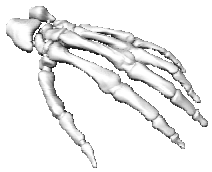
Solid Modeling

Tom Funkhouser
Princeton University
COS 426, Spring 2007

3D Object Representations

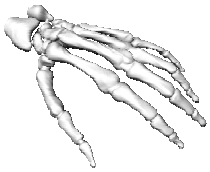
- Desirable properties of an object representation
  - Easy to acquire
  - Accurate
  - Concise
  - Intuitive editing
  - Efficient editing
  - Efficient display
  - Efficient intersections
  - Guaranteed validity
  - Guaranteed smoothness
  - etc.



Large Geometric Model Repository
Georgia Tech

3D Object Representations

- Properties of surface representations
  - Easy to acquire
  - Accurate
  - Concise
  - Intuitive editing
  - Efficient editing
  - Efficient display
  - ~~Efficient intersections~~
  - ~~Guaranteed validity~~
  - Guaranteed smoothness
  - etc.



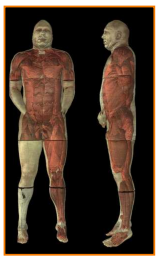
Large Geometric Model Repository
Georgia Tech

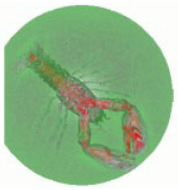
3D Object Representations

- Points
  - Range image
  - Point cloud
- Surfaces
  - Polygonal mesh
  - Subdivision
  - Parametric
  - Implicit
- Solids
  - Voxels
  - BSP tree
  - CSG
  - Sweep
- High-level structures
  - Scene graph
  - Application specific

Solid Modeling

- Represent solid interiors of objects
  - Surface may not be described explicitly





Visible Human
(National Library of Medicine)

Motivation 1

- Some acquisition methods generate solids
  - Example: CAT scan

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Motivation 2

- Some applications require solids
  - Examples: medicine, CAD/CAM

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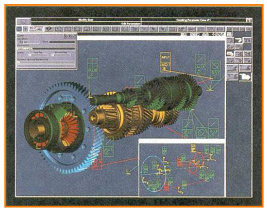
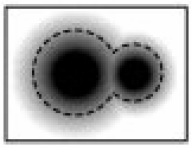


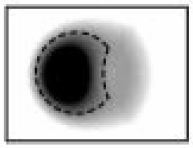
Intergraph Corporation

Motivation 3

- Some operations are easier with solids
  - Example: union, difference, intersection



Union



Difference

Bloomenthal

Solid Modeling Representations

- Voxels
- Quadtrees & Octrees
- KD and BSP Trees
- Constructive solid geometry

Solid Modeling Representations

- Voxels
- Quadtrees & Octrees
- KD and BSP Trees
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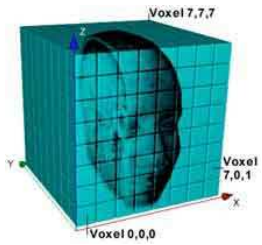
Voxels

- Regular array of 3D samples (like image)
  - Samples are called *voxels* (like pixels)



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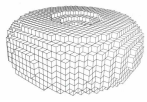
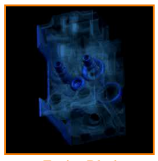


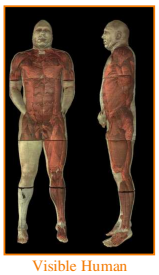
FvDFH Figure 12.20

Voxels

- Store properties of solid object with each voxel
  - Occupancy
  - Color
  - Density
  - Temperature
  - etc.

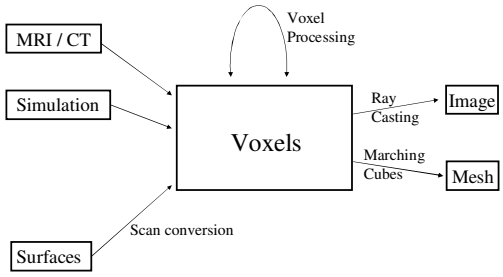


Engine Block
Stanford University



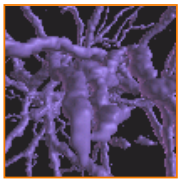
Visible Human
(National Library of Medicine)

Voxels

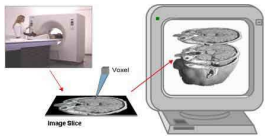


Voxel Acquisition

- Scanning devices
  - MRI
  - fMRI
  - CAT
  - etc.



SUNY Stoney Brook



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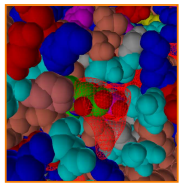
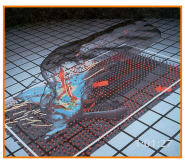
Voxel Acquisition

- Simulation
  - Models
  - FEM
  - etc.



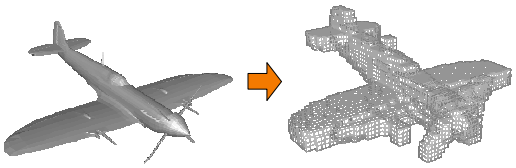


Airflow Inside a Thunderstorm

(Bob Wilhelmson, University of Illinois at Urbana-Champaign)

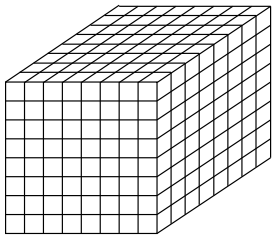
Voxel Acquisition

- Voxelization of surfaces



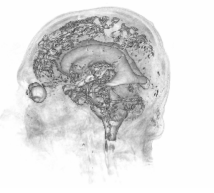
Voxel Storage

- $O(n^3)$ storage for nxnxn grid
  - 1 billion voxels for 1000x1000x1000



Voxel Processing

- Signal processing (just like images)
  - Reconstruction
  - Resampling
- Typical operations
  - Blur
  - Edge detect
  - Warp
  - etc.



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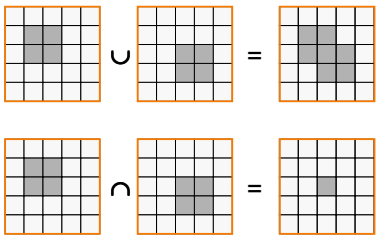
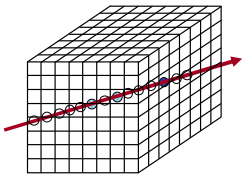
Voxel Boolean Operations

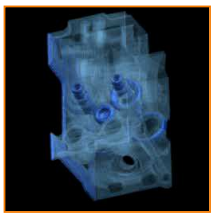
- Compare objects voxel by voxel
  - Trivial



Voxel Display

- Ray casting
  - Integrate density along rays through pixels





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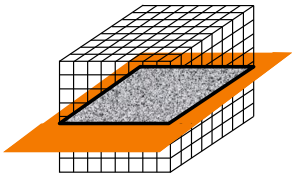
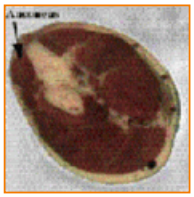
Voxel Display

- Slicing
  - Draw 2D image resulting from intersecting voxels with a plane





Visible Human
(National Library of Medicine)

Voxel Display

- Isosurface rendering
  - Render surfaces bounding volumetric regions of constant value (e.g., density)

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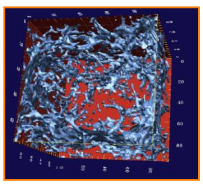
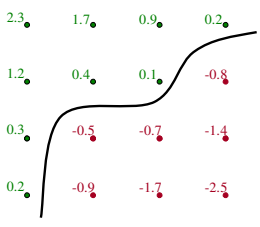


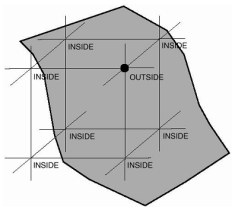
Princeton University

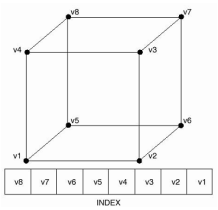
Voxel Display

- Isosurface rendering
  - Interpolate samples stored on regular grid
  - Isosurface at f(x,y,z) = 0 defines surface

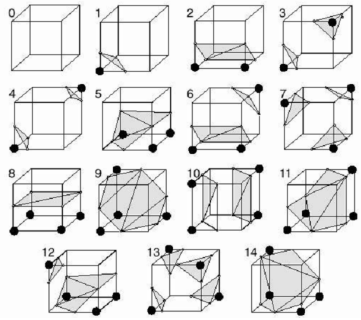


Marching Cubes





Marching Cubes (15 Cases)

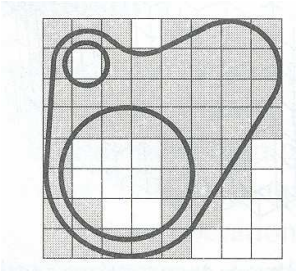


Voxels

- Advantages
  - Simple, intuitive, unambiguous
  - Same complexity for all objects
  - Natural acquisition for some applications
  - Trivial boolean operations
- Disadvantages
  - Approximate
  - Not affine invariant
  - Expensive display
  - Large storage requirements

Voxels

- What resolution should be used?



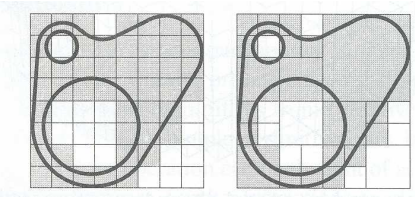
FvDFH Figure 12.21

Solid Modeling Representations

- Voxels
- Quadtrees & Octrees
- KD and BSP Trees
- Constructive solid geometry

Quadtrees & Octrees

- Refine resolution of voxels hierarchically
  - More concise and efficient for non-uniform objects

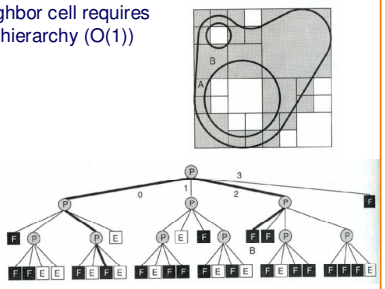


Uniform Voxels Quadtree

FvDFH Figure 12.21

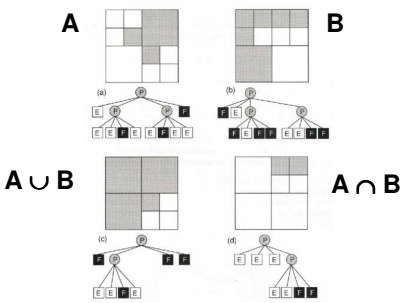
Quadtree Processing

- Hierarchical versions of voxel methods
  - Finding neighbor cell requires traversal of hierarchy (O(1))



FvDFH Figure 12.25

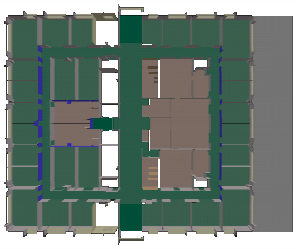
Quadtree Boolean Operations



FvDFH Figure 12.24

Quadtrees

- How concise/accurate are they?

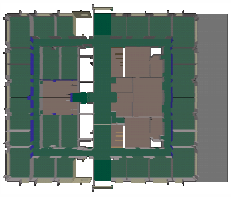


Solid Modeling Representations

- Voxels
- Quadtrees & Octrees
- KD and BSP Trees
- Constructive solid geometry

KD Trees

- Recursive binary partition of space by axis aligned planes



KD Trees

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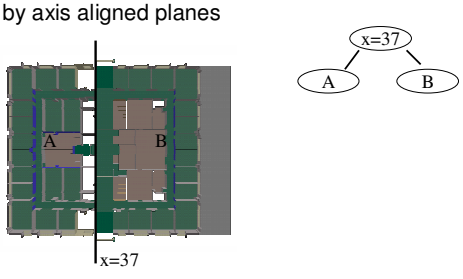

KD Trees

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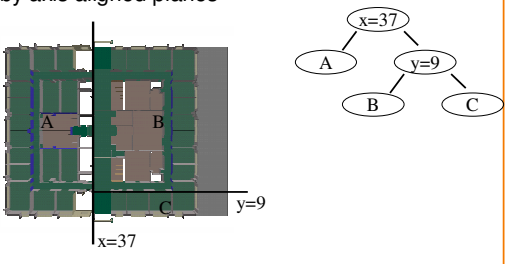

KD Trees

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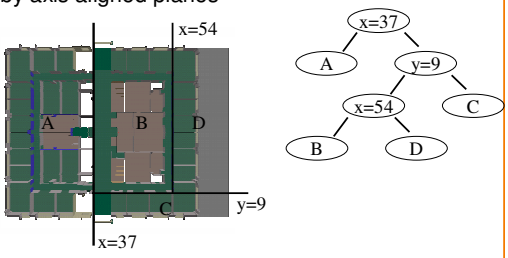
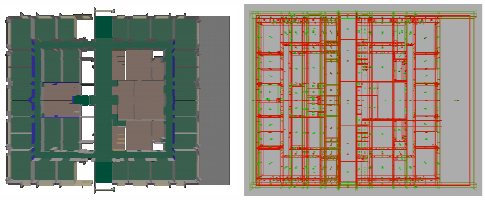


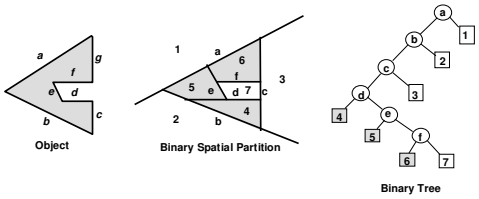
KD Trees

- Recursive binary partition of space by axis aligned planes



BSP Trees

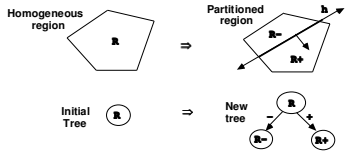
- Recursive binary partition of space by arbitrary planes



Naylor

BSP Trees

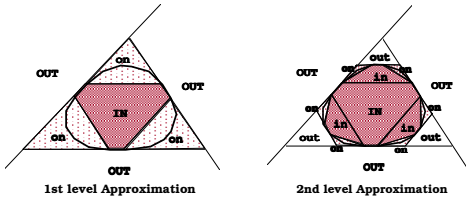
- Single geometric operation
  - Partition a convex region by a hyperplane
- Single combinatorial operation
  - Two child nodes added as leaf nodes



Naylor

BSP Trees

- Processing
  - Exploit hierarchy of convex regions
  - Exploit visibility ordering (later)



Naylor

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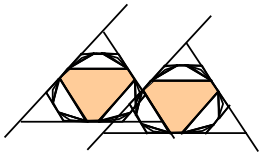


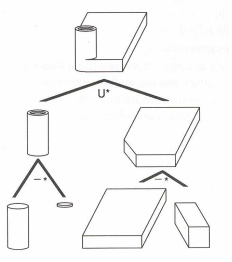
Naylor

Solid Modeling Representations

- Voxels
- Quadtrees & Octrees
- KD and BSP Trees
- Constructive solid geometry

Constructive Solid Geometry (CSG)

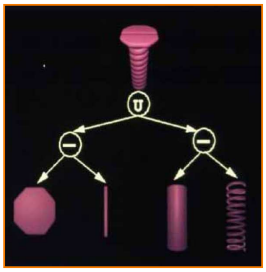
- Represent solid object as hierarchy of boolean operations
  - Union
  - Intersection
  - Difference



FvDFH Figure 12.27

CSG Acquisition

- Interactive modeling programs
  - Intuitive way to design objects



SUNY Stoney Brook

CSG Acquisition

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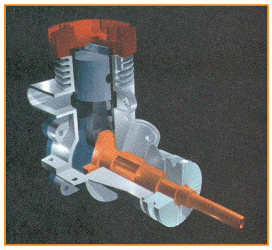
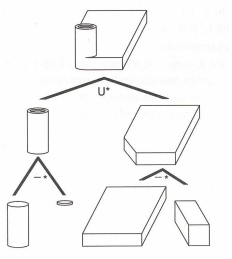


H&B Figure 9.9

CSG Boolean Operations

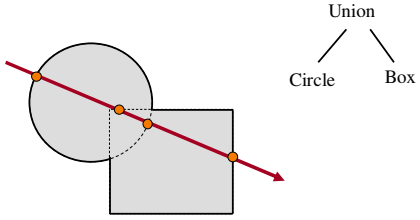
- Create a new CSG node joining subtrees
  - Union
  - Intersection
  - Difference



FvDFH Figure 12.27

CSG Display & Analysis

- Ray casting



Summary

	Voxels	Octree	BSP	CSG
Accurate	No	No	Some	Some
Concise	No	No	No	Yes
Affine invariant	No	No	Yes	Yes
Easy acquisition	Some	Some	No	Some
Guaranteed validity	Yes	Yes	Yes	No
Efficient boolean operations	Yes	Yes	Yes	Yes
Efficient display	No	No	Yes	No