Interactive Visualization Techniques for Complex Data Analysis

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(joined July 1st, 2011)

Funded by grants/gifts from NSF, NIH, DOE, IBM, Sandia, LLNL, and ExxonMobil

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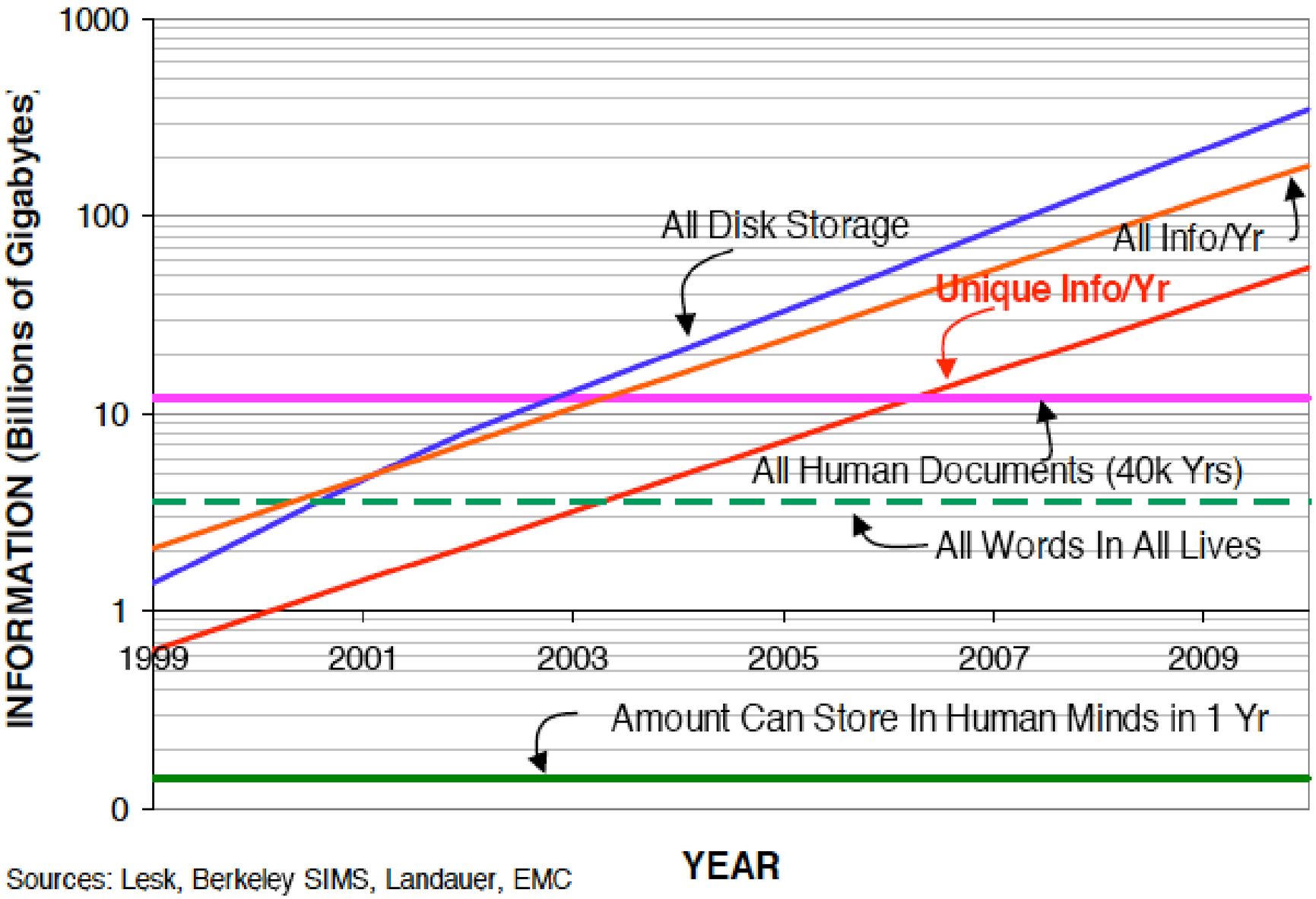
Information Big Bang



Sources: Lesk, Berkeley SIMS, Landauer, EMC

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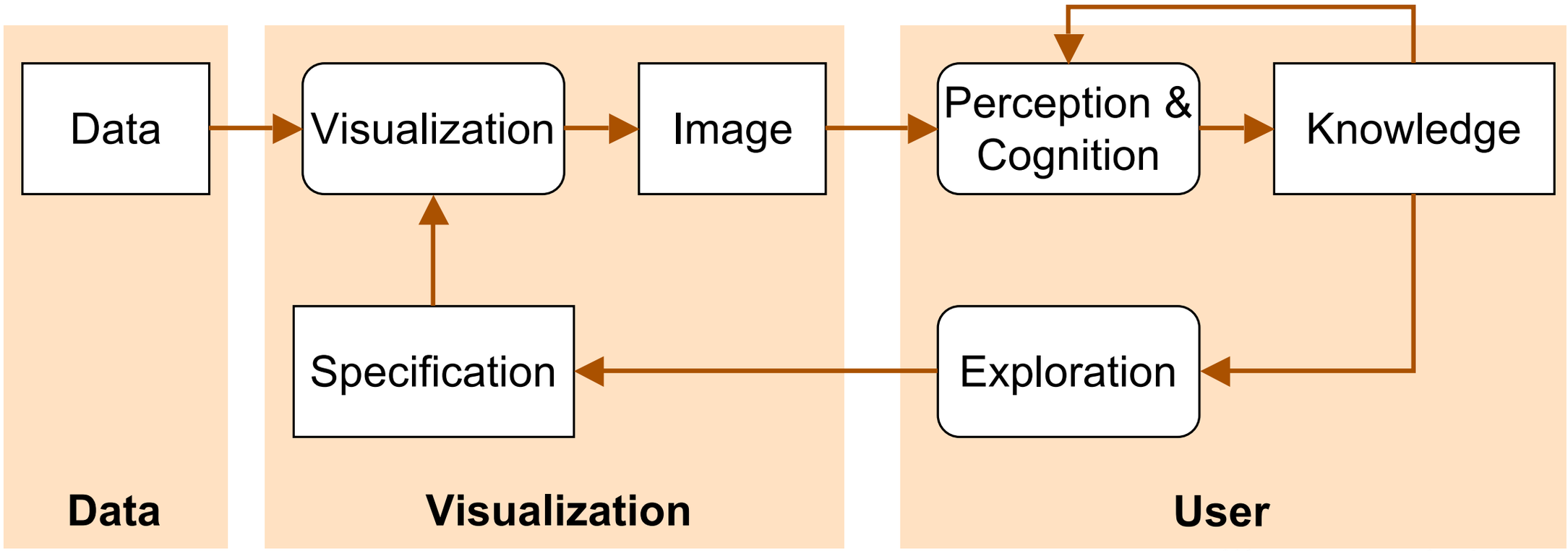
Data Exploration through Visualization



J. van Wijk, IEEE Vis 2005

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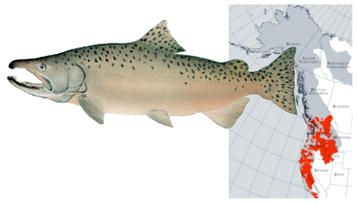
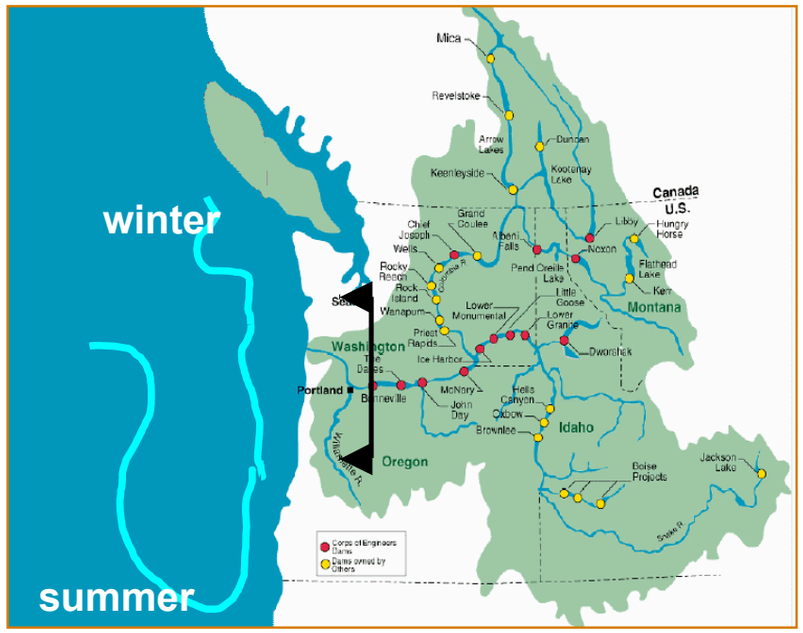
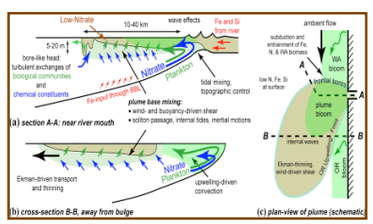
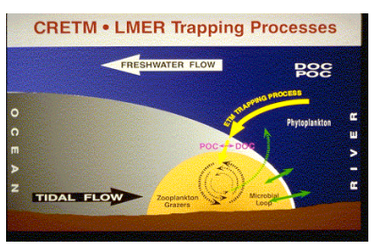
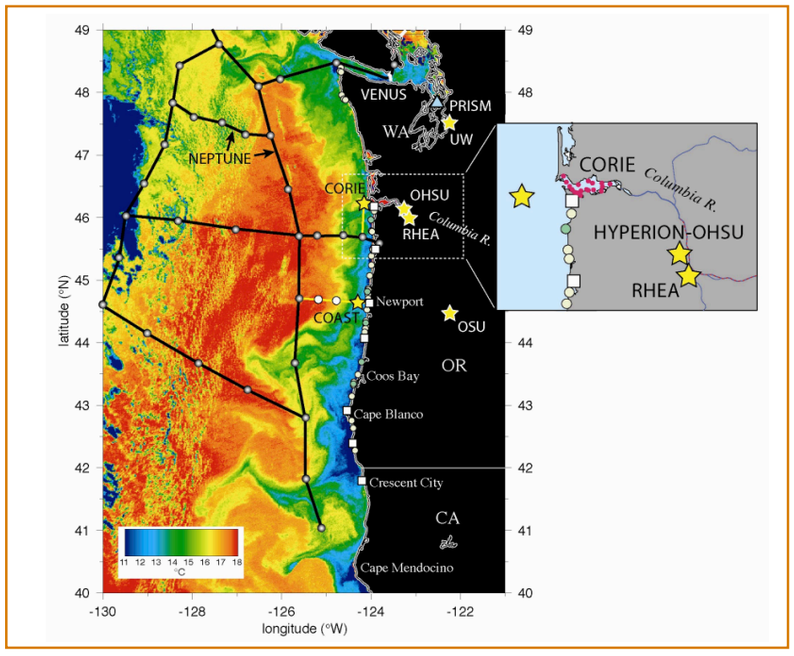
Ocean, Coastal, and Coastal-Margin Observatories…











… are EOFS for marine and estuarine systems

- Initiated in 1996, CORIE is a coastal margin observatory designed as a multi-purpose scientific and regional infrastructure for the Columbia River
- CORIE crosses traditional boundaries extending from freshwater to deep ocean
- CORIE has diversified user base and impact - consistent with regional needs
- NOAA Fisheries (NWFSC) has been a major partner
- Recent perspectives:
  - NEPTUNE
  - PNW observatory/SATURN
  - Coastal Storms Initiative

CORIE: Modeling System

VIS 2003

Short waves

Ocean circulation

Forcings

(NWS)

River discharges

Eastern North Pacific tides

(NCEP and OSU)

Atmospheric forcings (wind, pressure, heat exchange)

Typical Δt : 1.5 min

Circulation database

- **Contemporary**
  (Goal: 90-91, 96+)
- **Pre-development**
- **Scenarios**
- **Calibration**

Daily forecasts

Bathymetry

Codes

Data assimilation

08:00 PST 06/06/00

Simulations of circulation

In-situ data (CORIE, …)

Remote sensing

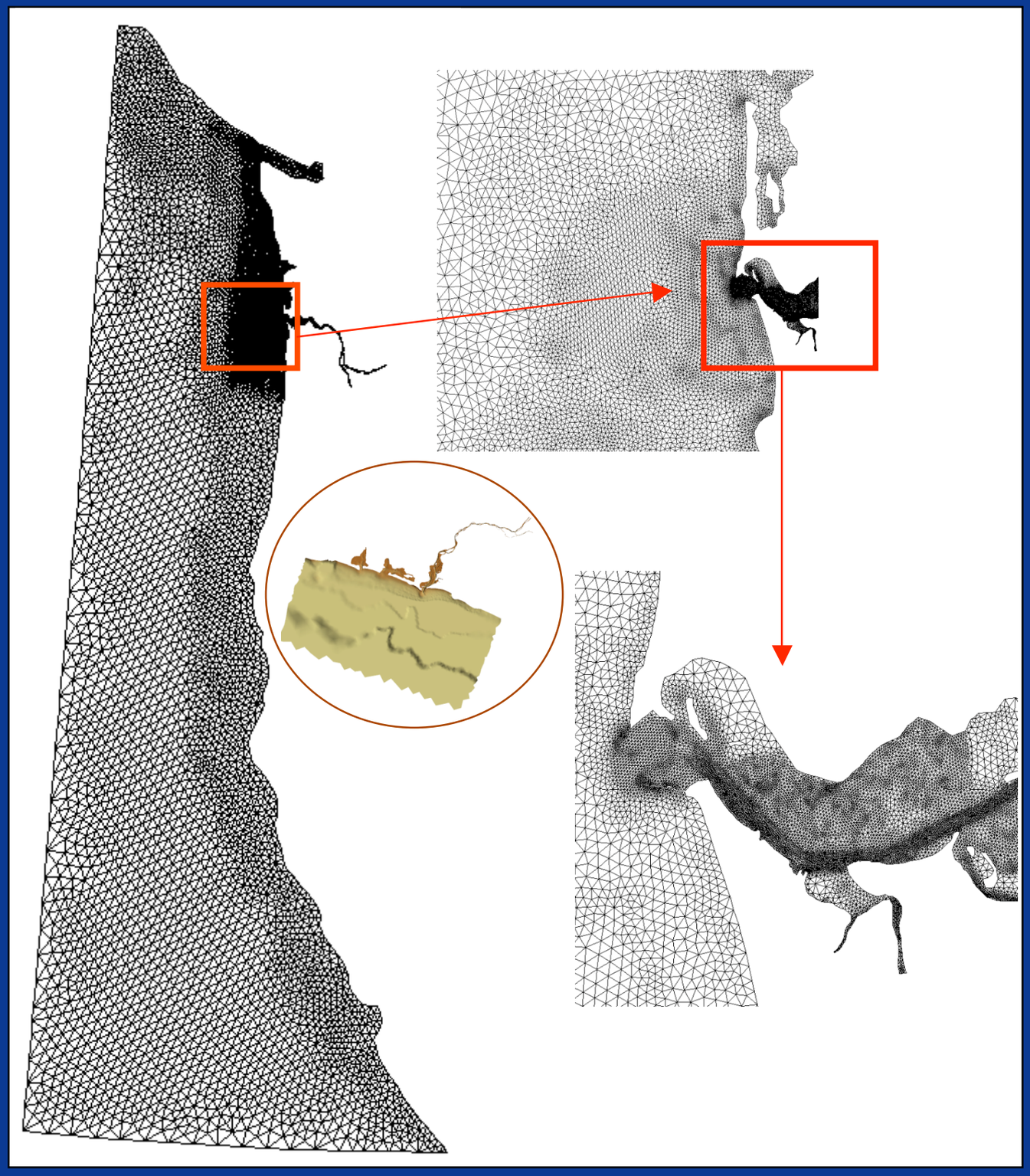
Quality Controls

. . .

- Sediments
- Lower food web
- …

Data products

CORIE: Modeling System



Integrates key regions of interest

- Freshwater to deep ocean
- Emphasis on estuary and plume

Grid characteristics

- unstructured in horizontal
  - 30,001 nodes, 55,880 elements
- Z-coordinates in vertical
  - 62 vertical layers
- ~2-million total prism faces

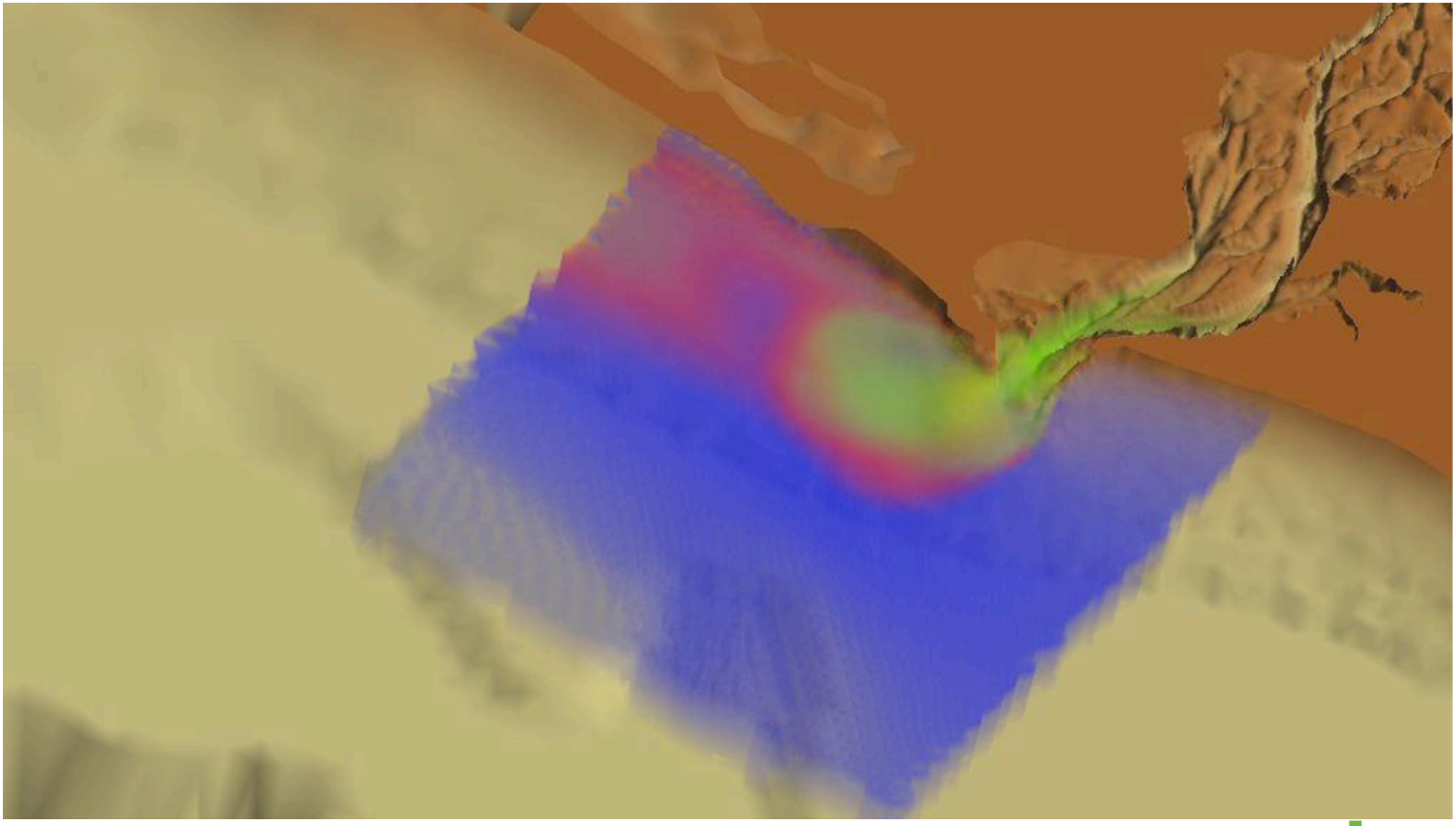
Computational infrastructure

- 20 Intel dual-CPU nodes (2.4 Ghz, 4 Gb)
- 16TB primary storage
- Code parallelization in progress

Noteworthy

- ~3x faster than real time in a single CPU Intel processor, for Δt=1.5 min
- ~0.5 TB of storage for one-year simulation @ 15 min sampling

Fresh Water Plume



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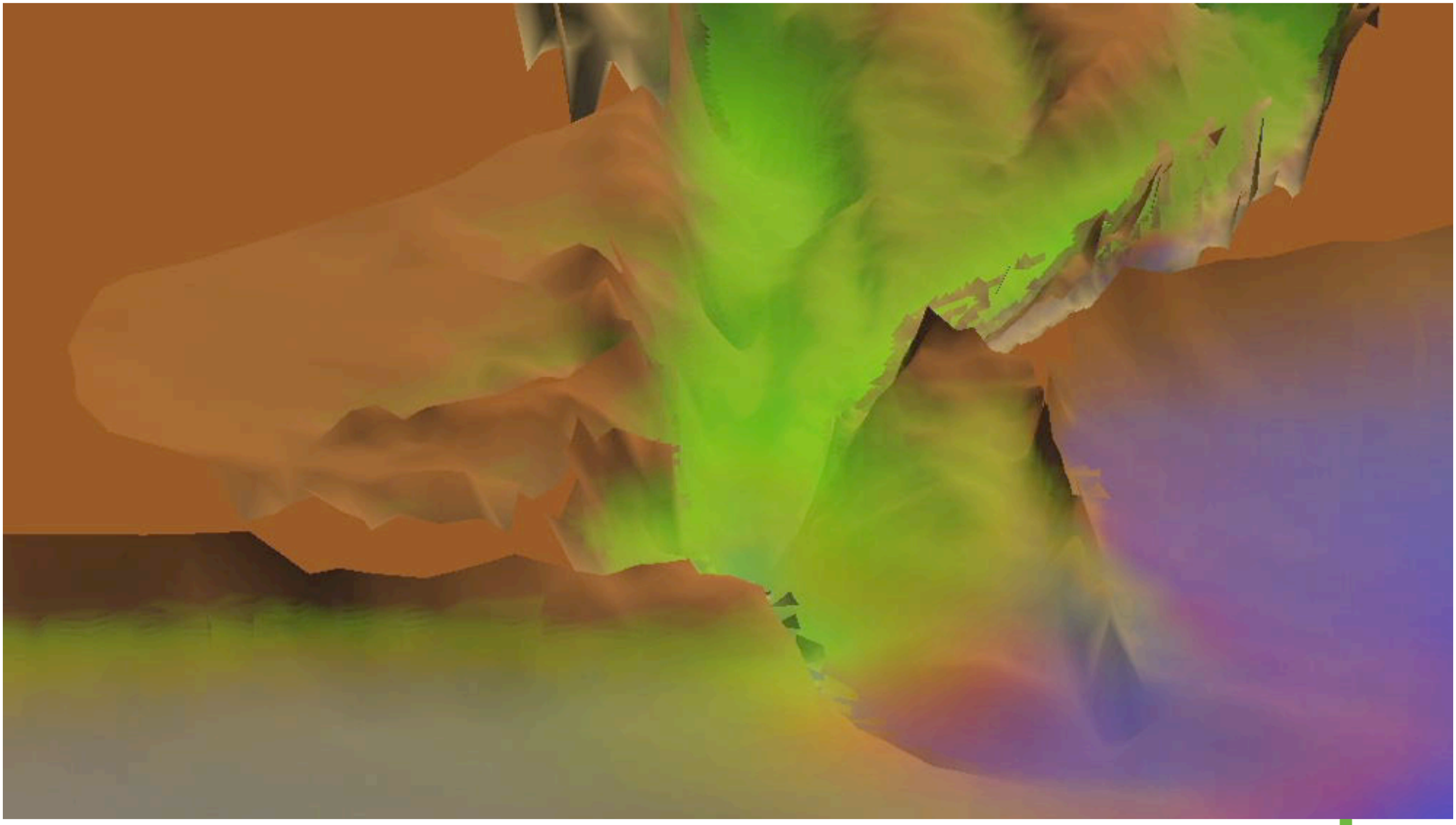
Salinity Intrusion



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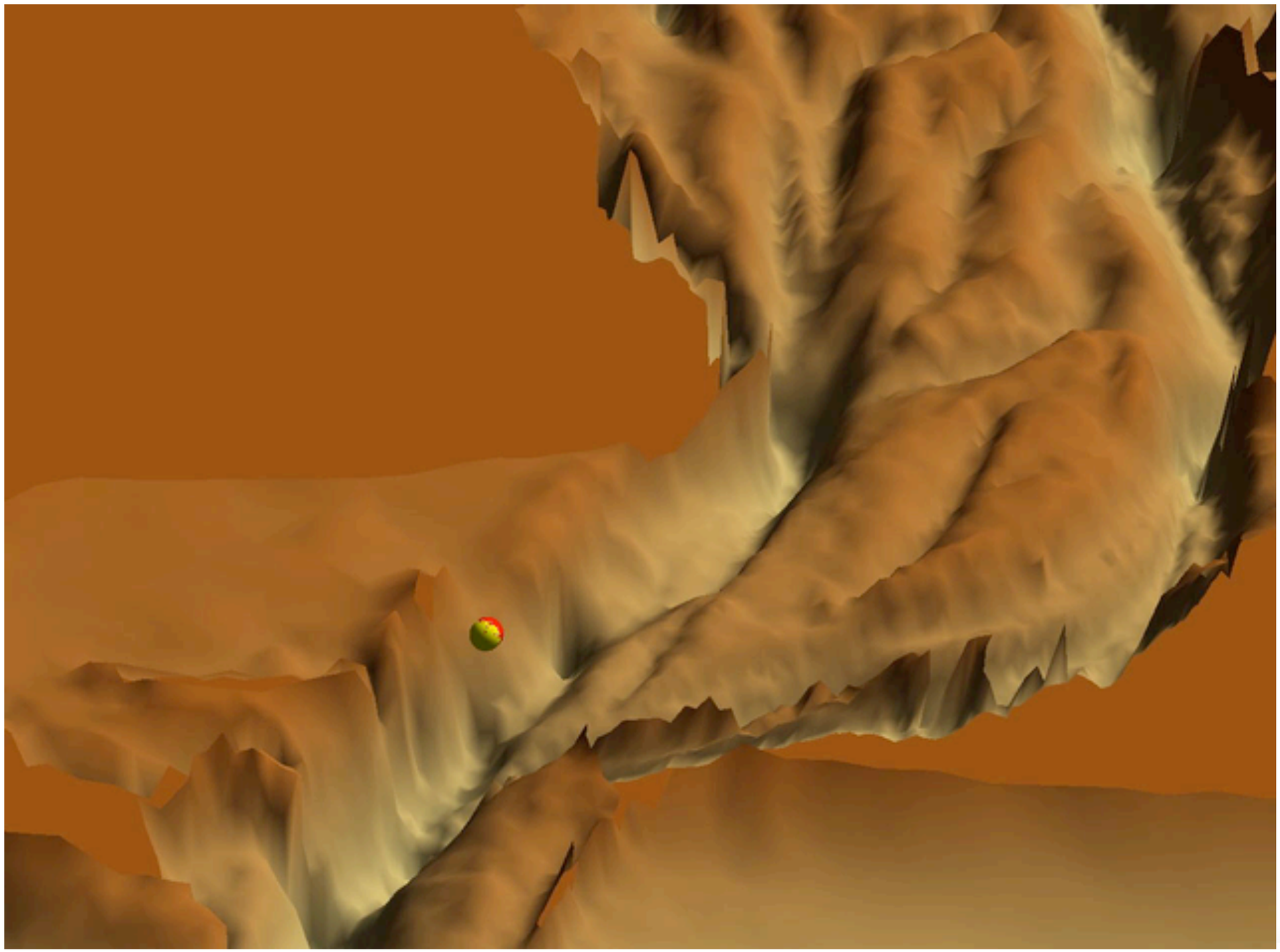
Quantifying Accuracy & Uncertainty



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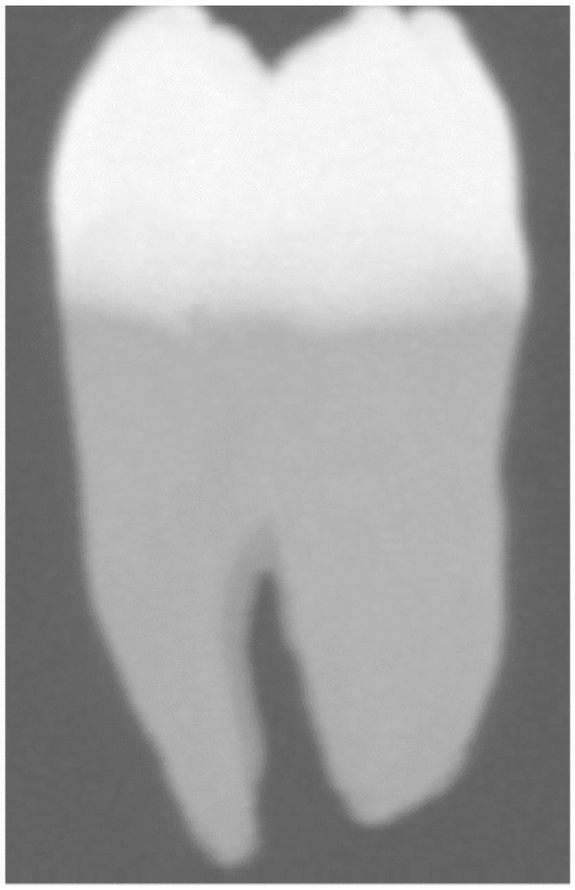
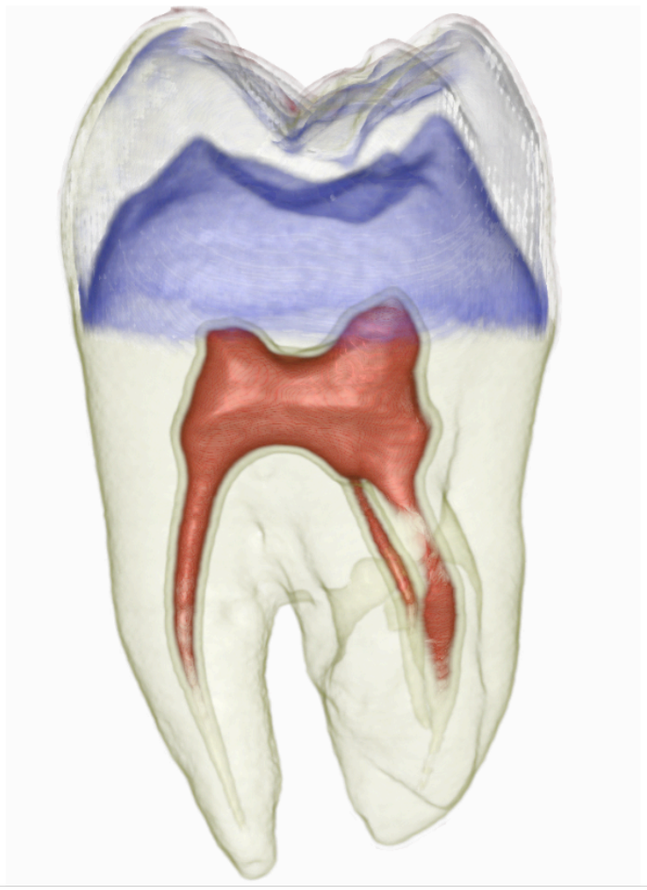
Visualization Infrastructure

- High-quality rendering algorithms



Maximum Intensity Projection (MIP)



Full Volume Rendering

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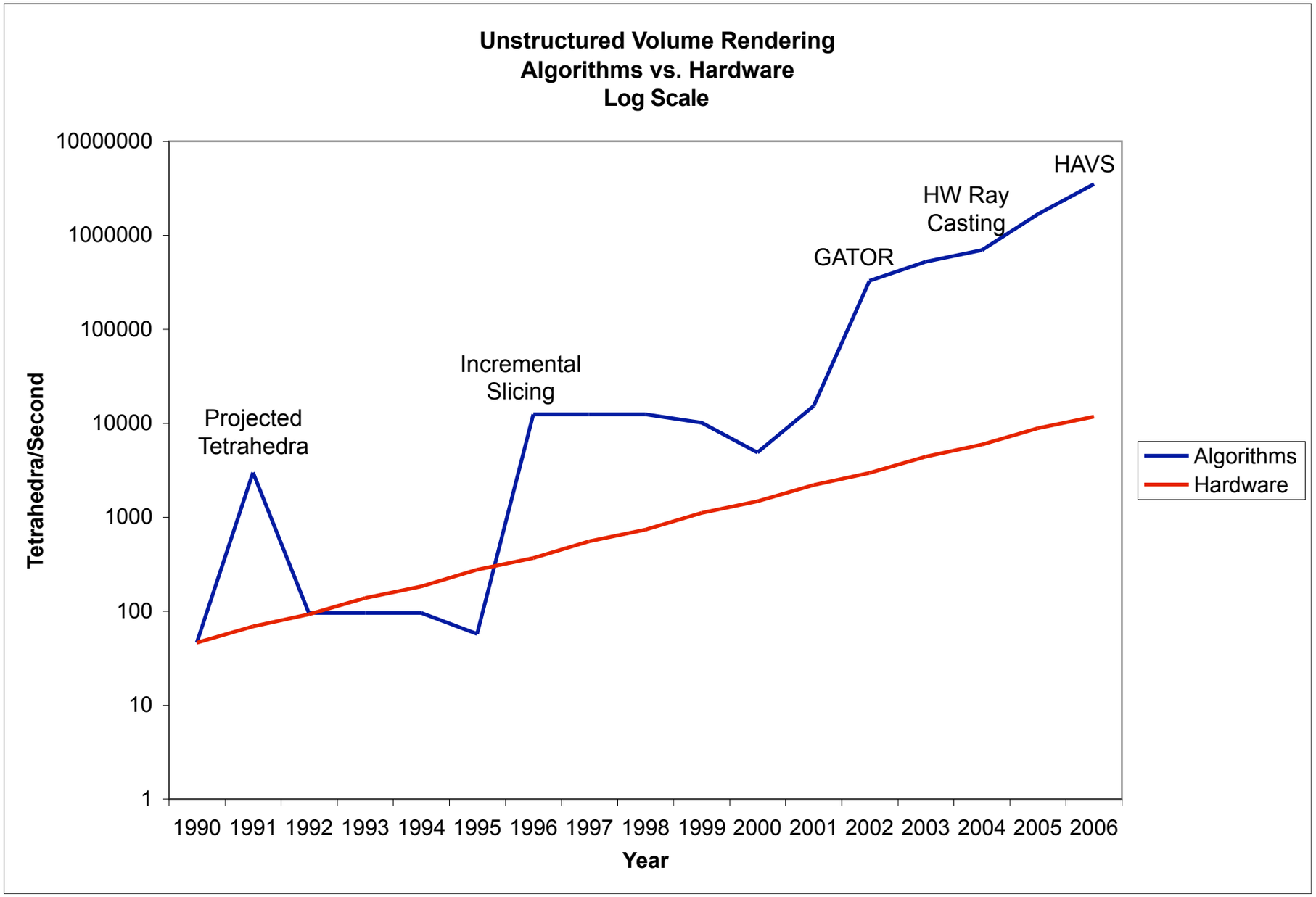
Visualization Infrastructure

- Improved visualization algorithms



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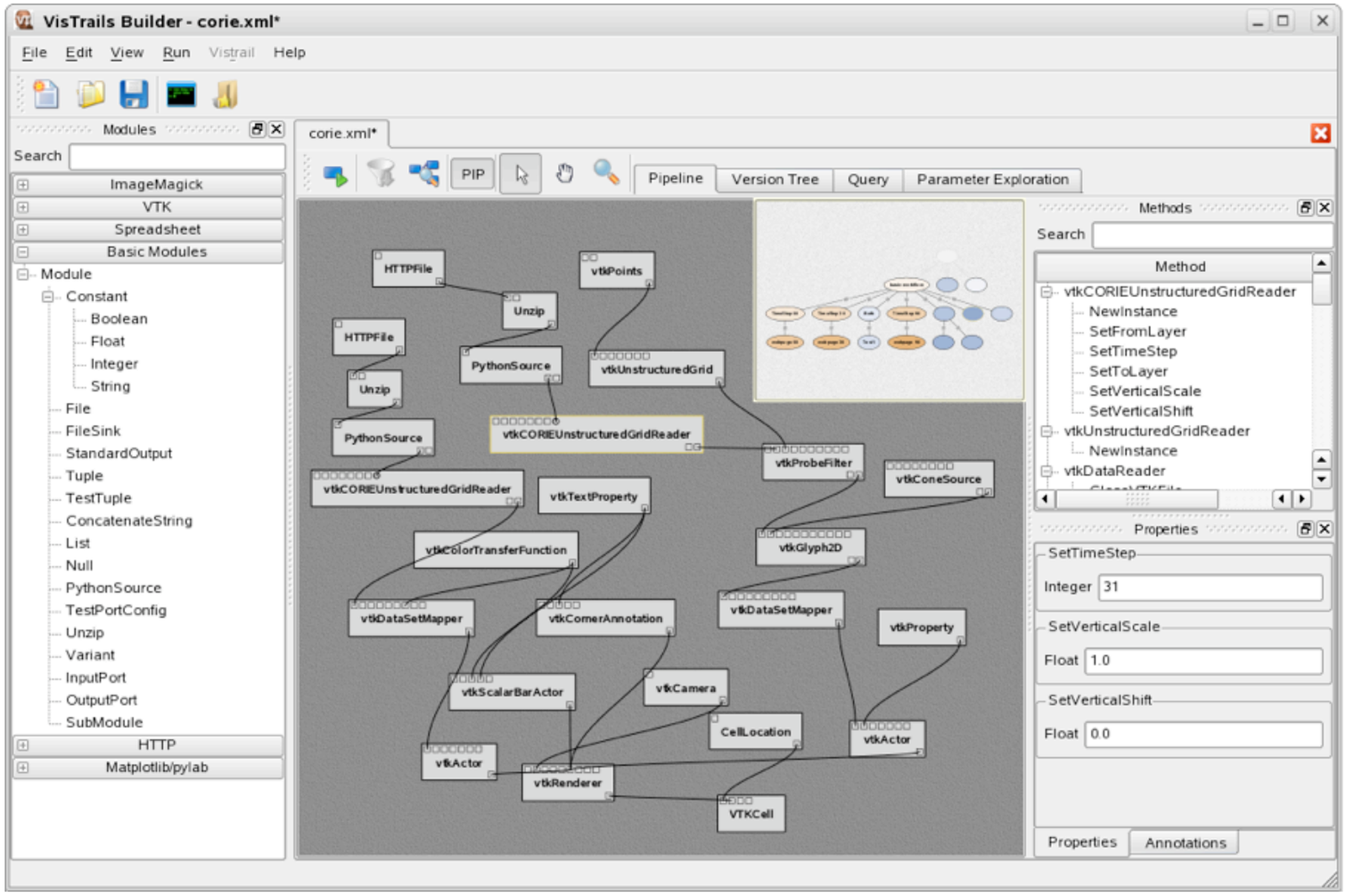
Visualization Infrastructure

- Visualization systems



VisTrails -- http://www.vistrails.org

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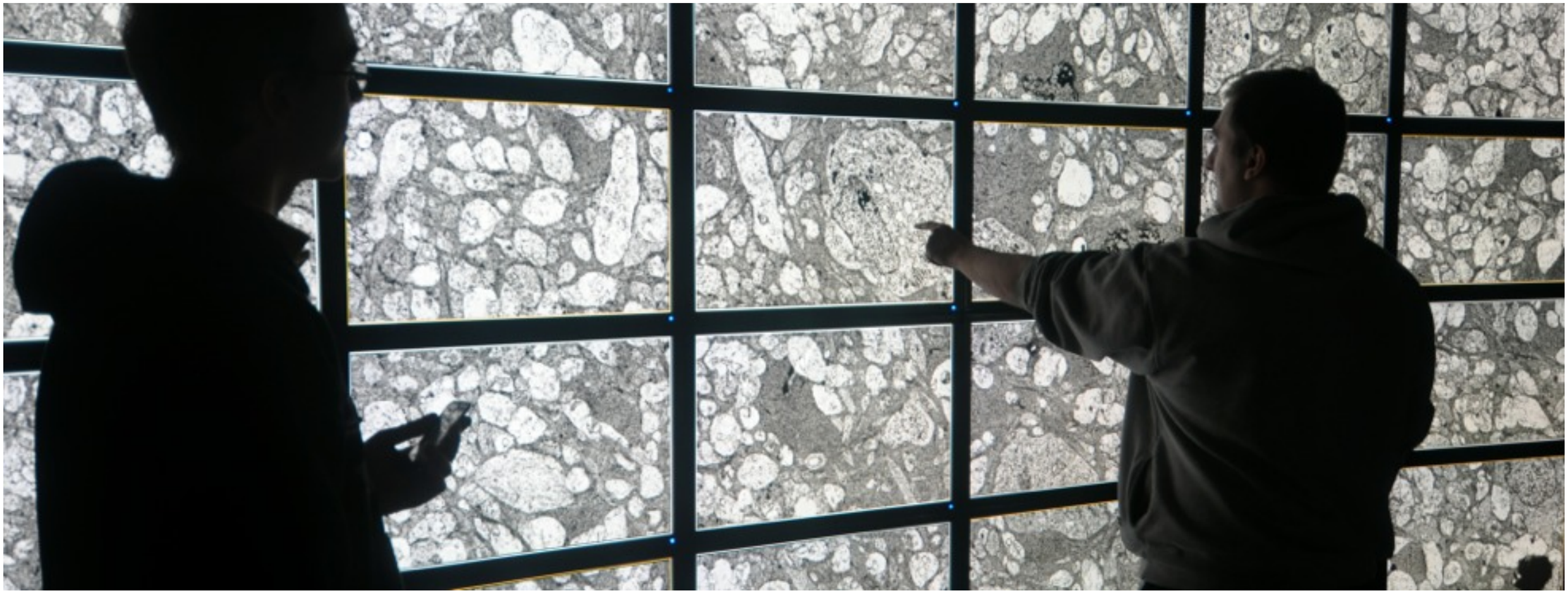
Visualization Infrastructure



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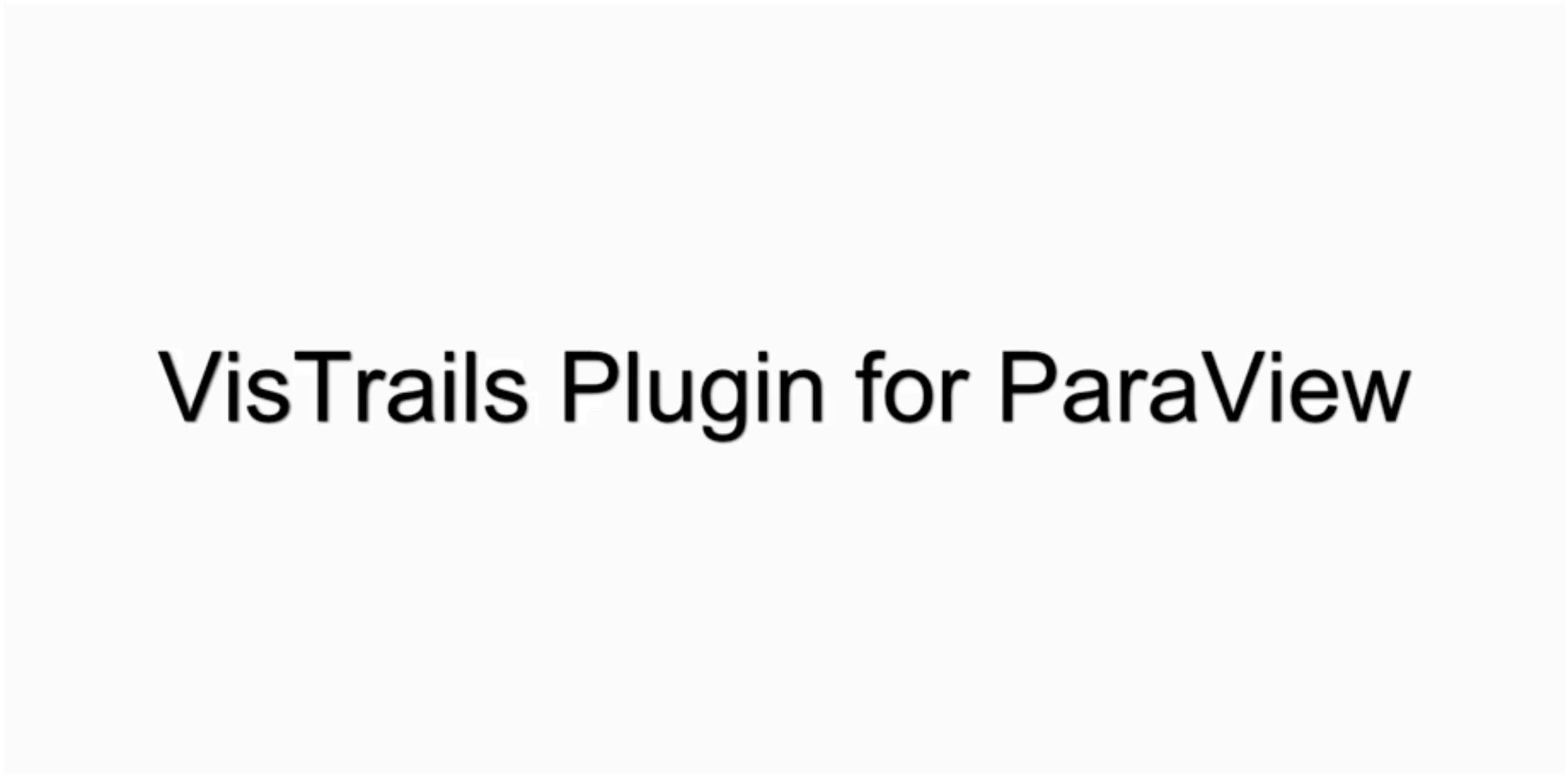
Visualization Infrastructure

- Provenance Capture



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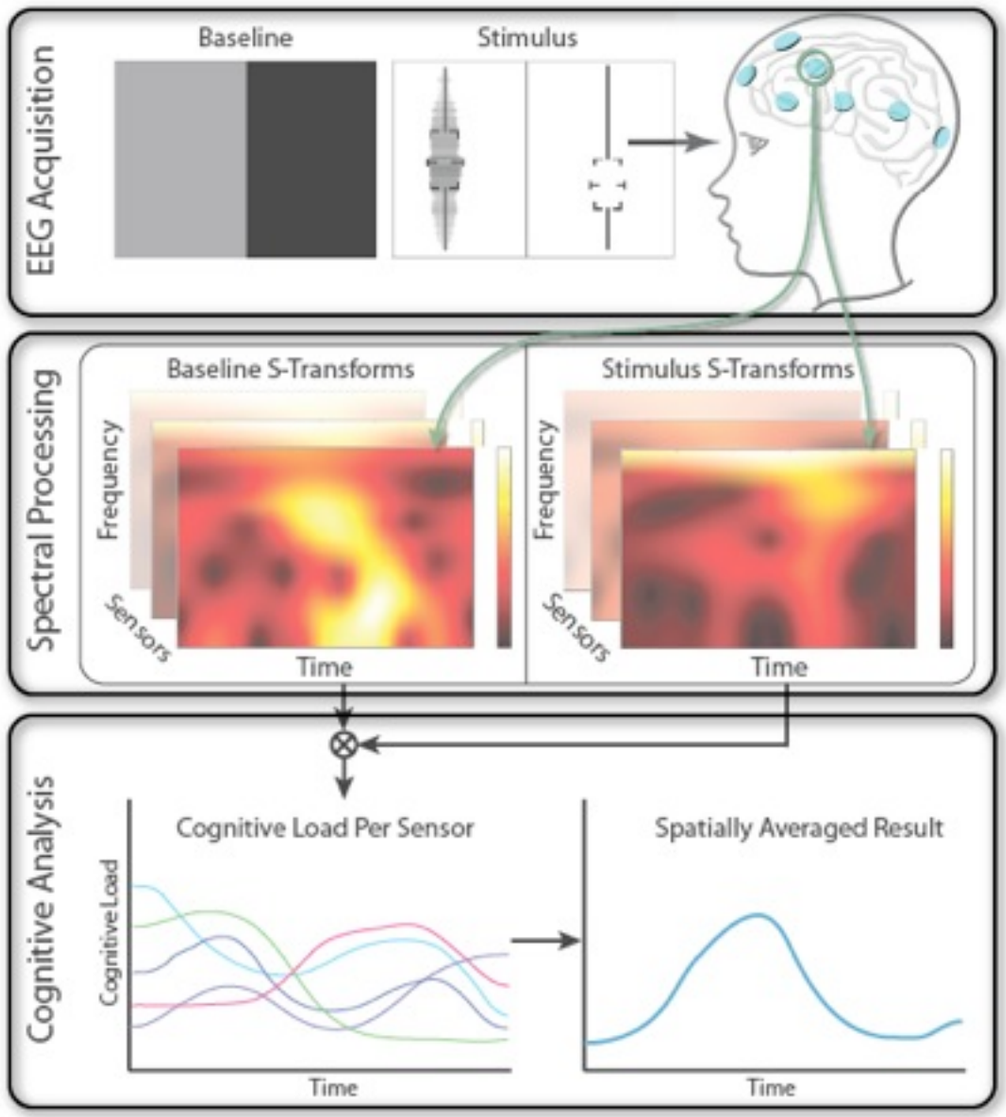
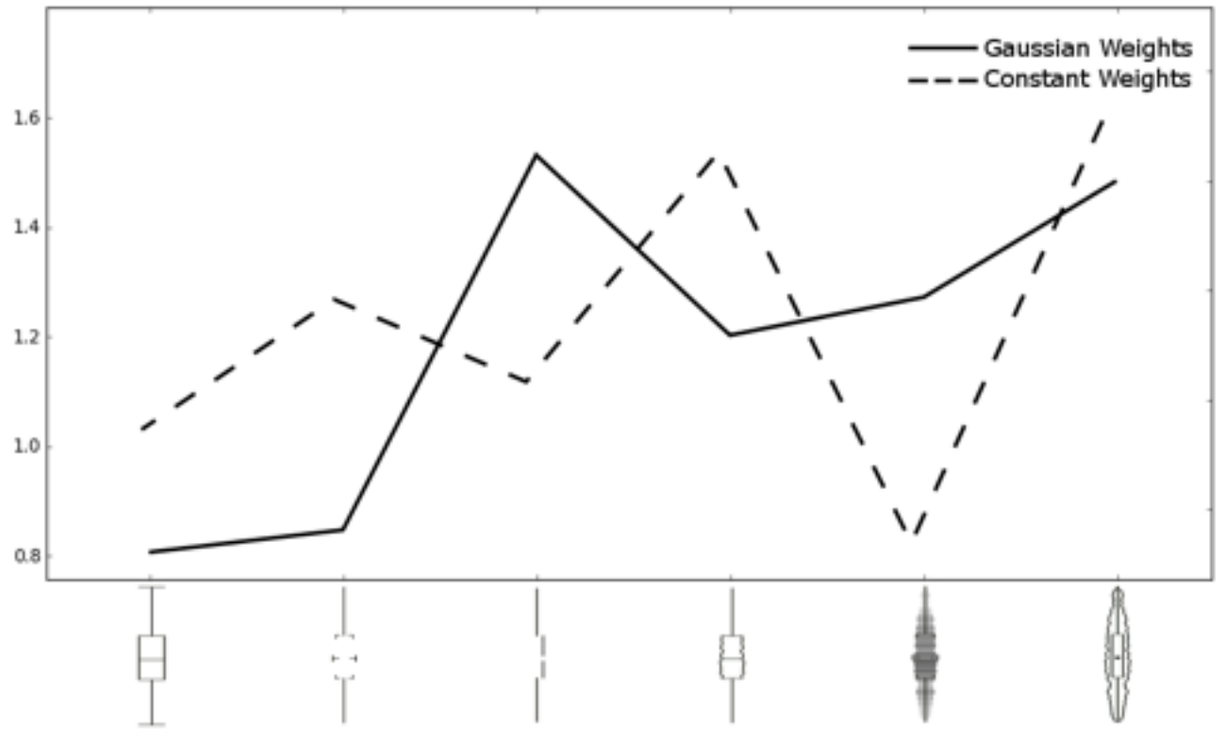
Coupling EEG and Cognitive Load





A User Study of Visualization Effectiveness Using EEG and Cognitive Load, E. Anderson, K. Potter, L. Matzen, J. Shepherd, G. Preston, and C. Silva, Computer Graphics Forum (Proceedings of EuroVis 2011). Best paper award -- 2nd prize.

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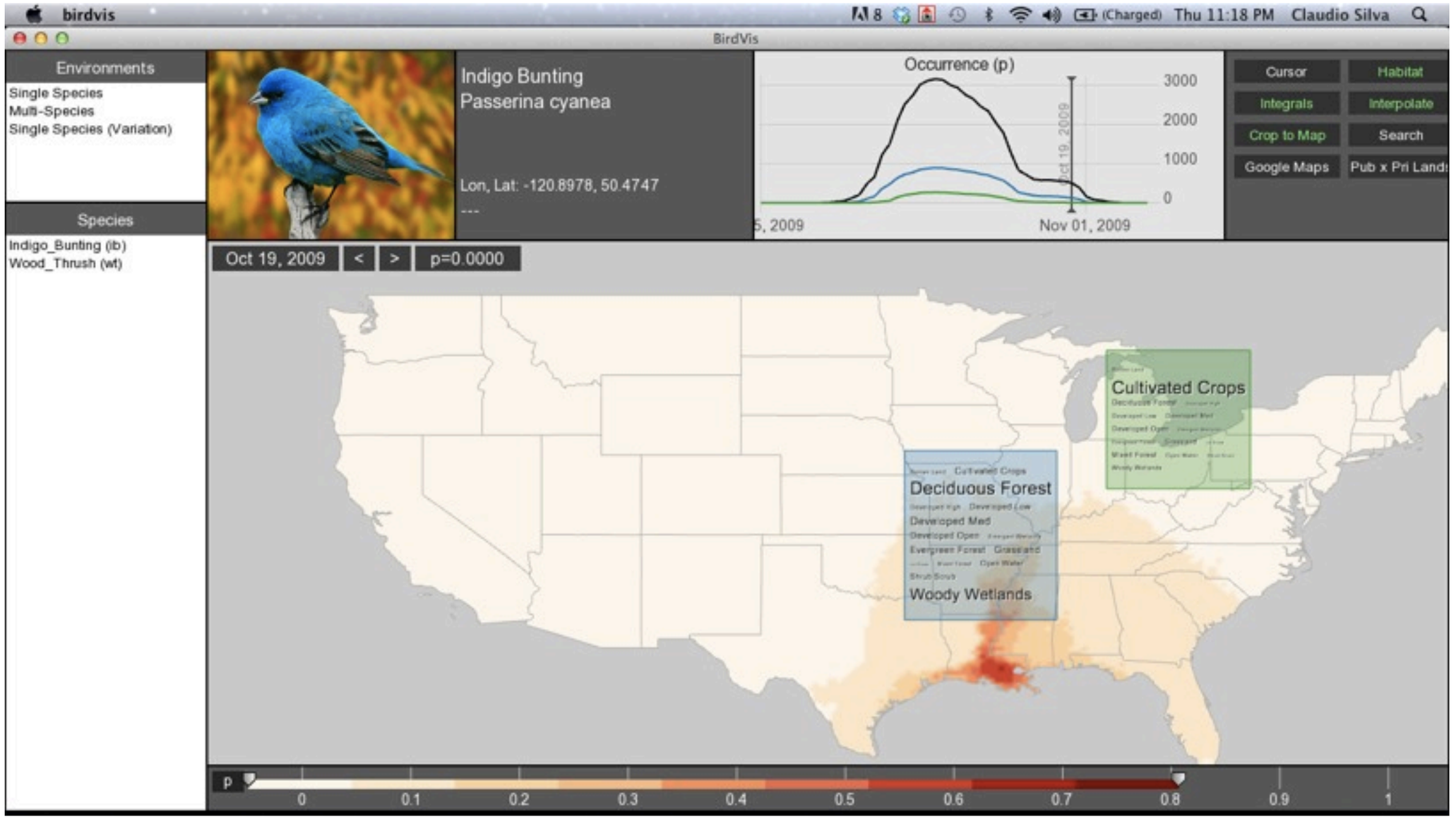
Systems: BirdVIS

- Collaboration with the Cornell Lab of Ornithology



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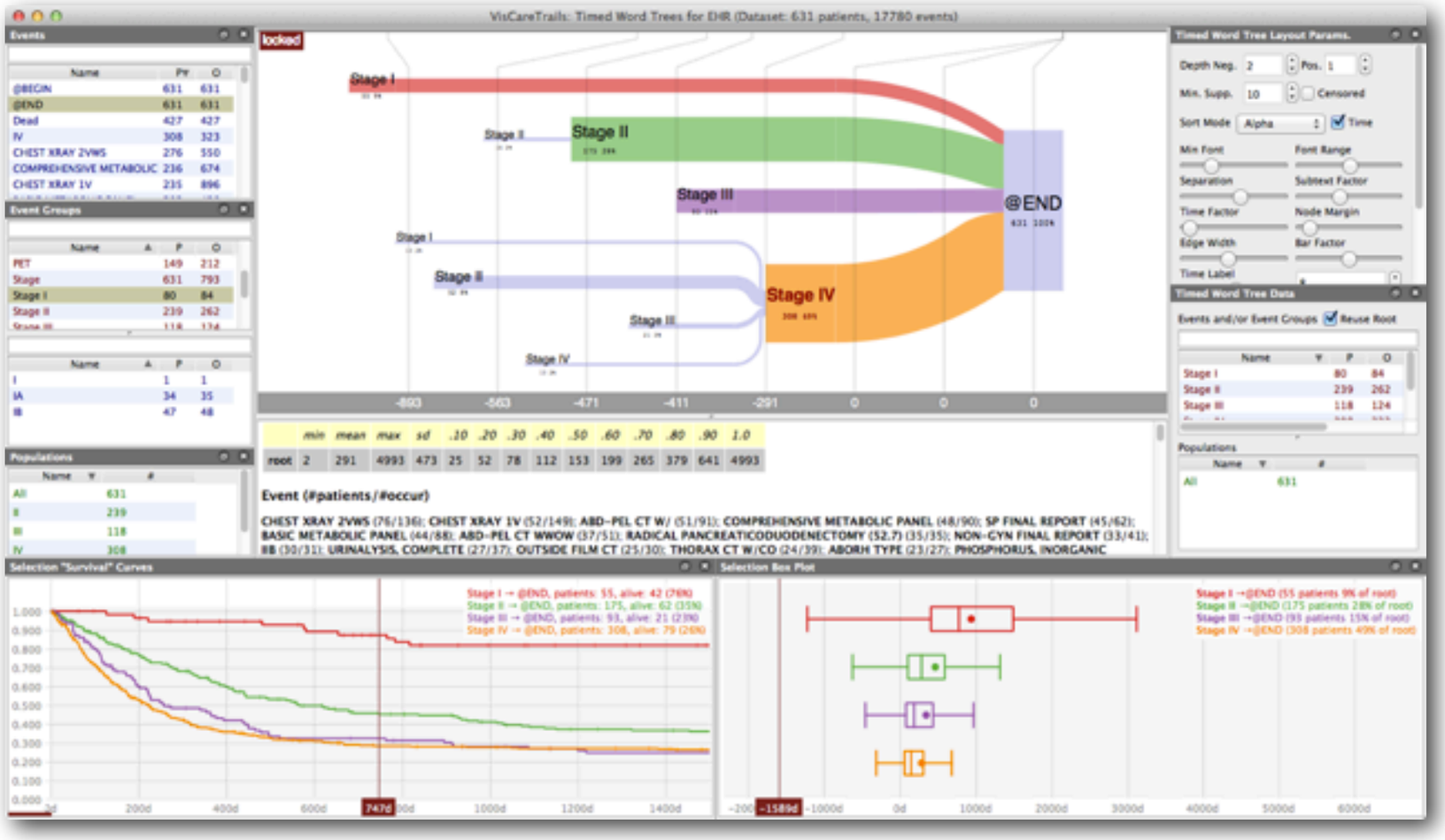
Systems: VisCareTrails

- Collaboration with Marta Heilburn (Radiology, Utah)
- Visualizing trails in the Electronic Health Record with Timed Word Trees, a pancreas cancer use case



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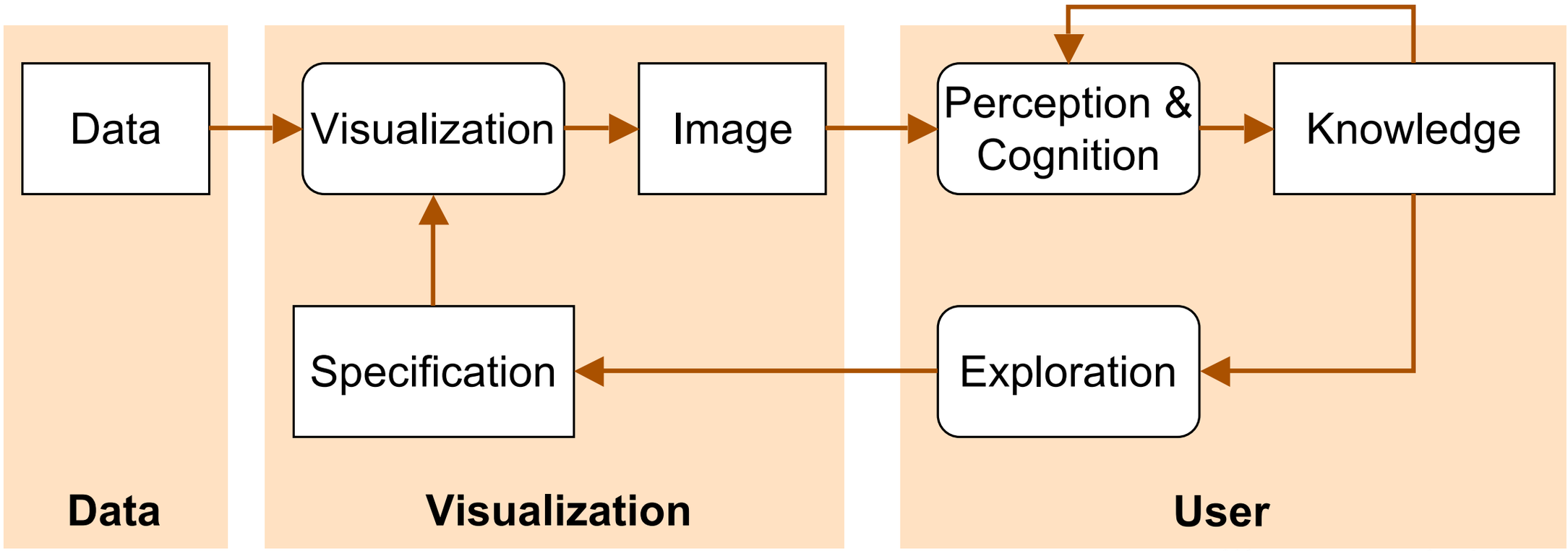
Data Exploration through Visualization



J. van Wijk, IEEE Vis 2005

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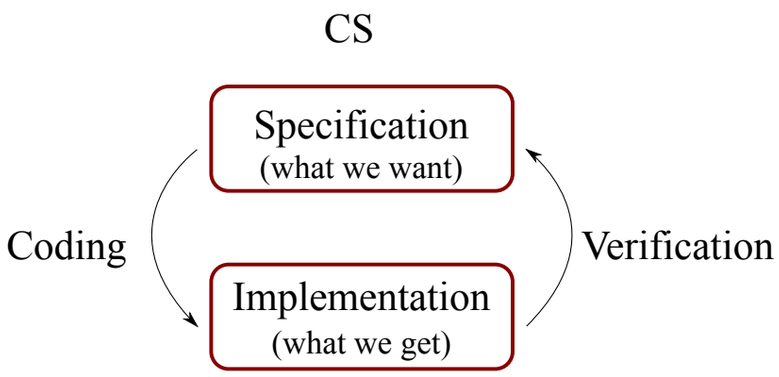
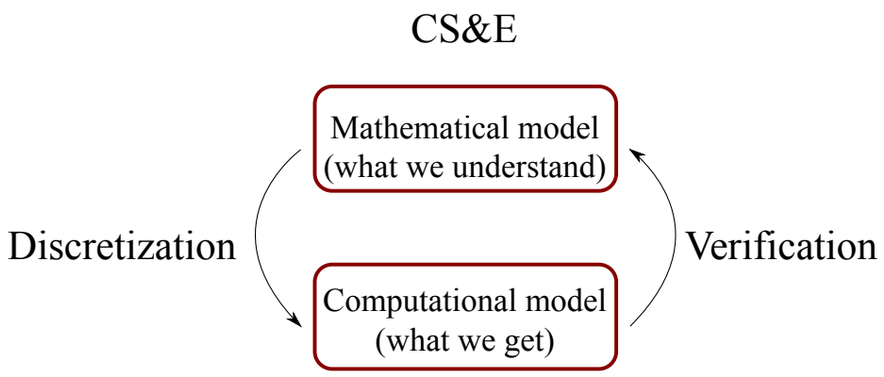
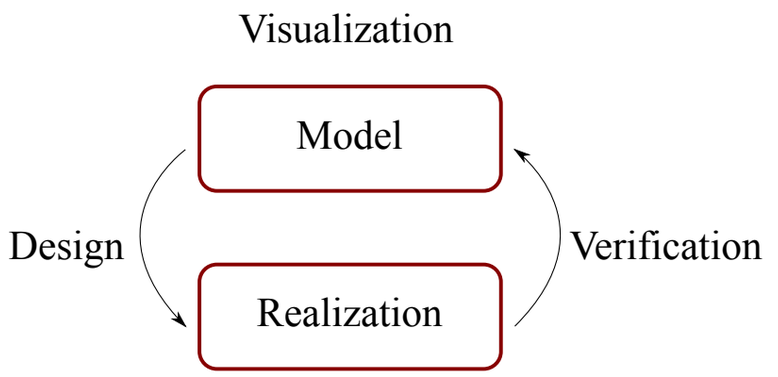
How to verify visualizations? algorithms?







- Two ingredients:
  - **Expected behavior:** mathematical description of algorithm properties
  - **Observed behavior:** output of the visualization technique
- Compare **expected** and **observed** behavior
  - If a mismatch occurs, something is wrong.

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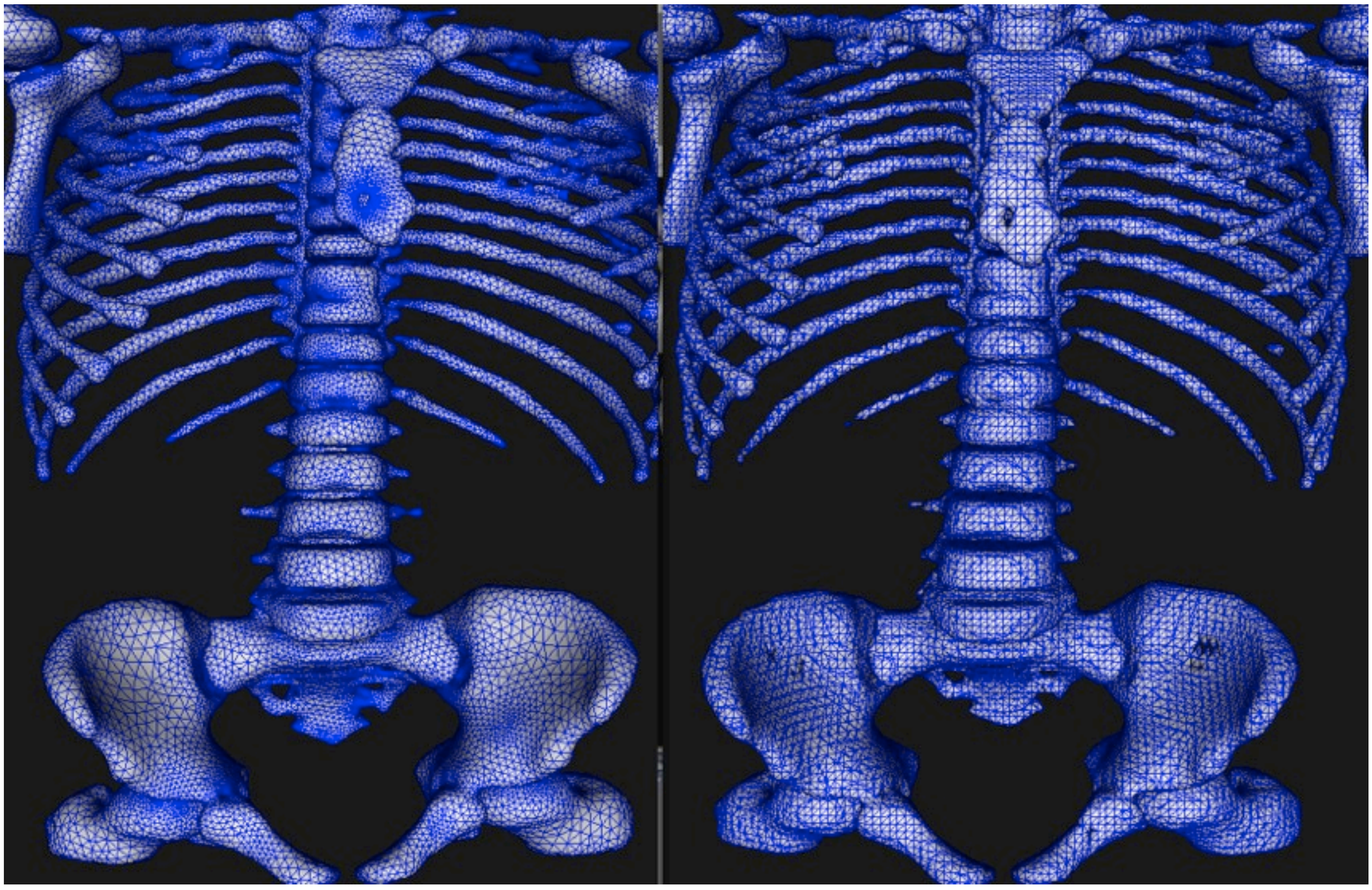
Application: Subject-Specific Modeling



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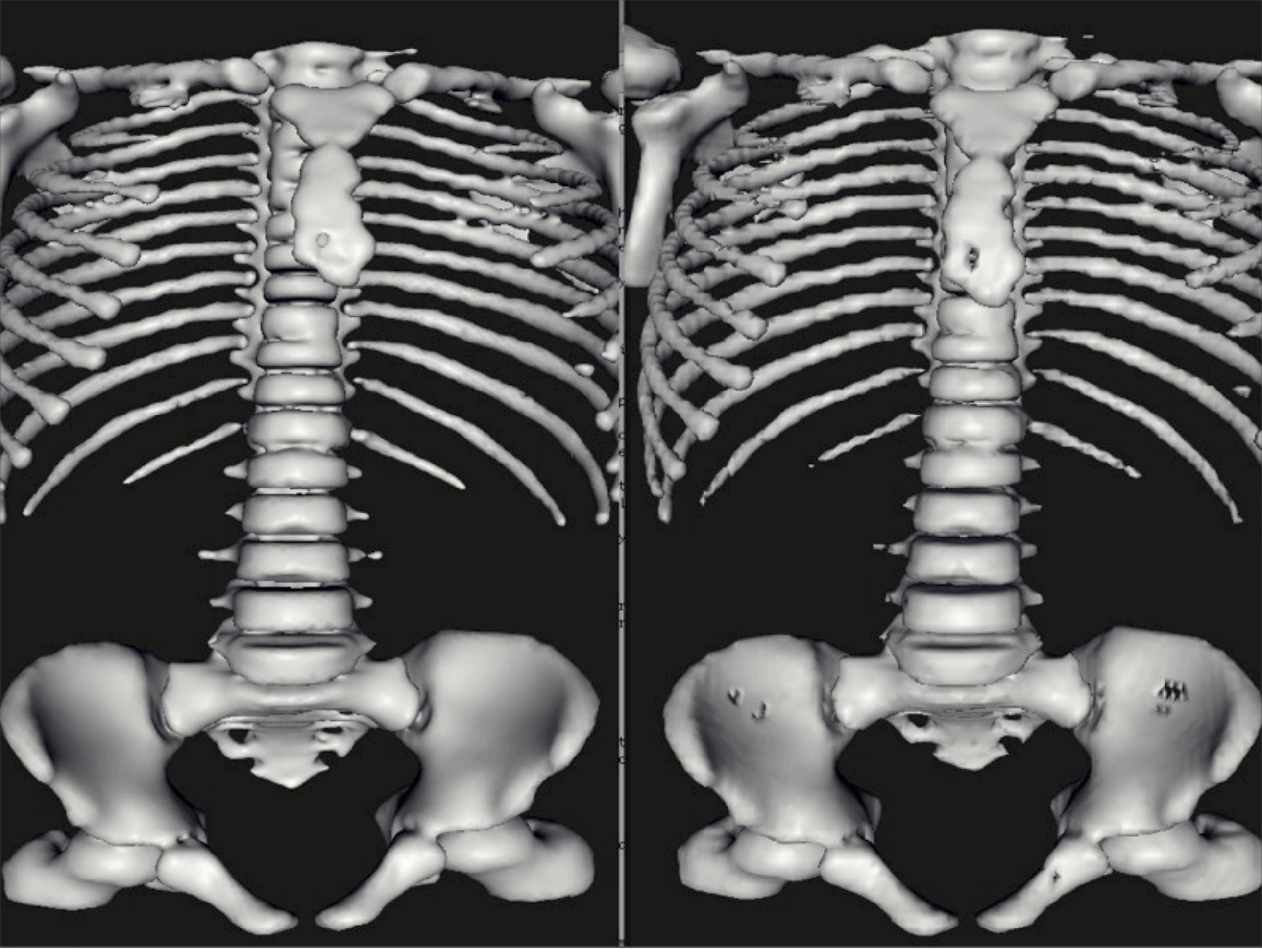
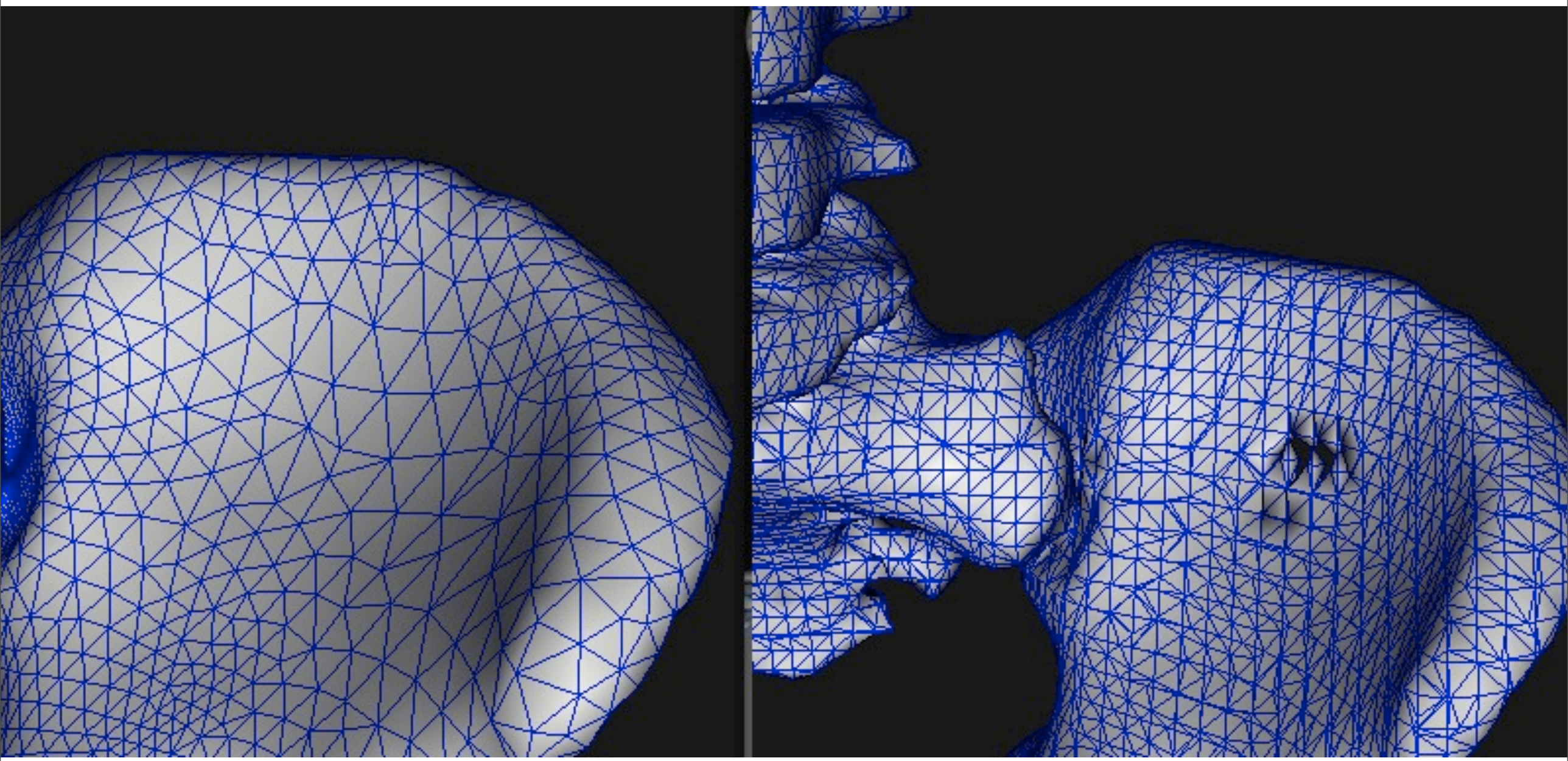
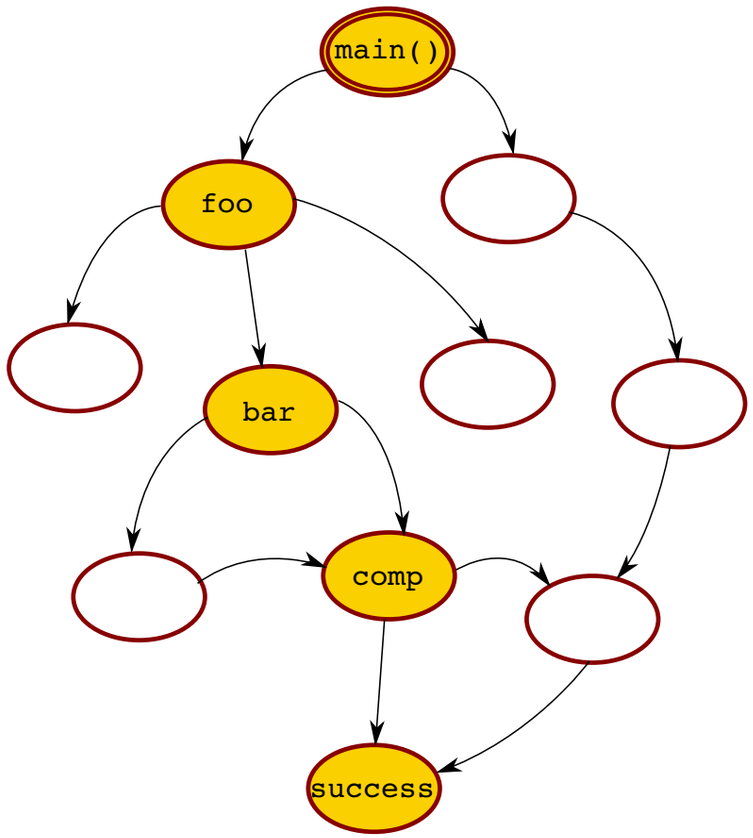


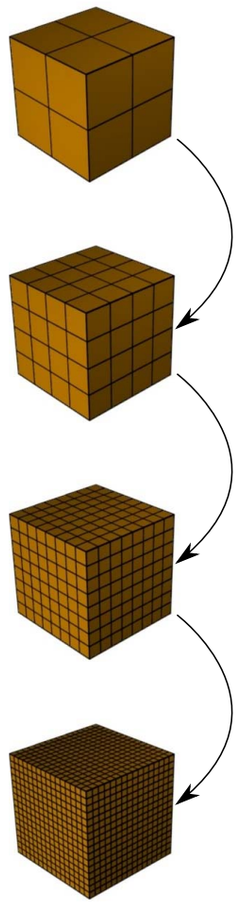


How to verify visualizations?

CS

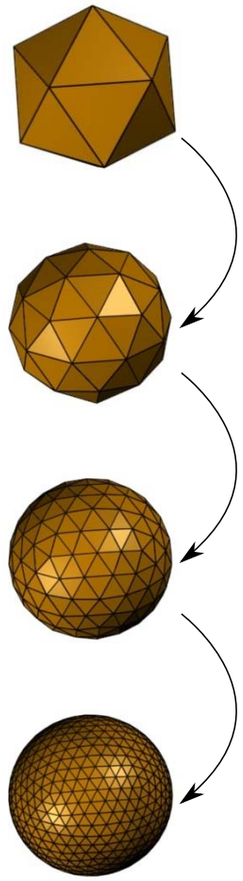


CS&E

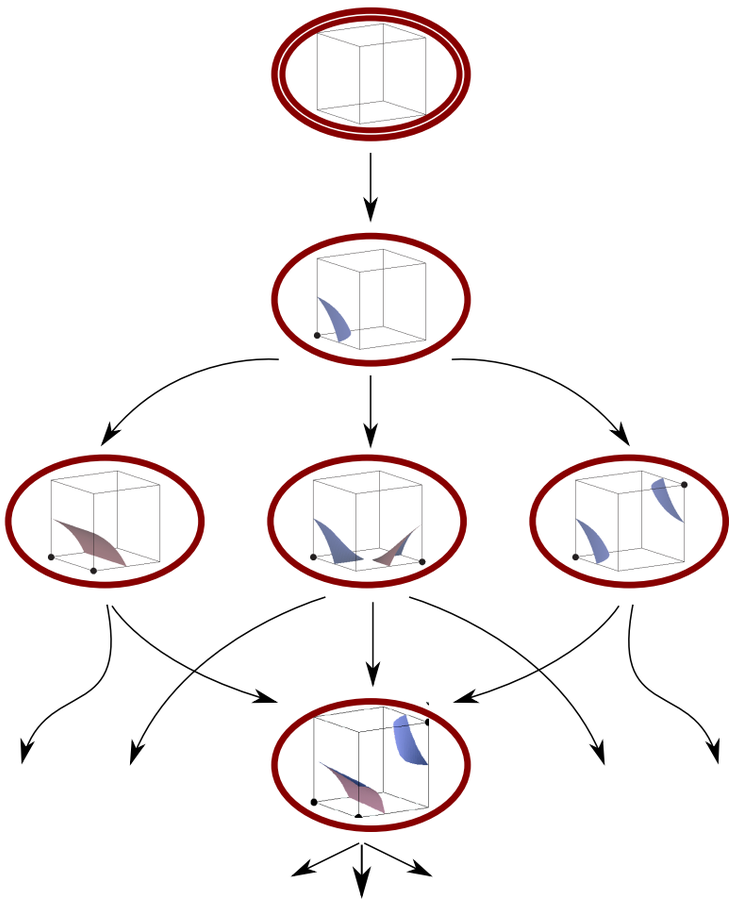


Visualization

Geometry



Topology



Geometry verification

Verifiable Visualization for Isosurface Extraction, T. Etiene, C. Scheidegger, L. G. Nonato, R. M. Kirby, and C. Silva. IEEE Transactions on Visualization and Computer Graphics (Proceedings of IEEE Visualization 2009).

Expected Order of Accuracy

- Given an isosurface $f = k$ and assuming linear interpolation
  - Algebraic distance:

$$\left\| f^h(\vec{x}) - f(\vec{x}) \right\| = O(h^2)$$

  - Normal (cross product of edges):

$$\left\| \nabla f^h(\vec{x}) - \nabla f(\vec{x}) \right\| = O(h)$$

  - Gaussian curvature (angle deficit method):

$$\left\| \kappa(f^h) - \kappa(f) \right\| = O(1)$$

  - Surface area:

$$\left\| area(f^h) - area(f) \right\| = ?$$

Verifiable Visualization for Isosurface Extraction, T. Etiene, C. Scheidegger, L. G. Nonato, R. M. Kirby, and C. Silva. IEEE Transactions on Visualization and Computer Graphics (Proceedings of IEEE Visualization 2009).

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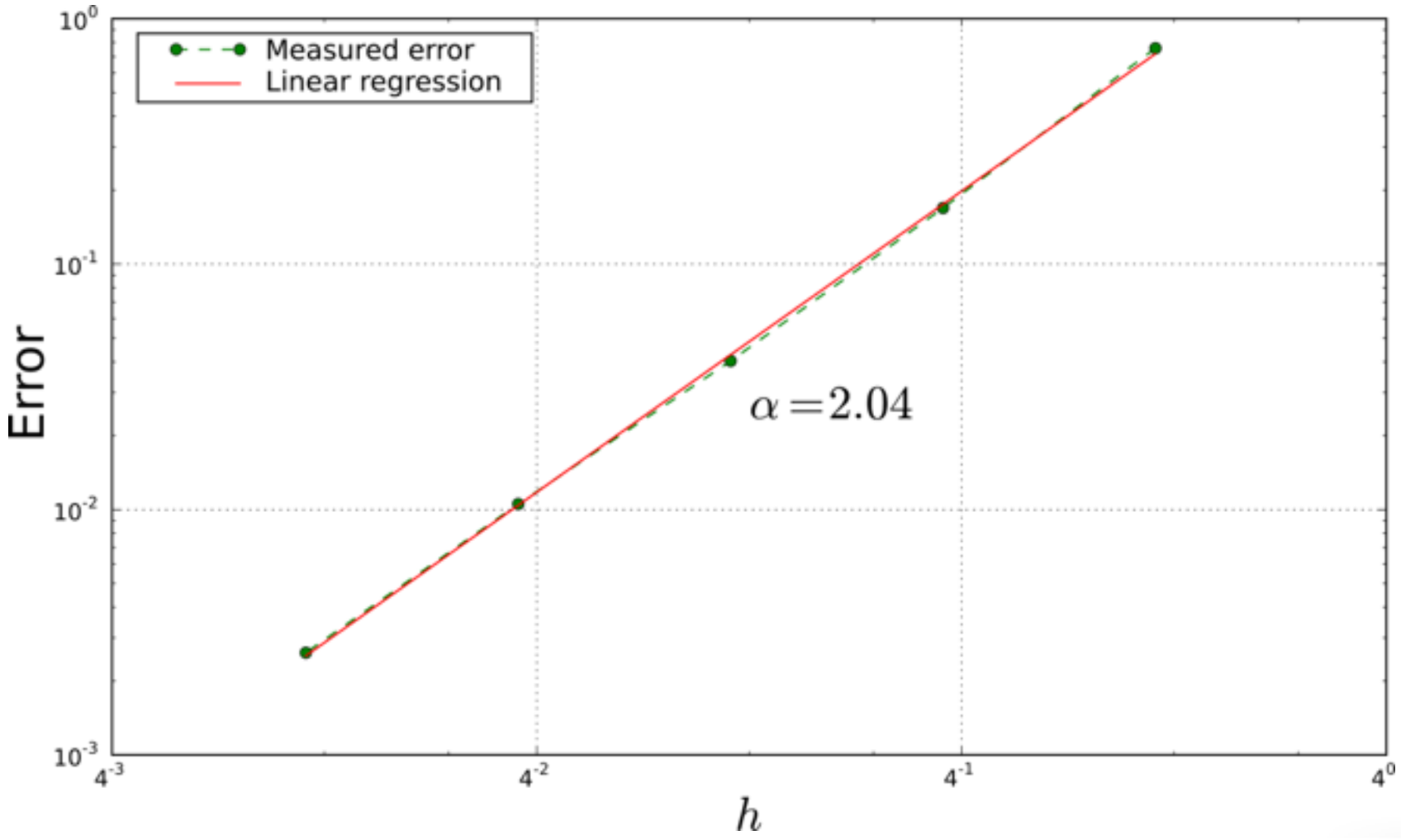
Observed Order of Accuracy

- In practice:

$$E_h = \left\| u^h(x) - u(x) \right\| = ch^{\alpha}$$

$$\log(E_h) = \log(c) + \alpha \log(h)$$



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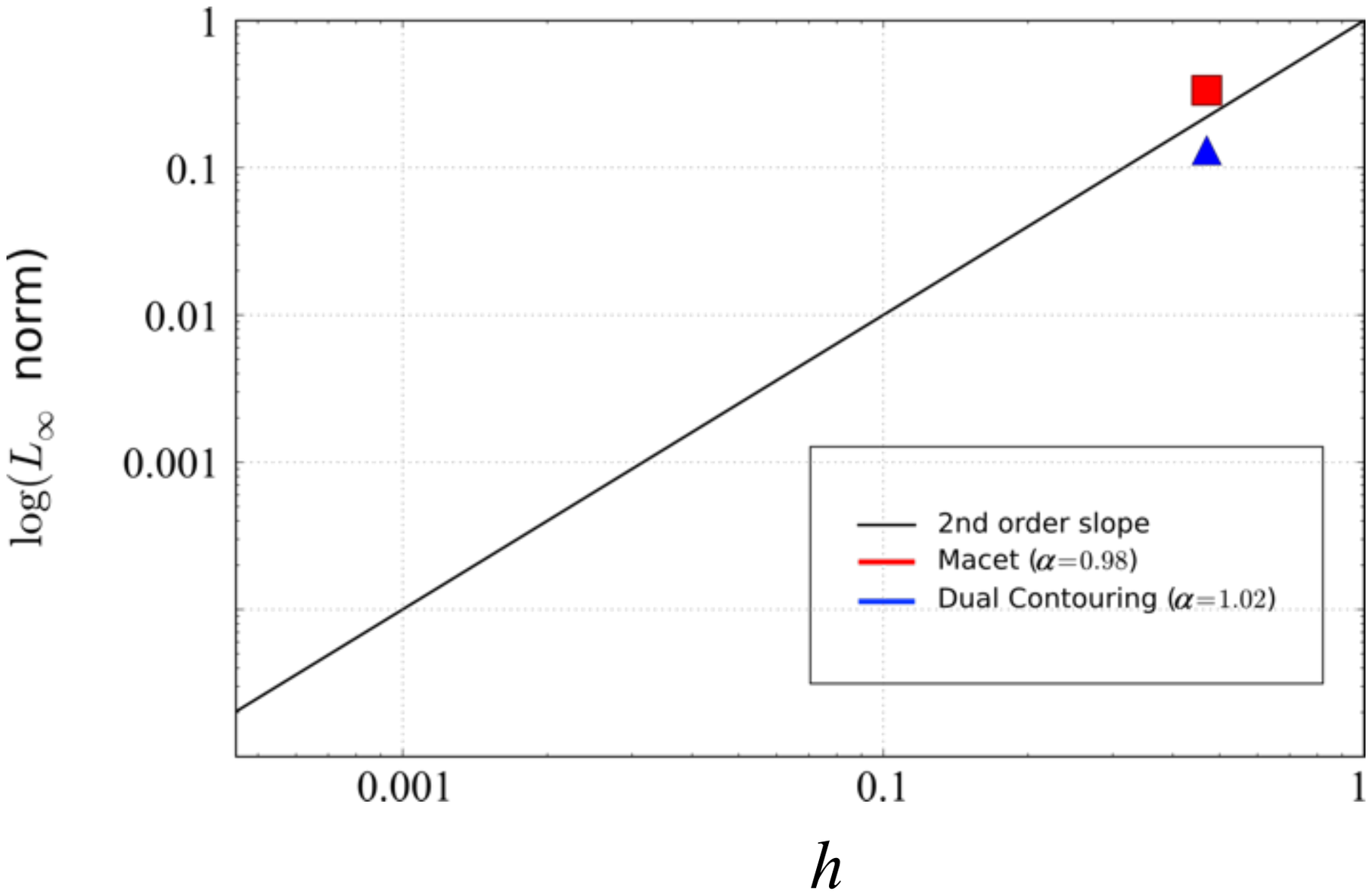
Observed order of accuracy Algebraic distance



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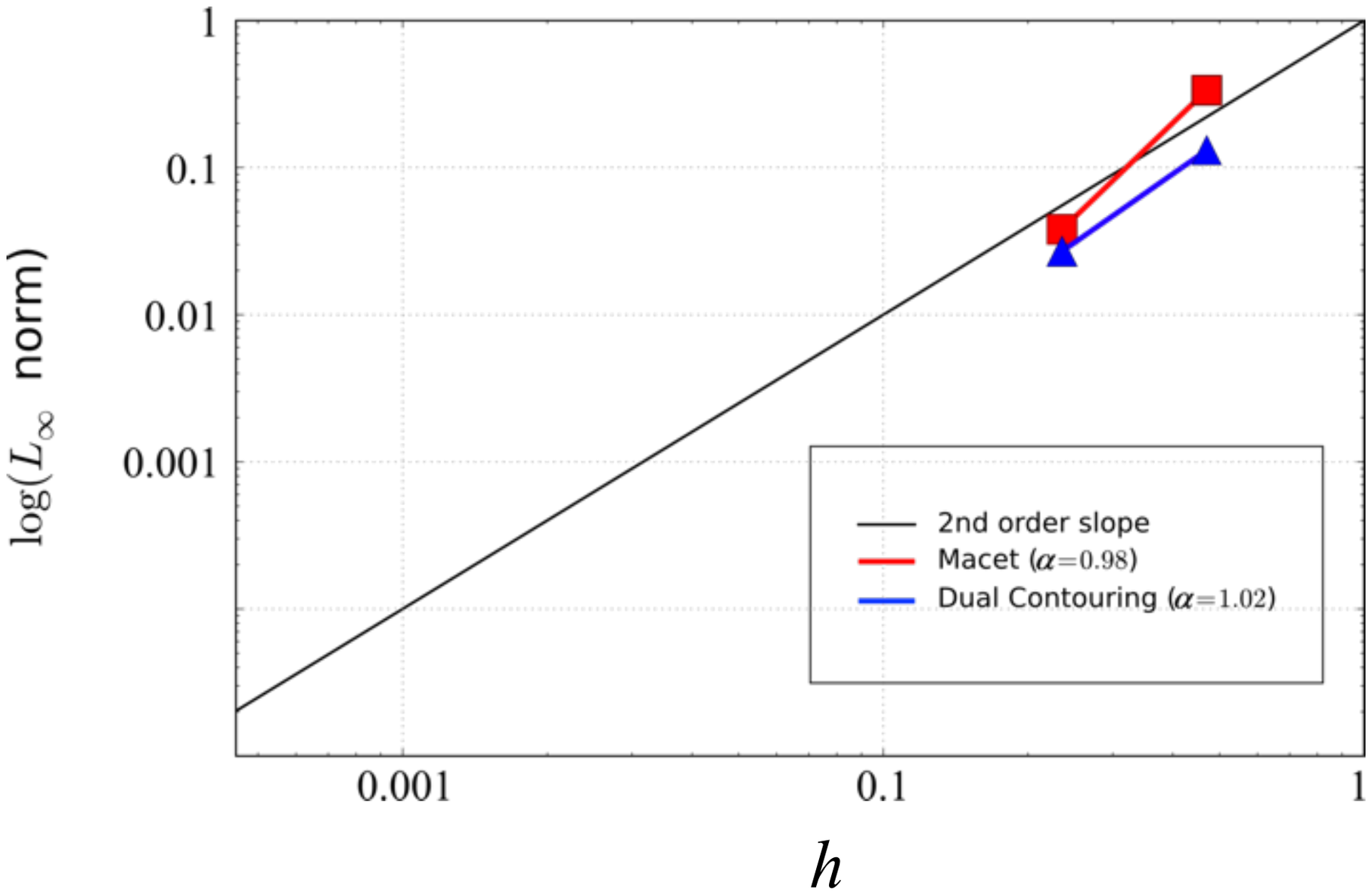
Observed order of accuracy Algebraic distance



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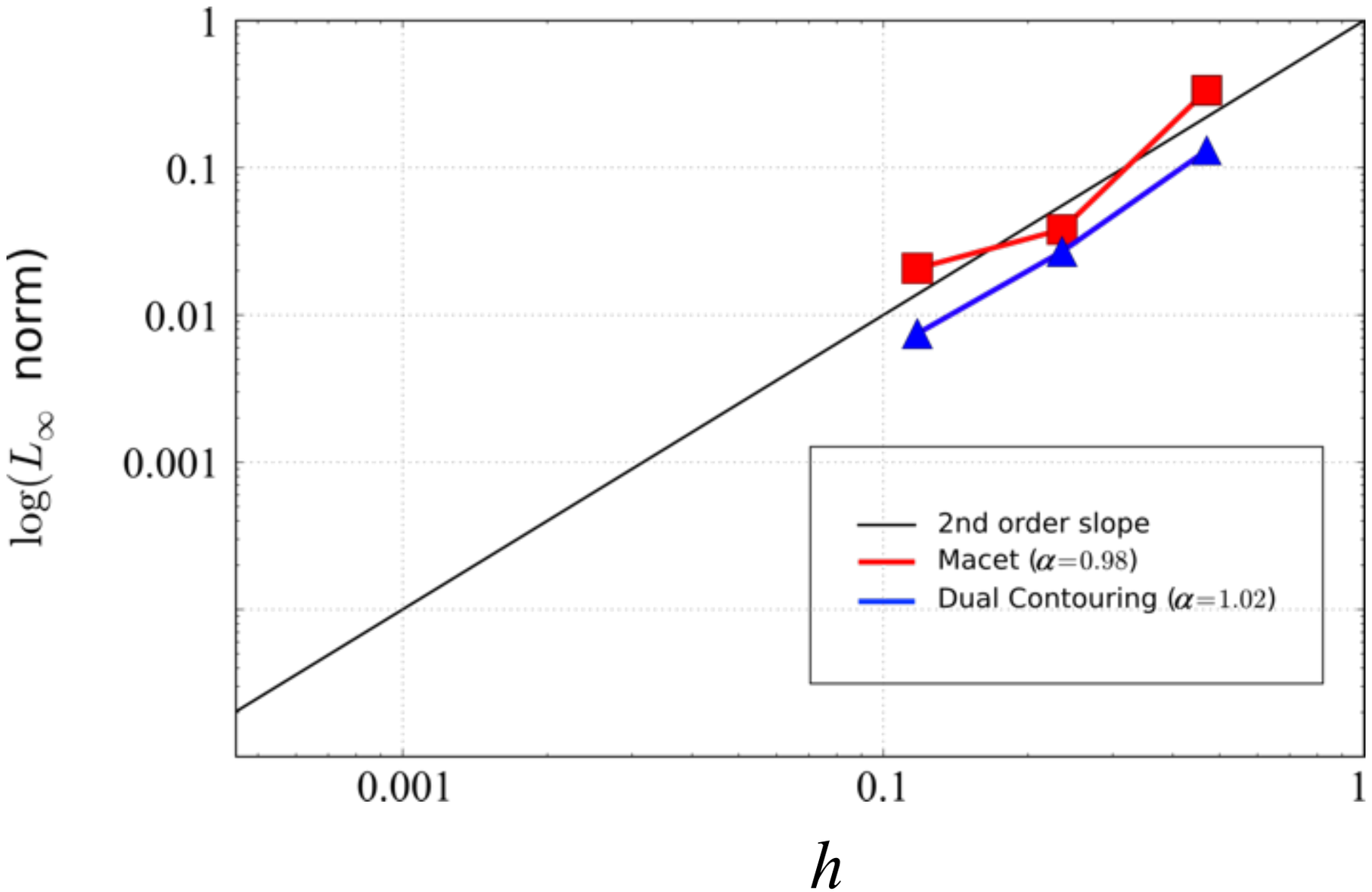
Observed order of accuracy Algebraic distance



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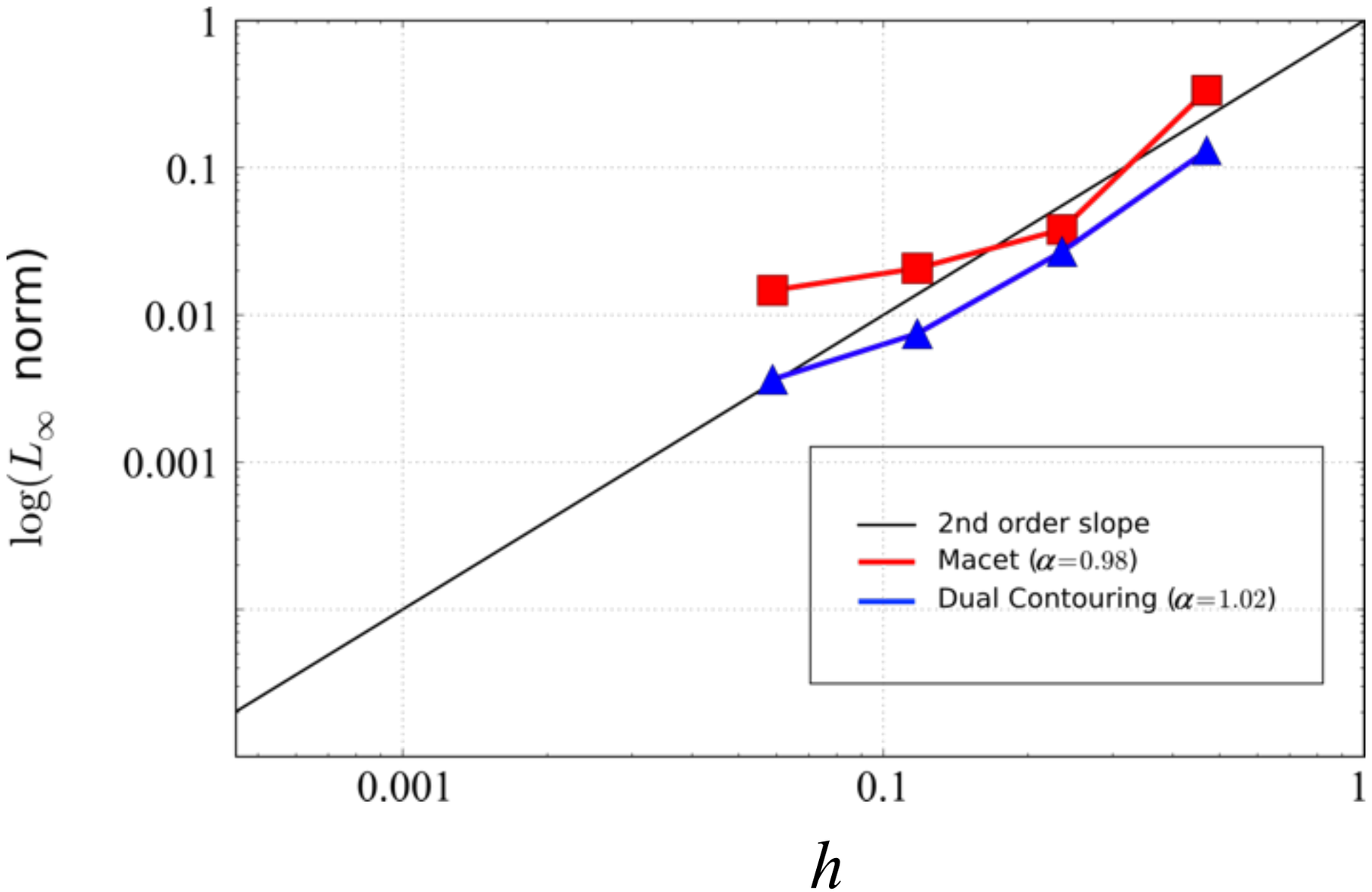
Observed order of accuracy Algebraic distance



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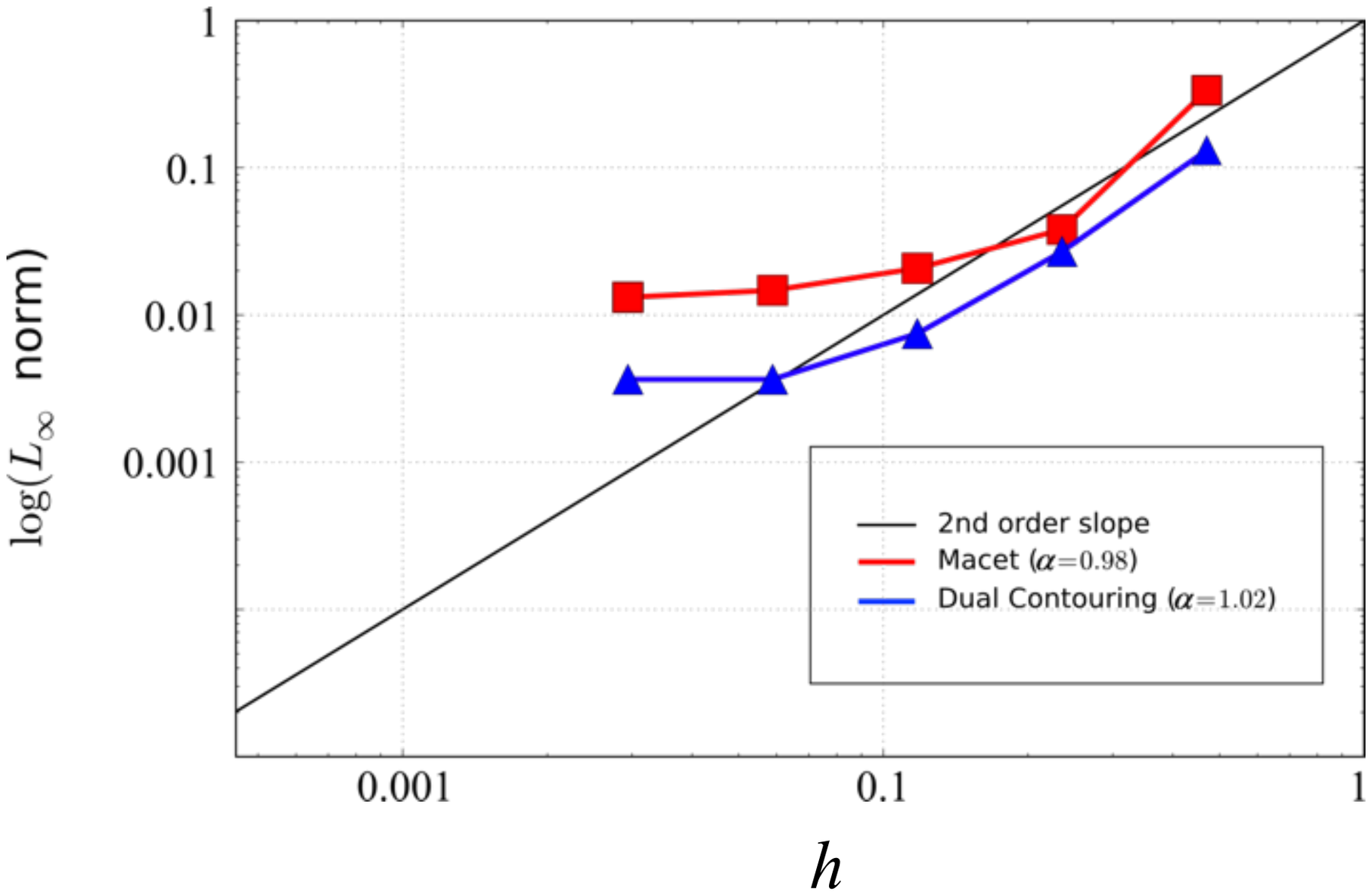
Observed order of accuracy Algebraic distance



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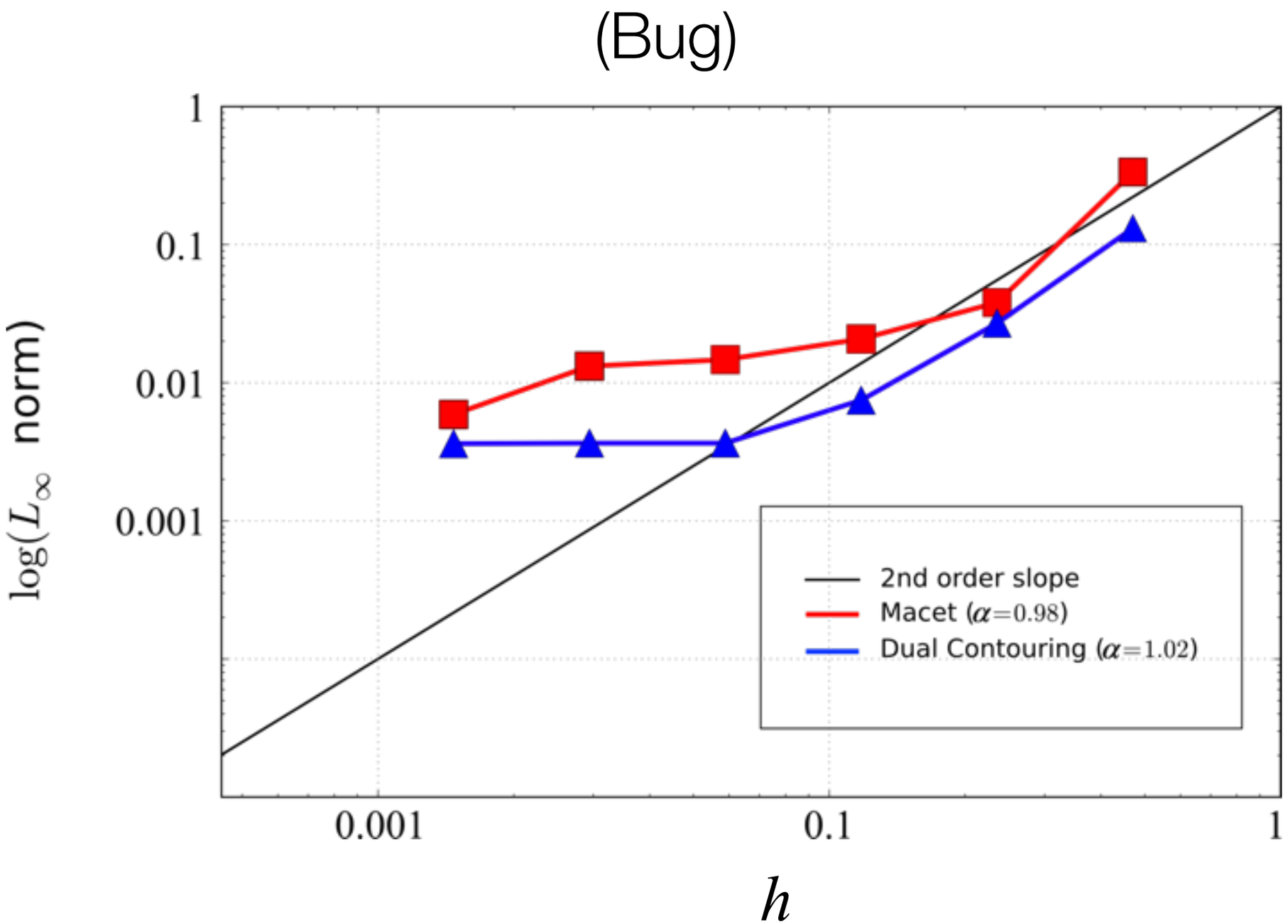
Observed order of accuracy Algebraic distance



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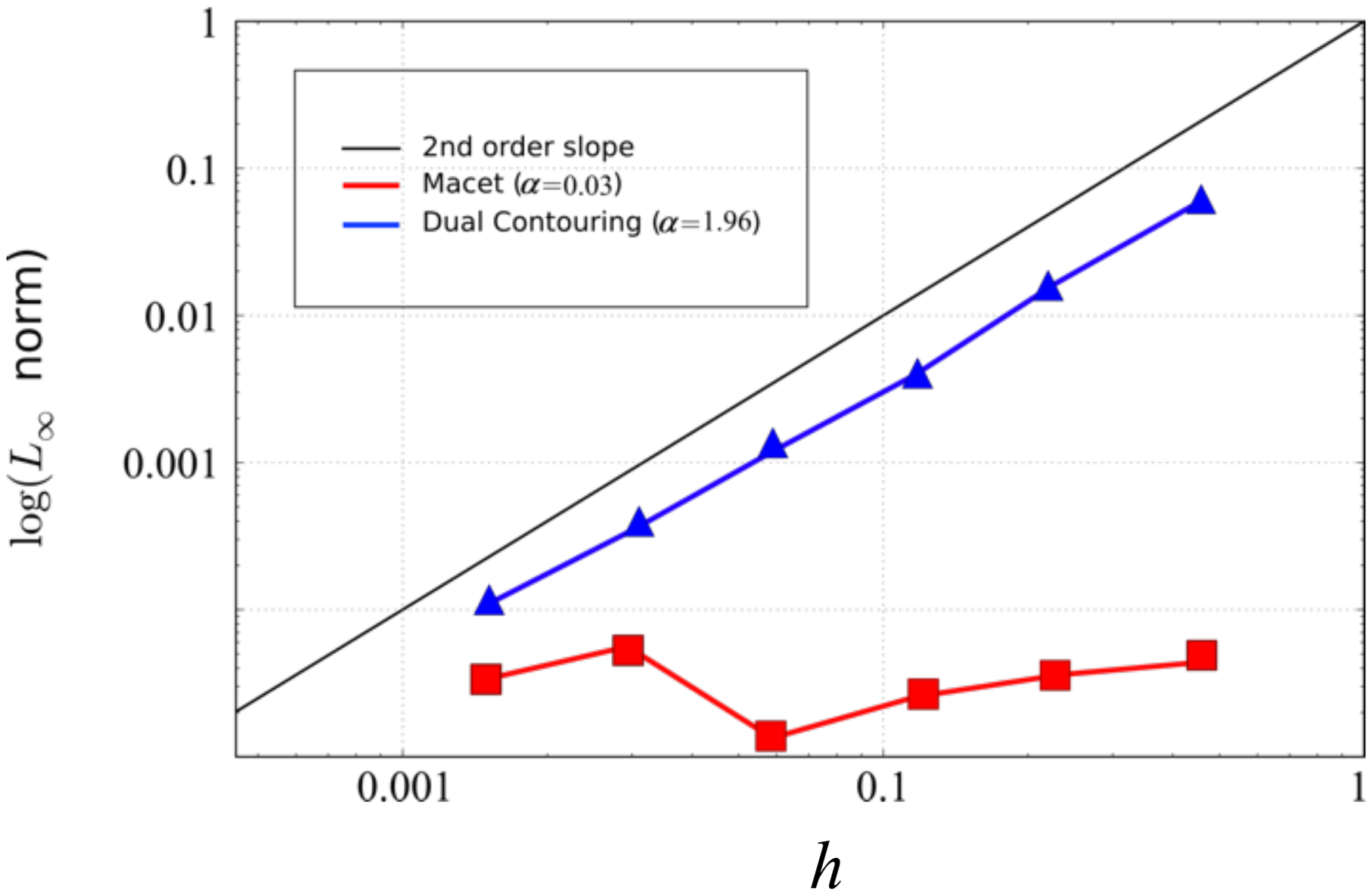
Observed order of accuracy Algebraic distance

(Fixed)



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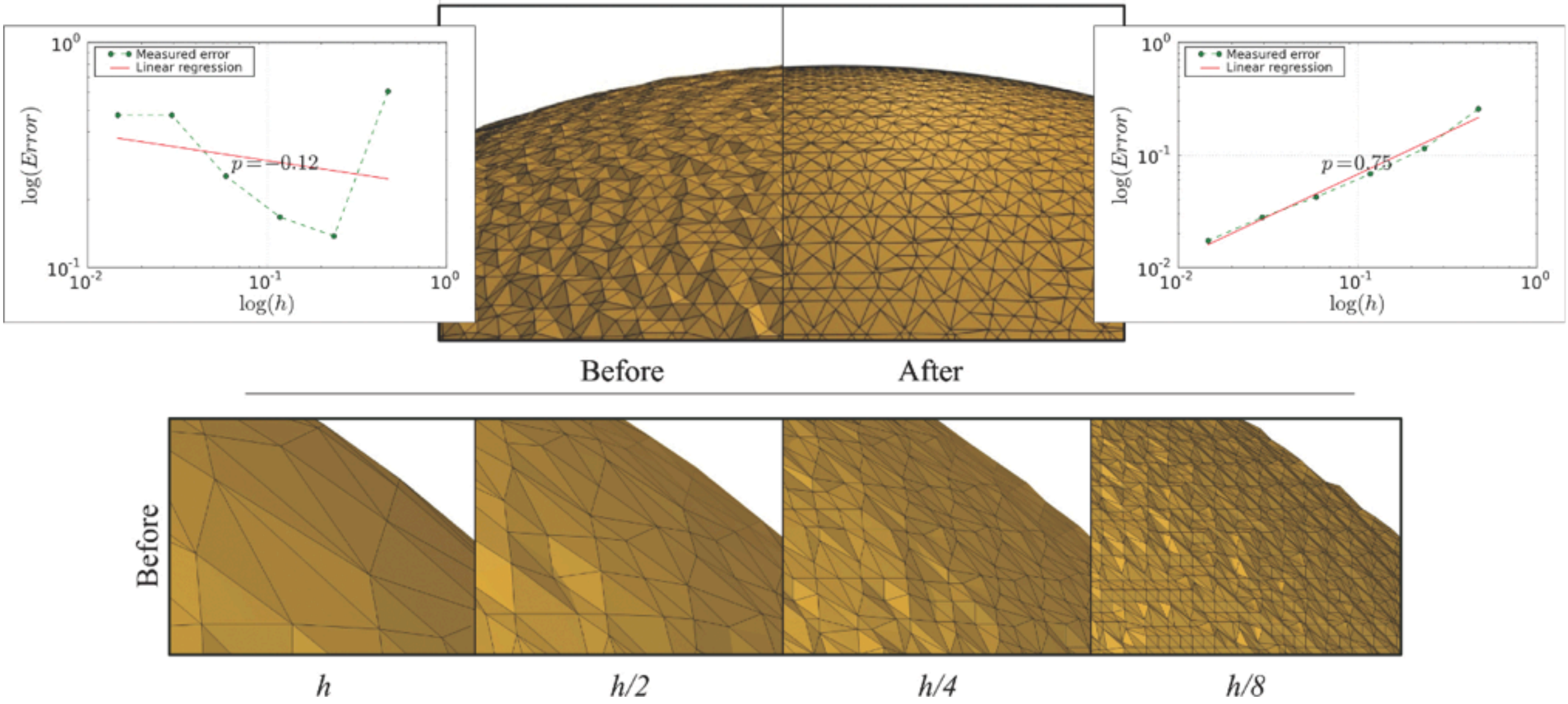
Visual Analysis -- User



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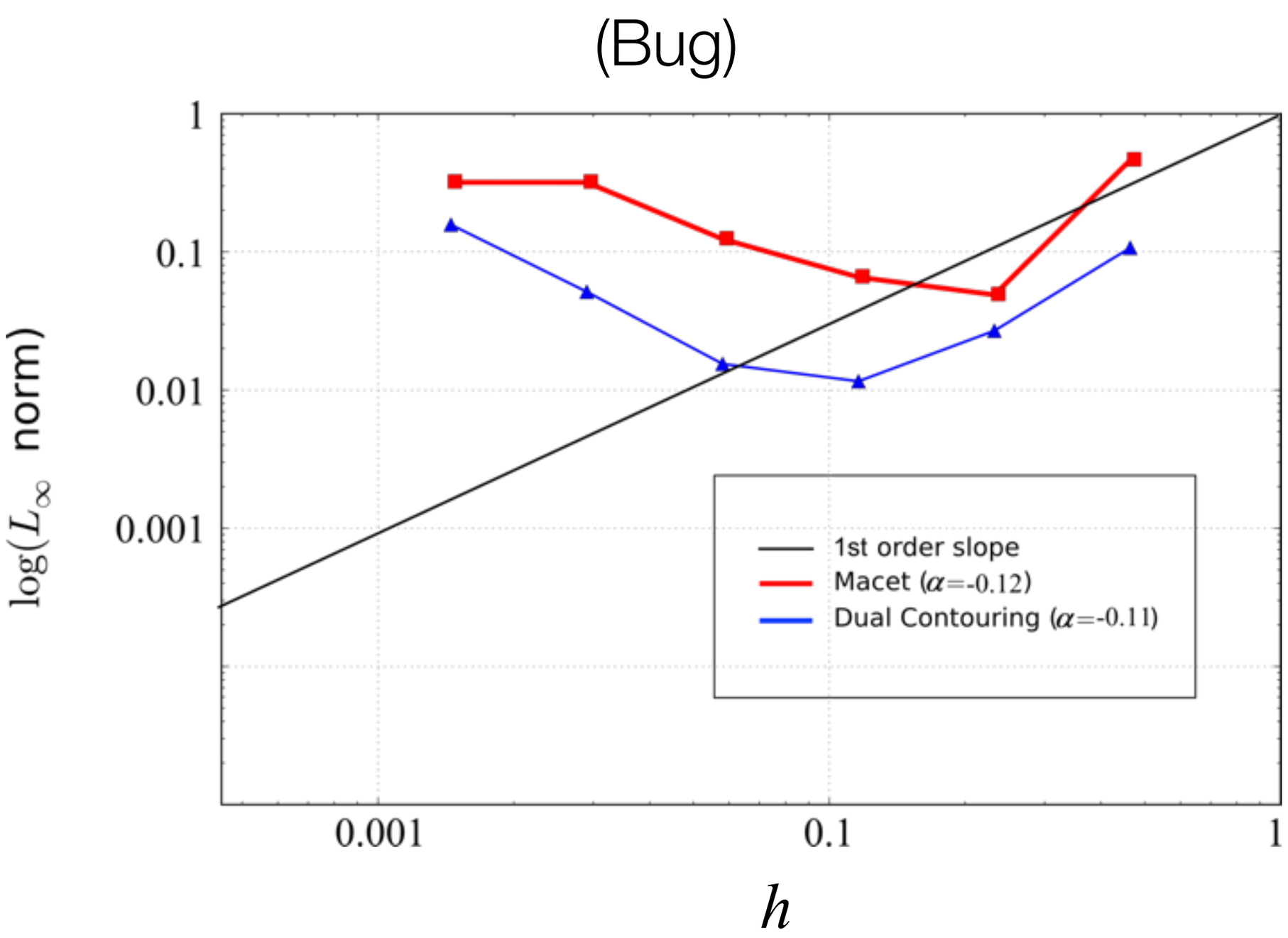
Observed order of accuracy Normal



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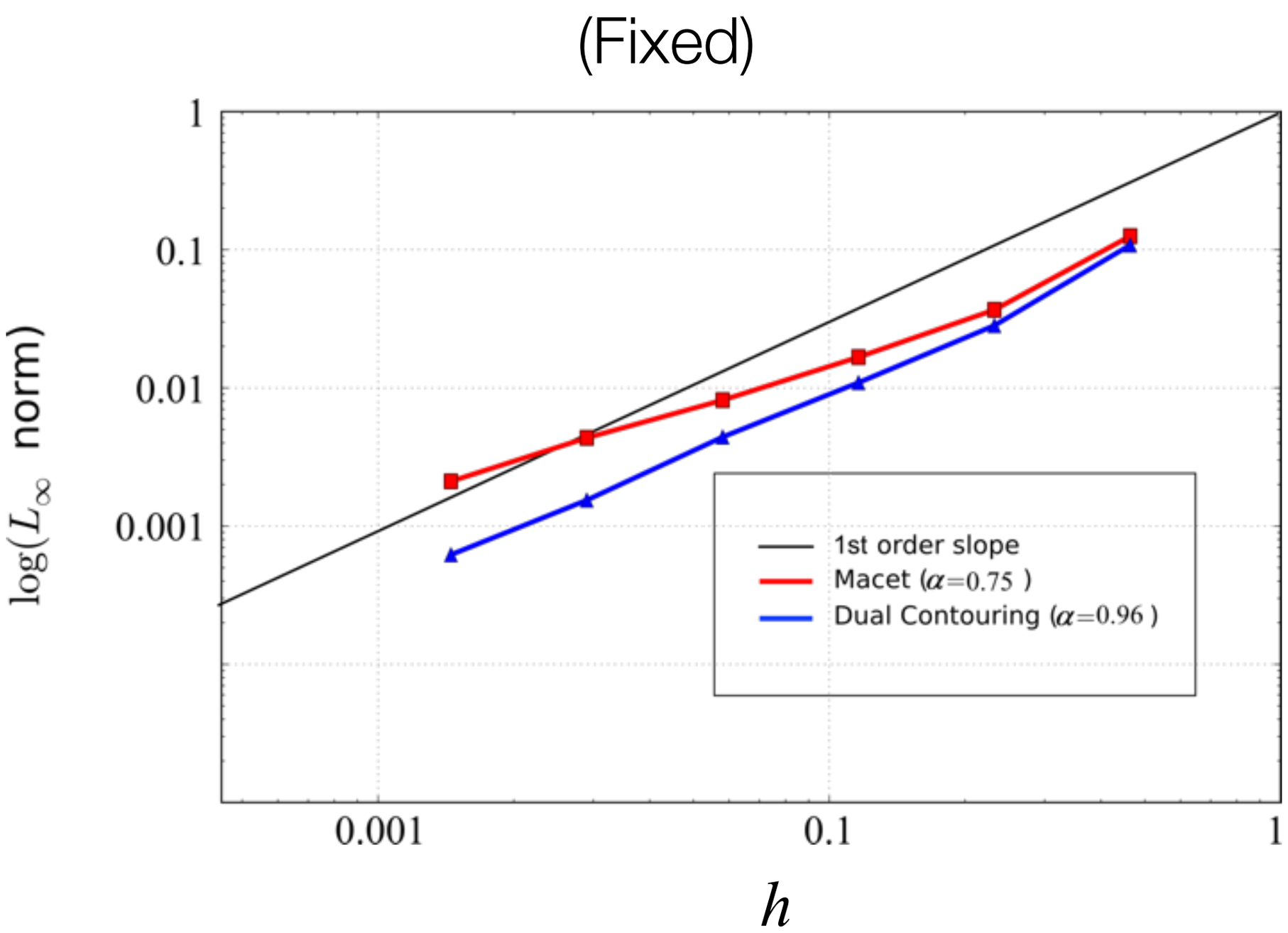
Observed order of accuracy Normal



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Topology verification

Topology Verification for Isosurface Extraction, T. Etiene, L. Nonato, C. Scheidegger, J. Tierny, T. Peters, V. Pascucci, R. M. Kirby, and C. Silva, IEEE Transactions on Visualization and Computer Graphics, to appear.
TO BE PRESENTED AT 4:30pm THIS AFTERNOON

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Results

- Rate of mismatch for topology invariants for algorithms without topological guarantees

	Consistency (%)	Digital Topology (%)				SMT (%)
		Betti 0	Betti 1	Betti 2	Euler	Euler
VTKMC	0	27.6	23.2	27.6	43.5	70.7
Afront	0	35.9	22.8	35.9	47.5	25.5
Macet	0	54.3	20.9	54.3	64.0	100.0

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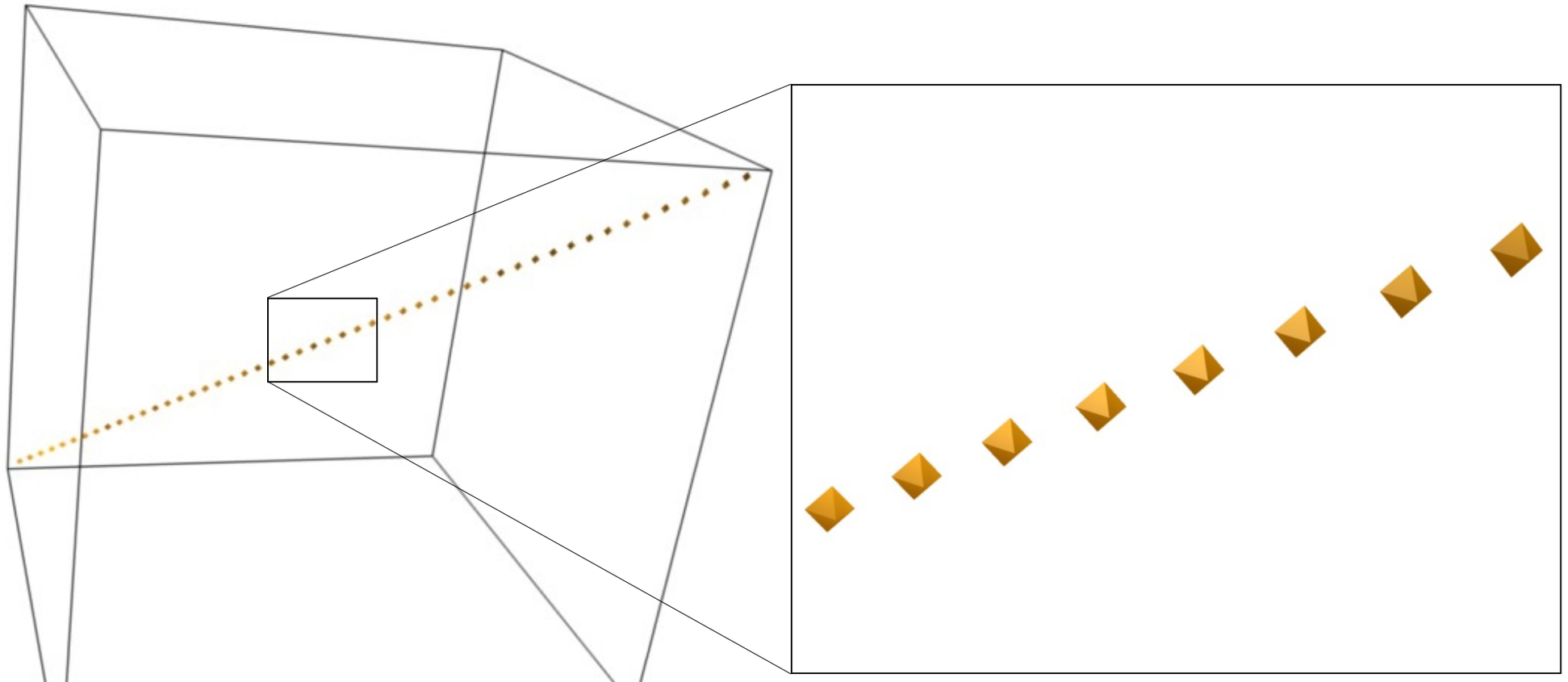
Concrete Example -- VTK MC



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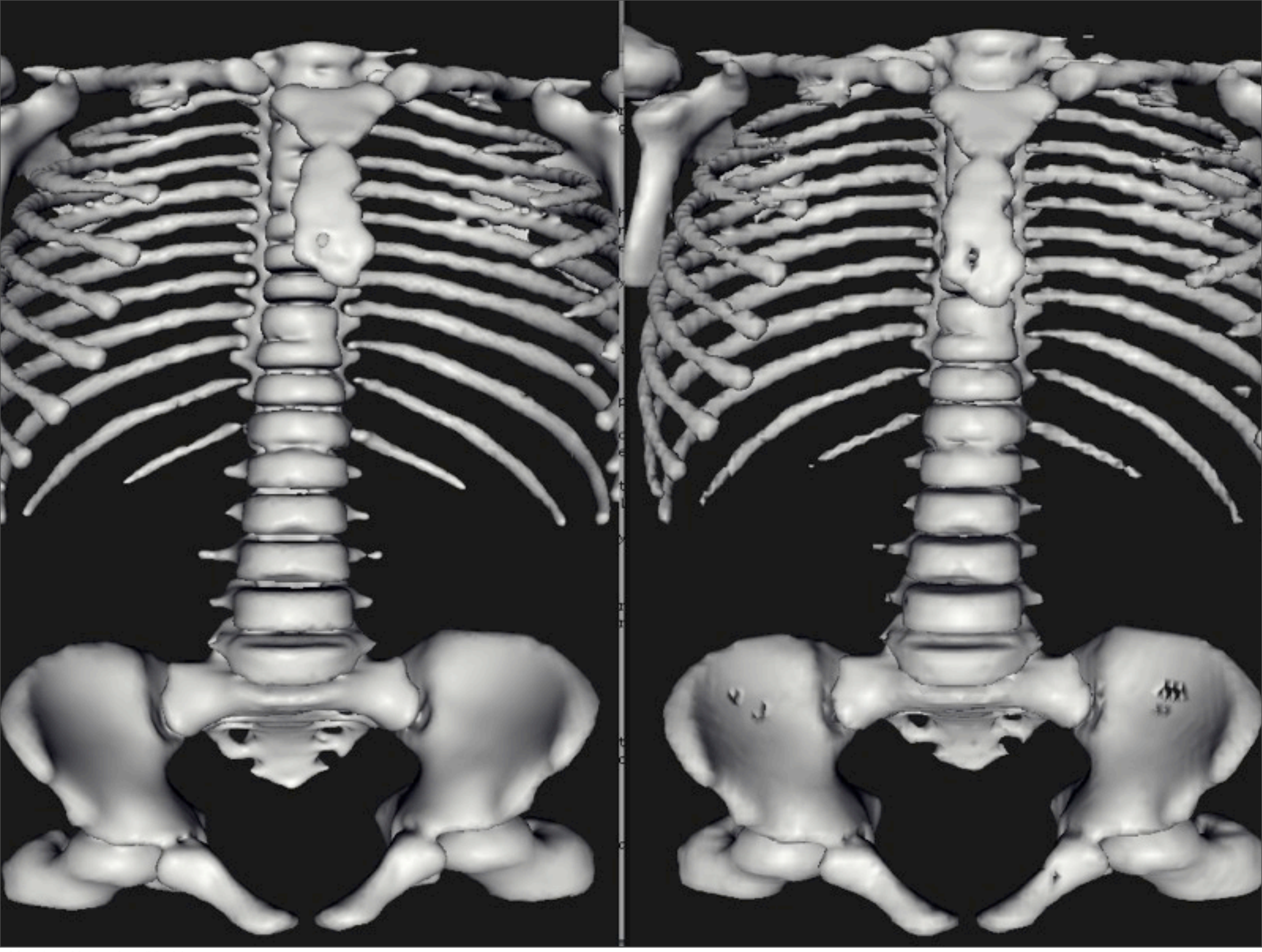
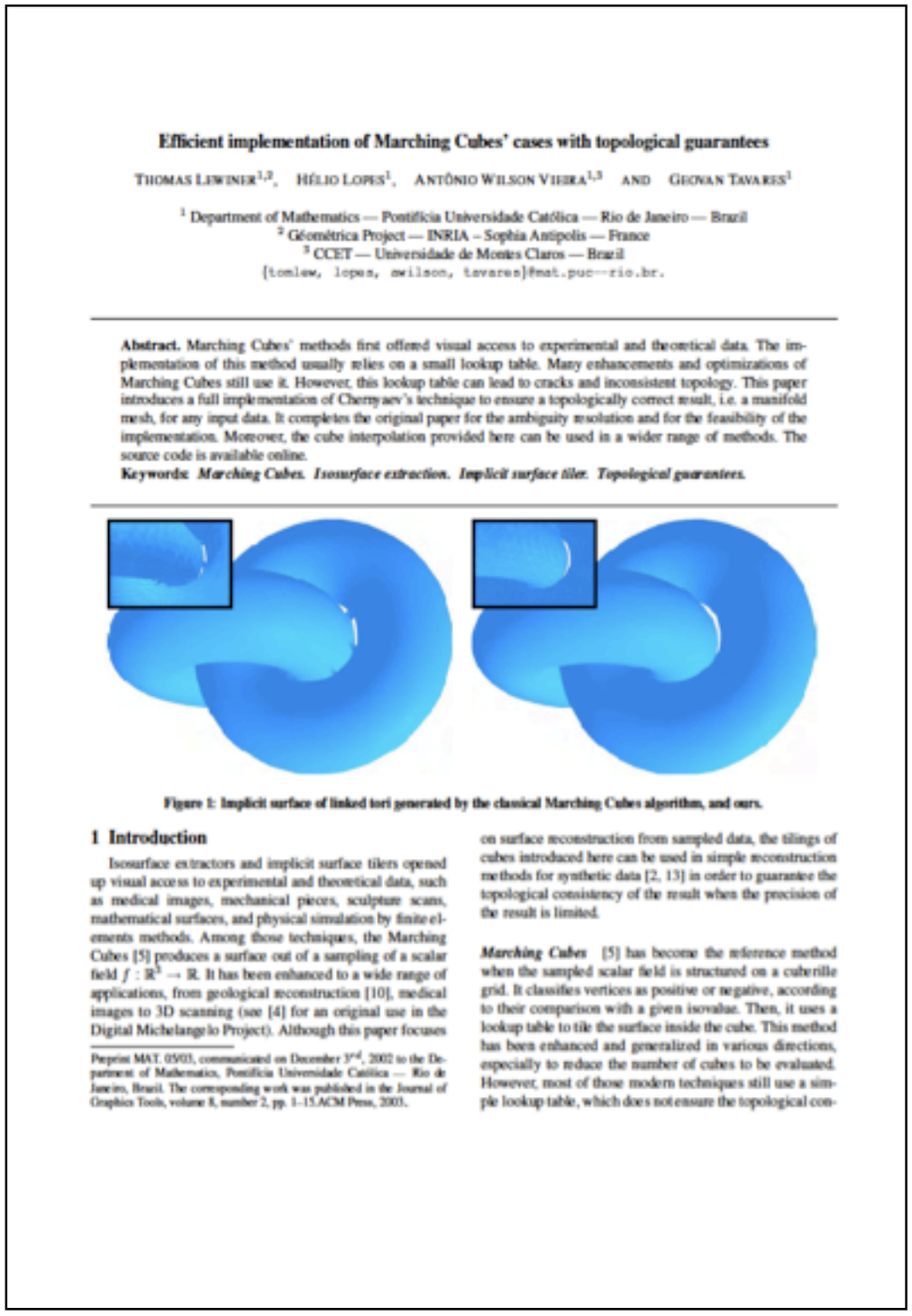


Results

- Rate of mismatch for topology invariants for **“topologically correct”** algorithms

		Digital Topology (%)				SMT (%)
	Consistency (%)	Betti 0	Betti 1	Betti 2	Euler	Euler
MC33	0	2.4	1.1	2.4	3.4	5.4
DelIso	19.1	24.4	0.1	20	37.2	33.2
MCFlow	0	0	0	0	0	0

MC33



Efficient implementation of Marching Cubes' cases with topological guarantees

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Abstract. Marching Cubes' methods first offered visual access to experimental and theoretical data. The implementation of this method usually relies on a small lookup table. Many enhancements and optimizations of Marching Cubes still use it. However, this lookup table can lead to cracks and inconsistent topology. This paper introduces a full implementation of Chernyaev's technique to ensure a topologically correct result, i.e. a manifold mesh, for any input data. It completes the original paper for the ambiguity resolution and for the feasibility of the implementation. Moreover, the cube interpolation provided here can be used in a wider range of methods. The source code is available online.

Keywords: *Marching Cubes. Isosurface extraction. Implicit surface tiler. Topological guarantees.*

Figure 1: Implicit surface of linked tori generated by the classical Marching Cubes algorithm, and ours.

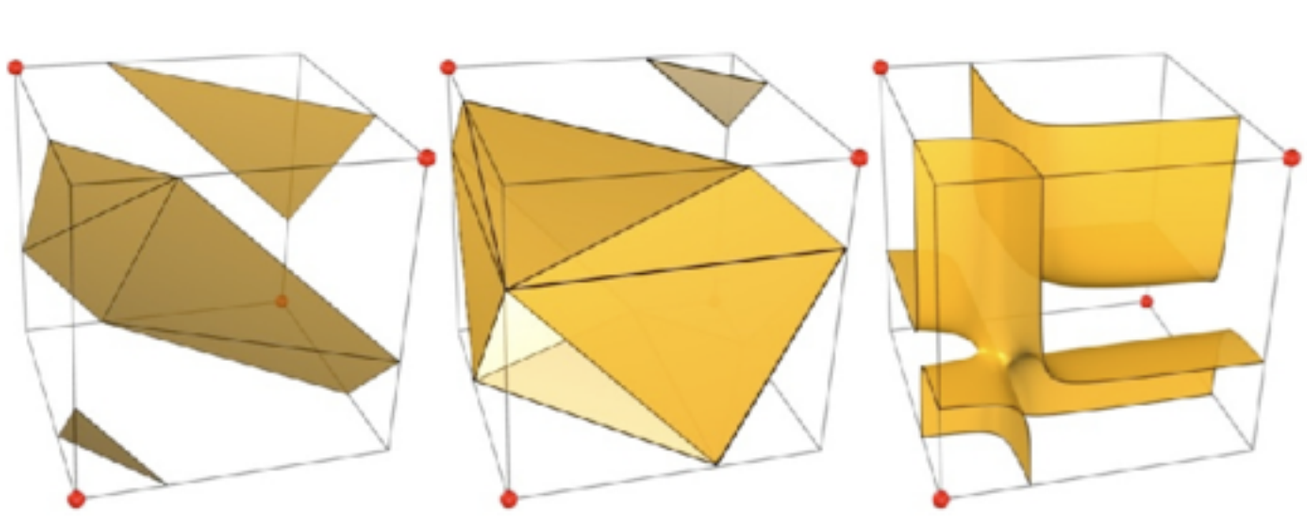
1 Introduction

Isosurface extractors and implicit surface tilers opened up visual access to experimental and theoretical data, such as medical images, mechanical pieces, sculpture scans, mathematical surfaces, and physical simulation by finite elements methods. Among those techniques, the Marching Cubes [5] produces a surface out of a sampling of a scalar field $f : \mathbb{R}^3 \to \mathbb{R}$. It has been enhanced to a wide range of applications, from geological reconstruction [10], medical images to 3D scanning (see [4] for an original use in the Digital Michelangelo Project). Although this paper focuses on surface reconstruction from sampled data, the tilings of cubes introduced here can be used in simple reconstruction methods for synthetic data [2, 13] in order to guarantee the topological consistency of the result when the precision of the result is limited.

Preprint MAT. 05/03, communicated on December 3rd, 2002 to the Department of Mathematics, Pontifícia Universidade Católica — Rio de Janeiro, Brazil. The corresponding work was published in the Journal of Graphics Tools, volume 8, number 2, pp. 1–15.ACM Press, 2003.

Marching Cubes [5] has become the reference method when the sampled scalar field is structured on a cuberille grid. It classifies vertices as positive or negative, according to their comparison with a given isovalue. Then, it uses a lookup table to tile the surface inside the cube. This method has been enhanced and generalized in various directions, especially to reduce the number of cubes to be evaluated. However, most of those modern techniques still use a simple lookup table, which does not ensure the topological con-

"Efficient implementation of Marching Cubes with topological guarantees" -- missing case in original theorem



Output from Isosurfacing

Expected Output

Trilinear surface

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Lessons

- Debugging, even “visual debugging” is hard, and incomplete
- Visual inspection is required but not sufficient
- Important codes and algorithms are still “incomplete” despite 20+ years of development
- Formal methods (of verification) used with parameter studies can greatly improve the quality of codes and techniques
- Each visualization & analysis technique needs their own analysis

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