CS 247 – Scientific Visualization
Lecture 17: Volume Rendering, Pt. 5

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Reading Assignment #9 (until Mar 29)

Read (required):

- Real-Time Volume Graphics, Chapter 4.5 – 4.8
- Paper:

  Markus Hadwiger, Ali K. Al-Awami, Johanna Beyer,
  Marco Agus and Hanspeter Pfister,

  SparseLeap: Efficient Empty Space Skipping for Large-Scale Volume Rendering, IEEE Scientific Visualization 2017,

  http://vccvisualization.org/publications/2017_hadwiger_sparseleap.pdf

  http://vccvisualization.org/publications/2017_hadwiger_sparseleap.mp4

Quiz #2: Mar 31

Organization

- First 30 min of lecture
- No material (book, notes, ...) allowed

Content of questions

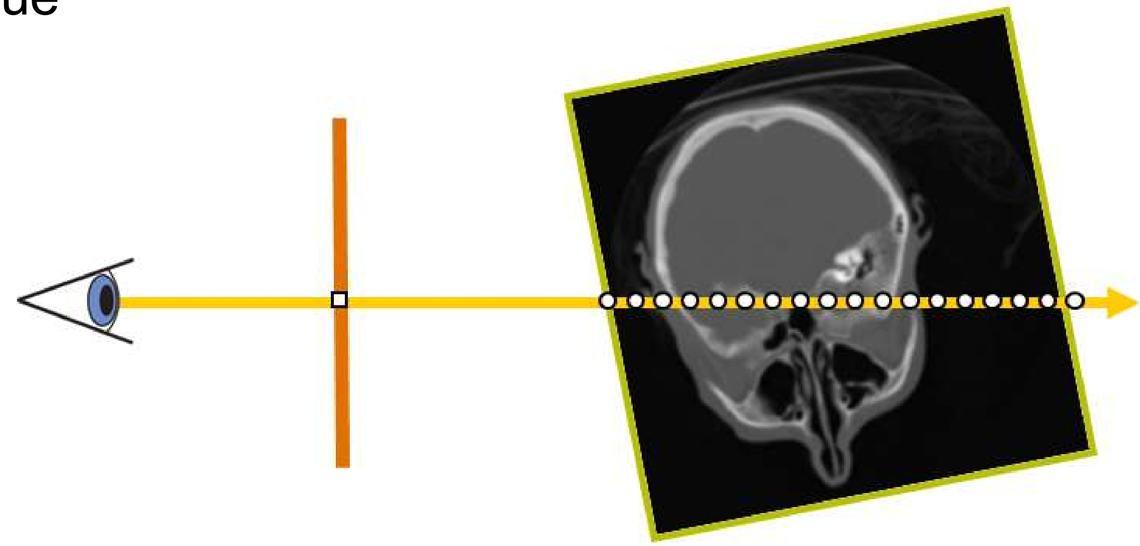
- Lectures (both actual lectures and slides)
- Reading assignments (except optional ones)
- Programming assignments (algorithms, methods)
- Solve short practical examples

Implementation

Ray setup

Loop over ray

- Resample scalar value
- Classification
- Shading
- Compositing



Implementation

Ray setup

Loop over ray

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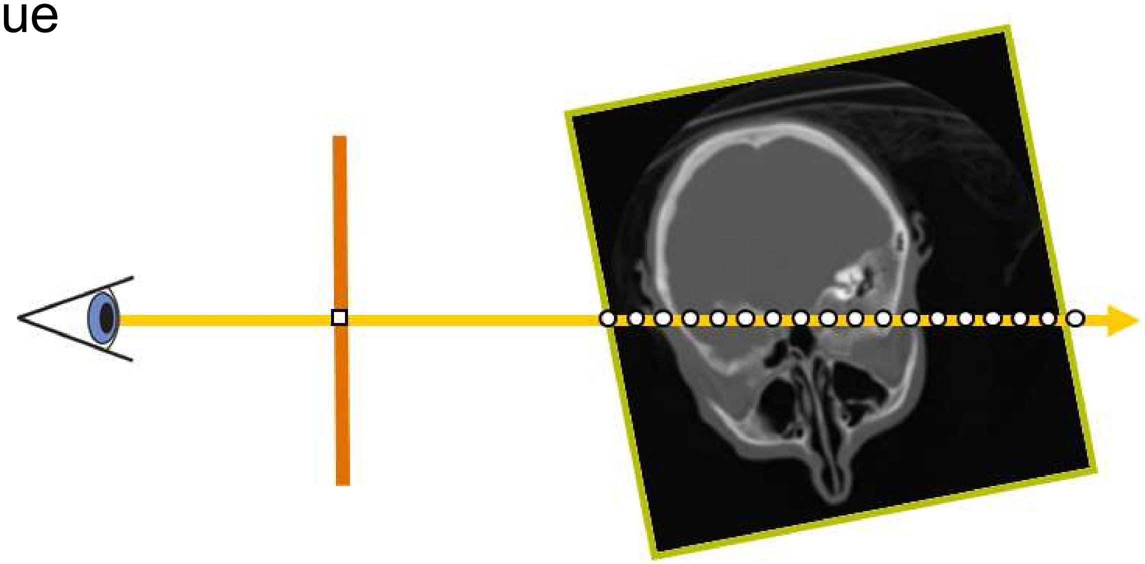
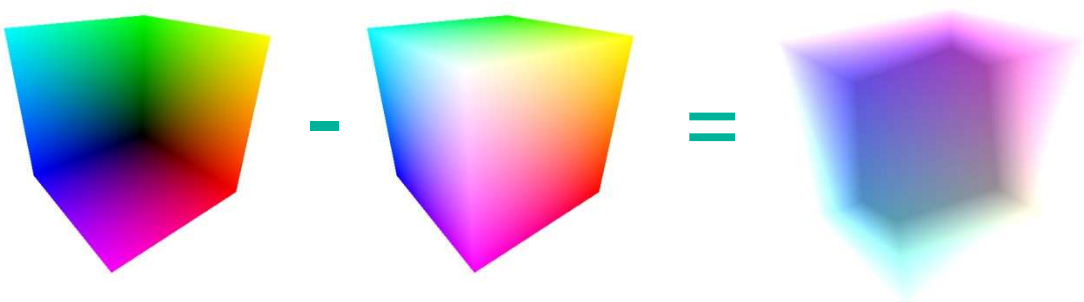
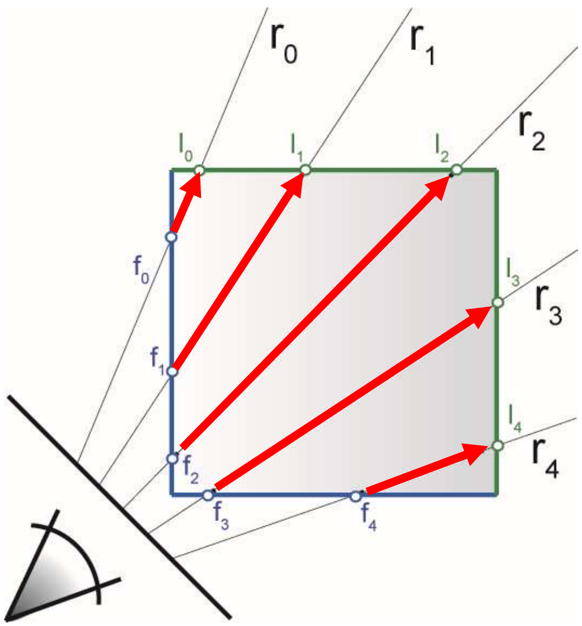


Rasterization-Based Ray Setup

- Fragment == ray
- Need ray start pos, direction vector
- Rasterize bounding box





- Identical for orthogonal and perspective projection!

Implementation

Ray setup

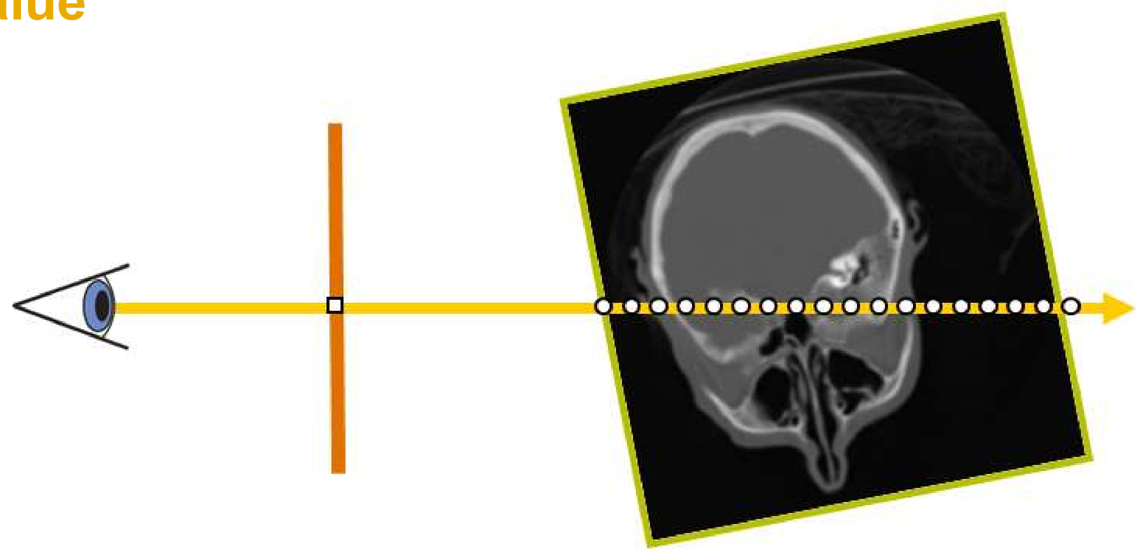
Loop over ray

Resample scalar value

Classification

Shading

Compositing

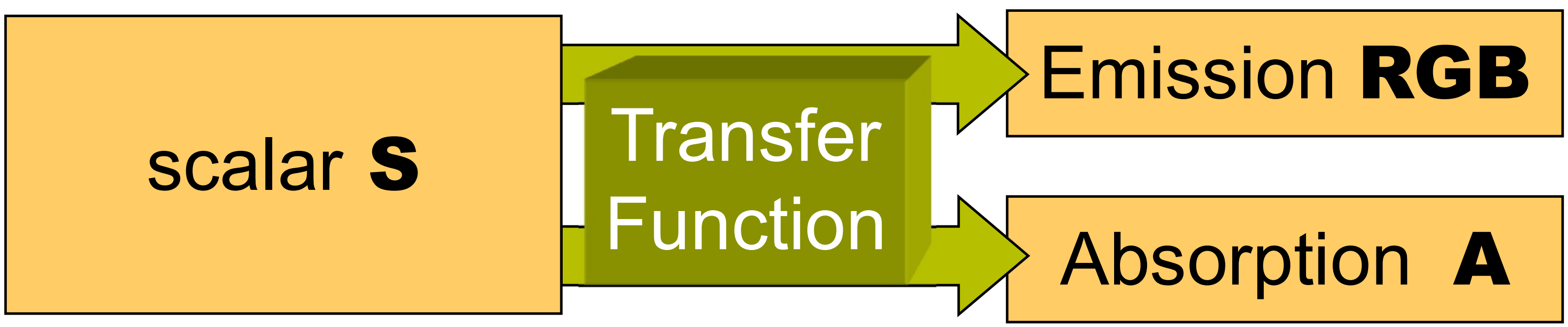


Classification – Transfer Functions

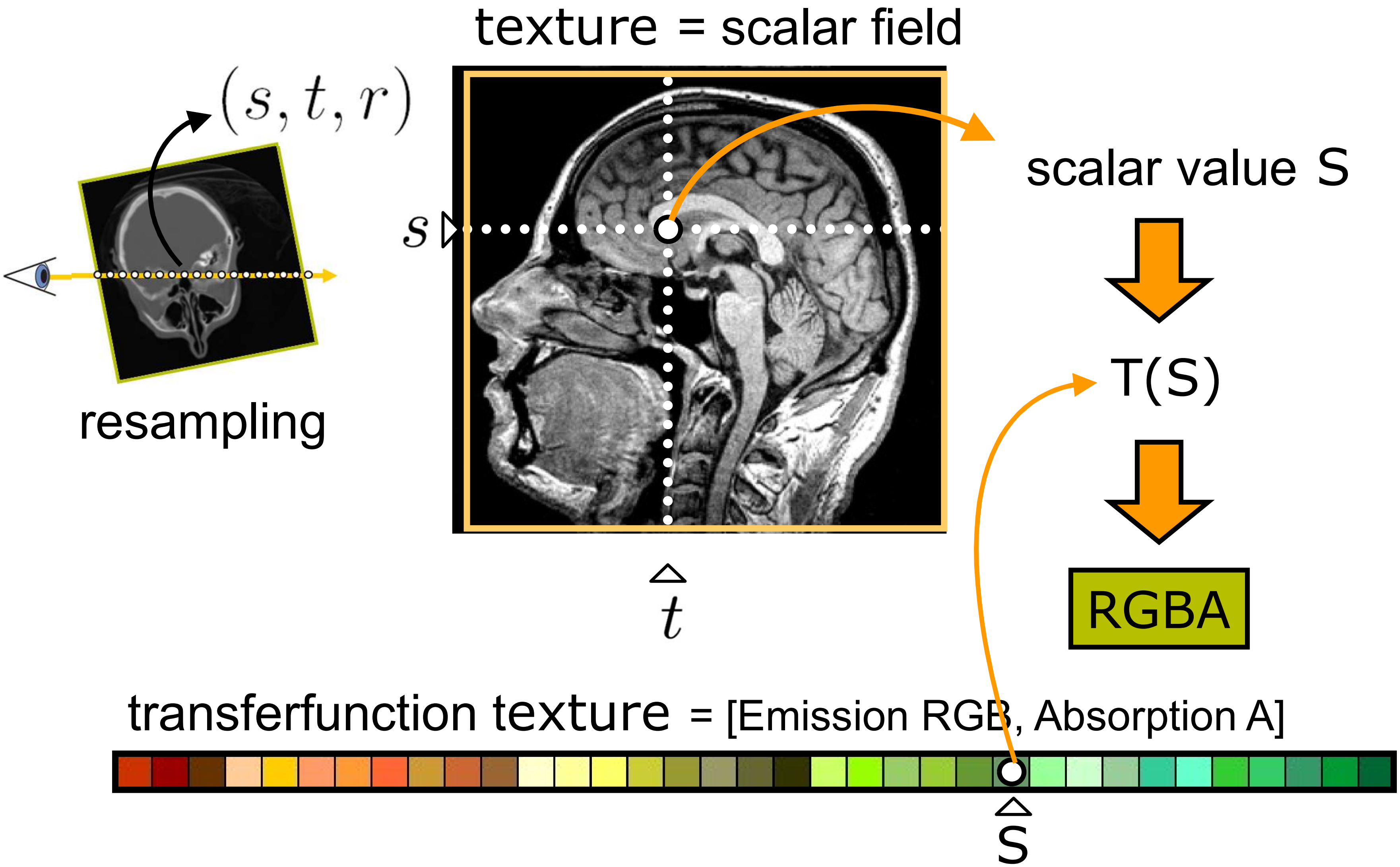
During Classification the user defines the ***“look“*** of the data.

- Which parts are transparent?
- Which parts have what color?

The user defines a ***transfer function.***



1D Transfer Functions

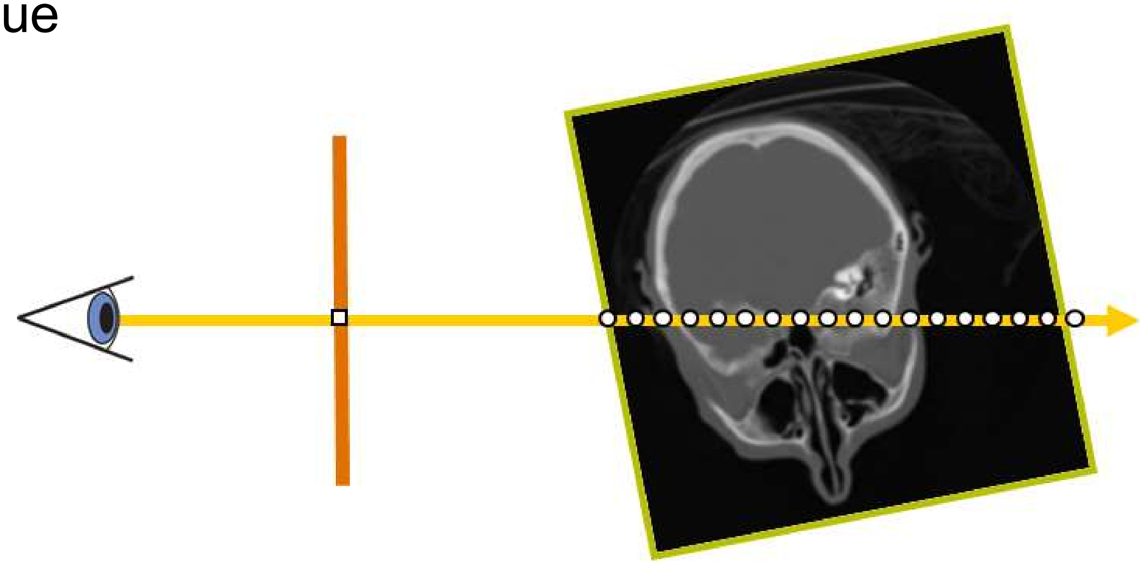


Implementation

Ray setup

Loop over ray

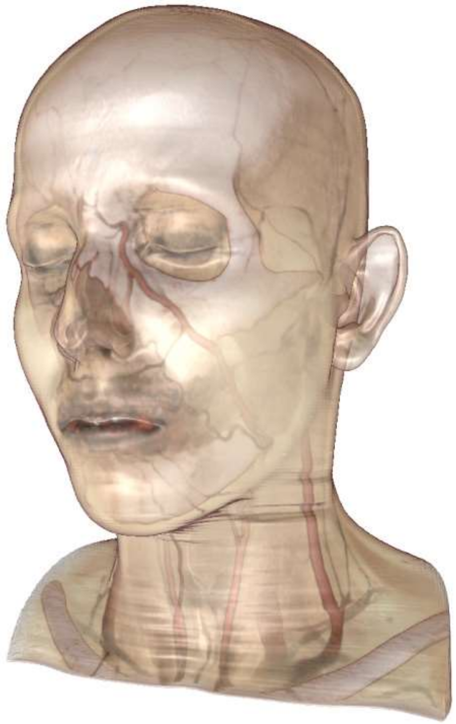
- Resample scalar value
- Classification
- **Shading**
- Compositing



Volume Shading

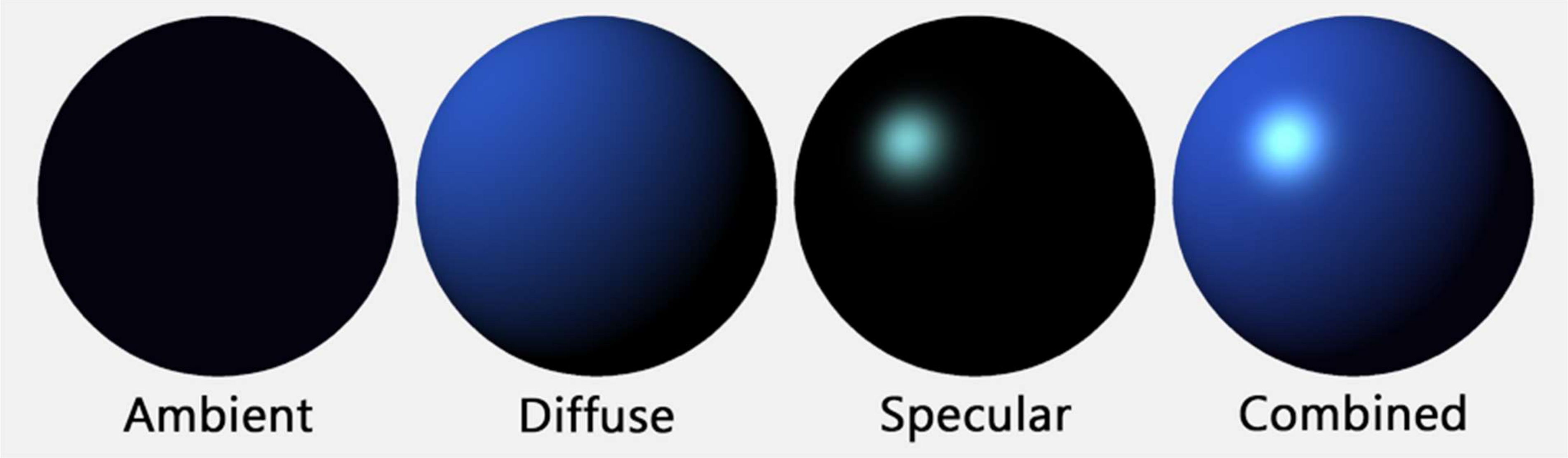
Local illumination vs. global illumination

- Gradient-based or gradient-less
- Shadows, (multiple) scattering, …



Local Illumination Model: Phong Lighting Model

$$\mathbf{I}_{\text{Phong}} = \mathbf{I}_{\text{ambient}} + \mathbf{I}_{\text{diffuse}} + \mathbf{I}_{\text{specular}}$$



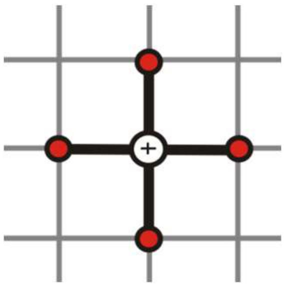
On-the-fly Gradient Estimation

$$\nabla f(x,y,z) \approx \frac{1}{2h} \begin{pmatrix} f(x+h,y,z) - f(x-h,y,z) \\ f(x,y+h,z) - f(x,y-h,z) \\ f(x,y,z+h) - f(x,y,z-h) \end{pmatrix}$$

```
float3 sample1, sample2;
// six texture samples for the gradient
sample1.x = tex3D(texture,uvw-half3(DELTA,0.0,0.0)).x;
sample2.x = tex3D(texture,uvw+half3(DELTA,0.0,0.0)).x;
sample1.y = tex3D(texture,uvw-half3(0.0,DELTA,0.0)).x;
sample2.y = tex3D(texture,uvw+half3(0.0,DELTA,0.0)).x;
sample1.z = tex3D(texture,uvw-half3(0.0,0.0,DELTA)).x;
sample2.z = tex3D(texture,uvw+half3(0.0,0.0,DELTA)).x;
// central difference and normalization
float3 N = normalize(sample2-sample1);
```

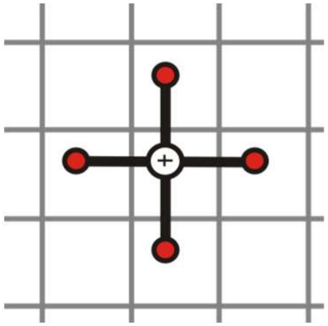
On-The-Fly Gradients

Reduce texture memory consumption!



Central differences before and after linear interpolation of values at grid points yield the same results

Caveat: texture filter precision



Filter kernel methods are expensive, but:

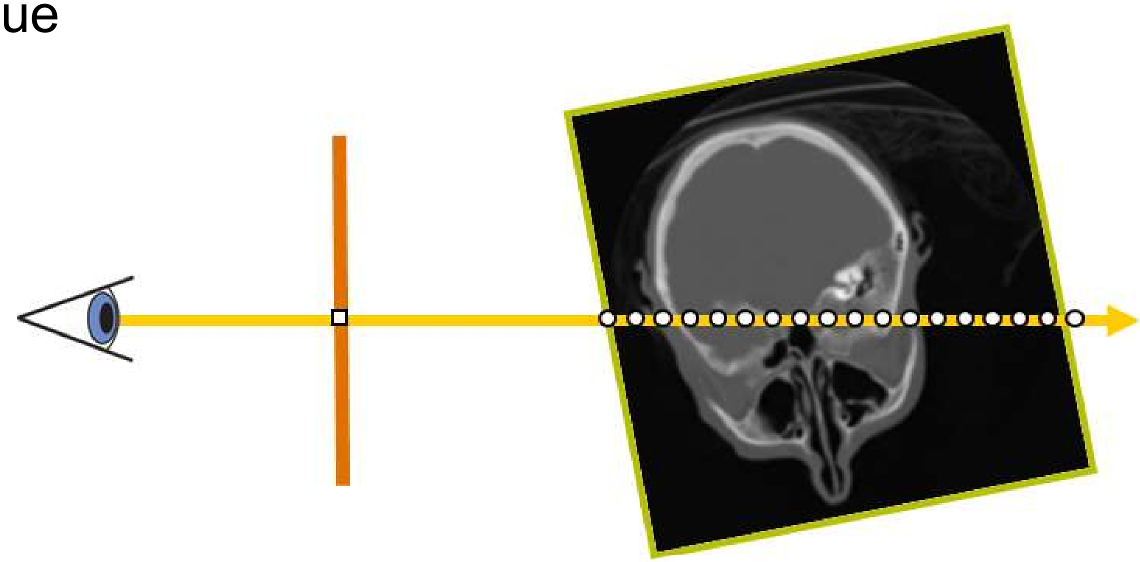
Tri-cubic B-spline kernels can be used in real-time (e.g., GPU Gems 2 Chapter “Fast Third-Order Filtering”)

Implementation

Ray setup

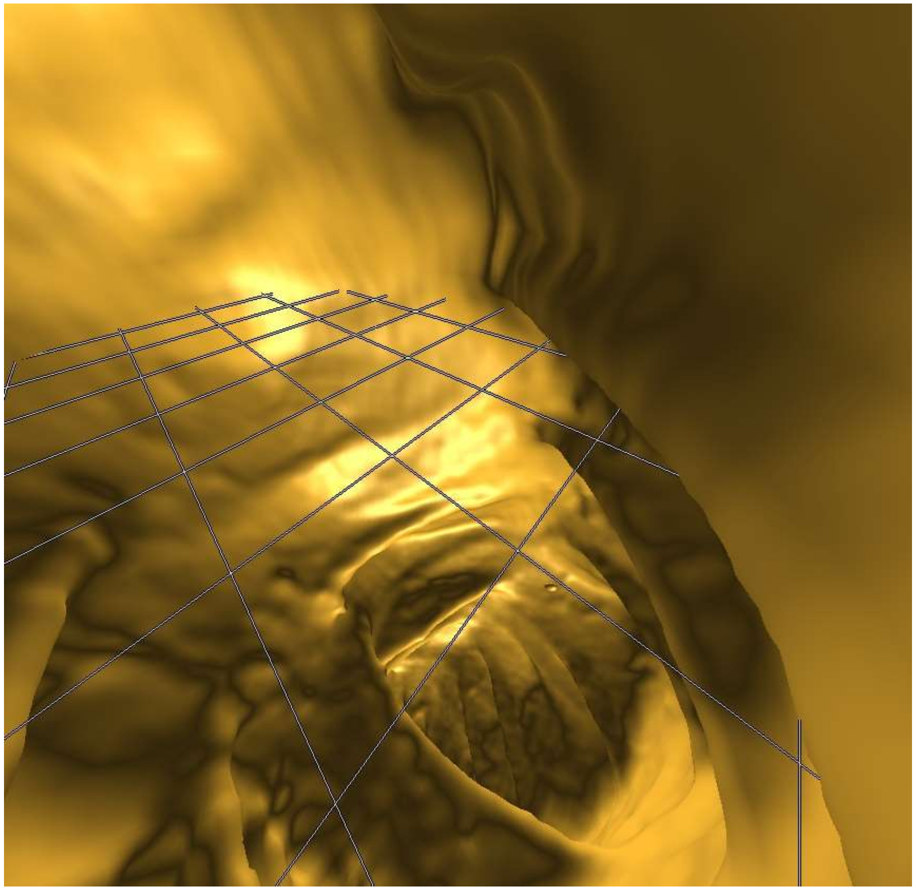
Loop over ray

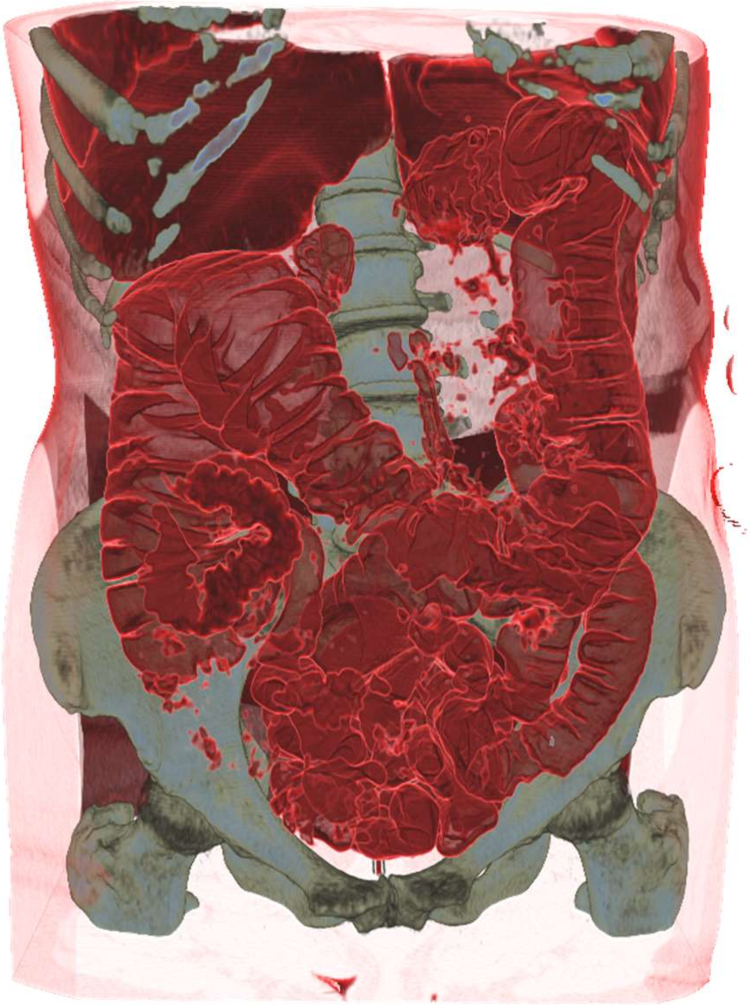
- Resample scalar value
- Classification
- Shading
- **Compositing**



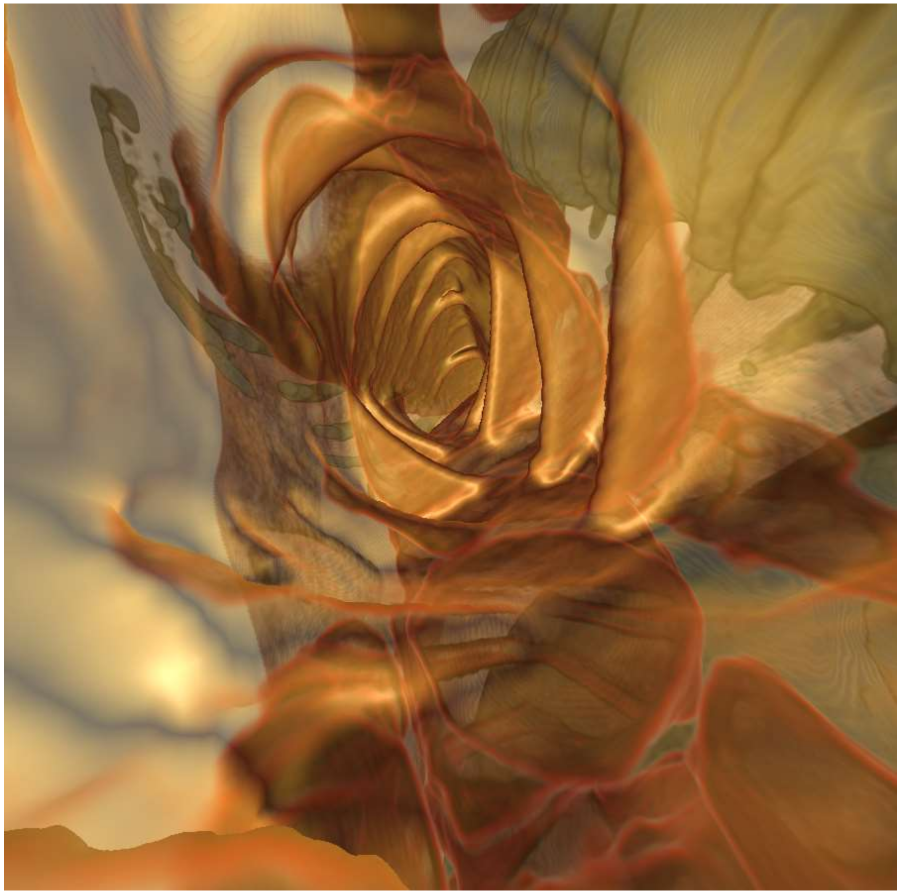
$$
\begin{aligned}
C'_i &= C'_{i+1} + (1 - A'_{i+1}) C_i \\
A'_i &= A'_{i+1} + (1 - A'_{i+1}) A_i
\end{aligned}
$$

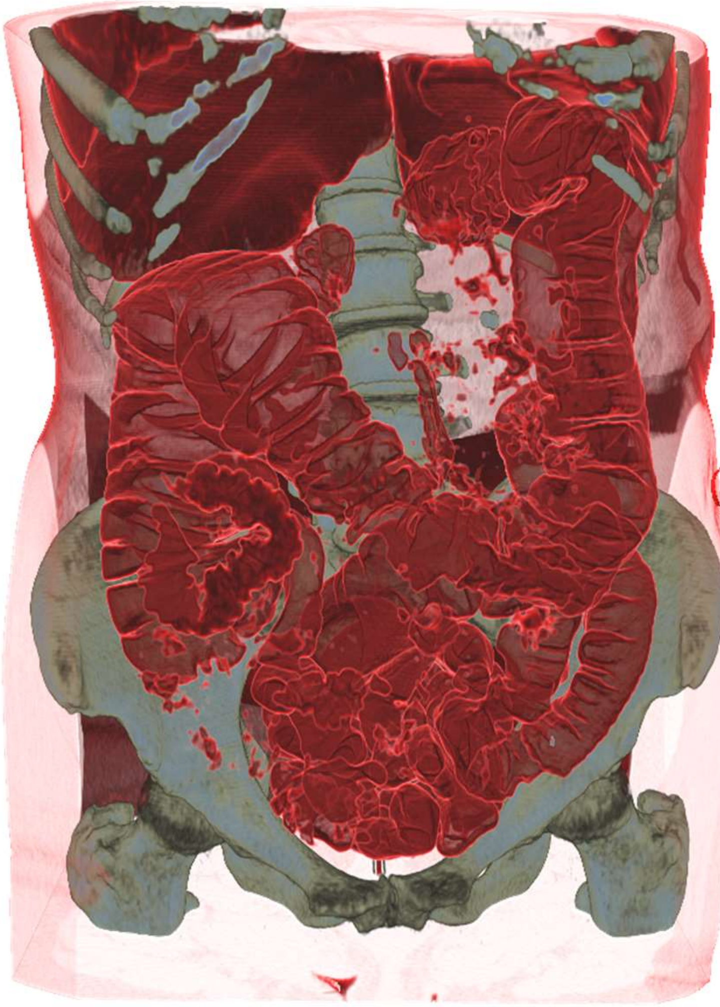
Compositing





Compositing





Fragment Shader

- Rasterize front faces of volume bounding box
- Texcoords are volume position in [0,1]
- Subtract camera position
- Repeatedly check for exit of bounding box

```
// Cg fragment shader code for single-pass ray casting
float4 main(VS_OUTPUT IN, float4 TexCoord0 :  TEXCOORD0,
            uniform sampler3D SamplerDataVolume,
            uniform sampler1D SamplerTransferFunction,
            uniform float3 camera,
            uniform float stepsize,
            uniform float3 volExtentMin,
            uniform float3 volExtentMax
            ) :  COLOR
{
    float4 value;
    float scalar;
    // Initialize accumulated color and opacity
    float4 dst =  float4(0,0,0,0);
    // Determine volume entry position
    float3 position = TexCoord0.xyz;
    // Compute ray direction
    float3 direction = TexCoord0.xyz - camera;
    direction = normalize(direction);
    // Loop for ray traversal
    for (int i = 0; i < 200; i++)  // Some large number
    {
        // Data access to scalar value in 3D volume texture
        value = tex3D(SamplerDataVolume, position);
        scalar = value.a;
        // Apply transfer function
        float4 src = tex1D(SamplerTransferFunction, scalar);
        // Front-to-back compositing
        dst = (1.0-dst.a) * src + dst;
        // Advance ray position along ray direction
        position = position + direction * stepsize;
        // Ray termination:  Test if outside volume ...
        float3 temp1 = sign(position - volExtentMin);
        float3 temp2 = sign(volExtentMax - position);
        float inside = dot(temp1, temp2);
        // ...  and exit loop
        if (inside < 3.0)
            break;
    }
    return dst;
}
```

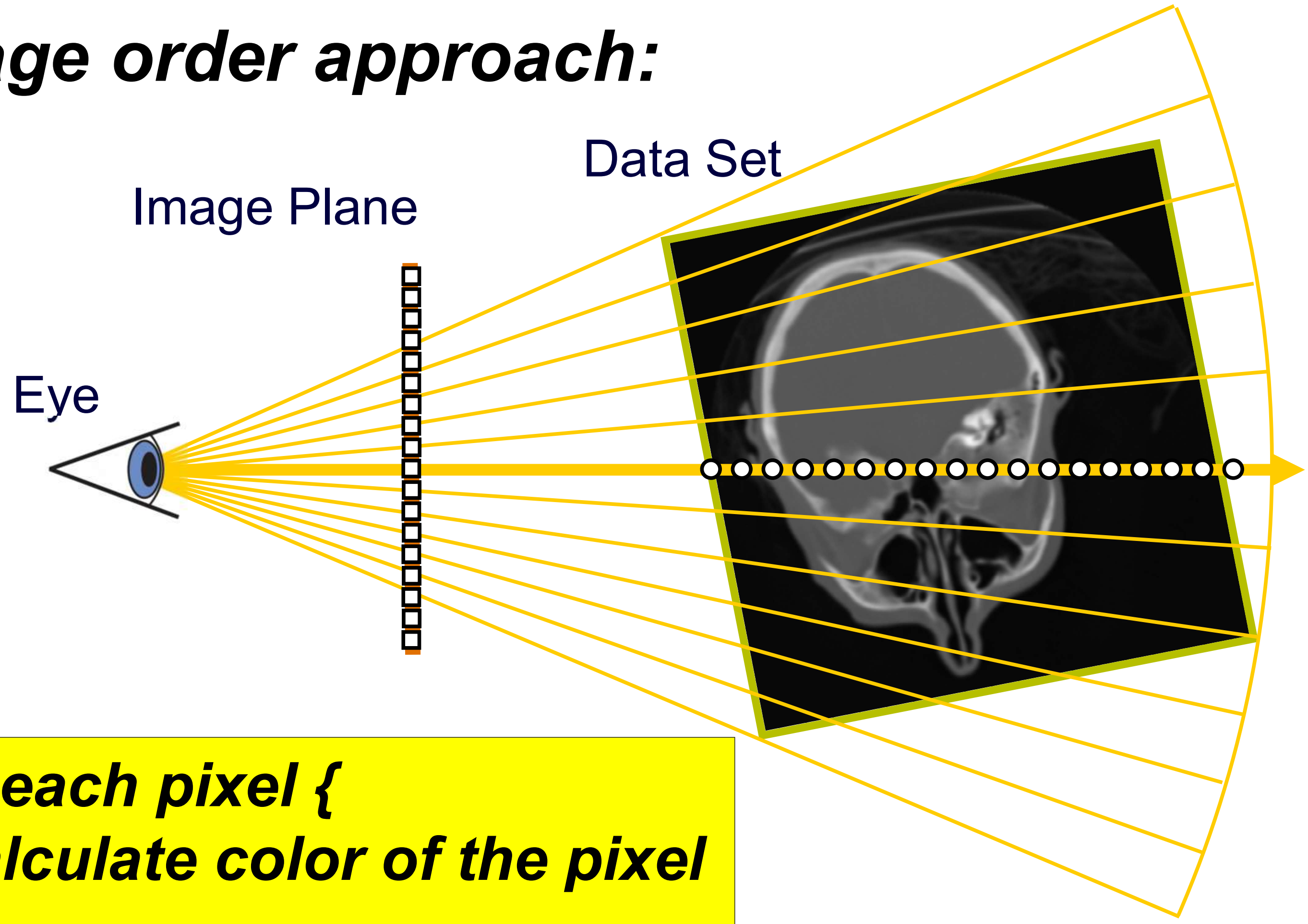
CUDA Kernel

- Image-based ray setup
  - Ray start image
  - Direction image
- Ray-cast loop
  - Sample volume
  - Accumulate color and opacity
- Terminate
- Store output

```
__global__
void RayCastCUDAKernel( float *d_output_buffer, float *d_startpos_buffer, float *d_direction_buffer )
{
    // output pixel coordinates
    dword screencoord_x = __umul24( blockIdx.x, blockDim.x ) + threadIdx.x;
    dword screencoord_y = __umul24( blockIdx.y, blockDim.y ) + threadIdx.y;

    // target pixel (RGBA-tuple) index
    dword screencoord_indx = ( __umul24( screencoord_y, cu_screensize.x ) + screencoord_x ) * 4;

    // get direction vector and ray start
    float4 dir_vec  = d_direction_buffer[ screencoord_indx ];
    float4 startpos = d_startpos_buffer[ screencoord_indx ];

    // ray-casting loop
    float4 color     = make_float4( 0.0f );
    float poscount   = 0.0f;
    for ( int i = 0; i < 8192; i++ ) {

        // next sample position in volume space
        float3 samplepos = dir_vec * poscount + startpos;
        poscount += cu_sampling_distance;

        // fetch density
        float tex_density = tex3D( cu_volume_texture, samplepos.x, samplepos.y, samplepos.z );

        // apply transfer function
        float4 col_classified = tex1D( cu_transfer_function_texture, tex_density );

        // compute (1-previous.a)*tf.a
        float prev_alpha = -color.w * col_classified.w + col_classified.w;

        // composite color and alpha
        color.xyz = prev_alpha * col_classified.xyz + color.xyz;
        color.w  += prev_alpha;

        // break if ray terminates (behind exit position or alpha threshold reached)
        if ( ( poscount > dir_vec.w ) || ( color.w > 0.98f ) ) {
            break;
        }
    }

    // store output color and opacity
    d_output_buffer[ screencoord_indx ] = __saturatef( color );
}
```

Direct Volume Rendering: Image Order

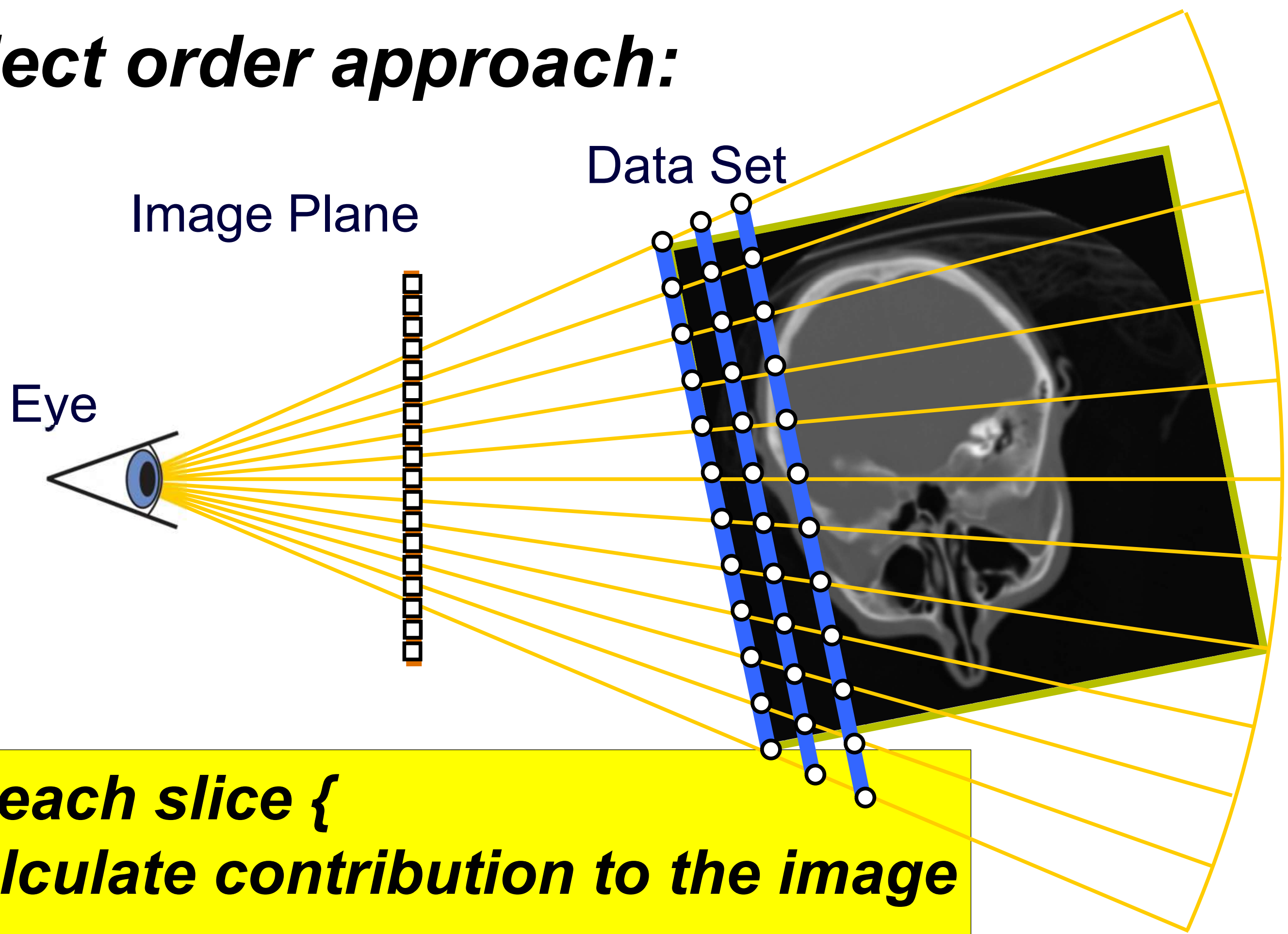
Image order approach:



For each pixel {
calculate color of the pixel
}

Direct Volume Rendering: Object Order

Object order approach:



For each slice {
calculate contribution to the image
}

Basic Volume Rendering Summary

Volume rendering integral
for *Emission Absorption* model

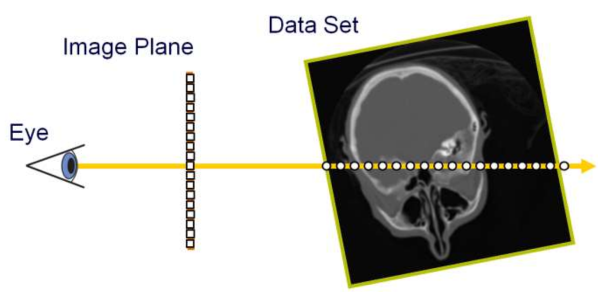
$$I(s) = I(s_0)\, e^{-\tau(s_0,s)} + \int_{s_0}^{s} q(\tilde{s})\, e^{-\tau(\tilde{s},s)}\, \mathrm{d}\tilde{s}$$

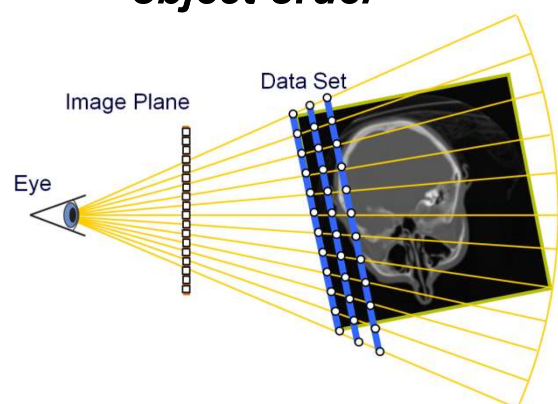
Numerical solutions: ***back-to-front*** ***vs.*** ***front-to-back compositing***

$$C'_i = C_i + (1 - A_i) C'_{i-1}$$

$$C'_i = C'_{i+1} + (1 - A'_{i+1}) C_i$$
$$A'_i = A'_{i+1} + (1 - A'_{i+1}) A_i$$

Approaches: ***image order*** ***vs.*** ***object order***





Isosurface Ray-Casting

Isosurface Ray-Casting

Isosurfaces/Level Sets

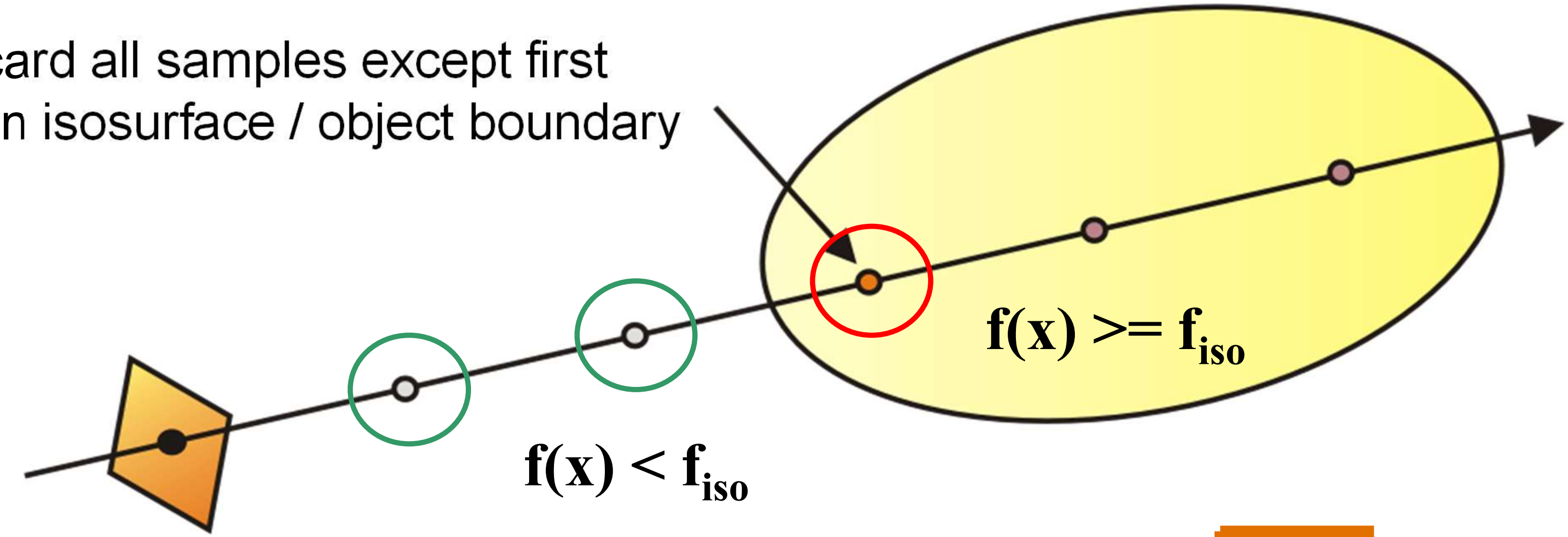
- Scanned data (fit signed distance function to points, ...)
- Signed distance fields
- CSG (constructive solid geometry) operations

..

Isosurface Ray-Casting

Opaque isosurfaces:
only one sample contributes per ray/pixel

Discard all samples except first
hit on isosurface / object boundary



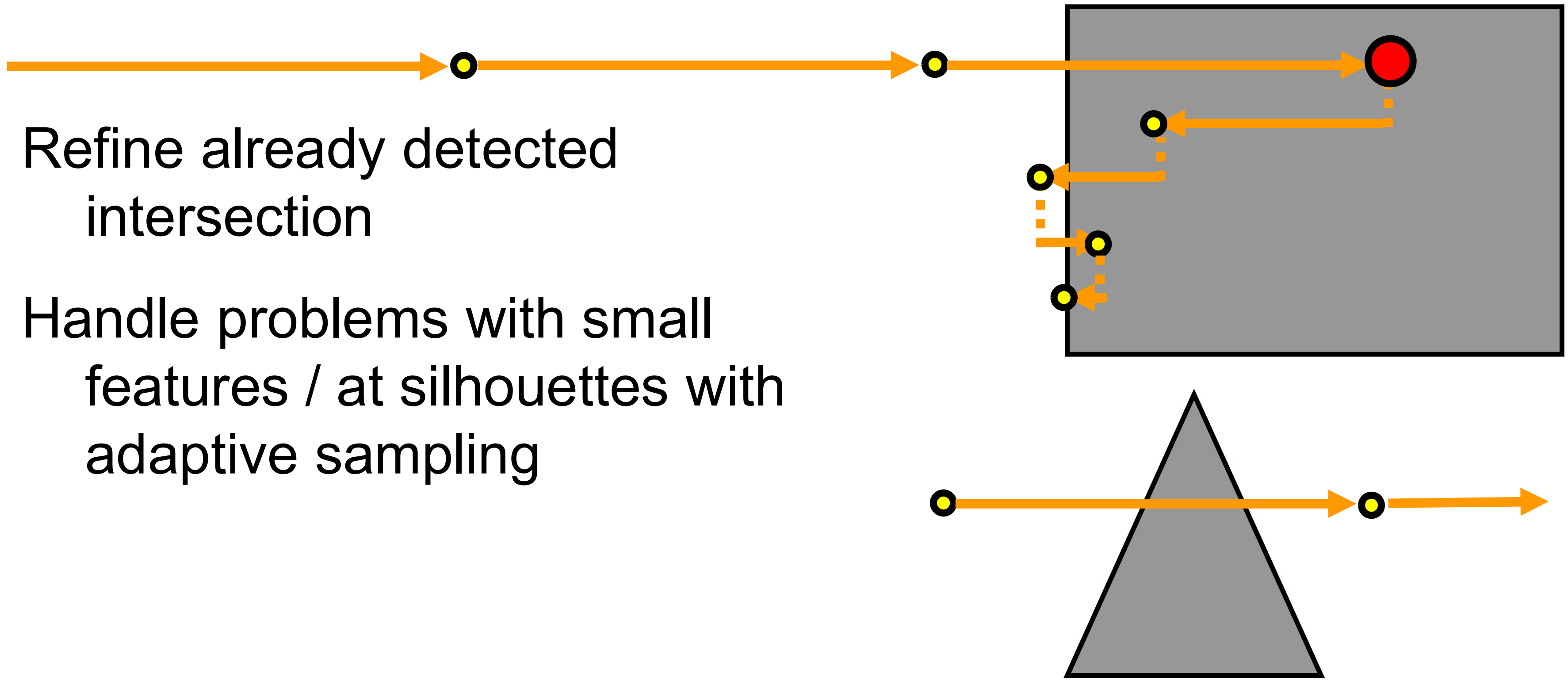
Threshold transfer function / alpha test

First hit ray casting

Intersection Refinement (1)

Fixed number of bisection / binary search steps

Virtually no impact on performance

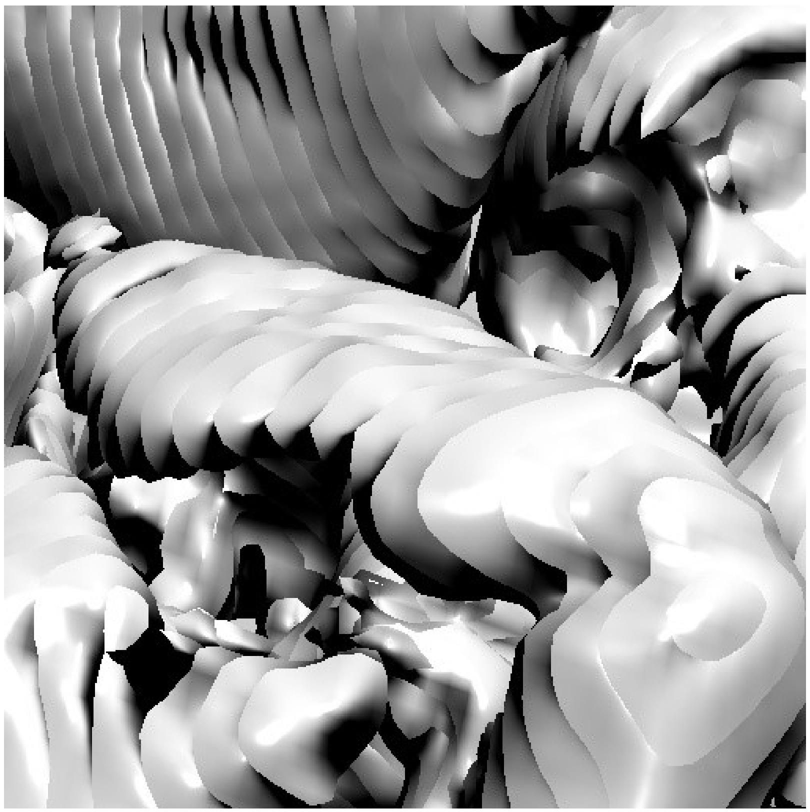


Refine already detected intersection

Handle problems with small features / at silhouettes with adaptive sampling

Intersection Refinement (2)

without refinement

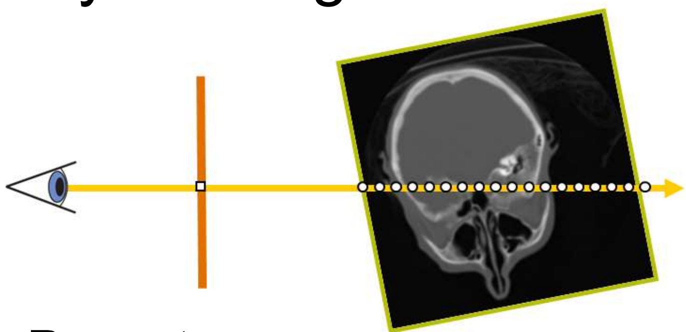


with refinement

sampling distance 5 voxels (no adaptive sampling)

Ray-Casting vs. Isosurface Ray-Casting

Ray-Casting

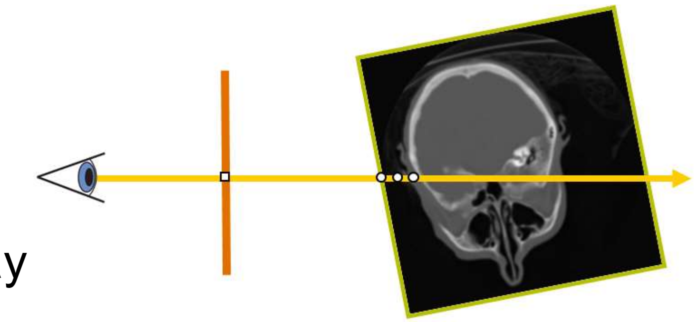


Ray setup

Loop over ray

- Sample scalar field
- Classification
- Shading
- Compositing

Isosurface Ray-Casting



Ray setup

Loop over ray

- Sample scalar field
- if value >= isoValue (i.e., first hit)
  - break out of the loop

[Refine first hit location] (optional)

Shading

(Compositing not needed)

Empty Space Skipping

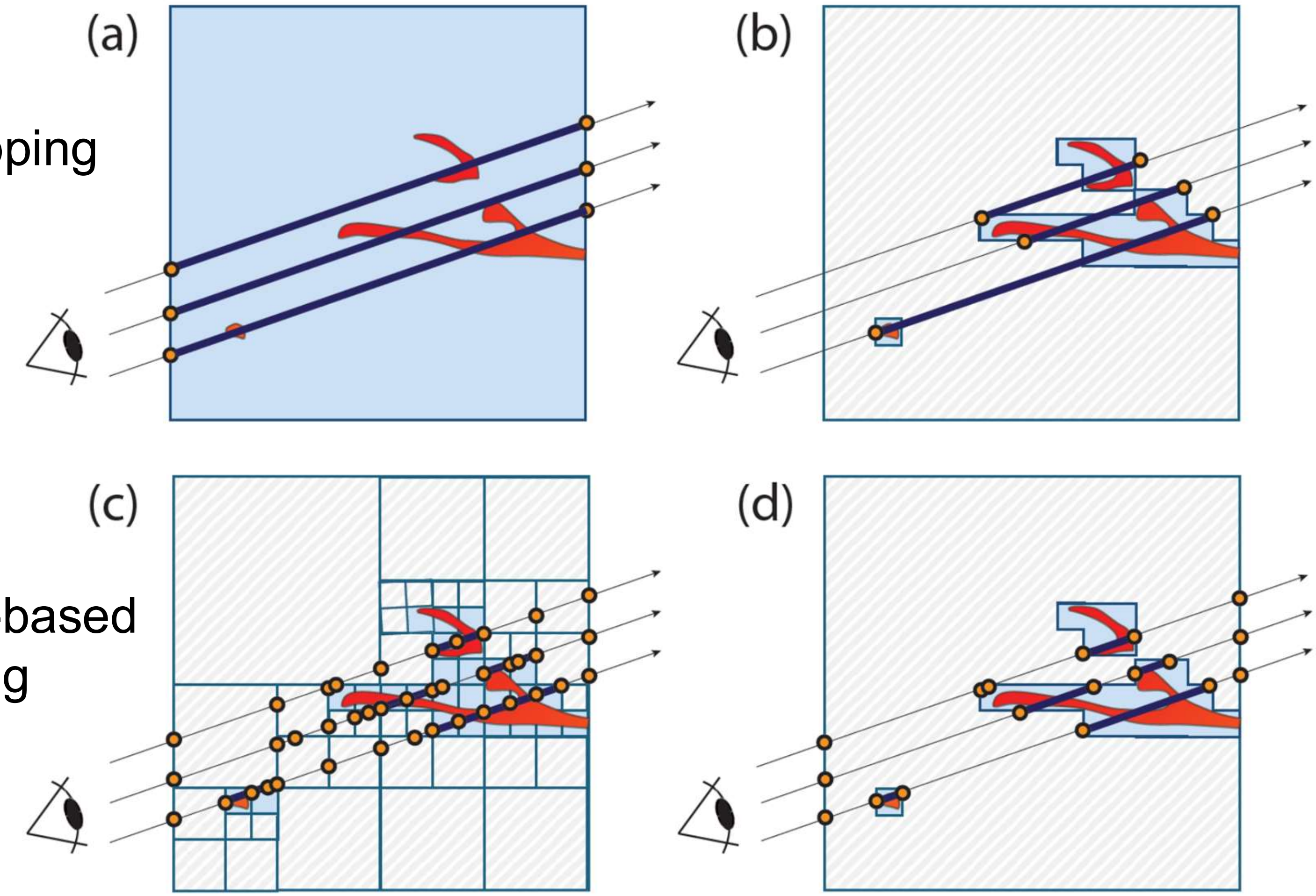
Different Approaches

no skipping

simple object-order skipping

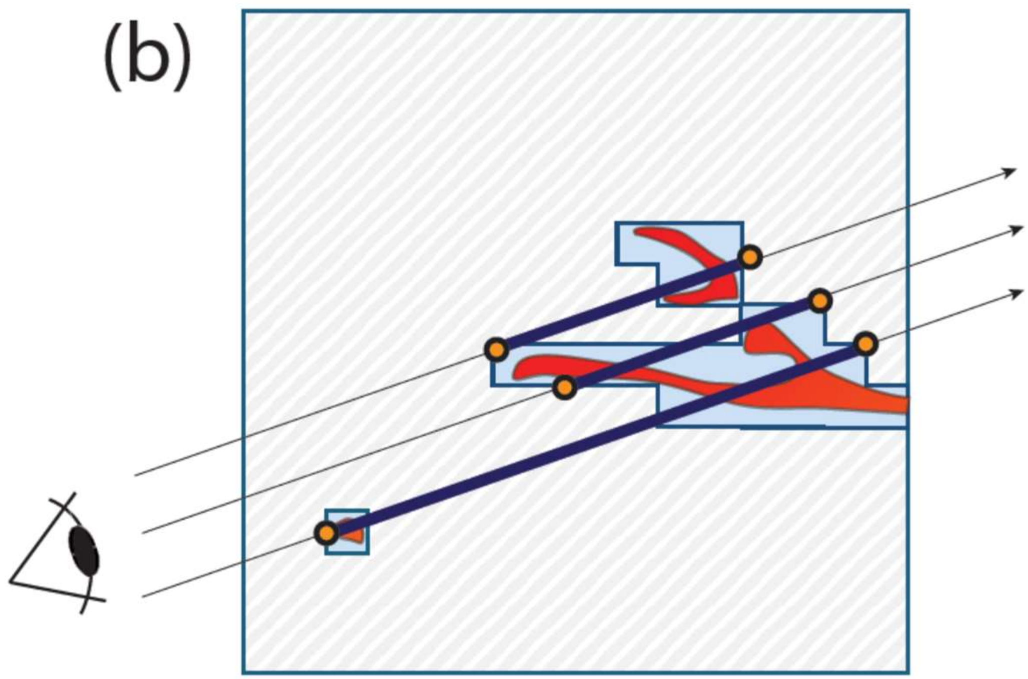
octree-based skipping

Sparse Leap



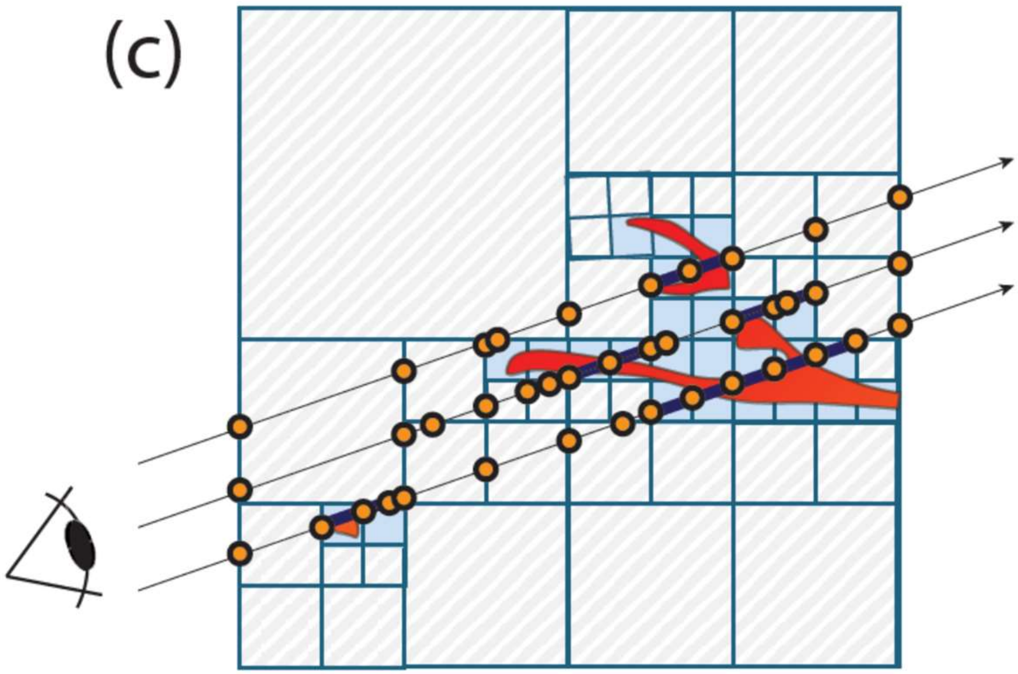
Object-Order Empty Space Skipping

Modify initial rasterization step for ray setup



Octree-Based Empty Space Skipping

Everything is done during tree traversal along the ray



Thank you.

Thanks for material

- Helwig Hauser
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- Christof Rezk-Salama