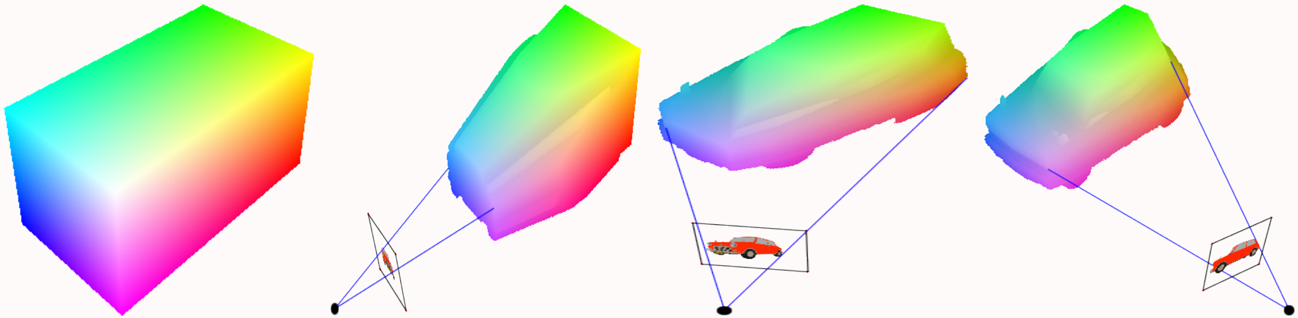
Spatial Data Structures for Computer Graphics



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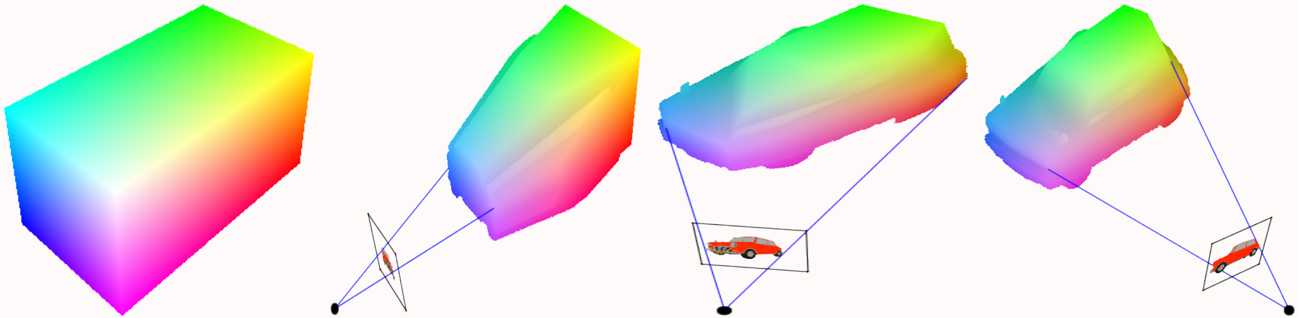
November 2008

Spatial Data Structures for Computer Graphics



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Acknowledgements:
Joint work with Biswarup Choudhury and Rhushabh Goradia

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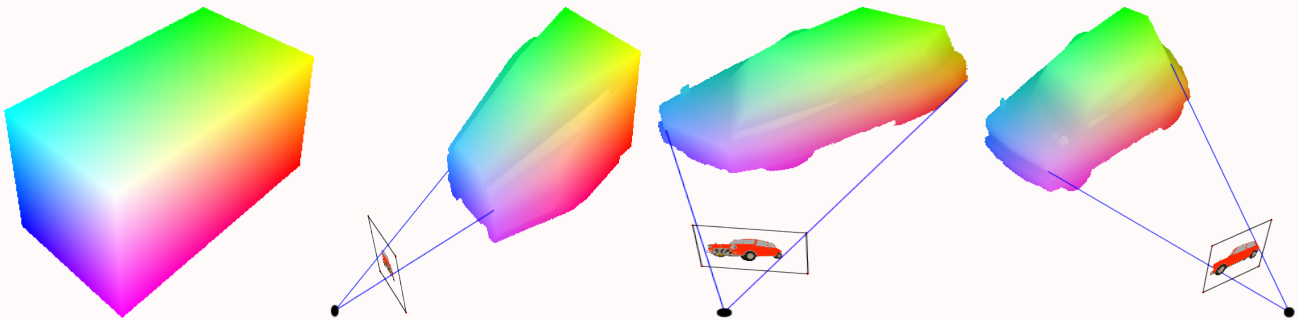

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Acknowledgements:
Joint work with Biswarup Choudhury and Rhushabh Goradia
Most examples are from ViGIL IIT Bombay.

Talk Overview

Exhibit B: Which picture do you like?

➟ Background about this talk

Talk Overview

Exhibit B: Which picture do you like?

- Background about this talk
- Application in Vision
  - Exhibit A: kd-trees

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- Application in Imaging
  - Exhibit B: Octrees

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- Application in Graphics
  - Exhibit C: Space Filling Curves, Compressed Octrees

Background

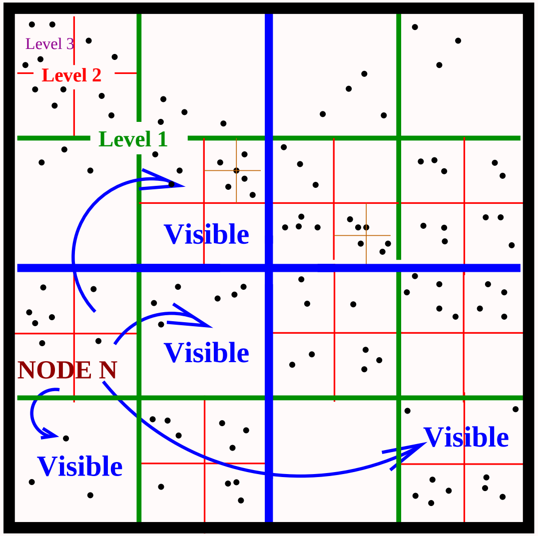

Exhibit C: Visibility Map

- Why this talk: Role of traditional CS and CSE in graphics

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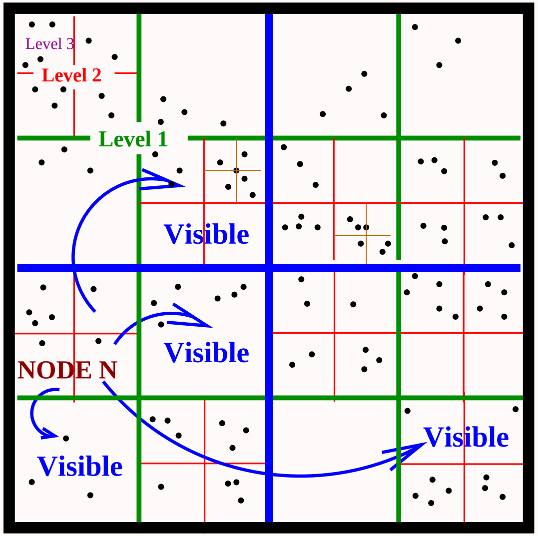

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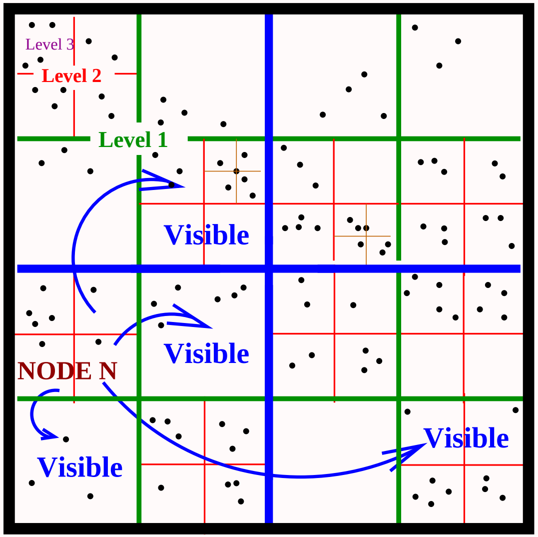

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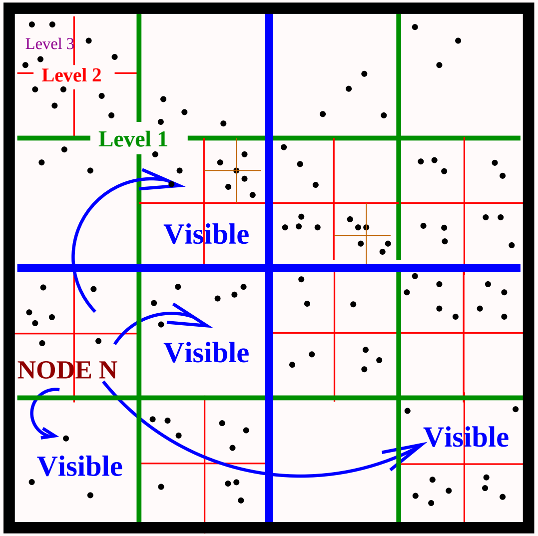

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- Please feel free to interrupt and ask questions at any stage

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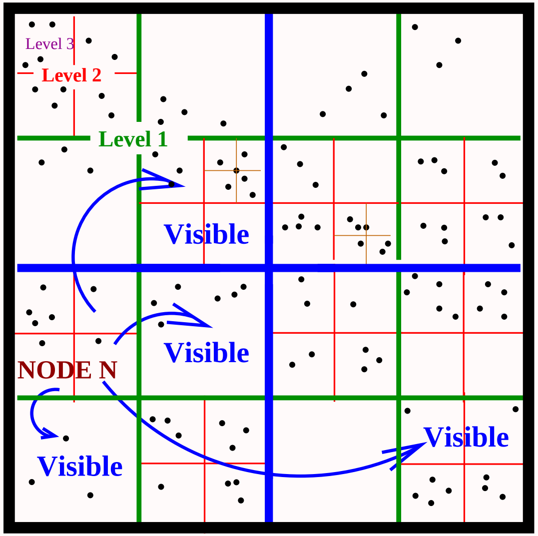

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- Use of images, and points as primitives in computer graphics
- Please feel free to interrupt and ask questions at any stage
- Vision, Graphics, and Imaging: Forward and Inverse Problems

Talk Overview

✔ Background about this talk

➠ Application in Vision

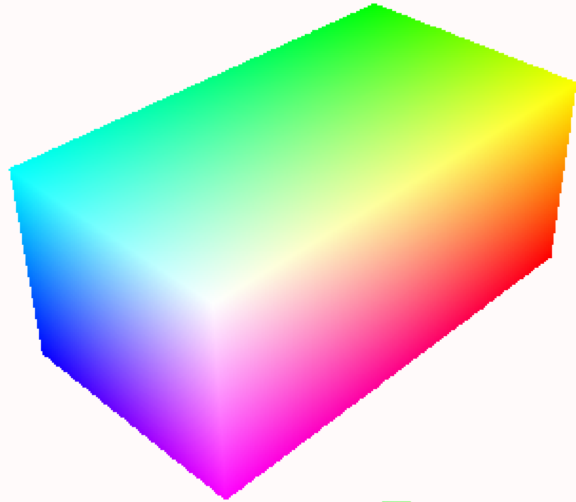
- Exhibit A: kd-trees

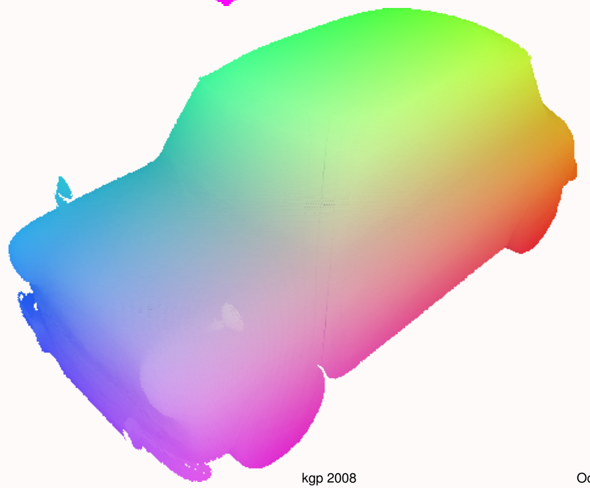
➠ Application in Imaging

- Exhibit B: Octrees

➠ Application in Graphics

- Exhibit C: Space Filling Curves, Compressed Octrees





Problem Definition: Object Pose

Object Pose: Given images of a static object, how to create the illusion of realistic motion of the object along any arbitrary path — composed realistically in arbitrary environments?

Object Pose Solution
Computer Vision In Action
kd-trees
Color Quantization
Point Models
Visibility Map
Space Filling Curves

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Problem Definition: Object Pose

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[Play Video]

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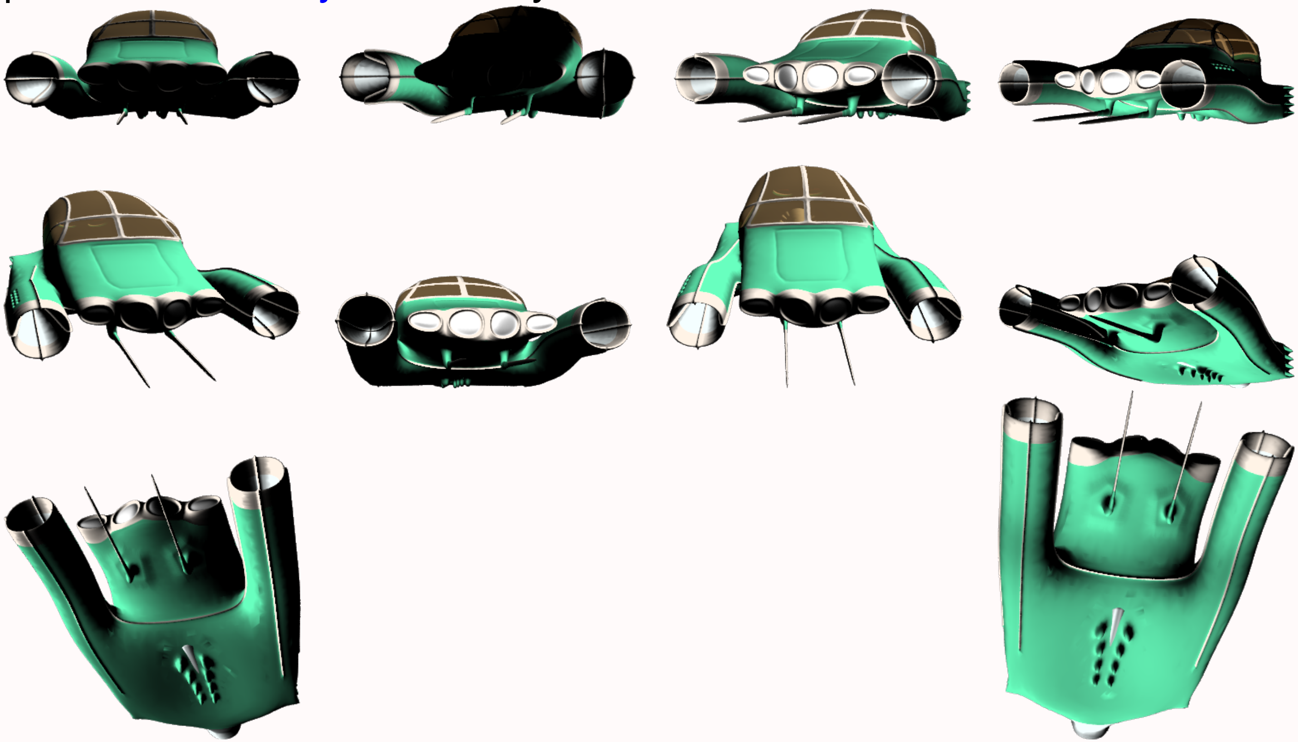

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1. Object Pose Solution

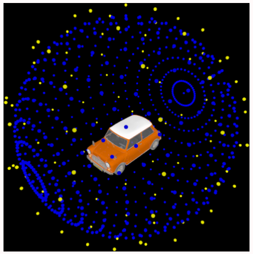
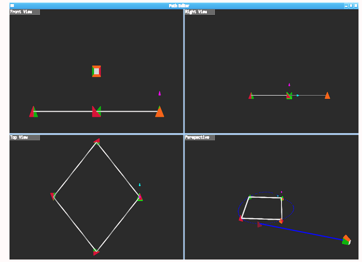
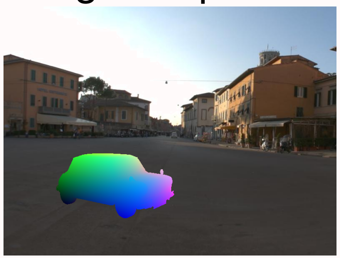


Image Acquisition (Studio)



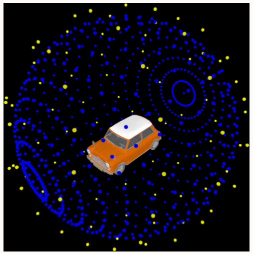
Path specification (Run-Time)



Computing Shape

Computing Color

1. Object Pose Solution



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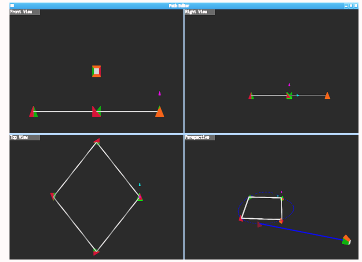

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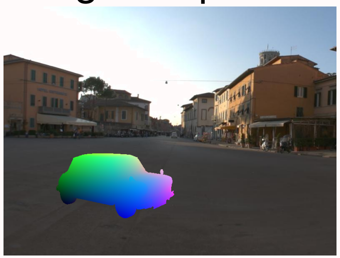

Computing Shape

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Clearly, we need to compute the shape and color from previously acquired close by images .... nearest neighbour computation in two dimensions

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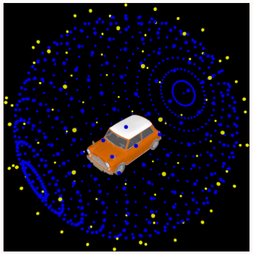
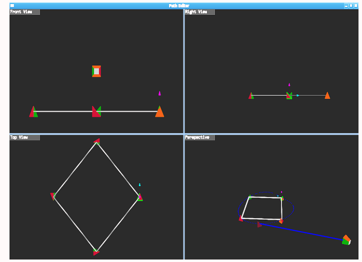


Image Acquisition (Studio)



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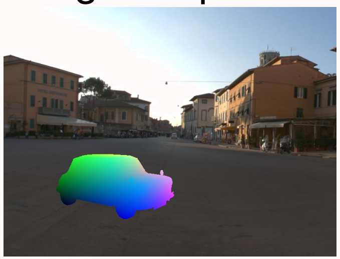
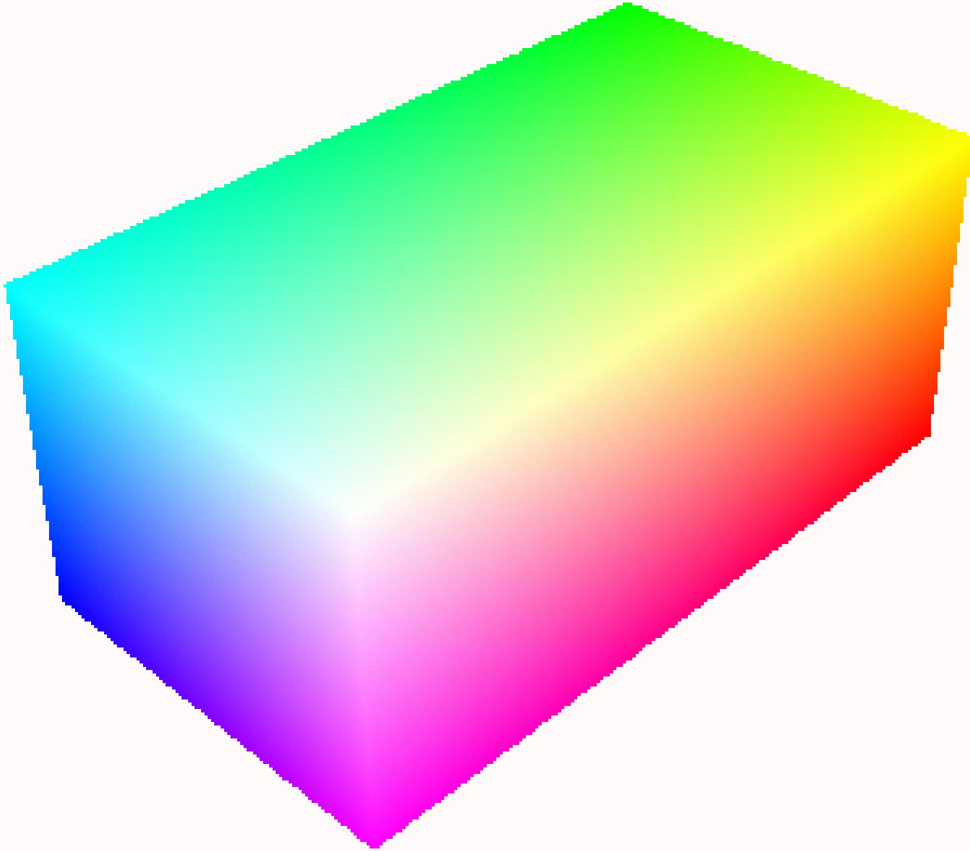


Computing Shape

Computing Color

Clearly, we need to compute the shape and color from previously acquired close by images .... nearest neighbour computation in two dimensions [Play Video]

View Interpolation via Visual Hull



Start

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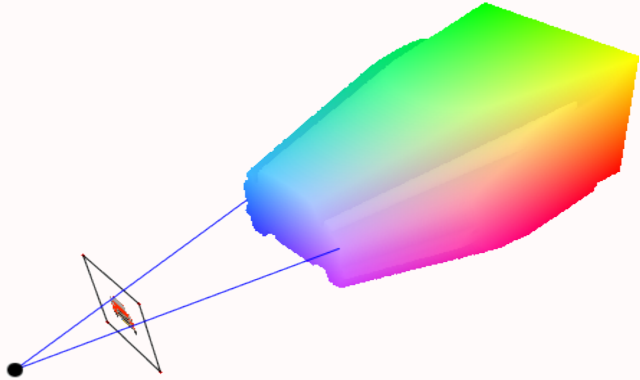
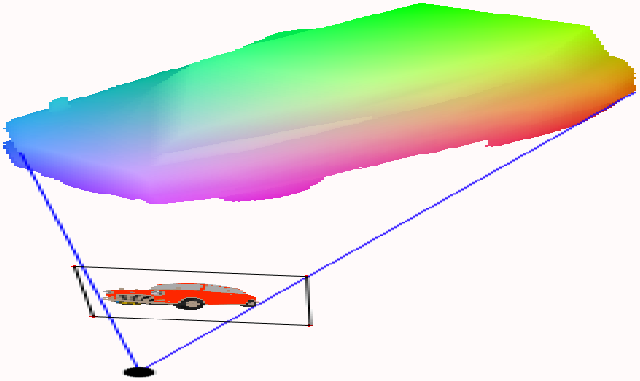
The Visual Hull



Carve



Carve again

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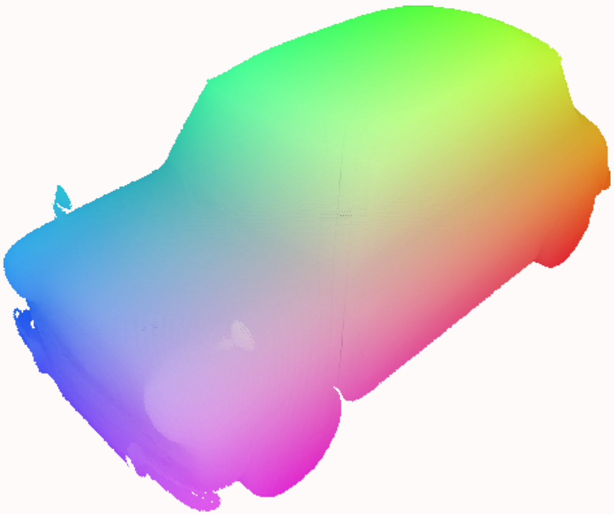
2. Computer Vision In Action



Hull

Compared to the real thing

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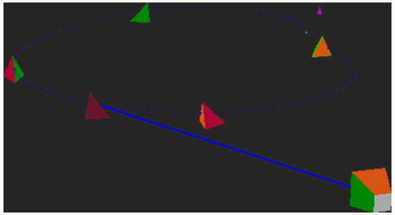
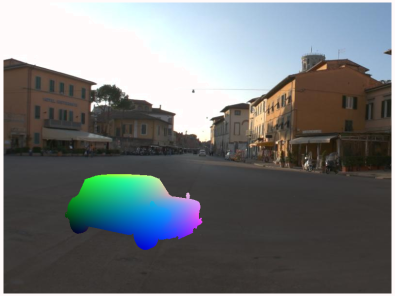
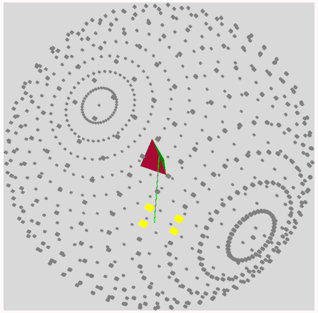
More details on the method







Question: Can we use the studio pictures ALSO for color computation?

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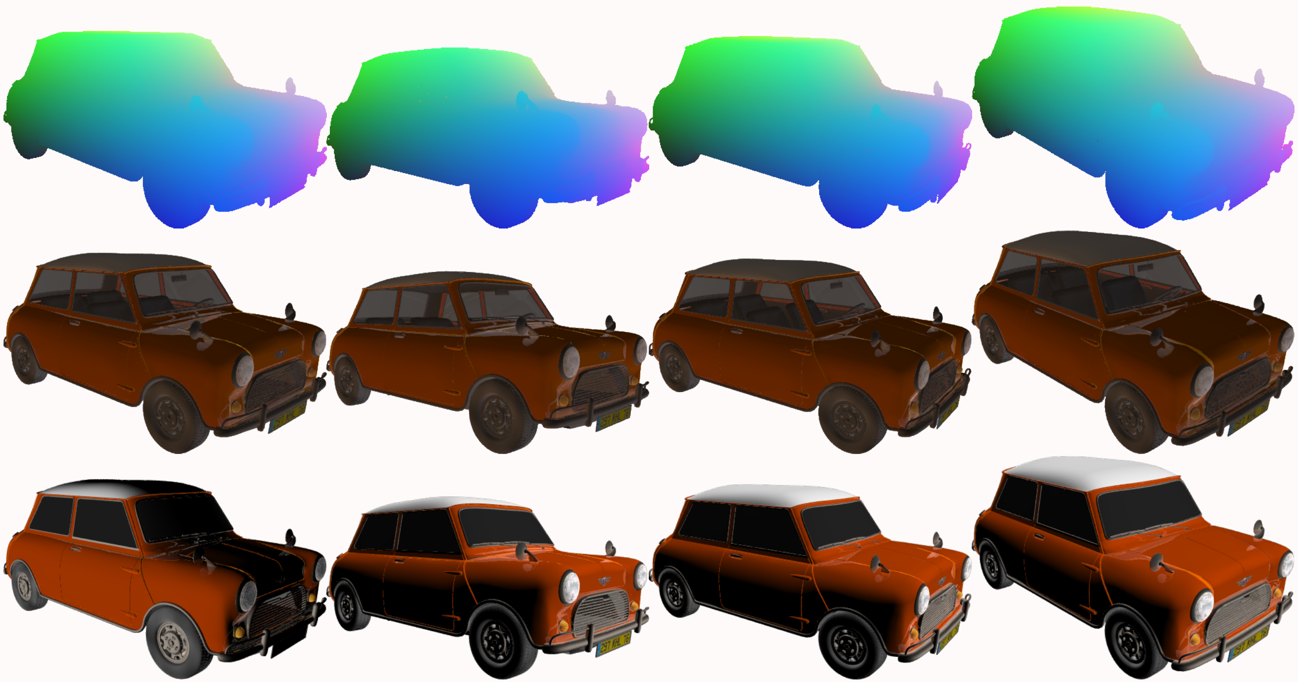
Color Computation



Requires solution to: Given images of an object captured under a set of lighting conditions, how to efficiently render the scene under new illumination configurations?

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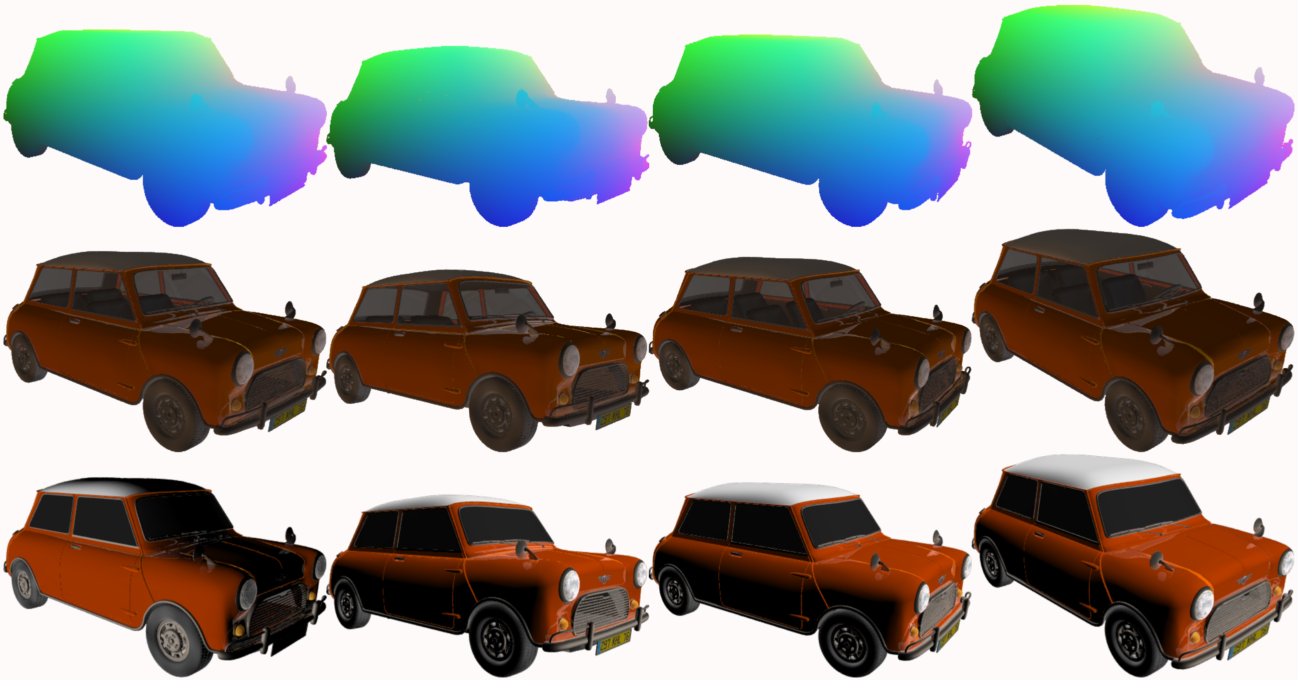
Color Computation



Requires solution to: Nearest Neighbors, and Bi-chromatic Nearest Neighbors

Output Frame

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3. kd-trees

- Dimension of data is k (but common to say k-d tree of dimension 3 instead of 3d-tree).
- kd-trees are binary trees
- Designed to handle spatial data in a simple way
- For n points, $O(n)$ space, $O(\log n)$ height (if balanced), supports range and nearest-neighbor queries.
- Node consists of
  - Two child pointers,
  - Satellite information (such as name).
  - A key: Either a single float representing a coordinate value, or a pair of floats (representing a dimension of a rectangle)

Basic Idea Behind kd-trees

Construct a binary tree

- At each step, choose one of the coordinate as a basis of dividing the rest of the points
- For example, at the root, choose x as the basis
  - Like binary search trees, all items to the left of root will have the x-coordinate less than that of the root
  - All items to the right of the root will have the x-coordinate greater than (or equal to) that of the root
- Choose y as the basis for discrimination for the root's children
- And choose x again for the root's grandchildren

Note: Equality (corresponding to right child) is significant

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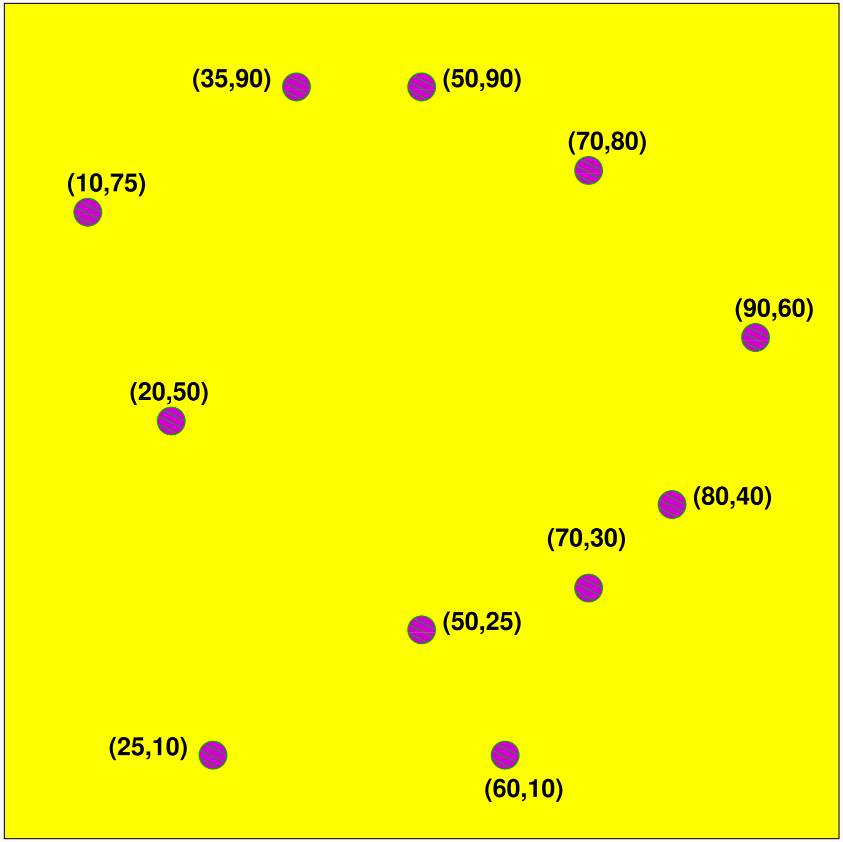
Example: Construct kd-tree Given Points

- Coordinates of points are $(35,90)$, $(70,80)$, $(10,75)$ $(80,40)$, $(50,90)$, $(70,30)$, $(90,60)$, $(50,25)$, $(25,10)$, $(20,50)$, and $(60,10)$
- Points may be given one a time, or all at once.
- Data best visualized as shown below



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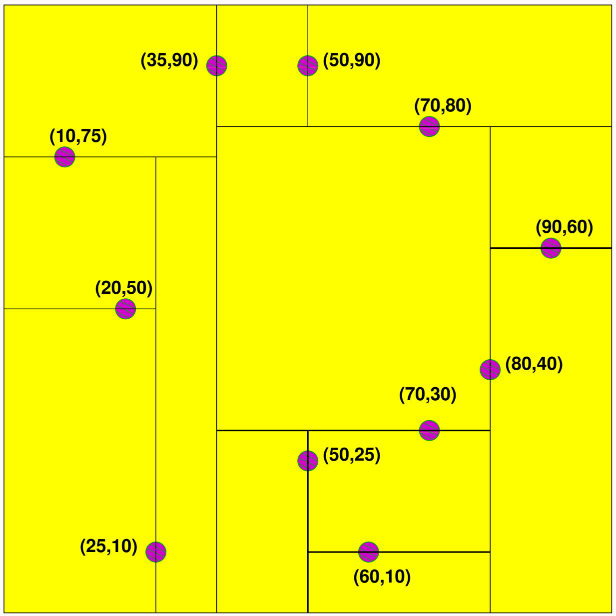
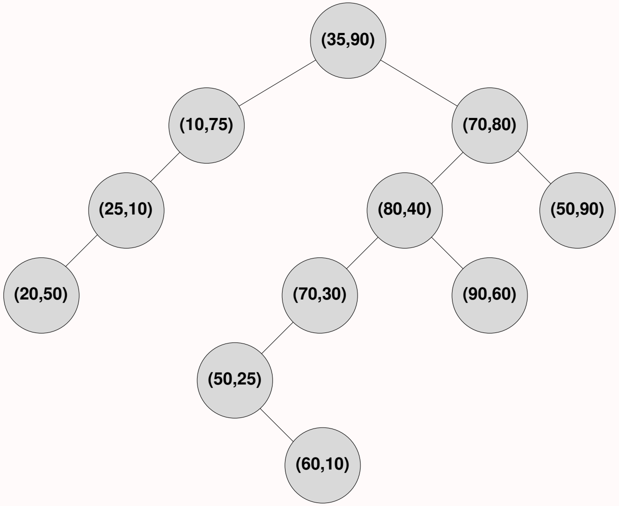
Example: kdtree Insertion





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Nearest Neighbors: The scenario

- “Find the nearest Pizza Hut.” (Compare with the McDonald problem).
- Assume kd-tree T given, and C is the region associated with a node.
- Input p is a point
- Searching for point p in T helps
  - In one dimension, T is very useful: the closest neighbor is from the set of nodes visited (MANY nodes are pruned)
  - In higher dimensions, T is not as useful (the closest neighbor may be far away).
- Nevertheless, pruning is possible.
- General strategy: Collect partial results, judicial traversal, and prune.

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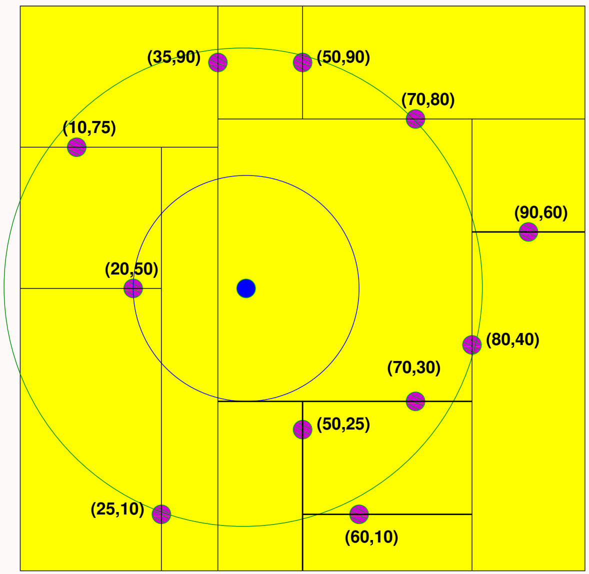
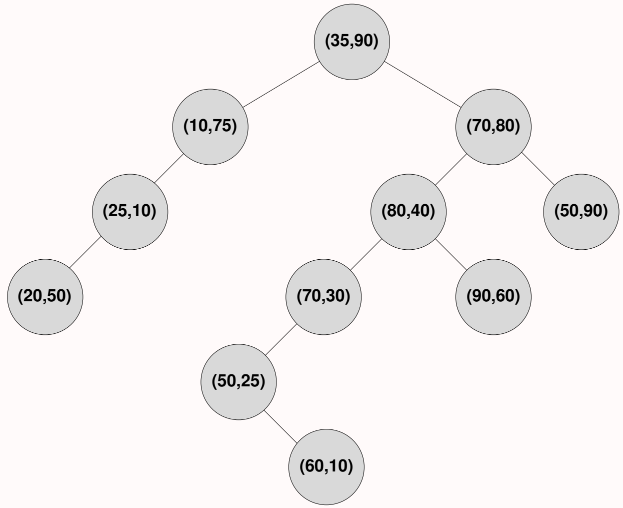
What If We Locate Point?





We visit $(35,90)$, $(70,80)$, . . . , and fall off $(70,30)$
Closest point is nowhere near this path. We must visit both subtrees.

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Nearest Neighbor: Pruned version

- Maintain the rectangle r associated with a node
- Compute a lower bound on the distance from the query q to the rectangle
  - Distance between q and *any* point in r is at least `lowerbound(r, q)`
  - Do not compute all distances between q and every point in r
- `lowerbound()` helps because if the lower bound is larger than the distance computed so far, we do not consider many points
- Must compute `lowerbound()` quickly

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Nearest Neighbor: Pruned Version

```
 float lowerbound(Rectangle r, Point p) {
  if (r.inside(p)) return 0;
  if (r.left(p))  return r.minX − p.x;
  ...
 }
Result process(KDNode k, int cd, Rectangle r, Result re
    if (k == null) return res;
    if (lowerbound(r, query) >= res.distance) return res
    ...
}
```

- If the lower bound is larger than the distance computed so far, exit!
- Otherwise compute the distance with the current node
- Process the two children in order!

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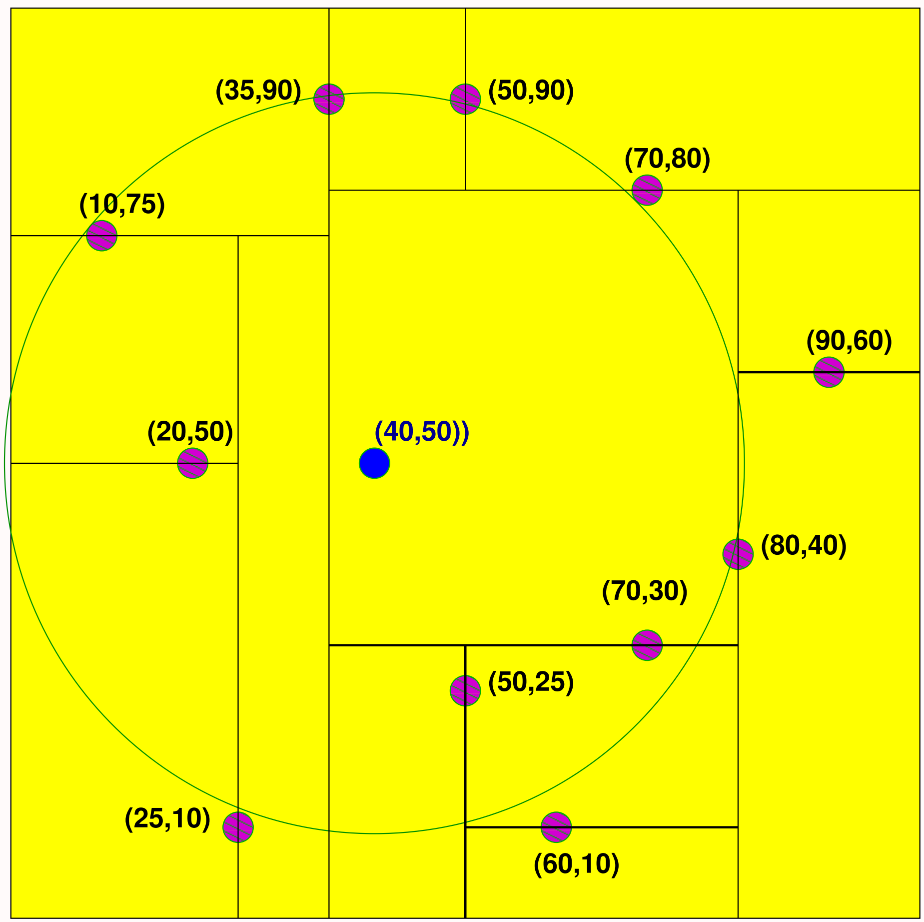
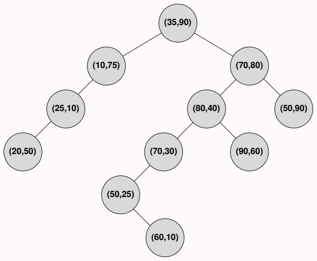
Pruned Version: Root (35,90)





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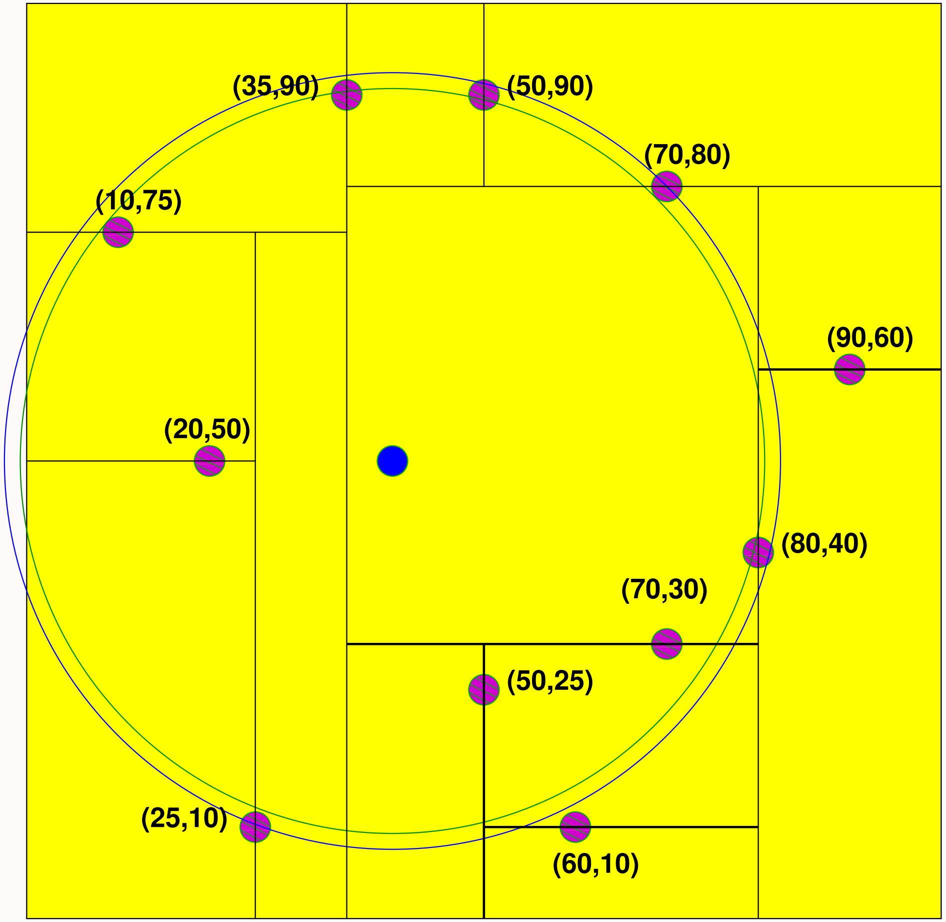
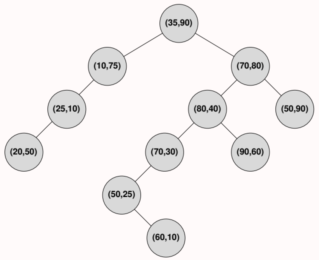
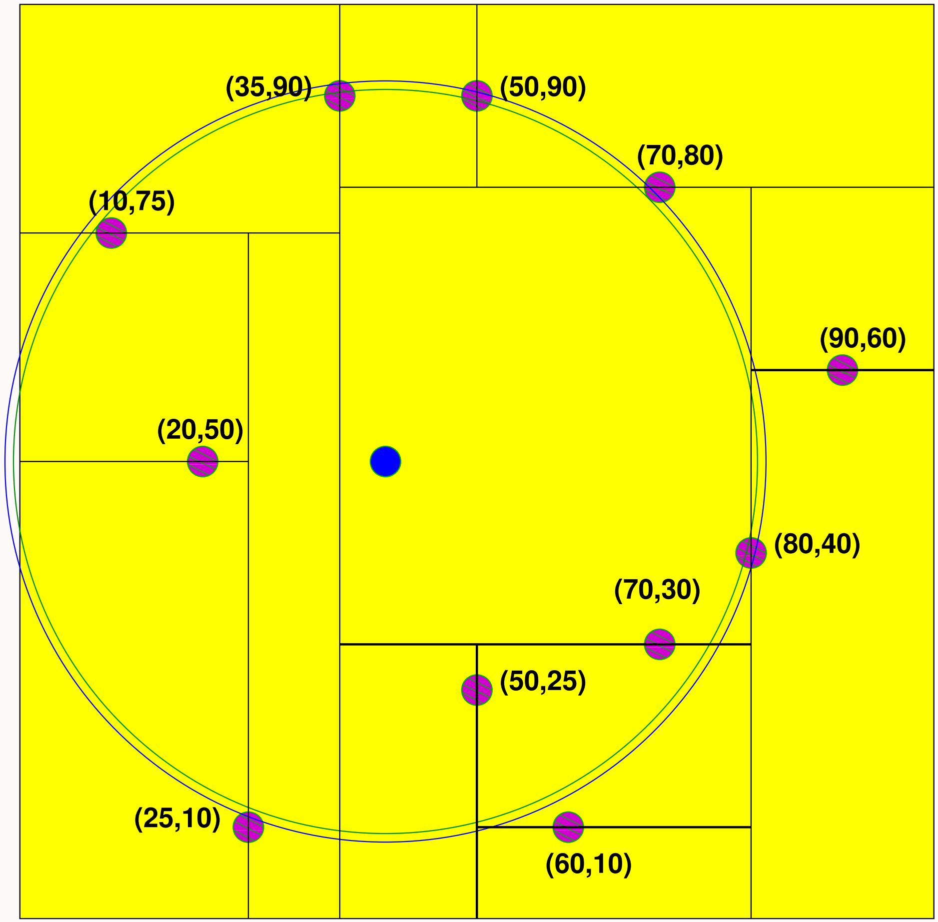
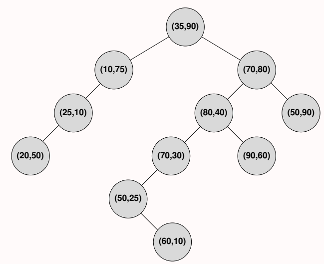
Pruned Version: (70,80)



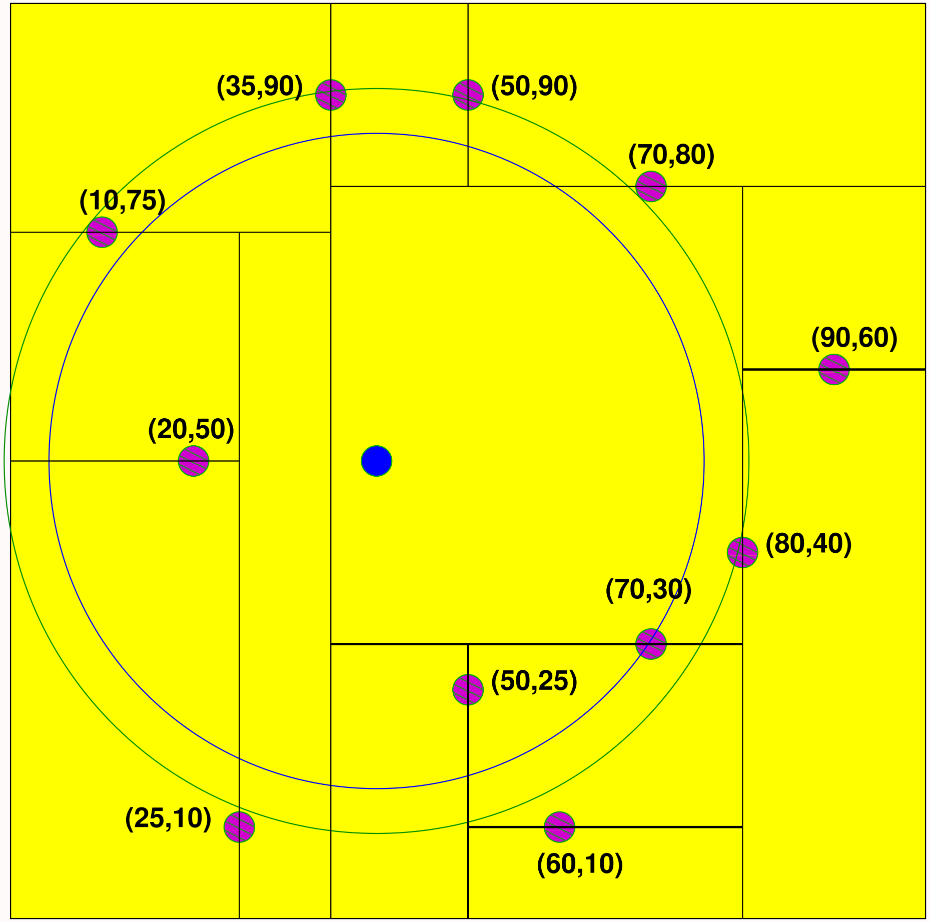


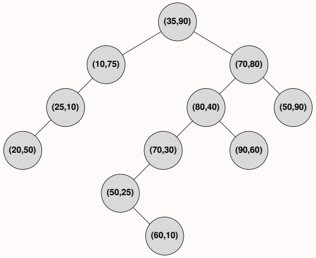
Pruned Version: (80,40)



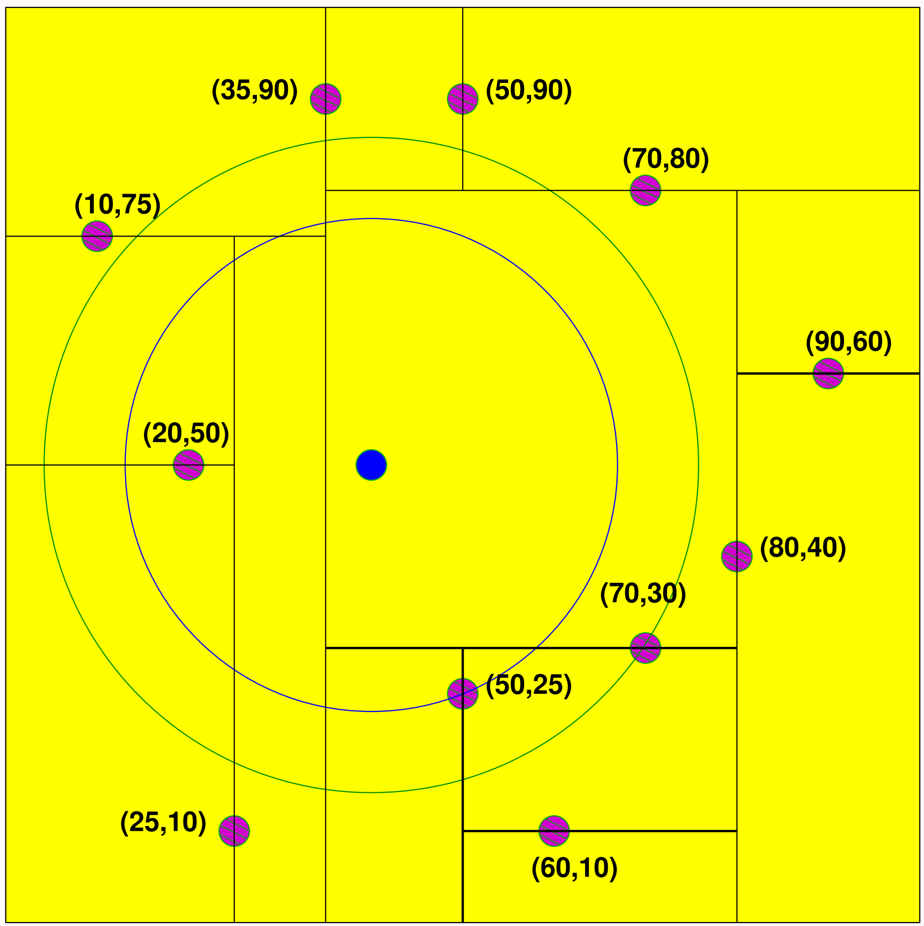


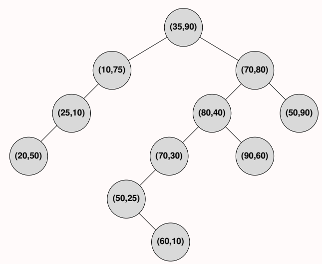
Pruned Version: (70,30)



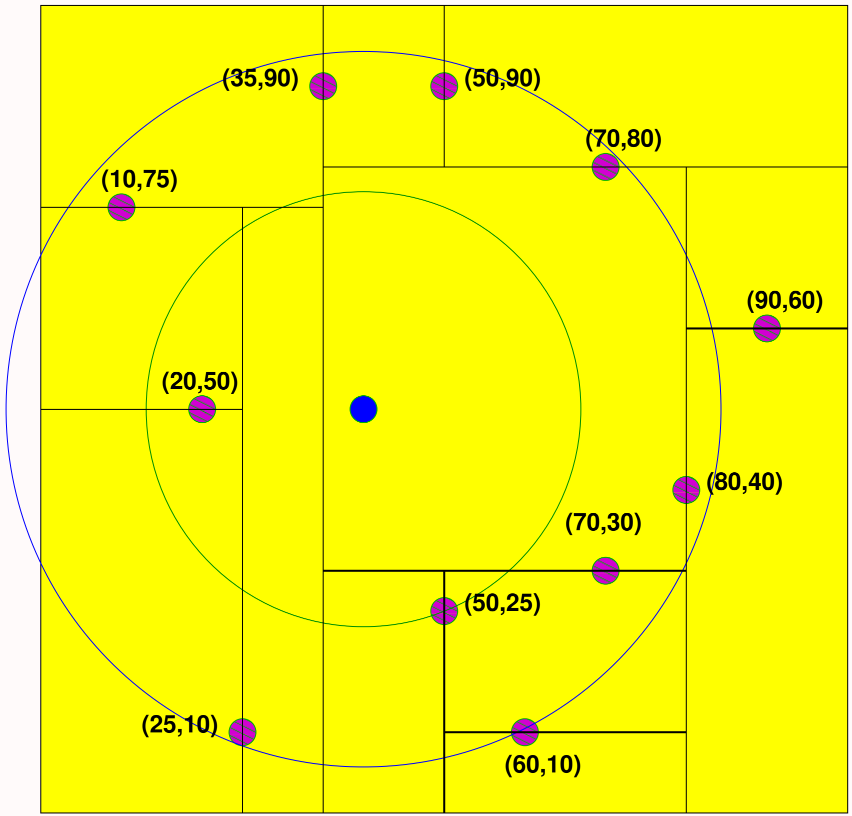


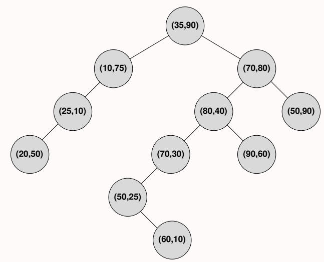
Pruned Version: (50,25)





Pruned Version: (60,10)





Note: (90,60) and (50,90) will be skipped next!

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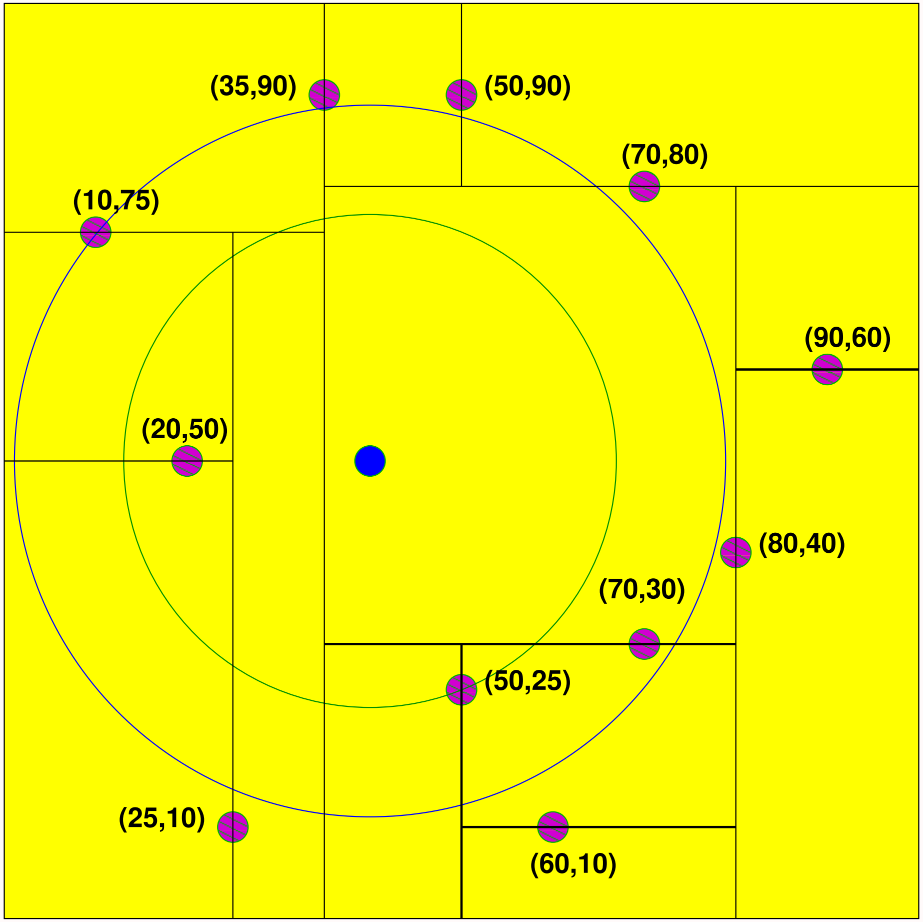
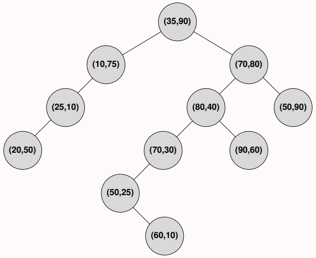
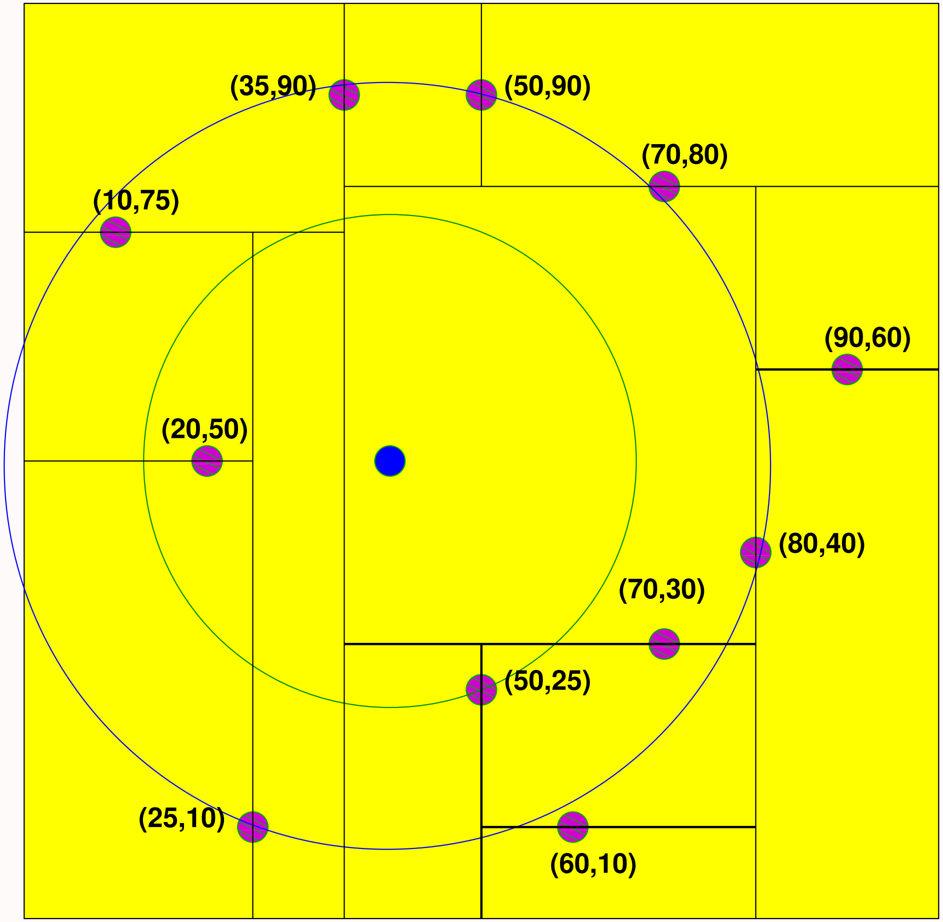
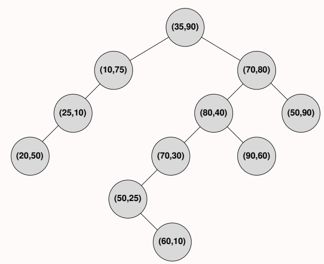
Pruned Version: (10,75)



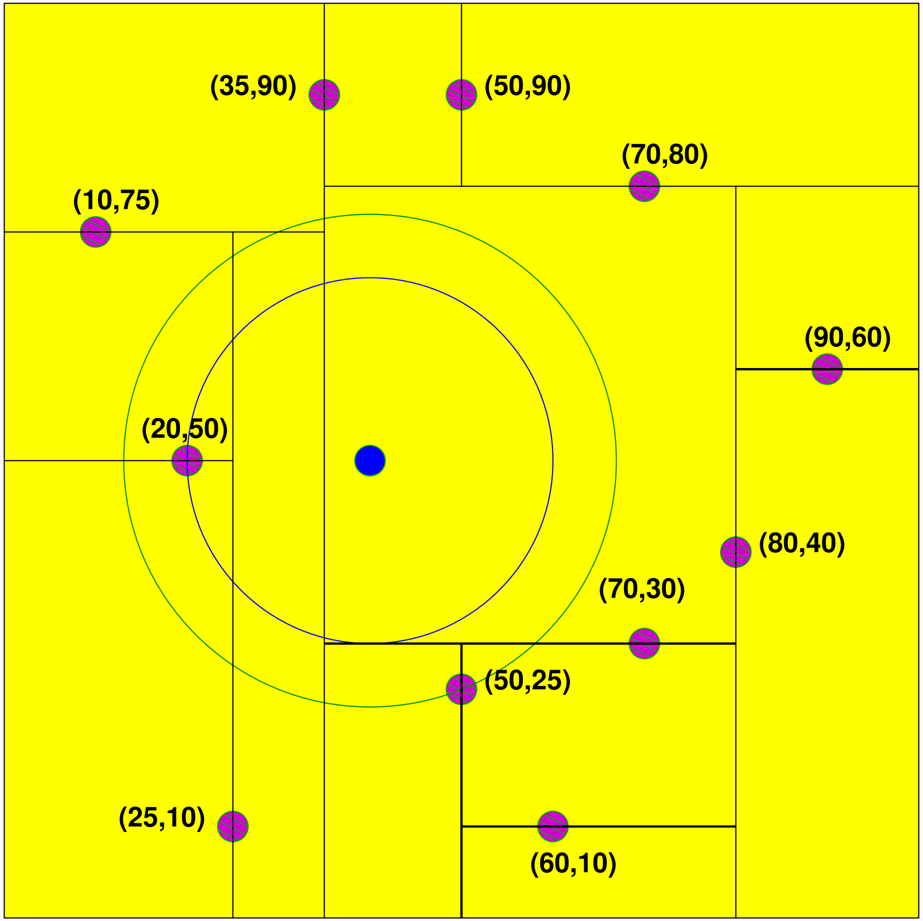


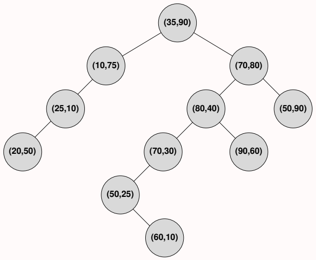
Pruned Version: (25,10)





Pruned Version: Answer





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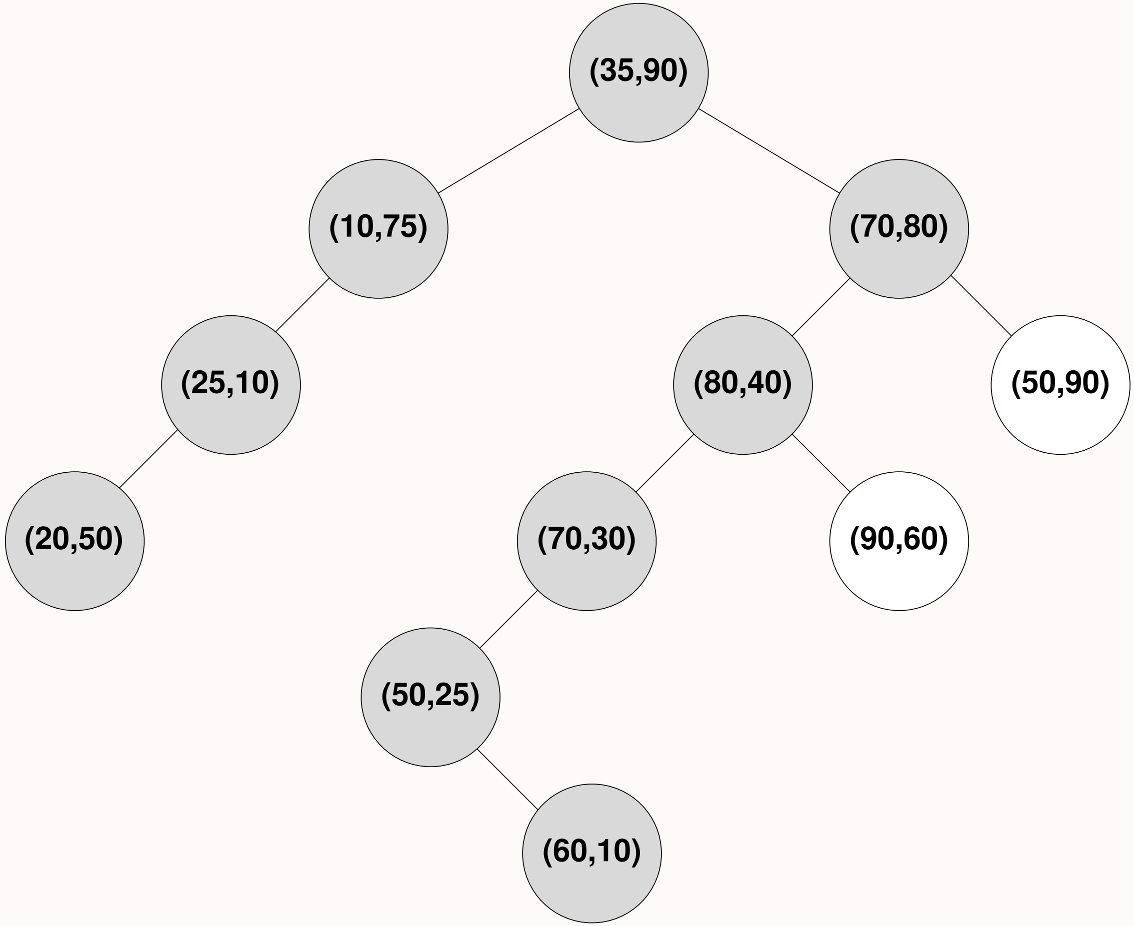
Which Nodes Are Processed?



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Any Improvement Possible?

- Nine nodes examined. Can we do better?
- Yes, if decision to pick a node is based on dynamic changing costs instead of initial `left-right` decision.
- Use a priority queue. (Seven nodes examined instead of nine)

Talk Overview

- ✔ Background about this talk
- ✔ Application in Vision
  - Exhibit A: kd-trees
- ➠ Application in Imaging
  - Exhibit B: Octrees
- ➠ Application in Graphics
  - Exhibit C: Space Filling Curves, Compressed Octrees

Exhibit B: Which picture do you like?

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4. Color Quantization

- By "quantization," here we mean the process of changing the given N number of colors to K colors. In the picture below, an image with N=33694 colors is changed to one with K=64 colors.

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- Can be done in any color space

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- By "quantization," here we mean the process of changing the given N number of colors to K colors. In the picture below, an image with N=33694 colors is changed to one with K=64 colors.

- Why? Lightweight; thus easy to transmit, store, share
- Mechanics? Create as output a lookup table
- Can be done in any color space
- Basic challenge: Efficient implementation of reverse lookup table, good representation of colors

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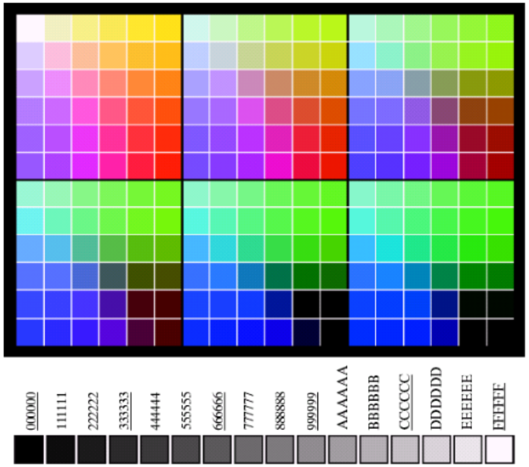
Digression: Web Safe Colors

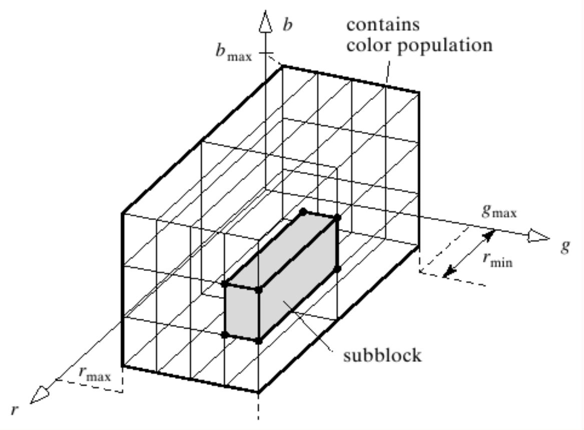
- 216 colors have been accepted as "safe" to display. Some of these colors are gray
- Each channel can take only values 00, 33, 66, 99, CC, and FF
- Figures shows the colors organized in *descending* RGB values. Value at top left is FFFFFF; first item in the second row has the value FFCCFF

Number System	Color Equivalents					
Hex	00	33	66	99	CC	FF
Decimal	0	51	102	153	204	255



Uniform Quantization

- First find the maximum and minimum range and allocate numbers R, G, and B such that R*G*B$<=$K
- *Uniformly* divide the range. For example, the range $[r_{\text{min}}, r_{\text{max}}]$ is divided into R parts.
- Map these R values to actual colors. For example, if R=4, then we might chose 1, 2, 4 and 8



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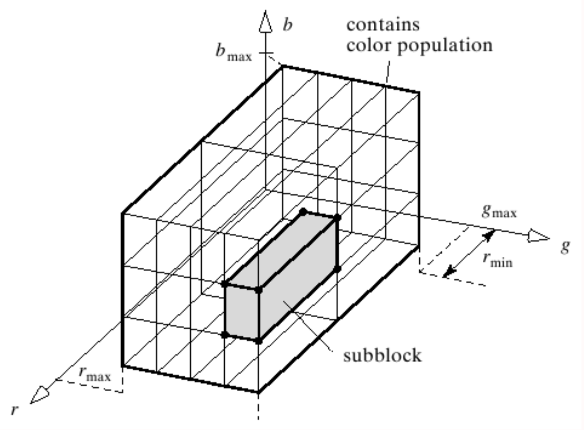

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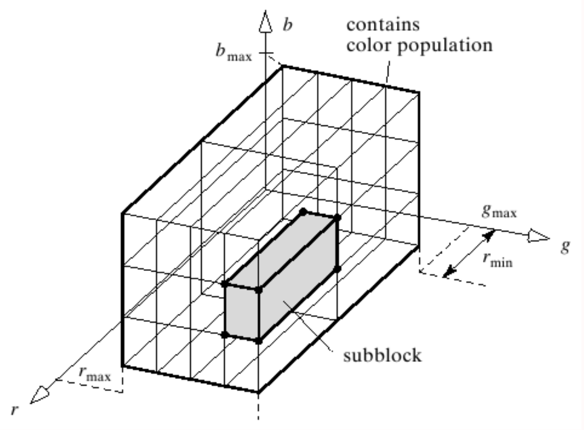

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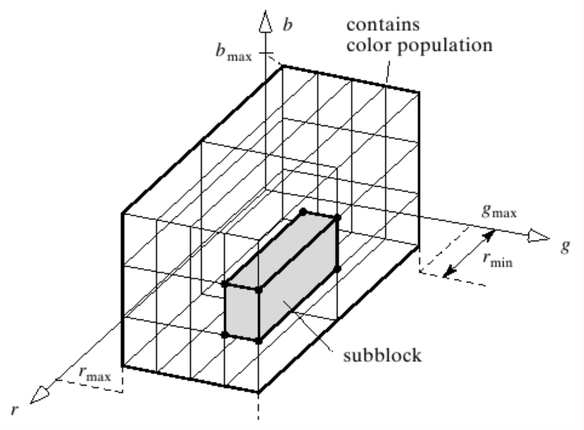

- Advantages: Easy to implement
- Drawbacks: Distribution of colors is ignored resulting in banding or false contours

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Popularity Algorithm

- Multi-pass algorithm

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- Count number of cells having a particular set of color, and take the top K colors

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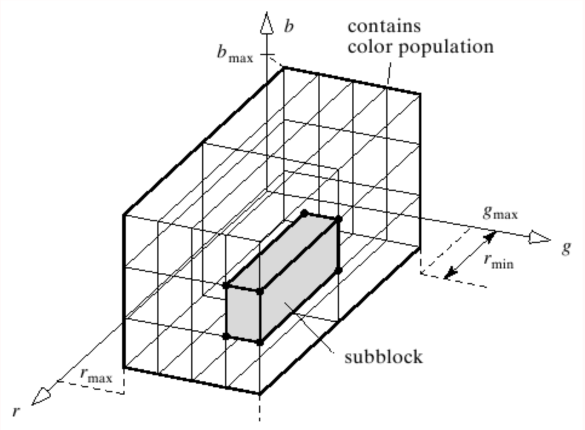
- But first quantize the colors $(2^{32} \rightarrow 2^{15})$
- Second pass: For each pixel, find the “closest” color
- Advantages: Easy to implement, popular colors show up in the resulting image
- Disadvantages: Expensive; clusters of ‘unpopular’ but significant colors are ignored

Median-Cut Algorithm

- Goal: Adaptively subdivide color block into K parts so that each sub-block has the same number of colors

Median-Cut Algorithm

- Goal: Adaptively subdivide color block into K parts so that each sub-block has the same number of colors
- Step 1: Divide the longest dimension by a plane into two parts so that there are equal number of colors (in this dimension)



- Recursively apply the same method until the number of sub-blocks is K
- Color reduction efficiently implemented using kd-Trees
- Inverse color lookup is still slow

Octree based quantization

Inverse color lookup is done using the bits of the incoming color.

R =	1	0	1	0	1	0	0	1
G =	0	1	1	0	1	0	0	1
B =	1	1	0	0	1	1	1	0
child:	5	3	6	0	7	1	1	6

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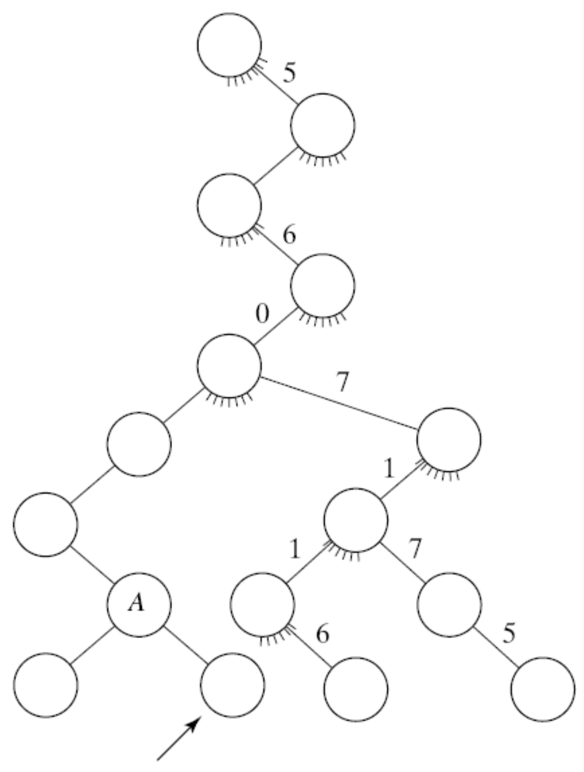

Surprisingly, color reduction is also done using the same octree

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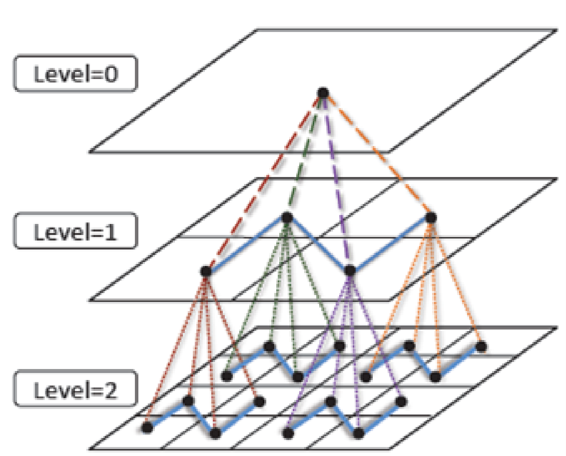
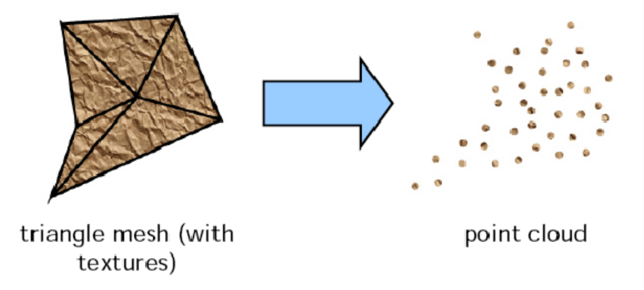
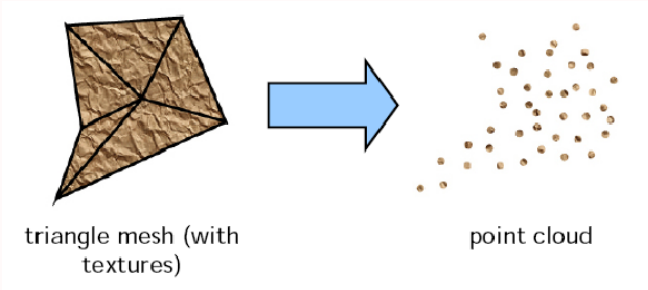


5. Point Models



- Model surfaces as points
- Each point has attributes: [coordinates, normal, reflectance, emisivity]

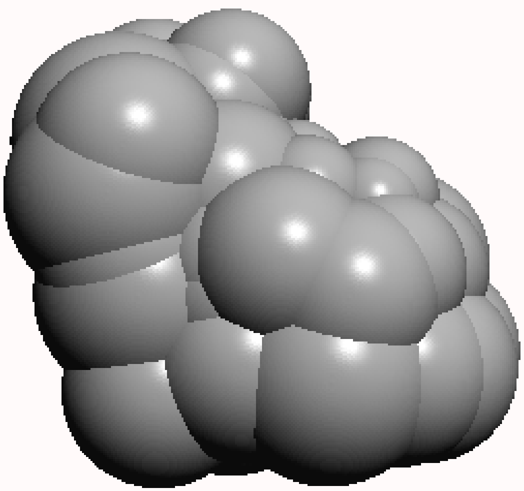
5. Point Models

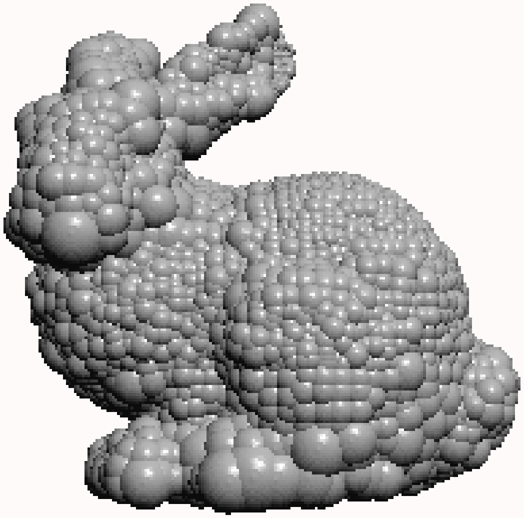


- Model surfaces as points
- Each point has attributes: [coordinates, normal, reflectance, emisivity]
- Immediate question: Why not triangles, why points? And how do we get these points?

Polygons v/s points: LOD

- Level of Detail (LOD) based hierarchy is simpler in point based models





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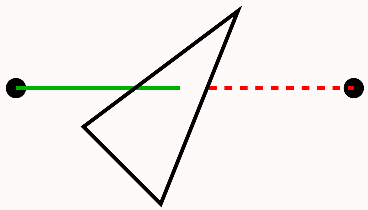
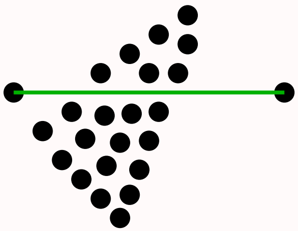
Visibility Between Point Pairs



VISIBILITY IN POLYGONAL MODELS



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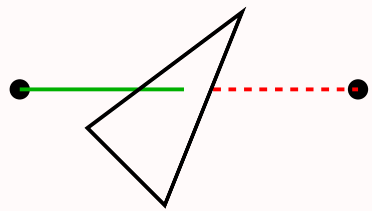
Visibility Between Point Pairs



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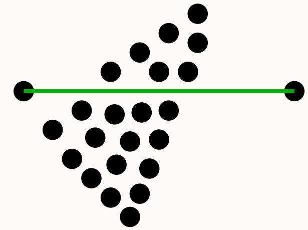
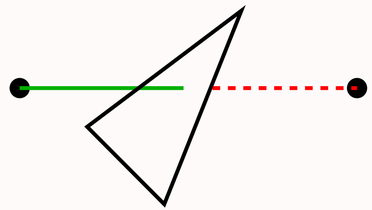


VISIBILITY IN POINT MODELS

- View dependent visibility versus view independent visibility

Visibility Between Point Pairs



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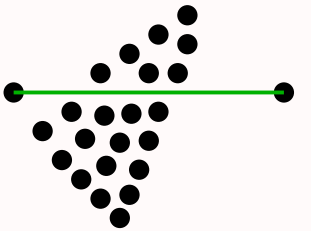
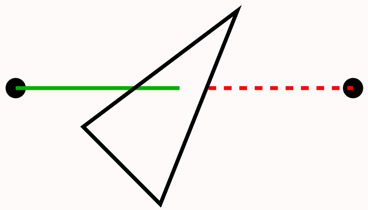


VISIBILITY IN POINT MODELS

- View dependent visibility versus view independent visibility
- Although view dependent visibility based point based rendering solutions exist,

Visibility Between Point Pairs



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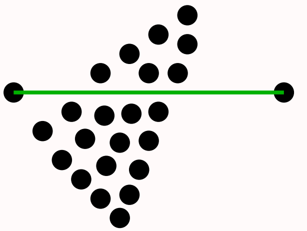

VISIBILITY IN POINT MODELS

- View dependent visibility versus view independent visibility
- Although view dependent visibility based point based rendering solutions exist, we present the first global illumination solution for point models based on the view independent paradigm

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Visibility Between Point Pairs

View Independent Visibility calculation between point pairs is essential to give **correct** Global Illumination results as a point receives energy from other point only if it is **visible**

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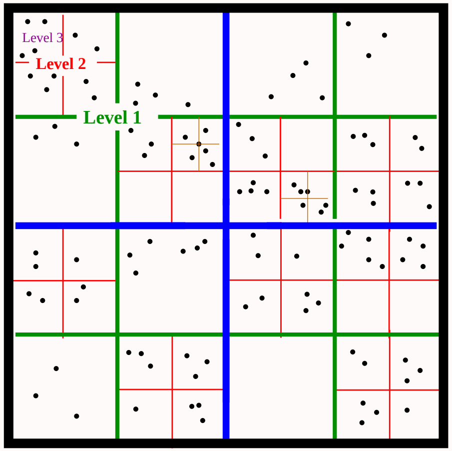
Hierarchical Visibility

Hierarchical Visibility enables *quick* answers to visibility queries, thus enabling a faster GI solution



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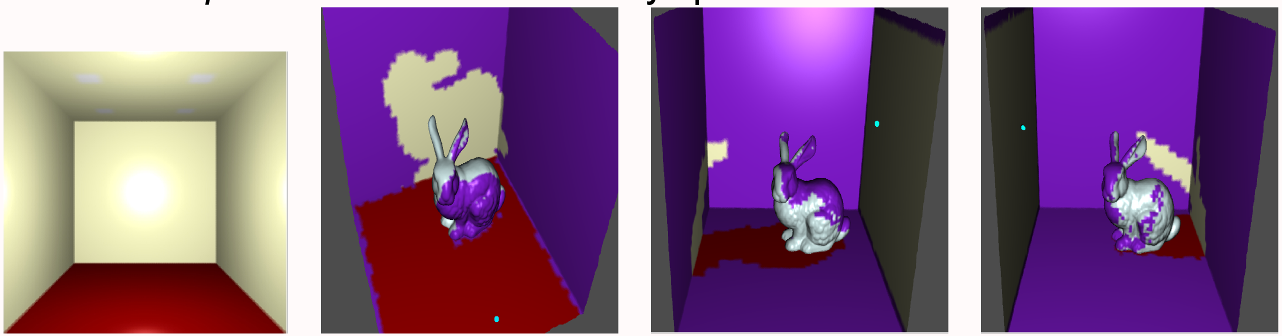
Hierarchical Visibility

Key Notion: We define a **Visibility Map (V-map)** for the resulting tree to enable *quick* answers to visibility queries.



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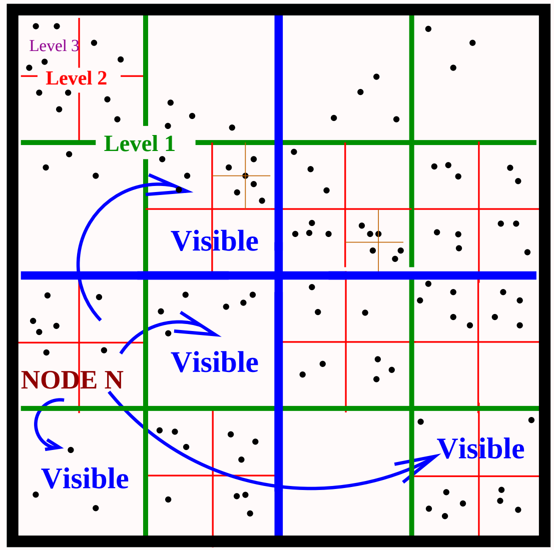
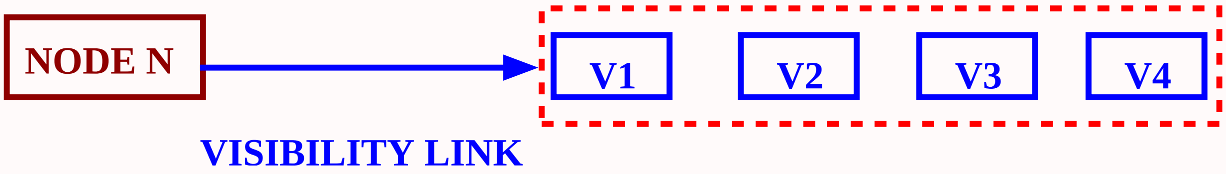
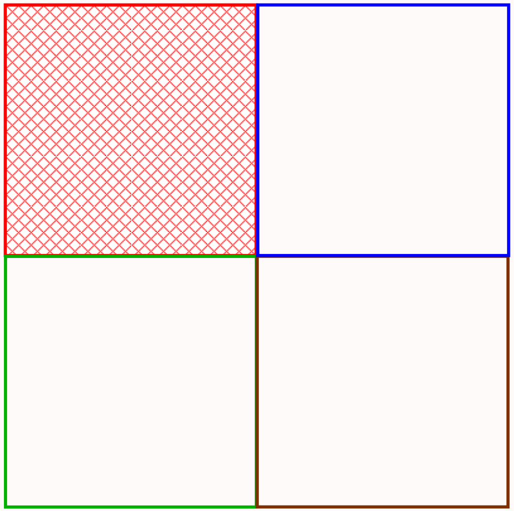
6. Visibility Map

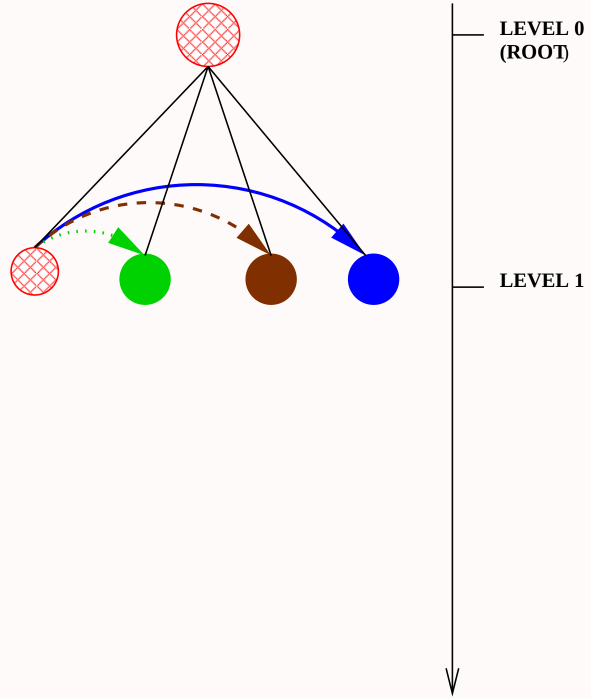
- The *visibility map* for a tree is a collection of visibility links for every node in the tree
- The *visibility link* for any node N is a set L of nodes
- Every point in any node in L is guaranteed to be visible from every point in N





What is a Visibility Map (V-map)?





With respect to [hatched circle] at any level,

- **−− COMPLETELY INVISIBLE** (green)
- **−− COMPLETELY VISIBLE** (blue)
- **−− PARTIALLY VISIBLE** (brown)

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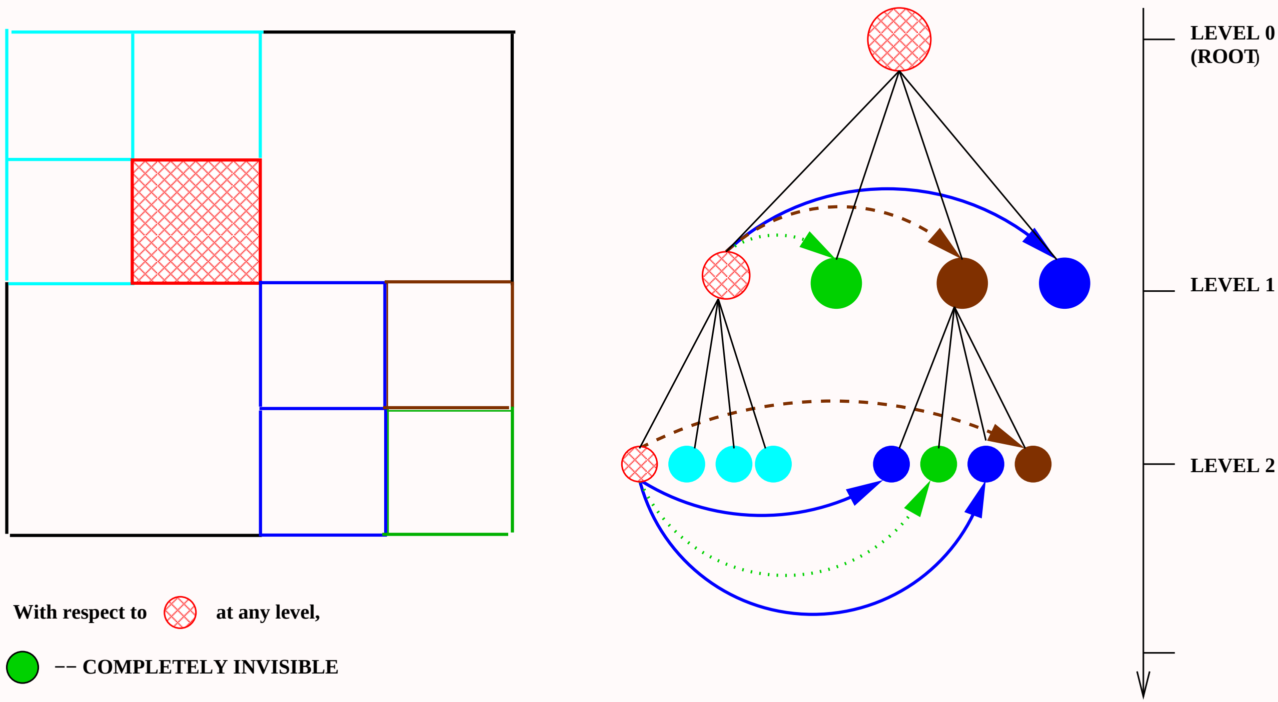
What is a Visibility Map (V-Map)?



With respect to (red hatched node) **at any level,**

- (green) –– **COMPLETELY INVISIBLE**
- (blue) –– **COMPLETELY VISIBLE**
- (brown) –– **PARTIALLY VISIBLE**

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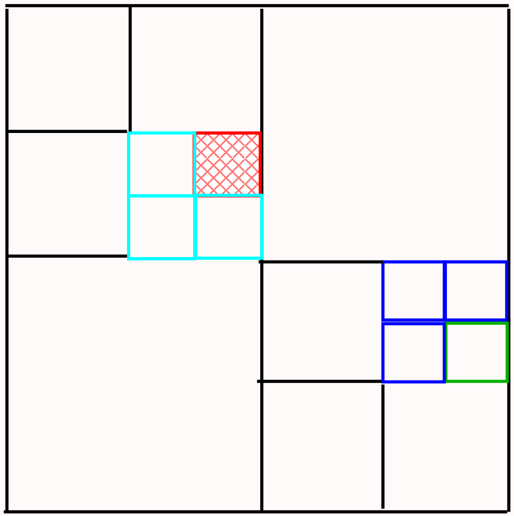
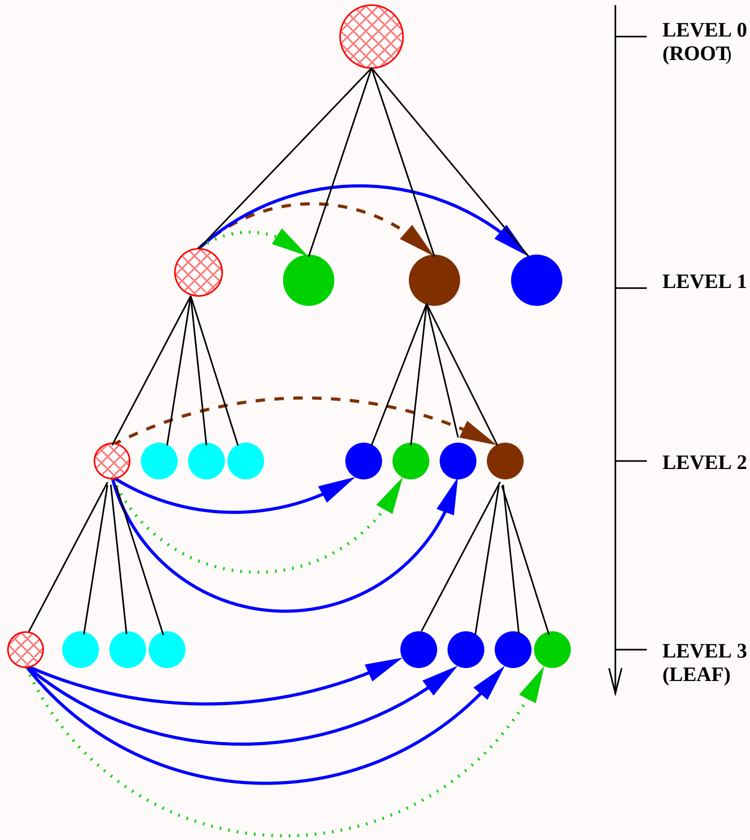
What is a Visibility Map (V-Map)?





With respect to (red hatched node) **at any level,**

(green) **–– COMPLETELY INVISIBLE**

(blue) **–– COMPLETELY VISIBLE**

(brown) **–– PARTIALLY VISIBLE**

Visibility Map Queries?

Visibility map entertain efficient answers:

1. Is point x visible from point y?
2. What is the visibility status of u points around x with respect to v points around y?
   - Repeat a "primitive" point-point visibility query uv times
   - V-map gives the answer with $O(1)$ point-point visibility queries.
3. Given a point x and a ray R, determine the first object of intersection.
4. Is point x in the shadow (umbra) of a light source?

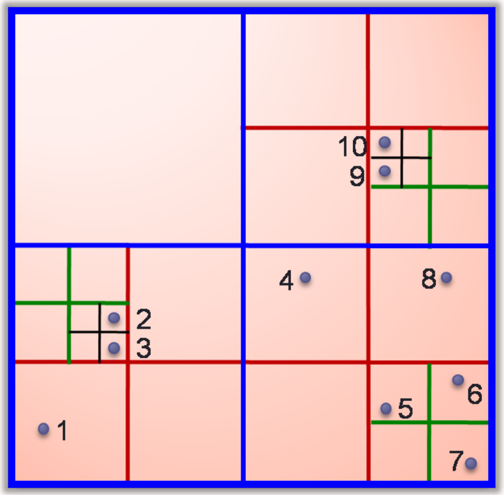
All queries answered with a simple octree traversal

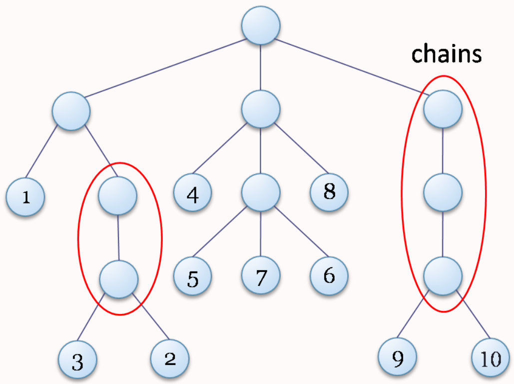
Quadtrees

Given a set of points, we need to know how to build octrees, or

Quadtrees

Given a set of points, we need to know how to build octrees, or for that matter, quadtrees





A quadtree built on a set of 10 points in 2D

Quadtrees

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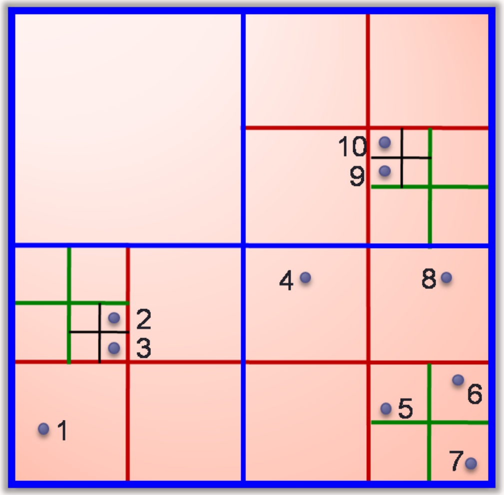

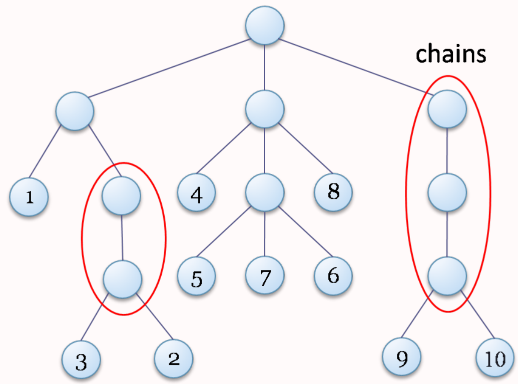

A quadtree built on a set of 10 points in 2D

Important: Interested in a parallel algorithm for building octrees

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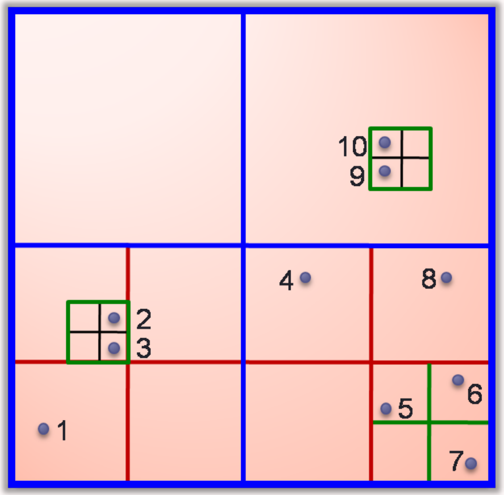
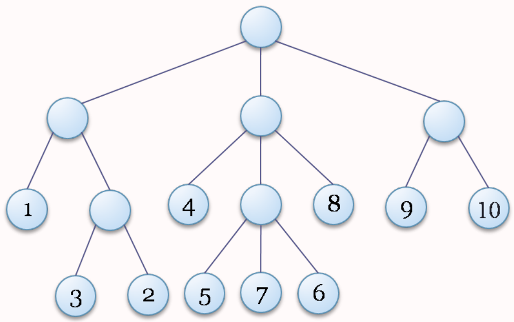
Compressed Quadtrees





Each node in compressed octree is either a leaf or has at least two children

This is going to be very useful

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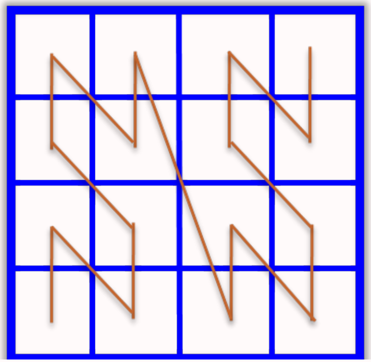
7. Space Filling Curves

- We recursively bisect space into $2^k \times 2^k \times 2^k$ non-overlapping cells of equal size.
- Key Idea: Mapping of these cells to a 1D linear ordering



3	0101	0111	1101	1111
2	0100	0110	1100	1110
1	0001	0011	1001	1011
0	0000	0010	1000	1010
	0	1	2	3

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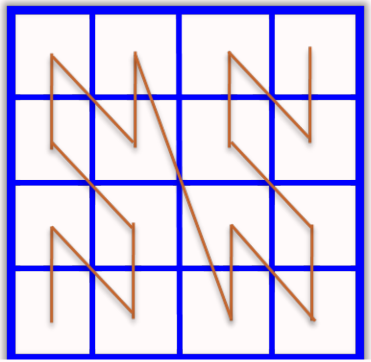

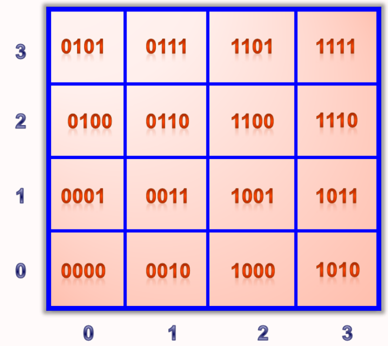

Each cell is thus assigned an index — which can be done cleverly
The Sfc index for k=2 for a cell in 3 Dimensions (d=3) with coordinates $(3,1,2) = (11,01,10)$ is $101110 = 13$

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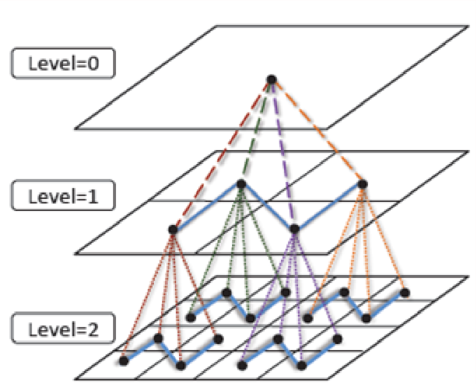
Octrees and Sfcs

- Leaves when sorted by Sfc indices represent bottom traversal
- In fact, this represents a post order traversal of a quadtree



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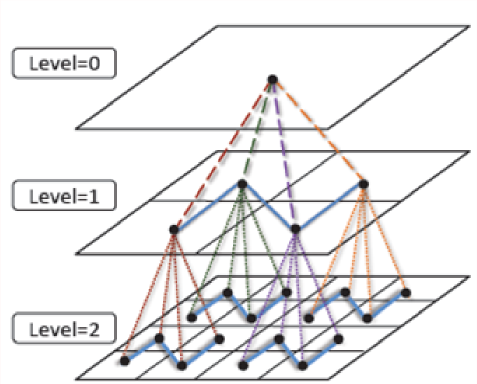
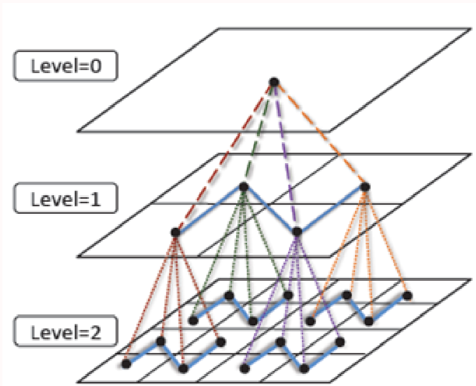


- Better still, can be viewed as multiple Sfcs at various resolutions
- Even better, parent can be generated from child's Sfc

Given two nodes c_1 and c_2,

Octrees and Sfcs

- Leaves when sorted by Sfc indices represent bottom traversal
- In fact, this represents a post order traversal of a quadtree

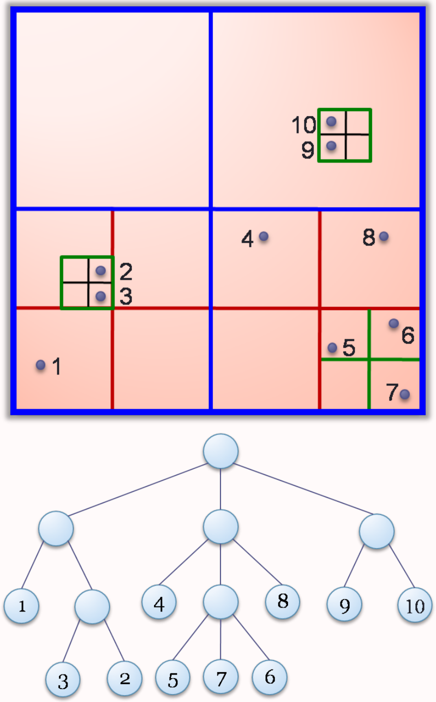


- Better still, can be viewed as multiple Sfcs at various resolutions
- Even better, parent can be generated from child's Sfc

Given two nodes c_1 and c_2, The longest common prefix of the Sfc indices (that's a multiple of the dimension d) represents the Sfc index of the LCA.

Talk Summary

- ✔ Spatial data structures is core in Vi,G,I
- ✔ Parallel algorithms on GPU are doable
- ✔ Application in Vision (Exhibit A: kd-trees)
- ✔ Application in Imaging (Exhibit B: Oc-trees)
- ✔ Application in Graphics (Exhibit C: Compressed Octrees)



Hope you liked it.. Email questions to sharat @ iitb.ac.in