Sampling Aspects of Volume Rendering

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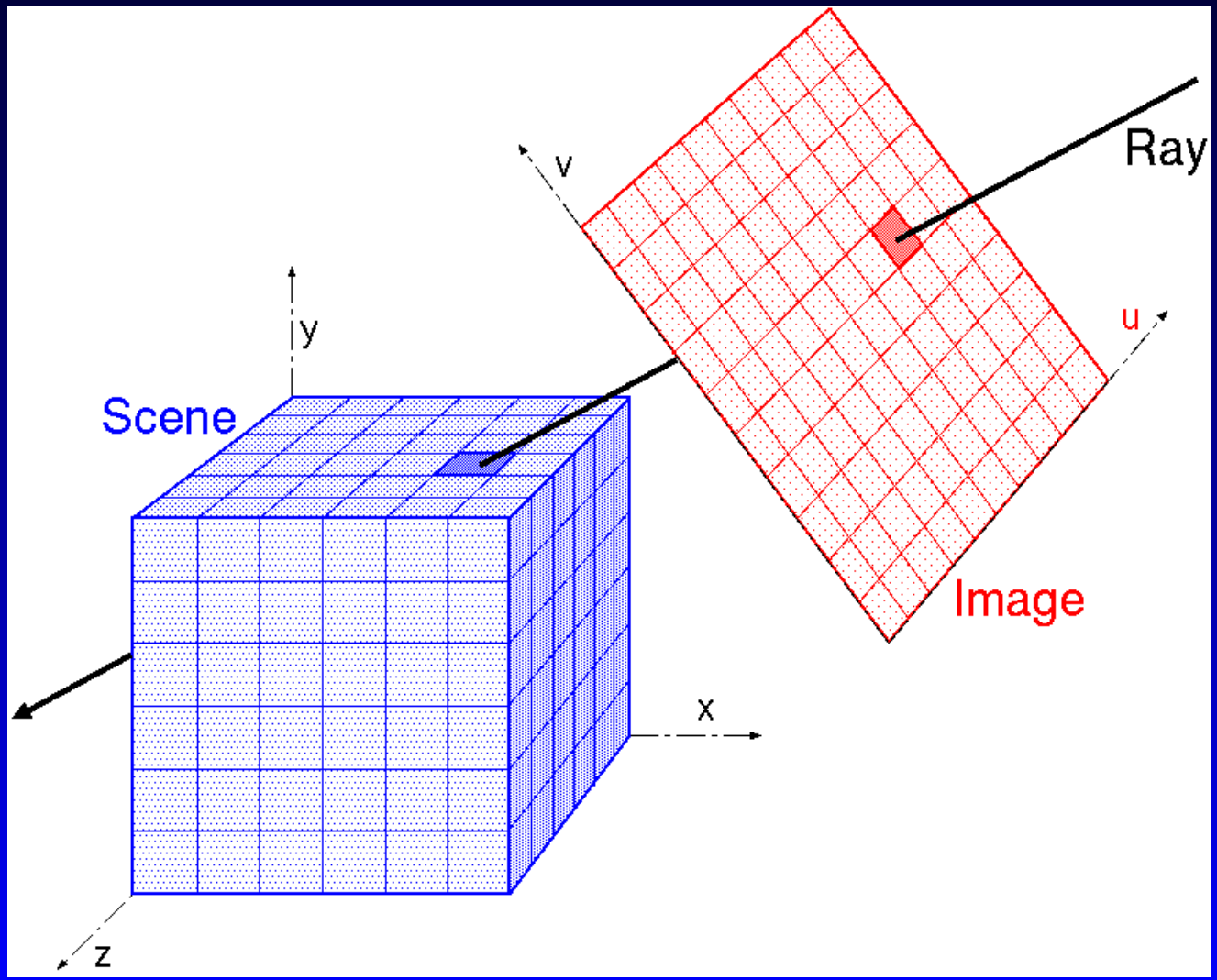
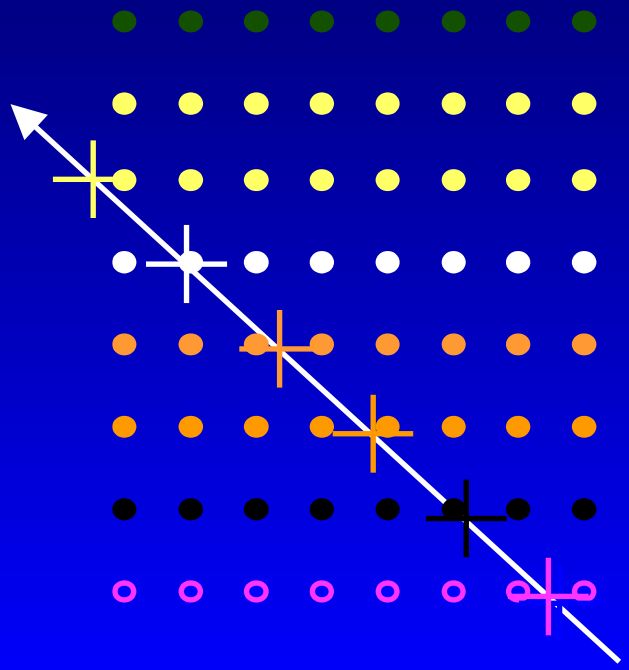
Volume Rendering



Ray-Casting

- Shoot rays from each pixel
- Define a sequence of samples
- Accumulate color along each ray



Compositing

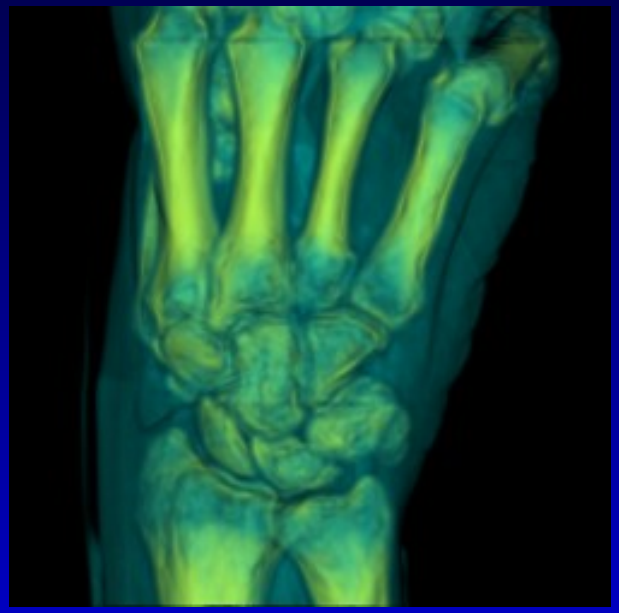
- Aproximate light attenuation
  e.g. Front-to-Back compositing:

$$I_m = I_{m-1} + (1 - \beta_{m-1}) C_m$$
$$\beta_m = \beta_{m-1} + (1 - \beta_{m-1}) \alpha_m$$

- Segment opacity

$$\alpha_i = 1 - e^{-\int_{t_i}^{t_{i+1}} \rho(u)\, du}$$

VR: Different Techniques



Shaded (gradients evaluated)

Unshaded (reprojection, no gradient)

MIP

VR Questions

- Which is the correct sampling density along a ray
- Which is the influence of gradient on the correct sampling density
- Which is the correct sampling density in perspective rendering

Frequency Properties of Sampled Data

- Maximum representable frequency:

$$f_{max} = \frac{1}{2VU}$$

- Optimal sampling (ideal): 1 sample/voxel
- Optimal sampling (real): more than 1 sample/voxel. It depends on
  - spectral properties of data
  - used visualization technique (gradients!)
  - Used reconstruction filters

Low vs. High Sampling Density

- Rendered images at
  - 10 samples along a ray / voxel
  - Samples on voxel boundaries (0.7 / voxel)
- Results:

$$SNR(dB) = 10 \log \frac{\sum f_i^2}{\sum |t_i - f_i|^2}$$

Technique	Image SNR [dB]
Shaded	63
Unshaded	120
MIP	87

Rules of Thumb

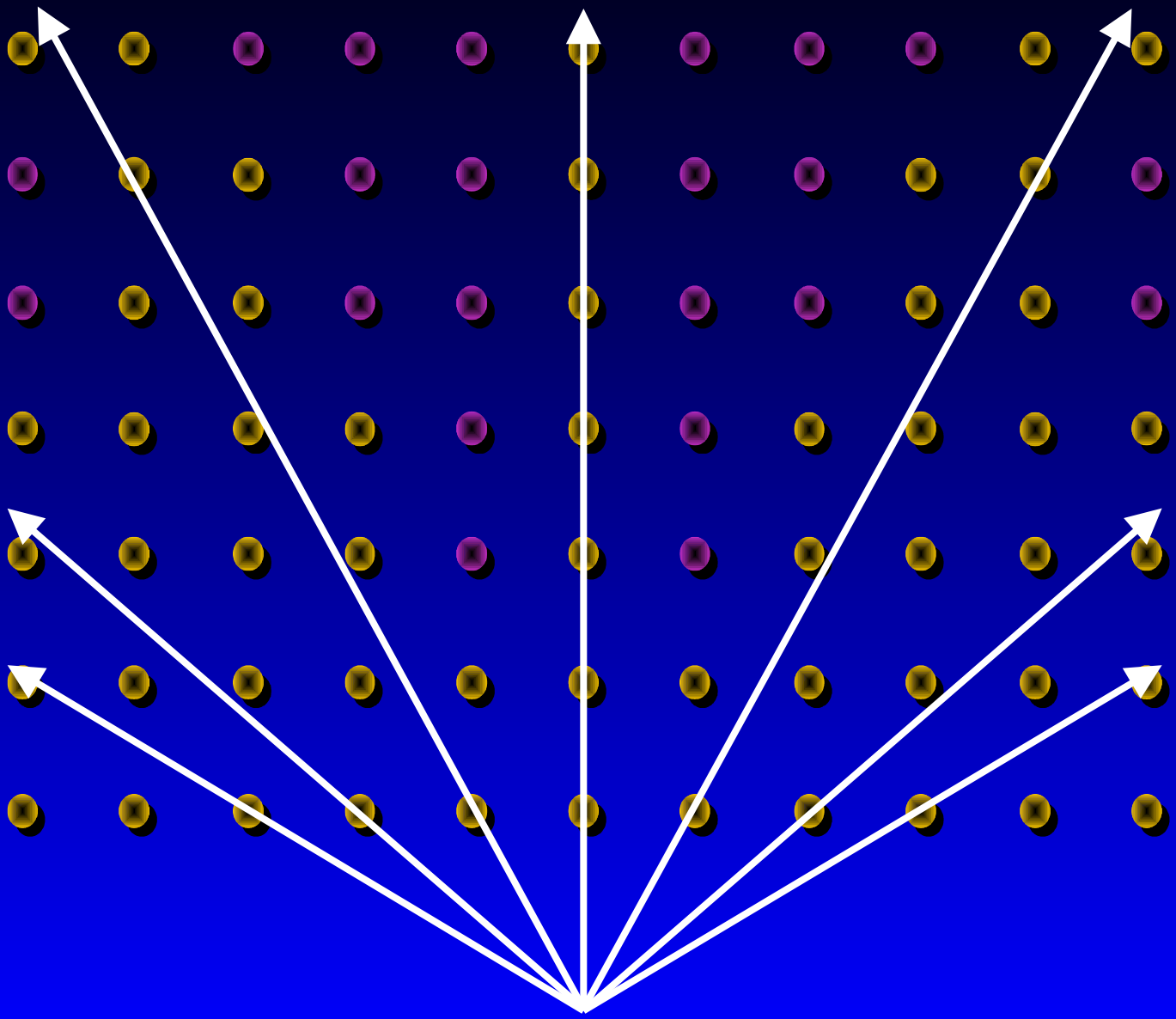
- **Unshaded** (reprojection)
  - 1 sample / voxel is OK
- **MIP**
  - 1 sample / voxel is not that bad
- **Shaded**
  - 1 sample / voxel is definitely bad (2, 4, 8 samples?)

Perspective Rendering

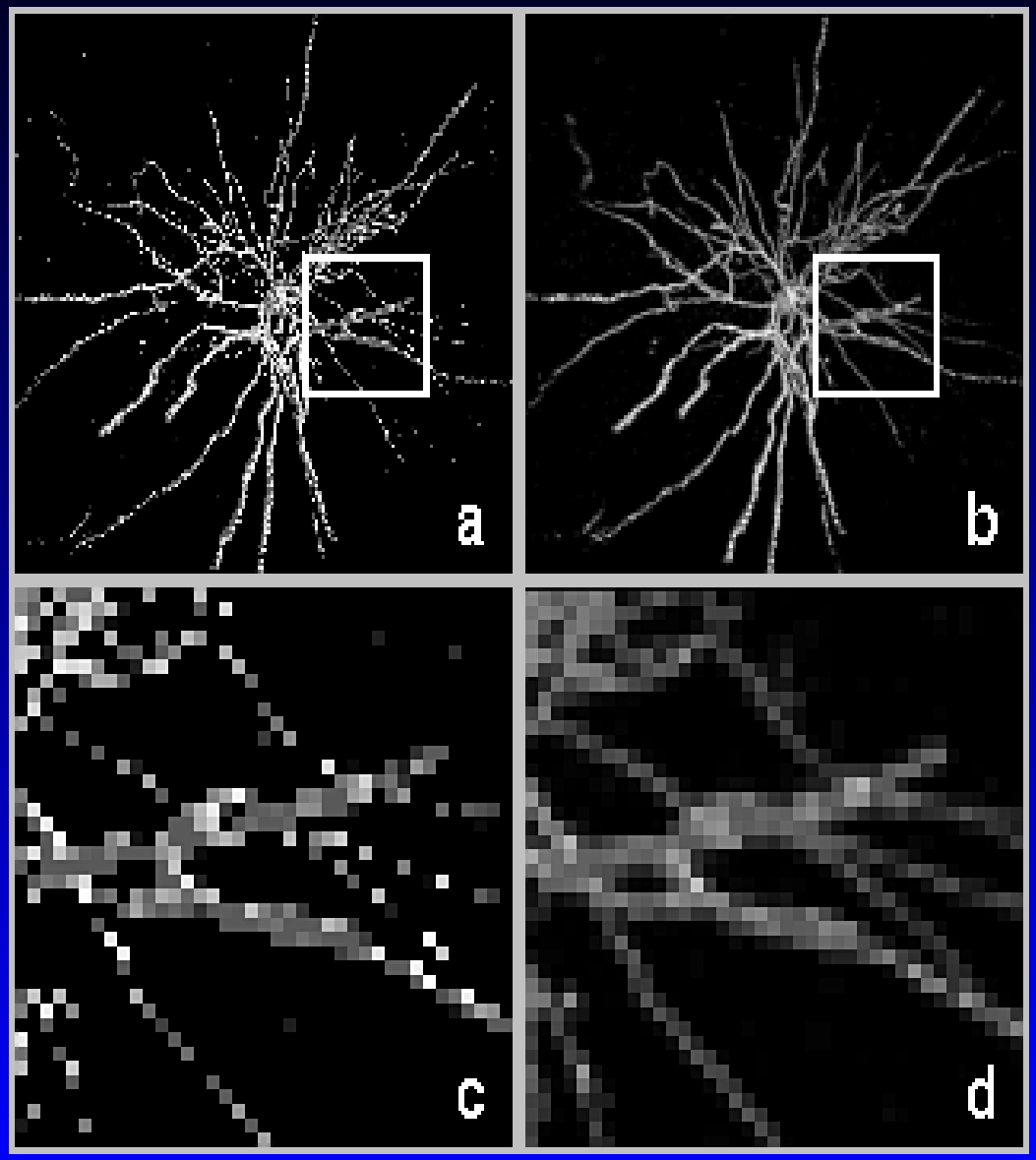
Problems in perspective rendering

- Incorrect spatialy variable sampling:
  - Oversamplig (long time)
  - Undersampling (low image quality)

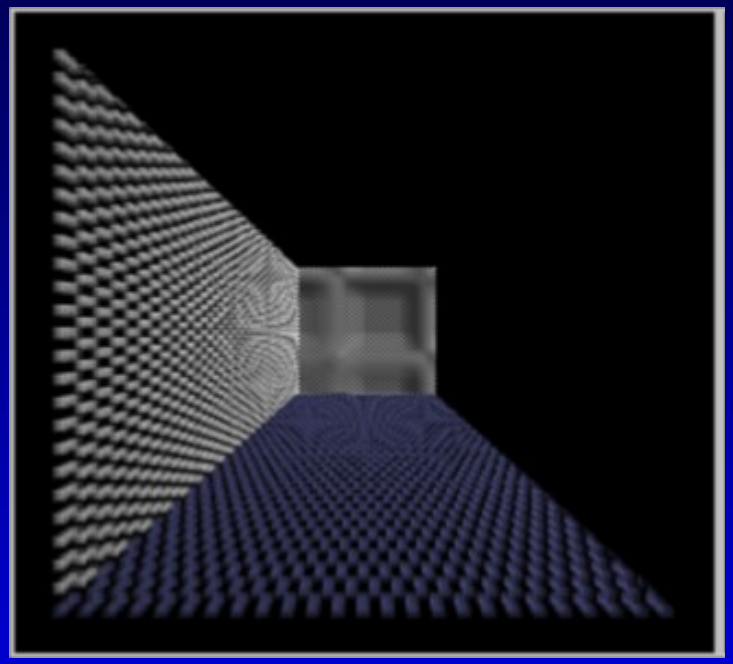
Motivation (Image Quality)

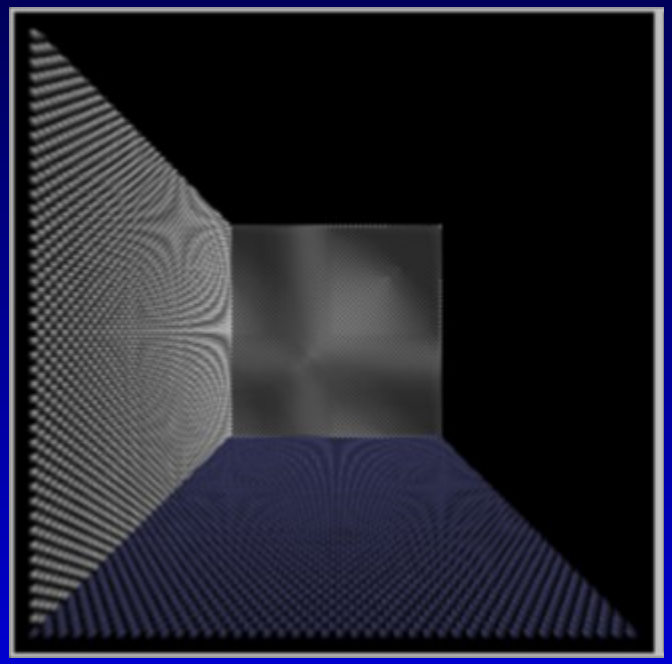


Motivation (Image Quality)

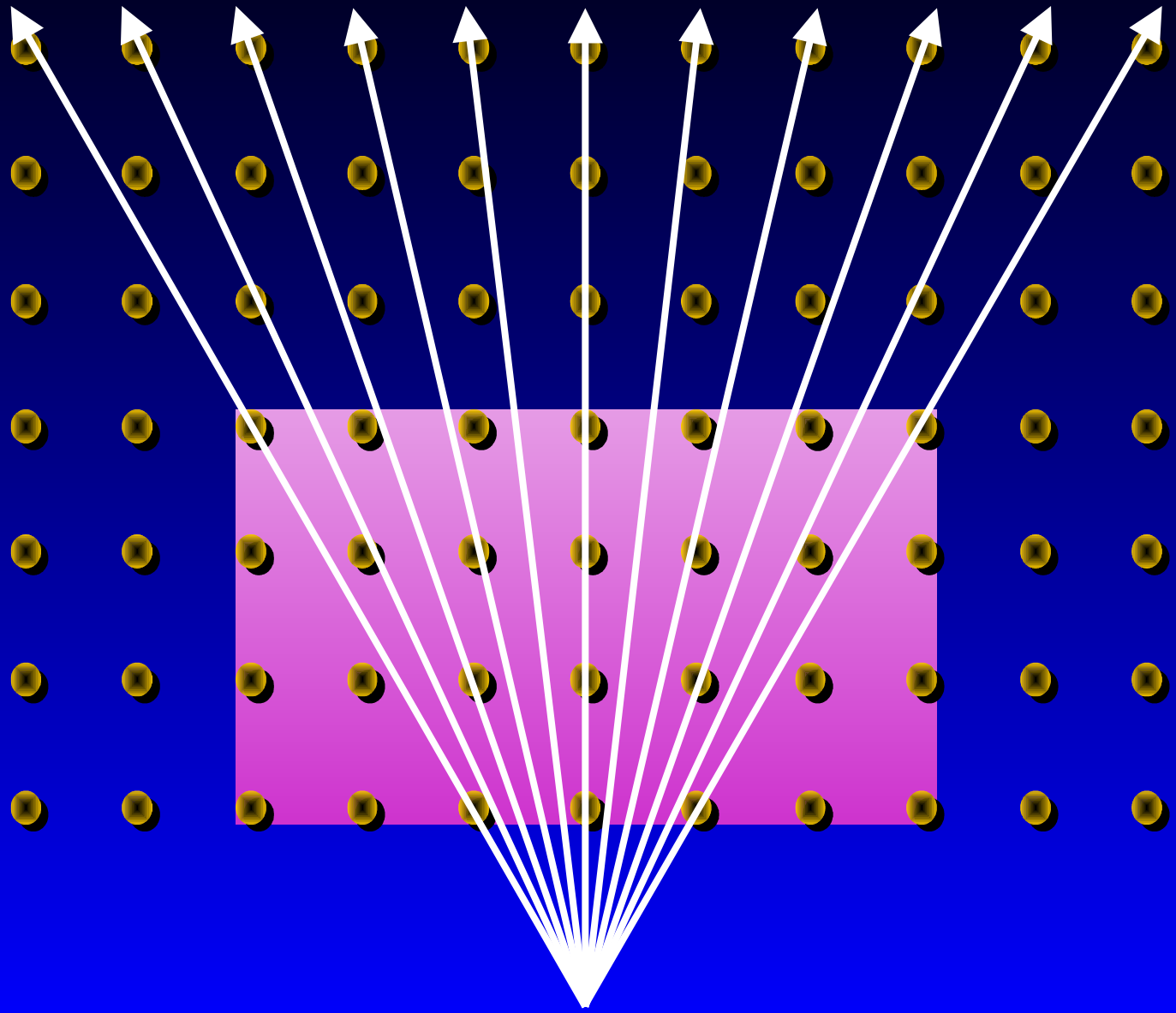


Motivation (Image Quality)





Motivation (Rendering Speed)



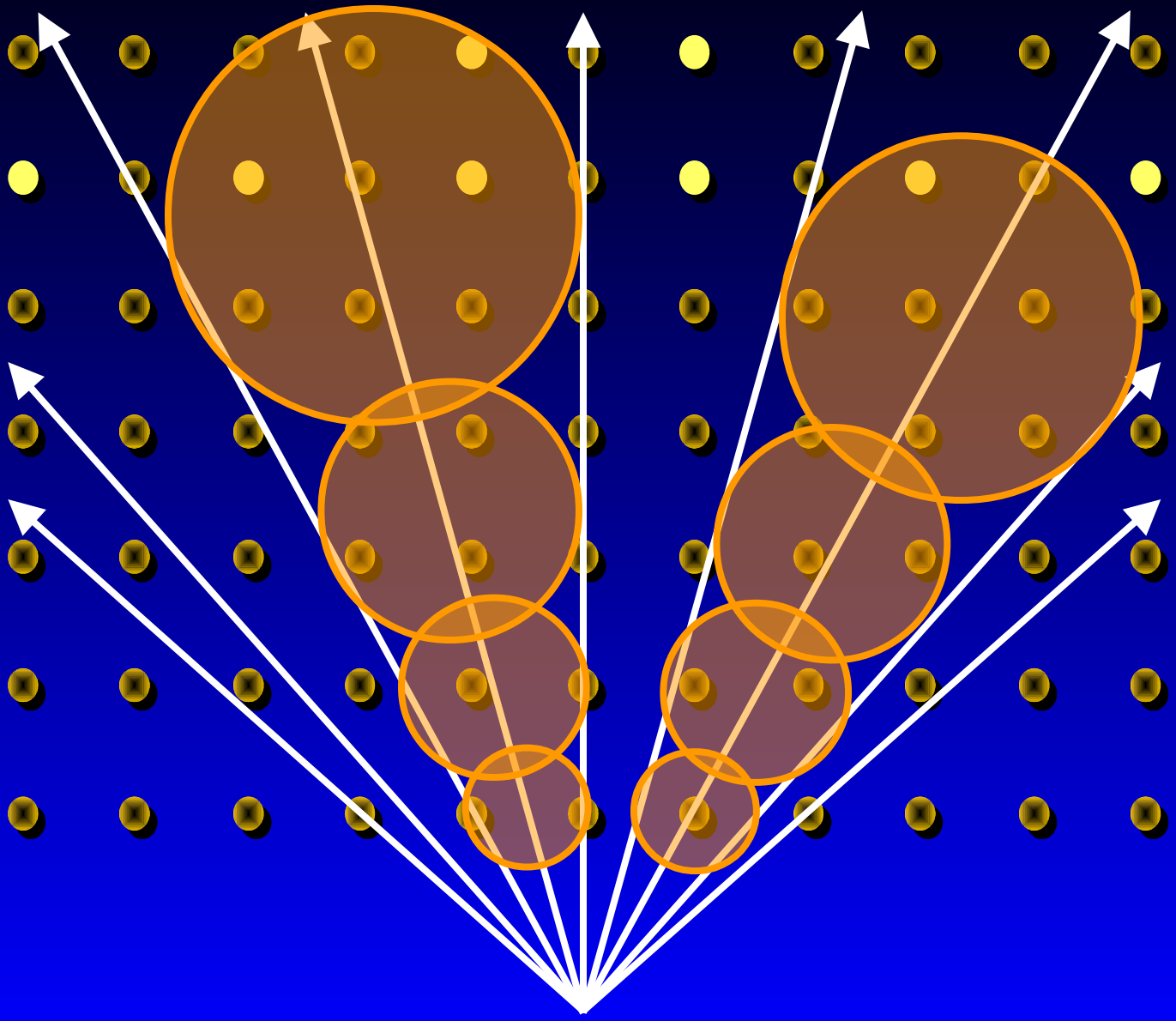
A Correct Solution

- VR is a resampling process:
  - Reconstruction of a continuous field
  - Antialiasing by low-pass filtering
  - Sampling
  - Compositing

Can be combined in one filter:

Size and sampling density depend on distance between rays

A Correct Solution



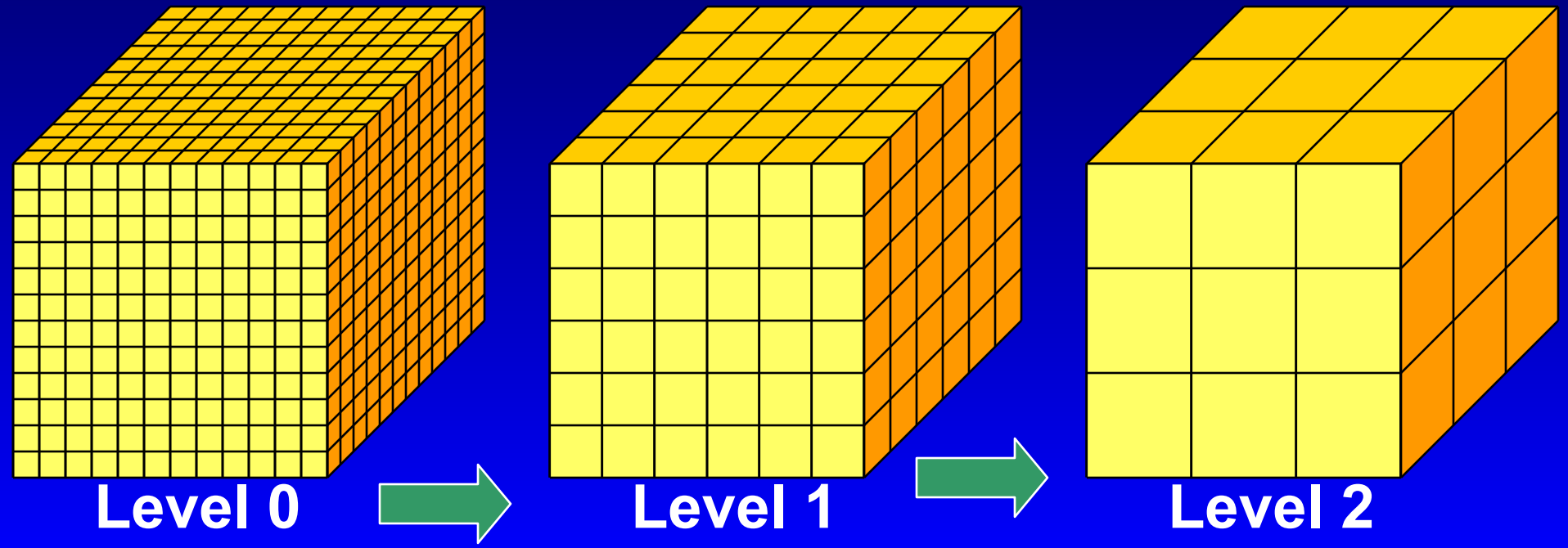
Practical Solutions

- 3D-mip map
  - *multum in parvo*, much in a small space

  [Levoy & Whitaker `90]
- Adaptive sampling [Novins et al. `90]
  - Splitting a ray in 4 rays when necessary
- Exponential Regions Perspective [Kreeger et al. `98]

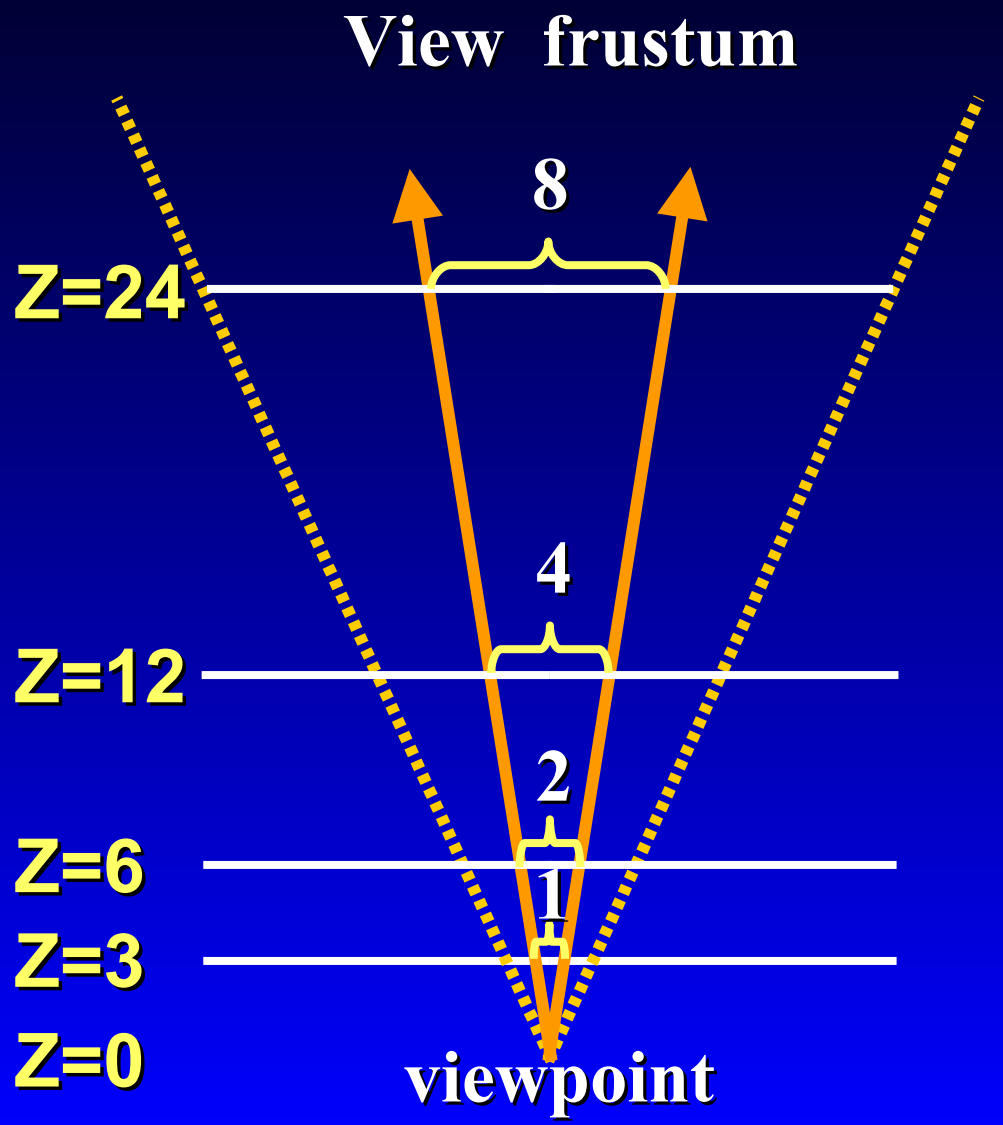
3D Mip Maps

- Build a hierarchy of volumes by downsampling:
  - Low pass filtering
  - Take every second sample
- Sample a pair of volumes simultaneously:
  - 2 x trilinear + linear interpolation

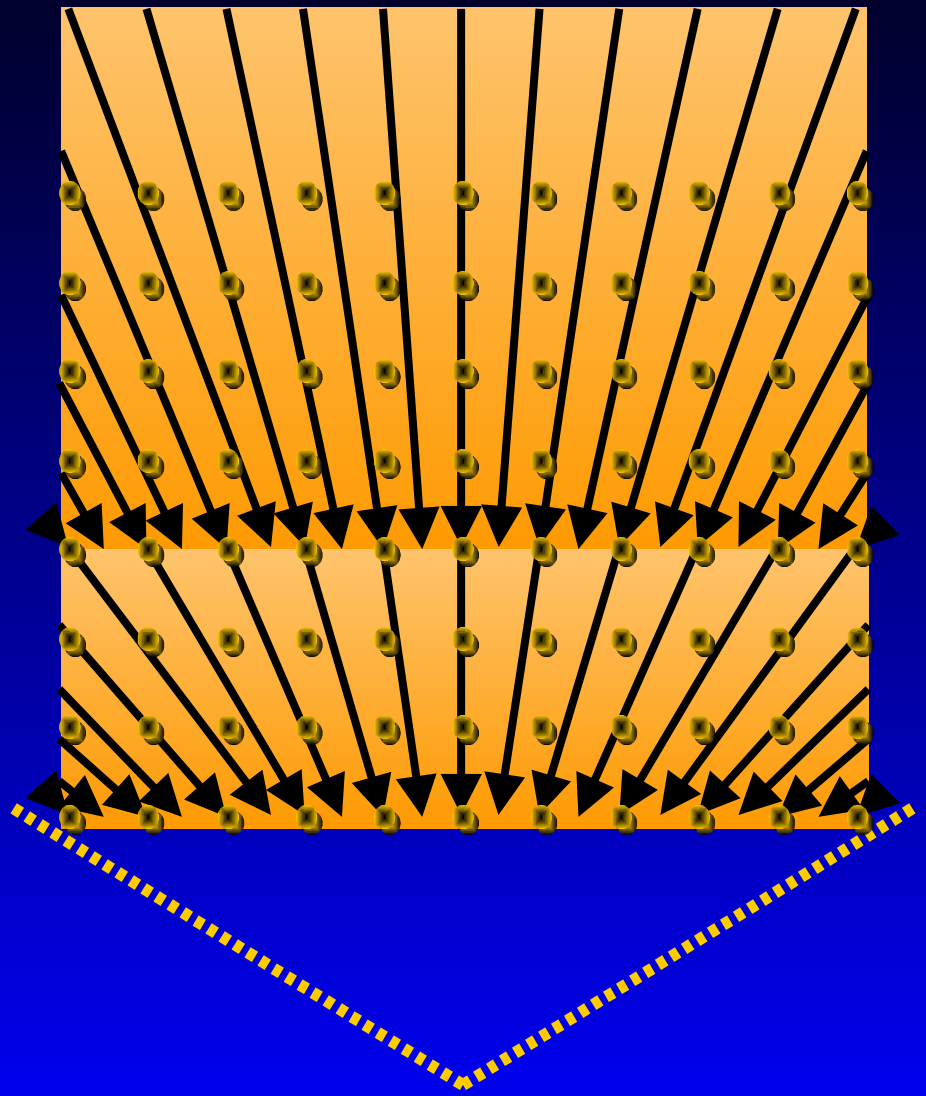


ER Perspective

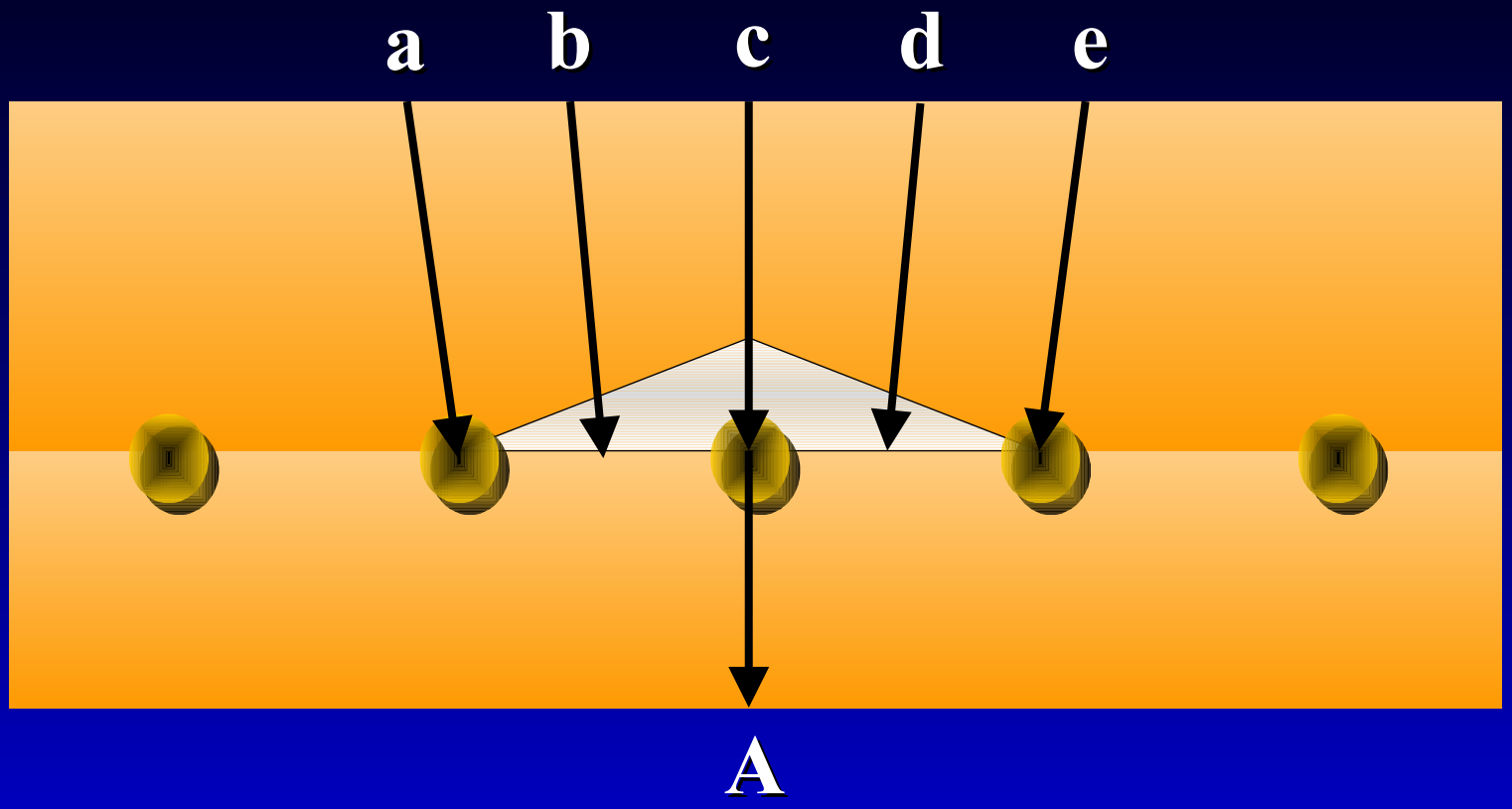
- One sample per voxel
- Regular pattern of merge/split
- Exponentially growing regions ⇒ uniform divergence



ER Perspective

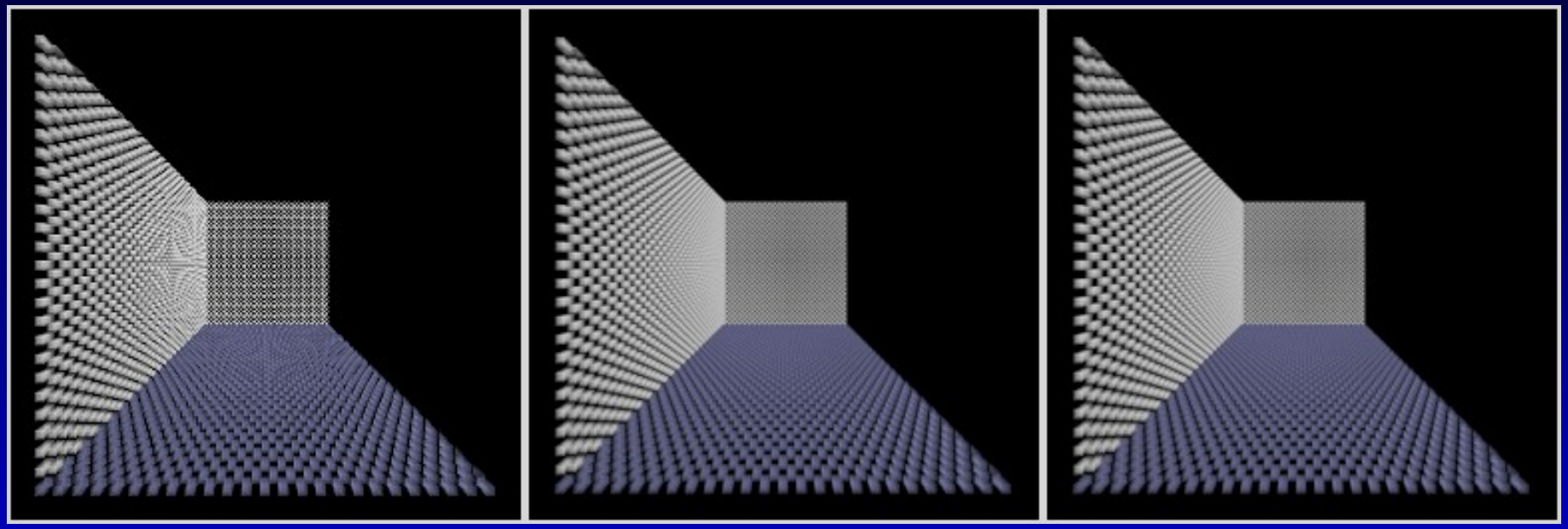


Ray Density Resampling



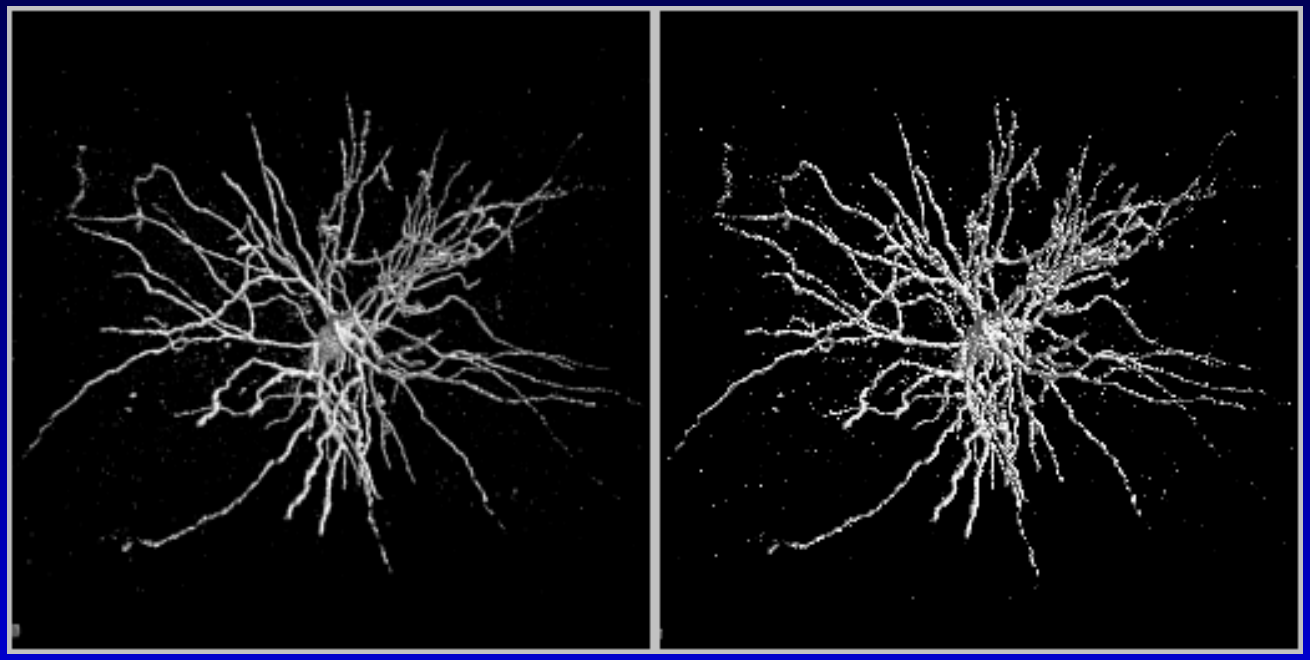
$$A = \frac{0}{4}a + \frac{1}{4}b + \frac{2}{4}c + \frac{1}{4}d + \frac{0}{4}e$$

ER Perspective - Results

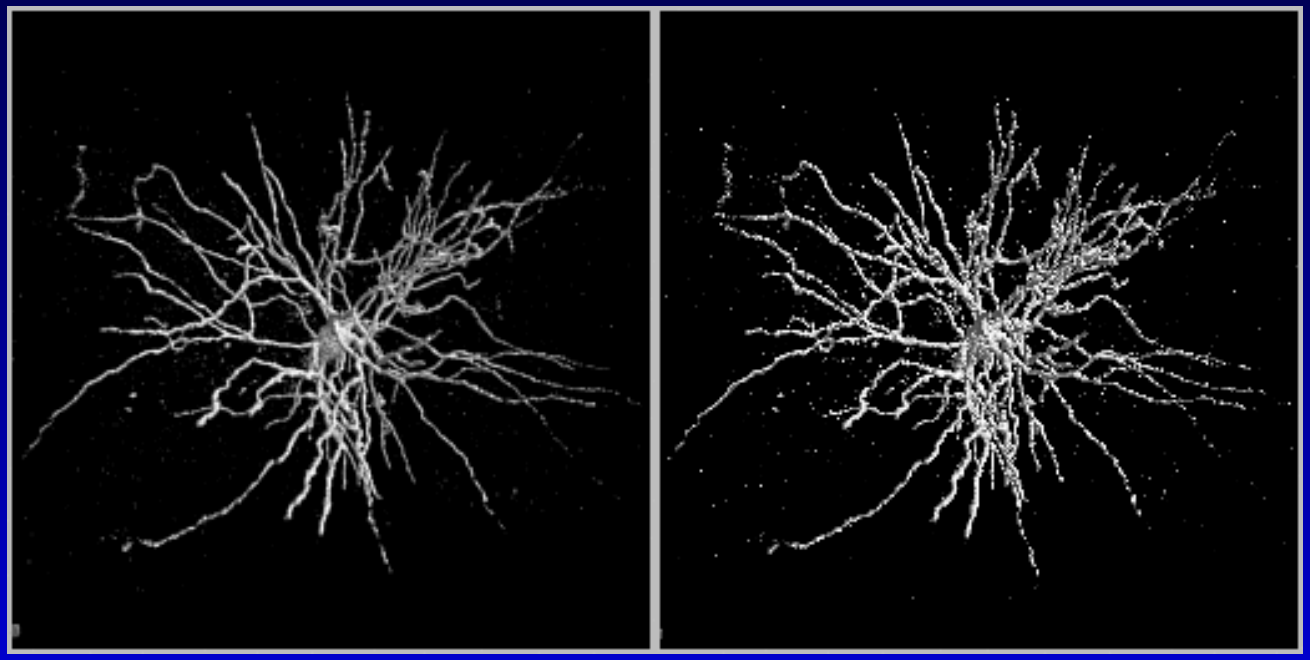


Undersampling ER - Perspective Oversampling

ER Perspective – Results



ER Perspective - Results



The End