6.837 F98 Lecture 17: November 12, 1998

Conservative Visibility Algorithms

Last time we saw several elegant object-precision or hybrid algorithms

However, difficult to justify superlinear processing when models get huge.

Let's review the visibility questions we posed last time:

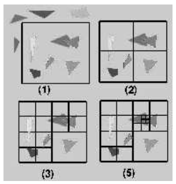
- How can invisible scene primitives be *eliminated* efficiently? Or...
- How can visible scene primitives be *identified* efficiently? Or...
- How can hybrid/alternative versions of the problem be posed? (Later.)

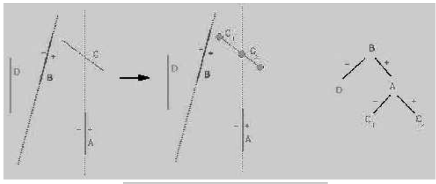
What are tradeoffs among the methods we saw last time?

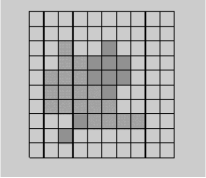
Parameters:
model size *n*, screen resolution *r* = *w* * *h*

Desiderata:

- **Object precision** (continuous) **or screen precision** (discrete framebuffer)**?**
- **Running time**
- **Storage overhead** (over and above model storage)
- **Working set:**
  - memory locations referenced over interval *delta t*, worst case
  - basically, how much memory is required to avoid excessive VM I/O
- **Overdraw (**also *depth complexity***):**
  - how many times a typical pixel is written by rasterization process







- **Screen-space subdivision** (Warnock's algorithm)
  - Working set size: O(*n*)
  - Storage overhead: O(*n* lg *r)*
  - Time to resolve visibility to screen precision: O(*n* * *r*)
    (though lots of optimizations possible -- worth another look!)
  - Overdraw: none
- **BSP** construction and traversal (*ordering* algorithm)
  - Working set size: depends on definition: O(1), O(lg n)
  - Storage overhead: O(n^2)
  - Time to resolve visibility to object precision: O(n^2)
  - Overdraw: maximum
- **Z-buffering**
  - Working set size: O(1)
  - Storage overhead: O(1)
  - Time to resolve visibility to screen precision: O(*n*)
  - Overdraw: maximum

For a time, vanilla clipping and z-buffering were the best option. However, soon the O(n) term itself became intolerable. So...

The notion of **conservative visibility oracles** arose:

Prefix pipeline with data structure & algorithm which efficiently

discards invisible polygons, and/or identifies visible polygons

Assume an ordinary z-buffered pipeline handles rendering

(that is, resolves visibility at screen resolution -- no fragments)

But: if oracle is to get the correct picture, what constraint

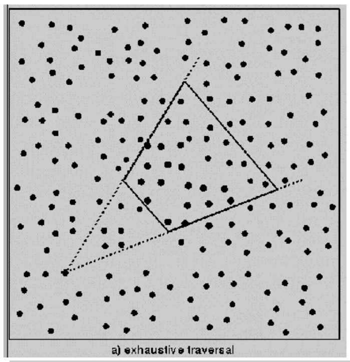
must it observe? This is called *conservative* culling.

Example conservative visibility oracles:

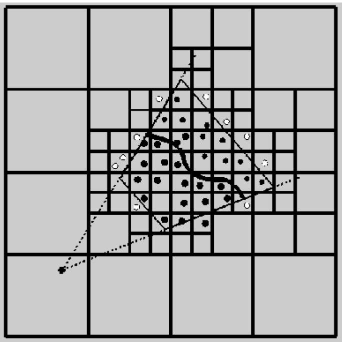
- Report whole model visible every frame
  - Cost?
  - Satisfies superset criterion? By how much?
- Use analytic solution from last lecture (e.g.,
  report exactly the set of visible fragments)
  - Cost?
  - Satisfies superset criterion? By how much?
- BSP tree
  - Is it a visibility oracle?

Is there an algorithmic "middle ground" between these two extremes?

Early conservative visibility oracle: hierarchical **frustum culling** (Garlick et al., 1990)



a) exhaustive traversal



b) frustum culling

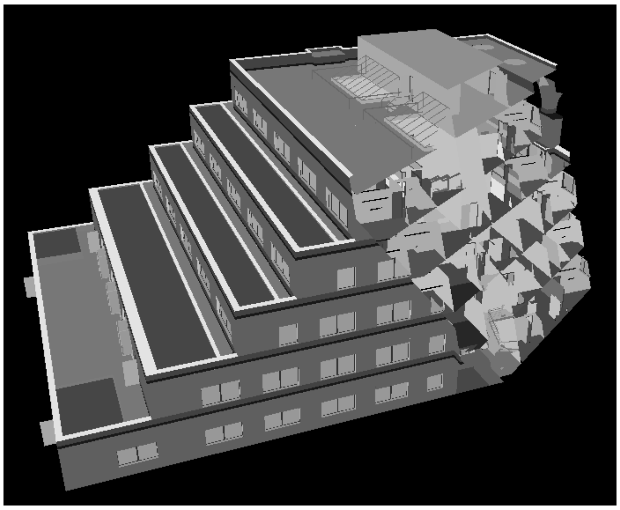
Pseudocode:

```
Cull (Frustum F, Tree T) {
   if ( F ^ T != null ) {  // if F and T are not spatially disjoint
      if ( T is a leaf )
         render portion of T's contents within F // how ?
      else { // examine subtrees (e.g., positive, negative halfspaces)
         Cull ( F, T->lochild )
         Cull ( F, T->hichild )
         }
      } // if F ^ T ...
} // Cull
```

Reduces overdraw somewhat, on average (for example beyond far clipping plane) but does not detect *occlusion* of one polygon by another

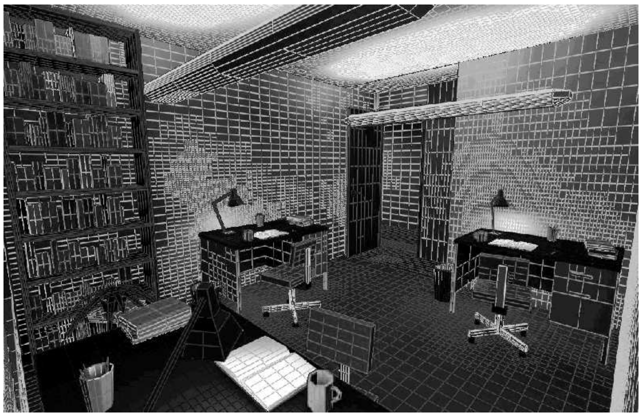
(For what kind of models/scenes would this algorithm be ideal -- about as well as you can do?)

... and there can be a whole lot of occlusion !



UC Berkeley Soda Hall

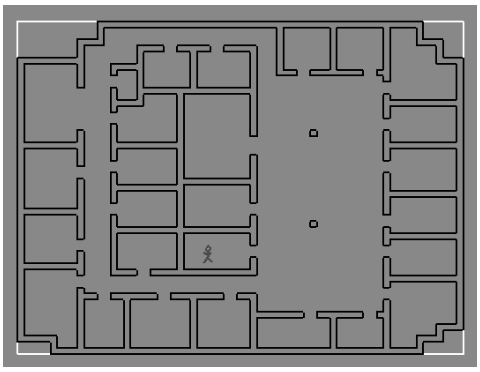
Typical interior office, with lighting



Same office, with polygon mesh shown

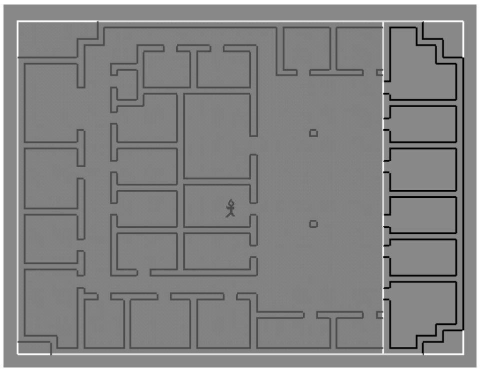
Idea for architectural scenes: partition model into *cells* and *portals* (Jones, 1971)

Schematic (2-D) architectural model (assume *detail objects* tagged as such).

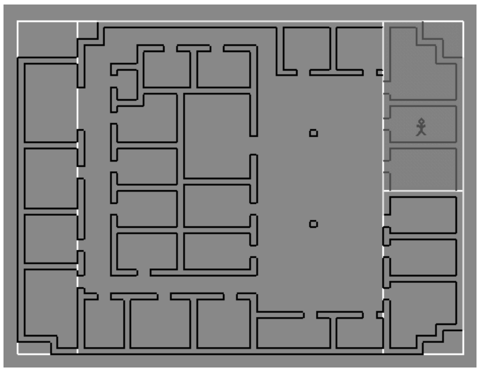


Intuitively: subdivide along *major structural elements* (walls, floors, ceilings)

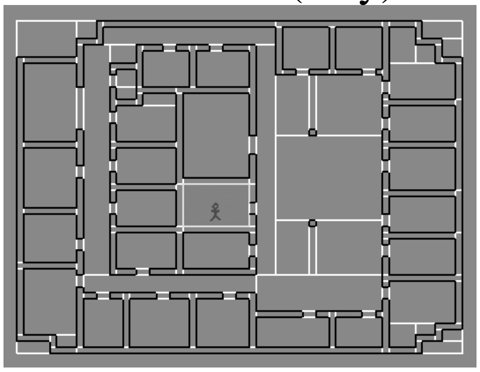
X split:



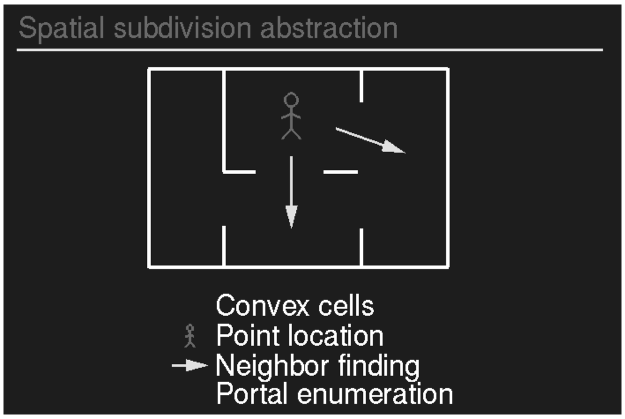
Y split:



Termination (why)?

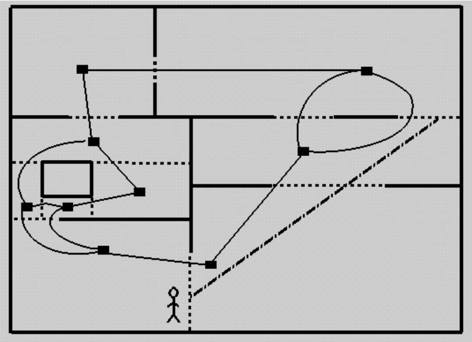


The *cells* are the regions at the leaf of the spatial subdivision
The *portals* are the non-opaque portions of each cell boundary
Abstraction: convexity, location, portals, adjacency graph



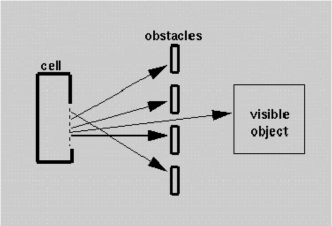
Spatial subdivision abstraction

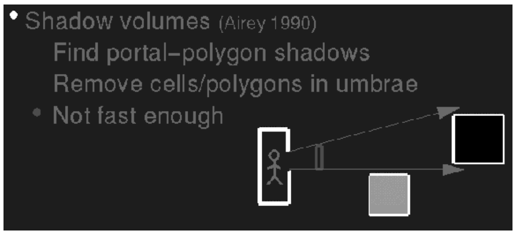
- Convex cells
- Point location
- → Neighbor finding
- Portal enumeration



Once the spatial subdivision "conforms" to this abstraction we can
begin to ask questions about conservative visibility.

For example: what objects are potentially visible from a cell *without regard to instantaneous position of observer* (Airey, 1990)?

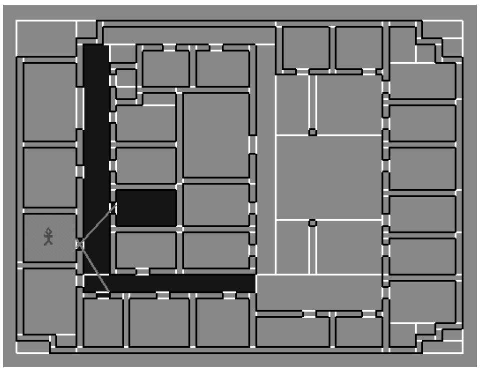




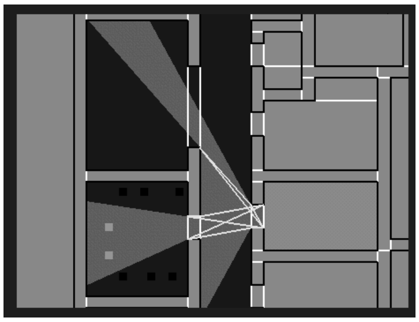
- Shadow volumes (Airey 1990)
  - Find portal–polygon shadows
  - Remove cells/polygons in umbrae
- Not fast enough

Store a PVS with each cell; then render it (subject to frustum culling) interactively.

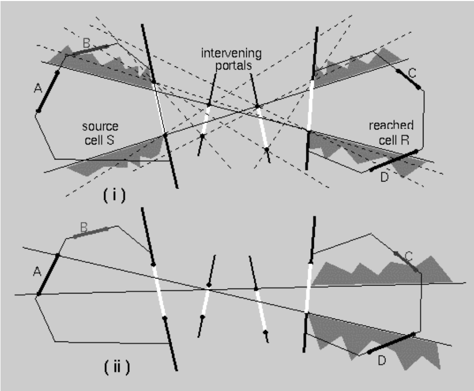
Later, other researchers established visibility *hierarchically:*
First, between cells:



Then, iff cell-cell visibility established, between cell and objects



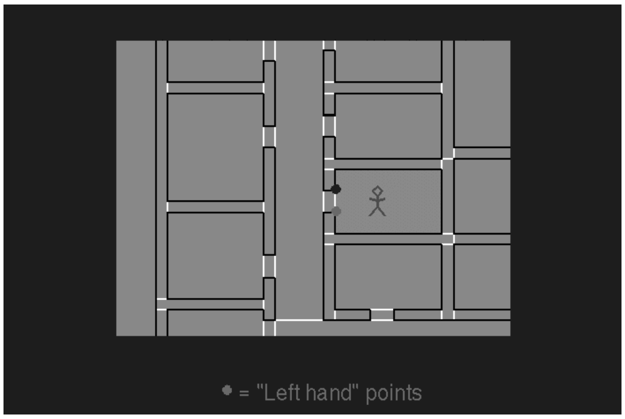
(Later, see application of inter-object visibility as well)



How does this work computationally?

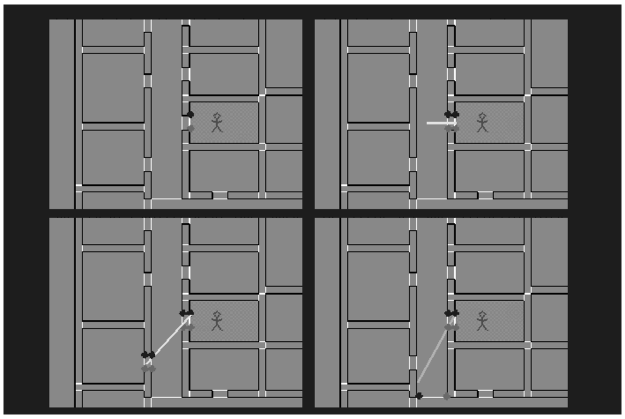
First, it's sufficient to establish visibility from cell portals (why?)

Second, the abstract operation of *traversing* a portal *orients* the portal (how?)

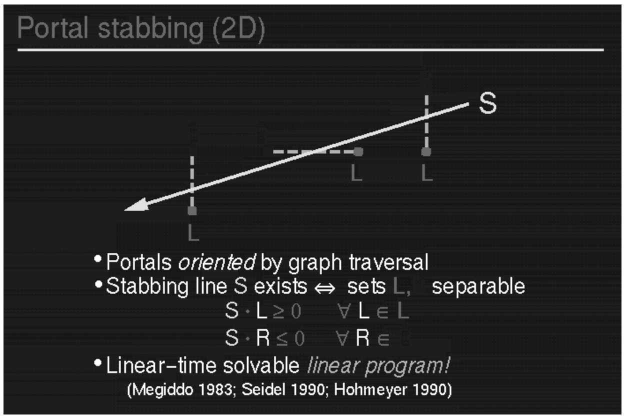


Now consider searching outward into cell adjacency graph

What is the constraint that truncates the visibility search?



Inter-cell visibility <=> existence of a *sightline* which "stabs" the portal sequence



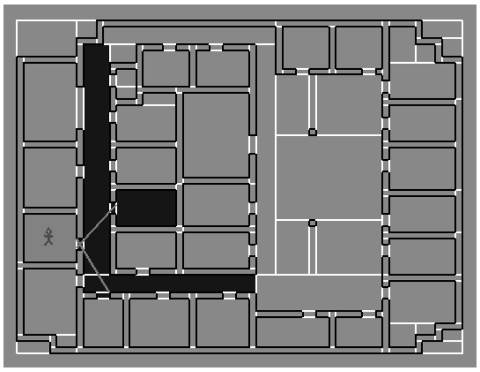
Portal stabbing (2D)

- Portals *oriented* by graph traversal
- Stabbing line S exists ⇔ sets L, separable

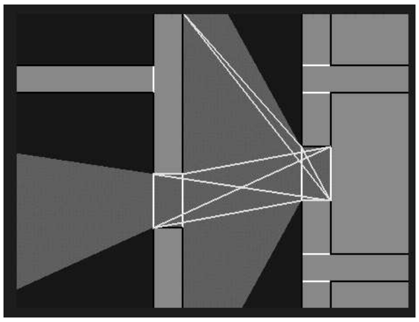
$$S \cdot L \geq 0 \quad \forall L \in L$$
$$S \cdot R \leq 0 \quad \forall R \in$$

- Linear–time solvable *linear program!*
  (Megiddo 1983; Seidel 1990; Hohmeyer 1990)

This establishes the existence of visibility links between cells:

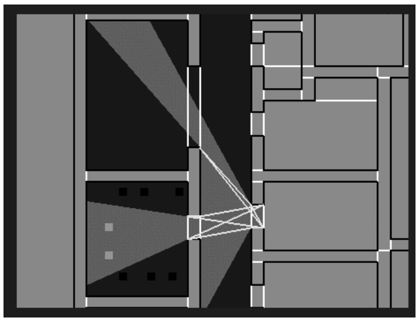


However, we can do better by establishing *cell-to-region* visibility (how?):



And, within these regions, potentially visible objects:

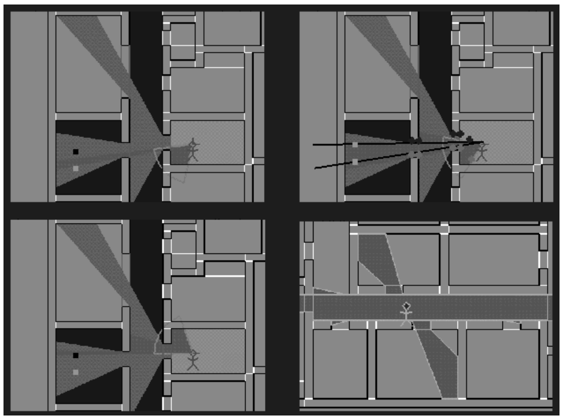
(still without regard to position of observer!)



All of the above can be done *offline* (or, perhaps better, *lazily* -- how?).

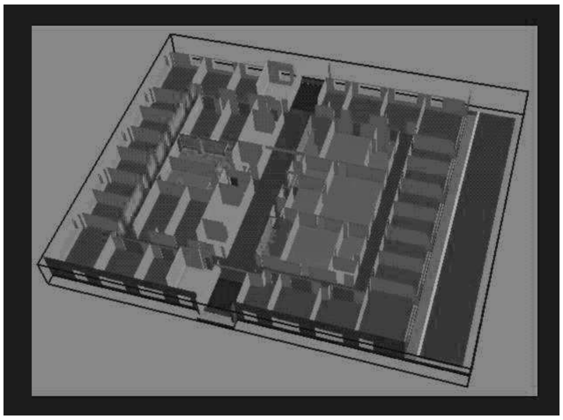
Now we introduce an *interactive query,* in which the user's instantaneous position is tracked, and his/her view is rendered rapidly (> 10 Hz)

What new information do we have about the user?

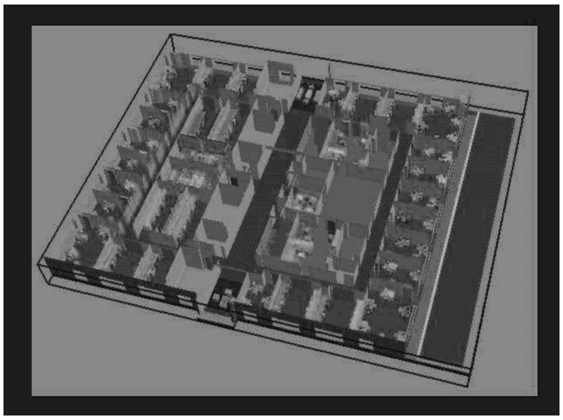


How are eye-to-cell sightlines established in 2D?

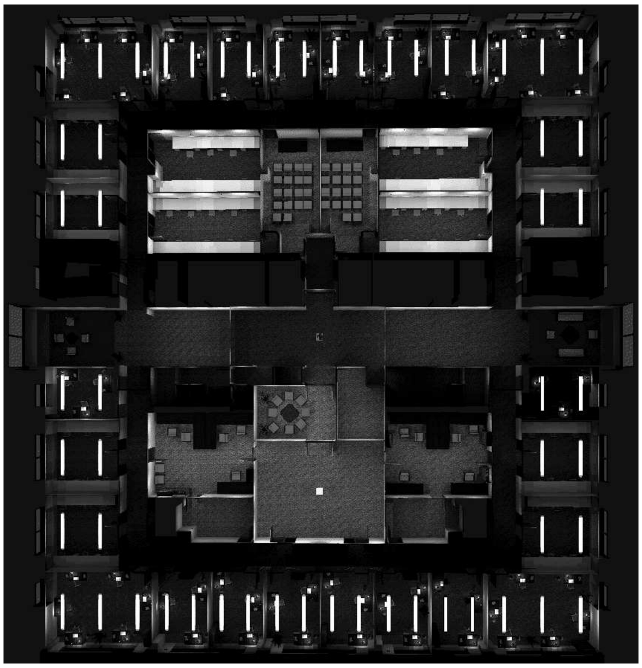
In fact, everything above works in 3D as well:



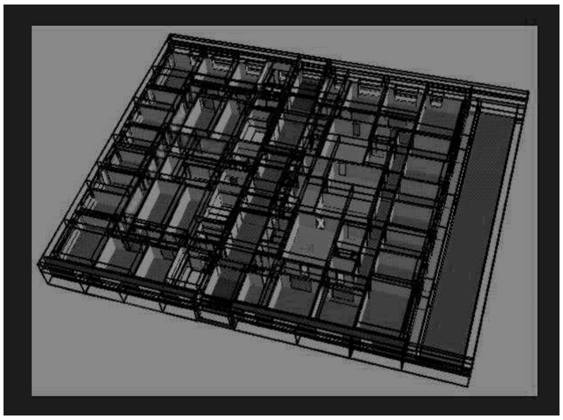
5th Floor of Soda Hall (Structural Elements)



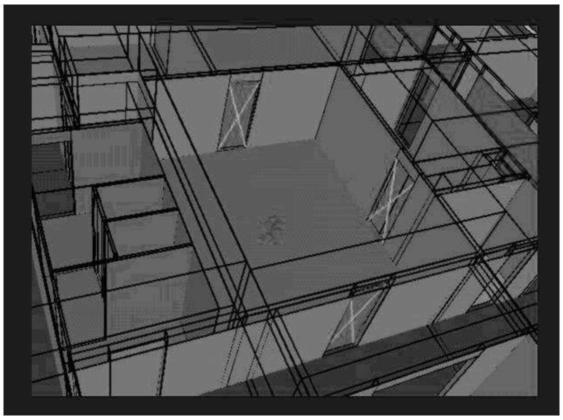
5th Floor of Soda Hall (Structural & Detail Element Bounding Boxes)



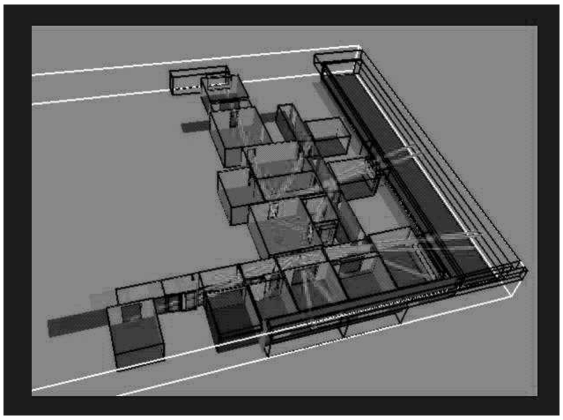
5th Floor of Soda Hall (Structural & Detail Elements -- Actual)



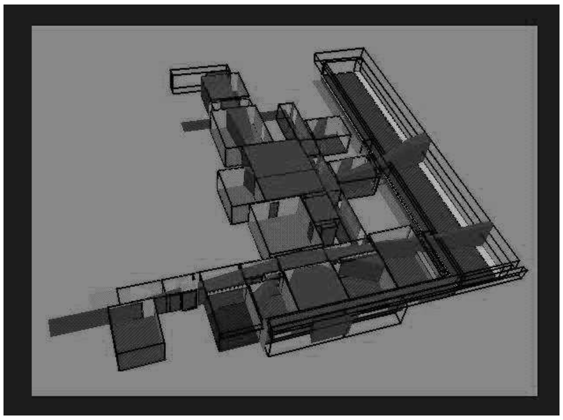
With Spatial Subdivision (Cells and Portals)



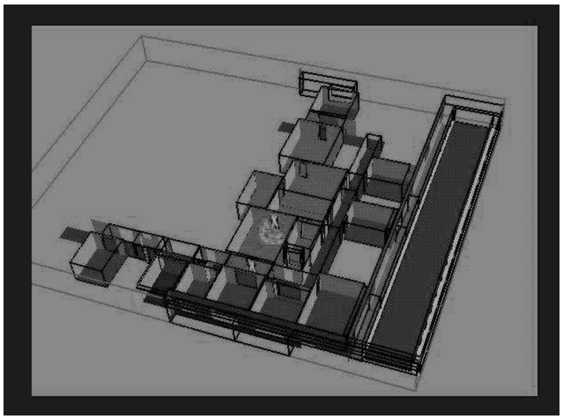
Detail View of a Cell and its Portals



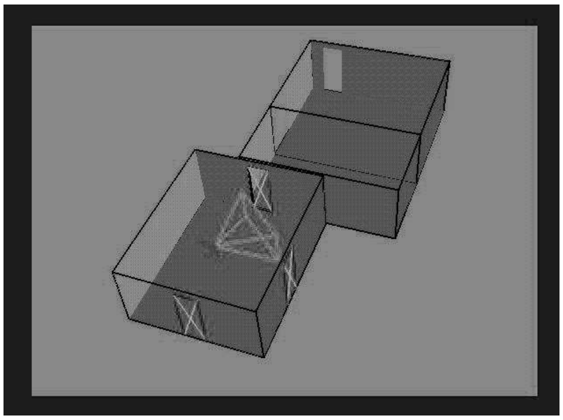
Cell-to-Cell Visibility for One Cell



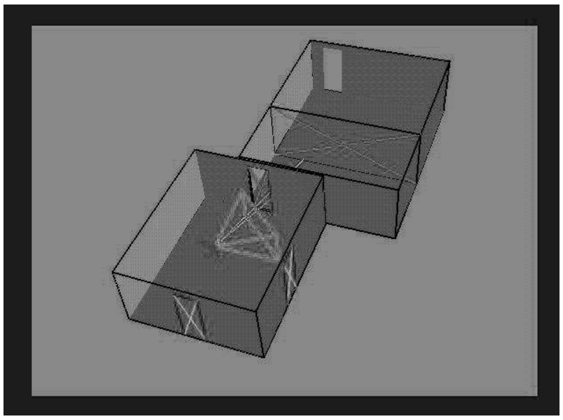
Cell-to-Region Visibility



Interactive Query (Observer Position, Field of View Known)

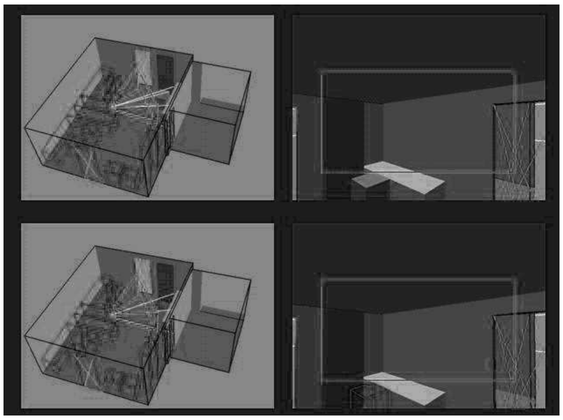


Detail View

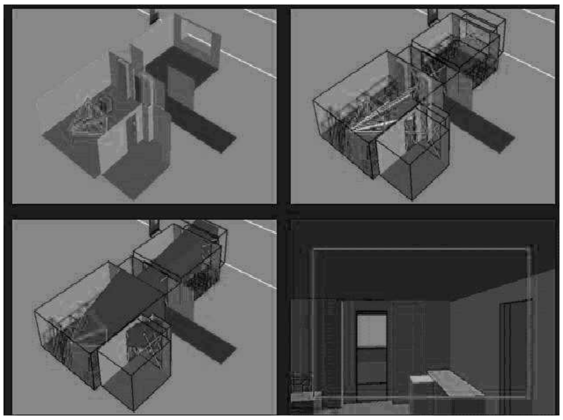


Eye-to-Cell Sightlines Determined by Linear Programming

How are eye-to-cell sightlines established in 3D?



Potentially Visible Objects (Wireframe) and In-Frustum Objects (Shaded)



View Through a Series of Portals

This technique is very effective for architectural *interiors;* it was quickly coded into commercial CAD packages, games (e.g., Quake et al.)

(though not too well: "level compilation" is completely unnecessary)

It has another benefit: one can upper bound the set of geometry that will be needed for the next frame, or several frames (why useful?)

But: what happens for *outdoor* environments?
  Urban regions
  Forests/natural scenes

Or simply very complex assemblies?
  Mechanical CAD parts (engine blocks, Boeing 777s)
  Molecular visualization

This is a **very hard and still unsolved** problem.

A variety of proposed algorithms exist:
  Hierarchical Z-buffers
  Hierarchical Occlusion Culling
  Hierarchical Occlusion Maps

Read the last few years' issues of Siggraph, Presence, and the ACM Symposium on Computational Geometry.

But all have serious drawbacks which prevent their widespread adoption.

So the book is still very much open on this fundamental problem !

Previous Meeting .... Next Meeting ... Course Page

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