ALICE

Bruno Lévy

INSTITUT NATIONAL
DE RECHERCHE
EN INFORMATIQUE
ET EN AUTOMATIQUE
INRIA

Evaluation seminar, October 21, 22

Theme:Interaction and Visualization

Overview

- **Introduction**
  - Overall objectives
  - Composition of the team
- **Zoom on Geometry Processing**
  - Fitting and Parameterization
  - Sampling and Meshing
- **Impact**
- **Evolution and Future Work**

Introduction
Overall objectives - geometry and light

Light

Introduction
Overall objectives - geometry and light

Light

- Realistic rendering
- Interative rendering
- Scientific visualization

Light

Introduction

Overall objectives - geometry and light

Geometry

Light

Introduction

Overall objectives - geometry and light

Geometry

Geometry

- Optimizing…
- Transforming…
- Constructing…

…representations

Composition of the team

May 2006 (creation):

4 permanent researchers

Composition of the team

May 2006 (creation):

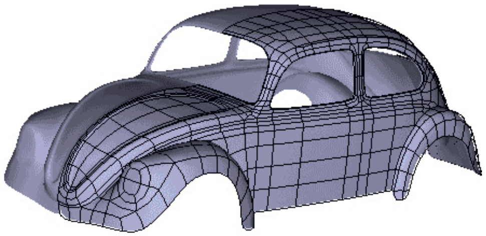
4 permanent researchers

October 2010:

7 permanent researchers

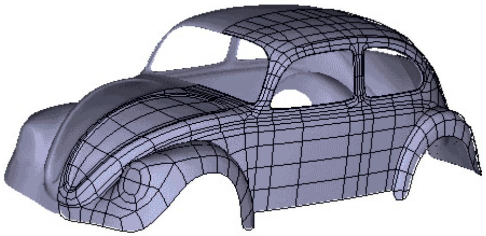
1 visiting associate professor

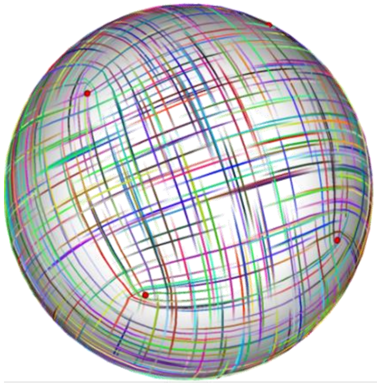
Zoom on Geometry Processing
Overview



1. Intro
Dynamic Function Basis

Zoom on Geometry Processing
Overview

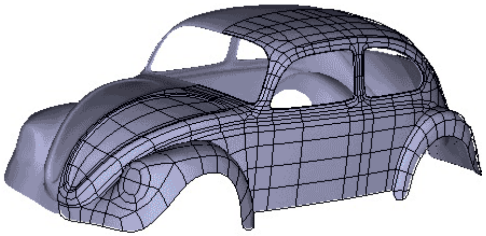




1. Intro
Dynamic Function Basis

2. Direction Fields

Zoom on Geometry Processing
Overview



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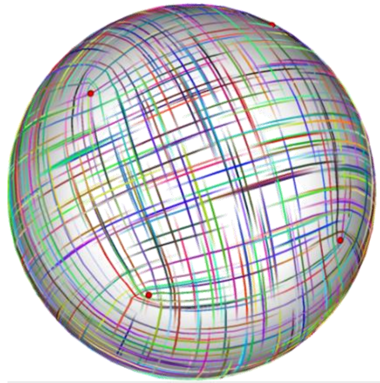
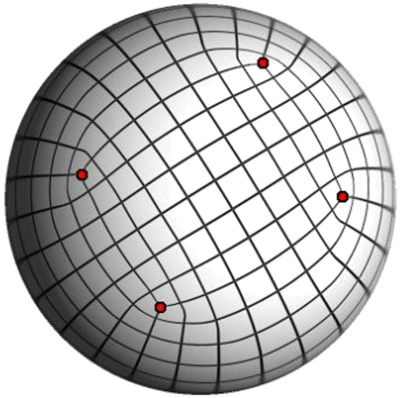
Dynamic Function Basis

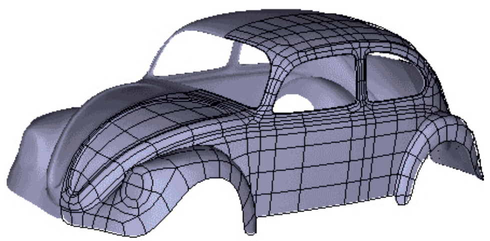


2. Direction Fields



3. Global Parameterization

Zoom on Geometry Processing
Overview



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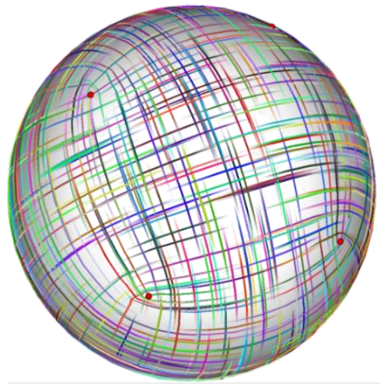
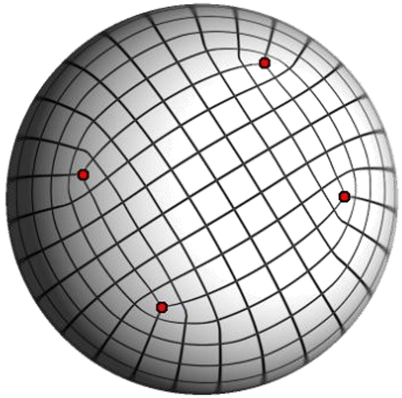
Dynamic Function Basis



2. Direction Fields



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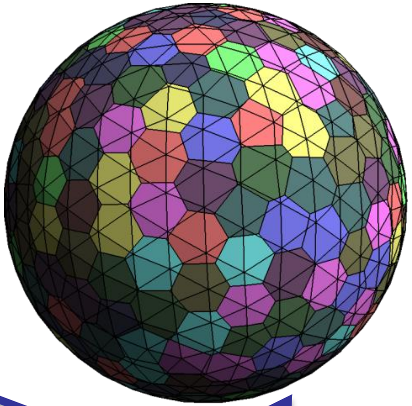
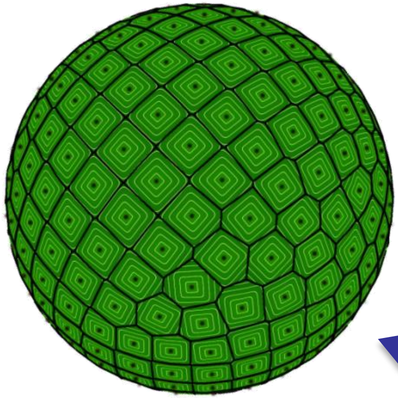
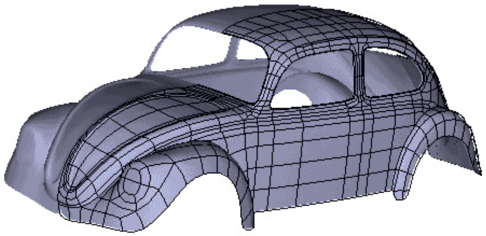




4. Optimal Sampling (L_p and L_2)

Zoom on Geometry Processing
Overview



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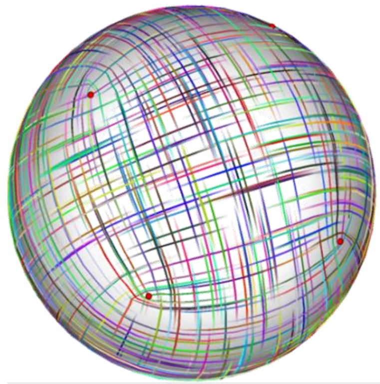
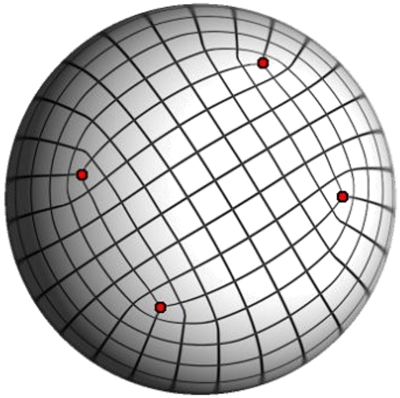
Dynamic Function Basis



2. Direction Fields



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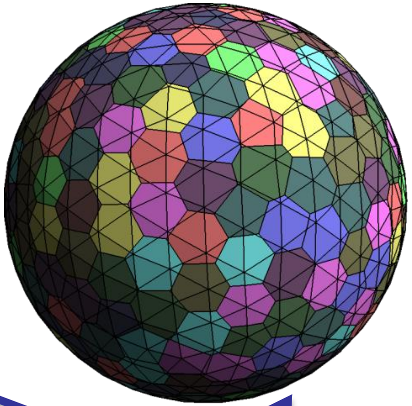

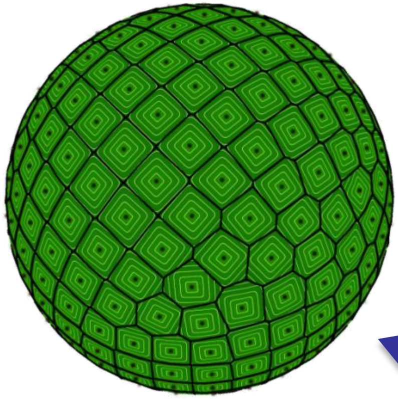

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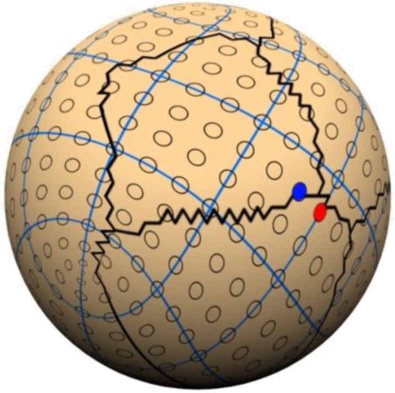
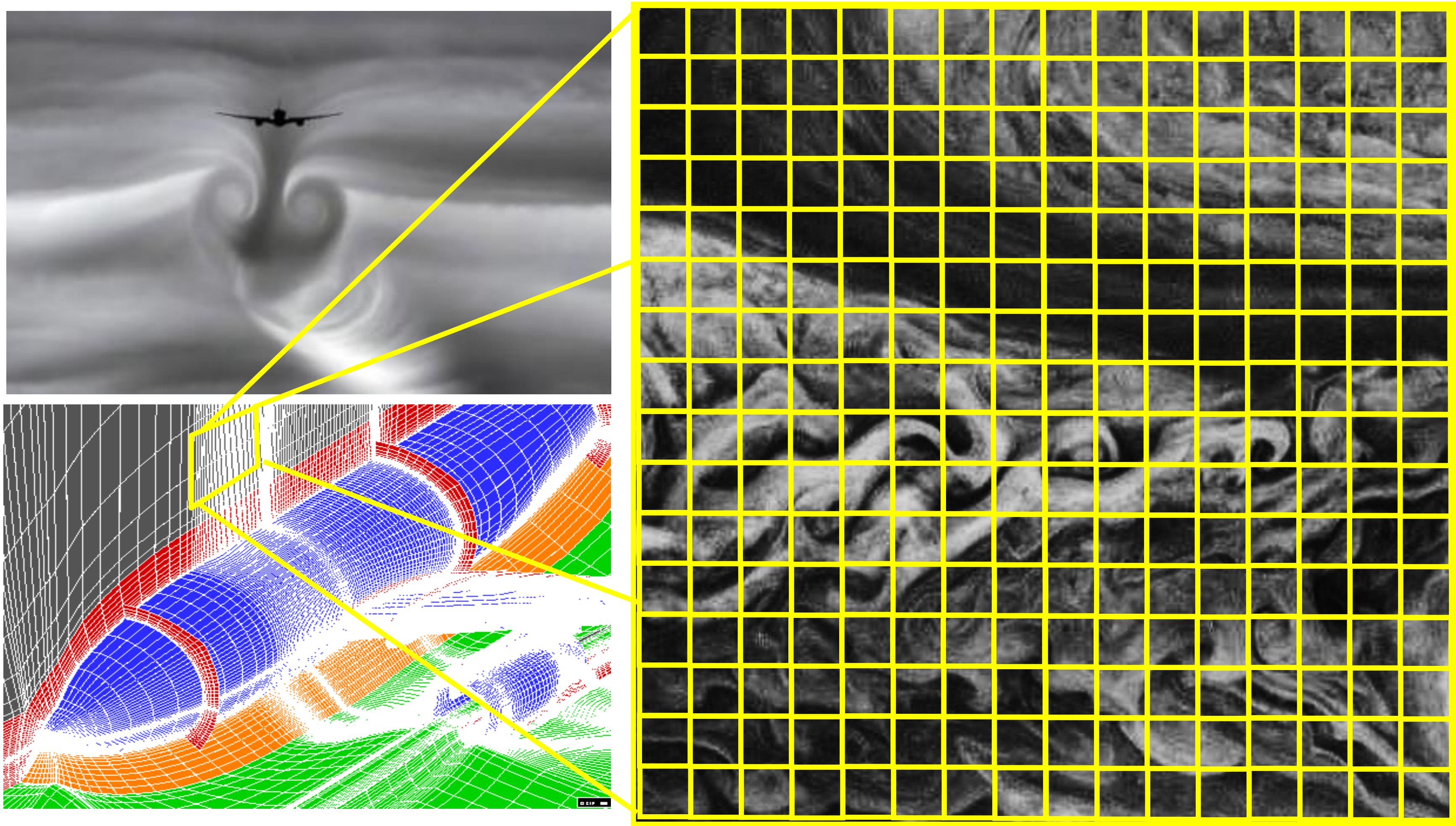
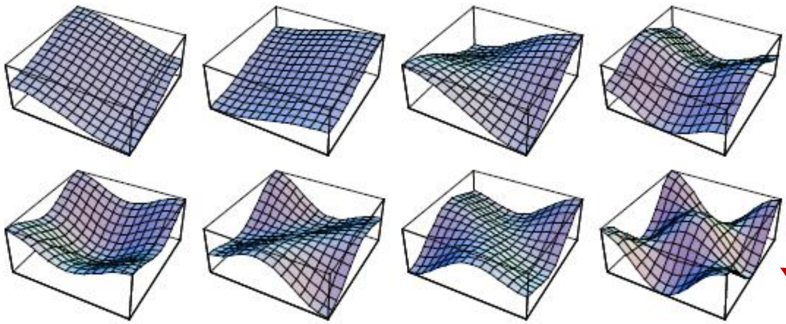


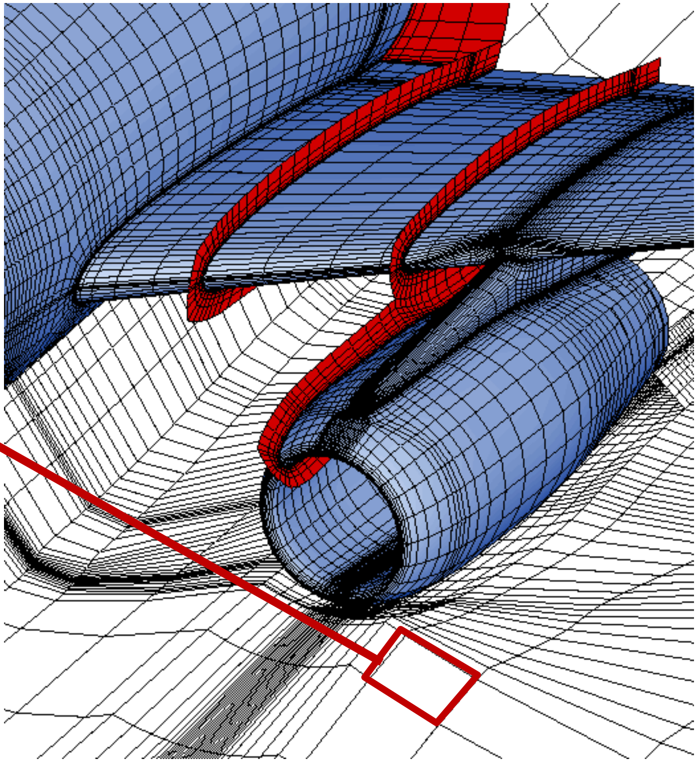
5. Seamless Texturing

Zoom on Geometry Processing
1. Dynamic Function Basis – classical FEM



Zoom on Geometry Processing
1. Dynamic Function Basis – classical FEM





- Function basis (ϕ_i): $f = \Sigma \alpha_i \phi_i$
- Operator equation: $Lf = g$
- Hilbert space, Inner Product: $\langle f,g \rangle = \int f(x)\, g(x)\, dx$
- $\forall i$, $\langle Lf, \phi_i \rangle = \langle g, \phi_i \rangle$

Zoom on Geometry Processing

1. Dynamic Function Basis – New framework

$$f = \sum \alpha_i \, \phi_i(p_1, p_2, \ldots, p_m, x, y)$$

$$= \sum \alpha_i \, \phi_i(\mathbf{p}, \mathbf{x})$$

Zoom on Geometry Processing

1. Dynamic Function Basis – New framework

$$f = \sum \alpha_i \, \phi_i(p_1, p_2, \ldots, p_m, x, y)$$

$$= \sum \alpha_i \, \phi_i(\mathbf{p}, \mathbf{x})$$

Galerkin: $\forall i$, $\langle Lf, \phi_i \rangle = \langle g, \phi_i \rangle$

Zoom on Geometry Processing

1. Dynamic Function Basis – New framework

$$f = \sum \alpha_i \, \phi_i(p_1, p_2, \ldots, p_m, x, y)$$

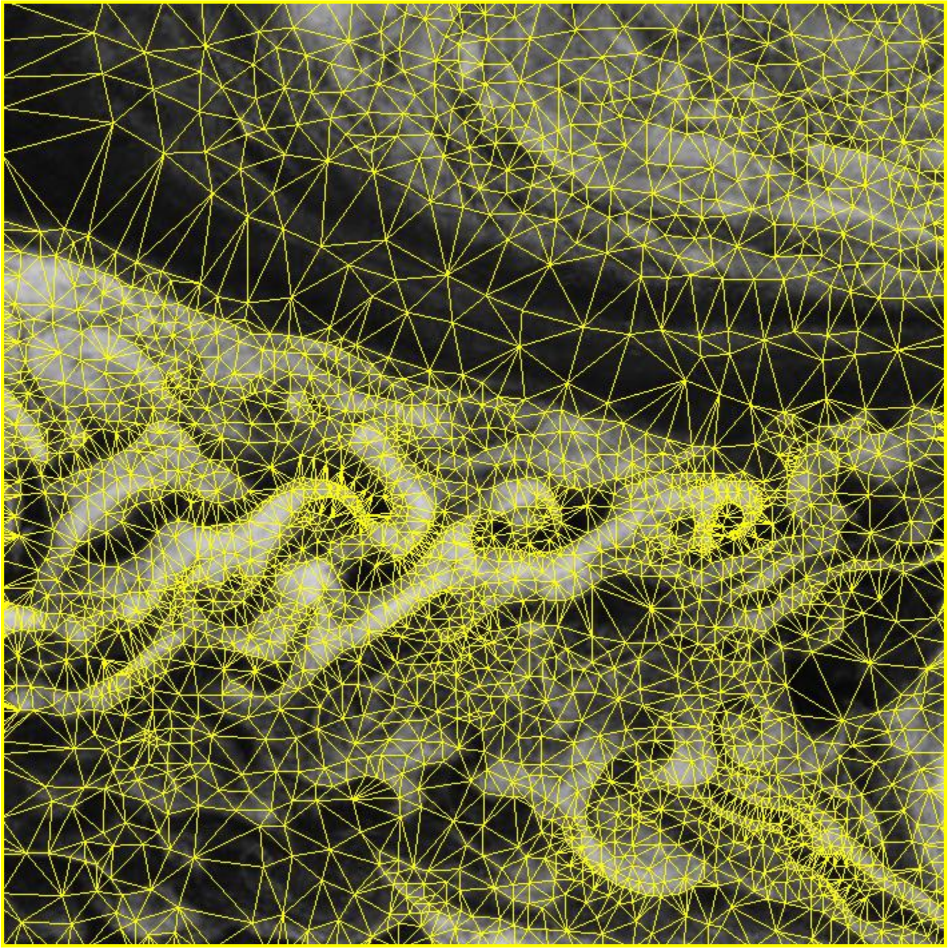
$$= \sum \alpha_i \, \phi_i(\mathbf{p}, \mathbf{x})$$

Galerkin: $\forall i, \langle Lf, \phi_i \rangle = \langle g, \phi_i \rangle$

DFB: minimize $F(p,\alpha) = |Lf - g|^2 = \left| \sum \alpha_i \, \phi_i(\mathbf{p}, \mathbf{x}) - g \right|^2$

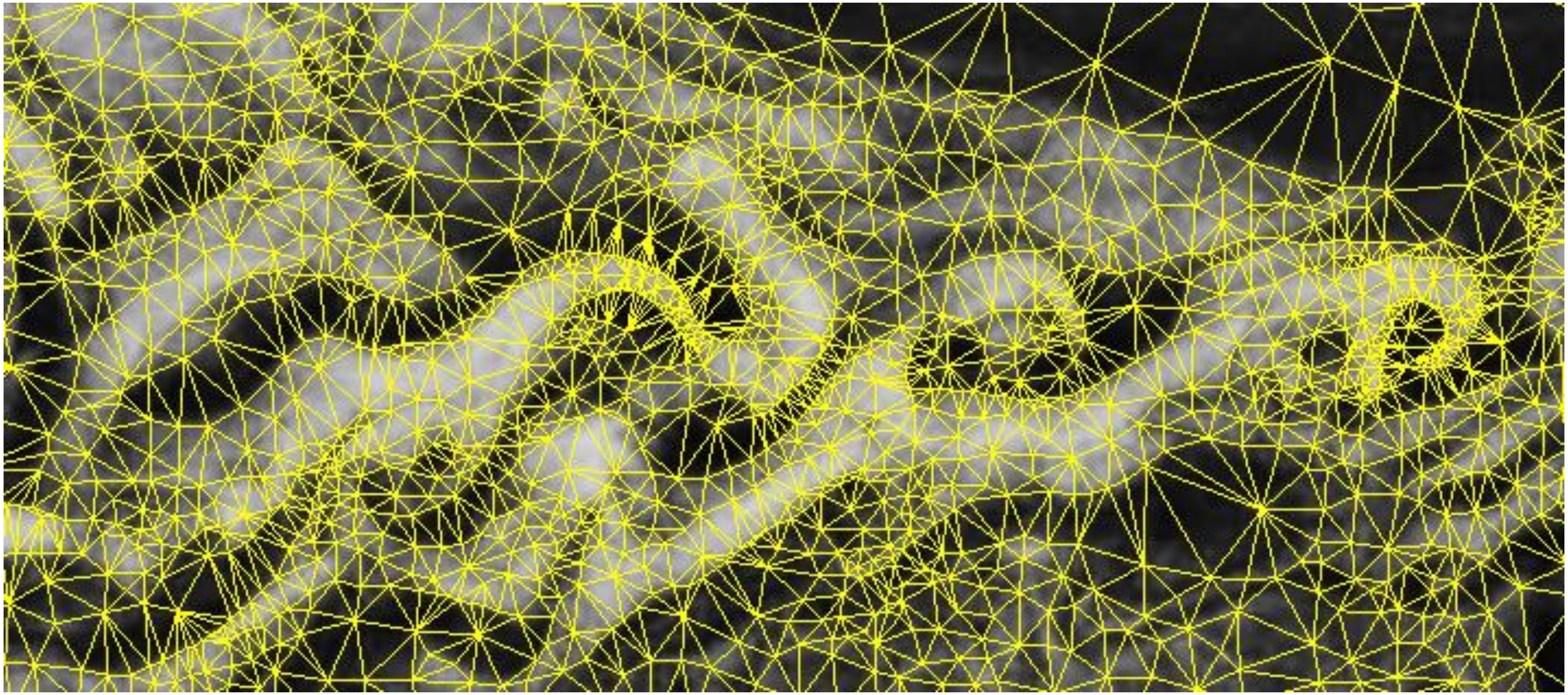
Solve for f [α] and for its sampling [p]

Zoom on Geometry Processing
1. Dynamic Function Basis – Expected result



Our new framework:
Dynamic Function Basis
(DFB)

Zoom on Geometry Processing
1. Dynamic Function Basis – Expected result



Our new framework: Dynamic Function Basis
Solve for ***approximation*** and ***sampling*** all together

Zoom on Geometry Processing
Dynamic Function Basis – Research Program

Geometric Intelligence
Microsoft Research

GOODSHAPE
European Research Council
1.1 Meuros, 5 years
0.3% acceptance
all disciplines of science

- 2D, L = Id : image approximation **[EGSR 2006]**
- 3D, L = Id : surface approximation **2006-2010**
- 3D, optimal sampling **2006-2010**
- 3D, L = light transport **2010-…**
- 3D+t, Navier Stokes **2010-…**

$$Lf = g$$

Zoom on Geometry Processing

Dynamic Function Basis – Research Program

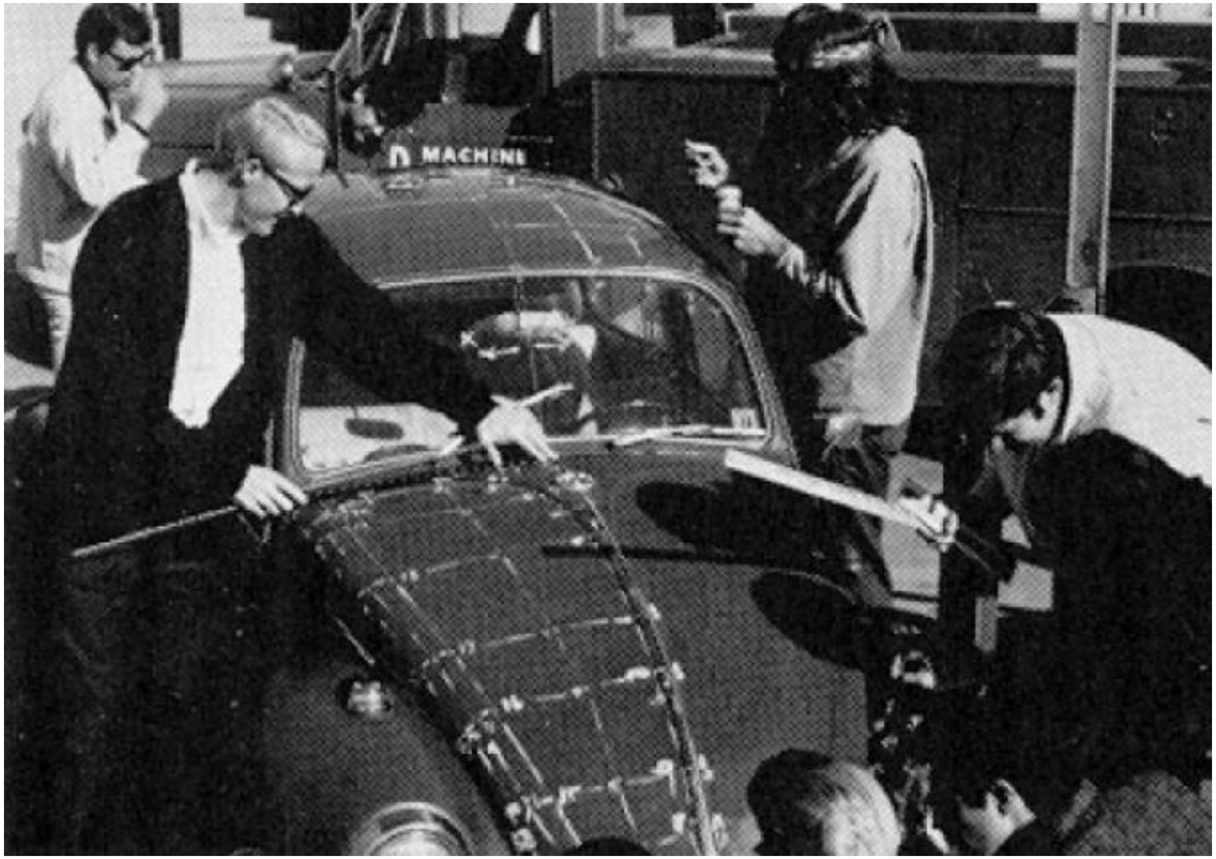
- 2D, L = Id : image approximation **[EGSR 2006]**
- 3D, L = Id : surface approximation **2006-2010**
- 3D, optimal sampling **2006-2010**
- 3D, L = light transport **2010-…**
- 3D+t, Navier Stokes, tracking **2010-…**

$$f = g$$

Zoom on Geometry Processing

1. Surface approximation – the challenge

Creating a CAD model from a real car ...



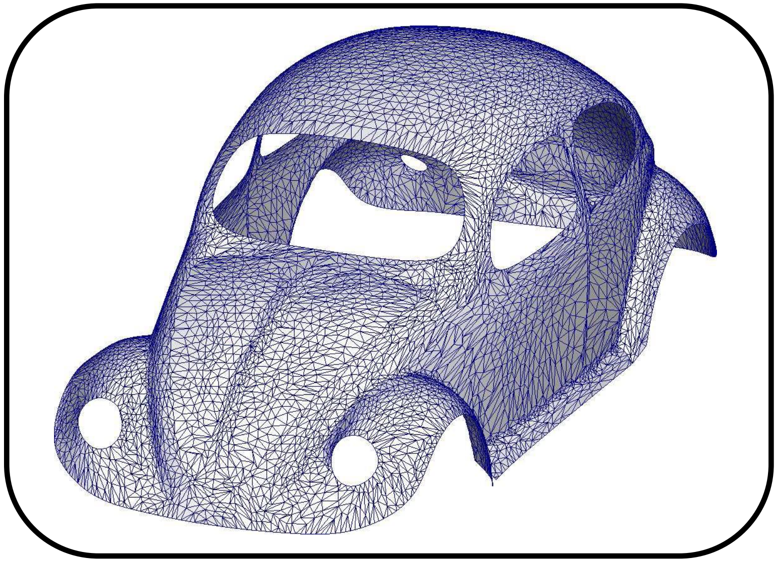
1970's: purely manual acquisition (Y. Sutherland)

Zoom on Geometry Processing

1. Surface approximation – the challenge

Creating a CAD/CAM model of a car

3D laser scanner

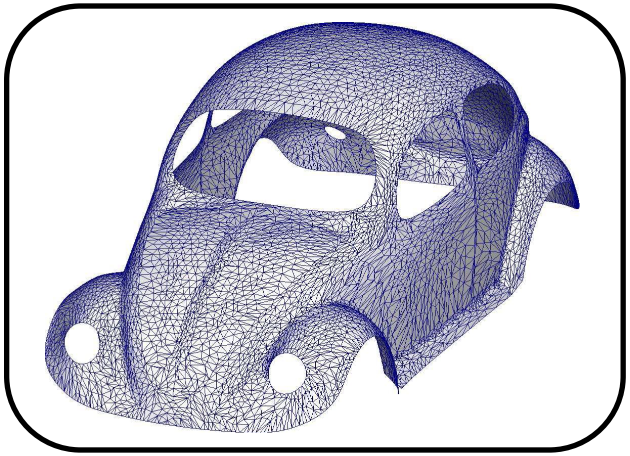


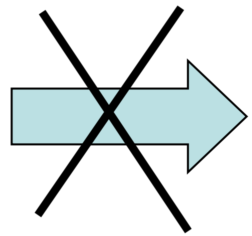
Reconstructed shape

1 million vertices, 2 million triangles:
Cannot be used in CAD/CAM software

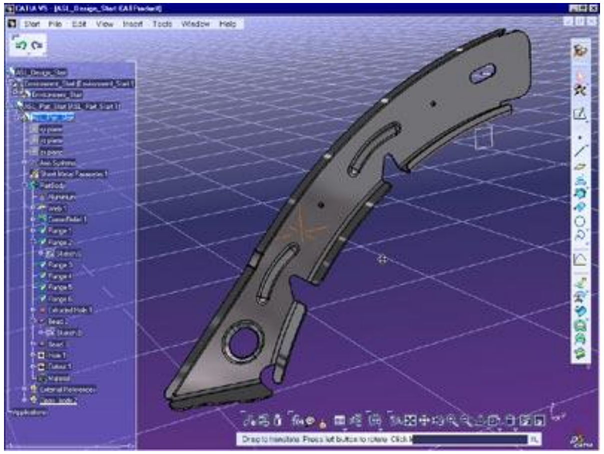
Zoom on Geometry Processing
1. Surface approximation – the challenge

output of the scanner





CAD/CAM software



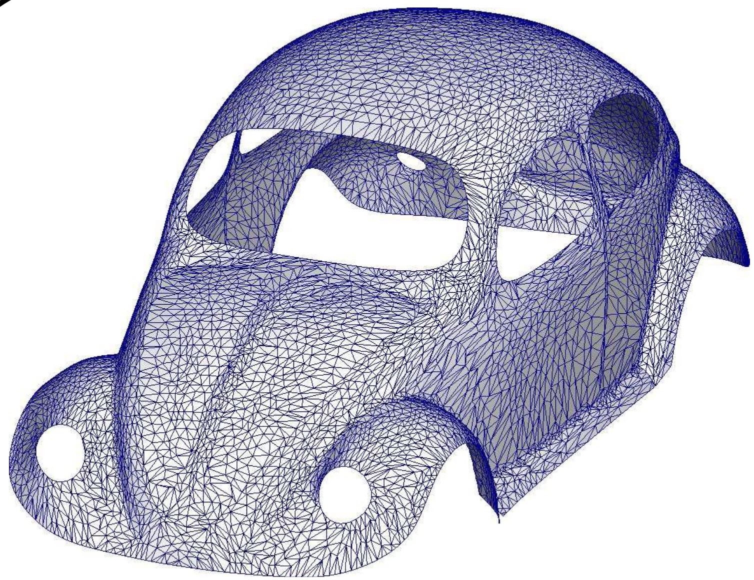
Wrong **representation**,
CAD/CAM needs **equations** instead of **samples**

Q: How can we "find the equation" of this car ?

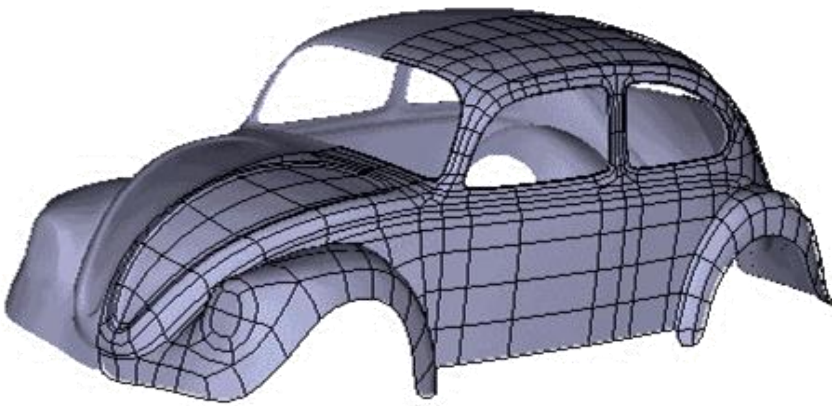
Zoom on Geometry Processing

1. Surface approximation – the challenge

output of the scanner



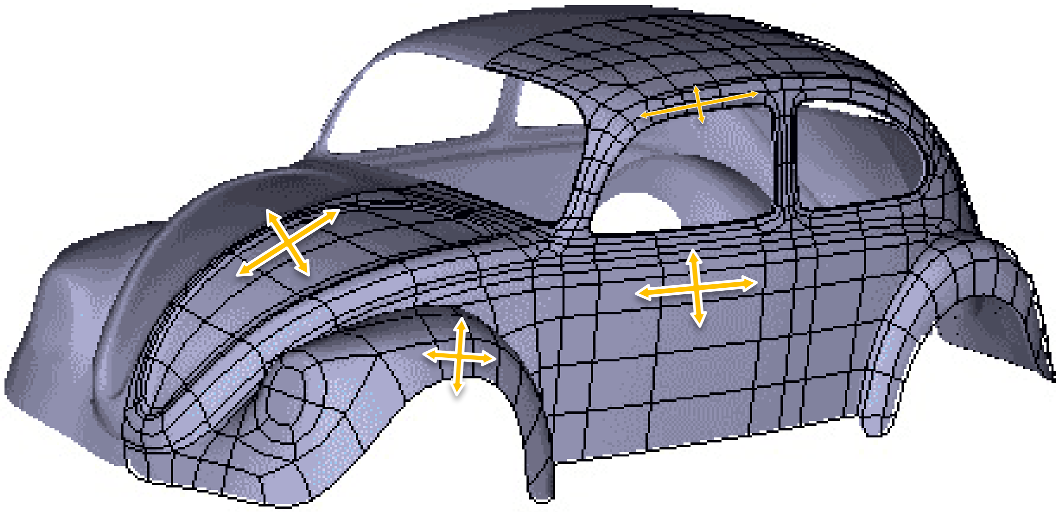
CAD/CAM representation



1 million points → 100 Splines (cubic equations)

Q: How can we "find the equation" of this car ?

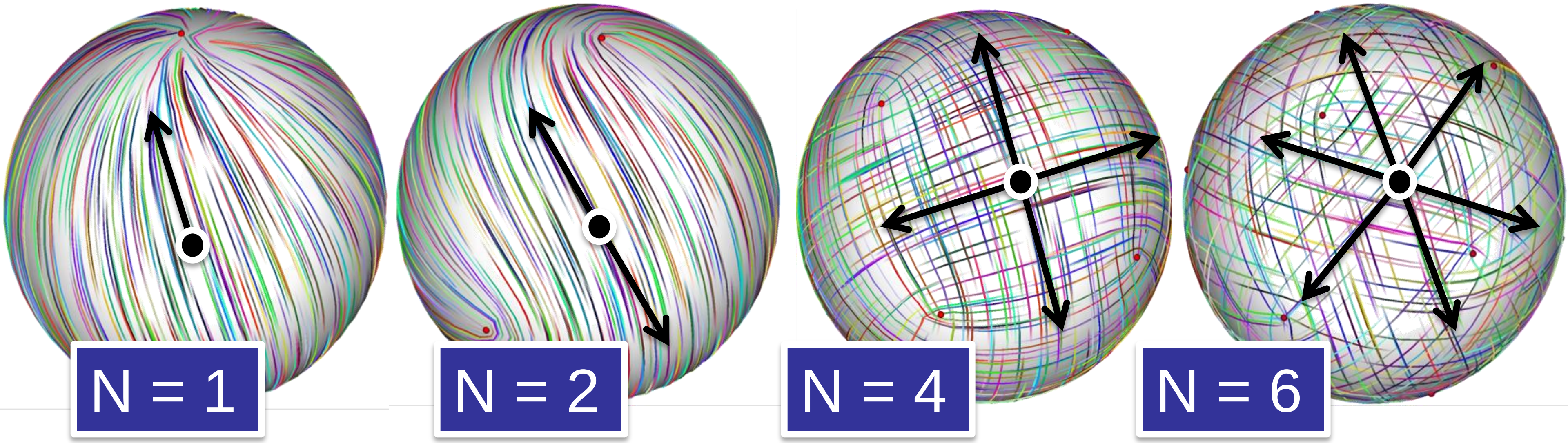
Zoom on Geometry Processing
2. Anisotropy and direction field design



Q: How can we control the orientation/shape/size of the mesh/basis elements ?

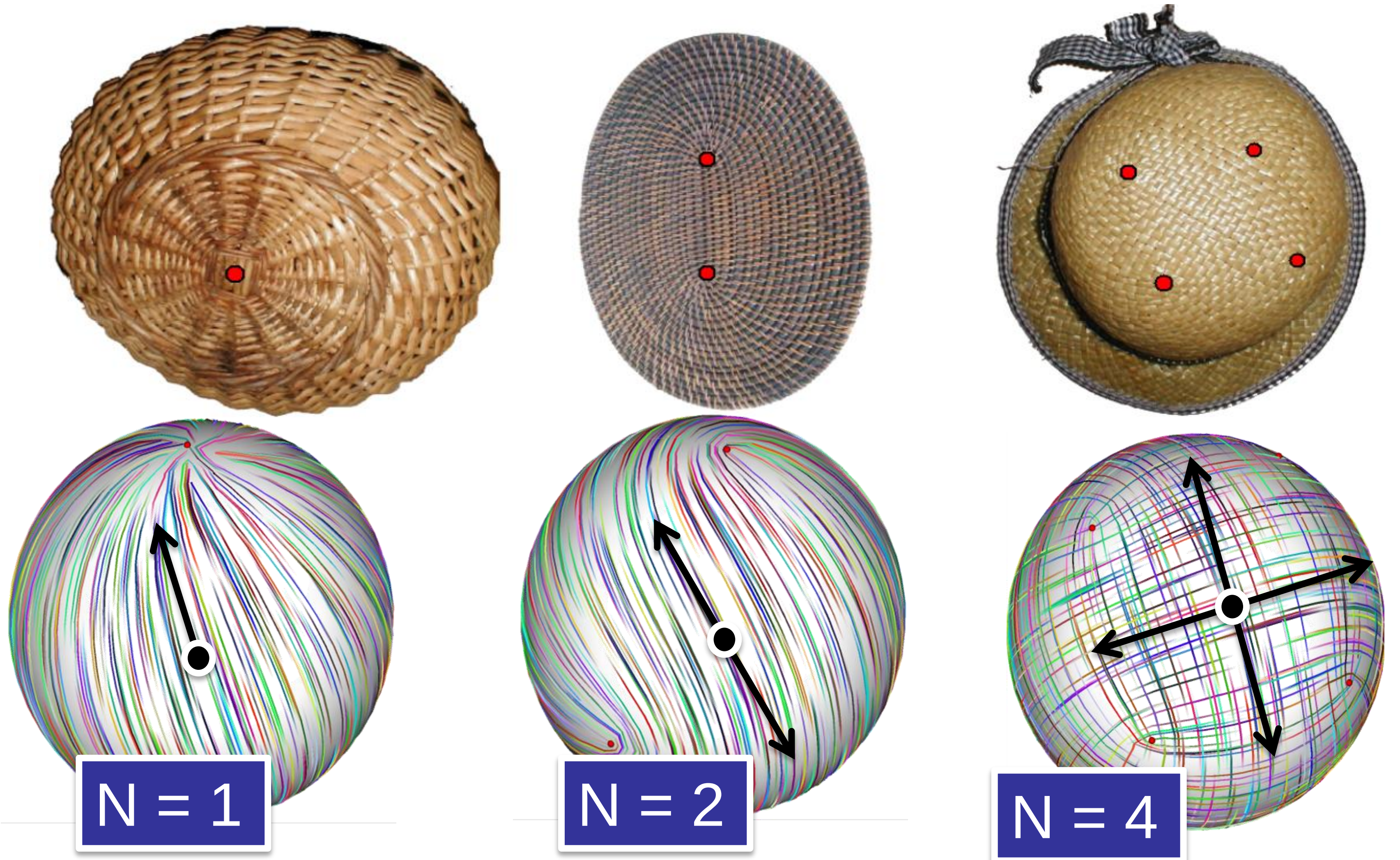
Zoom on Geometry Processing
2. Anisotropy and direction field design

- A **N-symmetry direction field** is, for each point of a surface, a set of N unit vectors of the tangent plane that is invariant by rotation of $2\pi/N$.



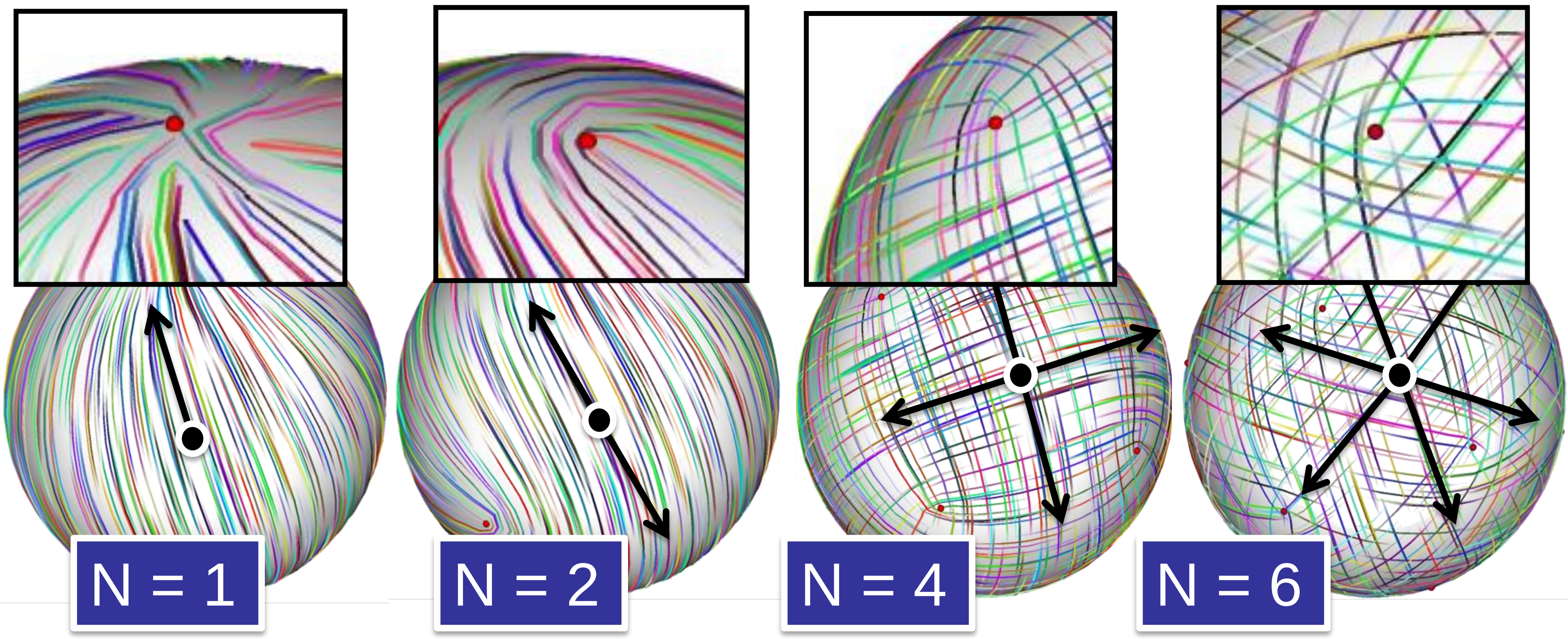
Zoom on Geometry Processing

2. Anisotropy and direction field design



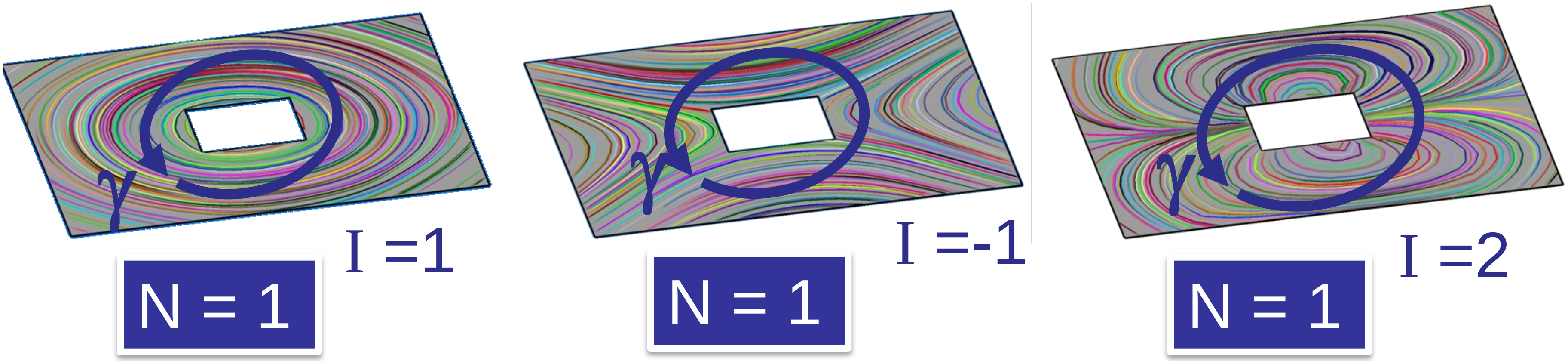
Zoom on Geometry Processing
2. Anisotropy and direction field design

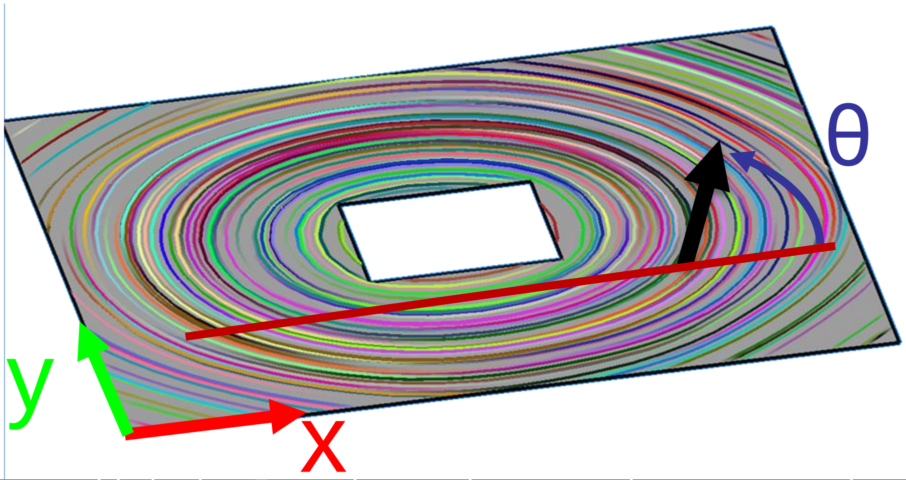
- **Singularities** generalize poles (and saddles) of vector fields.



Zoom on Geometry Processing

2. Anisotropy and direction field design



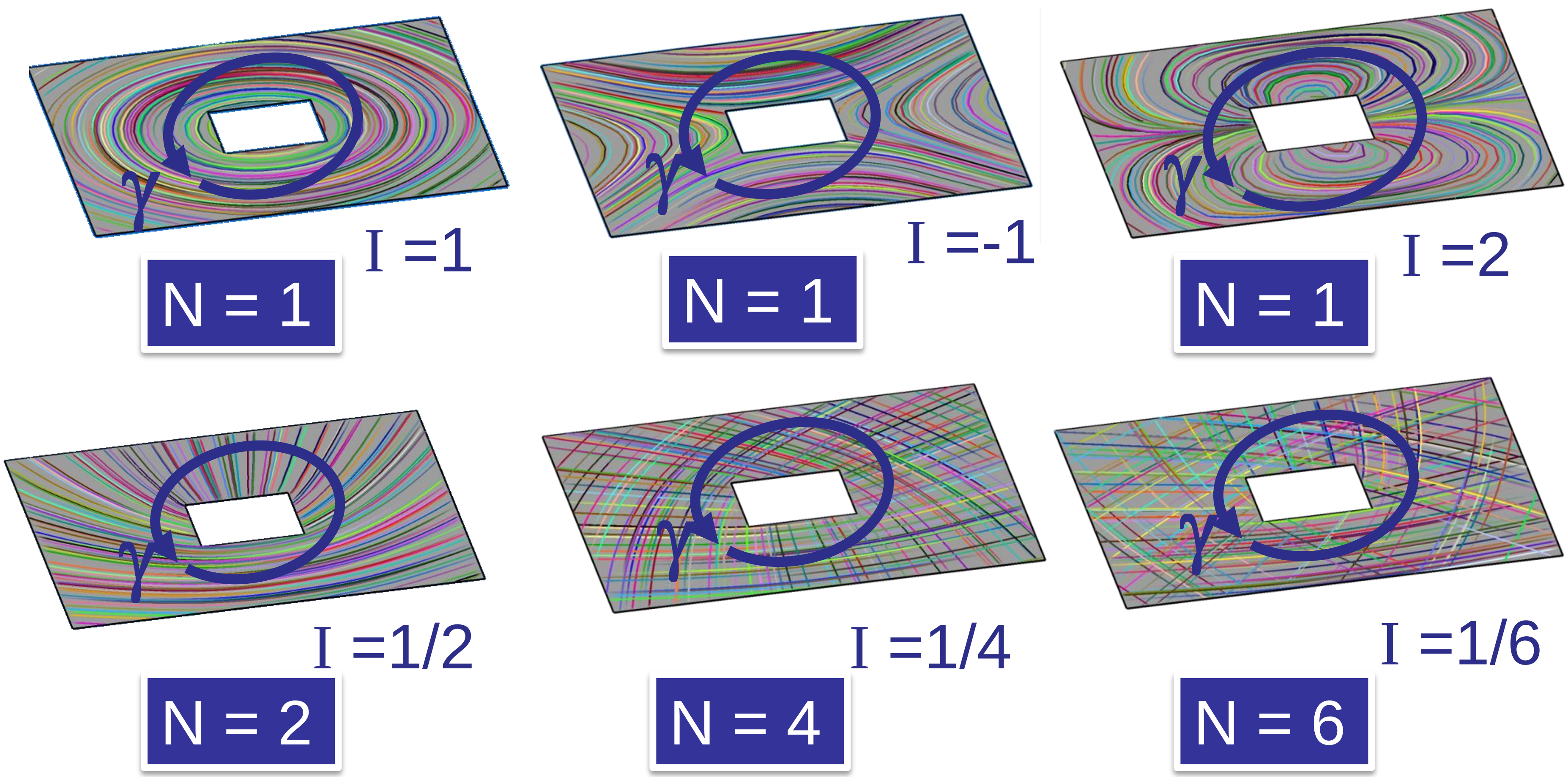


Index of a singularity

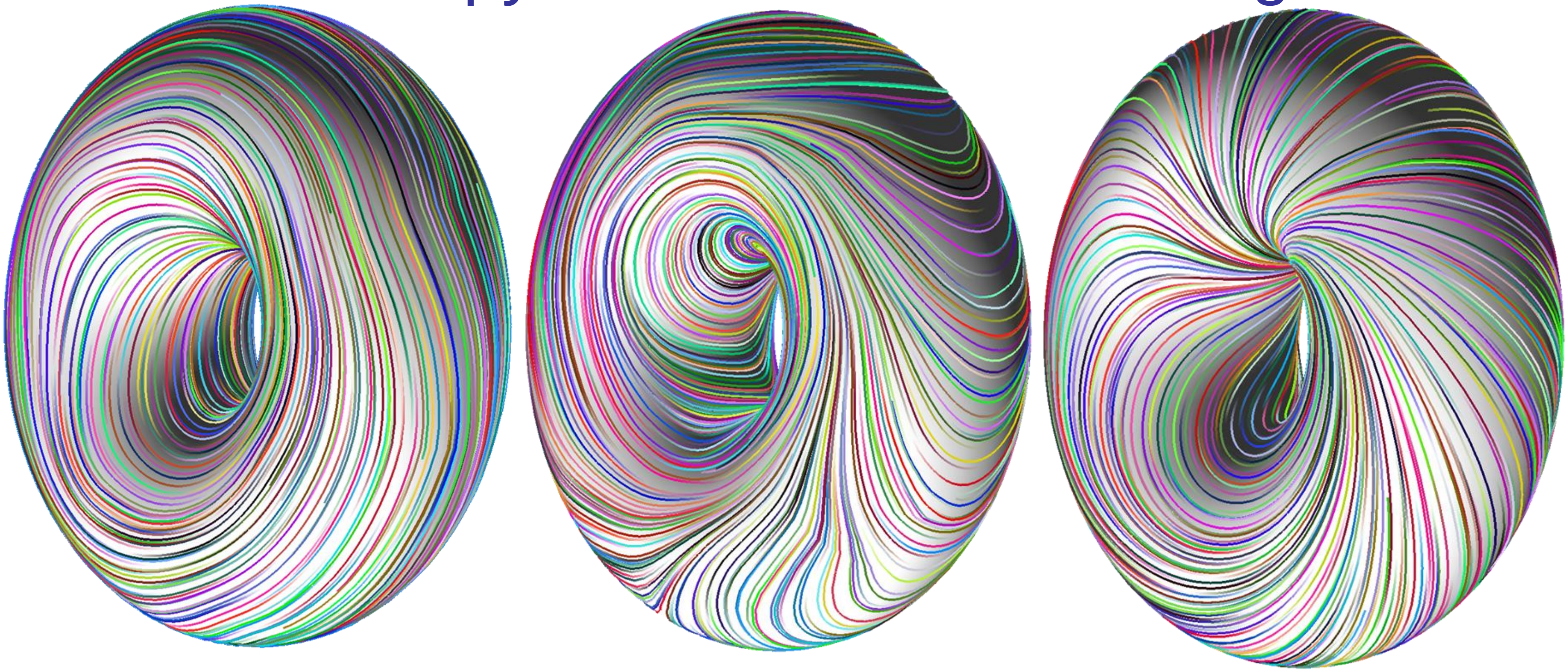
$$I = \int_\gamma d\theta / 2\pi$$

Zoom on Geometry Processing

2. Anisotropy and direction field design



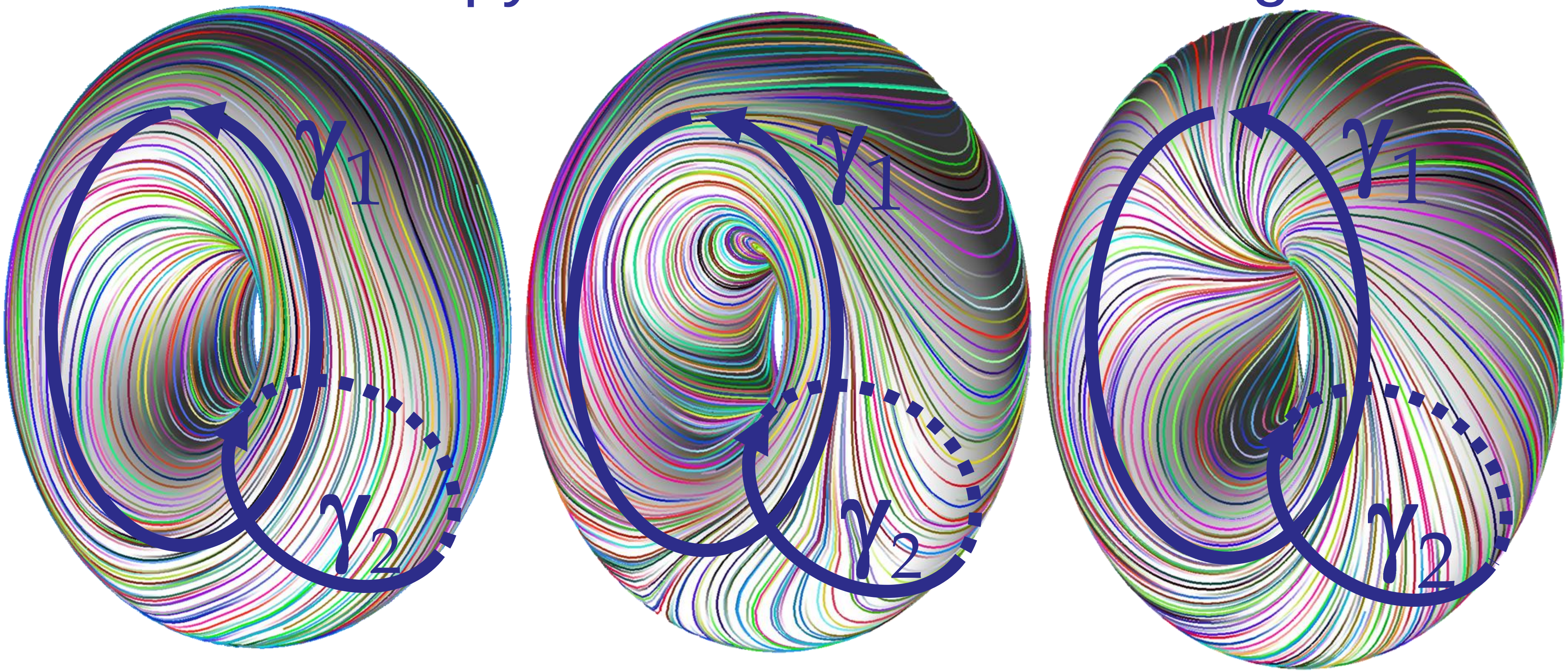
Zoom on Geometry Processing
2. Anisotropy and direction field design



Arbitrary genus

Zoom on Geometry Processing

2. Anisotropy and direction field design



$T(\gamma_1) = 0; T(\gamma_2) = 0$ | $T(\gamma_1) = 0; T(\gamma_2) = -1$ | $T(\gamma_1) = -1/2; T(\gamma_2) = 0$

Arbitrary genus ⟶ additional degrees of freedom

Zoom on Geometry Processing
2. Anisotropy and direction field design

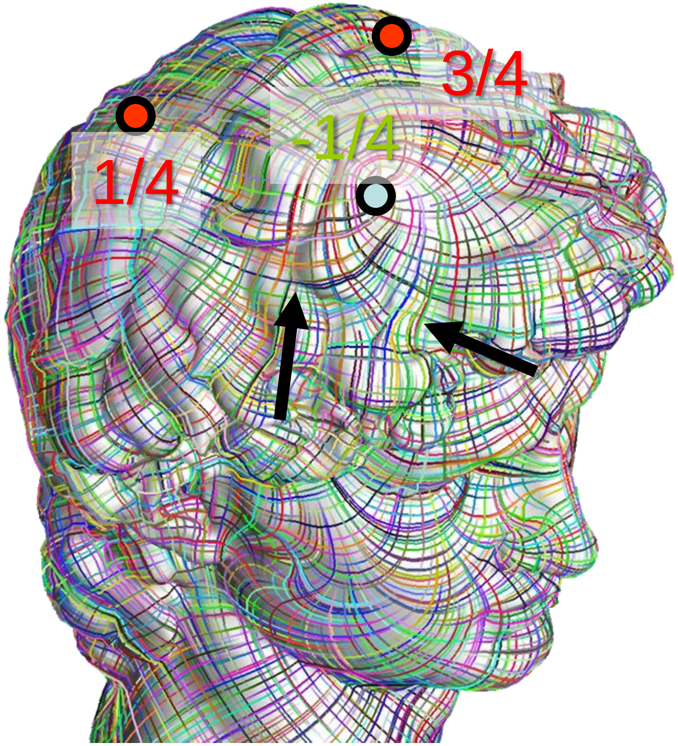
- Extension of the Poincaré-Hopf theorem to N-symmetry
- Discrete Index theory

[ACM TOG 2008]

$$\Sigma I = 2\text{-}2g$$

Index Genus

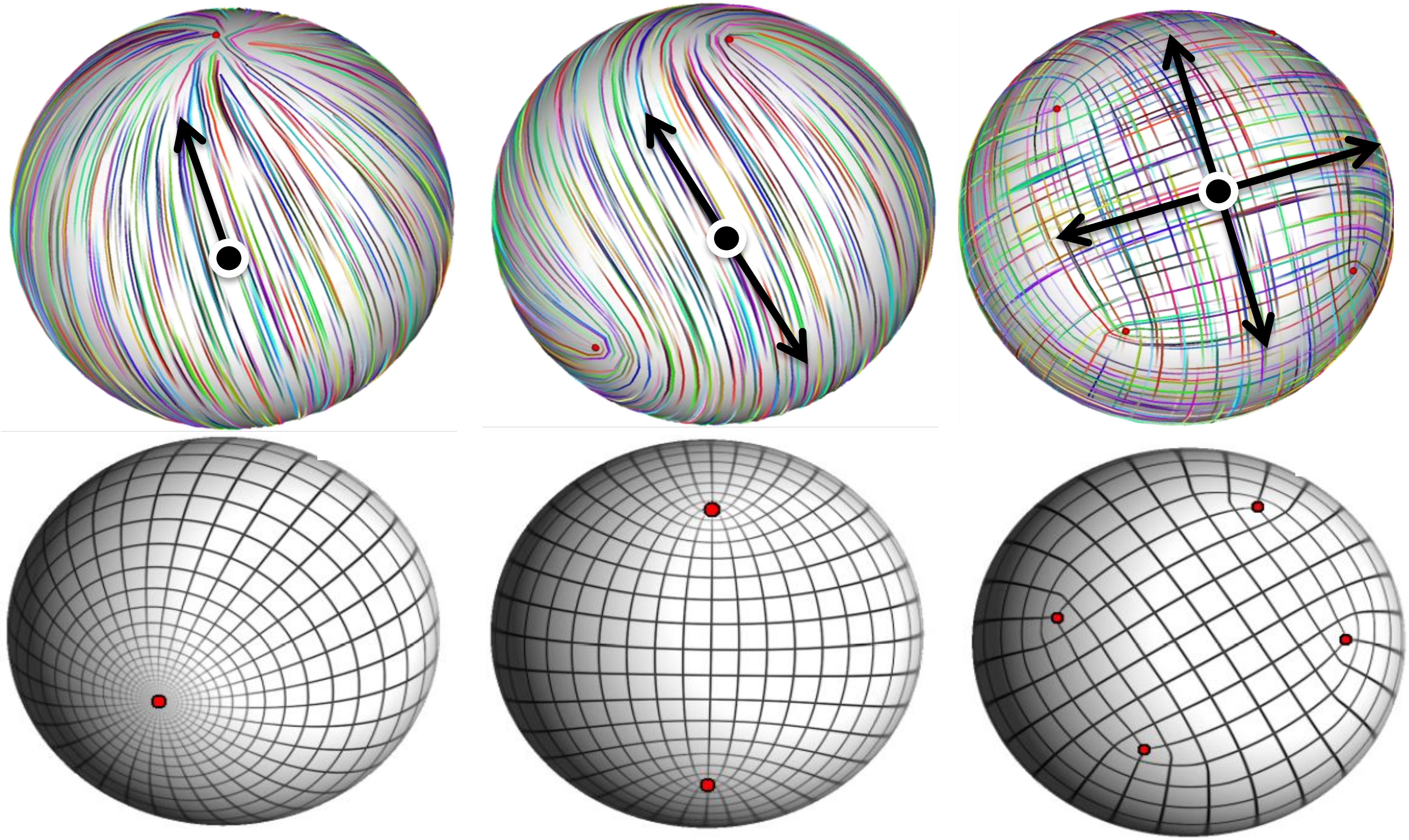
Design with full topology control



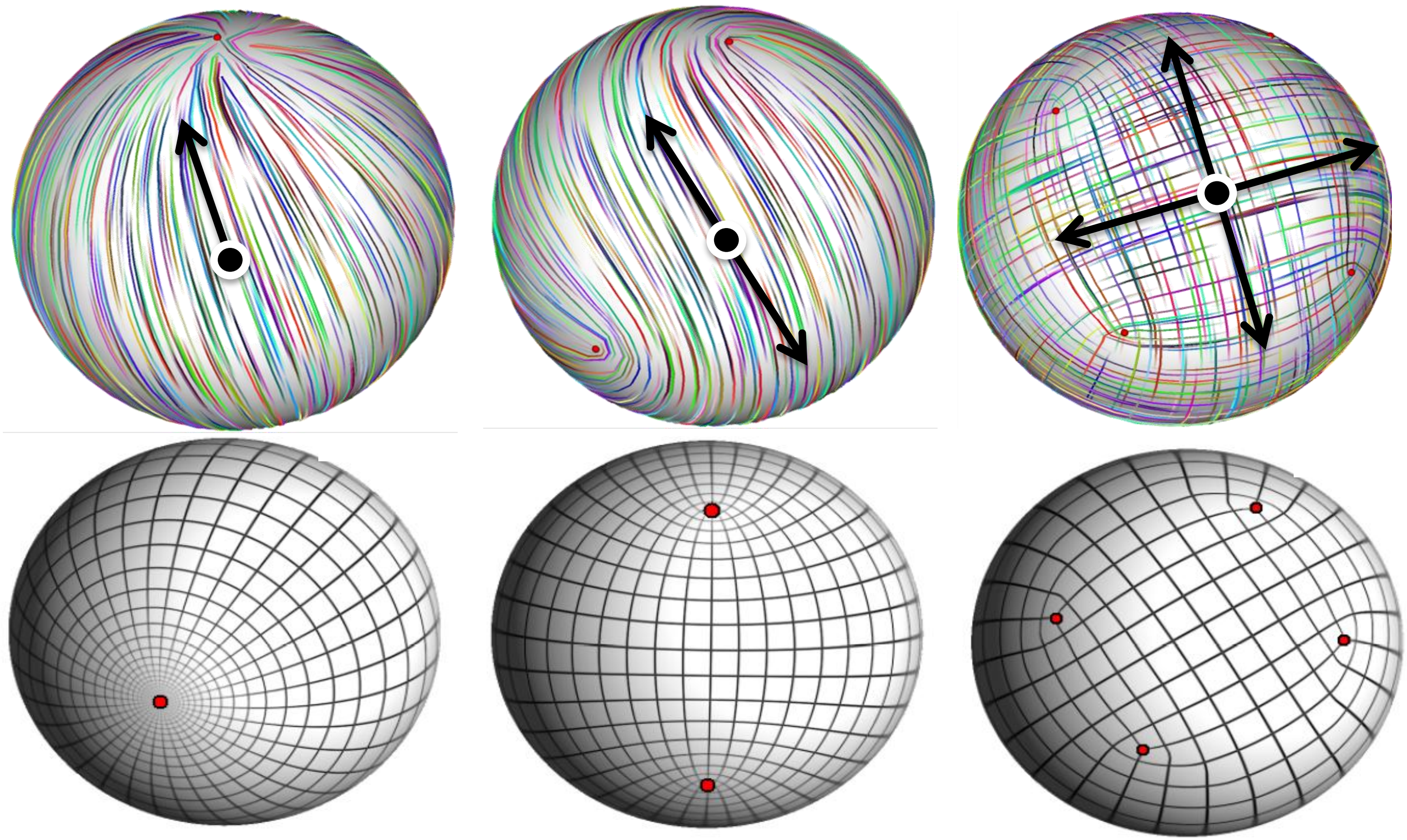
Controlled influence of geometry/topology **[ACM TOG 2009]**

Zoom on Geometry Processing

3. Global parameterization

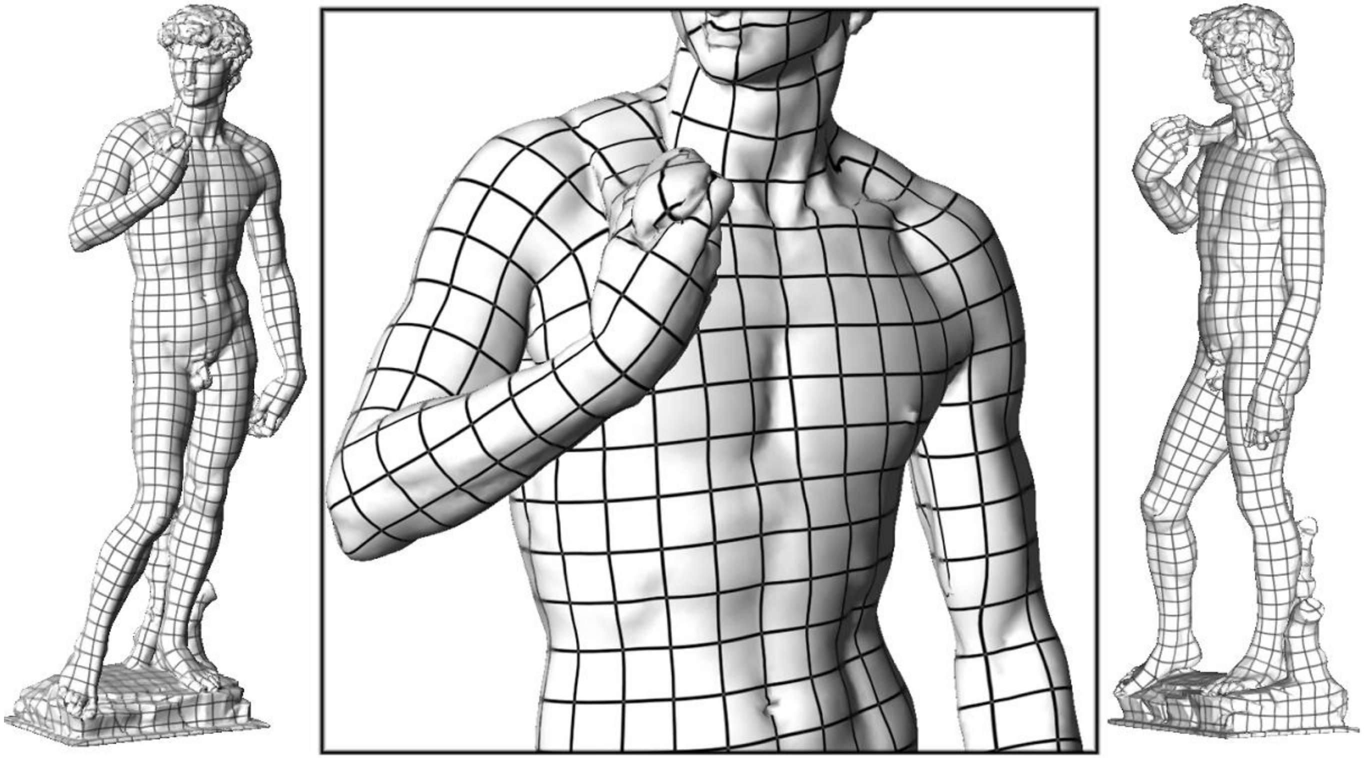


Zoom on Geometry Processing
3. Global parameterization



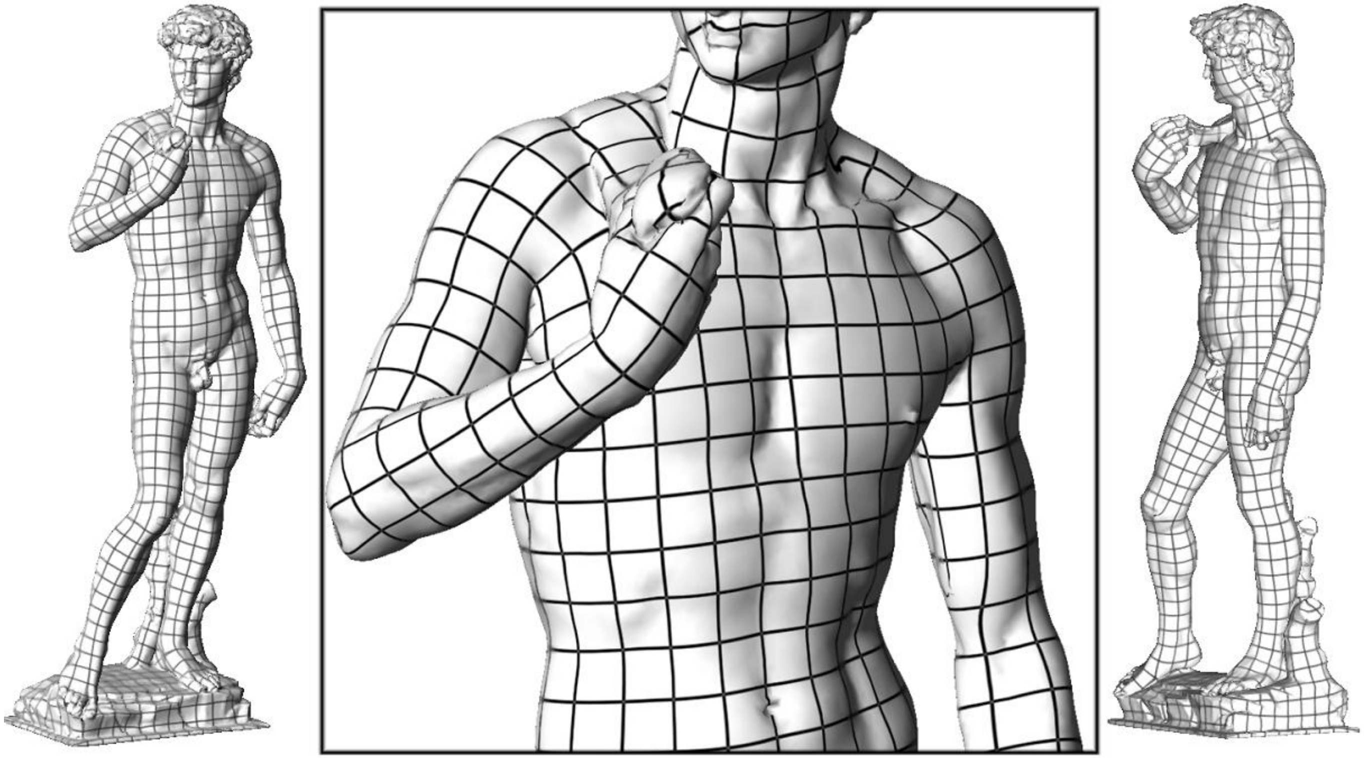
Q: How can we «integrate» a N-Symmetry direction field?

Zoom on Geometry Processing
3. Global parameterization



$$F^* = \sum_T \int_T \left(\|\nabla \theta^T - \omega \vec{K}_T\|^2 + \|\nabla \phi^T - \omega \vec{K}_T^{\perp}\|^2 \right) ds$$

Zoom on Geometry Processing
3. Global parameterization

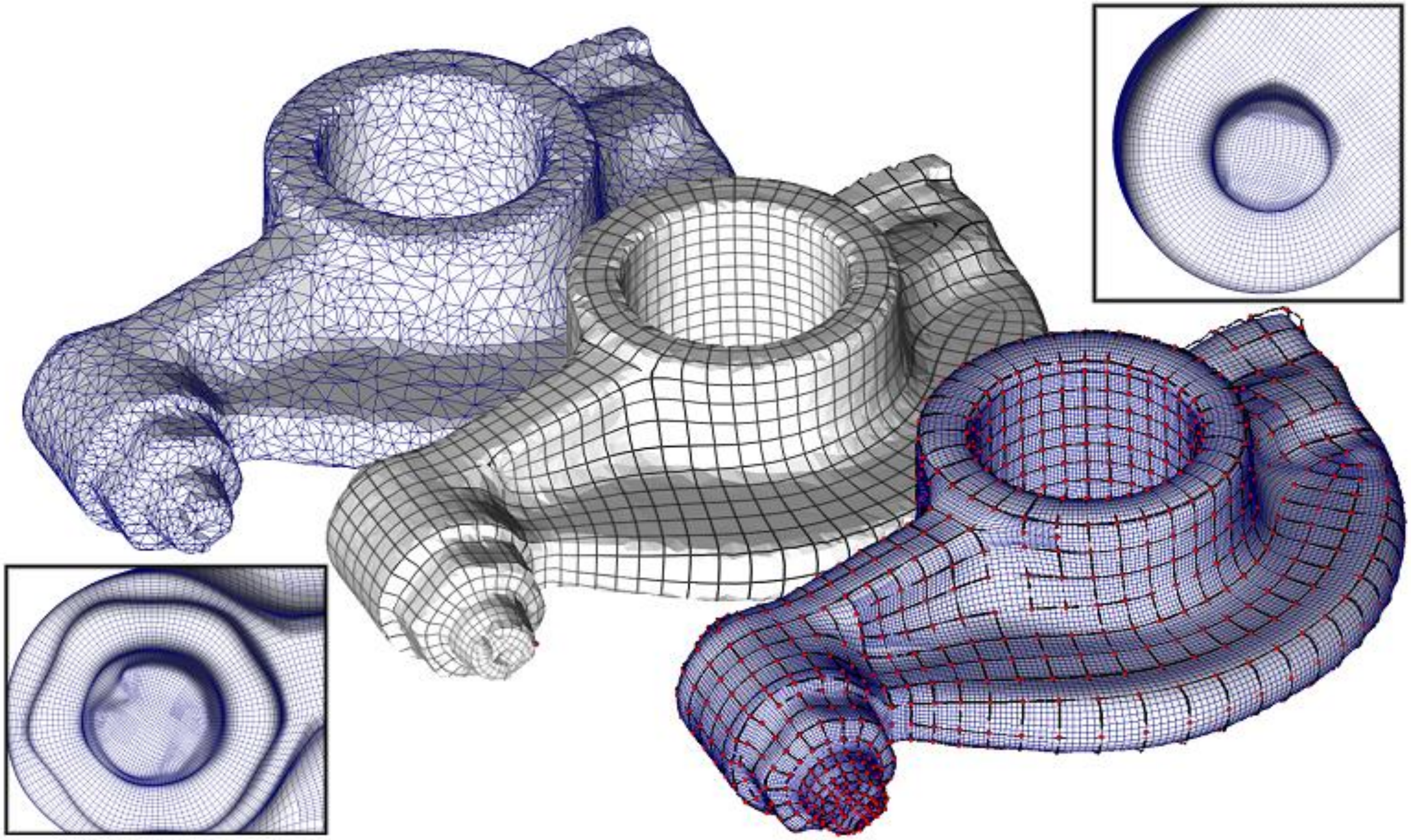


$$F^{\theta}_{T,i} \simeq \left\| U_{i\oplus 2} - \begin{pmatrix} \cos(\omega \vec{K}_i \cdot \vec{e}_i) & -\sin(\omega \vec{K}_i \cdot \vec{e}_i) \\ \sin(\omega \vec{K}_i \cdot \vec{e}_i) & \cos(\omega \vec{K}_i \cdot \vec{e}_i) \end{pmatrix} U_{i\oplus 1} \right\|^2$$

where:

$$U_i = (\cos\theta_i, \sin\theta_i)$$

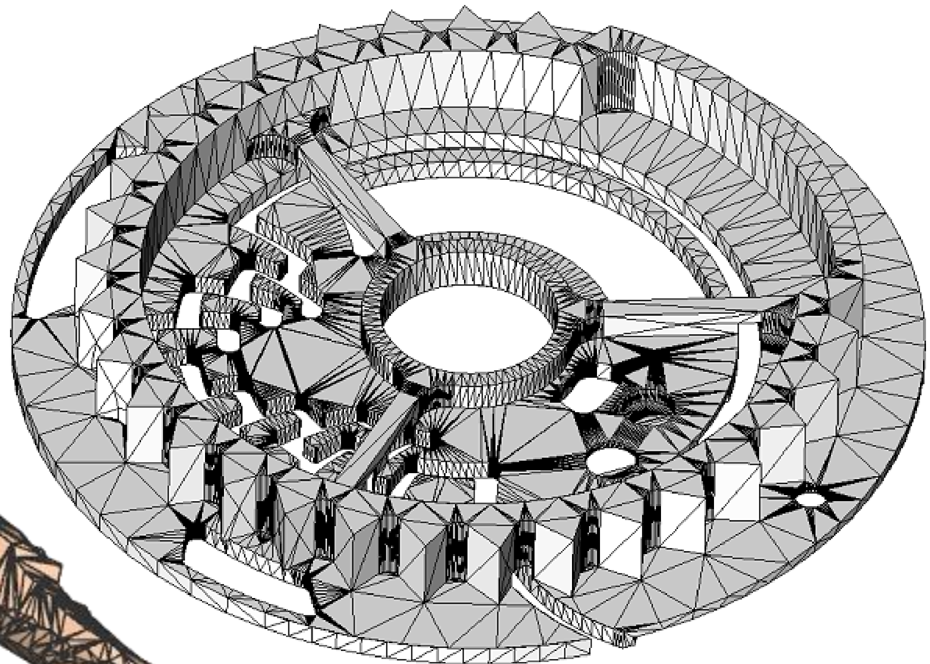
Zoom on Geometry Processing
3. Global parameterization



Zoom on Geometry Processing

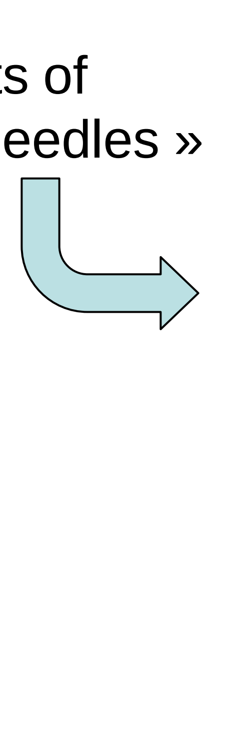
4. Optimal Sampling

Visual-hull



CAD mesh

Lots of
« needles »



Zoom on Geometry Processing

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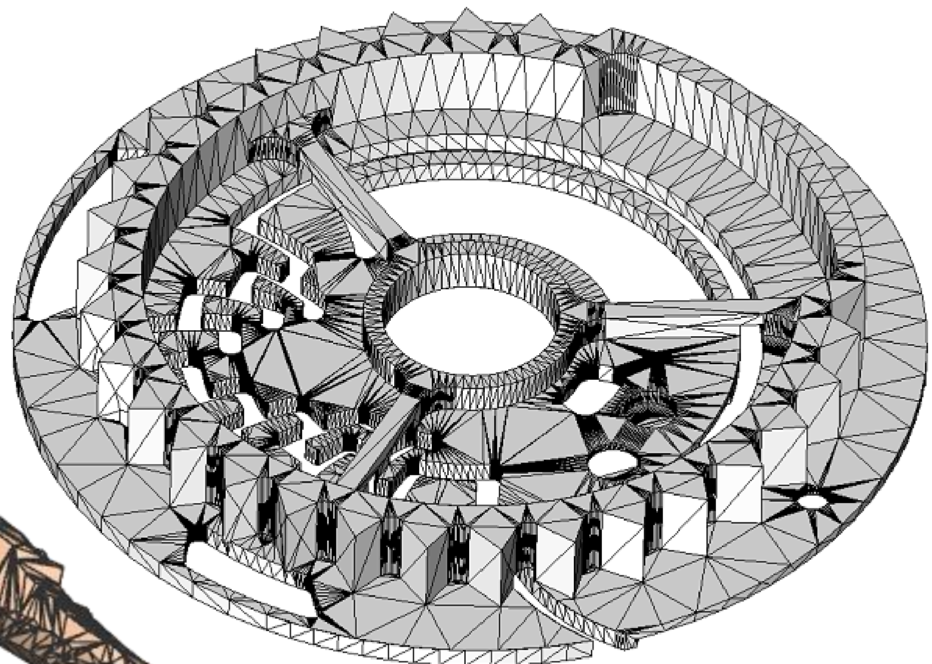

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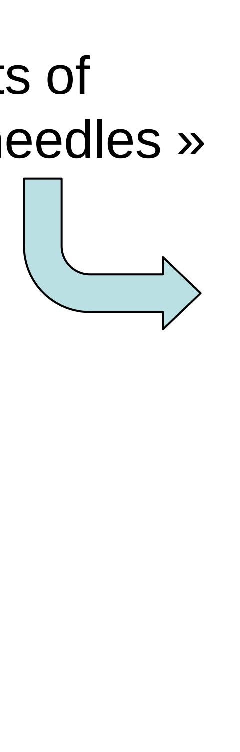
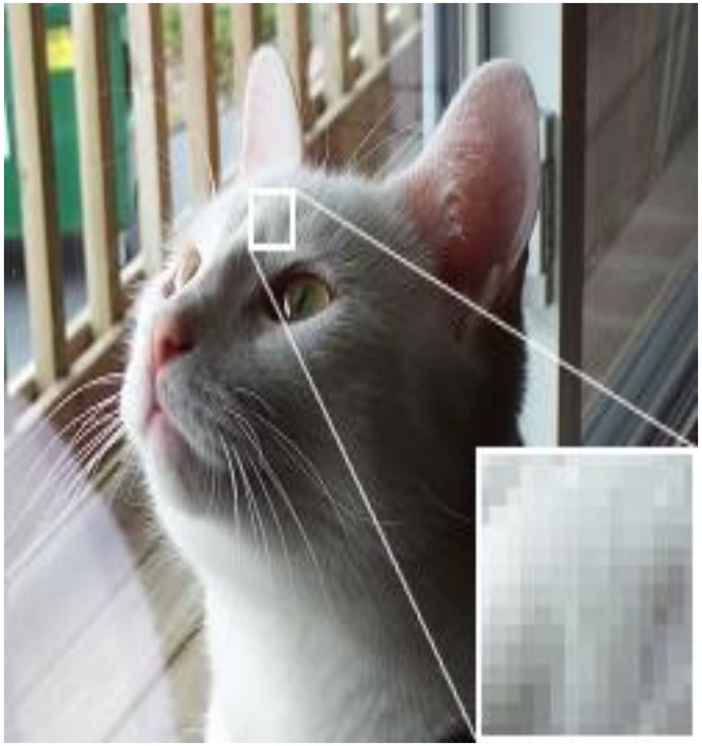
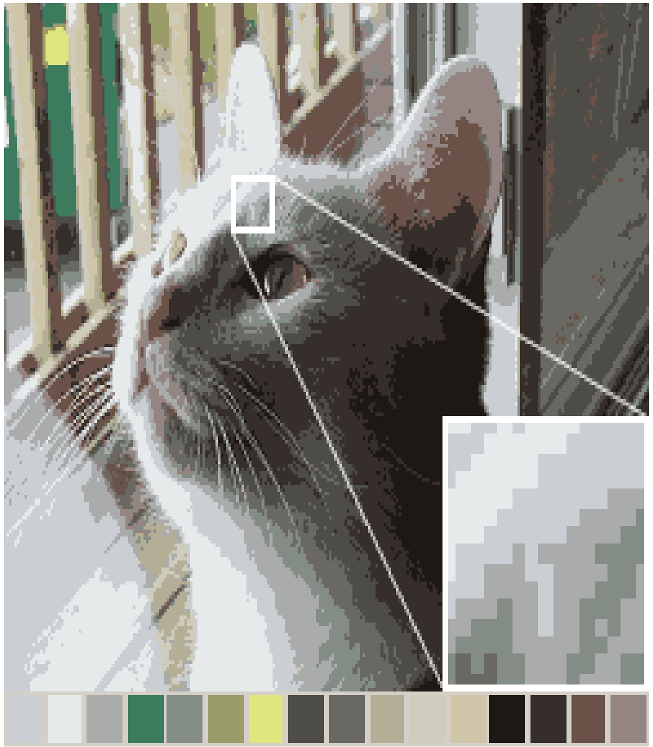


Q: How can we process these surfaces ?

Zoom on Geometry Processing
4. Optimal Sampling



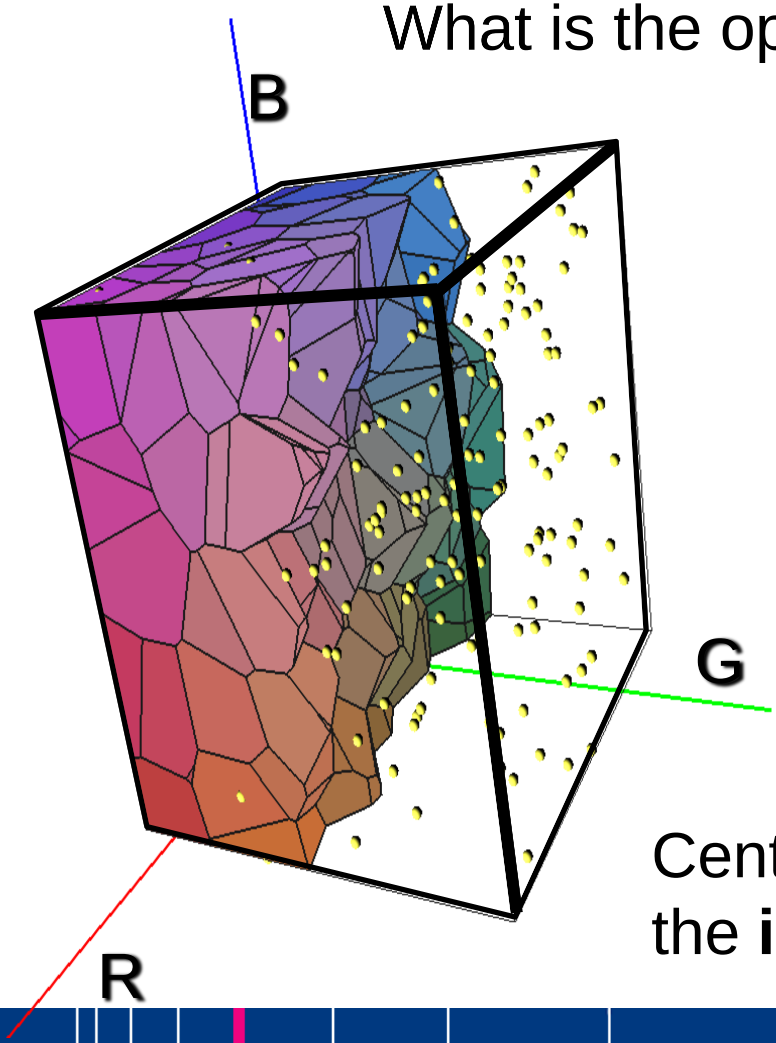


Color quantization

[Leung et.al, GPU Pro, AK Peters, 2010]

Zoom on Geometry Processing
4. Optimal Sampling

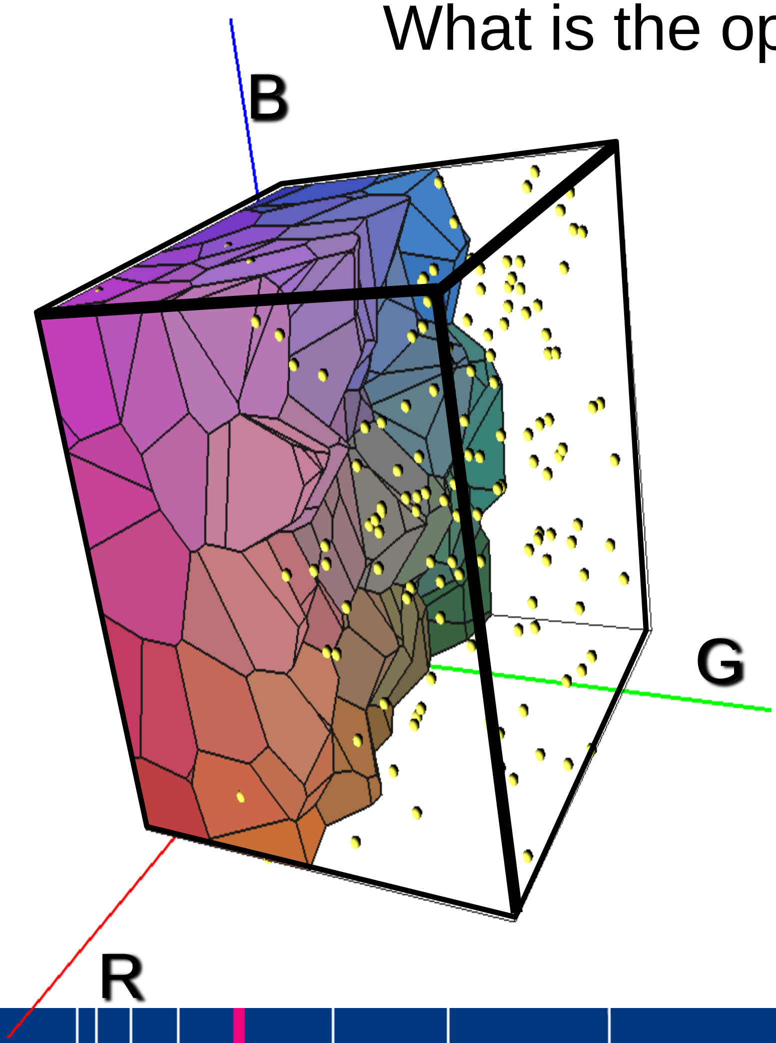
What is the optimal colormap ?

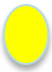


Centroidal Voronoi Tesselation from the **information theory** perspective…

Zoom on Geometry Processing
4. Optimal Sampling

What is the optimal colormap ?





$\mathbf{x}_i = (r_i, g_i, b_i)$ Colormap entry

Zoom on Geometry Processing
4. Optimal Sampling

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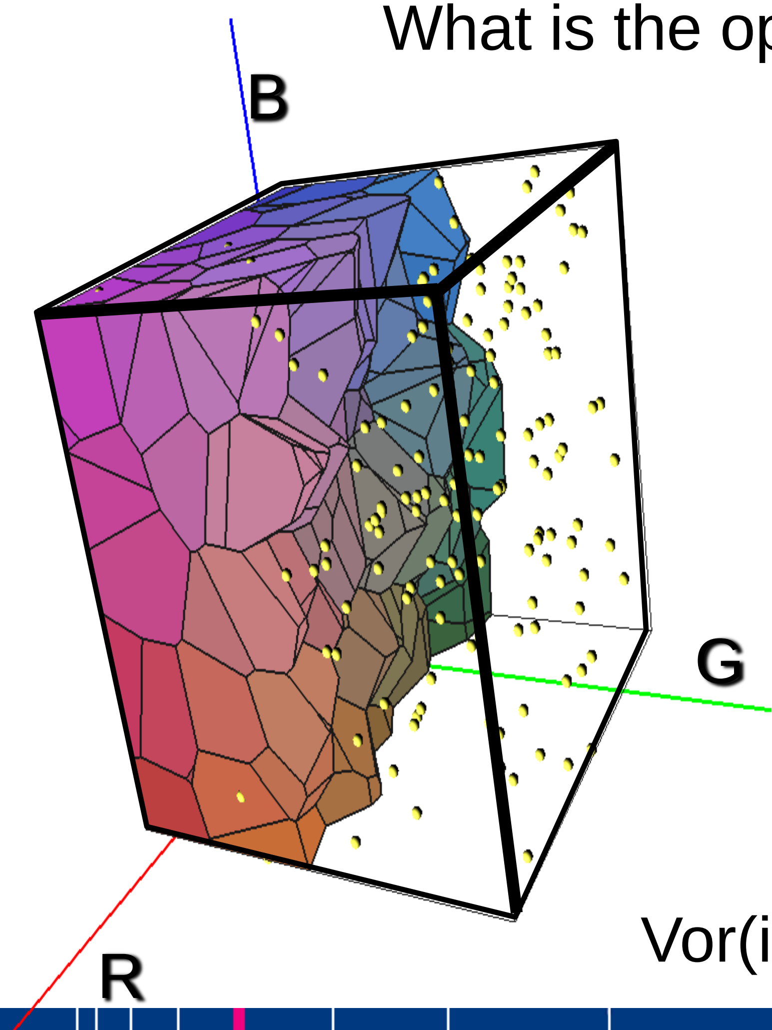
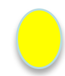
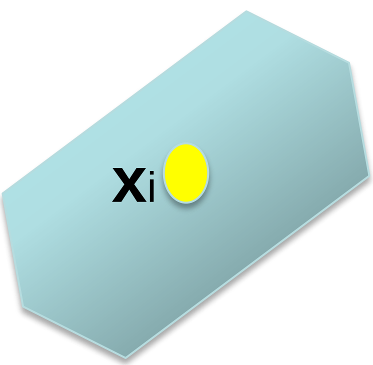




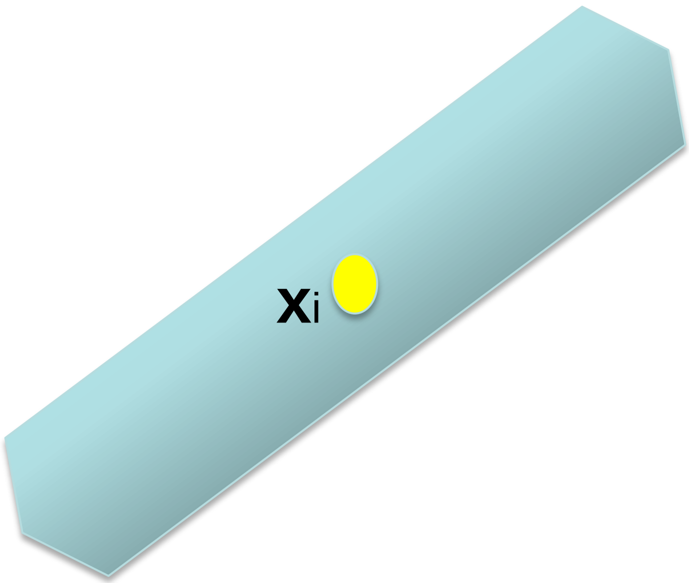
$\mathbf{x}_i = (r_i, g_i, b_i)$ Colormap entry



Vor(i) = $\{ \mathbf{x} \,/\, d(\mathbf{x},\mathbf{x}_i) < d(\mathbf{x},\mathbf{x}_j) \} \; \forall \; i \neq j$

Zoom on Geometry Processing
4. Optimal Sampling

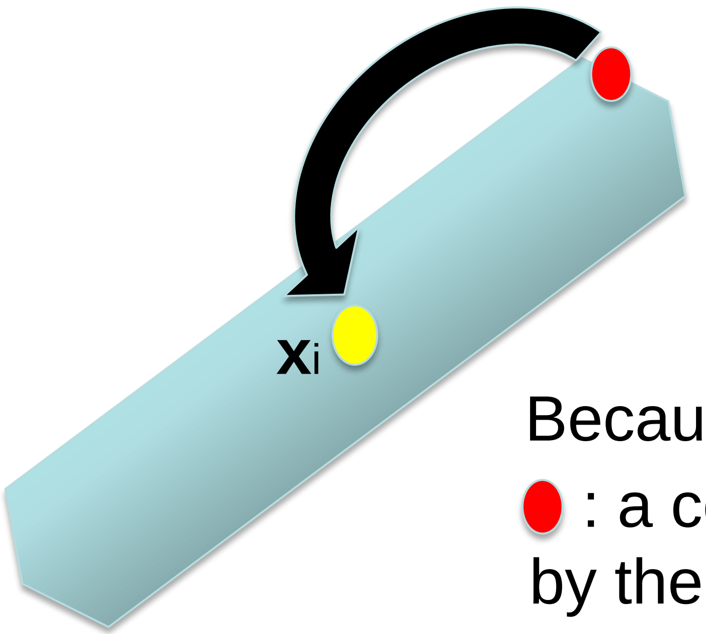
What is the optimal colormap ?



A « bad » colormap entry / Voronoi cell

Zoom on Geometry Processing
4. Optimal Sampling

What is the optimal colormap ?



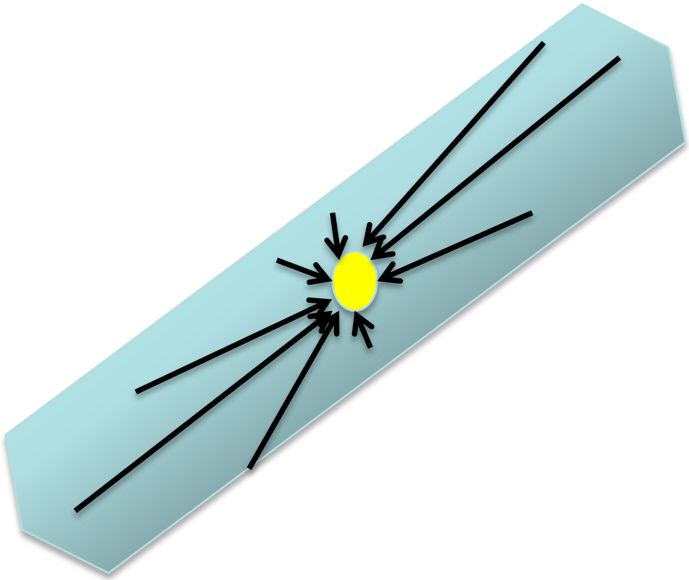
Why bad ?

Because Vor(**xi**) contains
● : a color poorly approximated by the colormap entry **xi** ●

A « bad » colormap entry / Voronoi cell

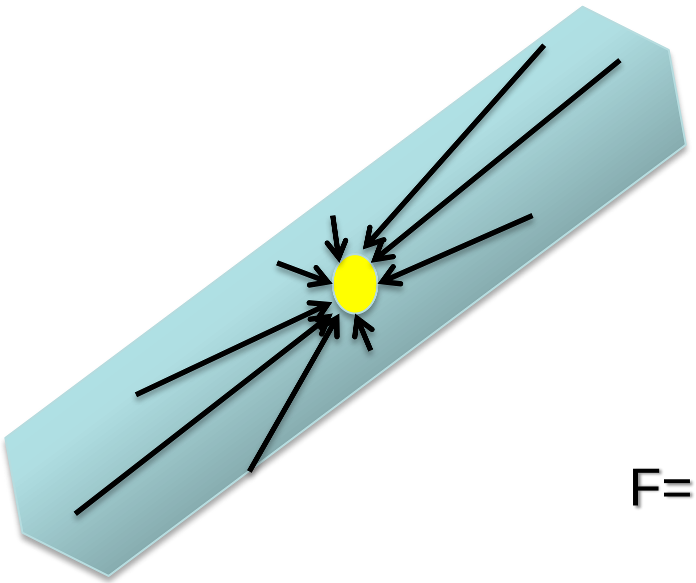
Zoom on Geometry Processing
4. Optimal Sampling

What is the optimal colormap ?



Zoom on Geometry Processing
4. Optimal Sampling

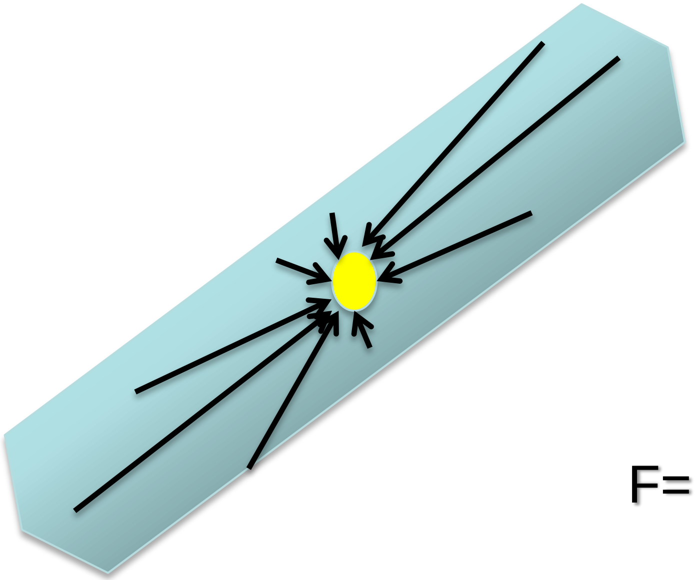
What is the optimal colormap ?



$$F = \int_{Vor(i)} \left\| \mathbf{x}_i - \mathbf{x} \right\|^2 d\mathbf{x}$$

Zoom on Geometry Processing
4. Optimal Sampling

What is the optimal colormap ?

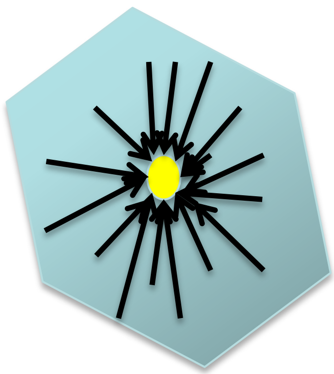


$$F = \int_{Vor(i)} \left\| \mathbf{x}_i - \mathbf{x} \right\|^2 d\mathbf{x}$$

F: **Quantization noise power**

Zoom on Geometry Processing
4. Optimal Sampling

What is the optimal colormap ?

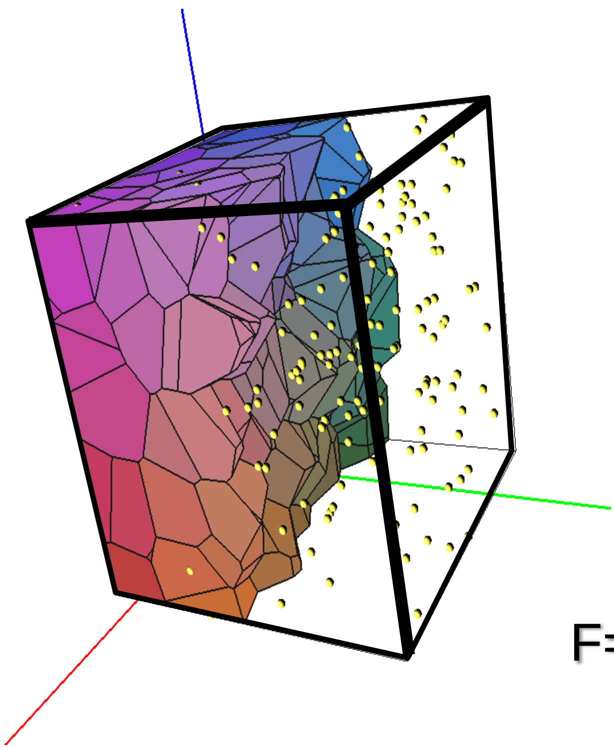


$$F = \int_{Vor(i)} \left\| \mathbf{x}_i - \mathbf{x} \right\|^2 d\mathbf{x}$$

F: **Quantization noise power**

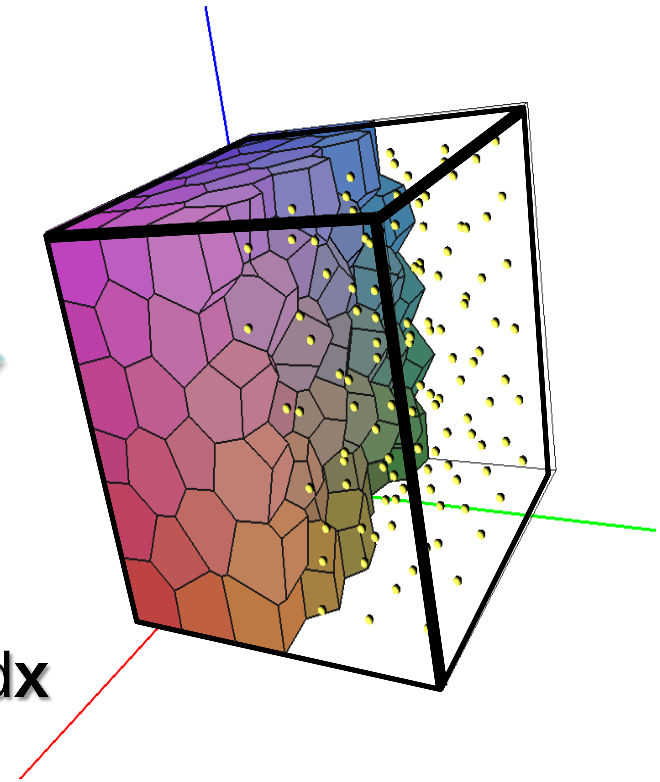
Zoom on Geometry Processing
4. Optimal Sampling

What is the optimal colormap ?



Minimize

$$F = \sum_i \int_{Vor(i)} \left\| \mathbf{x}_i - \mathbf{x} \right\|^2 d\mathbf{x}$$



Zoom on Geometry Processing
4. Optimal Sampling

The classical method:

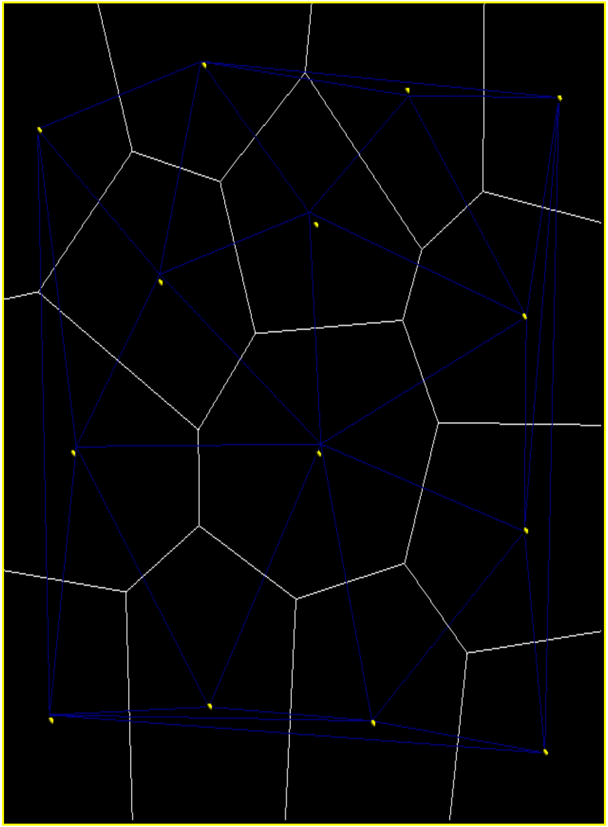
Lloyd's algorithm = gradient descent

$$F = \sum_i \int_{Vor(i)} \left\| \mathbf{x}_i - \mathbf{x} \right\|^2 d\mathbf{x}$$

Zoom on Geometry Processing
4. Optimal Sampling

Lloyd's Relaxation:
(Geometric point of view)

Loop
  Move the $\mathbf{x}_i$'s to the $\mathbf{g}_i$'s
  Re-triangulate
End loop



+ Provably decreases F [Du et.al]
+ Reasonably easy to implement
- Slow (linear) convergence

Zoom on Geometry Processing
4. Optimal Sampling

[ACM TOG 2009] (information theory point of view)

Newton's method for minimizing multivariate non-linear function F

While $|\nabla F| > \varepsilon$

solve $\left[\nabla^2_{x,x} F \right] \left[\delta X \right] = - \left[\nabla_x F \right]$

$X \leftarrow X + \delta X$

End while

Hessian = 2nd order derivatives

Is F sufficiently continuous ? (C^2)

Yes [Liu, Wang, **L**, Sun, Yan, Lu and Yang 09]

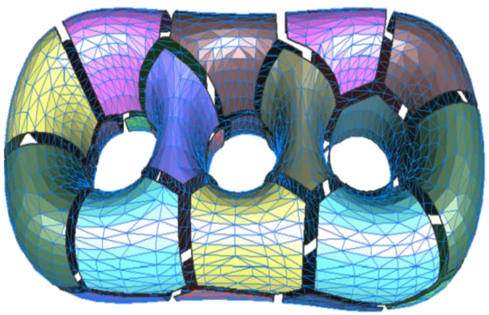
Zoom on Geometry Processing
4. Optimal Sampling

CVT in 2D

Zoom on Geometry Processing
4. Optimal Sampling

CVT in 2D

CVT on surfaces

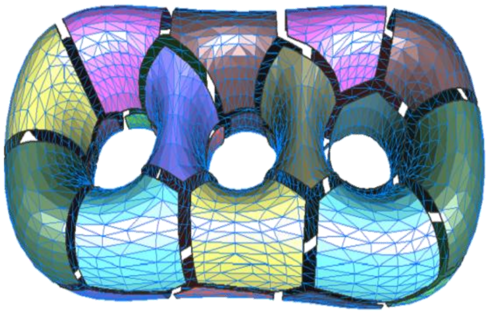


[Yan, **L**, Liu, Sun and Wang SGP2009]

Zoom on Geometry Processing
4. Optimal Sampling

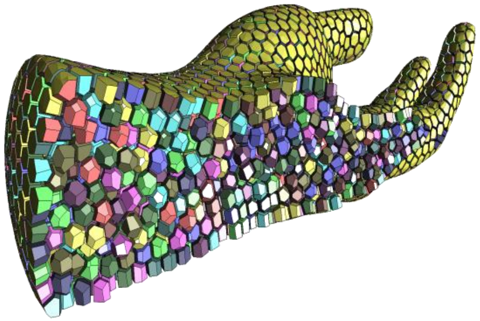
CVT in 2D

CVT on surfaces



CVT in volumes

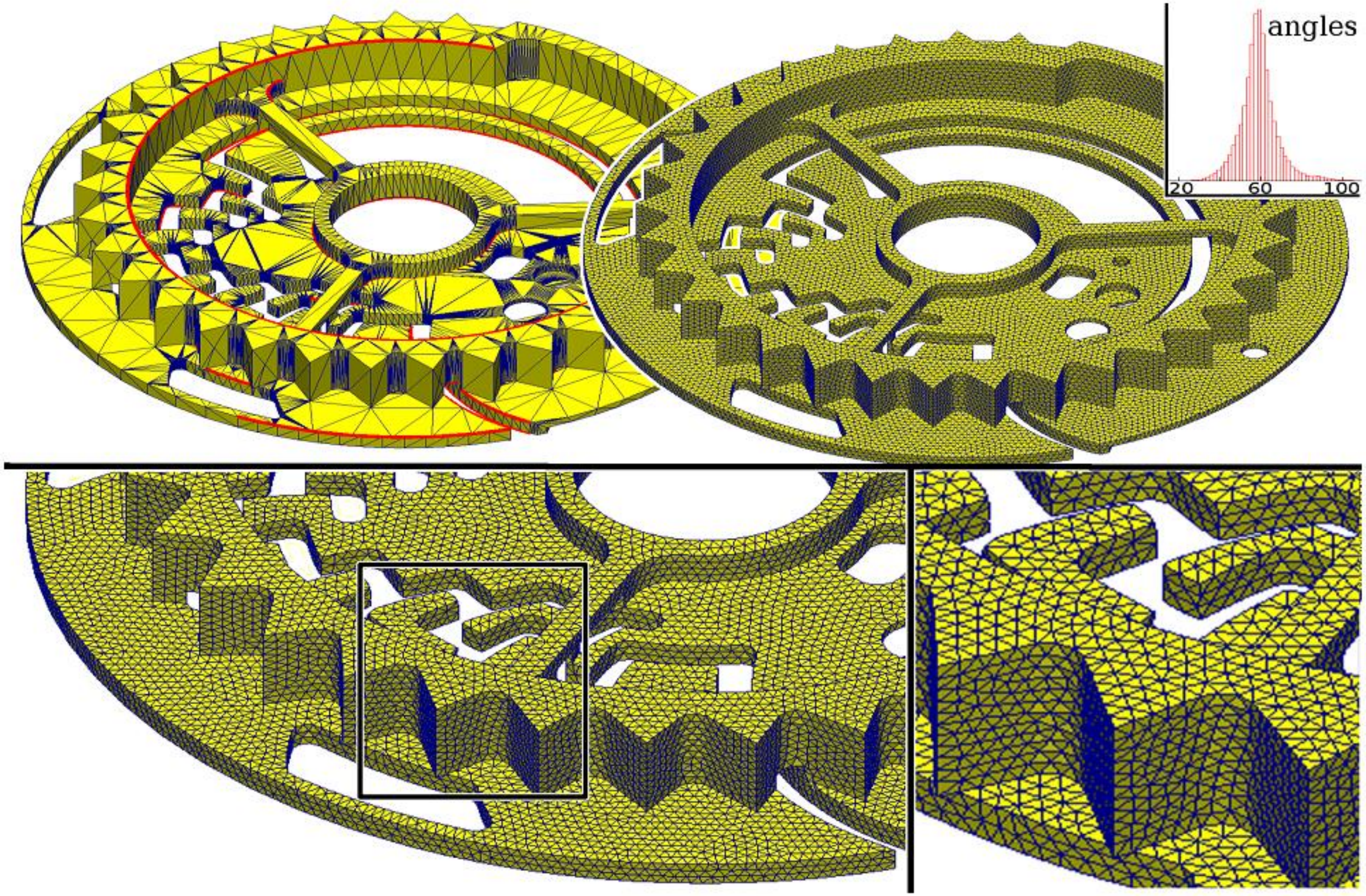
[Yan, Wang, **L**, Liu 2010]



Zoom on Geometry Processing
4. Optimal Sampling

Remeshing [Yan, **L**, Liu, Sun and Wang – SGP2009]

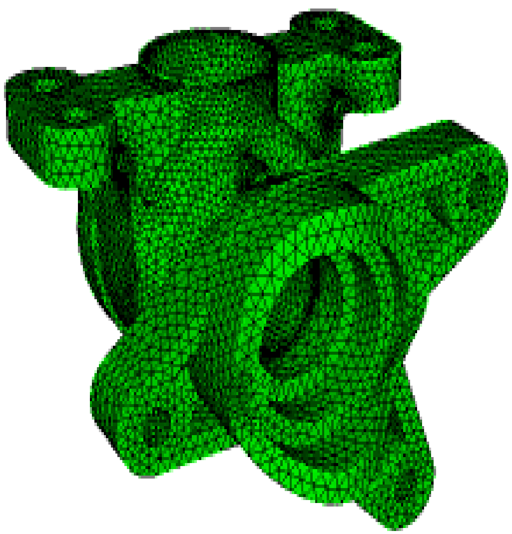
Zoom on Geometry Processing
4. Optimal Sampling

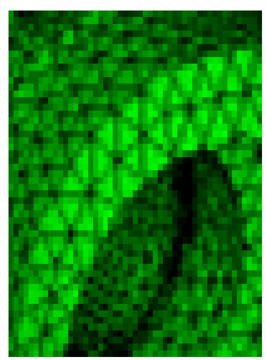


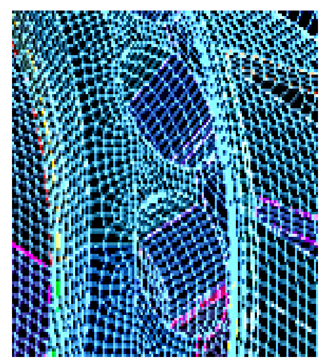
Zoom on Geometry Processing
4. Optimal Sampling

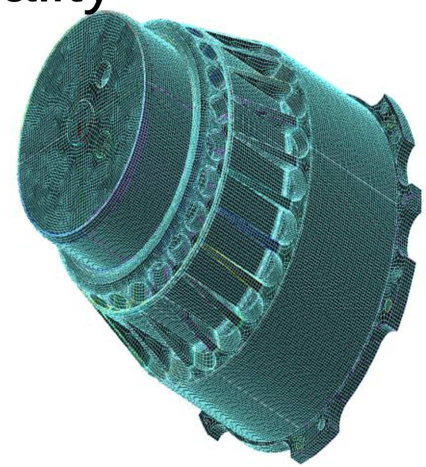
Tet Meshing
1. Fully Automated
2. Millions of elements in minutes/seconds
3. Adequate for some analysis
4. Inaccurate for other Analysis

Hex Meshing
1. Partially Automated, some Manual
2. Millions of elements in days/weeks/months
3. Preferred by some analysts for solution quality



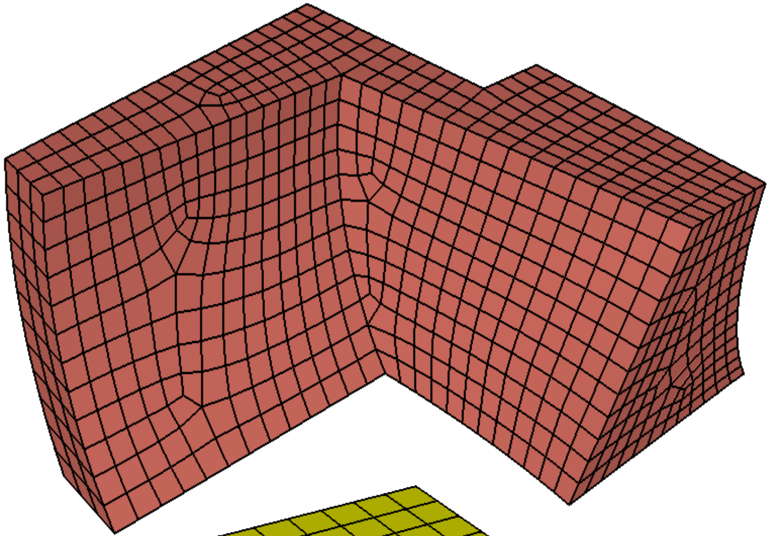


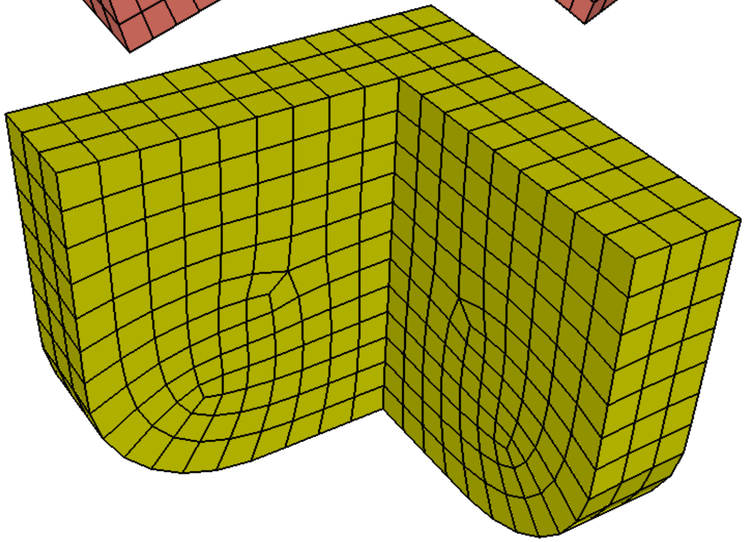


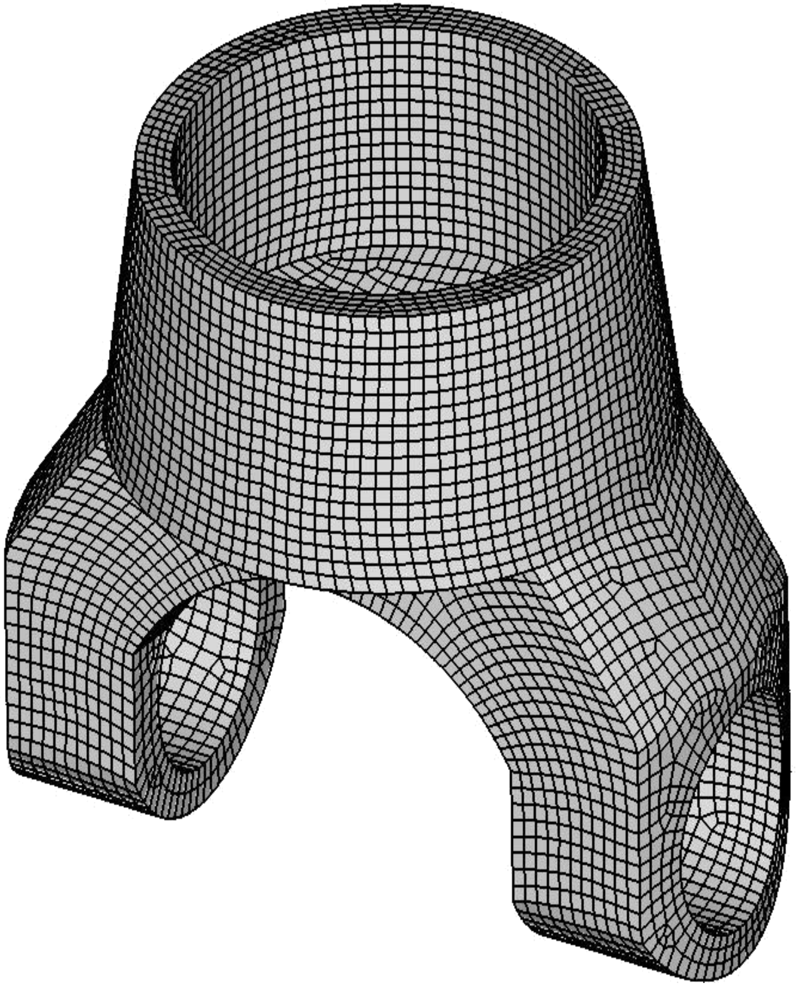


[Matt Staten] (Sandial Labs)

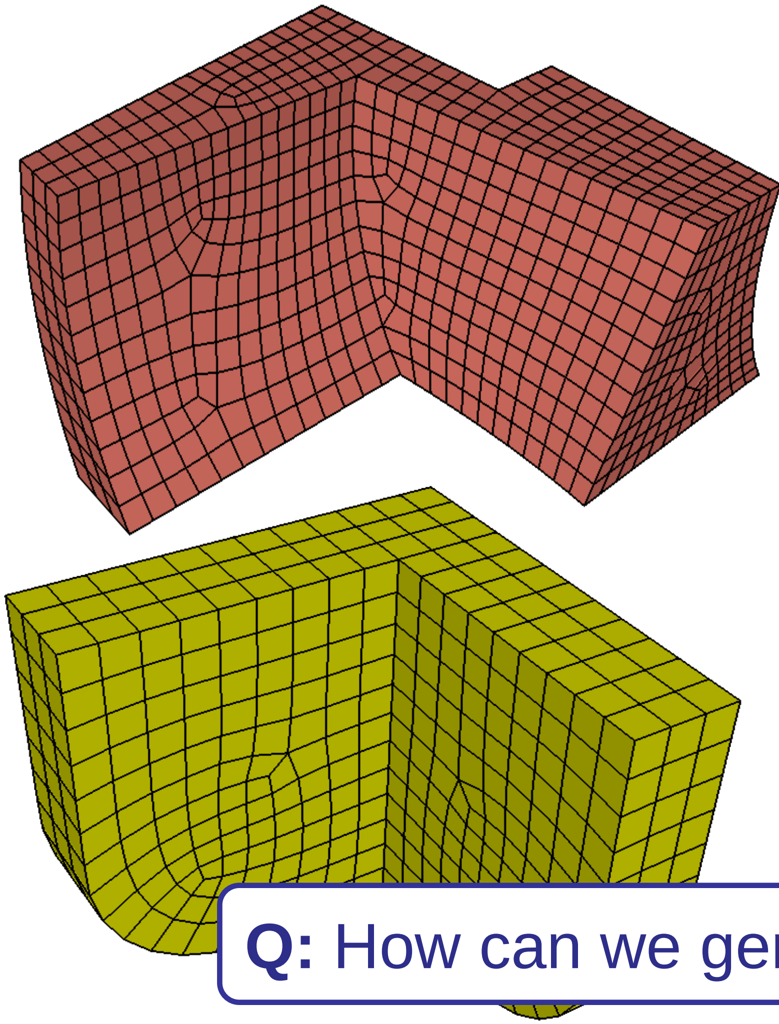
Zoom on Geometry Processing
4. Optimal Sampling

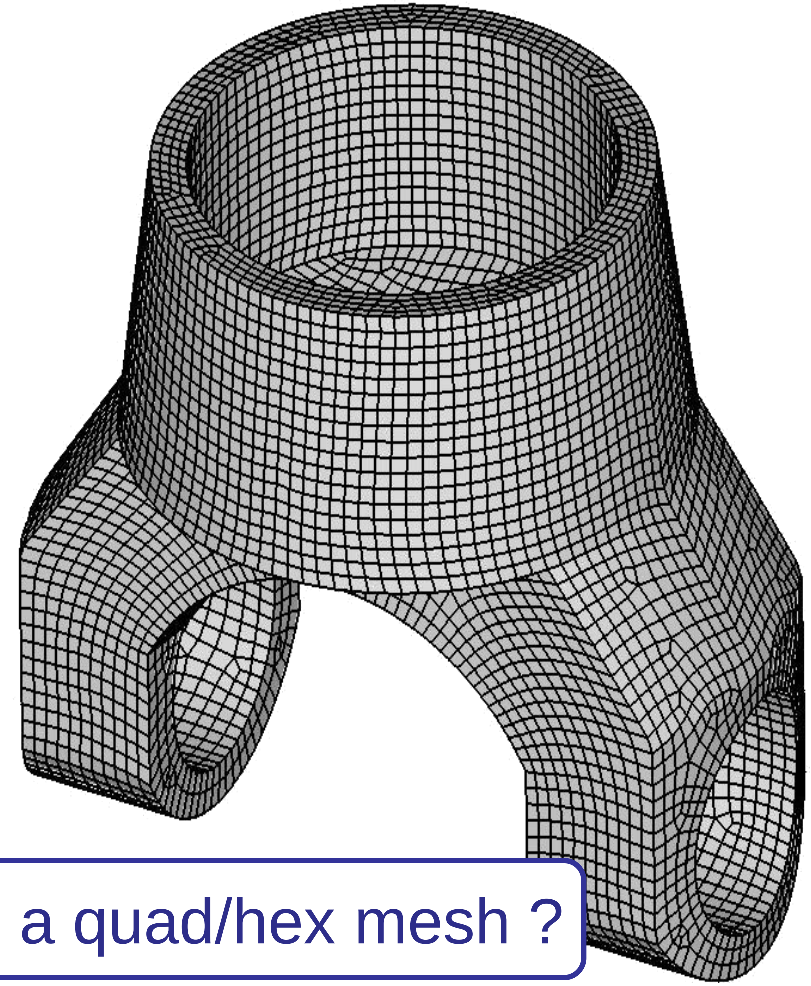






Zoom on Geometry Processing
4. Optimal Sampling





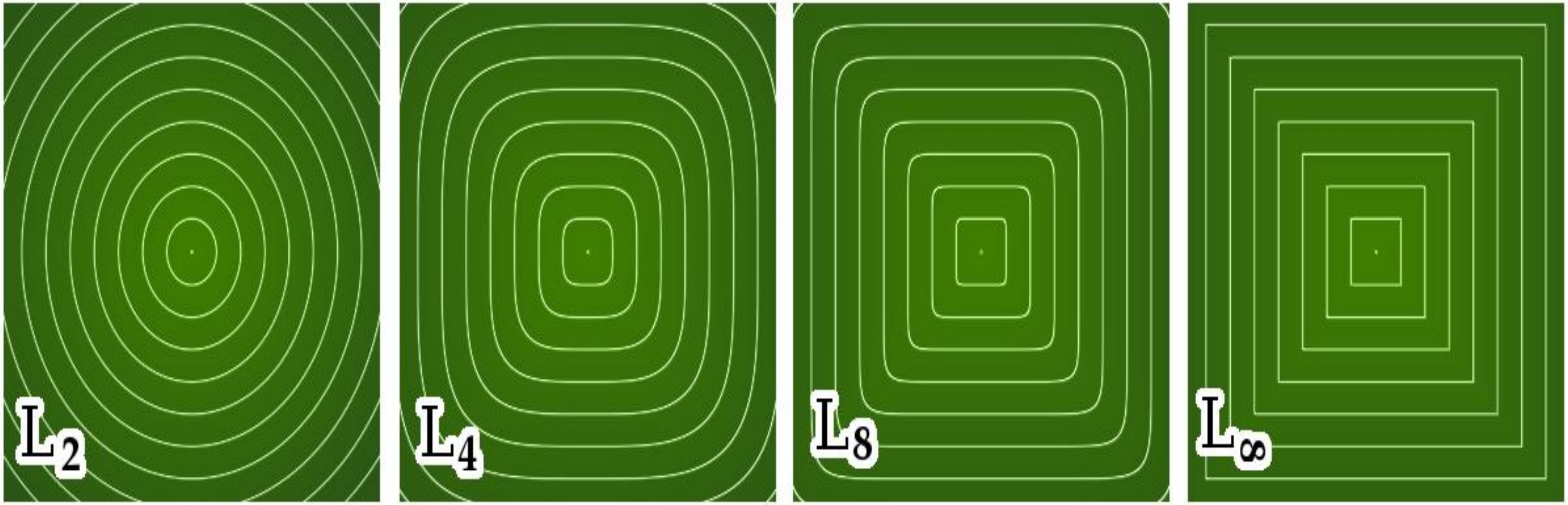
Q: How can we generate a quad/hex mesh ?

Zoom on Geometry Processing

4. Optimal Sampling

Blowing Square Bubbles …

p=2 p=4 p=8 ….



Zoom on Geometry Processing
4. Optimal Sampling

Standard CVT: $F = \sum_i \int_{Vor(i)} \| (\mathbf{x}_i - \mathbf{x}) \|^2 d\mathbf{x}$

Zoom on Geometry Processing
4. Optimal Sampling

Standard CVT: $$F = \sum_i \int_{Vor(i)} \left\| (\mathbf{x}_i - \mathbf{x}) \right\|^2 d\mathbf{x}$$

Lp CVT:
[**L** and Liu 2010]

$$F = \sum_i \int_{Vor(i)} \left\| \mathbf{M}(\mathbf{x}) (\mathbf{x}_i - \mathbf{x}) \right\|_p^p d\mathbf{x}$$

Zoom on Geometry Processing

4. Optimal Sampling

Lp CVT: $$F = \sum_i \int_{Vor(i)} \left\| M(x)\,(x_i - x) \right\|_p^p dx$$

Anisotropy, encodes desired orientation

Riemannian metric $\mathbf{G} = \mathbf{M}^t\,\mathbf{M}$

Zoom on Geometry Processing

4. Optimal Sampling

Lp CVT: $F = \sum_i \int_{Vor(i)} \left\| \mathbf{M(x)} \, (\mathbf{x}_i - \mathbf{x}) \right\|_p^p d\mathbf{x}$

Lp norm: $\| x \|_p = \sqrt[p]{|x|^p + |y|^p + |z|^p}$

If p is even: $\| x \|_p^p = x^p + y^p + z^p$

Zoom on Geometry Processing
4. Optimal Sampling

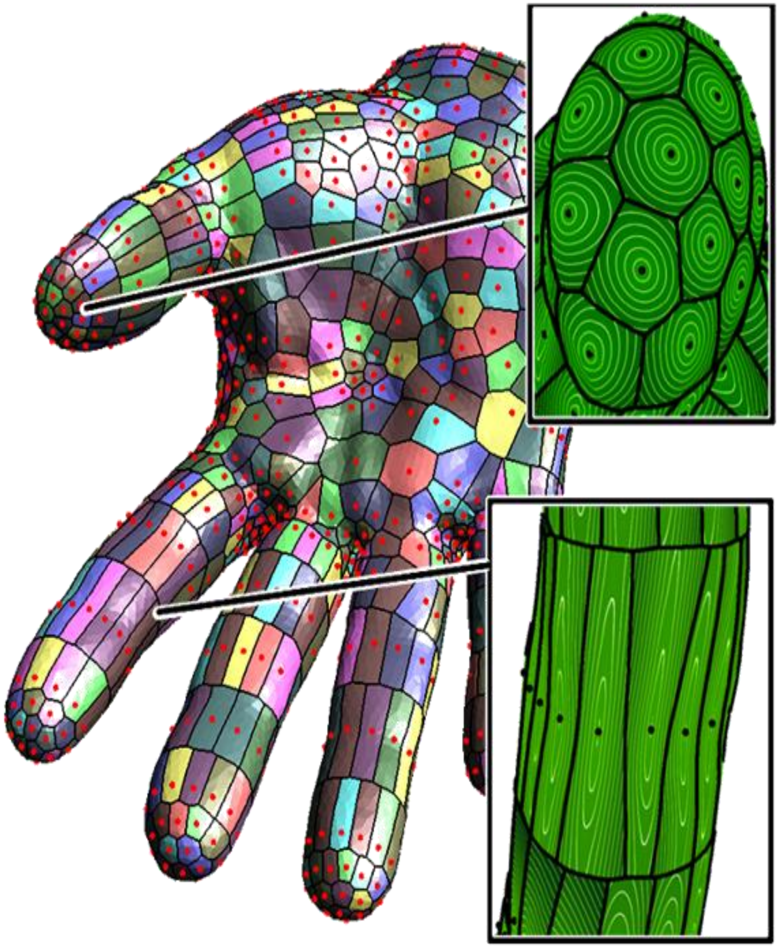
Lp CVT: $$F = \sum_i \int_{Vor(i)} \left\| \mathbf{M(x)} \, (\mathbf{x}_i - \mathbf{x}) \right\|_p^p d\mathbf{x}$$

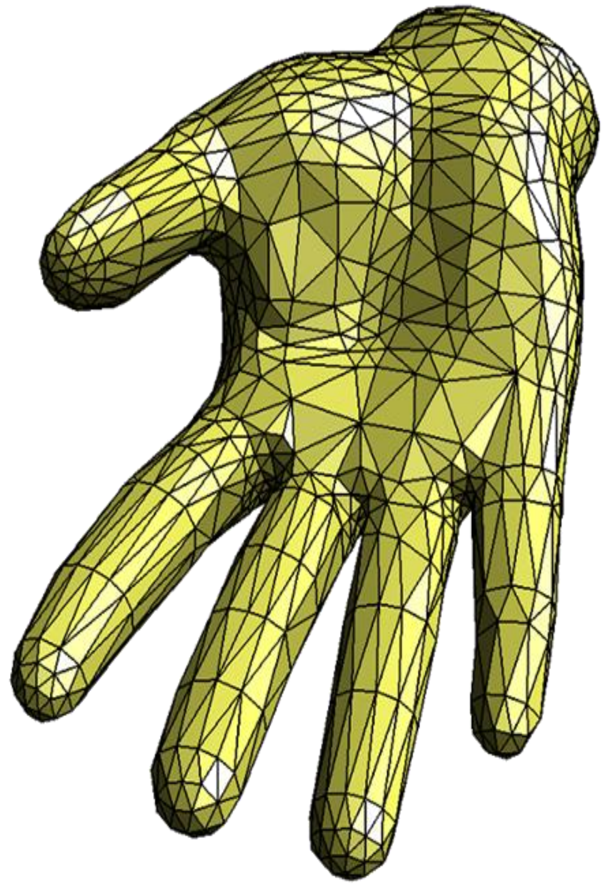
<u>Optimization with LBFGS (quasi-Newton)</u>

For each iterate $\mathbf{X}^{(k)}$:

Compute $F(\mathbf{X}^{(k)})$ and $\nabla F(\mathbf{X}^{(k)})$

Zoom on Geometry Processing
4. Optimal Sampling

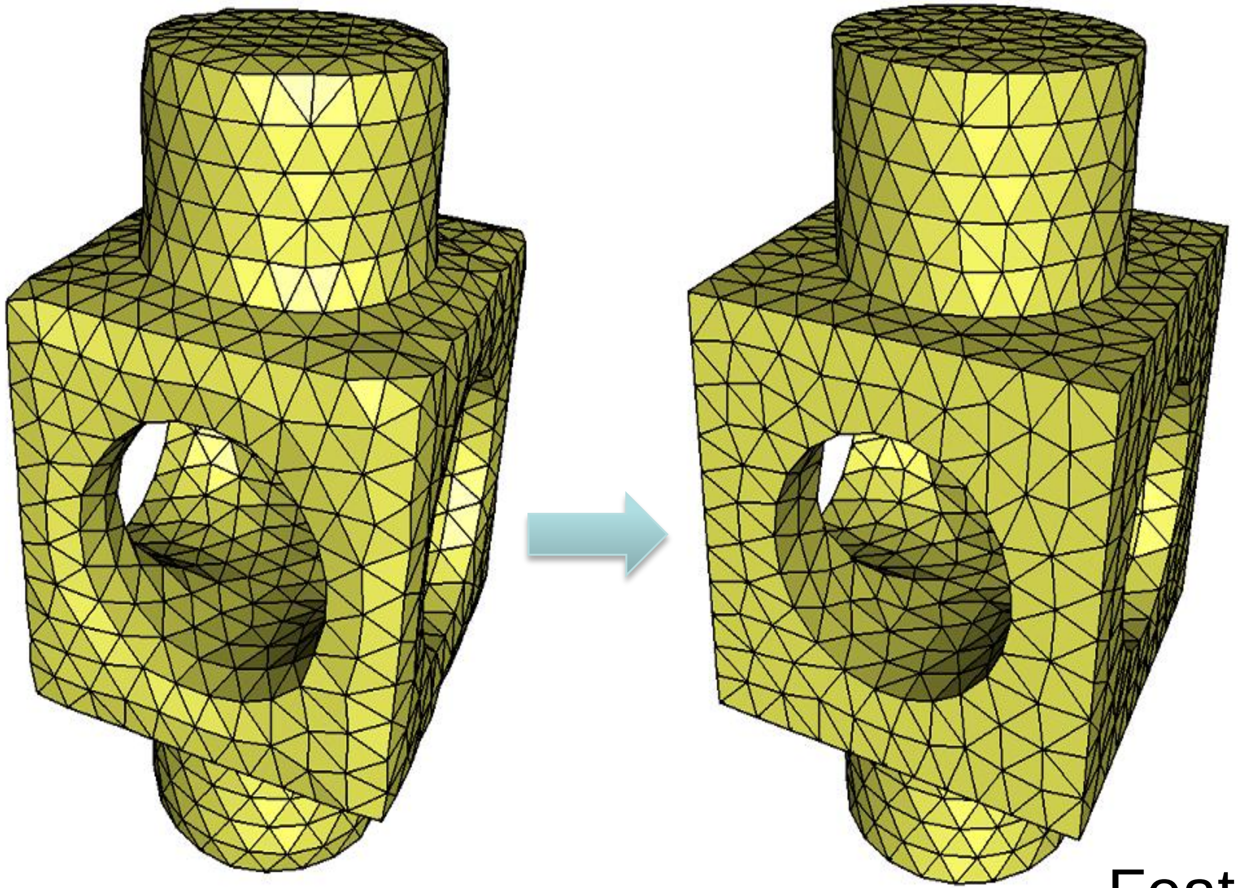




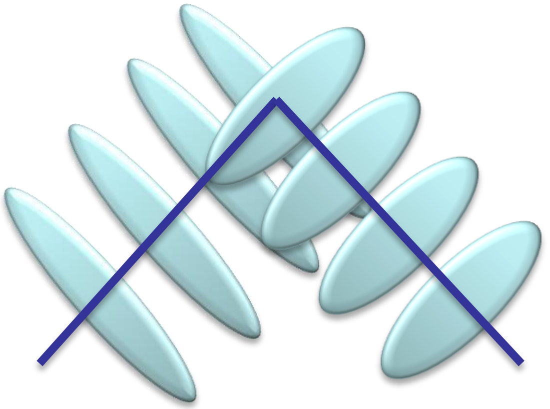
p = 2

M(x) = ppal dir. of curvature.

Zoom on Geometry Processing
4. Optimal Sampling



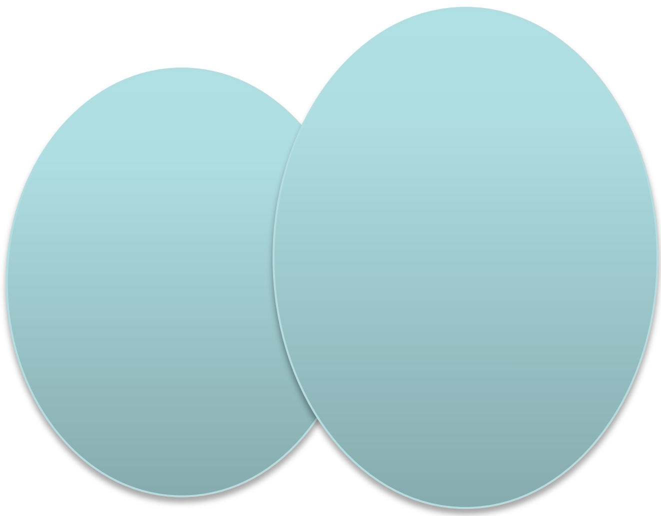
p = 2
M(x) = Normal anisotropy.



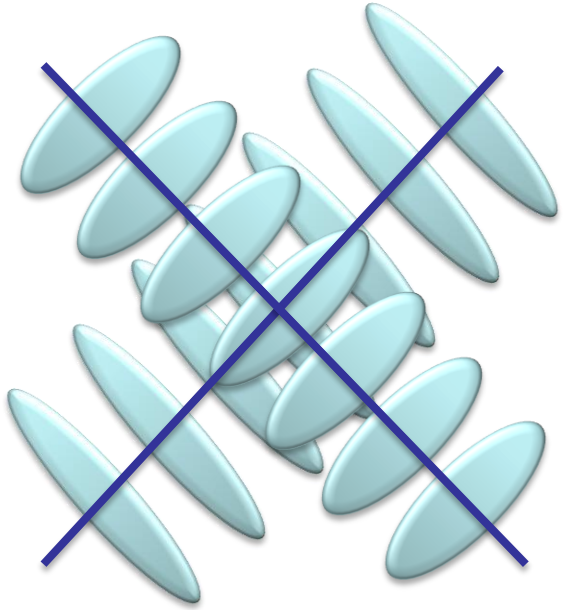
Feature-sensitive meshing

Zoom on Geometry Processing
4. Optimal Sampling

p = 2
M(x) = Normal
anisotropy.



CSG-Remeshing

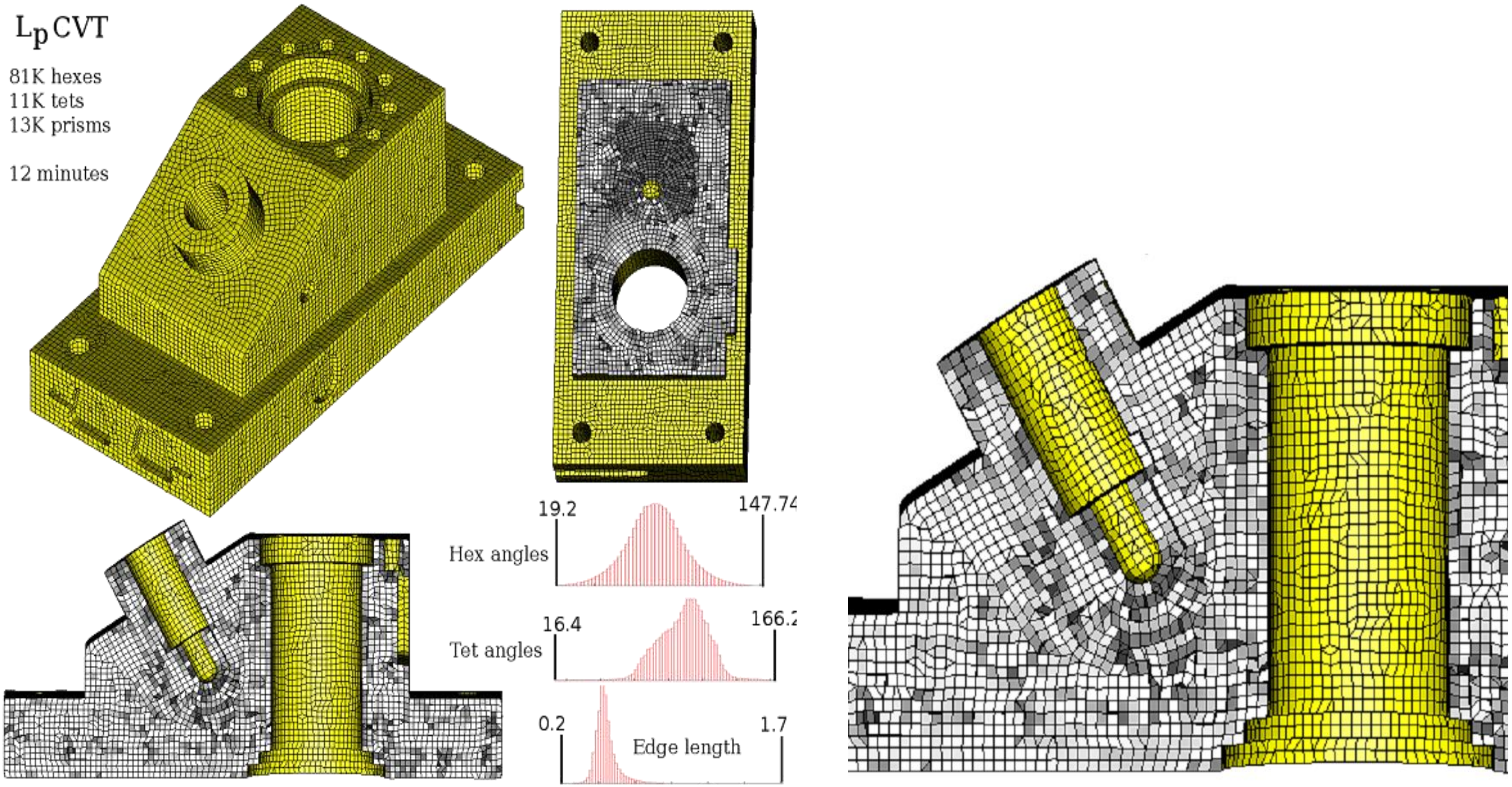


Feature-sensitive meshing

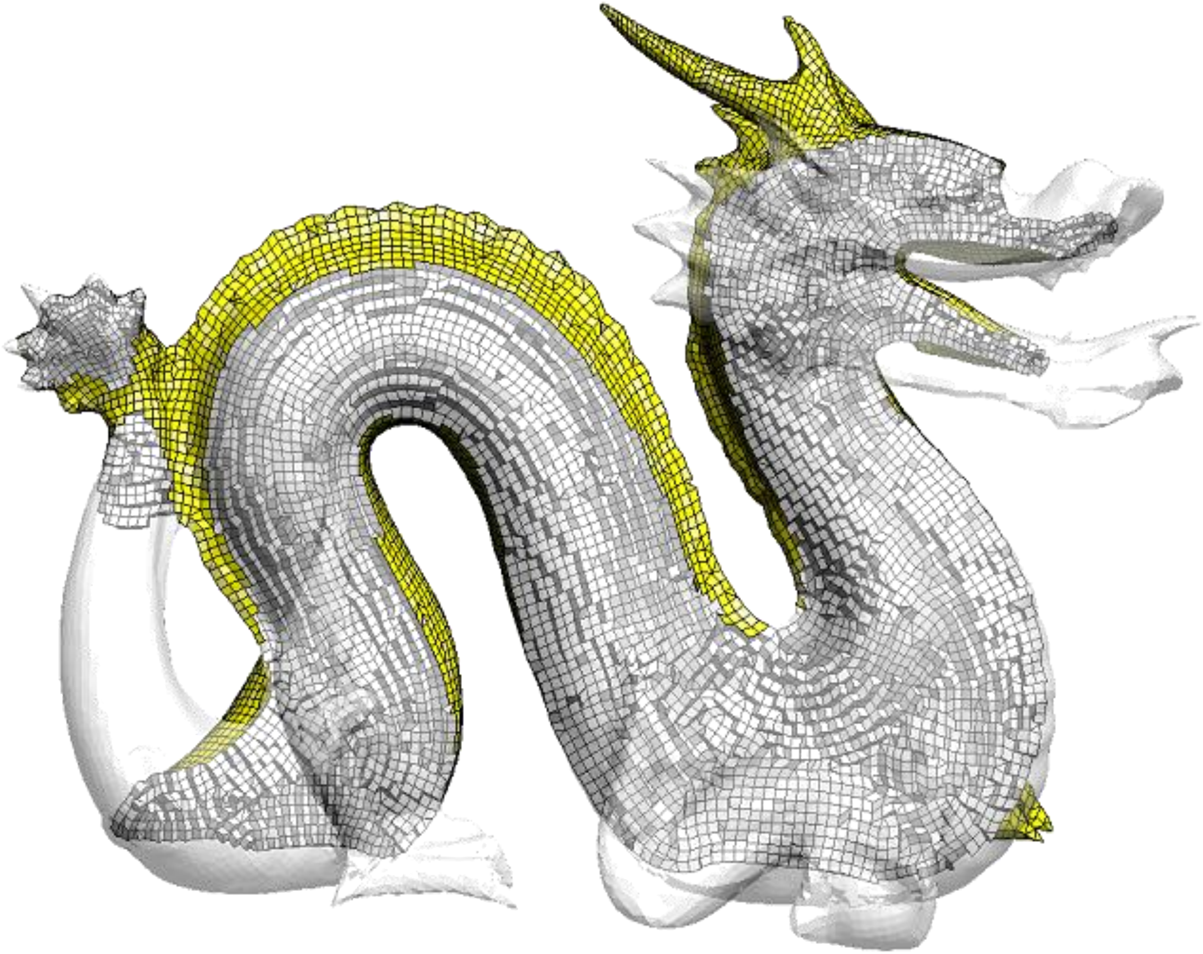
Zoom on Geometry Processing

4. Optimal Sampling

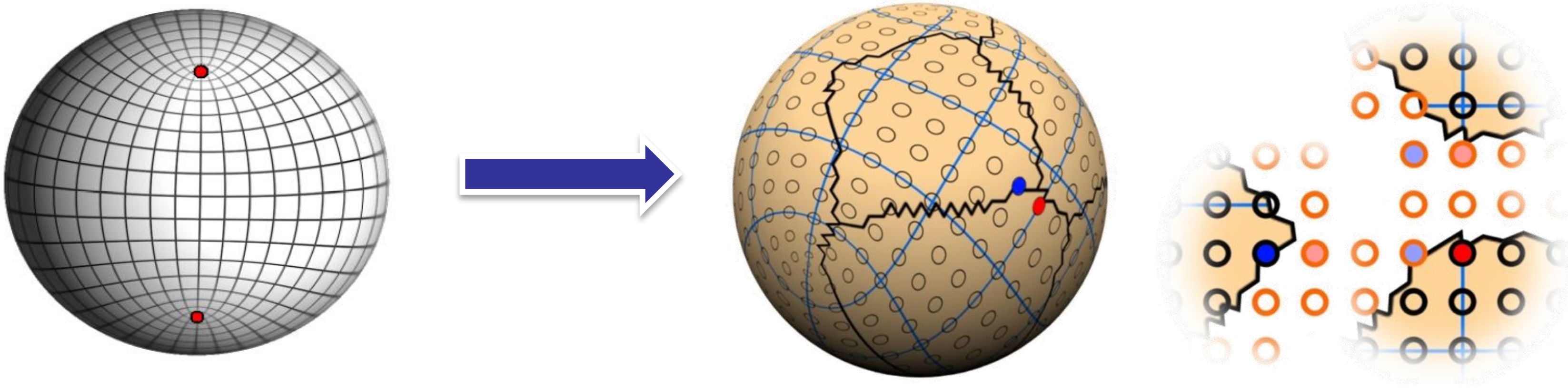
Zoom on Geometry Processing
4. Optimal Sampling



Zoom on Geometry Processing
4. Optimal Sampling

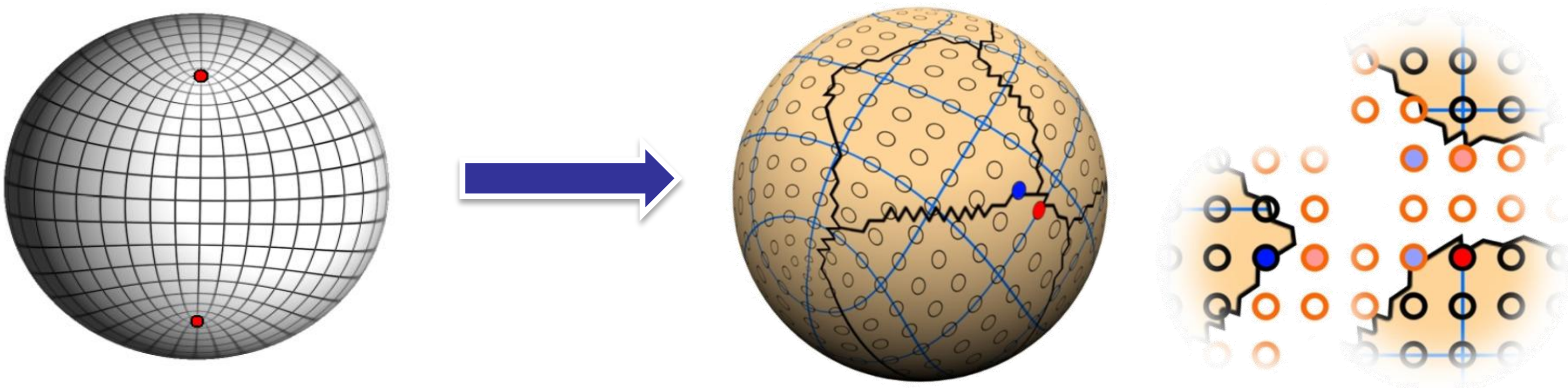


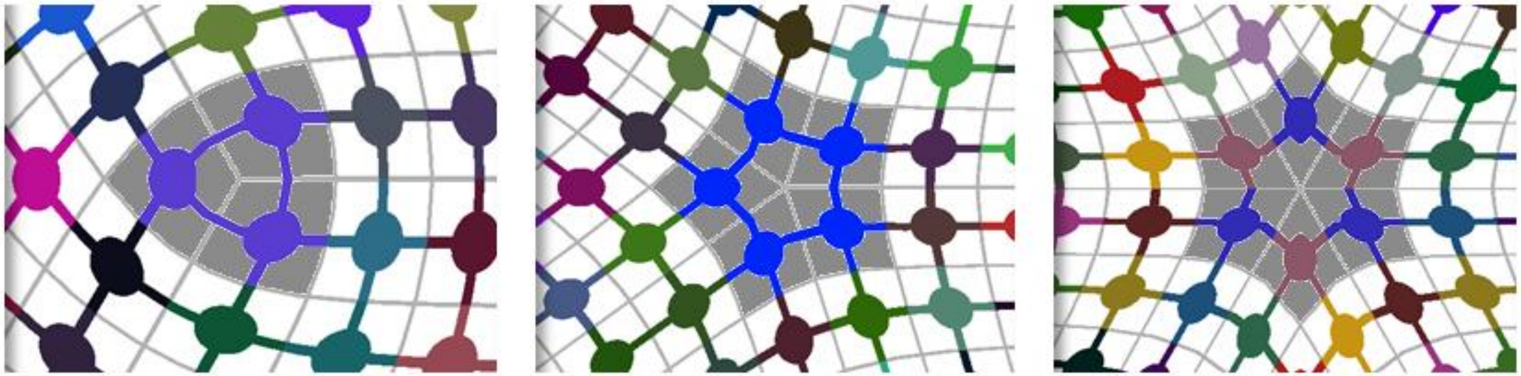
Zoom on Geometry Processing
5. Seamless texturing



Invisible Seams **[EGSR 2010]**

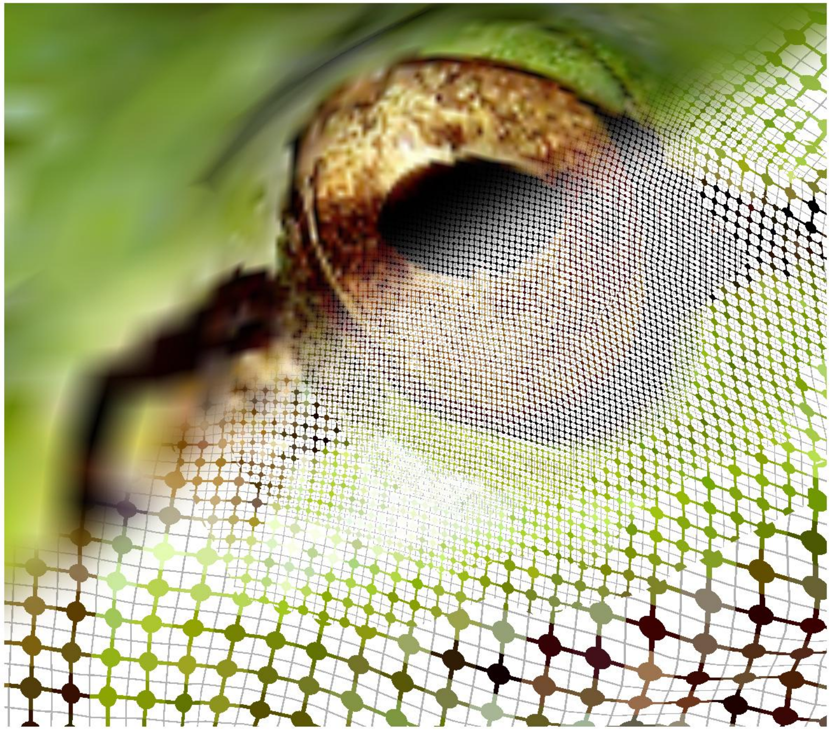
Zoom on Geometry Processing
5. Seamless texturing





Invisible Seams **[EGSR 2010]**

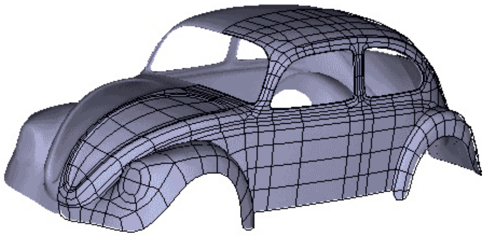
Zoom on Geometry Processing
5. Seamless Texturing



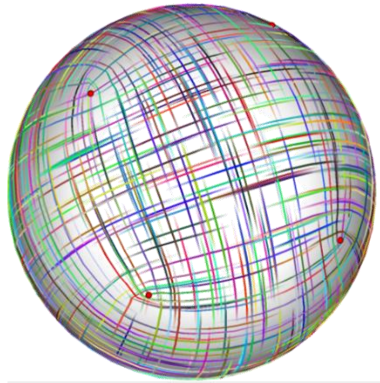
Invisible Seams **[EGSR 2010]**

Zoom on Geometry Processing

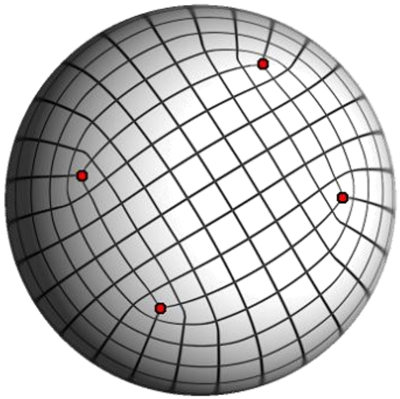
Summary



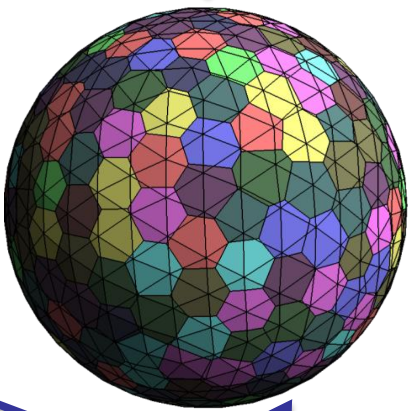
1. Intro
Dynamic Function Basis

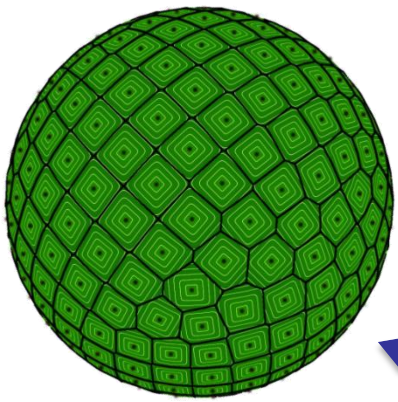


2. Direction Fields

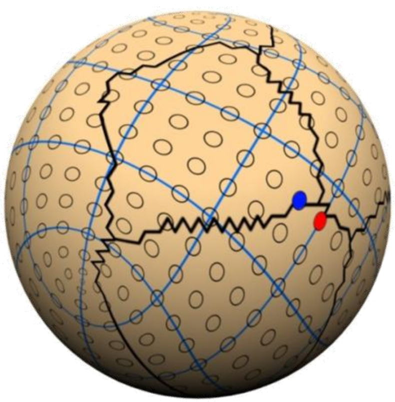


3. Global Parameterization



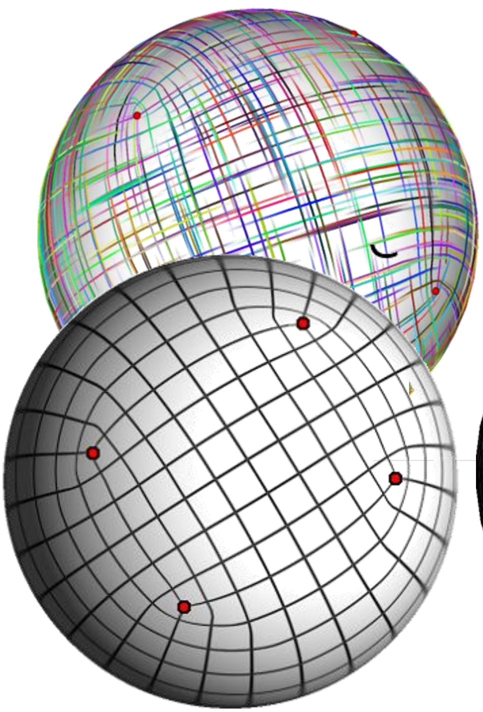


4. Optimal Sampling (L_p and L_2)

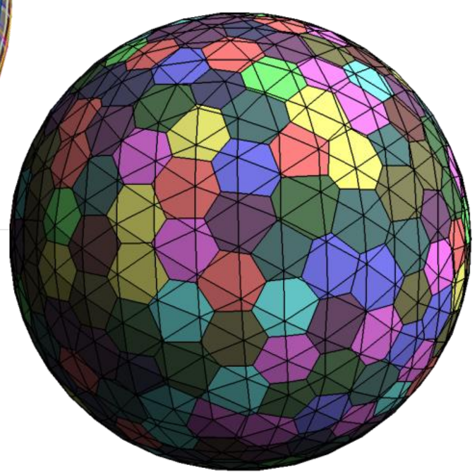


5. Seamless Texturing

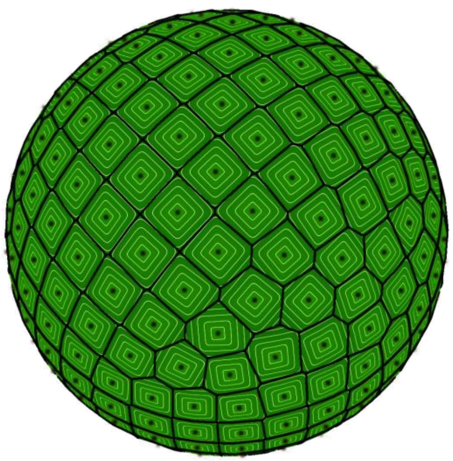
Zoom on Geometry Processing
Summary



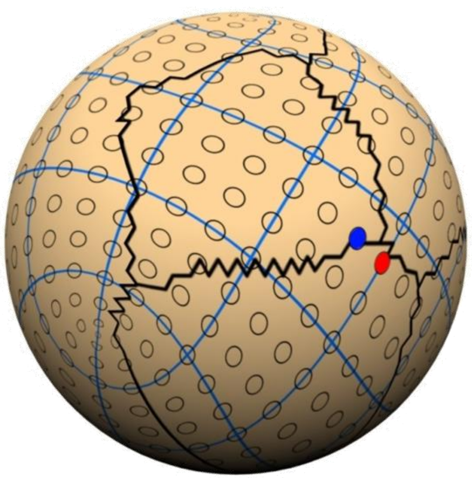
Measuring
[ACM TOG 06,08]



Sampling
[ACM TOG 09]



Meshing
[SIGGRAPH 10]

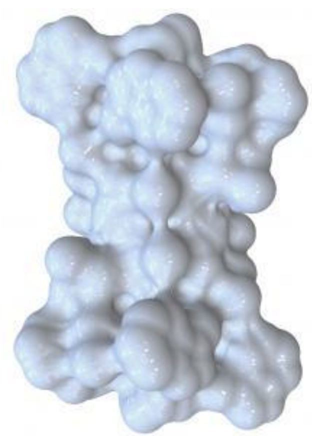


Mapping
[EGSR 10]

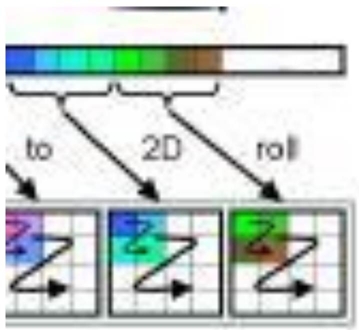
Other works

By-Example Synthesis of Architectural Textures, SIGGRAPH 2010
Sylvain Lefebvre, Samuel Hornus and Anass Lasram
(joint project with REVES)

Manifold Harmonics



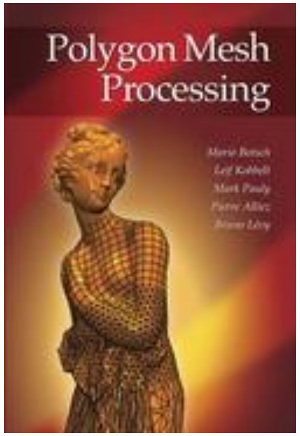
Molecular Visualization



Concurrent Number Cruncher (GPU Solver)

Impact
Highlights

* 4 paper presentations + 1 course
  at SIGGRAPH 2010 (total talks time: 260 min.)



* Book « Polygon Mesh Processing » AK Peters

* Eurographics researcher's prize (S. Lefebvre)

* European Research Council grant and
  ANR Chaire d'Excellence

* Graphite most innovative special prize at
« trophées du libre »

Impact
Visibility of Publications

(google scholar)

- 2008: Manifold Harmonics – 41 citations
- 2007: Concurrent Number Cruncher – 40 citations
- 2006: Periodic Global Parameterization – 90 citations

Impact
Visibility of Publications

(google scholar)

2008: Manifold Harmonics – 41 citations
2007: Concurrent Number Cruncher – 40 citations
2006: Periodic Global Parameterization – 90 citations

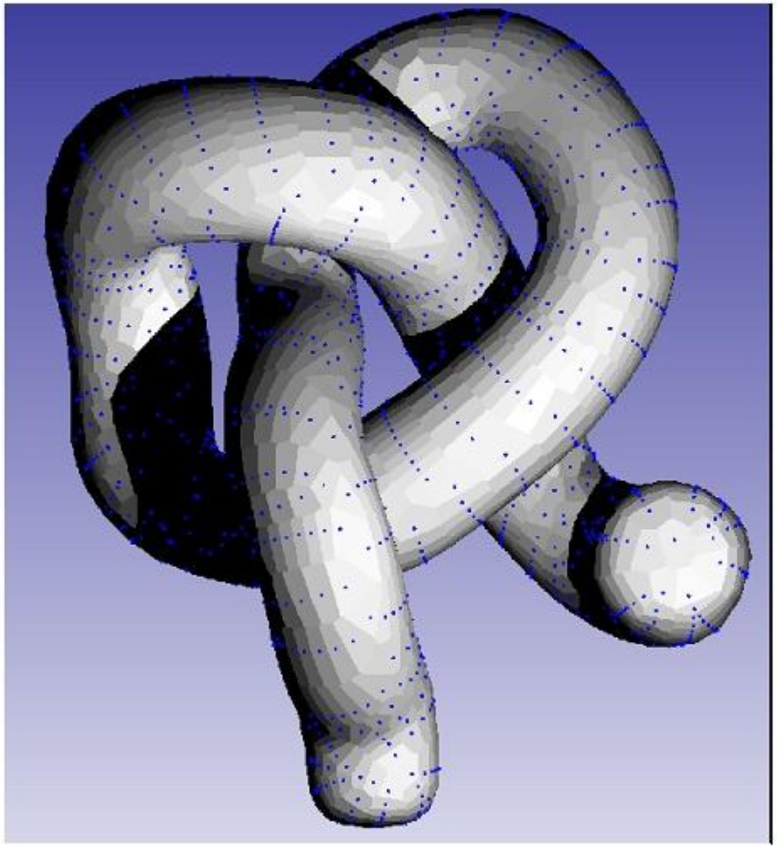
2002: Least Squares Conformal Maps – 504 citations

Future Work – 2010-2014
Dynamic Function Basis – Research Program

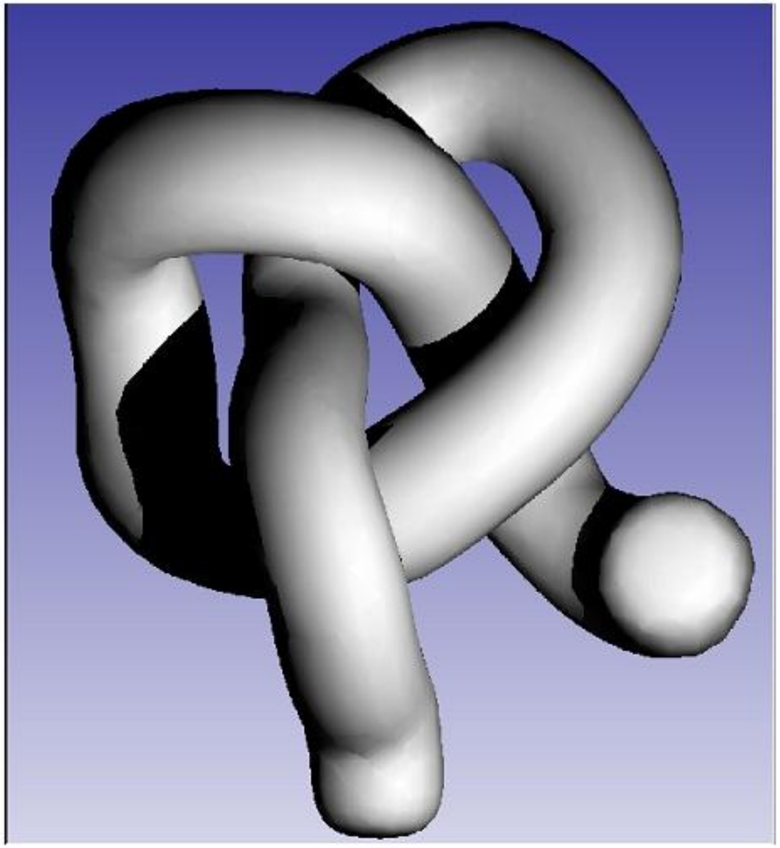
- 2D, L = Id : image approximation **[EGSR 2006]**
- 3D, L = Id : surface approximation **2006-2010**
- 3D, optimal sampling **2006-2010**
- 3D, L = light transport **2010-…**
- 3D+t, Navier Stokes,tracking **2010-…**

GOODSHAPE (ERC)
PHYSIGRAPHICS (ANR)
MORPHO (ANR)
MODITERE (ANR)

Future Work – 2010-2014
Dynamic Function Basis – Lighting



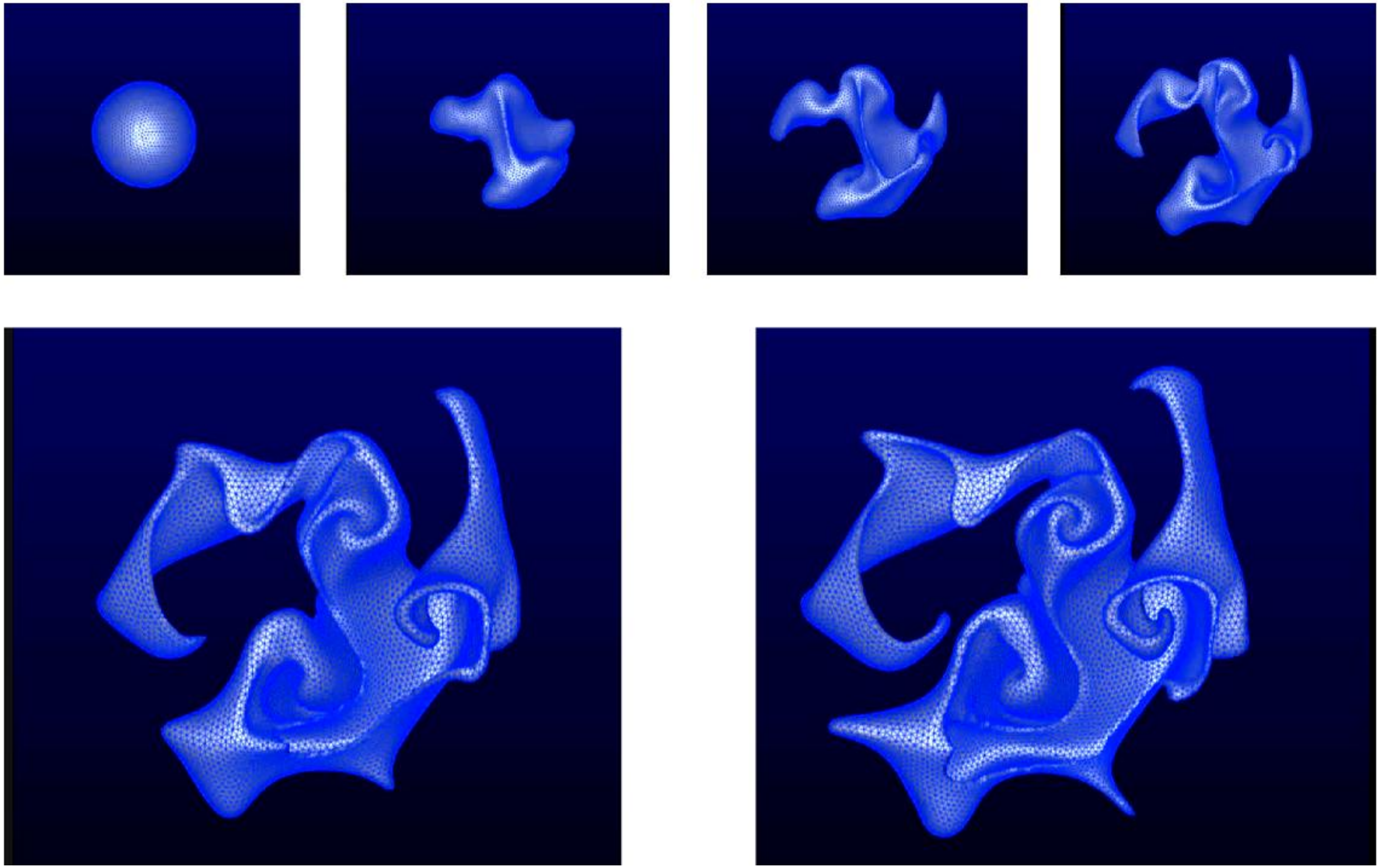
Dynamic Function Basis
Constant elements



Dynamic Function Basis
Quadratic elements

Future Work – 2010-2014

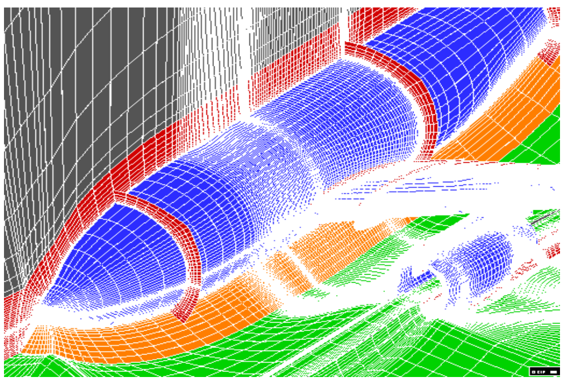
Dynamic Function Basis – Tracking



« Curlnoise » test

Future Work – 2010-2014

Longer term …(form bunnies to spaceships)



- 2D, L = Id : image approximation **[EGSR 2006]**
- 3D, L = Id : surface approximation **2006-2010**
- 3D, optimal sampling **2006-2010**
- 3D, L = light transport **2010-…**
- 3D+t, Navier Stokes,tracking **2010-…**
- **Finite Elements Modeling** **2012-…**

Connections with Applied Mathematics community
Wider project: New Fundations for Numerical Engineering

Future Work – 2010-2014
New ALICE research directions

Applied Mathematics

Finite Element Modeling
Numerics
Differential Geometry
Computational Physics

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Content Creation

By-Example Modeling
Texturing
Geometry Synthesis

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Thank you for your attention