ray tracing II

improving raytracing speed

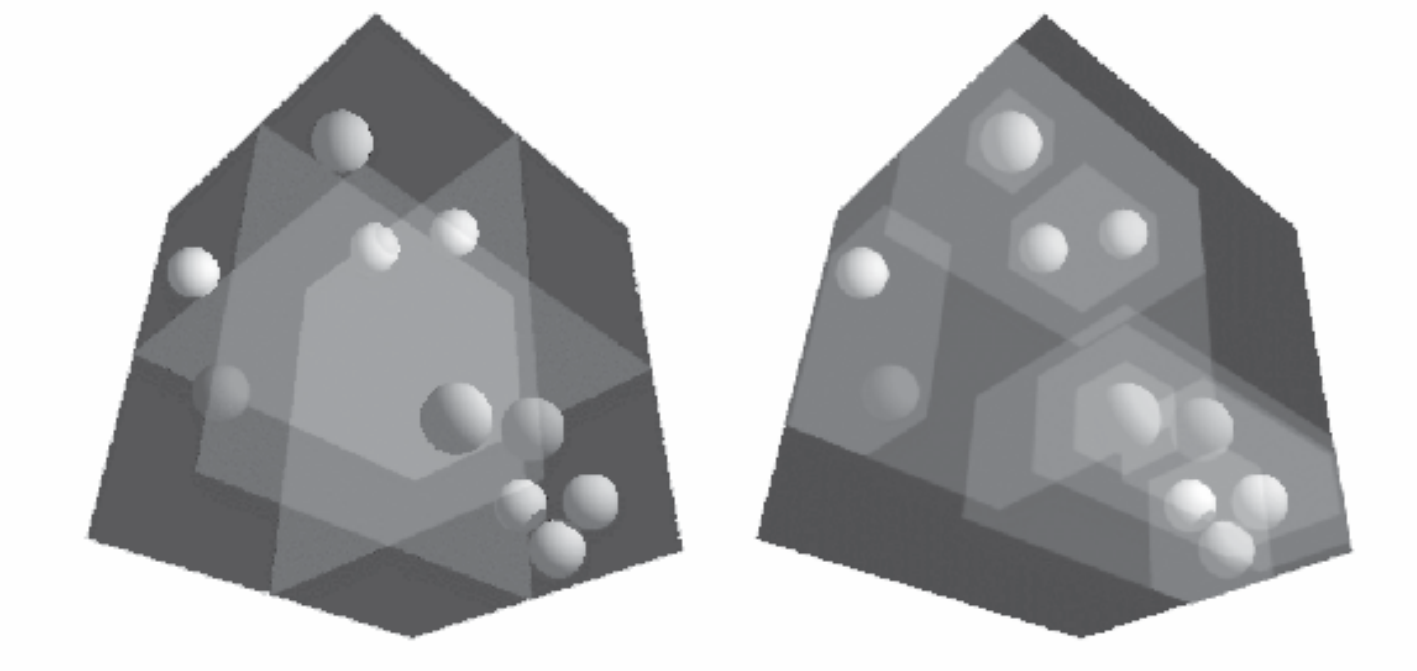
raytracing computational complexity

- ray-scene intersection is expensive
  - improve by low-level optimizations
    - important but does not provide scalability
  - improve by reducing computational complexity

improving computational complexity

- ray-scene intersection is an O(n) algorithm, where n is the number of objects
  - loop over each object, check intersection
  - note that it is fundamentally a search algorithm
- use divide and conquer to turn it to O(log n)
  - similar principles of search algorithms
    - divide objects into sets
    - discard sets of objects quickly
    - test inside set only when necessary
  - not as easy since data structures become complicated
- which data structures to use?

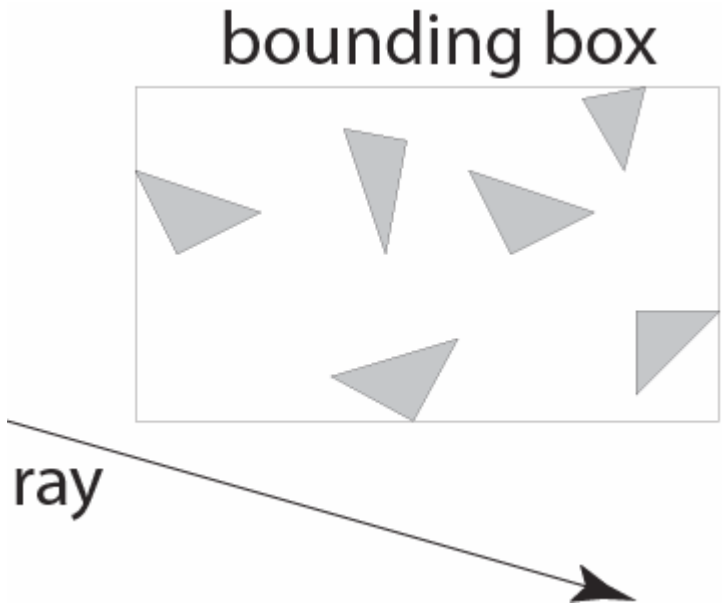
acceleration structures examples



[Shirley – original from Demarle]

bounding volumes

- wrap groups of objects in bounding volumes
  - all points on the objects are inside the bounding vol.
  - if ray does not hit volume, than it does hit the object
  - if ray hits the volume, test the object



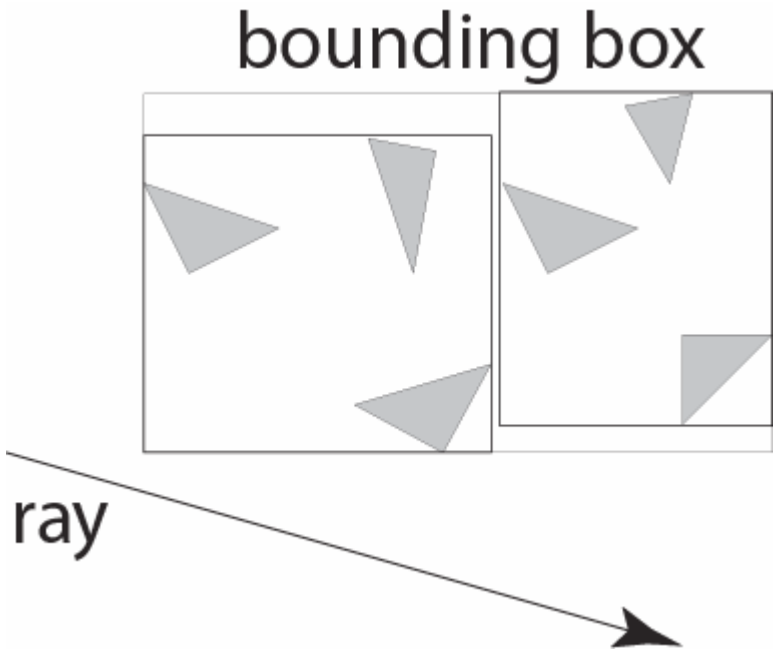
[Shirley]

bounding volumes

- worth if volume hit-testing cheaper than obejct's
  - e.g. polygon mesh inside a bounding sphere
- need to know if intersection exists, not where
  - speed up by removing computation
- use only simple primitives
  - sphere, axis-aligned boxes (AABB), oriented boxes (OBB)
  - choose based on tightness of fit vs. intersection speed
    - increasing tightness: spheres, AABBs, OOBBs
    - increasing speed: OOBBs, AABBs, spheres

axis-aligned bounding boxes

- most commonly used
- intersection with multiple infinite slabs



[Shirley]

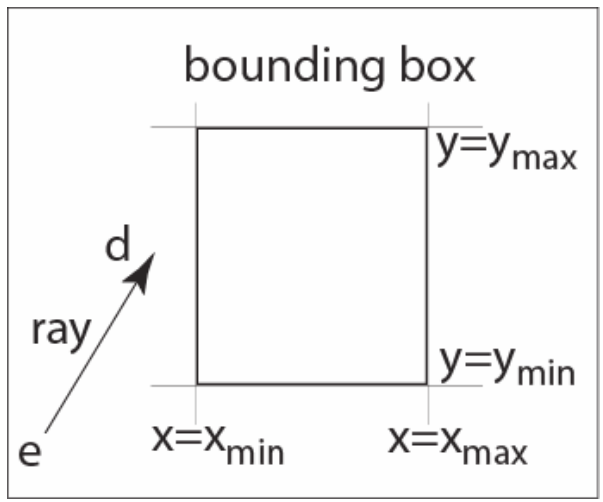
axis-aligned boxes in 2D

$$\mathbf{P} = \mathbf{E} + t\mathbf{I}$$ point on a ray

$$P_x \in [x_m, x_M] \wedge P_y \in [y_m, y_M]$$ point in the box

assume $I_x > 0 \wedge I_y > 0$

compute t for each plane



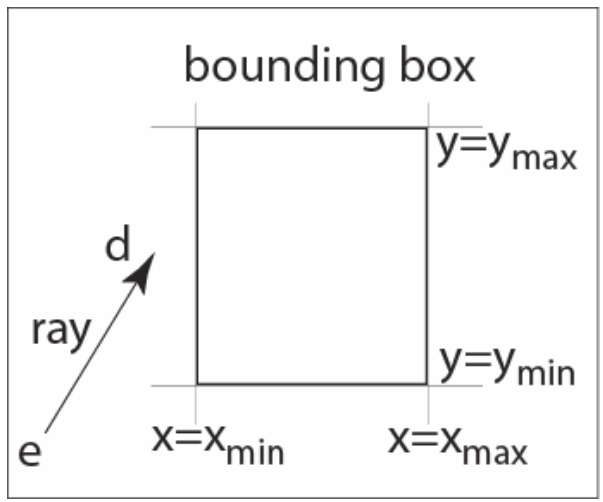
[Shirley]

axis-aligned boxes in 2D

$$t_{xm} = (x_m - E_x)/I_x \qquad t_{ym} = (y_m - E_y)/I_y$$
$$t_{xM} = (x_M - E_x)/I_x \qquad t_{xM} = (y_M - E_y)/I_y$$

intersect if $t_{xm} \le t_{yM} \wedge t_{ym} \le t_{xM}$

since $t \in [t_{xm}, t_{xM}] \wedge t \in [t_{ym}, t_{yM}]$



[Shirley]

axis-aligned boxes

extend to other quadrants by redefining intersections

for $I_x < 0$ define

$$t_{xm} = (x_M - E_x) / I_x$$
$$t_{xM} = (x_m - E_x) / I_x$$

for $I_y < 0$ define

$$t_{ym} = (y_M - E_y) / I_y$$
$$t_{yM} = (y_m - E_y) / I_y$$

avoid division by zero as in Shirley 10.9

extend to 3D by including two new planes

hierarchical bounding volumes

- group bounding volumes hierarchically
  - this is what gives us the *expected* O(log n)
    - not provable, strongly depends on input data
- volumes bound all surfaces inside them
- not a perfect split: siblings volumes can overlap
  - hierarchical intersection testing
    - if parent does not intersect, then no intersection
    - else intersect all children and pick the closest intersection (if any)

creating bounding hierarchies

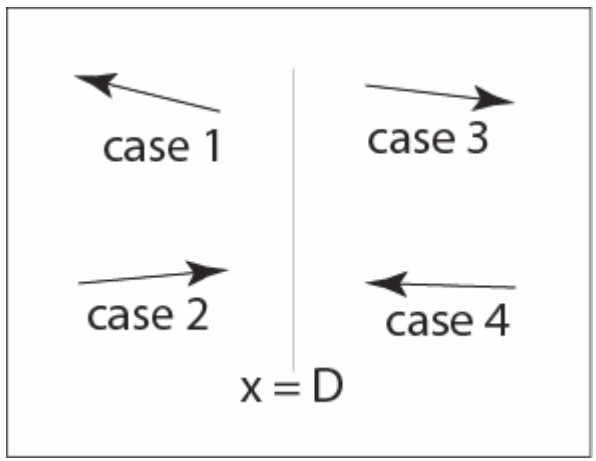
- effective space partitioning is necessary
  - following transform hierarchy is not always efficient
- basic greedy algorithm for binary trees
  - pick a direction, say along *x* axis
  - split objects into two groups, and bound them
  - continue splitting each group
  - change axis at each iteration: *x,y,z,x,y,z…*
- goal 1: balanced number of children in subtrees
  - split for same number of primitive in each group
- goal 2: equal space for each subtree
  - split the parent bounding box in the middle spatially

binary space partitioning (BSP) trees

- conceptually similar to bounding hier. creation
- node defined by splitting plane
  - often pick a plane orthogonal to *x*, then *y*, then *z*, …
    - call kd tree in this case
- children contain objects in one of two half spaces
  - objects intersecting plane are in each child

intersecting BSP trees

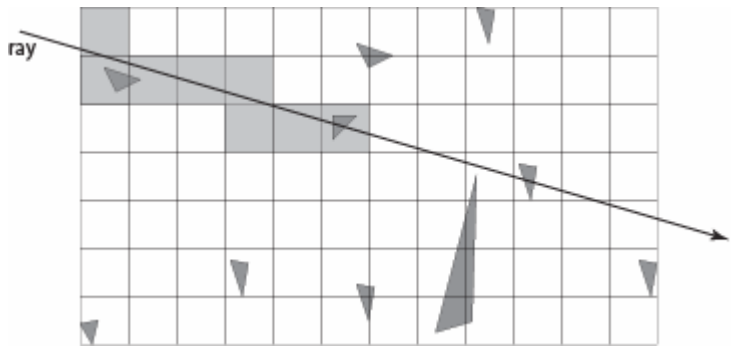
- starts at the top and determine which of
- case 1: test only Left
- case 2: test Left; if no intersections test Right
- case 3: test Right; if no intersections test Left
- case 4: test only Right



[Shirley]

regular space subdivision

- non hierarchical acceleration structure
- uniformly split scene in a volume grid
  - same object can be in multiple grid cell
  - but a point can only be in one cell at a time
- intersect by walking the grid incrementally



[Shirley]

hierarchical regular space subdivision

- at each cell of a regular grid, store a regular grid
  - normally 2-3 levels deep

- O(*kn*) behavior, with $k << 1$
  - expect to skip a constant fraction of all objects
  - very fast incremental walk
  - easy to update
  - not efficient for scenes with big holes in them

acceleration structures

- which one is the winner?
  - depends on type of input
  - and if we need to update for animation
- start with a kd tree

software engineering considerations

- acceleration structs are subclasses of Surface
  - high-level raytracing code should not know about them
  - can switch data structures
  - can combine data structures
    - hierarchical grids as grids of grids
    - hierarchical bounding volumes as volumes of surfaces
    - hierarchical boxes with a grid per box in the leaves
- regular grid: stores Surface[n][n][n]
- bounding volume: stores Surface[n]
  - often binary for simplicity
- BSP node: stores Surface[2]

texture mapping for raytracing

texture mapping considerations

- especially efficient in raytracing
  - since ray-object intersection is very expensive
  - trivial support for texture and bump mapping
  - unclear how to efficiently do displacement maps
    - makes us loose raytracing nice properties

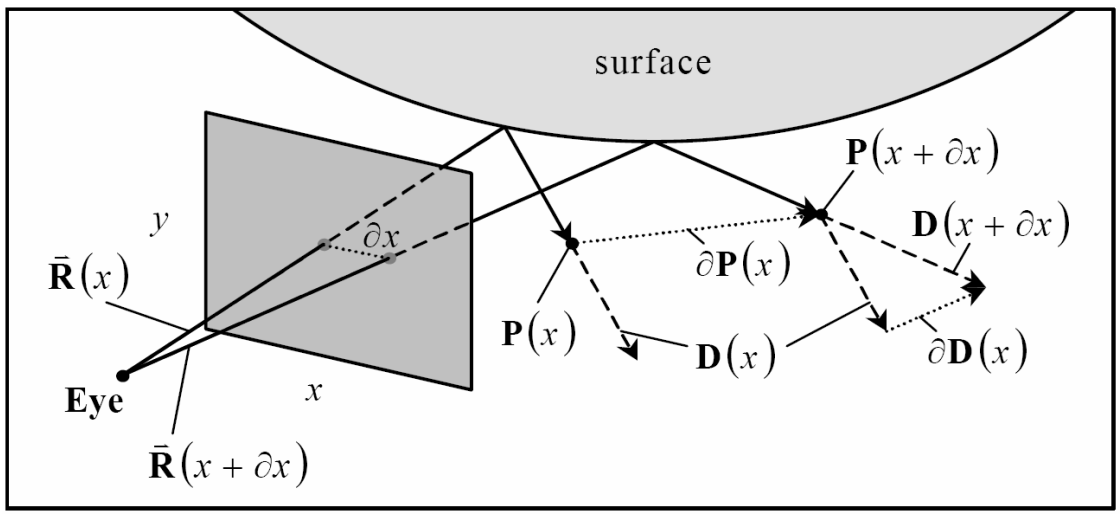
- mapping function: object-intersection code returns *uv* parameters

determining mapping function

- sphere: given intersection point P, return angles from spherical coordinates
- triangle: change intersection code to use baricentric coordinates
  - Shirley, Ch. 10.3.2

filtering textures

- compute average of texture subtended by pixel
  - in general quite hard for reflection/refraction
- ray differentials
  - new and elegant discovery: Igehy, SIGGRAPH 1999
  - propagate differentials together with rays



[Igehy, 1999]

filtering texture comparison

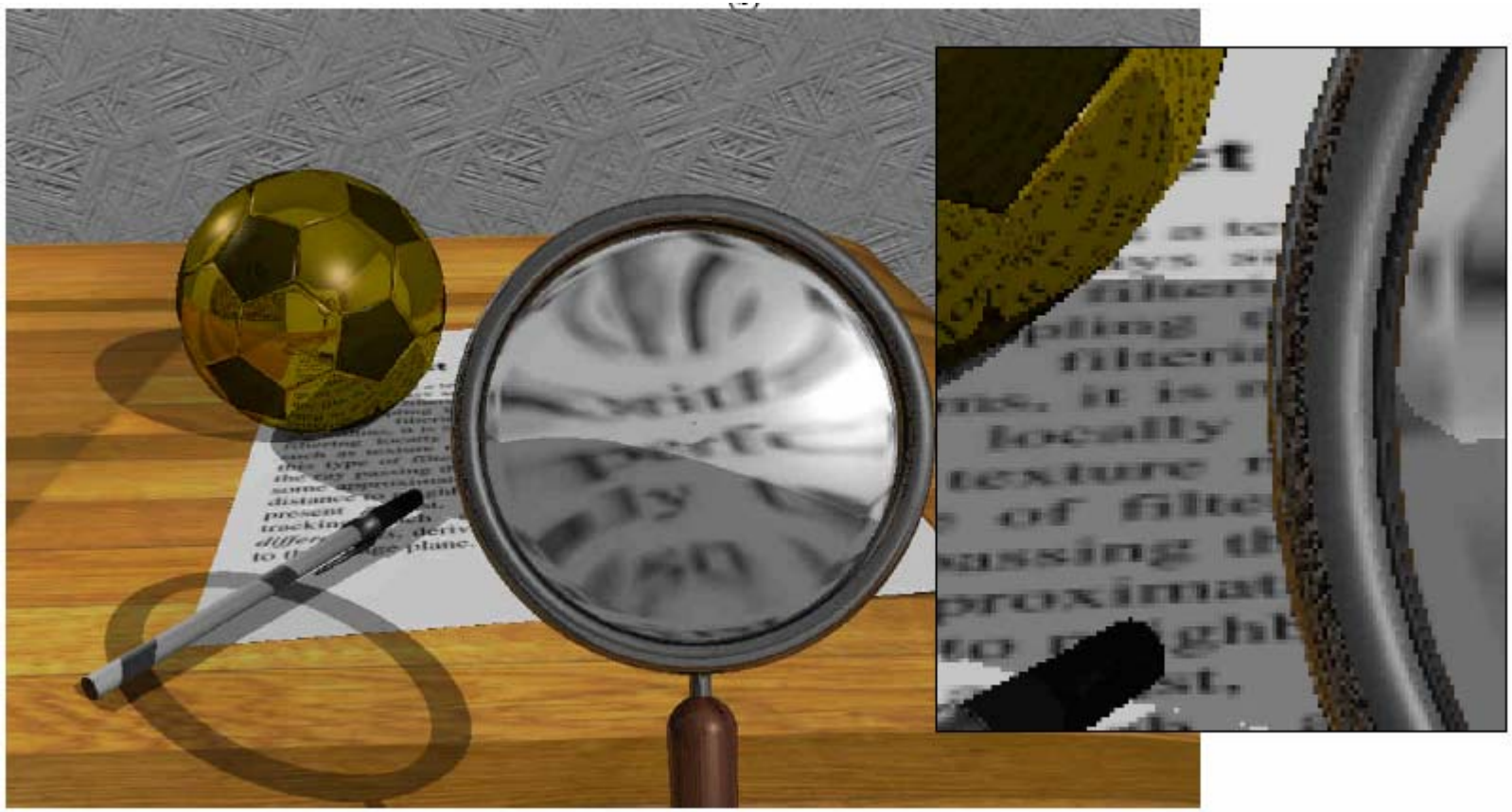
no filtering

[Igehy, 1999]

bad for view rays

filtering texture comparison

mip-map filtering based on distance



[Igehy, 1999]

ok for view ray, bad for reflection/refractions

filtering texture comparison

mip-map filtering based on ray differentials

[Igehy, 1999]

ok in most cases, just a bit of overblur

filtering texture comparison

accurate filtering based on ray differentials

[Igehy, 1999]

works great

