Volume Visualization

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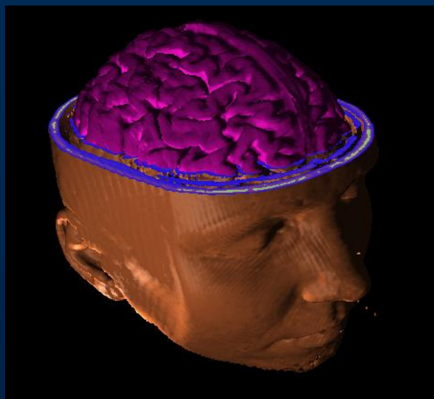
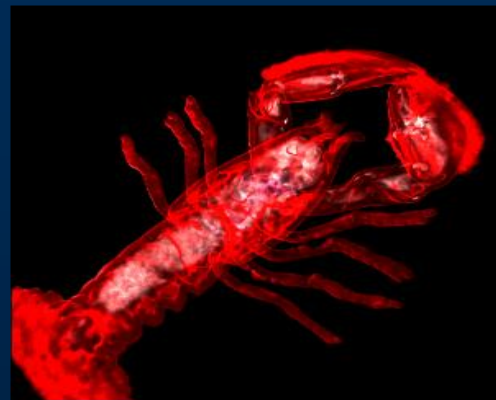
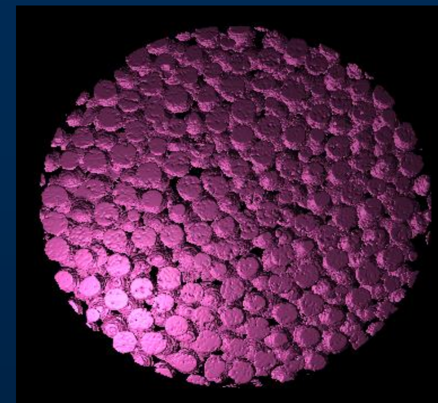
Volume Datasets

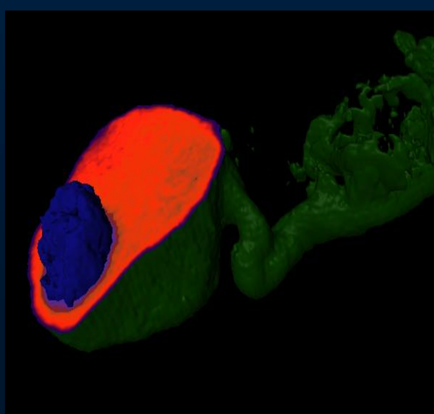




MRI / CT / PET / Ultrasonography

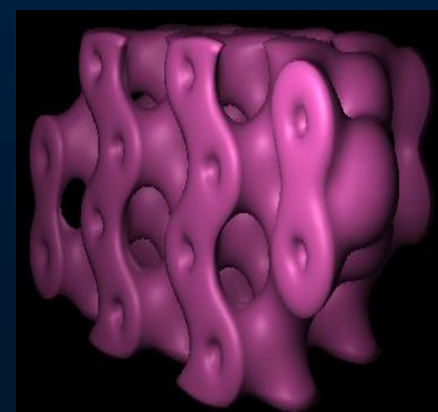


Micro-Tomography



Confocal Microscopy

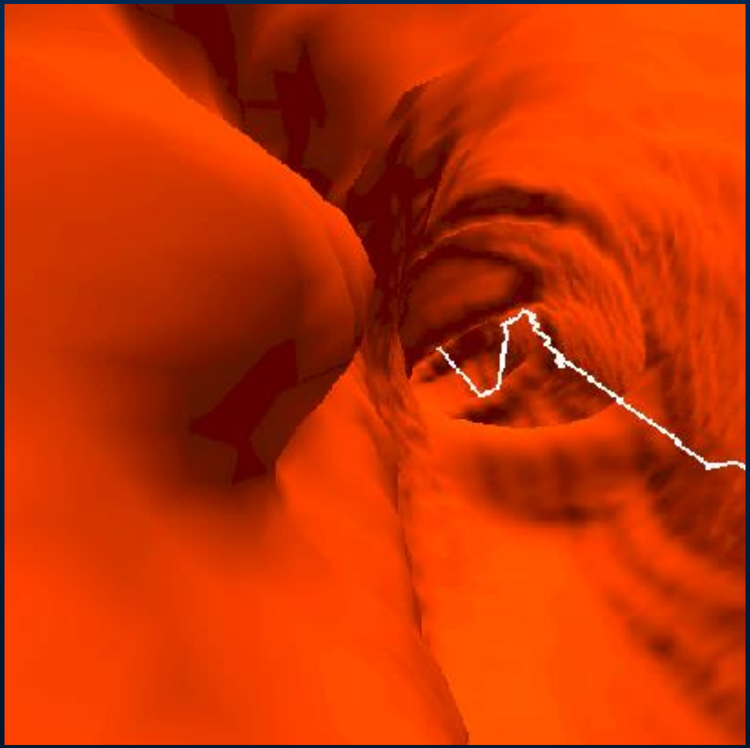
Voxelization



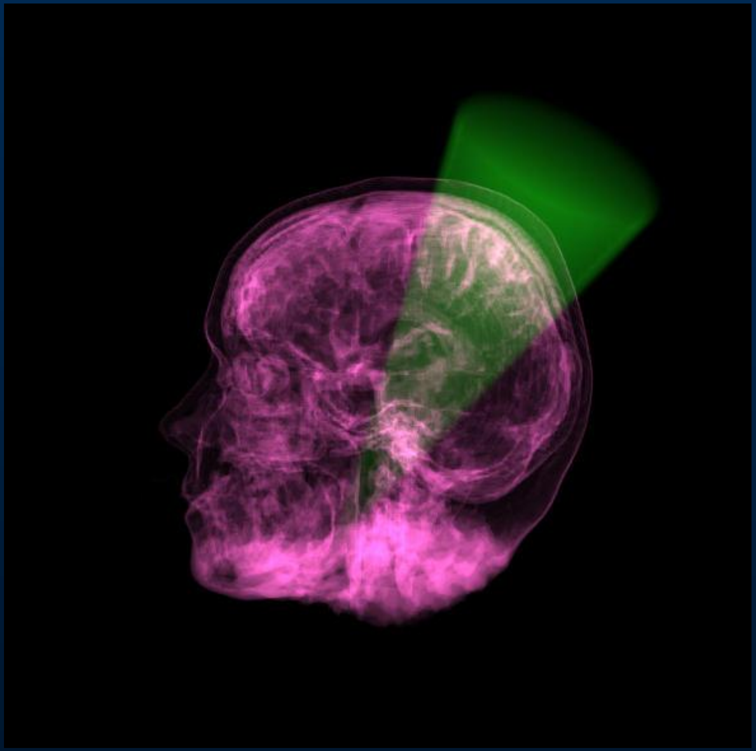
Simulation

Volumetric Application

Biomedical Visualization



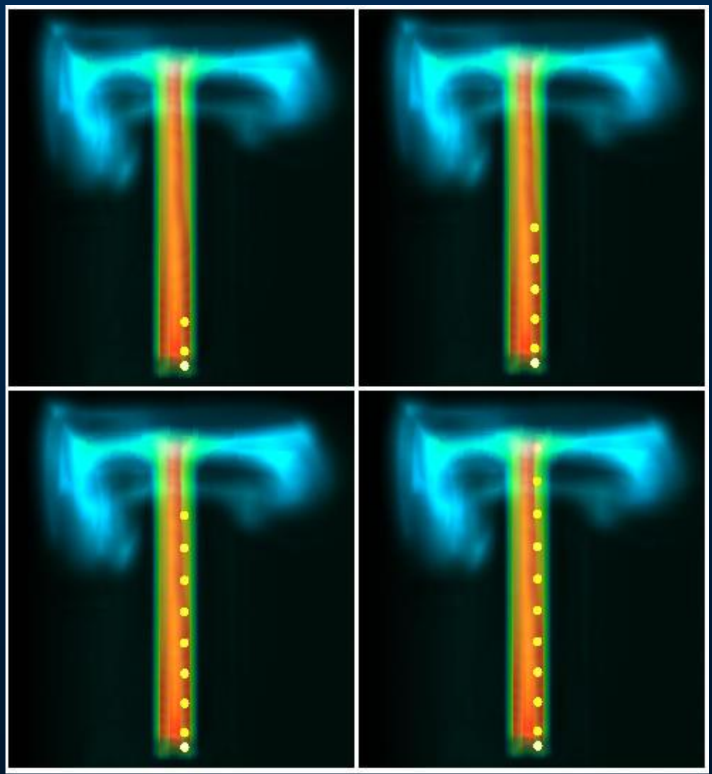
Virtual colonoscopy



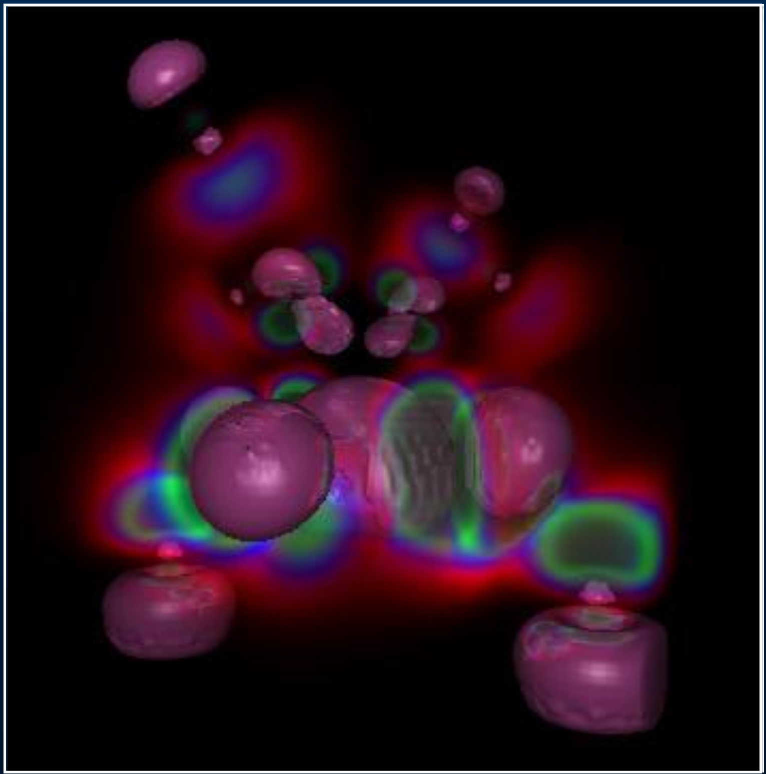
Radiation Therapy

Volumetric Application

Scientific Visualization



Computational
Fluid Dynamics (CFD)



High-potential
iron proteins

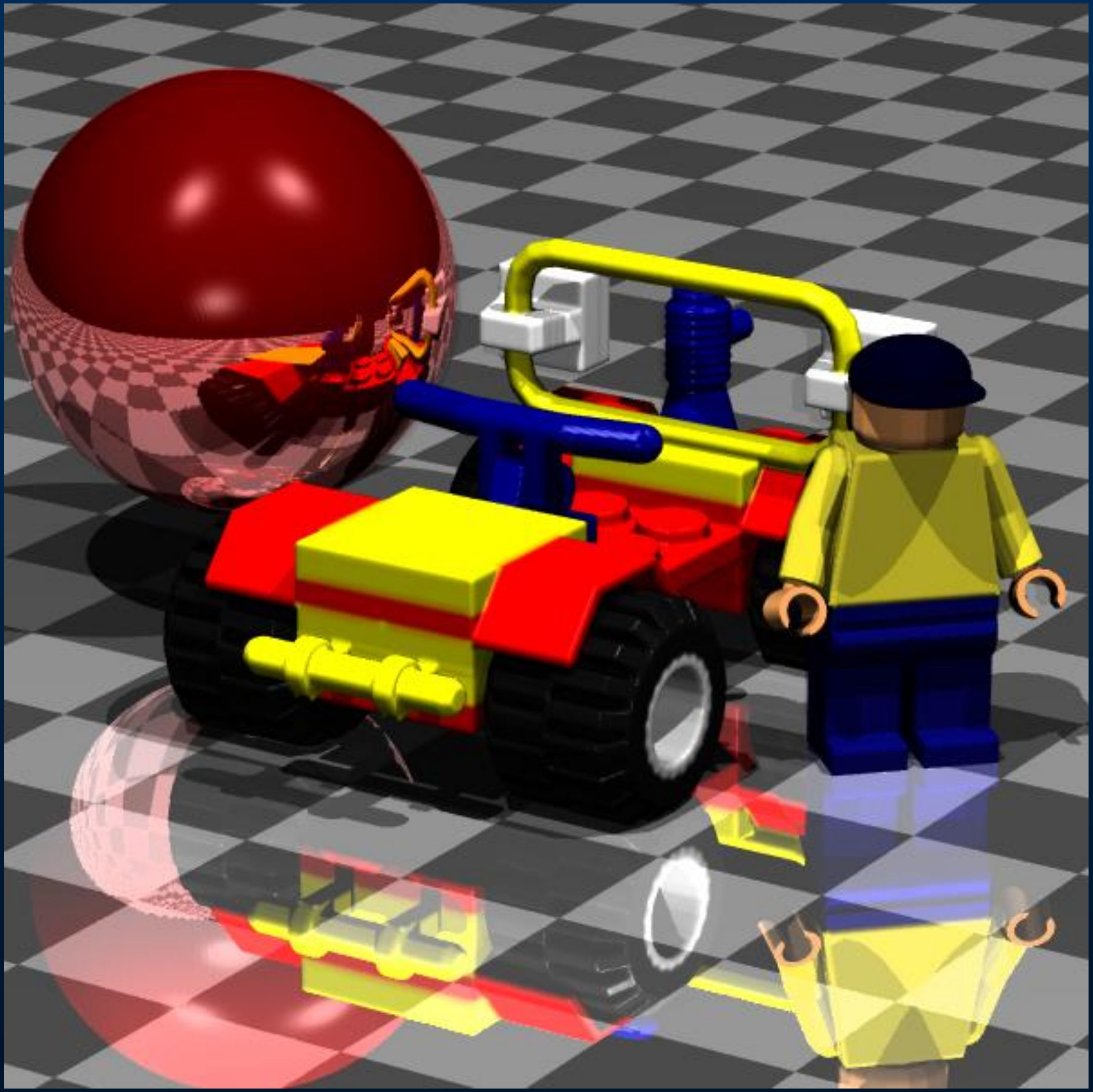
Volumetric Application

Amorphous Phenomena

Volumetric Application

Sculpting System

Volume Graphics



Volumetric objects

- have information inside it
- not consist of explicit surfaces and edges
- May be too voluminous to be represented geometrically

Volume Visualization Objective

- Peer inside voumetric objects
- Probe into voluminous & complex structures

Volume Visualization

A visualization method concerned with the representation, manipulation, and rendering of volumetric data.

History of Volume Visualization

1970 First report - 3D oscillioscopic images
1970's Medical imaging
1978 3D surface presentation [Sunguroff & Greengerg]
1979 Cuberille [Herman & Liu]
1981 Depth only shading [Herman & Udupa]
1982 Octree Machine [Meagher]
        Voxel processor [Goldwasser & Reynolds]
1984 Ray casting [Tuy & Tuy]
1985 Cube architecture [Kaufman & Bakalash]
        Back-to-front & Front-to-back
        Depth gradient shading [Gordon et al.]
        Contextual shading [Chen et al.]

History of Volume Visualization

1986 3D Scan conversion [Kaufman & Shimony]
Grey-level shading [Hoehne & Bernstein]
1987 Marching cubes [Lorensen & Kline]
1988 Volume rendering [Levoy; Derbin; Upson & Keeler; Sabella]
Dividing cubes [Cline et al.]
1989 Chapel Hill Workshop
Splatting [Westover]
1990 San Diego Workshop
1992 Boston Workshop
1994 Washington Workshop
1996 San Francisco Workshop

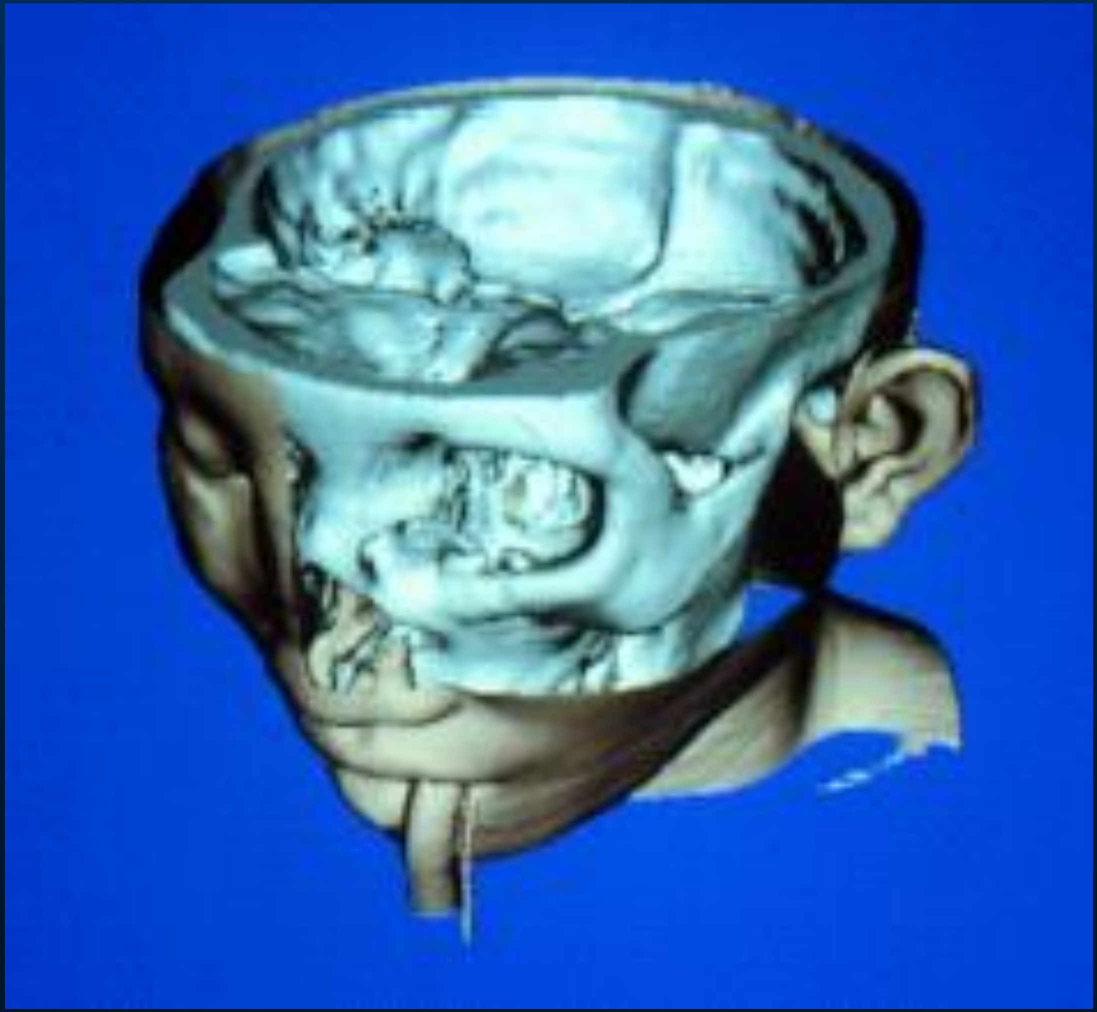
IEEE Symposium on Volume Visualization
IEEE Workshop on Volume Graphics
IEEE Visualization

Volume Visualization

- **Iso-surface extracting and rendering**
  - **Marching Cubes (Lorensen 87)**
  - **Marching Tetrahedra (Zhou&Chen 97)**
- **Direct volume visualization**
  - **Ray Casting (Levoy 89)**
  - **Splatting (Westover 90)**

Surface Rendering

An indirect technique used for visualizing volume primitives by first converting them into an intermediate surface representation and then employing conventional computer graphics techniques to render them to the screen.



Surface Rendering

- Intermediate representation
- Tangible surfaces
- Information on surfaces
- Continuous
- Compact representation
- Fast
- Iso-surfacing

Marching Cubes

- Creates triangles
- Floating point representation
- Uses case table to create triangles
- Can use general purpose polygon-based hardware for rendering

Marching Cubes History

- Developed in 1984
- Published in Siggraph ’87
- Marching Cubes in AVS and SGI Explorer, and ***everywhere***
- 12,537 citations by google scholar
- Lorensen won achievement award at IEEE Visualization 2004

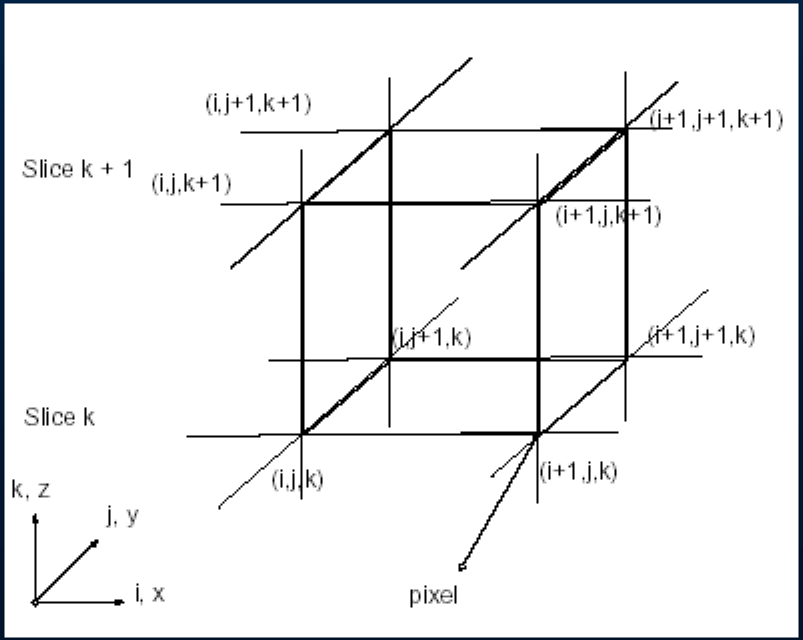
Marching Cubes Algorithm

1. Create a cube
2. Classify each vertex
3. Build an index
4. Get edge list
5. Interpolate triangle vertices
6. Calculate and interpolate normals

Marching Cubes

Step 1 - Create a cube

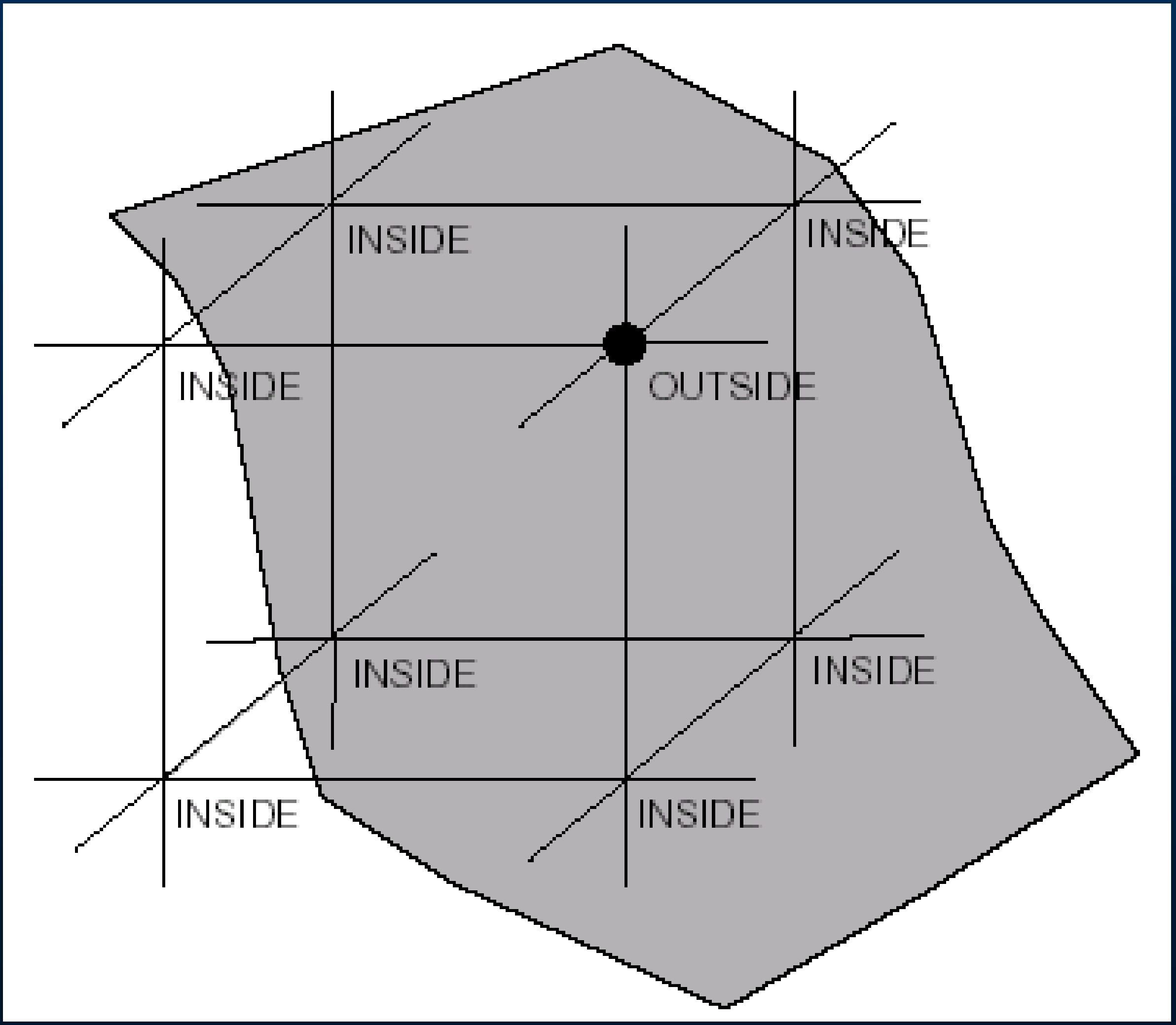
- Consider a cube defined by eight data values, four from slice k, and four from slice k + 1



Marching Cubes

Step 2 - Classify each vertex

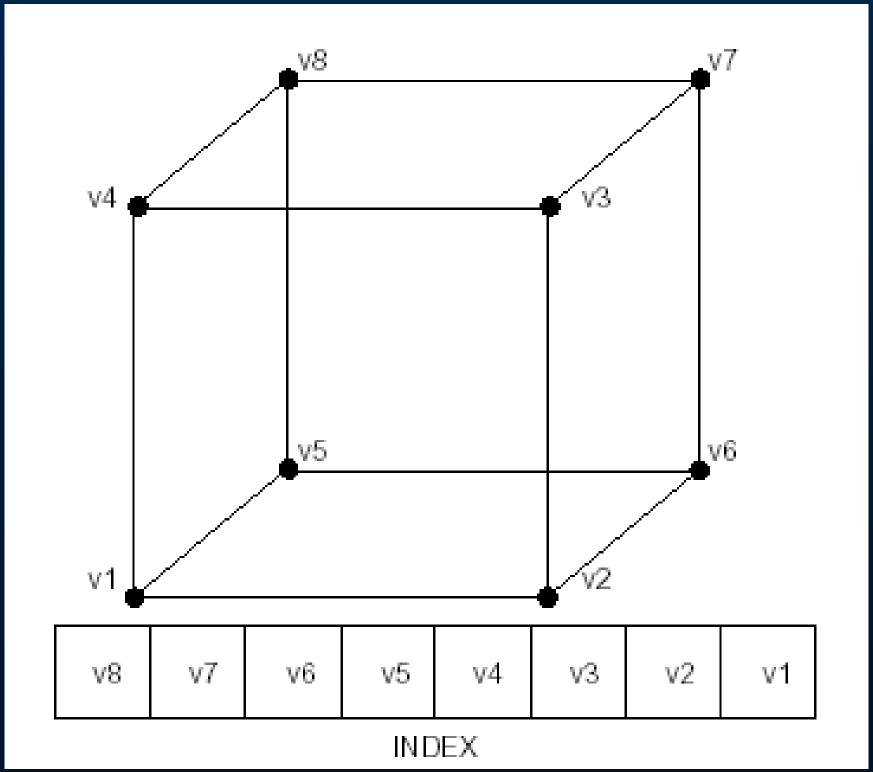
- Classify each vertex of the cube as to whether it lies outside surface or inside the surface
  - Outside if vertex value < surface value
  - Inside if vertex value >= surface


INSIDE
INSIDE
INSIDE
OUTSIDE
INSIDE
INSIDE
INSIDE
INSIDE

Marching Cubes

Step 3 - Build an index

- Create an index between 0 and 255 from the binary labeling of each vertex

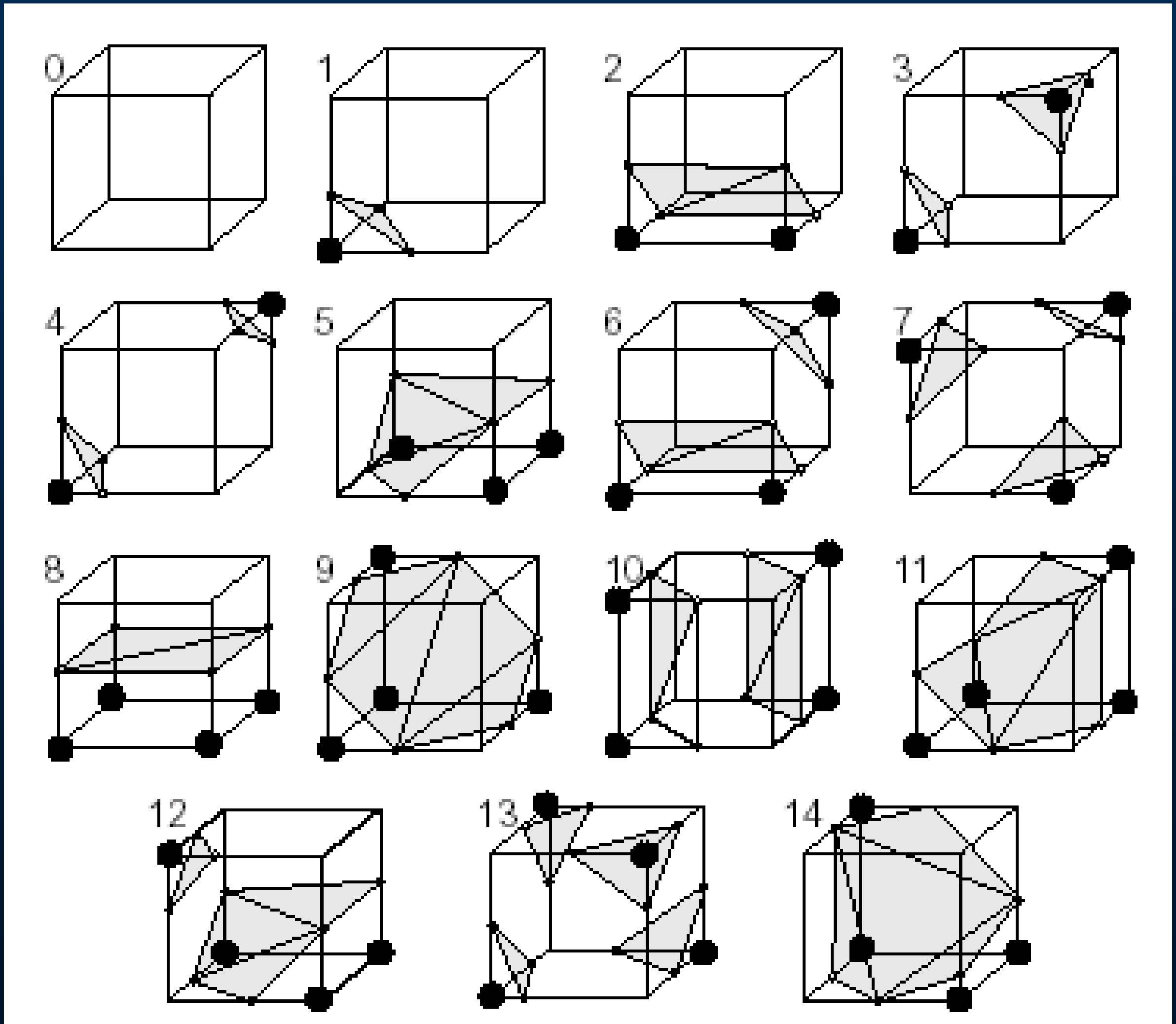


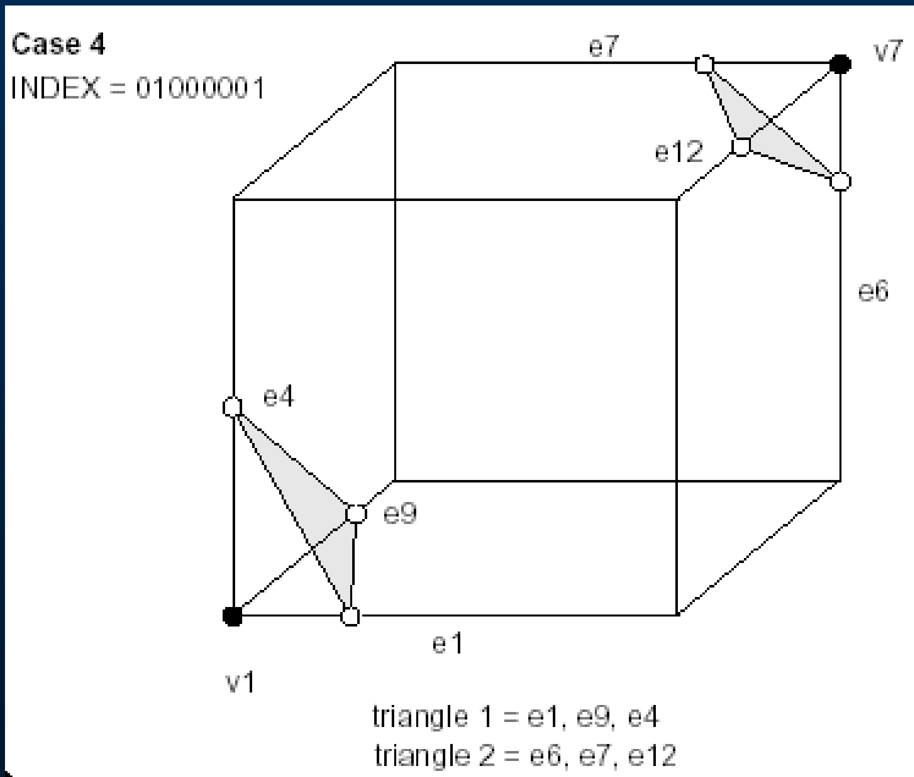
Marching Cubes

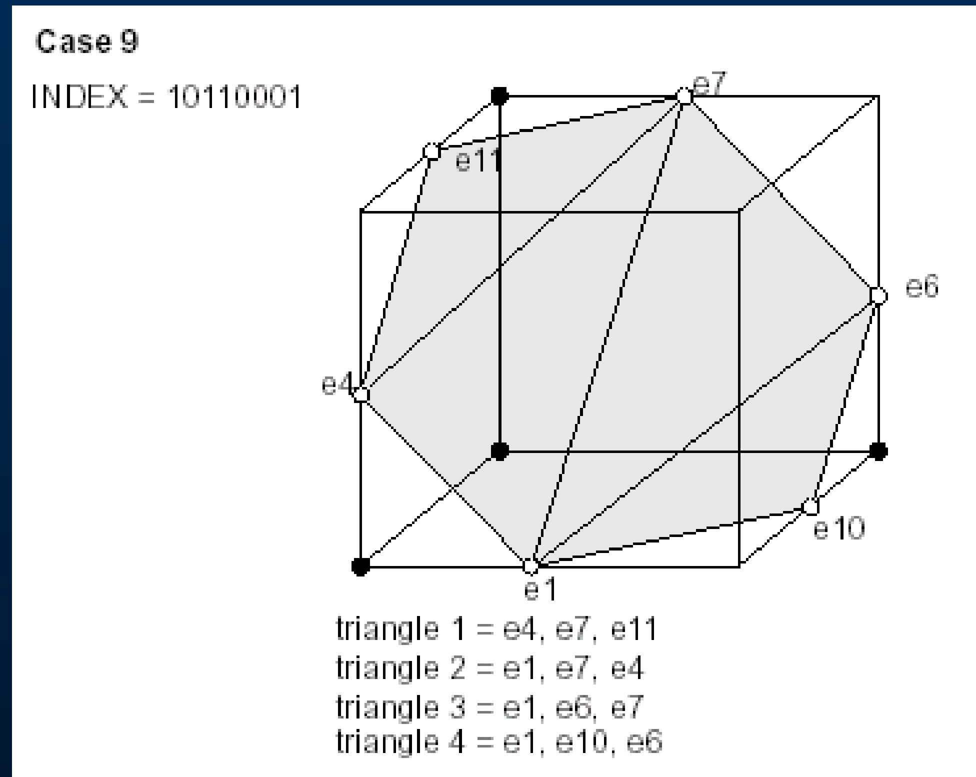
Step 4 - Get edge list

- For a given index, access a list of cubes edges that contain a triangle vertex
- Using symmetry of the cube, all 256 cases can be generated from fourteen cases

Marching Cubes




Case 4
INDEX = 01000001
e7
v7
e12
e6
e4
e9
e1
v1
triangle 1 = e1, e9, e4
triangle 2 = e6, e7, e12

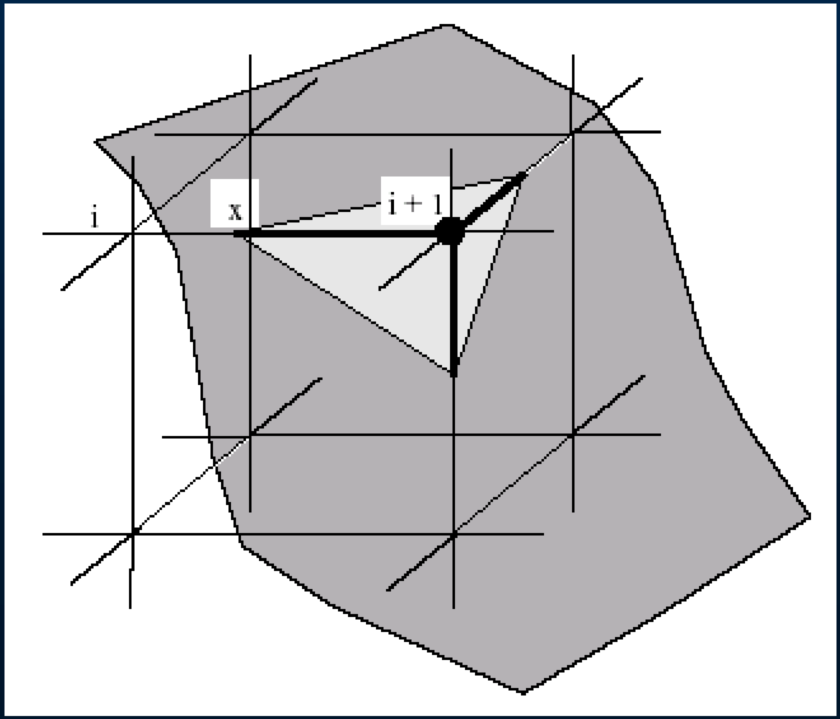

Case 9
INDEX = 10110001
e7
e11
e6
e4
e10
e1
triangle 1 = e4, e7, e11
triangle 2 = e1, e7, e4
triangle 3 = e1, e6, e7
triangle 4 = e1, e10, e6

Marching Cubes

Step 5 - Interpolate triangle vertices

- For each triangle edge, find the vertex using linear interpolation of the density values

$$x = i + (value - D(i)) / (D(i + 1) - D(i))$$



Marching Cubes

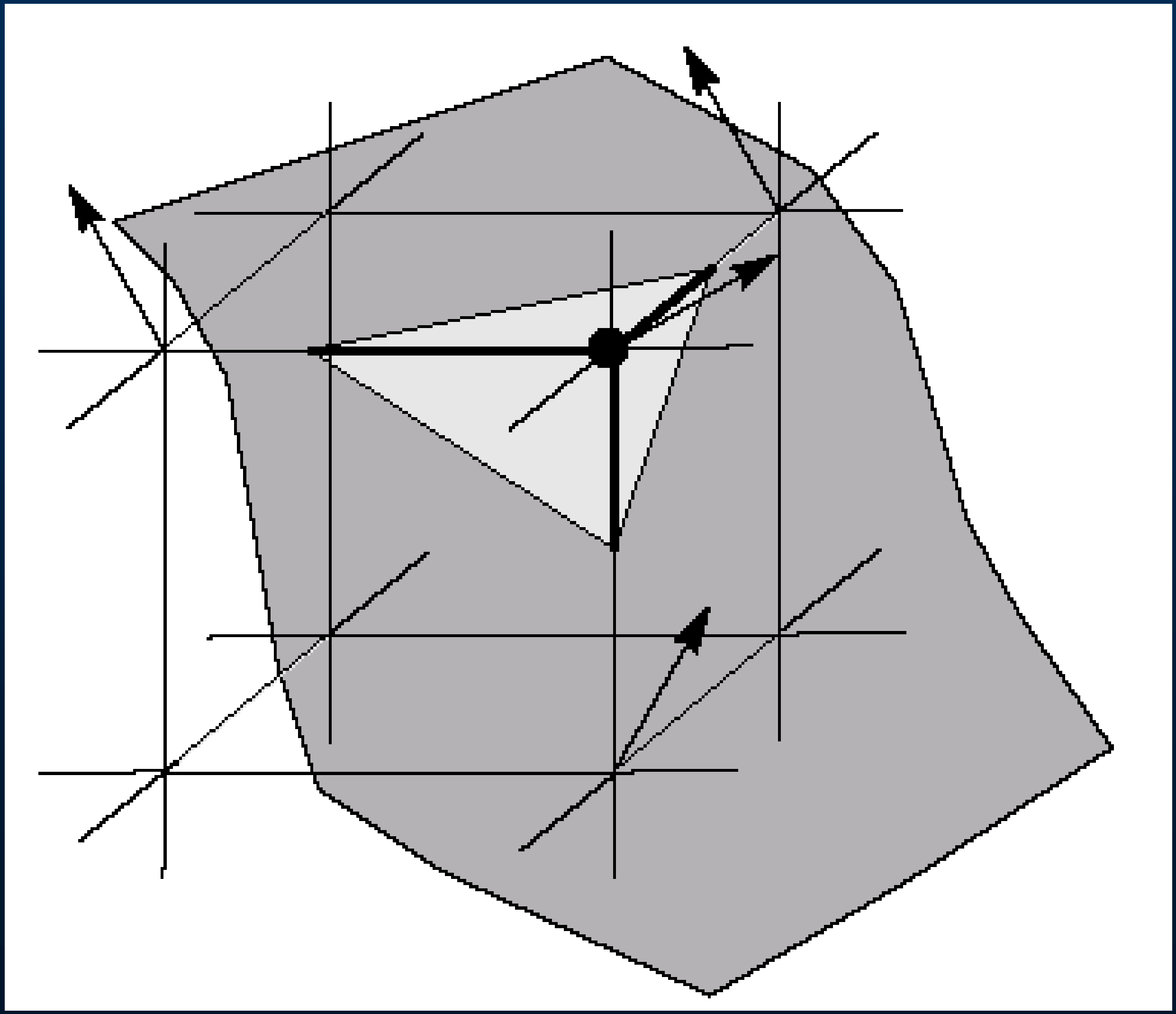
Step 6 - Calculate and interpolate normals

- For each triangle edge, find the vertex normals from the gradient of the density data using central differences

$$Gx = D(i + 1, j, k) - D(i - 1, j, k)$$

$$Gy = D(i , j + 1, k) - D(i , j - 1, k)$$

$$Gz = D(i , j, k + 1) - D(i , j, k - 1)$$



Marching Cubes

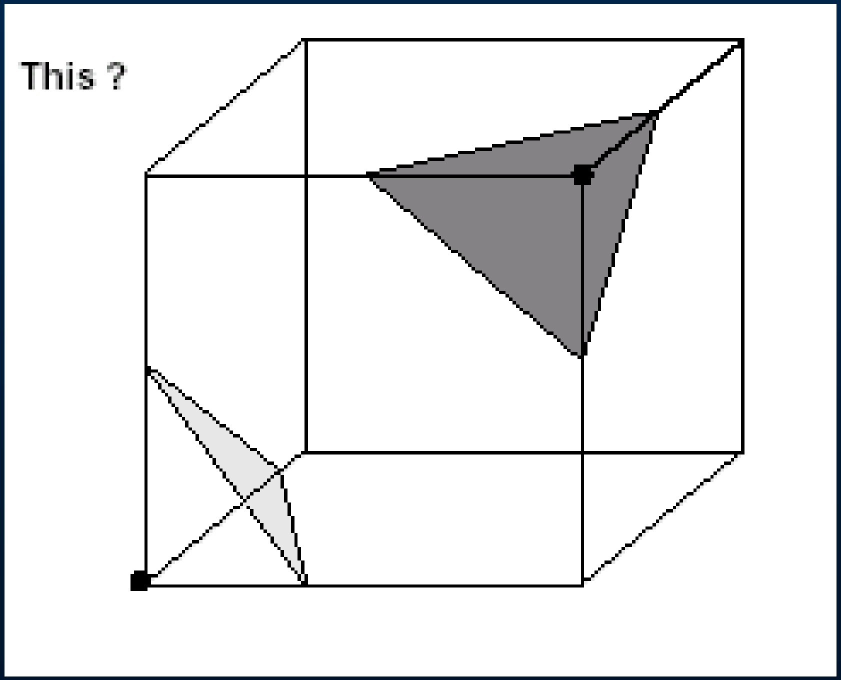
Extensions for Analysis

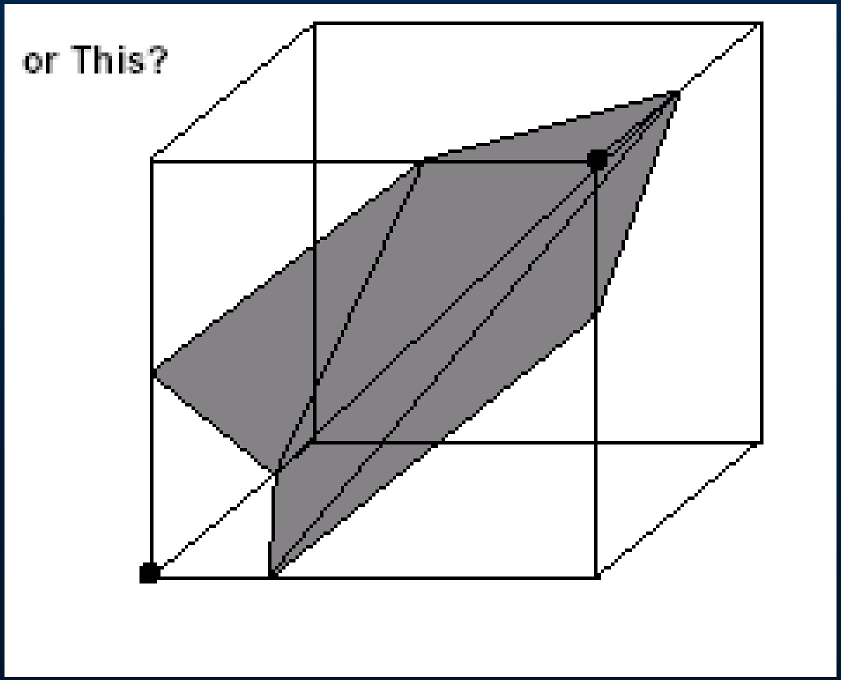
- Originally developed to produce surfaces for rendering
- Ambiguous cases can result in holes
- Many solutions proposed by many authors
  - Face patching
  - Tetrahedra
  - Function dependent triangulation

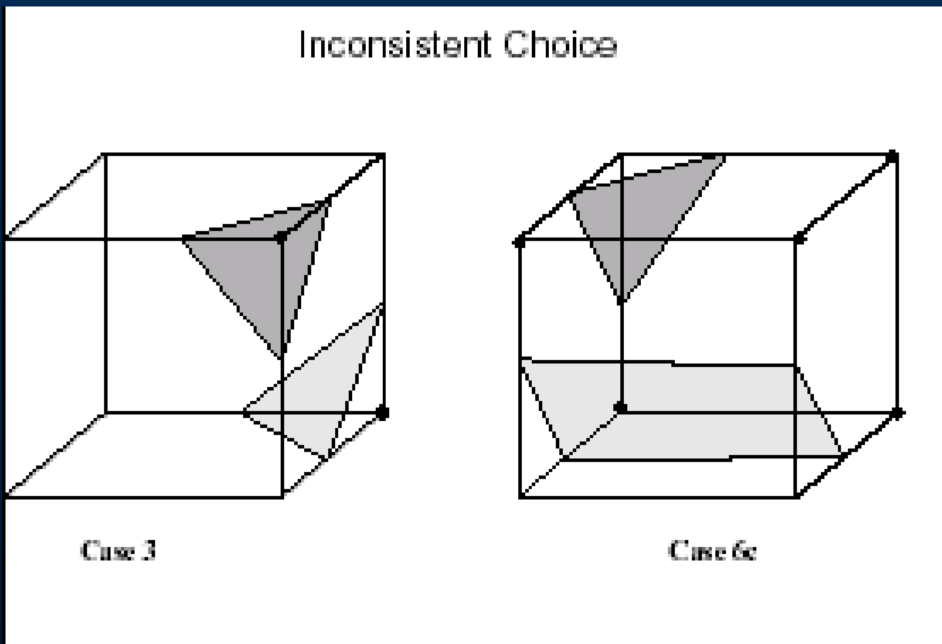
Marching Cubes

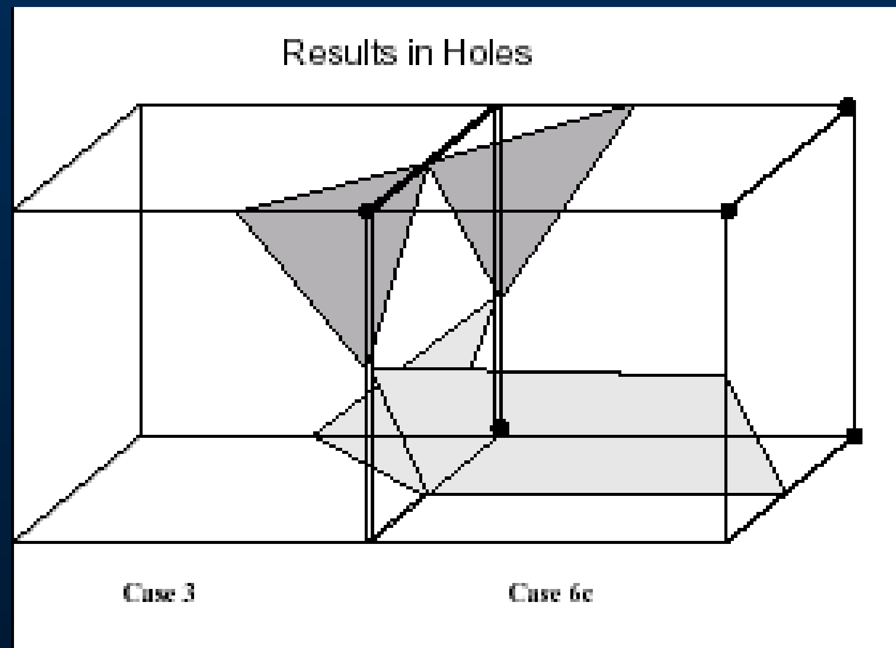
Ambiguous Cases

- Occur on any cube face that has adjacent vertices with different states, but diagonal vertices in same state
- There are six of these cases





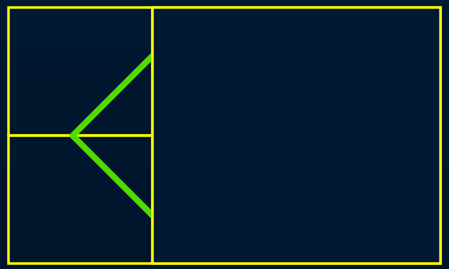

Inconsistent Choice
Case 3
Case 6c


Results in Holes
Case 3
Case 6c

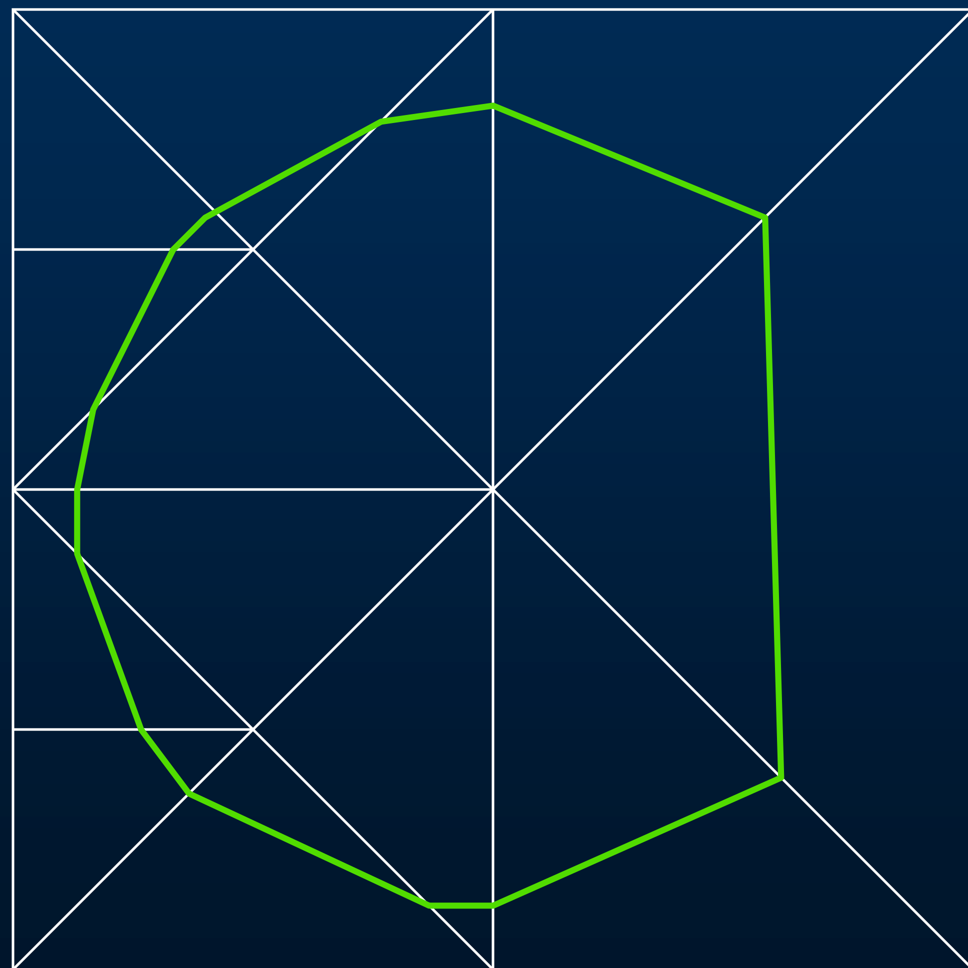
Marching Tetrahedra

- **Efficiency - Multi-resolution, Large Reduction in Number of Primitives**

- **Continuity - Smooth Transition Between Levels**



Our Approach



Algorithm Overview

Recursive Subdivision → Tetrahedra Representation

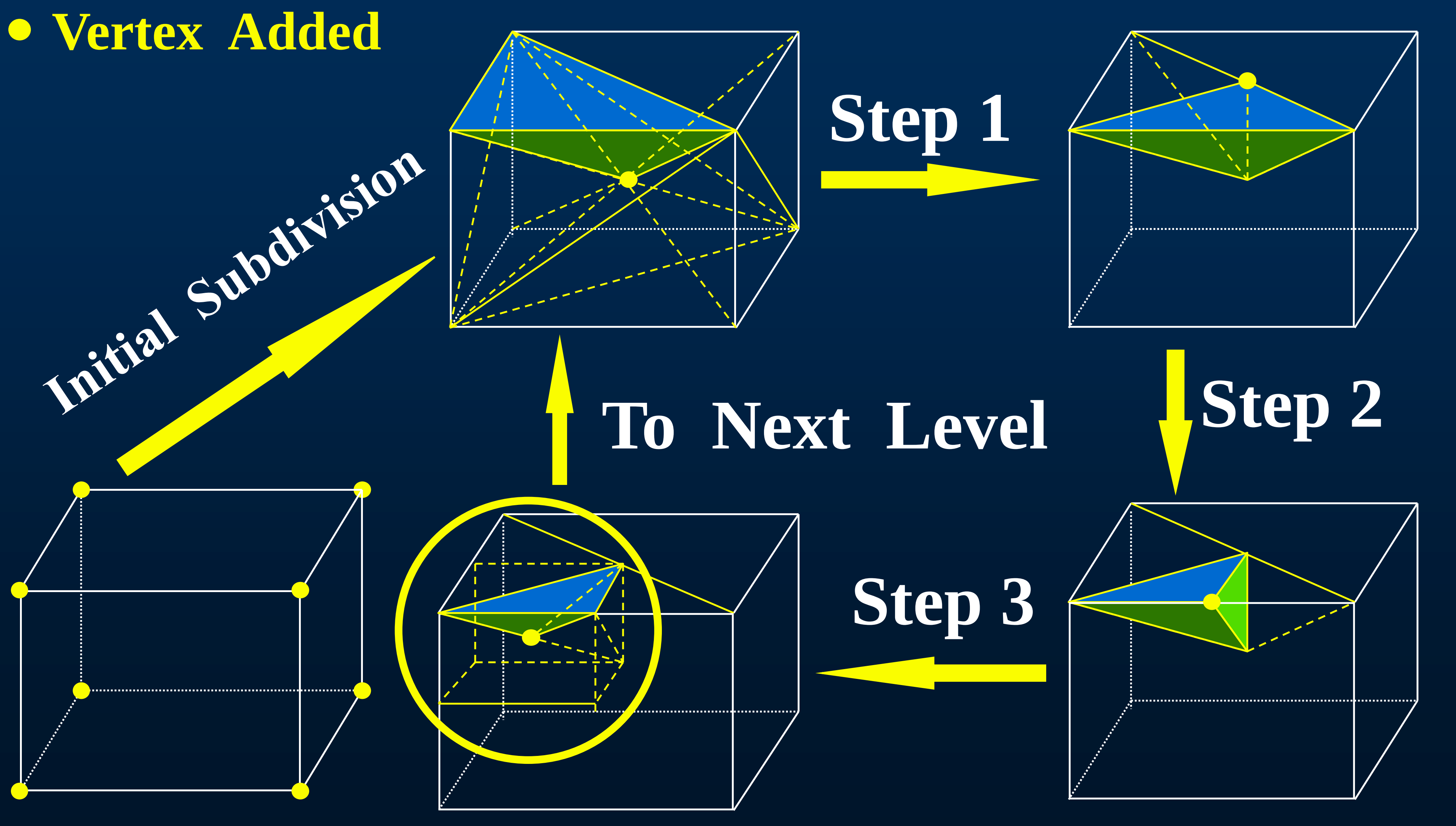
Tetrahedra Fusion → Multi-Level Tetrahedra Representation

Triangulation → Level-Of-Detail Triangular Surface

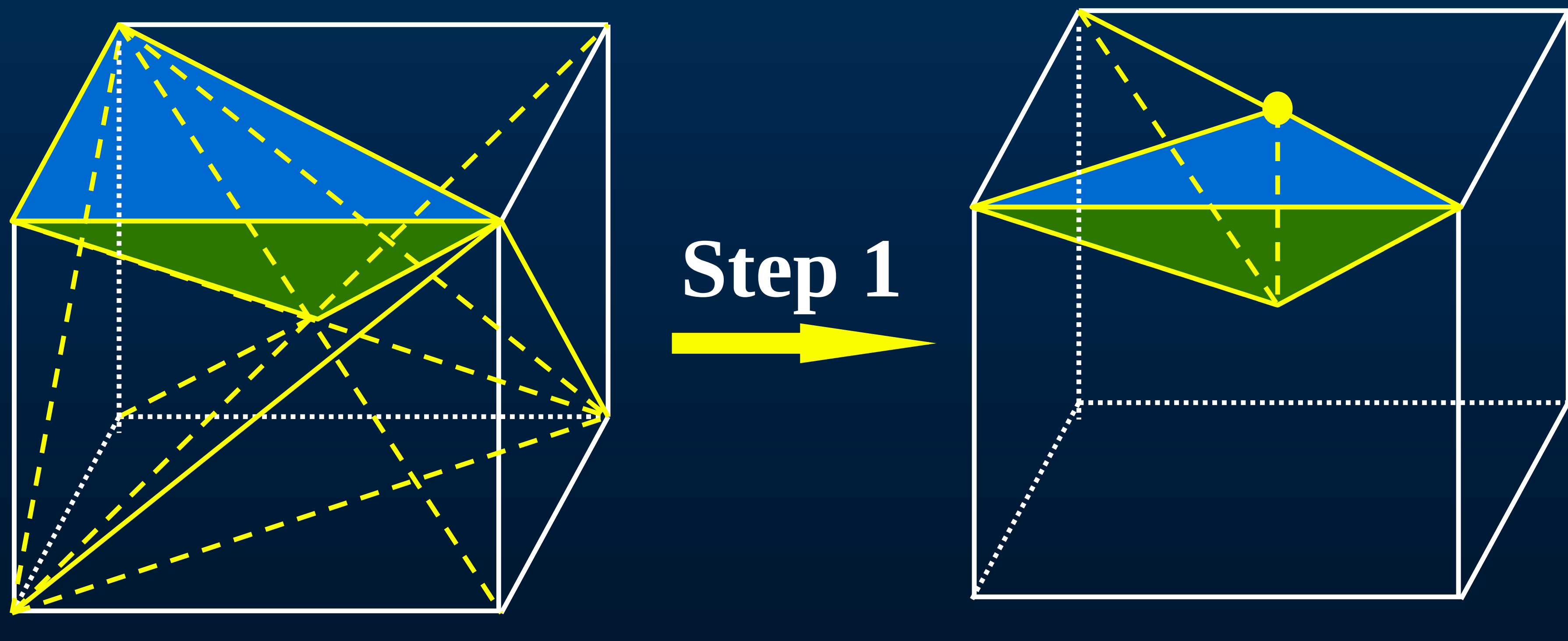
Metrics:

1. Geometry
2. Topology

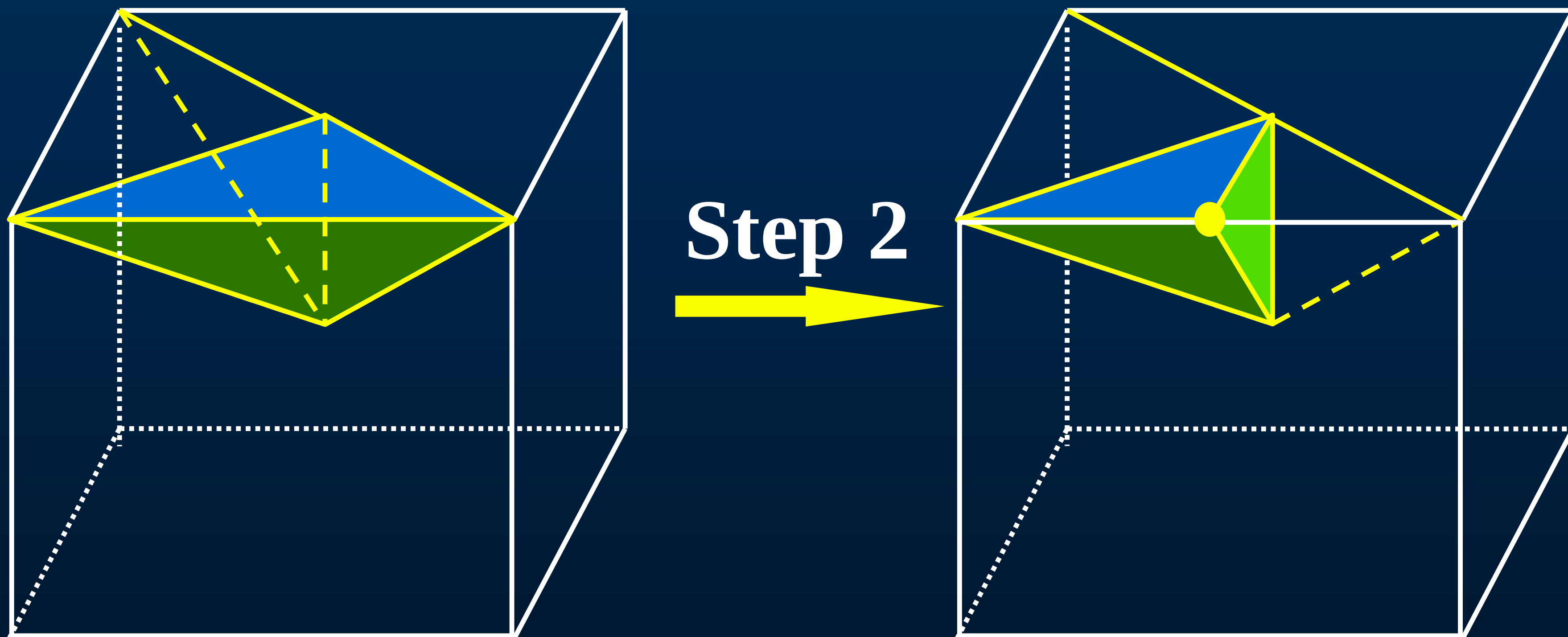
Recursive Subdivison (Virtual)



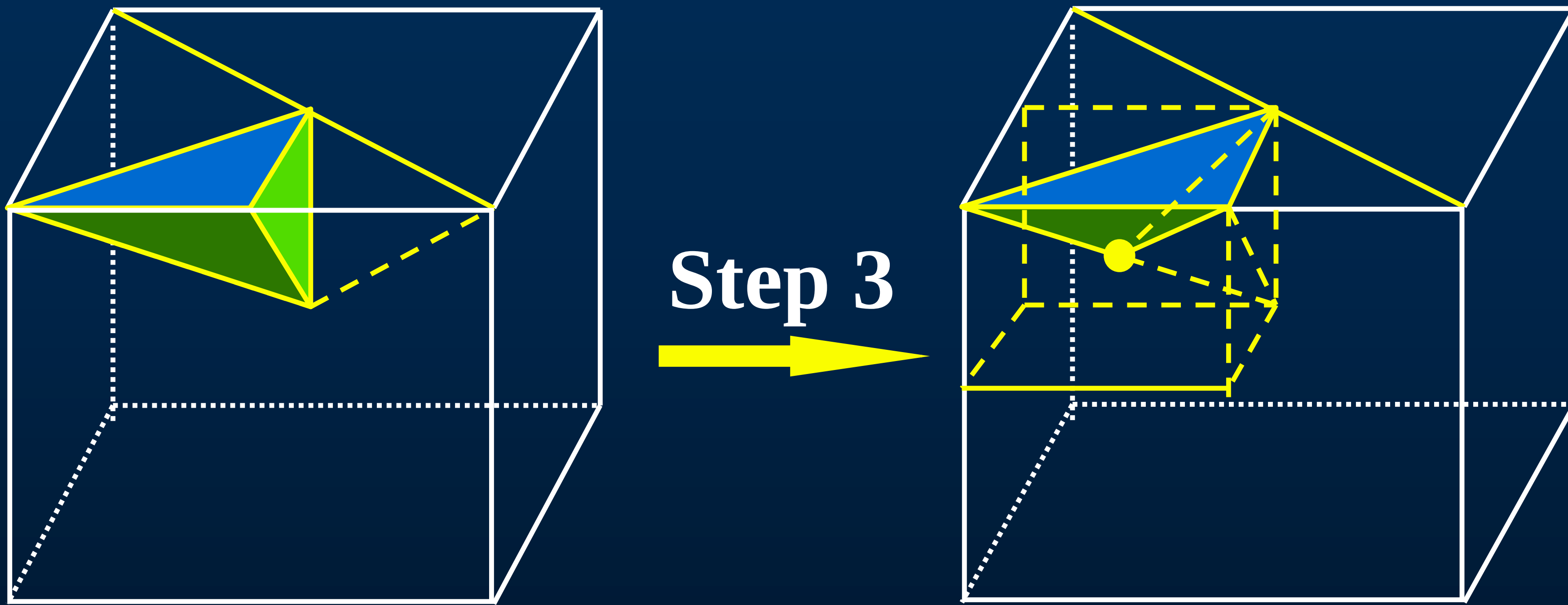
Recursive Subdivison



Recursive Subdivison

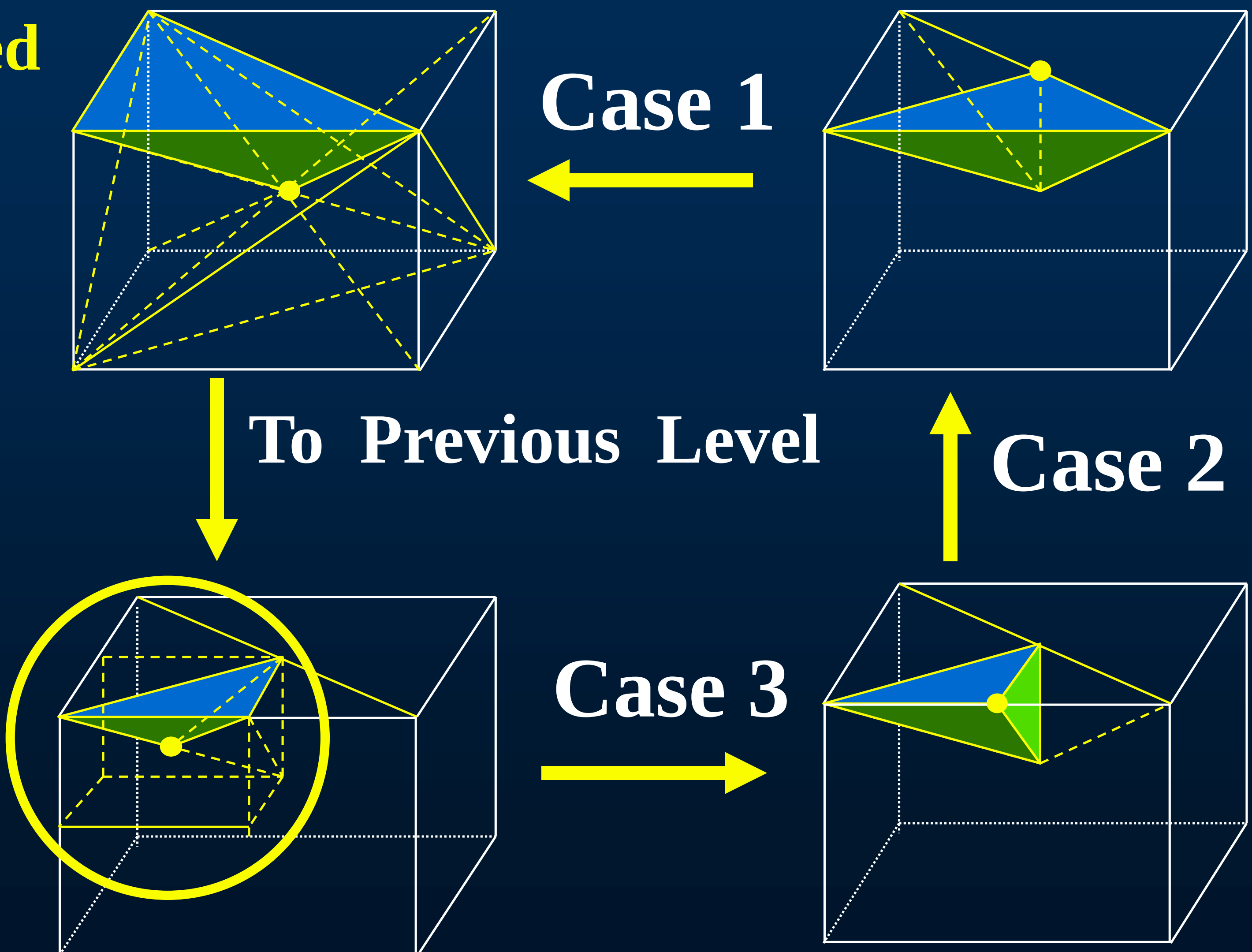


Recursive Subdivison

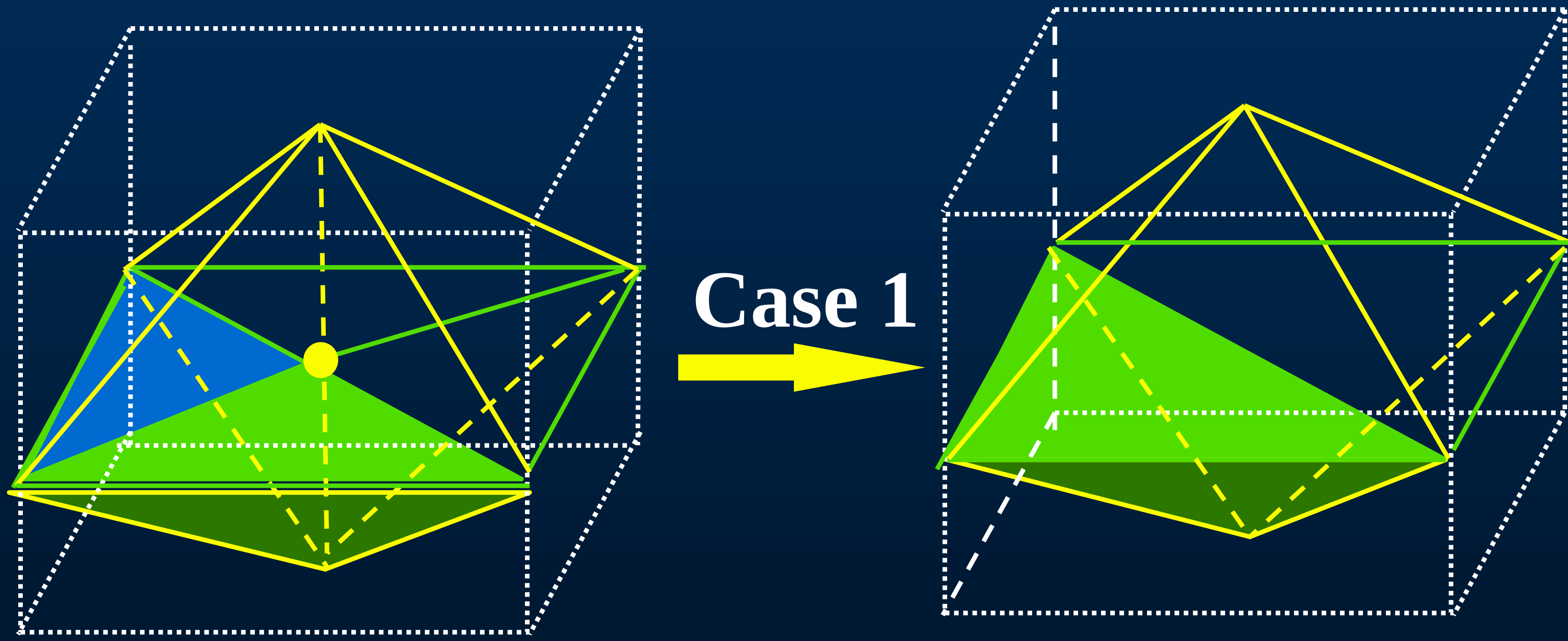


Recursive Fusion

- Vertex Removed

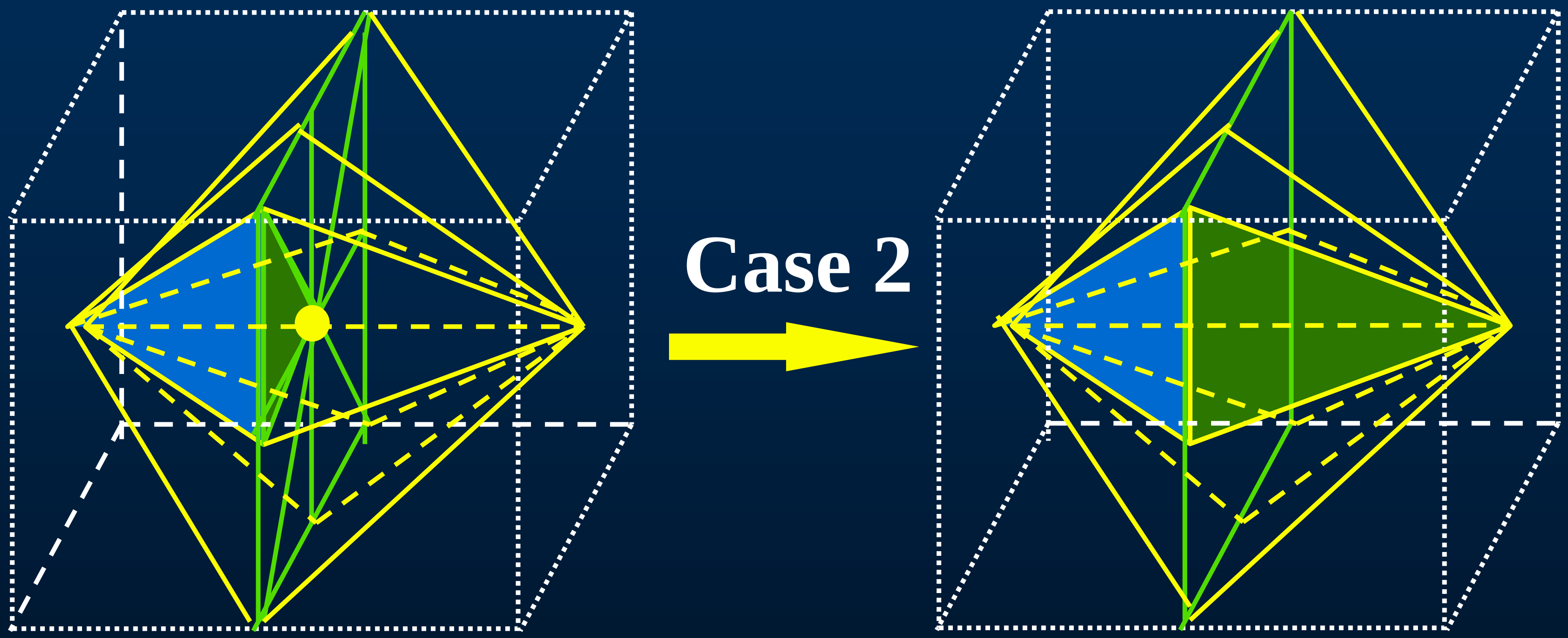


Recursive Fusion



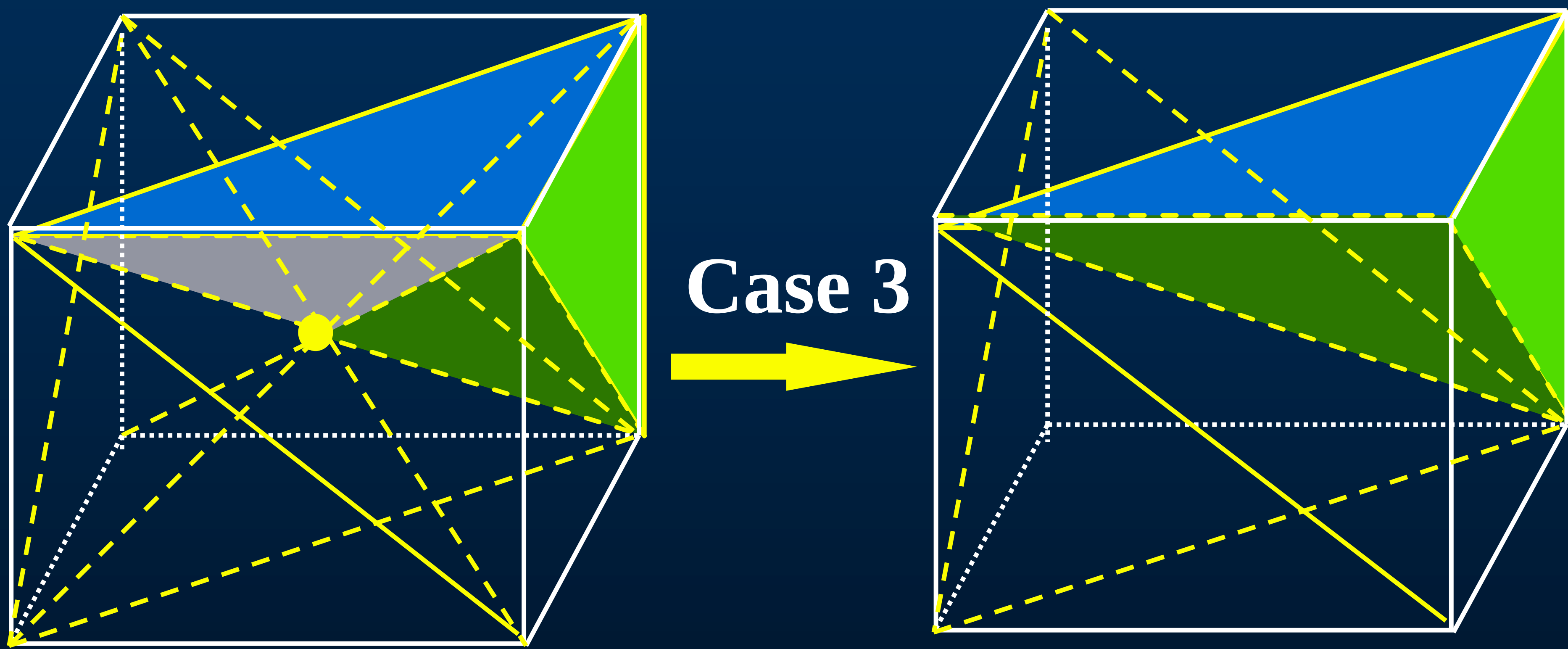
• Vertex Removed

Recursive Fusion



● Vertex Removed

Recursive Fusion

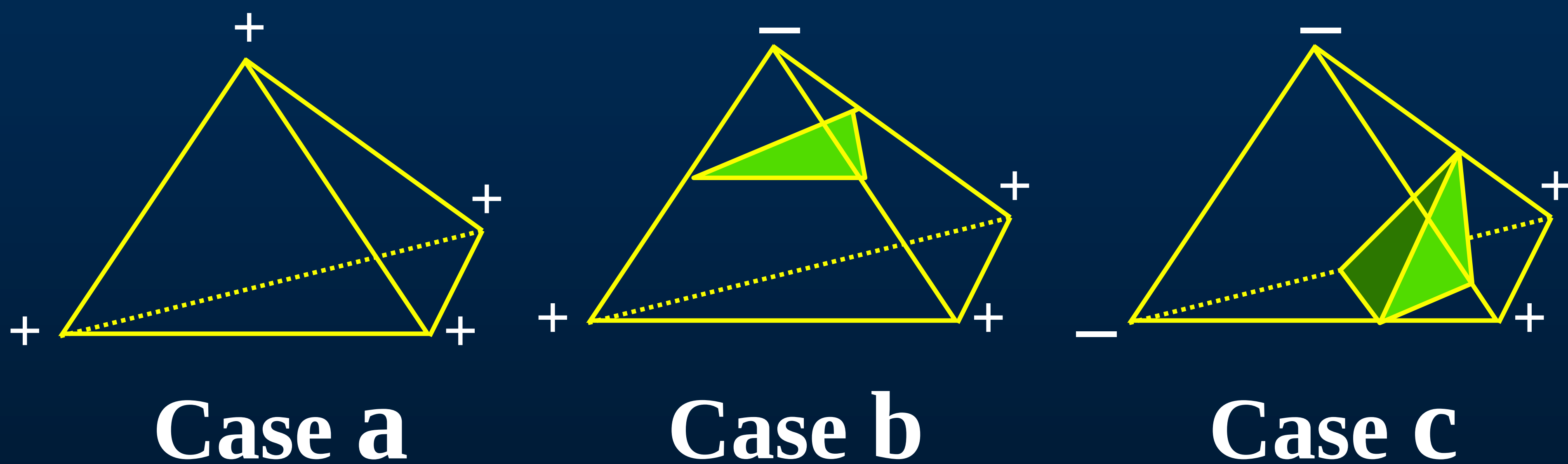


- Vertex Removed

Fusion Criteria

- Geometric Error Metric
- Topological Error Metric

Isosurface Configuration of Tetrahedron



Geometric Error Analysis

Error = Distance (New-iso-point, Old-iso-point)

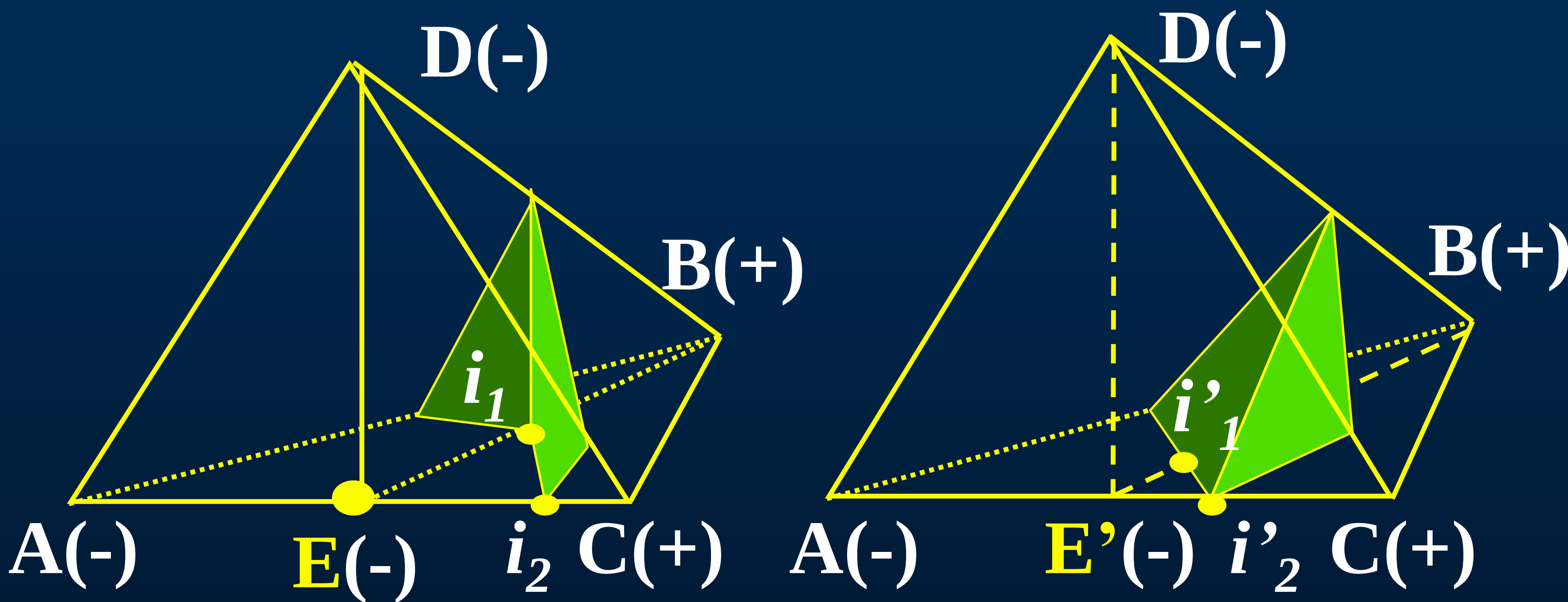
Distance: Object Space or Image Space

(view-independent) (view-dependent)

New-iso-point: Iso-point with Dividing Point

Old-iso-Point: Iso-point without Dividing Point

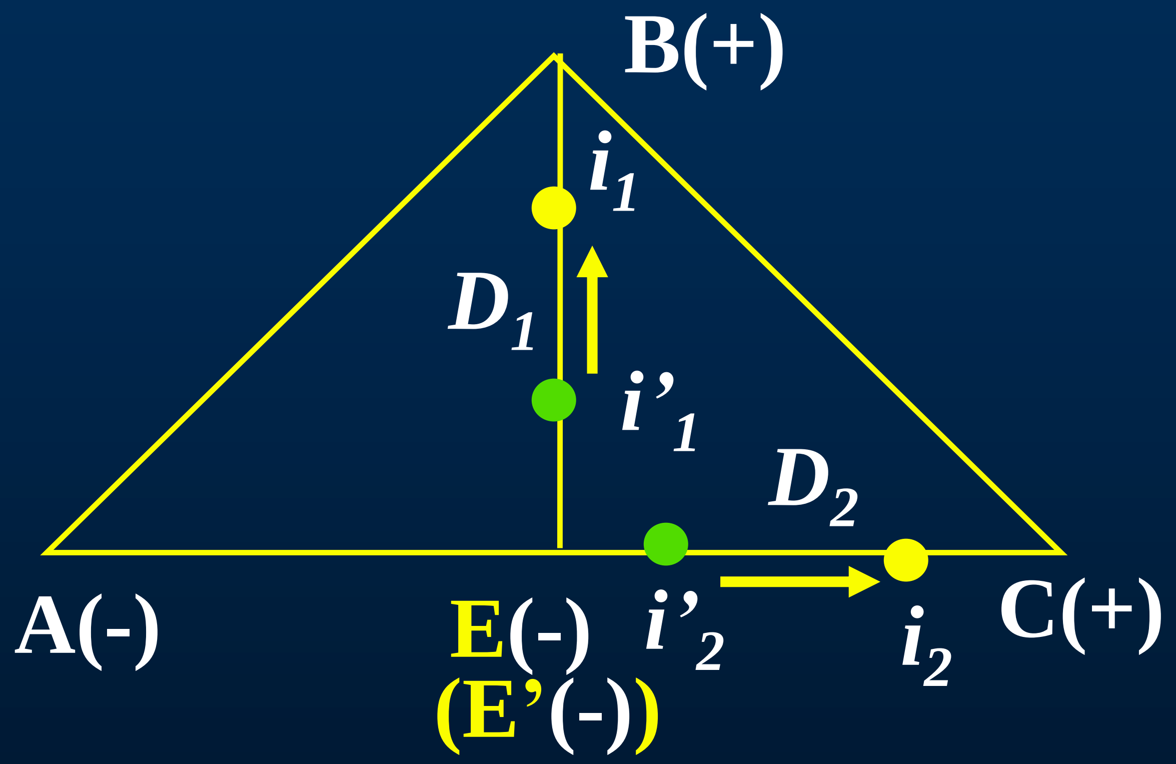
Geometric Error Analysis

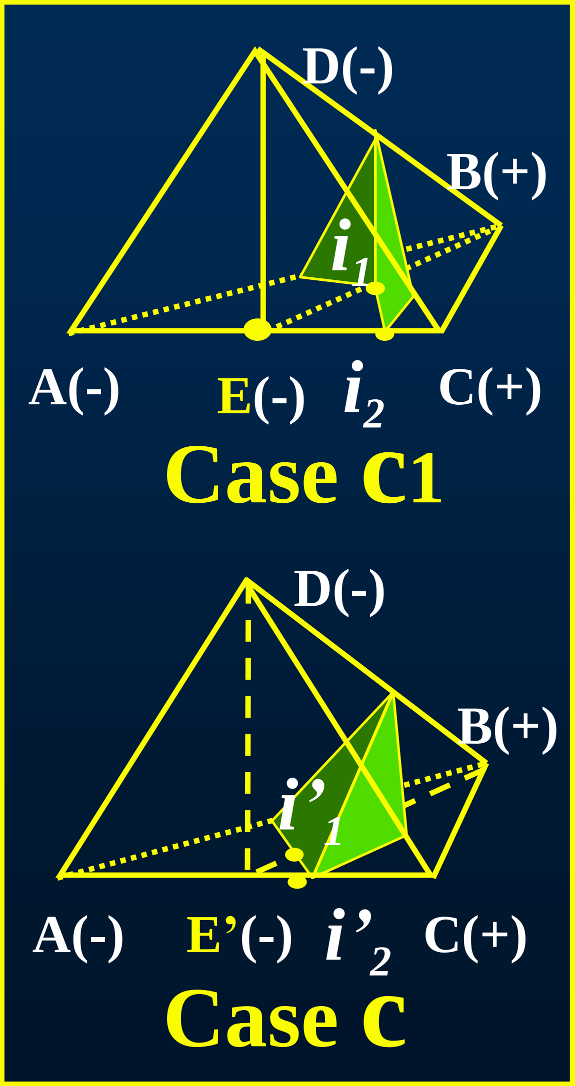


Case C1

Case C

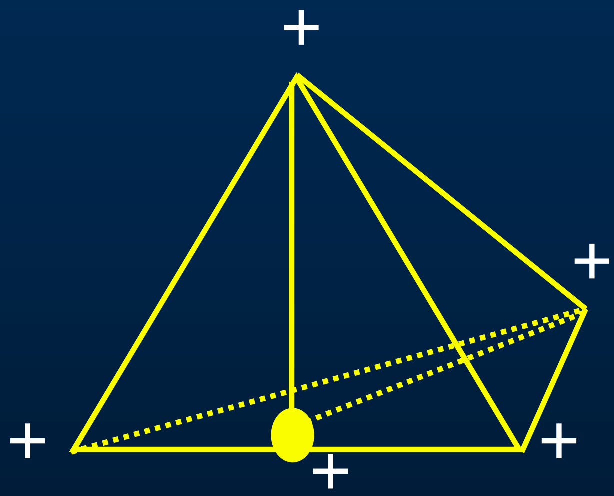
Geometric Error Analysis



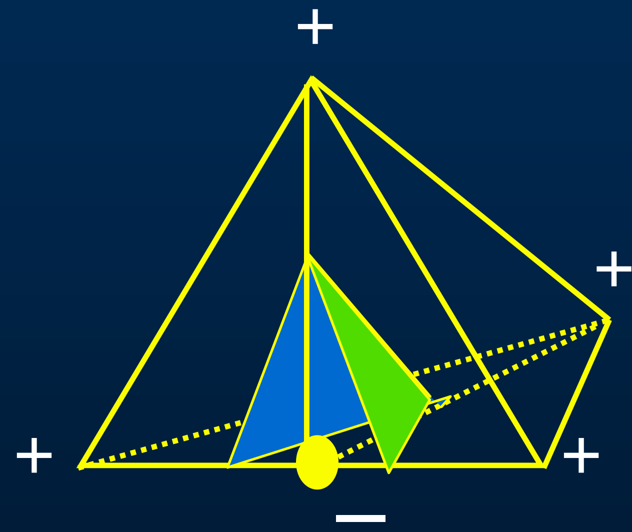


Error (E) = maximum (D_1 , D_2)

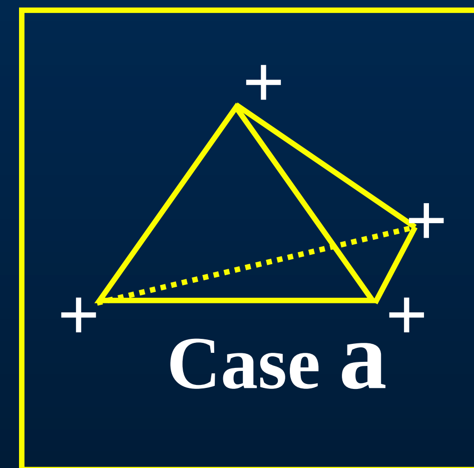
New Isosurface Configuration After Subdivision



Case a1



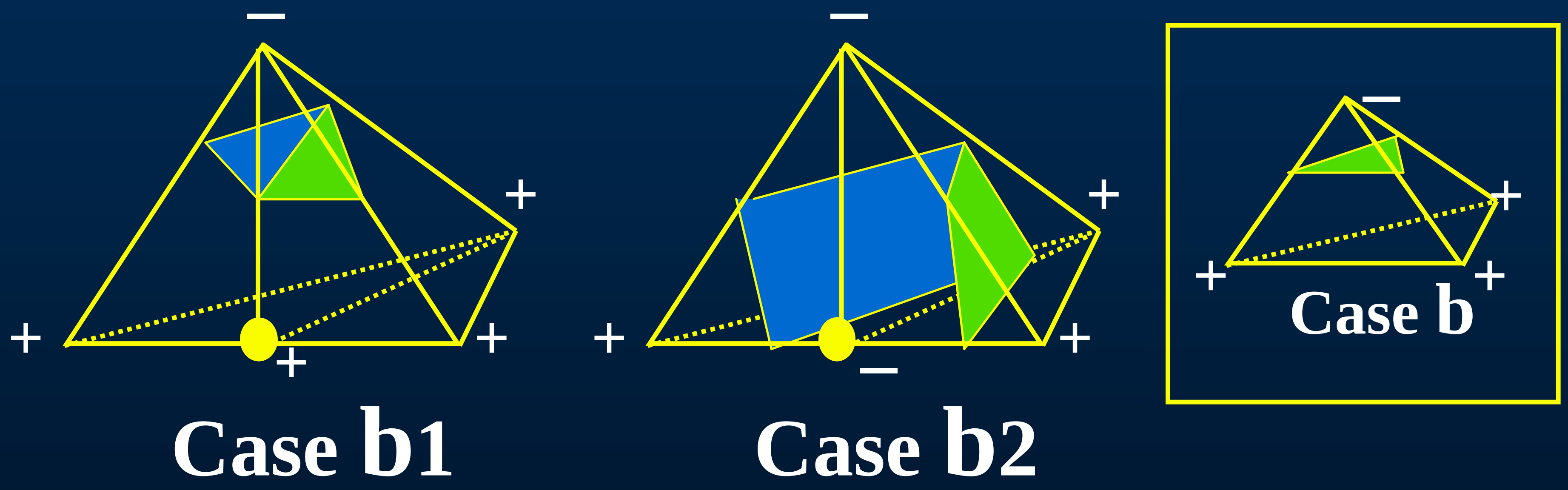
Case a2



Case a

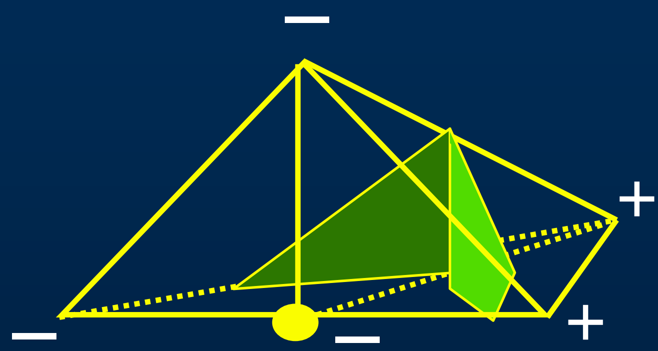
• Dividing Point

New Isosurface Configuration After Subdivision

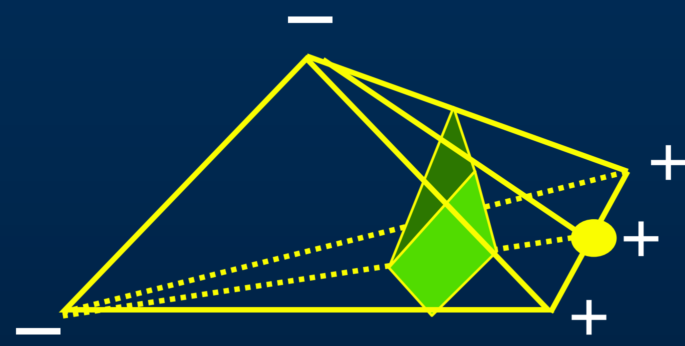


• Dividing Point

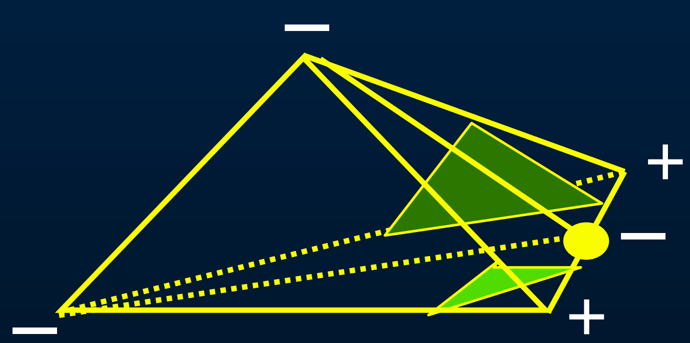
New Isosurface Configuration After Subdivision



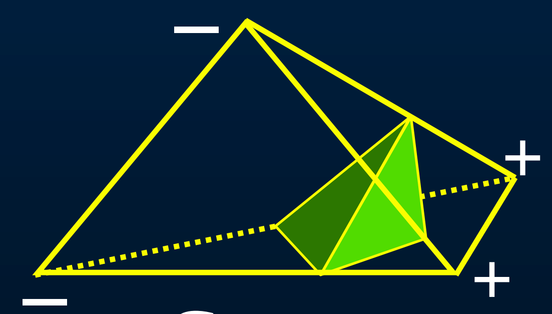
Case c1



Case c2



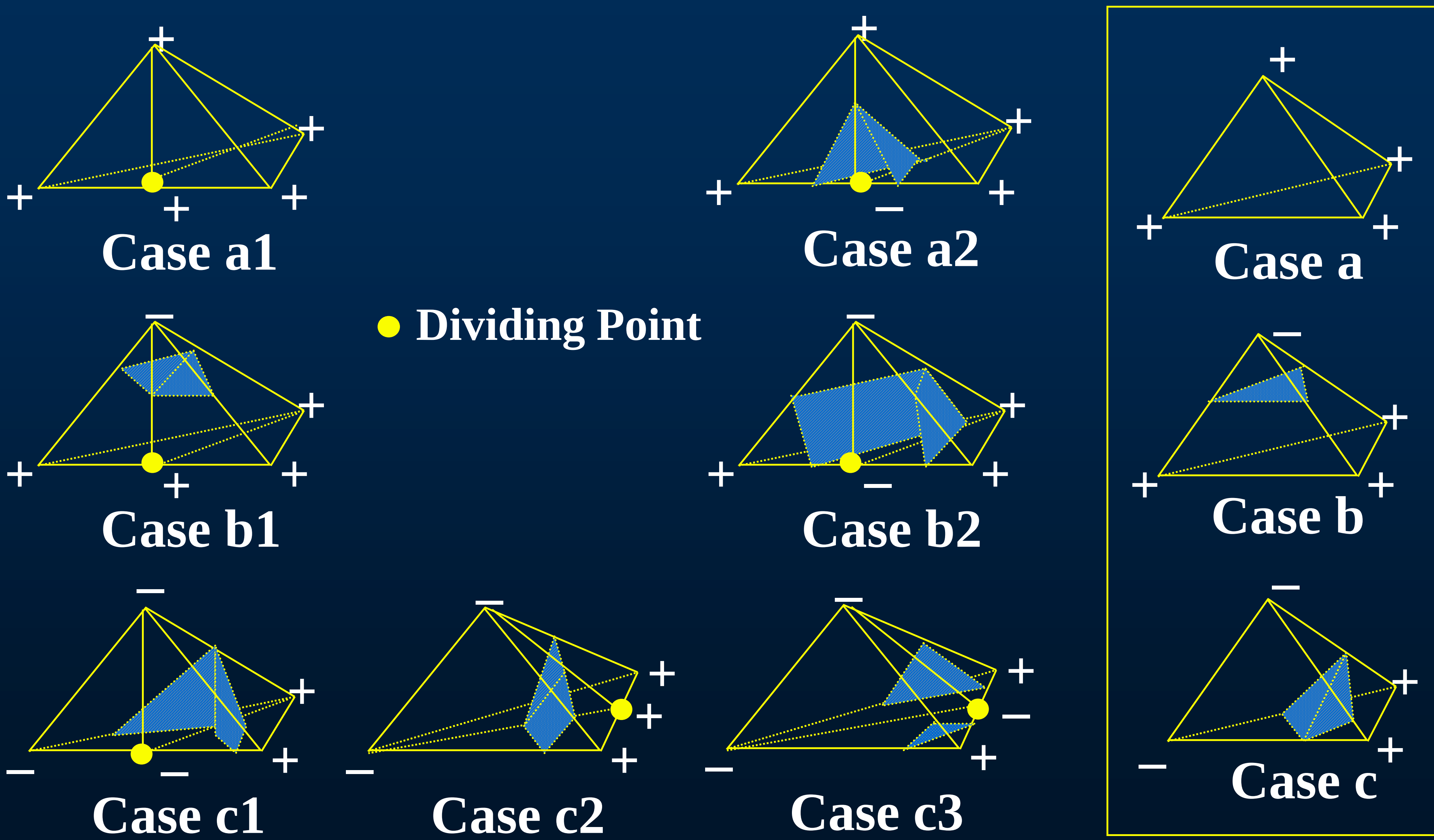
Case c3



Case c

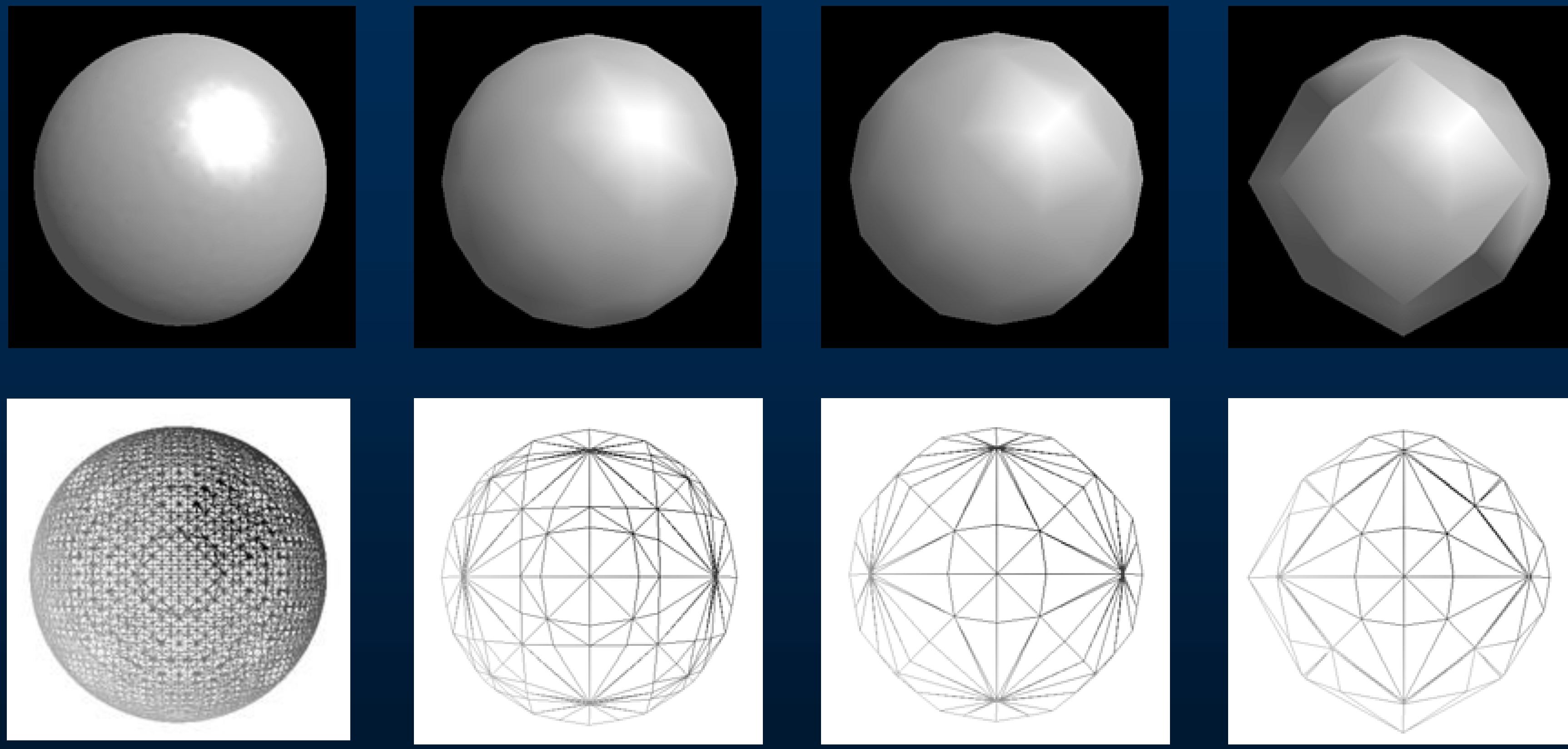
• Dividing Point

A Look-up Table



Results

(without topology simplification)

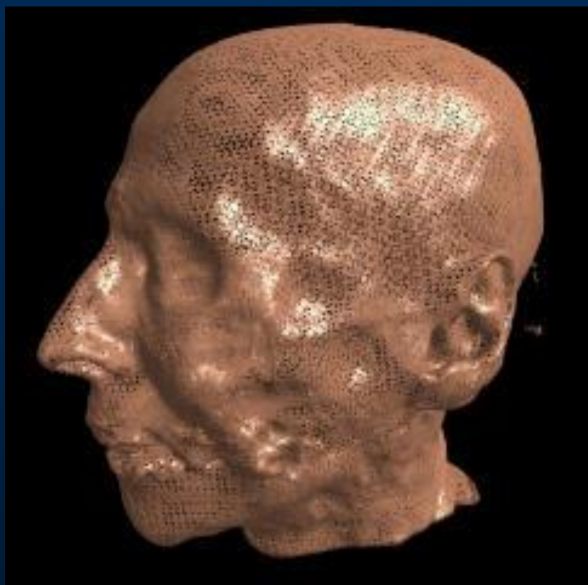


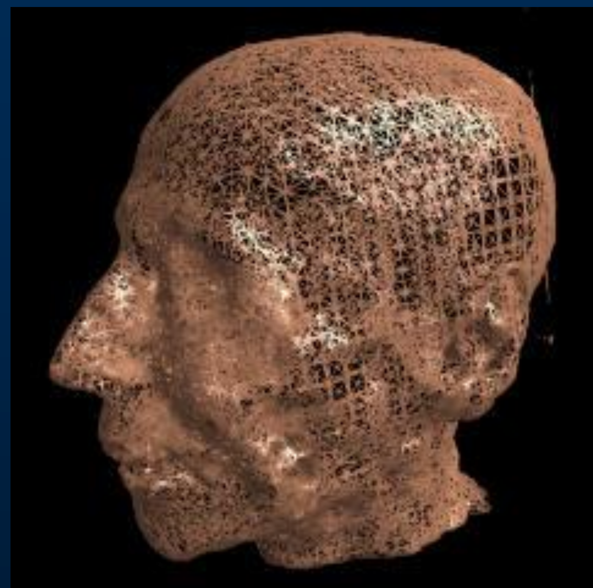
Error = 0
Tri: 44,696

Error = 1.
Tri: 720

Error = 2.
Tri: 432

Error = 6.
Tri: 192

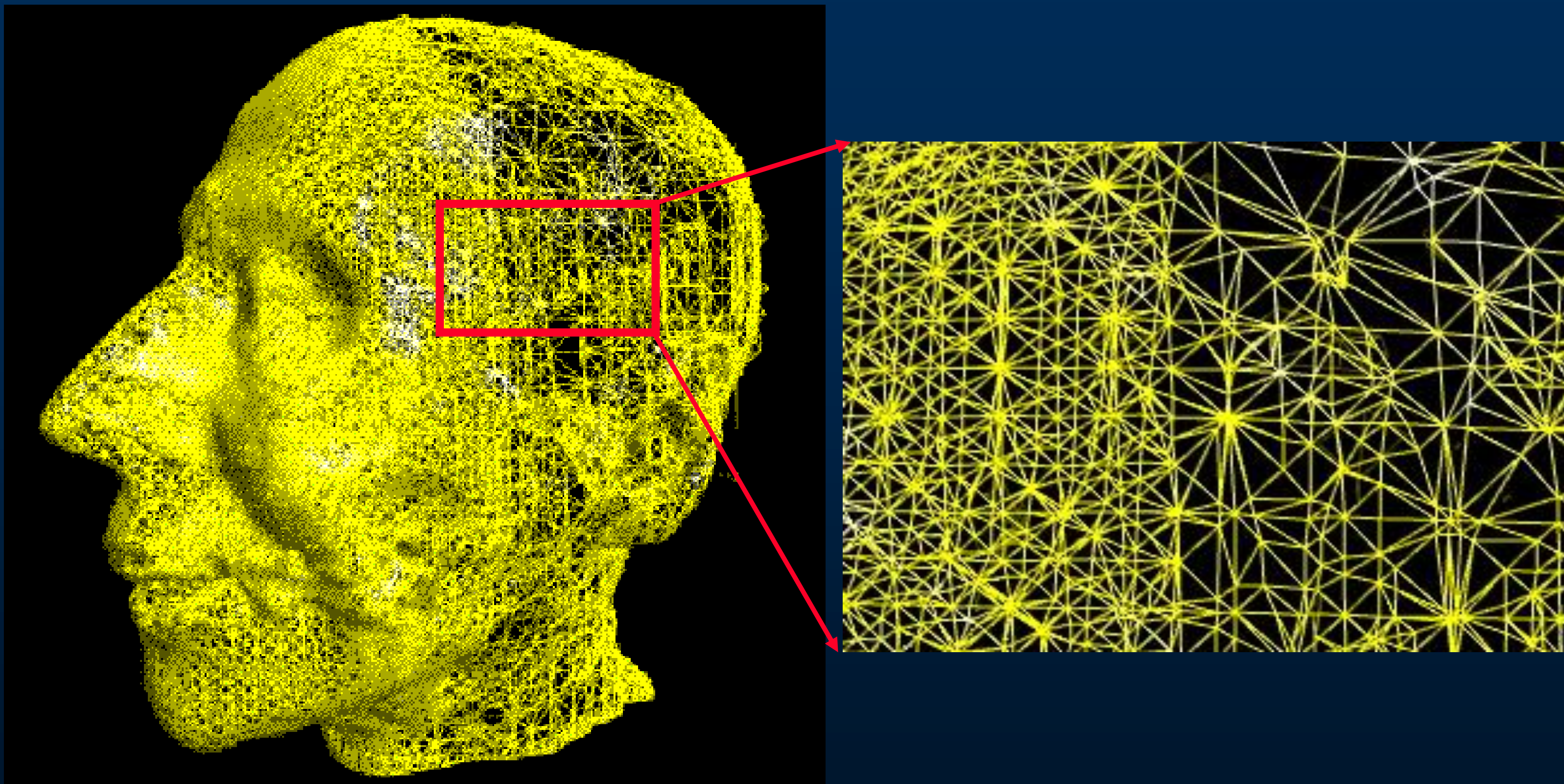




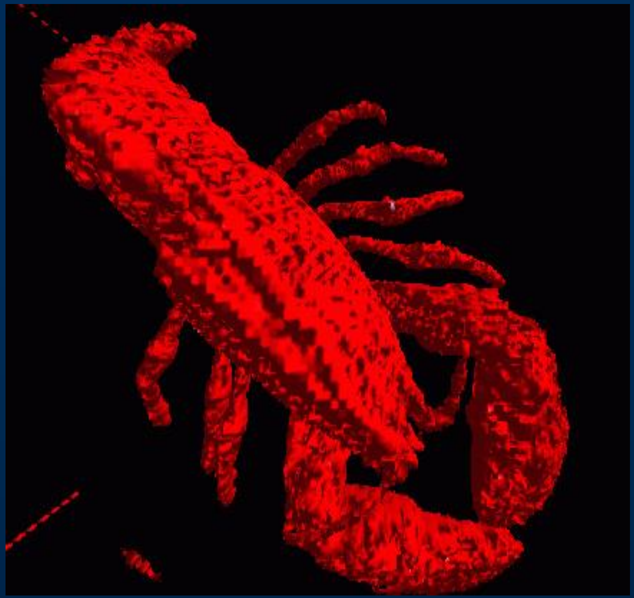
High level
(361,528 tris)

Medium level
(168,708 tris)

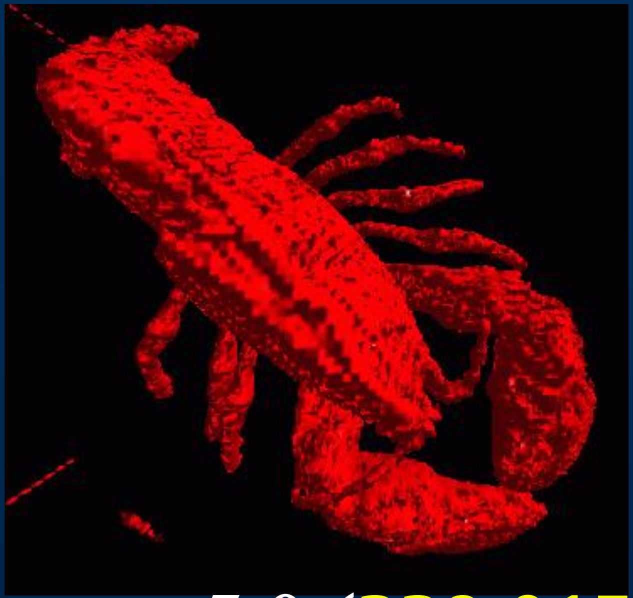
Low level
(81,246 tris)



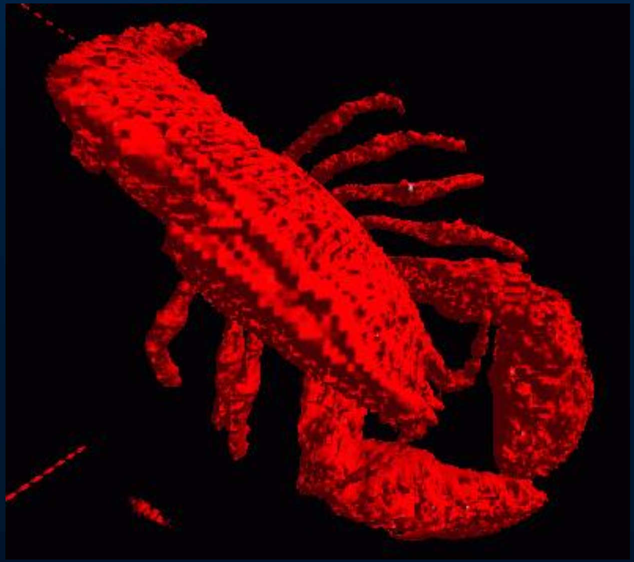
CT Head --- left:error=0 right:error=4.0



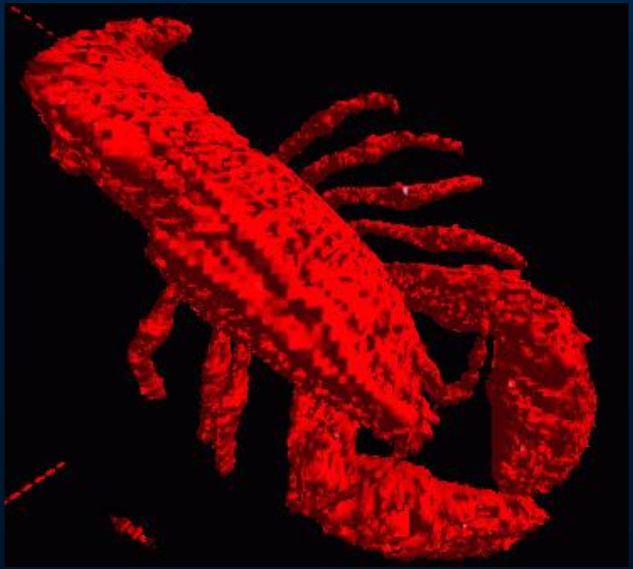
Error = 0 (536,629 tris)



Error = 5.0 (339,015 tris)



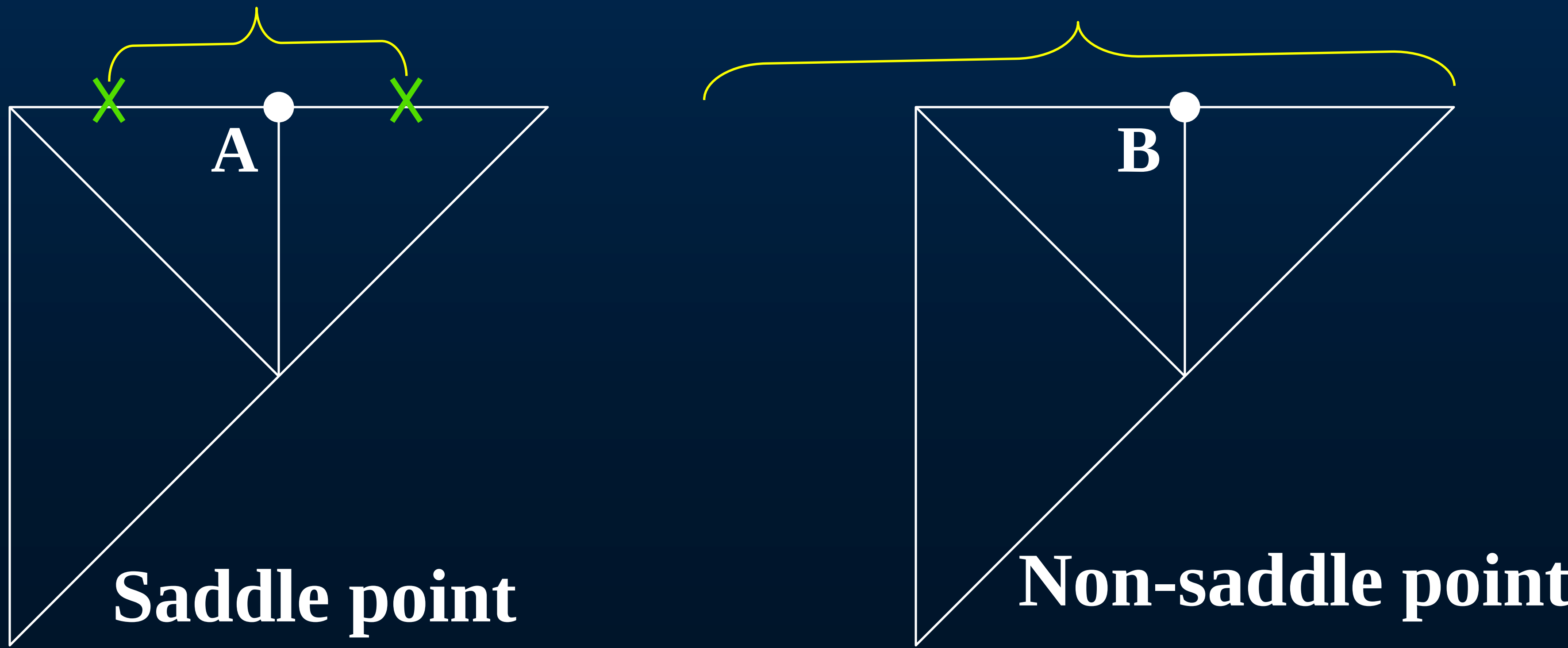
Error = 10.0 (310,522 tris)



Error = 15.0 (300,229 tris)

Topological Error Analysis

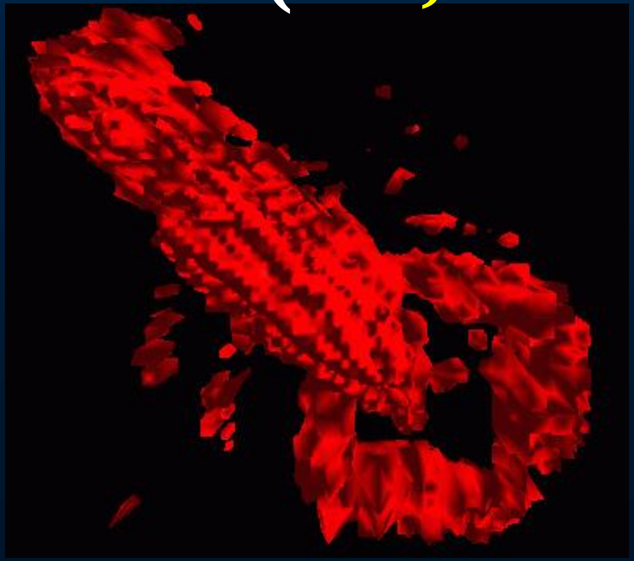
- Identify *Critical Points*
- Apply Topological Error Metric



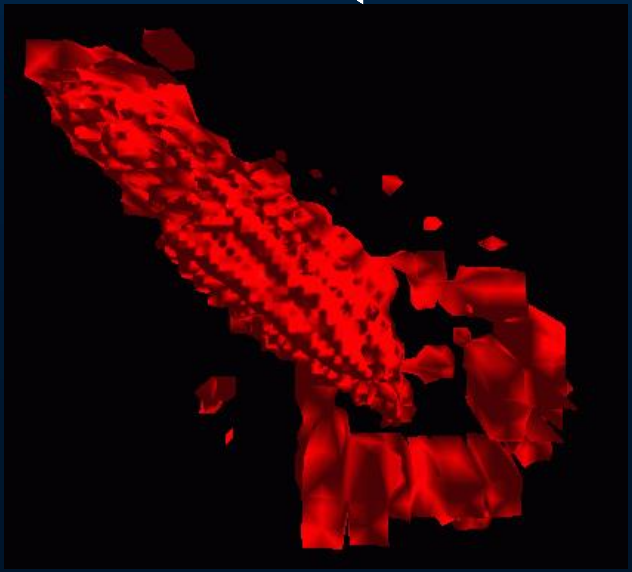
Results (with topology simplification)

Error = 0 (536,629 tris)

Error = 5.0 (98,142 tris)



Error = 10.0 (26,292 tris)



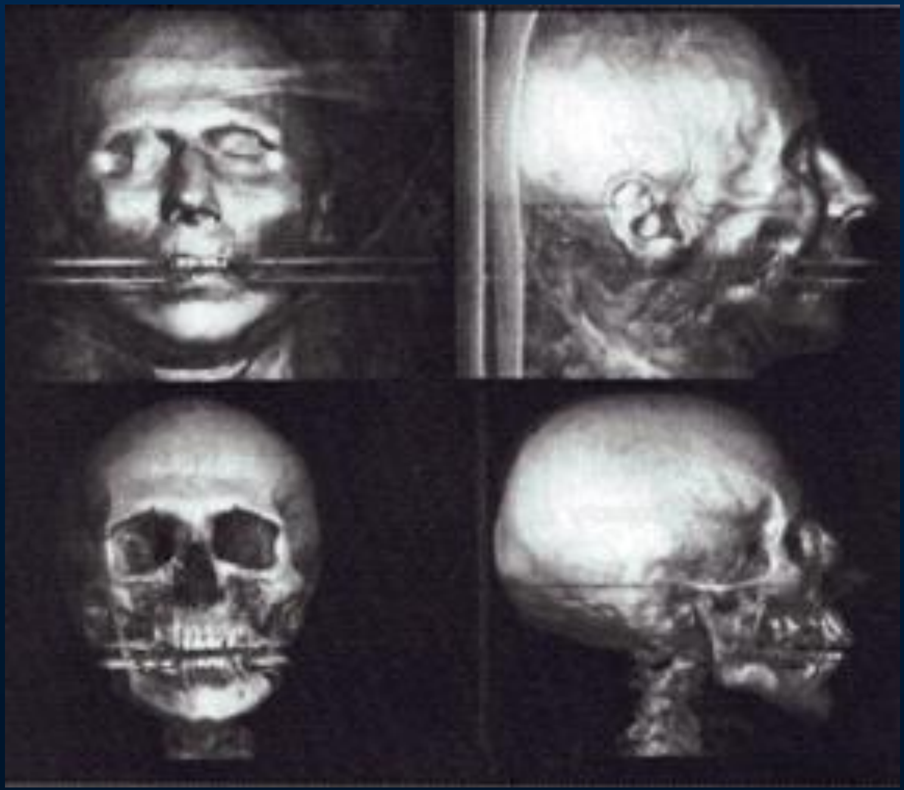
Error = 15.0 (16,436 tris)

Volume Rendering

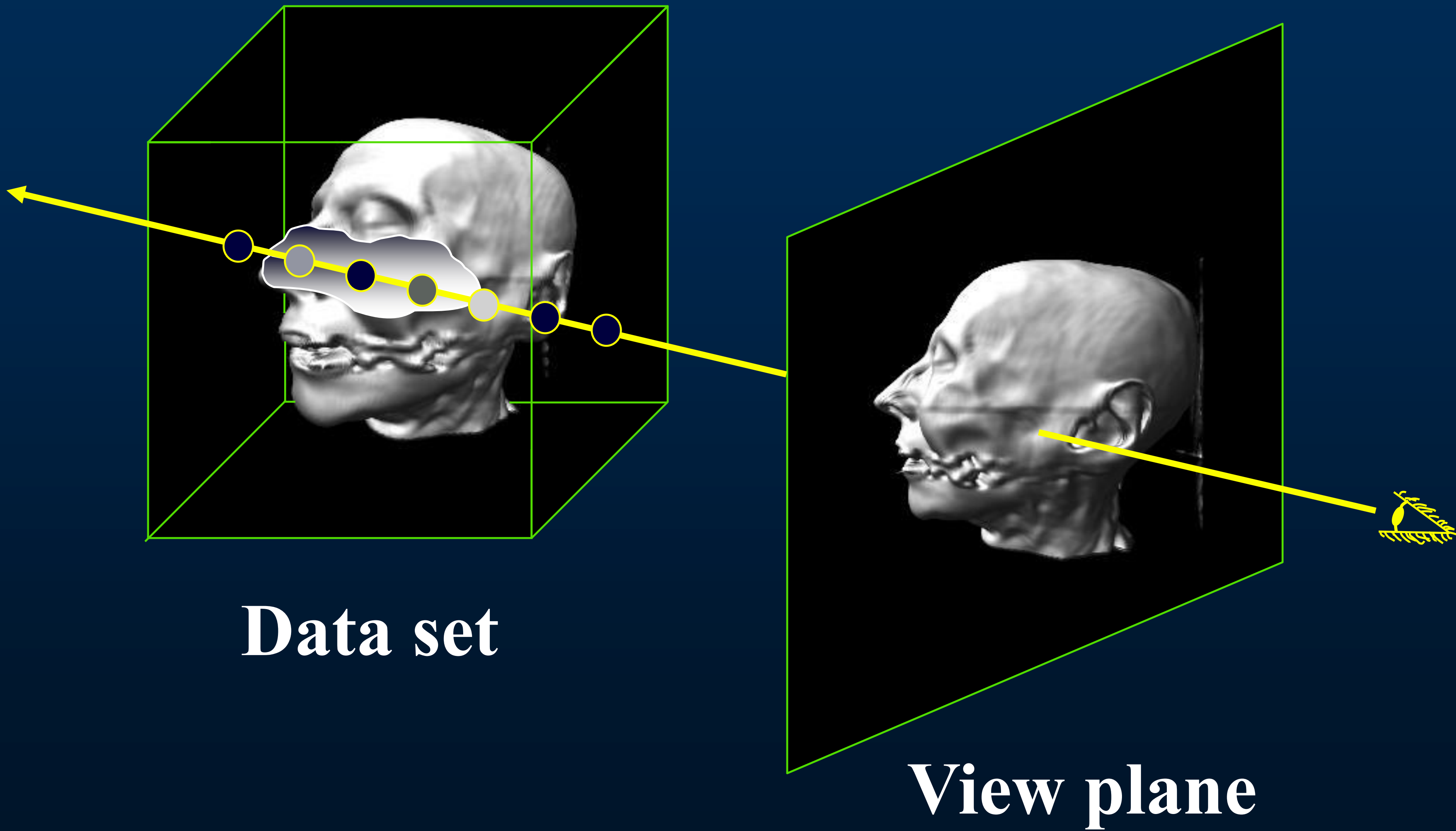
- Direct projection
- Translucent gel
- Information inside objects
- Discrete
- Large datasets
- Slow
- Classification
- Compositing

Direct Volume Rendering

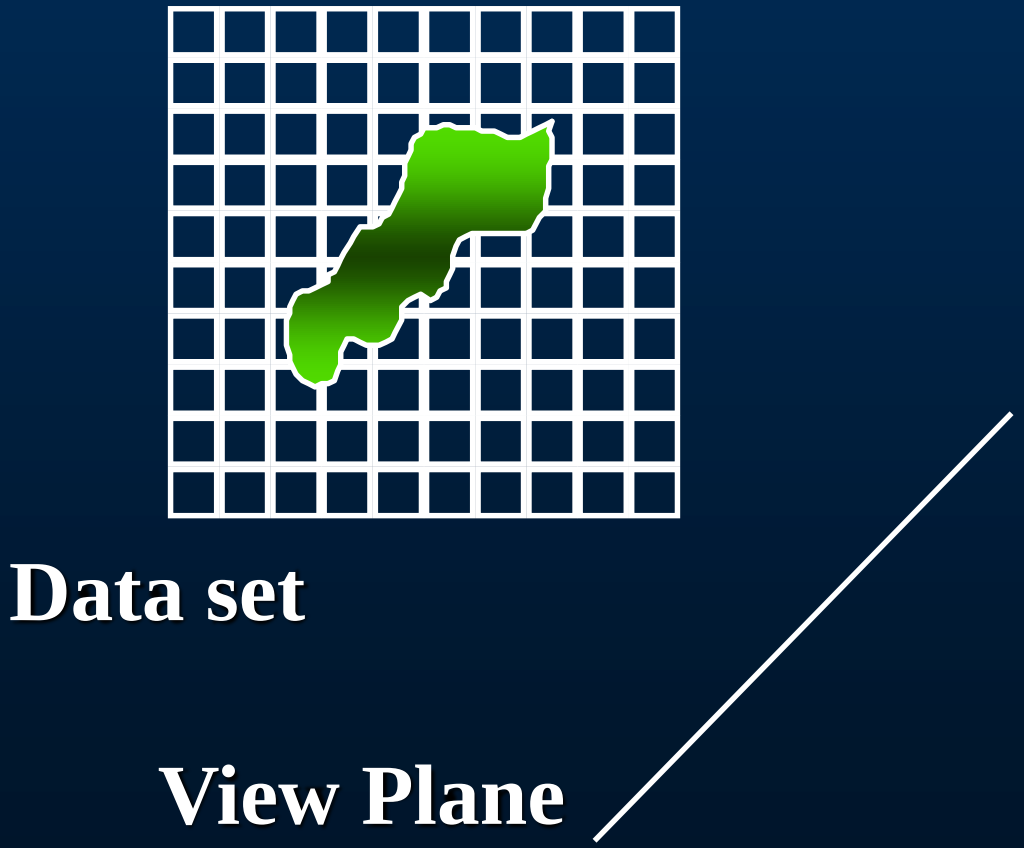
- Ray Casting
- Levoy 89 CG&A



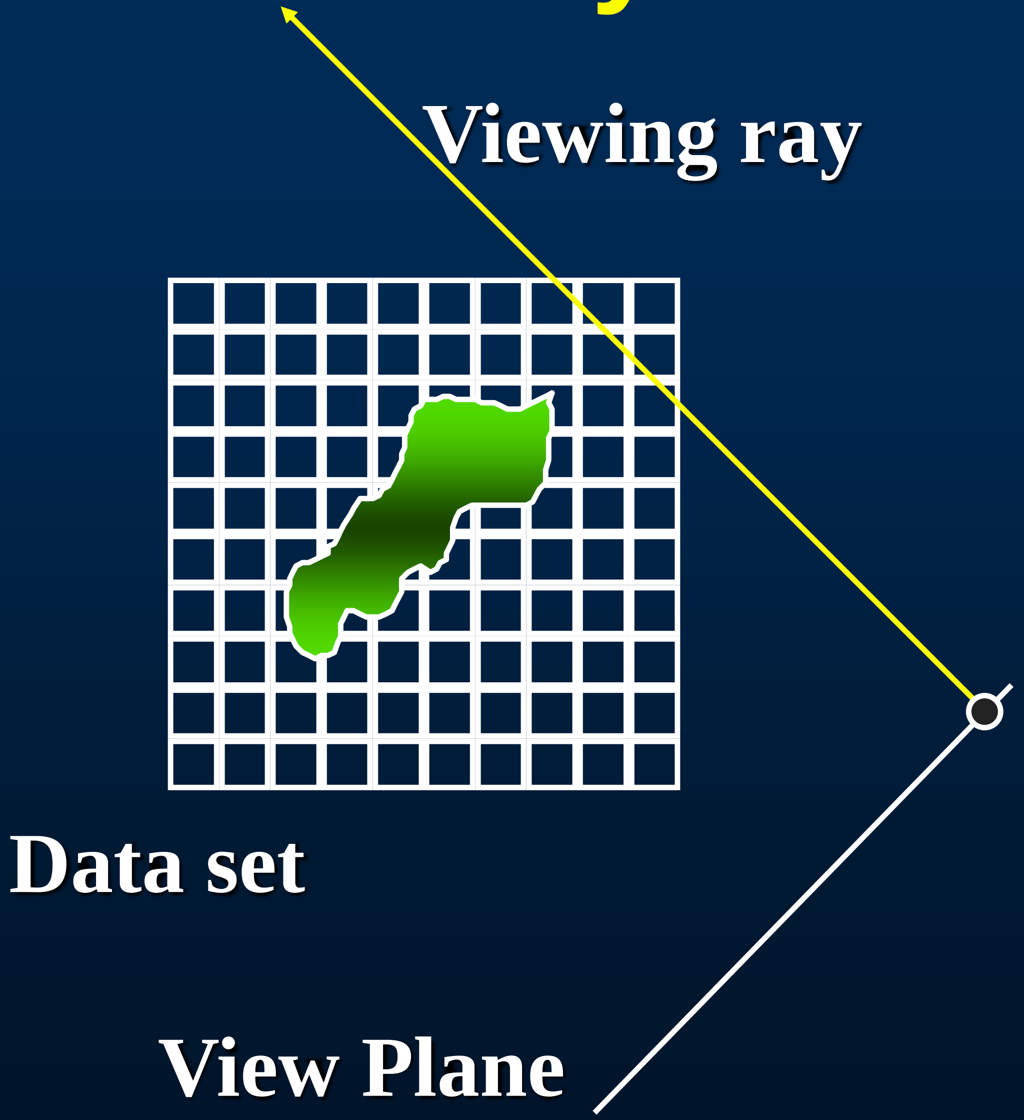
Volumetric Ray-Casting



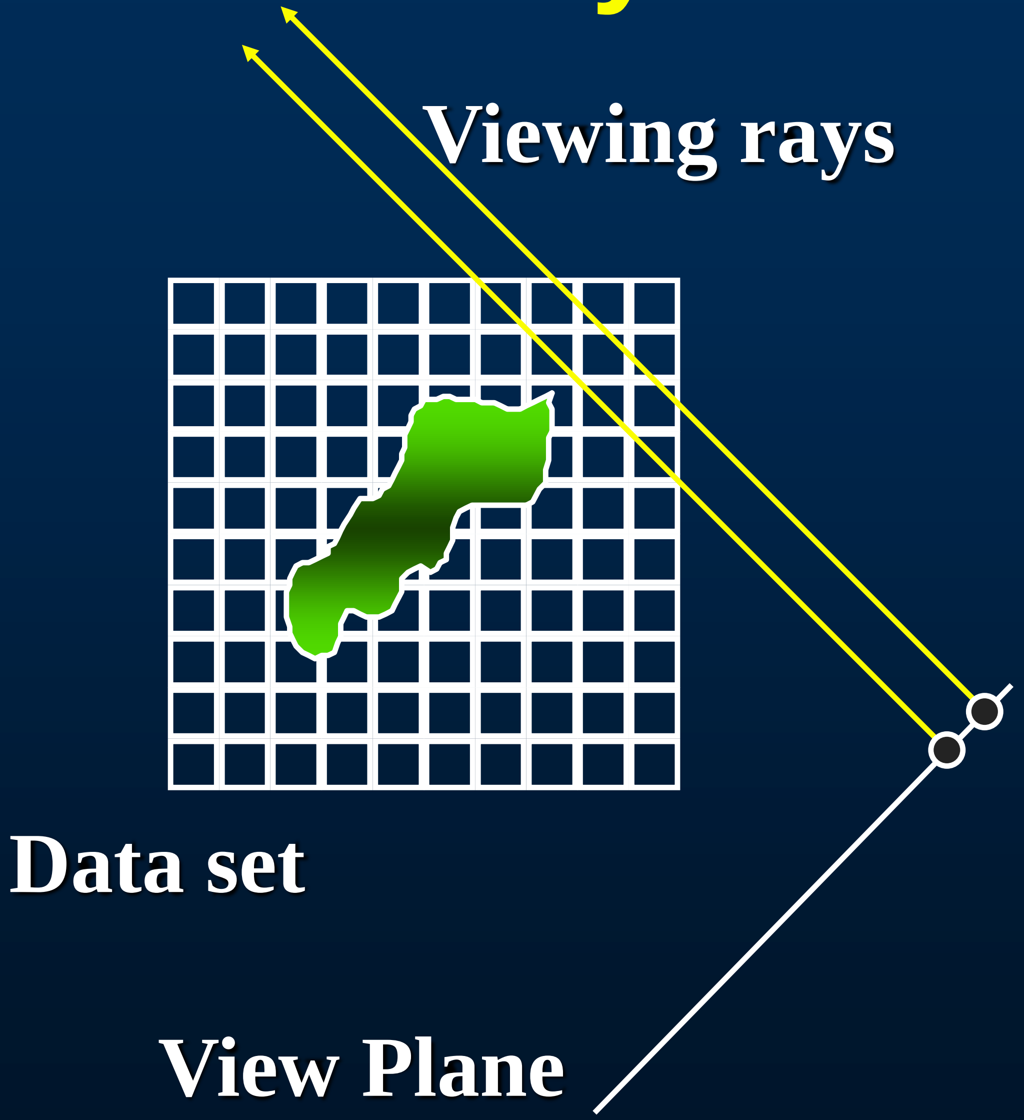
Basic Ray-Casting Algorithm



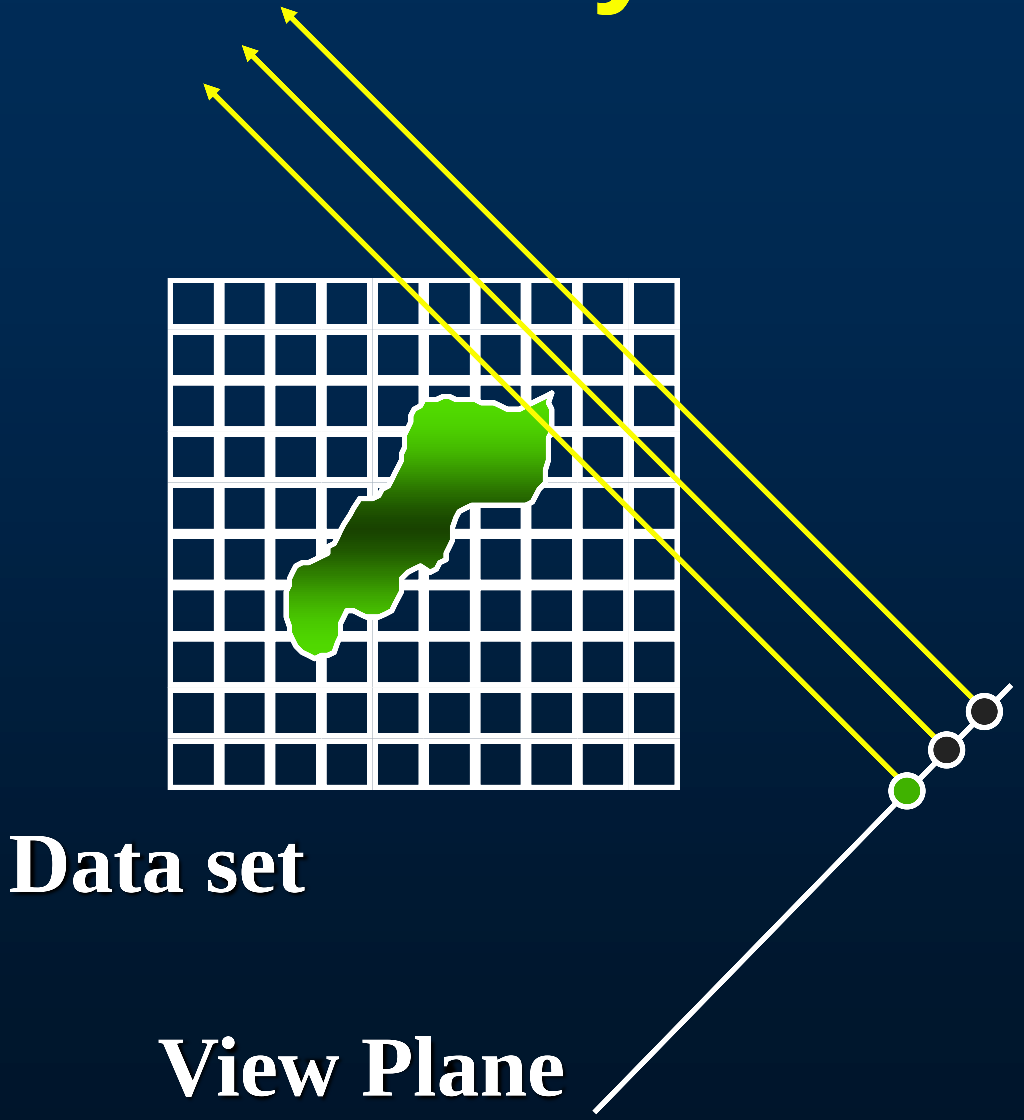
Basic Ray-Casting Algorithm



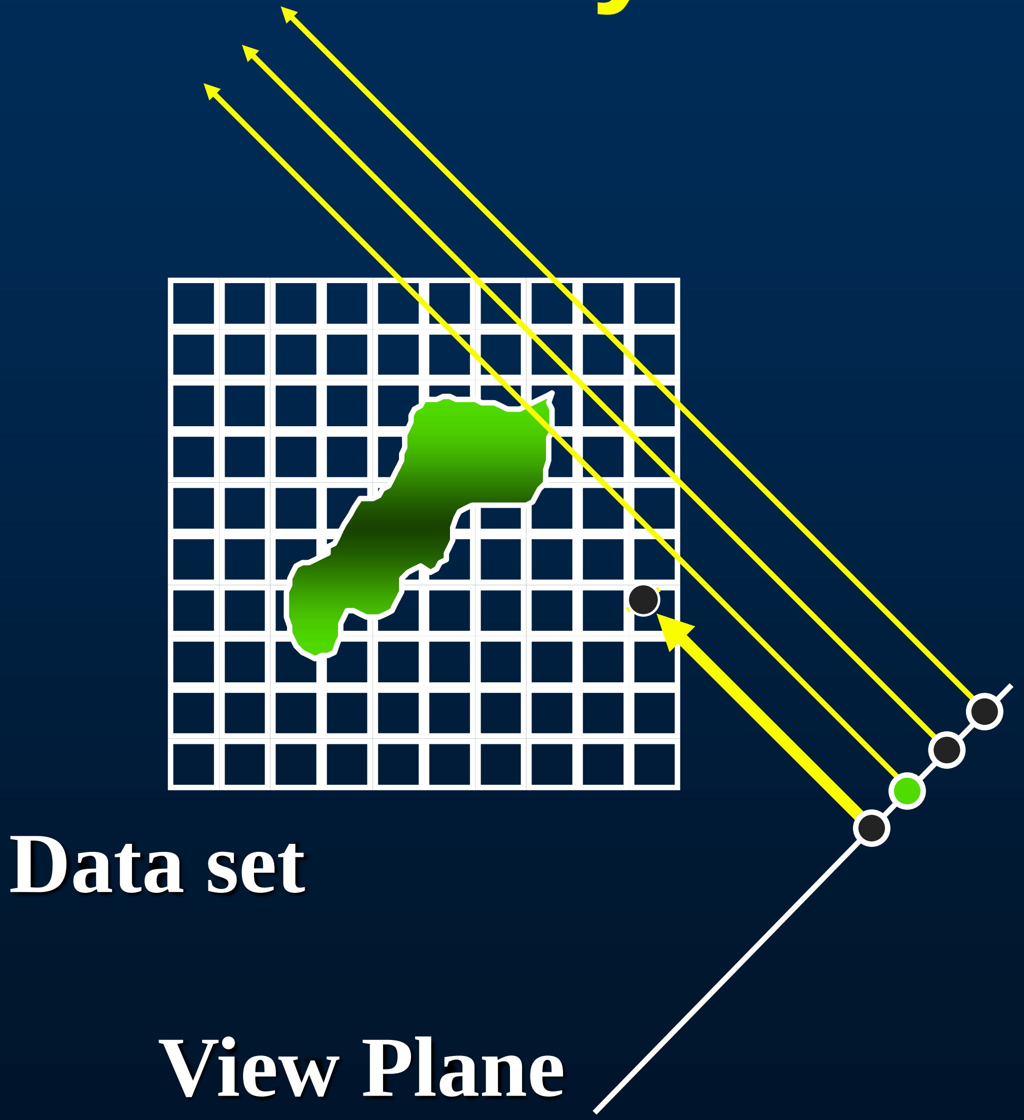
Basic Ray-Casting Algorithm



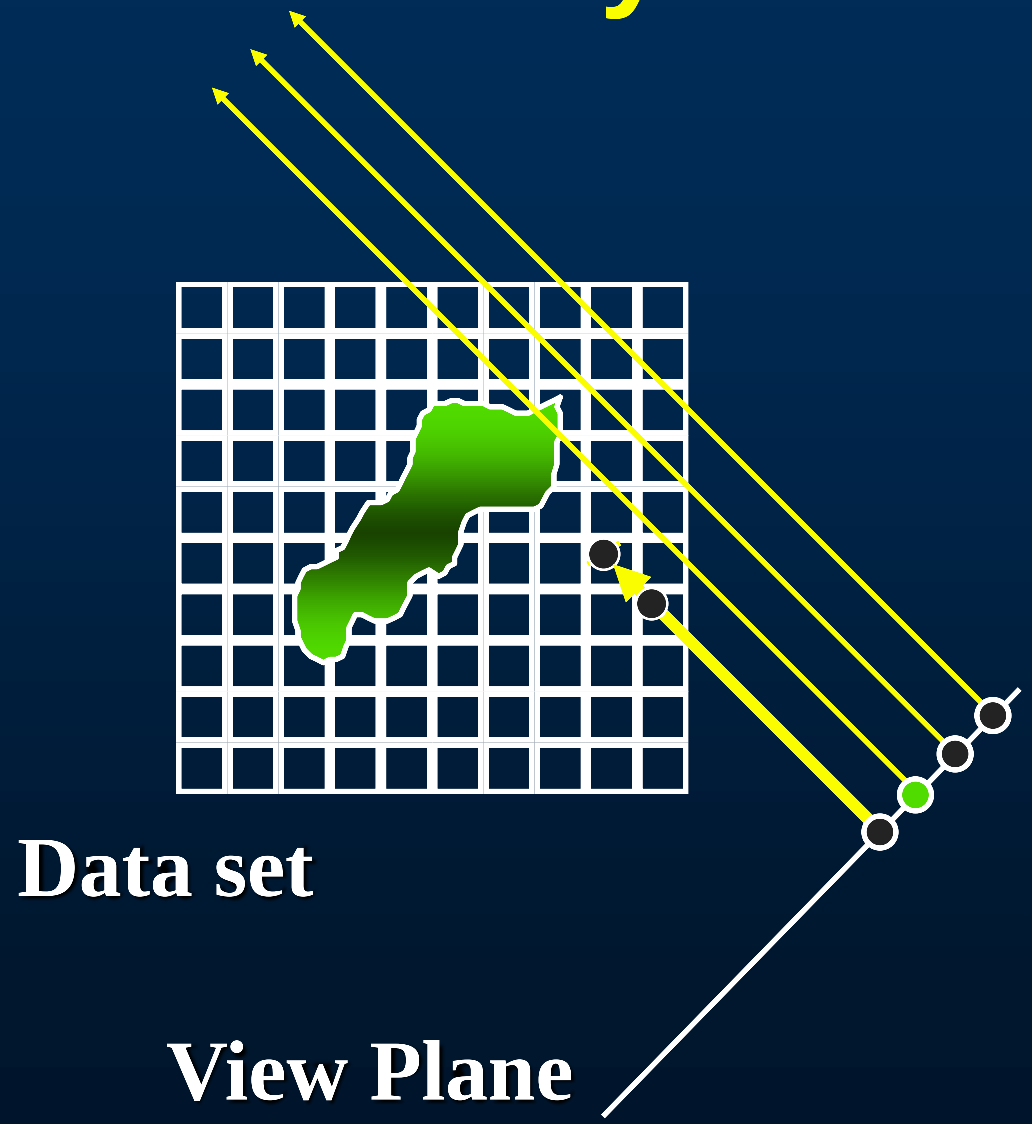
Basic Ray-Casting Algorithm



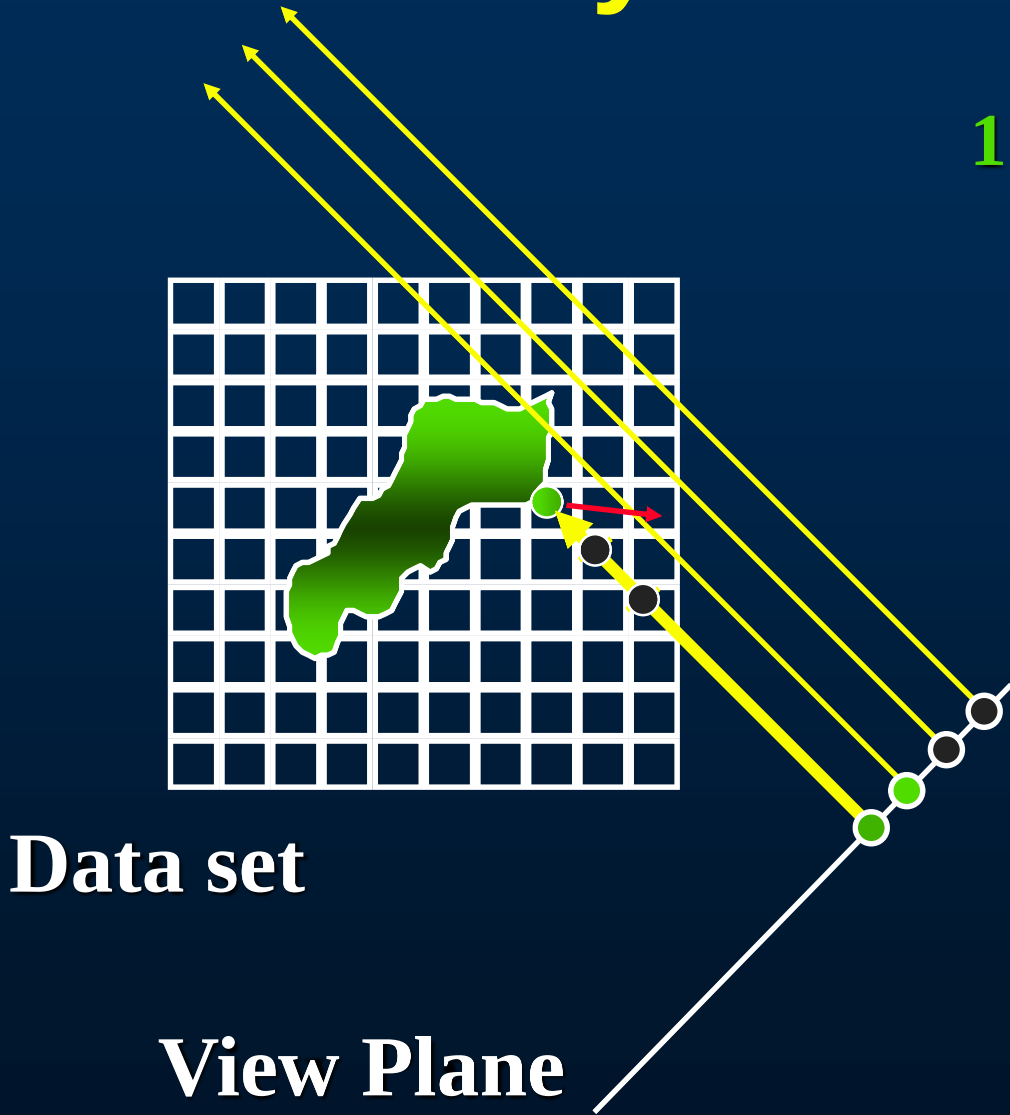
Basic Ray-Casting Algorithm



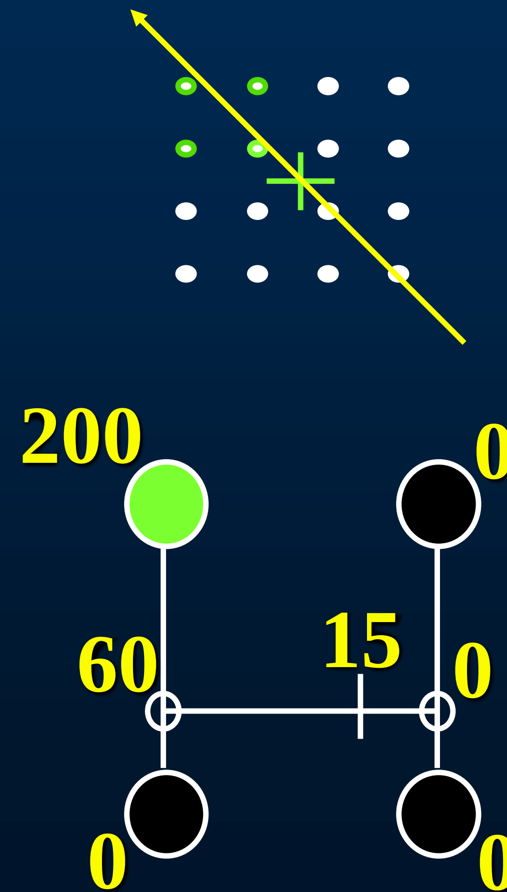
Basic Ray-Casting Algorithm



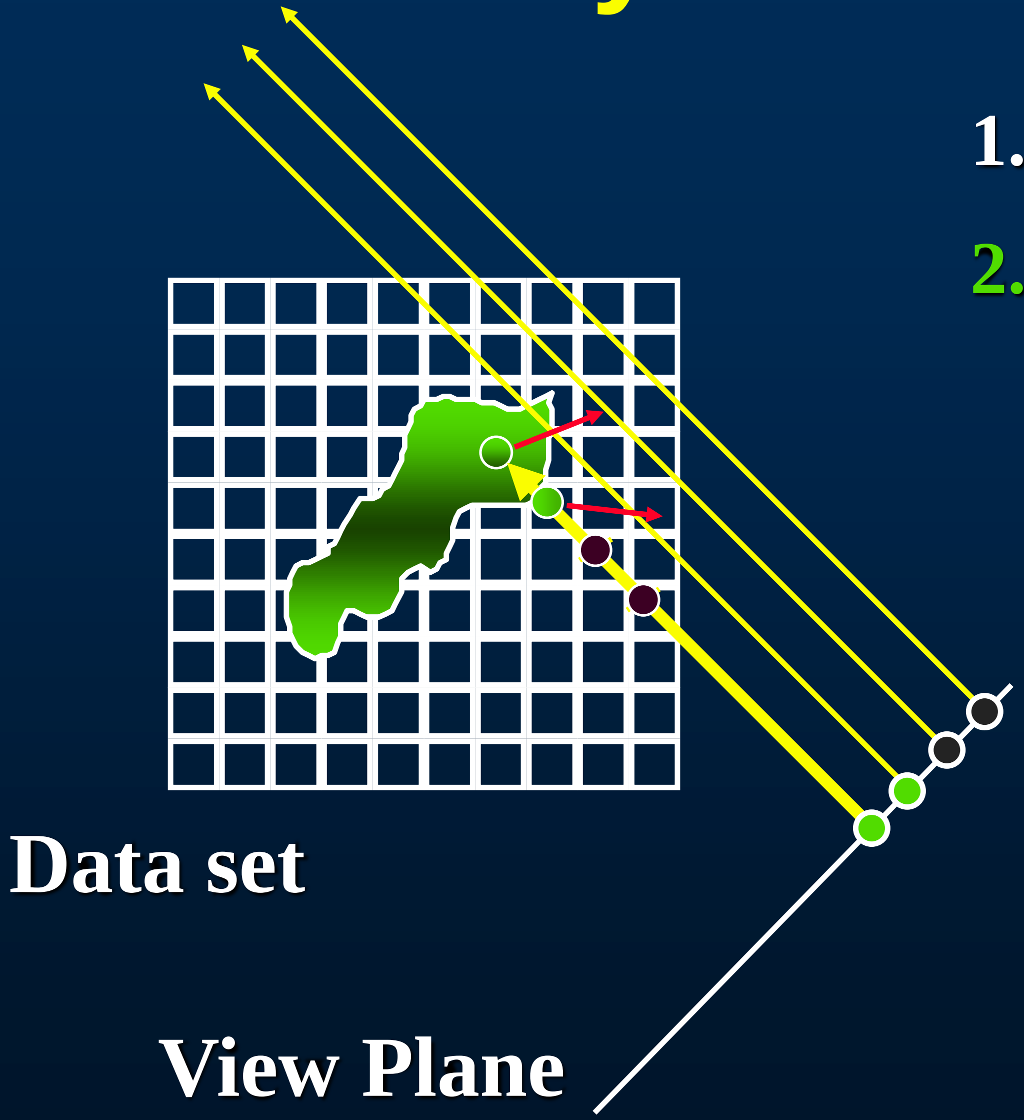
Basic Ray-Casting Algorithm



1. Interpolation

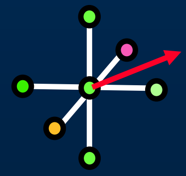


Basic Ray-Casting Algorithm



1. Interpolation

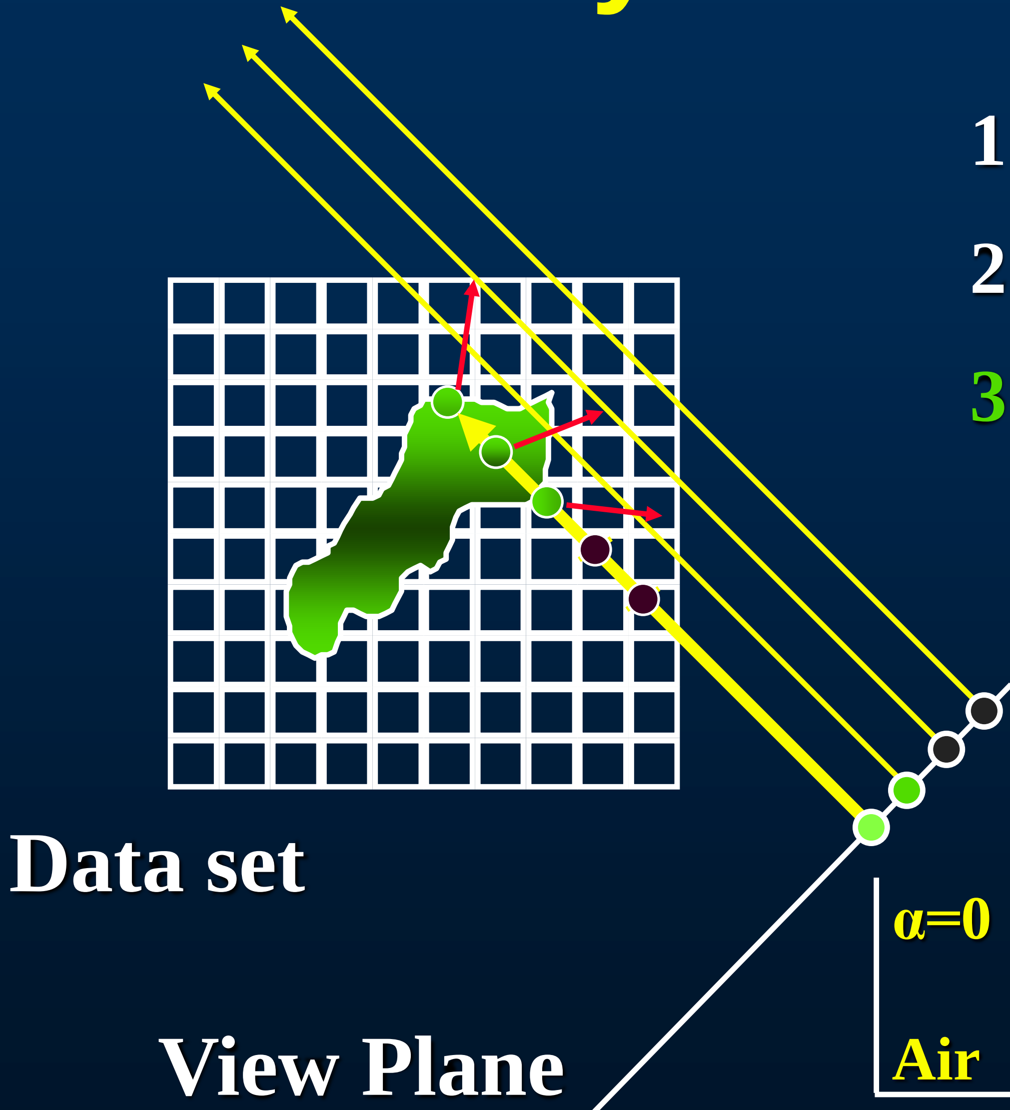
2. Gradient estimation

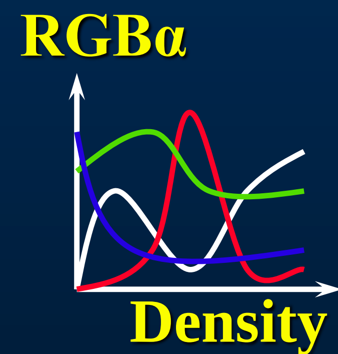


Estimated Gradient
= (Δx, Δy, Δz)

Basic Ray-Casting Algorithm

1. Interpolation
2. Gradient estimation
3. Classification



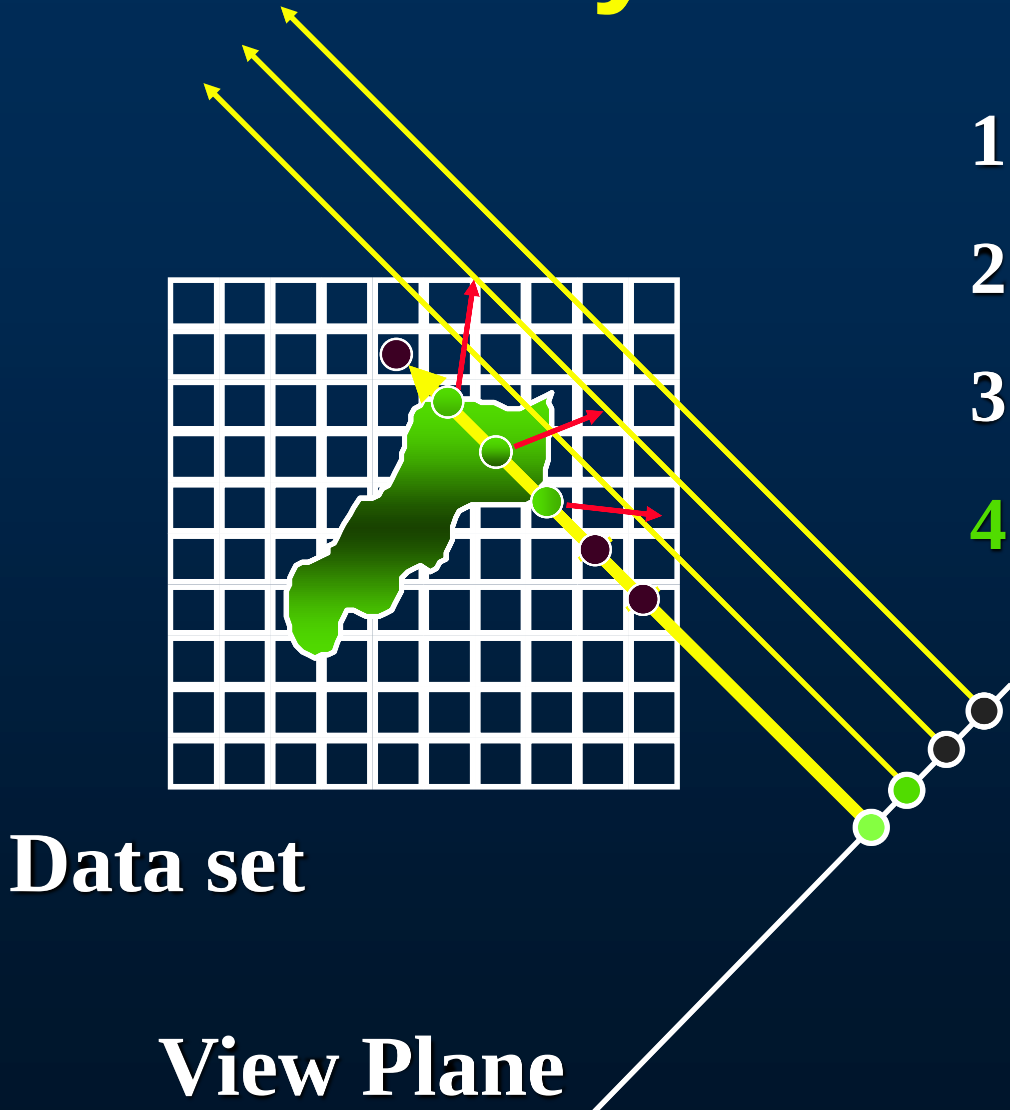


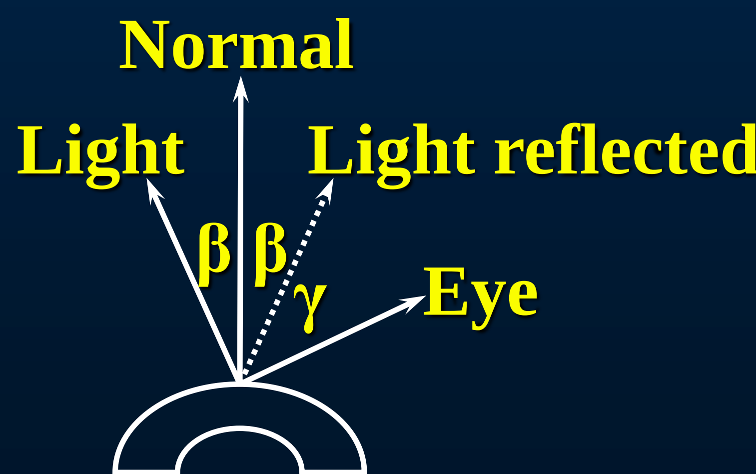
$\alpha=0$	$\alpha=1$	$\alpha=.2$	$\alpha=.5$
	gray	pink	red
Air	Bone	Muscle	Blood

0 30 100 130 255

Basic Ray-Casting Algorithm

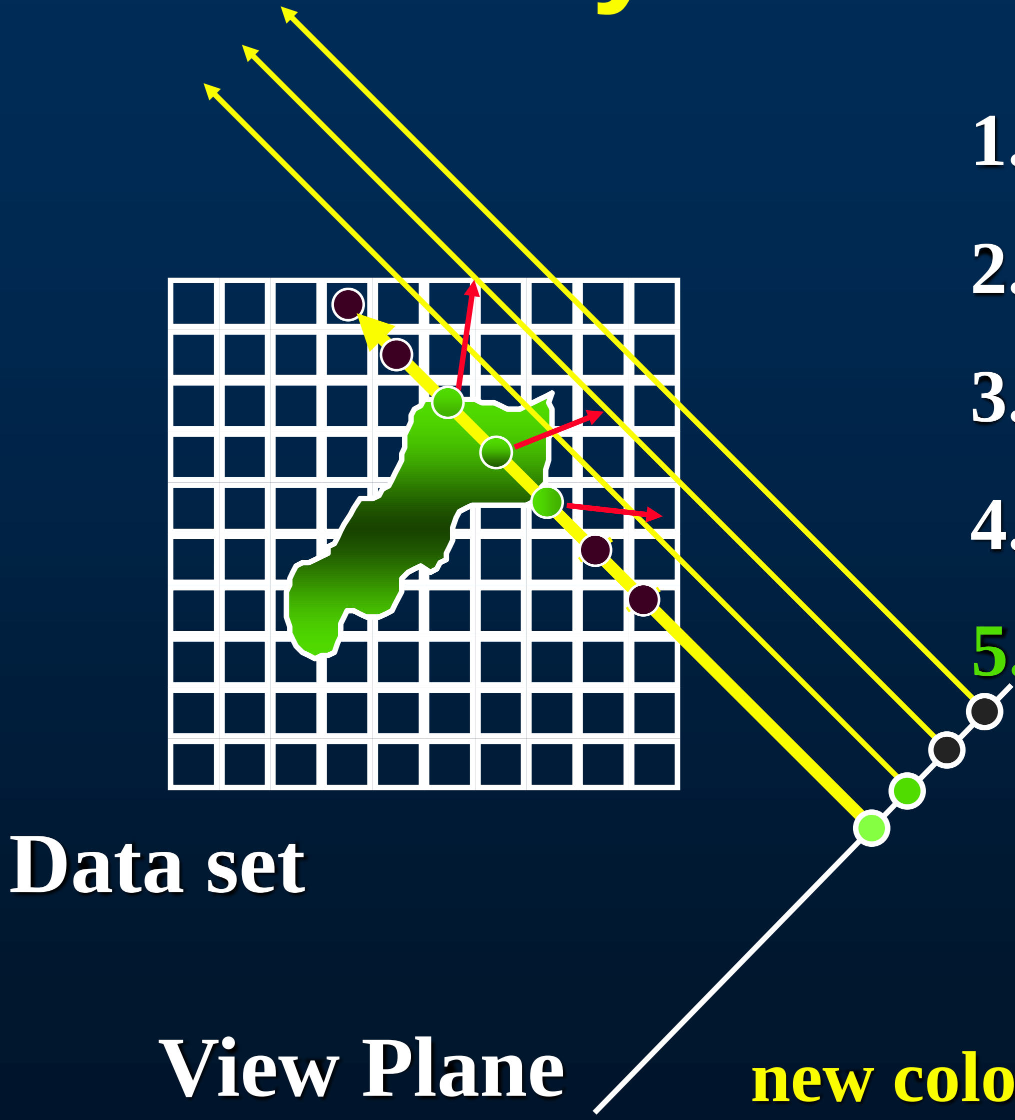
1. Interpolation
2. Gradient estimation
3. Classification
4. Shading





New Intensity = Intensity • cos(γ)

Basic Ray-Casting Algorithm

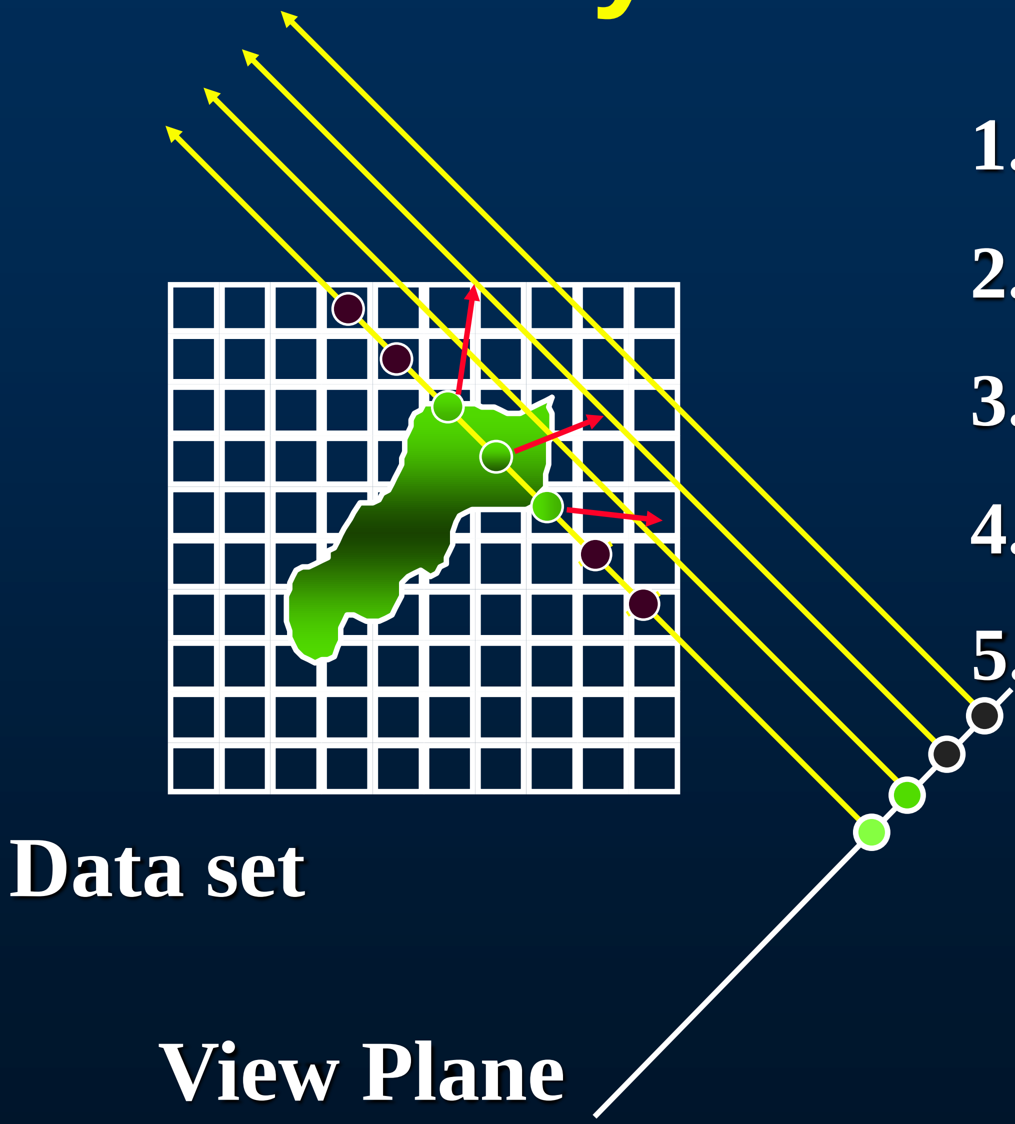


1. Interpolation
2. Gradient estimation
3. Classification
4. Shading
5. Compositing

Back-to-Front compositing :

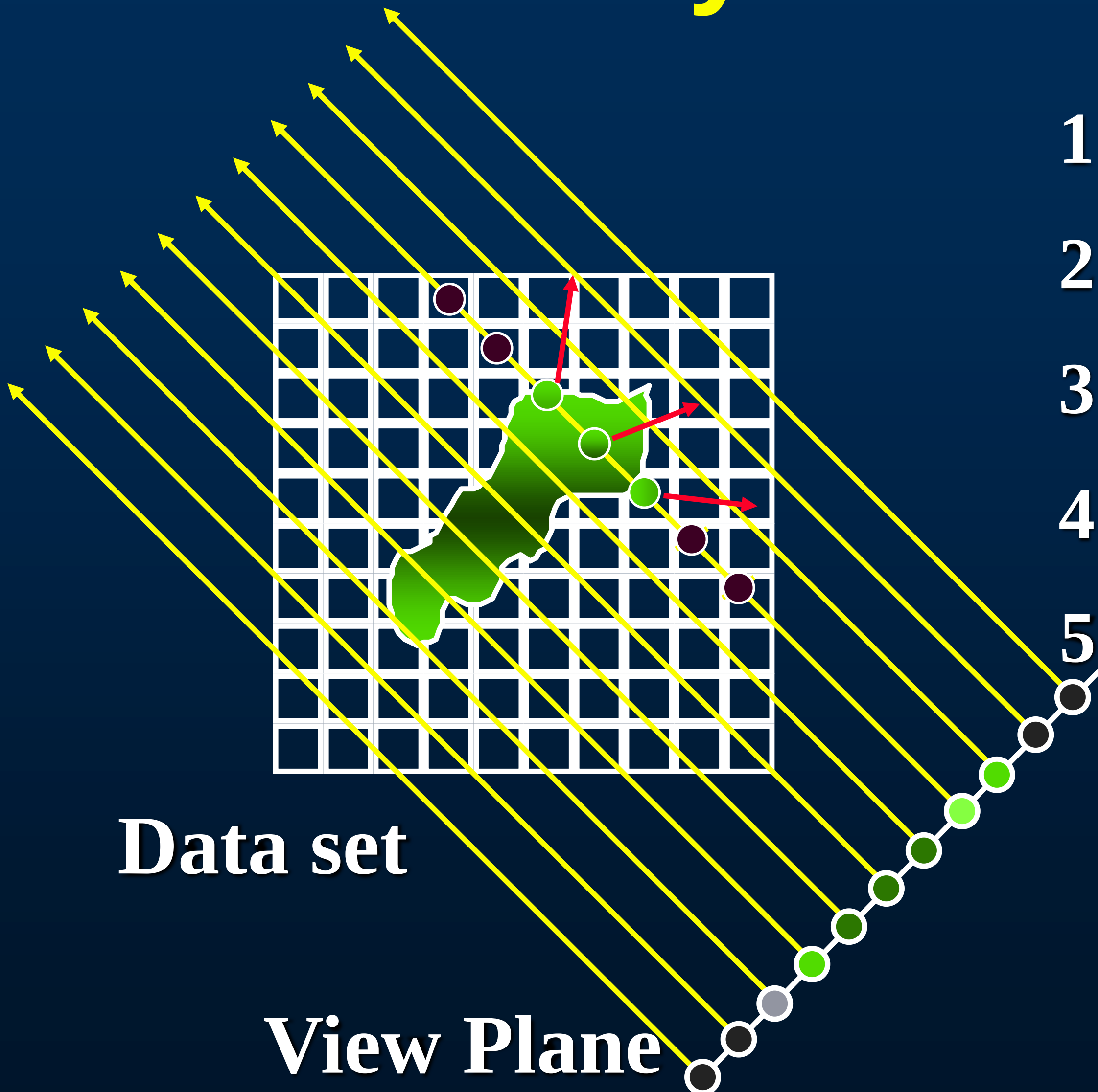
new color = front color • front α
+ back color • (1 - front α)

Basic Ray-Casting Algorithm



1. Interpolation
2. Gradient estimation
3. Classification
4. Shading
5. Compositing

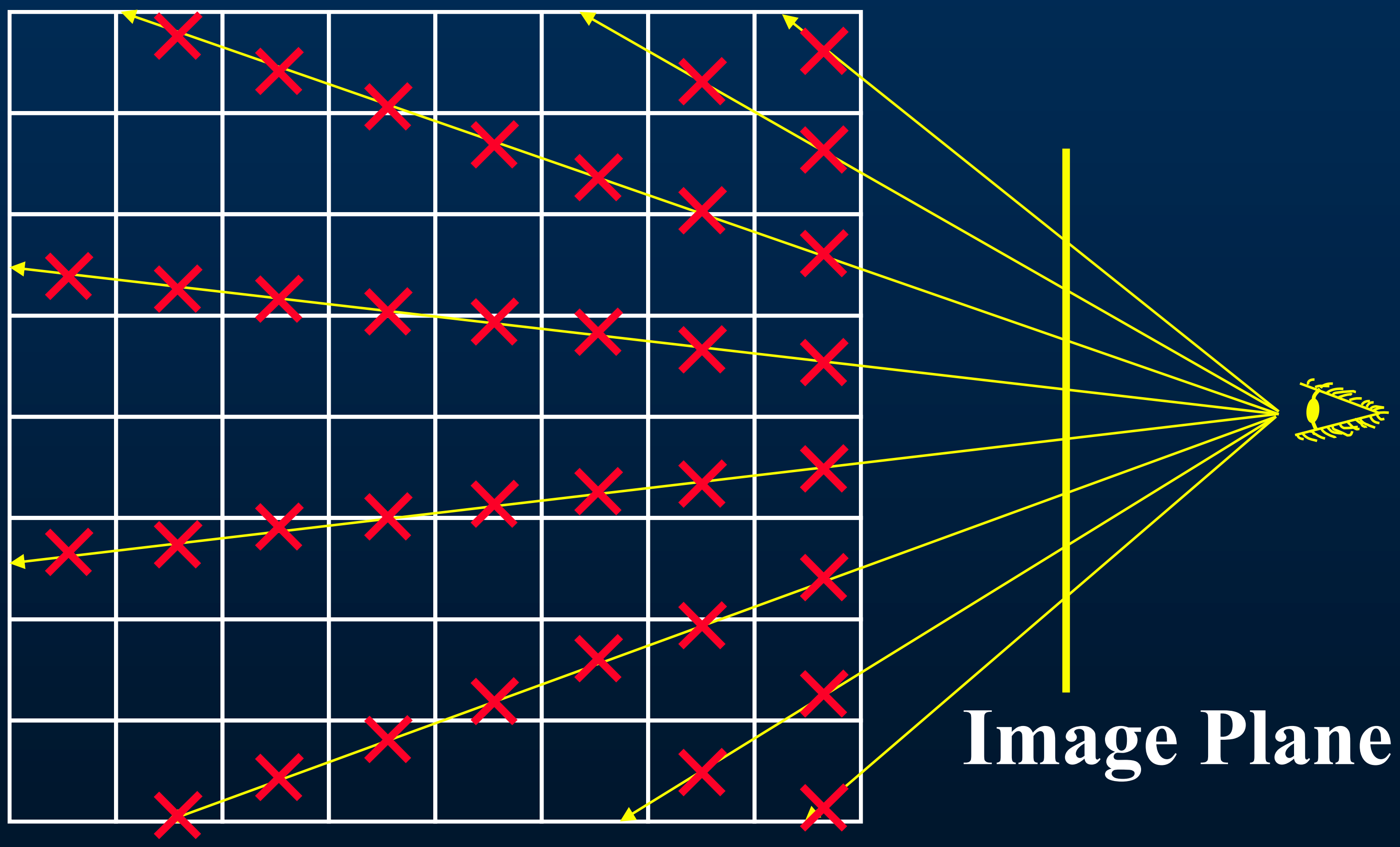
Basic Ray-Casting Algorithm



1. Interpolation
2. Gradient estimation
3. Classification
4. Shading
5. Compositing

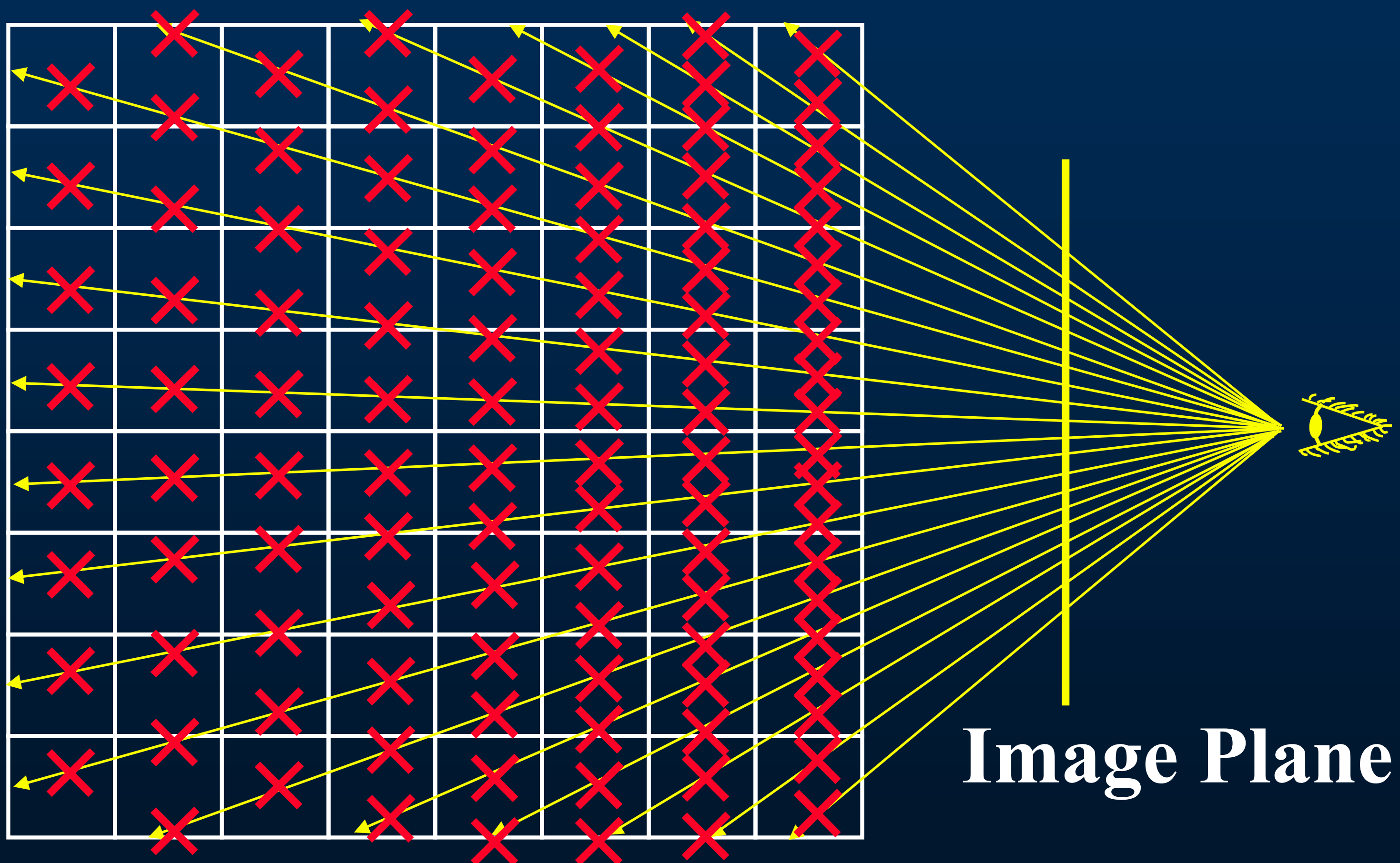
Perspective Projection

Aliasing!



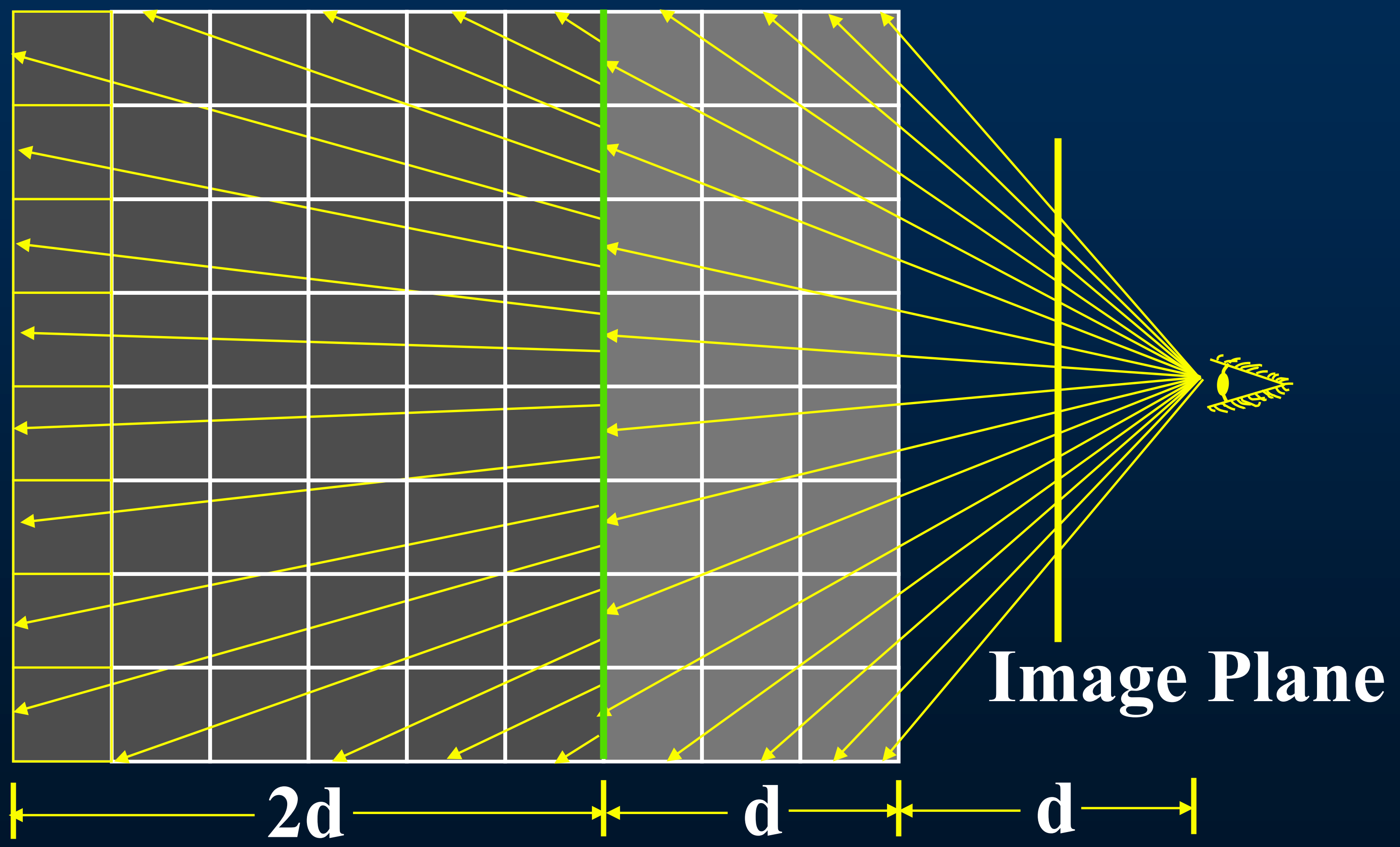
Supersampling

Too Expensive!

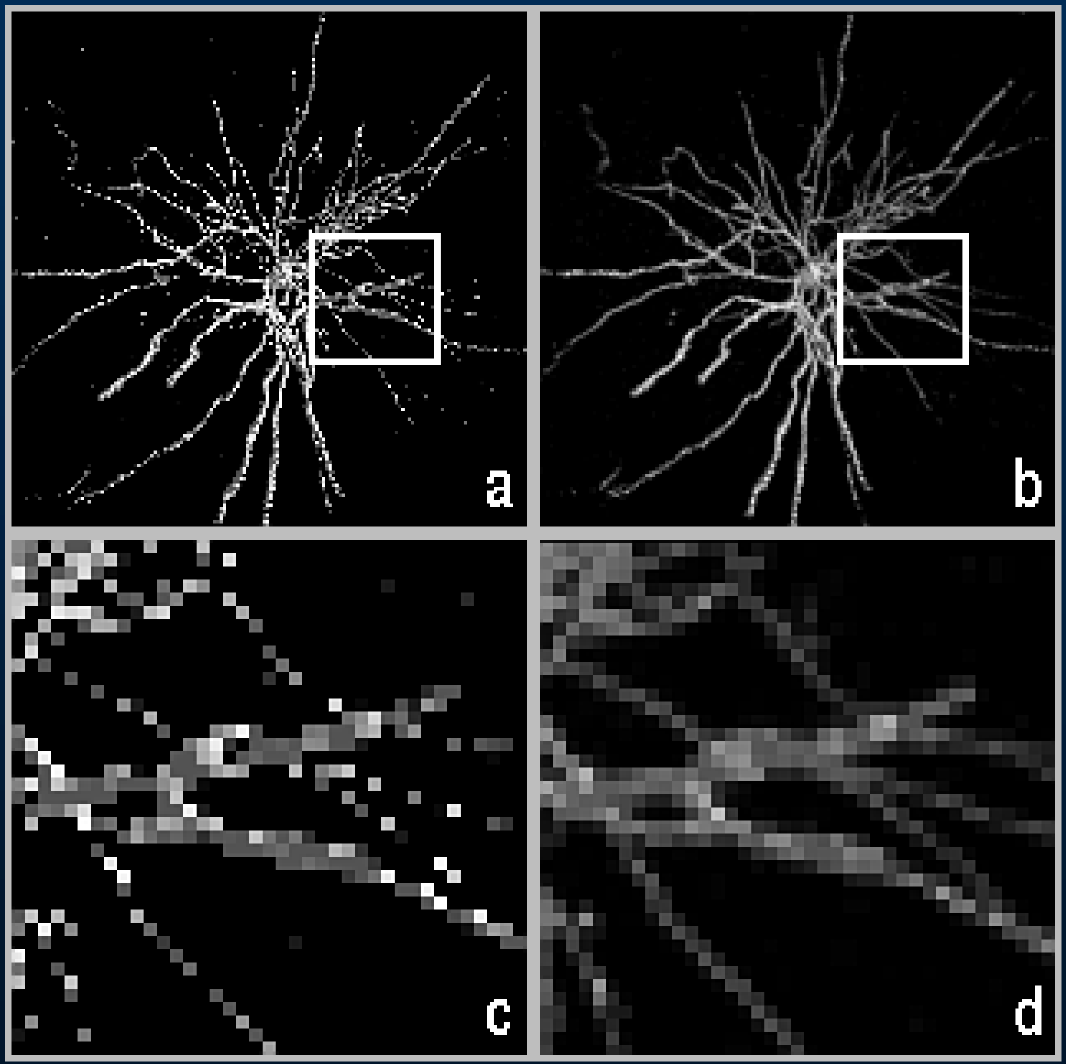


Adaptive Sampling

Kreeger, Dachille, Chen, Bitter, Kaufman, VolVis 98



Perspective Projection



LGN Nerve Cell

a) Undersampling

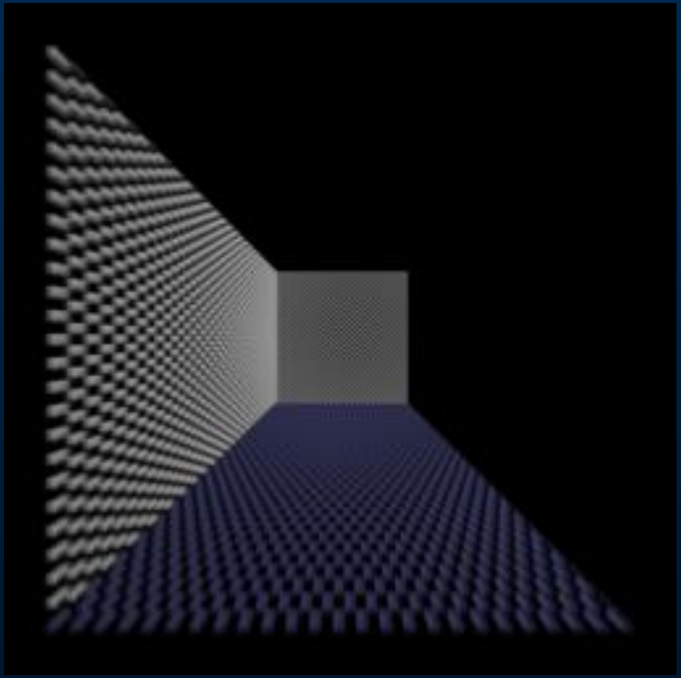
b) Adaptive Sampling

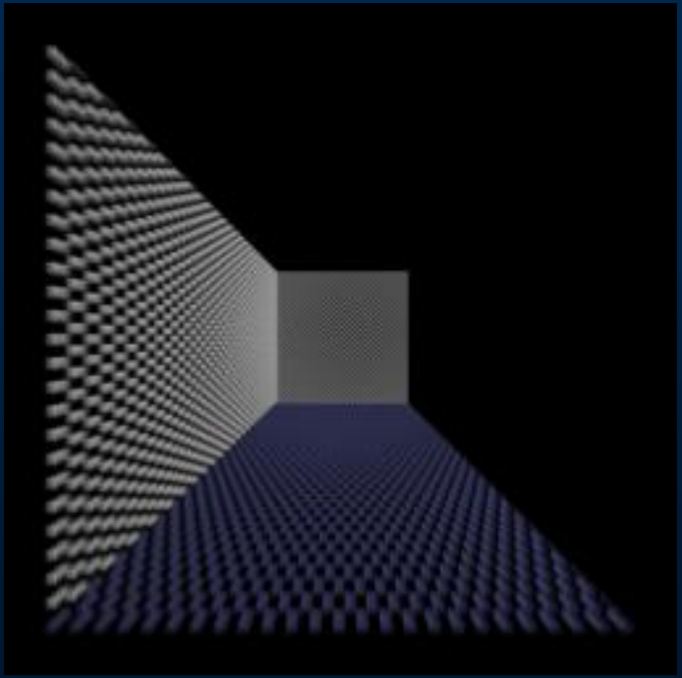
c) Undersampling Zoom

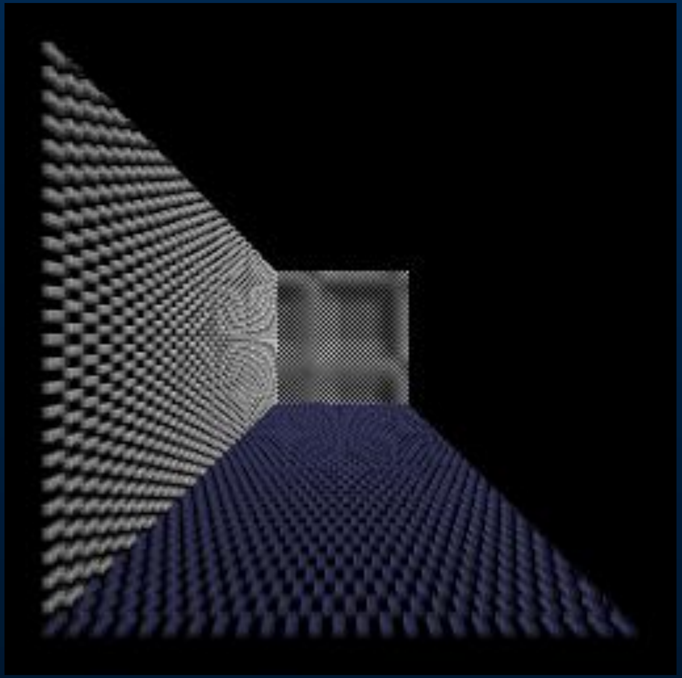
d) Adaptive Sampling Zoom

Perspective Projection

Oversampling **Adaptive Sampling** **Undersampling**





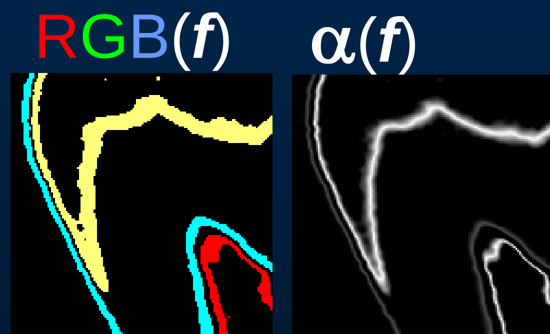


5^3 checker box room (128^3 volume)

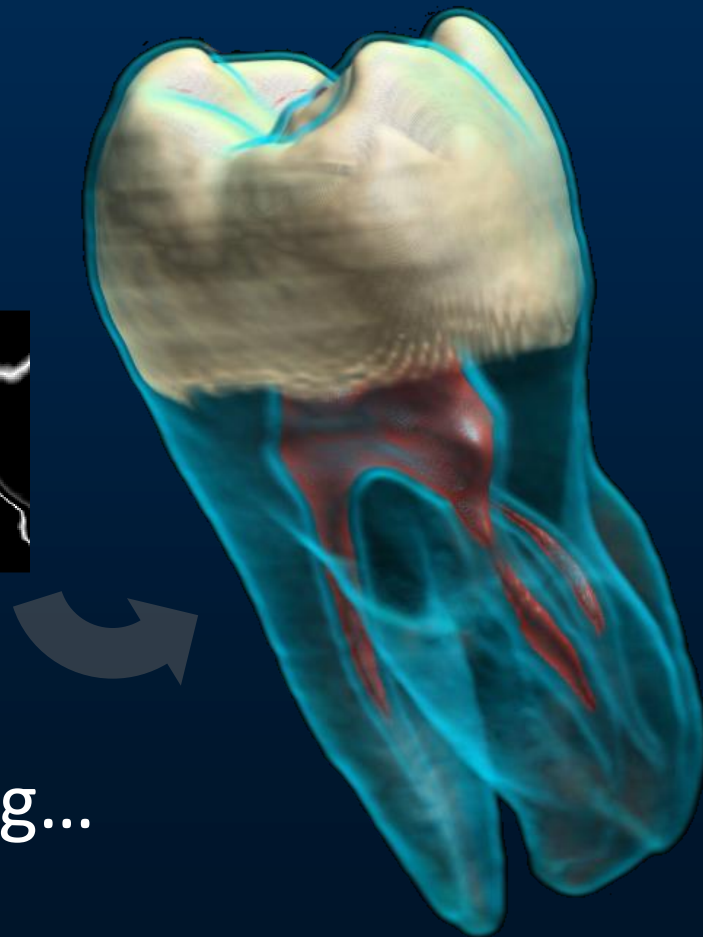
Transfer Functions (TFs)

Simple (usual) case: Map data value *f* to color and opacity

Human Tooth CT

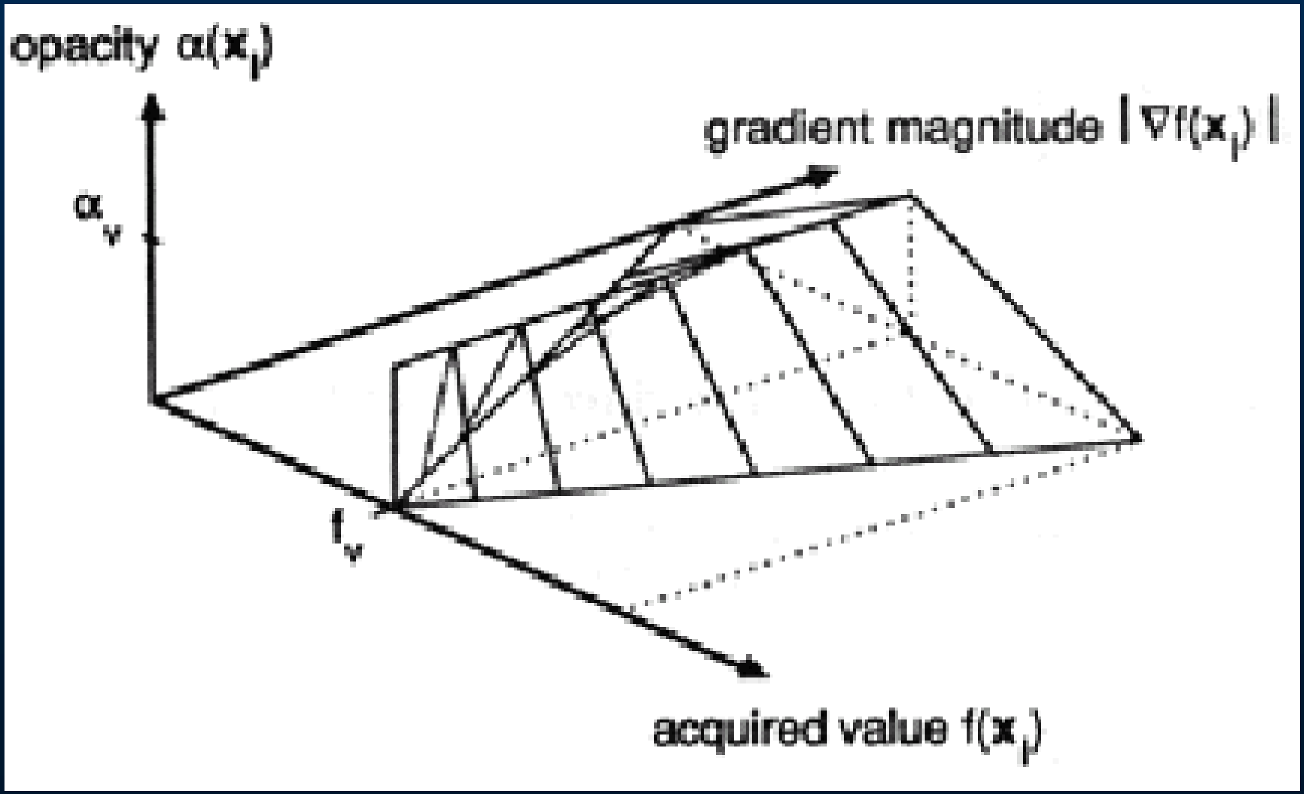


Shading,
Compositing...



Classification

- **Transfer Function**

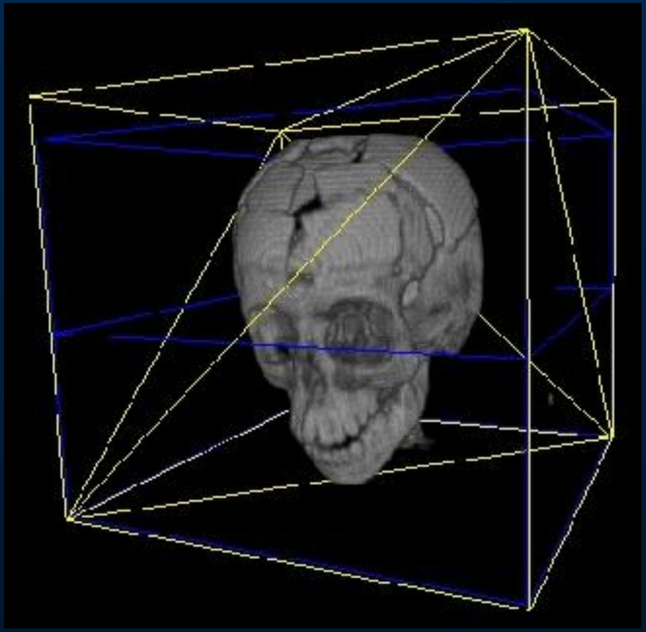


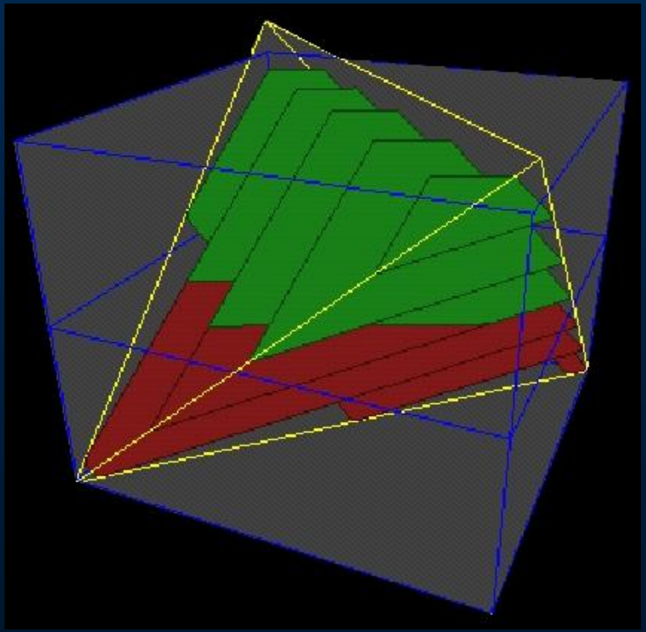
Volume Rendering Expenses

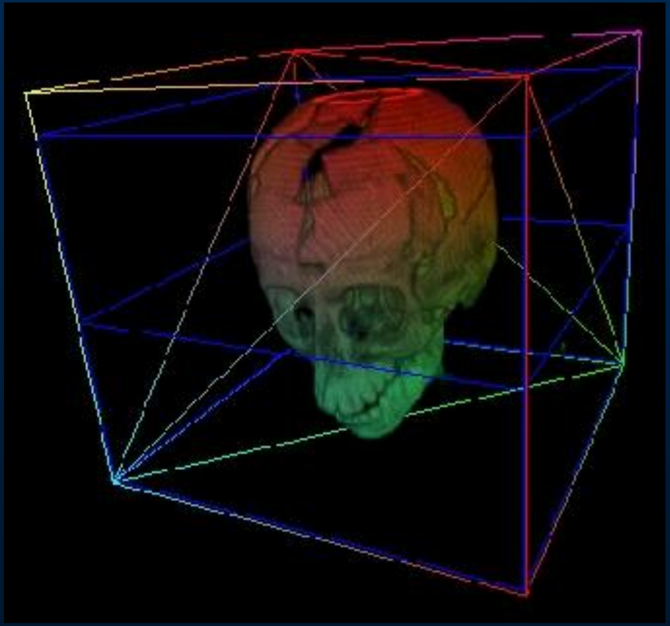
1024^3 16-bit volume @ 30 Hz

- 2GBytes storage
- 60GBytes/second memory bandwidth
  (one access per voxel)
- 900 billion instructions/second
  (30 instructions per voxel)

Volume Rendering Using Conventional Graphics Hardware



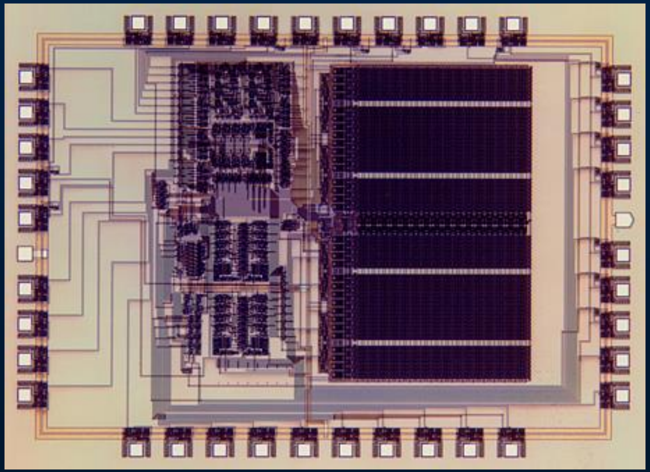




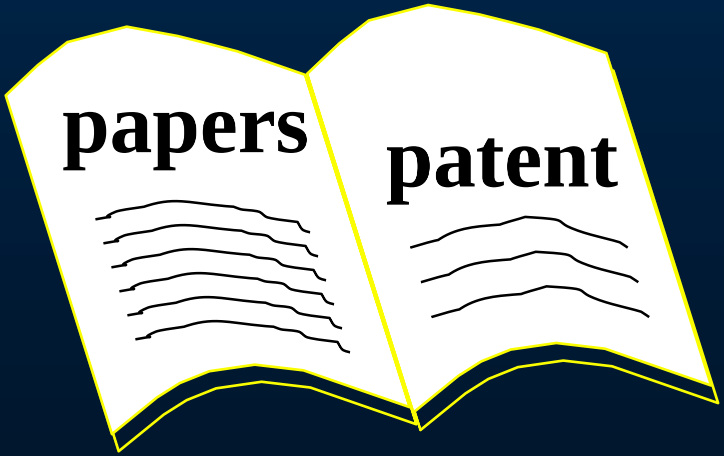
Cube Architecture Design

Cube-1

VolumePro (Cube-4)

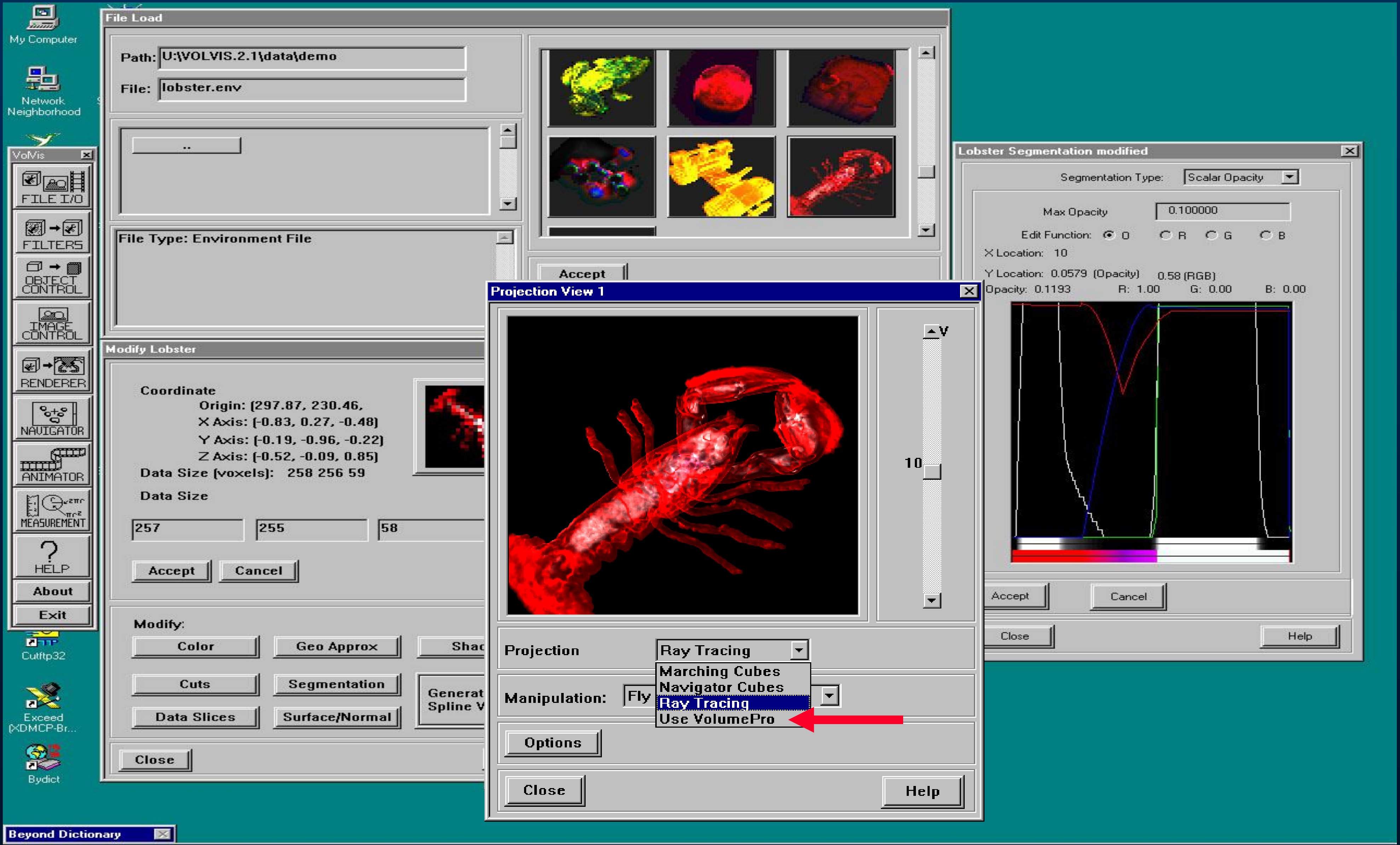


Cube-2

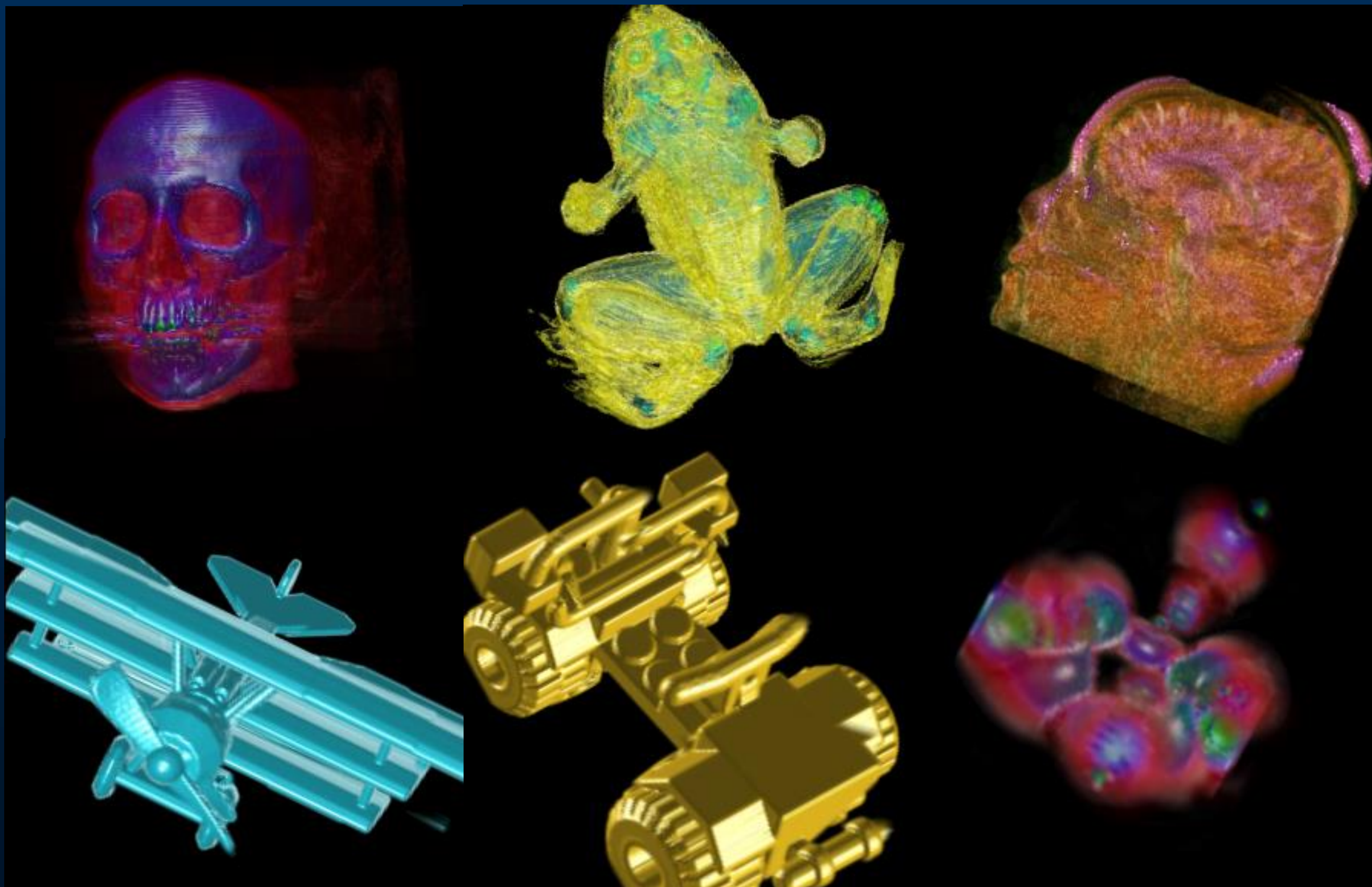


Cube-5

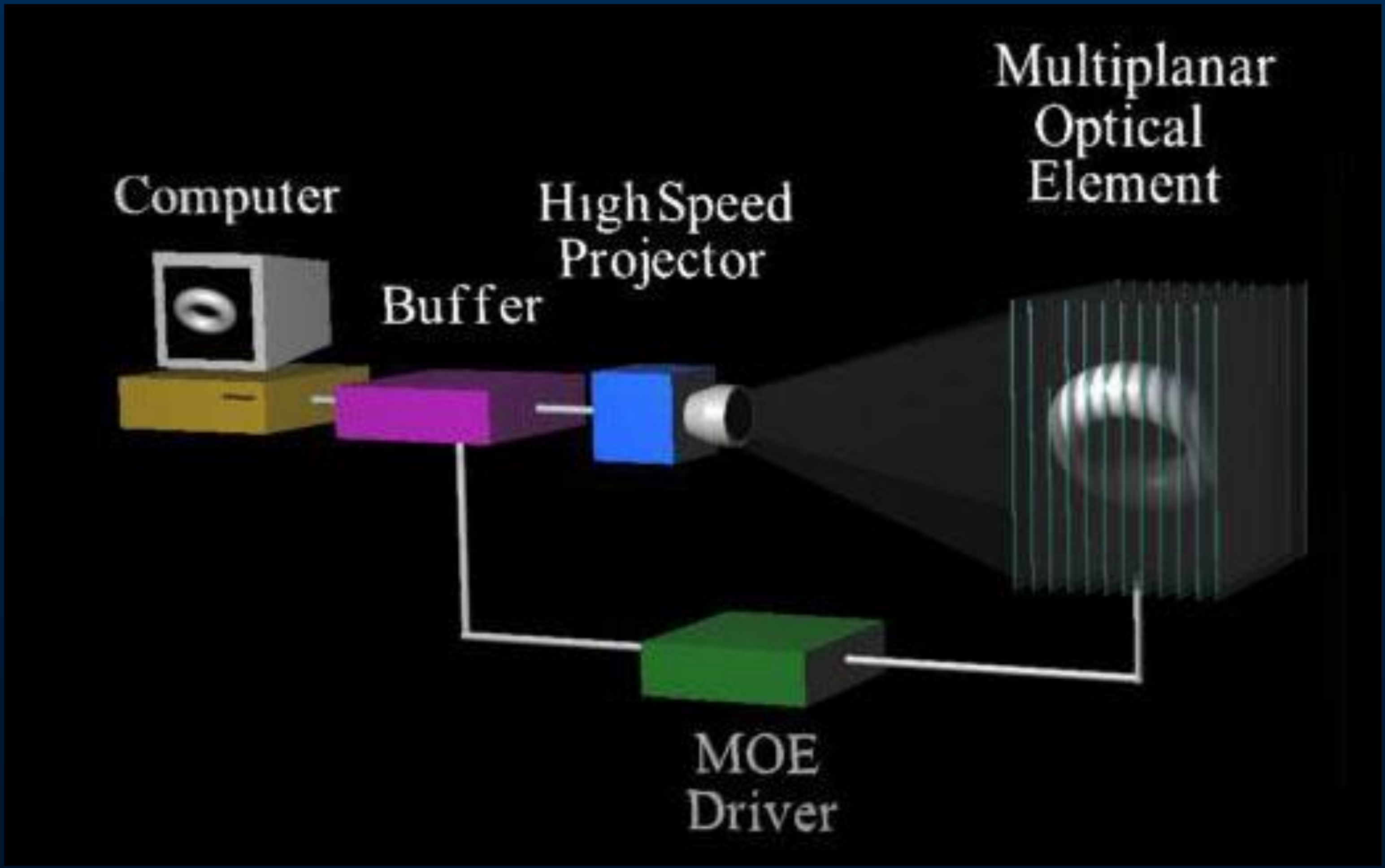
VolumePro / VolVis



VolumePro / VolVis



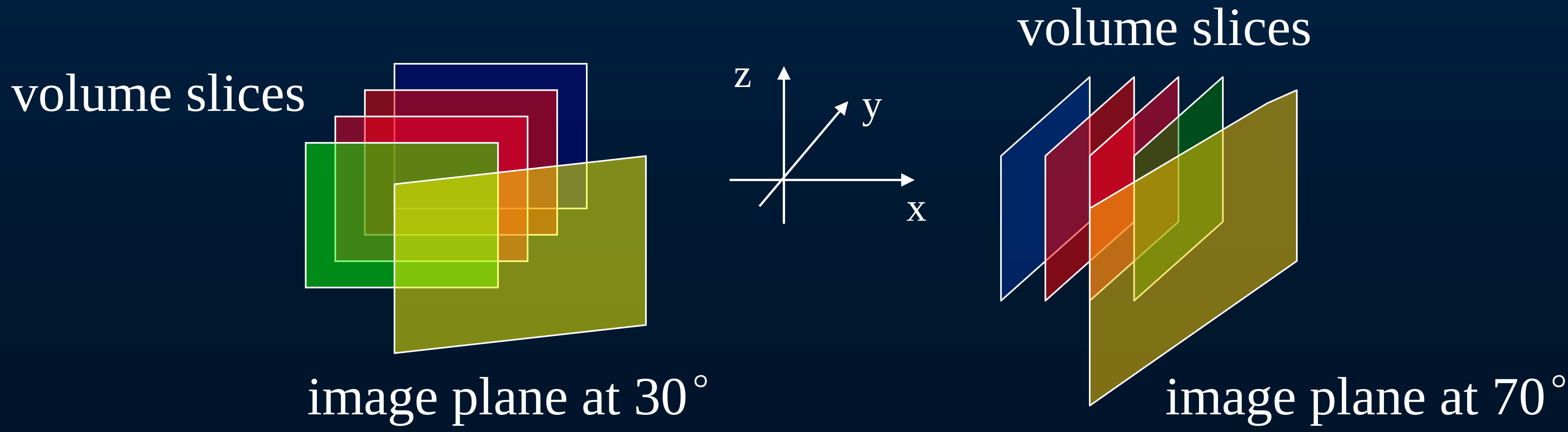
Volumetric Display



http://www.lightspacetech.com/

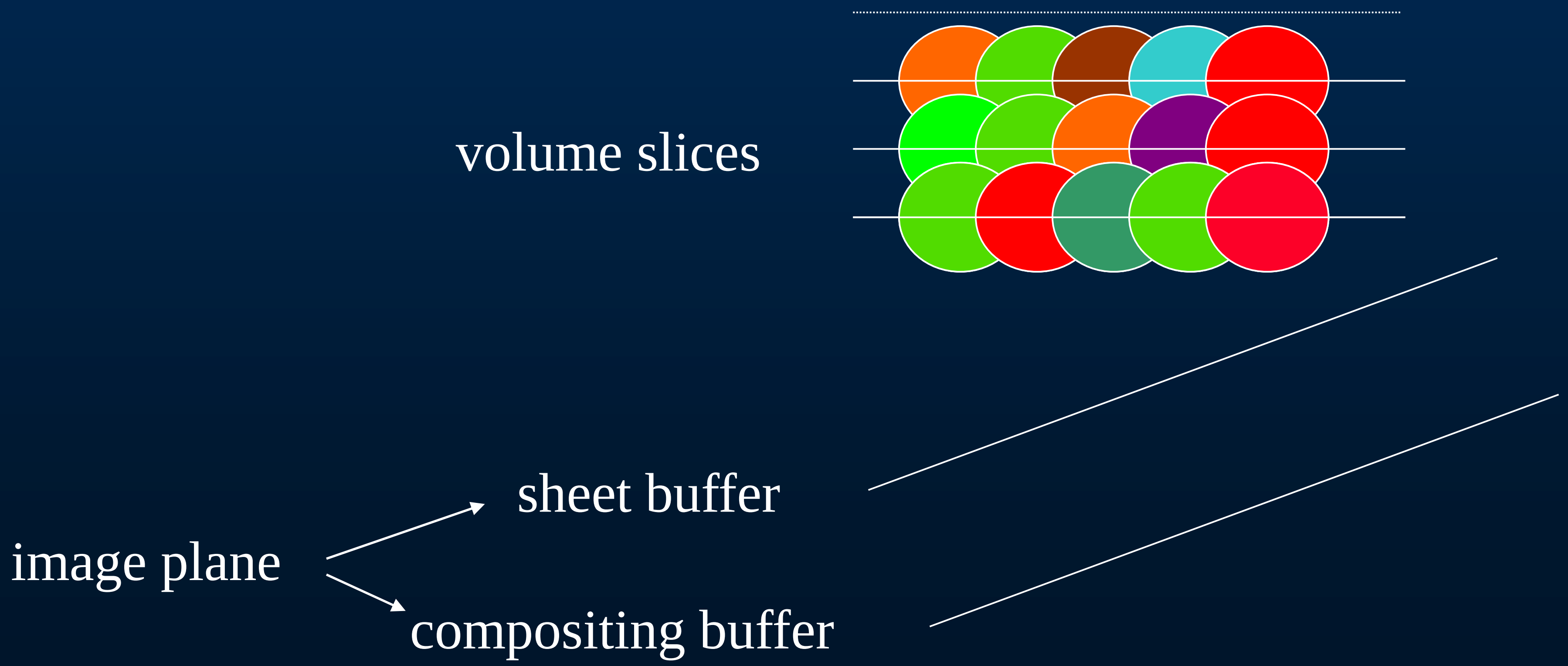
Volume Splatting

- **Voxel kernels are added within sheets**
- **Sheets are composited front-to-back**
- **Sheets = volume slices most perpendicular to the image plane**



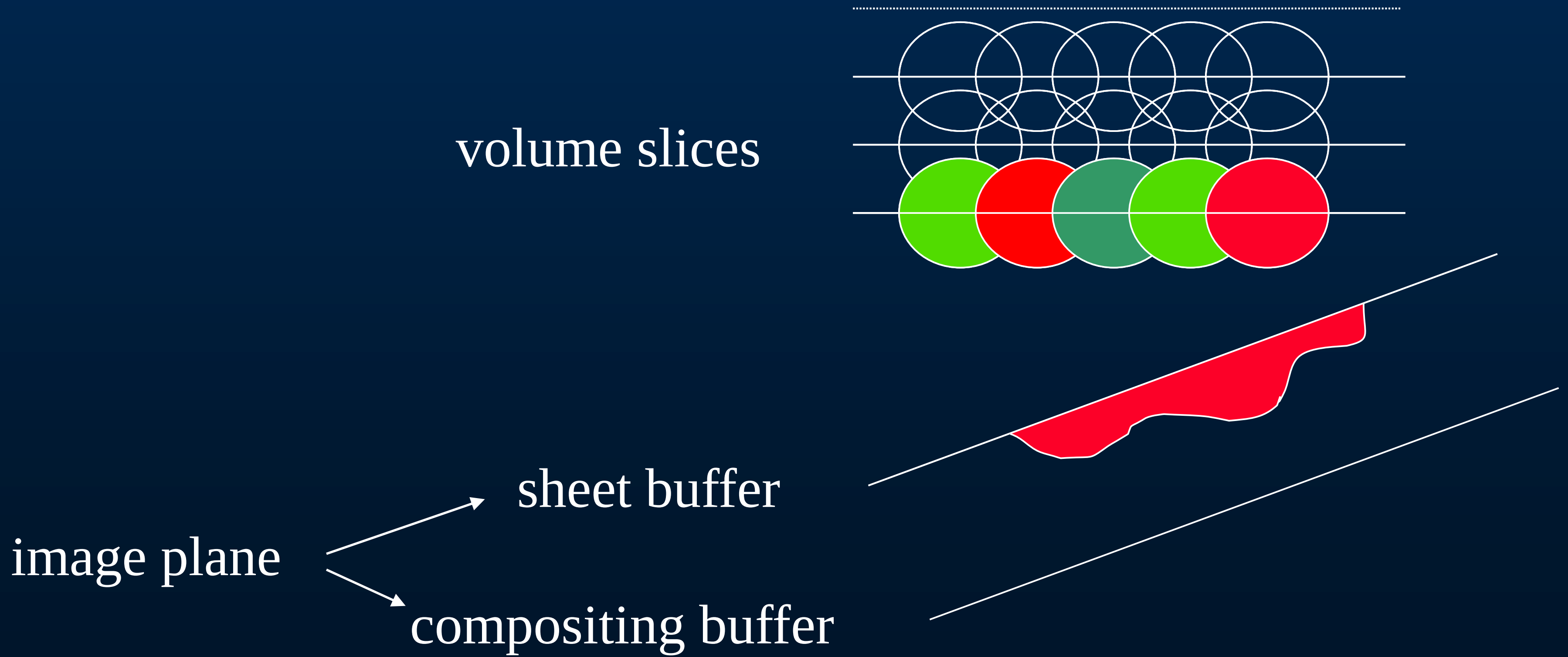
Volume Splatting

- **Volume**



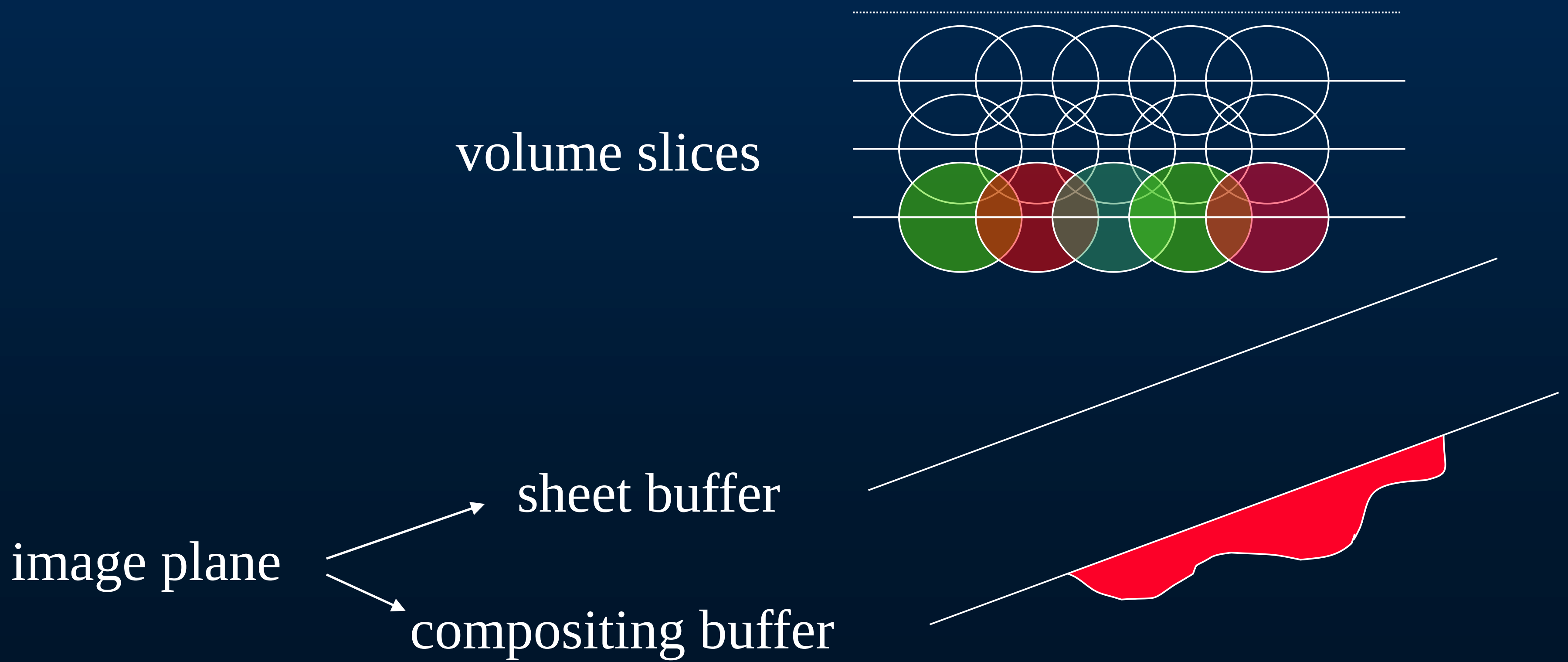
Volume Splatting

- **Add voxel kernels within first sheet**



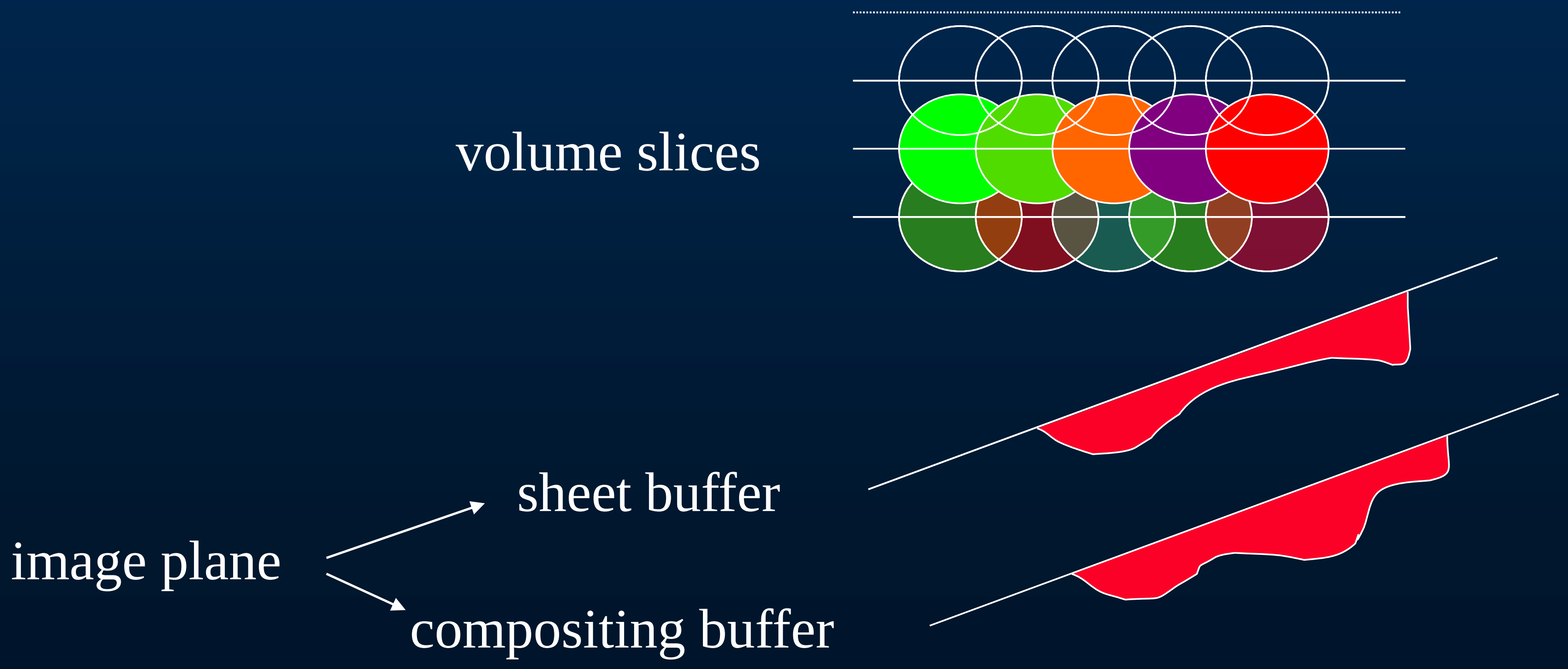
Volume Splatting

- **Transfer to compositing buffer**



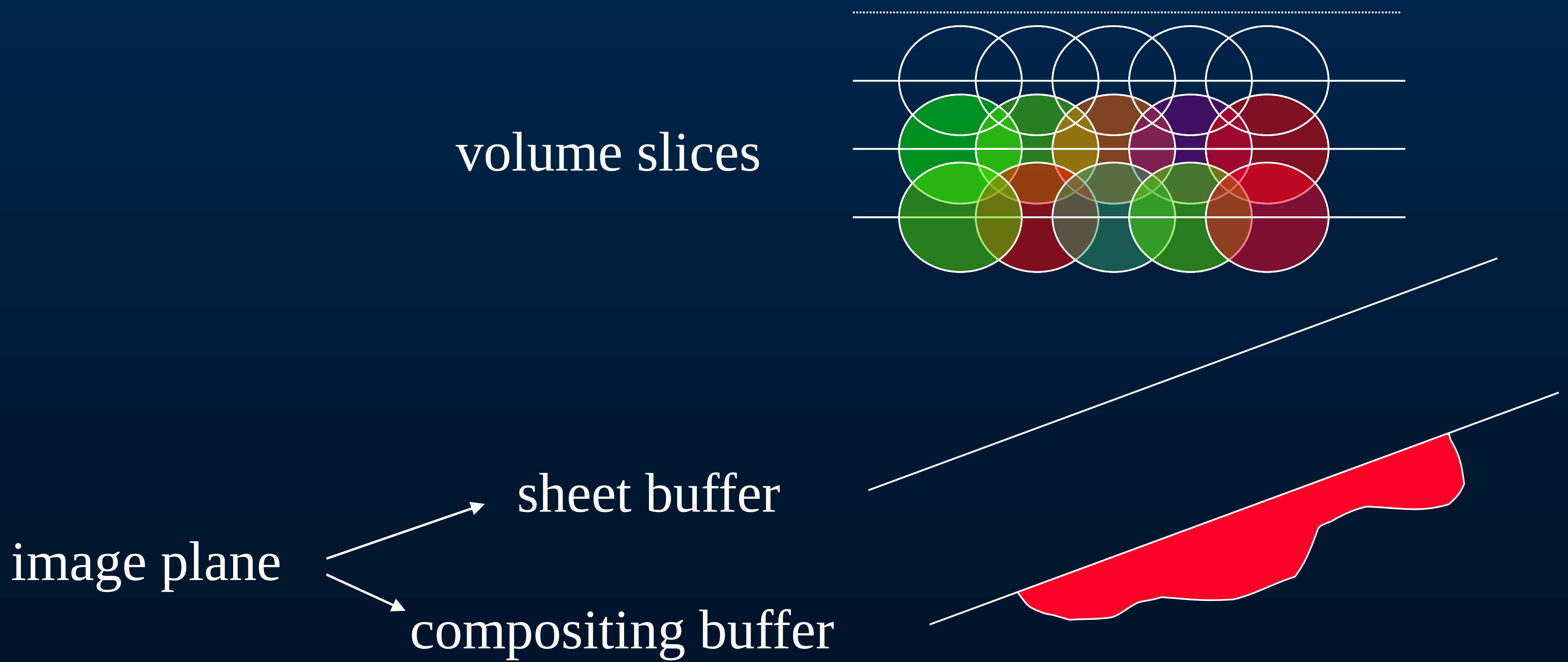
Volume Splatting

- **Add voxel kernels within second sheet**



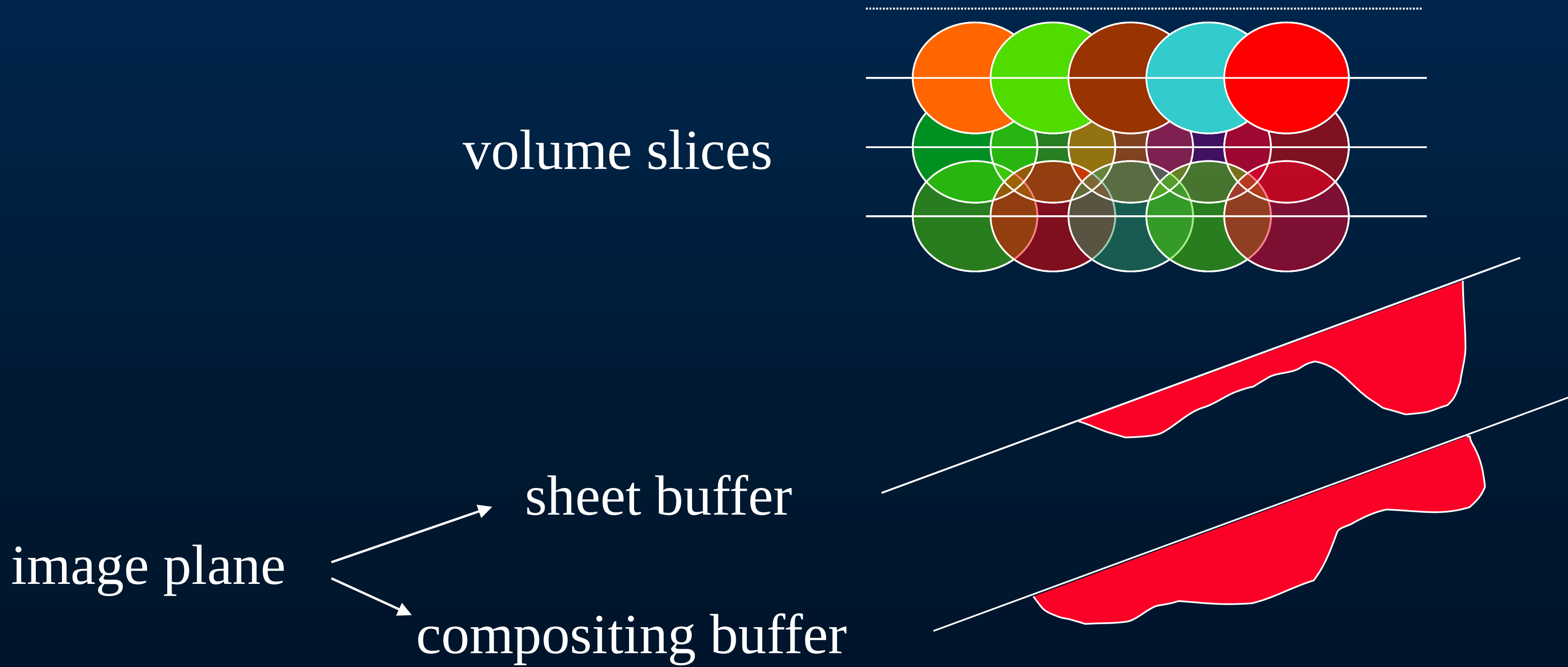
Volume Splatting

- **Composite sheet with compositing buffer**



Volume Splatting

- **Add voxel kernels within third sheet**



Volume Splatting

- **Composite sheet with compositing buffer**