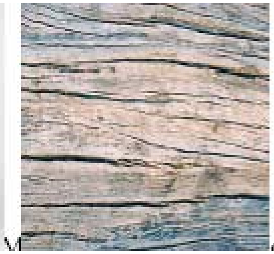
Local illumination

Which color shall we display in each pixel ?

⇒ Depends on the local amount of light coming back to the eyes

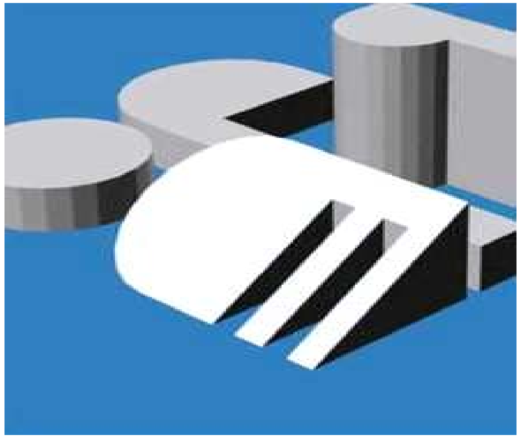
⇒ So it depends on :

- where the surface element is in 3D
- its orientation w.r.t. lights & camera
- the material the surface is made of

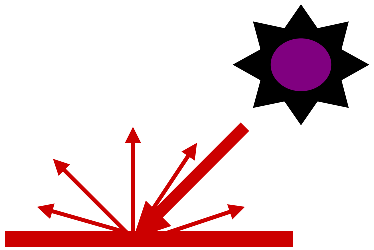
   

Phong's local illumination

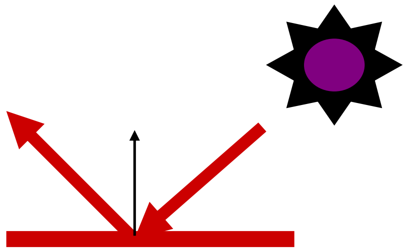
- A constant « ambiant » term
- Direct lighting from the sources
    - no shadows
- Opaque objects only



diffuse



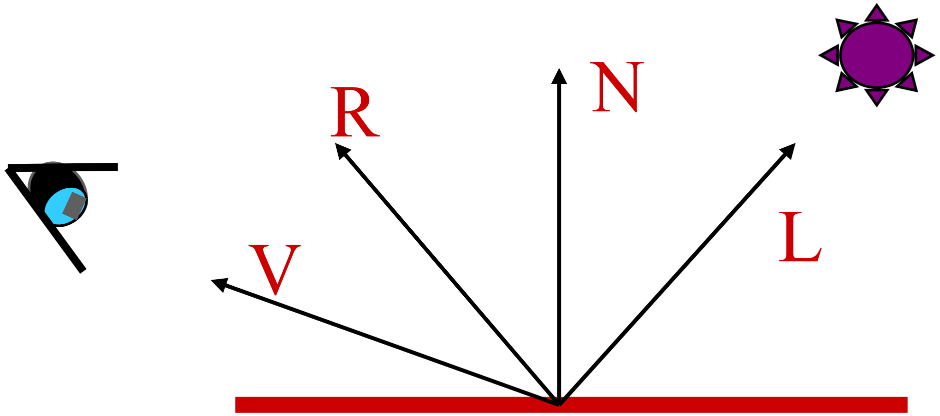
specular

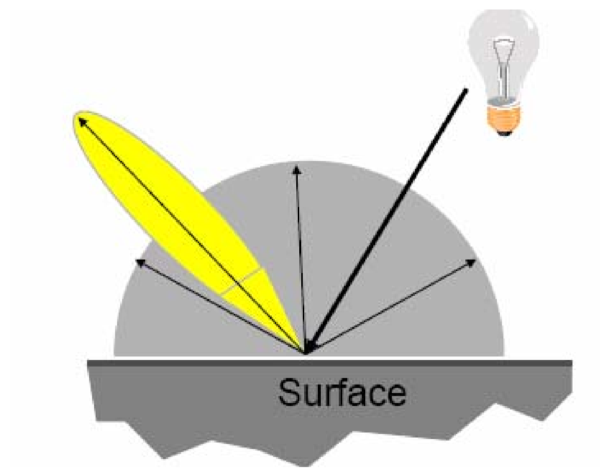


Phong's local illumination

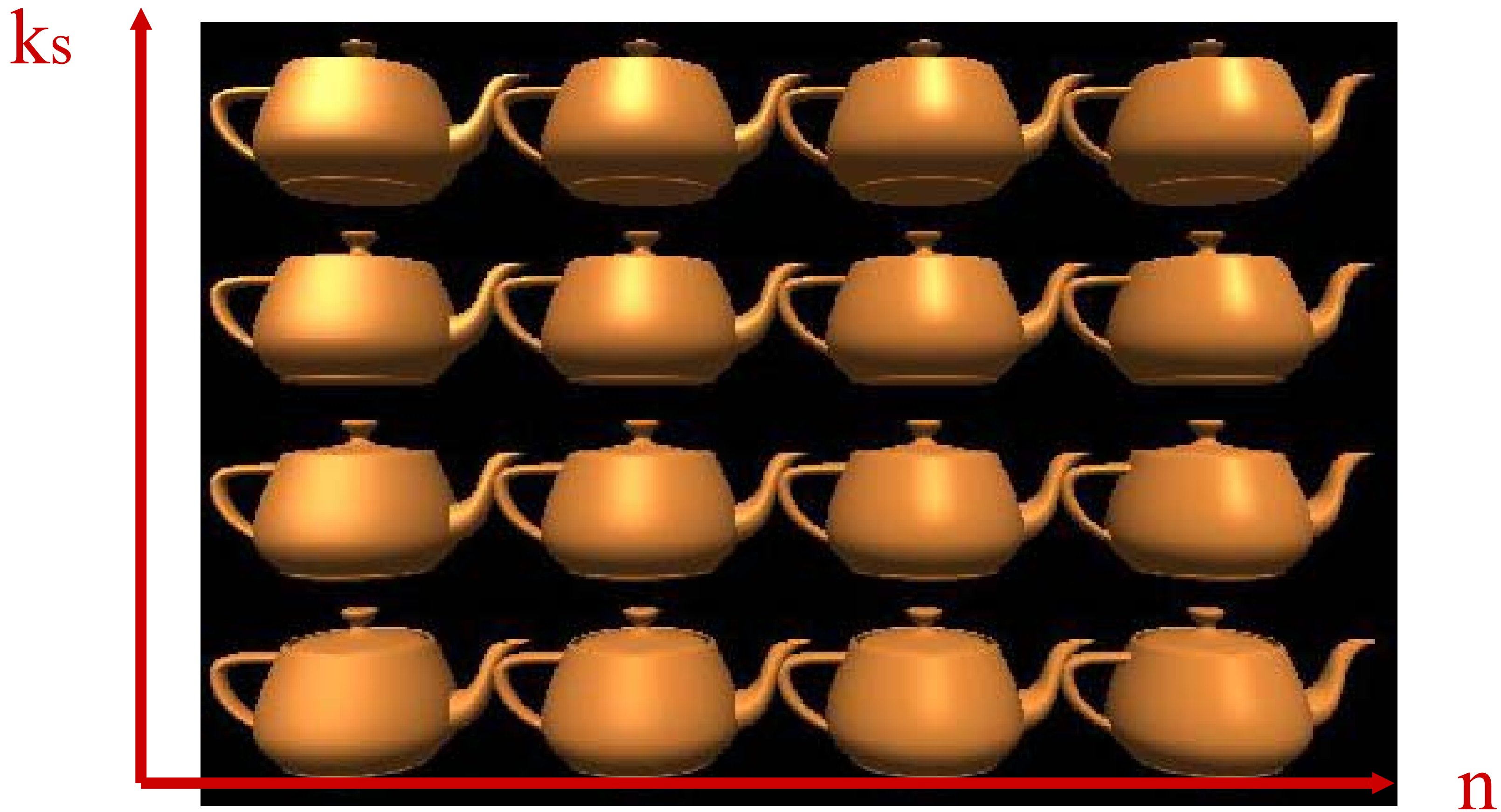
$$I = K_a + \sum I_s \,(K_d\, L \,.\, N + K_s\, (R \,.\, V)^n\,)$$

ambiant diffuse specular





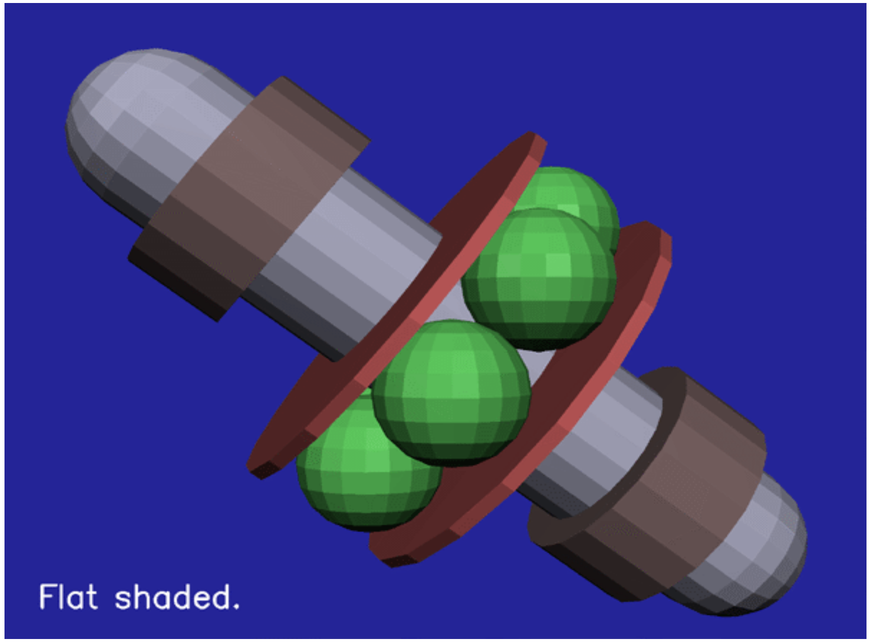
Phong's local illumination



Direct application

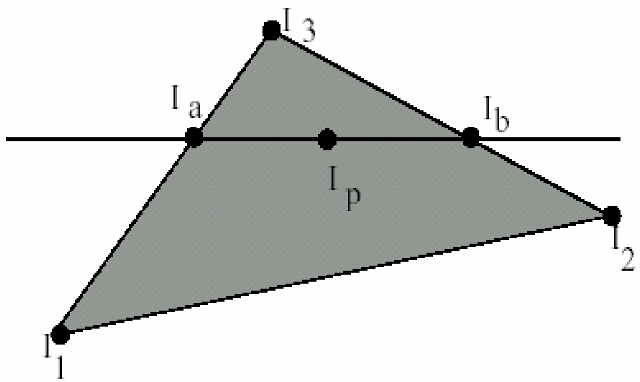
- A single normal by face

- Uniform colors!



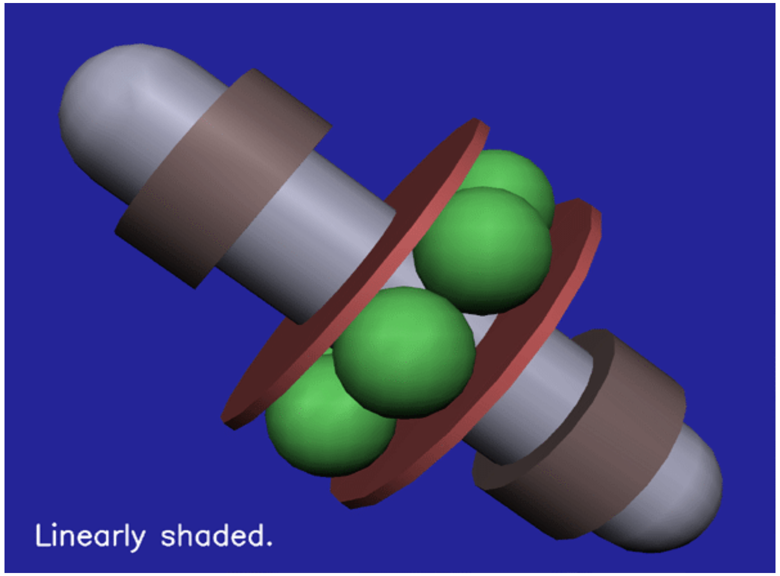
Gouraud's shading

- A normal by face
- Illumination on each vertex
- Bi-linear interpolation



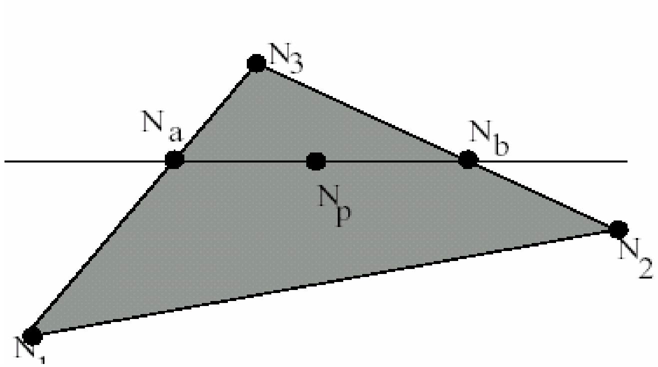
Better!

Some reflexions can be missed



Phong's shading

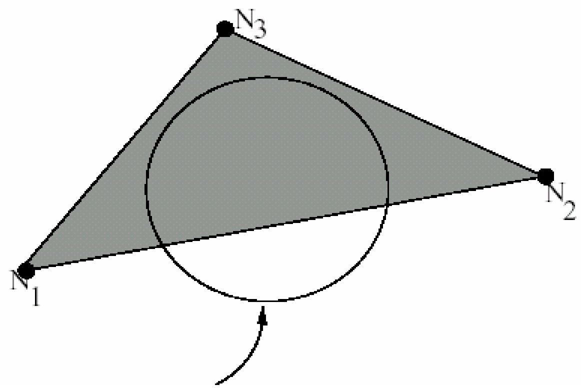
- A normal by vertex
- Interpolate normal directions
- Illumination at each pixel



Correct!

Still missing:

- Cast shadows
- Extended light sources
- Transparency



Specular reflexion

Phong's shading