Subsurface Scattering in Point-Based Rendering

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Abstract

Point-based graphics has gained much attention as an alternative to polygon-based approaches because of its simplicity and flexibility. However, current point-based techniques do not provide a sufficient rendering quality for translucent materials such as human skin. In this paper, we propose a point-based framework with subsurface scattering of light, which is important to create the soft and semi-translucent appearance of human skin. To accurately simulate subsurface scattering in multilayered materials, we present splat-based diffusion to apply a linear combination of several Gaussian basis functions to each surfel in object space. Compared to existing point-based approaches, our method offers a significantly improved visual quality in rendering human faces and provides a similar visual quality to polygon-based rendering using the texture space diffusion technique. We demonstrate the effectiveness of our approach in rendering scanned faces realistically.

1. Introduction

Point-based rendering is becoming an increasingly popular alternative to polygon-based rendering. Instead of rendering a triangular mesh, point-based rendering acts directly on an unstructured cloud of points. This is particularly beneficial if the model being rendered is undergoing frequent major geometric changes, when complicated modifications to connectivity information are avoided. It is also effective with high-resolution models. However, many of the existing rendering techniques are unsuitable for point clouds because they are originally designed for polygons. So, several researchers have made an effort to transfer techniques designed for polygon-based rendering to point-based rendering, allowing special effects to be achieved such as motion blur [GM04], non-photorealistic rendering [ZS04], and transparent shading [ZP06]. As point-based rendering becomes more popular, realistic rendering techniques for various materials have become necessary within a consistent framework for point clouds. One example is subsurface scattering, which is a realistic way of rendering translucent materials such as milk, marble, leaves, and human skin. Subsurface scattering in such materials has been extensively studied in recent years, but very little efforts have been made in point-based rendering.

We propose a method of modeling subsurface scattering which allows the appearance of translucent materials to be modeled by point-based rendering. Our key idea is inspired by d'Eon and Luebke's technique [dLE07] for realistic rendering of facial skin. They approximate a multipole diffusion profile [DJ05] for multilayered materials as a linear combination of Gaussian basis functions, and we have modified this procedure to suit point-based rendering. In our framework, the effect of light diffusion is represented by a Gaussian distribution applied to the radius of a surfel [PZvBG00] and multicolored layers of increasing radius are linearly combined in object space.

Earlier methods of modeling subsurface scattering required several seconds or even minutes to render one scene, making real time rendering impossible [DJ05, DJ06]. Various improvements have been introduced but require many pre-processing [WTL05, WWD*05]. This is ineffective if pre-processing has to be repeated for every scene because the model is undergoing animation or deformation. However, a recent method [dLE07] avoids pre-processing by combining texture space diffusion with an extended translucent shadow map. This allows translucent objects with changing scenes to be rendered in real time.

We propose a splat-based diffusion technique which uses a linear combination of Gaussian basis functions, in a similar way to texture space diffusion. This allows realistic rendering without pre-processing. Moreover, because the combination of Gaussian basis functions takes place in object

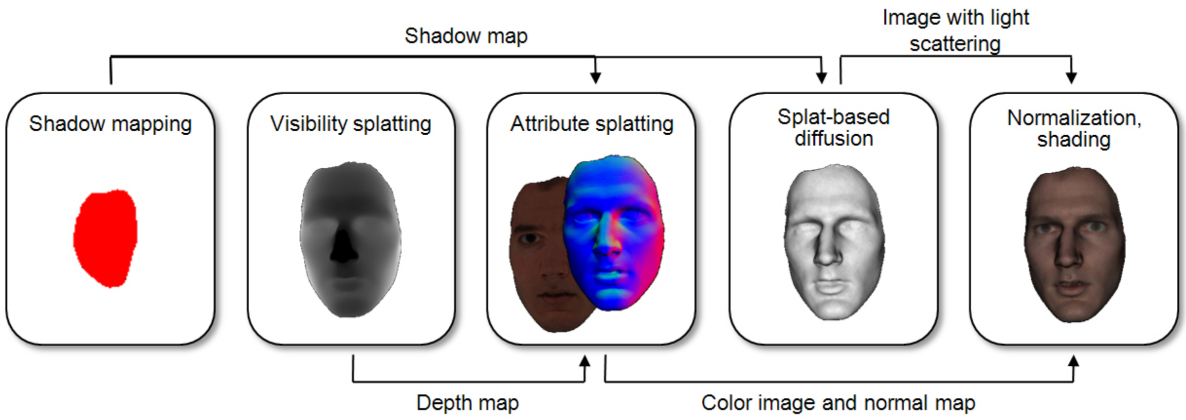

Figure 1: *Our rendering framework adds two new passes, shadow mapping and splat-based diffusion, to existing point-based rendering in order to simulate subsurface scattering.*

space, the texture distortions caused by the large ratio between distances in texture space and Euclidean space are avoided without any additional stretch correction step. We also can improve the speed by reducing the number of surfels when the amplitude of the radius is large during the process of the splat-based diffusion. We will show that the presented technique can be used to realistically render human skin represented as a point cloud.

2. Point-Based Rendering with Subsurface Scattering

We propose a new rendering framework for the realistic rendering of point-based models of multilayered translucent materials using a splat-based diffusion technique. Figure 1 shows our rendering framework which consists of typical three passes and newly added two passes.

2.1. Rendering Framework

The majority of GPU-accelerated point-based rendering methods create images through an orderly three-pass procedure: visibility-splatting pass, attribute-splatting pass, and shading pass. All these passes are performed by programmable shaders: the first two passes use the point geometry data as input, and the final pass operates on the image pixels generated by the previous two passes. In general, this number of passes is necessary because OpenGL, DirectX and other graphics libraries do not support a surfel datastructure as a rendering primitive, which consists of a disk with a central point, a radius, and a surface color, as well as a normal vector. To find the exact depth of a 3D surface made by a set of overlapping point splats, accurate depth information must be calculated in the first pass and stored in a depth buffer. The second pass accumulates surface attributes, like color values and normal vectors. In the last pass, the image produced during the second pass is normalized and further per-pixel shading generates the final image.

We add two new passes to the typical three-pass point-based rendering to make the appearance of translucent materials more realistic. These additional passes are shadow map generation and splat-based diffusion. Creating the shadow map precedes the three existing passes. The map that we construct contains the regions which are shadowed by the model's convex areas. It is generated by comparing distances from the light source to the surface of the model. Passes 2 and 3 in the new process are the first two passes of the original process, which determine depth information, color values, and interpolated normal vectors. In the fourth pass, splat-based diffusion is used to determine the effect of light diffusion. This will be explained in Section 2.2. The final, fifth pass computes the actual color for each image pixel to produce the viewable image.

In order to render the reflective light from the skin surface, the specular reflectance is added to the calculated diffusion color within the presented rendering framework. In our study, we use the surface roughness and skin reflectance parameters of the specular BRDF model measured by Weyrich et al. [WMP*06]. However, the Kelemen Szirmay-Kalos model is used instead of the Torrance-Sparrow model to speed up the calculation process.

2.2. Splat-based Diffusion

Splat-based diffusion is an efficient way of approximating the light diffusion phenomenon inside a material in object space using surfels. It assumes that the diffusion of light is isotropic, and then its effect at a surfel can be expressed as a Gaussian distribution applied to the radius of a surfel. The overall diffusion effect across the surface is determined by combining the contribution of all the surfels.

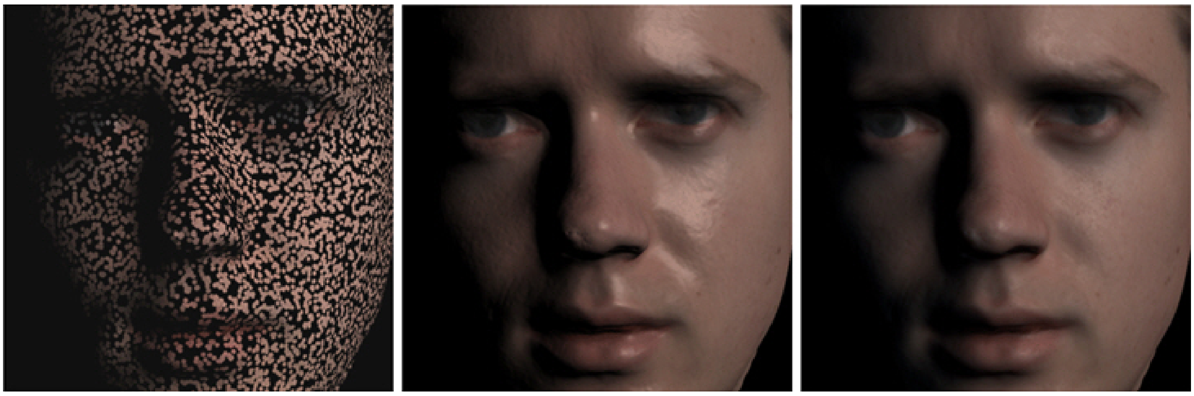

Figure 2: *(Left) disk-type rendering of surfels, (Middle) point-based rendering with bidirectional reflectance distribution function, (Right) point-based rending with bidirectional surface scattering reflectance distribution function.*

A diffusion color created by a single Gaussian function is usually inadequate to approximate a multilayered diffusion profile for skin. We therefore use a sum-of-Gaussian technique developed by d'Eon and Luebke [dLE07], in which six Gaussians of increasing radius are constructed on separate layers and subsequently combined by weighted addition. This is rendered in fourth pass of the process and the weighted splat-based diffusion technique resamples the diffuse color determined as the dot-product of the light direction and the surface normal. The resampled diffuse color is used for a surfel color and the diffusion of light at the surfel is approximated by surface splatting. The light diffusion phenomenon is strongly color dependent: red light scatters much farther than green and blue.

The computed diffuse color is represented as an image which is created by the linear combination of six images. The first image is computed by the diffusion process of the normal map, which is the result of the previous pass. The other five images are iteratively generated using surface splatting with increasing radius of the surfel. When the sum of Gaussian weights is 1.0, the weights of blue and green are increased for the first few images made by using the small-radius surfel. Conversely, the weight of red is increased for the images generated by using the large-radius surfel.

The process of the splat-based diffusion for making diffuse color images takes a large portion of the total processing time within the entire rendering framework. In the surface splatting process, as the radius of a surfel increases, the process is slower because the number of the fragments projected on the screen space is increased. A notable fact is that even though the number of surfels is decreased, the outcome does not change very much because the overlapping area between surfels is larger. In other words, the detail characteristics of the model disappear because of many blurs. Such observation allows us to reduce the number of surfels when the amplitude of the radius is large.

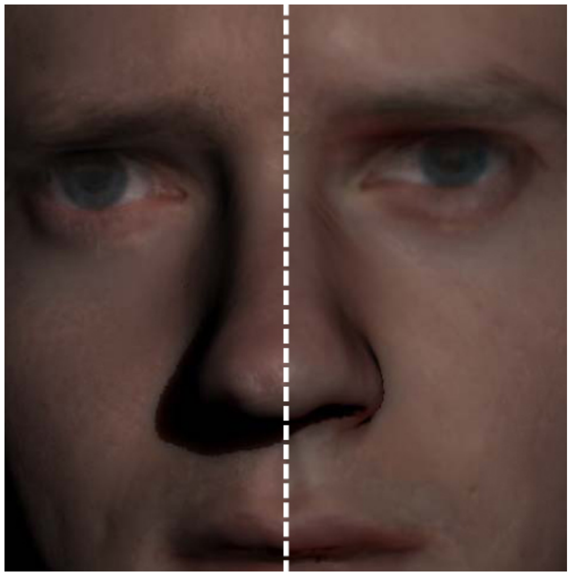

Figure 3: *We compare point-based and polygon-based rendering, with subsurface scattering. d'Eon and Luebke's approach allows realistic rendering of a face (Left). Our method (Right) creates much of the same look as the image achieved using their approach.*

3. Results

We performed experiments on four high-resolution face models. Our aims were to compare our technique with existing point-based rendering methods and with mesh-based subsurface scattering technique. All the experiments were conducted on an Intel Core 2 Quad CPU Q6600 2.4GHz PC with an nVidia GeForce 9800 GTX+ graphics processing unit.

Because previous point-based rendering techniques do not support subsurface scattering, resulting skin appears to be unrealistic, hard and dry. However, as it is possible to add scattering of light, our approach allows more smooth skin appearance using the splat-based diffusion. In Figure 2, three different results from disk-type rendering of the face model, high-quality surface splatting [BHZK05] and our rendering incorporating subsurface scattering effects are compared. Note that the smooth light appearance is distinctive as it moves to the right direction. The disk-type rendering appears to be similar to flat shading since there is no color and normal interpolation between surfels. Although the appearance of two images in the right is relatively soft, the image from our approach appears to be more realistic than the rendered results without scattering effects. Given the fact that EWA splatting [ZPvBG01] is a software-based method, small holes are generated during the projective mapping process. On the other hand, although the Phong splatting shows better performance for the low resolution case, some aliasing occurs often since it does not use a screen space filter. The advantage of our approach is that it allows more realistic rendering because the subsurface scattering effect is incorporated.

Figure 3 illustrates the different quality between two cases. The face image contains 683,549 points and the surface scattering is applied to the identical face model. The left half of the face model adopts polygon-based rendering, whereas the right half does point-based rendering. The polygon-based rendering uses d'Eon and Luebke's method [dLE07]. The conditions for two cases are identical except a fact that the method of calculating the diffuse color is different. The presented splat-based diffusion technique provides almost identical visual quality to polygon-based rendering using the texture space diffusion technique.

4. Conclusions and Future Work

We have proposed a subsurface scattering method for point-based rendering that uses a sum-of-Gaussian. The surface splatting technique using surfels was employed to combine the Gaussians in object space. We are able to render realistic light scattering within the skin surface by approximating a multilayer diffusion profile of skin. The quality of our point-based rendering is almost identical to that of the polygon-based rendering using the texture space diffusion. However, our method is currently not fully optimized in terms of speed. For future work, we plan to optimize the number of surfels required to produce each diffuse color image, and to adjust the resolution using perception-based metrics. Furthermore, we plan to improve the performance by shortening the iteration of the splat-based diffusion during the generation of diffuse color images.

Although we apply the surface splatting with subsurface scattering to human facial skin in this paper, the same method can be used for various translucent objects. Since the diffusion profiles can be measured by analyzing scattering of laser or structured light pattern, any translucent object can be represented through the process of fitting a sum-of Gaussian to the diffusion profile. Thus, whenever any diffusion profile is available, the corresponding splat-based diffusion can be applied.

Acknowledgement

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References

[BHZK05] BOTSCH M., HORNUNG A., ZWICKER M., KOBBELT L.: High-quality surface splatting on today's gpus. In *Symposium on Point-Based Graphics 2005* (June 2005), pp. 17–24.

[DJ05] DONNER C., JENSEN H. W.: Light diffusion in multi-layered translucent materials. *ACM Transactions on Graphics 24*, 3 (Aug. 2005), 1032–1039.

[DJ06] DONNER C., JENSEN H. W.: A spectral bssrdf for shading human skin. In *Rendering Techniques 2006: 17th Eurographics Workshop on Rendering* (June 2006), pp. 409–418.

[dLE07] D'EON E., LUEBKE D., ENDERTON E.: Efficient rendering of human skin. In *Rendering Techniques 2007: 18th Eurographics Workshop on Rendering* (June 2007), pp. 147–158.

[GM04] GUAN X., MUELLER K.: Point-based surface rendering with motion blur. In *Symposium on Point - Based Graphics 2004* (June 2004).

[PZvBG00] PFISTER H., ZWICKER M., VAN BAAR J., GROSS M.: Surfels: Surface elements as rendering primitives. In *Proceedings of ACM SIGGRAPH 2000* (July 2000), Computer Graphics Proceedings, Annual Conference Series, pp. 335–342.

[WMP*06] WEYRICH T., MATUSIK W., PFISTER H., BICKEL B., DONNER C., TU C., MCANDLESS J., LEE J., NGAN A., JENSEN H. W., GROSS M.: Analysis of human faces using a measurement-based skin reflectance model. *ACM Transactions on Graphics 25*, 3 (July 2006), 1013–1024.

[WTL05] WANG R., TRAN J., LUEBKE D.: All-frequency interactive relighting of translucent objects with single and multiple scattering. *ACM Transactions on Graphics 24*, 3 (Aug. 2005), 712–719.

[WWD*05] WANG L., WANG W., DORSEY J., YANG X., GUO B., SHUM H.-Y.: Real-time rendering of plant leaves. *ACM Transactions on Graphics 24*, 3 (Aug. 2005), 1202–1207.

[ZP06] ZHANG Y., PAJAROLA R.: Single-pass point rendering and transparent shading. In *Symposium on Point - Based Graphics 2006* (July 2006), pp. 37–48.

[ZPvBG01] ZWICKER M., PFISTER H., VAN BAAR J., GROSS M.: Surface splatting. In *Proceedings of ACM SIGGRAPH 2001* (Aug. 2001), Computer Graphics Proceedings, Annual Conference Series, pp. 371–378.

[ZS04] ZAKARIA N., SEIDEL H.-P.: Interactive stylized silhouette for point-sampled geometry. In *GRAPHITE 2004* (June 2004), pp. 242–249.