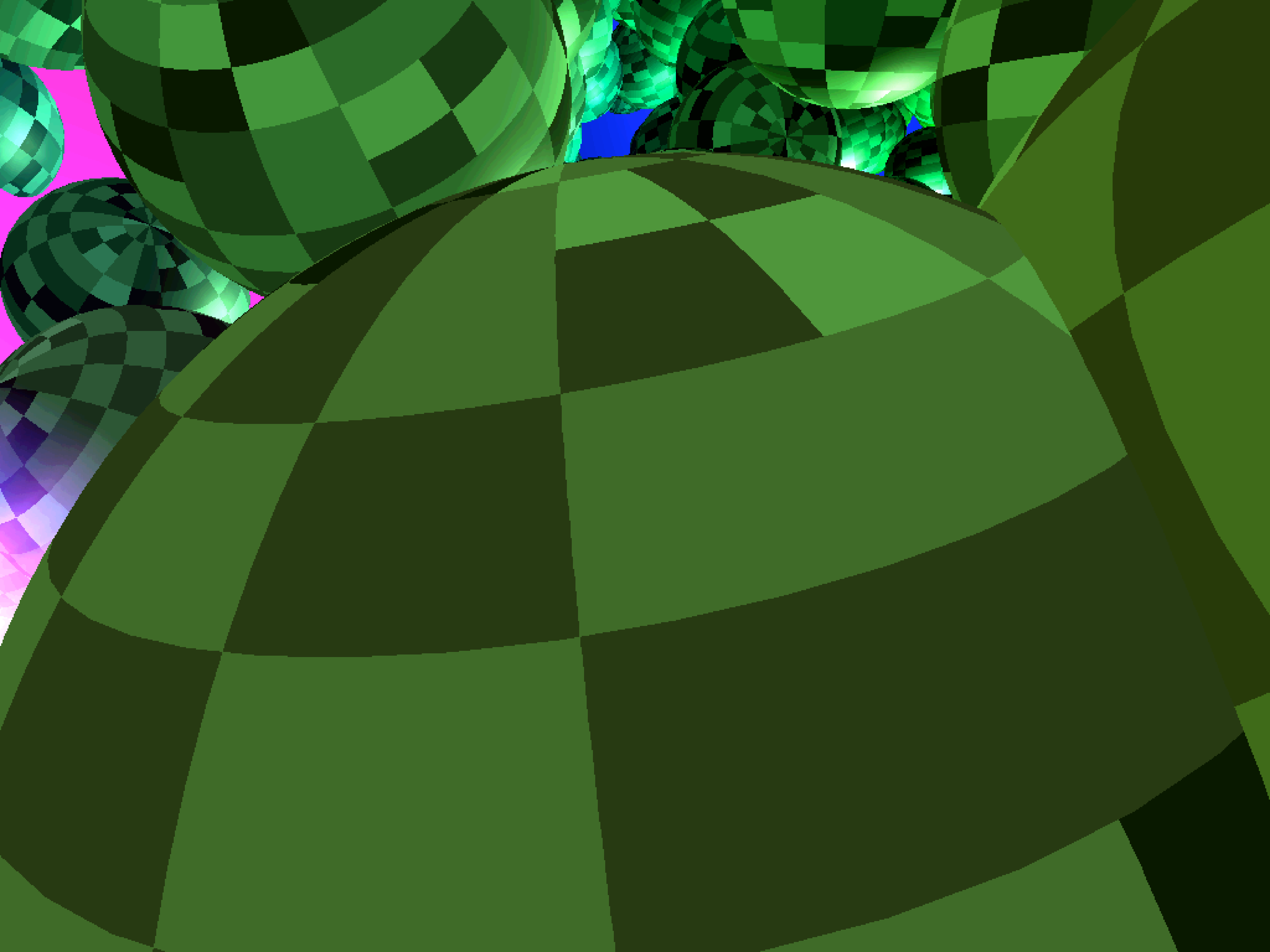
Dynamic Spatial Partitioning for Real-Time Visibility Determination

Joshua Shagam
Computer Science

Problem

- *Complex 3D environments have large numbers of objects*
- *Computer hardware can only render a finite number at any given speed*
- *Need to determine which ones will be visible*
- *Simple/intuitive approaches are extremely slow*



Outline

- *Prior work*
- *Dynamic AABB Tree Structure - definition, maintenance, usage*
- *Real-world performance example*
- *Heuristic comparison*
- *Conclusions*

Visibility Determination

- *Heavily-studied [Cohen-Or et al., 2000]*
- *Hundreds of algorithms*
- *Dozens of approaches*
- *Only a few in practical use*
- *Those in use are very limited*

Spatial Partitioning

- *Most visibility approaches use spatial partitioning*
- *Divide (partition) environment into cells (regions) in organized manner*
- *Many partitioning algorithms (most are static or limited in update ability)*

Partitioning Approaches

- *Binary Space Partition (BSP)*
- *K-D Tree/Quadtree/Octree*
- *Axis-Aligned Bounding Box (AABB) Tree*

Dynamic AABB Tree

- *Group objects based on relative position*
  - *Grouping determined by heuristic*
  - *Several heuristics available*
- *Recursively divide groups*
- *Group-level visibility determination*

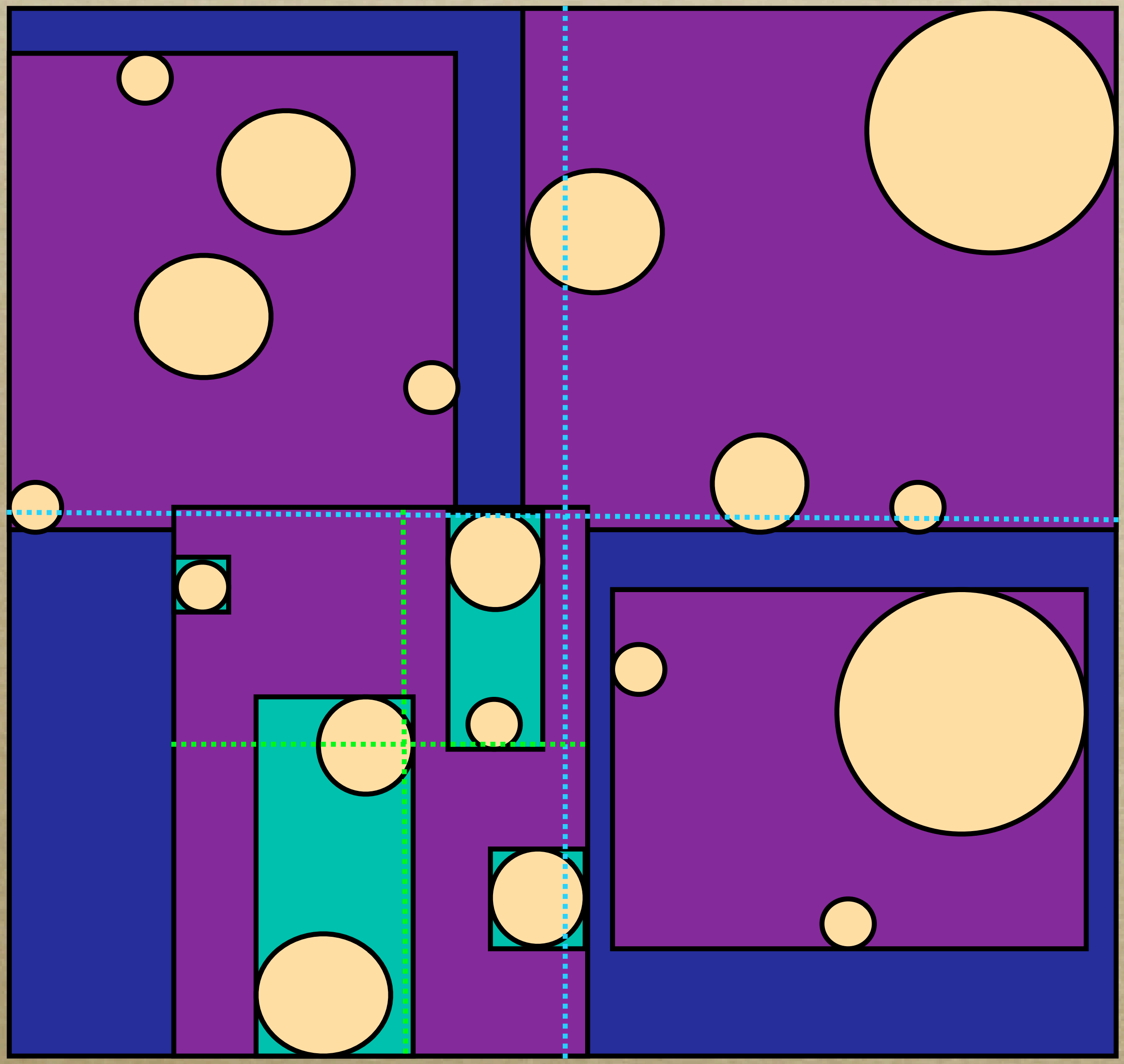
Data Structure Definition

- *Axis-Aligned Bounding Box (AABB)*
  - *Defined by two corner points*
  - *Sides are parallel to coordinate axes*
- *0 or more child nodes*
- *0 or more objects*

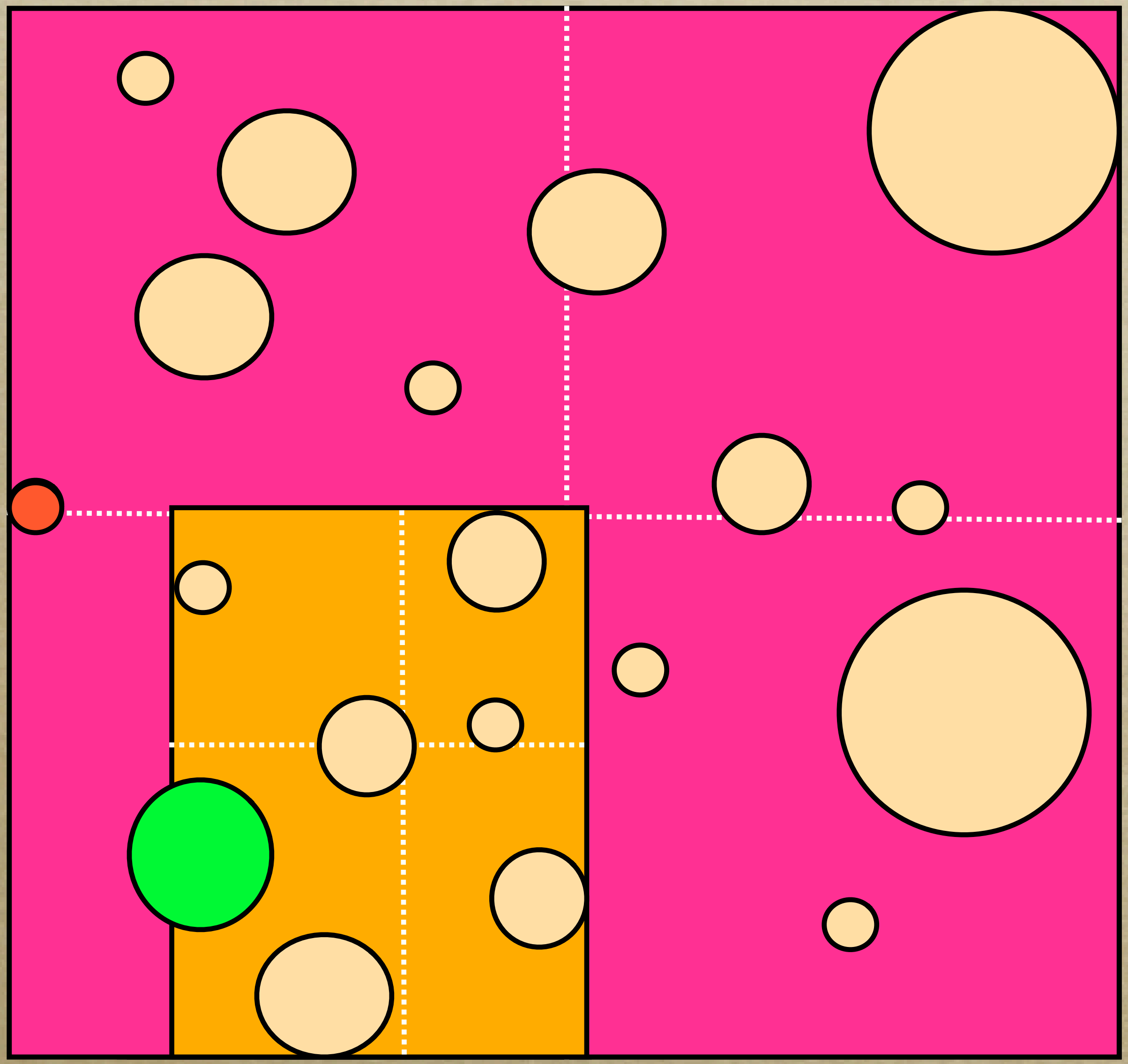
Constraints

- *Node's AABB must encompass*
  - *objects*
  - *child nodes*
- *No other constraints*

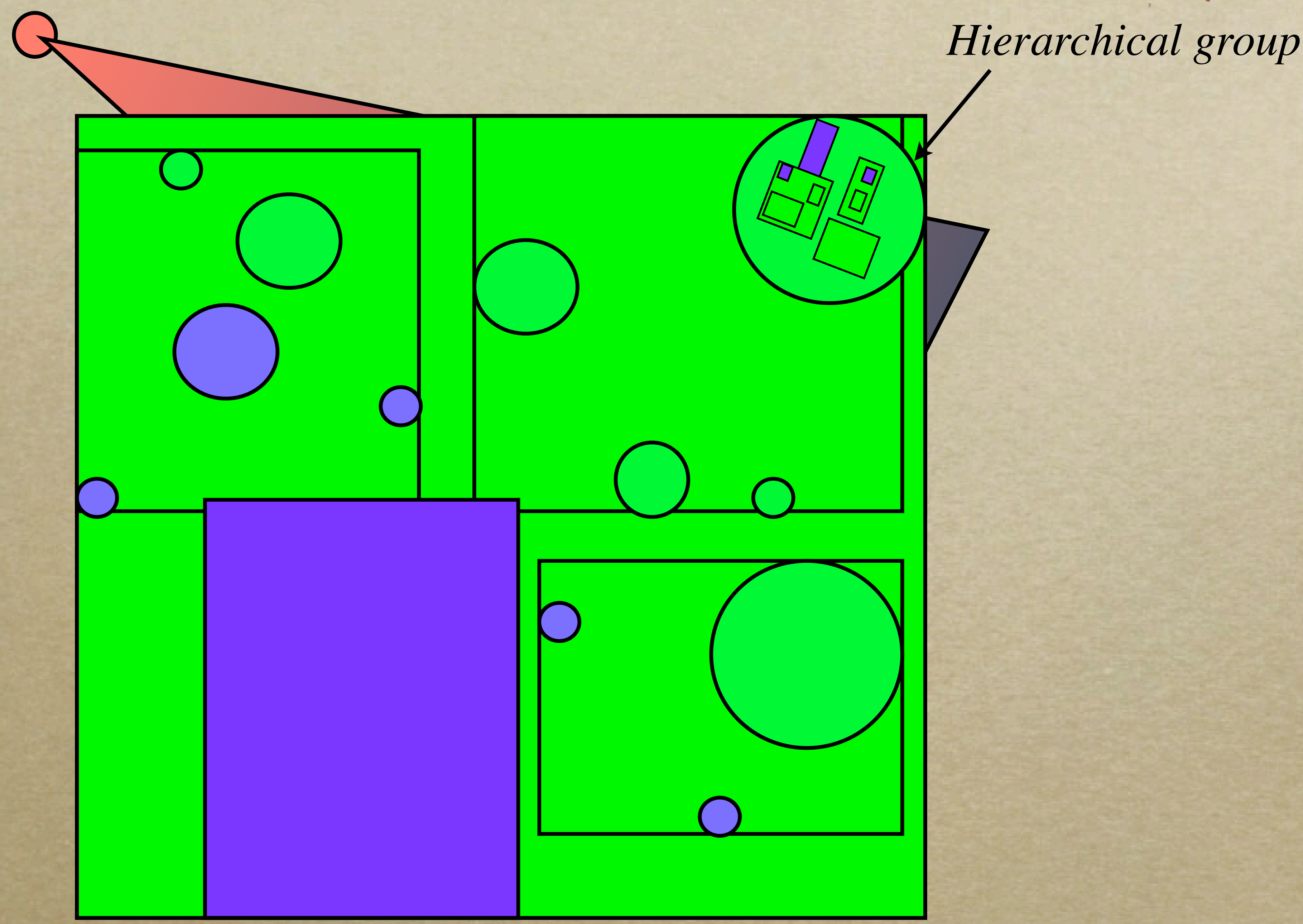
Splitting Nodes



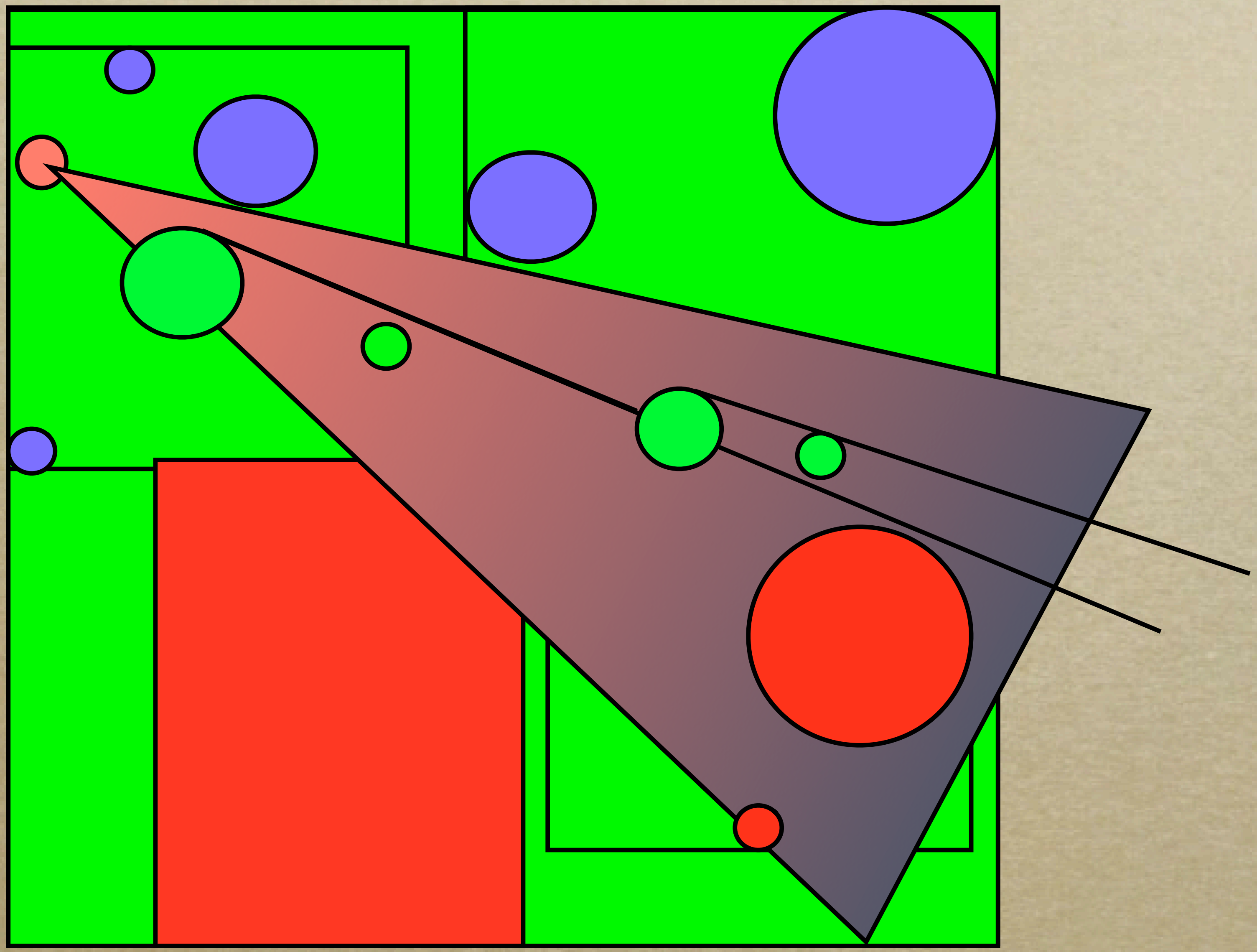
Object Management



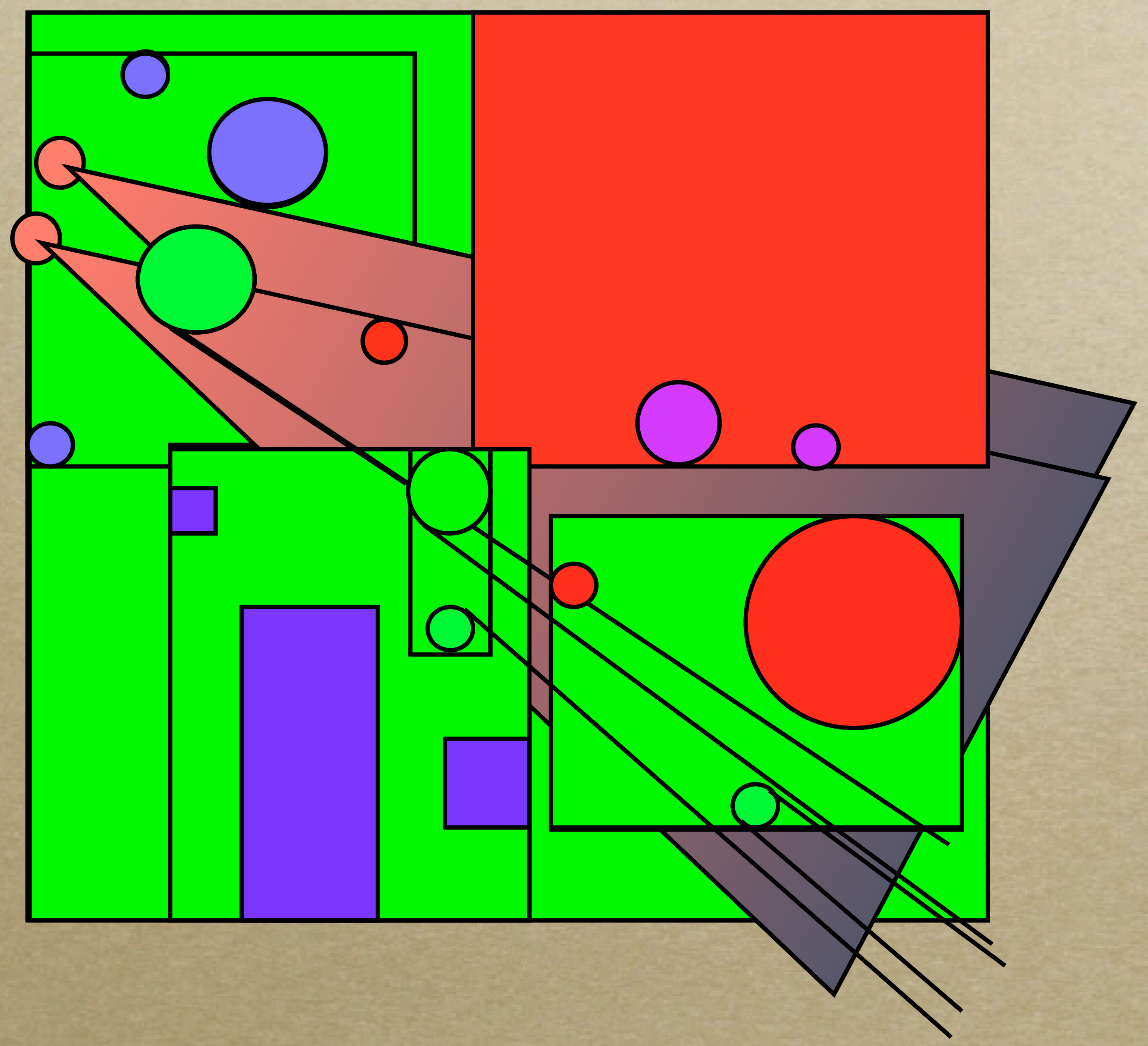
Visibility



Occlusion
(Spatial coherence)

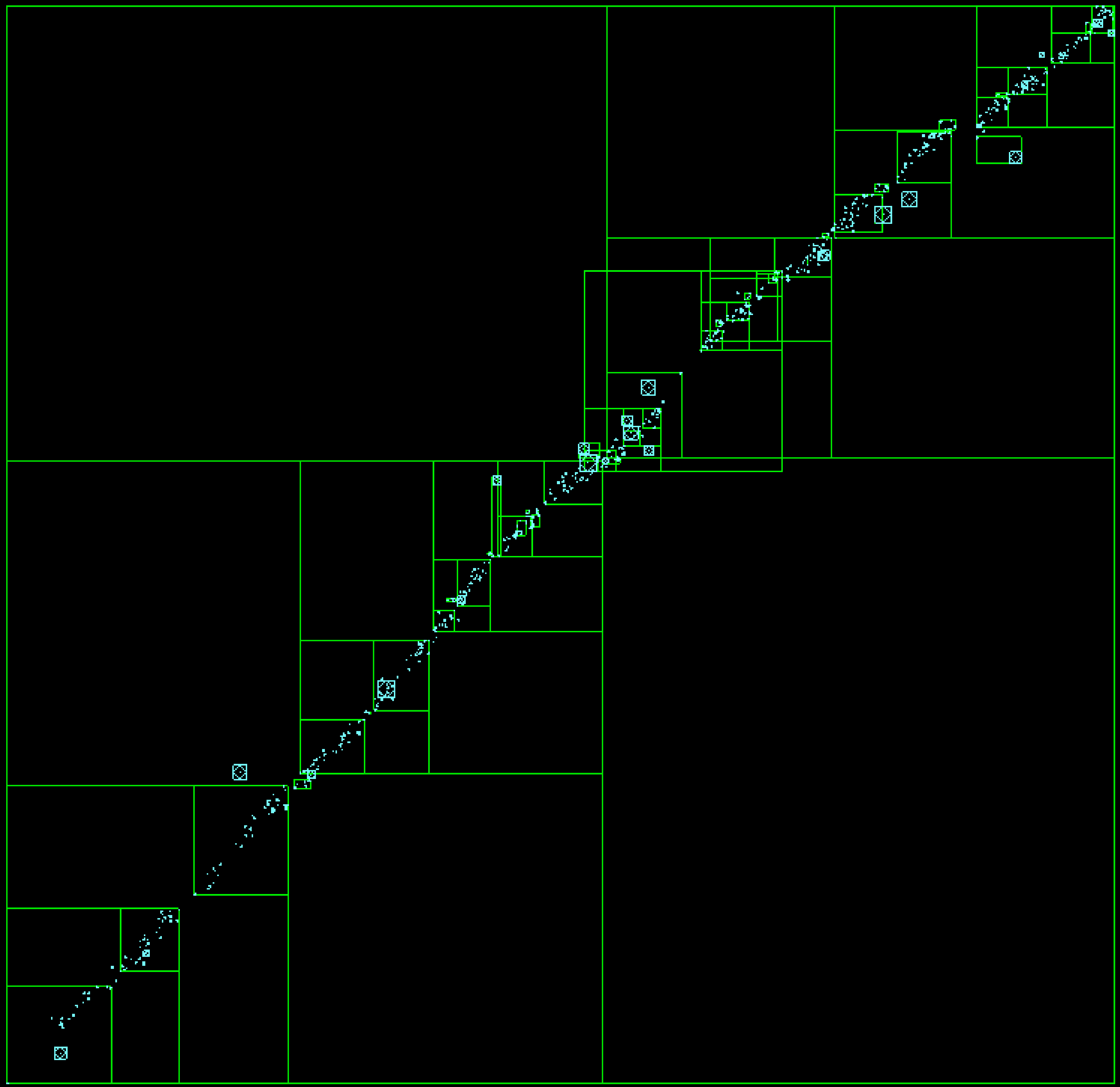


Occlusion
(Temporal + spatial coherence)



Fragmentation Avoidance

- *Moving/adding objects may cause tree imbalance*
- *When AABBs are recomputed, recompute split points w/ approximation*
- *New split point applies "pressure" to heuristic; stochastic rebalancing*



Video clip

Realtime render, 1.1GHz Athlon, Radeon 9700
using temporal coherence occluders only

Comparisons

Scene: tunnel2

	Objects Considered	Objects Rendered	Frames per Second
Brute-Force	1736	302	21
AABB Visibility	554	302	30
AABB Occlusion	554	302(95)	26

Comparisons

Scene: stress

	Objects Considered	Objects Rendered	Frames per Second
Brute-Force	1346	489	17
AABB Visibility	772	489	23
AABB Occlusion	568	101(100)	35

Comparisons

Scene: stress5

	Objects Considered	Objects Rendered	Frames per Second
Brute-Force	1761	528	23
AABB Visibility	928	528	24
AABB Occlusion	862	182(182)	33

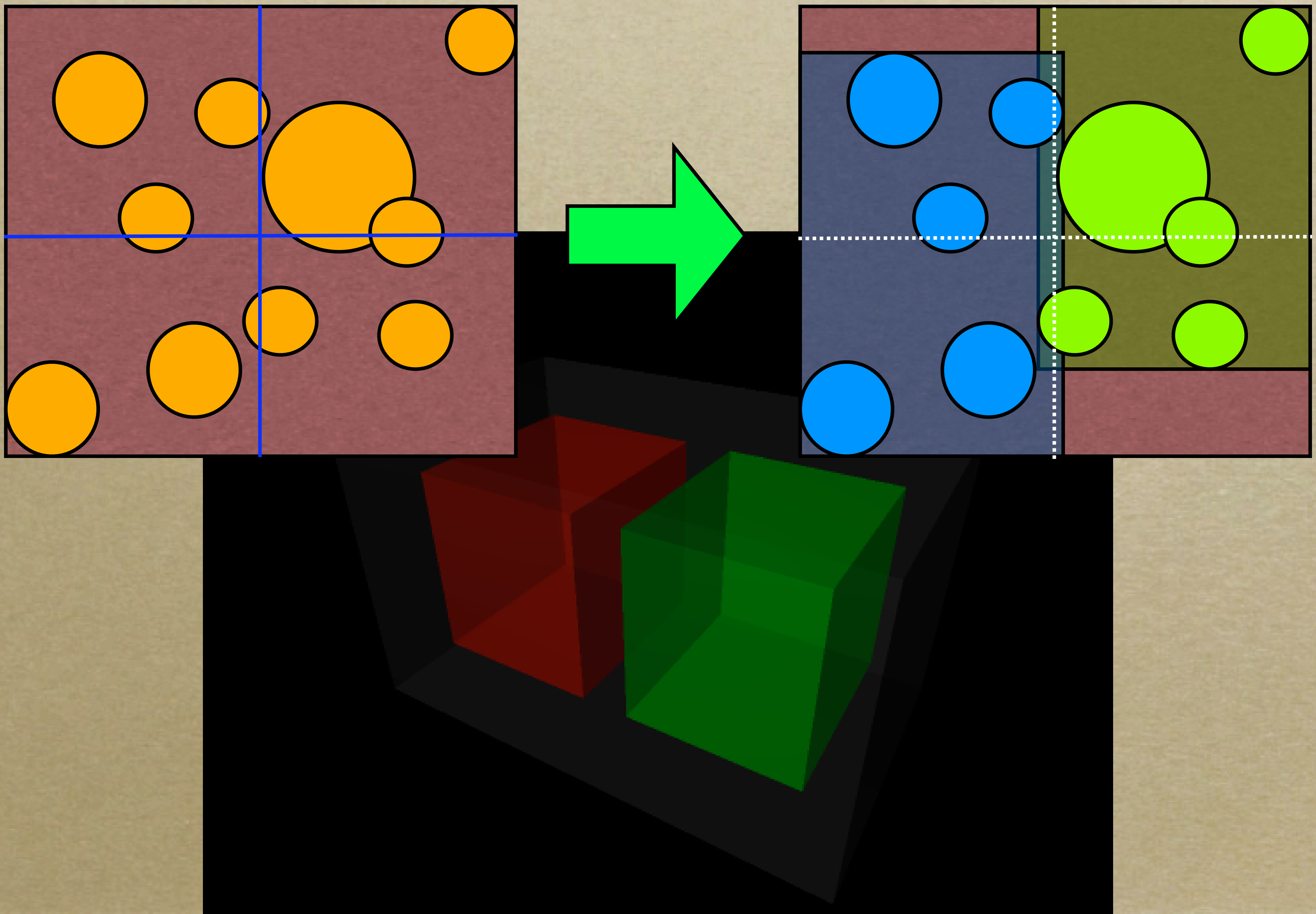
Nesting Heuristics

- *Determine how objects are distributed*
- *Goals:*
    - *Maximize tree balance*
    - *Minimize tree depth*
    - *Minimize number of visibility tests*

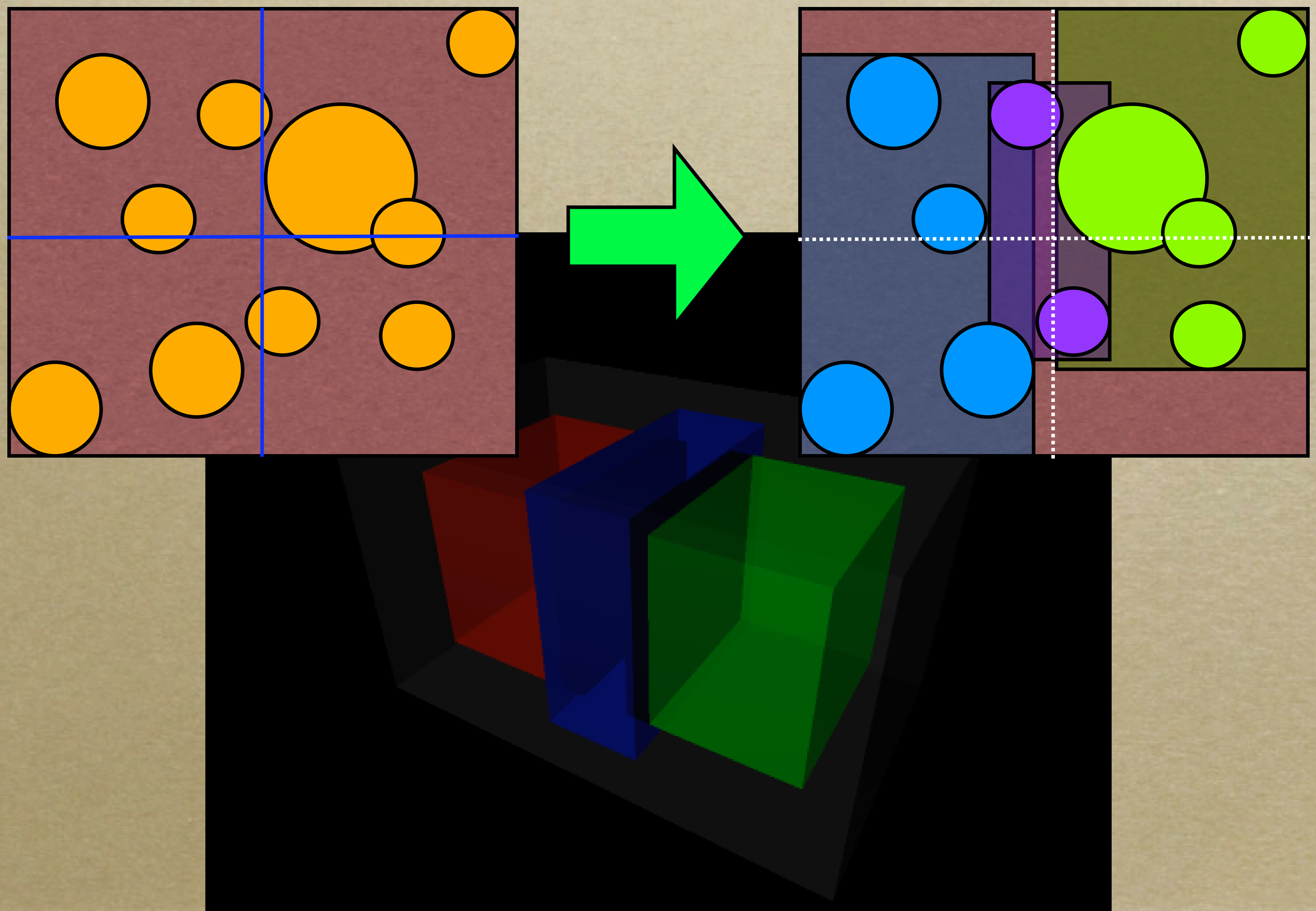
Nesting Heuristics

- *Two variants of each*
  - *Leafy - all objects stored in leaf nodes*
  - *Non-leafy - larger objects stored in internal modes*
- *Each named after a tree concept (not a strict implementation of the tree type)*

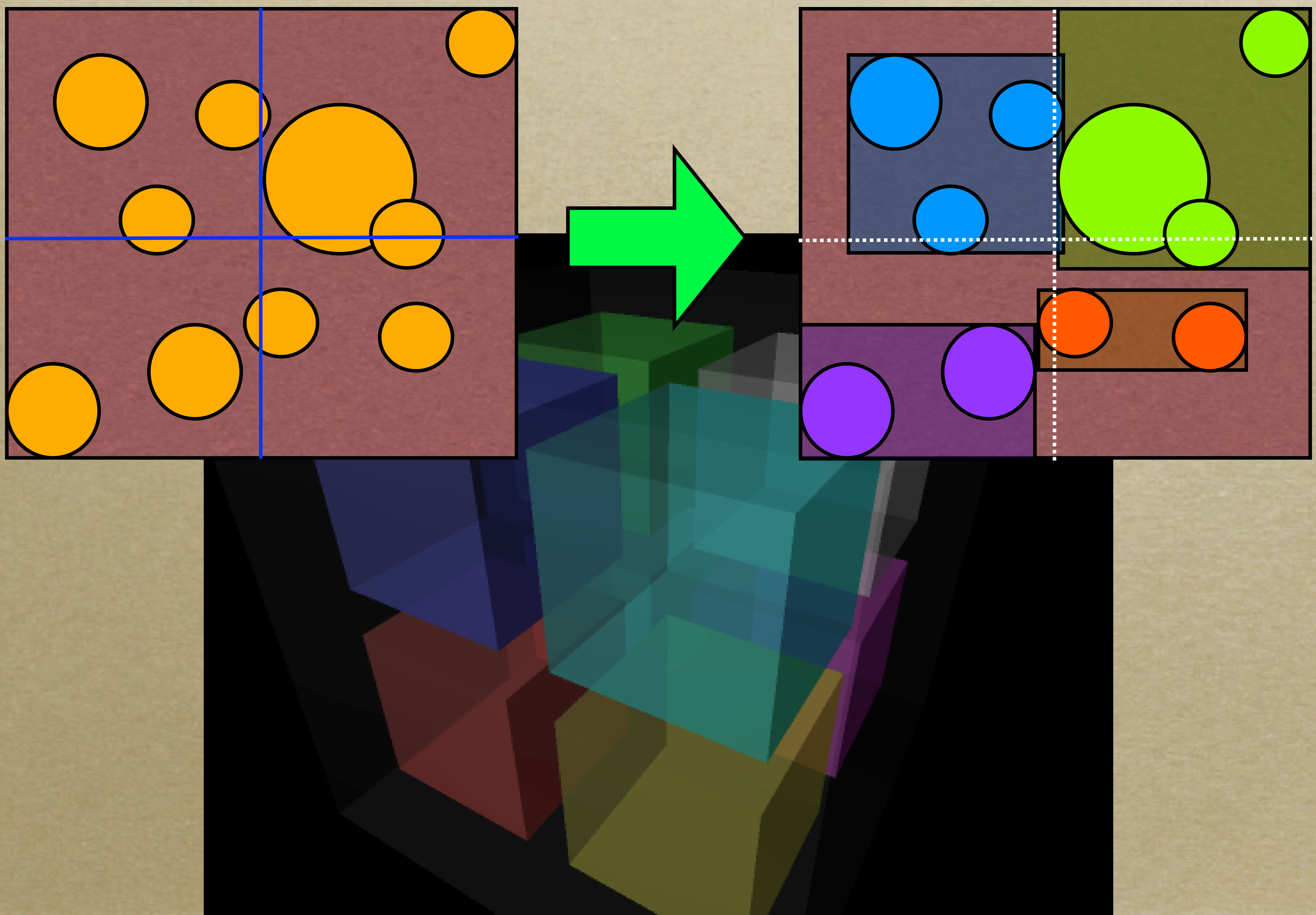
K-D



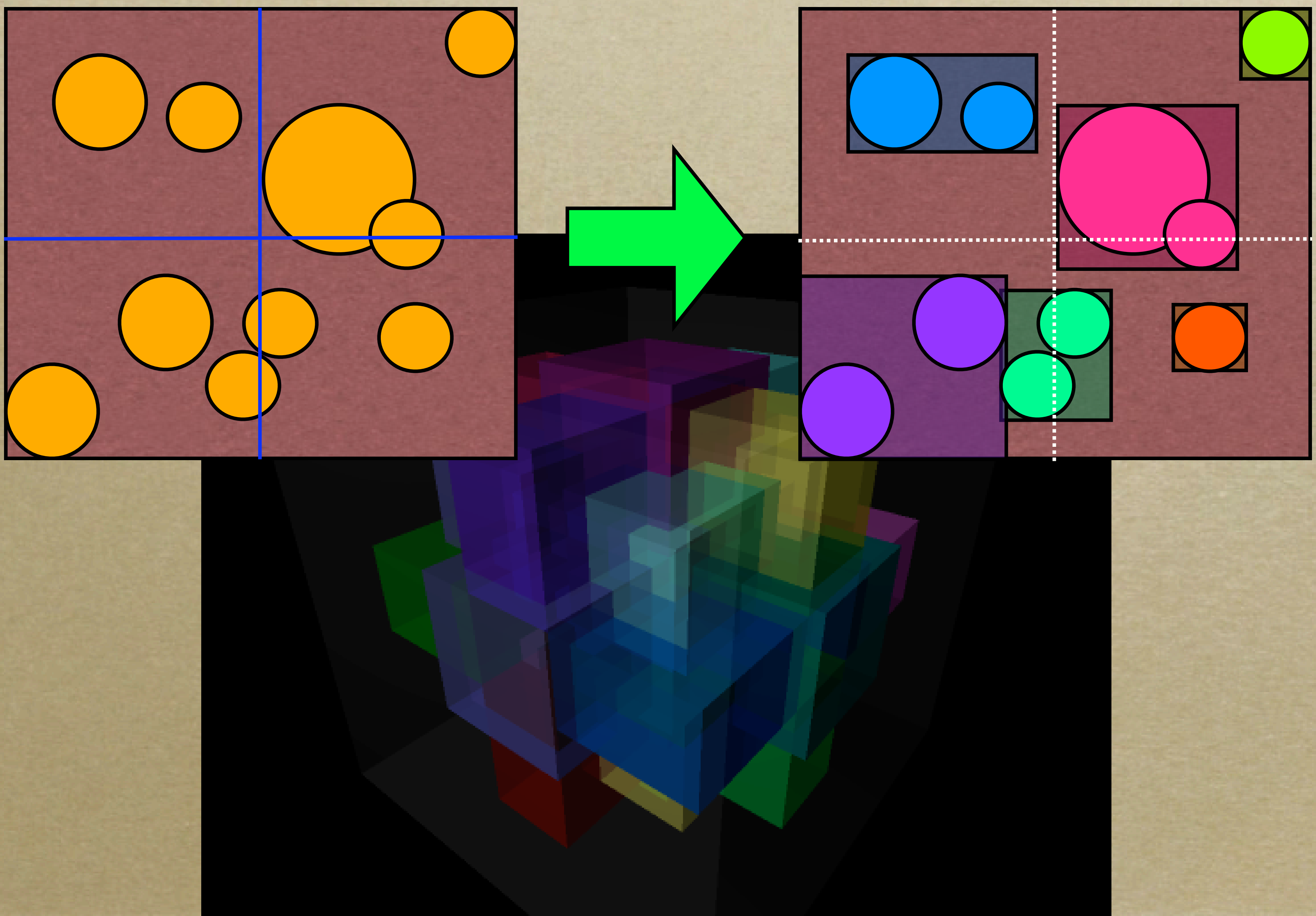
Ternary



Octree



Icoseptree



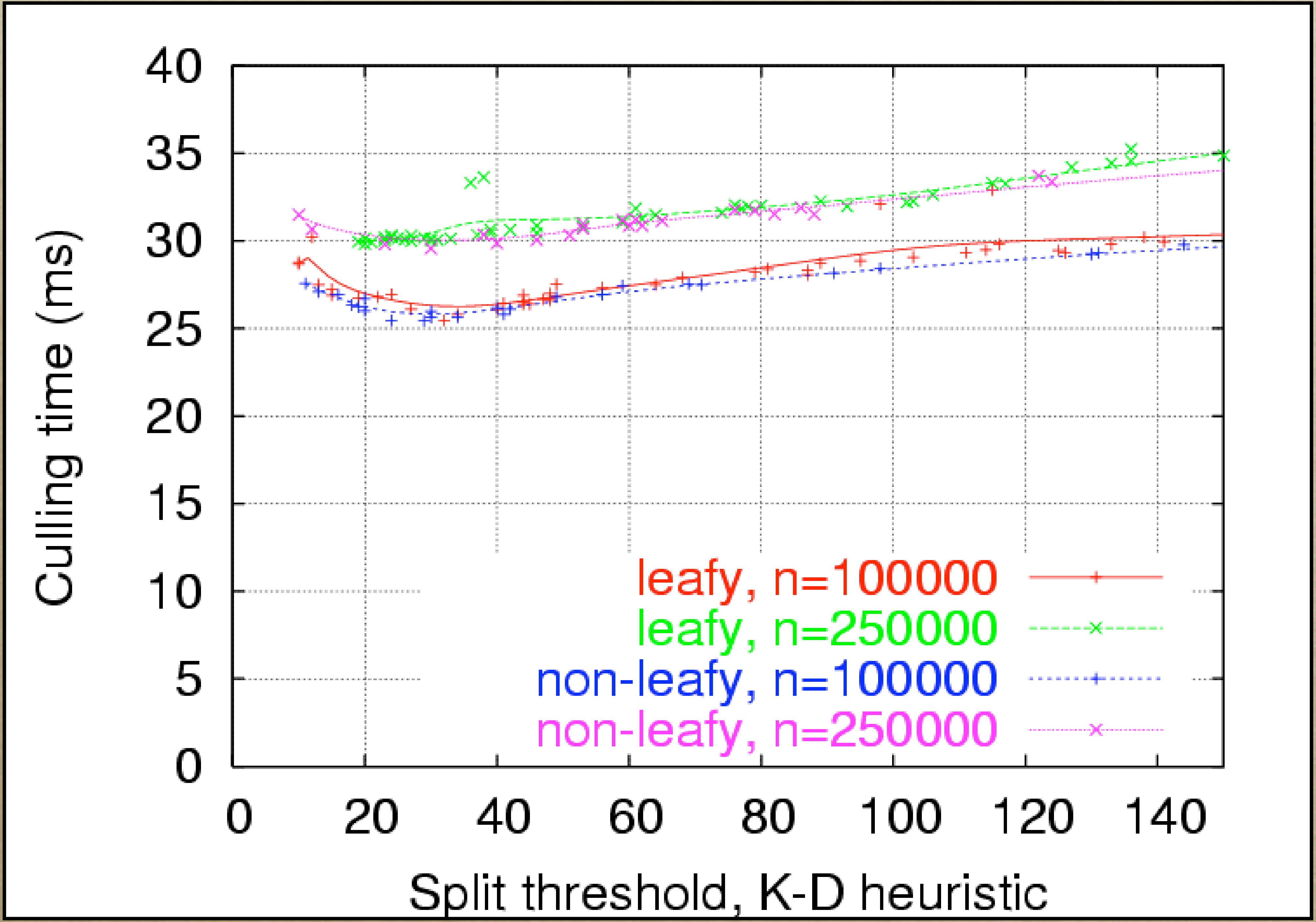
Timings

- *Generate large number of random objects*
- *Distribute throughout region*
  - *Variety of distributions*
  - *Consistent overall density*
- *Record avg. time for region query, object movement*

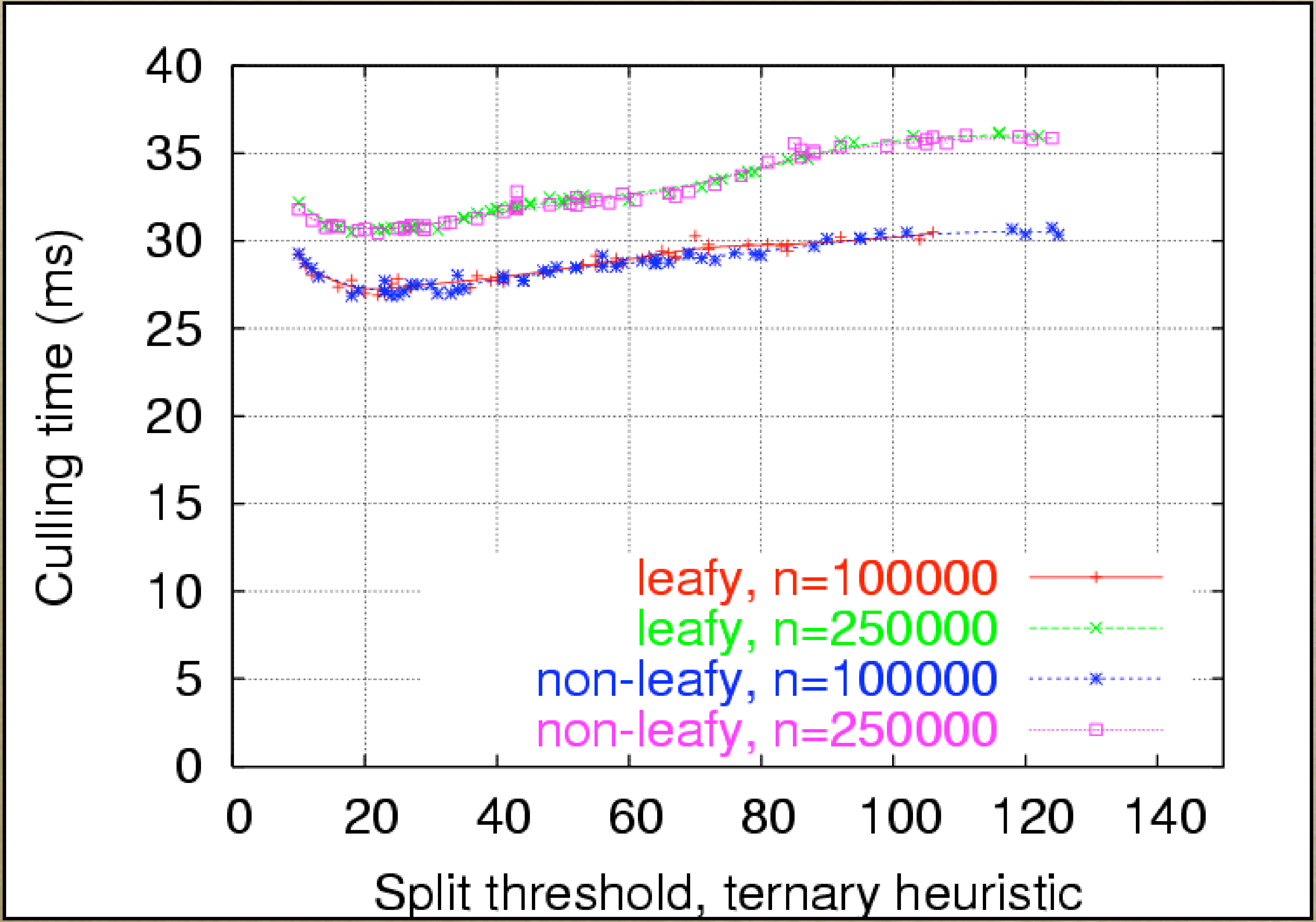
Optimum Split Threshold

- *Split threshold affects objects/node*
    - *Node test slower than object test*
    - *Need to balance node test vs. wasted object tests*
- *Find fastest average query per threshold with a dense uniform packing*

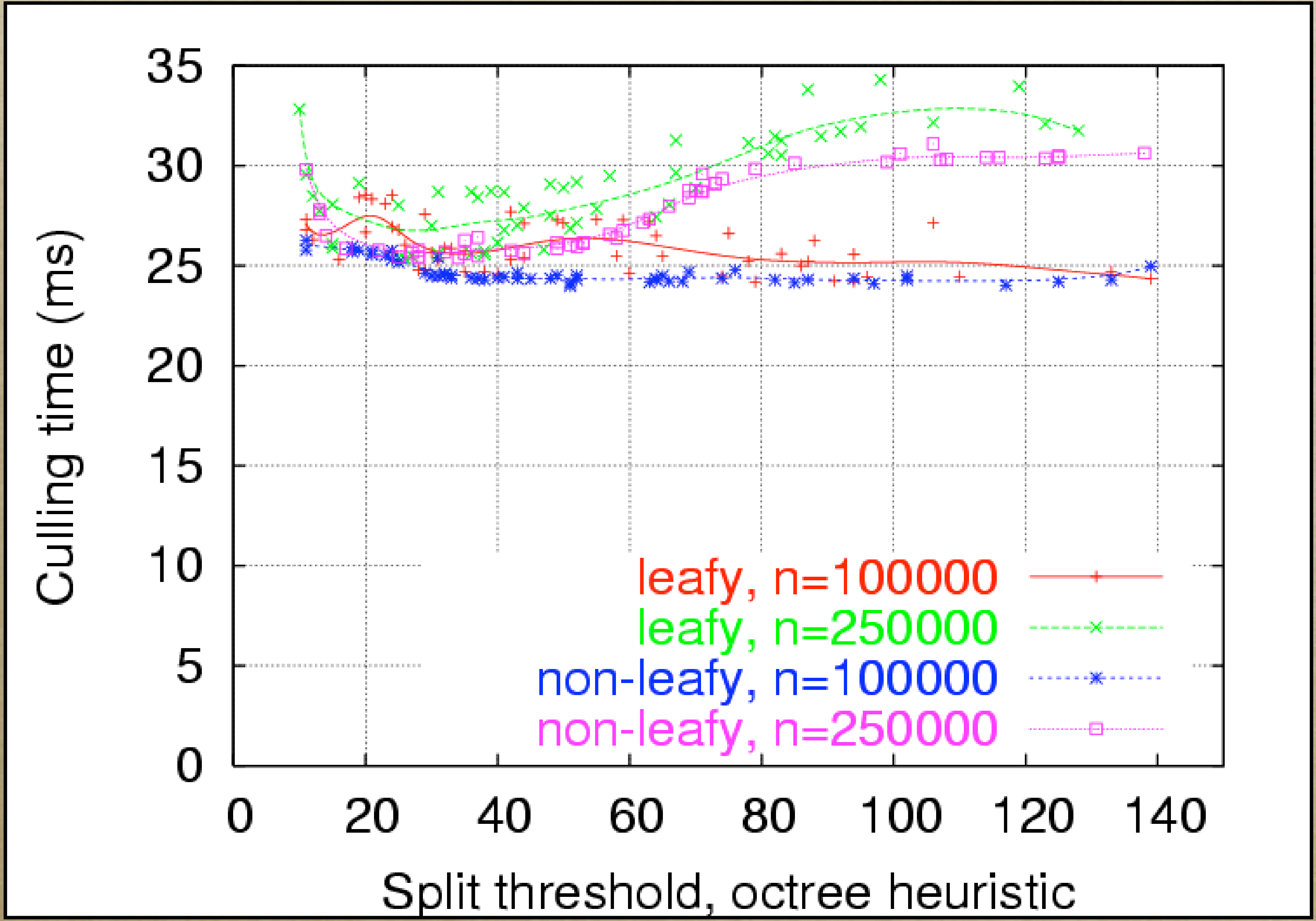
Optimum Split: K-D



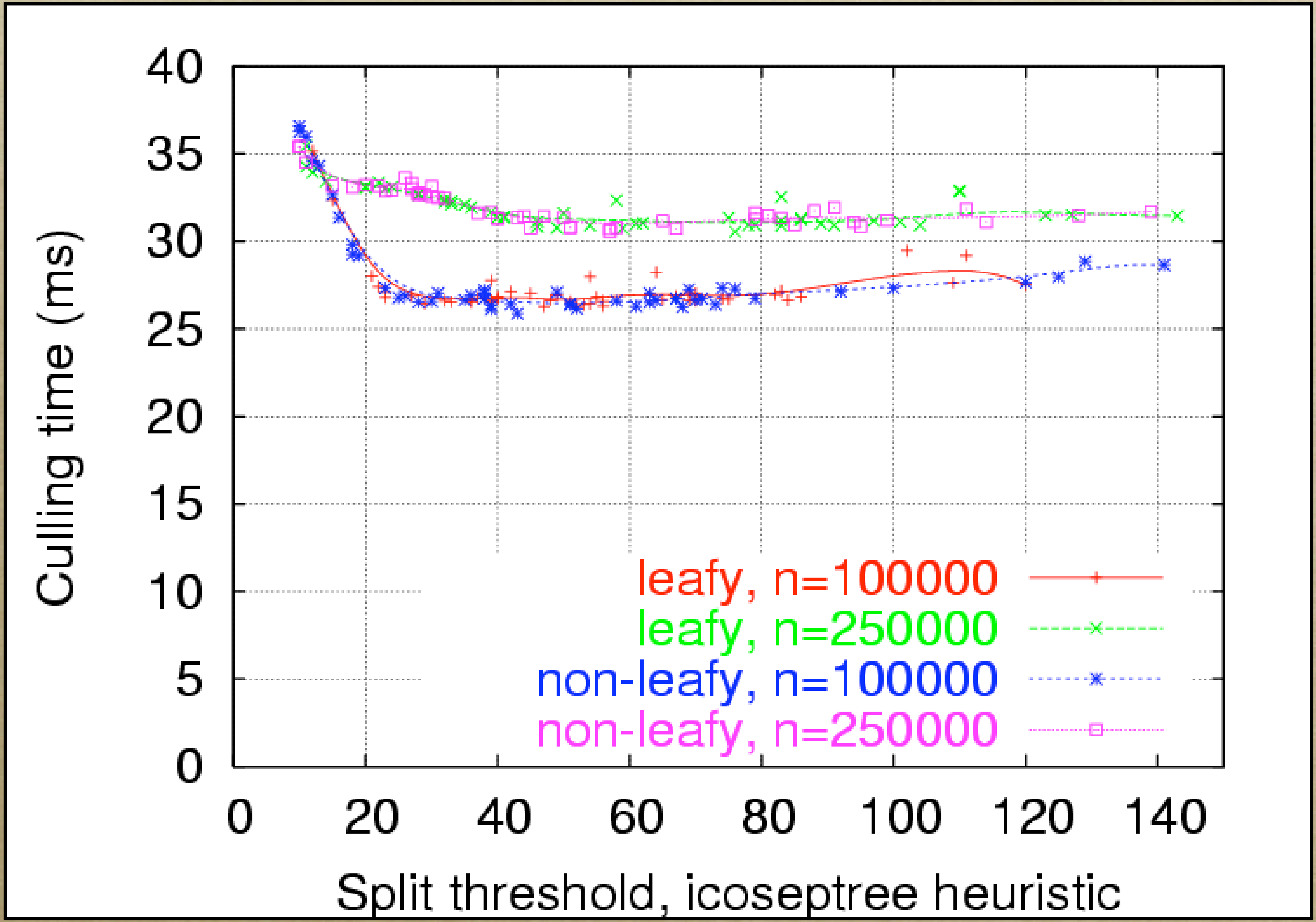
Optimum Split: Ternary



Optimum Split: Octree



Optimum Split: Icoseptree



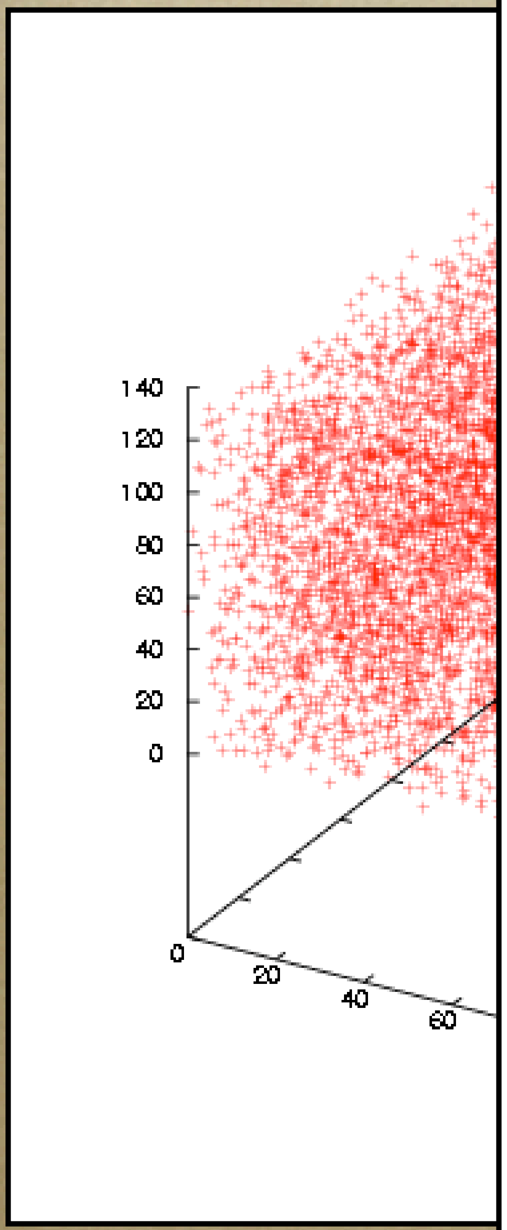
Immediate Observations

- *Split threshold can make noticeable difference (nearly double for icoseptree)*
- *Wide ranges for performance plateau*
- *Non-leafy variant always performs at least as good as leafy*
  - *No point in considering leafy further*

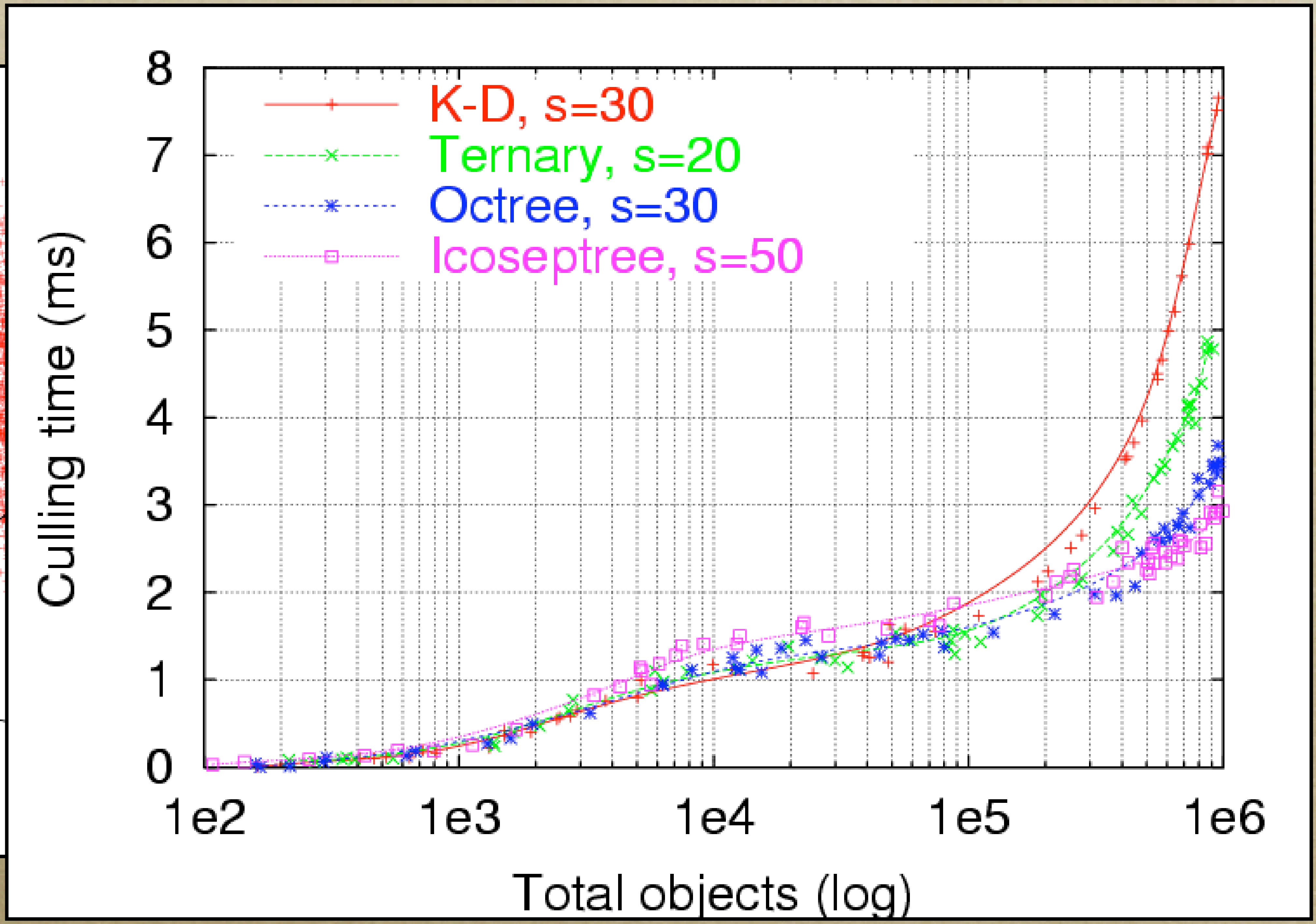
Best Overall Performance

- *Compare performance of heuristics*
  - *Vary number of objects up to 1 million*
  - *Four different random distributions (uniform, sphere, cluster, Lissajous)*

Uniform

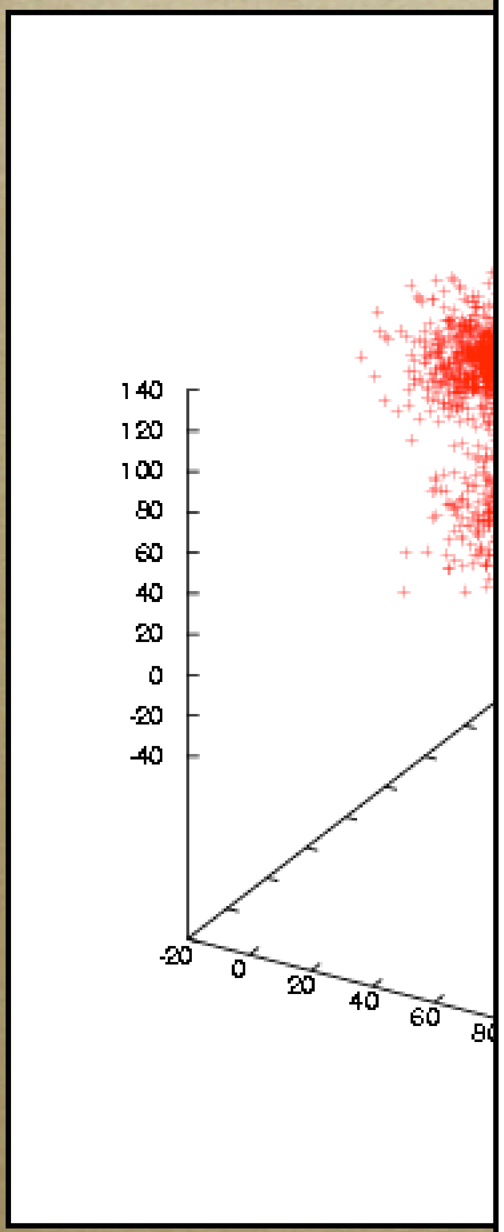


140
120
100
80
60
40
20
0
0
20
40
60



K-D, s=30
Ternary, s=20
Octree, s=30
Icoseptree, s=50
Culling time (ms)
0
1
2
3
4
5
6
7
8
1e2
1e3
1e4
1e5
1e6
Total objects (log)

Clustered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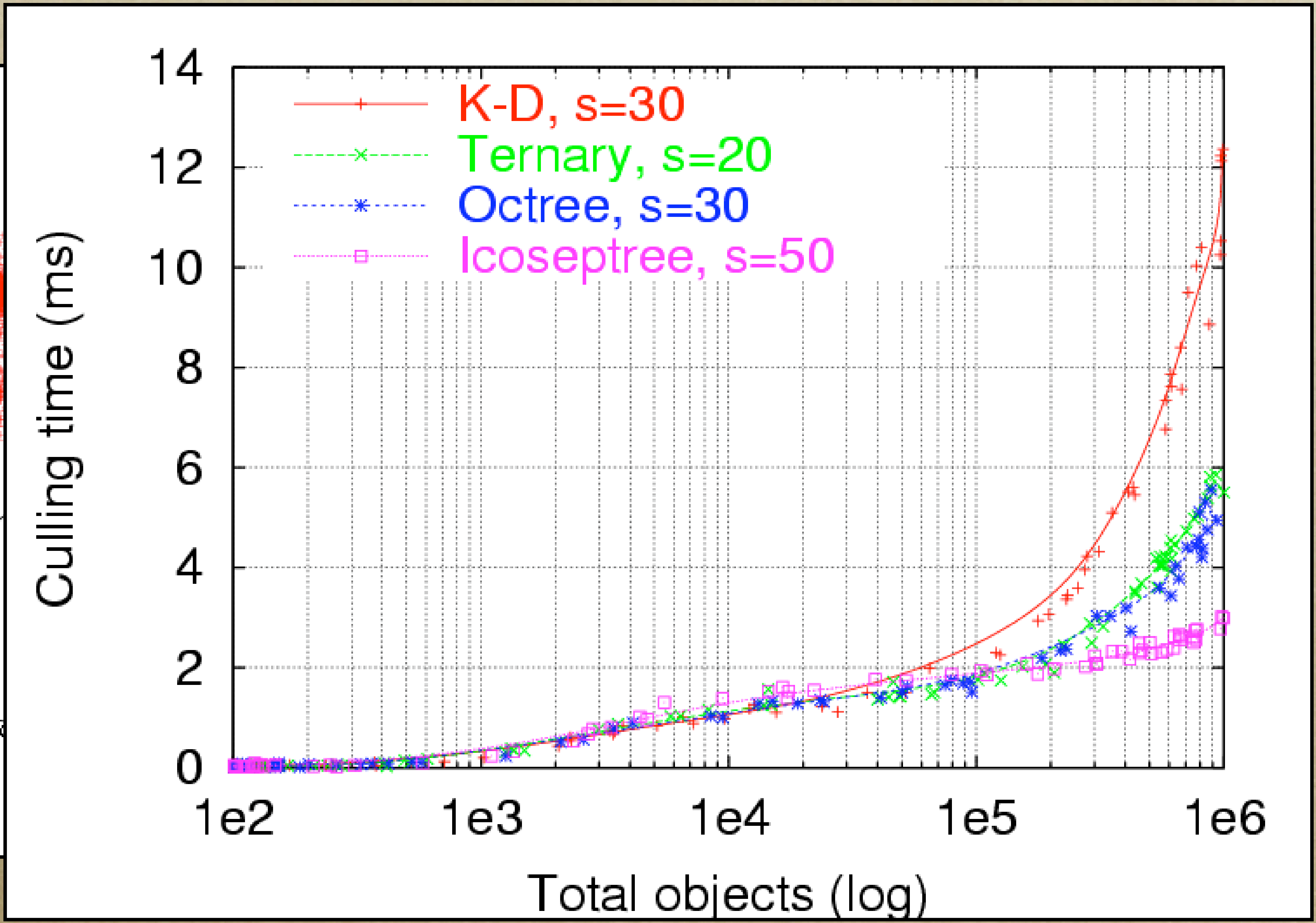
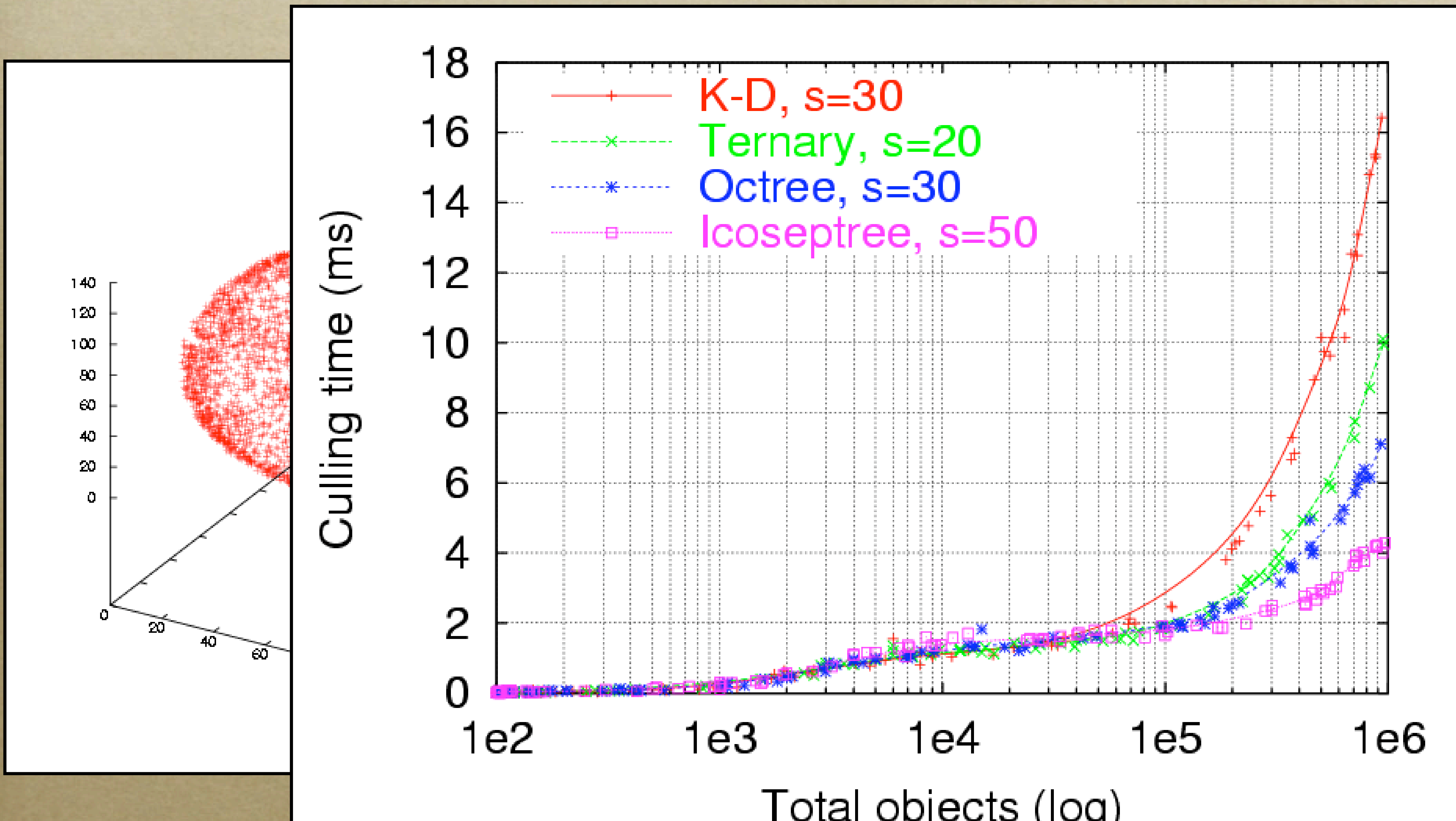
-20
0
20
40
60


K-D, s=30
Ternary, s=20
Octree, s=30
Icoseptree, s=50
Culling time (ms)
14
12
10
8
6
4
2
0
1e2
1e3
1e4
1e5
1e6
Total objects (log)

Sphere



140
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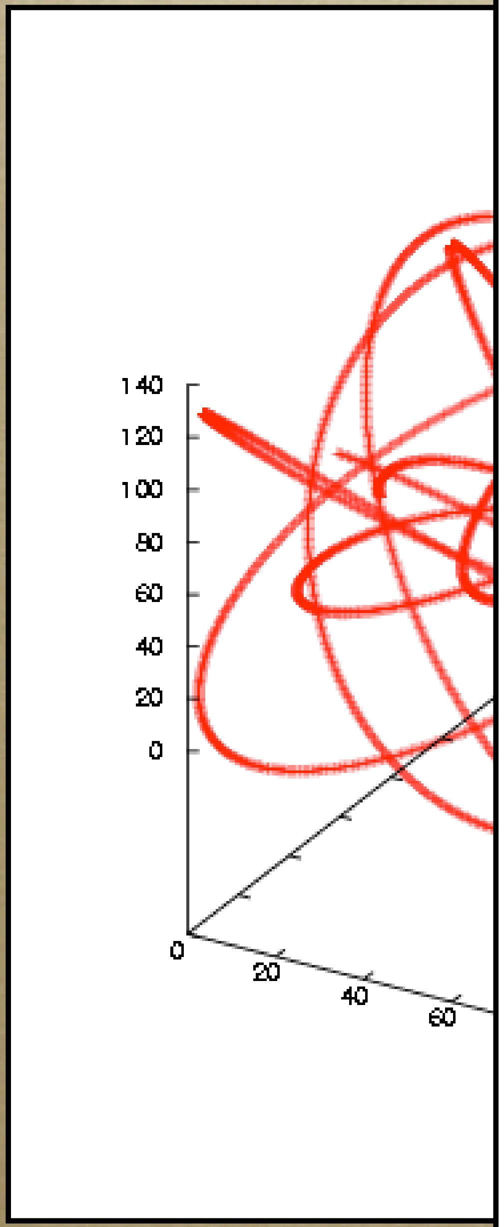
40
20
0
0
20
40
60
K-D, s=30
Ternary, s=20
Octree, s=30
Icoseptree, s=50
Culling time (ms)
0
2
4
6
8
10
12
14
16
18
1e2
1e3
1e4
1e5
1e6
Total objects (log)

Lissajous



140
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0
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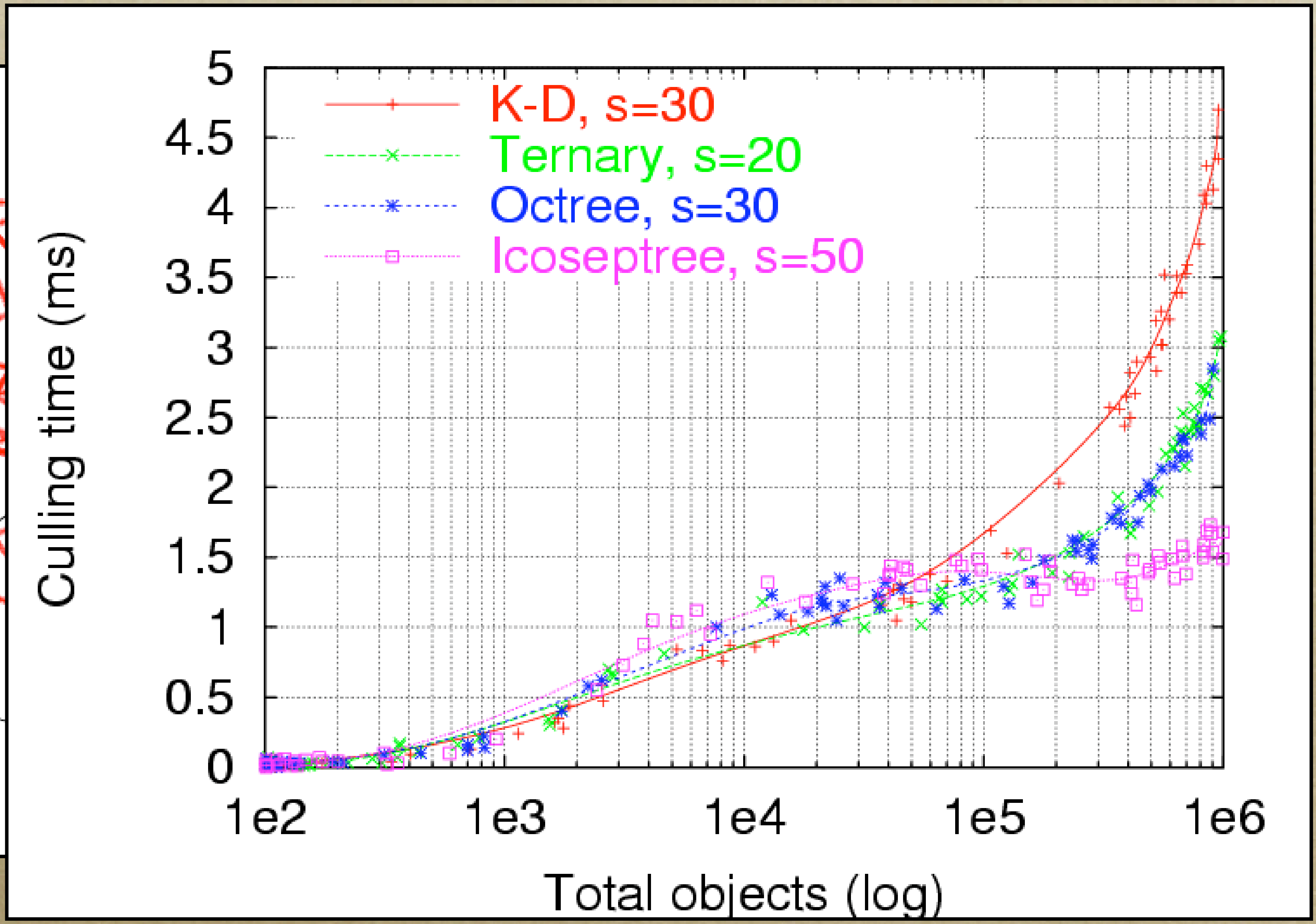
40
60



K-D, s=30
Ternary, s=20
Octree, s=30
Icoseptree, s=50
Culling time (ms)
Total objects (log)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1e2
1e3
1e4
1e5
1e6

Conclusions

- *D-AABB trees provide fast queries and updates on fully-dynamic environments*
- *Works w/ simple occlusion culling; accurate visibility w/o precomputation*
- *Icoseptree heuristic scales best of those tested*

Further Work

- *Determine efficient occlusion algorithm for spatial-coherence culling*
- *Better heuristics than icoseptree might be possible*

Acknowledgments

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Questions