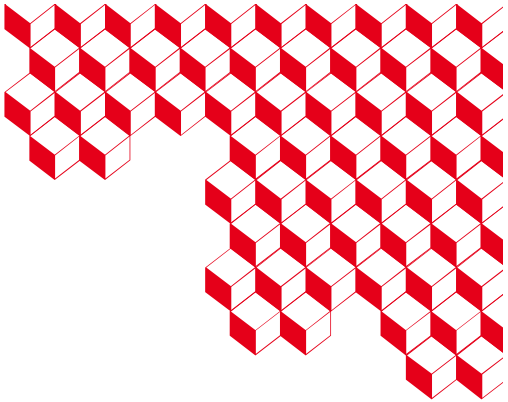


Evolutional Polycubes for Hex Blocking

Franck Ledoux[1,2]

with C. Bourcier[3], C. Dumery[3], N. Le Goff[1,2], S. Mestrallet[2,3], F. Protais[4], N. Ray[4], D. Sokolov[4]

[1] *CEA, DAM, DIF, F-91297, Arpajon, France*

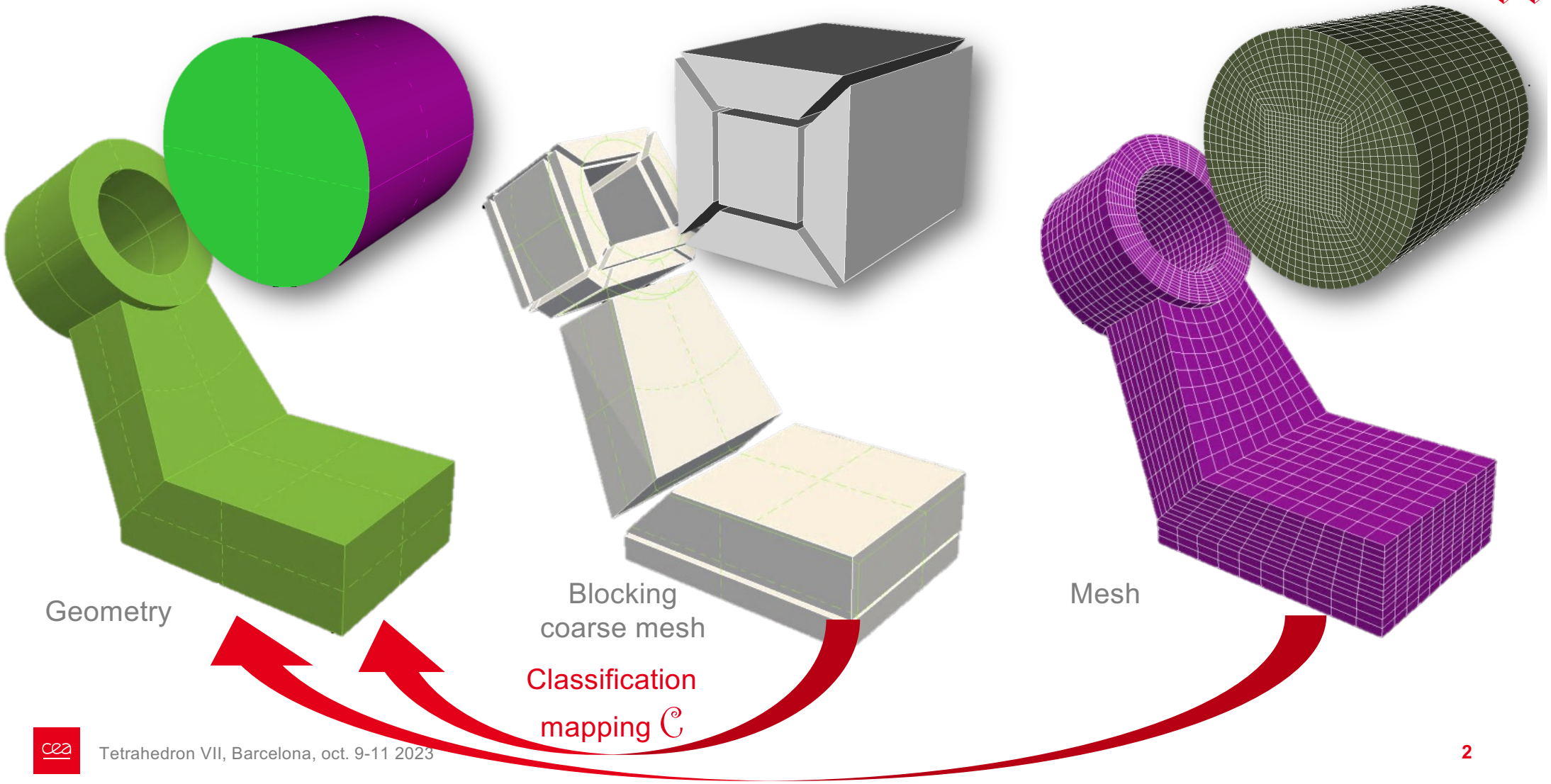
[2] *LIHPC, Université Paris-Saclay , Bruyères-le-Châtel, France*

[3] *ISAS,CEA, Université Paris-Saclay, Gif-sur-Yvette, France*

[4] *Université de Lorraine, CNRS, Inria, LORIA, F-54000 Nancy, France*

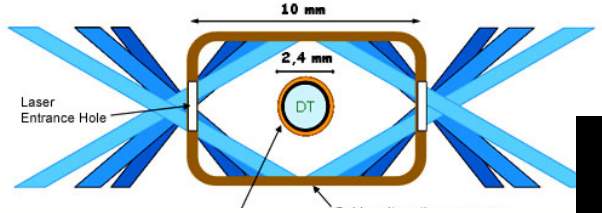
lihpc

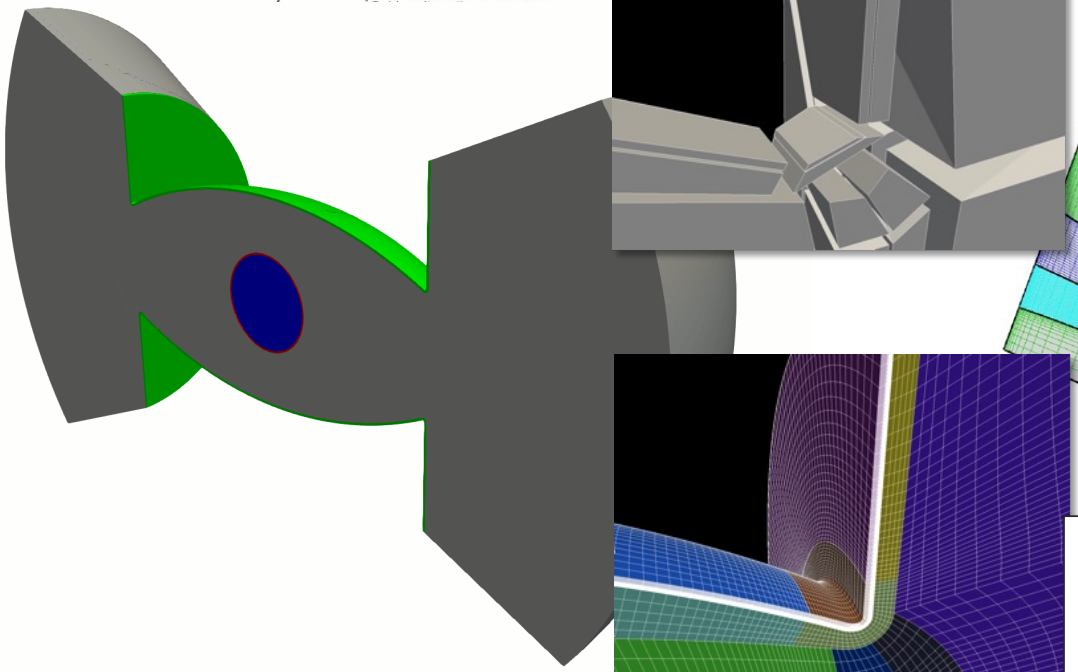
Evolutional Polycube for Hex Blocking



Evolutional Polycube for Hex Blocking
Context – CEA Simulation codes

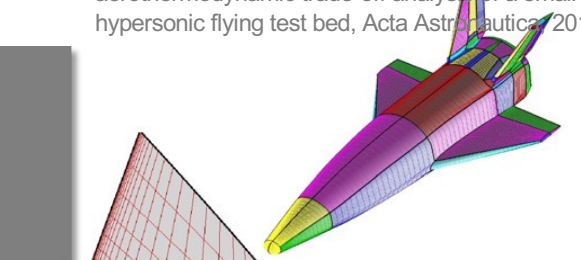
- Hydrodynamic codes

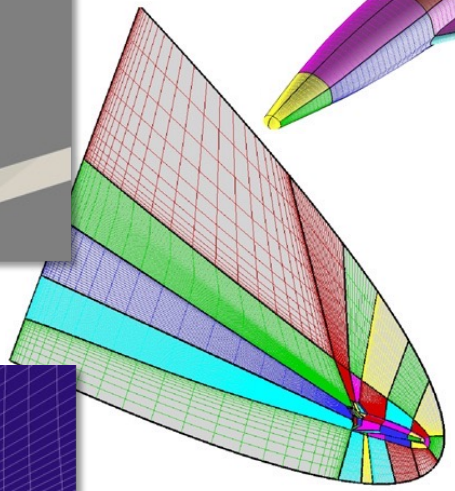


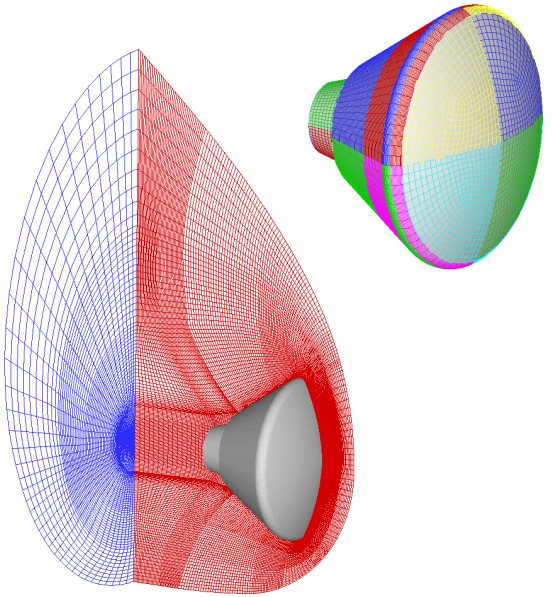


- Aerodynamics

Giuseppe Pezzella , Aerodynamic and aerothermodynamic trade-off analysis of a small hypersonic flying test bed, Acta Astronautica, 2011





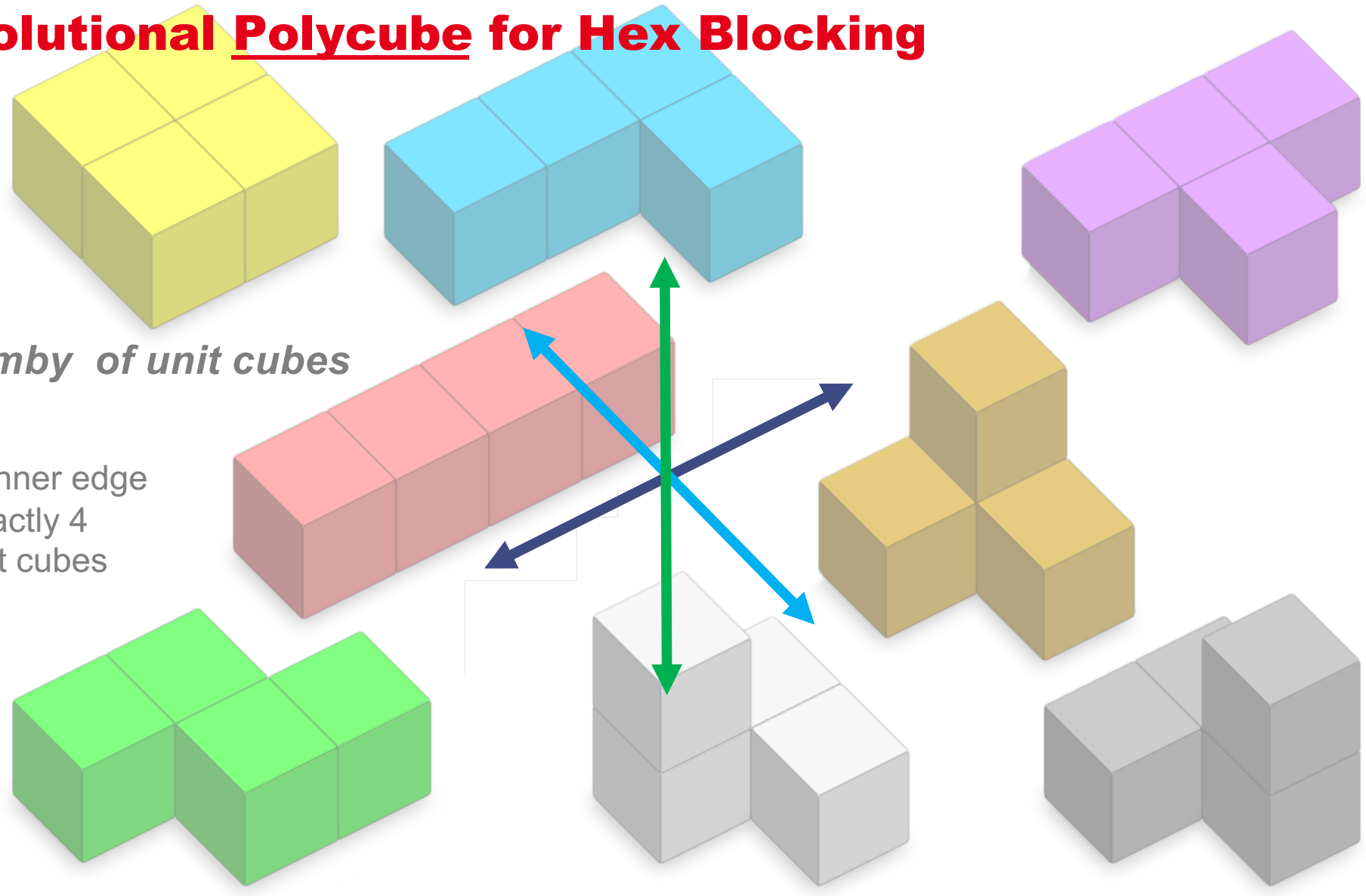


Antonio Viviani & Giuseppe Pezzella (2009) Nonequilibrium Aerothermodynamics for a Capsule Reentry Vehicle, Engineering Applications of Computational Fluid Mechanics, 3:4, 543-561

Common requirement

- *Hexahedral block structure*
- *Boundary layers*
- *Size control, boundary alignment, orthogonality*

Evolutional Polycube for Hex Blocking

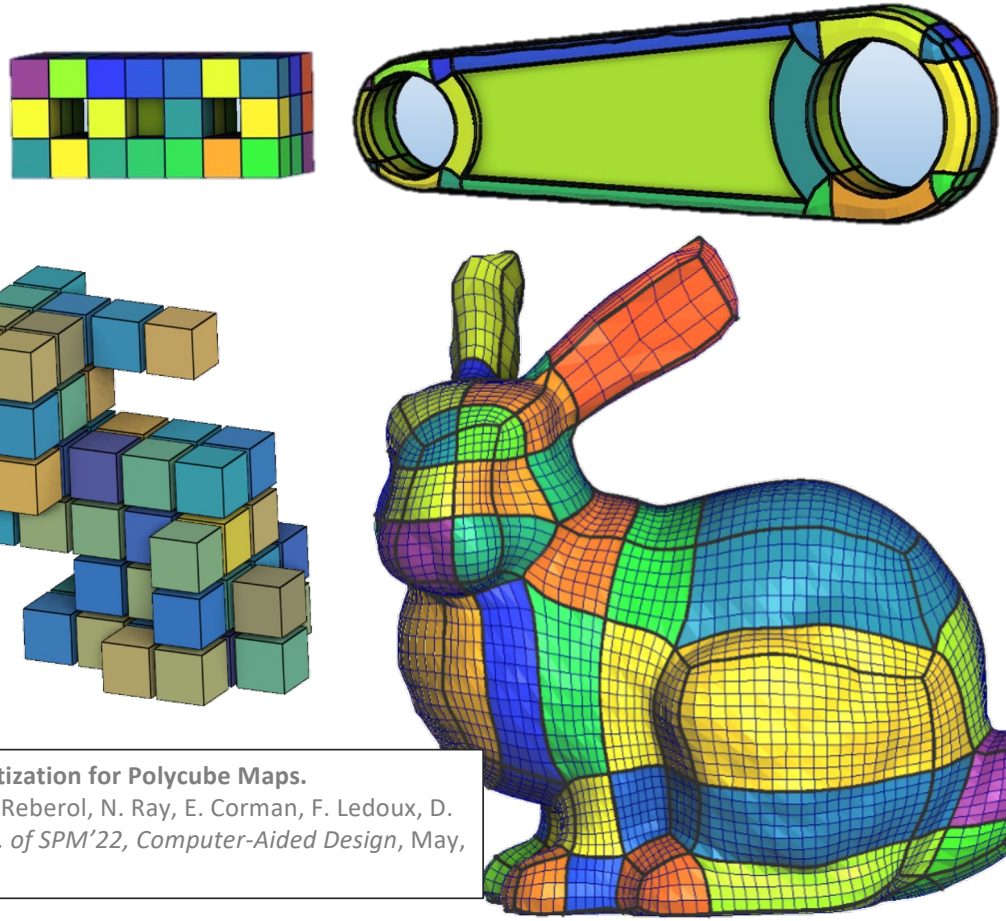


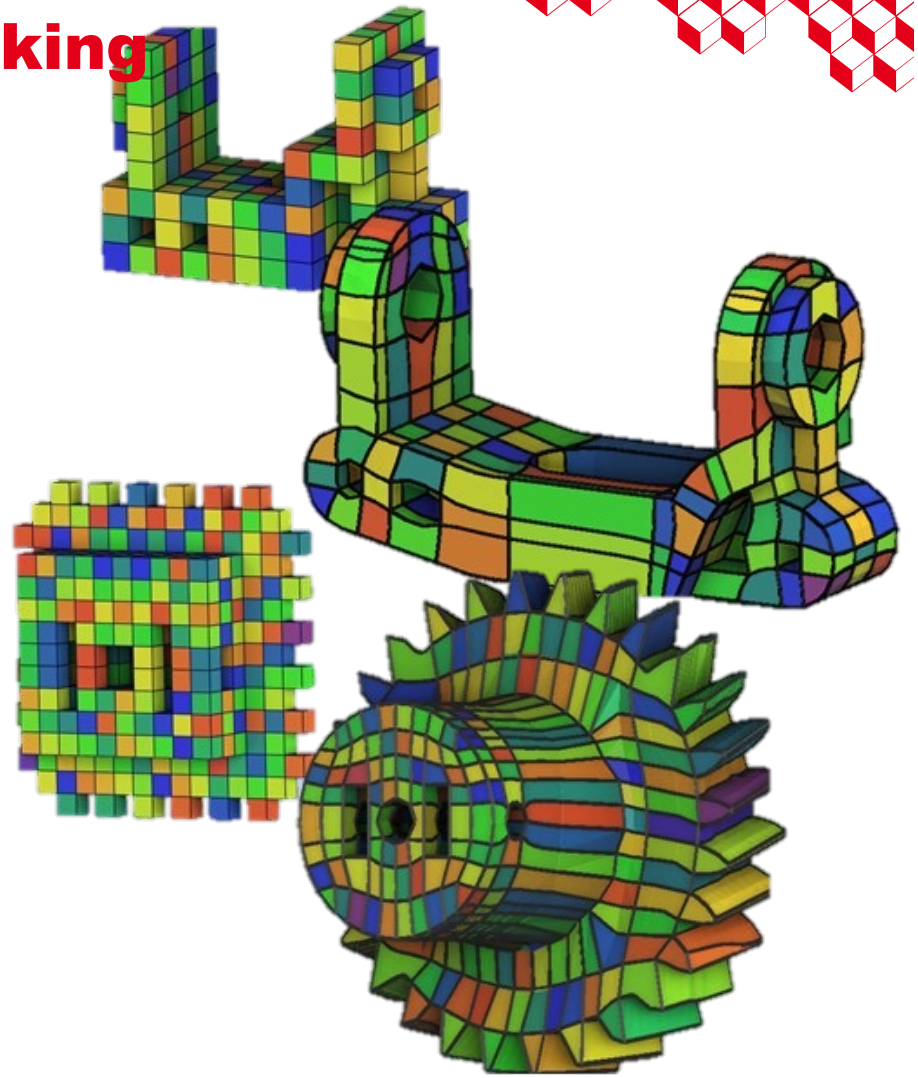
Assemby of unit cubes

Every inner edge has exactly 4 incident cubes

Evolutional Polycube for Hex Blocking

Assemby of unit cubes



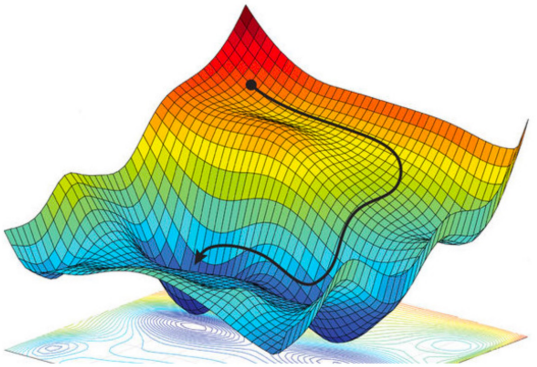


Robust Quantization for Polycube Maps.
F. Protais, M. Reberol, N. Ray, E. Corman, F. Ledoux, D. Sokolov, *Proc. of SPM'22, Computer-Aided Design*, May, 2022.

Evolutional Polycube for Hex Blocking

Evolutionary Algorithm

- population-based metaheuristic optimization algorithms inspired by biological evolution
- Make **evolve** a **population** of **genomes** to maximise the **fitness** of a genome, to better fit a certain environment



Why using them?

- We modelize many problems as multi-objective functions

soft constraints

$$\text{minimize } a.E(\mathbf{x}) + b.F(\mathbf{x}) + c.G(\mathbf{x}) + d.H(\mathbf{x}) + f.I(\mathbf{x})$$

s.c. $\mathbf{x}$ in N^3
$F(\mathbf{x})<Y$ with $Y>0$

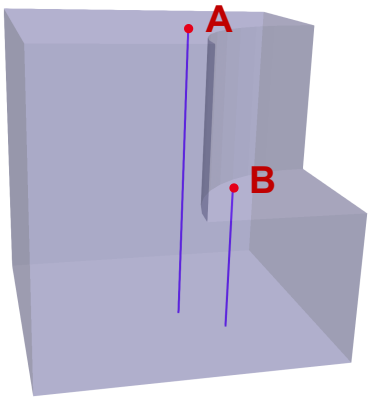
hard constraints

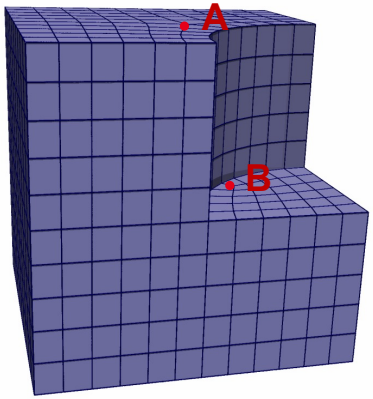
- non-convex, non linear
- Multiple extrema
- Choice of a, b, c, d, and f?
- How to mix topological and geometrical objectives?

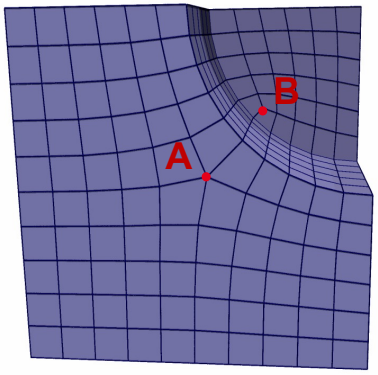
Evolutional Polycube for Hex Blocking

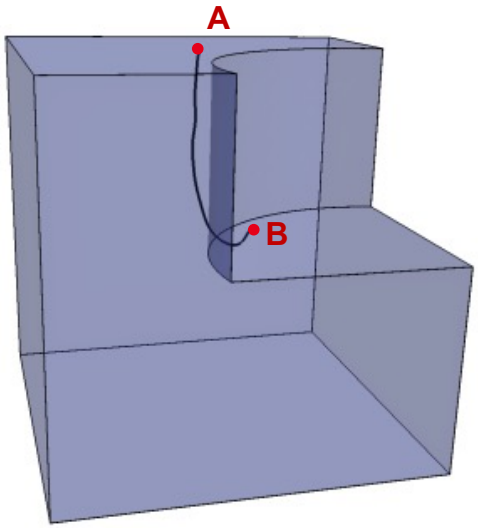
Difficulty to combine topological and geometrical objectives

- **Singularity graph** in frame field generation

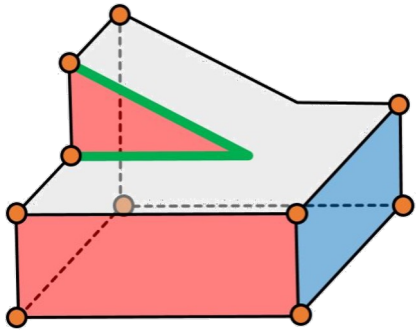


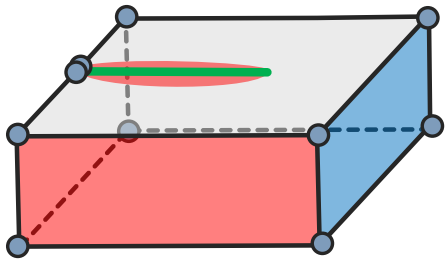


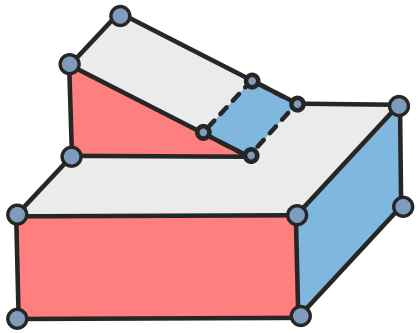


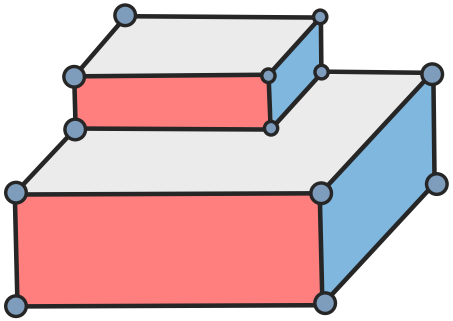


- **Chart labelling** in polycube boundary structure





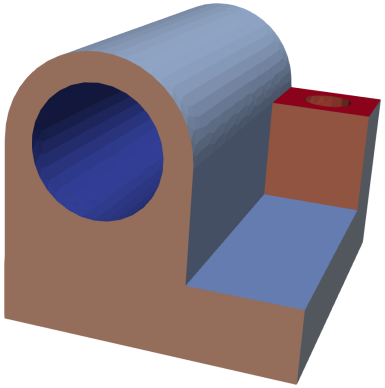




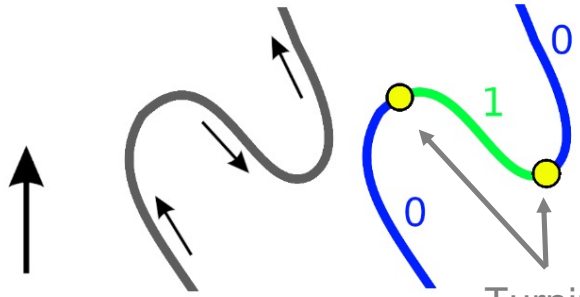
Evolutional Polycube for Hex Blocking

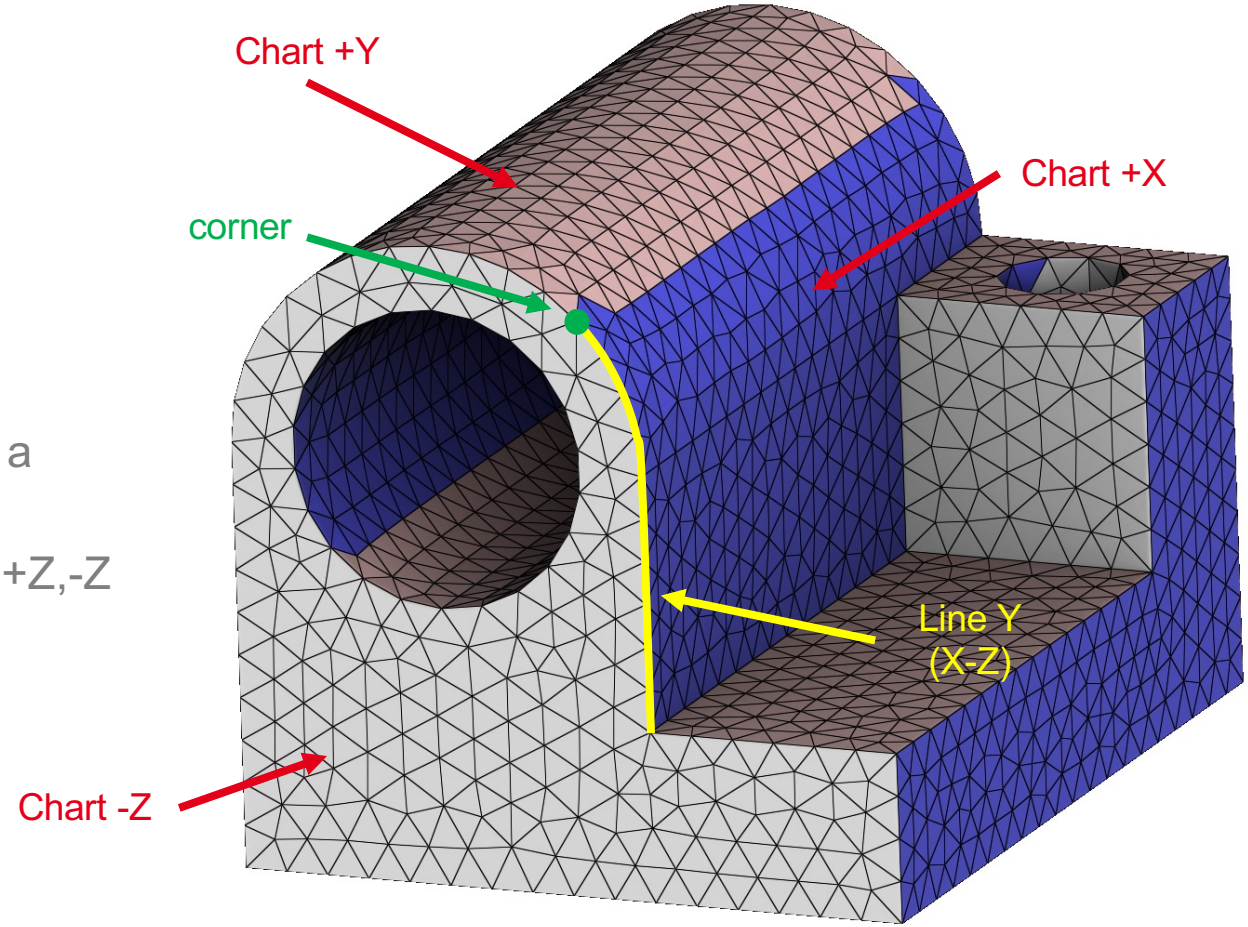
1. Global pipeline
2. Genetic Algorithm for labeling

Global pipeline

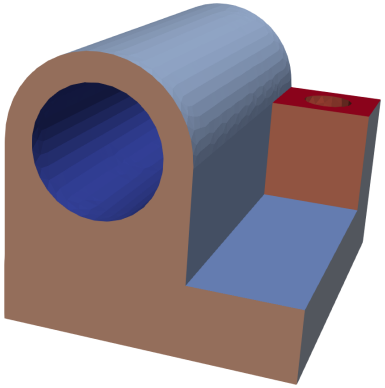


- Discretize the geometrical domain by a tetrahedral mesh
- Label each bnd triangle: +X,-X,+Y,-Y,+Z,-Z

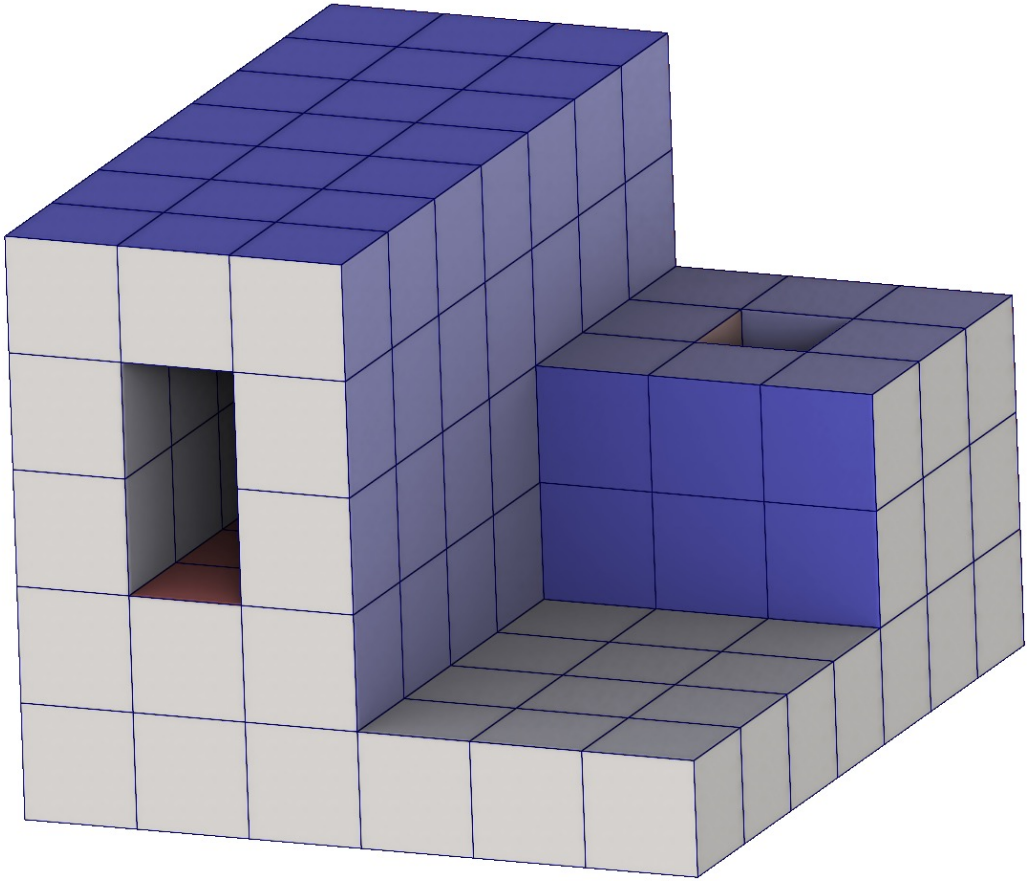




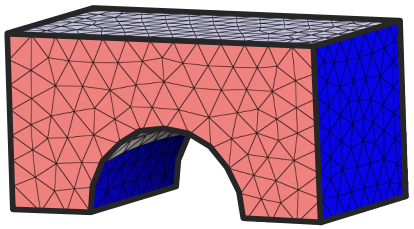
Global pipeline



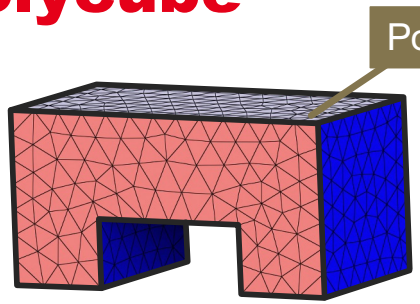
- Discretize the geometrical domain by a tetrahedral mesh
- Label each bnd triangle: +X,-X,+Y,-Y,+Z,-Z
- Build the polycube



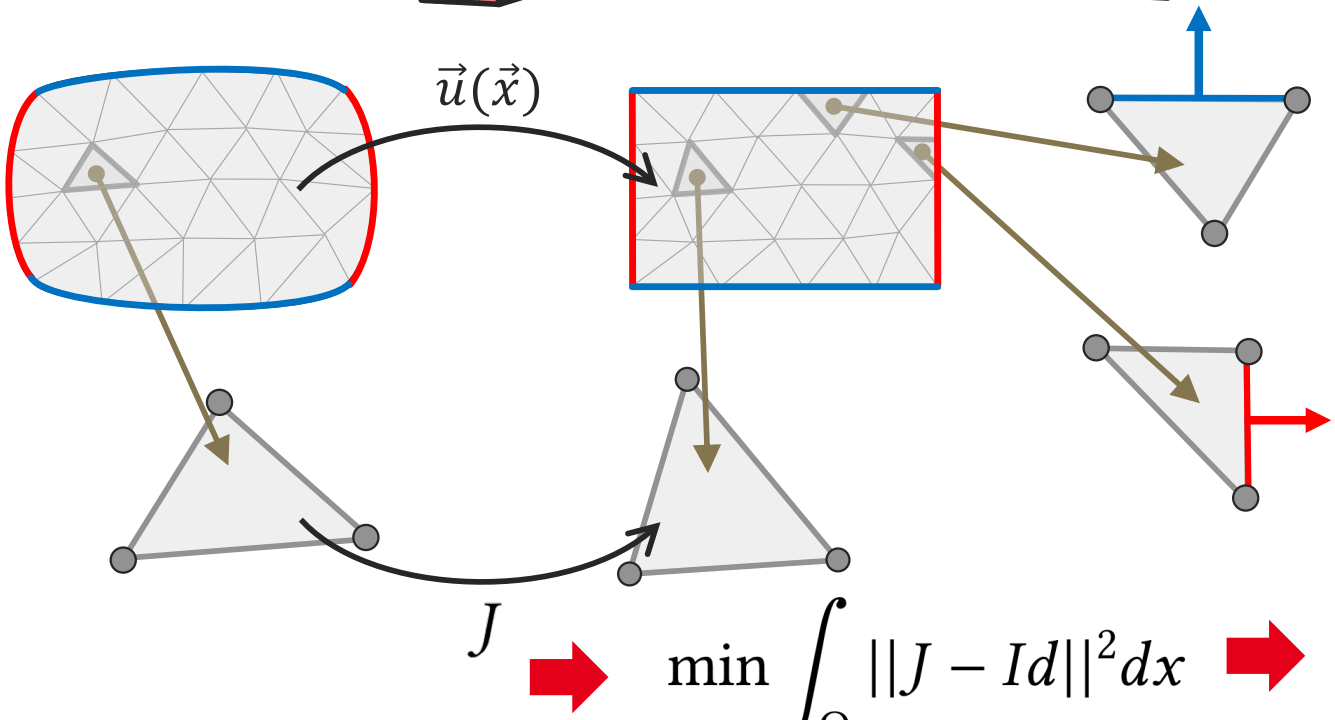
From a labeling to a polycube



deformation



quantization

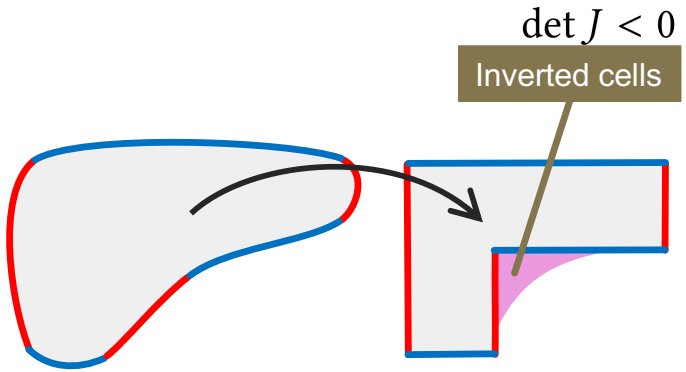


$$\min \int_{\Omega} ||J - Id||^2 dx$$

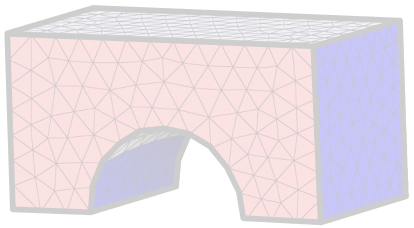
s.c. preserving boundary constraints

Gregson *et al.* 2011, Livesu *et al.* 2013

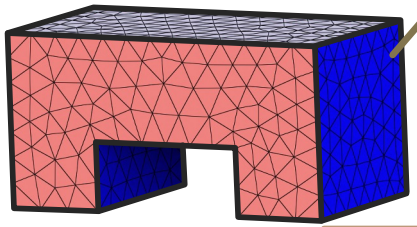
- ***Foldover-free maps in 50 lines of code***, Garanzha *et al.* TOG 2021
- ***On Local Invertibility and Quality of Free-boundary Deformations***, Garanzha *et al.* IMR 2021



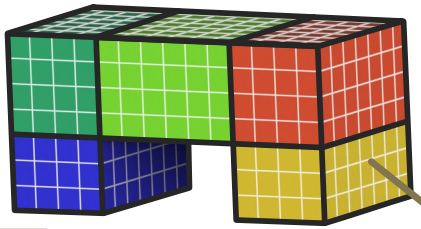
From a labeling to a polycube

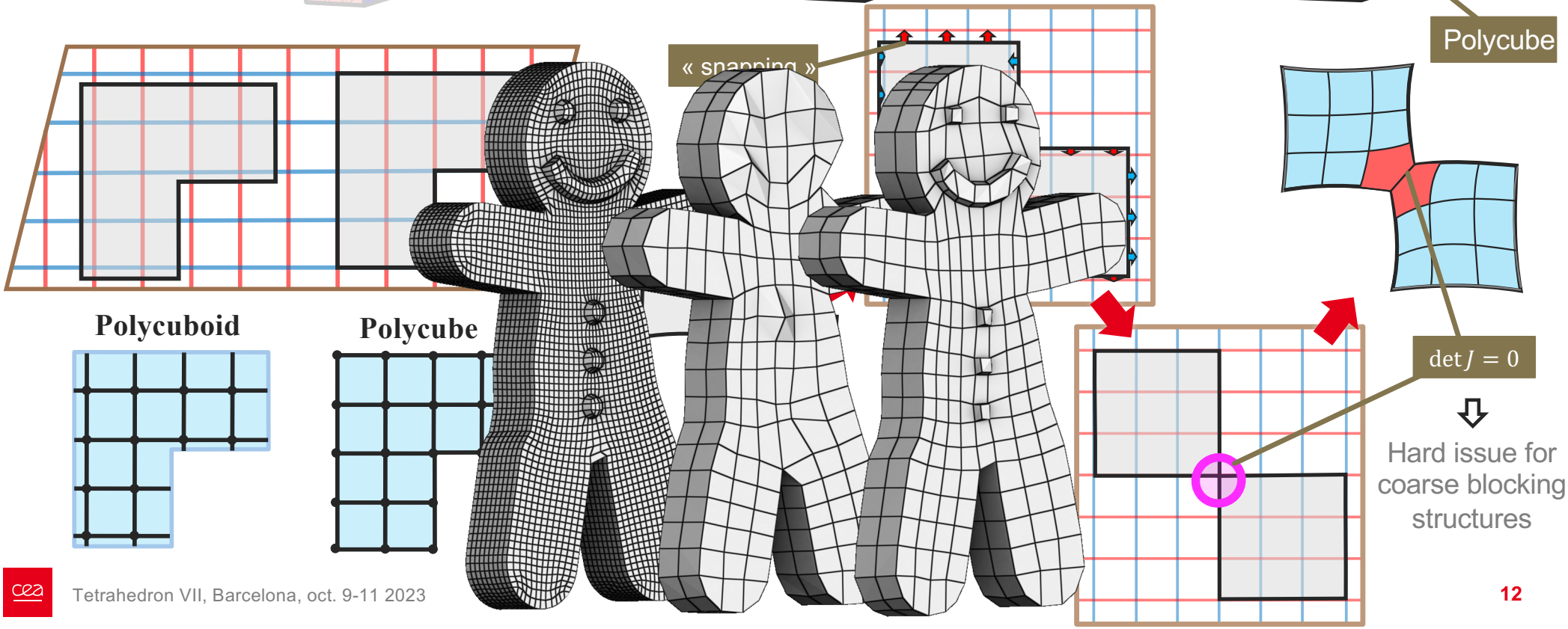


deformation



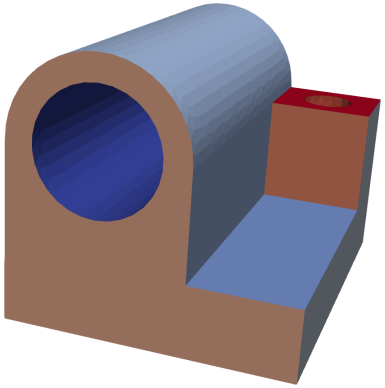
quantization



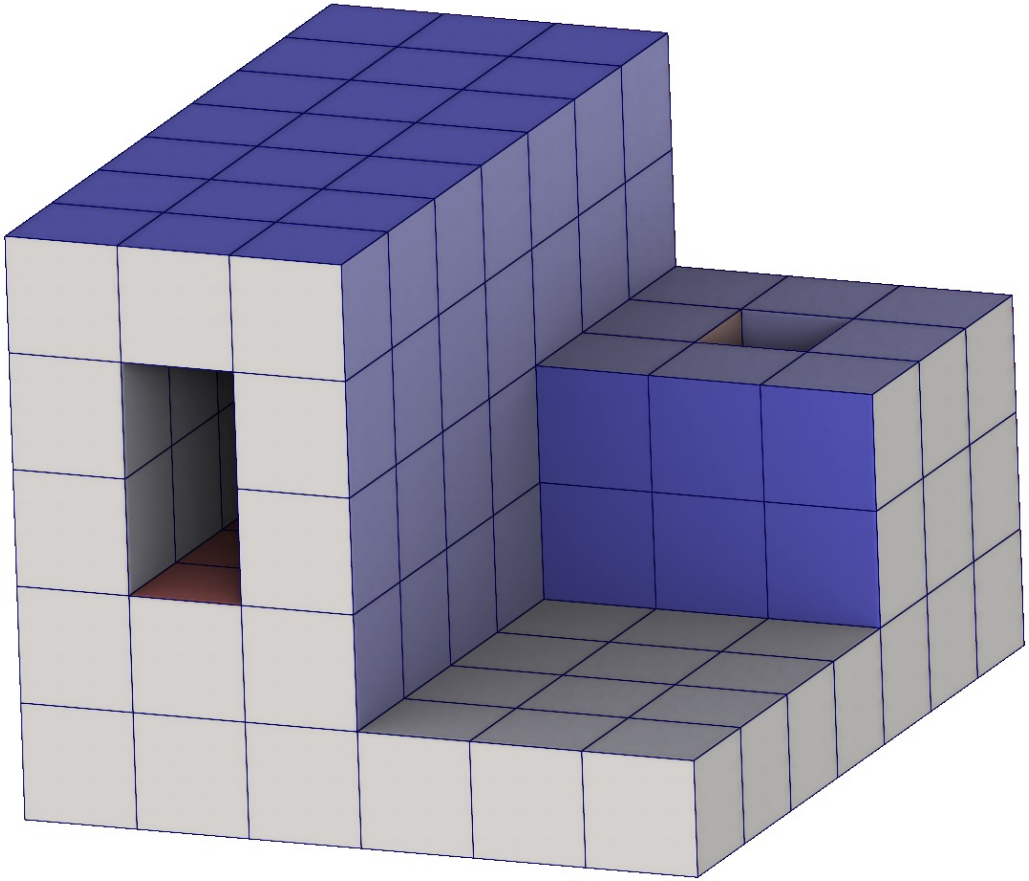


Hard issue for coarse blocking structures

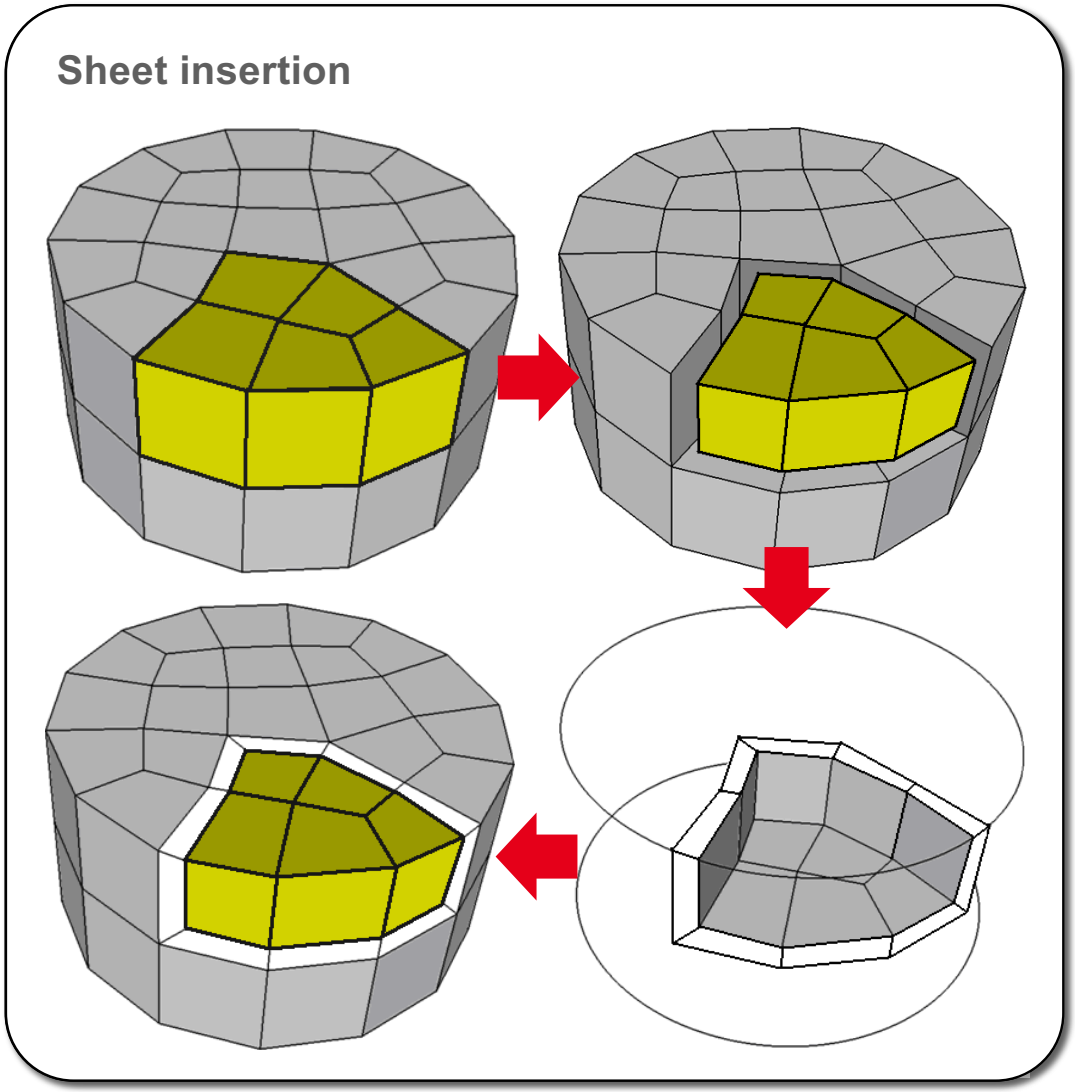
Global pipeline

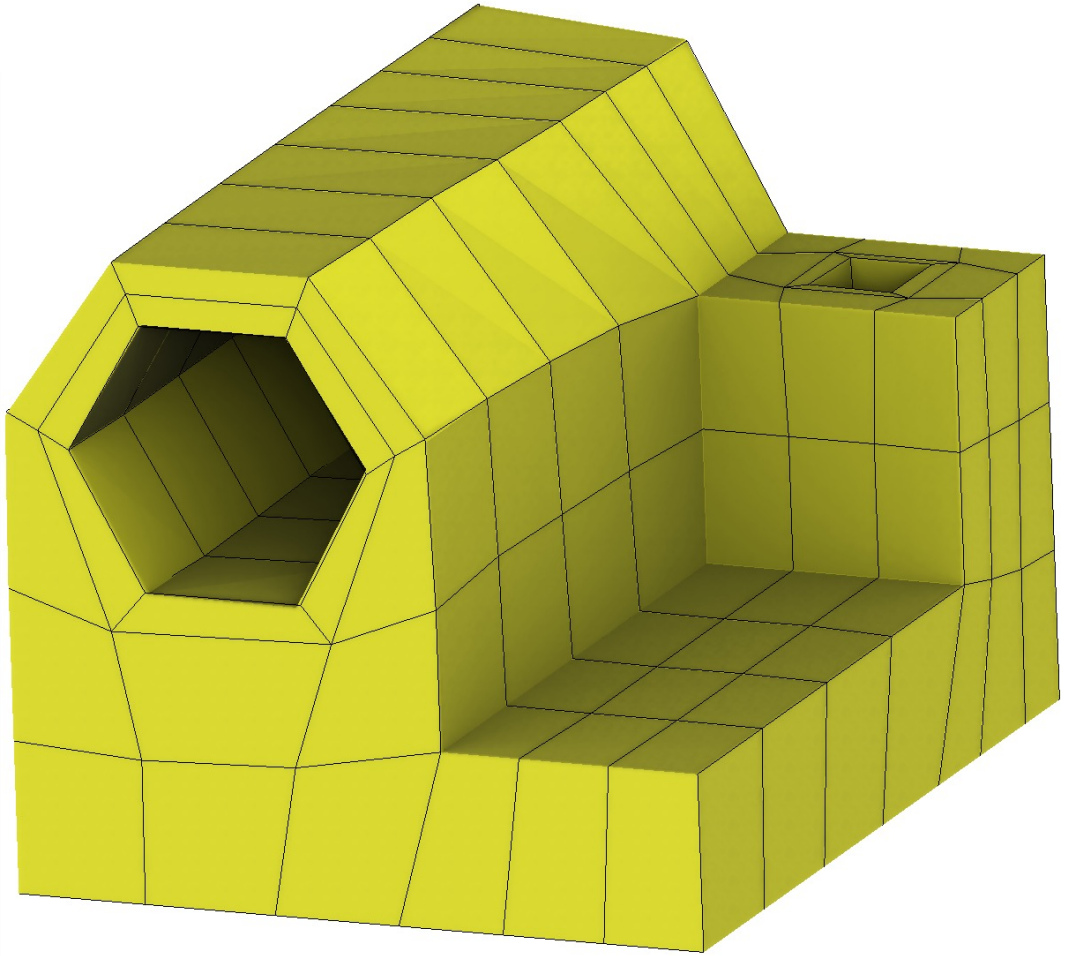


- Discretize the geometrical domain by a tetrahedral mesh
- Label each bnd triangle: +X,-X,+Y,-Y,+Z,-Z
- Build the polycube

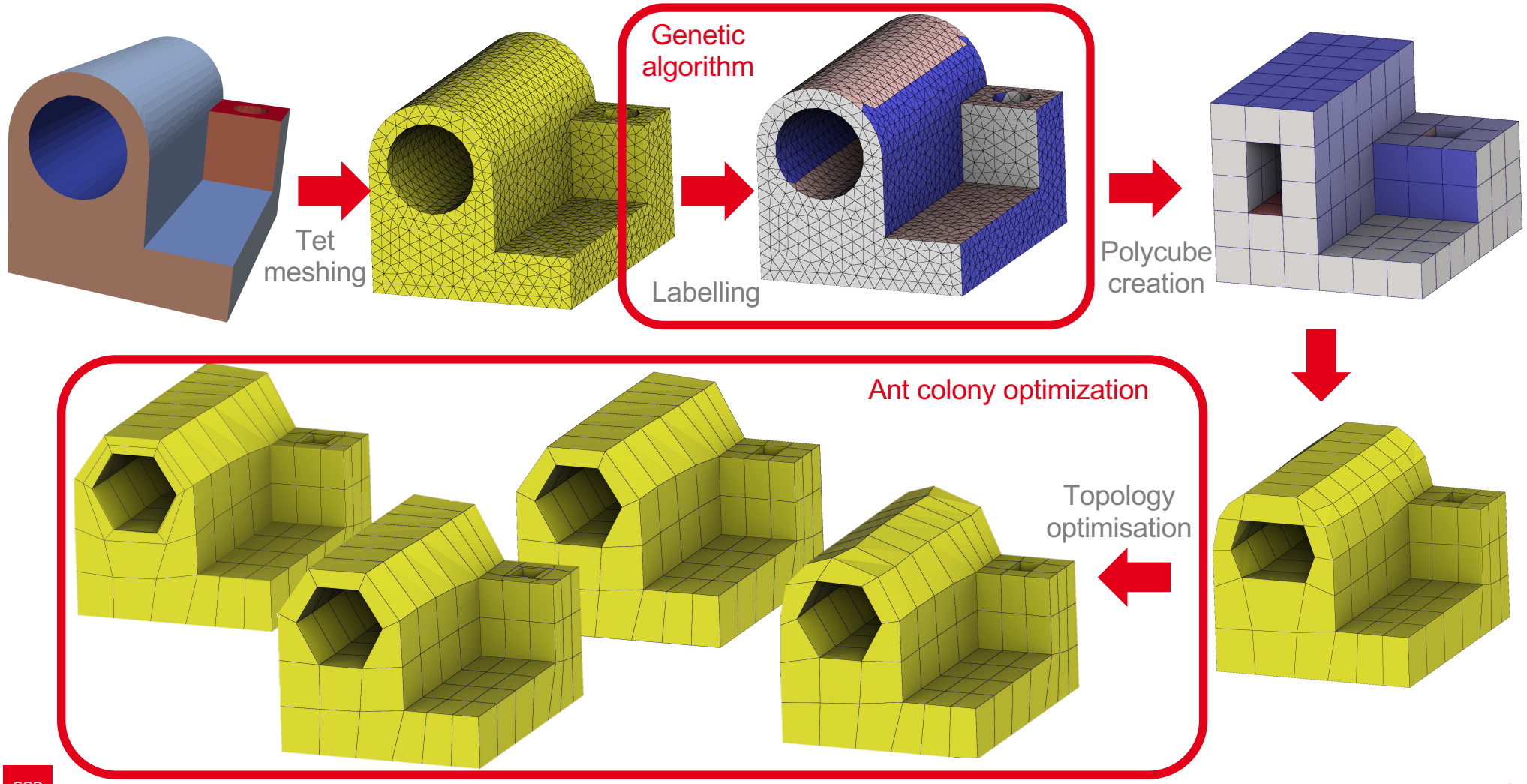


Global pipeline





Global pipeline with evolutionary stages



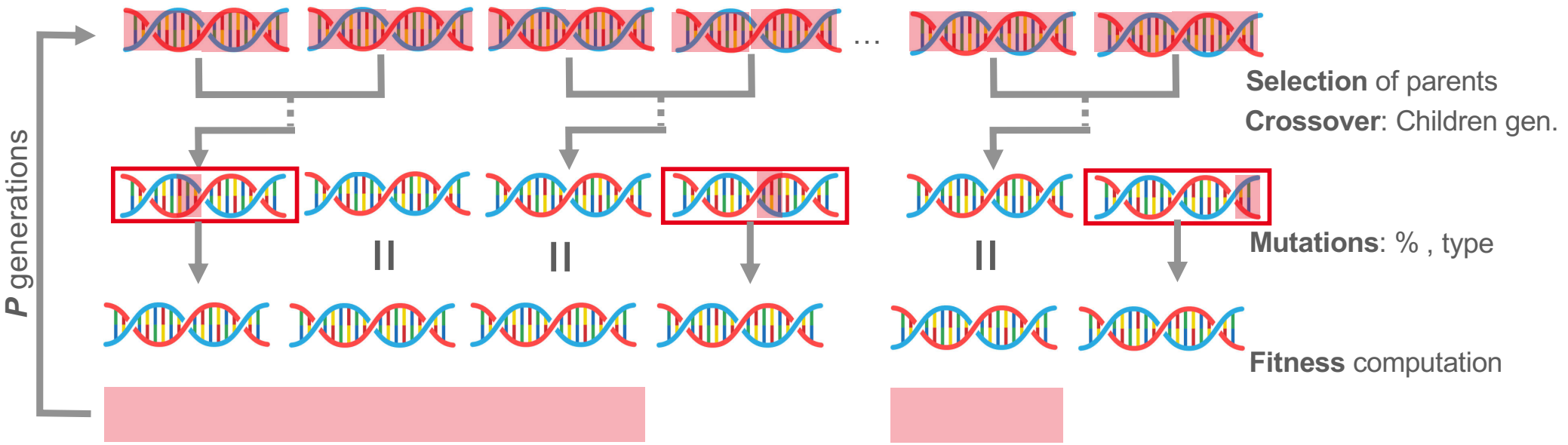
Evolutional Polycube for Hex Blocking

1 Global pipeline

2 Genetic Algorithm for labeling

Genetic Algorithms in a nutshell

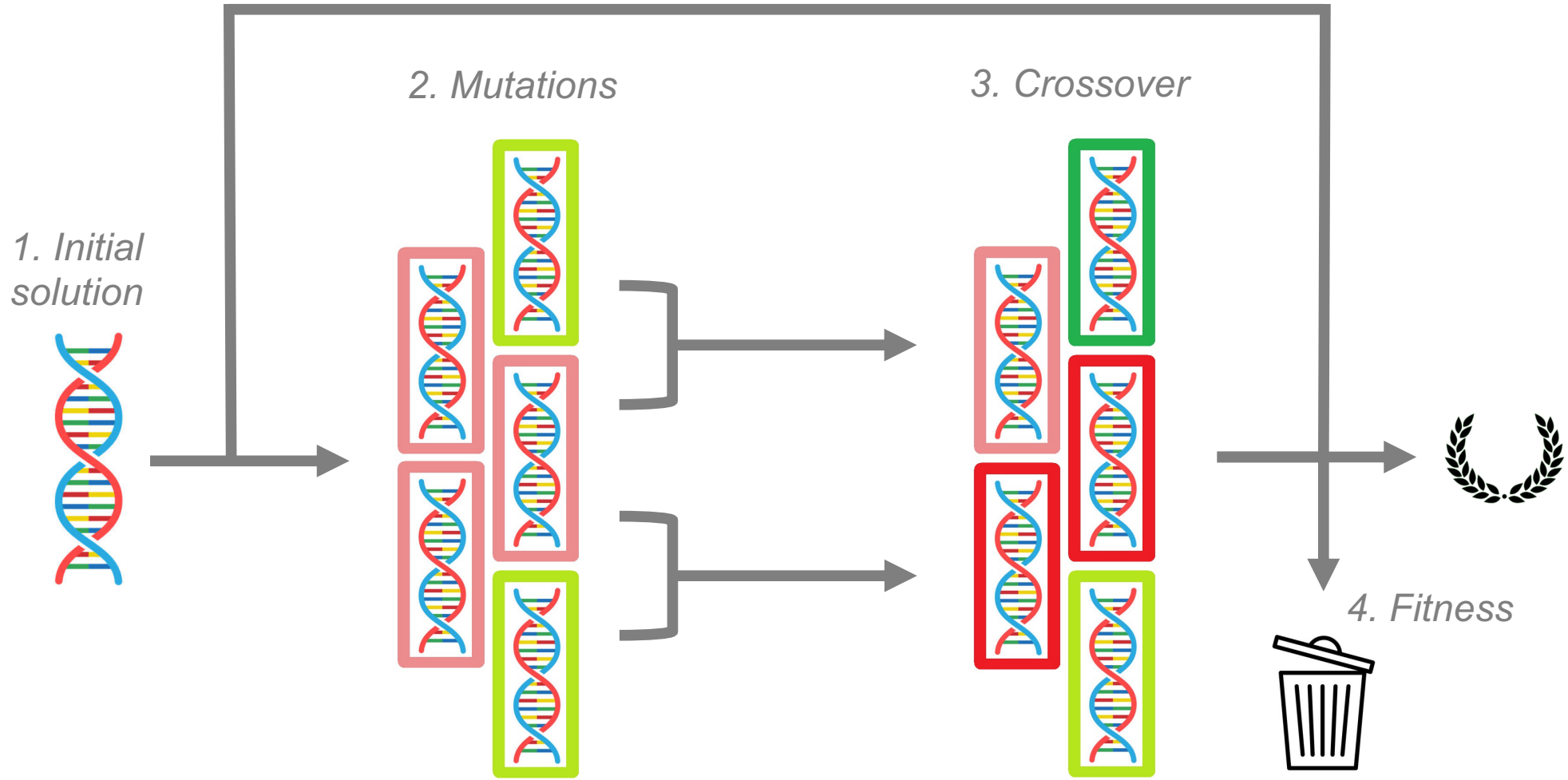
- Idea: follow the evolution of a population of individuals, and keep the best one(s)
- 1 individual = 1 solution 



Hyperparameters: *N*, *P*, mutation(%,type)

Strategies: parent selection, crossover, fitness, next gen. policy

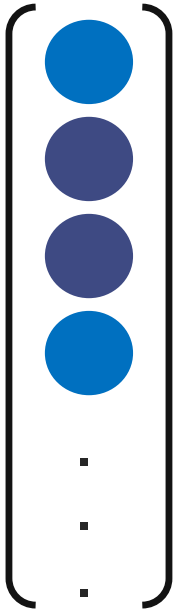
Genetic Algorithms for labeling



Genetic Algorithms for labeling

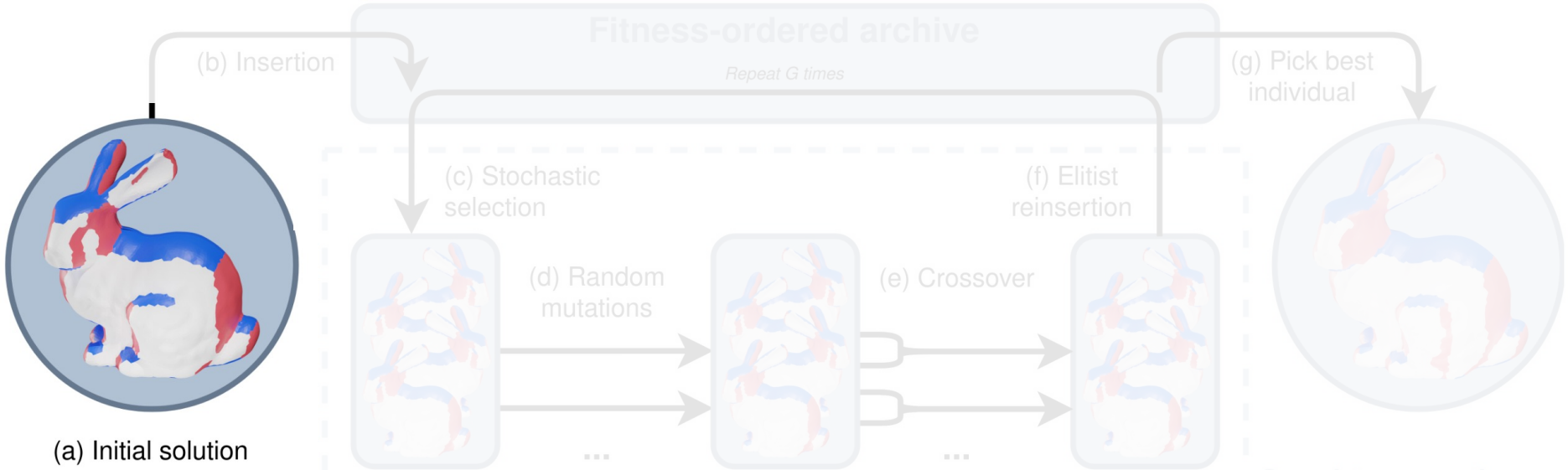
1. *Initial solution*
2. *Mutations*
3. *Crossover*
4. *Fitness*

=



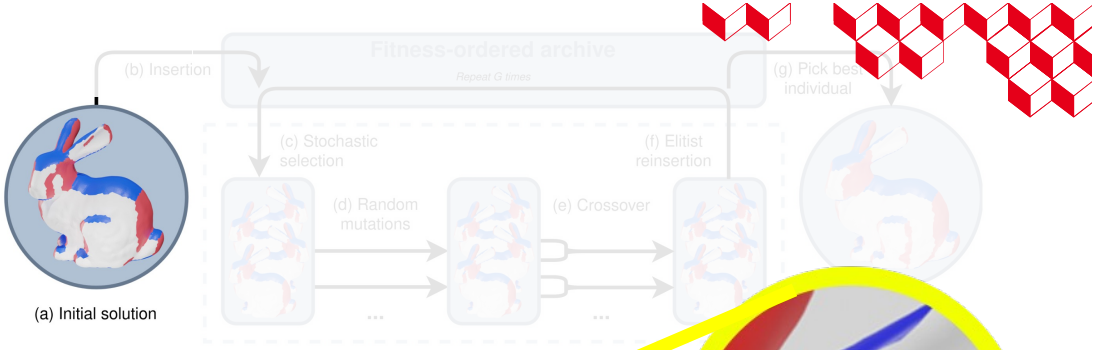
Vector of per-face labels

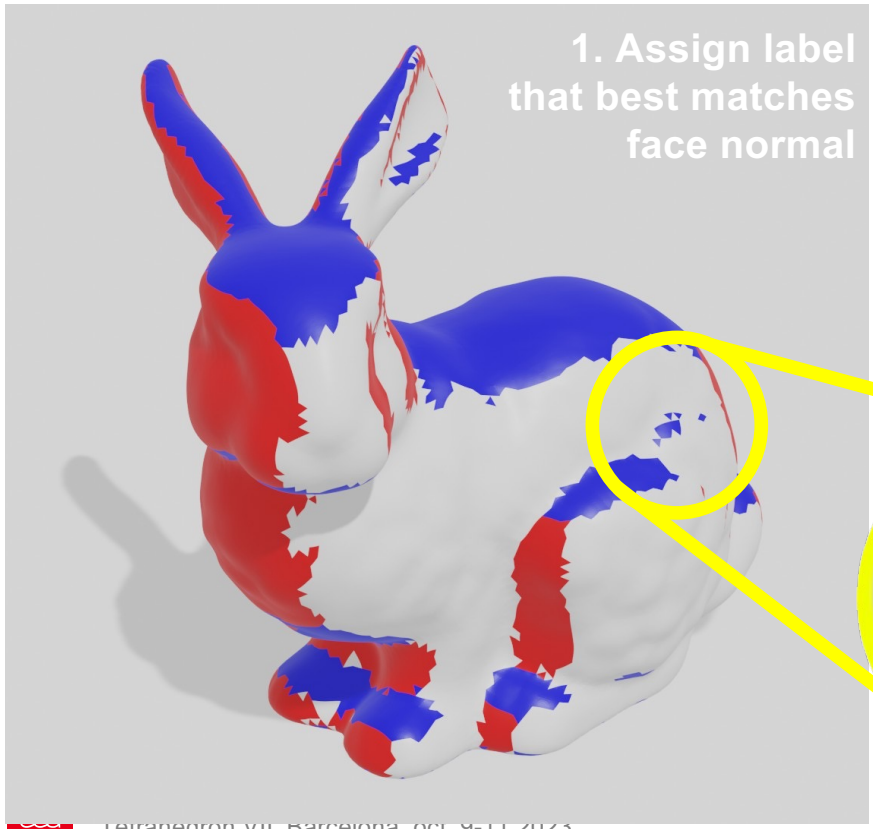
Genetic Algorithms for labeling

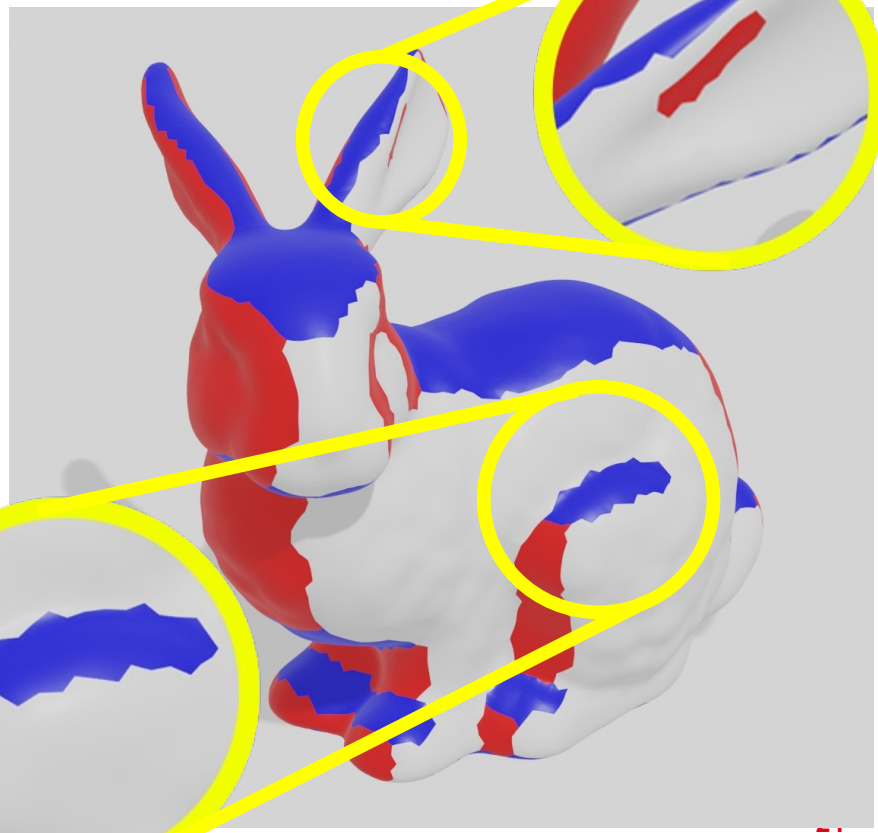


Initial population

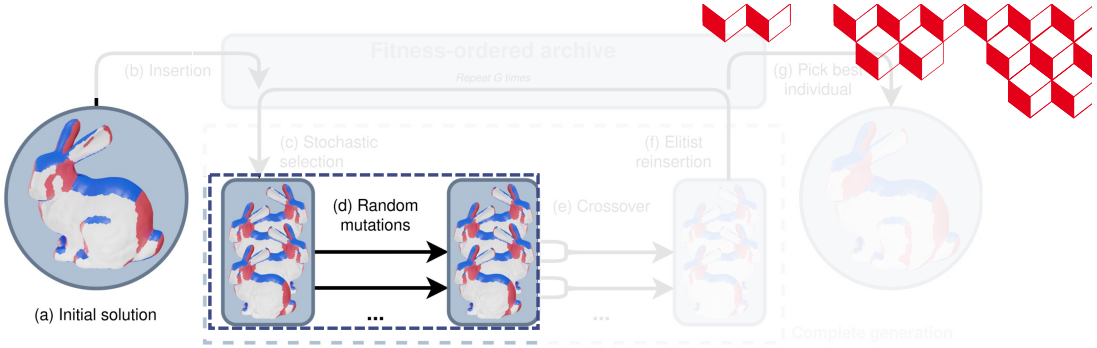
Initial population generated from a single individual

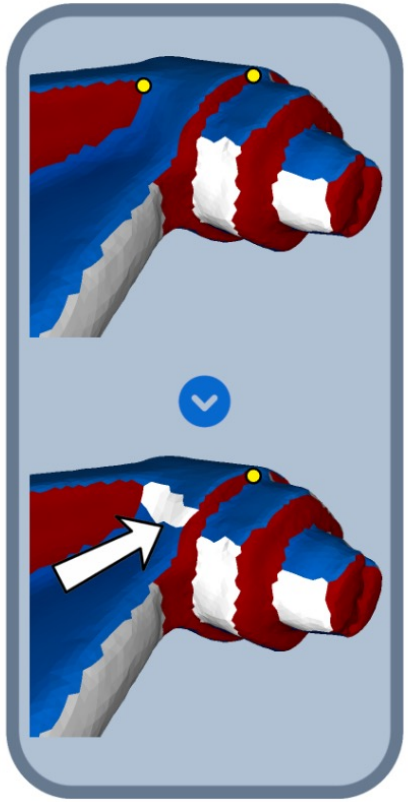






Mutations





Directional path

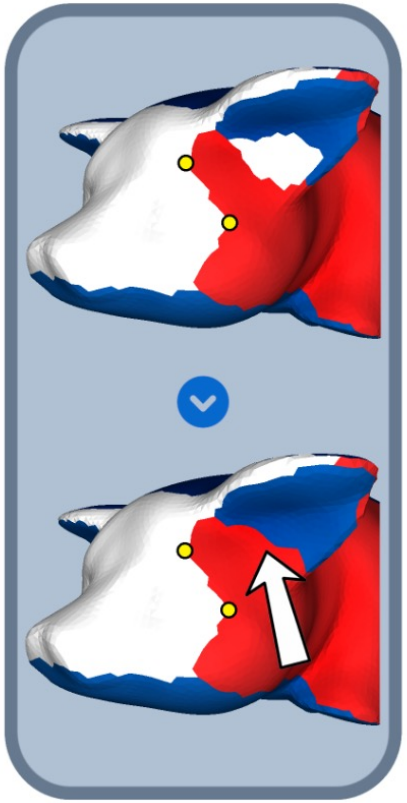


Chart removal

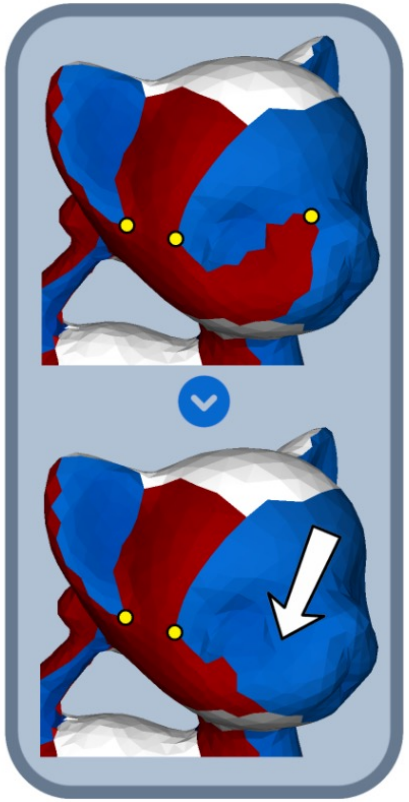
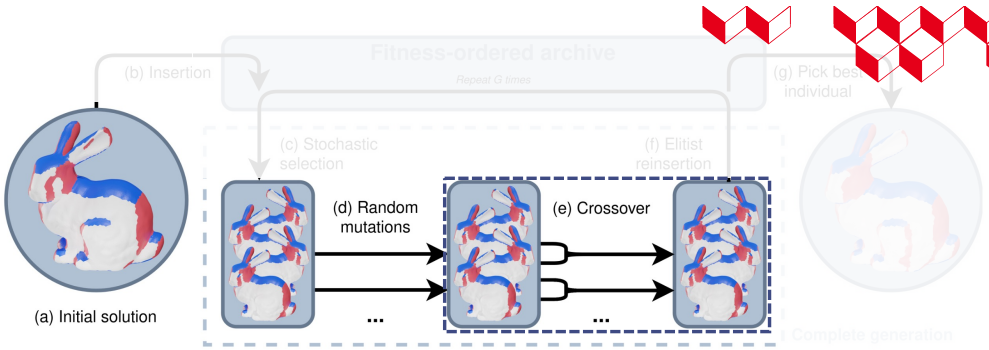
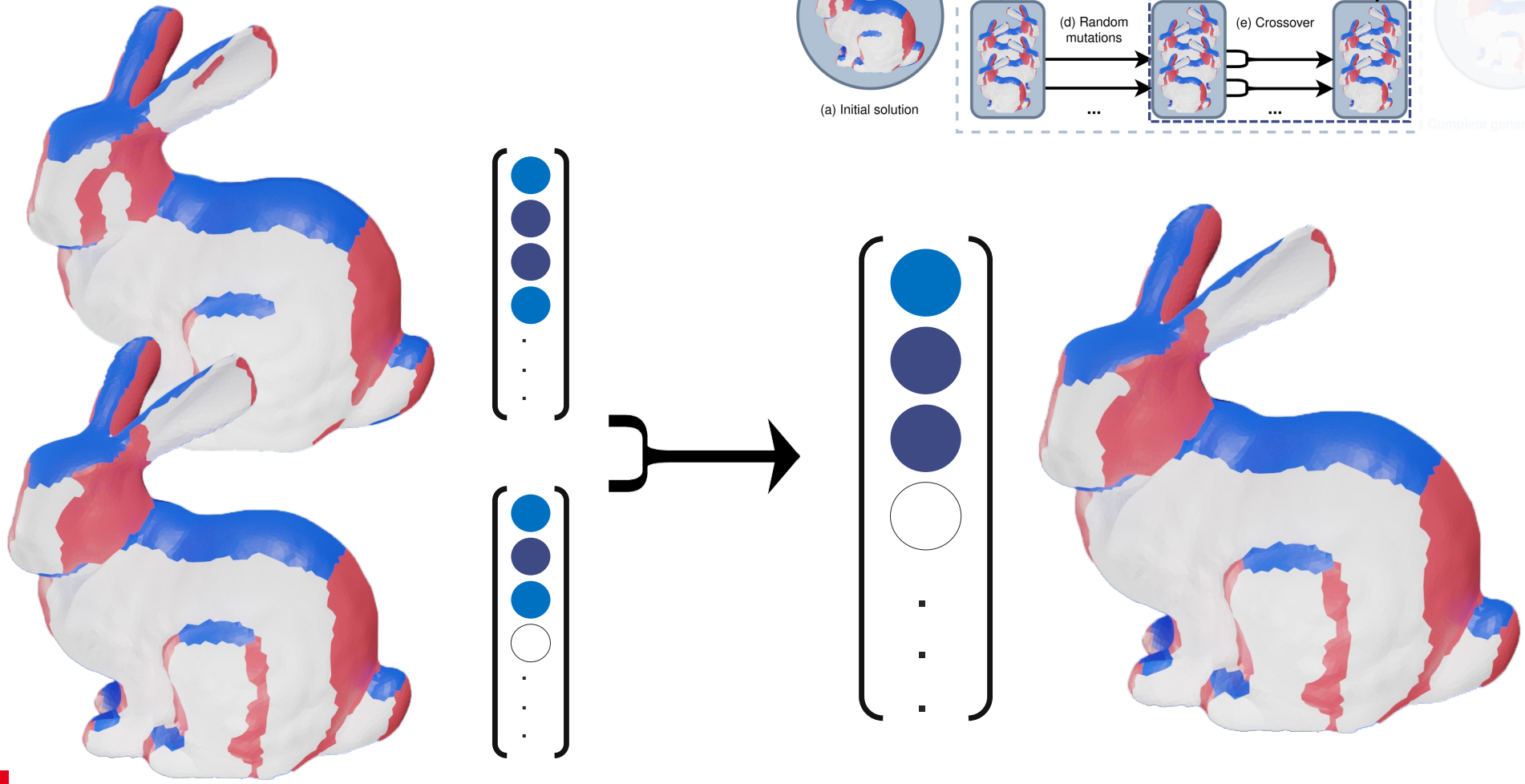


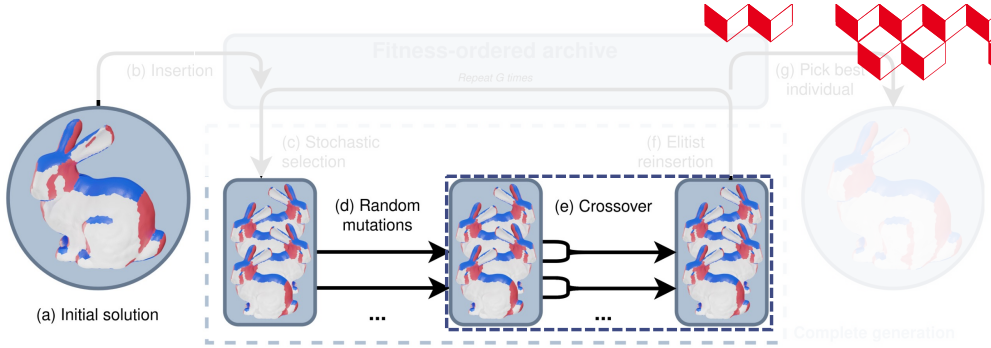
Chart propagation

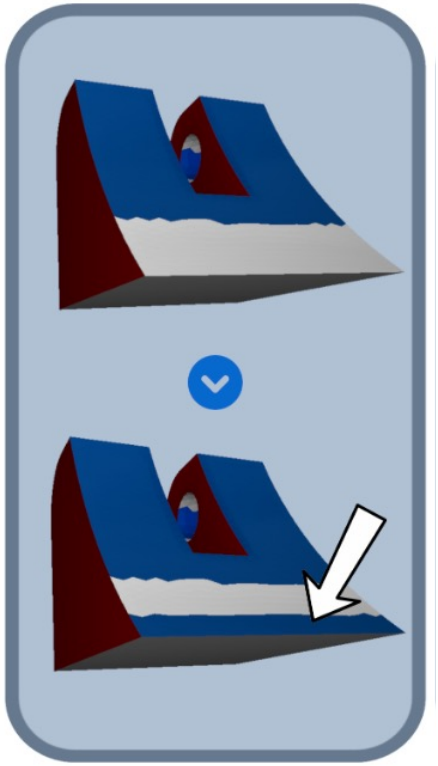
Crossover


(b) Insertion
Fitness-ordered archive
Repeat G times
(g) Pick best individual
(c) Stochastic selection
(f) Elitist reinsertion
(d) Random mutations
(e) Crossover
(a) Initial solution
...
...
Complete generation

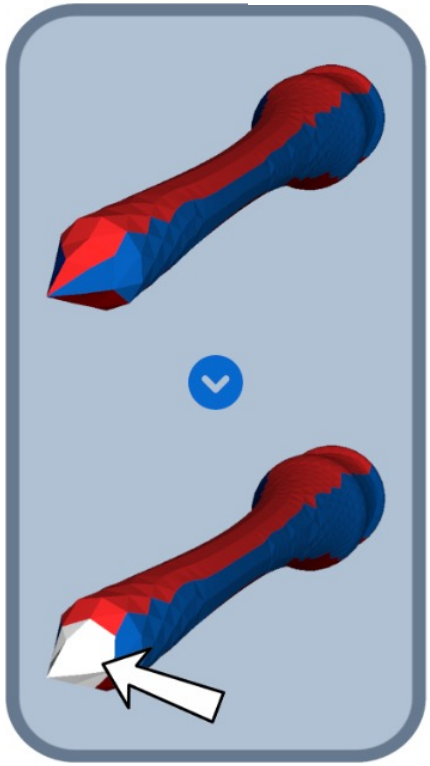


Crossover
Automatic labeling repairs
(mainly to ensure pseudo-validity)

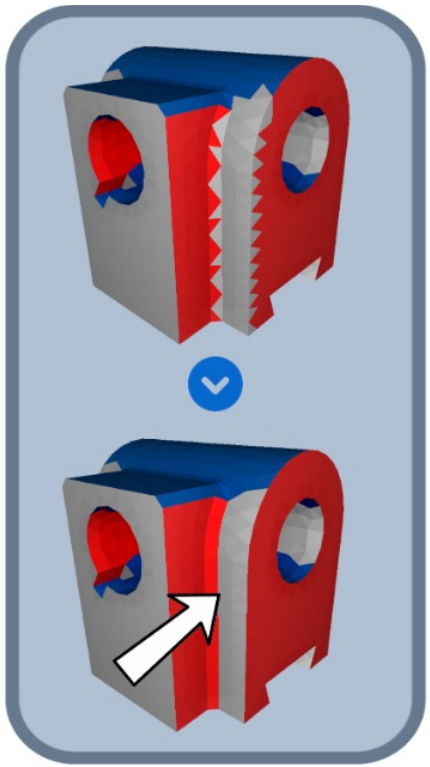




opposite boundarties

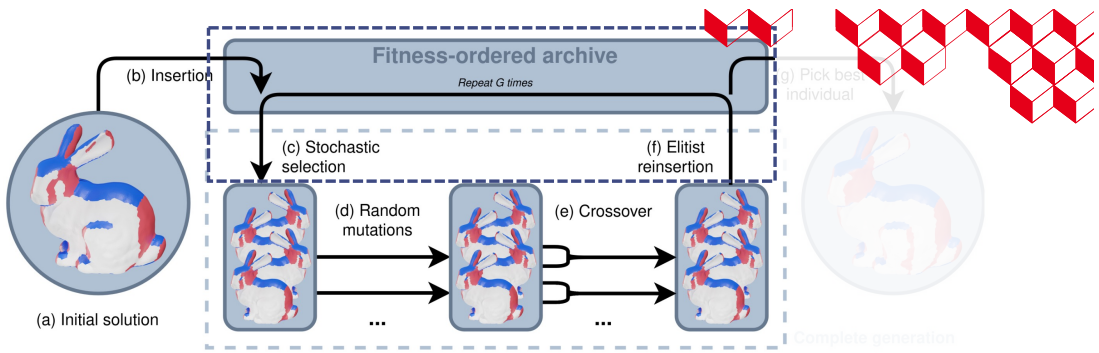


High valence corners



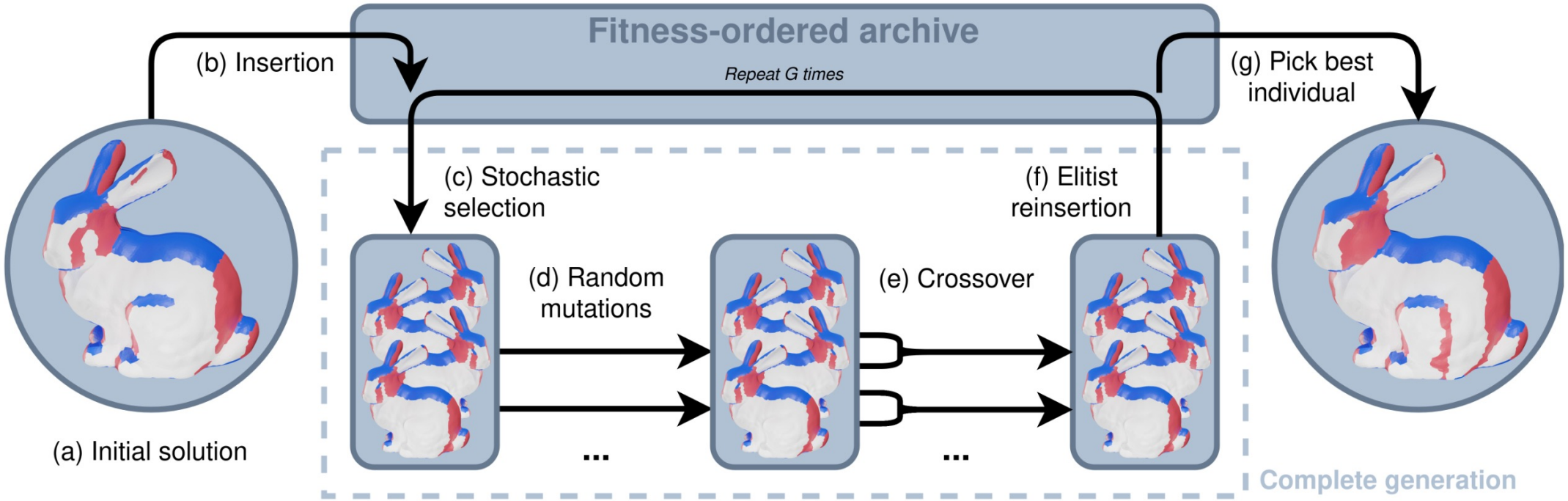
Path smoothing

Archive



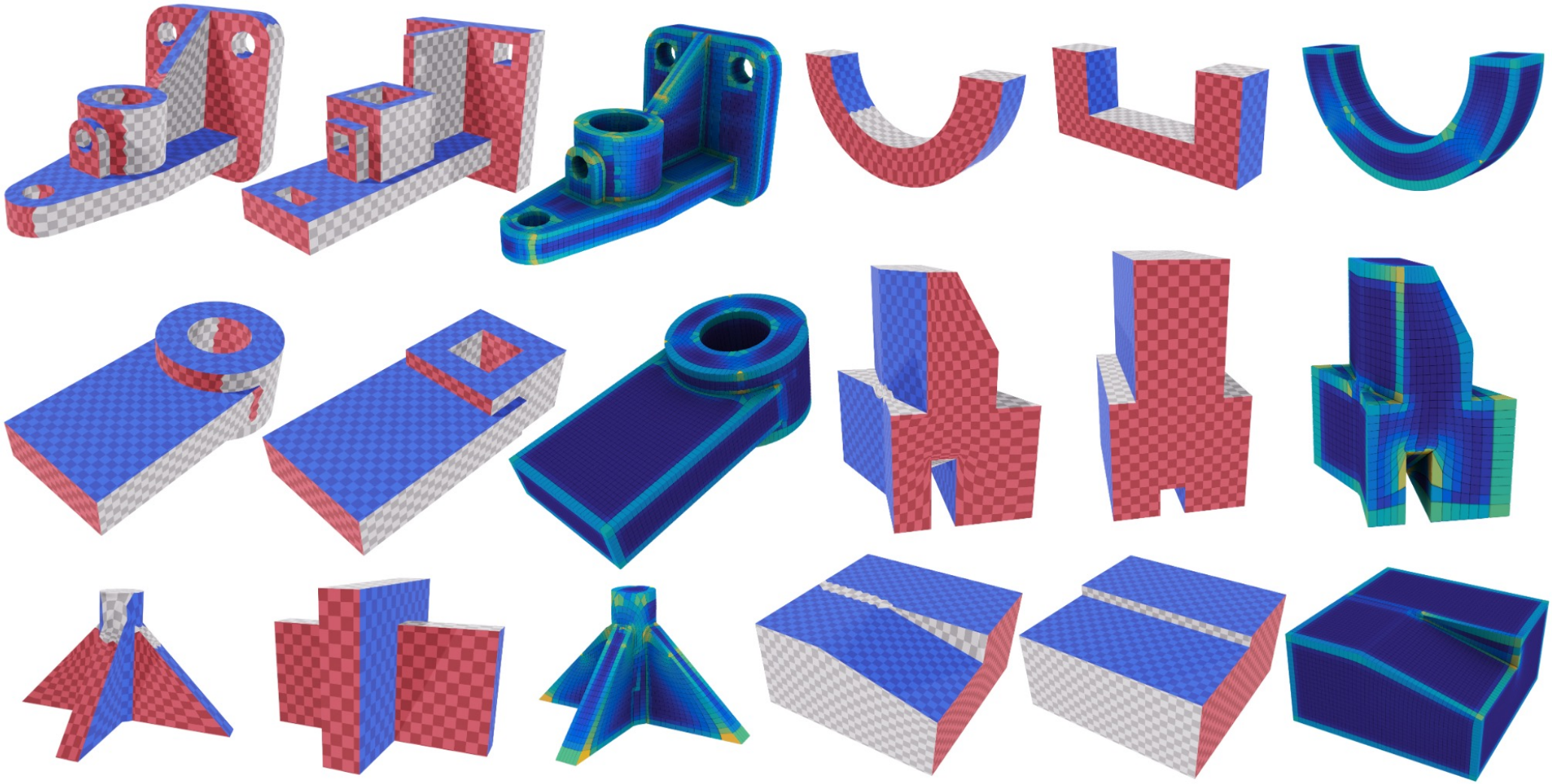
Container with fixed maximum size, ordered by *fitness*

Generations



Some results

1309 models *(see **C. Dumery, F. Protais, S. Mestrallet, C. Bourcier and F. Ledoux**, Evocube: a Genetic Labeling Framework for Polycube-Maps, Computer Graphics Forum, june, 2022)*



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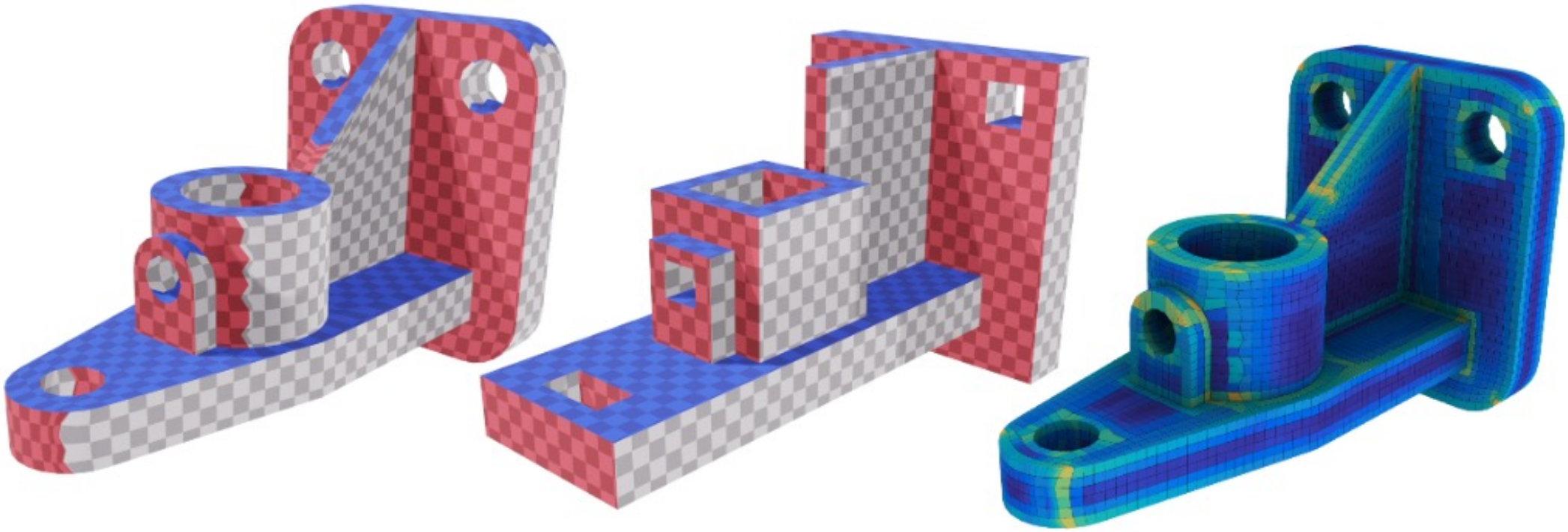

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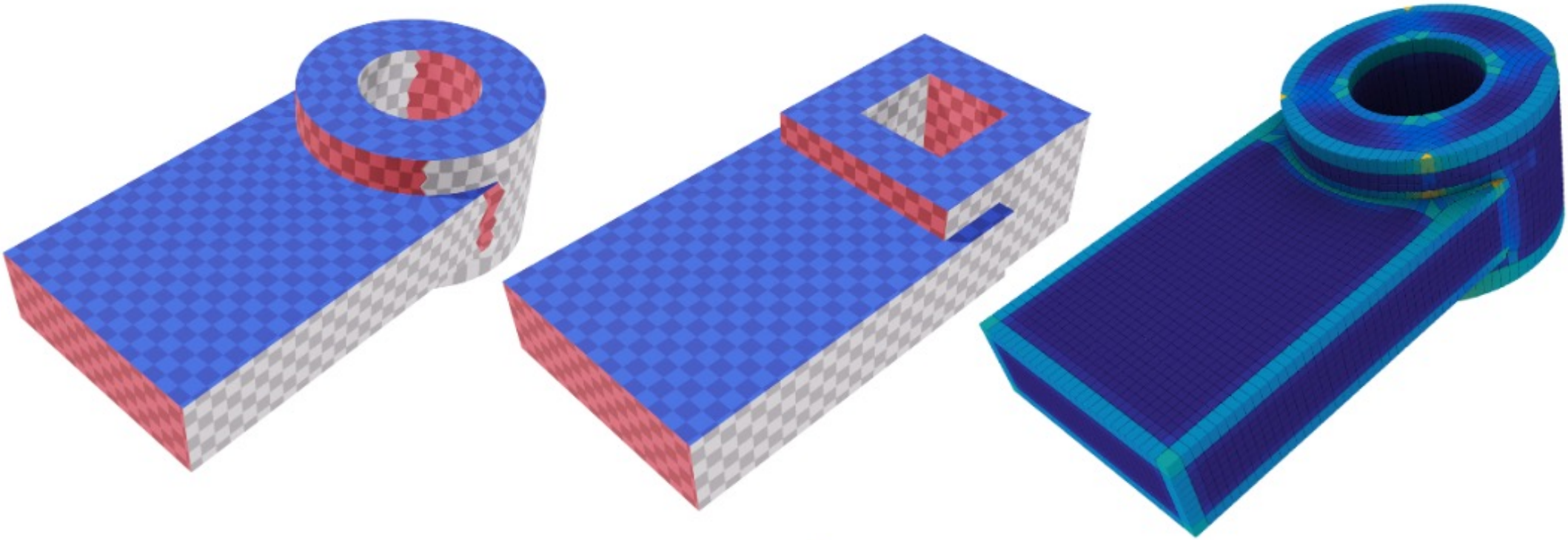

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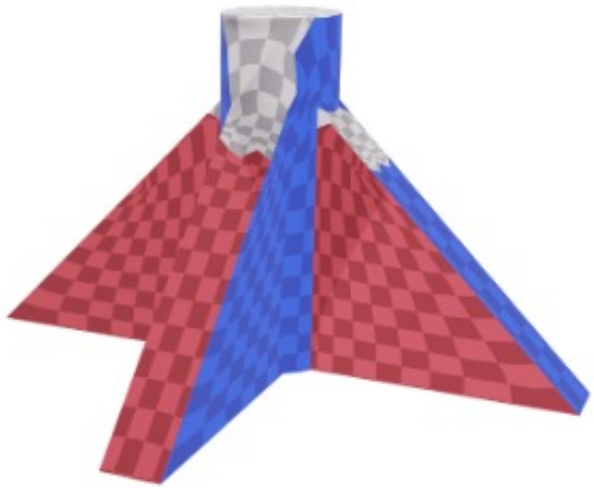

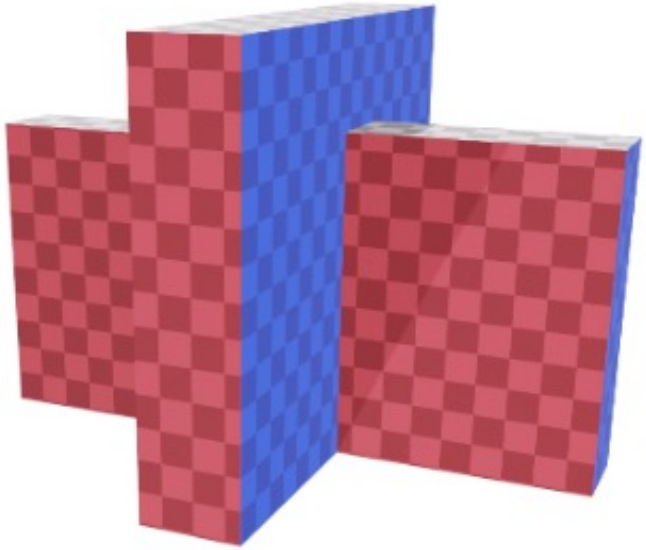

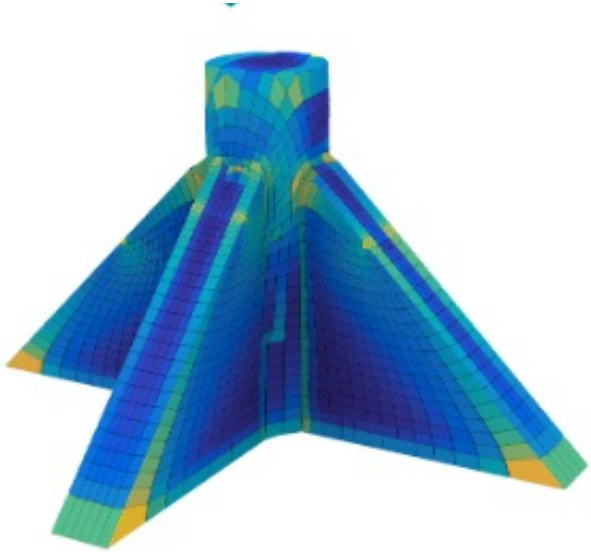

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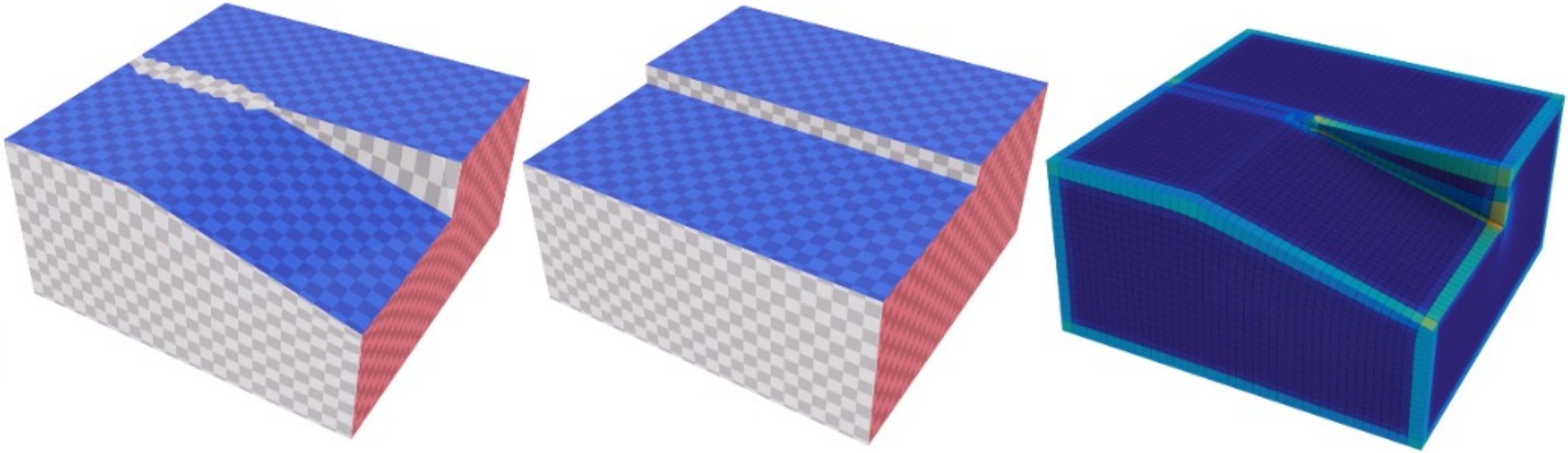
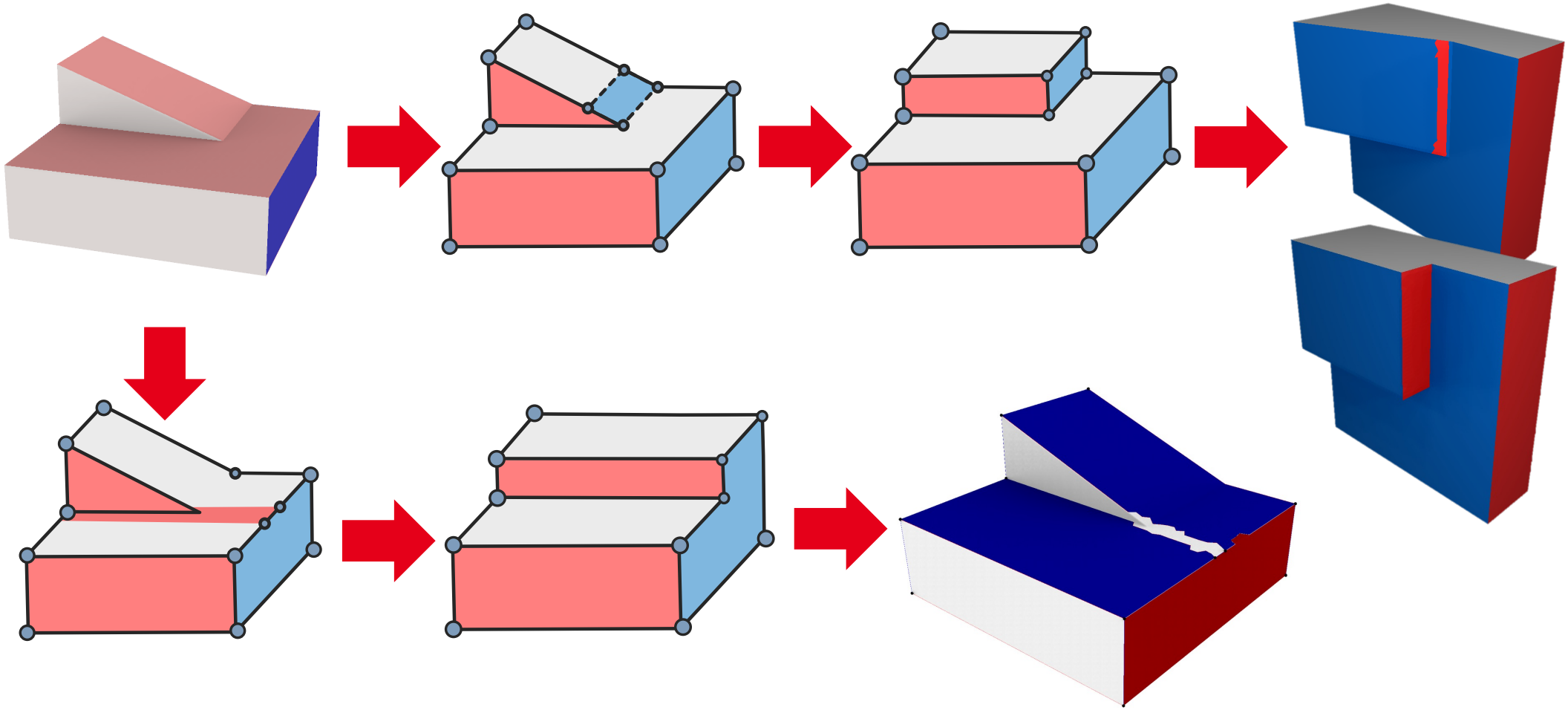
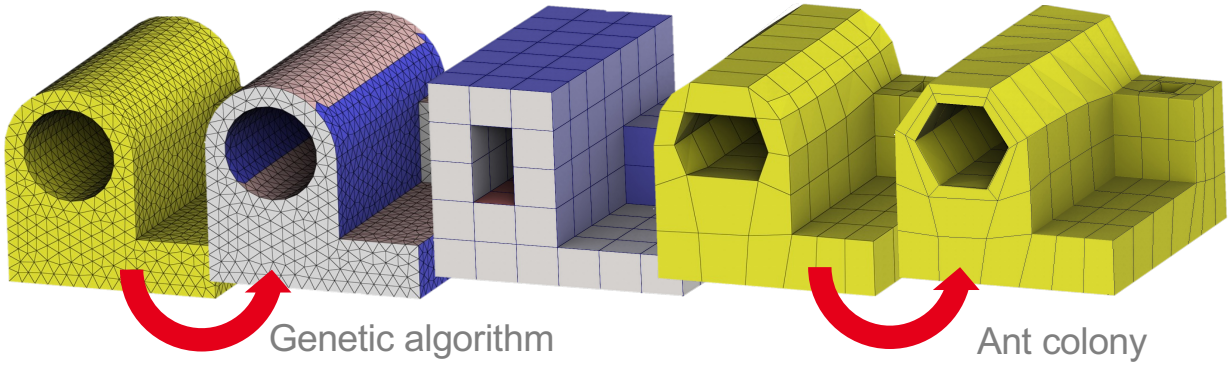
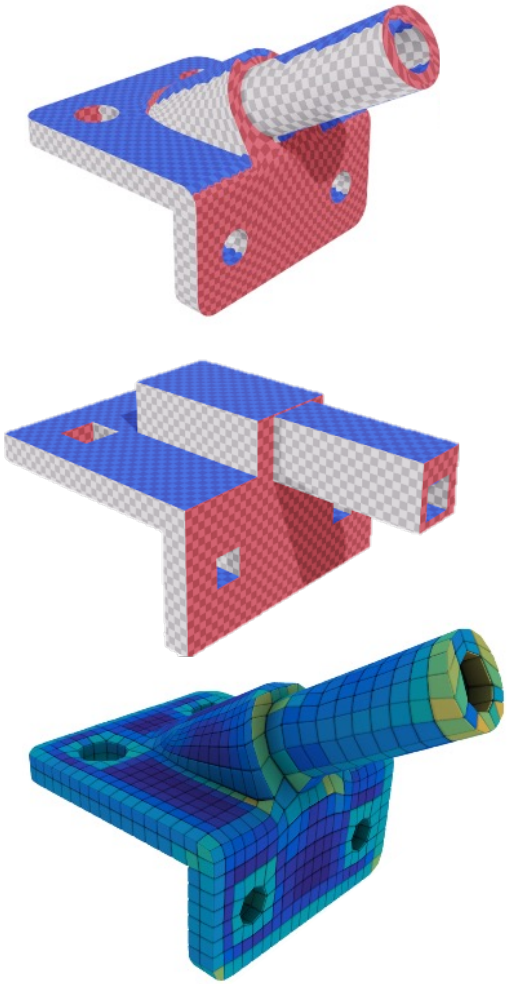


Some results … we don’t want



Concluding remarks





Evolutionary algorithms are a valid option for topology-geometry problems

- Reliable meta-heuristics, « random » exploration of solutions' space
- It requires robust and fast editing operations (mutations, crossover) and fitness computation

On-going work

- Solution space exploration can be long, how to optimize? ***easy to parallelize***
- Polycube labeling : add **sharp features constraints**
- Analysis of our ant colony optimisation approach for sheet insertion
- Reinforcement learning for hex blocking


cea
Thank you for your attention!