Fundamentals of Computer Graphics and Image Processing

Textures, Mappings (06)

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Overview

- Texture mapping
  - 3D Models with texture coordinates
  - UV map parametrization
  - Perspective correction
- Aliasing
- Anti-aliasing
  - Supersampling
  - Mip Maps
- Advanced textures
  - Environment mapping
  - Bump mapping
  - Normal mapping, Displacement mapping etc.

How the lectures should look like #1

- Ask questions, please!!!
- Be communicative
- More active you are, the better for you!

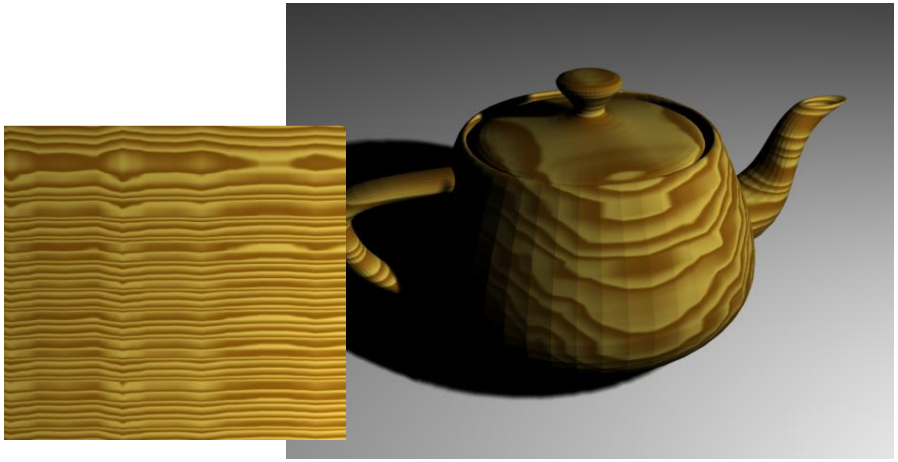
Material

- Visually distinguishes 2 objects with identical geometry

- For now, we focus on object’s own color

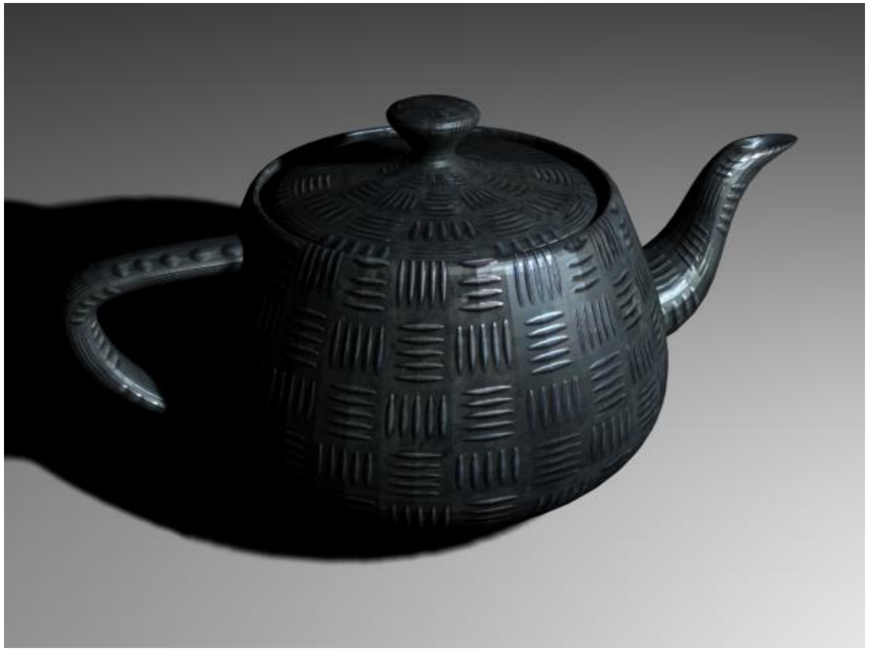
Texture

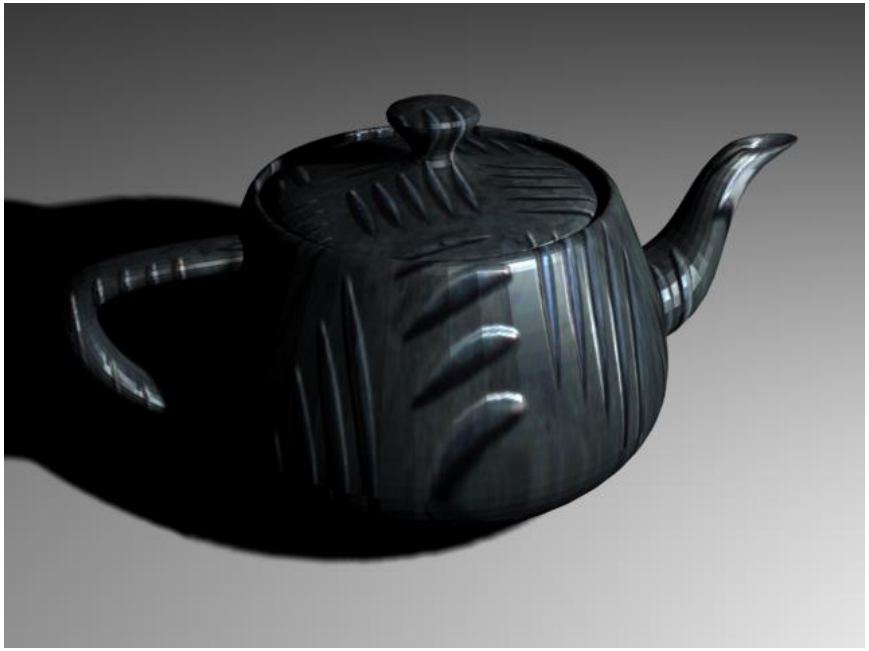
- Used to define object’s color appearance
  - 2D bitmap
  - Volumetric - texels
  - Procedural texture



Texture mapping

- Mapping between object space and 2D texture space





- New coordinate system: Texture coordinates

Texture mapping

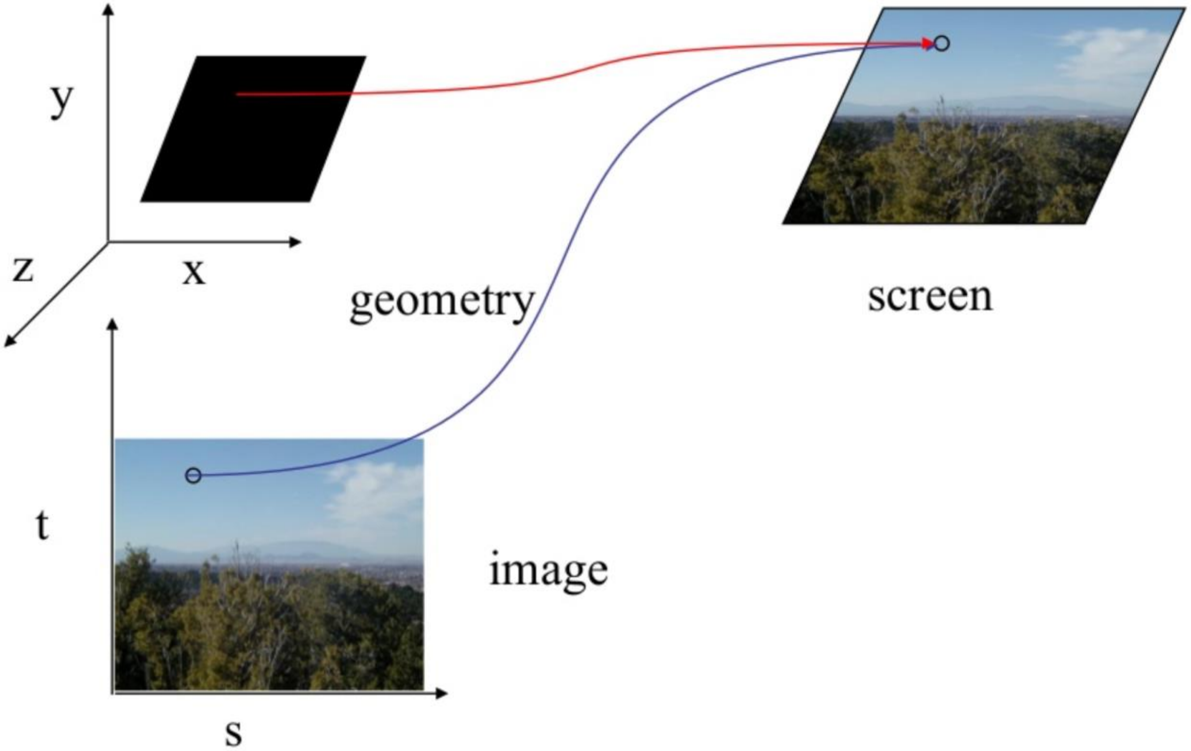
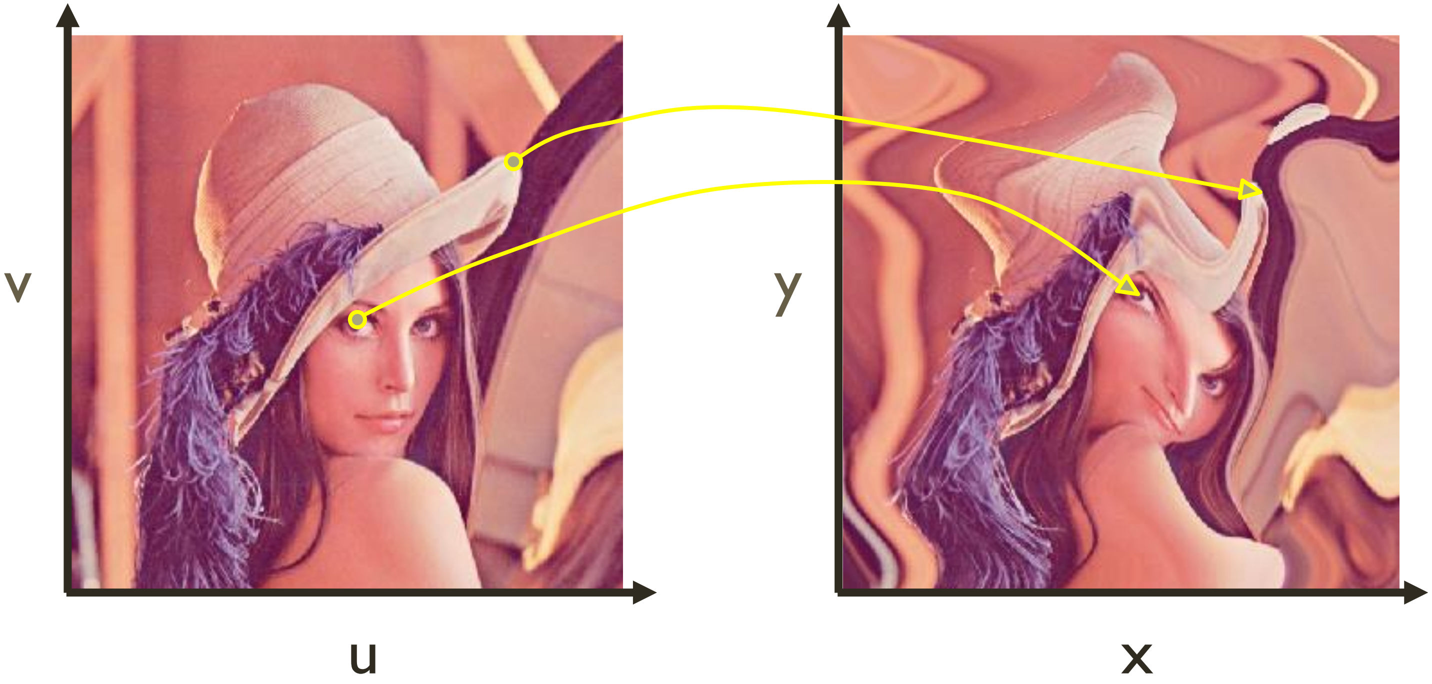


Image mapping

- Mapping
  - Forward
  - Inverse
- Resampling
- Filtering

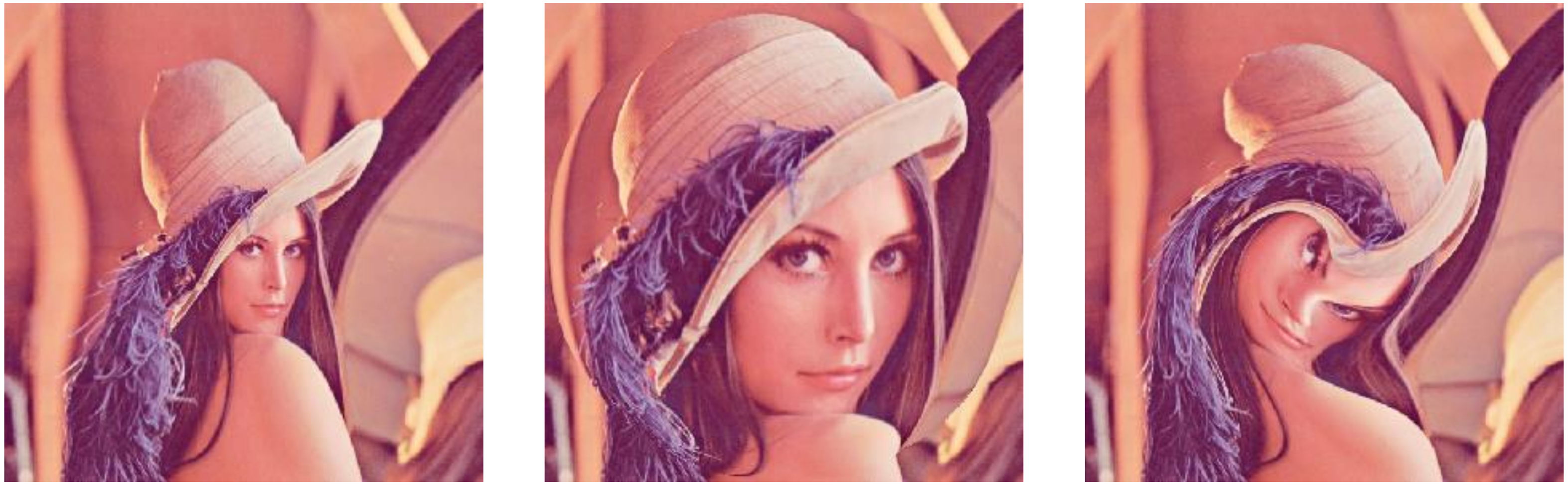
Mapping

- Define image transformation
  - Describe the destination (x, y) for every location (u, v) in the source (or vice-versa, if inversible)



Other mappings

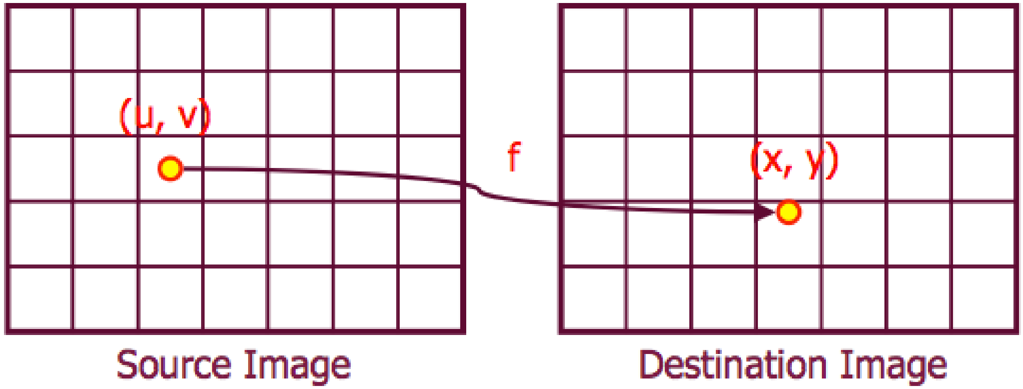
- Any function of u and v
  - x = f_x(u,v)
  - y = f_y(u,v)



Implementation

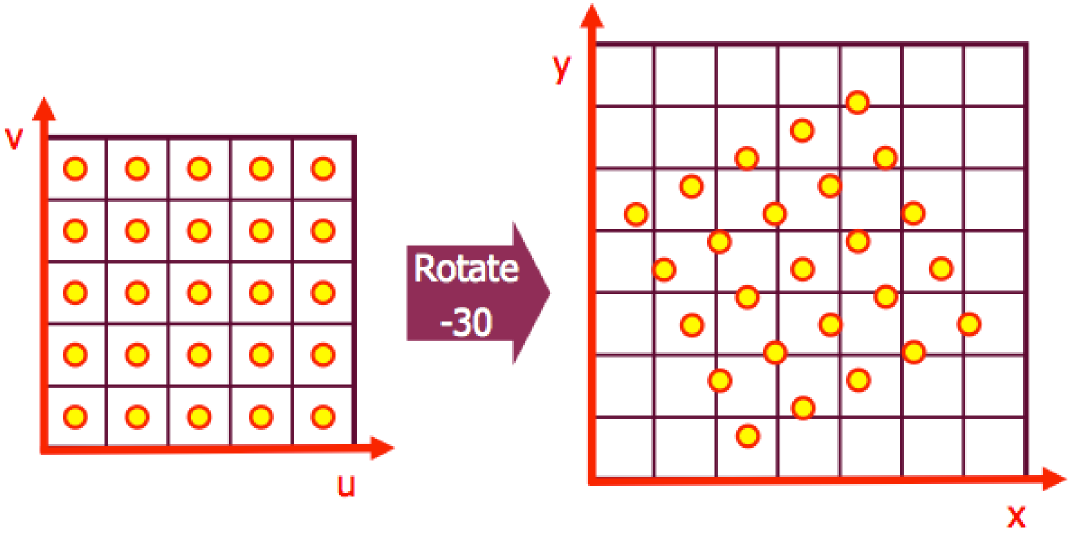
- Forward mapping

```
for(int u=0; u<umax; u++) {
  for(int v=0; v<vmax; v++) {
    float x = $f_x$ (u,v);
    float y = $f_y$(u,v);
    dst(x,y) = src(u,v);
  }
}
```



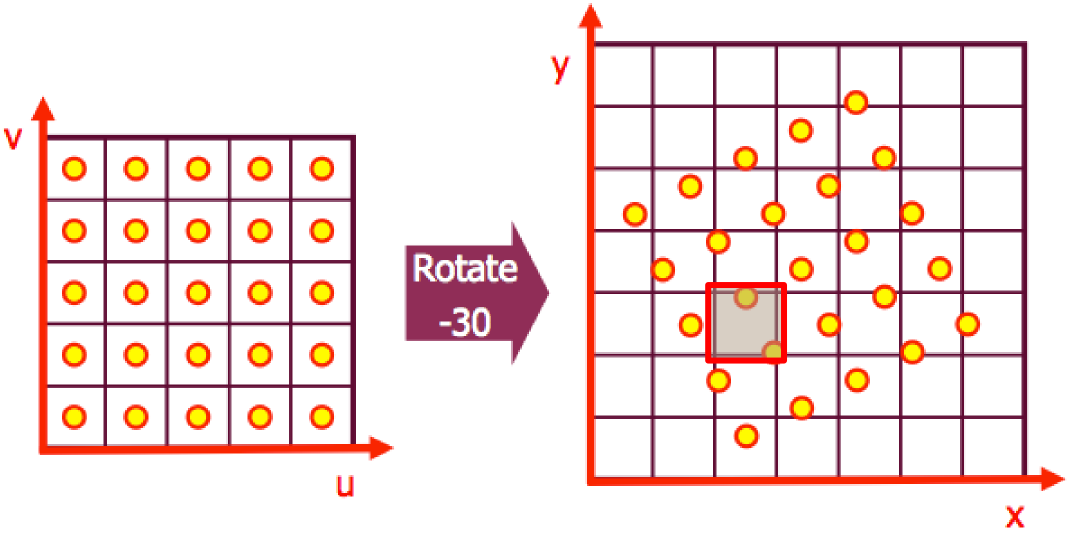
Forward mapping

- Iterate over source image
- But …



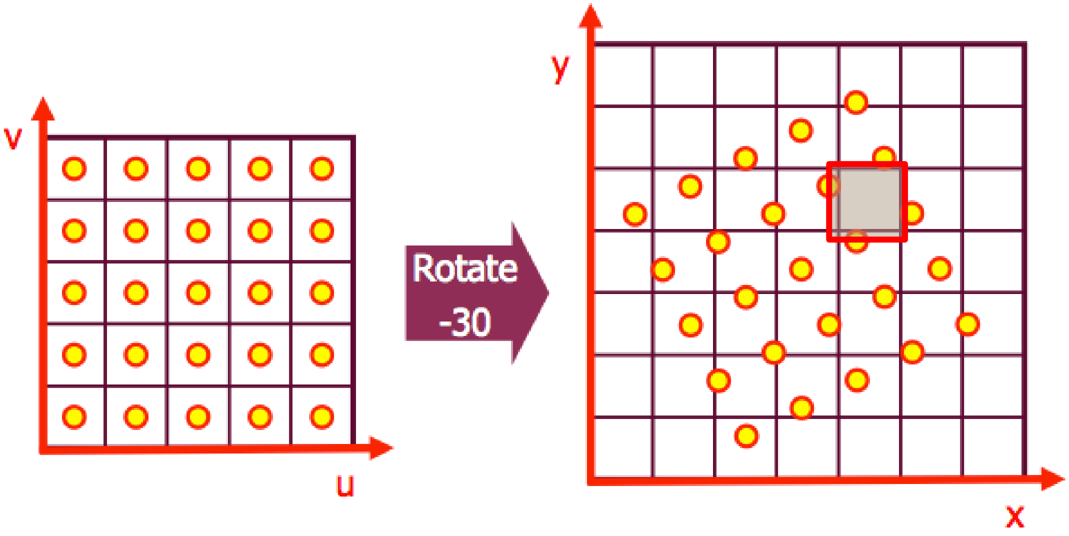
Forward mapping

- Iterate over source image
- Many pixels map on the same destination!



Forward mapping

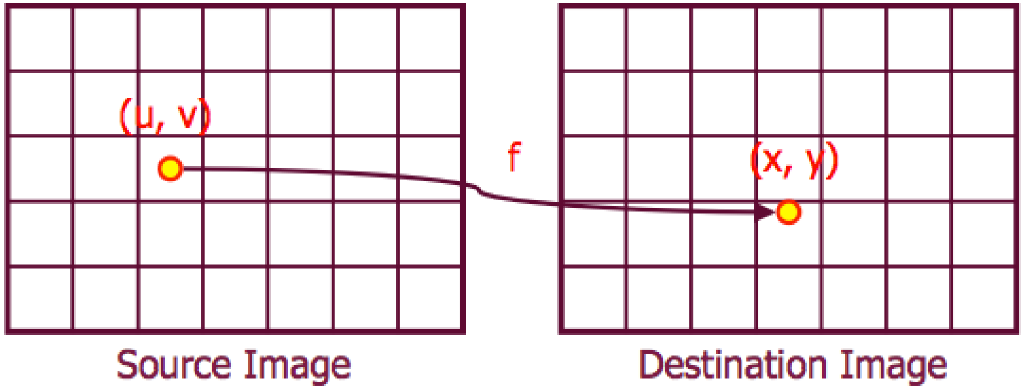
- Iterate over source image
- Some pixels will not be covered!



Implementation 2

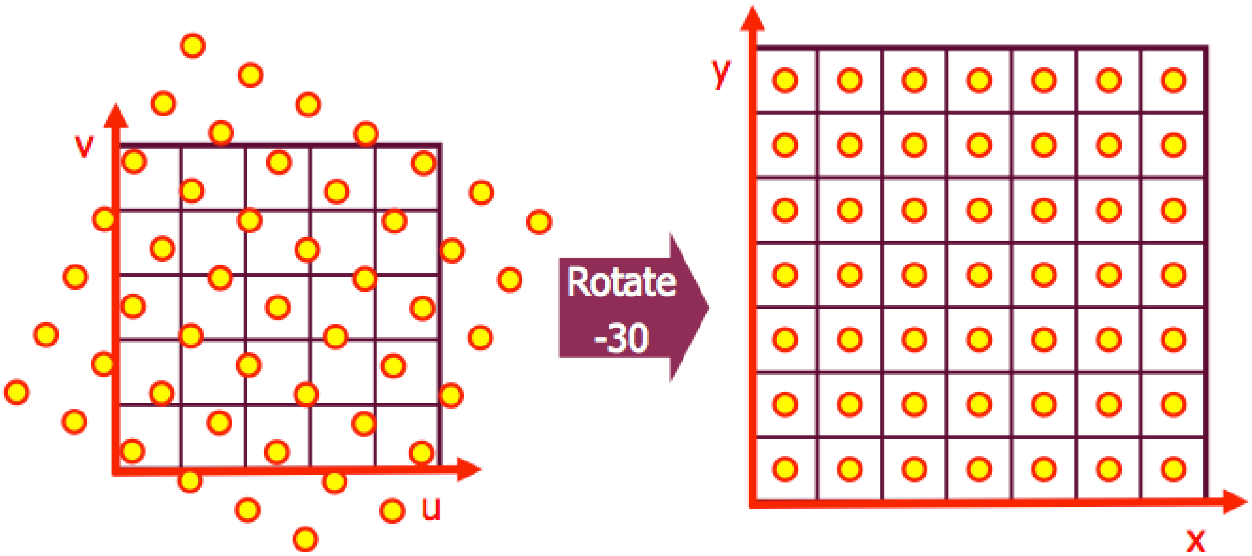
- Inverse mapping

```
for(int x=0; x<xmax; x++) {
  for(int y=0; y<ymax; y++) {
    float u = $f_x^{-1}$ (x,y);
    float v = $f_y^{-1}$ (x,y);
    dst(x,y) = *resample_src*(u,v);
  }
}
```



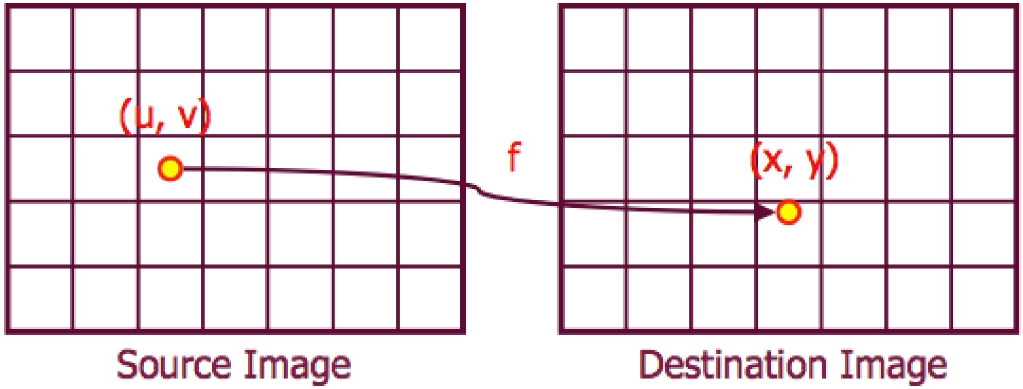
Inverse mapping

- Iterate over destination image
  - Must **resample** source
  - Much simpler but may oversample



Resampling

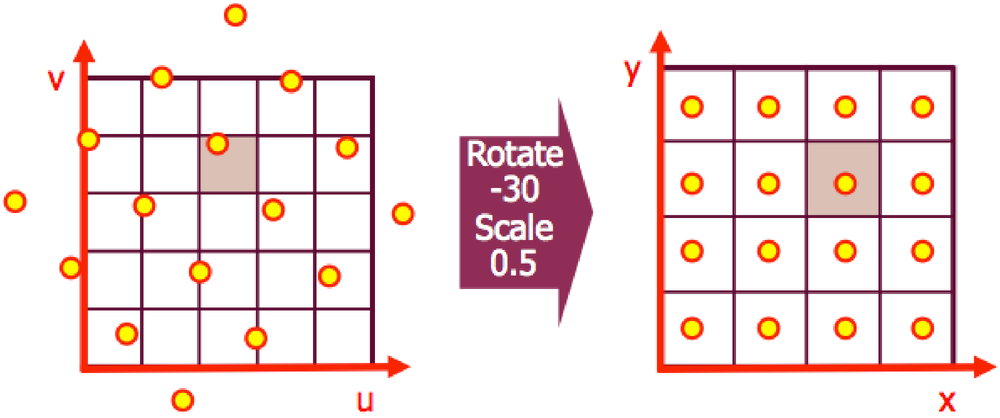
- Evaluate source image at arbitrary (u,v)
- (u,v) coordinates are generally not integer



Nearest neighbor

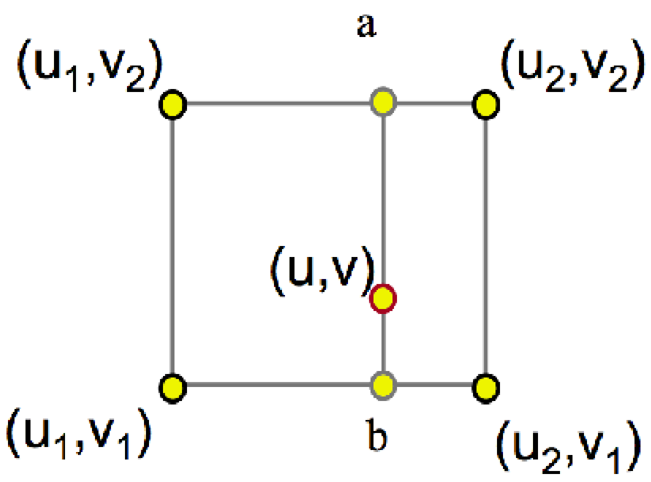
- Take value of closest pixel
- Fast! Low quality

```
int iu = trunc(u+0.5du);
int iv = trunc(v+0.5dv);
dst(x, y) = src(iu, iv);
```



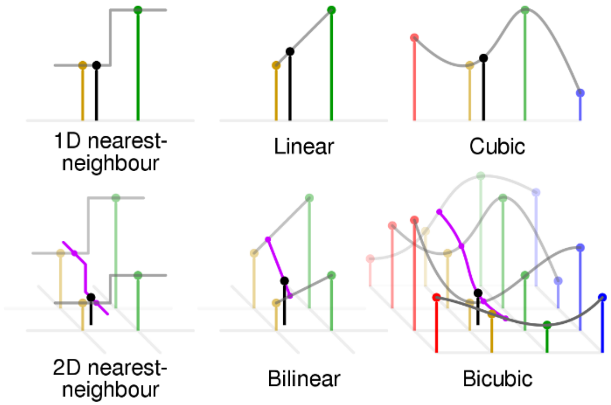
Bilinear filtering

- Bilinearly interpolate four closest pixels
  - a = linear interpolation of src(u1, v2) and src(u2, v2)
  - b = linear interpolation of src(u1, v1) and src(u2, v1)
  - dst(x, y) = linear interpolation of "a" and "b"
- Reasonably Fast. Good quality.

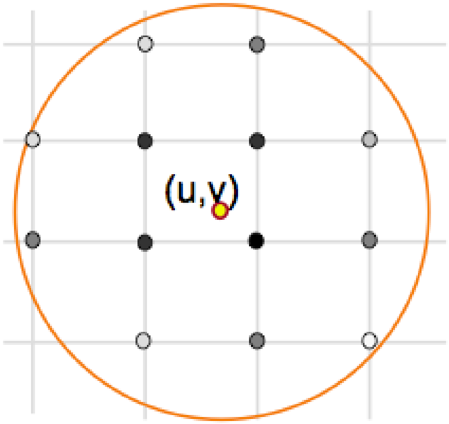


Other filters

- Bicubic Filtering
  - Considers 4x4 pixels (16 pixels)
  - Smoother, less artifacts
  - Computationally expensive

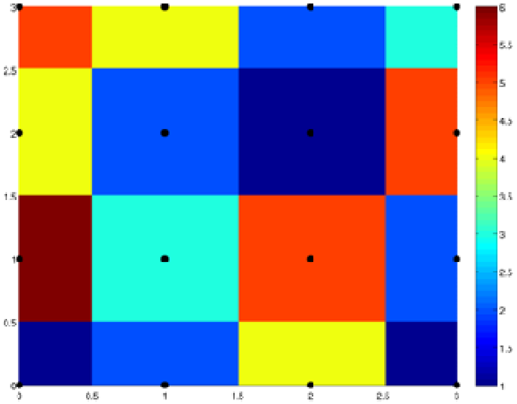


- Gaussian Filtering
  - Uses weighted sum of neighborhood
  - Weights are normalized using Gaussian function

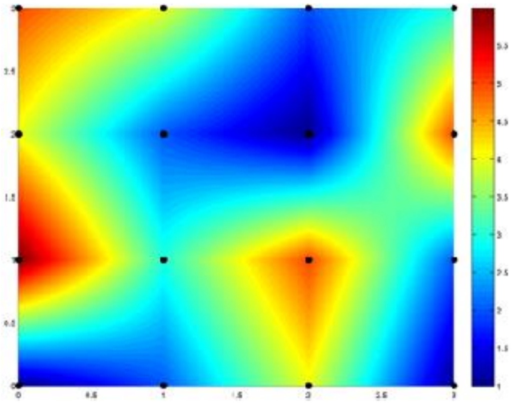


Filtering comparison

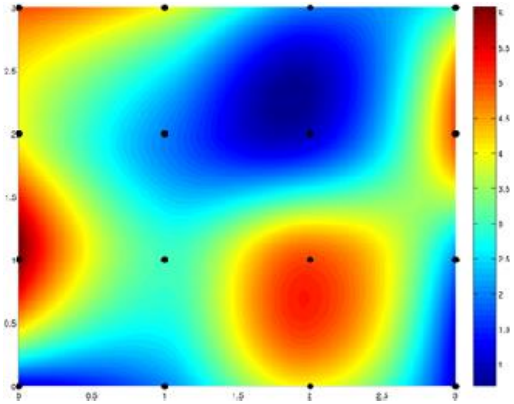
- Comparison of resampling quality



Nearest

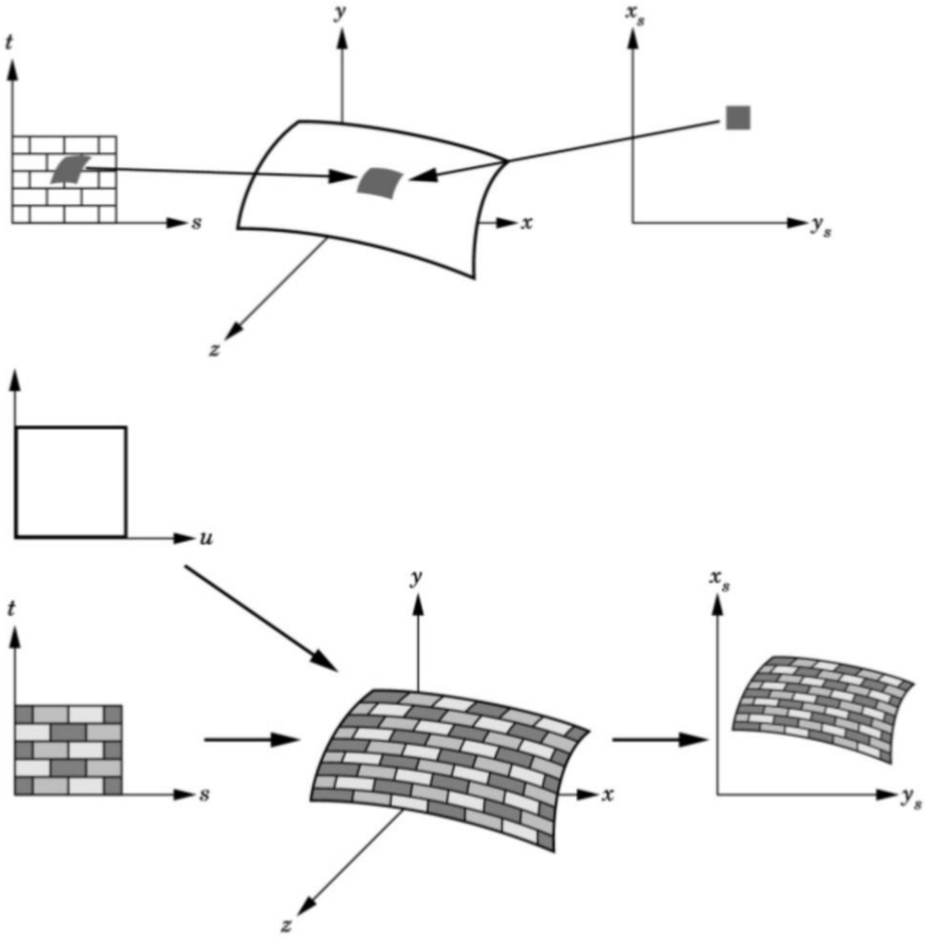


Bilinear



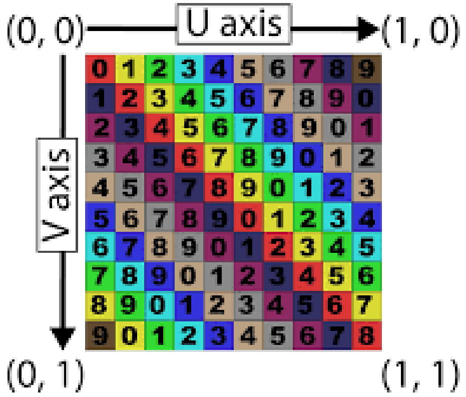
Bicubic

Texture mapping

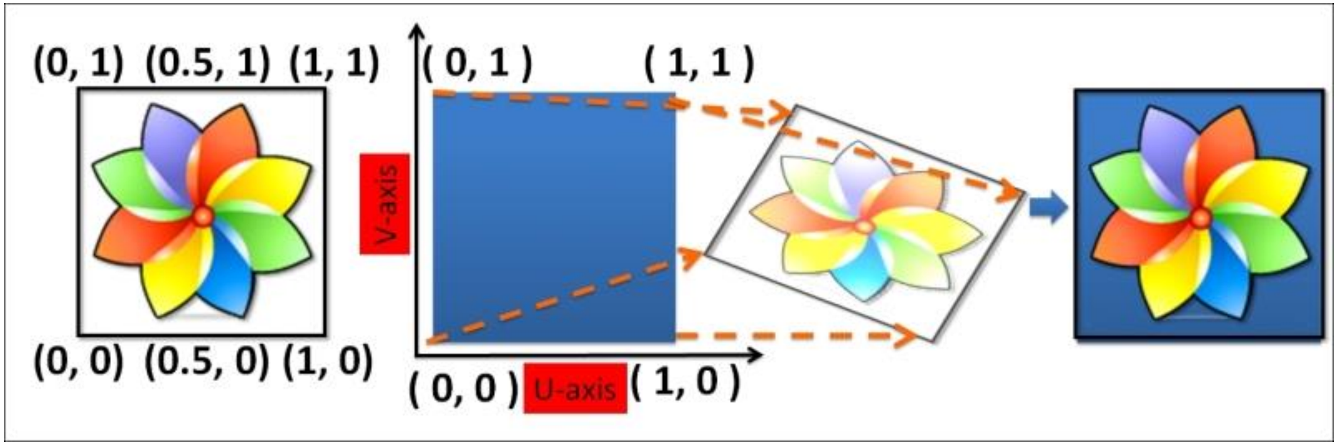


Texture mapping

Normalized Texture Coordinates



0	1	2	3	4	5	6	7	8	9
1	2	3	4	5	6	7	8	9	0
2	3	4	5	6	7	8	9	0	1
3	4	5	6	7	8	9	0	1	2
4	5	6	7	8	9	0	1	2	3
5	6	7	8	9	0	1	2	3	4
6	7	8	9	0	1	2	3	4	5
7	8	9	0	1	2	3	4	5	6
8	9	0	1	2	3	4	5	6	7
9	0	1	2	3	4	5	6	7	8



Texture mapping

2D texture space

↓ *parameterization*

3D object space

↓ *model transform*

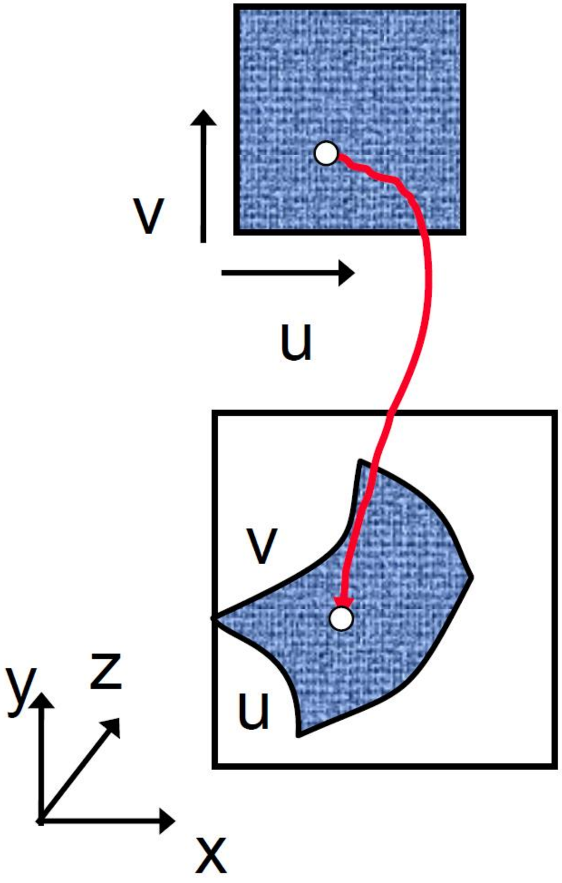
3D world space

↓ *viewing transform*

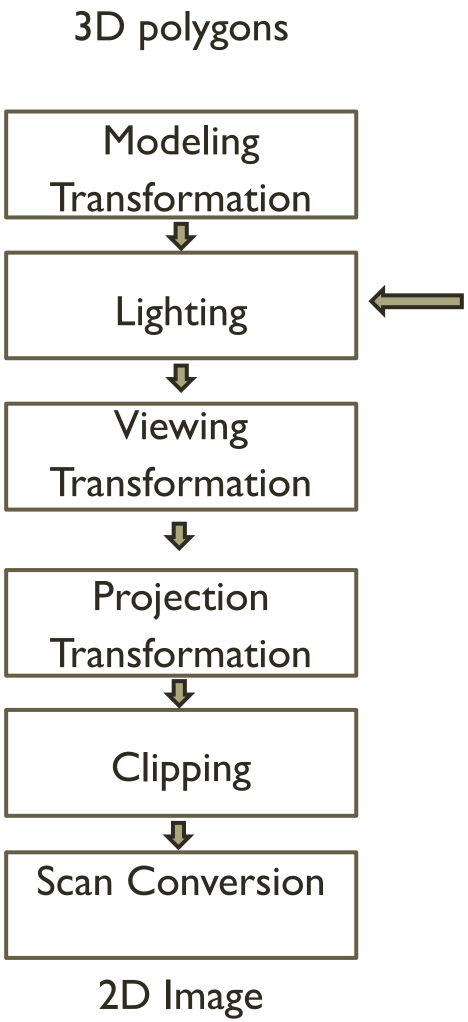
3D camera space

↓ *projection*

2D image space (screen)

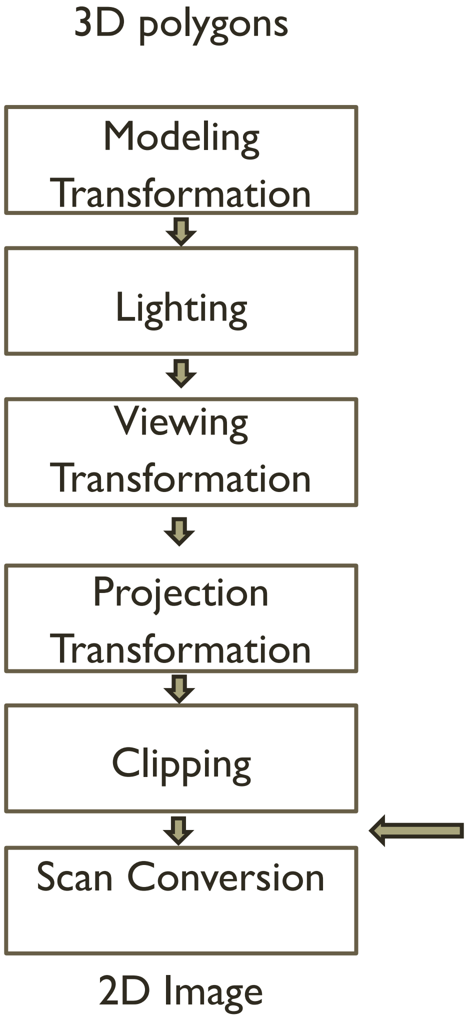


3D rendering pipeline



- Lighting + color from image
  - Could be implemented here

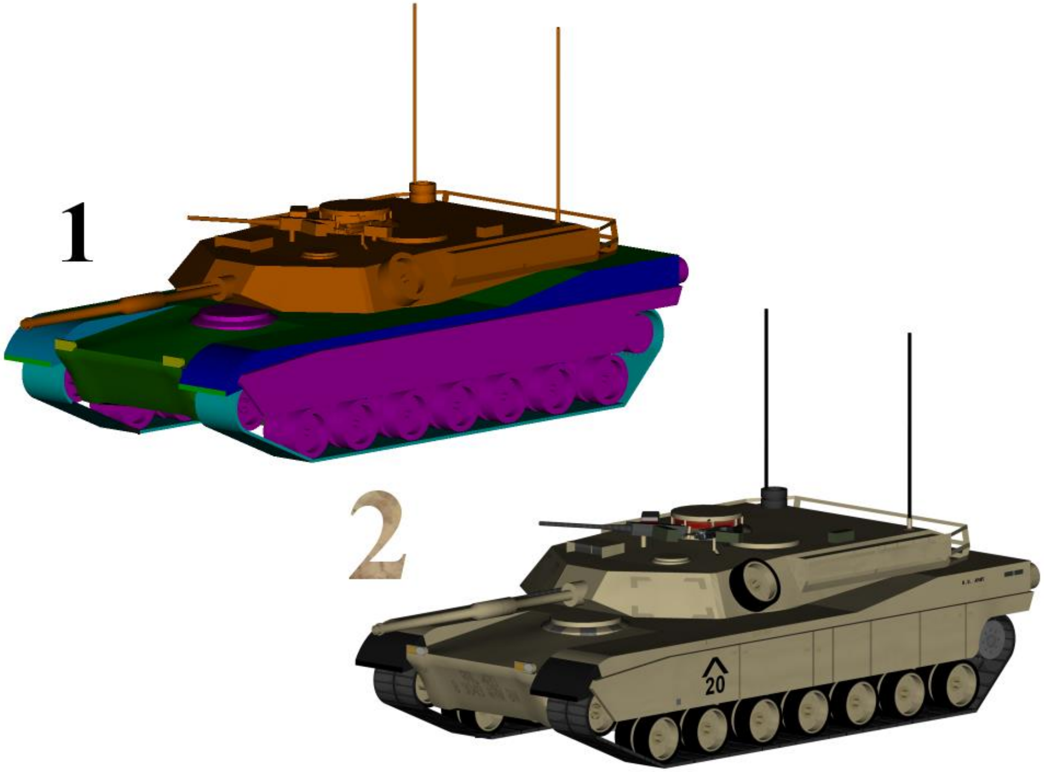
3D rendering pipeline



- GPU Texture mapping
  - Fragment shader implementation

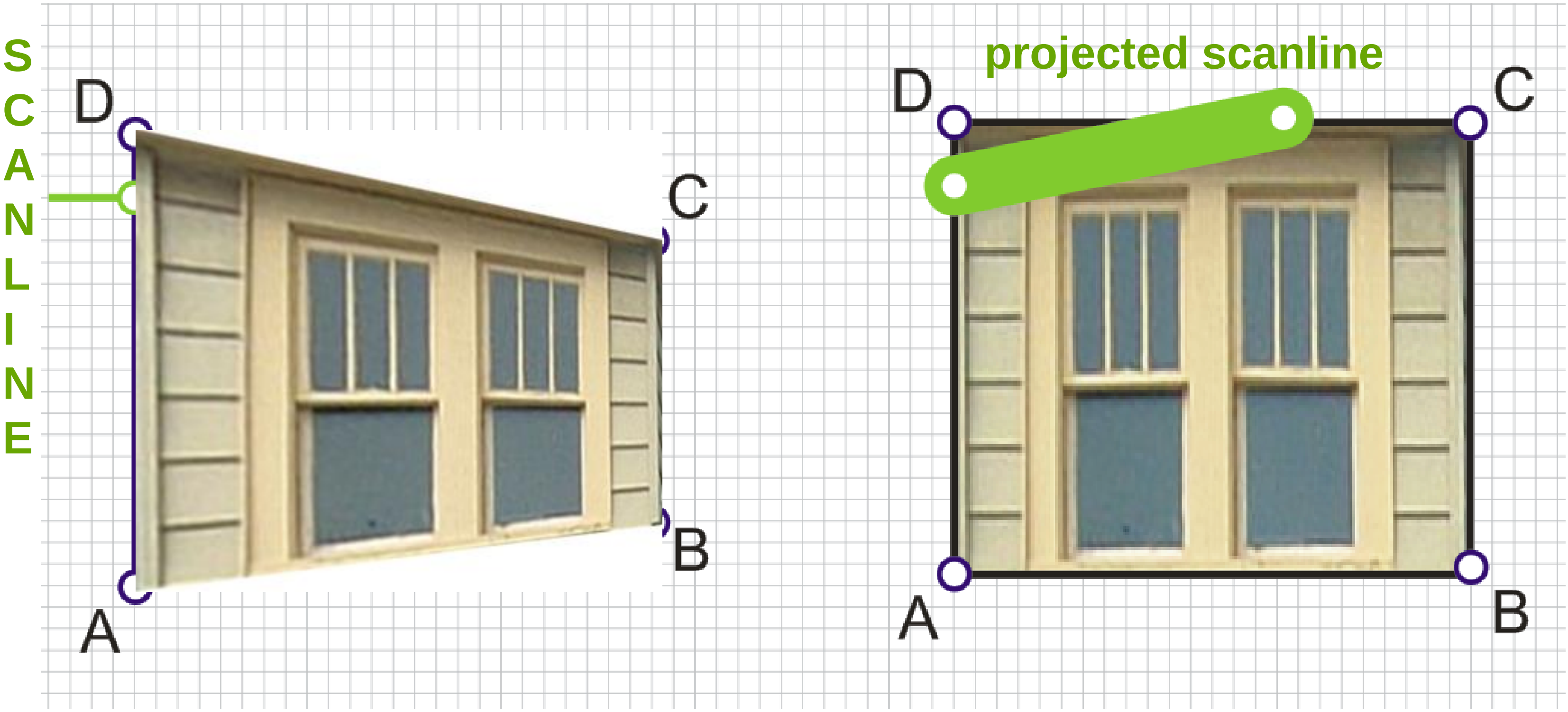
Texture mapping

- Add visual detail to surfaces of 3D objects
  - 1) Parameterized mesh
  - 2) Final textured model



Intermediate pixels

- Remember polygon rasterization



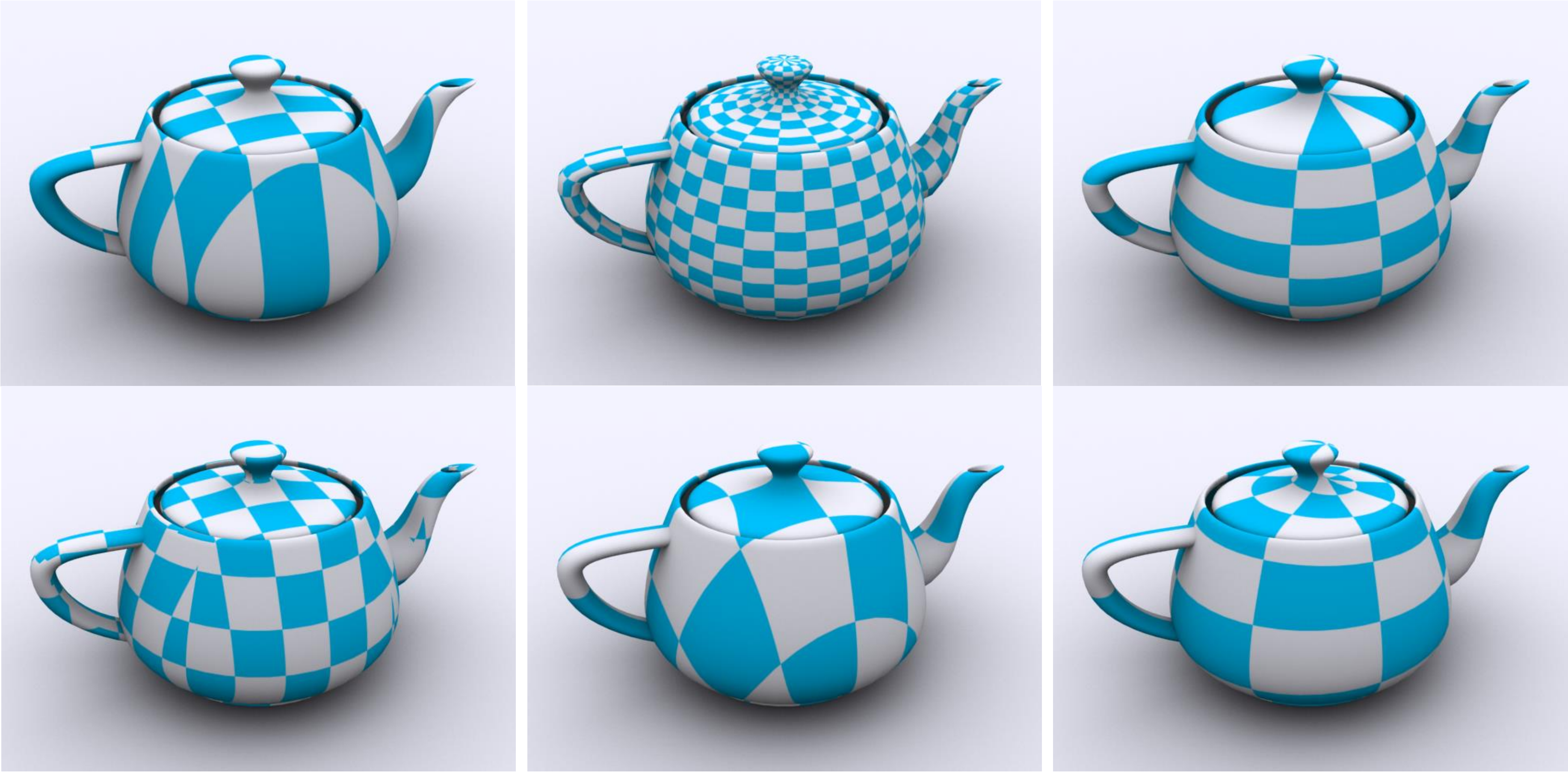
Screen space

Texture space

Texture usage

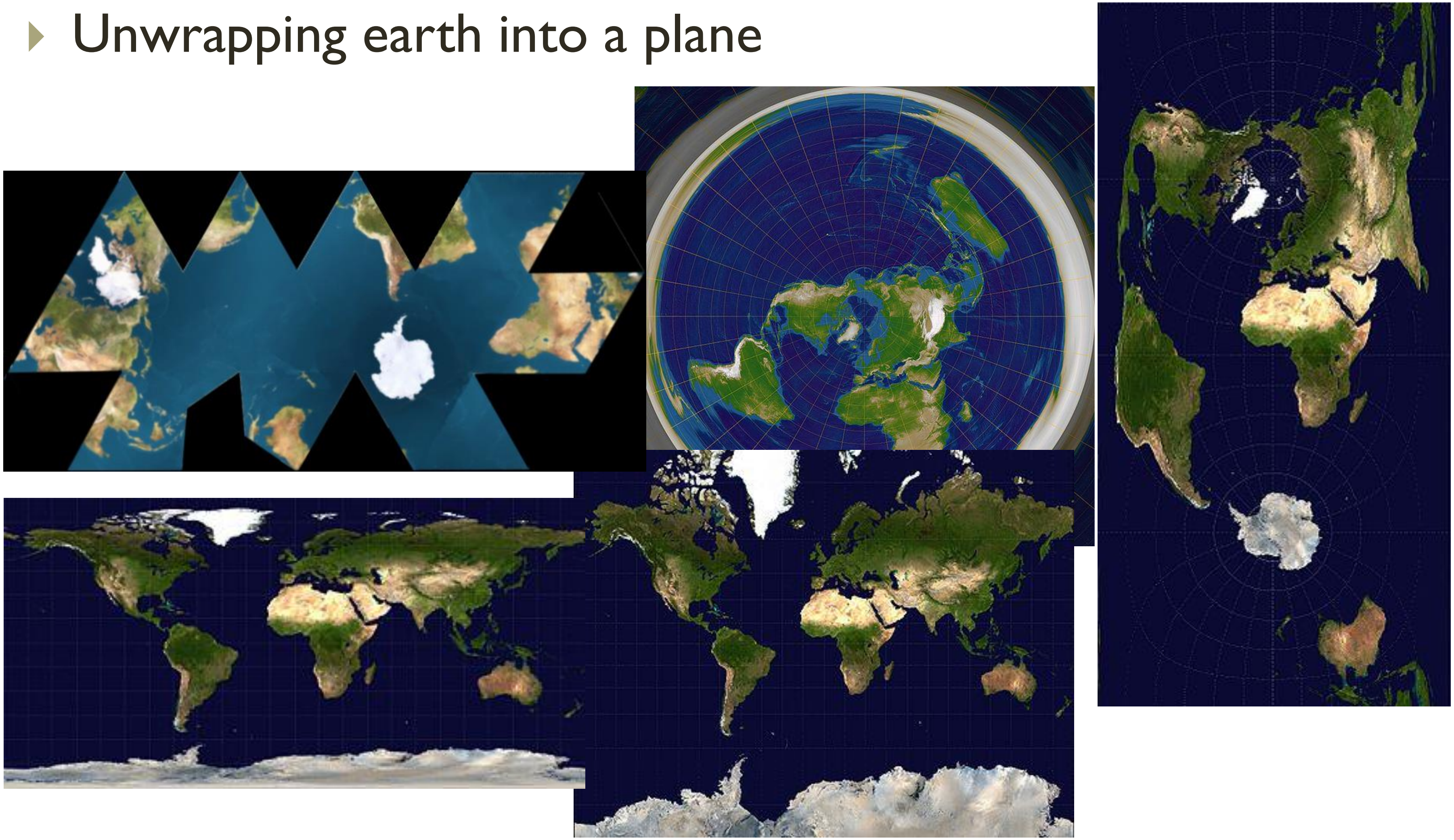
- object diffuse color
  - patterns, decals
- modulate surface properties
  - bumps, displacements
- modulate lighting properties
  - e.g. shininess
- simulate physical phenomena
  - reflection, refraction, global illumination

Texture mapping

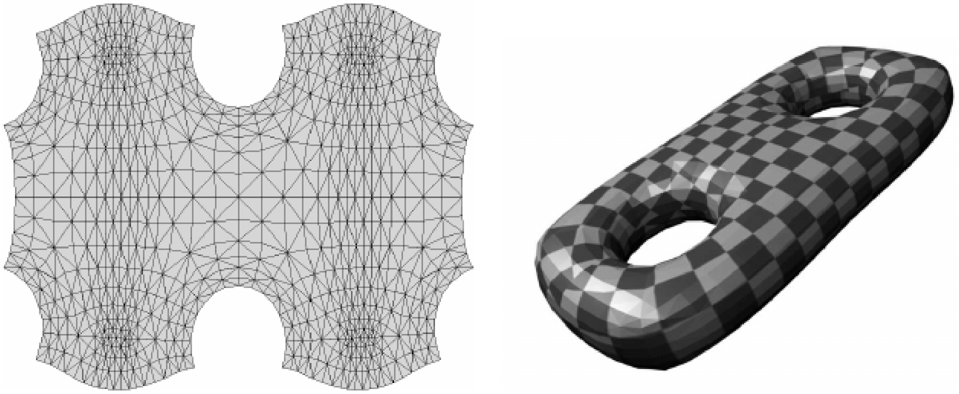


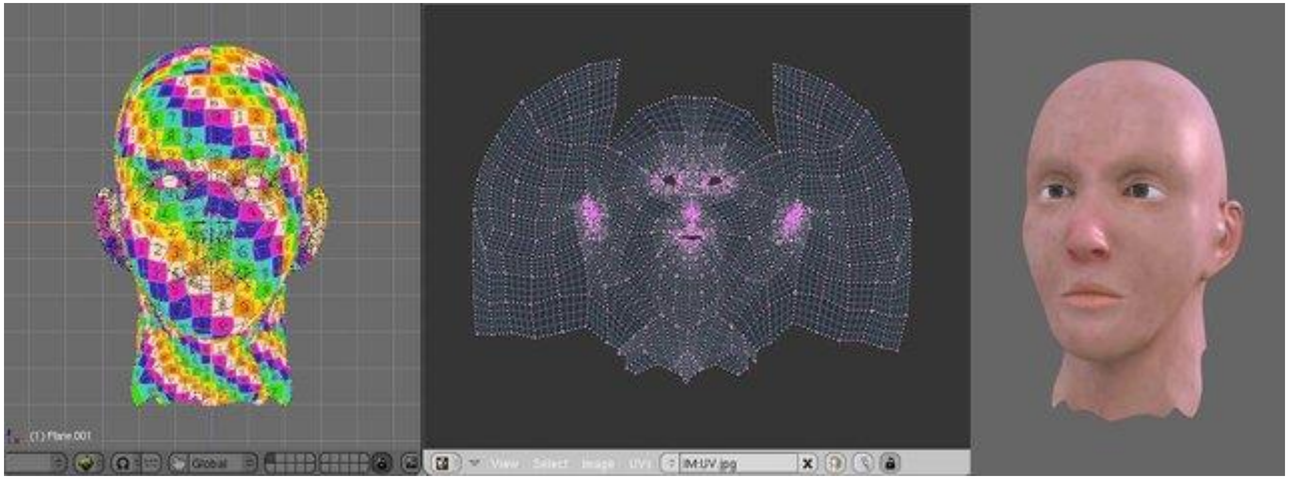
Example – cartography

- Unwrapping earth into a plane



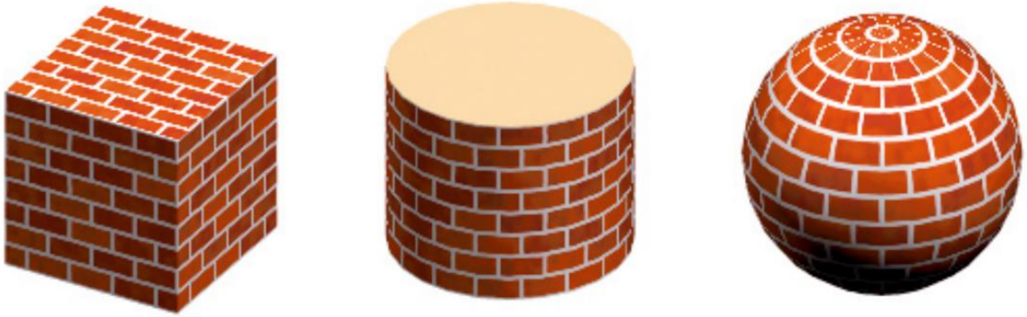
Parameterization





Parameterization

- Implicit parametrization by geometrical primitives

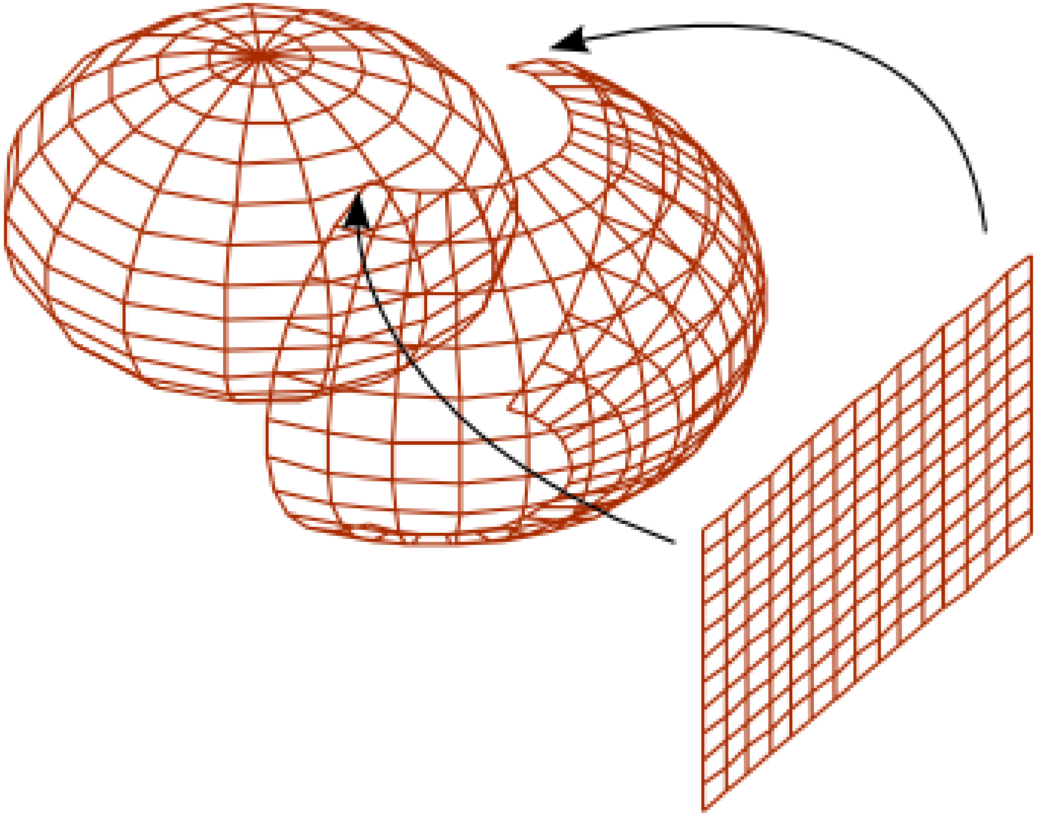


Parameterization

- XYZ to UV for sphere:

$$u = \frac{x}{\sqrt{x^2 + y^2 + z^2}}$$

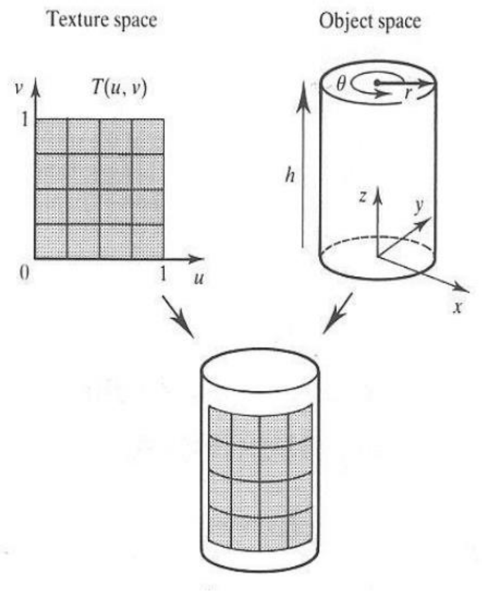
$$v = \frac{y}{\sqrt{x^2 + y^2 + z^2}}$$



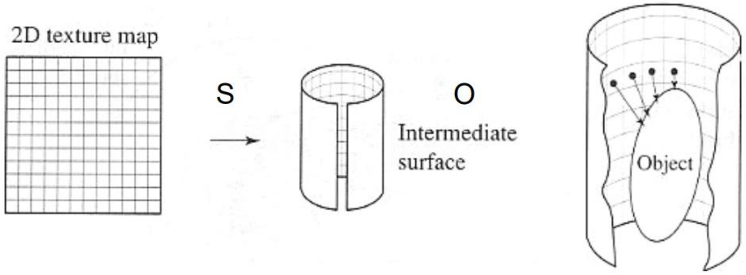
http://tobias.preclik.de/codeblog/?p=9

Parameterization

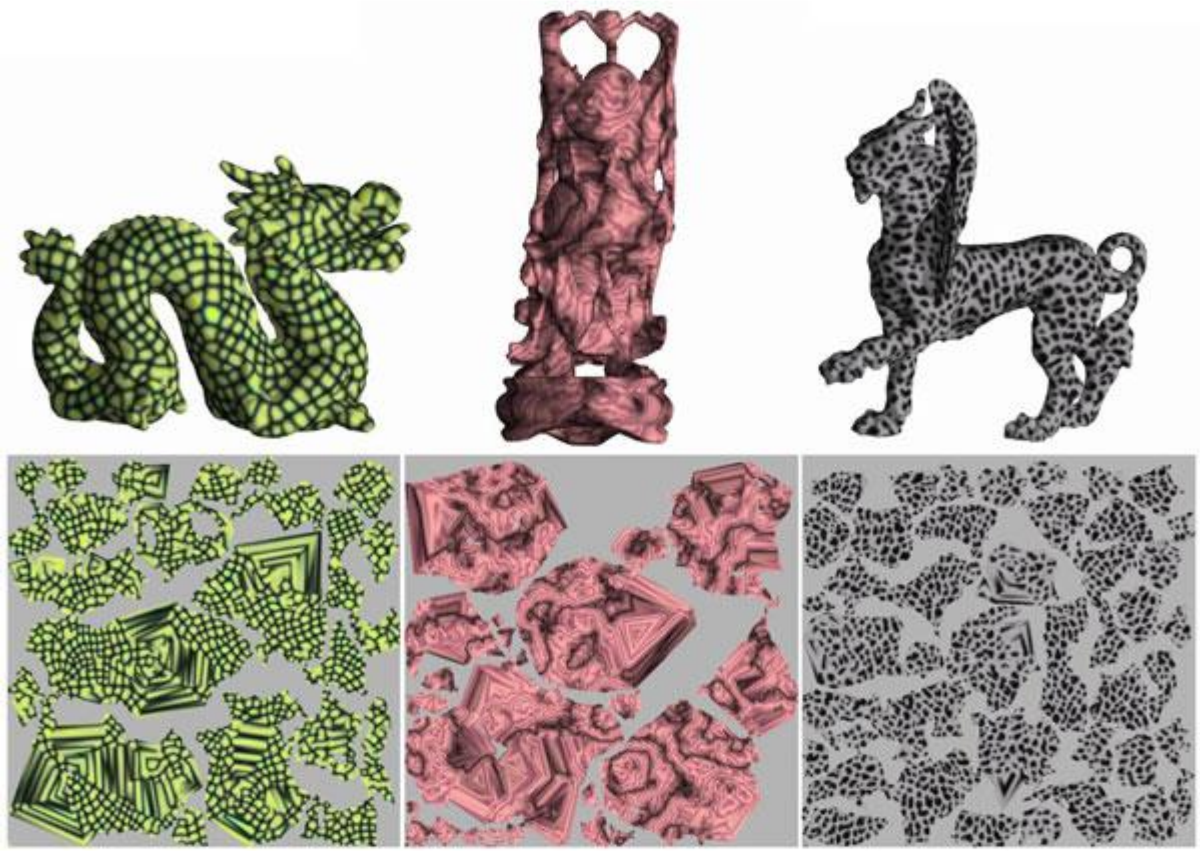
- Parameterization using an intermediate surface



$$x_o = r\cos\theta$$
$$y_o = r\sin\theta$$
$$z_o = h$$

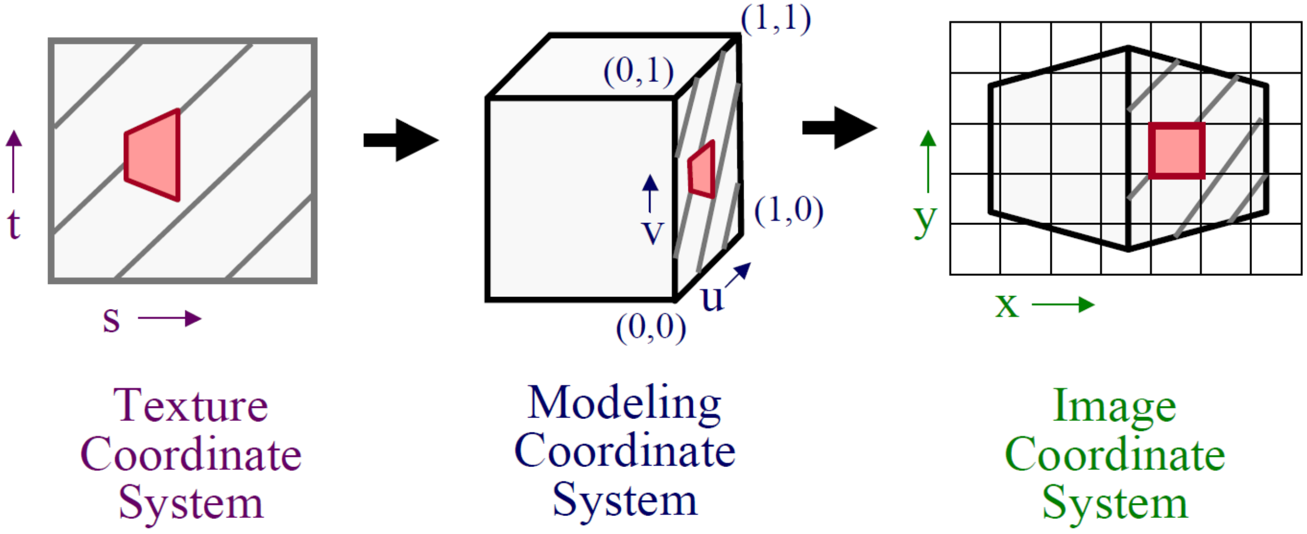


Parameterization



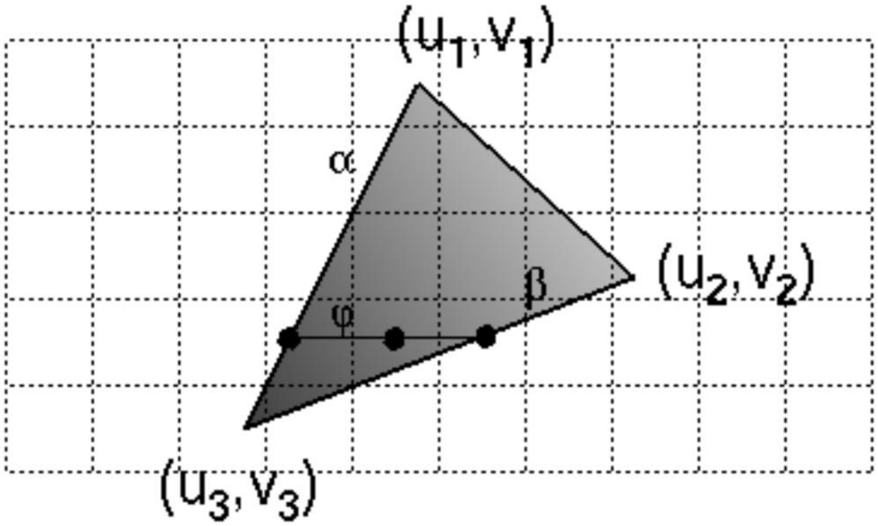
Texture mapping

- When drawing pixels, map from ...
  - image coordinate system (x,y) to
  - modeling coordinate system (u,v) to
  - texture coordinate system (t,s)



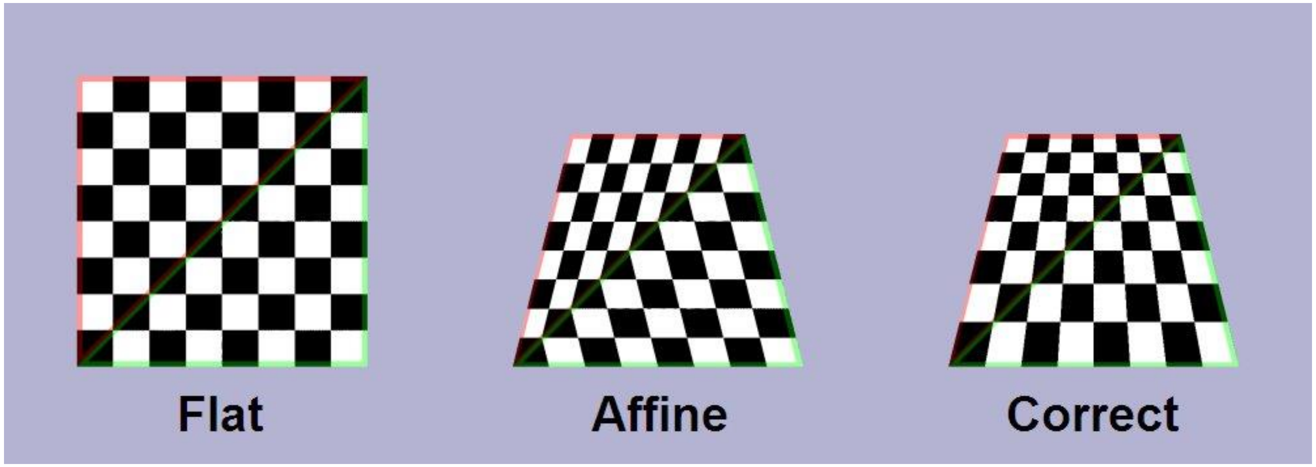
UV mapping

- Scan conversion
  - Interpolate texture coordinates down/across scan lines
  - Distort due to bilinear interpolation approximation
  - Cut polygons into smaller ones, or
  - Perspective divide at each pixel



Perspective correction

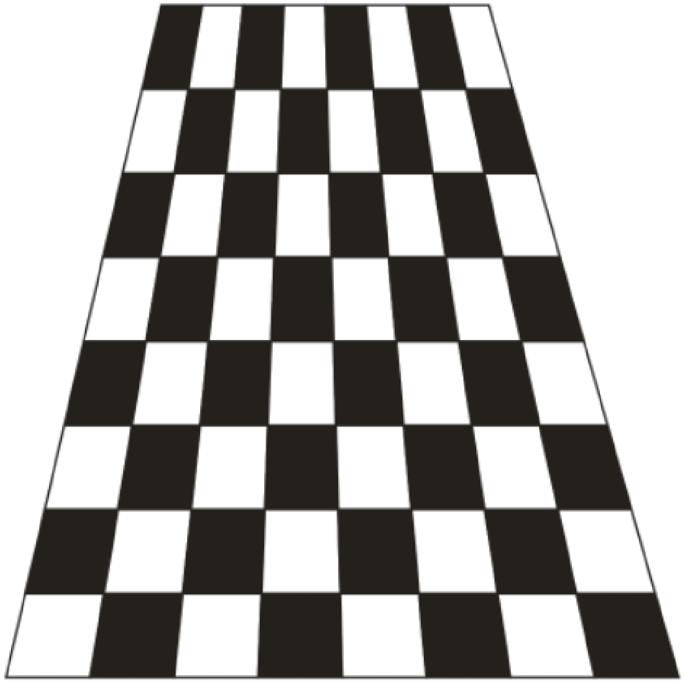
- Scan conversion
  - Interpolate texture coordinates down/across scan lines
  - Distort due to bilinear interpolation approximation
  - Cut polygons into smaller ones, or
  - Perspective divide at each pixel



Perspective correction

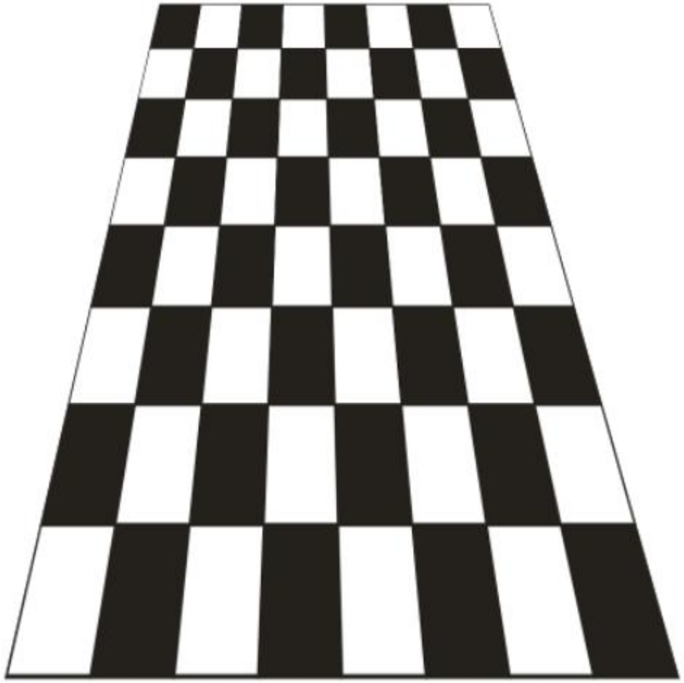
INCORRECT

$$T = (1-t)P + tQ$$



CORRECT

$$T = (1-t)\frac{P}{P_z} + t\frac{Q}{Q_z}$$

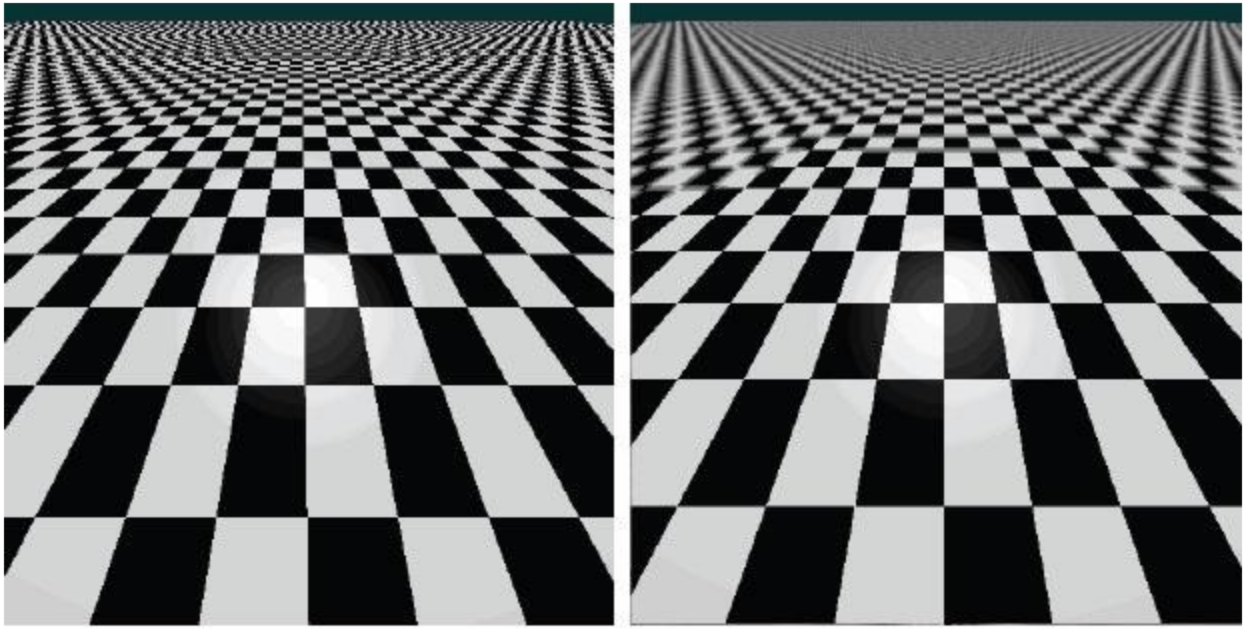


Overview

- Texture mapping
  - 3D Models with texture coordinates
  - UV map parametrization
  - Diffuse color textures
  - Other textures
    - Bump mapping
    - Environment mapping
- Aliasing
- Anti-aliasing
  - Supersampling
  - Mip Maps

Aliasing

- "Moire pattern"
- Nyquist frequency
  - Sampling frequency >= 2x signal frequency

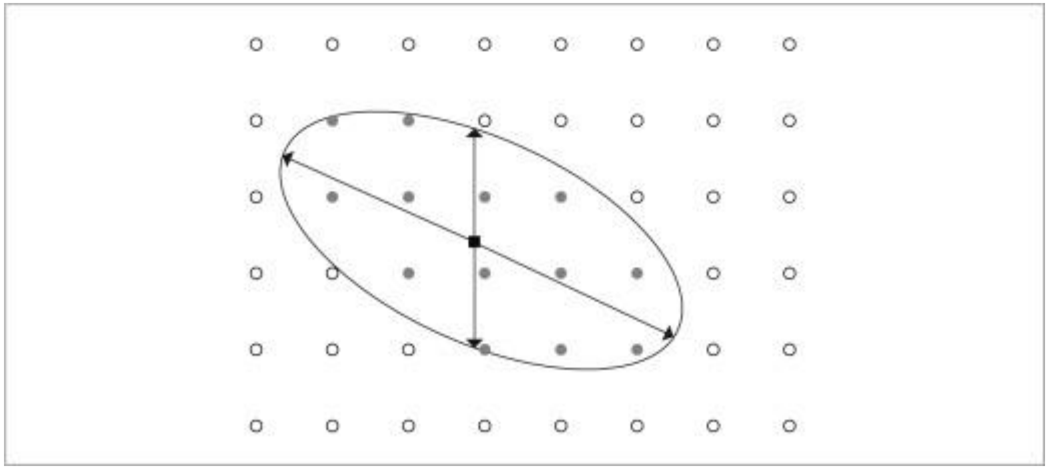


aliasing effects

anti-aliasing by over-sampling

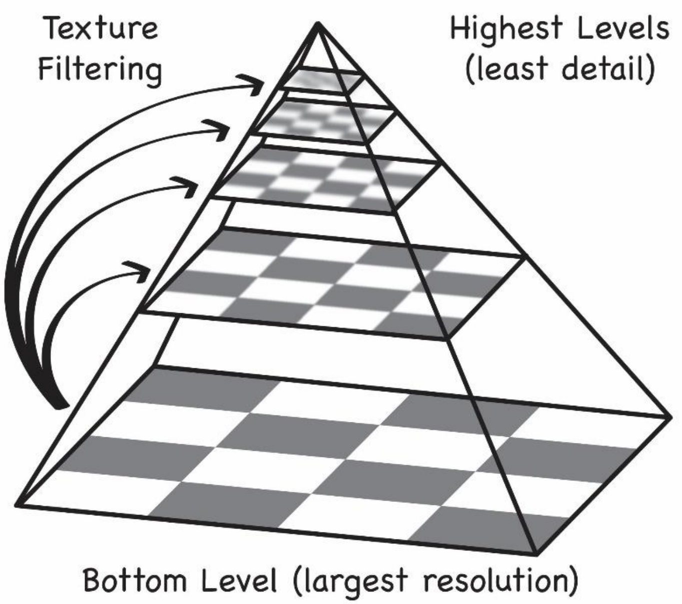
Texture filtering

- Ideally, use elliptically shaped convolution filter
- In practice we use rectangles



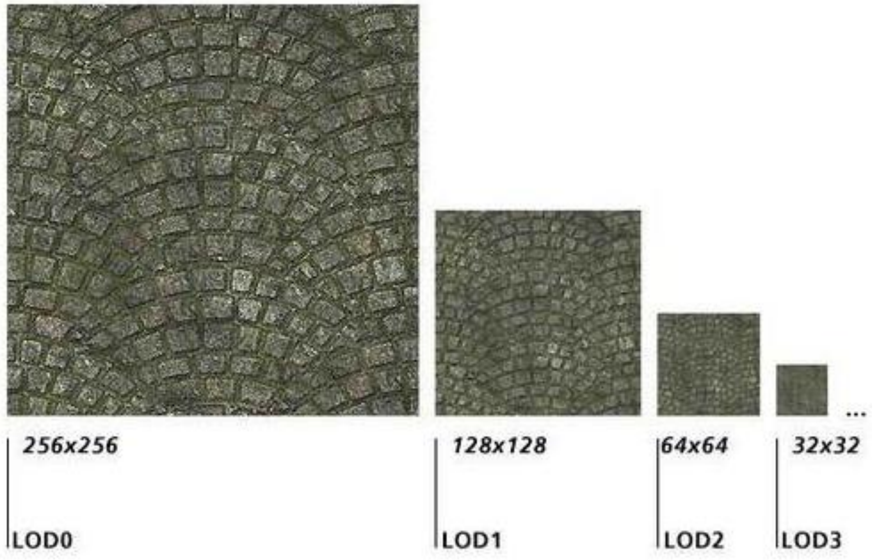
Texture filtering

- Size of filter depends on projective wrap
- Images can be pre-filtered
  - Mip Maps
  - Summed area tables

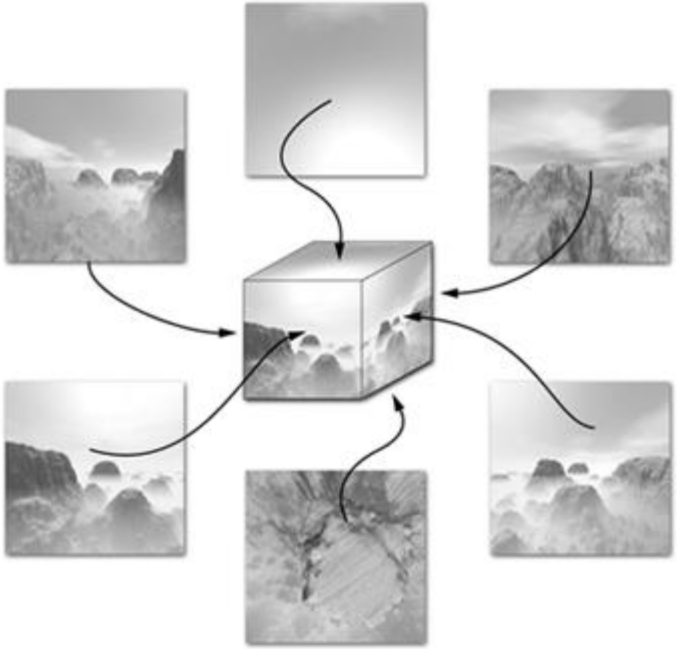

Texture Filtering
Highest Levels (least detail)
Bottom Level (largest resolution)

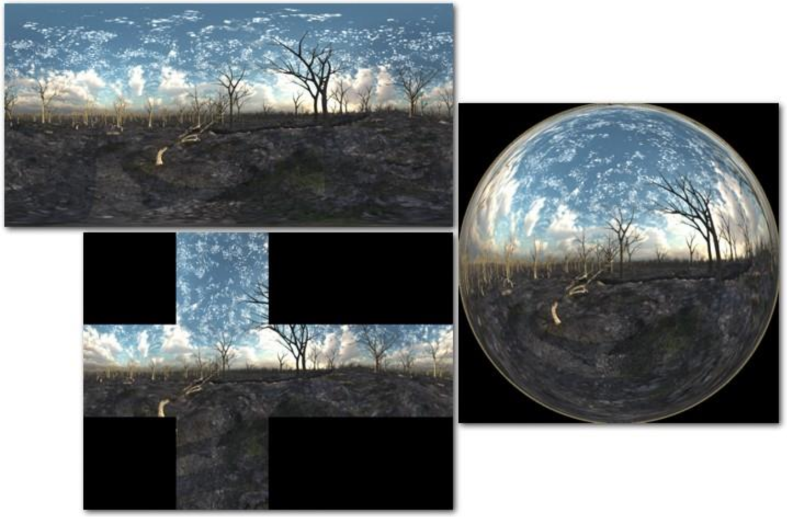
Mip maps

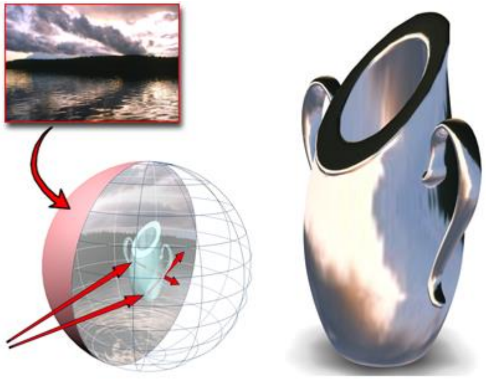
- Keep textures pre-filtered at multiple resolutions
  - For each pixel, linearly interpolate between two closest levels (e.g., trilinear filtering)
- Fast and easy for hardware



Environment mapping





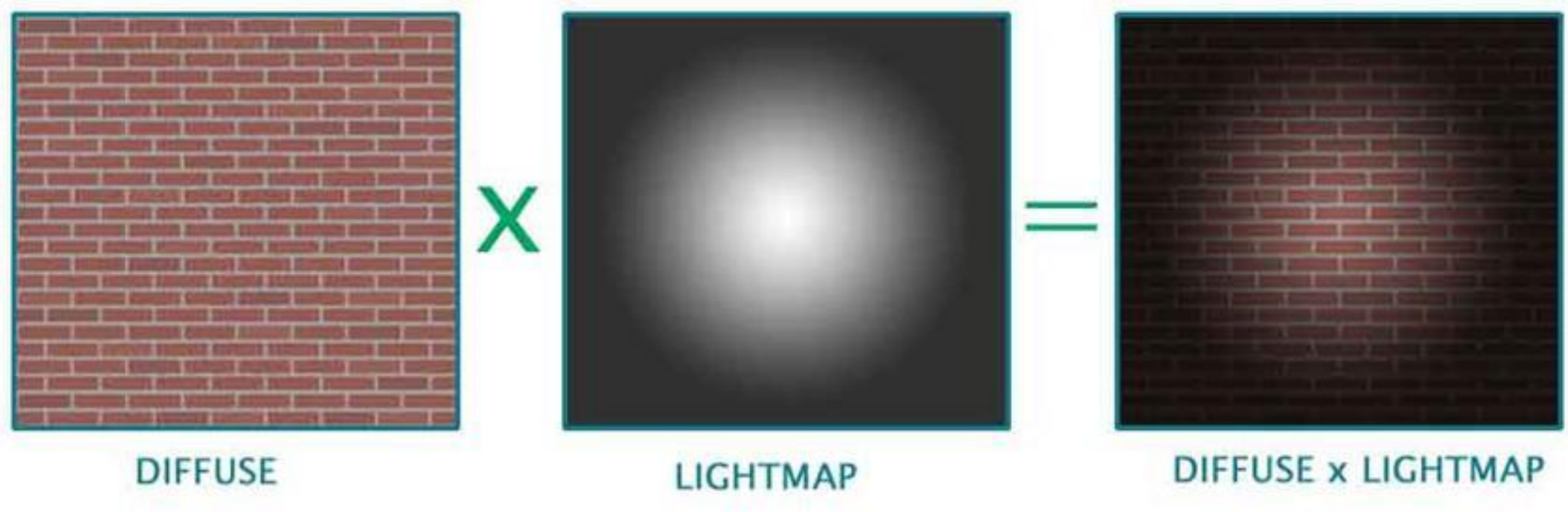


https://www.youtube.com/watch?v=LOeEfkzZ1ps

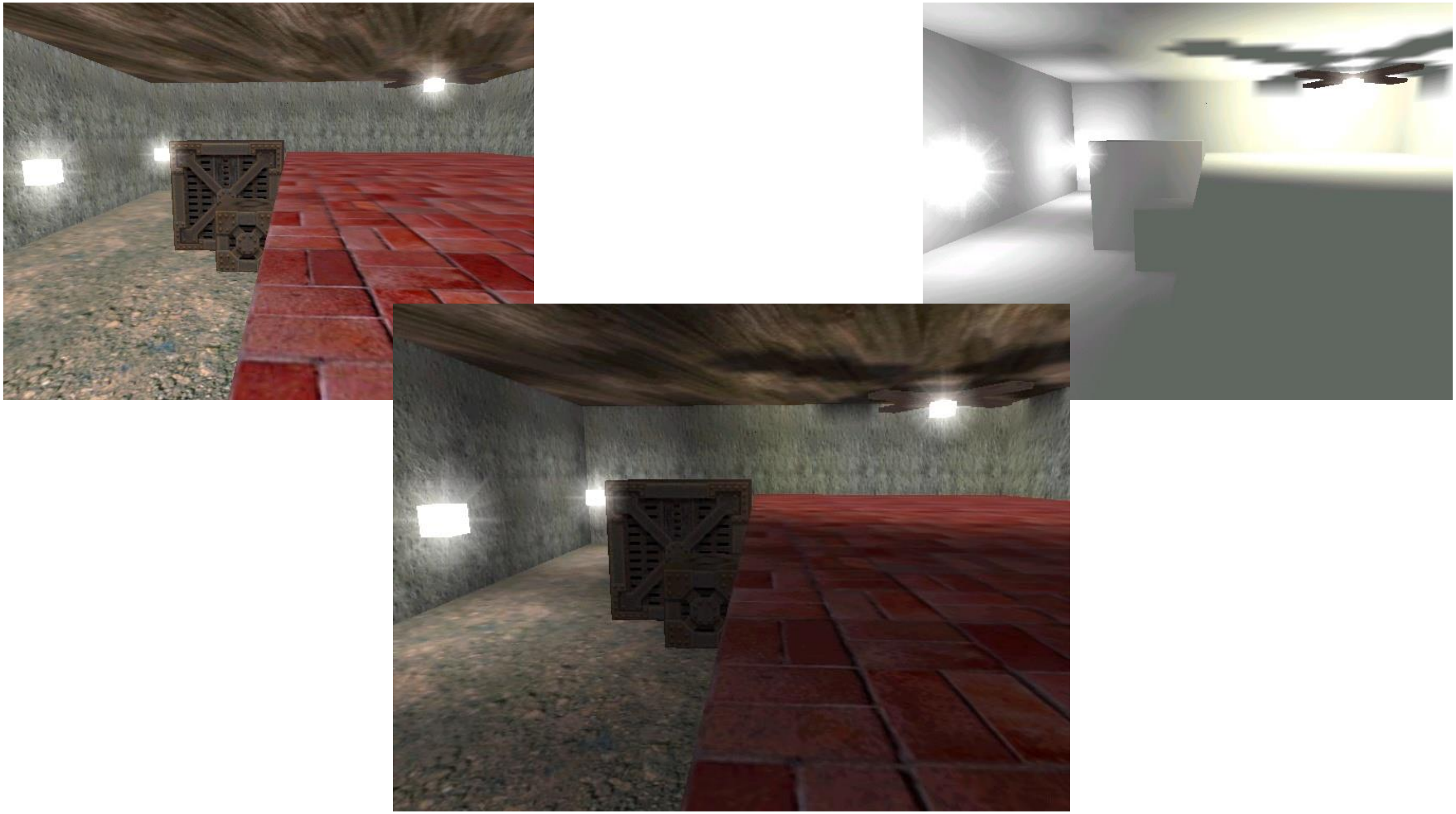
Light maps

Light maps

- Pre-computed high-quality lighting
- Stored into special texture (light map)
- Light map combined with the texture
- Texture baking (permanent)



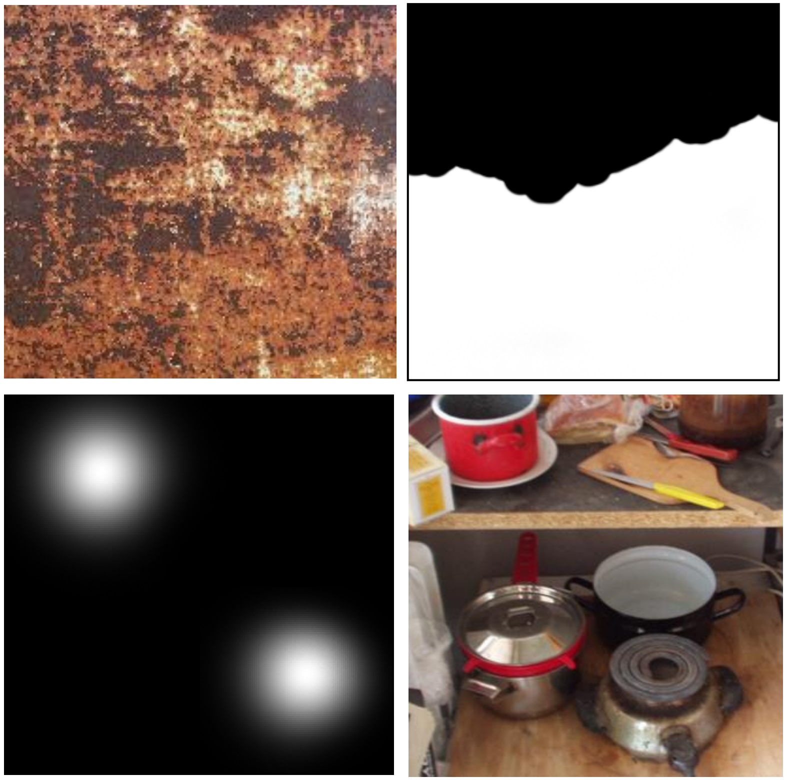
Light maps

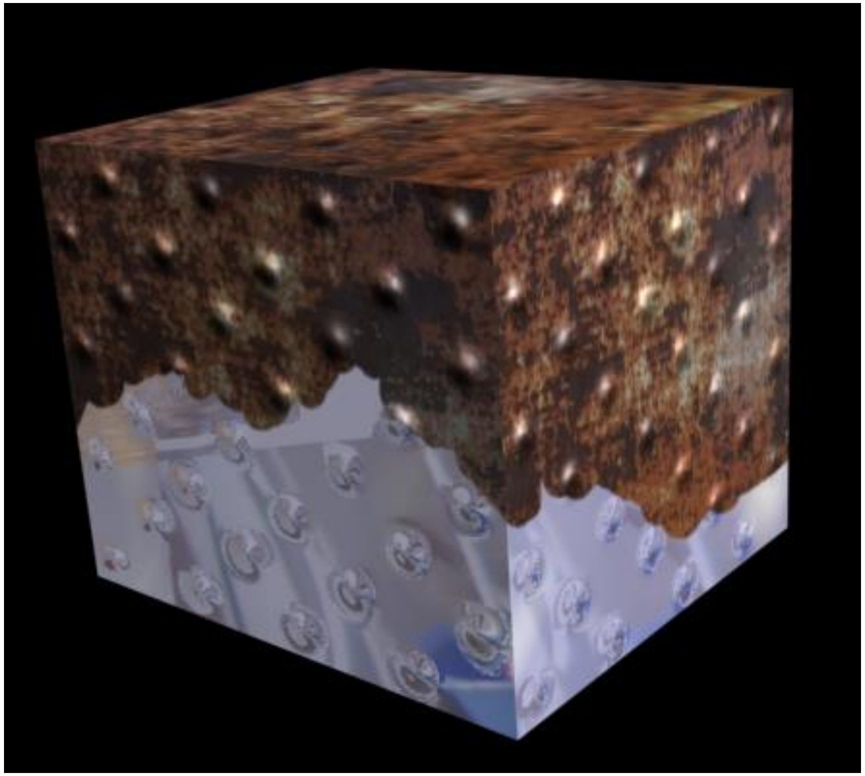


http://www.cs.bath.ac.uk/~pjw/NOTES/pics/lightmap.html

Multitexturing

- Combine multiple textures



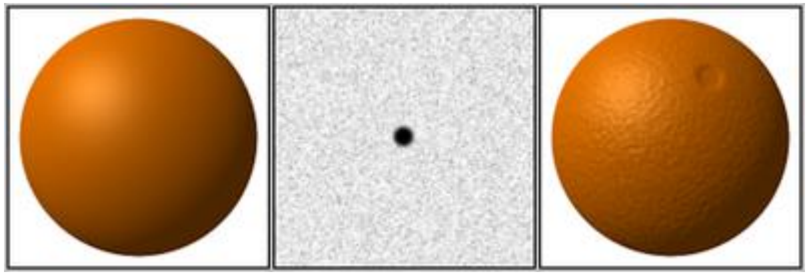


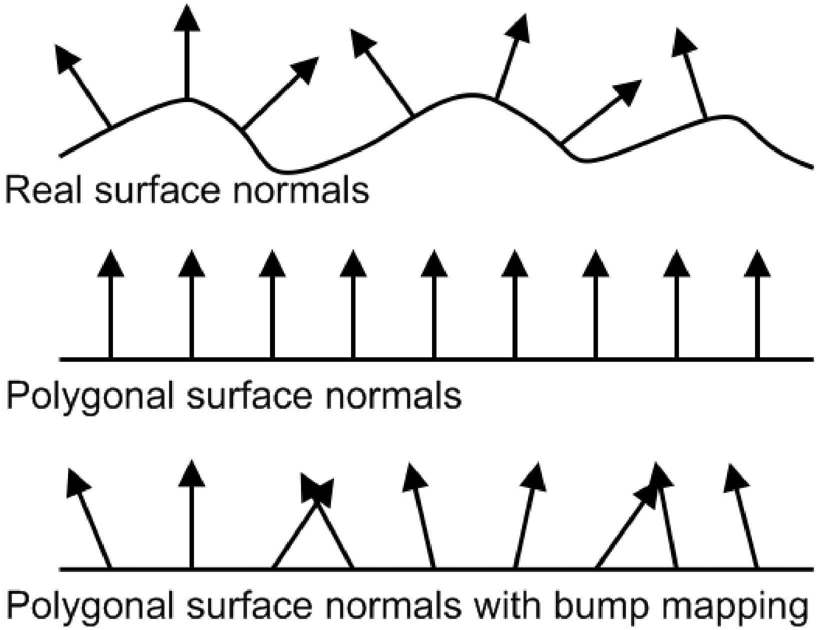
Overview

- Advanced Shading and Mapping
  - Bump Mapping
  - Normal Mapping
  - Displacement Mapping
  - Vector Displacement Mapping

Bump mapping

- A modified surface normal is calculated from the height map
- Modified normal is used during shading
- Geometry is not altered

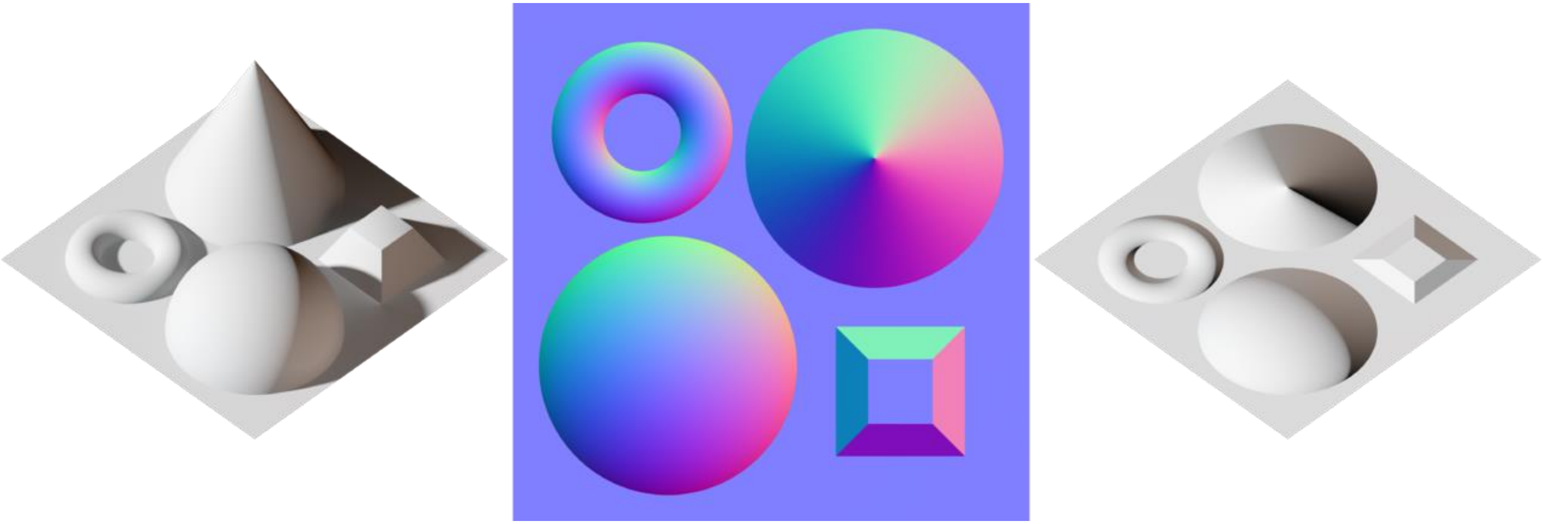



Real surface normals
Polygonal surface normals
Polygonal surface normals with bump mapping

Normal Mapping

- Fake lighting of bumps and dents
- “Dot3 bump mapping”
- Add lighting details without additional geometry
- Store normals from high-polygon object in texture
- Encode X,Y,Z as R,G,B color information

Normal Mapping



Normal Mapping

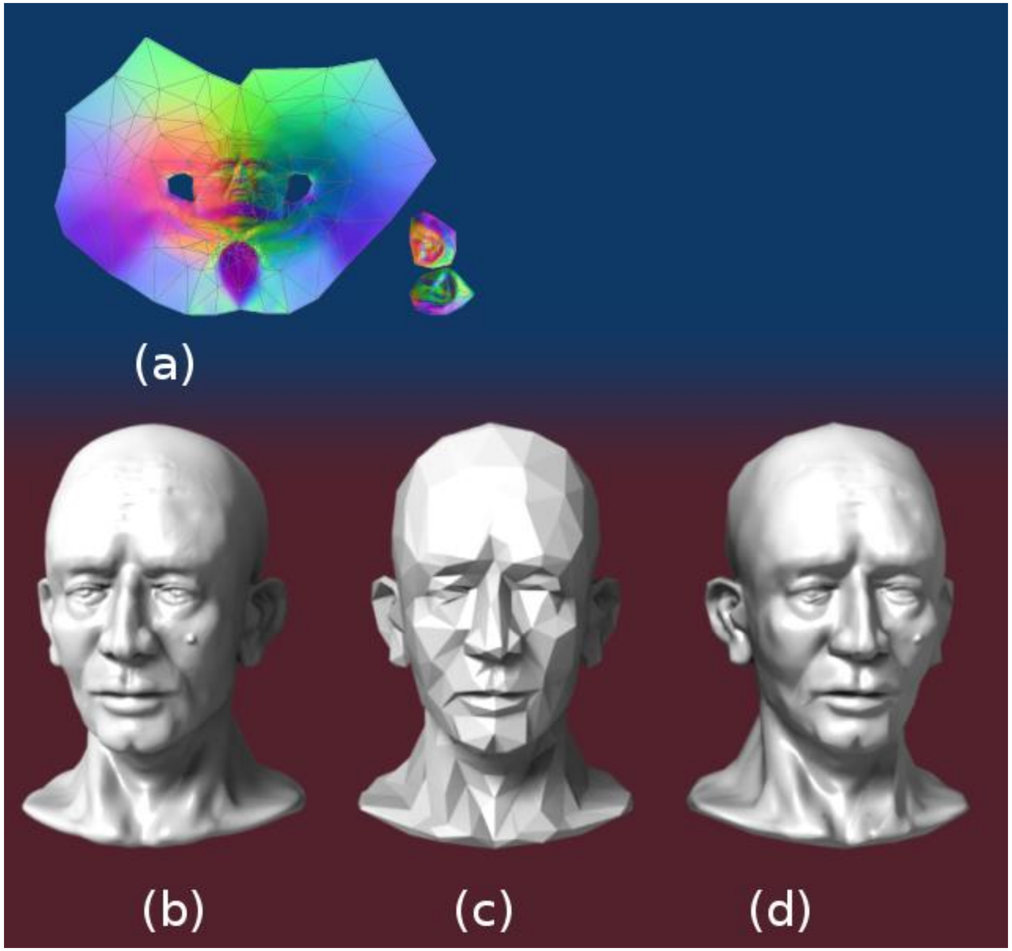
a) Normal map

(encoded in object space)

b) Original high-res model

c) Rendered low-res model

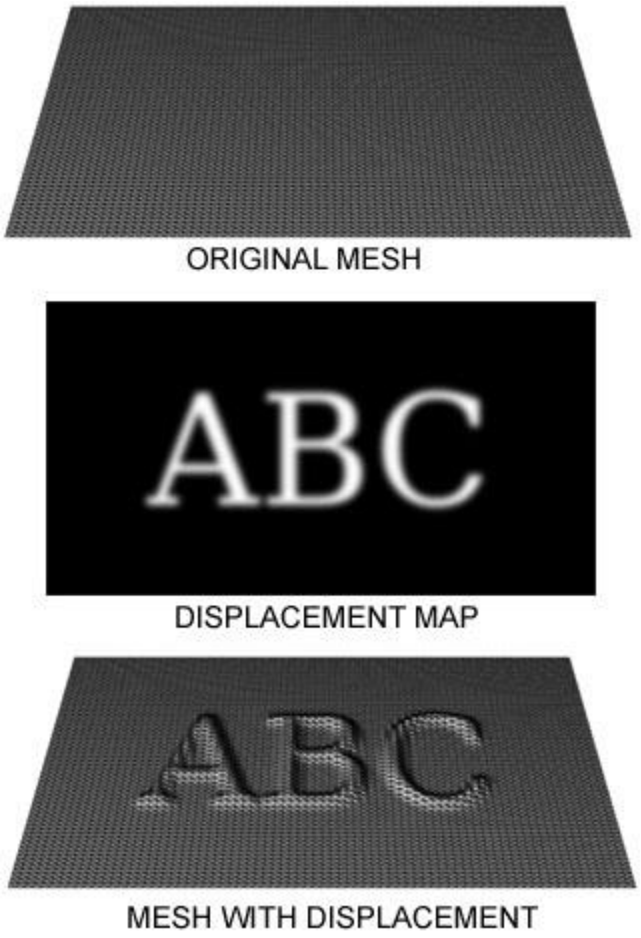
d) Applied normal map



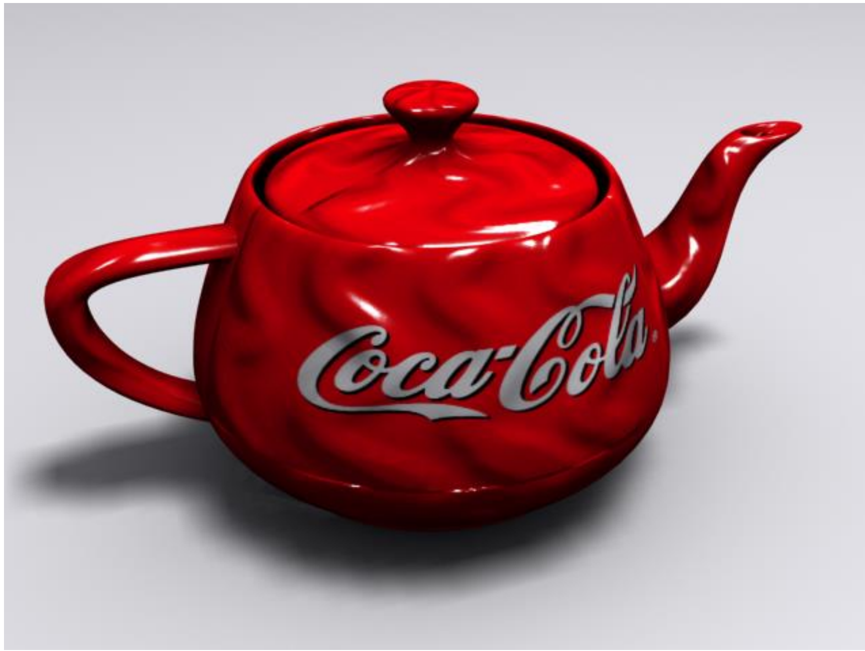
Displacement Mapping

- Move geometry as specified in texture
- Displacement in direction of surface normal
- Can add additional detail to a subdivided model
- Relies on dense geometry
- Usually used with adaptive tessellation techniques

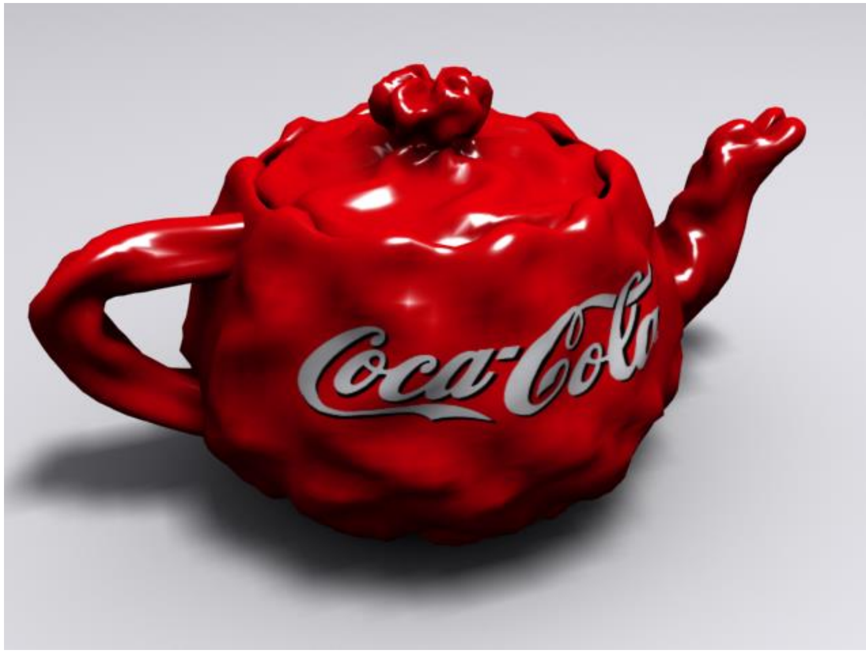
Displacement Mapping



Displacement Mapping



bump mapping

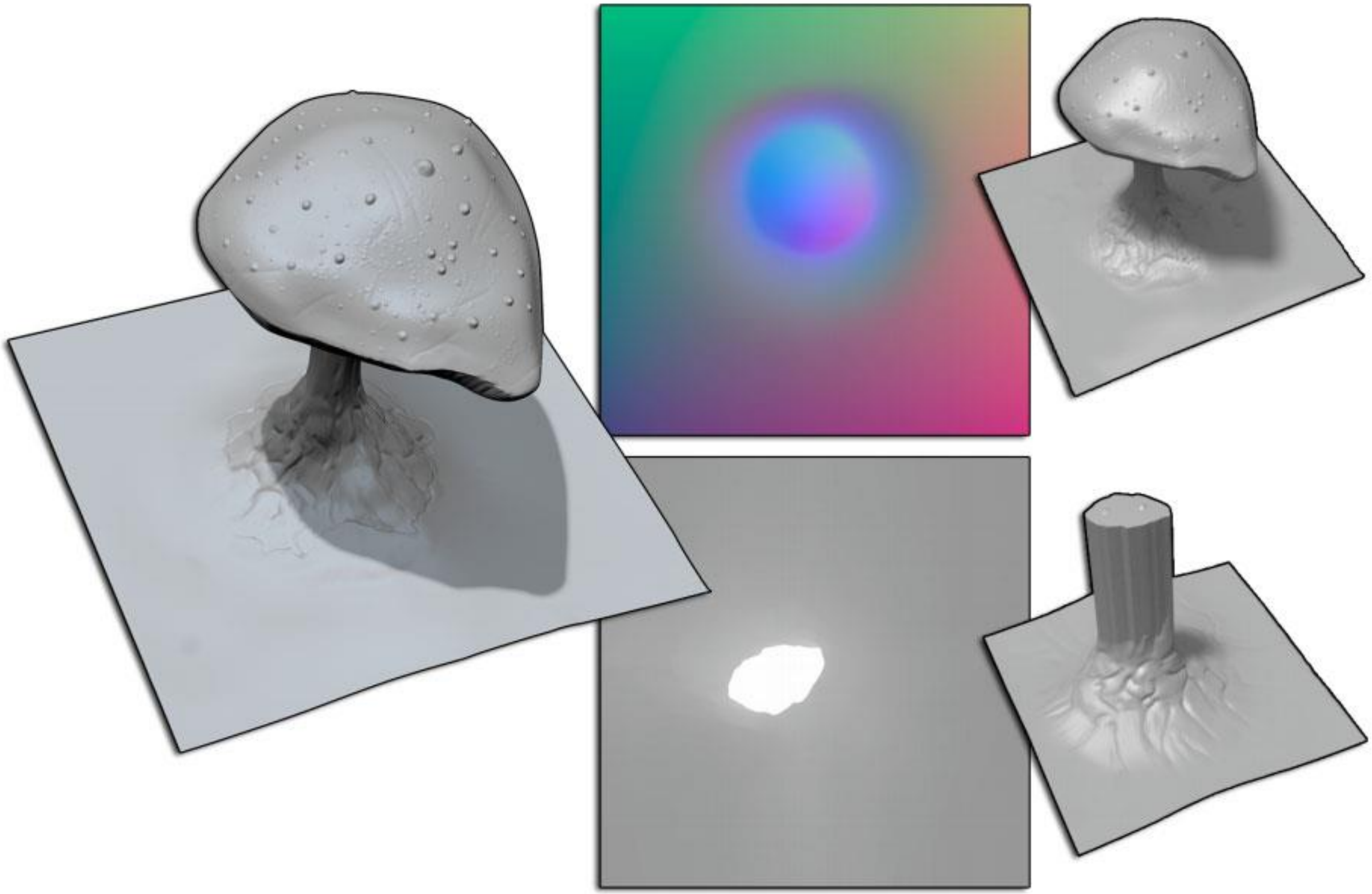


displacement mapping

Vector Displacement Mapping

- Displace geometry in any direction
- Generalization of displacement mapping
- Possible to store detailed geometry in textures
- Excellent for sculpting purposes (Z-Brush)

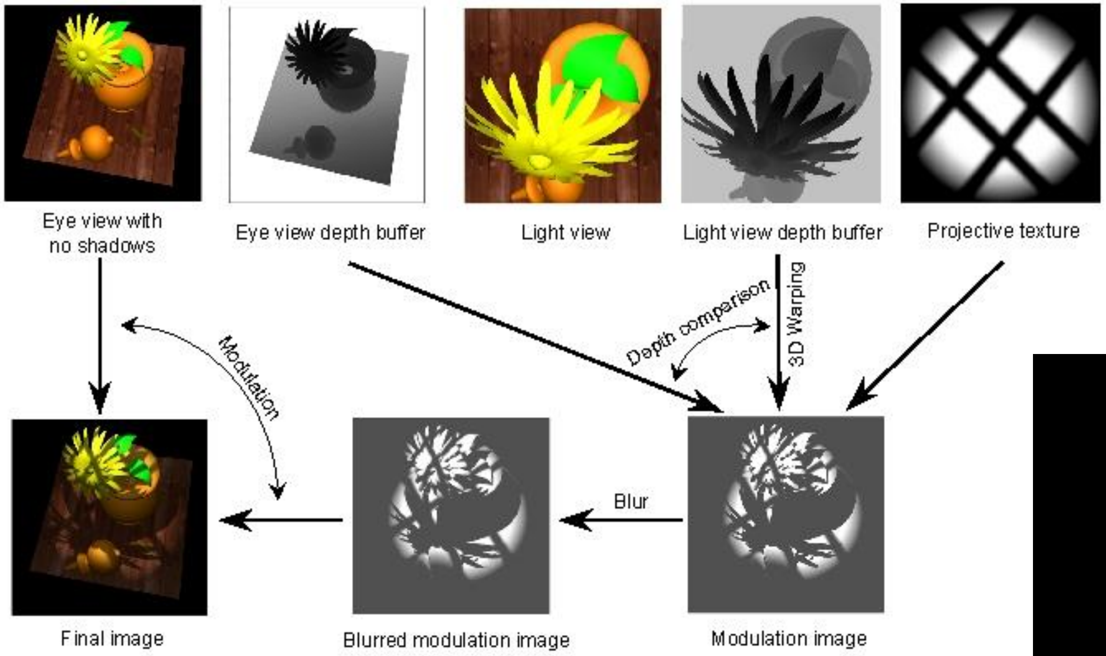
Vector Displacement Mapping



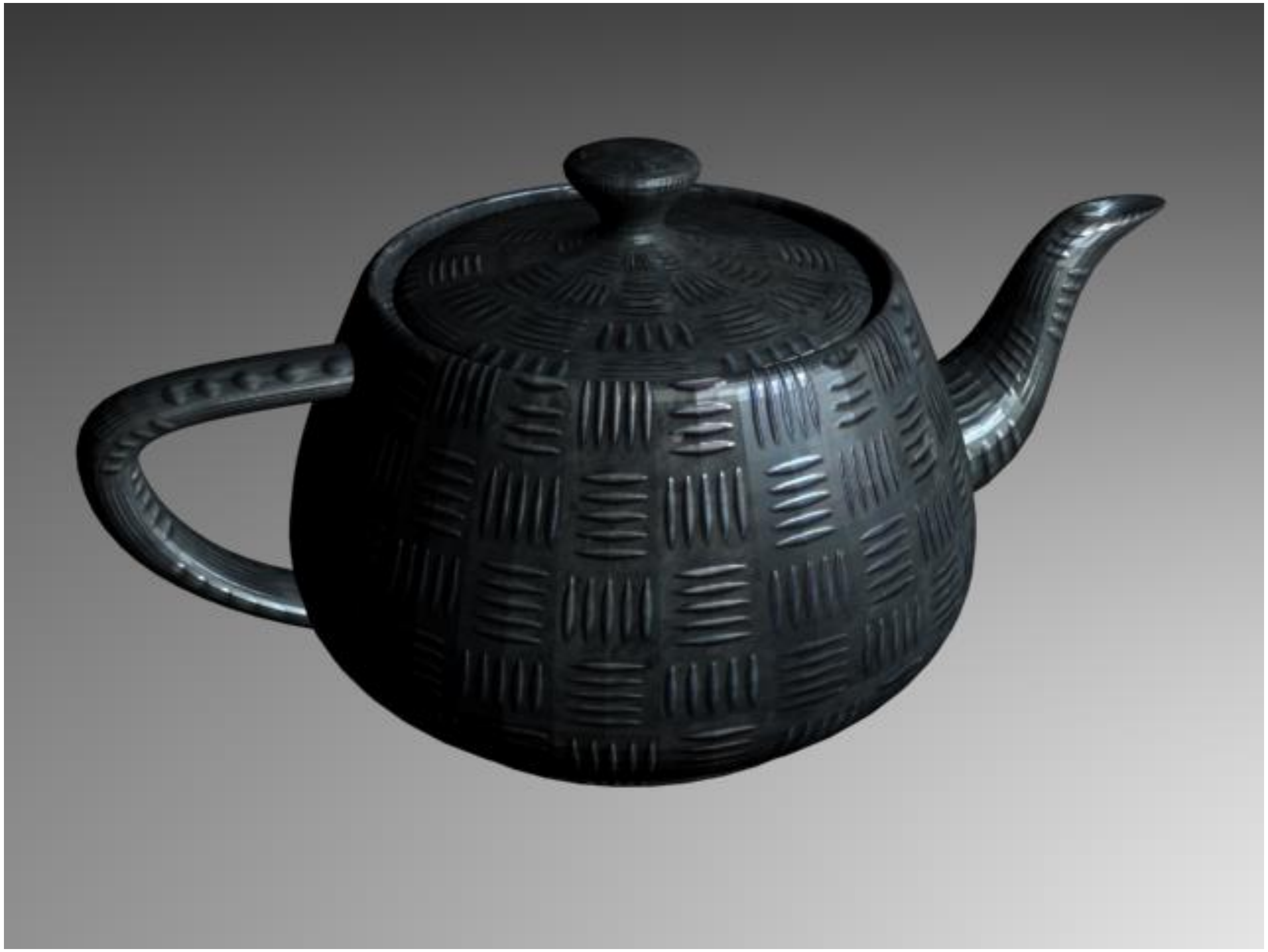
Shadow Mapping

- Two pass technique
- Obtain Light view depth buffer
- Compare each pixel rendered to with light depth
- Pixels further away are in shadow
- Needs margin of error for lit pixels
- Implementation usually has artifacts

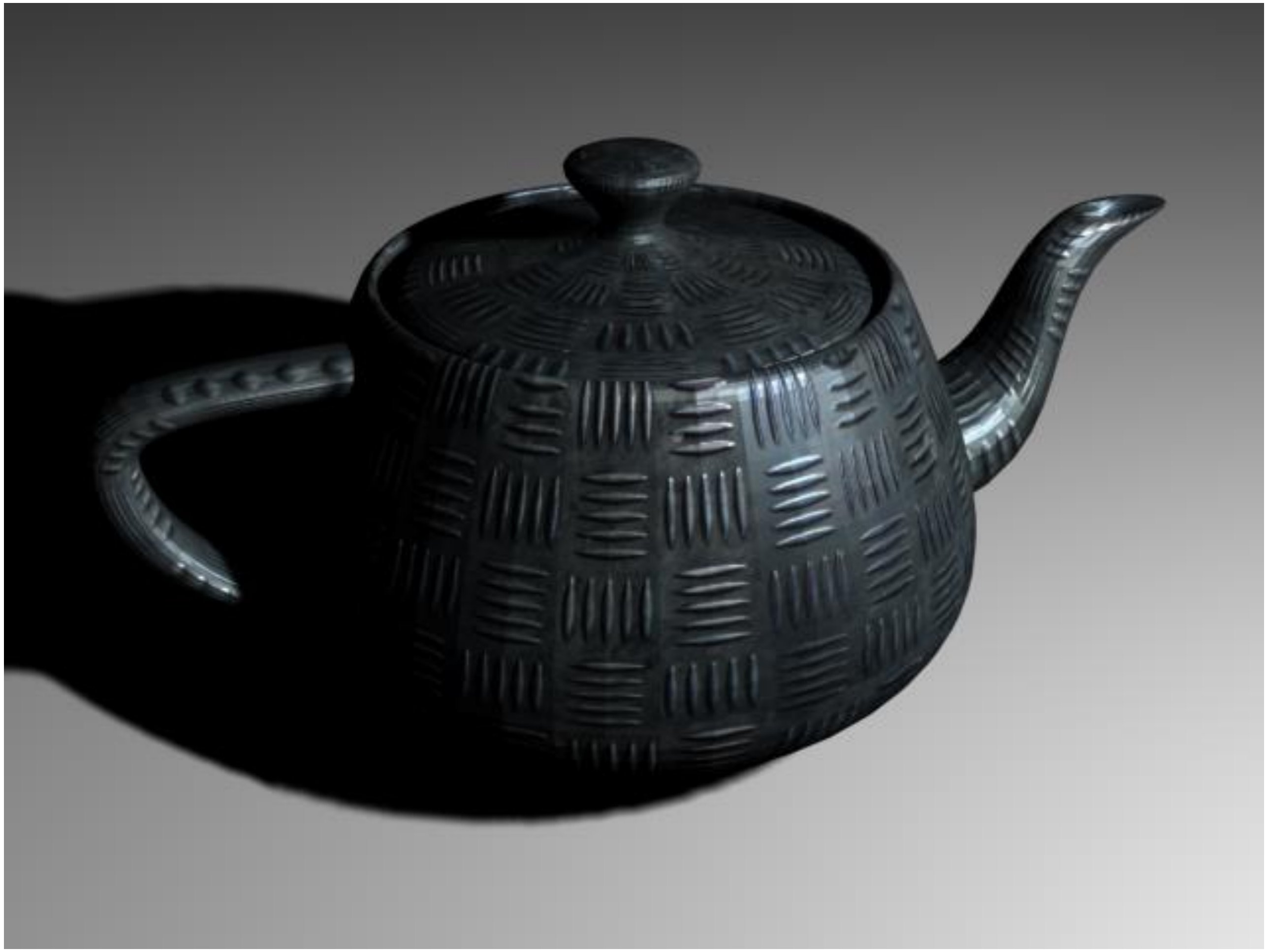
Shadow Mapping



Lights, visibility, texture…



What’s missing is shadow



Next Lecture

Shadows

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Very best data from 3D cameras

Questions ?!

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