The vg500 Real-Time Ray-Casting ASIC

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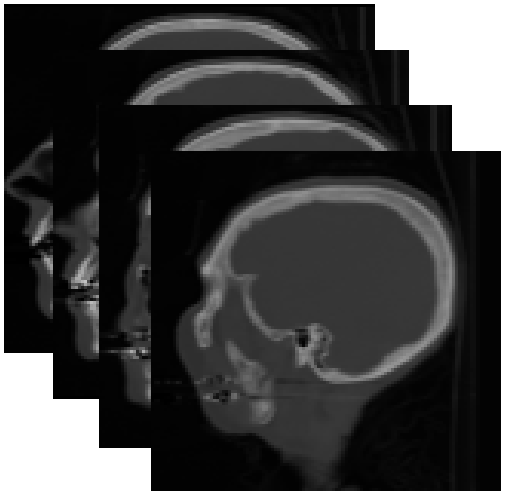
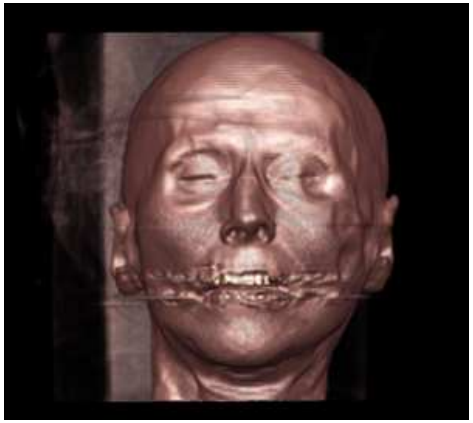
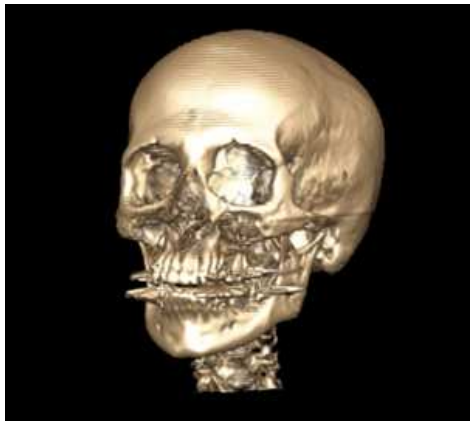
Volume Graphics

The representation, visualization, and manipulation of objects represented as sampled data in three or more dimensions



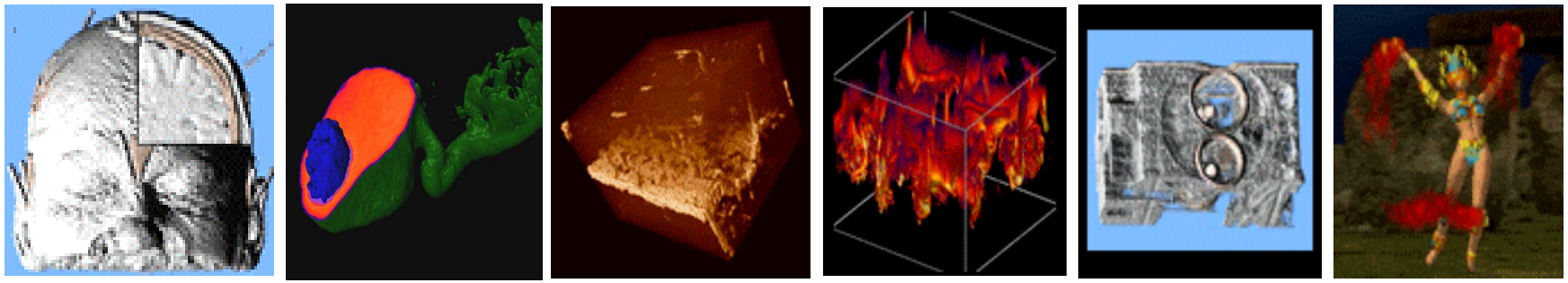
Stack of images,
e.g., CT slices





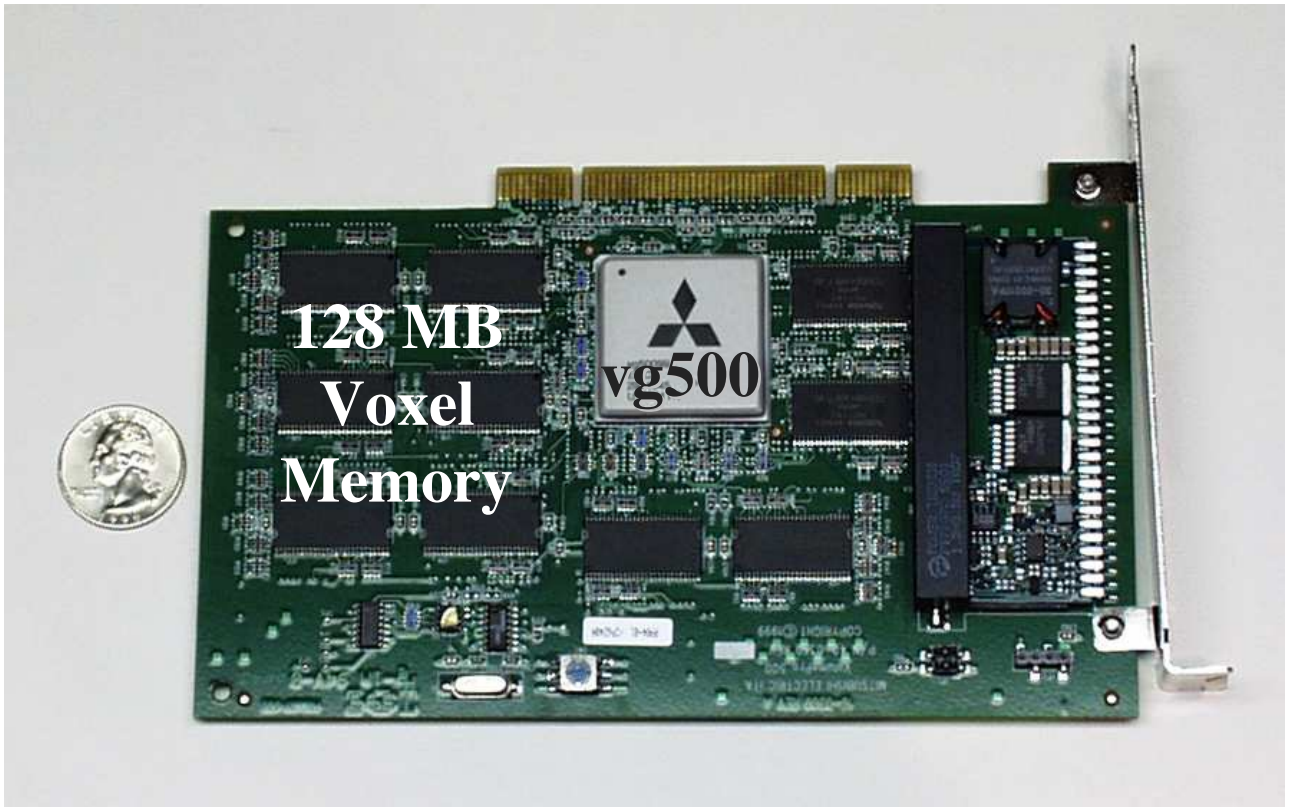
Volume Graphics Markets

- Bio-medical (CT, MRI, 3D ultrasound, confocal microscopy)
- Geophysical (seismic, environmental, oil & gas)
- Scientific simulations (CFD, astro-physics, weather)
- Complex 3D design and digital content creation
- Gaming and entertainment



VolumePro

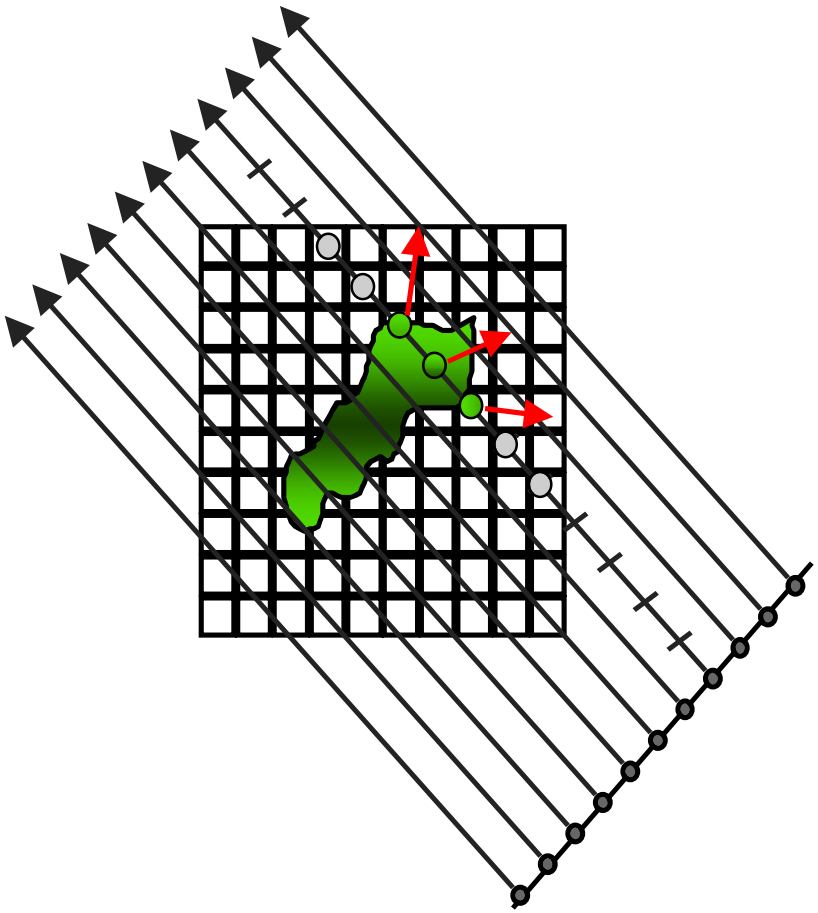
First single-chip real-time volume rendering engine for consumer PCs



Competing Solutions

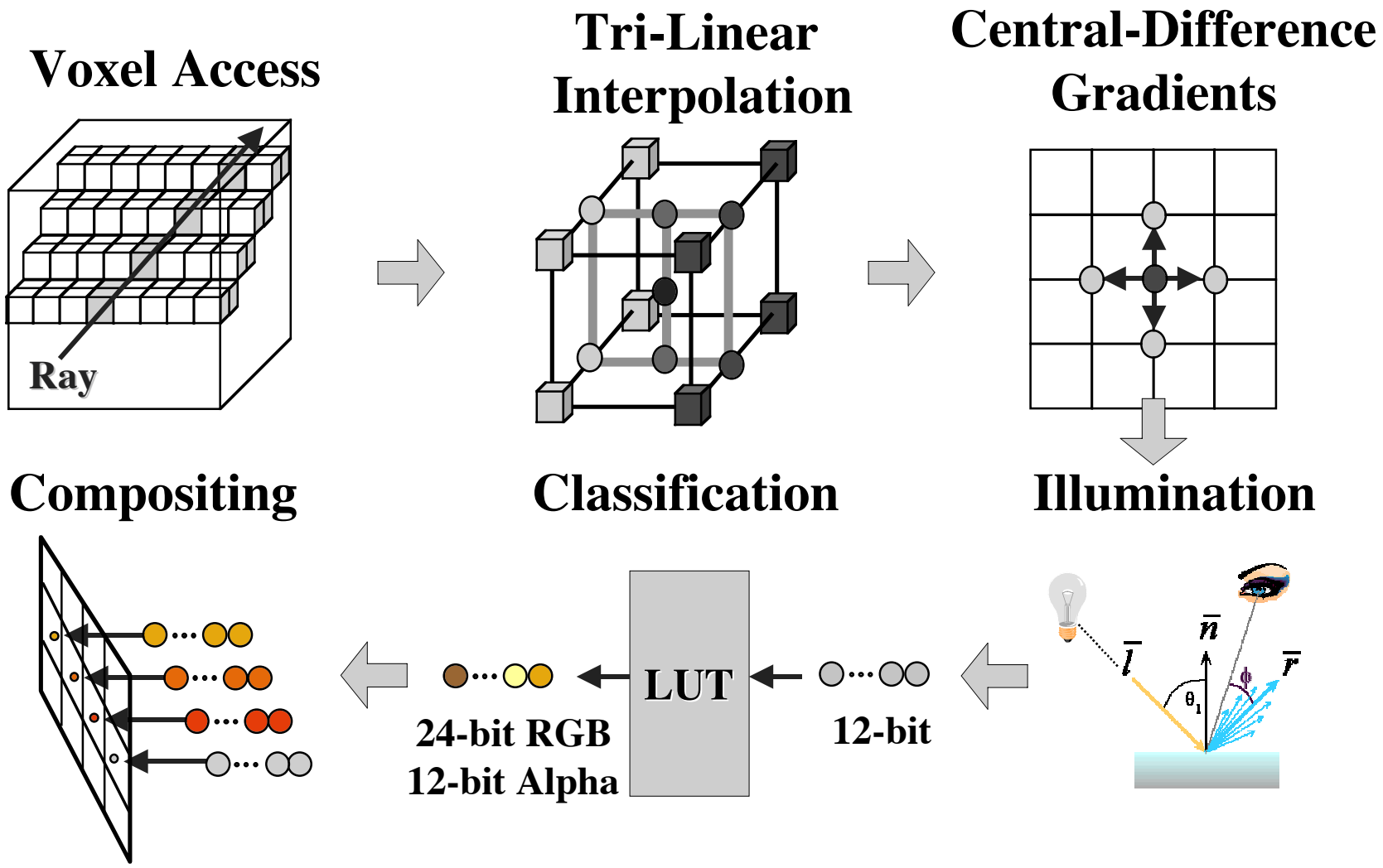
- Software rendering on high-end PCs
  - Speed through pre-computation and additional data storage
- 3D texture mapping
  - Slice volume with textured polygons parallel to image plane
  - Blend texture slices using OGL blending operations
  - No gradients and no per-sample illumination
  - Inferior speed and image quality

Volume Ray-Casting

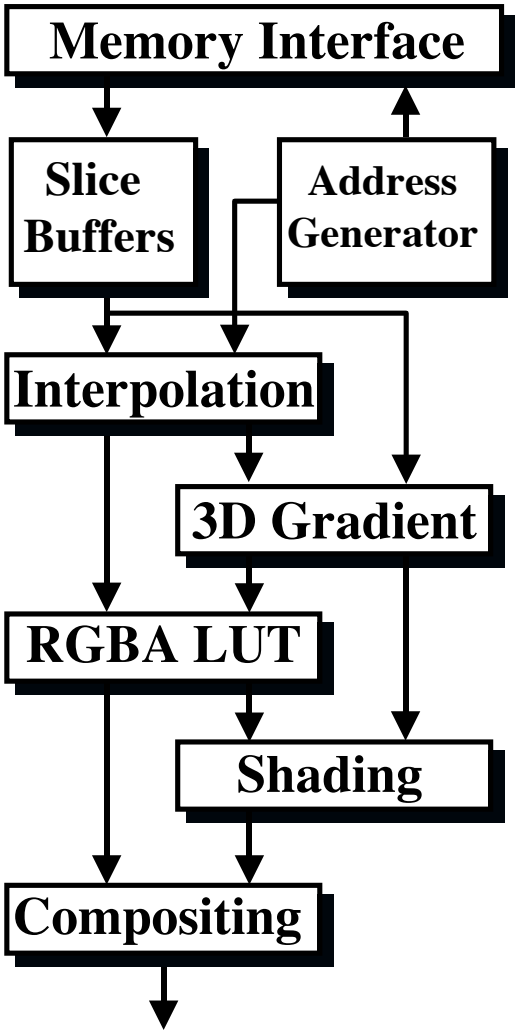


- Shoot rays for each pixel on the image plane
- Simple form of ray tracing
- Best image quality of all volume rendering methods
- Well understood
- Embarrassingly parallel

FOR (each Ray) DO



The vg500 Rendering Pipeline



Full ray-casting pipeline, parallel projections only

16-bit memory interface

8- and 12-bit scalar voxels

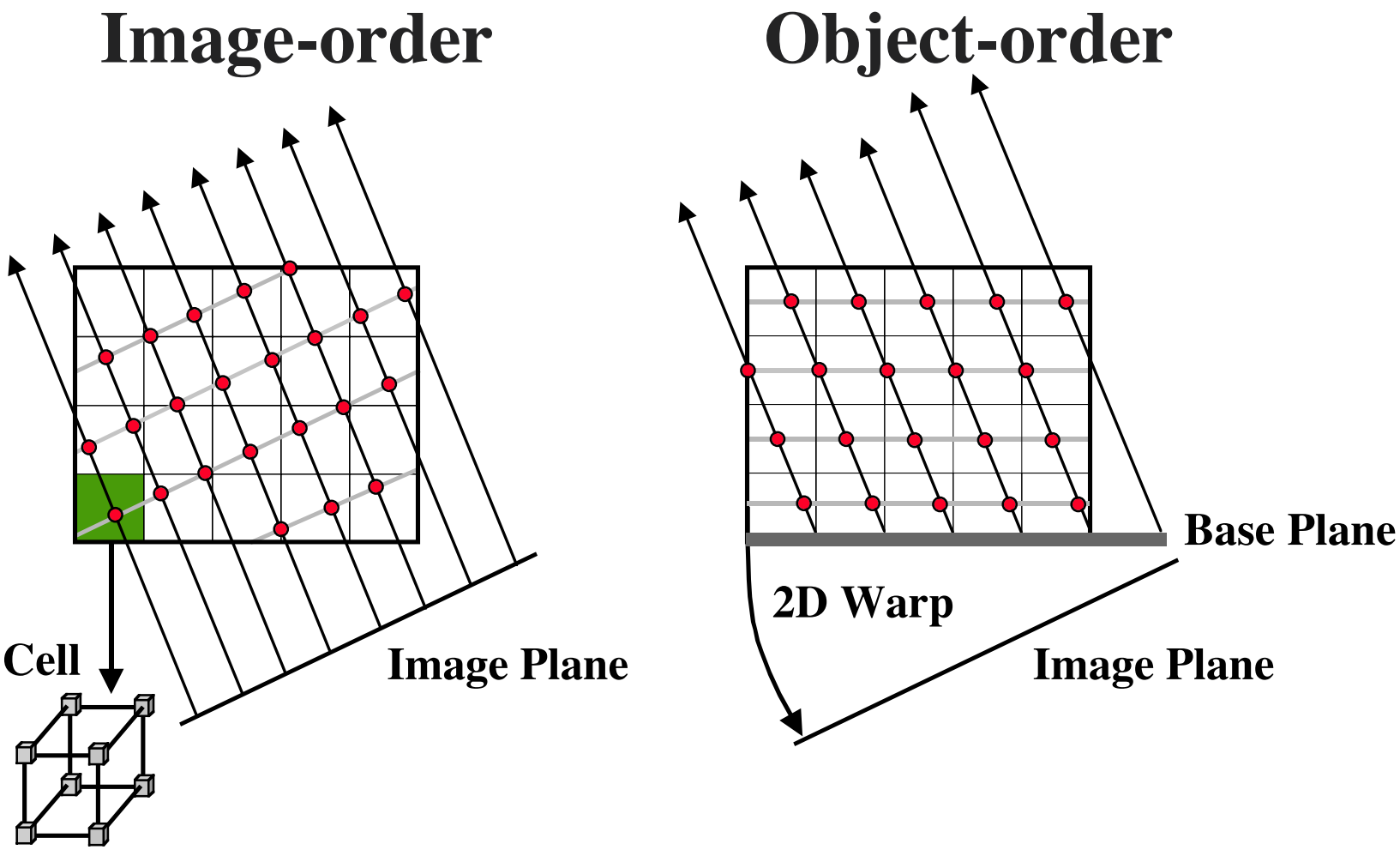
4k x 36 bit RGBA LUT

Per-fragment illumination

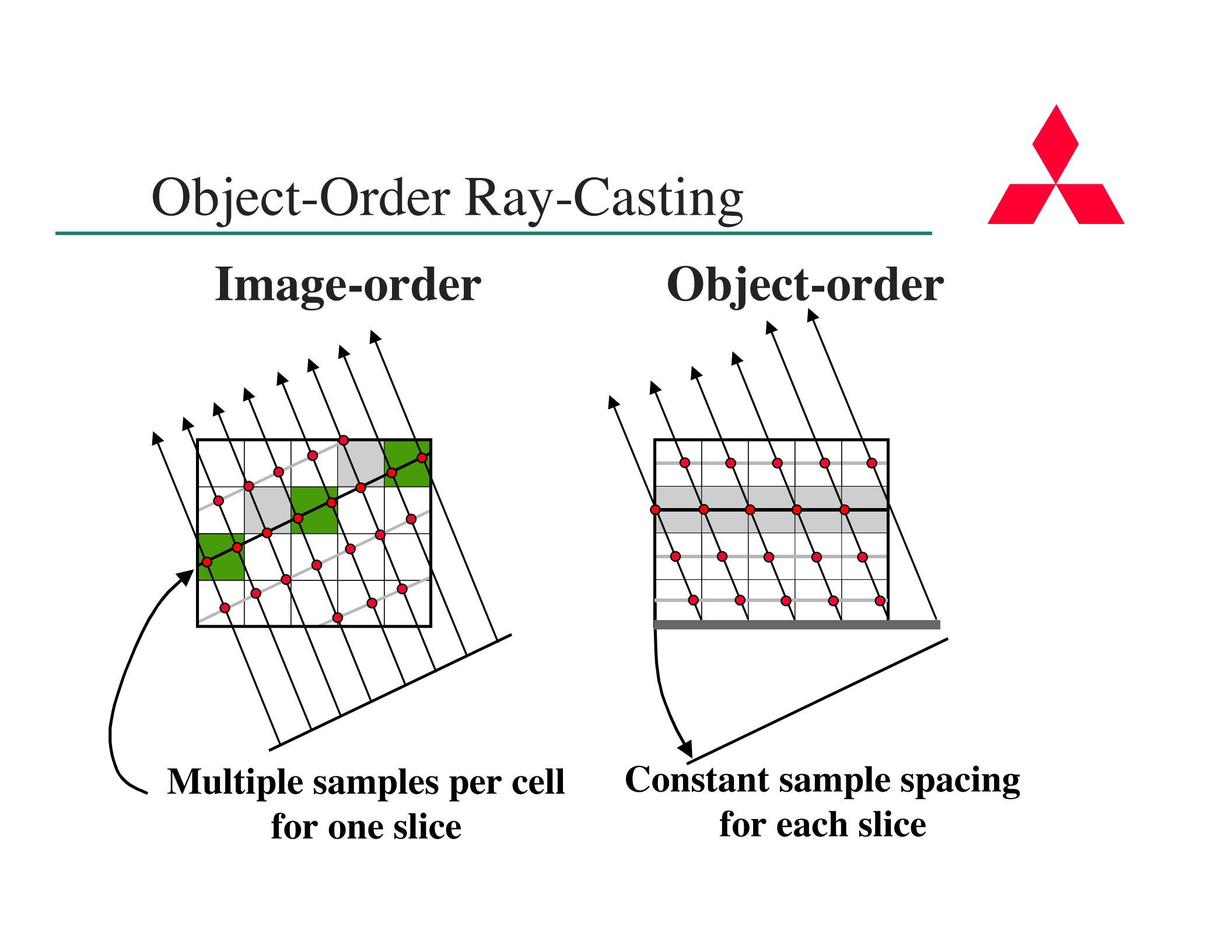
12-bit front-to-back α-blending

Maximum Intensity Projections (MIP)

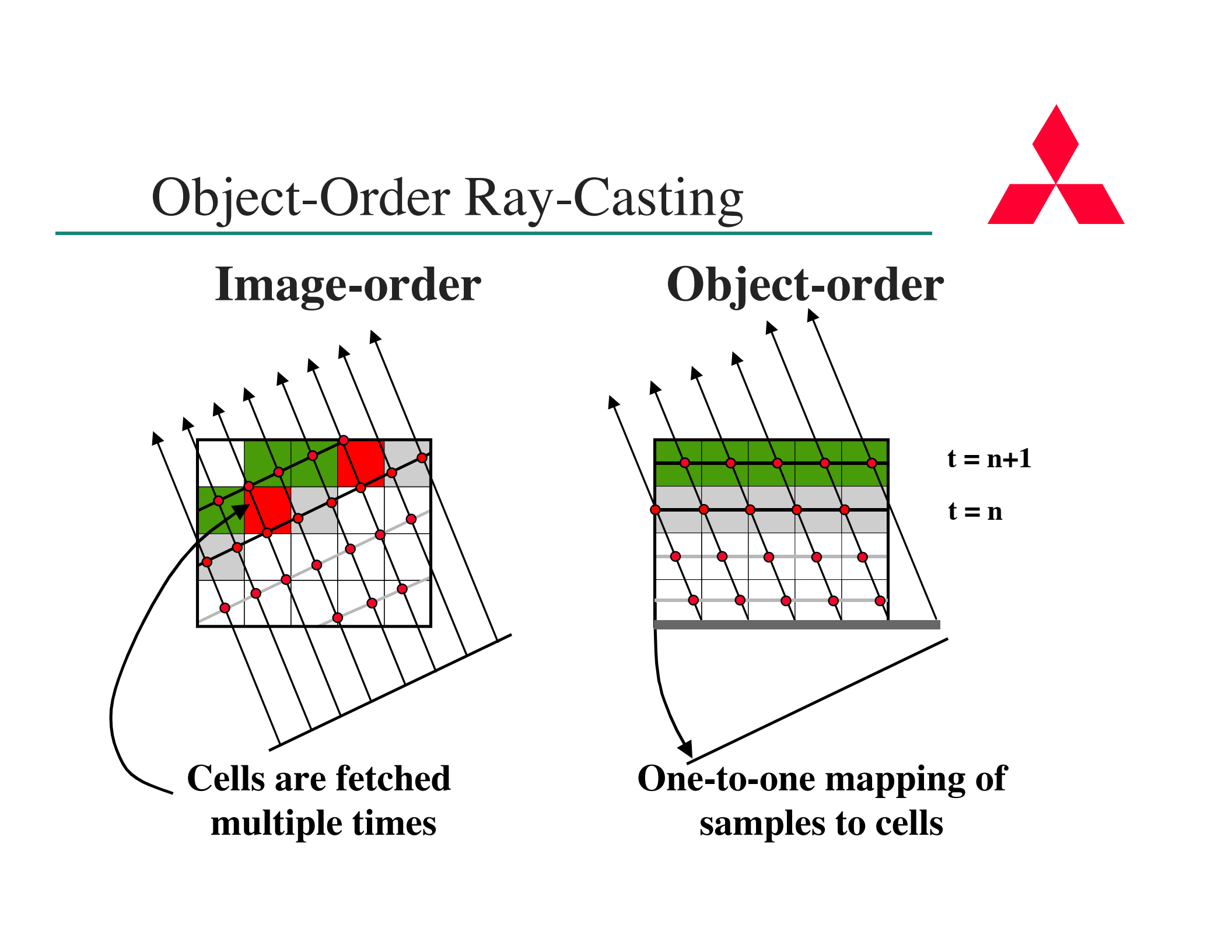
Object-Order Ray-Casting



Object-Order Ray-Casting

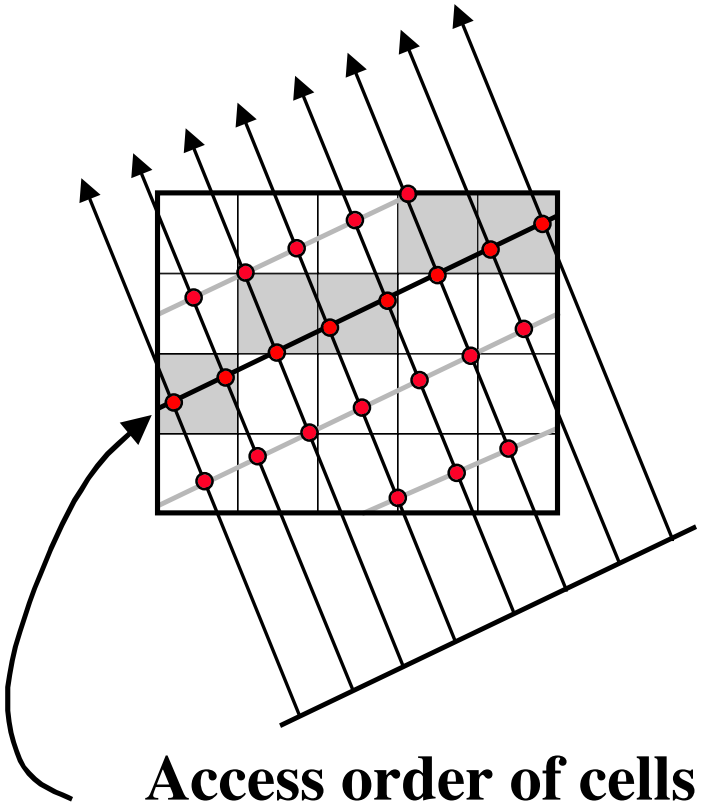


Object-Order Ray-Casting



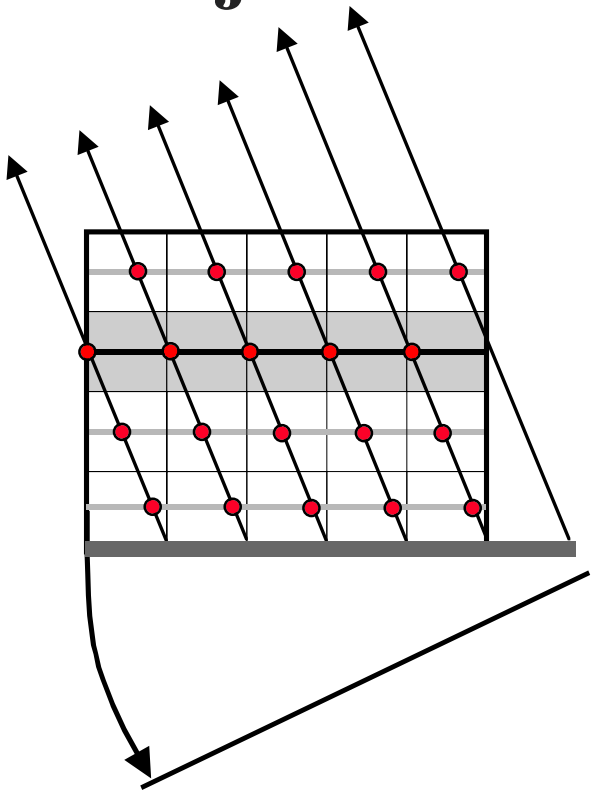
Object-Order Ray-Casting

Image-order



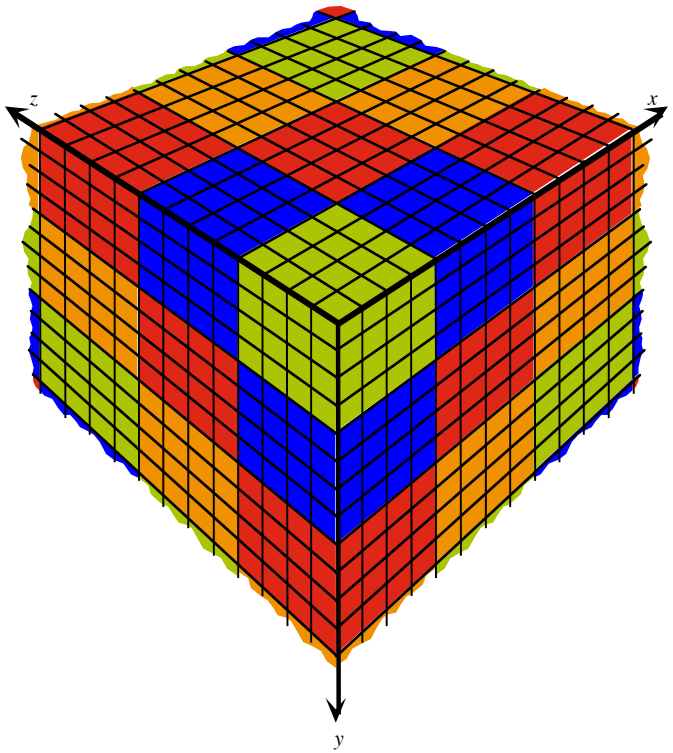
Access order of cells is as bad as random

Object-order



Linear access to cells amenable for vector memory

3D Skewing of Blocks

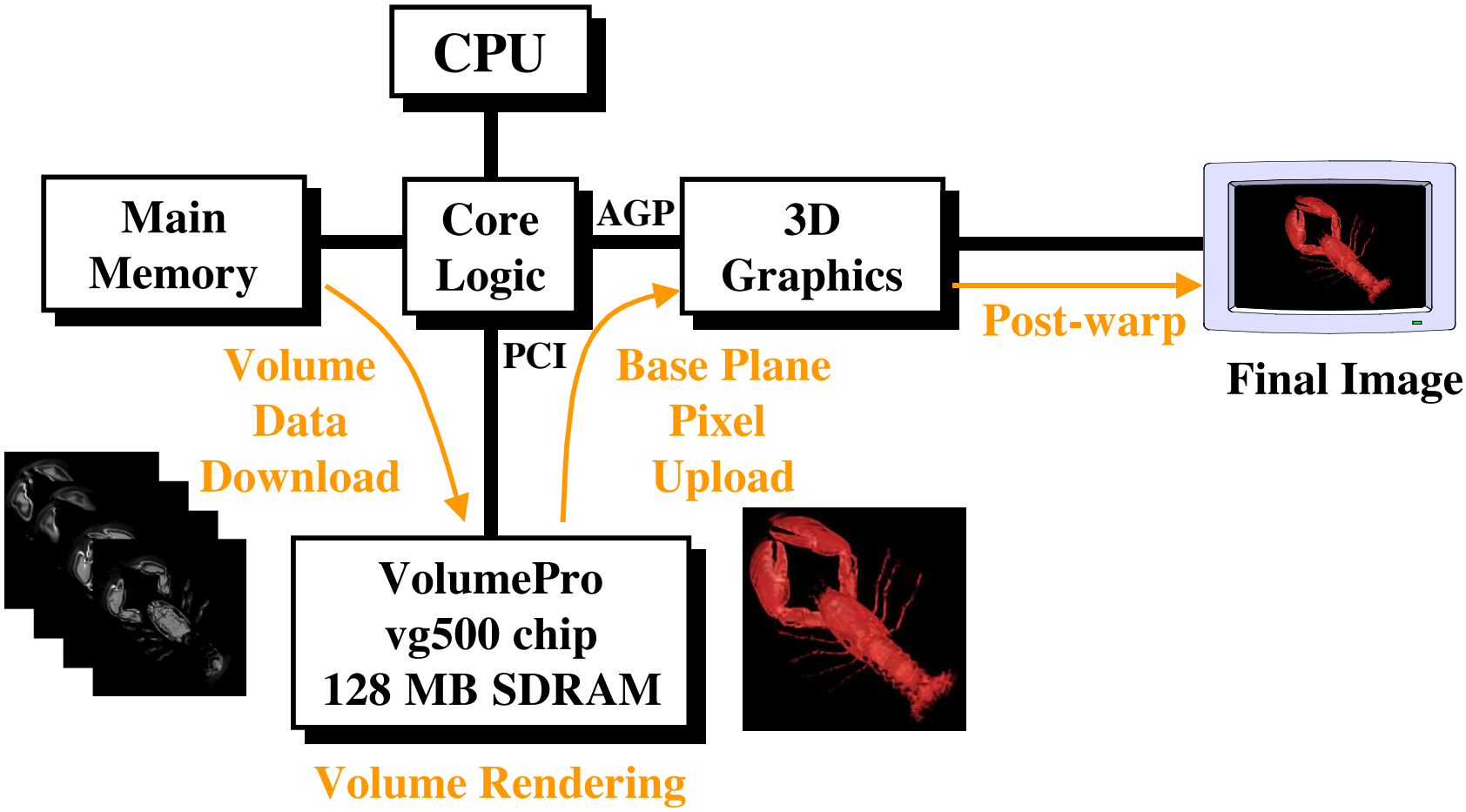


Store voxels inside a block consecutively in memory

Store blocks of voxels skewed in memory

Adjacent blocks are always in different memory modules, independent of view-direction

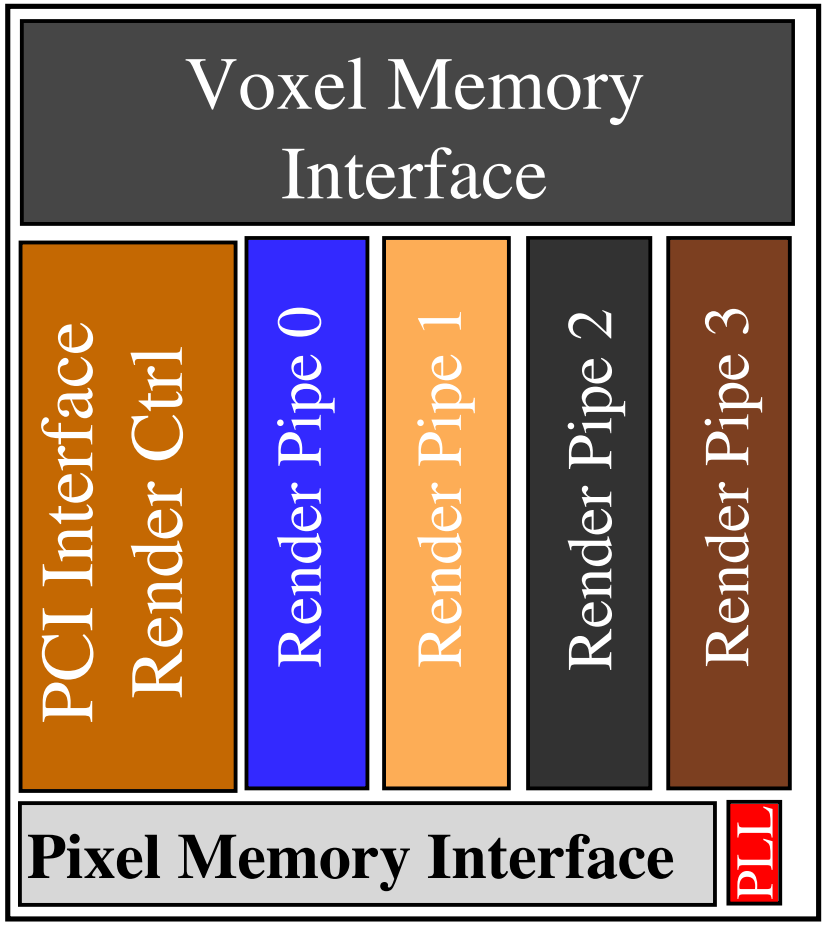
VolumePro System



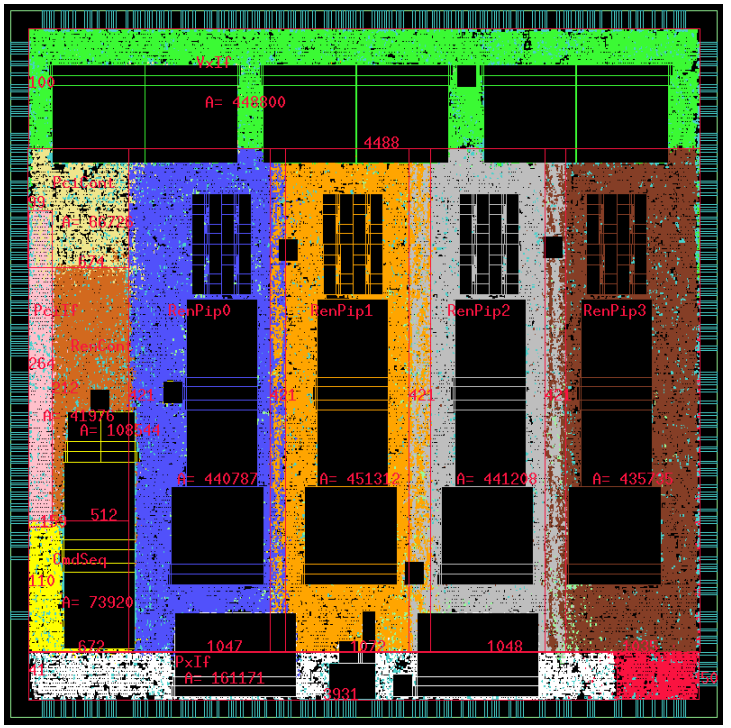
vg500 Volume Rendering ASIC

- Technology: 0.35 micron CMOS
- Die Size (mm): 13.65 x 13.65
- Package Size (mm): 32.5 x 32.5 CBGA
- Pins (signal / total): 397 / 624
- Operating Frequency: 125 Mhz
- Interfaces (Memory / PCI): 125 MHz / 66 MHz
- Voltage /Power: 3.3 V / 20.5 Watts
- Total on-chip SRAM: 2.2 M bits
- Random-logic: 795,000 gates

vg500 Volume Rendering ASIC

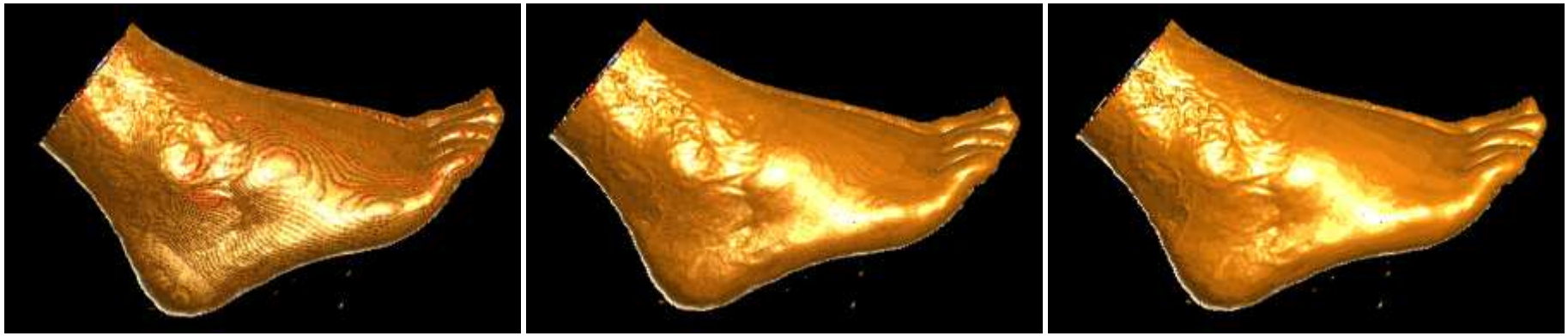


Four pipelines at 125 MHz

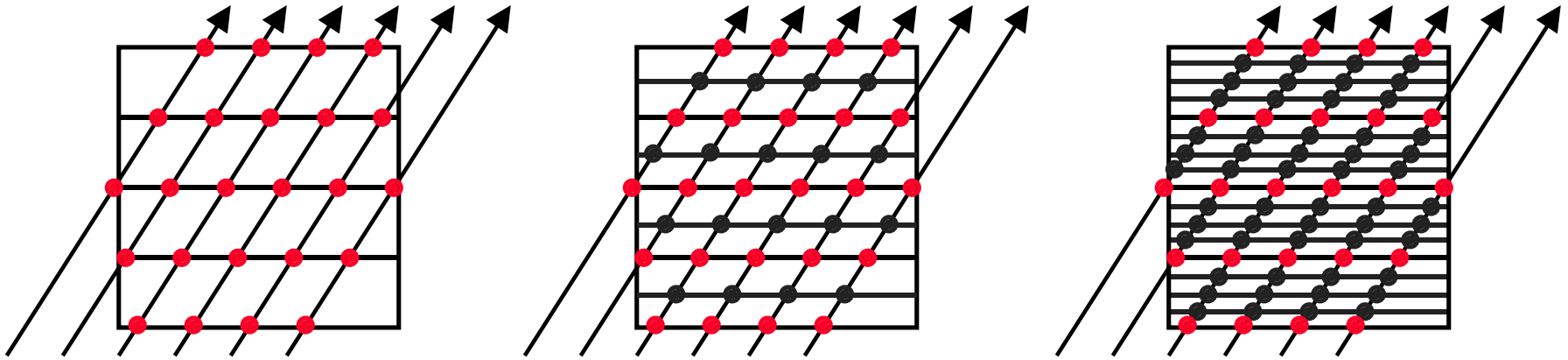


ASIC Floorplan

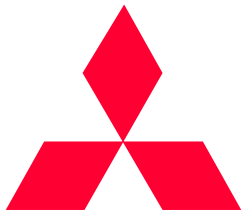
Super-Sampling Along Rays



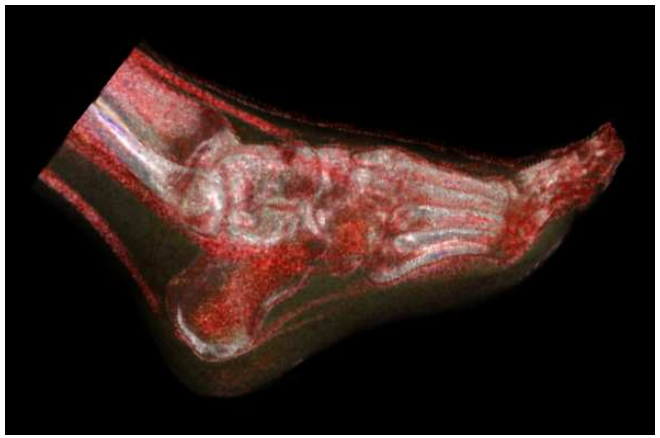
SS = 1 **SS = 2** **SS = 4**



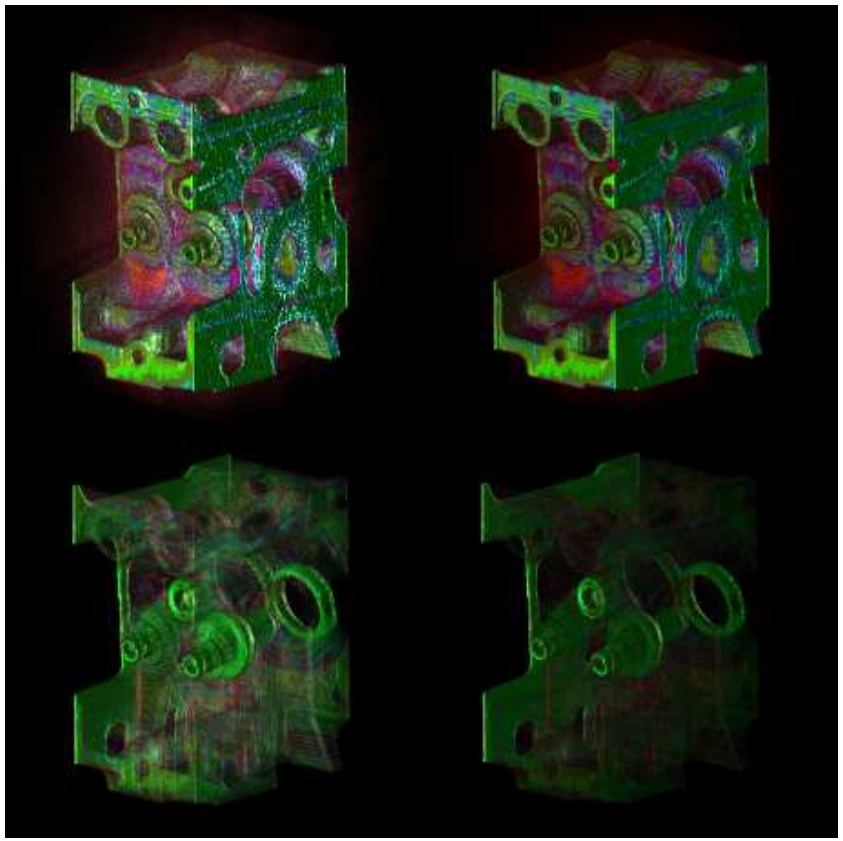
Real-Time Classification



Interactive design of color and opacity transfer functions

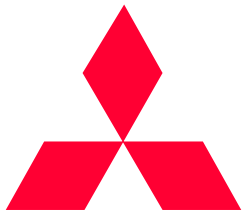


Gradient Magnitude Modulation



- Modulate opacity and illumination with the gradient magnitude
- Attenuate noisy or homogeneous regions with low gradient magnitudes
- Enhance areas of fast data changes with high gradient magnitudes

Per-Sample Lighting



Fully pipelined reflectance map shader

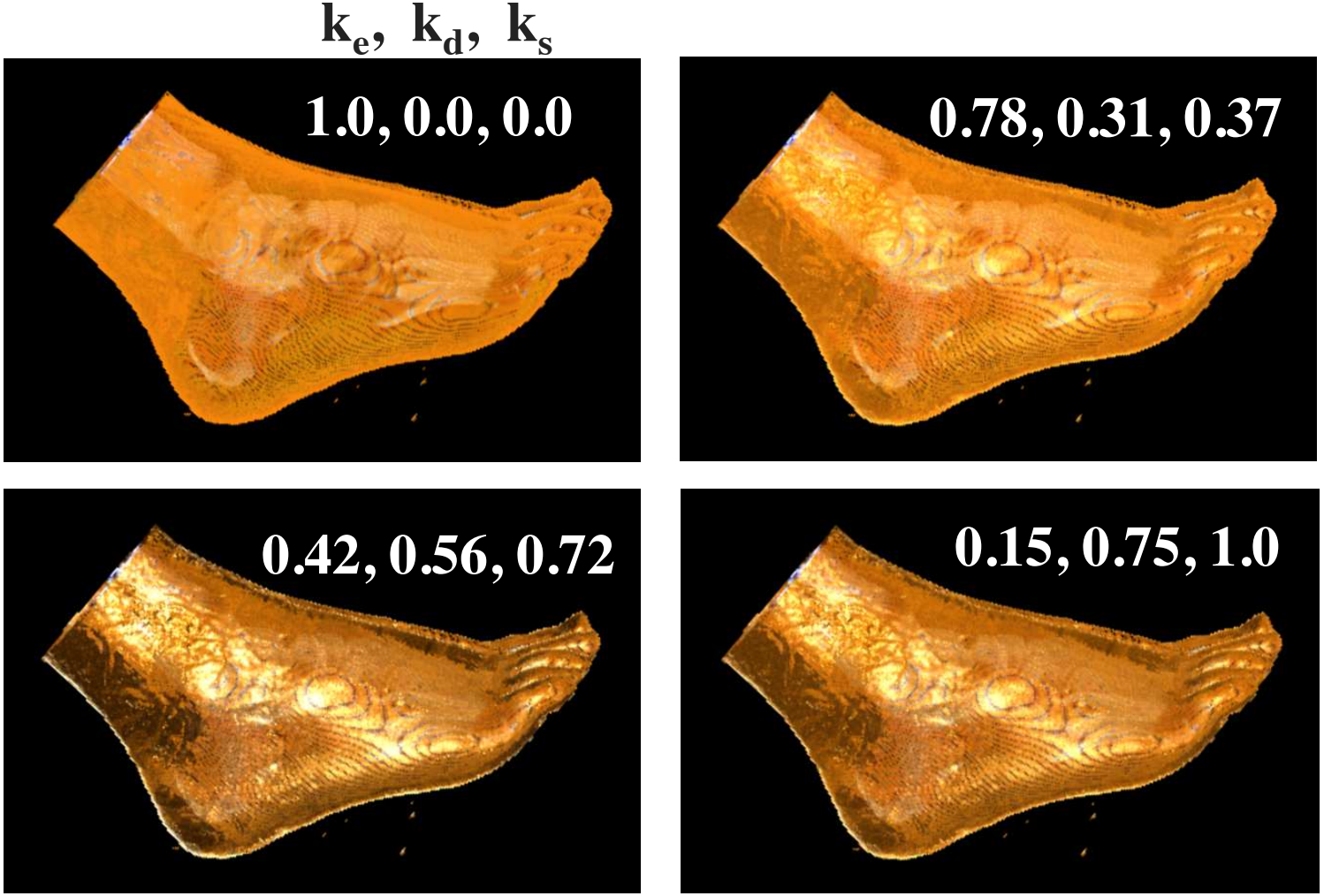
$$\text{Color} = (k_e + k_d\, I_d\, G_d)\ \text{ColorLUT}[\text{sampleValue}] + k_s\, I_s\, G_s\ \text{specularColor}$$

I_d = diffuseReflectanceLUT[Gradient]

I_s = specularReflectanceLUT[Gradient]

$G_{d,s}$ = GmLUT[GradientMagnitude]

VolumePro Phong Illumination



Summary

- First single-chip real-time volume rendering engine
- 500 million tri-linearly interpolated, Phong illuminated samples per second
- 30 frames /sec for 256^3 volumes (i.e., 16 M voxels)
- Product status:
  - Tapeout: End of 1998
  - First working silicon: April 1999
  - Shipment to customers: Started in May 1999
  - Volume production: Currently in production
  - Product rollout at SIGGRAPH ‘99 in August 1999

Future Work

- Polygon graphics embedded in volumes
- More flexible volume rendering pipeline
  - Multiple voxel formats (32bits, RGBA, etc.)
  - Segmented and multi-channel volumes etc.
- Higher performance
- Convergence of volume graphics and polygon graphics

Many thanks to...

- The VolumePro Development Team
- Forrester Cole, Harvard University
- Kevin Kreeger, SUNY Stony Brook
- Arie Kaufman, SUNY Stony Brook

VolumePro Information

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Bibliography

- H. Pfister, J. Hardenbergh, J. Knittel, H. Lauer, and L. Seiler, "*The VolumePro Real-Time Ray-Casting System*", Proceedings of SIGGRAPH 1999
- R. Osborne et. al, "*EM-Cube: An Architecture for Low-Cost Real-Time Volume Rendering*", SIGGRAPH / Eurographics Workshop on Graphics Hardware, 1997
- H. Pfister and A. Kaufman, "*Cube-4 - A Scalable Architecture for Real-Time Volume Rendering*", ACM / IEEE Symposium on Volume Visualization, 1996

Available online at http://www.merl.com/people/pfister/