Shape Modeling with Point-Sampled Geometry

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Motivation

• Surface representations
  – Explicit surfaces (B-reps)
    • Polygonal meshes  - Efficient rendering
    • Subdivision surfaces  - Sharp features
    • NURBS  - Intuitive editing
  – Implicit surfaces
    • Level sets  - Boolean operations
    • Radial basis functions  - Changes of topology
    • Algebraic surfaces  - Extreme deformations
Motivation

- Surface representations
  - Explicit surfaces (B-reps)
    - Polygonal meshes
    - Subdivision surfaces
    - NURBS
  - Implicit surfaces
    - Level sets
    - Radial basis functions
    - Algebraic surfaces

- Hybrid Representation
  - Explicit cloud of point samples
  - Implicit dynamic surface model

Pauly, Keiser, Kobbelt, Gross: Shape Modeling with Point-Sampled Geometry
SIGGRAPH 2003
**Outline**

- Implicit surface model
  - Moving least squares approximation
- Interactive shape modeling
  - Boolean operations
  - Free-form deformation
- Demo
- Results & Conclusions

**Surface Model**

- Goal: Define continuous surface from a set of discrete point samples

```
discrete set of point samples
P = \{ p, c, m, ... \}
```

```
continuous surface S
interpolating or approximating P
```
**Surface Model**

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

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**Boolean Operations**

![Boolean Operations Diagram]
**Boolean Operations**

- **Classification**
  - Inside-outside test using signed distance function induced by MLS projection

- **Sampling**
  - Compute exact intersection of two MLS surfaces to sample the intersection curve

- **Rendering**
  - Accurate depiction of sharp corners and creases using point-based rendering
**Boolean Operations**

- **Classification:**
  - given a smooth, closed surface $S$ and point $p$. Is $p$ inside or outside of the volume $V$ bounded by $S$?
  1. find closest point $q$ on $S$

  2. classify $p$ as
     - inside $V$, if $(p-q) \cdot n < 0$
     - outside $V$, if $(p-q) \cdot n > 0$
Boolean Operations

• Classification:
  – represent smooth surface $S$ by point cloud $P$

1. find closest point $q$ in $P$
2. classify $p$ as
   – inside $V$, if $(p-q) \cdot n < 0$
   – outside $V$, if $(p-q) \cdot n > 0$
**Boolean Operations**

- **Classification:**
  - piecewise constant surface approximation leads to false classification close to the surface
Boolean Operations

• Classification:
  – piecewise constant surface approximation leads to false classification close to the surface
Boolean Operations

- Classification:
  - piecewise constant surface approximation leads to false classification close to the surface

- Classification:
  - use MLS projection of $p$ for correct classification
Boolean Operations

- Sampling the intersection curve

1. identify pairs of closest points
**Boolean Operations**

- Sampling the intersection curve
  1. identify pairs of closest points
  2. find closest point on intersection of tangent spaces
**Boolean Operations**

- Sampling the intersection curve
  1. identify pairs of closest points
  2. find closest point on intersection of tangent spaces
  3. re-project point on both surfaces

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**Boolean Operations**

- Sampling the intersection curve
  1. identify pairs of closest points
  2. find closest point on intersection of tangent spaces
  3. re-project point on both surfaces
  4. iterate
Free-form Deformation

- Smooth deformation field $F: \mathbb{R}^3 \rightarrow \mathbb{R}^3$ that warps 3D space
- Can be applied directly to point samples

Free-form Deformation

- Intuitive editing using painting metaphor
  - Define rigid surface part and handle using interactive painting tool
  - Displace handle using translation and/or rotation
  - Create smooth blend towards rigid part

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Dynamic Sampling

- Robust free-form deformation requires dynamic adaptation of the sampling density

10,000 points
271,743 points

Dynamic Sampling

- Dynamic insertion of point samples:
  - measure local surface stretch
  - split samples that exceed stretch threshold
  - regularize distribution by relaxation
  - interpolate scalar attributes
Results

- Combination of free-form deformation with collision detection, boolean operations, particle-based blending, embossing and texturing

Results

- Interactive modeling with scanned data: noise removal, free-form deformation, cut-and-paste editing, interactive texture mapping
Results

• The Octopus: Free-form deformation with dynamic sampling

Conclusions

• Point cloud: *Explicit* representation
  – Minimal consistency constraints allow efficient dynamic re-sampling
  – Modeling of sharp features
  – Fast rendering

• MLS approximation: *Implicit* surface model
  – Fast inside/outside tests for boolean classification and collision detection
Future Work

- Physics-based modeling
- Haptic interfaces
- Robust handling of singularities for boolean operations
- More complex surfaces, e.g. hairy or furry models

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- Check out: www.pointshop3d.com