Some Thoughts on Visibility

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Visibility is hot !

- 4 papers at Siggraph
- 4 papers at the EG rendering workshop
- A wonderful dedicated workshop in Corsica !

- A big industrial interest
  - game engines
  - CAD display
  - walkthroughs of huge scenes
  - shadows

Plan

- A multidisciplinary survey on visibility
- Contributions of my thesis
- Some thoughts

A multidisciplinary survey

- Problems
- Classification
- Methods

Fields

- computer graphics
- computer vision
- robotics
- computational geometry

Computer graphics

- Hidden-surface removal
- Shadows
- Occlusion culling
- Radiosity
- Ray-tracing
- Image-based rendering and modeling
- Good viewpoint selection

Computer vision

- Model-based object recognition
- Contour intersection
- Sensor placement for known geometry
- Object exploration/scanning

Robotics

- Motion planning
- Pursuit-evasion
- Self localization

Computational geometry

- Hidden-surface removal
- Ray-shooting
- Lines in space
- Art galleries
- 2D visibility graph construction
- 2D visibility graph characterisation

Classification

- Object space
- Image space
- Viewpoint space
- Line space

Object space

- Space partition
- Path planning
- Visual hull
- Shadow volume, beams
- Shafts
- Portals
- Limits of shadows of area light sources

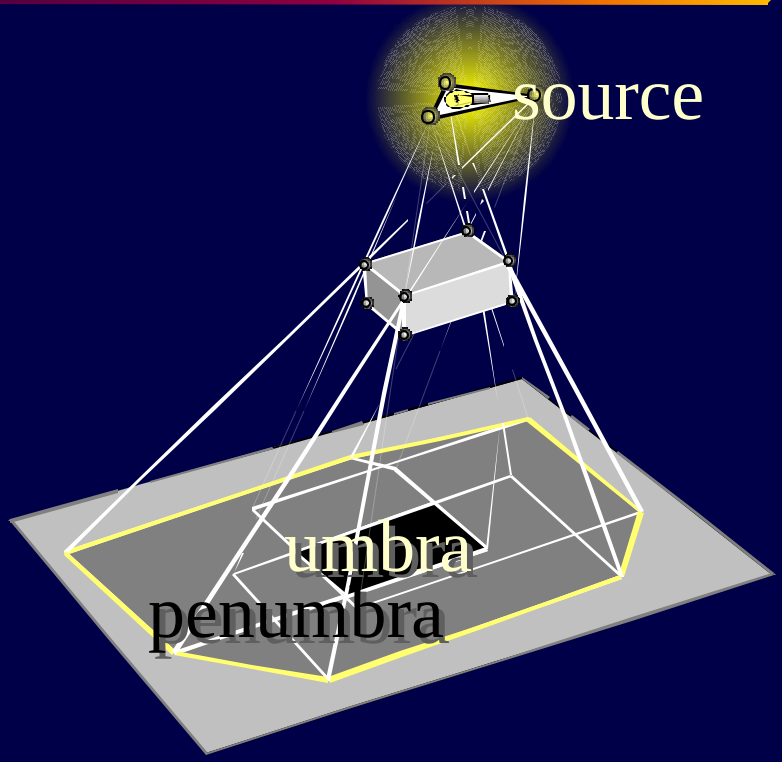
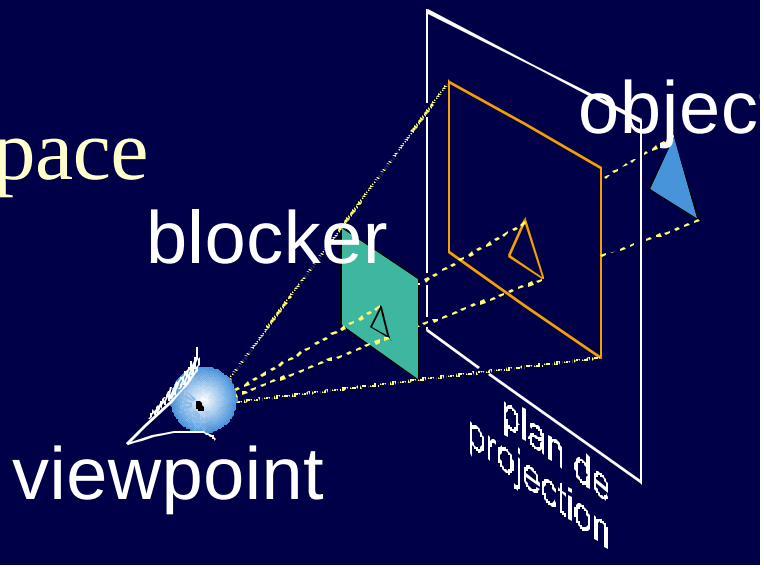


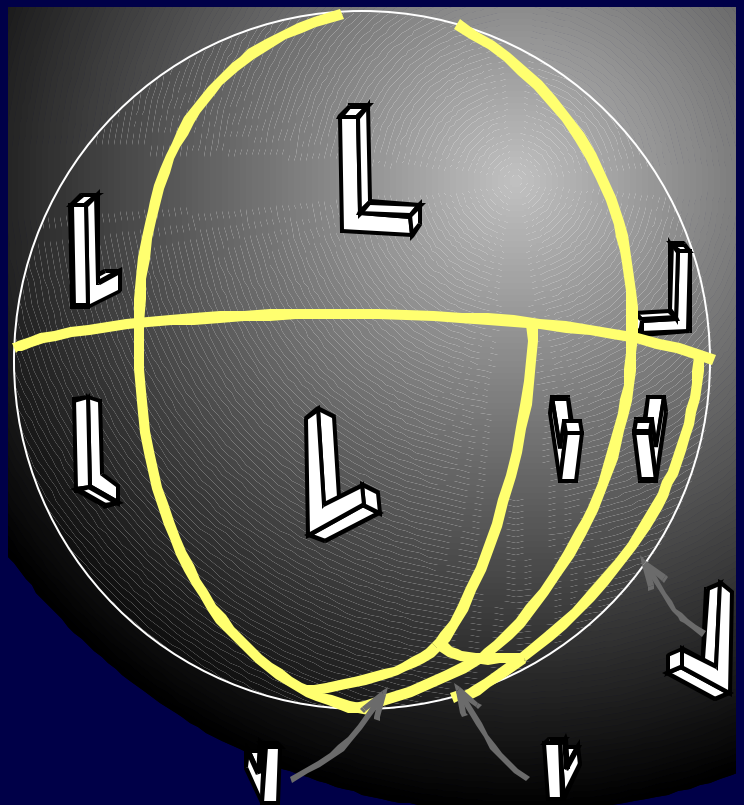
Image space

- Advanced z-buffer
  - shadow maps, item buffer, light buffer, hemicube
  - occluder footprints
- Hierarchical z-buffer
- Soft shadow with convolution
- Epipolar rendering
- Shadow coherence in image space
- Volumetric projections



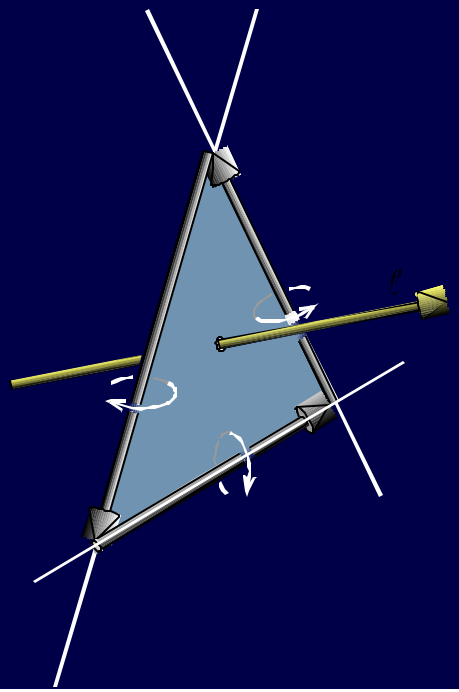
Viewpoint space

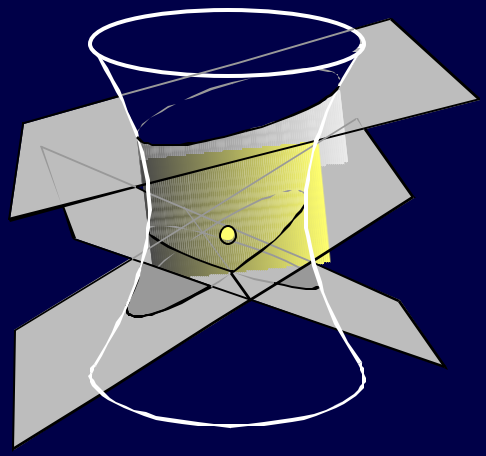
- Aspect graph
- *À la* aspect graph methods
  - localization,pursuit, discontinuity meshing
- Viewpoint optimization
- Frame to frame coherence



Line space

- Line space partition
- Graphs in line space
- Plücker coordinates
- Stochastic approaches





Conclusions

- Many efficient method
- Little understanding
- In practice, sampling rules

Thesis

- Visibility Skeleton
- Visibility Driven Hierarchical Radiosity
- 3D Visibility Complex
- Extended projections

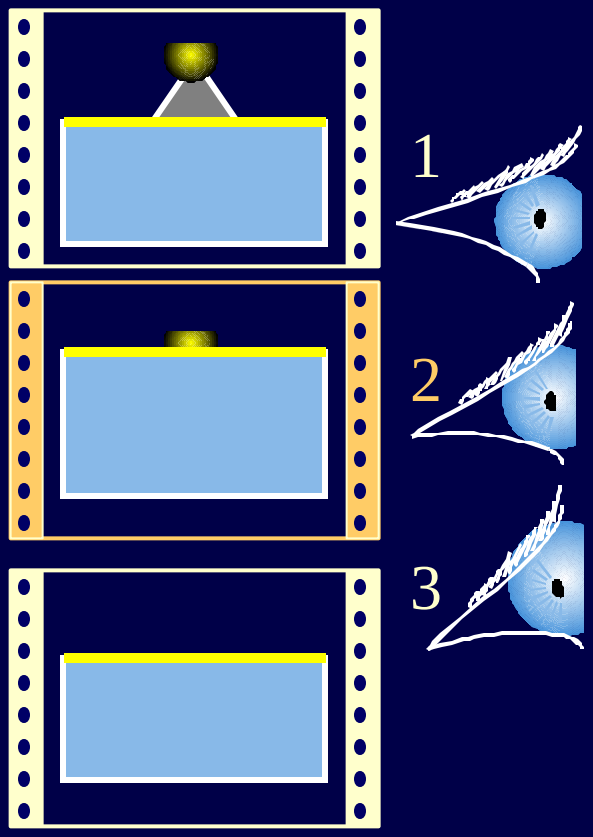
Visibility Skeleton

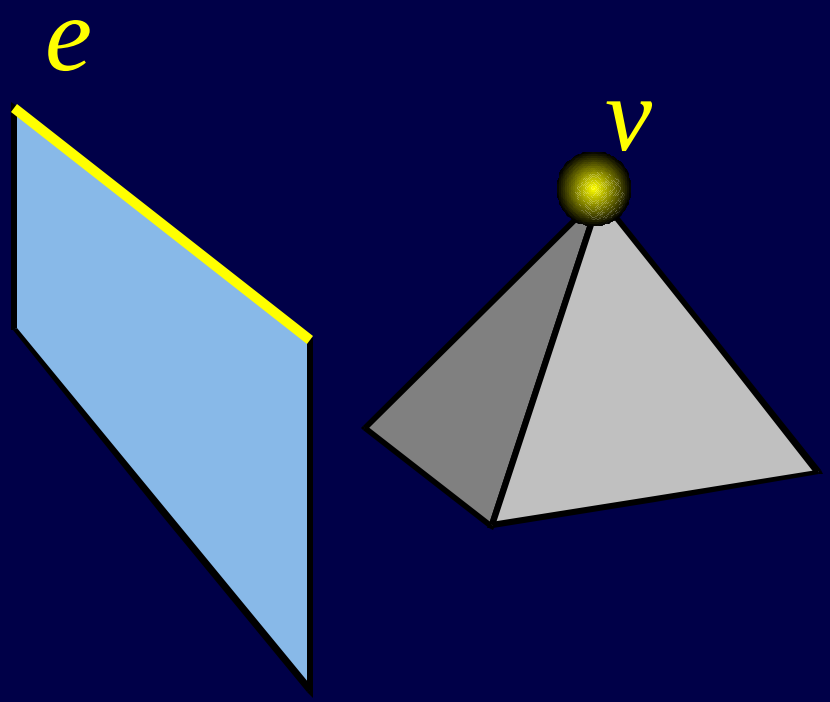
Goal

- Global visibility structure
  - views
  - limits of shadows
  - appearance of objects
  - mutual visibility
- Characterise the changes in visibility
  - where?
  - how?

Visual event

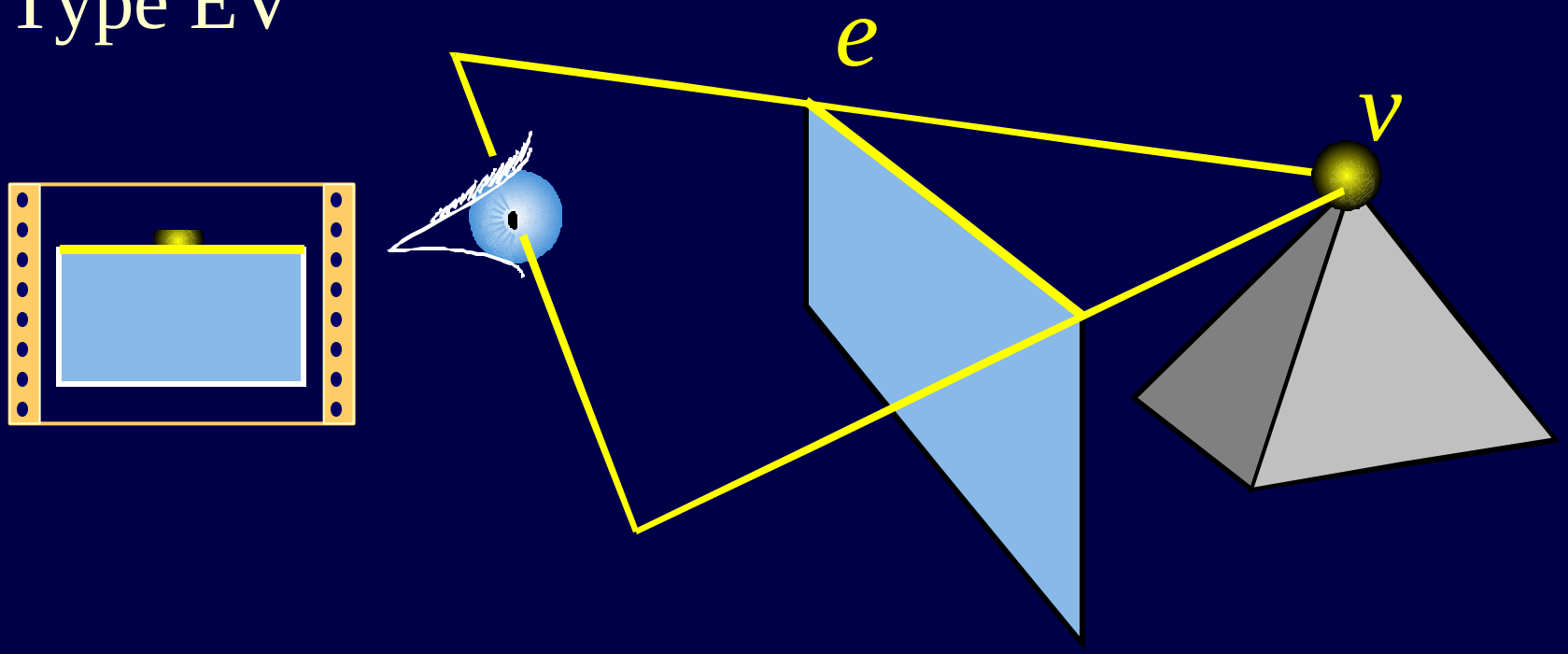
- Appearance-disappearance of objects (qualitative change of a view)





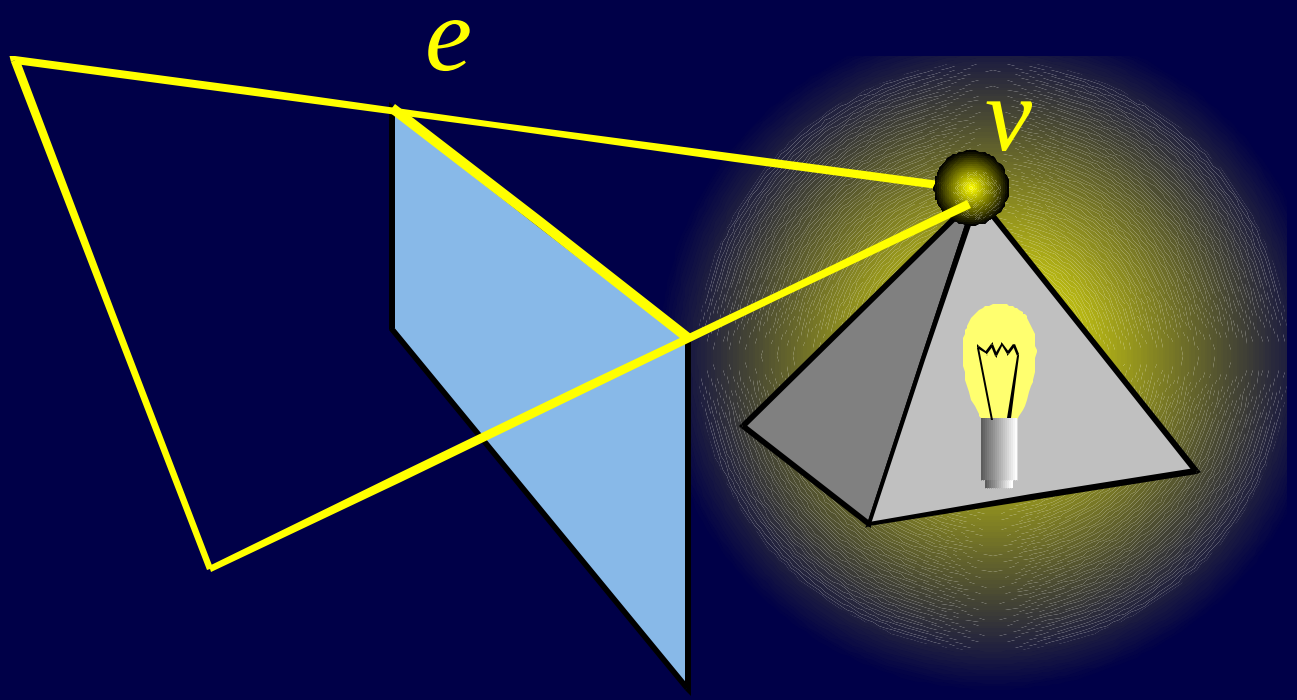
Visual event

- Appearance-disappearance of objects (qualitative change of a view)
- « Wedge » defined by a vertex and an edge
- Type EV



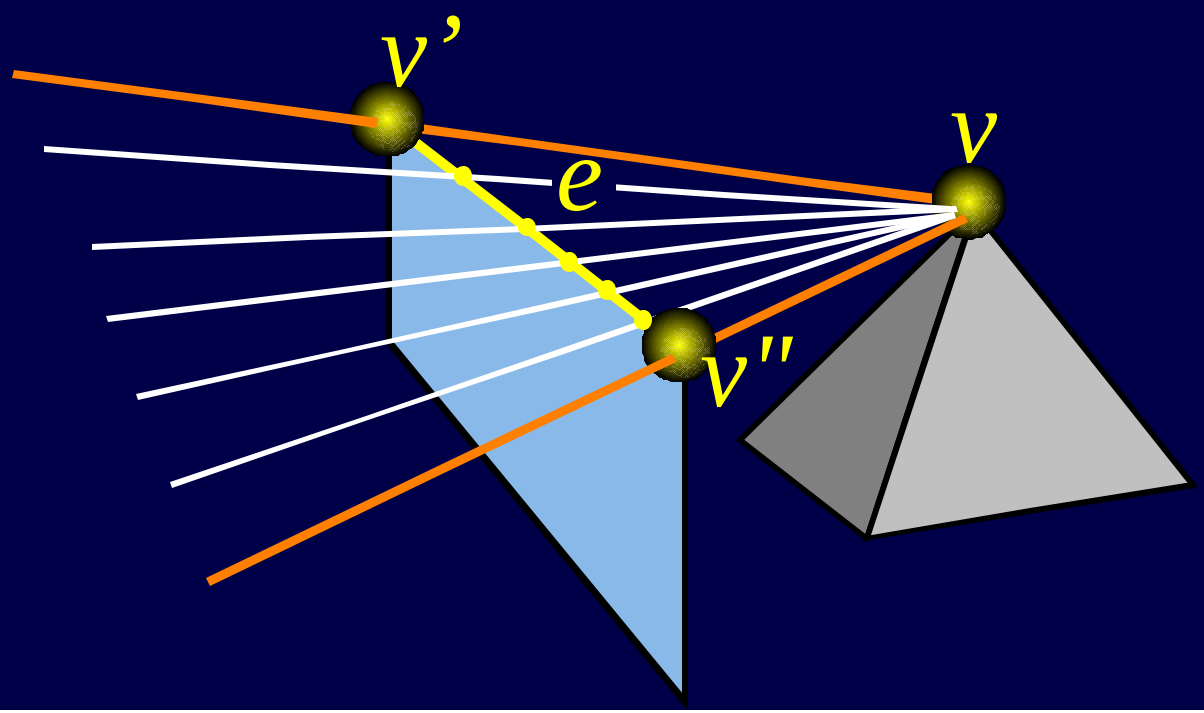
Visual event

- Appearance-disappearance of objects
- Limits of umbra

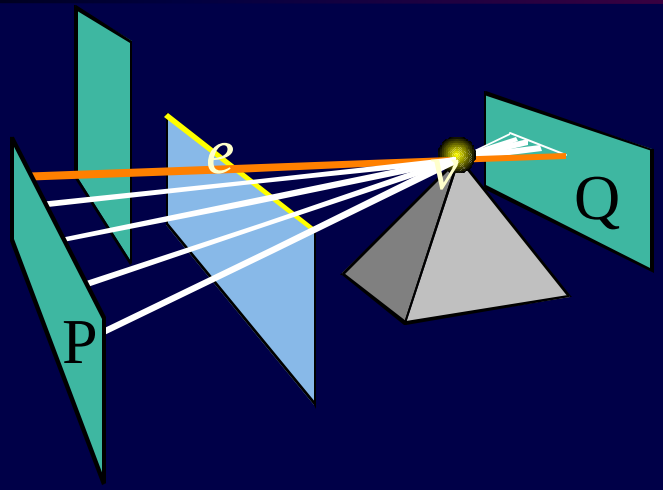


Critical and Extremal stabbing line

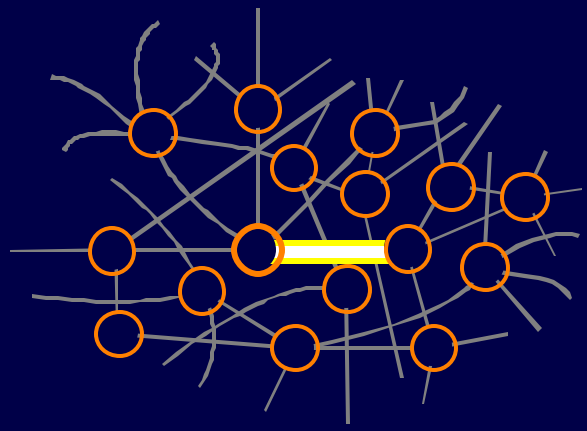
- 1D set of lines going through *e* and *v* (1 degree of freedom)
- Extremity: extremal stabbing line (VV) (0 degree of freedom)



Visibility skeleton

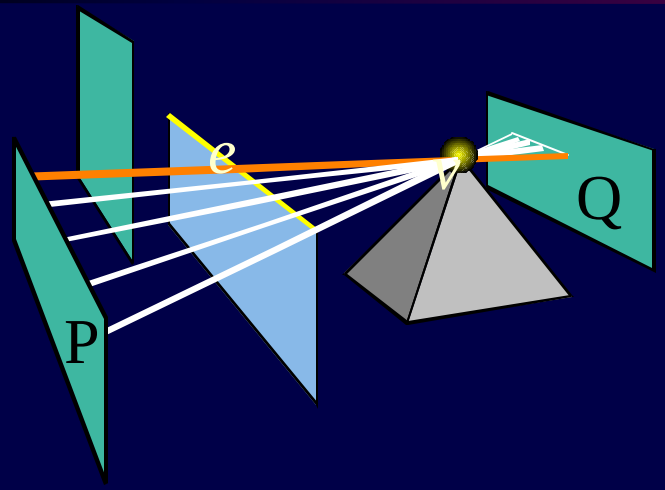


Visual event *ev*

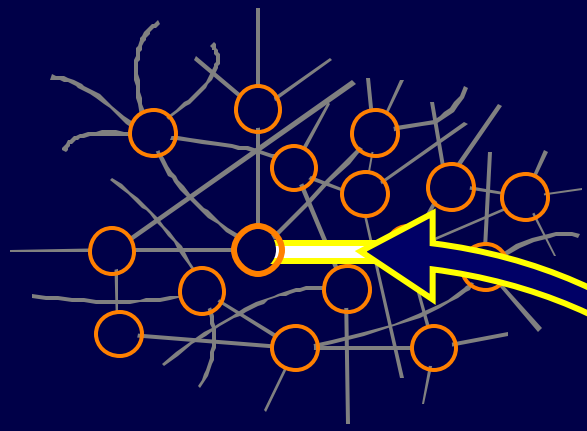


Arc of the skeleton

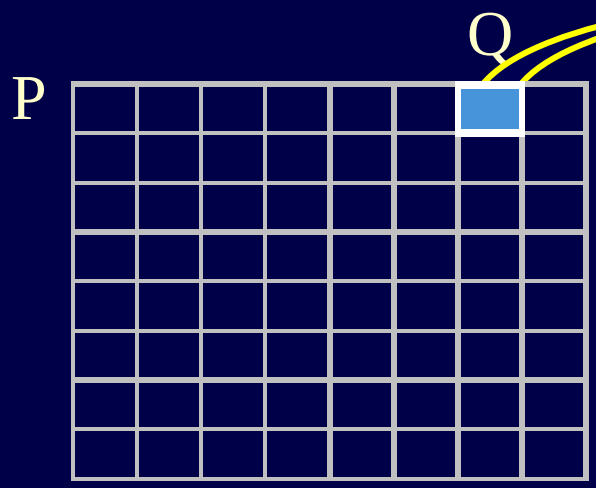
Visibility skeleton



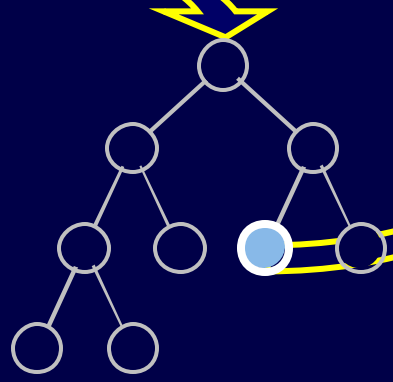
Visual event *ev*



Arc of the skeleton



Array indexed by the polygons



Search tree

Discussion

- General structure of global visibility
- Simple and local
  - on-demand construction
- Future work issues
  - robustness (partial treatment)
  - complexity: scalability
    (quadratic growth is unacceptable)

Use of the skeleton for illumination

- Exact computation of form-factors
  - point-polygon
- Discontinuity meshing
  - scene subdivision along shadow boundaries
  - also for indirect lighting
- Refinement criterion
  - perceptual metric
  - error estimation

Results

- 492 polygons : 10 minutes 23 seconds

Results

With skeleton: 11 minutes 10 seconds

Discussion

+ Precise and rapid
+ High quality
+ Difficult configurations
+ Simple and efficient criterion

- Memory cost
- Robustness
- Scalability

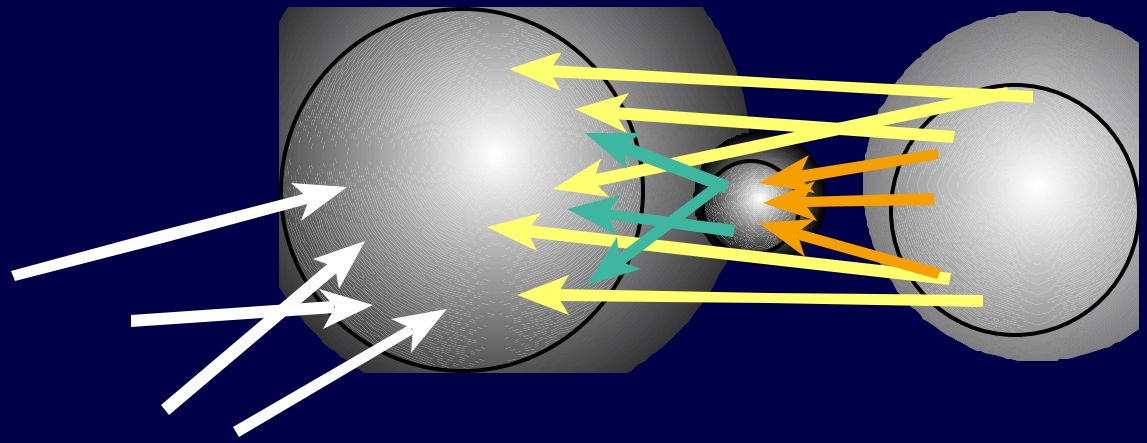
Visibility complex

Goals

- Framework to describe visibility
- Characterise coherence
- Origin of the visibility skeleton

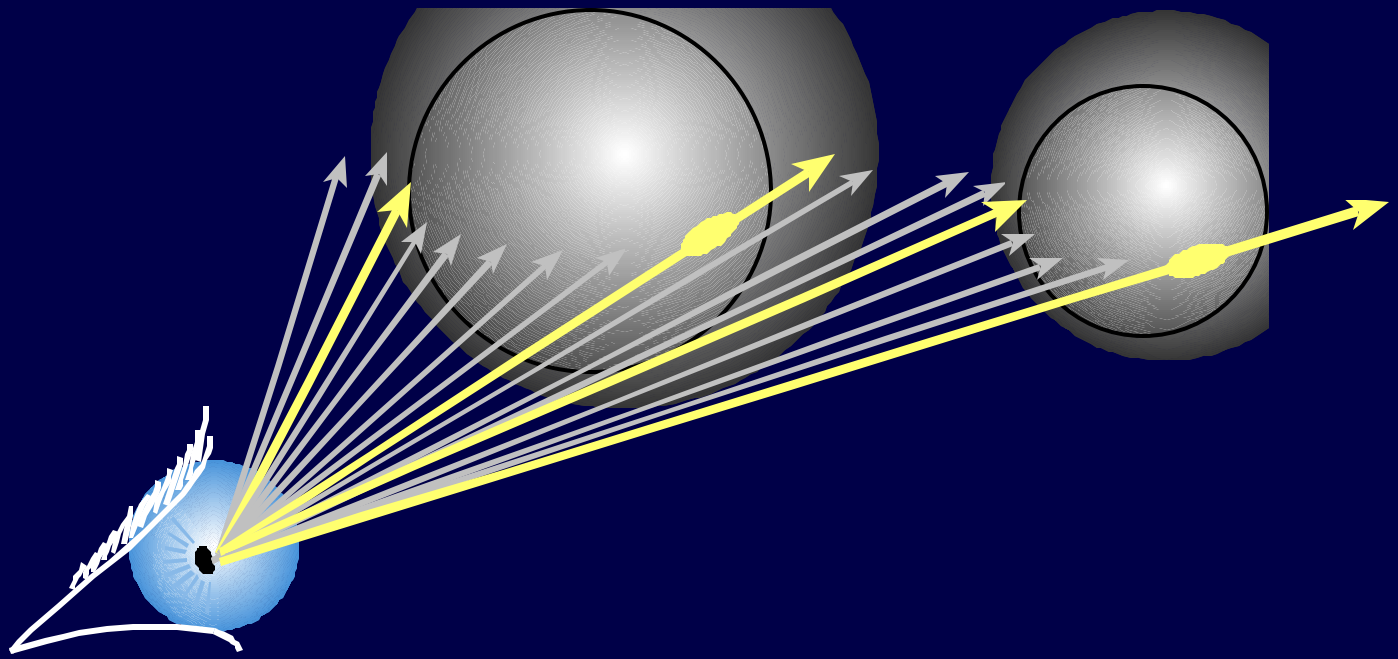
Visibility complex

- Group rays which “see” the same objects



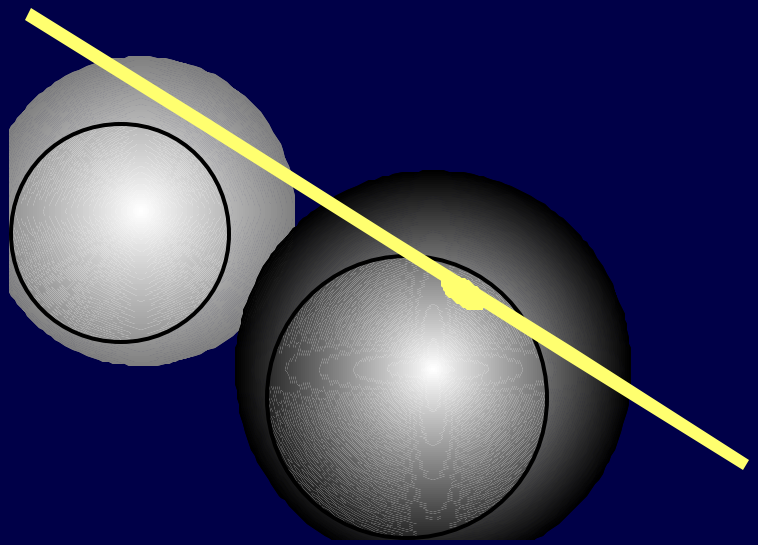
Tangents

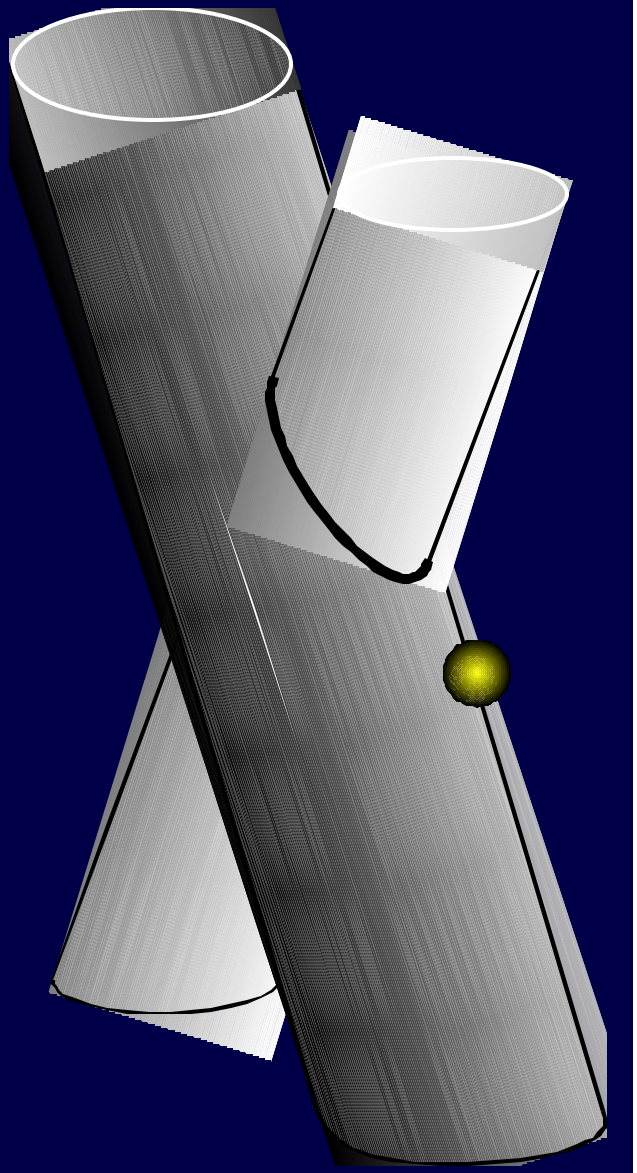
- The objects seen by a ray changes at the tangents



Classification of lines

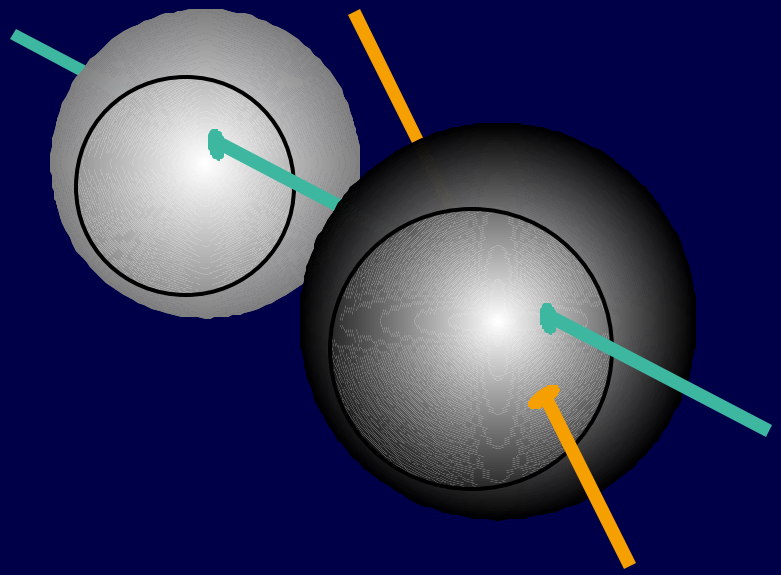
- In 4D line space
- Tangent

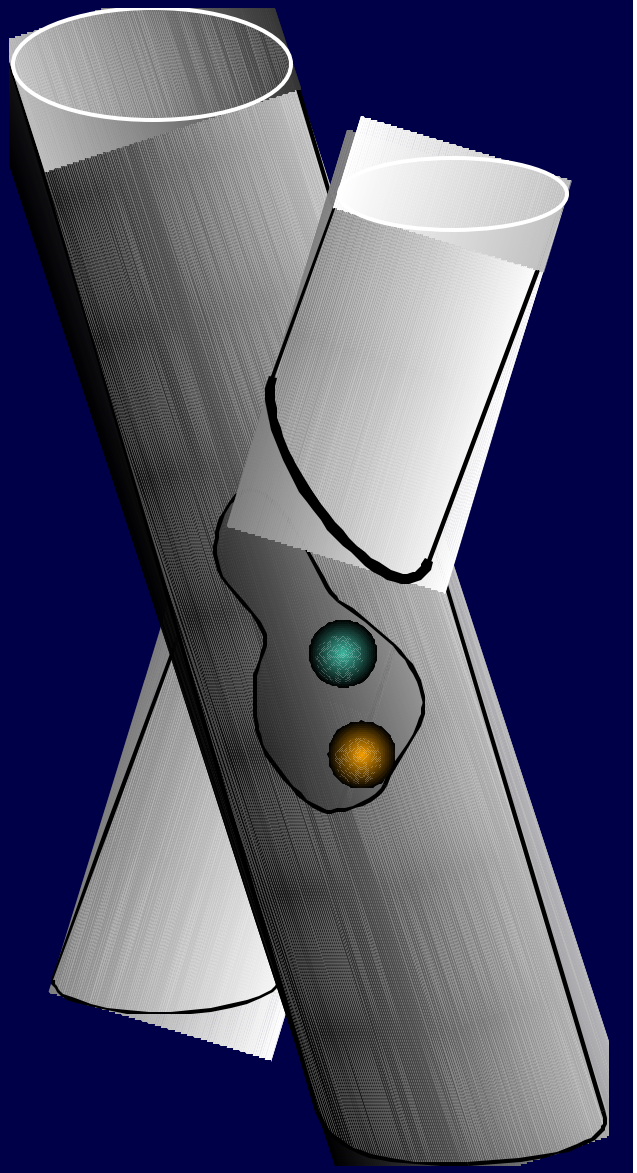




Classification of lines

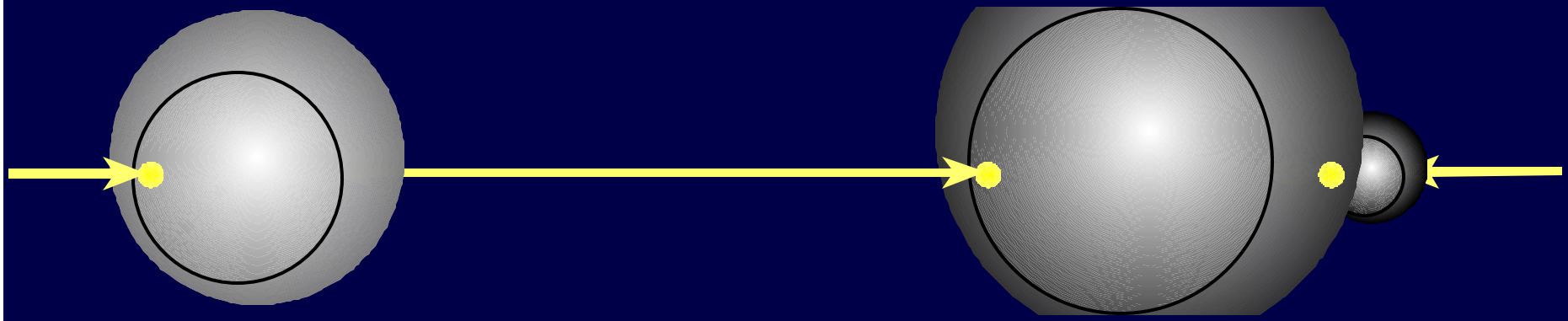
- Line intersecting an object
- Line intersecting two objects





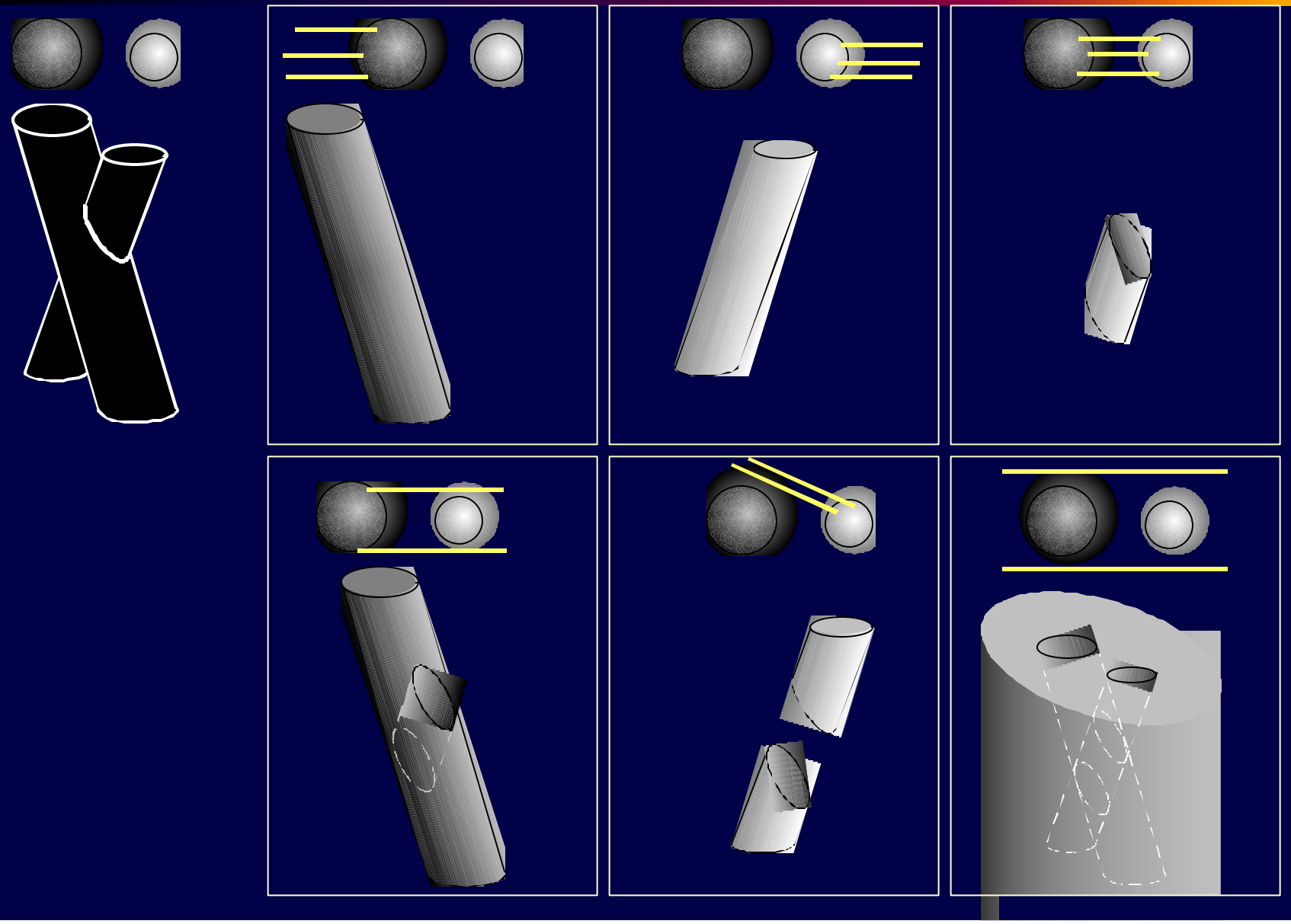
Maximal free segments

- 1 line = many segments
  - separated by intersections



- Same point in 4D space

Visibility complex



Visibility Complex

- Defined for polygons and curved objects
  - singularity theory for concave objects
- Size : *? (n)* and $O(n^4)$
- Probabilistic analysis: $O(n^{2,67})$
- Construction algorithm $O(k+n^3 \log n)$
  - where k is the size
- Interpretation
  - views, shadow limits, aspect graph
- Moving objects

Discussion

+ Natural framework for visibility
- unsatisfying complexity of the construction
- Hard to implement
    - robustness problems
    - tedious 4D adjacencies
+ Has permitted the development of the skeleton
+ Probabilistic analysis

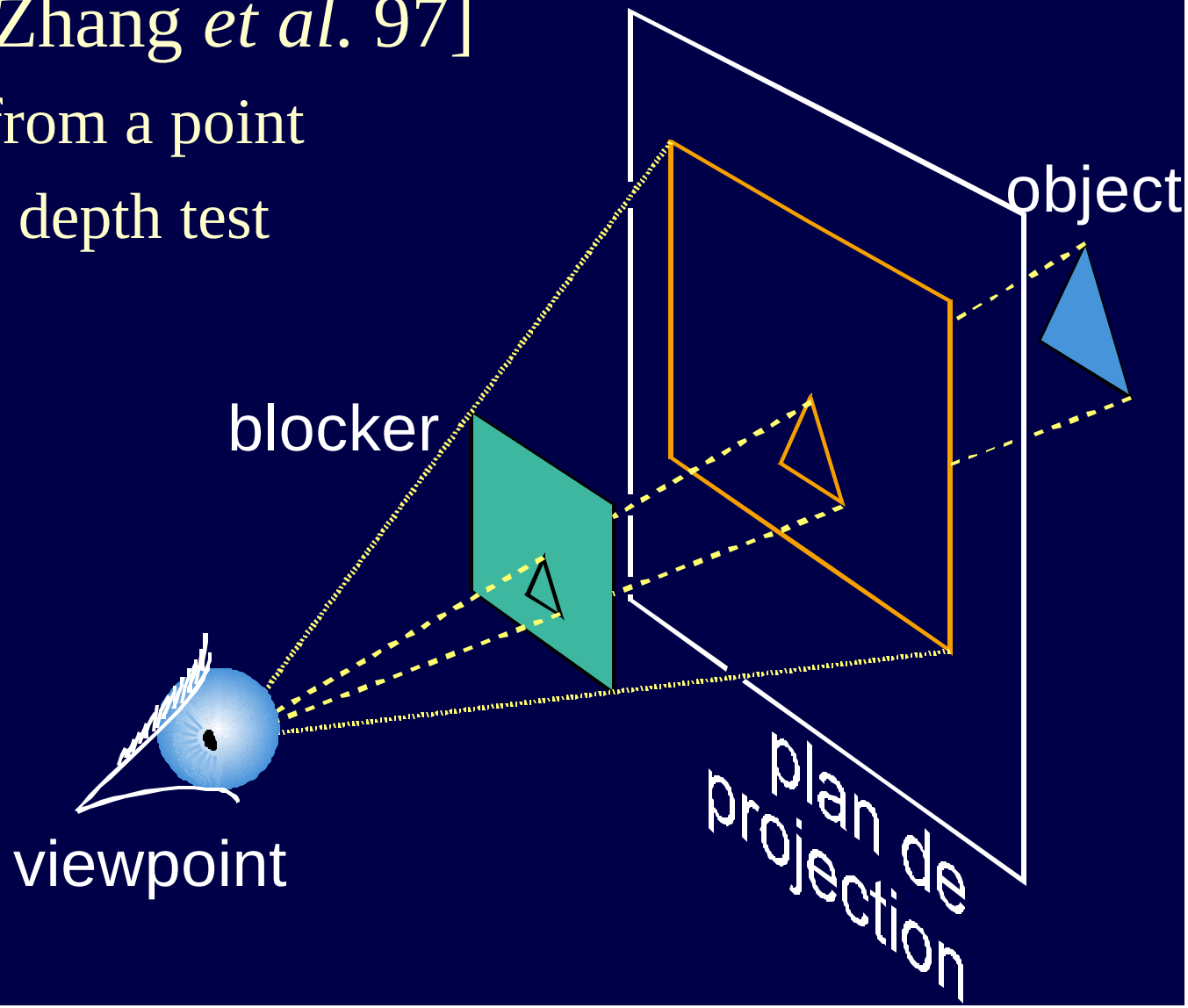
Occlusion preprocess

Goals

- Display of large scenes
- Rapid elimination of hidden objects
- Preprocess
  - determination of objects invisible from a volume
  - conservative computation

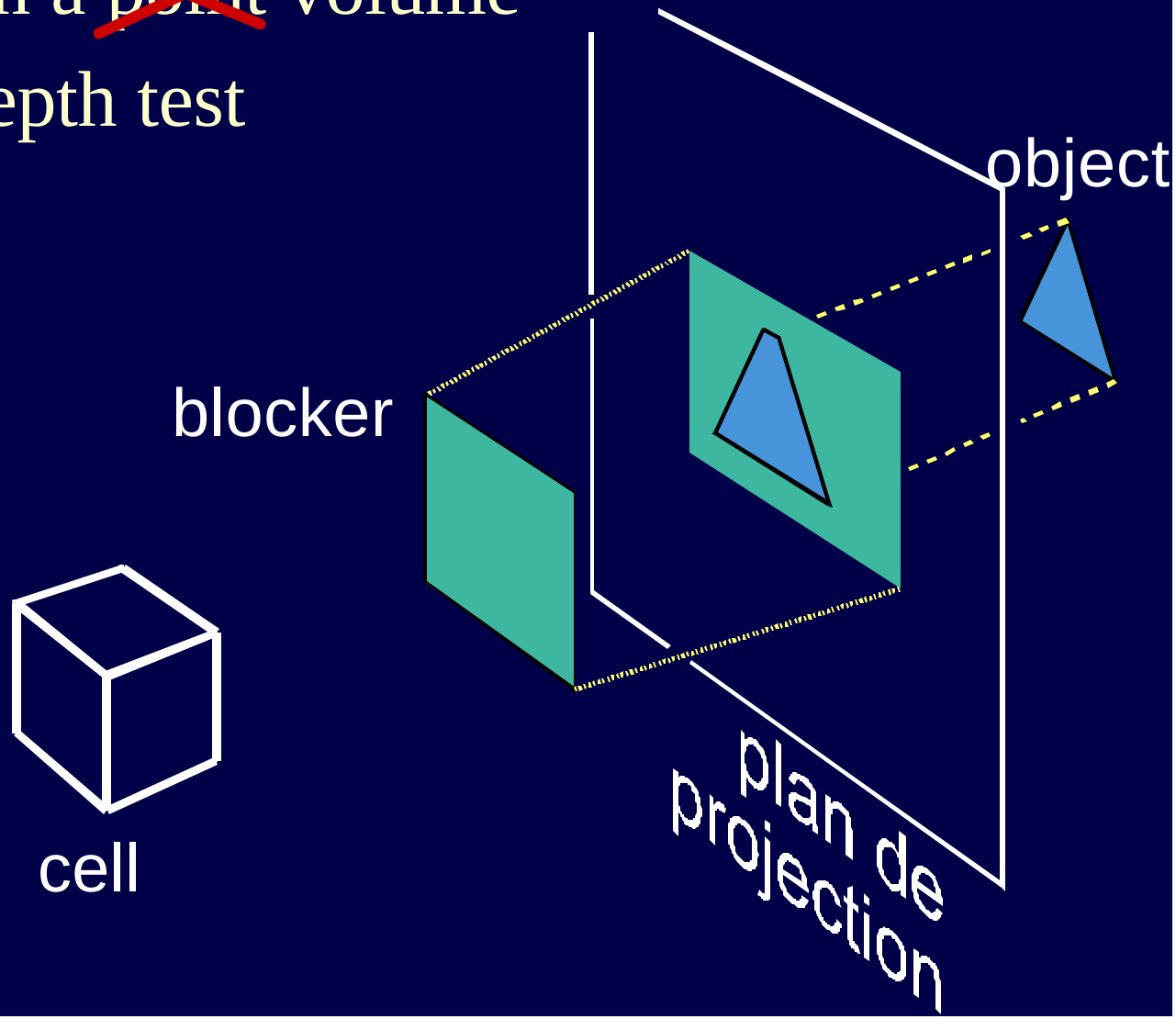
On-line occlusion culling

- [Greene 93, Zhang *et al.* 97]
  - Projection from a point
  - overlap and depth test



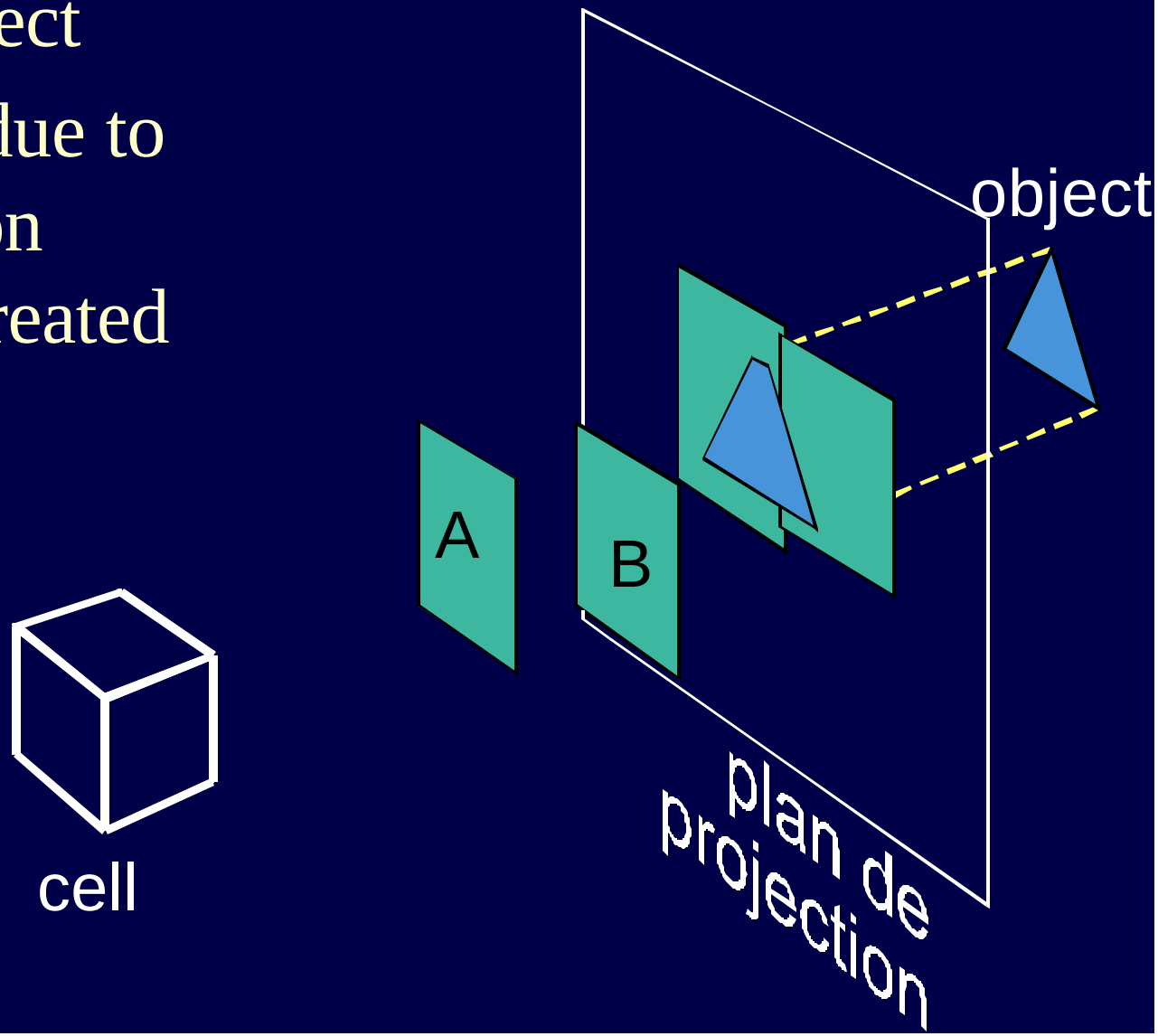
Extended projections

- Projection from a ~~point~~ volume
- Overlap and depth test



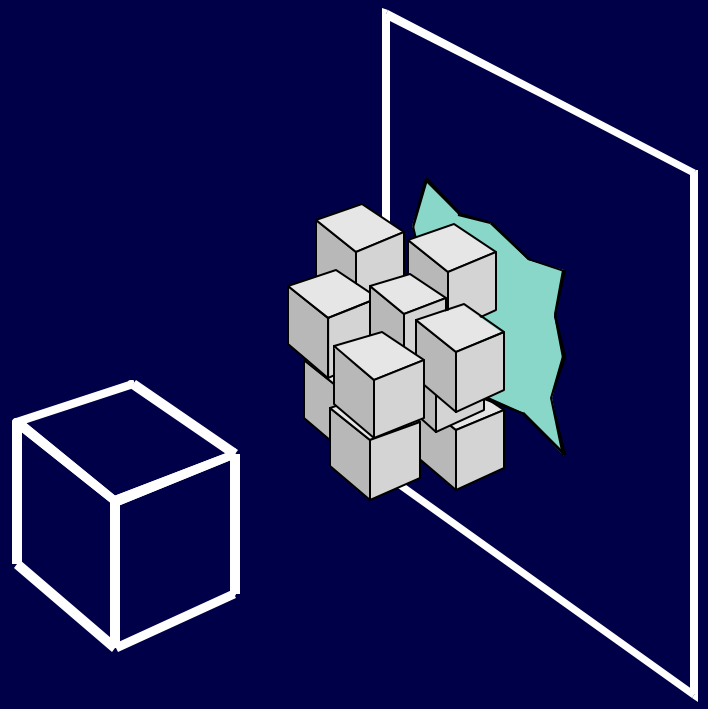
Blocker fusion

- Test of the object
- the occlusion due to the combination of *A* and *B* is treated



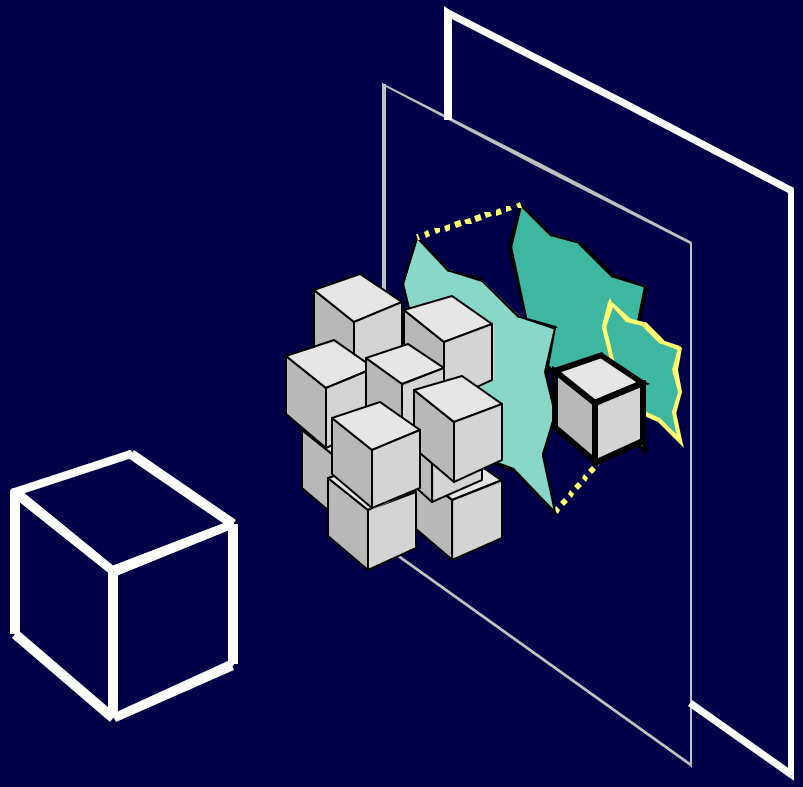
Occlusion sweep

- Initial projection plane



Occlusion sweep

- Re-projection
- Projection of new blockers



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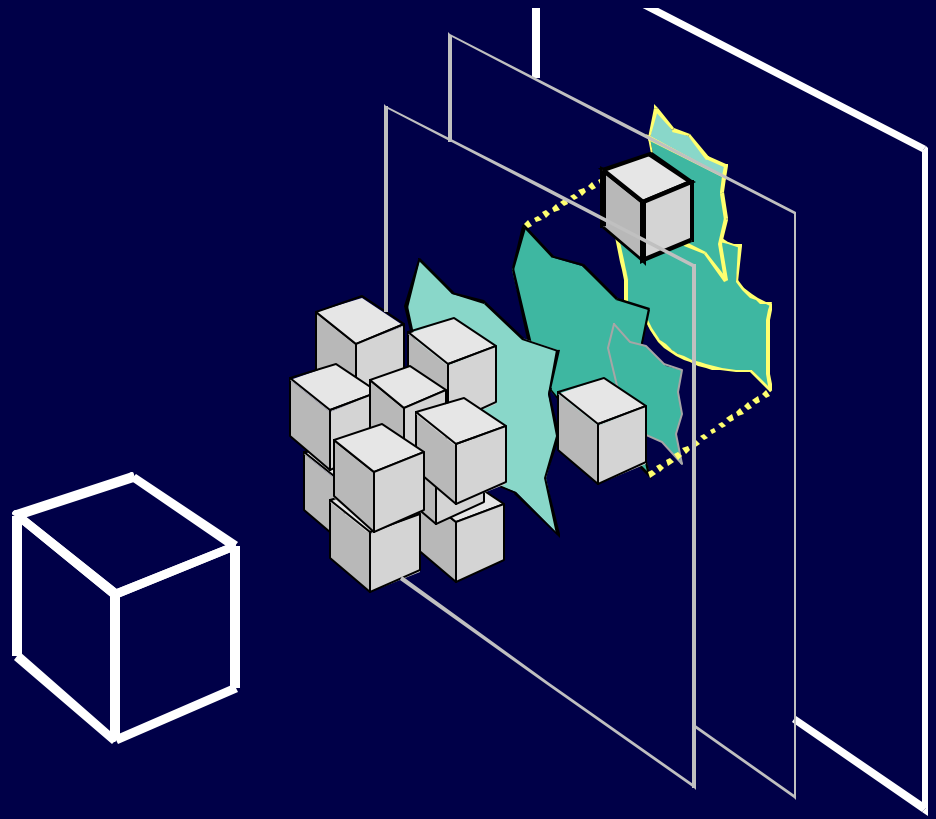

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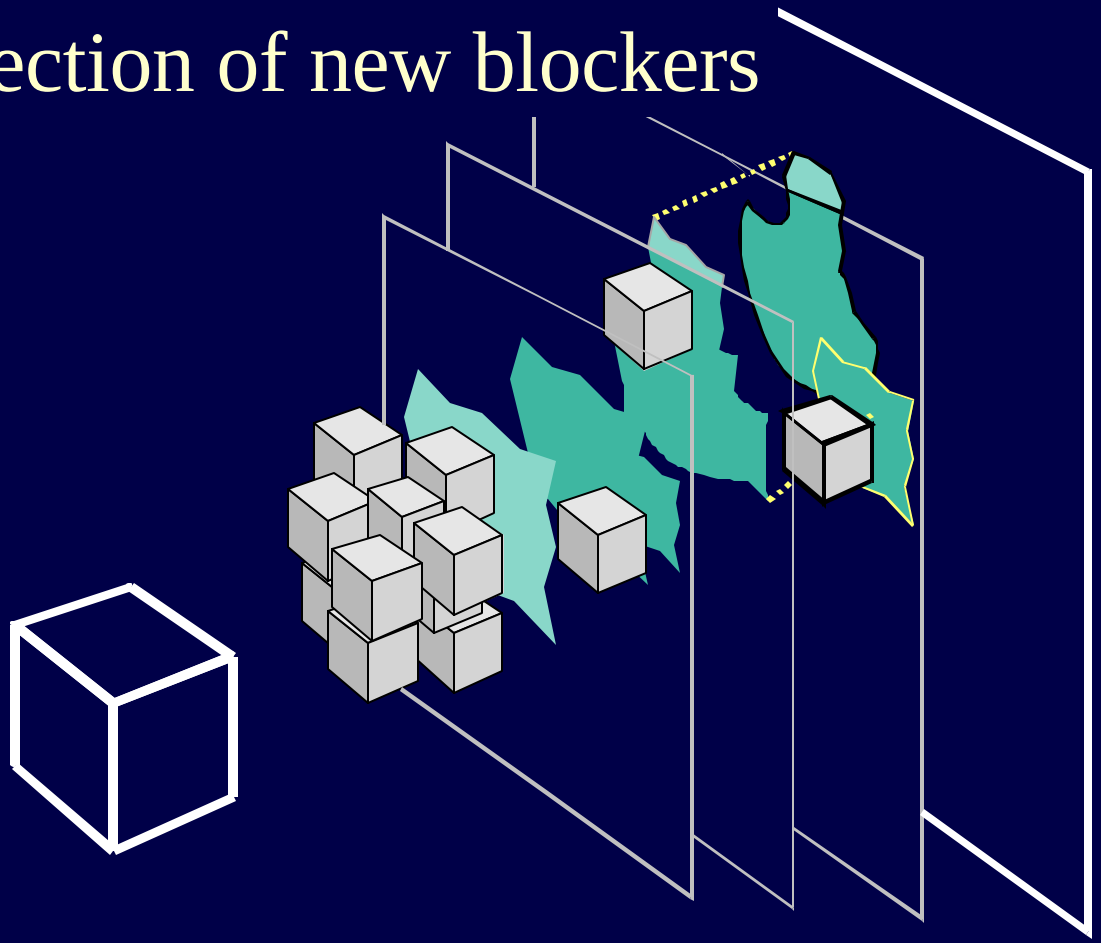

Discussion

- More remaining objects than on-linemethods
- No moving blockers

+ Blocker fusion
+ No cost at display time
+ Prediction capability

  scenes which do not fit into main memory

  pre-fetching (network, disk)

Discussion

- Software-based online occlusion-culling is dead
  - but research on point-based occlusion-culling is not!!
- Occluder generation/simplification
- Semi quantitative methods

Some thoughts

with a personal huge bias for graphics

Misc

- The step from 2D to 3D is high
- 2 1/2D is useful
- Worst case analysis is useless
  (or at least not enough)
- A lot of old problems come back!

The situation

- Modern graphics hardware is amazing
- Sampling rules

- But still, visibility is not solved in these conditions

3D models

- Polygons become incredibly tiny
- Models are messy
- Other primitives arrive
  - splines, nurbs
  - subdivision surfaces
  - points, IBR

Different types of scenes

- CAD/CAM one big localized object
- Walkthroughs: large extent
- Cities: 2.5 D

- polygonal soup

- We need to caracterize scenes!

Scalability, multiresolution

- Simplification (bottom up)
- Geometry alone fails, we need transparency
- Perceptual issues
- Criteria

- What the hell do we want to do ????

Robustness

- Geometric algorithms are often fragile
- Analytical calculations are not the answer
- We need to treat degeneracies as such
- For this, we need to detect them
- This can be related to scalability:
  - scale drives ?

Dynamic scenes

- A problem for 30 years
- In practice, everything restarts from scratch
- How can this be compatible with sampling?
- Complete set of visual events too costly
- We sort of have the analytical tools
- Very frustrating!

To summarize

- Scene
- Scalability
- Robustness
- Dynamic scenes

Pilosophical conclusions

- ? ?s ?S??t? ?s ??eat!
- Multidisciplinary
- Brute force approaches are powerful
- But they are not powerful enough

- So, visibility research is useful!

Thank you