CSCI 4530/6530 Advanced Computer Graphics

https://www.cs.rpi.edu/~cutler/classes/advancedgraphics/S25/

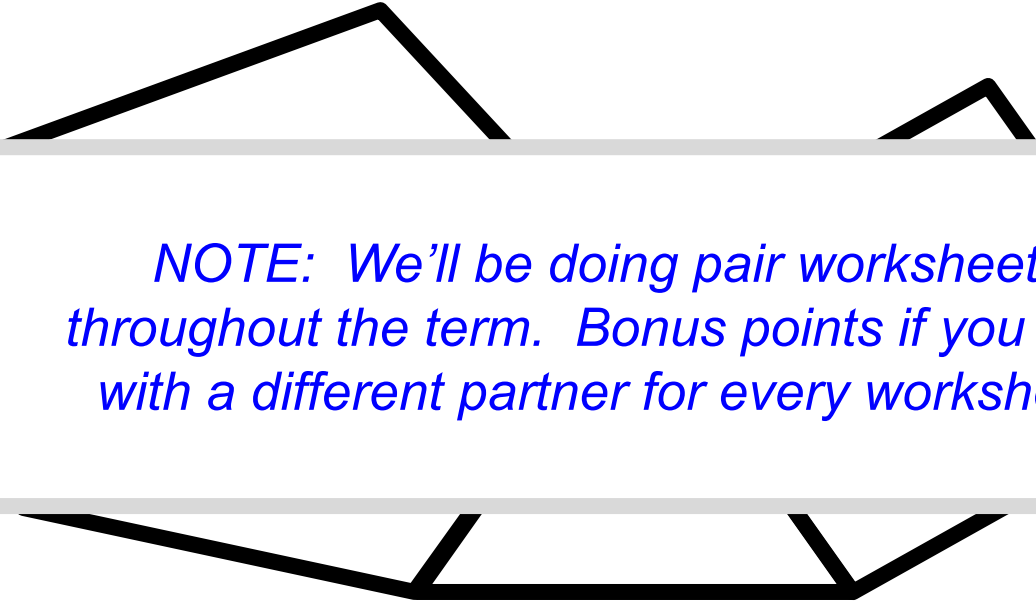
Lecture 5: Implicit Surfaces, Collision Detection, & Volumetric Data Structures


Hong Kong, China
https://imgur.com/gallery/aP3KVeX

Worksheet: Subdivision Surfaces Connectivity

Sketch the polygonal mesh after performing 2 iterations of subdivision (Loop/Butterfly, Catmull-Clark, and Doo-Sabin).

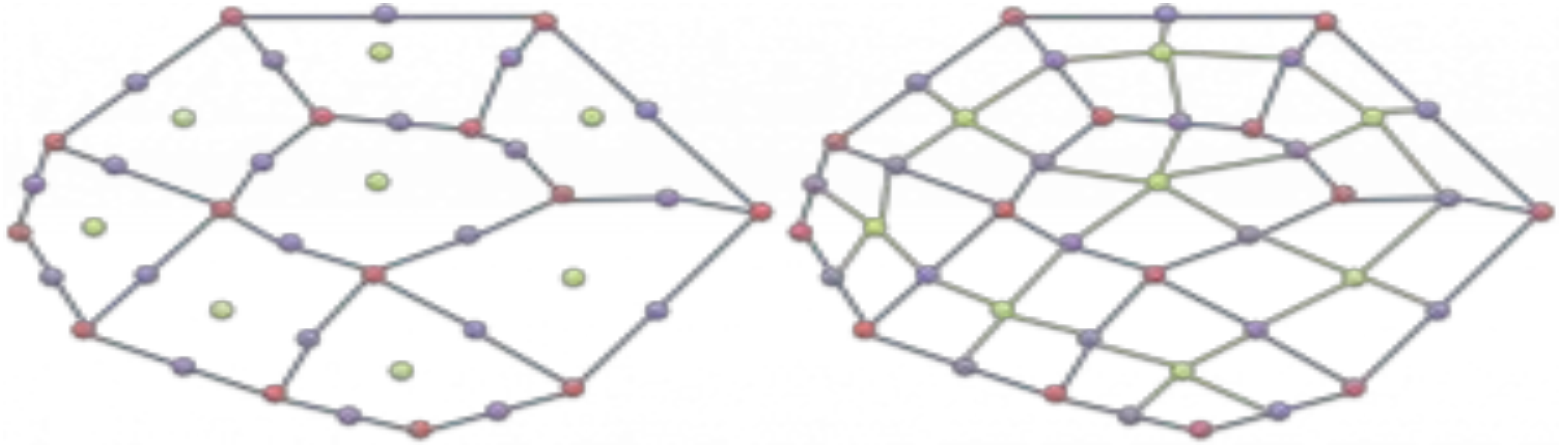
If necessary, pre-process the mesh to allow use of the specified method.



NOTE: We'll be doing pair worksheets throughout the term. Bonus points if you work with a different partner for every worksheet!

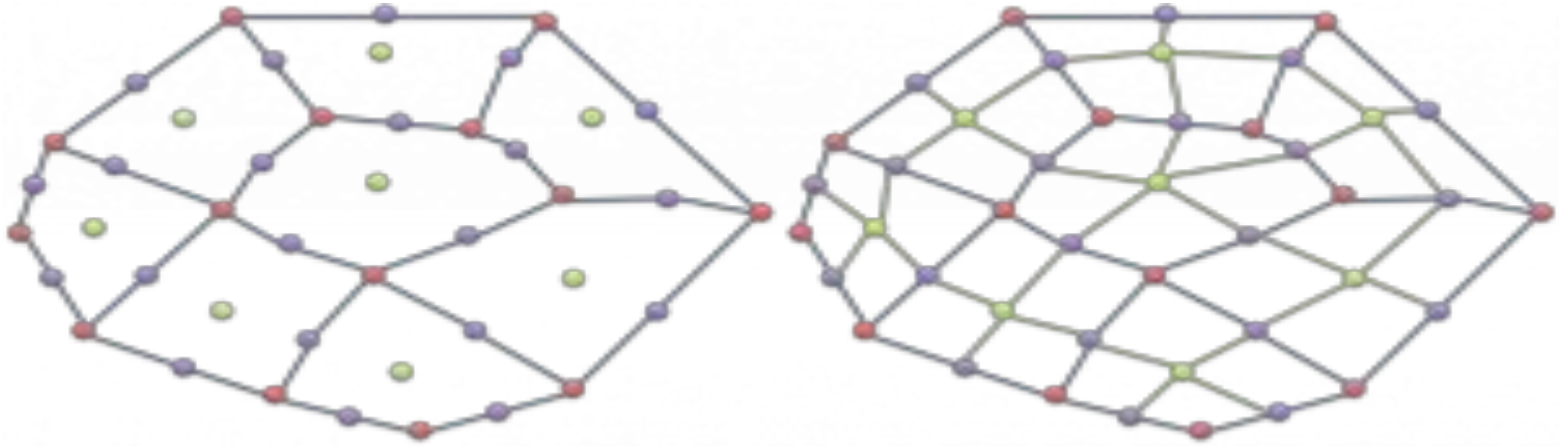
Catmull Clark Subdivision

- Add a vertex in the middle of each original edge
- Add a vertex in the middle of each original face
- Connect each new edge vertex to each new face vertex
- *NOTE: The mesh contains only quads after 1 iteration.*

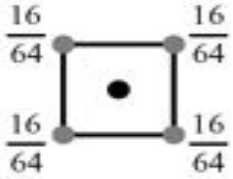


https://team.inria.fr/virtualplants/teaching/informatique-graphique-2016/tp4-instructions/

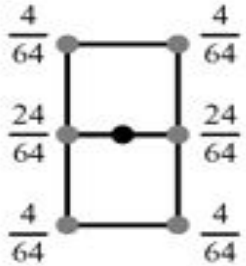
Catmull Clark Subdivision



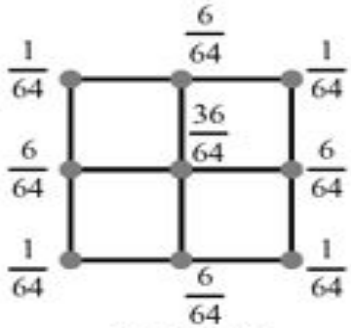
Adjust/average the position of every vertex (old & new) using these masks:



face



edge

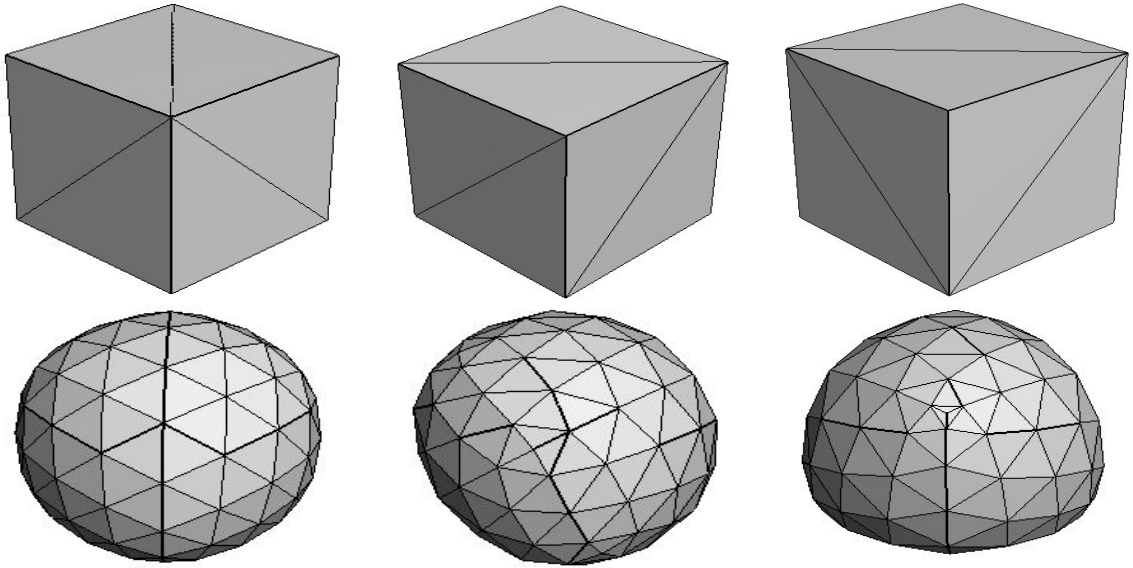


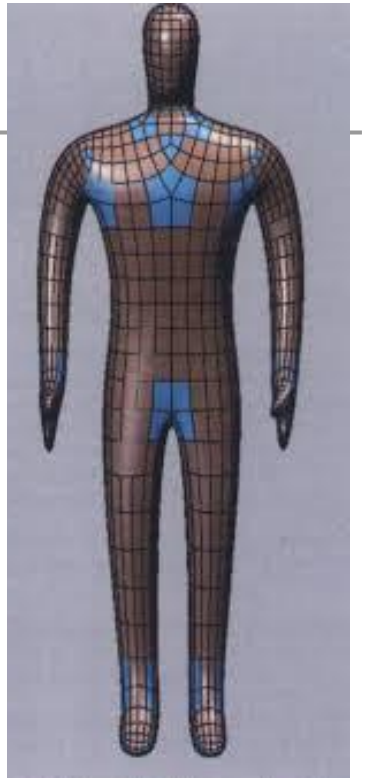
vertex

http://www.cl.cam.ac.uk/teaching/2005/AdvGraph/exercise2.html

Catmull Clark is preferred by Artists

- Catmull-Clark is based on quadrilaterals
  - Like NURBS, specifically cubic BSplines
  - Implicit adjacency in subdivided microgeometry
  - *Quads are better than triangles for symmetric objects*

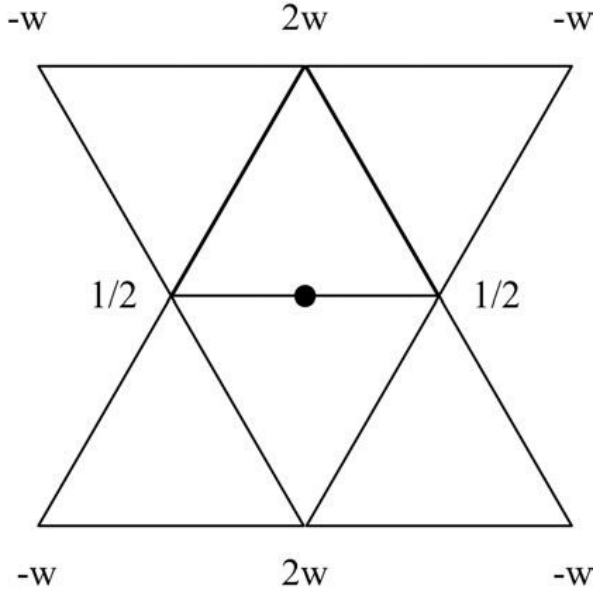




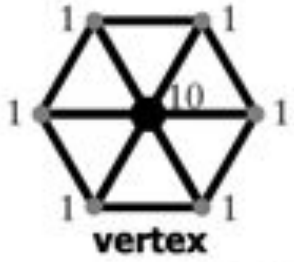
Does a cube turn into a sphere with Loop subdivision? What about with Catmull-Clark subdivision?

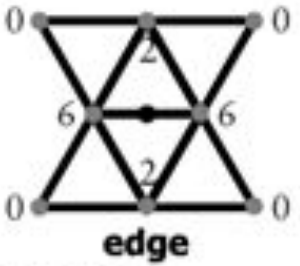
Butterfly Subdivision

- Triangle-based subdivision
- Alternate scheme to Loop

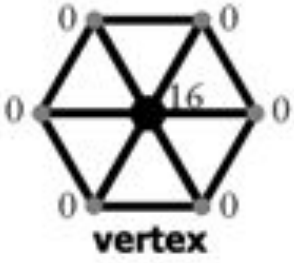


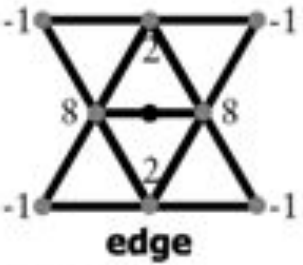
every triangle
is split into four





Loop scheme

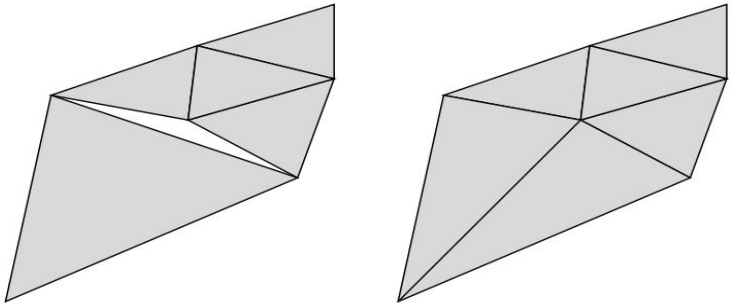




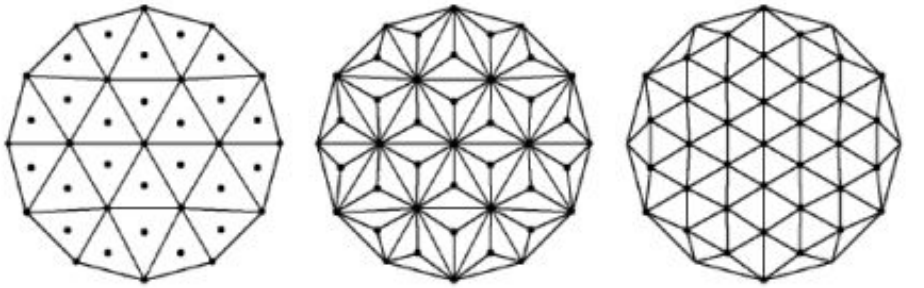
Butterfly scheme

http://www.cl.cam.ac.uk/teaching/2005/AdvGraph/exercise2.html

√3 Subdivision Kobbelt, SIGGRAPH 2000



Adaptive Subdivision (Loop): Need to close gaps between different levels of refinement

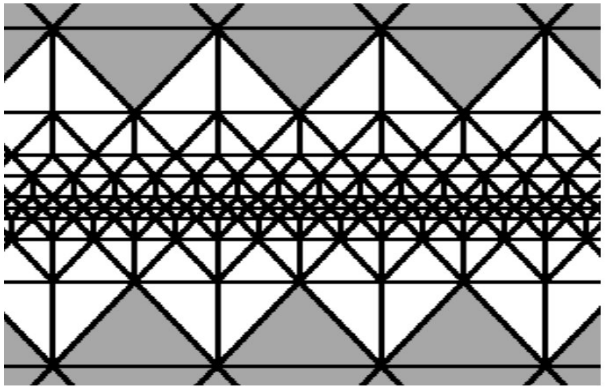


the split operation places a midvertex at the centre of each triangle

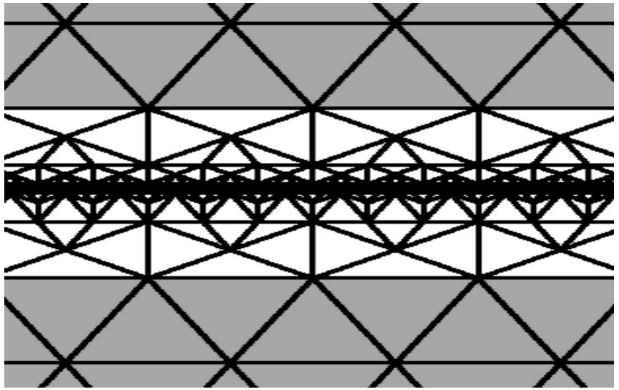
joining the midvertex to the vertices of the triangle realises the 1-to-3 split

after smoothing each old vertex, edges are flipped to connect pairs of midvertices

Loop: less localized refinement



√3: more localized refinement



Traveler's Insurance, Snowball

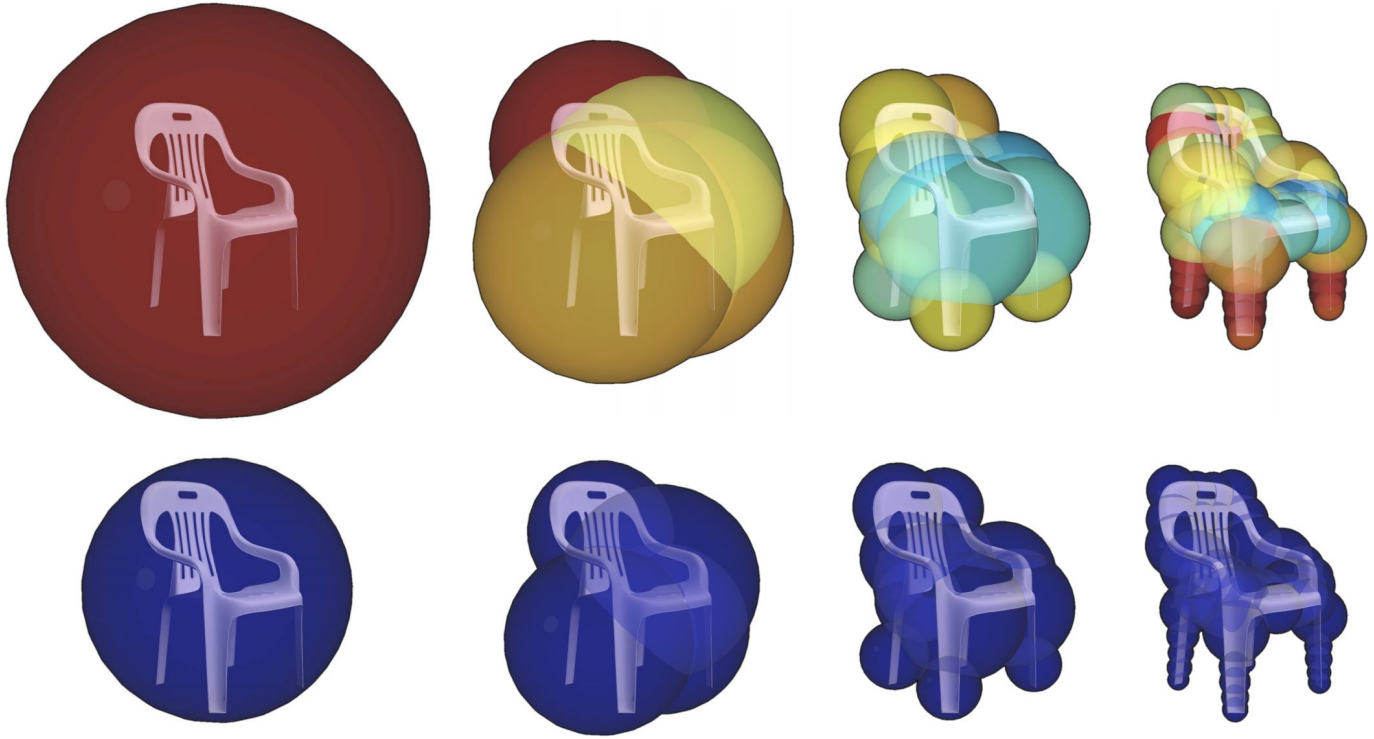
Weta Digital, 2007


travelers.com
TRAVELERS
Insurance. In-synch.℠

Katamari

BANDAI NAMCO Entertainment Inc., 2004-2018

Output-Sensitive Collision Processing for Reduced-Coordinate Deformable Models



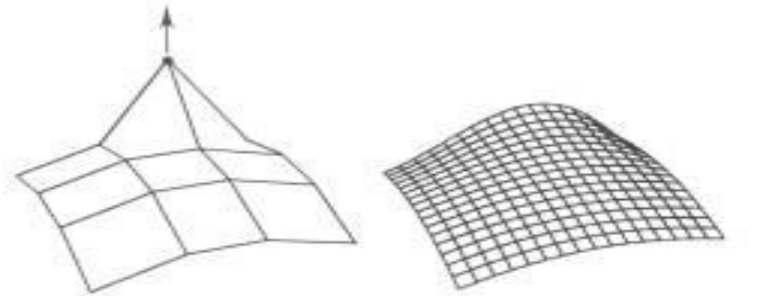
James, Pai, and Twigg, SIGGRAPH 2004

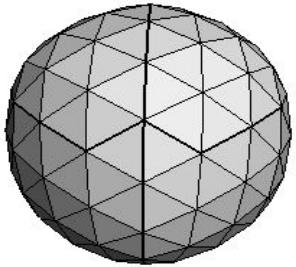
Untitled, 1550 chairs stacked, Doris Salcedo, 2003

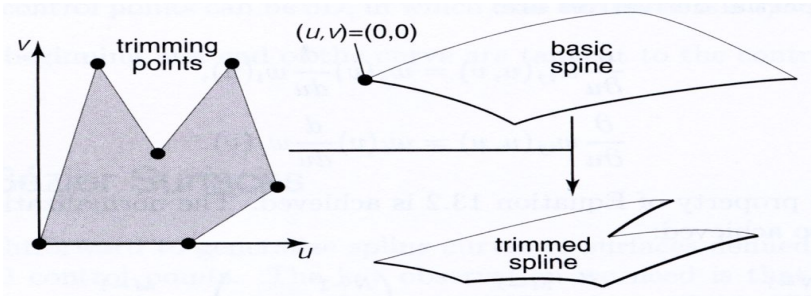
Untitled, 1550 chairs stacked, Doris Salcedo, 2003

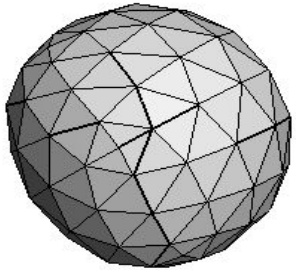
Last Time?

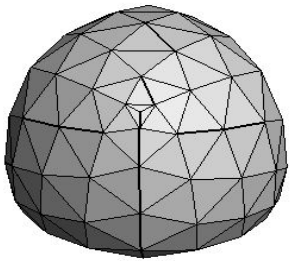
- Spline Surfaces
  - complex topology is challenging, requires trimming curves
- Subdivision Zoo
  - Doo-Sabin
  - Loop
  - Catmull-Clark
- Subdivision w/ Creases

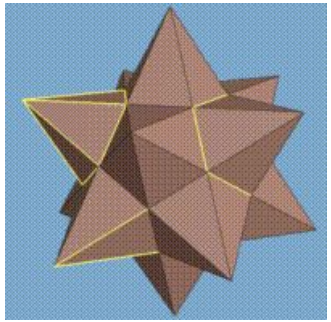


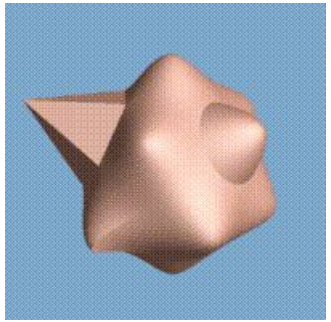










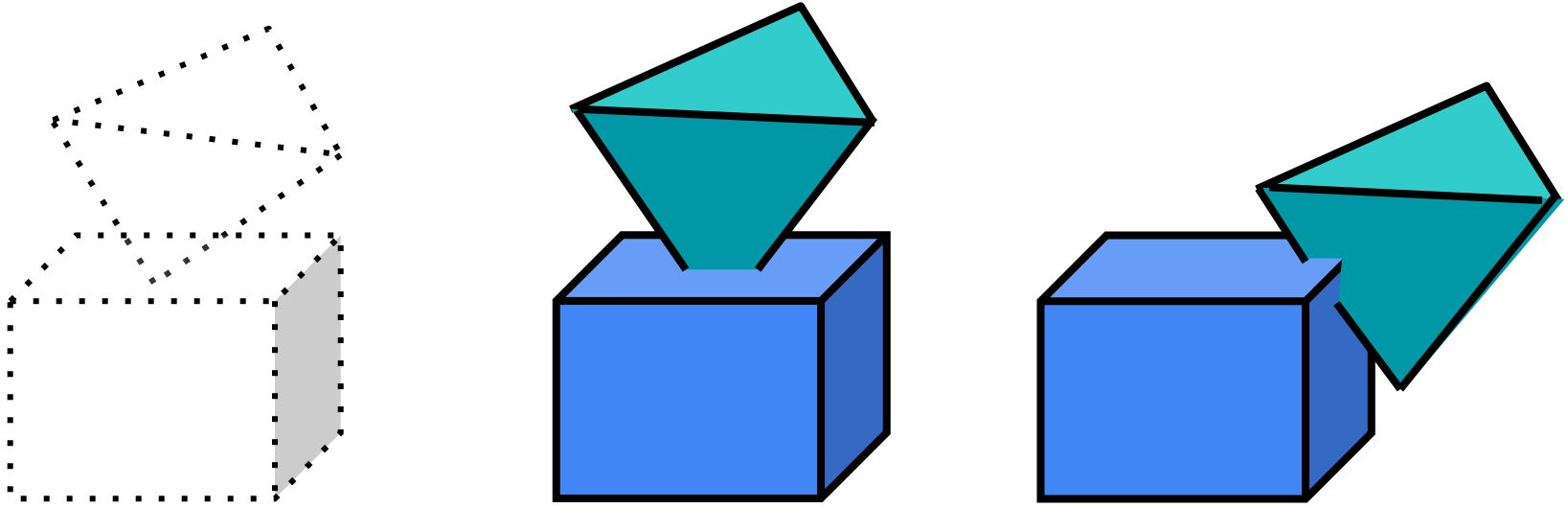


Today

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

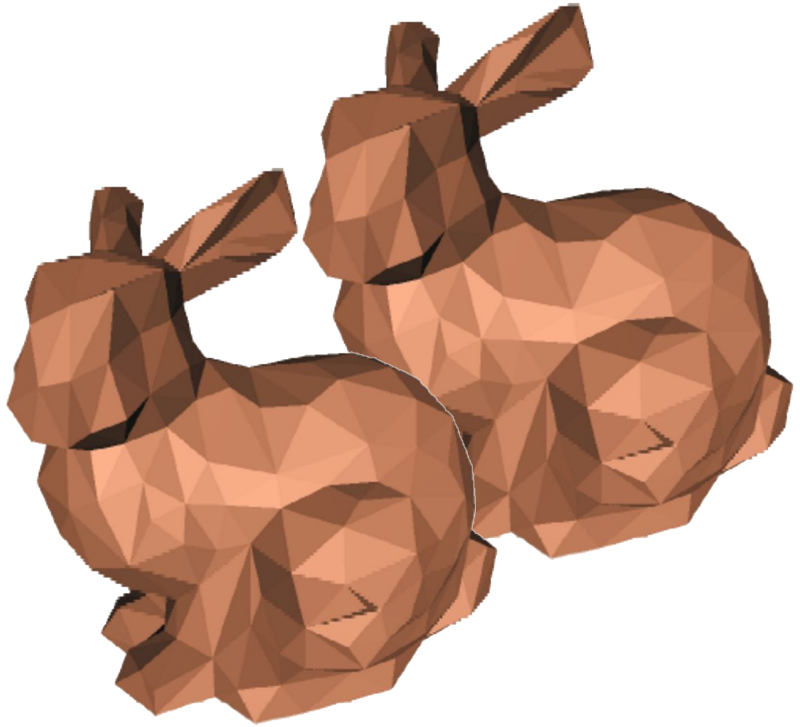
Collision Detection for Solids

- 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?
  - *$O(N^2)$, where N is the # of faces*
- How would you detect collision between two bunnies?
  - *$O(N^2)$ is too expensive…*
  - *How can we eliminate some of that checking?*
  - *Let's use a spatial data structure!*



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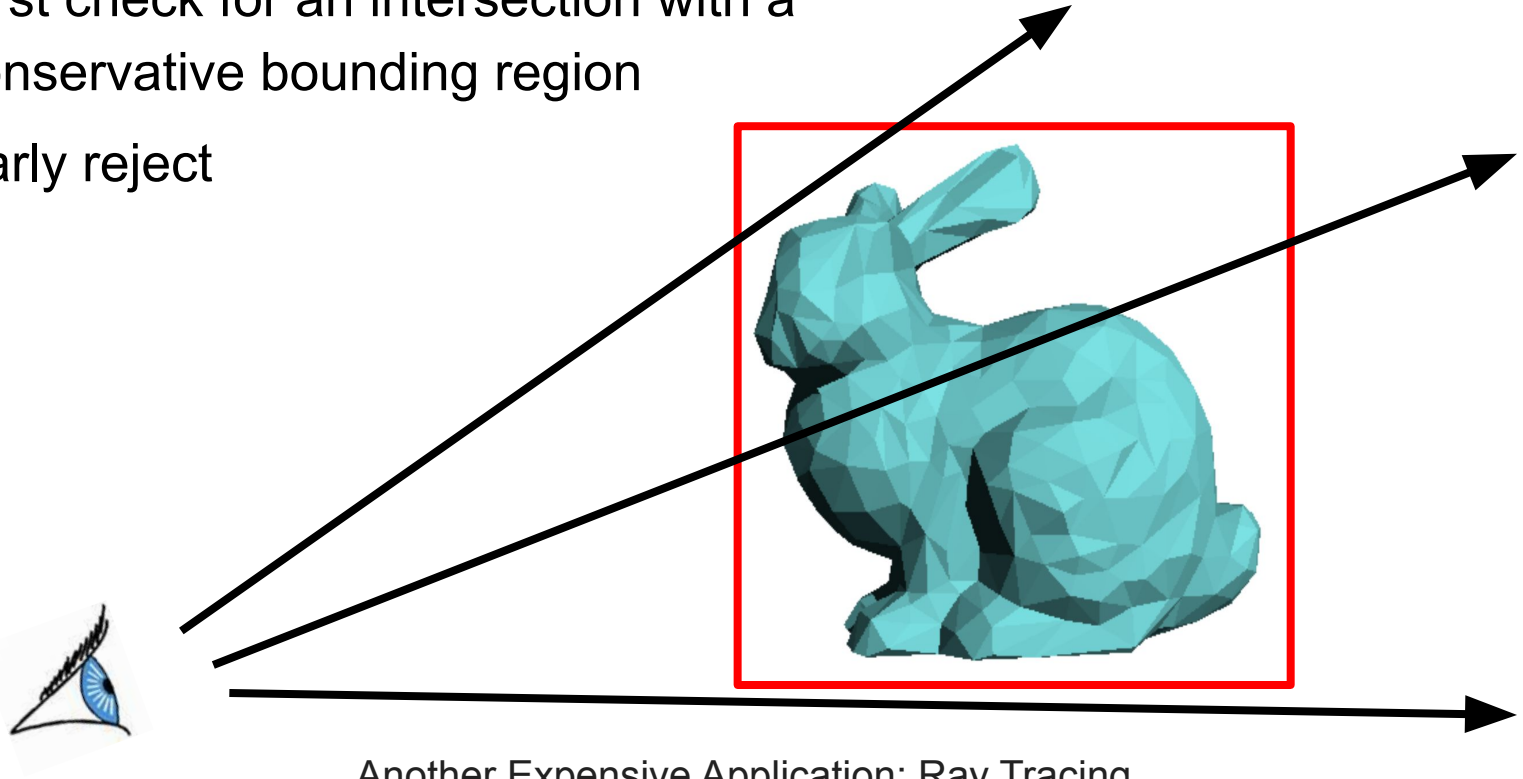
Conservative Bounding Region

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

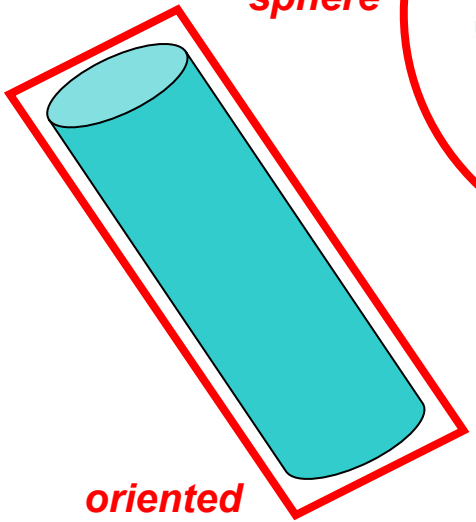


Another Expensive Application: Ray Tracing
Intersect object & ray… *more later this semester!!*

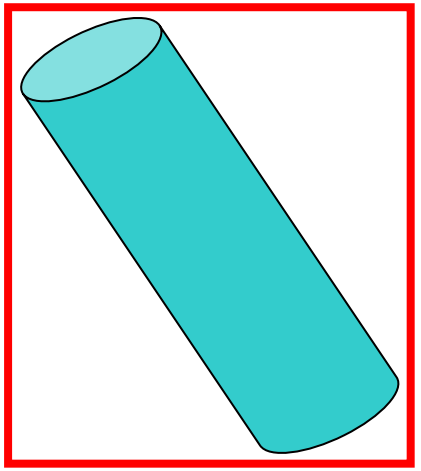
Conservative Bounding Regions

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

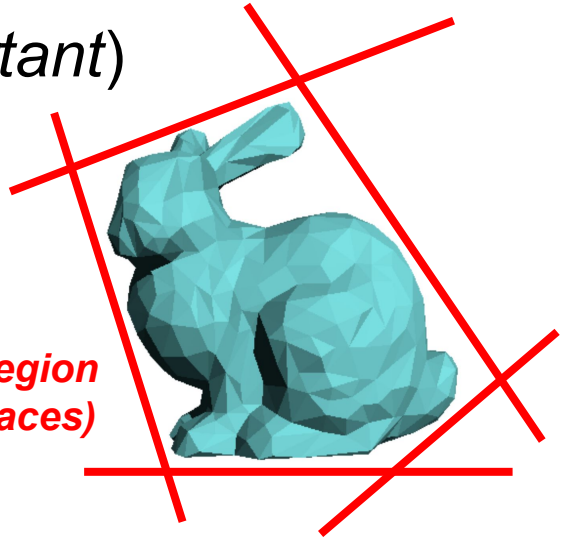
bounding sphere



oriented bounding box



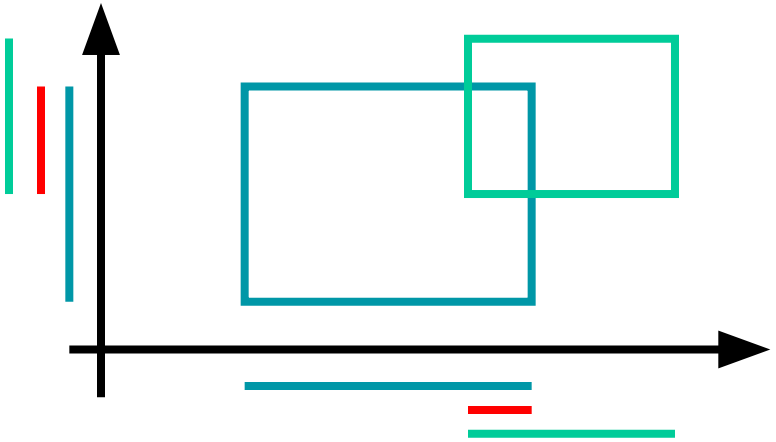
axis-aligned bounding box

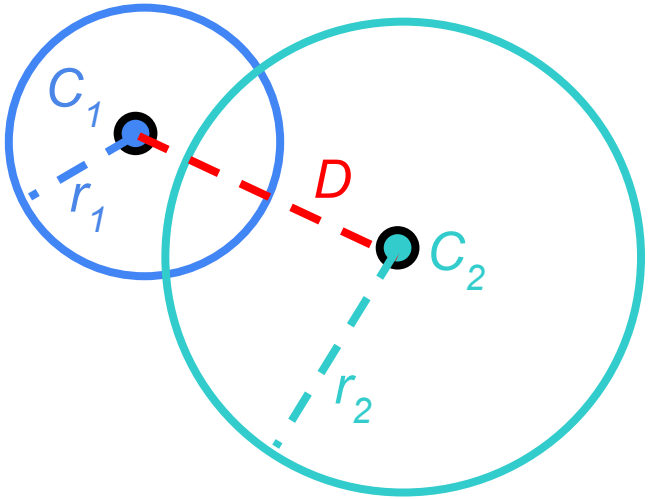


arbitrary convex region (bounding half-spaces)

Overlap Test

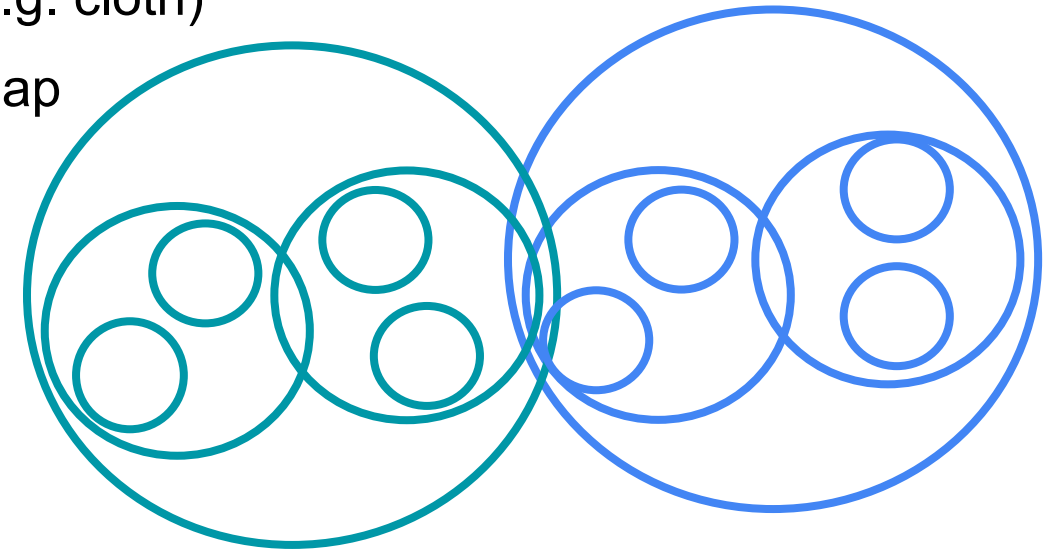
- Overlap between two axis-aligned boxes?
  - *Check if the intervals along the 3 dimensions overlap*
- Overlap test between two spheres?
  - *$D(center_1, center_2) < r_1 + r_2$*





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



Questions?

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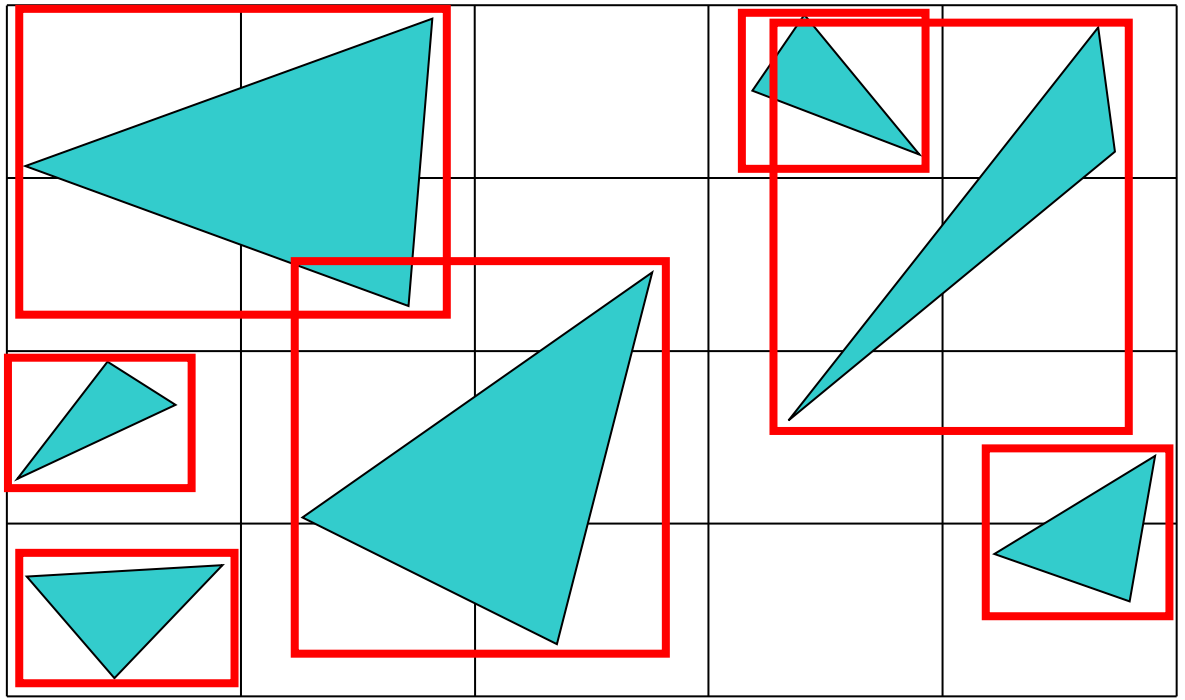
- Worksheet on Subdivision Surfaces
- Motivation: Collision Detection is Expensive
- Conservative Bounding Region
- Spatial Acceleration Data Structures
  - Fixed/Uniform/Regular Grid
  - Nested Grid
  - Octree
  - Binary Space Partition
  - K-d tree
  - Bounding Volume Hierarchy
- Readings for Today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

Fixed/Uniform/Regular Grid

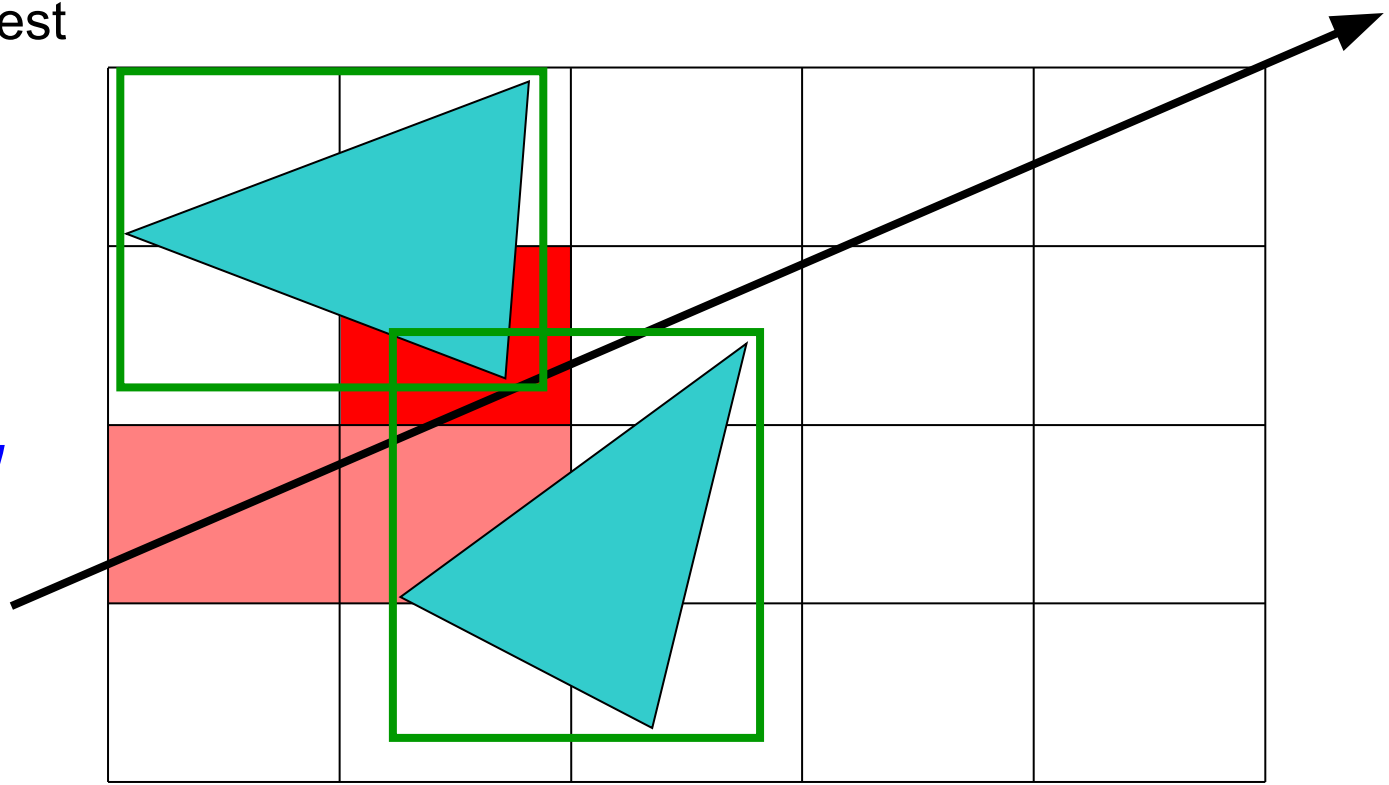
- Separate geometry into regions
- Reduces pairwise comparisons
- What to do with primitives that overlap multiple cells?

Insert into multiple cells (use pointers)



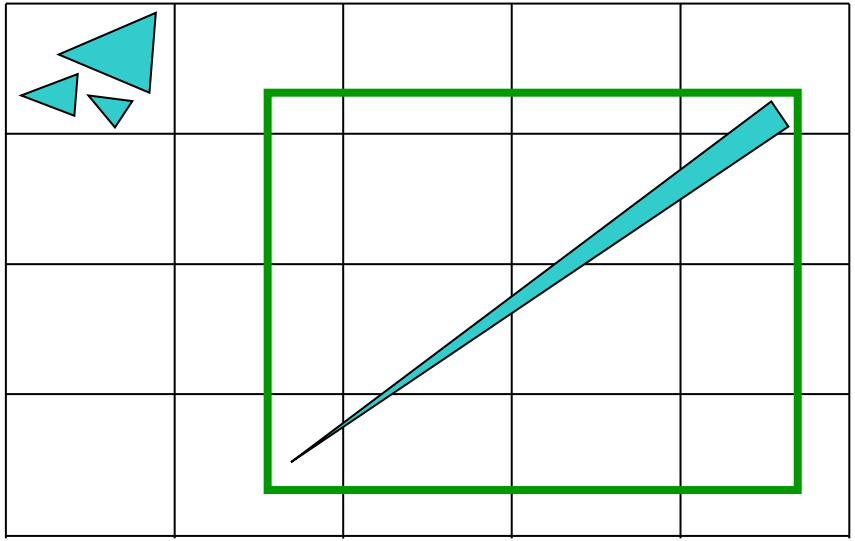
For Each Cell Along a Ray

- Does the cell contain an intersection?
- Yes: return closest intersection
- No: continue to march along ray
- *Be thorough with debugging!*



Fixed/Uniform Grid Discussion

- Advantages?
  - *easy to construct*
  - *easy to traverse*
- Disadvantages?
  - *may be only sparsely filled*
  - *geometry may still be clumped*
  - *object bounding box may overlap many cells*



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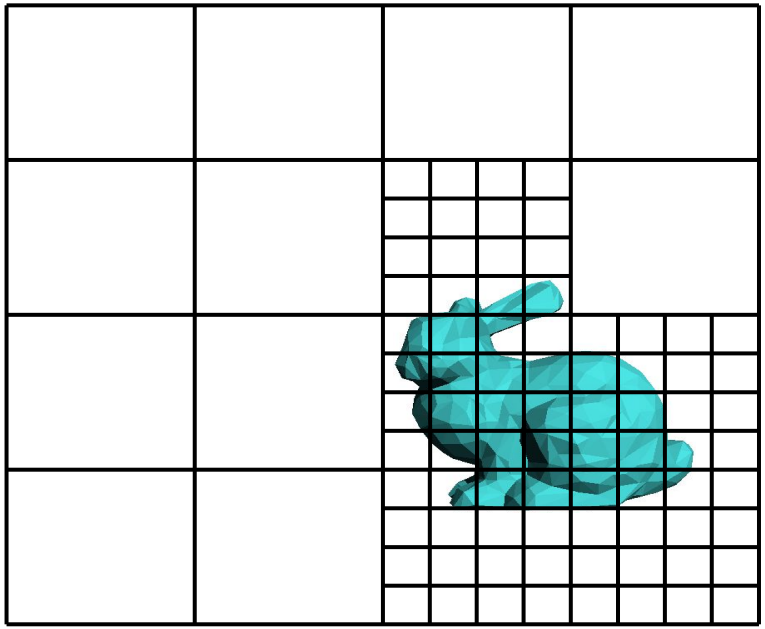
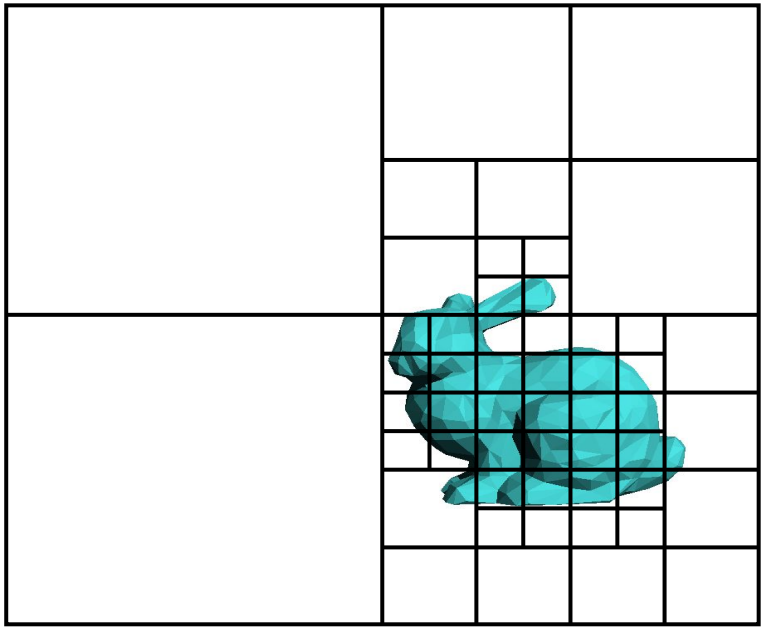
  Adaptive Grids
- Readings for Today
- Papers for Friday

Adaptive Grids

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



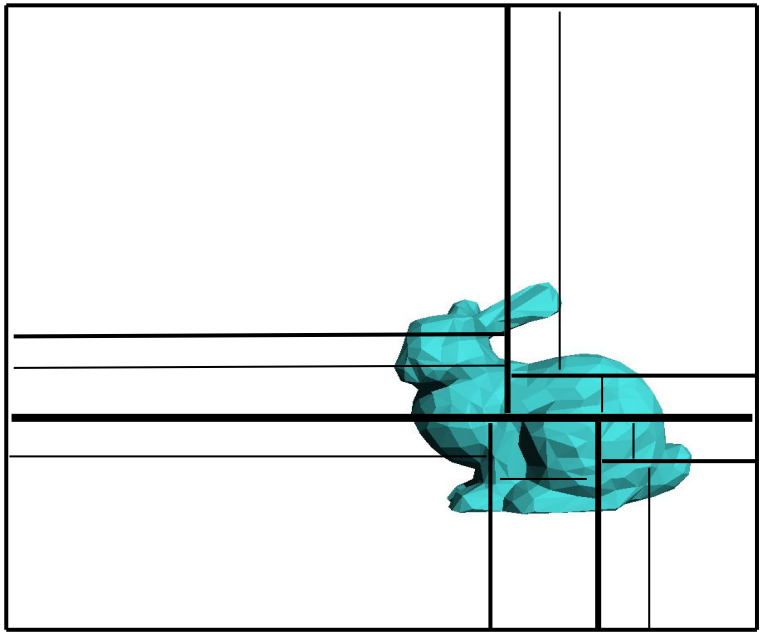
Nested Grids



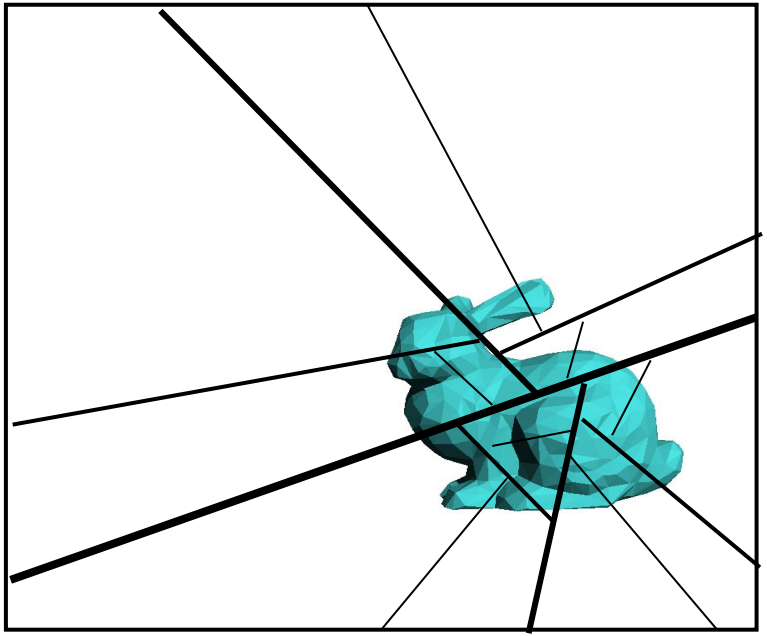
Octree/(Quadtree)

Adaptive Grids

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



K-D Tree

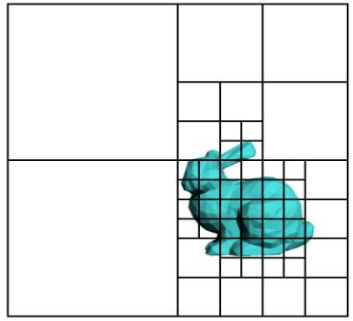


Binary Space Partition (BSP)

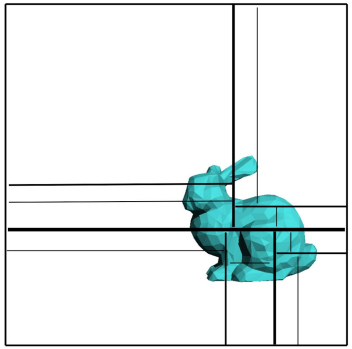
Variations of Adaptive Grids

- 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? *all improve $O(n^2) \rightarrow O(n \log n)$ but application needs & performance details vary*

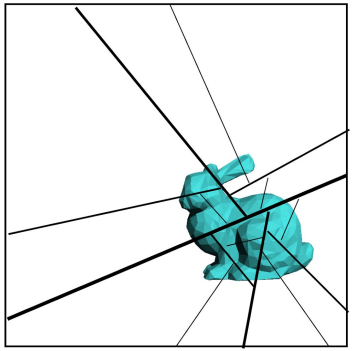
Quadtree/Octree



kd tree

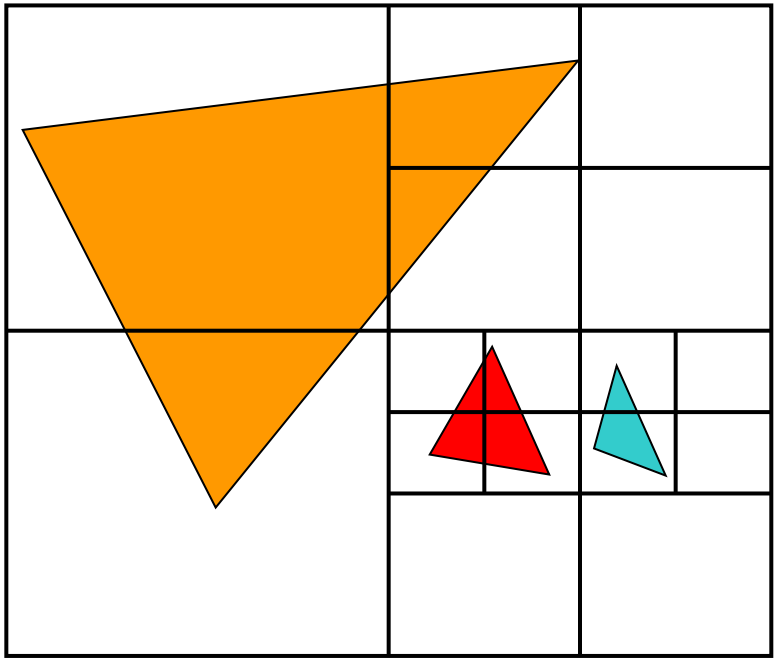


BSP

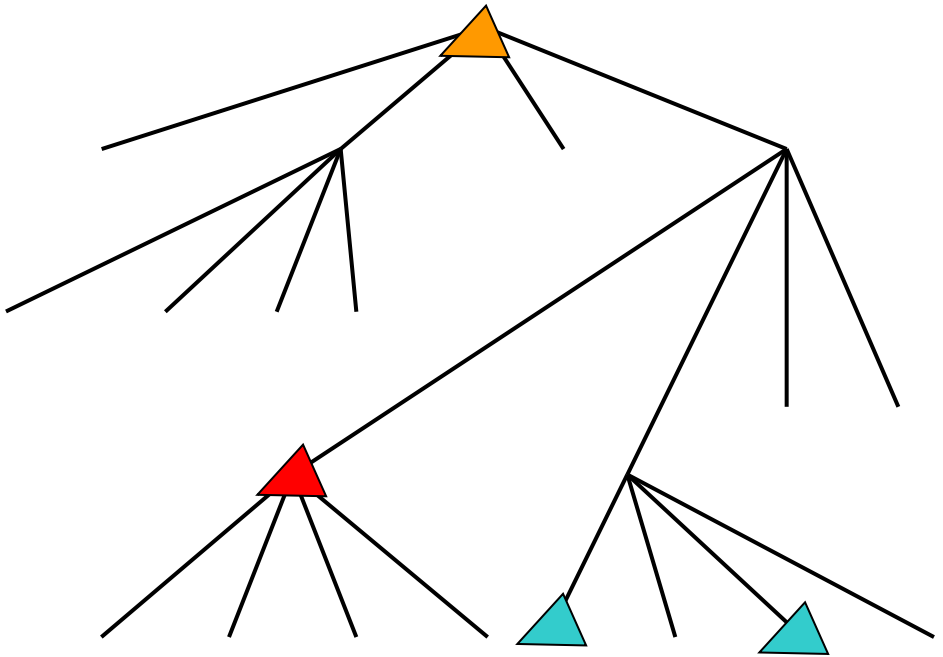


Primitives in an Adaptive Grid

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

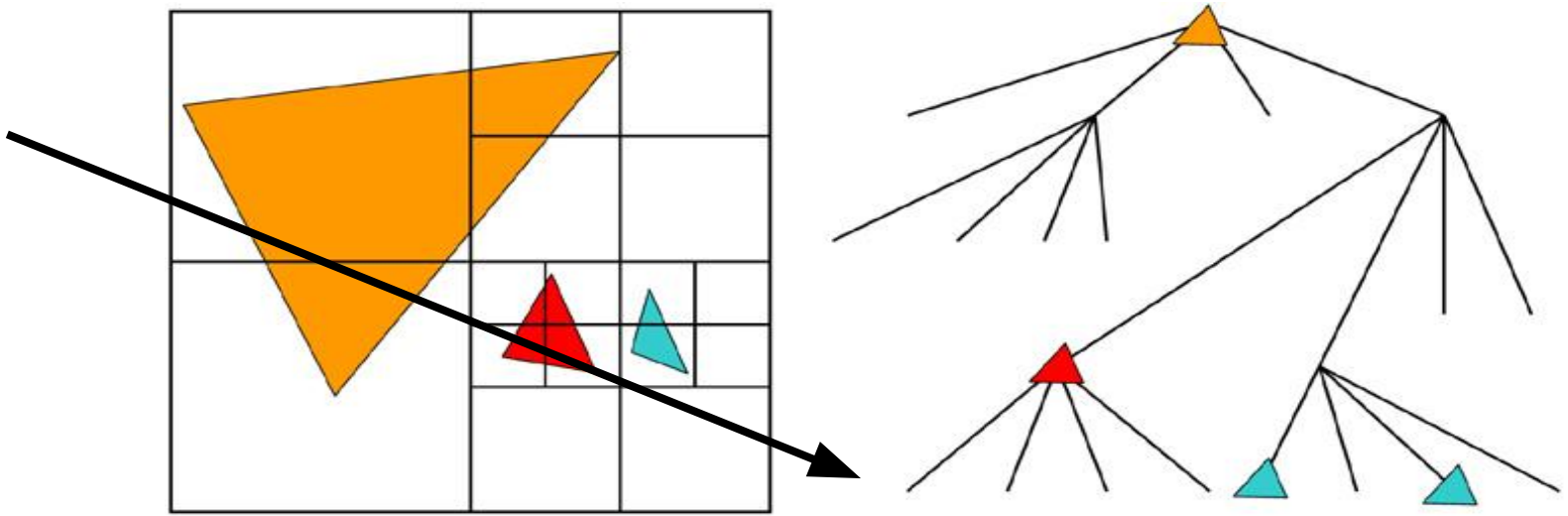


Octree/(Quadtree)



Adaptive Grid Discussion

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



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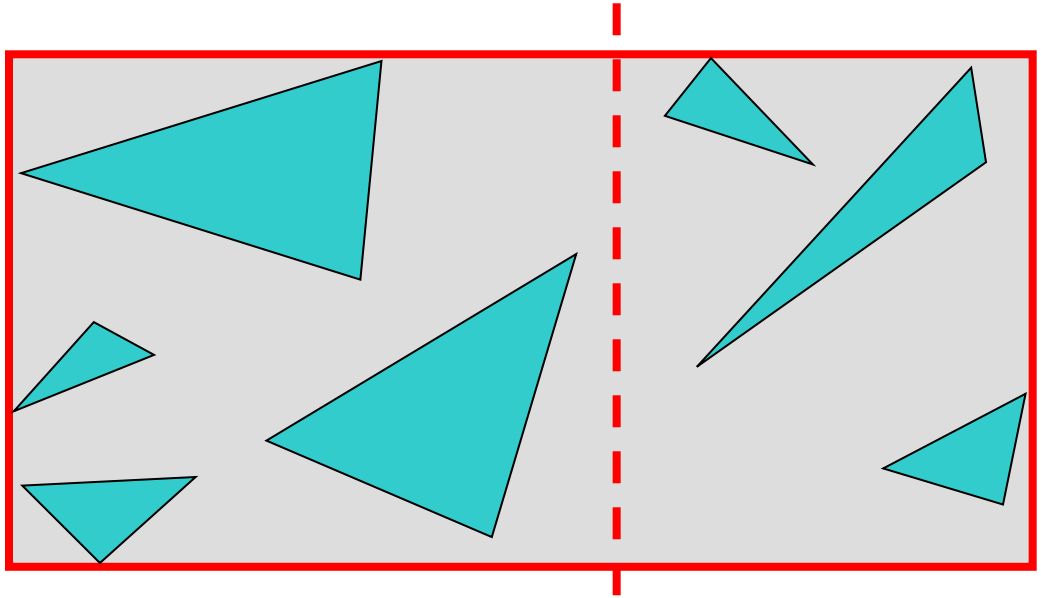
  - Binary Space Partition
  - K-d tree
  - Bounding Volume Hierarchy
- Readings for Today
- Papers for Friday

Bounding Volume Hierarchy

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



Bounding Volume Hierarchy

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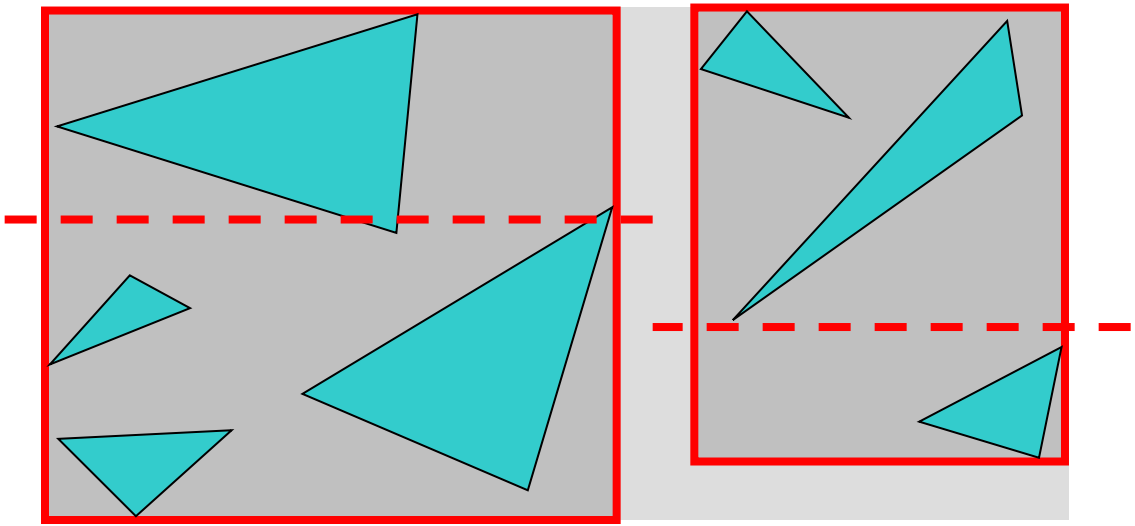
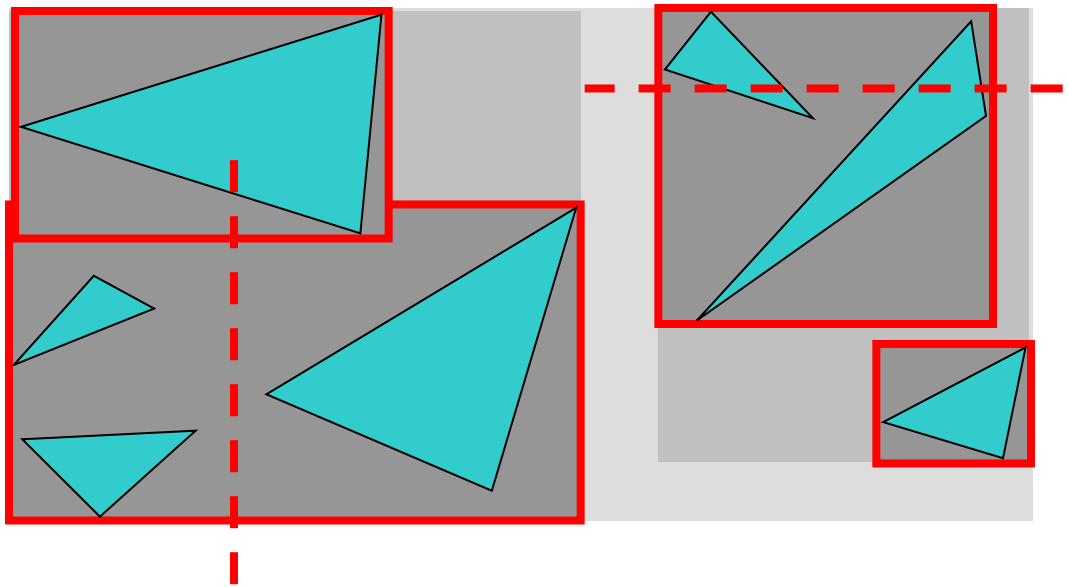
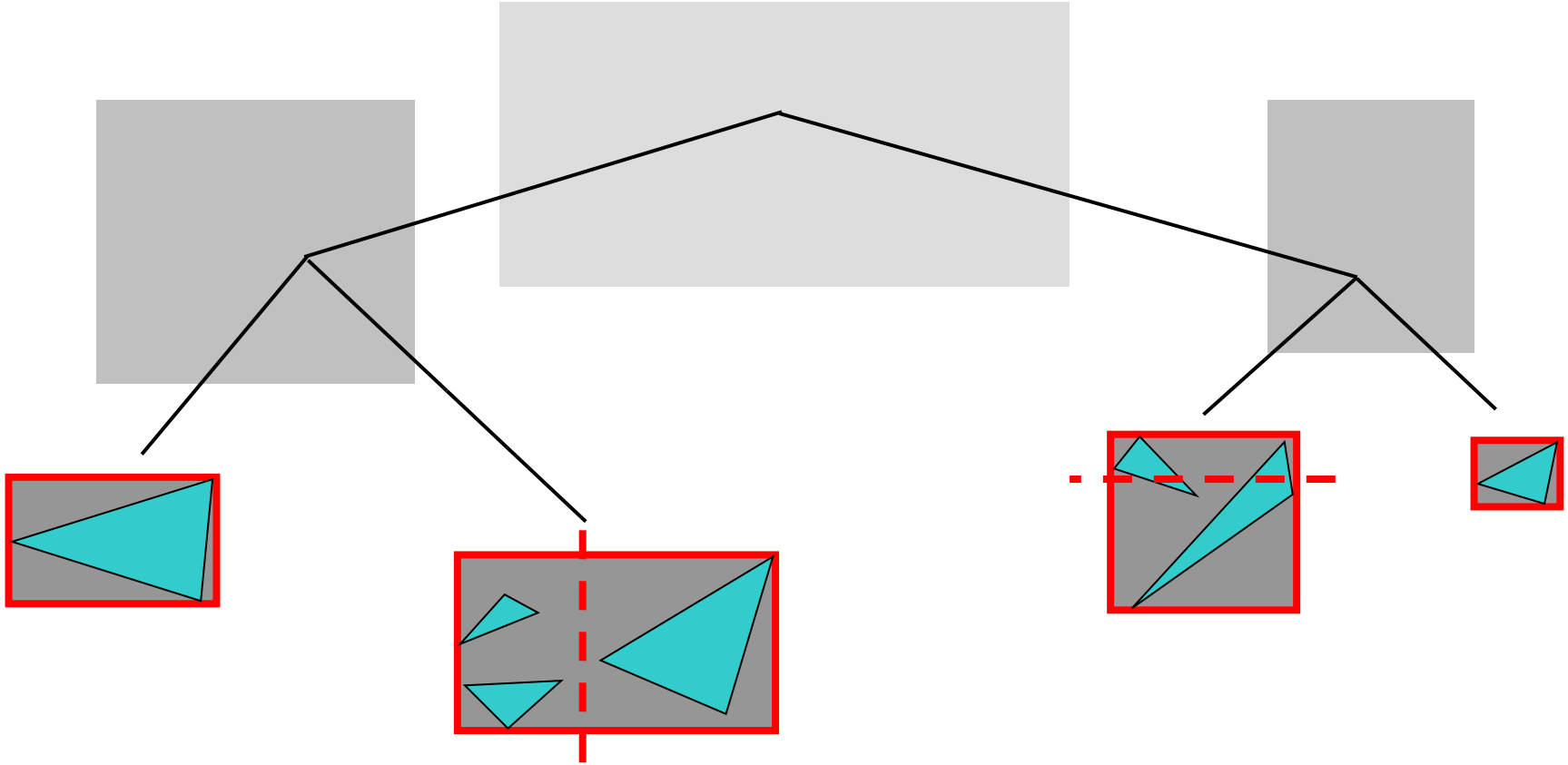


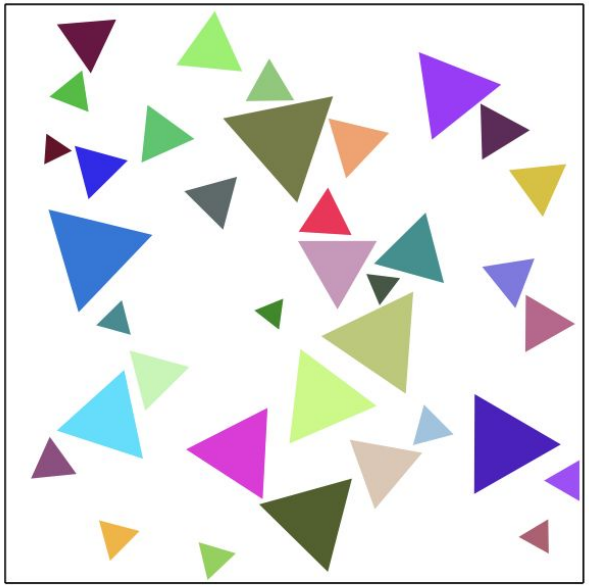
Where to Split Objects?

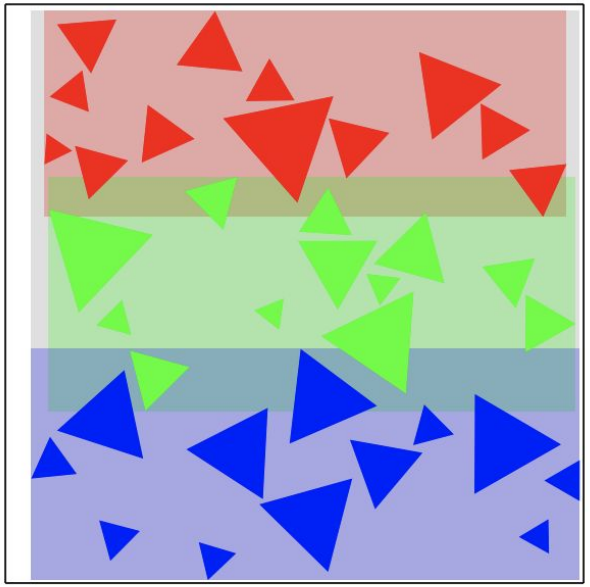
- At midpoint OR
- Sort, and put half of the objects on each side OR
- Use modeling hierarchy

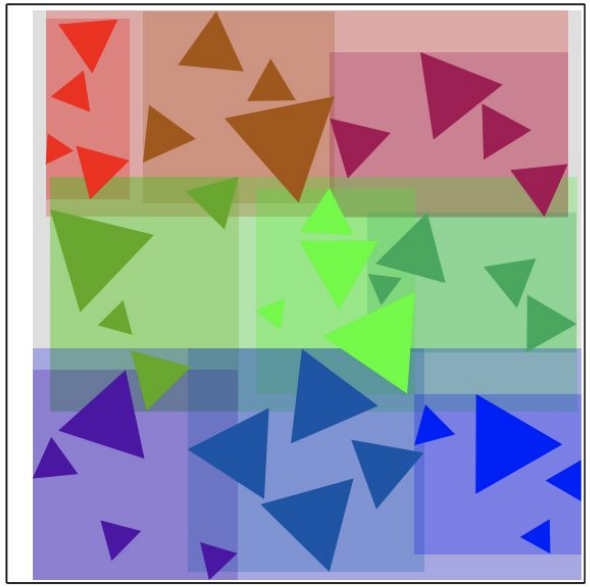


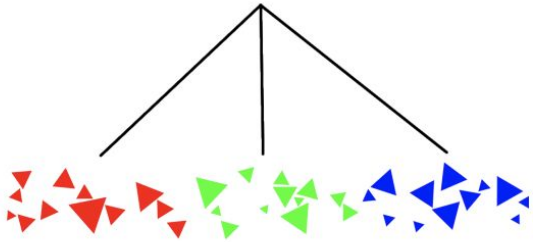


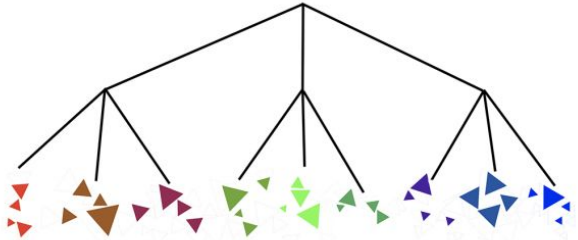
Data Structures Homework 8





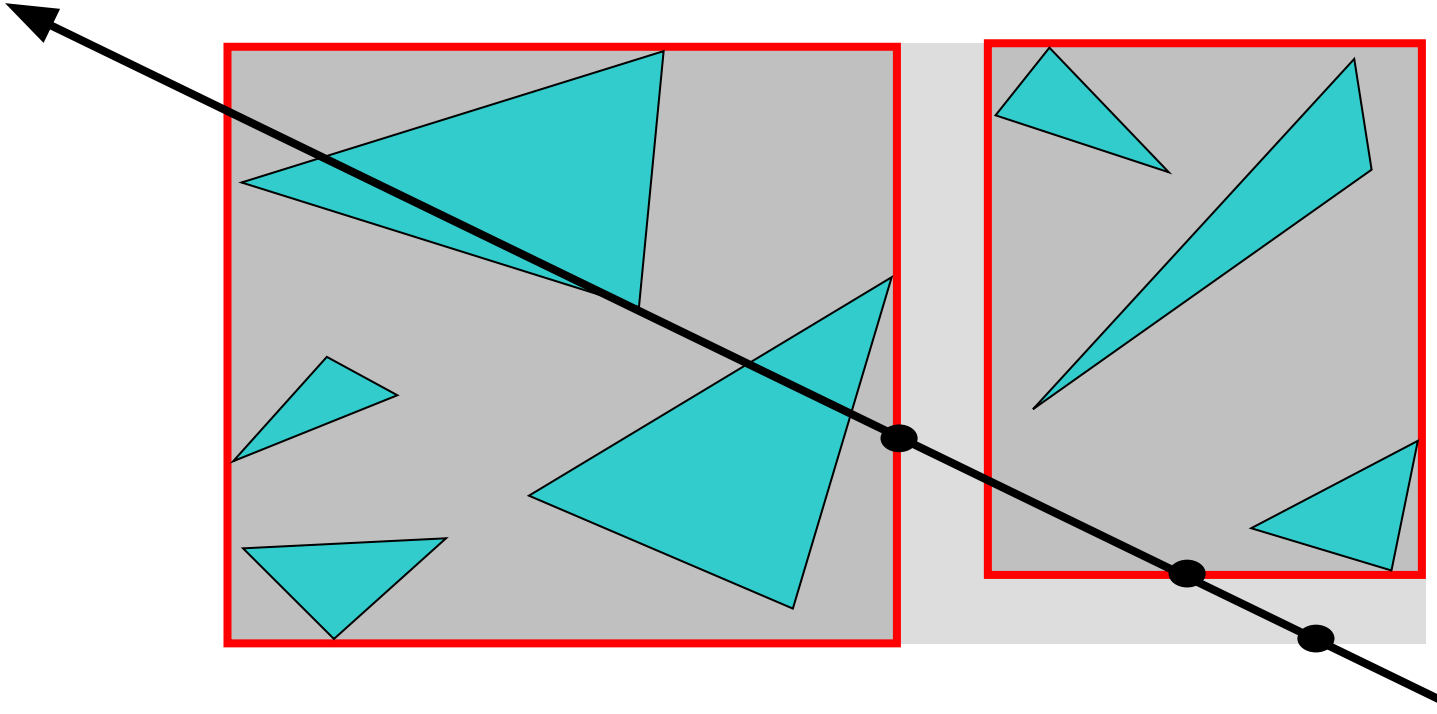






Intersection with BVH

- Check sub-volume with closer intersection first
- Requires careful & thorough with debugging!



Bounding Volume Hierarchy Discussion

- Advantages
  - *easy to construct*
  - *easy to traverse*
  - *binary*

- Disadvantages
  - *may be difficult to choose a good split for node*
  - *poor split may result in minimal spatial pruning*

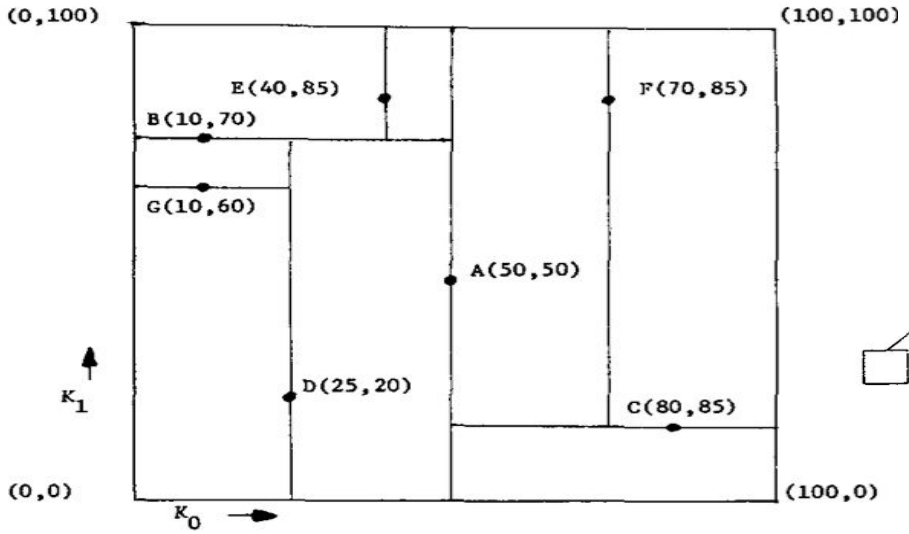
Questions?

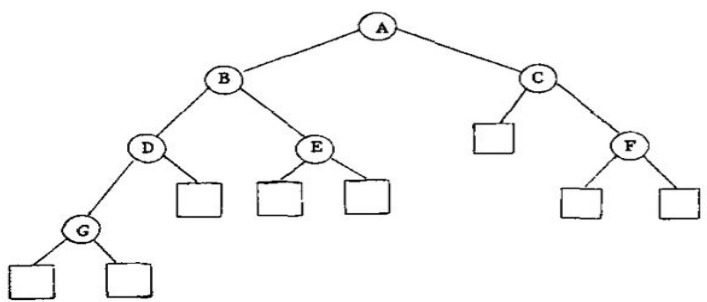
Today

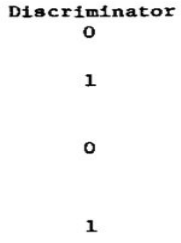
- Worksheet on Subdivision Surfaces
- Motivation: Collision Detection is Expensive
- Conservative Bounding Region
- Spatial Acceleration Data Structures
- Readings for Today
- Papers for Friday

Reading for Today

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

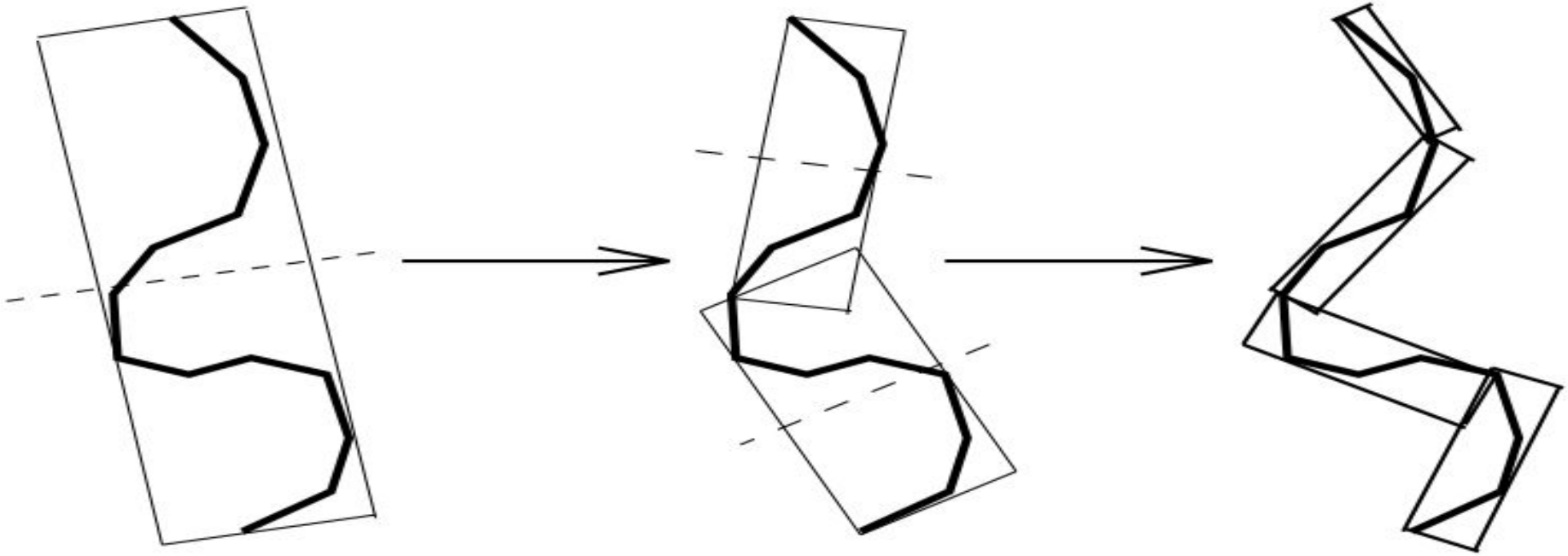






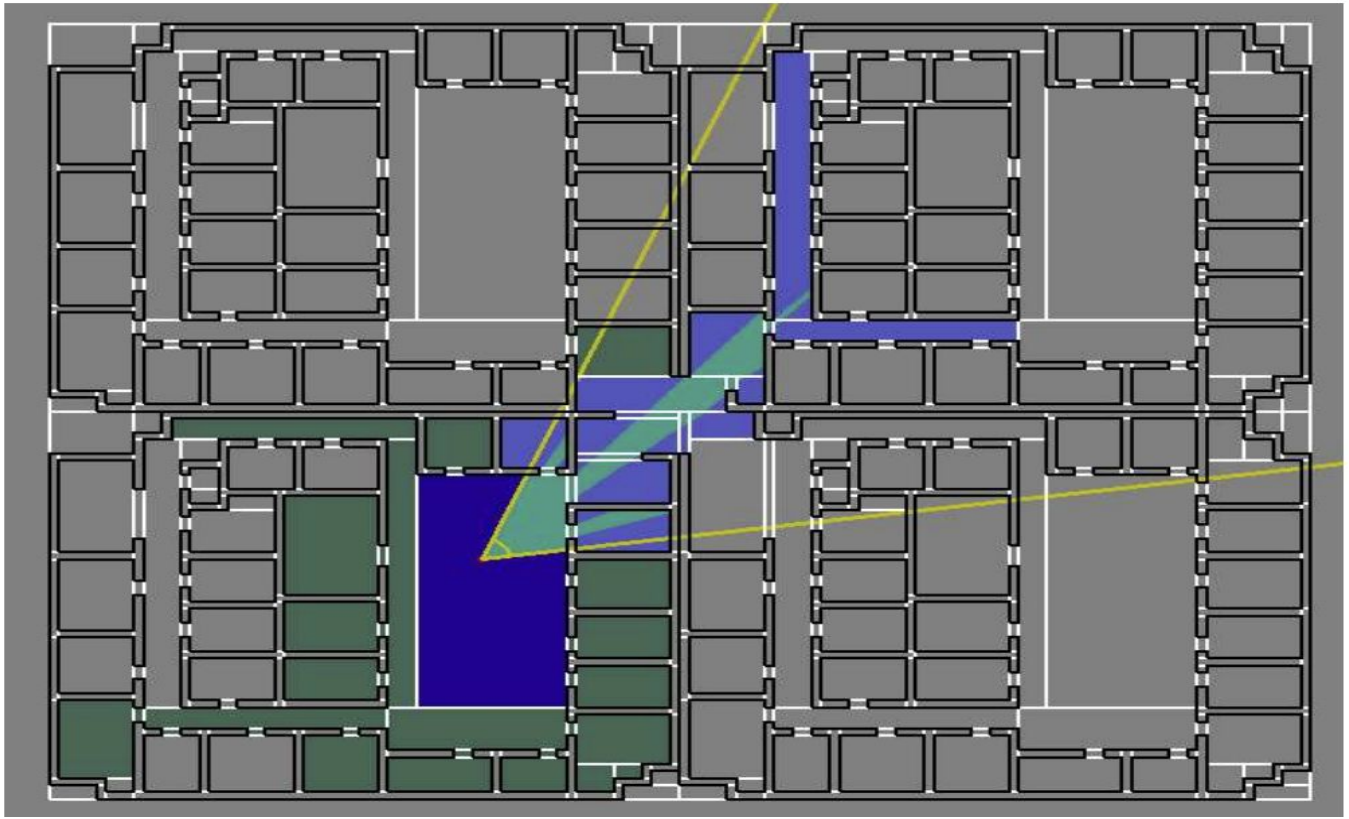
Reading for Today

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



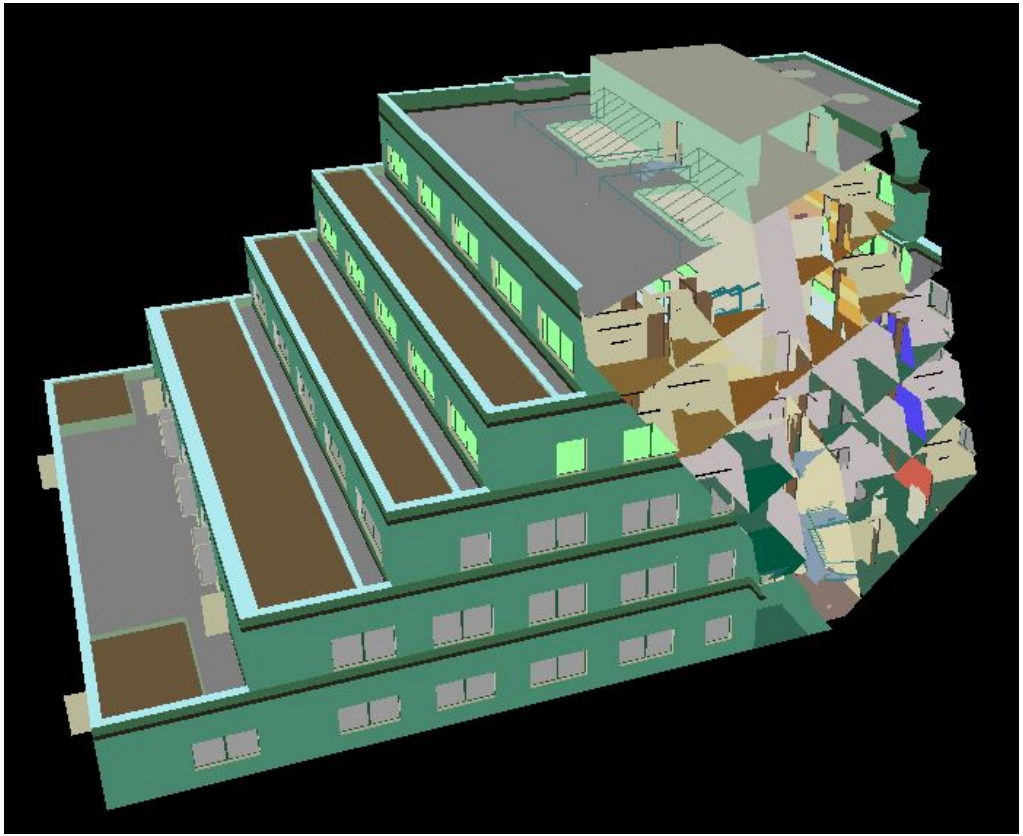
Reading for Today

"Visibility Preprocessing For Interactive Walkthroughs", Teller & Sequin, SIGGRAPH 1991.



Motivation: Architectural Walkthrough

- UC Berkeley's new Computer Science building
- Pre-construction visualization
- Very large dataset!
- Interactive/ real-time camera motion!



Seth Teller, PhD thesis, 1992, Berkeley Soda Hall walkthrough

Seth Teller, PhD thesis, 1992, Berkeley Soda Hall walkthrough

- Performance requirement: Interactive vs real time
- Conservative visibility: overestimate of polygons that might be visible (neither “exact” nor “underestimate”)
- Input assumptions - parallel to x or y axis & integer grid coordinates
- Subdivide space into ‘cells’ (rooms) & identify ‘portals’ between cells
- Portal sequences, sightlines, & stab tree
- Worst case quadratic storage not expected in typical architectural scenarios
- Temporal coherence (re-use/cache recent computations)
- 3D is challenging, windows made of many small panes of glass challenges scalability

Today

- Worksheet on Subdivision Surfaces
- Motivation: Collision Detection is Expensive
- Conservative Bounding Region
- Spatial Acceleration Data Structures
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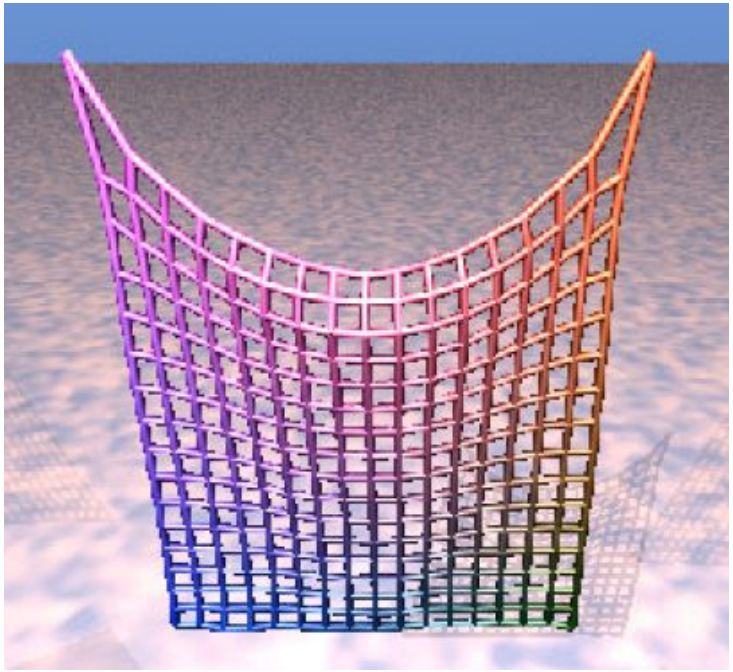
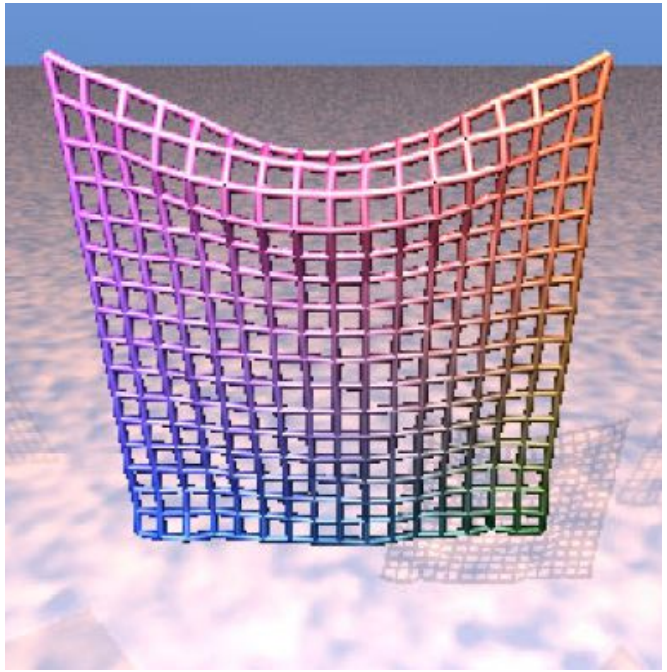
Reading for Next Time:

Everyone should read this paper!
(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 Friday

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