



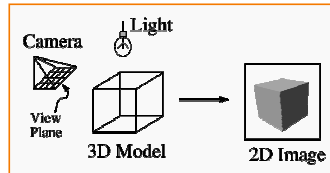
# Overview of 3D Object Representations

Tom Funkhouser  
Princeton University  
COS 426, Spring 2006



## Introduction

- What is computer graphics?
  - Imaging = representing 2D images
  - Rendering = constructing 2D images from 3D models
  - Modeling = representing 3D objects
  - Animation = simulating changes over time

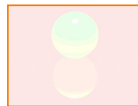


## Course Syllabus

- I. Image processing
- II. Rendering
- III. Modeling**
- IV. Animation



Image Processing  
*(Rusry Coleman, CS426, Fall09)*



Rendering  
*(Michael Bostock, CS426, Fall09)*



Modeling  
*(Dennis Zorin, CalTech)*

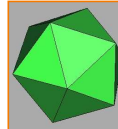


Animation  
*(Angel, Plate 1)*

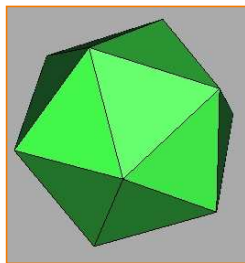


## Modeling

- How do we ...
  - Represent 3D objects in a computer?
  - Acquire computer representations of 3D objects?
  - Manipulate computer representations of 3D objects?
  - Analyze computer representations of 3D objects?



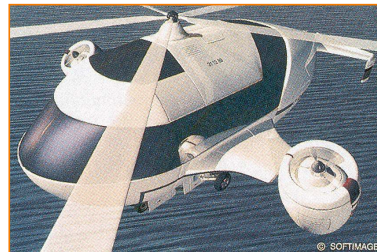
## 3D Objects



How can this object be represented in a computer?



## 3D Objects



This one?

© SOFTIMAGE  
H&B Figure 10.46

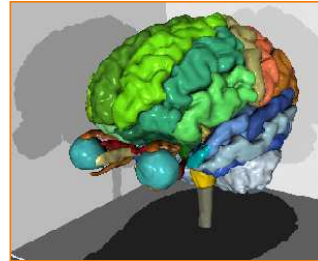
### 3D Objects



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How about this one?

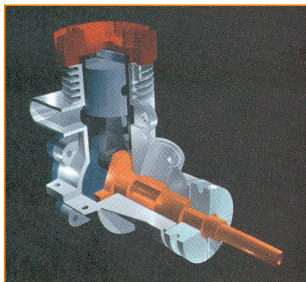
### 3D Objects



Lorensen

This one?

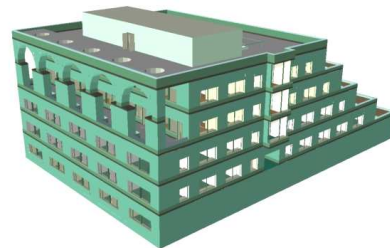
### 3D Objects



H&B Figure 9.9

This one?

### 3D Objects

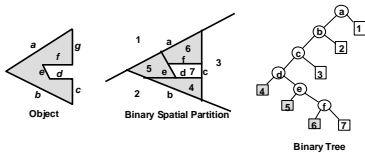


This one?

### 3D Object Representations



- A computational representation of geometry can be viewed as a language or a data structure

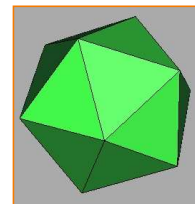


- The choice of 3D object representation can have great impact on algorithms
  - Data structures determine algorithms!

### 3D Object Representations



- Desirable properties
  - Accurate
  - Concise
  - Easy acquisition
  - Intuitive editing
  - Local support
  - Affine invariant
  - Arbitrary topology
  - Guaranteed validity
  - Guaranteed continuity
  - Natural parameterization
  - Efficient display
  - Efficient intersections



Polygonal Mesh

## 3D Object Representations



- Raw data
  - Point cloud
  - Range image
  - Polygon soup
- Surfaces
  - Mesh
  - Subdivision
  - Parametric
  - Implicit
- Solids
  - Voxels
  - BSP tree
  - CSG
  - Sweep
- High-level structures
  - Scene graph
  - Application specific

## Point Cloud



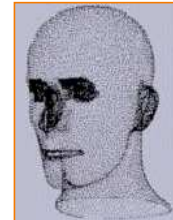
- Unstructured set of 3D point samples
  - Acquired from range finder, computer vision, etc



Polhemus



Microscribe-3D



Hoppe



Hoppe

## Range Image



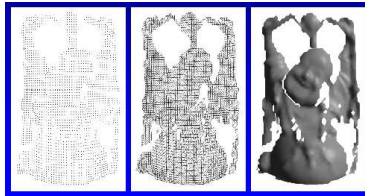
- Set of 3D points mapping to pixels of depth image
  - Acquired from range scanner



Cyberware



Stanford



Range Image

Tessellation

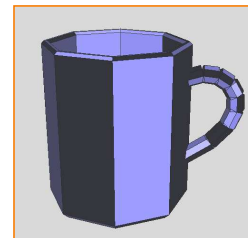
Range Surface

Brian Curless  
SIGGRAPH 99  
Course #4 Notes

## Polygon Soup



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



Larson

## 3D Object Representations

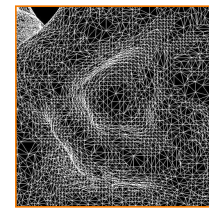


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## Mesh



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

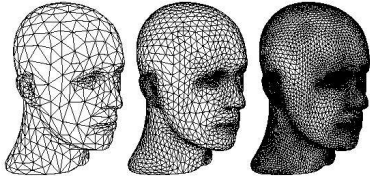


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## Subdivision Surface



- Coarse mesh & subdivision rule
  - Define smooth surface as limit of sequence of refinements

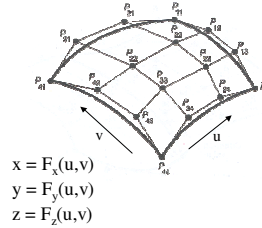


Zorin & Schroeder  
SIGGRAPH 99  
Course Notes

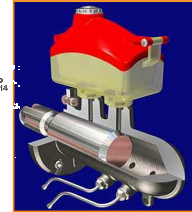
## Parametric Surface



- Tensor product spline patches
  - Each patch is parametric function
  - Careful constraints to maintain continuity



$$\begin{aligned} x &= F_x(u,v) \\ y &= F_y(u,v) \\ z &= F_z(u,v) \end{aligned}$$



FvDFH Figure 11.44

## Implicit Surface



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



Polygonal Model



Implicit Model

Bill Lorensen  
SIGGRAPH 99  
Course #4 Notes

## 3D Object Representations

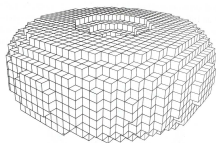


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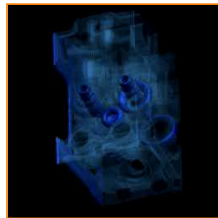
## Voxels



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



FvDFH Figure 12.20

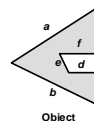


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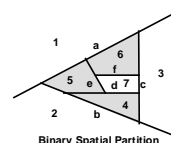
## BSP Tree



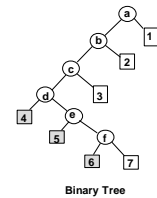
- Binary space partition with solid cells labeled
  - Constructed from polygonal representations



Object



Binary Spatial Partition



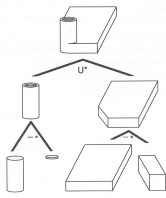
Binary Tree

Naylor

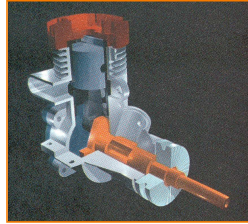
## CSG



- Hierarchy of boolean set operations (union, difference, intersect) applied to simple shapes



FvDFH Figure 12.27

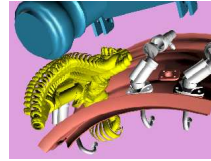


H&B Figure 9.9

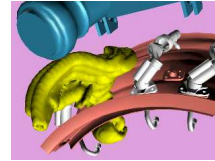
## Sweep



- Solid swept by curve along trajectory



Removal Path



Sweep Model

Bill Lorensen  
SIGGRAPH 99  
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## 3D Object Representations



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## Scene Graph



- Union of objects at leaf nodes



Bell Laboratories

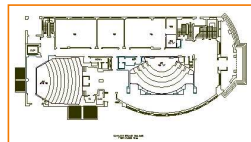


avalon.viewpoint.com

## Application Specific

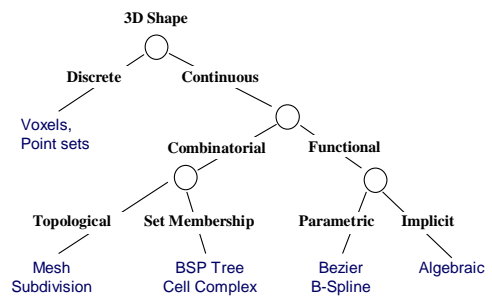


Apo A-I  
(Theoretical Biophysics Group,  
University of Illinois at Urbana-Champaign)



Architectural Floorplan  
(CS Building, Princeton University)

## Taxonomy of 3D Representations



Naylor

## Equivalence of Representations



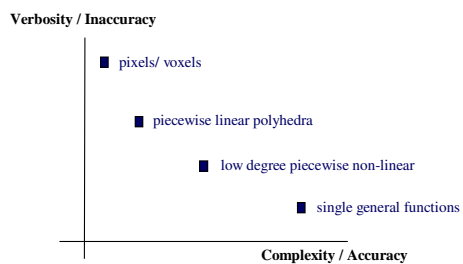
- Thesis:
  - Each fundamental representation has enough expressive power to model the shape of any geometric object
  - It is possible to perform all geometric operations with any fundamental representation!
- Analogous to Turing-Equivalence:
  - All computers today are turing-equivalent, but we still 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



## Summary



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