LABORATORIO DI REALTÀ AUMENTATA

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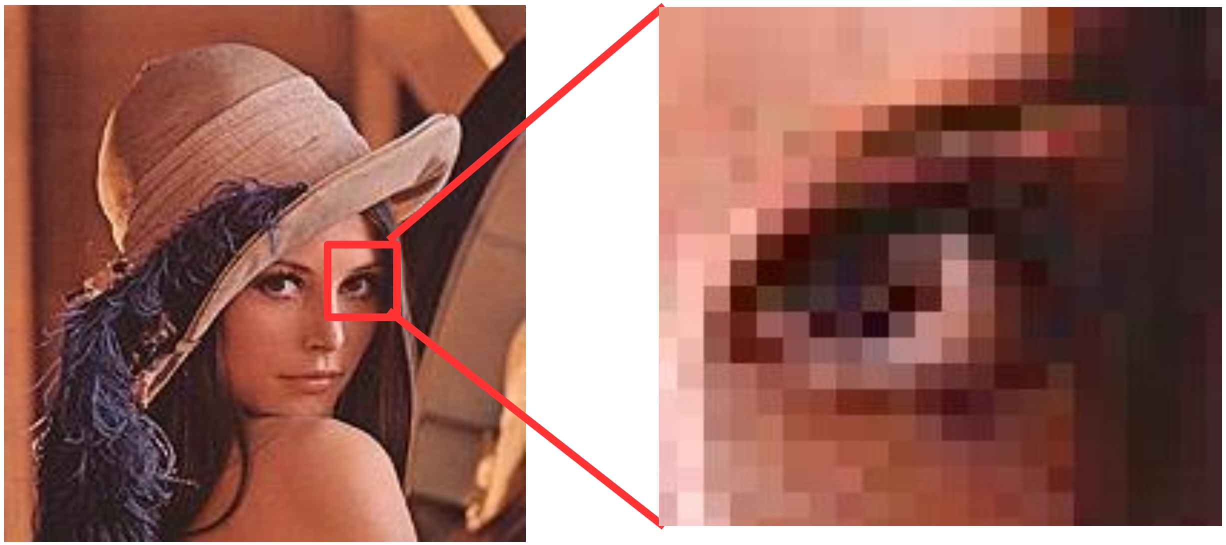
Introduction to 3D graphics

- Raster images
- Vector images
- From 2D to 3D
- Transformations
- Projections

Raster images

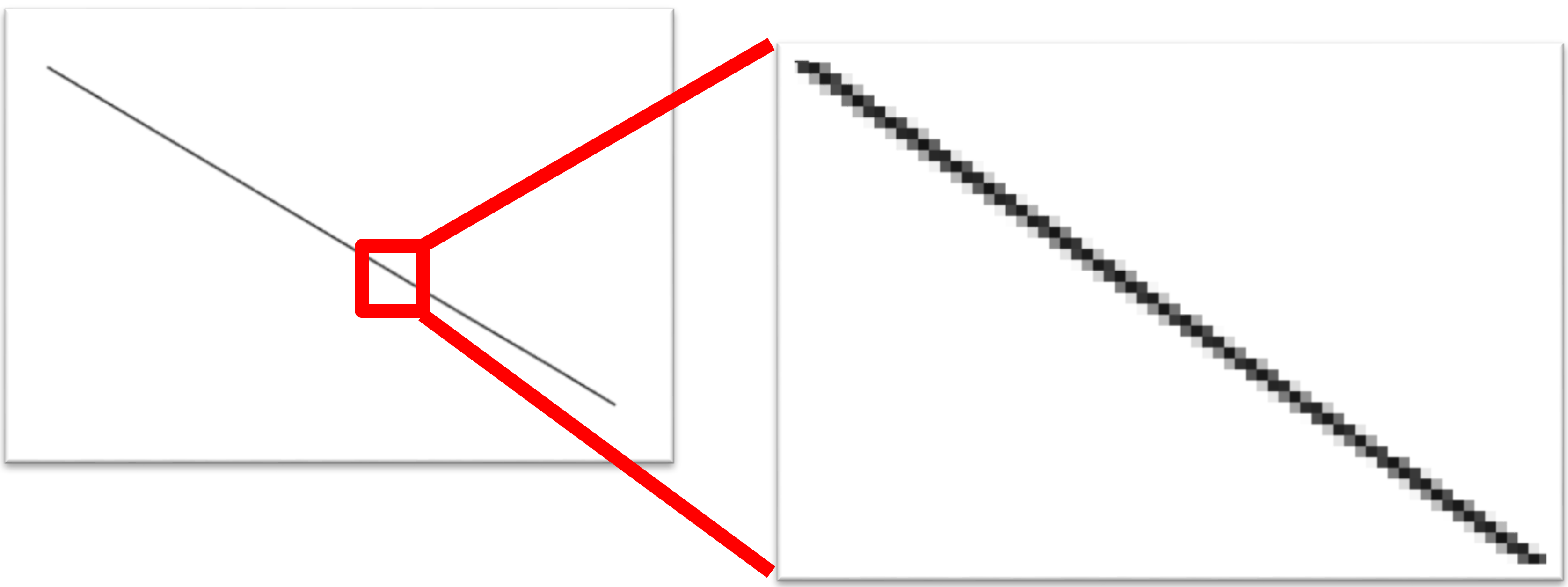
Raster images

- Raster images are composed of a grid of colored squares (the pixels)
- Pictures acquired with a digital cameras, each single frame of a digital video, the vast majority of web images… all of them are raster images



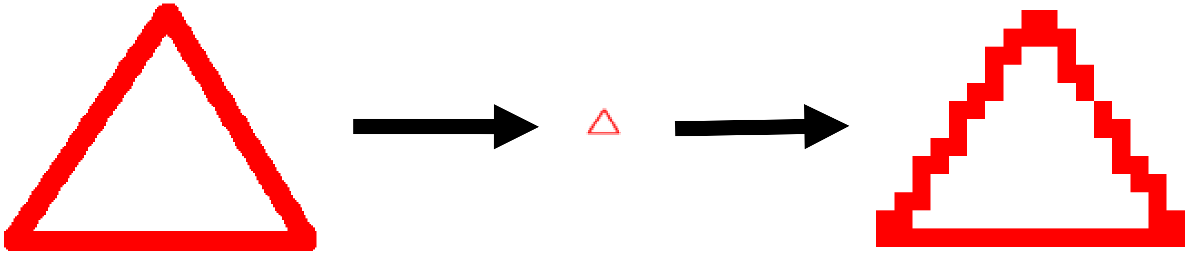
Semantic expressiveness

- The problem with raster images is their lack of semantic expressiveness.
- This line is actually just a bunch of gray pixels



Information loss

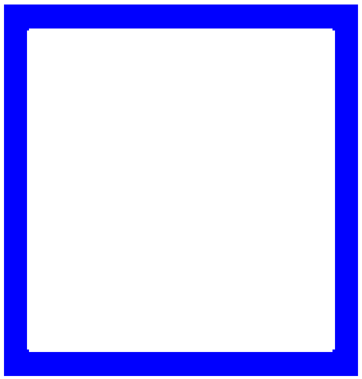
- The lack of semantic information has some drawbacks. What happens if you shrink and then enlarge an image?

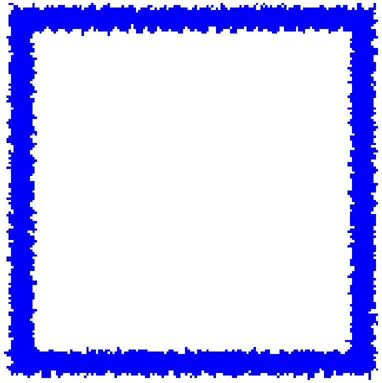


- Information loss!

Information loss

- Rotating by 90° and rotating 9 times by 10° do not lead to the same result



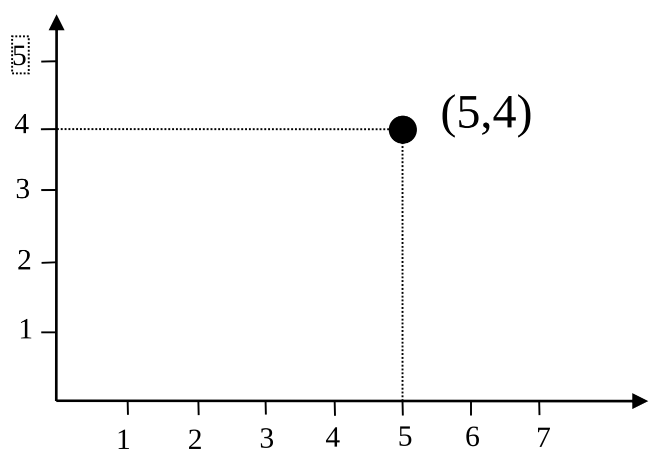


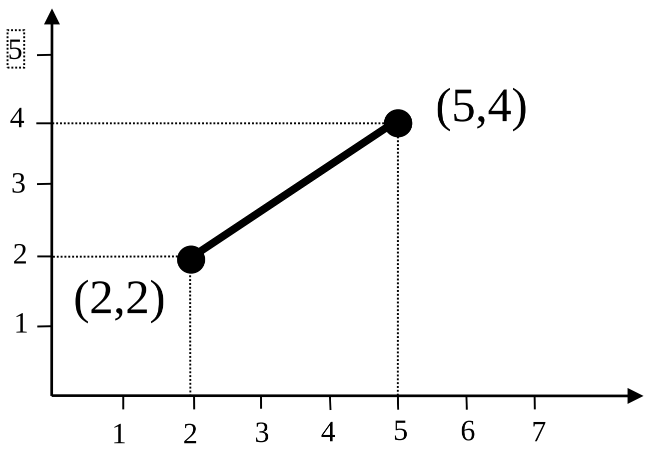
- Only rotations of 90° (or multiples) can be handled without information loss

2D vector graphics

2D vector graphics

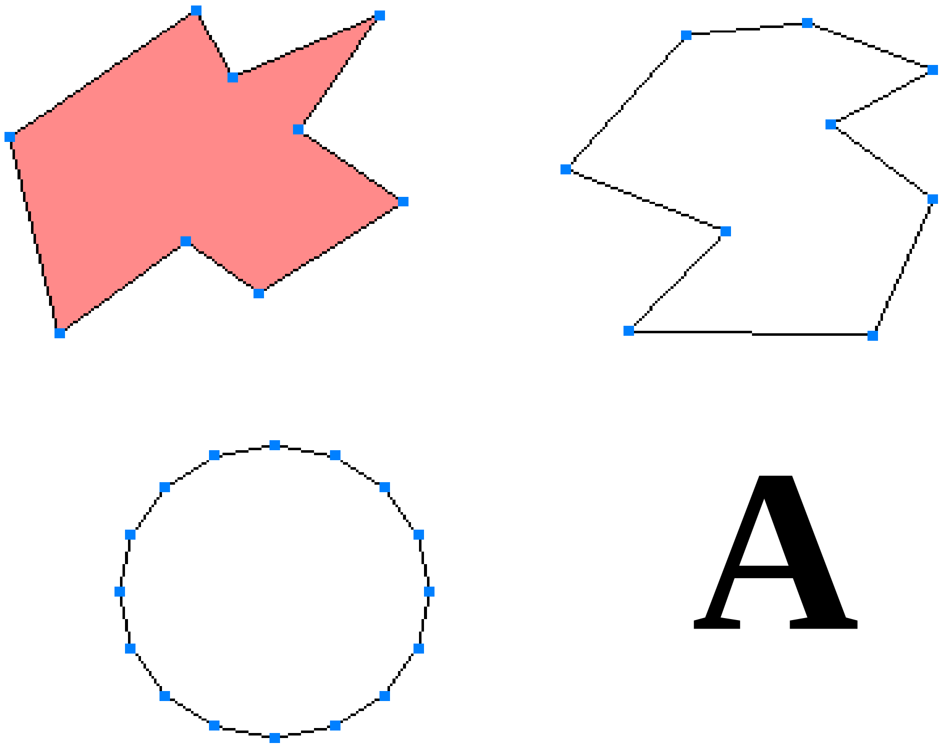
- Vector graphics relies on a geometric representation of images, using points (vertices) and segments (edges)





Vertices, edges and polygons

- Vertices and edges are the basic tools to build up polygons

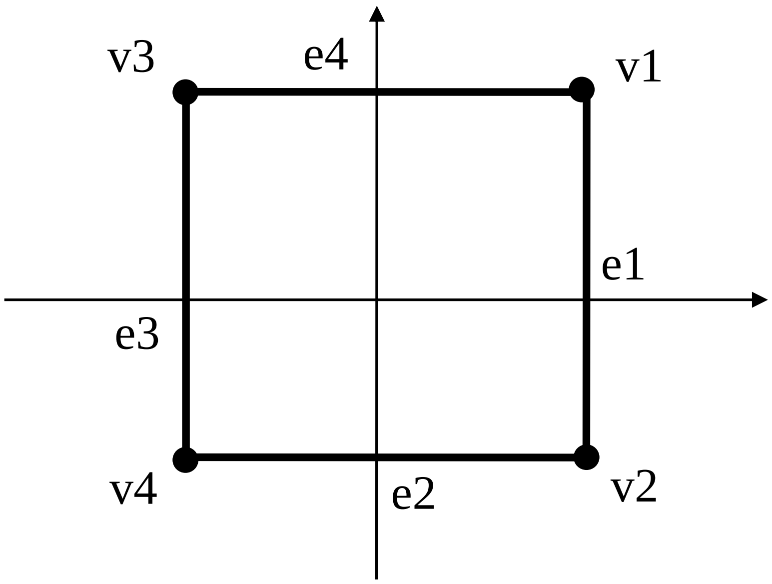


2D vector graphics representation

- A vector draw is no more composed of a set of pixels. Rather, it is described by two sets, the vertices and edges

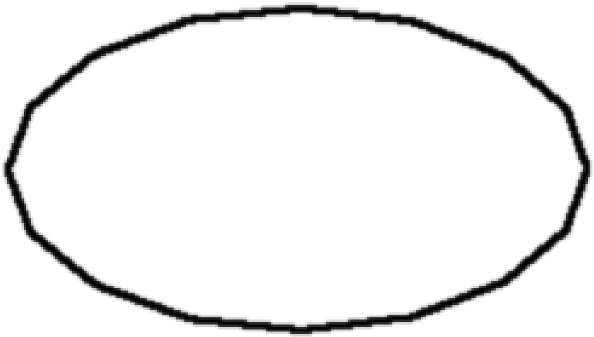
V = { v1(1,1),
v2(1,-1),
v3(-1,1),
v4(-1,-1) }

E = { e1(v1,v2),
e2(v2,v4),
e3(v4,v3),
e4(v3,v1) }



Curves in vector graphics

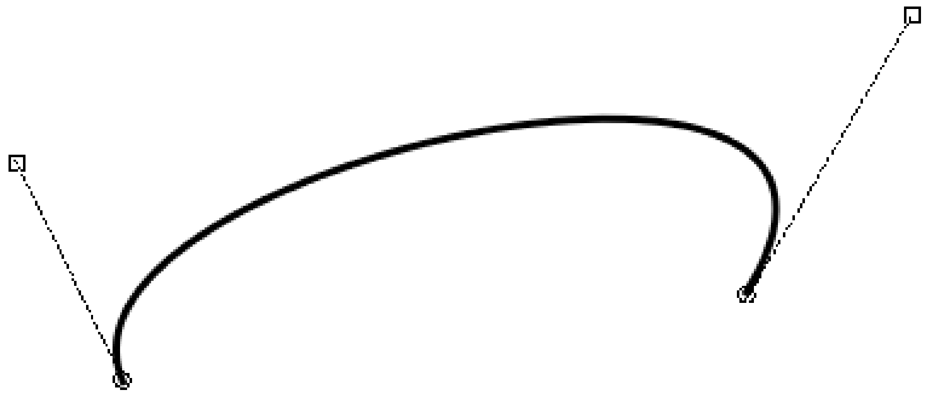
- What about curves?
- Two possible approaches:
  - Approximate the curve with segments



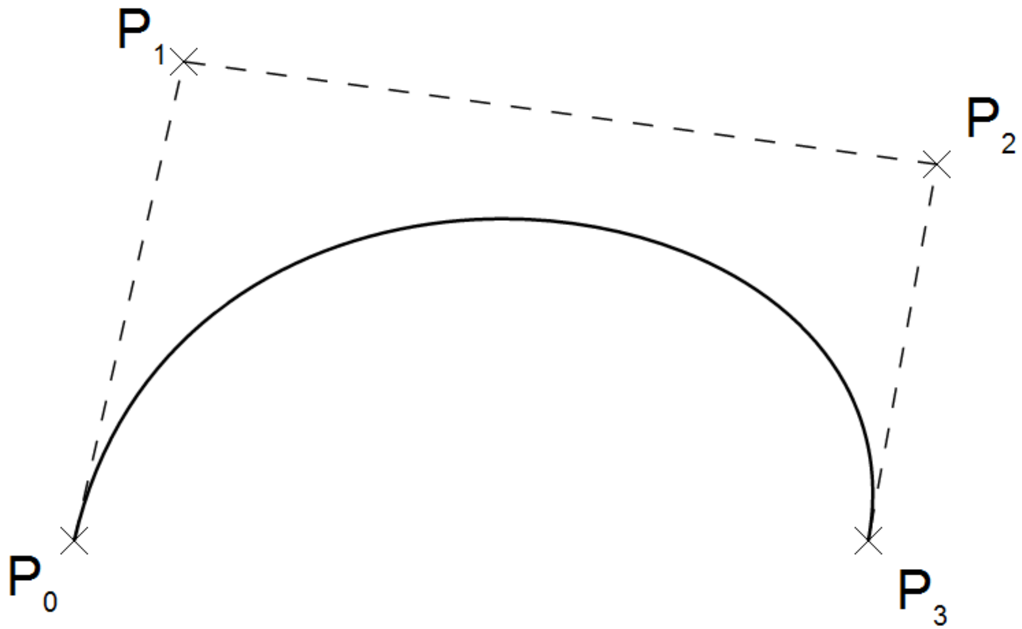
  - Give a mathematical description of what a curve is

Bézier Curves

- Mathematical description of a curve based on its geometric properties
- You need to define a start point, an end point, and the tangent directions of the curve in those points



Bézier curves



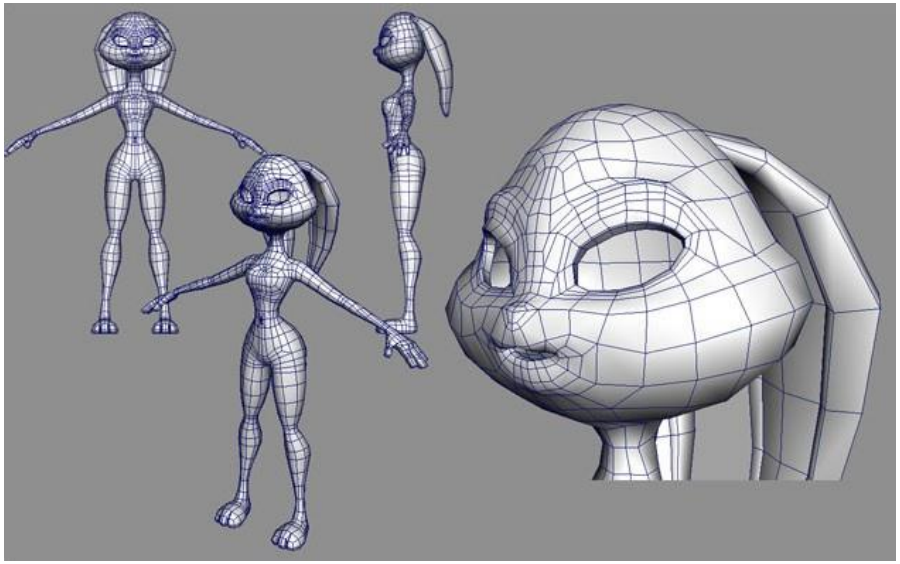
$$\mathbf{B}(t) = (1-t)^3\mathbf{P}_0 + 3(1-t)^2t\mathbf{P}_1 + 3(1-t)t^2\mathbf{P}_2 + t^3\mathbf{P}_3 \ , t \in [0,1].$$

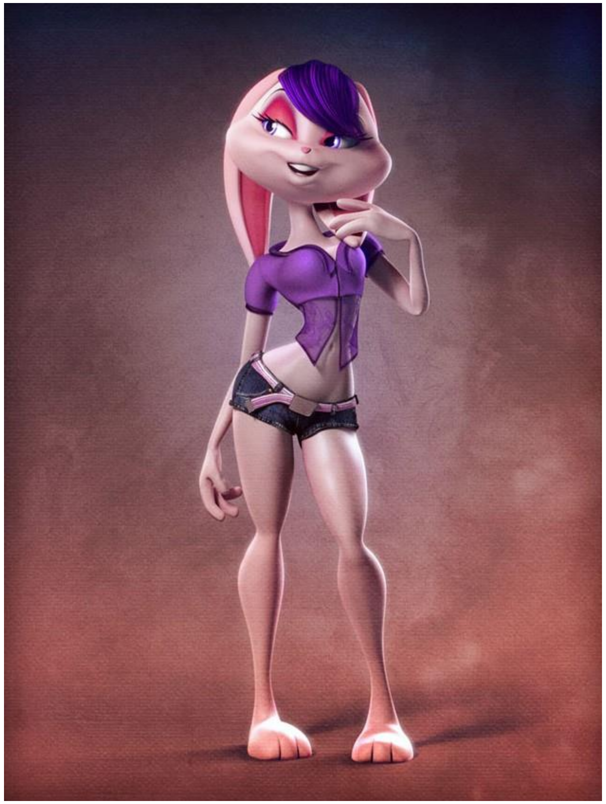
Parametric equation of a cubic Bézier curve

3D vector graphics

3D graphics

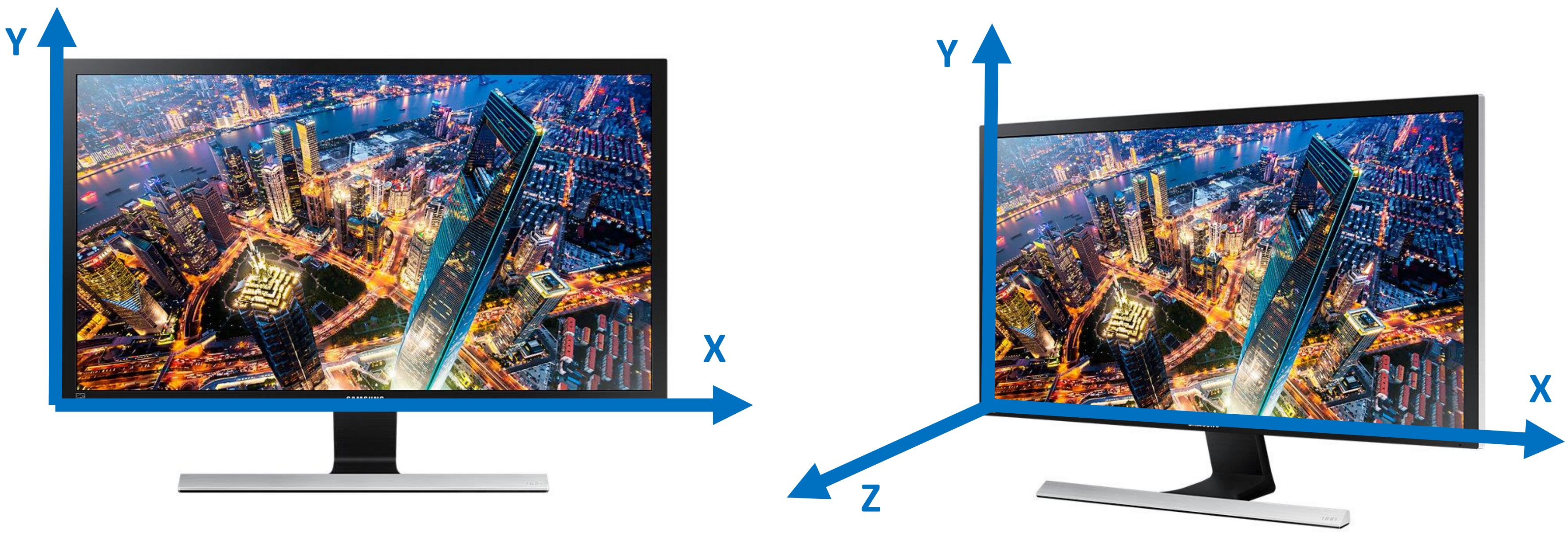
- We have seen that working on vector graphics allows to manipulate images without information loss
- This is why 3D artists work on **vector** models, which are converted to raster images only at the end of the creation process



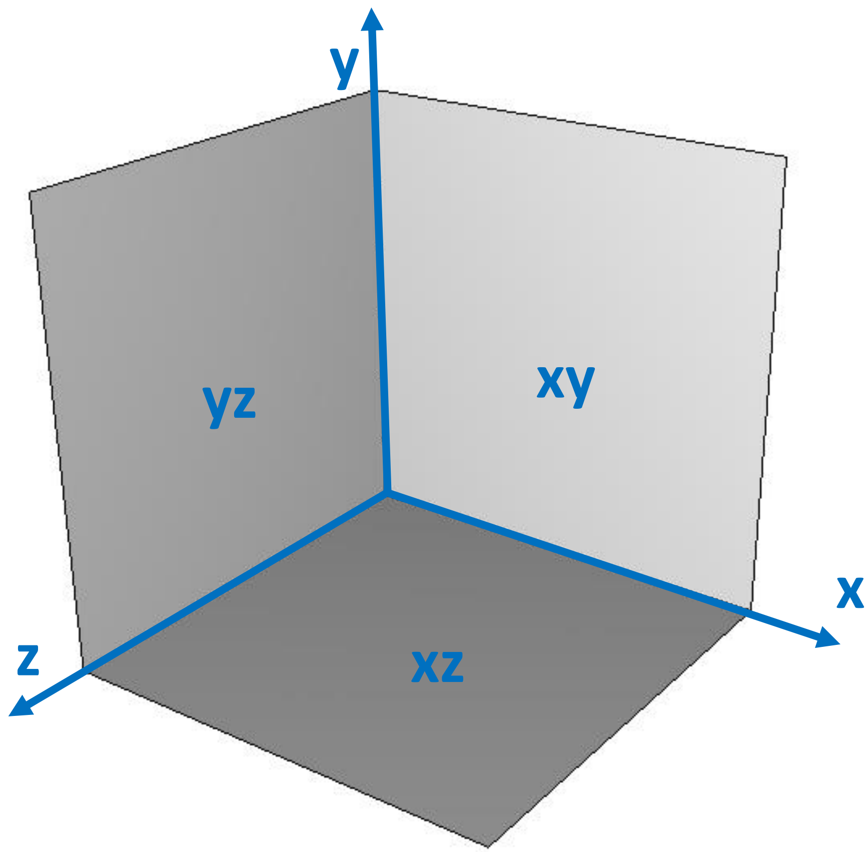


http://www.3dtotal.com/tutorial/359-making-bunny-photoshop-maya-by-carlos-ortega-character-animal-bunny-rabbit

From 2D to 3D



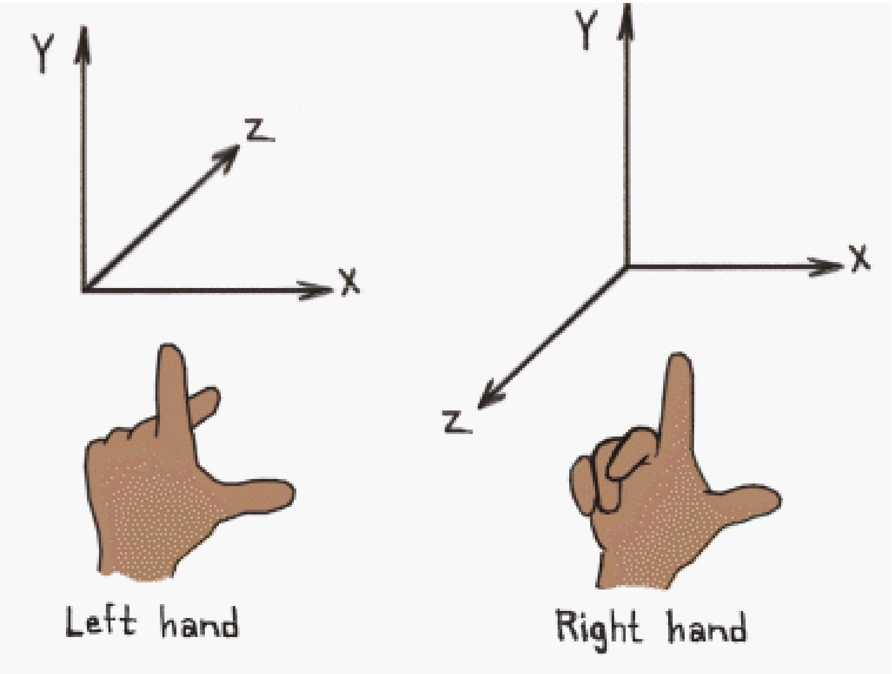
- The third dimension “exits” from the screen



- The three axes define the three main planes

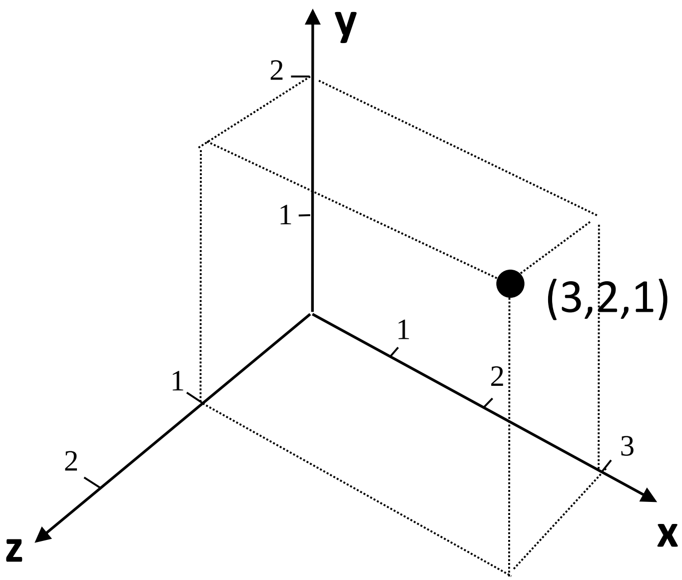
Reference systems

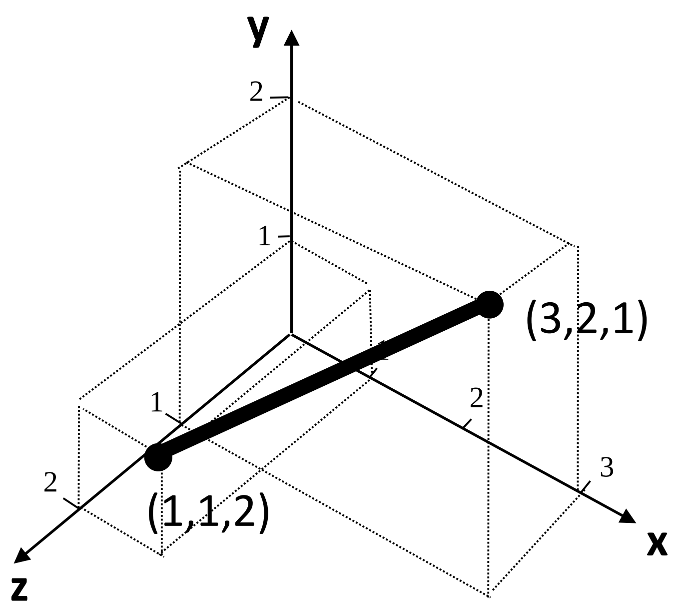
- The three axes define a reference system. Not all the systems are equal! Need to define:
  - Which axis aims upward (or downward)
  - If the system is left-handed or right-handed



3D image representation

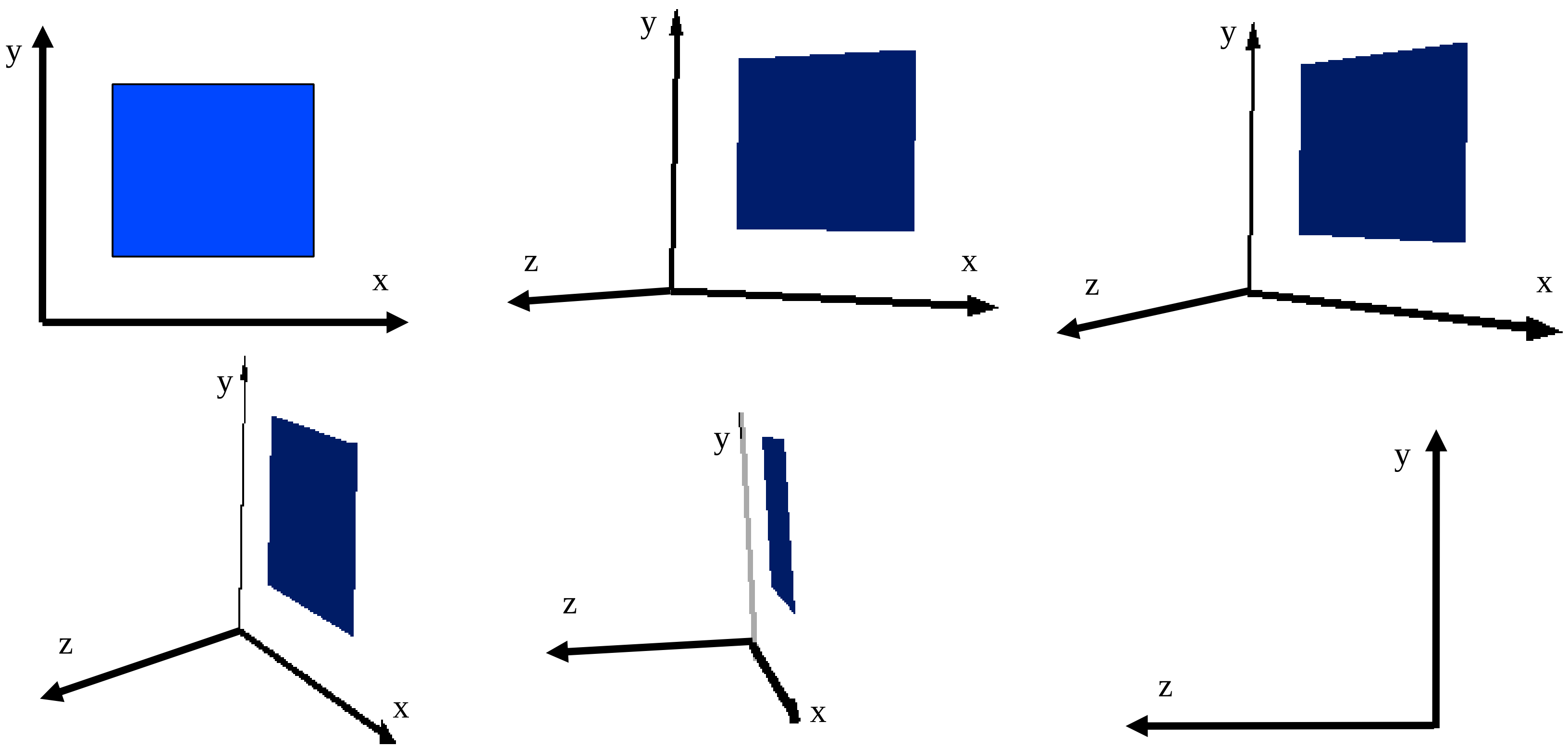
- Still vertices and edges, this time in a 3D space





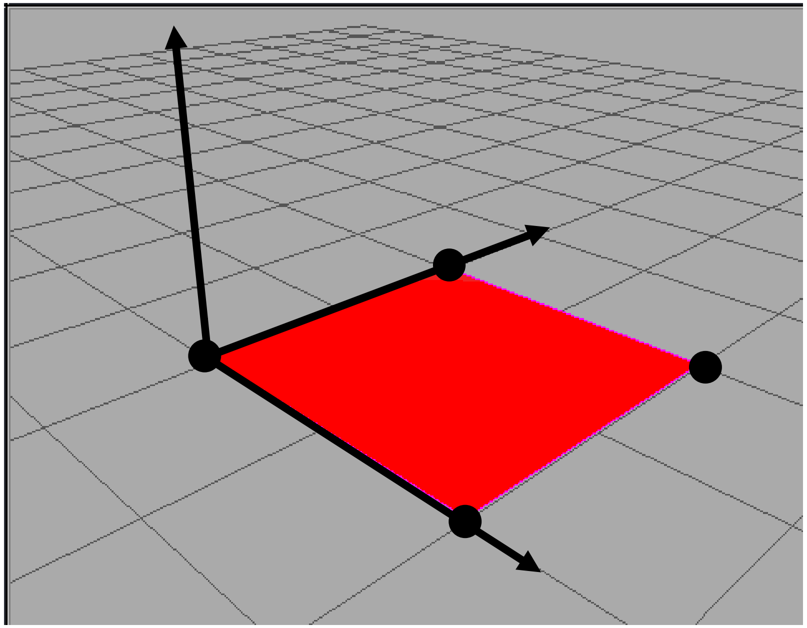
Polygons

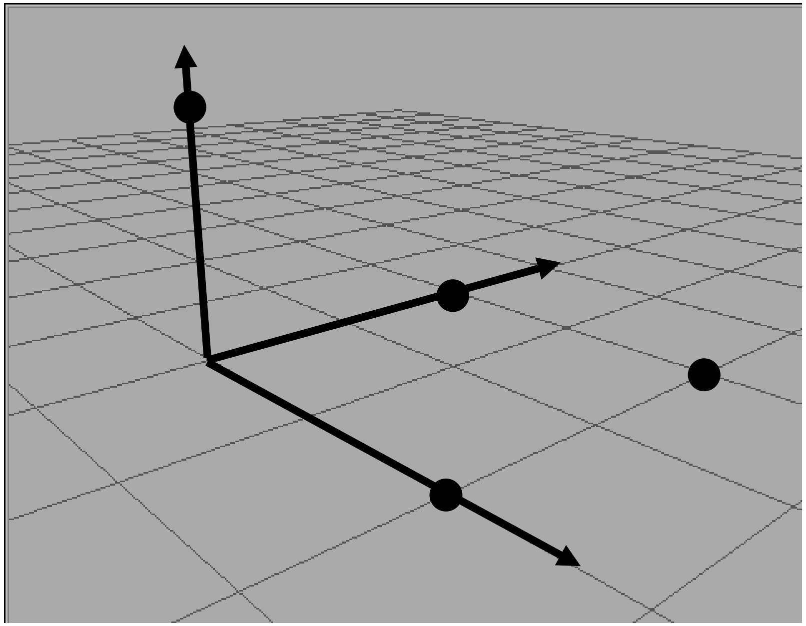
- Polygons are still 2D surfaces, they have no depth



Polygons in 3D

- Warning: not all sets of vertices and edges define a polygon. Polygons are flat surfaces, and if the vertices are > 3 the surface passing through all of them may not exist

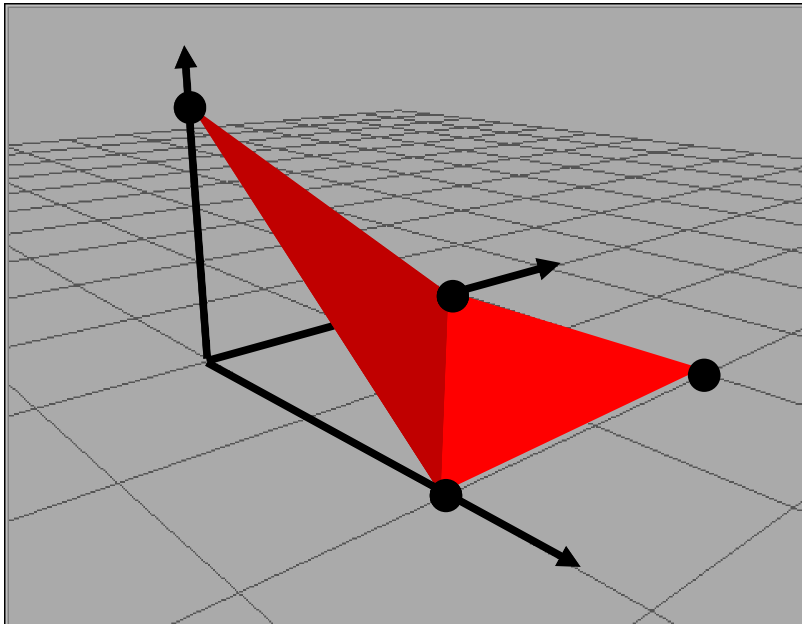




(2D equivalent: it is not always possible to draw a straight line across 3 or more points)

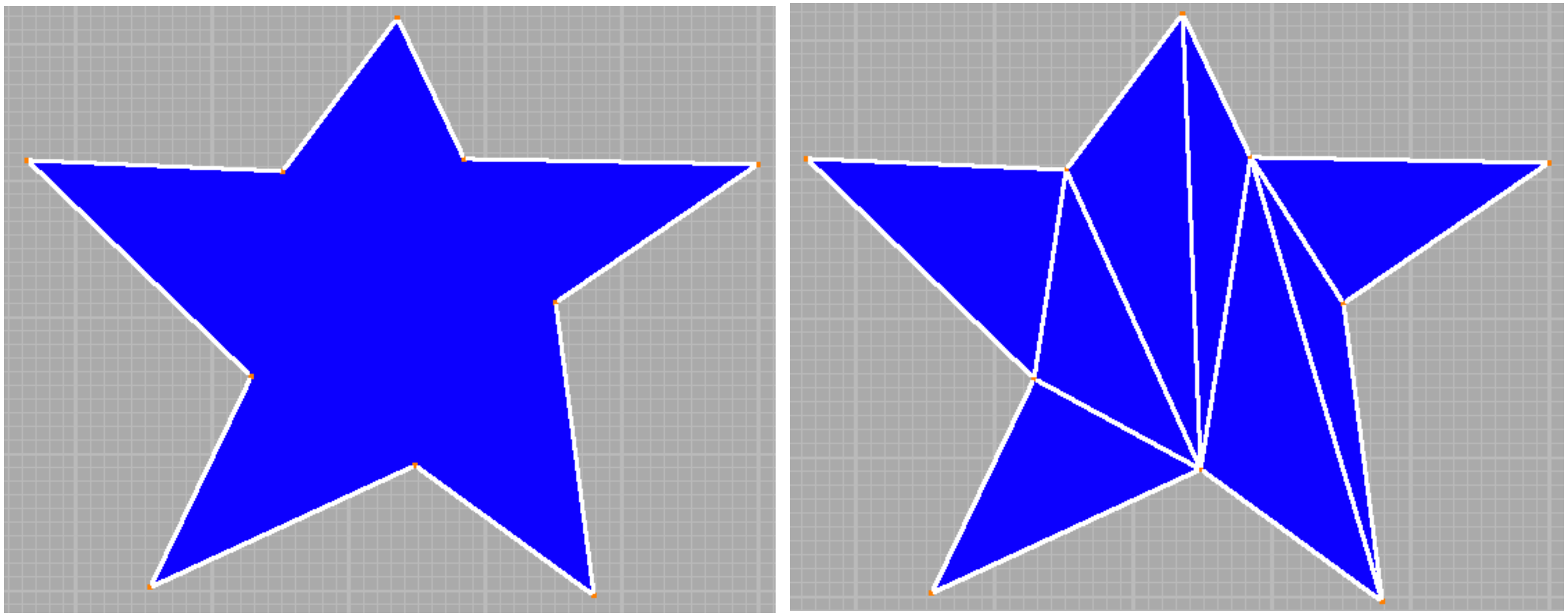
Triangles

- However, three vertices always define a polygon (a triangle). This is why triangles are so important in 3D graphics



Triangulation

- Any generic polygon can be decomposed in a set of triangles. The decomposition is not unique, but the number of resulting triangles is fixed



Curiosity: if the polygon has n vertices, the triangulated version has n-2 triangles and n-3 new edges. No new vertices are added

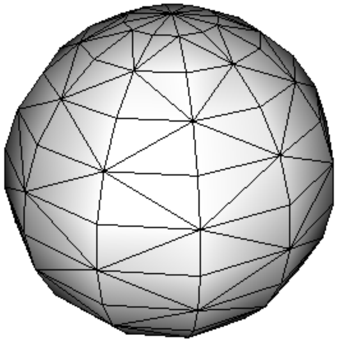
Triangulation: pros and cons

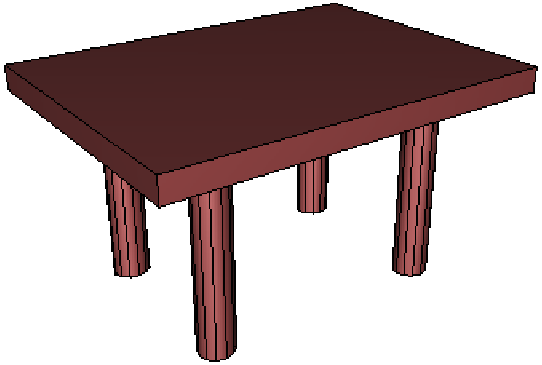
- Pros: no more impossible shapes due to vertices not lying on the same plane

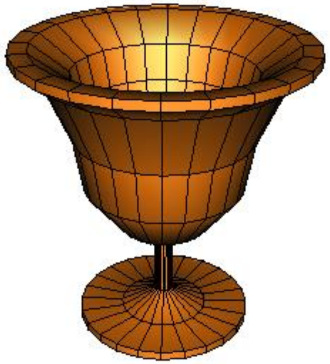
- Cons: the image complexity increases

Polyhedra

- A polyhedron is set of polygons held together by shared vertices and edges
- E.g. the result of triangulation is a polyhedron
- Polyhedra can describe 3D shapes



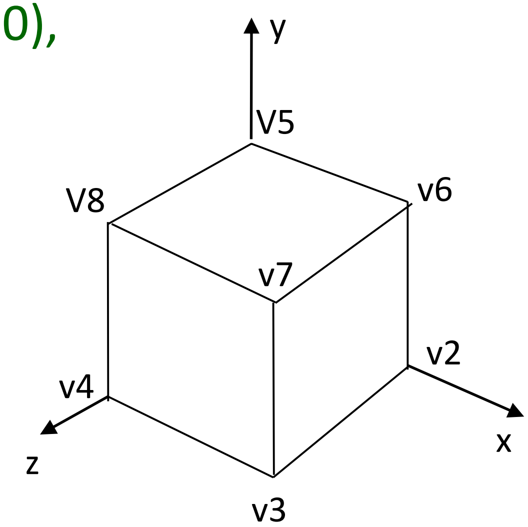




Representation of 3D polyhedra

- Described by a set of **vertices**, one of **edges** and one of polygons (**faces**)

V = {v1(0,0,0), v2(1,0,0), v3(1,0,1), v4(0,0,1), v5(0,1,0), v6(1,1,0), v7(1,1,1), v8(0,1,1)}

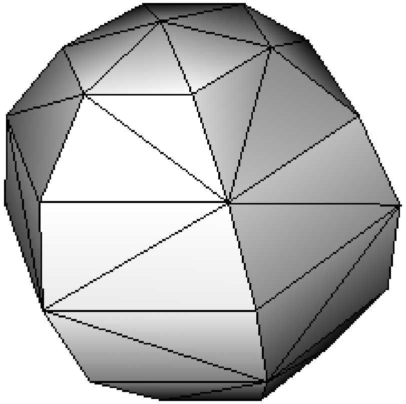


E = {e1(v1,v2), e2(v2,v3), e3(v3,v4), e4(v4,v1), e5(v5,v6), e6(v6,v7), e7(v7,v8), e8(v8,v5), e9(v1,v5), e10(v2,v6), e11(v3,v7), e12(v4,v8)}

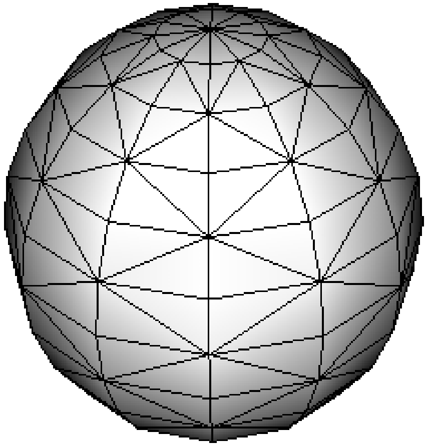
P = {p1(e1,e2,e3,e4), p2(e5,e6,e7,e8), p3(e3,e12,e7,e11), p4(e1,e9,e5,e10), p5(e4,e12,e8,e9), p6(e2,e11,e6,e10)}

Curved surfaces

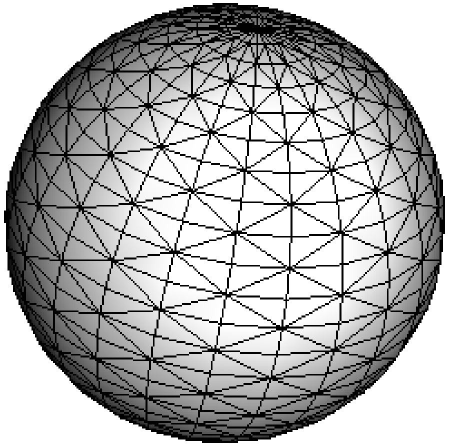
- Two approaches:
  - Mathematical description (e.g. NURBS)
  - Polyhedron approximation



32 vertices, 60 faces



134 vertices, 264 faces



554 vertices,1104 faces

Curiosity: in any polyhedron without holes, the number of vertices, edges and faces are related according to the Euler formula: faces = edges – vertices + 2

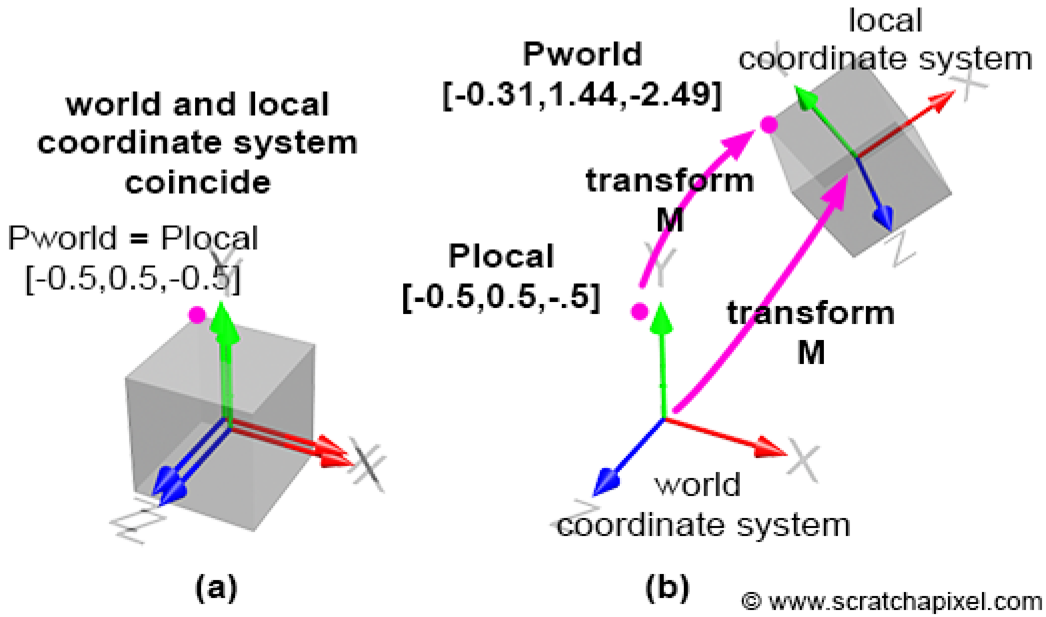
Transformations

Transformations

- Working on vector models allow us to manipulate (transform) 3D objects without information loss
- Basic transformations:
  - Translations
  - Rotations
  - Scale changes
- Mathematically described by algebraic operations (matrix-vector multiplications)

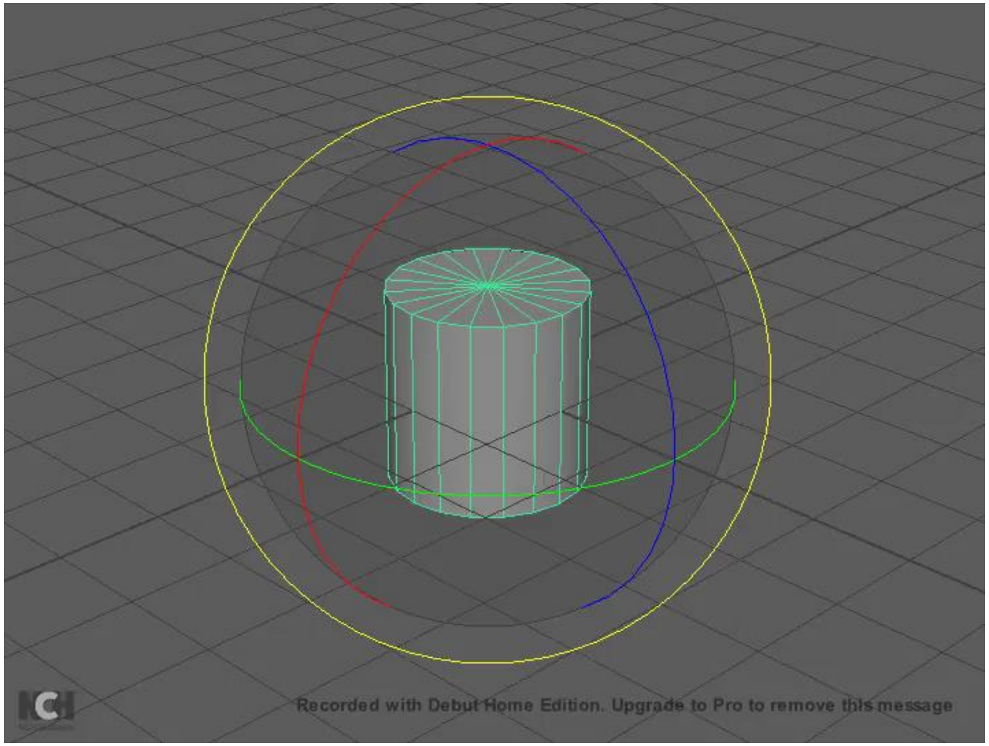
Local and global transformations

- Local: relative to a reference system that moves with the object (**object coordinates**)
- Global: relative to a fixed reference system (**world coordinates**)



Pivots

- The pivot is the center of a transformation, the point that does not move even when the objet is rotated/scaled



Projections

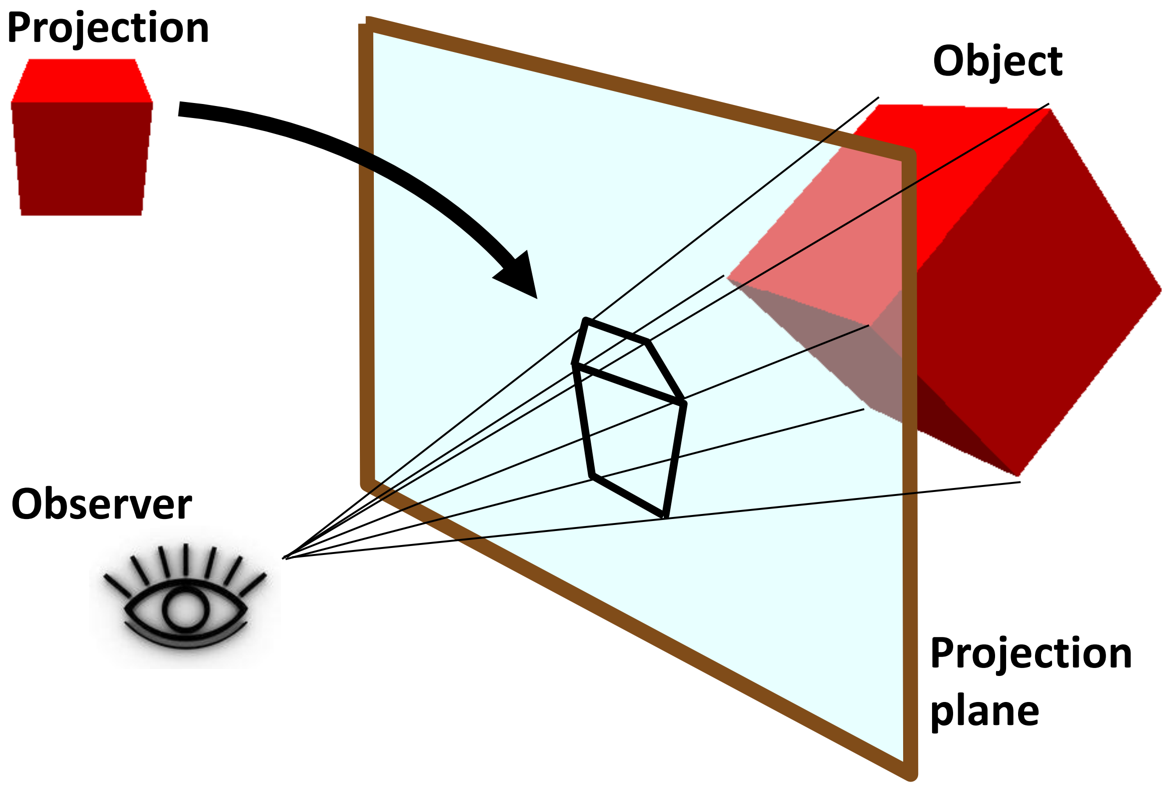
Projections

- In order to visualize a 3D image on a 2D screen, we must drop a dimension
- The process of creating 2D representations of 3D images is called projection

- Basic idea: the projection plane is like a transparent plane between the object and the observer
- The intersections of ray lights from the object to the observer with the plane define the projection

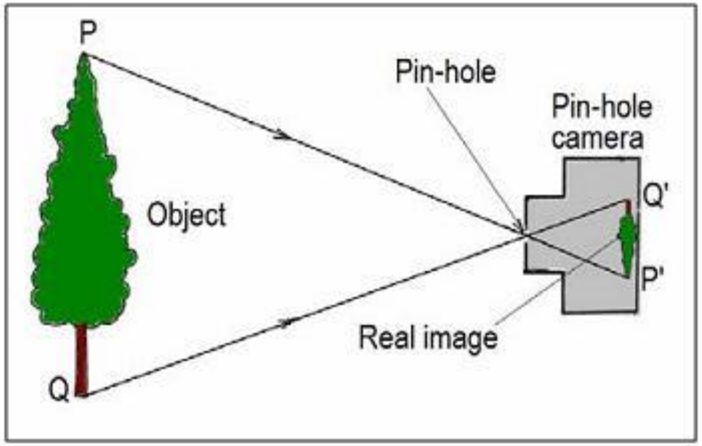
Perspective projections

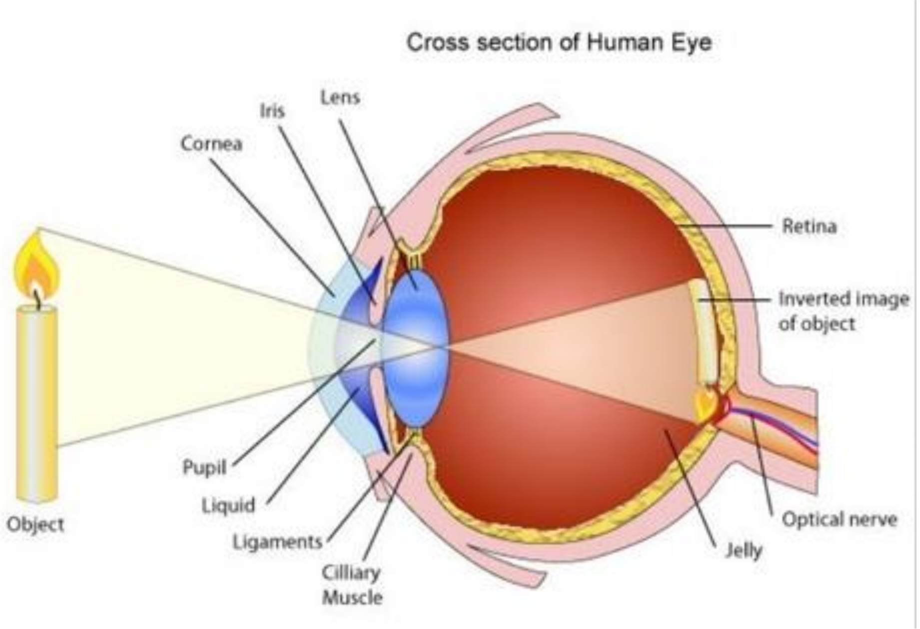
- In perspective projections, the observer is placed at finite distance from the projection plane



Perspective projections

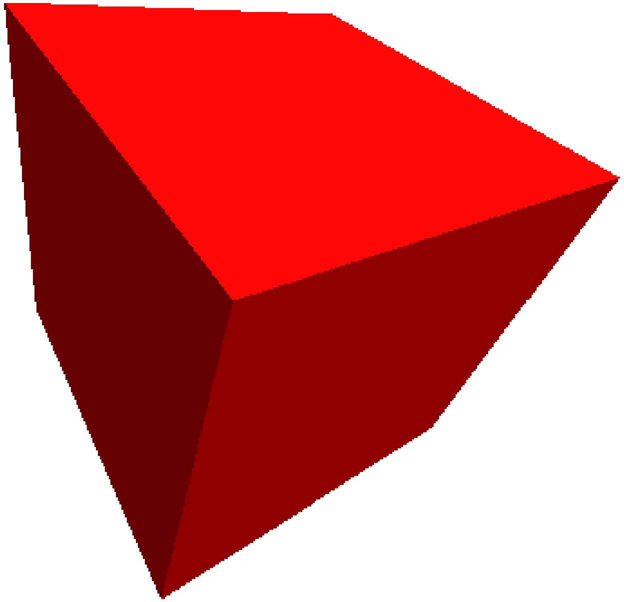
- This is what happens in cameras or eyes





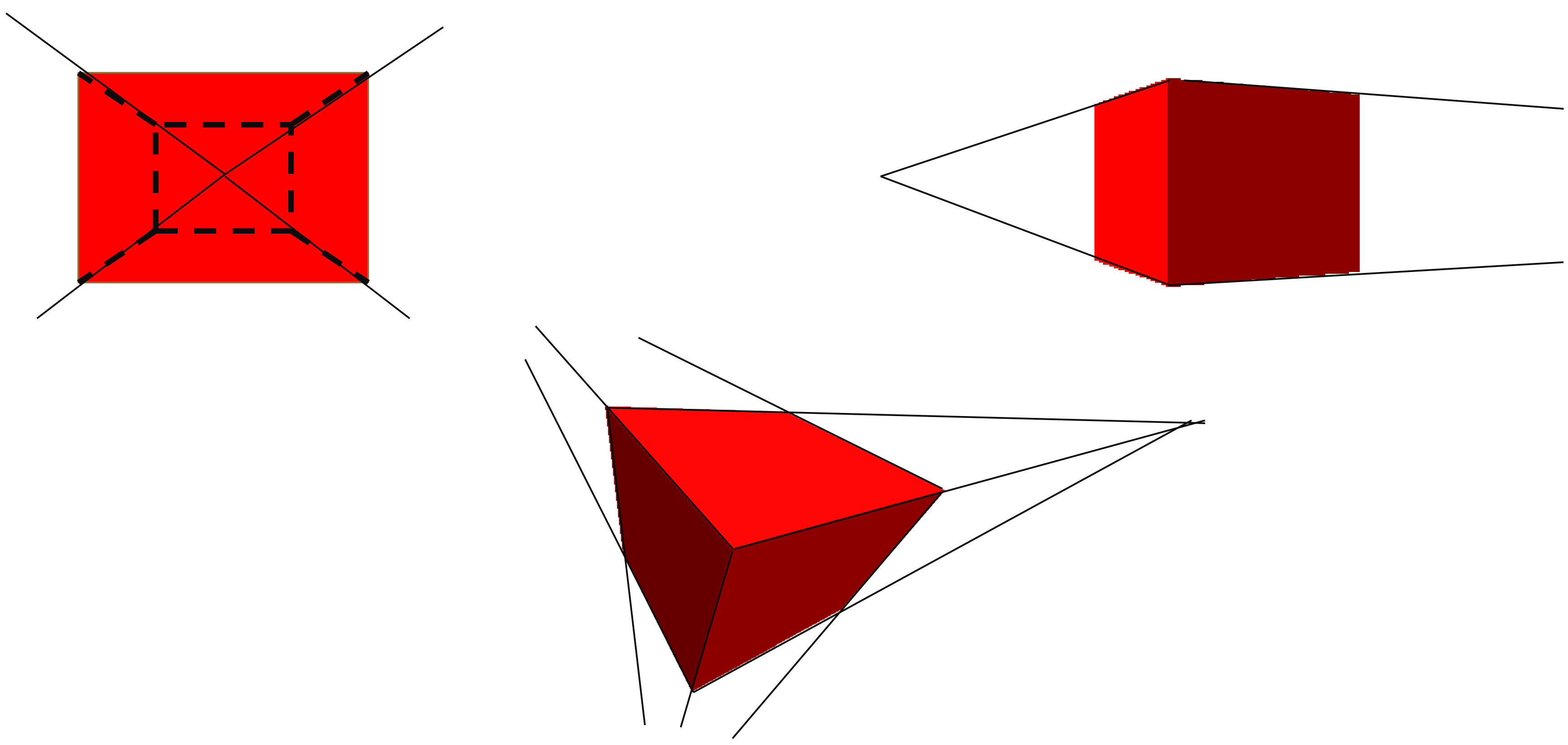
Perspective distortion

- In perspective projections, perspective **distortion** occurs: lines that are parallel in the 3D world, seem to converge towards a *vanishing point*



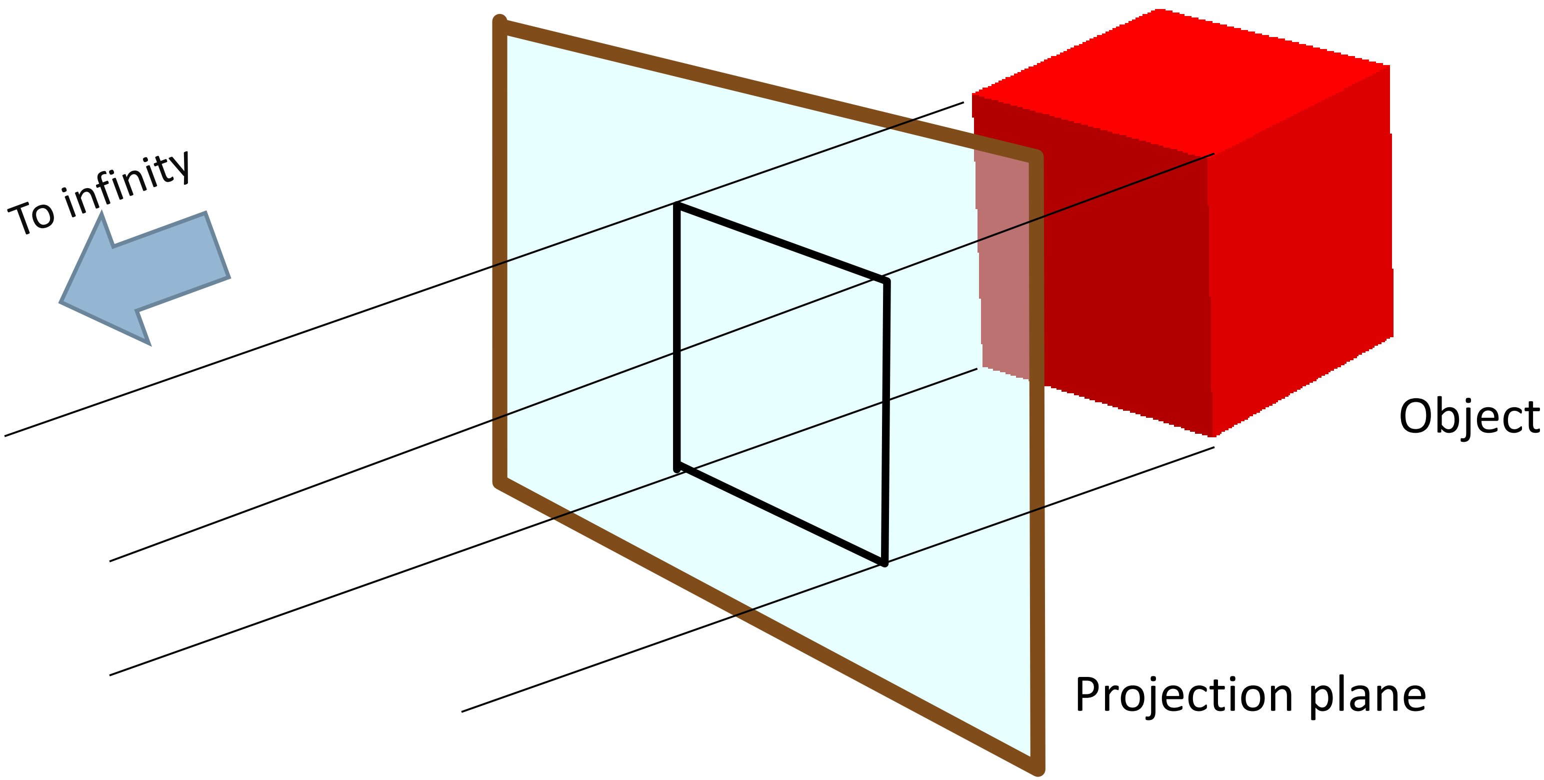
Vanishing points

- Parallelism is preserved only for lines parallel to the projection plane. Thus, depending on the object shape and position, there can be multiple vanishing points



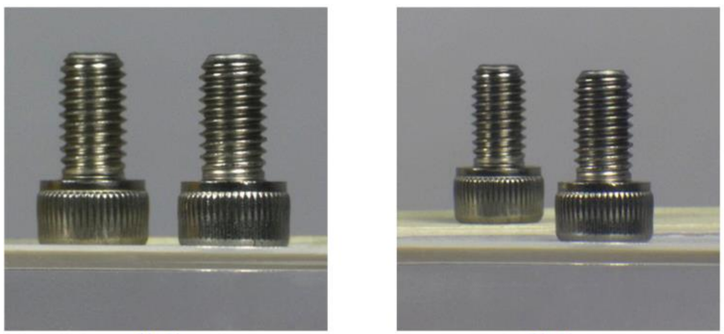
Axonometric projections

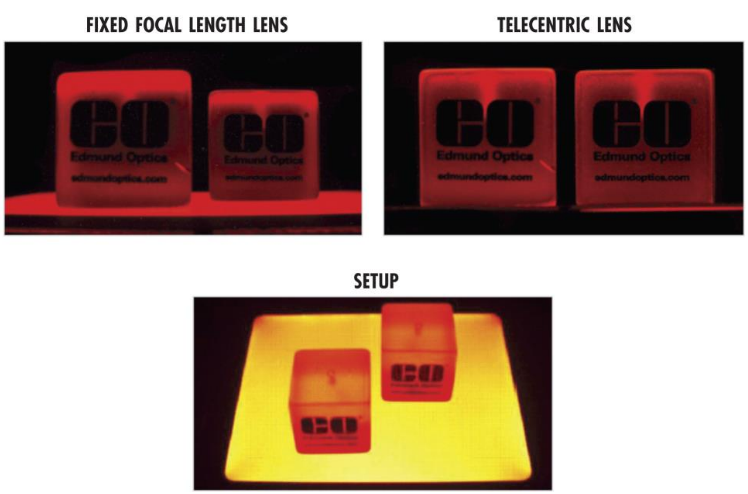
- In **axonometric projections**, the observer is placed at **infinity** and the light rays are **parallels**

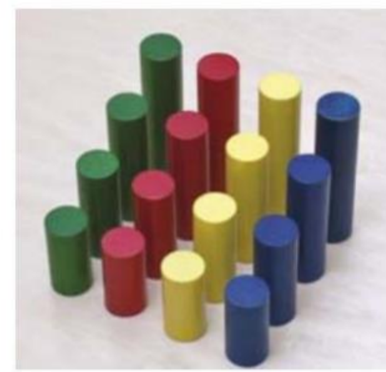


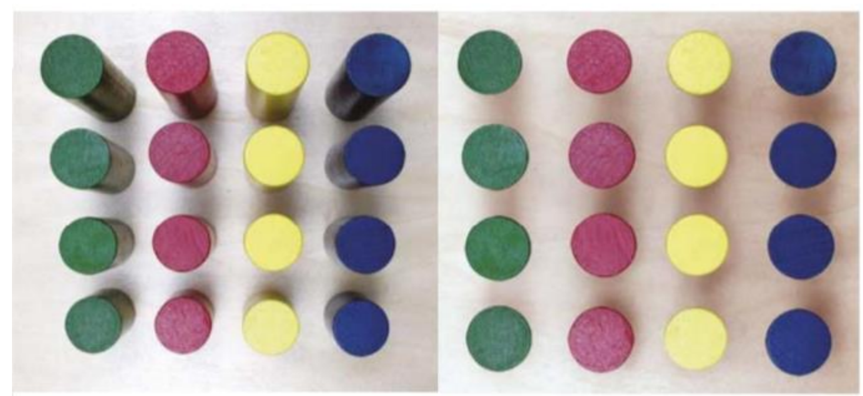
Axonometric projections

- Examples from machine vision, where special lenses (called telecentric lenses) are often used to achieve axonometric projections



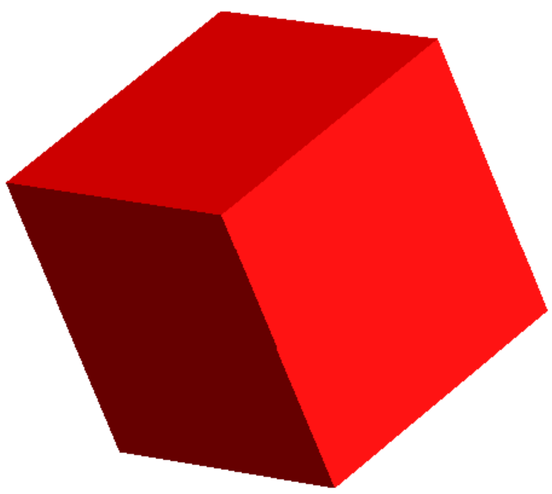






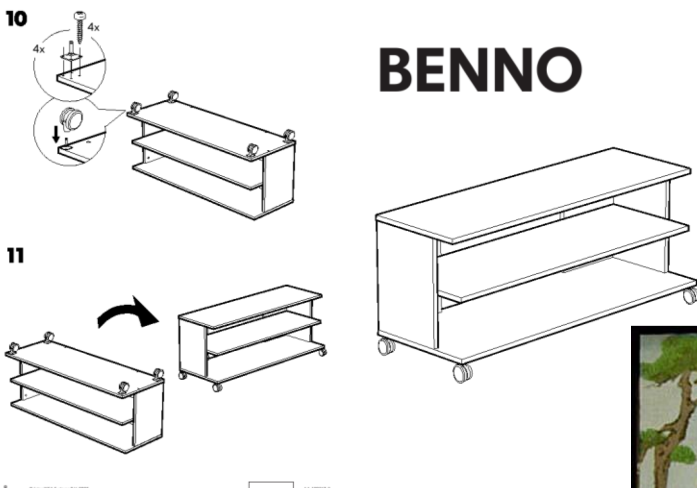
Axonometric projections

- Parallel lines in 3D are parallel in axonometric projections too.
- There is no perspective distortion. Objects with the same 3D size have the same 2D appearance



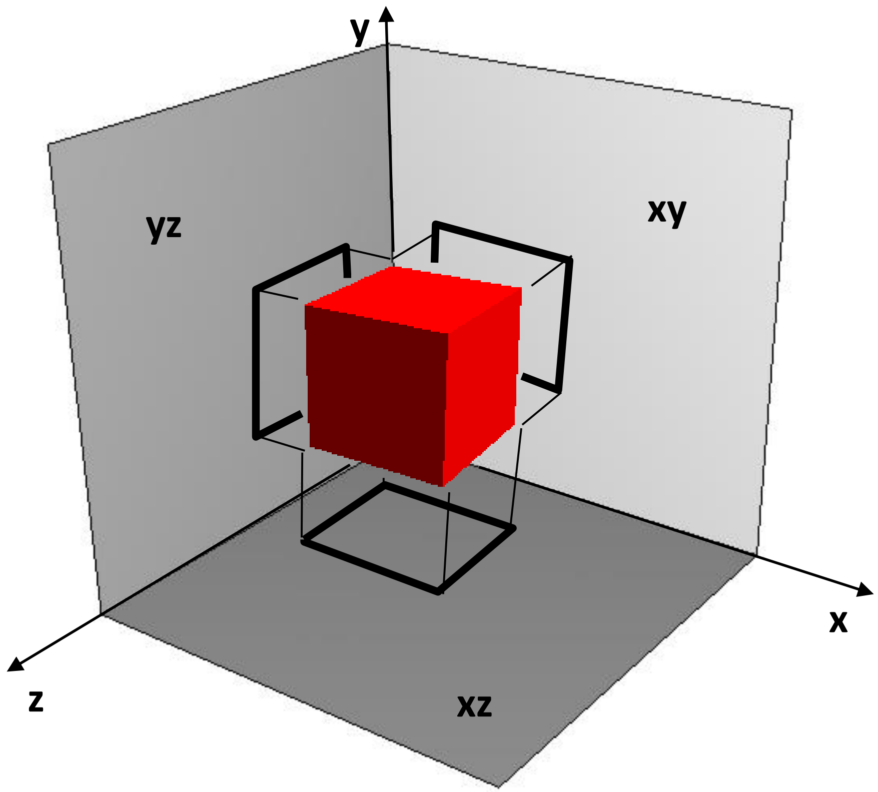
Axonometric projections

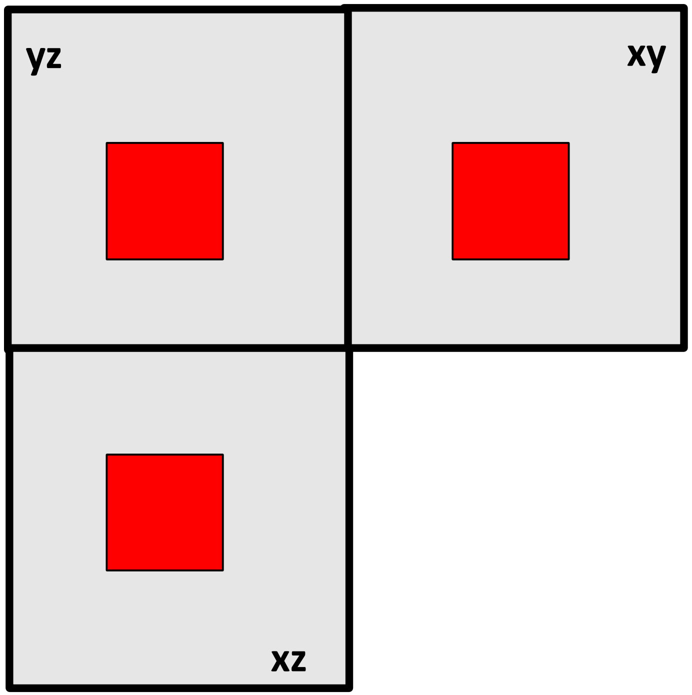
- Useful when it is important to clearly show spatial relations, because of the lack of distortion



Orthogonal projections

- Orthogonal (or orthographic) projections are just axonometric projections on the three main planes XY, XZ and YZ

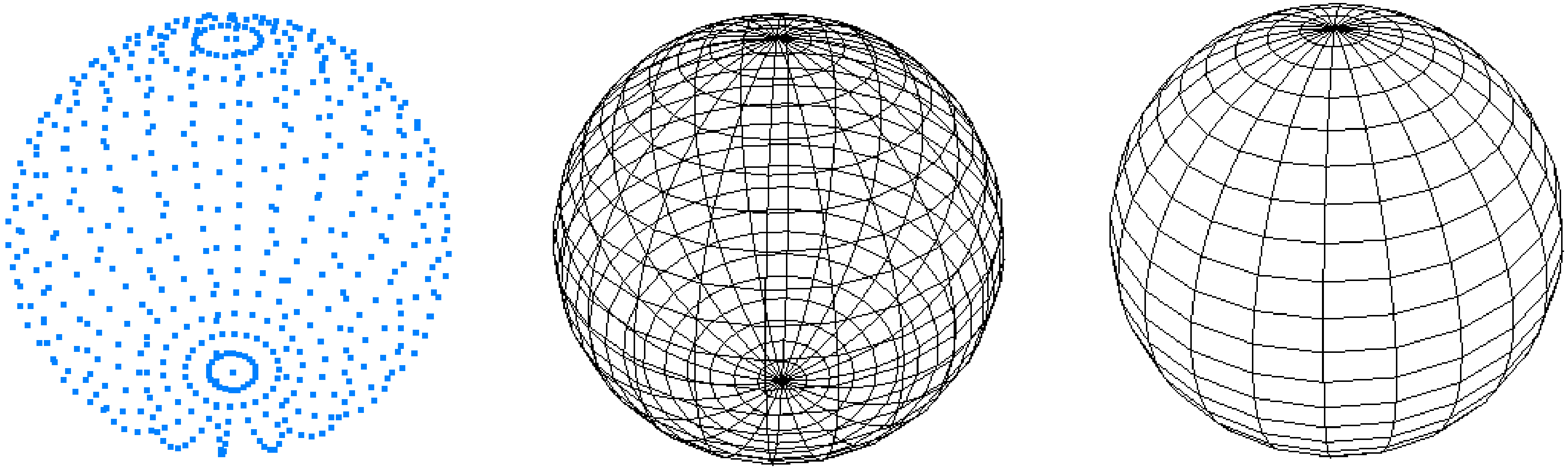




Visualization of 3D objects

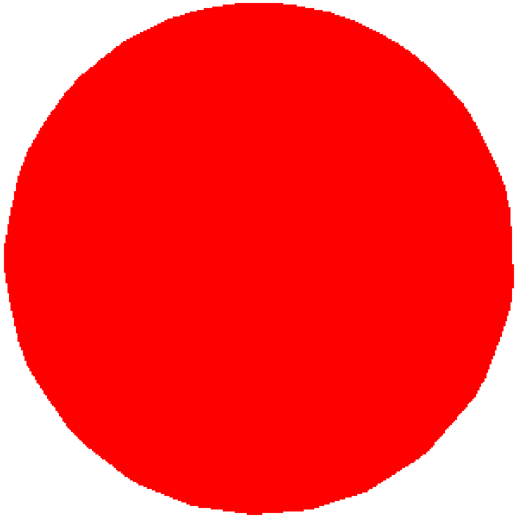
What to show

- Vertices only (point cloud)
- Edges only (wireframe)
- Faces



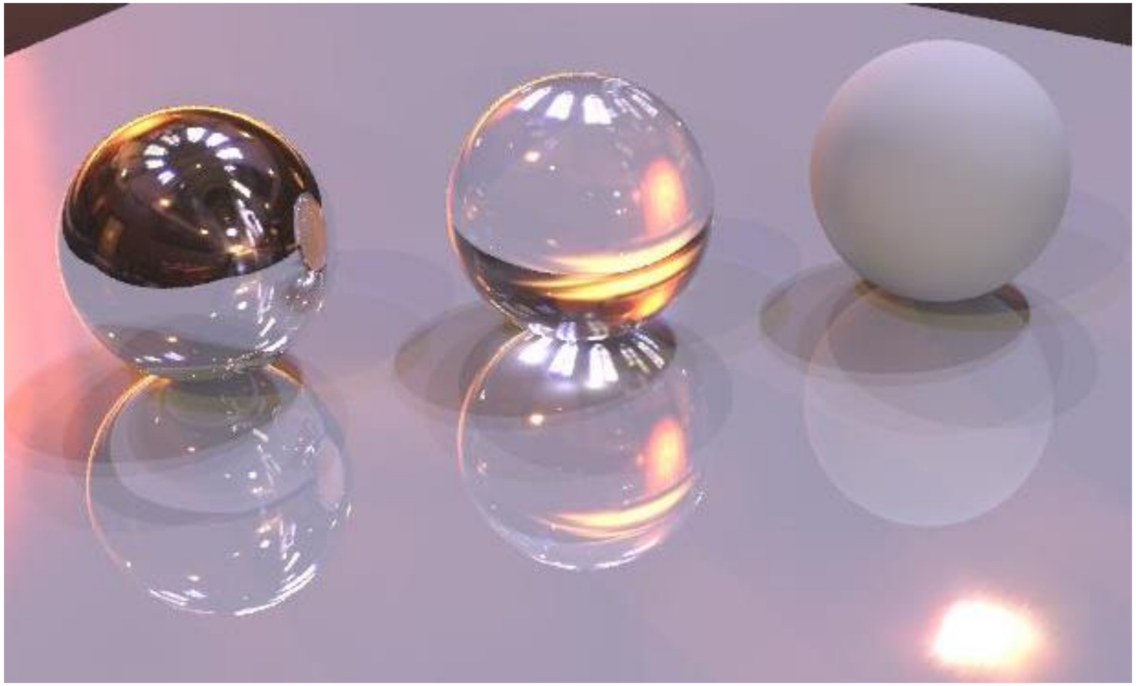
Showing faces

- In order to show the faces, they must have a color
- However, if all the faces were of the same color, the resulting image would be totally flat



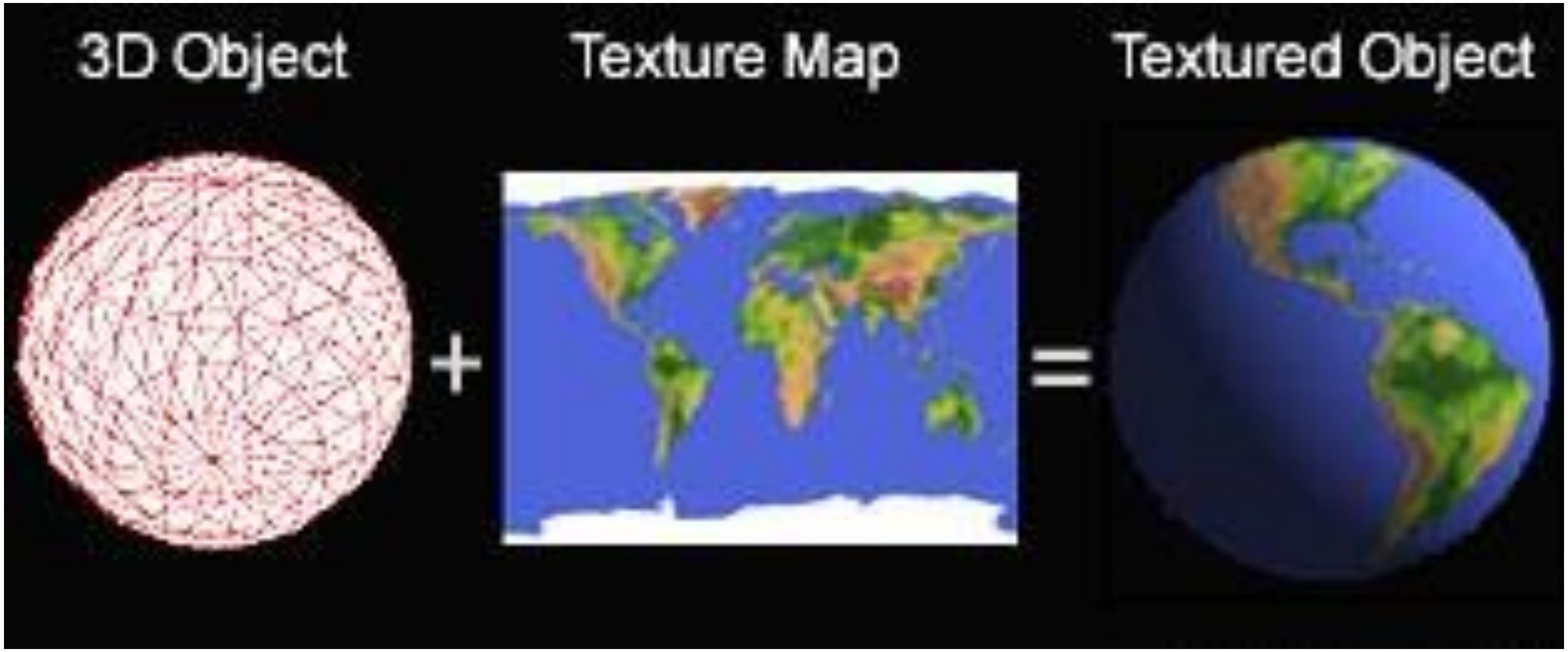
Materials

- A material defines not only the color, but also how the surface reacts to light, thus modelling several properties affecting the final appearance:
  - Color
  - Transparency
  - Shininess
  - …



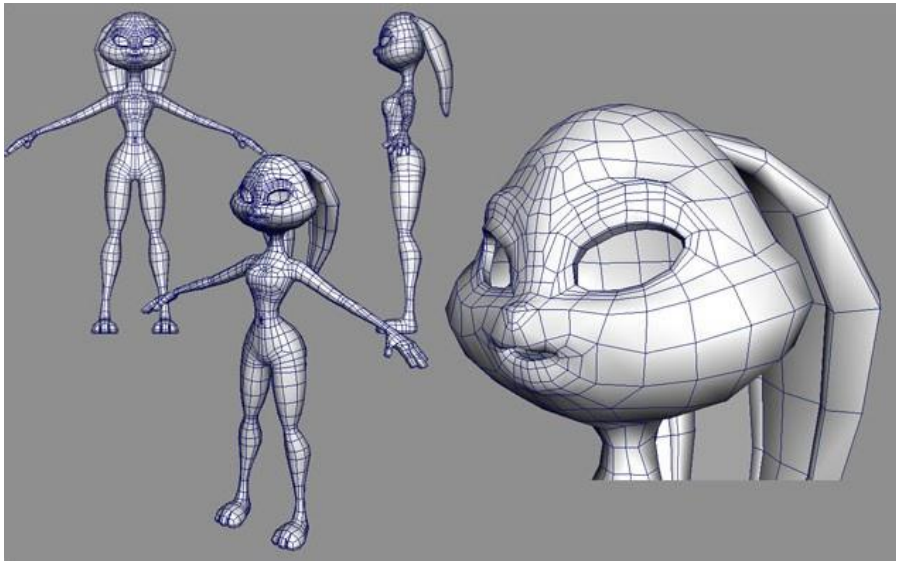
Textures

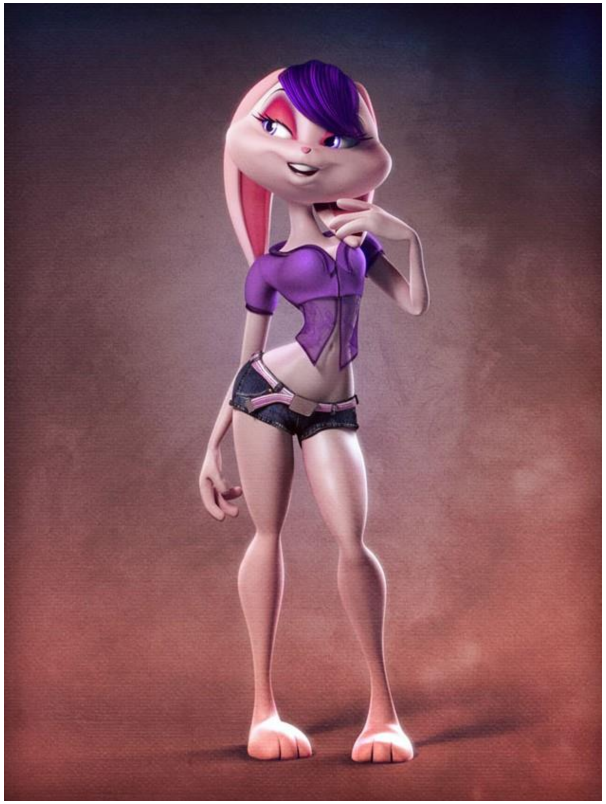
- Materials can be used to apply images (textures) on the surface of 3D objects



Rendering

- The term **rendering** denotes the process of creating a final raster image from a 3D model and the corresponding materials, lights, etc
- A **render engine** is a software computing renders





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