High-Quality Extraction of Isosurfaces from Structured and Unstructured Grids

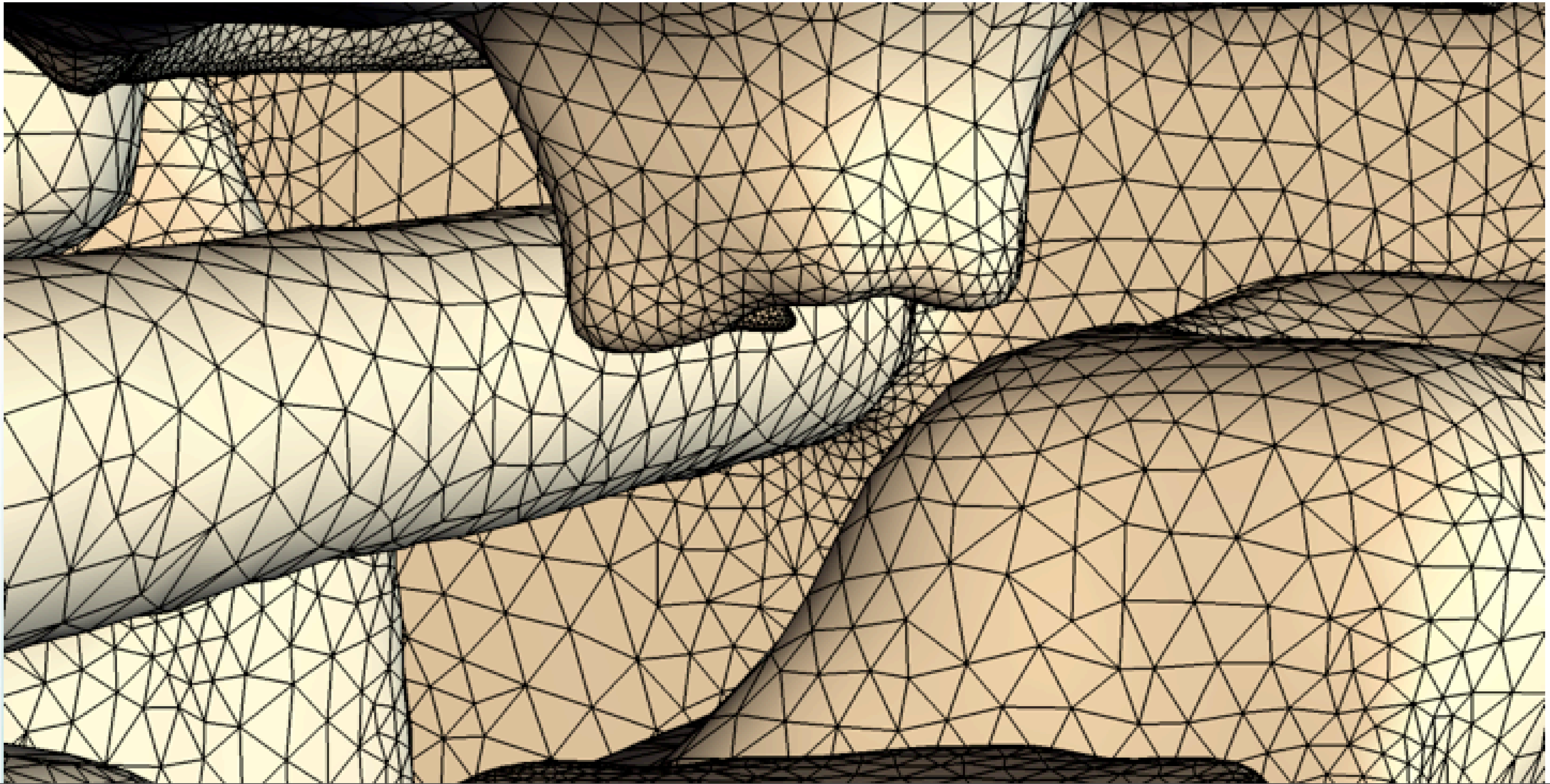
VIS 2006
BALTIMORE·MARYLAND·USA

John Schreiner
Carlos Scheidegger
Cláudio T. Silva

Scientific Computing and Imaging Institute
School of Computing
University of Utah

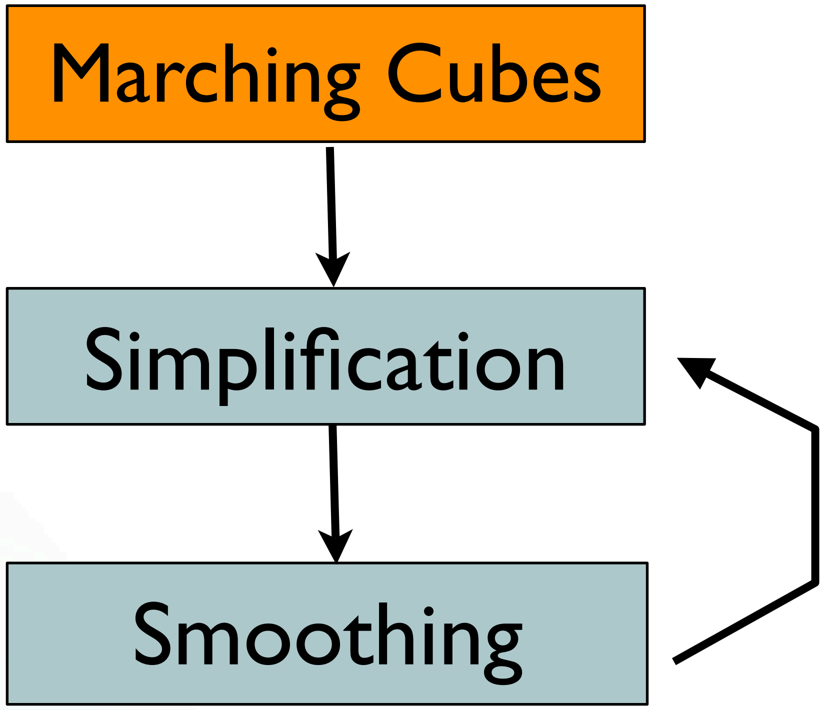
Overview

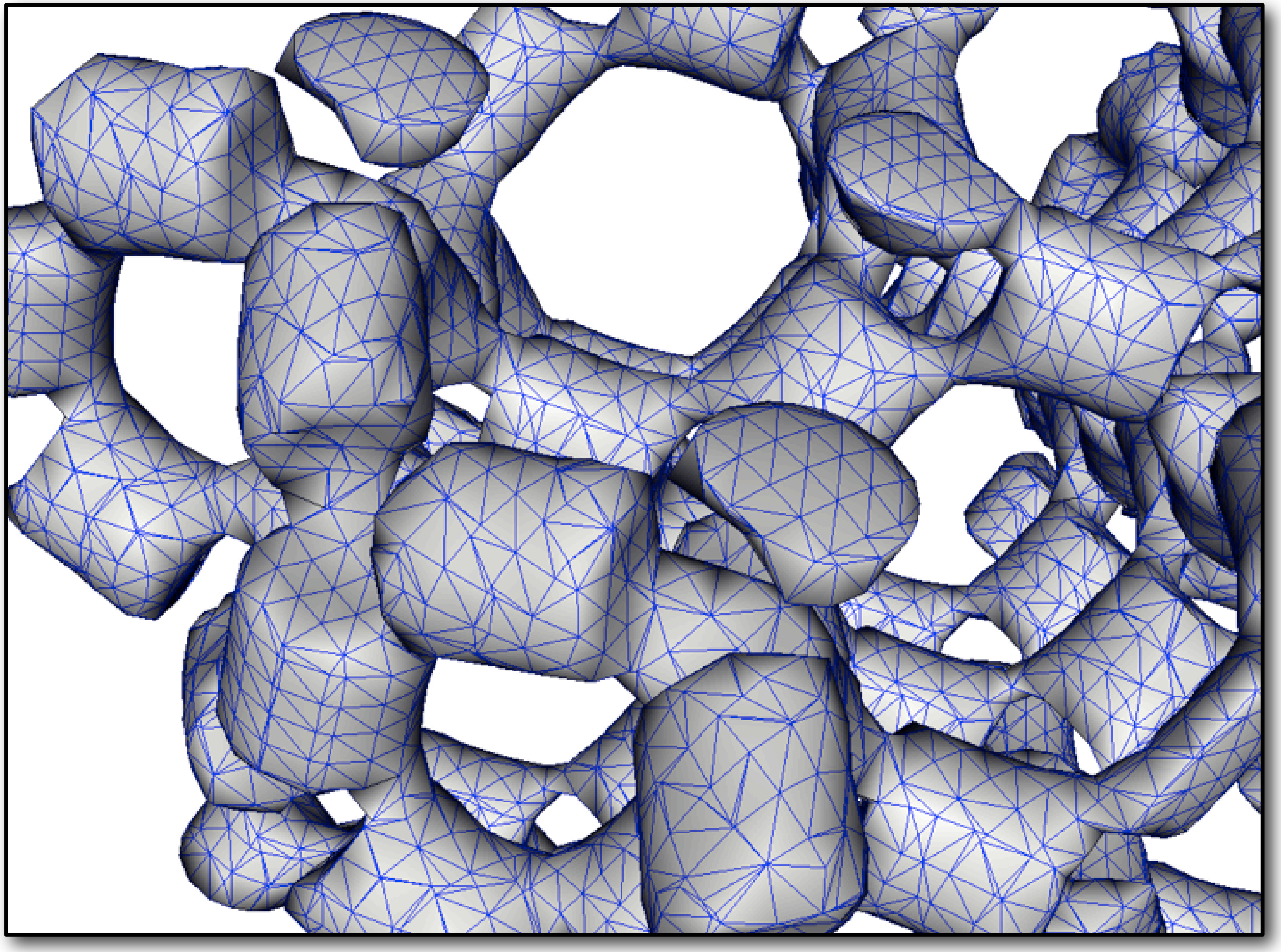
- Simple, fast method for generating good triangular approximations to isosurfaces



Motivation

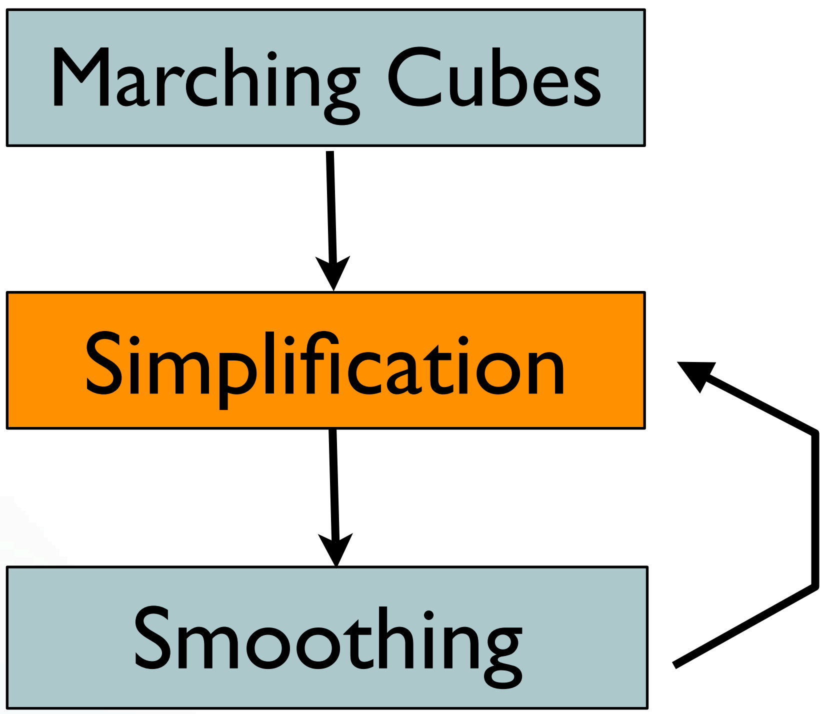
- Processing pipeline

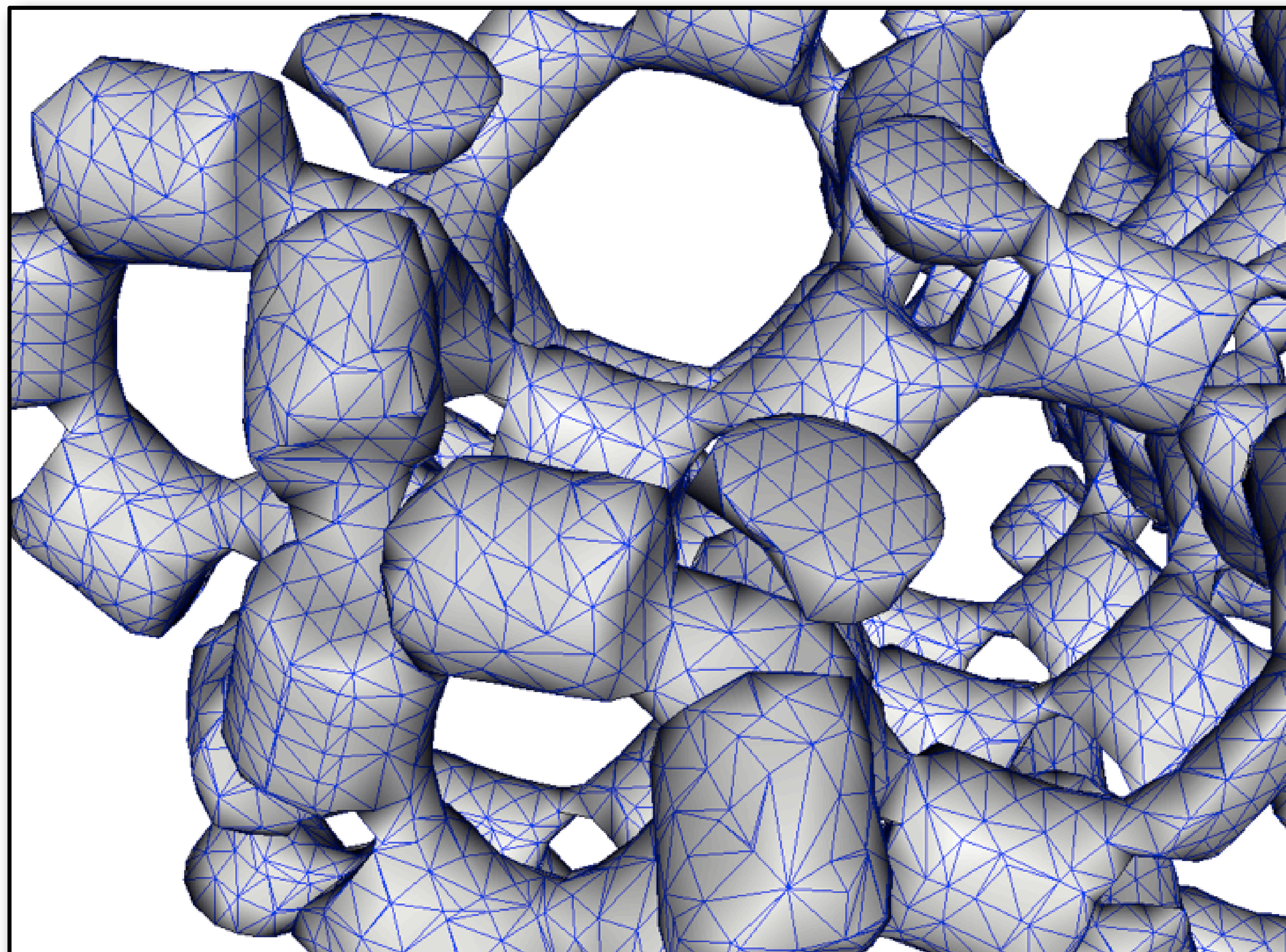




Motivation

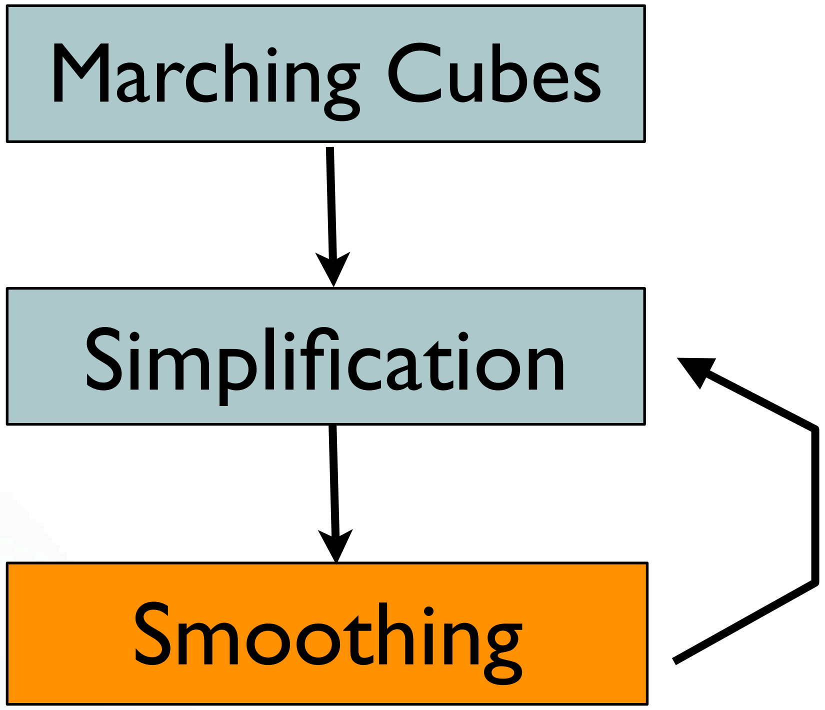
- Processing pipeline

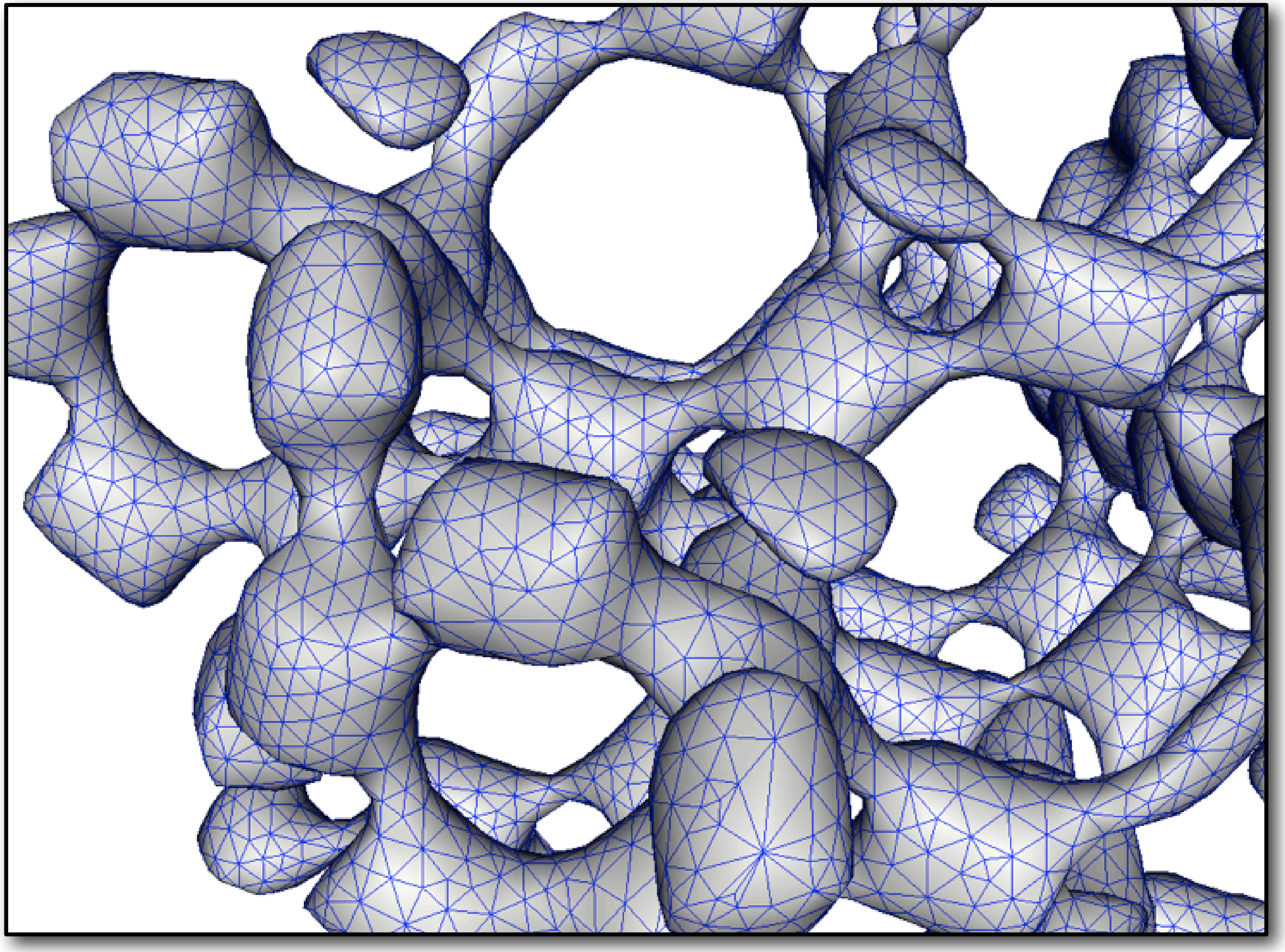




Motivation

- Processing pipeline

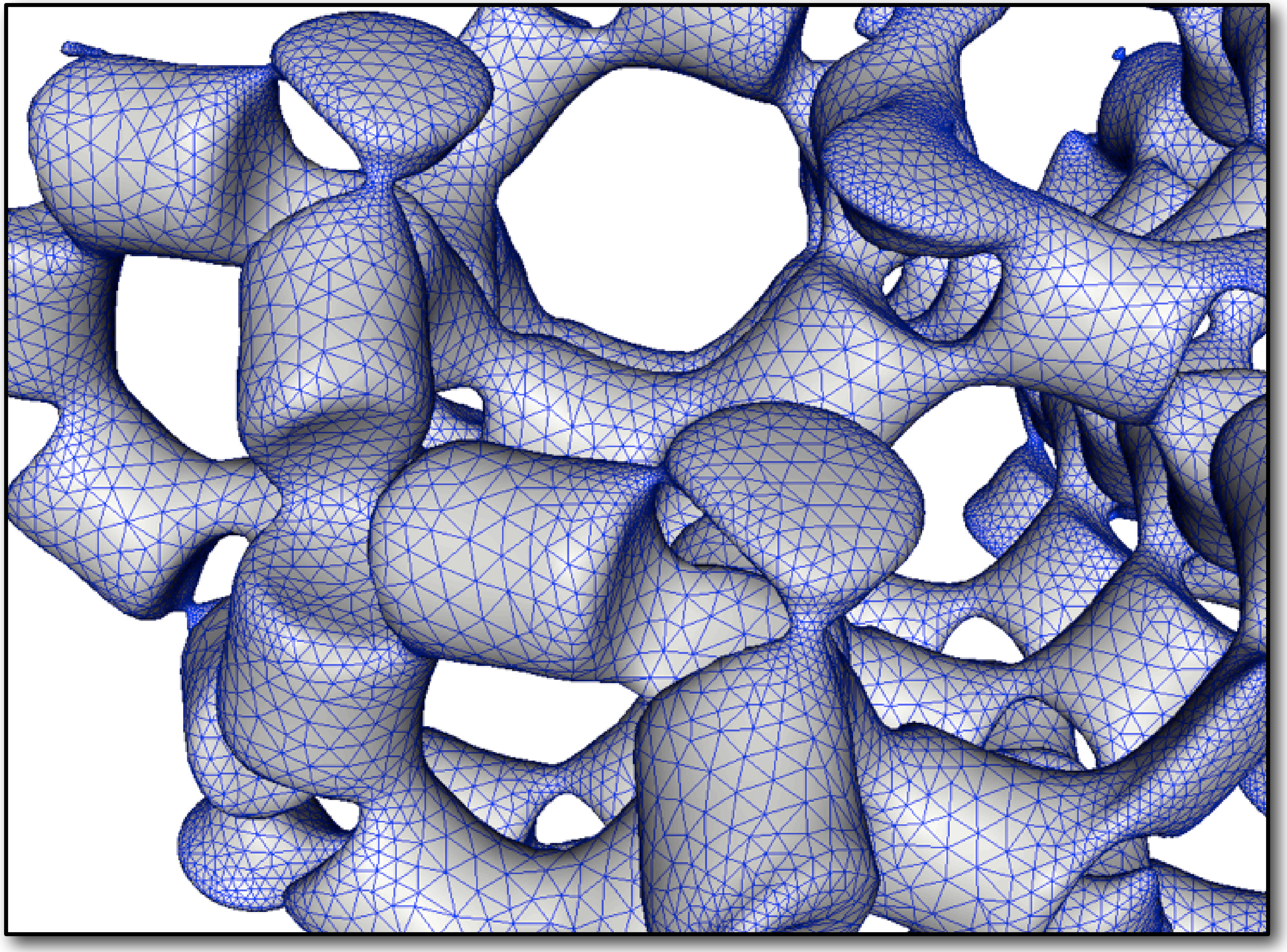




Motivation

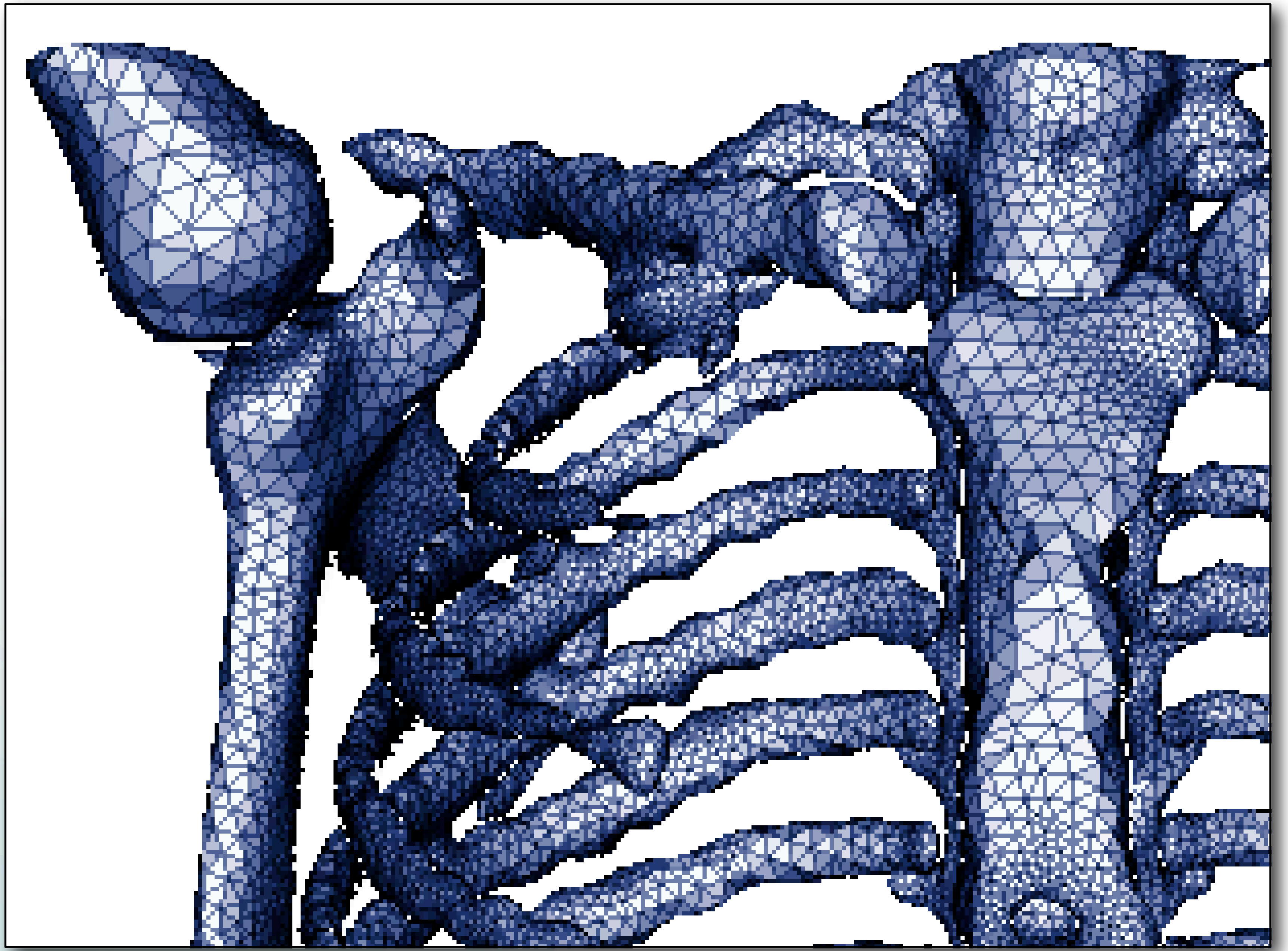
- Processing pipeline

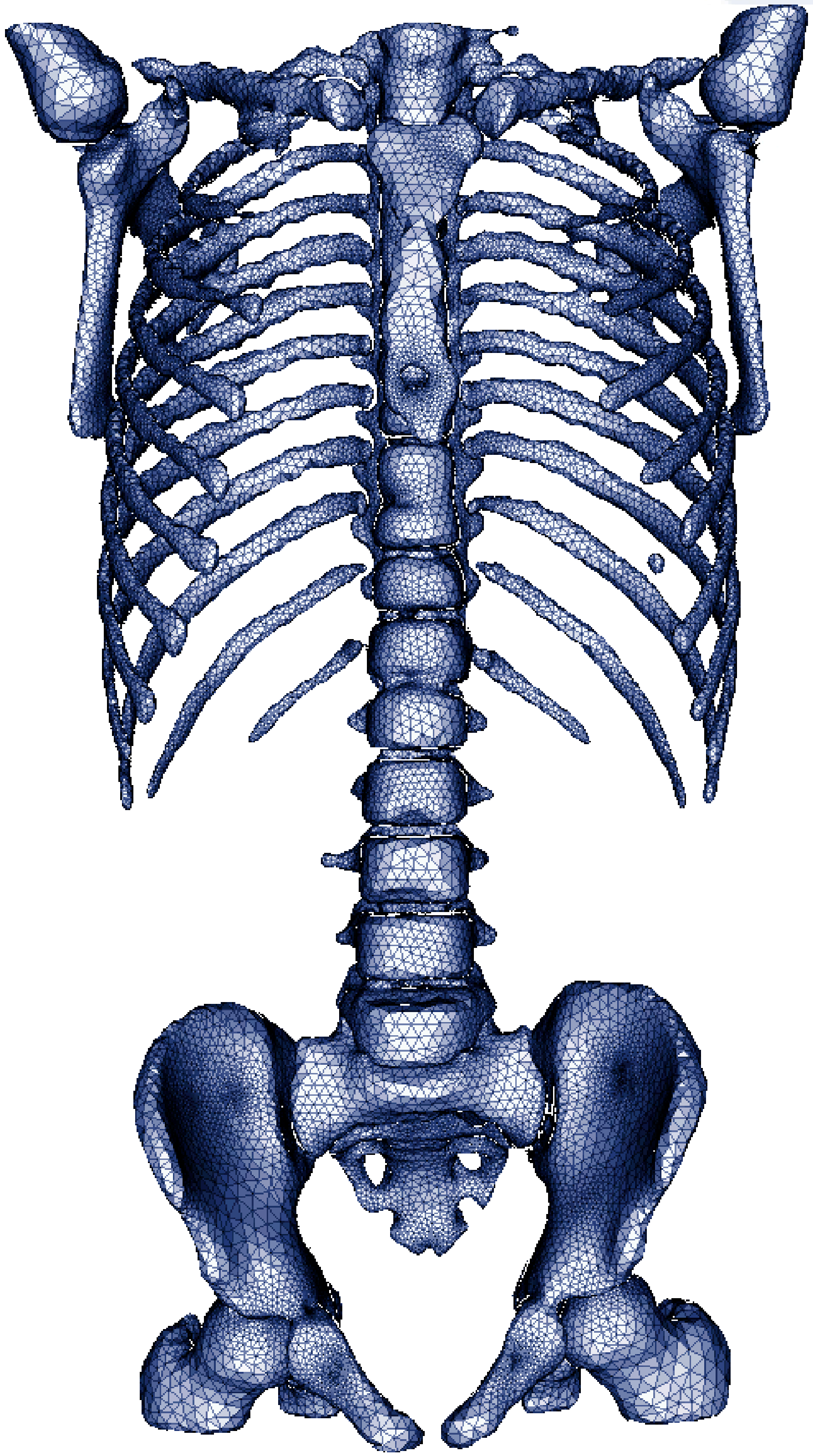
AFront



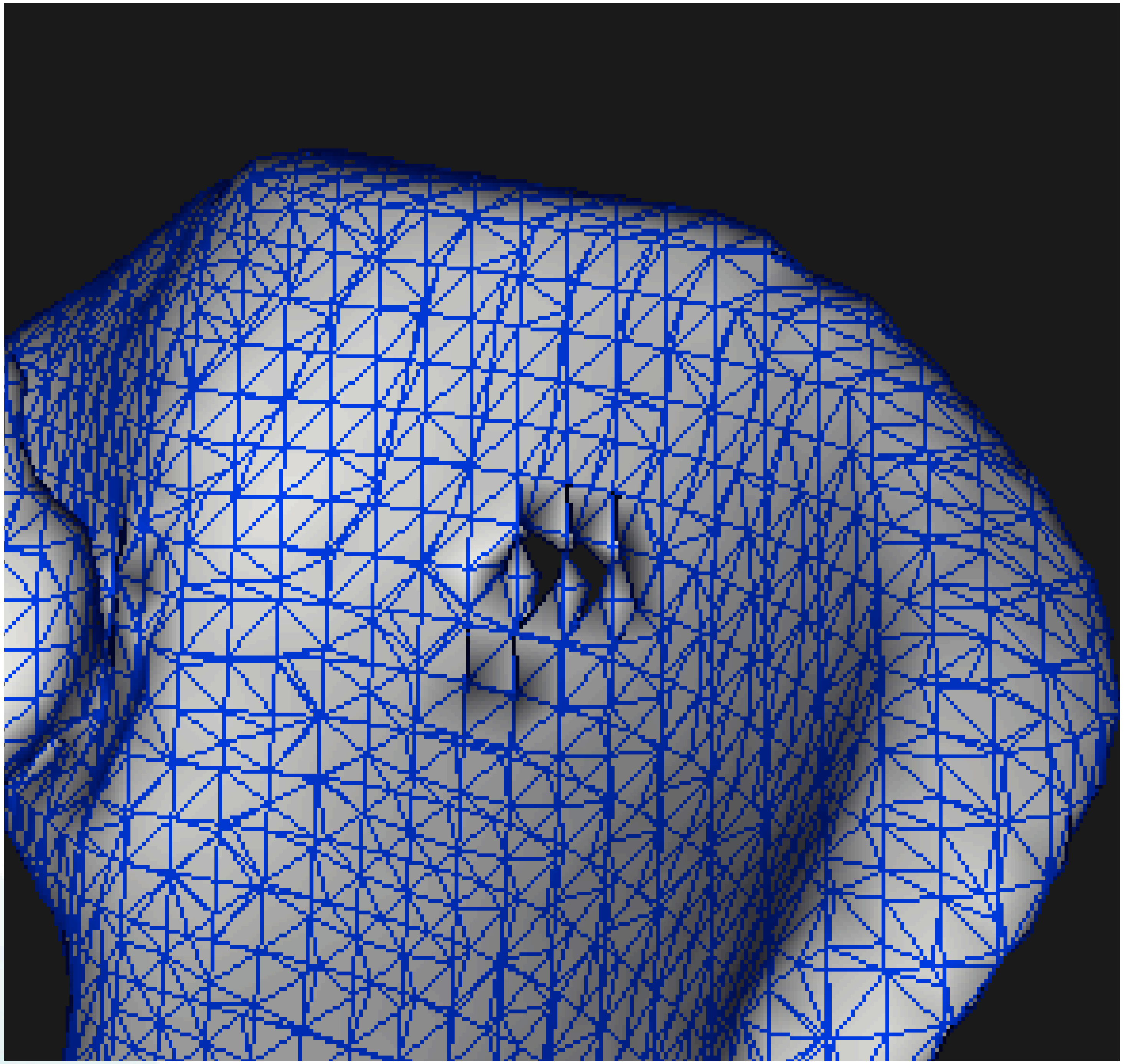
Overview

- Arbitrary topology
- Works with raw data

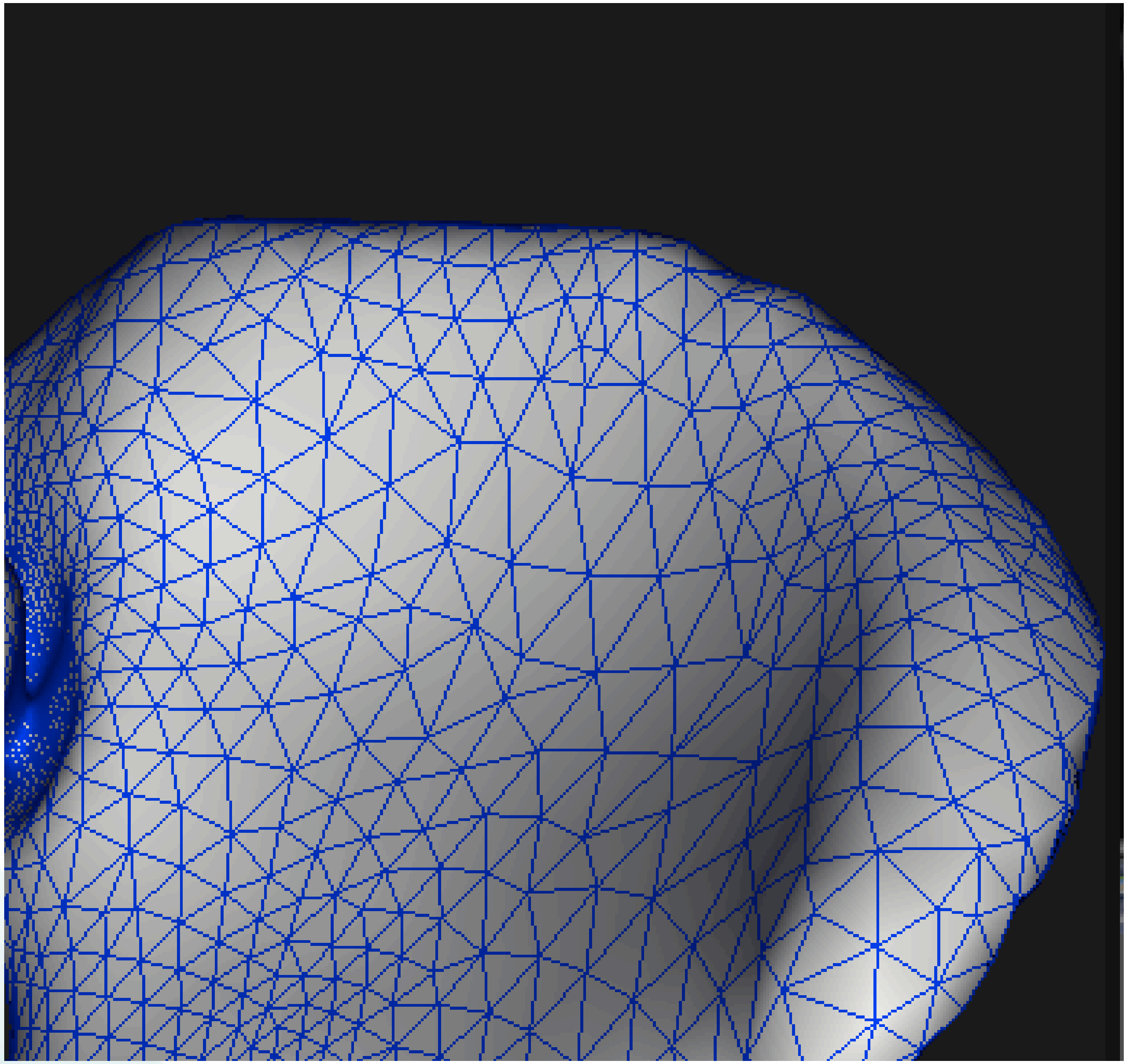




Meshes are important



Meshes are important



Related Work

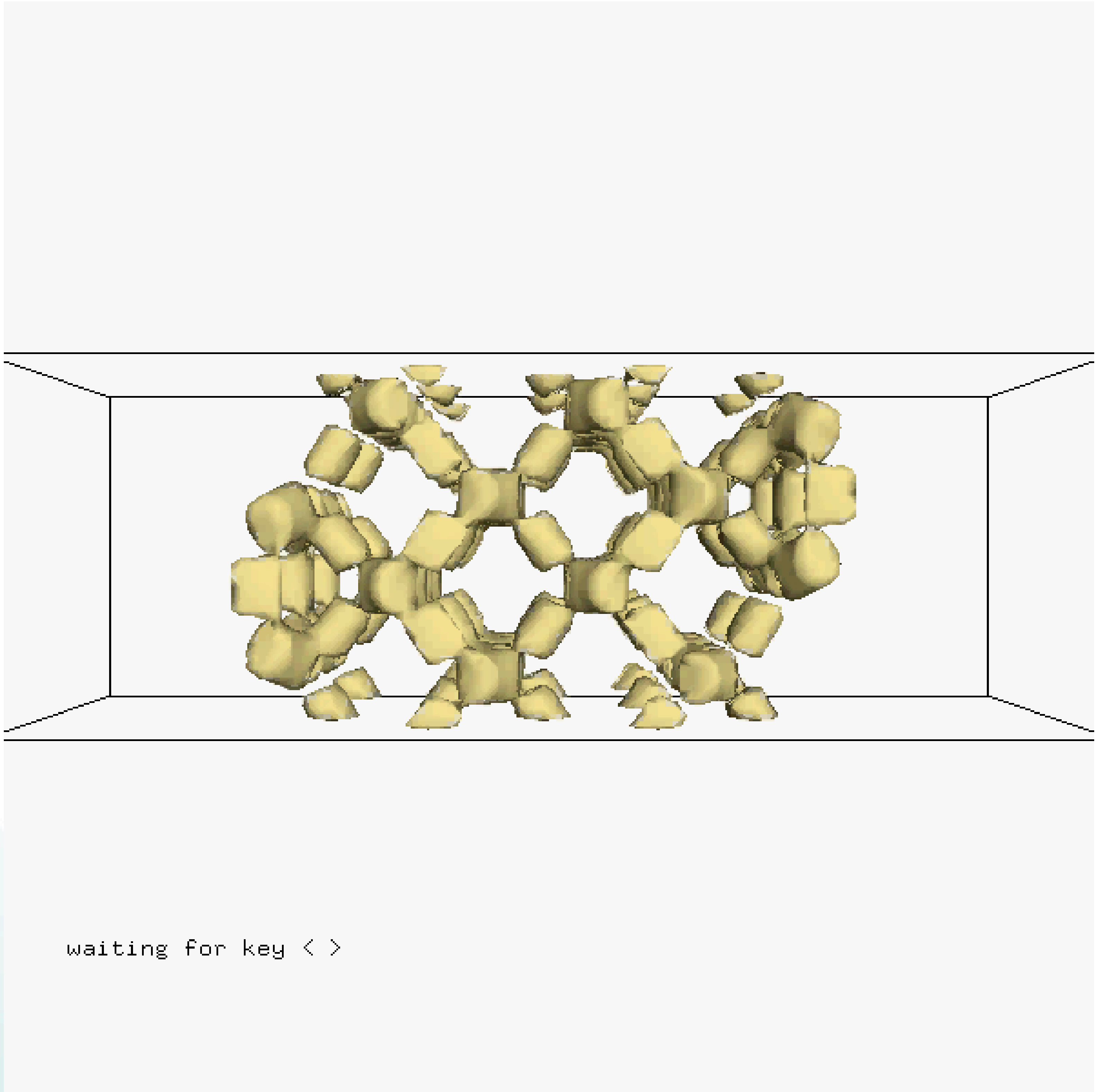
- Marching Cubes and variants
  - Cline and Lorensen
  - Efficiency: Wilhems et al, Cignoni et al, Shen et al
  - Correctness: Nielson, Lewiner et al

- Force-based systems
  - Particles: Crossno et al, Meyer et al

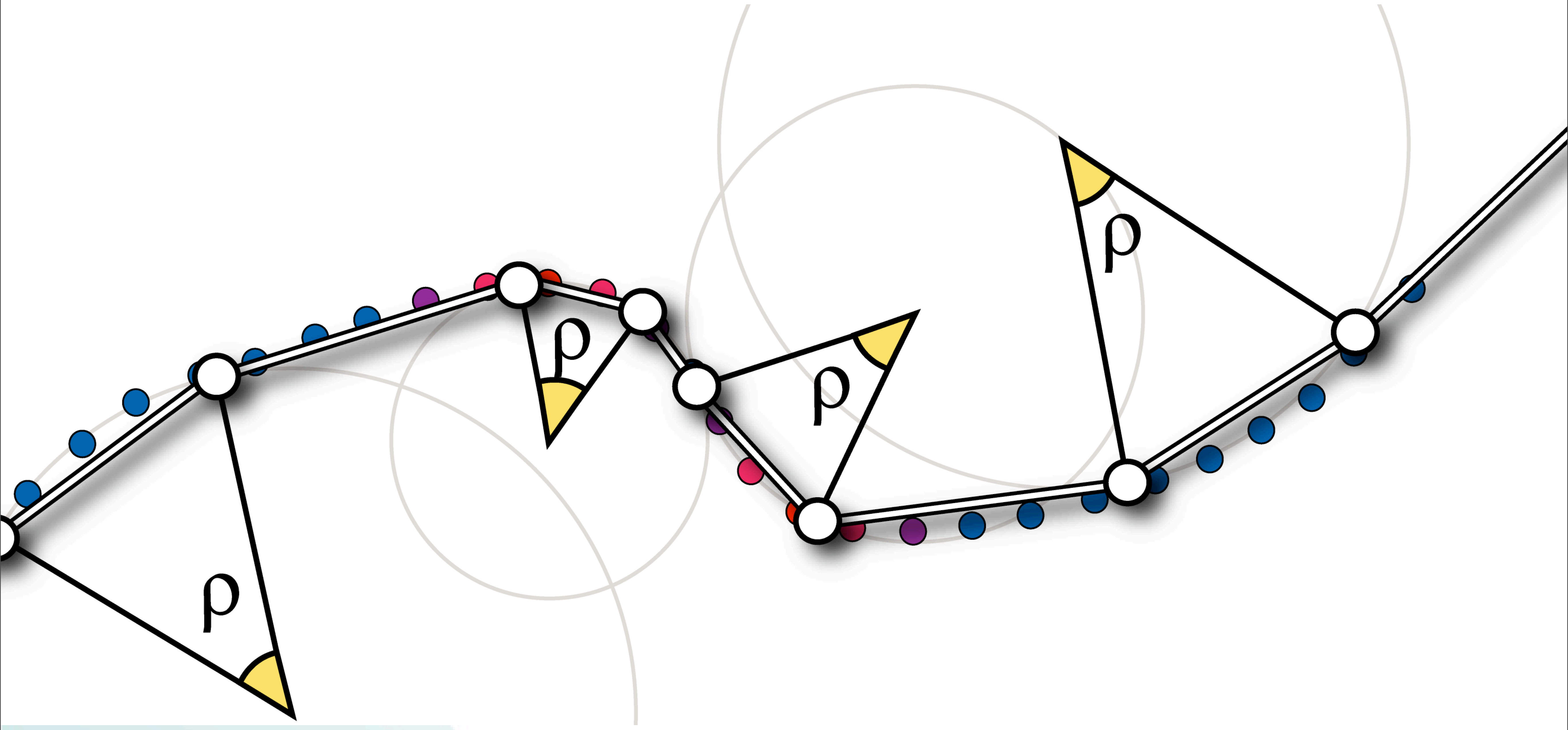
- Hybrid systems
  - Wood et al, Guskov et al
  - Gavriliu et al.

- Many, many others, see paper!

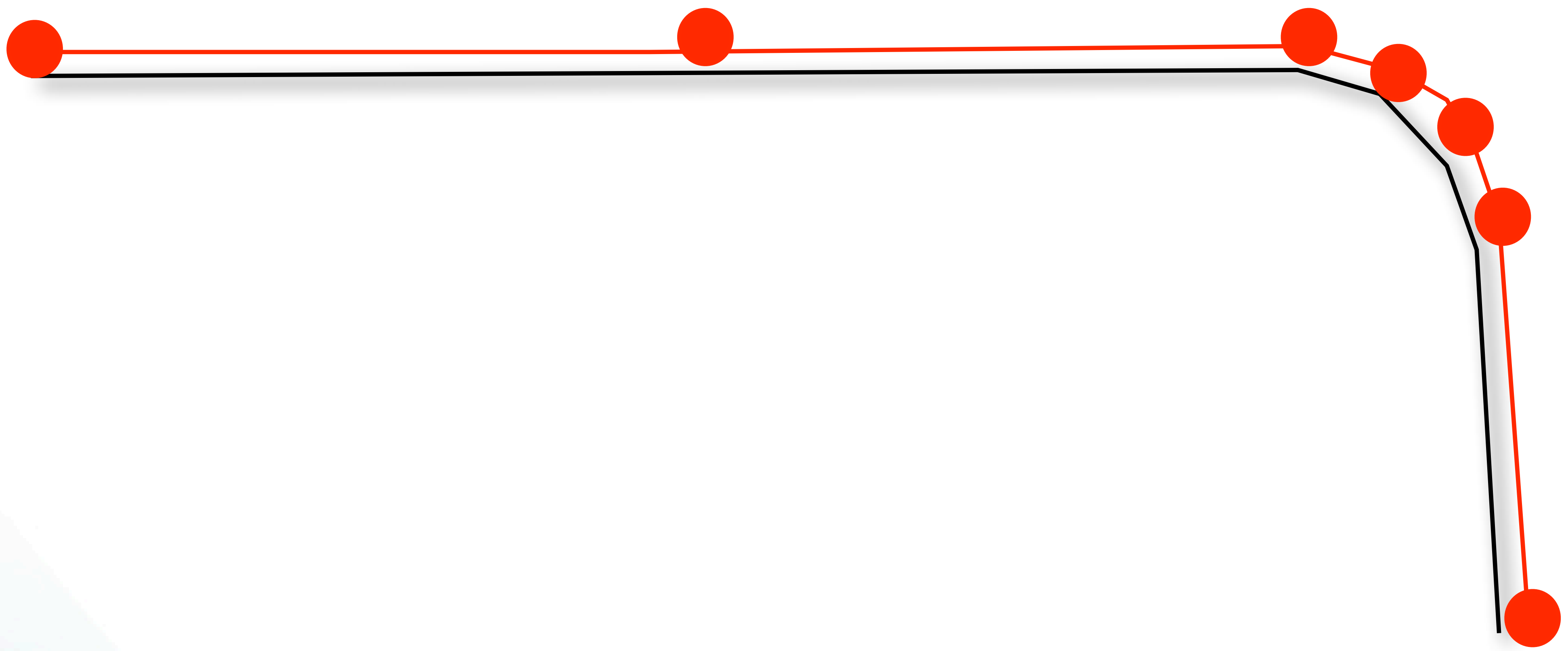
Advancing Fronts

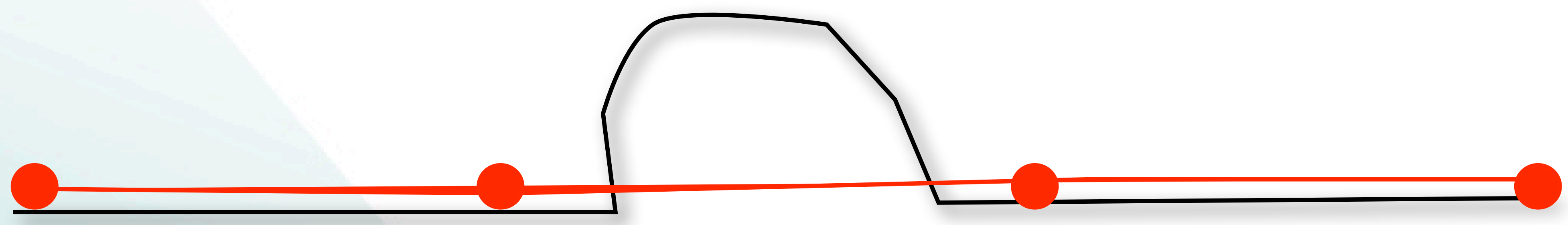


How do we size the elements?



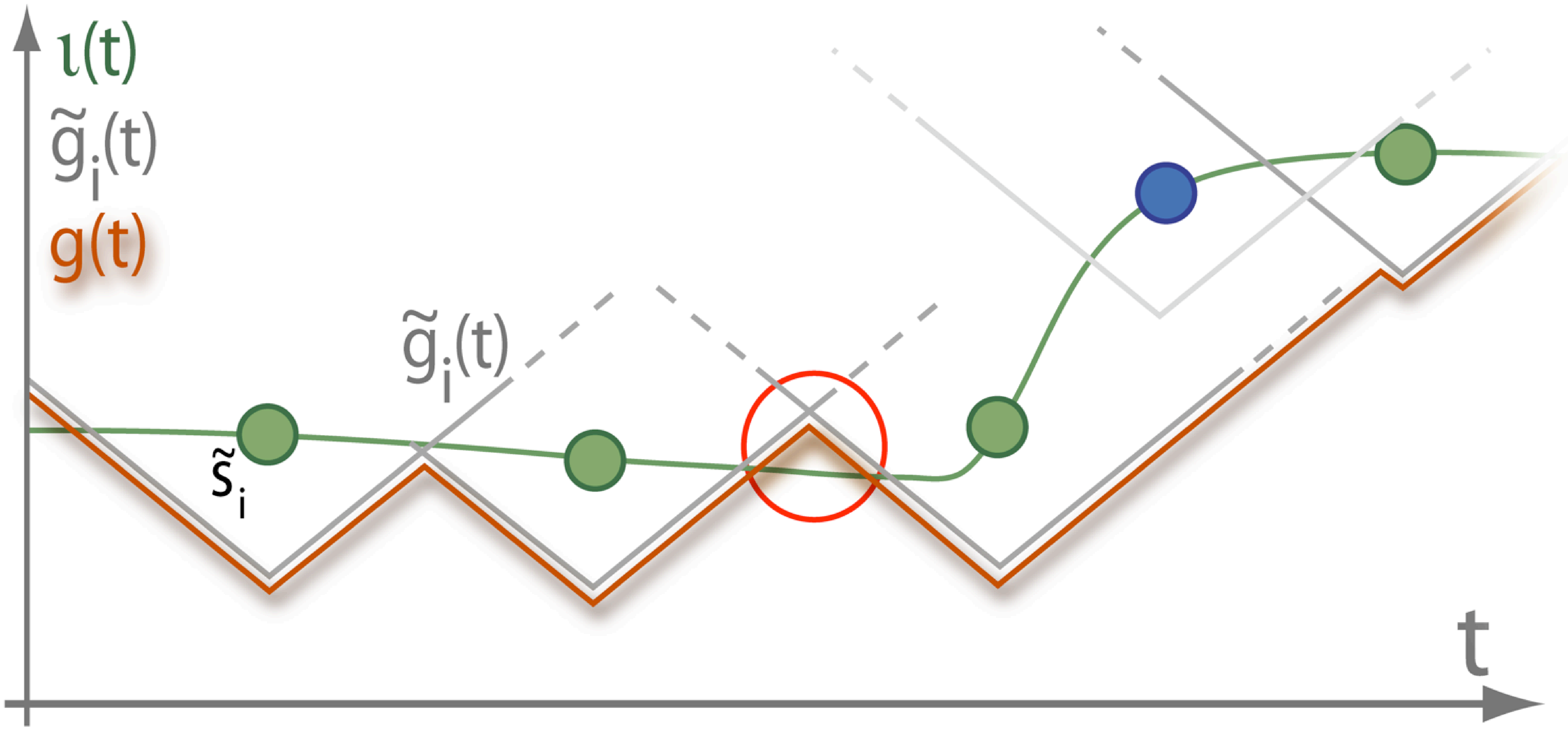
How do we size the triangles?





Guidance Field

Schreiner et al., Eurographics 2006



Guidance Field for Isosurface Extraction

- We use the spatial filter design formulation of Kindlmann et al.
- Geometry tensor
  - Compute curvature from gradient, Hessian

$$
\begin{aligned}
P &= I - nn^T \\
H &= \begin{bmatrix} \frac{\partial^2 f}{\partial x^2} & \frac{\partial^2 f}{\partial x \partial y} & \frac{\partial^2 f}{\partial x \partial z} \\ \frac{\partial^2 f}{\partial x \partial y} & \frac{\partial^2 f}{\partial y^2} & \frac{\partial^2 f}{\partial y \partial z} \\ \frac{\partial^2 f}{\partial x \partial z} & \frac{\partial^2 f}{\partial y \partial z} & \frac{\partial^2 f}{\partial z^2} \end{bmatrix} \\
G &= PHP/|\nabla f|
\end{aligned}
$$

T trace of G

F Frobenius norm of G

$$\kappa_{1,2} = \frac{T \pm \sqrt{2F^2 - T^2}}{2}$$

Guidance Field for Isosurface Extraction

- Determine if set of samples is dense enough
  - We want to bound minimum triangle size
  - Bound max curvature (spectral radius of geometry tensor)
    - Upper bound on _any_ consistent matrix norm of Hessian
    - Lower bound on gradient magnitude

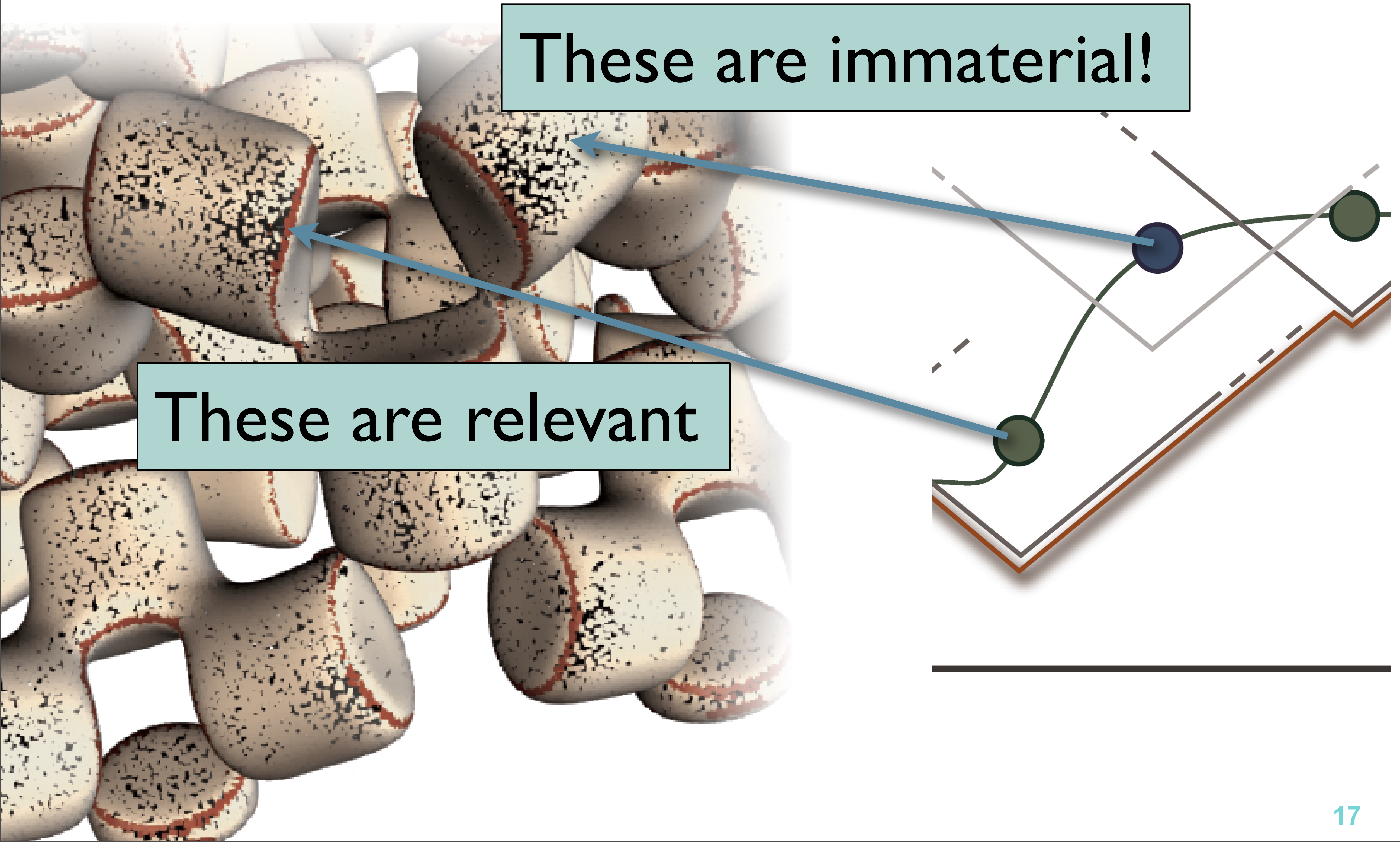
$$r(M) \leq ||M||$$

$$\begin{aligned} r(G) &= \kappa_{\max} \\ &\leq ||G|| \\ &\leq ||PHP/|\nabla f||| \end{aligned}$$

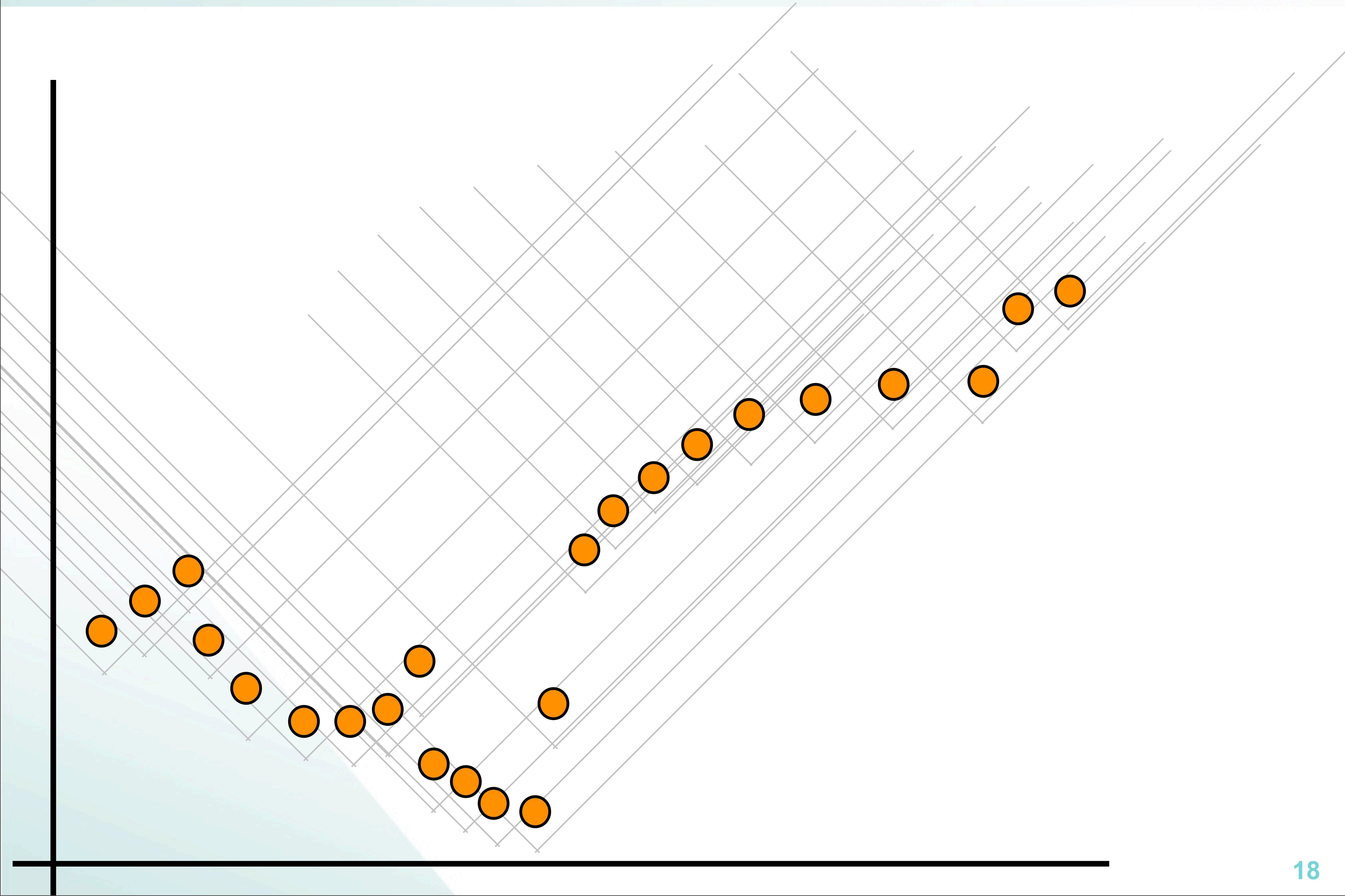
$$r(G) \leq \frac{2\sqrt{3}}{|\nabla f|} ||H||$$

(for Frobenius matrix norm)

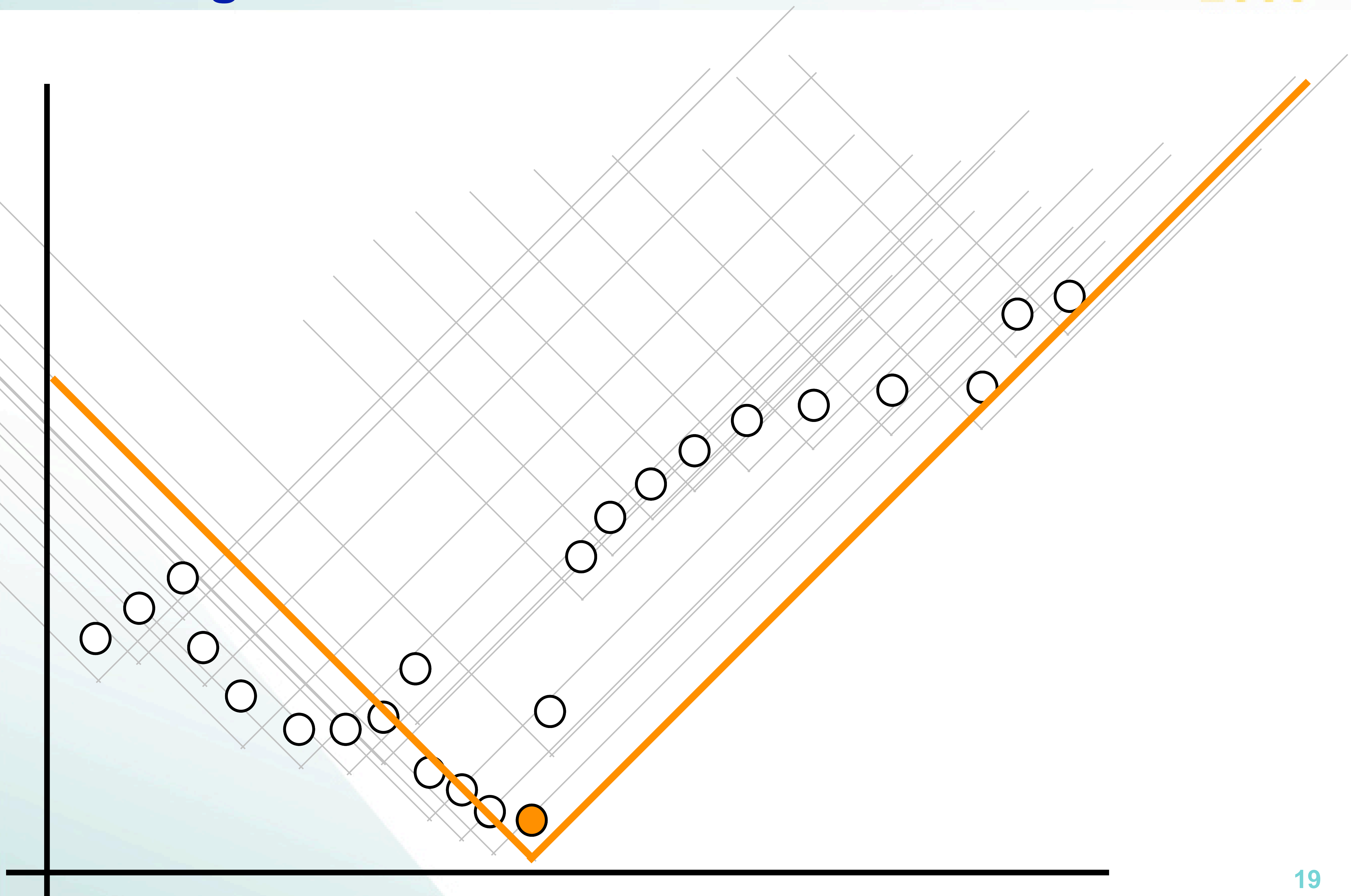
Culling the Guidance Field



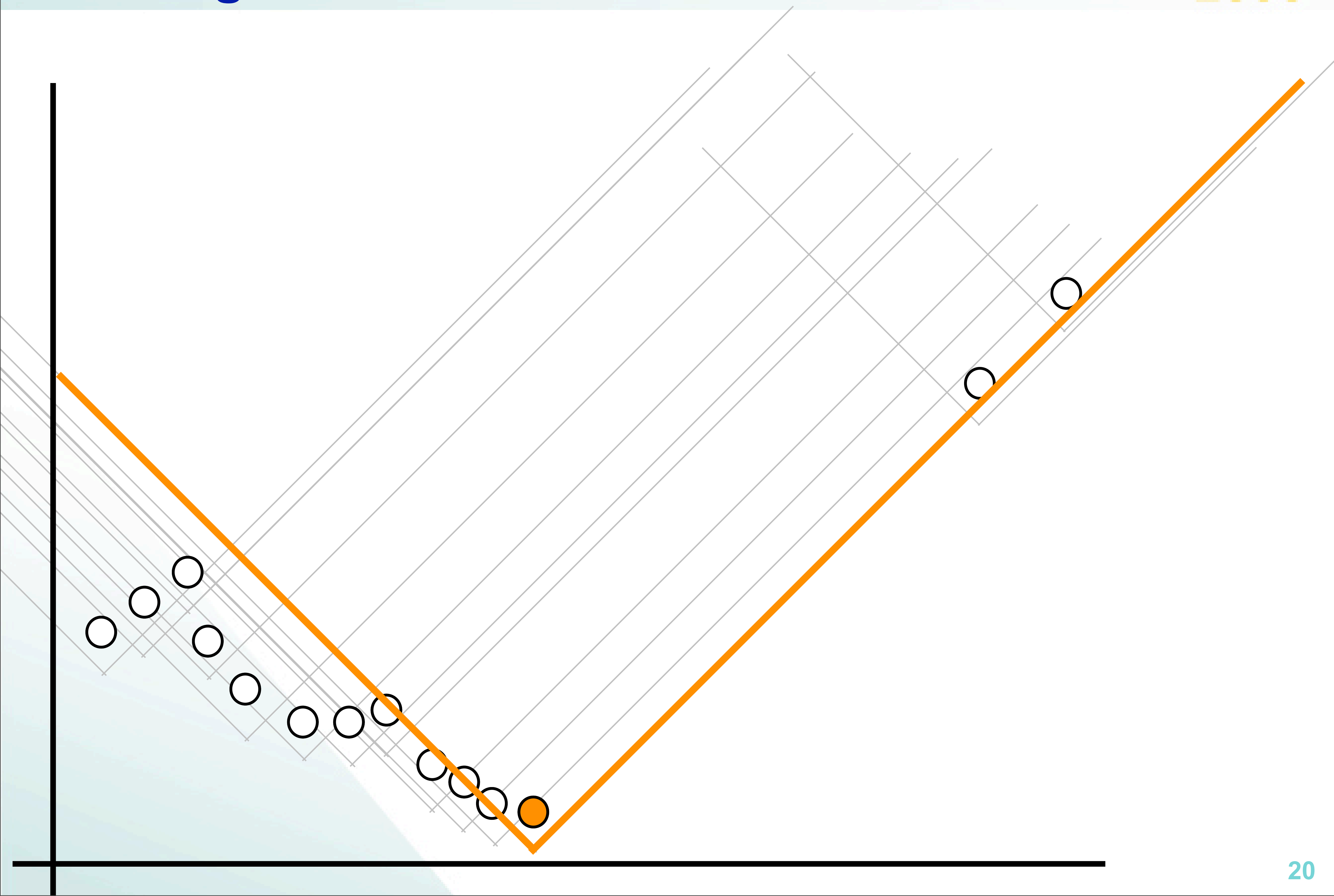
Culling the Guidance Field



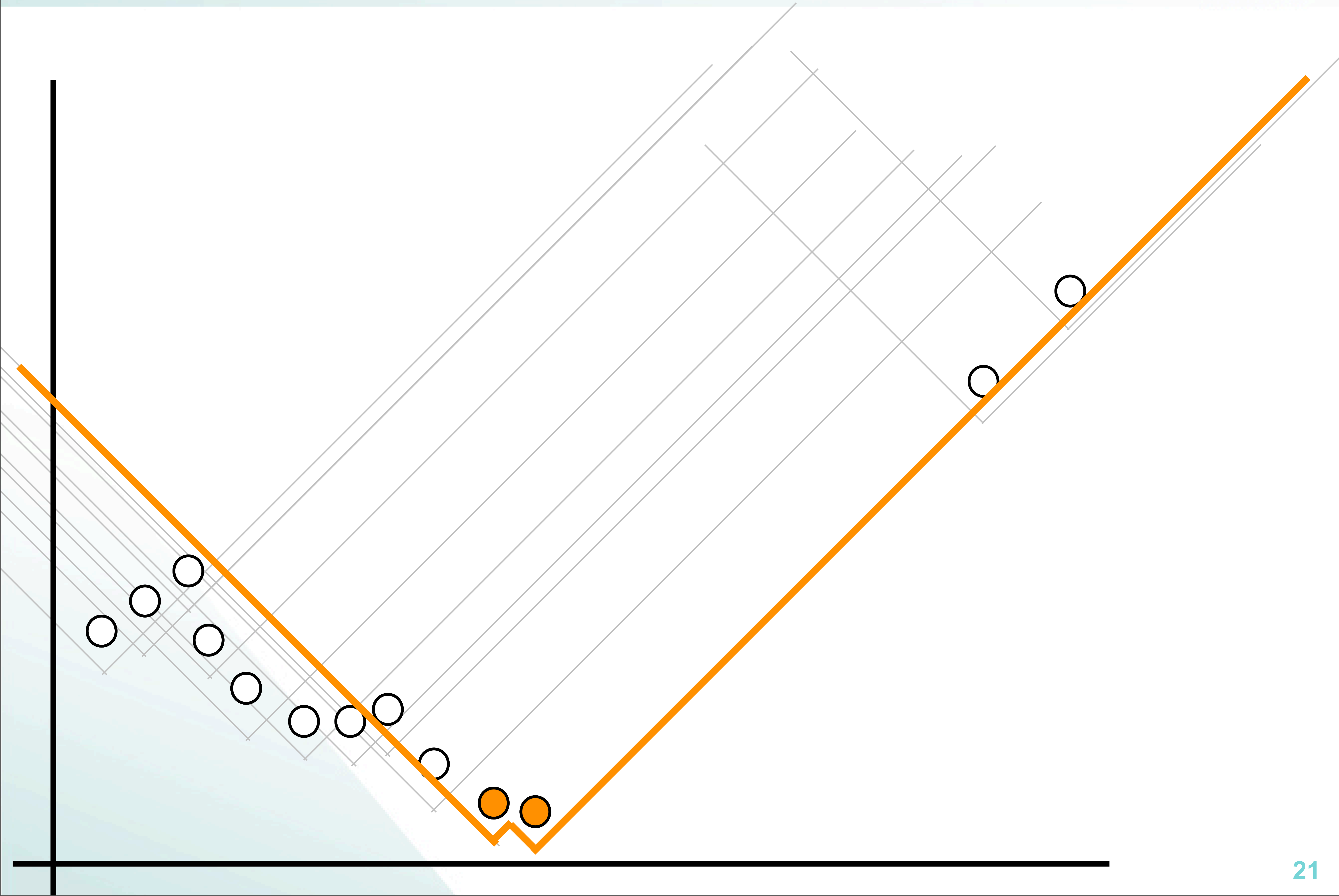
Culling the Guidance Field



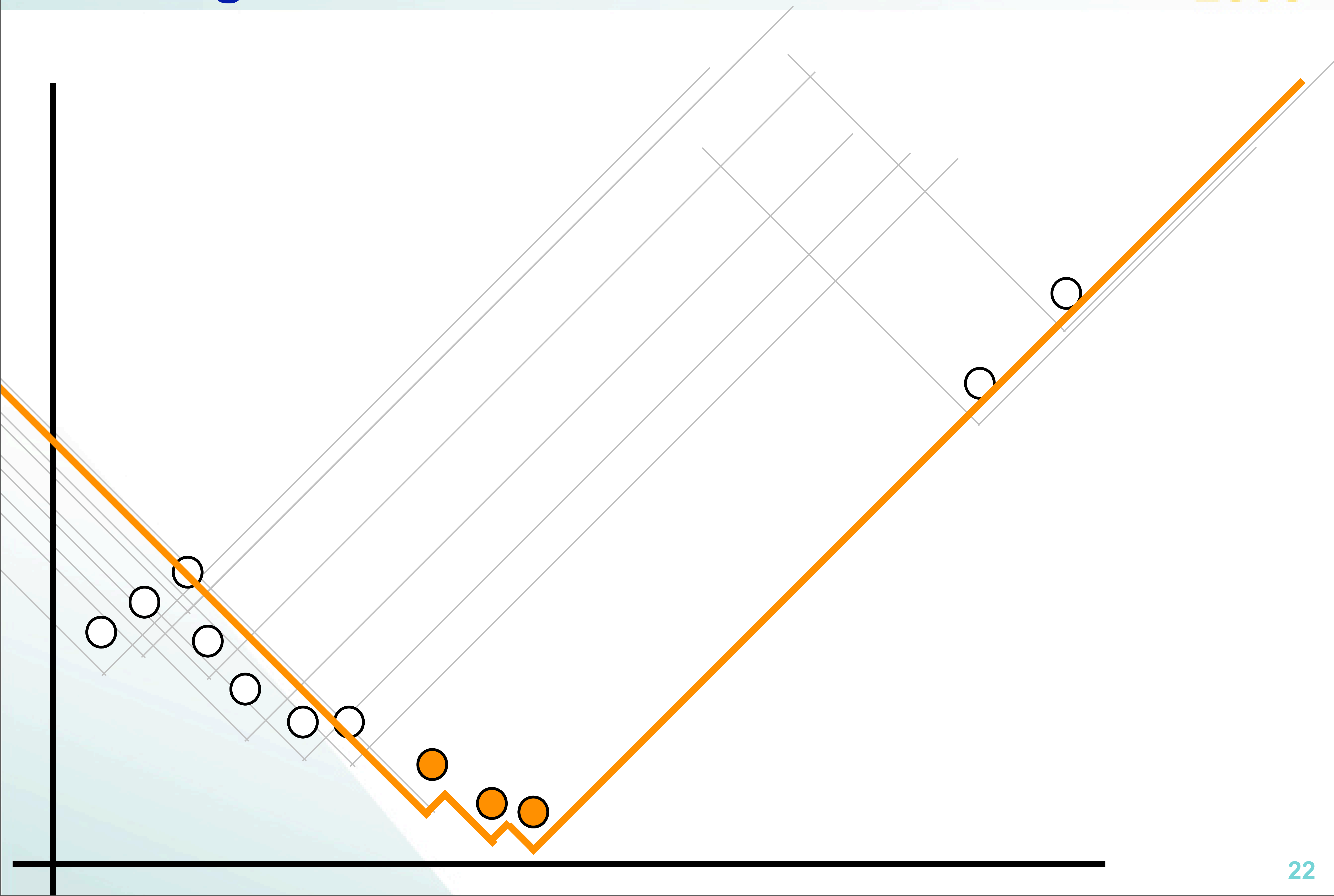
Culling the Guidance Field



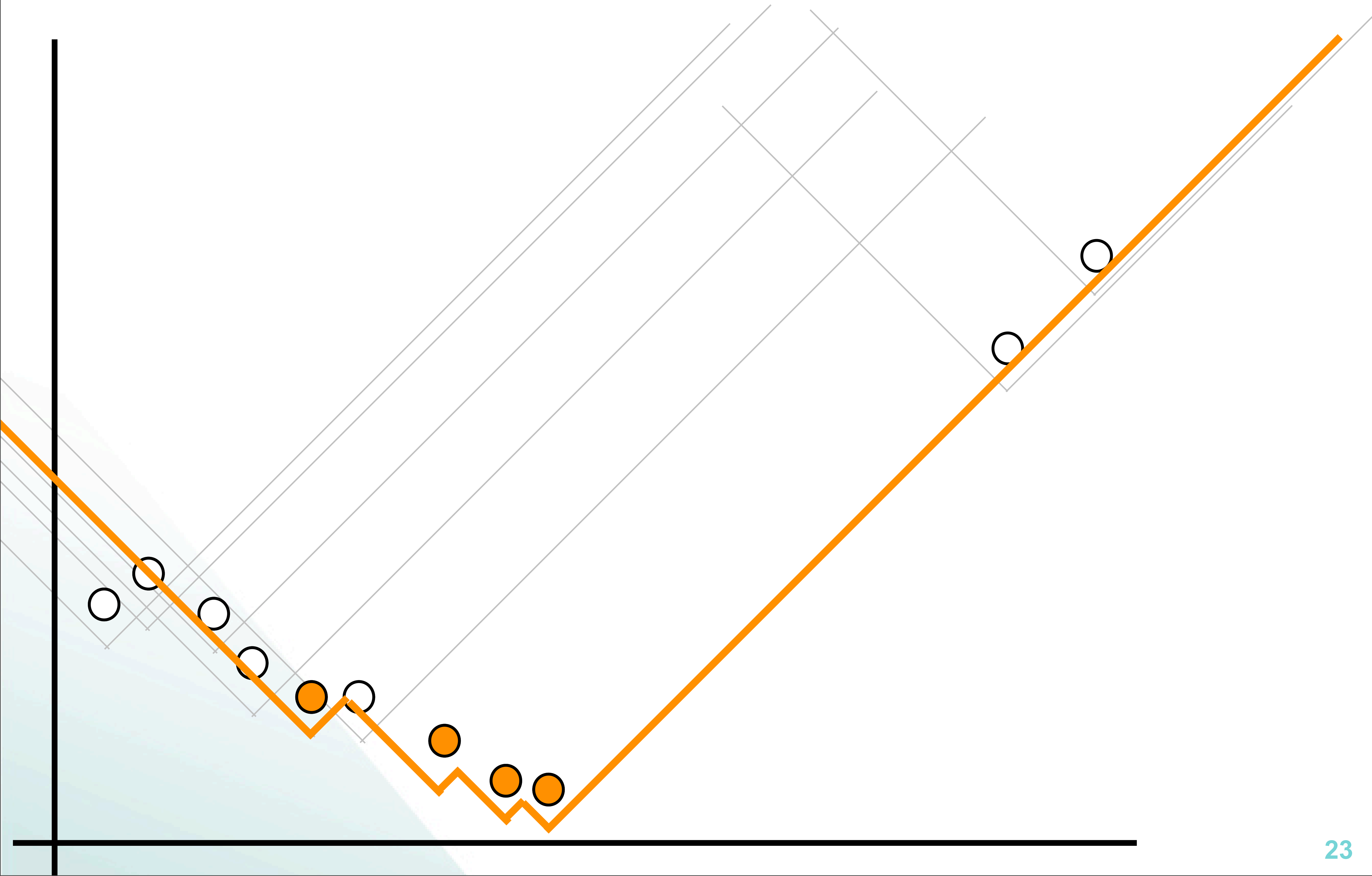
Culling the Guidance Field



Culling the Guidance Field

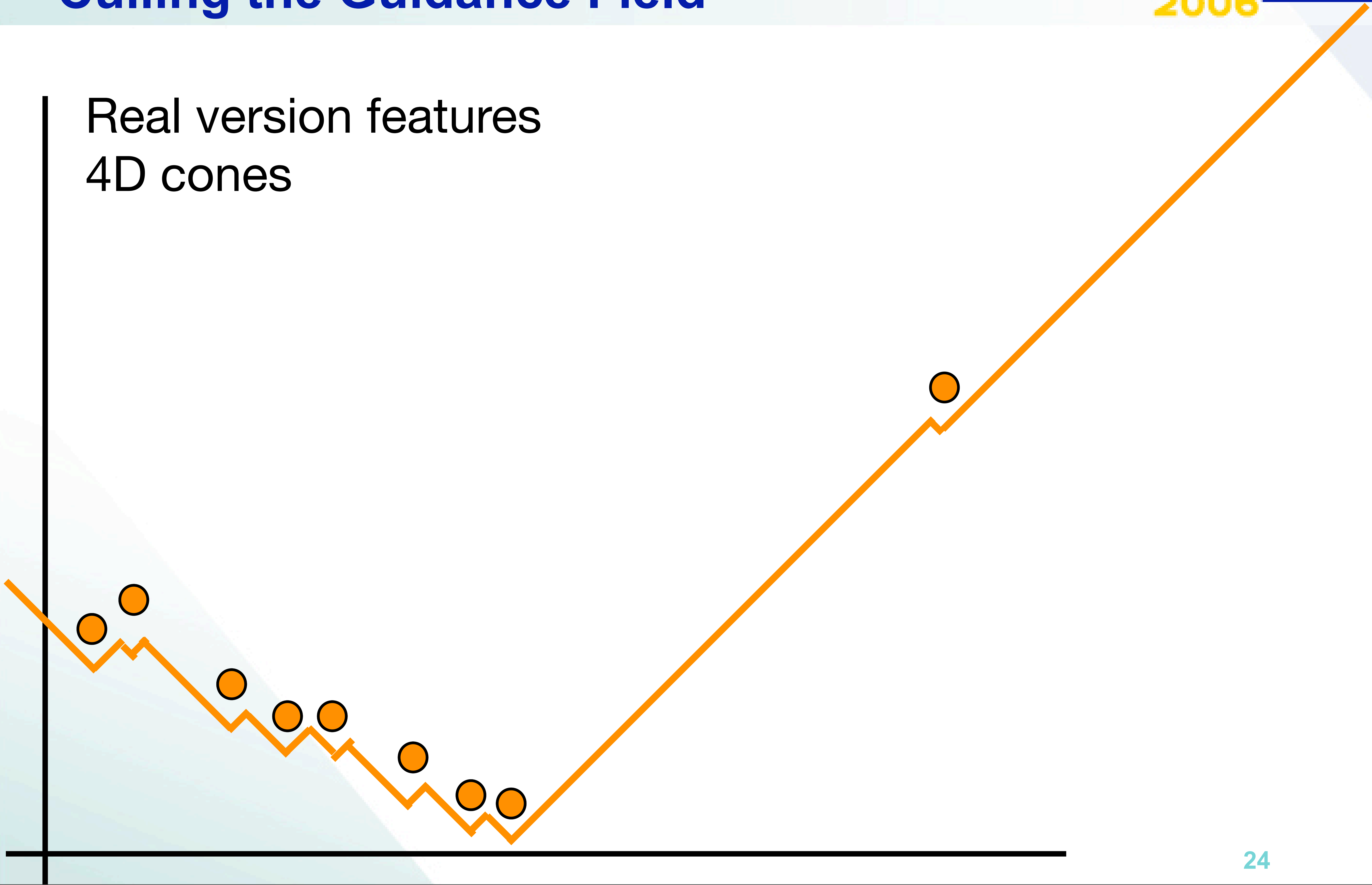


Culling the Guidance Field

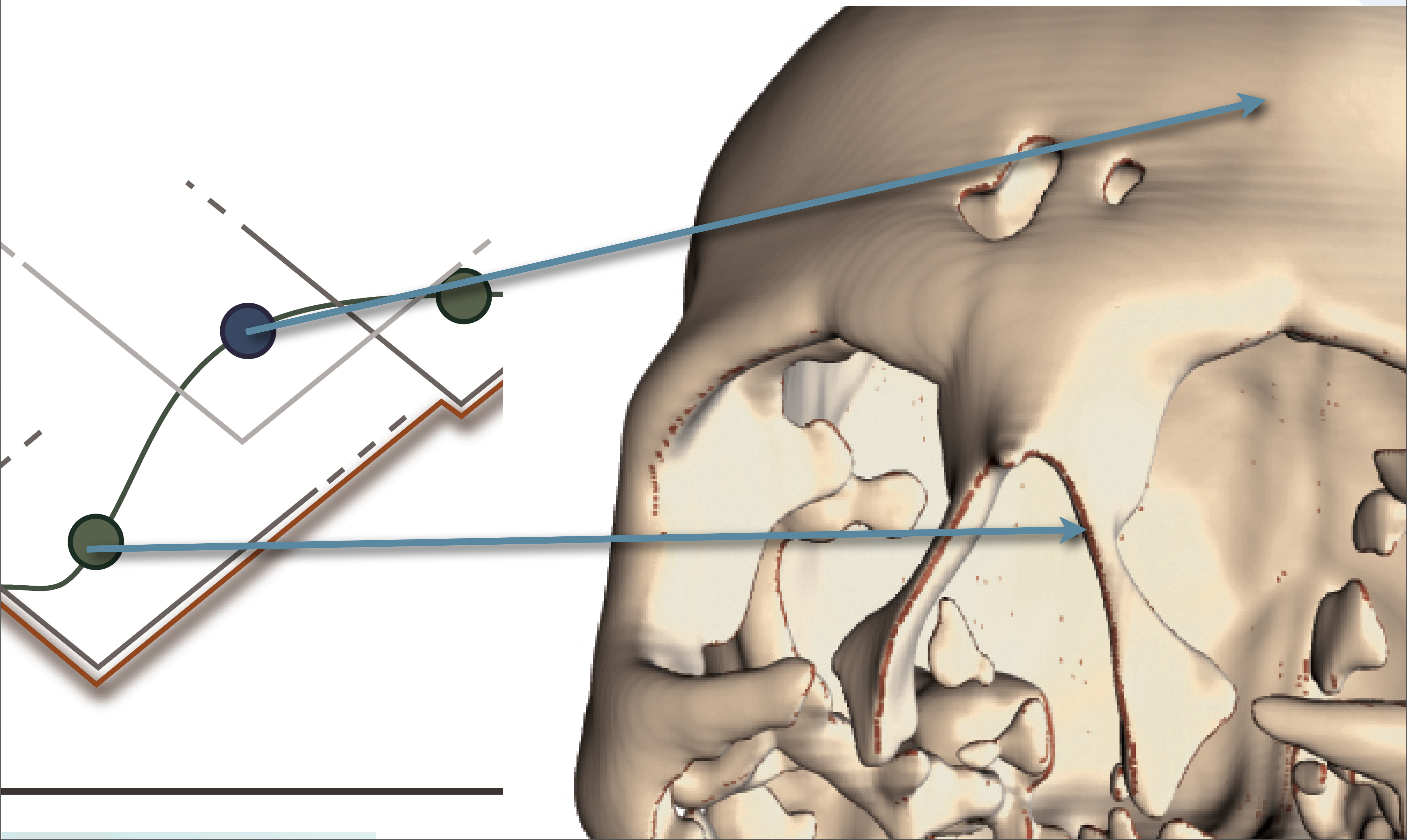


Culling the Guidance Field

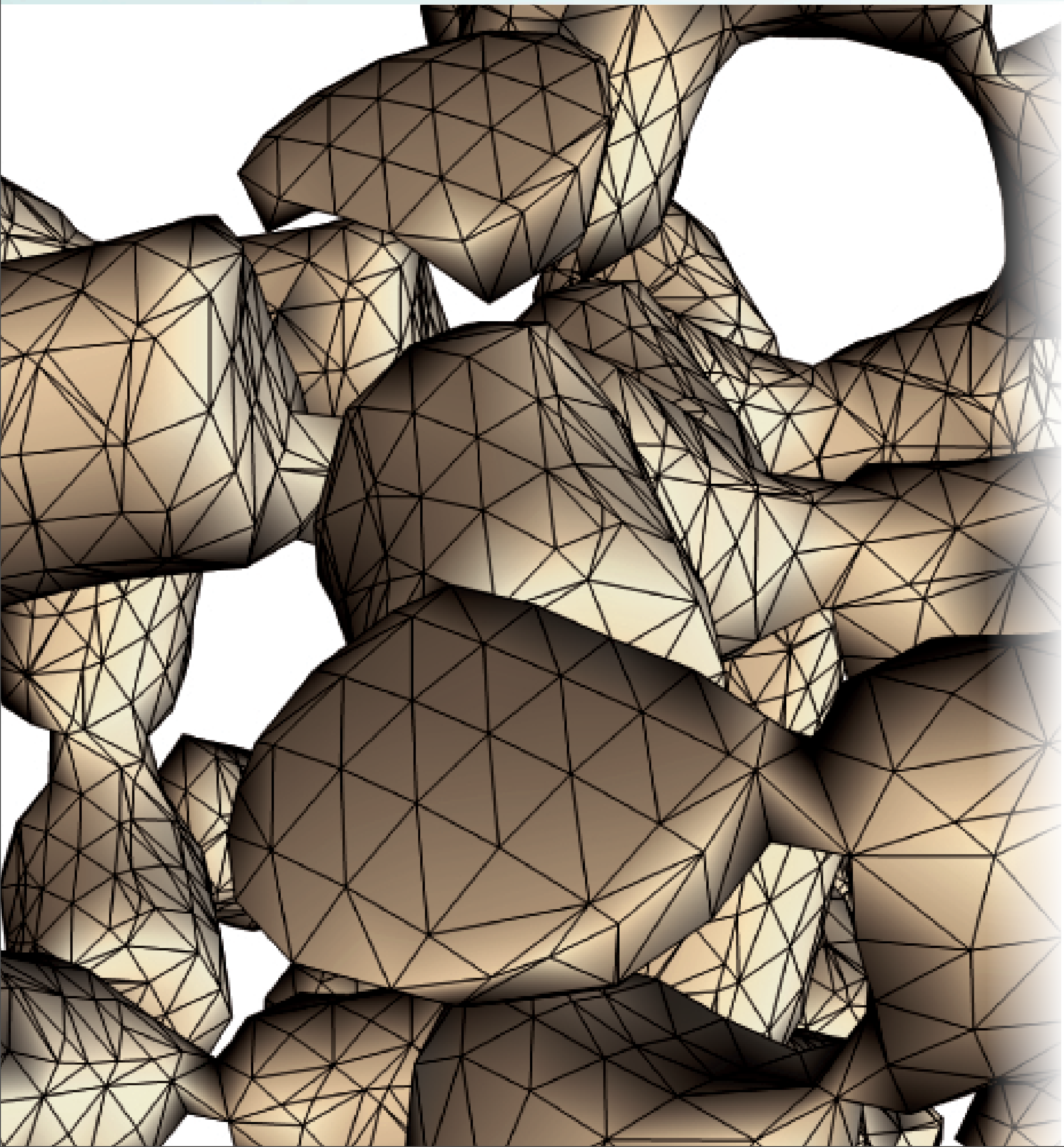
Real version features
4D cones



Culling the Guidance Field

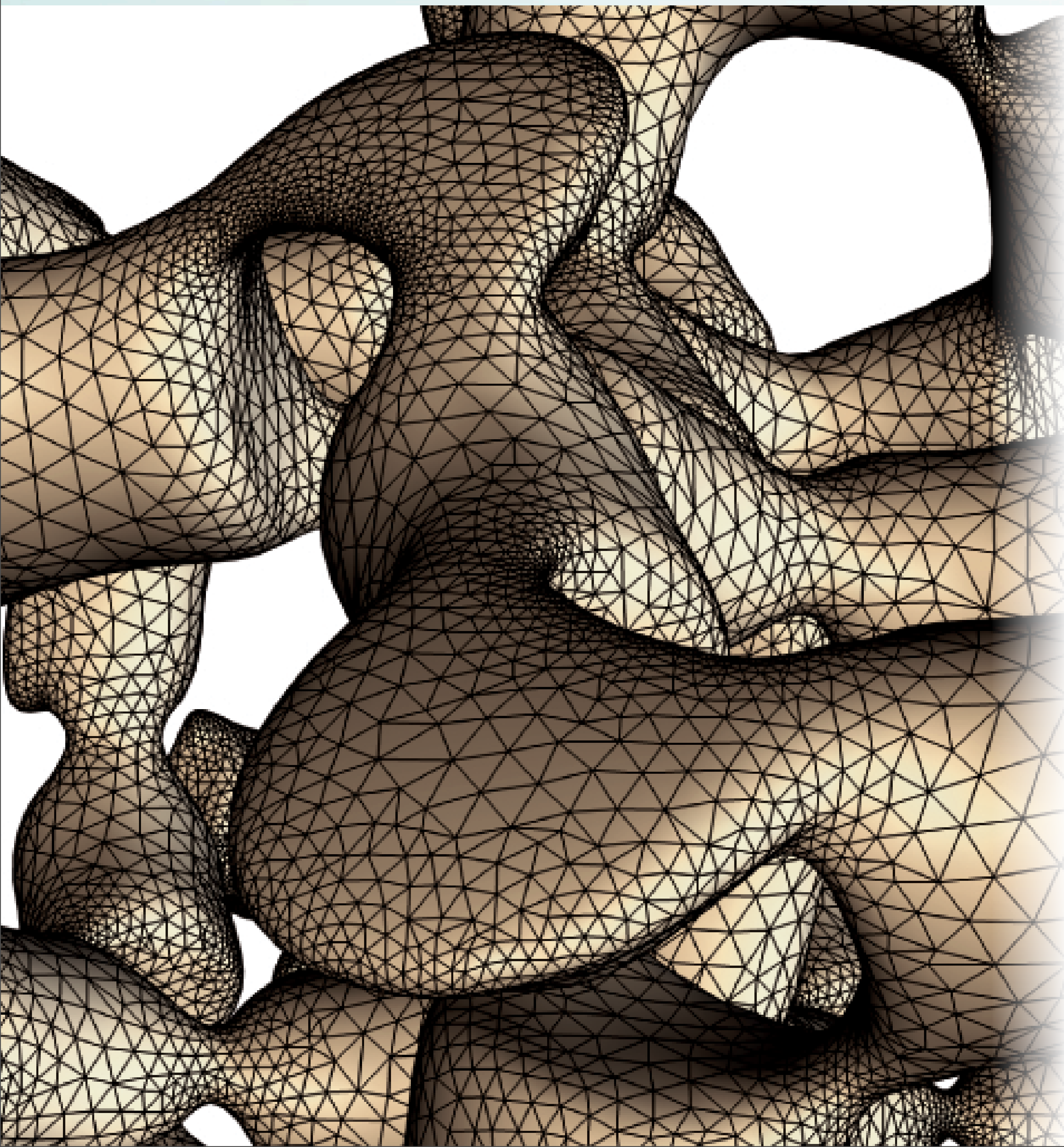


Results



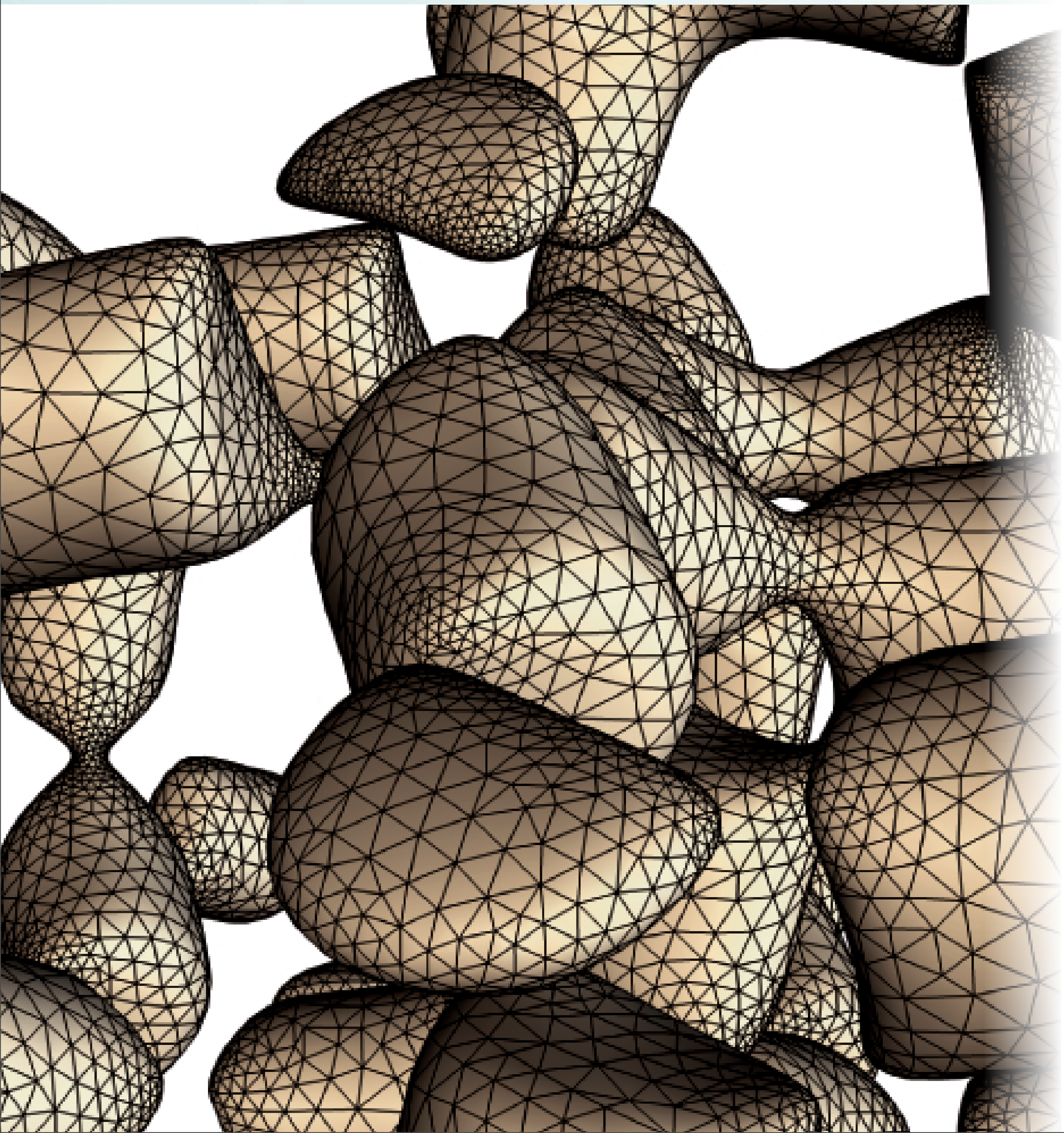
Marching Cubes

Results

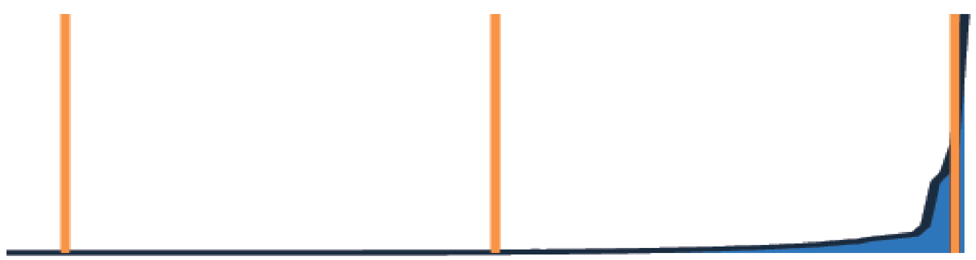


Catmull-Rom

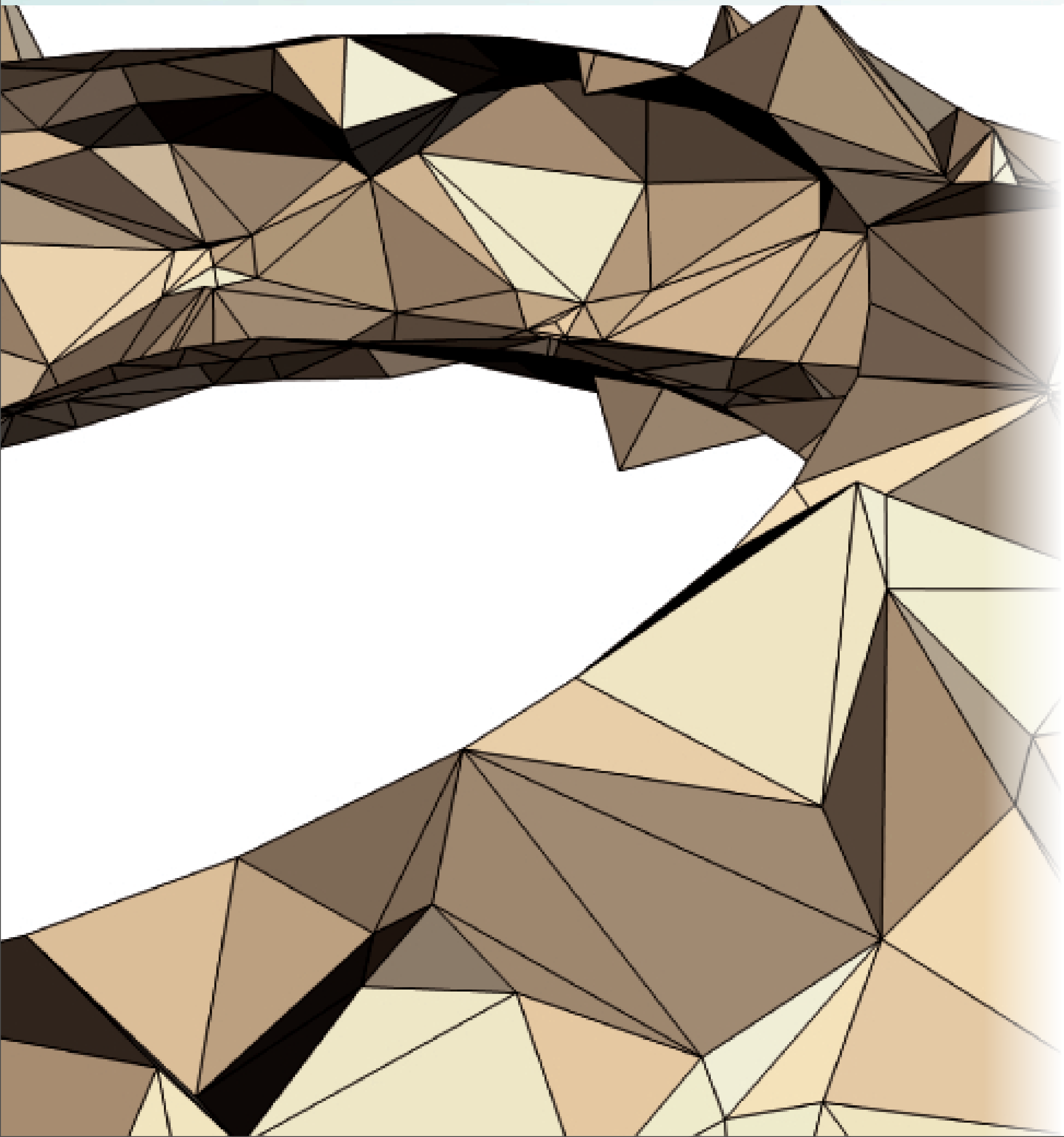
Results



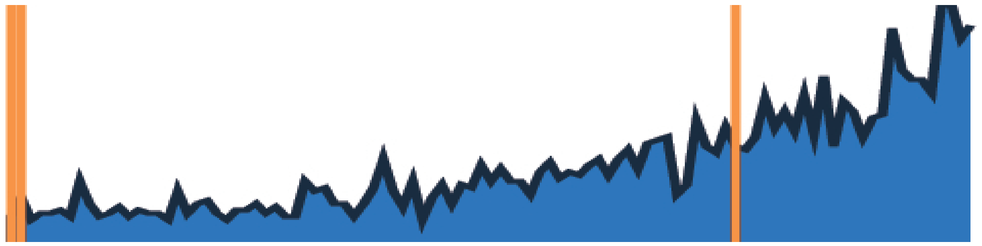
B-Spline



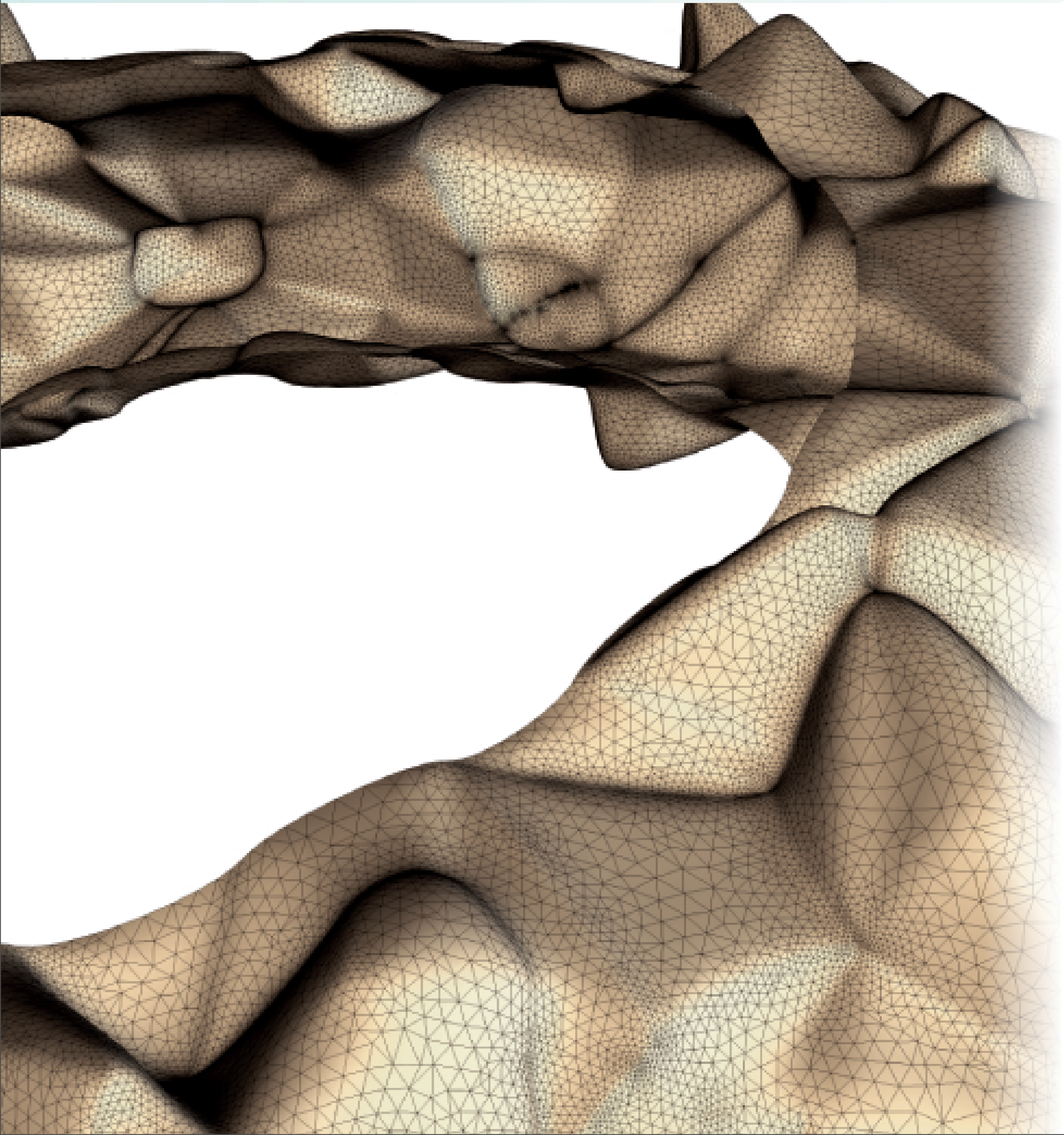
Results



Marching Tetrahedra

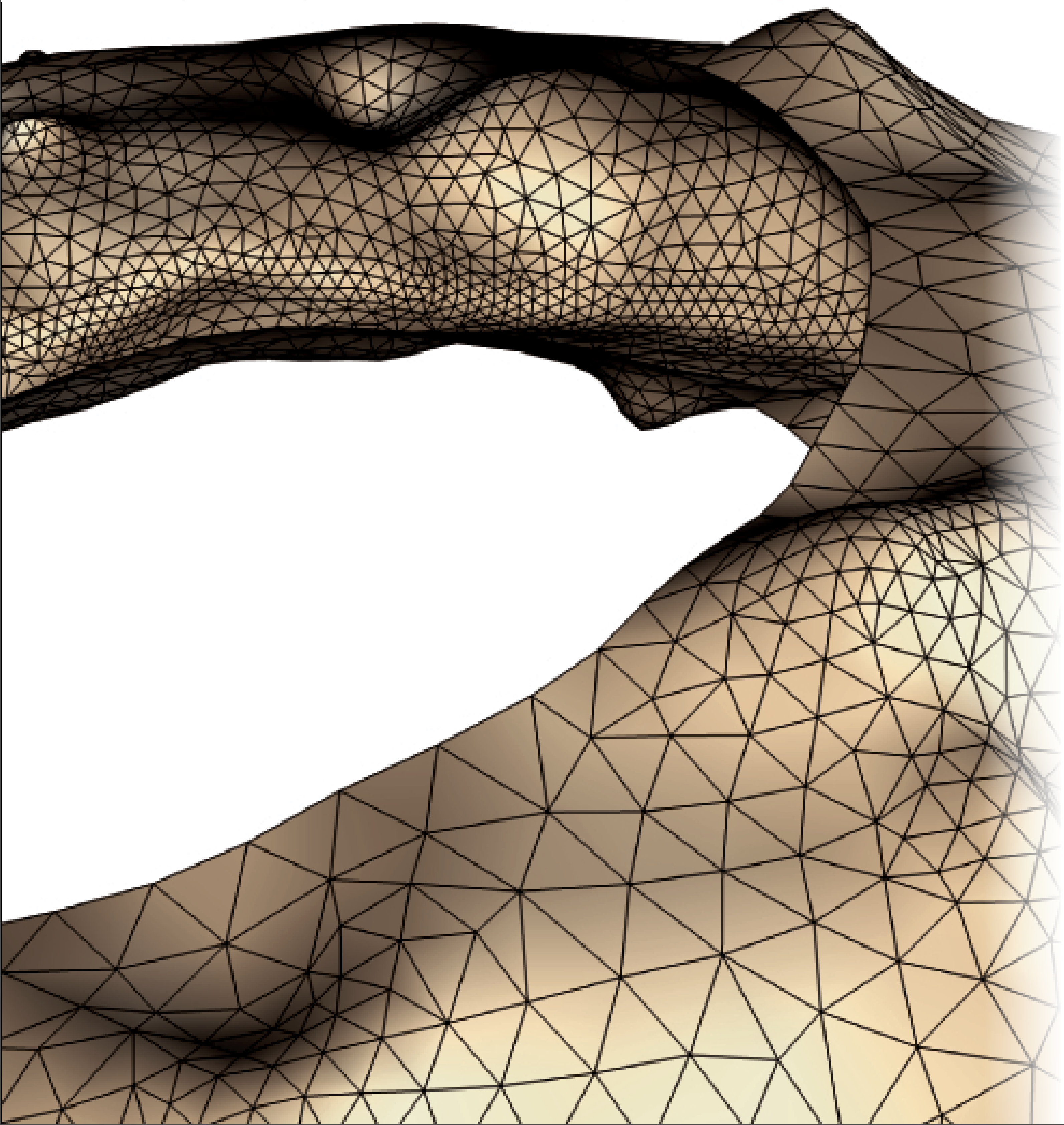


Results

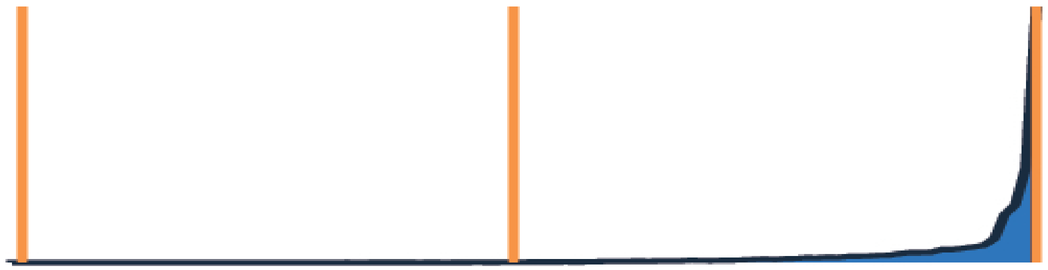


Nielson Interpolation

Results



Moving
Least Squares



(Demo)

Discussion

- Method is appropriate if subsequent processing is necessary
- One pass algorithm produces results comparable to global methods
- Output mesh is dependent on the isosurface itself, and not the domain on which it is defined

- Requires the gradient of function to be defined
  - True for all manifold isosurfaces
  - No sharp features

Future Work

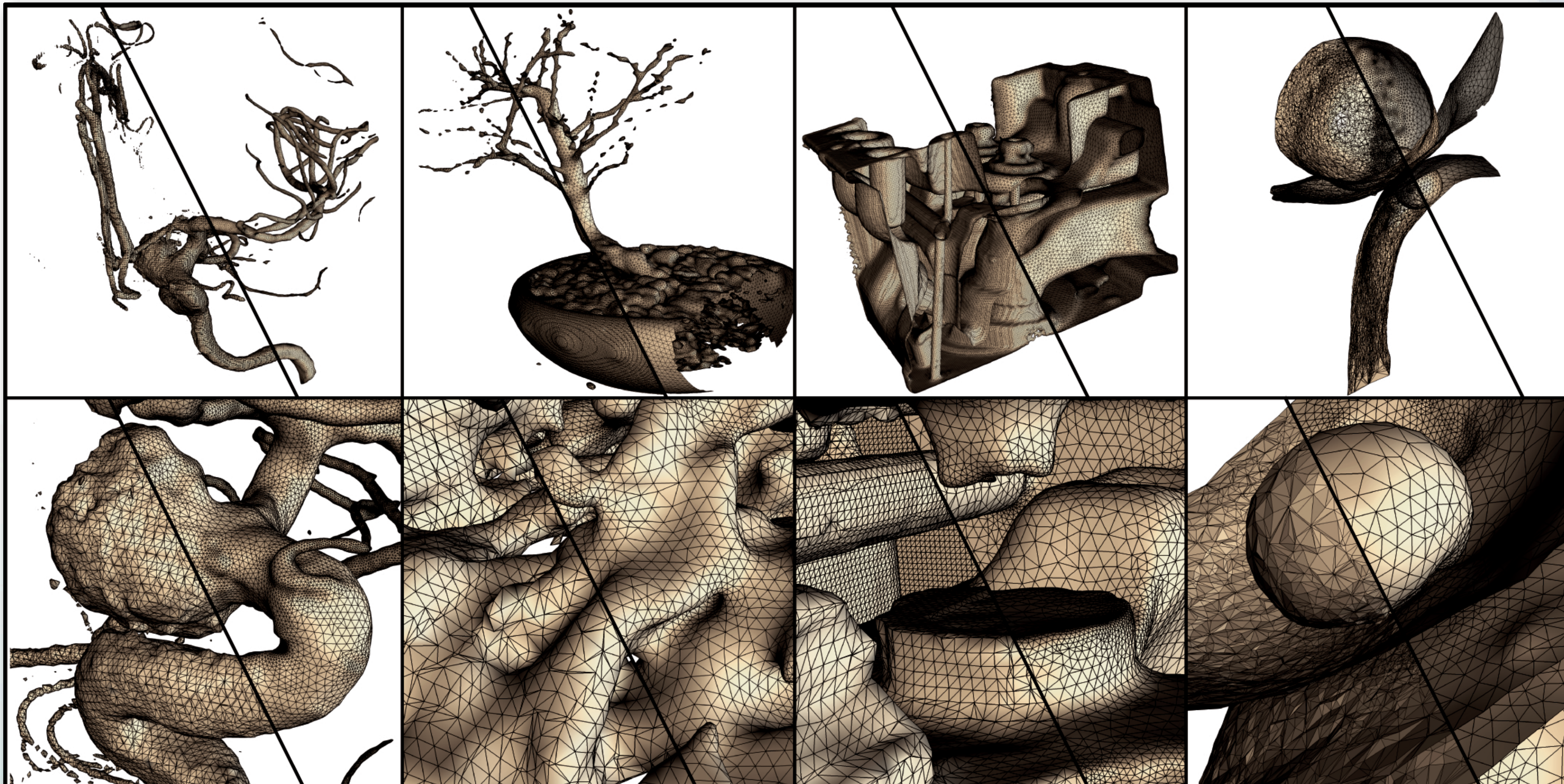
- Out of core meshing of gigantic data sets
  - Particularly for regular grids
  - Output already streamed, stream input
  - Control interaction between global guidance field and input stream
- Bound quality of all triangles
  - Not just those that create new vertices

Acknowledgments

- NSF grants
  - CCF-0401498
  - EIA-0323604
  - OISE-0405402
  - IIS-0513692
  - CCF-0528201
- DOE
- Sandia National Laboratories
- Lawrence Livermore National Laboratory
- IBM Faculty Award
- University of Utah Seed Grant

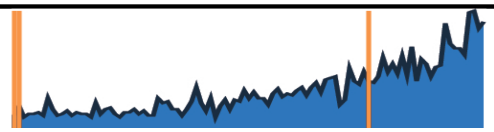
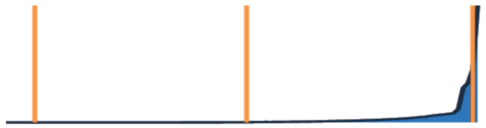
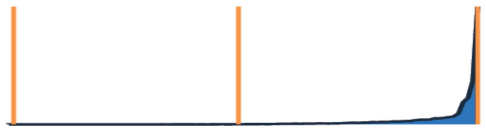
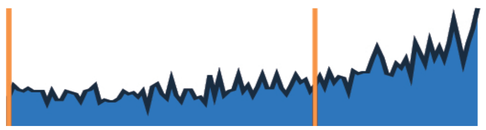
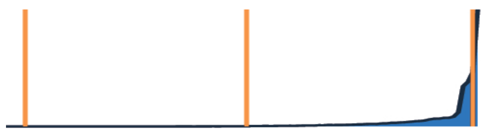
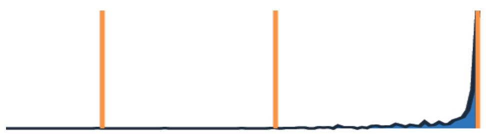
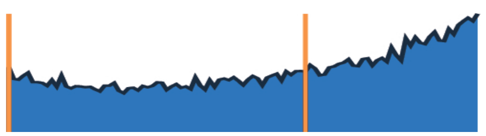
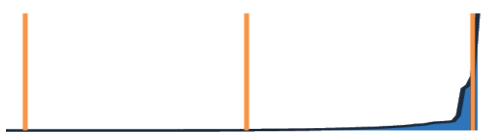
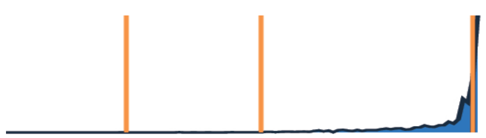
- http://www.volvis.org for volumes

Thank you!

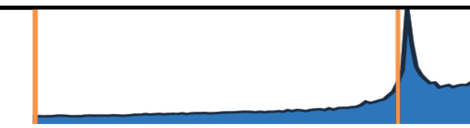
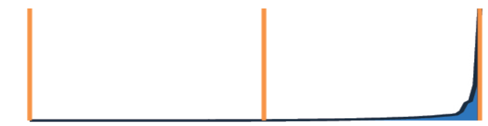
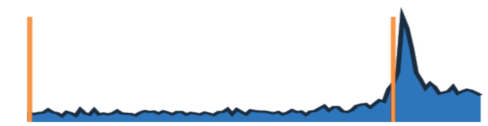
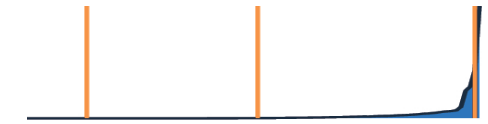
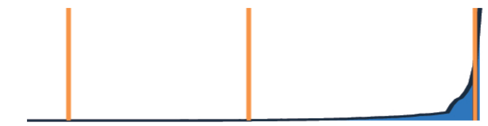
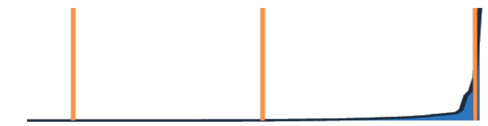


- Questions?

Results

Model	Alg.	ρ	η	time	# tris	Histogram
SPX	MT	—	—	0:00	2.3K	
	NI	0.5	1.2	14:06	645.9K	
	MLS	0.5	1.2	1:48	26.7K	
Torso-1	MT	—	—	0:01	3.1K	
	NI	0.5	1.2	2:28	72.8K	
	MLS	0.5	1.2	2:04	702	
Torso-2	MT	—	—	0:02	24.2K	
	NI	0.5	1.2	12:48	656K	
	MLS	0.5	1.2	4:24	2.4K	

Results

Model	Alg.	ρ	η	time	# tris	Histogram
Aneurism	MC	—	—	0:07	133.5K	
	BS	0.2	1.2	5:18	461.7K	
Silicium	MC	—	—	0:00	29.8K	
	CR	0.3	1.2	1:30	192.1K	
	CR	0.5	1.33	0:58	92.1K	
Engine	MC	—	—	0:09	592.1K	
	BS	0.3	1.2	12:16	304.4K	
Skull	MC	—	—	0:06	393.2K	
	CR	0.5	1.2	5:50	259.2K