Weeks 11–12

For many scattering materials we are only interested in the radiance emerging on the surface. This is especially true for highly scattering materials like skin, where we definitely will not place the camera inside the volume. Since the material still scatters light beneath the surface, we would in principle have to do a volume rendering, but the fact that we only need to worry about light emergent on the surface means that we can use an approximate analytical expression to describe the light diffusion under the surface. The following exercises are about using the dipole approximation for computing subsurface scattering.

Learning Objectives

- Simulate subsurface scattering using diffusion.
- Use the dipole approximation for rendering translucent materials.
- Integrate the dipole approximation with path tracing.
- Explain the BSSRDF and how it relates to volume rendering.

Subsurface Scattering

The material properties used in subsurface scattering are the same as the material properties used in volume rendering (complex index of refraction n, phase function p or asymmetry parameter g, and scattering coefficient σ_s).

- Draw a figure depicting the subsurface scattering setup. The following elements are essential: a closed surface, a light source, an observer, a point where light is incident, a point where light is emergent (outgoing), and three rays connecting source to observer via the medium. Identify normals, ray directions, and angles between those.
- The ray connecting point of incidence to point of emergence is not an actual ray of light, but rather a ray for measuring the subsurface distance between the two points. Given the normals and the directions of the ray from the observer and the ray toward the light, write down how to determine the cosines ($\cos\theta_i$ and $\cos\theta_o$) of the angles with the directions of the actual rays of light refracting in and out of the medium. These cosines are needed for computing Fresnel transmittance terms.
- Load the Cornell box (`CornellBox.obj`) and the blocks inside it (`CornellTallBlock.obj` and `CornellShortBlock.obj`) into your ray tracer. Ensure that the material of the tall block is marble and render a reference image using your Monte Carlo volume rendering shader (illumination model `illum 13`, implemented in the previous set of exercises). Store the resulting image such that you can compare it to the subsurface scattering result later.
- Subsurface scattering involves four major steps. The first step is to compute a single scattering contribution. This is a simplification of the full multiple scattering implemented in the previous set of exercises. The trick is simply to stop the multiple scattering computation after one scattering event. Render the marble block using single scattering only. (If you implemented multiple scattering in the previous set of exercises, this is already implemented in the framework. Switch the illumination model of the marble material to `illum 14` and render it again.) Store the resulting image.
- The three remaining steps evaluate the diffusion part of the BSSRDF as described in **P** and by Jensen et al. [2001, see reference below].[1] Do the following: (a) sample points of incidence on the surface of the translucent object, (b) sample incident illumination at these points of incidence, and (c) compute

[1] If you use the original article [Jensen et al. 2001], be sure to check all formulae against another reference [Donner 2006, for example] as the original article has a couple of errors.

the diffusion of the incident illumination to the point where light is emergent using the Fresnel transmittances and the dipole approximation. (In the `pathtrace` project of the framework, implement the missing parts of the functions `init_sample_surface` and `diffusion` in `MCSubsurf.cpp`.)

- Render an image showing the result for the diffusion term only. Store the result. Then render an image which shows the result of single scattering and diffusion combined. Store the result.
- As a final test, load the wineglass (`wineglass.obj`) and its contents (`wine_for_glass.obj`) and switch the contents of the glass to low fat chocolate milk. Render it using subsurface scattering (`illum 14`). Store the resulting image and compare it to the volume rendering result from a previous exercise.

Weeks 11–12 Deliverables

Reference images of the marble block in the Cornell box and the wineglass with low fat chocolate milk, both rendered using volume rendering with multiple scattering. Images of the marble block showing the single scattering term, the diffusion term, and the combined result, respectively. A final image showing the subsurface scattering version of the wineglass with low fat chocolate milk. Resolution down to 128×128 is acceptable for these images. In addition, you should provide a figure illustrating the subsurface scattering setup, a description of how to find the cosine terms for the Fresnel transmittances, and a comparison of the subsurface scattering results and the reference images.

Reading Material

The curriculum for Weeks 11–12 is

P Sections 5.6.2 and 11.6. *The BSSRDF*.
P Section 16.5. *Subsurface Scattering*.

Alternative literature available online or uploaded to CampusNet:

- Jensen, H. W., Marschner, S. R., and Levoy, M., and Hanrahan, P. A practical model for subsurface light transport. In *Proceedings of ACM SIGGRAPH 2001*, pp. 511–518, ACM, 2001.

Additional resources:

- Donner, C. Subsurface scattering of light using diffusion. In *Towards Realistic Image Synthesis of Scattering Materials*, Chapter 5, PhD dissertation, University of California, San Diego, 2006.
- Jensen, H. W., and Buhler, J. A rapid hierarchical rendering technique for translucent materials. *ACM Transactions on Graphics (Proceedings of ACM SIGGRAPH 2002) 21*(3), pp. 576–581, 2002.