King Abdullah University of Science and Technology

KAUST

CS 247 – Scientific Visualization
Lecture 19: Volume Rendering, Pt. 6 [preview]

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Reading Assignment #10 (until Apr 4)

Read (required):

- Real-Time Volume Graphics, Chapter 7 (GPU-Based Ray Casting)
- 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

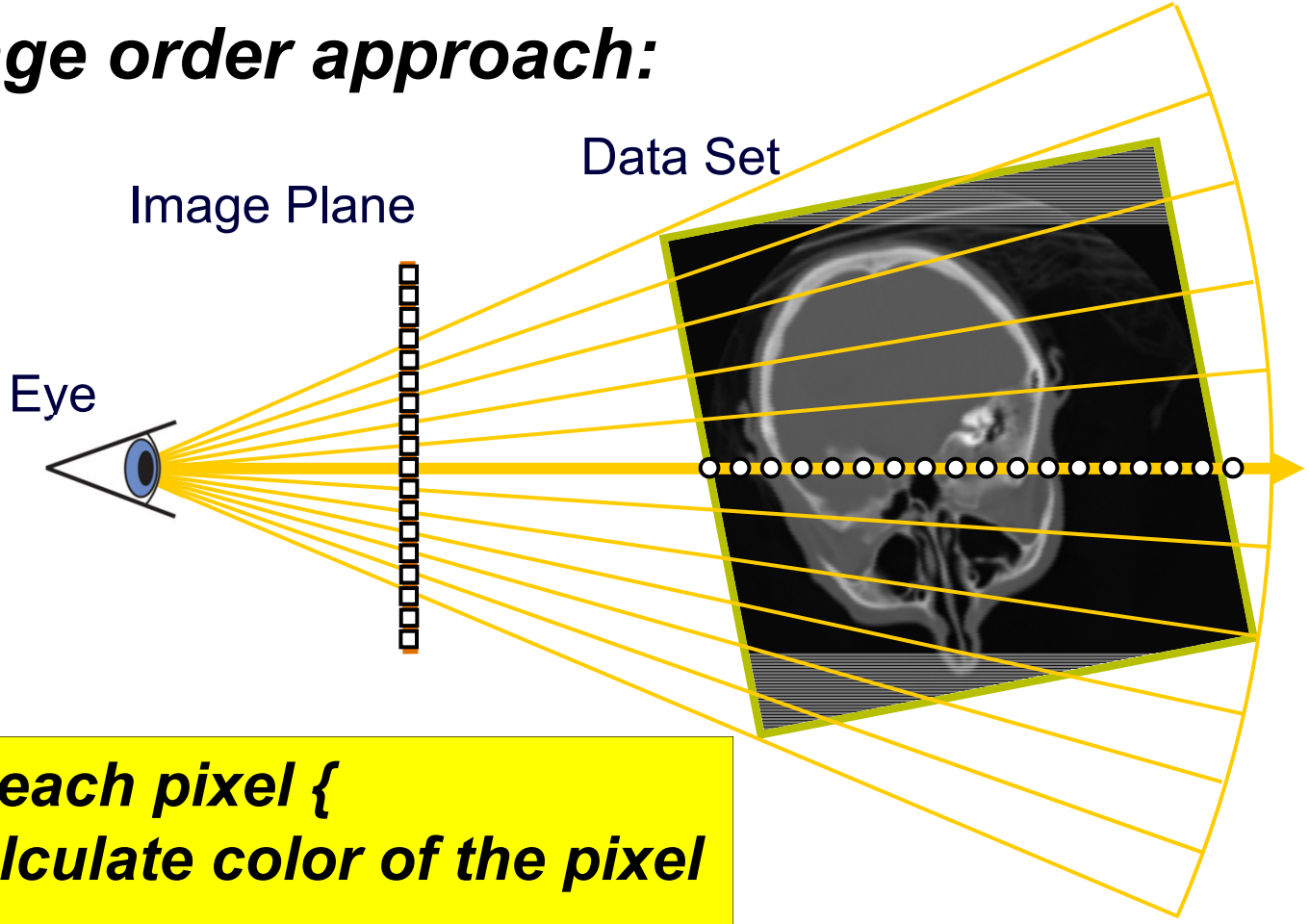
Read (optional):

- Real-Time Volume Graphics, Chapter 6 (Global Volume Illumination)

VolVis: Image vs. Object Order

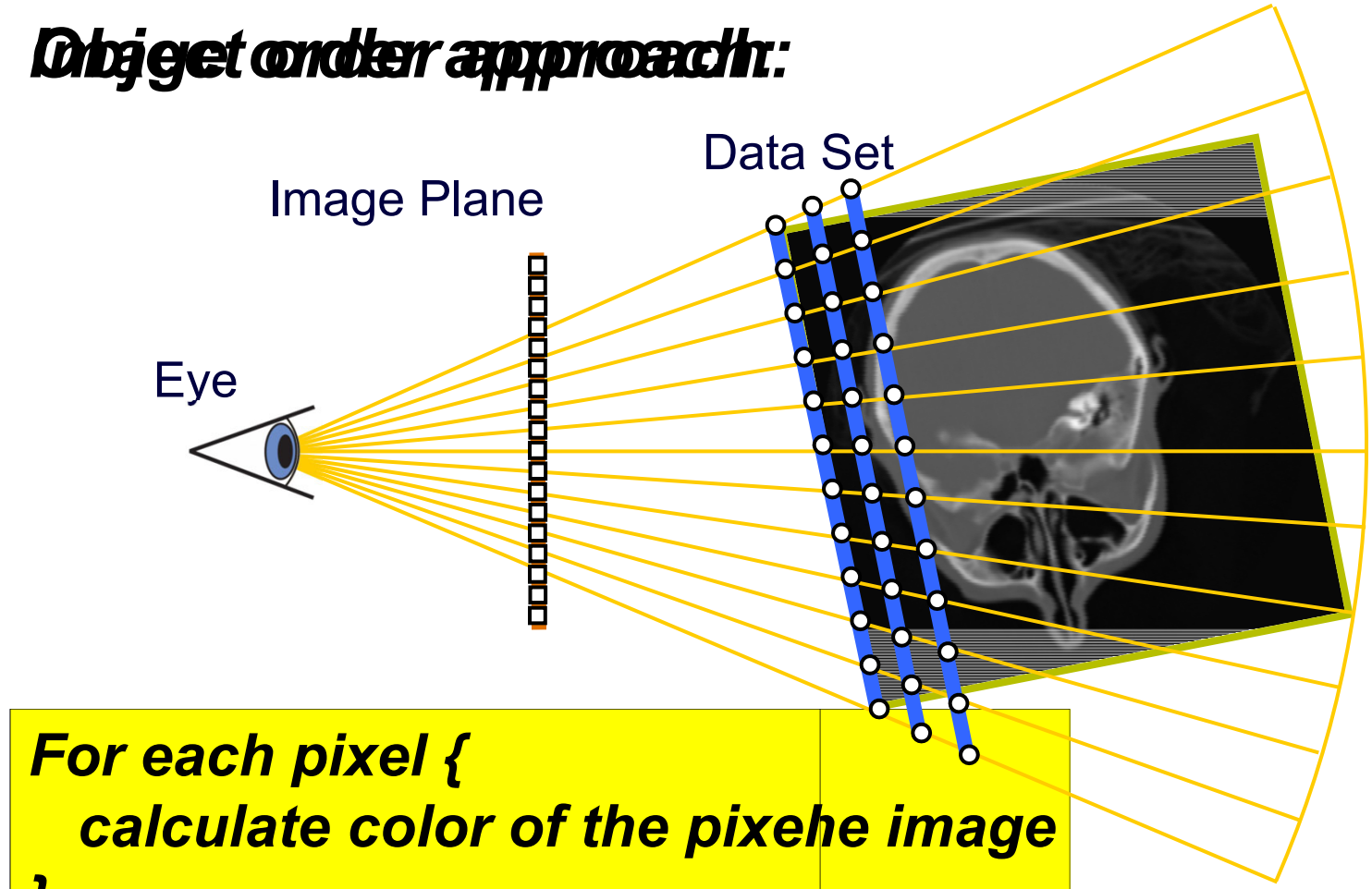
Direct Volume Rendering: Image Order

Image order approach:



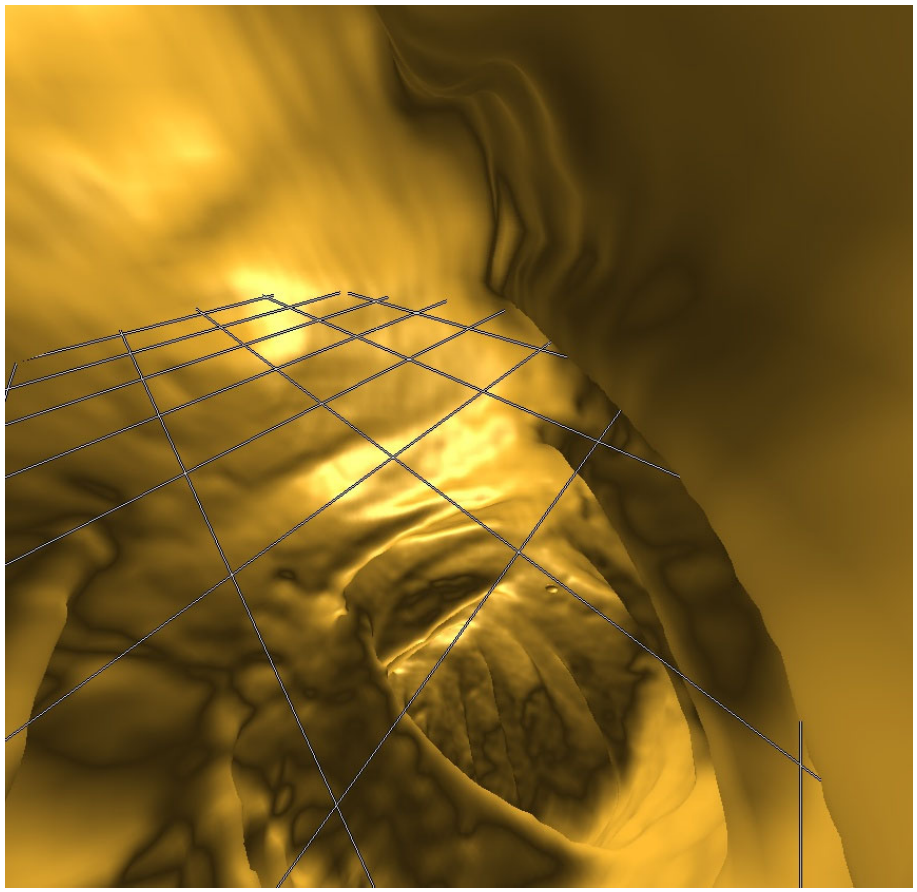

```
For each pixel {
   calculate color of the pixel
}
```

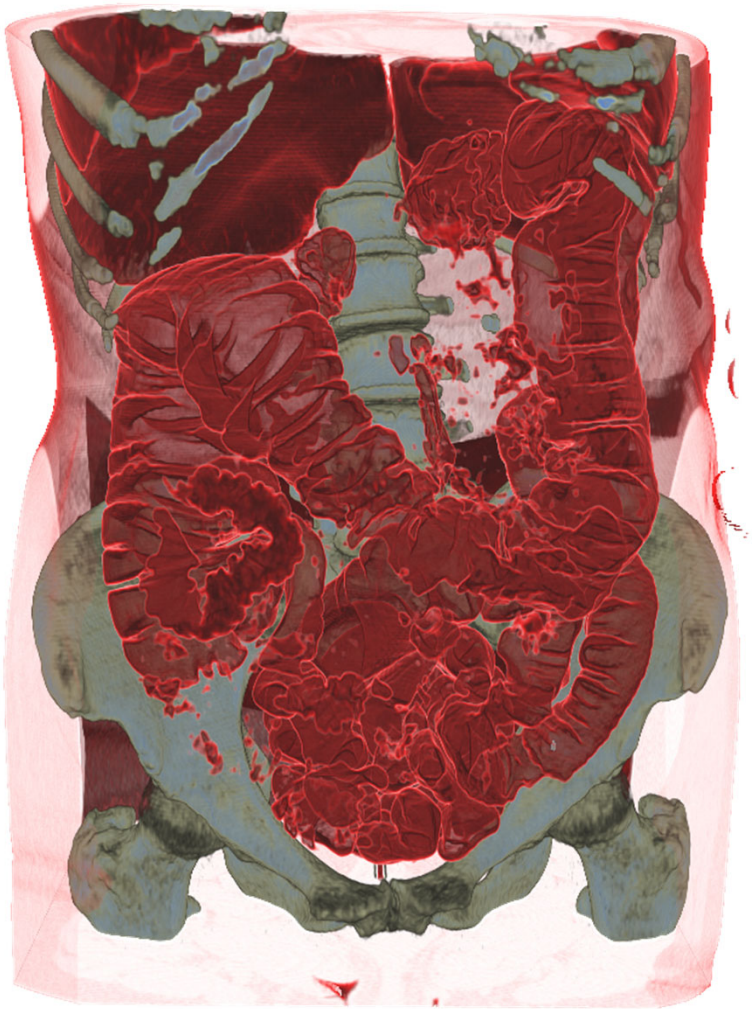
Direct Volume Rendering: Object Order



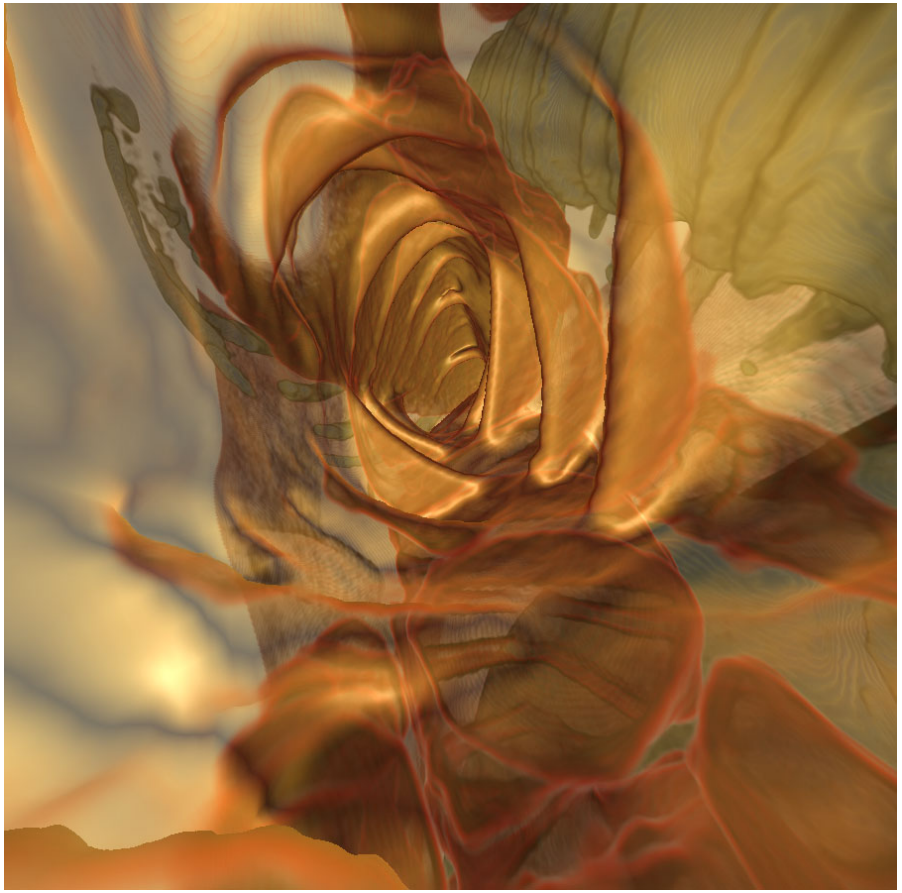
For each pixel {
calculate color of the pixel in the image
}

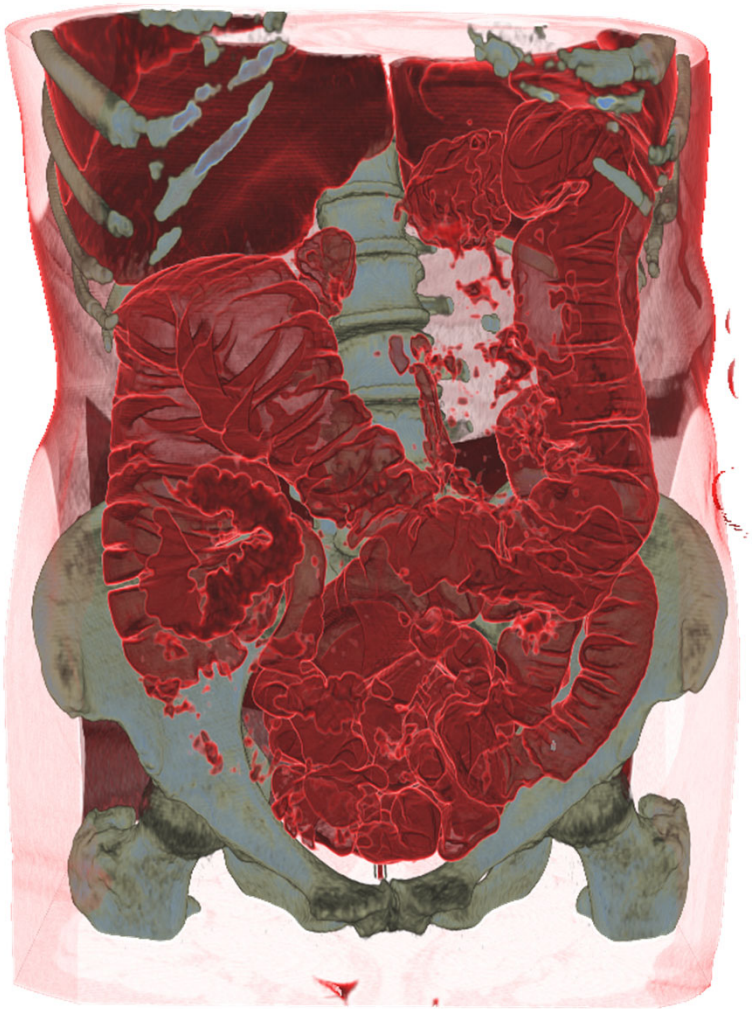
Compositing





Compositing





Basic Volume Rendering Summary

Volume rendering integral
for *Emission Absorption* model

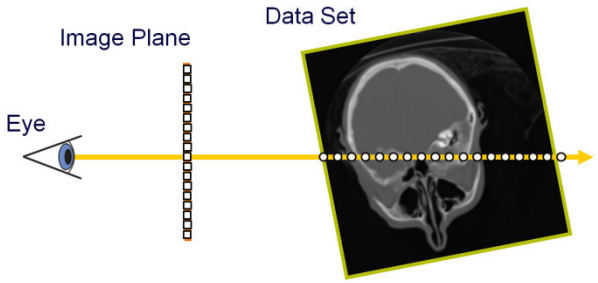
$$I(s) = I(s_0)\, e^{-\tau(s_0,s)} + \int_{s_0}^{s} q(\tilde{s})\, e^{-\tau(\tilde{s},s)}\, \mathrm{d}\tilde{s}$$

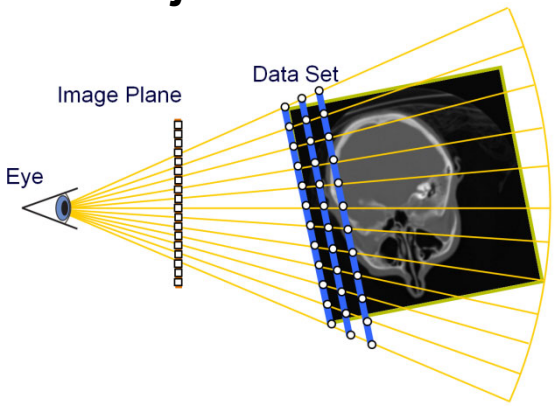
Numerical solutions: ***back-to-front*** ***vs.*** ***front-to-back compositing***

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

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

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





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 );
}
```

Isosurface Ray-Casting

Isosurface Ray-Casting

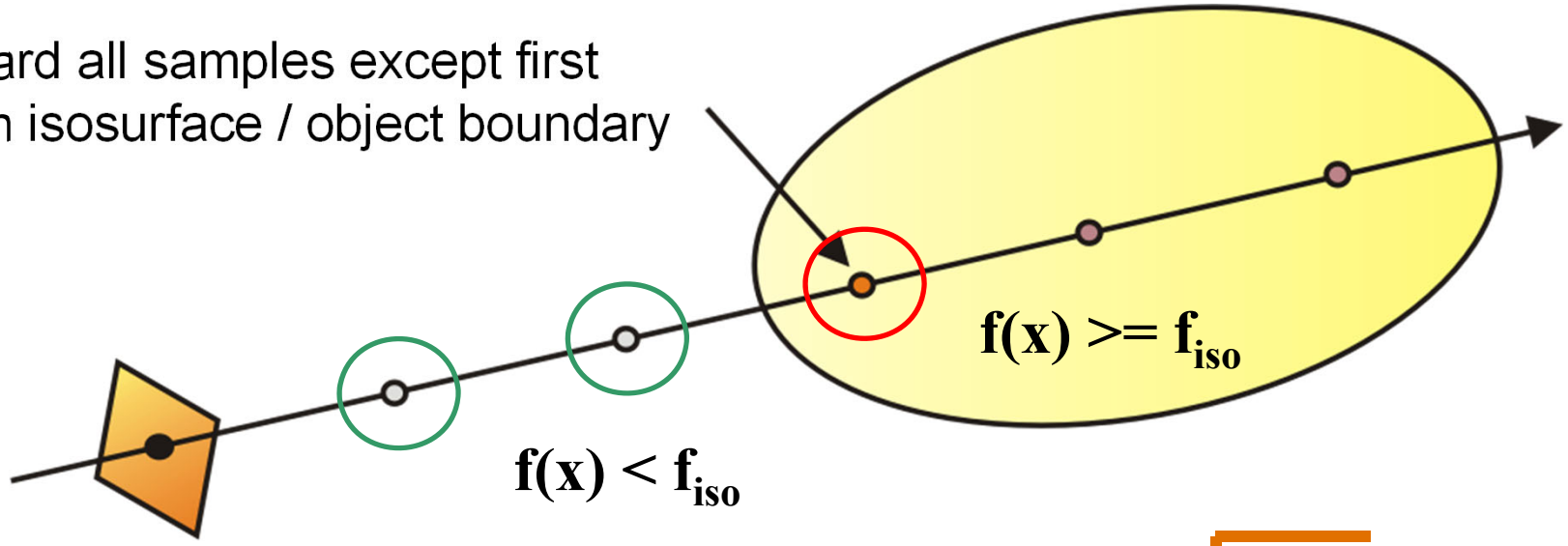
Isosurfaces/Level Sets

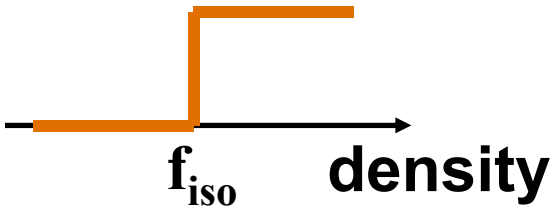
- Scanned data (fit signed distance function to points, ...)
- Signed distance fields
- CSG (constructive solid geometry) operations

Isosurface Ray-Casting

Opaque isosurfaces:
only one sample contributes per ray/pixel

Discard all samples except first
hit on isosurface / object boundary





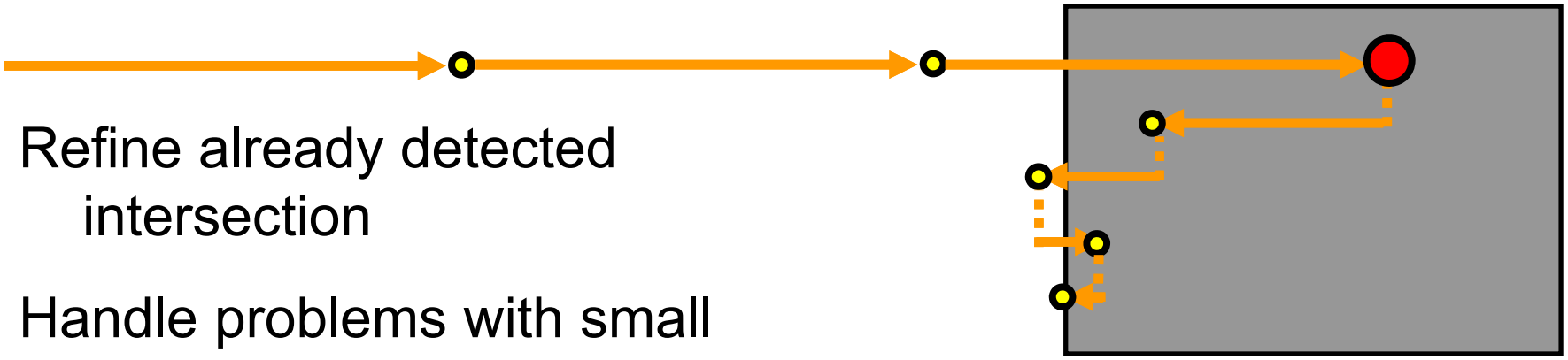
Threshold transfer function / alpha test

First hit ray casting

Intersection Refinement (1)

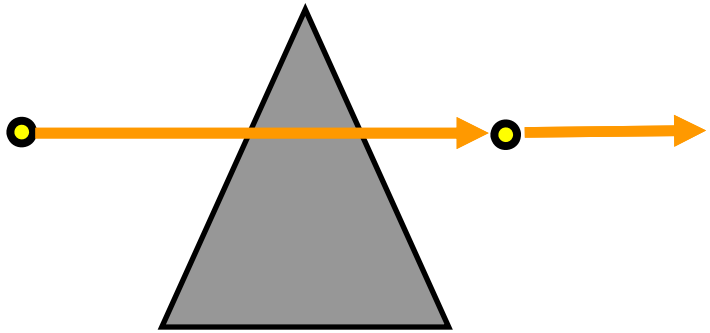
Fixed number of bisection / binary search steps

Virtually no impact on performance



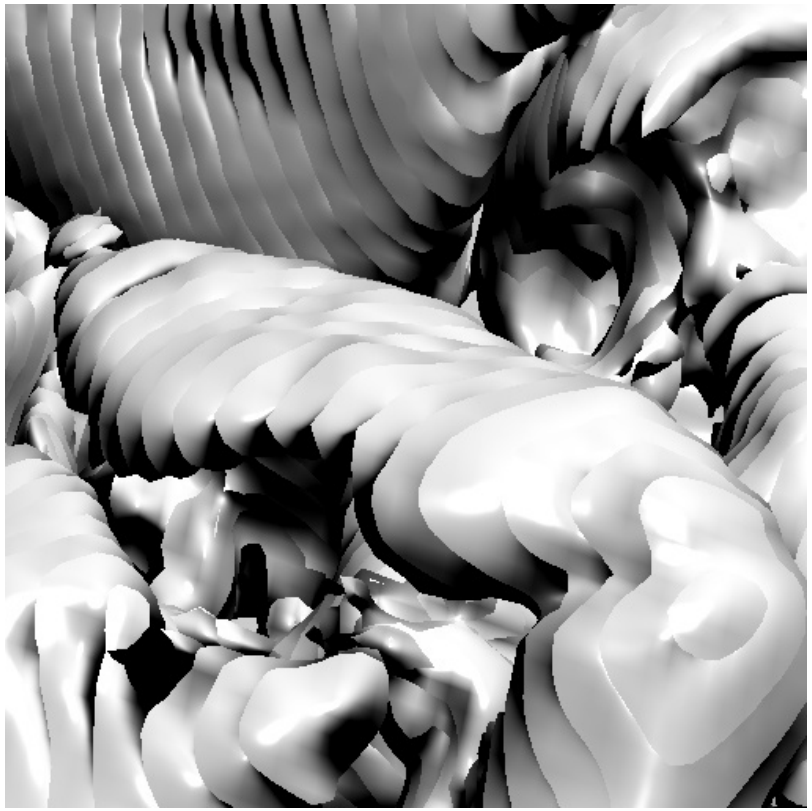
Refine already detected intersection

Handle problems with small features / at silhouettes with adaptive sampling



Intersection Refinement (2)

without refinement

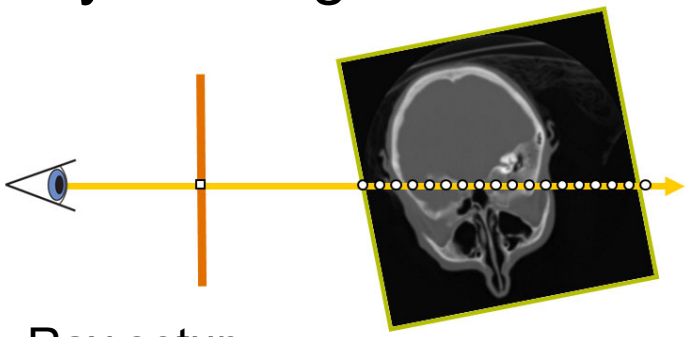


with refinement

sampling distance 5 voxels (no adaptive sampling)

Ray-Casting vs. Isosurface Ray-Casting

Ray-Casting

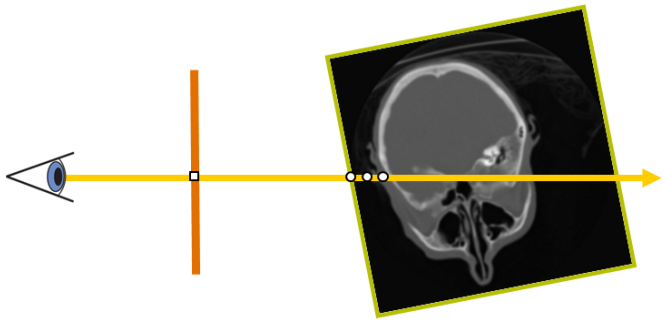


Ray setup

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

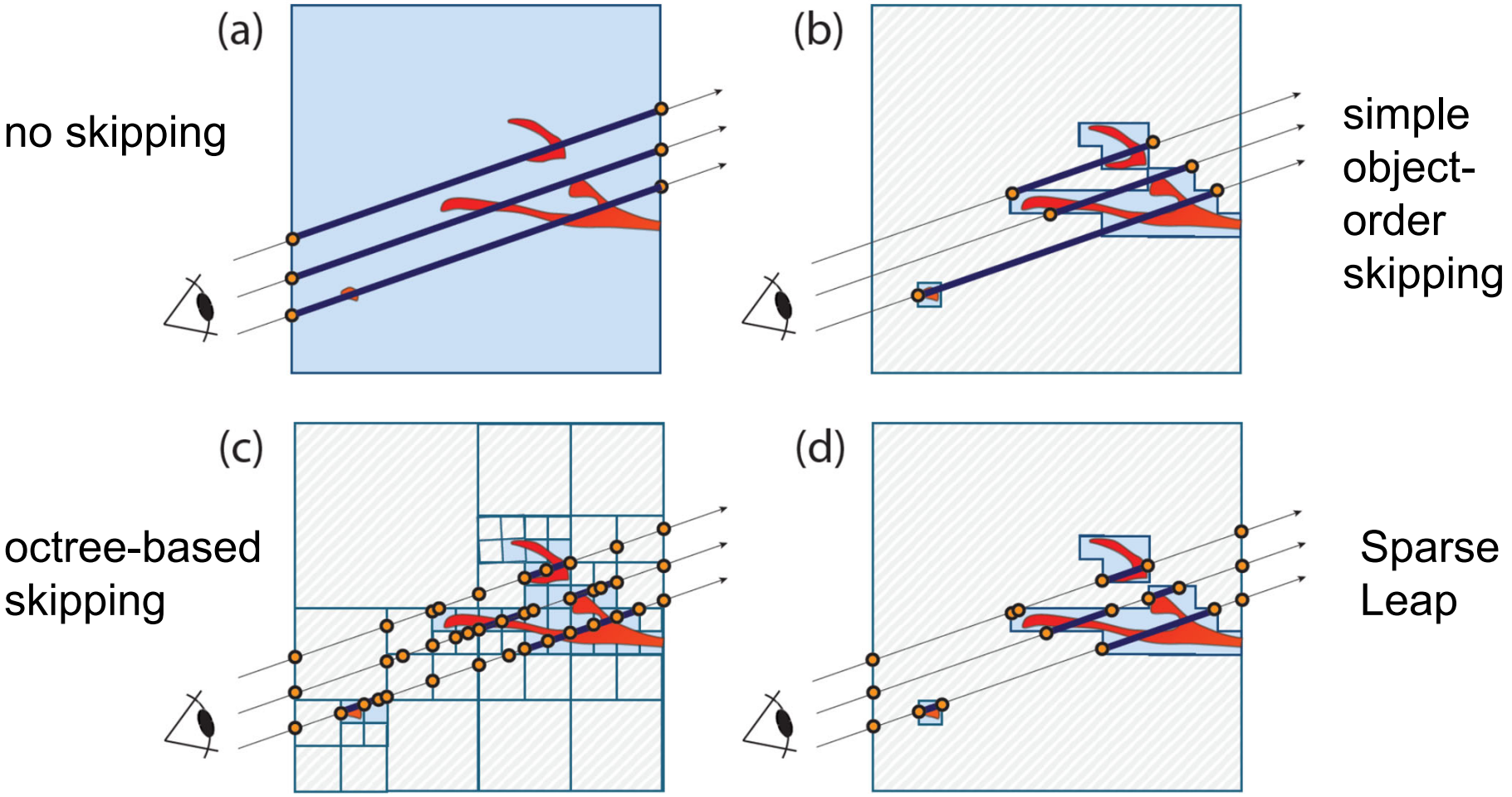
[Refine first hit location] (optional)

Shading

(Compositing not needed)

Empty Space Skipping

Different Approaches



no skipping

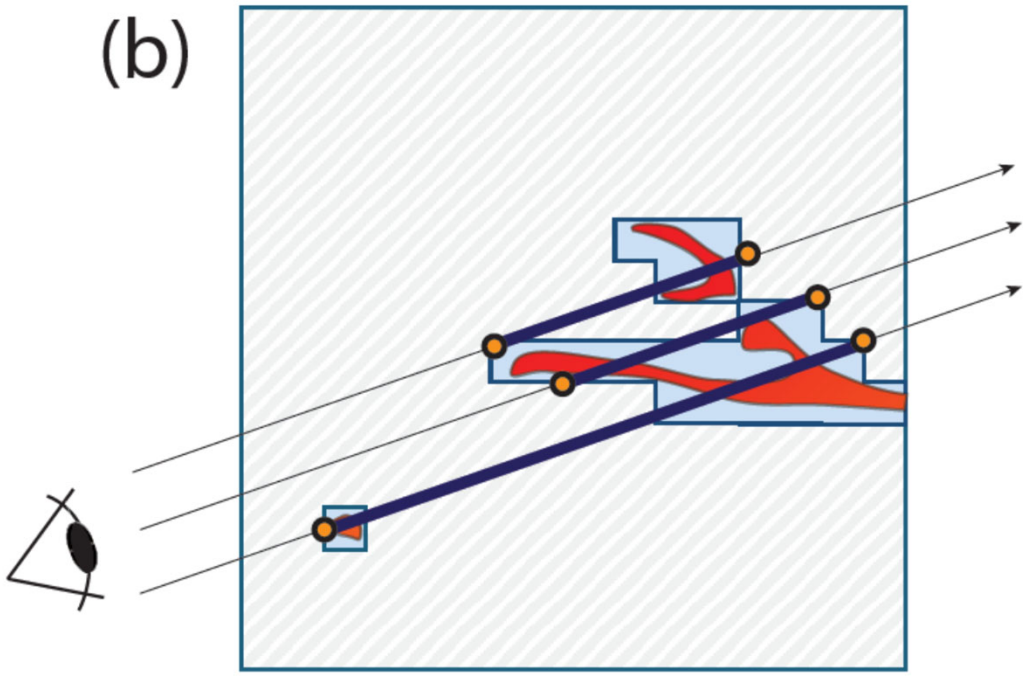
simple object-order skipping

octree-based skipping

Sparse Leap

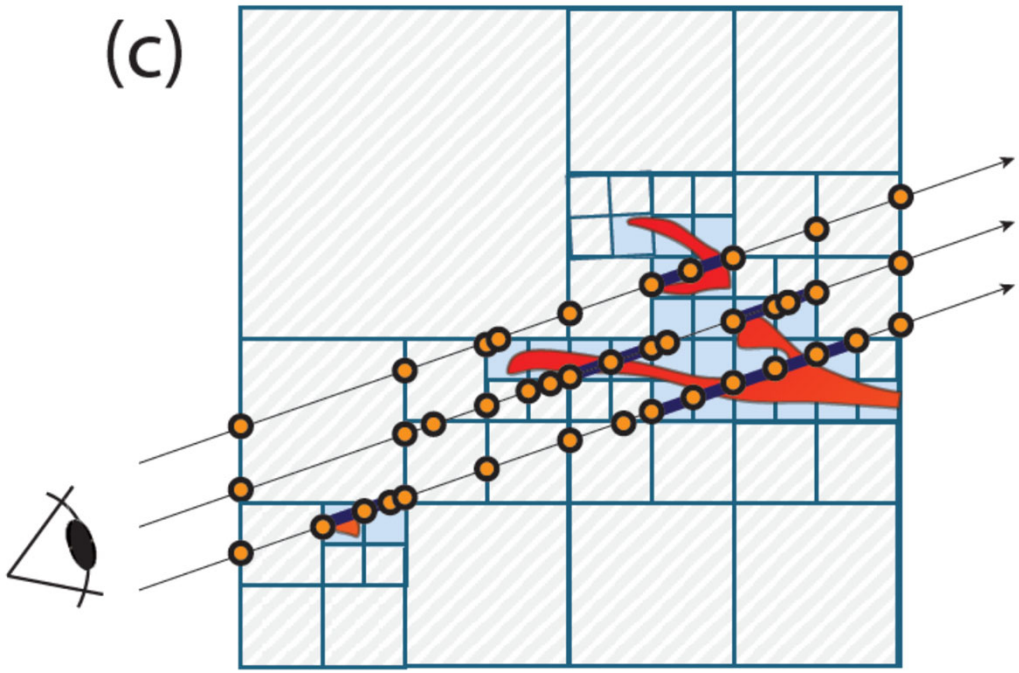
Object-Order Empty Space Skipping

Modify initial rasterization step for ray setup



Octree-Based Empty Space Skipping

Everything is done during tree traversal along the ray



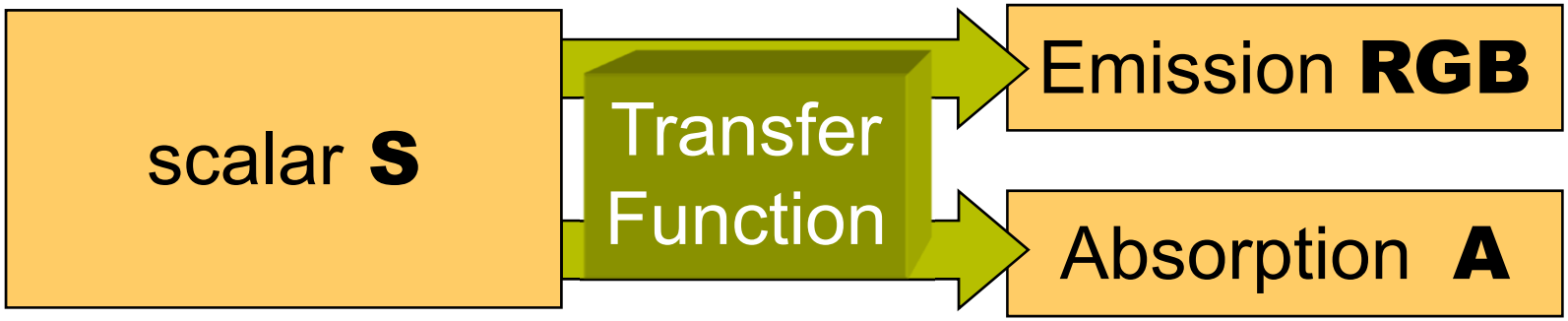
More on Transfer Functions

Classification – Transfer Functions

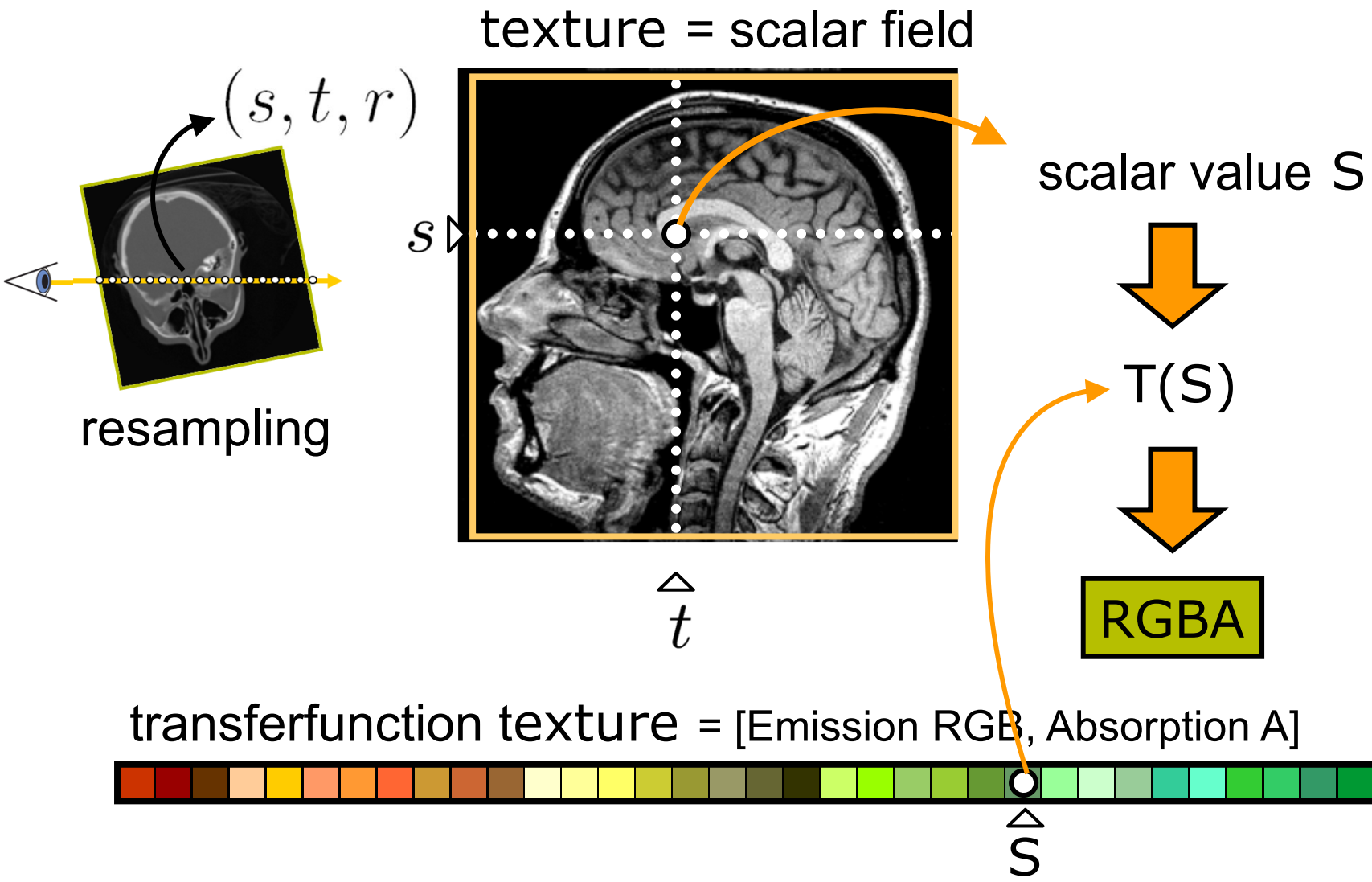
During Classification the user defines the ***"look"*** of the data.

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

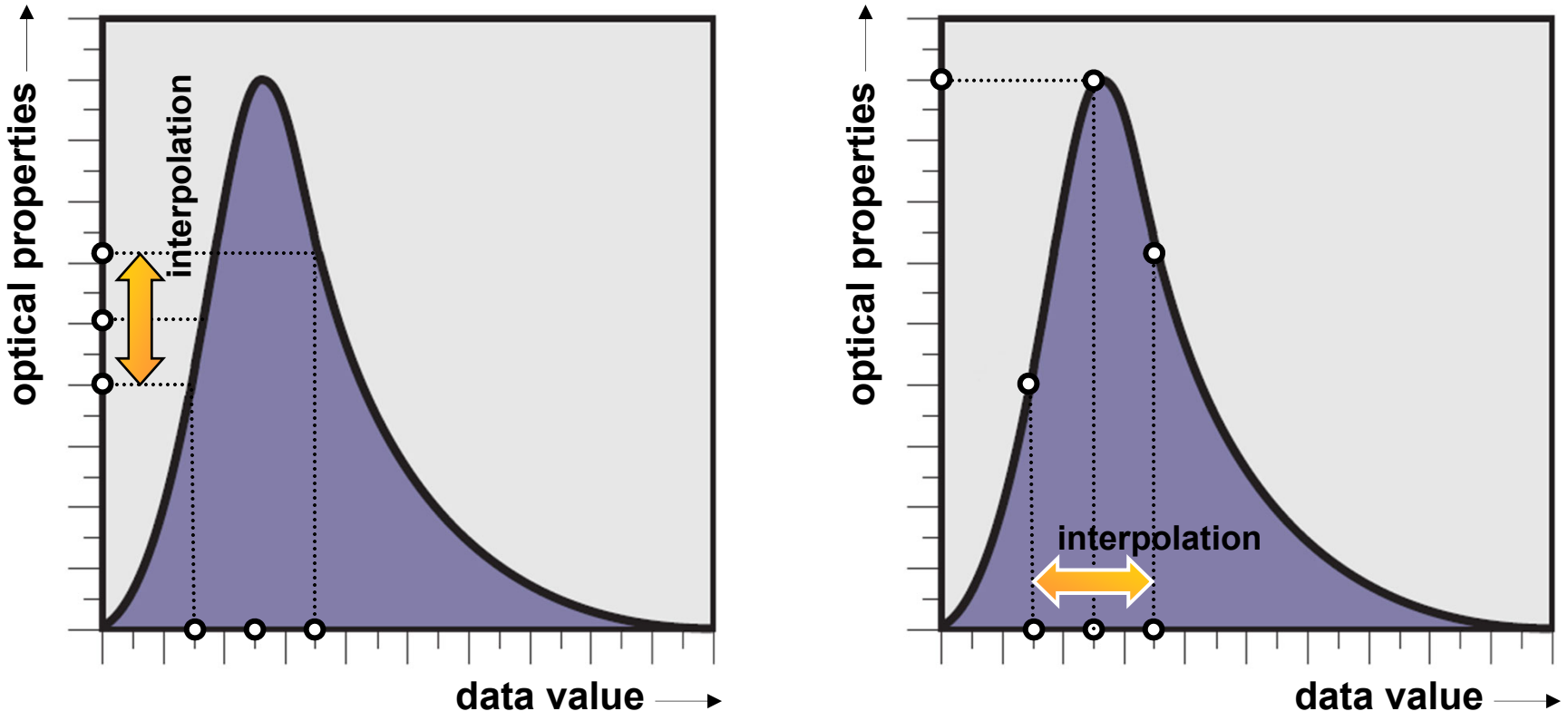
The user defines a ***transfer function.***



1D Transfer Functions

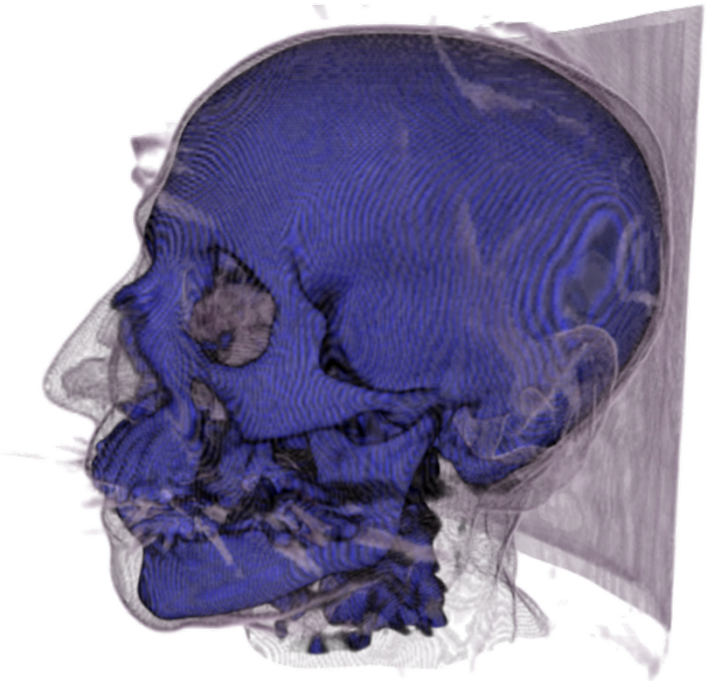


Pre- vs Post-Interpolative Classification

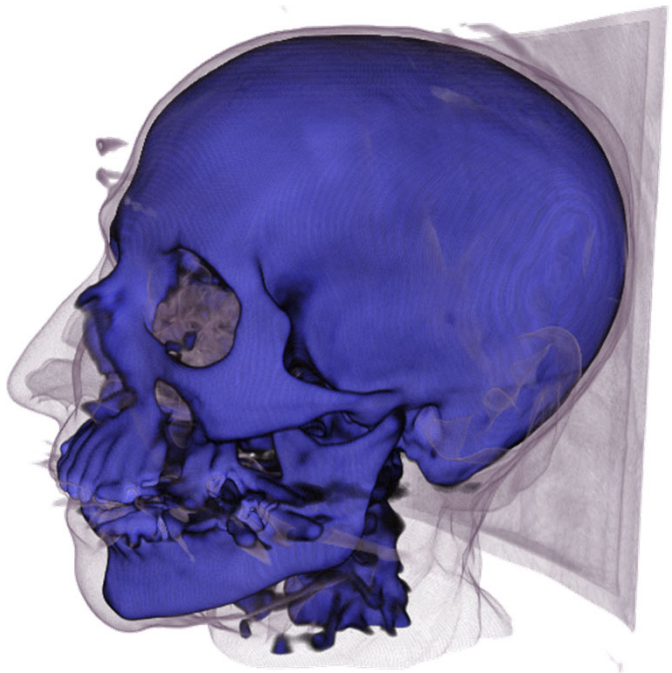


Quality: Pre- vs. Post-Classification

Comparison of image quality



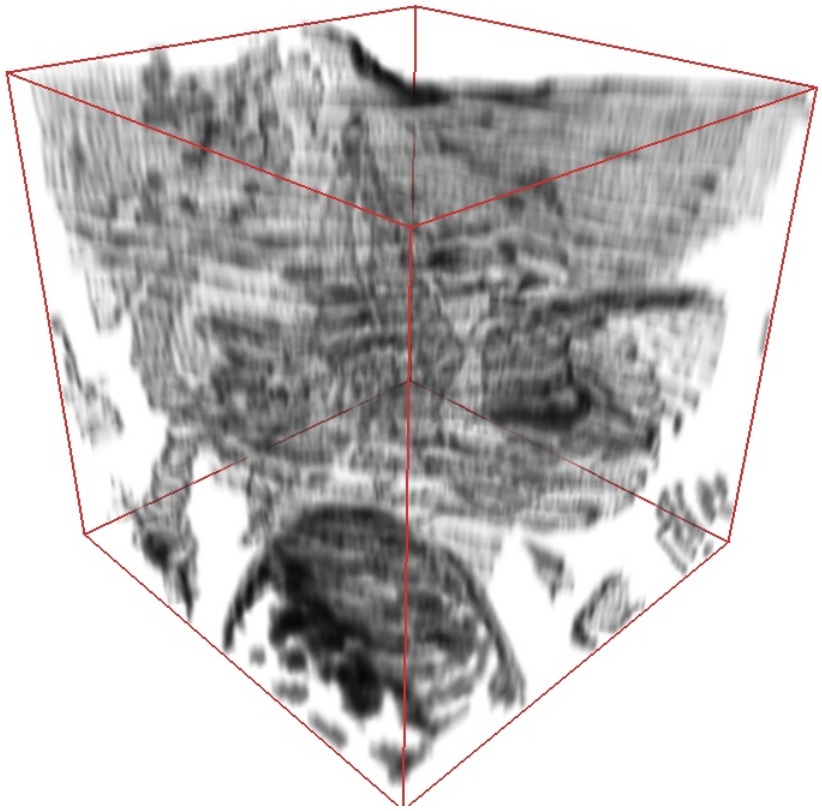
Pre-Classification



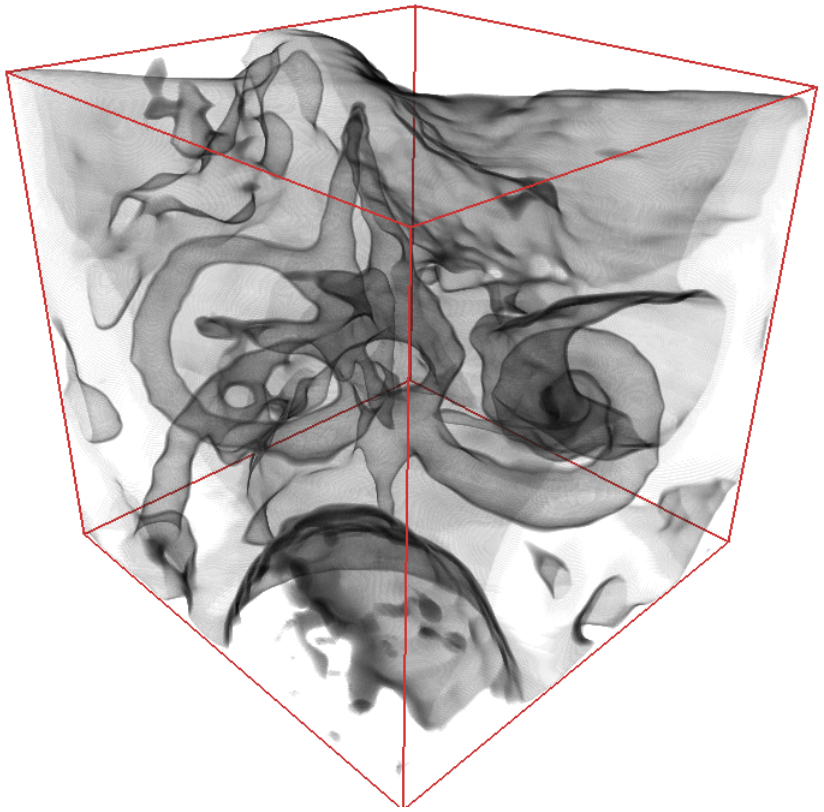
Post-Classification

same TF, same resolution, same sampling rate

Quality: Pre- vs. Post-Classification

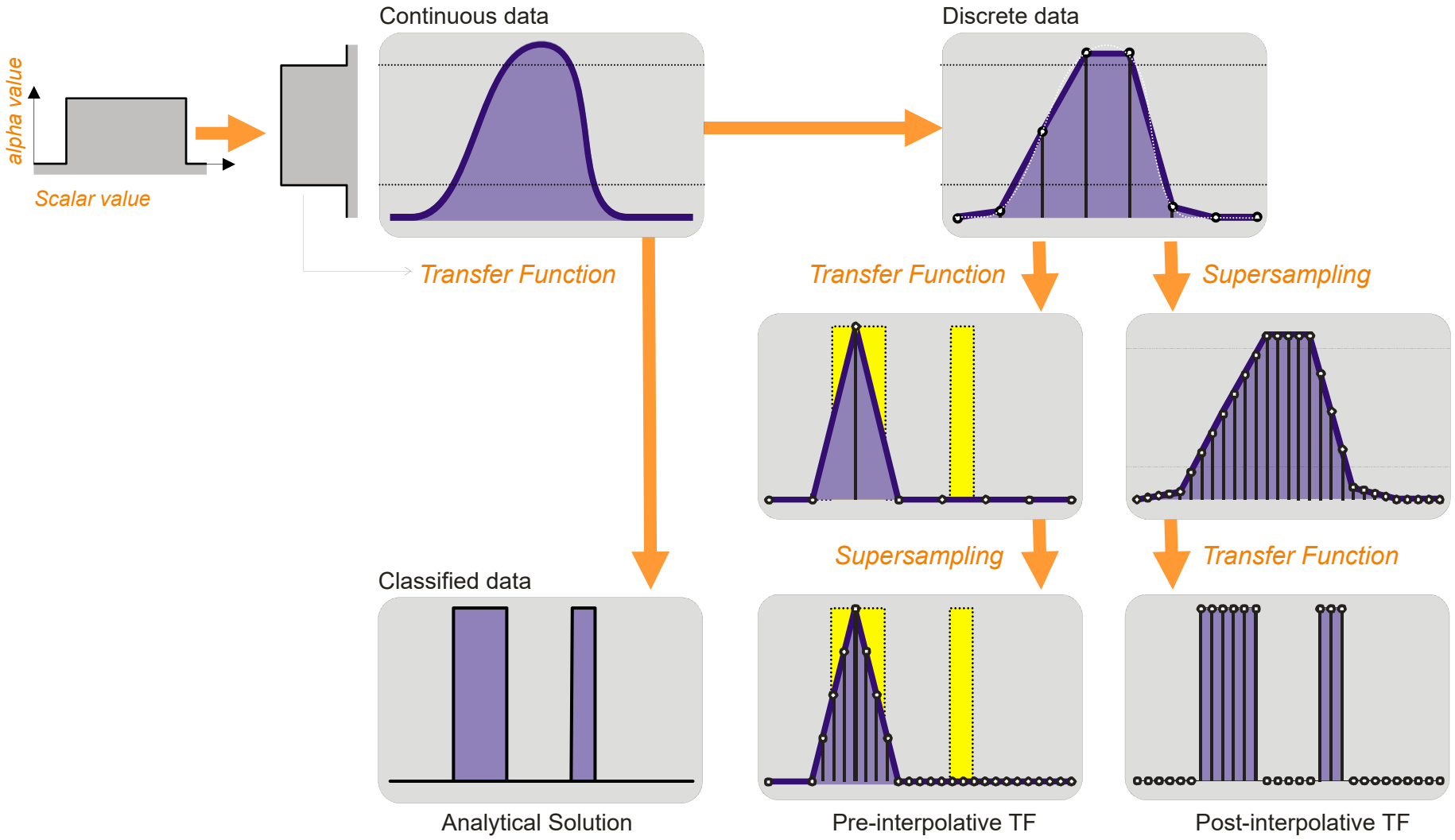


Pre-Classification

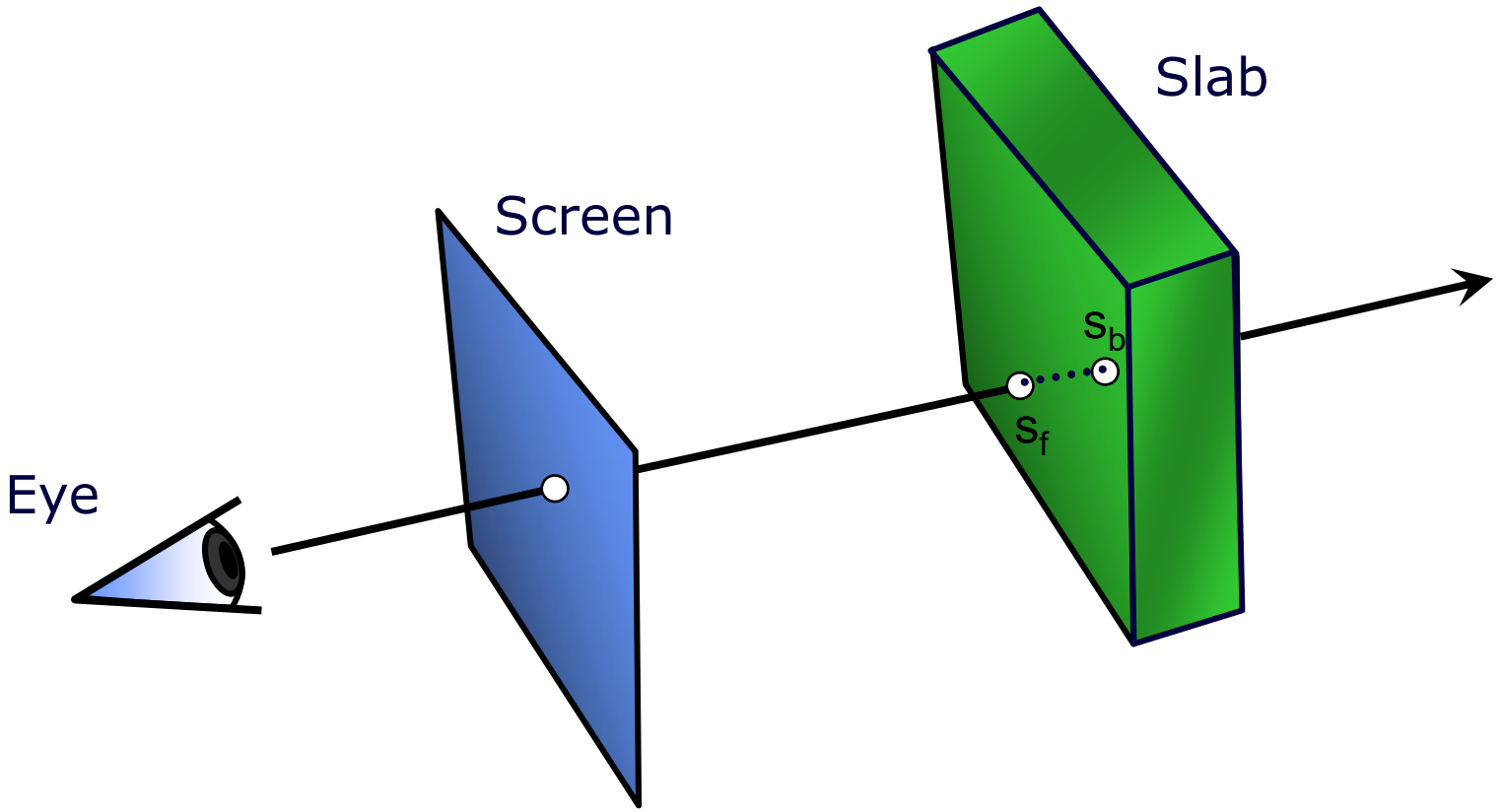


Post-Classification

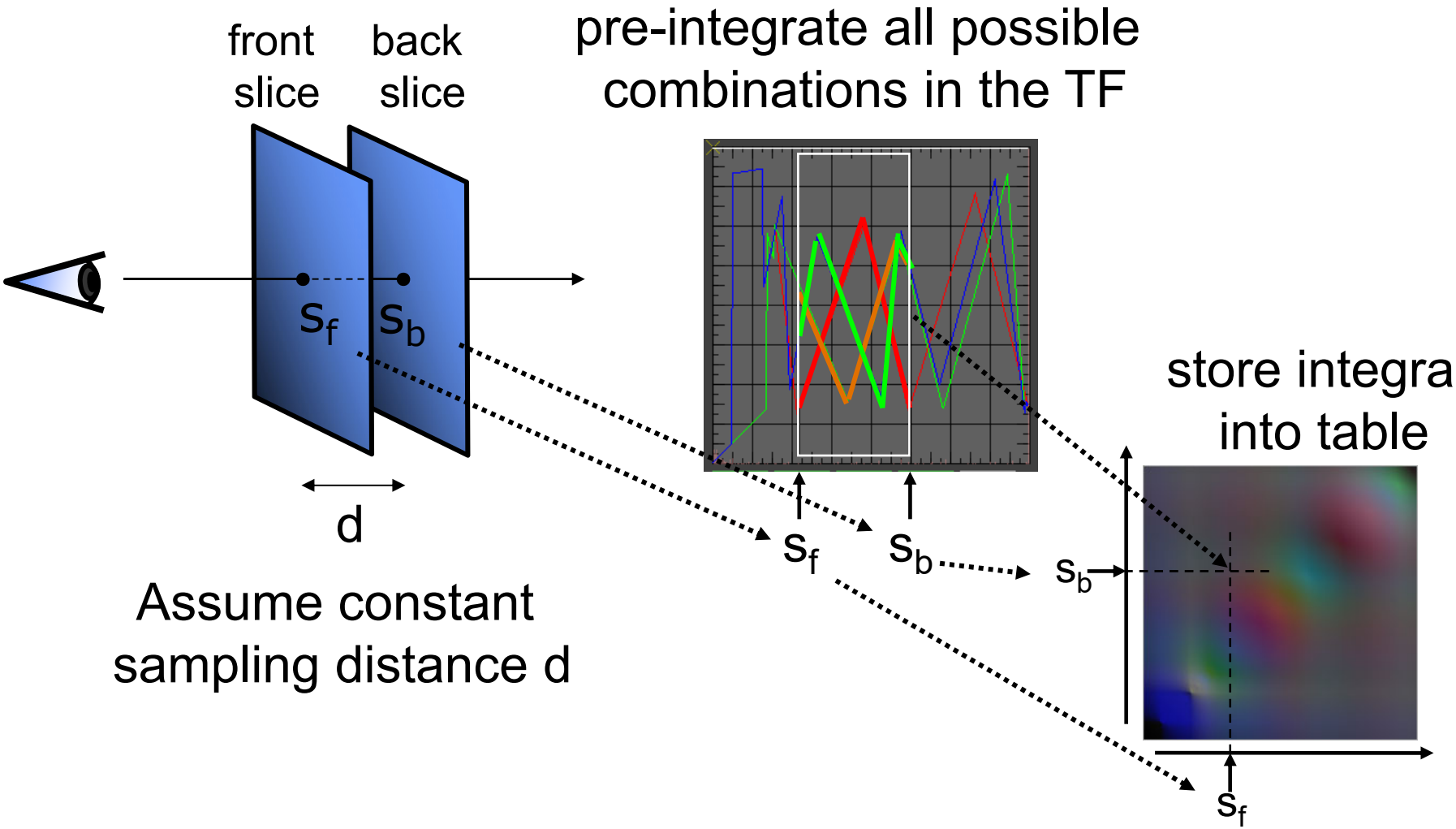
Pre- vs Post-Classification



Pre-Integrated Classification

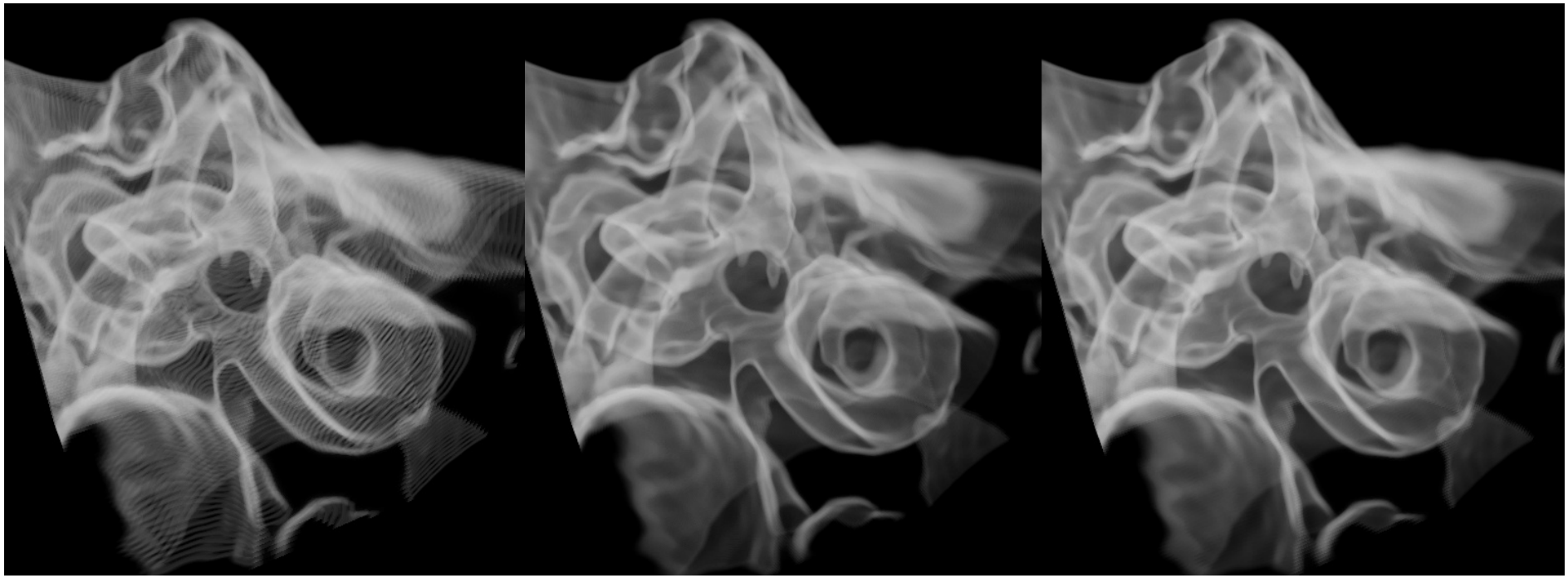


Pre-Integrated Classification



Pre-Integrated Classification

Quality comparison



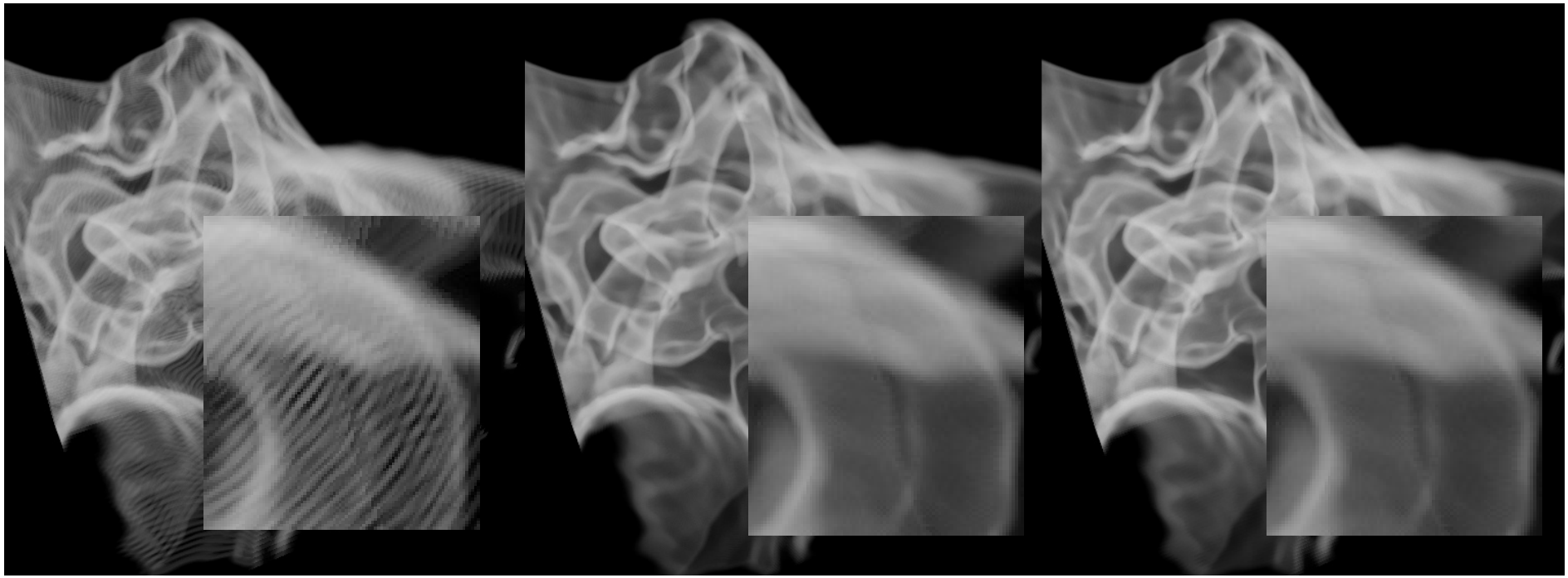
128 Slices

284 Slices

128 Slabs

Pre-Integrated Classification

Quality comparison

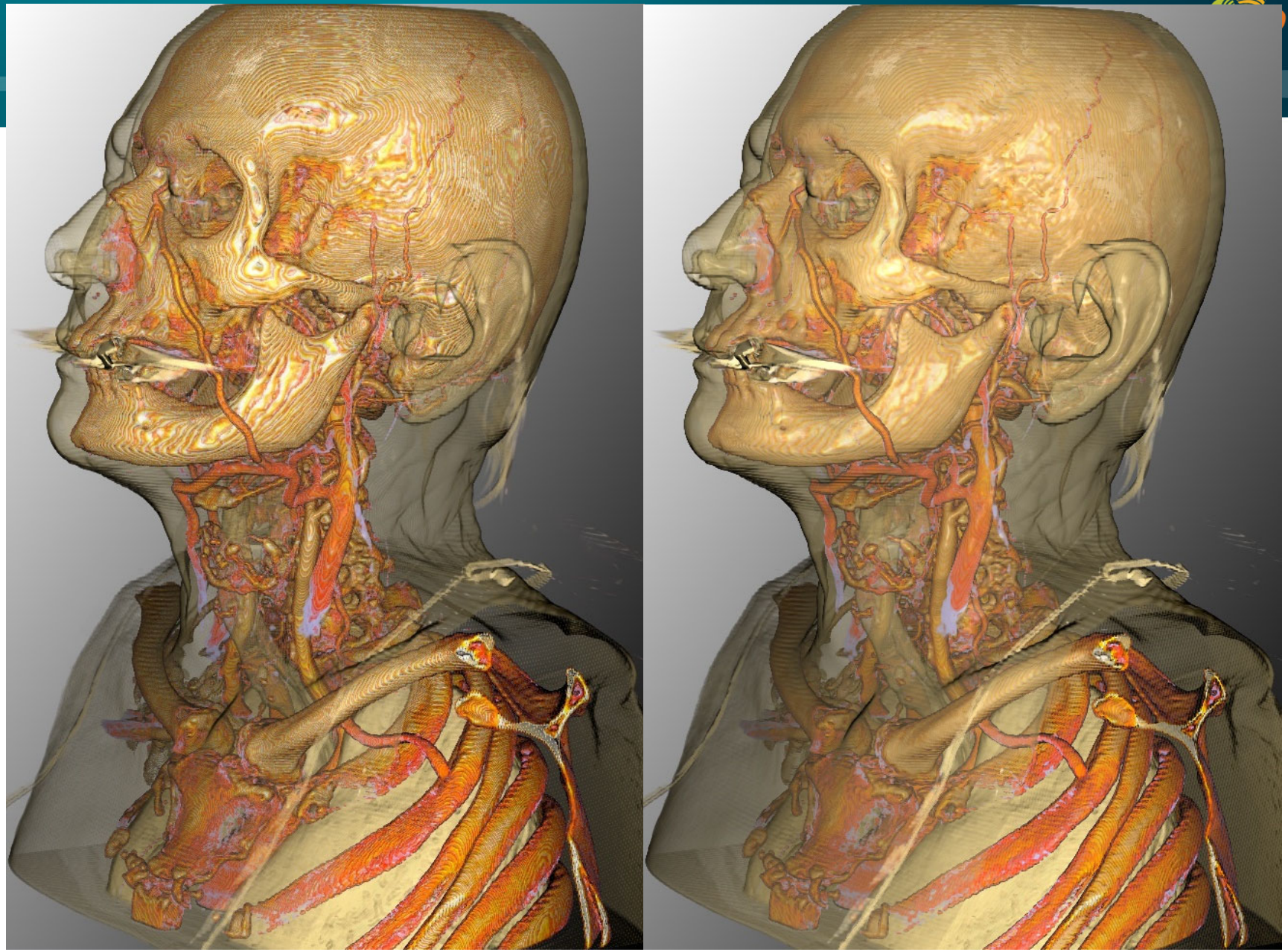


128 Slices

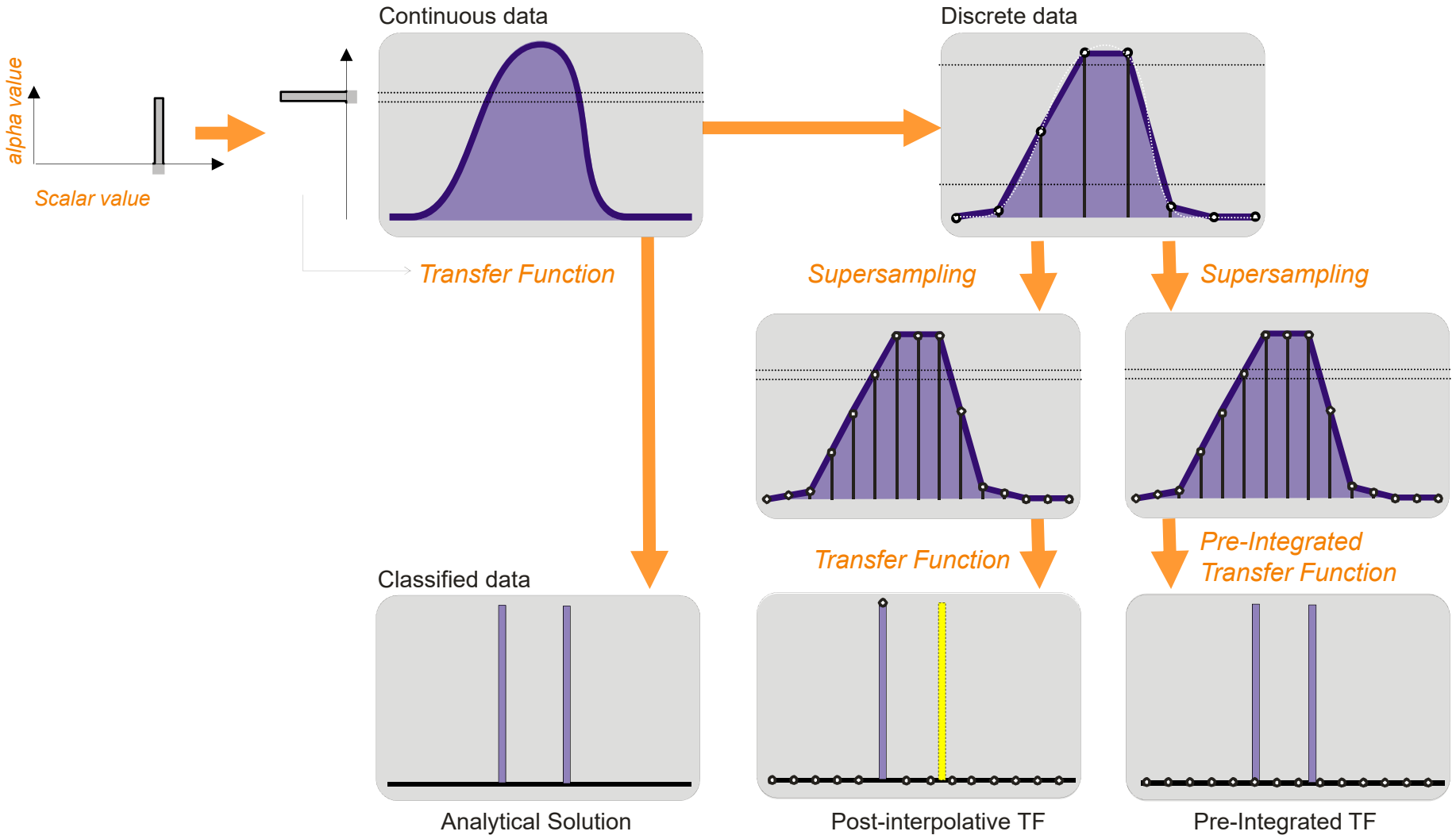
284 Slices

128 Slabs

Pre-Integrated Classification



Post- vs. Pre-Integrated Classification



2D (or higher) Transfer Functions

Transfer function look-up with more than one attribute

- T(scalar value, ... additional attributes ...)

Additional attributes:

- Derivatives (most common: gradient magnitude)
- Segmentation information (integer label IDs)
- Curvature (of isosurface going through each point)
- Spatial position
- ...

2D (or higher) Transfer Functions

Derivatives indicate where material boundaries are located

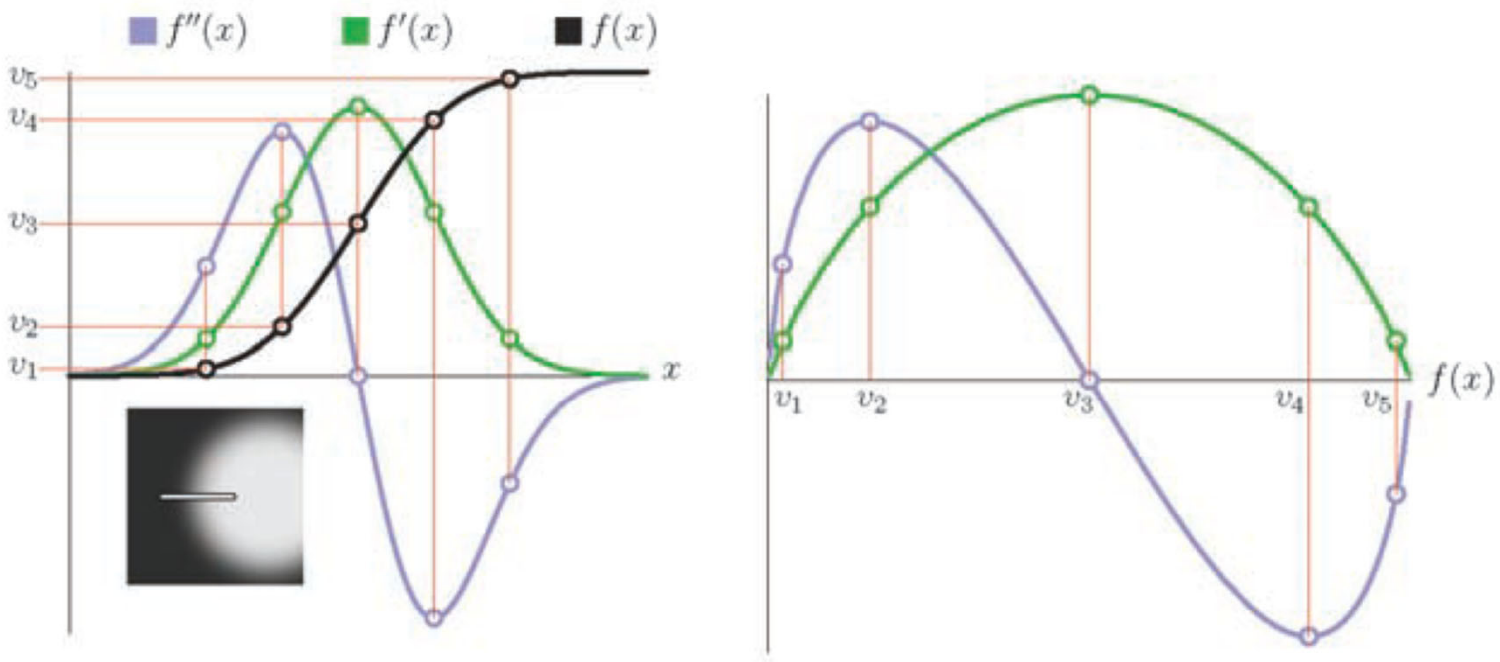


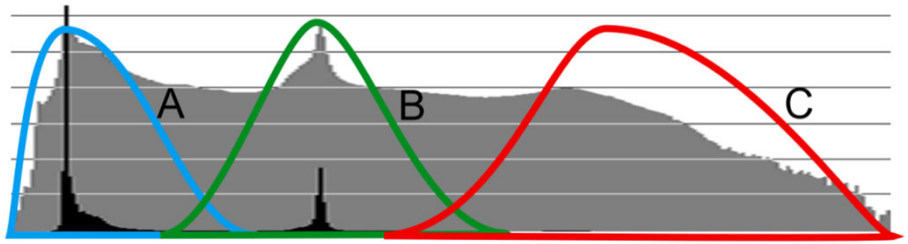
Figure 10.2. Relationships between f, f', f'' in an ideal boundary.

2D Transfer Functions

1D transfer function

- Horizontal axis: scalar value
- Vertical axis: number of voxels

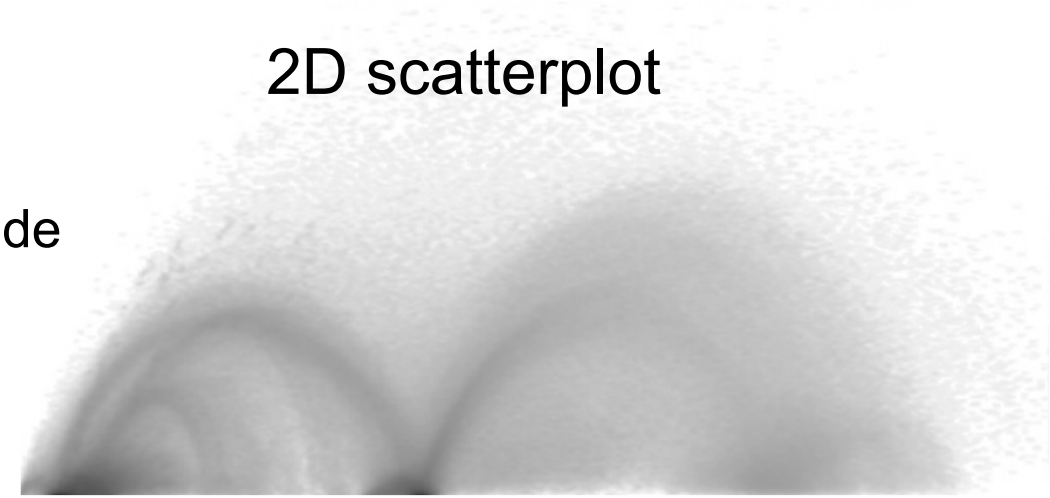
1D histogram



2D transfer function

- Horizontal axis: scalar value
- Vertical axis: gradient magnitude
- Brightness: number of voxels (here: darker means more)

2D scatterplot



[Kniss et al. 2002]

2D Transfer Functions

1D transfer function

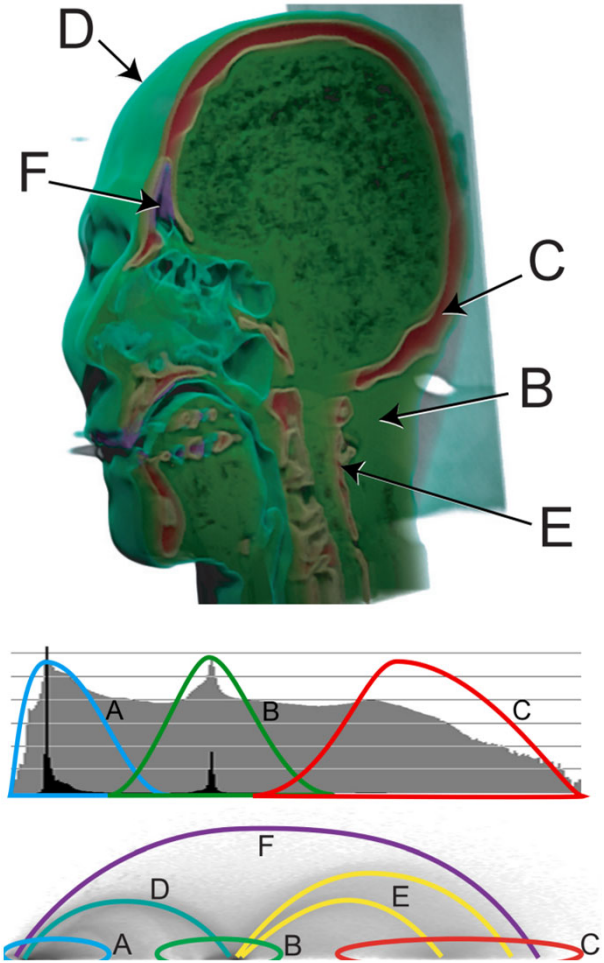
Horizontal axis: scalar value

Vertical axis: number of voxels

2D transfer function

Horizontal axis: scalar value

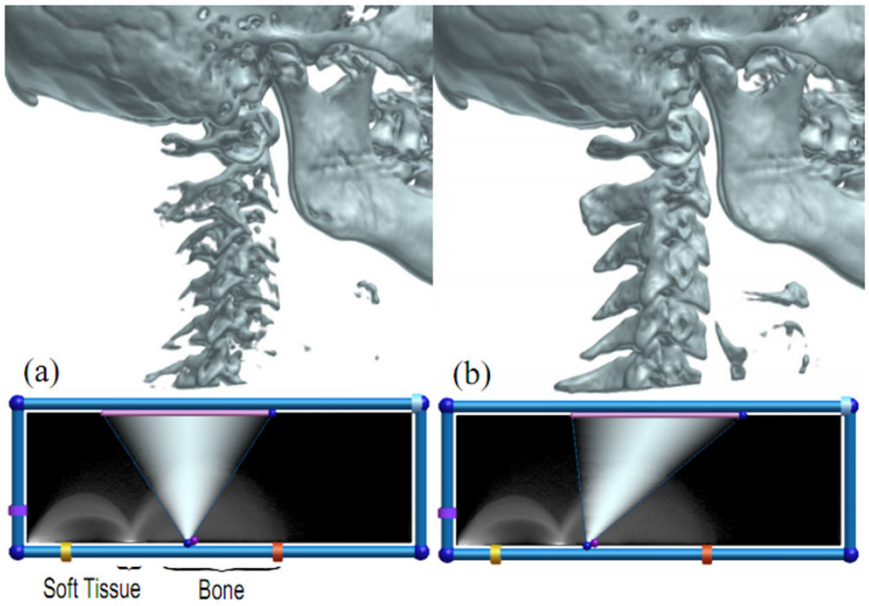
Vertical axis: gradient magnitude

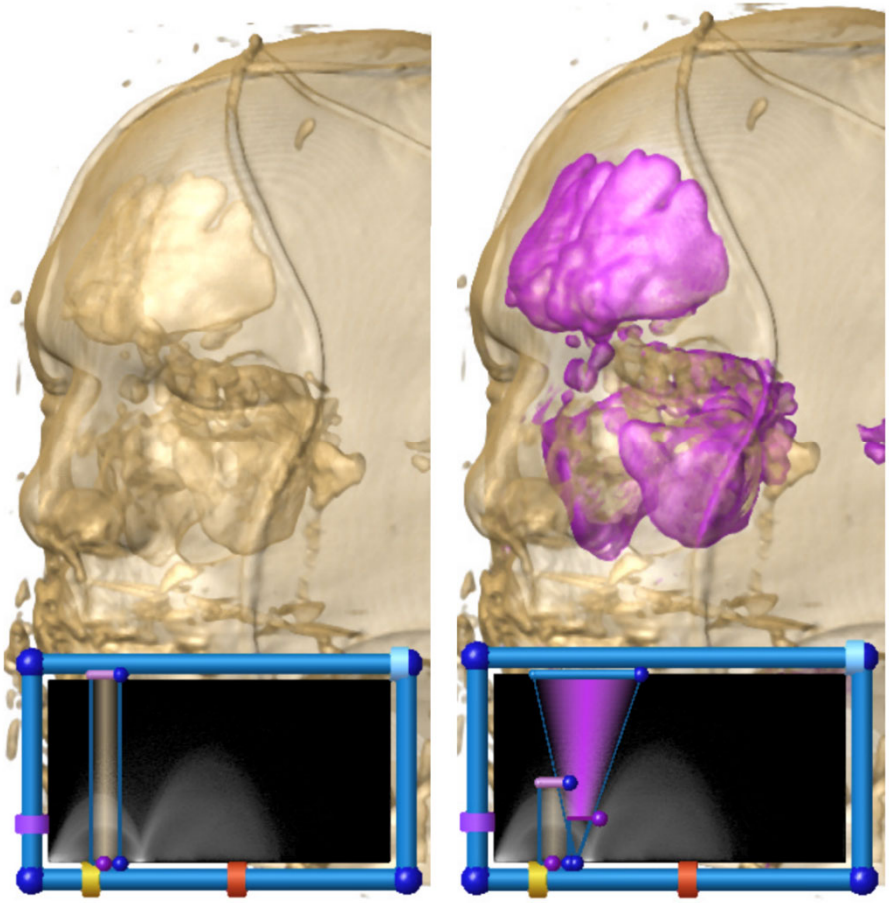


[Kniss et al. 2002]

2D Transfer Functions

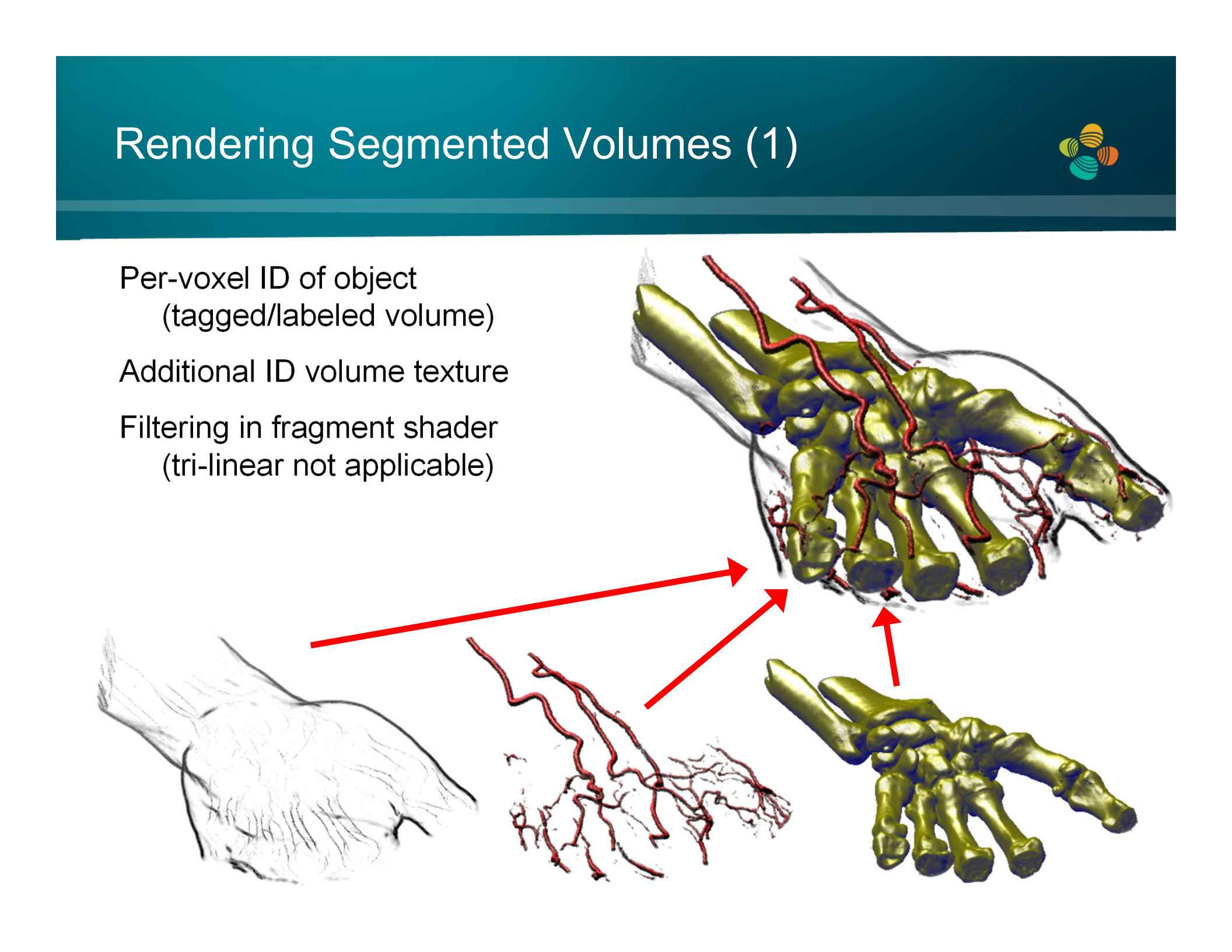
Comparisons





[Kniss et al. 2002]

Rendering Segmented Volumes (1)

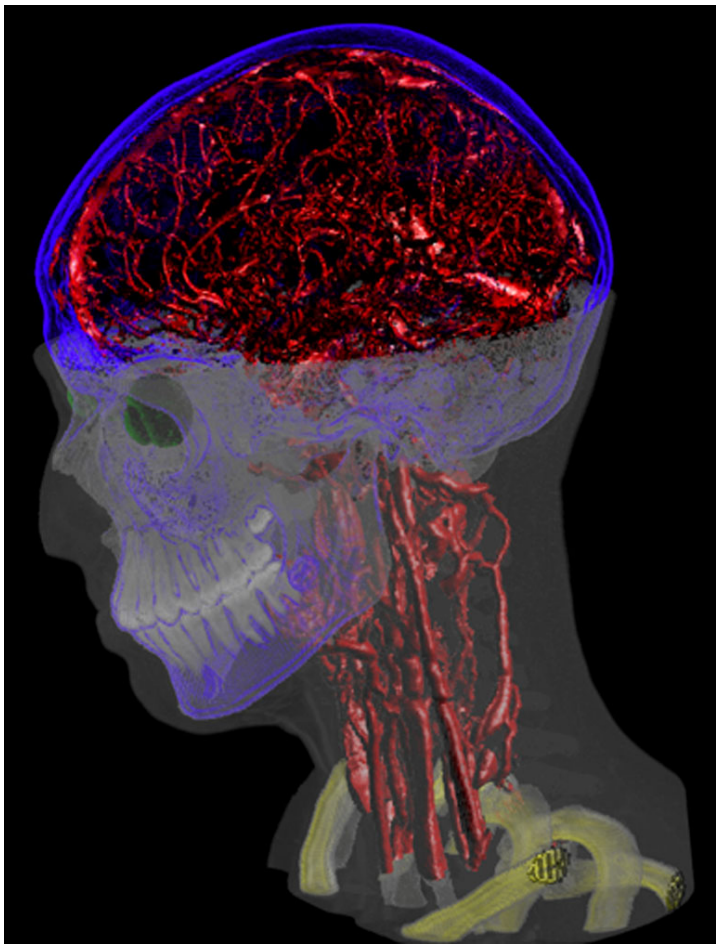


Per-voxel ID of object
(tagged/labeled volume)

Additional ID volume texture

Filtering in fragment shader
(tri-linear not applicable)

Rendering Segmented Volumes (2)



Focus and context

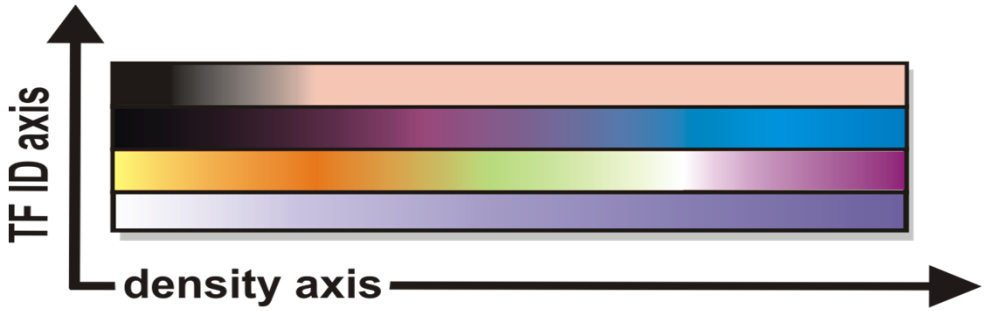
Per-object transfer function

Per-object rendering mode

Per-object compositing

Per-Object Transfer Functions

Put all transfer functions in one global TF texture



index with object ID
as additional axis

```
tf_coords.x = tex3D( density_tex, sample_pos );
tf_coords.y = tex3D( objectid_tex, sample_pos );
classified_sample.rgba = tex2D( tf_tex, tf_coords );
```

1D transfer functions → 2D texture

2D transfer functions → 3D texture

Thank you.

Thanks for material

- Helwig Hauser
- Eduard Gröller
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- Ronny Peikert
- Philipp Muigg
- Christof Rezk-Salama