Implicit Surfaces, Collision Detection, & Volumetric Data Structures
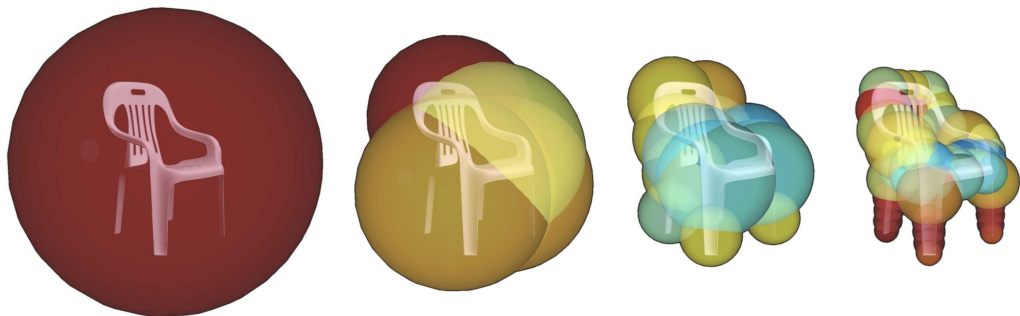

Traveler's Insurance, *Snowball*

Weta Digital, 2007

Katamari

BANDAI NAMCO Entertainment Inc., 2004-2018

Output-Sensitive Collision Processing for Reduced-Coordinate Deformable Models
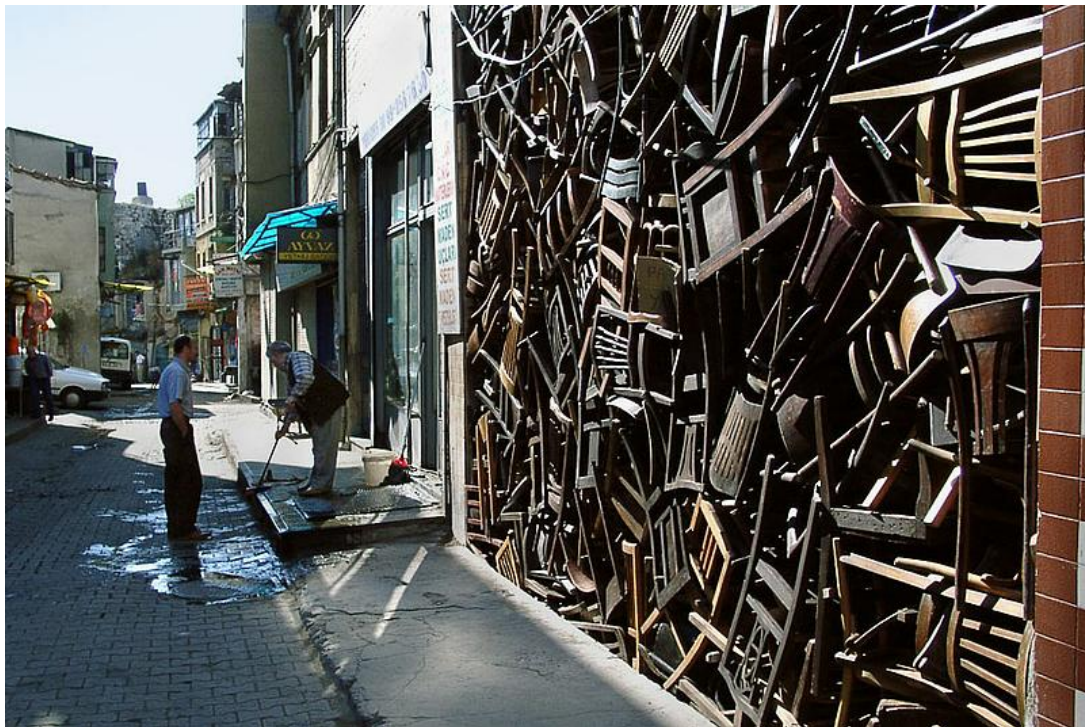

Level 0   Level 2   Level 4   Level 6

James, Pai, and Twigg, SIGGRAPH 2004

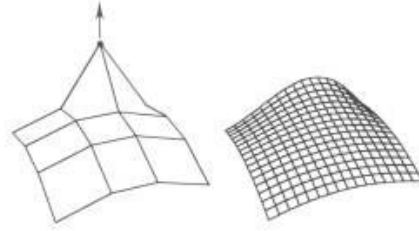*Untitled*, 1550 chairs stacked, Doris Salcedo, 2003

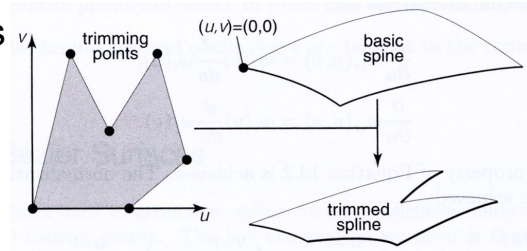*Untitled*, 1550 chairs stacked, Doris Salcedo, 2003

Last Time?

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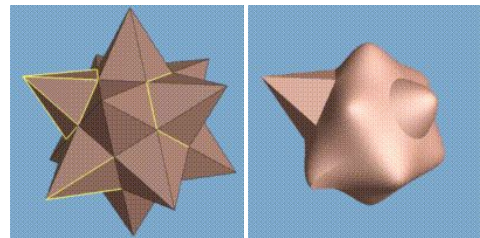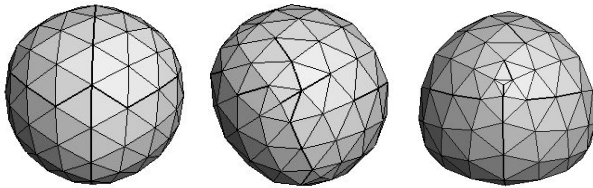 - complex topology is challenging, requires trimming curves
- Subdivision Zoo
  - Doo-Sabin
  - Loop
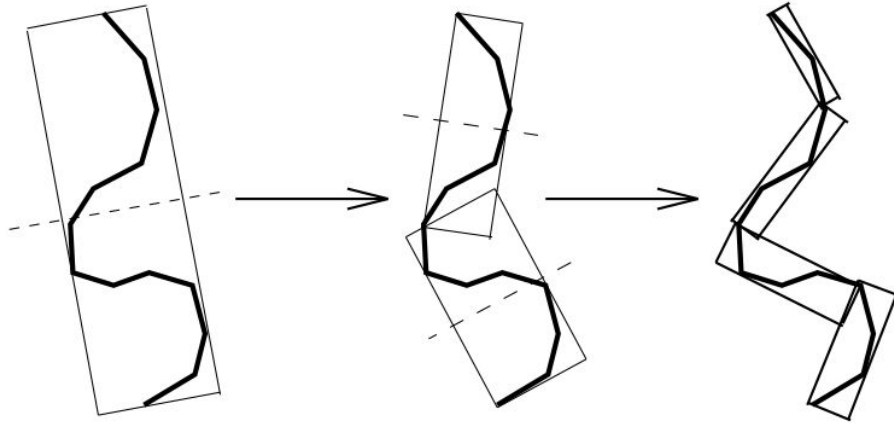 - Catmull-Clark
- Subdivision w/ Creases

Today

- Readings for Today
- Motivation: Collision Detection is Expensive
- Conservative Bounding Region
- Spatial Acceleration Data Structures
- Papers for Friday
- Questions about Homework 1
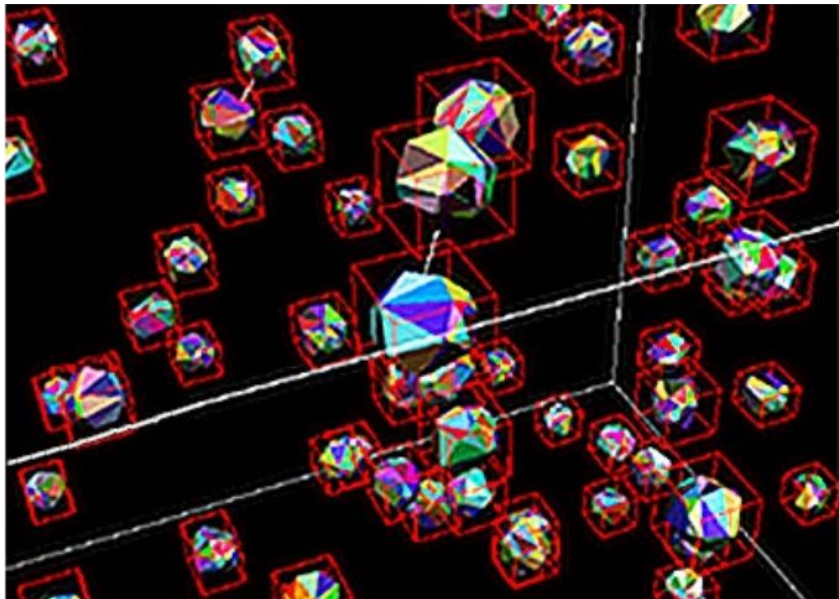- Worksheet on Subdivision Surfaces

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.
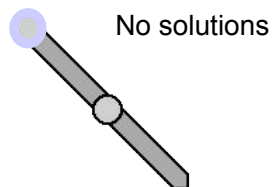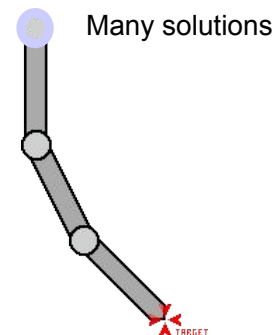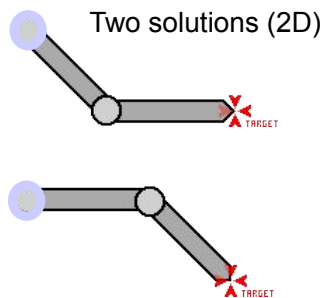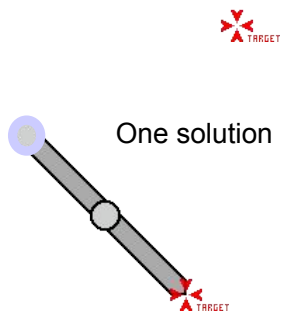
Reading for Today

- "C-Space Tunnel Discovery for Puzzle Path Planning", Zhang, Belfer, Kry, & Voucha, SIGGRAPH 2020.

Searching Configuration Space

No solutions
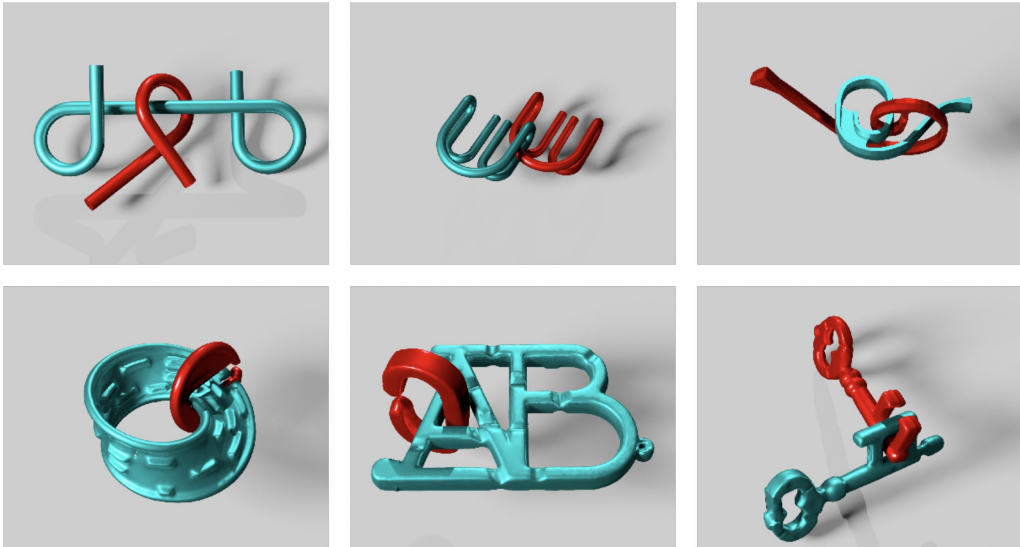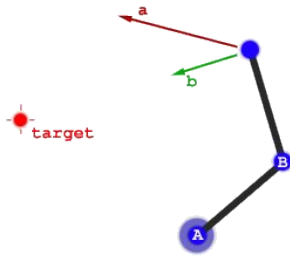
- Application: Robot Motion Planning

One solution

Two solutions (2D)

Many solutions

"The good-looking textured light-sourced bouncy fun smart and stretchy page"
Hugo Elias, **http://freespace.virgin.net/hugo.elias/models/m_ik.htm**

Searching Configuration Space

pose space shaded by distance to target

- What are the unknowns? What are the "degrees of freedom" of our robot arm?

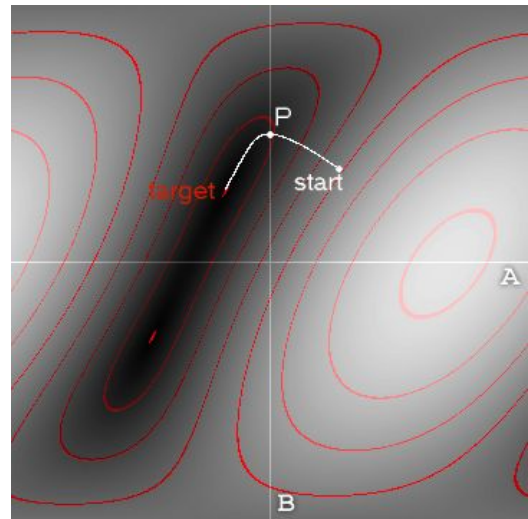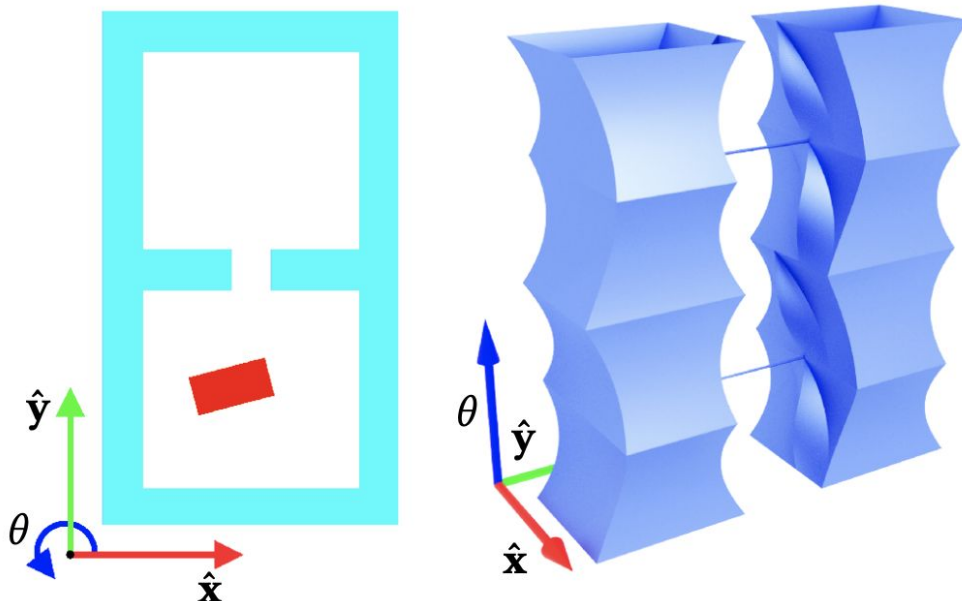- More degrees of freedom = higher dimensional configuration space

"The good-looking textured light-sourced bouncy fun smart and stretchy page"
Hugo Elias, **http://freespace.virgin.net/hugo.elias/models/m_ik2.htm**

Searching Configuration Space

"C-Space Tunnel Discovery for Puzzle Path Planning",
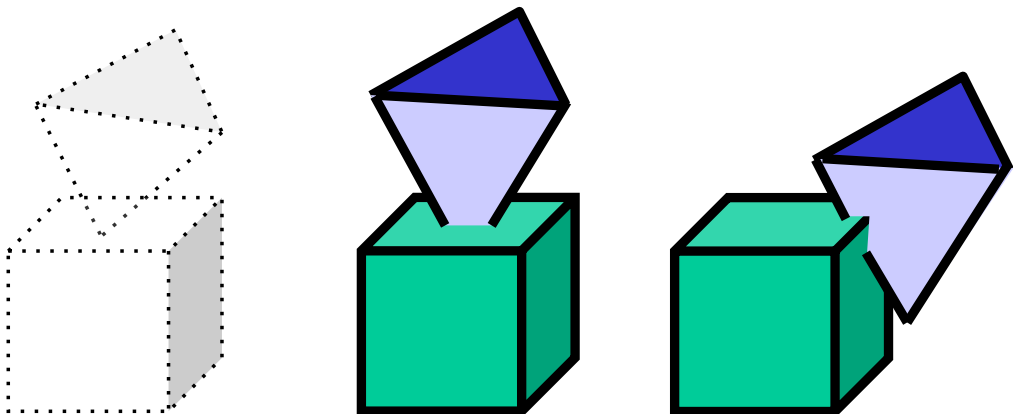Zhang, Belfer, Kry, & Voucha, SIGGRAPH 2020.

Today

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- Worksheet on Subdivision Surfaces

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
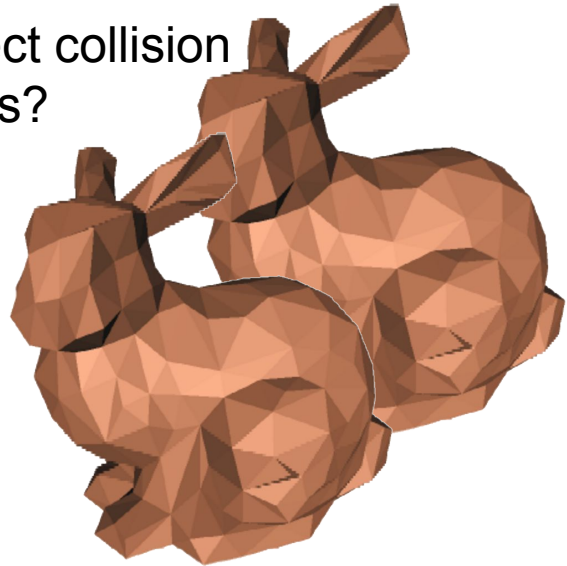- But treat also edge-edge intersection

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
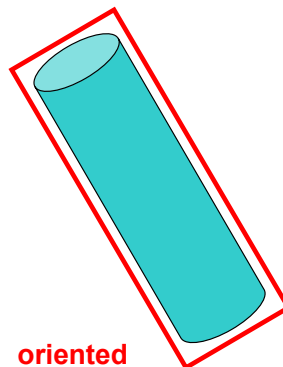- Early reject
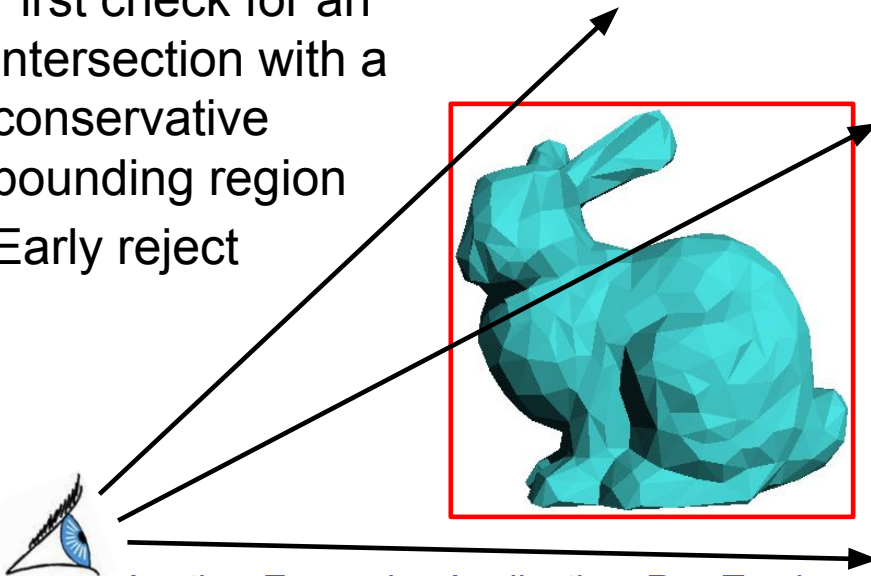
Another Expensive Application: Ray Tracing
Intersect object & ray… *more later this semester!!*

Conservative Bounding Regions

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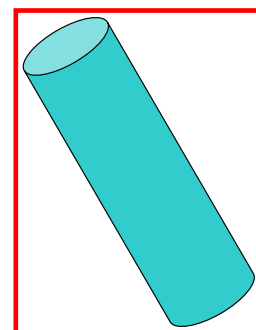
- easy/fast/perfect construction (*less important*)

bounding sphere

oriented bounding box
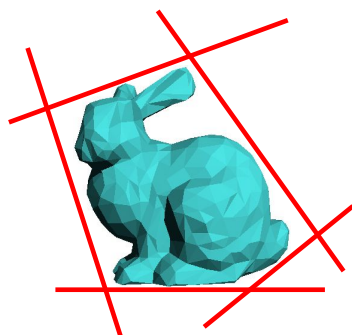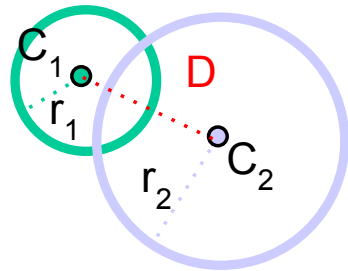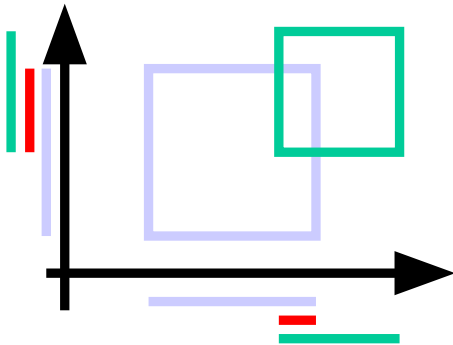
arbitrary convex region (bounding half-spaces)

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)
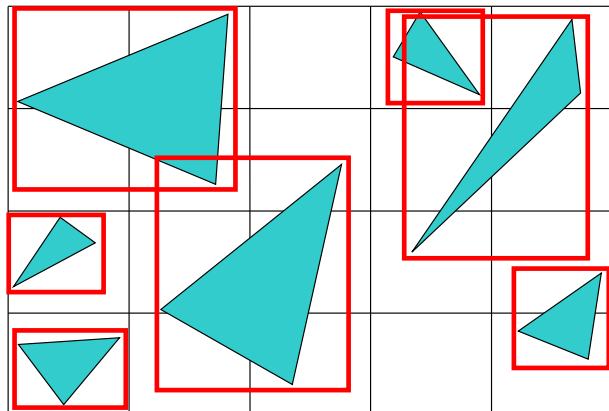 - Because there is more overlap
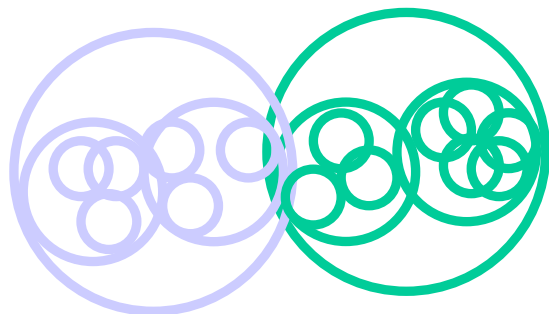
Today

- Readings for Today
- Motivation: Collision Detection is Expensive
- Conservative Bounding Region
- Spatial Acceleration Data Structures
  - Fixed/Uniform/Regular Grid
  - Nested Grid
  - Octree
  - Binary Space Partition
  - K-d tree
  - Bounding Volume Hierarchy
- Papers for Friday
- Questions about Homework 1
- Worksheet on Subdivision Surfaces

Fixed/Uniform/Regular Grid

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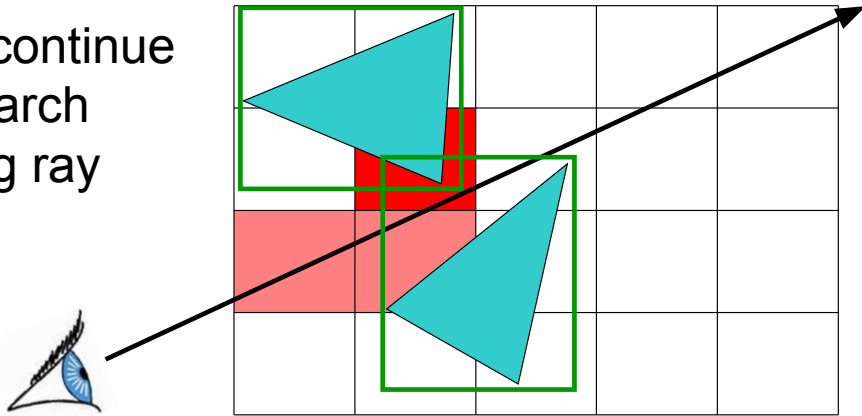- Reduces pairwise comparisons
- Primitives that overlap multiple cells?

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

Today

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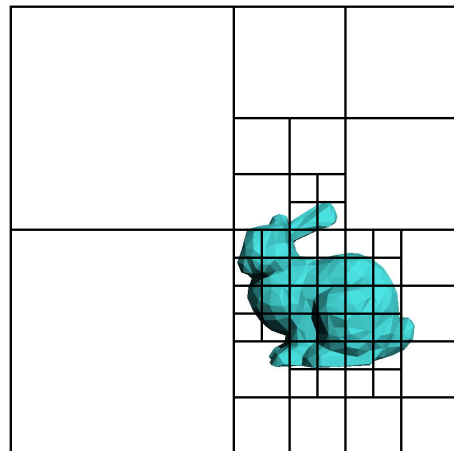- Questions about Homework 1
- Worksheet on Subdivision Surfaces

Adaptive Grids

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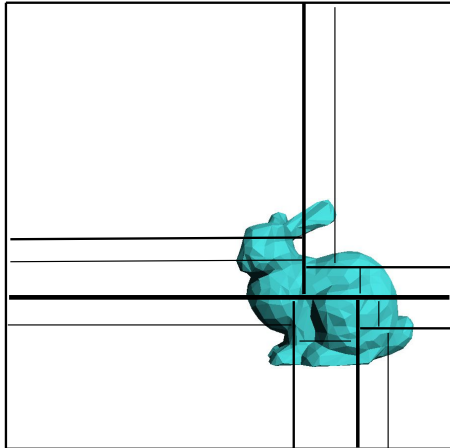 n elements, or maximum depth d is reached
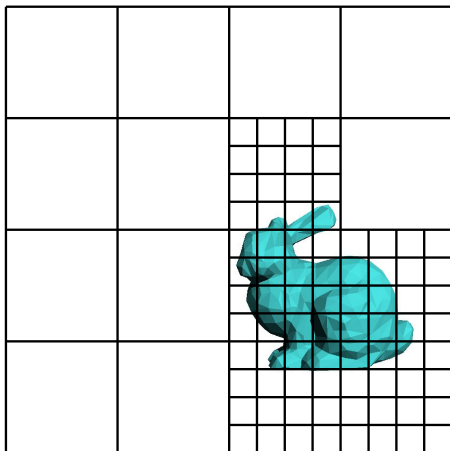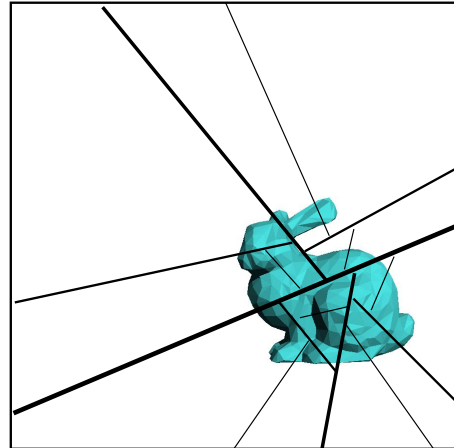

Nested Grids   Octree/(Quadtree)

Adaptive Grids

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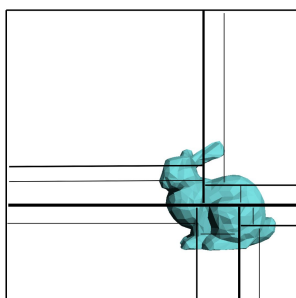
K-D Tree

Binary Space Partition (BSP)

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!*
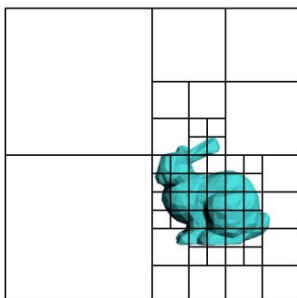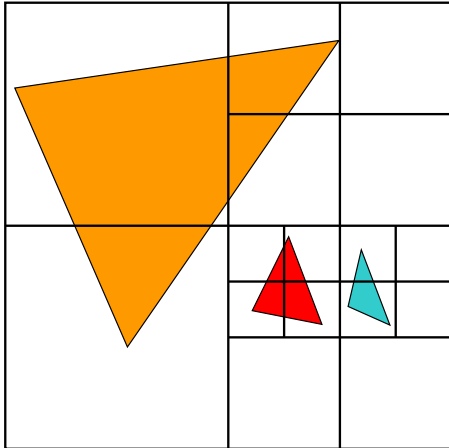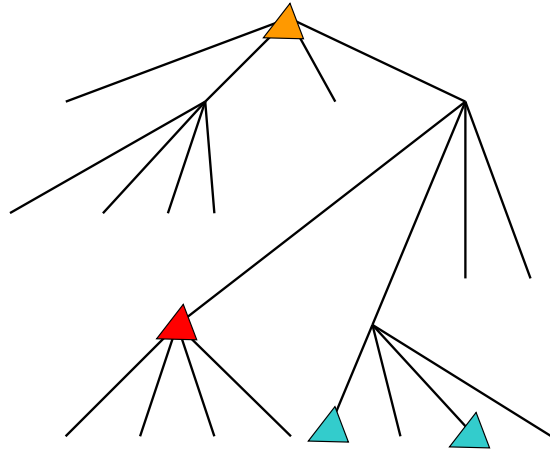
Quadtree/Octree

kd tree
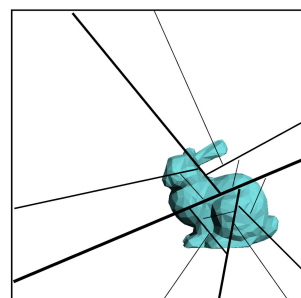
BSP Tree

Primitives in an Adaptive Grid

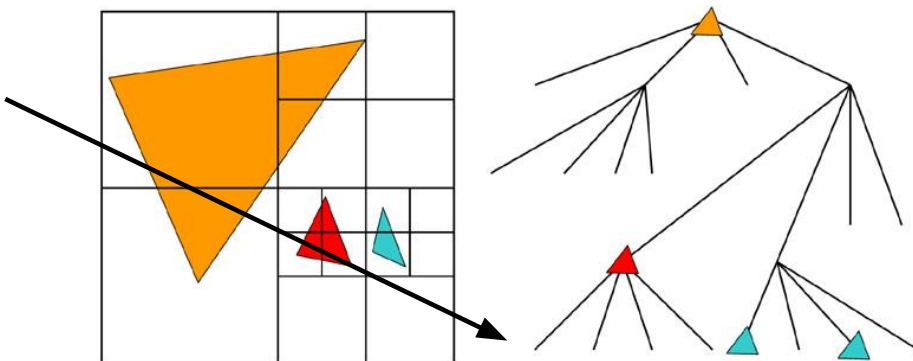- Can live at intermediate levels, or be pushed to lowest level of grid
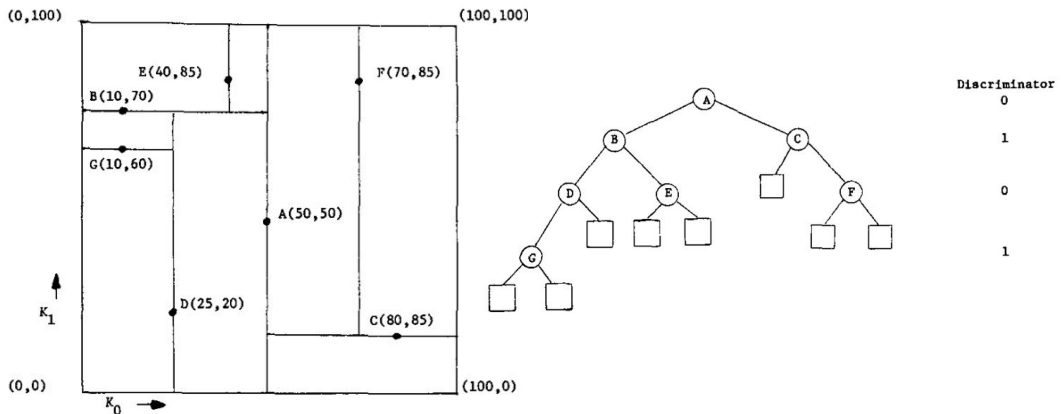
Octree/(Quadtree)

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
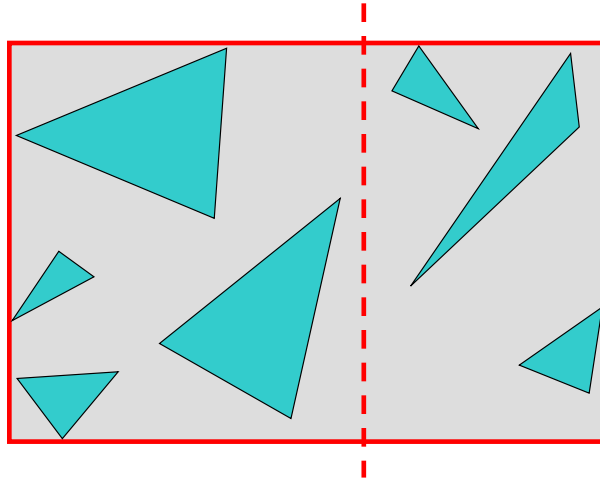

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Bounding Volume Hierarchy

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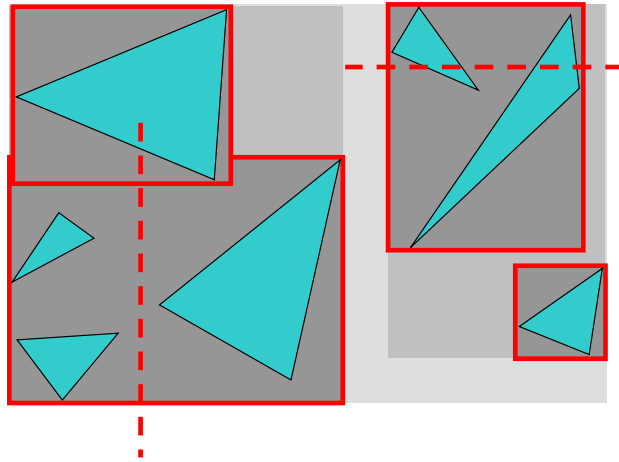- Recurse

Bounding Volume Hierarchy

- Find bounding box of objects
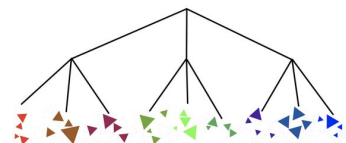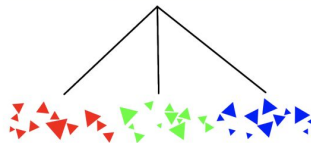- Split objects into two groups
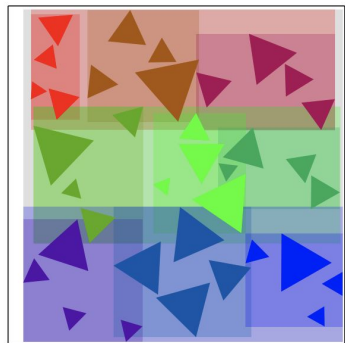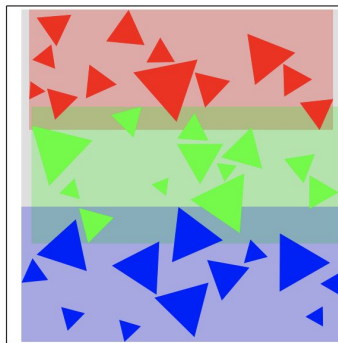- Recurse
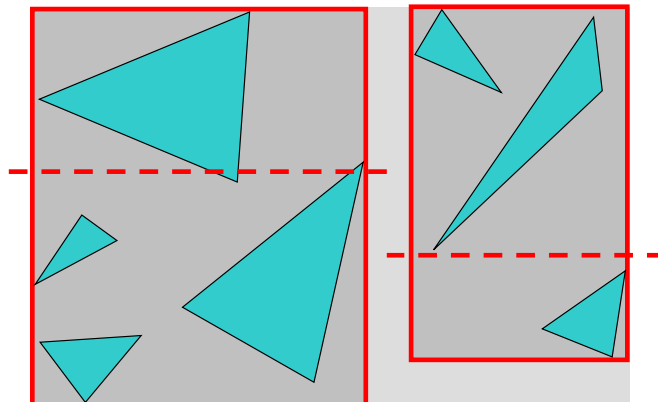
Where to split objects?
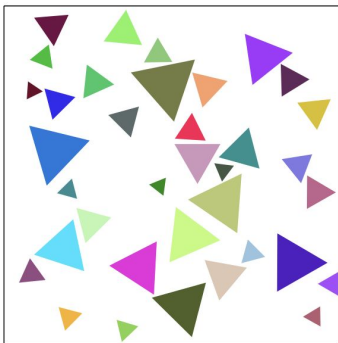
- At midpoint   OR
- Sort, and put half of the objects on each side   OR
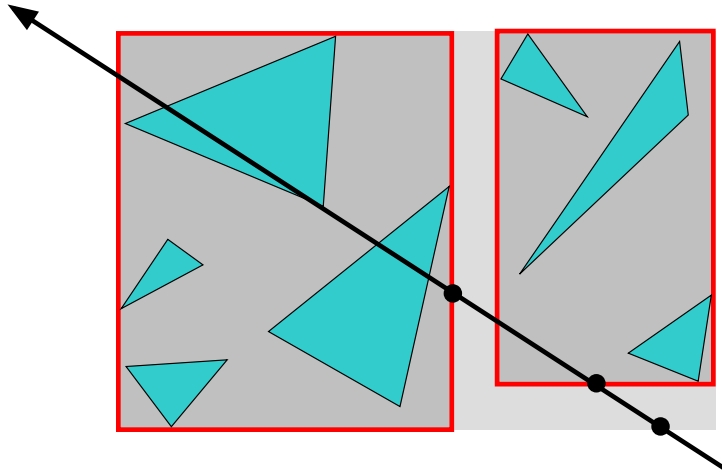- Use modeling hierarchy

Data Structures Homework 8

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

Today

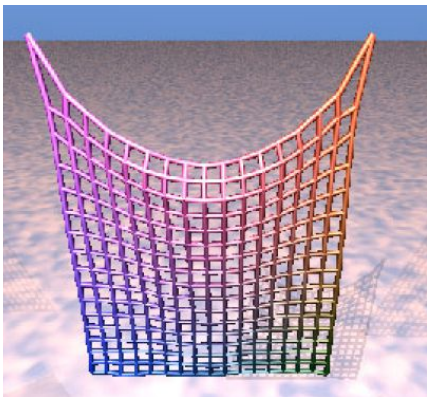- Readings for Today
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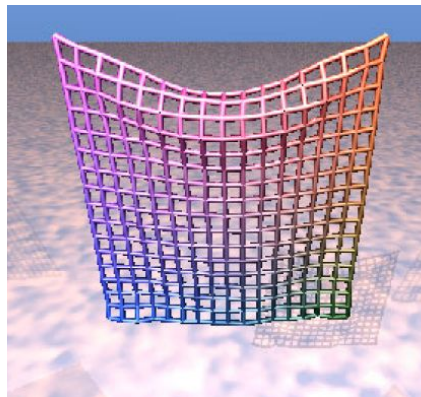- Worksheet on Subdivision Surfaces

Reading for Next Time:

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

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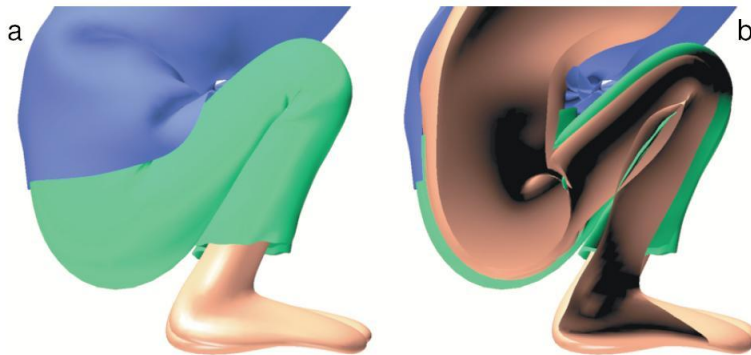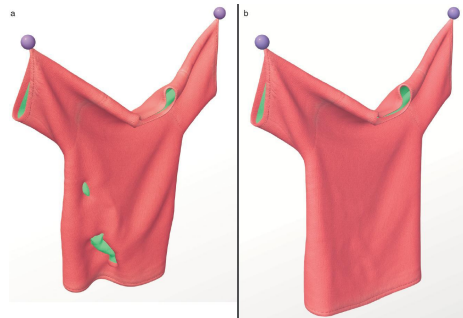

Simple mass-spring system   Improved solution

Cloth in Practice (w/ Animation)

OPTIONAL READING FOR NEXT TIME

- Baraff, Witkin & Kass
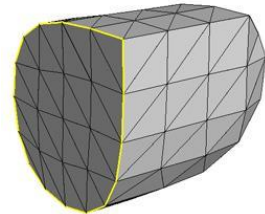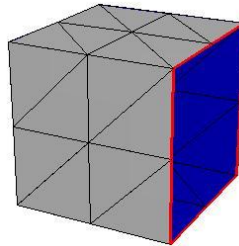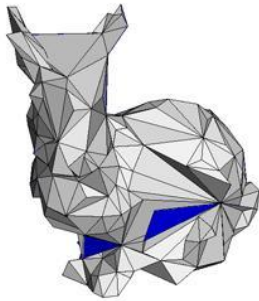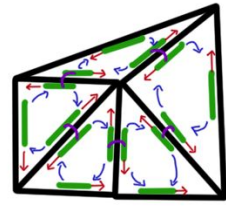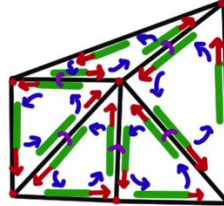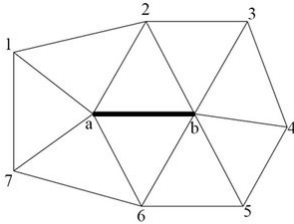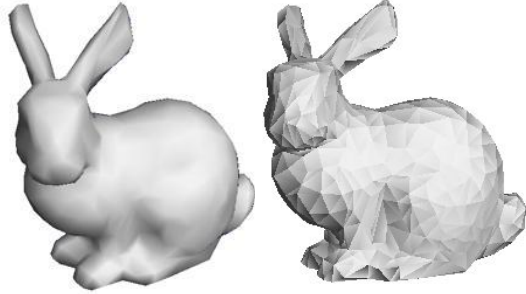 *Untangling Cloth*
  SIGGRAPH 2003

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Homework 1:

- Questions/Comments?

Pop Worksheet!

Sketch the polygonal mesh after performing 2 iterations of
su   ).
If
sp