UCLouvain

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Towards automatic block decomposition of 3D domains by exploiting frame fields

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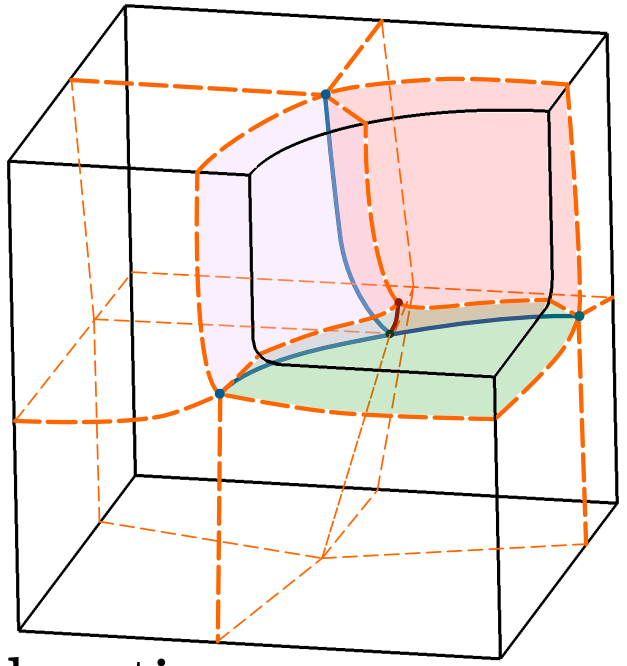
Hextreme team (https://hextreme.eu)

IGA 2019

18th of September 2019, Munich

The problem: from B-Rep to **block decomposition**

Finding block decomposition is the same as (coarse) hexahedral meshing



Difficult problem (> 30 years) because :

Hard constraints	Usefulness constraints
▪ 6-faces cube topology	• good block qualities
▪ boundary geometry	• min nb of irregular edges and vertices (e. valence $\neq 4$, v. valence $\neq 8$)

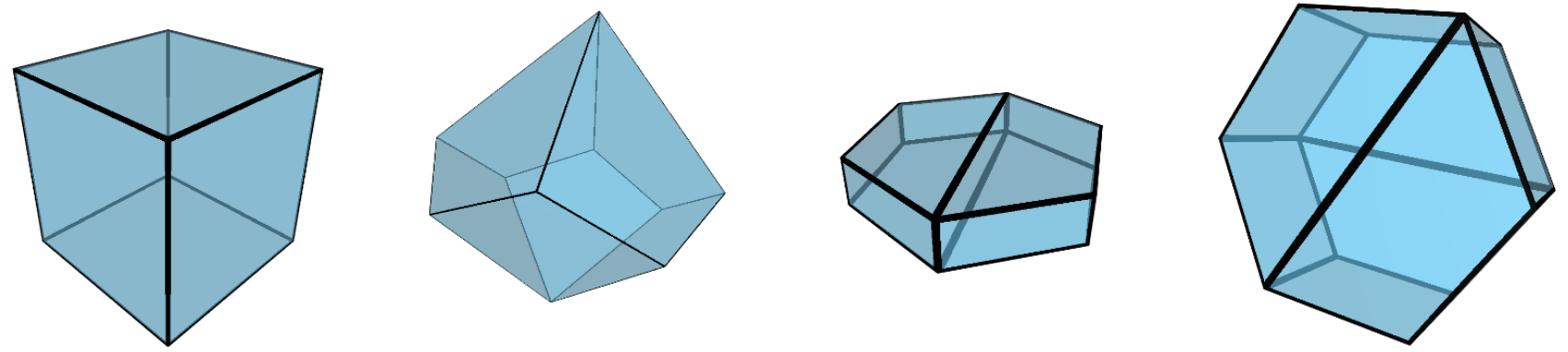
Holy Grail: an automatic method that satisfies all these constraints

Trivariate parametrization of each block, ready for IGA analysis

Block decomposition :

Finding hexahedrizations for small quadrangulations of the sphere

K. Verhetsel, J. Pellerin, J.F. Remacle, SIGGRAPH 2019



bdr quads:	6	8	10	10
best block decomposition:	1	40 !	2	36 !

⇒ bad block qualities, lot of irregular edges/vertices

The block decomposition problem

Not possible to satifsy all the constraints:

- hex topology
- boundary geometry
- good block qualities
- good regularity (small nb of irregular edges/vertices)
- genericity (work on all models)

Two main classes of block decomposition (~hex meshing) approaches :

- Keep genericity but abandon quality and regularity
  (e.g. topological approaches, octree+snapping techniques)

- Keep regularity and quality but abandon genericity
  (e.g. sweeping, medial axis, polycube, frame fields)

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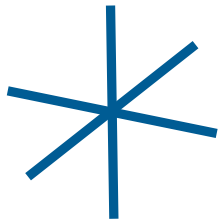
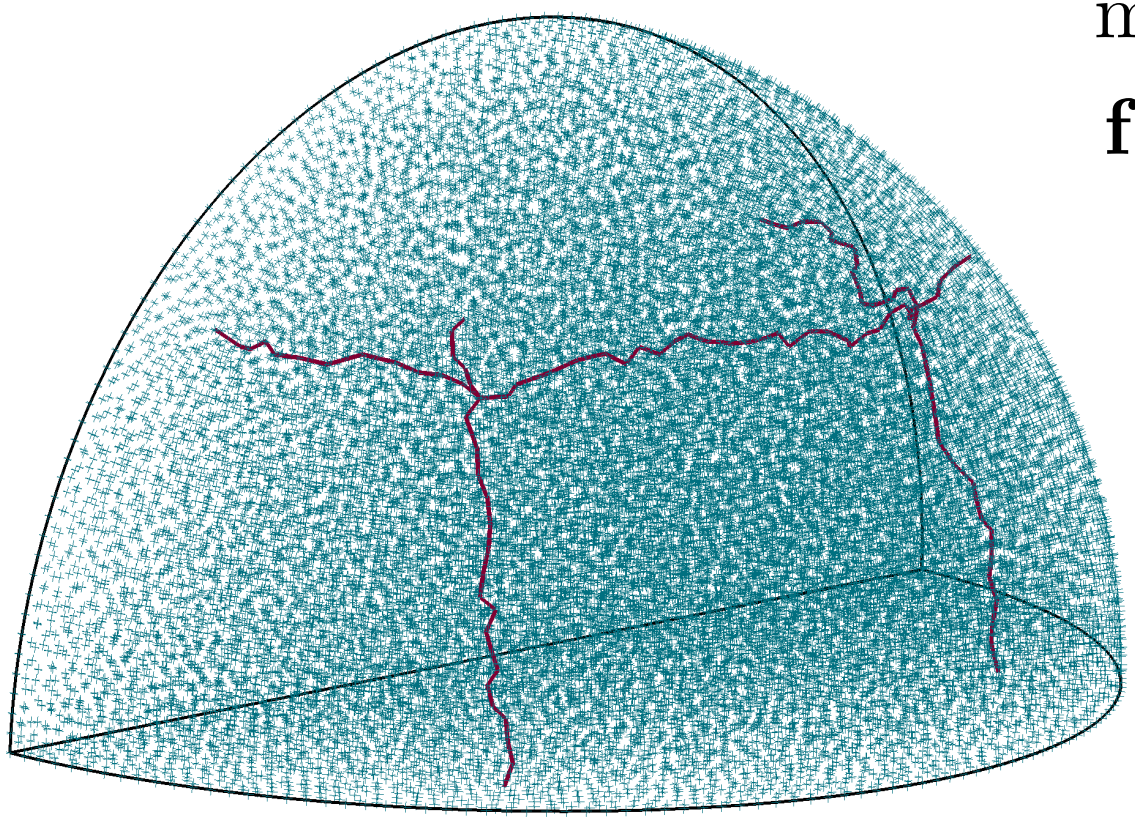
Why (boundary aligned) frame fields ?

2D cross:

3D cross or frame:



$$\min \int_\Omega ||\nabla \mathbf{f}||^2$$
$$\mathbf{f} \;//\; \mathbf{n} \text{ on } \partial\Omega$$



Main ideas:

frame field $\Leftrightarrow$ field of infinitesimal cubes

frame field singular curves $\Leftrightarrow$ irregular edges of block decomposition

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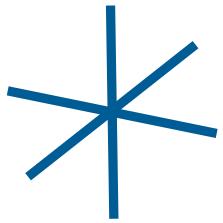

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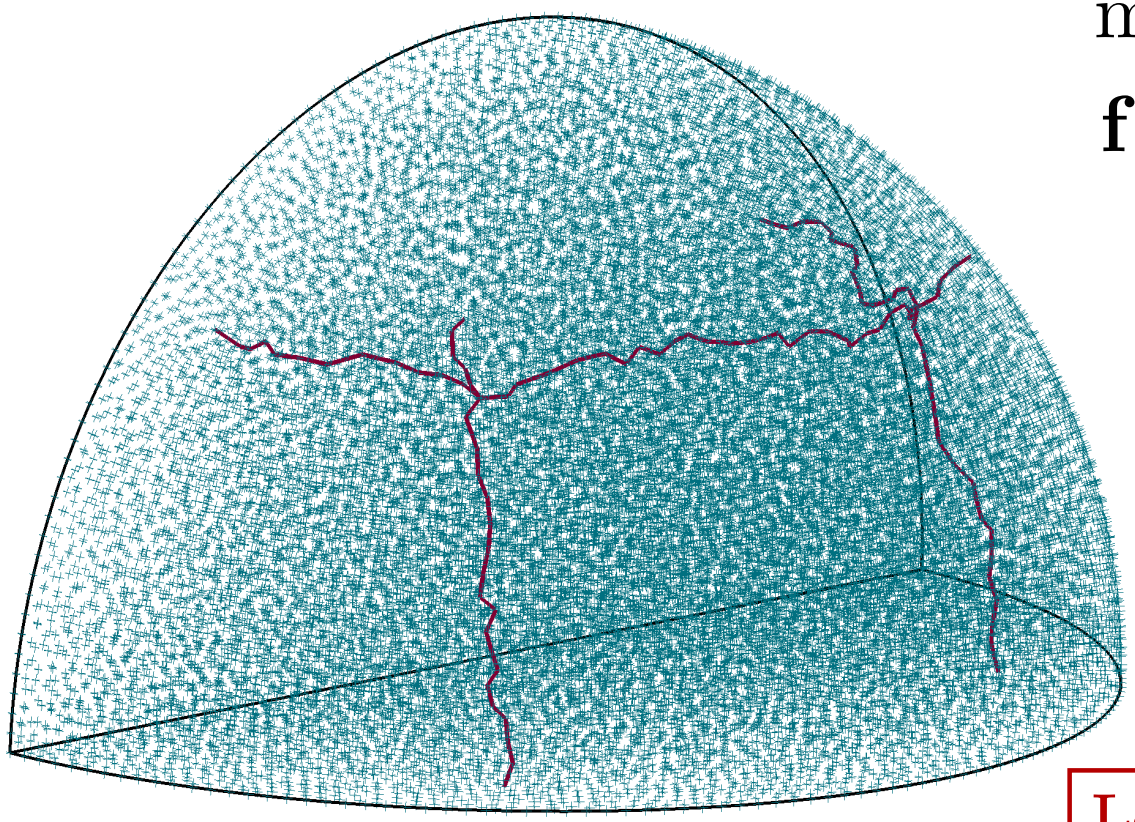


Main ideas:

frame field $\Leftrightarrow$ field of infinitesimal cubes

frame field singular curves $\Leftrightarrow$ irregular edges of block decomposition

Local geometry

Global topology

How to compute a 3D frame field from scratch ?

Minimize the Dirichlet energy

$$\min \int_\Omega ||\nabla \mathbf{f}||^2$$

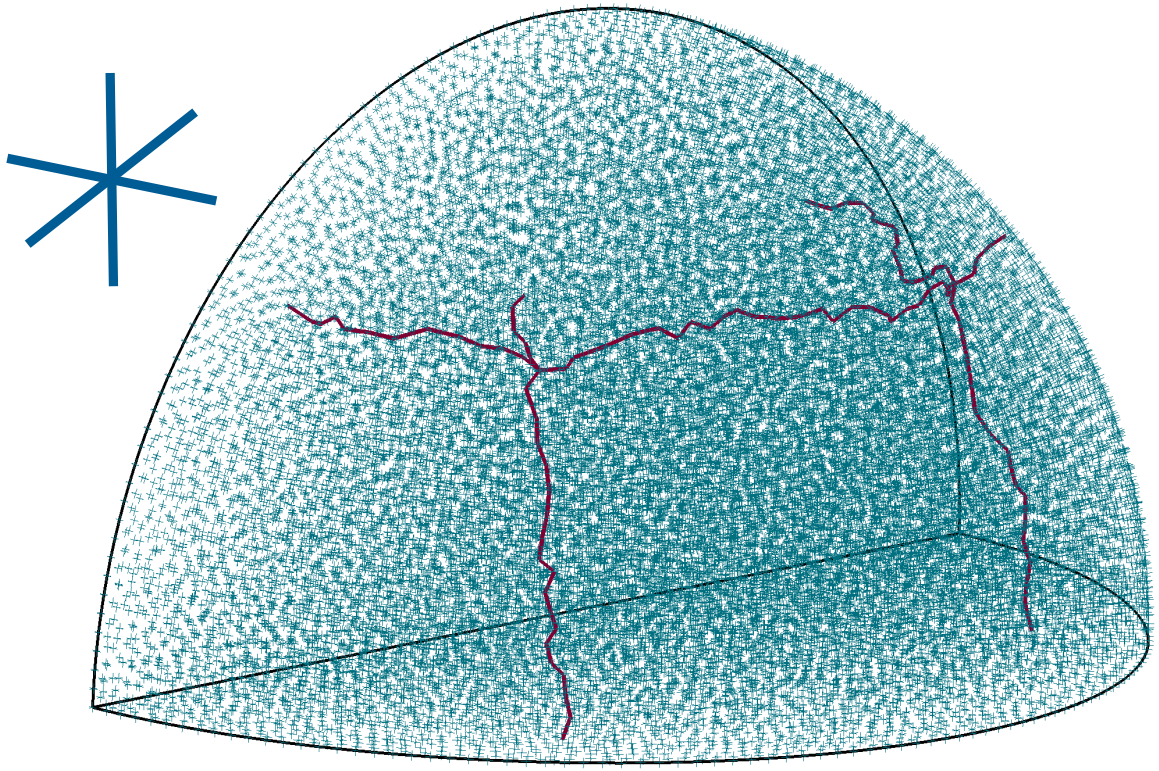
Tangency boundary conditions

$$\mathbf{f} \;//\; \mathbf{n} \text{ on } \partial\Omega$$

Space of frames is not simple :

$$\mathcal{F} = SO(3)/O$$

(with O the octahedral group)



Still an active research topic:

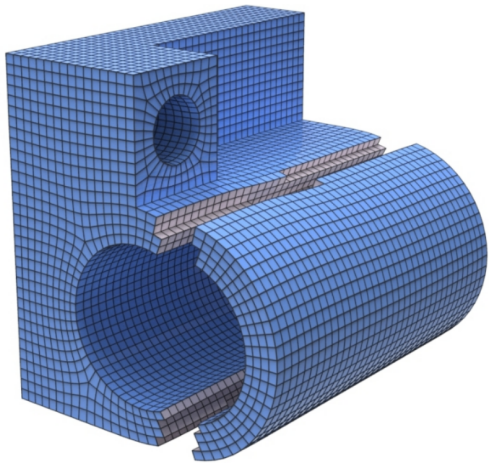
Huang et al. 2011, Li et al. 2012, Ray et al. 2016, Solomon et al. 2017.,
Chemin et al. 2018, Palmer et al. 2019, Golovaty et al. 2019, etc

... but not the focus of this talk !

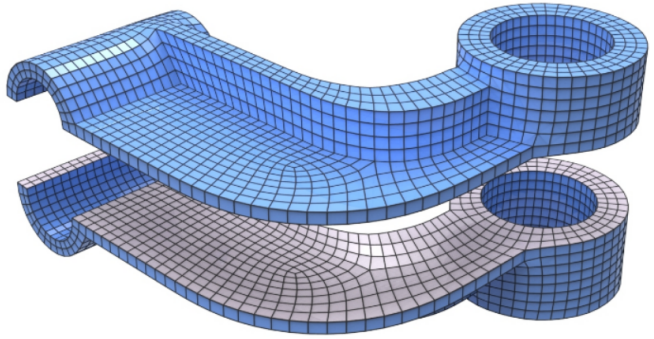
From frame field to block decomposition / block-structured hex mesh

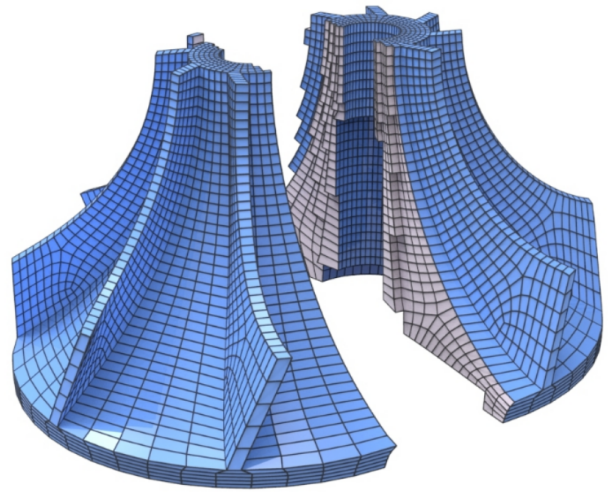
CubeCover parametrization (mixed-integer problem) + hex extraction:

Nieser et al. 2011
Li et al. 2012
Lyon et al. 2016
and others



Li et al. 2012

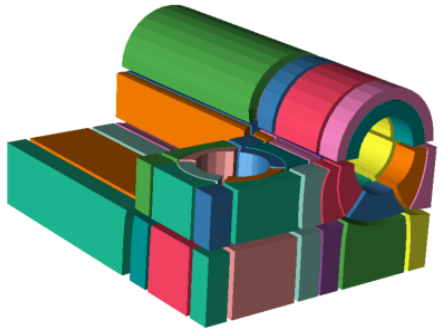




Dual surface construction + primalization:

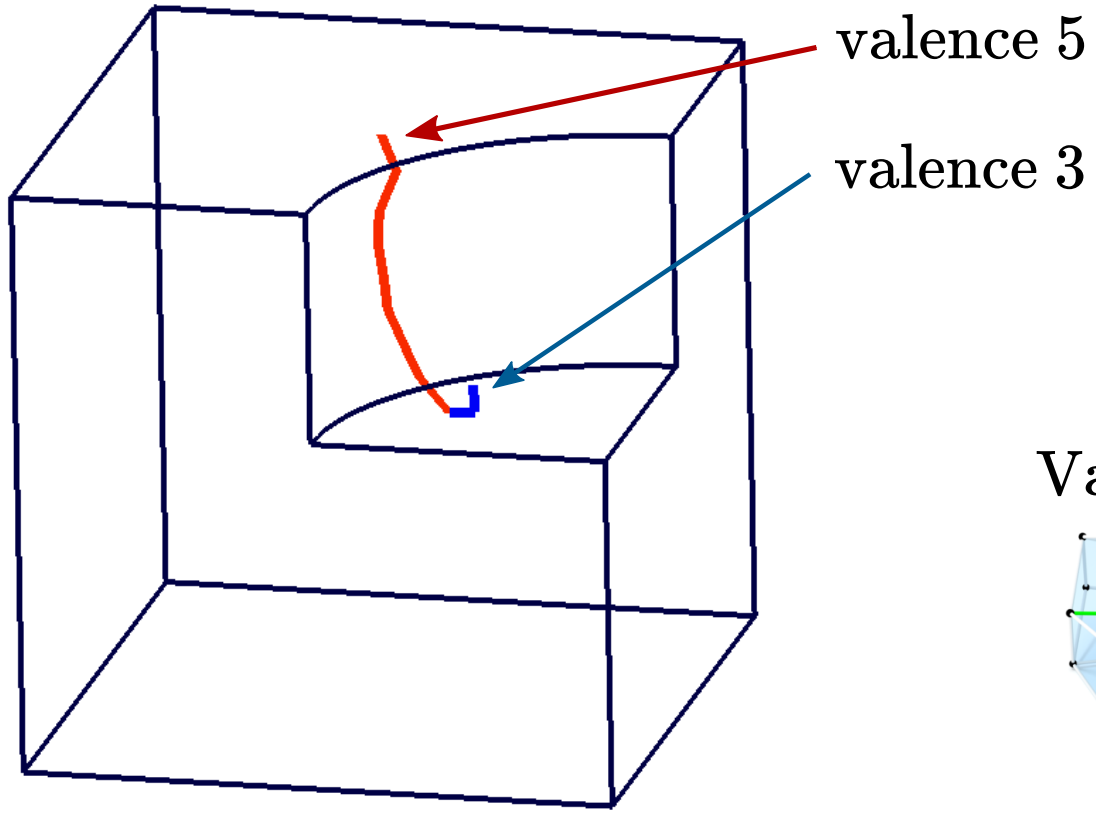
Zheng et al. 2018
Livesu et al. 2019

Zheng et al. 2018



Works for some models, but not generic due to frame field limitations

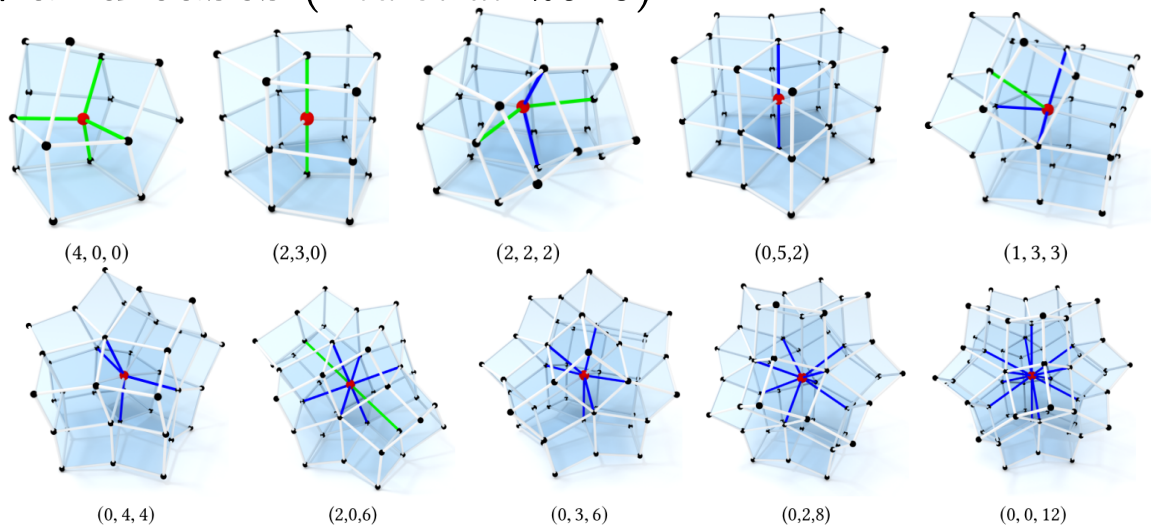
Frame field topology is not always compatible with hex topology



(FF singularity graph)

3-5 singular curve are
not valid hex connectivity

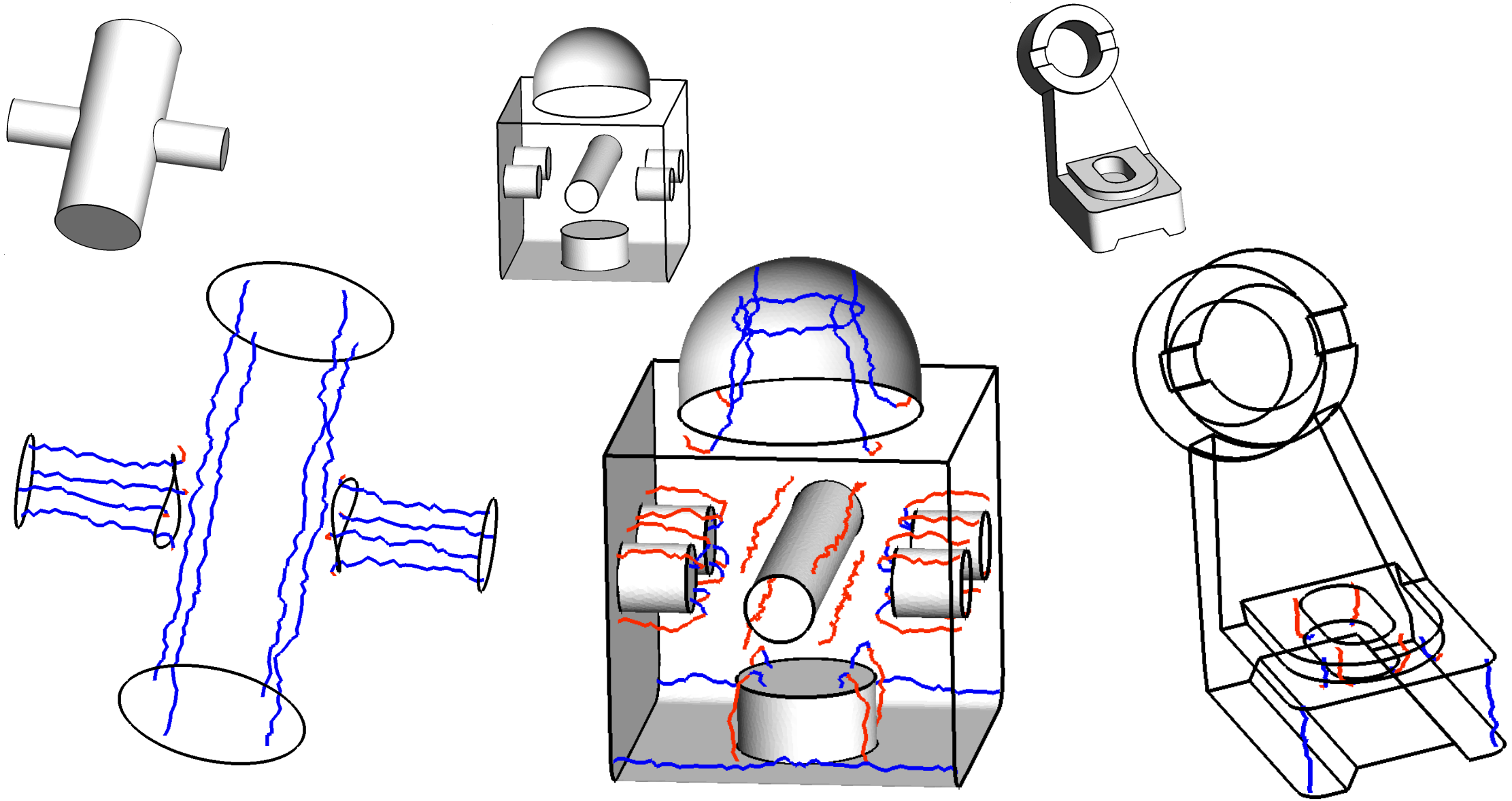
Valid cases (*Liu et al. 2018*):



Multiple approaches to frame field correction for CAD models

M. Reberol, A. Chemin, J.F. Remacle, 28th IMR (2019)

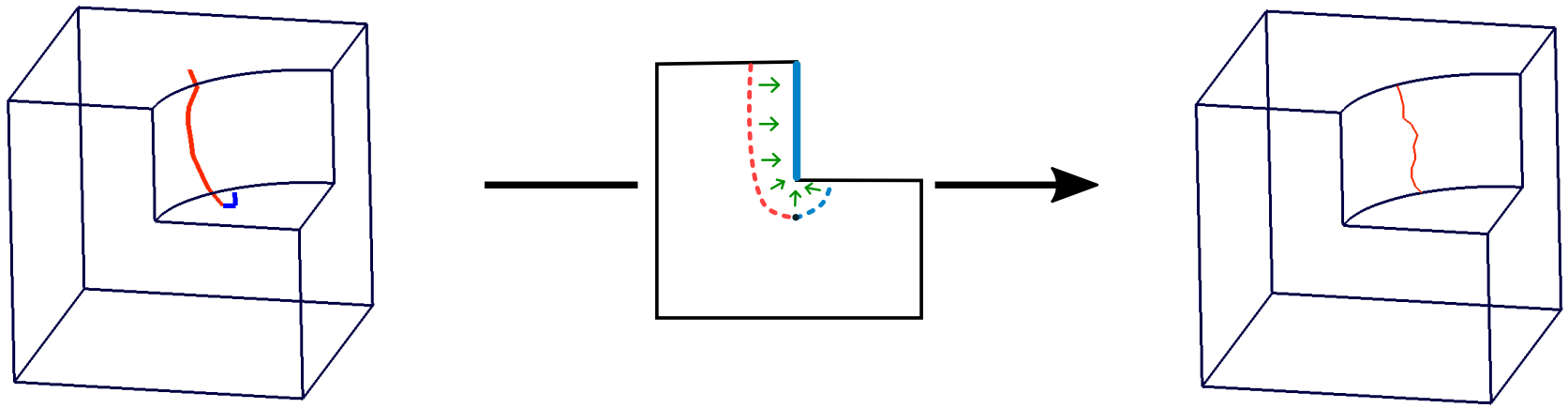
3-5 singular curves : a common issue for CAD models



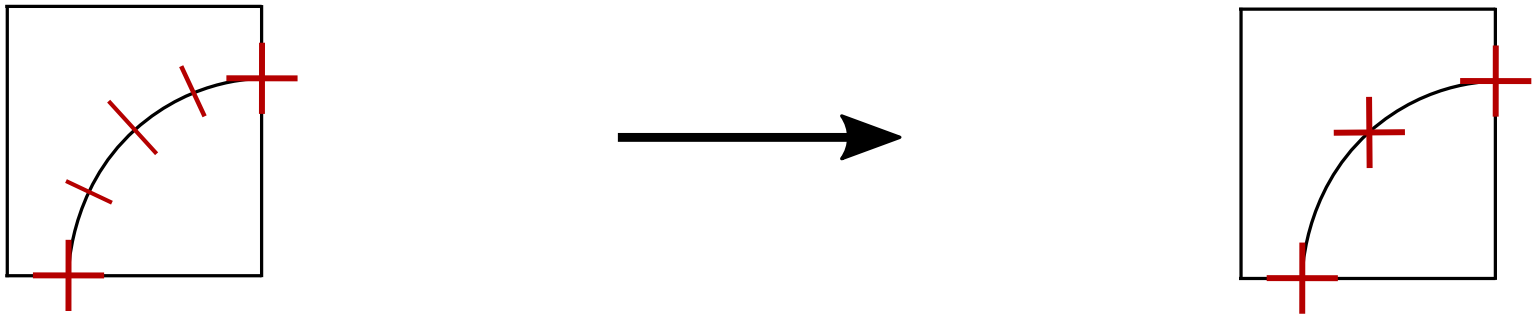
3-5 singular curves can be easily fixed in most CAD cases !

Main idea:

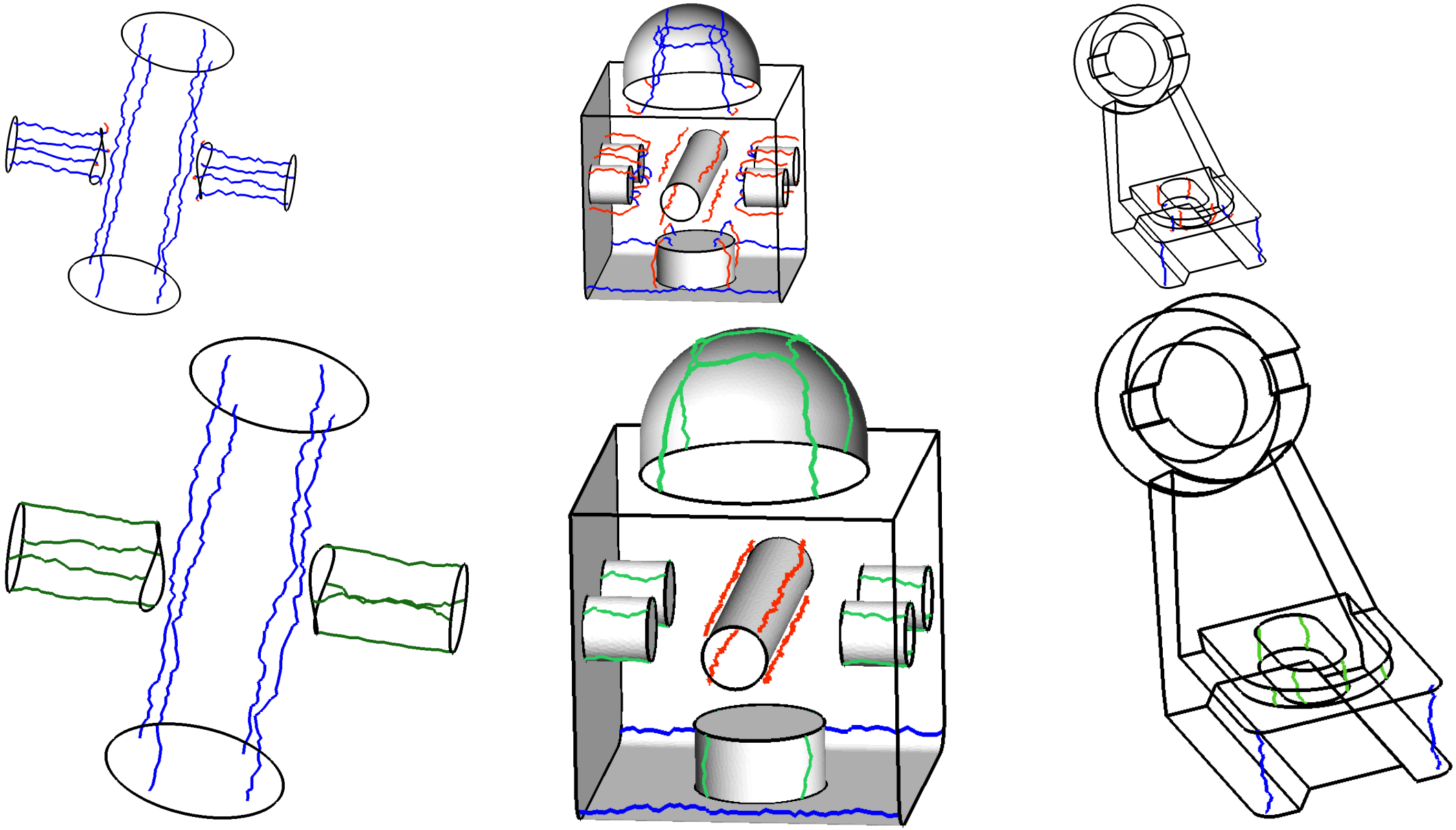
- invalid interior singular curves —*snapping*→ boundary valid singular curves



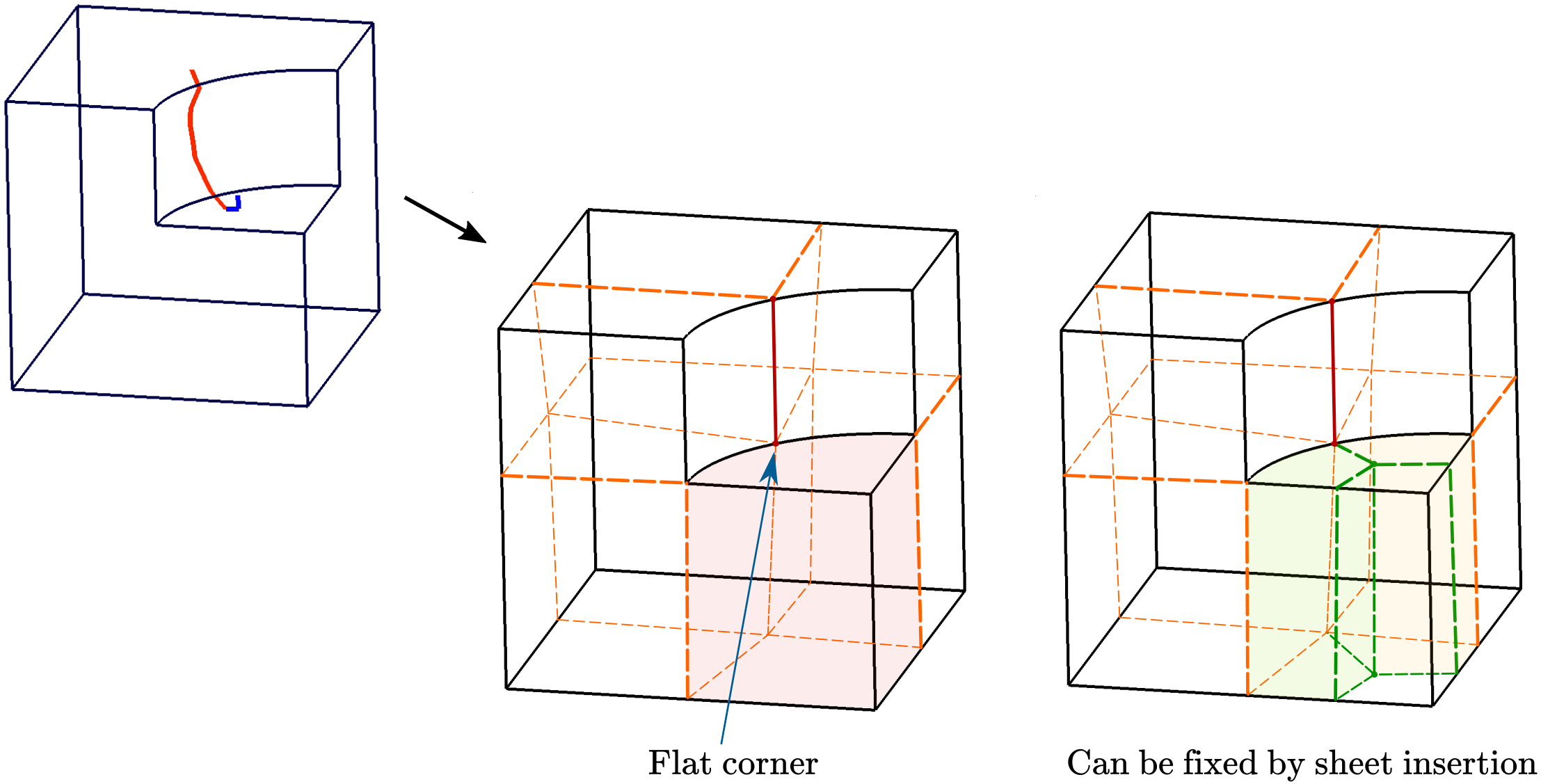
- update frame field boundary conditions to enforce boundary singularities



Results of 3-5 singular curve boundary snapping



Impact of on block geometry



From frame field to block decomposition / block-structured hex mesh

CubeCover parametrization (mixed-integer problem) + hex extraction:

Nieser et al. 2011
Li et al. 2012
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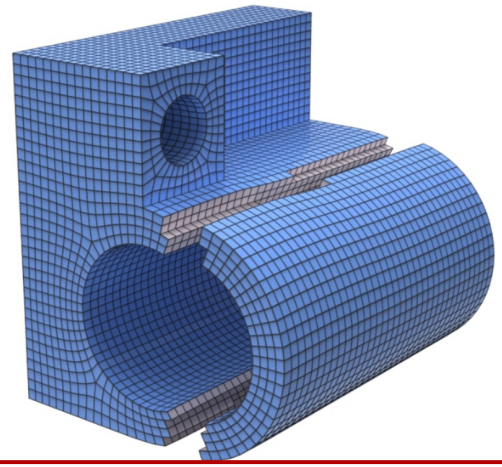
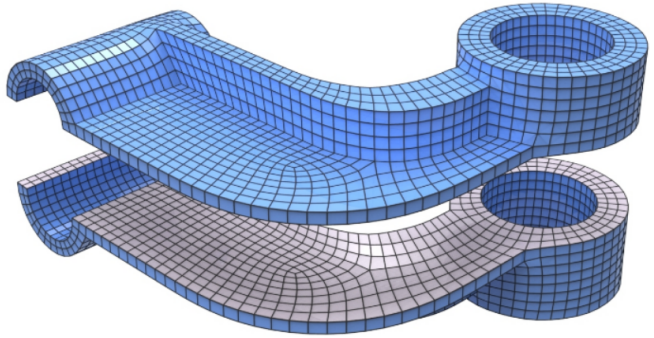
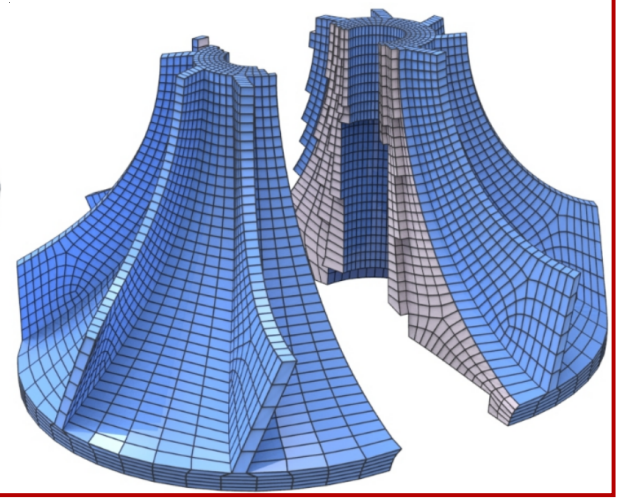
and others



Li et al. 2012





Dual surface construction + primalization:

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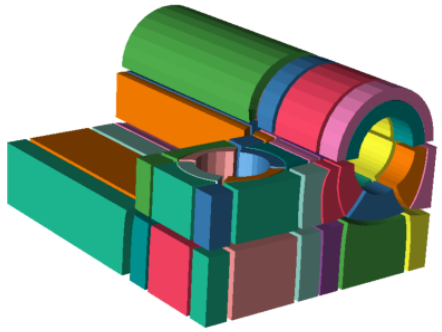
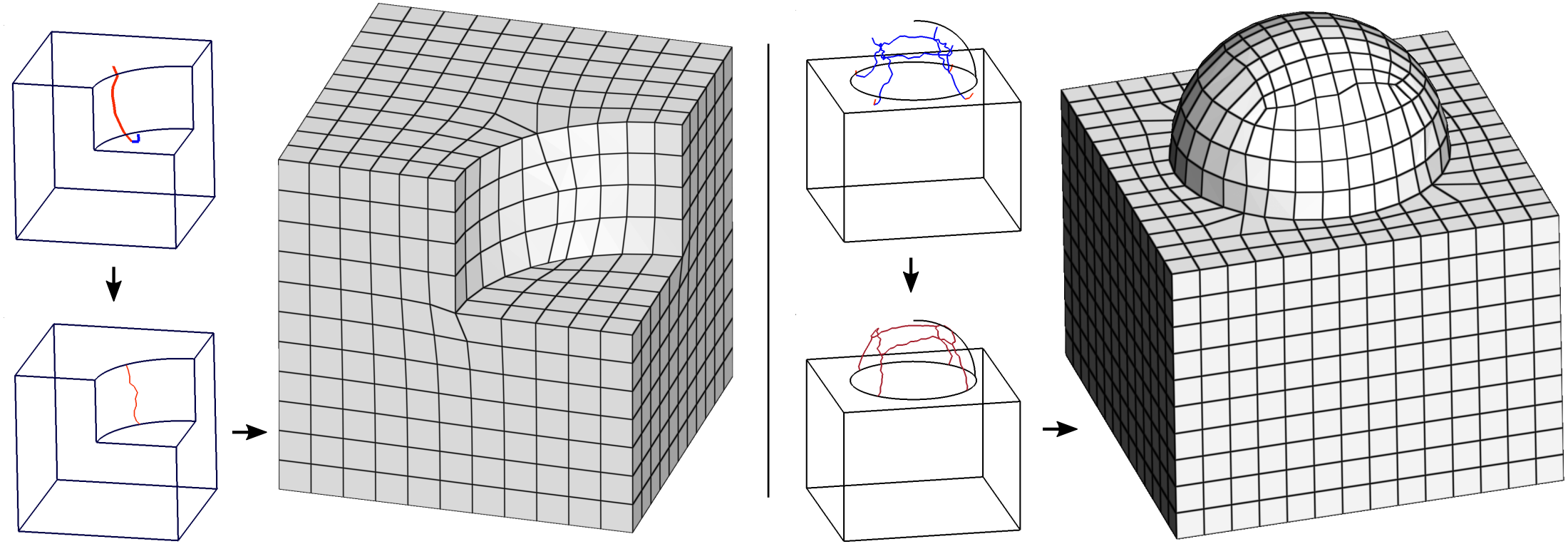


From corrected frame field to block decomposition

To get block-structured hexahedral meshes :

- Frame field with new BCs (changed after snapping)
- CubeCover parameterisation (using CoMISo [Bommes et al. 2011])
- Hexahedra extraction (using HexEx [Lyon et al. 2016])



... but robustness and performance issues due to mixed-integer formulation

From frame field to block decomposition / block-structured hex mesh

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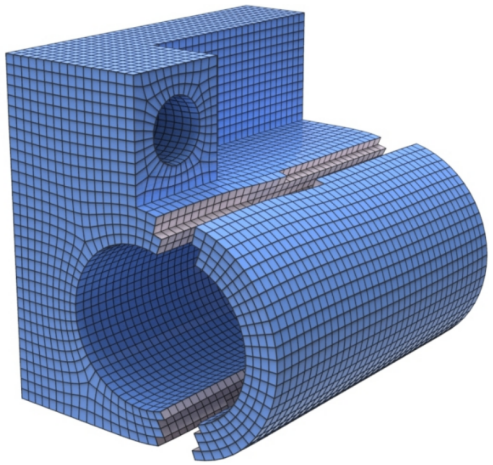

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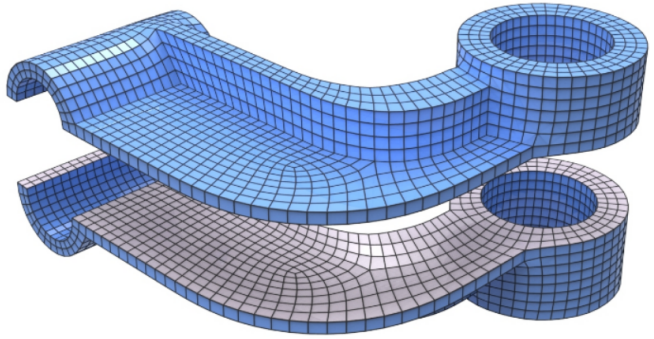

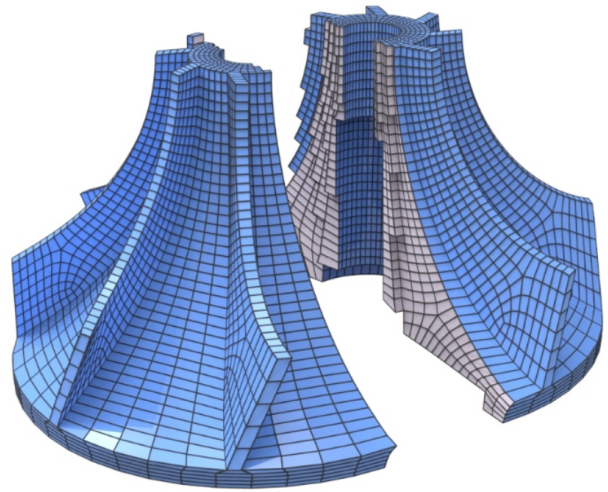

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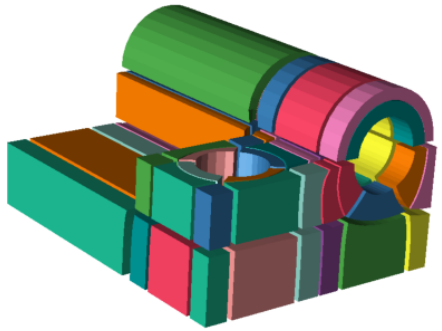


Work in progress, from frame field to block decomposition

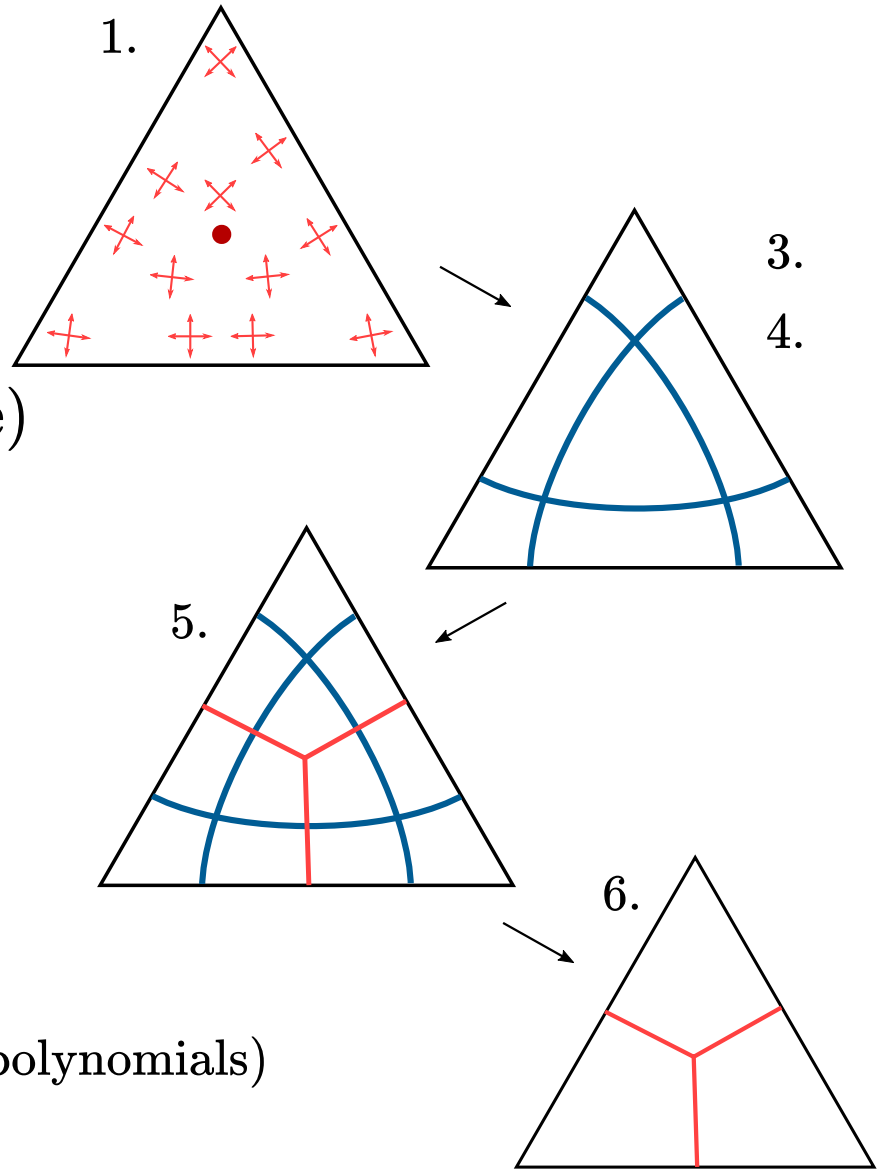
Overview of our future pipeline :

1. Compute a frame field
2. Frame field correction if required (and possible)

3. Build dual sheets
4. Build the dual block decomposition

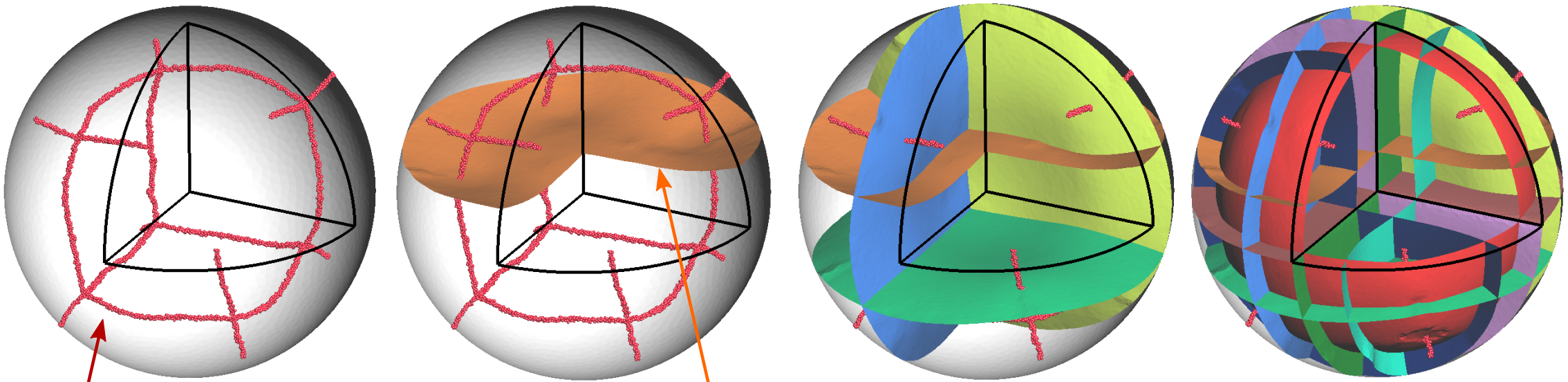
5. Primalization (mid-point subdivision)
6. Structure simplification

7. Geometric parametrization of blocks (trivariate polynomials)



Work in progress: dual block decomposition

Idea: work where the frame field is smooth, i.e. far from singularities
successive cuts of the model by dual sheets (internal surfaces)

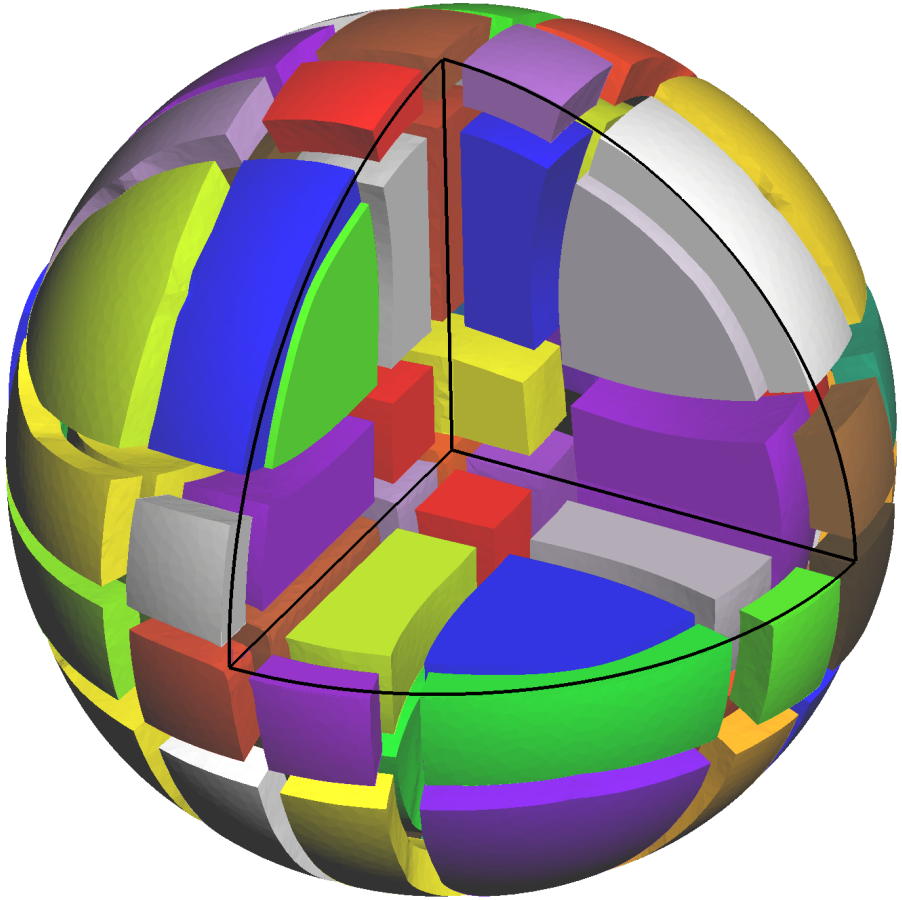


FF singularity graph

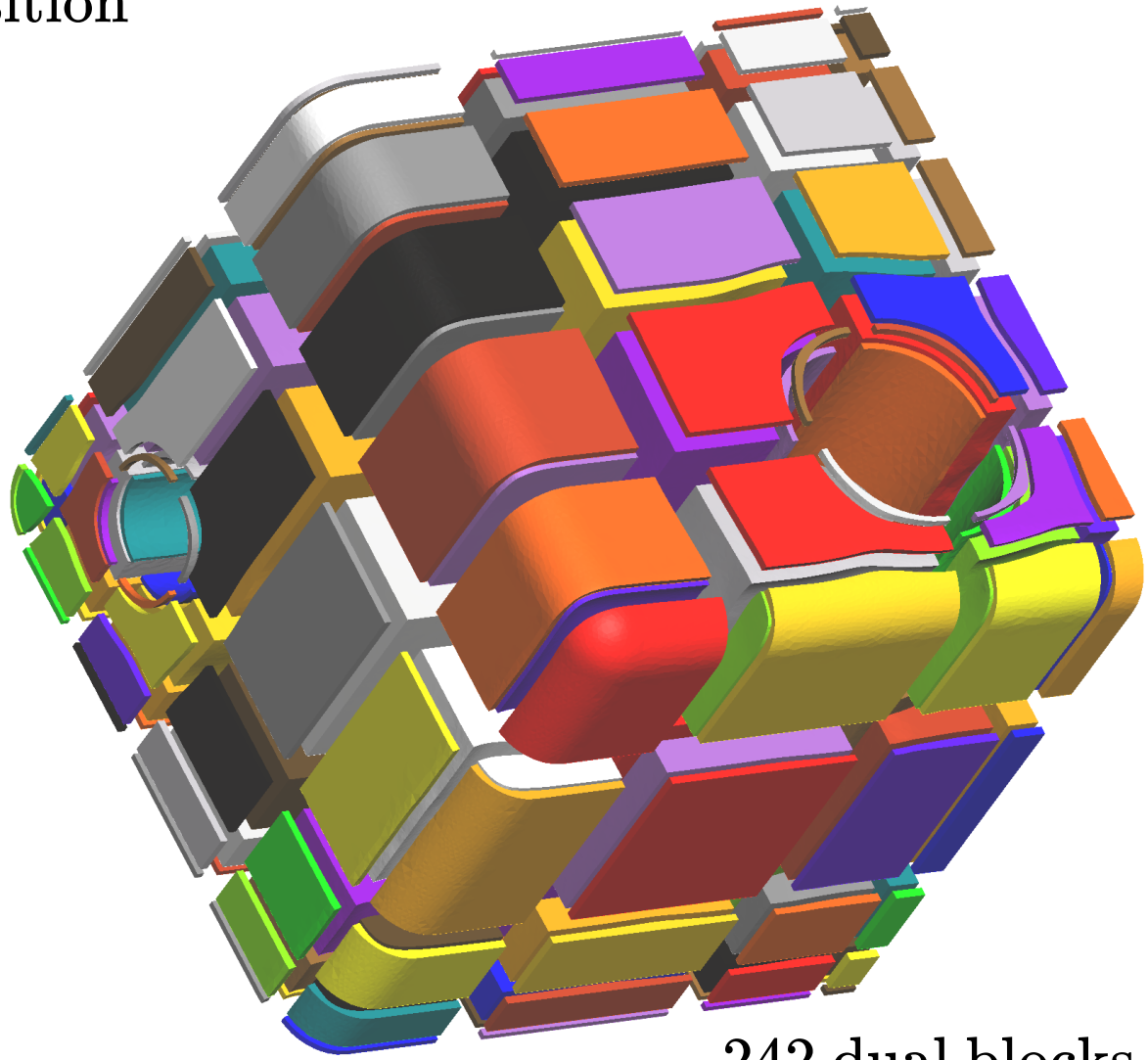
dual sheet
(tangent to the frame field)

From frame field to block decomposition

Work in progress: dual block decomposition



130 dual blocks



242 dual blocks

Conclusion and perspectives

End goal: automatic block decomposition from B-Rep for reasonable models *

* *the block decomposition can be found by hand, no pathogical cases*

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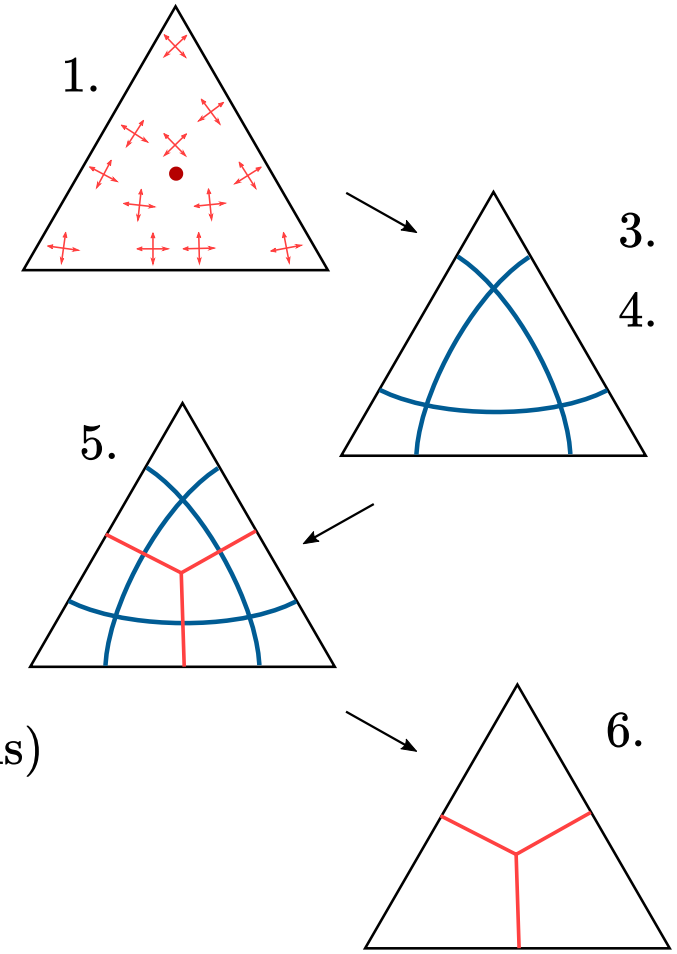
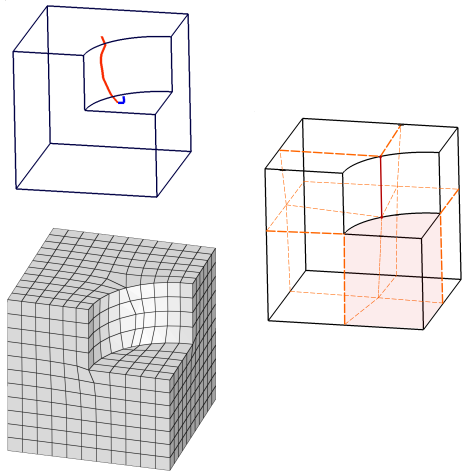


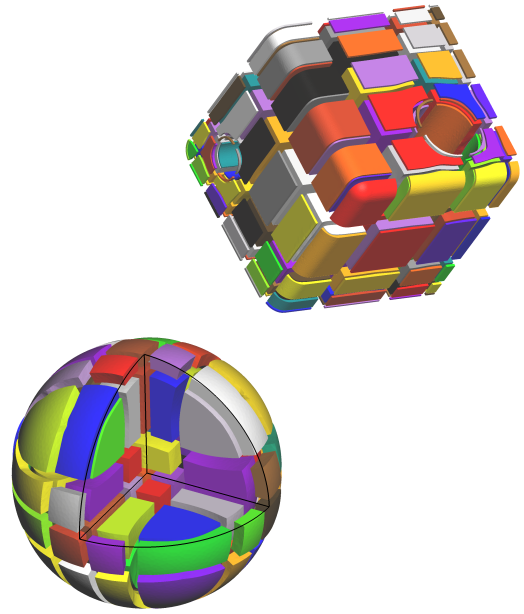
Hopefully, integration into *gmsh* next year

Frame field based approaches have great potential
for automatic block decomposition of B-Rep



Thank you for you attention

Any questions ?



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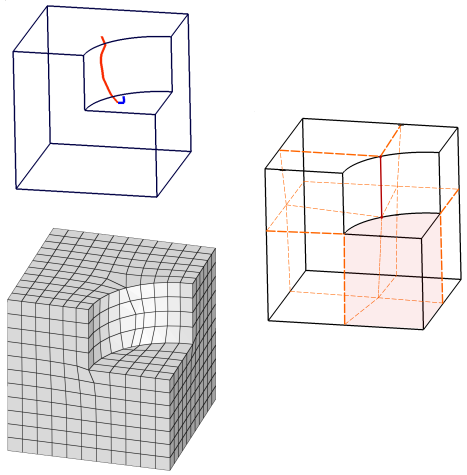

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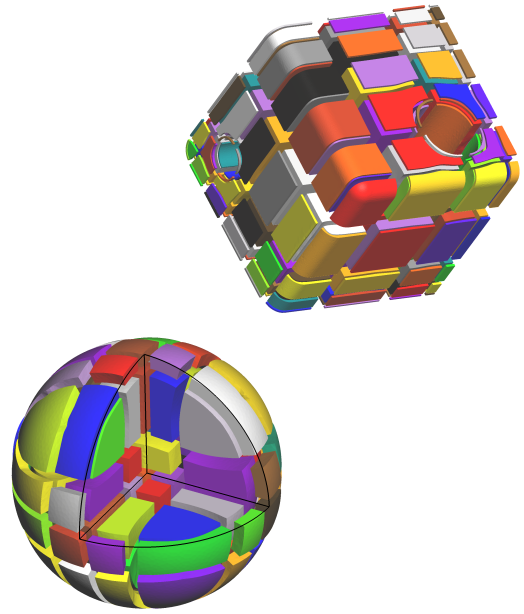

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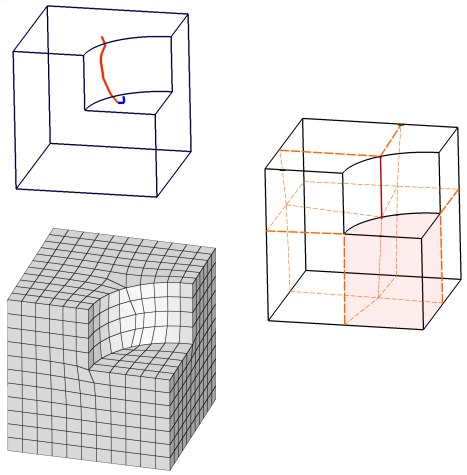

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