Overview of 3D Object Representations

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(covering for Finkelstein)
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Course Syllabus
I. Image processing
II. Rendering
III. Modeling
IV. Animation

Modeling
• How do we ...
  ▪ Represent 3D objects in a computer?
  ▪ Construct such representations quickly and/or automatically with a computer?
  ▪ Manipulate 3D objects with a computer?

Different methods for different object representations

3D Objects
How can this object be represented in a computer?

3D Objects
This one?
3D Objects

How about this one?

Lorensen

This one?

H&B Figure 9.9

This one?

Representations of Geometry

- 3D Representations provide the foundations for

- They are languages for describing geometry

  Semantics
  - values
  - operations

  Syntax
  - data structures
  - algorithms

- Data structures determine algorithms!

3D Object Representations

- Raw data
  - Point cloud
  - Range image
  - Polygon soup

- Solids
  - Voxels
  - BSP tree
  - CSG
  - Sweep

- Surfaces
  - Mesh
  - Subdivision
  - Parametric
  - Implicit

- High-level structures
  - Scene graph
  - Skeleton
  - Application specific
Point Cloud
- Unstructured set of 3D point samples
  - Acquired from range finder, computer vision, etc

Range Image
- Set of 3D points mapping to pixels of depth image
  - Acquired from range scanner

Polygon Soup
- Unstructured set of polygons
  - Created with interactive modeling systems?

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Mesh
- Connected set of polygons (usually triangles)
  - May not be closed

Subdivision Surface
- Coarse mesh & subdivision rule
  - Define smooth surface as limit of sequence of refinements
Parametric Surface
- Tensor product spline patches
  - Careful constraints to maintain continuity

Implicit Surface
- Points satisfying: $F(x,y,z) = 0$

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Voxels
- Uniform grid of volumetric samples
  - Acquired from CAT, MRI, etc.

BSP Tree
- Binary space partition with solid cells labeled
  - Constructed from polygonal representations

CSG
- Hierarchy of boolean set operations (union, difference, intersect) applied to simple shapes
Sweep
• Solid swept by curve along trajectory

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Scene Graph
• Union of objects at leaf nodes

Skeleton
• Graph of curves with radii

Application Specific

Taxonomy of 3D Representations
Equivalence of Representations

- Thesis:
  - Each fundamental representation has enough expressive power to model the shape of any geometric object.
  - It is possible to perform all geometric operations with any fundamental representation!

- Analogous to Turing-Equivalence:
  - All computers today are turing-equivalent, but we still have many different processors.

Computational Differences

- Efficiency
  - Combinatorial complexity (e.g. \( O(n \log n) \))
  - Space/time trade-offs (e.g. z-buffer)
  - Numerical accuracy/stability (degree of polynomial)

- Simplicity
  - Ease of acquisition
  - Hardware acceleration
  - Software creation and maintenance

- Usability
  - Designer interface vs. computational engine

Complexity vs. Verbosity Tradeoff

- Verbosity / Inaccuracy
  - Pixels/voxels
  - Piecewise linear polyhedra
  - Low degree piecewise non-linear
  - Single general functions

- Complexity / Accuracy

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