Mathématiques - Informatique

# ALICE

## Evaluation 2018

Bruno Lévy
**ALICE Géométrie & Lumière**
**CENTRE INRIA Nancy Grand-Est**

# Overview

- **Introduction**
  - The team and its history
- **Research Axes**
  - Geometry Processing
  - Computer-Aided Fabrication
- **Highlights**
- **Perspectives**

# The team - History

**ALICE** *Geometry and Light*

Inception: 2004
Inria project: 2006

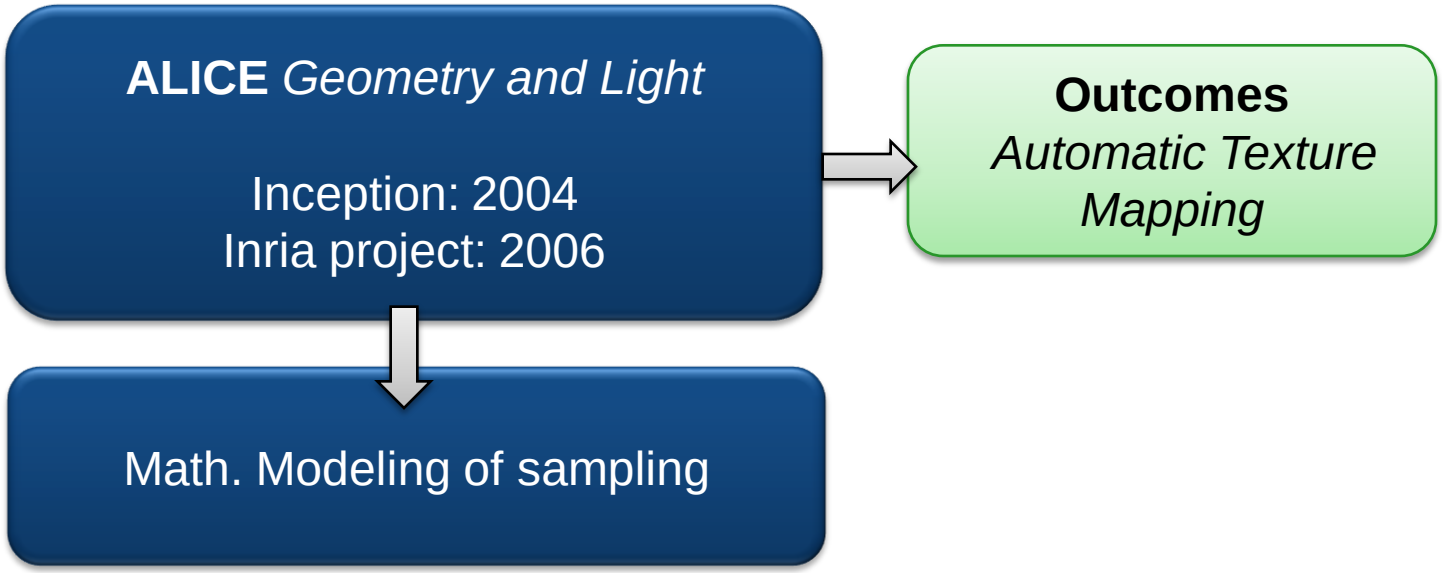
# The team - History

**ALICE** *Geometry and Light*

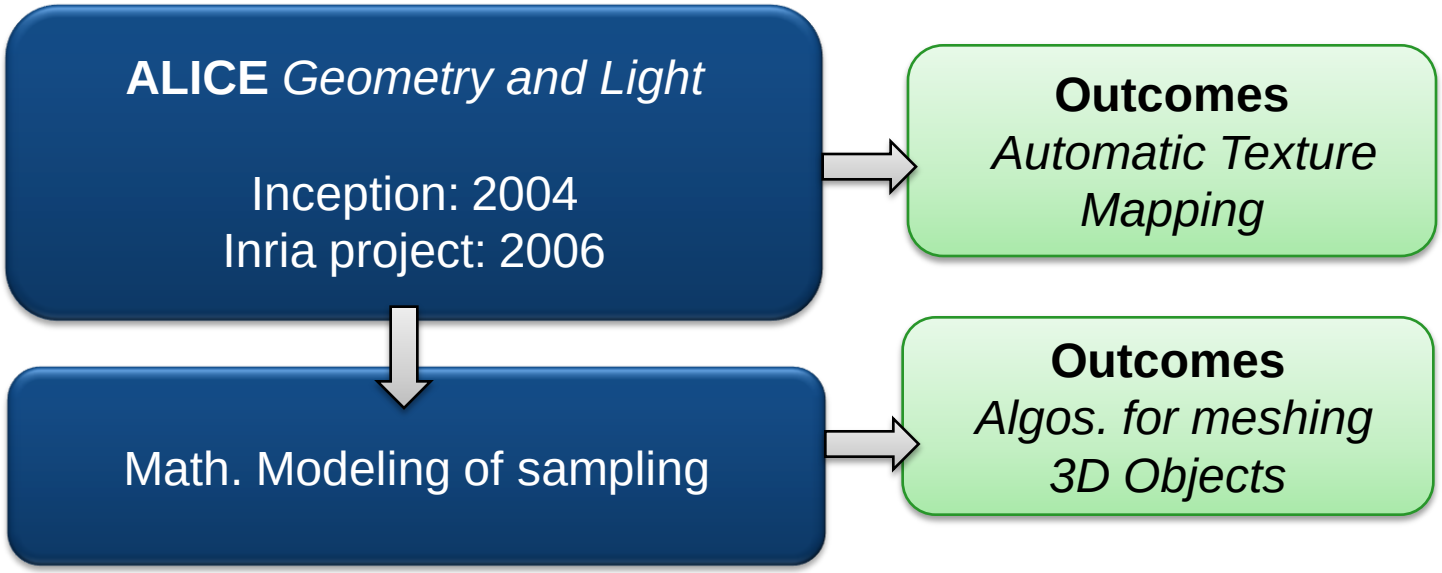
Inception: 2004
Inria project: 2006

**Outcomes**
*Automatic Texture Mapping*

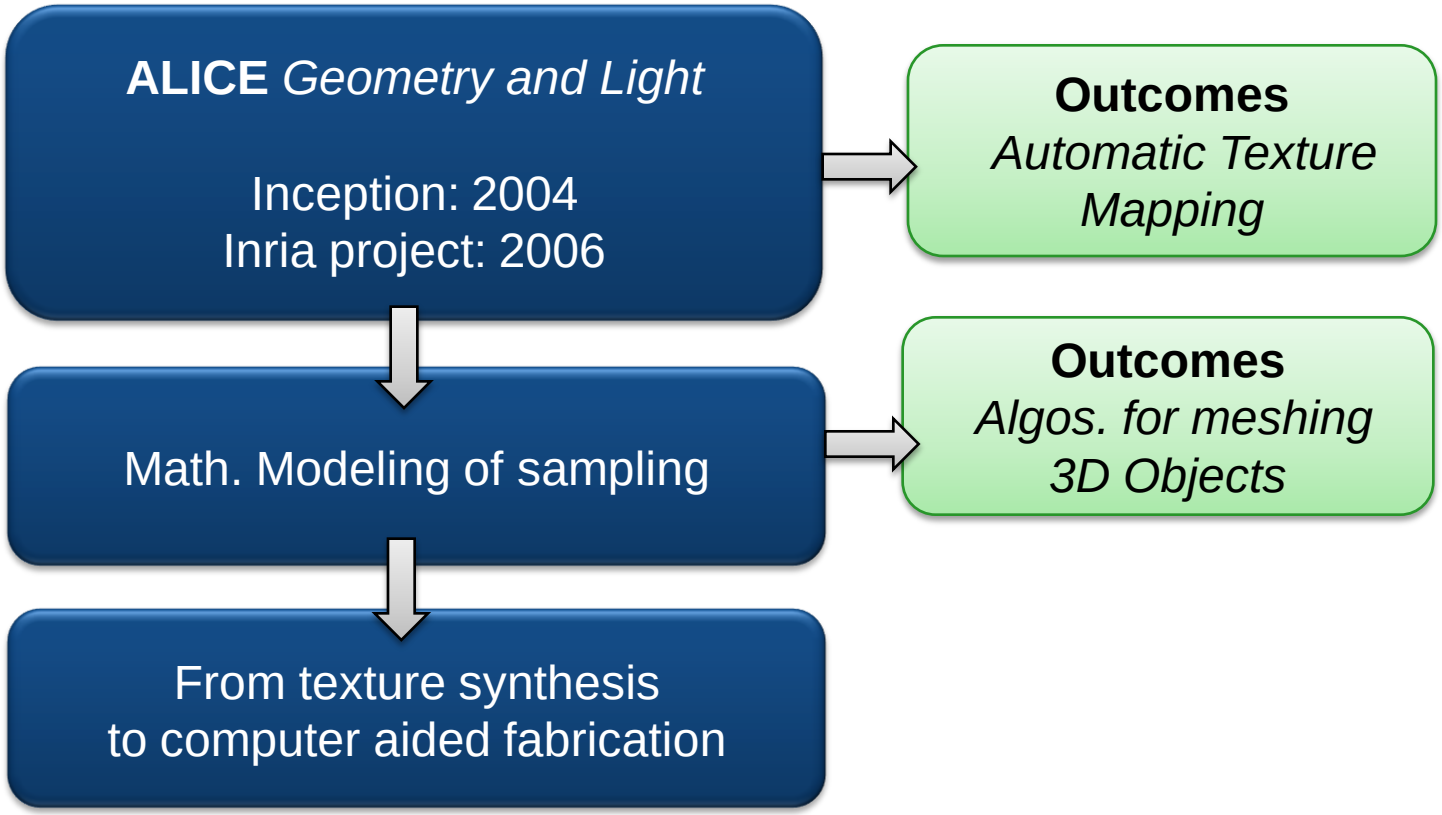
# The team - History



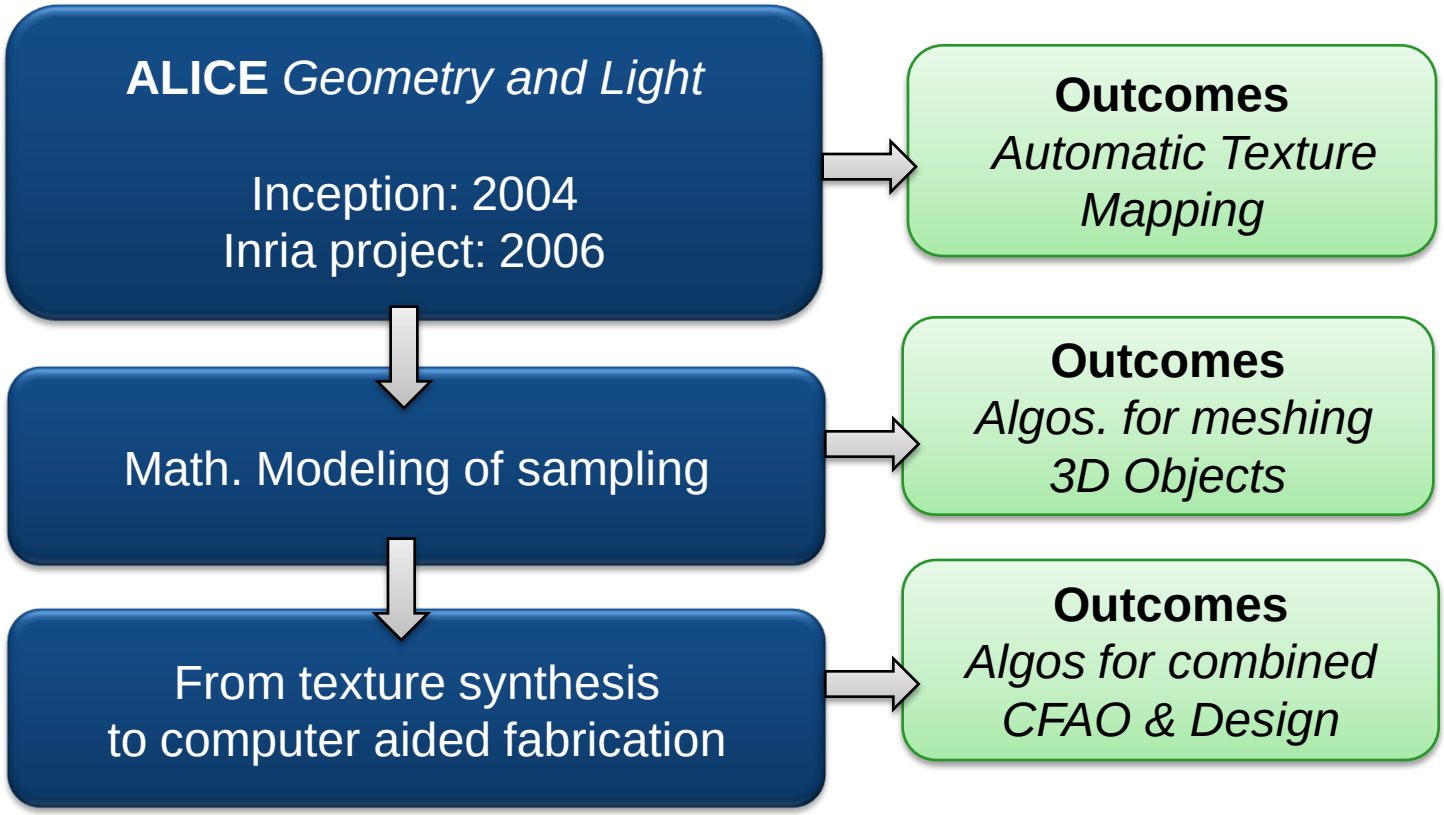
# The team - History



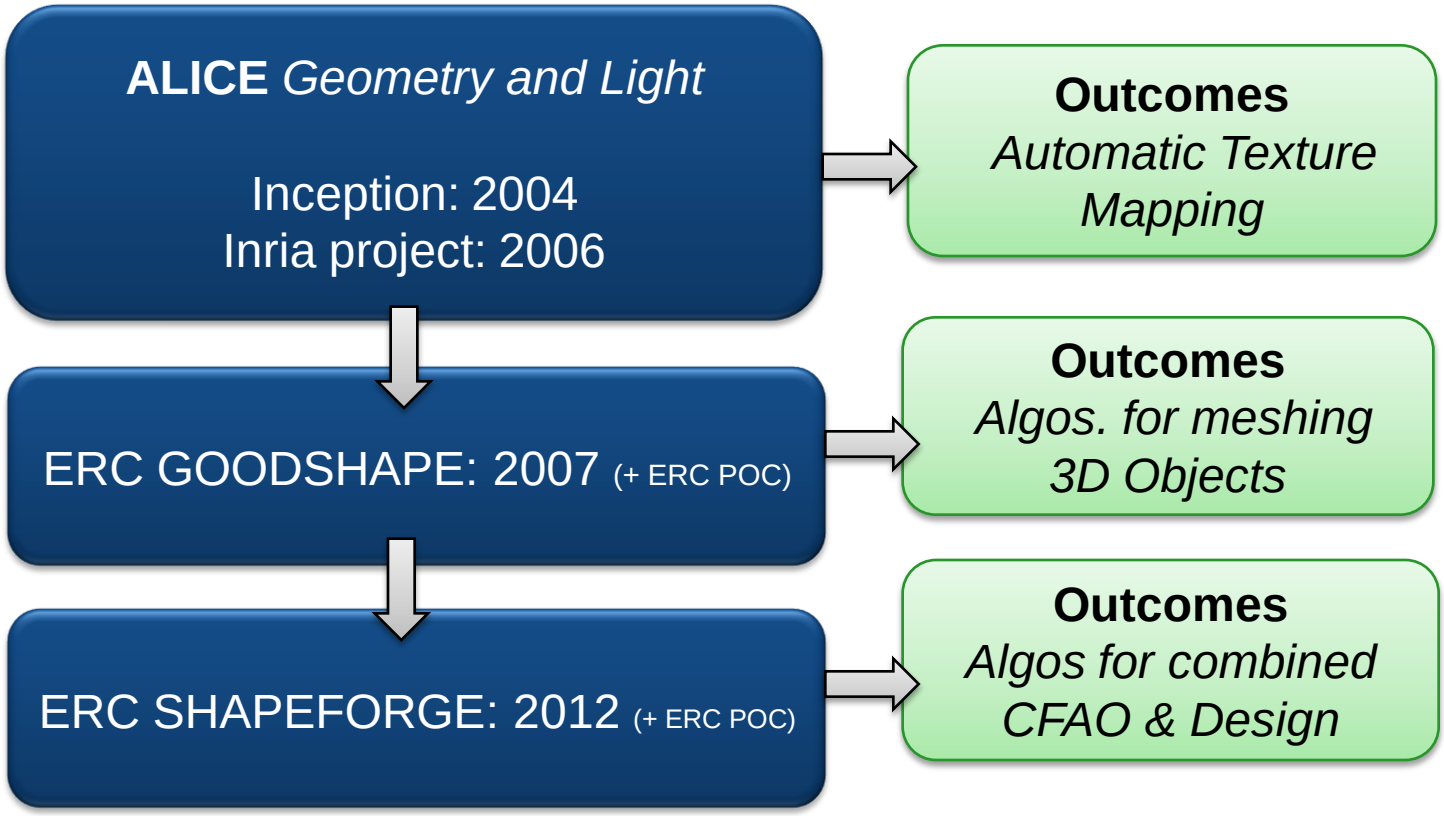
# The team - History



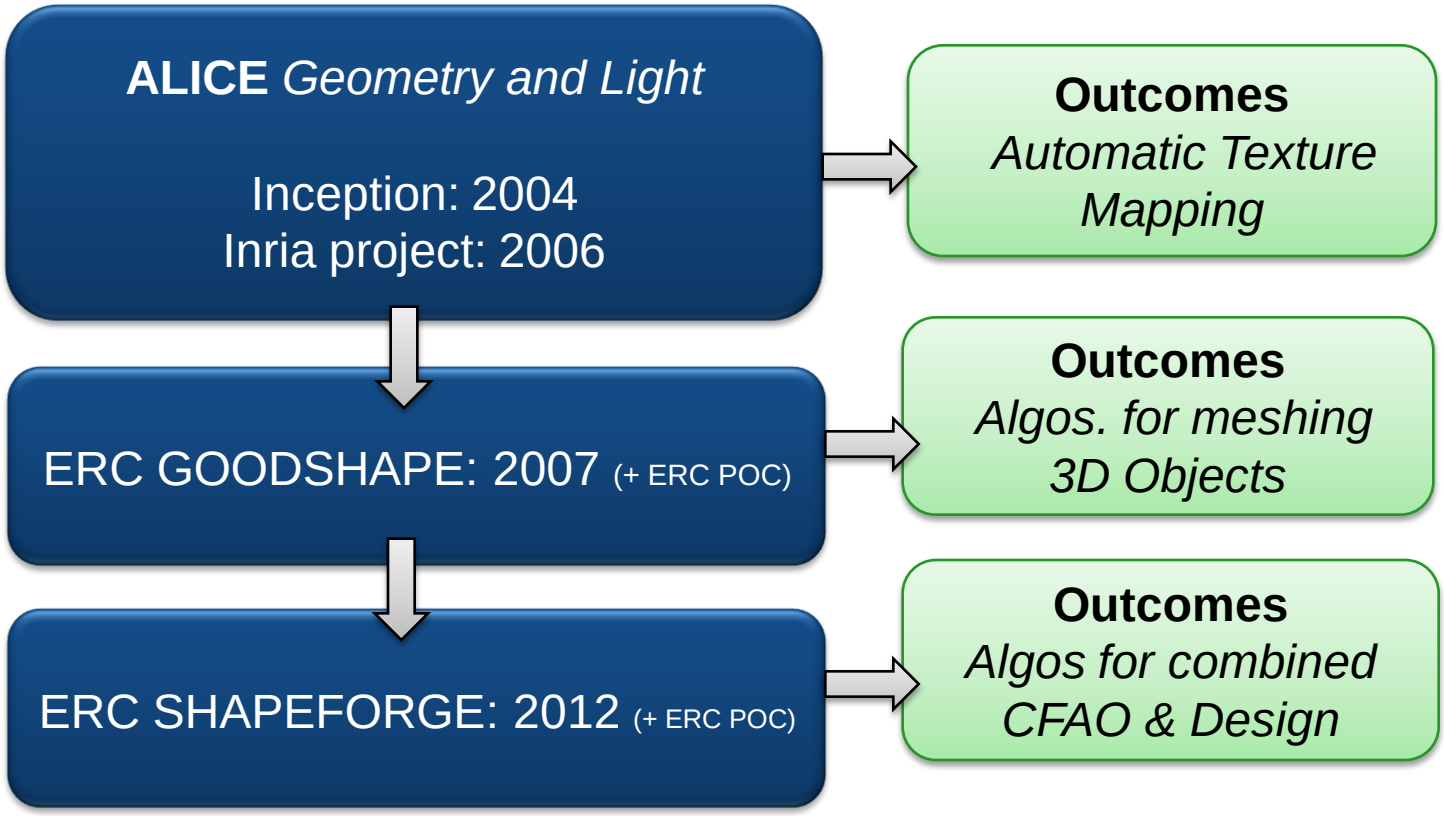
# The team - History



# The team - History



# The team - History




***Funding helped developing and structuring the team thematically***

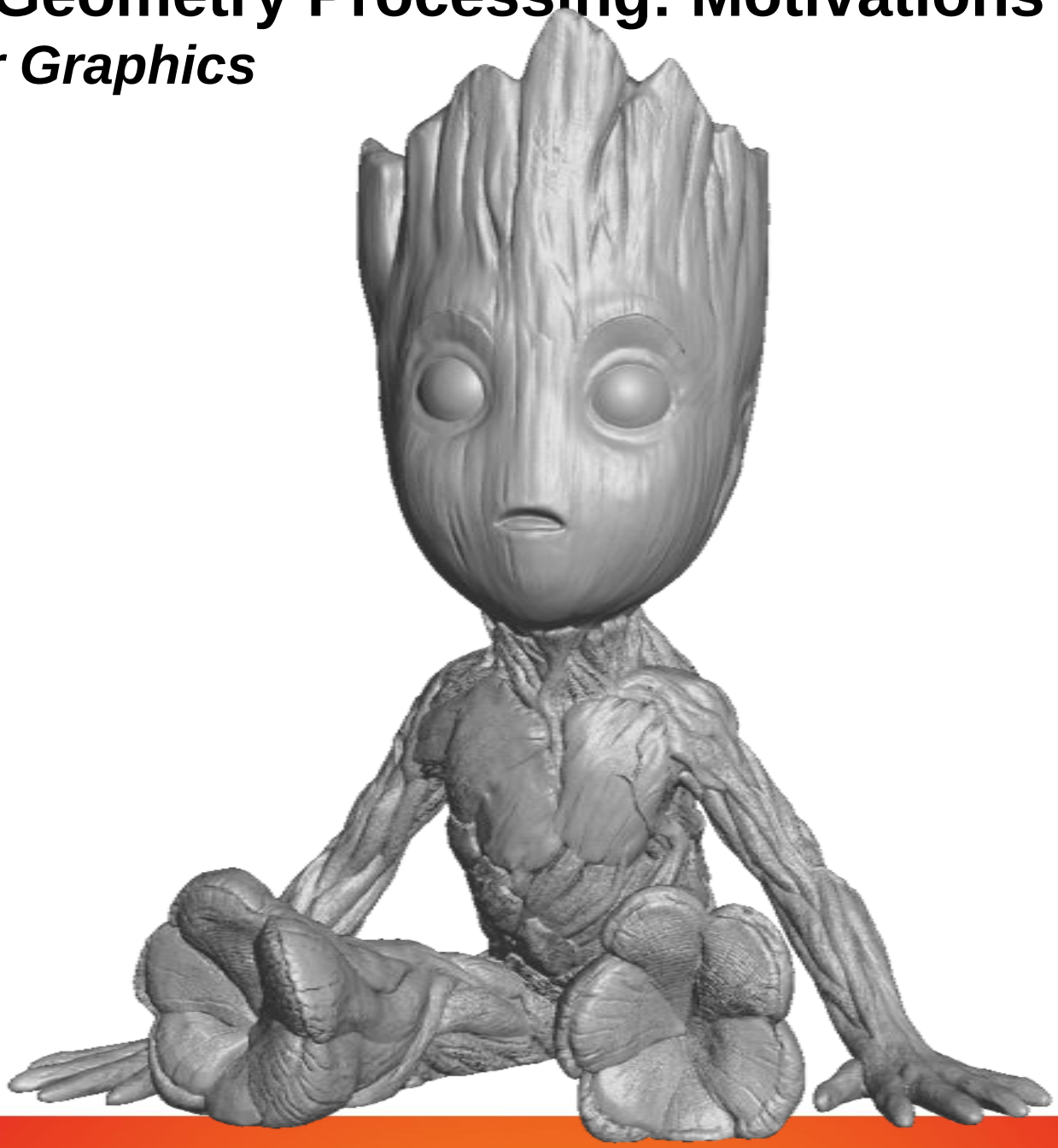
Axis 1: Geometry Processing

Axis 2: Computer Aided Fabrication

# Axis 1:
# Geometry Processing

# Axis 1 - Geometry Processing: Motivations

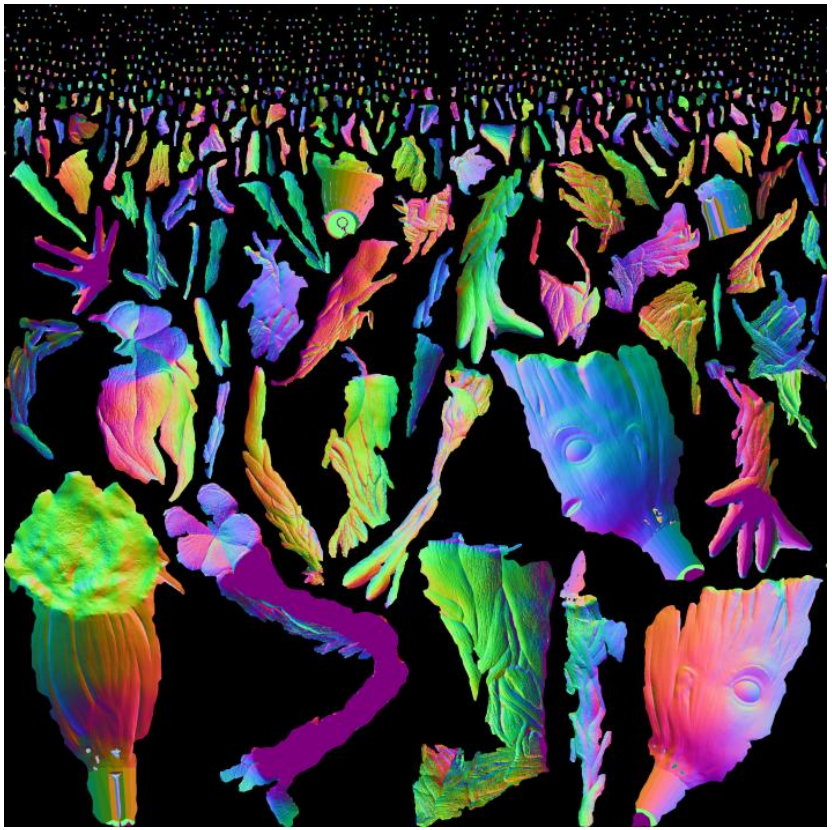
***Computer Graphics***

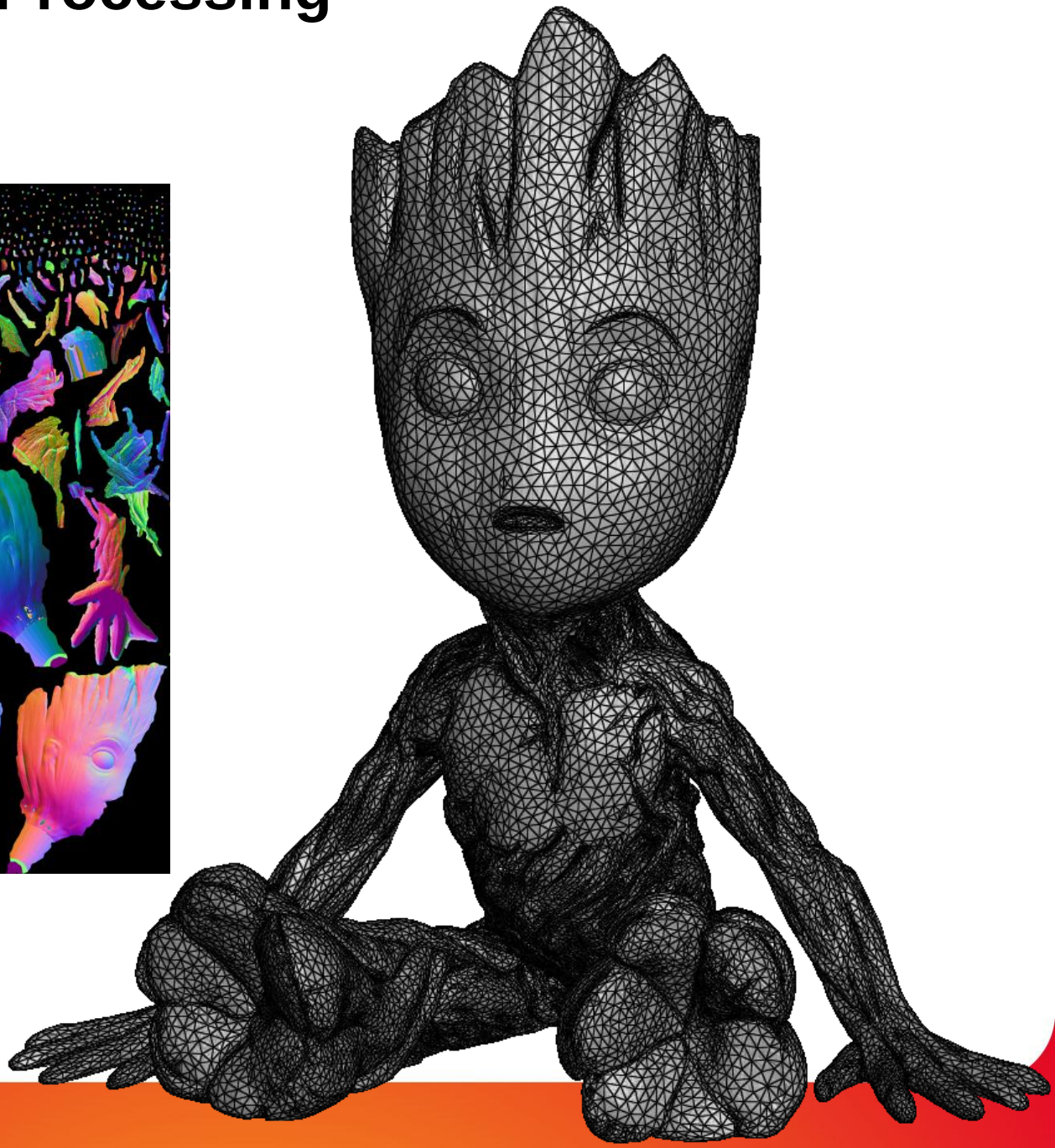


# Axis 1: Geometry Processing

## Motivations

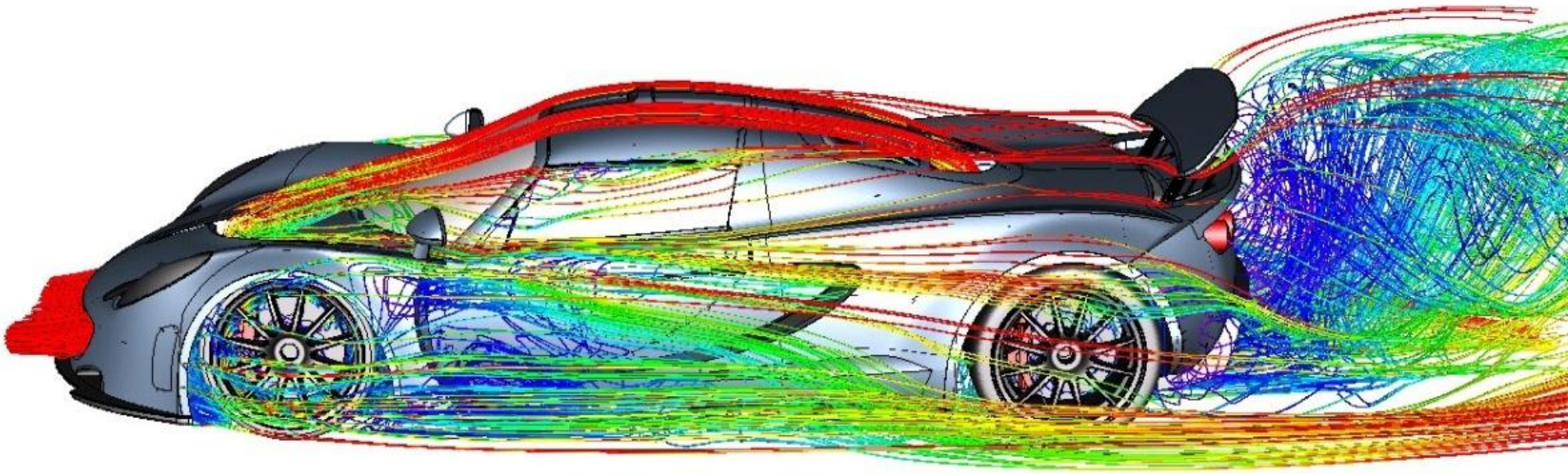
### *Computer Graphics*





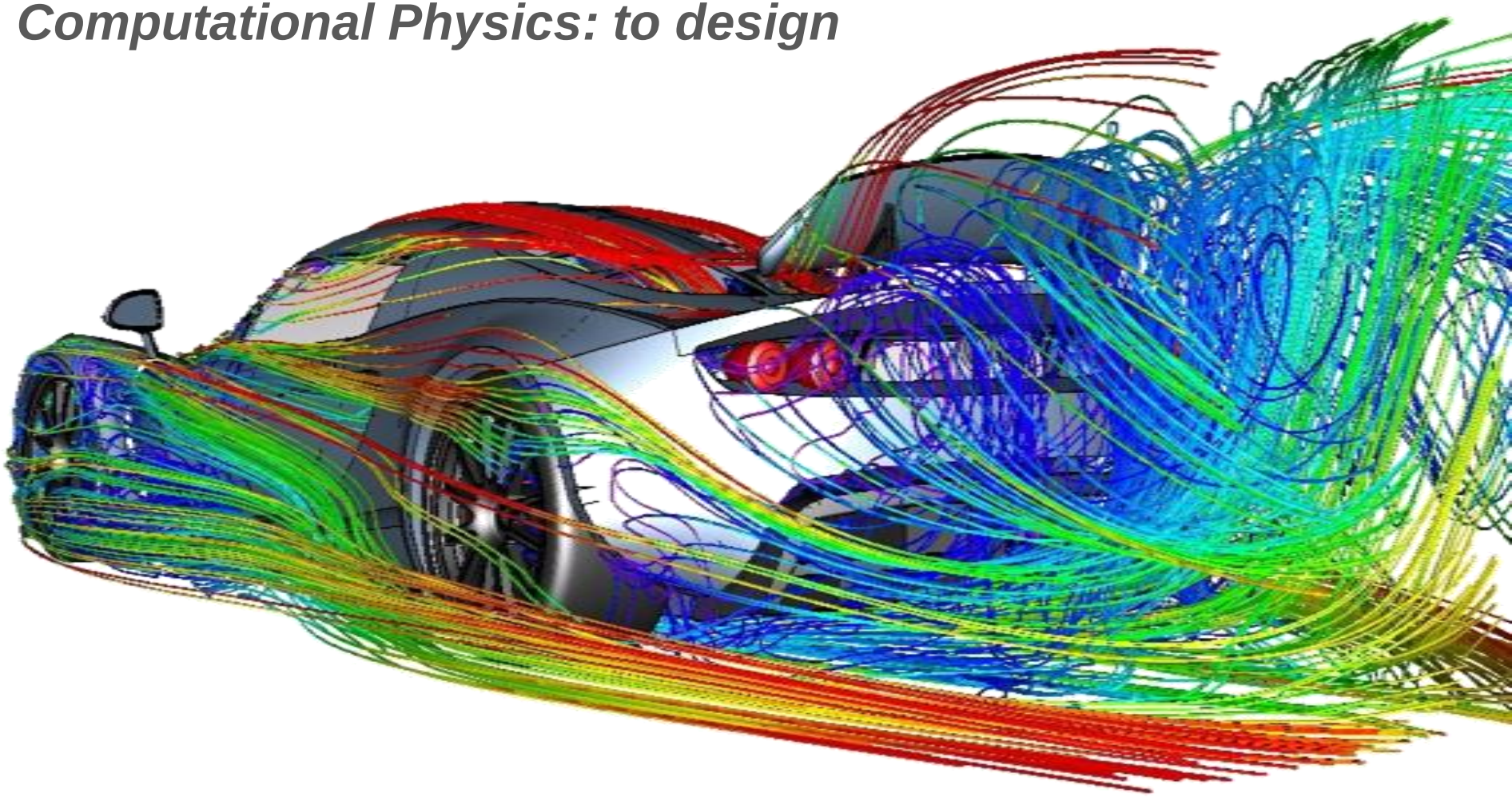
# Axis 1 - Geometry Processing: Motivations

## *Computational Physics: to design*



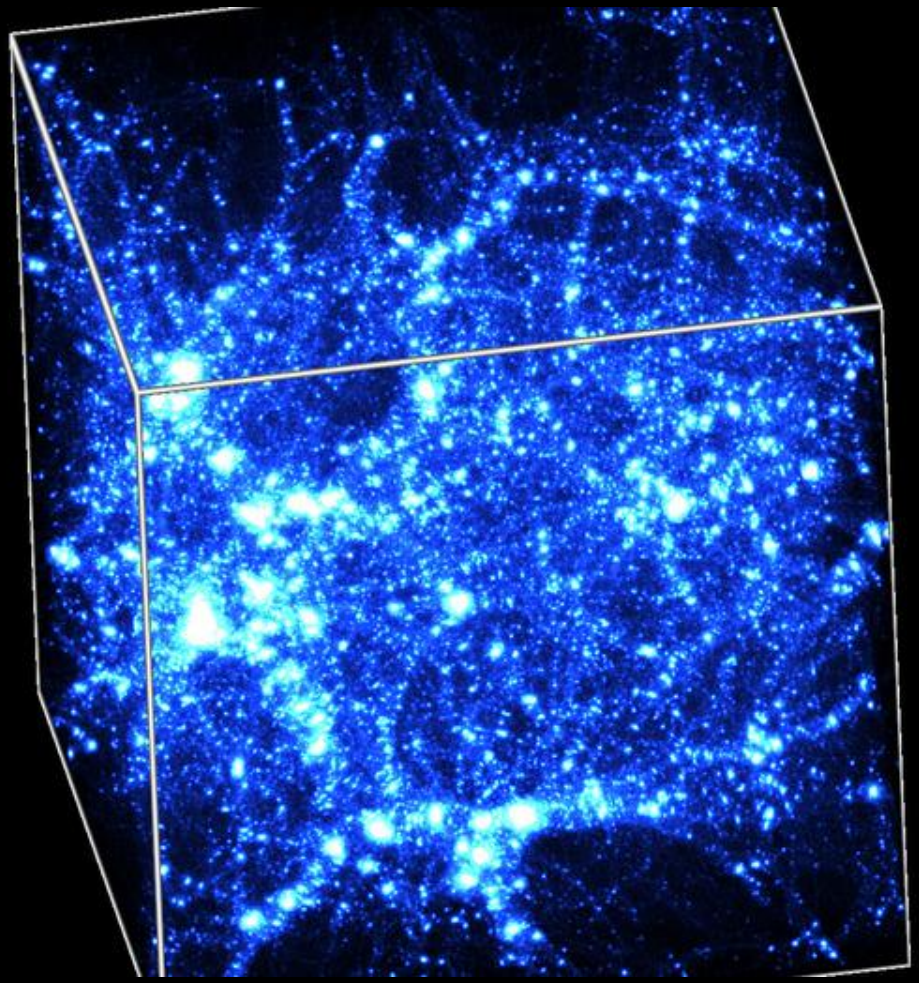
# Axis 1 - Geometry Processing: Motivations

## *Computational Physics: to design*



# Axis 1: Geometry Processing: Motivations

## *Computational Physics: to understand*

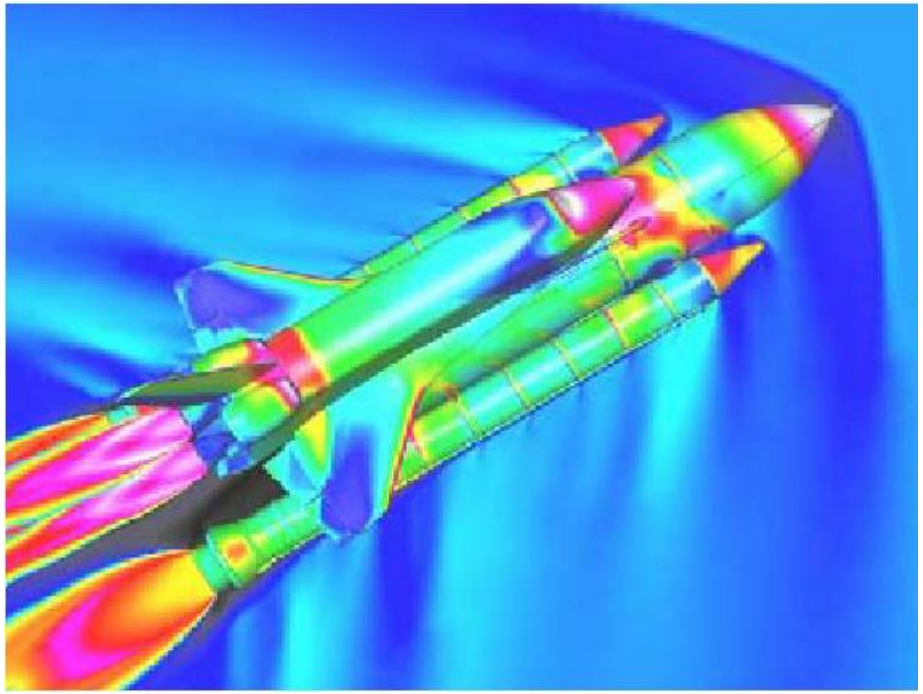


*Data: N-body simulation, R. Mohayaee, Instit. Astrophys. Paris*

# Axis 1: Geometry Processing: Motivations

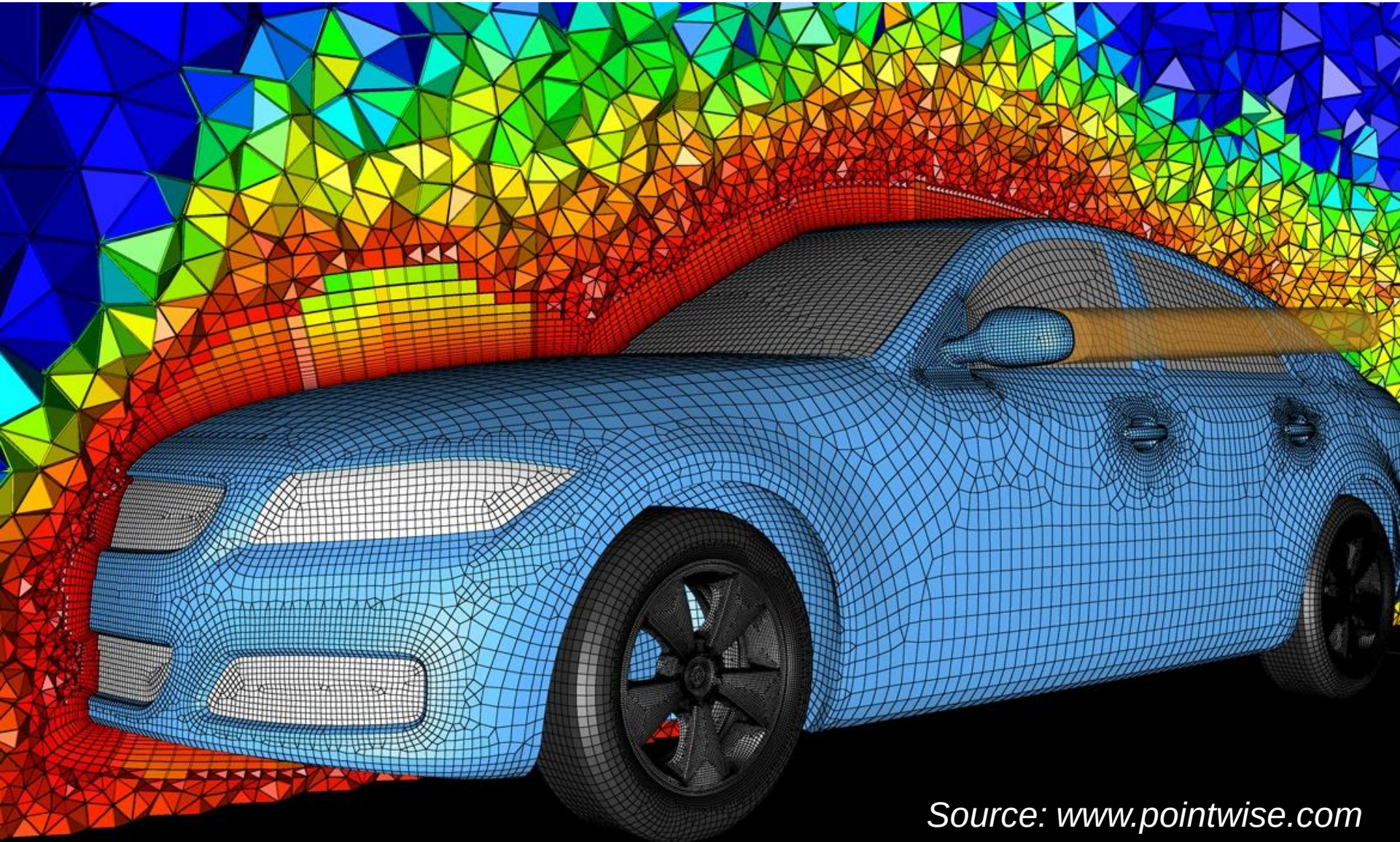
Computational Fluid Dynamics Vision 2030 Study
NASA report, 2014

Today, the generation of suitable meshes for CFD simulations about complex configurations constitutes **a principal bottleneck** in the simulation workflow process. Often the mesh generation phase constitutes **the dominant cost in terms of human intervention**.



# **Axis 1:** Geometry Processing: Motivations

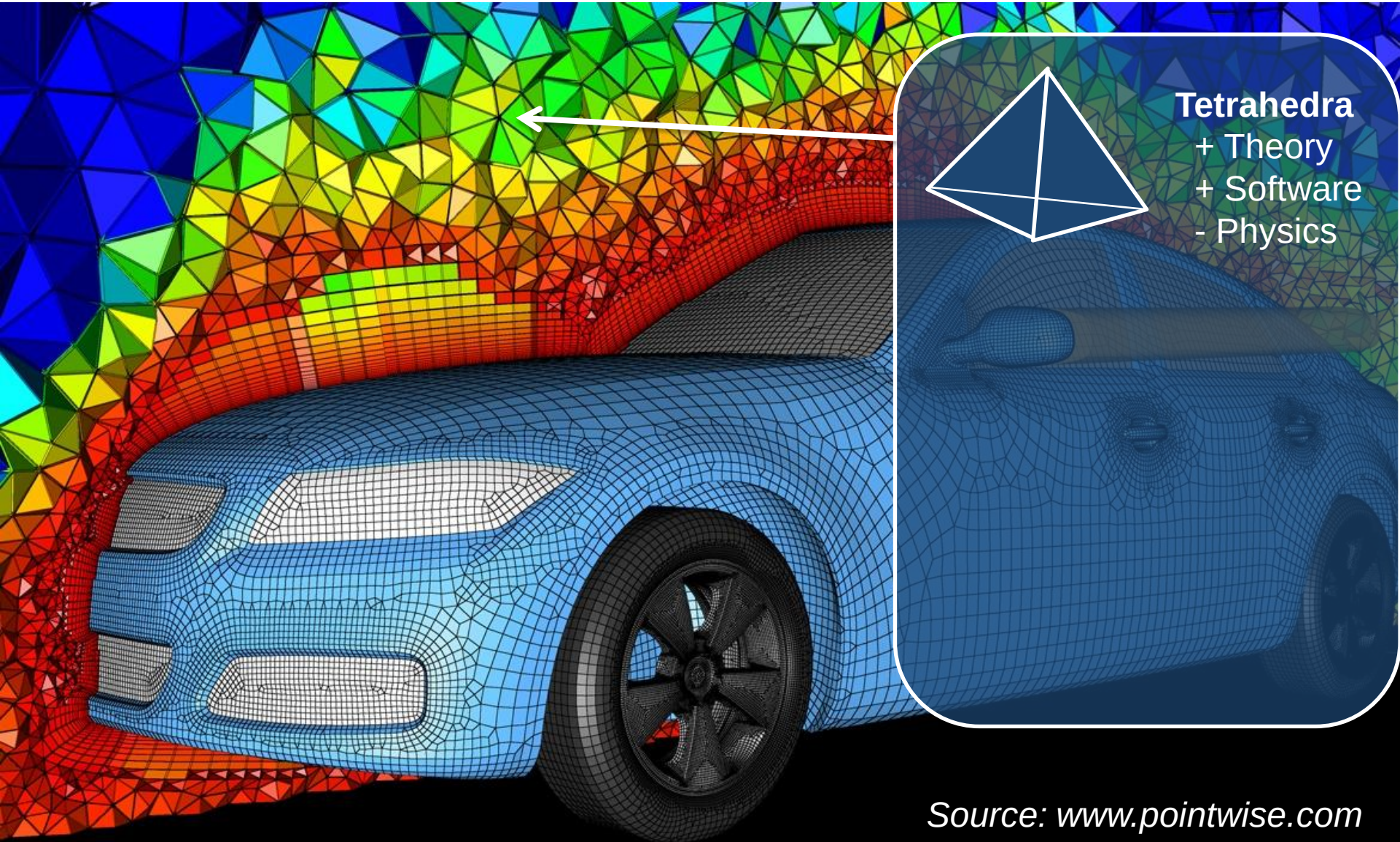
## *Meshing is a major difficulty*



*Source: www.pointwise.com*

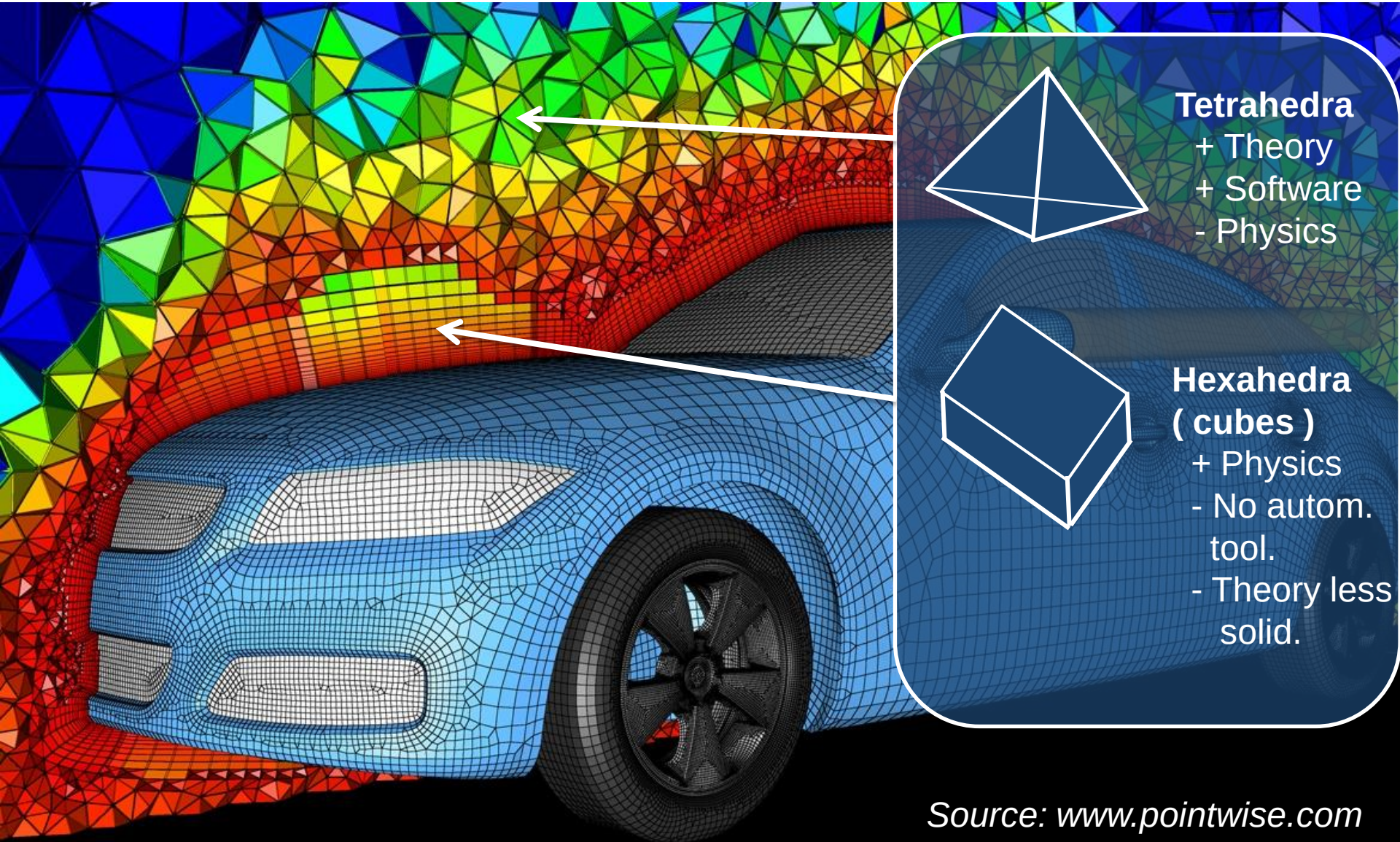
# **Axis 1:** Geometry Processing: Motivations

## *Meshing is a major difficulty*



# Axis 1: Geometry Processing: Motivations

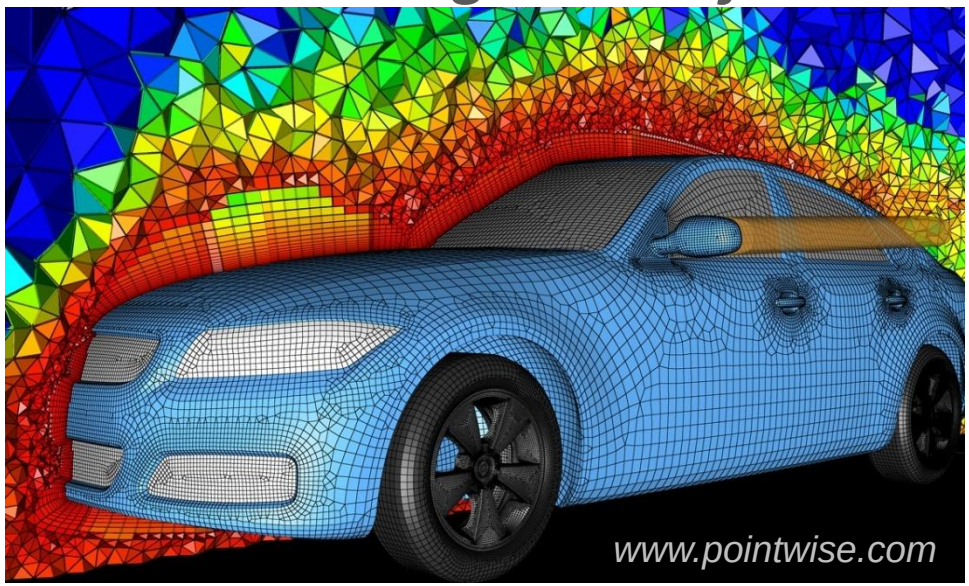
## *Meshing is a major difficulty*

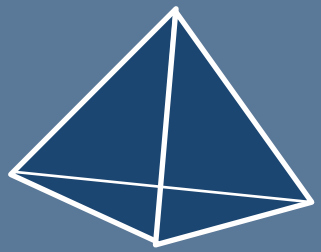



*Source: www.pointwise.com*

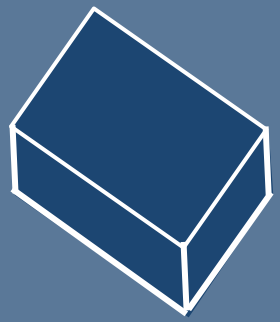
# Axis 1: Geometry Processing: Motivations

## *Meshing is a major difficulty*



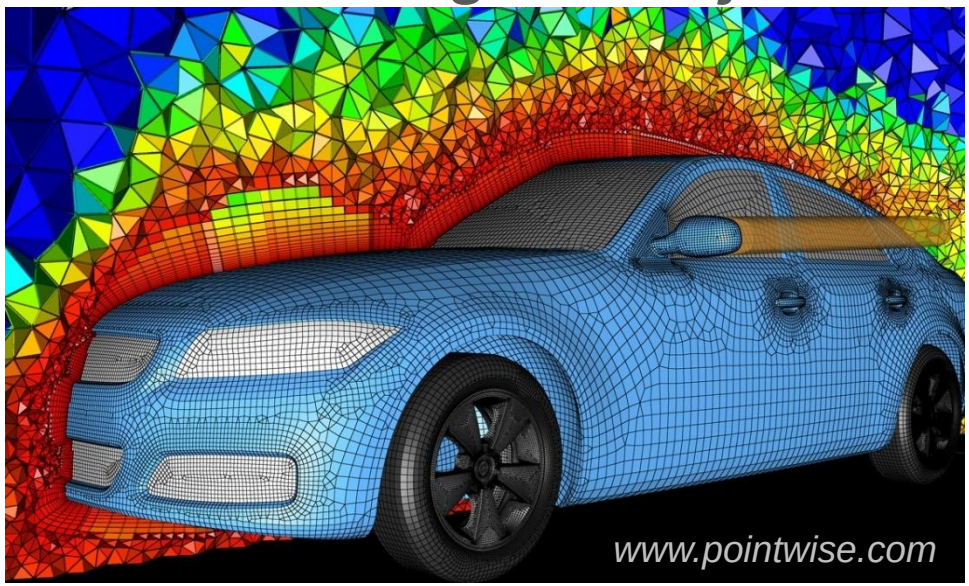
**Tetrahedra**
+ theory, soft
- Physics

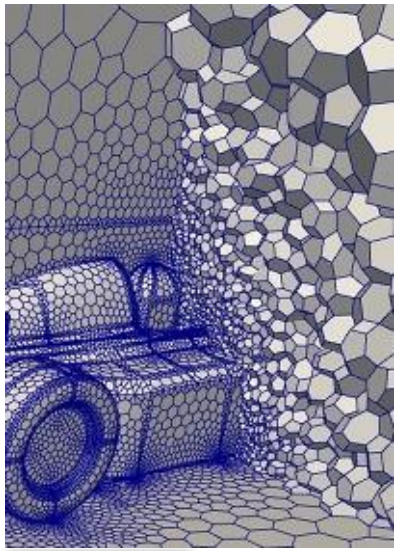


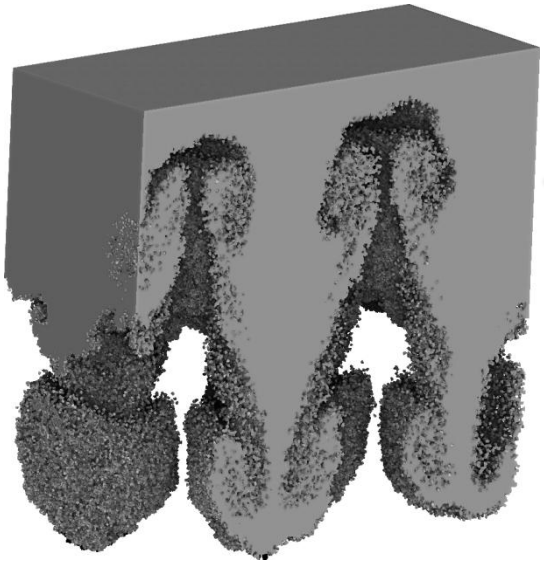
**Hexahedra**
+ Physics
- Theory, soft

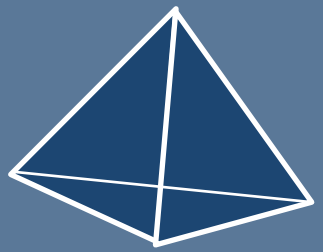
# Axis 1: Geometry Processing: Motivations

## *Meshing is a major difficulty*

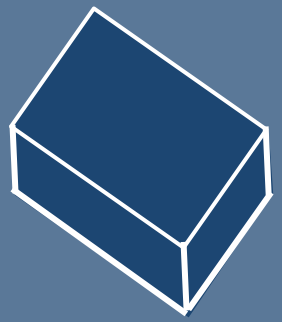


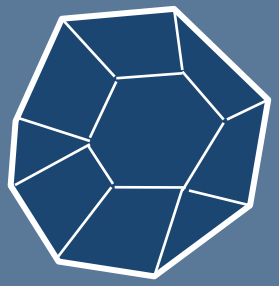




**Tetrahedra**
+ theory, soft
- Physics



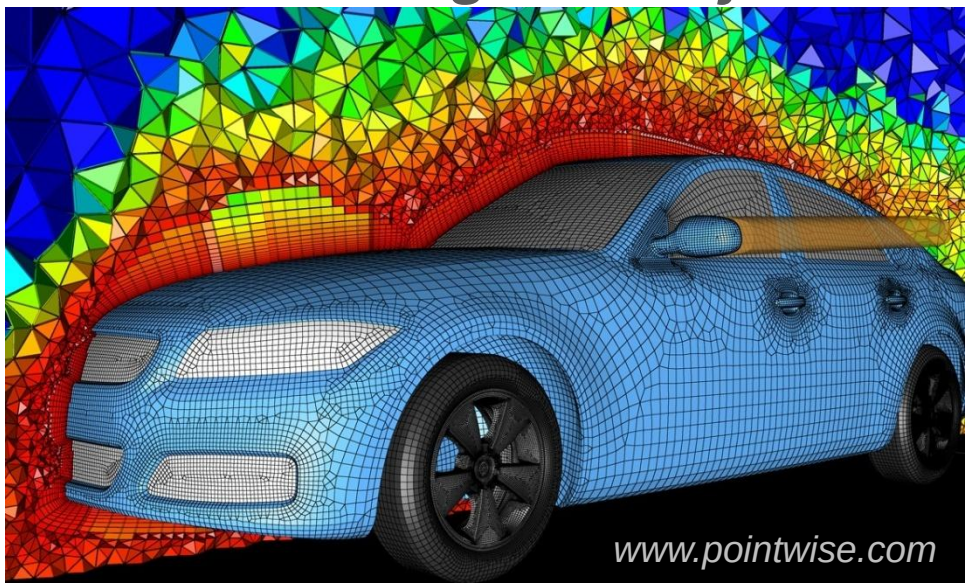
**Hexahedra**
+ Physics
- Theory, soft

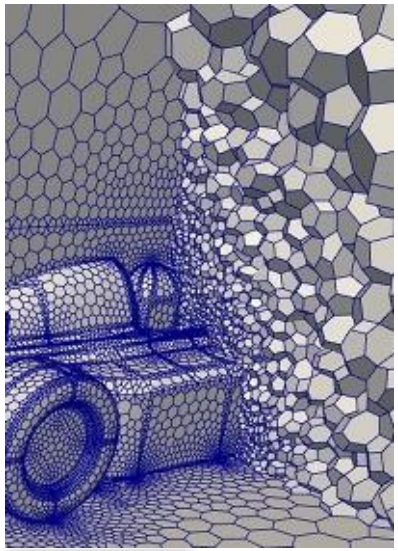


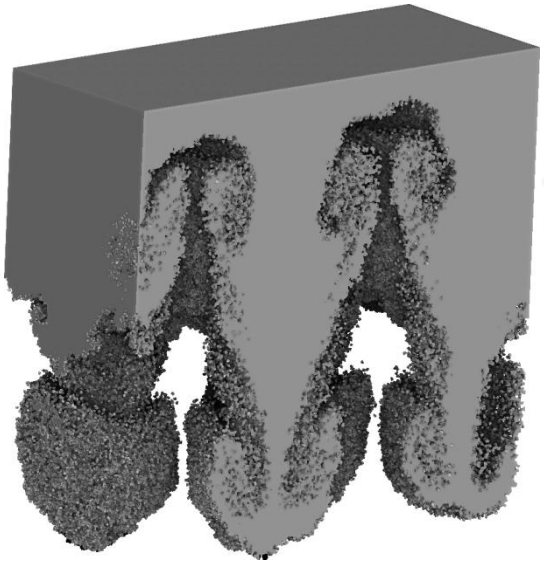
**Polyhedra (Dynamic)**
+ Physics
+ Theory
+ Topology
- Algo.

# Axis 1: Geometry Processing: Motivations

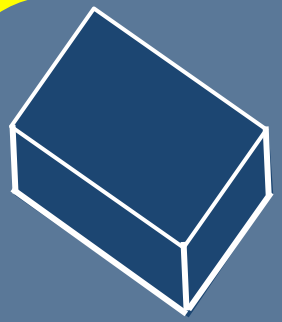
## *Meshing is a major difficulty*



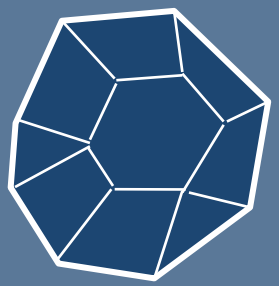





**Tetrahedra**
+ theory, soft
- Physics



**Hexahedra**
+ Physics
- Theory, soft



**Polyhedra (Dynamic)**
+ Physics
+ Theory
+ Topology
- Algo.

# Axis 1: Geometry Processing

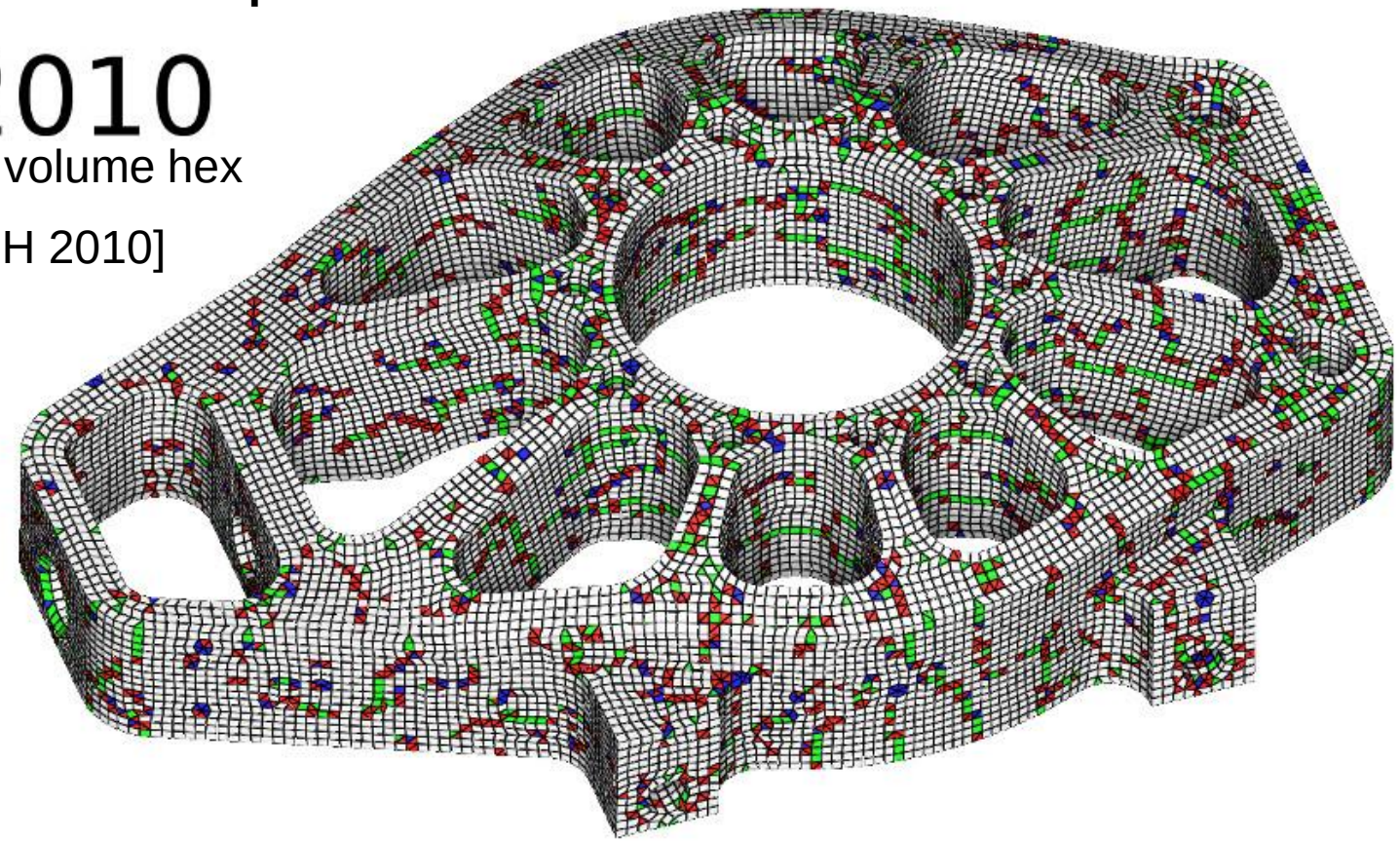
## *Selected result: automatic hexahedral dominant meshing*

Our results: **LpCVT**

2010

70% volume hex

[SIGGRAPH 2010]



# Axis 1: Geometry Processing

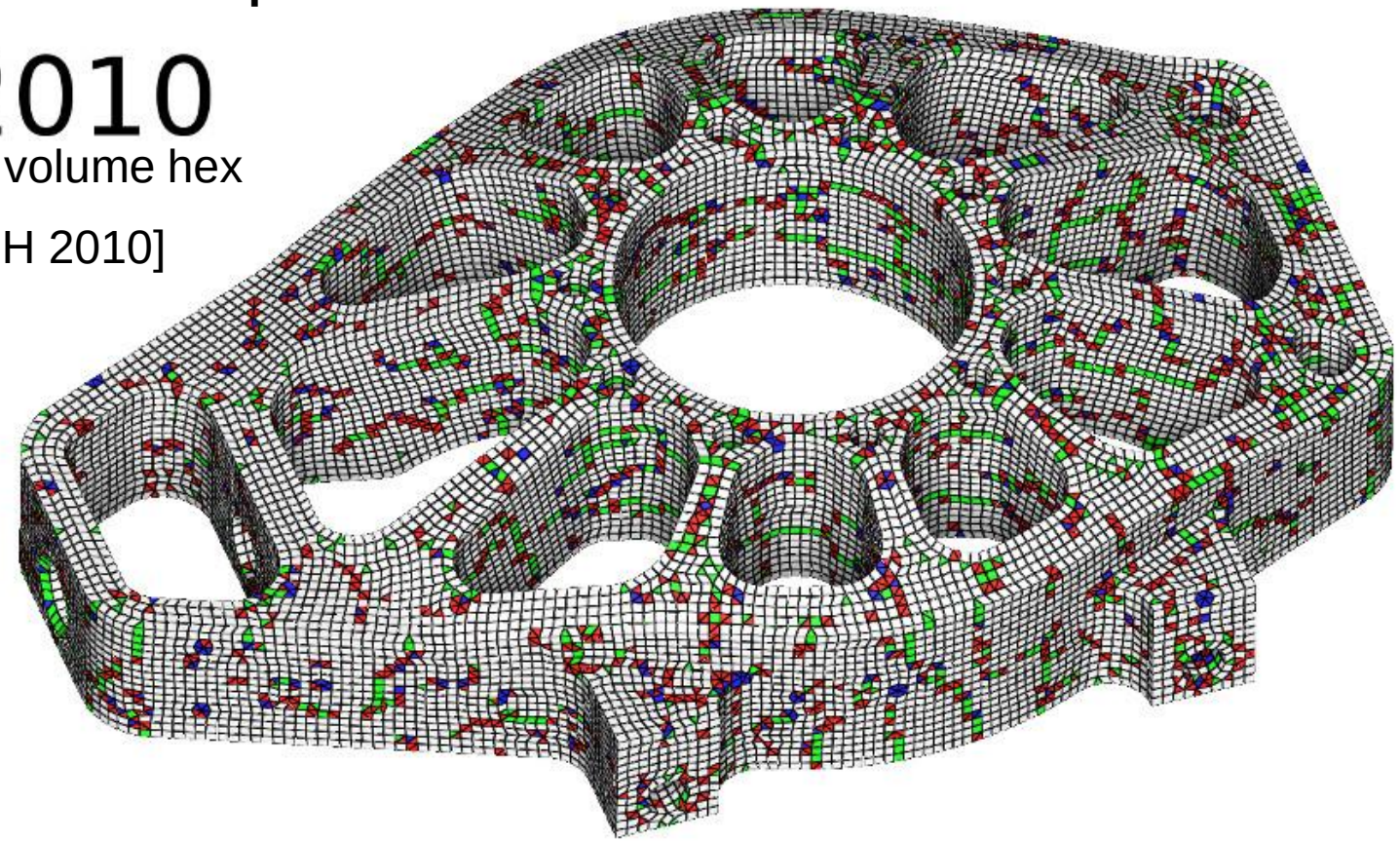
## *Selected result: automatic hexahedral dominant meshing*

Our results: **LpCVT**

2010

70% volume hex

[SIGGRAPH 2010]



***LpCVT cited in [2018 Aerospace Sciences Meeting], used in NASA AMES***

**[Ekelschot, Ceze, Garai, Murman] (anisotropic mesh adaptation for flow sim.)**

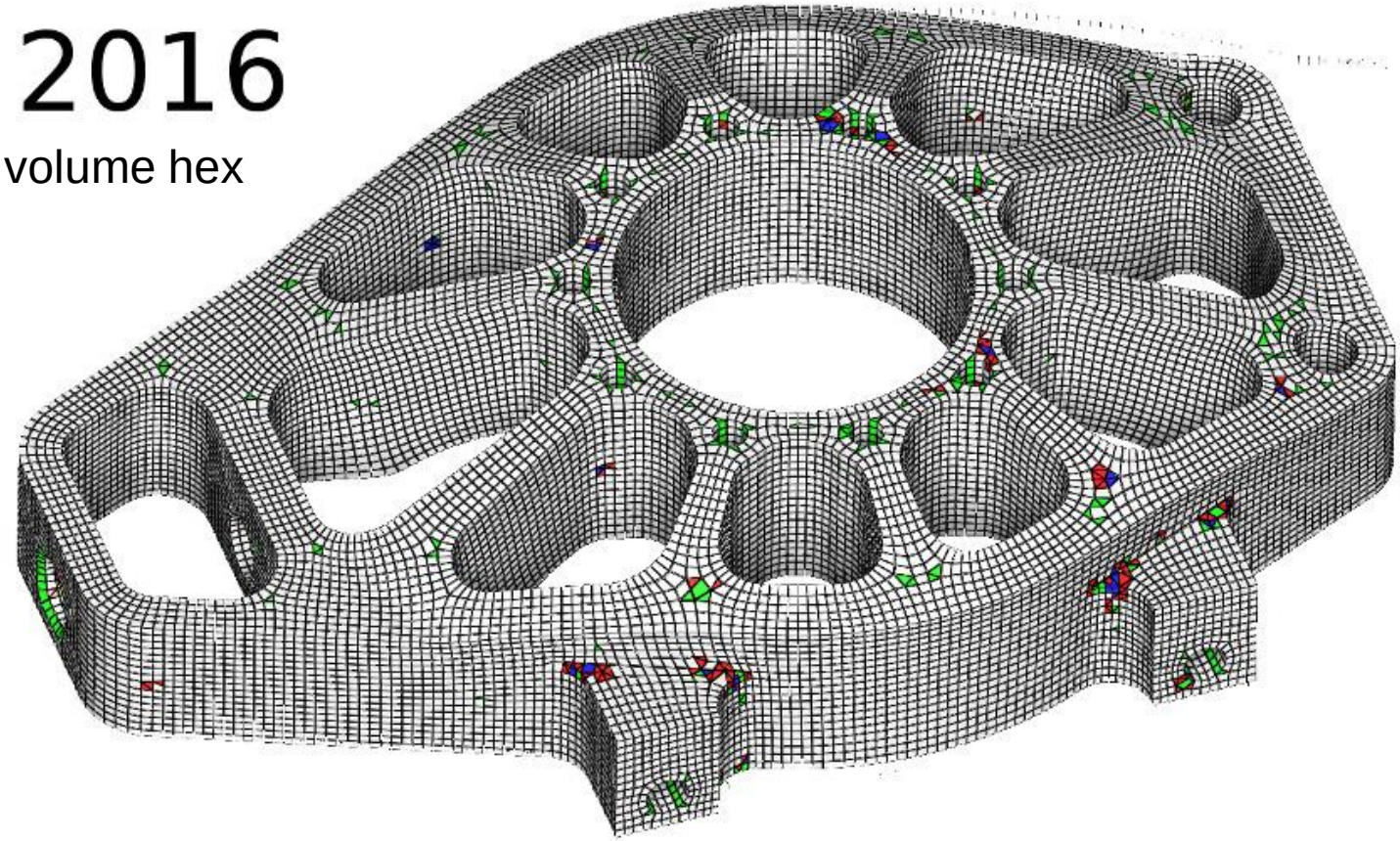
# Axis 1: Geometry Processing

## *Selected result: automatic hexahedral dominant meshing*

Our results:

2016

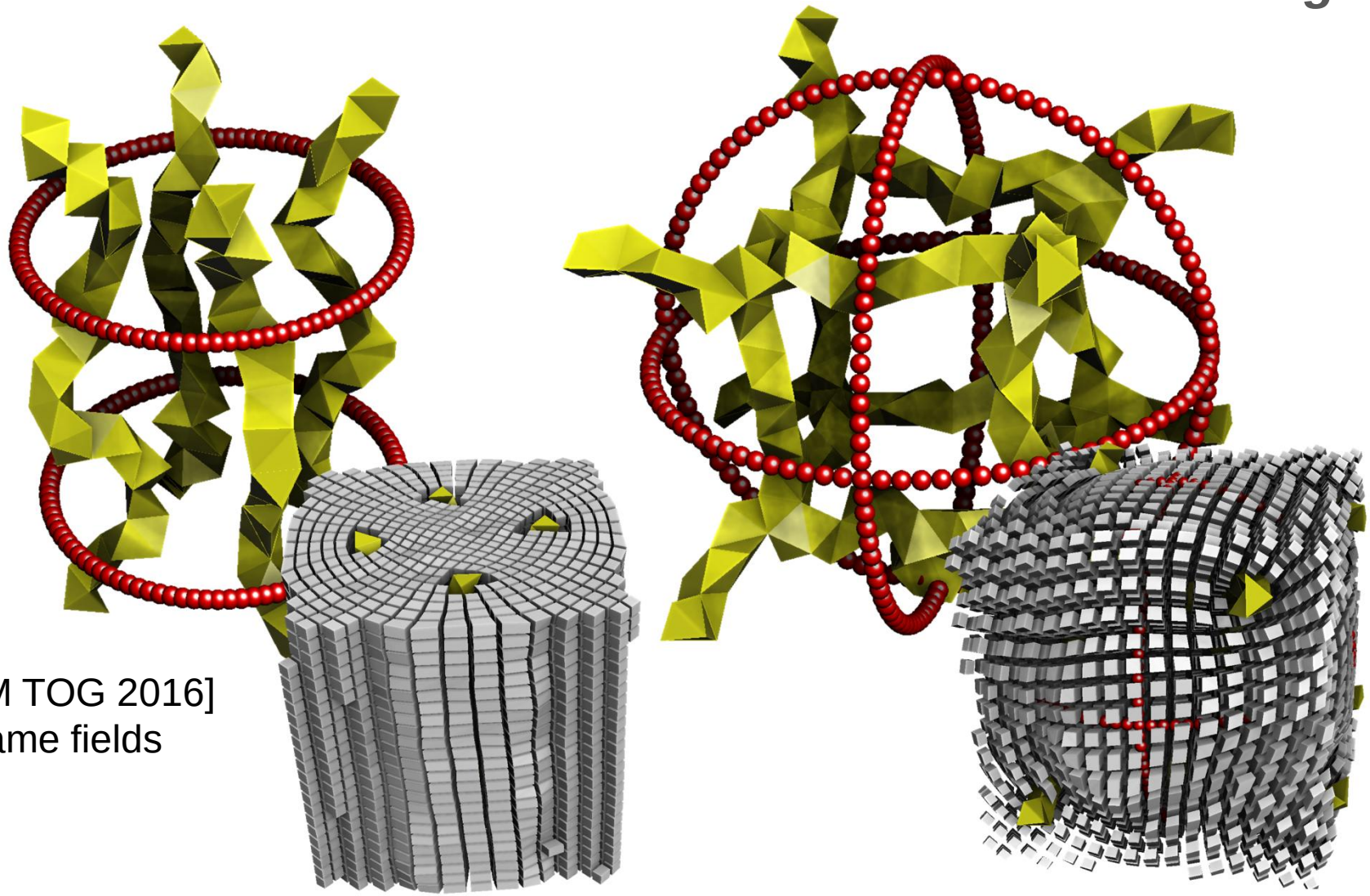
98% volume hex



Colored: non-hexahedral elements

# Axis 1: Geometry Processing

## *Selected result: automatic hexahedral dominant meshing*

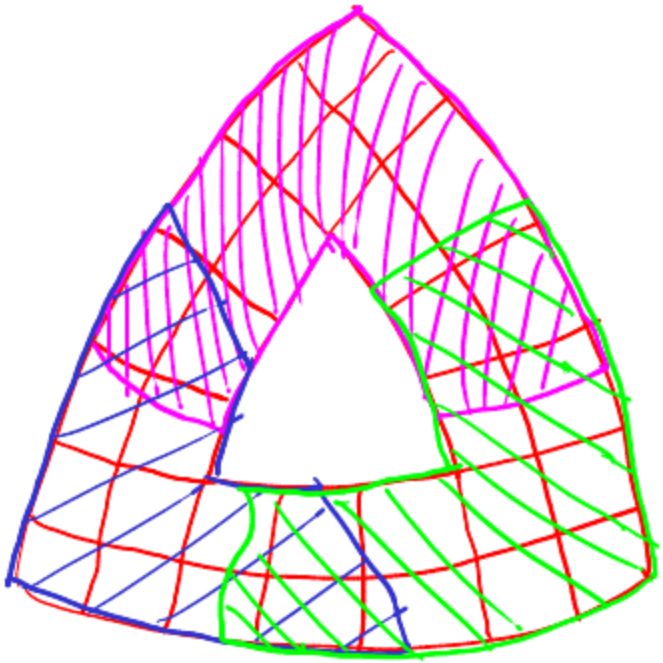


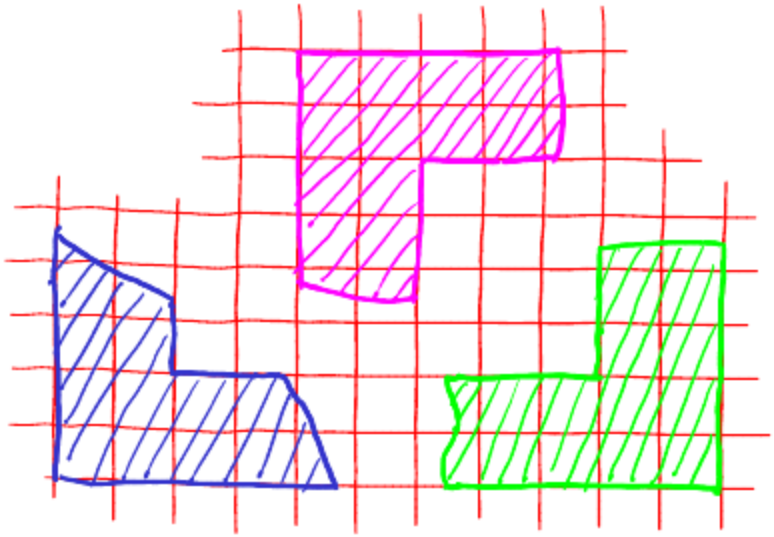
[ACM TOG 2016]
Frame fields

Direction fields in 3D and periodic coordinates

# Axis 1: Geometry Processing

## *Selected result: automatic hexahedral dominant meshing*



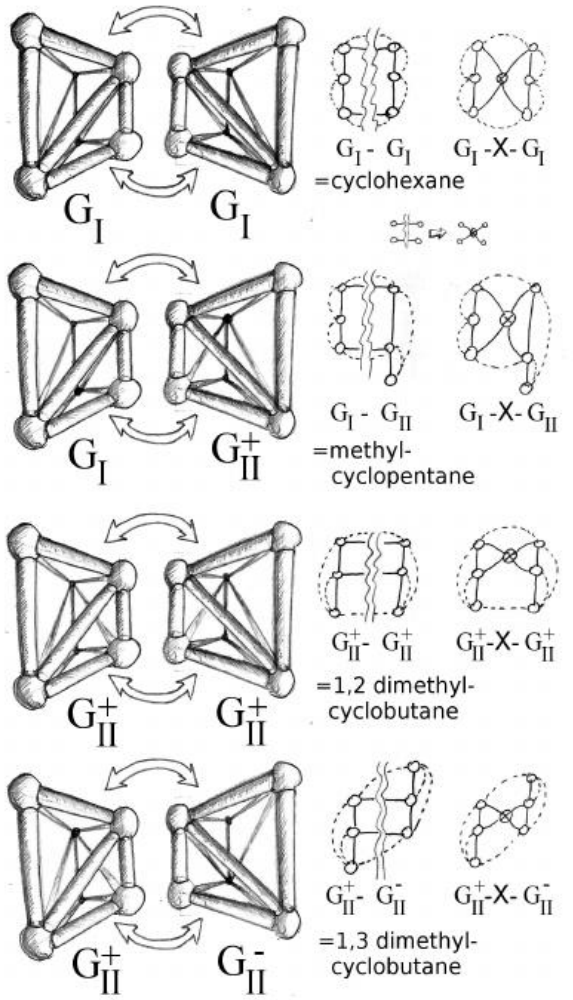


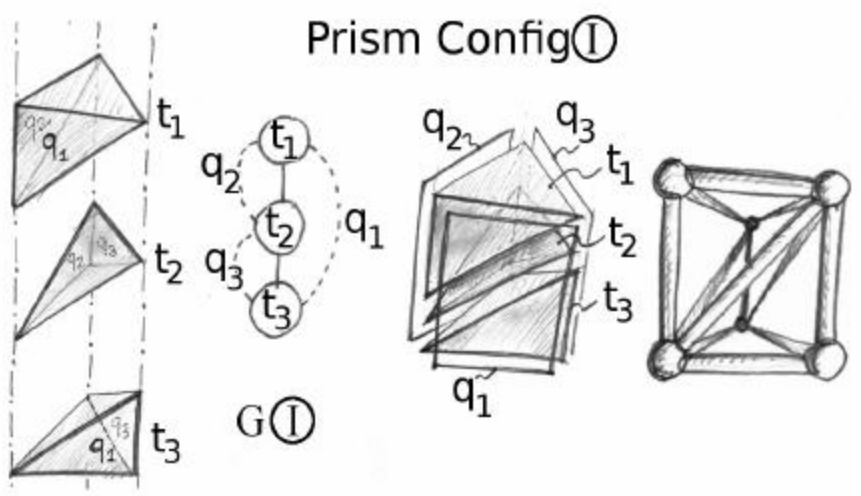
[ACM TOG 2016] 3D Periodic Global Parameterization

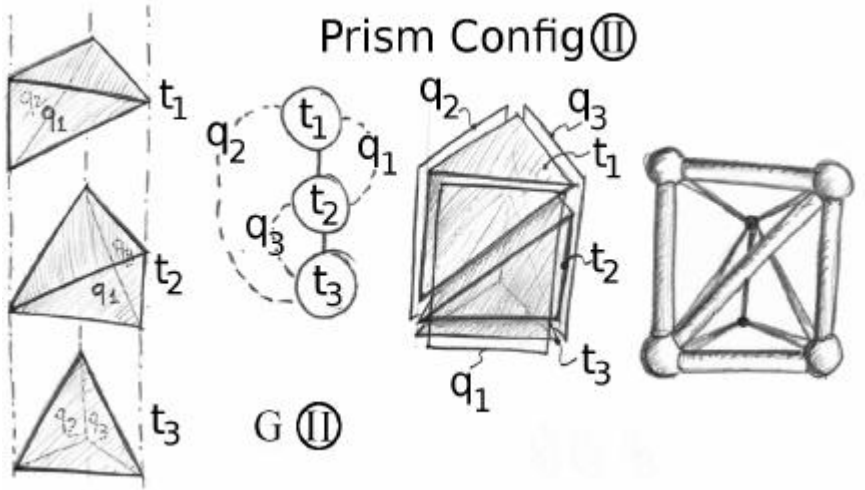
Local parameterization charts, periodic coords.

# Axis 1: Geometry Processing

## *Selected result: automatic hexahedral dominant meshing*



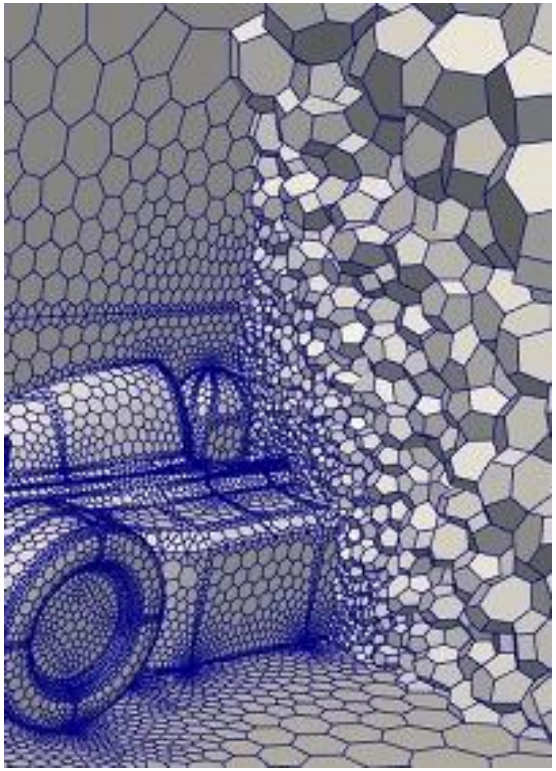



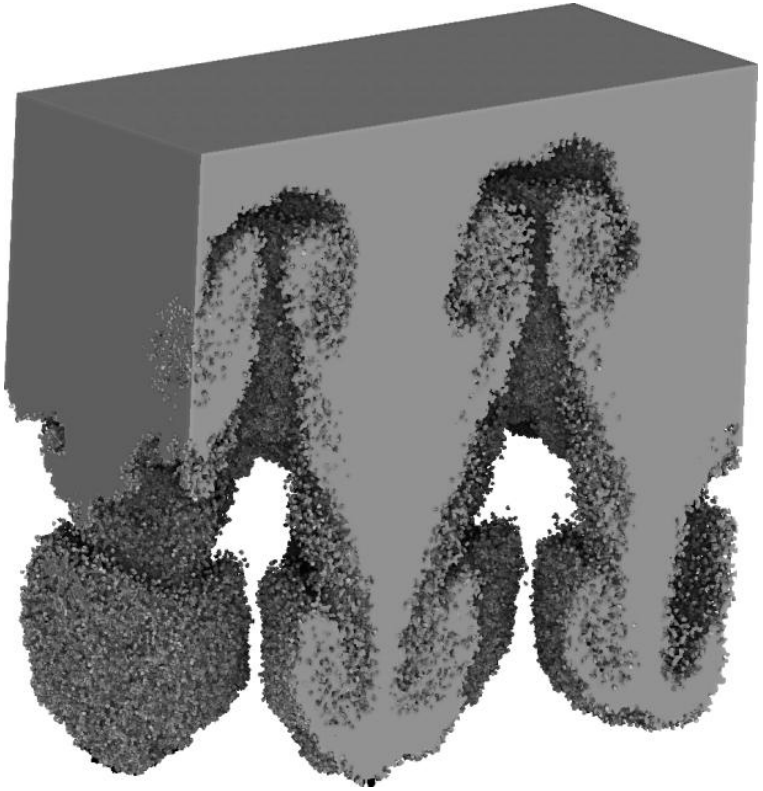




Recognizing hexahedra in tet meshes.

# Axis 1: Geometry Processing

## *non-conventional discretizations*





# Axis 1: Geometry Processing

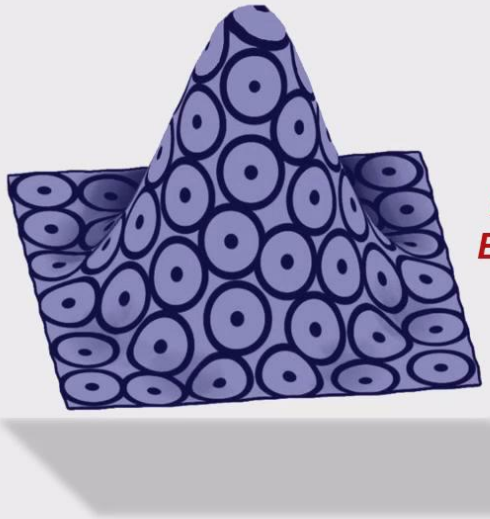
*non-conventional discretizations*

# Axis 1: Geometry Processing

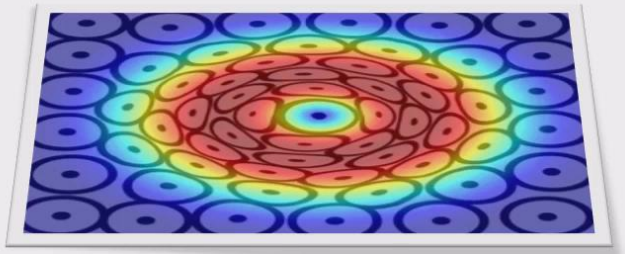
## *Selected result: Anisotropic Voronoi Diagrams*

**Nash Embedding Theorem**

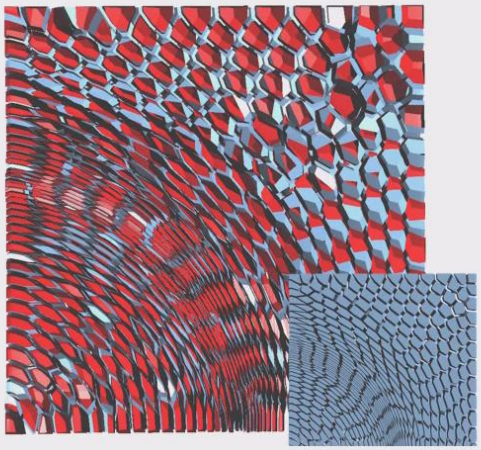
$$\frac{m(3m+11)}{2}$$



*Higher dimensional Euclidean embedded manifold*



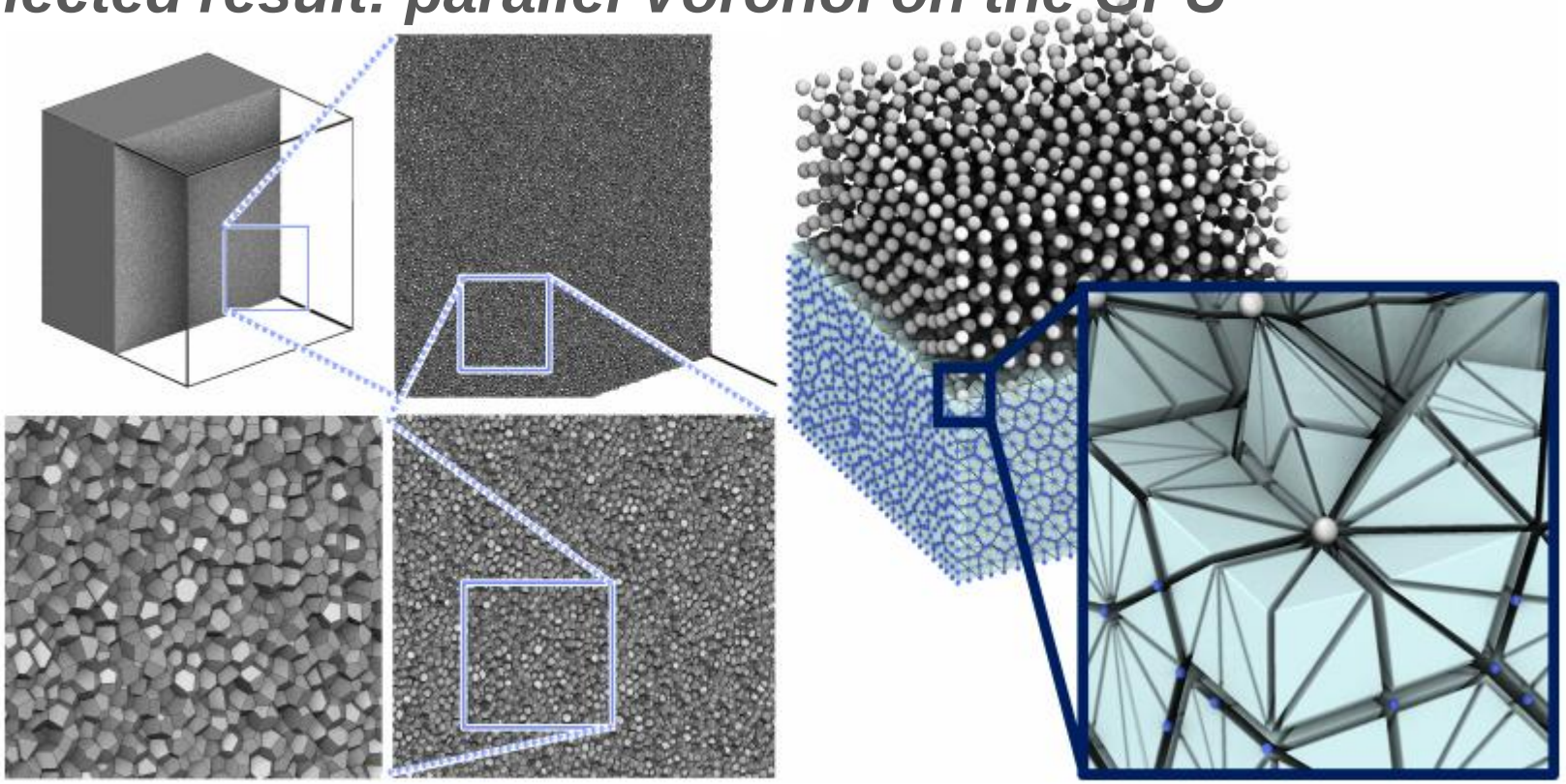
*Original Riemannian manifold*



**[SIGGRAPH 2018]**

# Axis 1: Geometry Processing

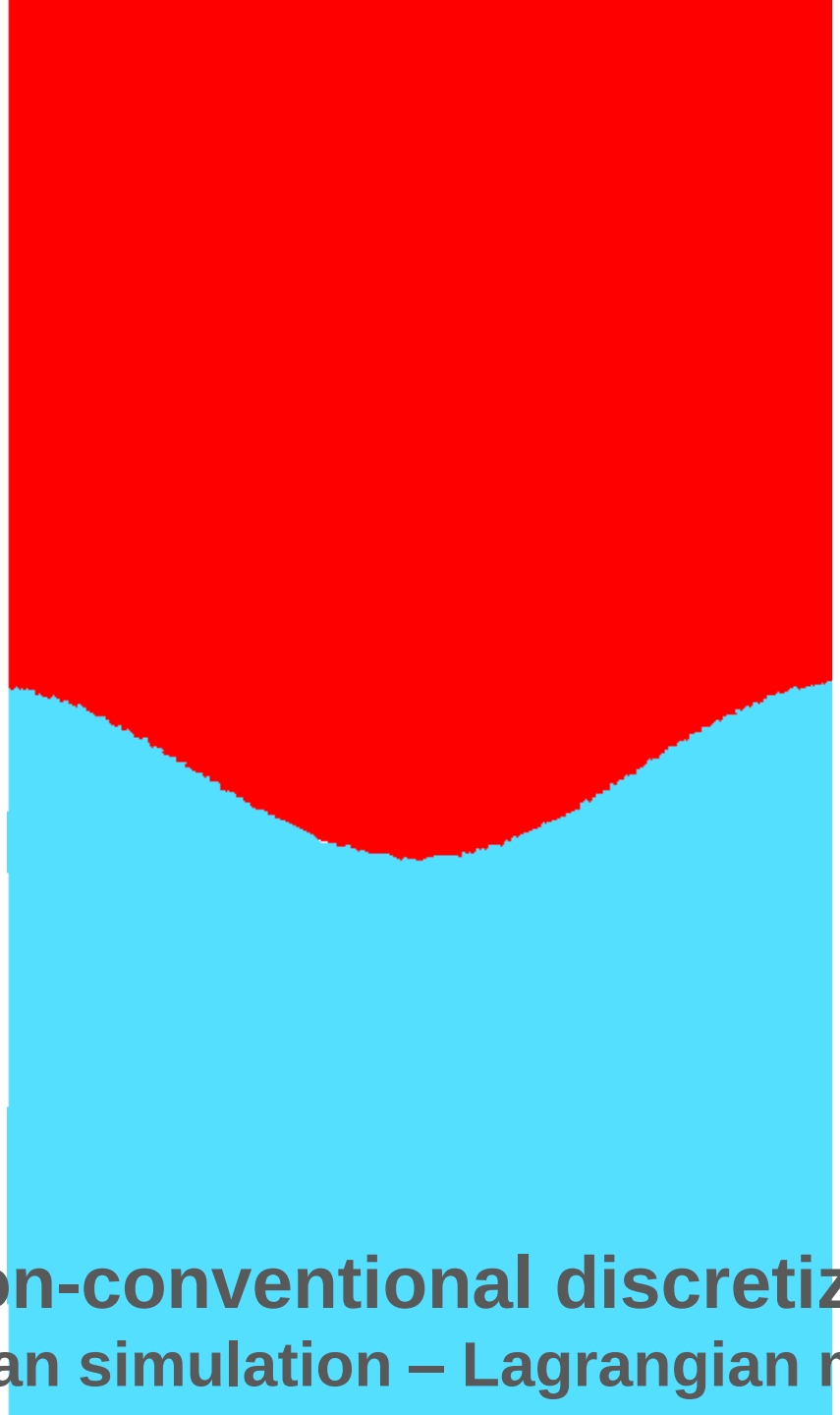
## *Selected result: parallel Voronoi on the GPU*



[Siggraph ASIA 2018]: Fast Voronoi diagrams on the GPU

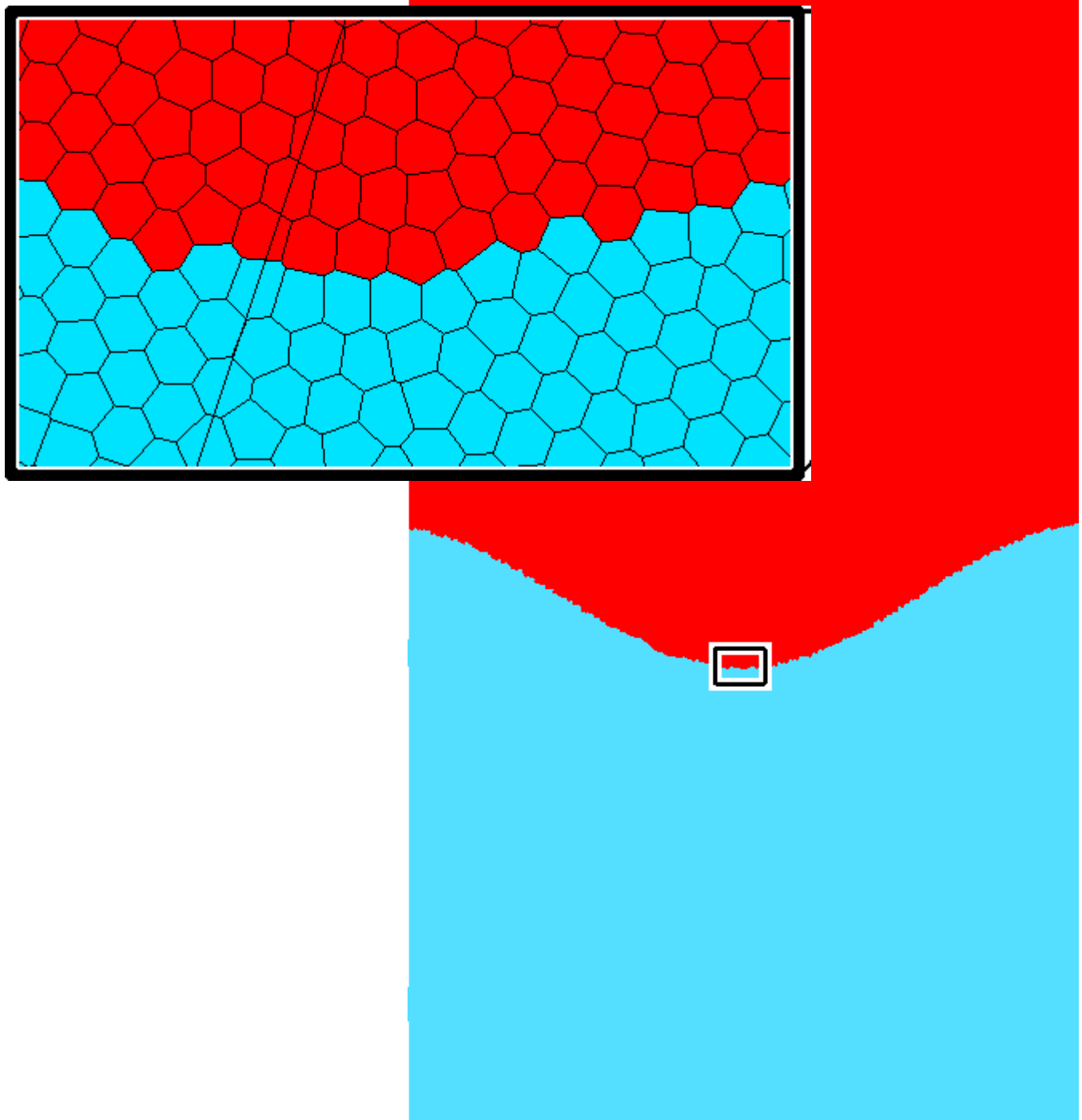
Tracking interfaces
Non-mixing fluids
Free surface

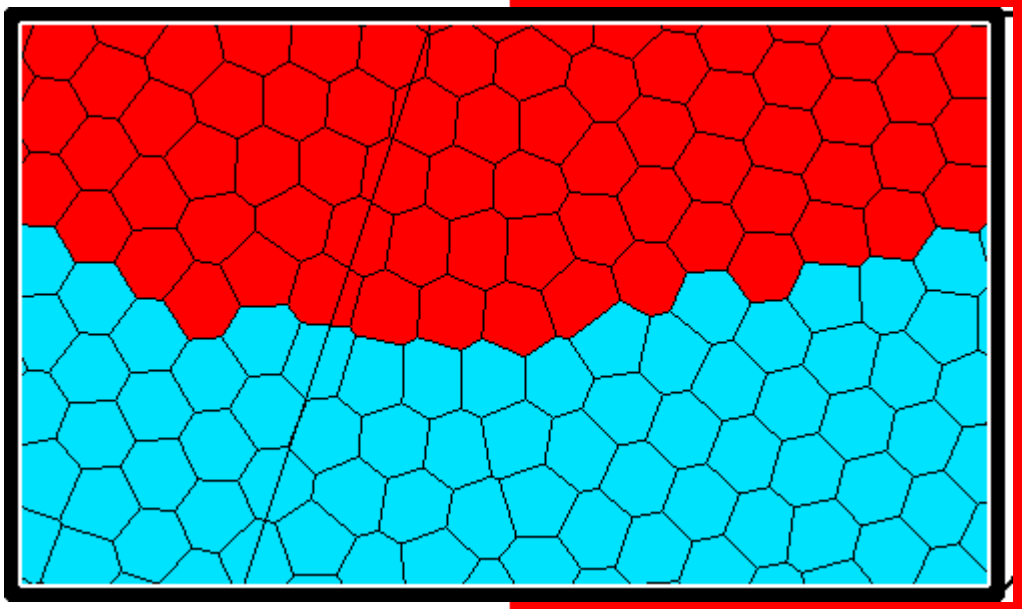
[Gallouet-Merigot]
[De-Goes-Desbrun]



# Axis 1: Non-conventional discretizations

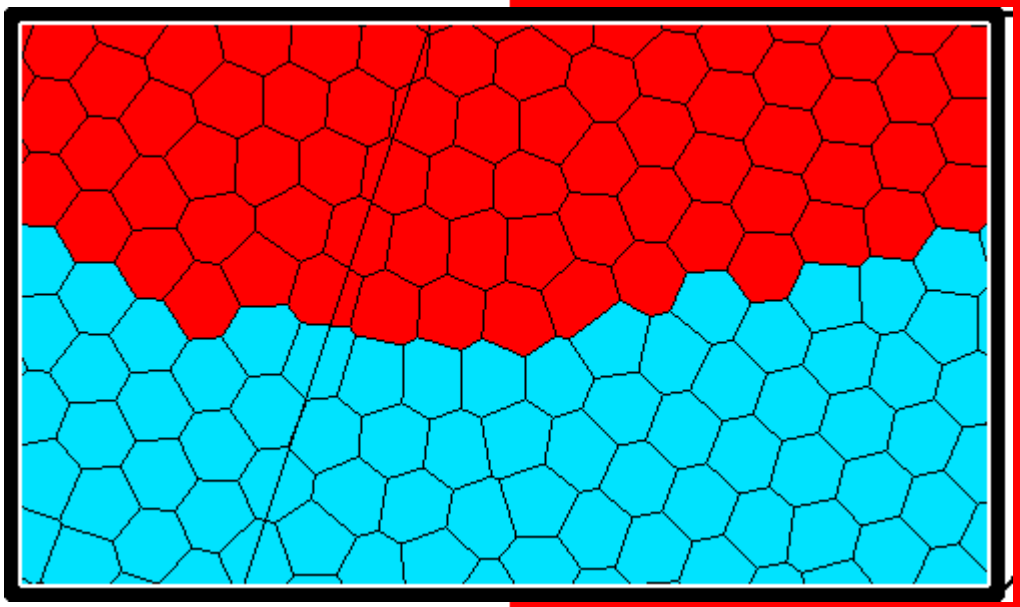
## Lagrangian simulation – Lagrangian meshes







**How can we enforce incompressibility ? (i.e. constant volume of the cells)**



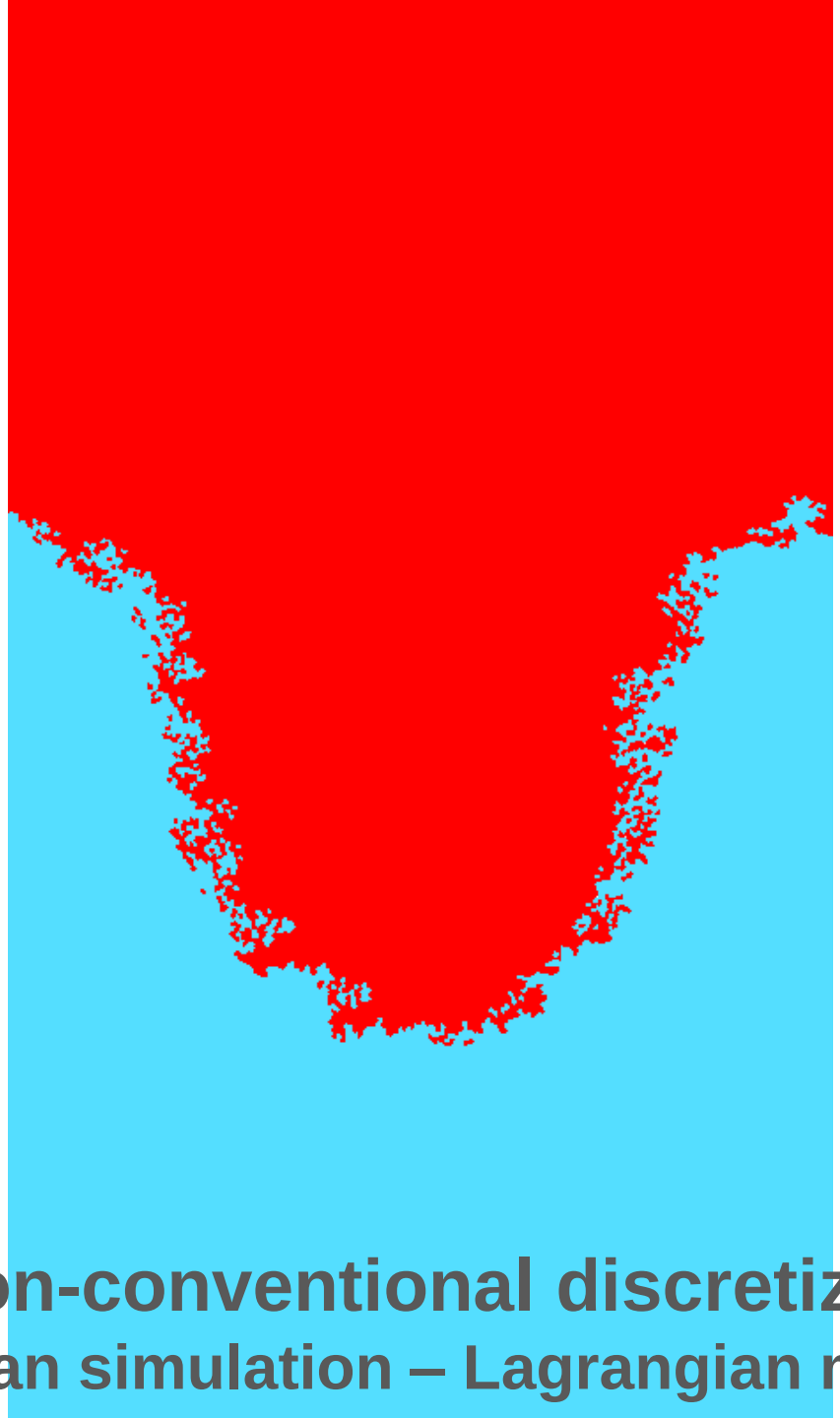
[Math. Model. and Analysis]
A num. algo. for L2
optimal transport in 3D

[Computer & Graphics]
Notions of optimal transport
and how to implement them

**How can we enforce incompressibility ? (i.e. constant volume of the cells)**

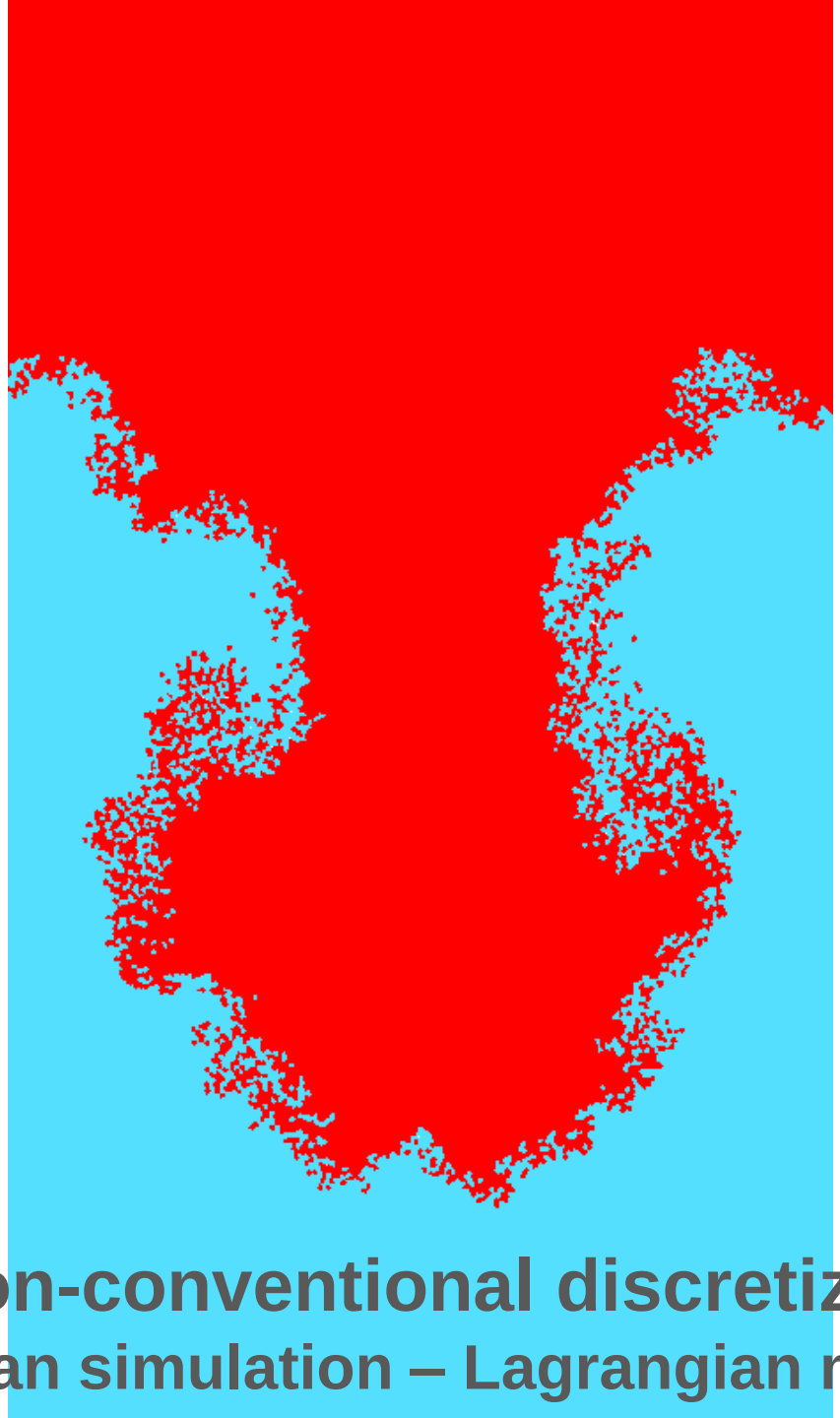
There is a theorem we can use !

[AHA], [Gangbo McCann], [Brenier] : we can prescribe the volume of the cells in a power diagram (**optimal transport**)



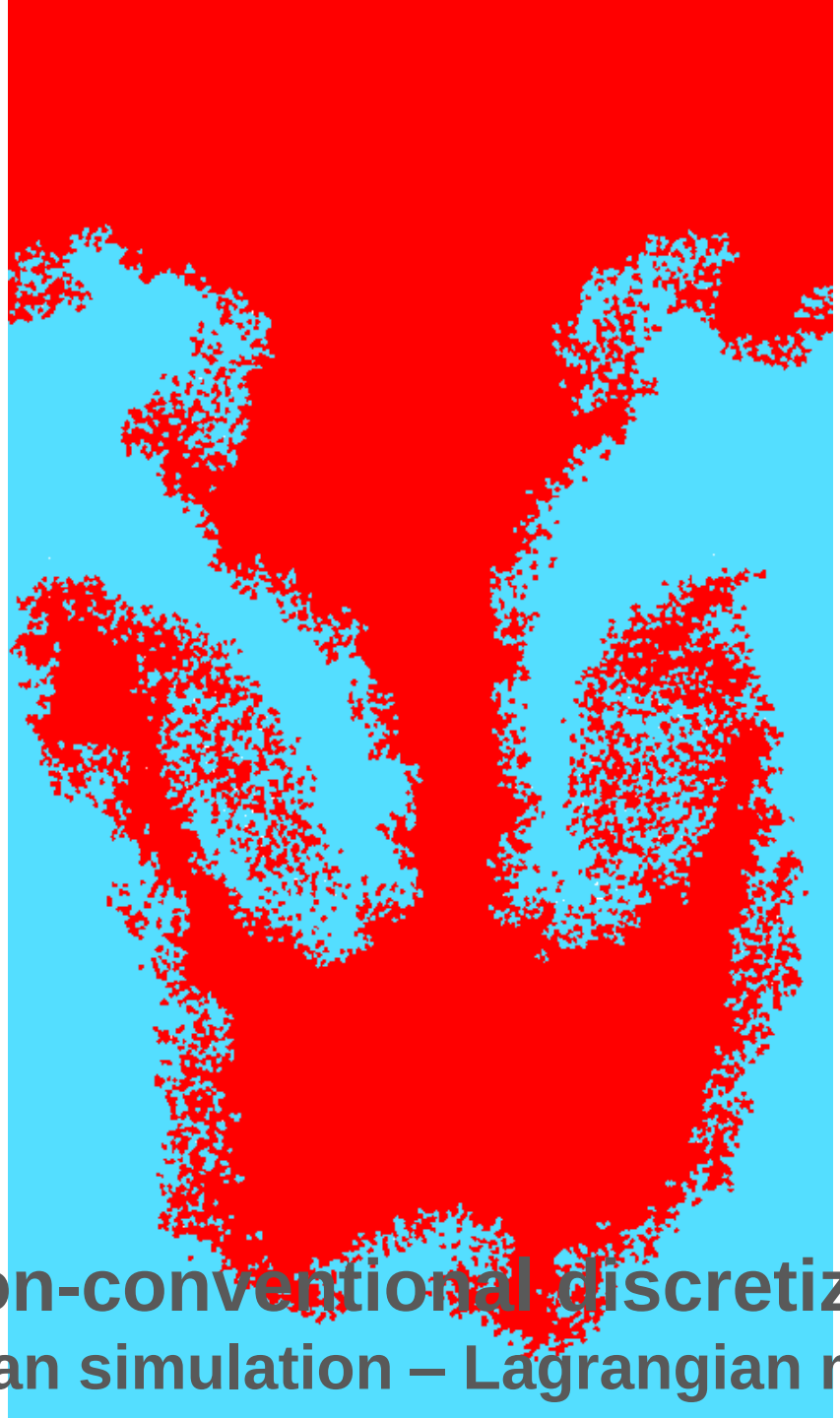
# Axis 1: Non-conventional discretizations

## Lagrangian simulation – Lagrangian meshes



# Axis 1: Non-conventional discretizations

## Lagrangian simulation – Lagrangian meshes



# Axis 1: Non-conventional discretizations

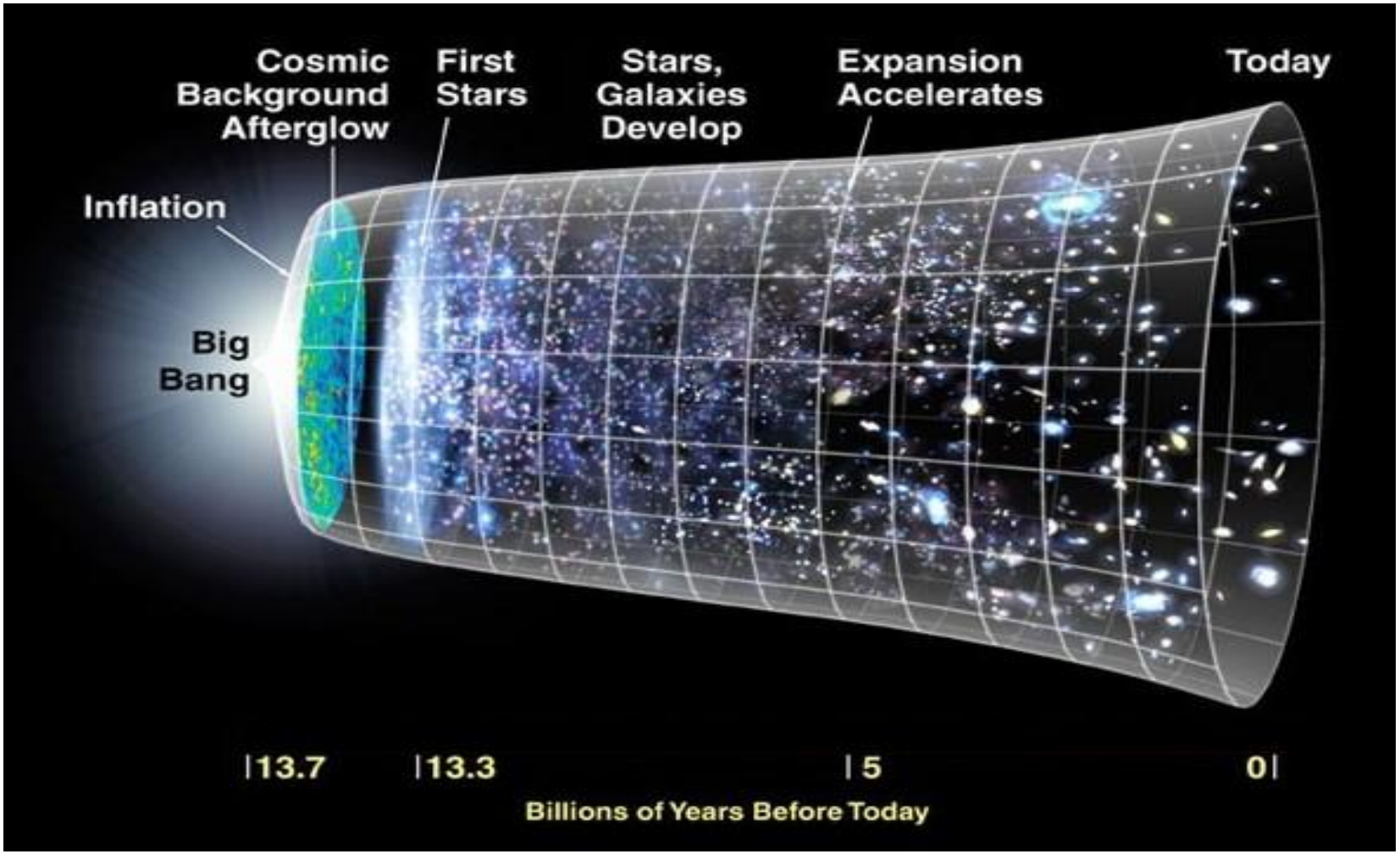
## Lagrangian simulation – Lagrangian meshes

From 2014 ALICE evaluation report

## Recommendations / Measure of success:

**Numerical solutions to problems considered impossible to solve (SIC!)**

# Early Universe Reconstruction

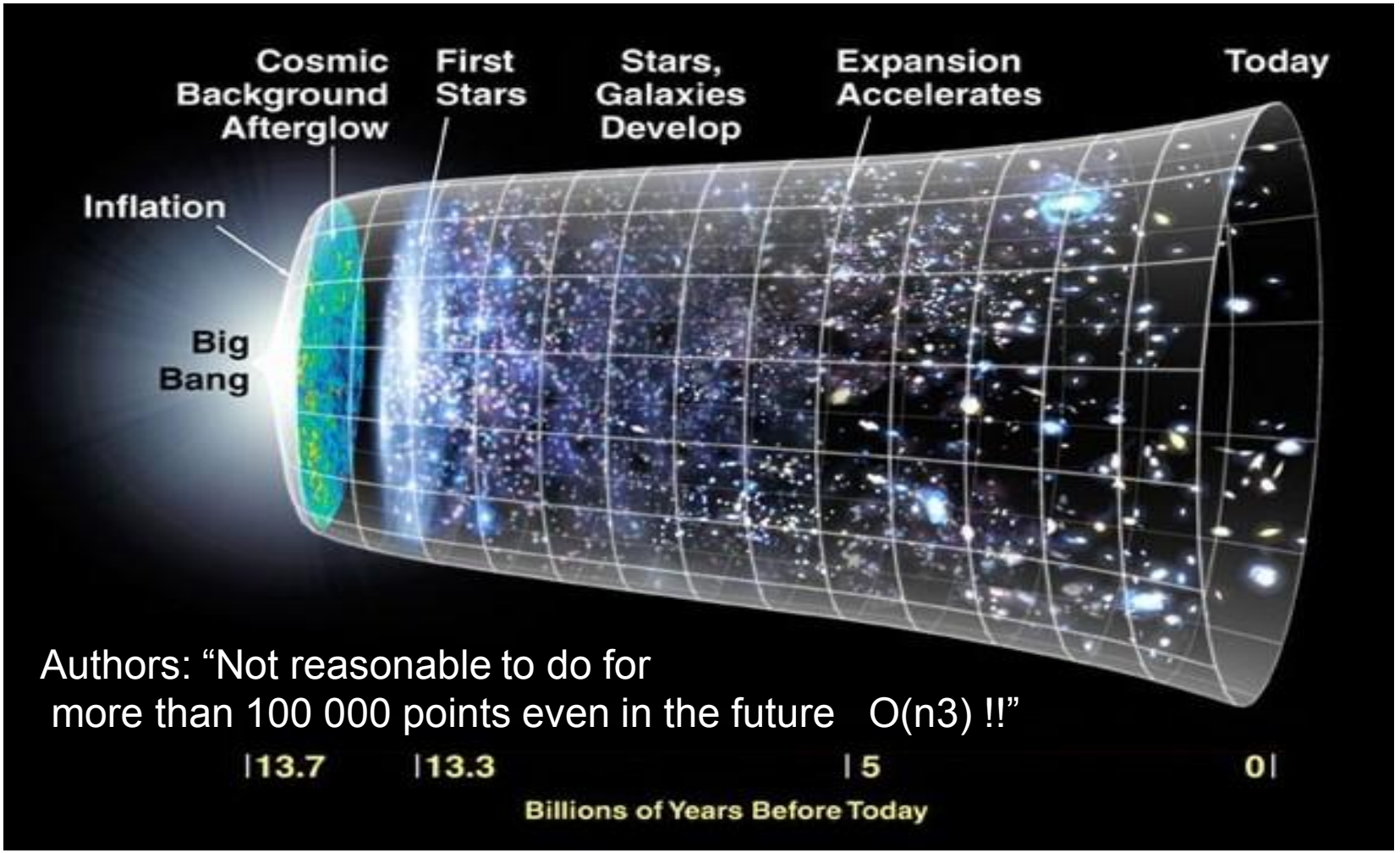



Y. Brenier,[1] U. Frisch,[2,3⋆] M. Hénon,[2] G. Loeper,[1] S. Matarrese,[4] R. Mohayaee,[2] A. Sobolevskiĭ[2,5]

**Reconstruction of the early Universe as a convex optimization problem**

2003

# Early Universe Reconstruction




Authors: “Not reasonable to do for more than 100 000 points even in the future O(n3) !!”

Y. Brenier,[1] U. Frisch,[2,3⋆] M. Hénon,[2] G. Loeper,[1] S. Matarrese,[4] R. Mohayaee,[2] A. Sobolevskiĭ[2,5]

Reconstruction of the early Universe as a convex optimization problem

2003

# Early Universe Reconstruction

$$\begin{cases} \frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} &= (\mathbf{F} - \nabla p) \\ \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) &= 0 \\ \Delta p &= \nabla \cdot (\mathbf{F} - (\mathbf{u}.\nabla)\mathbf{u}) \end{cases}$$

Fluid equation (incompressible Euler)

# Early Universe Reconstruction

$$\begin{cases} \boxed{\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} = (\mathbf{F} - \nabla p)} \\ \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \\ \Delta p = \nabla \cdot (\mathbf{F} - (\mathbf{u}.\nabla)\mathbf{u}) \end{cases}$$

***Newton II***

Fluid equation (incompressible Euler)

# Early Universe Reconstruction

$$\begin{cases} \frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} = (\mathbf{F} - \nabla p) \\ \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \\ \Delta p = \nabla \cdot (\mathbf{F} - (\mathbf{u}.\nabla)\mathbf{u}) \end{cases}$$

***Newton II***

***Mass conservation***

Fluid equation (incompressible Euler)

# Early Universe Reconstruction

$$\begin{cases} \frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} = (\mathbf{F} - \nabla p) \\ \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \\ \Delta p = \nabla \cdot (\mathbf{F} - (\mathbf{u}.\nabla)\mathbf{u}) \end{cases}$$

***Newton II***

***Mass conservation***

***Poisson equation for the pressure***

Fluid equation (incompressible Euler)

# Early Universe Reconstruction

$$\begin{cases} \frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}\cdot\nabla)\mathbf{u} &= (\mathbf{F} - \nabla p) \\ \frac{\partial \rho}{\partial t} + \nabla\cdot(\rho\mathbf{u}) &= 0 \\ \Delta p &= \nabla\cdot(\mathbf{F} - (\mathbf{u}.\nabla)\mathbf{u}) \end{cases}$$

***Incompressible fluids***

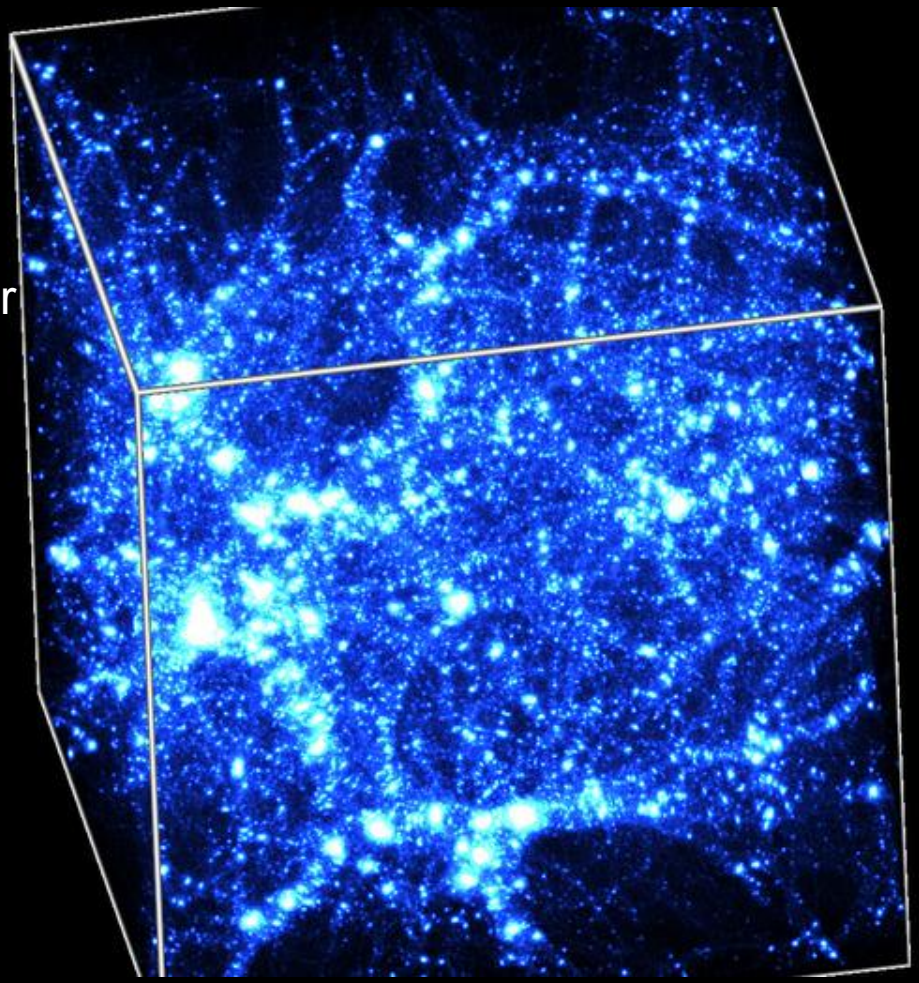
$$\begin{cases} \frac{\partial \mathbf{u}'}{\partial \tau} + (\mathbf{u}'\cdot\nabla)\mathbf{u}' &= -\frac{3}{2\tau}(\mathbf{u}' + \nabla\varphi) \\ \frac{\partial \rho'}{\partial \tau} + \nabla\cdot(\rho'\mathbf{u}') &= 0 \\ \Delta\varphi &= \frac{\rho'-1}{\tau} \end{cases}$$

***Self-gravitating matter + relativity***

# Axis 1: non-conventional discretizations
# Selected result: Early Universe Reconstruction

Time = Now

"Not reasonable to do for more than 100 000 points even in the future O(n3) !!"



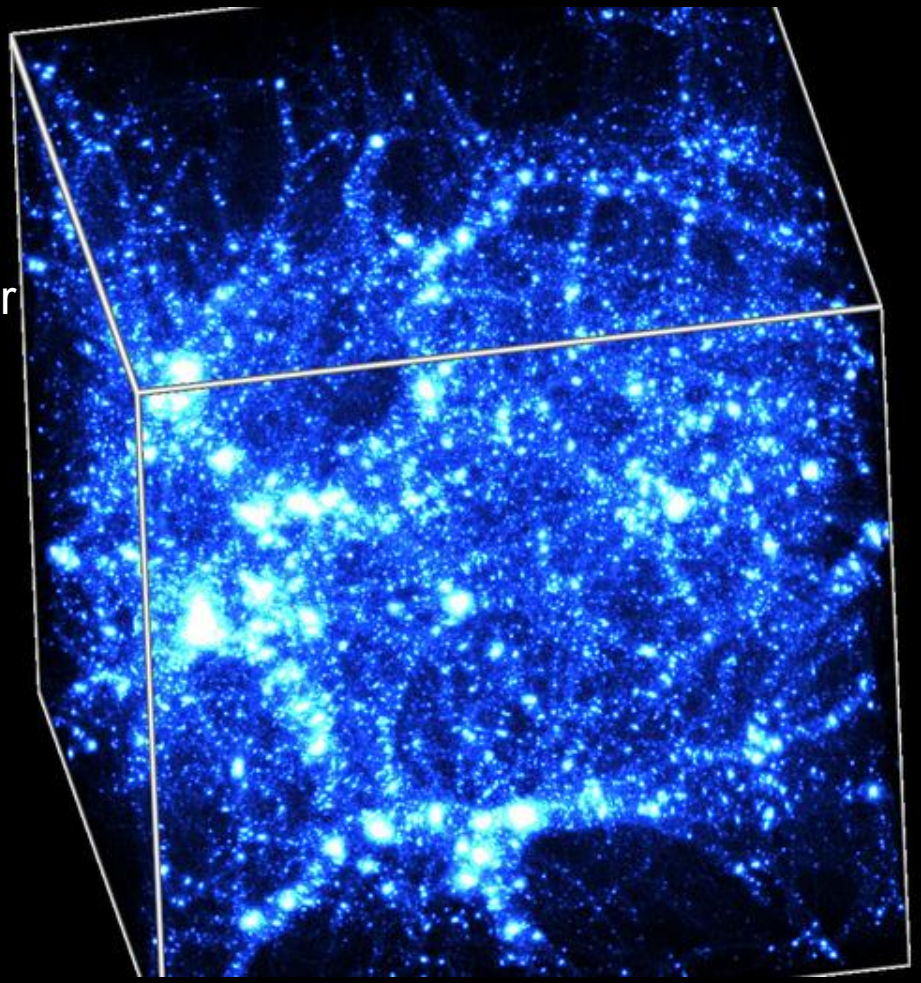
*Coop. with MOKAPLAN & Institut d'Astrophysique de Paris*

# Axis 1: non-conventional discretizations
# Selected result: Early Universe Reconstruction

Time = Now

"Not reasonable to do for more than 100 000 points even in the future O(n3) !!"

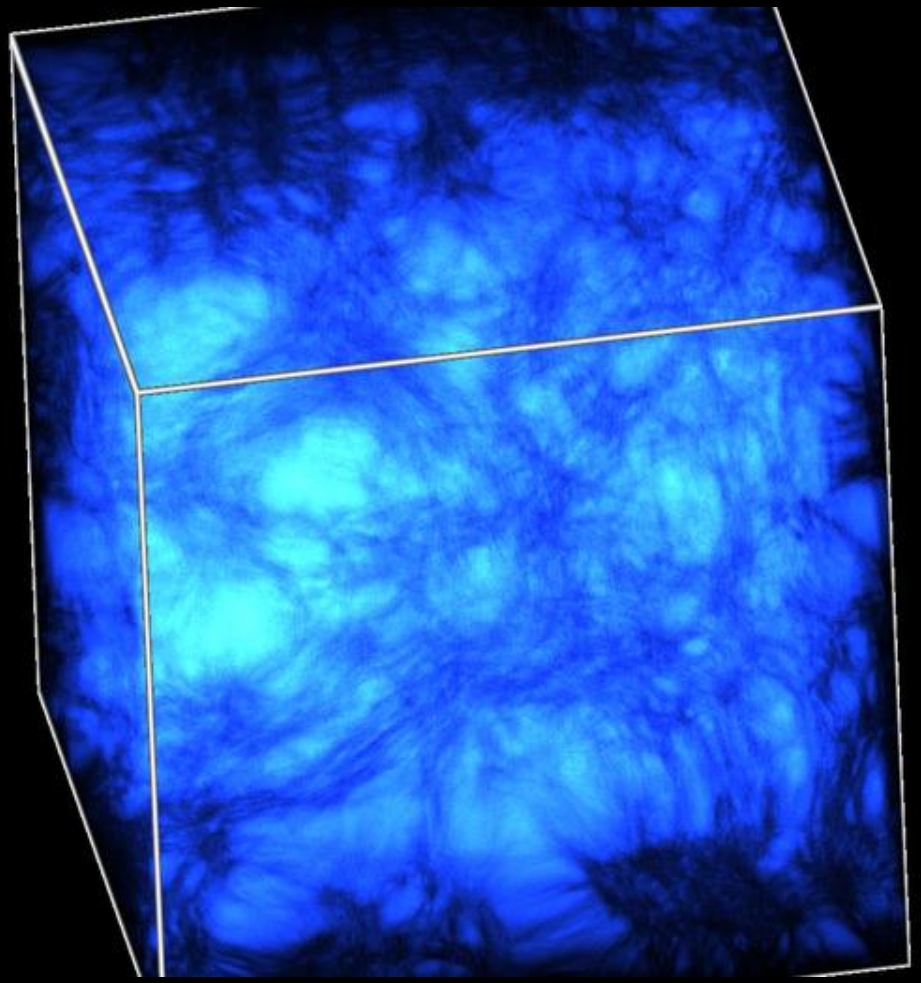
OK, let's do 16 million points



*Coop. with MOKAPLAN & Institut d'Astrophysique de Paris*

# Axis 1: non-conventional discretizations
# Selected result: Early Universe Reconstruction

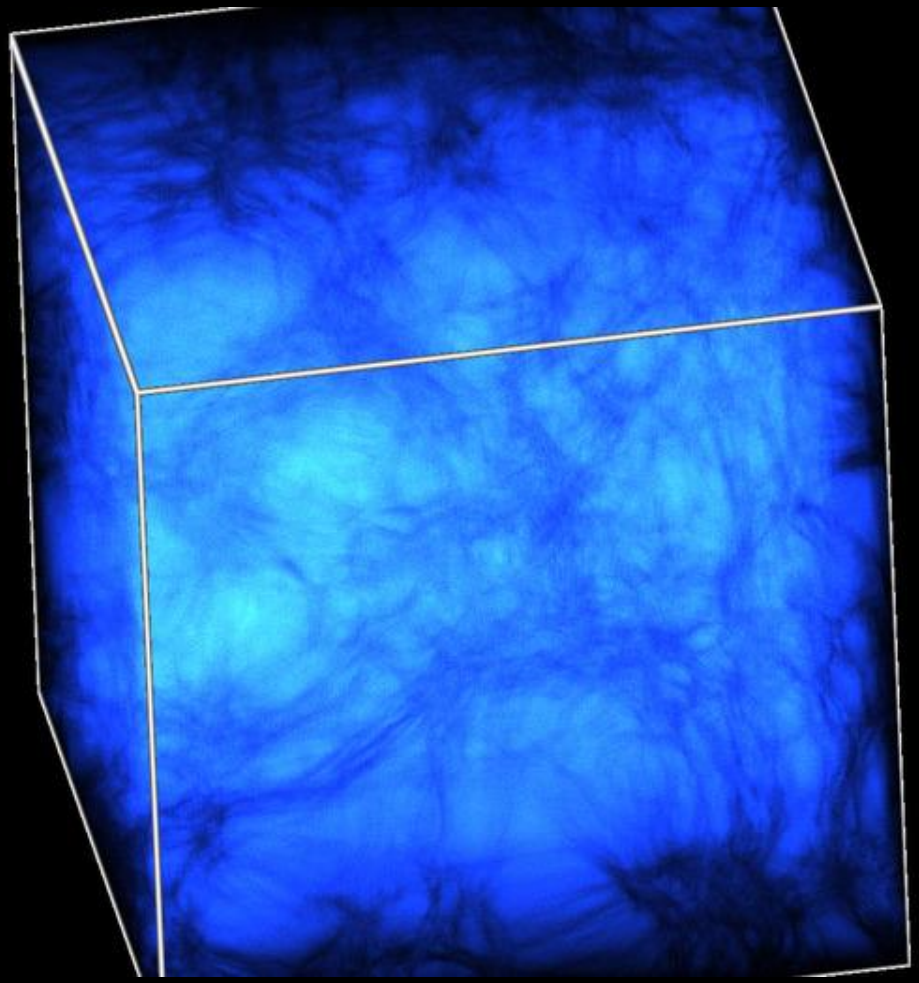
. . . . .



*Coop. with MOKAPLAN & Institut d'Astrophysique de Paris*

# Axis 1: non-conventional discretizations
# Selected result: Early Universe Reconstruction

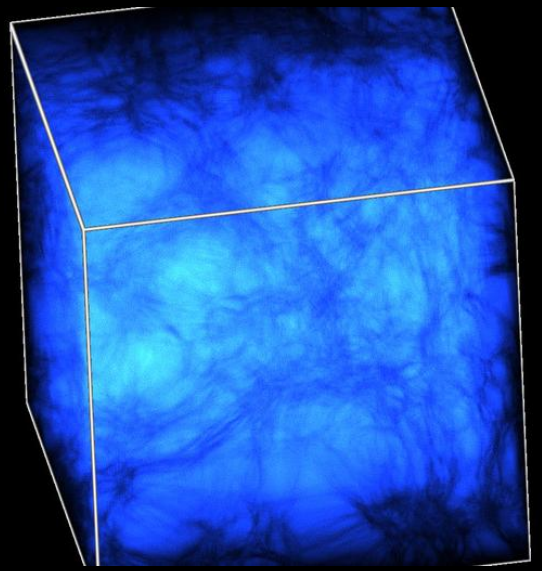
Time = BigBang
(- 13.7 billion Y)



*Coop. with MOKAPLAN & Institut d'Astrophysique de Paris*

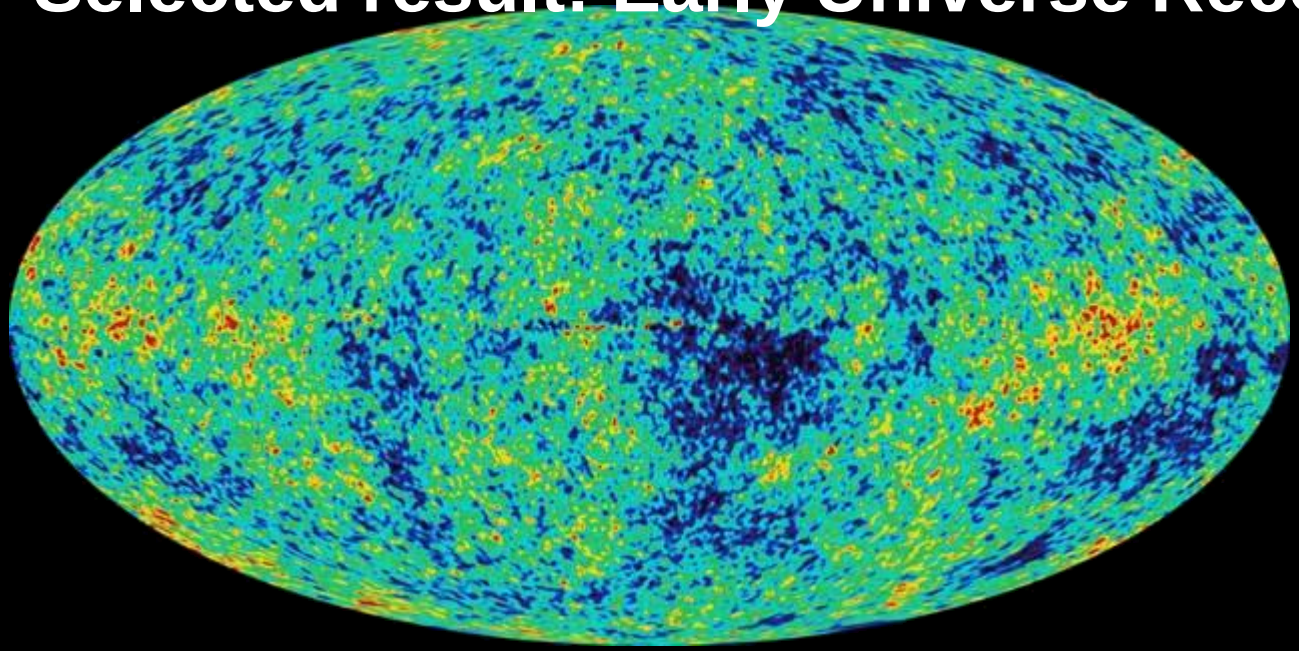
# Axis 1: non-conventional discretizations
# Selected result: Early Universe Reconstruction

"Time-warped" map of the universe



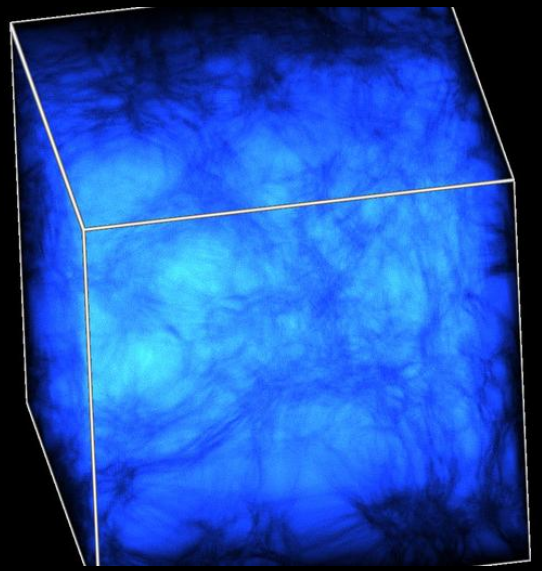
*Coop. with MOKAPLAN & Institut d'Astrophysique de Paris*

# Axis 1: non-conventional discretizations
# Selected result: Early Universe Reconstruction



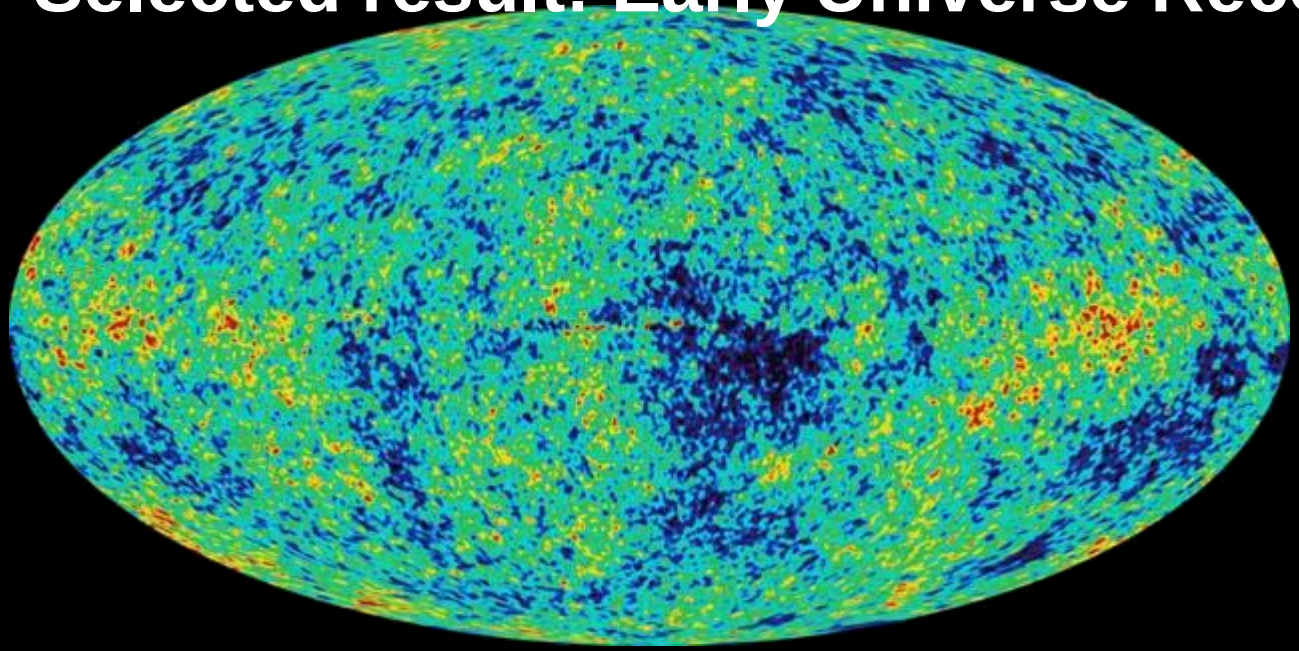
**Cosmic Microware Background:**
"Fossil light" emitted 380 000 Y after BigBang
and measured now

"Time-warped" map of the universe



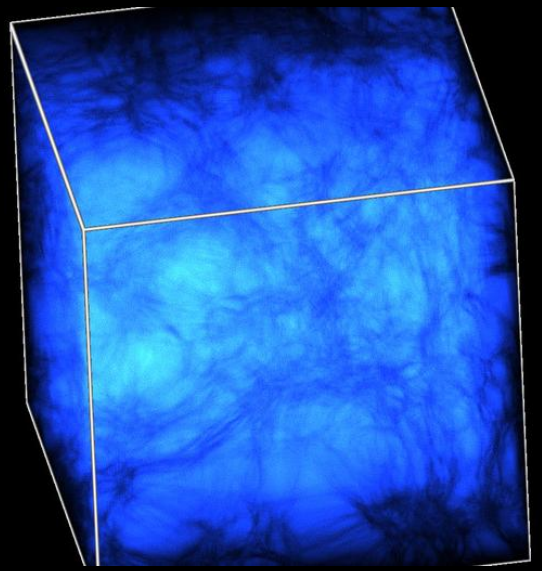
*Coop. with U. Paris Sud, MOKAPLAN, Institut d'Astrophysique de Paris, Obs. de Paris*

# Axis 1: non-conventional discretizations
# Selected result: Early Universe Reconstruction



**Cosmic Microware Background:**
"Fossil light" emitted 380 000 Y after BigBang
and measured now

"Time-warped" map of the universe



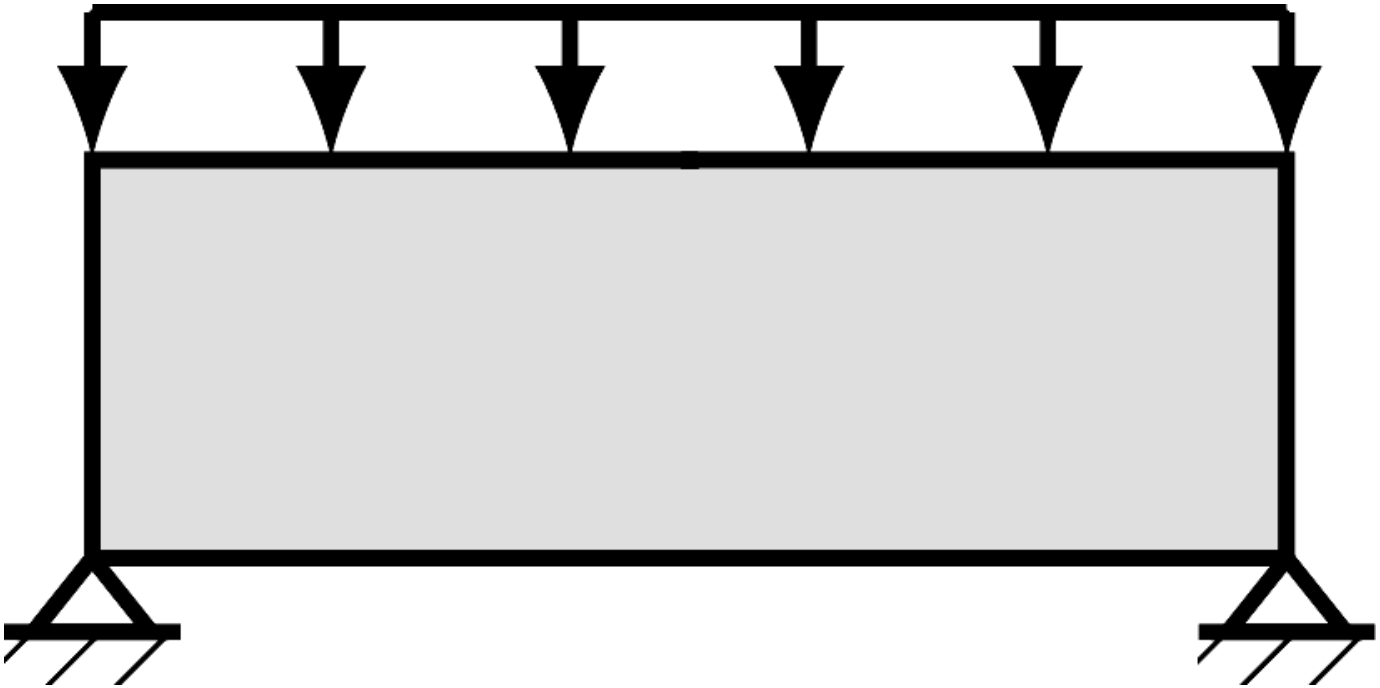
*Do they match ?*

*Coop. with U. Paris Sud, MOKAPLAN, Institut d'Astrophysique de Paris, Obs. de Paris*

# Axis 2:
# Computer-Aided Fabrication

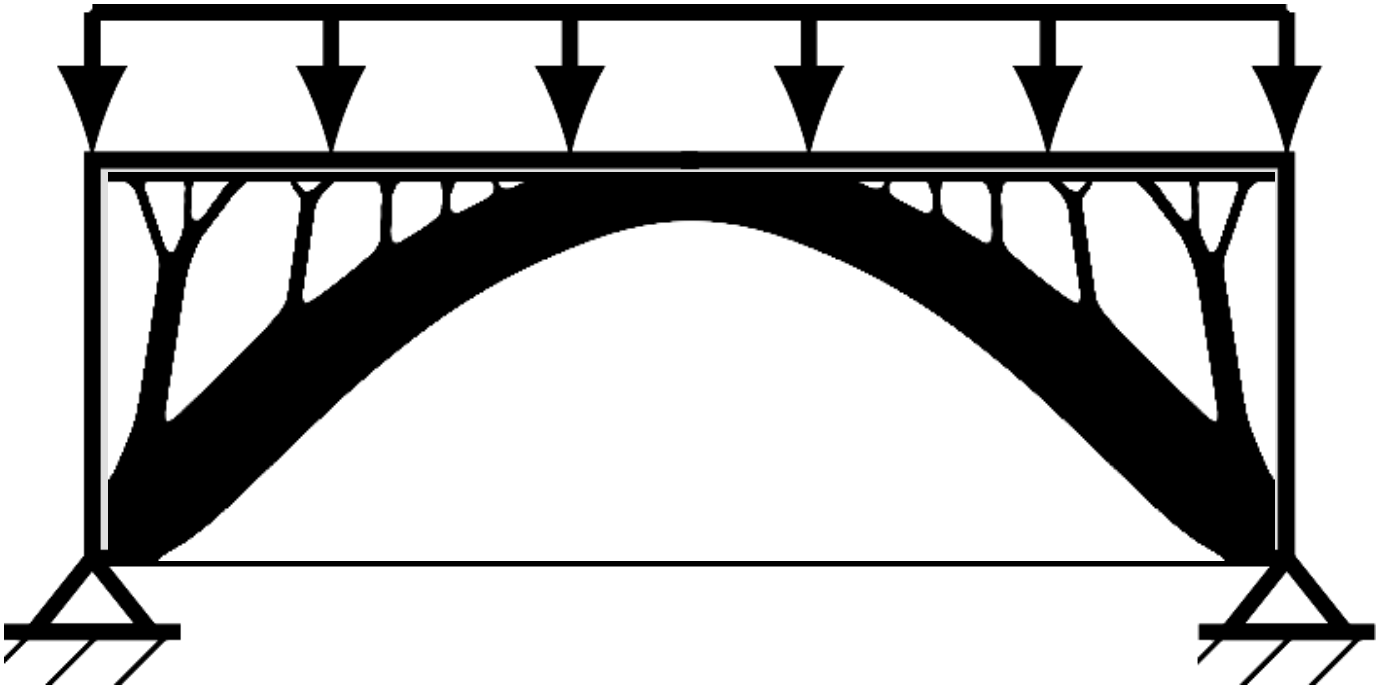
# Axis 2: Structured Materials

Shape-Appearance-Function



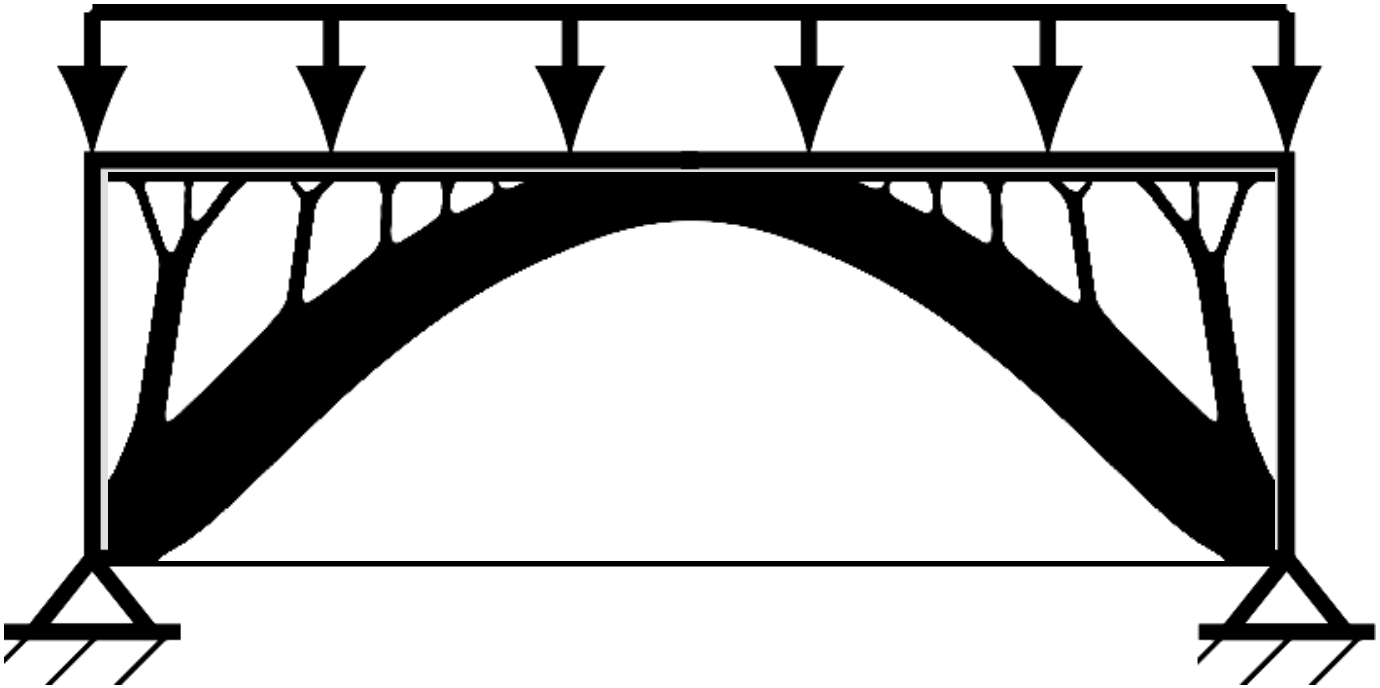
# Axis 2: Structured Materials

Shape-Appearance-Function



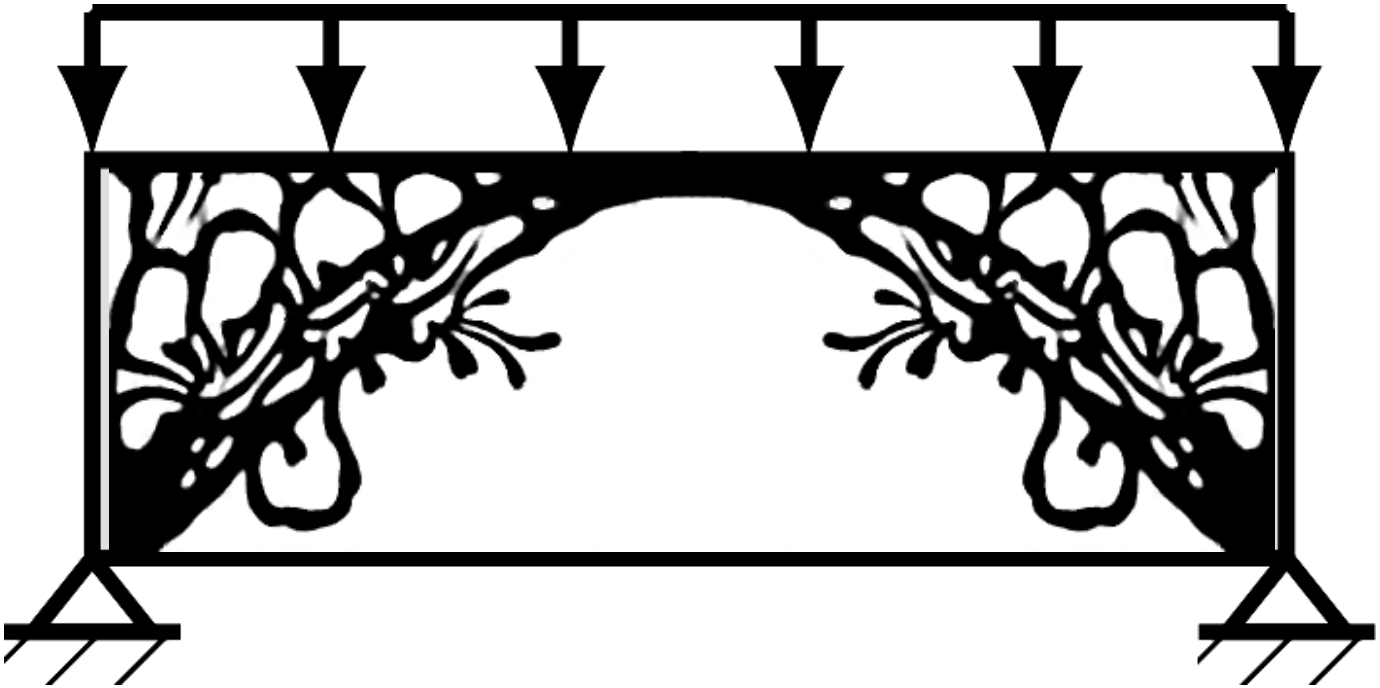
# Axis 2: Structured Materials

Shape-Appearance-Function



# Axis 2: Structured Materials

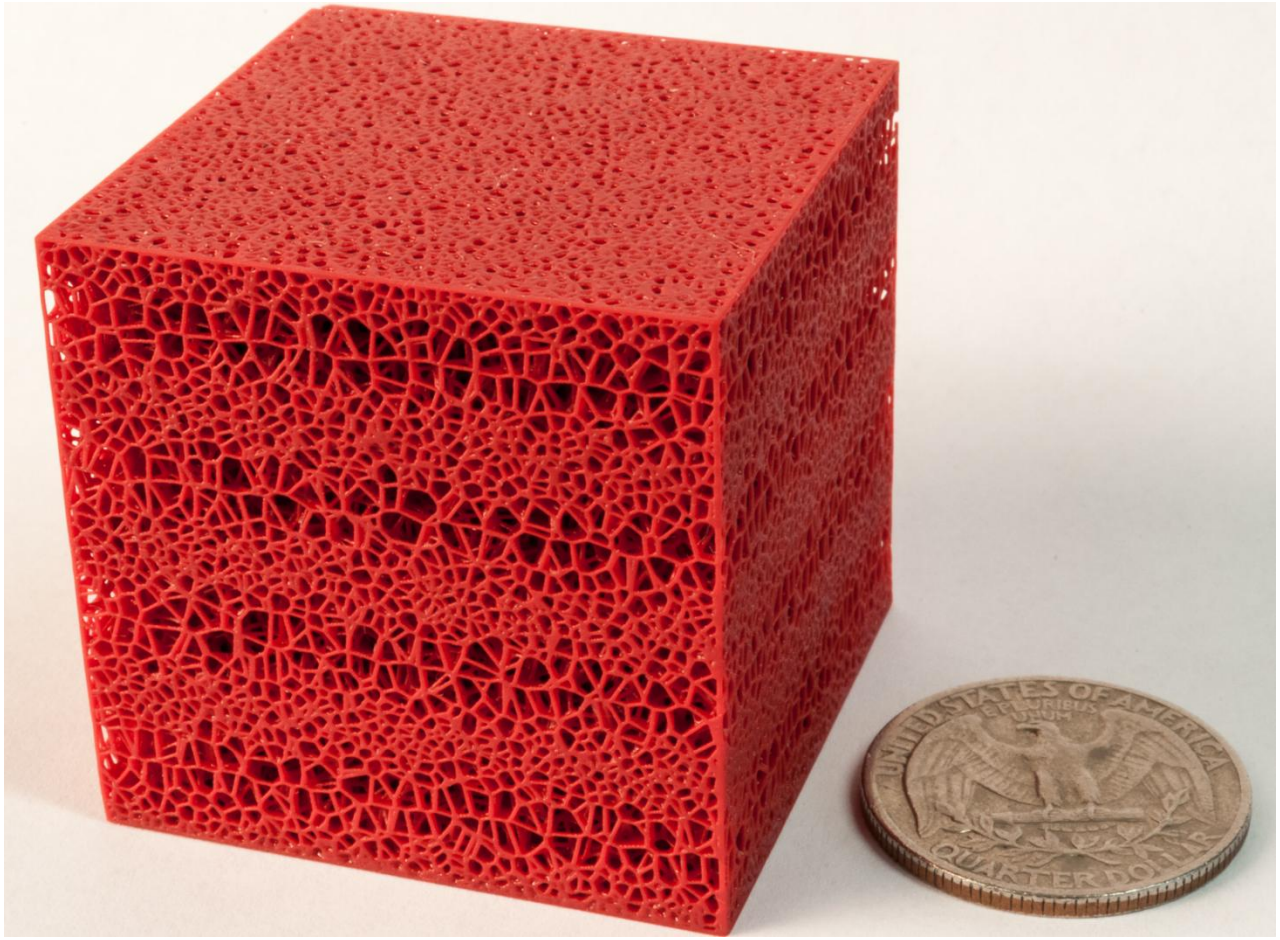
Shape-Appearance-Function



**[SIGGRAPH Asia 2015]**

# Axis 2: Structured Materials

Procedural foams **[SIGGRAPH 2016]**

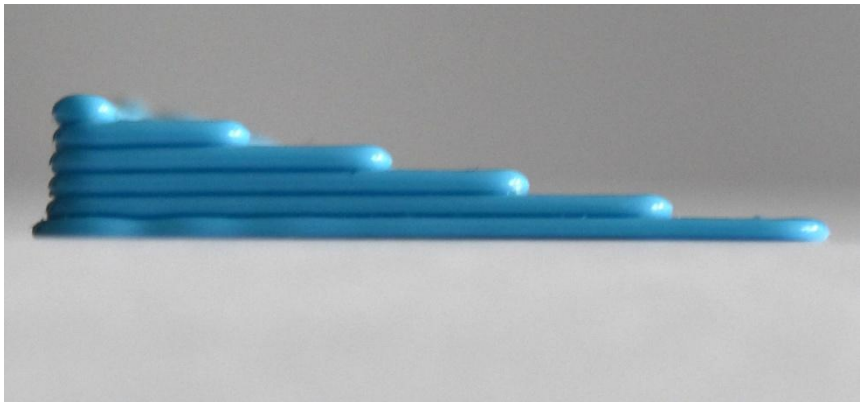


# Axis 2: Structured Materials

Procedural foams **[SIGGRAPH 2017]**

# Axis 2: Fine control of the printer

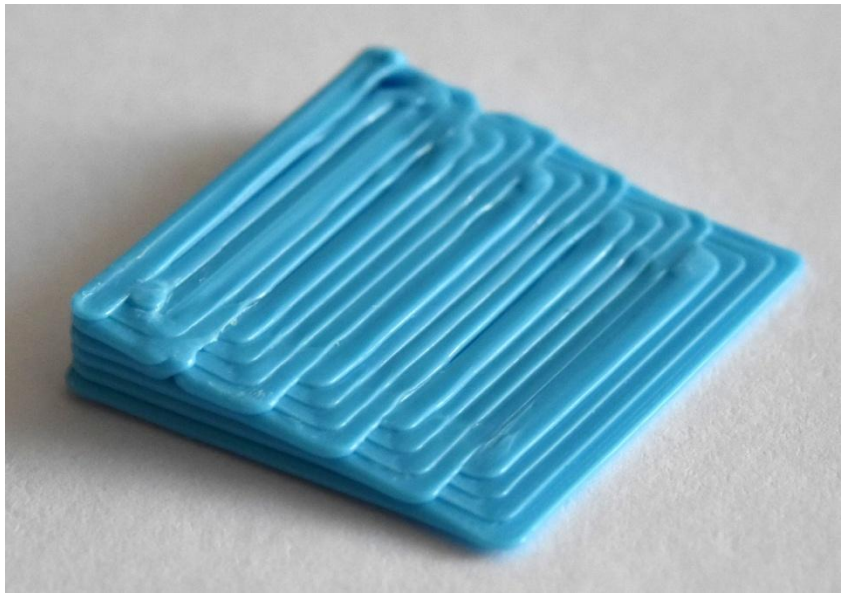
“Antialiasing”

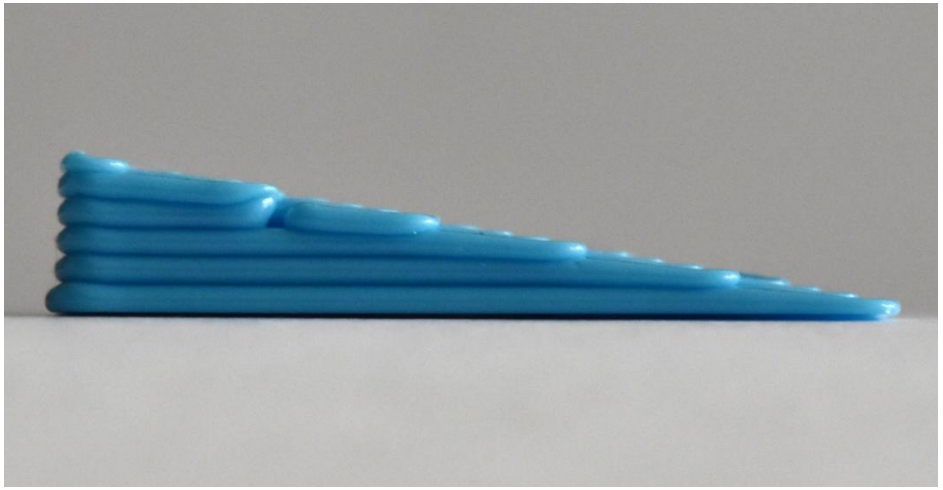


**[CAD J.]**

# Axis 2: Fine control of the printer

“Antialiasing”





**[CAD J.]**

# Highlights / Impact

Highlights:

Software Heritage Event, Unesco, with François Hollande and Irina Bokova

Highlights:

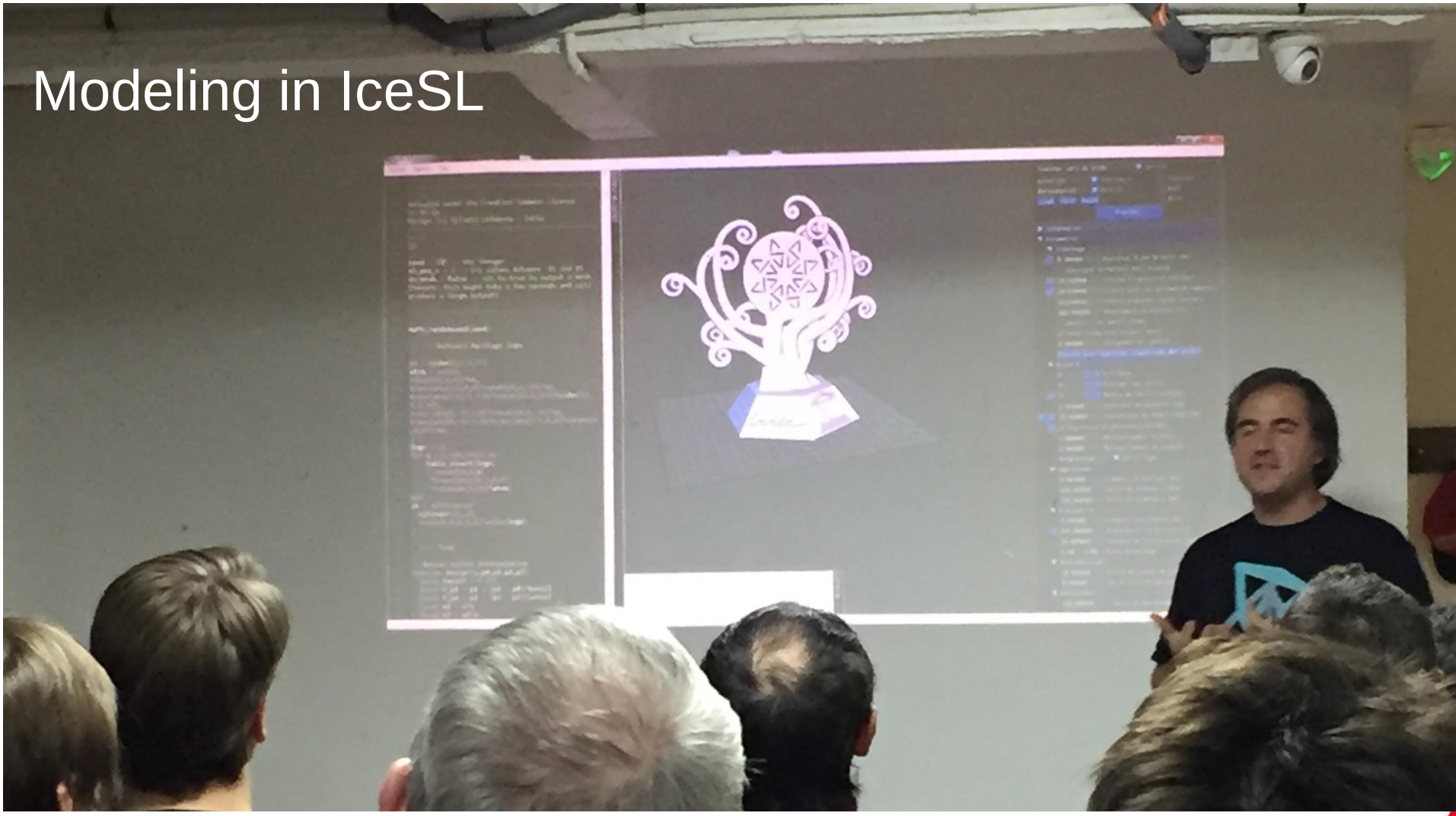
Software Heritage Event, Unesco, with François Hollande and Irina Bokova

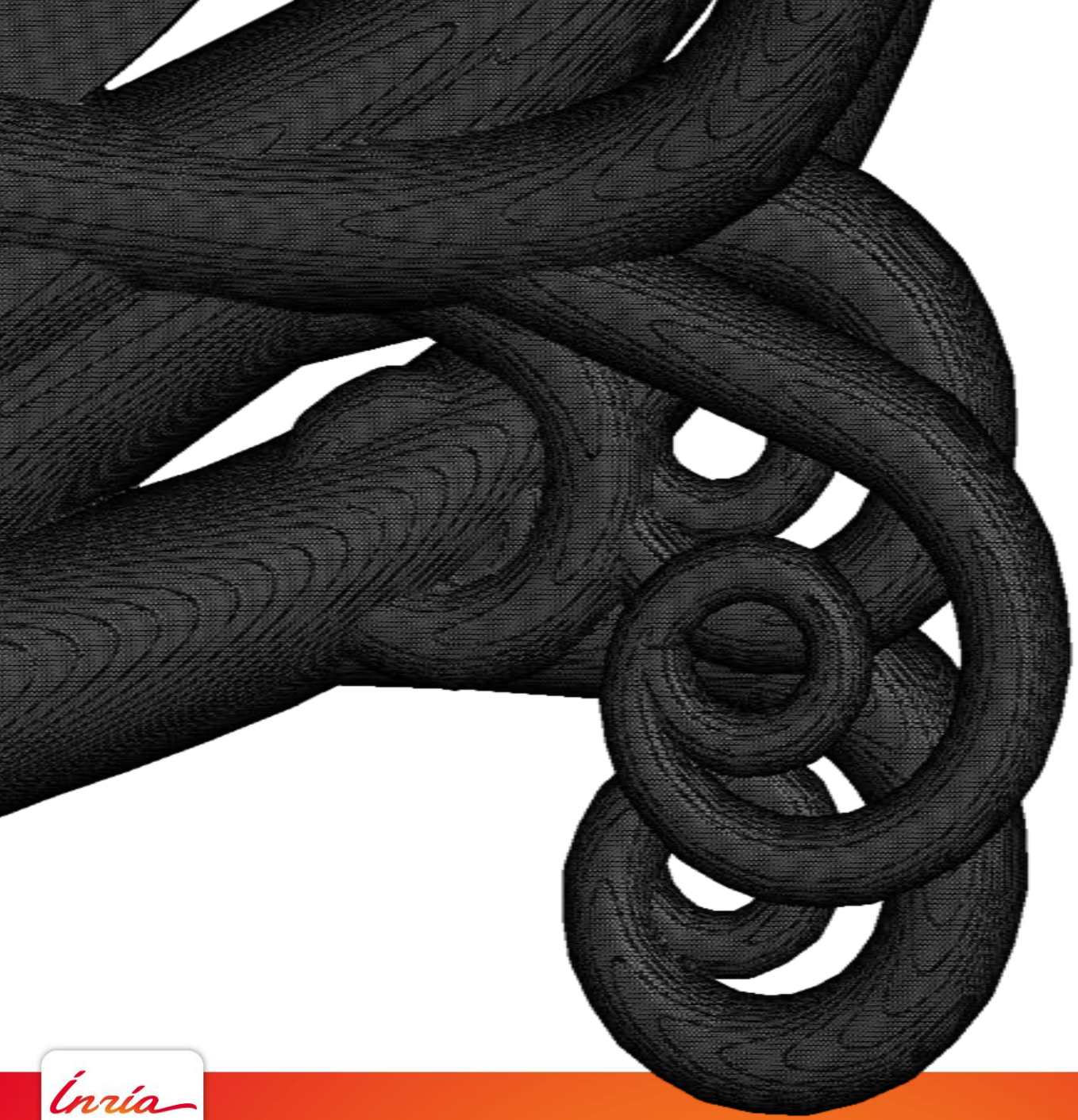

Software Heritage Event, Unesco,
with François Hollande and Irina Bokova

Trophee modeled with IceSL,
remeshed with Vorpaline,
sliced with IceSL

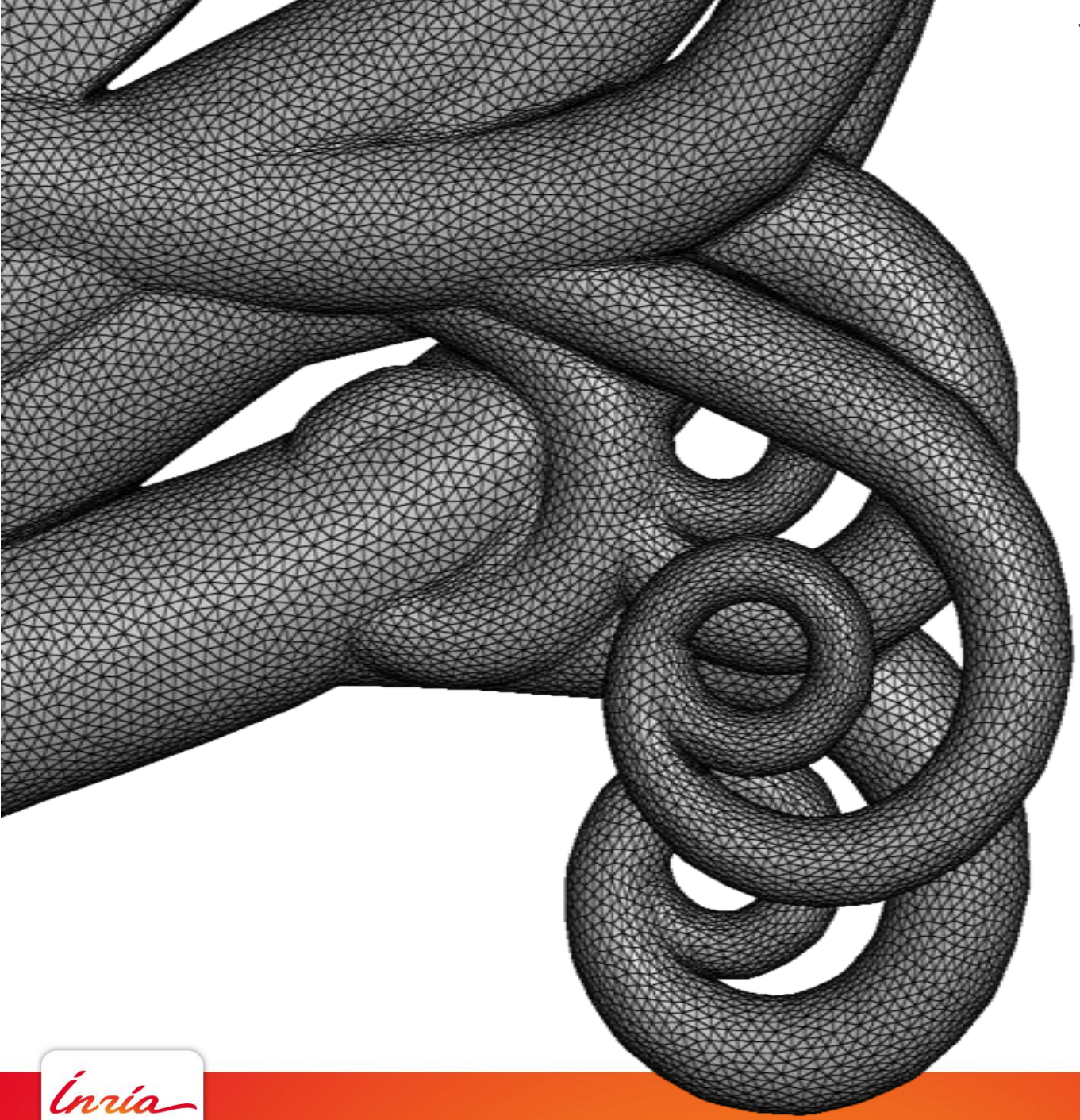
Highlights:

Software Heritage Event, Unesco, with François Hollande and Irina Bokova





Regularized MC
4.6 M facets

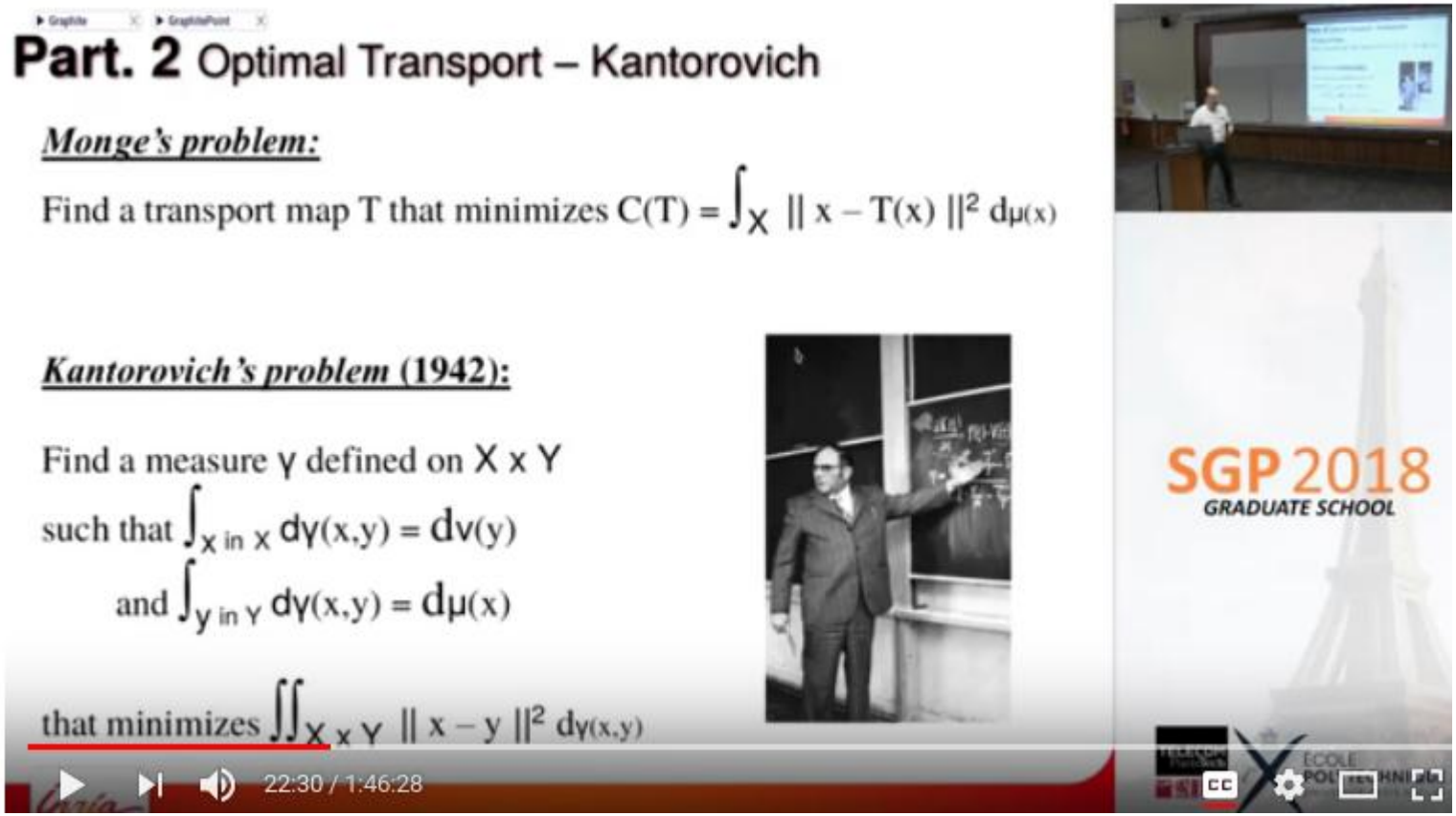


Vorpaline
remesh
700 K facets

# Highlights: *IceSL event in Paris*


# Highlights: *Books and Courses*

[Mathematical Modeling and Analysis J. 2015] 50 citations
Numerical Optimal Transport, SGP 2018

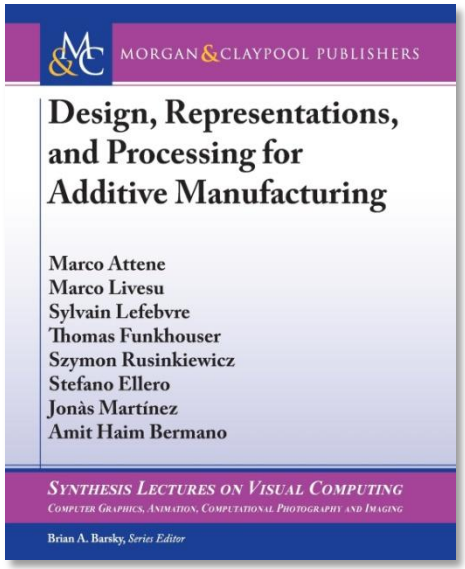


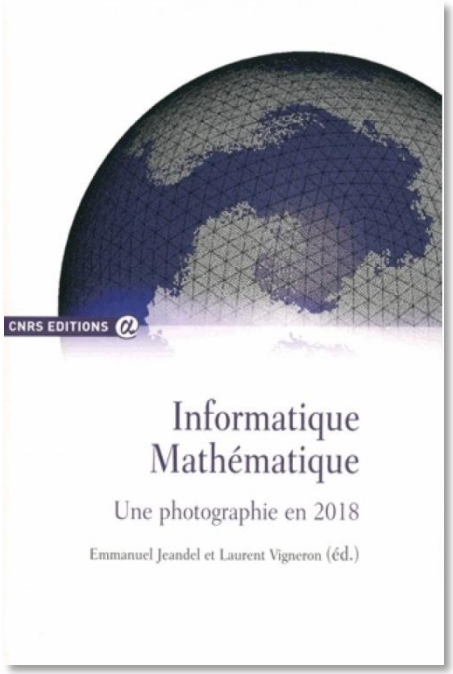
# Highlight: *Books and Courses*

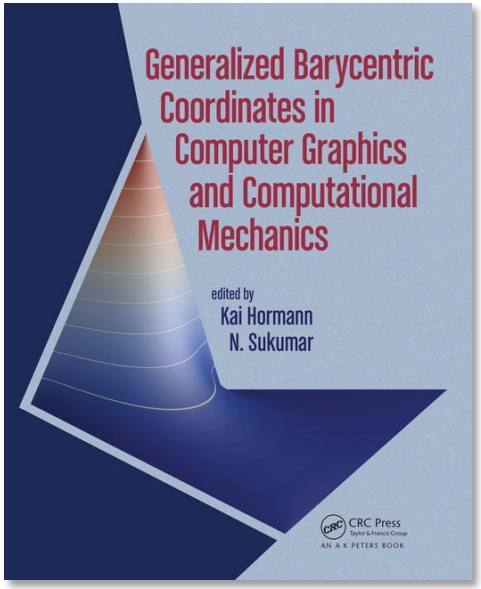
Design, Representation and Processing for Additive Manufacturing, Morgan & Claypool

Informatique Mathématique – une photographie en 2018
(chapter course on numerical geometry)

Generalized Barycentric Coordinates in Computer Graphics, CRC Press



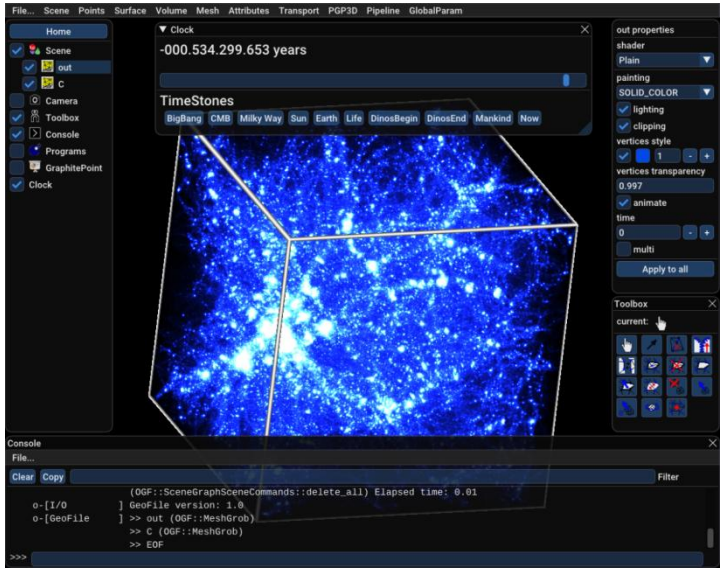
# Highlights: Software

## OpenSource (BSD):

**Geogram/Graphite**

More than 58 000 downloads (since 2014)

- Houdini (uses Predicate Construction Kit)
- Trimble (3D scanning company)
- Chevron Petroleum R&D
- …

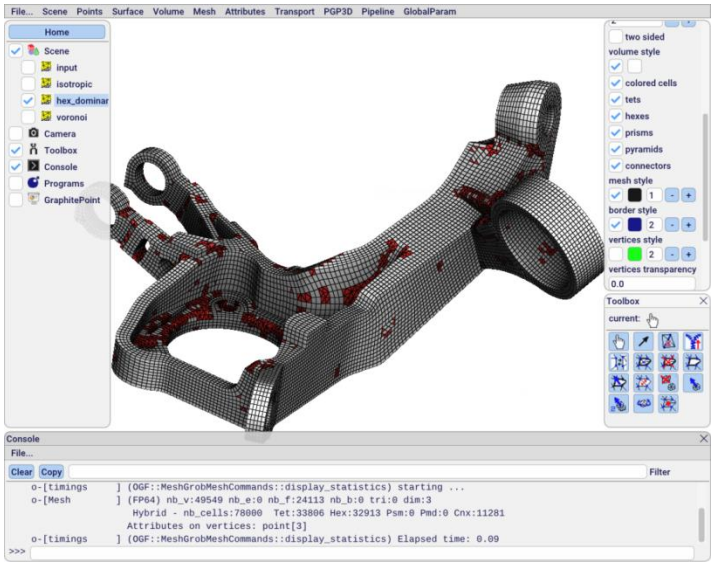



## Proprietary:

Start-up creation project
**Vorpaline/MeshSpace**

Dassault Systems, Total
Ansys (eval license)

**IceSL / IceXL**



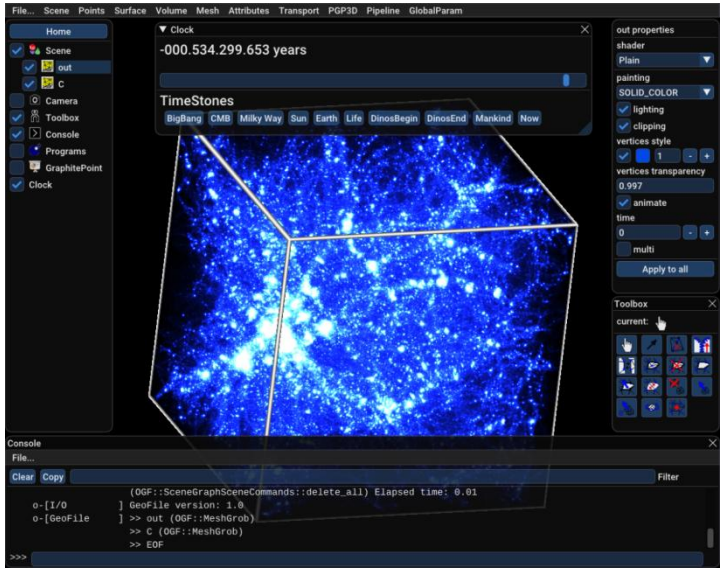
# Highlights: Software

## OpenSource (BSD):

**Geogram/Graphite**

More than 58 000 downloads (since 2014)

- Houdini (uses Predicate Construction Kit)
- Trimble (3D scanning company)
- Chevron Petroleum R&D
- …




## Proprietary:

Start-up creation project
**Vorpaline/MeshSpace**

Dassault Systems, Total
Ansys (eval license)

**IceSL / IceXL**


***Start-up creation***
(results of older ERC StG+POC)
Inria support, ATT action
Wan-Chiu Li
Generative Design + Phones

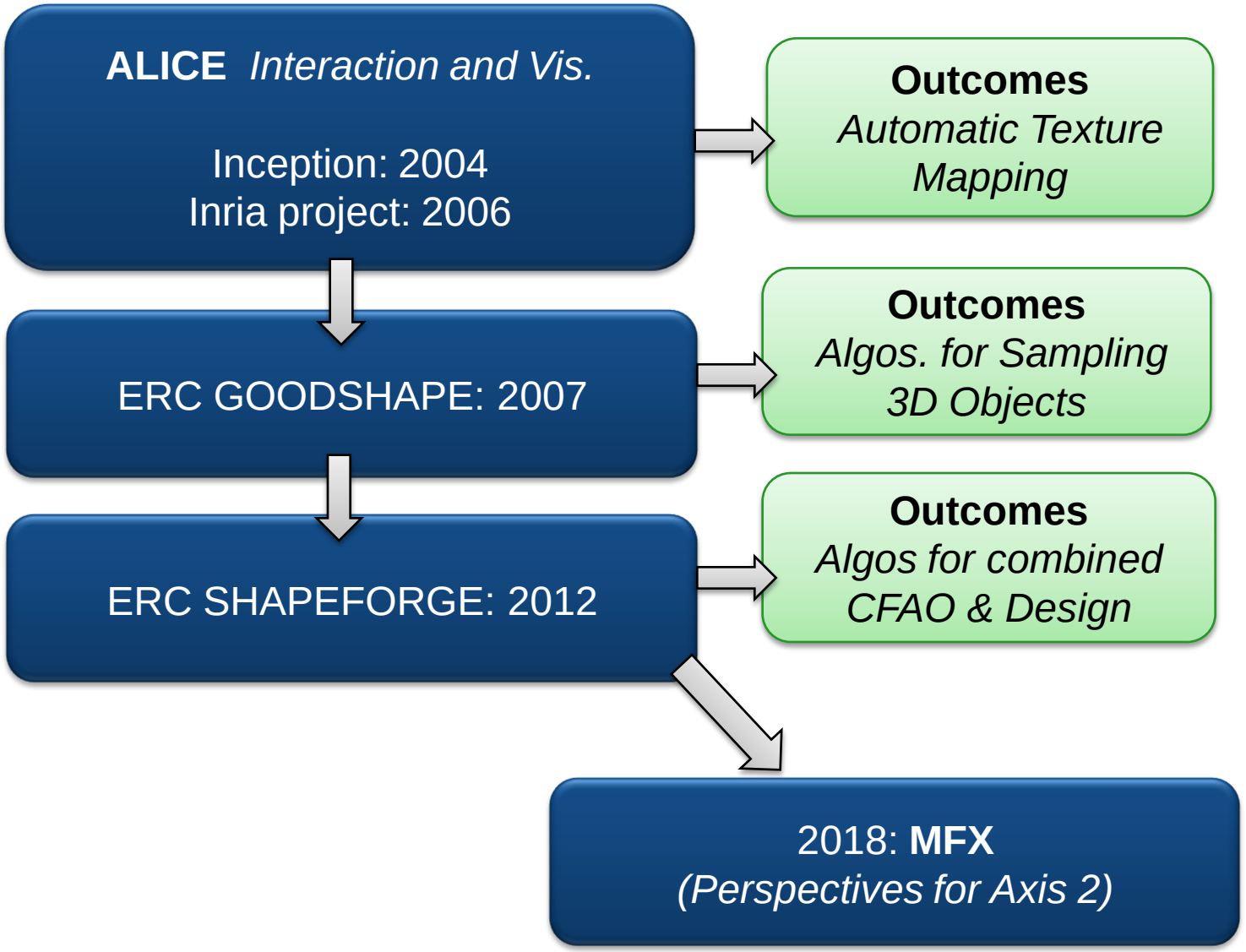
# Perspectives

**From 2014 ALICE evaluation report**

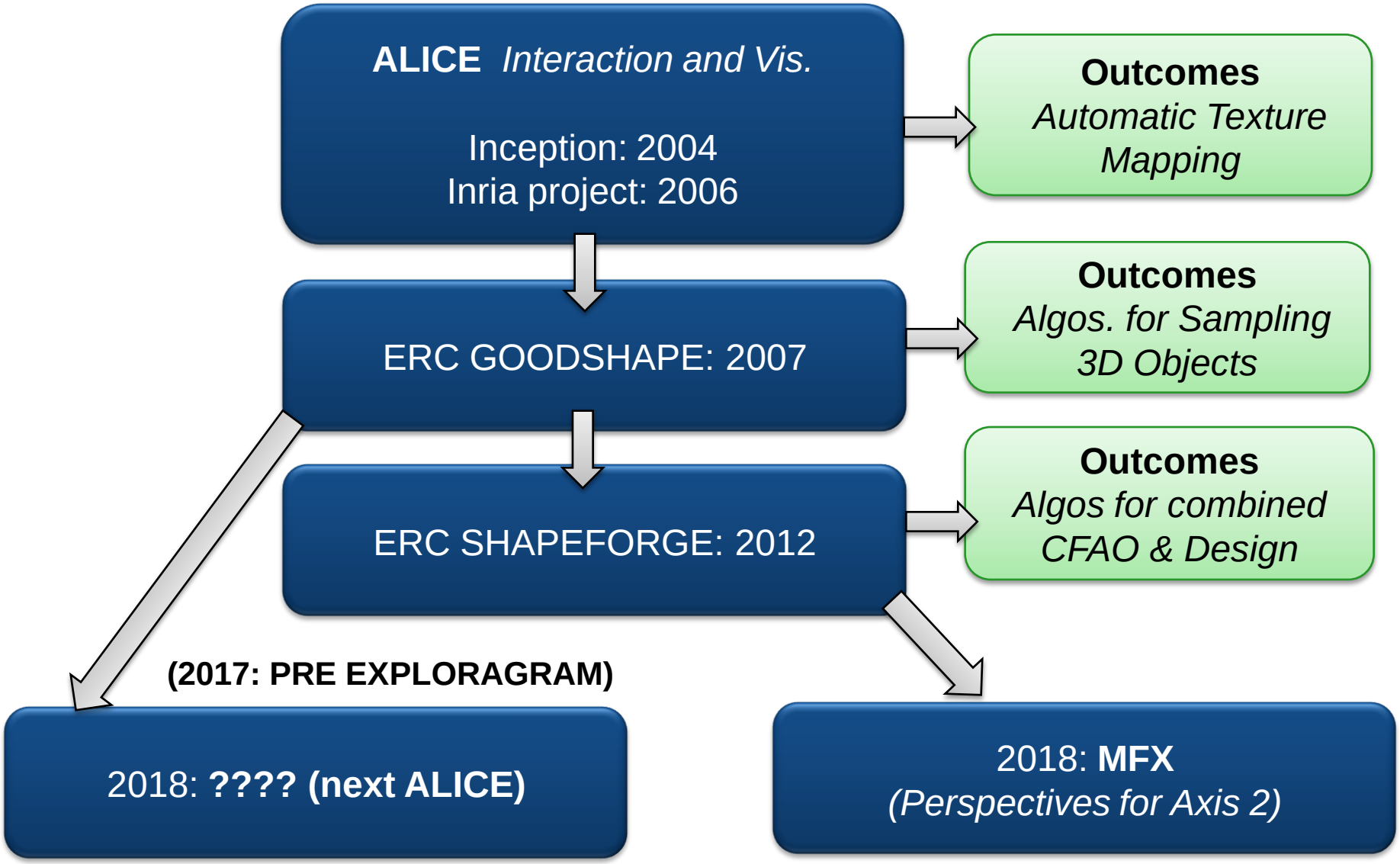
## Recommendations :

**Create a new group on computer fabrication**
**Focus the other group on fundamentals**

# The team - Perspectives

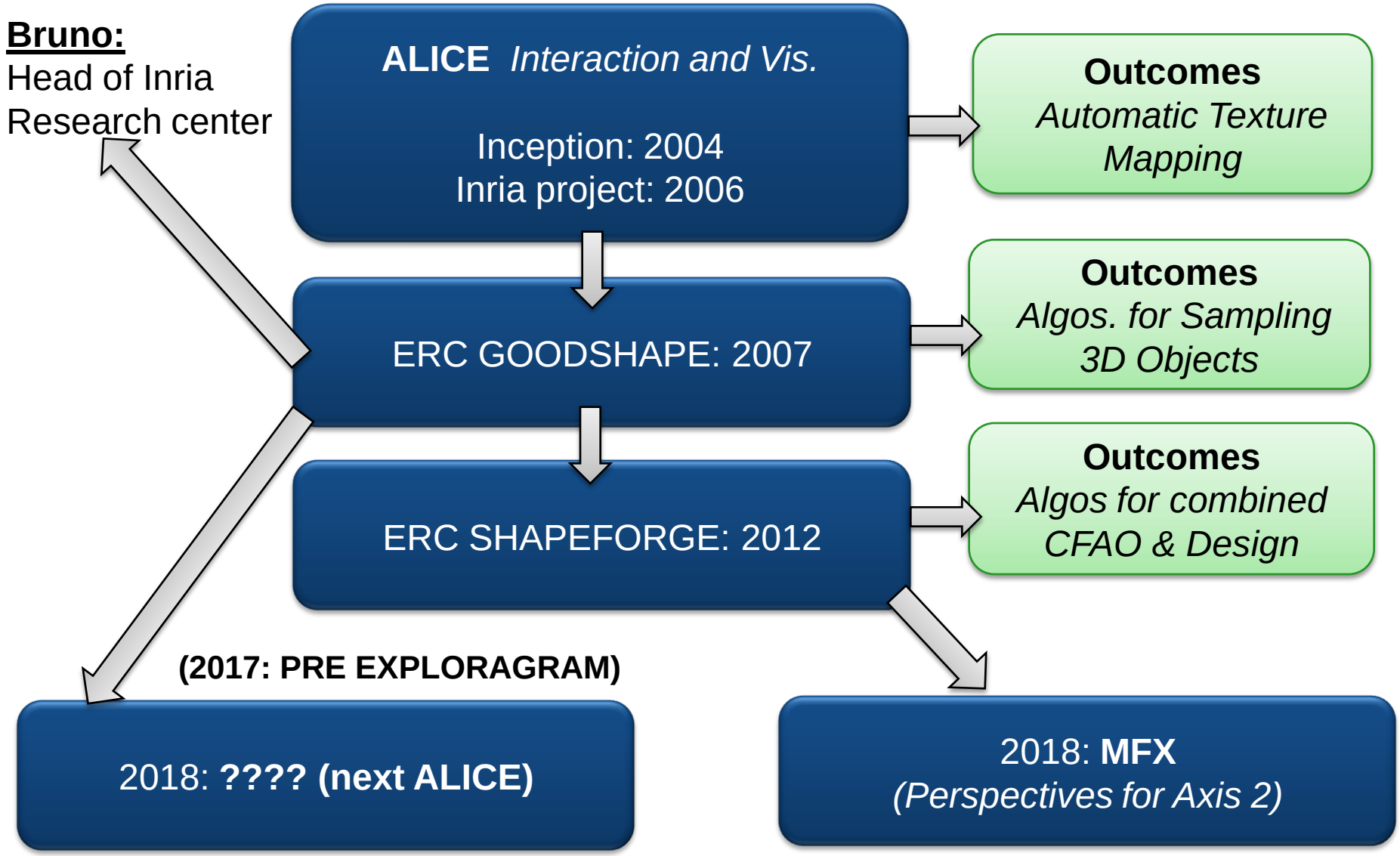


# The team - Perspectives



# The team - Perspectives

**Bruno:**
Head of Inria
Research center



# The team - Perspectives

**Bruno:**
Head of Inria
Research center

**Astrophysics:**
Q. Mérigot
R. Mohayaee
J.-M. Alimi

**ALICE** *Interaction and Vis.*

Inception: 2004
Inria project: 2006

**Outcomes**
*Automatic Texture Mapping*

ERC GOODSHAPE: 2007

**Outcomes**
*Algos. for Sampling 3D Objects*

ERC SHAPEFORGE: 2012

**Outcomes**
*Algos for combined CFAO & Design*

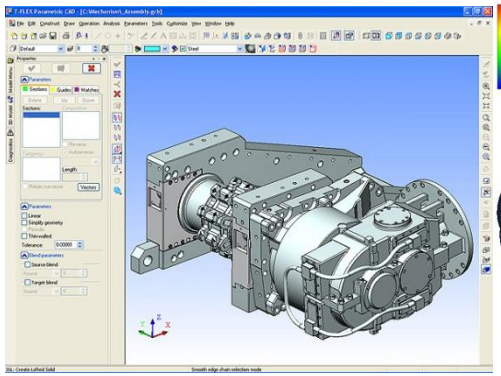
**(2017: PRE EXPLORAGRAM)**

2018: **???? (next ALICE)**

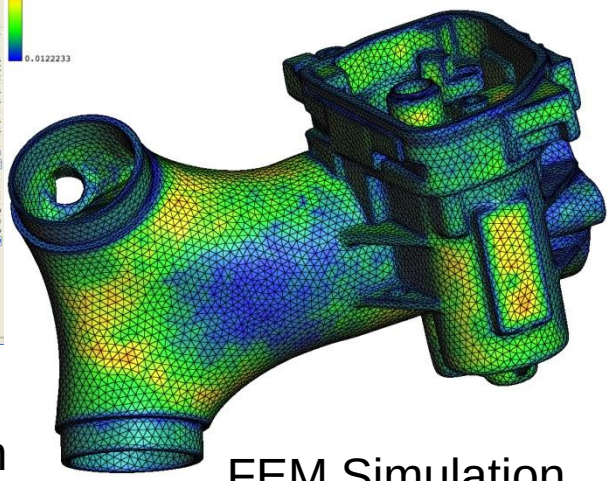
2018: **MFX**
*(Perspectives for Axis 2)*

# Perspectives for Axis 1: Geometry Processing

## *Current situation: Garbage in – Garbage out*

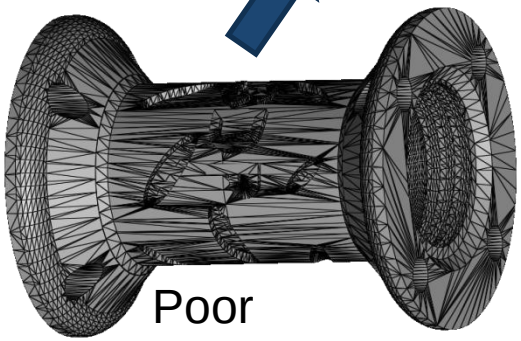


Computer Aided Design



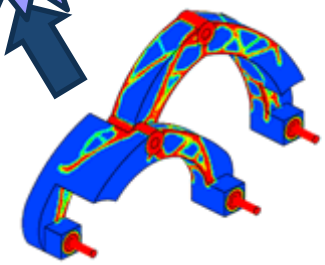

FEM Simulation

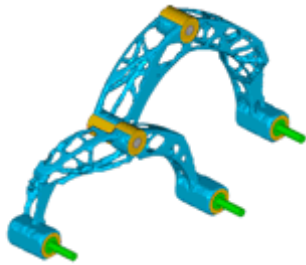
**Tight barrier:**
Representation
& Sampling



Poor
geometries

3D scanners

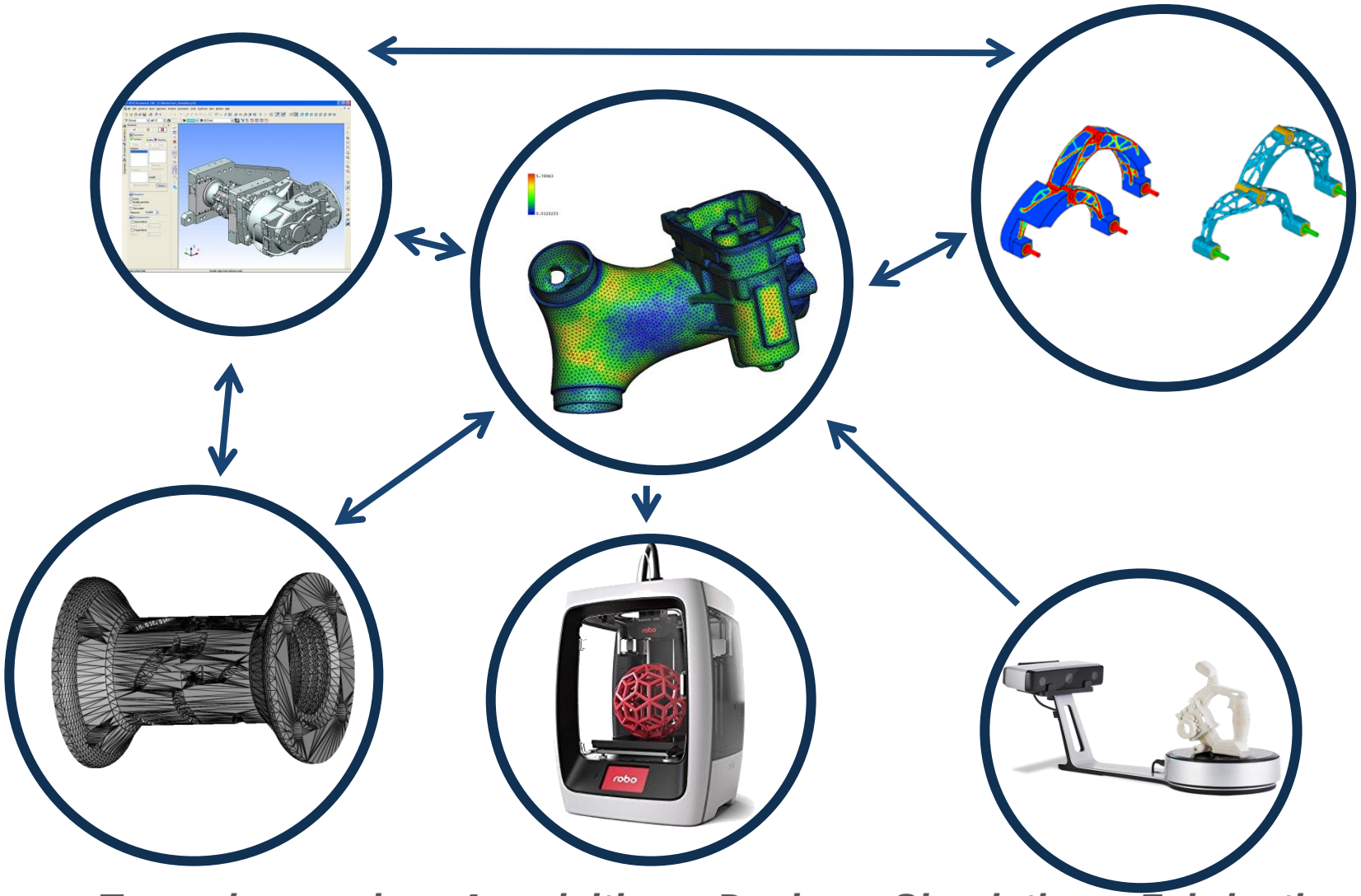




Topology optimization

# Perspectives for Axis 1: Geometry Processing

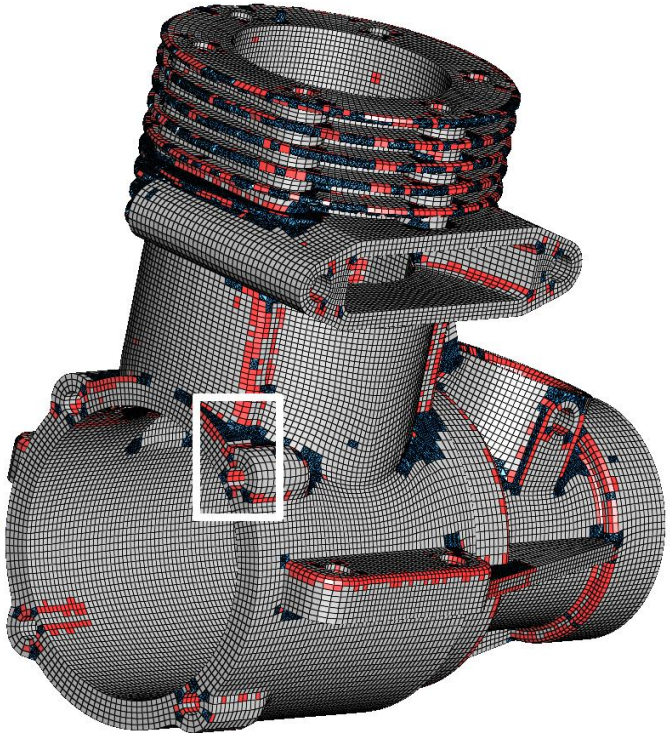
***Abstract Shape Representation – ‚google translate‘ for shapes***

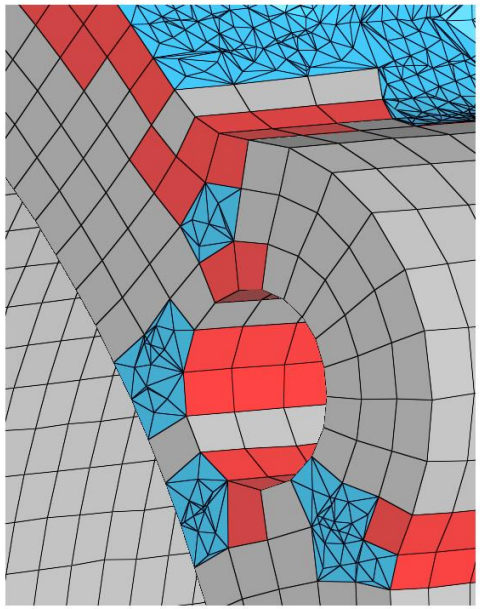


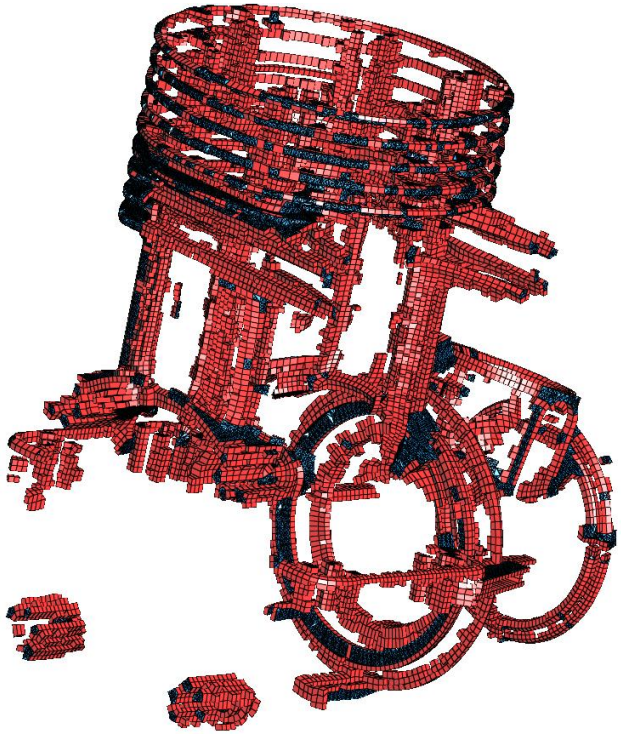
***Towards seemless Acquisition – Design – Simulation – Fabrication***

# Perspectives for Axis 1: Geometry Processing

***From hex-dominant to full-hex, the last miles….***







Singularities – Modular meshing

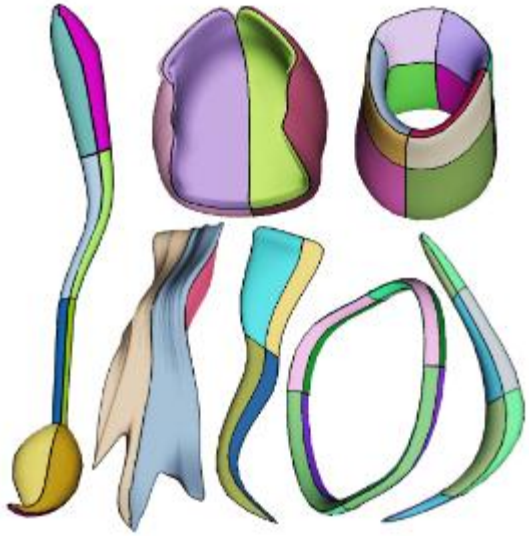
# Perspectives for Axis 1: Geometry Processing

## *Texture Mapping Reloaded*

**Automatic Mesh Segmentation**
New Ph.D. thesis, Coop. with Polygonal Design

UNFOLD3D® 2018 UV WIZARD®

New Features



**Polygonal Design … SciTech O. committee**

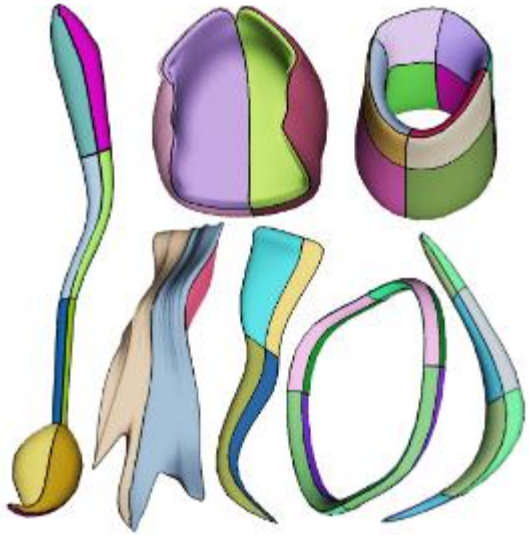
# Perspectives for Axis 1: Geometry Processing

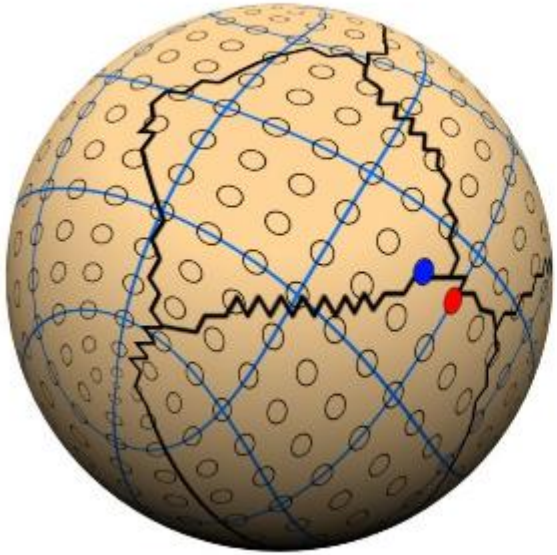
## *Texture Mapping Reloaded*

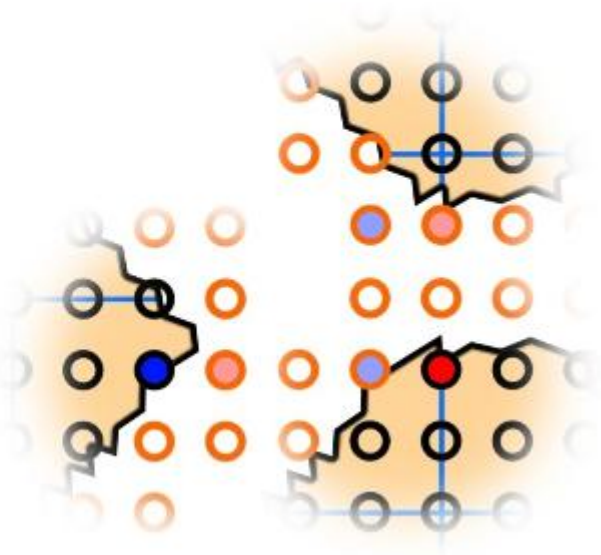
**Automatic Mesh Segmentation**
New Ph.D. thesis, Coop. with Polygonal Design

UNFOLD3D® 2018 UV WIZARD®

New Features







**Continuous Texture Mapping**
$C^n$ texture space [EGSR 2010] .

# *Thank you for your attention !*