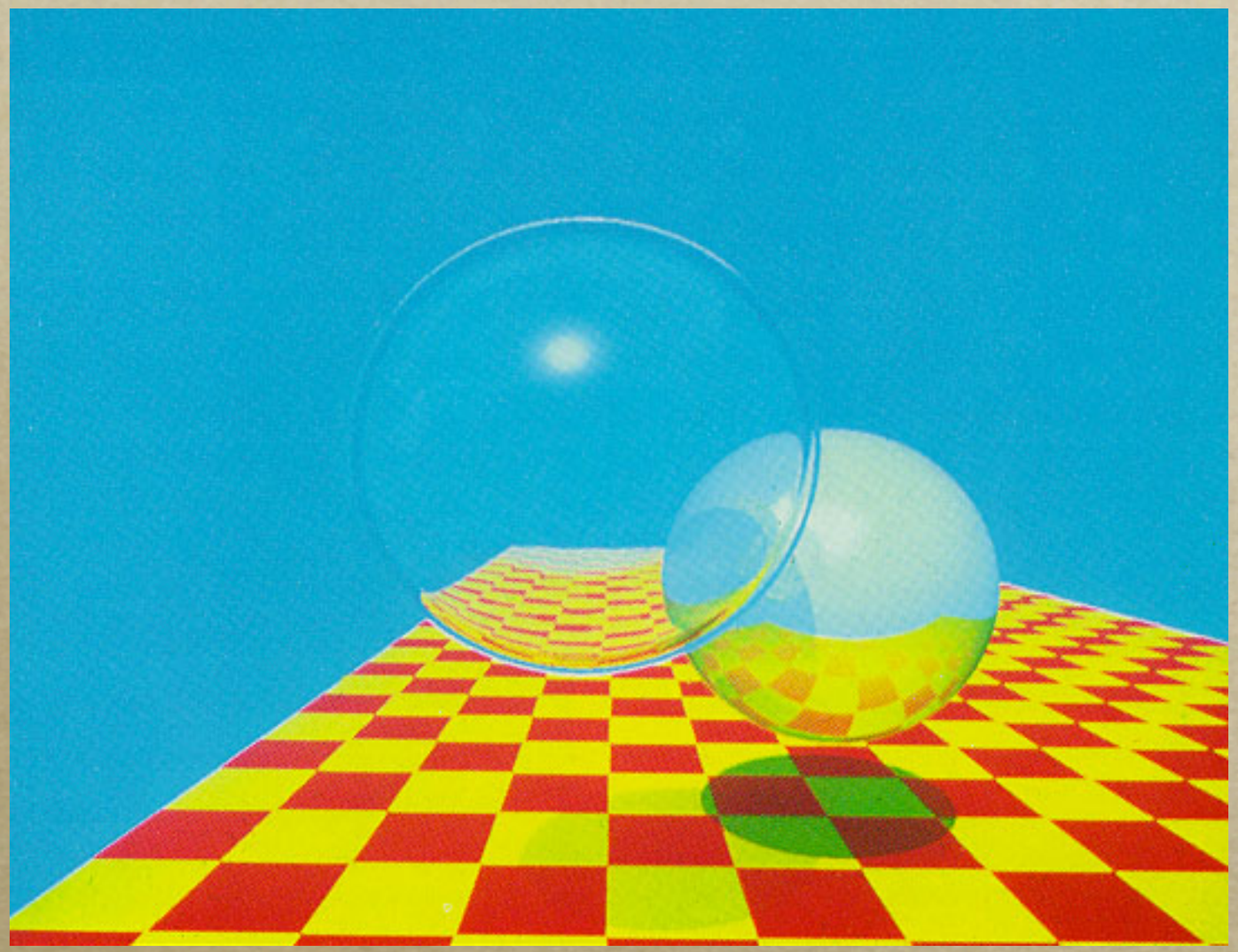
Ambient, Lambert, Phong, reflection, refraction, point light sources.

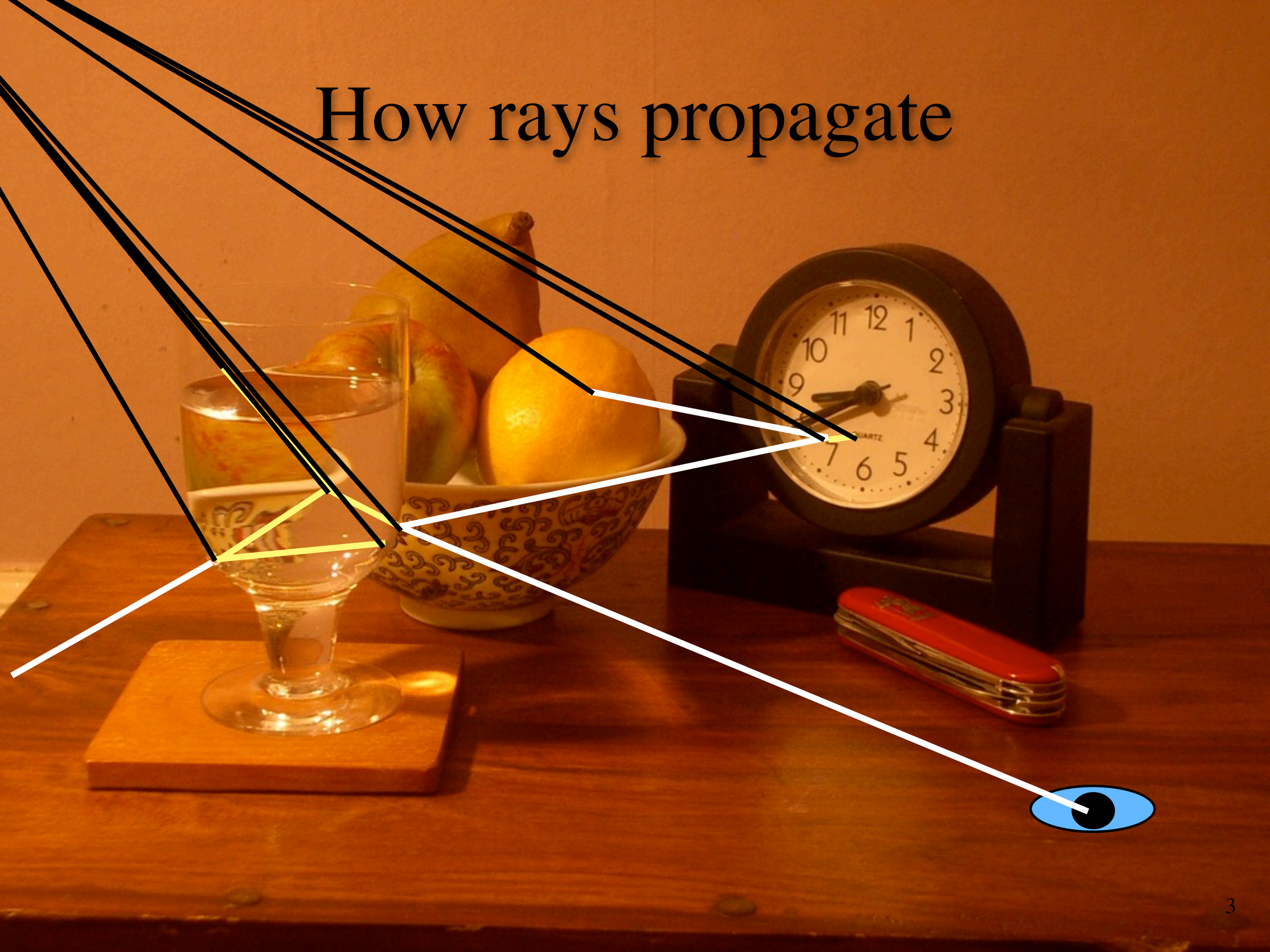


(Slides on spatial content thanks to James Arvo and David Kirk)

Just the beginning…

- *Aliasing artefacts*
- *No surface/surface illumination*
- *No caustics*
- *Real shadows are soft*
- *Colour problems*
- ***Very slow***

How rays propagate



Where are we spending the time?

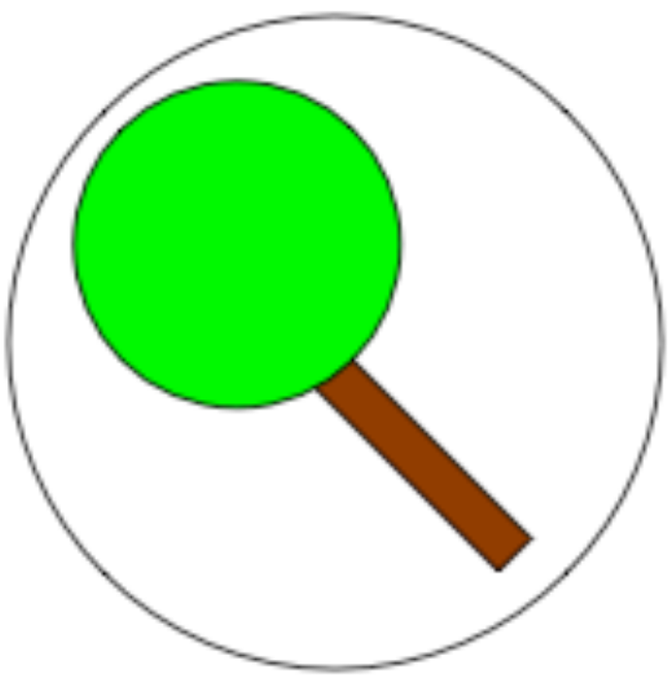
- *1000 x 1000 pixels*
- *Say 6 secondary rays per pixel*
- *100k objects; 10 ops per intersection*
- *2GHz processor; maybe 5 cycles per op*
- *So how long to render?*
- *And is that really all?*
- *And: where is the time really spent?*

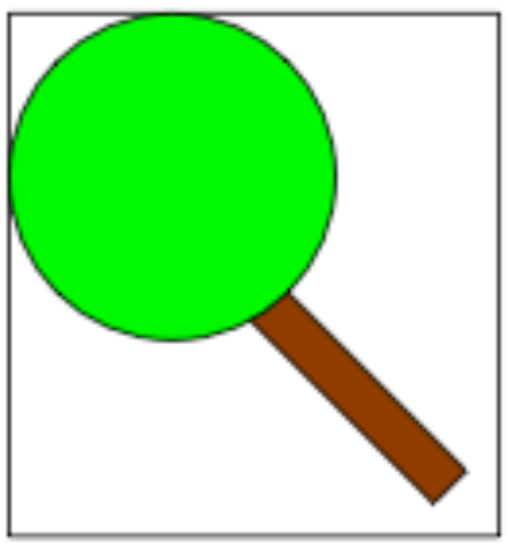
Bounding Volumes

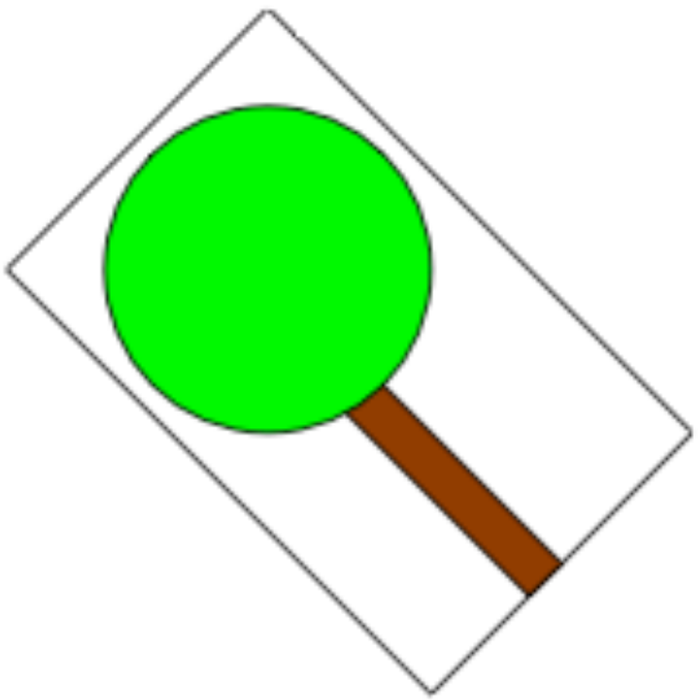
- *Enclose objects inside a volume with a simple intersection test (e.g. a sphere)*
- *You only need to know IF the ray hits the volume, not where*
- *Does this decrease or increase computation? It depends…*
- *Cost: n * B + m * I*
  - *n rays, B cost of intersection with bounding volume, m rays intersect bounding volume, I cost of intersecting with objects.*

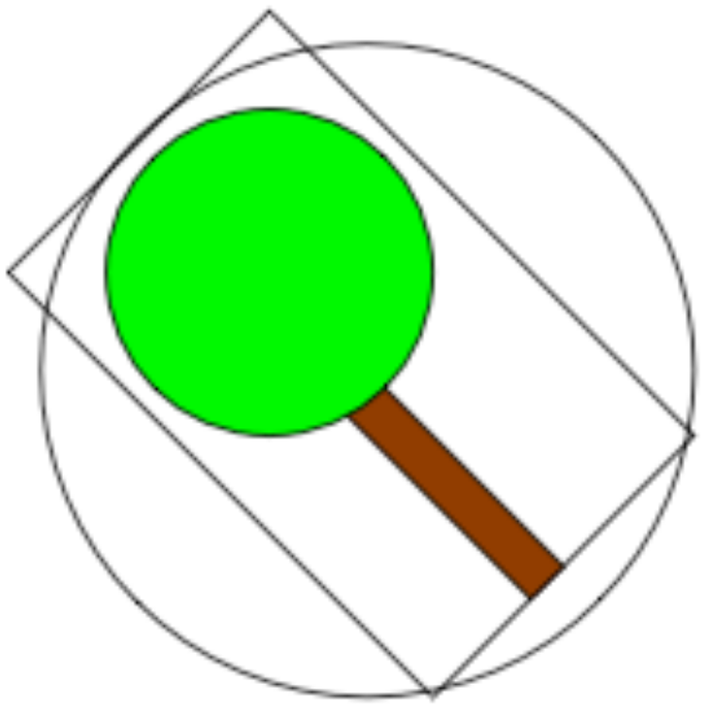
Bounding Volumes

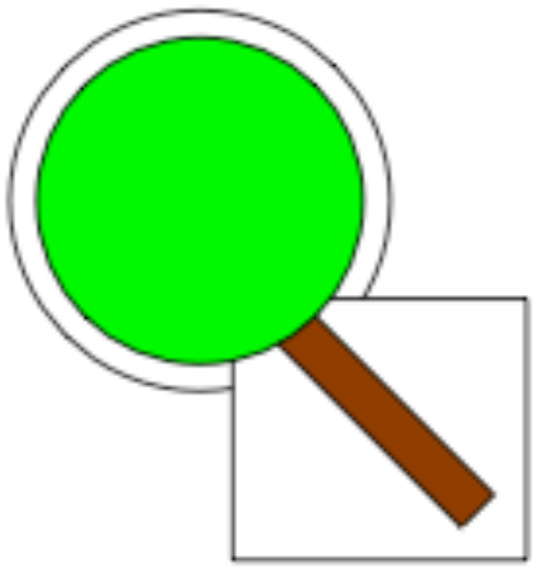
Bounding Volumes











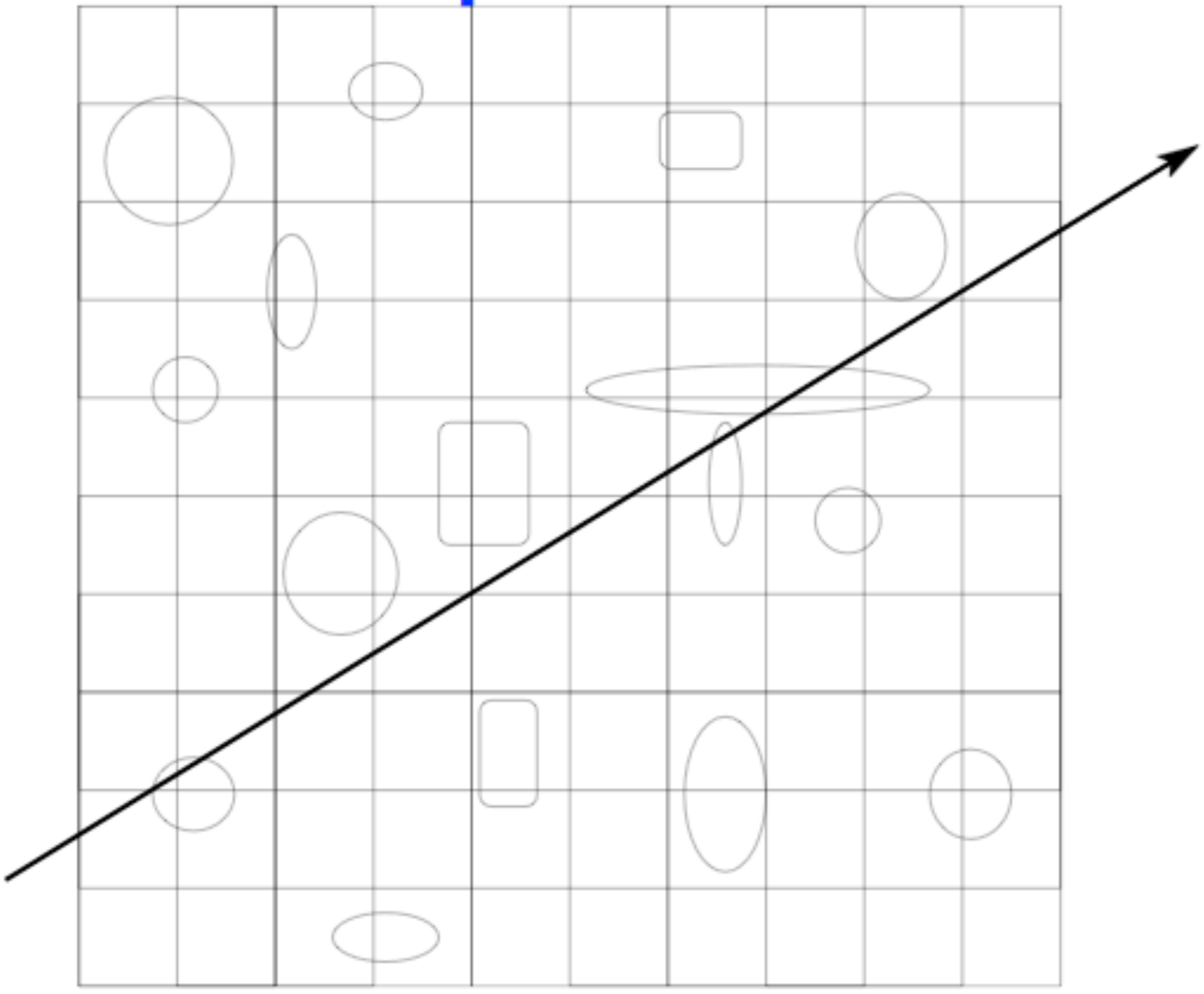
Hierarchical Volumes

- *Put volumes within volumes*
- *I.e., we form a **tree** of bounding volumes*
- *If the volumes are placed **really well**, then we get O(log n) intersection tests*
- *Unfortunately, it isn't automatic*
- *Non-spherical volumes produce tighter bounds, but aren't automatic either.*

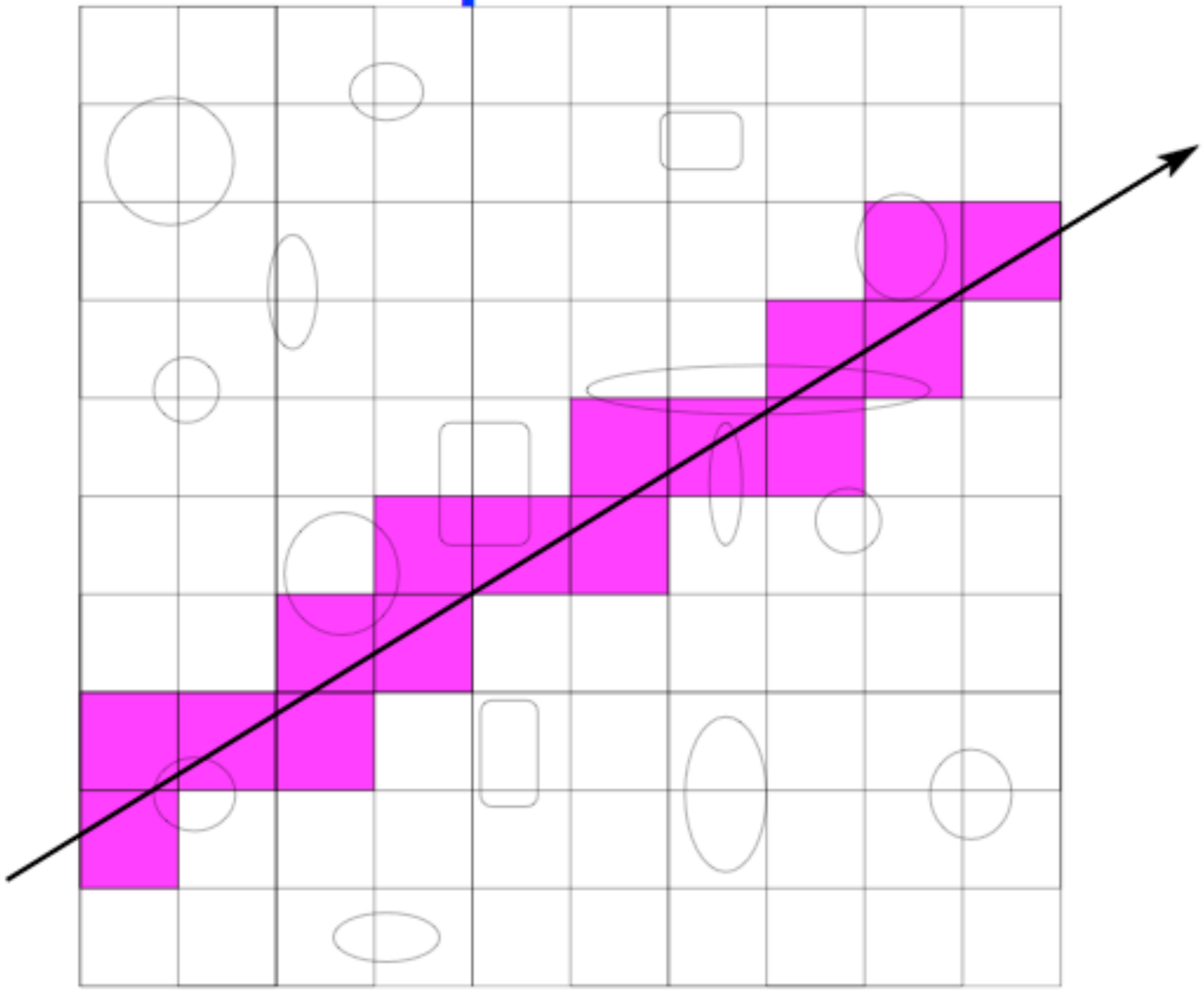
Spatial Subdivision

- *Rather than adding new (invisible) objects as boundaries…*
- *Let's just divide the space.*
- *If a **picture element** is called a **pixel**…*
- *Then a **volume element** must be called?*
  - *A **voxel***

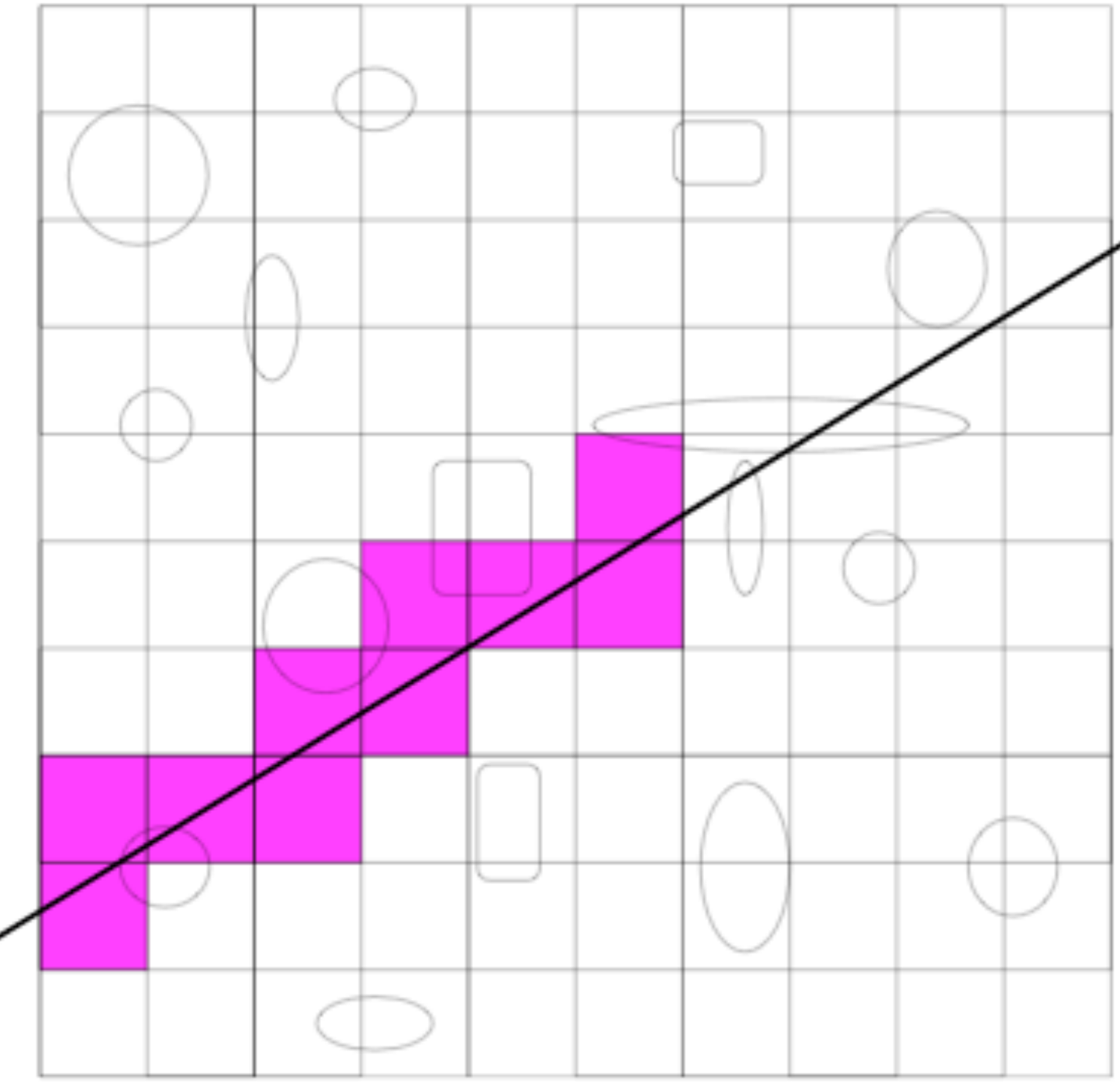
Uniform Space Subdivision



Uniform Space Subdivision

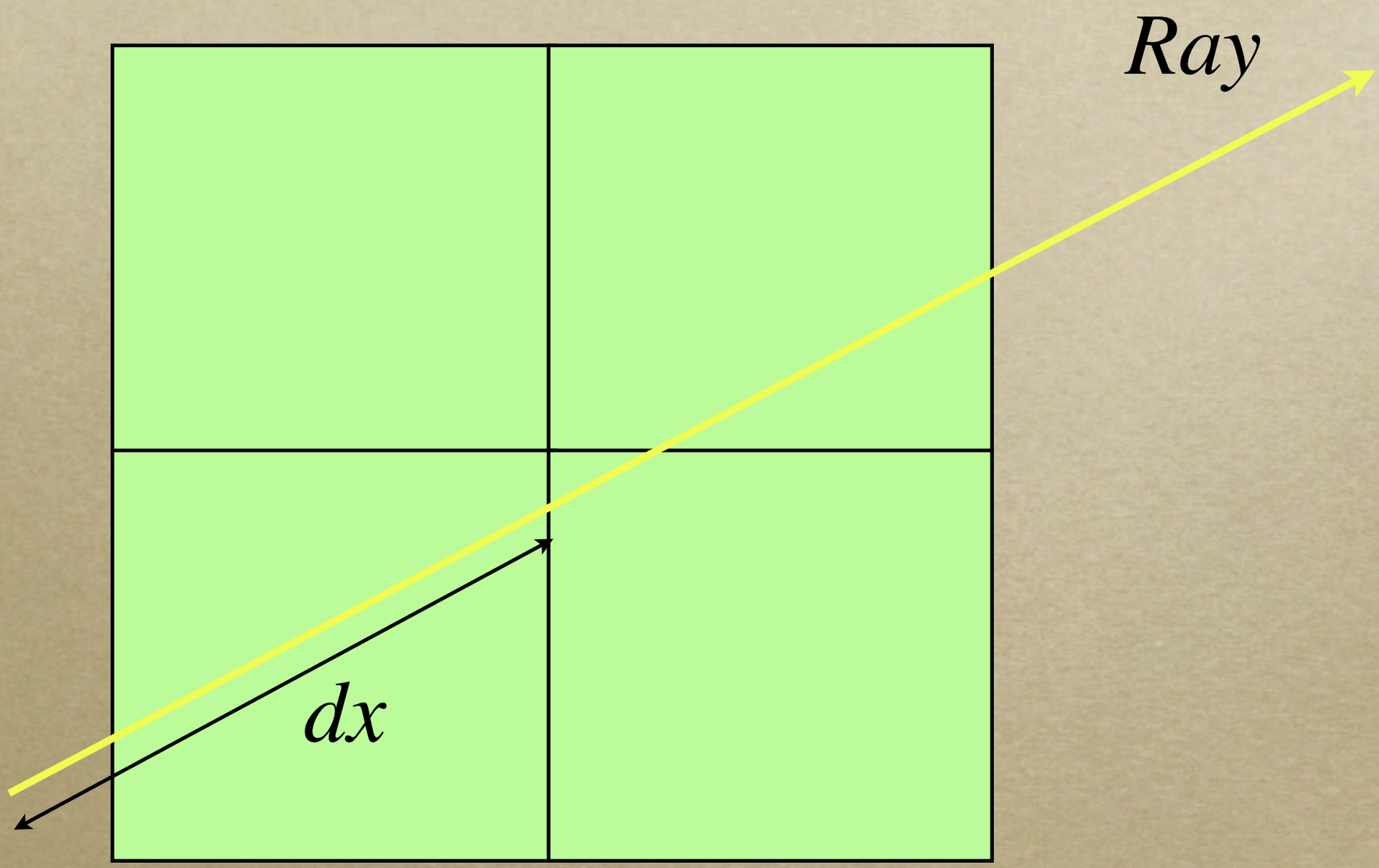


Uniform Space Subdivision

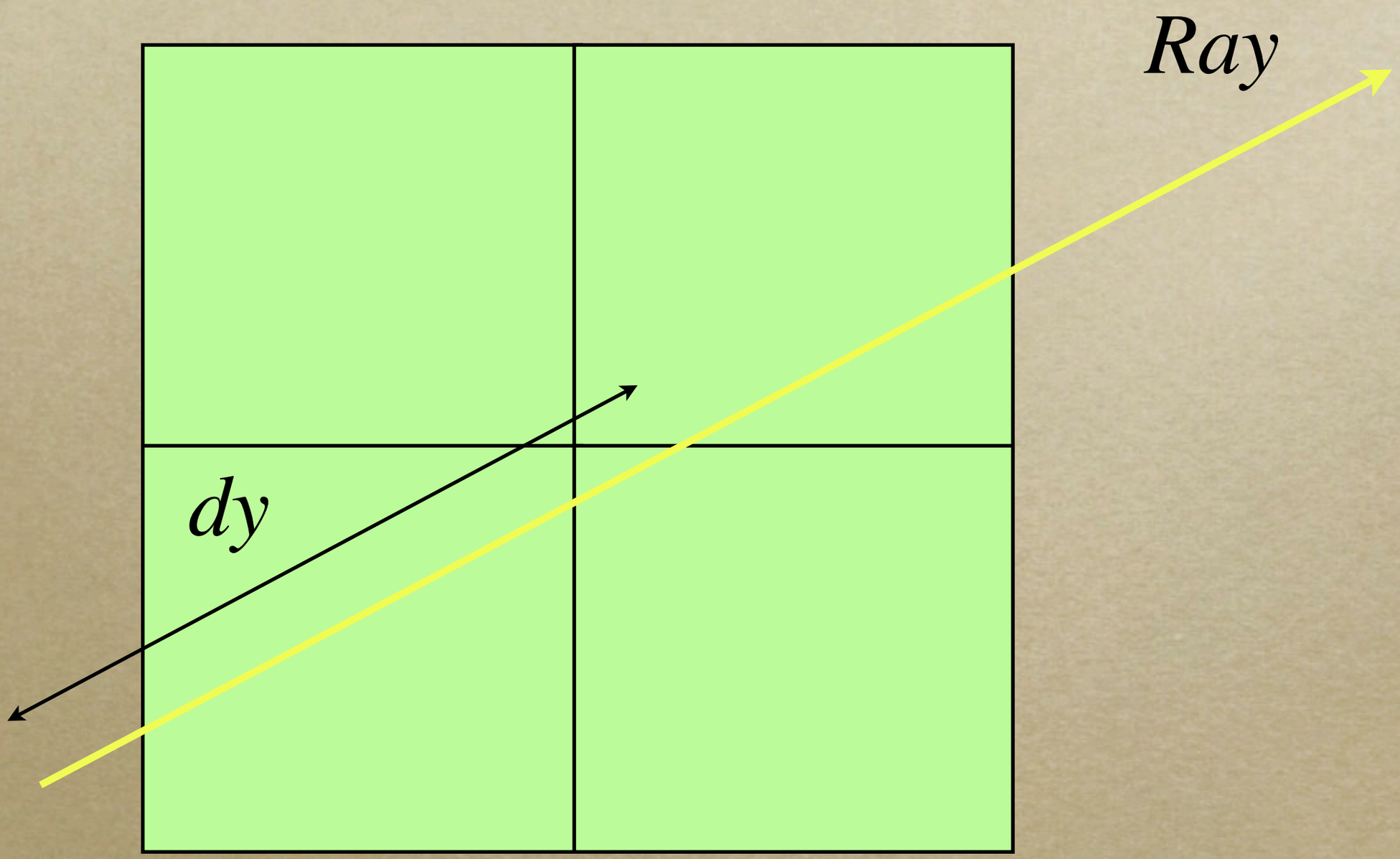


How do we determine the next voxel to test?

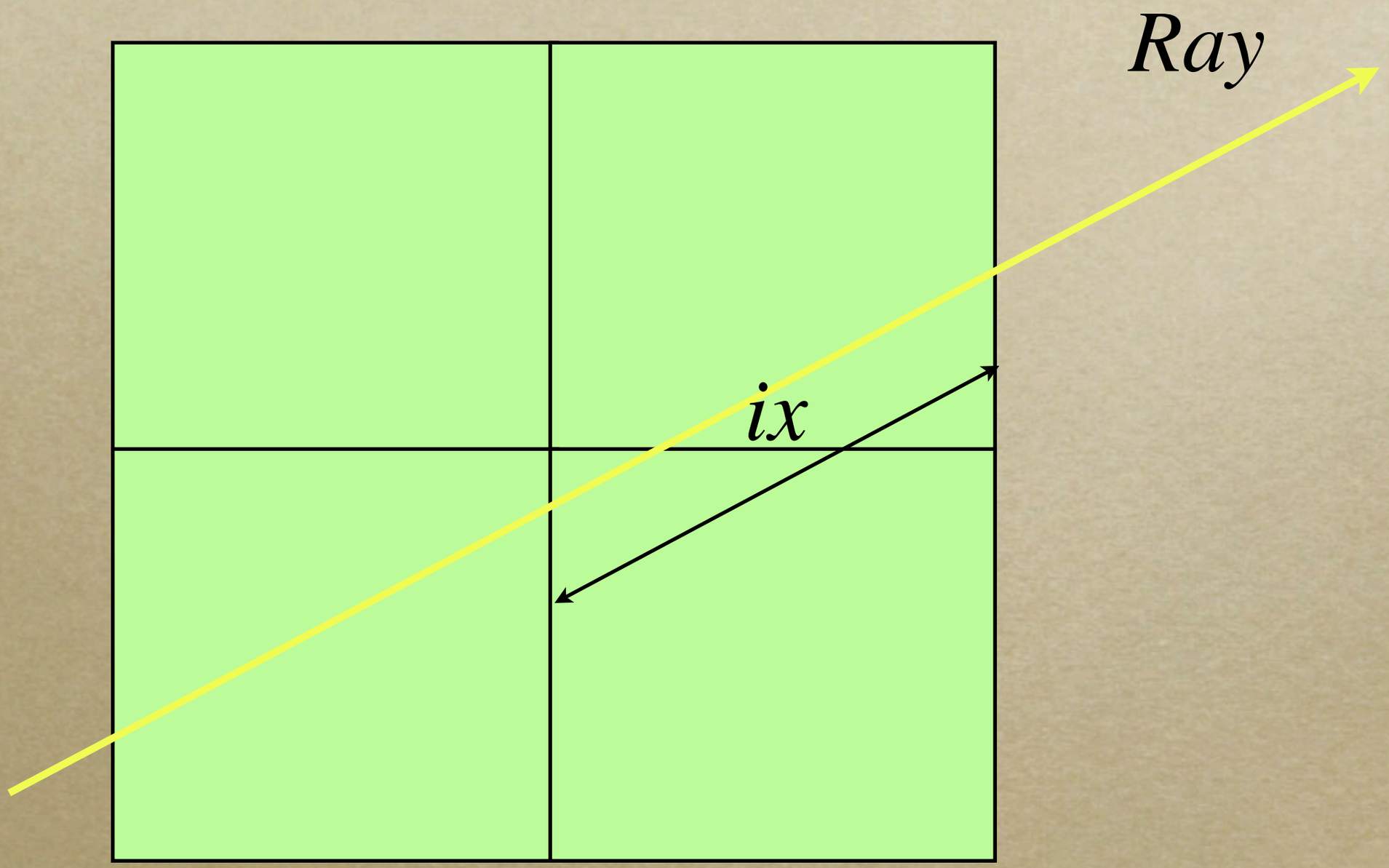
Cleary's Algorithm



Cleary's Algorithm



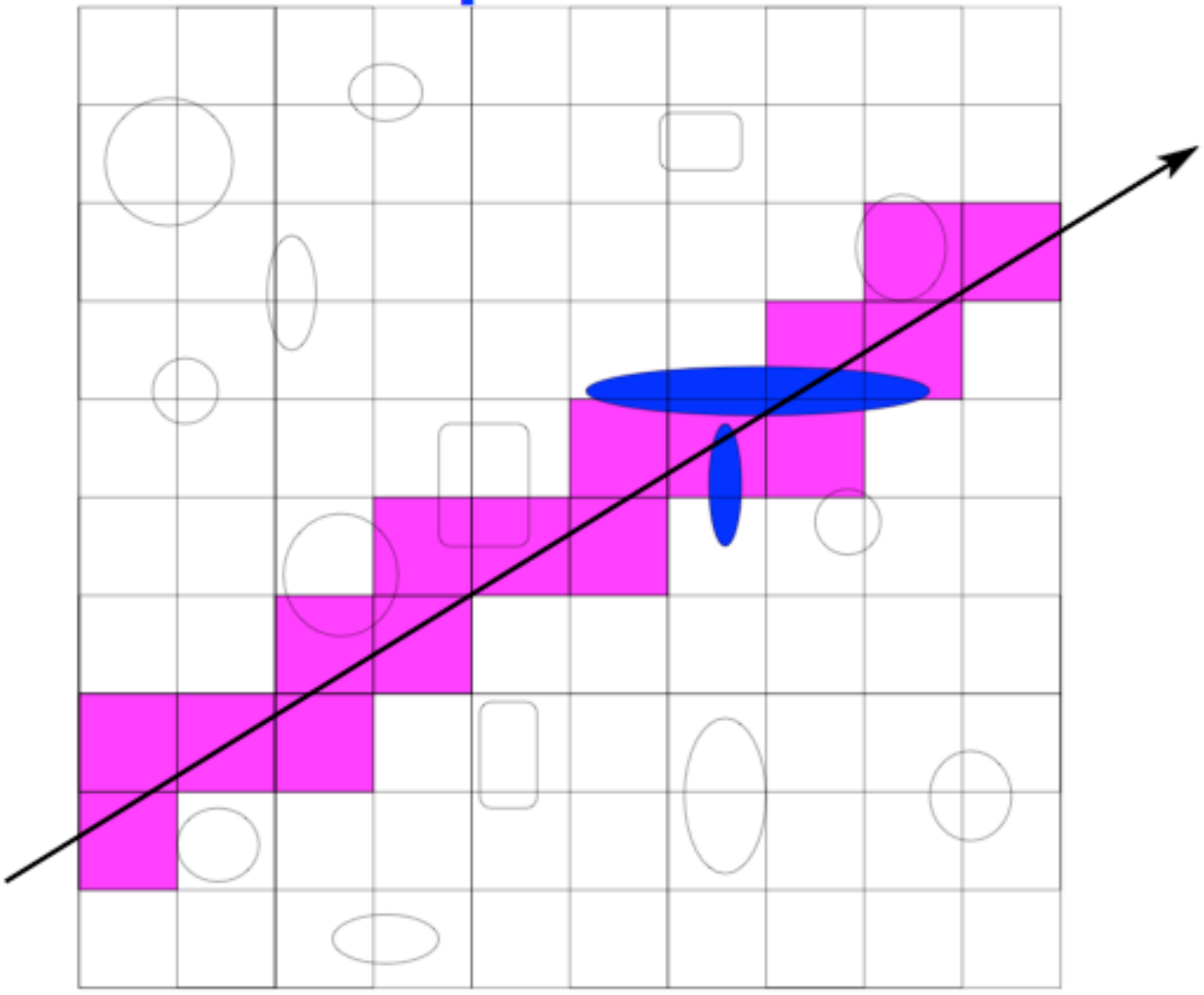
Cleary's Algorithm



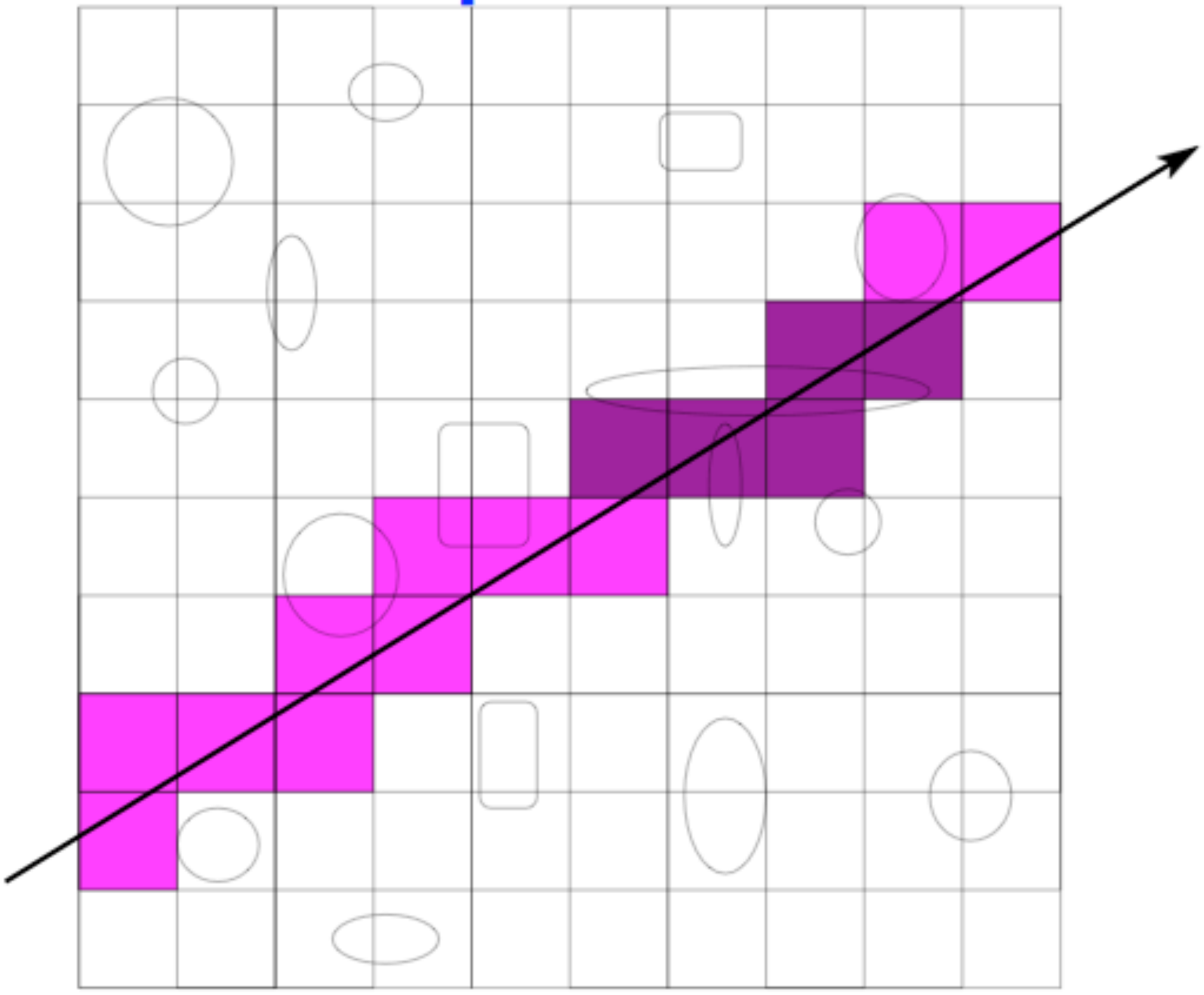
Process

- *Find smallest of dx, dy, dz*
- *increment that axis e.g: for dx, x:=x+1*
- *update value, e.g: dx := dx + ix*
- *check voxel x,y,z*
- *check for end of world*

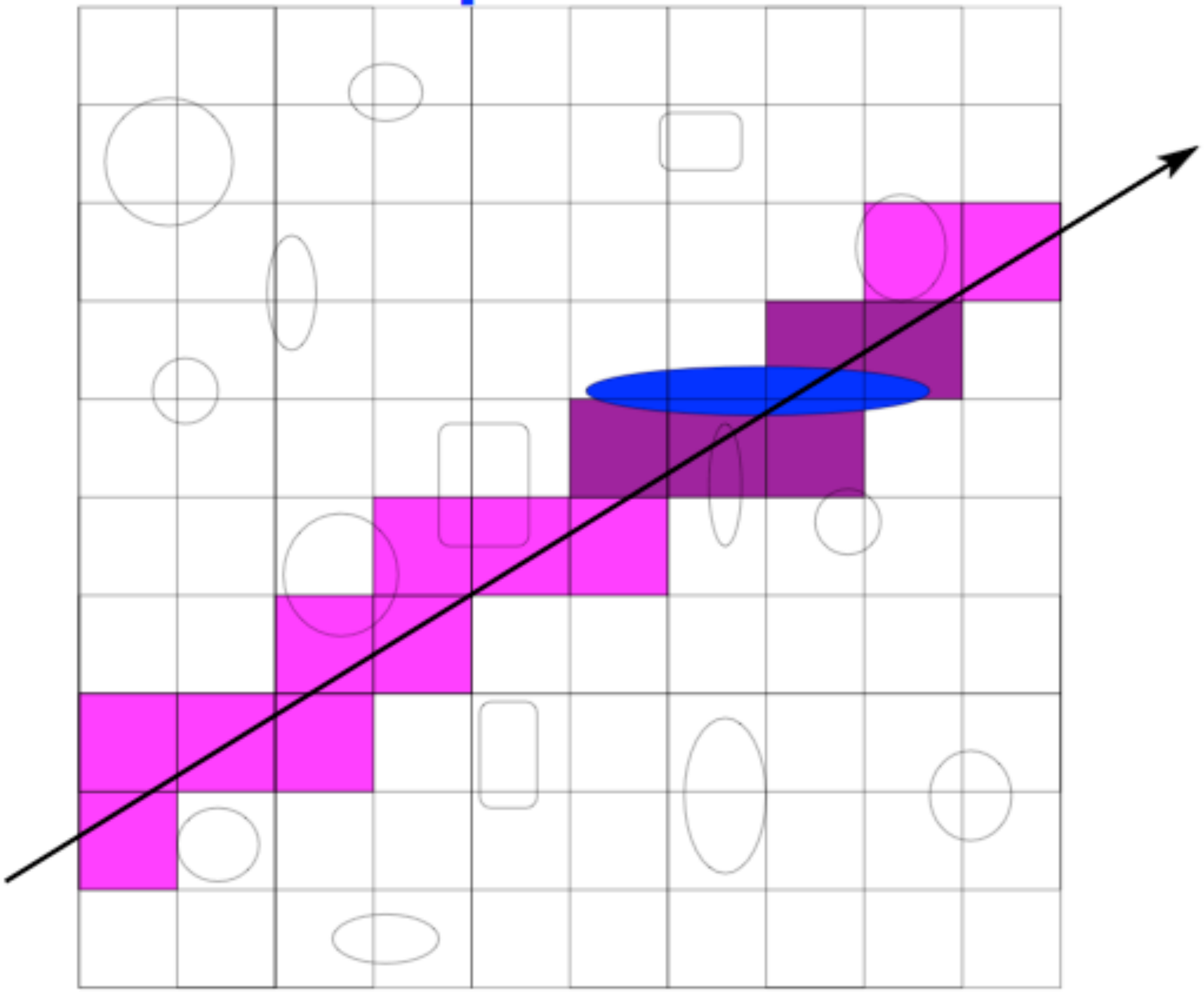
Uniform Space Subdivision



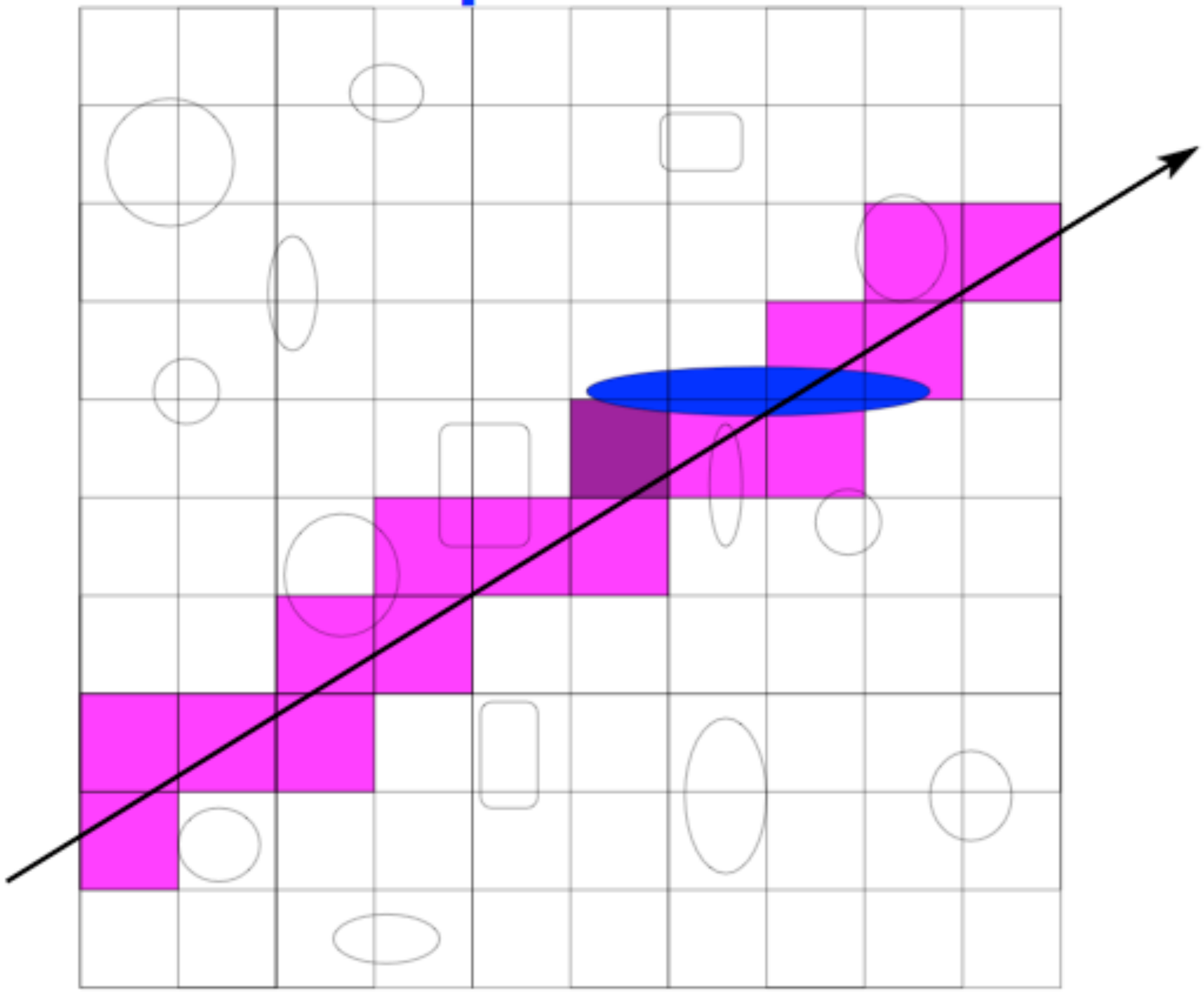
Uniform Space Subdivision



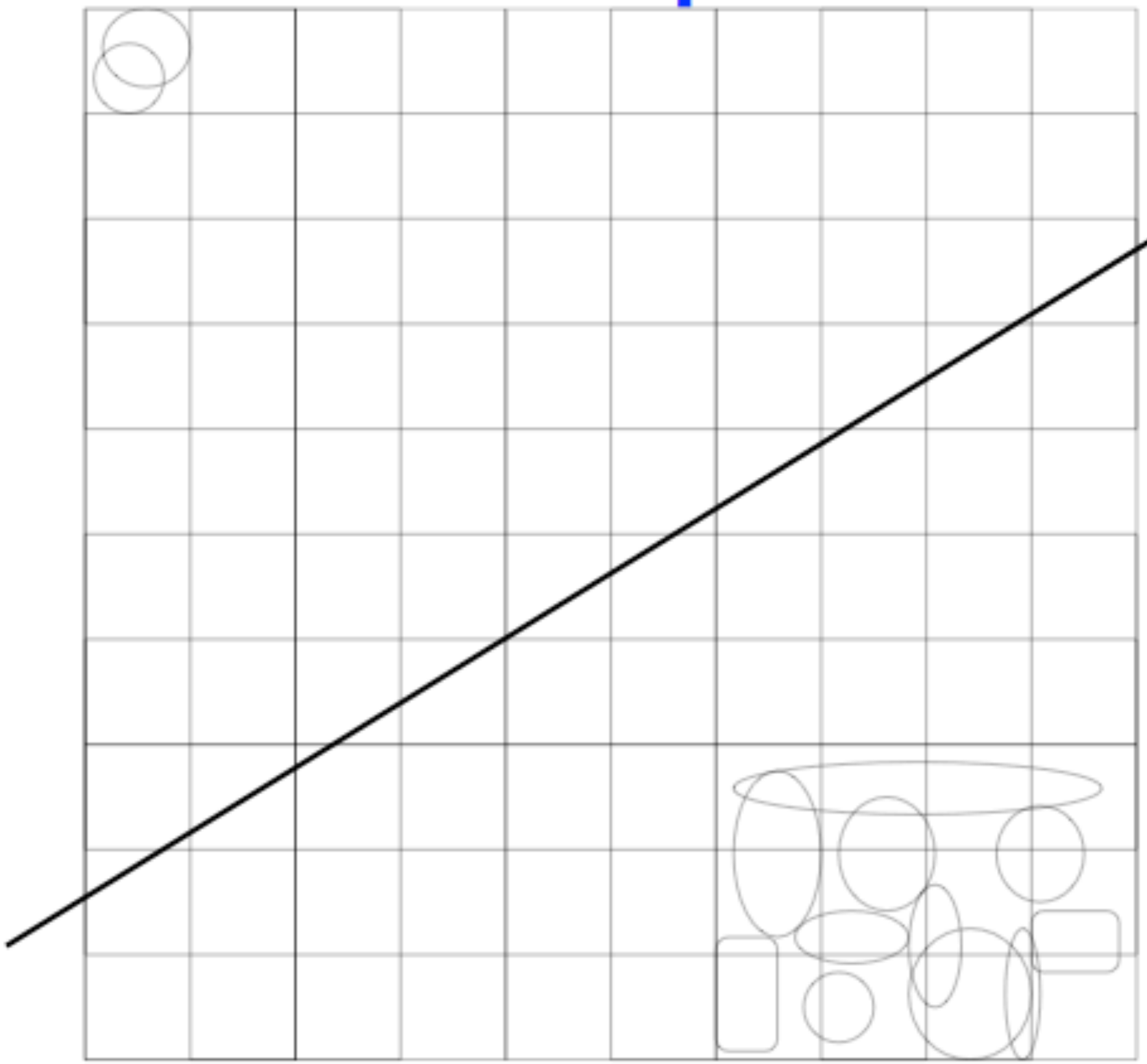
Uniform Space Subdivision



Uniform Space Subdivision



Uniform Space Subdivision

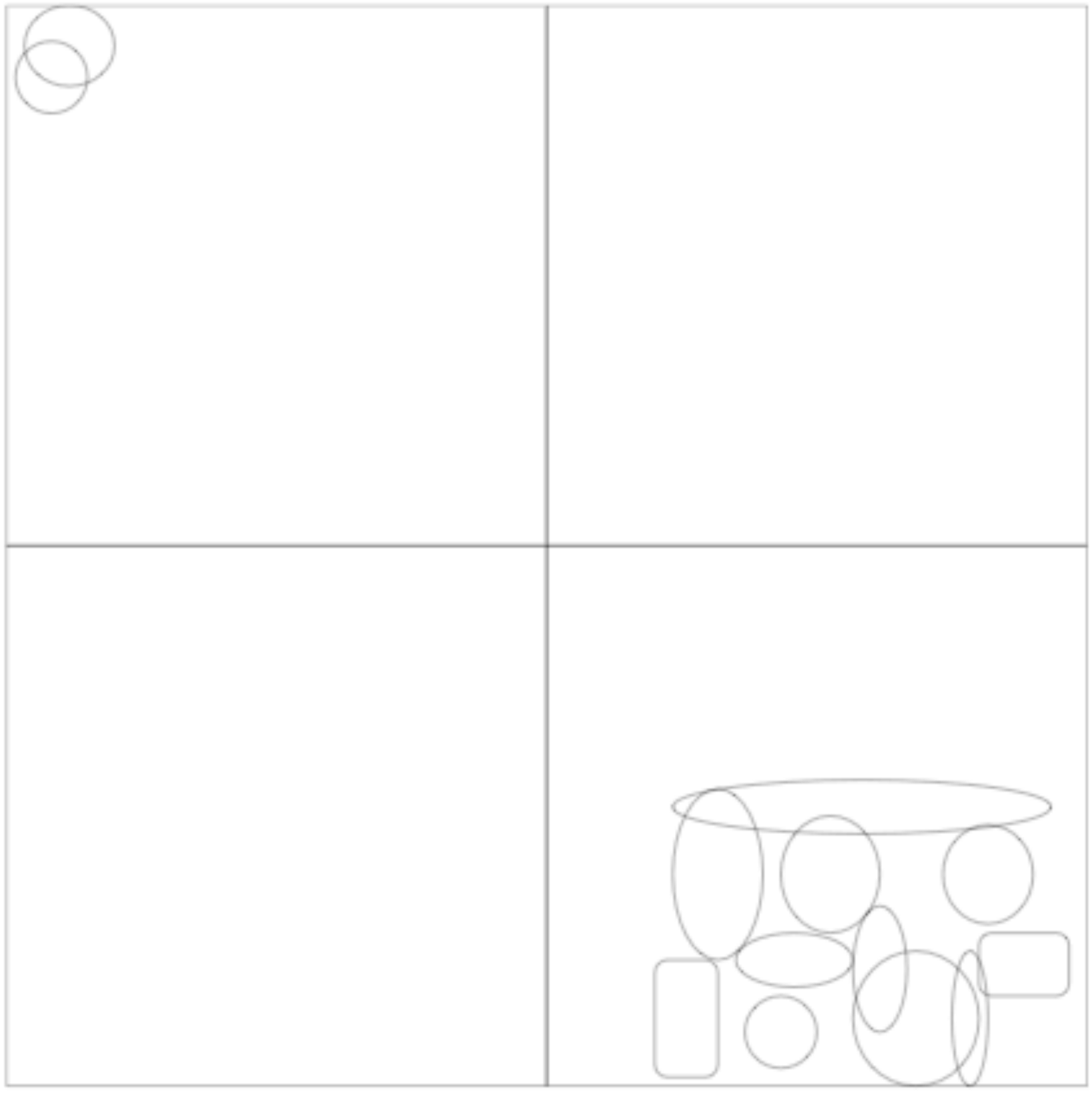


Why is this bad?

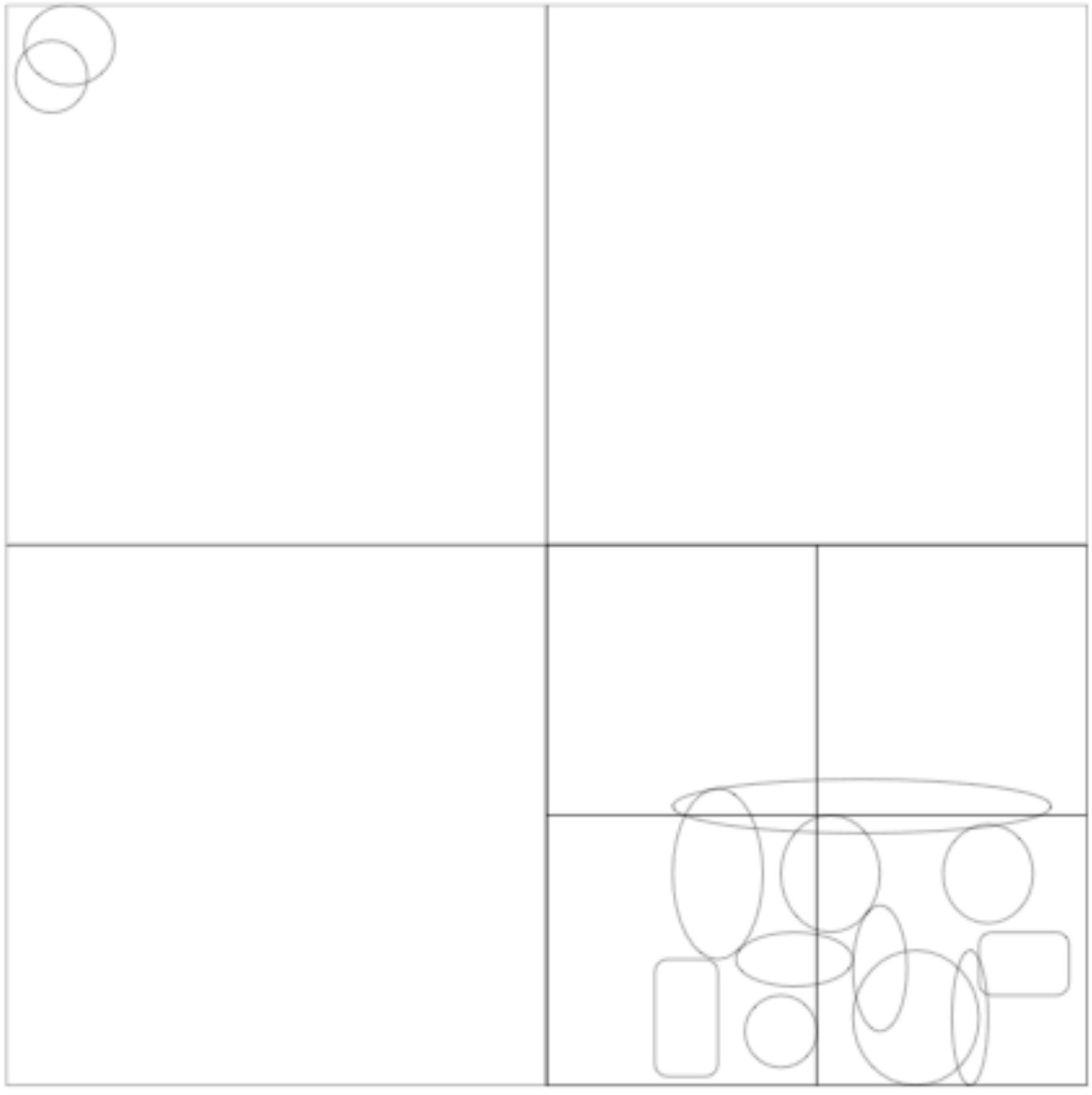
Adaptive Subdivision

- *Instead of lots of little empty cells, make empty cells as big as possible*
- *Use a tree structure to create a hierarchy of bounding cubes*
- *You will get fewer voxels*
- *Is there a down side?*
- *Octrees/BSP trees/kd-trees*

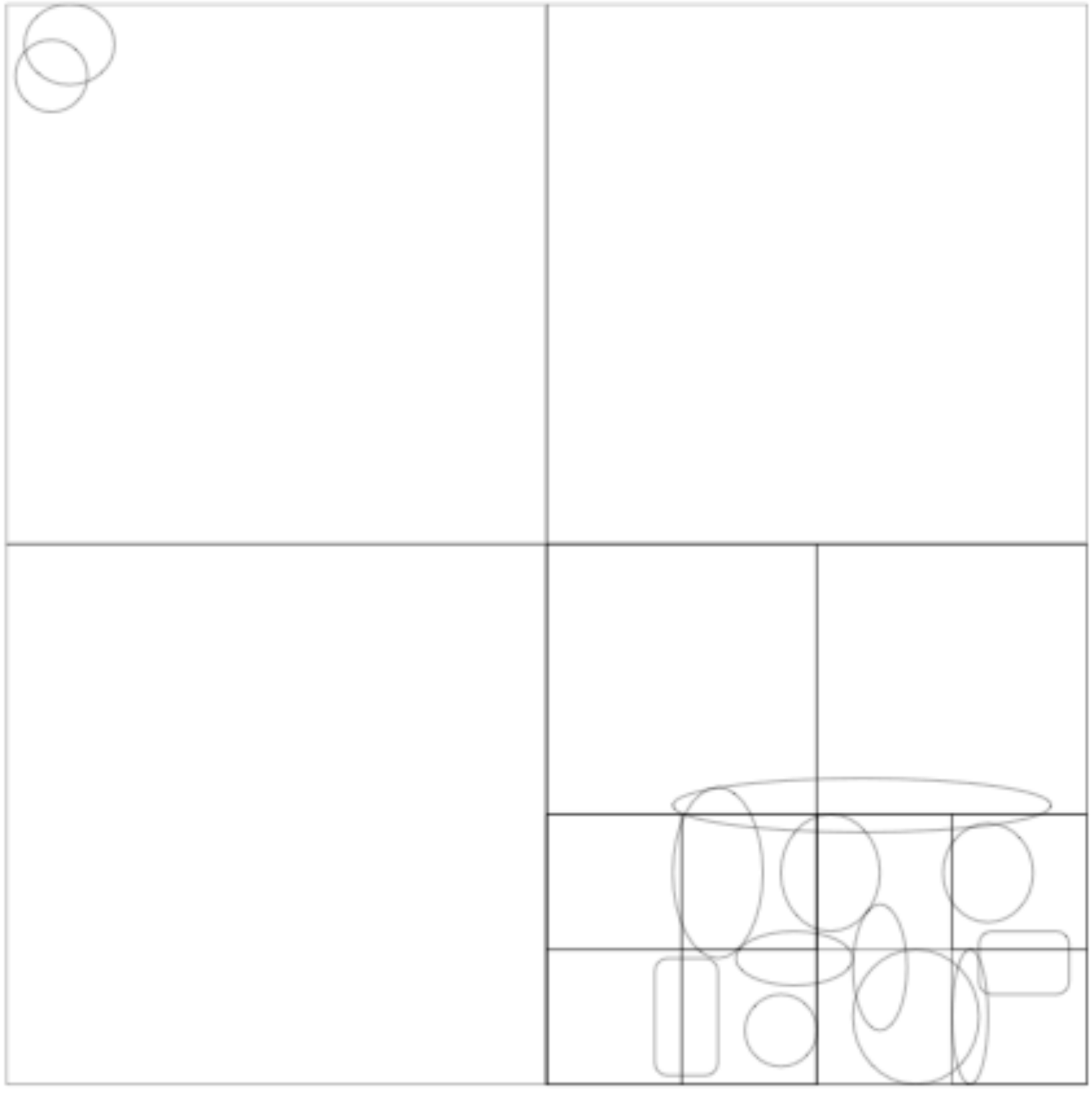
Quadtrees



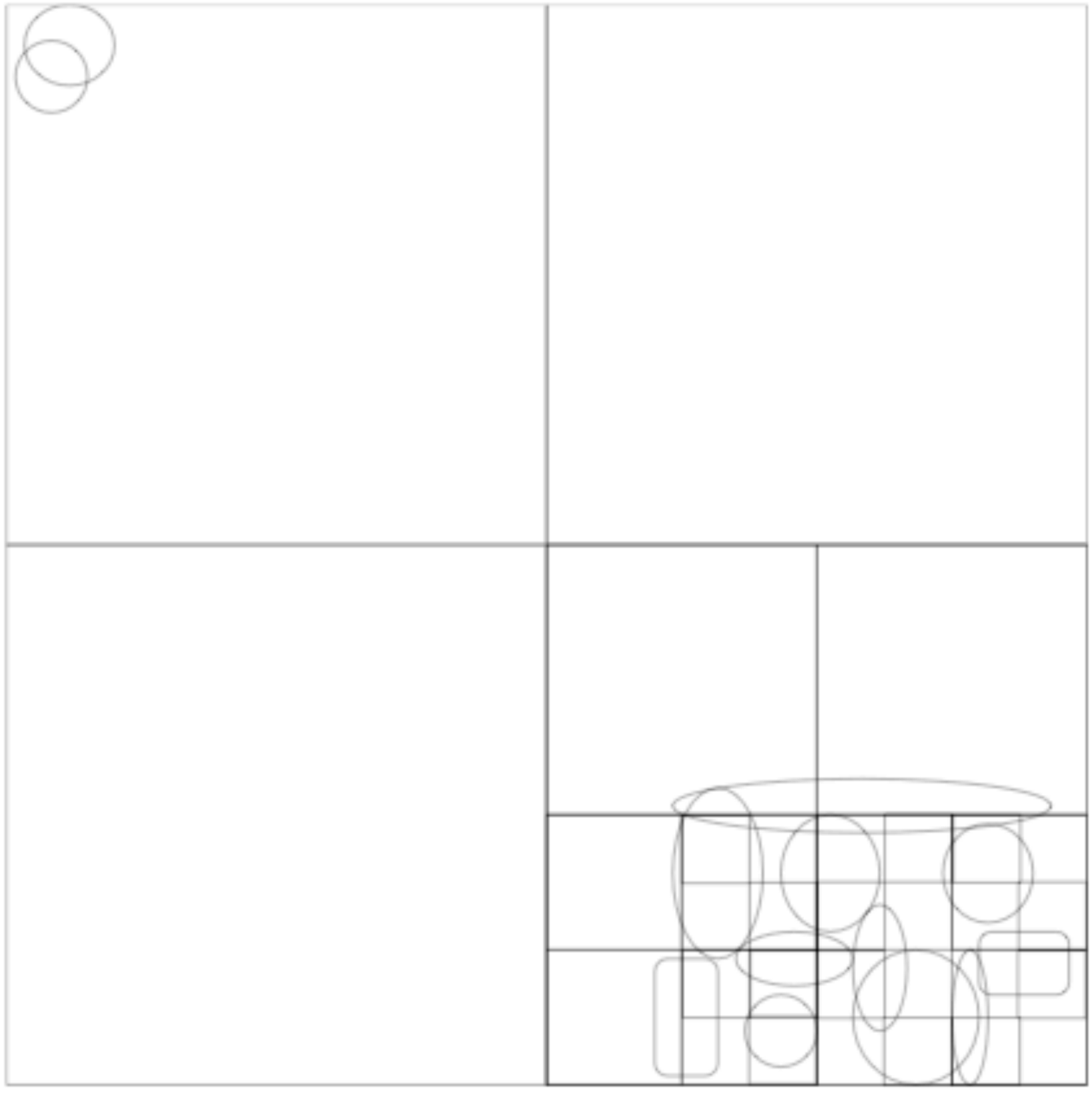
Quadtrees



Quadtrees



Quadtrees



Octrees

- *Divide until a cell has one object or is too small*
- *Facilitates raytracing CSG objects (later)*
- *But the cell-skipping algorithm is NOT obvious*
- *Info in "Ray Tracing News" archives*

Neat Tricks

- *Limit recursion depth by contribution made to pixel*
- *Keep a reference to the last object that caused a shadow*
- *Do inside/outside test on triangles before plane intersection*

Instead of:
(b - a) x (p - a).n, (c - b) x (p - b).n, (a - c) x (p - c).n
do
(b - a) x (u - a).v, (c - b) x (u - b).v, (a - c) x (u - c).v