GENERATIONS / VANCOUVER 12-16 AUGUST
SIGGRAPH2018

Stitch Meshing

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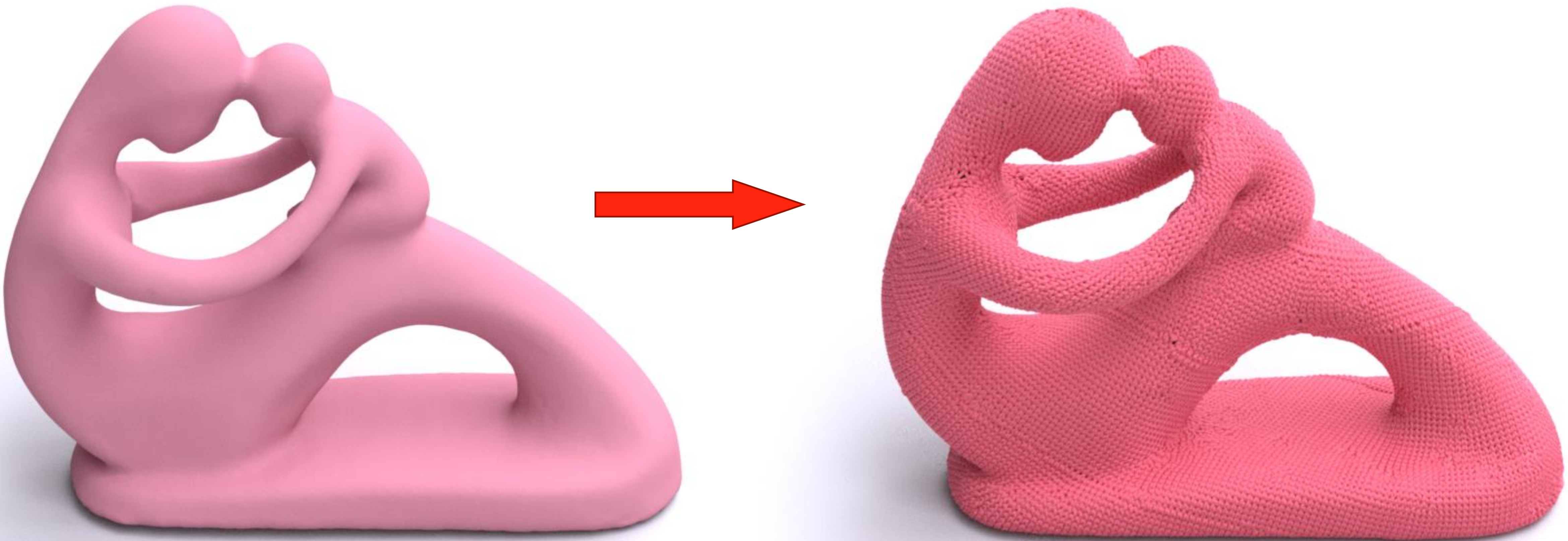
[1] University of Utah
[2] New York University

NYU

Stitch Meshing

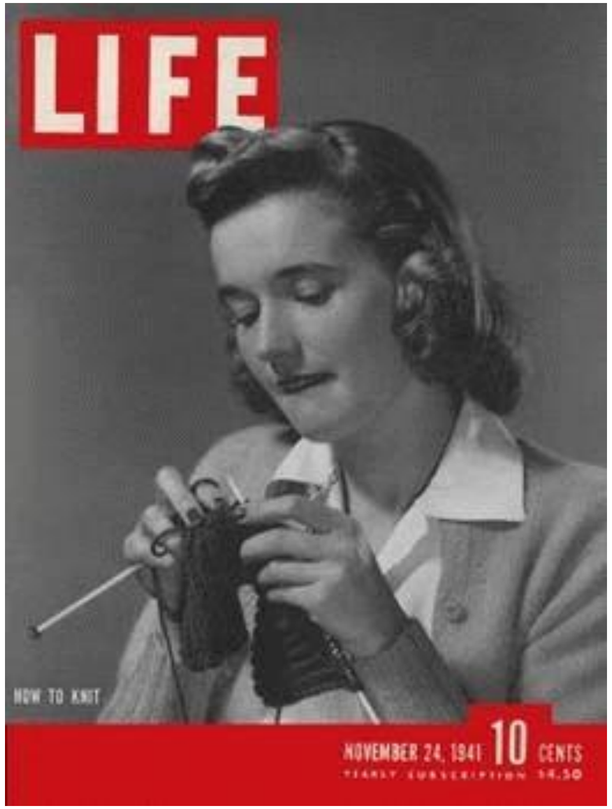
Convert arbitrary 3D shapes into knit models fully automatically



Knitting has a long history

Sock in Ancient Egypt
200 - 400
From: the British Museum

Madonna Knitting
by Bertram of Minden
1400 - 1410



Life magazine's cover story
November 24, 1941

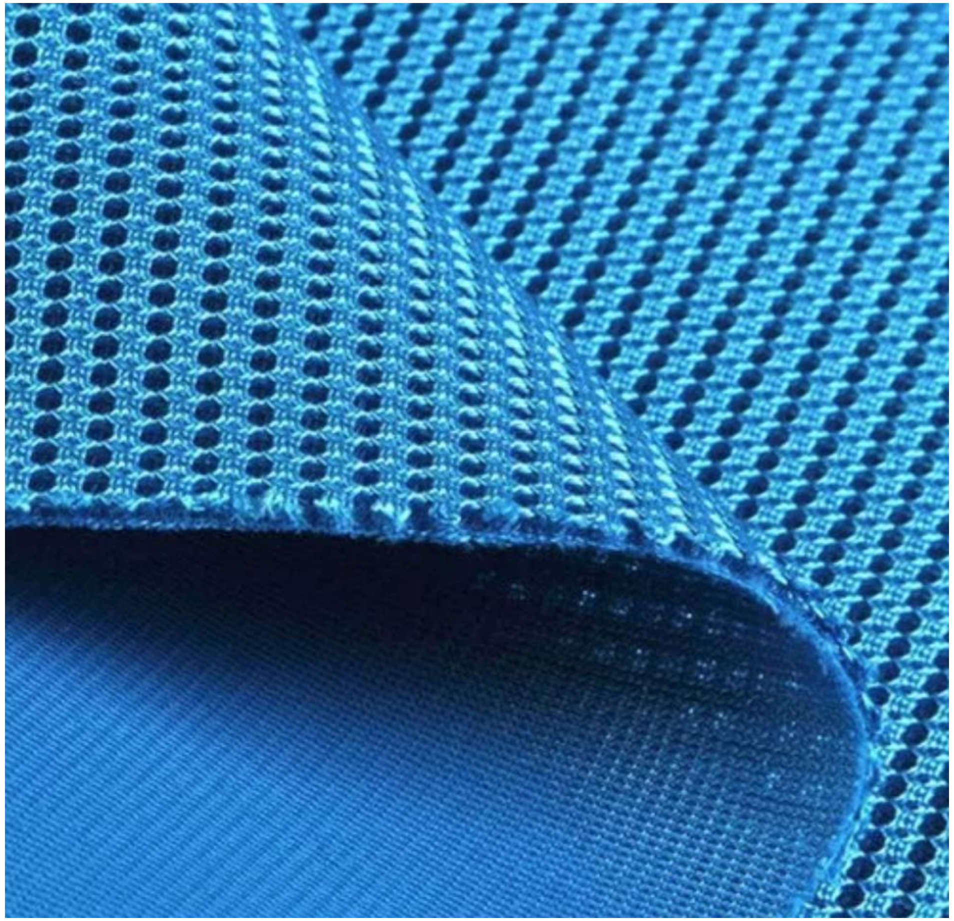
Common Products

Fashion Element

Paris Fashion Week, Fall/Winter 2016/17

New Manufacture Materials

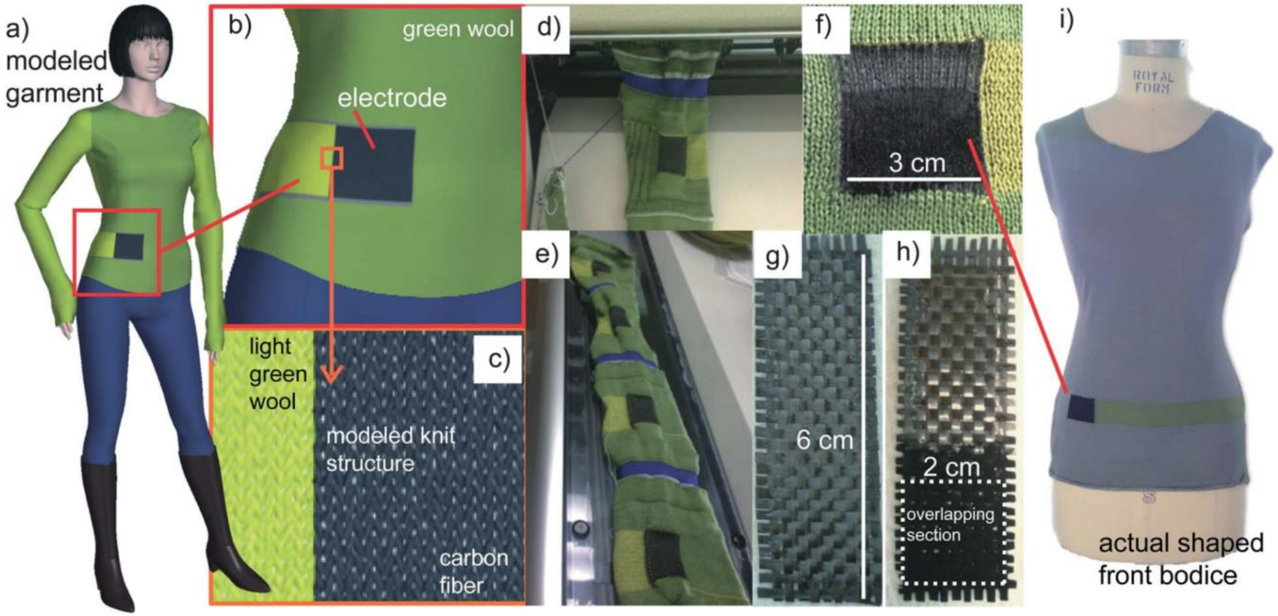
Nike Flyknit



Car Seat Cover

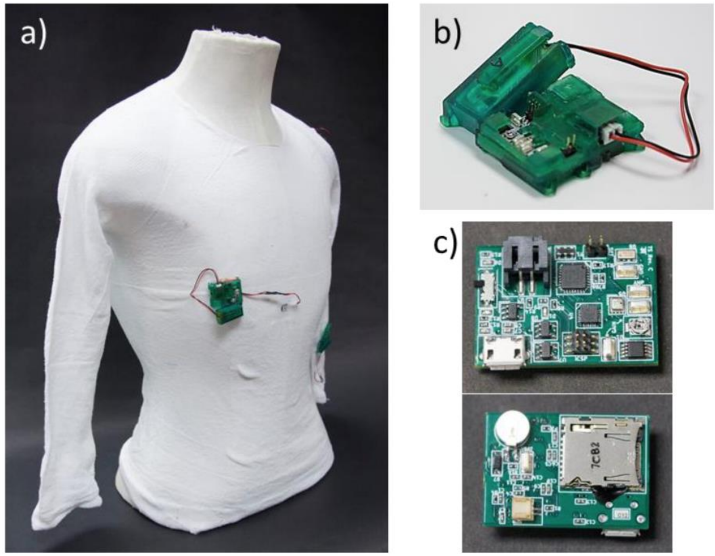
More Applications in Future

- Knitted carbon fiber electrodes



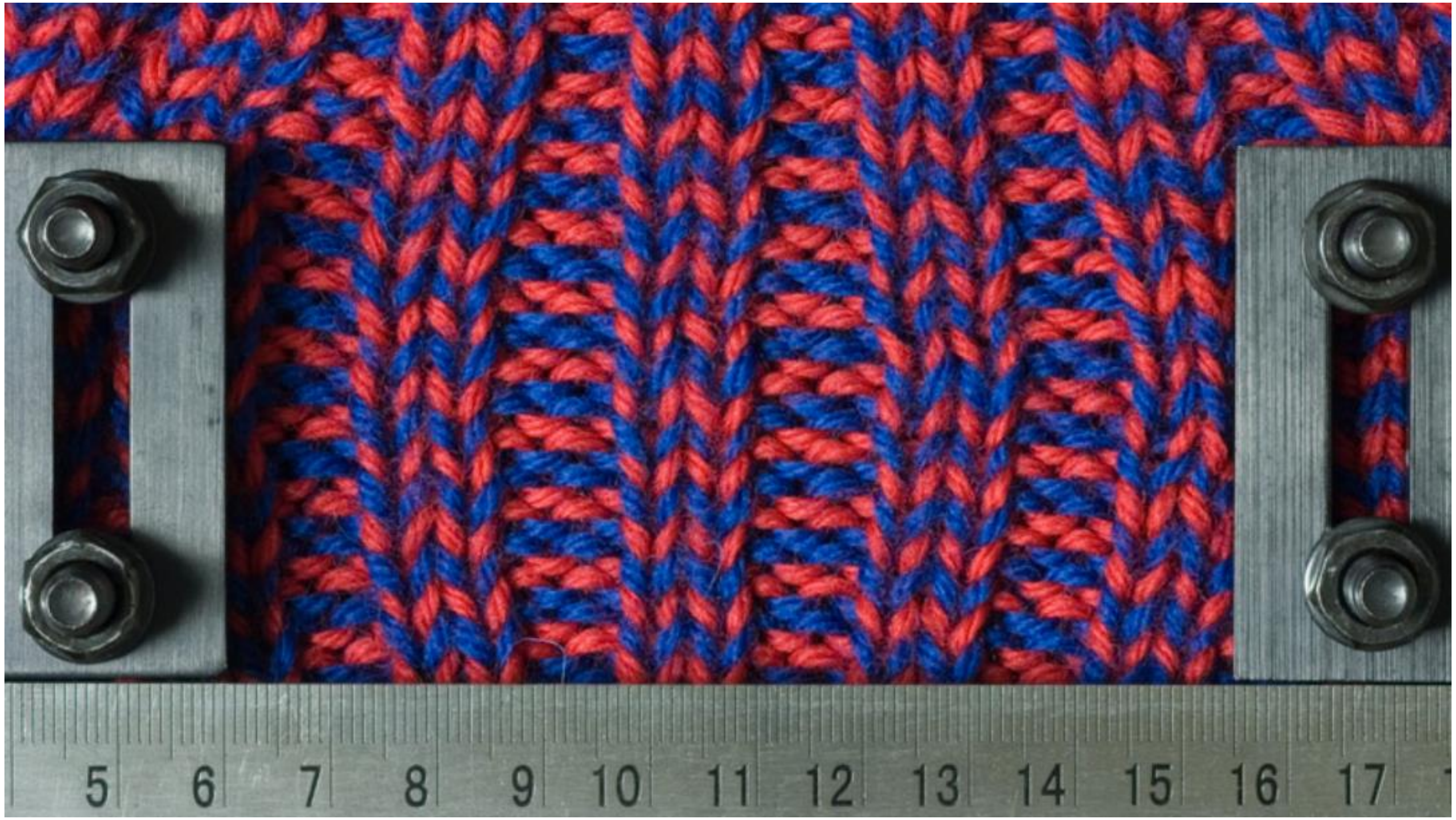
[Jost et al. 2013]

- Wearable thermal energy harvesting



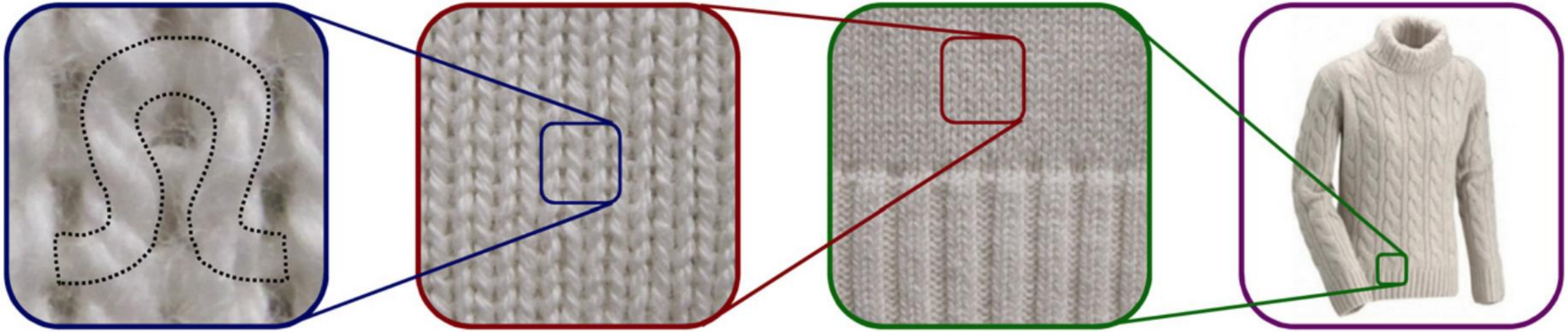
[Myers et al. 2017]

Knitted structure allows some stretches



[Kaldor et al. 2008]

Knit Structure

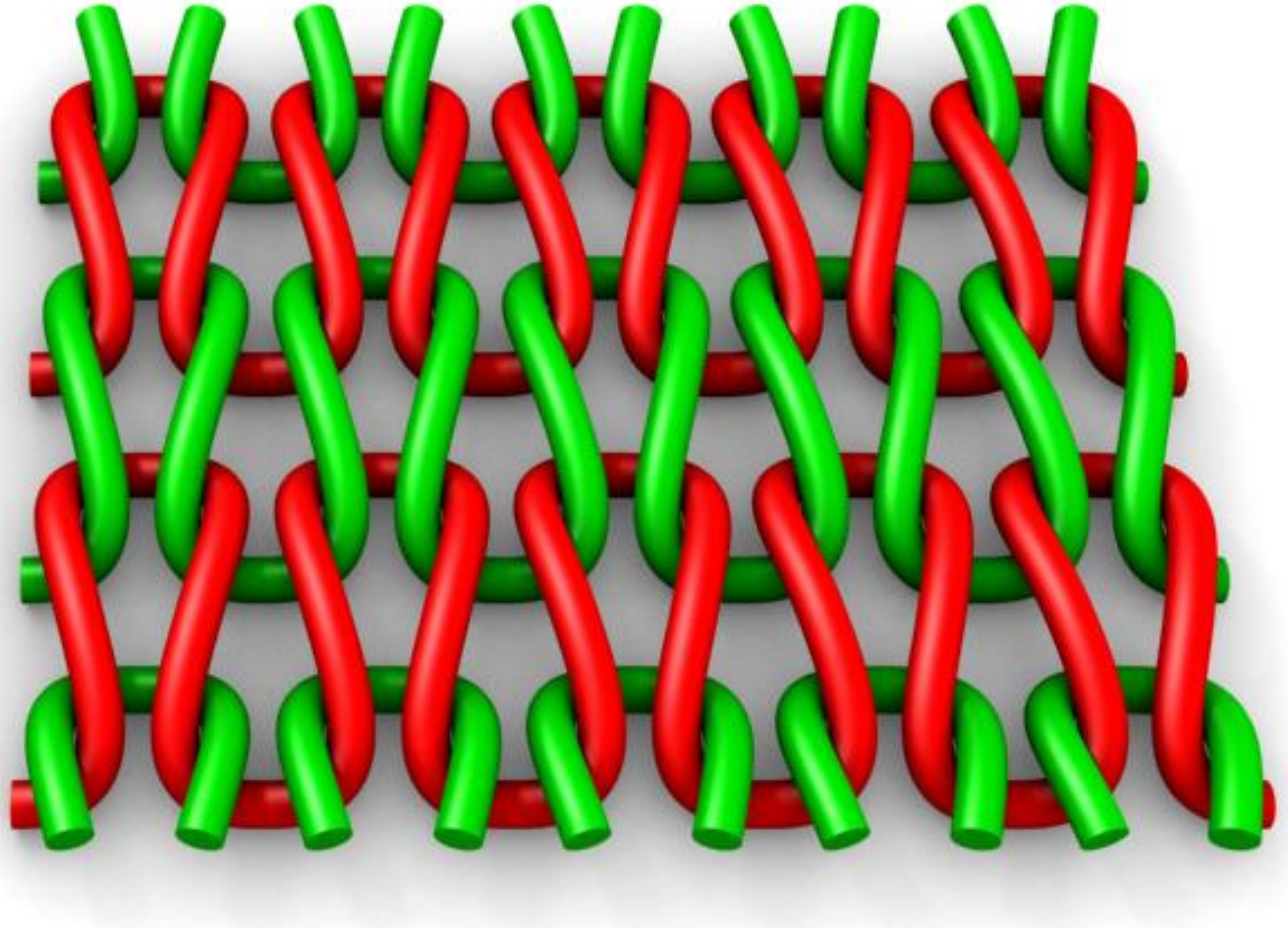


Yarn Loop

[Abel et al. 2013]

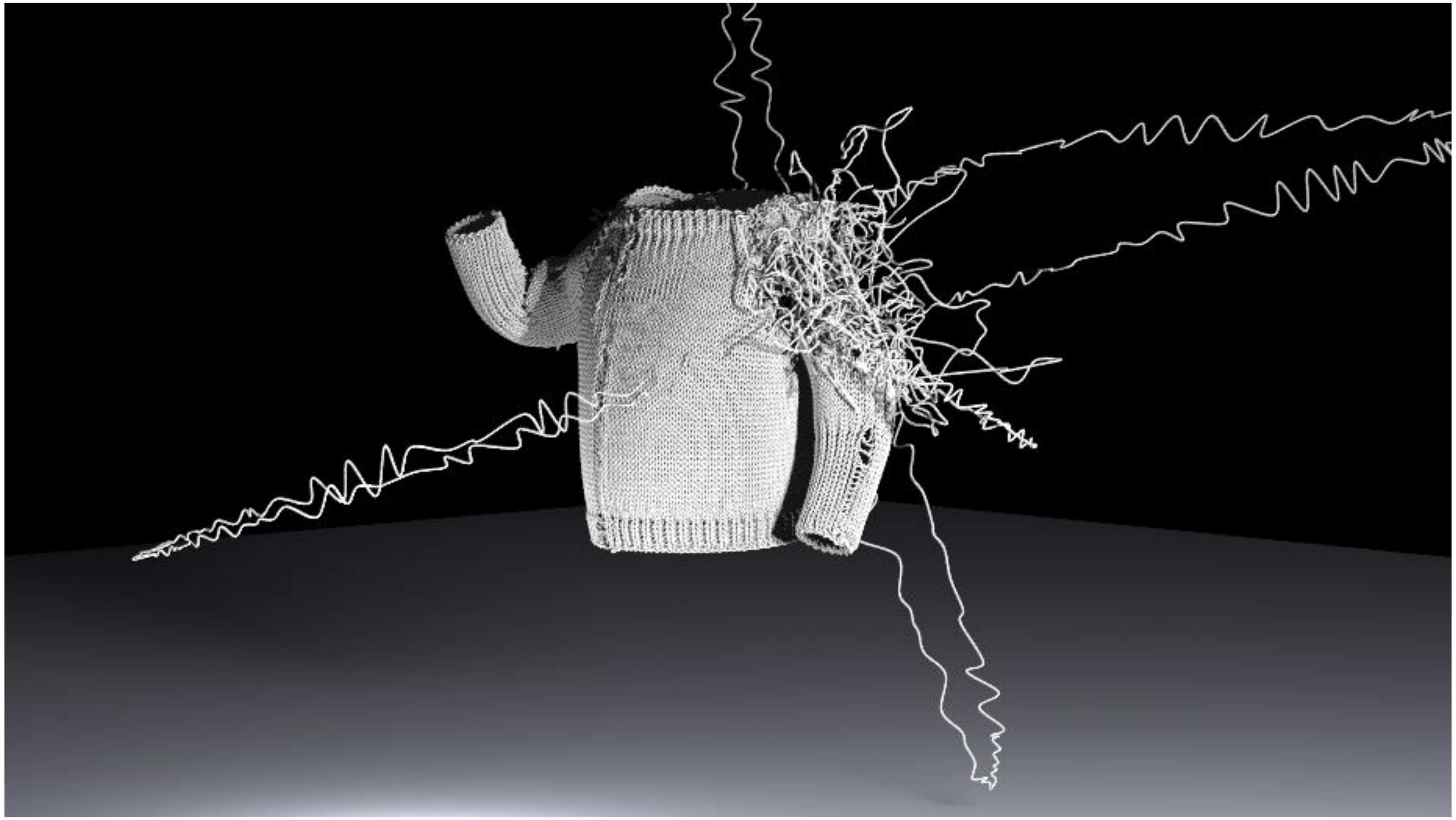
Knit Structure

Yarn Loop



[Yuksel et al. 2012]

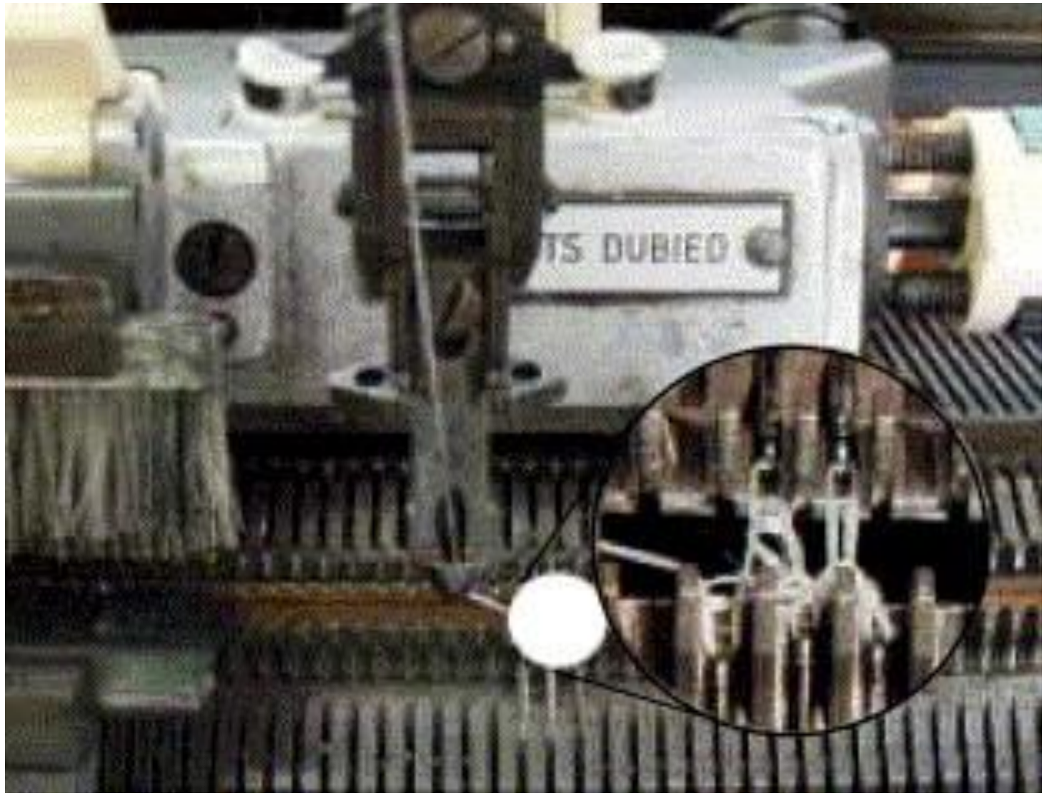
But not too much

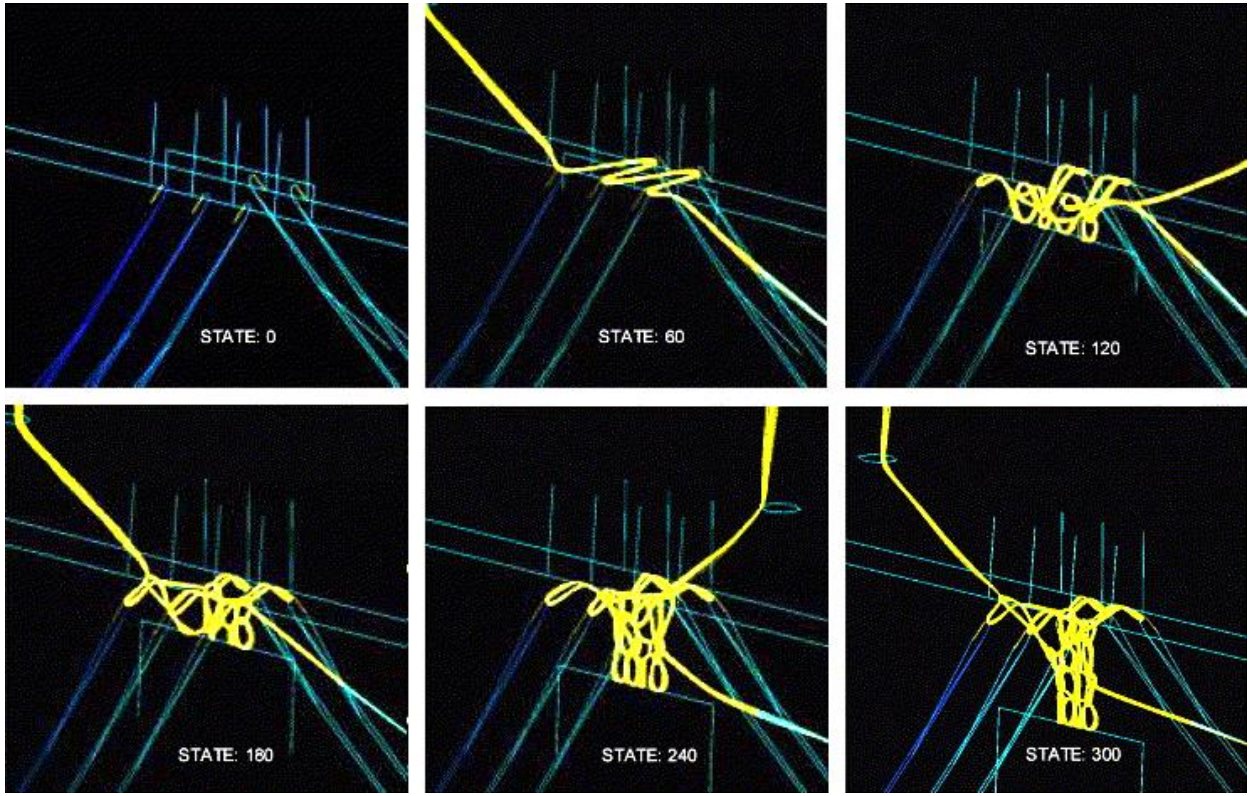


But not too much

Prior Work

- Replicating the process of **knitting machines**

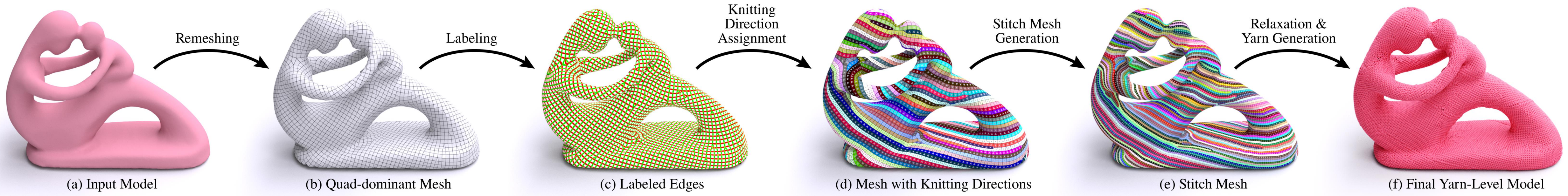




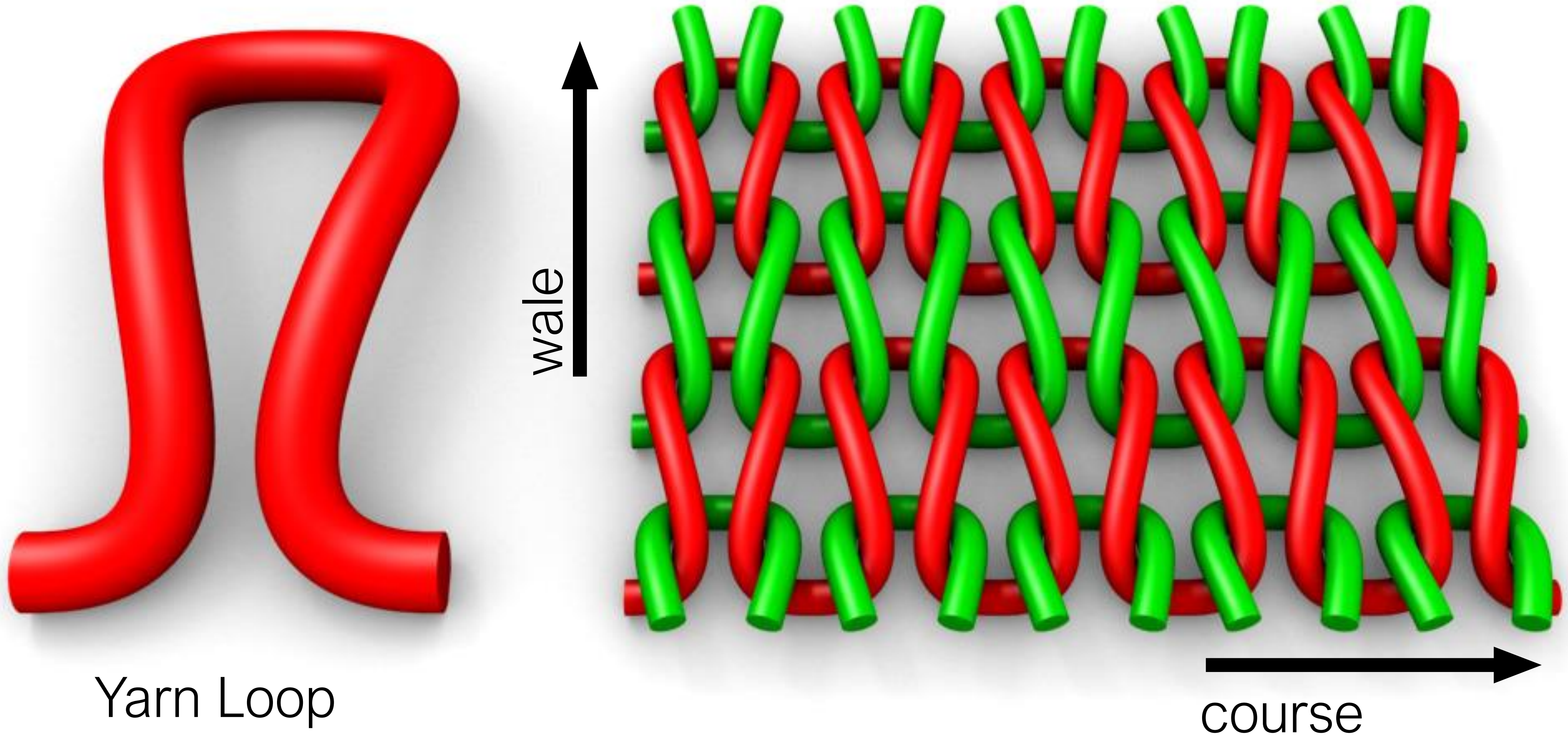
[Duhovic and Bhattacharyya 2006]

Stitch Meshes [Yuksel et al. 2012]

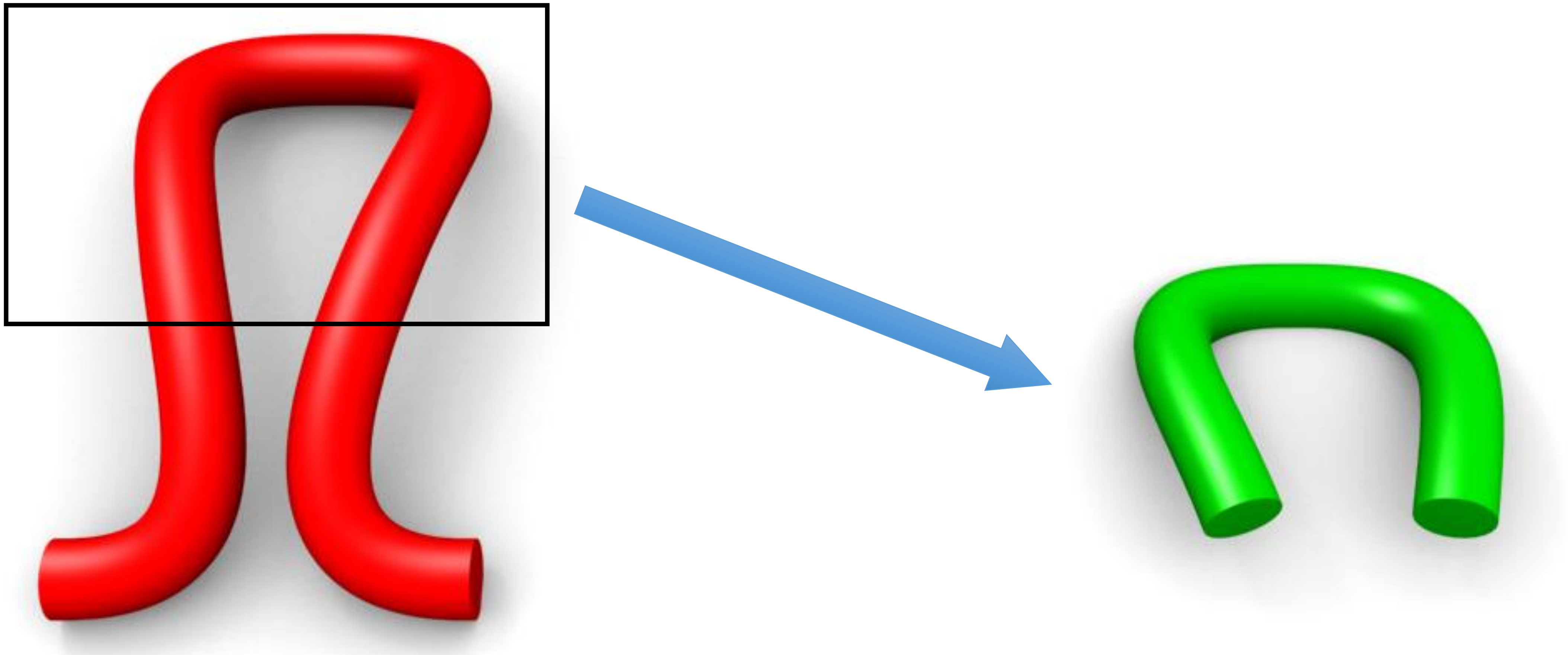
Stitch Meshing



Yarn Loops & Stitches [Yuksel et al. 2012]

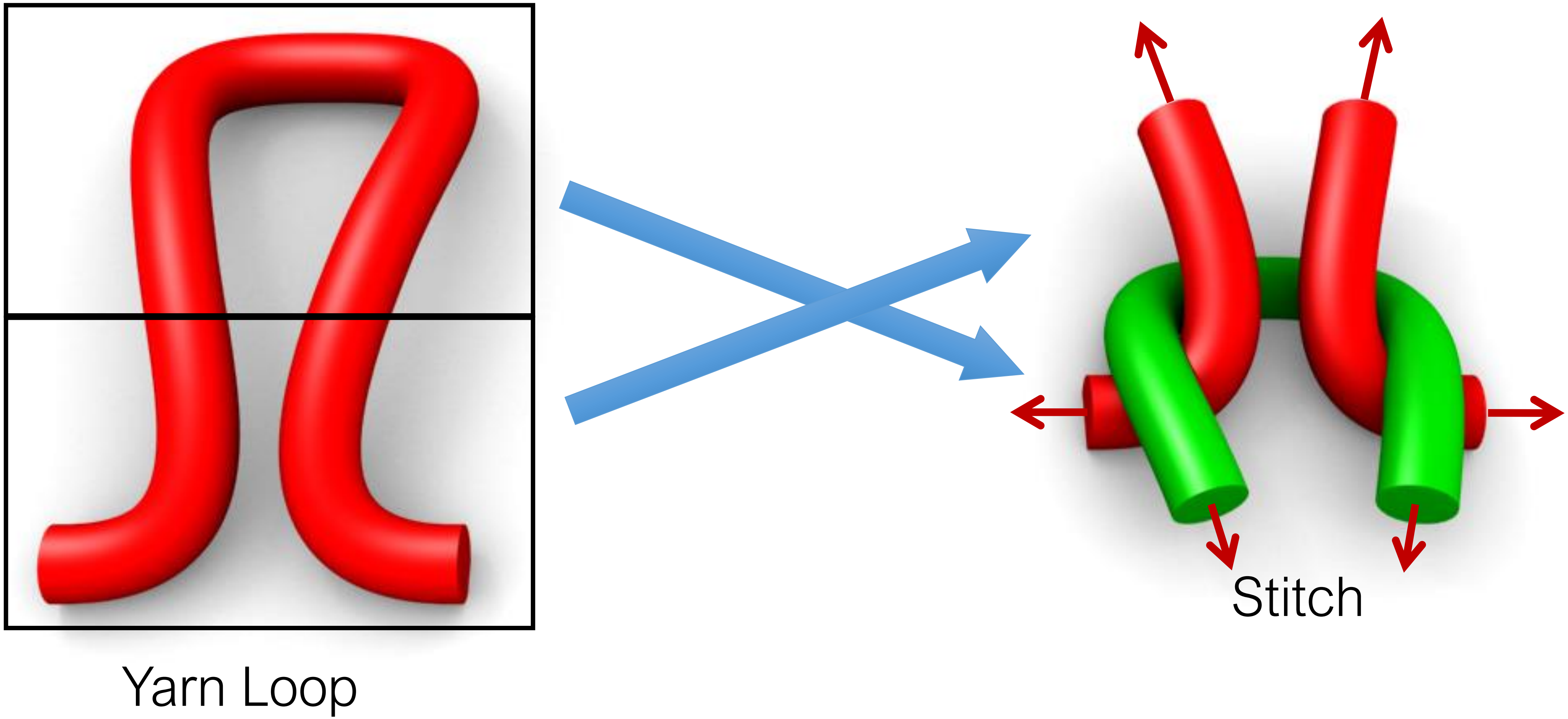


Yarn Loops & Stitches [Yuksel et al. 2012]



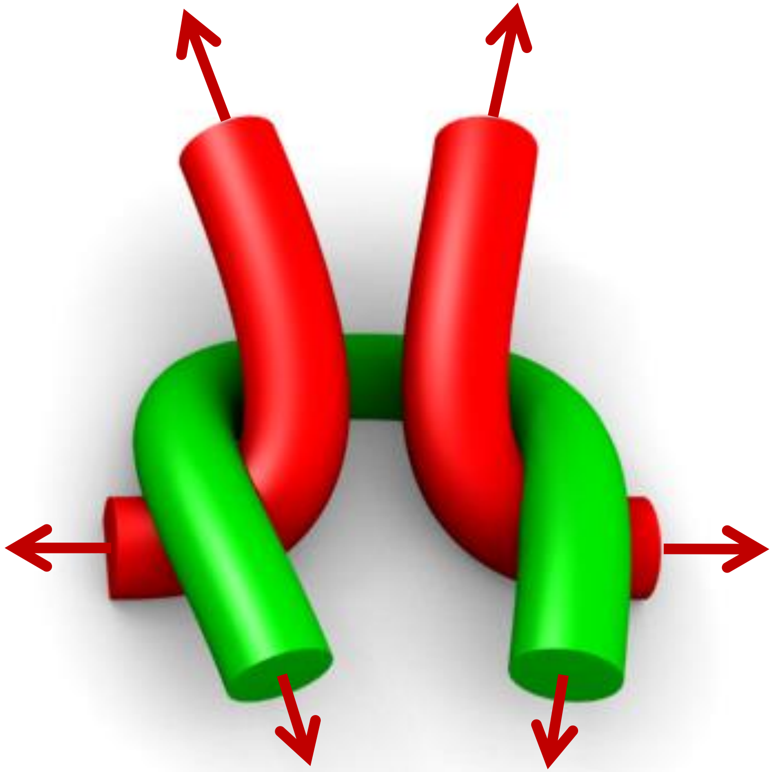
Yarn Loop

Yarn Loops & Stitches [Yuksel et al. 2012]



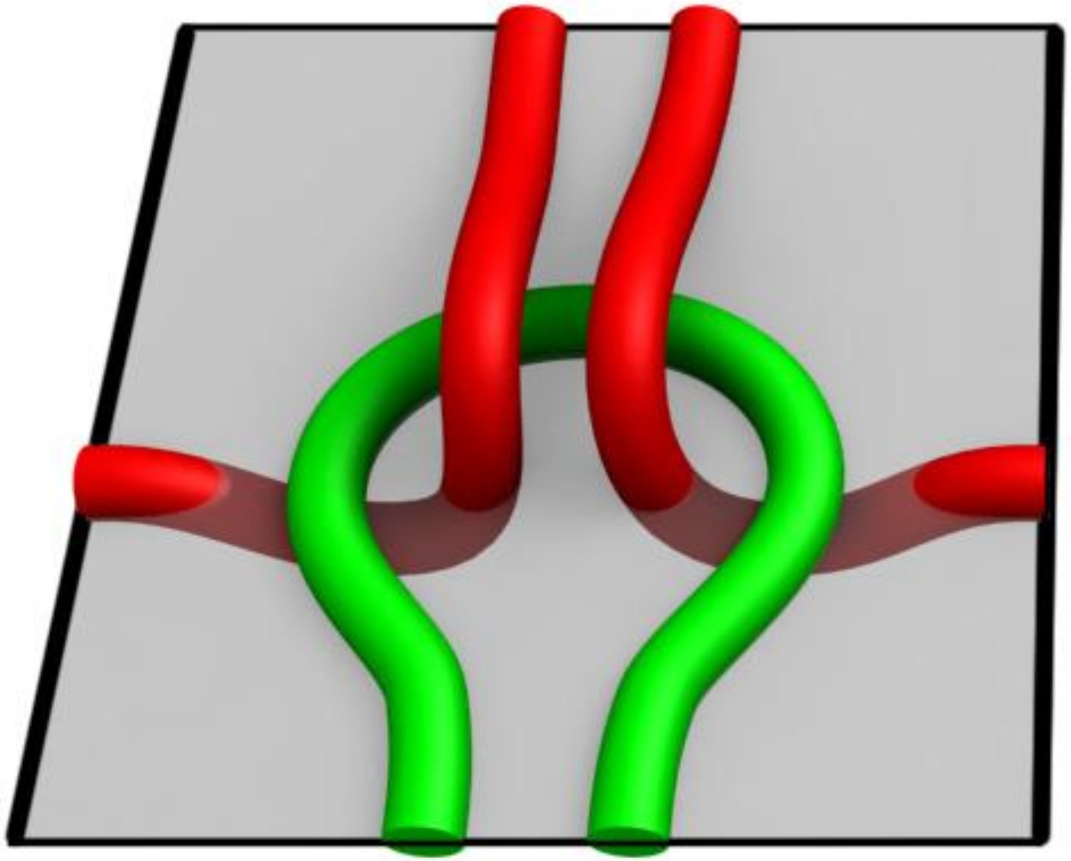
Stitch Mesh Face [Yuksel et al. 2012]

Stitch Mesh Face

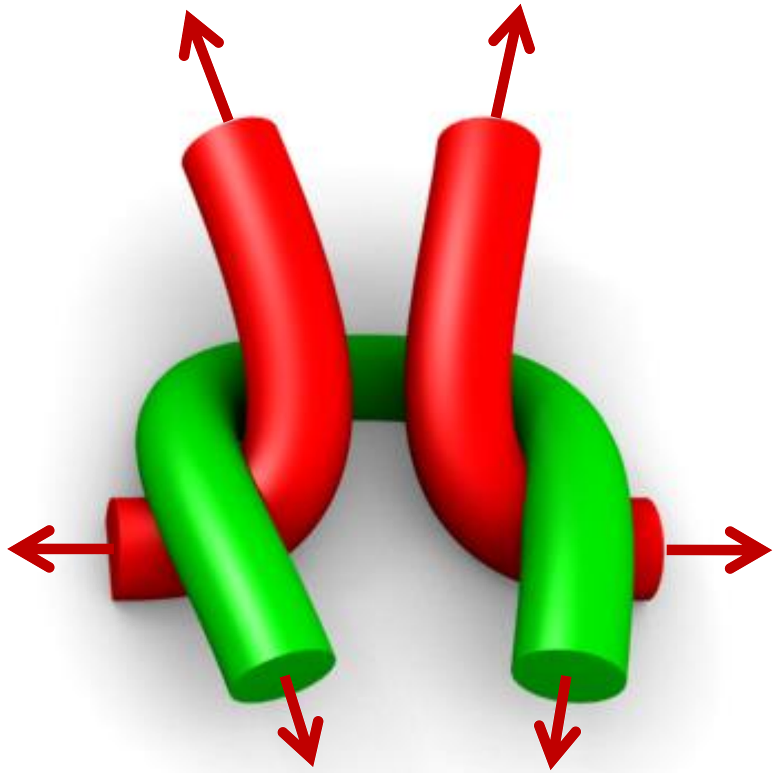


Stitch

Stitch Mesh Face [Yuksel et al. 2012]

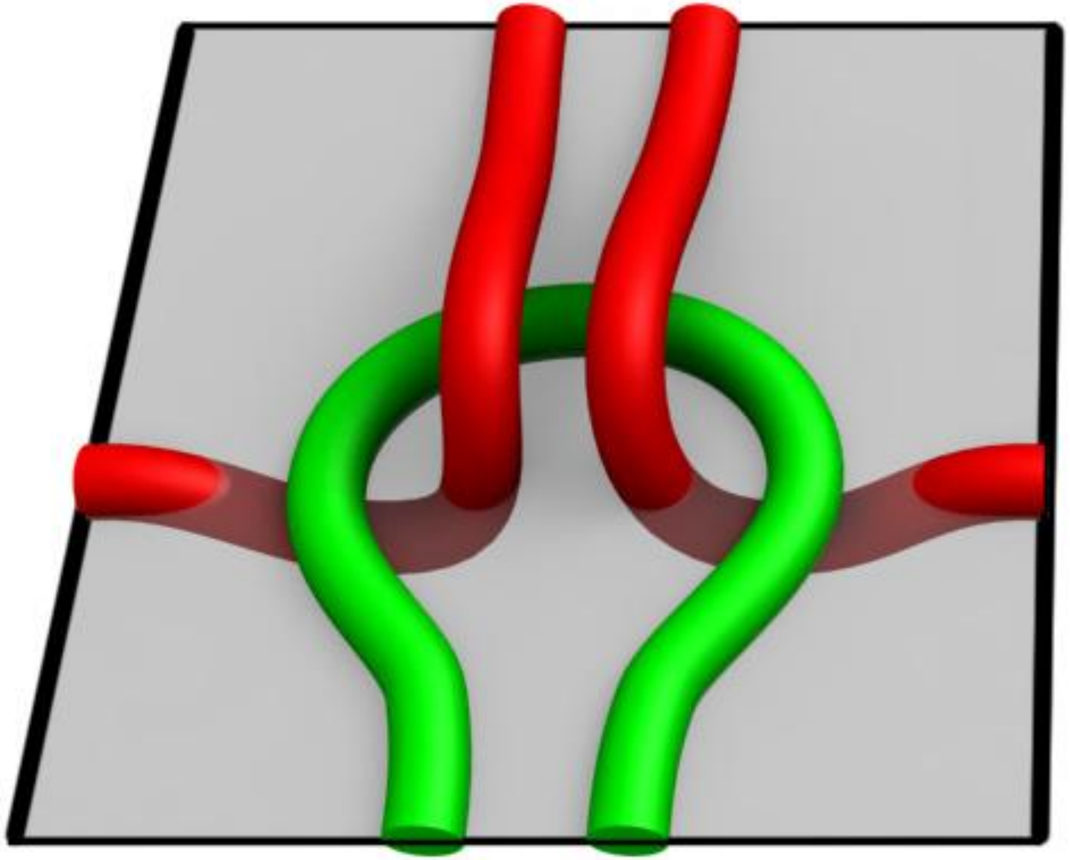


Stitch Mesh Face

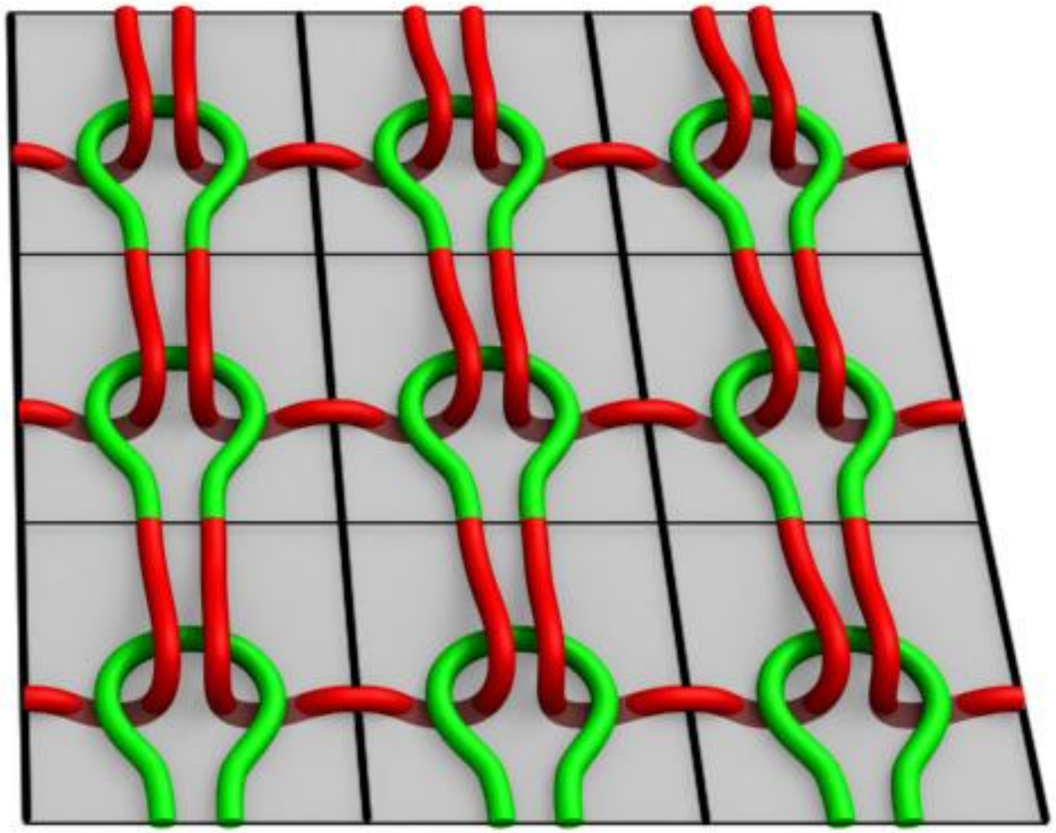


Stitch

The Stitch Mesh Face [Yuksel et al. 2012]

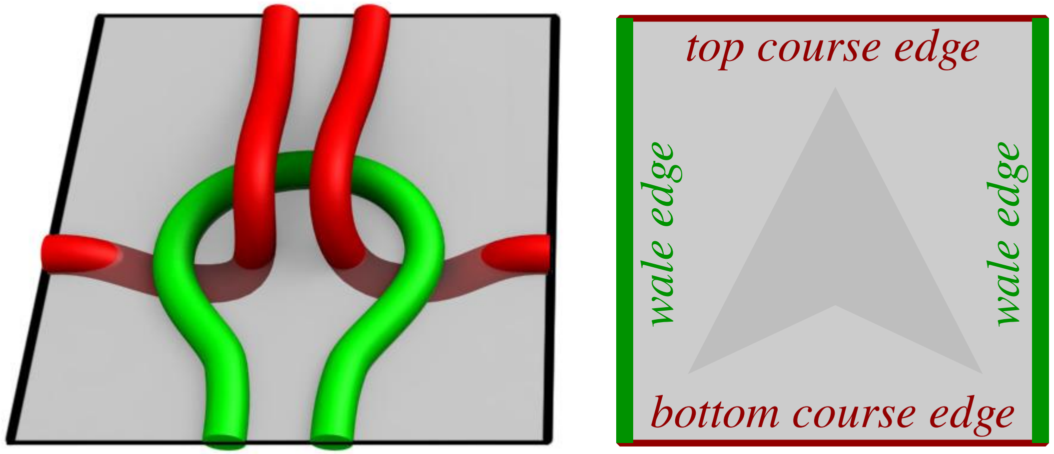


Stitch Mesh Face

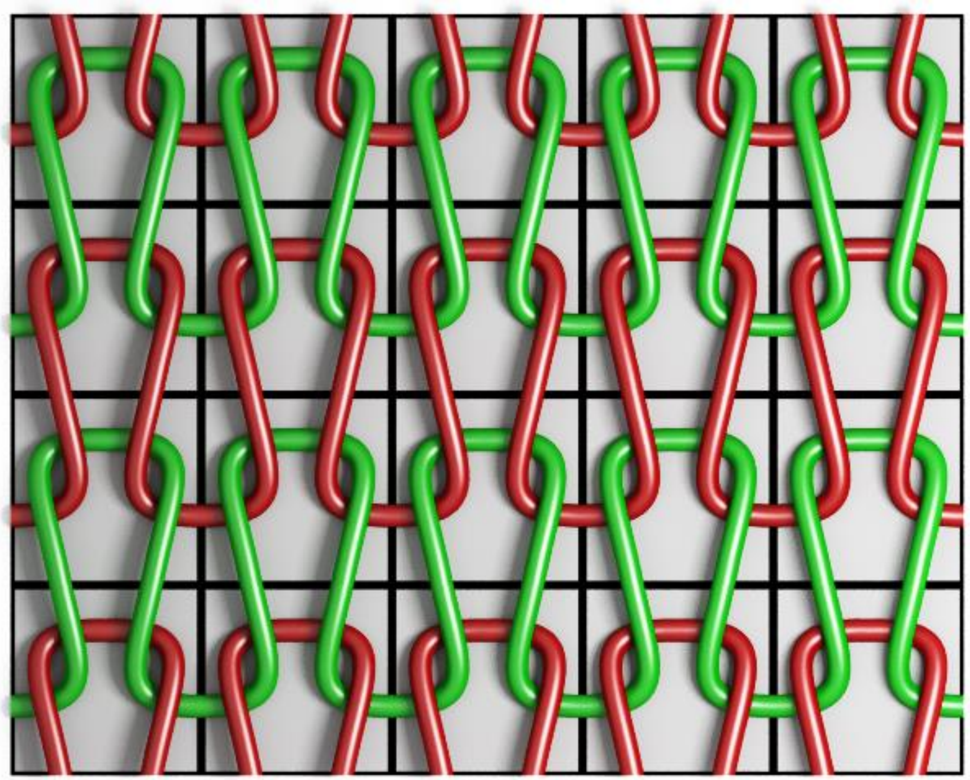


Stitch Mesh

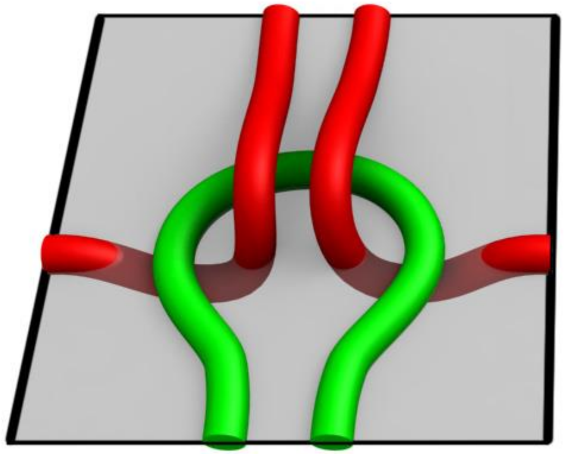
Stitch Meshes



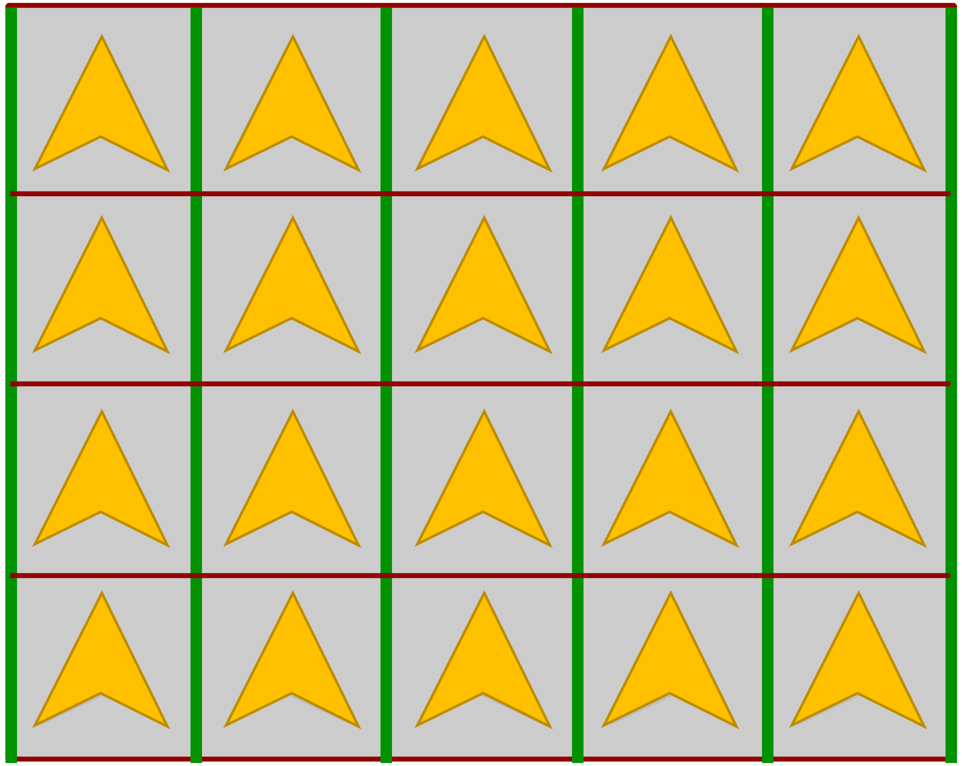
Stitch Mesh Face


Stitch Mesh

Stitch Meshes

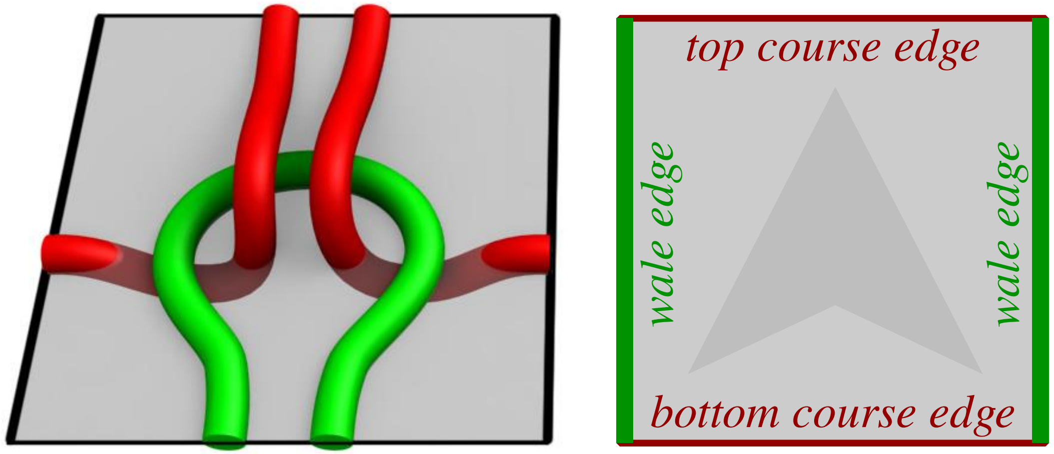


Stitch Mesh Face

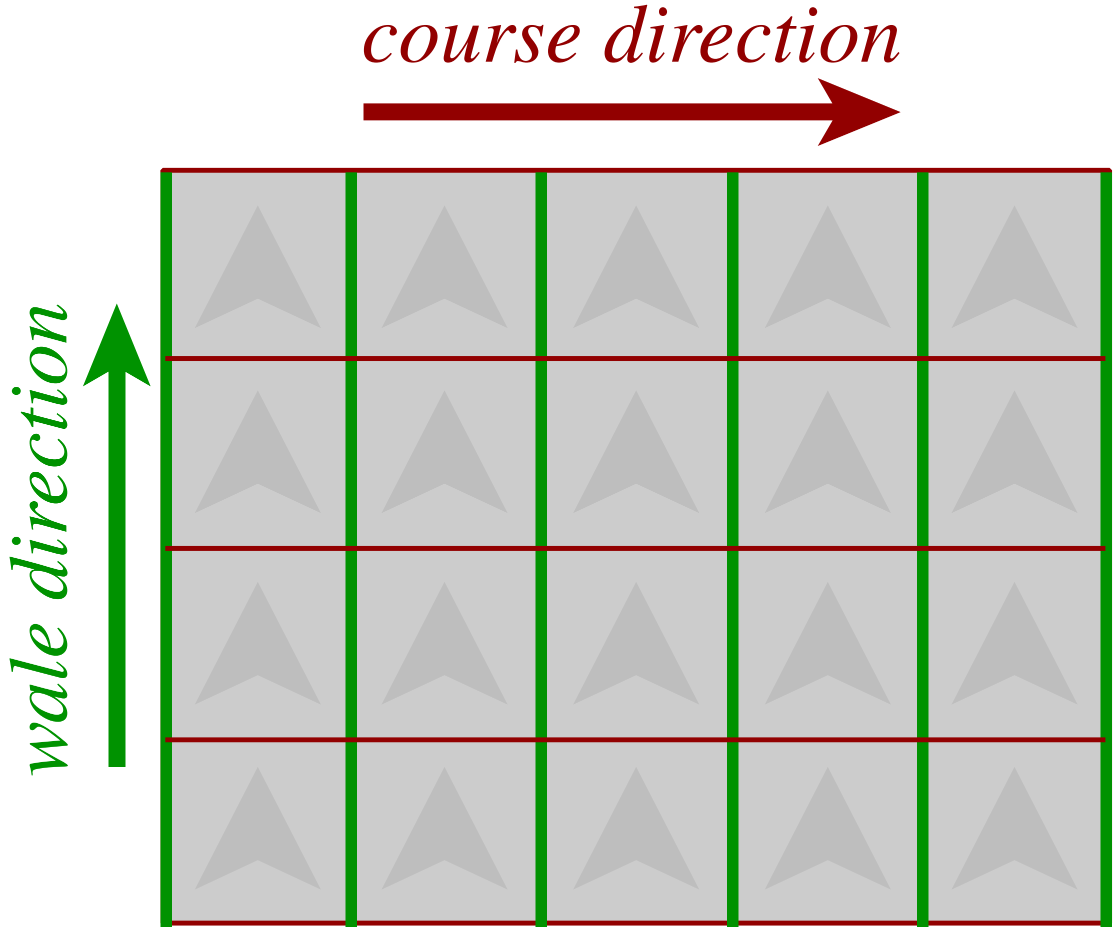


Stitch Mesh

Stitch Meshes

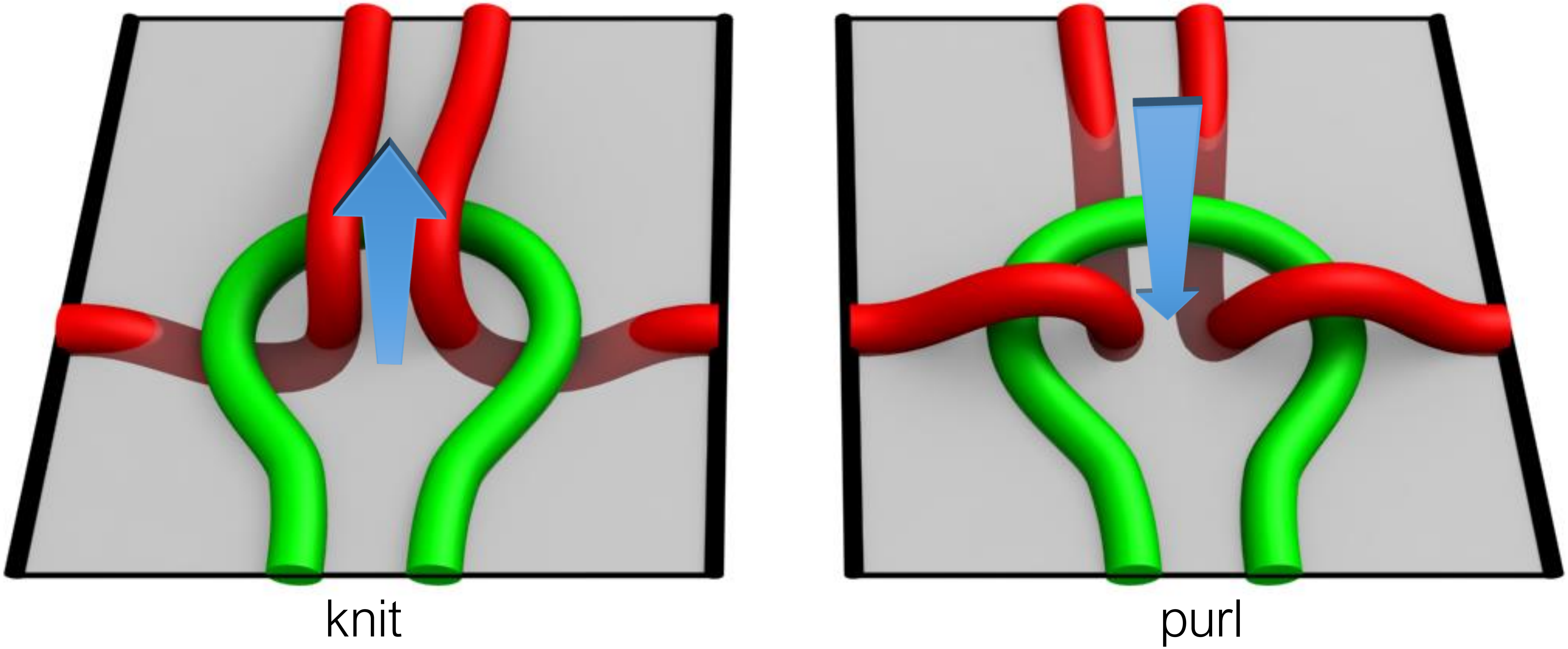


Stitch Mesh Face

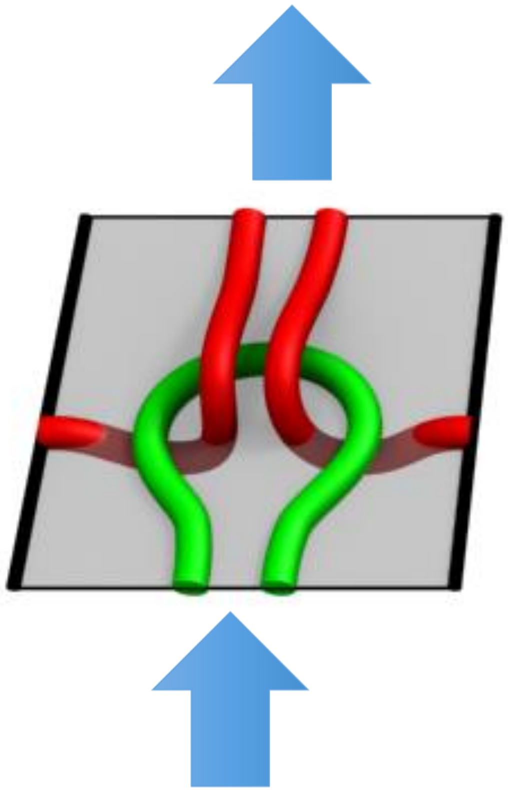


Stitch Mesh

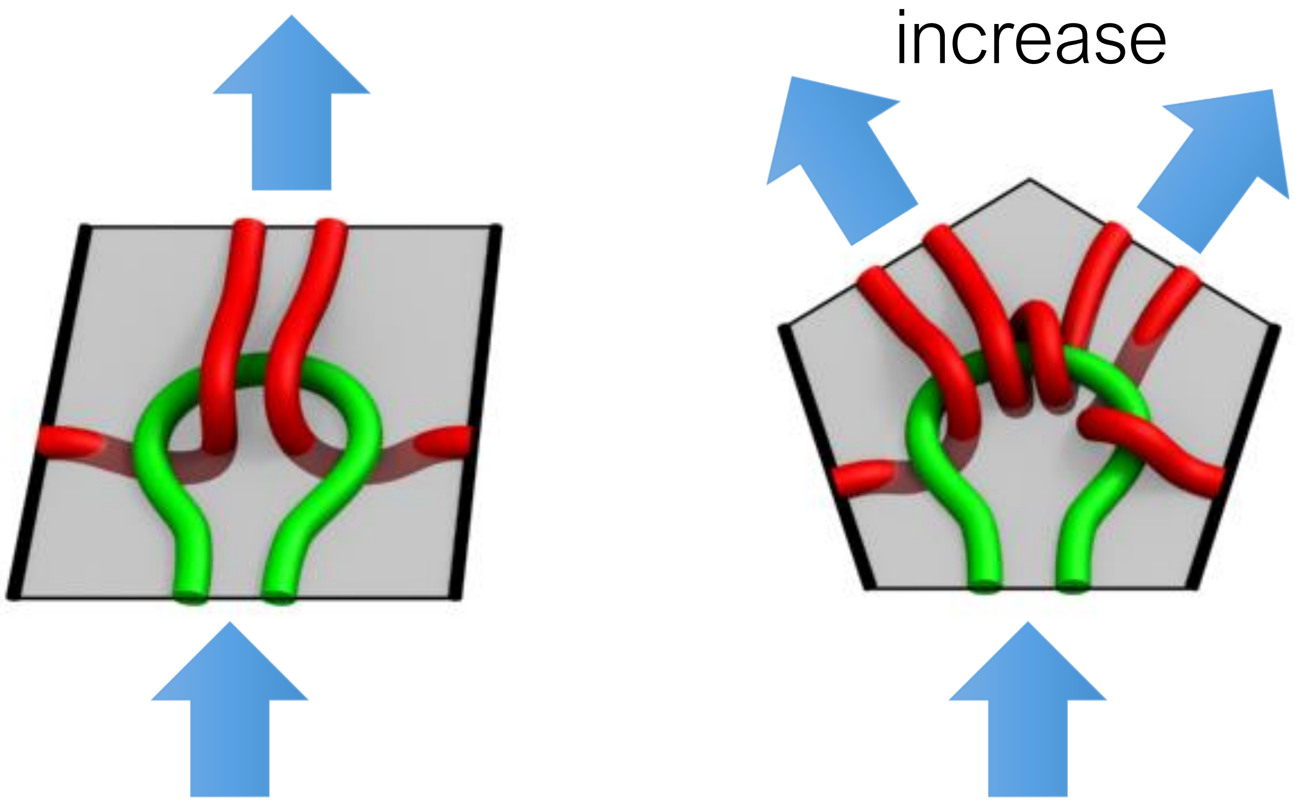
The Stitch Mesh Face [Yuksel et al. 2012]



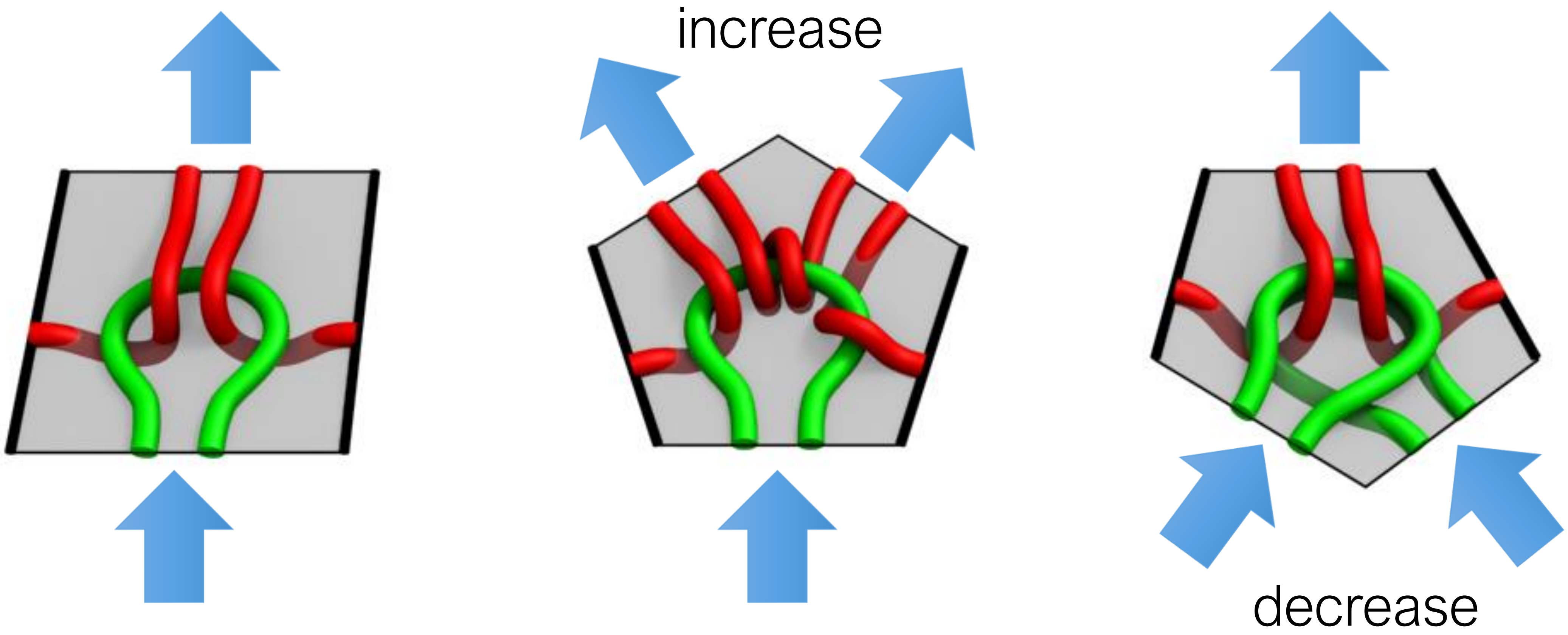
Increases & Decreases [Yuksel et al. 2012]



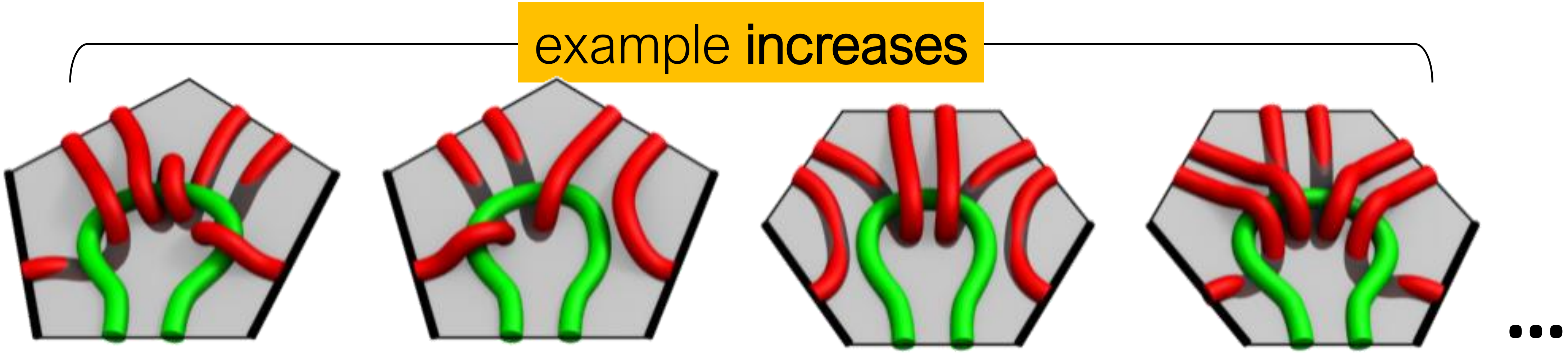
Increases & Decreases [Yuksel et al. 2012]



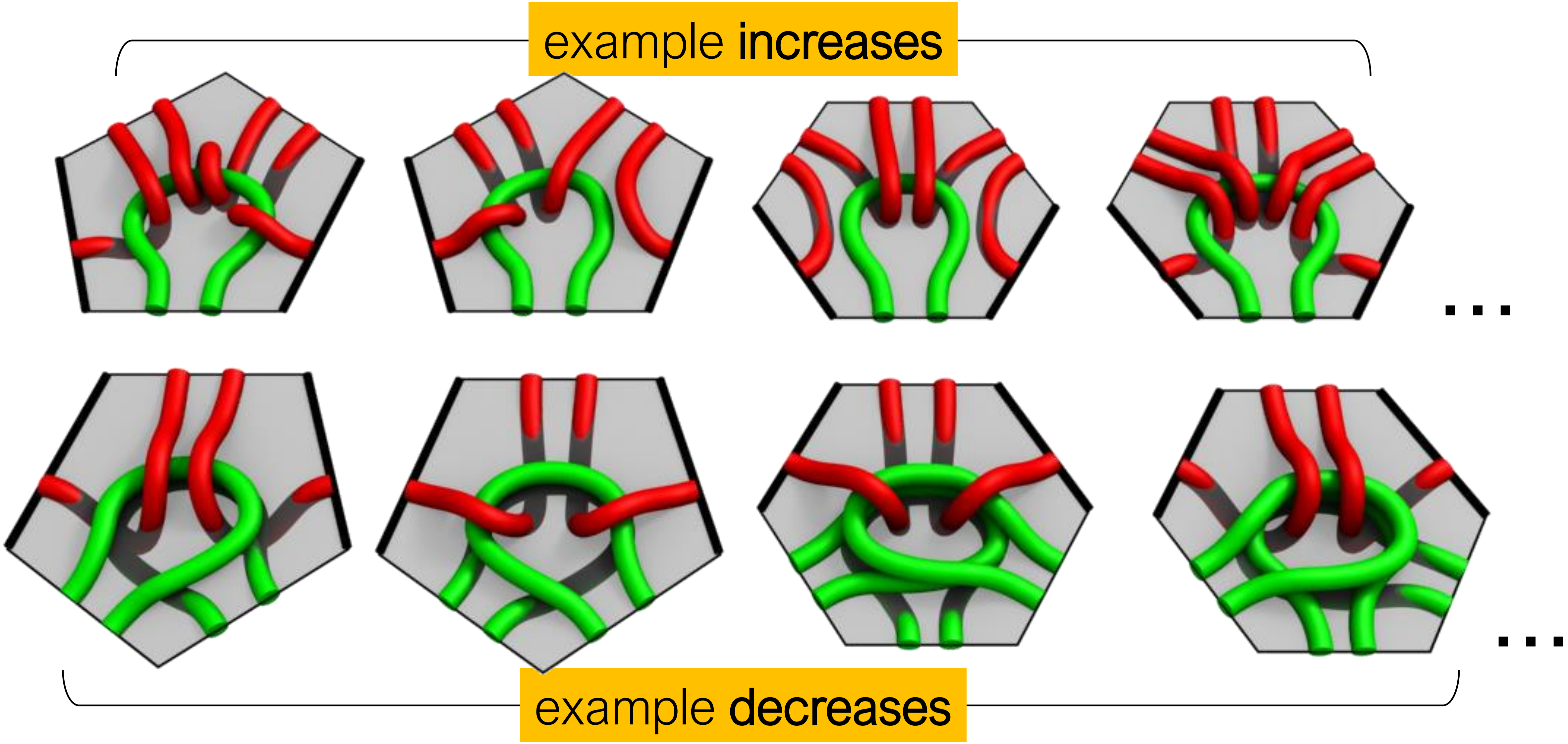
Increases & Decreases [Yuksel et al. 2012]



Increases & Decreases [Yuksel et al. 2012]

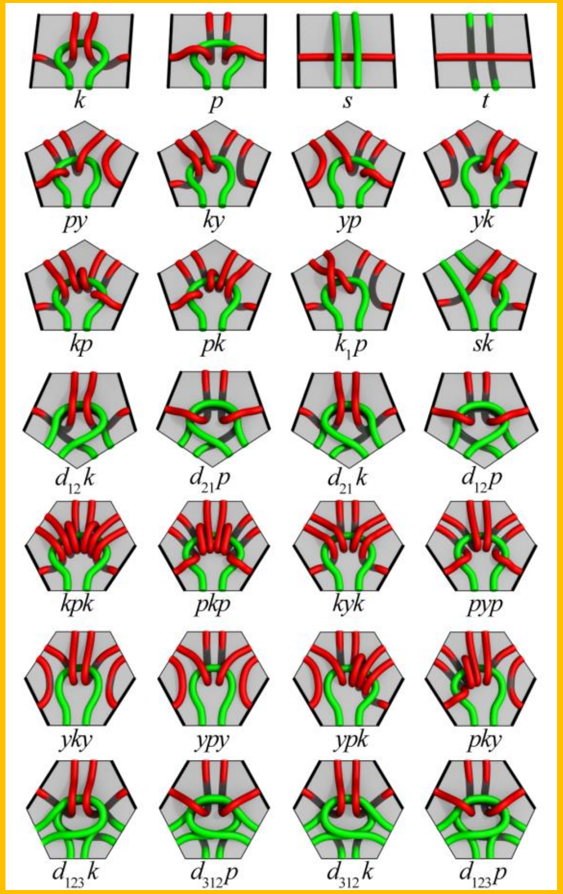


Increases & Decreases [Yuksel et al. 2012]

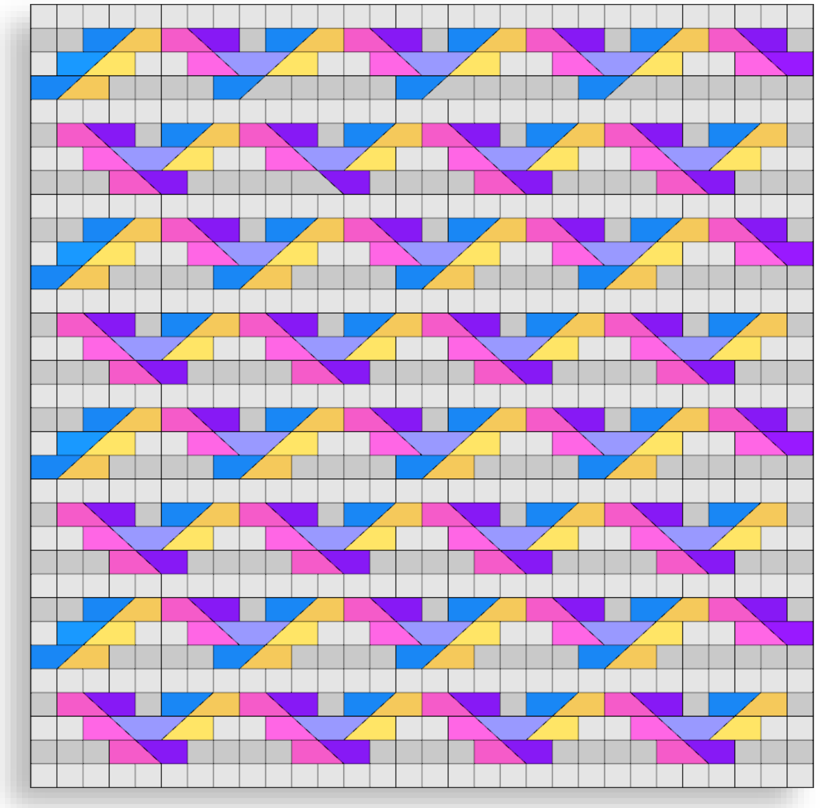


Stitch Type Library [Yuksel et al. 2012]

Stitch Type Library

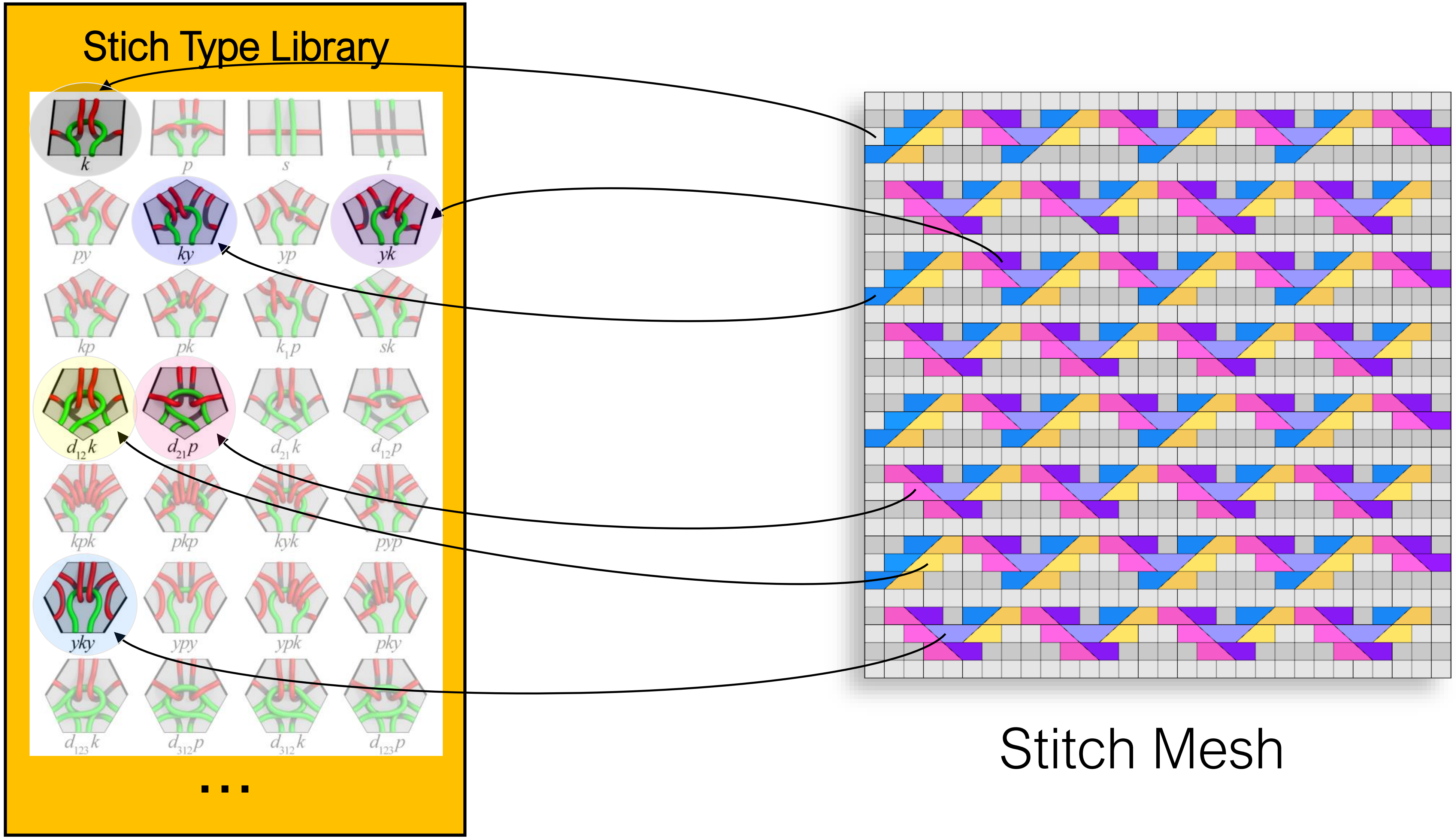


...

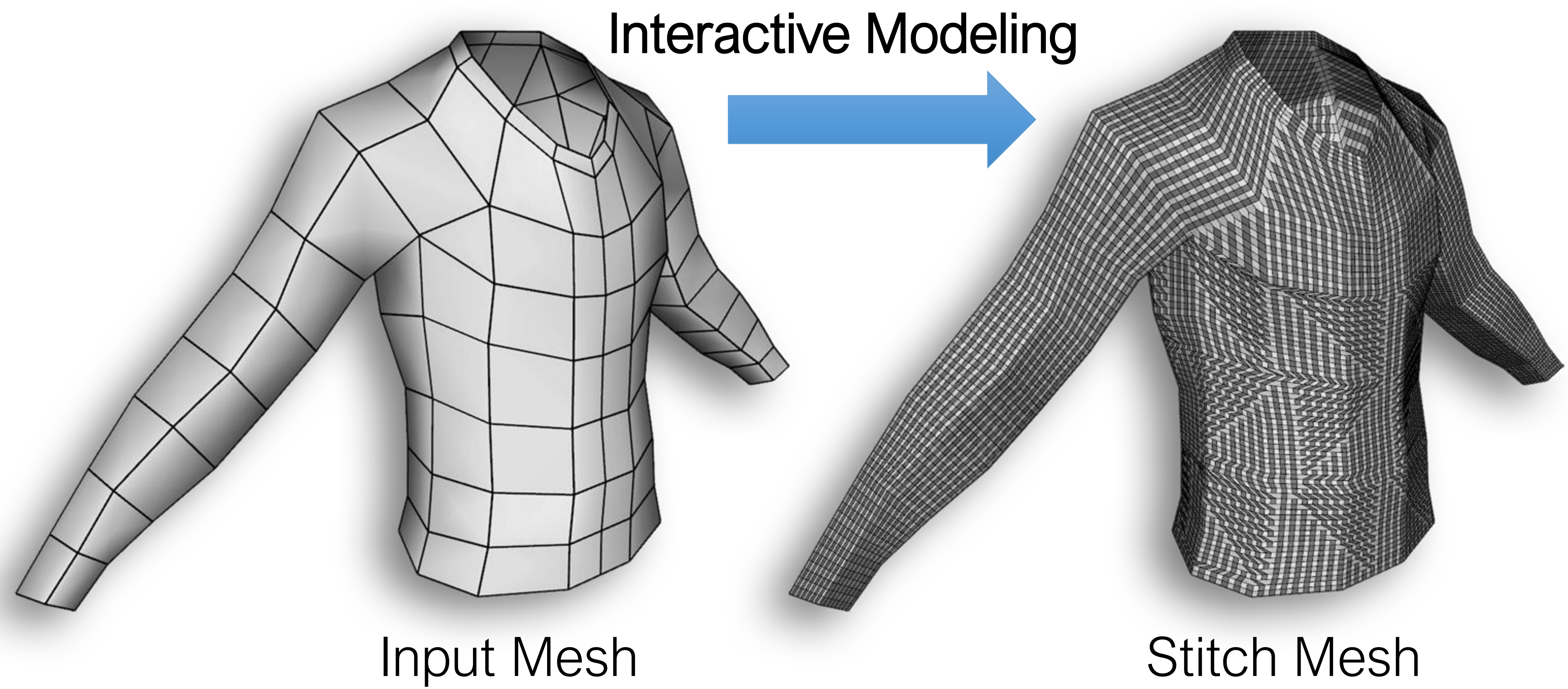


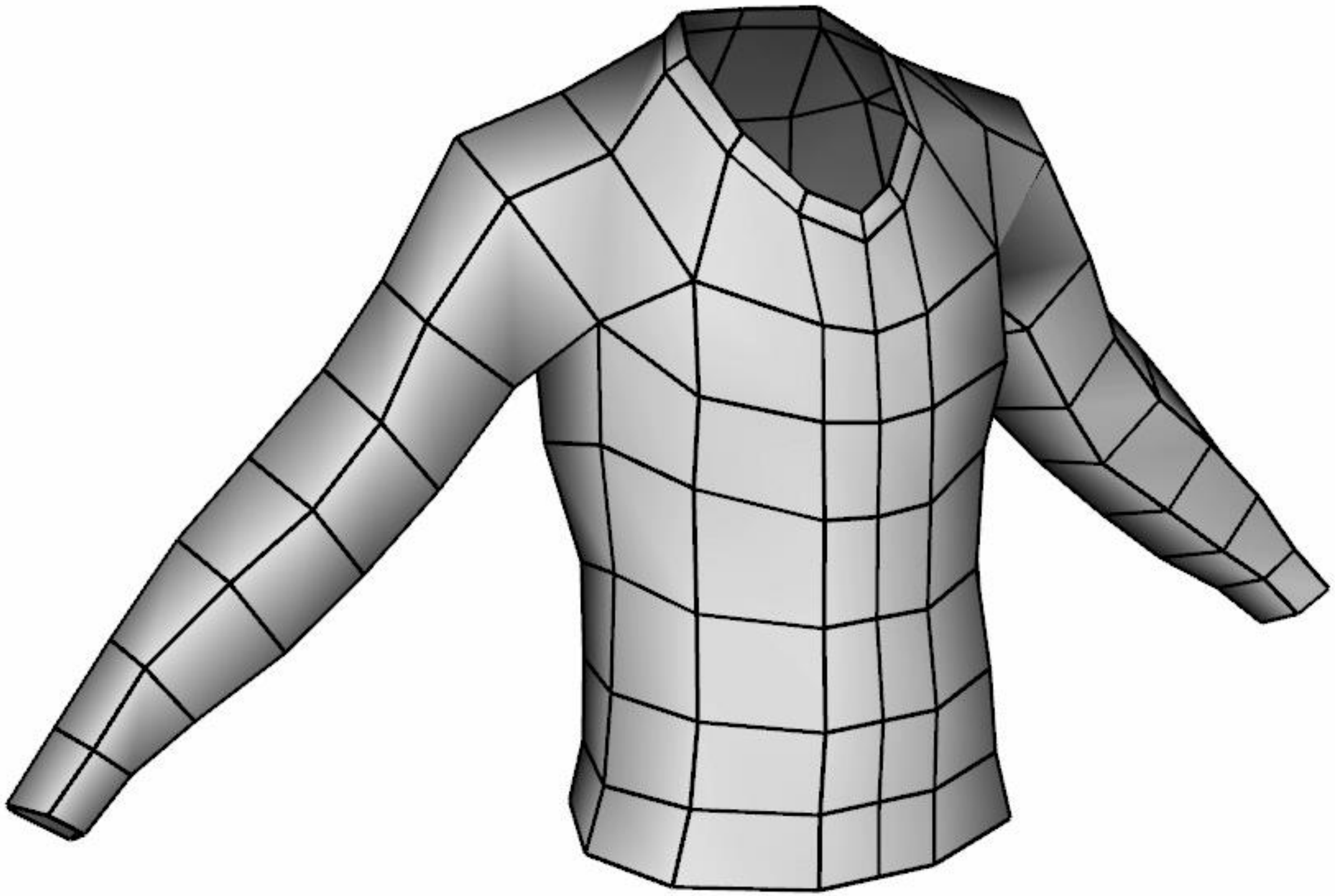
Stitch Mesh

Stitch Type Library [Yuksel et al. 2012]

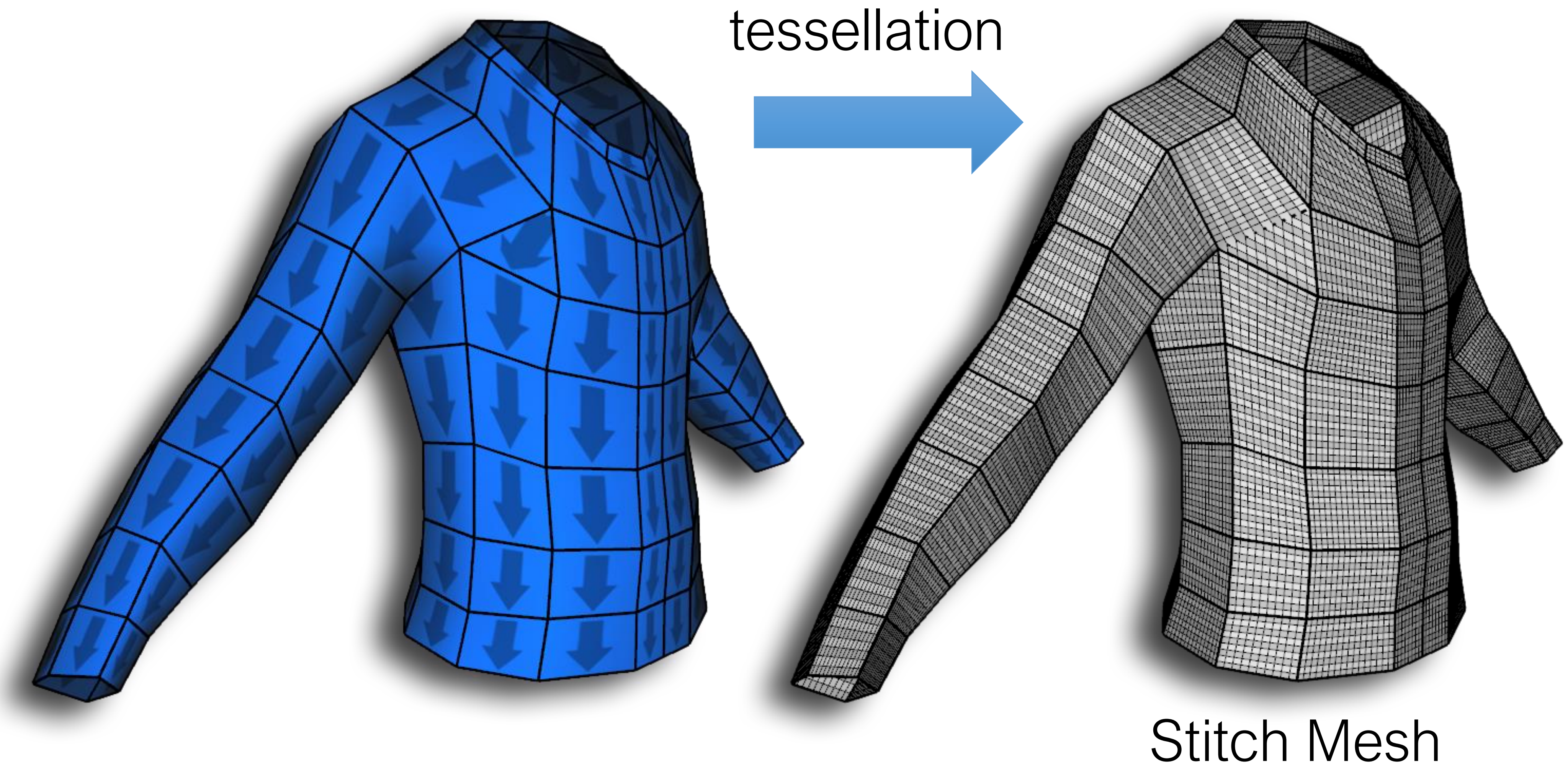


Stitch Mesh [Yuksel et al. 2012]

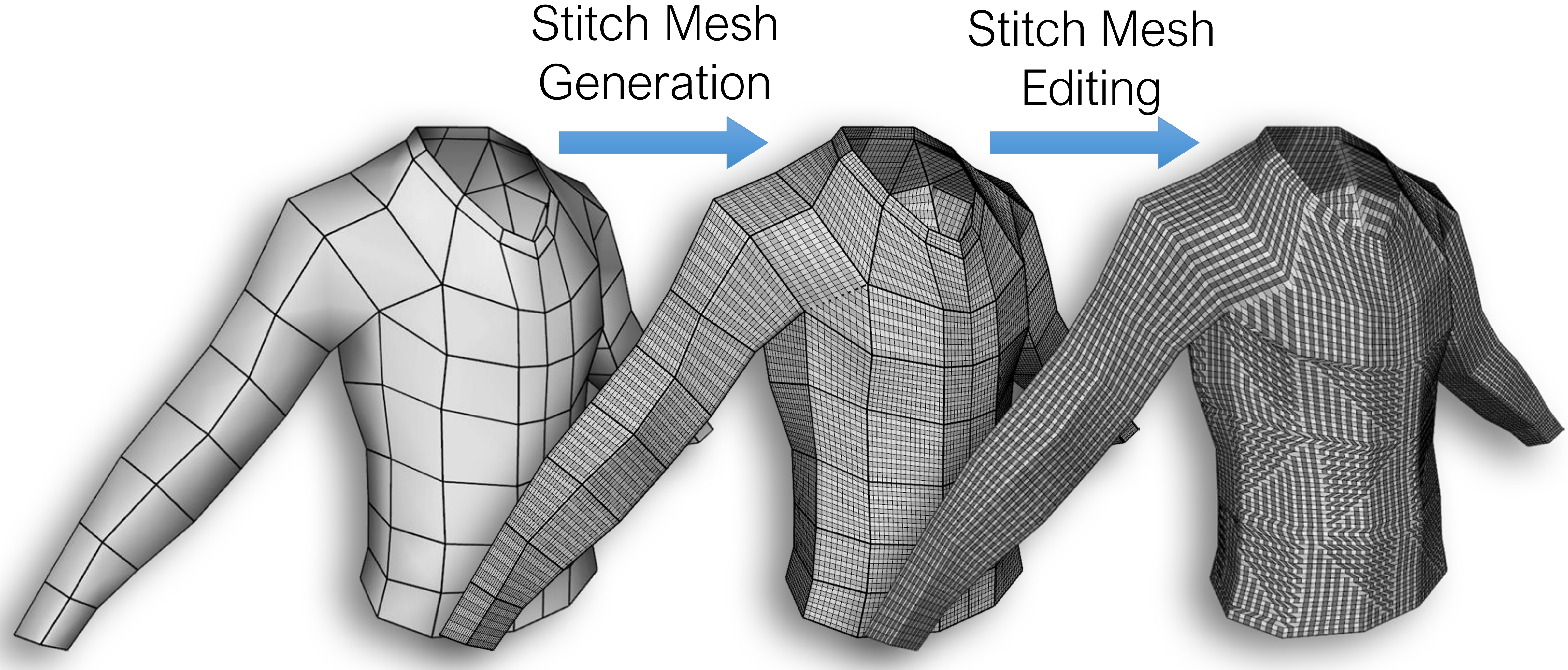




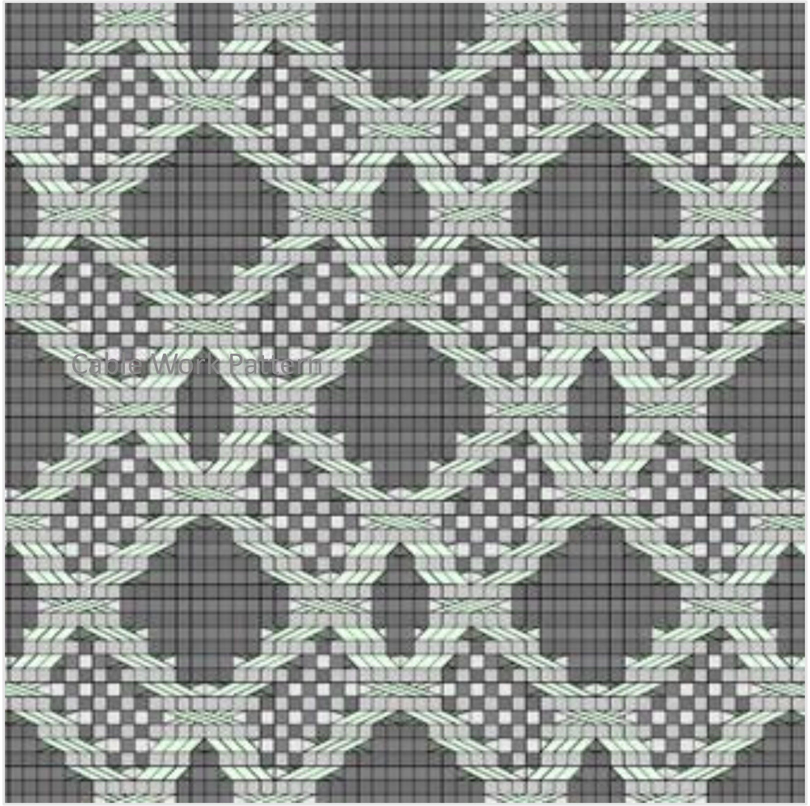
Stitch Mesh Generation [Yuksel et al. 2012]



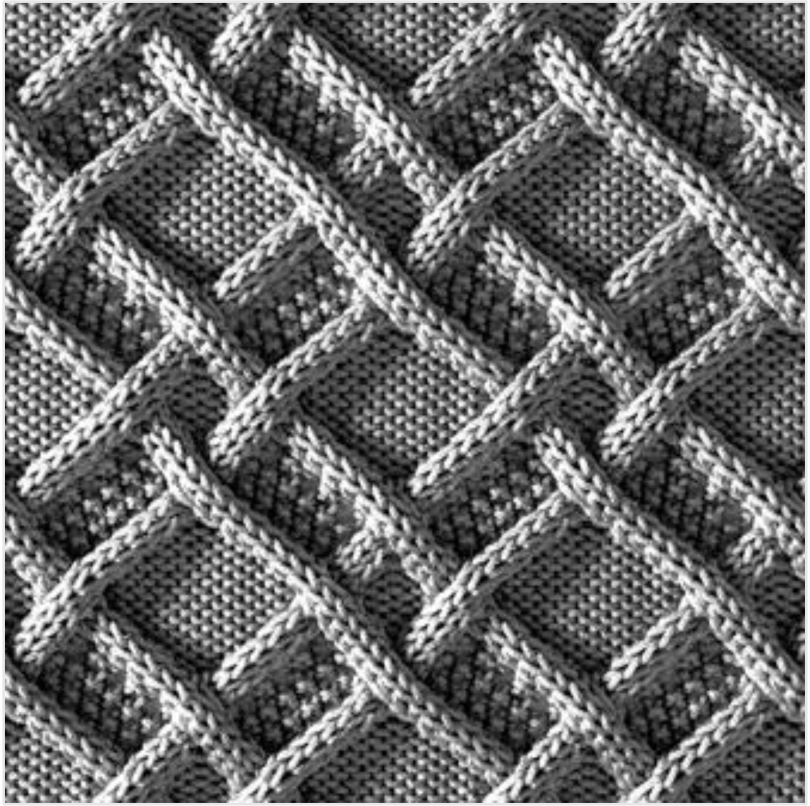
Interactive Modeling [Yuksel et al. 2012]



Example Pattern [Yuksel et al. 2012]



Stitch Mesh



Final Result

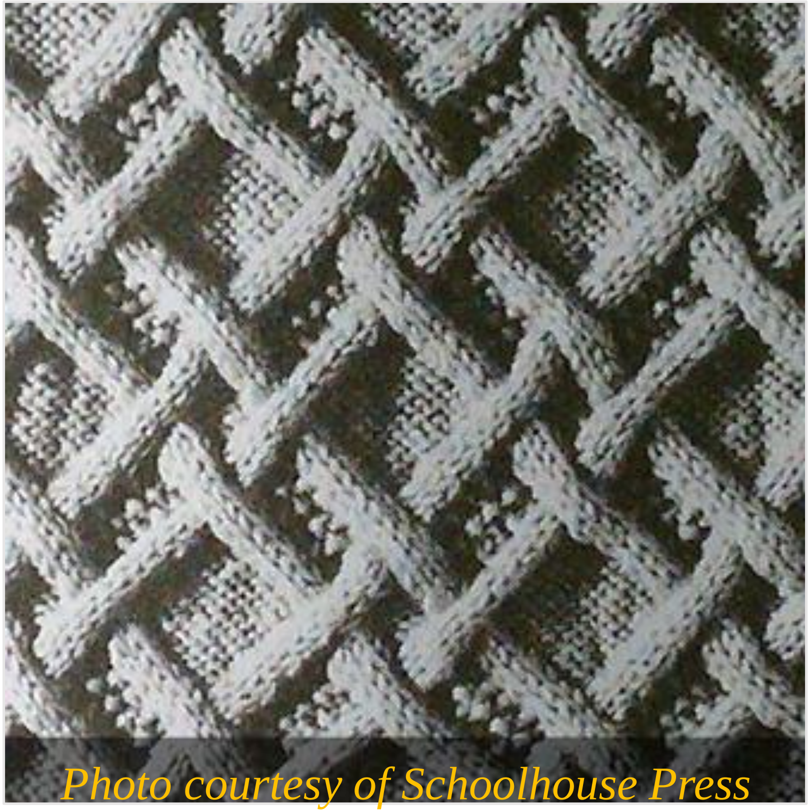
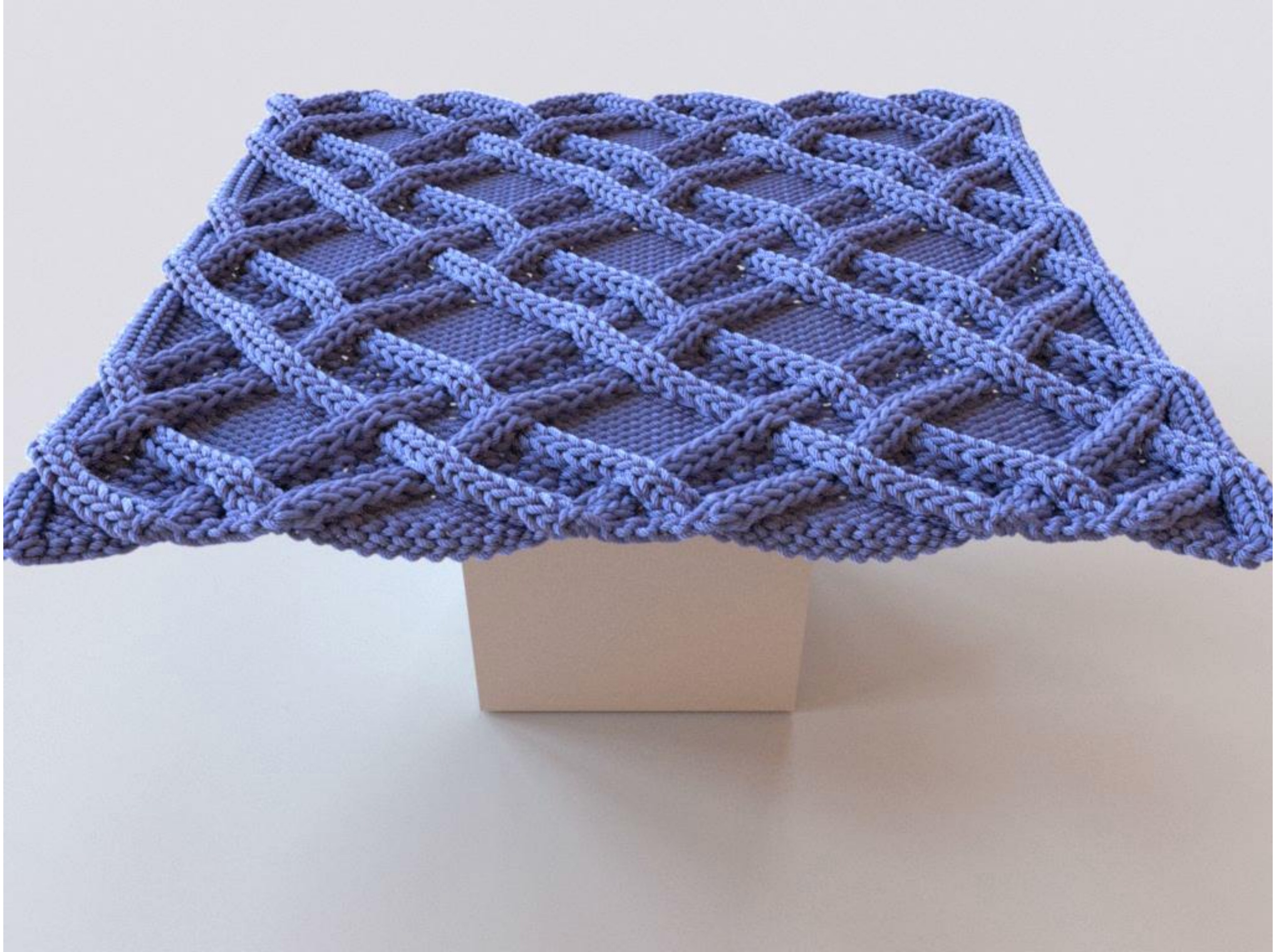
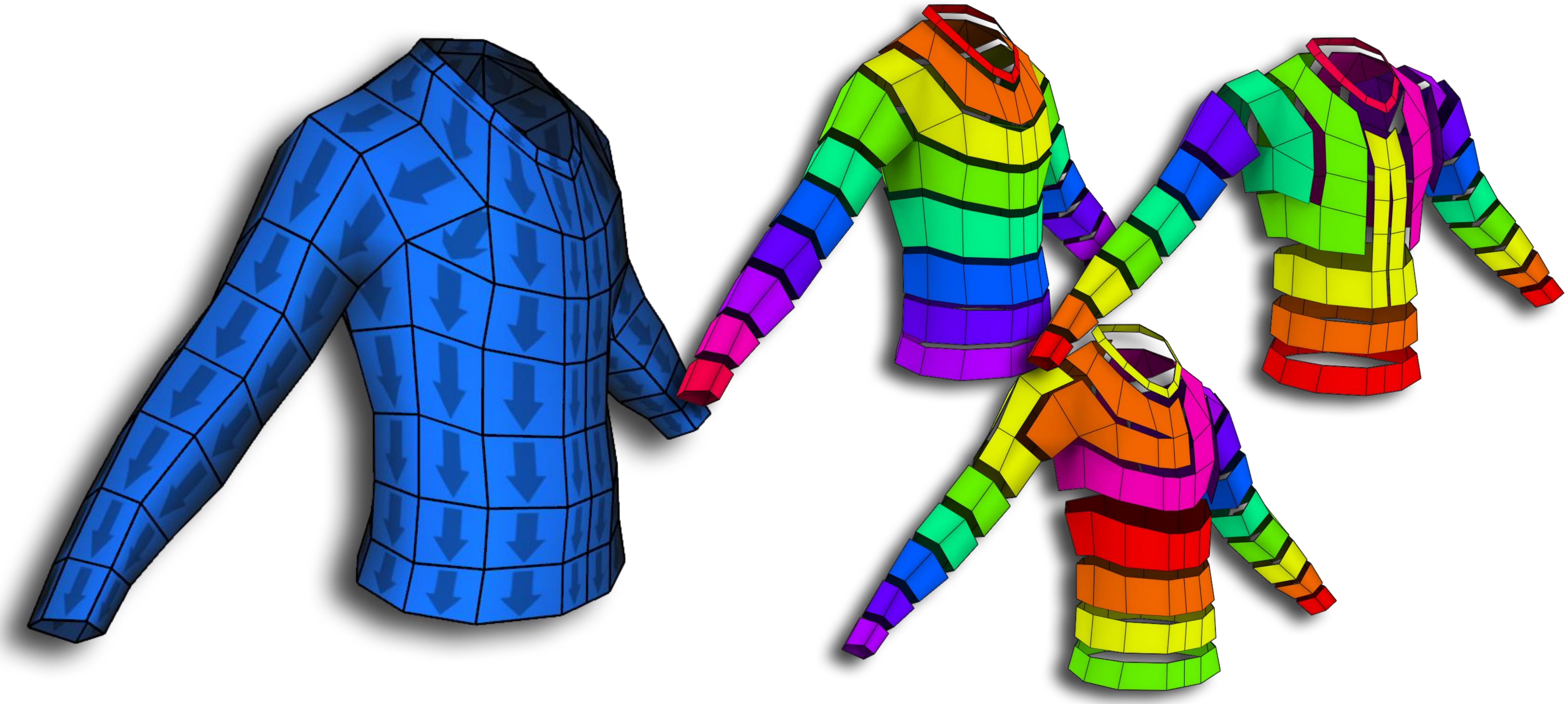


Photo Reference



Labeling the Input Mesh [Yuksel et al. 2012]



Stitch Meshes

Input low polygon mesh must be “labelable”

Input Mesh ➡ Labeled Mesh ➡ Stitch Mesh ➡ Yarn-level Model

Stitch Meshes

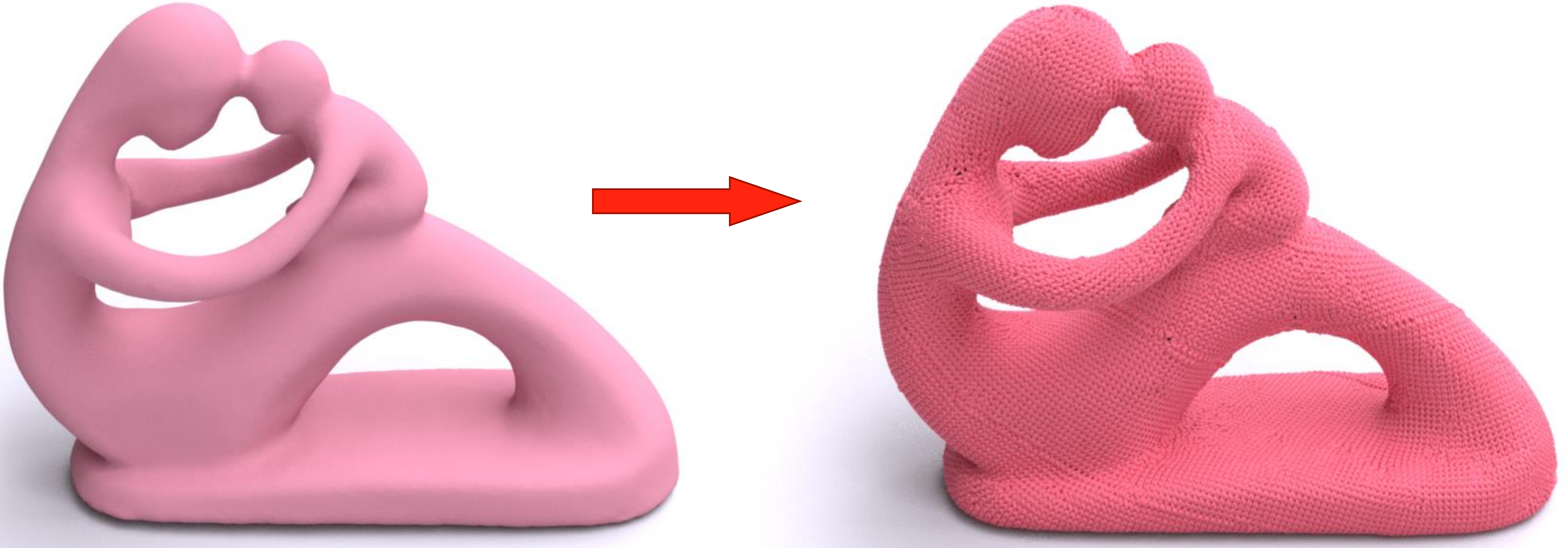
Hours of modeling with many iterations

Input Mesh ➡ Labeled Mesh ➡ Stitch Mesh ➡ Yarn-level Model

[Yuksel et al. 2012]

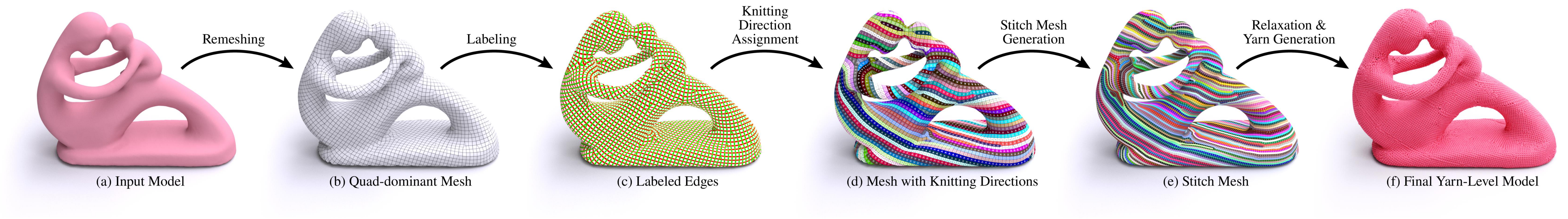
Problem

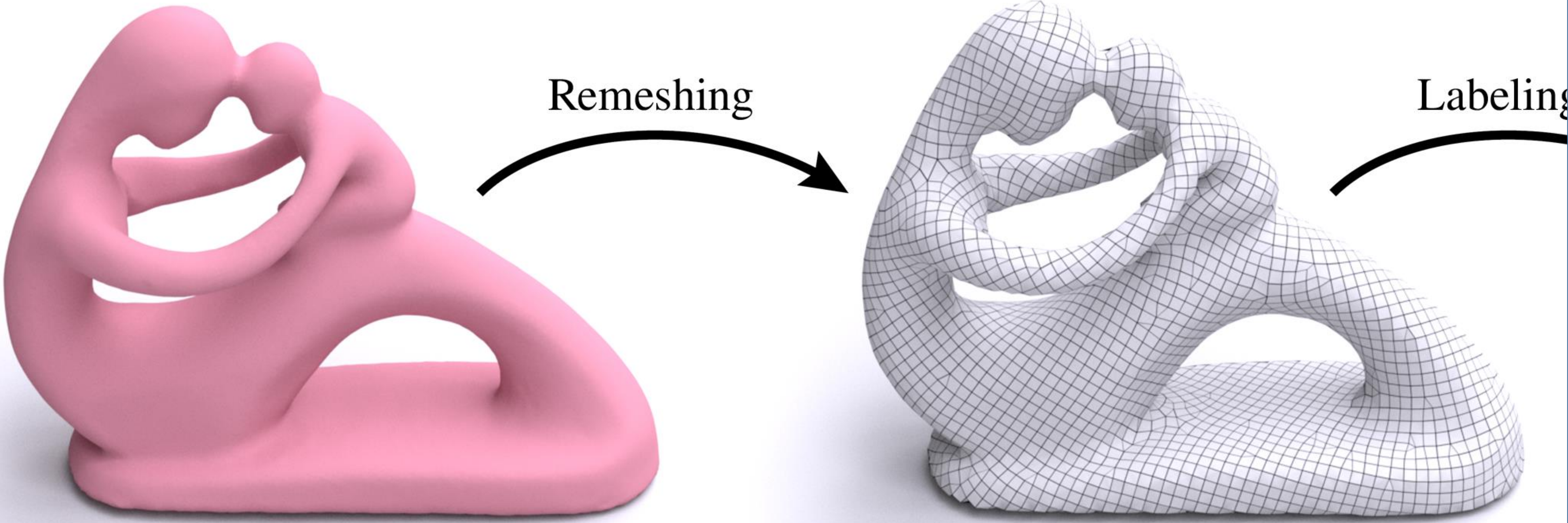
How to convert arbitrary mesh to stitch mesh for yarn-level modeling?



Our Method

We introduce the first fully automatic pipeline to convert arbitrary 3D shapes into knit models.





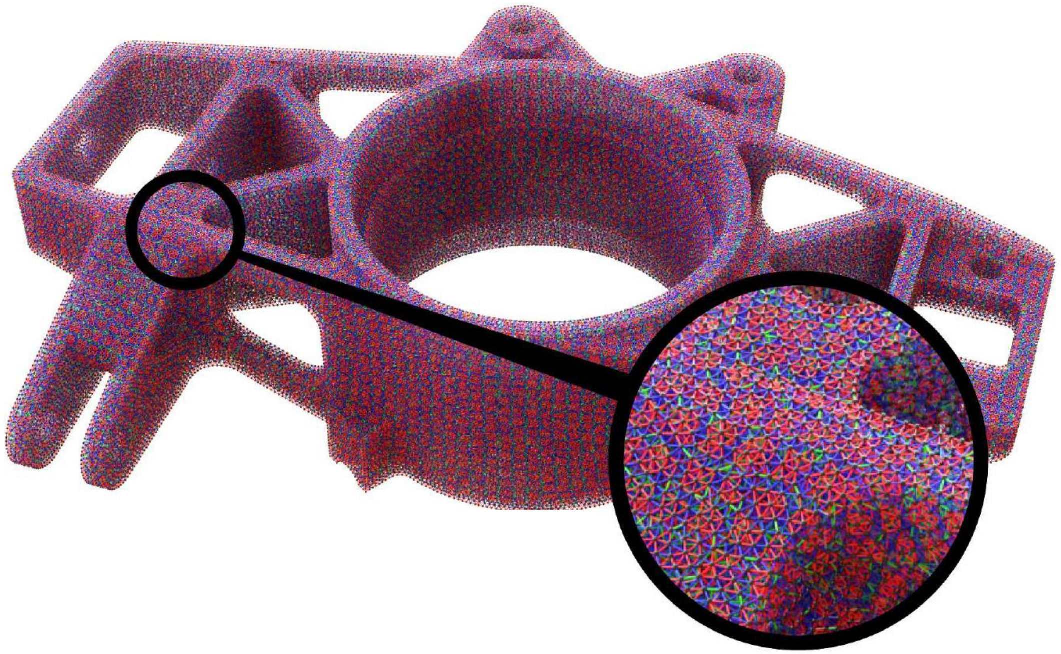
(a) Input Model

(b) Quad-dominant Mesh

Remeshing

We extend the robust quad-dominant meshing pipeline [Gao et al. 2017] to produce meshes

- Robust
- All face are similar size
- All angles are close to 90 degree

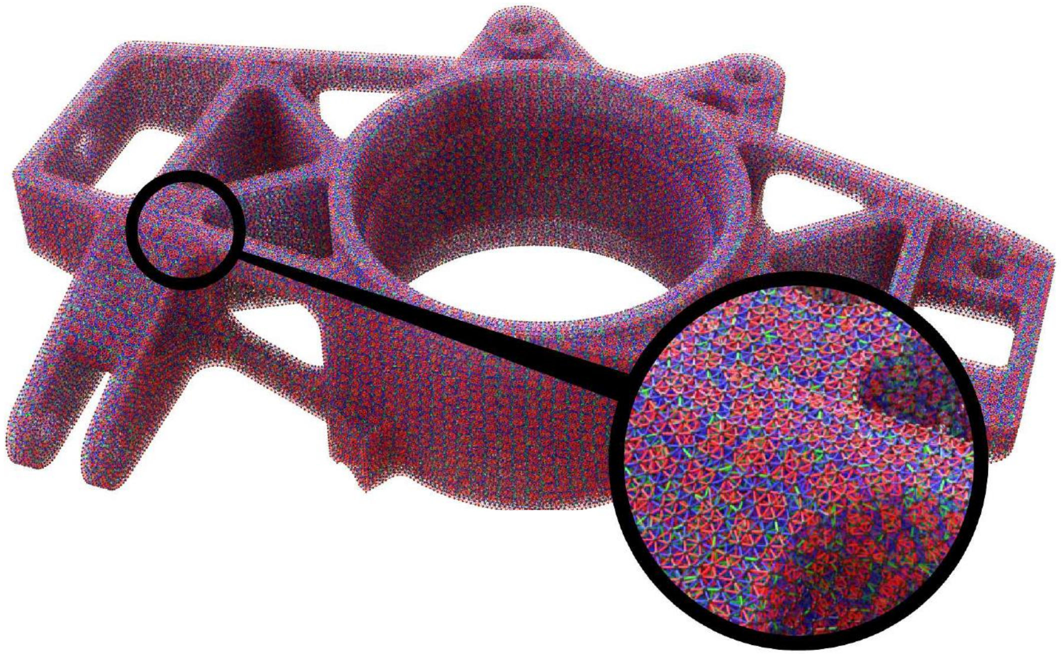


Robust Hex-Dominant Mesh Generation using Field-Guided Polyhedral Agglomeration
Xifeng Gao, Wenzel Jakob, Marco Tarini, Daniele Panozzo
ACM Transactions on Graphics (SIGGRAPH, 2017)

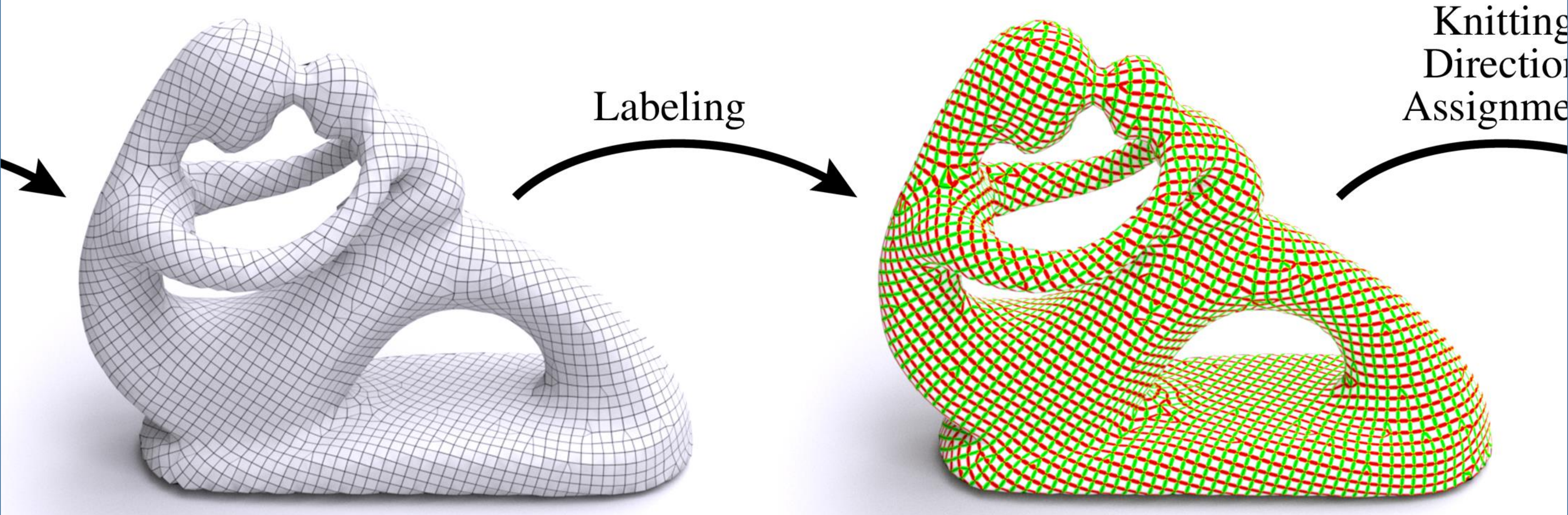
Remeshing

We extend the robust quad-dominant meshing pipeline [Gao et al. 2017] to produce meshes

- Robust
- All face are similar size
- All angles are close to 90 degree
  - Use 2-RoSy (two-fold rotational symmetry) field
  - Cut each polygon with more than 5 sides by adding the edge that is most aligned with the orientation field



[Gao et al. 2017]

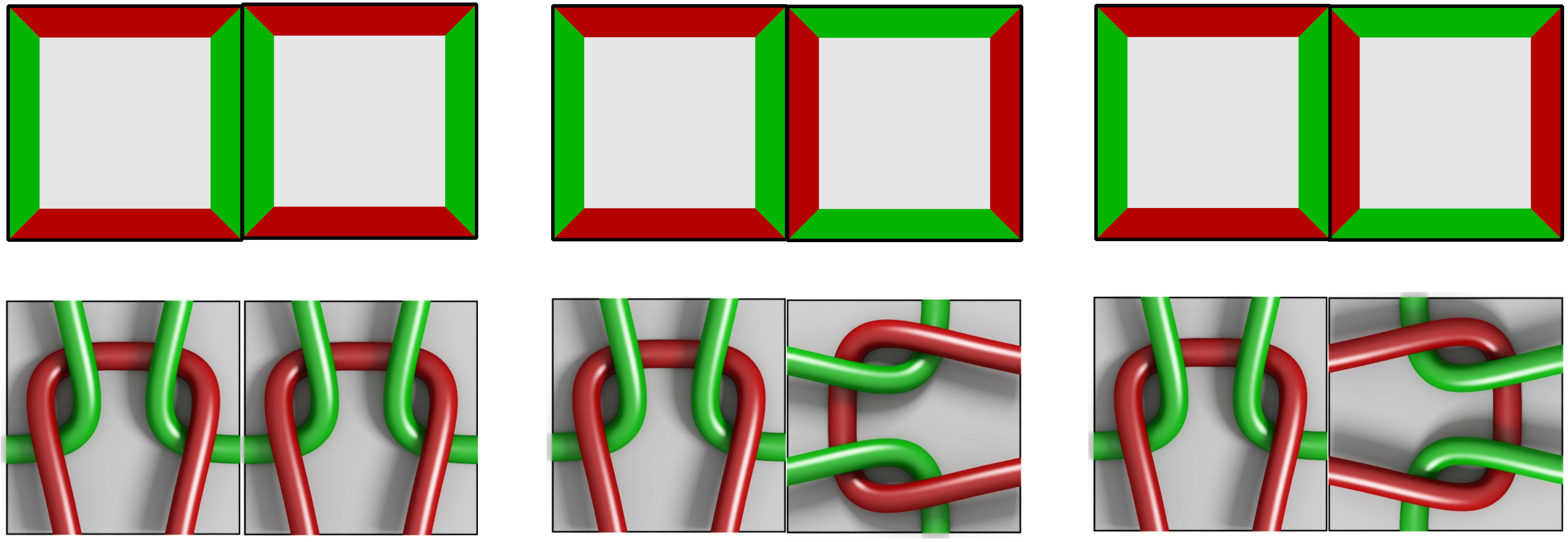


(b) Quad-dominant Mesh

(c) Labeled Edges

Labeling

We use half-edge data structure for labeling



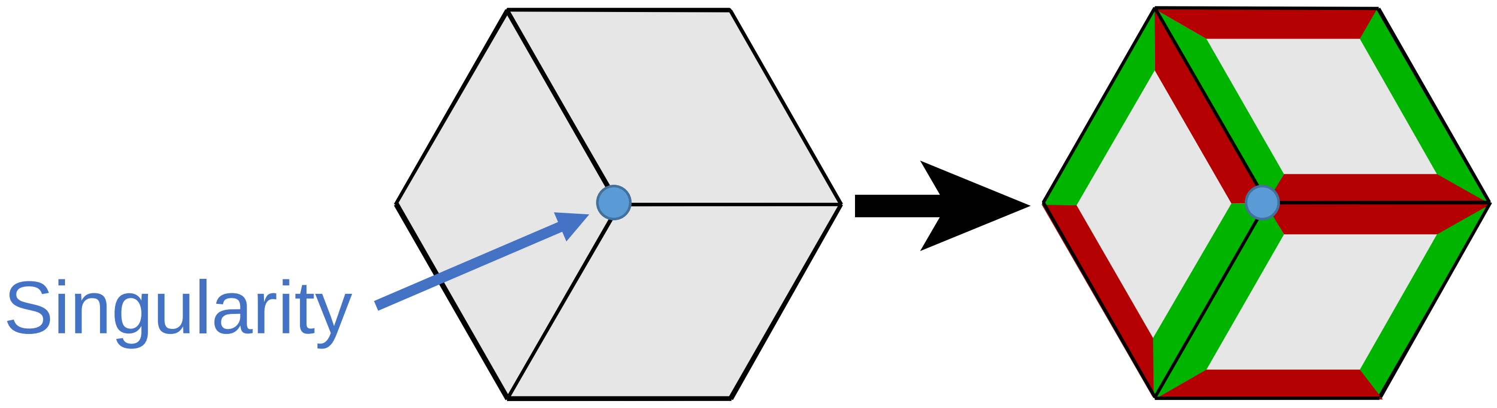
no conflicting   conflicting (1)   conflicting (2)

Labeling

1. Preprocess
   - Triangulation near singularities
2. Minimize conflicting by solving Mixed-integer Programming (MIP) problem
3. Postprocess
   - solving conflicts
   - merging triangles

Labeling

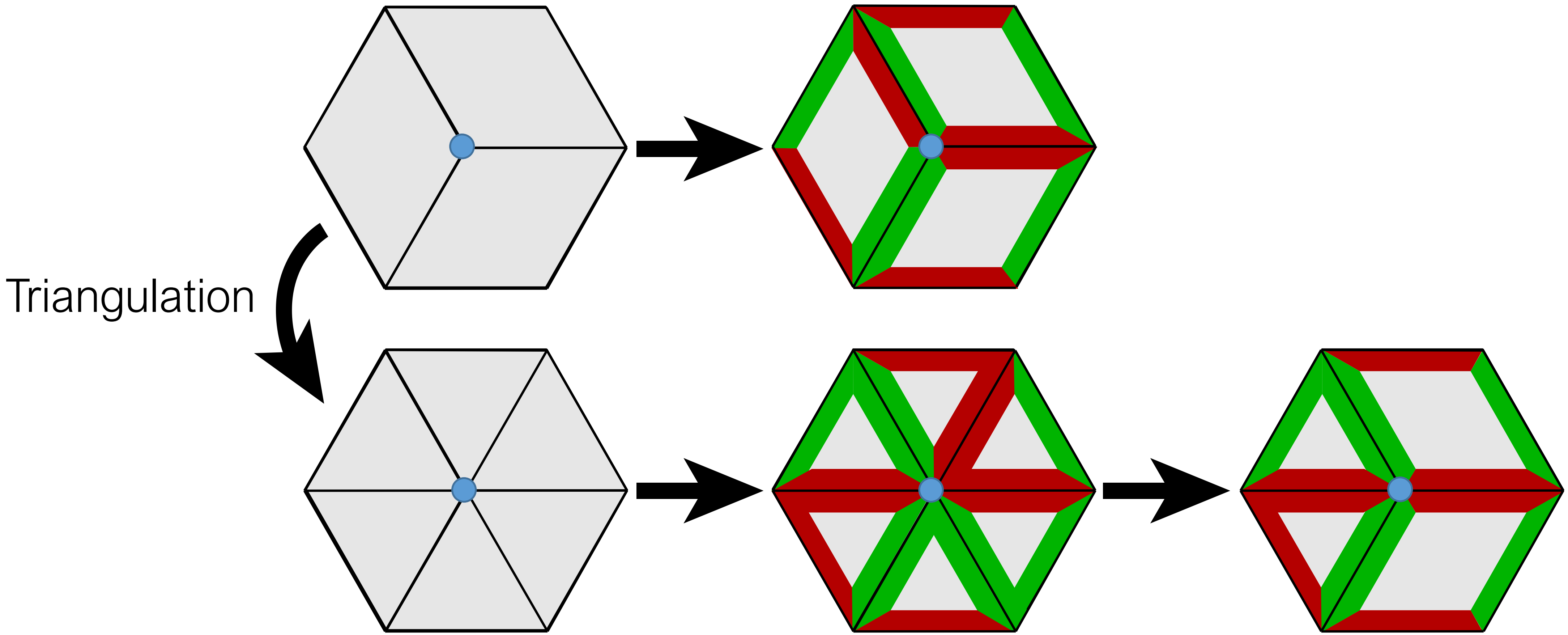
Preprocess



Conflicting is unavoidable

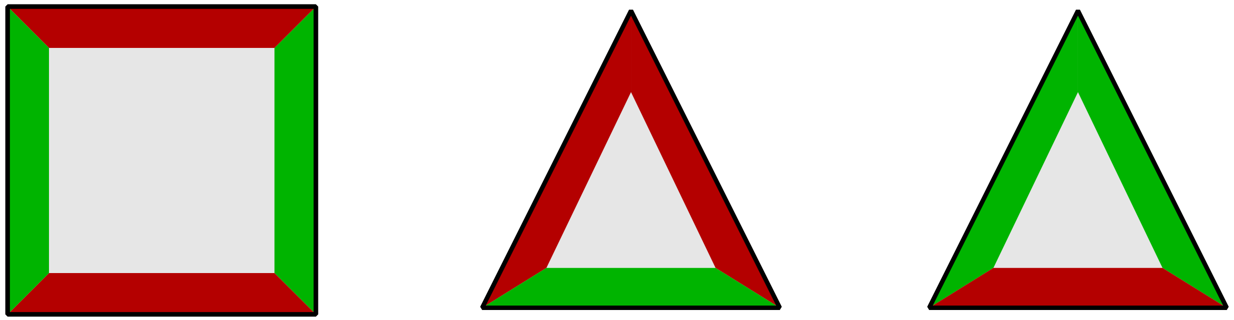
Labeling

Preprocess



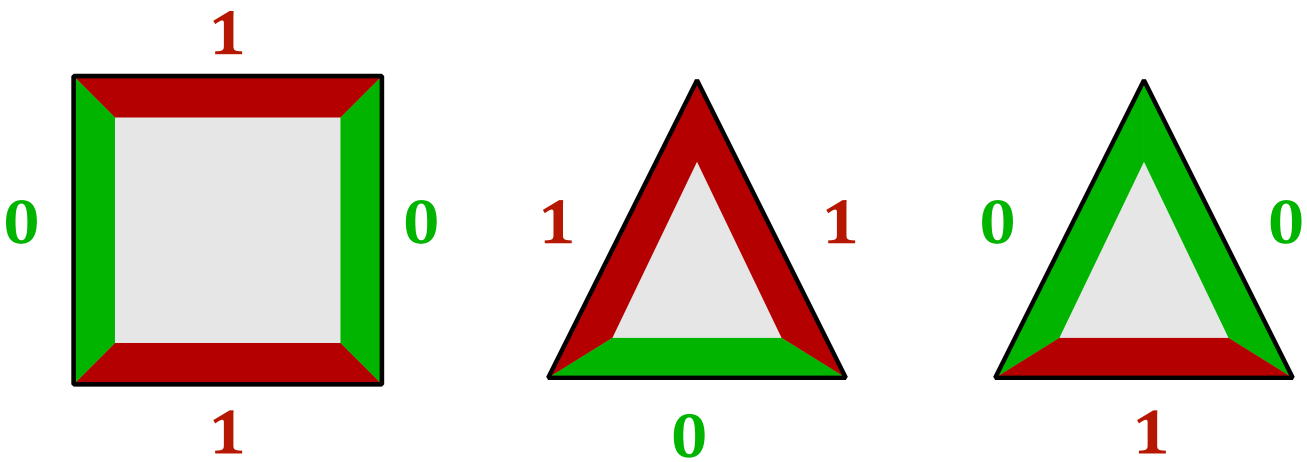
Labeling

Three valid half-edge configurations



Labeling

Three valid half-edge configurations



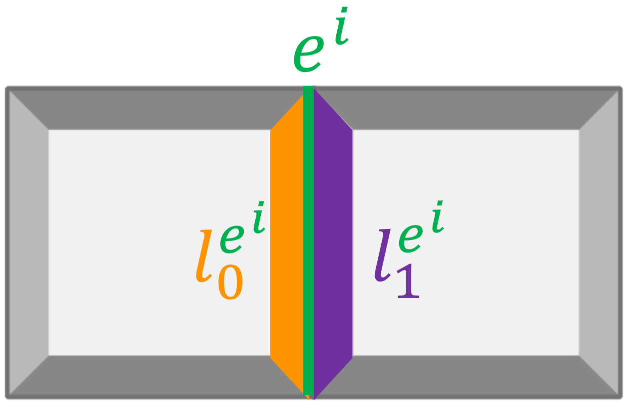
1 - course edge
0 - wale edge

Labeling

Mixed-integer Programming problem

$$\textbf{minimize} \quad \sum_{i=0}^{n-1} (\ell_0^{e_i} - \ell_1^{e_i})^2$$

$$l_0^{e^i}, l_1^{e^i} \in \{0, 1\}$$



Labeling

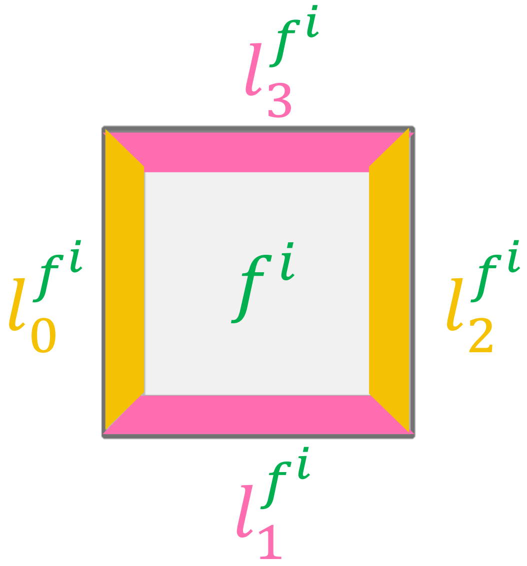
Mixed-integer Programming problem

$$\textbf{minimize} \quad \sum_{i=0}^{n-1} (\ell_0^{e_i} - \ell_1^{e_i})^2$$

subject to

for each quad face f_j, $\quad \ell_0^{f_j} = \ell_2^{f_j}, \quad \ell_1^{f_j} = \ell_3^{f_j}, \quad \ell_0^{f_j} \neq \ell_1^{f_j}$

$$\ell_k^{fj} \in \{0, 1\}, \quad k = 0, 1, 2, 3$$



Labeling

Mixed-integer Programming problem

$$\textbf{minimize} \quad \sum_{i=0}^{n-1} (\ell_0^{e_i} - \ell_1^{e_i})^2$$

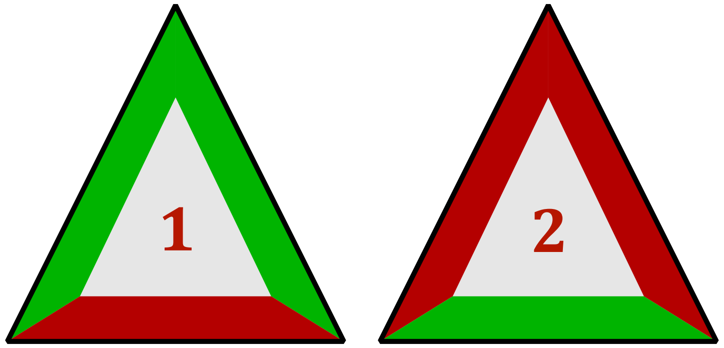
subject to

for each quad face f_j, $\quad \ell_0^{f_j} = \ell_2^{f_j}, \quad \ell_1^{f_j} = \ell_3^{f_j}, \quad \ell_0^{f_j} \neq \ell_1^{f_j}$

$\ell_k^{f_j} \in \{0, 1\}, \quad k = 0, 1, 2, 3$

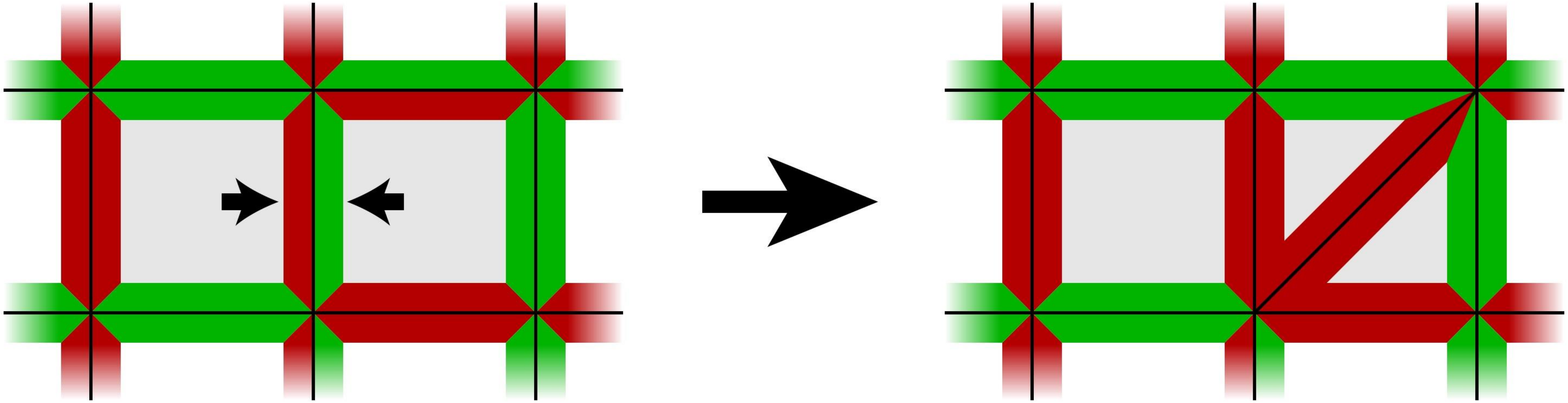
for each triangle face f_j, $\quad \mathbf{1} \leq \ell_0^{f_j} + \ell_1^{f_j} + \ell_2^{f_j} \leq \mathbf{2}$

$\ell_k^{f_j} \in \{0, 1\}, \quad k = 0, 1, 2$



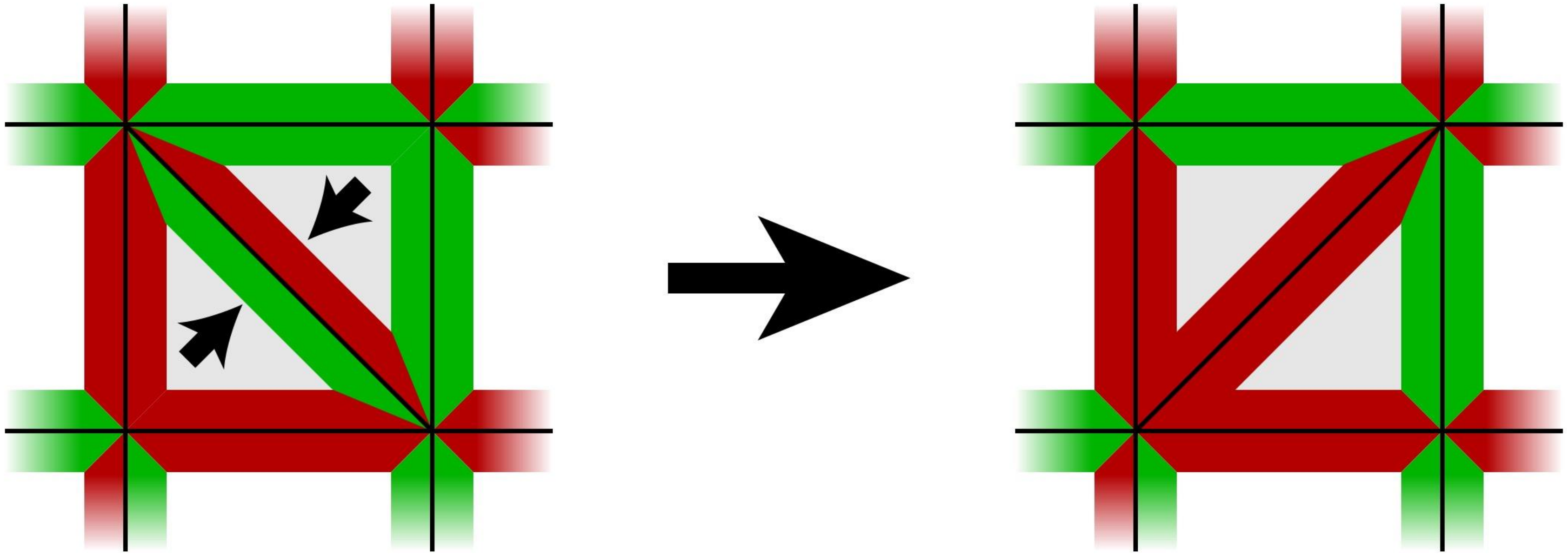
Labeling

Postprocess – face splitting



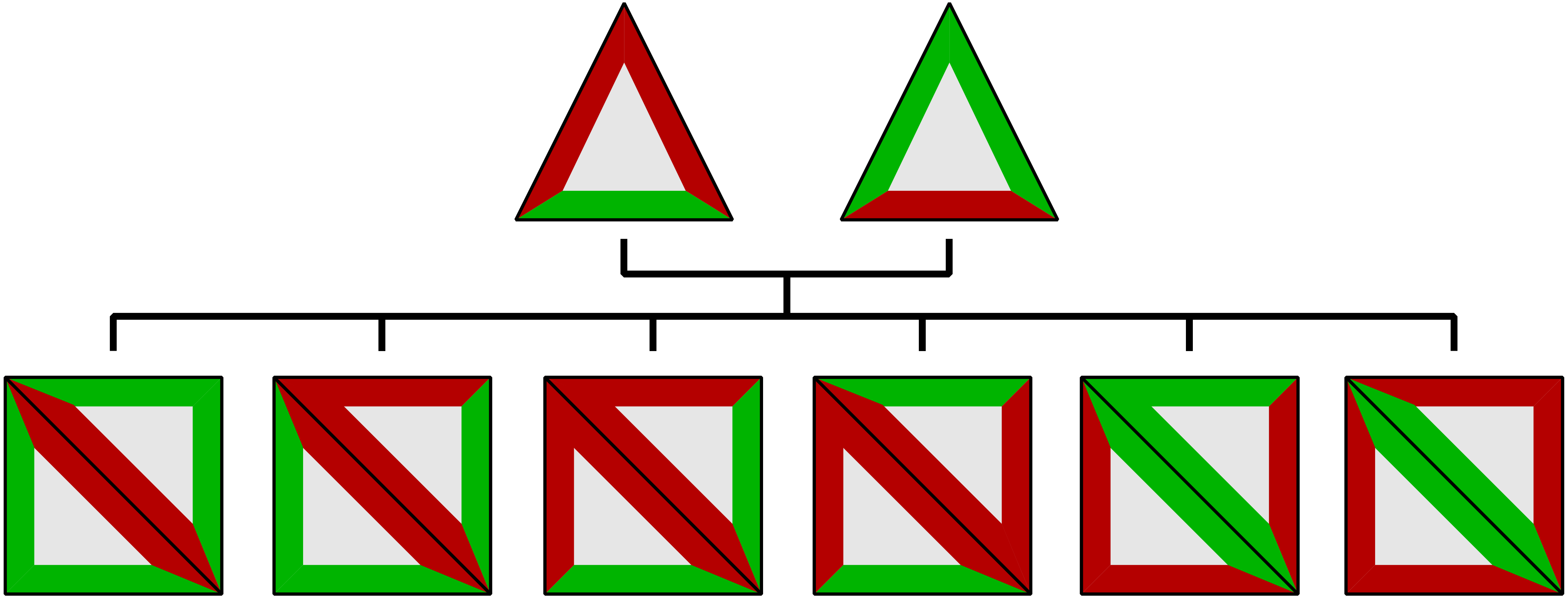
Labeling

Postprocess – edge rotation



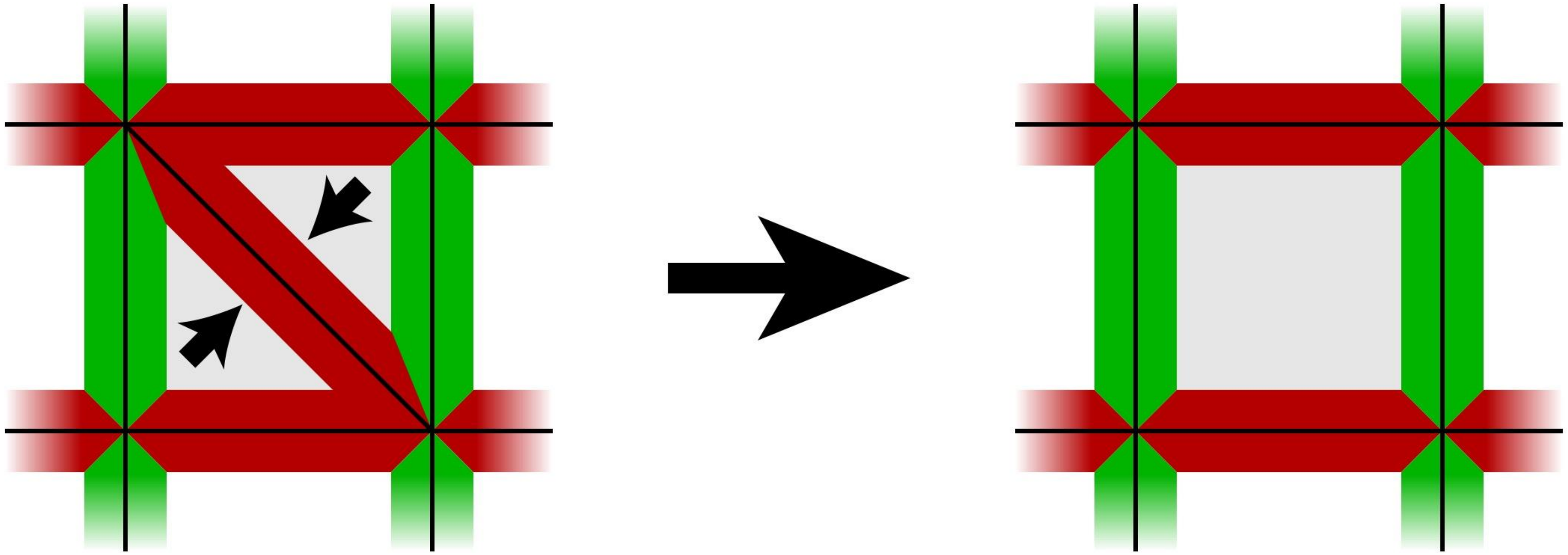
Labeling

Any type of quads can be represented by two triangles



Labeling

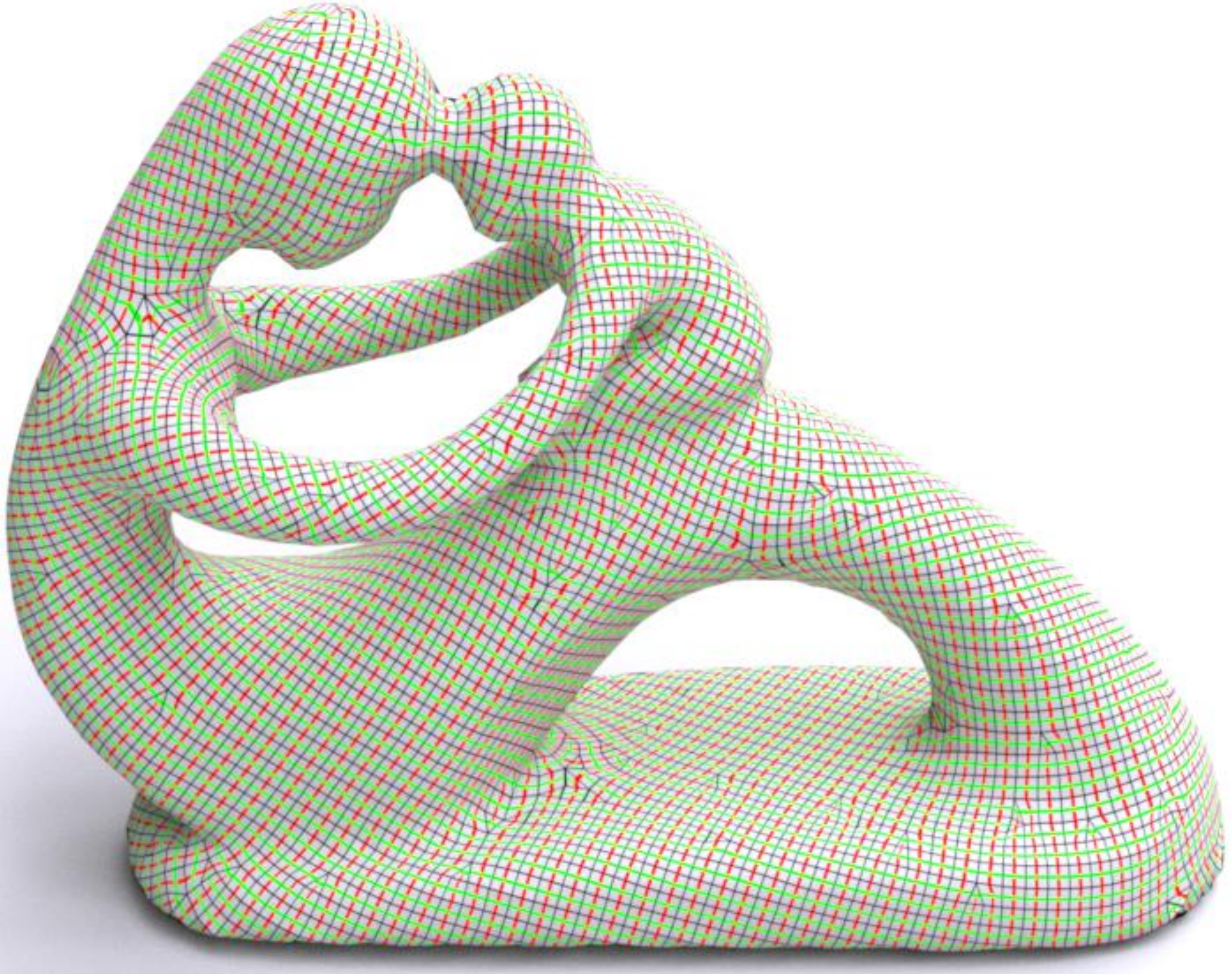
Postprocess – triangles merging

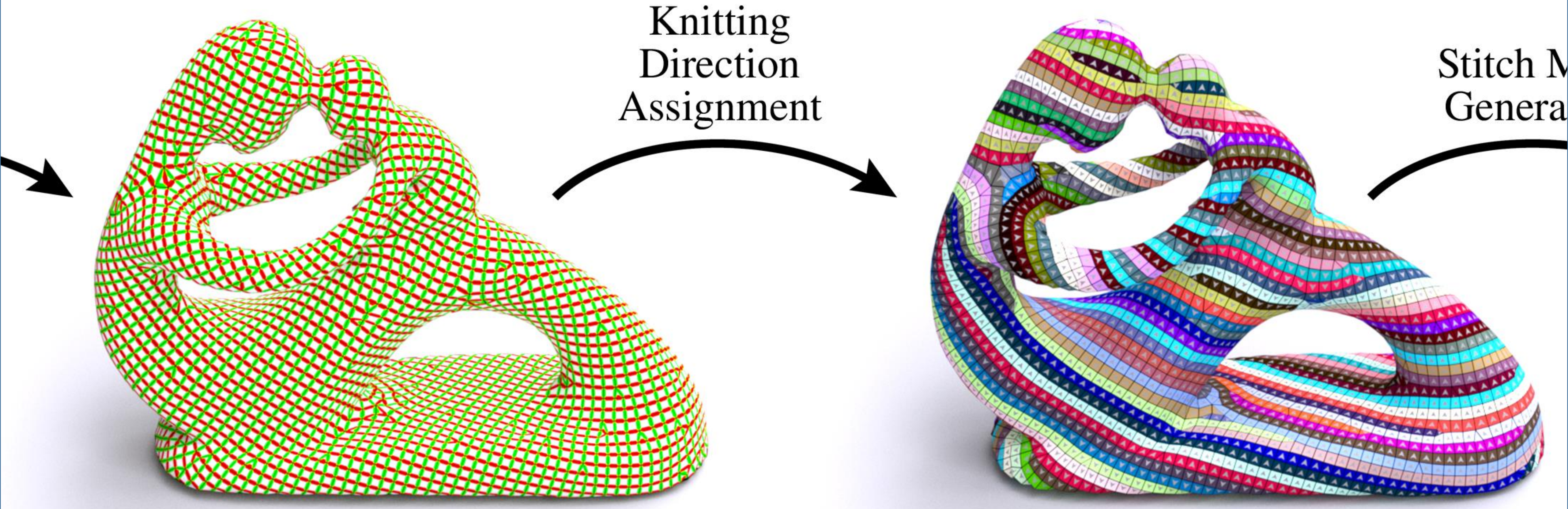


Labeling

Topology
- No conflicting

Geometry
- All faces have approximately the same size
- All angles are close to 90 degree

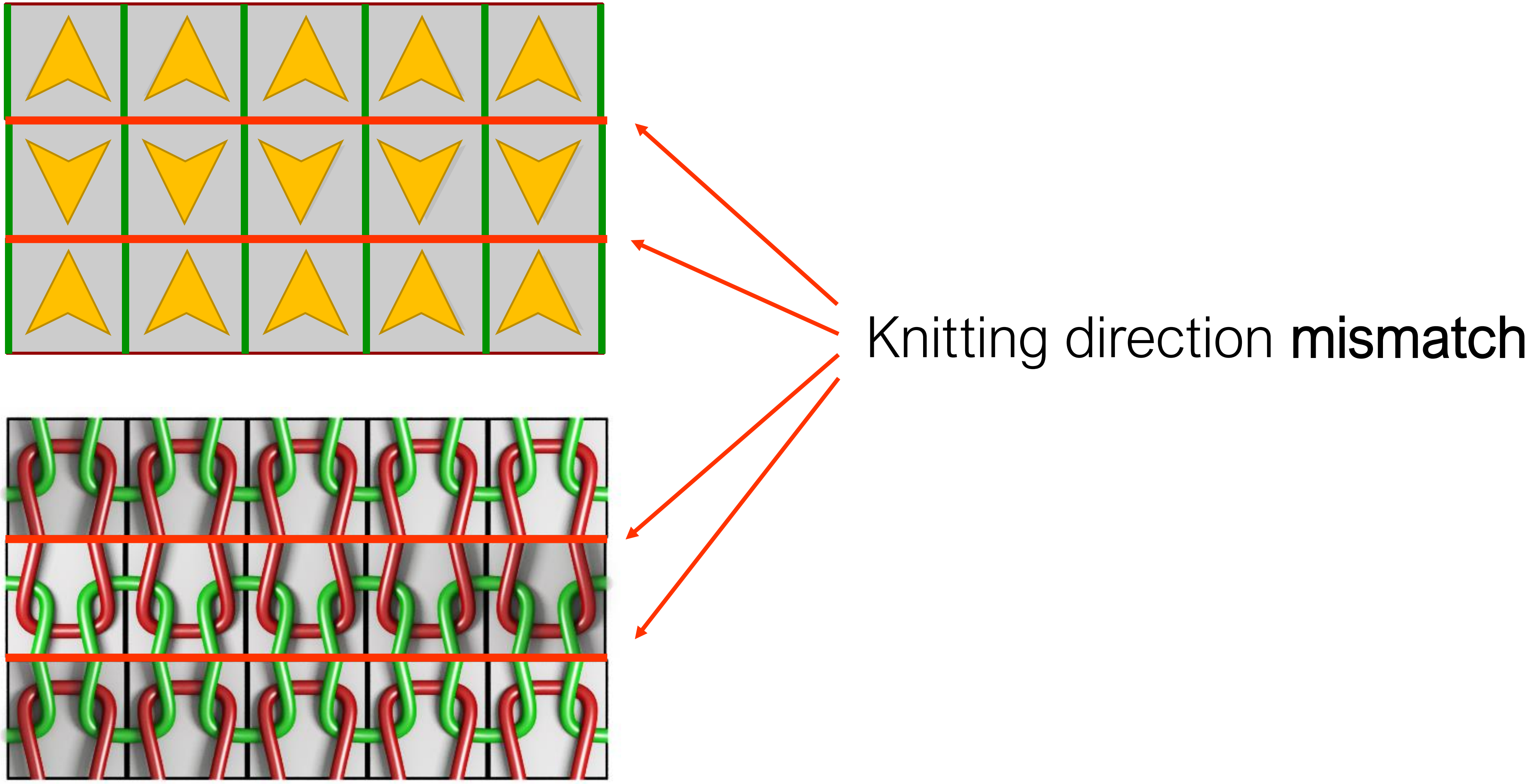




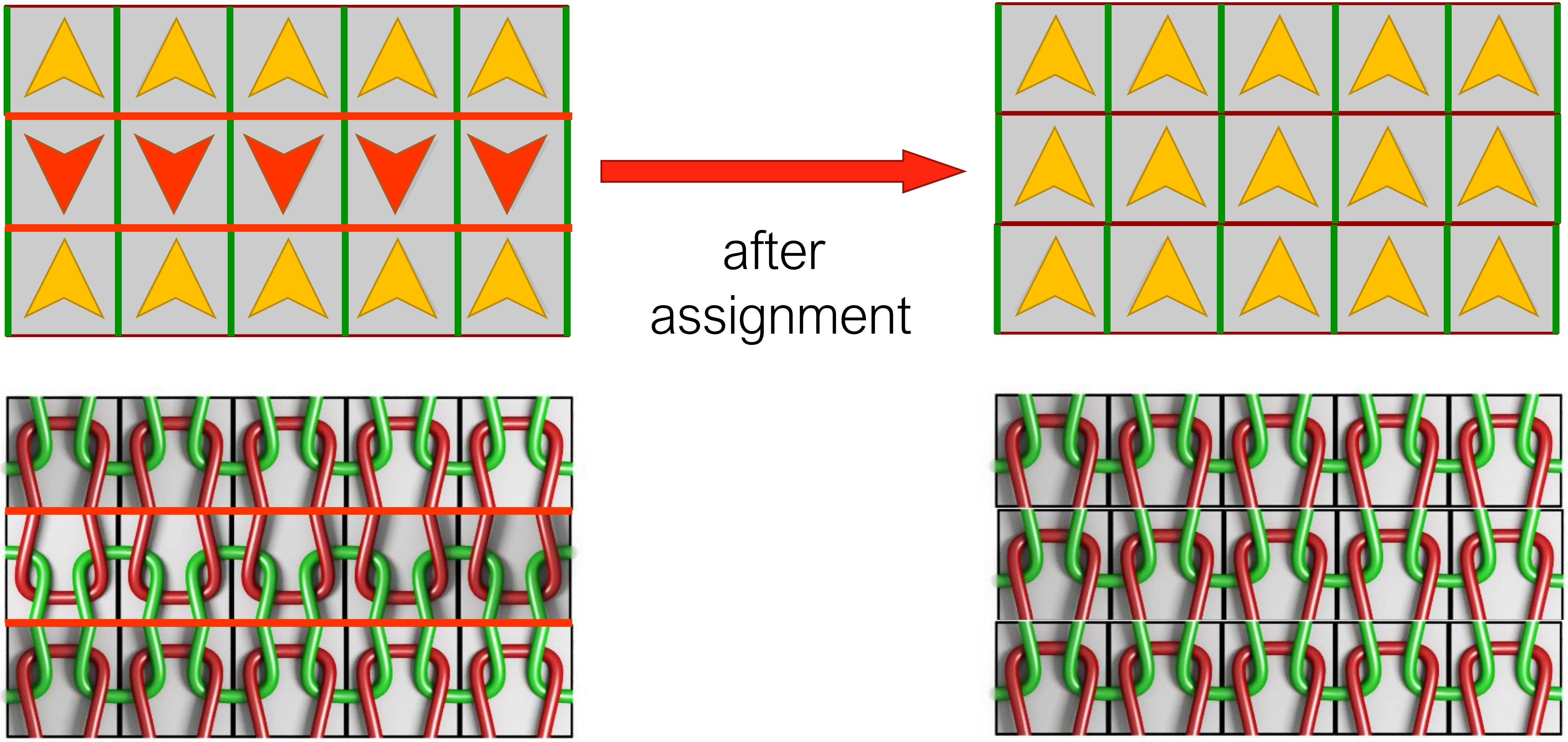
(c) Labeled Edges

(d) Mesh with Knitting Directions

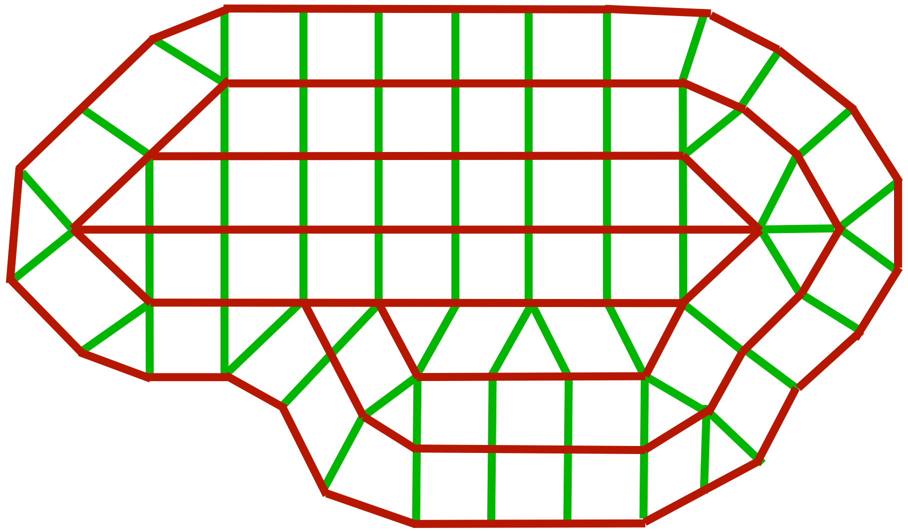
Knitting Direction Assignment



Knitting Direction Assignment

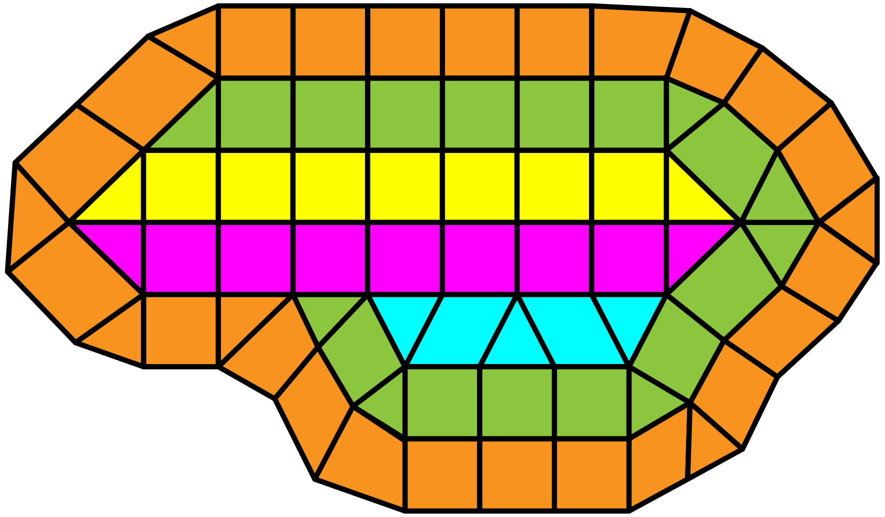


Knitting Direction Assignment

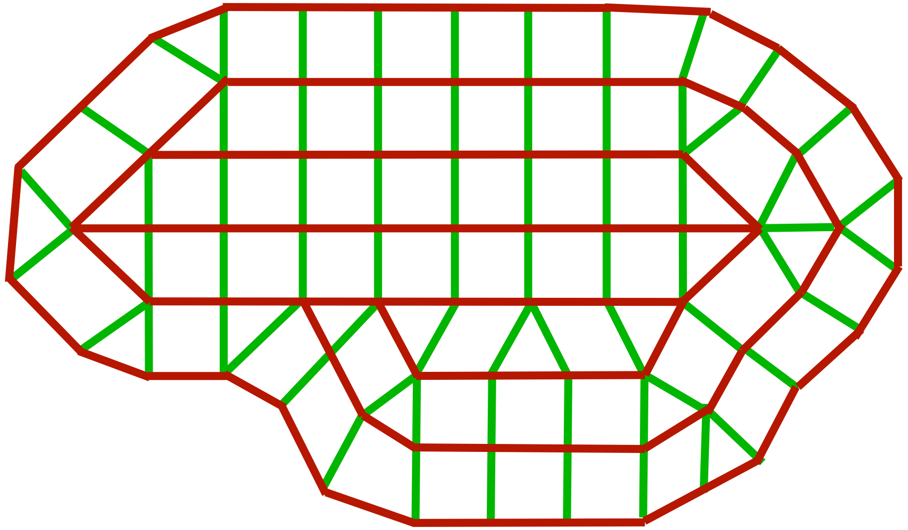


Knitting Direction Assignment

1. group faces by wale edges to form rows
2. build a meta-graph
3. minimizes the number of course edges
   with mismatched wale directions

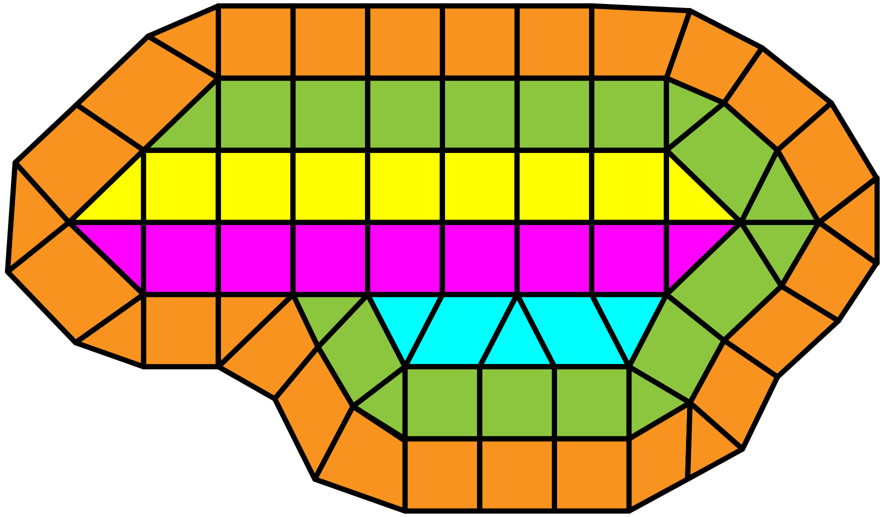


Grouped Stitch Mesh

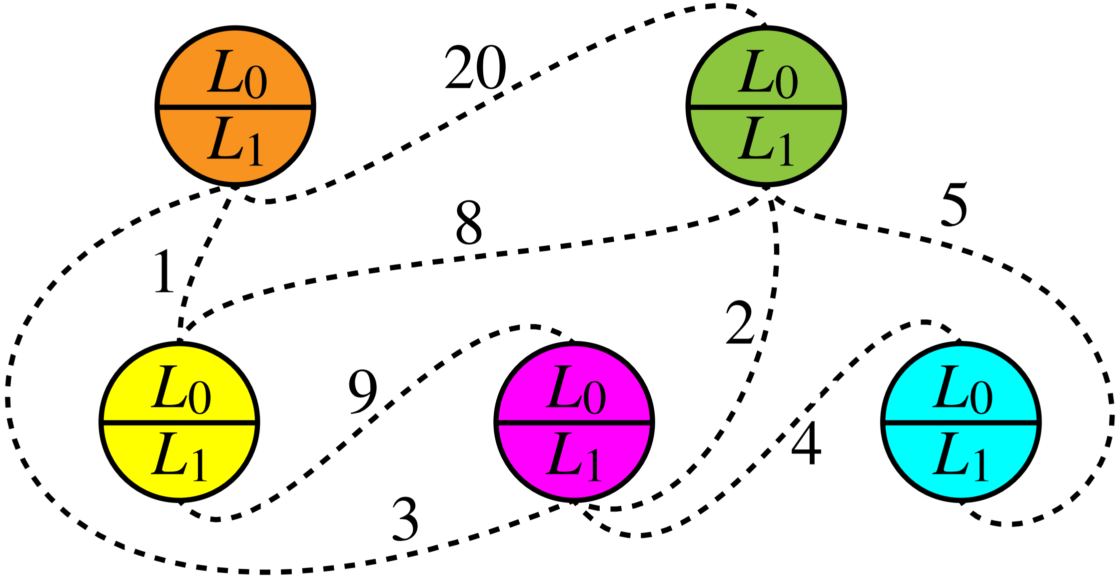


Knitting Direction Assignment

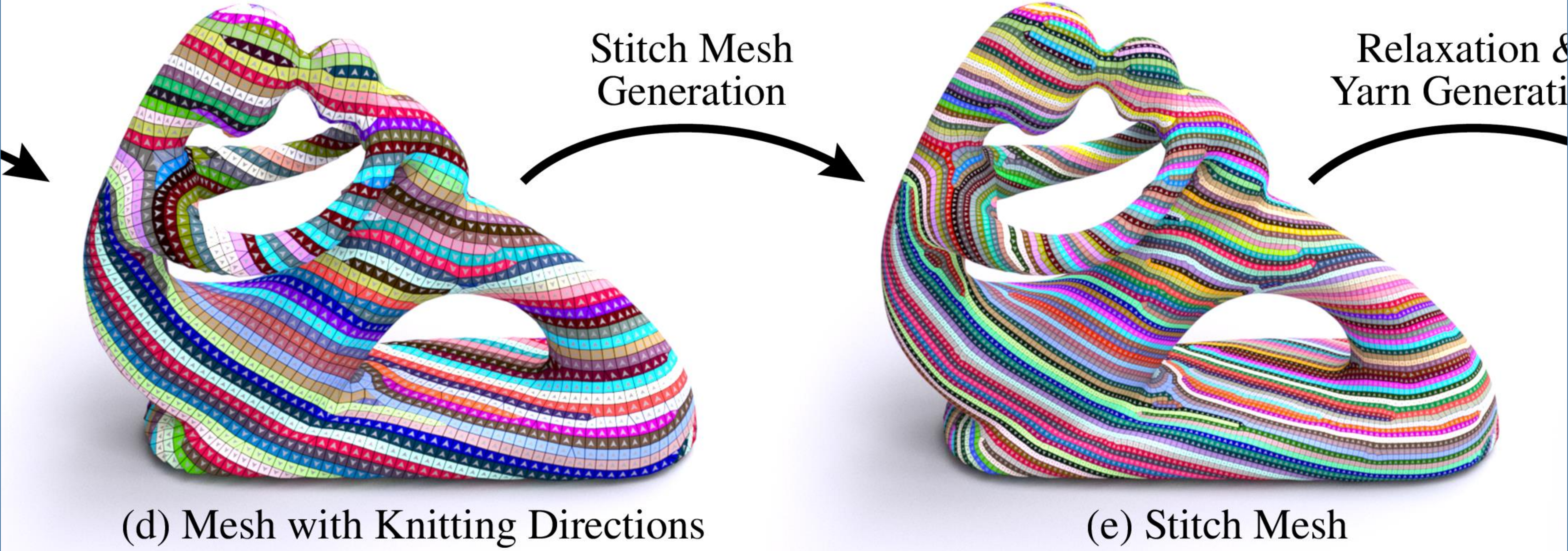
1. group faces by wale edges to form rows
2. build a meta-graph
3. minimizes the number of course edges with mismatched wale directions



Grouped Stitch Mesh

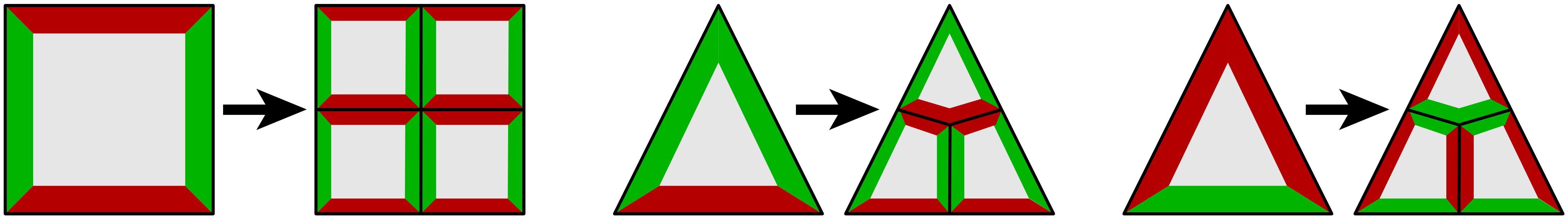


Meta-graph


Stitch Mesh
Generation
Relaxation &
Yarn Generati
(d) Mesh with Knitting Directions
(e) Stitch Mesh

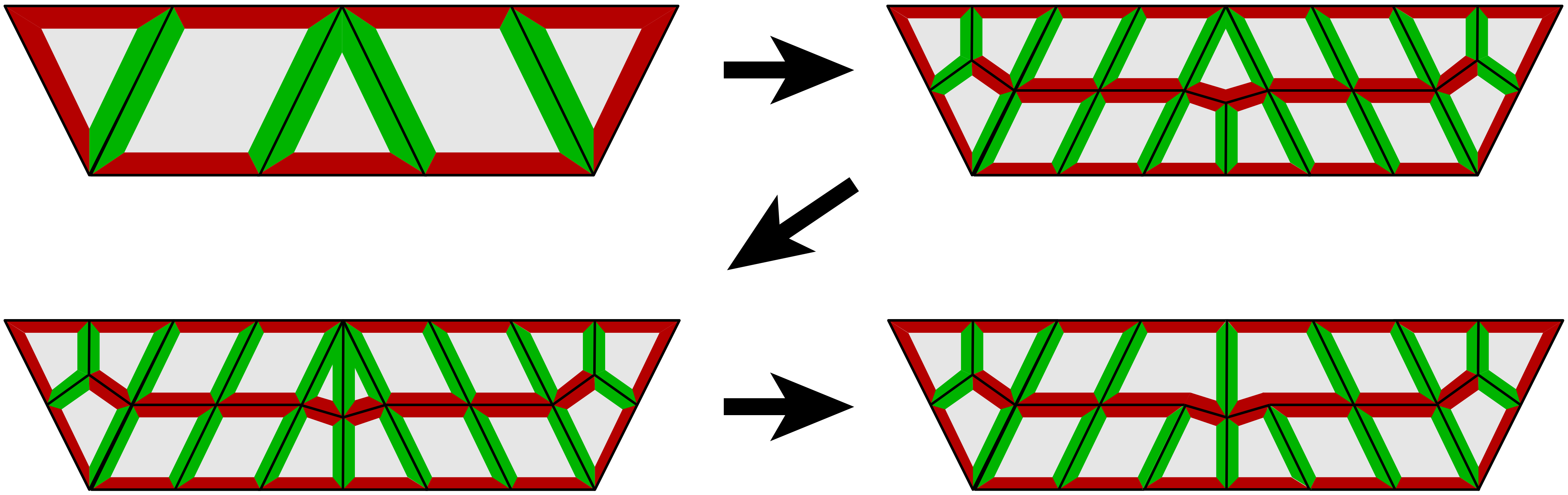
Stitch Mesh Generation

Subdivide mesh to stitch mesh



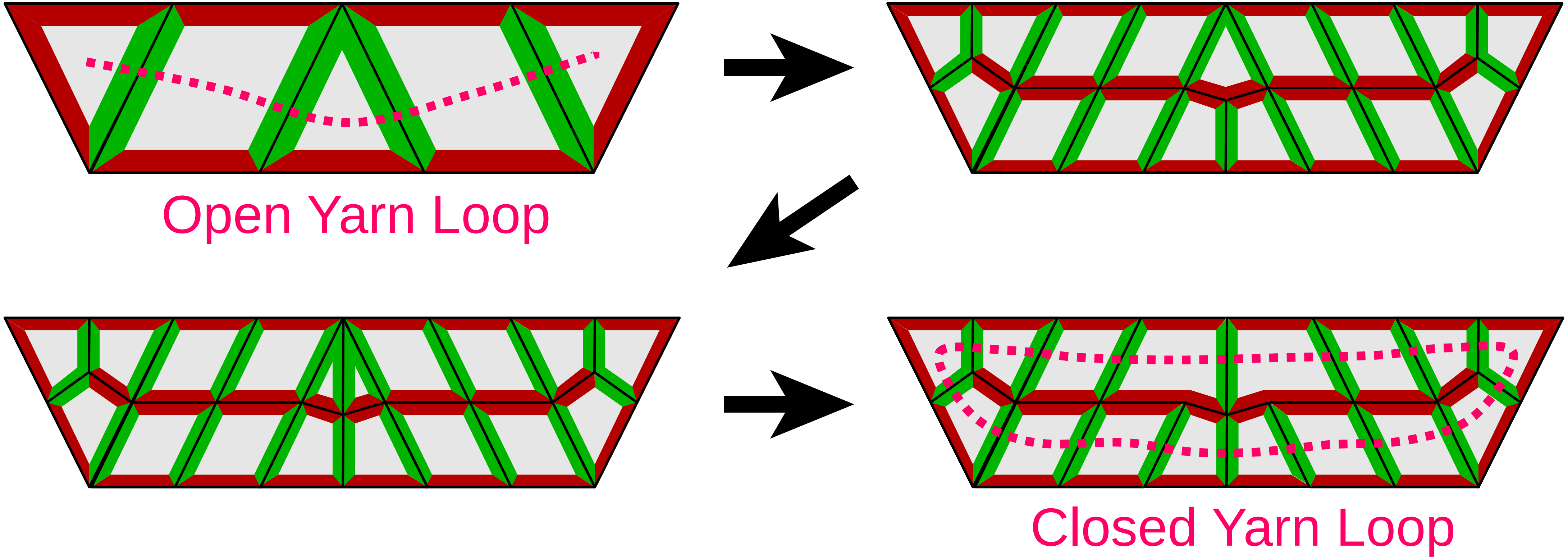
Stitch Mesh Generation

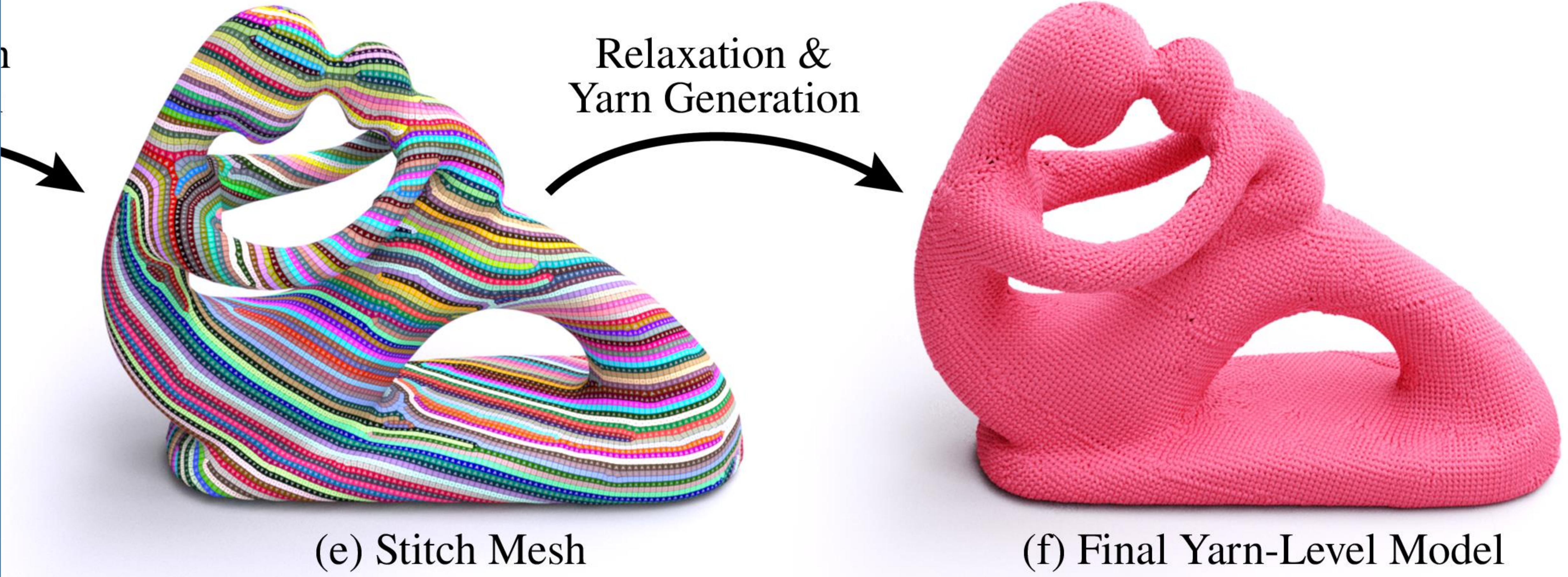
Subdivide mesh to stitch mesh



Stitch Mesh Generation

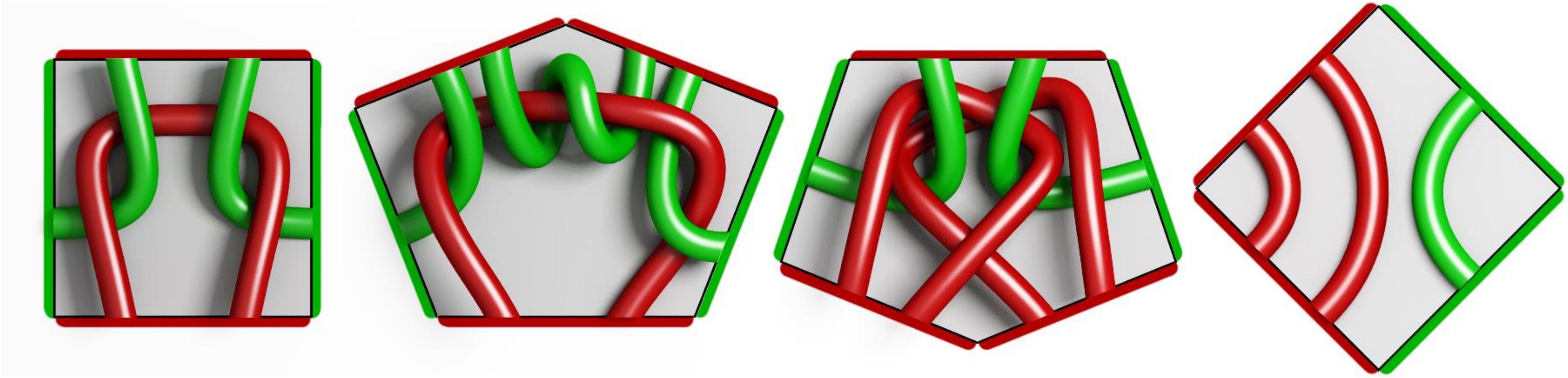
Subdivide mesh to stitch mesh




Relaxation &
Yarn Generation
(e) Stitch Mesh
(f) Final Yarn-Level Model

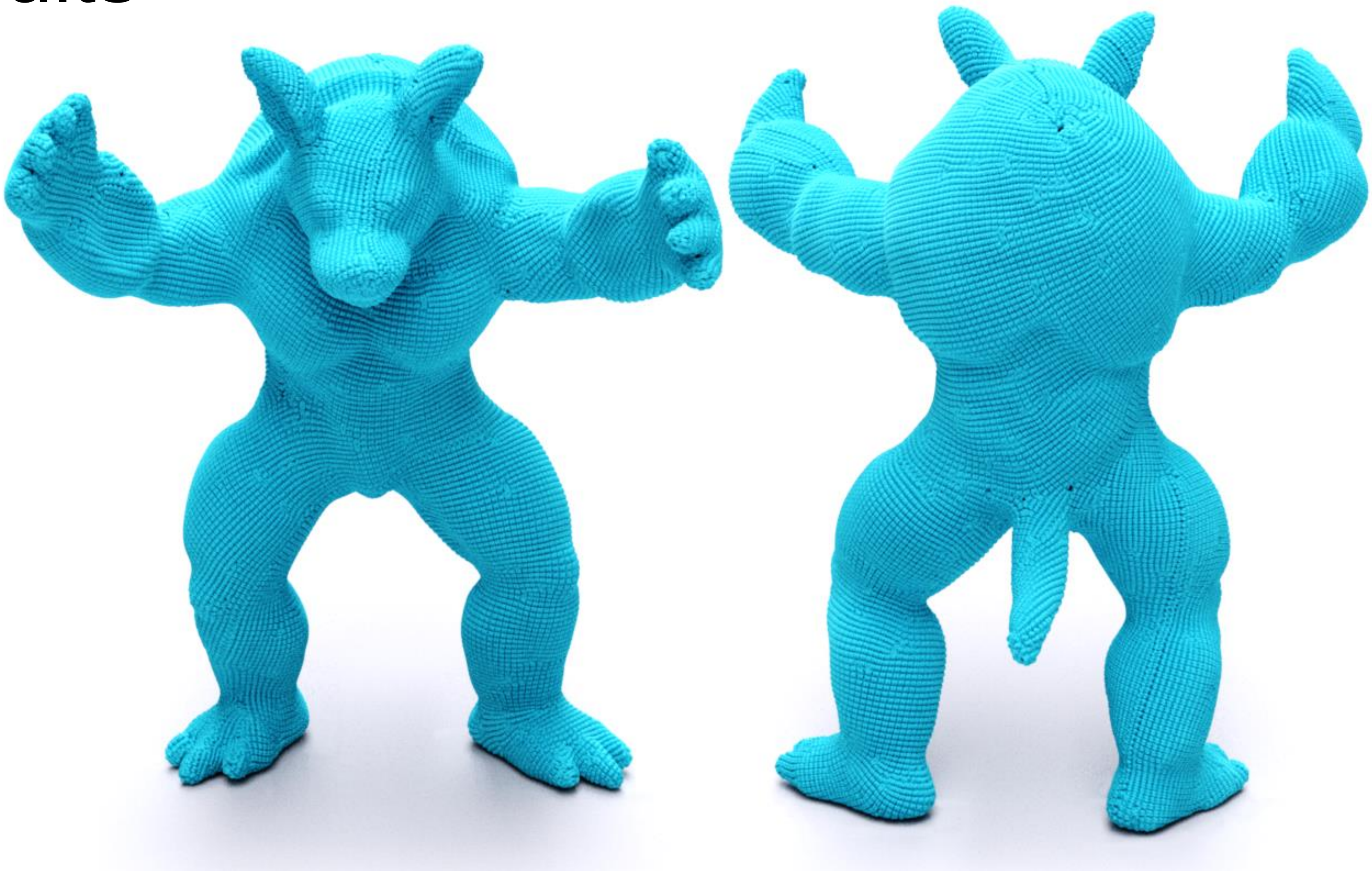
Yarn Generation

Replace stitch mesh face with corresponding yarn loop topology

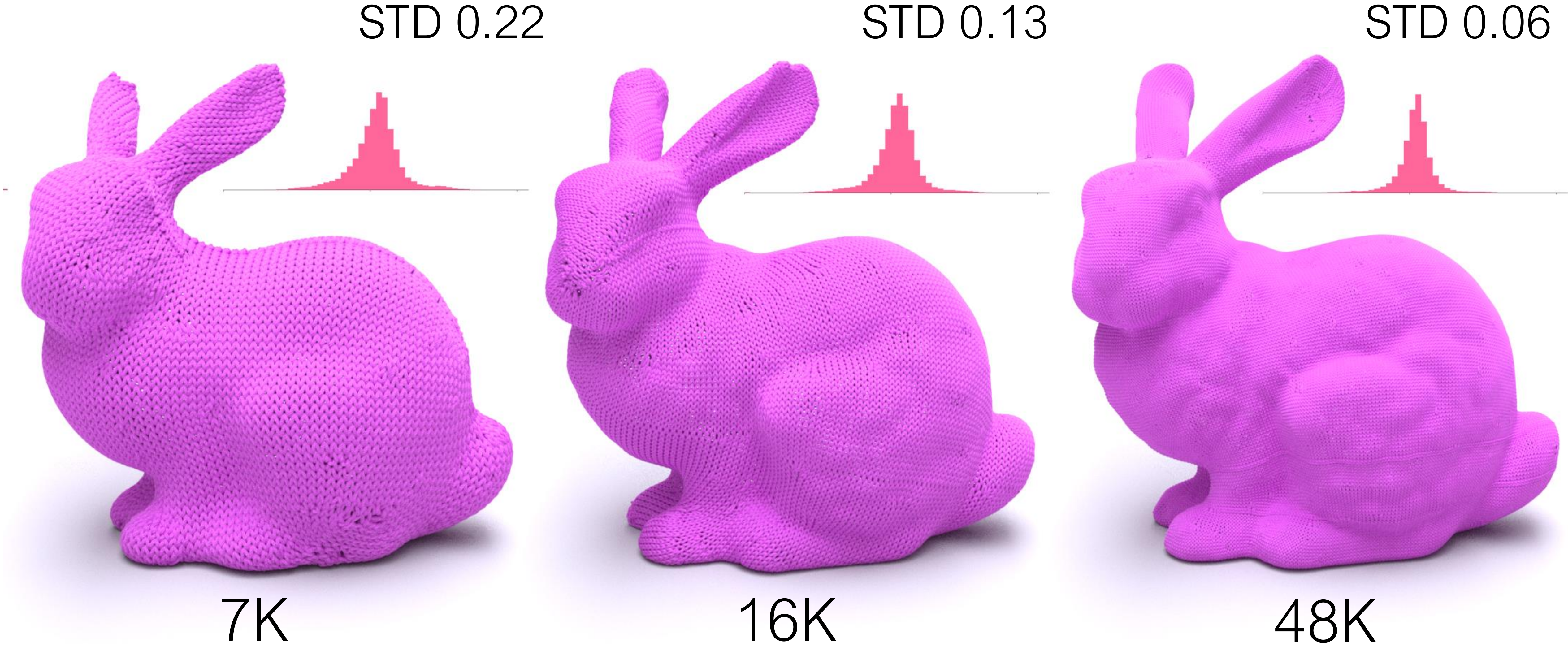


Results

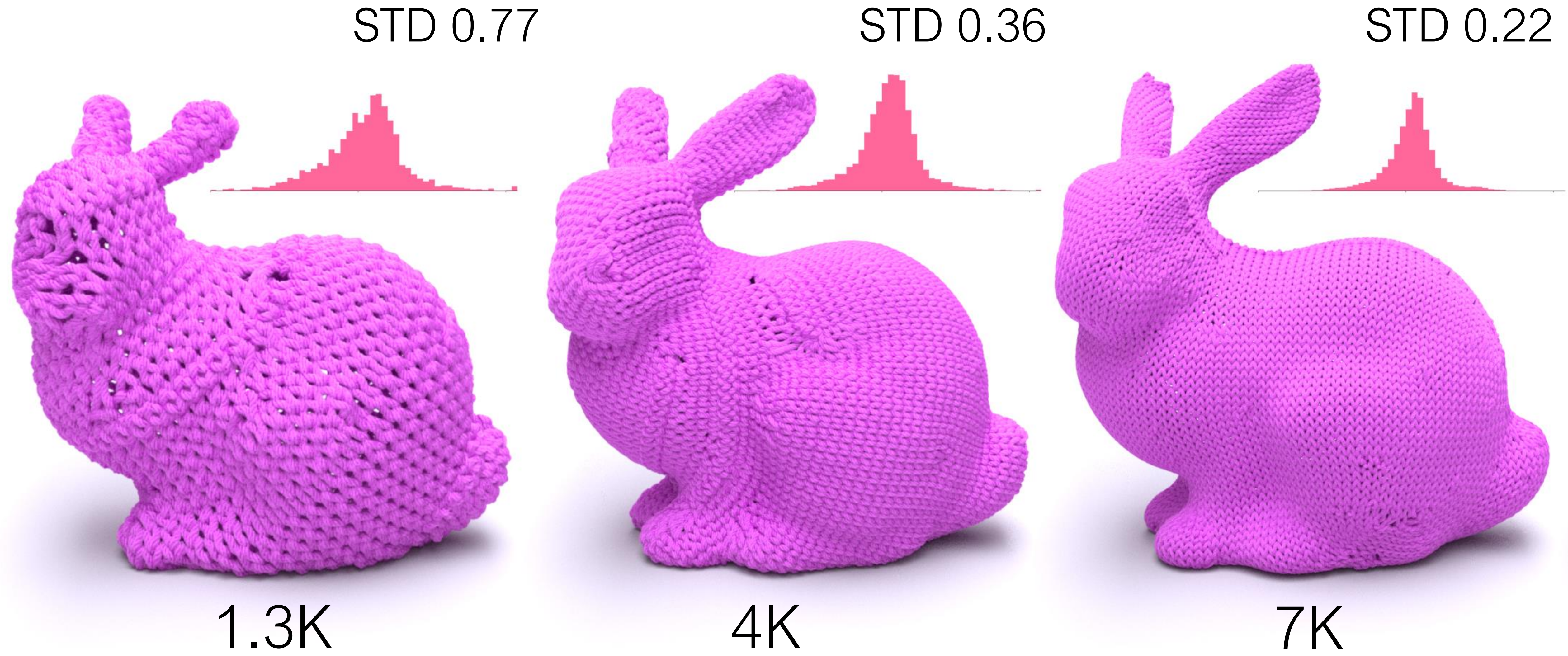
Results



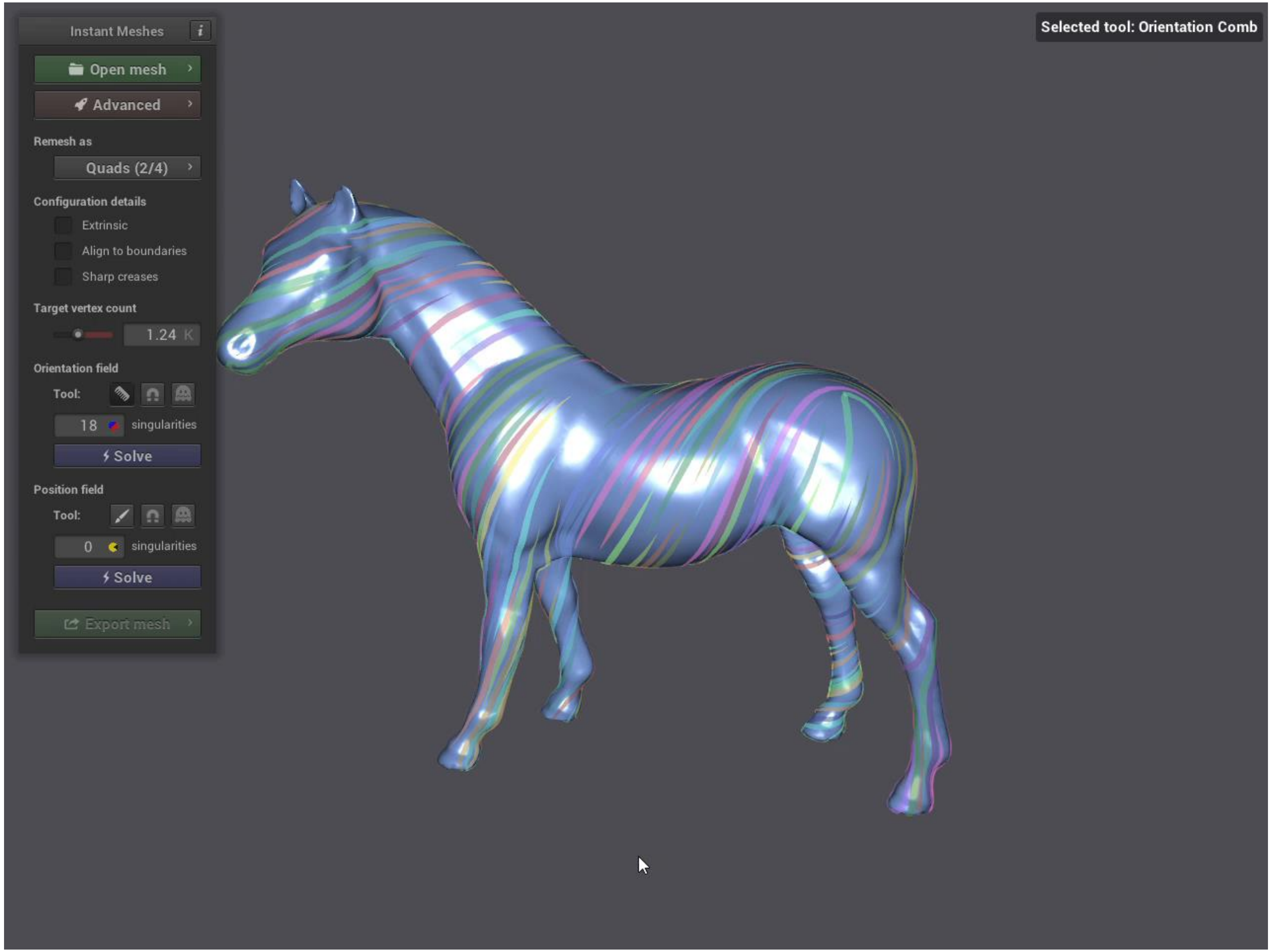
Results



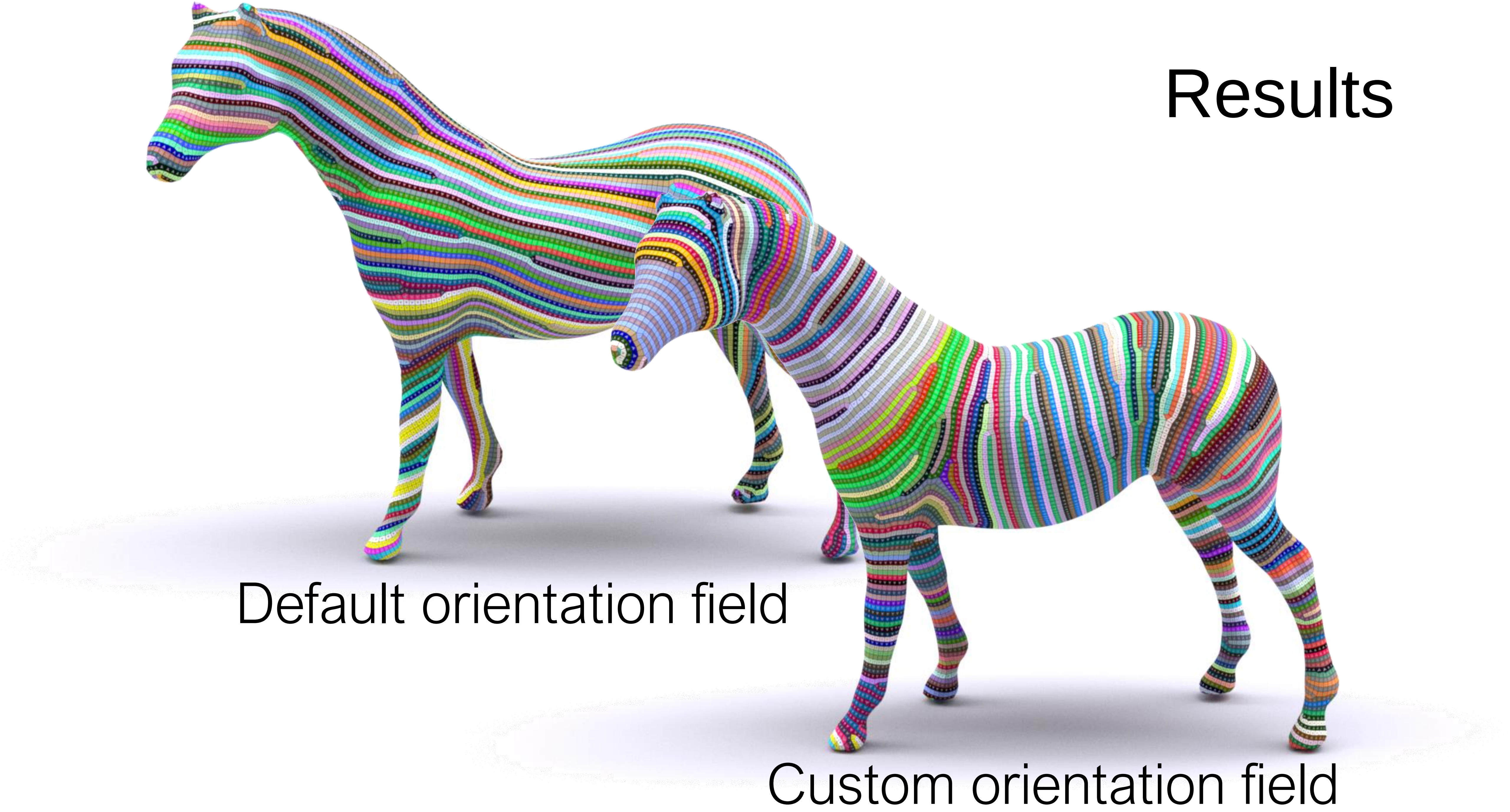
Results



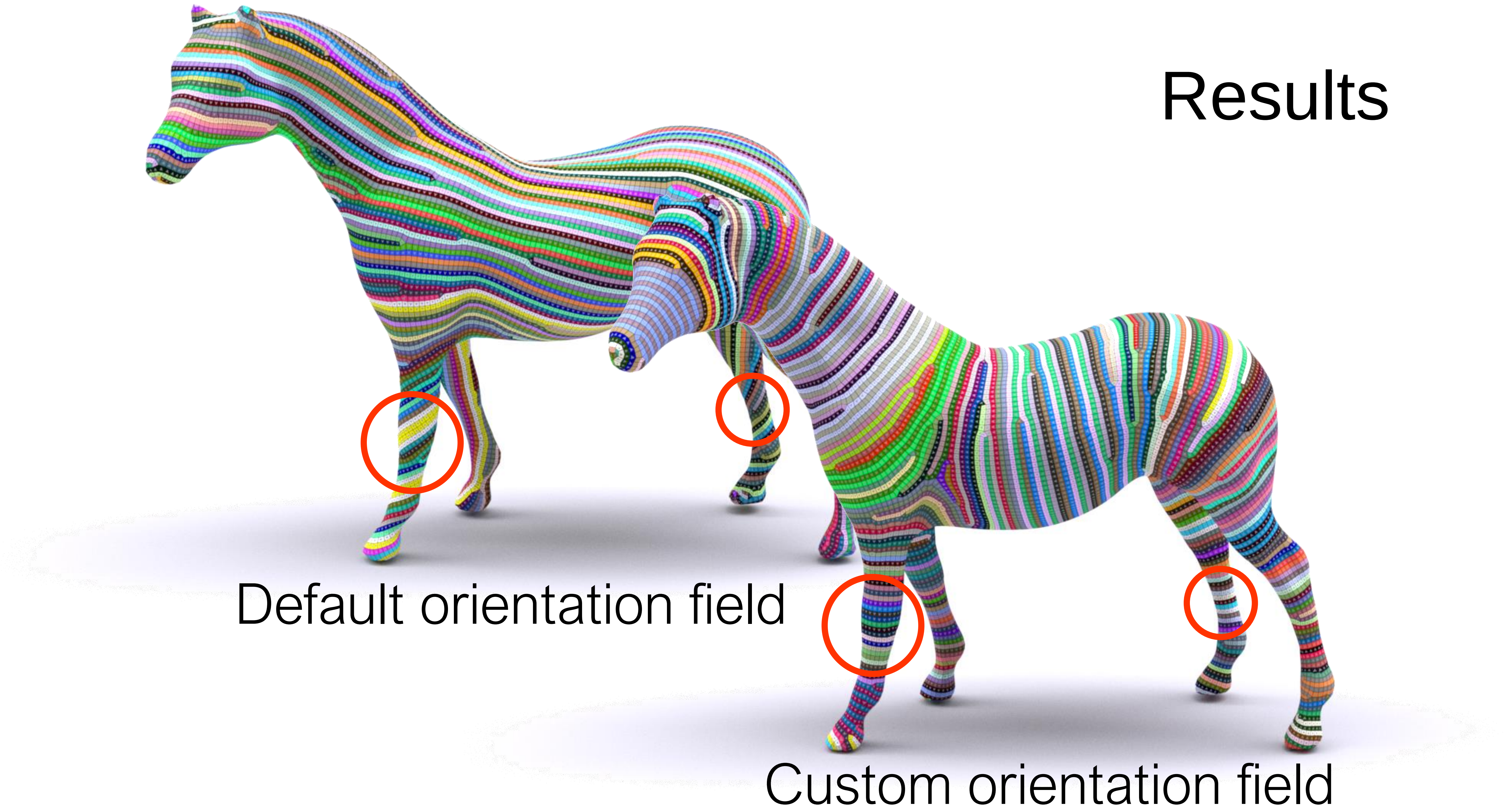
Results


Instant Meshes
Open mesh
Advanced
Remesh as
Quads (2/4)
Configuration details
Extrinsic
Align to boundaries
Sharp creases
Target vertex count
1.24 K
Orientation field
Tool:
18 singularities
Solve
Position field
Tool:
0 singularities
Solve
Export mesh
Selected tool: Orientation Comb

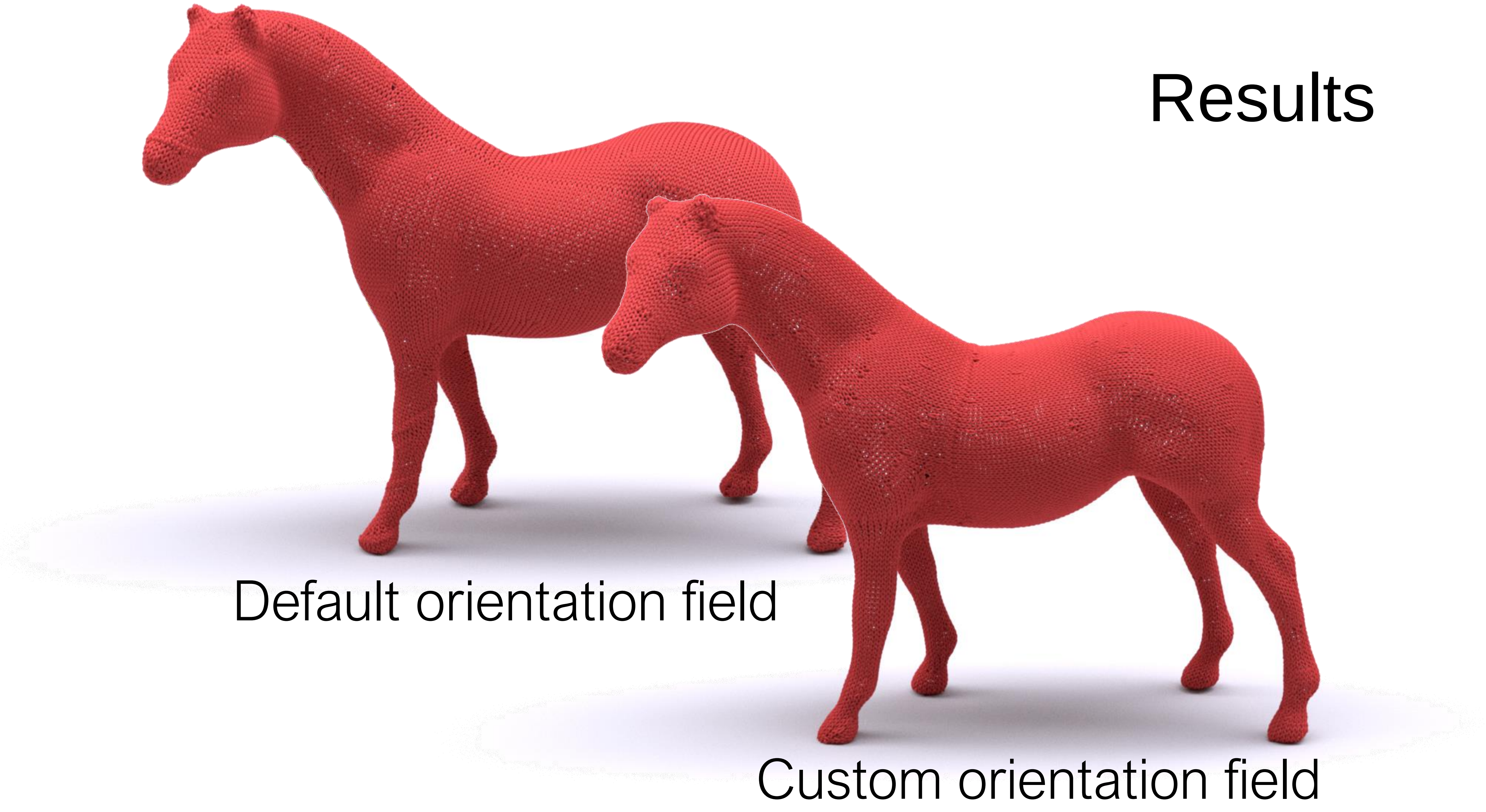
Results



Results



Results



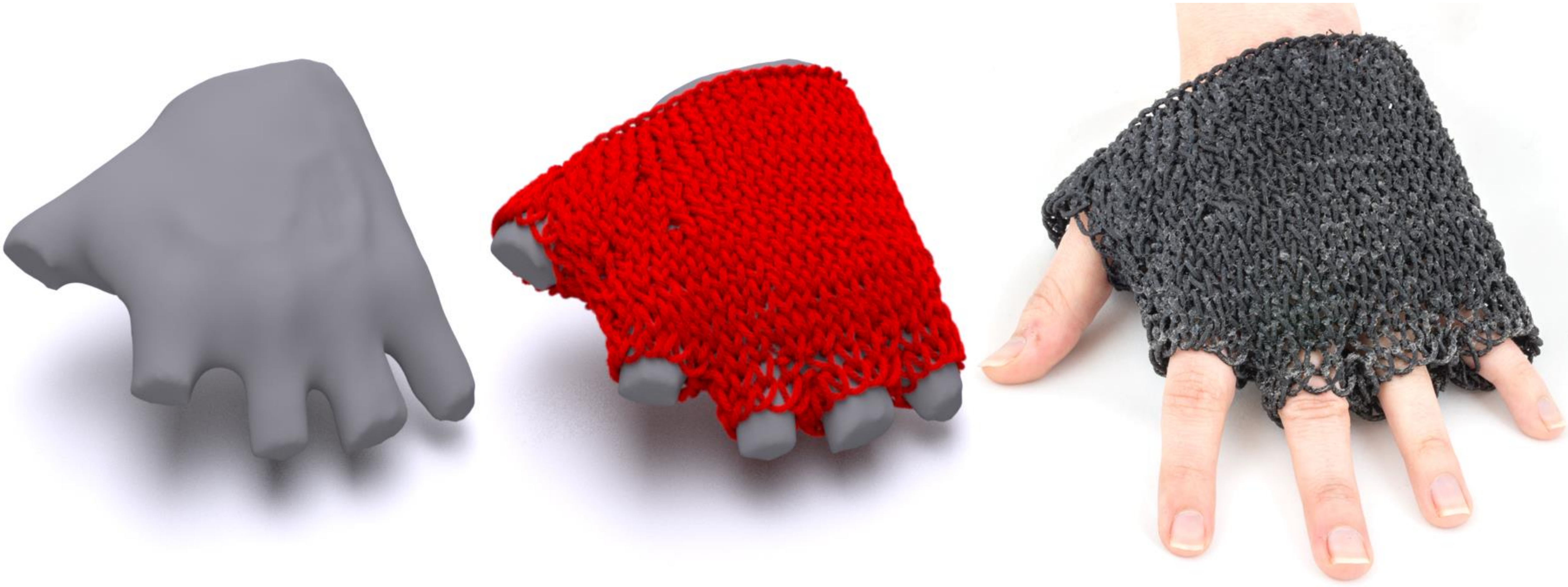
Results

Table 1. ***The computation performance*** *measurements for the steps of our pipeline.*

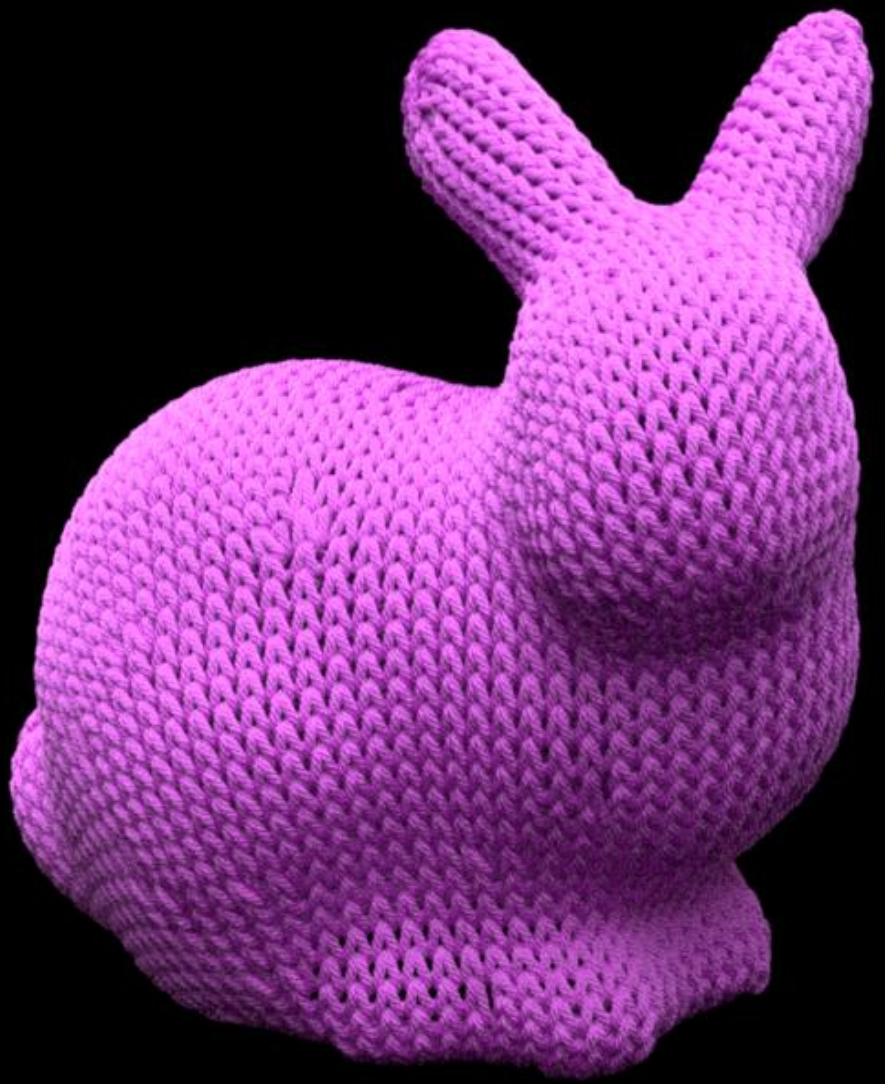
		# Input Faces	# Mesh Faces	# Stitch Faces	**Remesh**	**Labeling**	**K. Direction Assignment**	**Stitch Mesh Gen.**	**Mesh-based Relaxation**	**Yarn Gen.**	**Yarn-level Relaxation**
Rocker Arm	(Fig.19a)	62K	2,018	7,880	2 s	8 s	99 ms	593 ms	12 s	18 ms	2 hr
Rocker Arm	(Fig.19b)	62K	2,037	7,790	2 s	4 s	127 ms	583 ms	9 s	22 ms	2 hr
Chinese Lion	(Fig.1)	100K	3,495	13,606	4 s	19 s	198 ms	1,049 ms	18 s	39 ms	2 hr*
Kitten	(Fig.1)	100K	3,690	14,460	4 s	16 s	124 ms	1,083 ms	16 s	37 ms	3 hr
Dragon	(Fig.1)	104K	4,218	16,458	4 s	26 s	370 ms	1,234 ms	53 s	35 ms	4 hr*
Horse	(Fig.20a)	134K	4,640	18,172	6 s	17 s	159 ms	1,297 ms	25 s	55 ms	2 hr
Horse	(Fig.20b)	134K	4,655	18,160	6 s	18 s	306 ms	1,311 ms	45 s	52 ms	2 hr
Elephant	(Fig.1)	299K	4,791	18,686	13 s	26 s	237 ms	1,421 ms	28 s	51 ms	2 hr
Fertility	(Fig.3)	167K	4,979	19,490	8 s	32 s	192 ms	1,495 ms	46 s	54 ms	1 hr*
Armadillo	(Fig.17)	280K	6,591	25,734	13 s	58 s	567 ms	1,963 ms	88 s	77 ms	2 hr*
Bunny (1.3K)	(Fig.16)	111K	353	1392	4 s	2 s	45 ms	119 ms	6 s	4 ms	<1 hr
Bunny (4K)	(Fig.16)	111K	1059	4124	4 s	2 s	66 ms	315 ms	8 s	12 ms	<1 hr
Bunny (7K)	(Fig.16)	111K	1,821	7,090	4 s	2 s	131 ms	550 ms	10 s	19 ms	1 hr*
Bunny (16K)	(Fig.16)	111K	4,003	15,704	5 s	16 s	147 ms	1101 ms	12 s	45 ms	2 hr
Bunny (48K)	(Fig.16)	406K	12,195	48,096	37 s	84 s	399 ms	3526 ms	130 s	159 ms	3 hr*

The computation times are generated using a computer with Intel Core i7 6700HQ CPU @ 2.60 GHz with 16 GB RAM.
** Yarn-level relaxation timings are generated using a computer with Intel Core i7 3930K CPU @ 3.20 GHz with 32 GB RAM.*

Customized 3D Print Glove



3D Print Octopus Sweater




Results

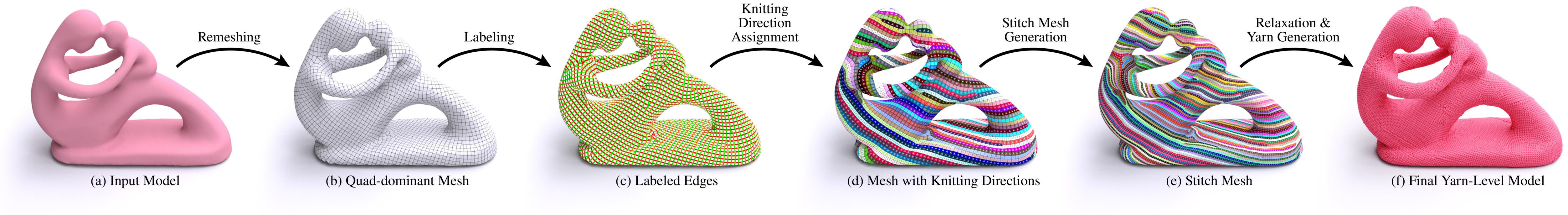
Results

Results

Tests with 106 models

Conclusion

We introduce the first fully automatic pipeline to convert arbitrary 3D shapes into knit models.

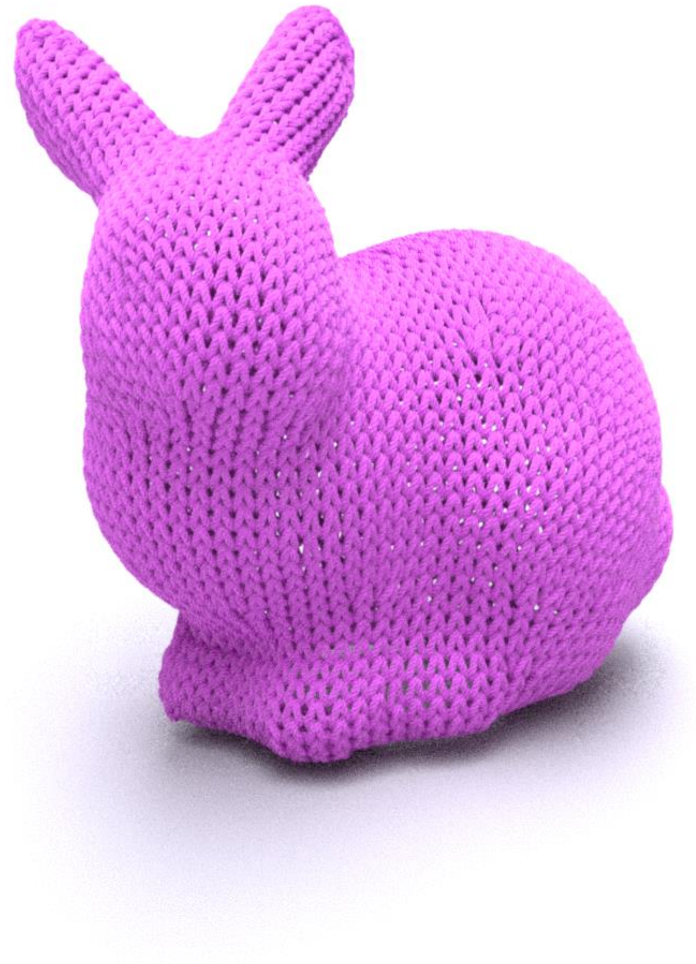


Future Work

Convert knitted structure to knittable structure

Hand Knitting

Machine Knitting



Thanks!

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Email: kwu@cs.utah.edu