TSBB21 Computer Exercise
3D Visualization

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Contents

1 Preliminaries

Before attending the computer exercise it is nescessary to read this guide to the computer exercise. It is also nescessary to read through the lecture slides regarding visualization. For those who wants a more thorough treatise, Chapter 5 in the E-book [1] is recommended.

2 Exercises

Copy the files:
`/courses/TSBB09/Visualization/ctvolread.m`
`/courses/TSBB09/Visualization/cylvolread.m`
`/courses/TSBB09/Visualization/cylmake.m`
`/courses/TSBB09/Visualization/grad_x.m`
`/courses/TSBB09/Visualization/prog1.m`
`/courses/TSBB09/Visualization/imleft.mat`
`/courses/TSBB09/Visualization/imright.mat`
to your home directory. The volume
`/courses/TSBB09/Visualization/ctvol.mat`
is big and better not to copy.

2.1 Exercise 1

In the file `ctvolread.m`, set up the right path to `ctvol.mat`. The script shows 3 slices from a $320 \times 320 \times 230$-volume. The volume was created with computed tomography (CT) of a child with deformed skull that is going to be operated. Run `ctvolread.m` and show a slice to the bottom right. Let it be a cross-section through the teeth.

2.2 Exercise 2

Run `cylmake.m`. It creates a small $64 \times 64 \times 64$-volume of a cylinder named `cyl.img`. It is good to develop your programs on this small volume, since the CT-volume is big and causes heavy calculations. Then run `cylvolread.m`. It loads the `cyl.img` volume and creates a depth-coded image, see Figure 1. Note that `(row,col,z)` corresponds to `(y,x,z)` in MATLAB.

2.3 The Phong Model

The Phong model is given in the lecture slides. Provided that the angles are less than $\pi/2$, the formula is:

$$\begin{aligned}\mathbf{I}_{Phong} &= \mathbf{I}_{ambient} + \mathbf{I}_{diffuse} + \mathbf{I}_{specular} \\ &= k_a \mathbf{M}_a \mathbf{I}_a + k_d \mathbf{M}_d \mathbf{I}_d \cos(\phi) + k_s \mathbf{M}_s \mathbf{I}_s \cos^n(\rho).\end{aligned}$$

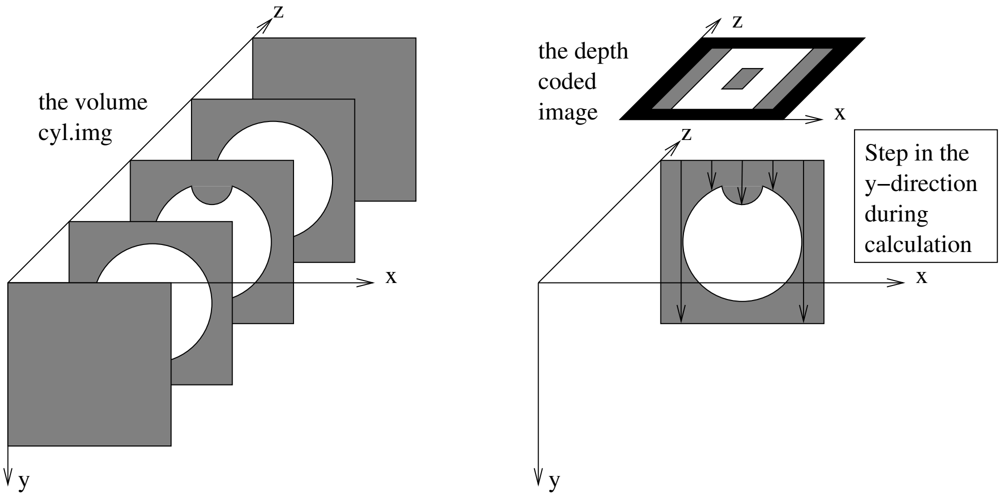


Figure 1: Depthcoding of the cylinder volume.

2.4 Exercise 3

Modify `cylvolread.m` so that it calculates shading with the Phong model, but use only diffuse reflection, $\mathbf{I}_{diffuse}$. Set $k_d = \mathbf{M}_d = \mathbf{I}_d = 1$. Perform the calculations on the cylinder. The derivatives should be calculated with 3D Sobel-filters. Let the viewer and light source be located in same direction. (We also assume that they are sufficiently far away to motivate our approximate calculation with parallel rays.) Check carefully that your shaded image looks as in Figure 2, right.

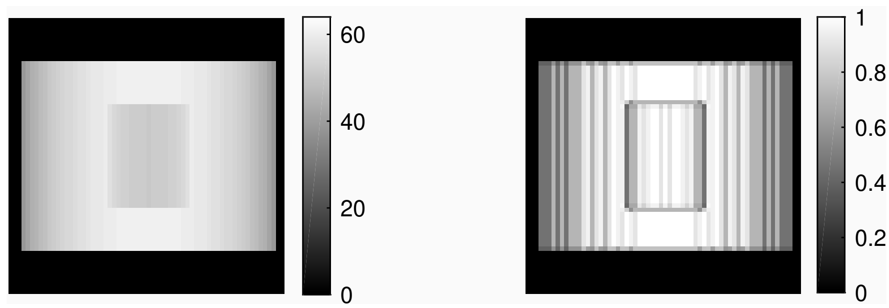


Figure 2: Left: The depthcoded image. Right: The diffuse shaded image.

Tip: Do not calculate a gradient volume. It will occupy the memory of the computer and slow down the calculations. Instead, for each ray, just calculate the gradient value when you have reached the surface. The function `grad_x.m` calculates the derivative in the x-direction in a 3×3×3 surrounding volume. Expand the function to calculate the derivative in the y- and z-direction, also.

2.5 Exercise 4

Now add specular reflection to your Phong model. Set $\mathbf{M}_s = \mathbf{I}_s = 1$. Perform the calculations on the cylinder. Note that in case of specular reflection, you must specifically treat rays that are reflected away from the viewer. Check carefully that your shaded image looks reasonable, see Figure 3.

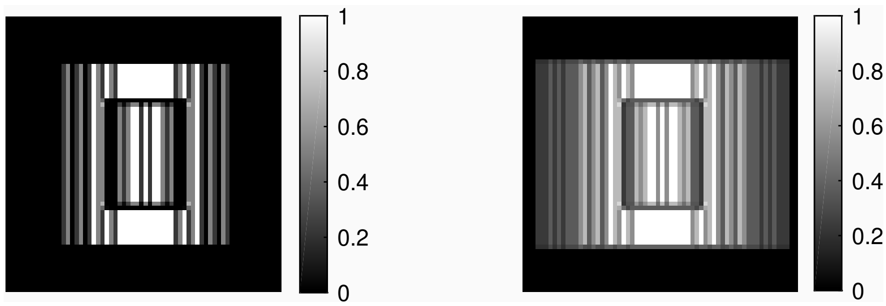


Figure 3: Shaded images. Left: $k_d = 0$, $k_s = 1$, $n = 3$. Right: $k_d = 0.5$, $k_s = 0.5$, $n = 3$.

2.6 Exercise 5

Modify cylvolread.m so that it performs depth-coding and Phong shading on the head instead. How can you get an image of the skin? How can you get an image of the skull? How can you get a matte appearance? How can you get a metallic appearance? Produce four different images.

2.7 Exercise 6

Compute shading at different angles. Start with rotating each slice with `imrotate` (write `help imrotate` in the MATLABwindow). Calculate two images with a slight difference in rotation angle (about 8°). Put these images beside each other and perform stereo viewing as described in the appendix. Also, let the teacher try.

Extra

2.8 Exercise 7 (optional)

Put the two images in the previous exercise in the red- and green/blue-plane in a color image. The technique can be found in the program `prog1.m`. Look at the color image with red-green glasses which you borrow from the teacher.

2.9 Exercise 8

Let the intensity $\mathbf{I} = [R_I, G_I, B_I]$ and material $\mathbf{M} = [R_M, G_M, B_M]$, with values in the range $[0, 1]$. What is the color of the reflected light in the cases below?

a) Assume white light $\mathbf{I} = [1, 1, 1]$ and white material $\mathbf{M} = [1, 1, 1]$.

b) Assume white light $\mathbf{I} = [1, 1, 1]$ and red material $\mathbf{M} = [1, 0, 0]$.

c) Assume red light $\mathbf{I} = [1, 0, 0]$ (e.g. laser) and white material $\mathbf{M} = [1, 1, 1]$.

d) Assume red light $\mathbf{I} = [1, 0, 0]$ and blue material $\mathbf{M} = [0, 0, 1]$.

2.10 Exercise 9

We will now assume that our data consist of one material.
Assume white light $\mathbf{I_a} = \mathbf{I_d} = \mathbf{I_s} = [1, 1, 1]$.
Assume $k_a = k_d = k_s = 1$.
Material properties, i.e. $\mathbf{M_a} = [R_a, G_a, B_a]$, $\mathbf{M_d} = [R_d, G_d, B_d]$,
$\mathbf{M_s} = [R_s, G_s, B_s]$ and shininess n are given in Appendix: Materials.

Suggested procedure:

a) Calculate a binary ambient shaded image. When there is a voxel along the ray that is larger than the threshold, the corresponding pixel is set to 1. Otherwise the pixel is set to 0.

b) Calculate a diffuse shaded image. Set $k_d = \mathbf{M}_d = \mathbf{I}_d = 1$.

c) Choose a material. Look for the shininess n. Then calculate a specular shaded image. Set $k_s = \mathbf{M}_s = \mathbf{I}_s = 1$.

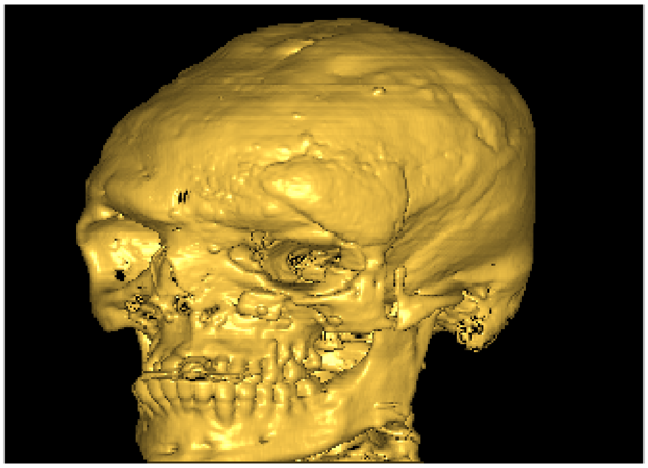
d) Show the ambient image in a) as a color image. Look for $\mathbf{M_a} = [R_a, G_a, B_a]$ for your chosen material.

d) Show the diffuse shaded image in b) as a color image. Look for $\mathbf{M_d} = [R_d, G_d, B_d]$ for your chosen material.

e) Show the specular shaded image in c) as a color image. Look for $\mathbf{M_s} = [R_s, G_s, B_s]$ for your chosen material.

e) Sum up everything in the individual RGB color channels and show the fully shaded image as a color image.

Select the material gold. A resulting image for a gold skull is shown below.



2.11 Exercise 10

Choose any other material and repeat the procedure.

3 Appendix

Images recieved by a camera are 2D projections of a 3D world. Suppose that a set of such projection images have been obtained from different angles around an object. If the projection images are used together in a systematic way, it is possible to improve the 3D impression of the object. Rotation and stereo are two powerful effects that can be used for enhancing the 3D visualization.

3.1 Visualization using rotation

To obtain the impression of rotation, do like this:

- Compute a sequence of projection images with different angles, $p_\phi(x, y)$, $\phi = [\phi_0, \phi_1, ..., \phi_N]$. The angular difference between consequtive angles should be approximately constant.
- Show the images on the screen, one at a time in a suitable speed.
- Our brain gets the impression of a rotating object volume.

3.2 Calculation of look-trough projections

Instead of normal camera images, it is also possible to use look-through projections consisting of line integrals. Another alternative is to simulate X-ray projections.

A projection image, $p_\phi(x, z)$, consisting of line integrals in the ϕ-direction can be computed as

$$p_\phi(x, z) = \int f_\phi(x, y, z)\, dy, \tag{1}$$

where $f_\phi(x, y, z)$ is a rotated version of the original object function $f(x, y, z)$. The discrete version

$$p_\phi(x, z) = \sum_y f_\phi(x, y, z) \tag{2}$$

is illustrated in Figure 4. An alternative is to step through the volume in a slanted direction and interpolate the value in each step. To get a more realistic view, especially when the viewer is close to the object, divergent rays are preferrable.

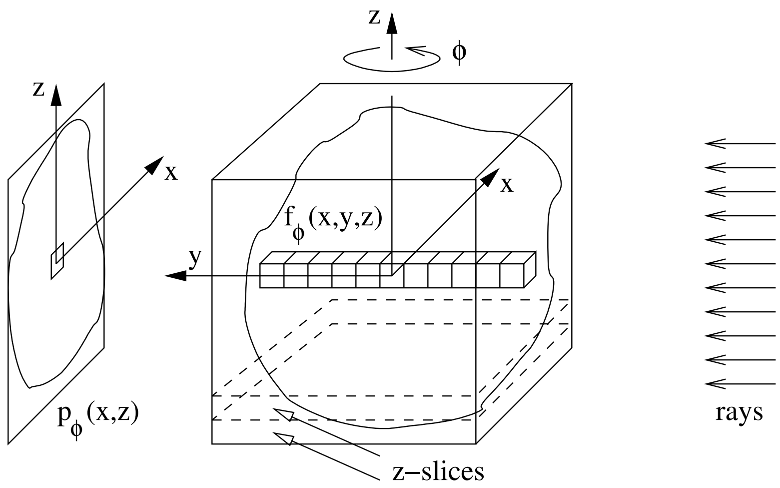


Figure 4: X-ray projection generation from different angles ϕ.

To get X-ray projections, compute

$$I_0 - I_\phi(x,z) = I_0 - I_0 \exp\left[-\int f_\phi(x,y,z)\ dy\right], \tag{3}$$

where $f_\phi(x,y,z)$ now corresponds to the X-ray attenuation coefficient of the matter, I_0 is the incident X-ray intensity and $I_0 - I_\phi(x,z)$ is the conventional developed X-ray image.

3.3 Visualization using stereo

A stereo effect is recieved if the left and right eye of a person is provided with two different projection images obtained at different angles. The eyes match different objects in the two projection images, for example A and B in Figure 5. The parallax angles for these objects are α and β, respectively. The brain note these angles and conclude that object A is closer than B, since α is greater than β.

To obtain the stereo images, perform like this:

- Compute two projection images with different angles, ϕ_1 and ϕ_2. As a rule of thumb, the angle difference should be approximately four to eight degrees.
- Show one image to the left eye and the other to the right eye.

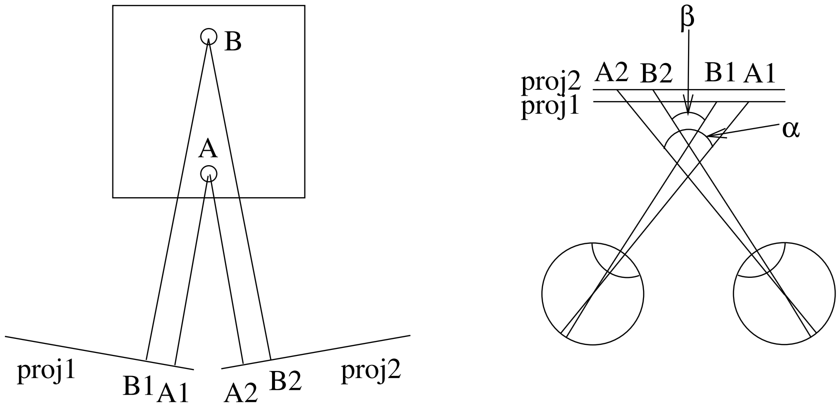


Figure 5: Stereo vision. Left: Projection generation by a camera or by the eyes. Right: Creating stereo effect by showing the two projection images to the eyes.

- The brain gets the impression of looking at a 3D scene with two eyes, i.e. stereo vision.
- If the images are shifted, close objects will seem to be far away, and distant objects will seem to be near.

It is not trivial to provide a person with stereo images according to the figure. One solution is to use spectacles with different polarization for the left and right eye and simultaneously show the two projection images with different polarization. The polarization of projection 1 should match the polarization of the left eye, and similarly for projection 2 and the right eye. Another solution is too use a green and a red projection image combined with red-green spectacles. Yet another solution is to show the two projection images beside eachother and to look att one image with the left eye and the other image with the right eye. There are two variants, one with parallel gaze and another with crossed gaze. Some persons think that the parallel variant is easier to obtain, others like the crossed version better, and some people seems to lack this ability.

To obtain stereo vision with crossed gaze do like this:

- Look at Figure 6 with crossed gaze from a distance of approximately 30 cm. It may be helpful to hold your finger between your eyes and the stereo pair.
- After a while, you can see three blurred images.
- Take away the finger.

- Concentrate on the middle image and try to make it sharp and steady.
- Hopefully, you have now obtained stereo vision!

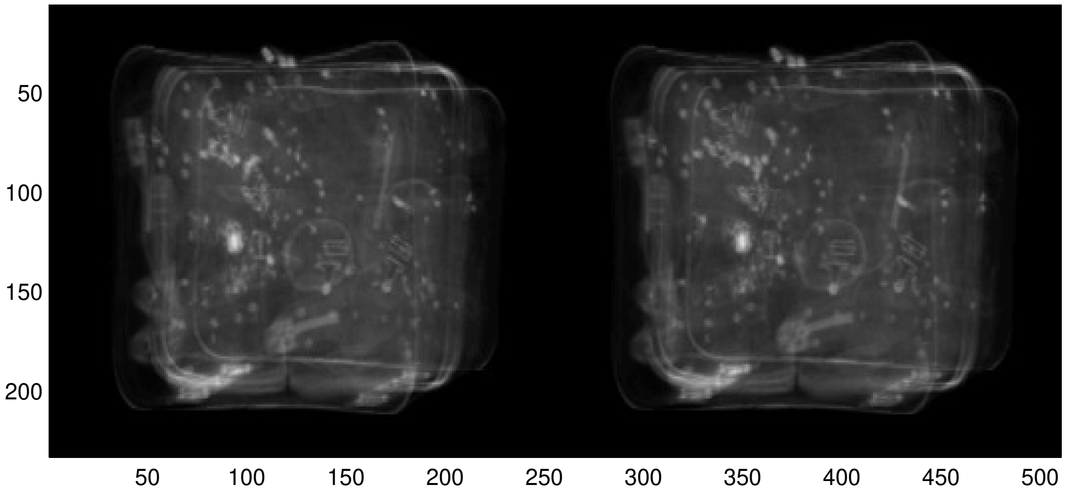


Figure 6: A stereo pair of X-ray projections of a bag.

References

[1] Klaus Engel. *Real-Time Volume Graphics.* A K Peters, Ltd., Wellesley, Massachusetts, 2006.

3.4 Materials

The material data on the next page can be used in the Phong model to simulate different materials. Shininess has been multiplied with 32 to fit the model we use. (OpenGL uses a slightly different model, where shininess should be multiplied with 128 instead.) The material data are taken from `http://devernay.free.fr/cours/opengl/materials.html`,
but are originally from the OpenGL teapots.c demo, Silicon Graphics, Inc., 1994, Mark J. Kilgard.

Name	Ambient			Diffuse			Specular			Shininess
emerald	0.0215	0.1745	0.0215	0.07568	0.61424	0.07568	0.633	0.727811	0.633	32*0.6
jade	0.135	0.2225	0.1575	0.54	0.89	0.63	0.316228	0.316228	0.316228	32*0.1
obsidian	0.05375	0.05	0.06625	0.18275	0.17	0.22525	0.332741	0.328634	0.346435	32*0.3
pearl	0.25	0.20725	0.20725	1	0.829	0.829	0.296648	0.296648	0.296648	32*0.088
ruby	0.1745	0.01175	0.01175	0.61424	0.04136	0.04136	0.727811	0.626959	0.626959	32*0.6
turquoise	0.1	0.18725	0.1745	0.396	0.74151	0.69102	0.297254	0.30829	0.306678	32*0.1
brass	0.329412	0.223529	0.027451	0.780392	0.568627	0.113725	0.992157	0.941176	0.807843	32*0.21794872
bronze	0.2125	0.1275	0.054	0.714	0.4284	0.18144	0.393548	0.271906	0.166721	32*0.2
chrome	0.25	0.25	0.25	0.4	0.4	0.4	0.774597	0.774597	0.774597	32*0.6
copper	0.19125	0.0735	0.0225	0.7038	0.27048	0.0828	0.256777	0.137622	0.086014	32*0.1
gold	0.24725	0.1995	0.0745	0.75164	0.60648	0.22648	0.628281	0.555802	0.366065	32*0.4
silver	0.19225	0.19225	0.19225	0.50754	0.50754	0.50754	0.508273	0.508273	0.508273	32*0.4
black plastic	0.0	0.0	0.0	0.01	0.01	0.01	0.50	0.50	0.50	32*.25
cyan plastic	0.0	0.1	0.06	0.0	0.50980392	0.50980392	0.50196078	0.50196078	0.50196078	32*.25
green plastic	0.0	0.0	0.0	0.1	0.35	0.1	0.45	0.55	0.45	32*.25
red plastic	0.0	0.0	0.0	0.5	0.0	0.0	0.7	0.6	0.6	32*.25
white plastic	0.0	0.0	0.0	0.55	0.55	0.55	0.70	0.70	0.70	32*.25
yellow plastic	0.0	0.0	0.0	0.5	0.5	0.0	0.60	0.60	0.50	32*.25
black rubber	0.02	0.02	0.02	0.01	0.01	0.01	0.4	0.4	0.4	32*.078125
cyan rubber	0.0	0.05	0.05	0.4	0.5	0.5	0.04	0.7	0.7	32*.078125
green rubber	0.0	0.05	0.0	0.4	0.5	0.4	0.04	0.7	0.04	32*.078125
red rubber	0.05	0.0	0.0	0.5	0.4	0.4	0.7	0.04	0.04	32*.078125
white rubber	0.05	0.05	0.05	0.5	0.5	0.5	0.7	0.7	0.7	32*.078125
yellow rubber	0.05	0.05	0.0	0.5	0.5	0.4	0.7	0.7	0.04	32*.078125