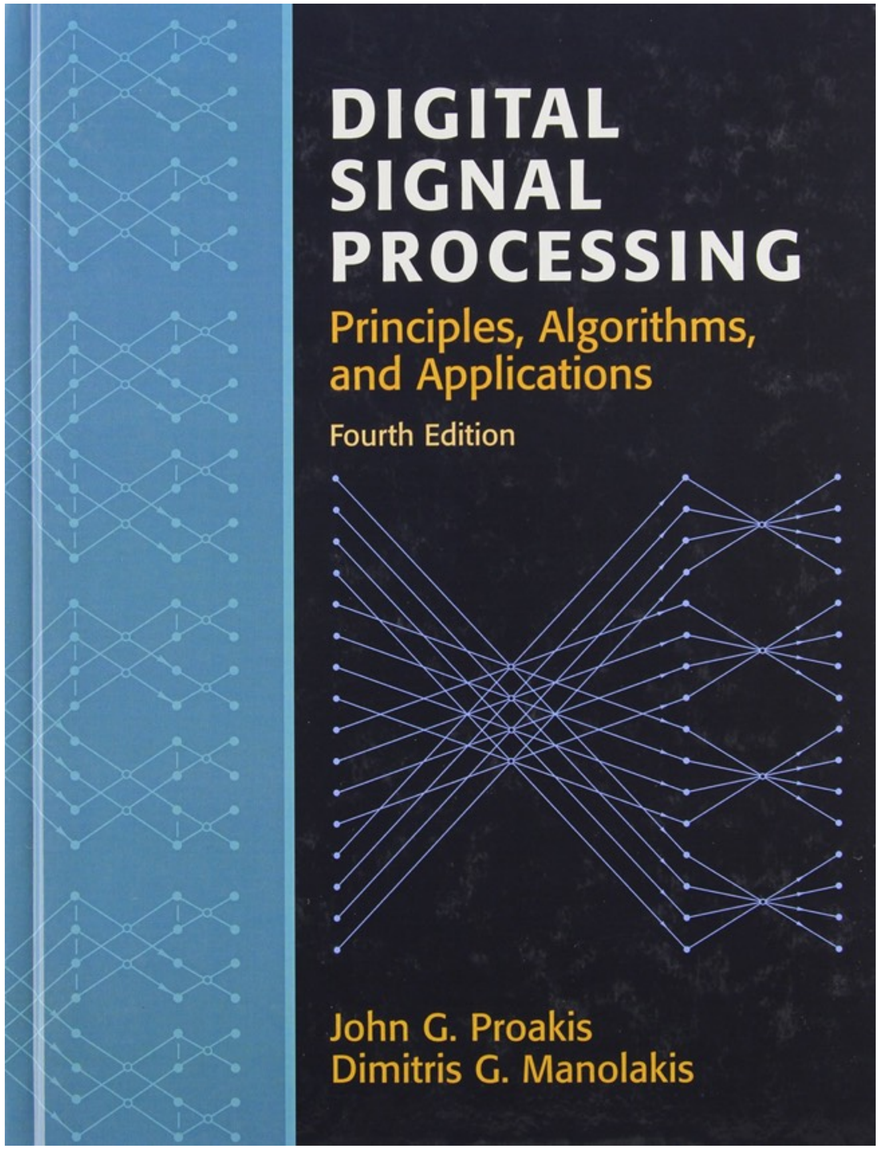
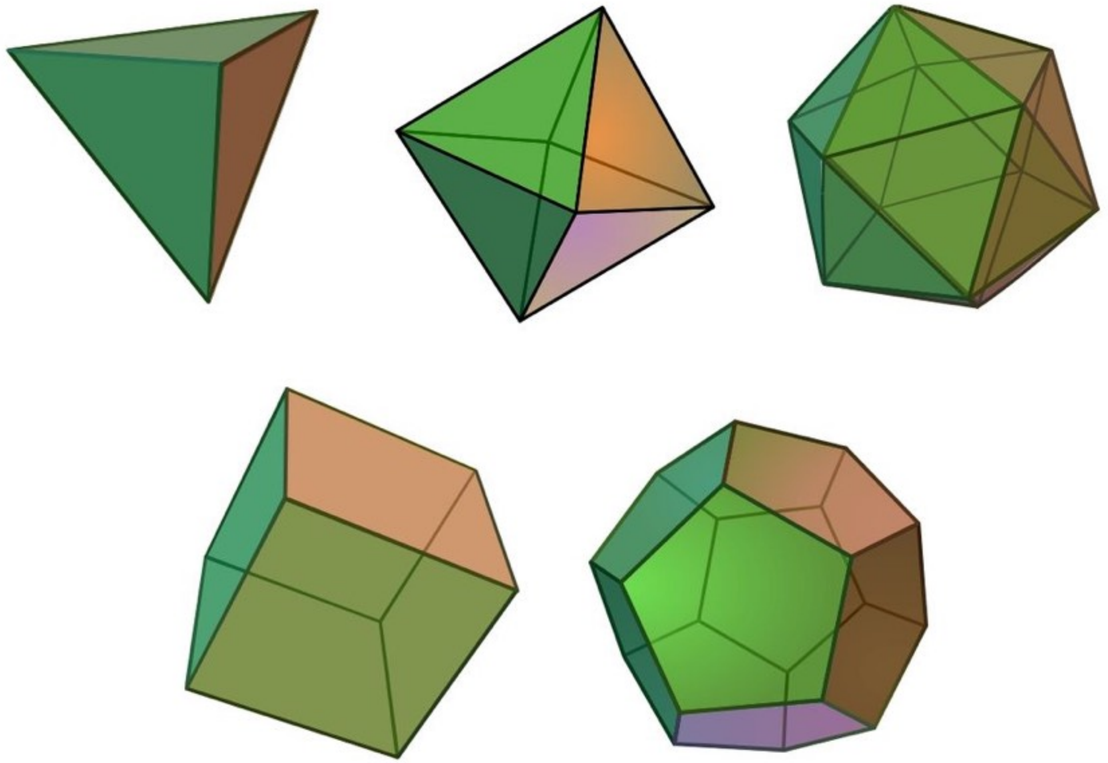
Digital Geometry Processing

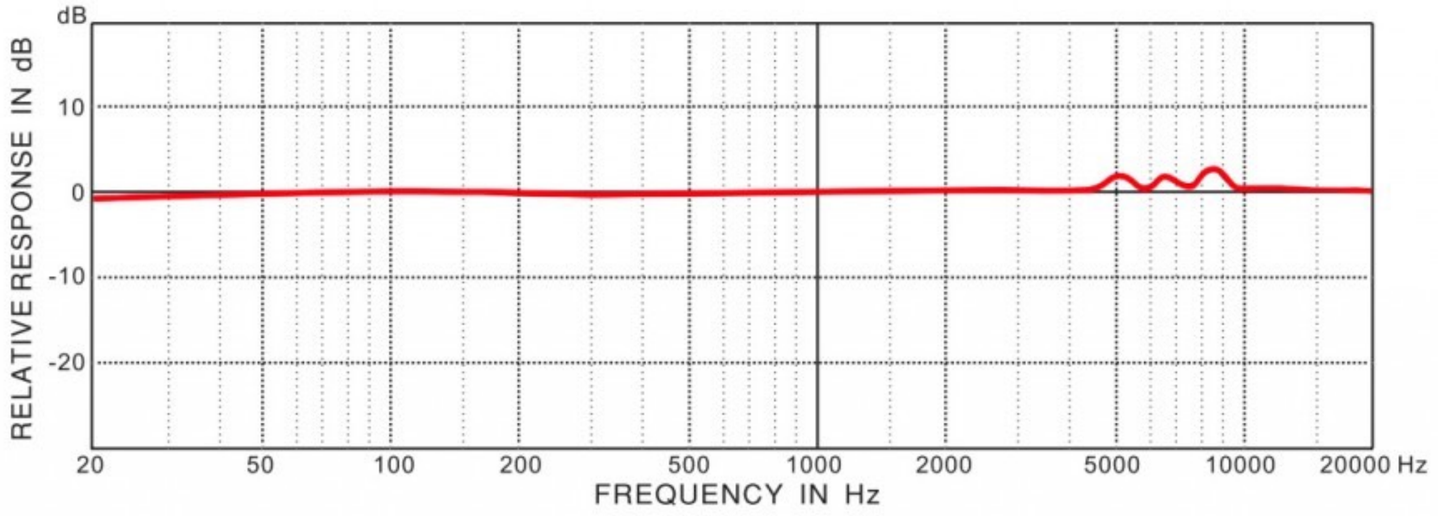
Keenan Crane • Computer Graphics Seminar (15-869) • CMU Fall 2015


DIGITAL
SIGNAL
PROCESSING
Principles, Algorithms,
and Applications
Fourth Edition
John G. Proakis
Dimitris G. Manolakis



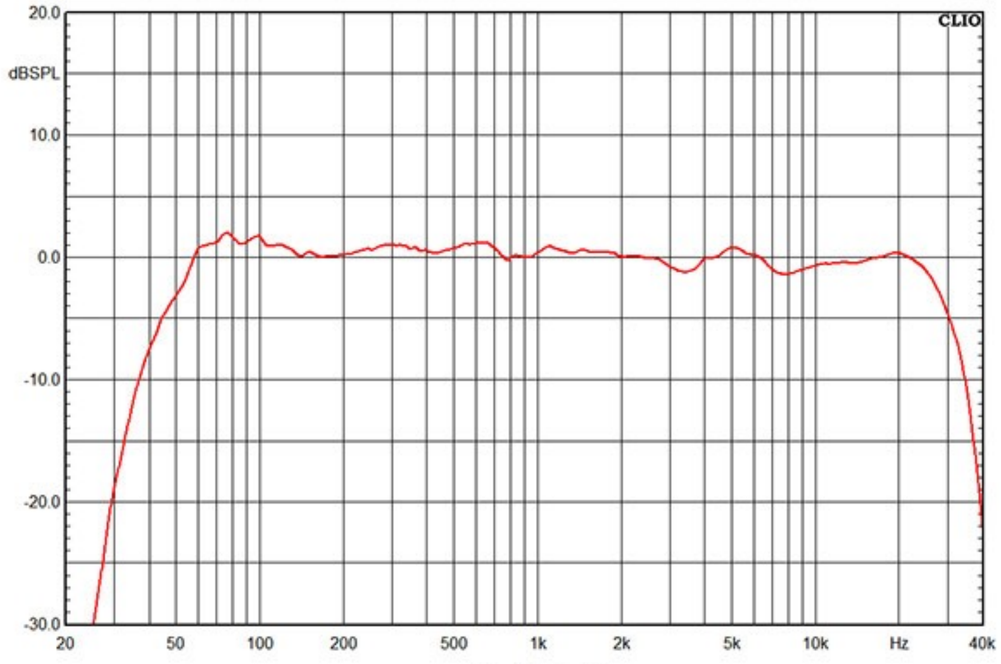
tech·nol·o·gy /tekˈnäləjē/

A tool or idea so well understood and well engineered that it "just works" without requiring expert knowledge. You just do it the way everyone else does it and it works "pretty good." (See also: *bo–ring*.)



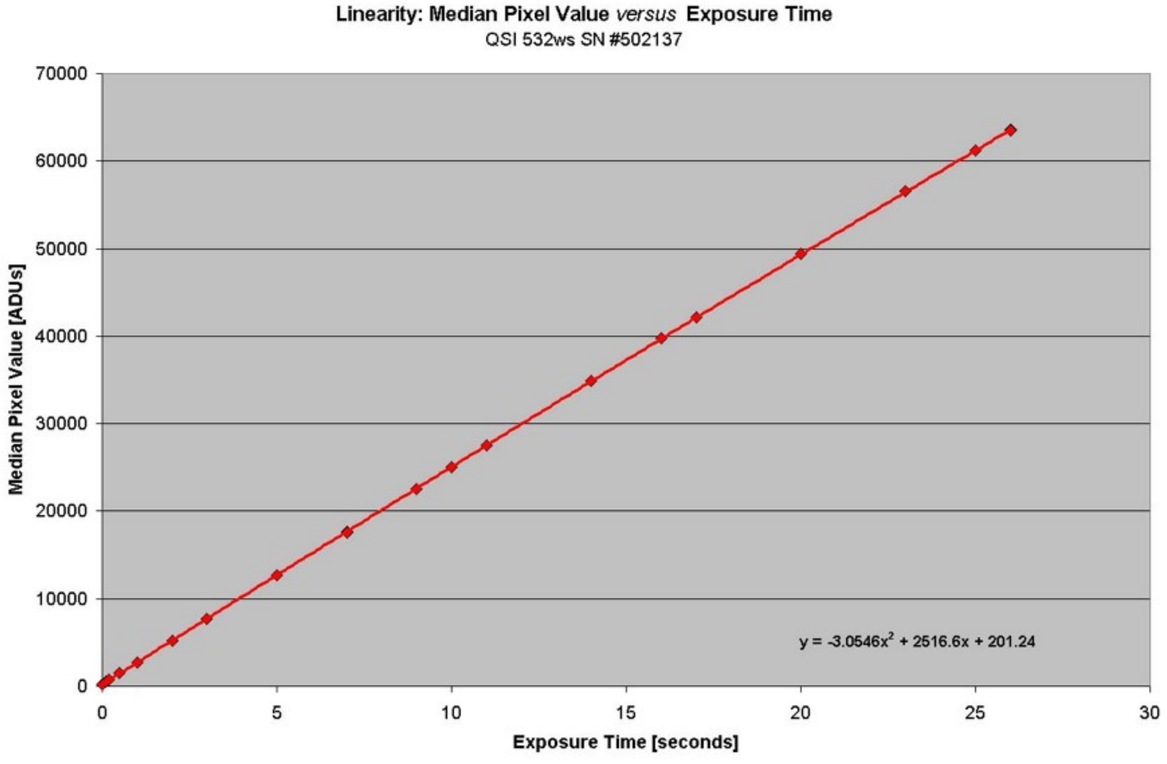
Behringer ECM8000 Frequency Response

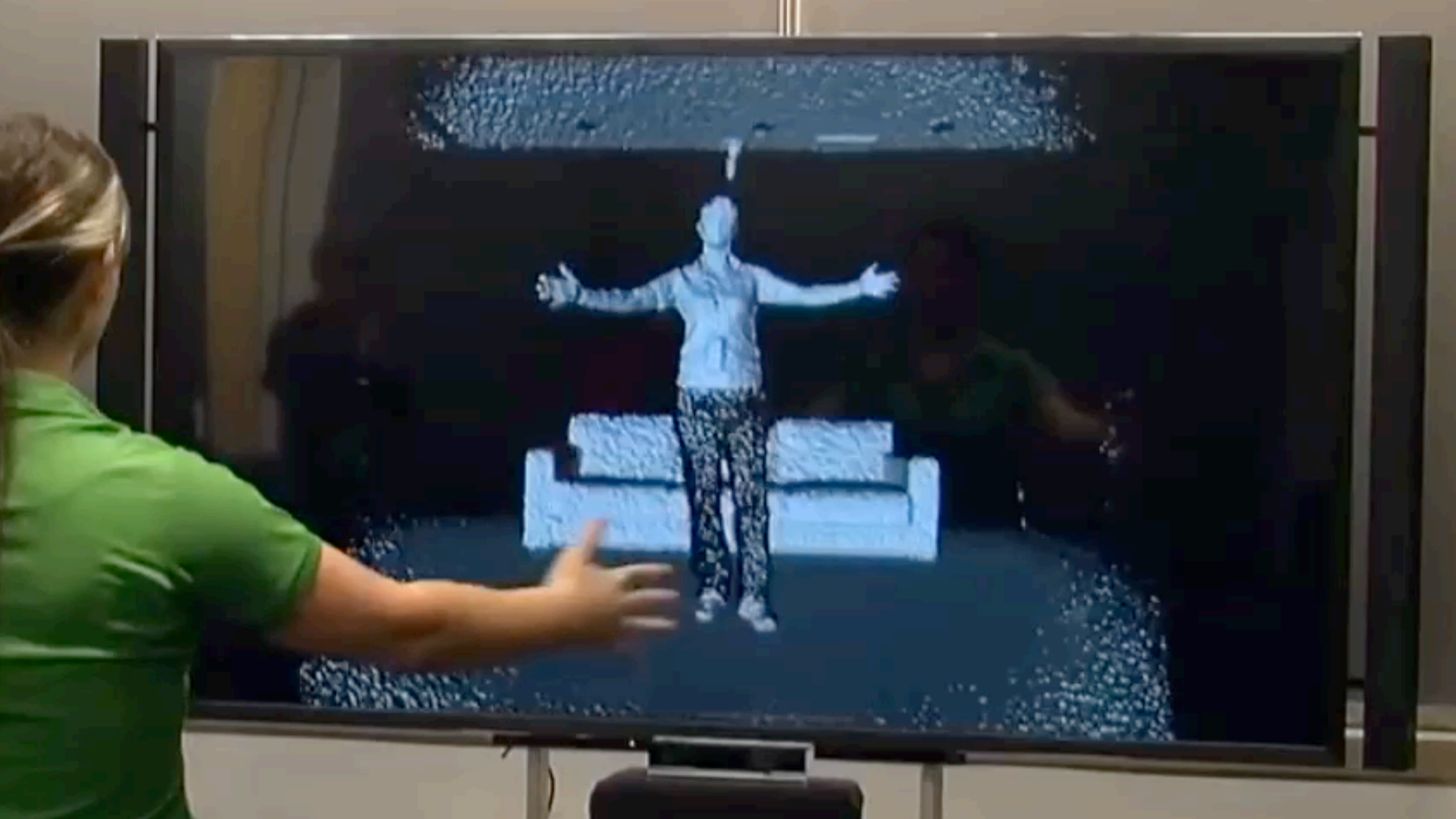

KRK
ROKIT 6
KRK
ROKIT 6


CLIO
20.0
dBSPL
10.0
0.0
-10.0
-20.0
-30.0
20
50
100
200
500
1k
2k
5k
10k
Hz
40k

Rokit 6 G3


QSI
Astronomy
HOT
Product


Linearity: Median Pixel Value versus Exposure Time
QSI 532ws SN #502137
Median Pixel Value [ADUs]
70000
60000
50000
40000
30000
20000
10000
0
0
5
10
15
20
25
30
Exposure Time [seconds]
y = -3.0546x2 + 2516.6x + 201.24




MakerBot
Monitor Mode
Build from SD
Jog Mode
Home Axes

“I hate meshes.
I cannot believe how hard this is.
Geometry is hard.”

—David Baraff
Senior Research Scientist
Pixar Animation Studios

Slide cribbed from Jeff Erickson

300,000 models (total)

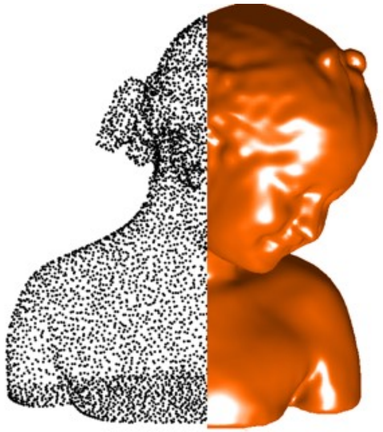
10–100k vertices

10,400,000 photos

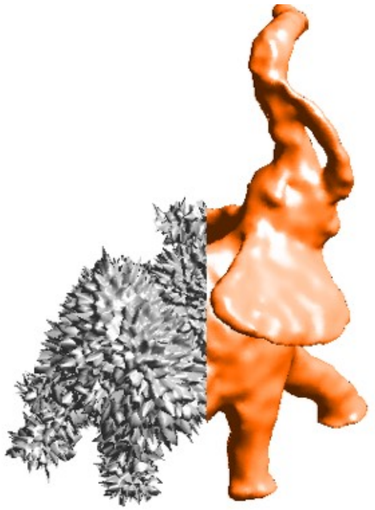
...per hour!

1–10M pixels

scan → process → print

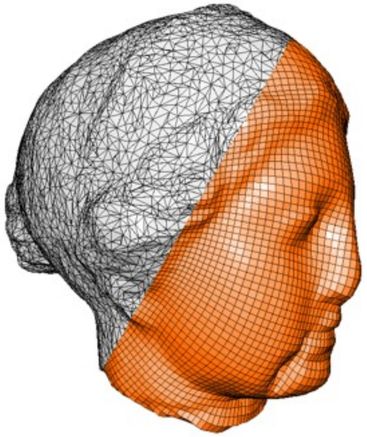


reconstruction

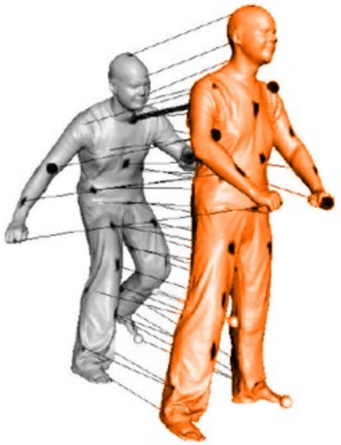


filtering

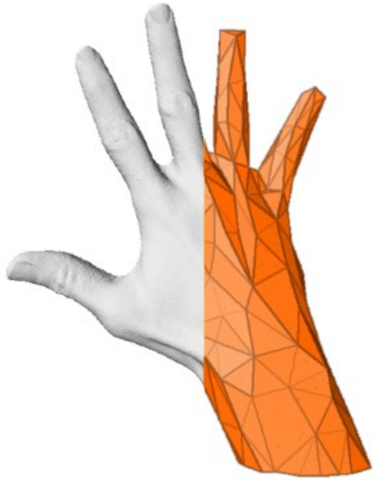
parameterization



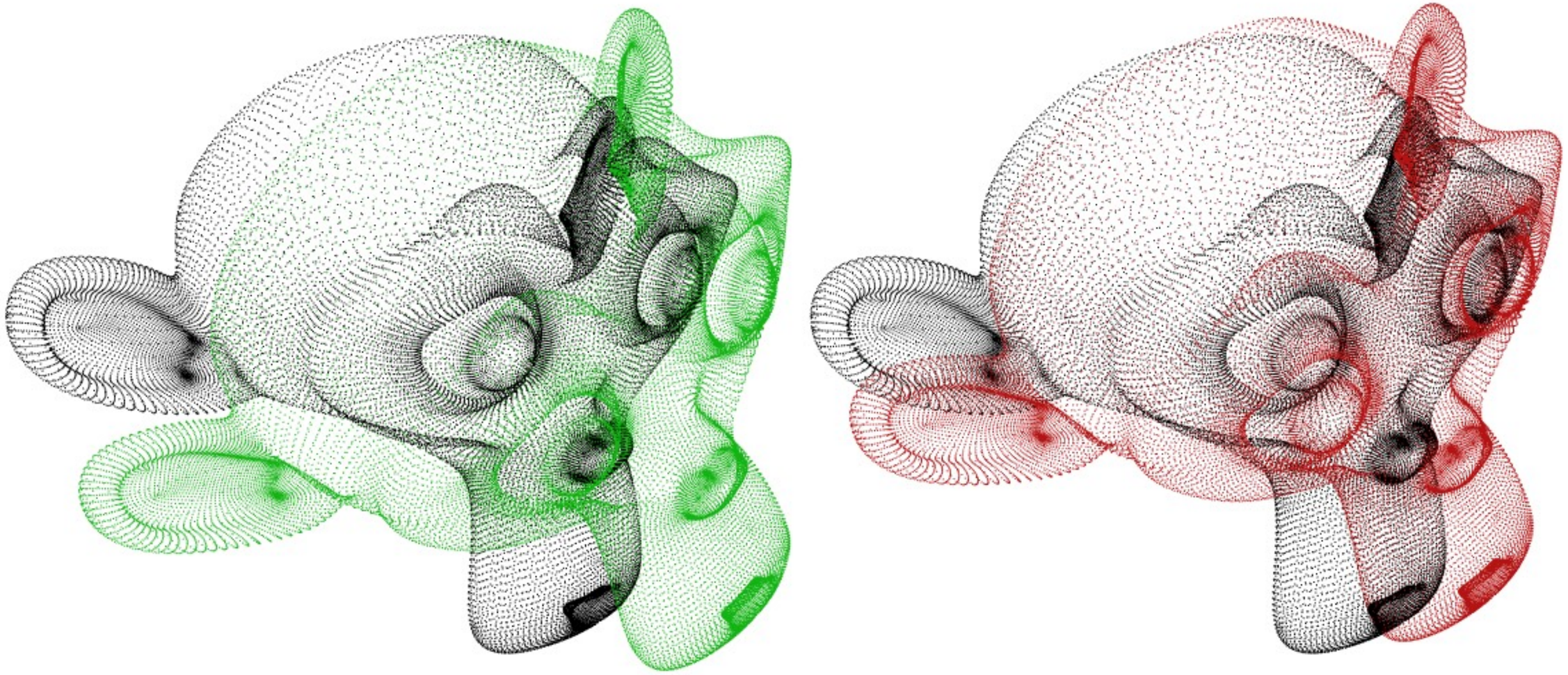
remeshing



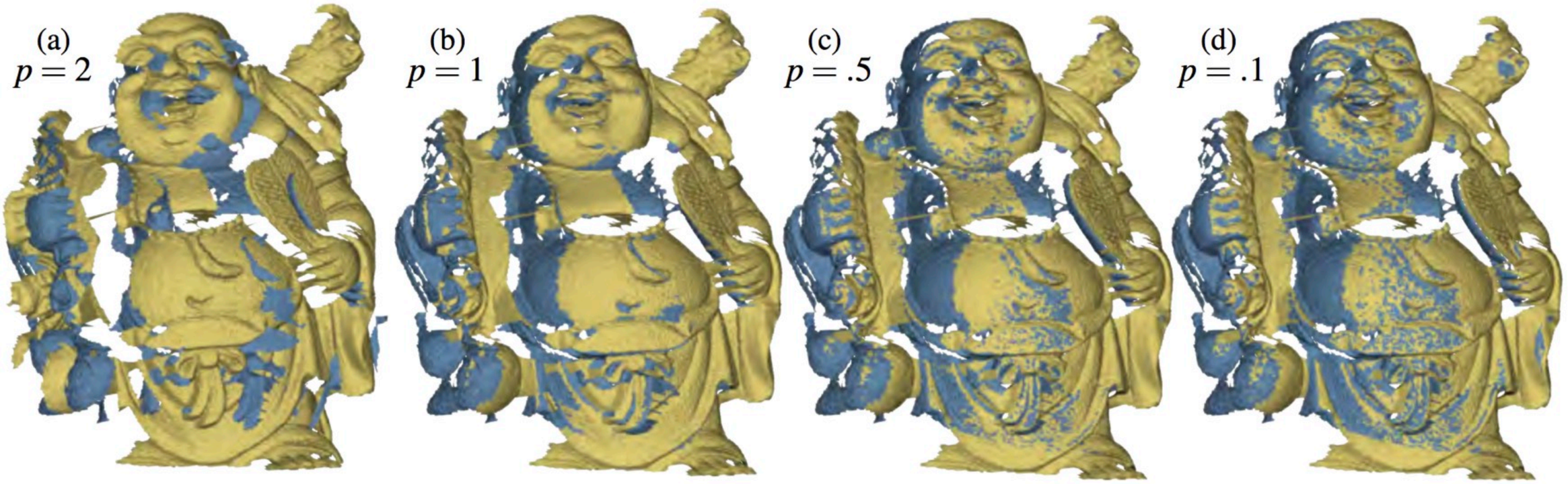
shape analysis



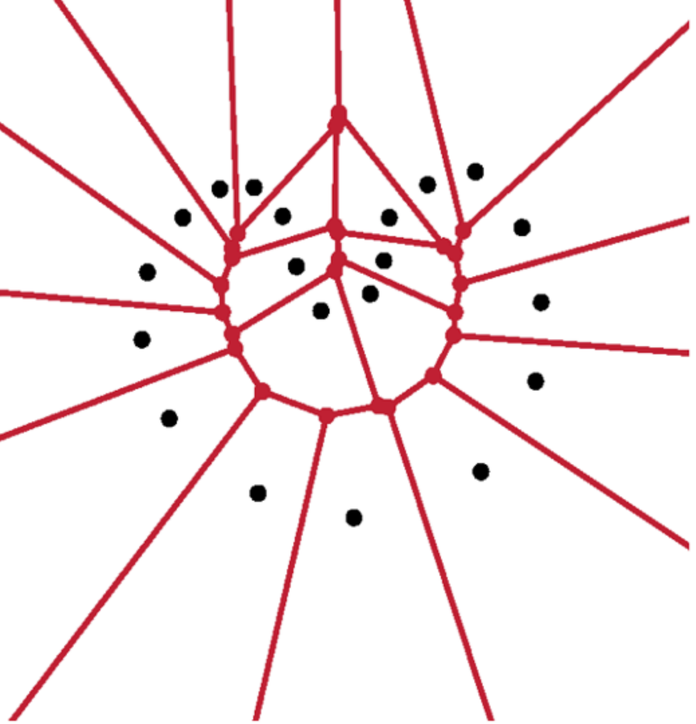
compression



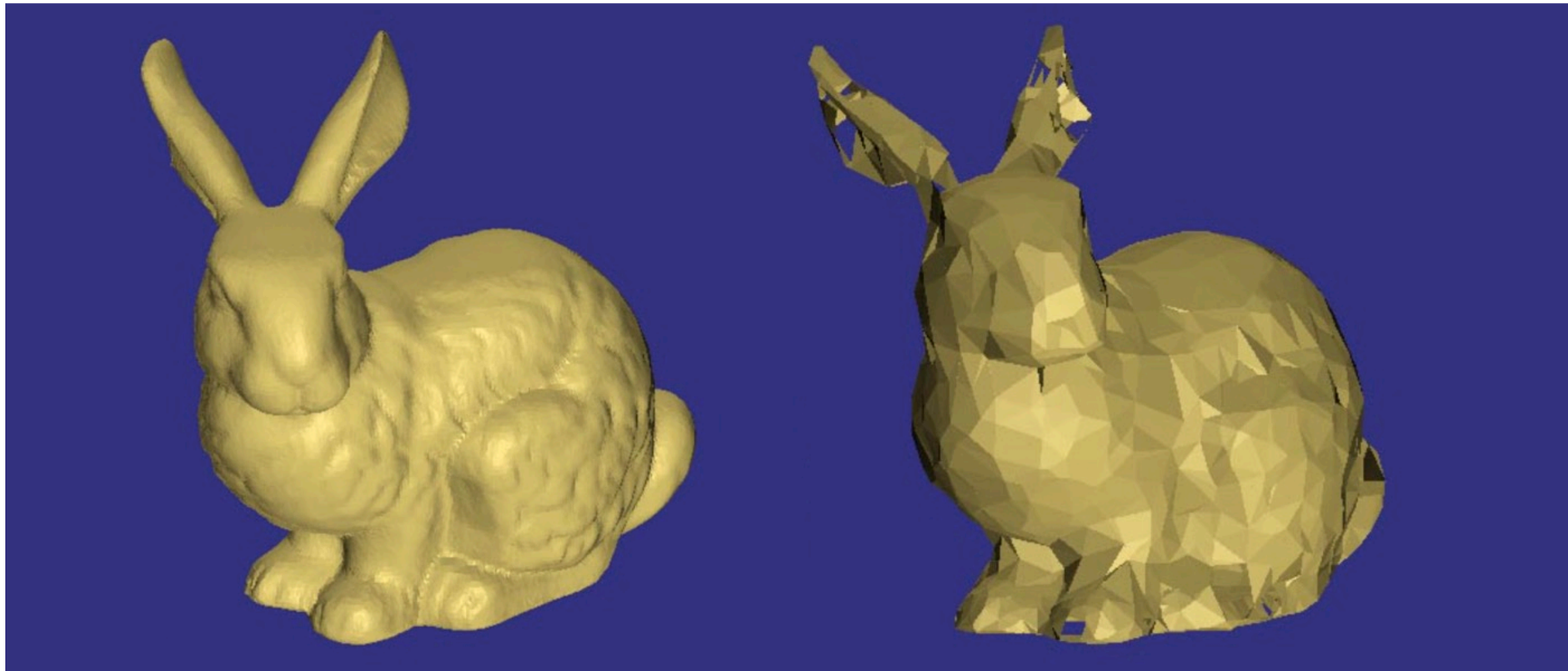
Besl & McKay (1992)
“A method for registration of 3D shapes”

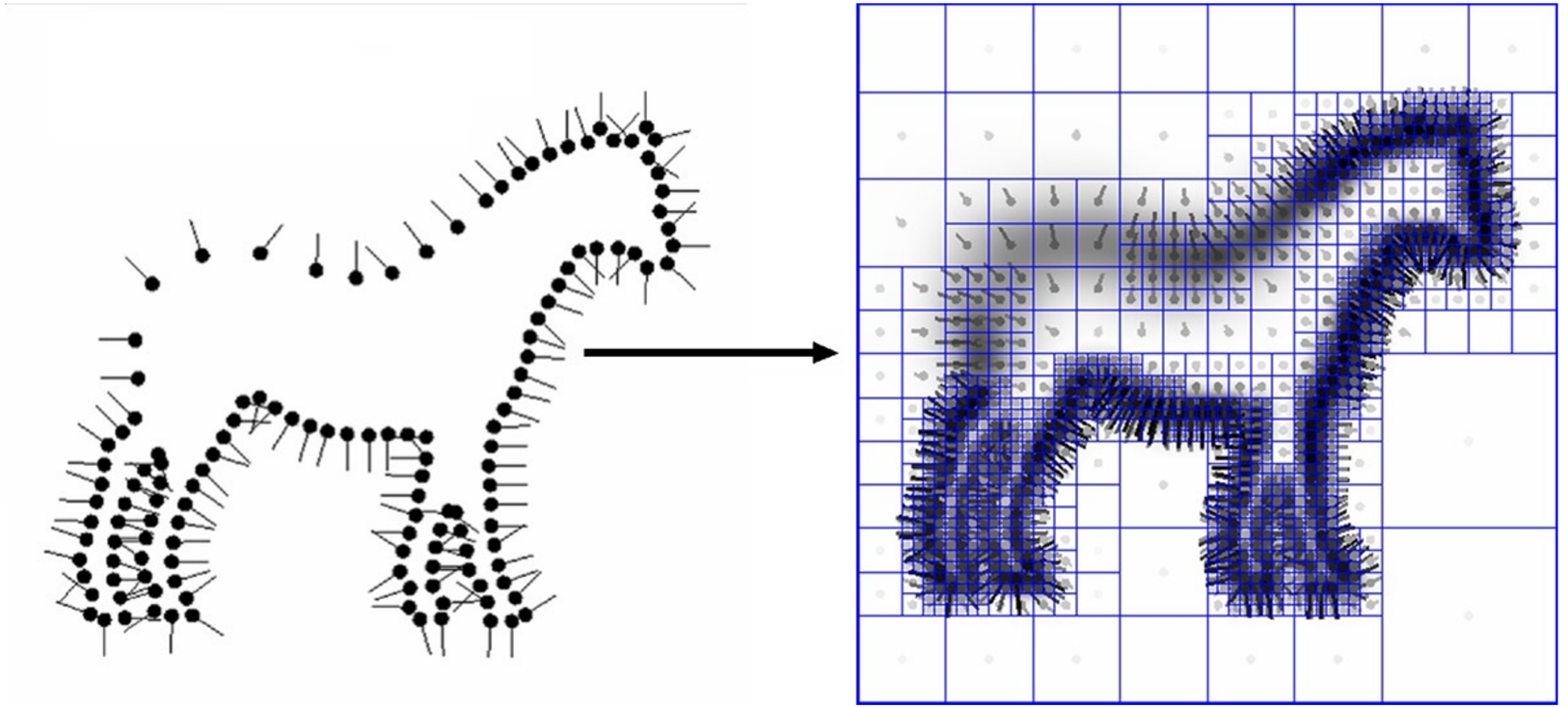


Bouaziz et al (2013)
“Sparse Iterative Closest Point”

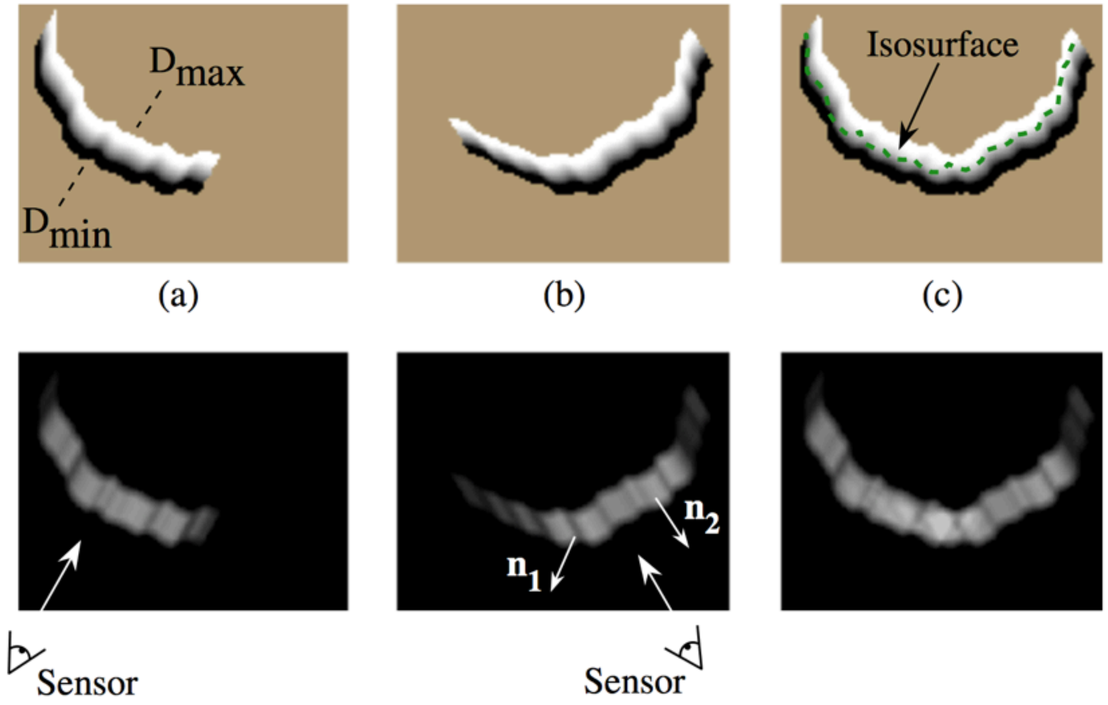


“A New Voronoi-Based Surface Reconstruction”
Amenta et al (1998)





Kazhdan et al (2006)
“Poisson Surface Reconstruction”



Curless & Levoy (1996)

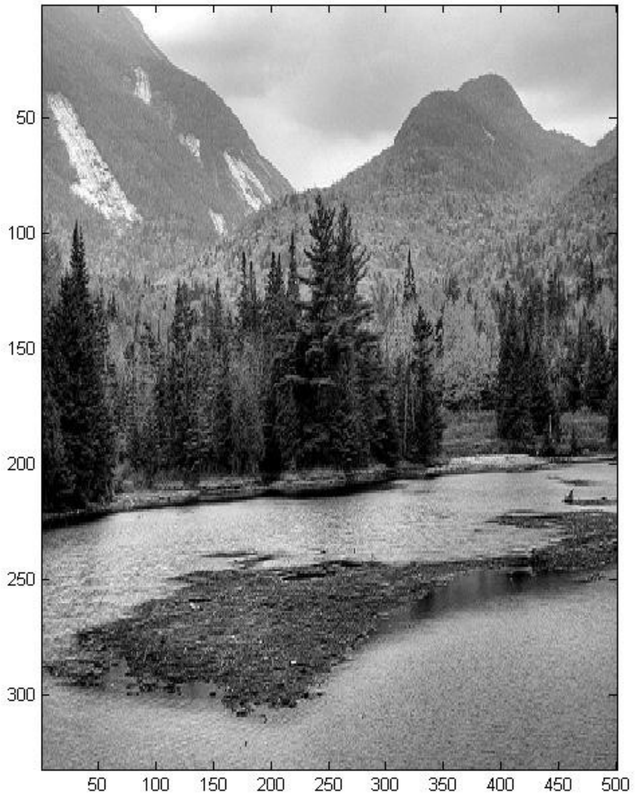
“A Volumetric Method for Building Complex Models from Range Images”

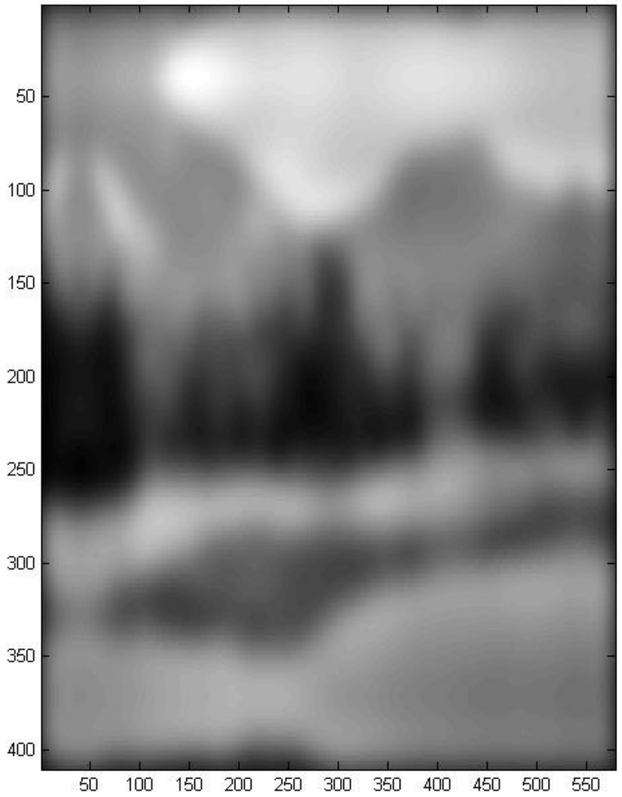
“State of the Art in Surface Reconstruction from Point Clouds”
Berger et al (2014)

Method	Point Cloud Artifacts					Input Requirements				Shape Class	Reconstruction Output
	nonuniform sampling	noise	outliers	misalignment	missing data	unoriented normals	oriented normals	scanner information	RGB image		
Surface Smoothness											
Tangent Planes [HDD*92]	○	○								general	implicit field
RBF [CBC*01]	○				○		✓			general	implicit field
MLS [ABCO*03]	○	○				✓				general	point set
MPU [OBA*03a]	○	○			○		✓			general	implicit field
Poisson [KBH06]	○	●	○	○	○		✓			general	implicit field
Graph Cut [HK06]	○	○	○	○	○					general	volumetric segmentation
Unoriented Indicator [ACSTD07]	○	●	○	○	○	✓				general	implicit field
LOP [LCOLTE07]	●	●	○	○						general	point set
Visibility											
VRIP [CL96]	○	●			○			✓		general	implicit field
TVL1-VRIP [ZPB07]	○	●	○	○	○			✓		general	implicit field
Signing the Unsigned [MDGD*10]	○	●	●		○	✓				general	implicit field
Cone Carving [SSZCO10]	○	○			●		✓	✓		general	implicit field
Multi-Scale Scan Merge [FG11]	●	●			○			✓		general	implicit field
Volumetric smoothness											
ROSA [TZCO09]	○	○			●		✓			organic	skeleton curve
Arterial Snakes [LLZM10]	○	○			●		✓			man-made	skeleton curve
VASE [TOZ*11]	○	○			●			✓		general	implicit field
l_1 Skeleton [HWCO*13]	○	○			●					organic	skeleton curve
Geometric Primitives											
Primitive Completion [SDK09]	○	○	○		●		✓			CAD	volumetric segmentation
Volume Primitives [XF12]	○	○	○		●			✓		indoor environment	interior volume
Point Restructuring [LA13]	○	○	○	○	○	✓		✓		general	volumetric segmentation
CCDT [vKvLV13]	○	○	○		○	✓		✓		urban environment	volumetric segmentation
Global Regularity											
Symmetry [PMW*08]	○	○			●	✓				architectural	point set
Nonlocal Consolidation [ZSW*10]	●	○	○		●	✓				architectural	point set
2D-3D Facades [LZS*11]	○	○			●	✓			✓	architectural	point set
Globfit [LWC*11]	●	○	○	●		✓				man-made	primitive relations
Data-driven											
Completion by Example [PMG*05]	○	○			●		✓			general	point set
Semantic Modeling [SXZ*12]	○	○			●	✓			✓	indoor scene objects	deformed model
Shape Variability [KMYG12]	○	○			●	✓				indoor scene objects	deformed model
Part Composition [SFCH12]	○	○			●	✓			✓	man-made	deformed model parts
Interactive											
Topological Scribble [SLS*07]	○	○			●		✓			general	implicit field
Smartboxes [NSZ*10]	●	○	○		●	✓				architectural	primitive shapes
O-Snap [ASF*13]	○	○	○		●	✓				architectural	primitive shapes

“A very attractive aspect of Delaunay methods is that they come with guarantees if a sufficiently dense sampling of the input surface is provided … These methods place rather strong requirements on the point cloud and are impractical for real-world scenes containing significant imperfections.”

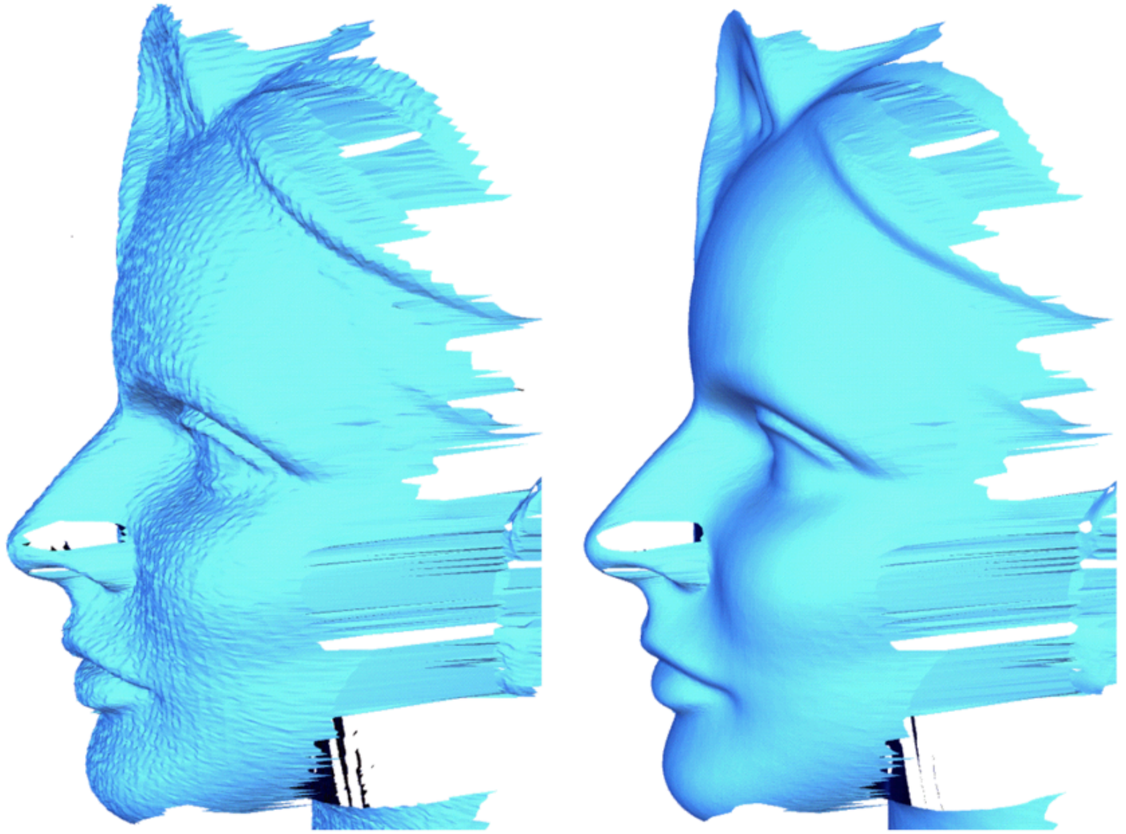

6



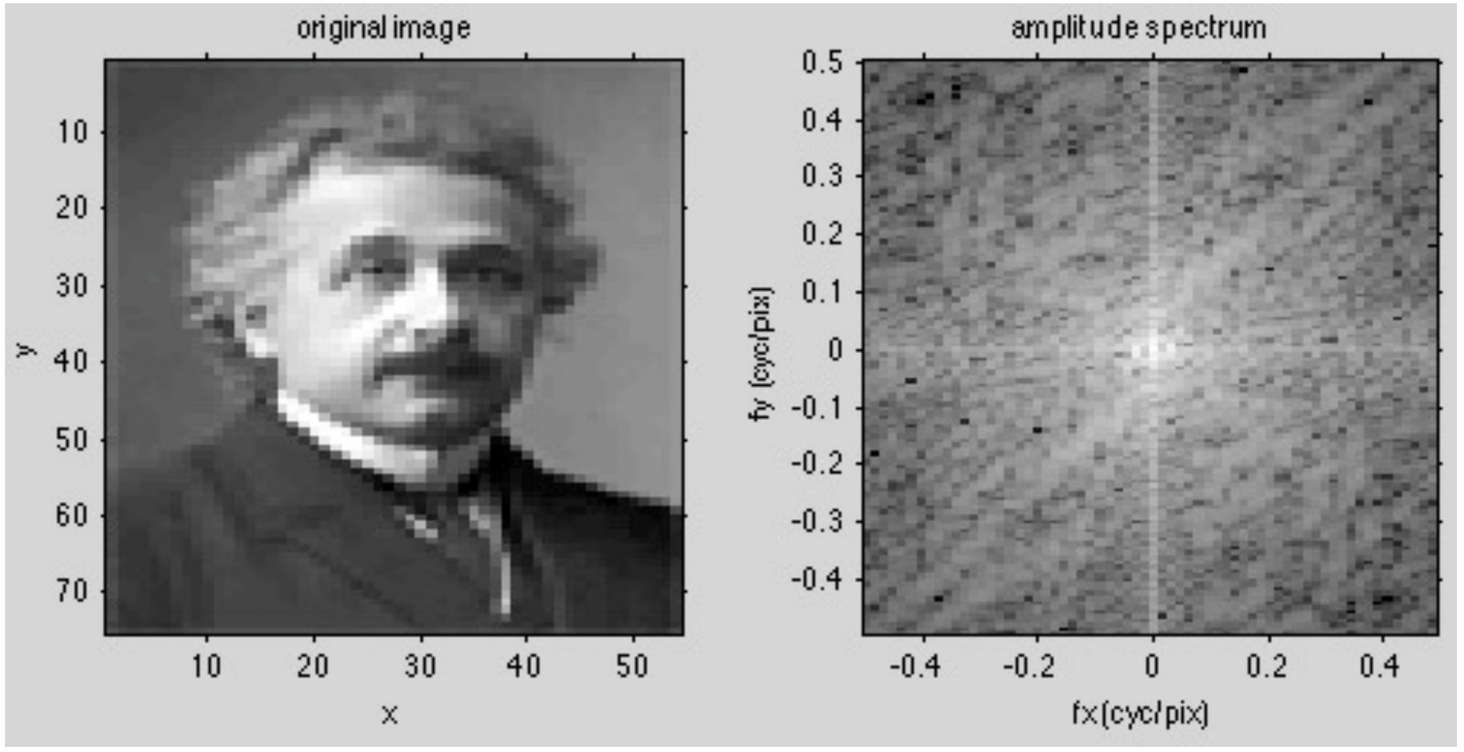


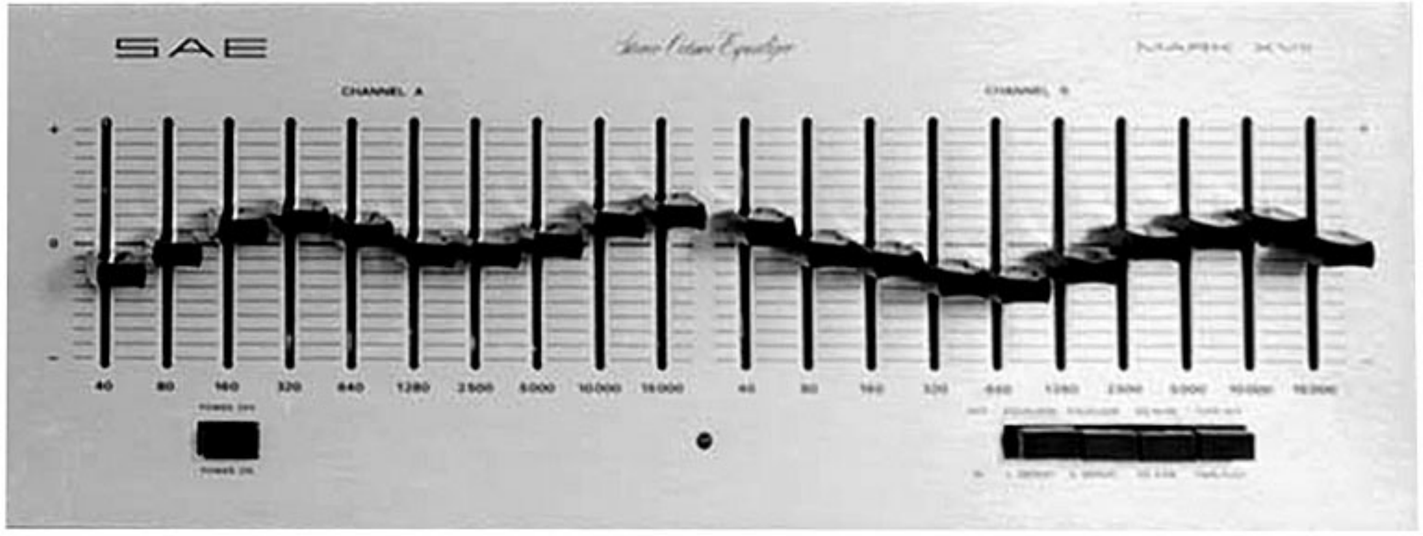
$$(f * k)(x) := \int_{\Omega} f(x)k(x-y)dy$$

“Implicit Fairing of Irregular Meshes using Diffusion and Curvature Flow”
Desbrun et al (1999)



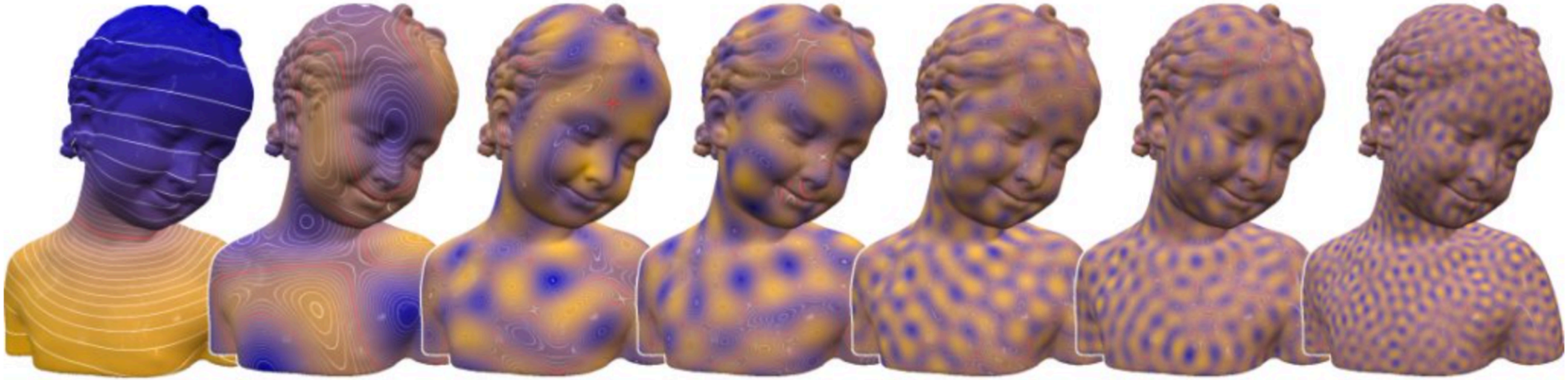
$$\frac{d}{dt}f = \Delta f$$



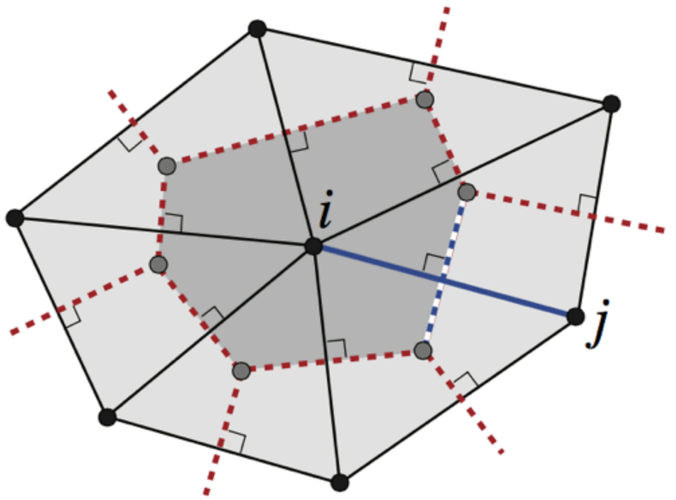


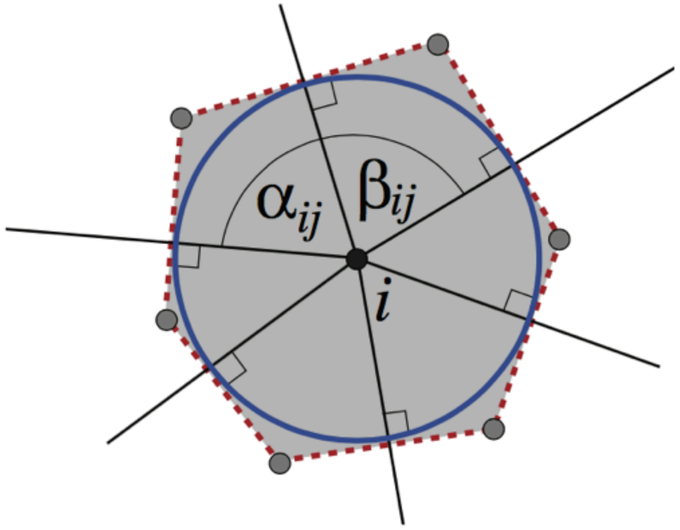
There is no FFT for geometry.

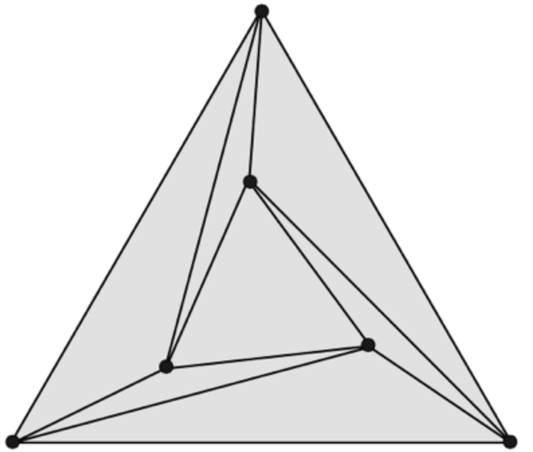
$$\frac{\partial}{\partial x^2}\cos(nx) = -n^2\cos(nx)$$



“Discrete Laplace Operators: No Free Lunch”
Wardetzky et al (2007)

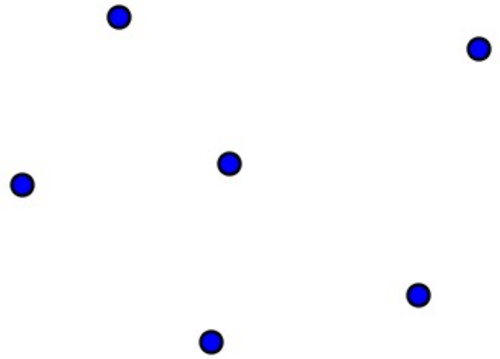




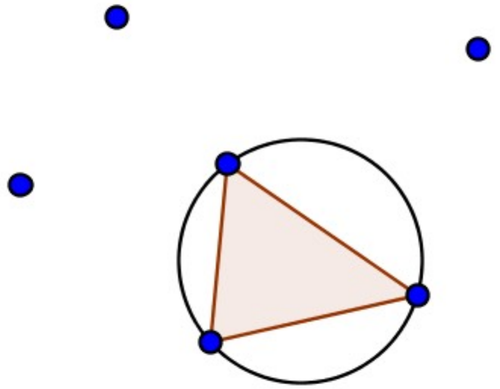


	SYM	LOC	LIN	POS	PSD	CON
MEAN VALUE	○	●	●	●	○	○
INTRINSIC DEL	●	○	●	●	●	?
COMBINATORIAL	●	●	○	●	●	○
COTAN	●	●	●	○	●	●

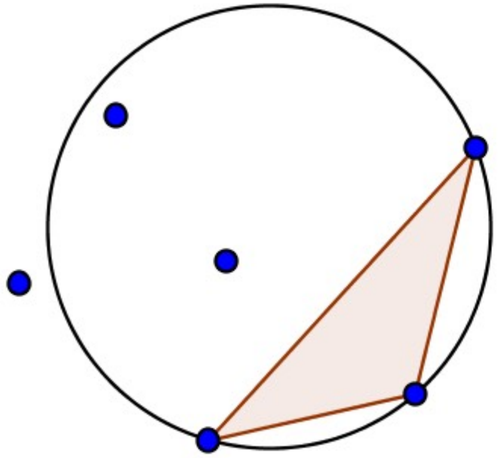
Observe that none of the Laplacians considered in graphics fulfill *all* desired properties. Even more: none of them satisfy the first four properties. This is not a coincidence.



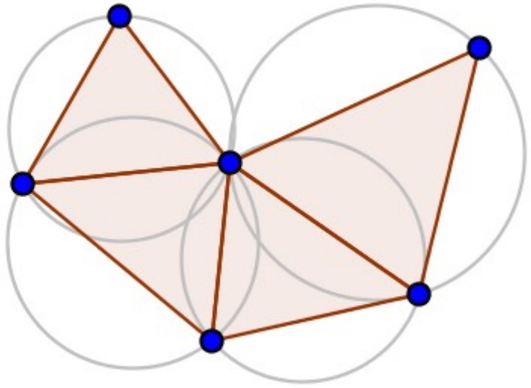
A collection of points



A Delaunay triangle

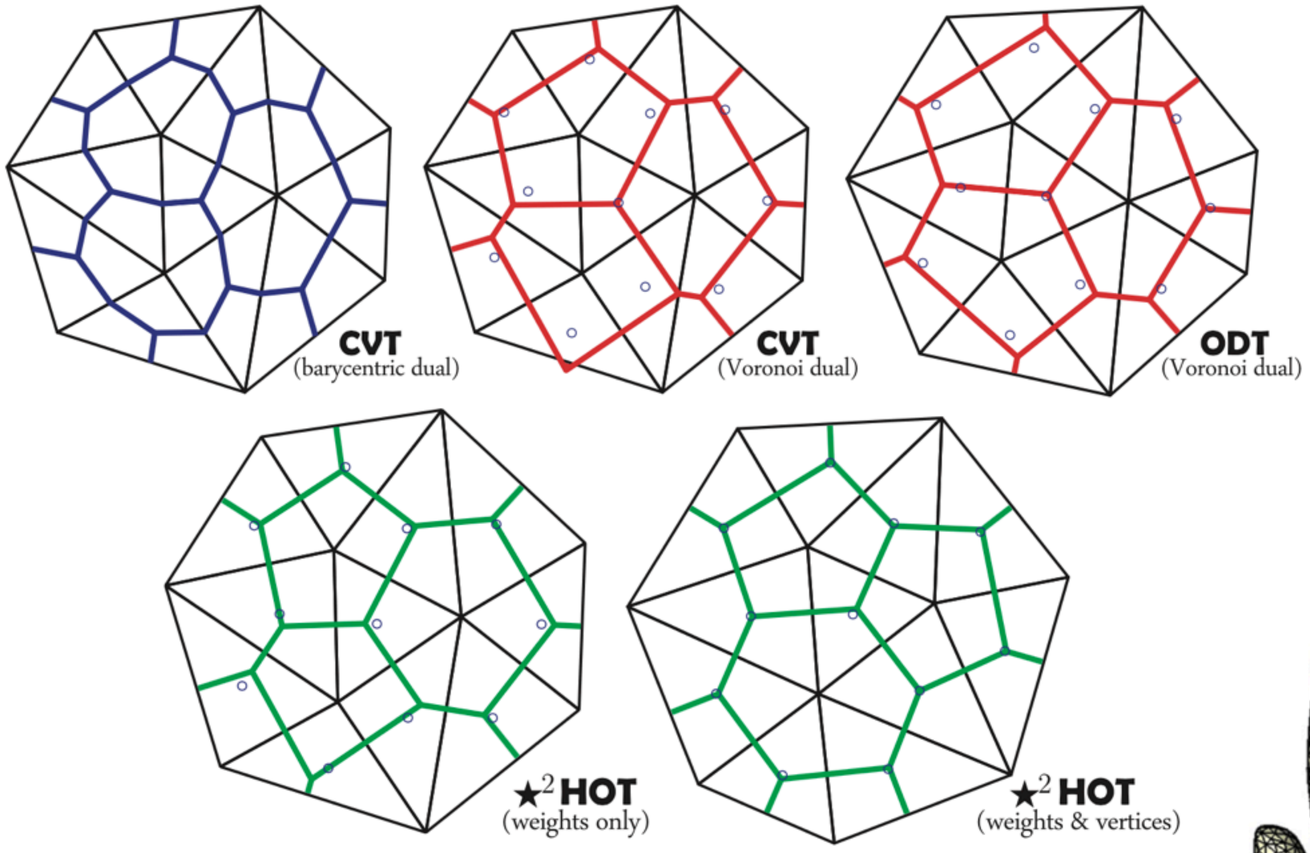


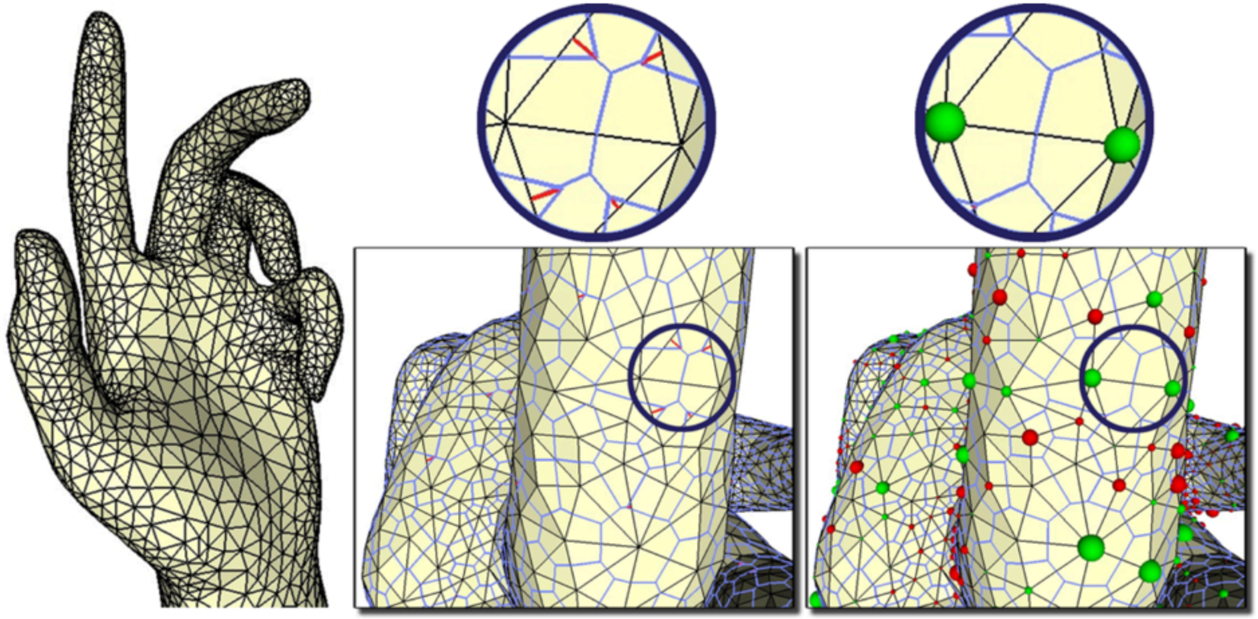
A non-Delaunay triangle



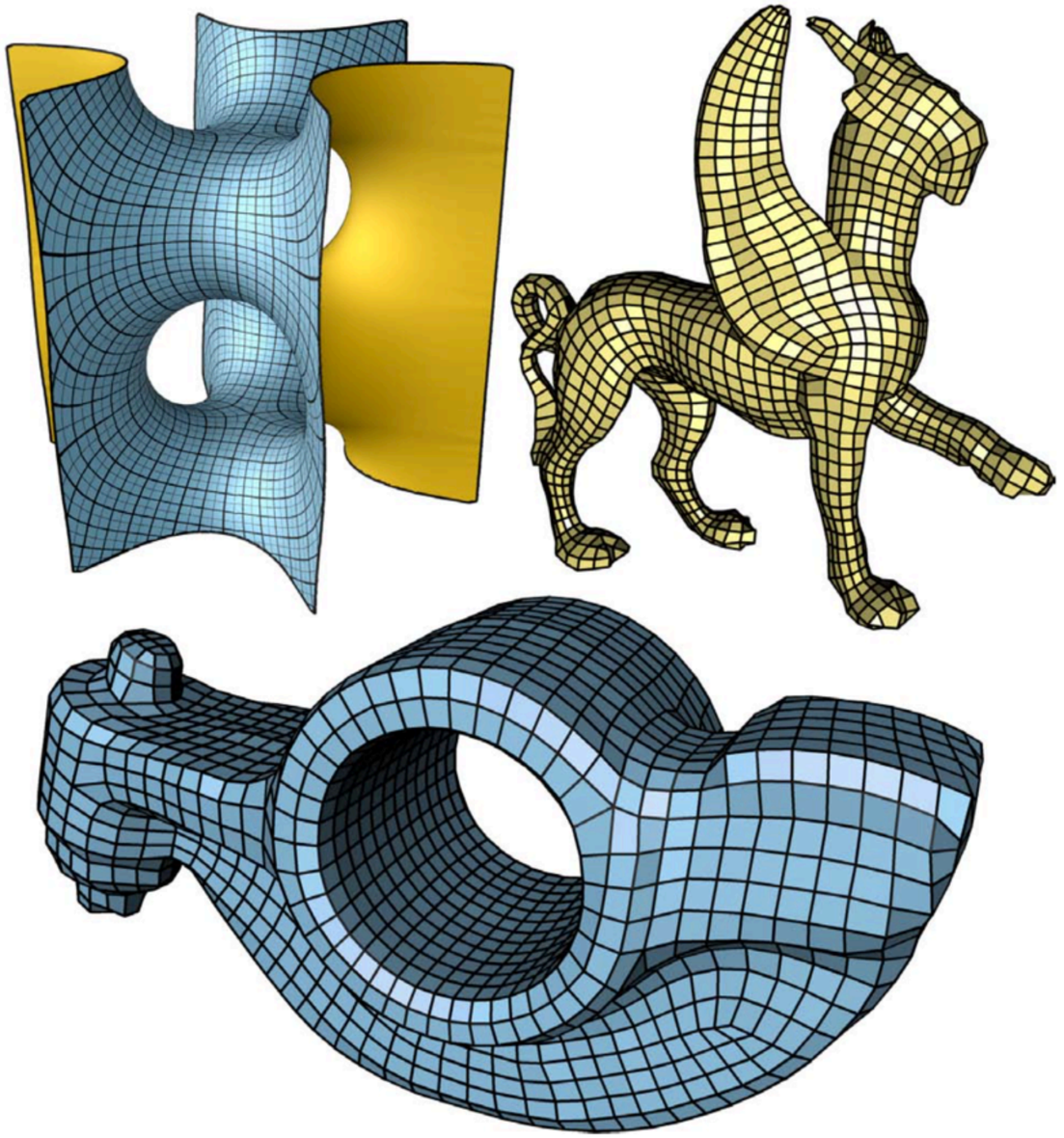
A Delaunay triangulation

“Hodge Optimized Triangulations”
Mullen et al (2011)

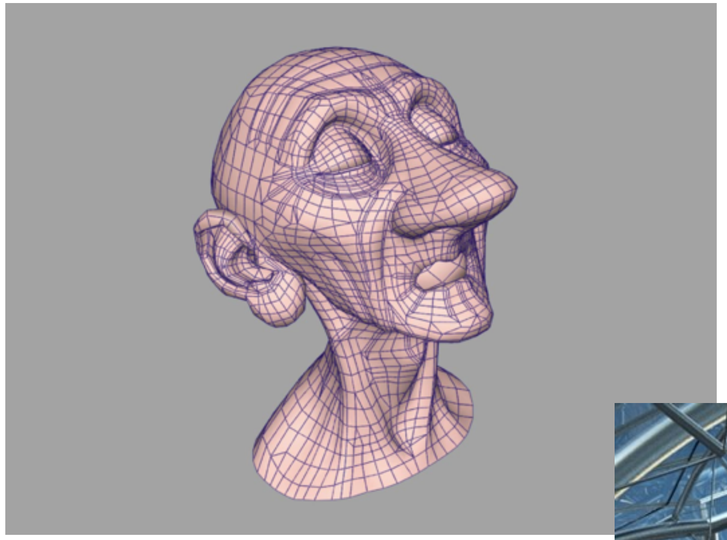


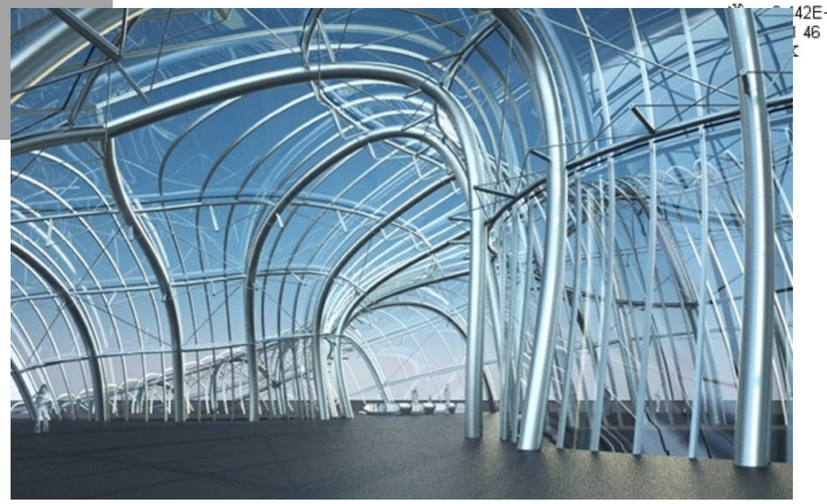


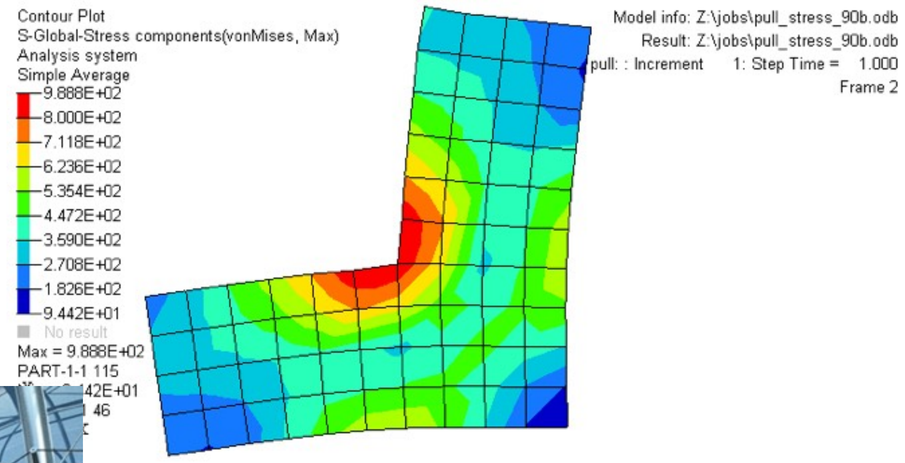
“QuadCover: Surface Parameterization using Branched Coverings”
Kälberer et al (2007)

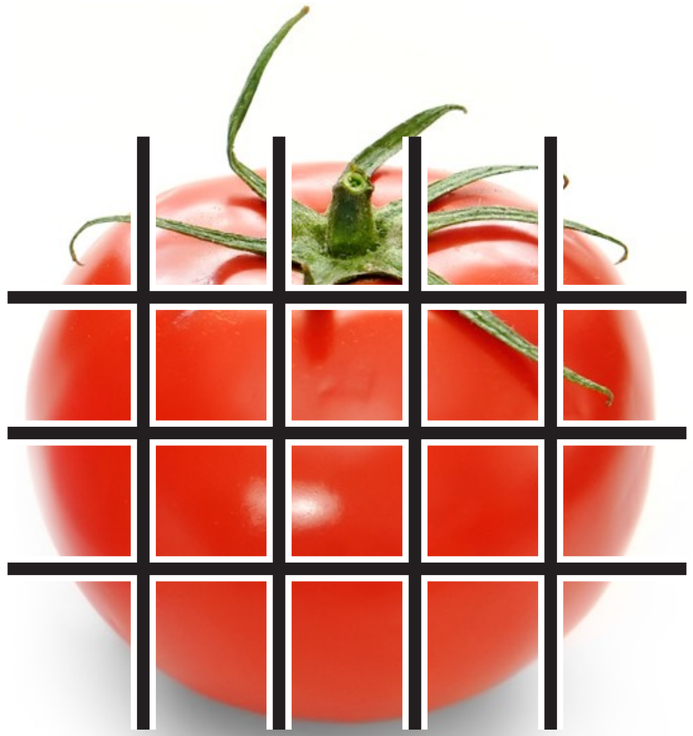


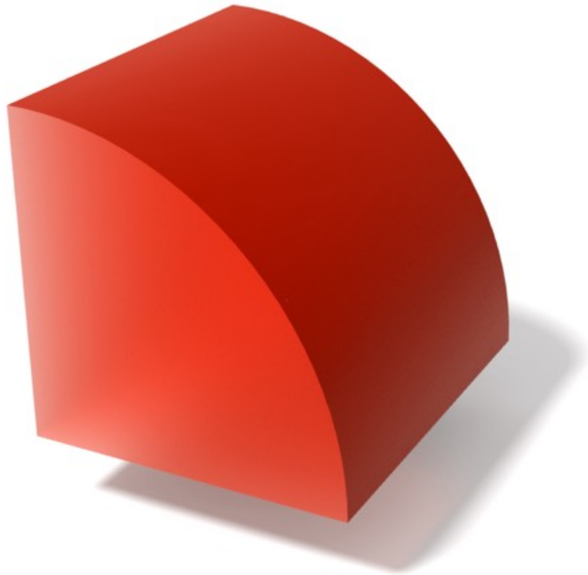
The quad meshing problem is not well-defined!



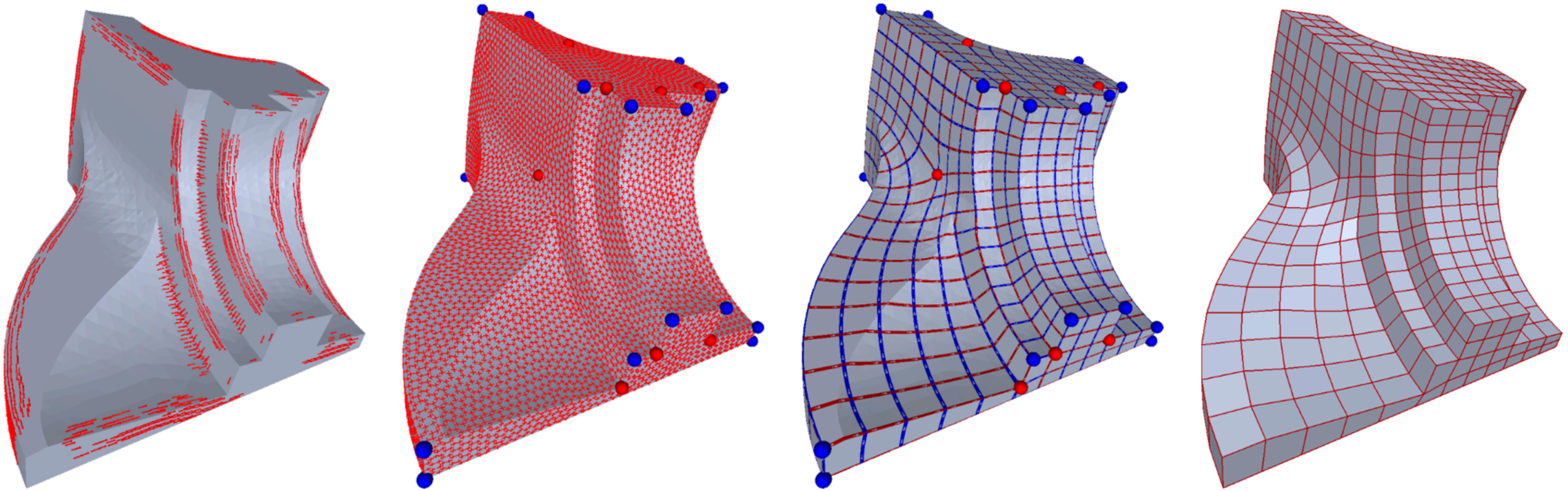






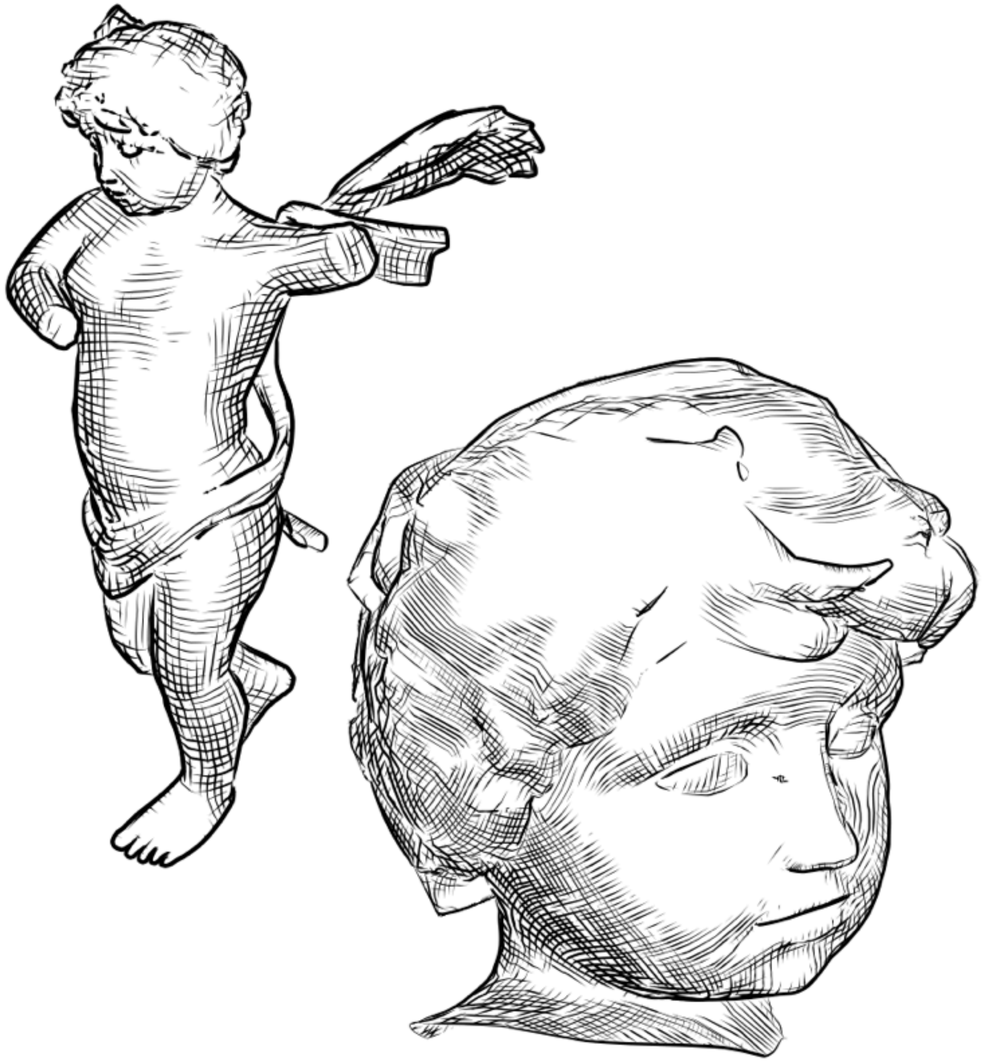


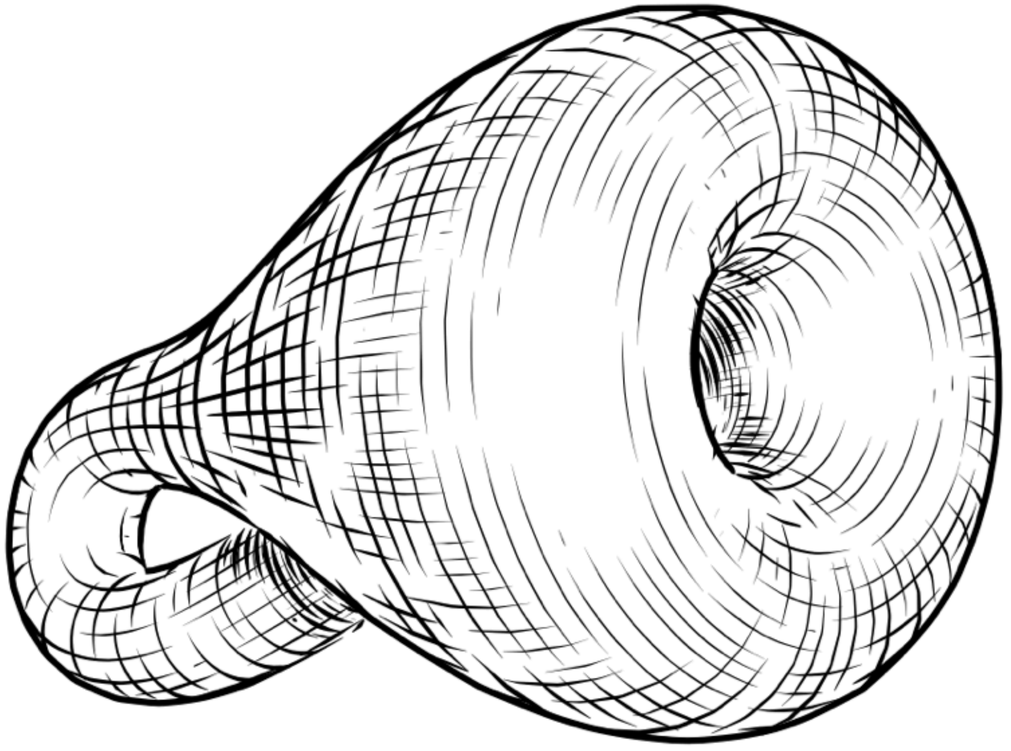
“Mixed Integer Quadrangulation”
Bommes et al (2009)



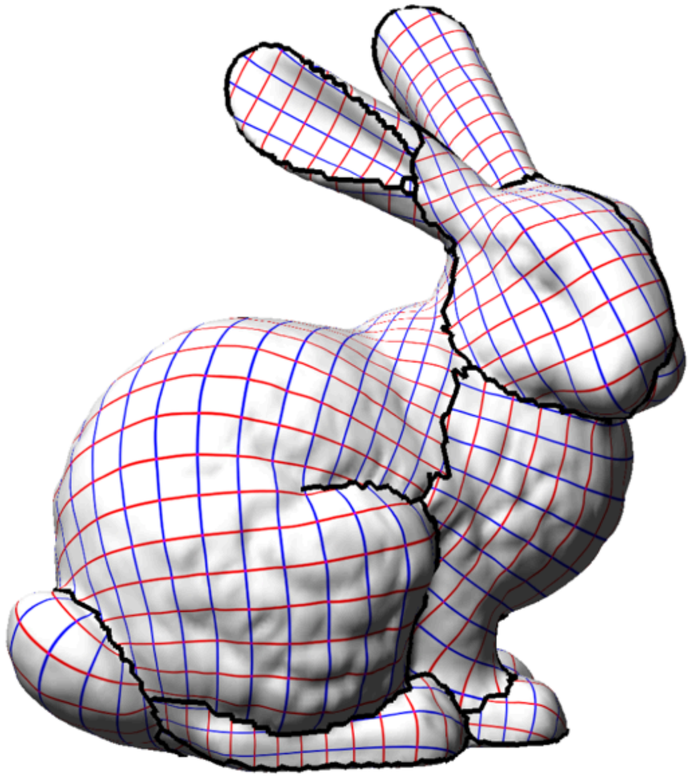
“An Operator Approach to Tangent Vector Field Processing”
Azencot et al (2013)

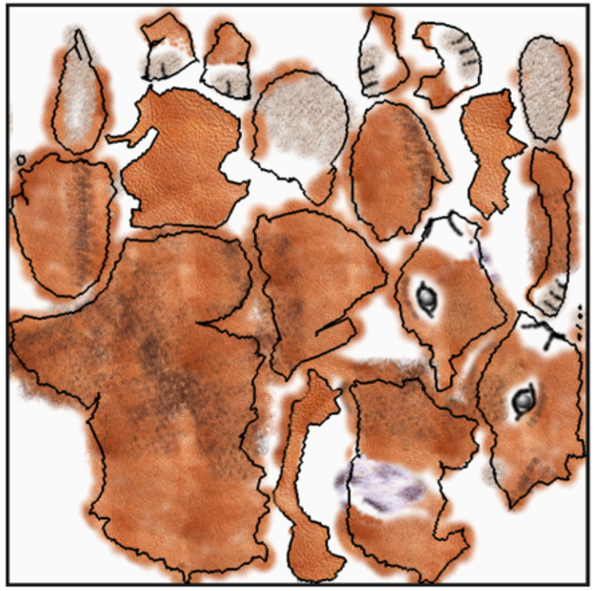
“Illustrating smooth surfaces”
Hertzmann & Zorin (2000)



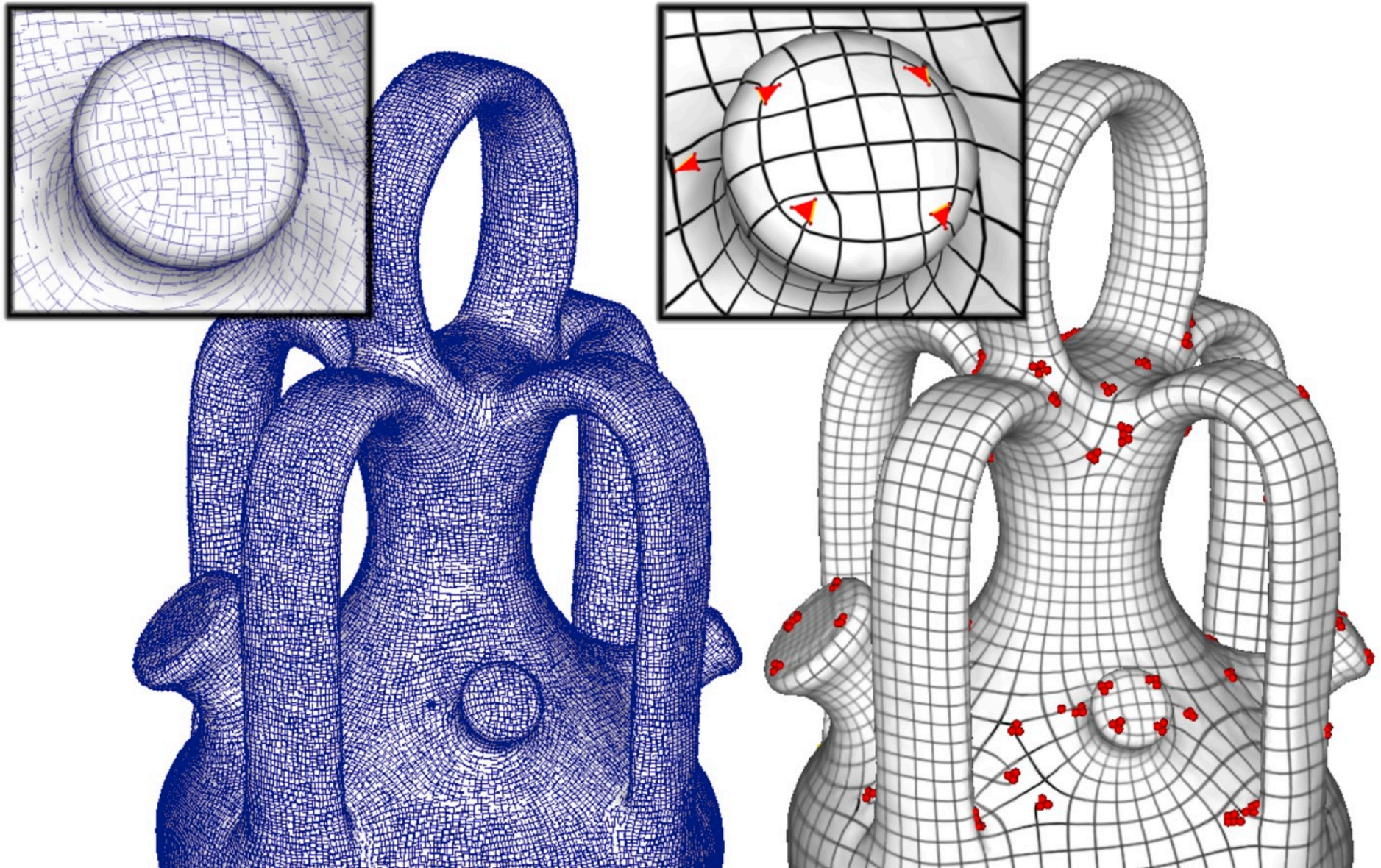


“Least Squares Conformal Maps”
Lévy et al (2000)



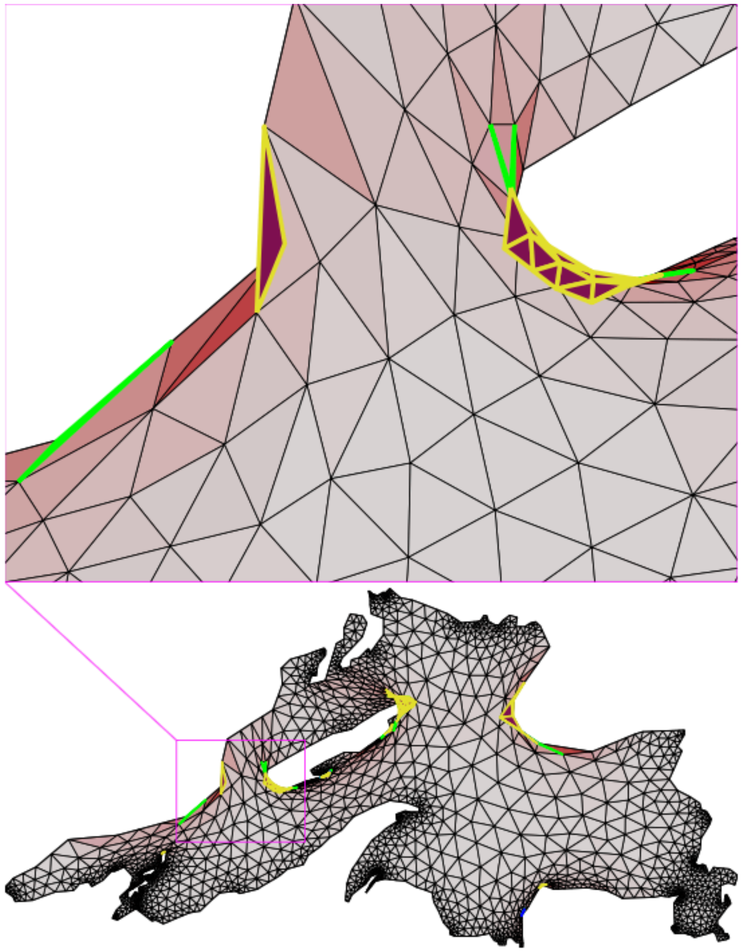


“Periodic Global Parameterization”
Ray et al (2006)

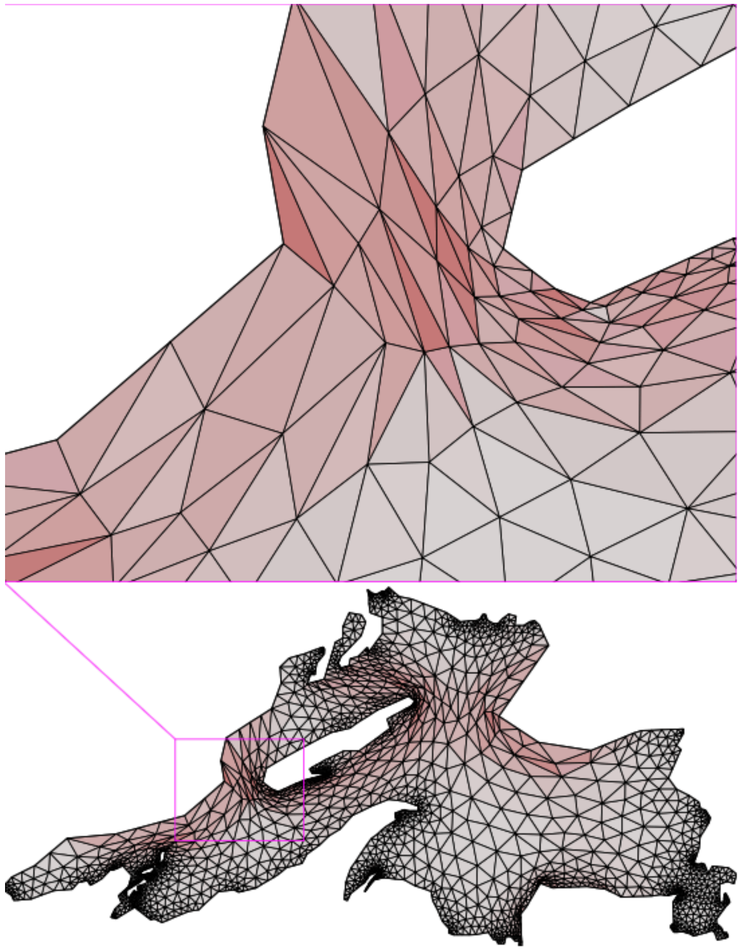


Very few *guarantees*.

“Bounded Distortion Mapping Spaces for Triangular Meshes”
Lipman (2012)

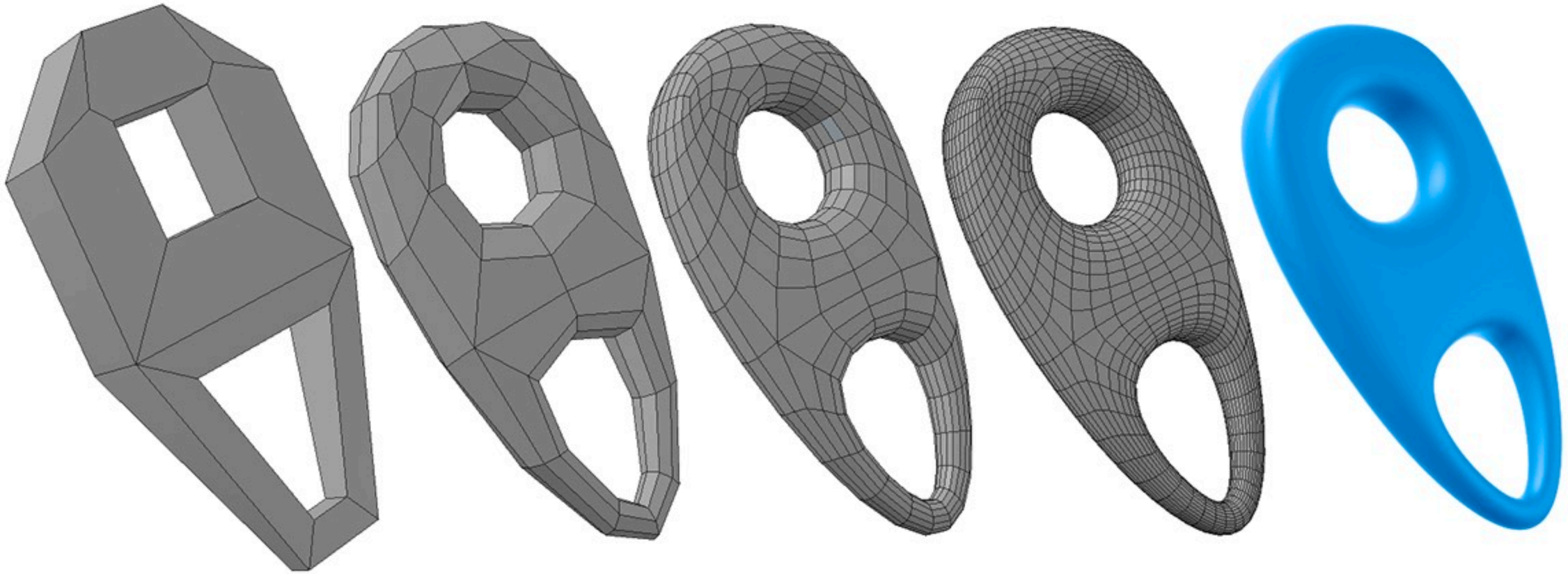


(b) harmonic



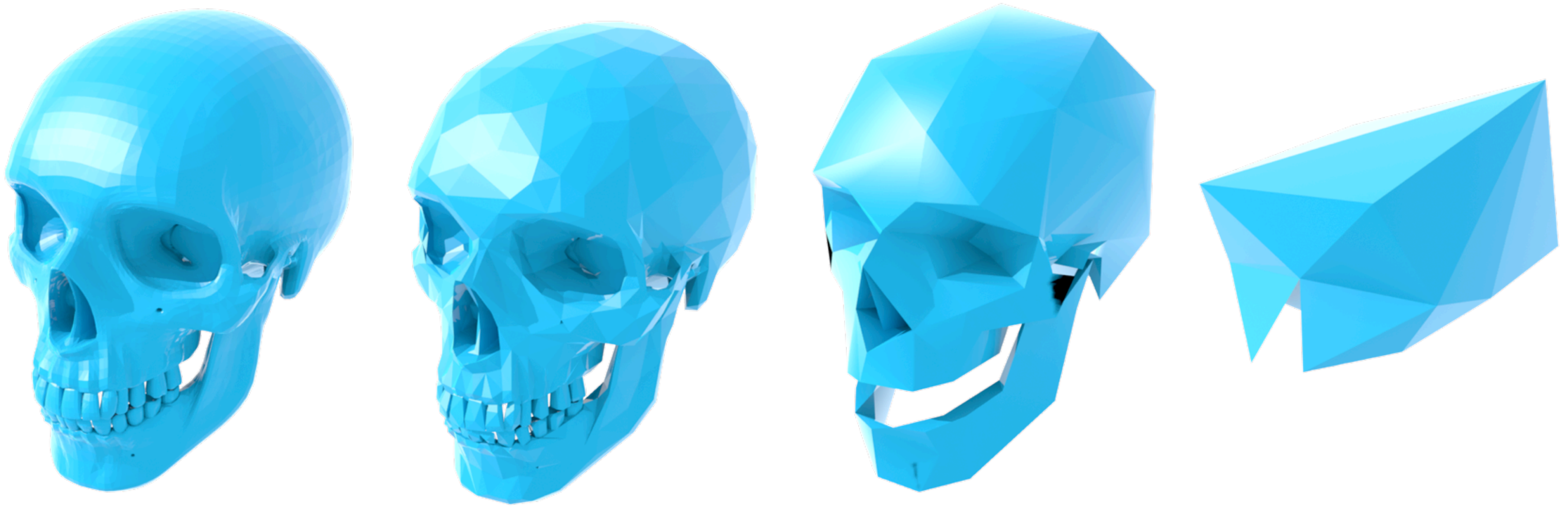
(d) BD-harmonic

“Recursively Generated B-Spline Surfaces on Arbitrary Topological Meshes”
Catmull & Clark (1978)

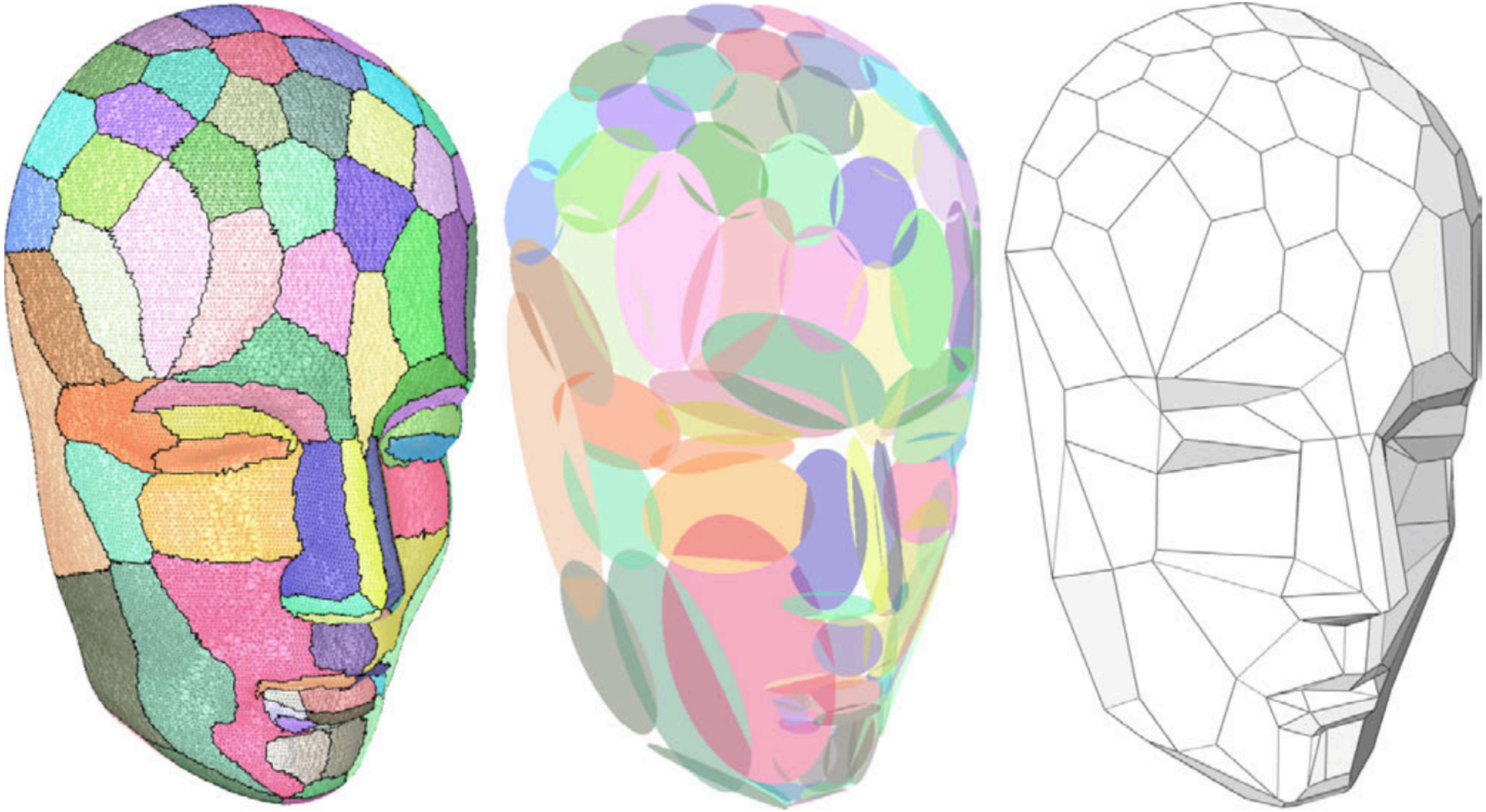




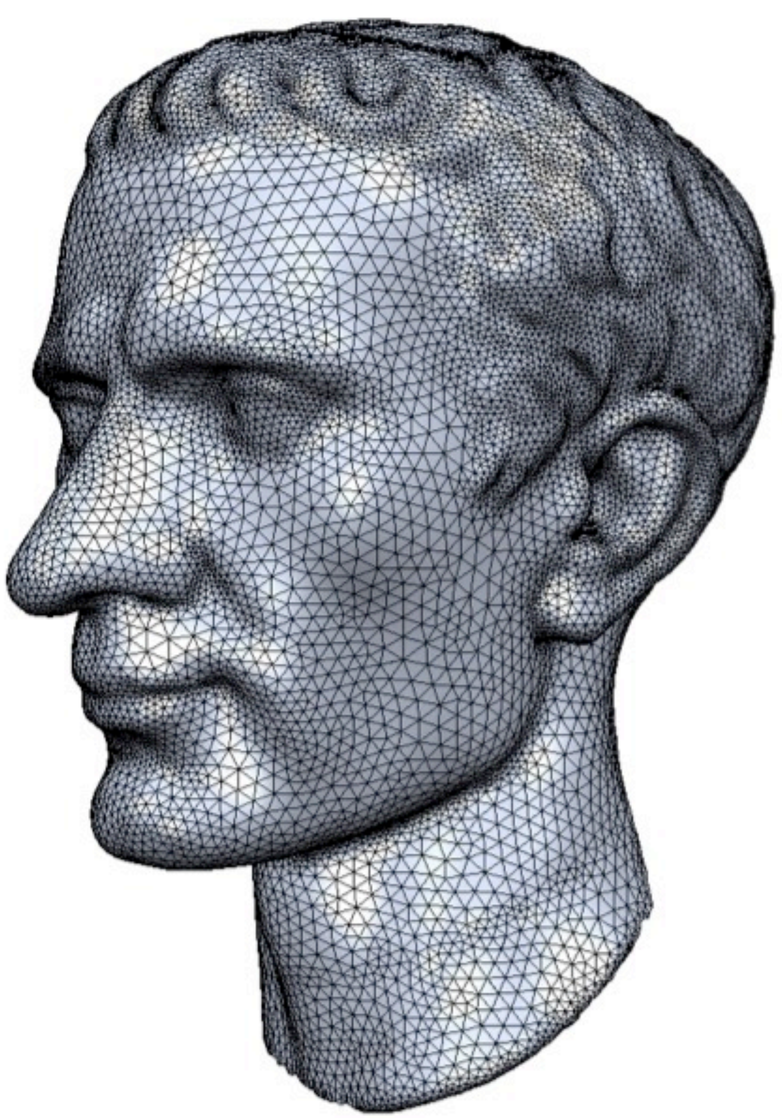

“Surface Simplification Using Quadric Error Metrics”
Garland & Heckbert (1997)

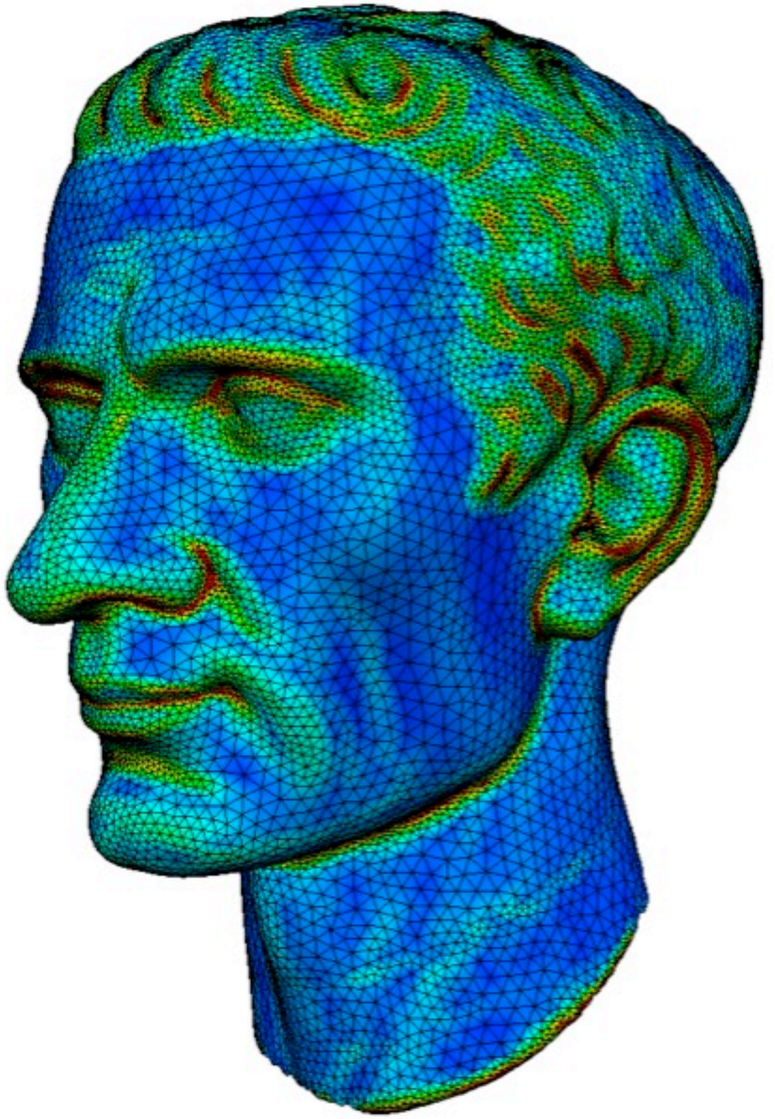


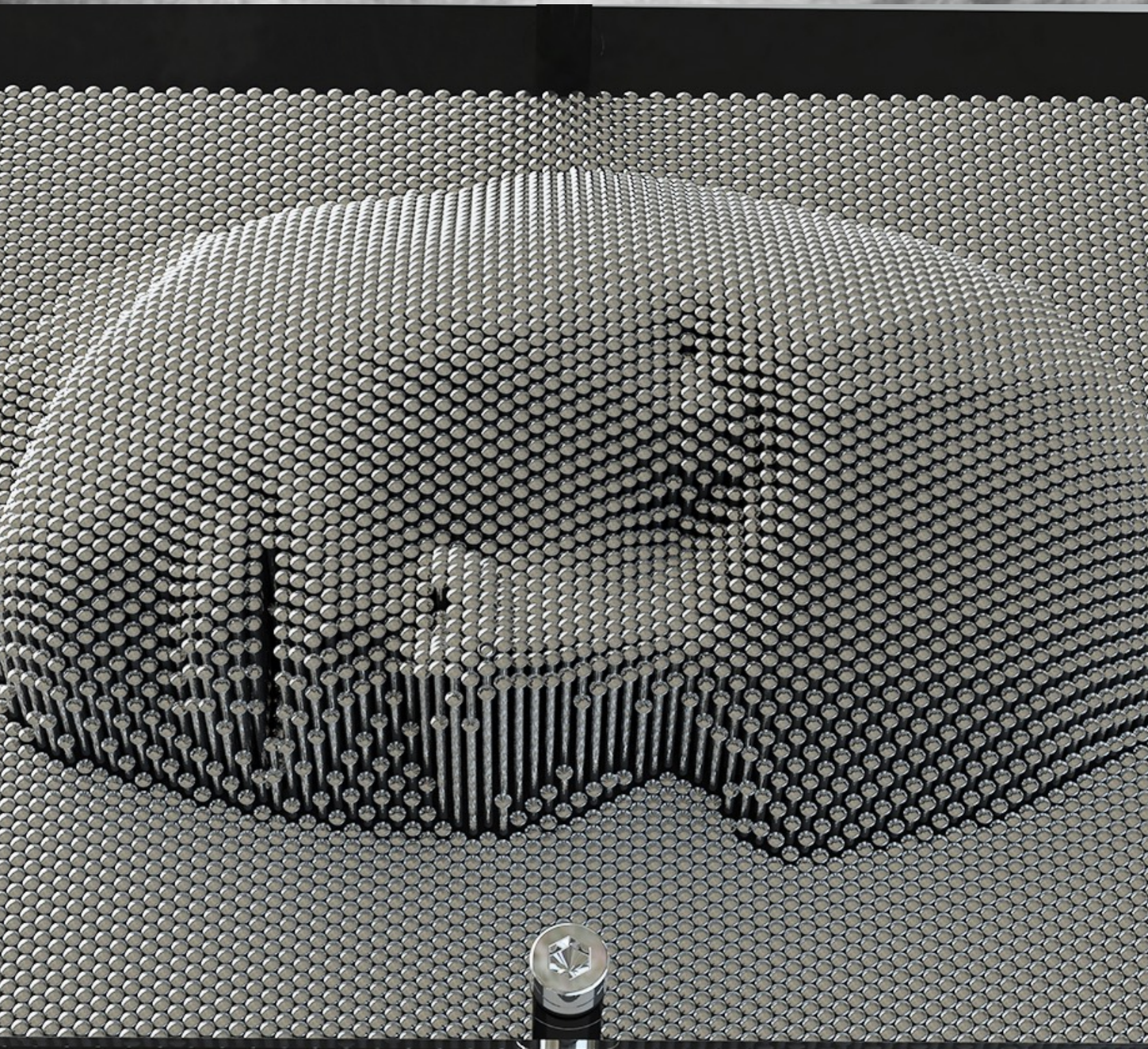
“Variational Shape Approximation”
Cohen–Steiner et al (2004)



“Adaptive Remeshing for Real-Time Mesh Deformation”
Dunyach et al (2013)

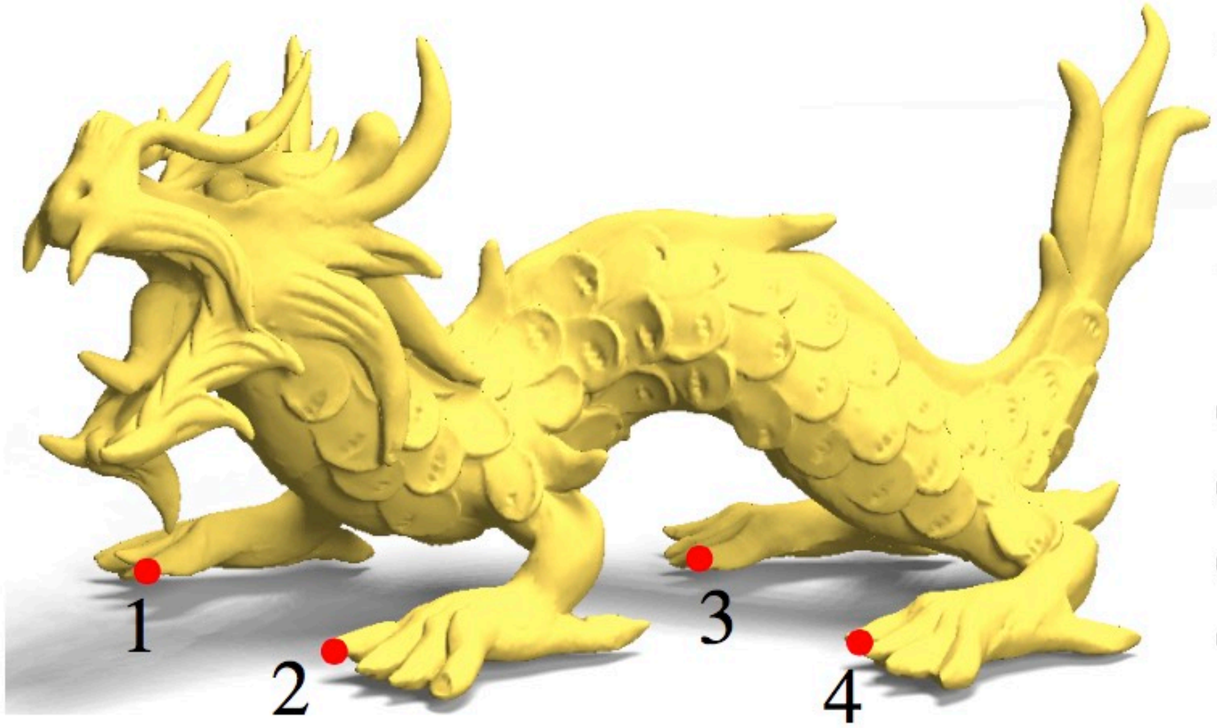


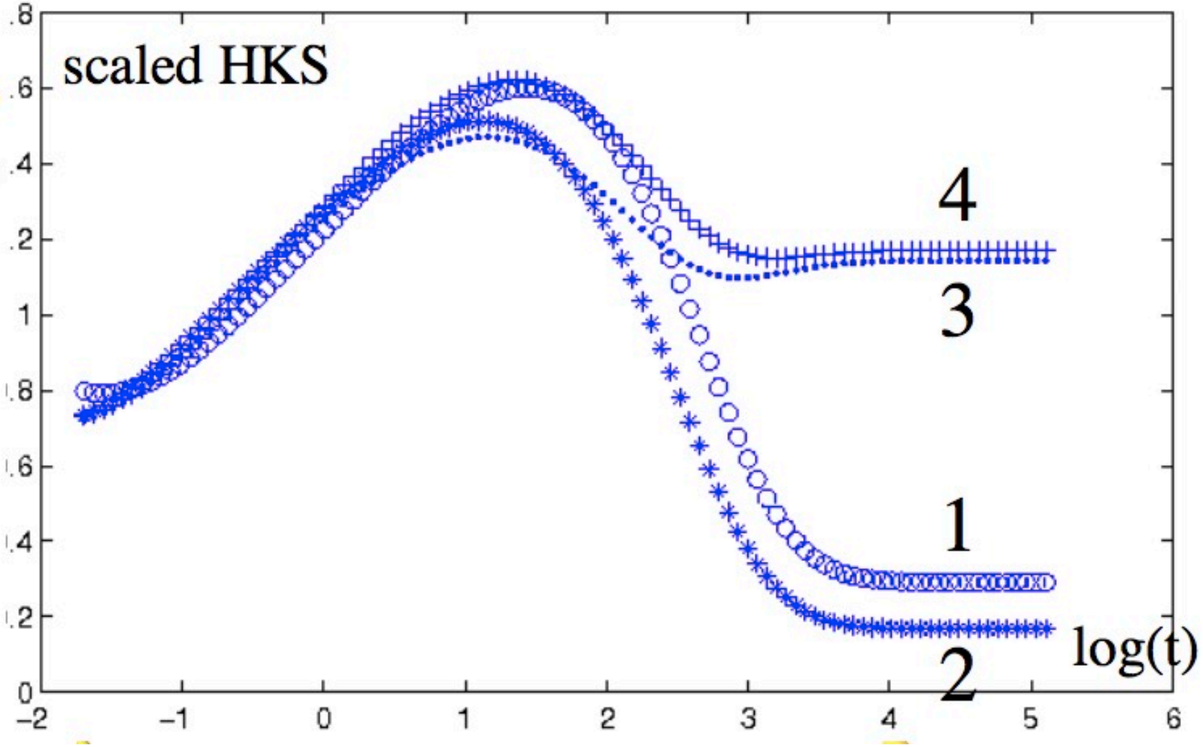




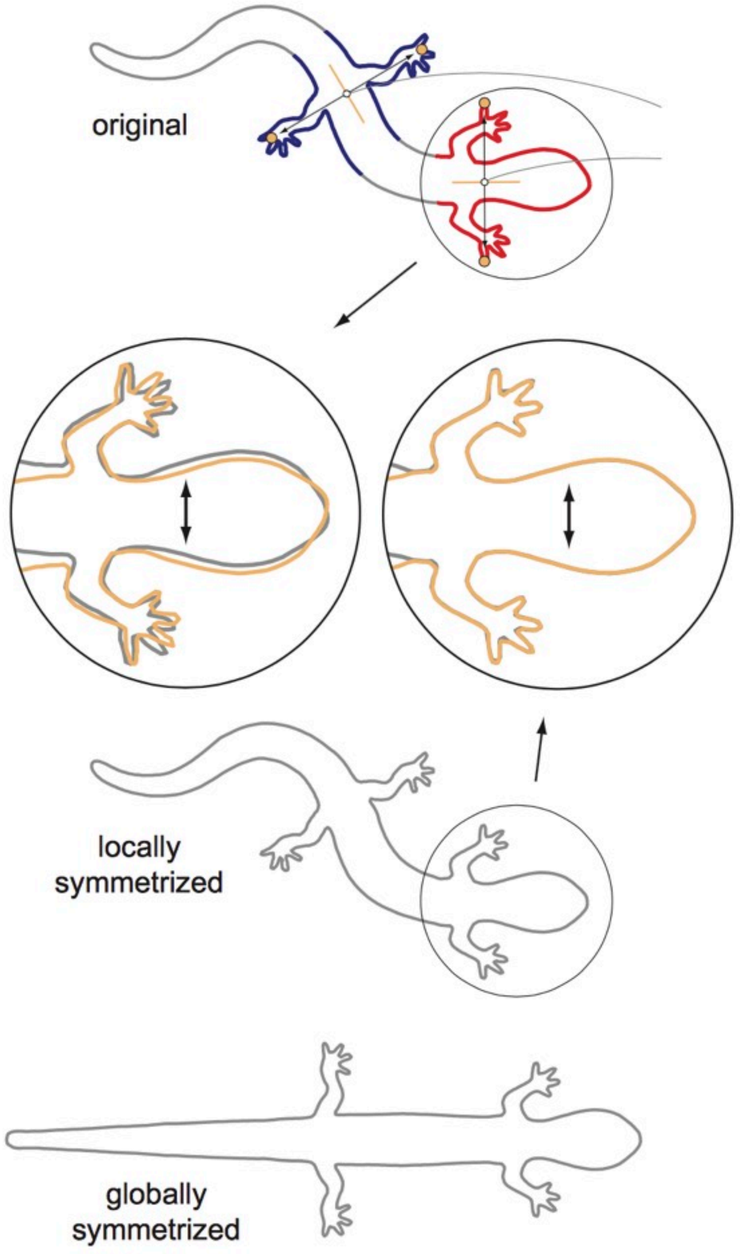
How much *information* does a surface contain?

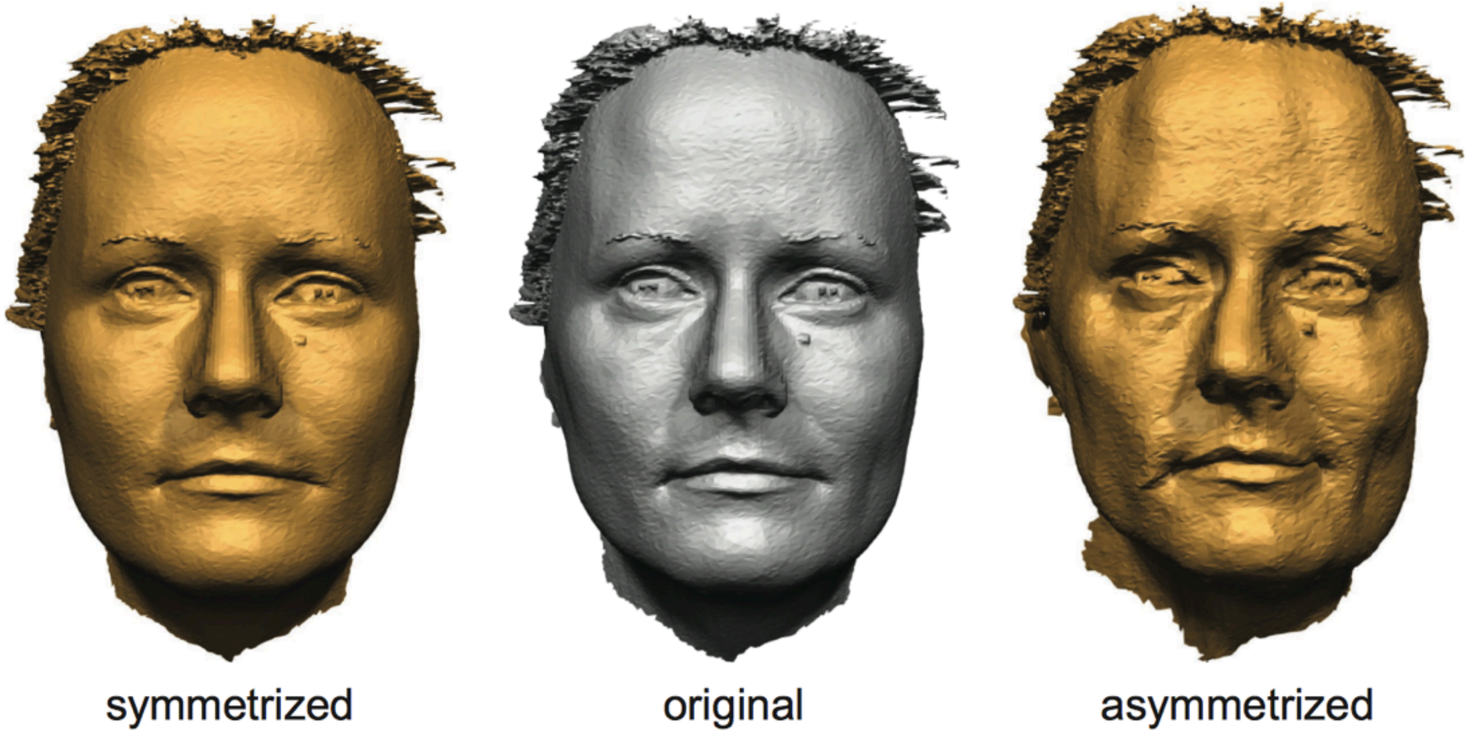
"A Concise and Provably Informative Multi-Scale Signature Based on Heat Diffusion"
Sun et al (2009)



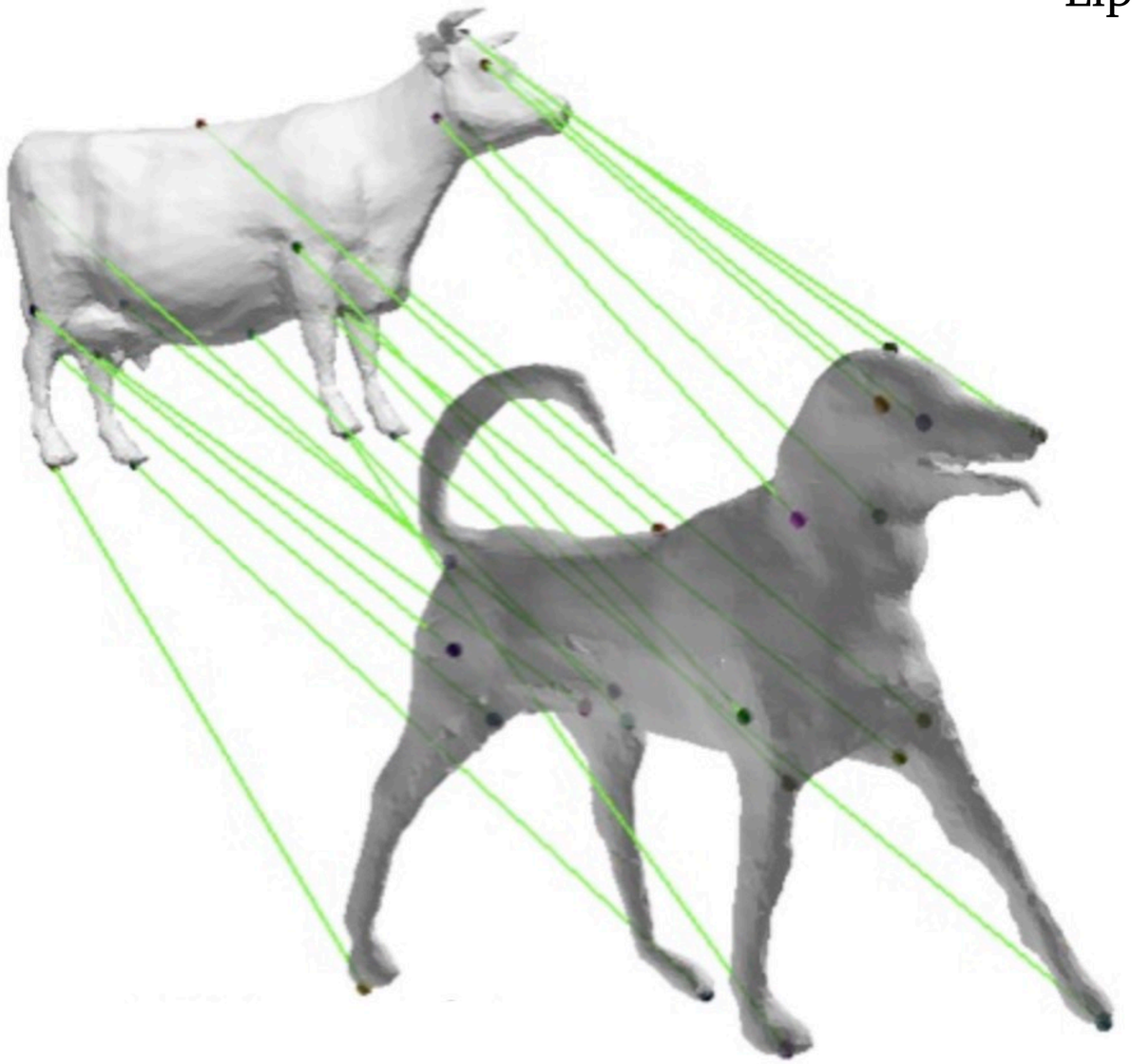


“Symmetrization”
Mitra et al (2007)

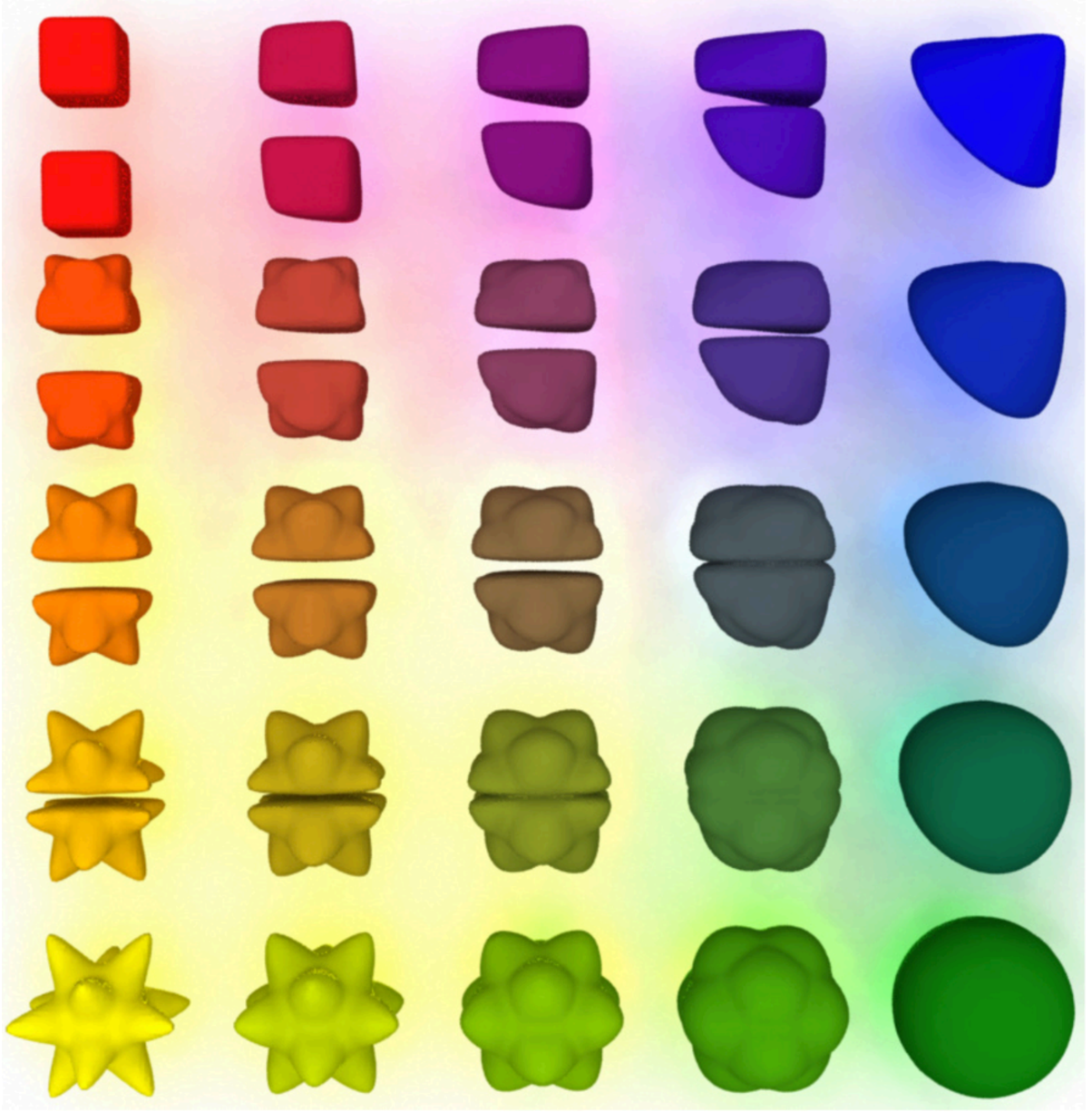




“Möbius Voting for Surface Correspondence”
Lipman & Funkhouser (2009)

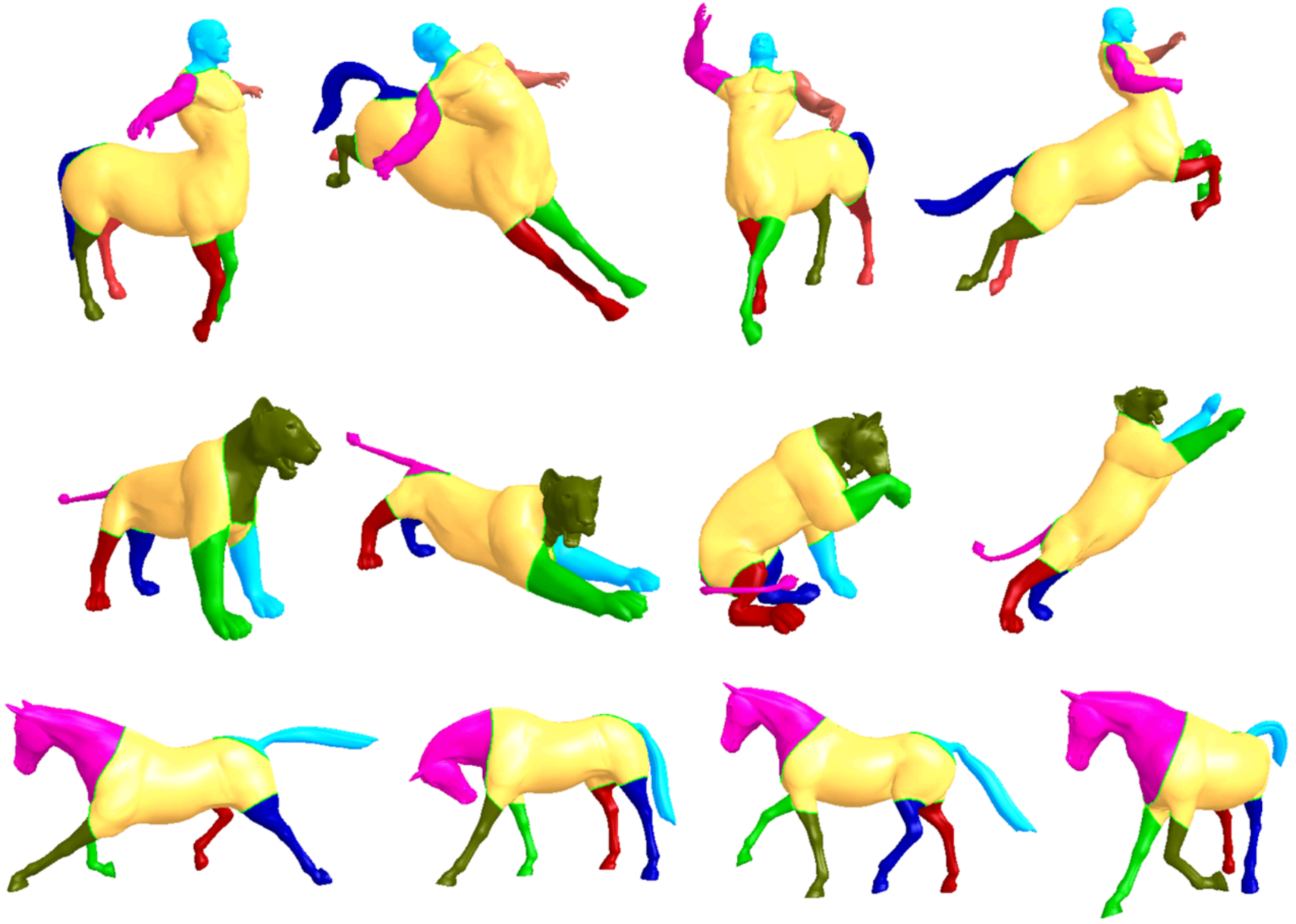


“Convolutional Wasserstein Distances: Efficient Optimal Transportation on Geometric Domains”
Solomon et al (2015)

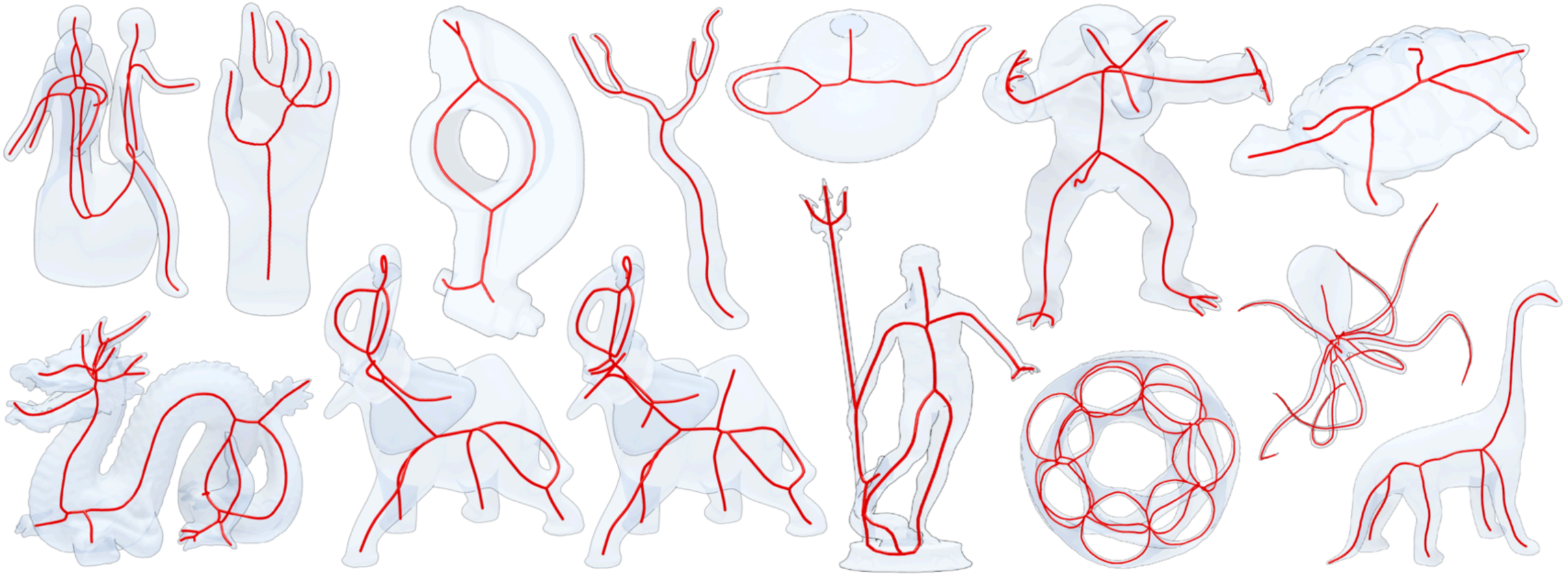


SHREC Benchmark

“Shape Segmentation and Registration via Topological Features of Laplace-Beltrami Eigenfunctions”
Reuter (2009)

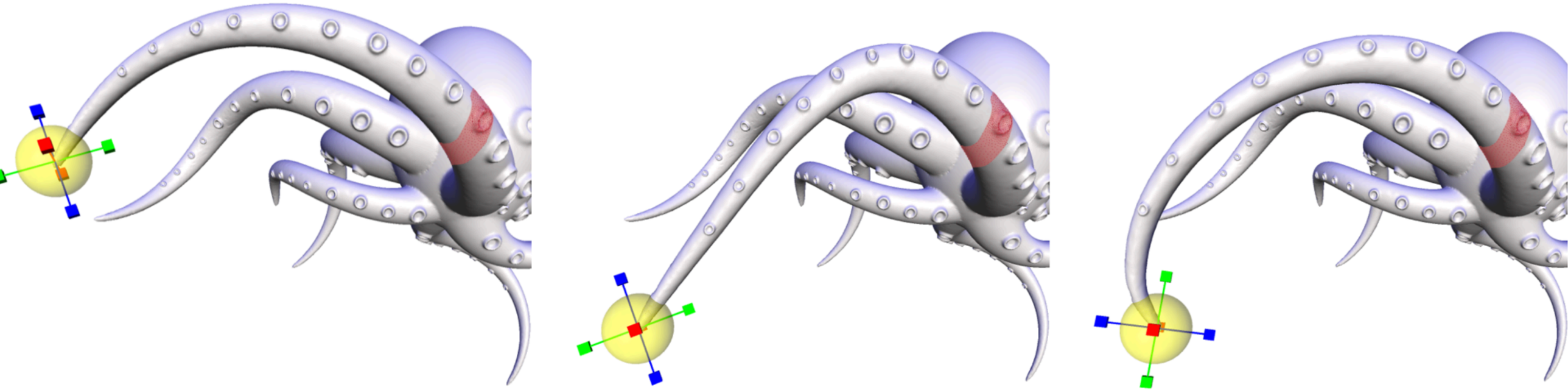


“Mean Curvature Skeletons”
Tagliasacchi et al (2008)

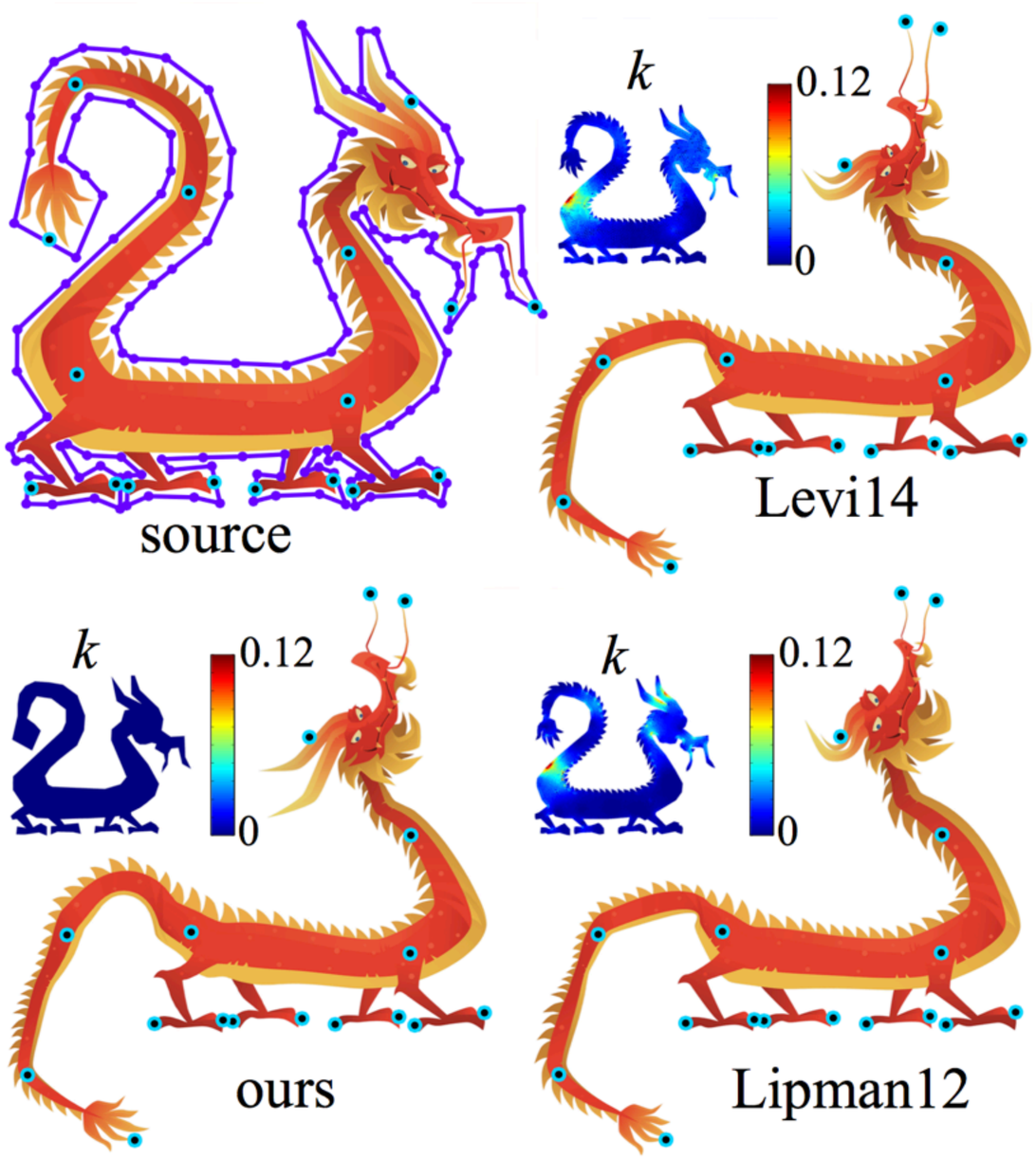


How do you know you got the answer right?

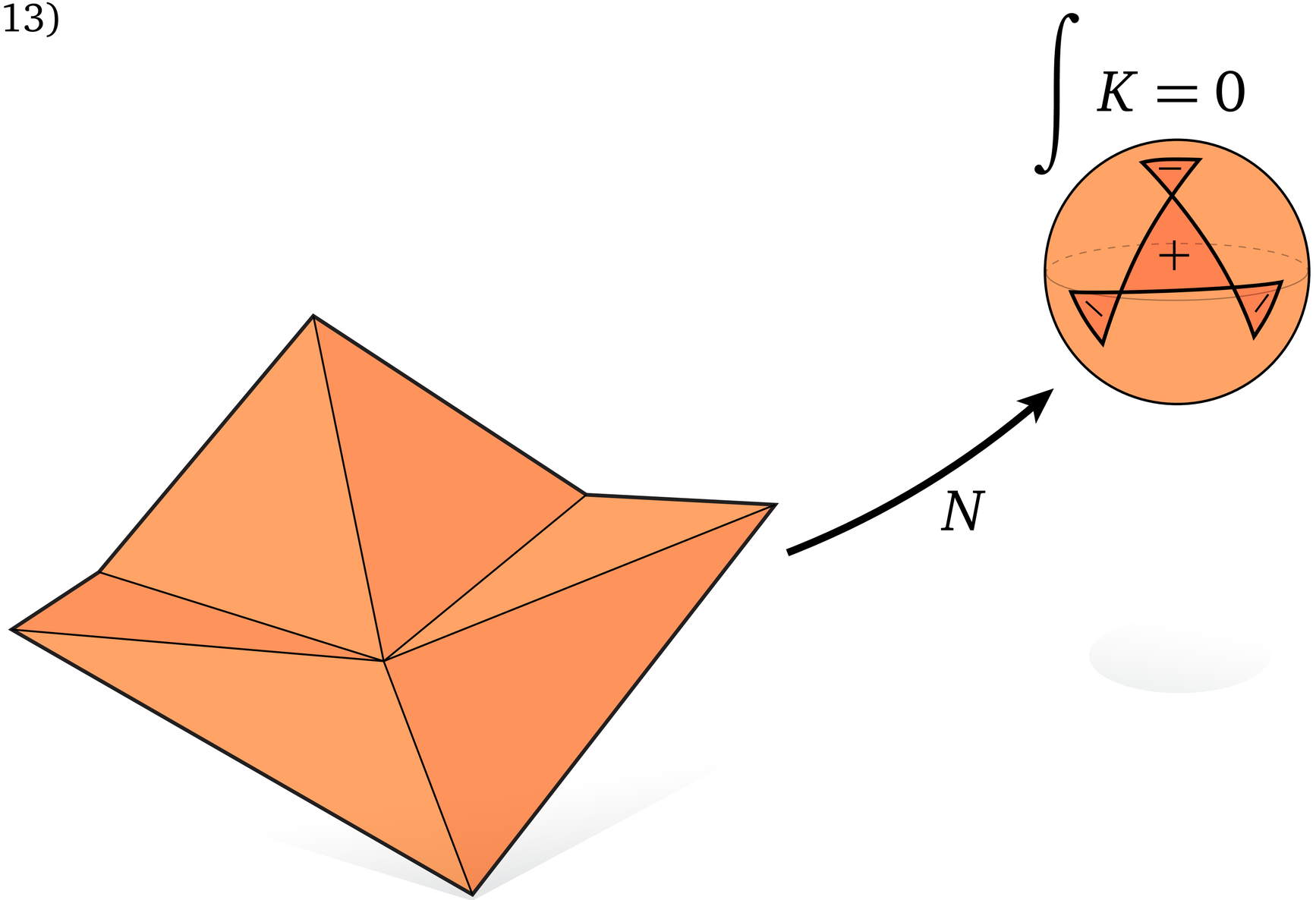
“Laplacian Surface Editing”
Sorkine et al (2004)



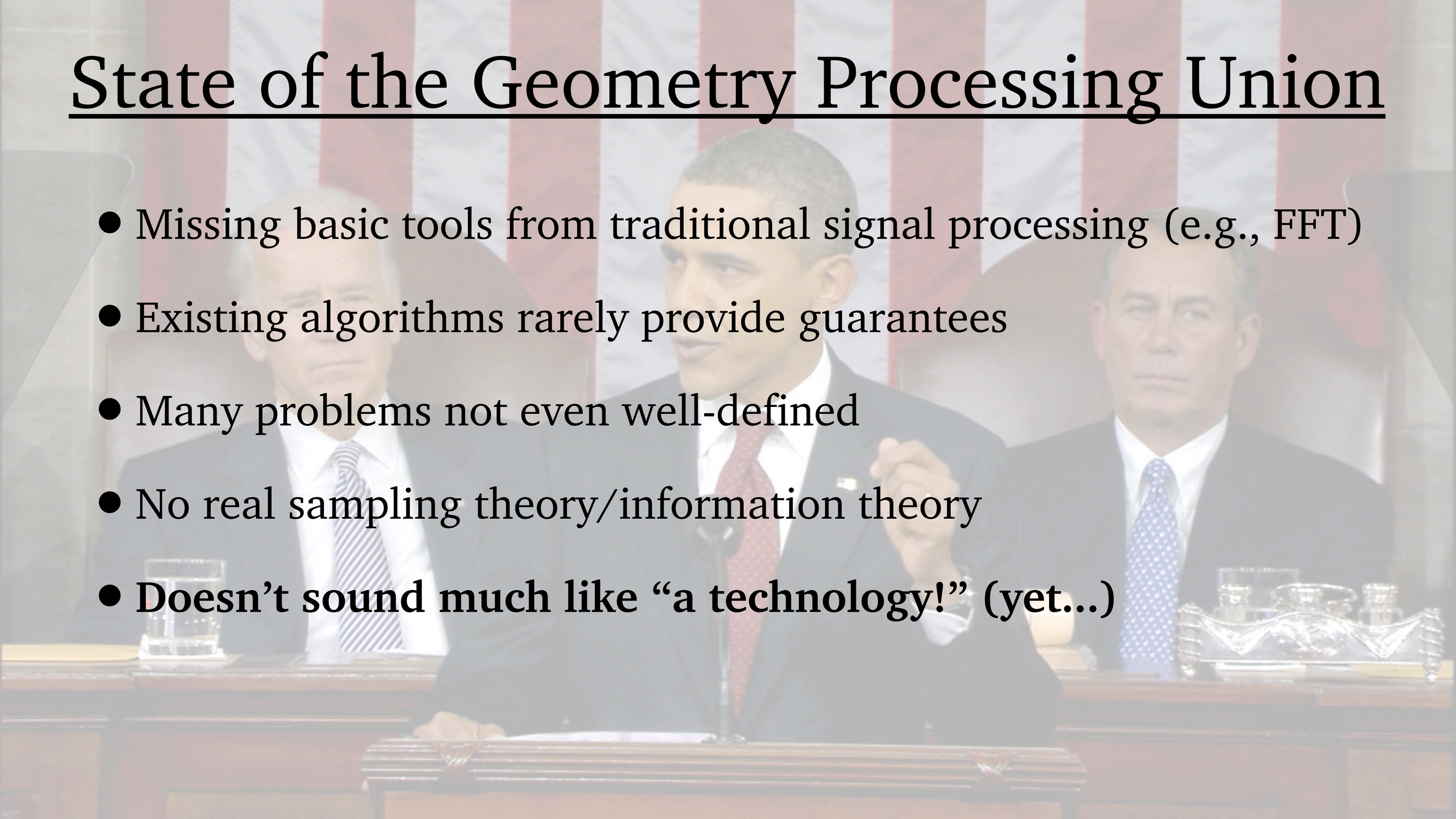
“Bounded Distortion Harmonic Mappings in the Plane”
Chen & Weber (2015)



“Digital Geometry Processing with Discrete Exterior Calculus”
Crane et al (2013)



State of the Geometry Processing Union



- Missing basic tools from traditional signal processing (e.g., FFT)
- Existing algorithms rarely provide guarantees
- Many problems not even well-defined
- No real sampling theory/information theory
- **Doesn’t sound much like “a technology!” (yet…)**

Thanks!