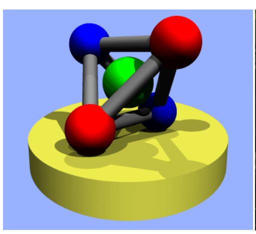
Acceleration Data Structures for Ray Tracing

Today

- Review & Schedule
- Motivation – Distribution Ray Tracing
- Bounding Boxes
- Spatial Acceleration Data Structures
- Flattening the transformation hierarchy

Cool results from Assignment 2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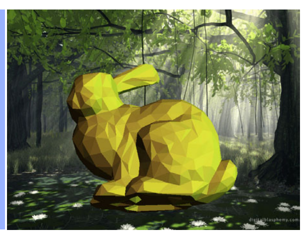
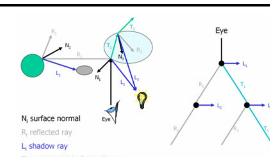
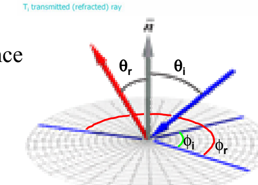

seantek

Last Week:

- Ray Tracing
  - Shadows
  - Reflection
  - Refraction
- Local Illumination
  - Bidirectional Reflectance Distribution Function (BRDF)
  - Phong Model





Schedule

- Wednesday October 1st:
  Assignment 3 (Ray Tracing & Phong Materials) due
- Sunday October 5th, 5 7PM, Room TBA:
  Review Session for Quiz 1
- Tuesday October 7th:
  Quiz 1: In class
- Wednesday October 15th:
  Assignment 4 (Grid Acceleration) due

Questions?

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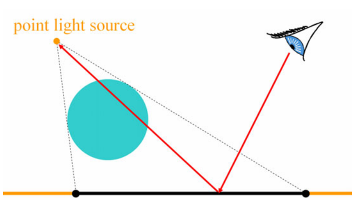
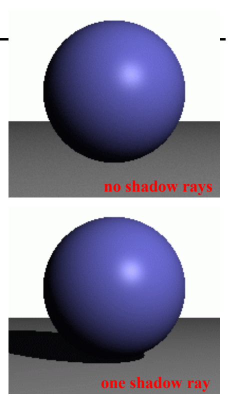
Extra rays needed for these effects:

- Distribution Ray Tracing
  - Soft shadows
  - Anti-aliasing (getting rid of jaggies)
  - Glossy reflection
  - Motion blur
  - Depth of field (focus)

Shadows

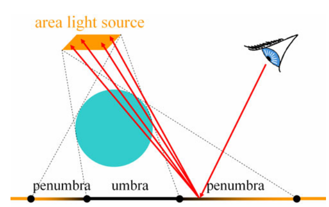
- one shadow ray per intersection per point light source

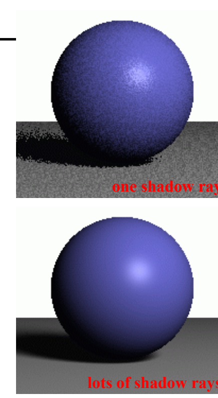




Soft Shadows

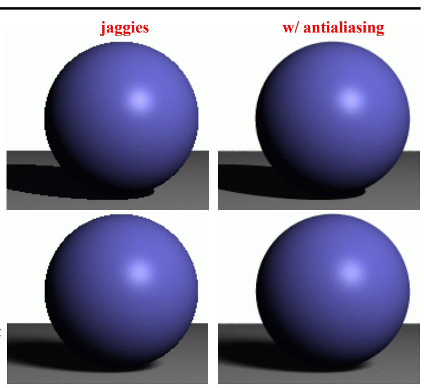
- multiple shadow rays to sample area light source





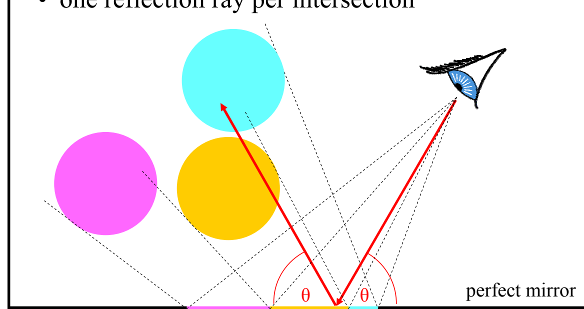
Antialiasing – Supersampling

- multiple rays per pixel



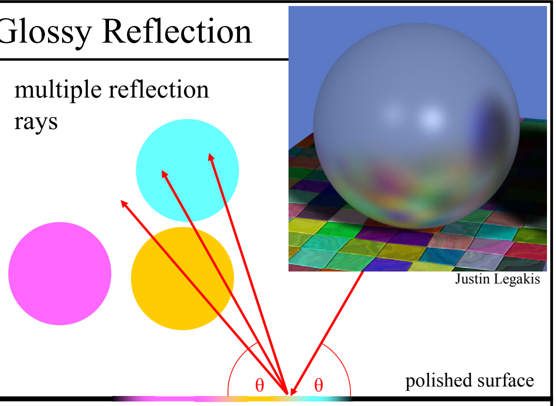
Reflection

- one reflection ray per intersection



Glossy Reflection

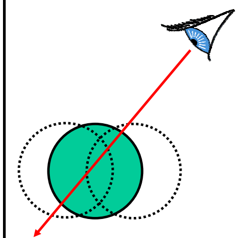
- multiple reflection rays



Justin Legakis

Motion Blur

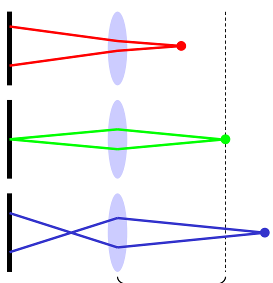
- Sample objects temporally

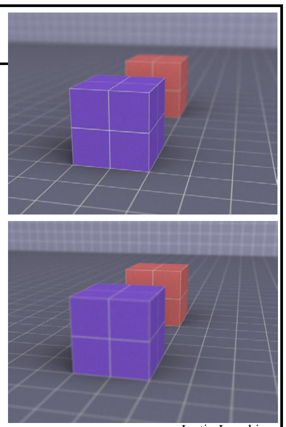


Rob Cook

Depth of Field

- multiple rays per pixel





Justin Legakis

Algorithm Analysis

- Ray casting
- Lots of primitives
- Recursive
- Distributed Ray Tracing Effects
  - Soft shadows
  - Anti-aliasing
  - Glossy reflection
  - Motion blur
  - Depth of field

cost ≤ height * width *
num primitives *
intersection cost *
num shadow rays *
supersampling *
num glossy rays *
num temporal samples *
max recursion depth *
. . .

can we reduce this?

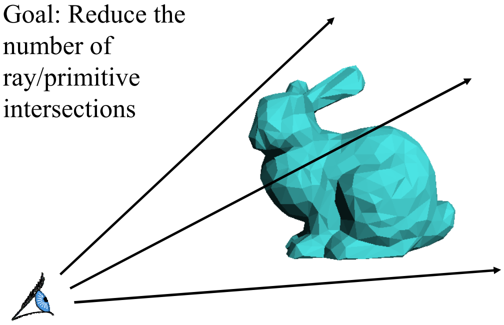
Questions?

Today

- Review & Schedule
- Motivation – Distribution Ray Tracing
- Bounding Boxes
  - of each primitive
  - of groups
  - of transformed primitives
- Spatial Acceleration Data Structures
- Flattening the transformation hierarchy

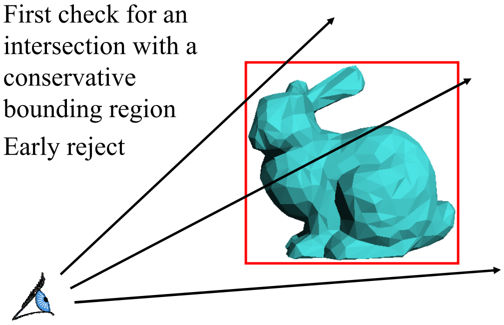
Acceleration of Ray Casting

- Goal: Reduce the number of ray/primitive intersections



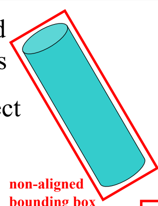
Conservative Bounding Region

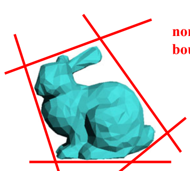
- First check for an intersection with a conservative bounding region
- Early reject

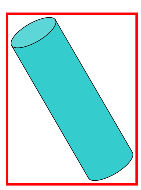


Conservative Bounding Regions

- tight → avoid false positives
- fast to intersect

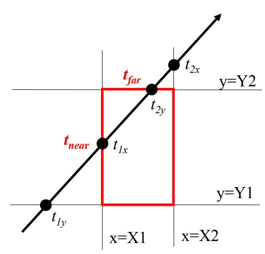






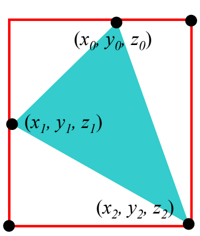
Intersection with Axis-Aligned Box

From Lecture 3, Ray Casting II



- For all 3 axes, calculate the intersection distances t_1 and t_2
- $t_{near} = \max(t_{1x}, t_{1y}, t_{1z})$
  $t_{far} = \min(t_{2x}, t_{2y}, t_{2z})$
- If $t_{near} > t_{far}$, box is missed
- If $t_{far} < t_{min}$, box is behind
- If box survived tests, report intersection at t_{near}

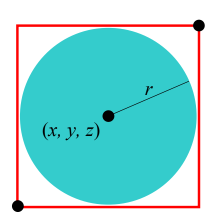
Bounding Box of a Triangle



$(x_{max}, y_{max}, z_{max})$
$= (\max(x_0,x_1,x_2), \max(y_0,y_1,y_2), \max(z_0,z_1,z_2))$

$(x_{min}, y_{min}, z_{min})$
$= (\min(x_0,x_1,x_2), \min(y_0,y_1,y_2), \min(z_0,z_1,z_2))$

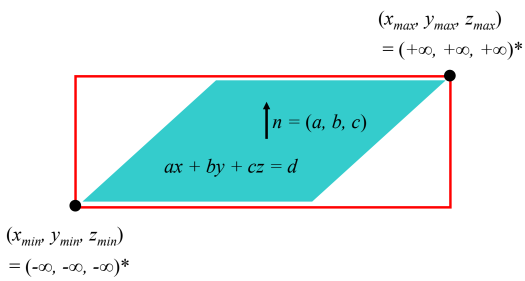
Bounding Box of a Sphere



$(x_{max}, y_{max}, z_{max})$
$= (x+r, \ y+r, \ z+r)$

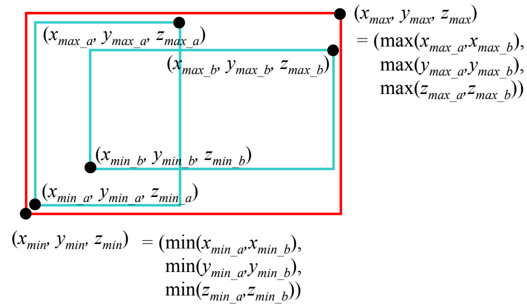
$(x_{min}, y_{min}, z_{min})$
$= (x-r, \ y-r, \ z-r)$

Bounding Box of a Plane

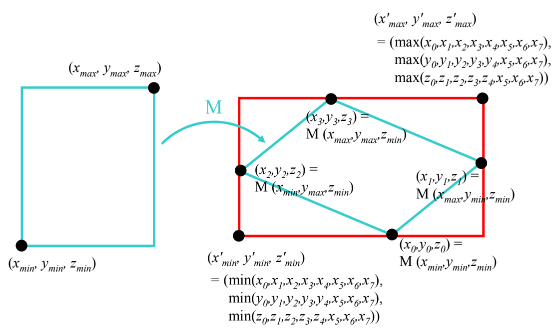


* *unless n is exactly perpendicular to an axis*

Bounding Box of a Group

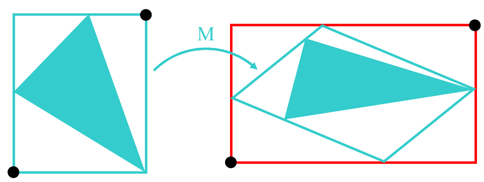


Bounding Box of a Transform

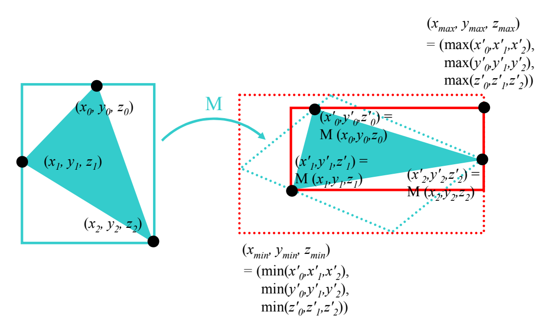


Special Case: Transformed Triangle

Can we do better?



Special Case: Transformed Triangle



Questions?

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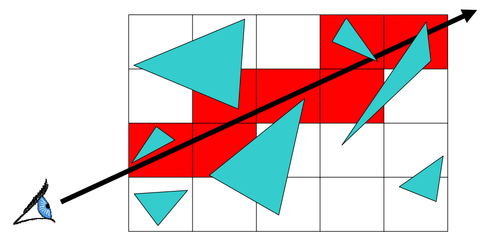
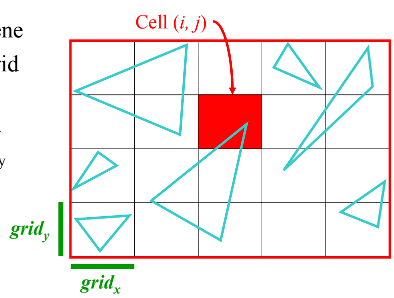
- Review & Schedule
- Motivation – Distribution Ray Tracing
- Bounding Boxes
- Spatial Acceleration Data Structures
  - Regular Grid
  - Adaptive Grids
  - Hierarchical Bounding Volumes
- Flattening the transformation hierarchy

Regular Grid



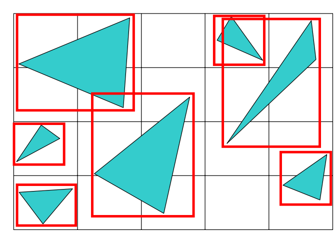
Create grid

- Find bounding box of scene
- Choose grid spacing
- $grid_x$ need not = $grid_y$



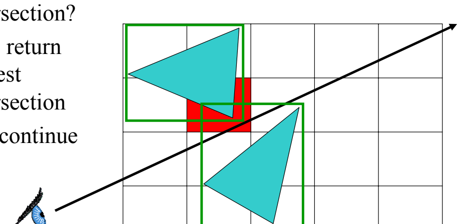
Insert primitives into grid

- Primitives that overlap multiple cells?
- Insert into multiple cells (use pointers)



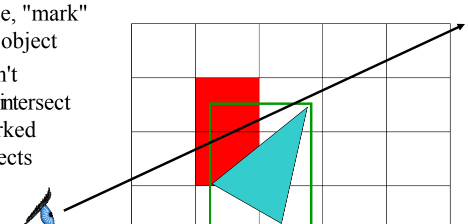
For each cell along a ray

- Does the cell contain an intersection?
- Yes: return closest intersection
- No: continue



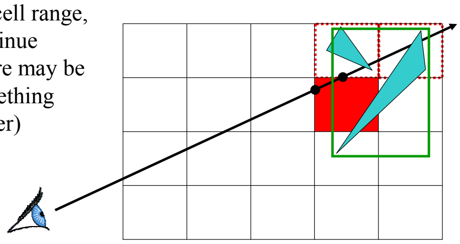
Preventing repeated computation

- Perform the computation once, "mark" the object
- Don't re intersect marked objects



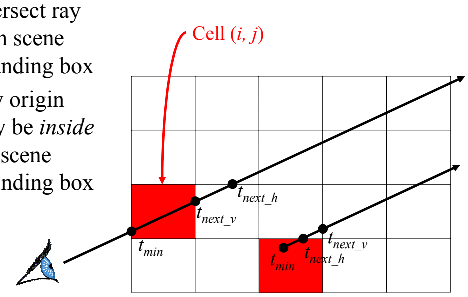
Don't return distant intersections

- If intersection t is not within the cell range, continue (there may be something closer)



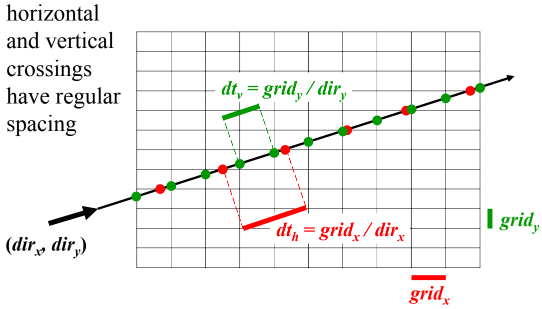
Where do we start?

- Intersect ray with scene bounding box
- Ray origin may be *inside* the scene bounding box



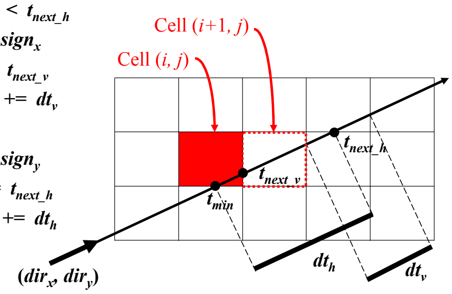
Is there a pattern to cell crossings?

- Yes, the horizontal and vertical crossings have regular spacing



What's the next cell?

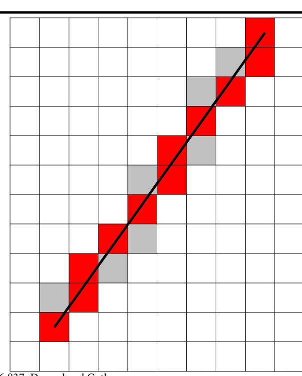
if $t_{next\_v} < t_{next\_h}$
  i += $sign_x$
  $t_{min} = t_{next\_v}$
  t_{next_v} += dt_v
else
  j += $sign_y$
  $t_{min} = t_{next\_h}$
  t_{next_h} += dt_h



if ($dir_x > 0$) $sign_x = 1$ *else* $sign_x = -1$
if ($dir_y > 0$) $sign_y = 1$ *else* $sign_y = -1$

What's the next cell?

- 3DDDA – Three Dimensional Digital Difference Analyzer
- We'll see this again later, for line rasterization



Pseudo-code

```
create grid
insert primitives into grid
for each ray r
  find initial cell c(i,j), t_min, t_next_v & t_next_h
  compute dt_v, dt_h, sign_x and sign_y
  while c != NULL
    for each primitive p in c
      intersect r with p
      if intersection in range found
        return
    c = find next cell
```

Regular Grid Discussion

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

Questions?

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  - Adaptive Grids
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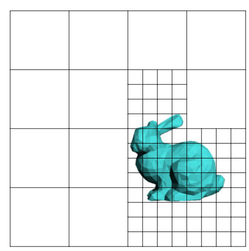
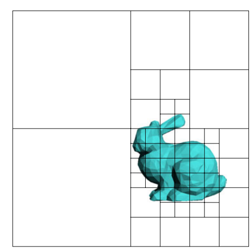
Adaptive Grids

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



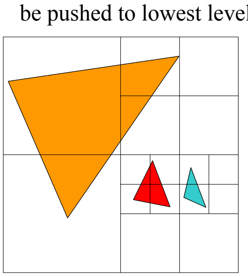
Nested Grids



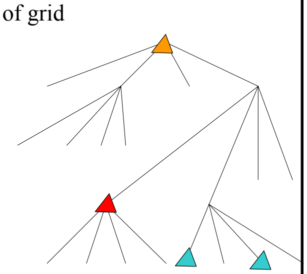
Octree/(Quadtree)

Primitives in an Adaptive Grid

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

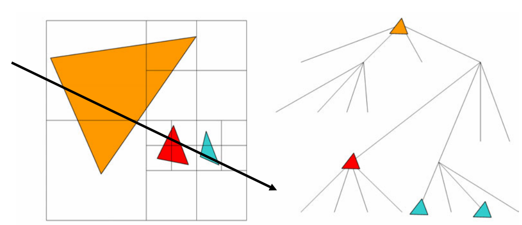


Octree/(Quadtree)



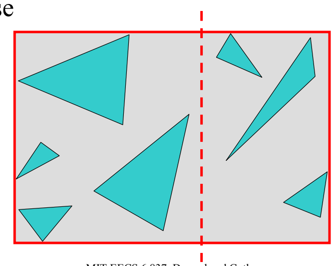
Adaptive Grid Discussion

- Advantages?
  - grid complexity matches geometric density
- Disadvantages?
  - more expensive to traverse (especially octree)



Bounding Volume Hierarchy

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



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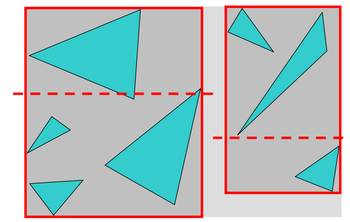

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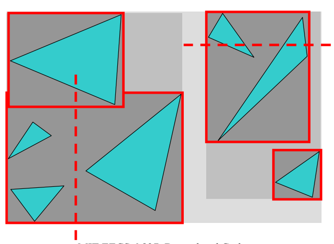

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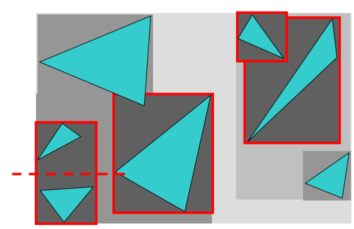

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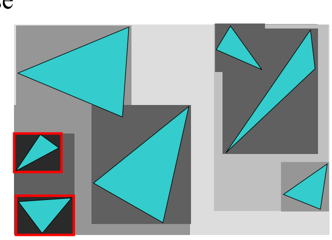
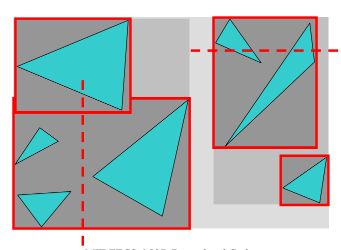


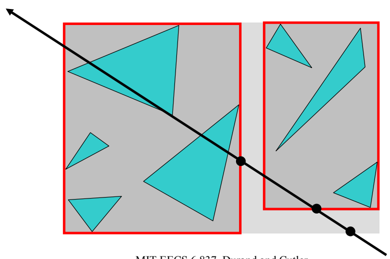
Where to split objects?

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



Intersection with BVH

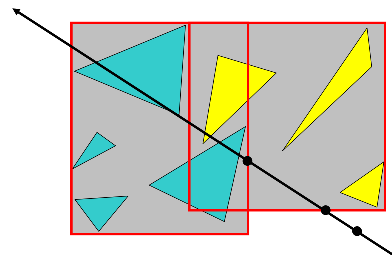
- Check subvolume with closer intersection first



MIT EECS 6.837, Durand and Cutler

Intersection with BVH

- Don't return intersection immediately if the other subvolume may have a closer intersection



MIT EECS 6.837, Durand and Cutler

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

MIT EECS 6.837, Durand and Cutler

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- Flattening the transformation hierarchy

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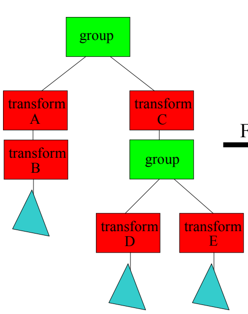
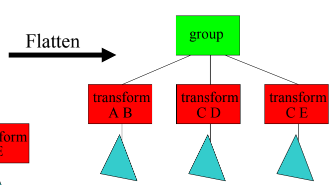
Transformation Hierarchy

- Group & Transformation hierarchy may not be a good spatial hierarchy





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Questions?

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Assignment 4 (due Oct 15th)

- Bounding boxes for primitives
- Regular grid acceleration data structure
- Flatten the transformation hierarchy
- Collect statistics
  - Average # of rays per pixel
  - Average # of ray/primitive intersections per pixel
- Extra Credit: Distribution Ray Tracing
  (and anything else from past weeks)

Next Time:

Curves & Surfaces