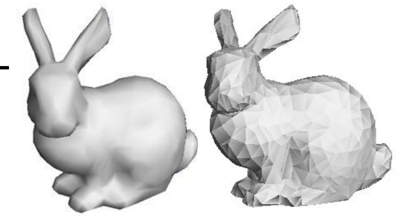
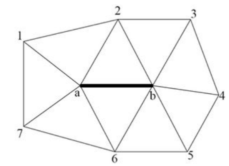
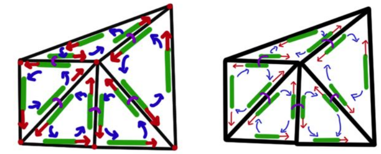
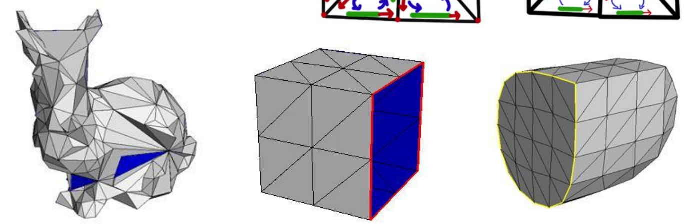
Implicit Surfaces, Collision Detection, & Volumetric Data Structures

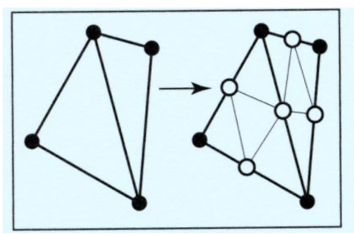
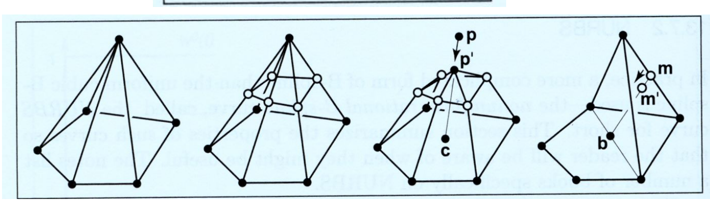
Homework 1:

- Questions/Comments?

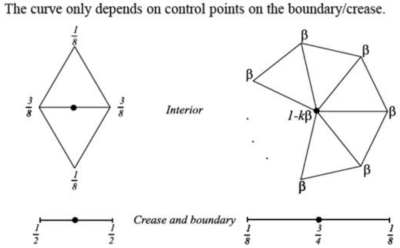
Loop Subdivision

Shirley, Fundamentals of Computer Graphics

Loop Subdivision

Subdivision Rules. The masks for the Loop scheme are shown in Figure 4.3. For boundaries and edges tagged as *crease* edges, special rules are used. These rules produce a cubic spline curve along the boundary/crease. The curve only depends on control points on the boundary/crease.



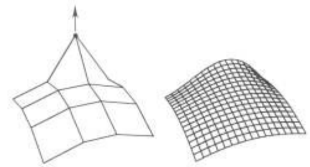
a. Masks for odd vertices *b. Masks for even vertices*

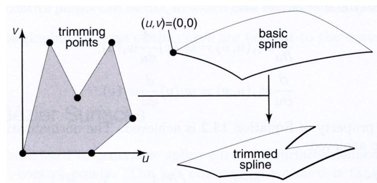
Figure 4.3: *Loop subdivision: in the picture above, β can be chosen to be either $\frac{1}{n}(5/8-(\frac{3}{8}+\frac{1}{4}\cos\frac{2\pi}{n})^2)$ (original choice of Loop [16]), or, for $n > 3$, $\beta = \frac{3}{8n}$ as proposed by Warren [33]. For $n = 3$, $\beta = 3/16$ can be used.*

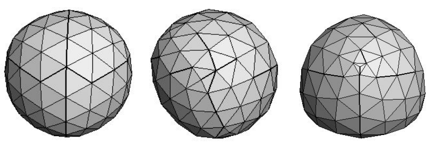
SIGGRAPH 2000 course notes
Subdivision for Modeling and Animation (page 70)

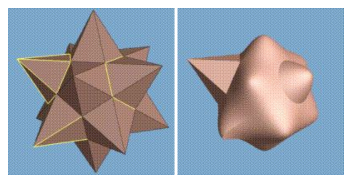
Last Time?

- Spline Surfaces
  - complex topology is challenging, requires trimming curves
- Subdivision Zoo
  - Doo-Sabin
  - Loop
  - Catmull-Clark
- Subdivision w/ Creases







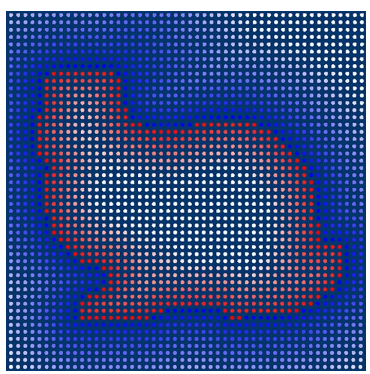


Today

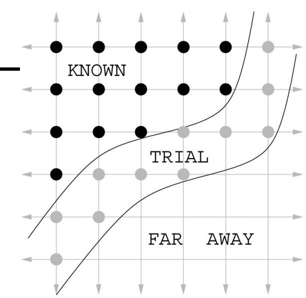
- Implicit Surfaces, Voxels, & Marching Cubes
- Collision Detection
- Conservative Bounding Region
- Spatial Acceleration Data Structures
  - Fixed Grid
  - Nested Grid
  - Octree
  - Binary Space Partition
  - K-d tree
  - Bounding Volume Hierarchy
- Papers for Friday

Implicit Surfaces

- For a sphere:
  $H(x,y,z) = x^2 + y^2 + z^2 - r^2$
- If $H(x,y,z) = 0$, on surface
- If $H(x,y,z) > 0$, outside surface
- If $H(x,y,z) < 0$, inside surface

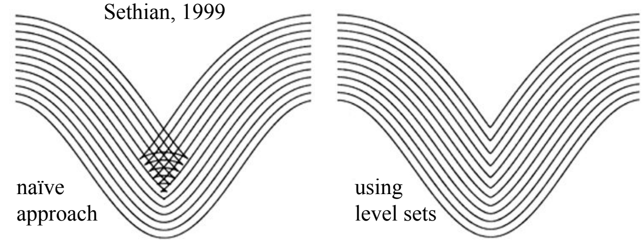


Level Sets



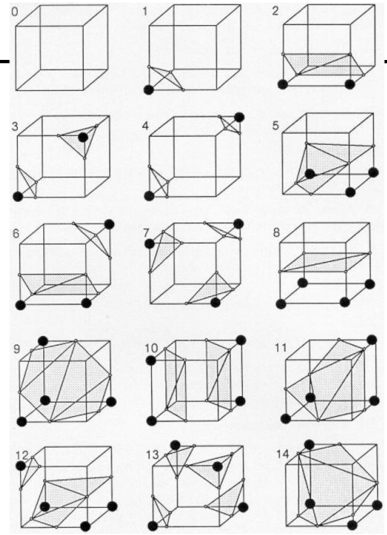
- Efficient method for computing signed distance field

Level Set Methods and Fast Marching Methods, Sethian, 1999



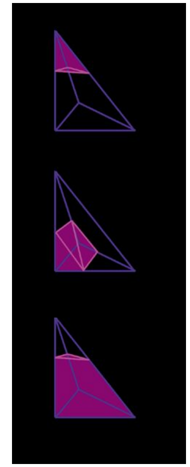
Marching Cubes

- Polygonization: extract triangle mesh from signed distance field

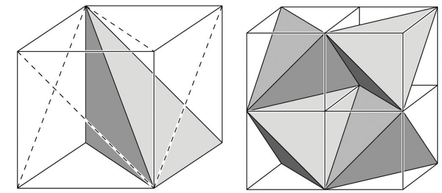


"Marching Cubes: A High Resolution 3D Surface Construction Algorithm", Lorensen and Cline, SIGGRAPH '87.

"Marching Tetrahedra"

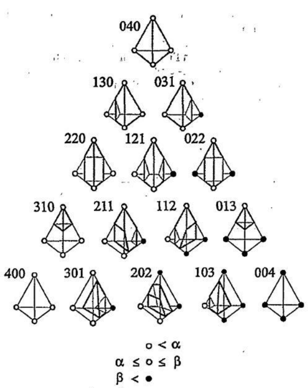


Jules Bloomenthal
"An implicit surface polygonizer"
Graphics Gems IV



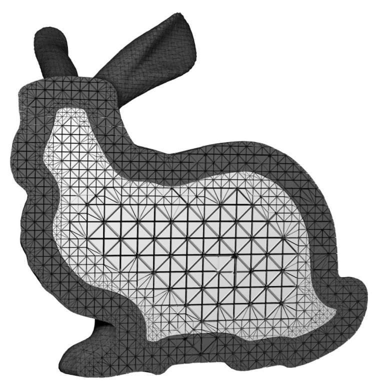
"When the Blobs Go Marching Two by Two", *Jeff Lander,* Gamasutra

"Marching Tetrahedra"



"Interval volume tetrahedrization"
Visualization '97
Nielson & Sung

Similarly, we can create volumetric models:



Questions?

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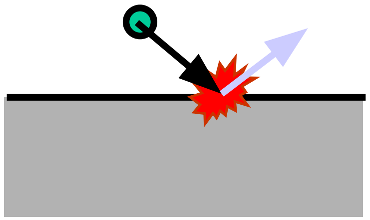
Collisions

- Detection
- Response
- Overshooting problem (when we enter the solid)

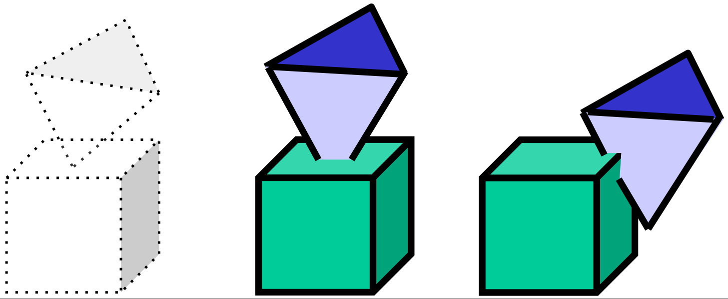


Detecting Collisions

- Easy with implicit equations of surfaces
- H(x,y,z)=0 at surface
- H(x,y,z)<0 inside surface
- So just compute H and you know that you're inside if it's negative
- More complex with other surface definitions

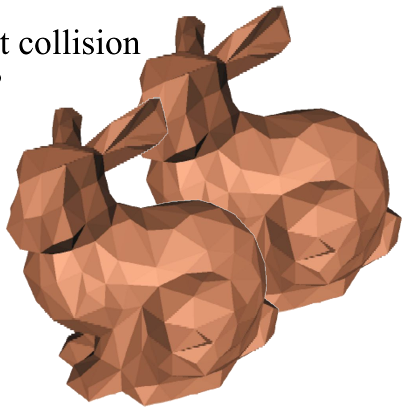
Collision Detection for Solids

- How to detect collision between 2 polyhedra?
- Need an inside/outside test
- Test if a vertex is inside the other polyhedron
- But treat also edge-edge intersection



Cost of Detection?

- Test each edge with each face?
  - $O(N^2)$
- How would you detect collision between two bunnies?
  - $O(N^2)$ is too expensive!
  - Let's use a spatial data structure



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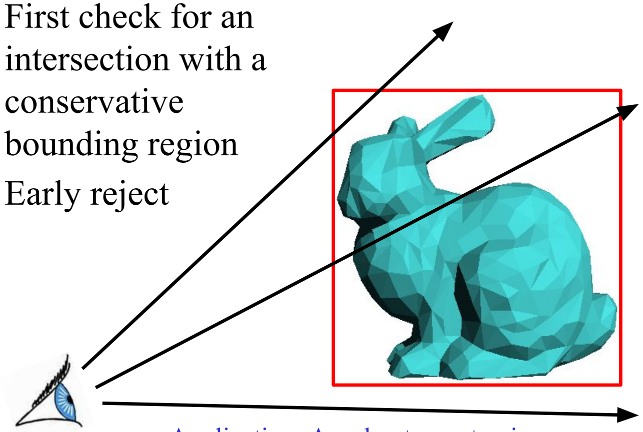
Conservative Bounding Region

- First check for an intersection with a conservative bounding region
- Early reject

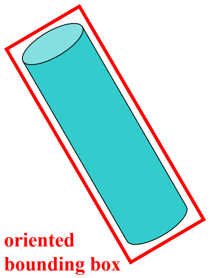


Application: Accelerate ray tracing
Intersect object & ray… *more later this semester!!*

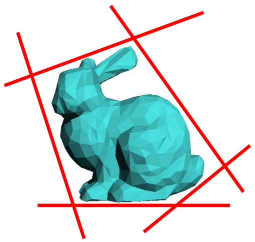
Conservative Bounding Regions

- tight → avoid false positives
- fast to intersect
- easy/fast/perfect construction (*less important*)

bounding sphere

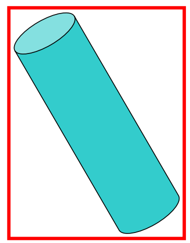


oriented bounding box



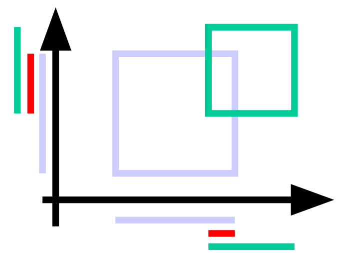
arbitrary convex region (bounding half-spaces)

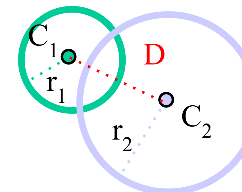
axis-aligned bounding box



Overlap test

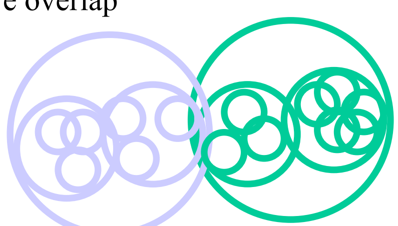
- Overlap between two axis-aligned boxes?
  - Check if the intervals along the 3 dimensions overlap
- Overlap test between two spheres?
  - $D(center_1, center_2) < r_1+r_2$





General Collision Detection

- Put a hierarchy around your objects
- Use the fast overlap test recursively
- Handle exact case at the leaves (when necessary)
- More difficult for self-collision (e.g. cloth)
  - Because there is more overlap



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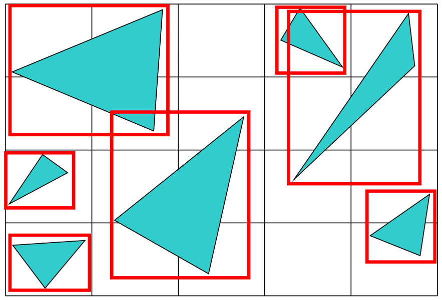
Fixed/Uniform/Regular Grid

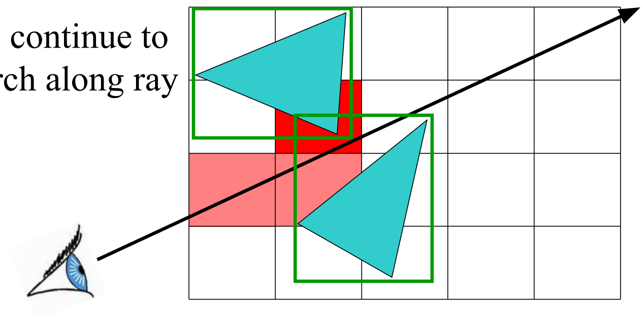
- Separate geometry into regions
- Reduces pairwise comparisons
- Primitives that overlap multiple cells?

Insert into multiple cells (use pointers)



For Each Cell Along a Ray

- Does the cell contain an intersection?
- Yes: return closest intersection
- No: continue to march along ray



Fixed/Uniform Grid Discussion

- Advantages?
  - easy to construct
  - easy to traverse
- Disadvantages?
  - may be only sparsely filled
  - geometry may still be clumped

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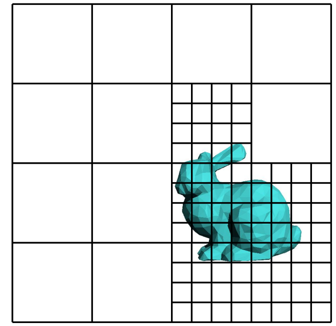
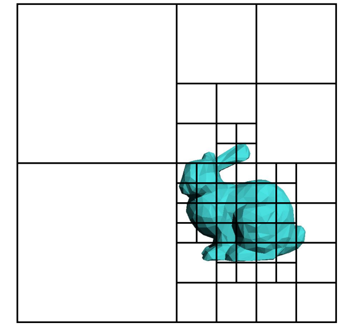
Adaptive Grids

- Subdivide until each cell contains no more than *n* elements, or maximum depth *d* is reached



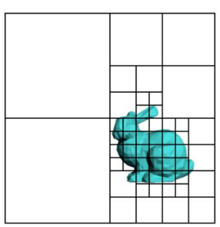
Nested Grids



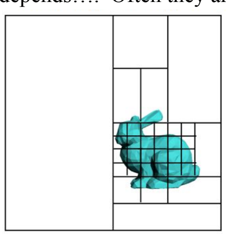
Octree/(Quadtree)

Variations of Adaptive Grids

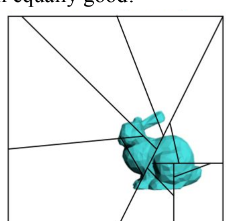
- **When to split?** When a cell contains "lots" of geometry, but has not yet reached the max tree depth
- **Where to split?**
  - Quadtree/Octree: split *every* dimension in half, always axis aligned
  - kd-tree: choose *one* dimension (often the largest dimension) and split it axis aligned (but not necessarily at the midpoint)
  - Binary Space Partition (BSP): choose an *arbitrary* cut plane
- **Which one is best?** It depends…. Often they are all equally good!



Quadtree/Octree



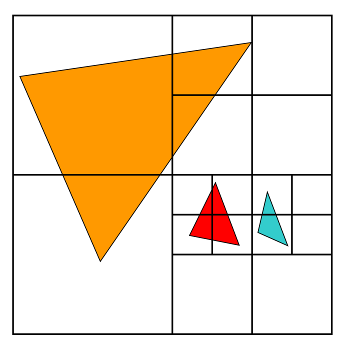
kd tree



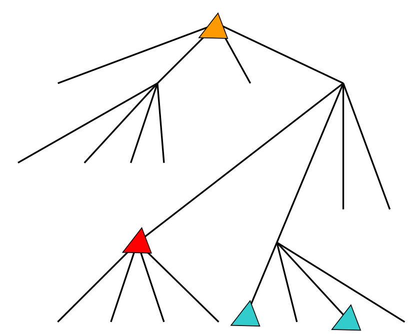
BSP Tree

Primitives in an Adaptive Grid

- Can live at intermediate levels, or be pushed to lowest level of grid

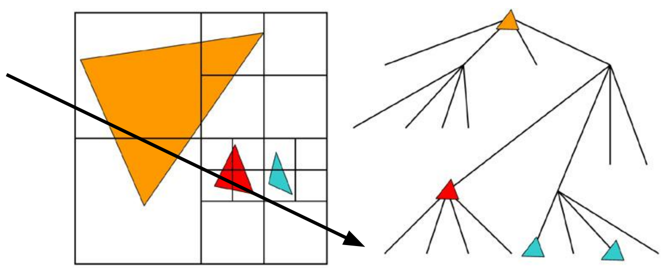


Octree/(Quadtree)



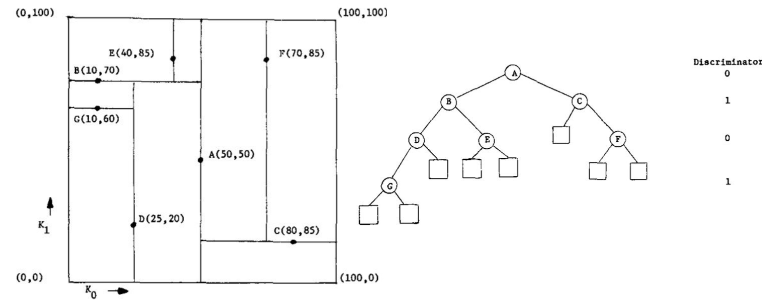
Adaptive Grid Discussion

- Advantages?
  - grid complexity matches geometric density
- Disadvantages?
  - more expensive to traverse (binary tree, lots of pointers)



Early k-d tree paper

- "Multidimensional Binary Search Trees Used for Associative Searching", Bentley, Communications of the ACM, 1975



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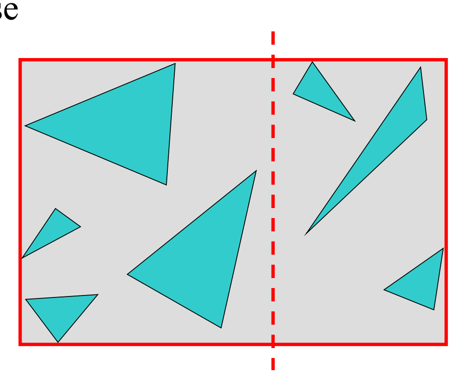
Bounding Volume Hierarchy

- Find bounding box of objects
- Split objects into two groups
- Recurse



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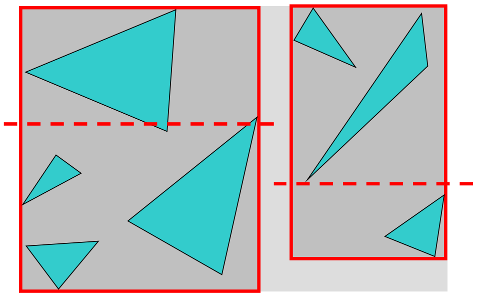
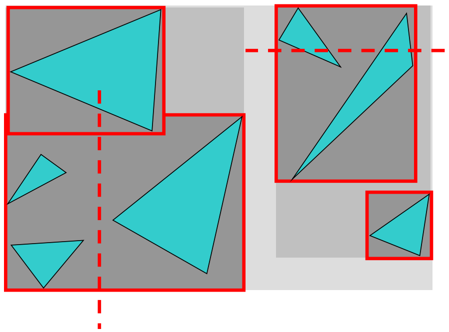


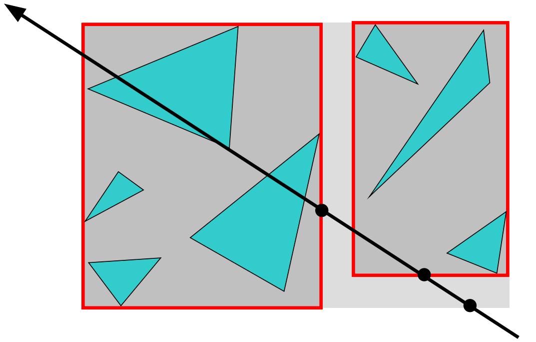
Where to split objects?

- At midpoint OR
- Sort, and put half of the objects on each side OR
- Use modeling hierarchy



Intersection with BVH

- Check sub-volume with closer intersection first

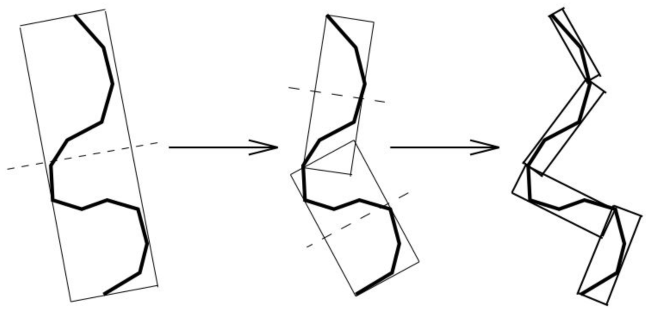


Bounding Volume Hierarchy Discussion

- Advantages
  - easy to construct
  - easy to traverse
  - binary
- Disadvantages
  - may be difficult to choose a good split for a node
  - poor split may result in minimal spatial pruning

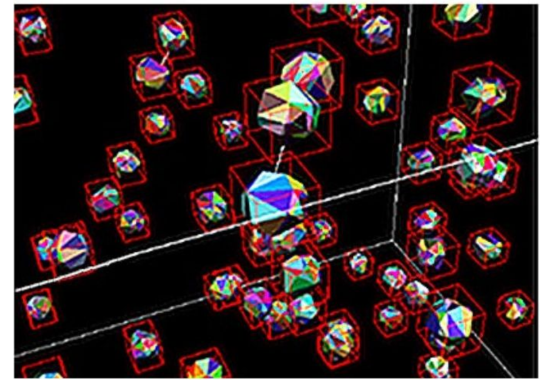
Reading for Today:

- Oriented Bounding Box (OBB): generalization of the (axis-aligned) BVH



OBB-Tree: A Hierarchical Structure for Rapid Interference Detection,
Gottschalk, Lin, & Manocha, SIGGRAPH 1996.

- "I-COLLIDE: An Interactive and Exact Collision Detection System for Large-scaled Environments", Cohen, Lin, Manocha, & Ponamgi, I3D 1995.



Reading for Today:

- "Octree Textures", Benson & Davis, SIGGRAPH 2002

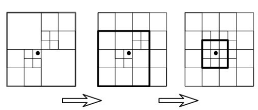
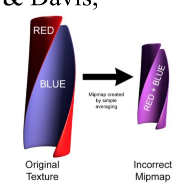
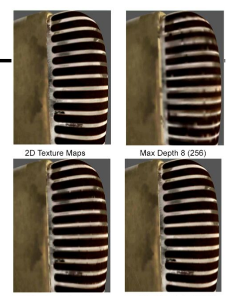
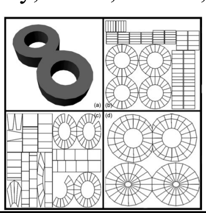


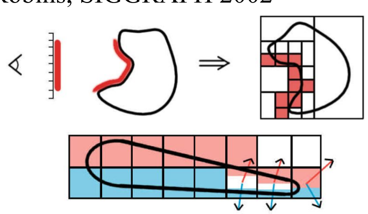
Figure 3 Texture interpolation between the different resolutions of a sample point's surrounding cells is achieved by following a 3x3x3 neighborhood from the octree root.





- "Painting and Rendering Textures on Unparameterized Models", DeBry, Gibbs, Deleon, and Robins, SIGGRAPH 2002





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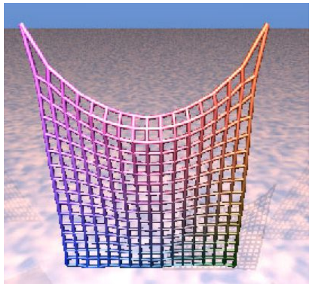
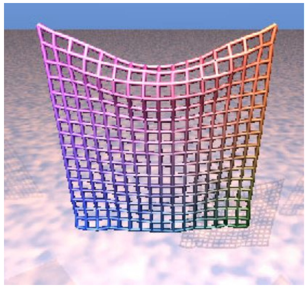
Reading for Friday:

Everyone should read this
(simple cloth model used in HW2)

- "Deformation Constraints in a Mass-Spring Model to Describe Rigid Cloth Behavior", Provot, 1995.


Simple mass-spring system

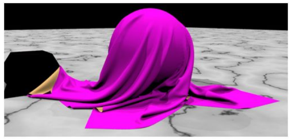

Improved solution

Post a comment/question on the LMS discussion by 10am

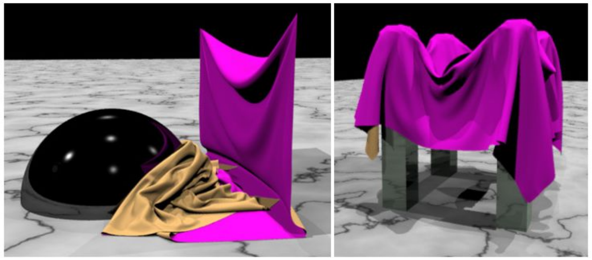
Cloth Collision

OPTIONAL READING FOR FRIDAY

Robert Bridson, Ronald Fedkiw & John Anderson
Robust Treatment of Collisions, Contact and Friction for Cloth Animation
SIGGRAPH 2002



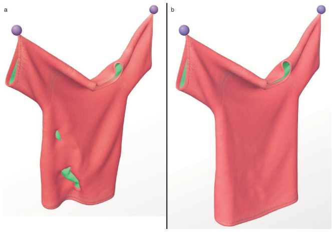
- A cloth has many points of contact
- Often stays in contact
- Requires
  - Efficient collision detection
  - Efficient numerical treatment (stability)

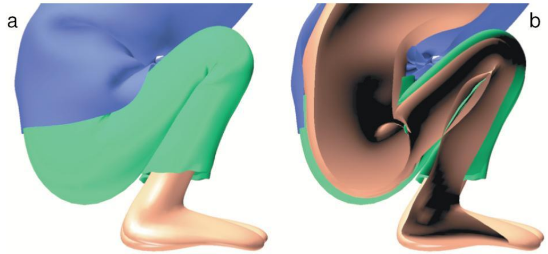


Cloth in Practice (w/ Animation)

OPTIONAL READING FOR FRIDAY

- Baraff, Witkin & Kass
  Untangling Cloth
  SIGGRAPH 2003



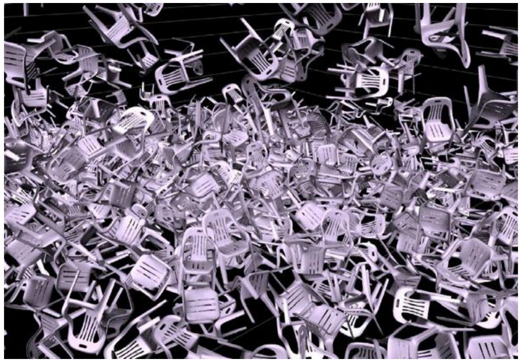


Reduced Deformation

OPTIONAL READING FOR FRIDAY

Doug L. James & Dinesh K. Pai
BD-Tree: Output-Sensitive Collision Detection for Reduced Deformable Models
SIGGRAPH 2004

- Collisions are expensive
- Deformation is expensive
- This is a lot of geometry!
- Simplify the simulation model



Pop Worksheet!

Teams of 2. Hand in to Jeramey after we discuss.

- For each adaptive grid method (quad tree, k-d tree, binary space partition) sketch the resulting grid if we split cells with > 2 elements and allow a maximum tree height of 5 (max of 4 splits from root).