Lecture 21: Point-based Rendering

Fall 2004

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Announcements

- In-class exam next week Nov 18th.
- Regrade requests in writing
  - Will regrade whole assignment

Complexity

- Lighting: many lights, environment maps
  - Global illumination, shadows
- Materials: BRDFs, textures
- Geometry: Level-of-detail, point-based representations
- All: impostors, image-based rendering

Motivation

- Scene complexity is increasing
- Scanning is producing large point datasets
- Procedural model generation (trees, plants)

4 million pts.
[Levoy et al. 2000]

Motivation

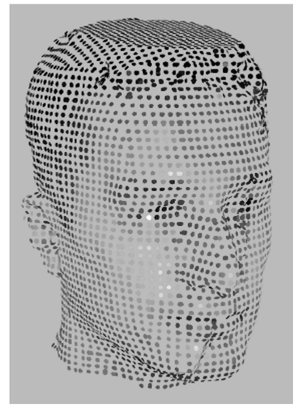
- Creating meshes from scanned datasets
  - Hard
  - Not robust
- Projected triangles too small
  - Many triangles per pixel
  - Setup and rasterization useless

Insight

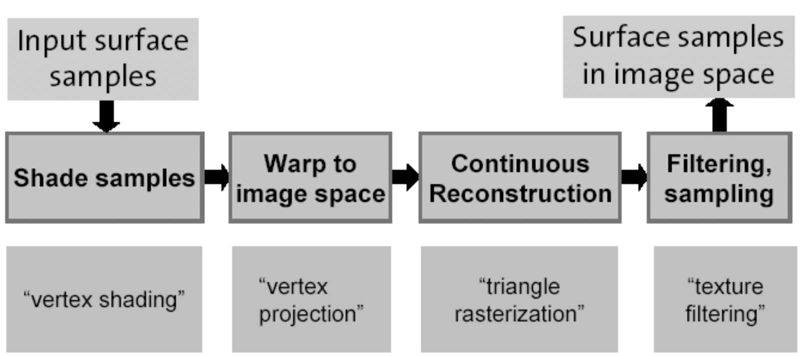
- Use points as a rendering primitive
- Avoid creating meshes
  - Connectivity information
  - More robust
  - Compact
  - Matches data sets better…

Point-Based Representation

- Point cloud represents
  - 3D geometry of surface
  - Surface reflectance
    - Diffuse, color
- No connectivity
- No texture information



Rendering Pipeline

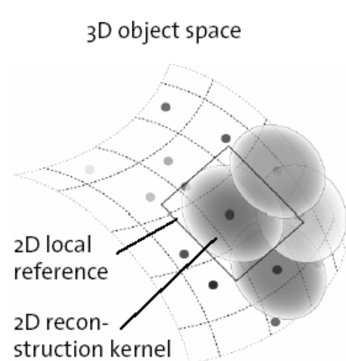


Rendering points

- Map a point to image plane
- What do we do with holes?
- Filter kernels (Gaussian)
  - Merge nearby points to reconstruct pixel

Surface Splatting

- Surface samples are specified in local reference frame with respect to normal
  - Sphere or disk representation



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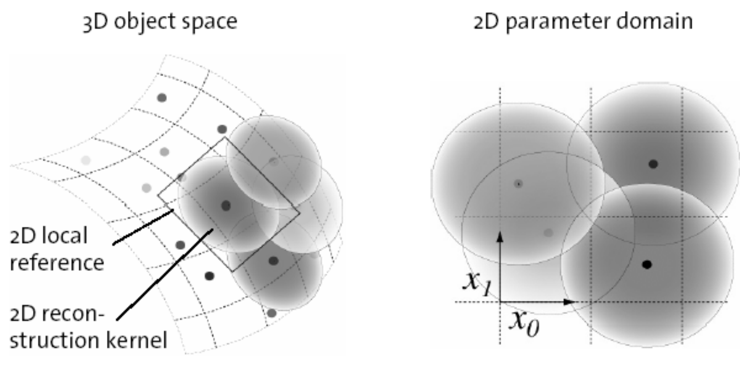
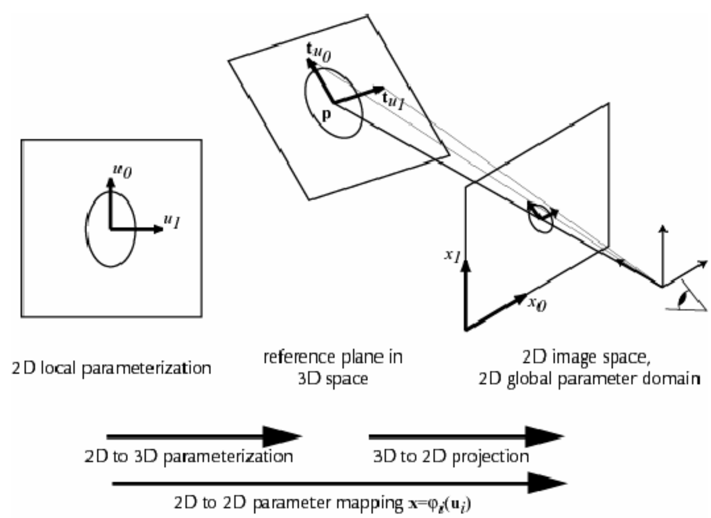
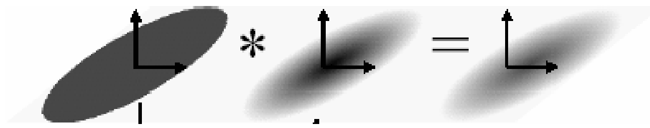
Splat on image plane

- Warp to image space
  - 2D to 2D projective mapping





Combining multiple points

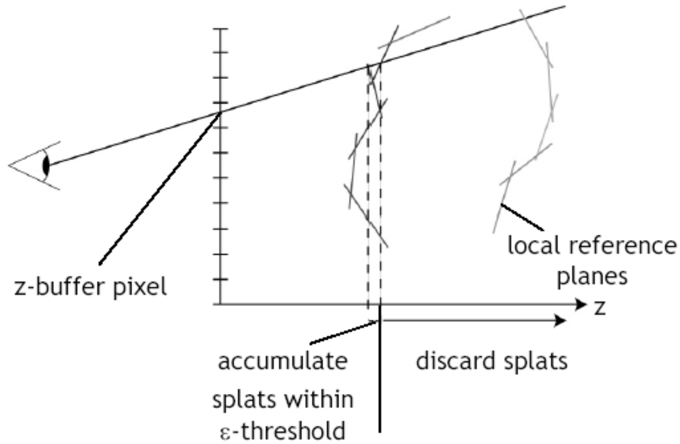


- Weighted sum of kernels in image space
  - Normalize weights of kernels

Algorithm

- For each point
  - Shade point
  - Splat = projected reconstruction filter kernel
  - Rasterize and accumulate splat
- For each output pixel
  - normalize

Z-buffer

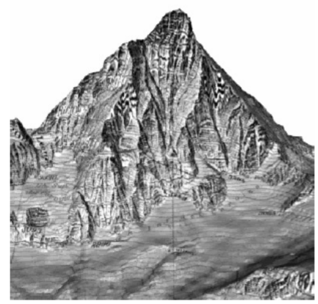


3-pass GPU Algorithm

- Pass 1: Depth image with depth offset epsilon away from viewpoint
  – Do z-buffer tests
- Pass 2: Draw colored splats with additive blending. Accumulate
  – Colors of visible splats in color channels
  – Visible footprint in alpha channels
- 3rd pass: Normalize color channels (divide by alpha channel)

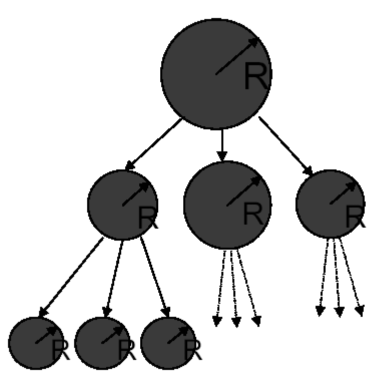
Results

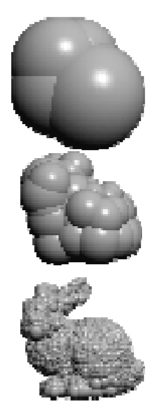
- Scanned head: 429k points
- Matterhorn: 4,787k points
- On GPUs: 3M points/sec



LODs with points

- Hierarchical data structure
- Q-splat [SIGGRAPH 2000]

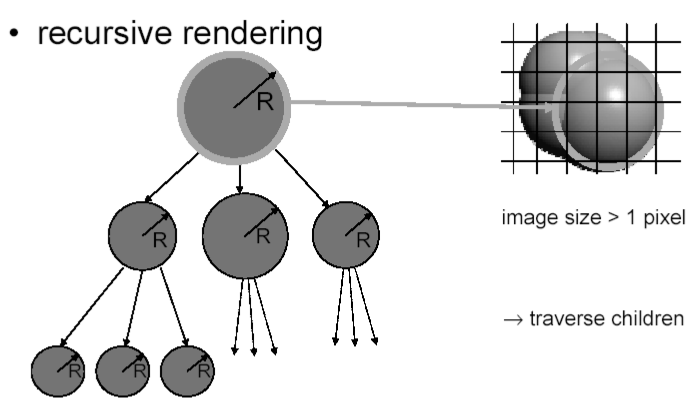




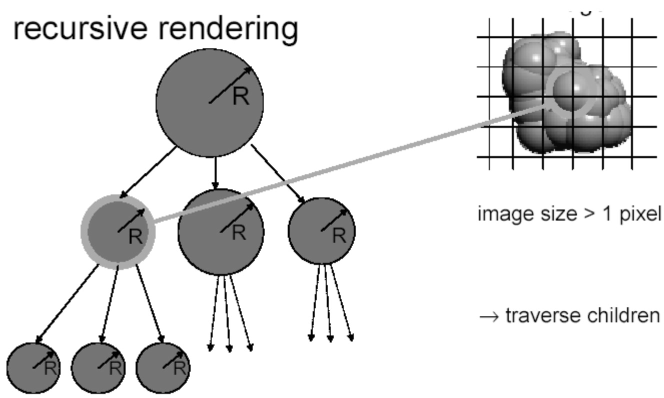
Construction

- Each vertex of original mesh is leaf sphere (such that adjacent vertices overlap)
- Construct top down
- Store sphere center, radius, normal
  - All quantized for compactness

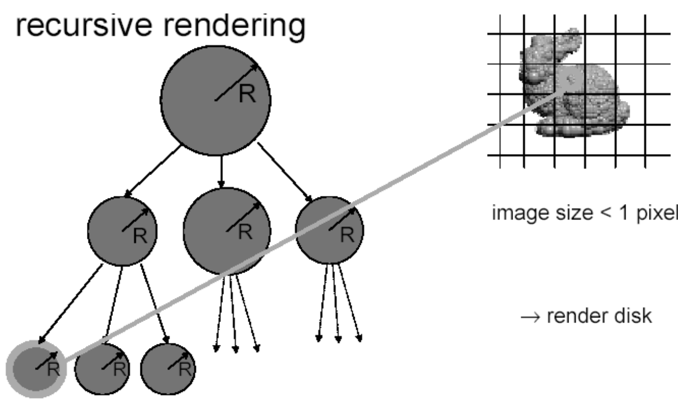
Hierarchical Traversal



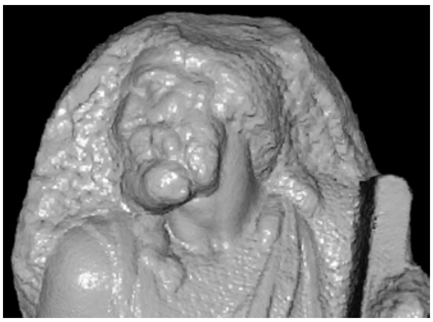
- recursive rendering



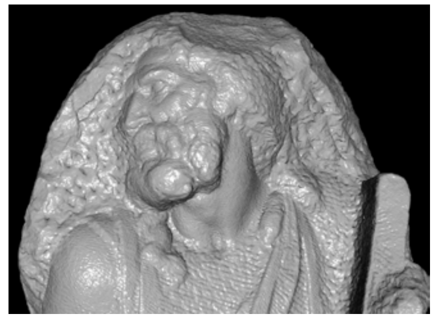
- recursive rendering



Results



130k splats, 132 ms



1M splats, 722 ms

Other point-based work

- Anti-aliasing of points/textures
- Hybrid rendering: polygons and points
- Point editing and animation
- Expensive shading with points: open question

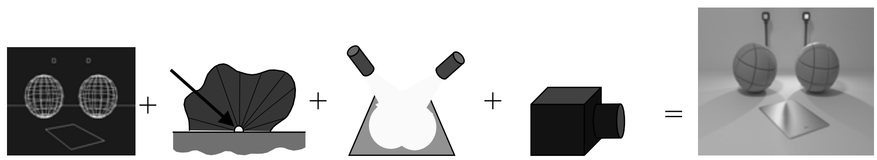
Complexity

- Lighting: many lights, environment maps
  – Global illumination, shadows
- Materials: BRDFs, textures
- Geometry: Level-of-detail, point-based representations
- All: image-based rendering

Scene Complexity

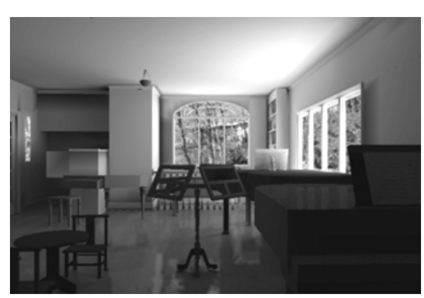
Computer Graphics

Geometry + Material (BRDF) + Lights + Camera = **Image**



Why is image generation slow?

- Requires labor-intensive modeling: geometry and BRDF
  - Hard
  - Tedious
  - Error-prone



- Rendering time long
  - Global illumination
  - Proportional to complexity

One Approach: Texture Mapping

- Use textures to create the effect of complex geometry and lighting conditions
  - displacement mapping
    - change position of surface
  - bump mapping
    - change normal
  - reflection/environment mapping

Bump Mapping

Reflection Mapping

(Terminator II - 1991)

Texture Mapping not enough!

- How do we create textures?
  - Model BRDFs and colors
- To what geometry should we apply textures? How?
  - Model geometry
  - But, simple models
    - flat textures, don't look good
  - Complex models
    - time consuming, tedious, hard to map

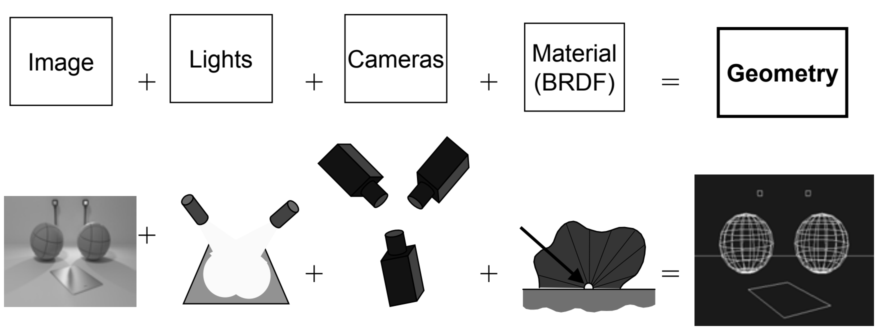
Idea

- **Can we use photographs?**

- **Photographs capture**
  - High geometric complexity
  - High lighting and material (BRDF) complexity

- **How do we use them?**

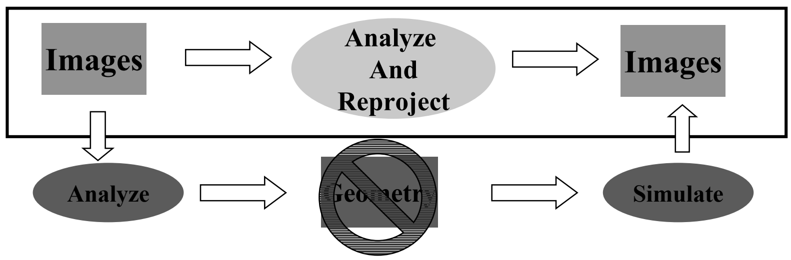
Machine Vision



- **Given images, find geometry of scene**
- **Problem: very hard inverse problem**
  - **too many unknowns**

Image-based Approaches

- Combine vision and graphics
- Given images and *some* geometry
  – Render new images from existing images
  – New idea: Image is input *and* rendering primitive
  – No (or very little) geometry recovery



Pros

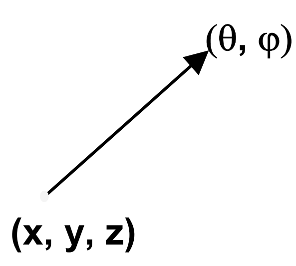
- Promising approach to handle complexity
- Benefits:
  – No labor-intensive modeling
  – Captures high geometric/material complexity
  – Rendering time constant: proportional to image size, independent of scene complexity

Outline

- Theory
- Image-based Rendering
- Image-based Modeling
  - Façade

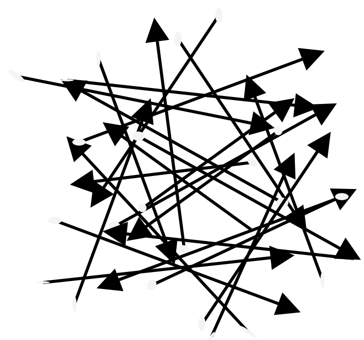
The Plenoptic Function

- P(x, y, z, θ, φ): radiance over all points in space and in all directions
  - 5D function: theoretical concept
- Why do we care? Rendering computes P



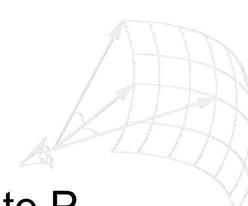
Plenoptic function

- Radiance value for all possible rays = P



Images are subset of P

- Think of an image in a new way!!!
- Image = radiance for each ray in image
  = radiance through a collection of rays
  = subset of plenoptic function P



- 1 Input image = subset of P
- Several input images approximate P
- All possible images = P

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IBR idea

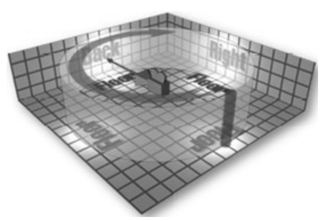
- Idea: Replace scene by images
- Output: new viewpoint
  - Look up plenoptic fn. → look up input images
- What are the assumptions?
  - Existing scene
  - Static scene
  - Fixed lighting

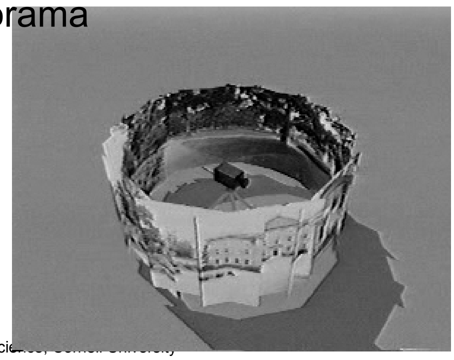
Approaches

- Systems that have no depth
  - Quicktime VR
  - Plenoptic Modeling
  - Lightfields/Lumigraphs
  - Image-based visual hulls
- Systems that have full geometry
  - Surface Lightfields
- Systems that have partial geometry: Image-Based Modeling
  - Façade

QuickTime VR

- Fixed viewpoint + full range of viewing directions (360^0)
- Panoramic images:
  - Stitch image to form panorama
  - Can look around panorama





Quicktime VR

- Demo
- Pros
  - Simple, fast, effective
- Cons
  - Camera position is confined to predefined observer positions
  - Distortion when user deviates from position