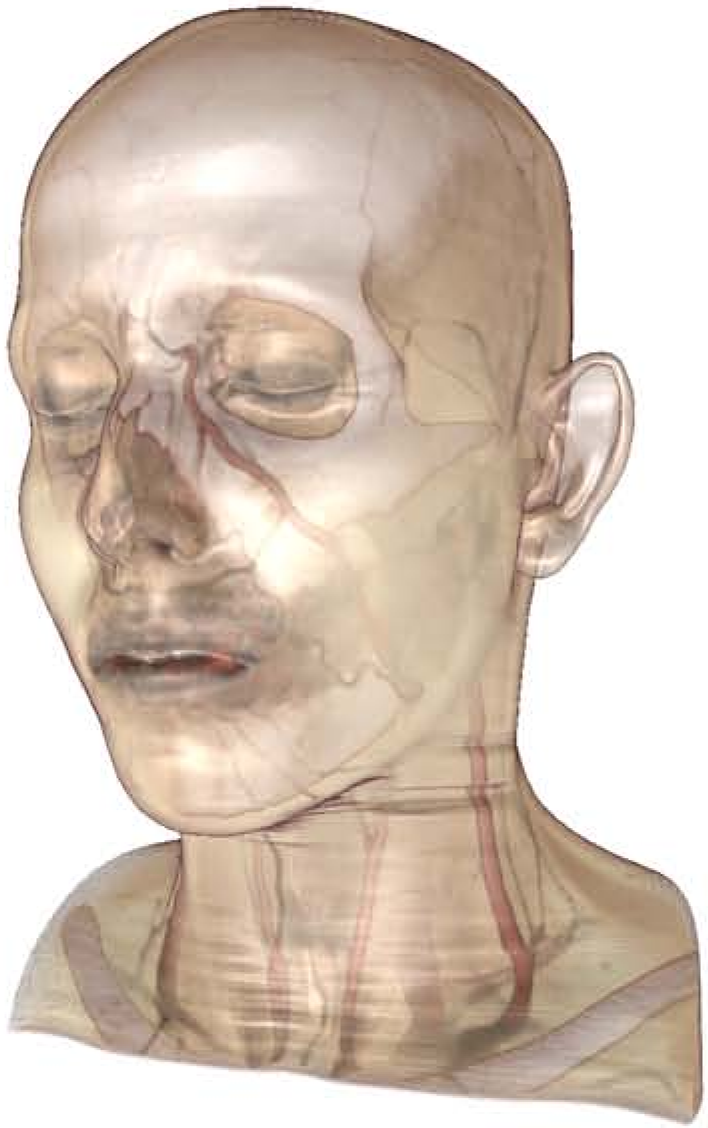
Real-Time Volume Graphics

[04] GPU-Based Ray-Casting

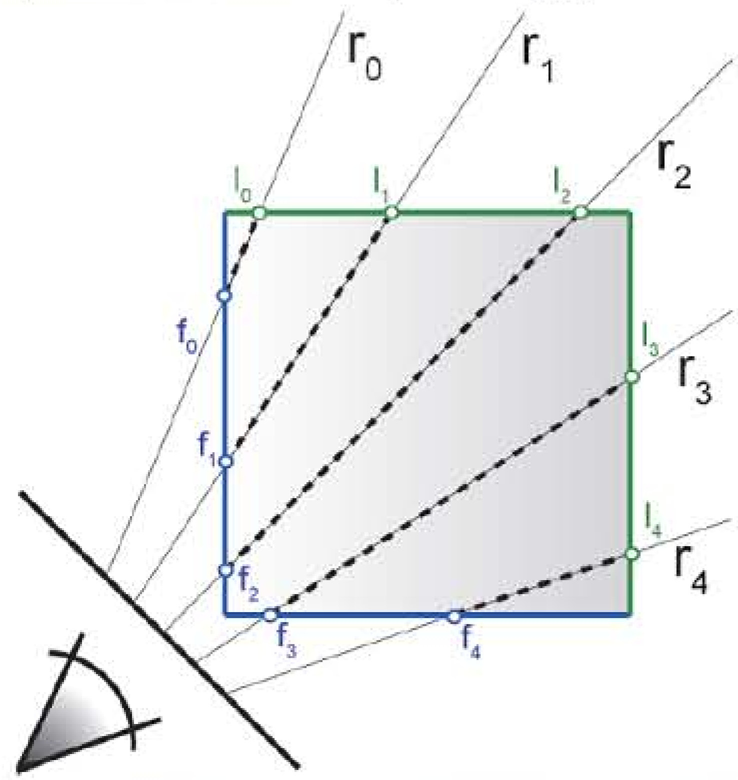


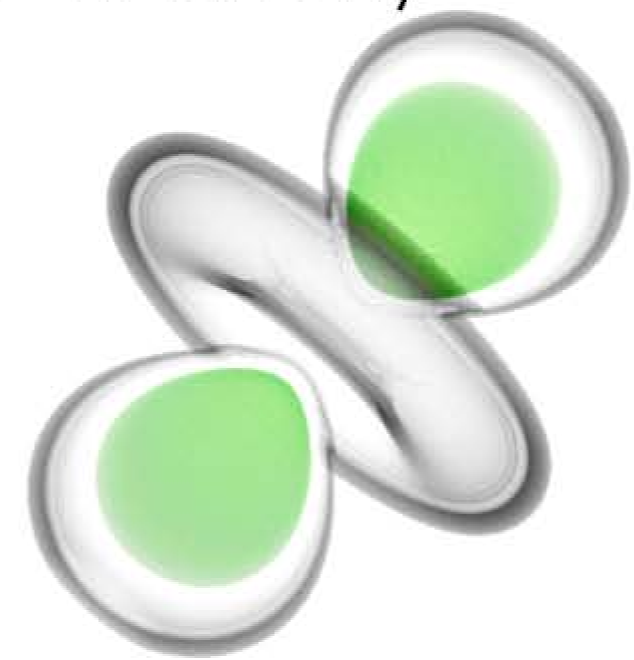
Talk Outline

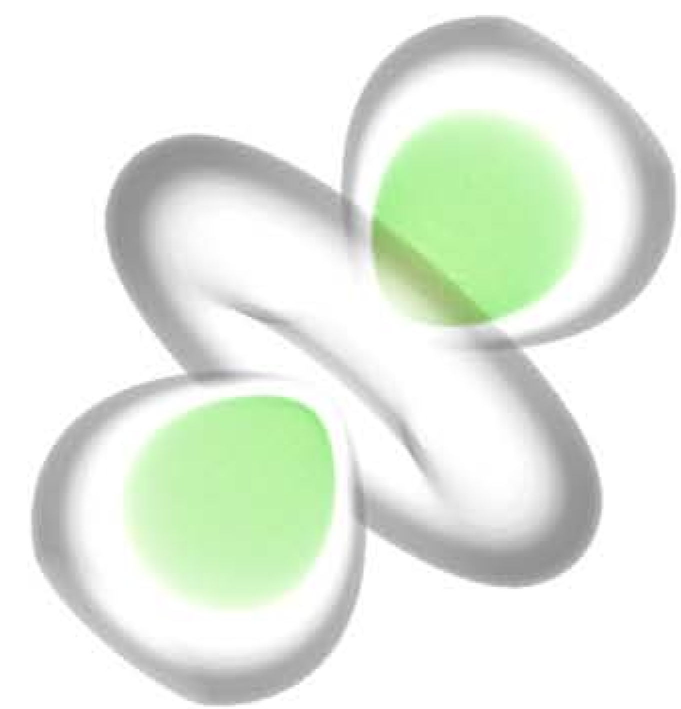
- Why use ray-casting instead of slicing?
- Ray-casting of rectilinear (structured) grids
  - Basic approaches on GPUs
  - Basic acceleration methods
  - Object-order empty space skipping
  - Isosurface ray-casting
  - Endoscopic ray-casting

Why Ray-Casting on GPUs?

- Most GPU rendering is object-order (rasterization)
- Image-order is more "CPU-like"
  - Recent fragment shader advances
  - Simpler to implement
  - Very flexible (e.g., adaptive sampling)
  - Correct perspective projection
  - Can be implemented in single pass!
  - Native 32-bit compositing



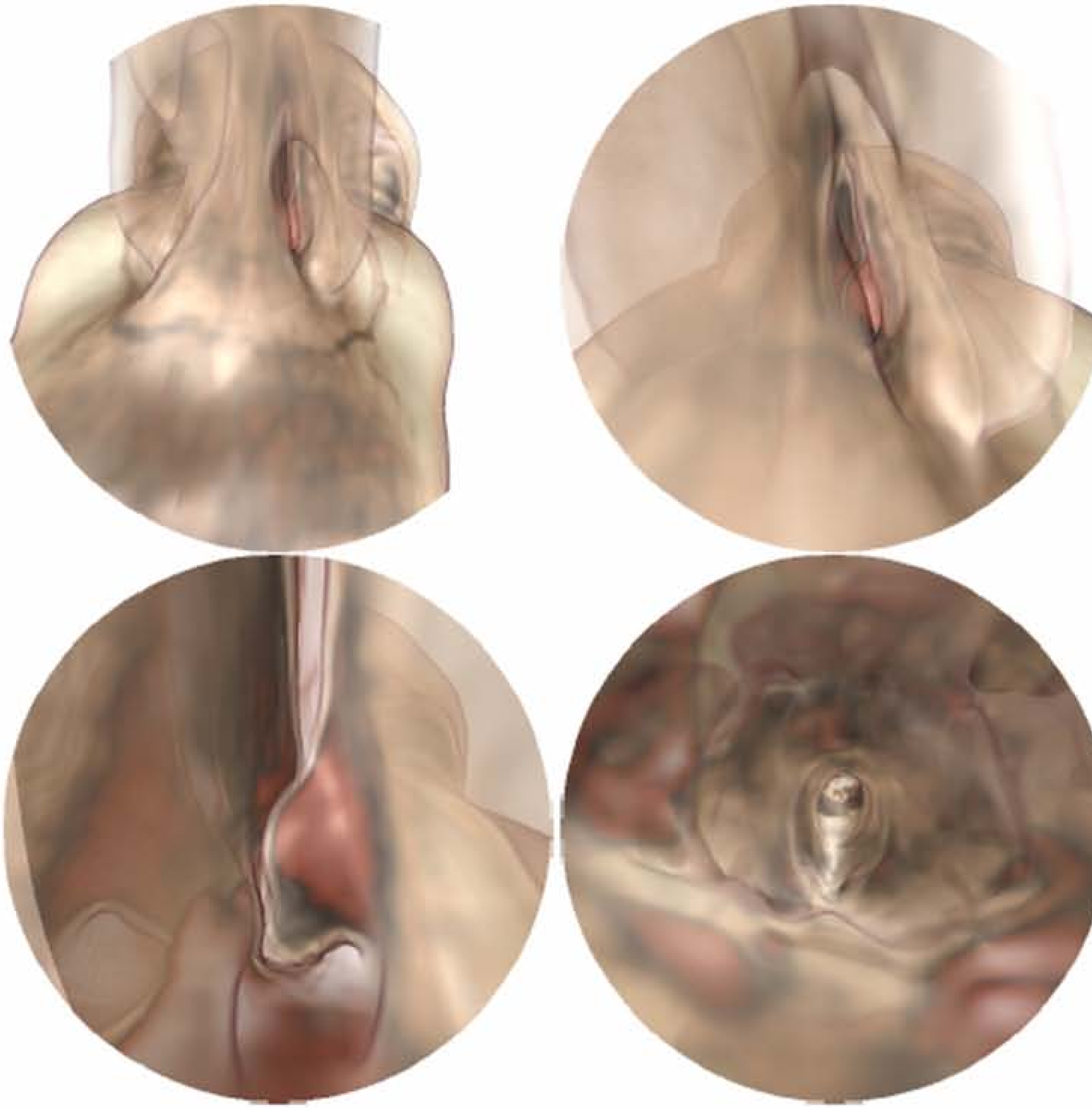




Where Is Correct Perspective Needed?

- Entering the volume
- Wide field of view

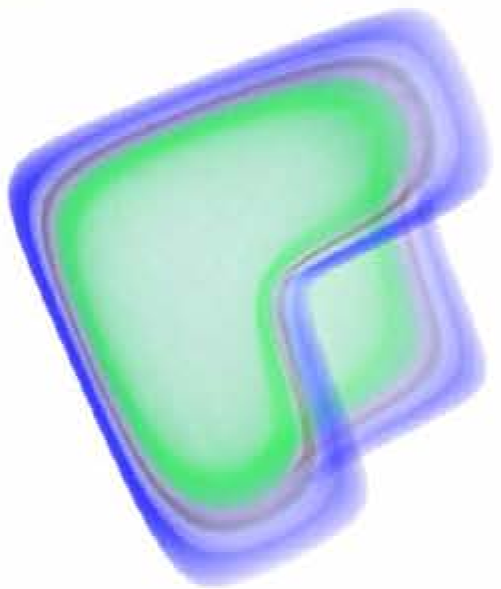
- Fly-throughs
- Virtual endoscopy
- Integration into perspective scenes, e.g., games



Recent GPU Ray-Casting Approaches

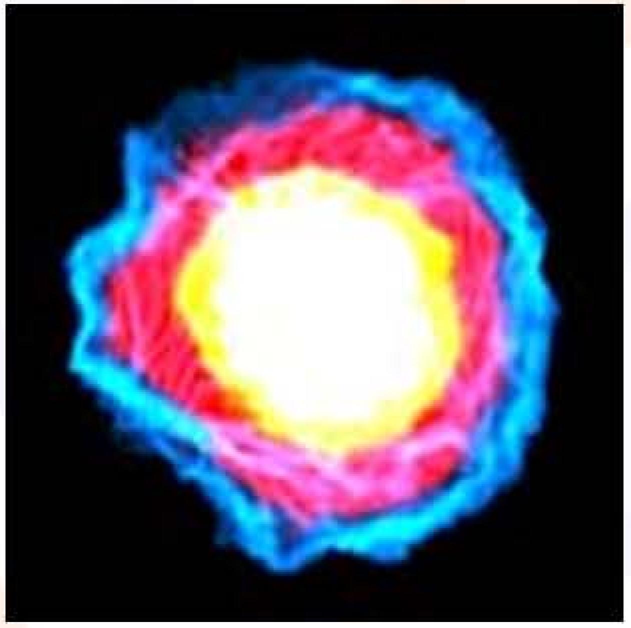
- Rectilinear grids
  - [Krüger and Westermann, 2003]
  - [Röttger et al., 2003]
  - [Green, 2004] (NVIDIA SDK Example)
  - [Stegmaier et al., 2005]
  - [Scharsach et al., 2006]

- Unstructured (tetrahedral) grids
  - [Weiler et al., 2002, 2003, 2004]
  - [Bernardon, 2004]



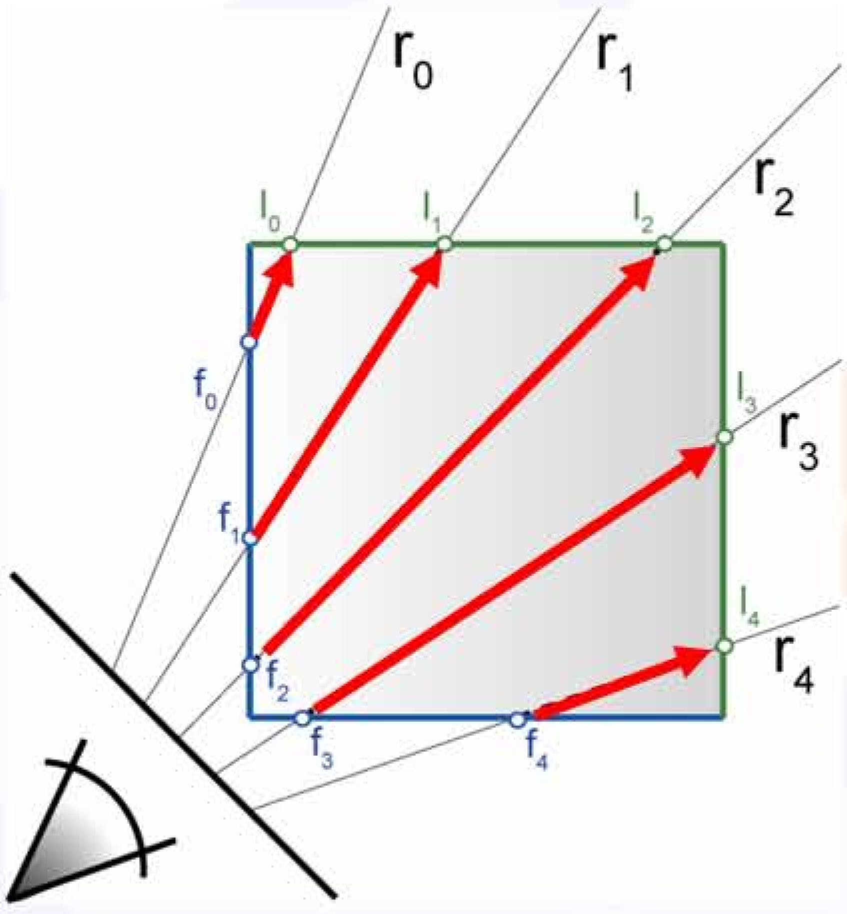
Single-Pass Ray-Casting

- Enabled by conditional loops in fragment shaders (Shader Model 3; e.g., Geforce 6800, ATI X1800)
- Substitute multiple passes and early-z testing by single loop and early loop exit
- No compositing buffer: full 32-bit precision!
- NVIDIA example: compute ray intersections with bounding box, march along rays and composite



Basic Ray Setup / Termination

- Two main approaches:
  - Procedural ray/box intersection [Röttger et al., 2003], [Green, 2004]
  - Rasterize bounding box [Krüger and Westermann, 2003]
- Some possibilities
  - Ray start position and exit check
  - Ray start position and exit position
  - Ray start position and direction vector

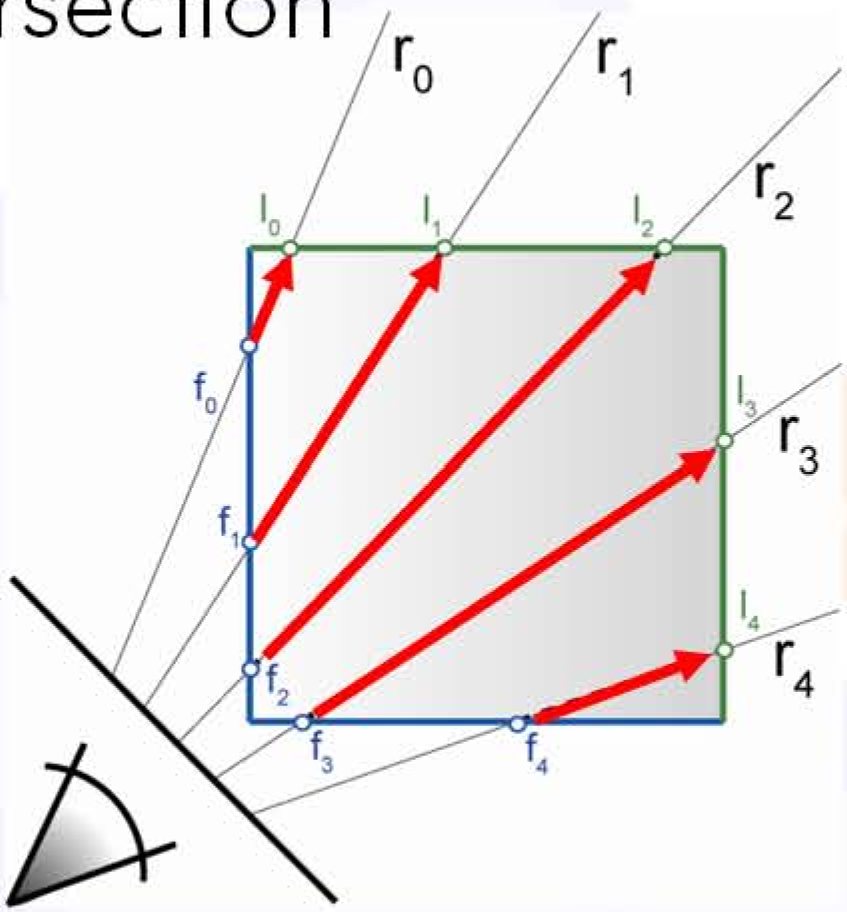


Procedural Ray Setup/Termination

- Everything handled in the fragment shader
- Procedural ray / bounding box intersection

- Ray is given by camera position and volume entry position
- Exit criterion needed

- Pro: simple and self-contained
- Con: full load on the fragment shader



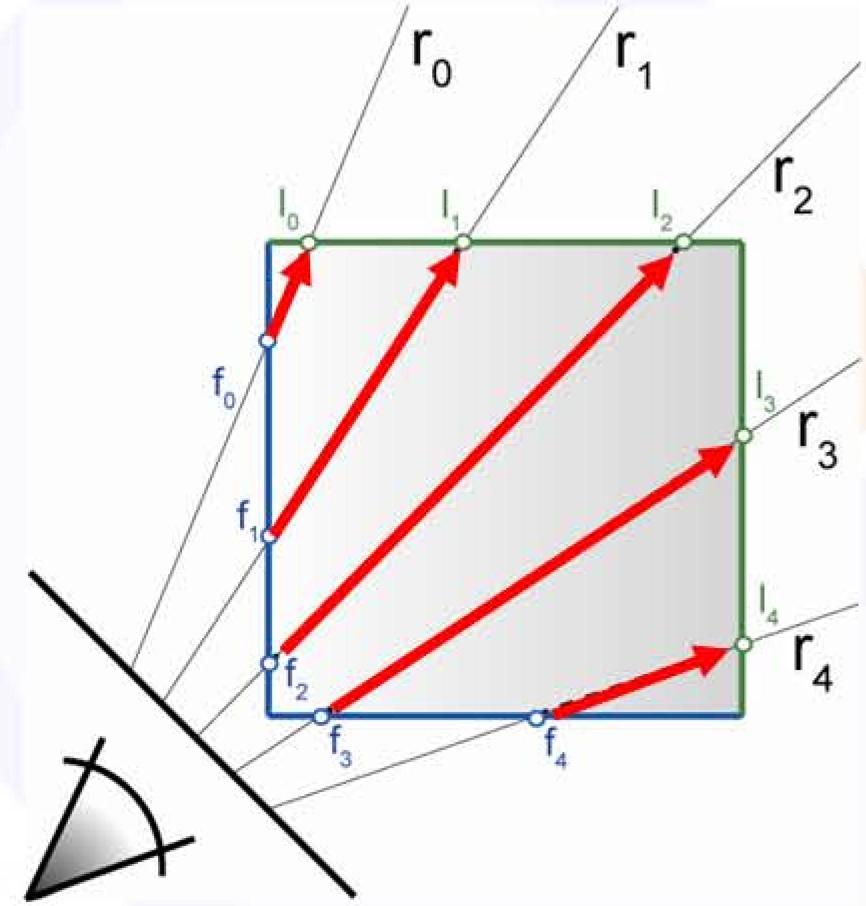
Fragment Shader

- 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;
}
```

"Image-Based" Ray Setup/Termination

- Rasterize bounding box front faces and back faces [Krüger and Westermann, 2003]
- Ray start position: front faces
- Direction vector: back−front faces

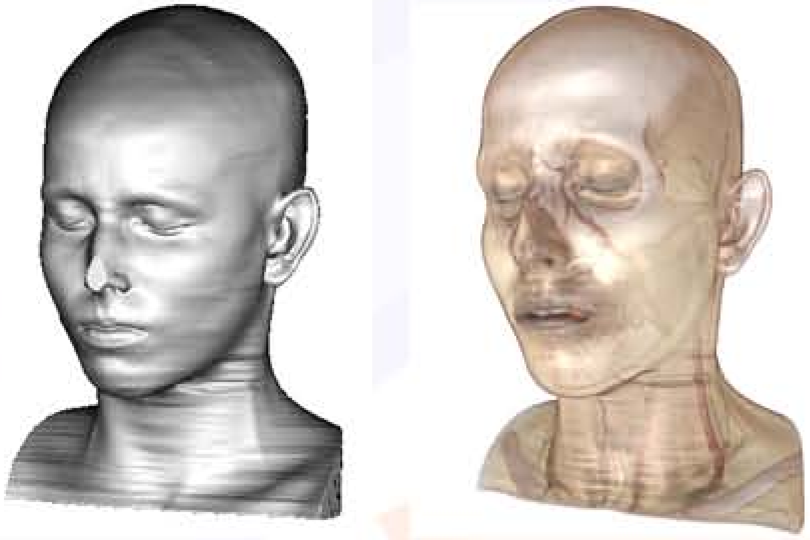


- Independent of projection (orthogonal/perspective)

Standard Ray-Casting Optimizations (1)

Early ray termination

- Isosurfaces: stop when surface hit
- Direct volume rendering:
  stop when opacity >= threshold

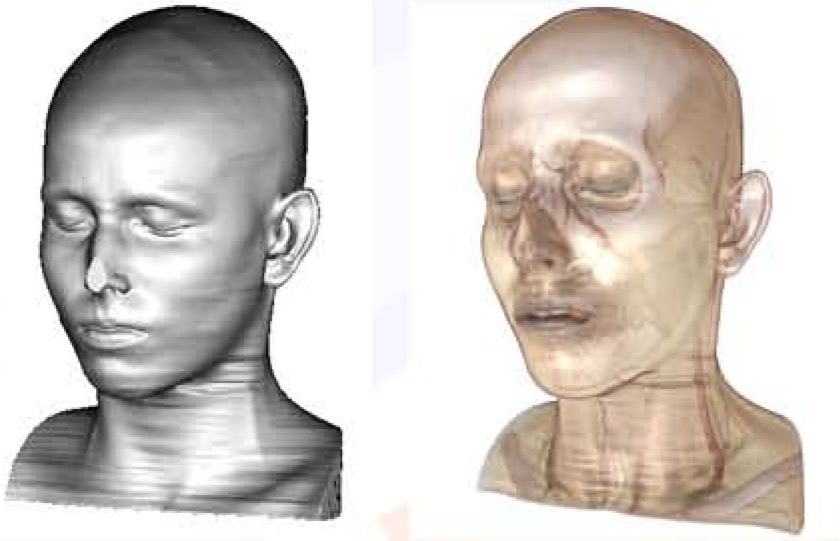


- Several possibilities
  - Older GPUs: multi-pass rendering with early-z test
  - Shader model 3: break out of ray-casting loop
  - Current GPUs: early loop exit not optimal but good

Standard Ray-Casting Optimizations (2)

Empty space skipping

- Skip transparent samples
- Depends on transfer function
- Start casting close to first hit

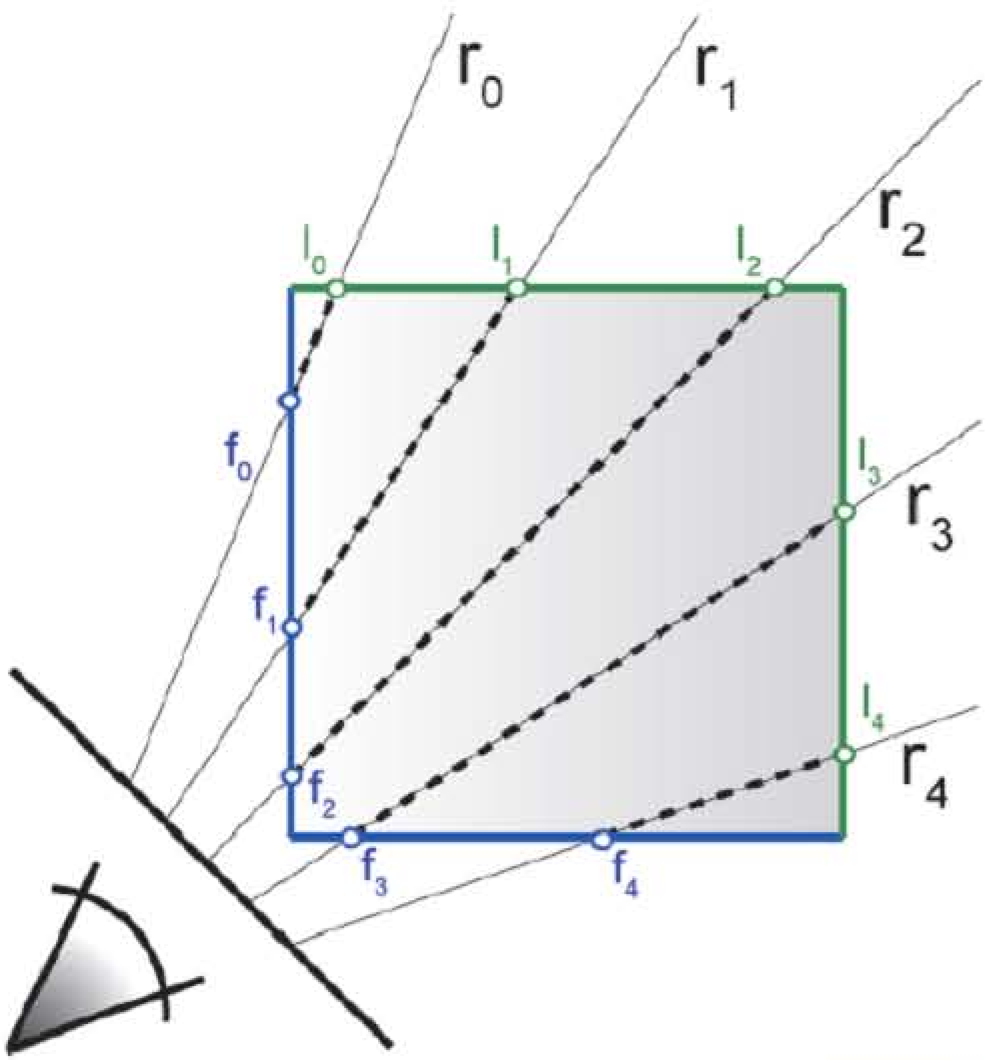


- Several possibilities
  - Per-sample check of opacity (expensive)
  - Traverse hierarchy (e.g., octree) or regular grid

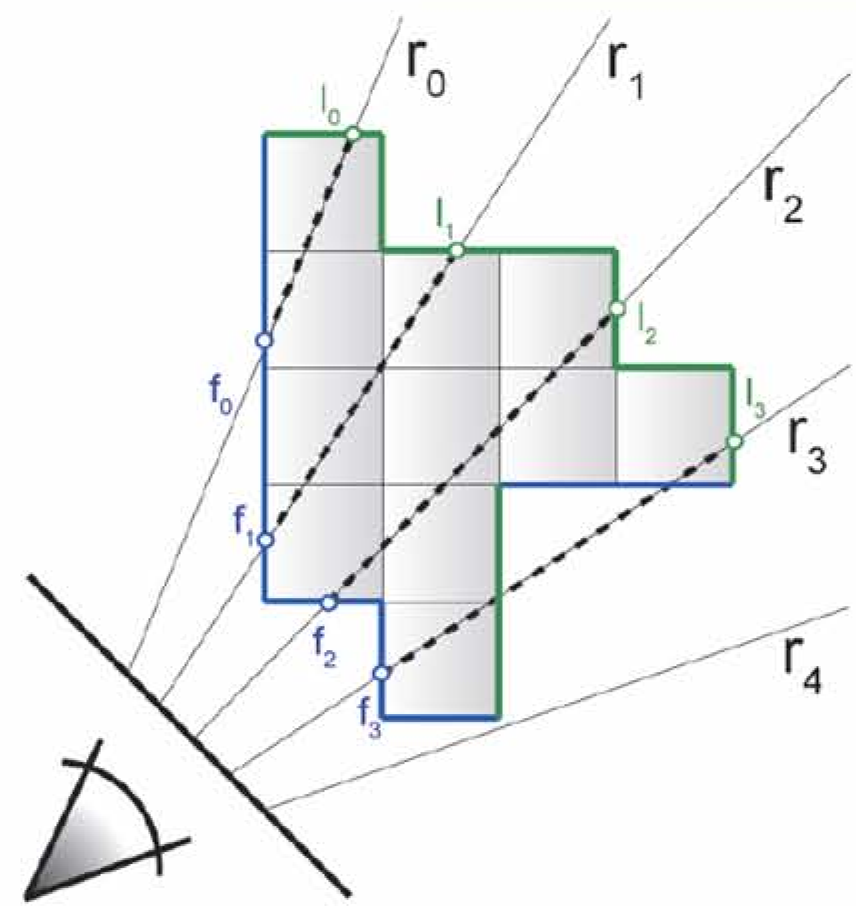
  - These are image-order: what about object-order?

Object-Order Empty Space Skipping (1)

- Modify initial rasterization step



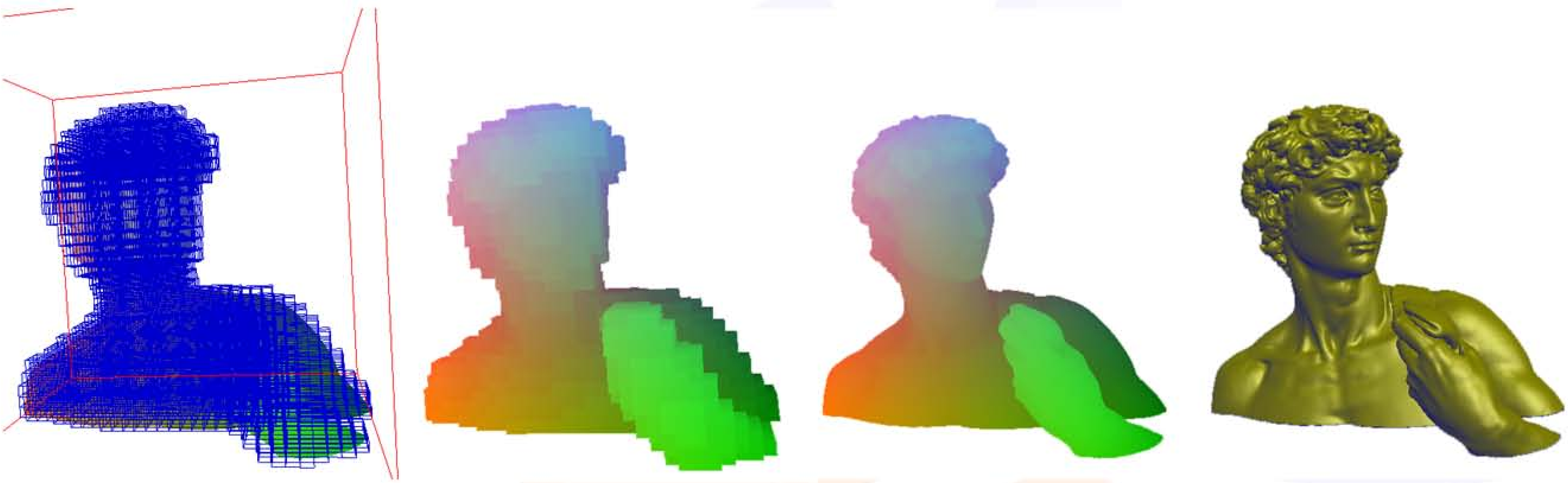
rasterize bounding box



rasterize “tight" bounding geometry

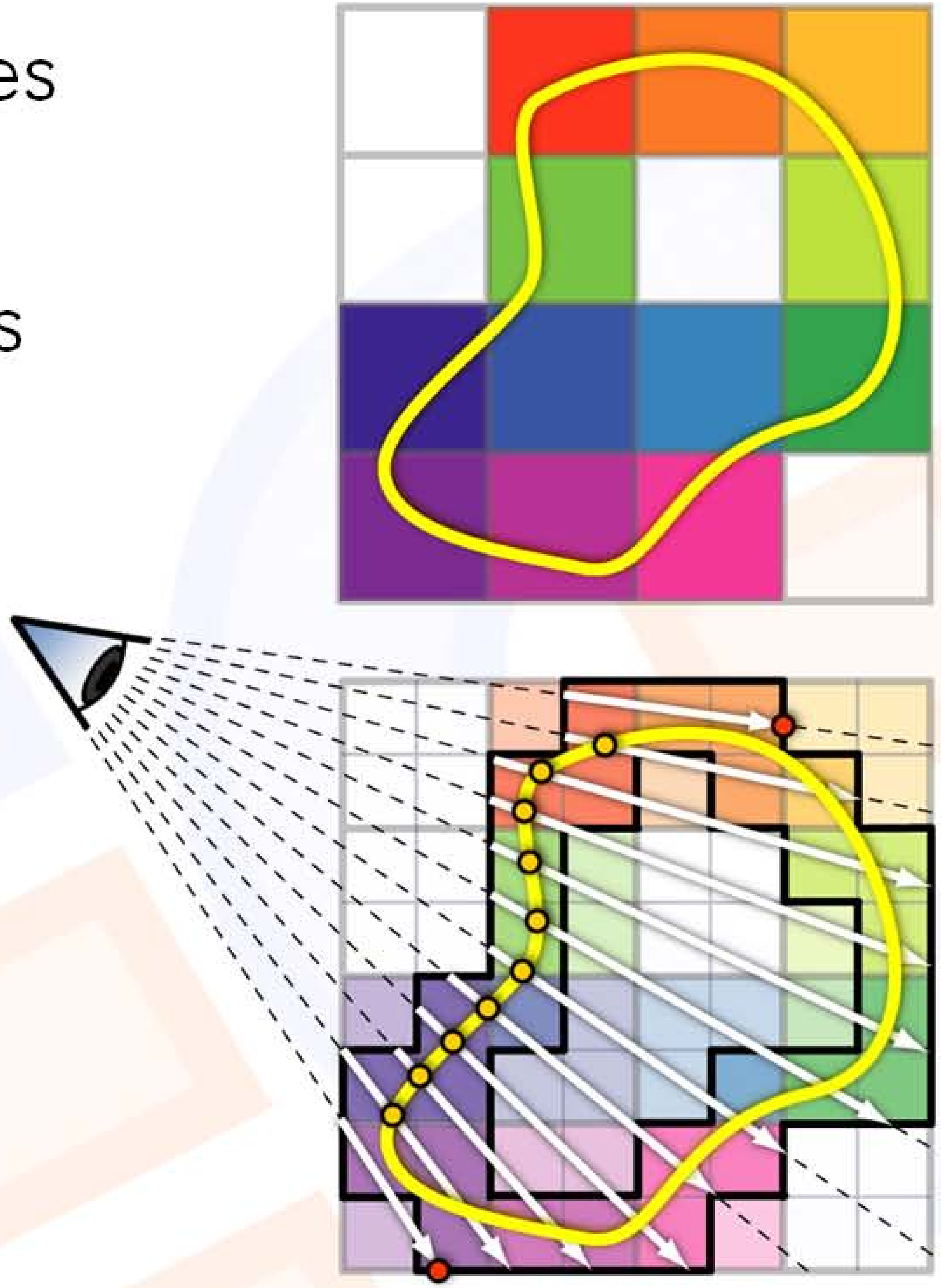
Object-Order Empty Space Skipping (2)

- Store min-max values of volume bricks
- Cull bricks against isovalue or transfer function
- Rasterize front and back faces of active bricks



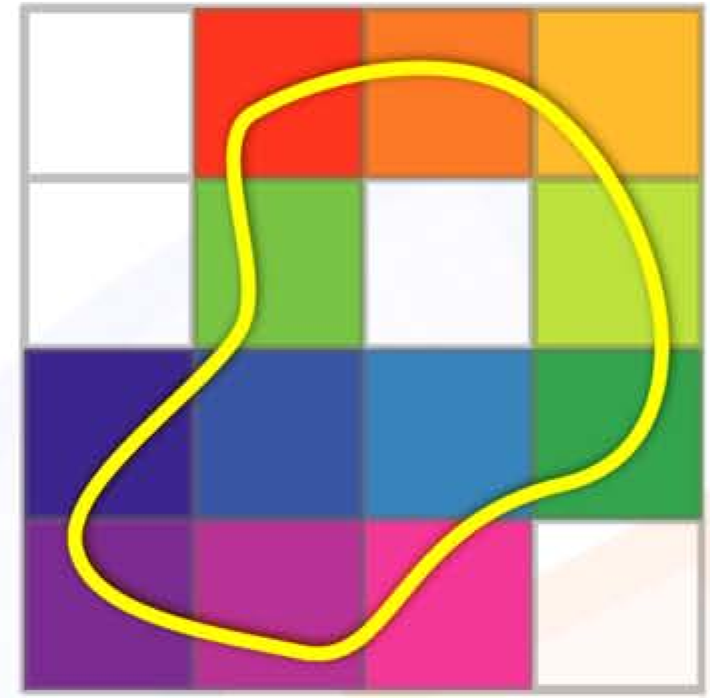
Object-Order Empty Space Skipping (3)

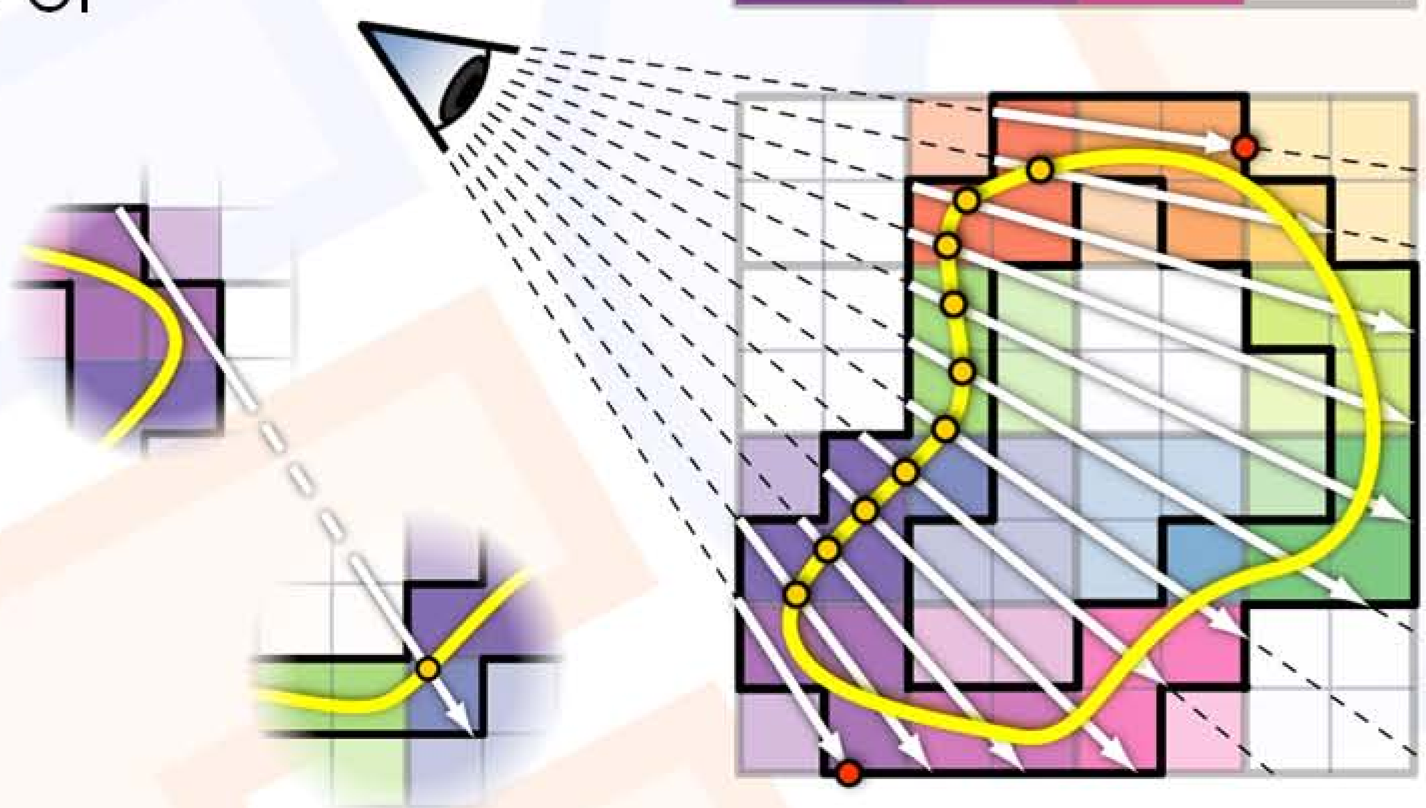
- Rasterize front and back faces of active min-max bricks
- Start rays on brick front faces
- Terminate when
  - Full opacity reached, or
  - Back face reached



Object-Order Empty Space Skipping (3)

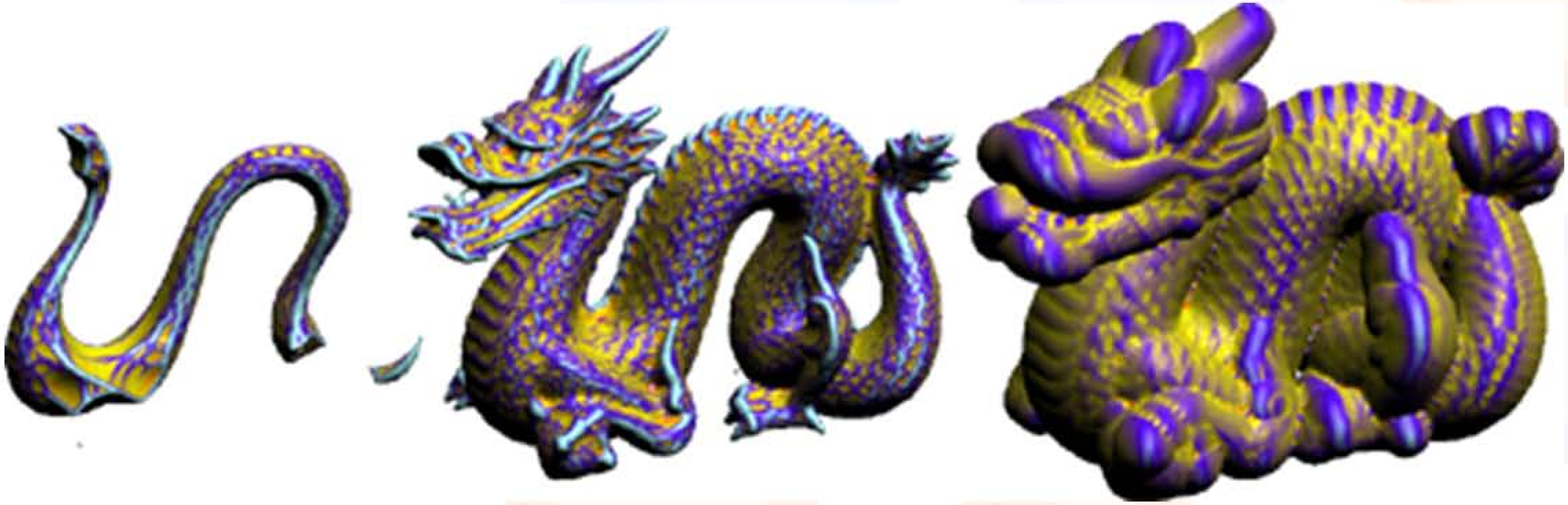
- Rasterize front and back faces of active min-max bricks
- Start rays on brick front faces
- Terminate when
  - Full opacity reached, or
  - Back face reached
- Not all empty space is skipped





Isosurface Ray-Casting

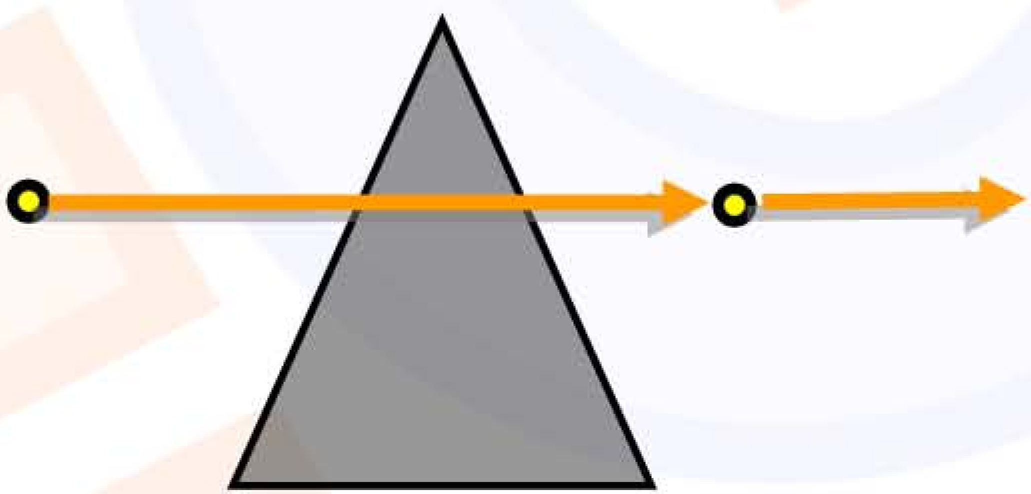
- Isosurfaces/Level Sets
  - scanned data
  - distance fields
  - CSG operations
  - level sets: surface editing, simulation, segmentation, ...



Intersection Refinement (1)

- Fixed number of bisection or 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)

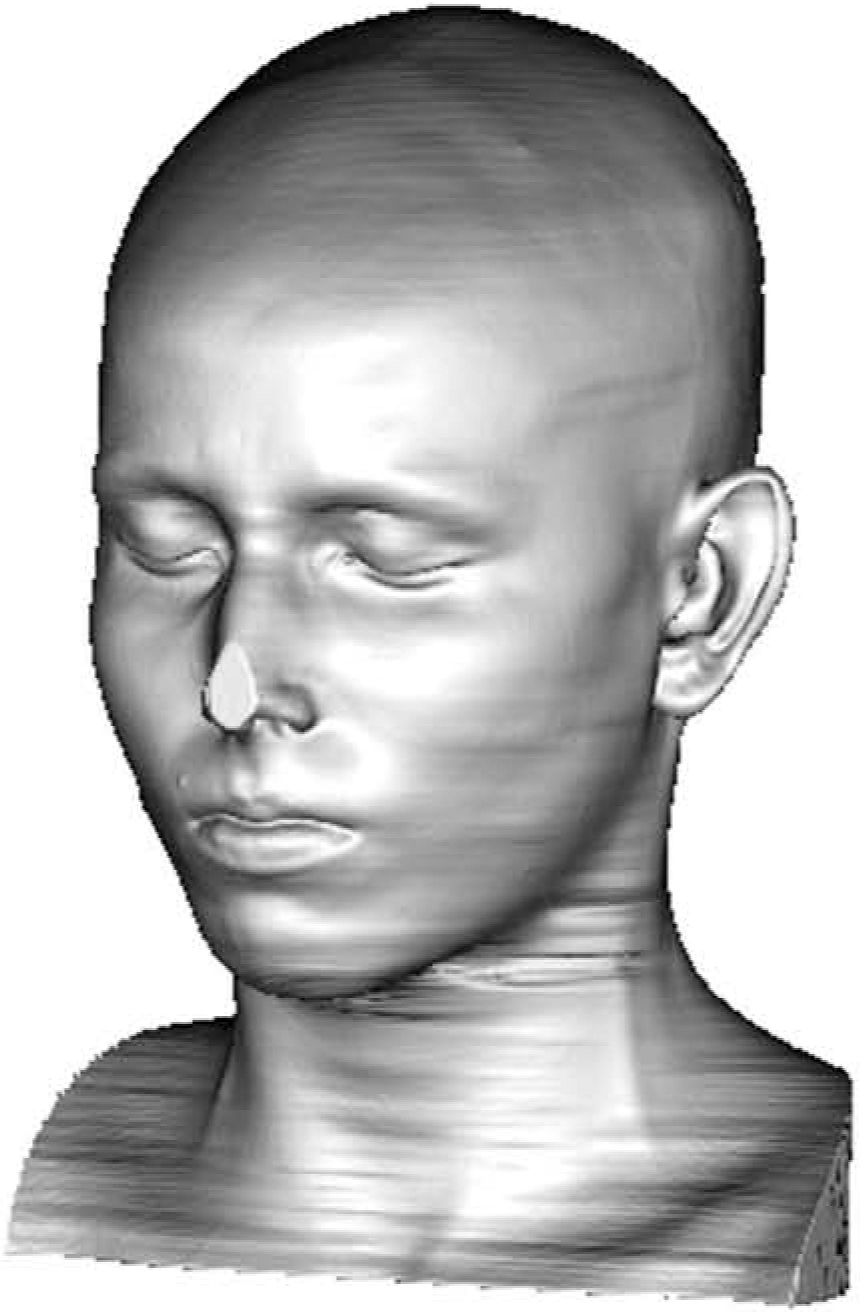
without refinement

with refinement

sampling rate 1/5 voxel (no adaptive sampling)

Intersection Refinement (3)

Sampling distance 1.0, 24 fps



Sampling distance 5.0, 66 fps

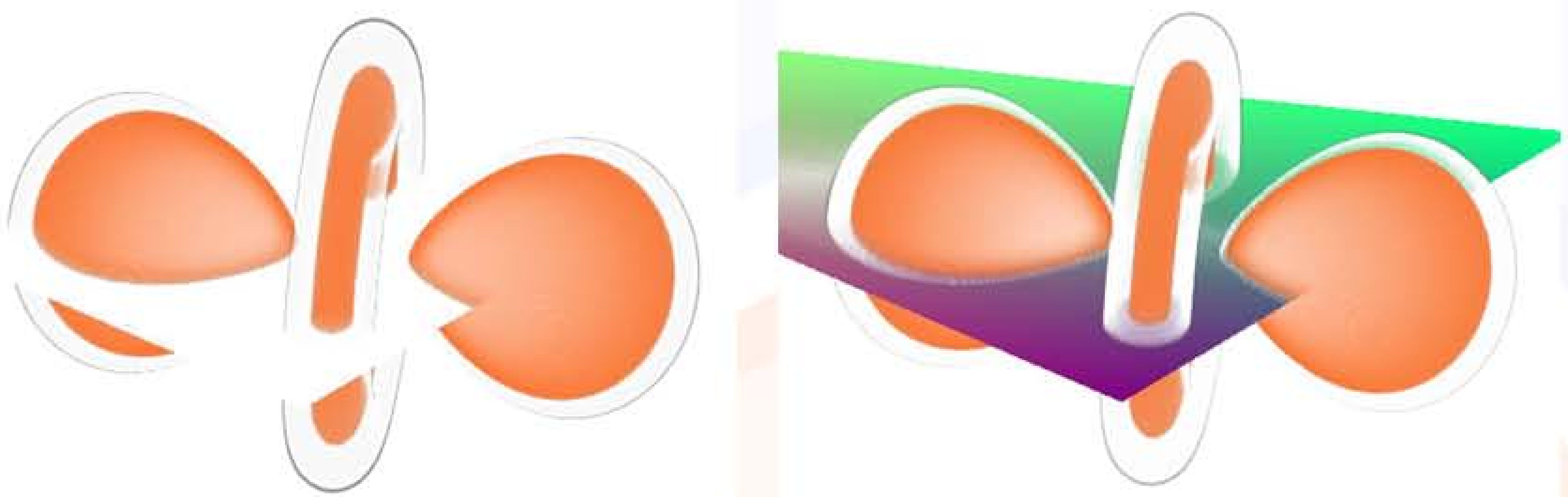
Deferred Isosurface Shading

- Shading is expensive
  - Gradient computation; conditional execution not free
- Ray-casting step computes only intersection image

Enhancements (1)

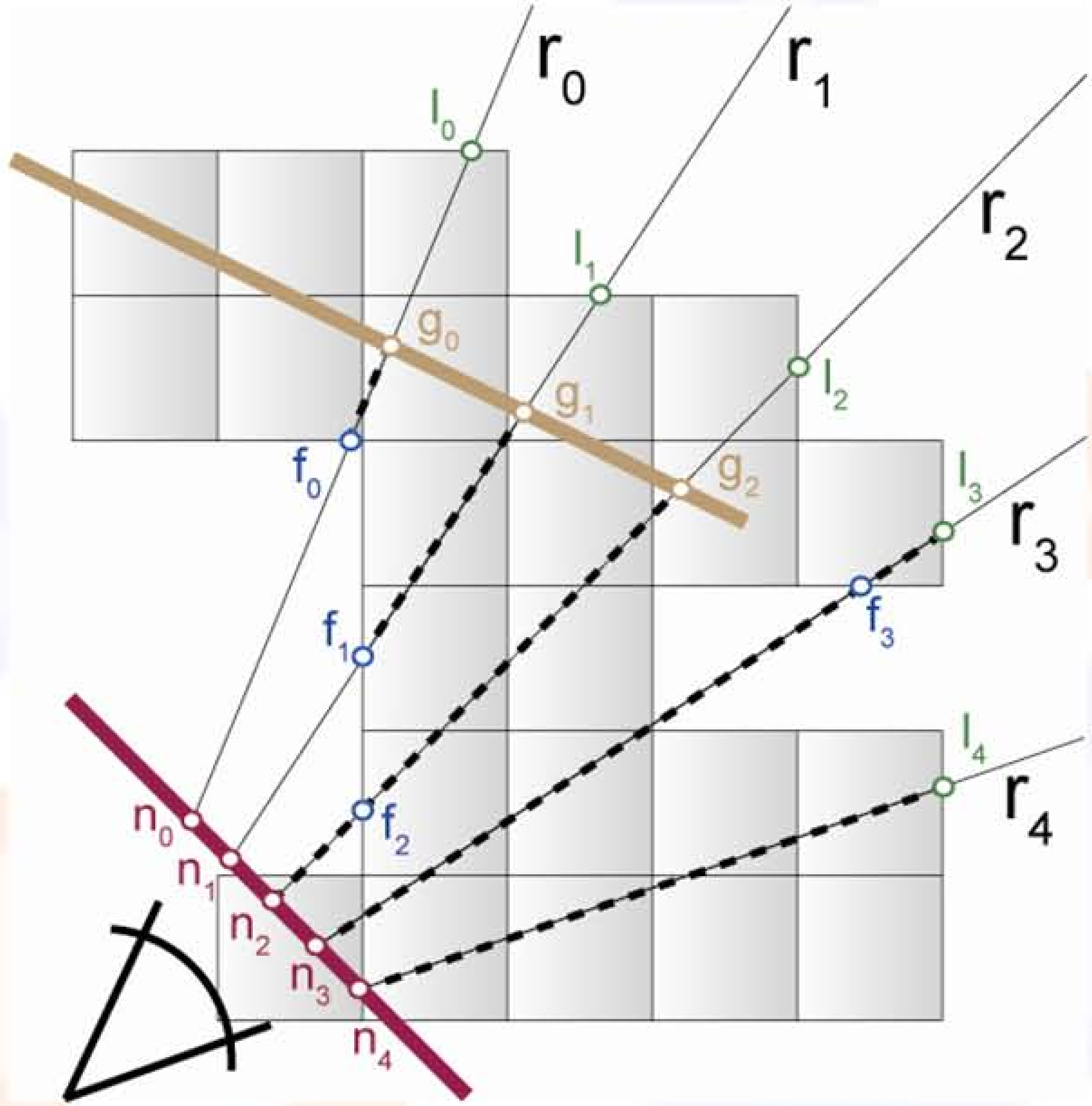
- Build on image-based ray setup
- Allow viewpoint inside the volume

- Intersect polygonal geometry



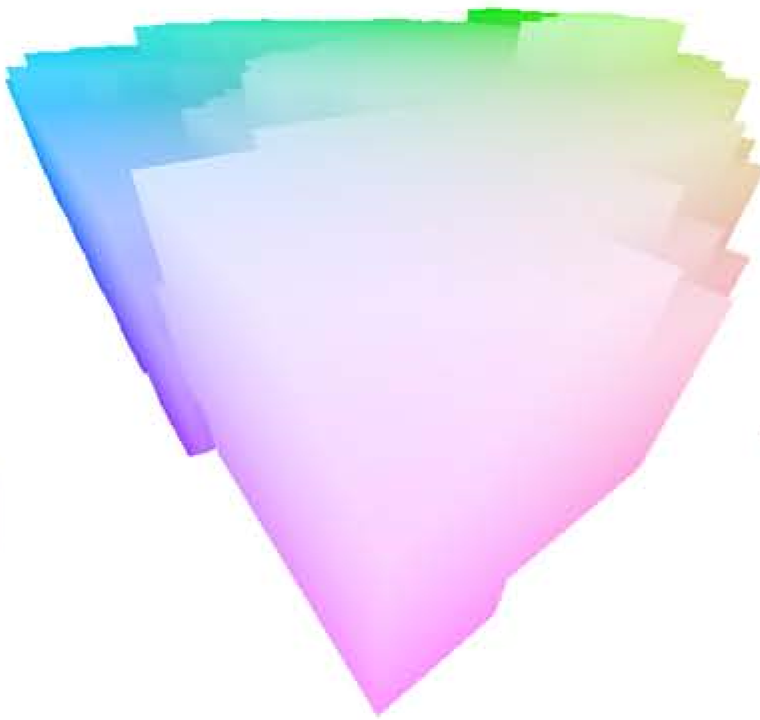
Enhancements (2)

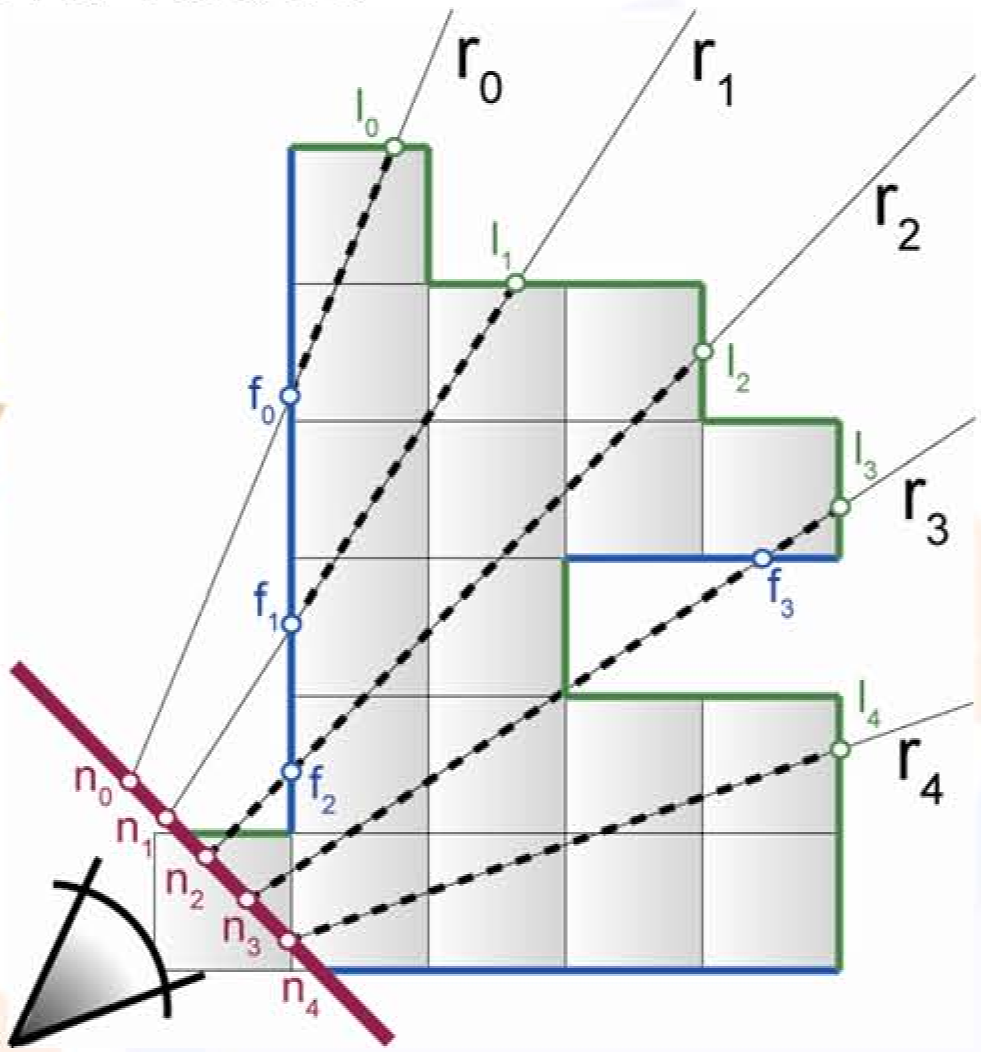
1. Starting position computation
   - ⇨ Ray start position image
2. Ray length computation
   - ⇨ Ray length image
3. Render polygonal geometry
   - ⇨ Modified ray length image
4. Raycasting
   - ⇨ Compositing buffer
5. Blending
   - ⇨ Final image



Moving Into The Volume (1)

- Near clipping plane clips into front faces



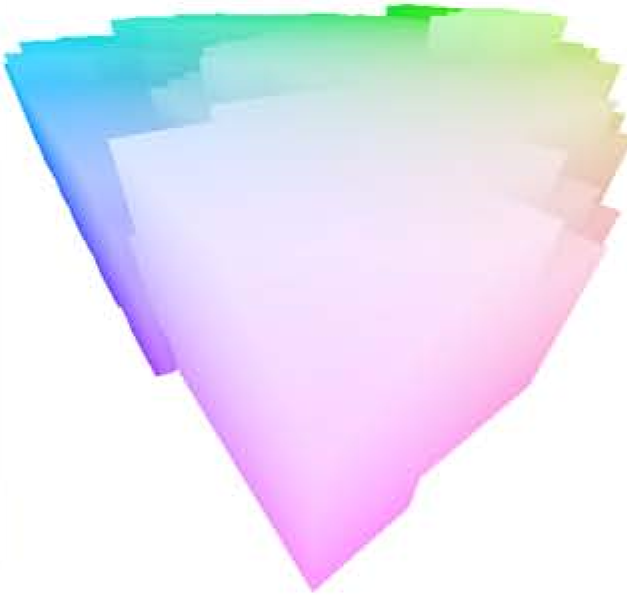


- Fill in holes with near clipping plane
- Can use depth buffer [Scharsach et al., 2006]

Moving Into The Volume (2)

1. Rasterize near clipping plane
   - Disable depth buffer, enable color buffer
   - Rasterize entire near clipping plane

2. Rasterize nearest back faces
   - Enable depth buffer, disable color buffer
   - Rasterize *nearest back faces* of active bricks



3. Rasterize nearest front faces
   - Enable depth buffer, enable color buffer
   - Rasterize *nearest front faces* of active bricks

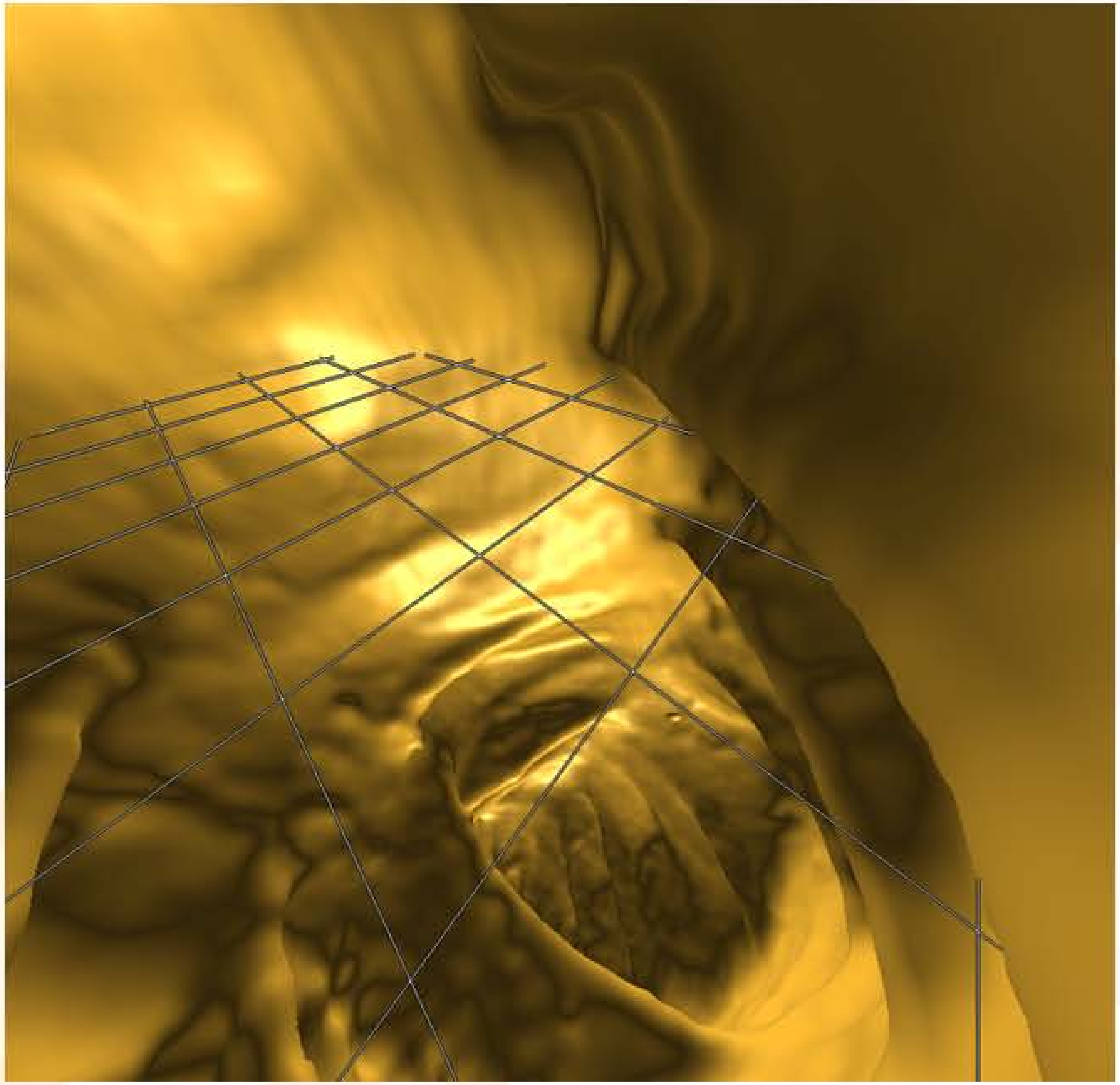
Virtual Endoscopy

- Viewpoint inside the volume with wide field of view
- E.g.: virtual colonoscopy

- Hybrid isosurface rendering / direct volume rendering
- E.g.: colon wall and structures behind

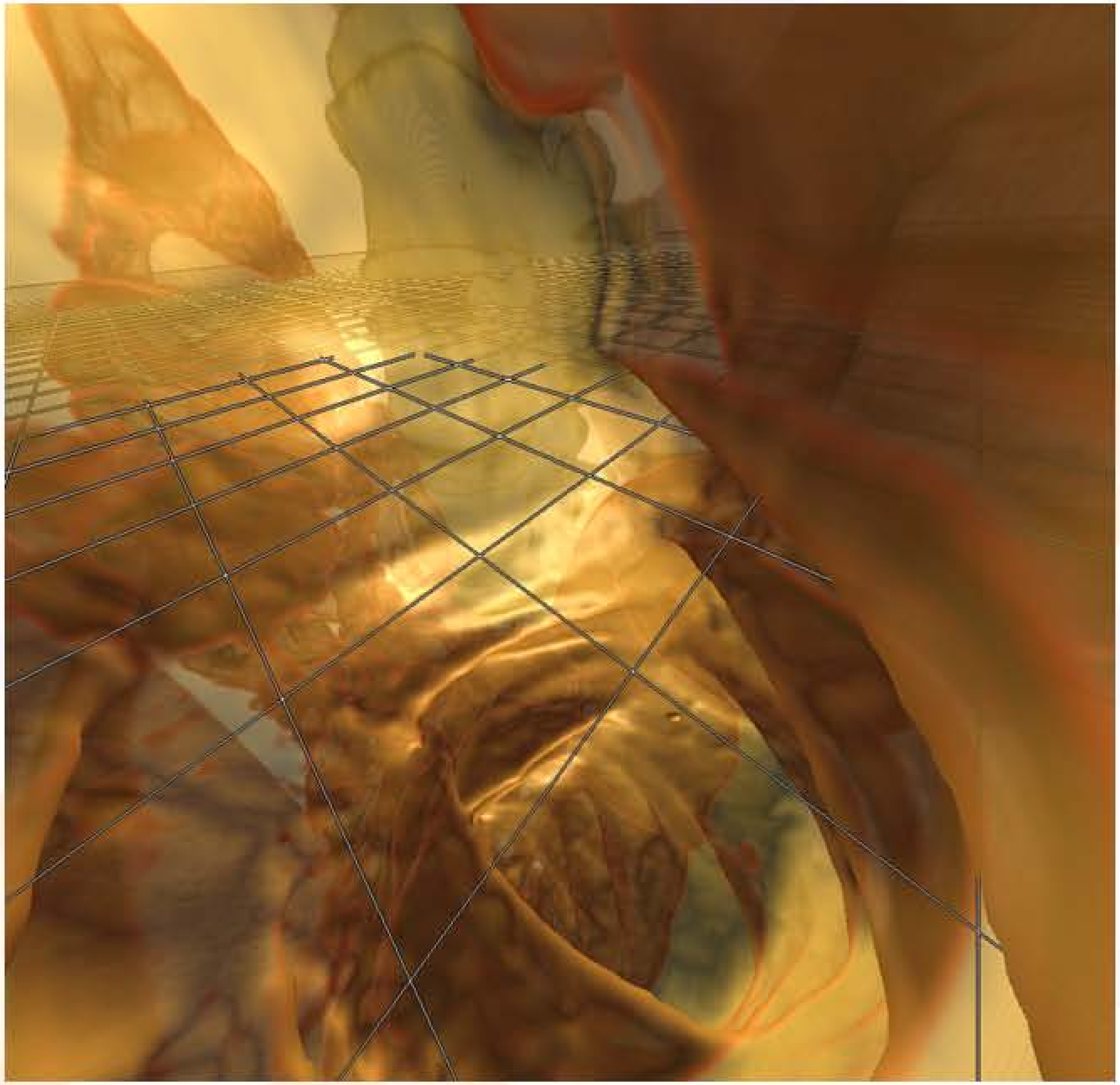
Virtual Colonoscopy

- First find isosurface; then continue with DVR



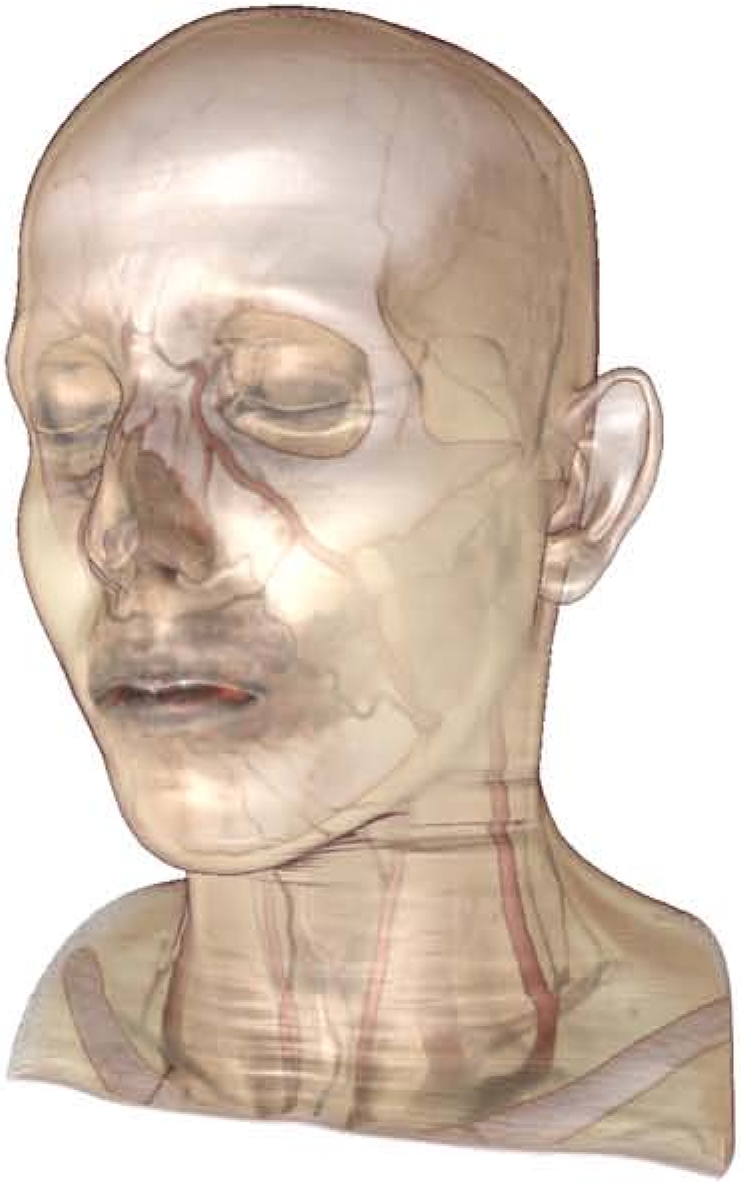
Virtual Colonoscopy

- First find isosurface; then continue with DVR



Hybrid Ray-Casting (1)

- Isosurface rendering
  - Find isosurface first
  - Semi-transparent shading provides surface information



- Additional unshaded DVR
  - Render volume behind the surface with unshaded DVR
  - Isosurface is starting position
  - Start with (1.0-iso_opacity)

Hybrid Ray-Casting (2)

- Hiding sampling artifacts (similar to interleaved sampling, [Heidrich and Keller, 2001])

Conclusions

- GPU ray-casting is an attractive alternative
- Very flexible and easy to implement
- Fragment shader conditionals are very powerful; performance pitfalls very likely to go away
- Mixing image-order and object-order well suited to GPUs (vertex and fragment processing!)
- Deferred shading allows complex filtering and shading at high frame rates

Thank You!

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