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Historical Introduction to Photon Differential Splatting

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Abstract

This document provides a historical overview of the development in computer graphics that led to photon differential splatting. We highlight how photon differential splatting differs from this early related work.

1. Early Related Work

It seems that a two-pass method for rendering caustics, where a tracing from the light sources is added to a tracing from the eye, was first suggested by Heckbert and Hanrahan [HH84]. Their proposal is related to ours, since they suggest that beams are traced from the light. Beam tracing is, however, more like a space discretization method as beams cover the entire visible/illuminated field and are split upon intersection with polygons in the scene. This means that beam tracing, just like radiosity techniques, is tightly coupled to the scene geometry and dependent on proper scene tessellation or *uv*-mapping of all surfaces. A single reflection/refraction version of this idea was realized by Watt [Wat90]. And Strauss [Str88] turned it into a splatting technique by requiring a *uv*-mapping for all surfaces and storing the result of an eye beam tracing as visible regions in these texture spaces. While we are also tracing beams from the light, our beams are based on ray differentials (first-order derivatives) and are traced using a point sampling approach.

Discrete space methods carry a number of problems as visible regions may be overlapping after reflection or refraction. Sampling methods offer an alternative approach. Tracing light rays to construct illumination maps using a sampling approach was first suggested by Arvo [Arv86]. This was done in order to handle caustic illumination. Then, to devise a rendering technique which includes all light paths, a hybrid of light ray tracing and radiosity was presented both by Heckbert [Hec90] and by Shirley [Shi90]. Heckbert mentions that the construction of illumination maps by accumulation of flux carried by light rays is much like density estimation and that kernel density estimation could be applied. A follow-up on this insight was presented by Chen et al. [CRMT91]. They introduce path tracing of particles from the light sources and illumination reconstruction using *k*nn adaptive kernel density estimation.

The first splatting technique for rendering caustics using kernel density estimation was presented by Collins [Col95]. His approach is quite similar to that of Strauss [Str88], except that Collins keeps track of the connectivity between rays instead of tracing beams, and then he splats a kernel into the illumination maps for each ray. Each kernel adapts its size according to the area of the quadrilateral spanned by the neighboring rays. Conceptually, this is very close to splatting photon differentials. In comparison, the key benefits of our method are that we do not need to keep track of neighboring rays and we do not need a *uv*-mapping of all surfaces as our differentials are not splatted into illumination maps. In addition, we use anisotropic kernels. Collins used isotropic kernels, but it would have been possible for him to make them anisotropic using the information about the neighboring rays.

Instead of using density estimation for caustics only, it was used for all light paths by Shirley et al. [SWH*95] and Walter et al. [WHSG97]. Photon mapping [JC95] is a technique which uses density estimation for all indirect light paths. It was introduced to decouple the rendering algorithm from the scene geometry such that *uv*-mapping and/or proper tessellation of all scene geometry is no longer necessary. The trick is to store light particles (photons) that reach non-specular surfaces in a three-dimensional data structure (usually a *k*d tree), and then reconstruct illumination using *k*nn adaptive kernel density estimation by look-up into this scene-independent data structure. What we refer to as standard photon mapping was presented by Jensen [Jen96]. Here a smooth, isotropic kernel is used for rendering caustics.

Photon splatting [SB97, LP03] was introduced as a technique to speed up density estimation using rasterization. It is done by additive blending of textured point splats which are placed where photons are stored. The texture is outgoing radiance weighted by a kernel function. The size of a splat (the bandwidth) is adjusted by a heuristic measure based on the total number of photons that hit a surface and the area of that surface. This heuristic requires that photons are stored before they are splatted. Storing is expensive in terms of memory and computation. Since we get the shape and size of our kernels from the photon differentials, we eliminate the need to store photons without compromising rendering quality.

Herzog et al. [HHK*07] developed a splatting method which uses a map of eye path vertices (importons [PP98]). They splat to both directly visible positions in a scene and positions seen via one or more interactions with specular surfaces. We adopt this eye path map to include all caustic light paths when splatting photon differentials. They also use adaptive isotropic kernels with a splat size heuristic based on the inverse path probability density and, in addition, radiance caching in the spherical harmonic basis to reduce low-frequency noise. This yields better results than standard photon mapping for soft (low-frequency) indirect illumination. However, it is not well-suited for the sharp illumination features that often appear in caustics.

The idea of using the path probability density to control the splat size was originally developed by Suykens and Willems [SW01]. They used it in combination with ray differentials [Ige99] to render caustics in a hybrid global illumination framework similar to Heckbert's [Hec90]. This technique is called path differentials, and it was the first decoupling of ray differentials from the image space *uv*-coordinates. This decoupling is necessary to trace ray differentials from arbitrary light sources instead of an eye point. Suykens and Willems [SW01] mention that path differentials could also be used with photon mapping and that the differentials could be used to introduce anisotropic kernel density estimation.

Adaptive anisotropic kernels were first used for density estimation in photon mapping by Schjøth et al. [SOS06, SOS07]. This approach is called diffusion-based photon mapping. The kernel shape is based on an estimate of the illumination gradient, which is found by a look-up into the photon map for every photon. This is quite expensive and it introduces two more parameters to tweak (maximum search radius and maximum number of photons in the gradient estimate) in addition to the diffusivity coefficient which is used to control the anisotropy in this method. The suggestions of Suykens and Willems were realized with the concept of photon differentials [SFES07]. The main problem with using photon differentials as an add-on to standard photon mapping is that kernels may become quite anisotropic, and, to ensure that energy is not lost, all photon differentials overlapping a density estimation point must be included. This means that it is necessary to search for a rather large number of photons in the *k*d tree when reconstructing illumination from a photon map using photon differentials. The splatting approach betters this issue.

References

[Arv86] ARVO J.: Backward ray tracing. In *Developments in Ray Tracing* (August 1986), ACM SIGGRAPH 86 Course Notes. 252

[Col95] COLLINS S.: Adaptive splatting for specular to diffuse light transport. In *Photorealistic Rendering Techniques* (June 1995), Sakas G., Shirley P., Müller S., (Eds.), Springer, Berlin Heidelberg, Germany, pp. 121–135. Proceedings of the Fifth Eurographics Workshop on Rendering, Paris, France, 1994. 252

[CRMT91] CHEN S. E., RUSHMEIER H. E., MILLER G., TURNER D.: A progressive multi-pass method for global illumination. *Computer Graphics (Proceedings of ACM SIGGRAPH 91) 25*, 4 (July 1991), 165–174. 252

[Hec90] HECKBERT P. S.: Adaptive radiosity textures for bidirectional ray tracing. *Computer Graphics (Proceedings of ACM SIGGRAPH 90) 24*, 4 (August 1990), 145–154. 252, 253

[HH84] HECKBERT P. S., HANRAHAN P.: Beam tracing polygonal objects. *Computer Graphics (Proceedings of ACM SIGGRAPH 84) 18*, 3 (July 1984), 119–127. 252

[HHK*07] HERZOG R., HAVRAN V., KINUWAKI S., MYSZKOWSKI K., SEIDEL H.-P.: Global illumination using photon ray splatting. *Computer Graphics Forum (Proceedings of Eurographics 2007) 26*, 3 (September 2007), 503–513. 253

[Ige99] IGEHY H.: Tracing ray differentials. In *Proceedings of ACM SIGGRAPH 1999* (Los Angeles, California, USA, August 1999), ACM Press/Addison-Wesley, New York, USA, pp. 179–186. 253

[JC95] JENSEN H. W., CHRISTENSEN N. J.: Photon maps in bidirectional Monte Carlo ray tracing of complex objects. *Computers & Graphics 19*, 2 (March 1995), 215–224. 252

[Jen96] JENSEN H. W.: Global illumination using photon maps. In *Rendering Techniques '96* (June 1996), Pueyo X., Schröder P., (Eds.), Springer, Vienna, Austria, pp. 21–30. Proceedings of the Seventh Eurographics Workshop on Rendering, Porto, Portugal. 252

[LP03] LAVIGNOTTE F., PAULIN M.: Scalable photon splatting for global illumination. In *Proceedings of GRAPHITE 2003* (Melbourne, Australia, 2003), ACM, pp. 203–210. 252

[PP98] PETER I., PIETRIK G.: Importance driven construction of photon maps. In *Rendering Techniques '98* (June 1998), Drettakis G., Max N., (Eds.), Springer, Vienna, Austria, pp. 269–279. Proceedings of the Ninth Eurographics Workshop on Rendering, Vienna, Austria. 253

[SB97] STÜRZLINGER W., BASTOS R.: Interactive rendering of globally illuminated glossy scenes. In *Rendering Techniques '97* (June 1997), Dorsey J., Slusallek P., (Eds.), Springer, Vienna, Austria, pp. 93–102. Proceedings of the 8th Eurographics Workshop on Rendering, Saint-Etienne, France. 252

[SFES07] SCHJØTH L., FRISVAD J. R., ERLEBEN K., SPORRING J.: Photon differentials. In *Proceedings of GRAPHITE 2007* (Perth, Australia, December 2007), ACM, pp. 179–186. 253

[Shi90] SHIRLEY P.: A ray tracing method for illumination calculation in diffuse-specular scenes. In *Proceedings of Graphics Interface '90* (Halifax, Nova Scotia, Canada, May 1990), Academic Press Professional, pp. 205–212. 252

[SOS06] SCHJØTH L., OLSEN O. F., SPORRING J.: Diffusion based photon mapping. In *Proceedings of the First International Conference on Computer Graphics Theory and Applications (GRAPP 2006)* (Setúbal, Portugal, February 2006), INSTICC, pp. 168–175. 253

[SOS07] SCHJØTH L., OLSEN O. F., SPORRING J.: Diffusion based photon mapping. In *Advances in Computer Graphics and Computer Vision*, vol. 4 of *Communications in Computer and Information Science*. Springer, Berlin Heidelberg, Germany, 2007, pp. 109–122. 253

[Str88] STRAUSS P. S.: *BAGS: The Brown Animation Generation System*. PhD thesis, Brown University, May 1988. 252

[SW01] SUYKENS F., WILLEMS Y. D.: Path differentials and applications. In *Rendering Techniques 2001* (June 2001), Gortler S. J., Myszkowski K., (Eds.), Springer, Vienna, Austria, pp. 257–268. Proceedings of the 12th Eurographics Workshop on Rendering, London, UK. 253

[SWH*95] SHIRLEY P., WADE B., HUBBARD P. M., ZARESKI D., WALTER B., GREENBERG D. P.: Global illumination via density-estimation. In *Rendering Techniques '95* (June 1995), Hanrahan P., Purgathofer W., (Eds.), Springer, Vienna, Austria, pp. 219–230. Proceedings of the Sixth Eurographics Workshop on Rendering, Dublin, Ireland. 252

[Wat90] WATT M.: Light-water interaction using backward beam tracing. *Computer Graphics (Proceedings of ACM SIGGRAPH 90) 24*, 4 (August 1990), 377–385. 252

[WHSG97] WALTER B., HUBBARD P. M., SHIRLEY P., GREENBERG D. P.: Global illumination using local linear density estimation. *ACM Transactions on Graphics 16*, 3 (July 1997), 217–259. 252