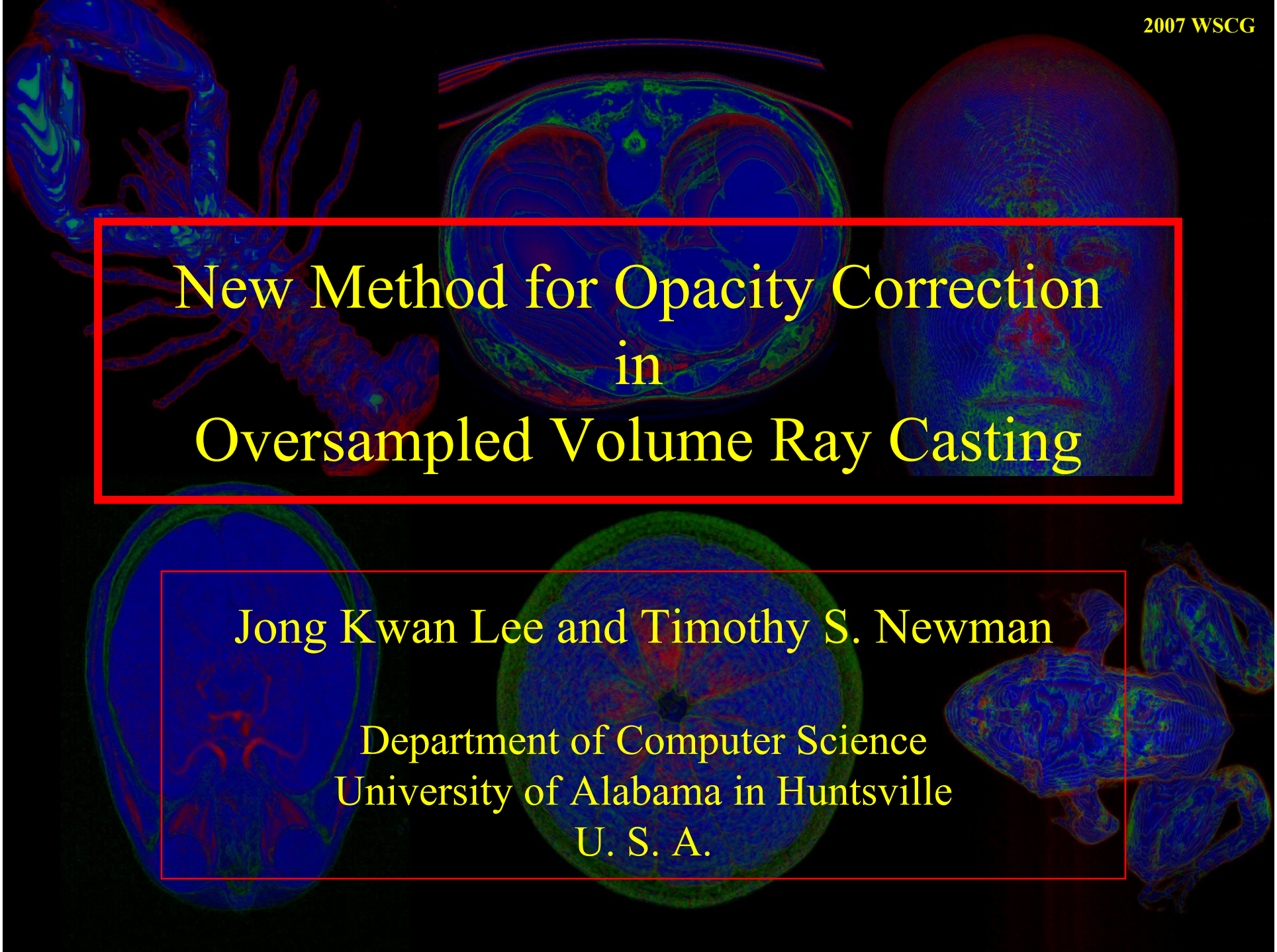
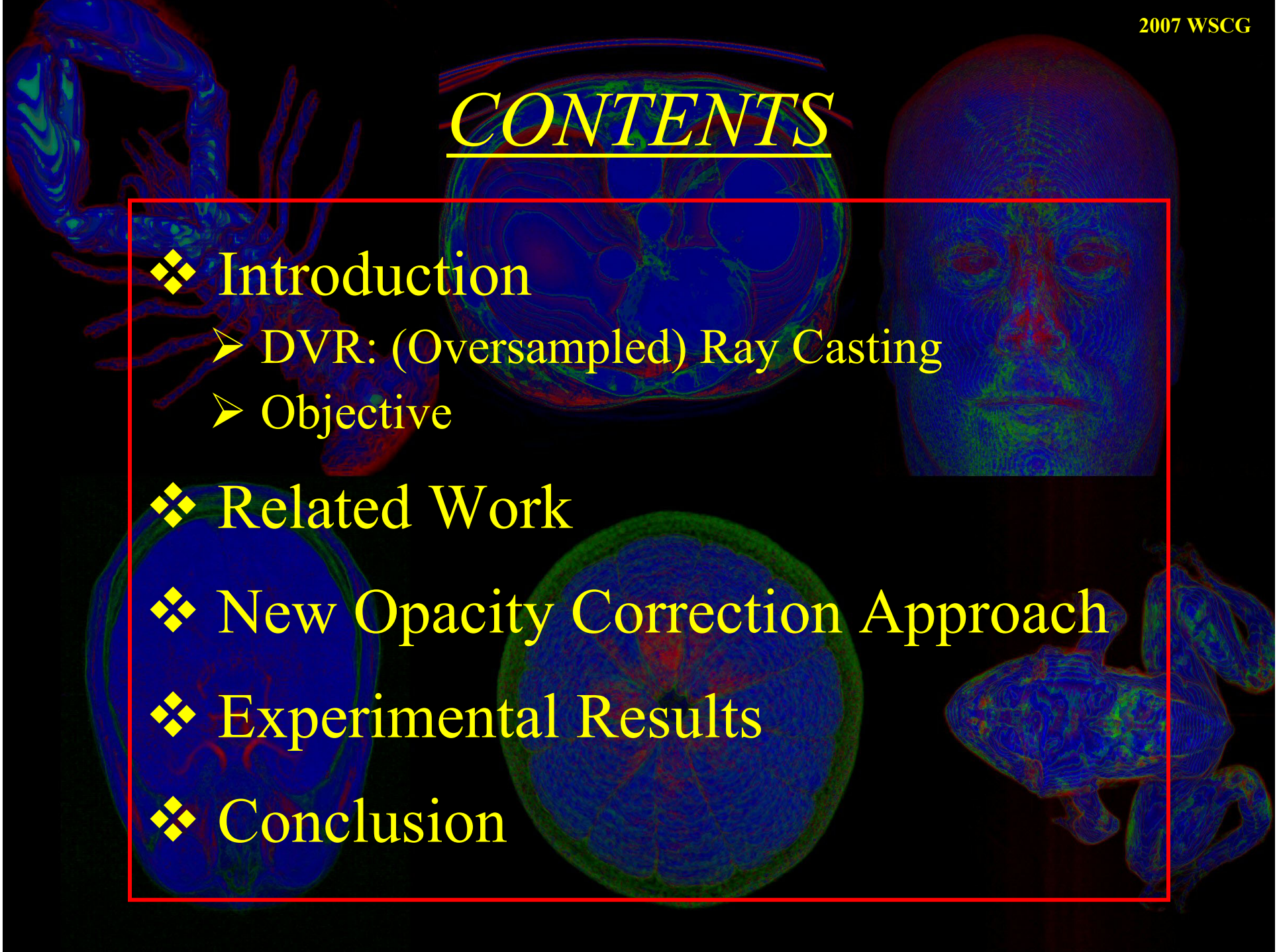


New Method for Opacity Correction in Oversampled Volume Ray Casting

Jong Kwan Lee and Timothy S. Newman

Department of Computer Science
University of Alabama in Huntsville
U. S. A.

CONTENTS



INTRODUCTION

- Volume Ray Casting
  - Direct volume rendering (DVR)
  - Composite samples (F-to-B or B-to-F)
  - # samples > Nyquist sampling freq.
- Oversampled Ray Casting
  - Multiple samples within a voxel
    → over-composited opacity
  - Objective
    → Correct opacity to avoid artifacts from over-composited opacity

RELATED WORK

- Lichtenbelt et al. [2]:
  - Assumption: homogeneous datasets
  - Motivated by Lacroute [1]
  - $\alpha' = 1 - \sqrt[N]{1-\alpha}$ (1)

    N : oversampling factor, α : original opacity, α': corrected opacity
- Lacroute [1]:
  - Opacity formula in terms of sampling spacing
  - Equivalent to Equation (1)
- [1,2]'s opacity correction is used in [3, 4]

[1] P. Lacroute, *Fast Volume Rendering Using a Shear-Warp Factorization of the Viewing Transformation*, Doctoral Dissertation (Technique Report CSL-TR-95-678), Stanford University, 1995.

[2] B. Lichtenbelt, R. Crane, and S. Naqvi, *Introduction to Volume Rendering*, Prentice Hall, Upper Saddle River, NJ, 1998.

[3] J. P. Schulze, M. Kraus, U. Lang, and T. Ertl, "Integrating Pre-Integration into the Shear-Warp Algorithm," *Proc., Third Int'l Workshop on Volume Graphics*, Tokyo, pp. 109-118, July, 2003.

[4] M. Weiler, R. Westermann, C. Hansen, K. Zimmerman, and T. Ertl, "Level-Of-Detail Volume Rendering via 3D Textures," *Proc., 2000 IEEE Symp. On Volume Visualization*, Salt Lake City, pp. 7-13, 2000.

NEW OPACITY CORRECTION APPROACH

- Generalize **derivation** of Equation (1)
- No homogeneity assumption

- E.g., Composited transparency

  for oversampling x2 within a voxel:

  - $(1-\alpha_{u1}) = (1-p\alpha_{o1}) \times (1-p\alpha_{o2})$, where

    α : opacity, u, o : unit- & over- sampling

    Rearranging → $F : (\alpha_{o1}\alpha_{o2})p^2 - (\alpha_{o1}+\alpha_{o2})p + \alpha_{o1} = 0.$

    $(\alpha_{u1} = \alpha_{o1})$

NEW CORRECTION

- Generalization

$$(-1)^0\left(\prod_{s=1}^{N}\alpha_{os}\right)p^N+(-1)^1\left\{\sum_{t=1}^{N}\left(\prod_{s=1,s\neq t}^{N}\alpha_{os}\right)\right\}p^{N-1}$$

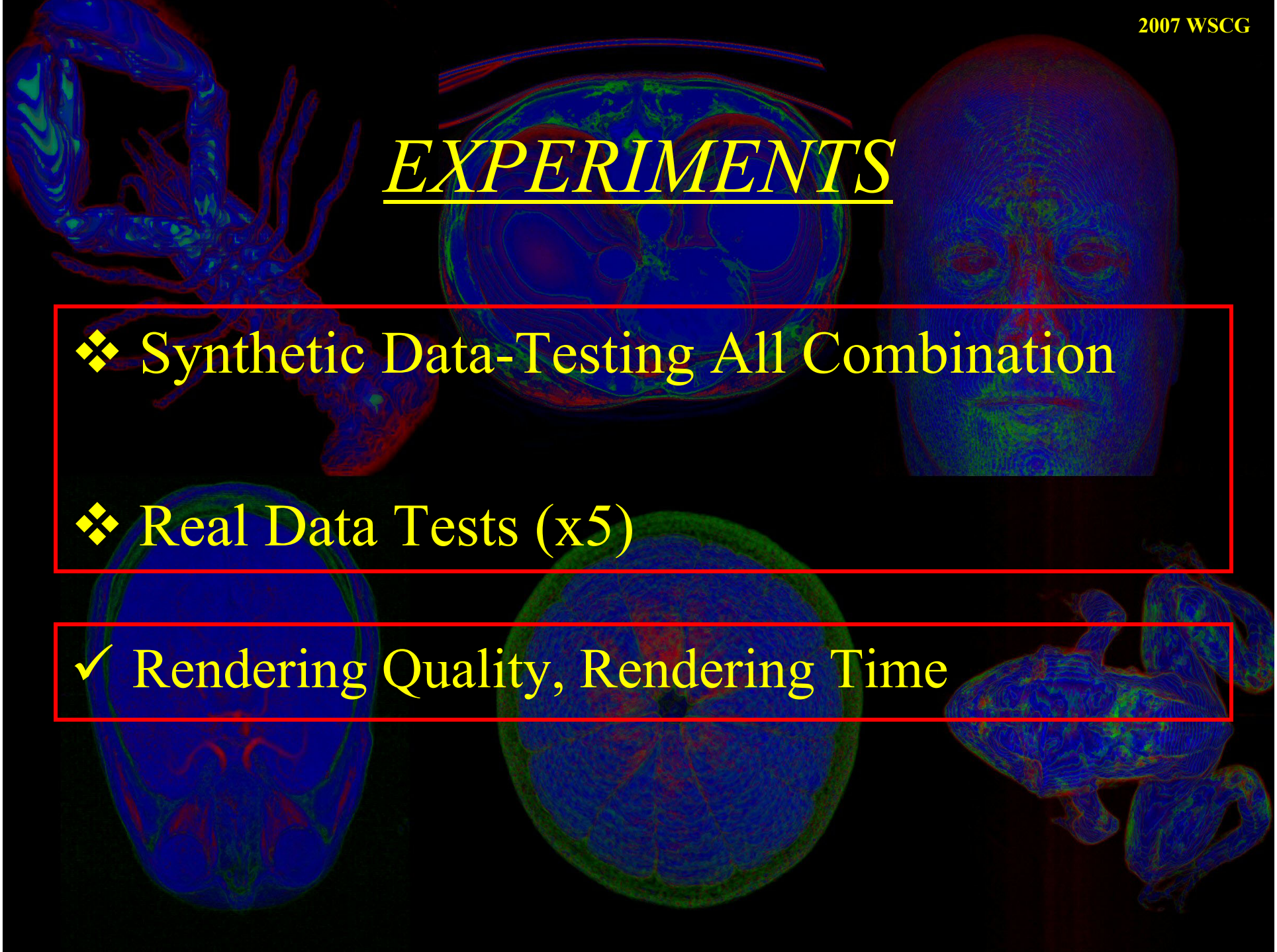
$$+(-1)^2\left\{\sum_{u=1}^{N-1}\sum_{t=u+1}^{N}\left(\prod_{s=1,s\neq t,u}^{N}\alpha_{os}\right)\right\}p^{N-2}+(-1)^3\left\{\sum_{v=1}^{N-2}\sum_{u=v+1}^{N-1}\sum_{t=u+1}^{N}\left(\prod_{s=1,s\neq t,u,v}^{N}\alpha_{os}\right)\right\}p^{N-3}$$

$$+\cdots+(-1)^N\alpha_{o1}p^0=0$$

- Solve for p ($0 <= p <= 1$): new correction factor
- Accelerate computation via deg. 2 poly. fitting
  - Approximation: $\hat{F}(p)=A\times p^2+B\times p+C$
  - Passing through $p_0=0.0,\quad p_1=0.5,\quad p_2=1.0.$

New Opacity Correction Approach

- Computational advantages
  - Avoid $\sqrt[N]{1 - \alpha}$ operations
  - Multiple use of new correction factor, p
  - Reuse of inverse matrix



EXPERIMENTS

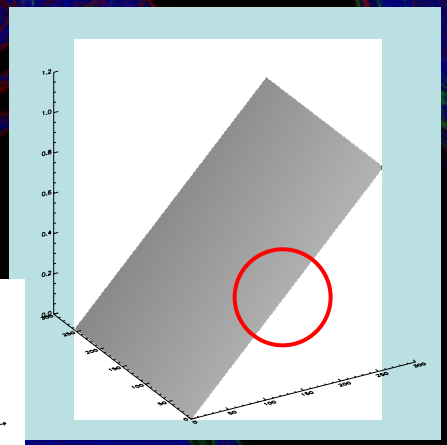
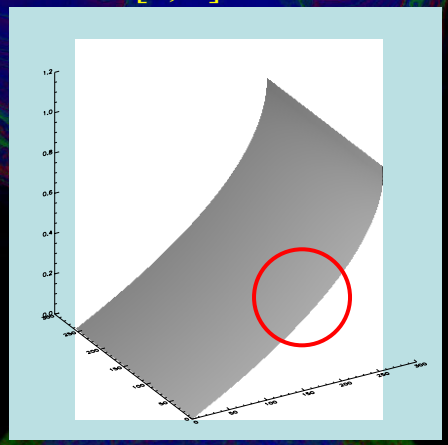
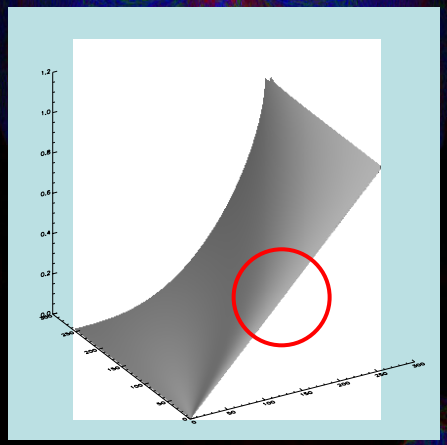
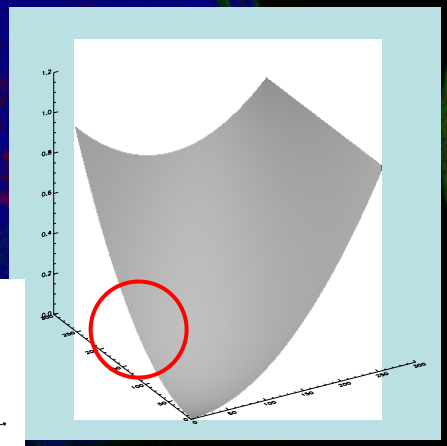
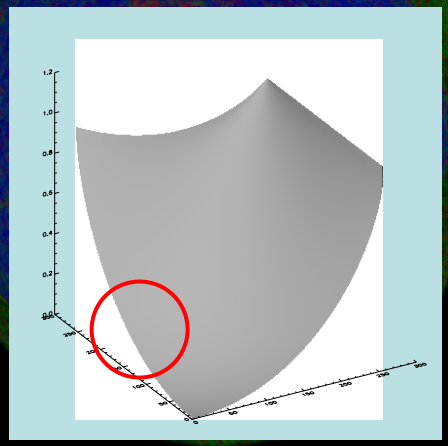
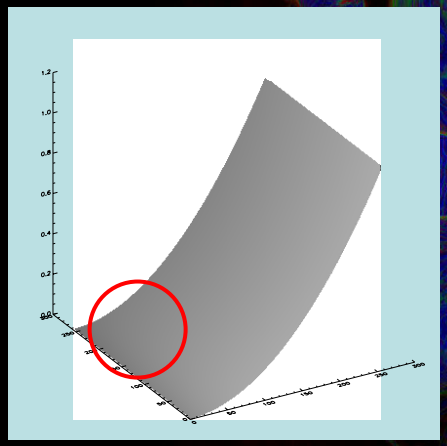
- Synthetic Data-Testing All Combination
- Real Data Tests (x5)

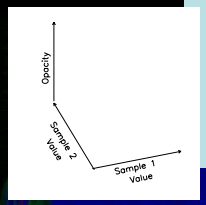
- ✓ Rendering Quality, Rendering Time

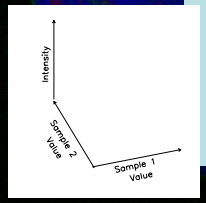
EXPERIMENTAL RESULTS I

COMPARISONS OVER ALL POSSIBLE COMBINATIONS OF SAMPLE VALUES (x2)

* SYNTHETIC DATA *

	no correction	w/ [1, 2] correction	w/ new correction
RESULTANT OPACITY			
COMPOSITED INTENSITY			

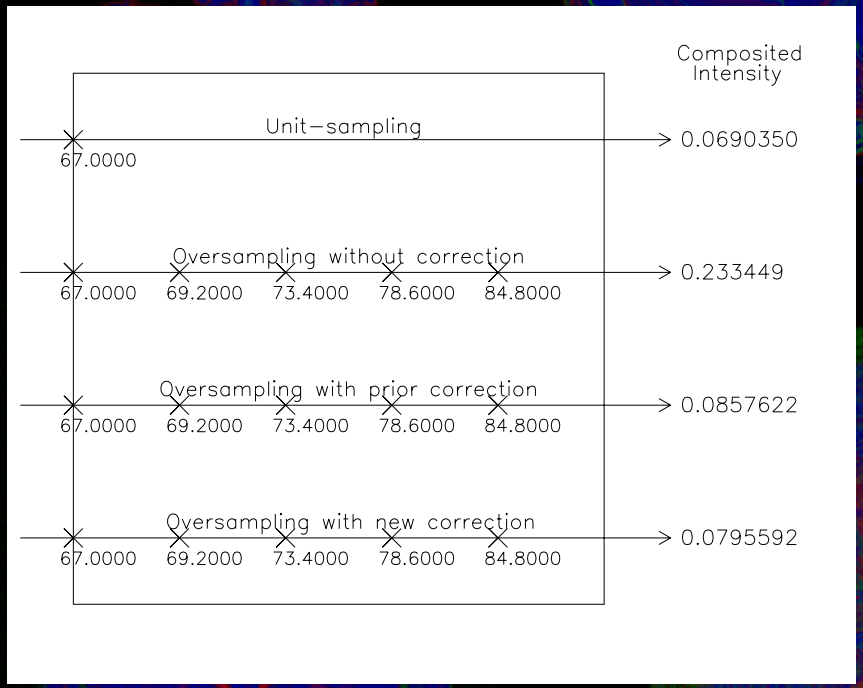


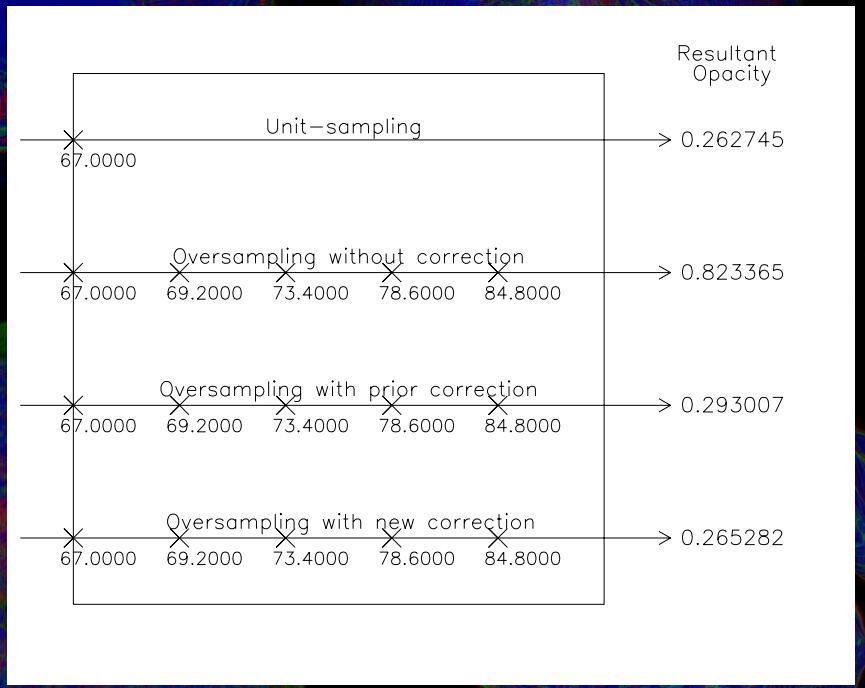


EXPERIMENTAL RESULTS II

COMPARISON OF COMPOSITED OPACITIES & INTENSITIES FOR A VOXEL

* AN EXAMPLE *

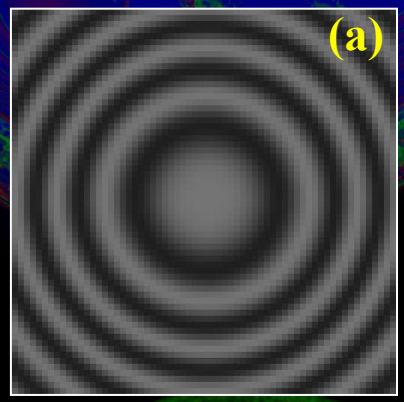


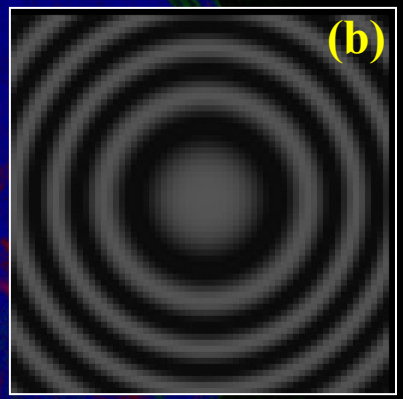


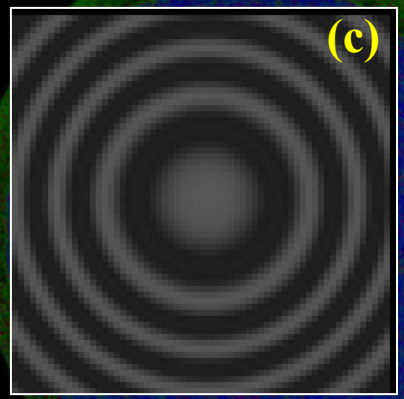
An example of comparison of composited intensities & resultant opacities for a voxel: Rays within a voxel for unit-sampling, oversampling without correction, oversampling with [1,2]'s correction, and oversampling with new correction from top to bottom, respectively

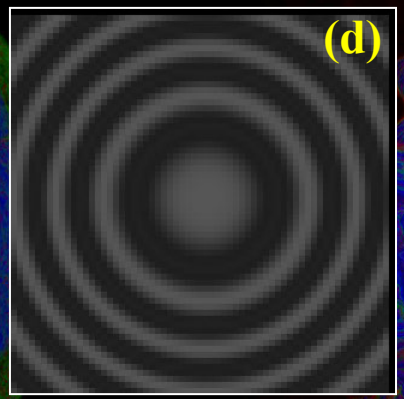
EXPERIMENTAL RESULTS III

* COMPARISON vs. BENCHMARK *









Marschner-Lobb dataset renderings (64x64x64) from (a) analytical integration and (b-d) oversampling (5 times) volume ray casting, (b) without opacity correction, (c) with [1,2]'s correction (d) with new opacity correction

COMPARISON RENDERINGS I


(a)


(c)

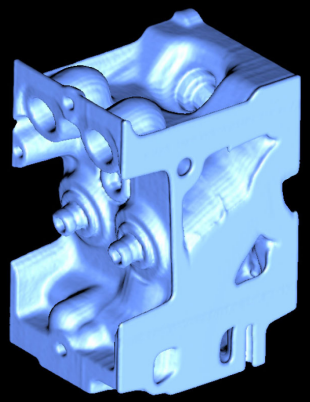

(b)


(d)

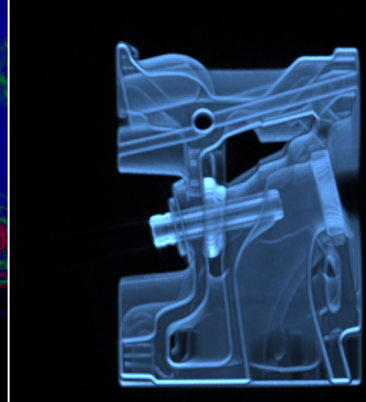
Lobster renderings (120x120x34, CT) from (a) Marching Cubes isosurfacing and (b-d) oversampling (5 times) volume ray casting, (b) without opacity correction, (c) with [1,2]'s correction (d) with new opacity correction

COMPARISON RENDERINGS II

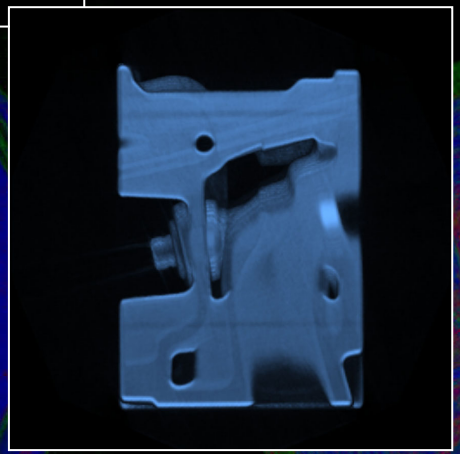
(a)



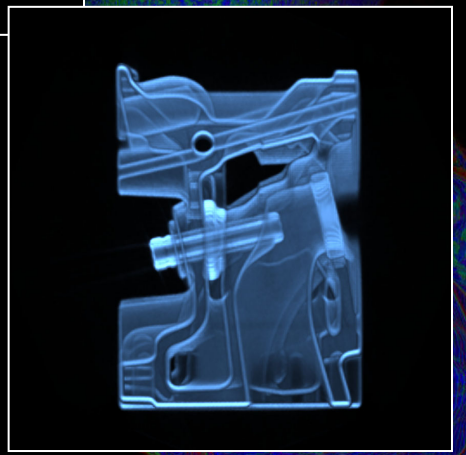
(c)



(b)

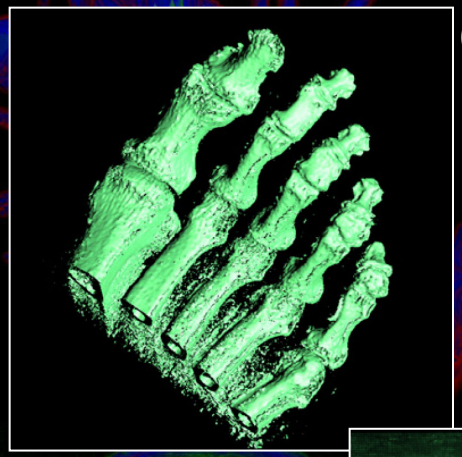


(d)

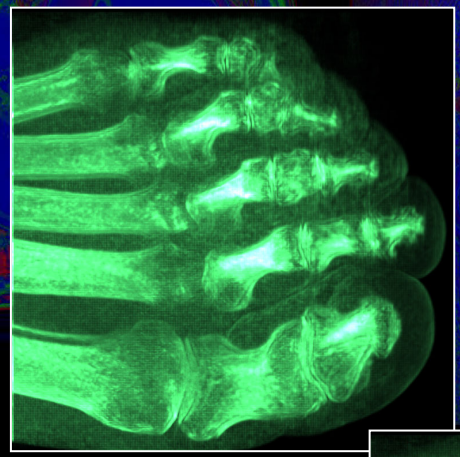


Engine block renderings (256x256x256, CT) from (a) Marching Cubes isosurfacing and (b-d) oversampling (5 times) volume ray casting, (b) without opacity correction, (c) with [1,2]'s correction (d) with new opacity correction

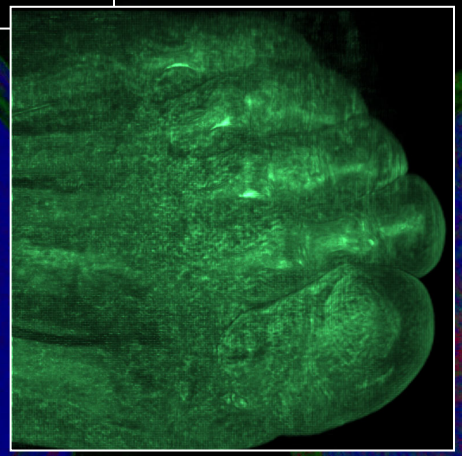
COMPARISON RENDERINGS III



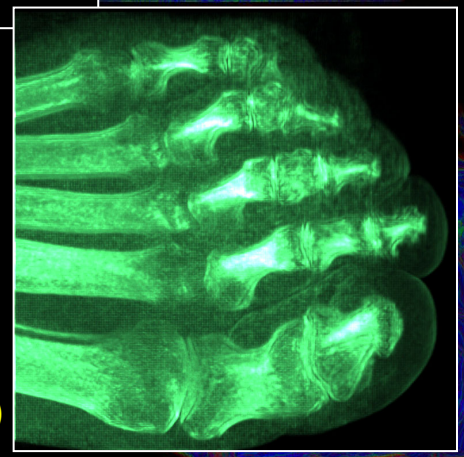
(a)



(c)



(b)



(d)

Foot renderings (256x256x256, CT) from (a) Marching Cubes isosurfacing and (b-d) oversampling (5 times) volume ray casting, (b) without opacity correction, (c) with [1,2]'s correction (d) with new opacity correction

APPROXIMATION ERROR

Fitting Error, New Opacity Correction,
Lobster Dataset (120x120x34, CT)

Fitting Error	Avg.	Std. Dev.	> 0.1
x5 Oversampling	0.0031	0.011	0.088%

PROCESSING TIME

Opacity Correction *Speedup*

New opacity correction vs. [1,2]'s correction for 40 real datasets

x5 oversampling	Max.	Avg.	Min.
Speedup	14.7	12.4	6.8

Overall *VRC Rendering Speedup*

New opacity correction vs. [1,2]'s correction for 40 real datasets

x5 oversampling	Max.	Avg.	Min.
Speedup	2.00	1.85	1.77

CONCLUSION

- New opacity correction
  - Generalization of existing opacity correction
    - ✓ Similar rendering quality
    - ✓ Faster rendering (~2 times overall)
  - No dataset homogeneity assumption
- Future work:
  - Even faster opacity correction?
  - Better accuracy?