

THE PREMIER CONFERENCE & EXHIBITION ON
COMPUTER GRAPHICS & INTERACTIVE TECHNIQUES



LOCALLY MESHABLE FRAME FIELDS

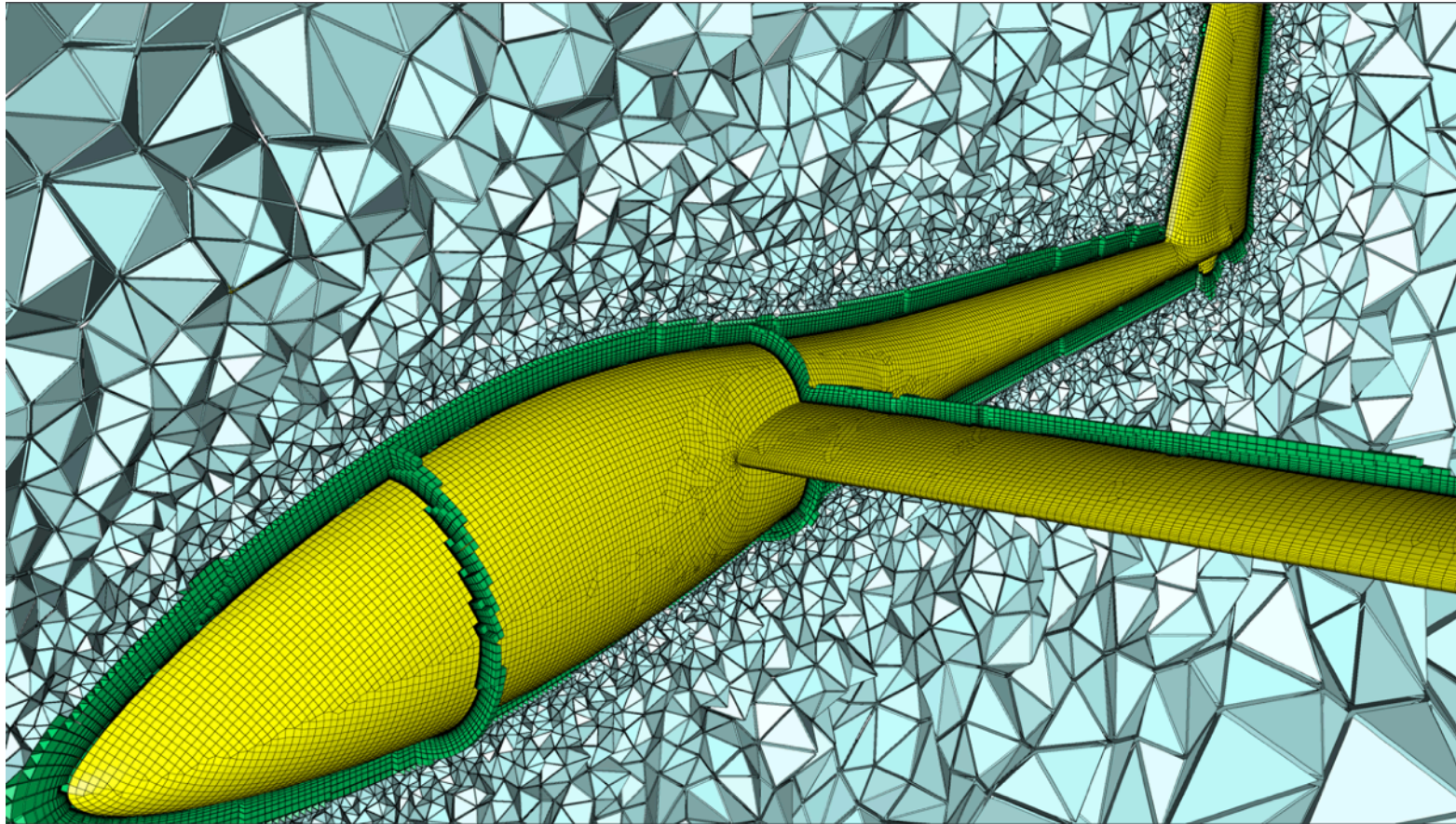
HENG LIU - UNIVERSITY OF BERN
DAVID BOMMES - UNIVERSITY OF BERN

u^b

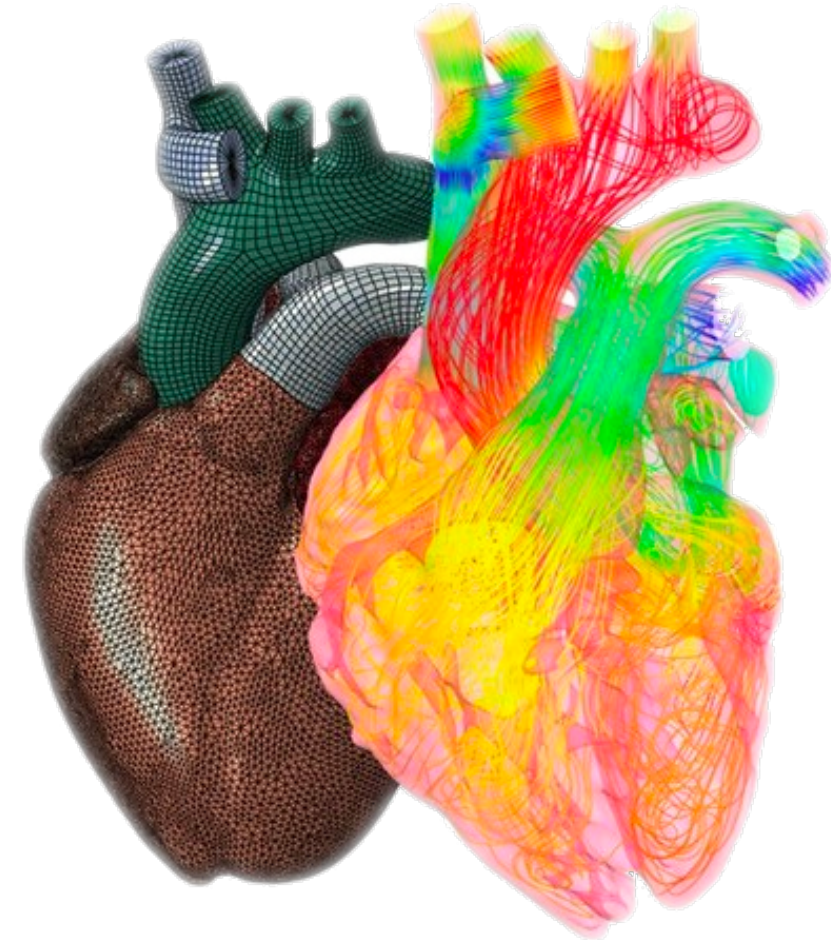
UNIVERSITÄT
BERN



CONTEXT



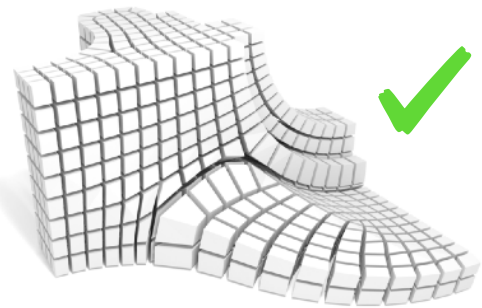
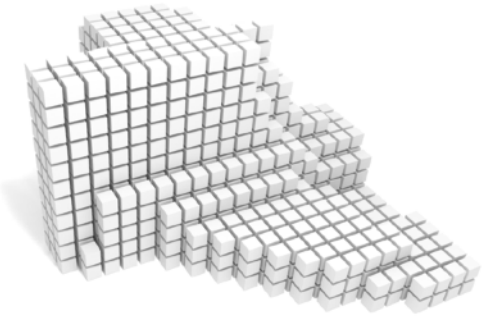
[© Cadence]



[© FlowVision]

→ HEX MESH QUALITY

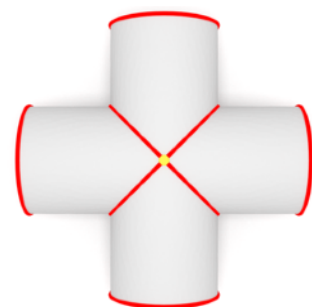
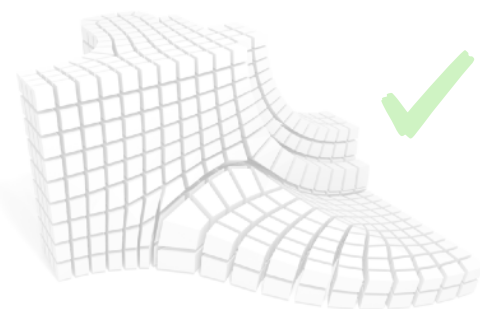
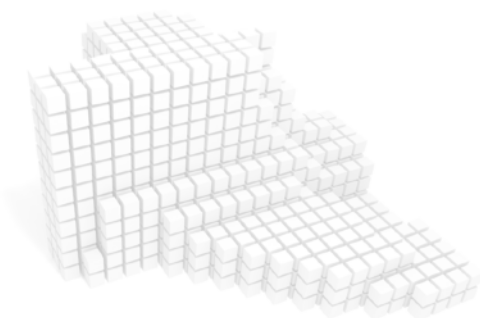
- Geometric Fidelity



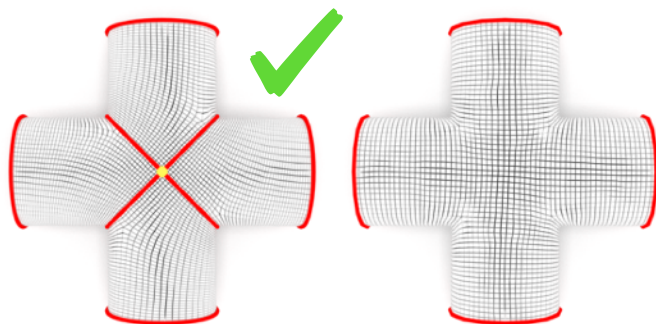
→ HEX MESH QUALITY

- Geometric Fidelity

- Feature preservation



Input shape

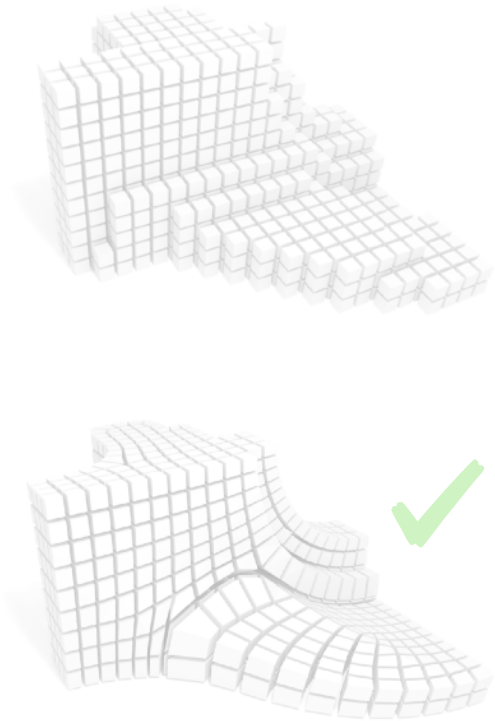


Output hex mesh 1

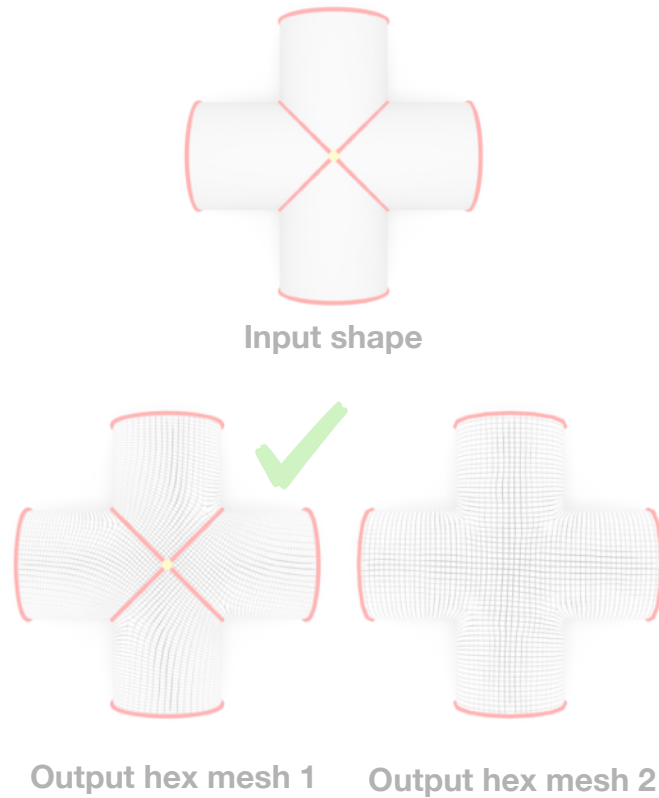
Output hex mesh 2

→ HEX MESH QUALITY

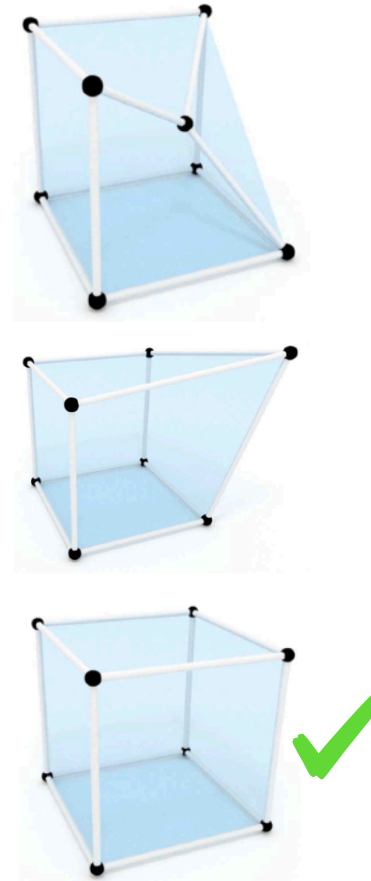
- Geometric Fidelity



- Feature preservation

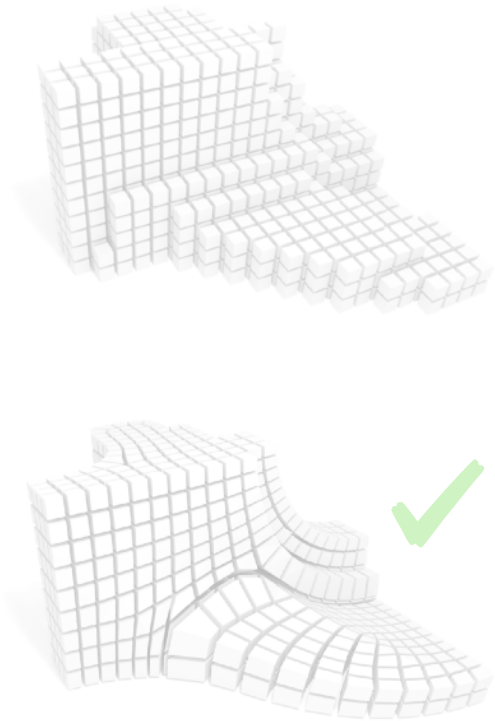


- Element quality

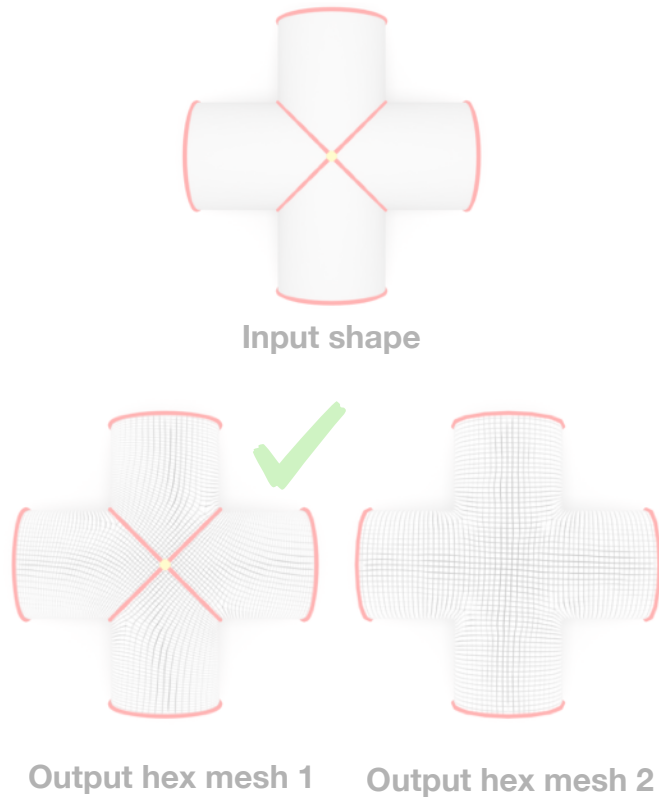


→ HEX MESH QUALITY

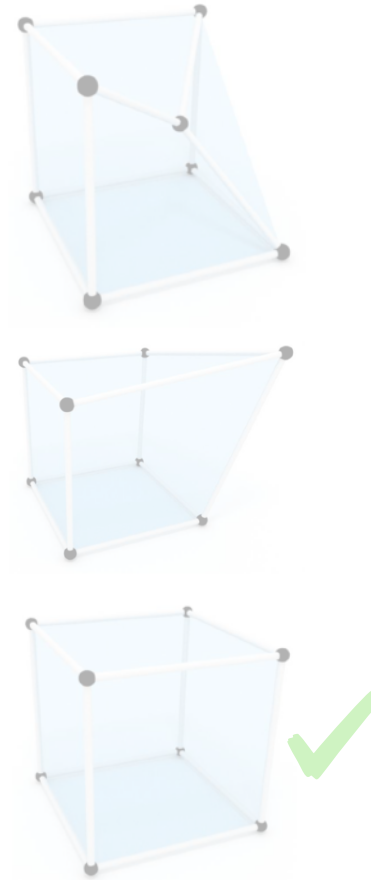
- Geometric Fidelity



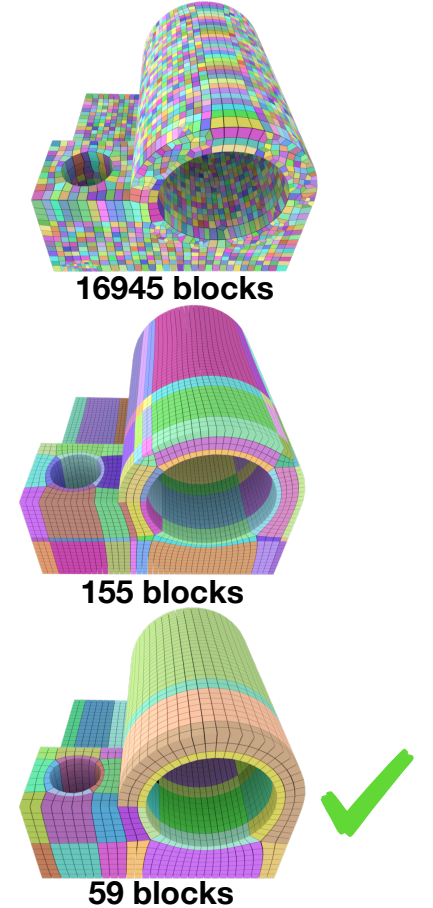
- Feature preservation



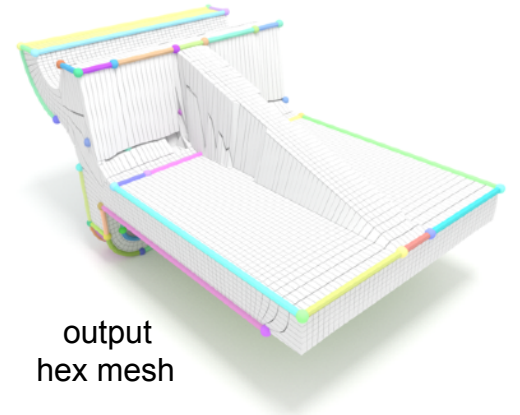
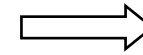
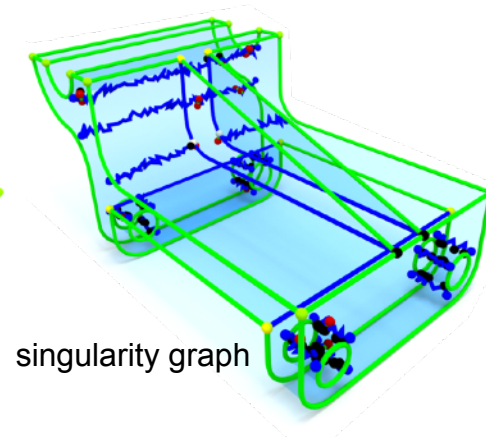
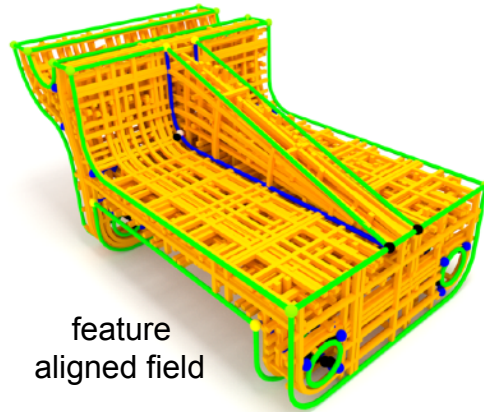
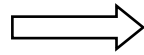
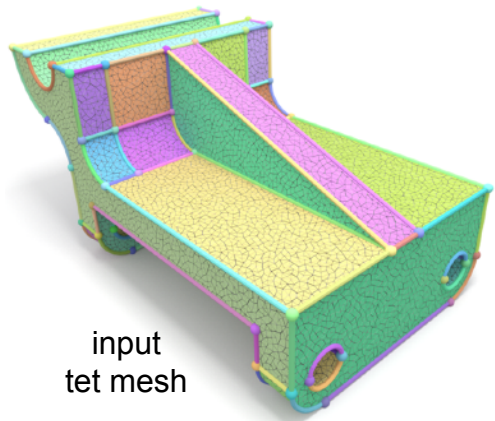
- Element quality



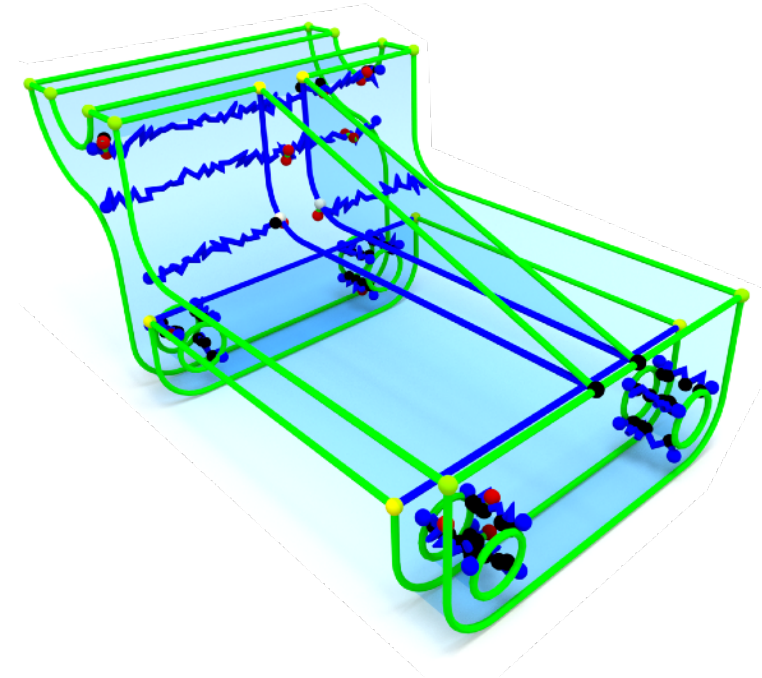
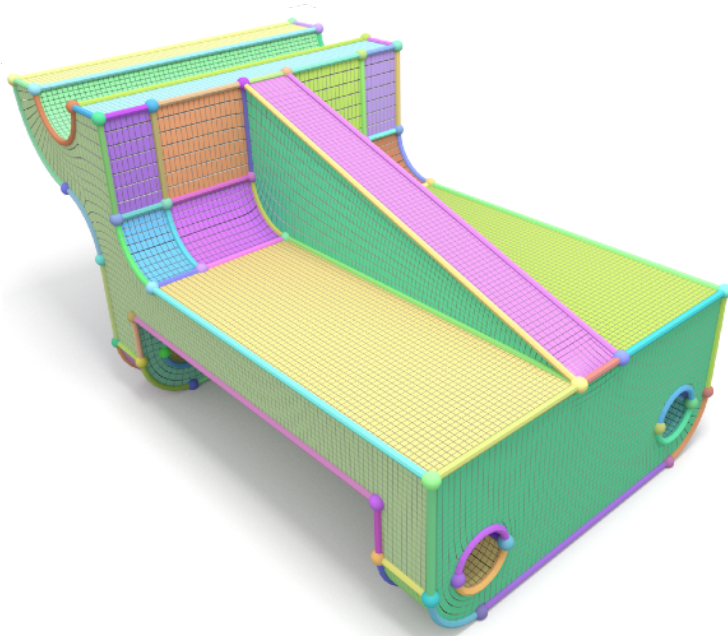
- Regularity



→ FRAME FIELD BASED HEX MESHING



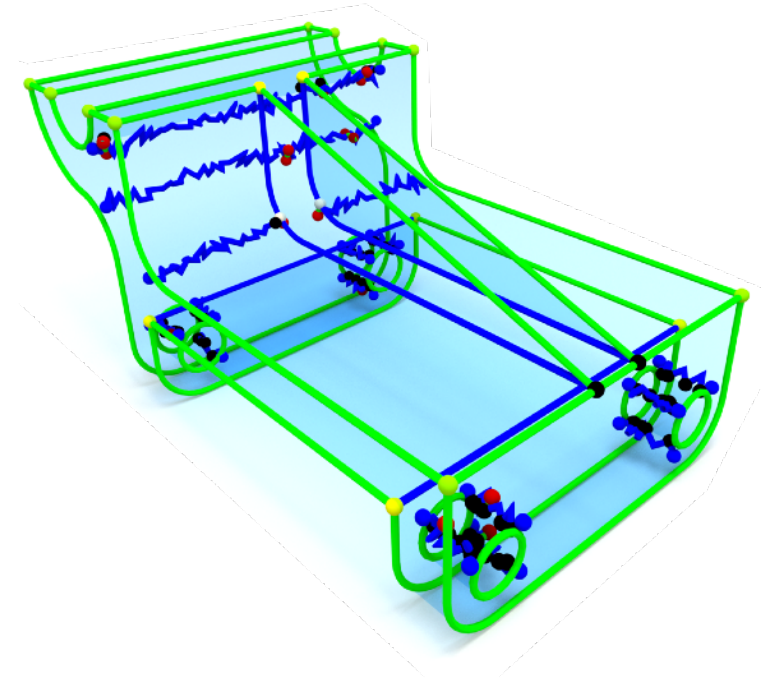
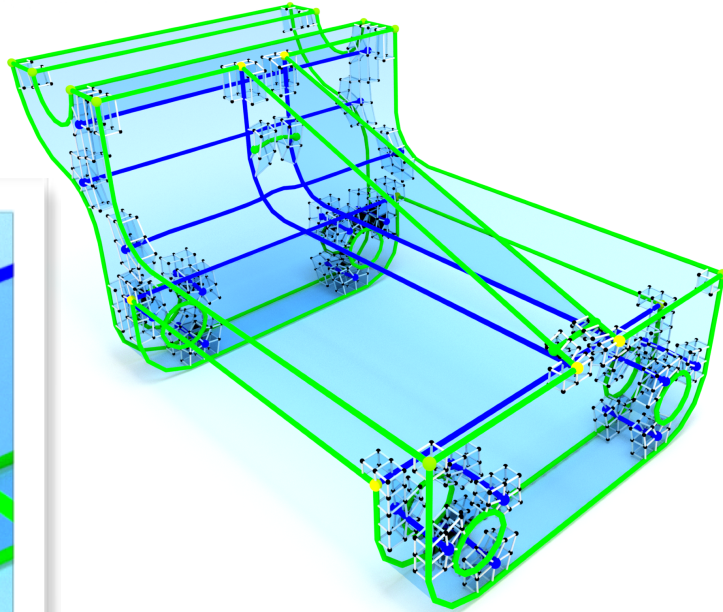
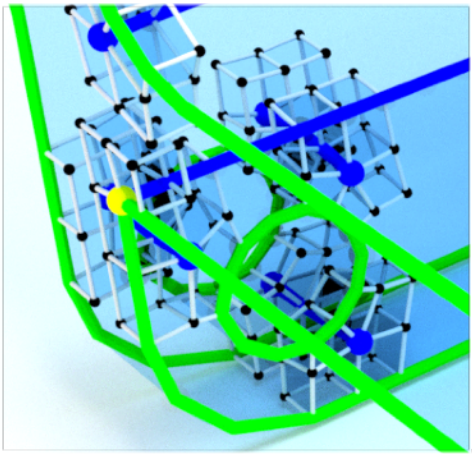
→ PROBLEM



**Locally Meshable
Frame Fields**

Frame Fields

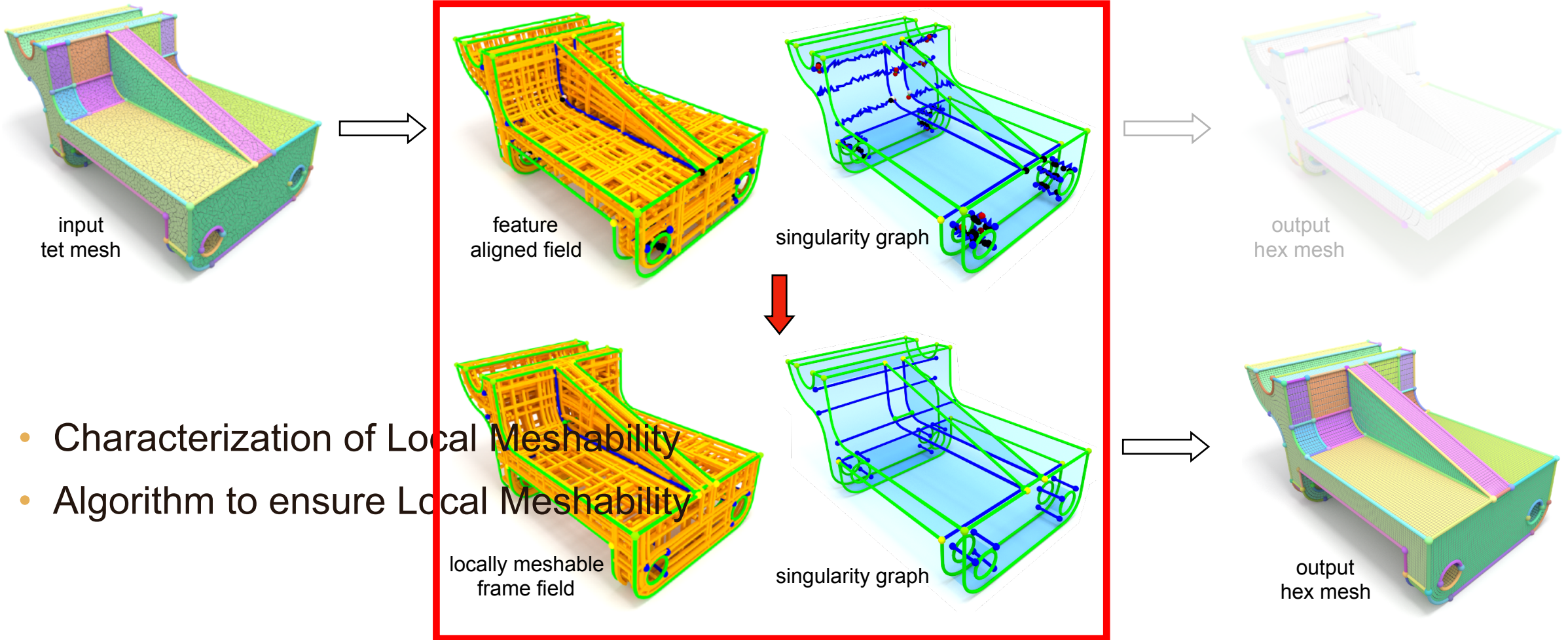
→ **GOAL**



**Locally Meshable
Frame Fields**

Frame Fields

→ CONTRIBUTIONS

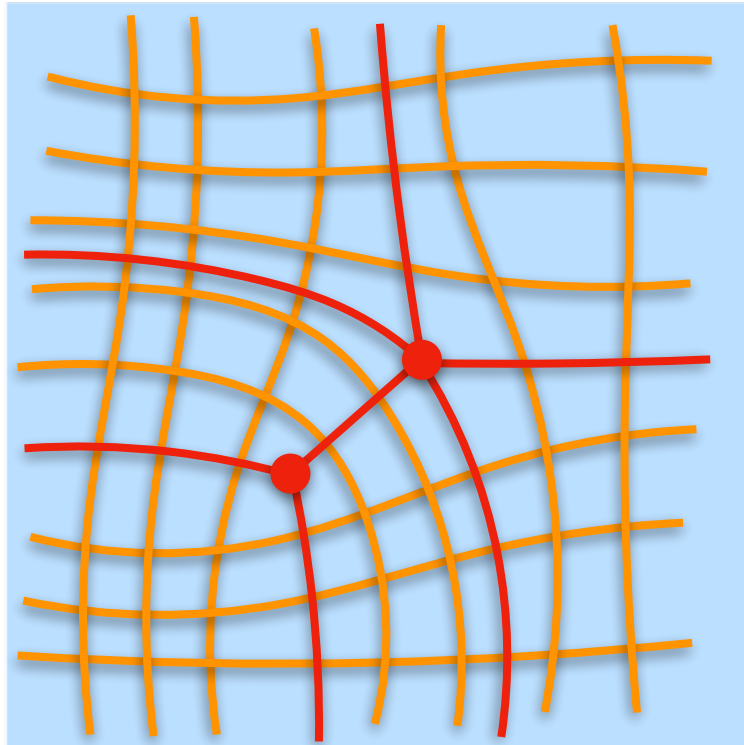


- Characterization of Local Meshability
- Algorithm to ensure Local Meshability

Frame Field Meshability

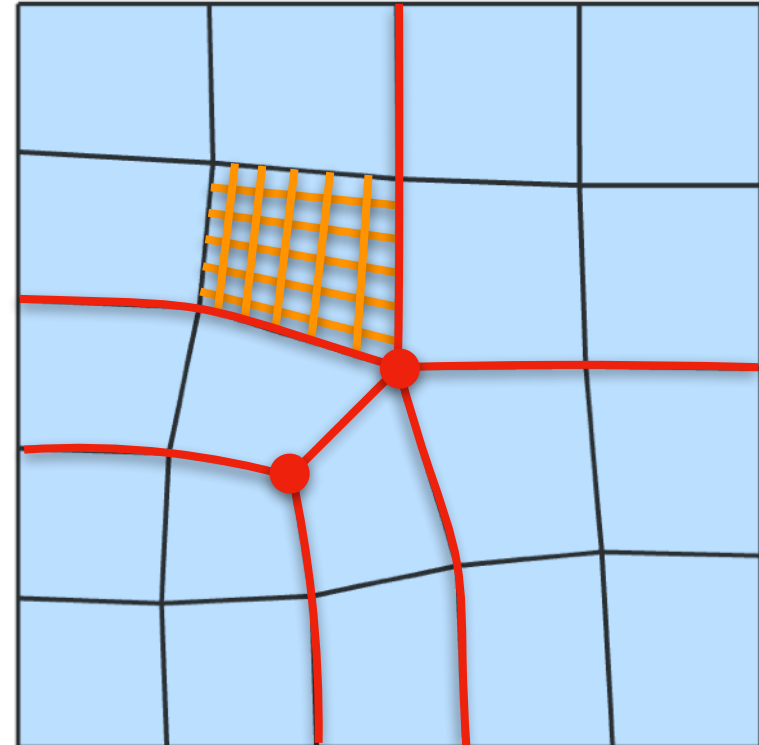
2D

→ QUAD MESH VS. FRAME FIELD TOPOLOGY



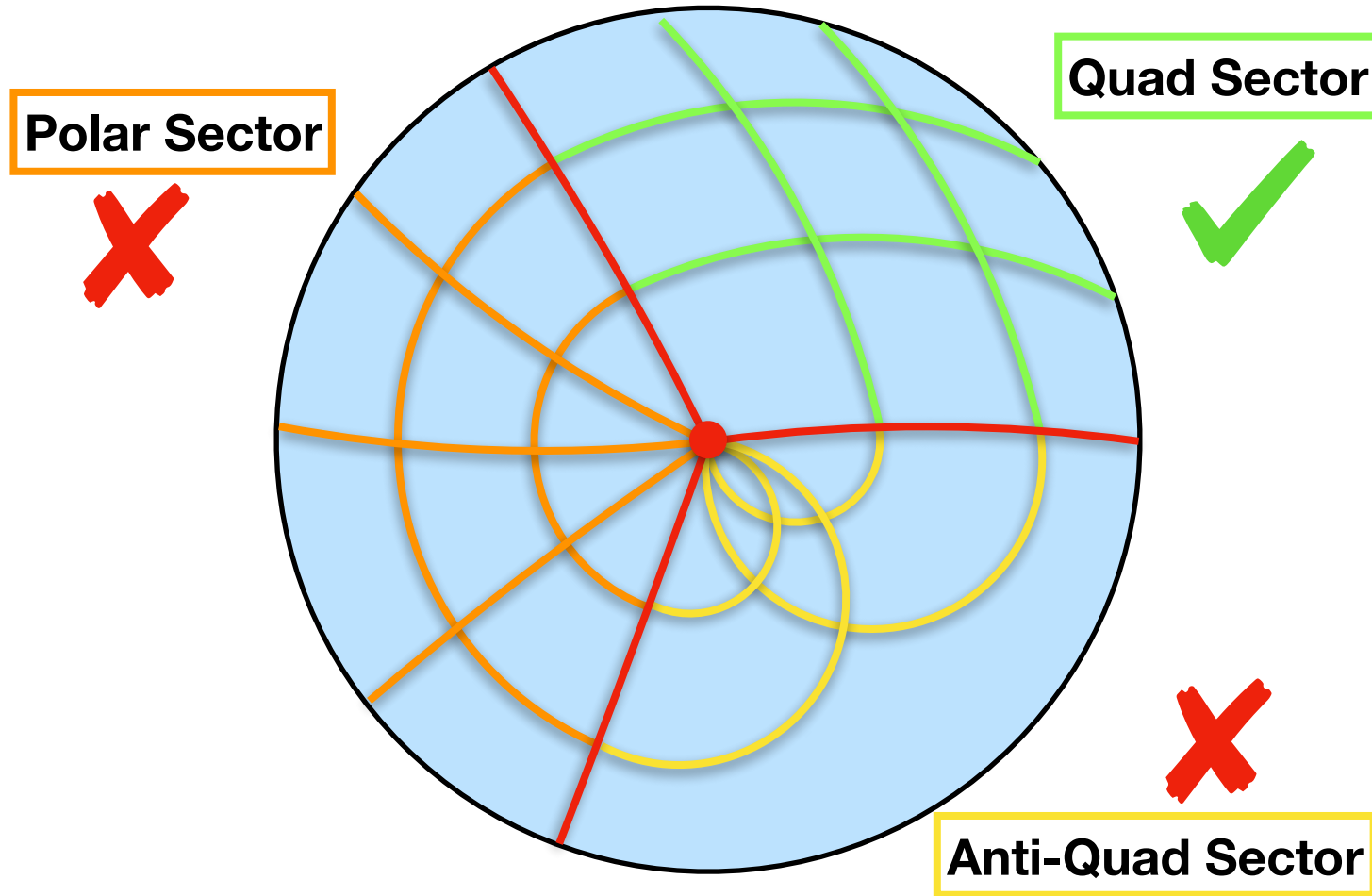
Frame Field

Induced Field
← always
sometimes →
Meshability



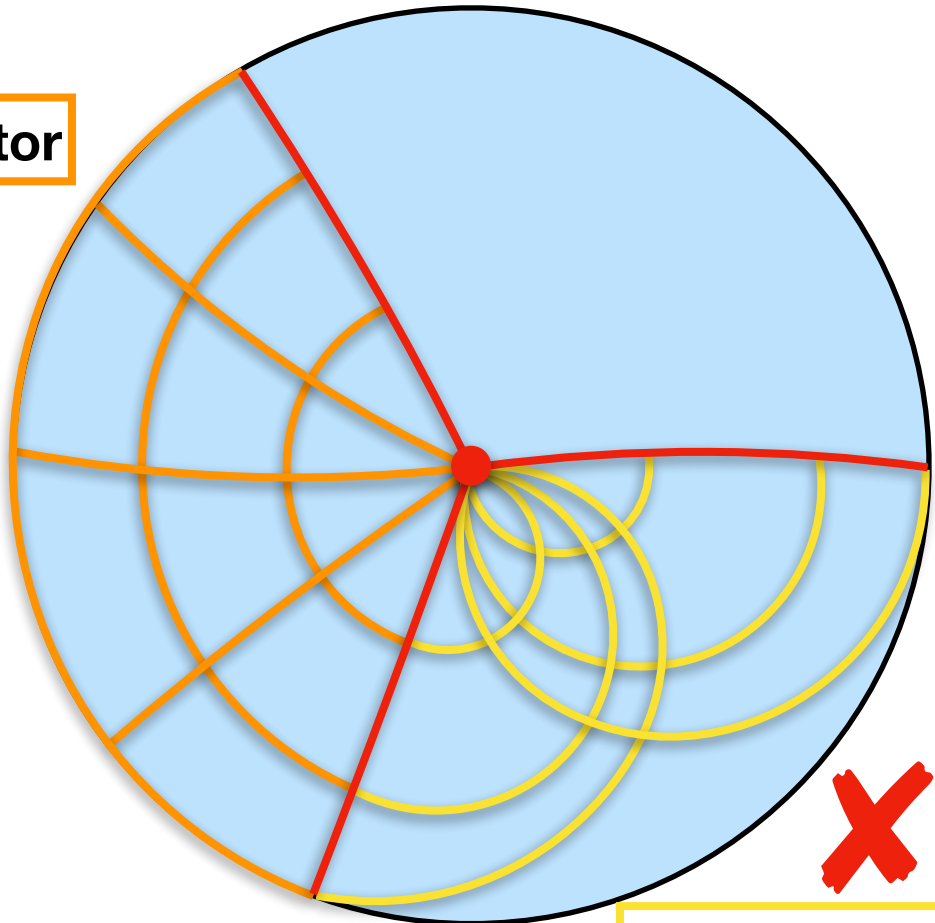
Quad Mesh

→ LOCAL MESHABILITY CONDITION

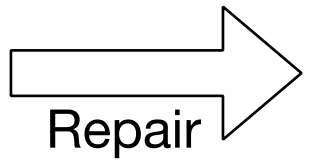


→ LOCAL MESHABILITY REPAIR

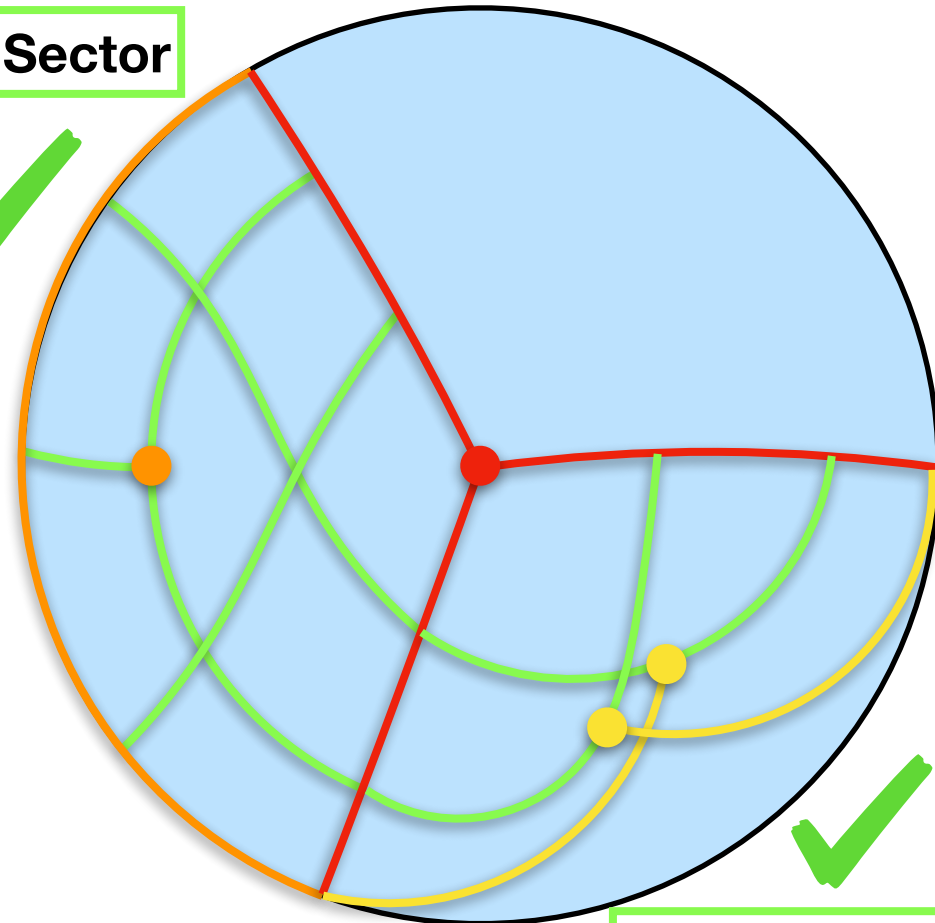
Polar Sector



Anti-Quad Sector



Quad Sector



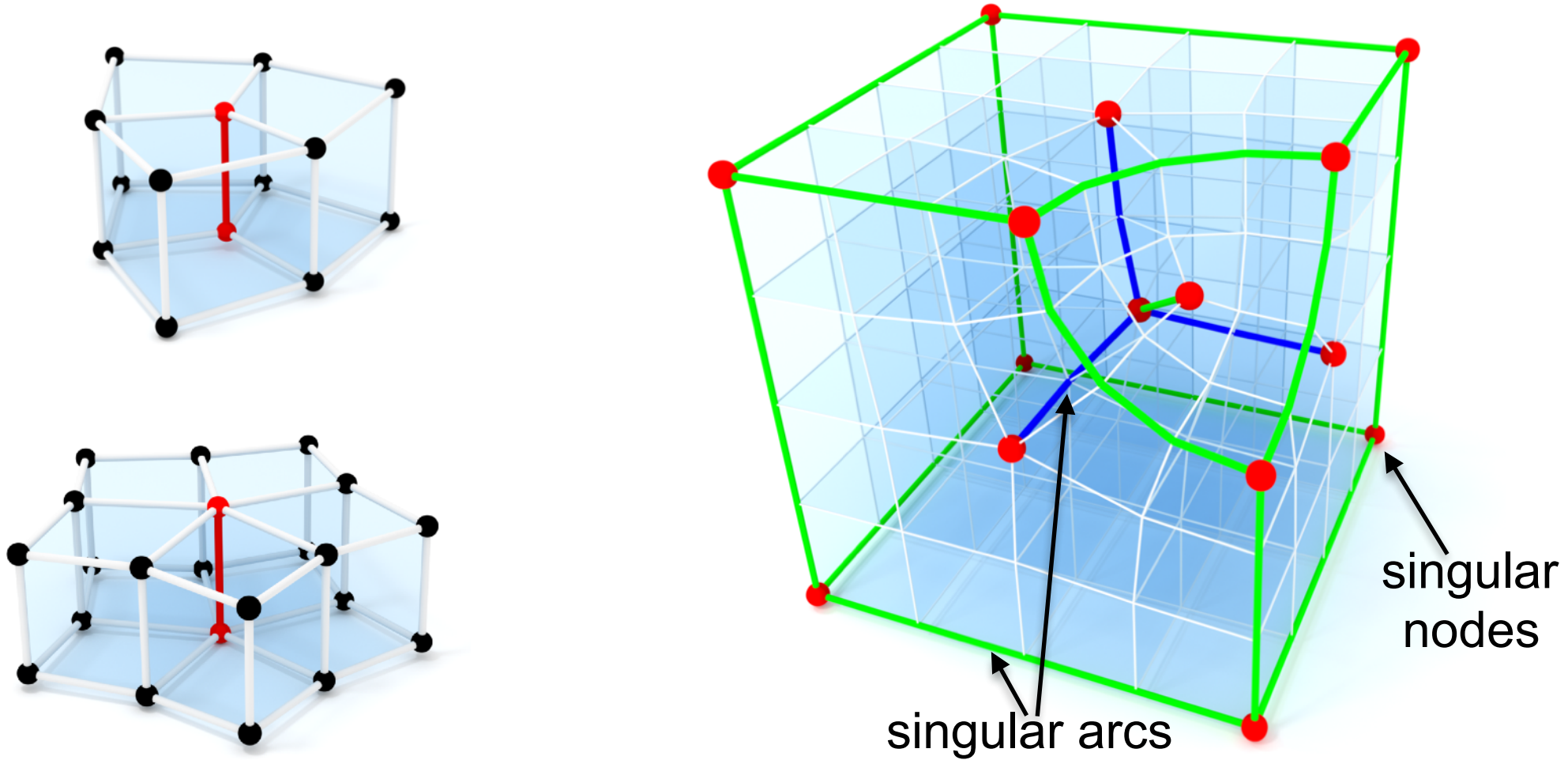
Quad Sector

Frame Field Meshability

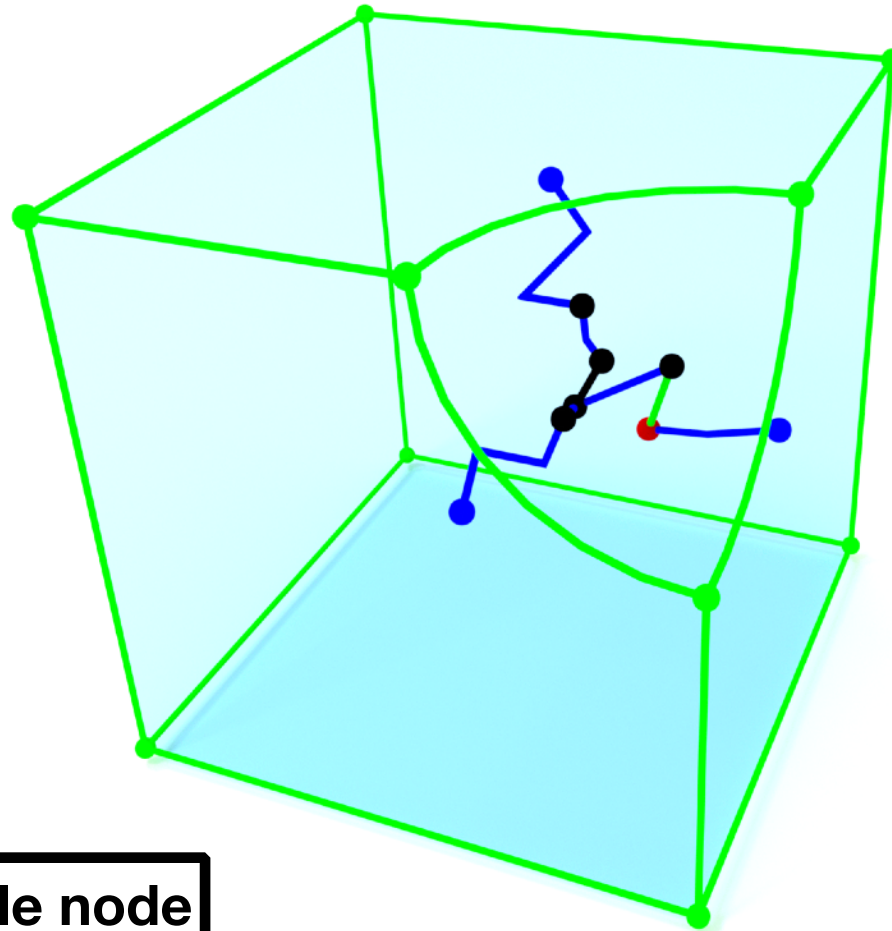
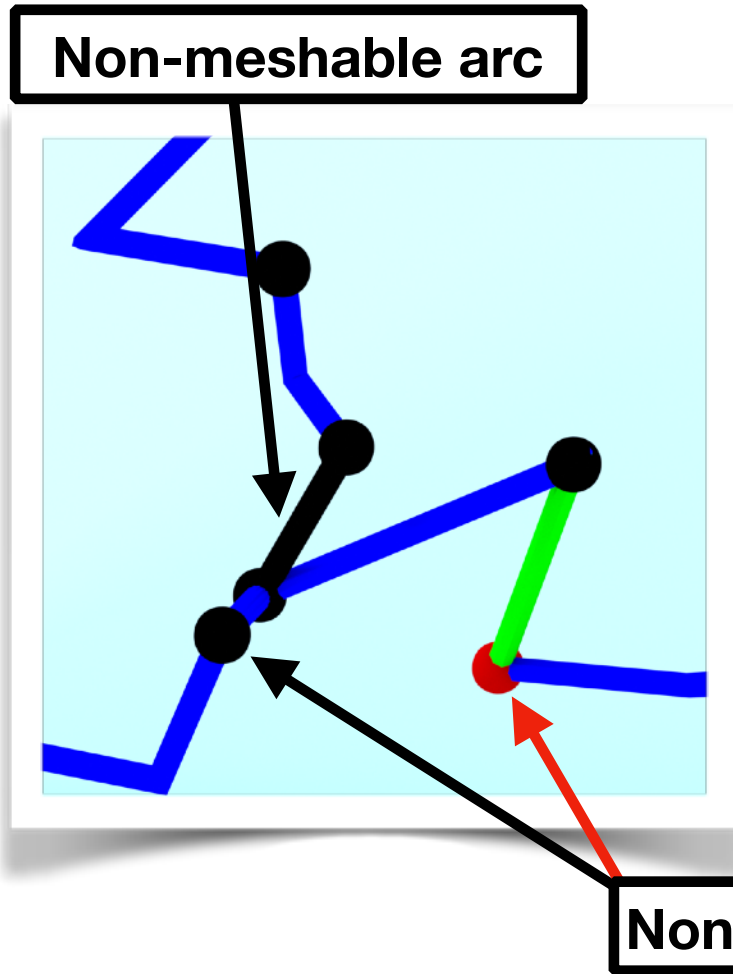
3D



HEX MESH SINGULAR GRAPH



→ FRAME FIELD SINGULARITIES



Algorithm

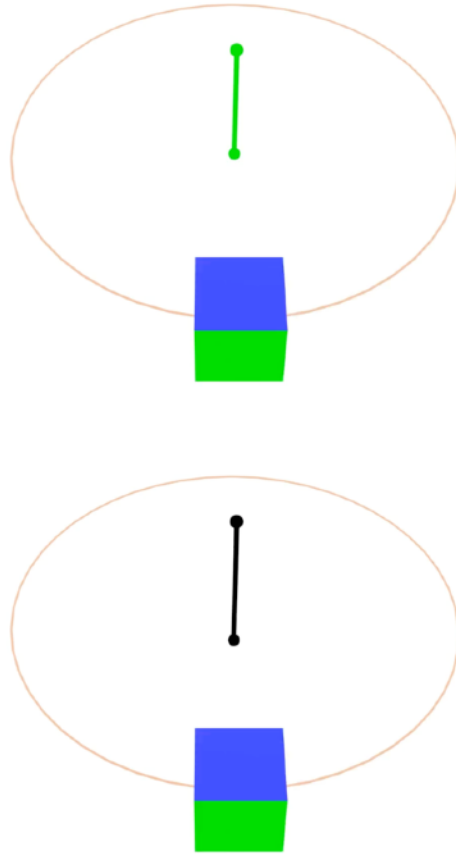
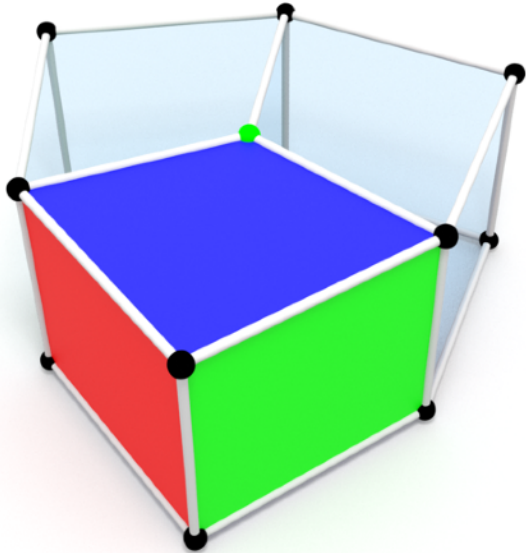
1. Repair non-meshable **arcs**
2. Repair non-meshable **nodes**



Arc Meshability

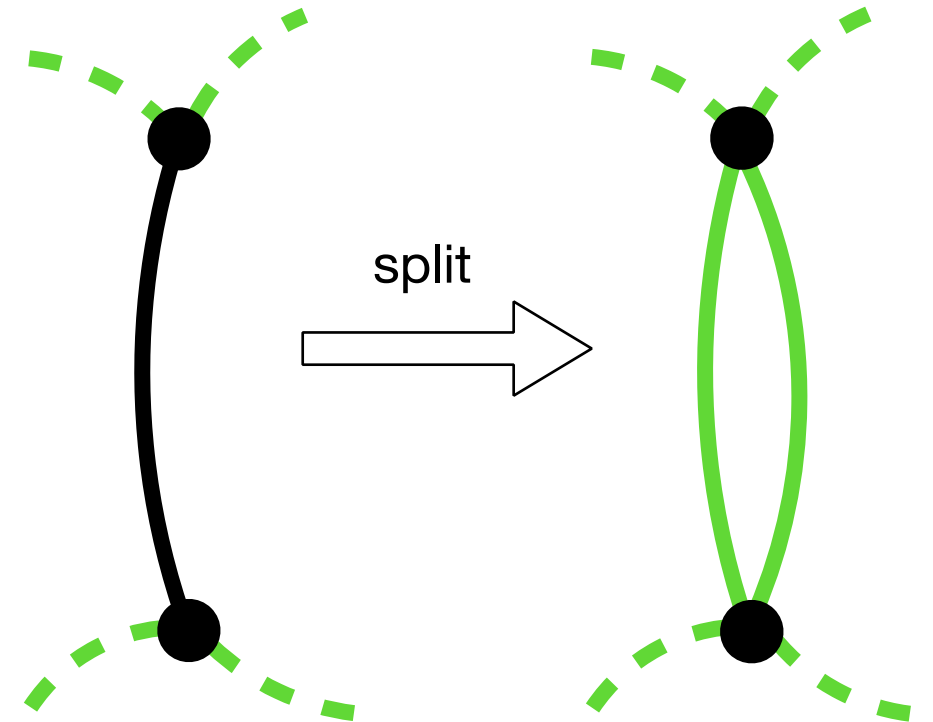
→ ARC MESHABILITY

- Non-meshable Monodromy



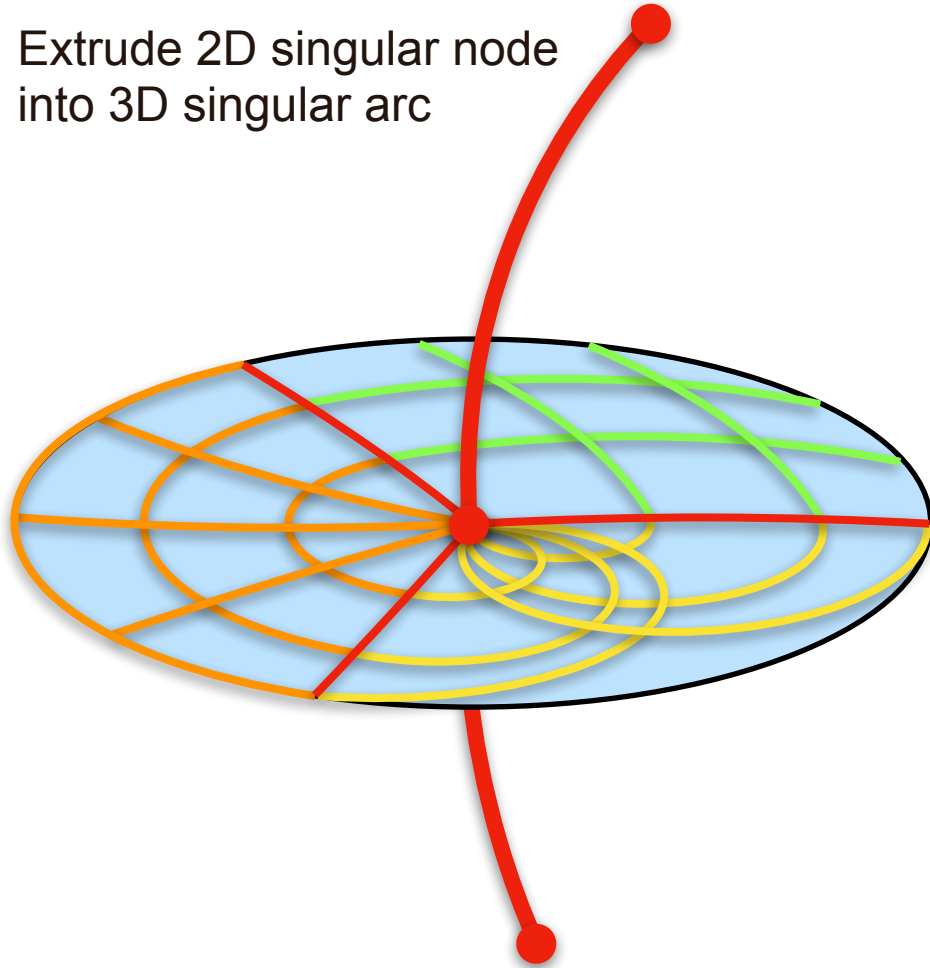
- Repair

— always splittable into two flow-aligned arcs [Jiang et al. 2014]



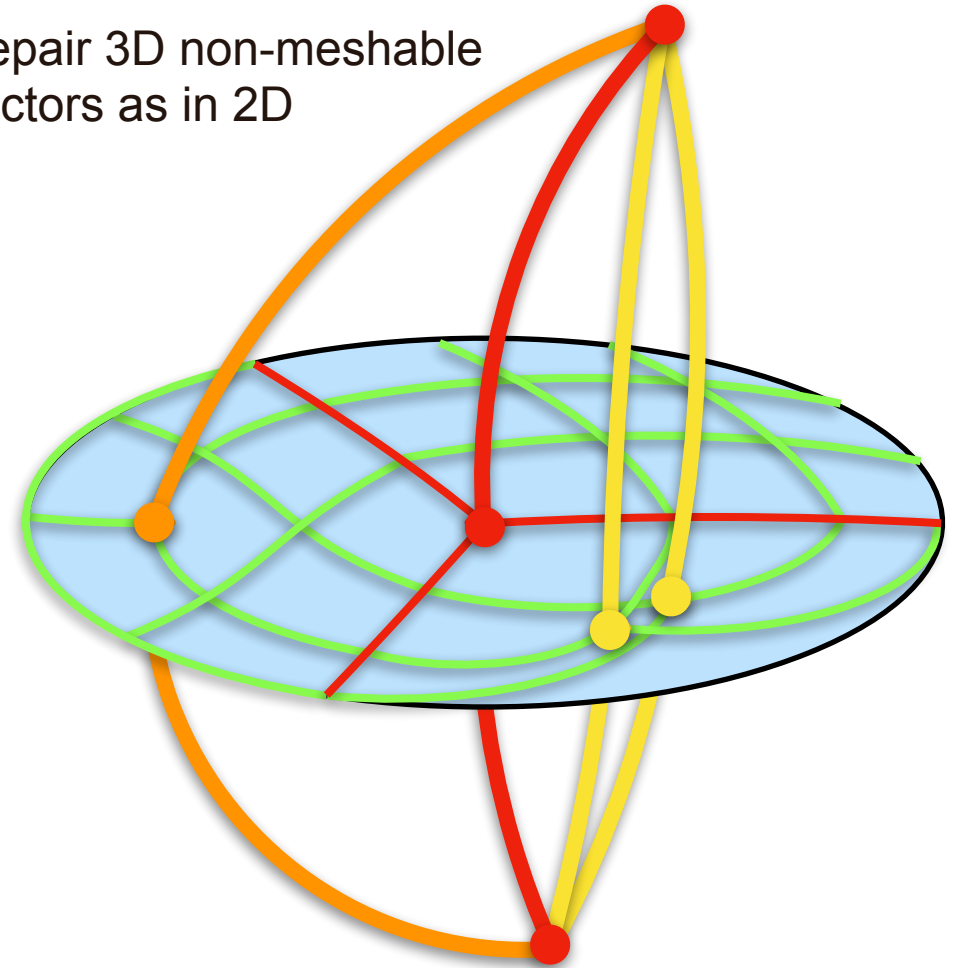
→ FLOW-ALIGNED SINGULAR ARCS

- Extrude 2D singular node into 3D singular arc



Repair

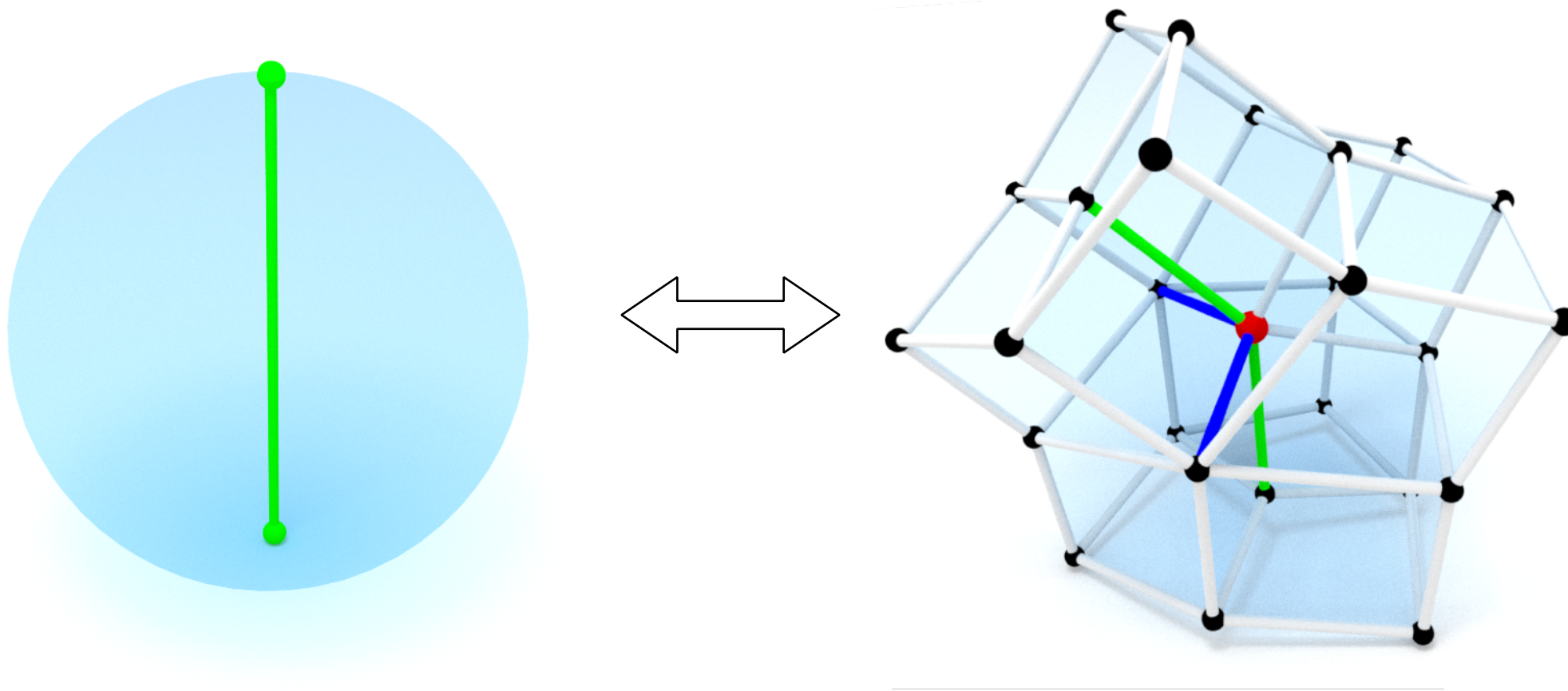
- Repair 3D non-meshable sectors as in 2D



Node Meshability

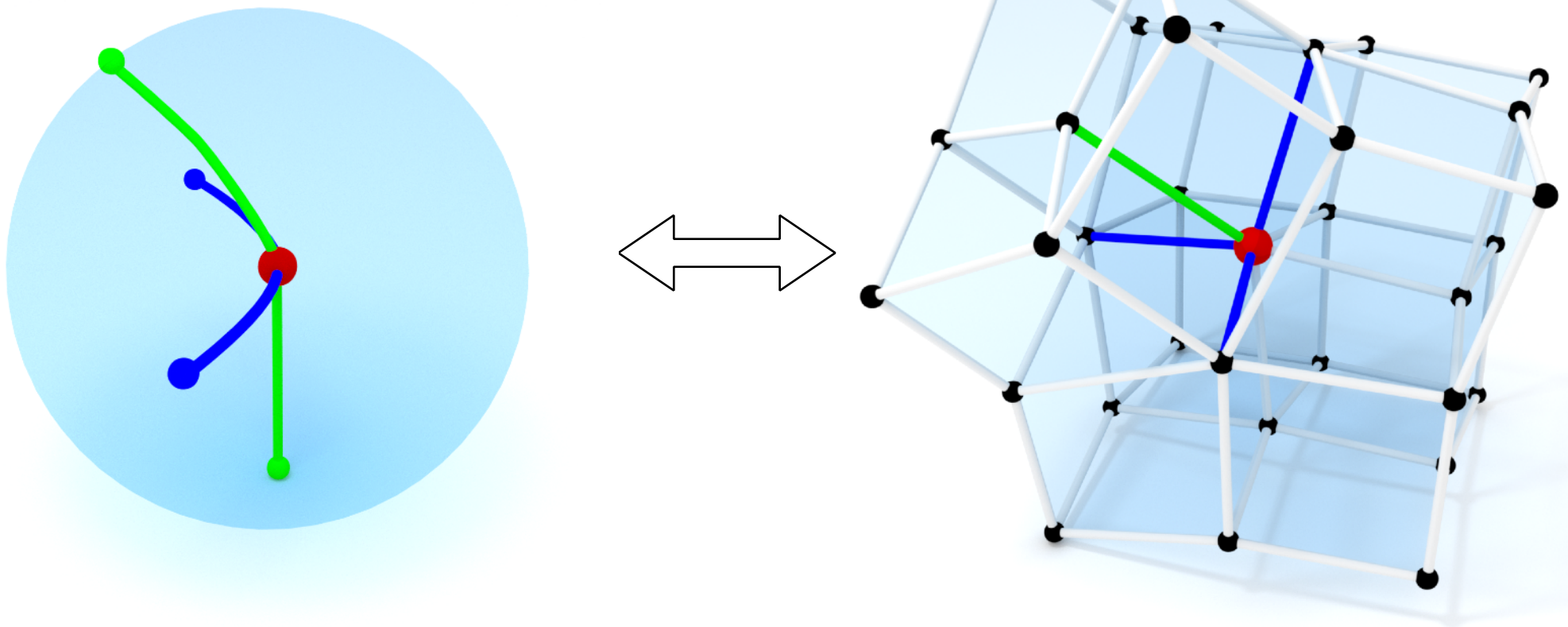
→ SINGULAR NODES

- Singular nodes result from the interaction between multiple singular arcs



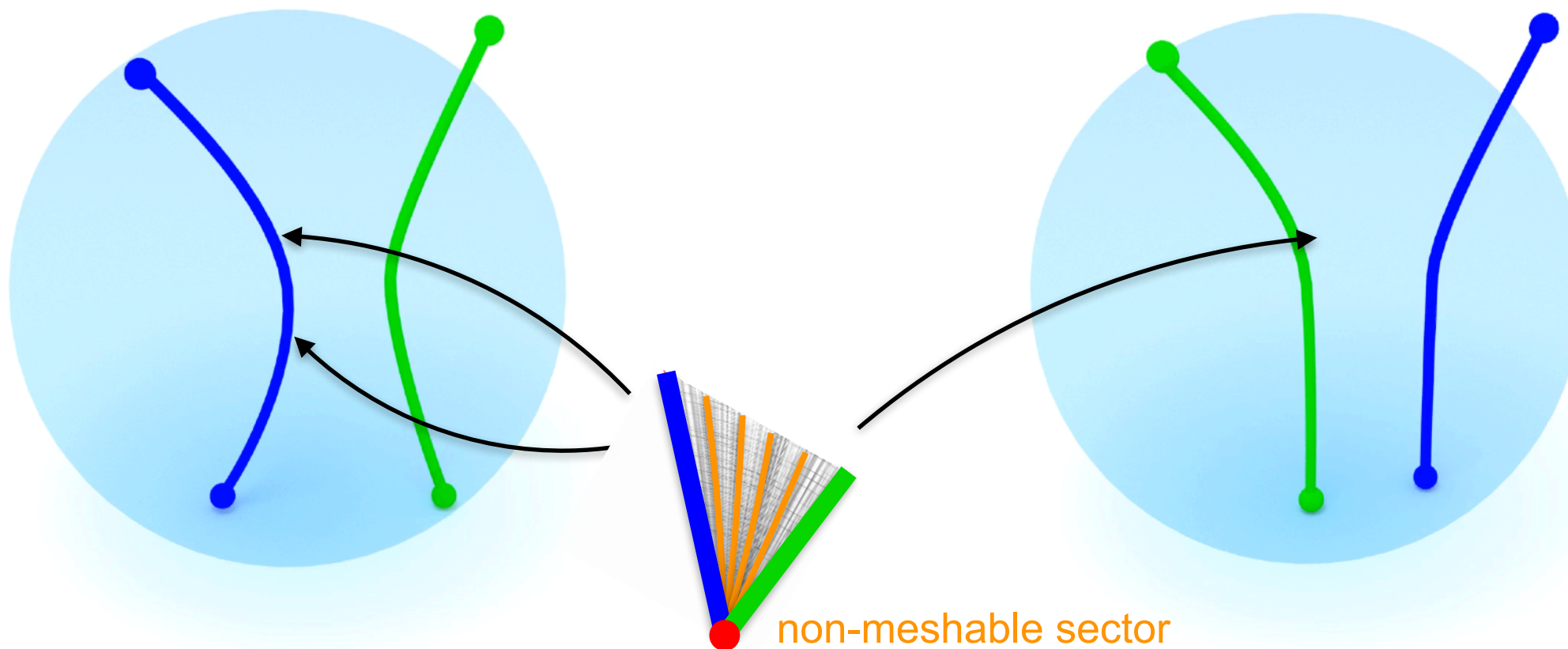
→ SINGULAR NODES

- Singular nodes result from the interaction between multiple singular arcs



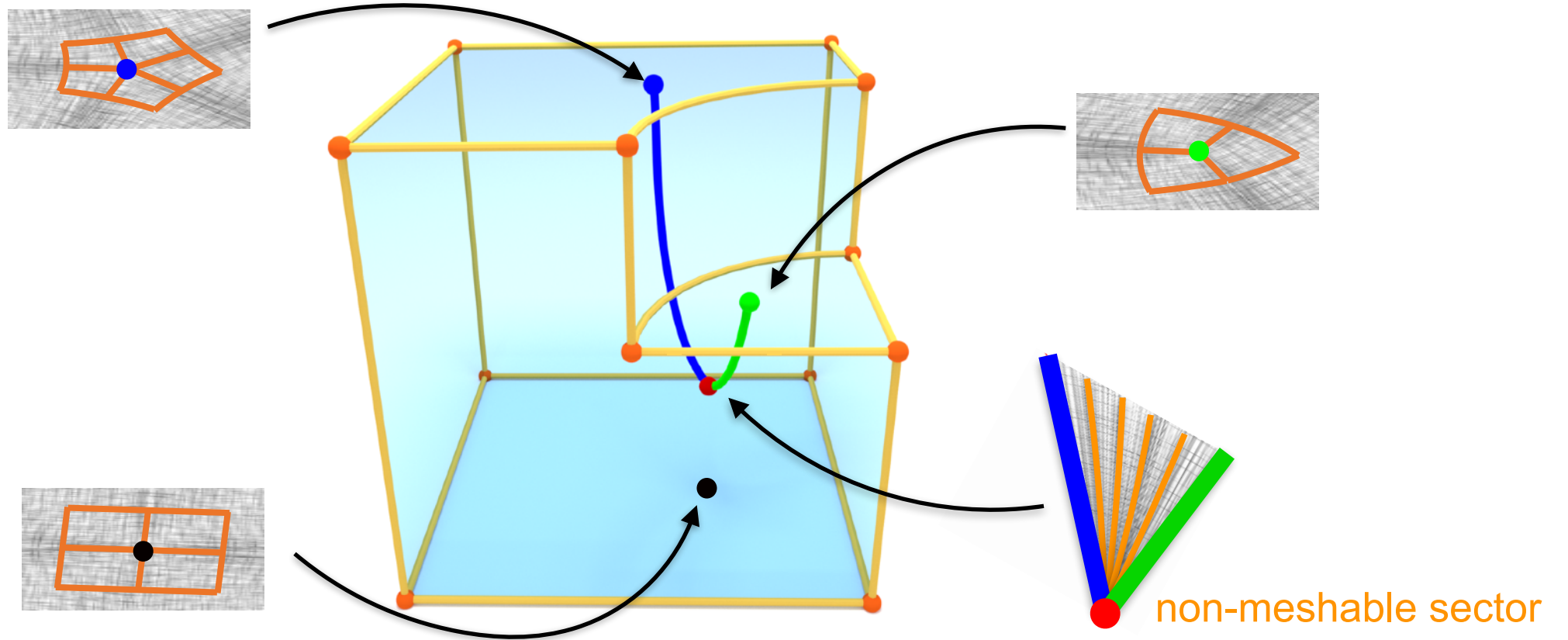
→ NON-MESHABLE INTERACTIONS

- Partial overlap of parallel arcs



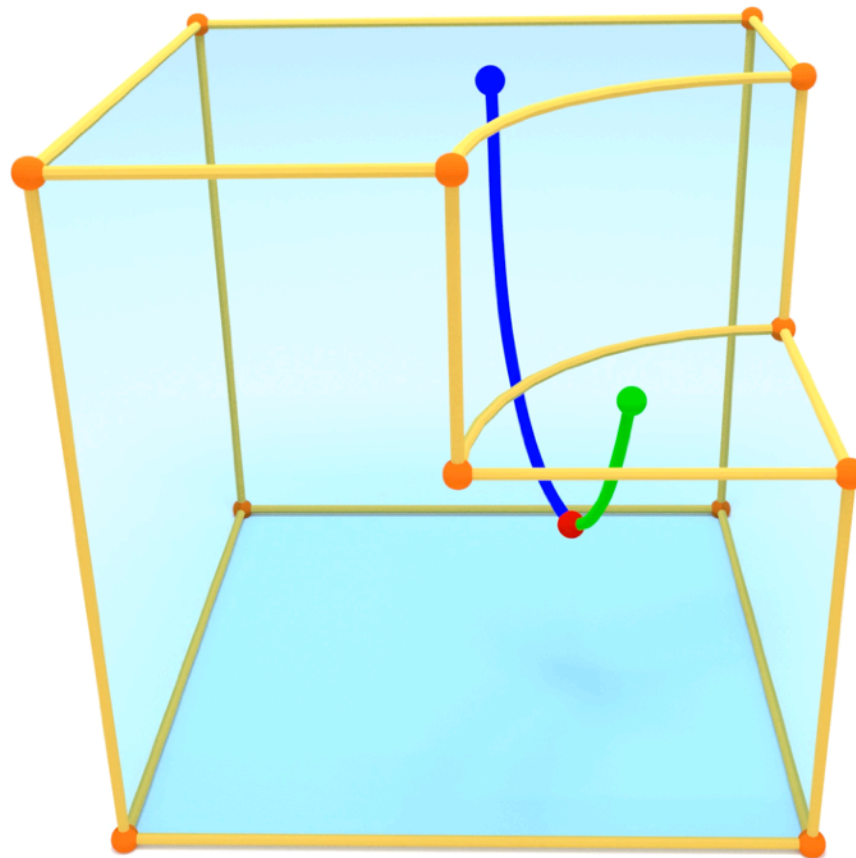
→ REPAIRING ZIPPER NODES

- Smoothest Fields contain non-meshable **Zipper Nodes**



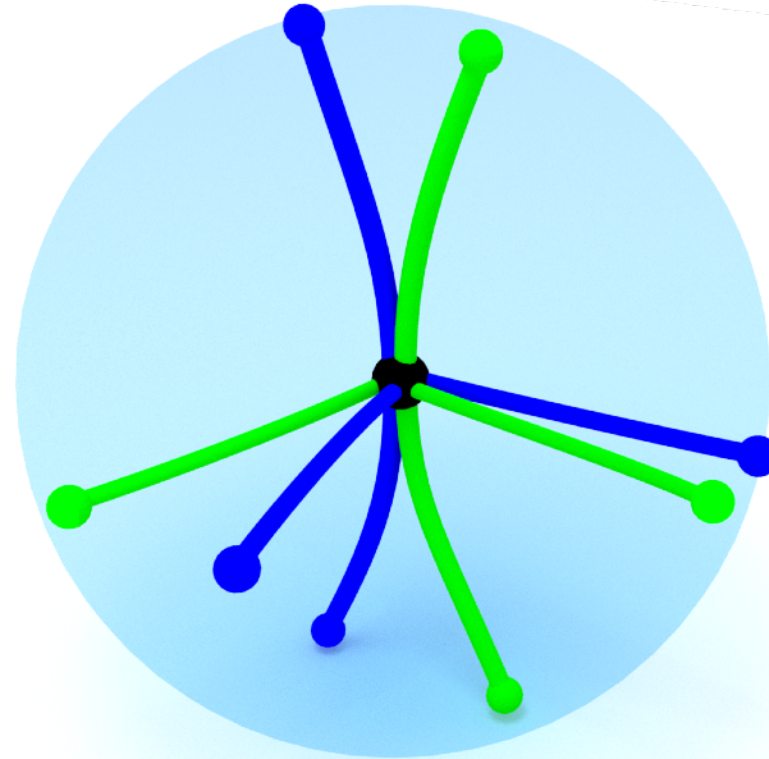
→ REPAIRING ZIPPER NODES

- Resolve partial overlap by **unzipping** along common streamline



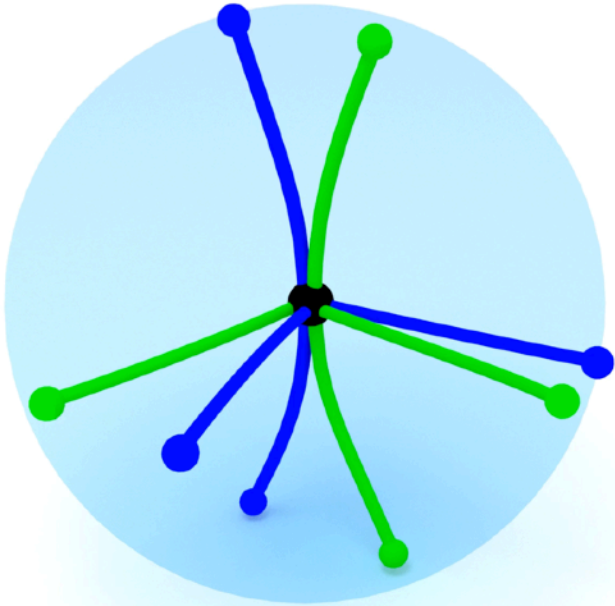
- **Decomposition Theorem**

Every singular node can locally be decomposed into isolated singular arcs and zipper nodes.

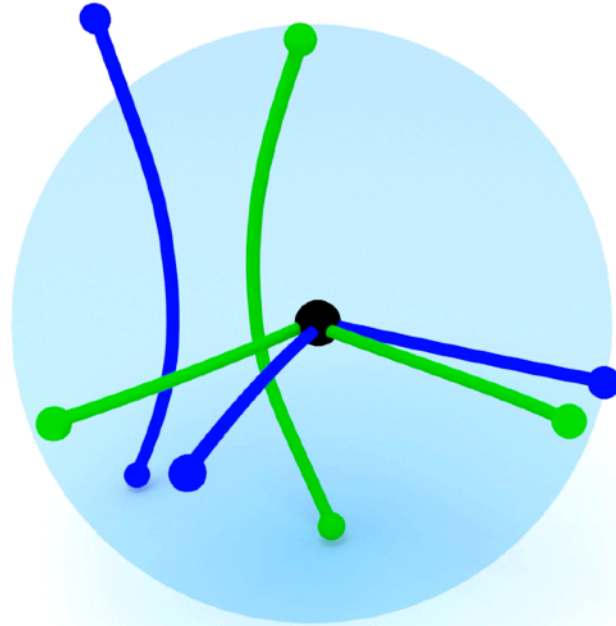


→ REPAIRING GENERAL NODES

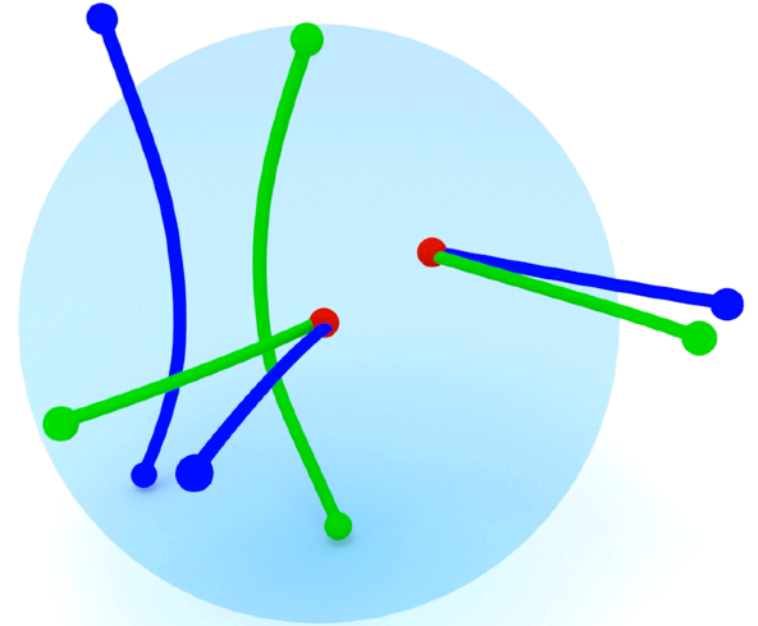
- Detaching arcs



- Detaching zipper nodes



- Repairing zipper nodes



Algorithm

Algorithm

1. Repair non-meshable **arcs**
2. Decompose non-meshable **nodes**
3. Repair **zipper nodes**

local modifications

global modifications

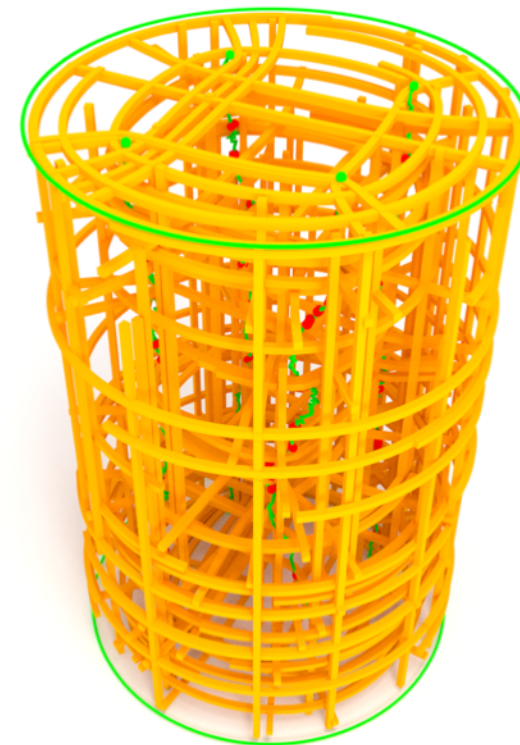
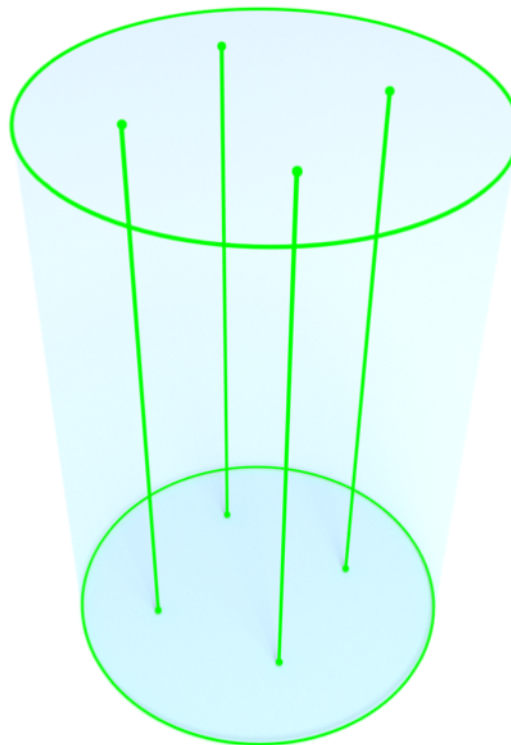
Handling Noisy Singularities

- **Discrete Singular Arcs**

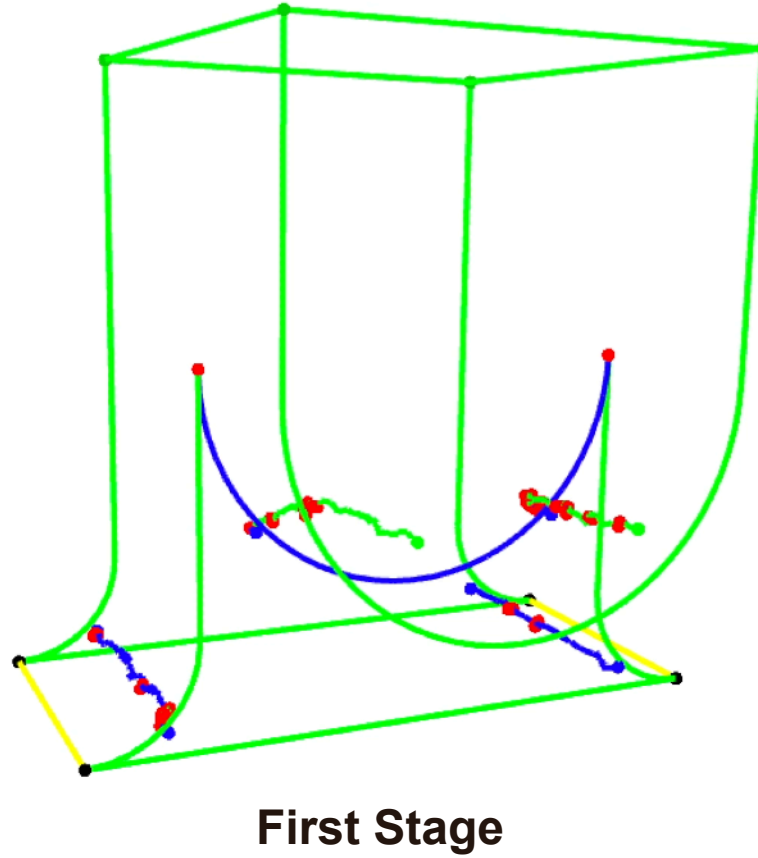
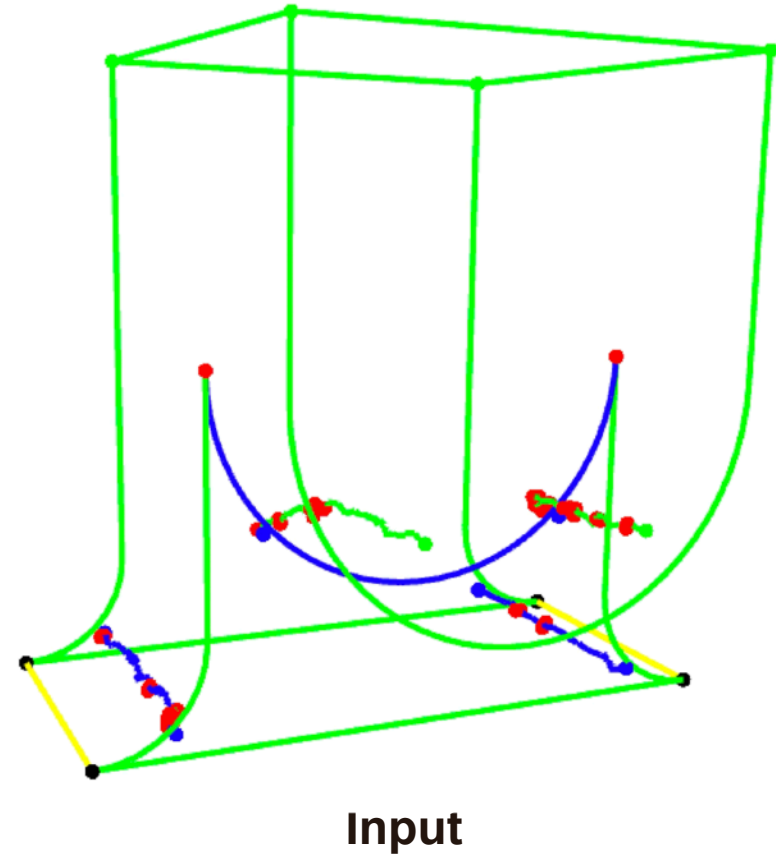
- are edges of input tetrahedral mesh
- not necessarily align to frame field
- often contain many zipper nodes

- **Strategy**

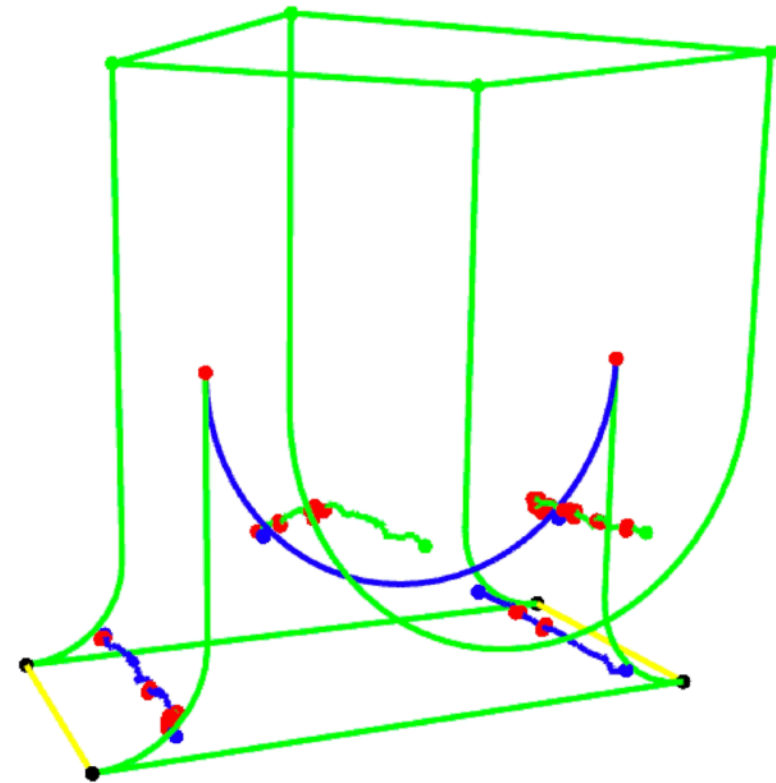
- delay zipper node repair
- geometrically optimize singular arcs
- co-optimize frame field and tet mesh



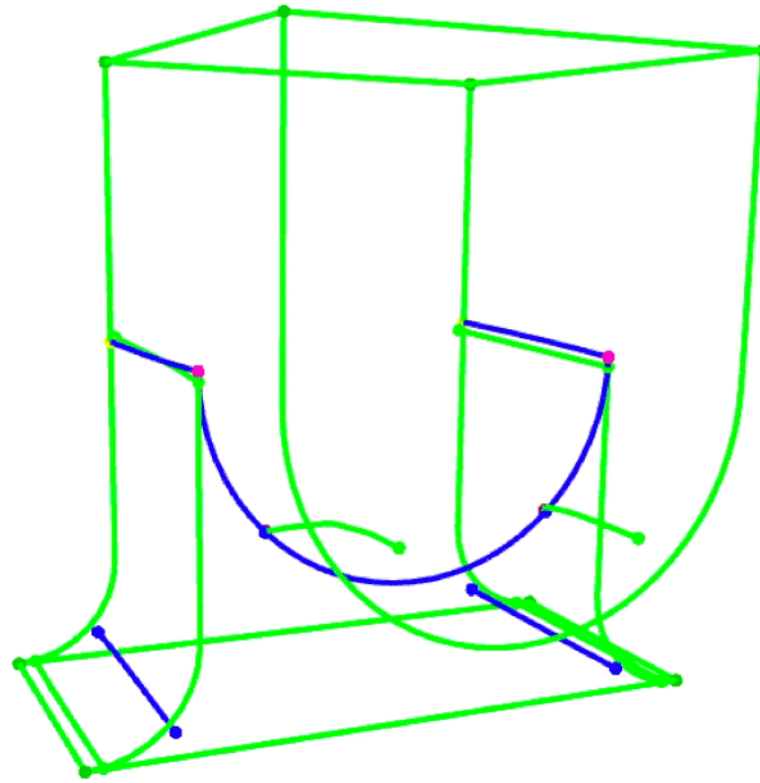
→ TWO-STAGE ALGORITHM



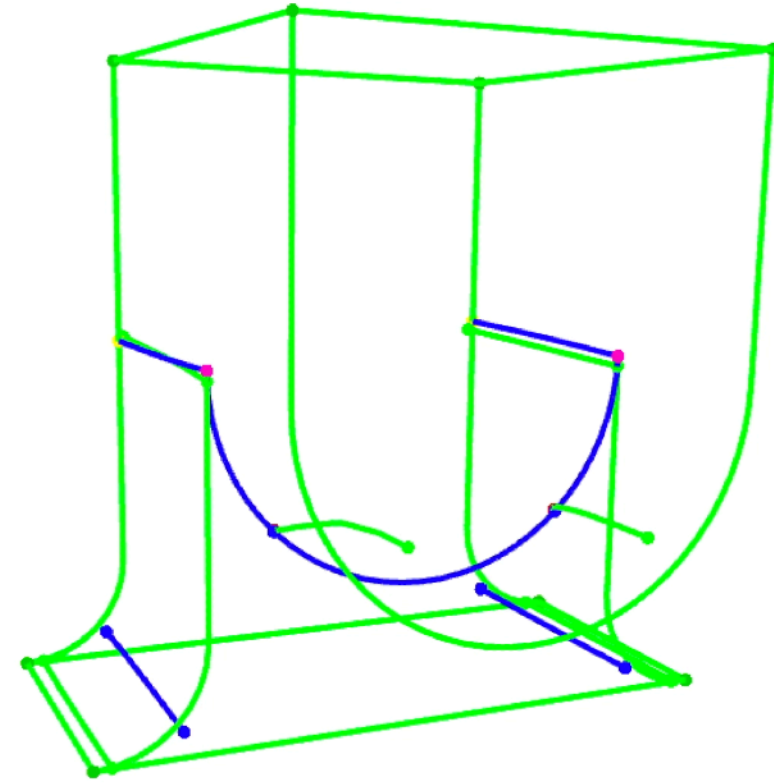
→ TWO-STAGE ALGORITHM



Input

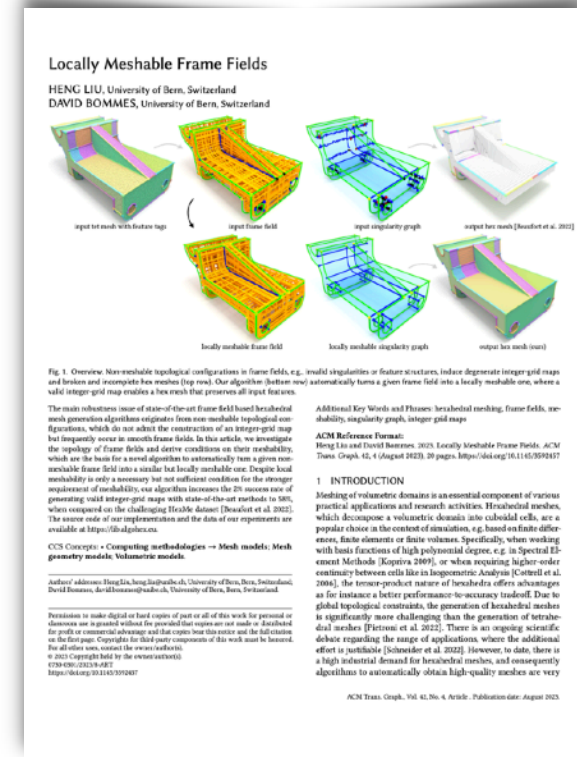


First Stage



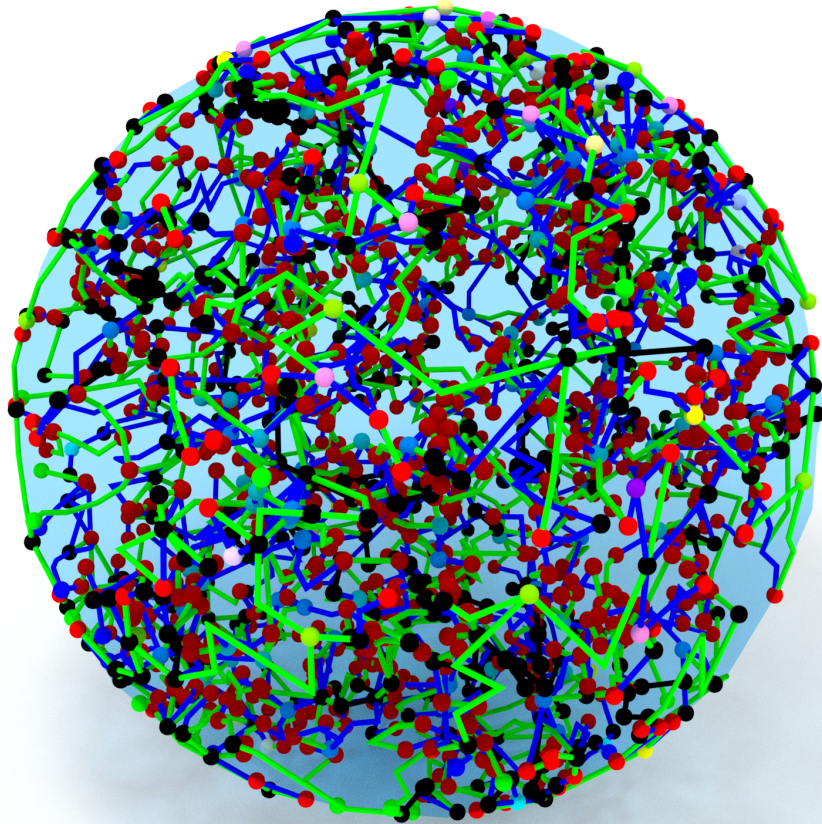
Second Stage

- Feature Constraints
 - Curves & Surfaces
- Zipper Node Repair
- Discretization on Tetrahedral Mesh
- Singularity Graph Optimization
- ...

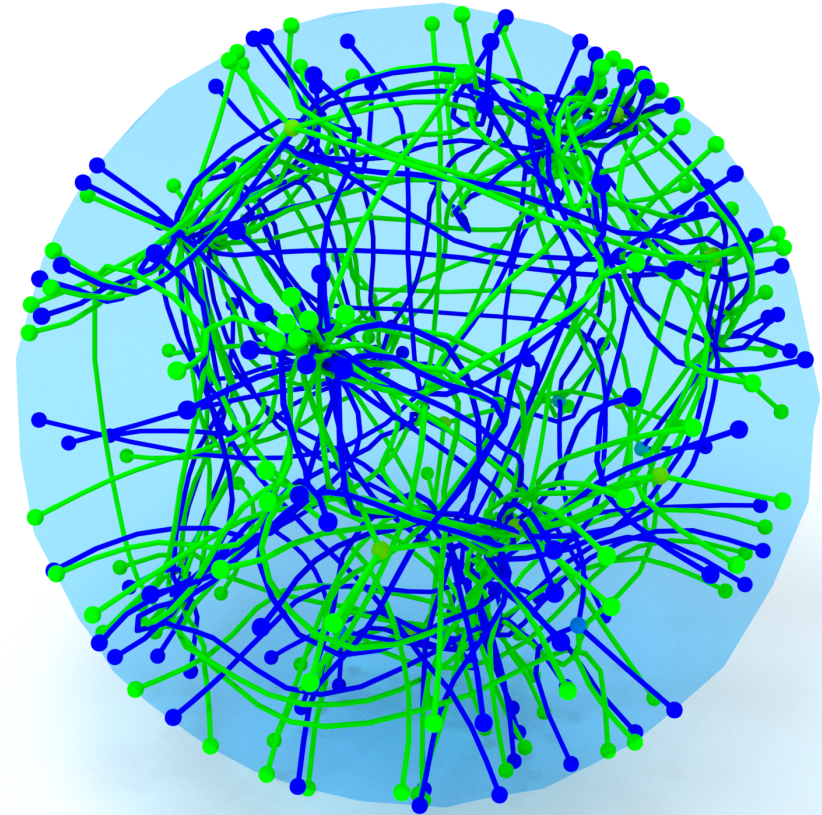
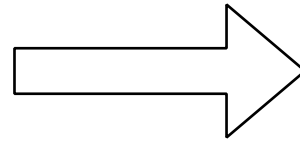


Results

→ STRESS TEST - RANDOM FRAME FIELD

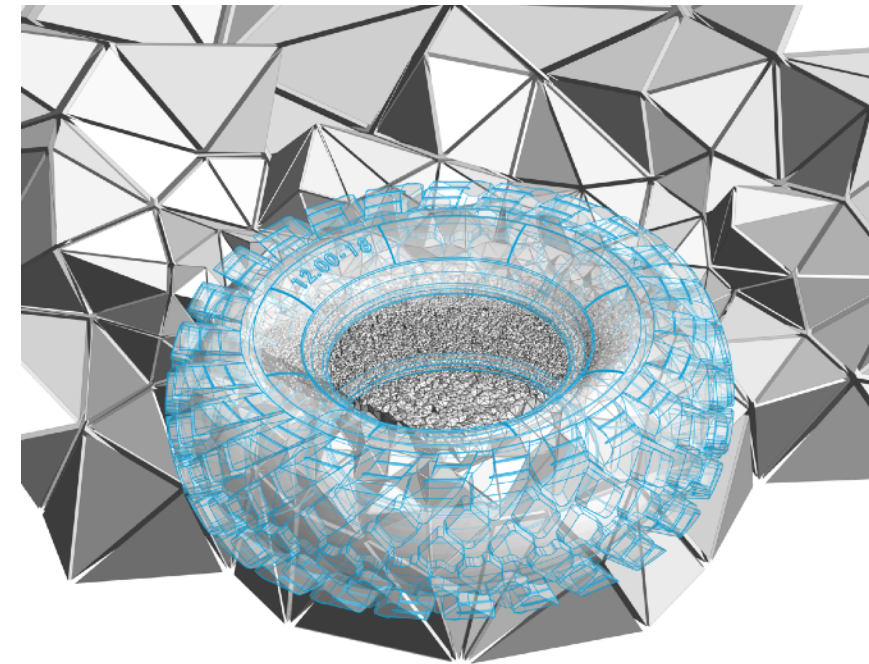
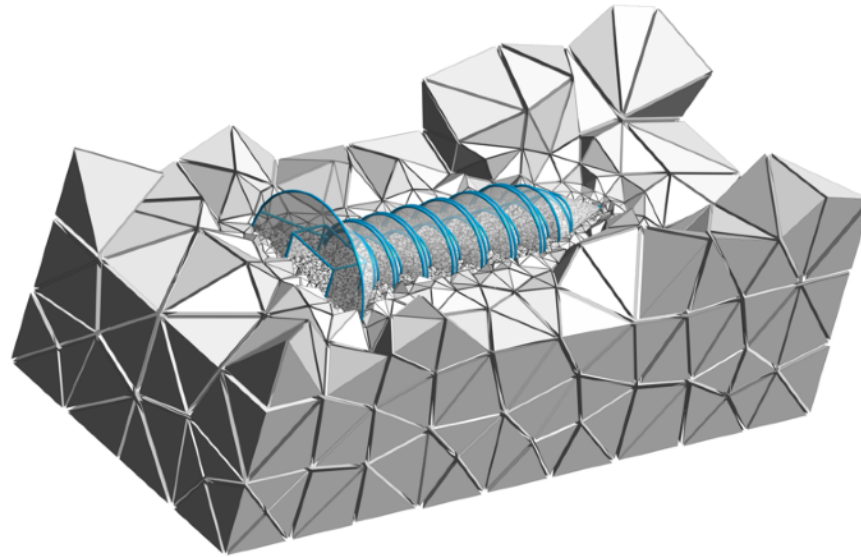
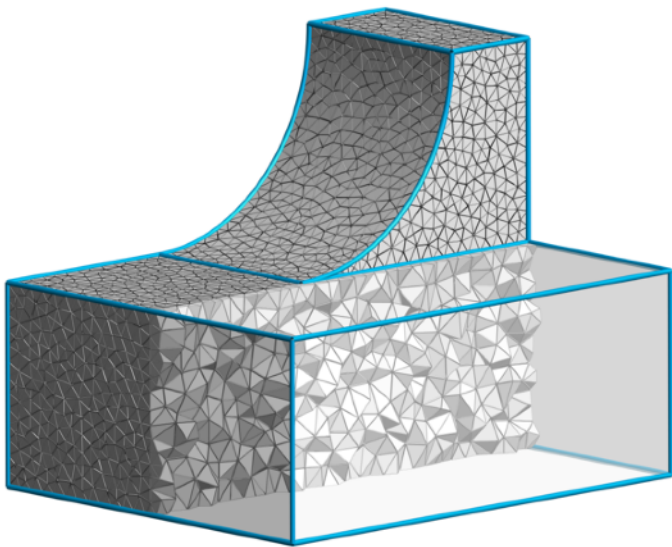


input



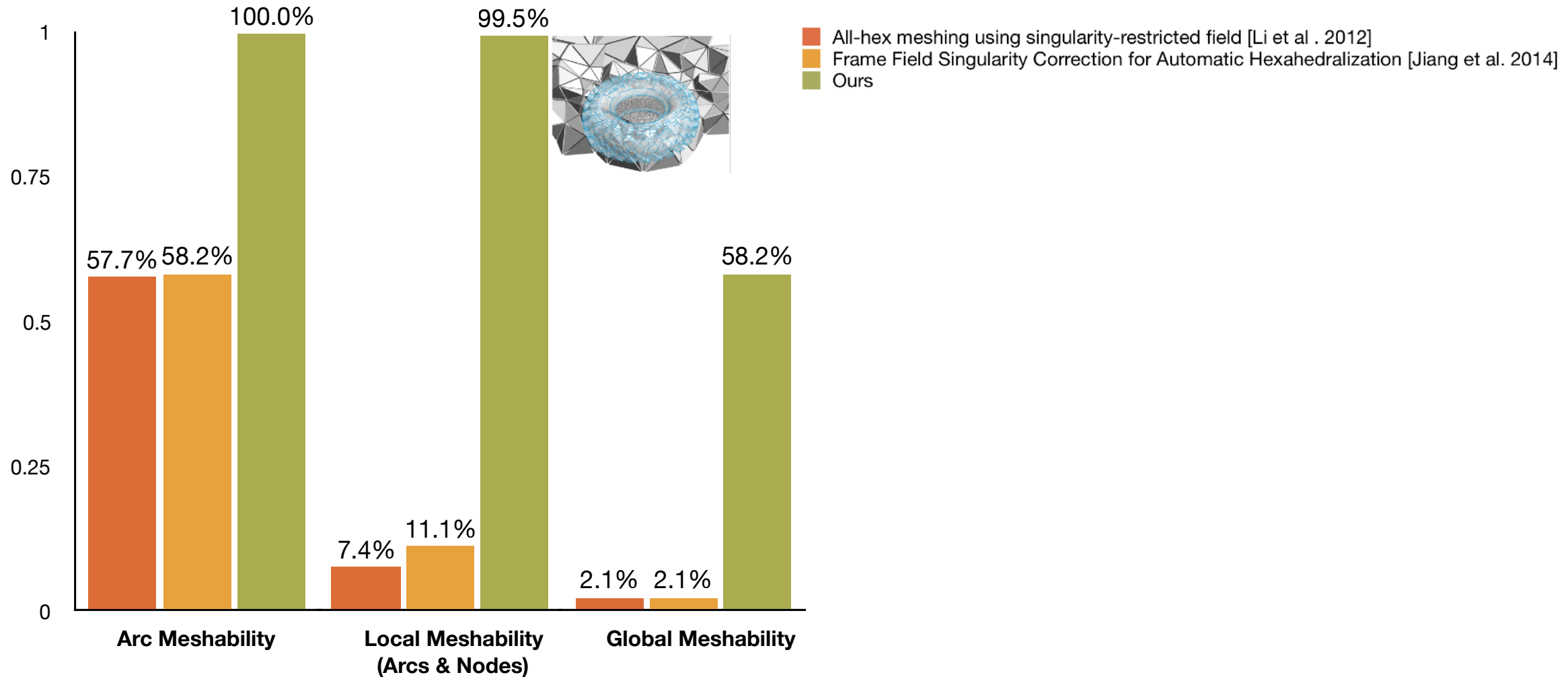
locally meshable

- **HEXME - Dataset** [Beaufort et al. 2022]
 - collection of 189 domains to evaluate and challenge hexmeshers
 - categories: simple, nasty, industrial, including multi-material
 - **goal:** facilitate comparison & guide future research





EVALUATION - COMPARISON

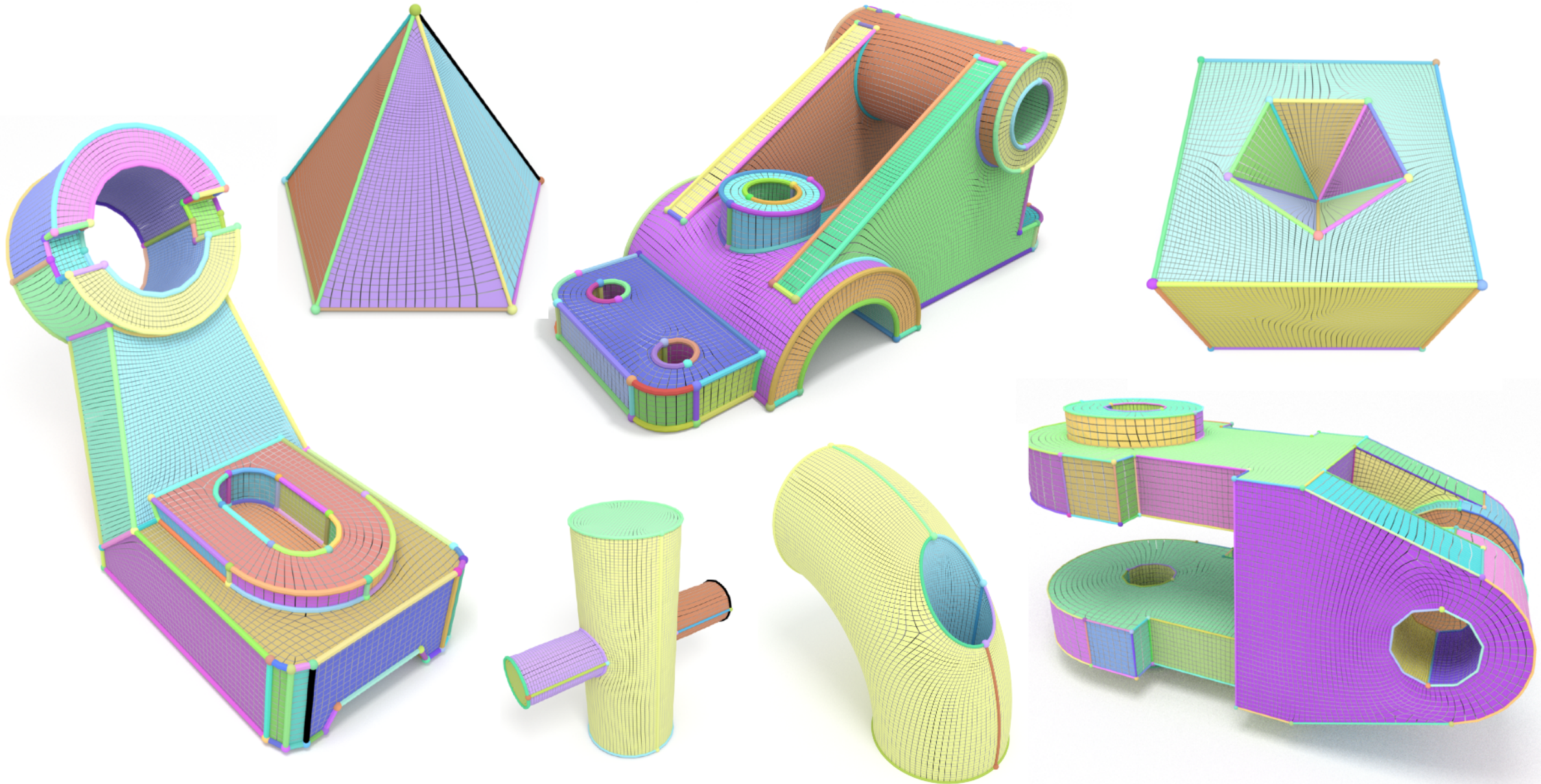




EVALUATION - HEX MESHES



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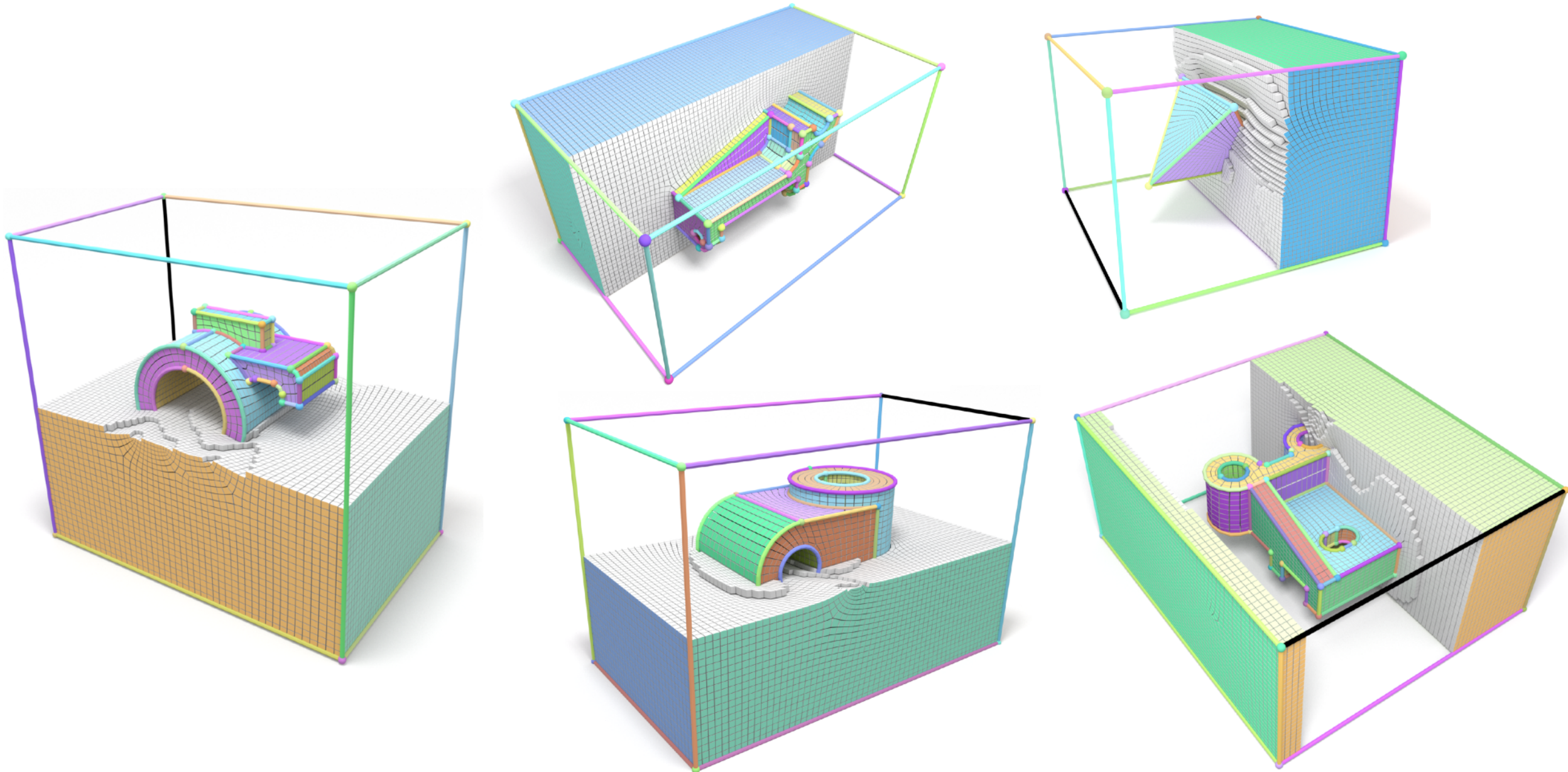




EVALUATION - HEX MESHES



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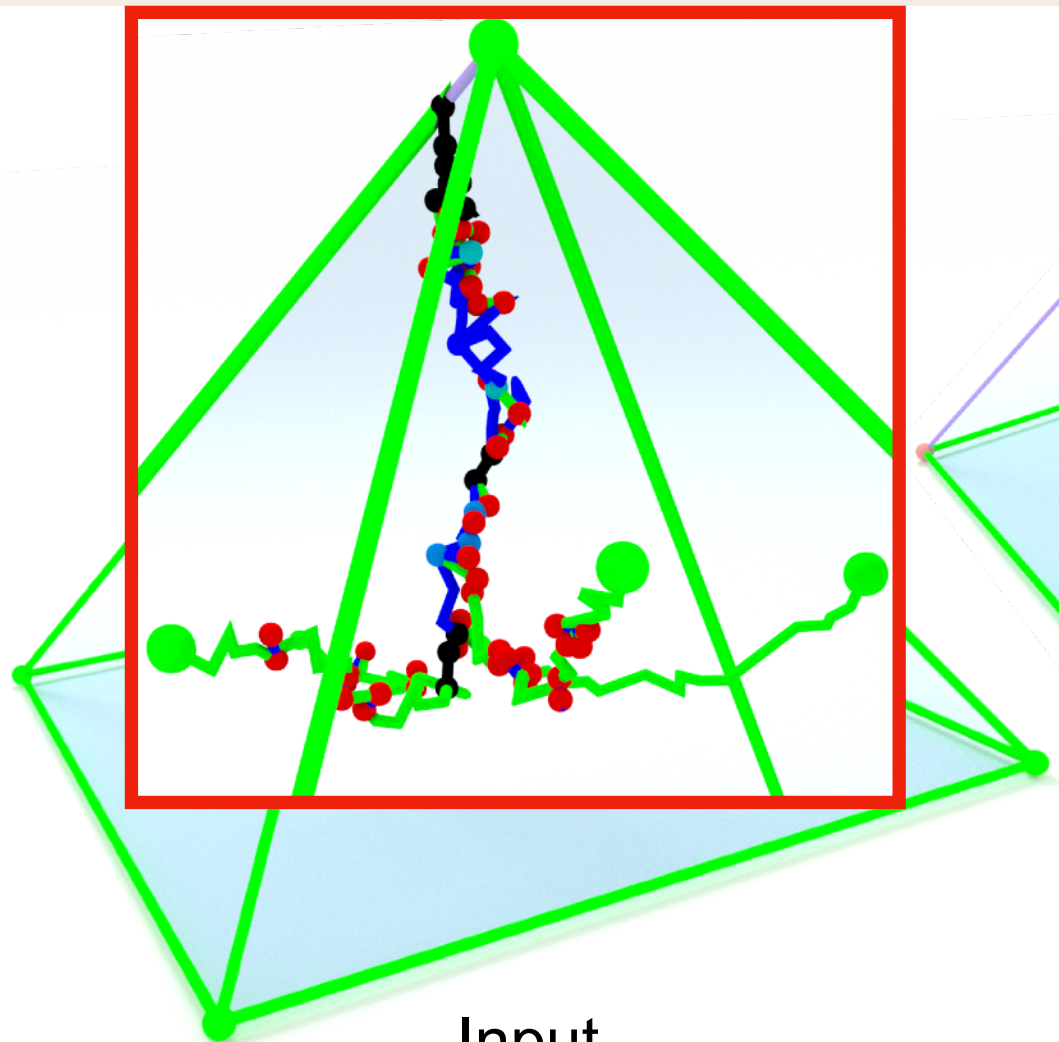




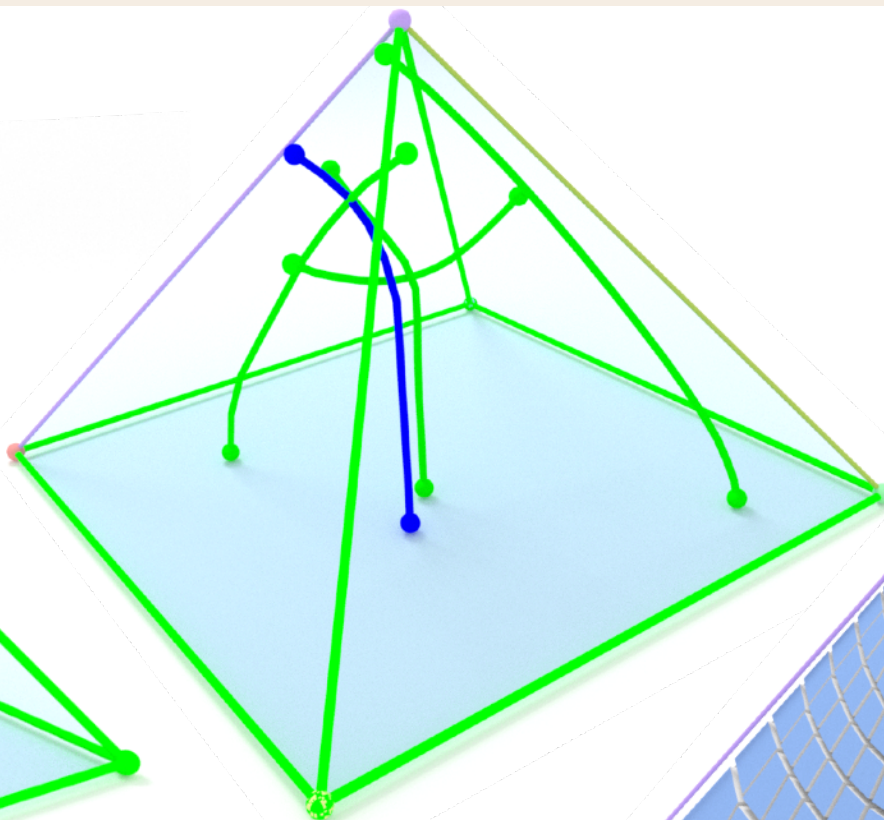
PYRAMID



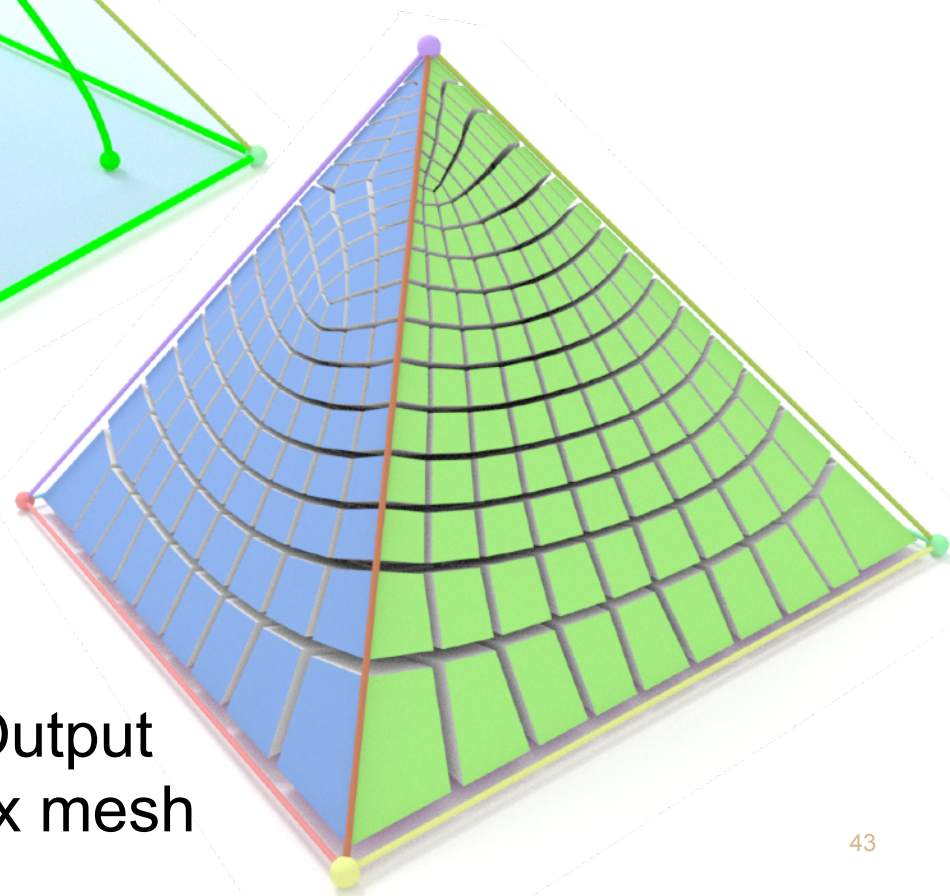
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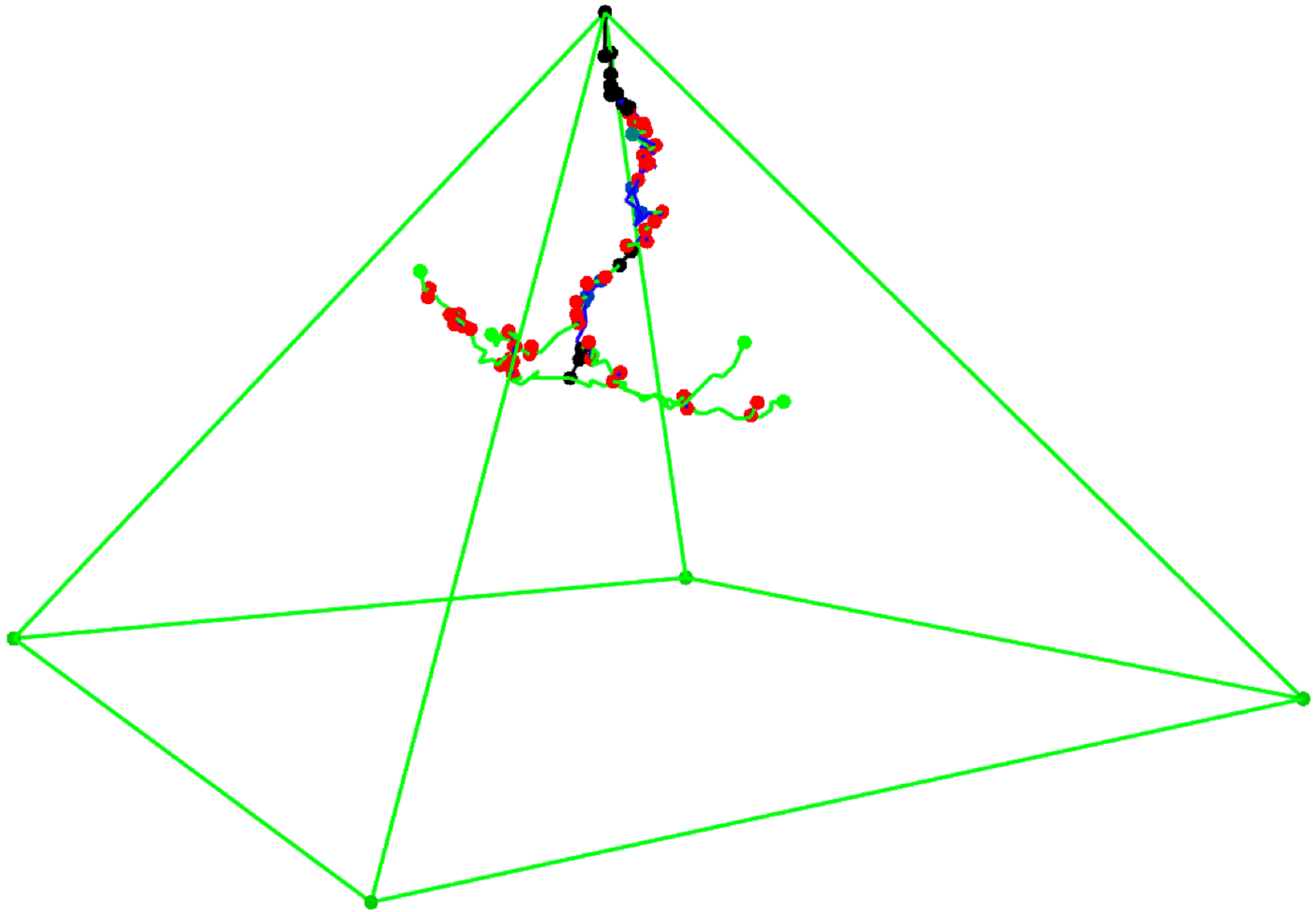
Input



Locally
meshable



Output
hex mesh





MECHANICAL BRACKET - HEXME I29



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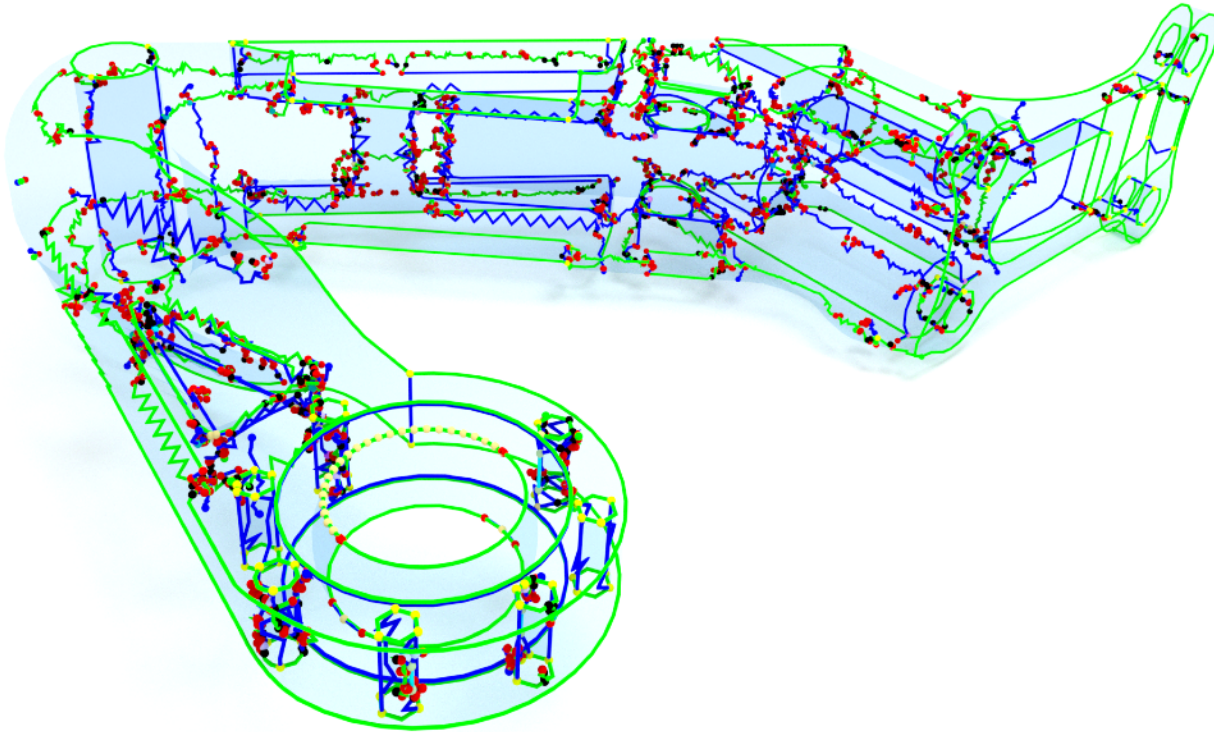




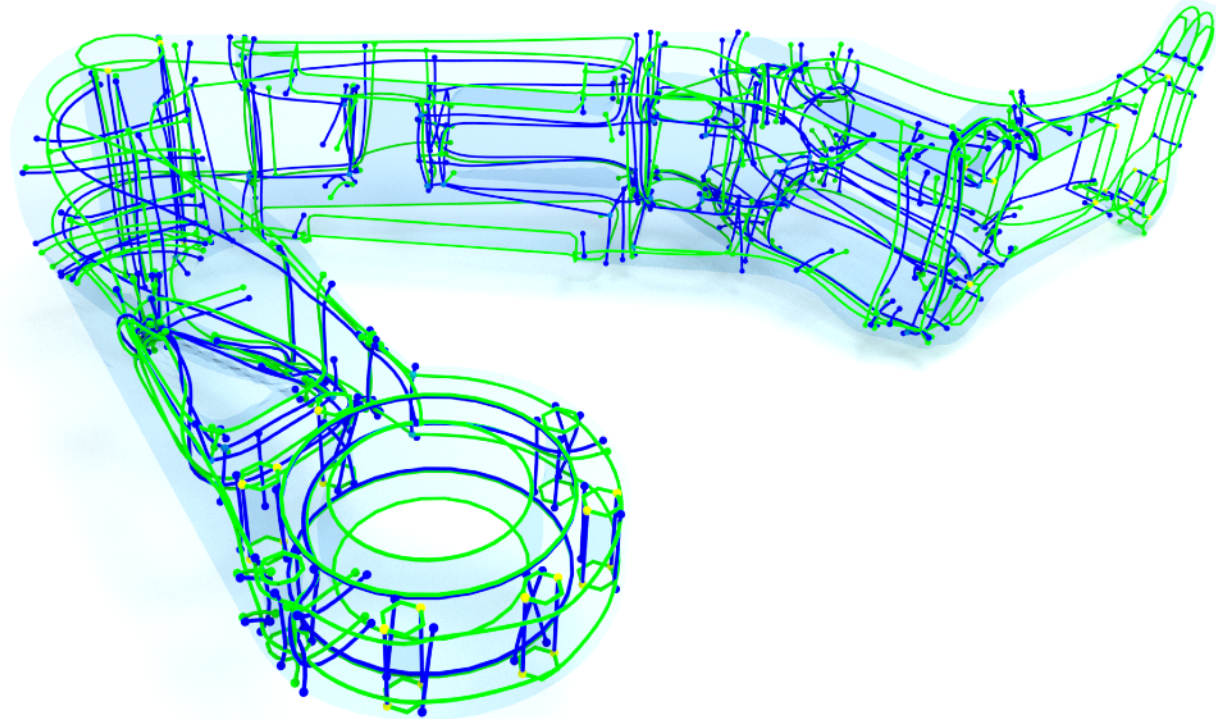
MECHANICAL BRACKET - HEXME I29



SIGGRAPH 2023
LOS ANGELES+ 6-10 AUG



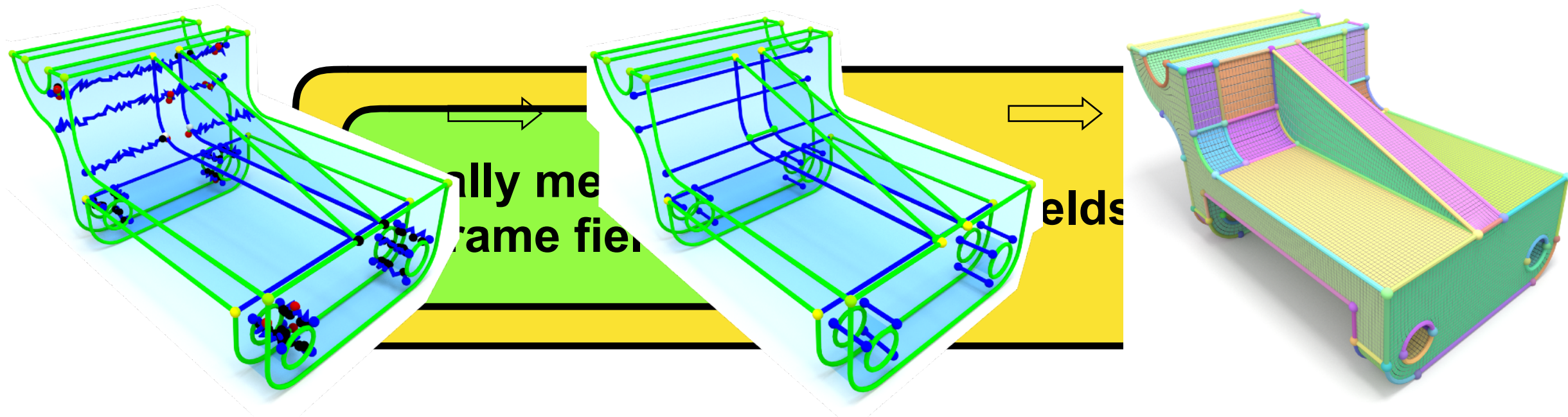
input



locally meshable

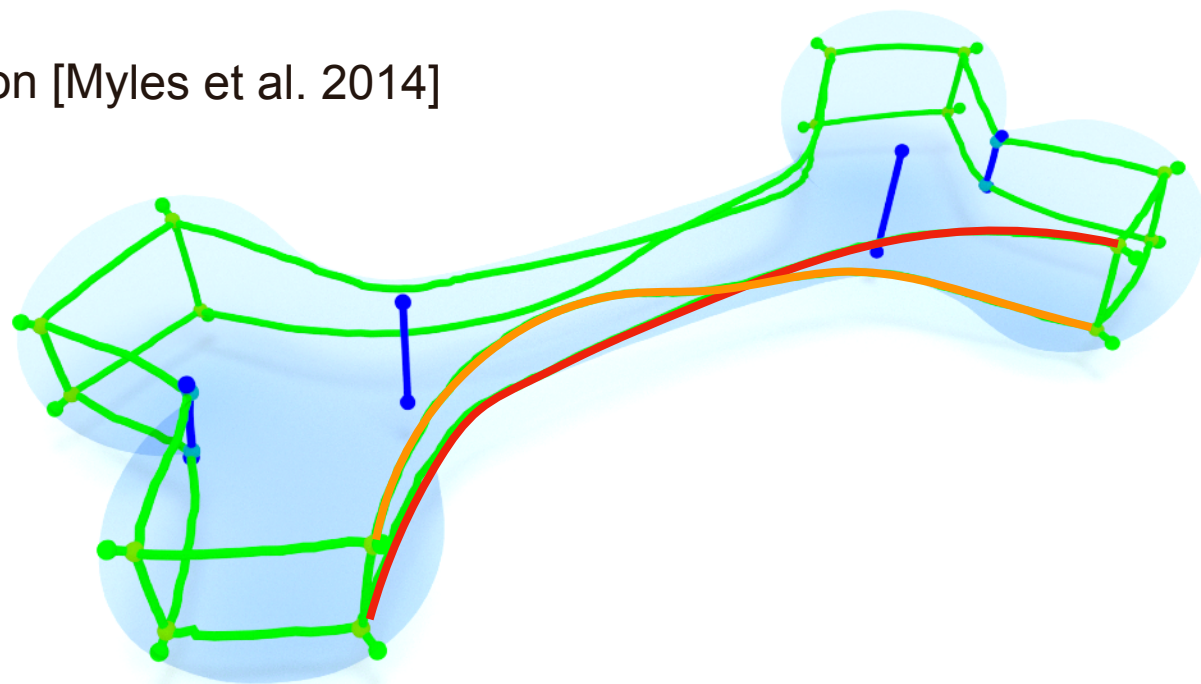
• Contributions

- Characterization of Local Meshability
- Algorithm to ensure Local Meshability



• Future Work

- Global Meshability
 - Solved in 2D: Robust Field-Aligned Parametrization [Myles et al. 2014]
 - Open Problem in 3D





THANK YOU!



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Locally Meshable Frame Fields
 HENG LIU, University of Bern, Switzerland
 DAVID BOMMES, University of Bern, Switzerland

Fig. 1. Overview. Non-meshable topological configurations in frame fields, e.g., invalid singularities or feature structures, induce degenerate integer grid maps and broken and incomplete hex meshes (top row). Our algorithm (bottom row) automatically turns a given frame field into a locally meshable one, where a valid integer grid map enables a hex mesh that preserves all input features.

The main robustness issue of state-of-the-art frame-field based hexahedral mesh generation algorithms originates from non-meshable topological configurations, which do not admit the construction of an integer grid map but frequently occur in smooth frame fields. In this article, we investigate the topology of frame fields and derive conditions on their meshability, which are the basis for a novel algorithm to automatically turn a given non-meshable frame field into a similar but locally meshable one. Despite local meshability is only a necessary but not sufficient condition for the stronger requirement of meshability, our algorithm increases the 2D success rate of generating valid integer-grid maps with state-of-the-art methods to 58%, when compared on the challenging Heale dataset [Dauterle et al. 2022]. The source code of our implementation and the data of our experiments are available at <https://alghex.eu>.

CCS Concepts • Computing methodologies → Mesh models; Mesh geometry models; Volumetric models.

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Code available!