High Quality Rendering of Surfaces Represented Using Large Number of Points.

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by

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Synopsis

Triangles are the most basic primitives of surface modeling and rendering in computer graphics. Graphics hardware and pipeline are optimized for processing triangle primitives. However, *points* as rendering primitives has received a lot of attention recently. The idea of using points as surface primitives was proposed by Levoy and Whitted in 1985. The new found interest in points is due to advances in scanning technologies and rapidly growing complexity of polygonal geometric objects. Recent advances in 3D model-acquisition technologies, such as laser scanning, have led us to a stage where we can now scan more accurately (at sub-micron levels) as well as at great distances (even entire cities, in some cases). This has led to the emergence of massive and highly detailed 3D point-cloud data. Such large point-cloud datasets have inspired new research direction in their representation and rendering.

The most attractive feature of the point-based primitives is its simplicity. No information about connectivity or topology of the surface is stored explicitly. Adaptive modification and dynamic sampling of the surface do not suffer from complexity and robustness like triangle mesh. The level of detail is simple, fast and almost continuous. However, points based methods suffer from surface normal discontinuities in representation. Shading is also not independent from sampling rate.

Point based models can be visualized by rendering the points directly. Each sample in the representation has certain attributes (normal, color, material properties) for rendering and shading them as a continuous surface. Typically a point sample also has a radius to define an area around it. Such samples are called *surfels* and approximate the shape of the surface linearly in their neighborhood. A large number of surfels are needed for a good representation of the geometry. They must cover the whole surface to assure hole-free reconstruction of surface. Since linear splats can only be flat shaded, such representations require a large number of samples for a good shading quality. The use of a large number of splats slows the rendering due to increase in rendering computation and related memory bus activity.

Point-based rendering suffer from the limited resolution of the fixed number of samples representing the model. At some distance, the screen space resolution is high relative to the point samples, which causes under-sampling. A better way of rendering a model is to re-sample the surface during the rendering at the desired resolution in object space, guaranteeing a sampling density sufficient for image resolution. Output sensitive sampling samples objects at a resolution that matches the expected resolution of the output image. This is crucial for hole-free point-based rendering. Many technical issued related to point-based graphics boil down to reconstruction and re-sampling. A point based representation should be as small as possible while conveying the shape well.

In first part of this thesis, we present a compact representation for point based models using non-linear surface elements. In second part, we present a method for fast ray casting of a dynamic surface defined by large number of attributed points called Metaballs.

Algebraic Splats: Linear splats or surfels are popular rendering primitives for point based representation. Higher-order approximations of the local neighborhood have the potential to represent the shape using fewer primitives, simultaneously achieving higher rendering speeds and quality. In this thesis, we present *algebraic splats*, which are low-order polynomials that approximate the local neighborhood of a pointset. We adapt the Moving Least Squares (MLS) approximation to generate algebraic splat representations for a given point set. Quadratic and cubic splats as basic rendering primitive are able to approximate point-based models using 10% or fewer points than linear splats, for equivalent visual quality. Though rendering a non-linear patch is slower compared to a linear splat, the overall speed of rendering of an object could be faster. The approximation error can also be less using a small number of higher order primitives. We represent a given point set with a user-specified small number of algebraic splats with optimal rendering quality. This is done by decimating the point set and jointly approximating each using a local algebraic surface based on the Moving Least Squares (MLS) approximation.

Our rendering provides smooth surfaces with normals everywhere. We can render polynomials directly on today's GPUs using ray-tracing because of the semi-implicit nature of the splats in the local reference domain. The major contributions of this work are: (i) A compact and lightweight representation for point geometry using nonlinear surface elements, called algebraic splats. (ii) The representation is also extended to a multi-resolution structure which provides continuous Level of Detail. and (iii) A ray-tracing approach to render the algebraic splats on the GPU. The method includes an adaptive anti-aliasing step to obtain smooth silhouettes. The David 2mm model can be represented using about 30K (or 0.8% of original) algebraic splats with little or low reduction in visual quality. We can raycast the David model with adaptive antialiasing (3×3 grid) at 130-150 fps and 80-90 fps with shadowing.

Metaballs: Since the available computational power is steadily growing, more and more science areas rely on simulations of ever-growing problem sizes producing a respectively huge amount of data output. Simulation and experimental measurement in life sciences, physics, chemistry, materials, and thermodynamics yield large and often also time-dependent datasets. Interactive visualization is the key service that facilitates the analysis of such datasets and thus enables the researchers in those fields to quickly assess and compare the results of a simulation or measurement, verify and improve their models, and in so doing coming ever closer to understanding how dynamic processes work.

Metaballs are used to visualize the results of particle based simulations. Metaballs (also known as blobs) are popular particle-based implicit surface representations. Metaballs are attributed point set. Every metaball has a density function. A set of them can represent smooth deformable, free-form shapes represented as the iso-surface of a scalar field. They have been used widely to visualize the results of particle based simulations, fluids, and other dynamic objects. Such simulations use a very large number of particles, usually in the order of millions. A fast method to render a large number of metaballs at

high quality is thus desirable. Current methods can handle only a moderate number of metaballs at interactive rates on commodity GPUs. In this thesis, we present a method to handle a million or more dynamic metaballs at interactive rates. We use a perspective grid as the acceleration structure, which is built in each frame on the GPU using fast primitives. Perspective grids provide perfect coherence to primary rays. We ray trace each grid cell at a time using an adaptation of the marching points methods to metaballs. This method extracts high performance from the SIMD GPUs of today. We show interactive handling of upto a million balls. Our method is also able to handle secondary rays, though at much reduced speeds due to the lack of coherence but is suitable for live visualization of particle-based simulations.

Related Publications

1. Naveen Kumar Bolla, Narayanan P J, **Algebraic Splat Representation For Point Based Models** (Conference Paper), *IEEE Sixth Indian Conference on Computer Vision, Graphics and Image Processing (ICVGIP 2008)*,$71-78$, 16-19 Dec,2008, Bhubaneswar, India.

2. Naveen Kumar Bolla, Narayanan P J, **Algebraic Splats for High-Quality Rendering of Points** (Journal Submission) *(Submitted to Graphical Models, Under Review)*

3. Naveen Kumar Bolla, Narayanan P J, **Real-time Ray-tracing of Million Metaballs** (Submitted to EGSR)