What is direct volume rendering?

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Any rendering process which maps from volume data to an image ***without*** introducing binary distinctions / intermediate geometry, i.e., using color and opacity

What is the difference between iso-surfacing and volume rendering?

What important concepts/techniques are needed for volume rendering?

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- Interpolation
- **Color/opacity transfer functions**
- **Color/opacity composition**
- *Gradient (optional for transfer function design and enhancing rendering quality)*

What is the process of Raycasting?

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For each pixel ...
- cast ray
- sampling along ray
- interpolate
- get colors/opacity
- composite

What color and opacity compositions strategies are there?

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Maximum intensity projection (MIP)
Local maximum intensity projection (LMIP)
Average
**\alpha-composition**

How does \alpha-composition work?

How does \alpha-composition work?

Recursively compose/blend colors and opacities in order (either back-to-front or front-to-back) in a linear fashion.

$$c = a_f * c_f + (1 - a_f) * a_b * c_b$$
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What physical model is \alpha-composition built on?

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What physical model is \alpha-composition built on?

Emission-absorption

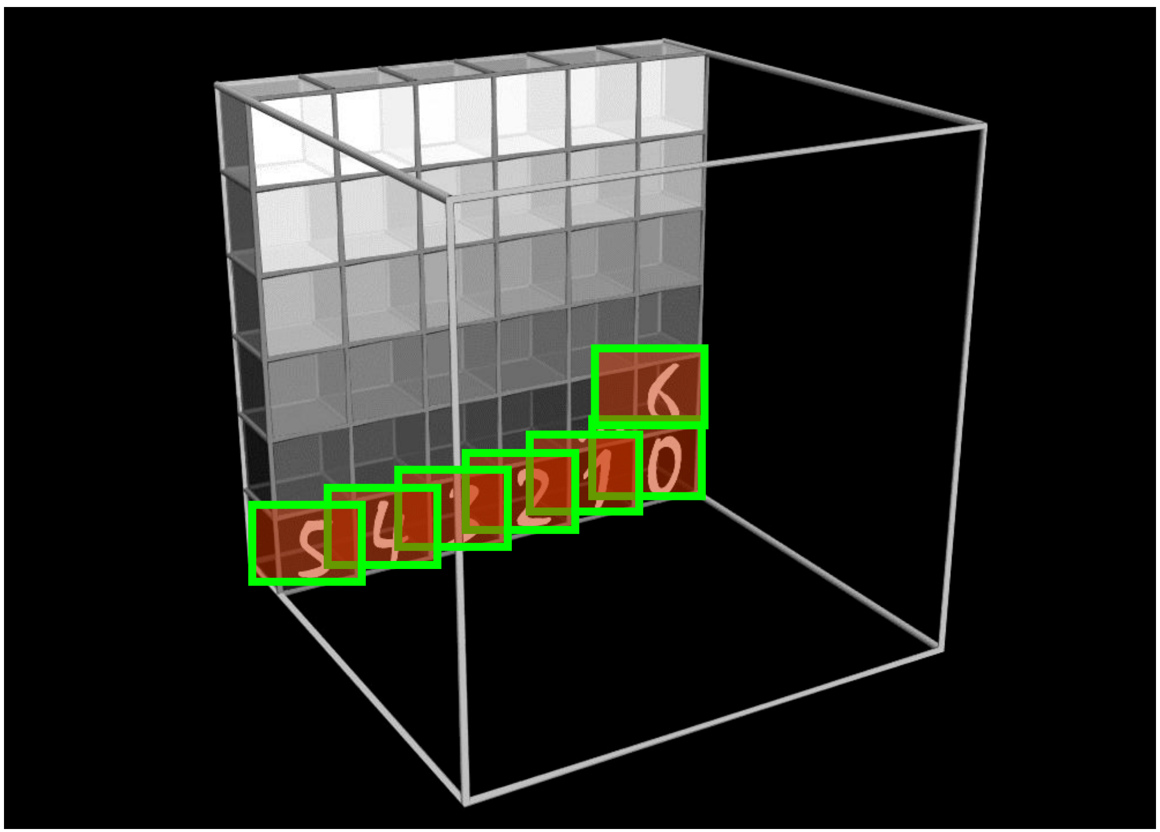
# Direct Volume Rendering: Splatting & Texture-based

# Computational Strategies

- How can the basic ingredients be combined:
  - Image Order
    - Ray casting (many options)
  - Object Order (in world coordinate)
    - splatting, texture-mapping
  - Combination (neither)
    - Shear-warp, Fourier

# Object Order

- Render image **one voxel at a time**




for **<u>each voxel</u>** ...
- get color/opacity
- determine image contribution
- composite

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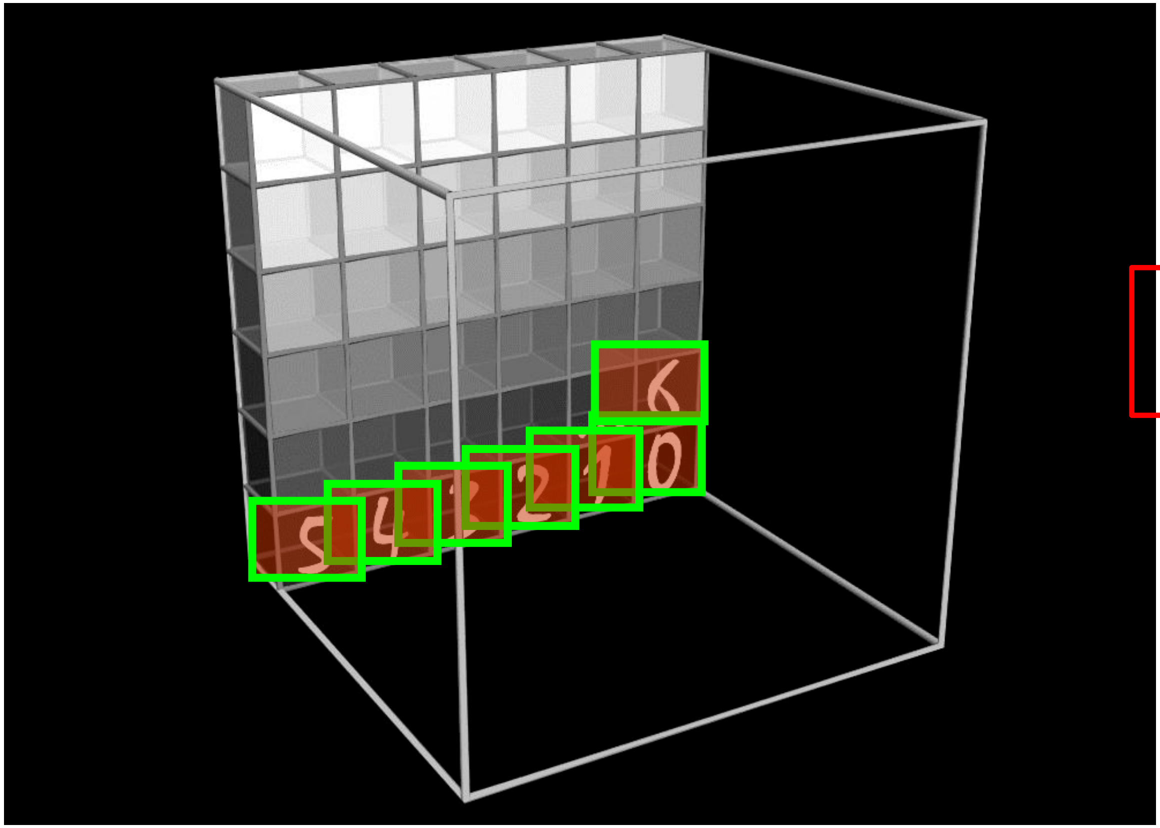


for **each voxel** ...
- get color/opacity
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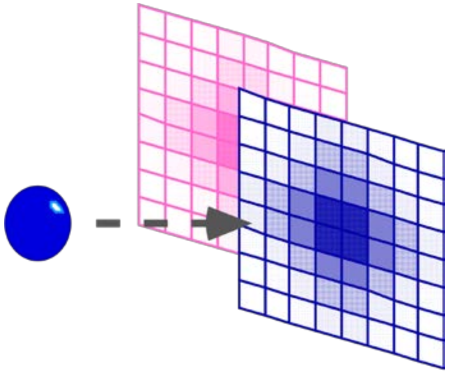
# Splatting-literature

- Lee Westover - Vis 1989; SIGGRAPH 1990
- Object order method
- Front-To-Back or Back-To-Front
- **Main idea:**

  **Throw voxels to the image**

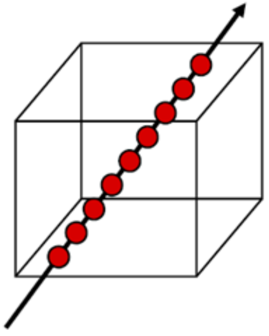


- Many improvements since then!
  - Crawfis'93: textured splats
  - Swan'96, Mueller'97: anti-aliasing
  - Mueller'98: image-aligned sheet-based splatting
  - Mueller'99: post-classified splatting
  - Huang'00: new splat primitive: FastSplats

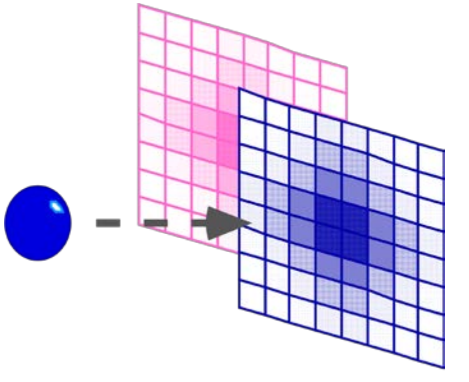
# Splatting

Instead of asking which data samples contribute to **a** pixel value, ask, ***to which pixel values does a data sample contribute***?

- **Ray casting:** pixel value computed from multiple data samples
- **Splatting:** multiple pixel values (partially) computed from a single data sample



Raycasting



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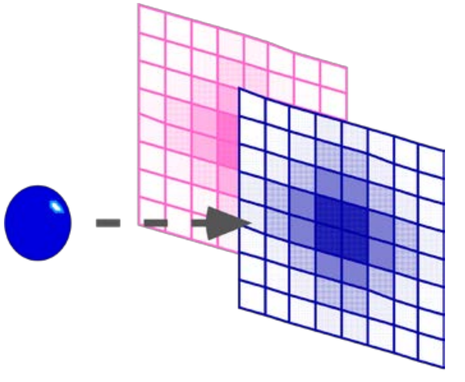
**Idea:** contribute every voxel to the image

- projection from voxel: splat
- composite in image space



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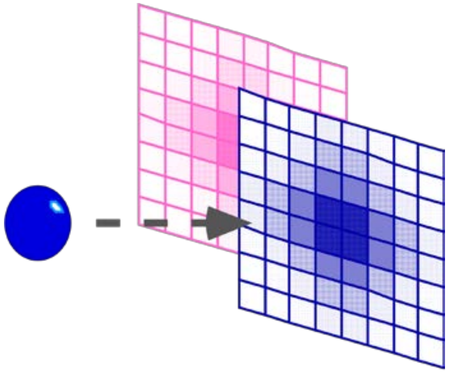


**Props**

- high-quality, why?

**Cons**

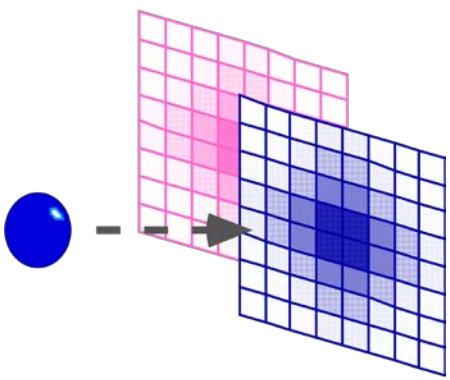
- relatively costly ->relatively slow, why?

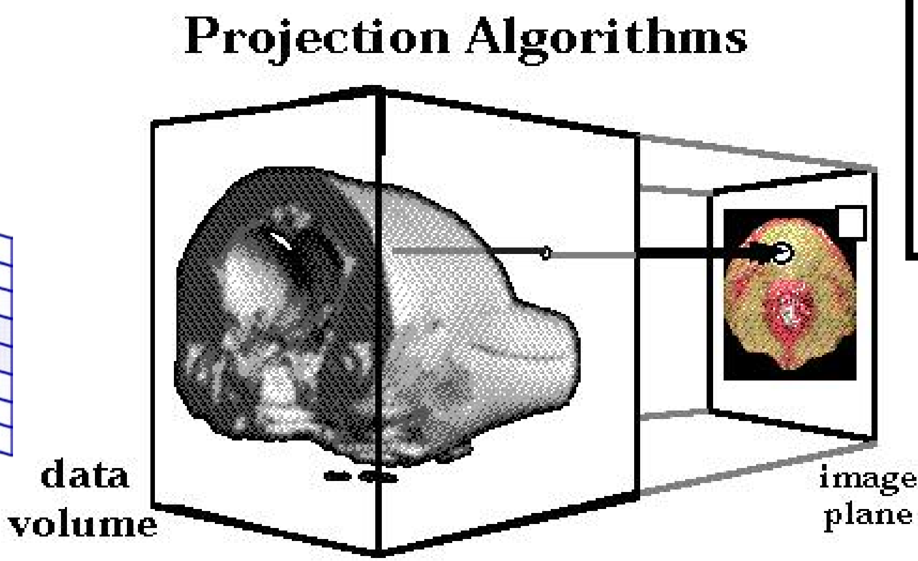
# Splatting - Footprint

- Typically, process from closest voxel to furthest voxel (**front-to-back**)

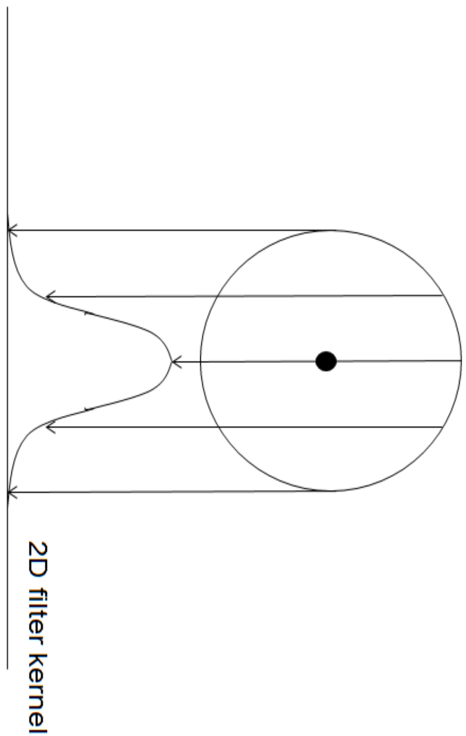
- **The important step is splat**. A biggest problem: determination of voxel's projected area called its **footprint**

for **each voxel** ...
- get color/opacity
- determine image contribution
- composite





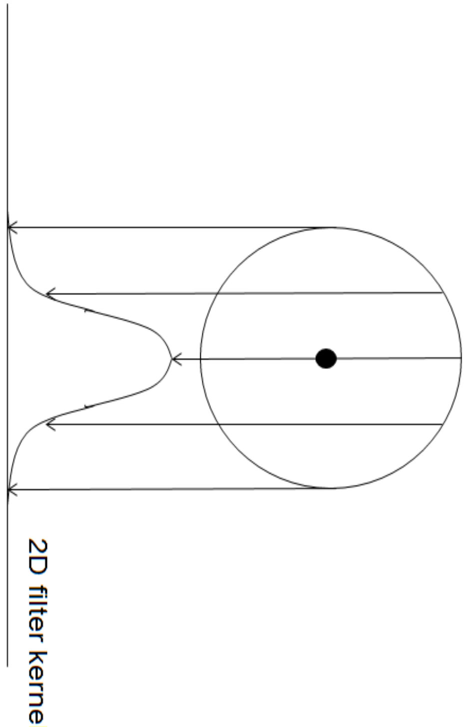
# Splatting - Footprint




Draw each voxel as **a cloud of points** (footprint) that spreads the voxel contribution across multiple pixels

A natural way to compute the footprint is to add **a filter kernel**, which determines how much contribution this voxel makes to those pixels nearby the **projected pixel** corresponding to the center of the voxel.

# Splatting - Footprint

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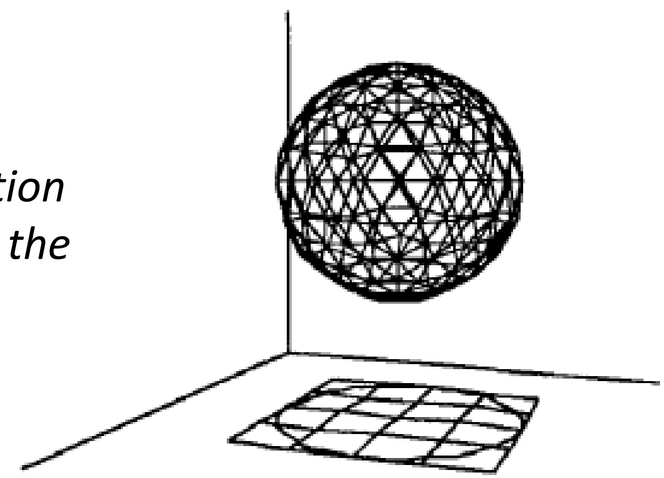
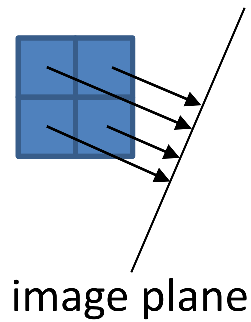
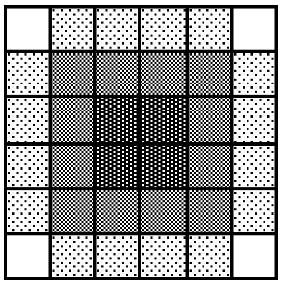


*Different pixels receive different amount of contribution computed as the multiplication of some weight with the original color or other value.*

# Splatting - Footprint

- Footprint geometry
  - **Orthographic projection**: footprint is independent of the viewpoint
  - Pre integration of footprint (like a template)



# Splatting - Footprint

- Footprint geometry
  - **Orthographic projection**: footprint is independent of the viewpoint
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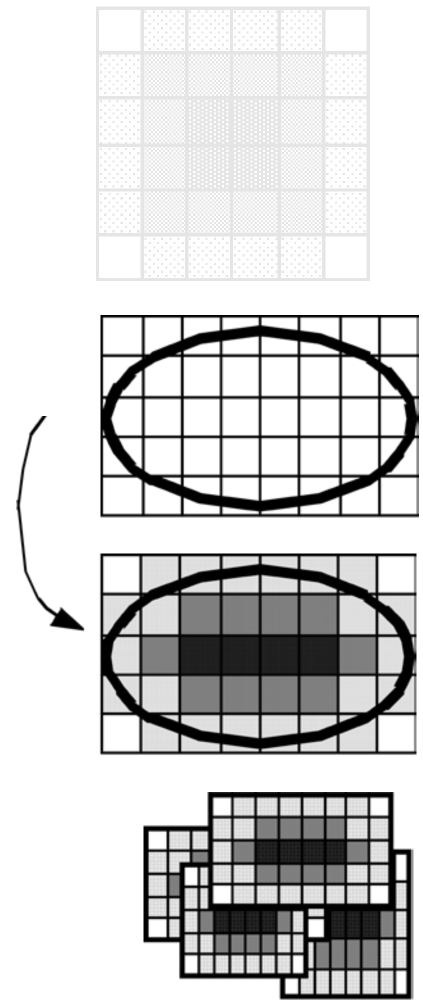
  - **Perspective projection**: footprint is elliptical
  - additional computation of the orientation of the ellipse



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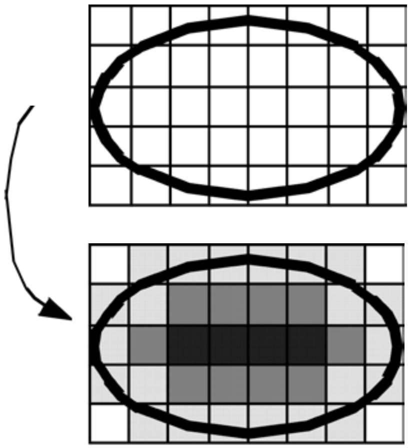
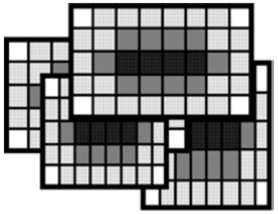


- **Importance of choosing footprint size!**
  - Larger footprint increases blurring and used for high pixel-to-voxel ratio



# Splatting - Footprint

- Volume = field of 3D interpolation kernels
  - One kernel at each grid voxel
- Each kernel leaves a 2D footprint on screen
  - **Voxel contribution = footprint ·(C, opacity)**
- Weighted footprints accumulate into image

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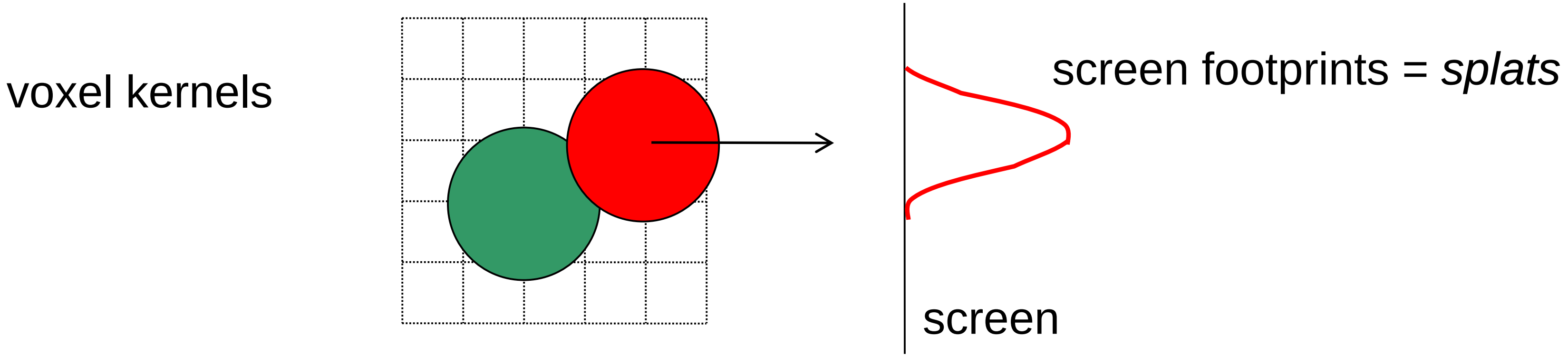

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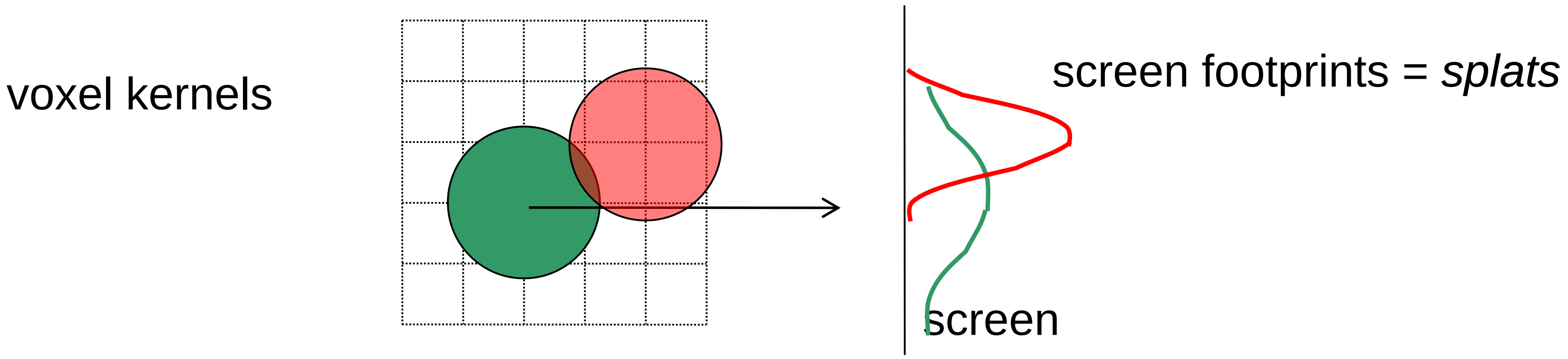

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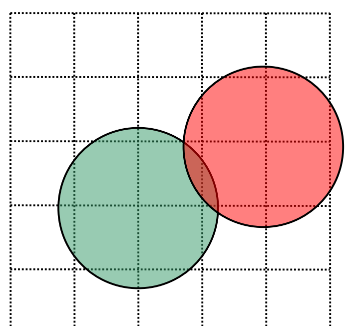
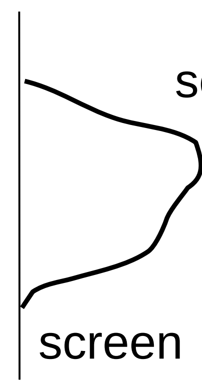
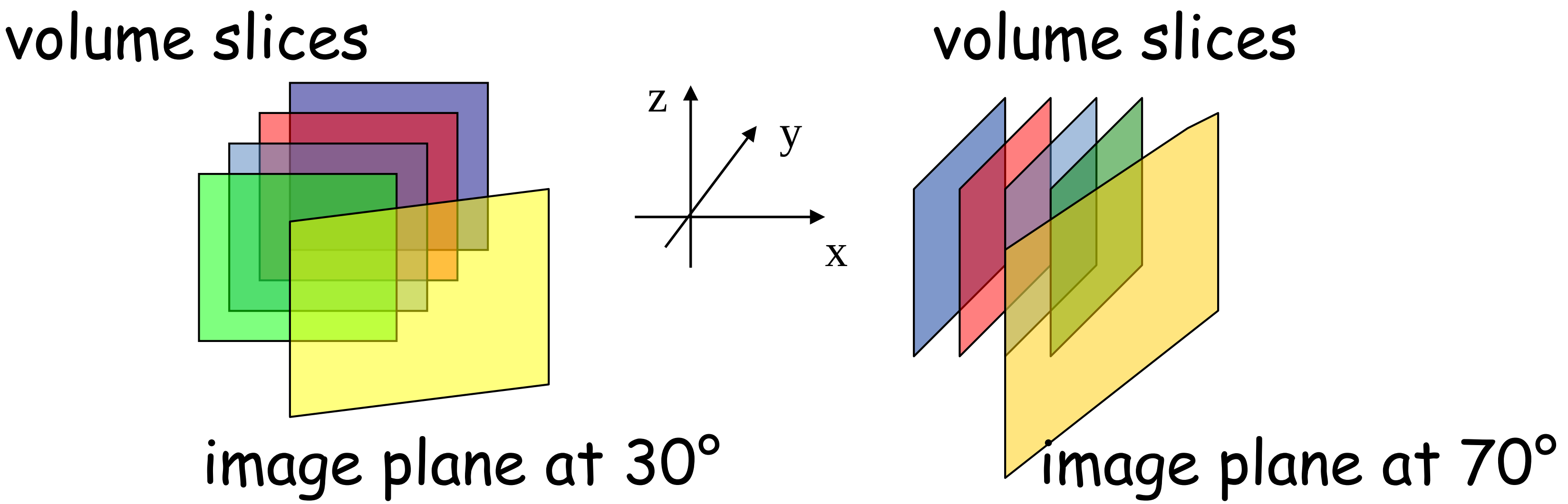
voxel kernels





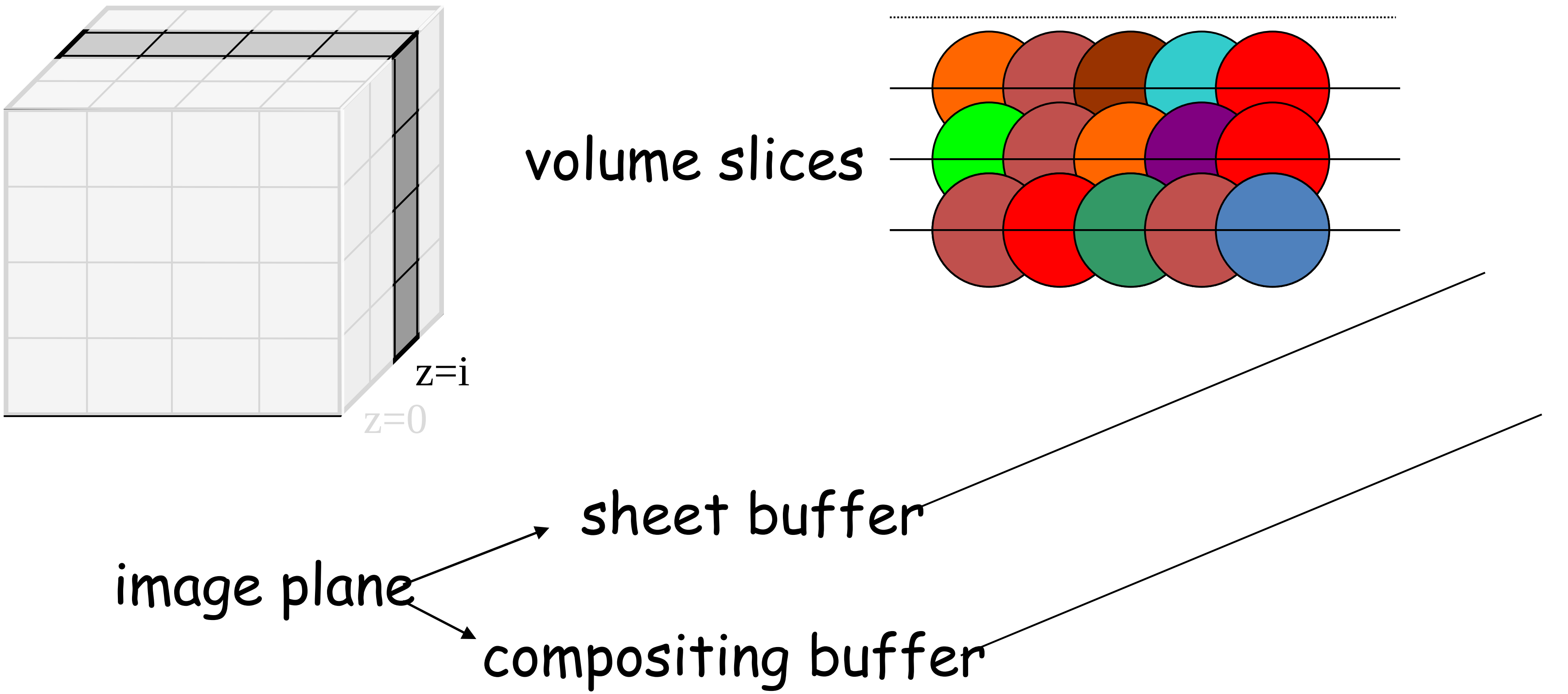
# Splatting - Compositing

- Voxel kernels are added within sheets
- Sheets are composited front-to-back
- **Sheets = volume slices most parallel to the image plane (i.e., base plane!)**



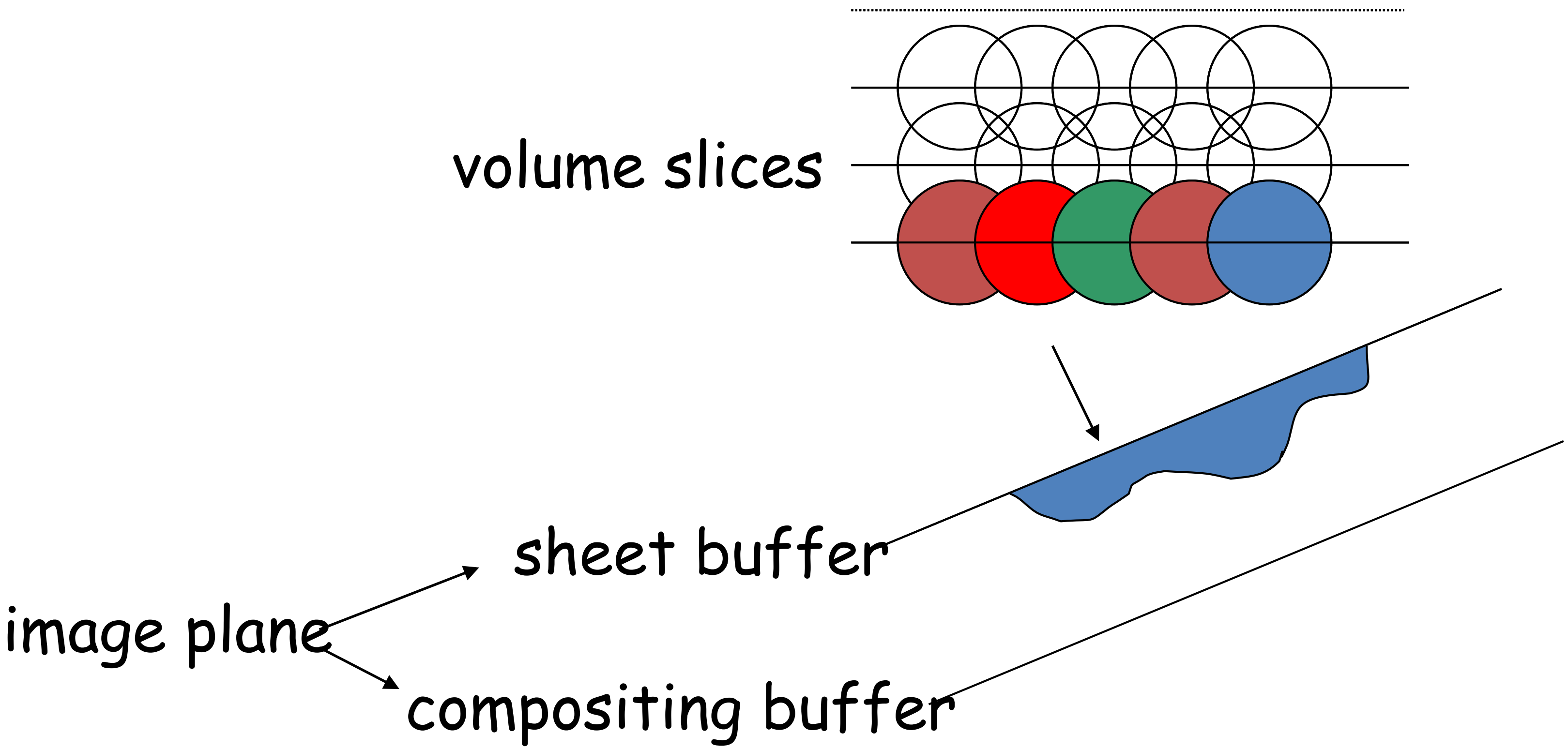
# Splatting - Implementation

- Volume



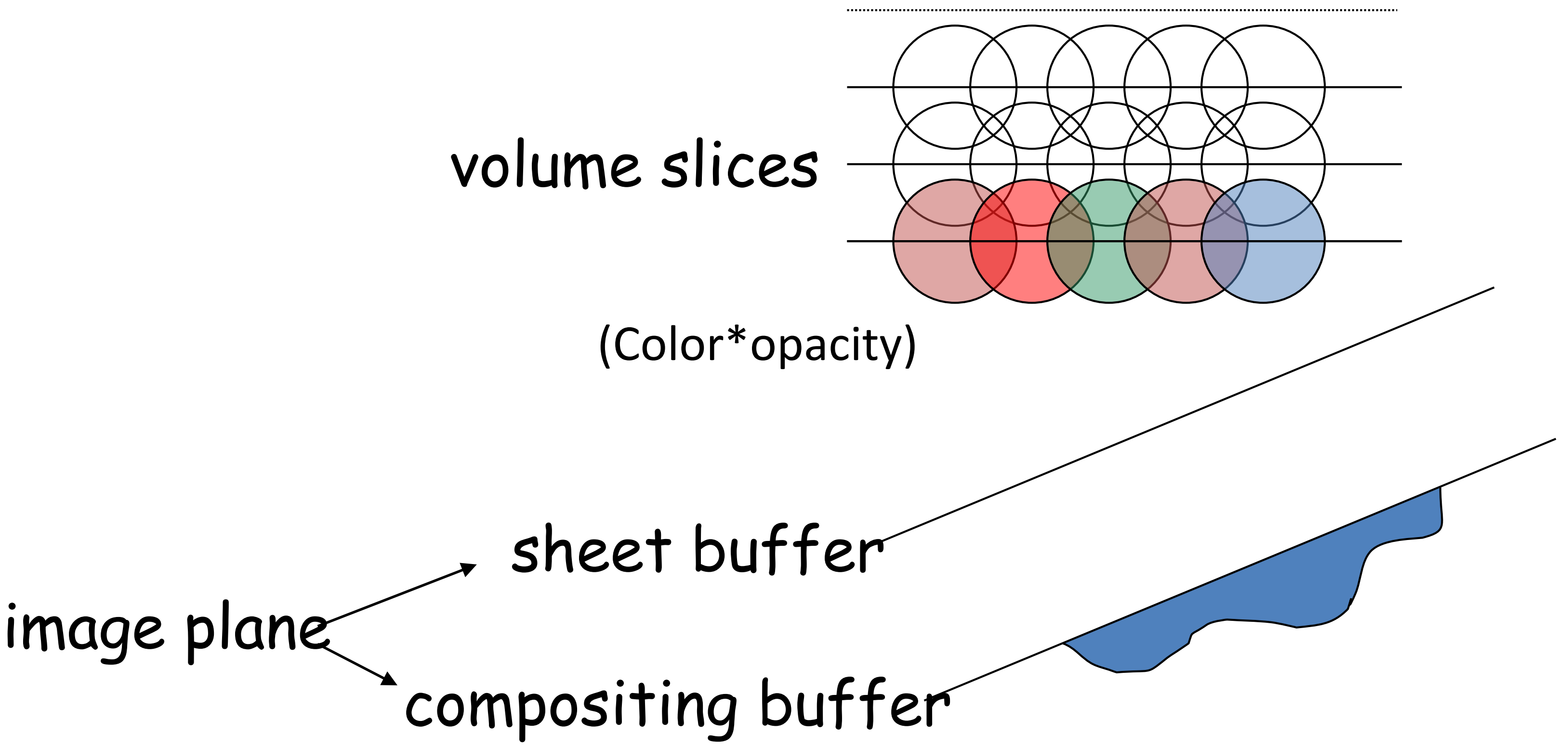
# Splatting - Implementation

- Add voxel kernels within first sheet



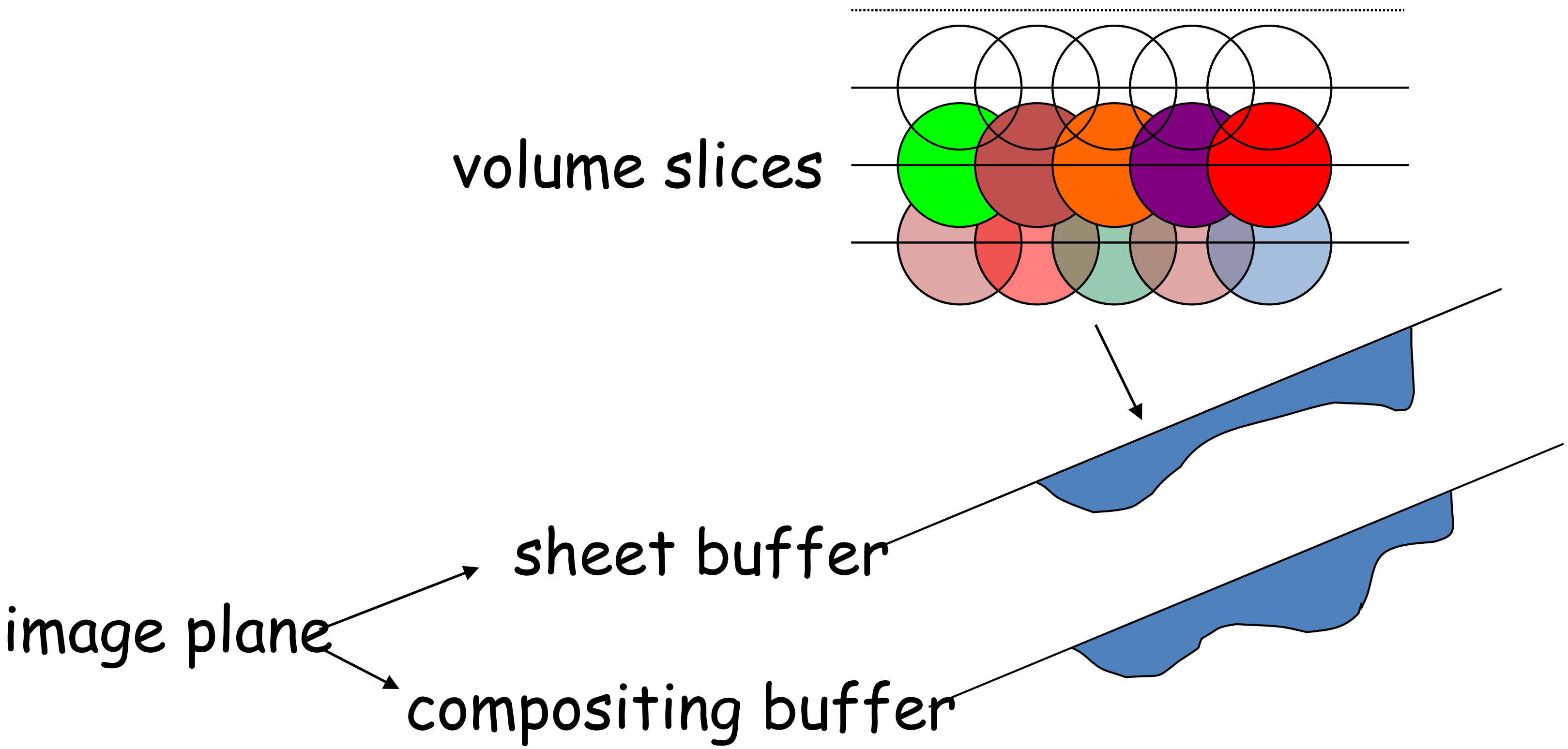
# Splatting - Implementation

- Transfer to compositing buffer



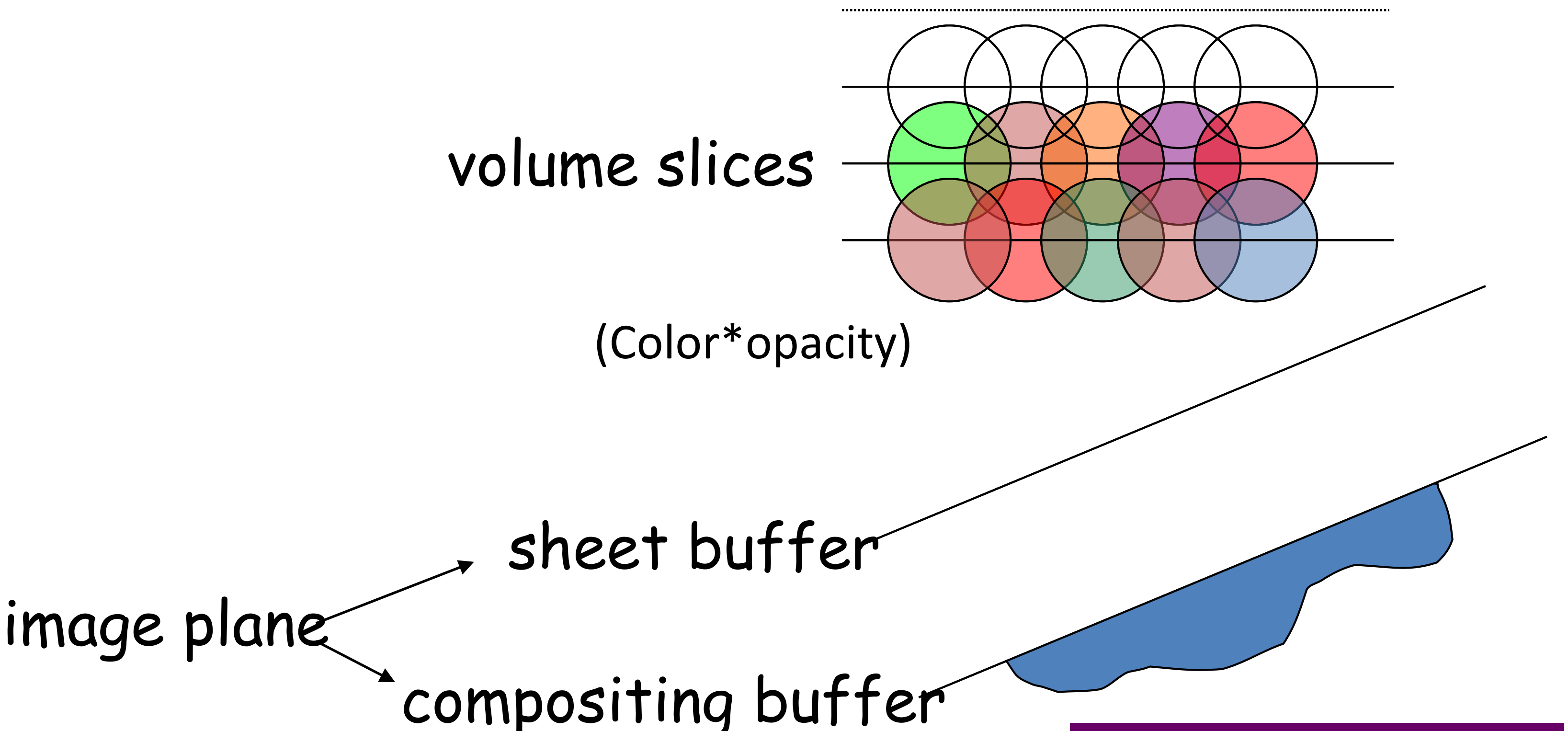
# Splatting - Implementation

- Add voxel kernels within second sheet



# Splatting - Implementation

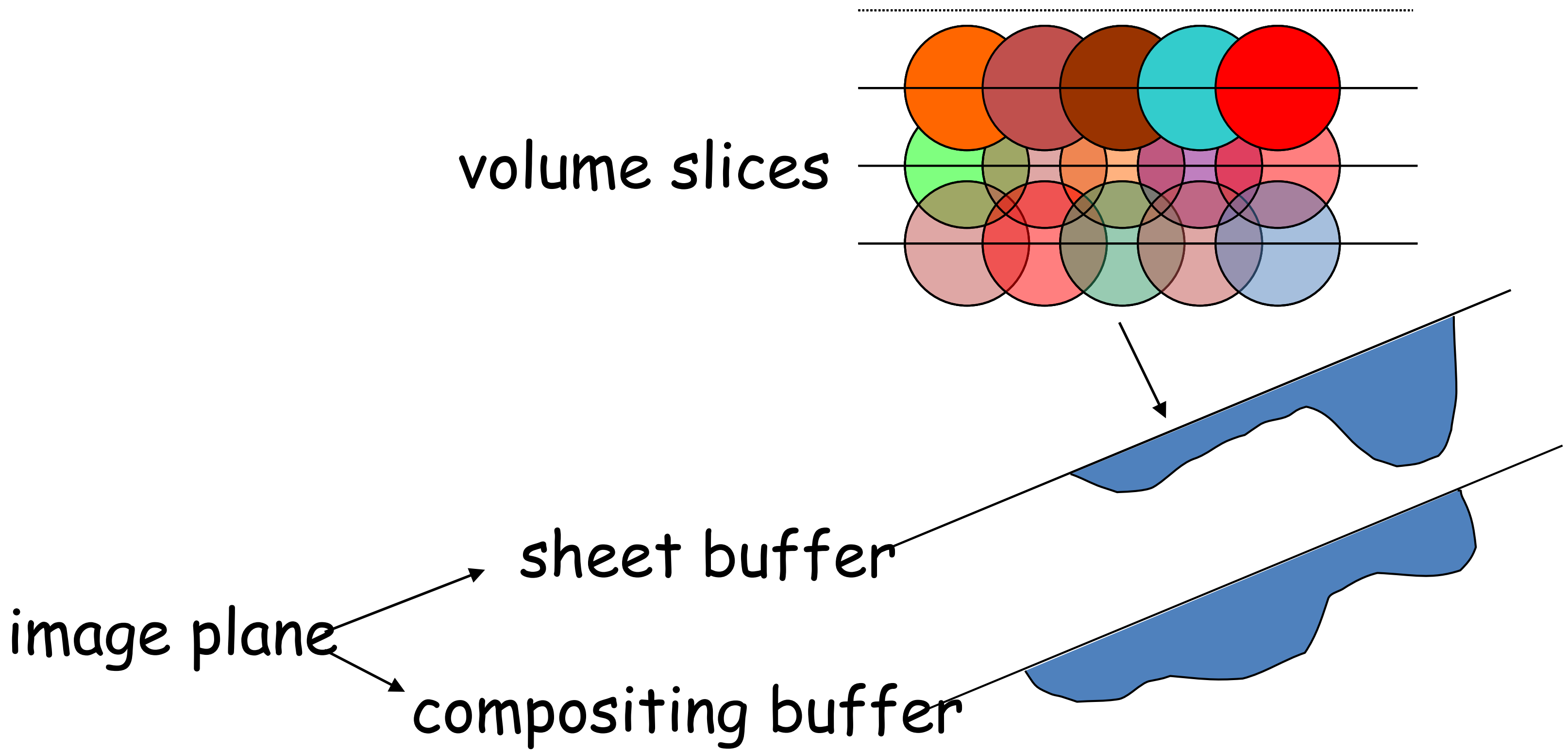
- Composite sheet with compositing buffer




$$c = a_f * c_f + (1 - a_f) * a_b * c_b$$
$$a = a_f + (1 - a_f) * a_b$$

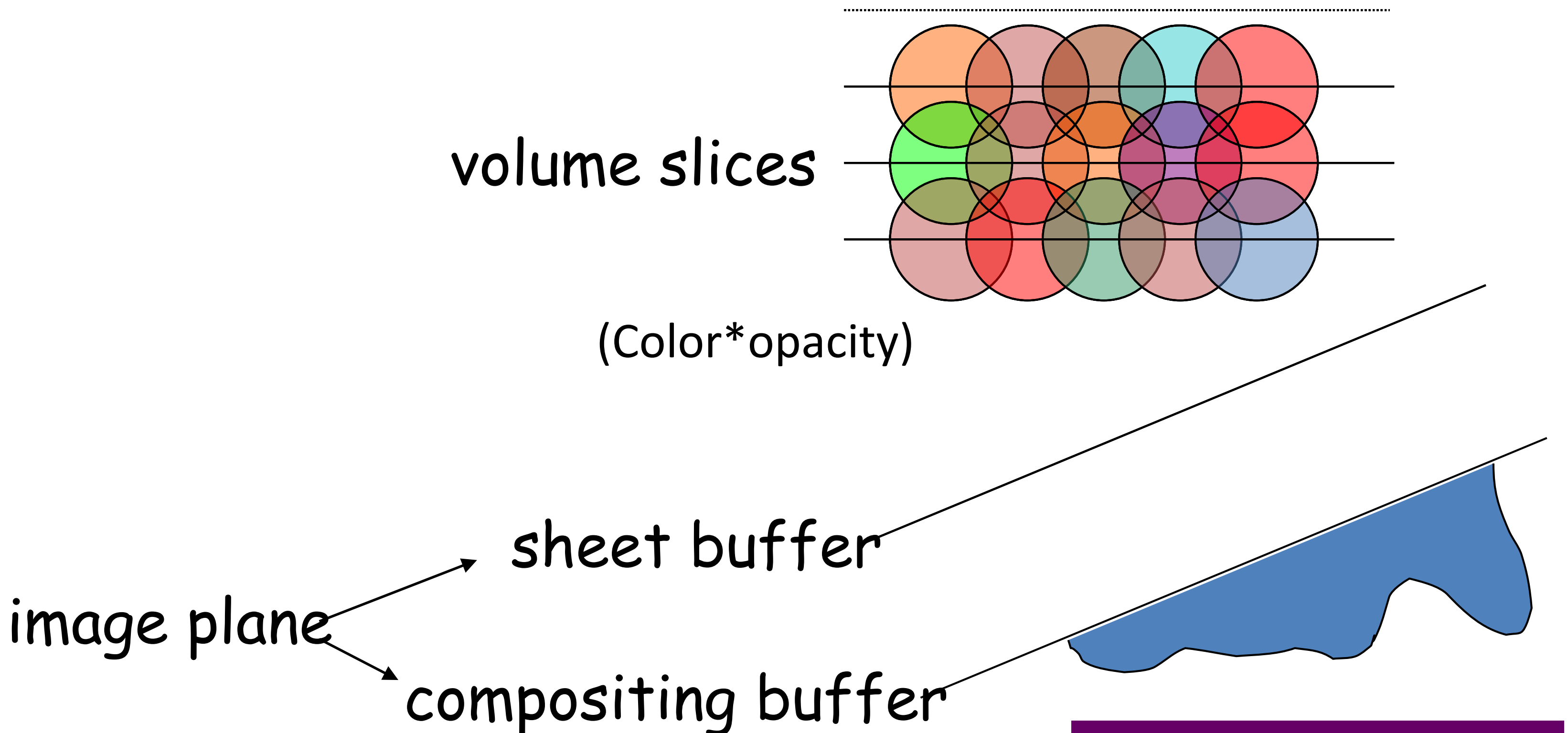
# Splatting - Implementation

- Add voxel kernels within third sheet



# Splatting - Implementation

- Composite sheet with compositing buffer




$$c = a_f * c_f + (1 - a_f) * a_b * c_b$$
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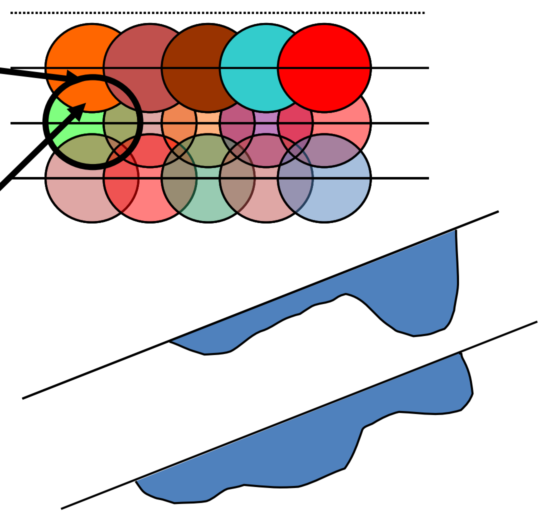
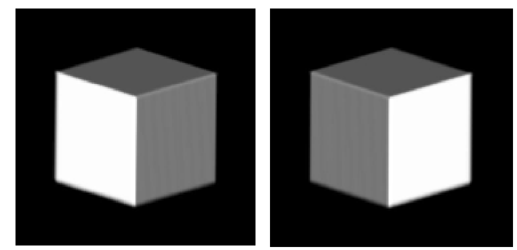
# Problems Early Implementation – Axis Aligned Splatting

- Inaccurate compositing, result in color bleeding and popping artifacts

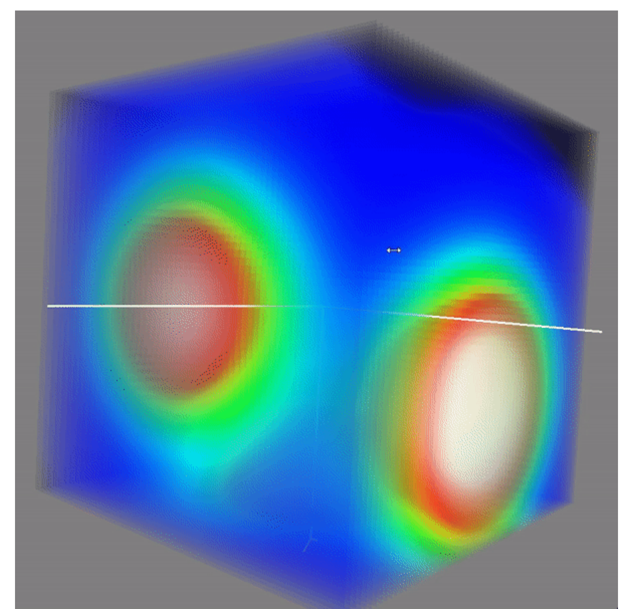
Part of this voxel



gets composited **before** part of this voxel

44.9°  45.1°

Problem:
"popping" of brightness when the image plane becomes more parallel to a different volume face



# Image-Aligned Sheet-Buffer

- Slicing slab cuts kernels into sections
- Kernel sections are added into sheet-buffer
- Sheet-buffers are composited

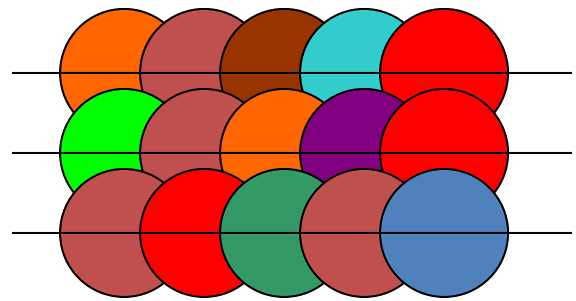
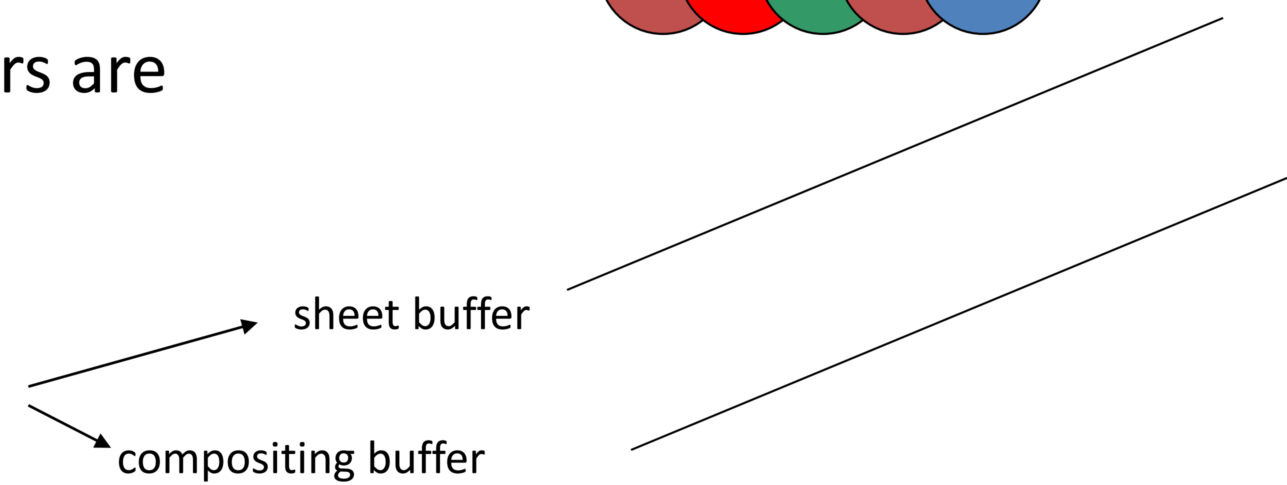


image plane



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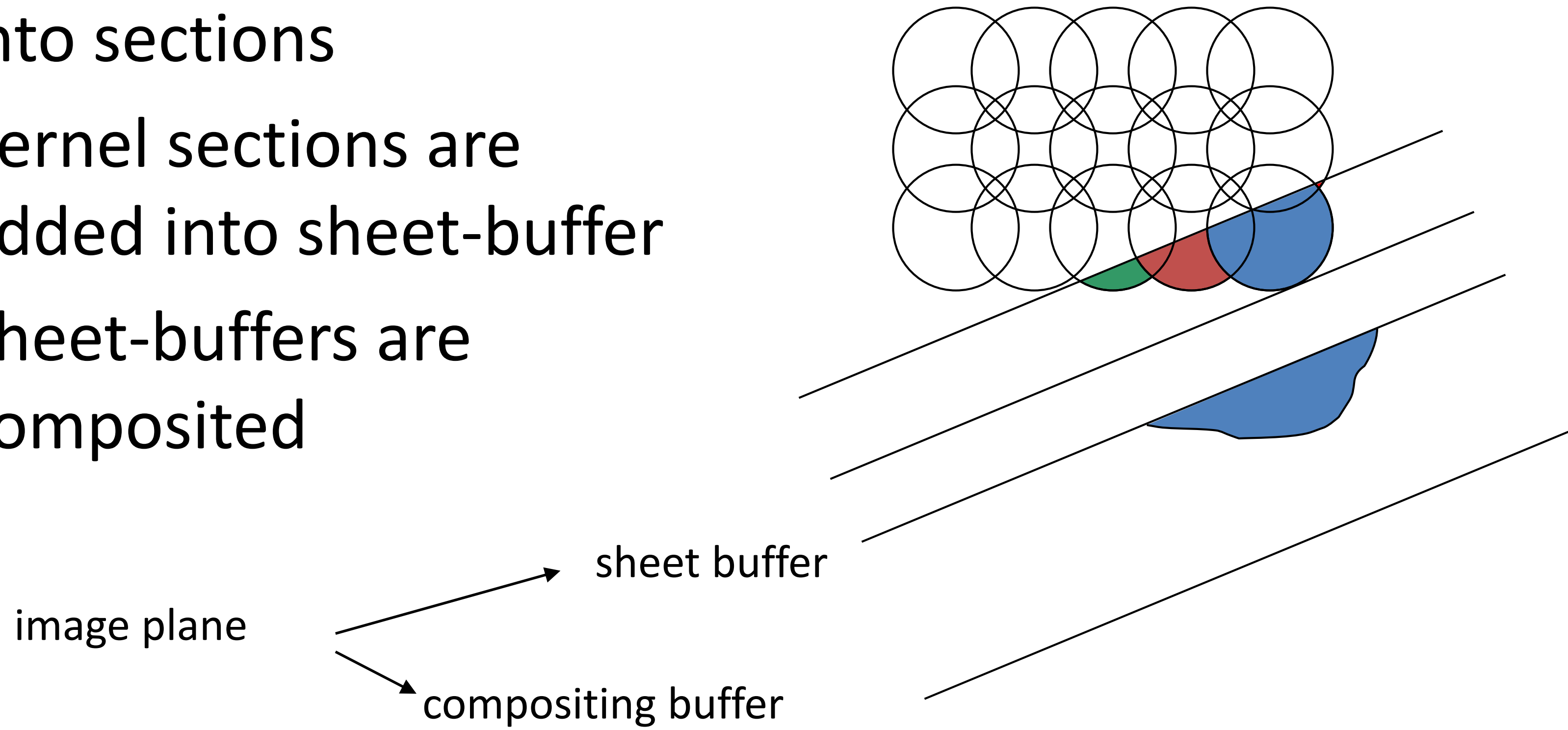

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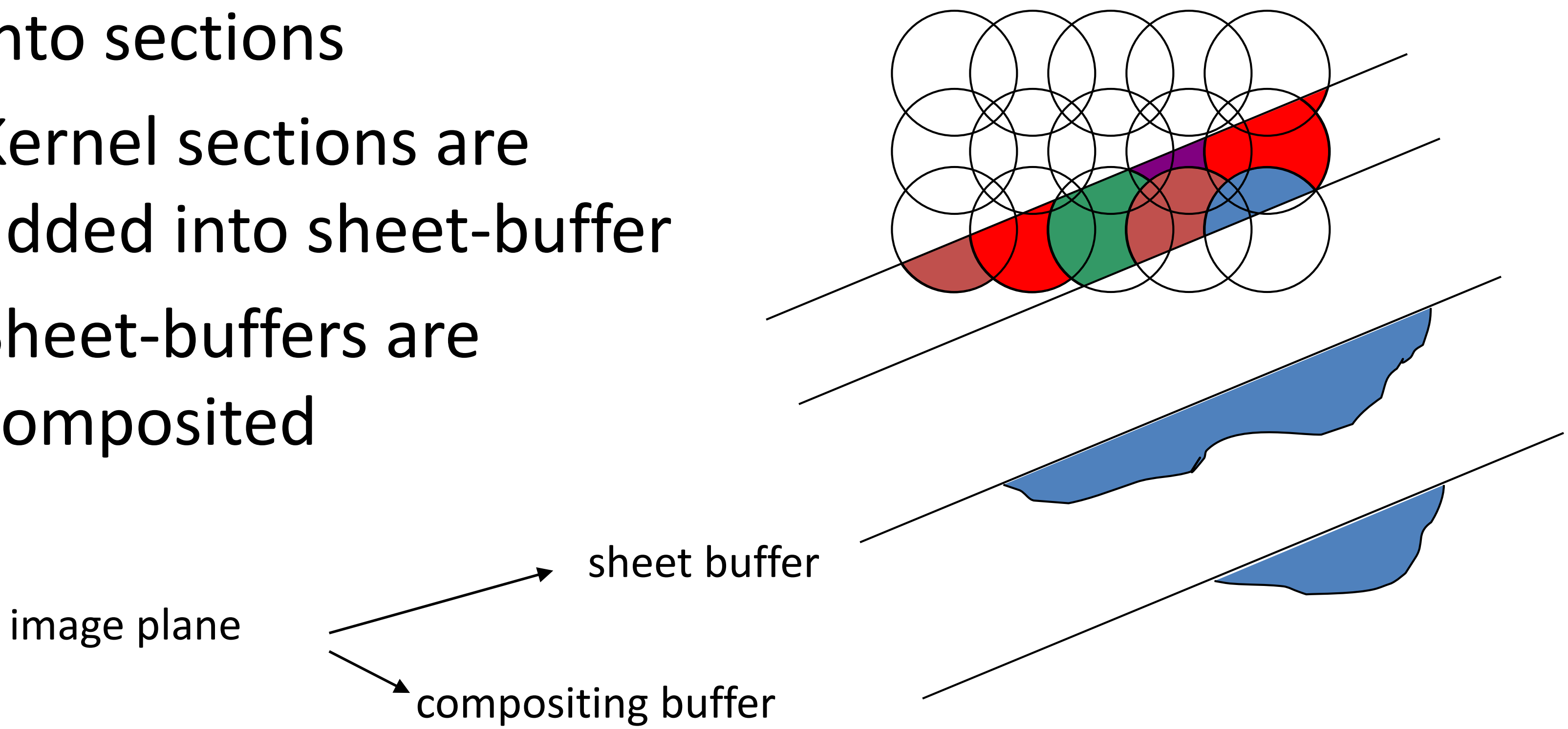

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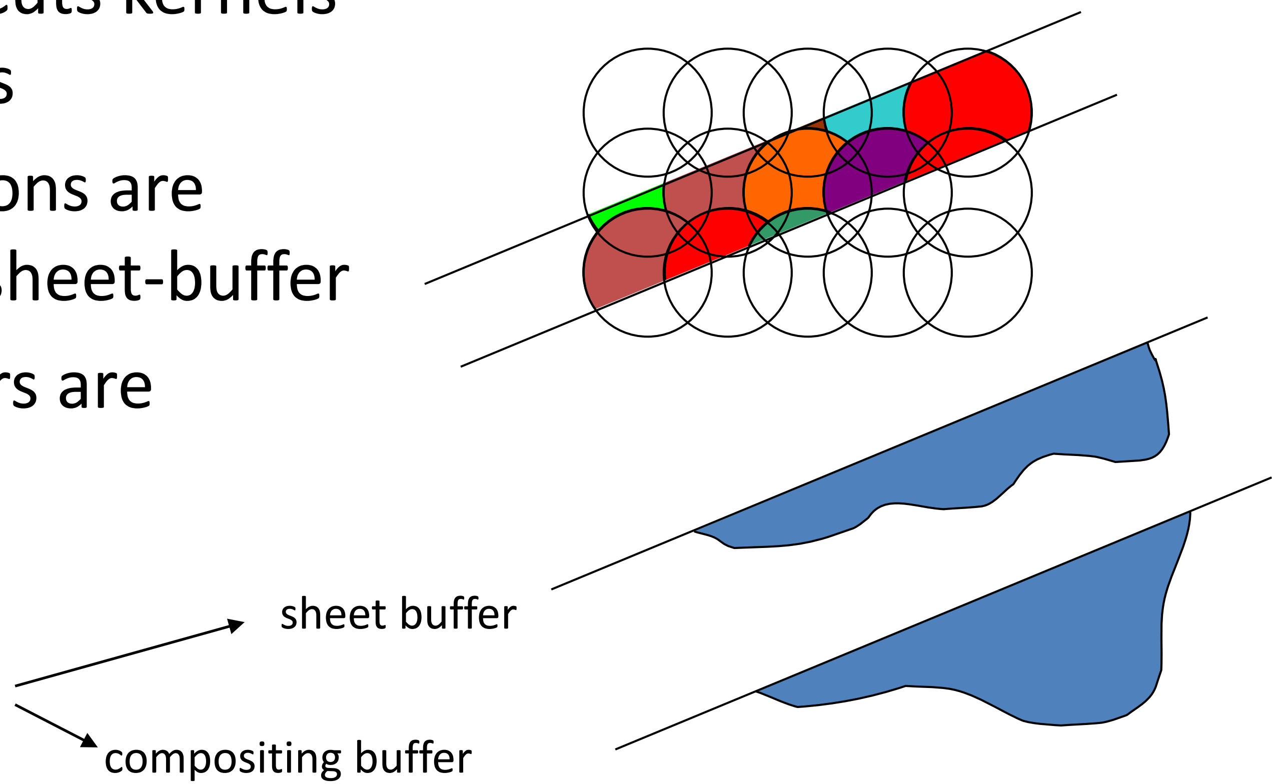

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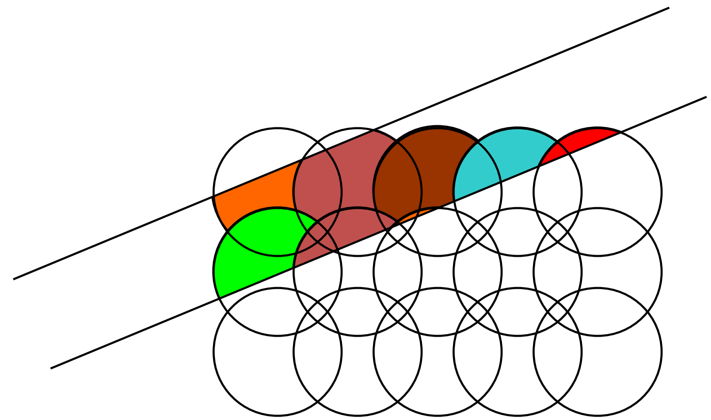
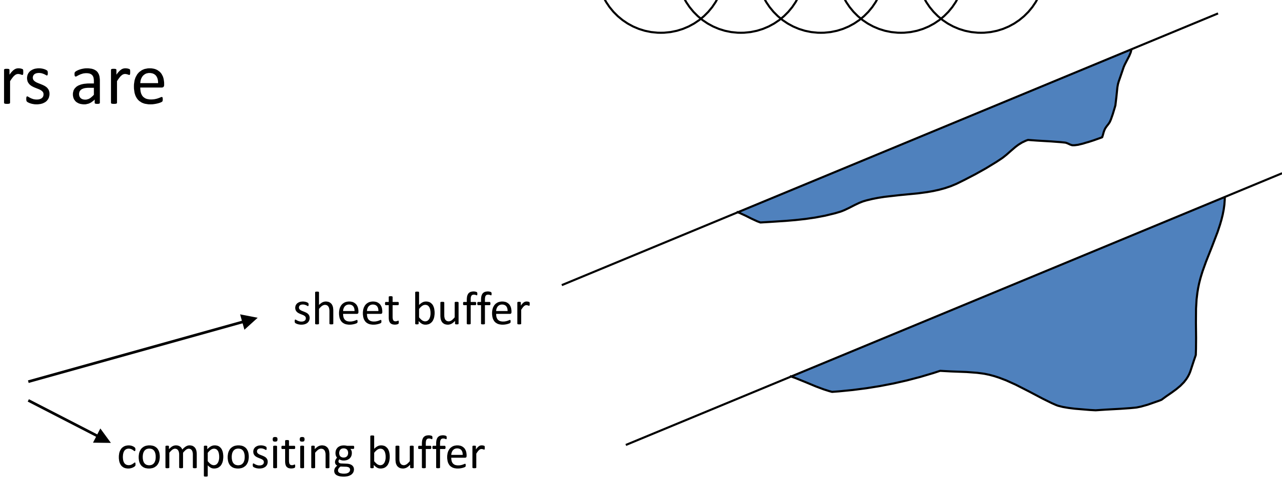


image plane



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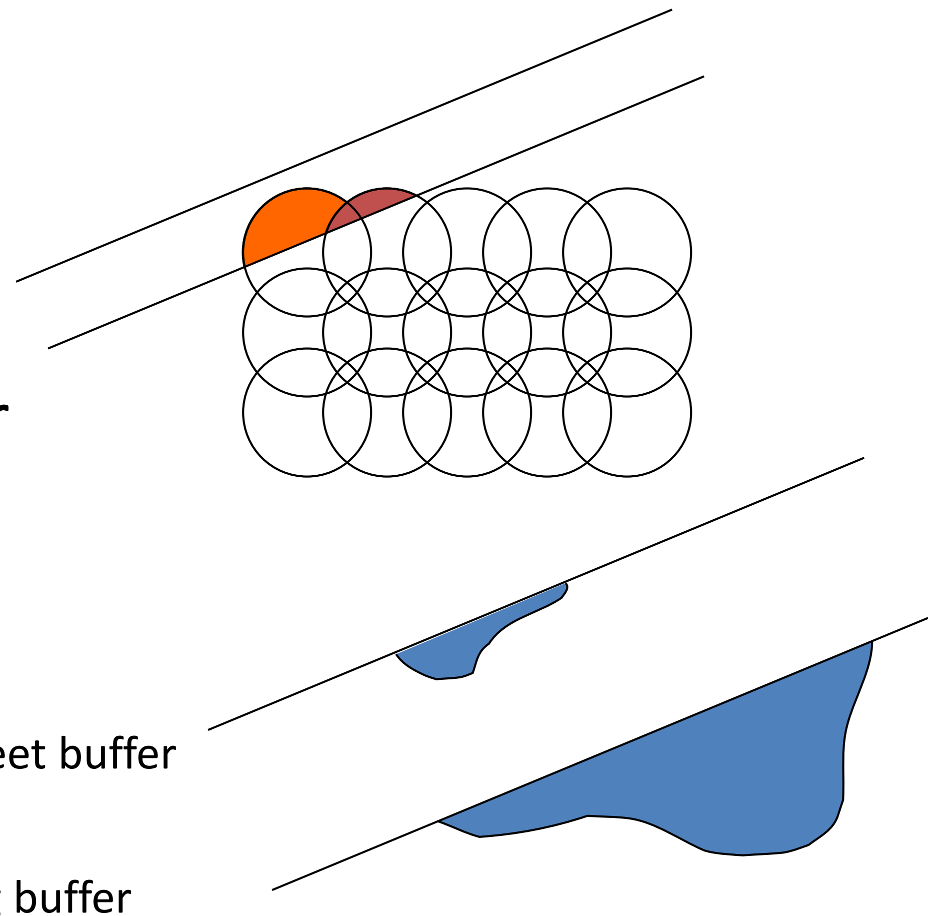

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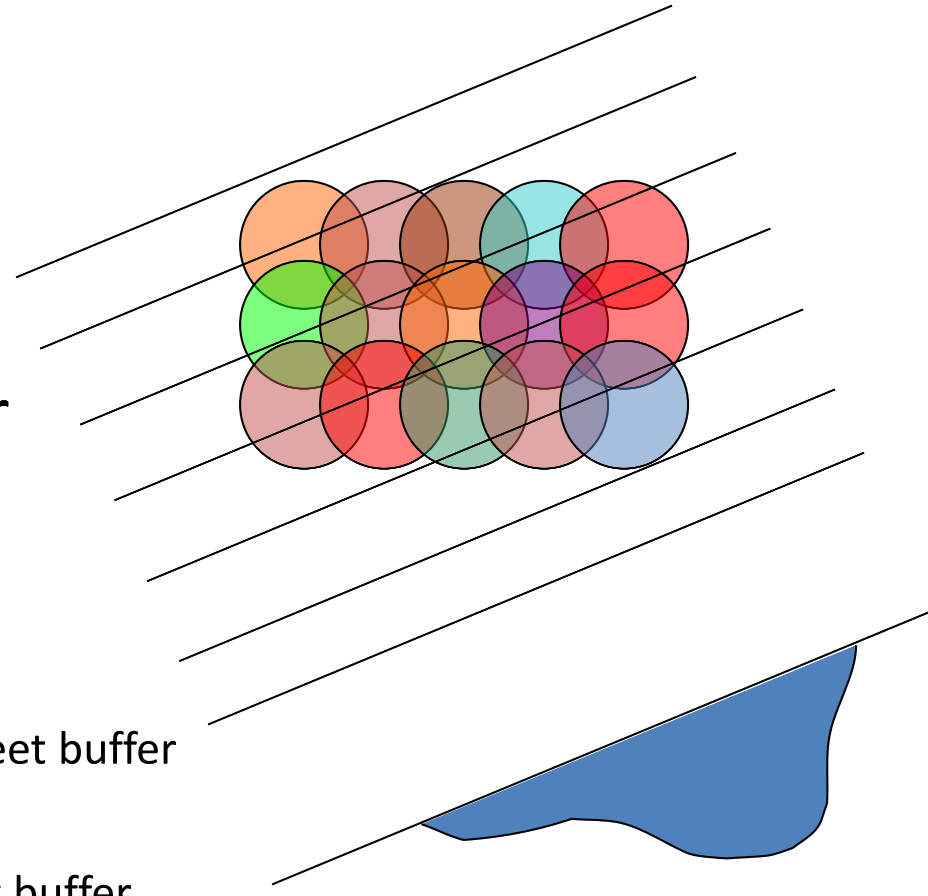
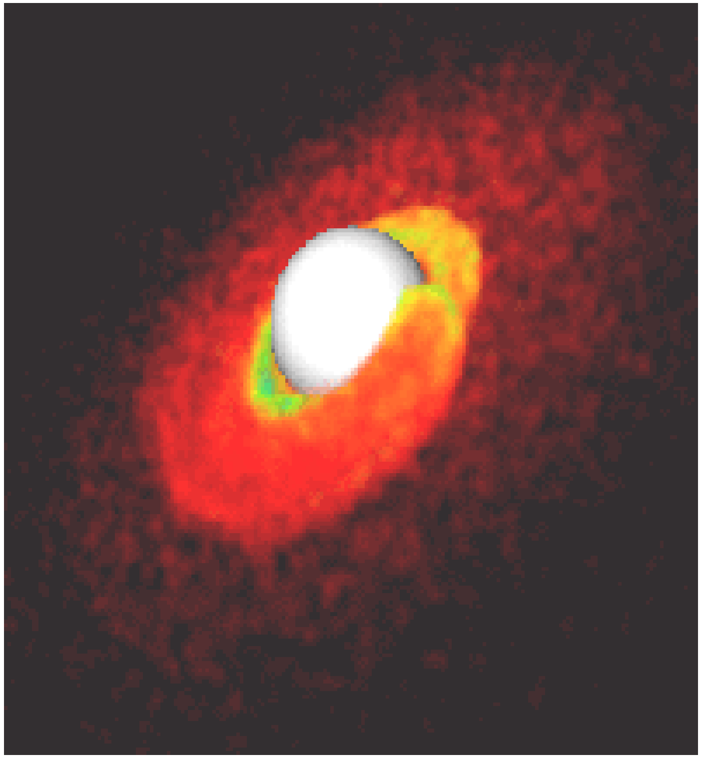
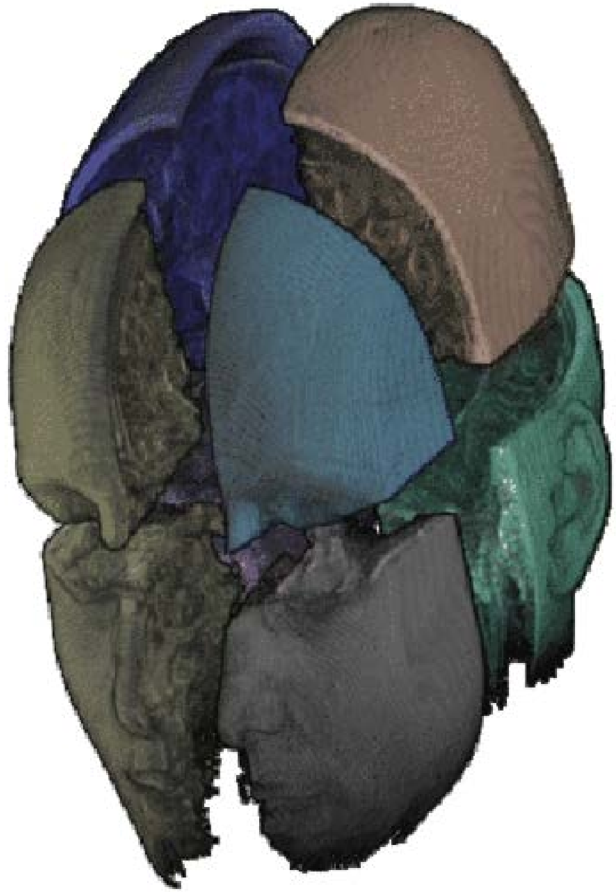


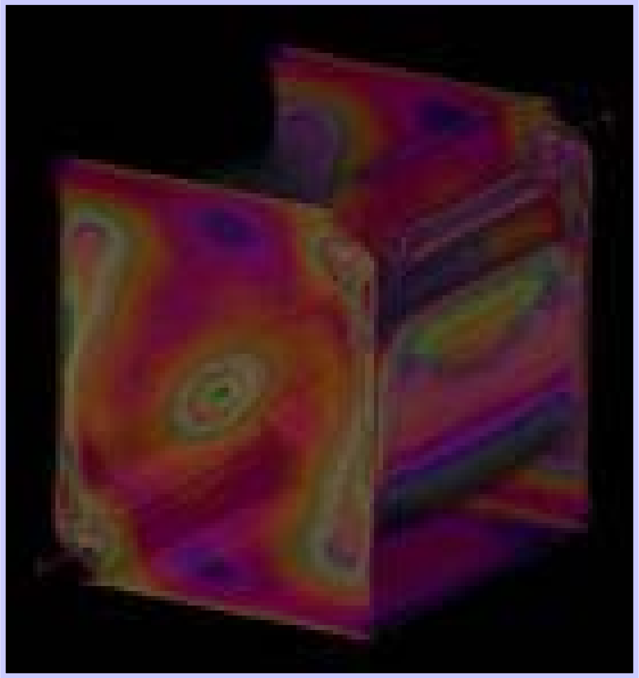
# Splatting

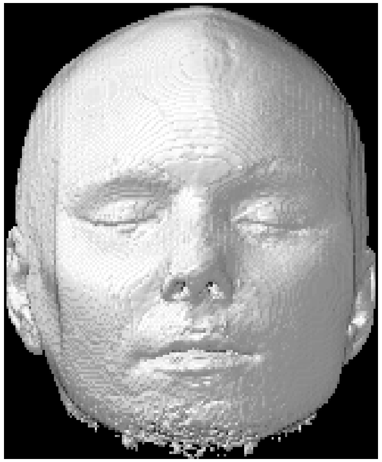
- **Simple extension to volume data without grids**
  - Scattered data with kernels
  - Example: SPH (smooth particle hydrodynamics)
  - **Needs sorting** of sample points (e.g., front to back)



# Splatting – Images







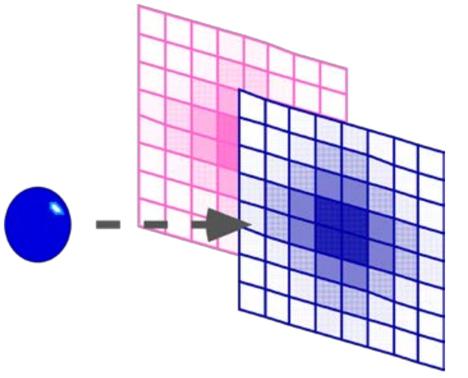
# Splatting – Conclusion

- Pros:
  - high-quality
  - works for anisotropic data (dz > dx = dy)
  - perspective projection possible
  - adaptive rendering possible
- Cons:
  - relatively slow
  - yields somewhat blurry images (in original)

# Splatting vs Ray Casting

**Splatting:**

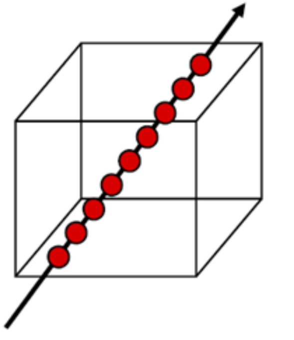
- Object-order: FOR each voxel (x,y,z) DO
  - sample volume at (x,y,z) using filter kernel
  - project reconstruction result to x-y image plane (leaving footprint)



- FOR each pixel (x,y) DO:
  - composite (color, opacity) result of all footprints

**Ray Casting:**

- Image-order: FOR each pixel (x,y) DO
  - cast ray into volume
  - FOR each sample point along ray (x,y,z)
    - Sample volume at (x,y,z) using filter kernel
    - composite (color, opacity) in image space at pixel (x,y)



**What parameters control the DVR quality for each method?**

# Direct Volume Rendering: Texture-based

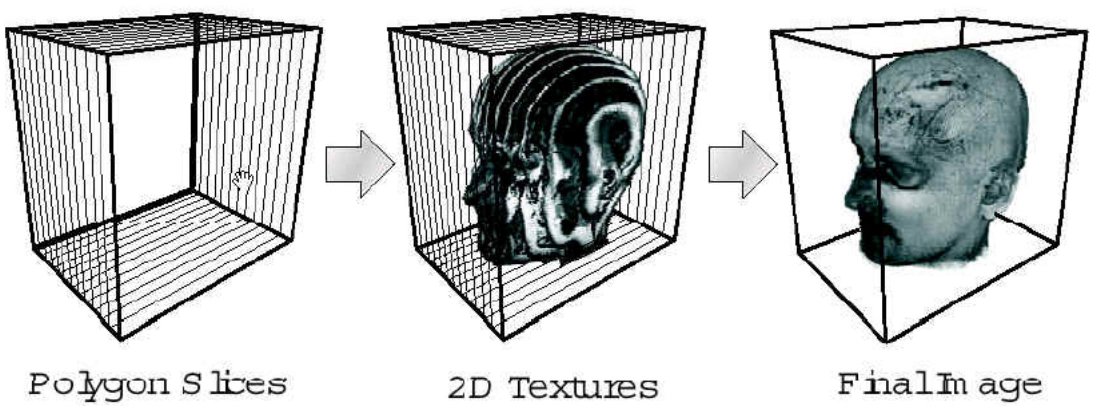
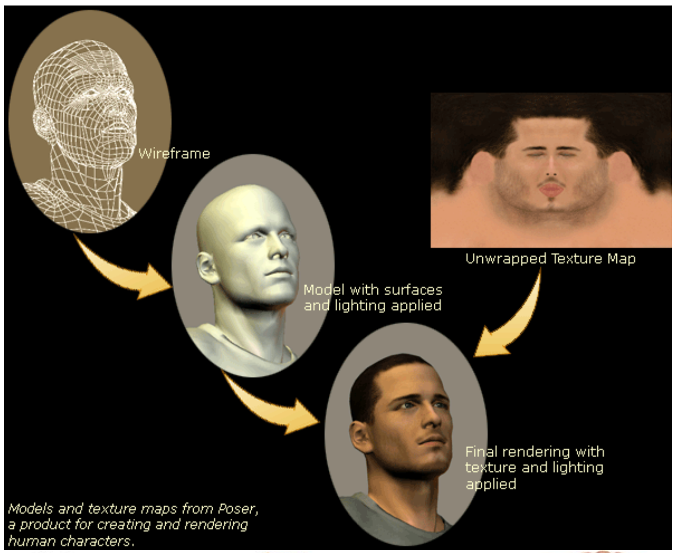



Image credit: H.W.Shen, Ohio State U.

# Texture in Graphics

Texture mapping can large enhance the reality of the 3D objects




How does it work?

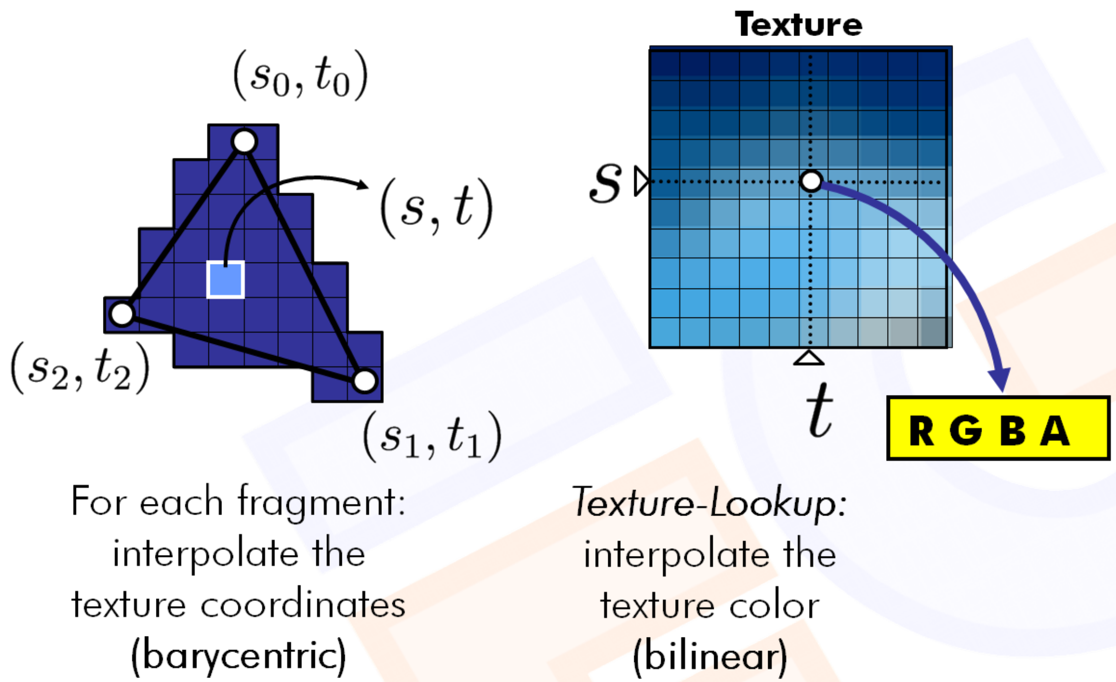



Image source: Google image

[EuroGraphics 2006 Tutorial]

# Texture-based Volume Rendering

- Volume rendering by **2D texture** mapping:
  - use planes parallel to **base plane** (front face of volume which is "most orthogonal" to view ray). **This is an axis-aligned approach!**

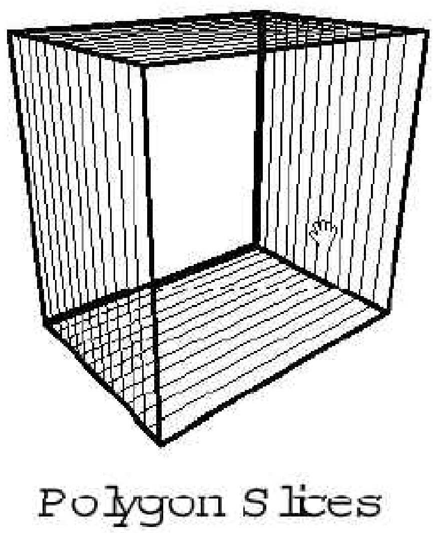
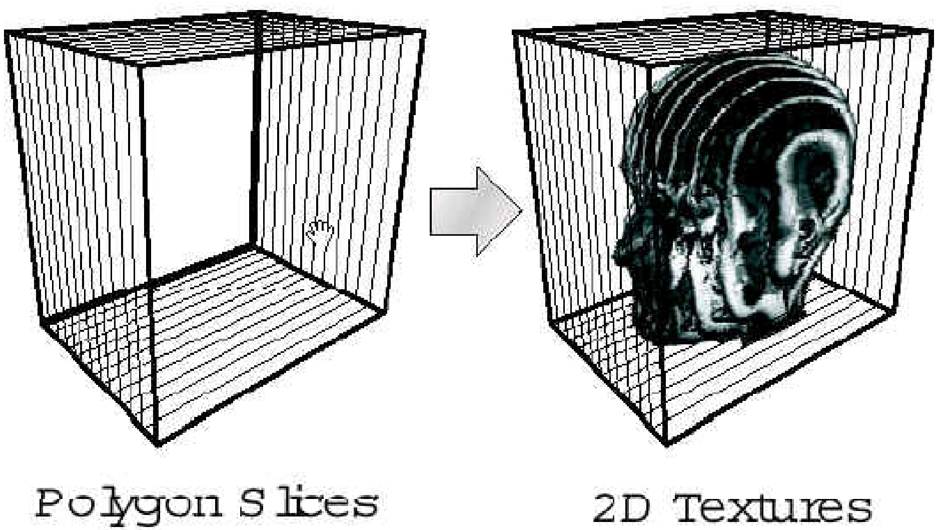



Image credit: H.W. Shen Ohio State Univ.

# Texture-based Volume Rendering

- Volume rendering by **2D texture** mapping:
  - use planes parallel to **base plane** (front face of volume which is "most orthogonal" to view ray). **This is an axis-aligned approach!**
  - draw textured rectangles, using **bilinear** interpolation filter



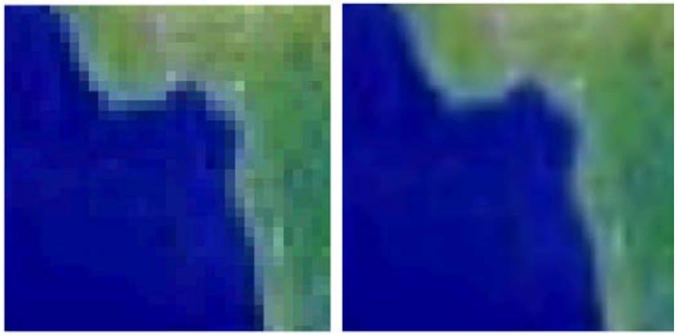



Image credit: H.W. Shen Ohio State Univ.

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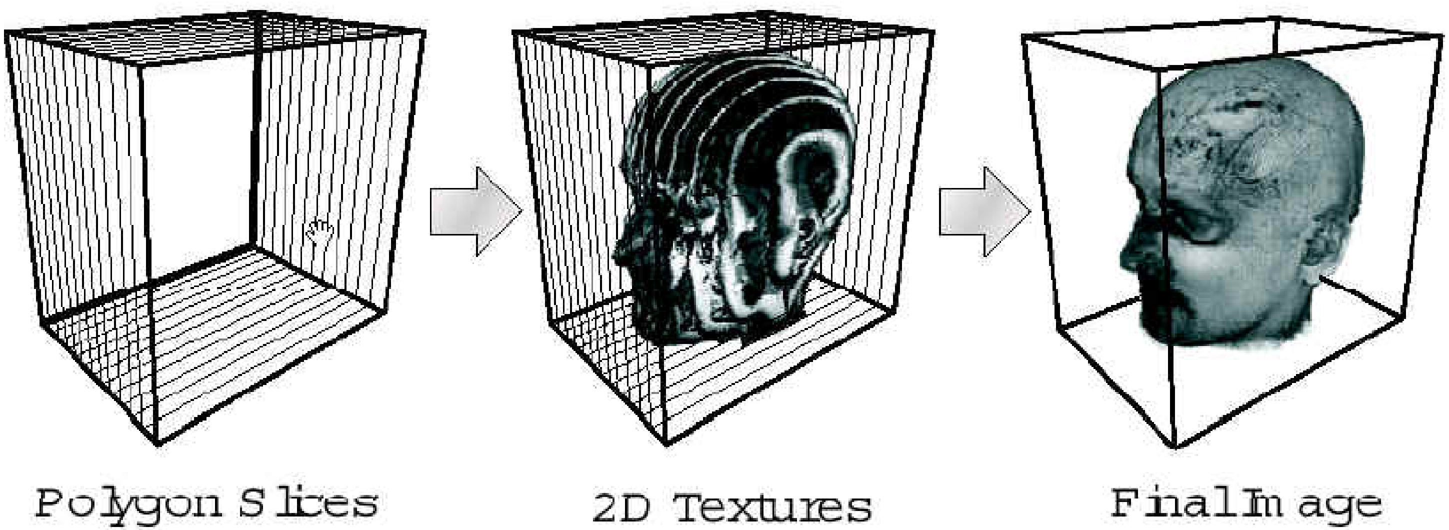


Image credit: H.W. Shen Ohio State Univ.

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**Is texture-based volume rendering an object-order or image-order approach? Why?**

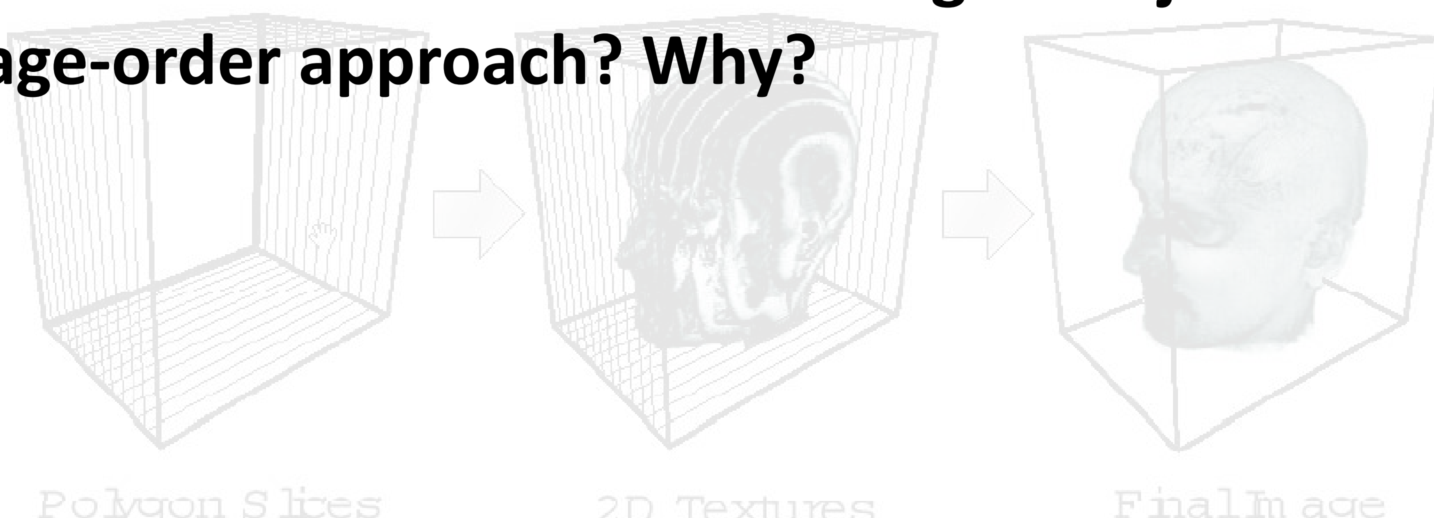



Image credit: H.W.Shen, Ohio State U.

# Texture-based Volume Rendering

- Volume rendering by **2D texture** mapping:
  - use planes parallel to **base plane** (front face of volume which is "most orthogonal" to view ray). **This is an axis-aligned approach!**
  - draw textured rectangles, using **bilinear** interpolation filter
  - render back-to-front, using α-blending for the α-compositing

**Essentially, a simplified version of splatting without splatting!**


Image credit: H.W.Shen, Ohio State U.

# Texture-based Volume Rendering

- Volume rendering by **3D texture** mapping:
  - use the voxel data as the 3D texture
  - render an arbitrary number of slices (eg. 100 or 1000) **parallel to image plane** (3- to 6-sided polygons)
  - back-to-front compositing as in 2D texture method

Limited by size of texture memory.

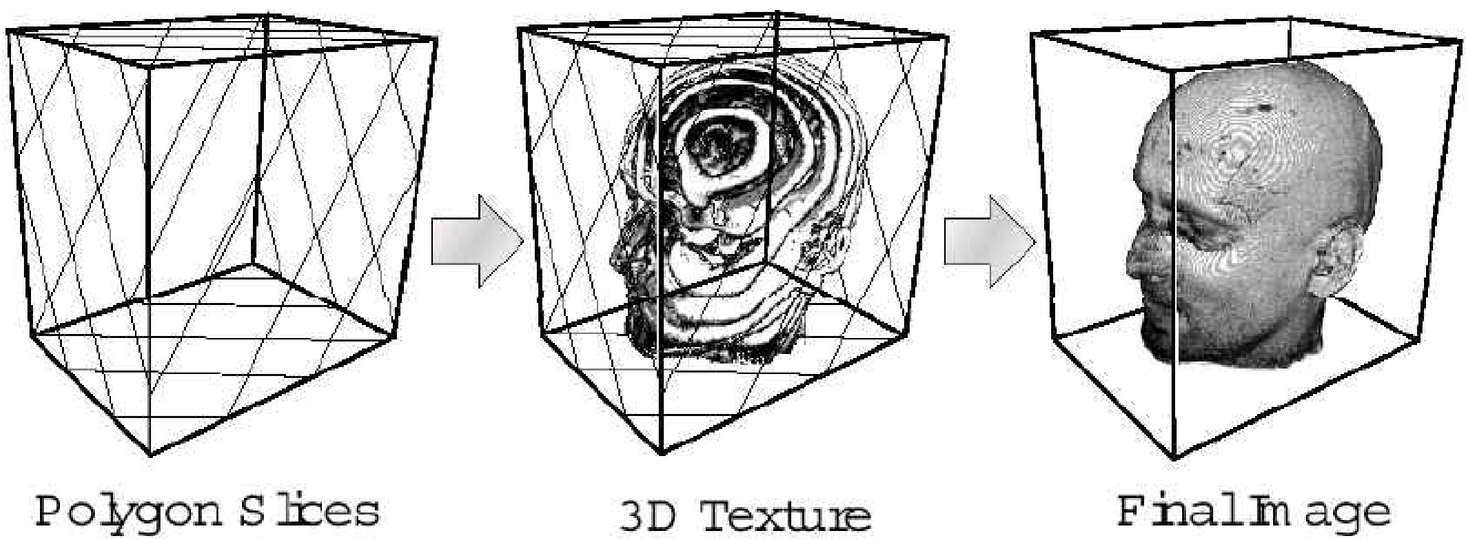
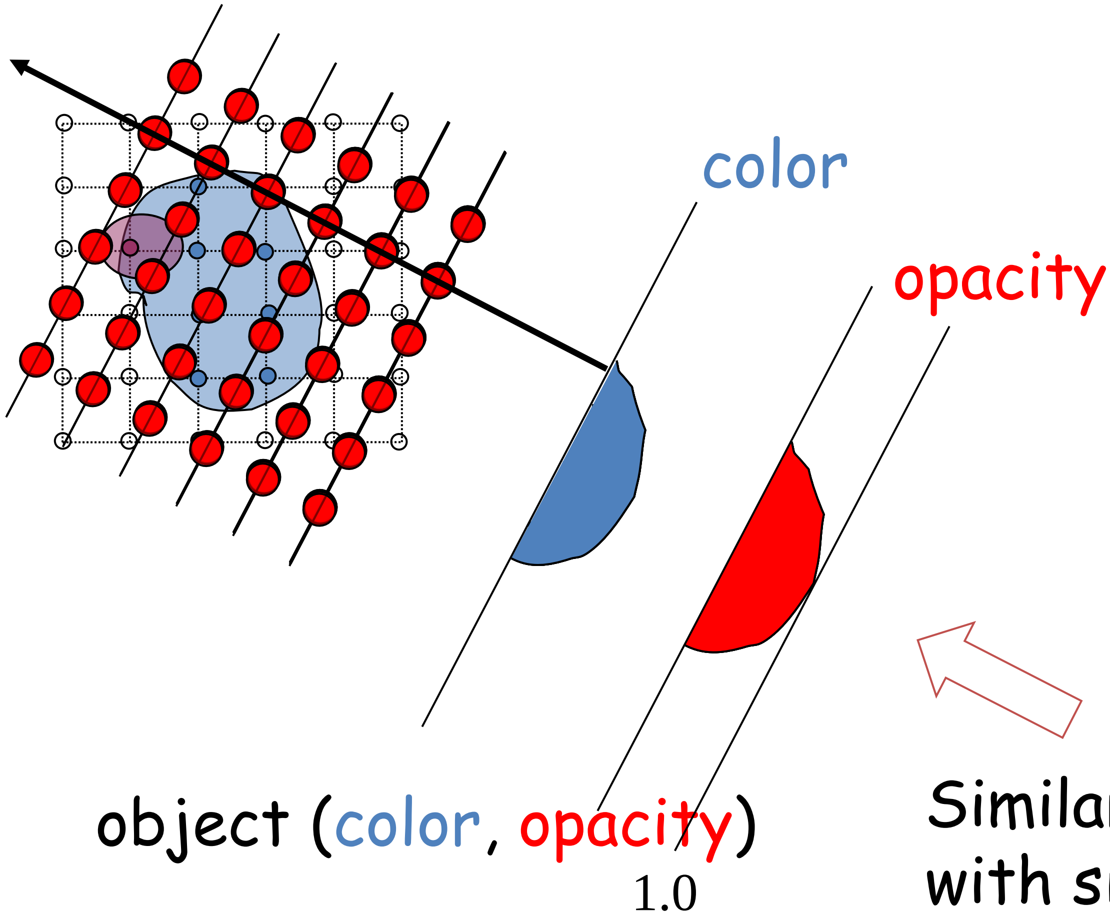


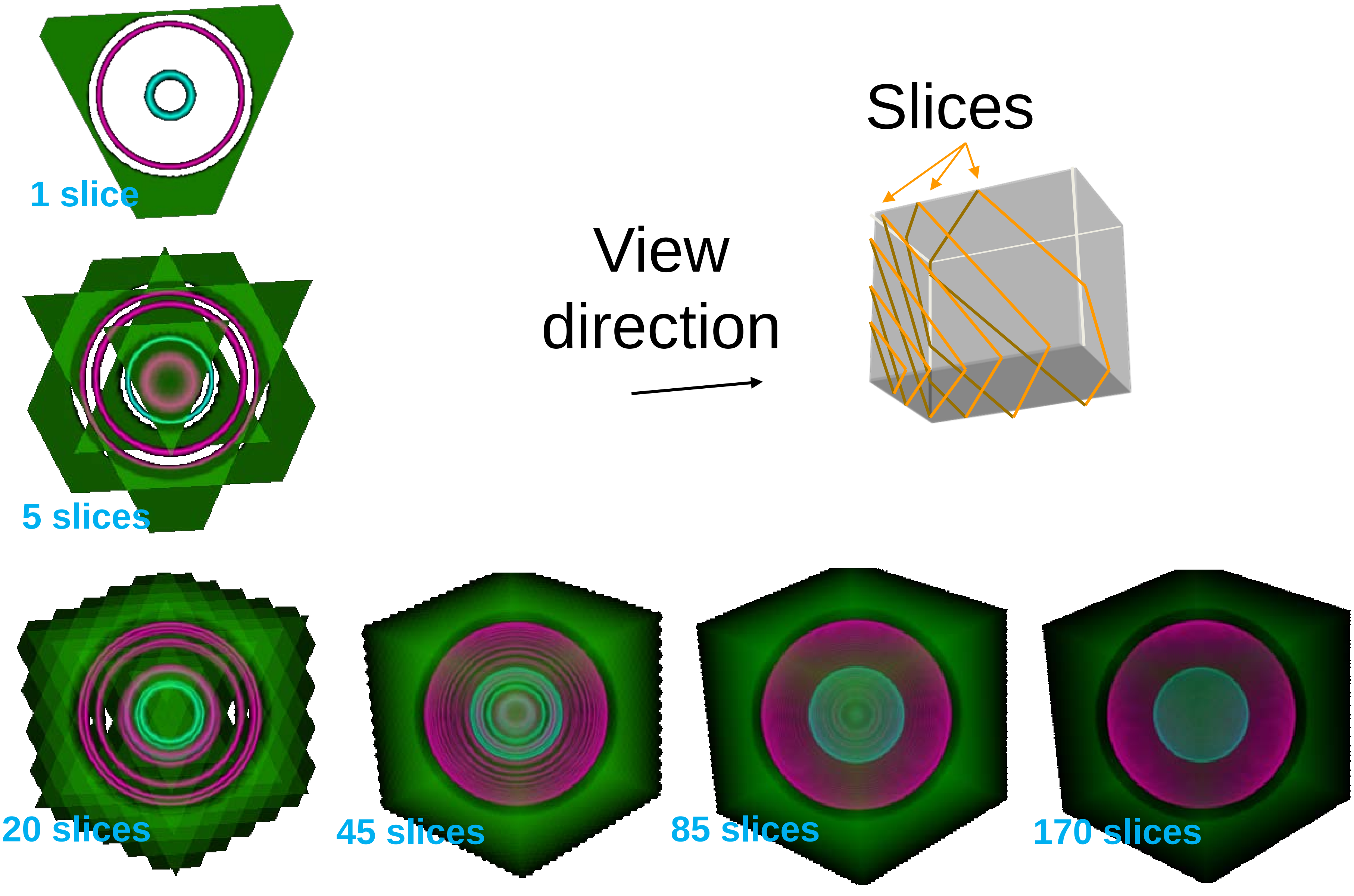

Image credit: H.W.Shen, Ohio State U.

# Slicing




Similar to ray-casting
with simultaneous rays

# Effect of the Sample Rate



# Slice Based Problems?

- Does not perform correct
  - Illumination
  - Accumulation - but can get close
- Can not easily add correct illumination and shadowing
  - See the Van Gelder paper for their addition for illumination
    - Stored in LUT quantized normal vector directions

# Additional Reading

For Ray casting

- Marc Levoy: "**Display of Surfaces from Volume Data**" in *IEEE Computer Graphics & Applications*, Vol. 8, No. 3, June 1988

- **Data Visualization, Principles and Practice**, **Chapter 10 Volume Visualization**, by A. Telea, AK Peters, 2008

For splatting, please see,

- **Data Visualization, Principles and Practice, Chapter 9, Image Visualization**, by A Telea, AK Peters 2008

- **Footprint Evaluation for Volume Rendering**, by Lee Westover, in *ACM Computer Graphics* Volume 24, Number 4, August 1990, pages, 367-376

For shear-warp factorization, please see,

- Philippe Lacroute and Marc Levoy, **Fast Volume Rendering Using a Shear-Warp Factorization of the Viewing Transformation**, *Proc. SIGGRAPH '94*, Orlando, Florida, July, 1994, pp. 451-458

# Acknowledgment

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- Prof. Mike Bailey, Oregon State University