Computer Graphics

Point Based Representations

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Overview

1. Motivation
2. Representation
3. Processing, Editing, and Modeling
4. Rendering and Display
5. Point Based Video
6. Lessons learned
7. Physics Based Animation (Next lecture)
1. Motivation
Polynomials....

✓ Rigorous mathematical concept
✓ Robust evaluation of geometric entities
✓ Shape control for smooth shapes

✗ Require proper parameterization
✗ Discontinuity modeling
✗ Topological flexibility

Reduce $p$, refine $h$!
Triangles...

✓ Simple geometric primitives
✓ Hardware to support them
✓ Digital processing
✓ Explicit topology
✓ The widely accepted queen of graphics primitives

✗ Separation of geometry and attributes
✗ Complex LOD management
✗ Compression and streaming is highly non-trivial
Getting to the point…

✓ Natural representation for many 3D acquisition systems
✓ No separation of geometry and appearance/attributes
✓ No separation of surfaces and volumes

✗ No connectivity or topology
✗ …possibly more…?
Points – A Motivation

• 3D content creation pipeline 1997-2009

Points generalize Pixels!
2. Representation
Surface Model

• Compute continuous surface from a set of discrete point samples

\[ P = \{ p_i, c_i, m_i, \ldots \} \]

discrete set of point samples

continuous surface interpolating or approximating \( P \)
Surface Model

- Moving least squares (MLS) approximation
  - Surface defined as stationary set of projection operator $\Psi_P \Rightarrow$ implicit surface model
    \[
    S_P = \{ x \in \mathbb{R}^3 \mid P(x) = x \}
    \]
  - Weighted least squares optimization
    - Gaussian kernel function
      - local, smooth
      - mesh-less, adaptive

[Alexa, Levin, Amenta, et al.]
Point Set Surfaces (PSS)

2D-example: smooth curve from a set of points using moving least squares (MLS) approximation

[Levin 2003], [Alexa et al. 2001, 2003]
Simple PSS definition

\[ \{ \mathbf{x} \mid f(\mathbf{x}) = |\mathbf{x} - \hat{\mathbf{p}}(\mathbf{x})|^T \hat{\mathbf{n}}(\mathbf{x}) = 0 \} \]
Issues

• Loss of detail, tight fits, stability
Spherical MLS

[Guennebaud, Gross, Siggraph 2007]

- Projection onto algebraic sphere
- Improved Stability
- Curvature for free
- Very fast on GPU
Progressive Downsampling

Level 0
Sampling count: 152807

From 150K to 5 points ...
Stability

Spherical fit
Filter radius: 1.2

Plane fit

APSS

SPSS
Differential Operators

Real-Time APSS
Phong shading

APSS aims to define a smooth surface by fitting spheres.

=> e.g., accessibility shading
Results - Kernel Regression

- Edges and Corners

LKR

APSS
3. Processing, Editing, Modeling
Local Surface Analysis

[Pauly, Gross, Kobbelt, IEEE Vis 2002]
Resampling - Particles

- Resample surface by distributing particles
  - Relaxation - Adjust repulsion radius
  - Upsampling possible (Heckbert)

original model
296,850 points

uniform repulsion
2,000 points

adaptive repulsion
3,000 points
Particle Simulation
Resampling - Simplification

- Iteratively contracts point pairs (Hoppe)
  - Uses quadric error metric (Heckbert)
  - Similar to QSlim

296,850 points
2,000 points
remaining contraction pairs
3D Image Editing

- Interactive 3D painting
- Cleaning
- Carving
- Textureing and antialiasing
- Modeling
- Spectral processing
- ...of point sampled geometry

From 2D Pixels to 3D Points
Pointshop 3D

- Interactive system for point-based surface editing
- Generalize 2D photo editing concepts and functionality to 3D point-sampled surfaces
- Use 3D surface pixels (surfels) as versatile display and modeling primitive

- Does not require intermediate triangulation

[Zwicker, Pauly, Knoll, Gross, Siggraph 2002]
Concept

Parameterization

Resampling

Editing Operator
Parametrization

- Constrained minimum distortion parameterization
  \[ C(X) = \sum_j \left\{ X(u_j) - x_j \right\}^2 + \int_\Omega \frac{\partial^2 X}{\partial u^2} \, du = \text{min}. \]

- Feature points
- Distortion

- Extension to irregular point clouds
- Multigrid solver for resulting sparse linear least squares problem
Parametrization

- Landmarks set interactively by the user (Levy)
Examples

• Painting textures
Examples

- Engraving surface detail
Examples

• Filtering appearance and geometry
Examples

• Multiscale feature extraction

[Pauly, Keiser, Gross, Eurographics 2003]
3D Haptic Painting

- Mass-spring skeleton
  - Physically-based deformation
  - Force feedback

- Point-sampled surface
  - Geometric deformation
  - Paint transfer

Paint Transfer

1. Sample Collection
2. Paint Buffer Construction
3. Object Sample Projection
4. Brush Sample Projection
5. Paint Model Evaluation
6. Reprojection

No separation of geometry and texture, no connectivity!
Brush Splitting
Paint Transfer
Results
Painted Bunnies

- No separation of geometry and texture
- No charting and parametrization
Multi-Scale Modeling

- Scale spaces: levels of smoothness

⇒ same degrees of freedom on smoothest level
Multi-Scale Modeling

- Discretization: base domain + orthogonal diff.

[Pauly, Kobbelt, Gross, TOG 2006]
Free-form Deformation
Filtering
Interactive Editing

- Editing metaphor
  - continuous free-form deformation function
  - smooth transition between deformed and un-deformed region
  - deformation function composed of simple translation and rotation components
Example

• Large Deformations, Dynamic Resampling

[Pauly, Keiser, Kobbelt, Gross Siggraph 2003]

10,000 points

271,743 points
Dynamic Sampling

- Interpolate scalar attributes
Boolean Operations

- Signed distance function by MLS operator

![Diagram of Boolean operations with shapes: cylinder, sphere, and other geometric objects.](image)
4. Rendering
Surfels

- Framebuffer resolutions stay roughly the same
- Size of typical triangles in complex 3D models project to < 1 pixel
- Point or pixel based rendering methods become more and more attractive
- Points store several surface attributes (**surfels**)
- To render, forward project each point separately
• After projection the image may contain holes

• Texture and edge aliasing
Forward Warping

347 K points

204 K points
A Closer Look onto Sampling

- Unified approach to reconstruction and aliasing
- EWA, Heckbert 86

minification

magnification

128 x 192

aliasing

holes
Warping Reconstruction Kernels

forward projection

reconstruction kernel

warped reconstruction kernel
Gaussian Kernels

\[ g(x) = \sum_k w_k r_k(m^{-1}(x)) \otimes h(x) \]

Gaussian reconstruction kernel
Gaussian low-pass filter

screen space

screen space
Irregular Textures

pixel sampling

optimized screen space EWA

sampling pattern

[Zwicker, Pfister, Baar, Gross Siggraph 2001]
Examples

• Combine reconstruction and band limitation
Improvements

- Phong Shading & Shadow Maps

[Botsch at al. PBG 2005]
Ray-Tracing

• Compute ray intersection with MLS surface

[Adams, Keiser, Dutre, Pauly, Gross, Guibas, EG 05]
Examples

[Alexa et al. 2004], [Adams et al. 2005]
Point Rendering Hardware

- ASIC and FPGA design
- 30 Mio. EWA splats/s
- Lean architecture
- FP units for geometry
- 0.25 μm, 500KG
Integration Into Poly Pipelines

• Re-use of existing GPU units
• Novel Units
  – Splat rasterizer
  – Ternary depth test
  – Accumulation
  – Surface reconstruction buffer
  – Normalize

[Weyrich et al., Siggraph 2007]
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