CSE 167: Introduction to Computer Graphics Lecture #18: Volume Rendering

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Announcements

- Please check Ted grades for accuracy. All grades except final project and final exam should be there.
- Final project to be presented on **Friday, Dec 2nd, between 1 and 3pm in room 1202**
  - What time constraints do groups have?
  - Need to know which computer used for presentation
    - If lab PC: which OS?
- Final Exam Dec 8th 3-6pm in regular classroom (Peterson Hall 104)

Demo

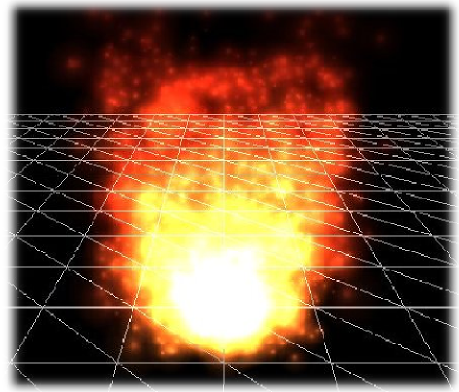
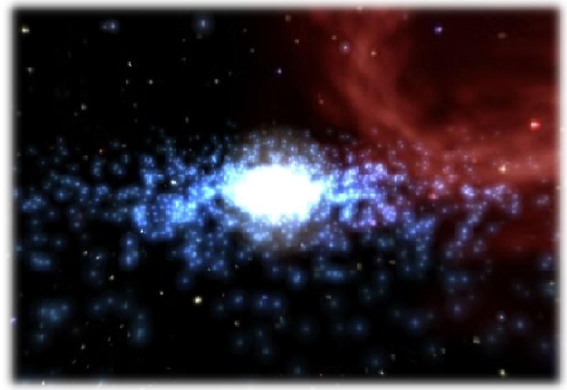
- Geisel Returns Home
  - By Robert Pardridge, Christopher Jenkins, Kevin Reynolds
  - "It is well known that Geisel Library resembles a huge spaceship. Almost every UCSD student has this thought at least once while walking past the library."

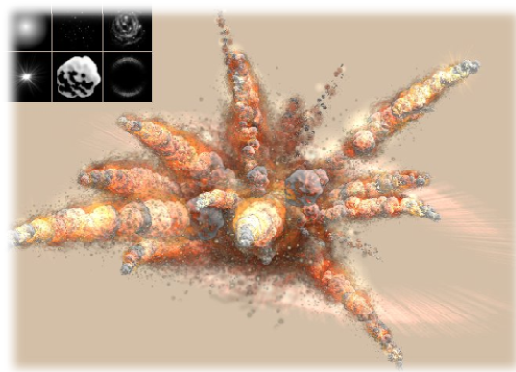
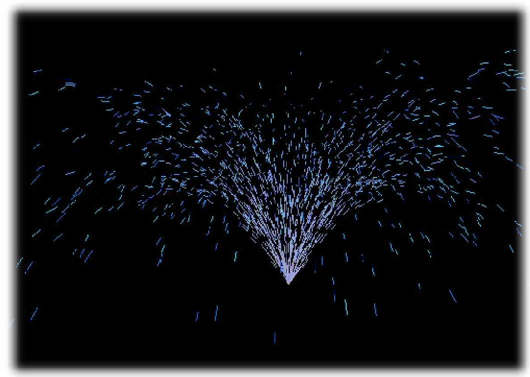
Lecture Overview

- Particle Systems
- Collision Detection
- Volume Rendering

Particle Systems

- Used for:
  - Fire/sparks
  - Rain/snow
  - Water spray
  - Explosions
  - Galaxies

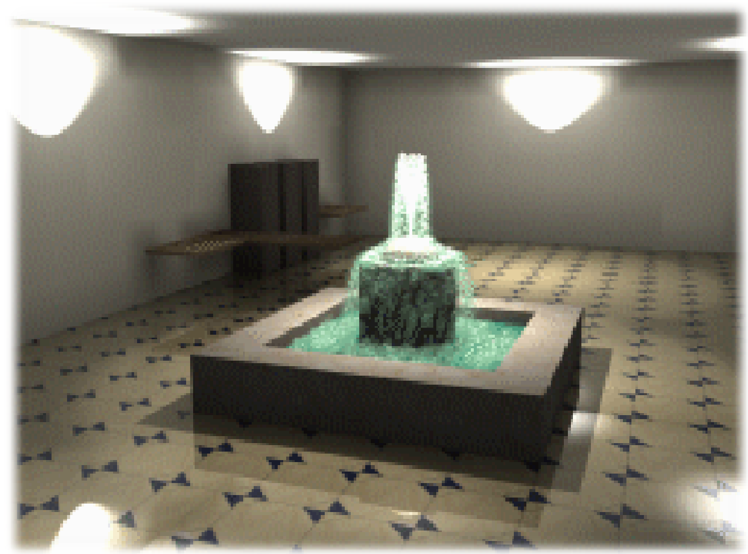



Internal Representation

- Particle system is collection of a number of individual elements (particles)
  - Controls a set of particles which act autonomously but share some common attributes
- Particle Emitter: Source of all new particles
  - 3D point
  - Polygon mesh: particles' initial velocity vector is normal to surface
- Particle attributes:
  - position (3D)
  - velocity (vector: speed and direction)
  - color + opacity
  - lifetime
  - size
  - shape
  - weight

Dynamic Updates

- Particles change position and/or attributes with time
- Initial particle attributes often created with random numbers
- Frame update:
  - Parameters: simulation of particles, can include collisions with geometry
    - Forces (gravity, wind, etc) accelerate a particle
    - Acceleration changes velocity
    - Velocity changes position
  - Rendering: display as
    - OpenGL points
    - (Textured) billboarded quads
    - Point sprites



Source: http://www.particlesystems.org/

Point Sprite

- **Screen-aligned element of variable size**
- **Defined by single point**
- **Sample code:**

```
glTexEnvf(GL_POINT_SPRITE, GL_COORD_REPLACE, GL_TRUE);
glEnable(GL_POINT_SPRITE);
glBegin(GL_POINTS);
  glVertex3f(position.x, position.y, position.z);
glEnd();
glDisable(GL_POINT_SPRITE);
```

Demo

- Source: http://www.particlesystems.org/Distrib/Particle221Demos.zip

References

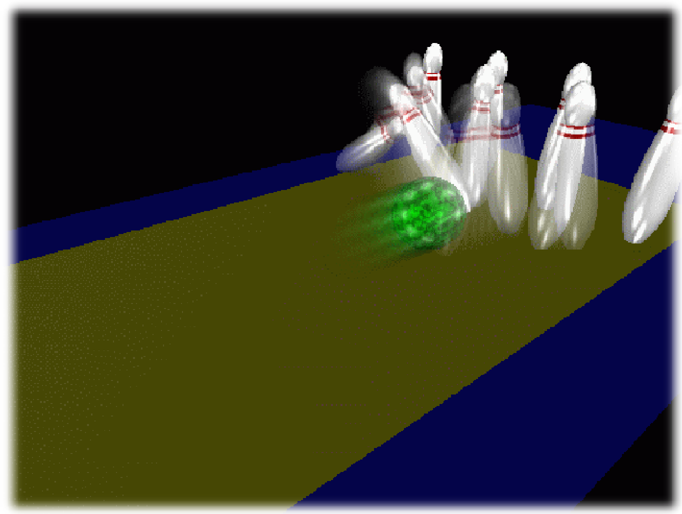
- Free particle systems API:
  - http://particlesystems.org/
- On-line tutorial: http://www.naturewizard.com/tutorial08.html
- Initial scientific paper:
  - Reeves: "Particle Systems - A Technique for Modeling a Class of Fuzzy Objects", ACM Transactions on Graphics (TOG) Volume 2 Issue 2, April 1983
- Article with source code:
  - Jeff Lander: "The Ocean Spray in Your Face", Game Developer, July 1998, http://www.darwin3d.com/gamedev/articles/col0798.pdf
- John Van Der Burg: "Building an Advanced Particle System", Gamasutra, June 2000
  - http://www.gamasutra.com/view/feature/3157/building_an_advanced_particle_.php

Lecture Overview

- Particle Systems
- Collision Detection
- Volume Rendering

Collision Detection

- Possible goals:
  - Physically correct simulation of collision of objects
    - Not covered here
  - Determine if two objects intersect
- Slow because of exponential growth $O(n^2)$:
  - # collision tests = n*(n-1)/2



Intersection Testing

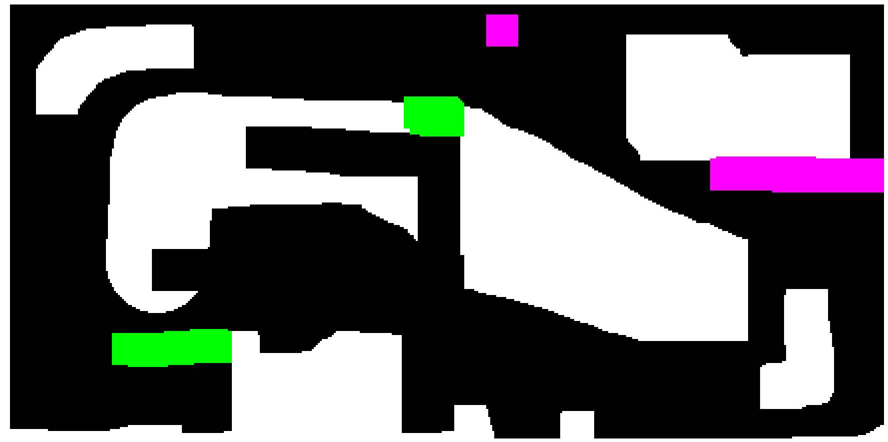
- Purpose:
  - Keep moving objects on the ground
  - Keep moving objects from going through walls, each other, etc.
- Goal:
  - Believable system, does not have to be physically correct
- Priority:
  - Computationally inexpensive
- Typical approach:
  - Spatial partitioning
  - Object simplified for collision detection by one or a few
    - Points
    - Spheres
    - Axis aligned bounding box (AABB)
  - Pairwise checks between points/spheres/AABBs and static geometry

Sweep and Prune Algorithm

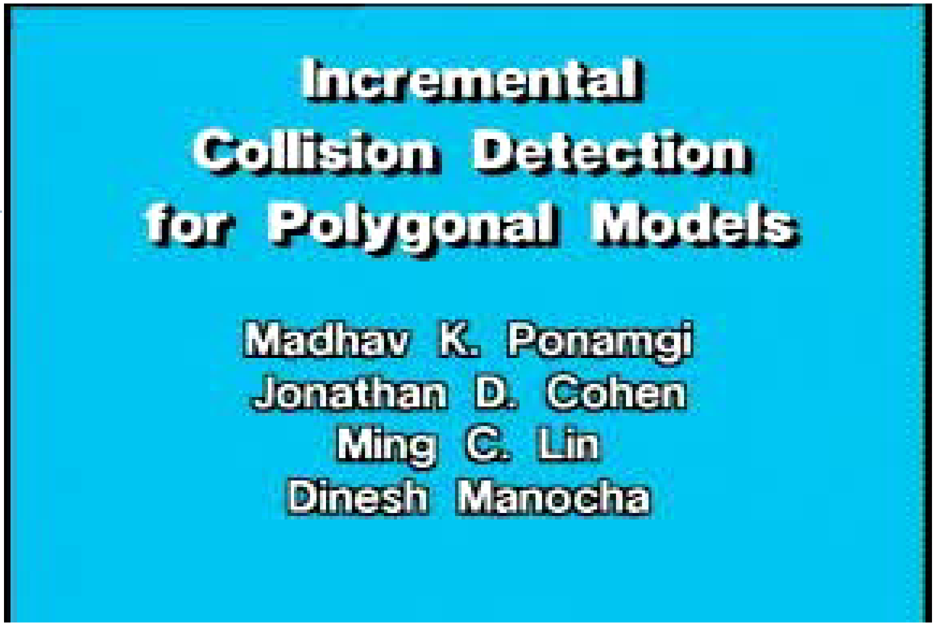
- Sorts bounding boxes
- Not intuitively obvious how to sort bounding boxes in 3-space
- Dimension reduction approach:
  - Project each 3-dimensional bounding box onto the x,y and z axes
  - Find overlaps in 1D: a pair of bounding boxes can overlap if and only if their intervals overlap in all three dimensions
    - Construct 3 lists, one for each dimension
    - Each list contains start/end point of intervals corresponding to that dimension
    - By sorting these lists, we can determine which intervals overlap
    - Reduce sorting time by keeping sorted lists from previous frame, changing only the interval endpoints
- Alternative: project bounding boxes onto coordinate axis planes and look for overlaps in 2D

Collision Map (CM)

- 2D map with information about where objects can go and what happens when they go there
- Colors indicate different types of locations
- Map can be computed from 3D model, or hand drawn with paint program
- Granularity: defines how much area (in object space) one CM pixel represents



References



- I-Collide:
  - Interactive and exact collision detection library for large environments composed of convex polyhedra
  - http://gamma.cs.unc.edu/I-COLLIDE/
- OZ Collide:
  - Fast, complete and free collision detection library in C++
  - Based on AABB tree
  - http://www.tsarevitch.org/ozcollide/

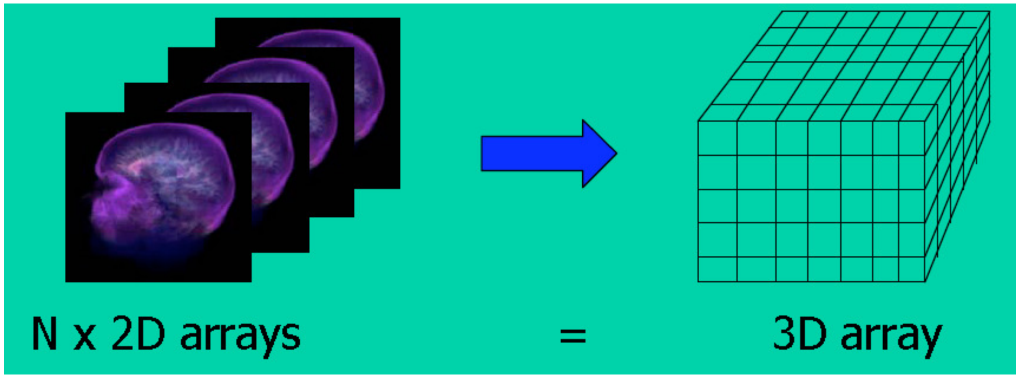
Lecture Overview

- Particle Systems
- Collision Detection
- Volume Rendering

What is Volume Rendering

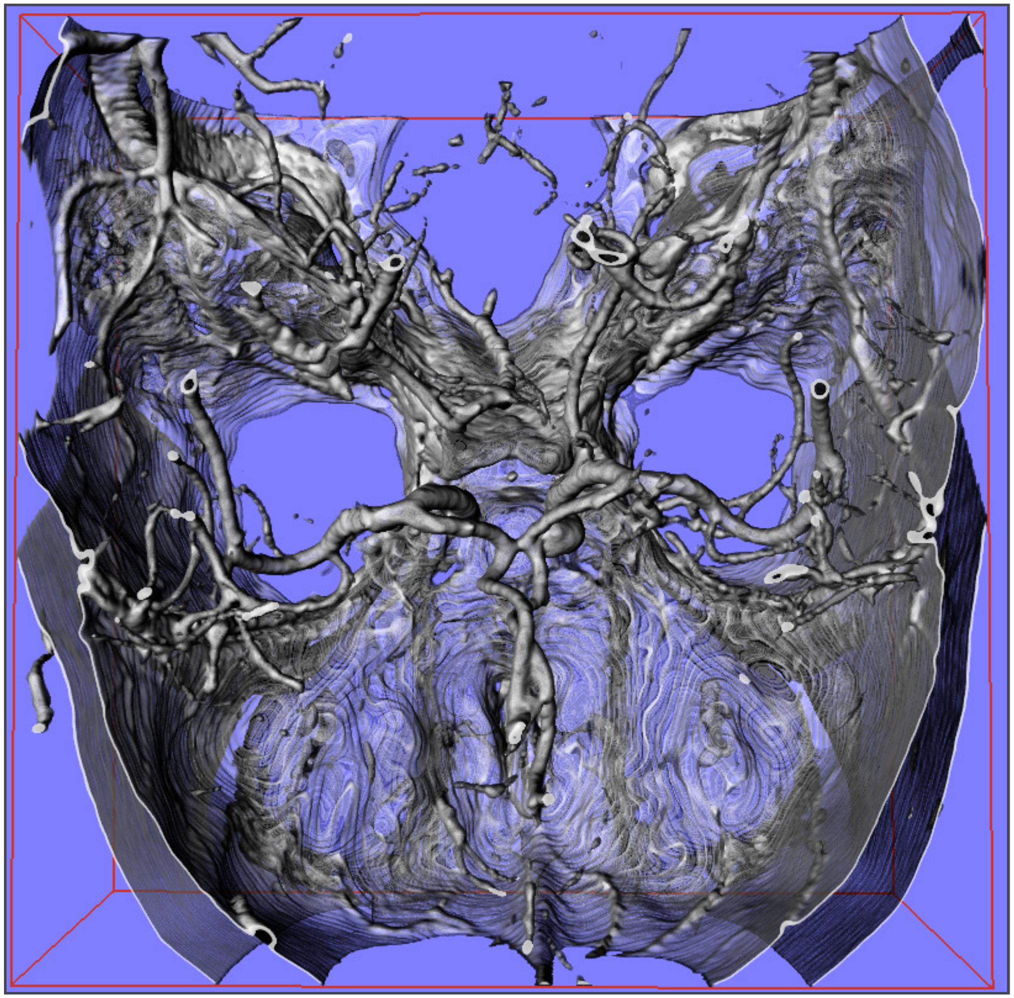
- A *Volume* is a 3D array of voxels (volume elements, 3D equivalent of pixels)
- 3D images produced by CT, MRI, 3D mesh-based simulations are easily represented as volumes
- The *Voxel* is the basic element of the volume
  Typical volume size may be 128^3 voxels, but any other size is acceptable.
- *Volume Rendering* means rendering the voxel-based data into a viewable 2D image.

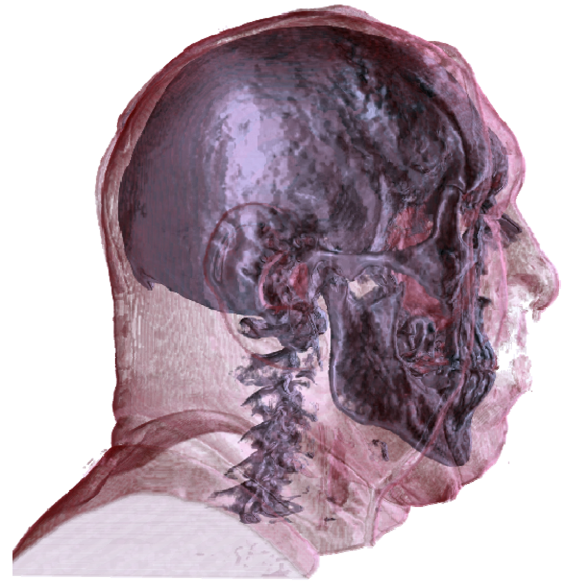
Volume Data Types



- 3D volume data are represented by a finite number of cross-sectional slices (3D grid)
- Each voxel stores a data value
  - Single bit: binary data set
  - Typical: 8 or 16 bit integers
  - Simulations often generate floating point
  - Sometimes multi-valued (multiple data values per voxel), for instance RGB, multi-channel confocal microscopy

Applications: Medicine





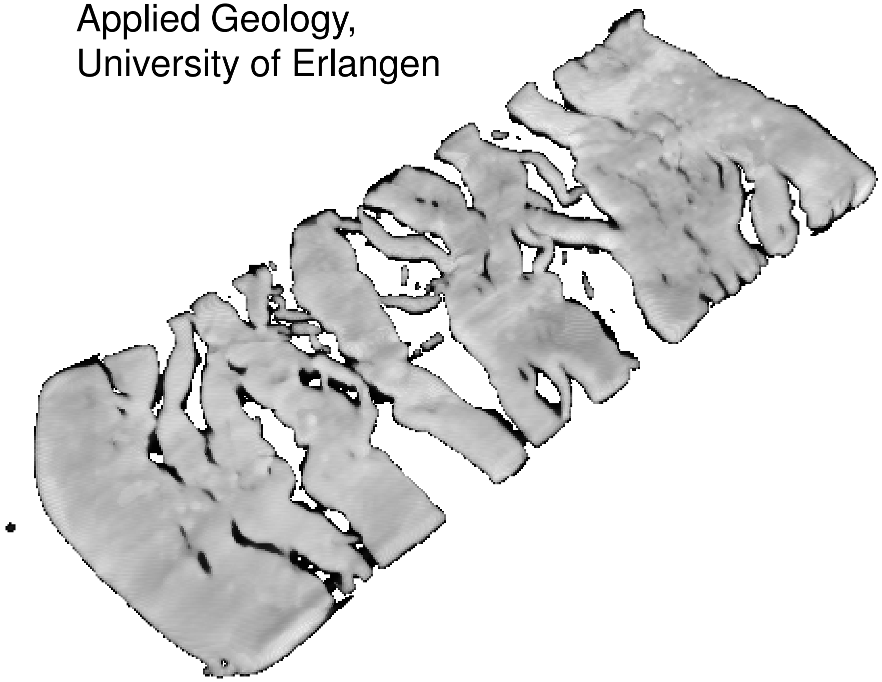
CT Human Head:
Visible Human Project, US National Library of Medicine, Maryland, USA

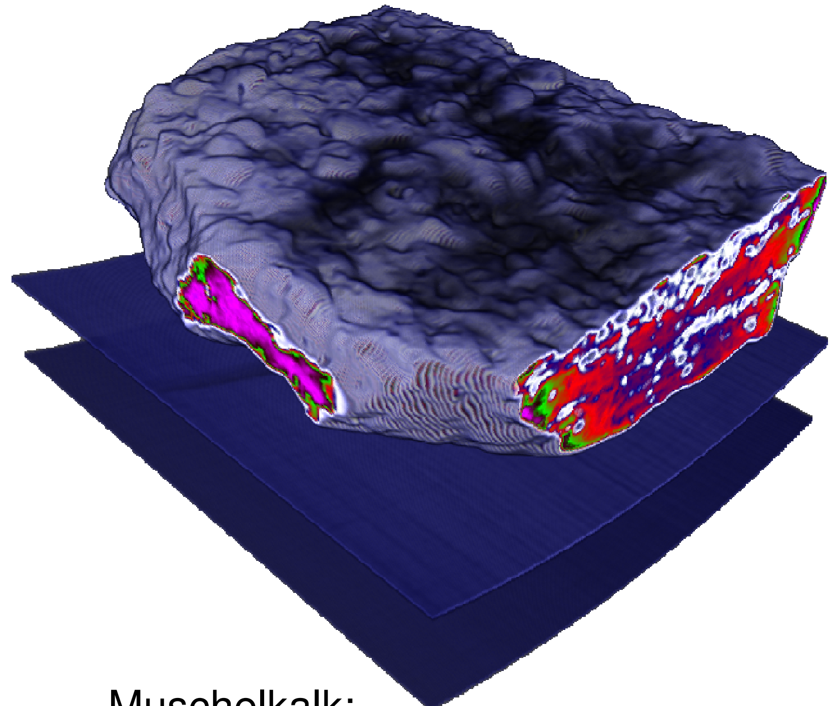
CT Angiography:
Dept. of Neuroradiology University of Erlangen, Germany

This and some of the following slides are from a Eurographics 2006 course by Dr. Christof Rezk Salama, Computer Graphics and Multimedia Group, University of Siegen, Germany

Applications: Geology

Deformed Plasticine Model,
Applied Geology,
University of Erlangen





Muschelkalk:
Paläontologie,
Virtual Reality Group,
University of Erlangen

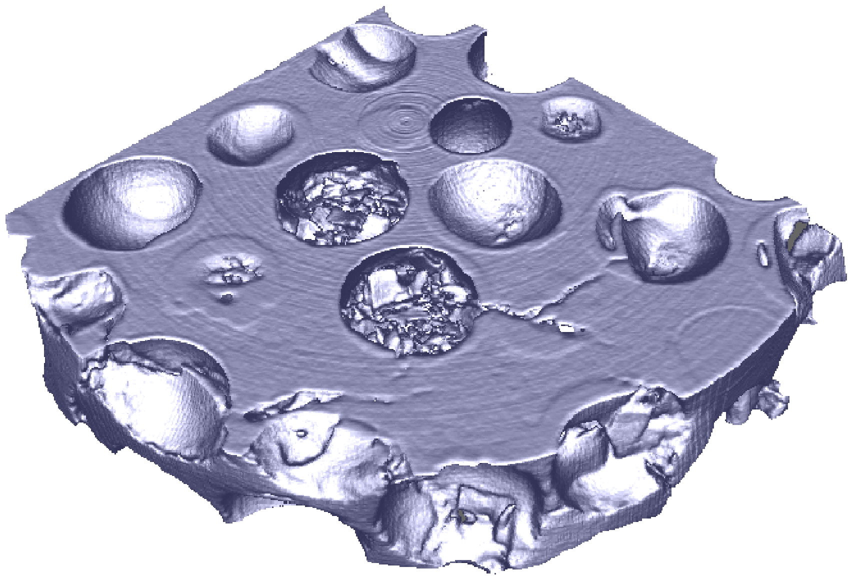
Applications: Archaeology

Hellenic Statue of Isis
3rd century B.C.
ARTIS, University of Erlangen-Nuremberg, Germany

Sotades Pygmaios Statue
5th century B.C
ARTIS, University of Erlangen-Nuremberg, Germany

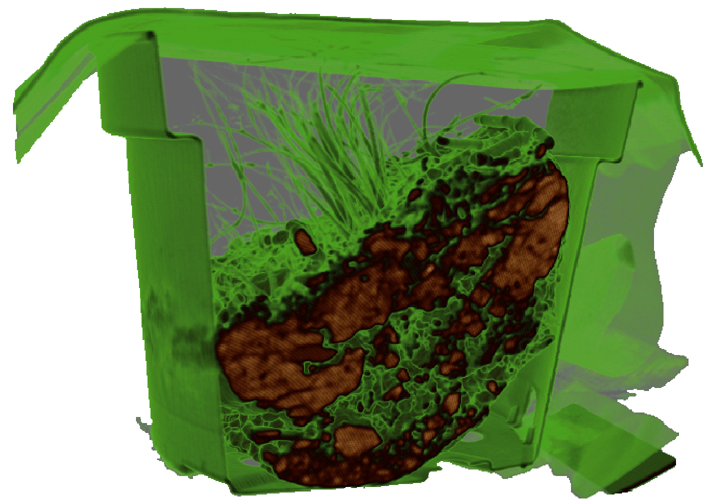
Applications

Material Science, Quality Control



Micro CT, Compound Material
Material Science Department, University of Erlangen

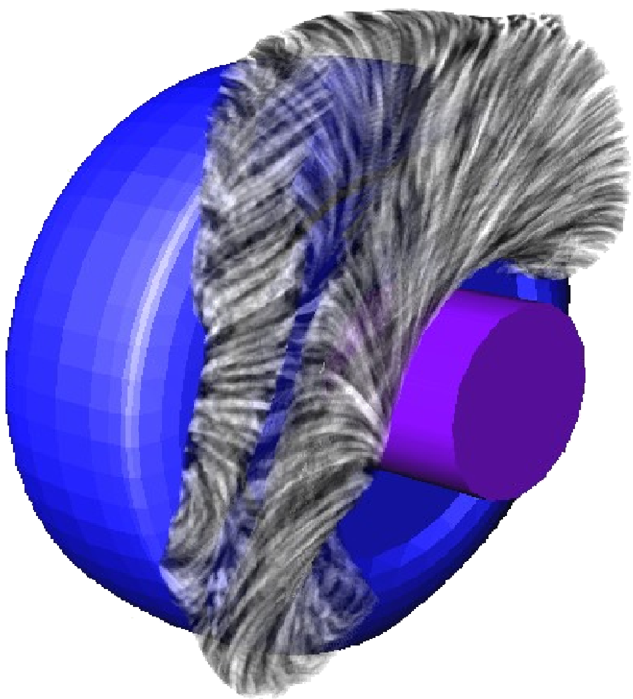
Biology

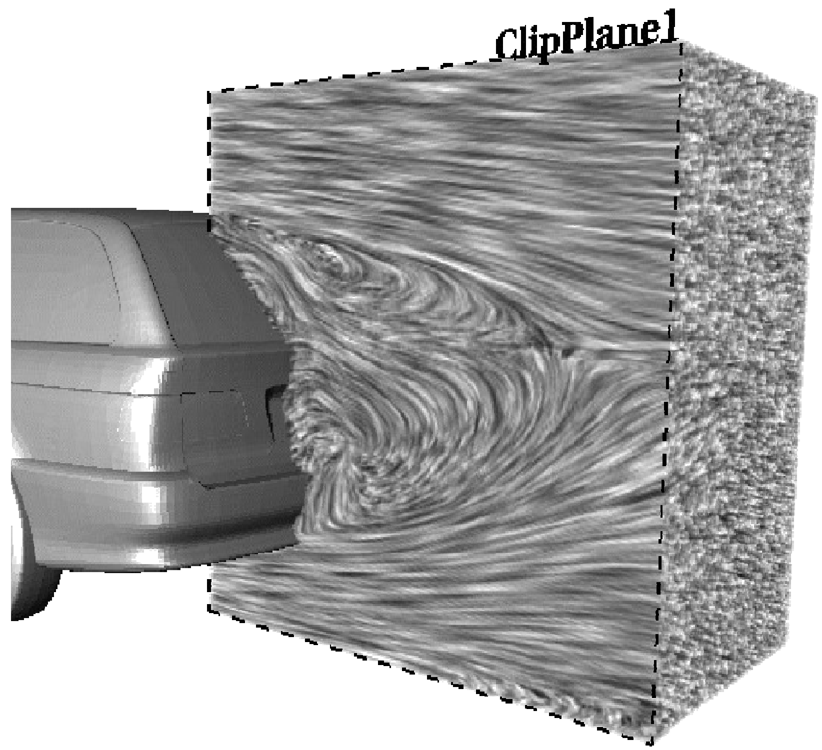


Biological sample of soil, CT
Virtual Reality Group, University if Erlangen

Applications

Computational Science and Engineering





Methods of Representation

- Polygonal - Triangle Mesh
- Freeforms - parametric curves, patches…
- Solid Modelling - CGS (Constructive Solid Geometry)
- Direct Volume Rendering

Why Direct Volume Rendering?

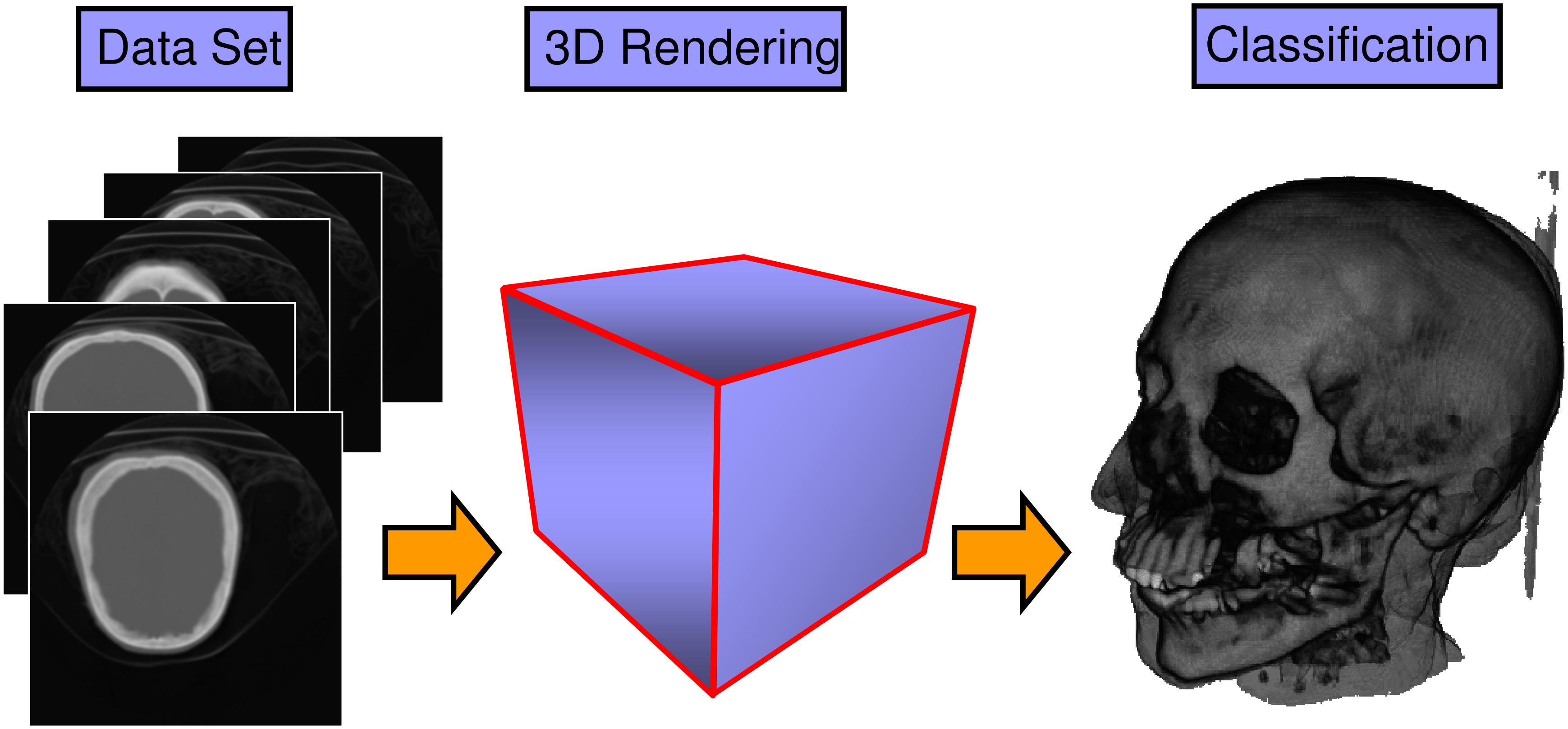
Pros

- Natural representation of CT/MRI images
- Transparency effects (Fire, Smoke…)
- High quality

Cons

- Huge data sets
- Computationally expensive
- Cannot be embedded easily into polygonal scene

Volume Rendering Outline



- in real-time on commodity graphics hardware

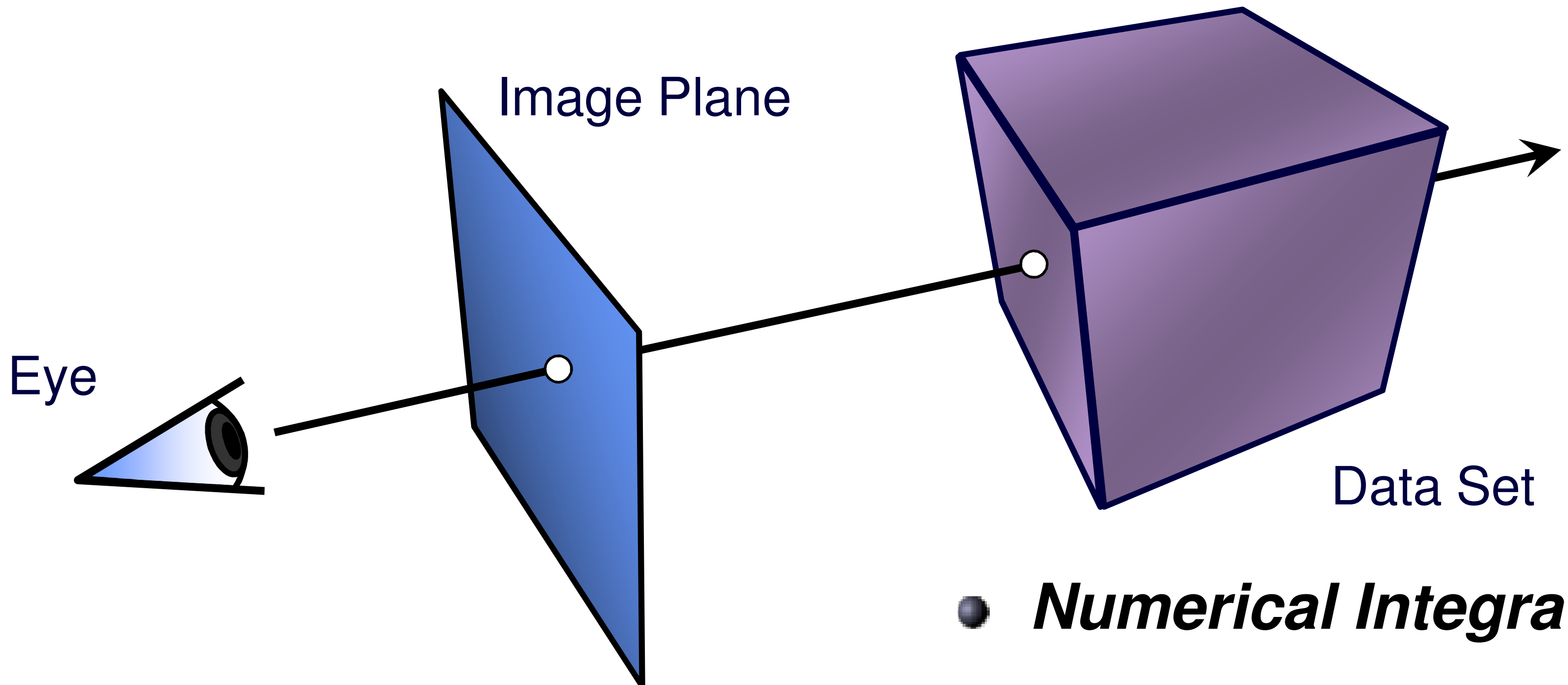
Rendering Methods

There are two categories of volume rendering algorithms:

1. Ray casting algorithms (Object Order)
   - Basic ray-casting
   - Using octrees
2. Plane Composing (Image Order)
   - Basic slicing with 2D textures
   - Shear-Warp factorization
   - Translucent textures with image-aligned 3D textures

Ray Casting

- Software Solution



- ***Numerical Integration***
- ***Resampling***

➡ ***High Computational Load***

Rendering Methods

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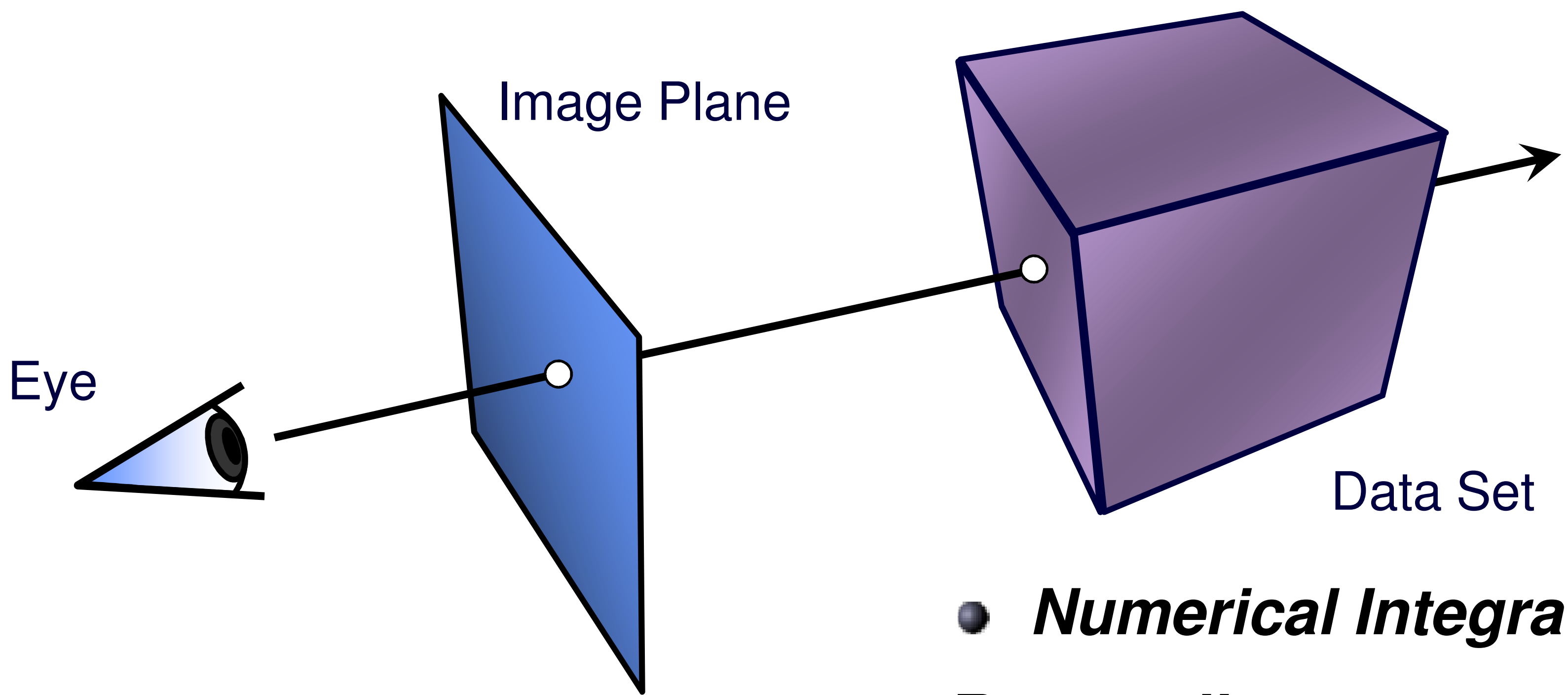
Ray Casting

- Software Solution

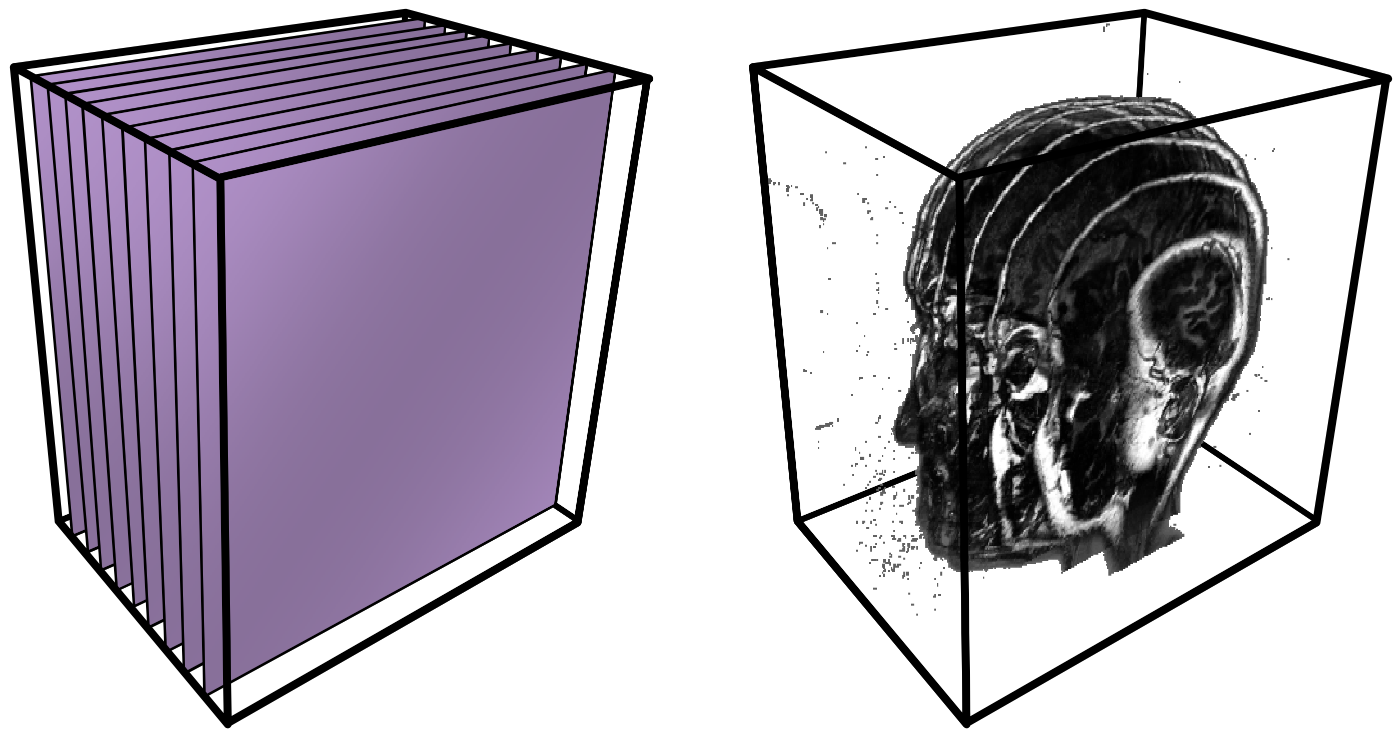


- ***Numerical Integration***
- ***Resampling***

➡ ***High Computational Load***

Plane Compositing

- Proxy geometry (Polygonal Slices)

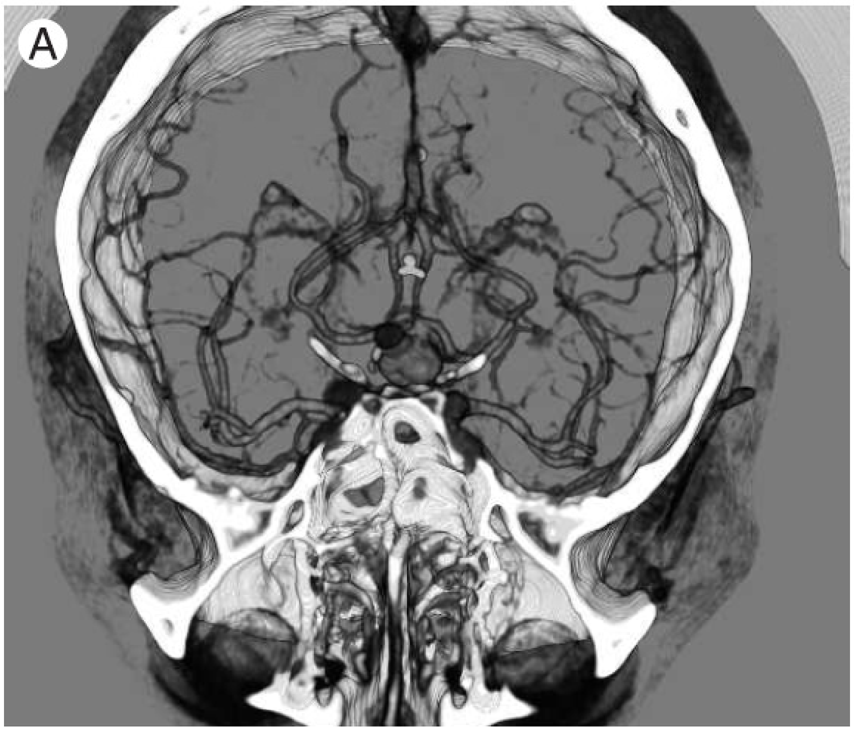


Compositing

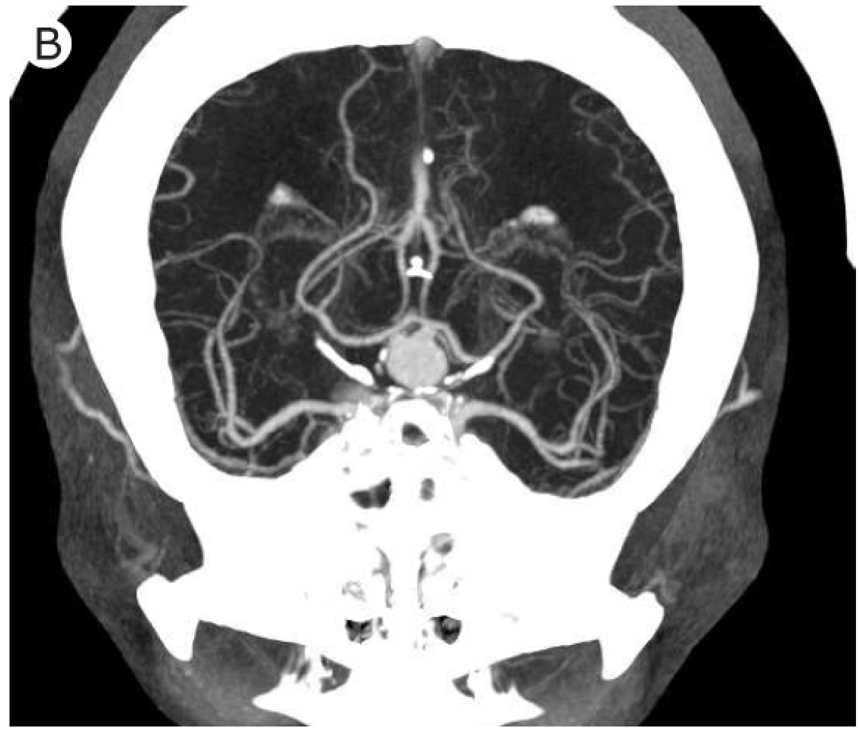
- ***Maximum Intensity Projection***

  No emission/absorption

  Simply compute maximum value along a ray



Emission/Absorption

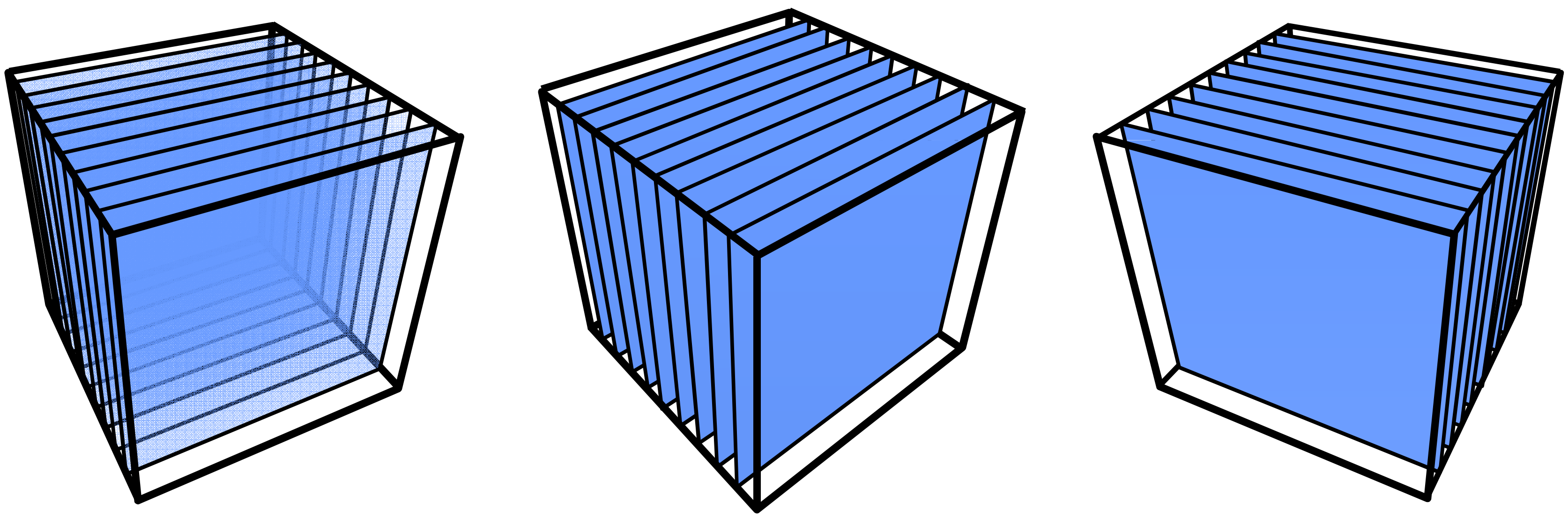


Maximum Intensity Projection

2D Textures

- Draw the volume as a stack of 2D textures
  Bilinear Interpolation in Hardware

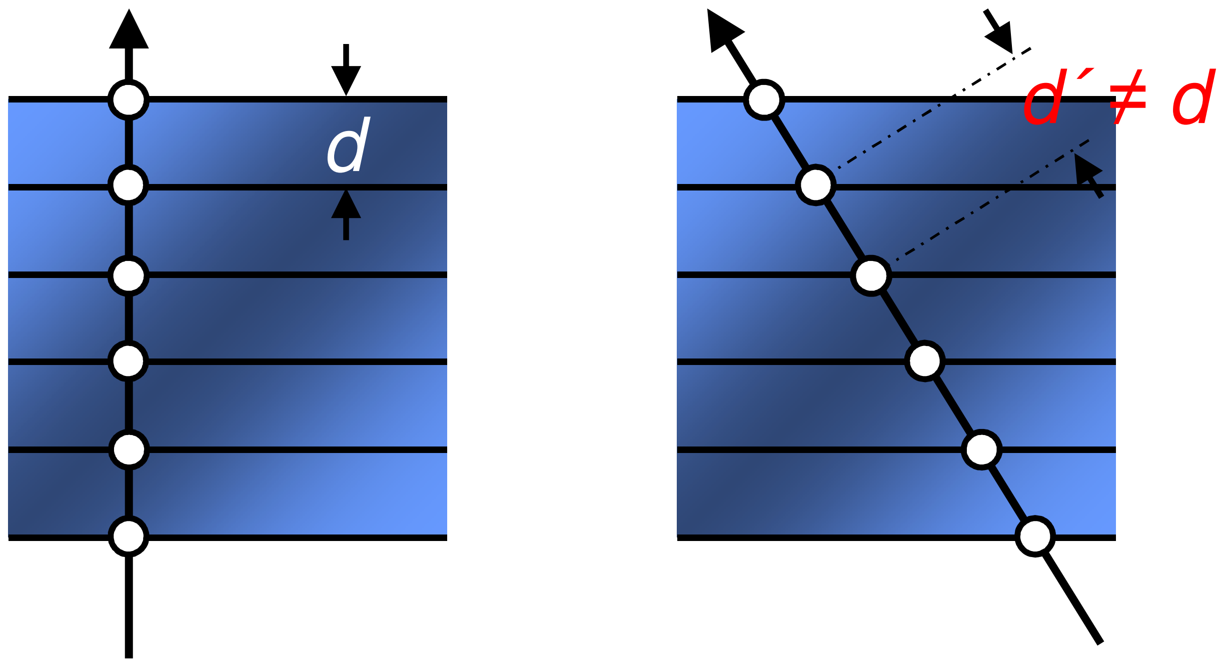
➡ Decompostition into axis-aligned slices



- 3 copies of the data set in memory

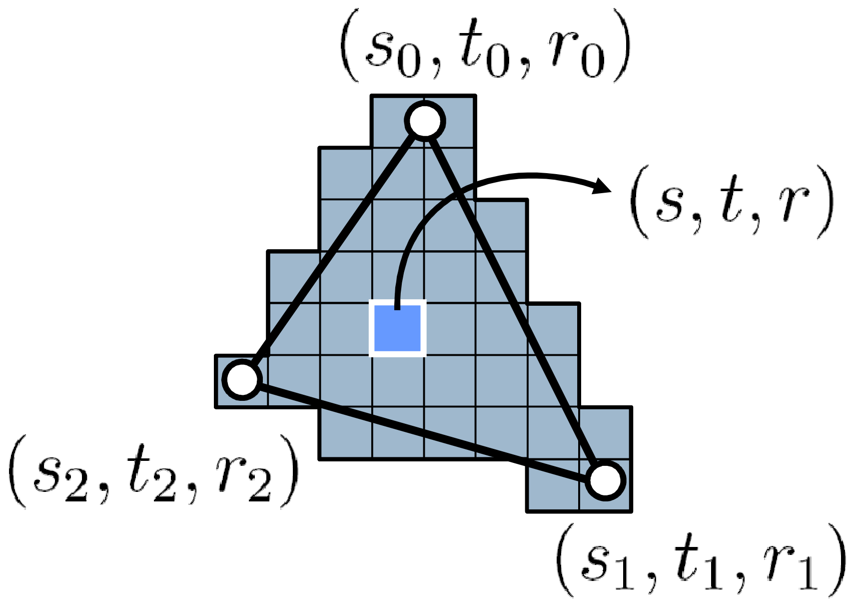
2D Textures: Drawbacks

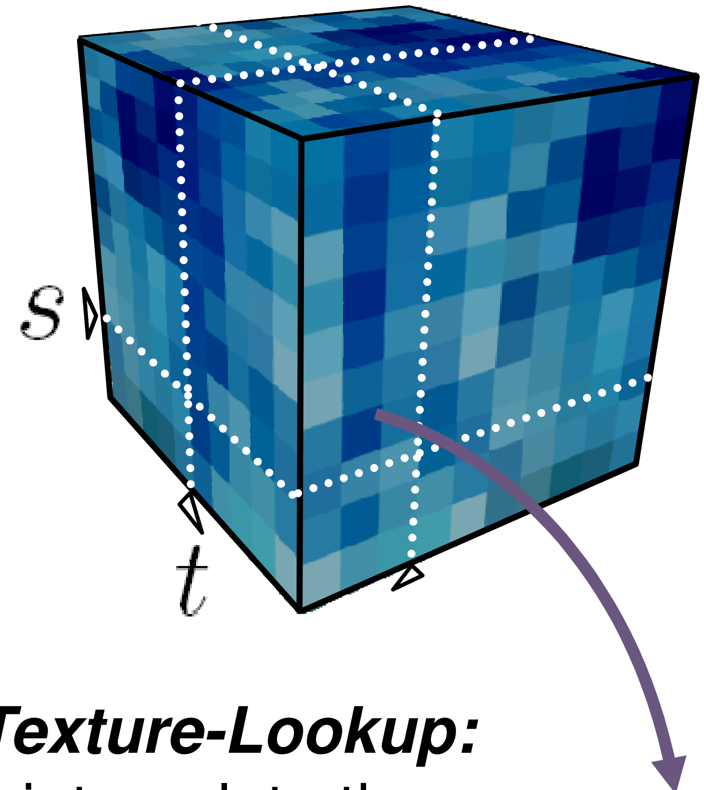
- Sampling rate is inconsistent



- Emission/absorption slightly incorrect
- ***Super-sampling on-the-fly impossible***

3D Textures





For each fragment:
interpolate the
texture coordinates
(barycentric)

Texture-Lookup:
interpolate the
texture color
(trilinear)

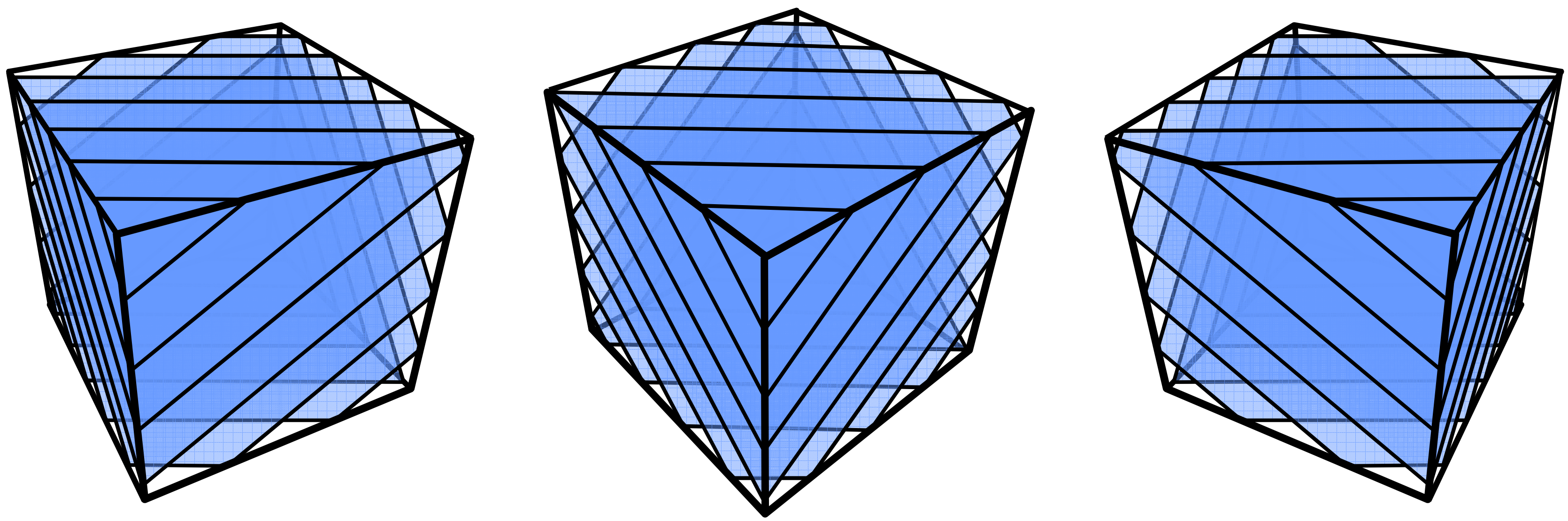
R G B A

3D Textures

3D Texture: Volumetric Texture Object

- Trilinear Interpolation in Hardware

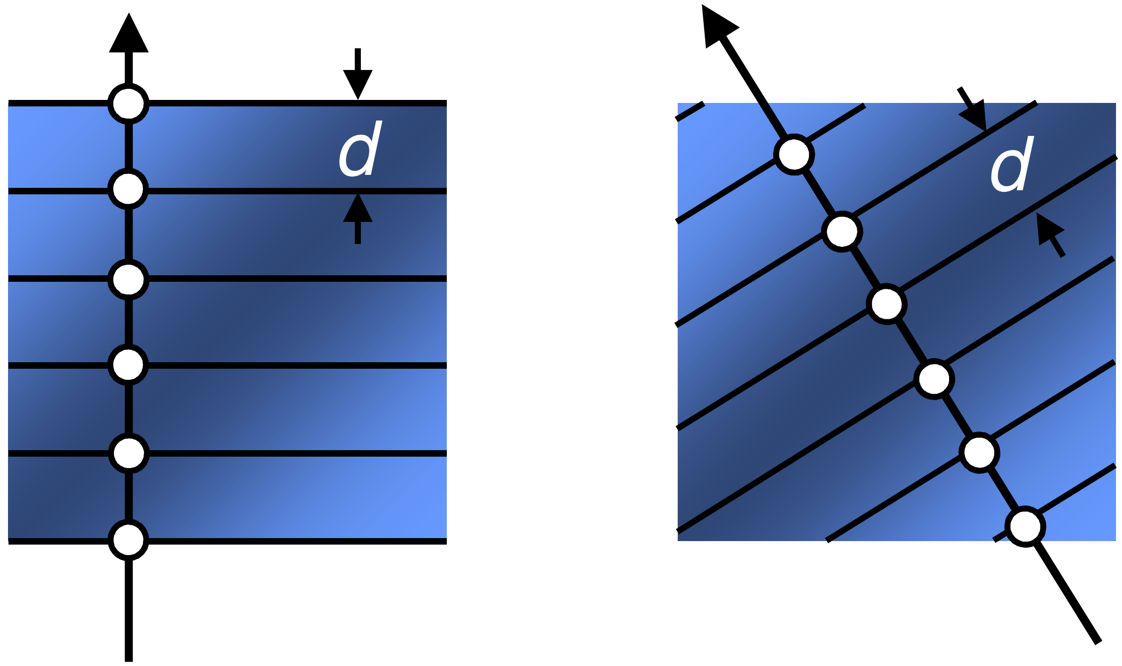
➡ Slices parallel to the image plane



- One large texture block in memory

Resampling via 3D Textures

- ***Sampling rate is constant***



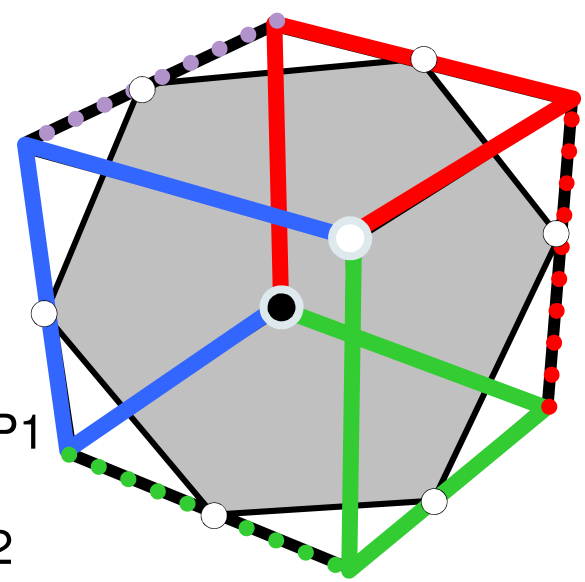
- Supersampling by increasing the number of slices

Cube-Slice Intersection

Question: Can we compute this in a vertex program?

Vertex program:

- ***Input:*** 6 Vertices
- ***Output:*** 6 Vertices



P0: Intersection with red path

P1: Intersection with dotted red edge or P0

P2: Intersection with green path

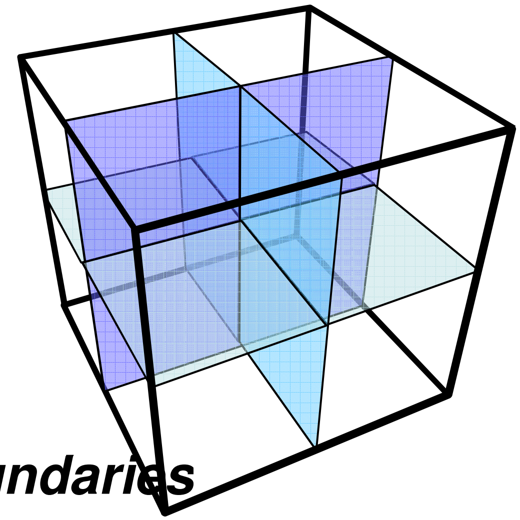
P3: Intersection with dotted green edge or P1

P4: Intersection with blue path

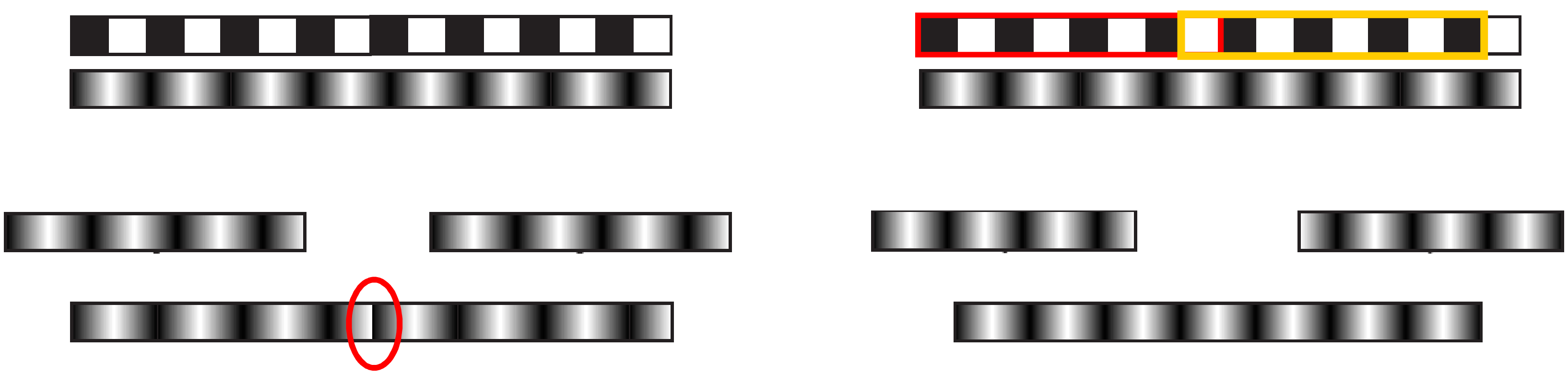
P5: Intersection with dotted blue edge or P2

Bricking

- What happens if data set is too large to fit into local video memory?
- Divide the data set into smaller chunks (bricks)



One plane of voxels must be duplicated to enable correct interpolation across brick boundaries



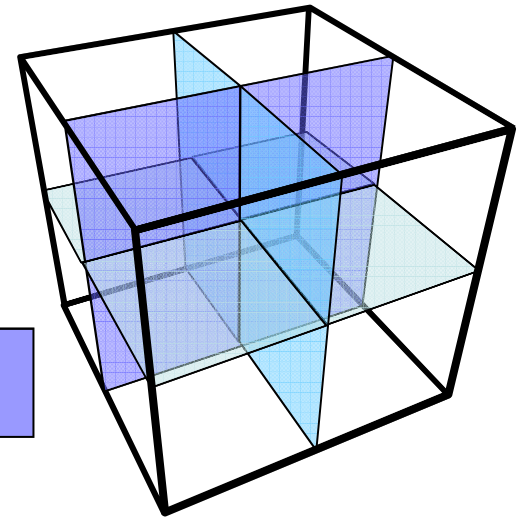
incorrect interpolation!

Bricking

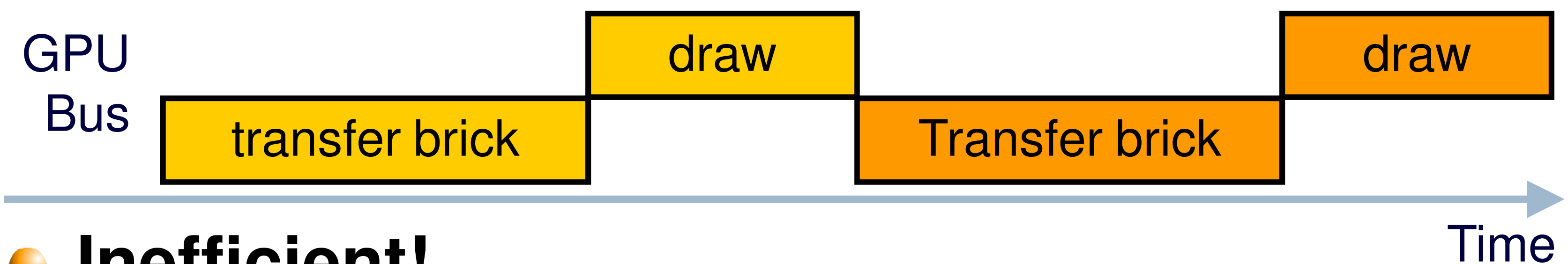
- What happens if data set is too large to fit into local video memory?

➡ Divide the data set into smaller chunks (bricks)

Problem: Bus-Bandwidth



- Unbalanced Load for GPU und Memory Bus

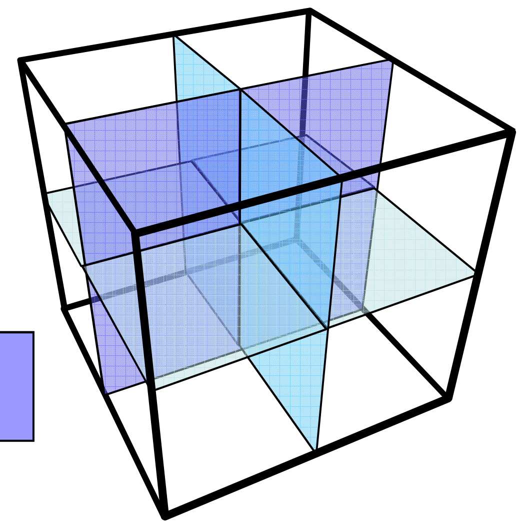


- **Inefficient!**

Bricking

- What happens if data set is too large to fit into local video memory?

➡ Divide the data set into smaller chunks (bricks)



Problem: Bus-Bandwidth

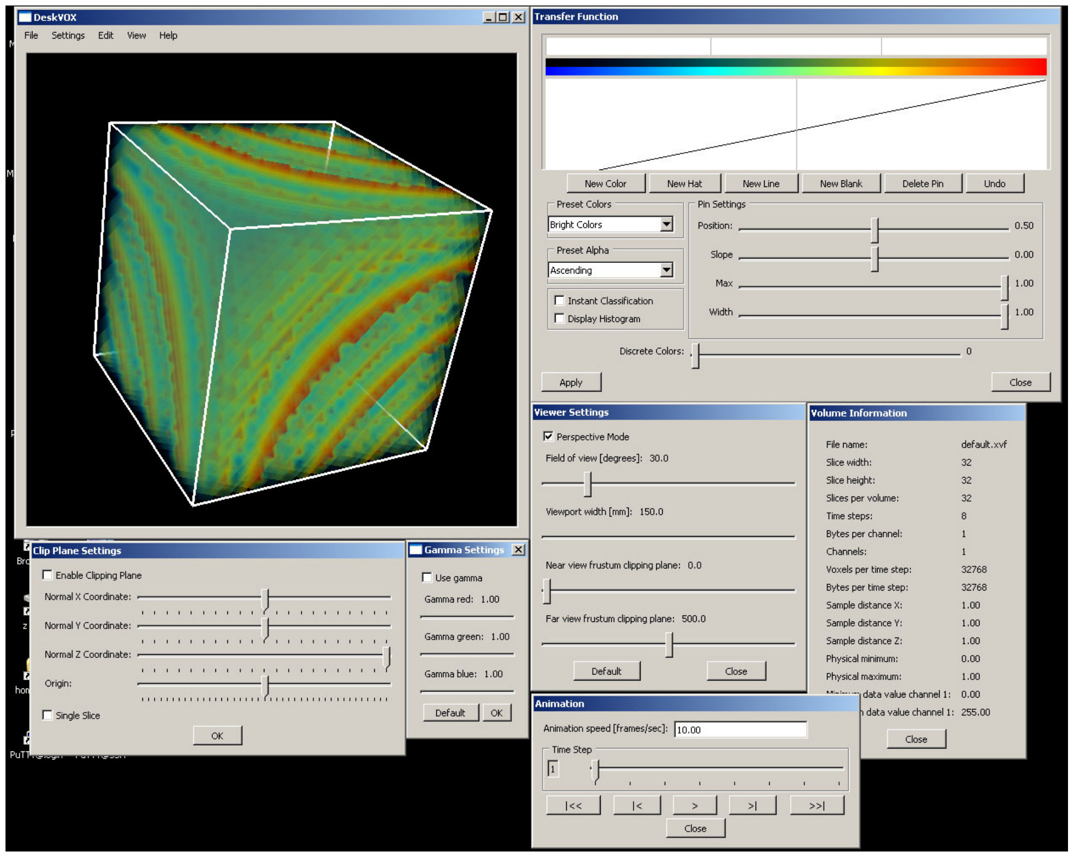
- Keep the bricks small enough!
  More than one brick must fit into video memory !
  - Transfer and Rendering can be performed in parallel
  - Increased CPU load for intersection calculation!
  - ***Effective load balancing still very difficult!***

Videos

- Human head, rendered with 3D texture: http://www.youtube.com/watch?v=94_Zs_6AmQw&feature=related
- GigaVoxels: http://www.youtube.com/watch?v=HScYuRhgEJw&feature=related

Free Volume Rendering Software

- Virvo:
  http://www.calit2.net/~jschulze/projects/vox/



Next Lecture

- Final exam review