Stitch Meshes for Knitting Design

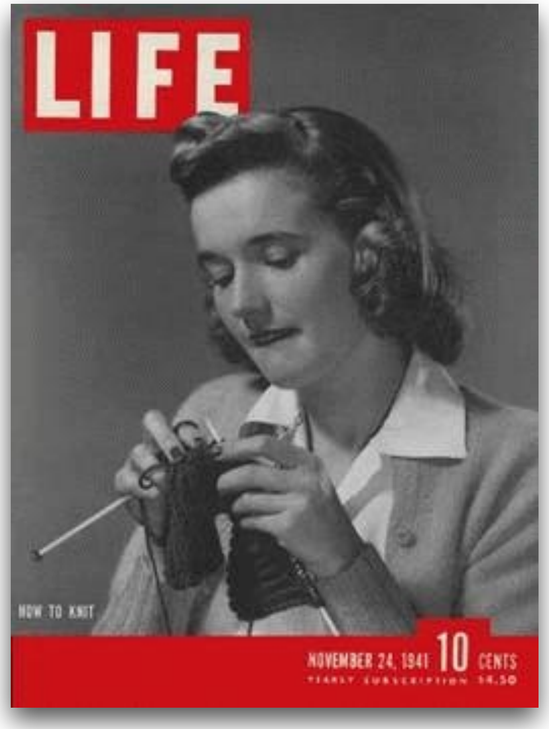
Kui Wu

MIT

Knitting has a long history

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

Madonna Knitting
by Bertram of Minden
1400 - 1410



Life magazine's cover story
November 24, 1941

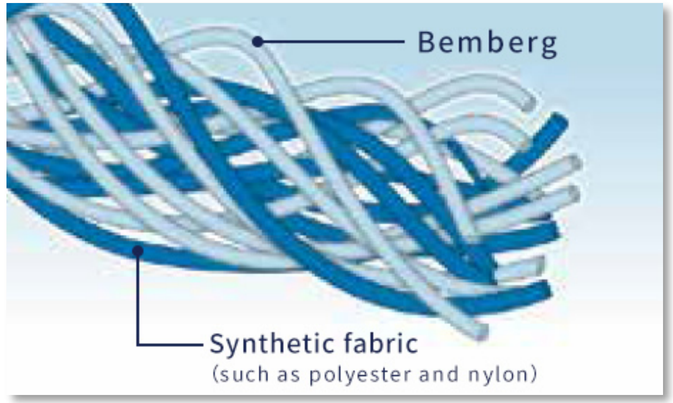
Knitting is everywhere

Paris Fashion Week, Fall/Winter 2016/17

Why knitting?

Stretchable

Credit: AsahiKASEI



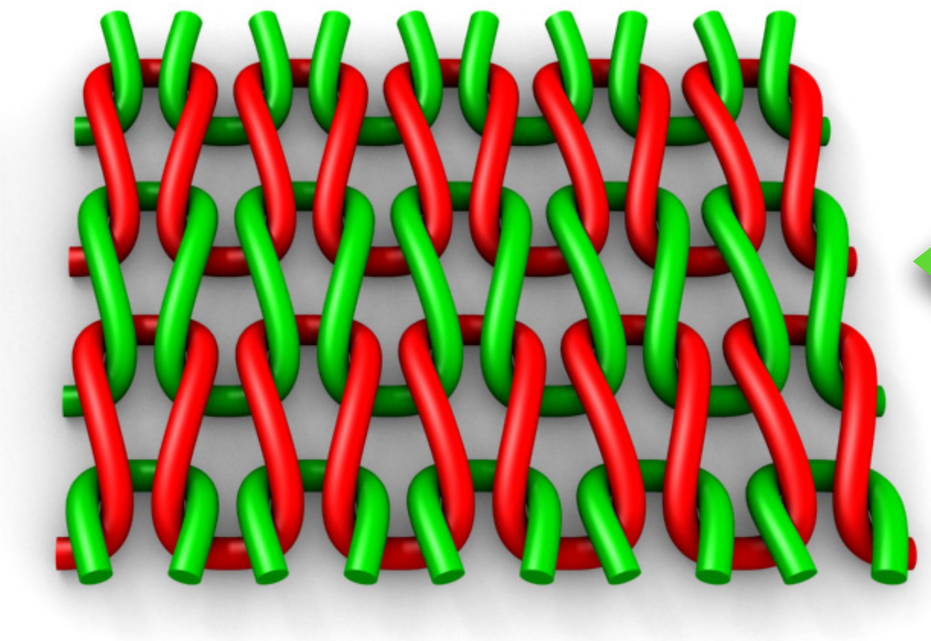
Composite material

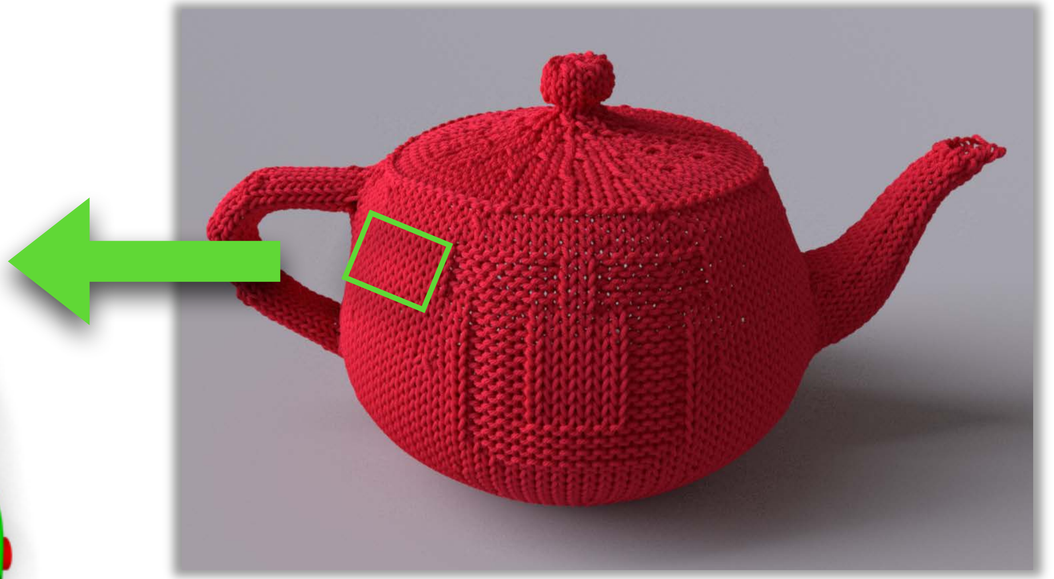
Structural continuity

Pattern -> mircostructure

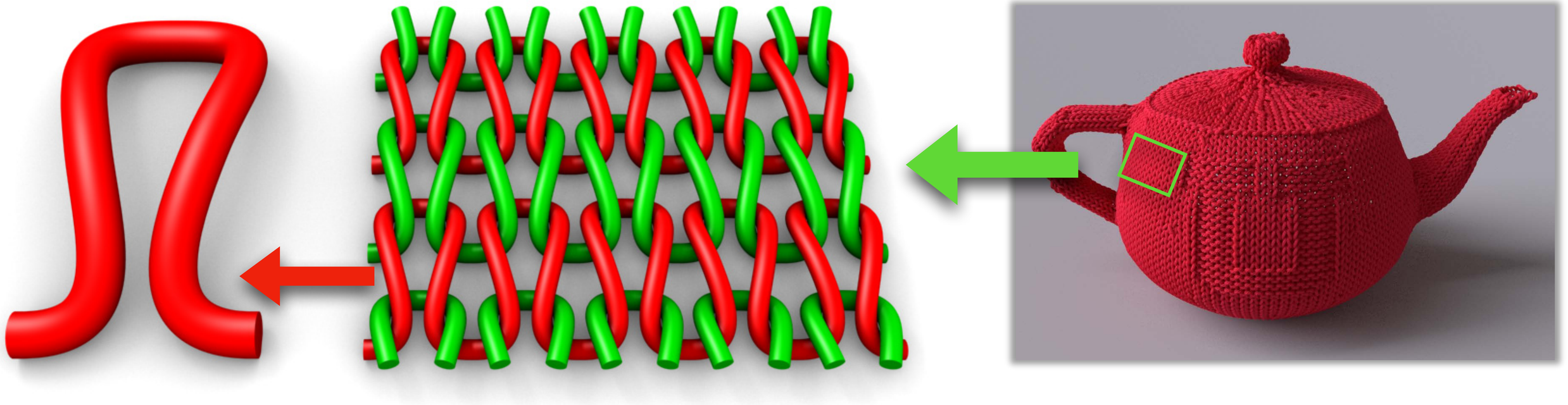
Geometric Structure

Geometric Structure





Geometric Structure



Various Knitting Patterns & Shapes

[Leaf et al. ’18]

[Underwood ’09]

Knittable Stitch Meshes

Kui Wu Hannah Swan Cem Yuksel

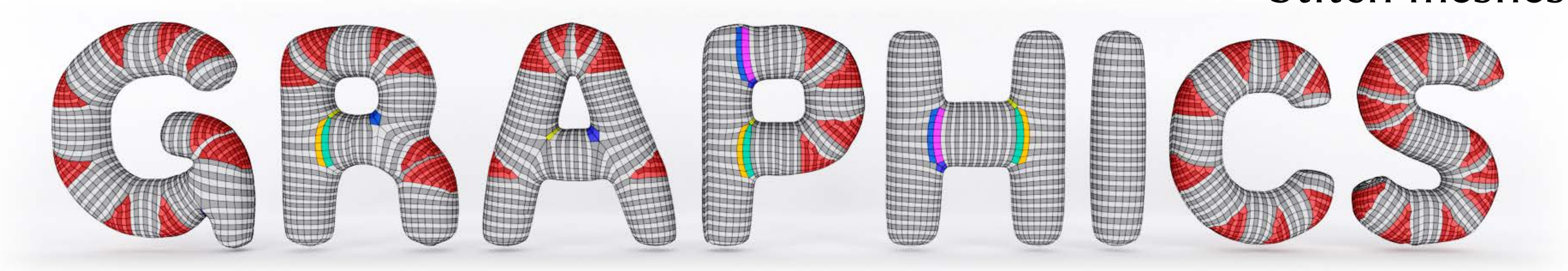
University of Utah

thrive
SIGGRAPH2019
LOS ANGELES • 28 JULY – 1 AUGUST

Stitch Meshes [Yuksel et al. ’12]

Knittable Stitch Mesh

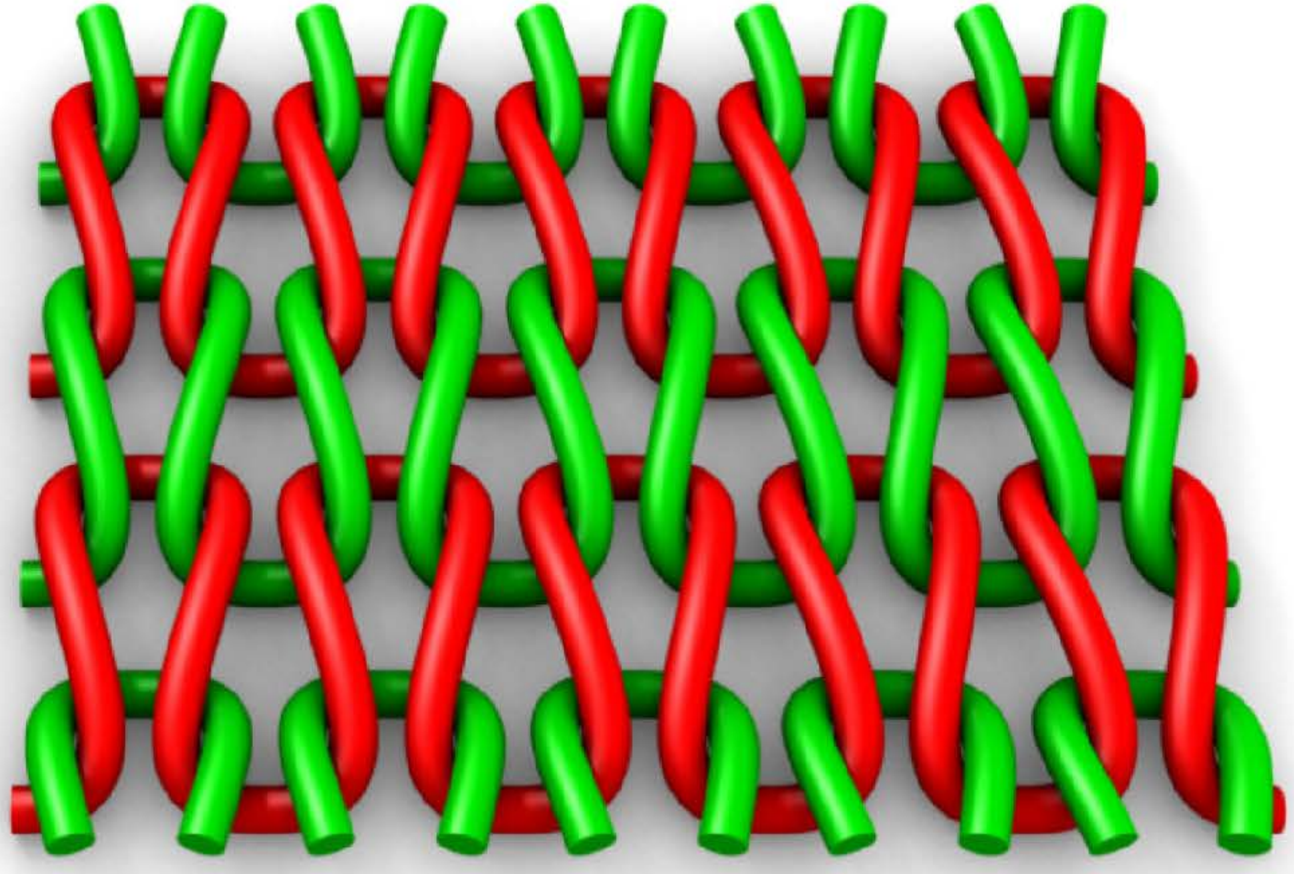
Stitch meshes



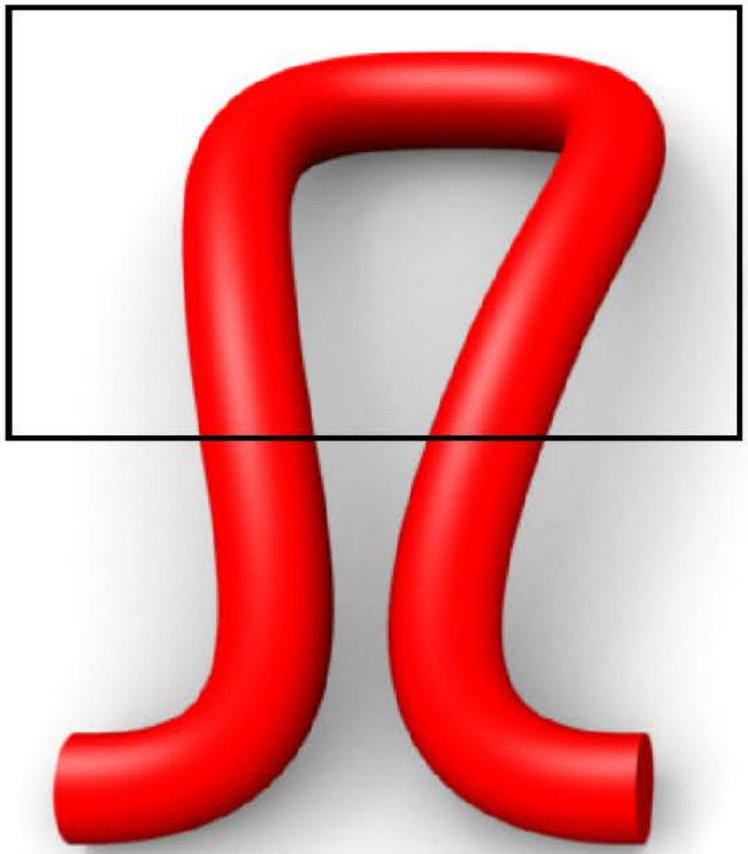
Knitted results

Stitch Meshes [Yuksel et al. ’12]

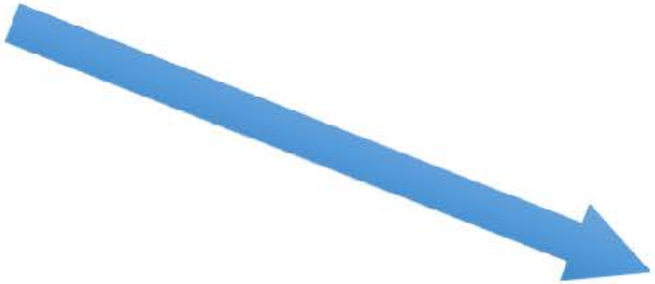
Yarn Loop



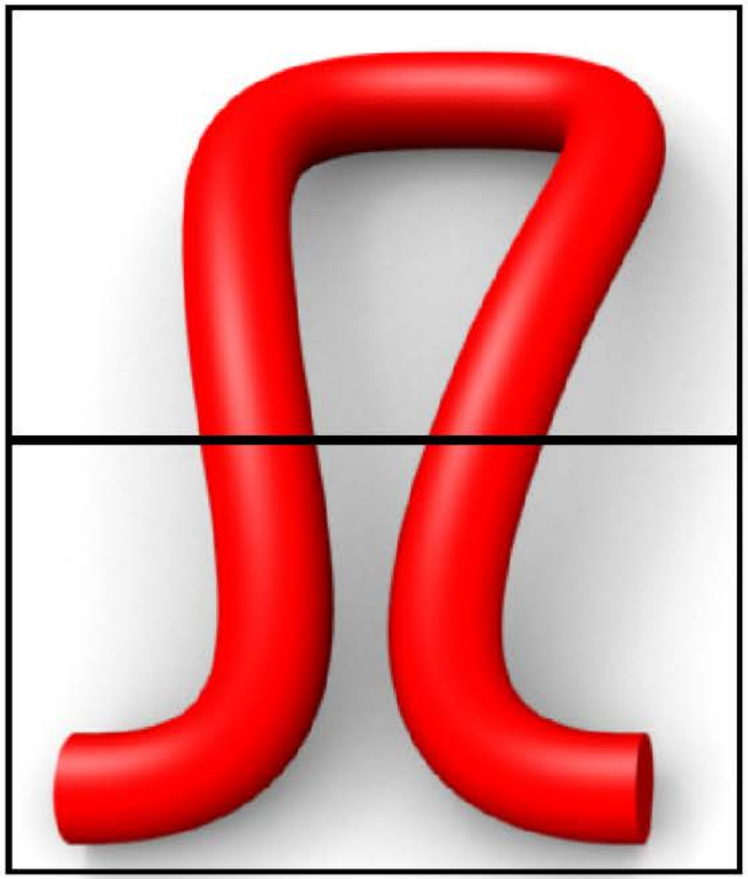
Stitch Meshes [Yuksel et al. ’12]



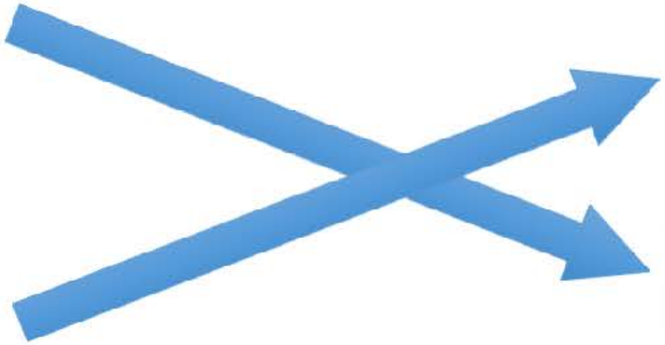
Yarn Loop

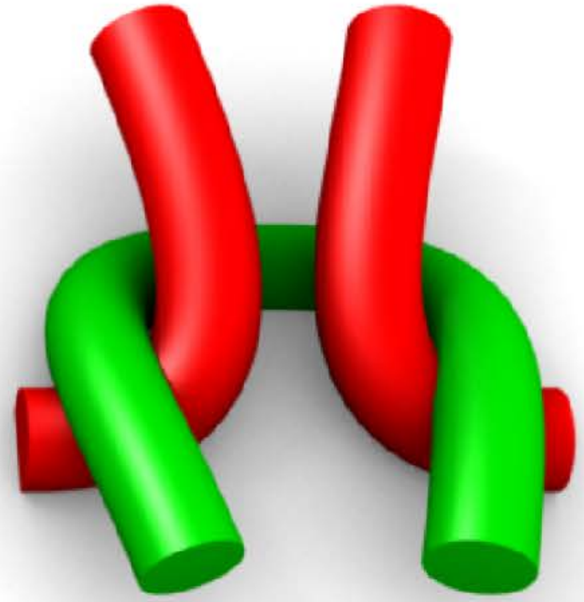


Stitch Meshes [Yuksel et al. ’12]

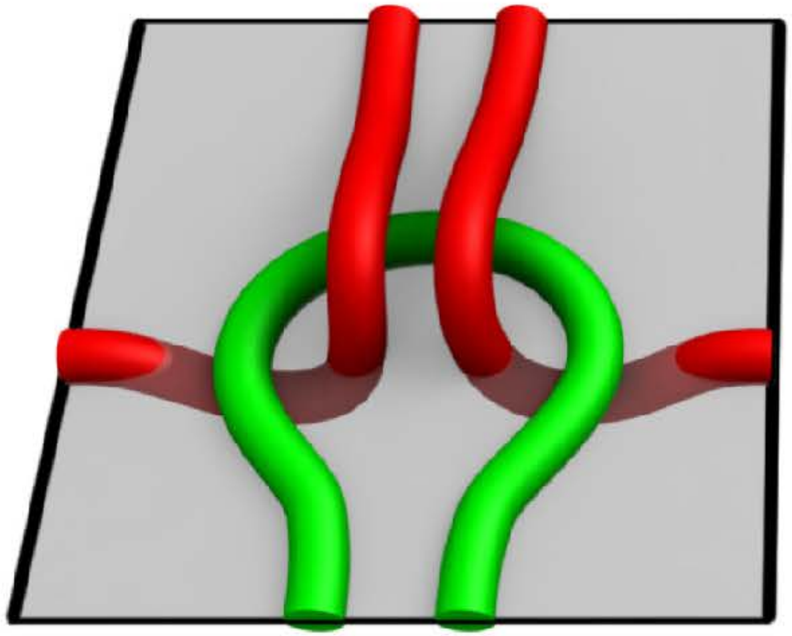


Yarn Loop

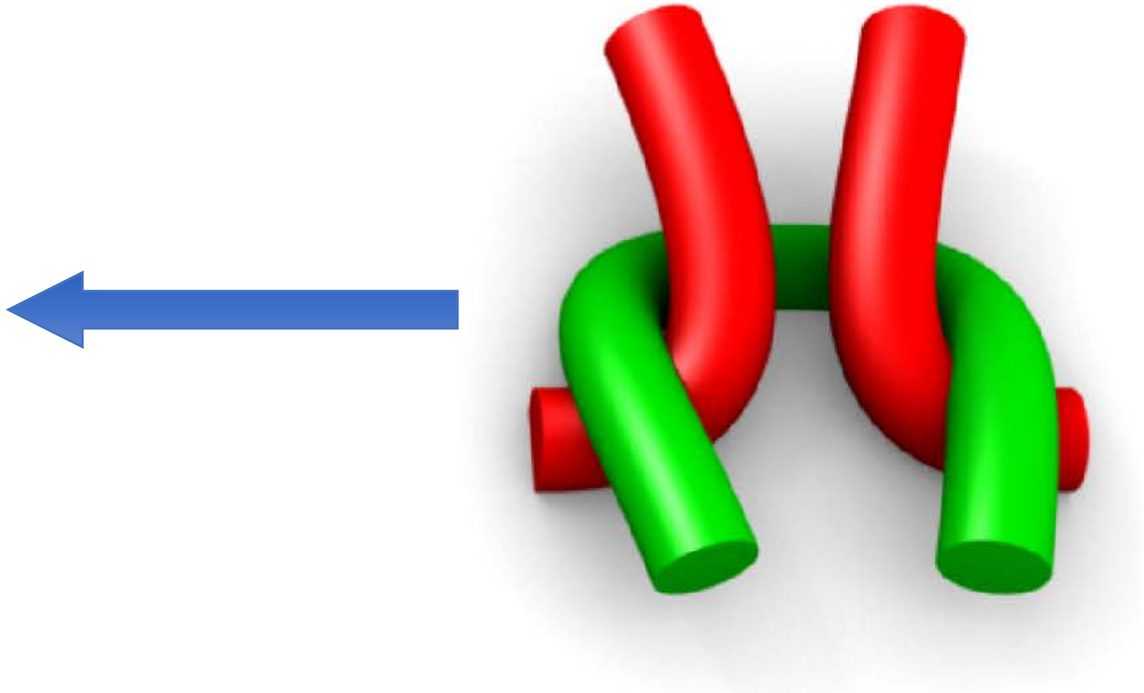




Stitch Meshes [Yuksel et al. ’12]

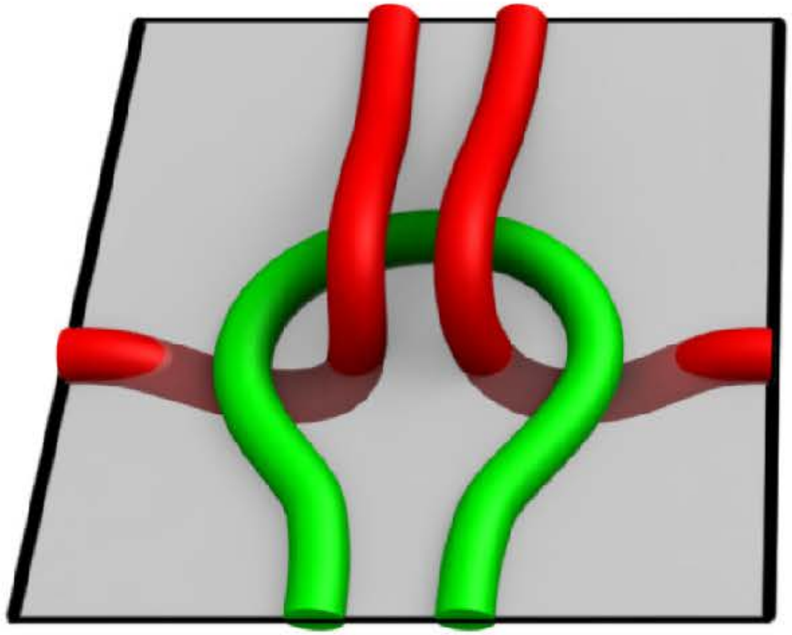


Stitch mesh face



Stitch

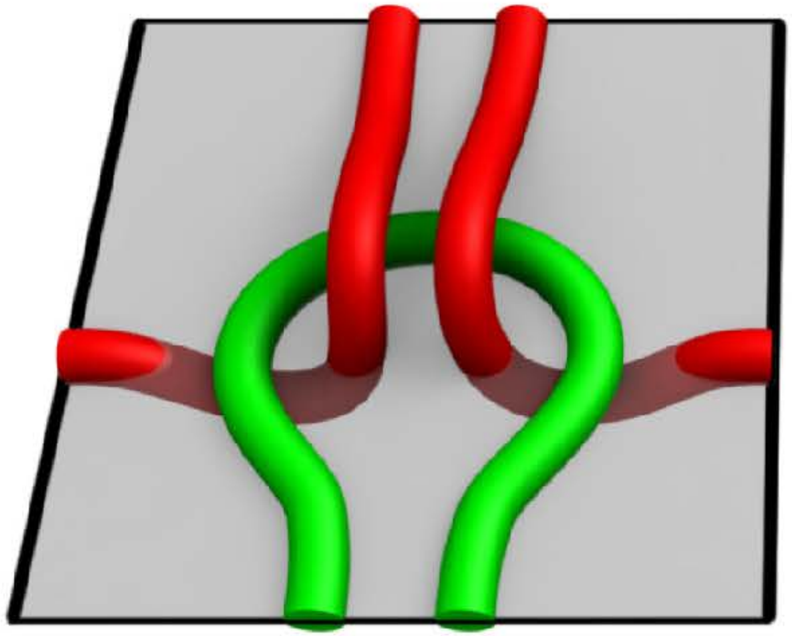
Stitch Meshes [Yuksel et al. ’12]



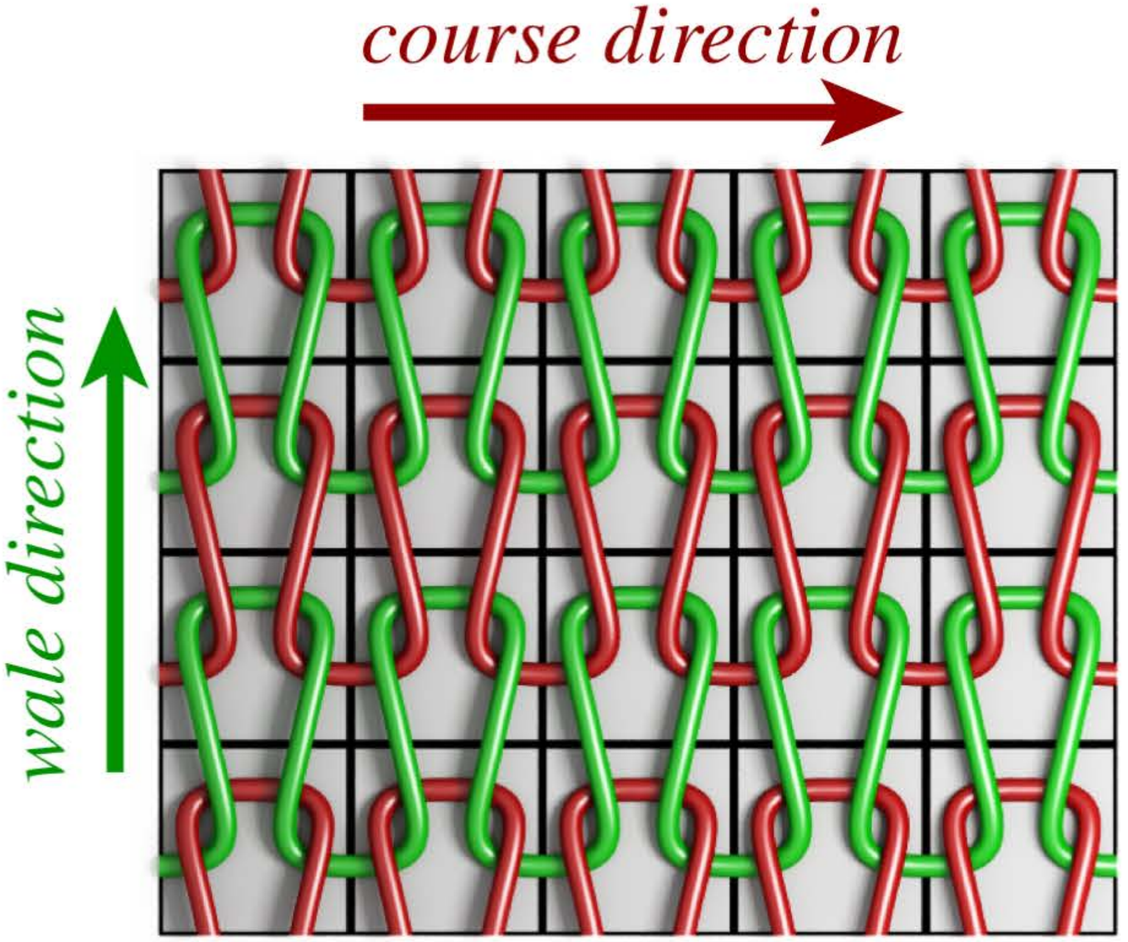
Stitch mesh face

Edge labels

Stitch Meshes [Yuksel et al. '12]



Stitch mesh face



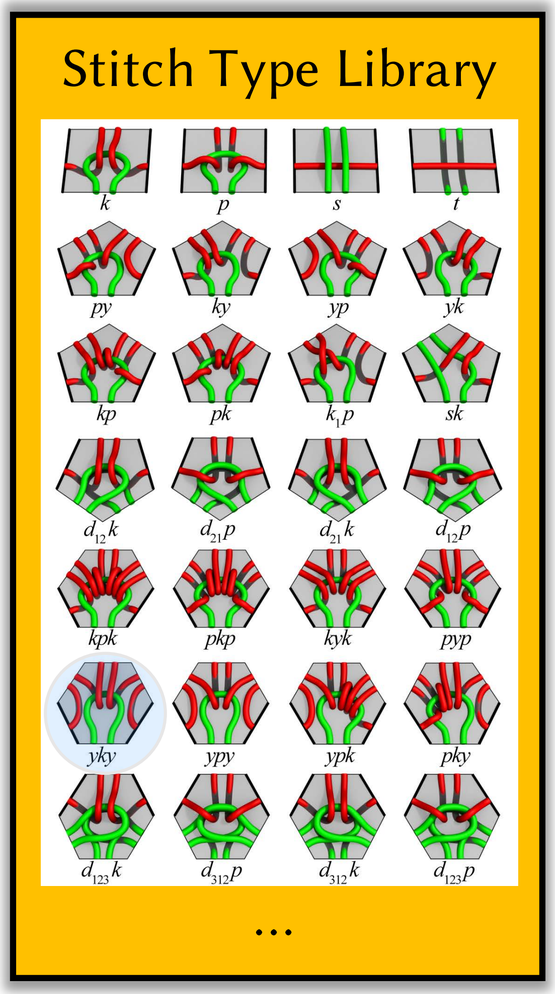
Patch

Stitch Meshes [Yuksel et al. ’12]

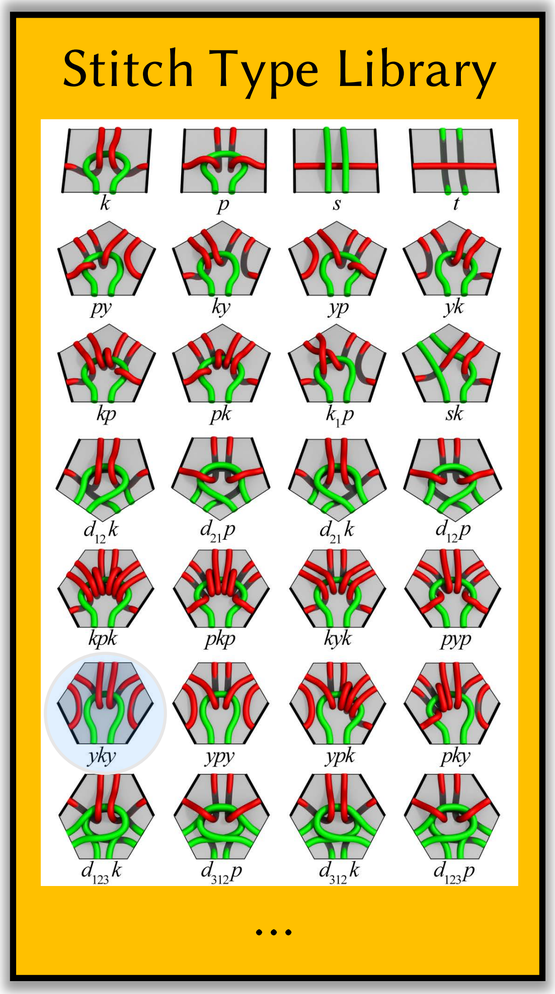
Stitch meshes provide a practical way of modeling knitted structure

Input mesh Labelled mesh Stitch mesh Yarn-level model

Stitch Meshes [Yuksel et al. ’12]

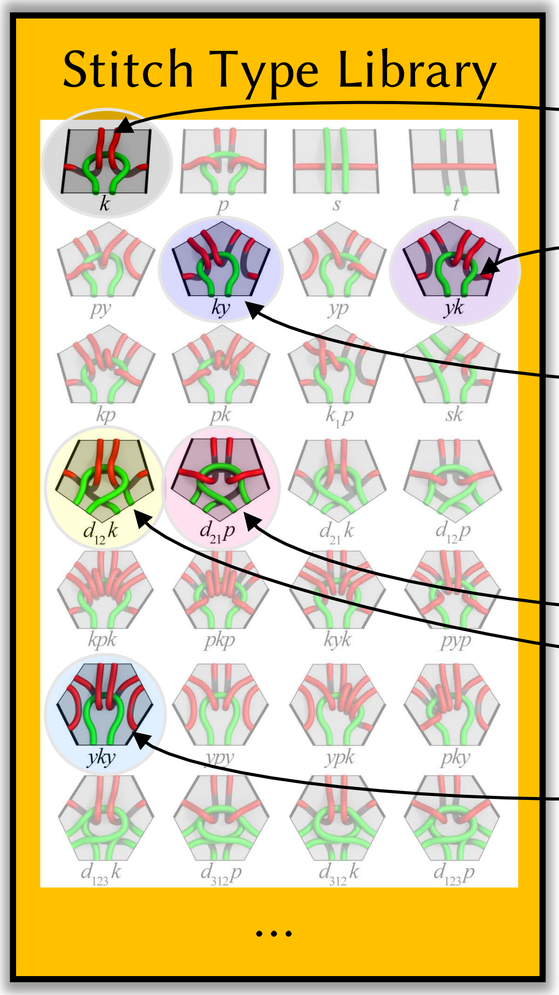


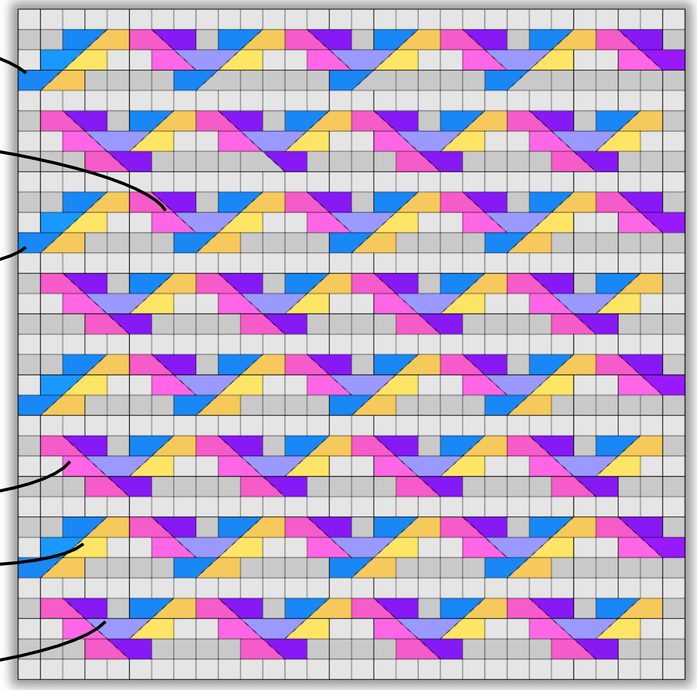
Stitch Meshes [Yuksel et al. ’12]



Openwork Trellis Pattern

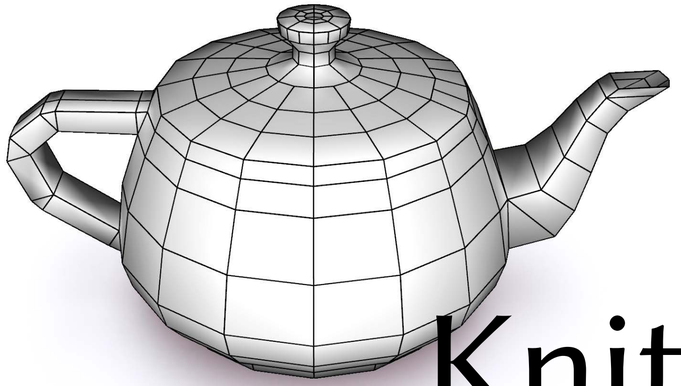
Stitch Meshes [Yuksel et al. '12]





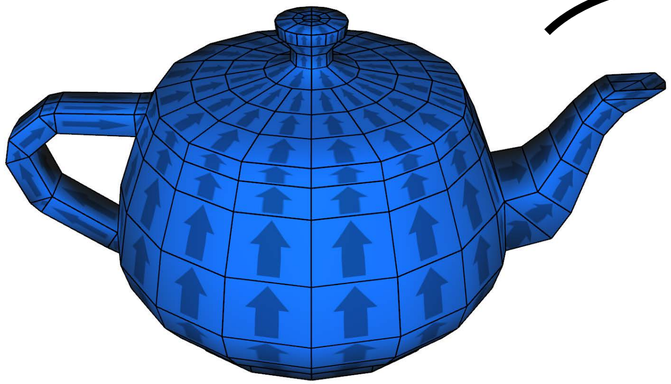
Openwork Trellis Pattern

Knittable Stitch Mesh

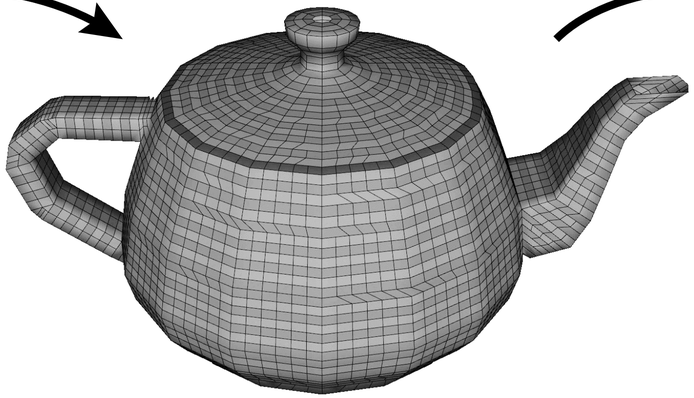


Input mesh

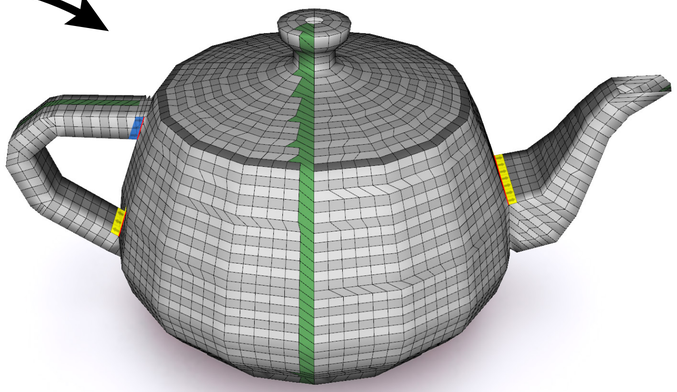
Knitted model



Labelled mesh

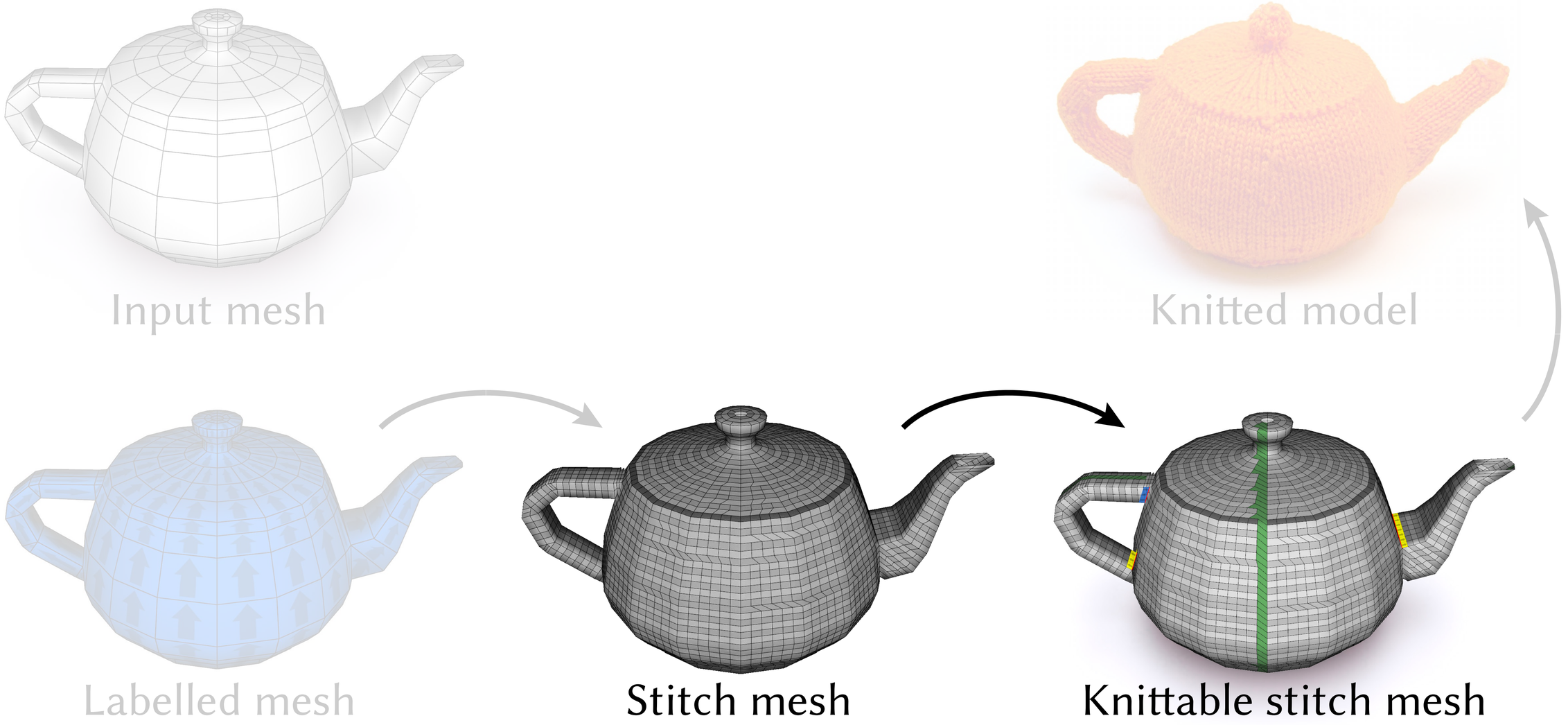


Stitch mesh

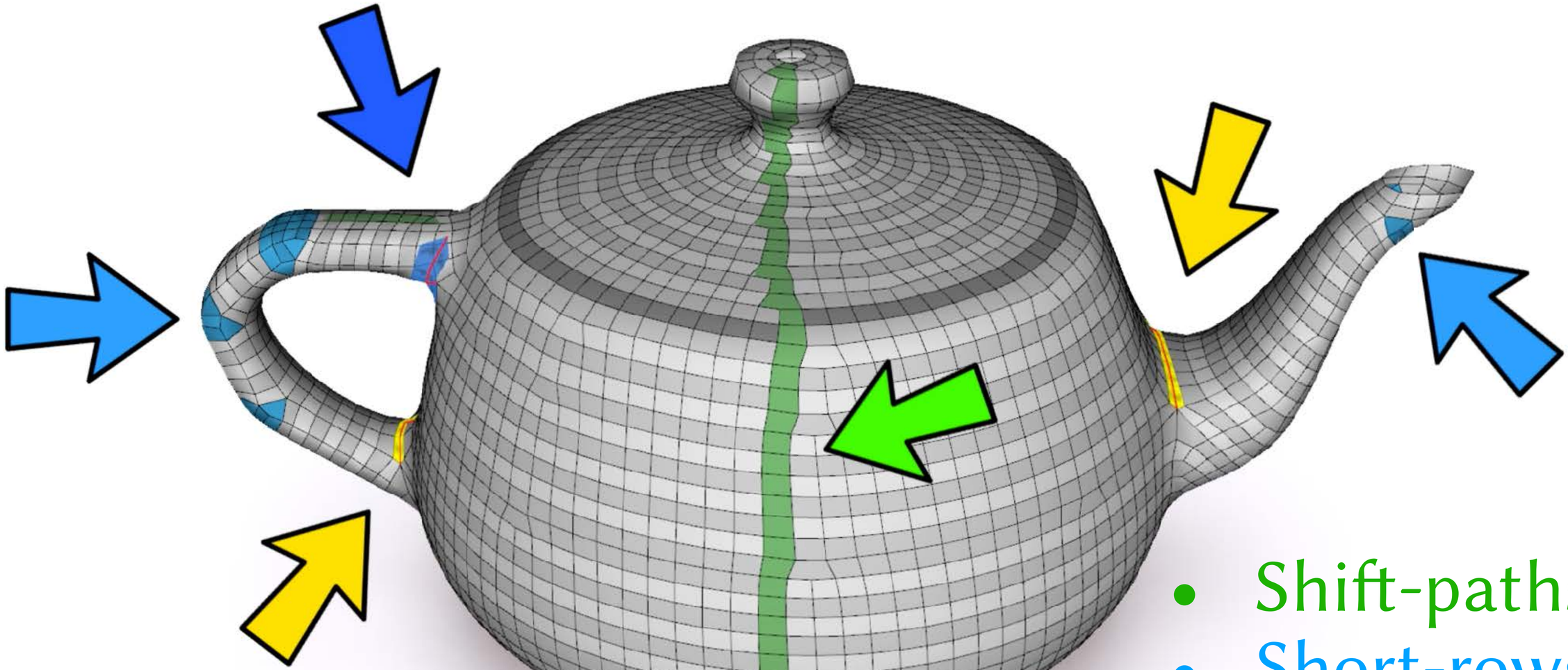


Knittable stitch mesh

Knittable Stitch Mesh

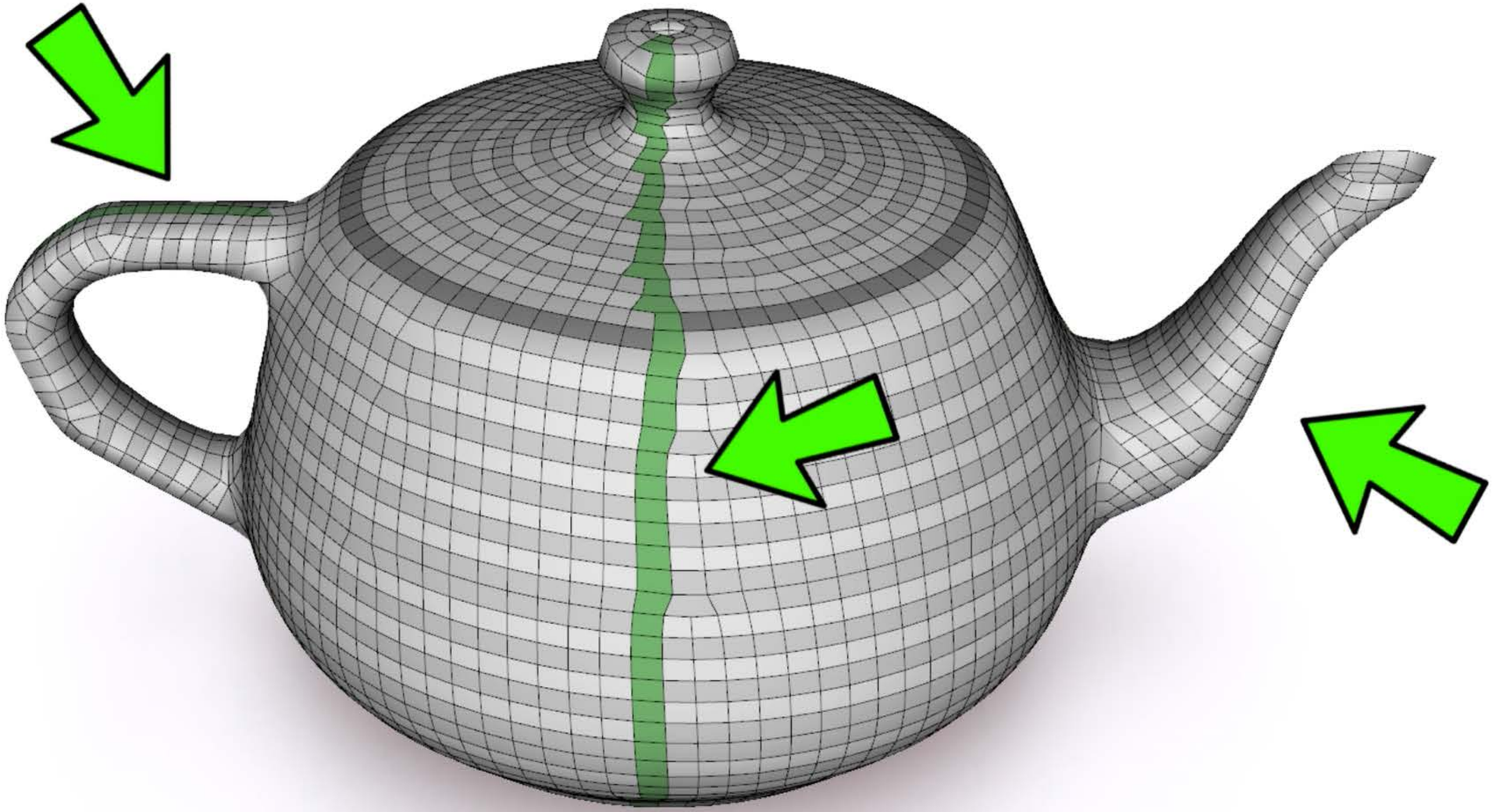


Knittable Stitch Mesh

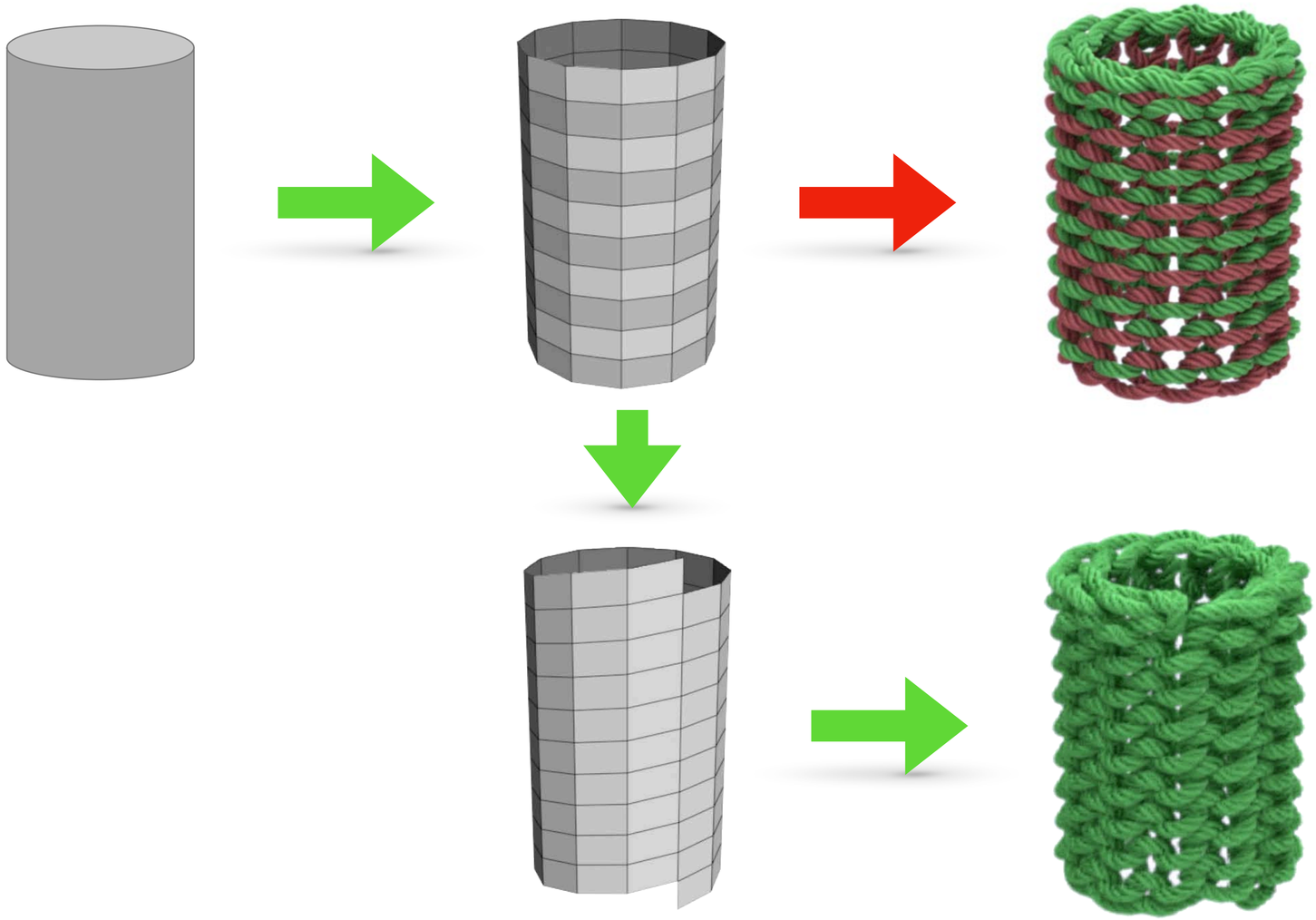


- Shift-paths
- Short-rows
- Knittable mismatch

Shift-Paths



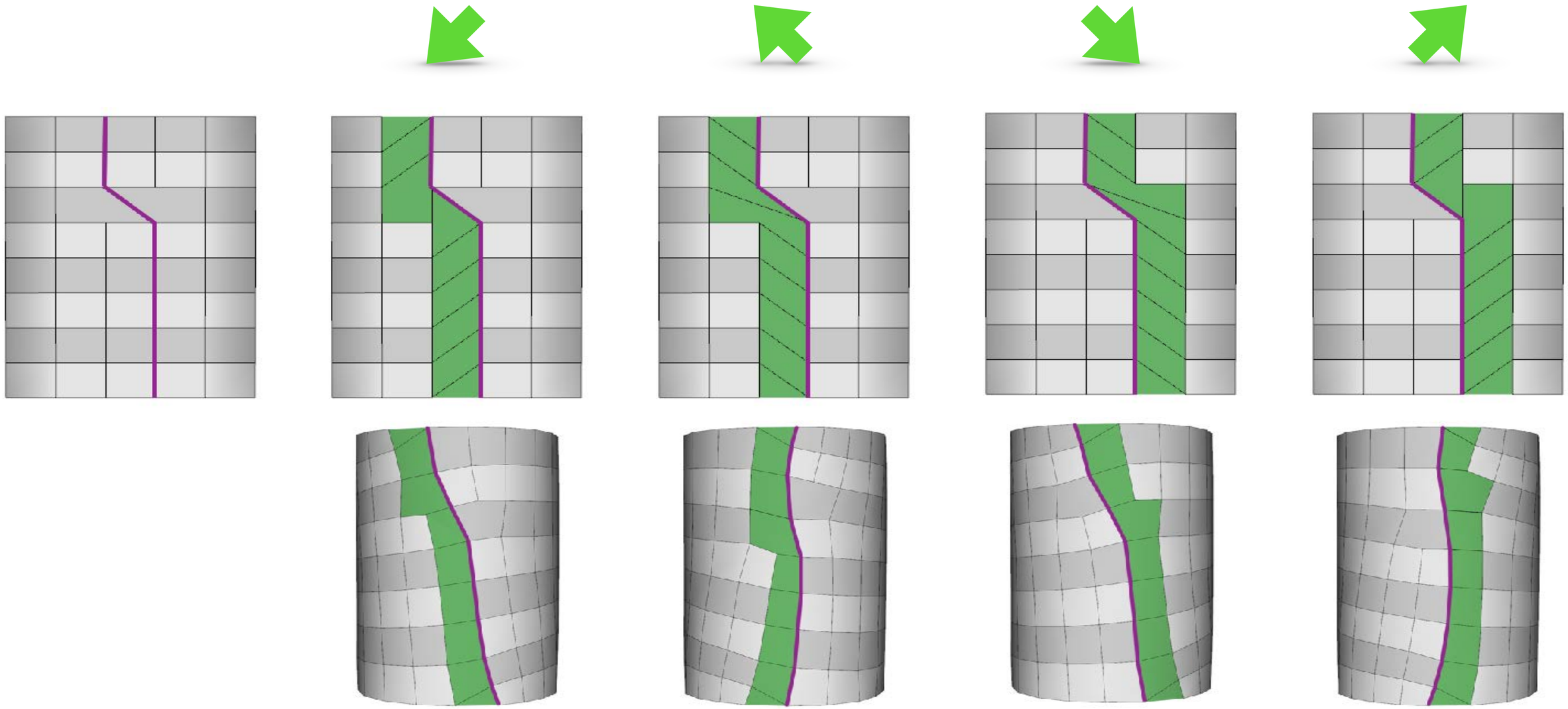
Shift-Paths



Separated rows
(Unknittable)

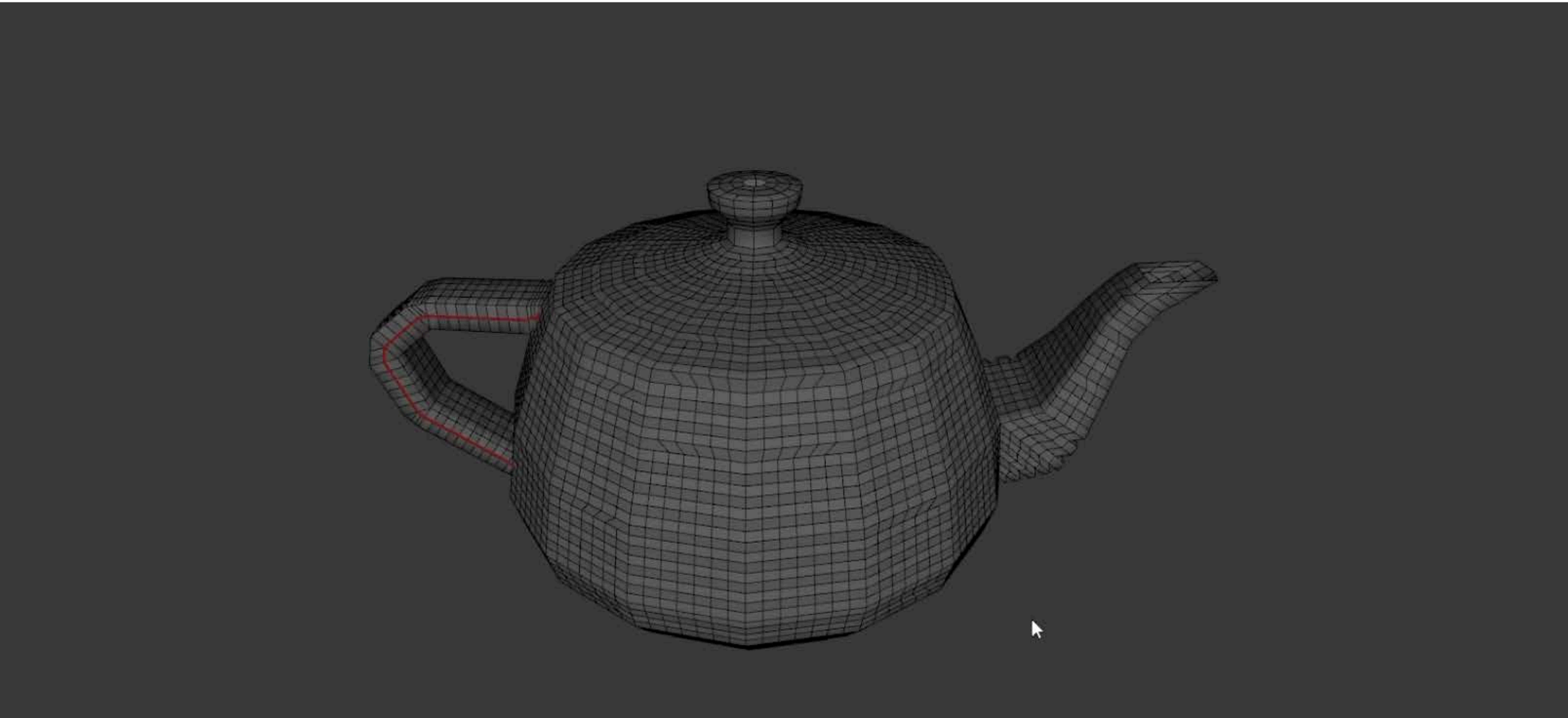
Helix progression
(Knittable)

Shift-Paths

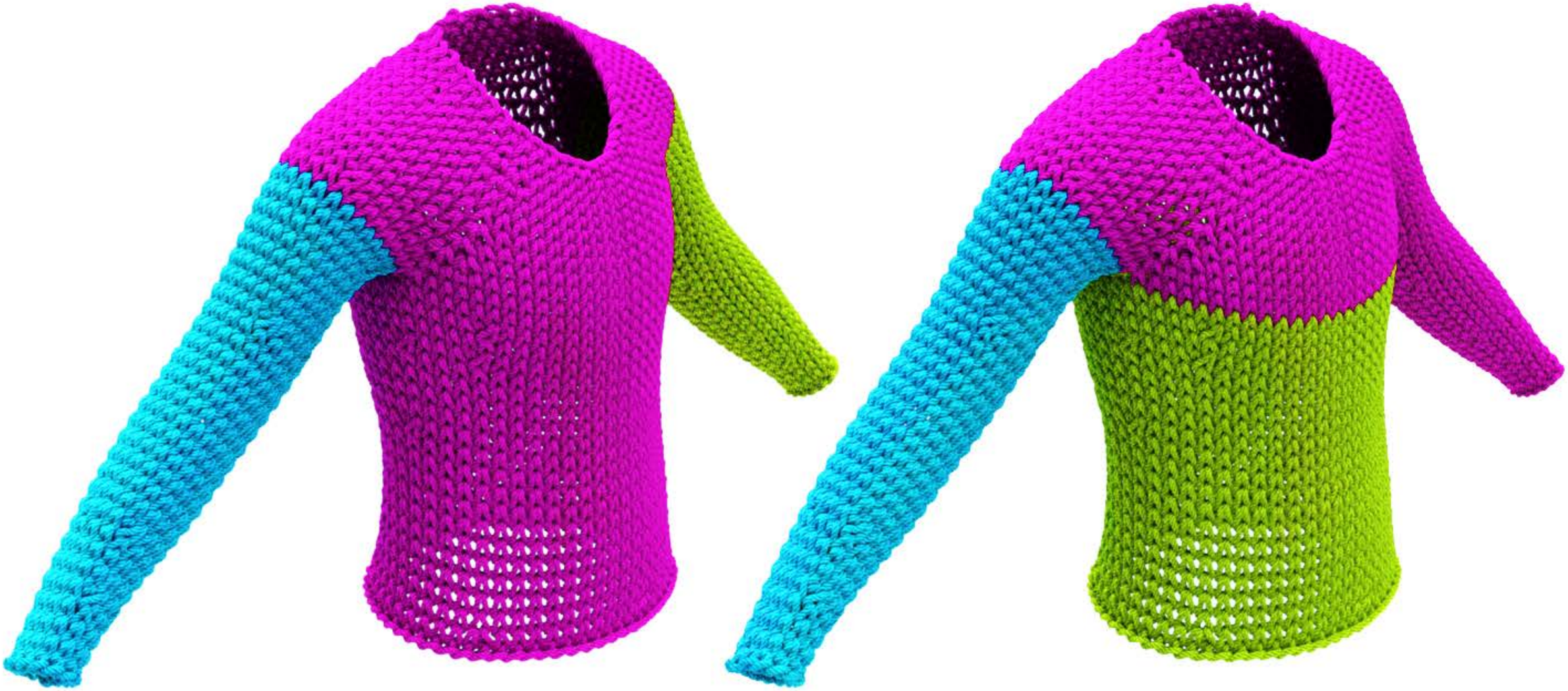


View

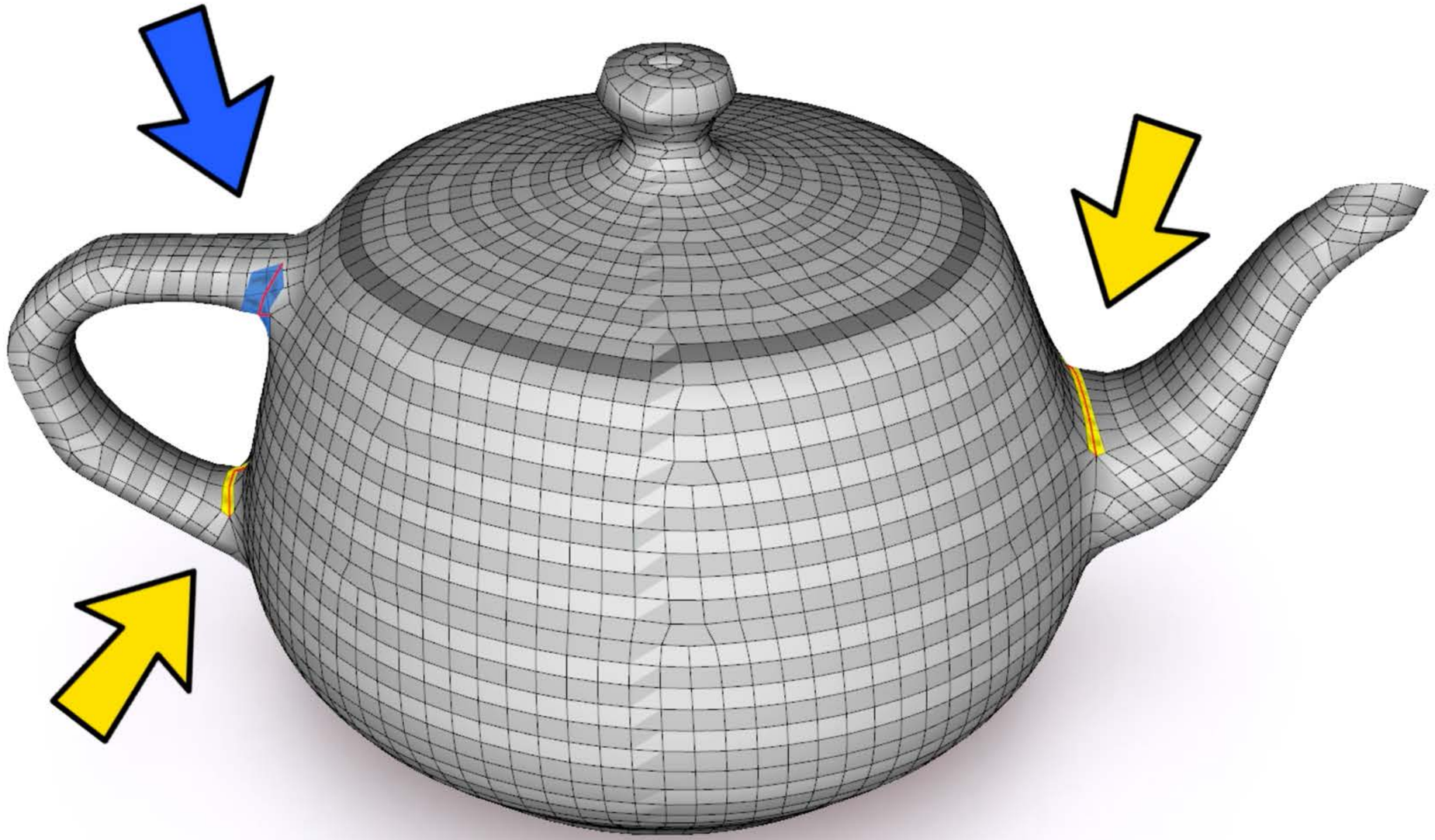
Shift-Paths



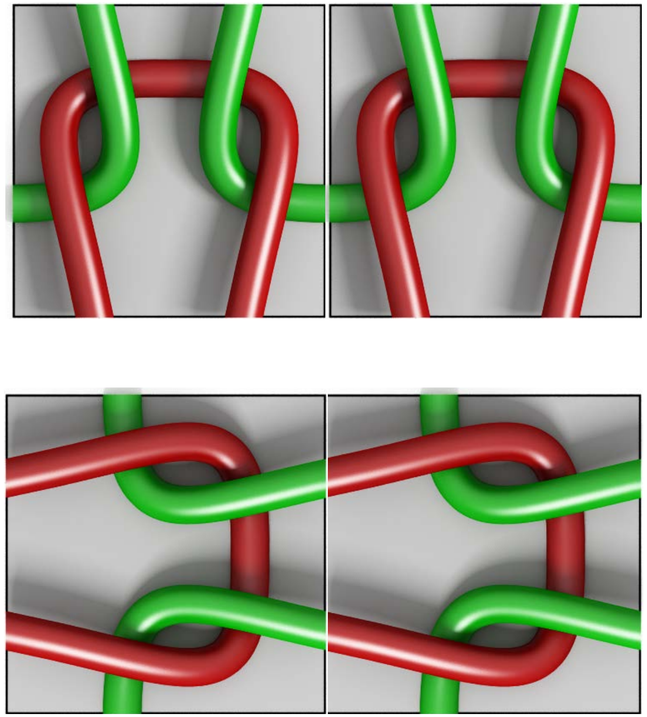
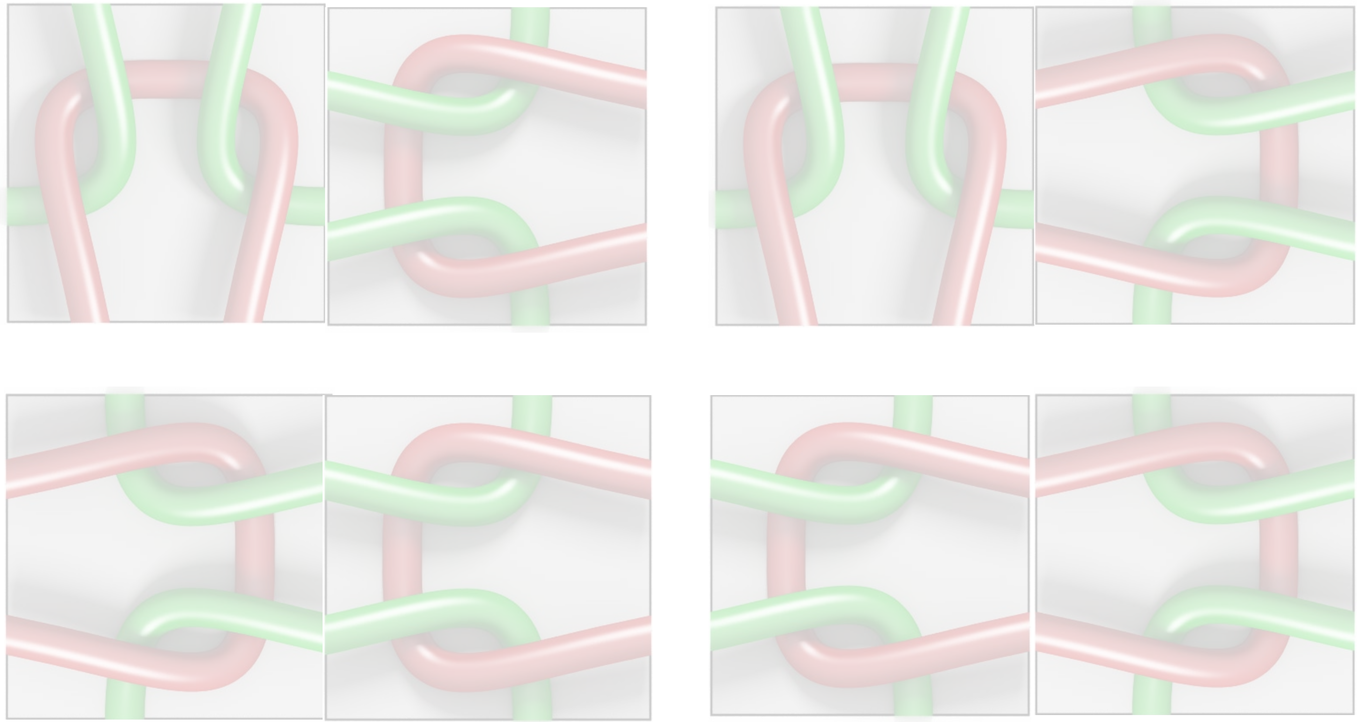
Shift-Paths



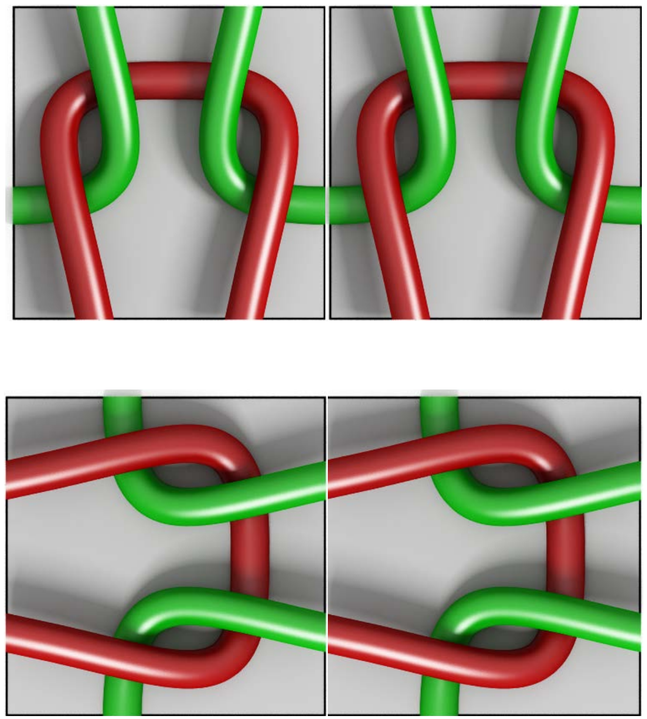
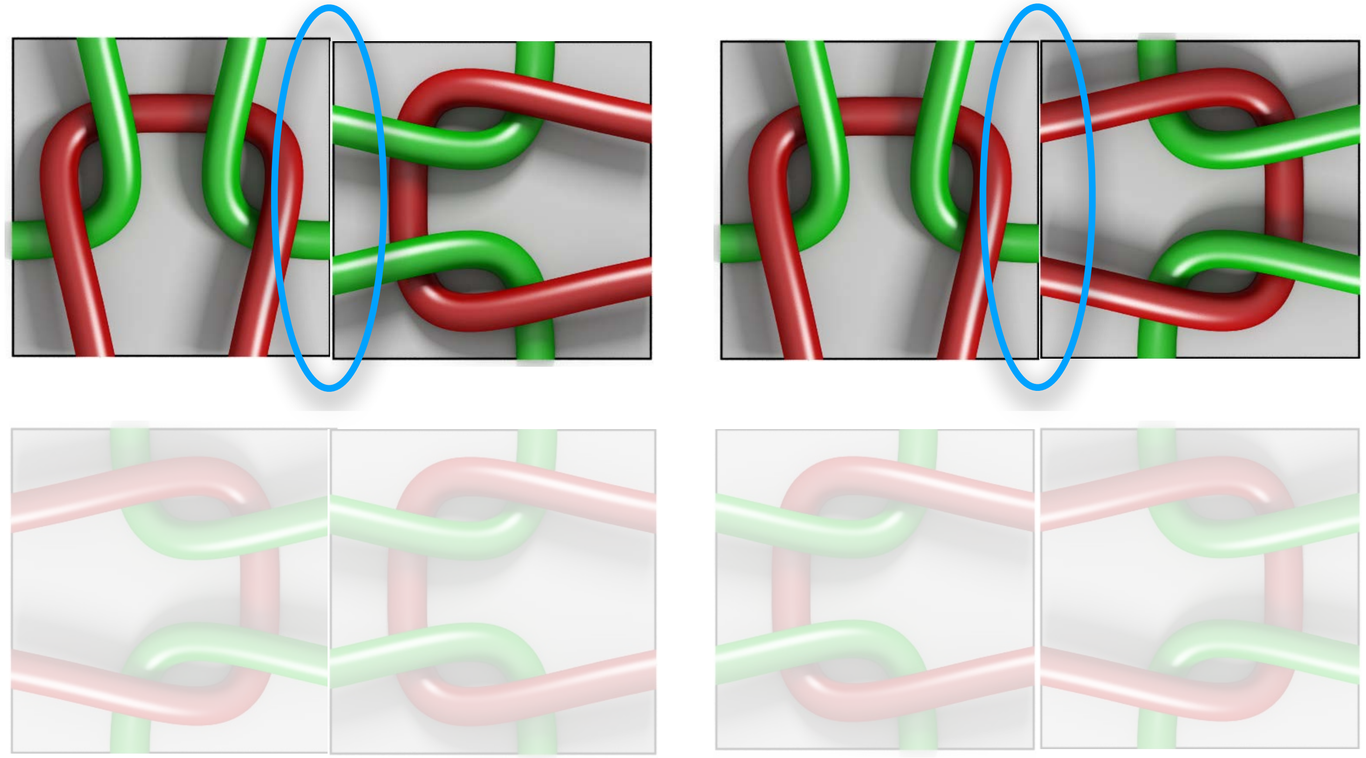
Knittable Mismatched Directions



Knittable Mismatched Directions

Consistent	Mismatched knitting direction
	

Knittable Mismatched Directions

Consistent	Mismatched knitting direction
	

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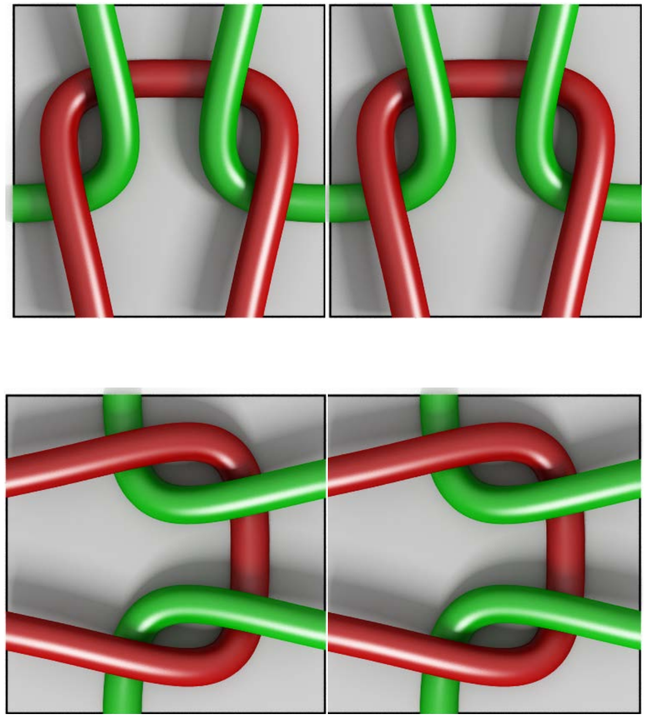
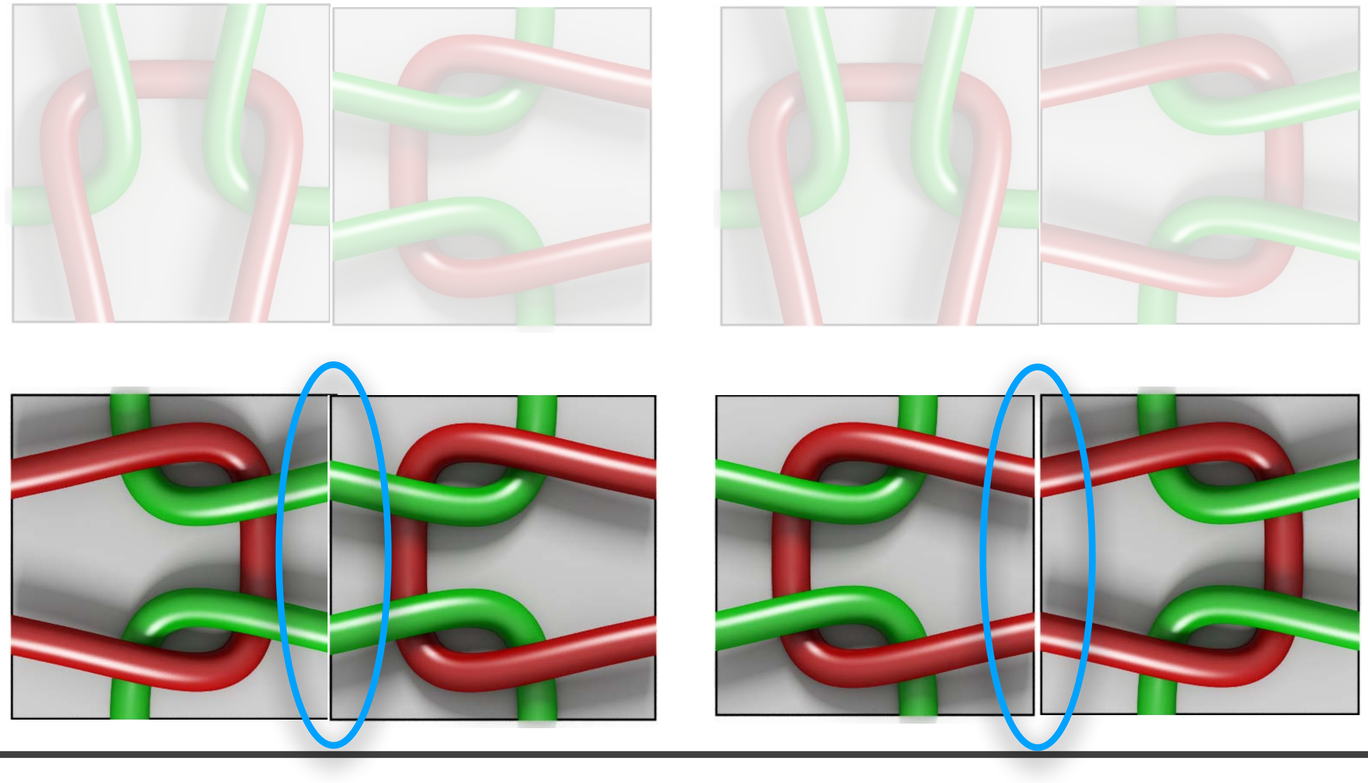
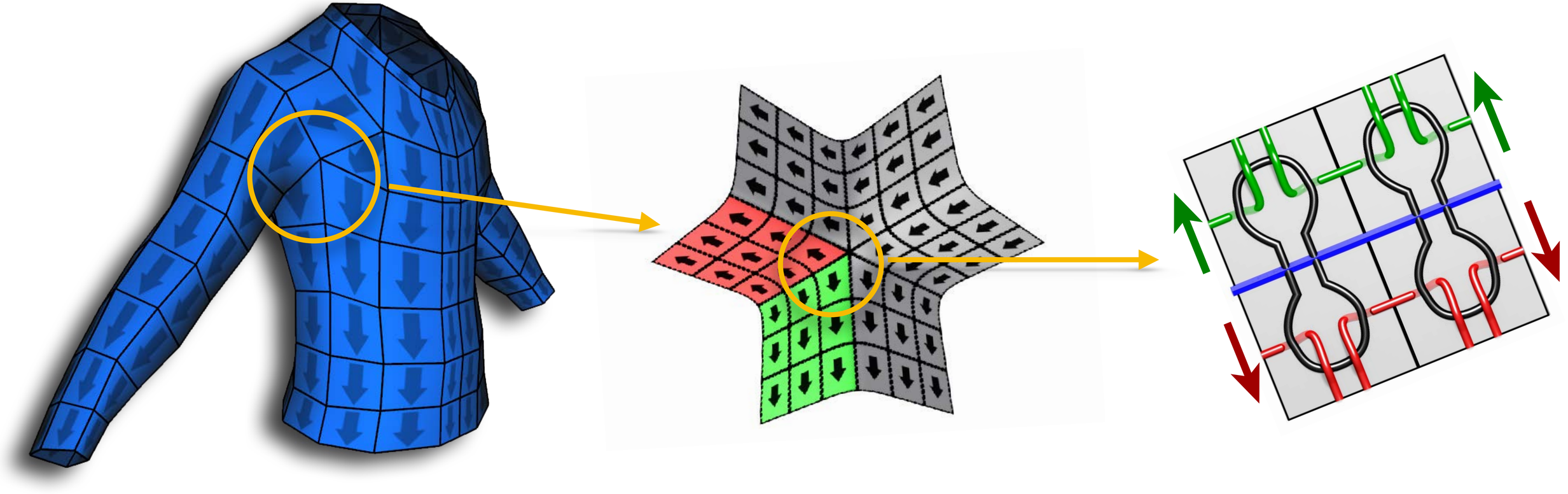
	

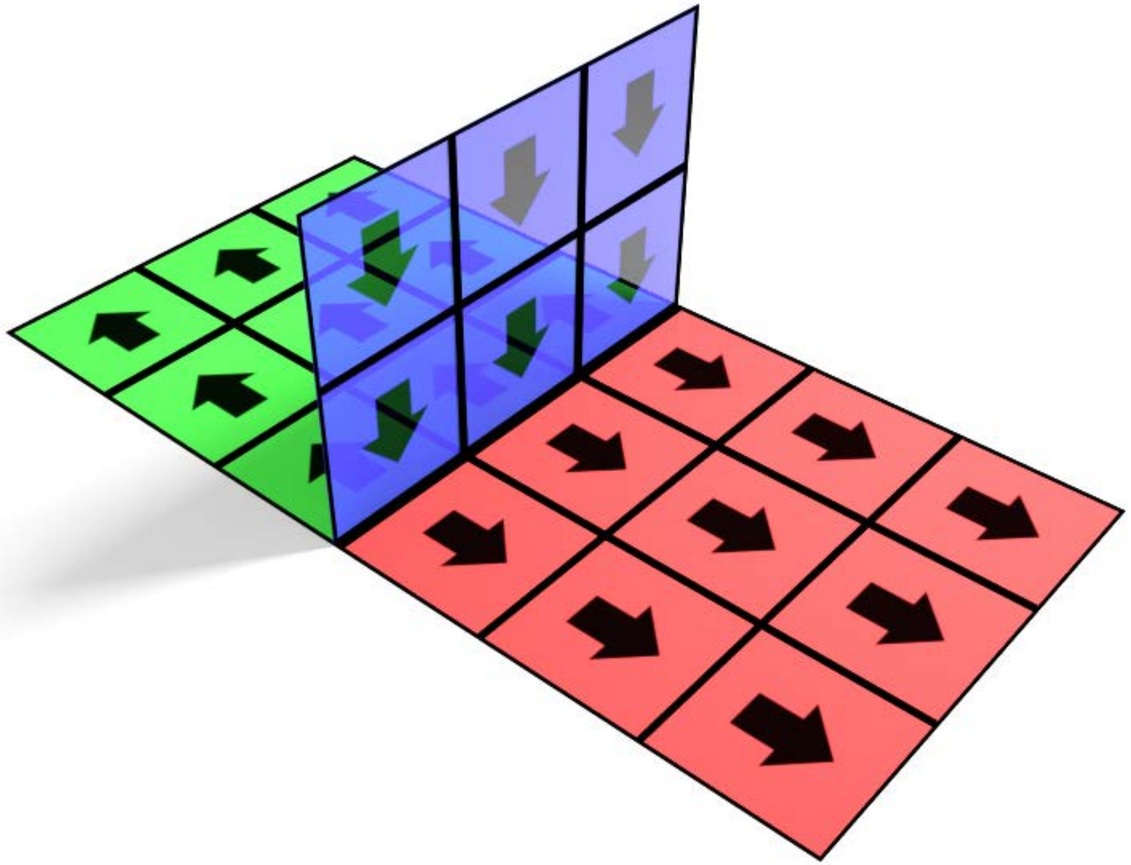
Knittable Mismatched Directions

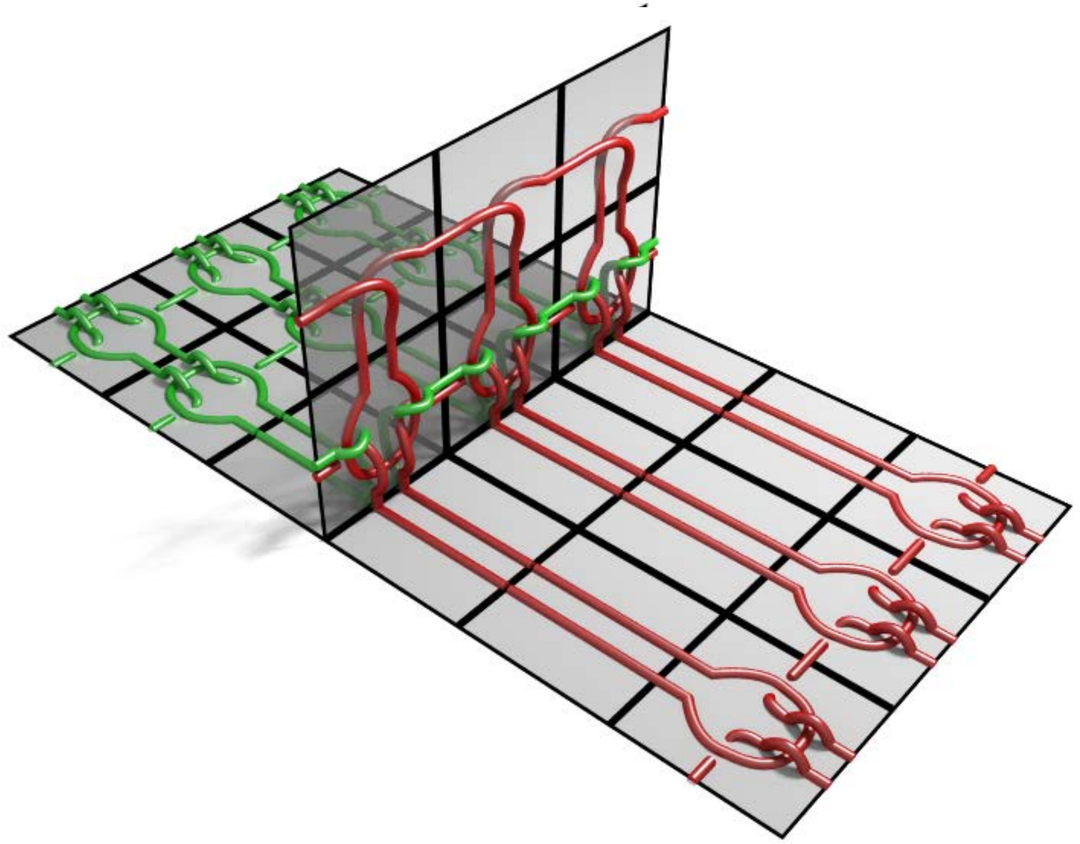
Splitting



Knittable Mismatched Directions

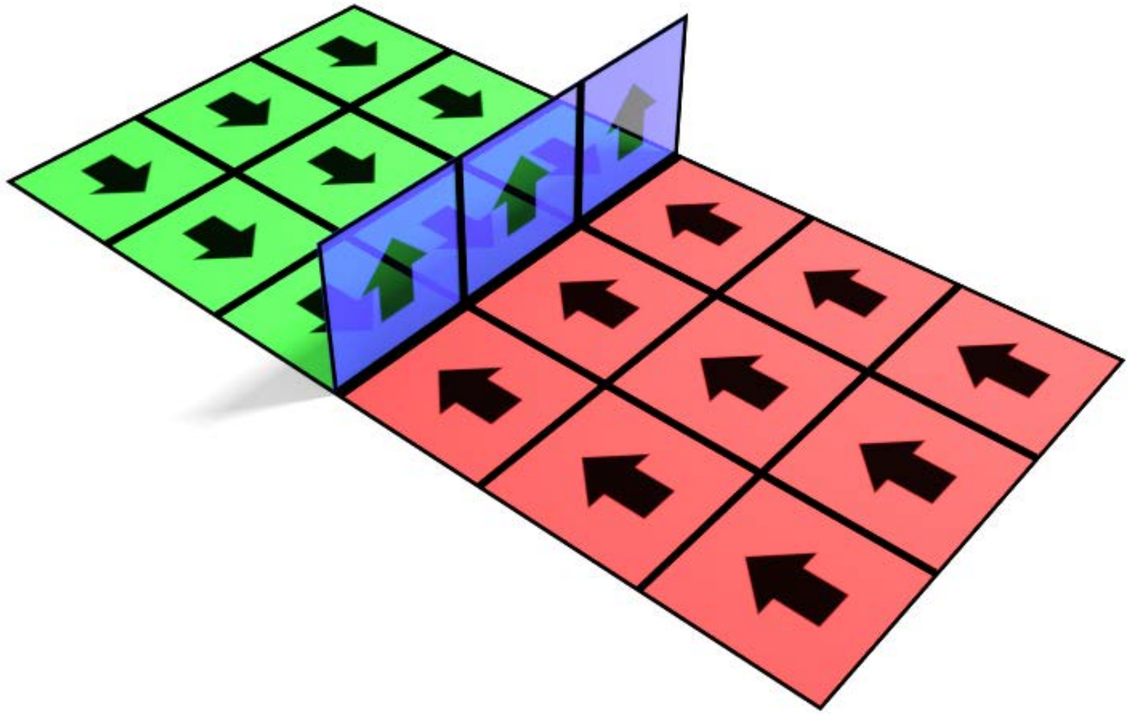
Splitting

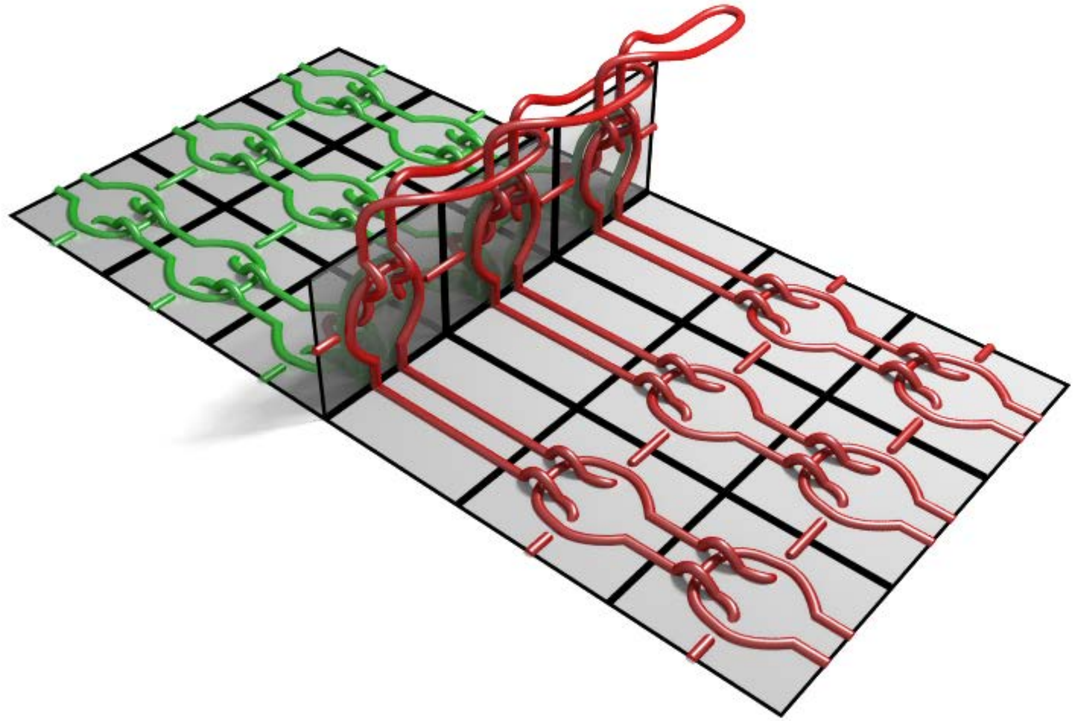




Knittable Mismatched Directions

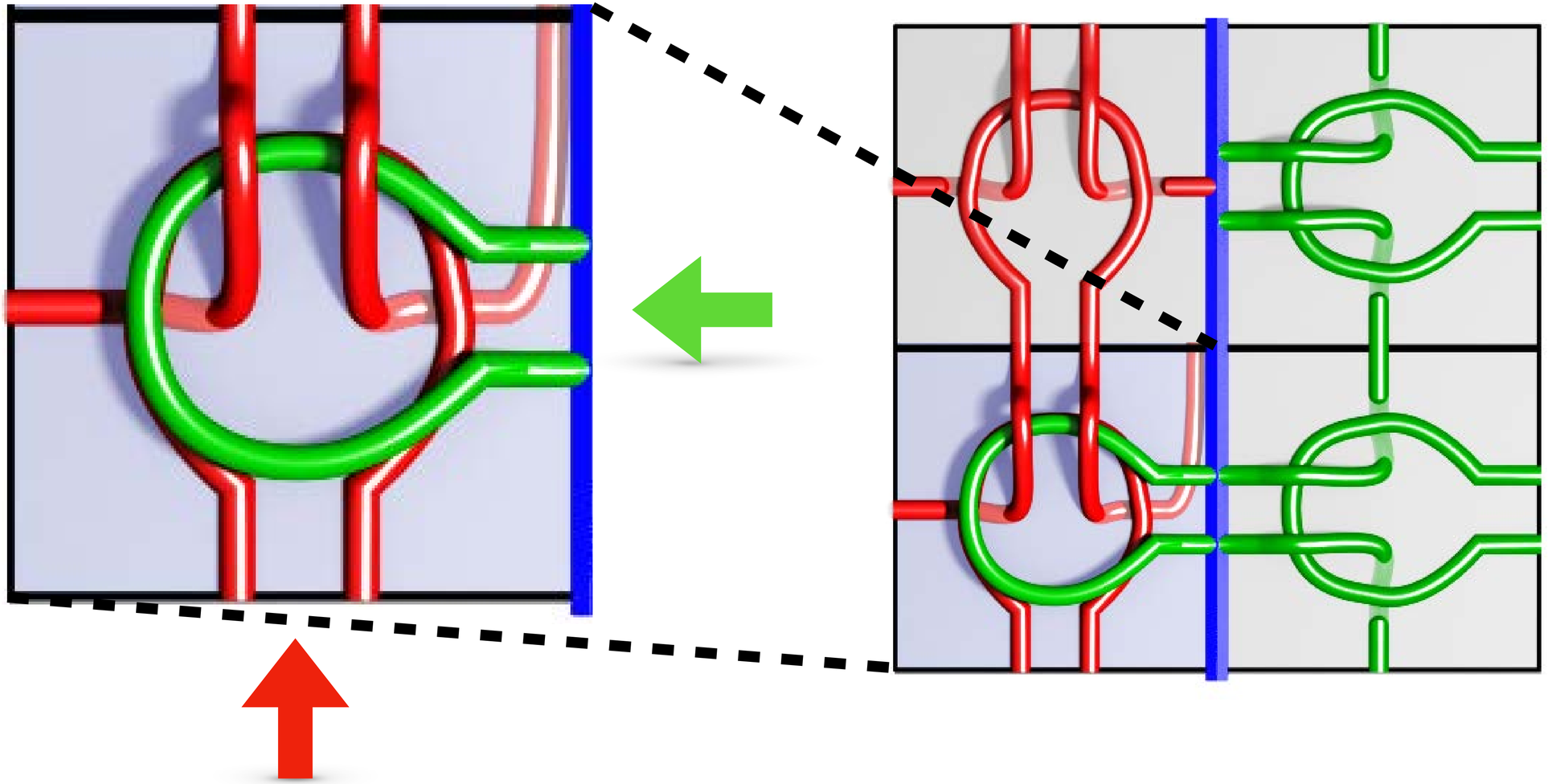
Joining





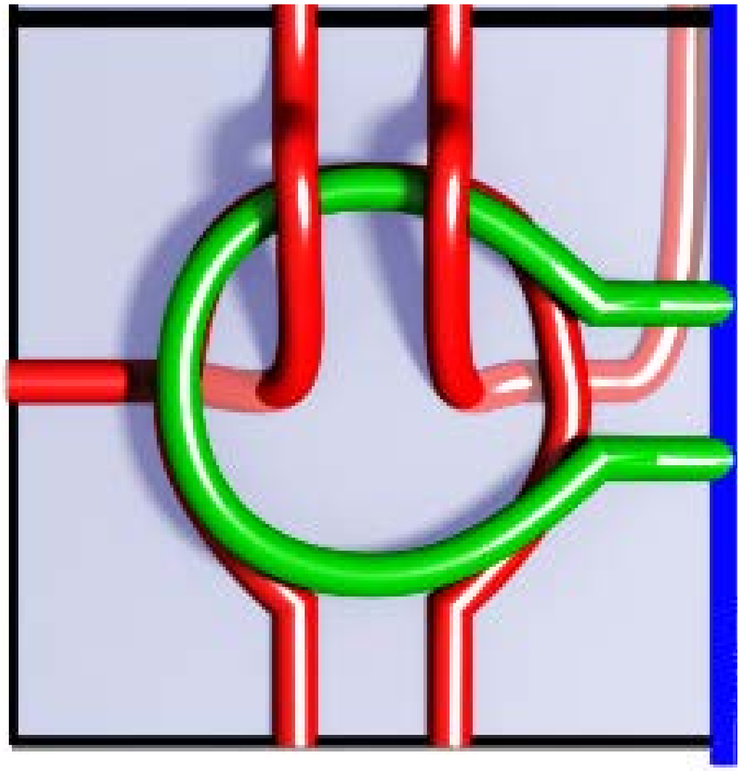
Knittable Mismatched Directions

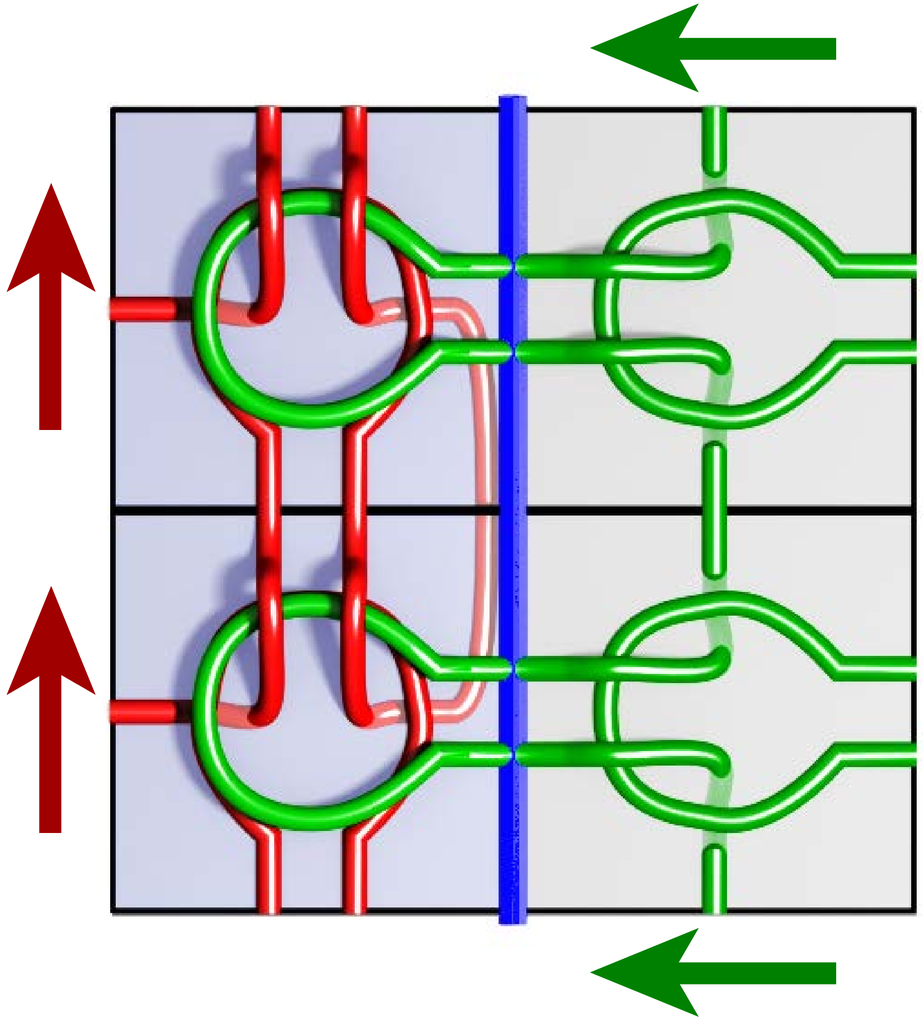
Contracting



Knittable Mismatched Directions

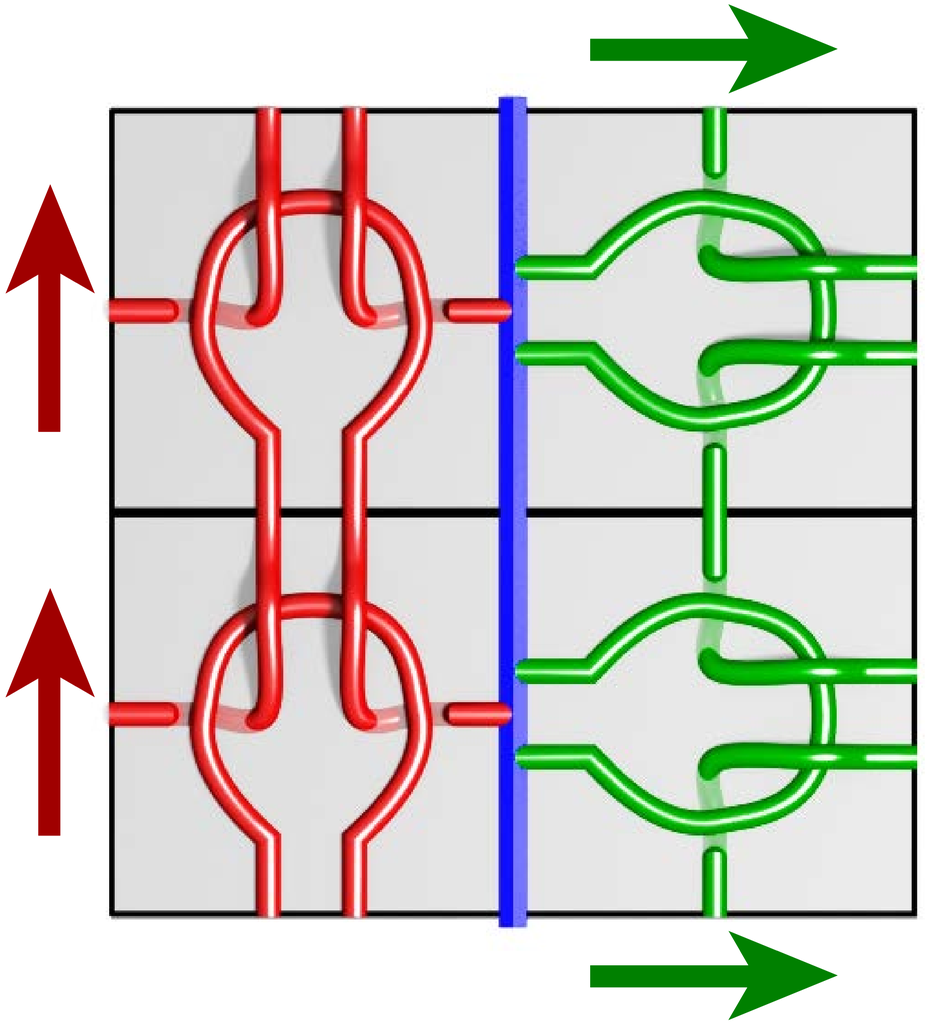
Contracting





Knittable Mismatched Directions

Expanding



Knittable Mismatched Directions

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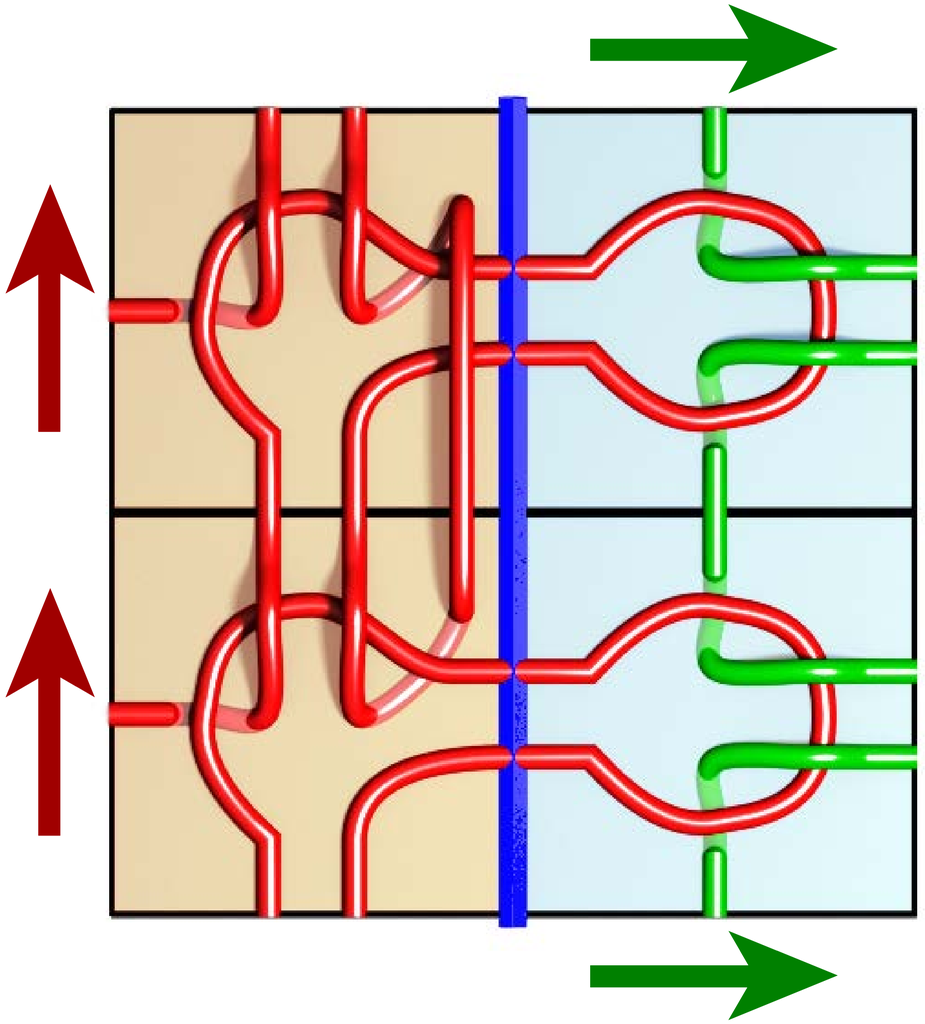
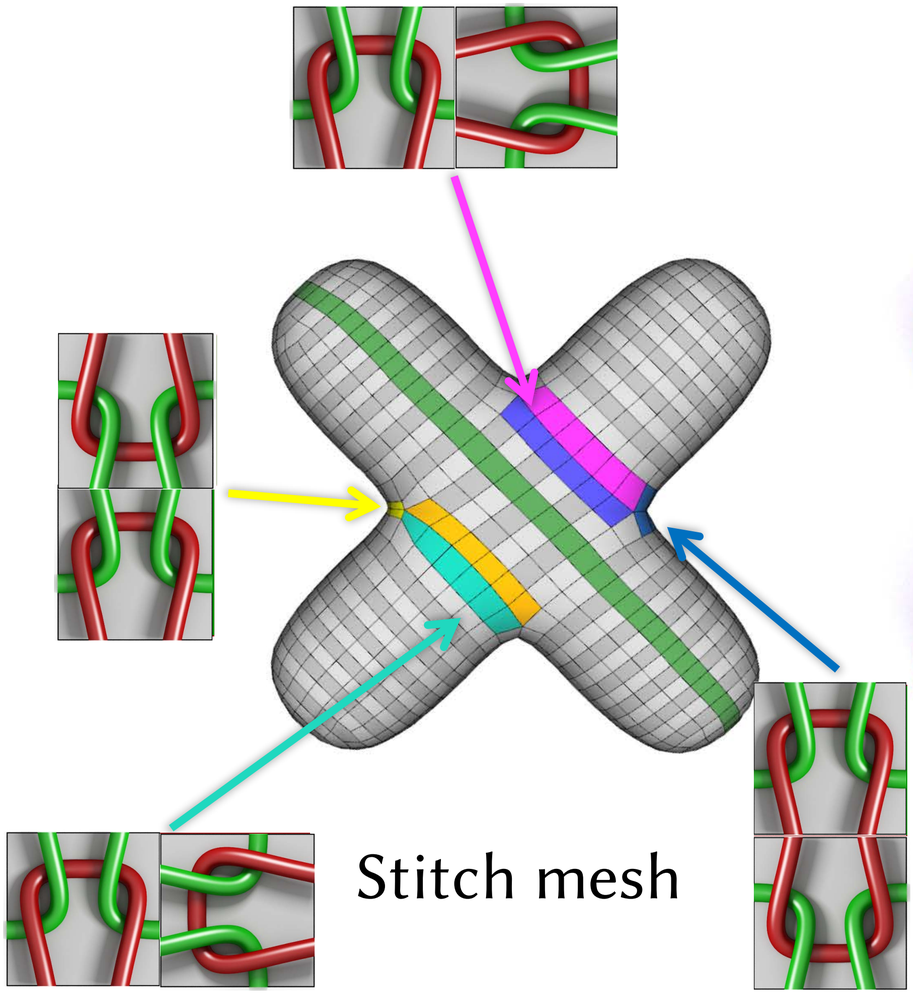
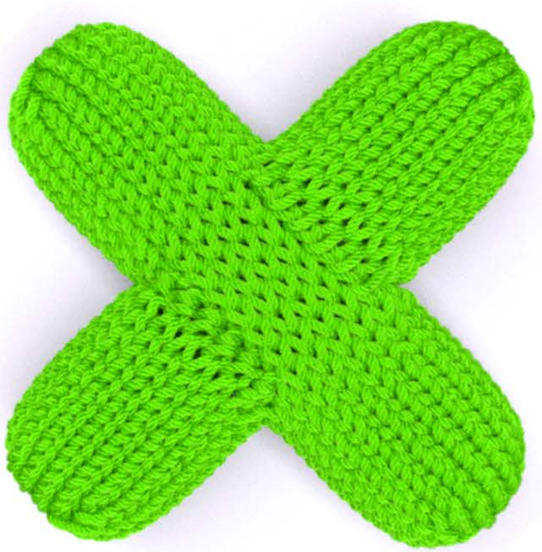


Results



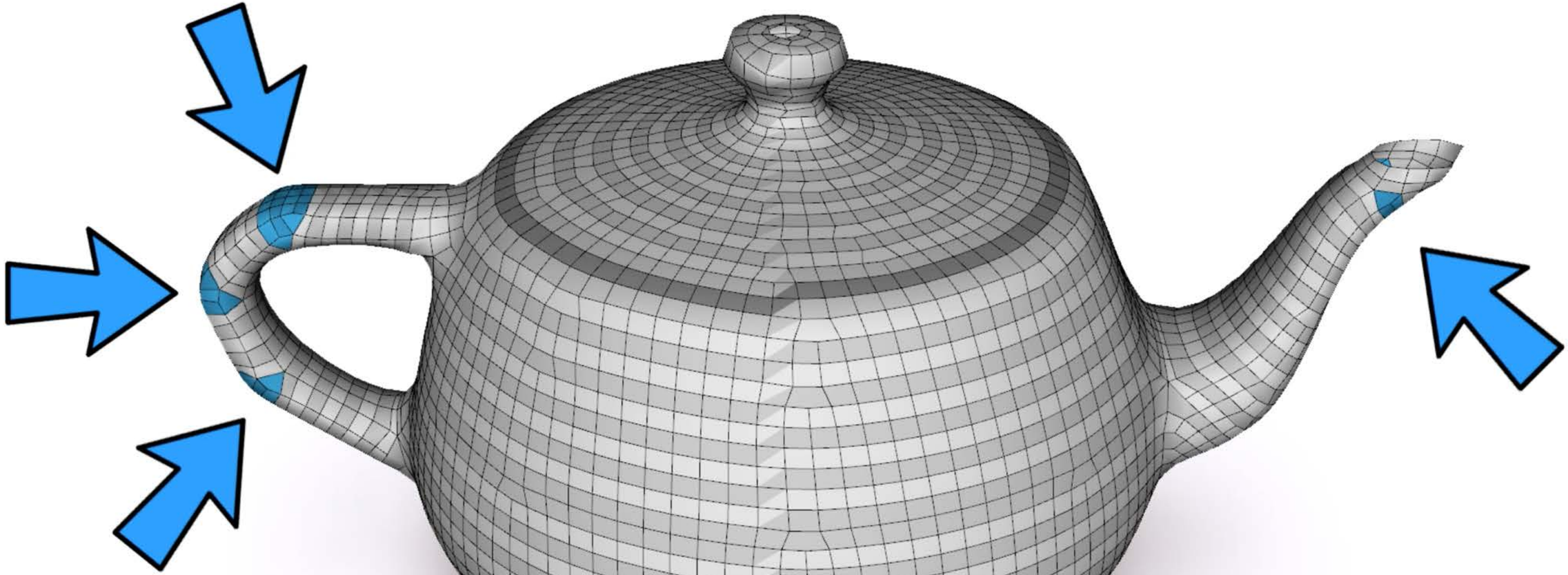
Stitch mesh



Simulated

Knitted

Short-rows

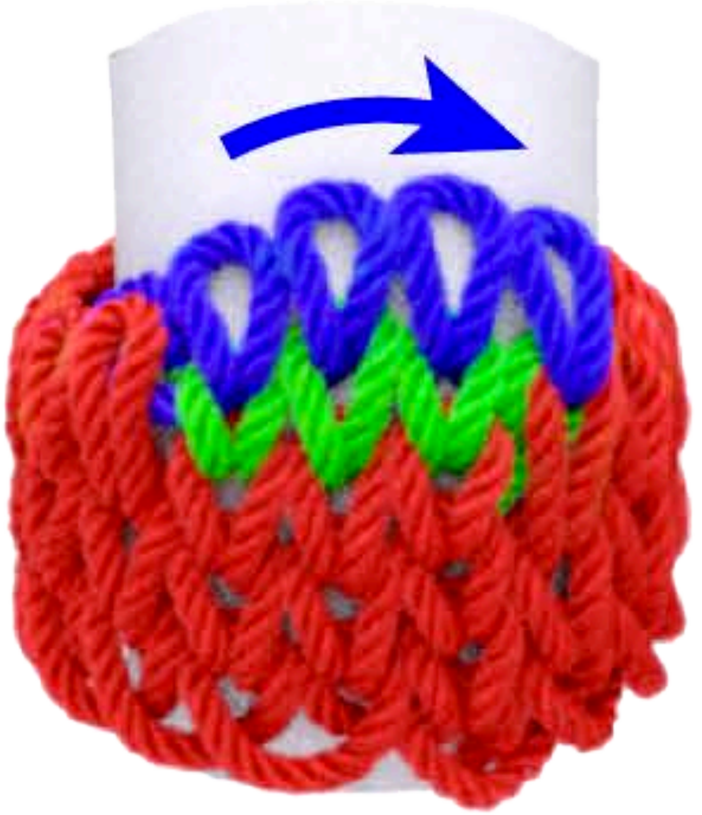


Short-rows

Short-rows

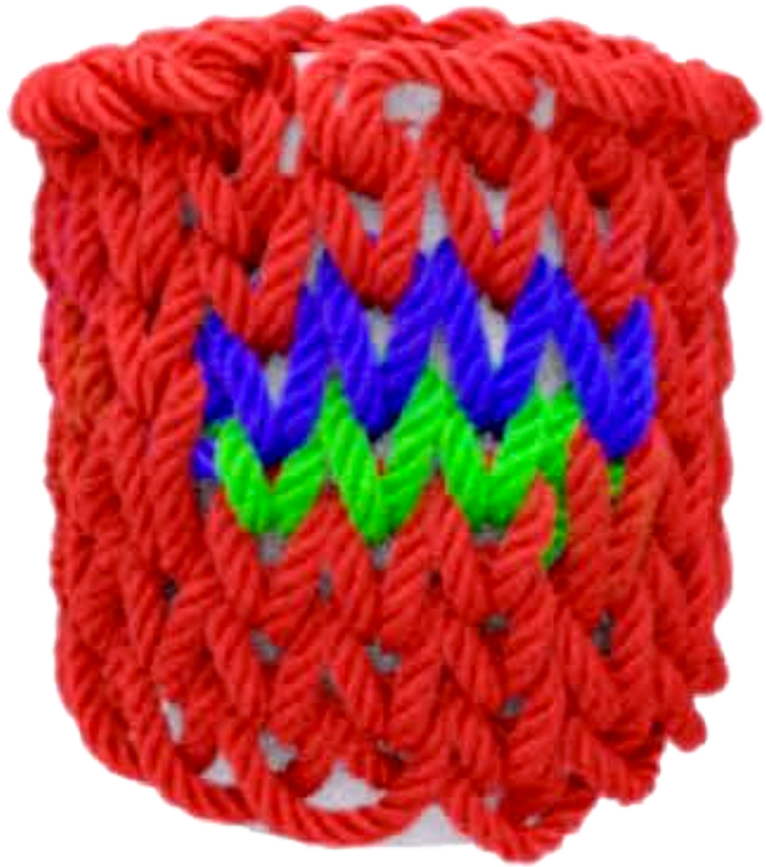
Short-rows

Short-rows

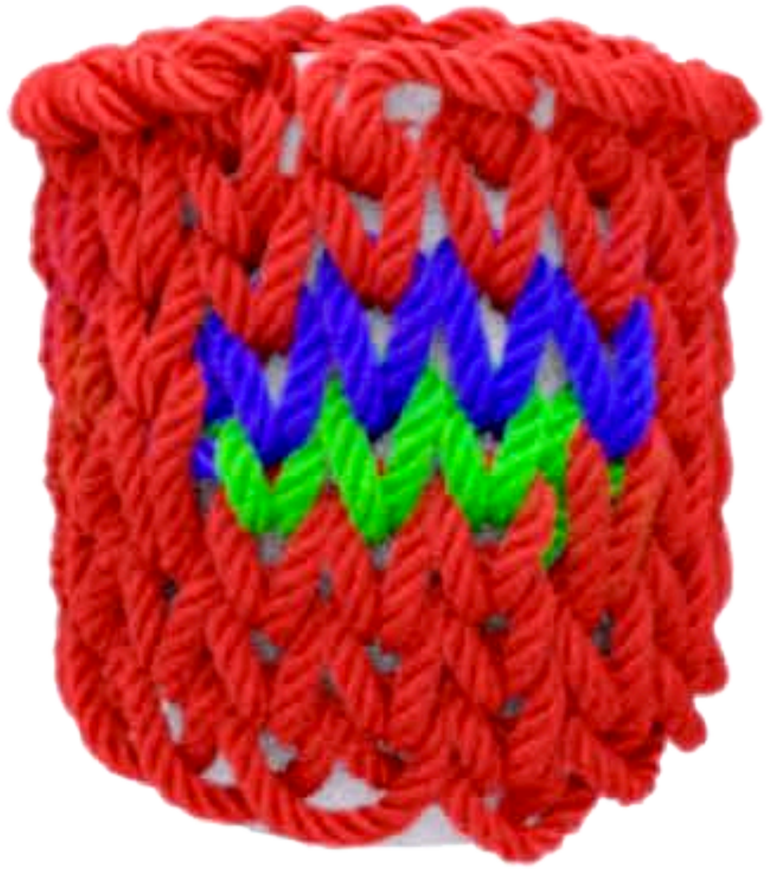


Short-rows

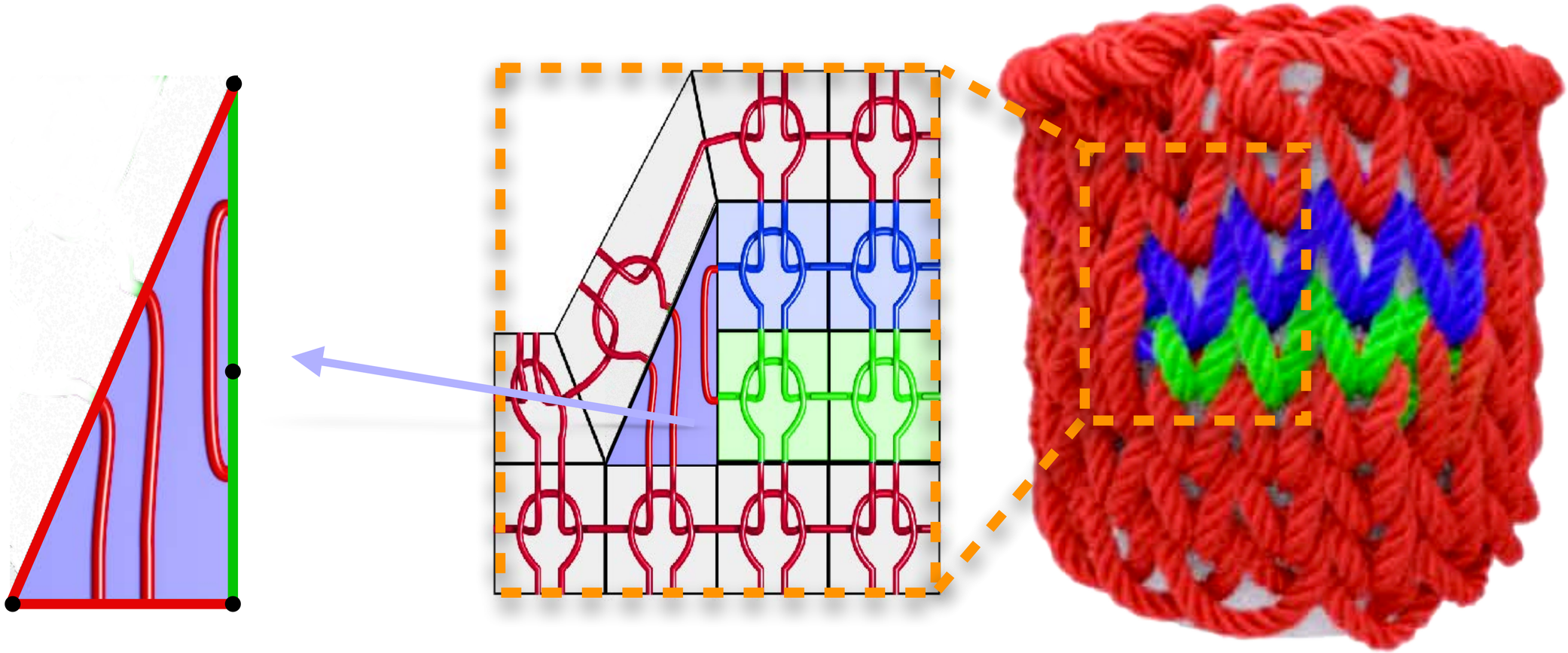
Short-rows



Short-rows

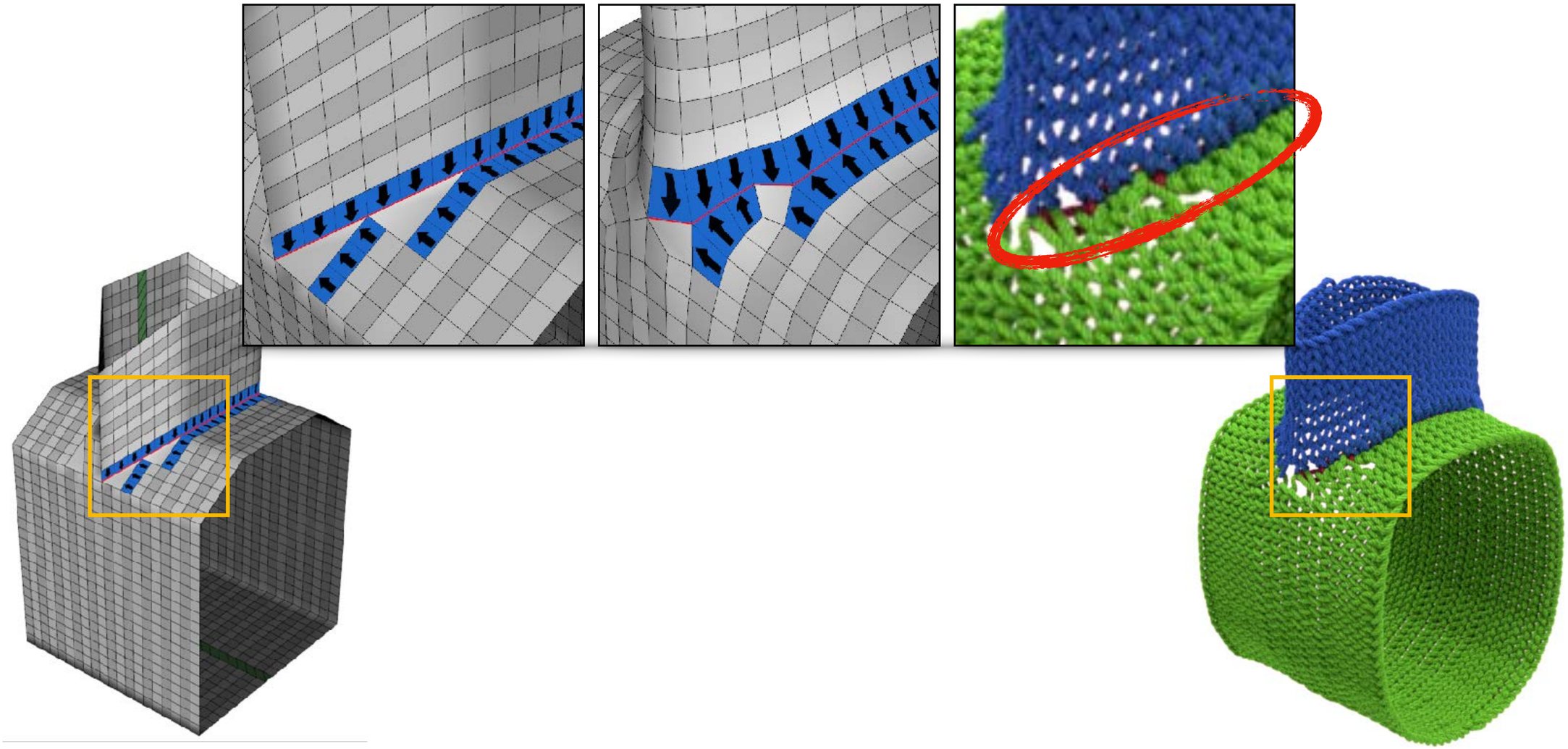


Short-rows

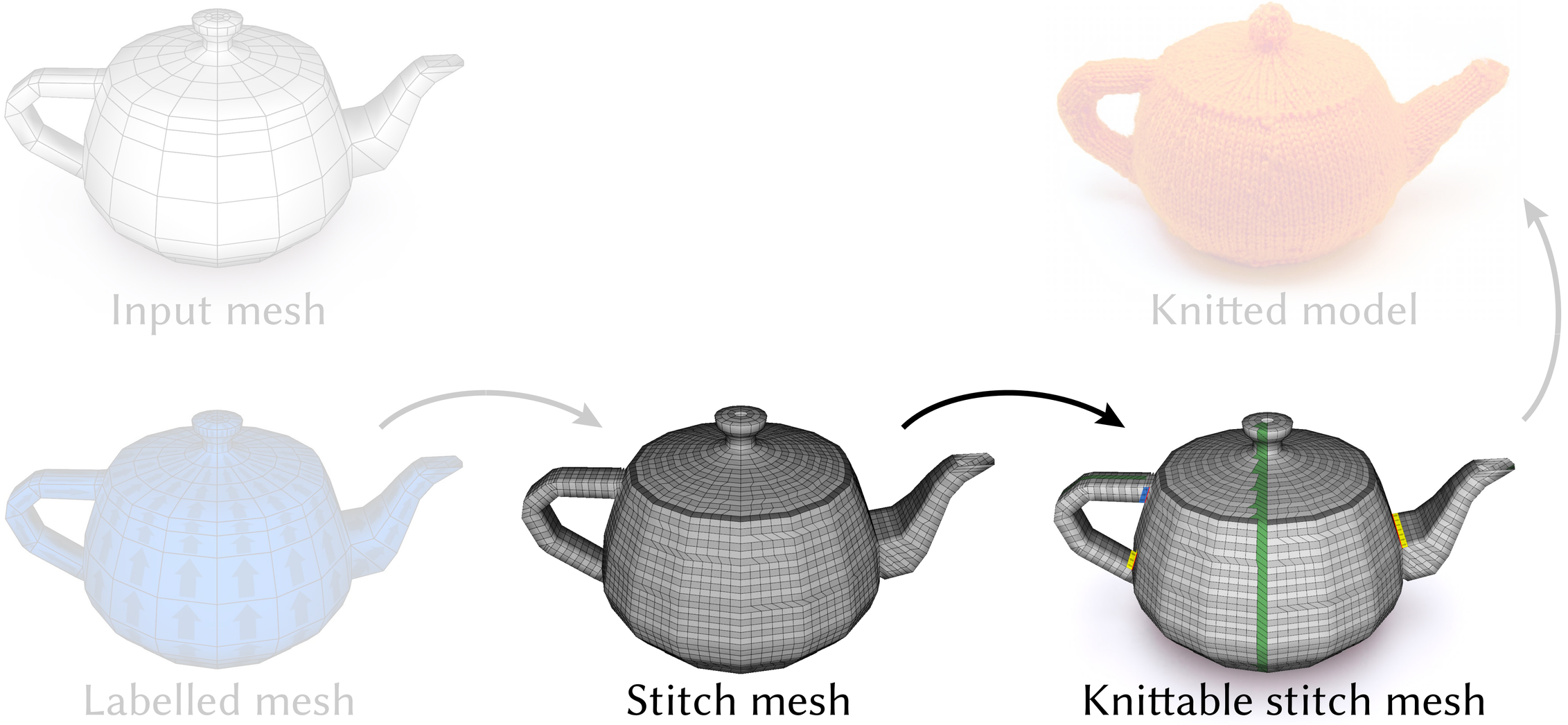


Short-row face

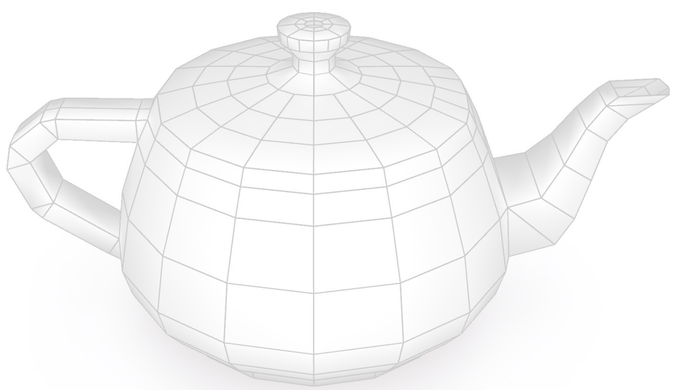
Short-row + Mismatch



Knittable Stitch Mesh



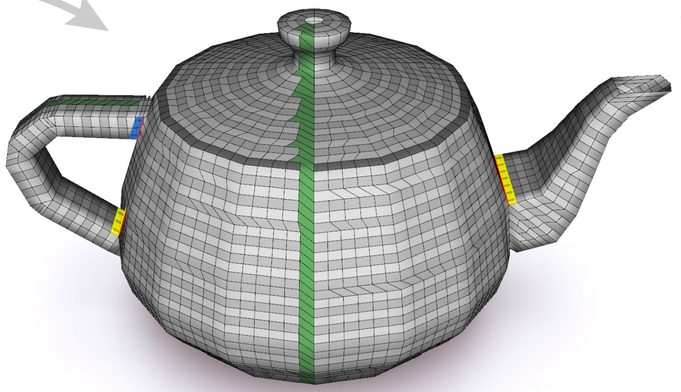
Knitting Instructions Generation



Input mesh

Labelled mesh

Stitch mesh

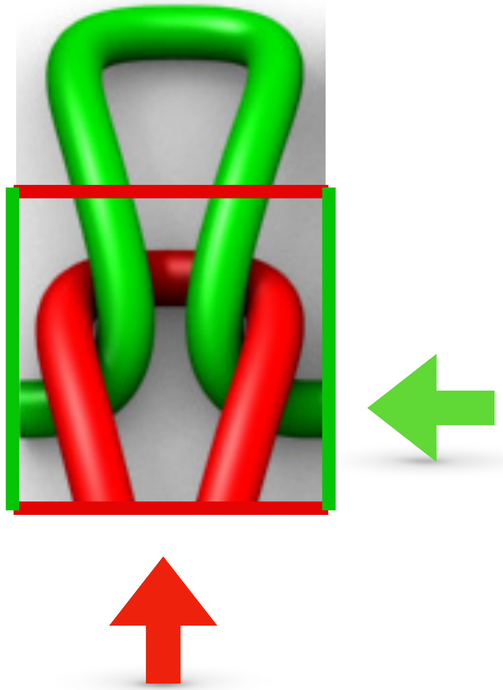


Knittable stitch mesh

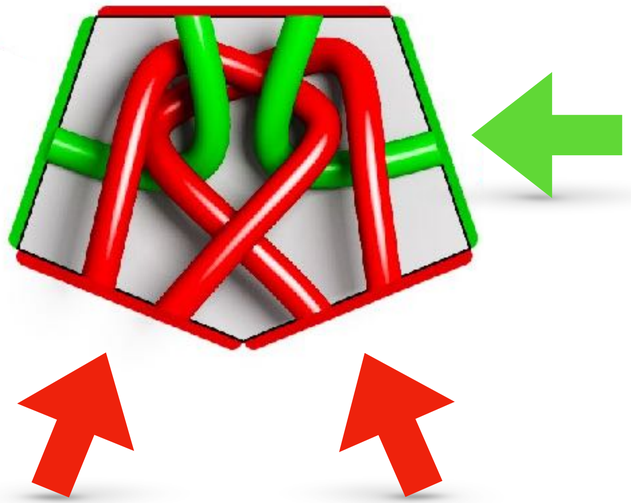
Knitted model

Knitting Dependency

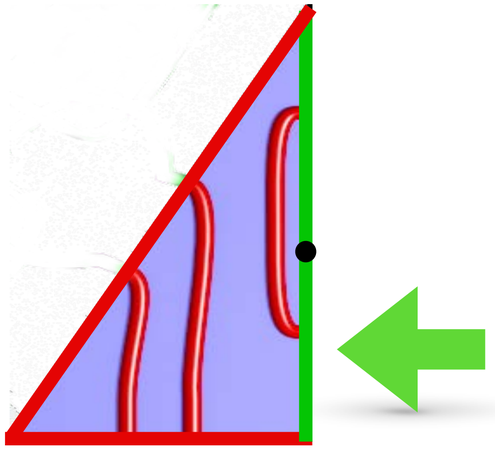
Regular



Decrease

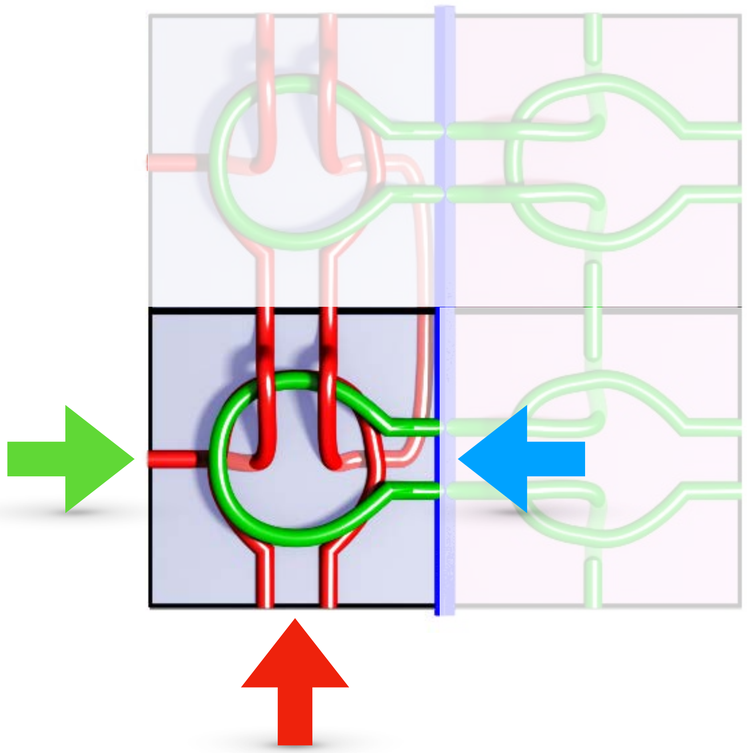


Short-row

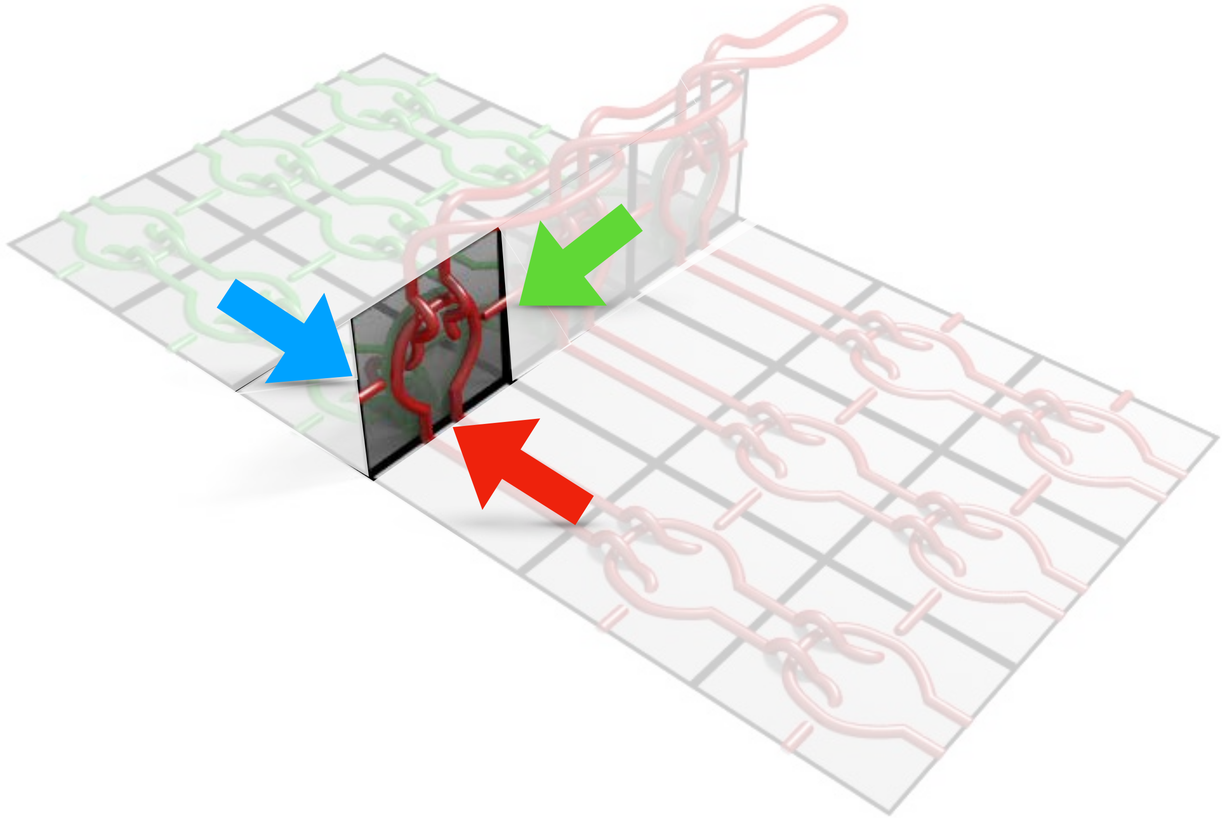


Knitting Dependency

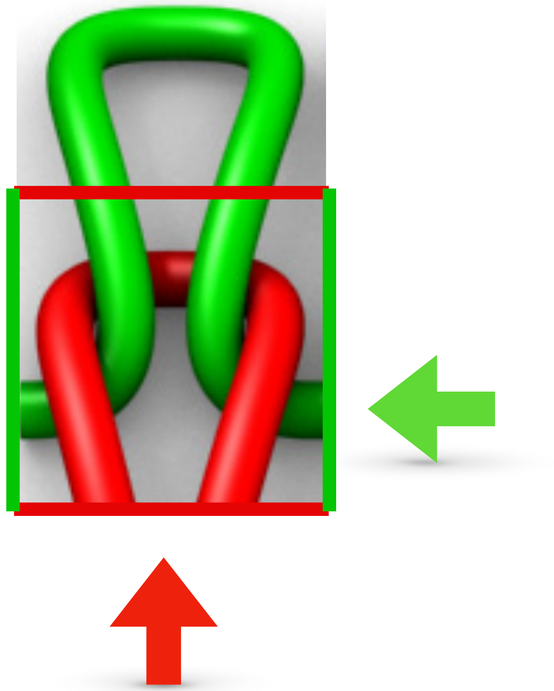
Contracting



Joining



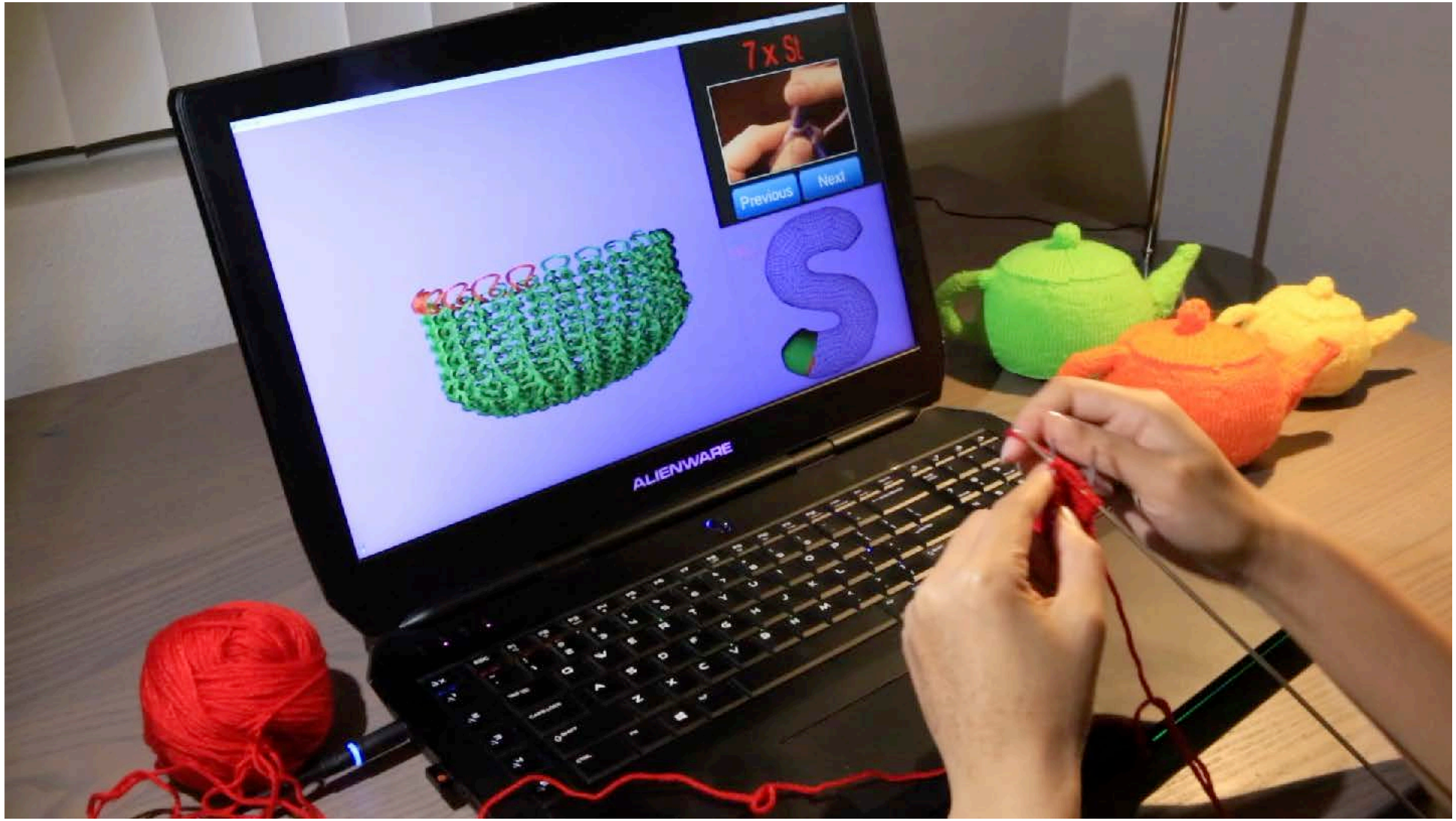
Knitting Instruction Generation



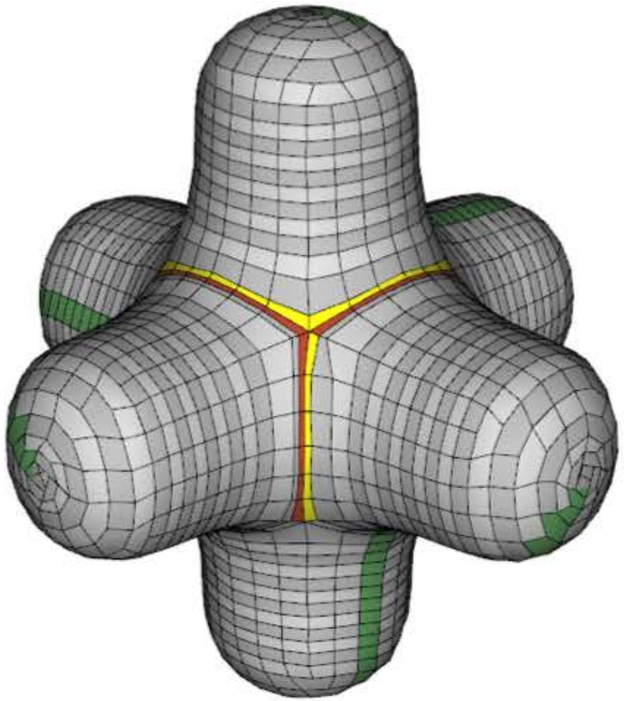
ALGORITHM 1: Generate Knitting Instructions

```
Q ← list of first stitches for each yarn piece
while Q is not empty do
    s ← the next ready stitch from Q
    while true do
        Generate knitting instructions for s.
        Mark s as knitted.
        s_c ← the next stitch after s along the course direction
        if s_c exists then
            s ← s_c
        else
            s_w ← the stitch after s on the next row in wale direction
            if s_w exists and yarn of s_w = yarn of s then
                s ← s_c
            else
                Terminate the yarn piece
                break
        if s is not ready then
            Enqueue s into Q.
            break
```

Hand Knitting Interface



Results

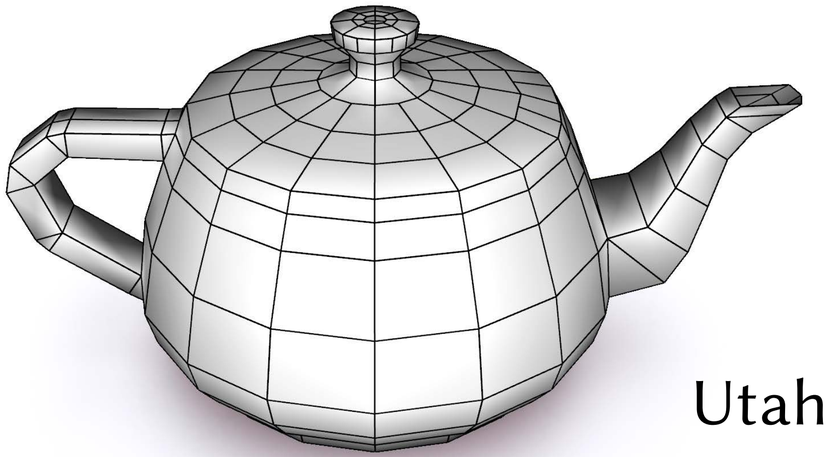


Stitch mesh

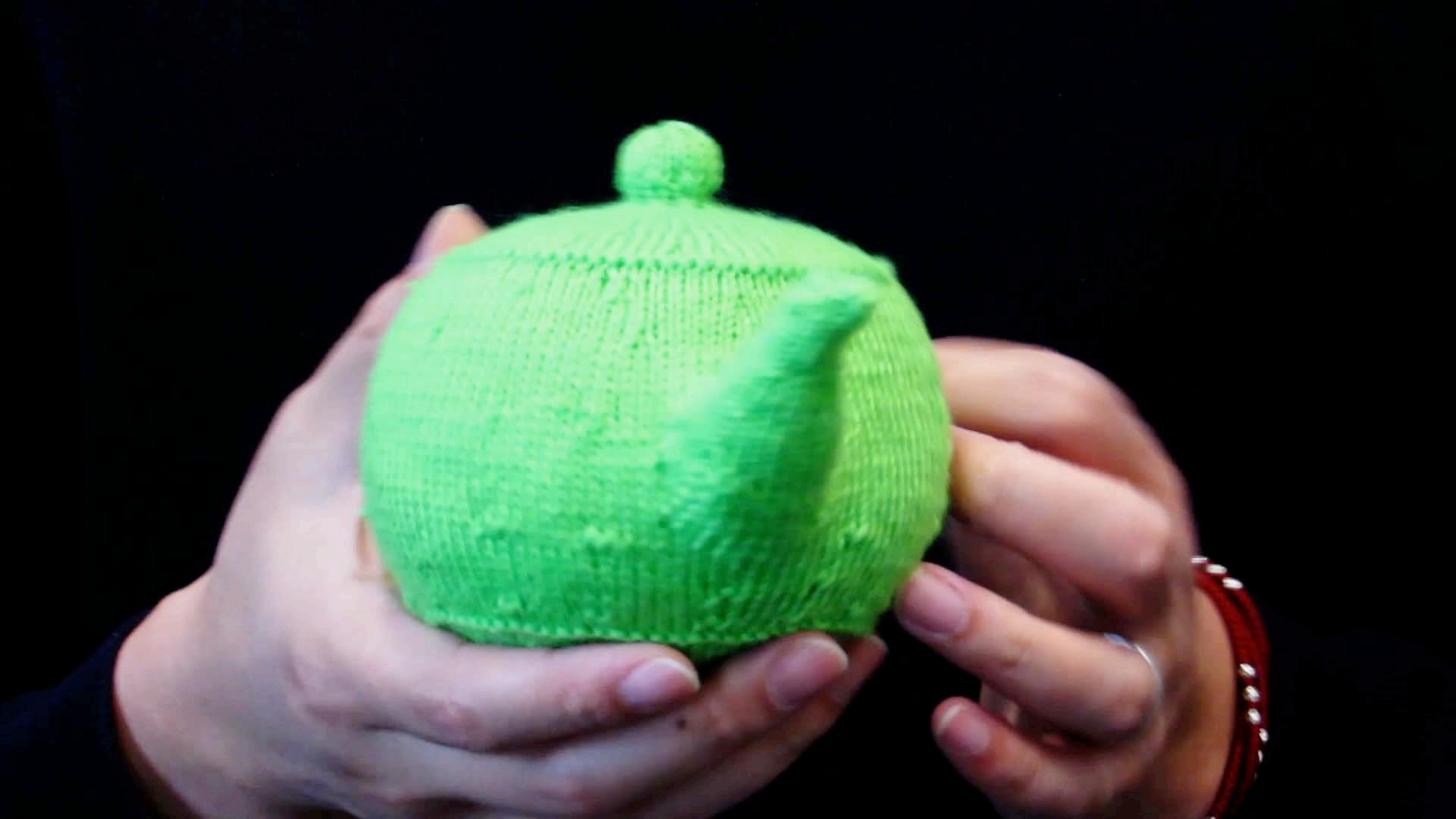
Simulated

Knitted

Results



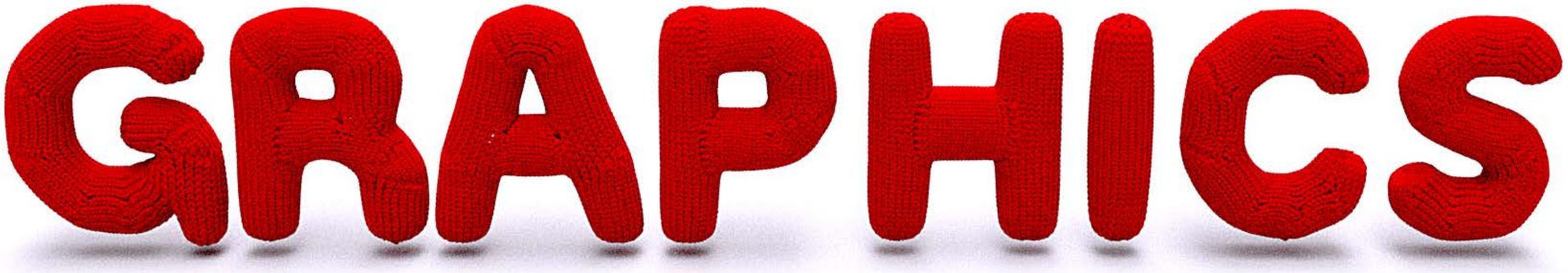
Utah Teapot



Results

Results

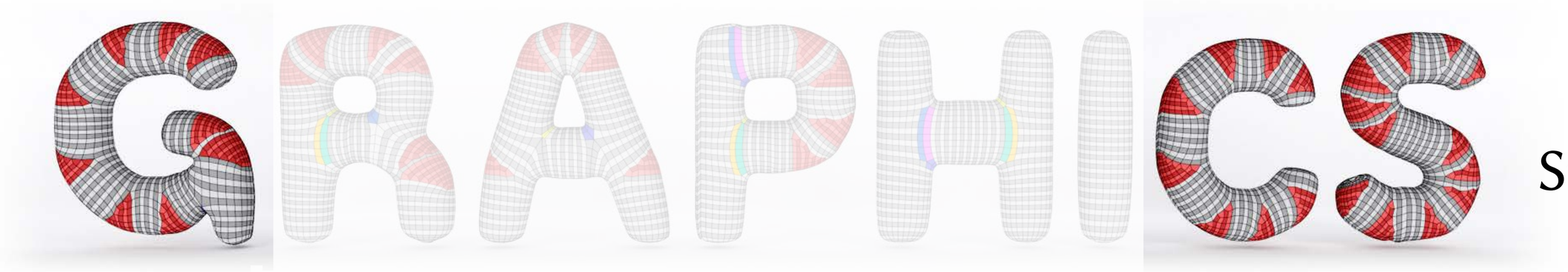
Stitch mesh



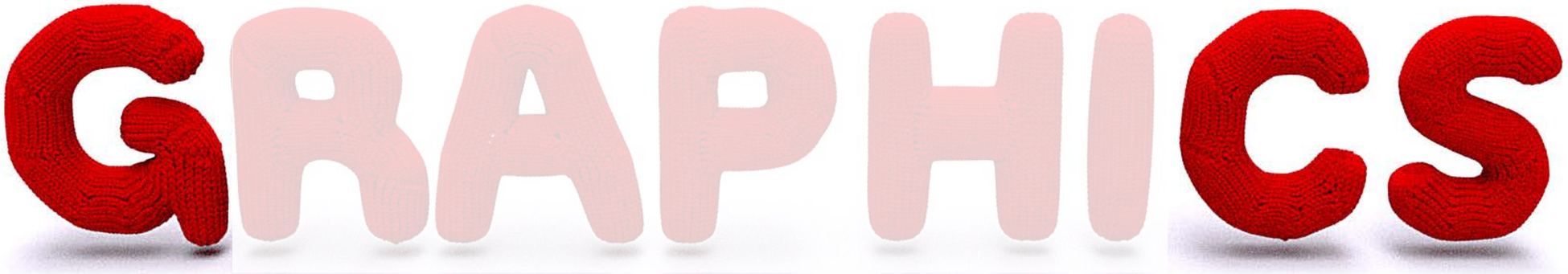
Simulated

Knitted

Results



Stitch mesh

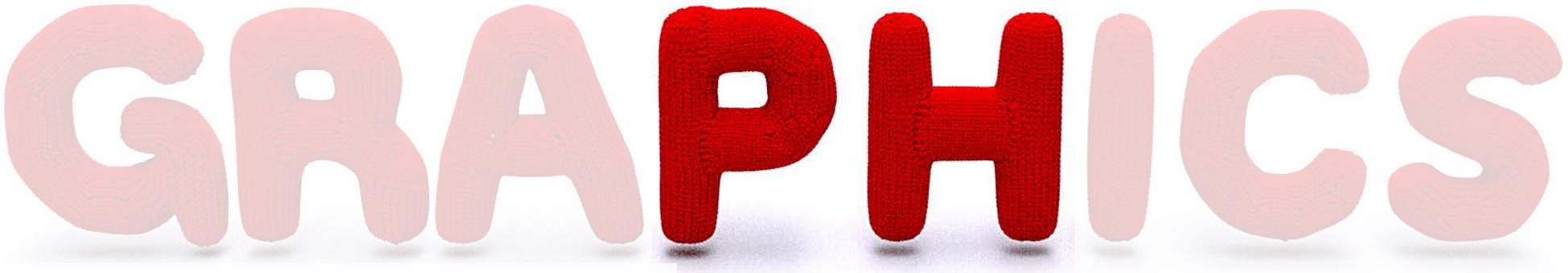


Simulated

Knitted

Results

Stitch mesh



Simulated

Knitted

Results

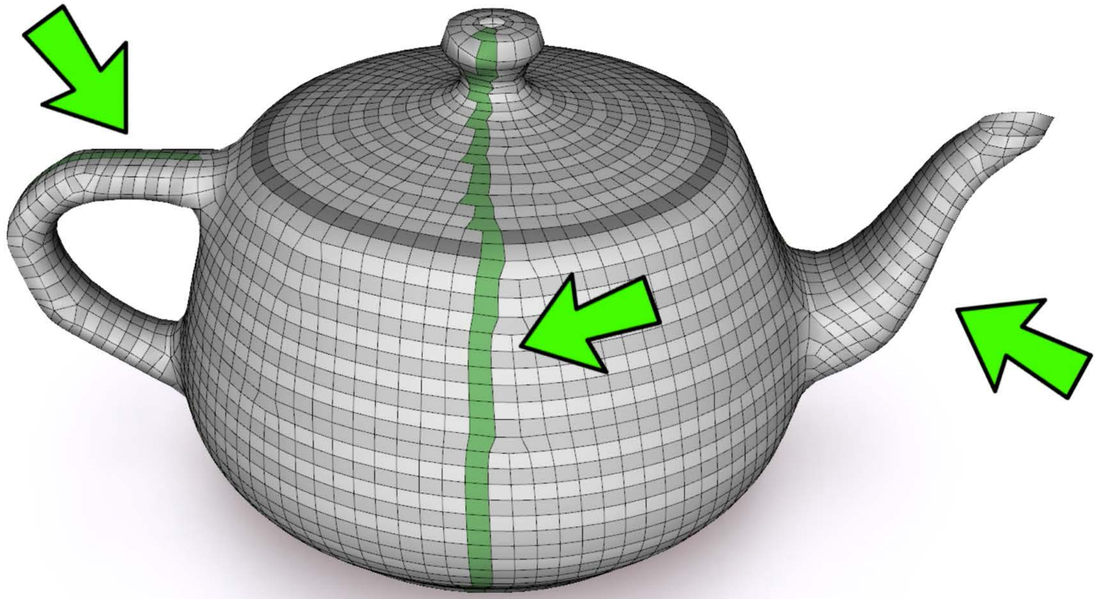
Results

Conclusion

- Knittable stitch mesh framework

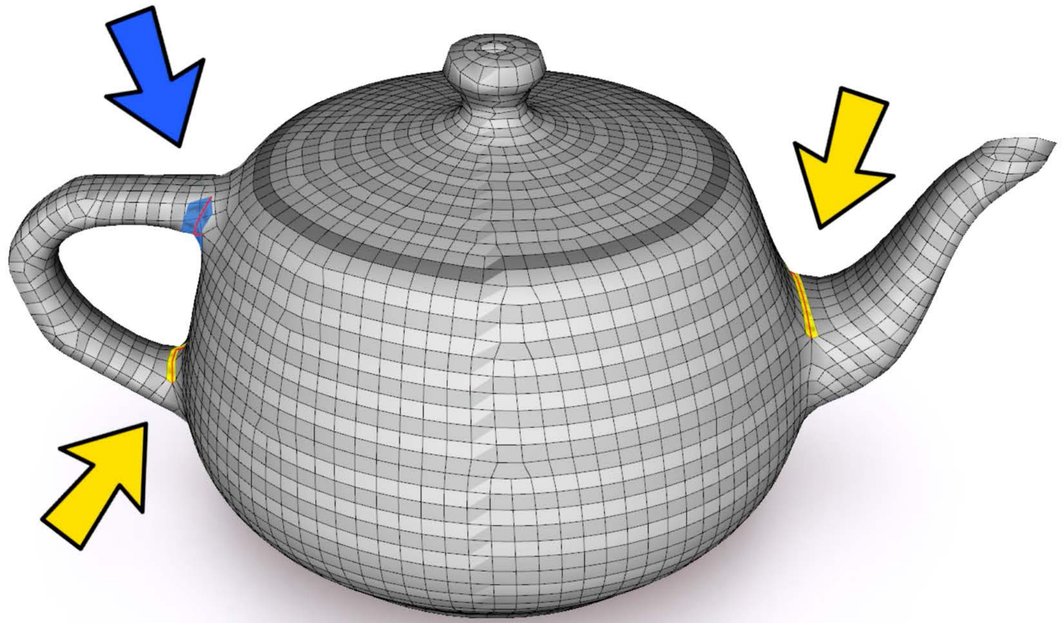
Conclusion

- Knittable stitch mesh framework
  - Shift-paths



Conclusion

- Knittable stitch mesh framework
  - Shift-paths
  - Knittable mismatched directions



Conclusion

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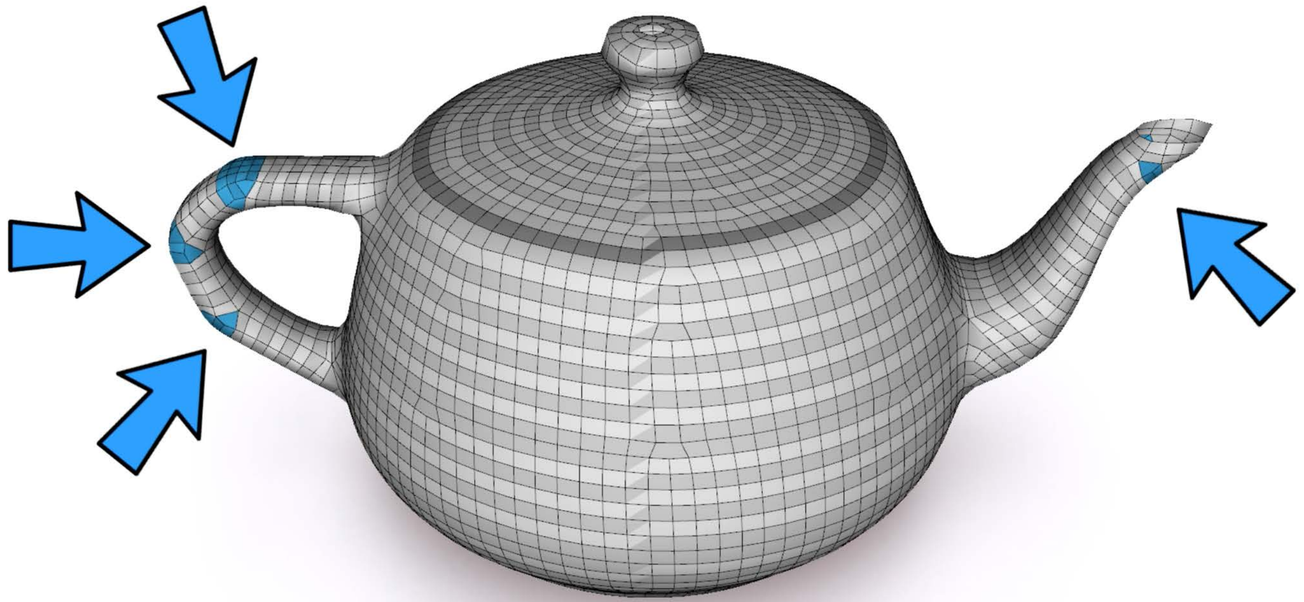
  - Shift-paths
  - Knittable mismatched directions
  - Short-rows

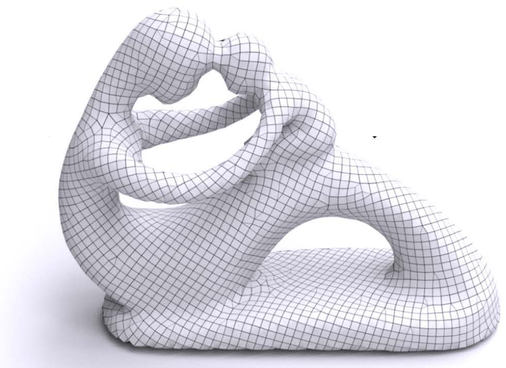
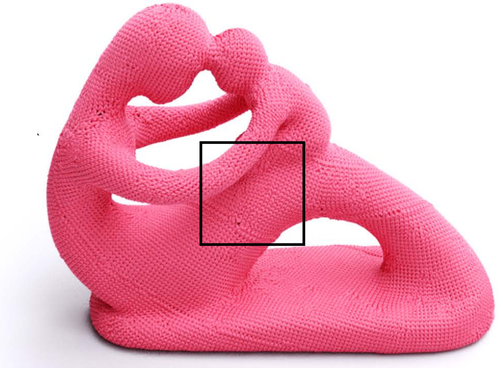


Conclusion

- Knittable stitch mesh framework
  - Shift-paths
  - Knittable mismatched directions
  - Short-rows
- Knitting instruction generation algorithm

Stitch Mesh Modeling Pipeline

- Automatic stitch meshing

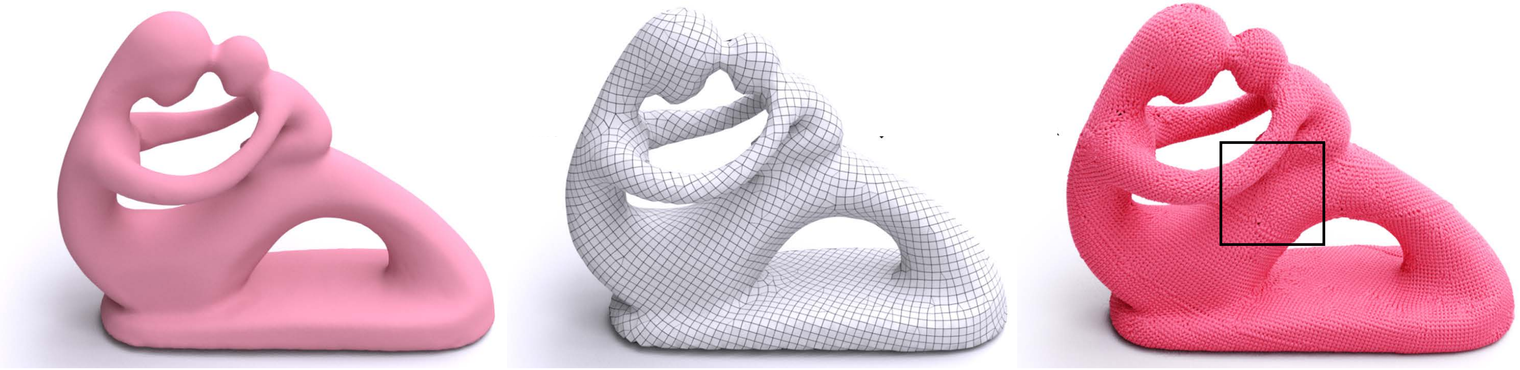
Stitch Meshing

Kui Wu, Xifeng Gao, Zachary Ferguson, Daniele Panozzo, Cem Yuksel

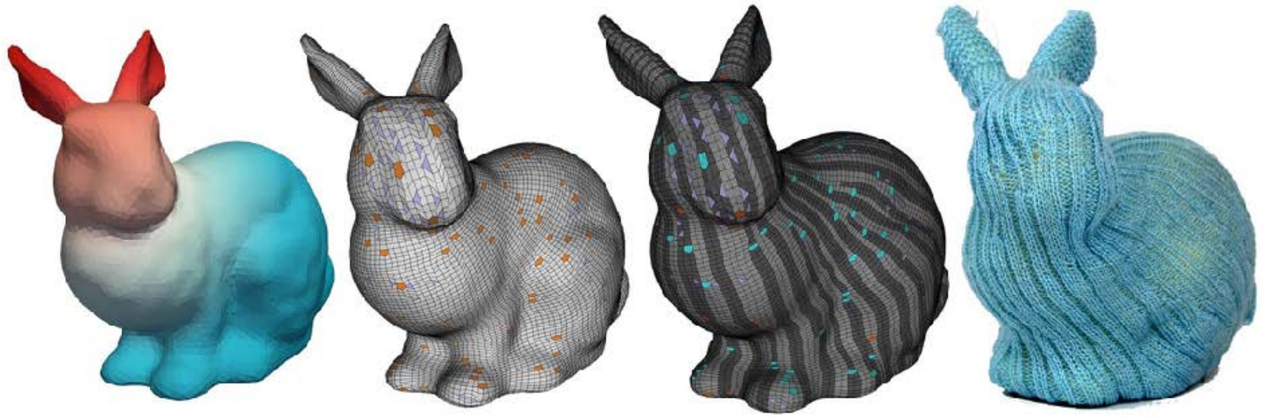
Siggraph 2018

Stitch Mesh Modeling Pipeline

- Automatic stitch meshing



- Machine knittable stitch mesh (next talk!)



Visual Knitting Machine Programming

Vidya Narayanan*
Kui Wu*
Cem Yuksel
Jim McCann

* joint first authors

Visual Knitting Machine Programming

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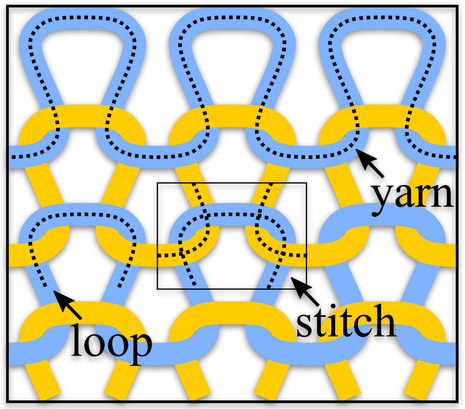
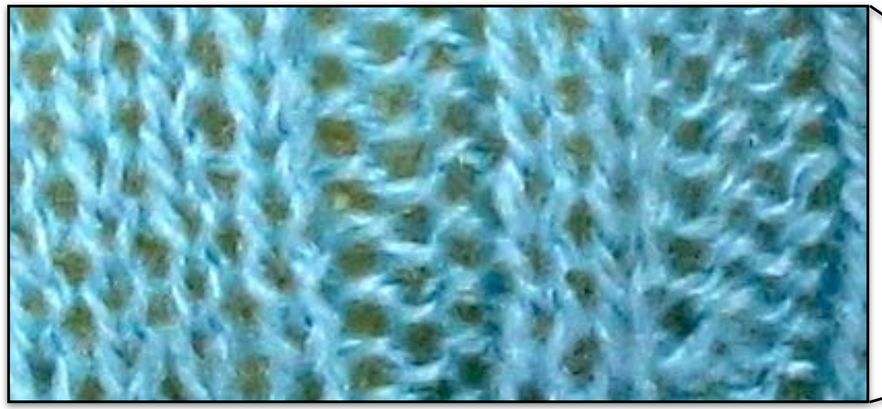
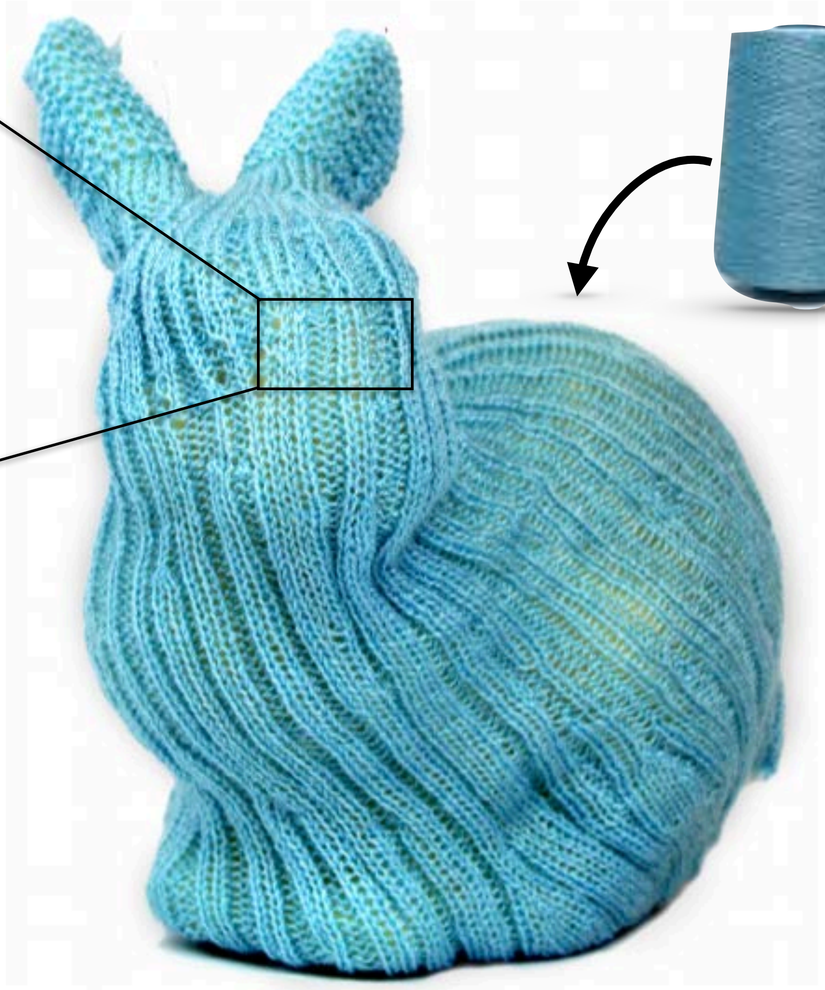
Visual Knitting Machine Programming

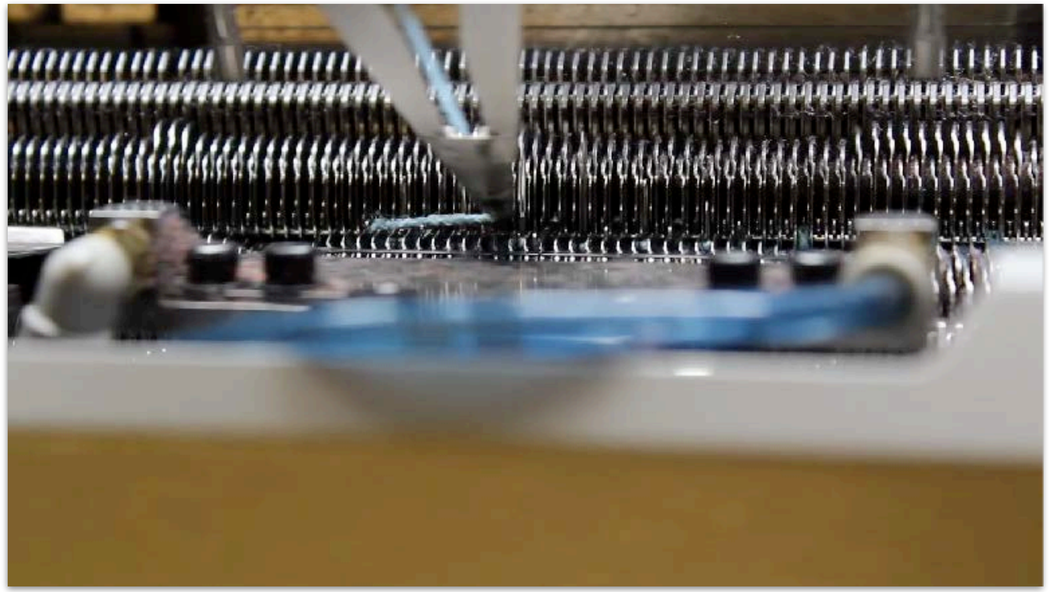


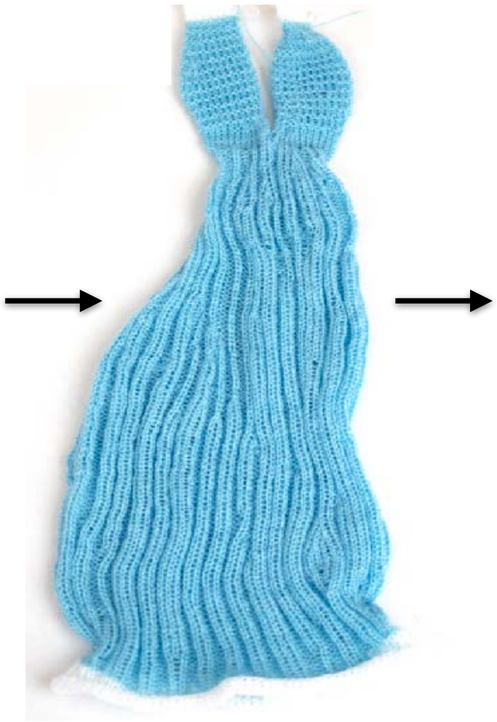




Fabric constructed using a single yarn (usually) by forming and intertwining *loops*

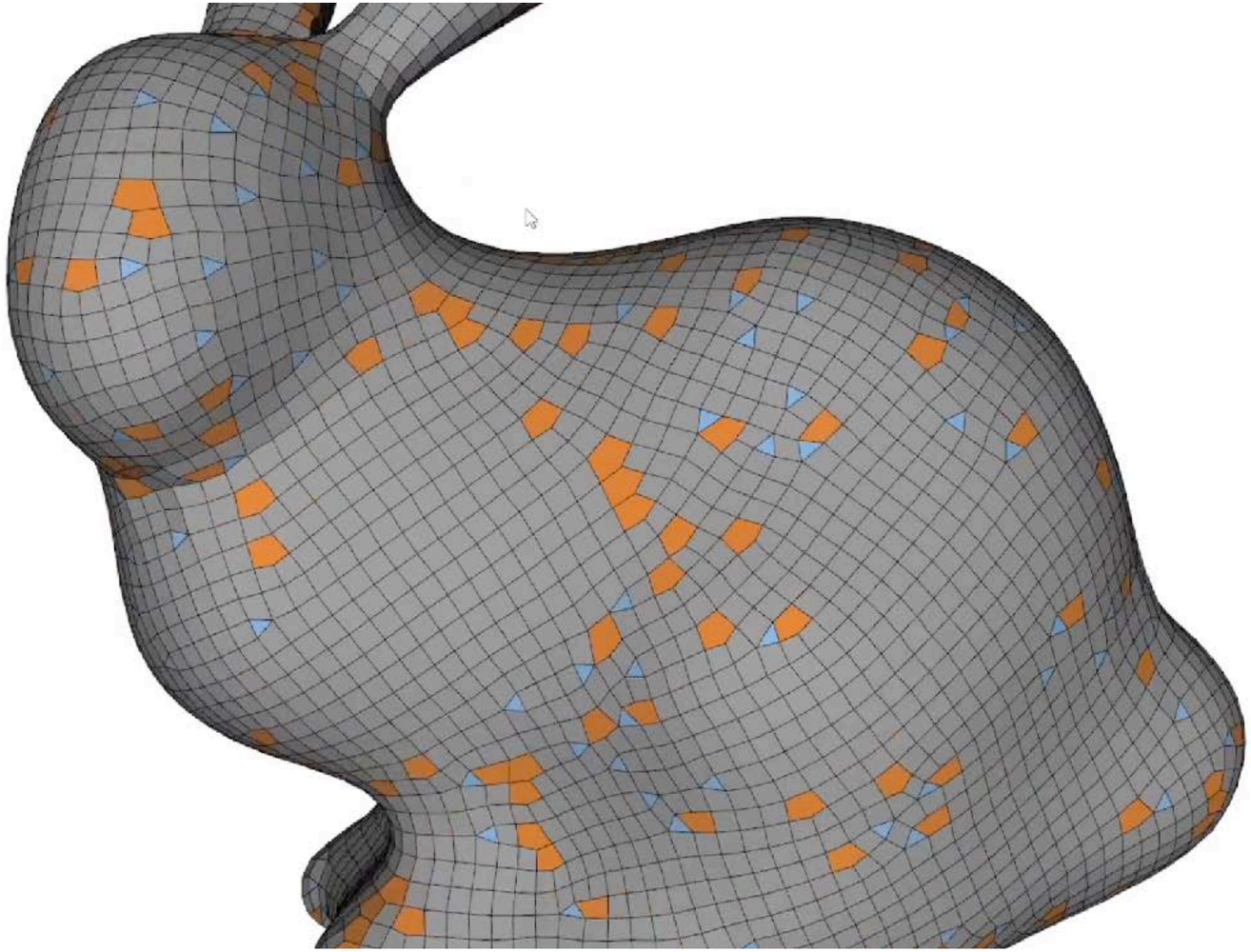
Visual Knitting Machine Programming





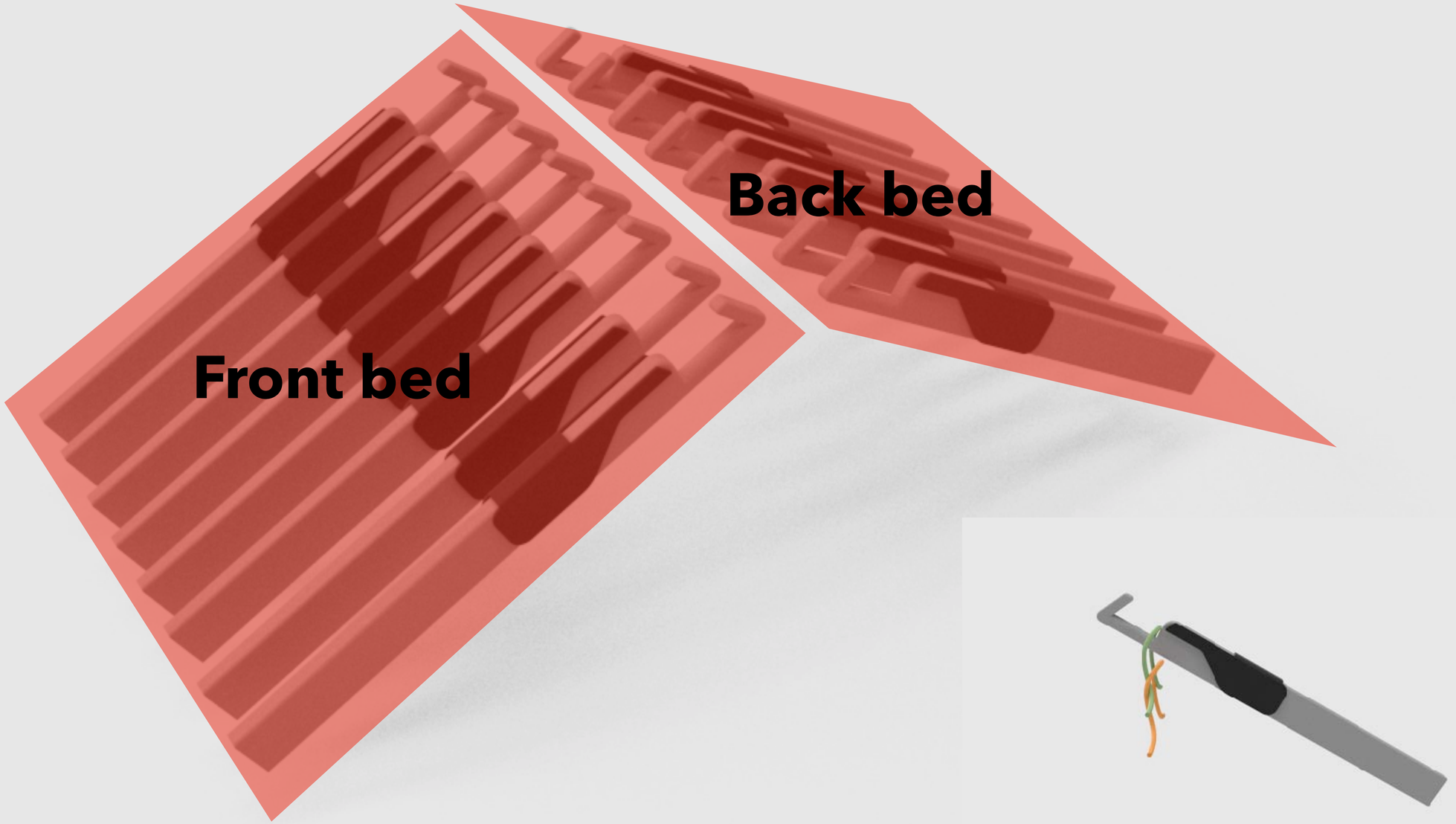
Manufactured using industrial knitting machines (usually used for garments)

Visual Knitting Machine Programming



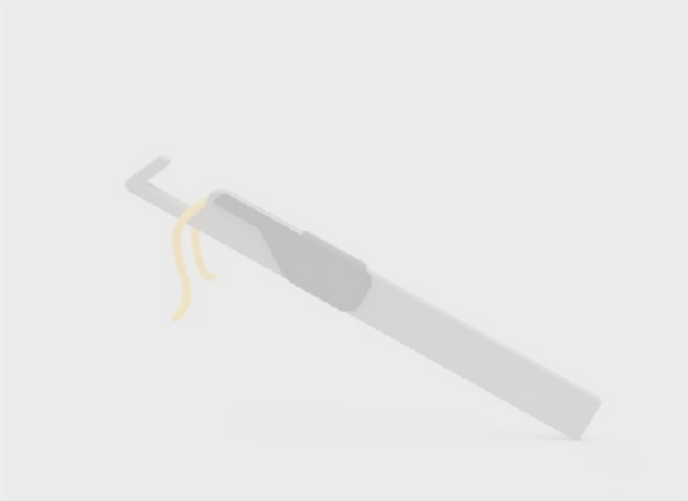
What is Machine Knitting?

Knitting Machine Layout



Basic Machine Operations

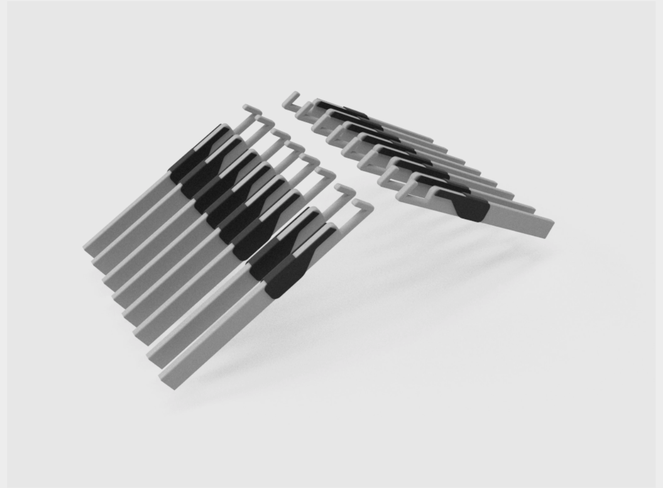
tuck



xfer

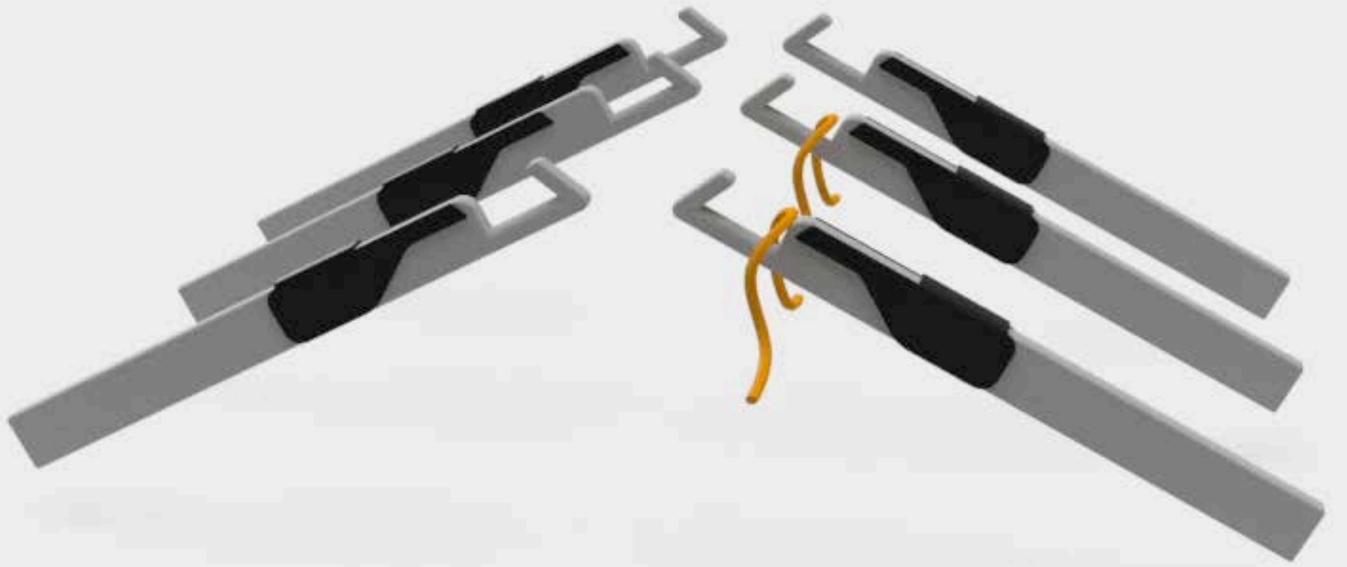
knit

rack

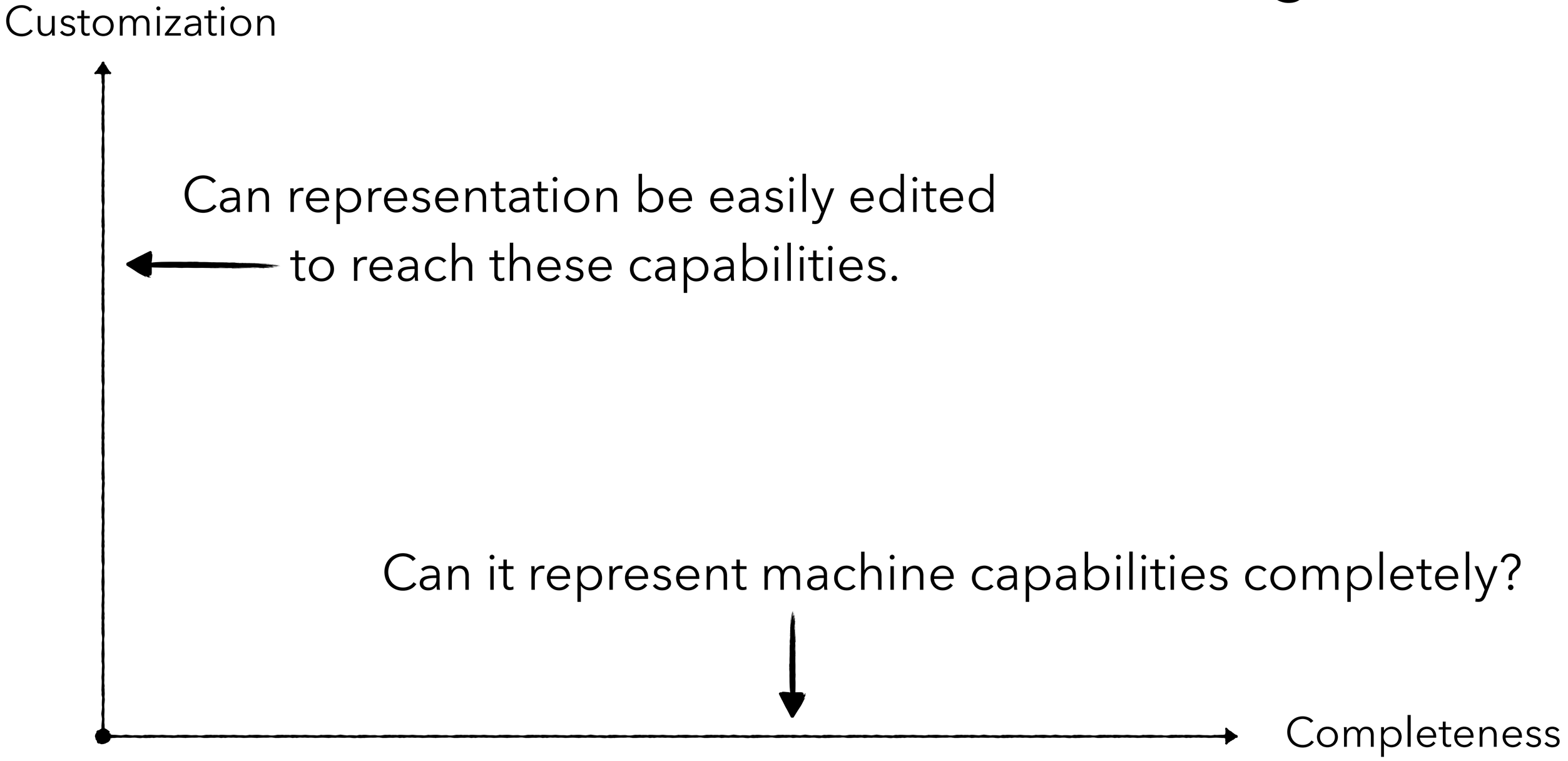


Basic Machine Operations

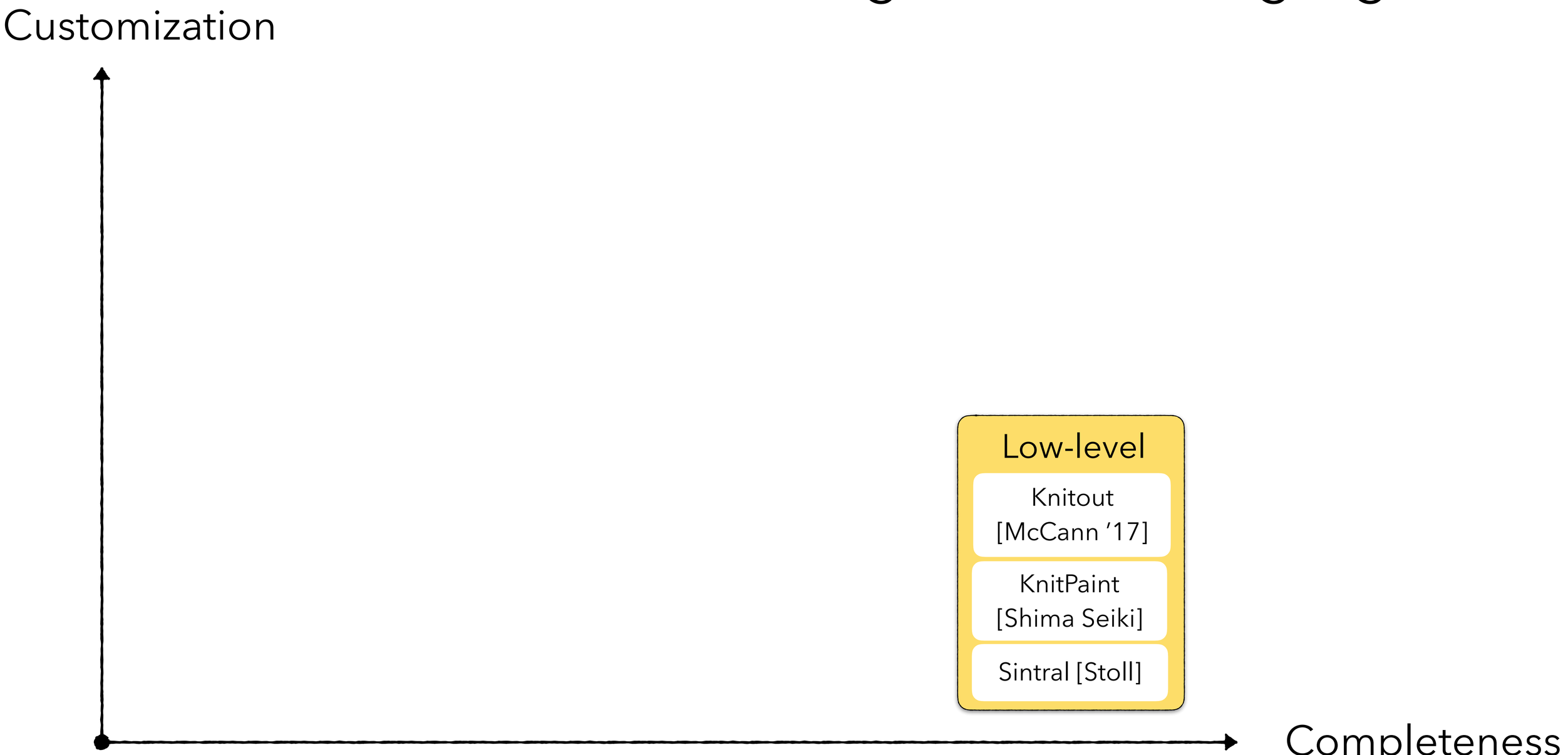
Use *xfer* and *rack* to move loops between needles



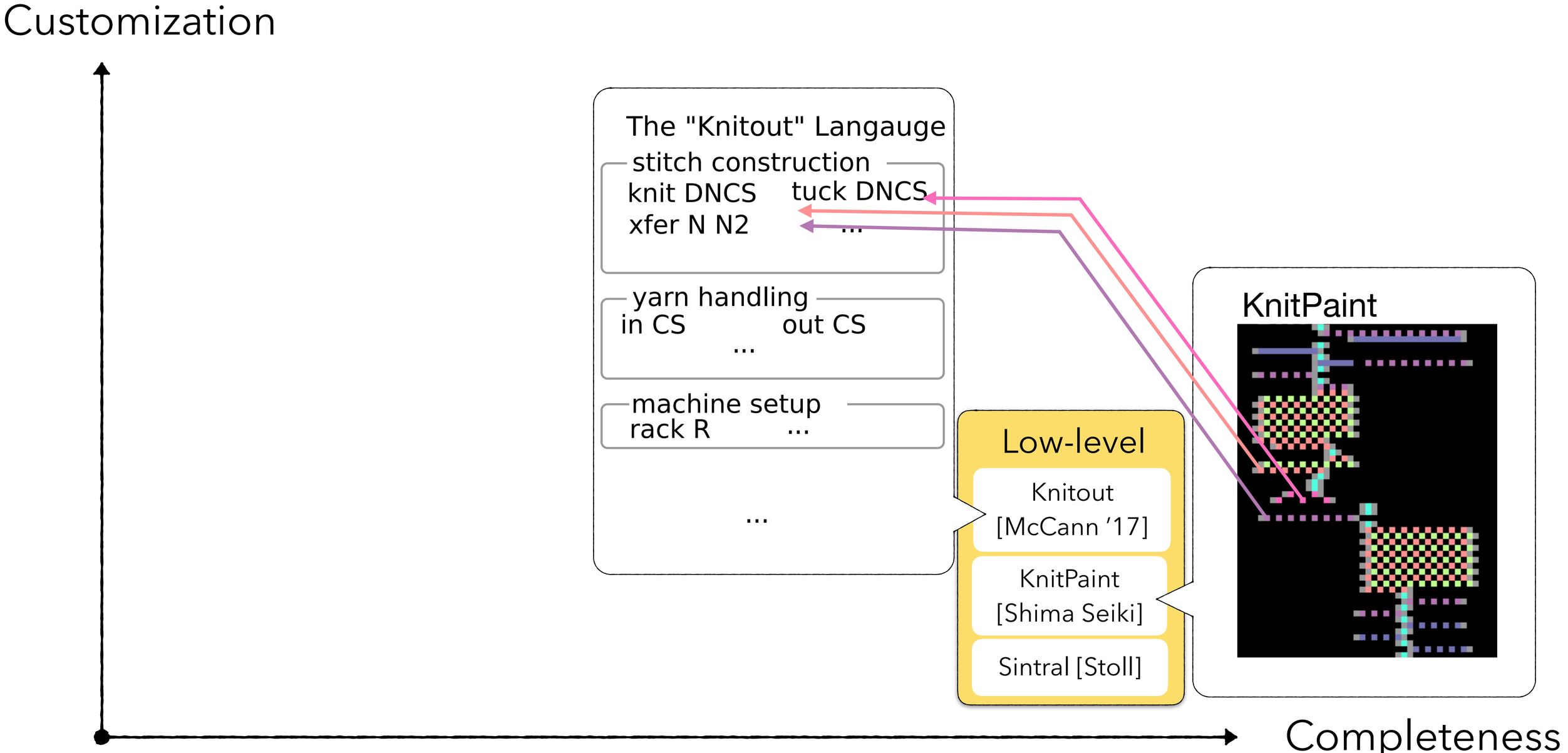
Solutions for machine knitting



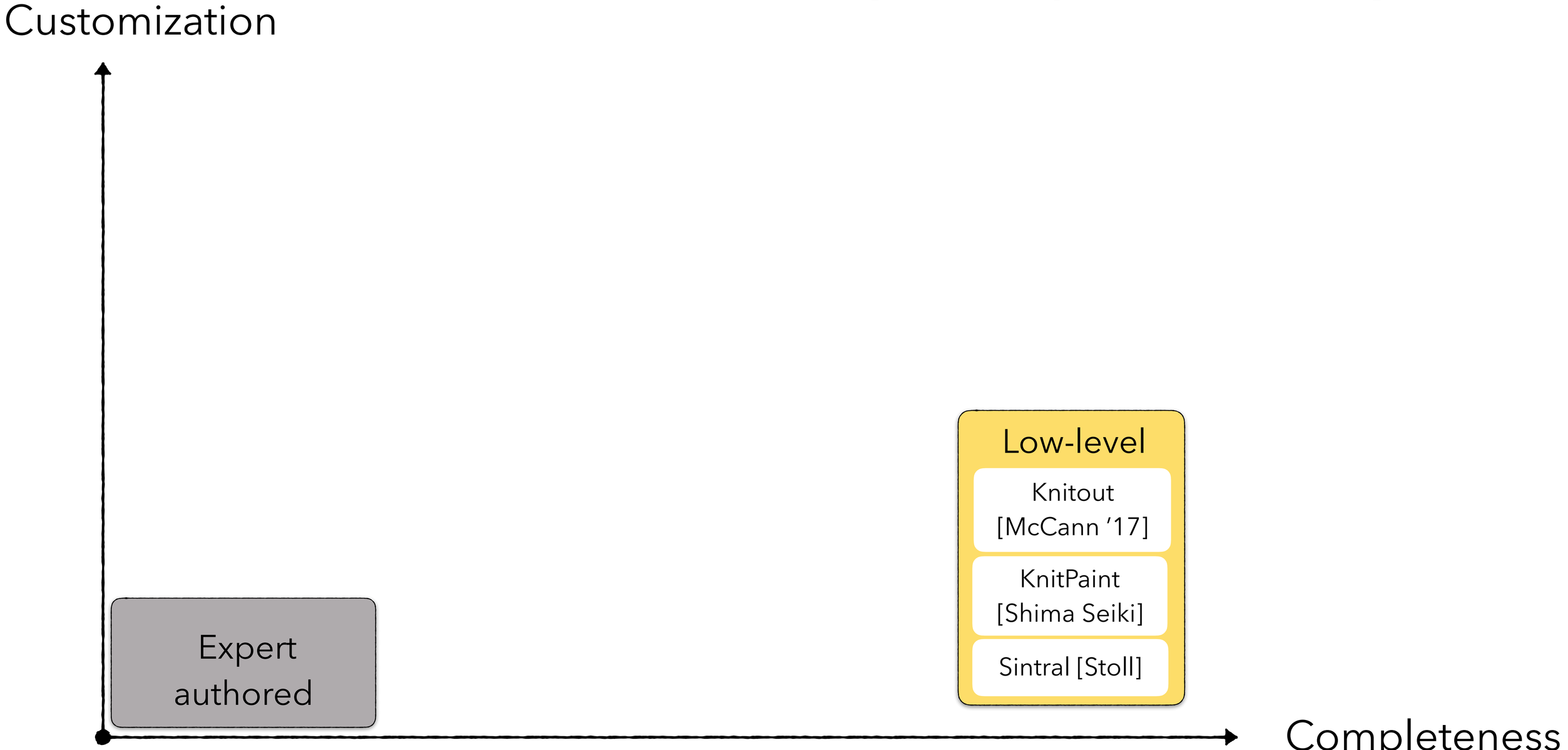
Solutions for machine knitting : low-level languages



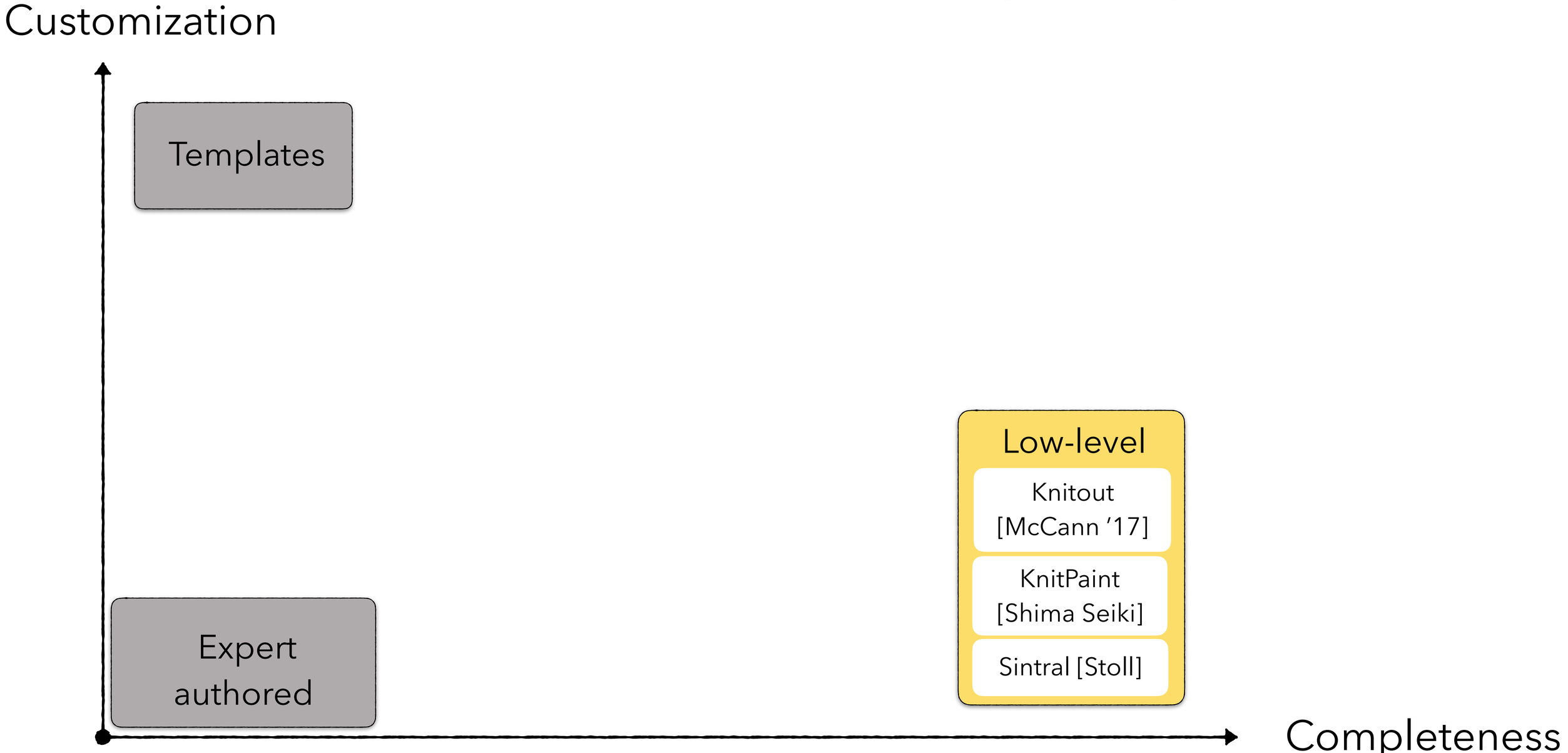
Solutions for machine knitting : low-level languages



Solutions for machine knitting : ready-made designs



Solutions for machine knitting : templates



Solutions for machine knitting : higher abstractions

Customization

Mid-level

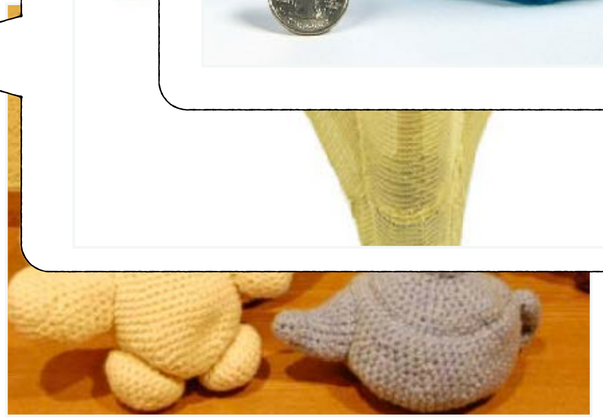
[McCann et al. ’16]

High-level

[Narayanan et al. ’18]

[Popescu et al. ’18]

[Igarashi et al. ’08]



Expert authored

Completeness

Solutions for ~~machine~~ knitting

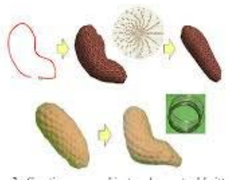
Customization

Completeness

Stitch Meshes

Knitty

Figure 2: *Screenshot of the Knitty system.*



Any topological surface can be knit

Modeling & Hand knitting

[Yuksel et al. ’12]

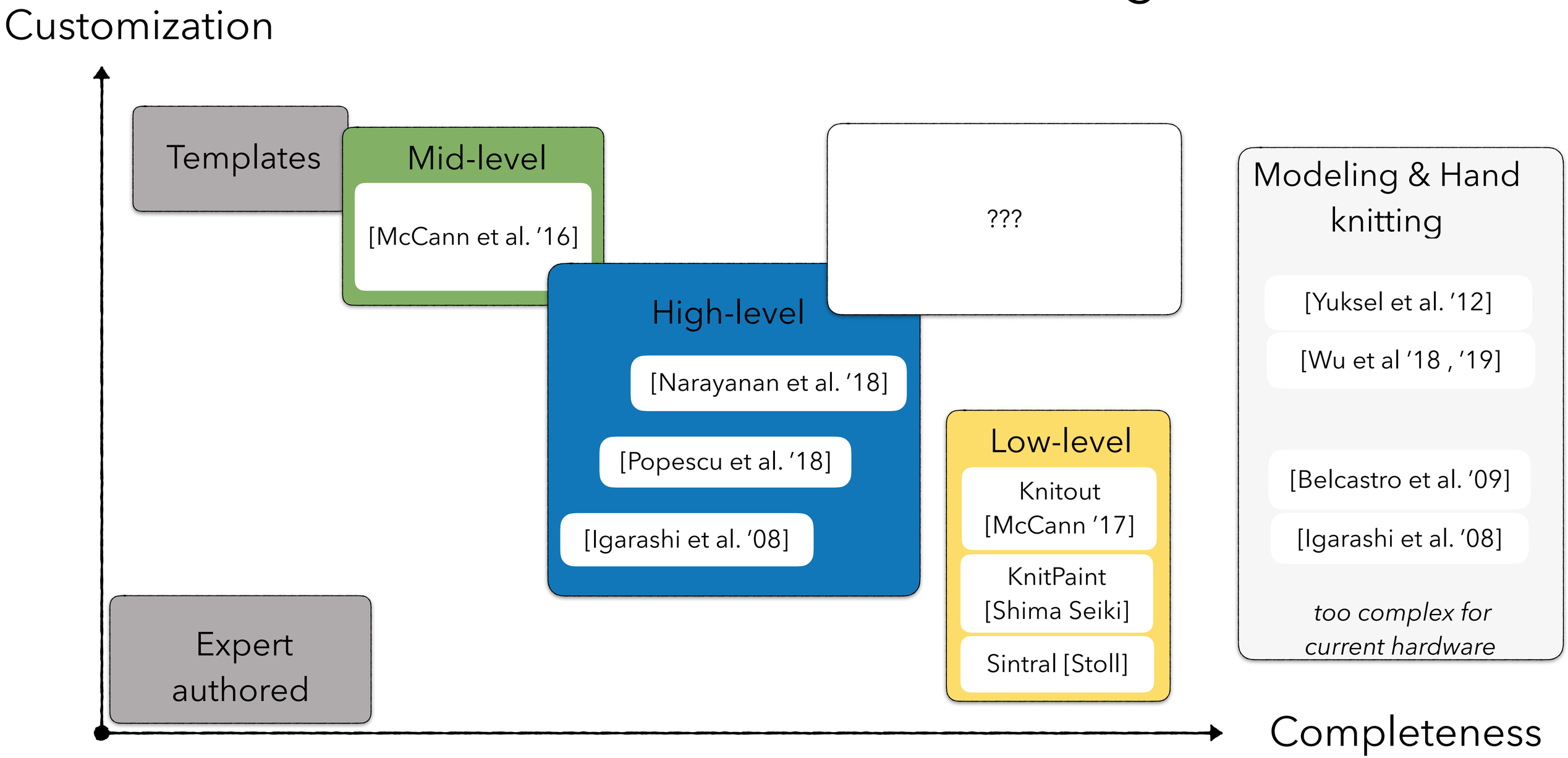
[Wu et al ’18 , ’19]

[Belcastro et al. ’09]

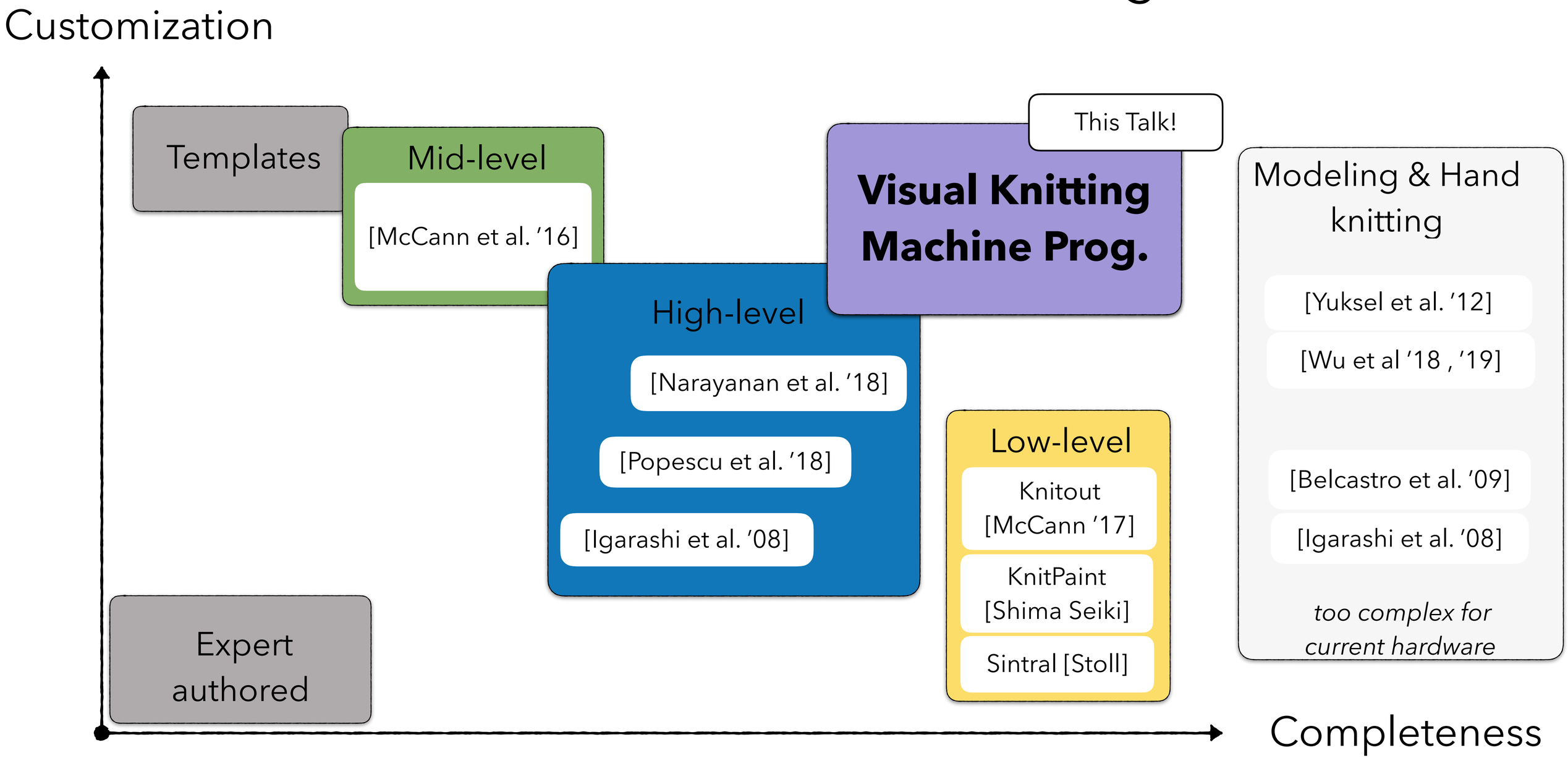
[Igarashi et al. ’08]

too complex for current hardware

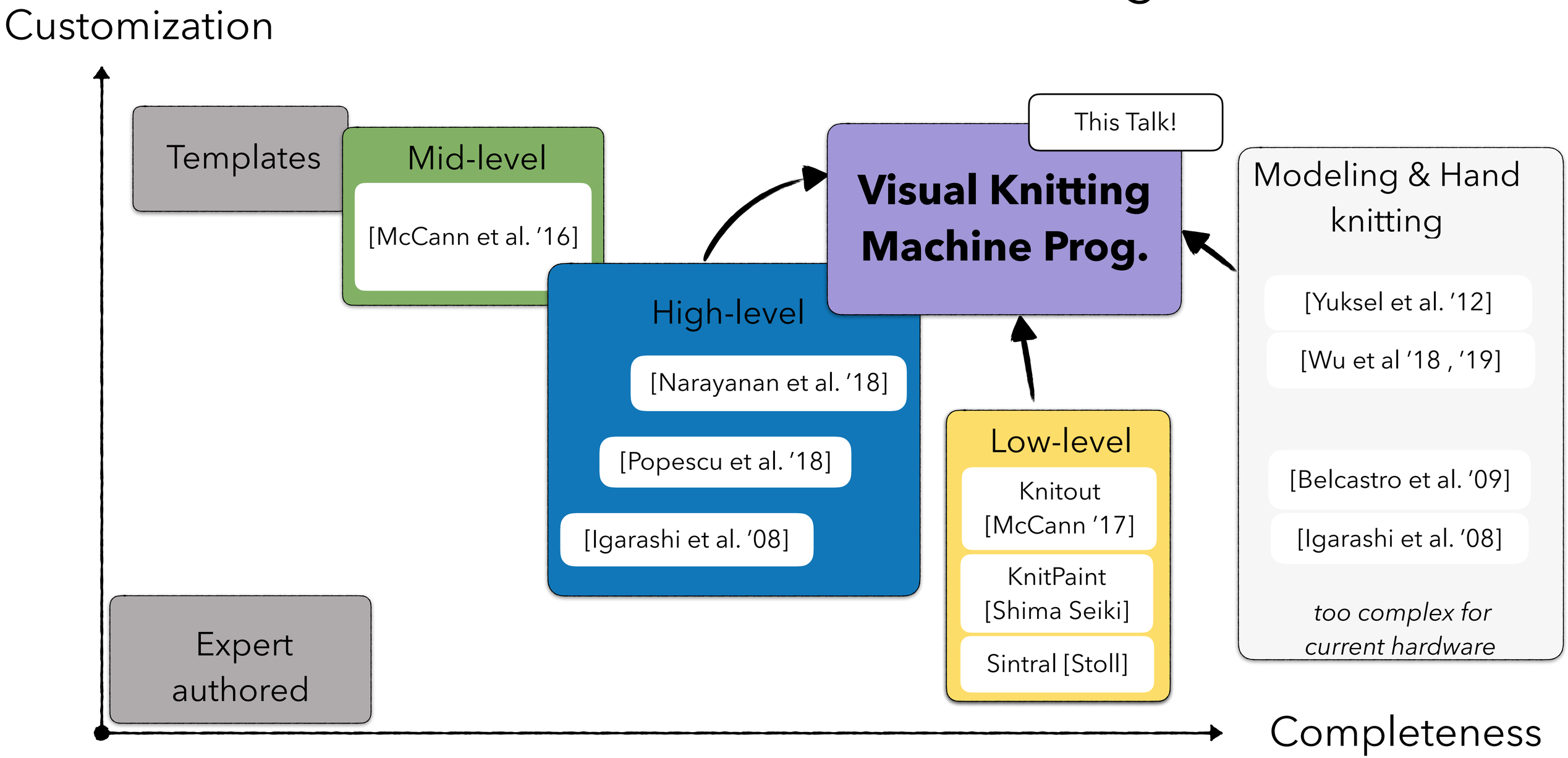
Solutions for machine knitting



Solutions for machine knitting

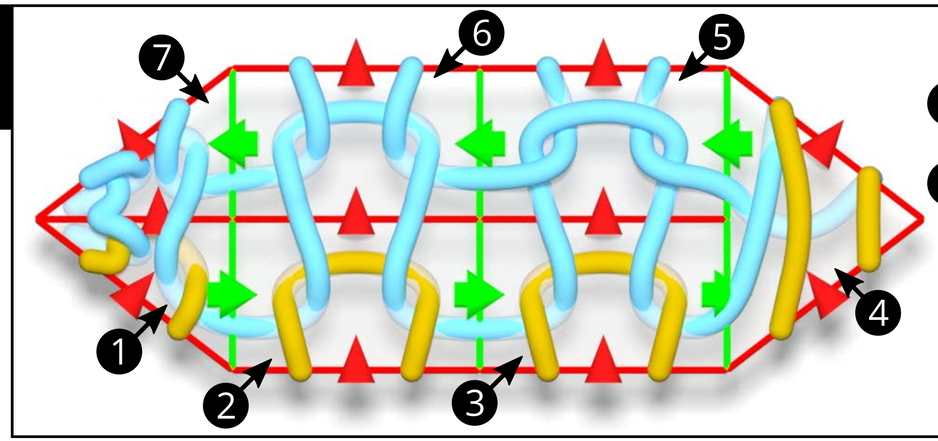


Solutions for machine knitting



Visual Knitting Machine Programming

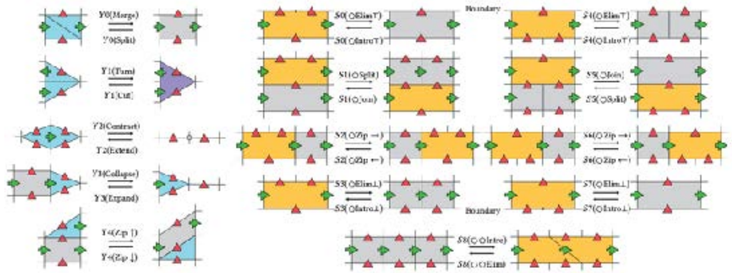
1




```
1  in A
   knit + f1 A
2  knit + f2 A
3  knit + f3 A
4  tuck + f4 A
5  xfer f3 b3
   knit - b3 A
6  knit - f2 A
7  knit - f1 A
   out A
   xfer b3 f3
```

Augmented Stitch Mesh Representation

2

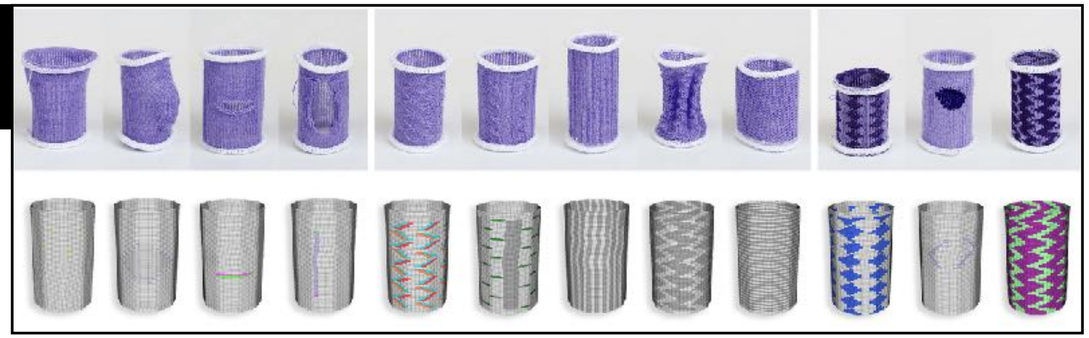


Interactive Editor

Tube Scheduler

System

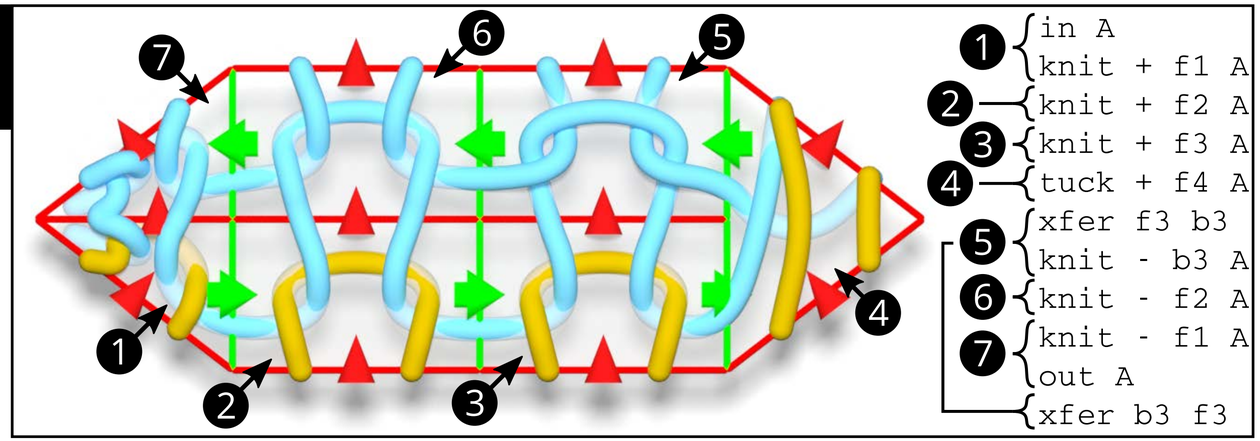
3



Results

Visual Knitting Machine Programming

1



Augmented Stitch Mesh Representation

2

Interactive Editor

Tube Scheduler

System

3

Results

Stitch meshes for representing *machine* knittable structures

Stitch Mesh

\+ Represented in the output space

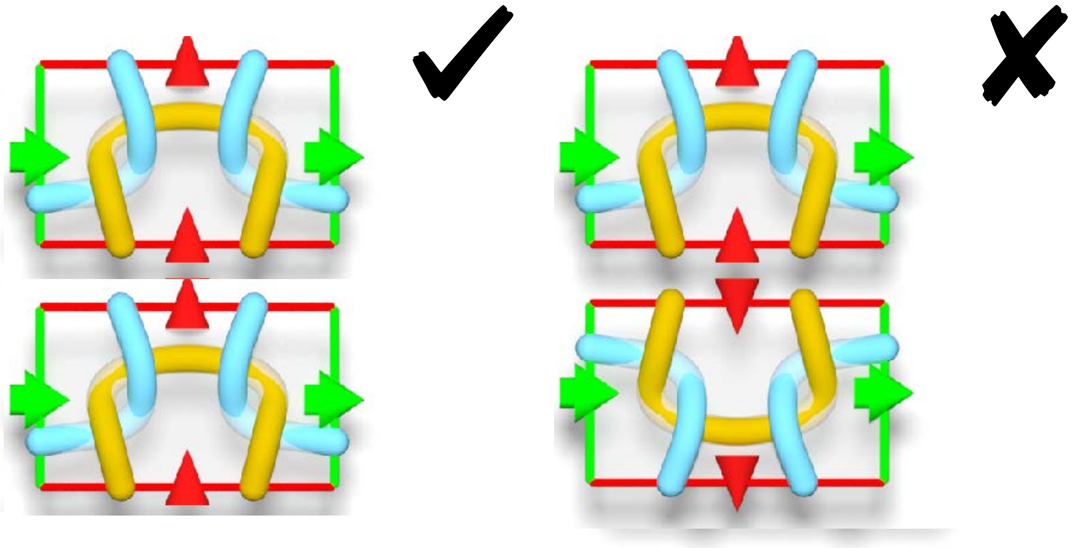
\+ Potentially intuitive to edit

– Can easily represent unknittable configurations (cycles).

– Machine instructions for fabrication are unknown.

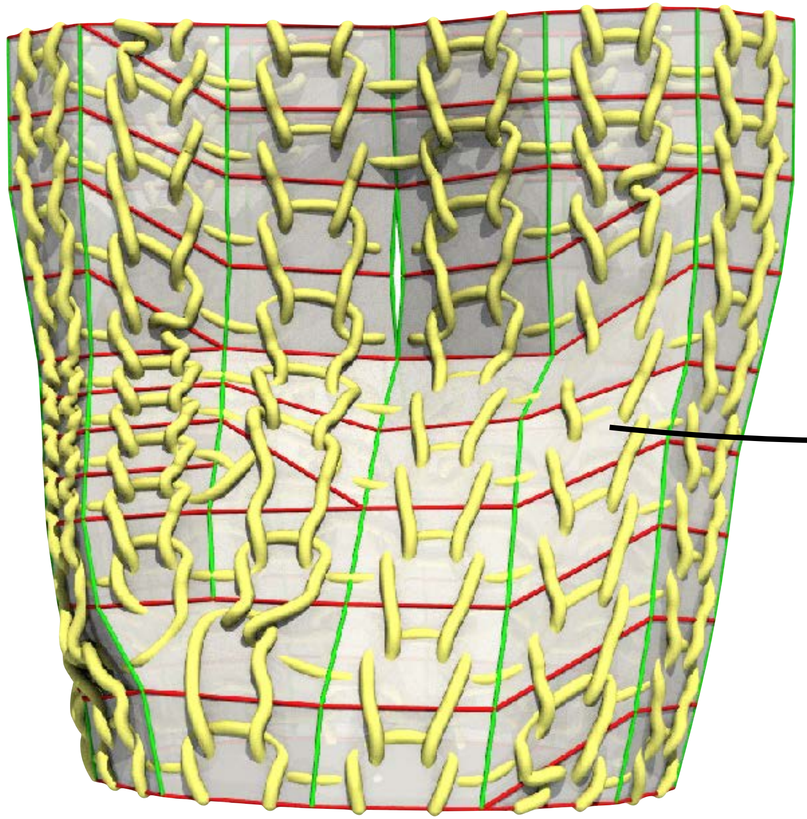
Encoding dependencies with edge directions

Stitch Mesh



Only directed acyclic stitch meshes are valid.

Encoding face programs for construction



Stitch Mesh + Directions

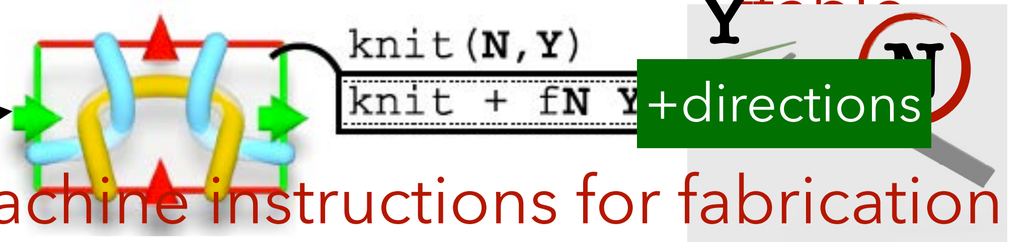
+ Represented in the output space

+ Potentially intuitive to edit

Decouple *what* is constructed from *where* it is constructed.

– ~~Co~~

~~cor~~



– Machine instructions for fabrication are unknown.

Augmented Stitch meshes for machine knittable structures

+ Represented in the output space

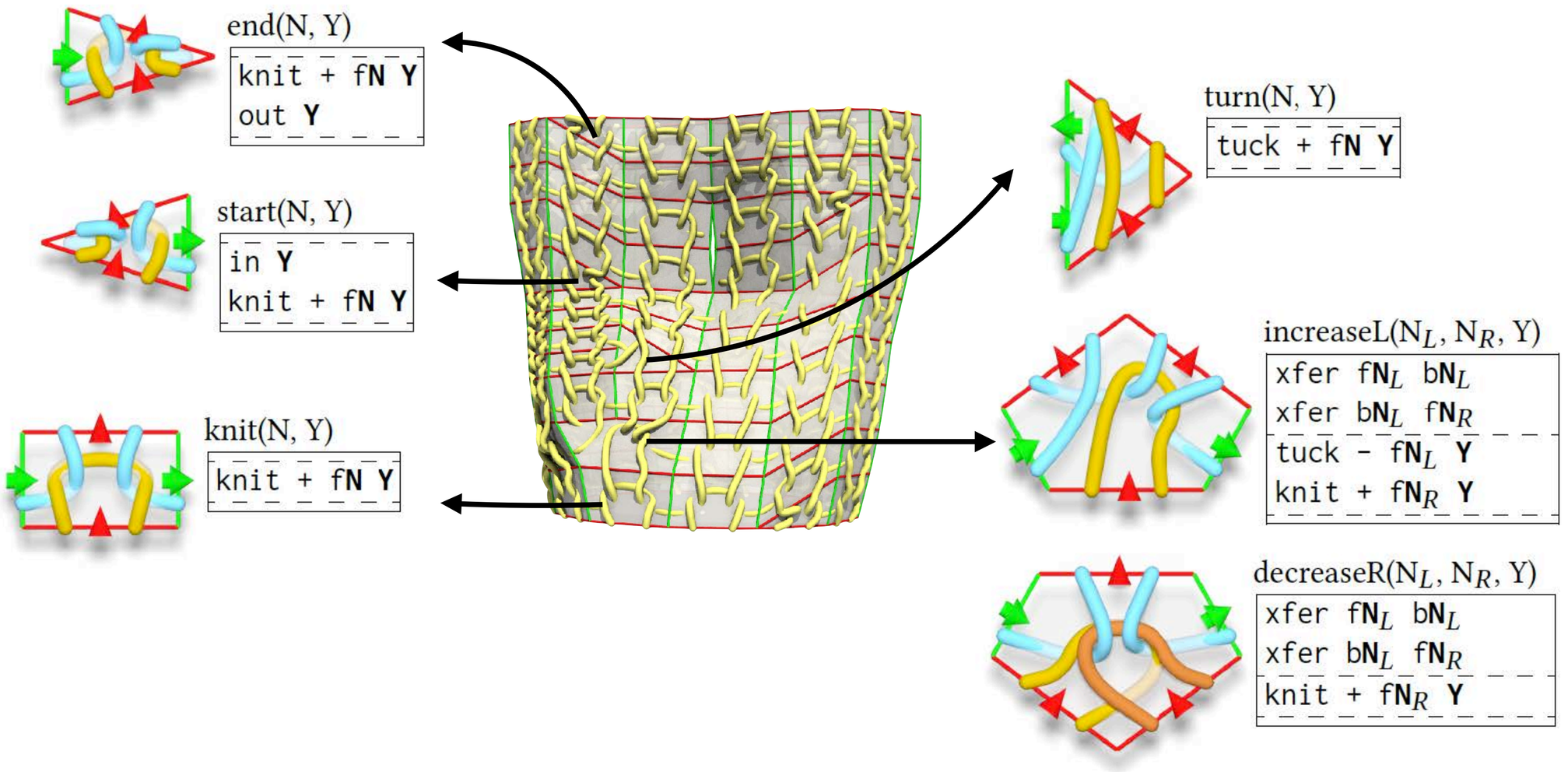
+ Potentially intuitive to edit

~~– Can easily represent unknittable configurations (cycles).~~ +directions

~~– Machine instructions for fabrication are unknown.~~ +code

Stitch Mesh + Directions + Code = **Augmented Stitch mesh**

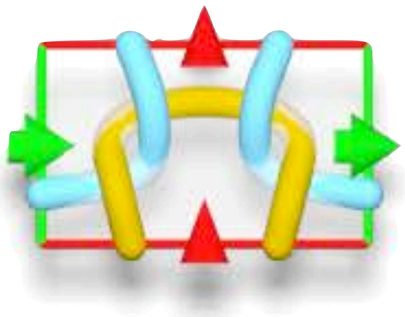
Only a small library of face programs needed



Edge labels do not imply face programs

Any compatible face program can be executed within a face.

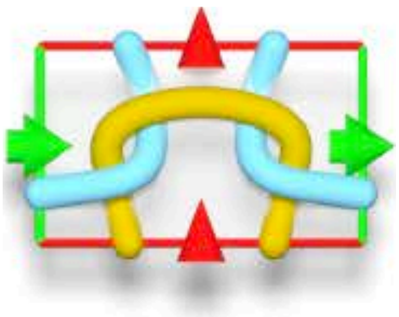
knit



knit(N, Y)

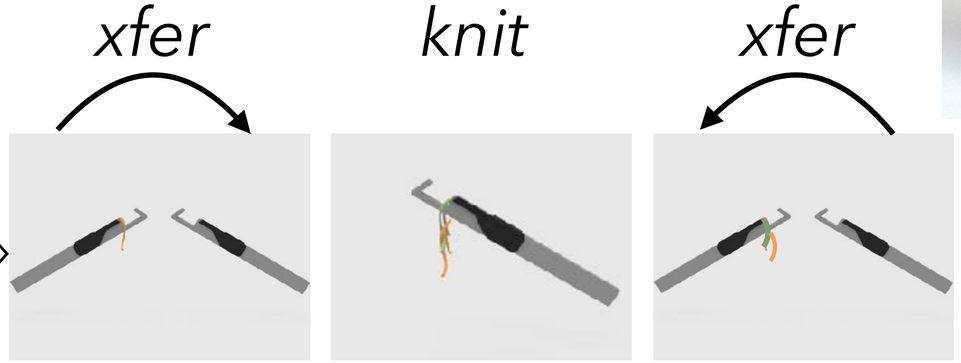
```
knit + fN Y
```

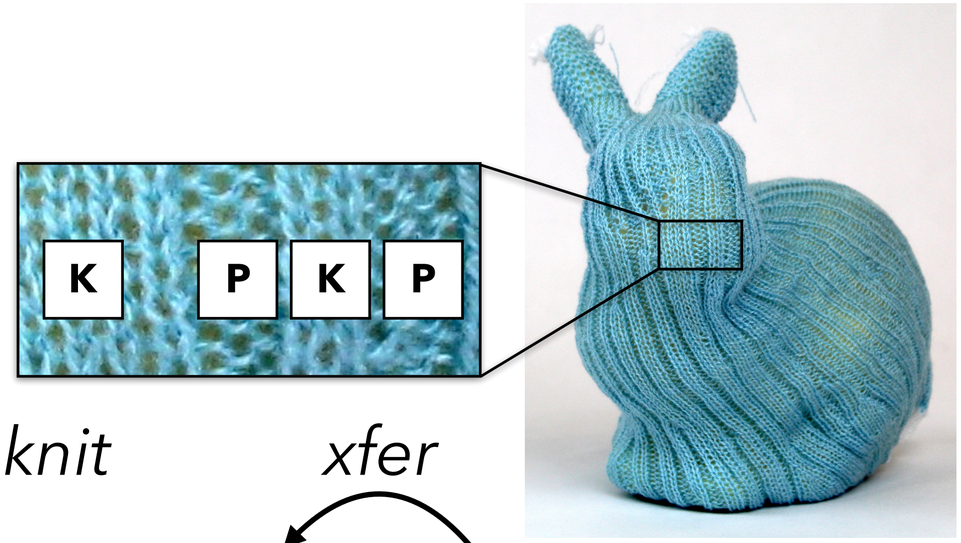
purl



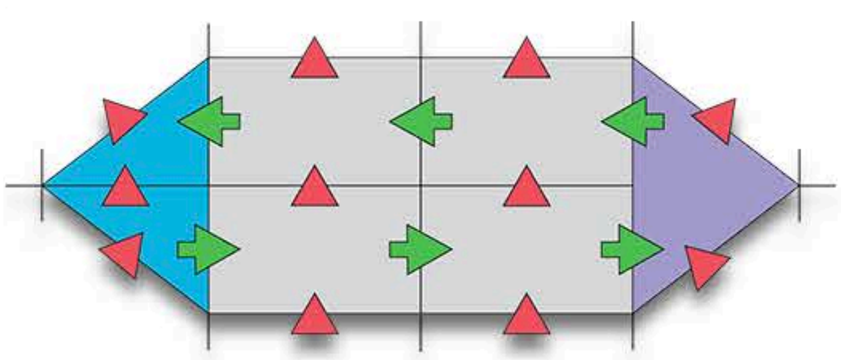
purl(N, Y)

```
xfer fN bN
knit + bN Y
xfer bN fN
```

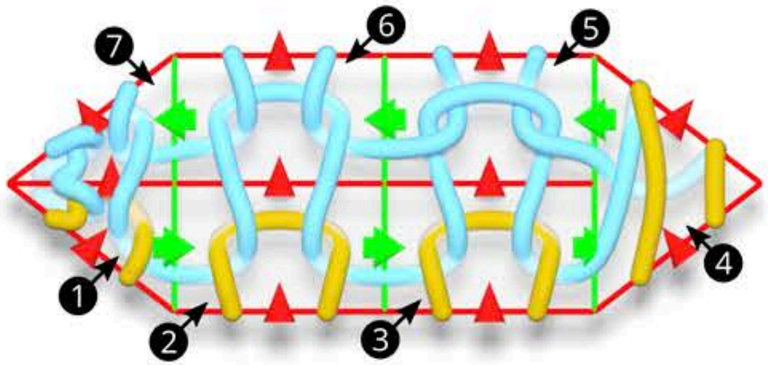




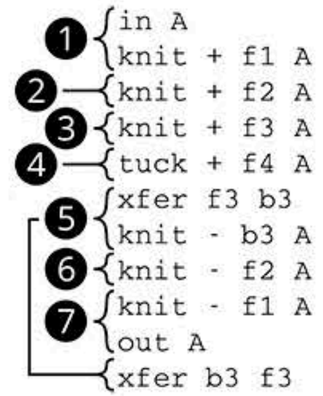
Augmented Stitch Mesh



=



+



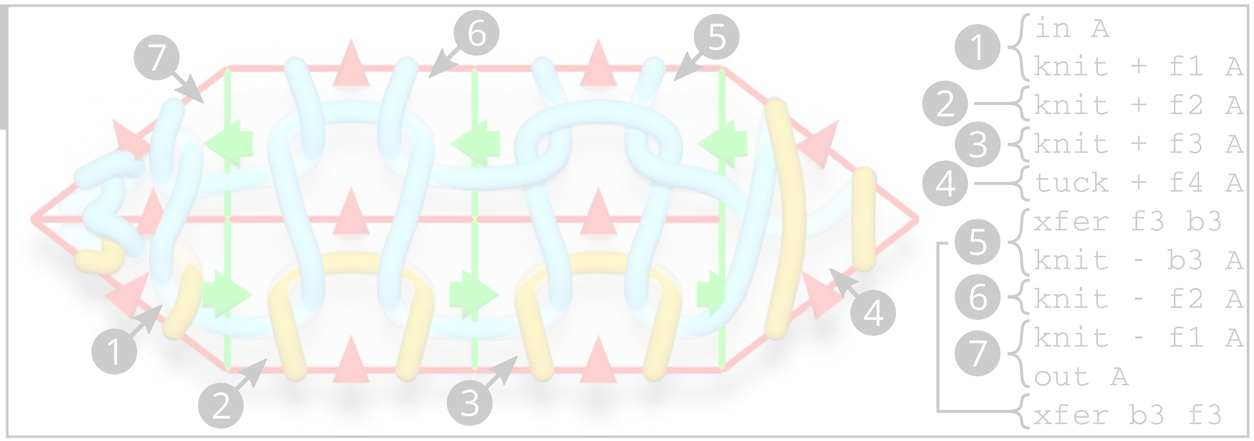
Augmented Stitch Mesh

Dependency

Knitting Program

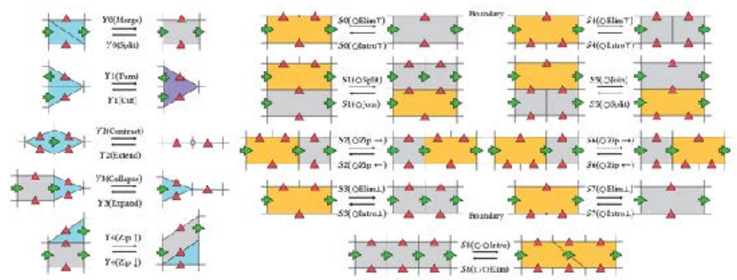
Visual Knitting Machine Programming

1



Augmented Stitch Mesh Representation

2



Interactive Editor

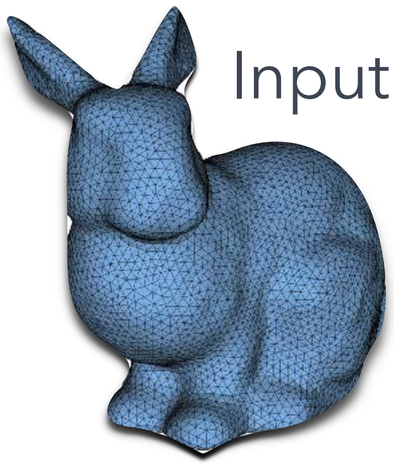
Tube Scheduler

System

3

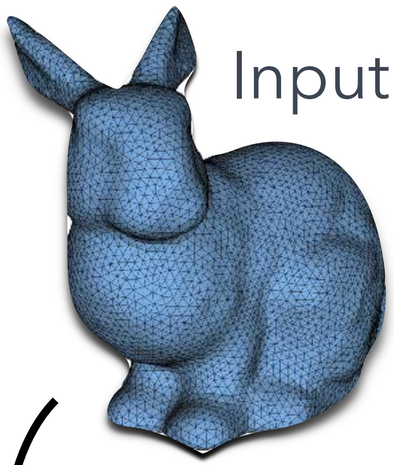
Results

Pipeline of our design system

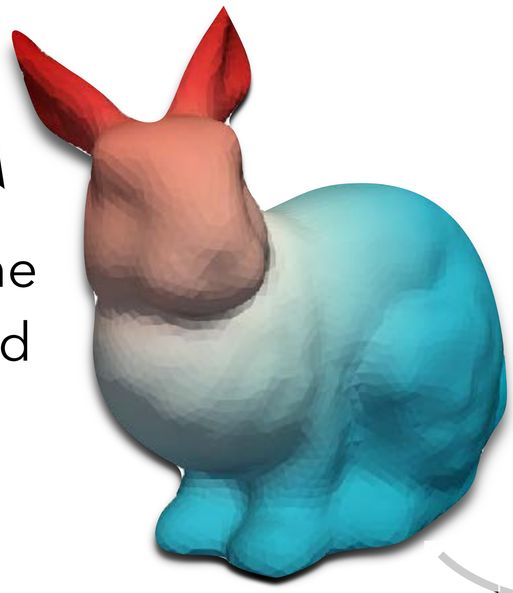


Input

Pipeline of our design system



Input



Time field

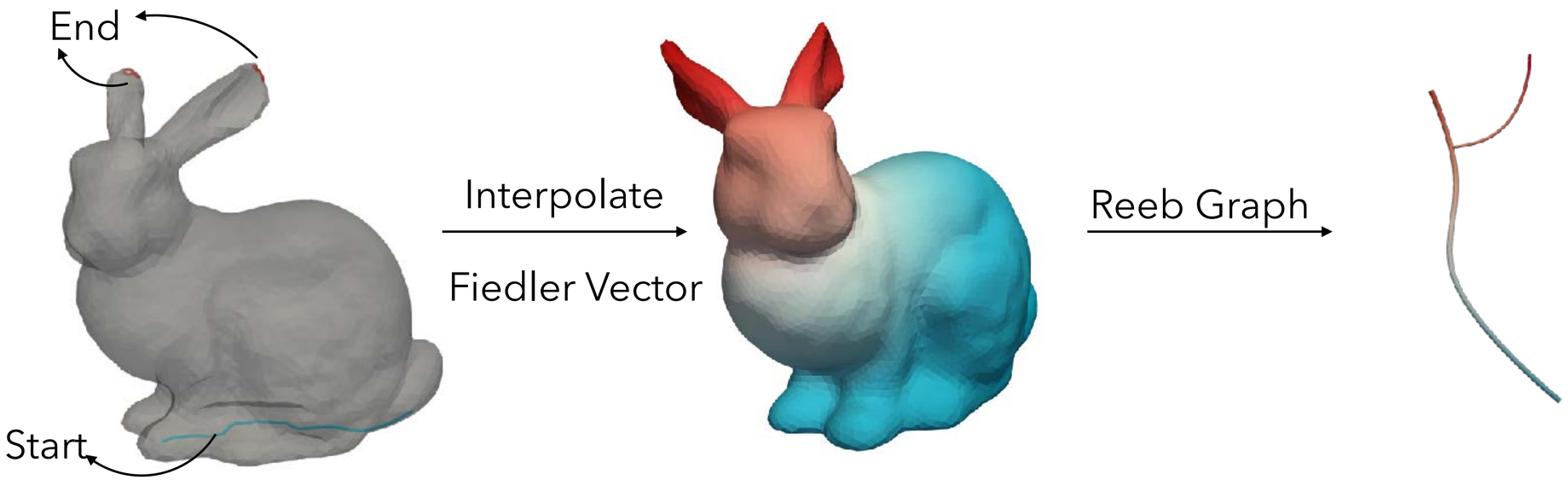
Mesh generation

Editing


```
knit f0 +
knit f1 +
knit f2 +
knit f3 +
knit f4 +
knit f5 -
xfer f4 f4
…
```

Schedule

Knitting time function

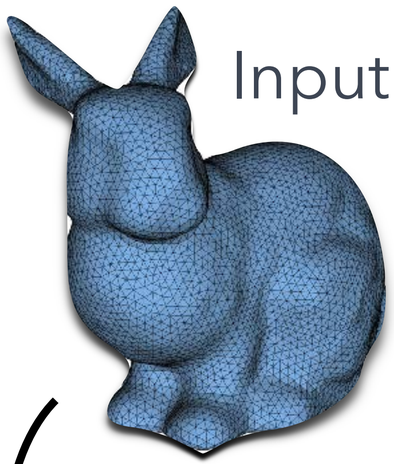


A scalar function over the mesh that defines knitting order

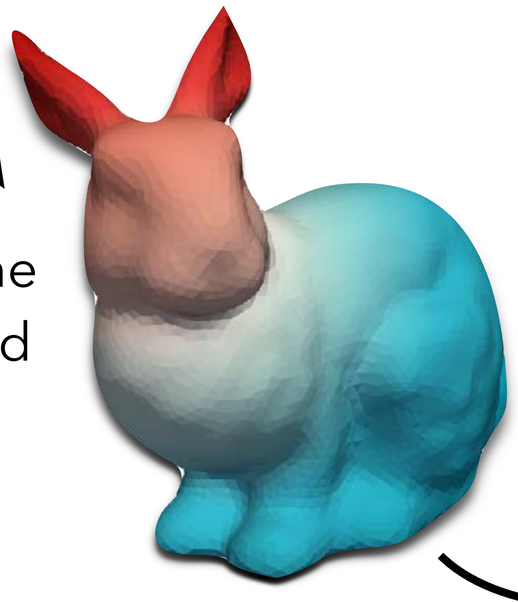
Reeb Graph has an upward planar embedding ⟺ machine knittable

[Narayanan et al. ’18]

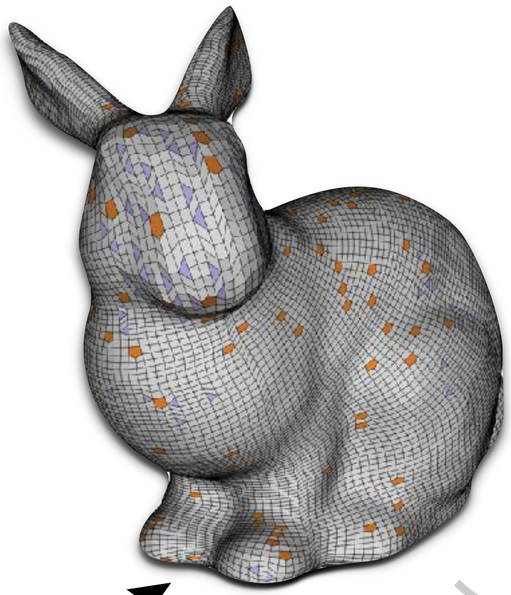
Pipeline of our design system



Input



Time field

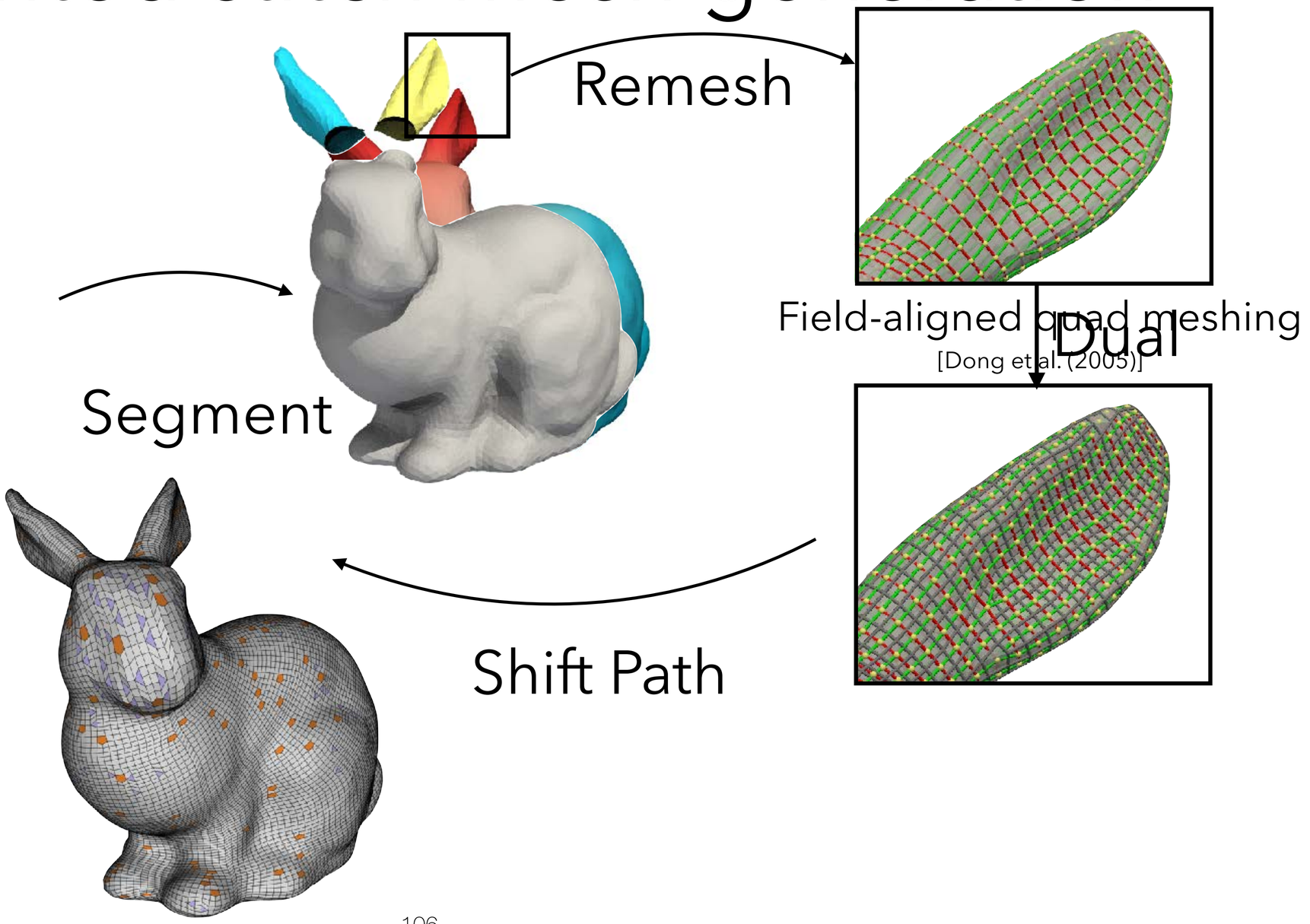


Mesh generation

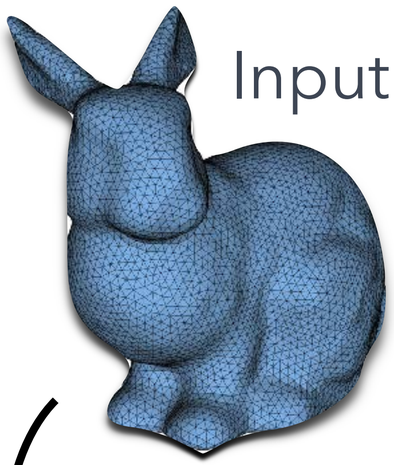
Editing

Schedule

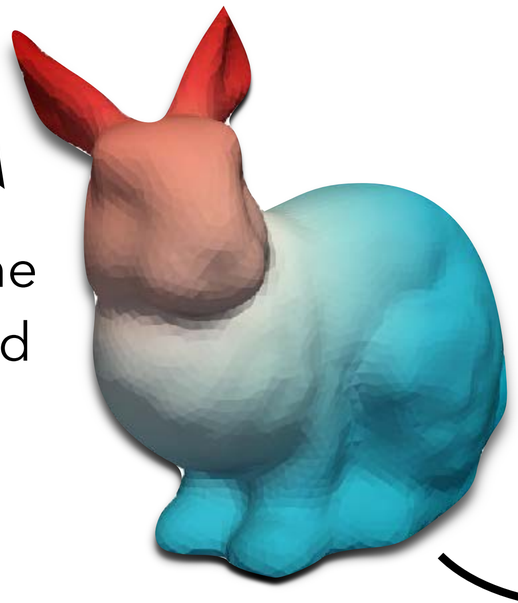
Augmented stitch mesh generation



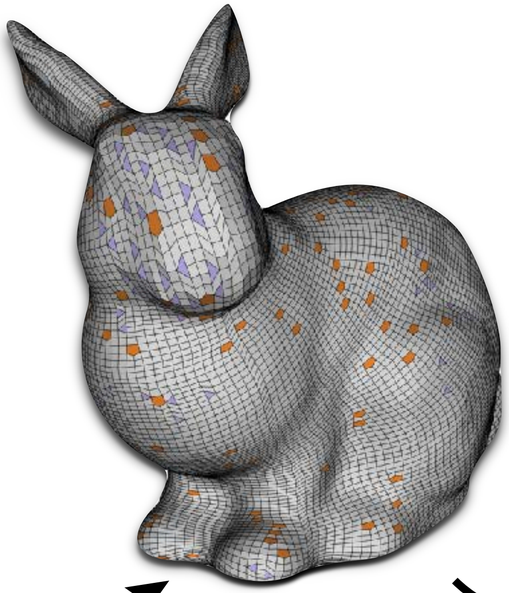
Pipeline of our design system



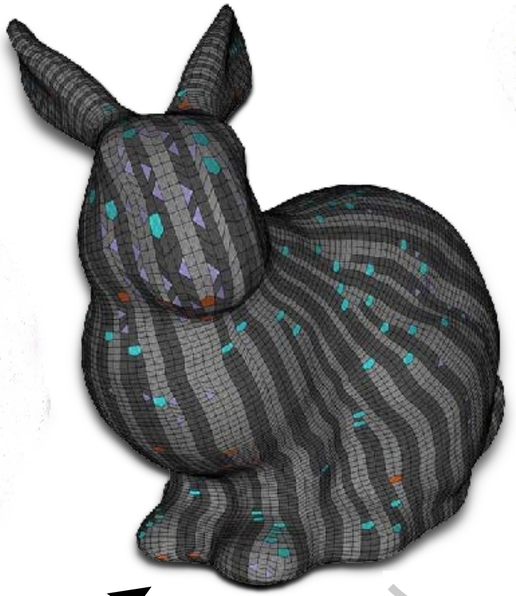
Input



Time field



Mesh generation

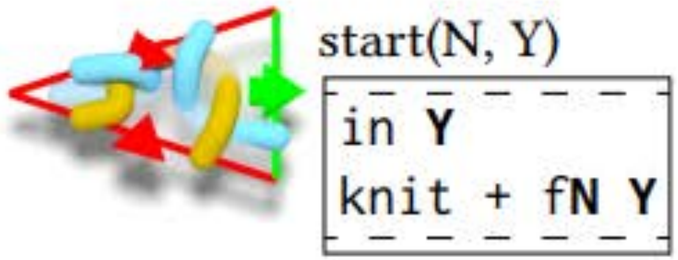


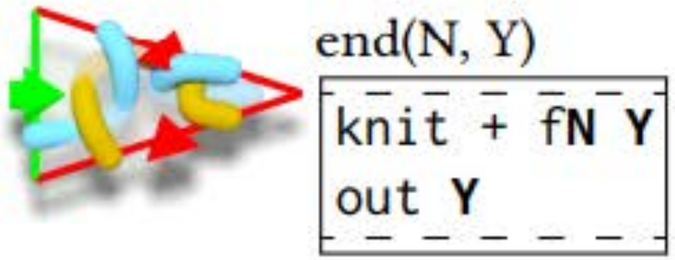
Editing


```
knit f0 +
knit f1 +
knit f2 +
knit f3 +
knit f4 +
knit f5 -
xfer f4 f4
…
```

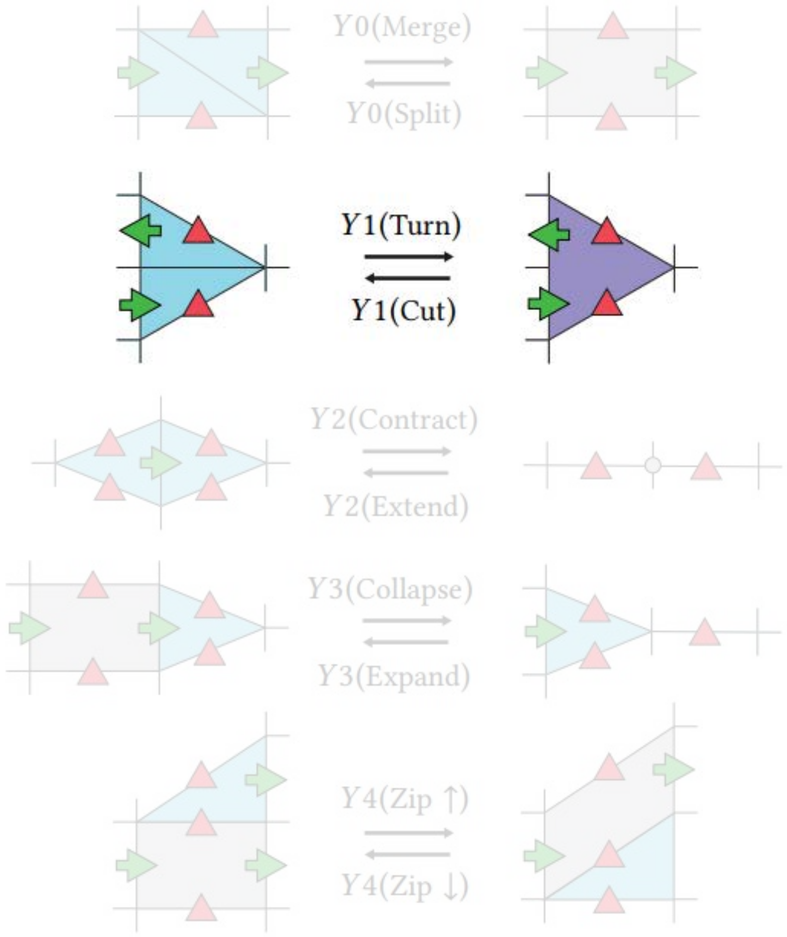
Schedule

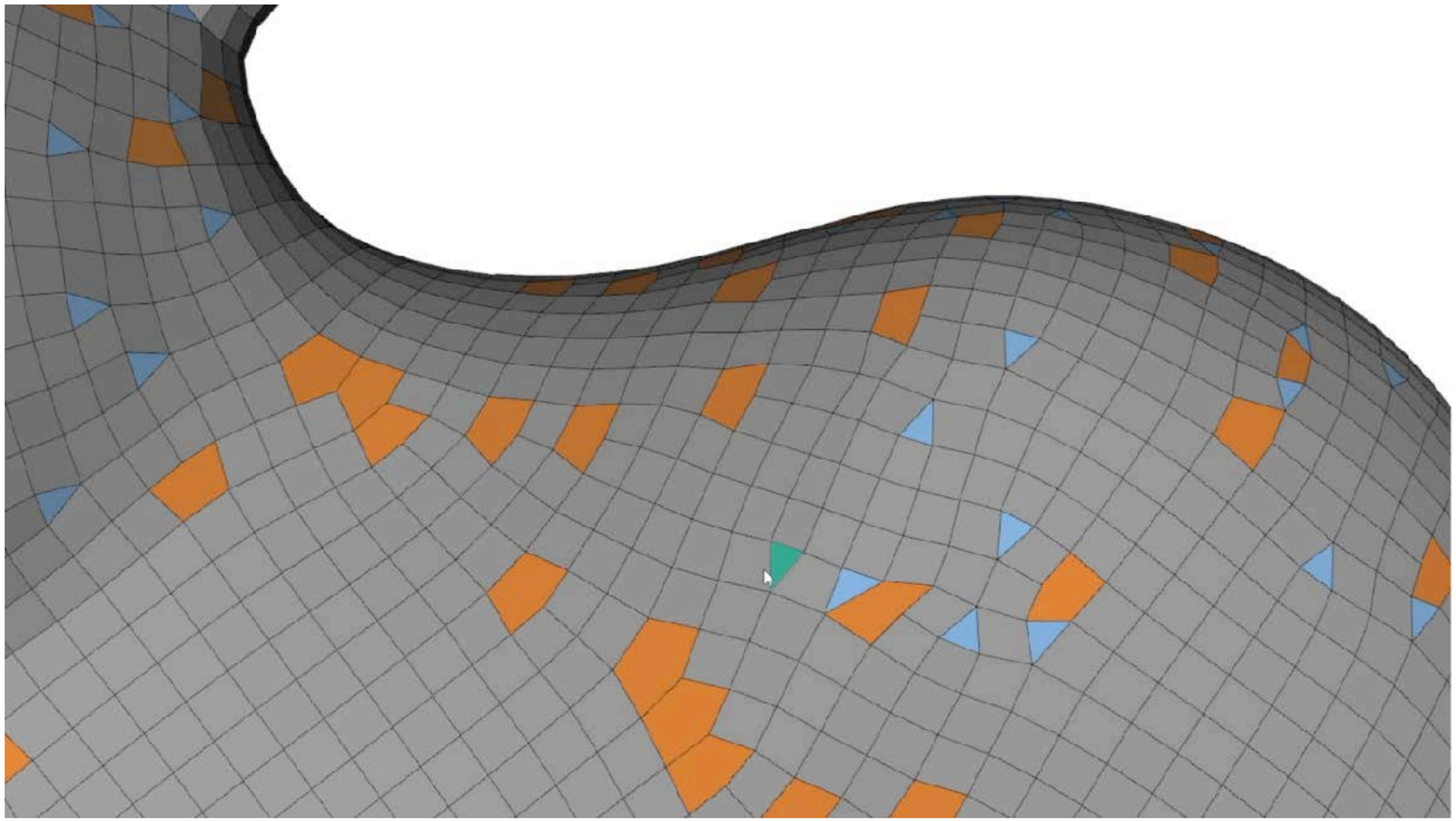
Yarn Operations



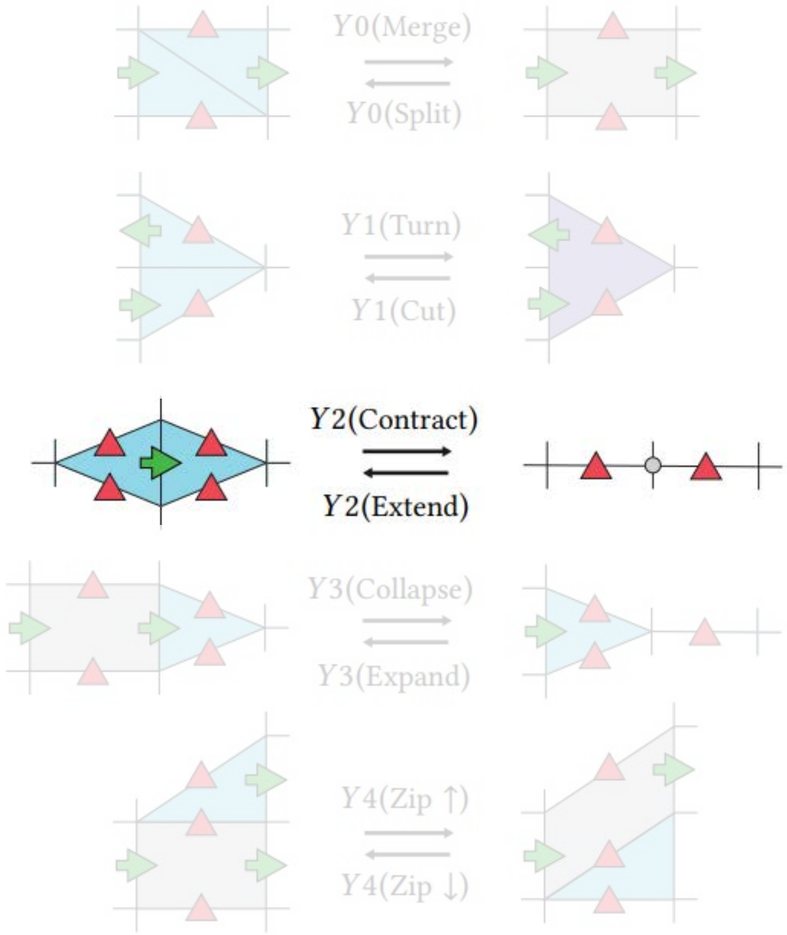


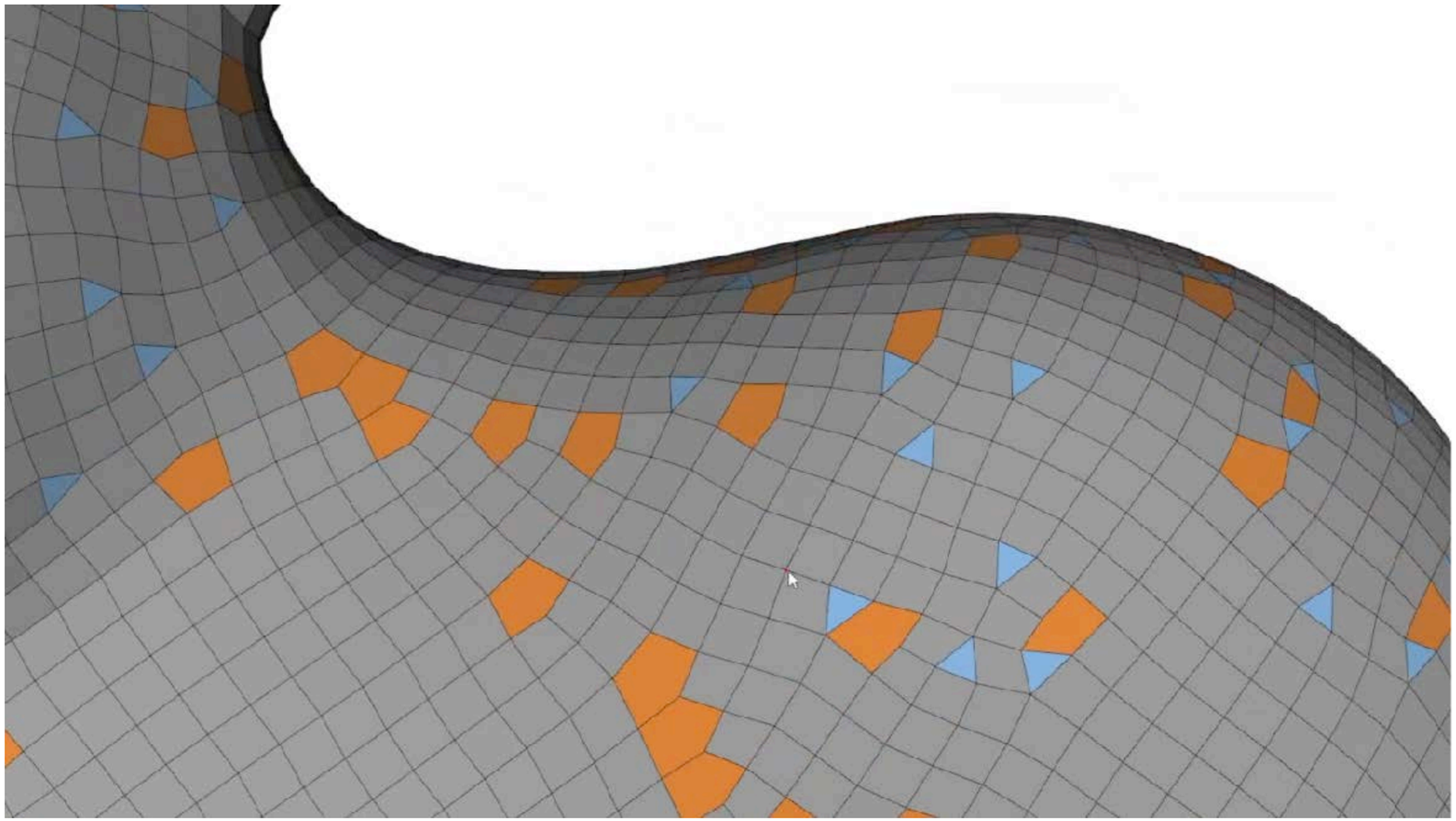
Yarn Operations



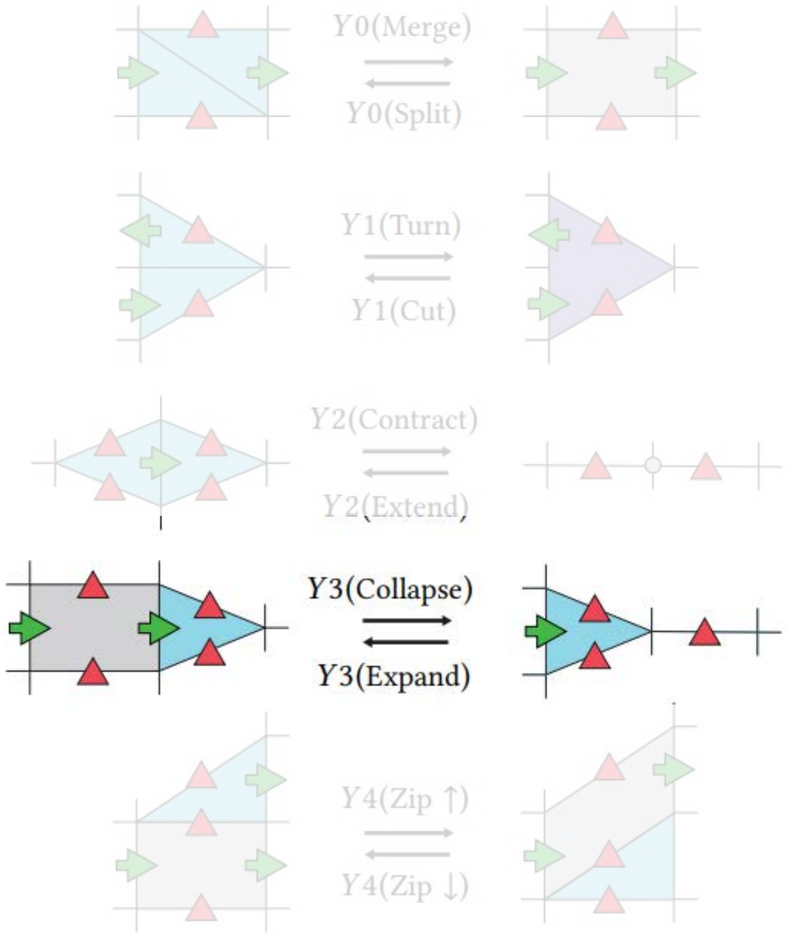


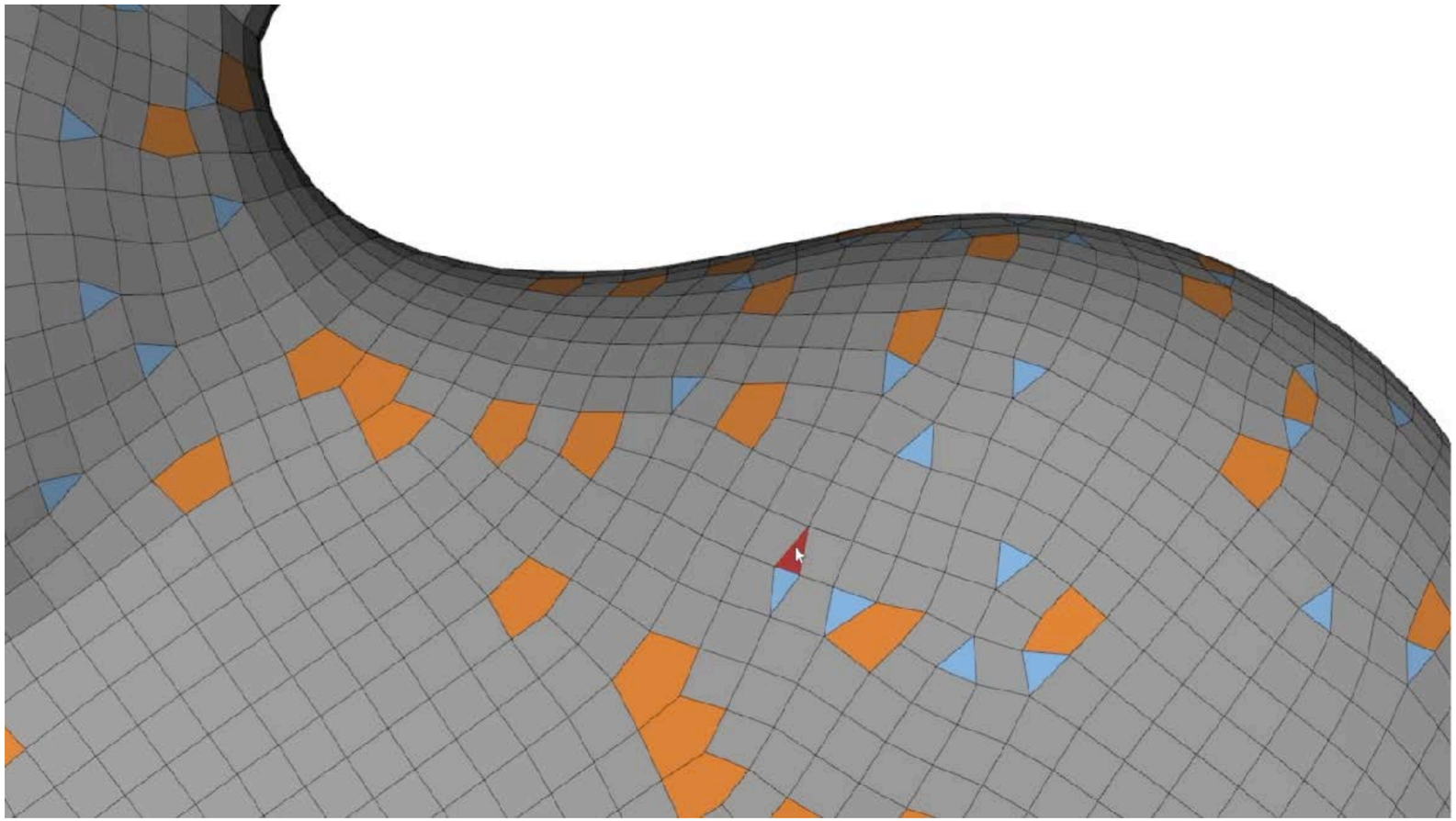
Yarn Operations





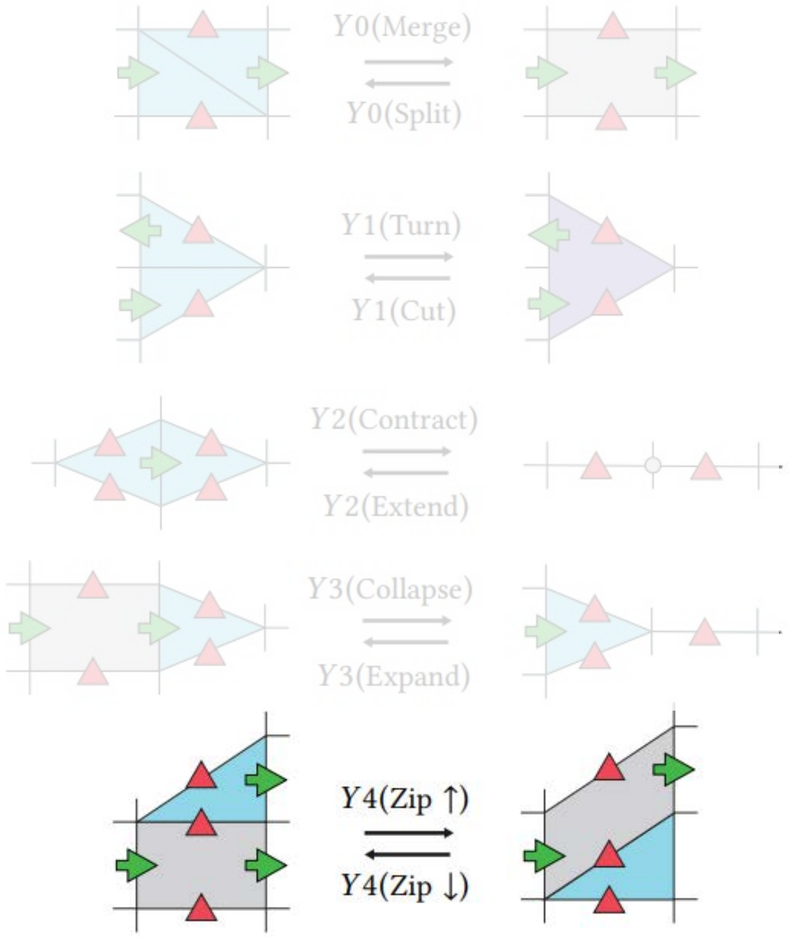
Yarn Operations

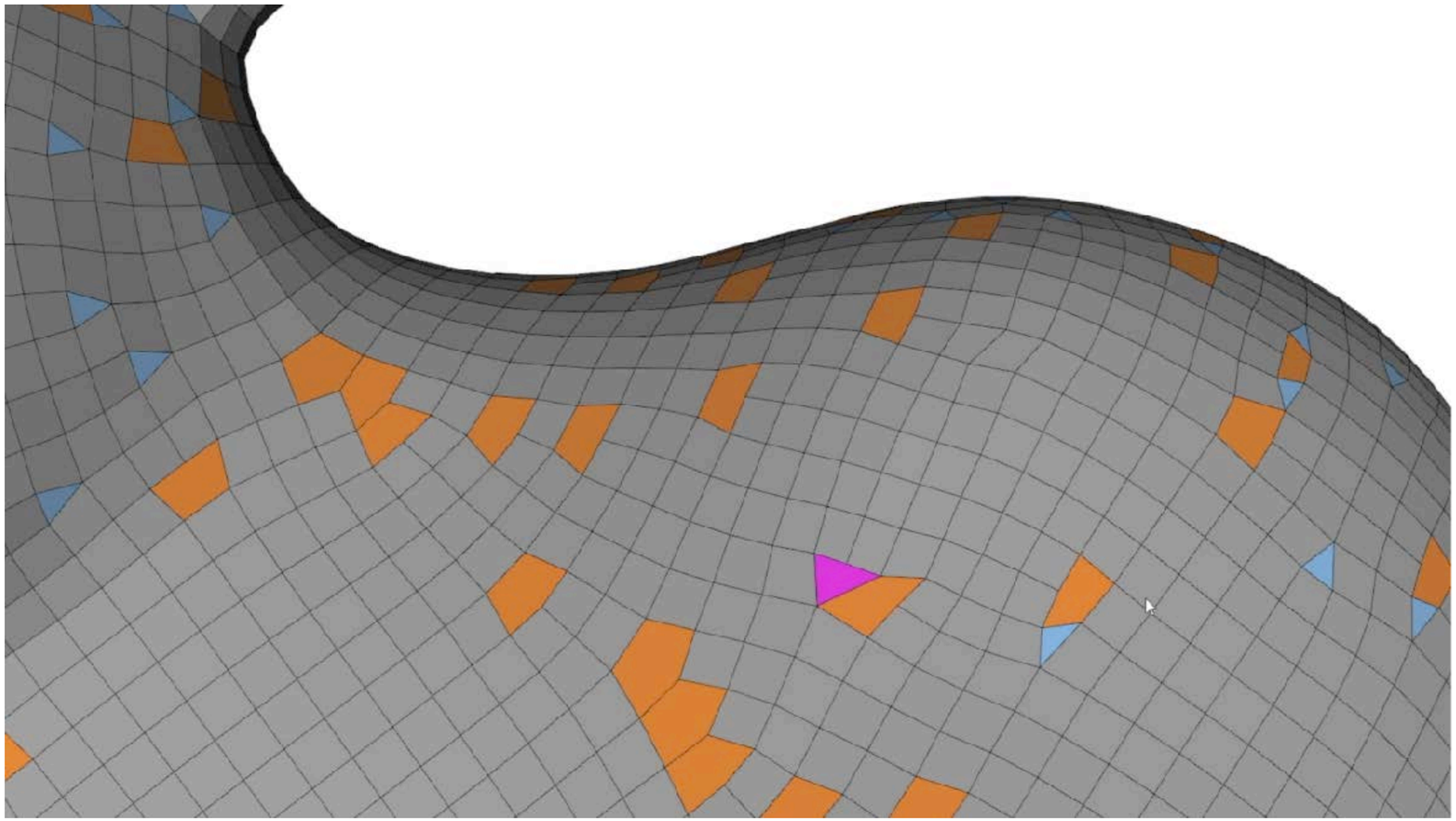




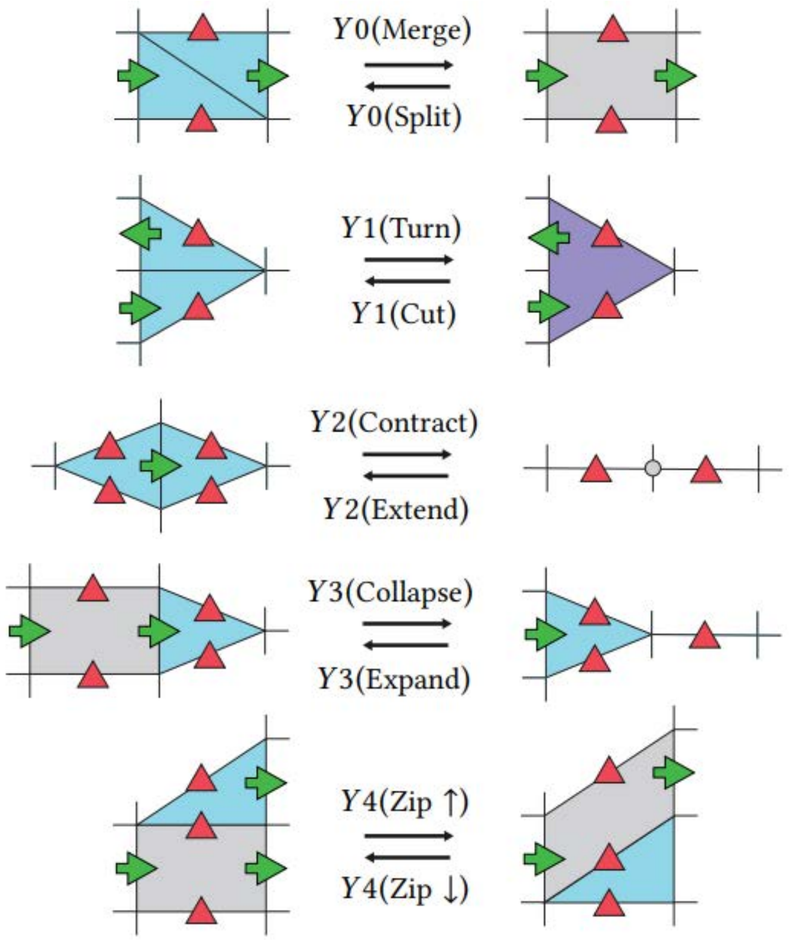
Similar to [Peng et al. 13] for connectivity editing

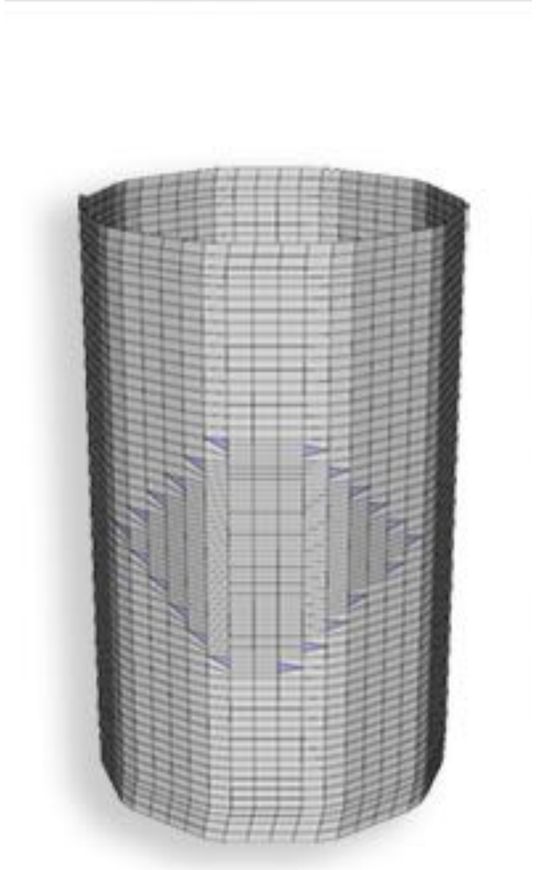
Yarn Operations



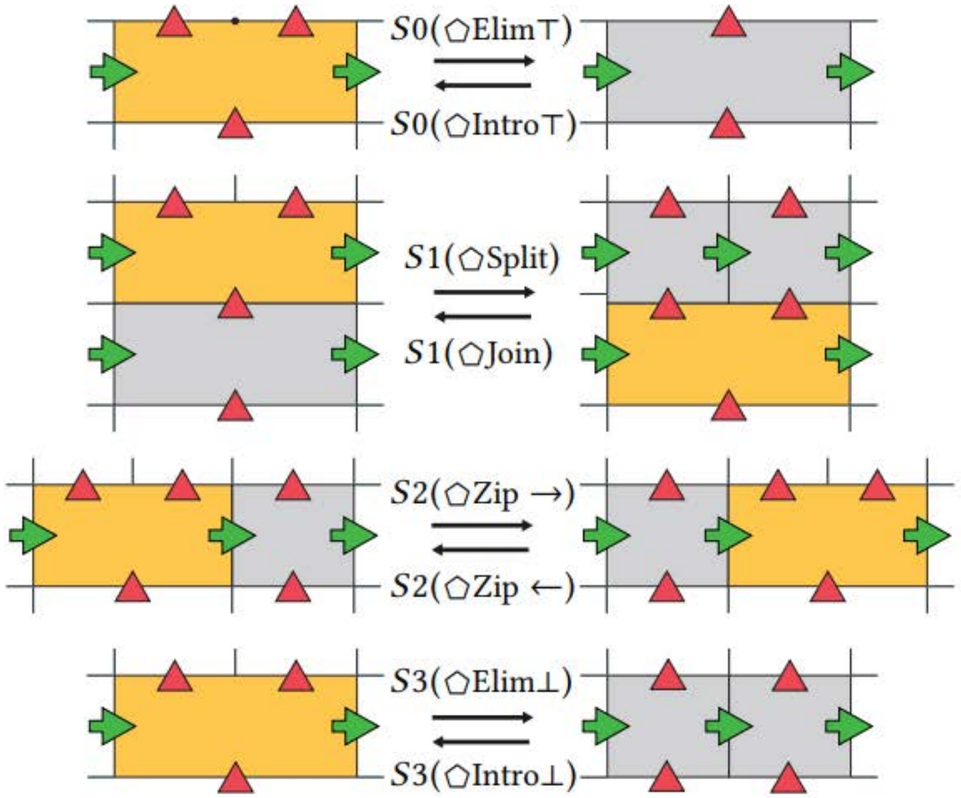


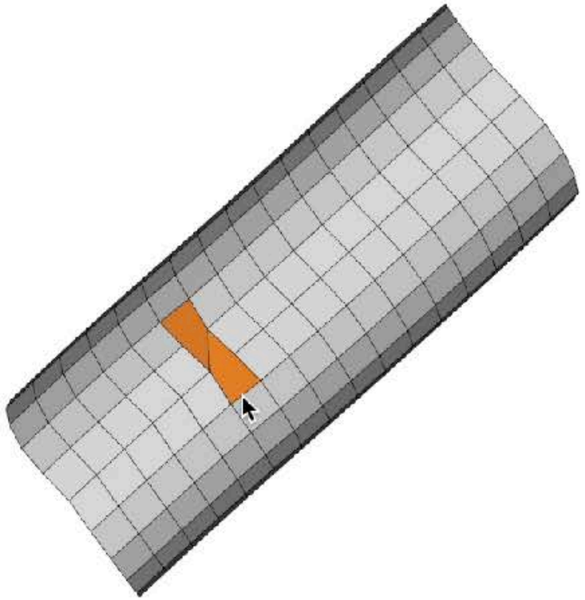
Yarn Operations



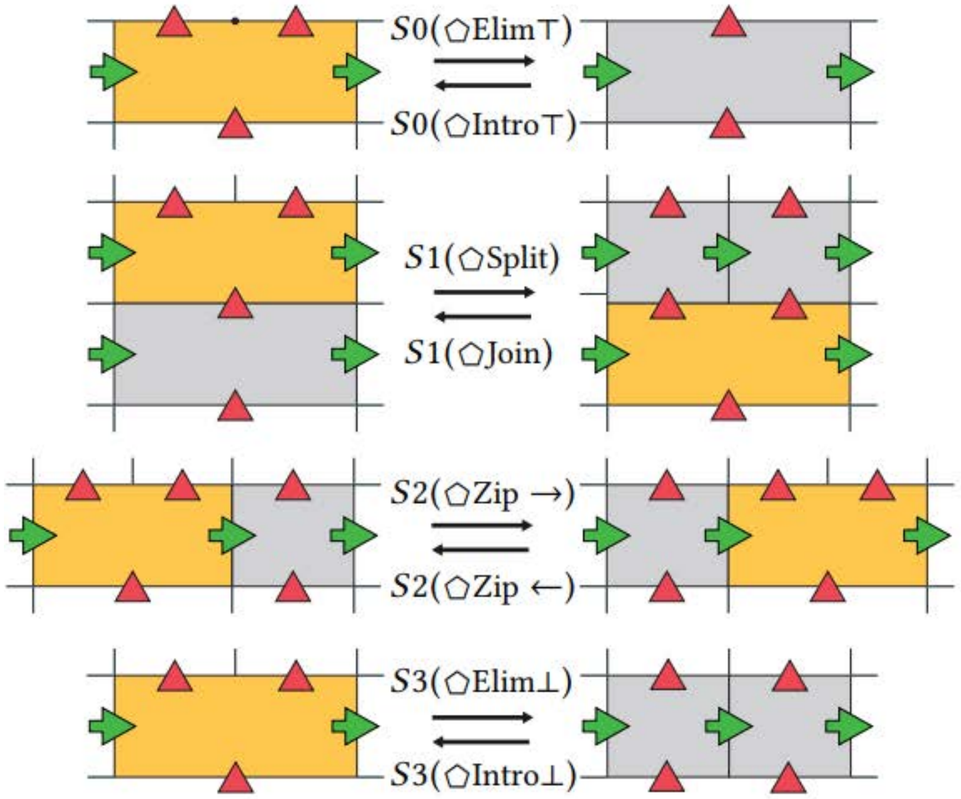


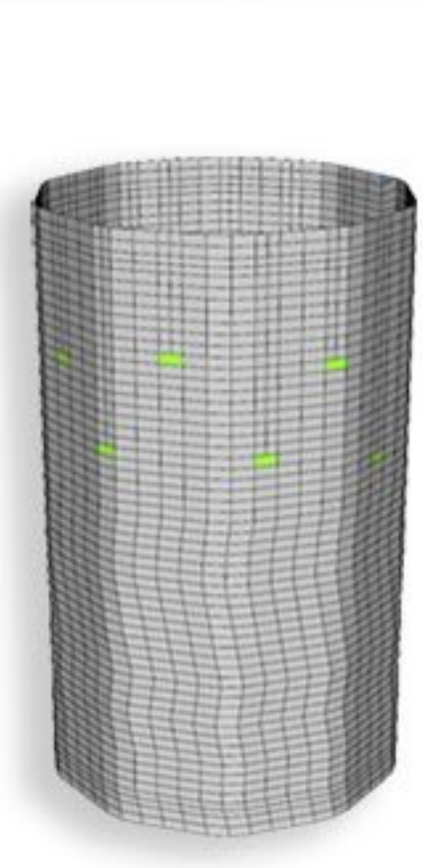
Shape Operations



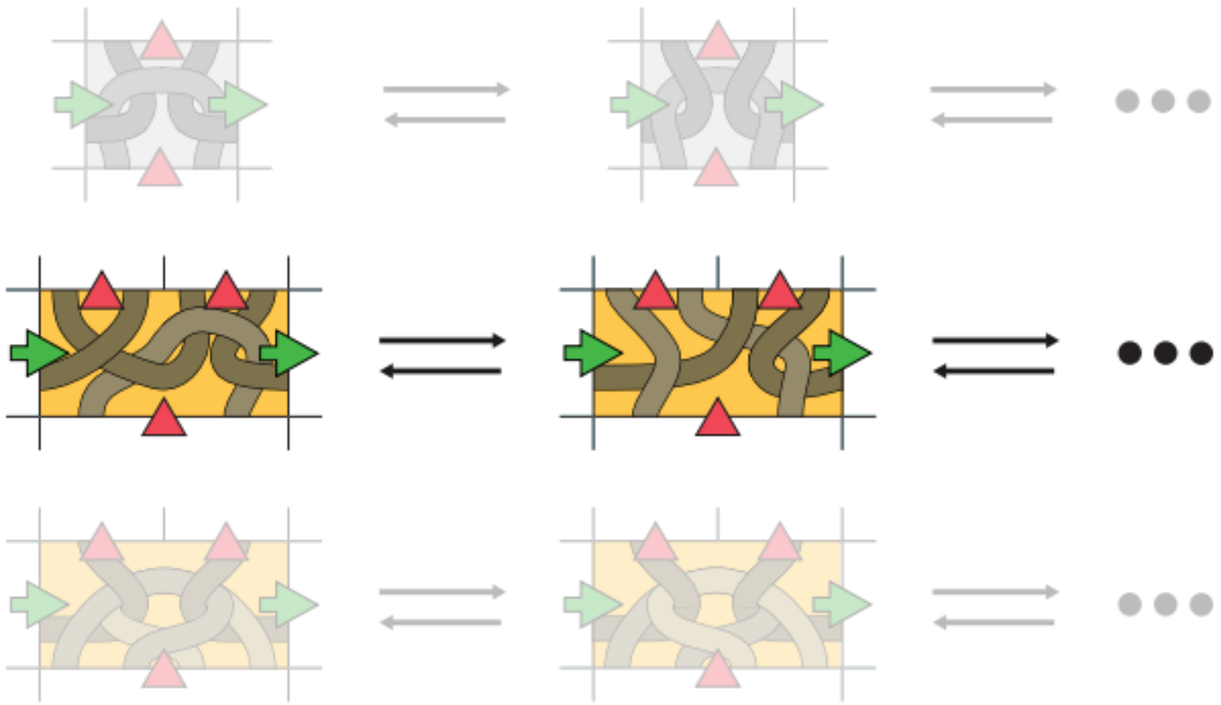


Shape Operations





Type Operations



increaseL(N_L, N_R, Y)

```
xfer fN_L bN_L
xfer bN_L fN_R
tuck - fN_L Y
knit + fN_R Y
```

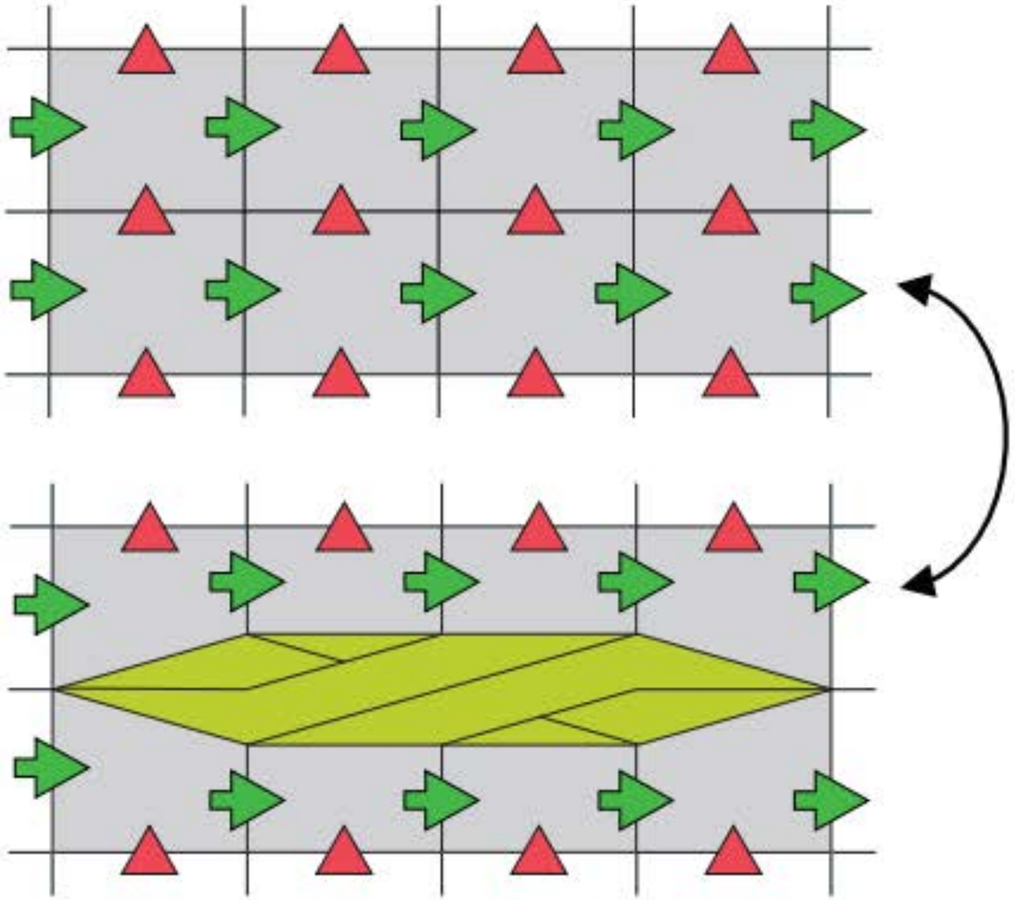
increaseR(N_L, N_R, Y)

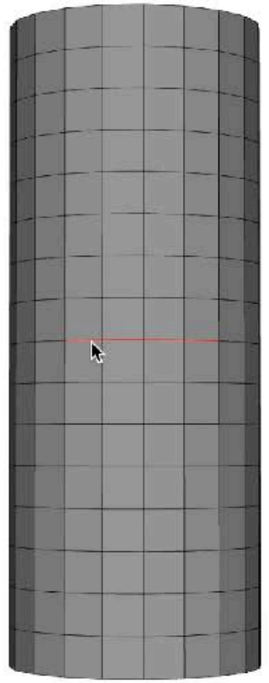
```
knit + fN_L Y
tuck - fN_R Y
```

function (N_L, N_R, Y)

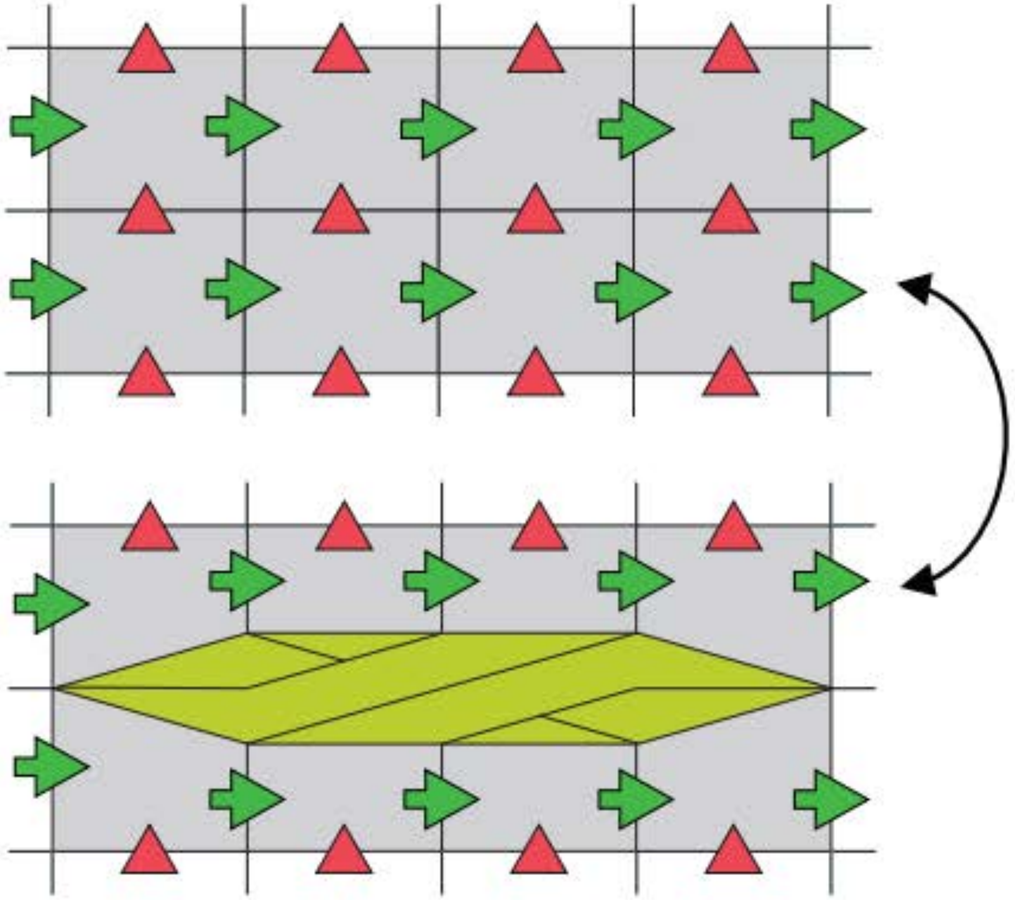
User specified knitting program as long as it obeys edge conditions

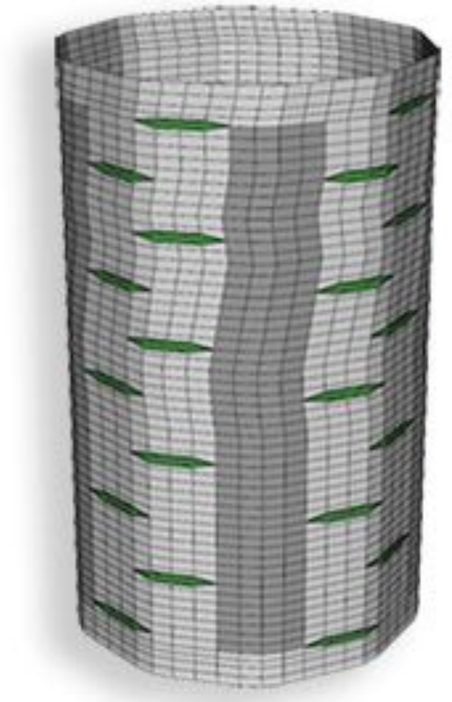
Cable Face Types





Cable Face Types

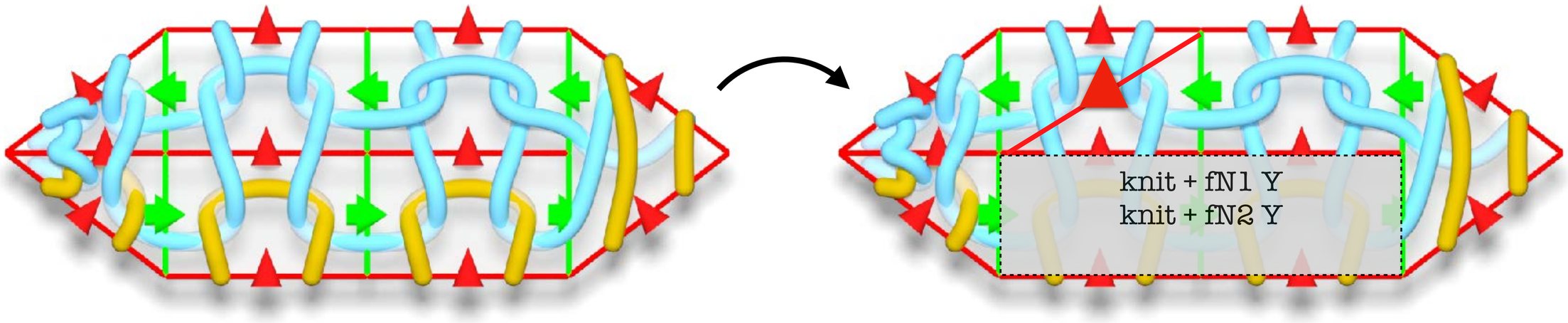




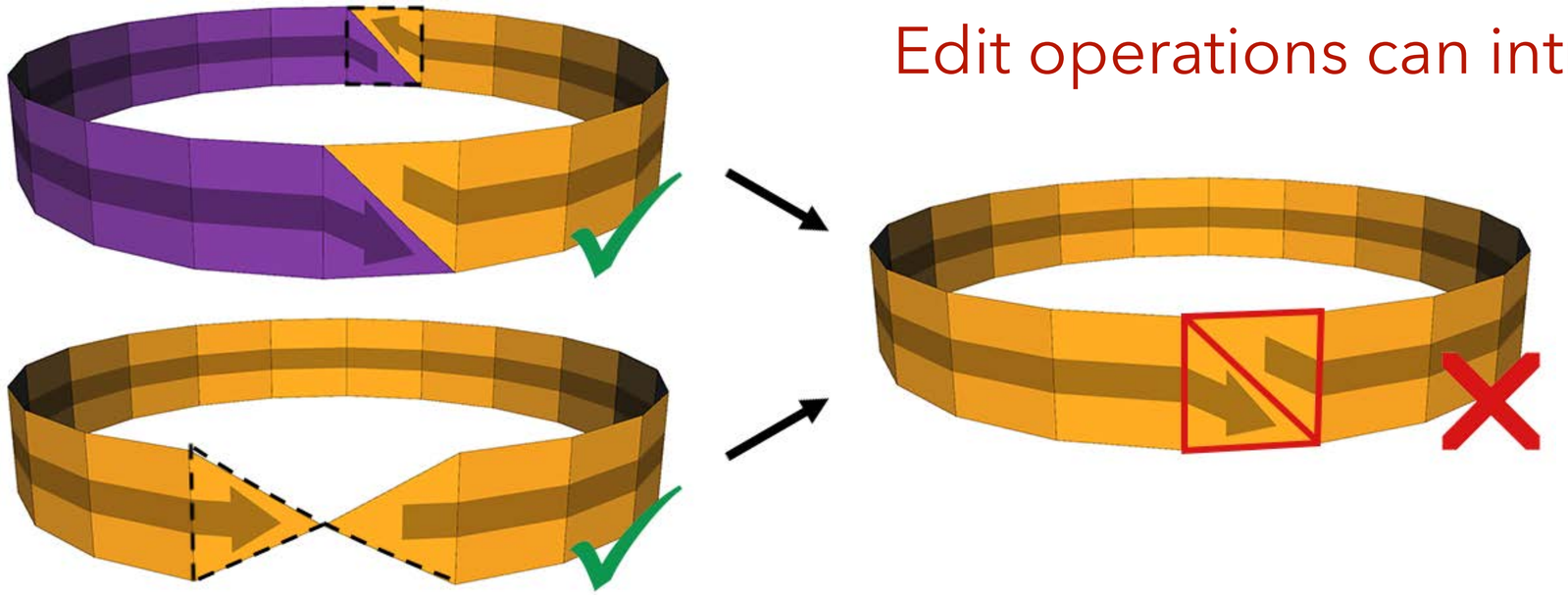
Augmented stitch mesh editing

Mesh must remain directed acyclic after performing the edit operation.

Edits must agree with existing edge labels and direction



Valid operations maintain directed acyclic property



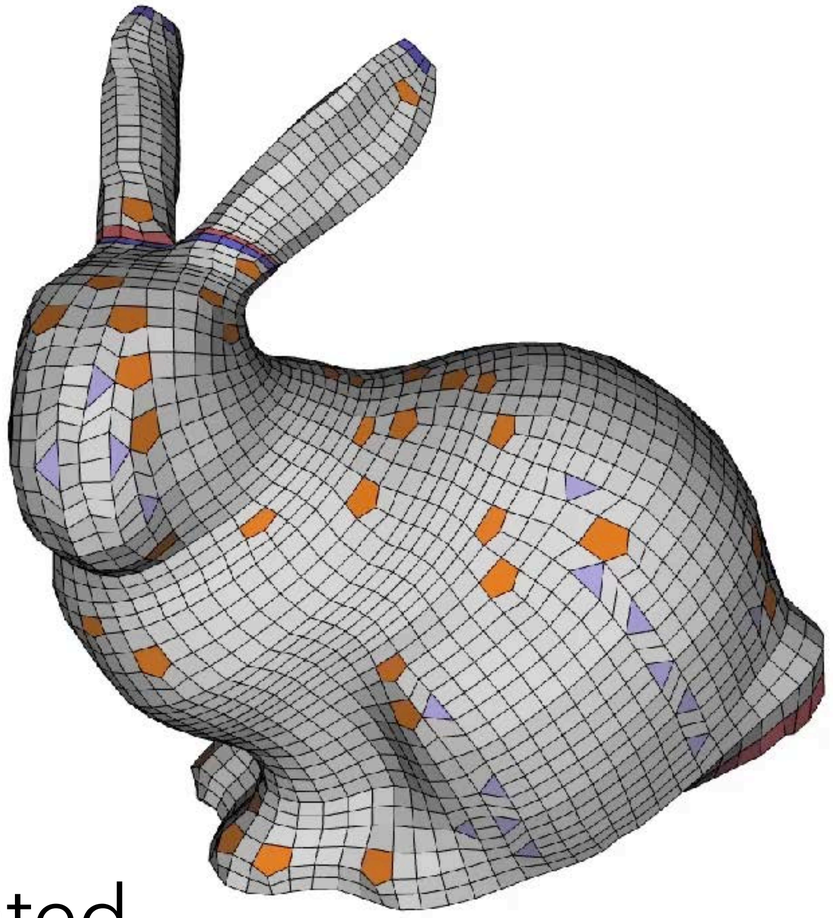
Edit operations can introduce a cyclic dependency.

Our system *restricts* such edits but can still *span the space* of knittable stitch meshes of the same surface topology class.

Edits can span the space of knittable shapes

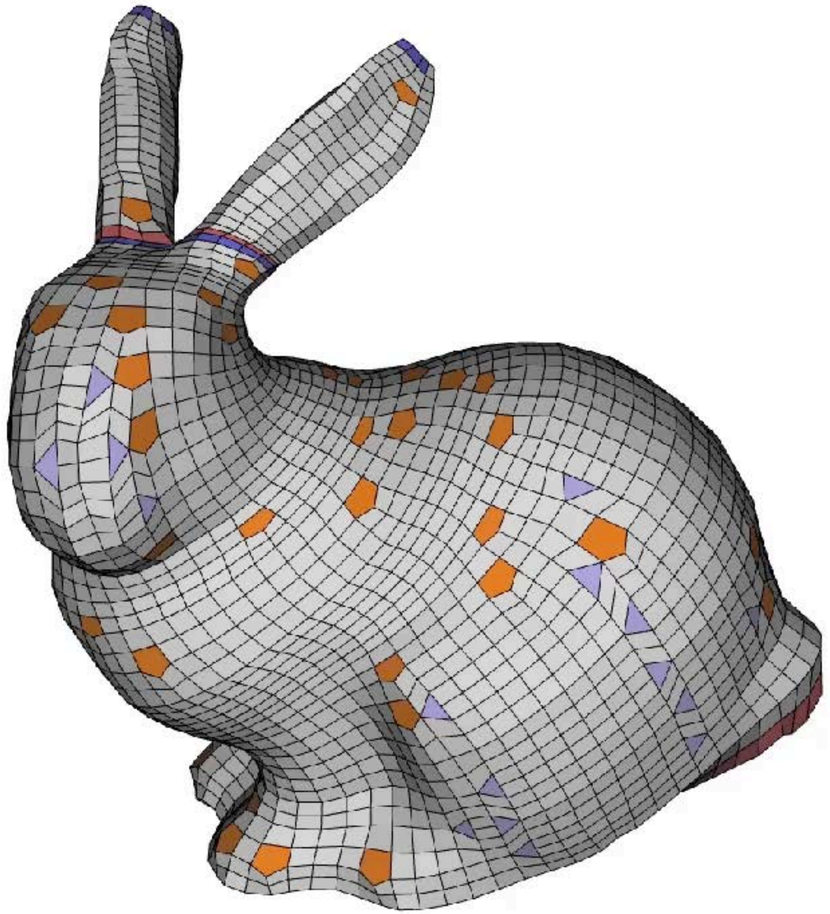
Any valid augmented stitch mesh can be edited into a trivial knittable structure

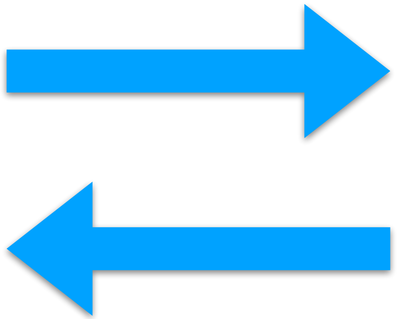
By a sequence editing operations, any valid knittable surface **in the same surface topology class** can be reached.

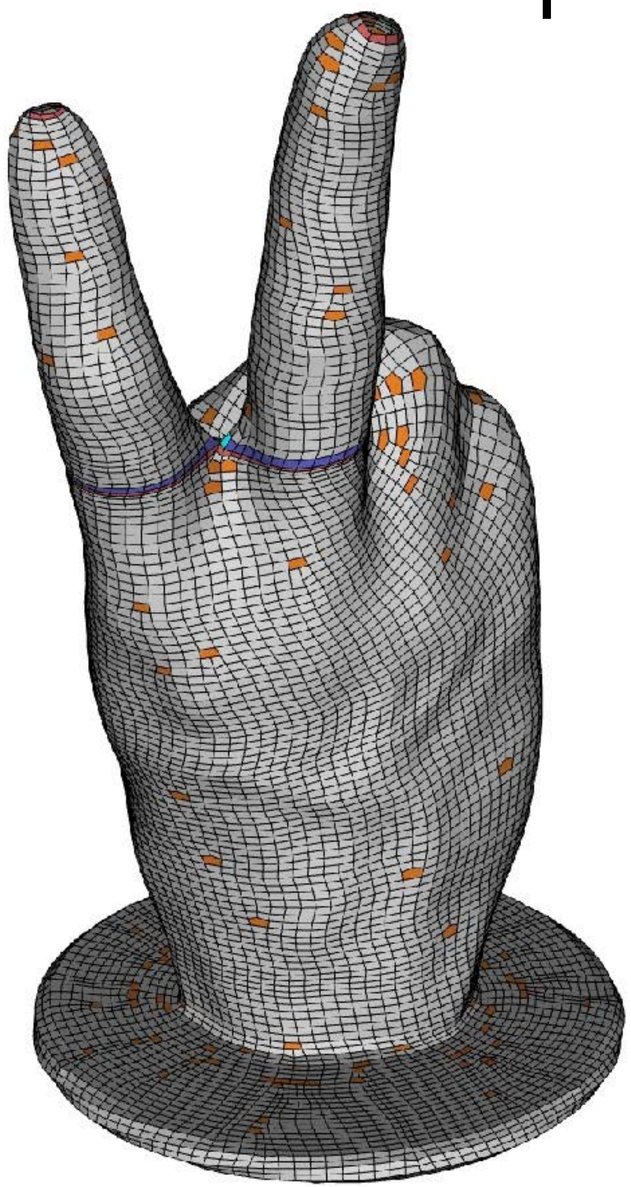


Our system can span the space of augmented stitch meshes using our editing operations

Edits can span the space of knittable shapes

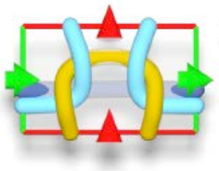






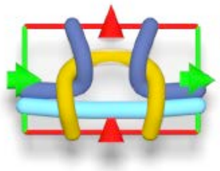
Extending face types for multiple yarns

Fair-Isle



fairIsle1(N, Y)

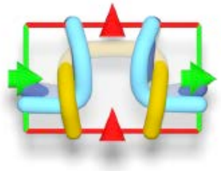
```
knit + fN Y1
```



fairIsle2(N, Y)

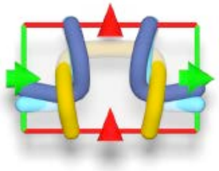
```
knit + fN Y2
```

Plating



plating1(N, Y)

```
knit + fN Y1 Y2
```

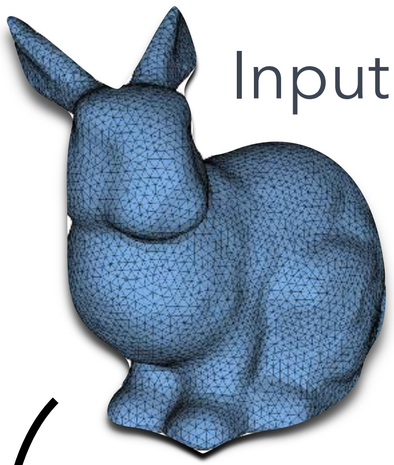


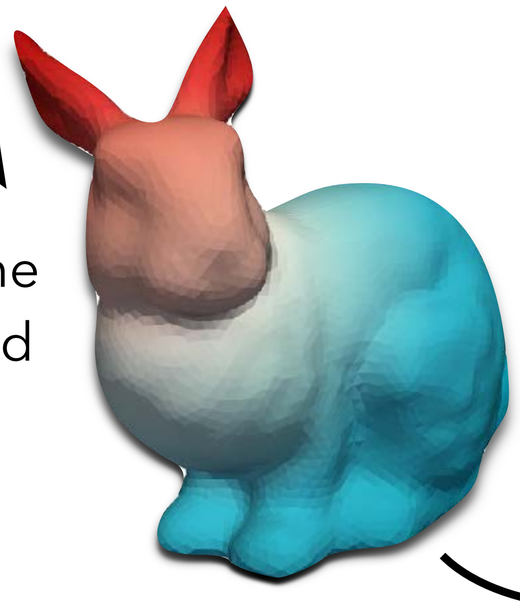
plating2(N, Y)

```
knit + fN Y2 Y1
```

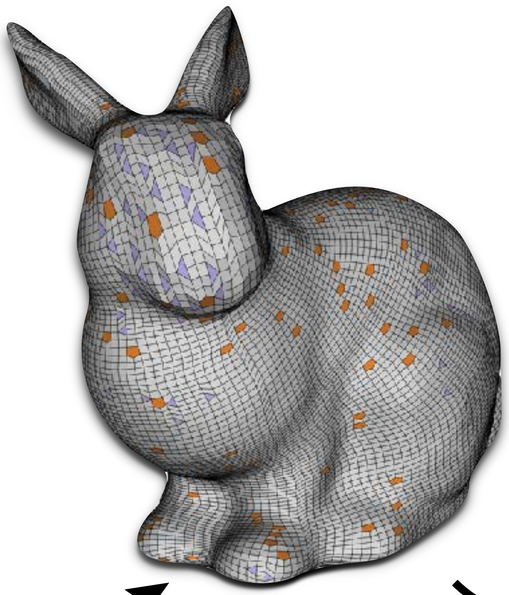
Pipeline of our design system

Input

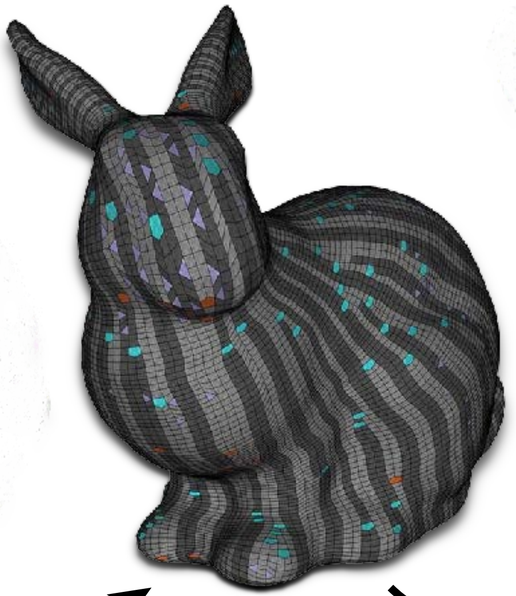




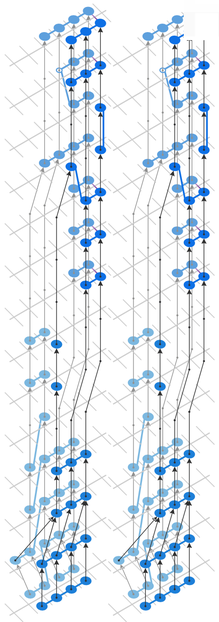
Time field



Mesh generation



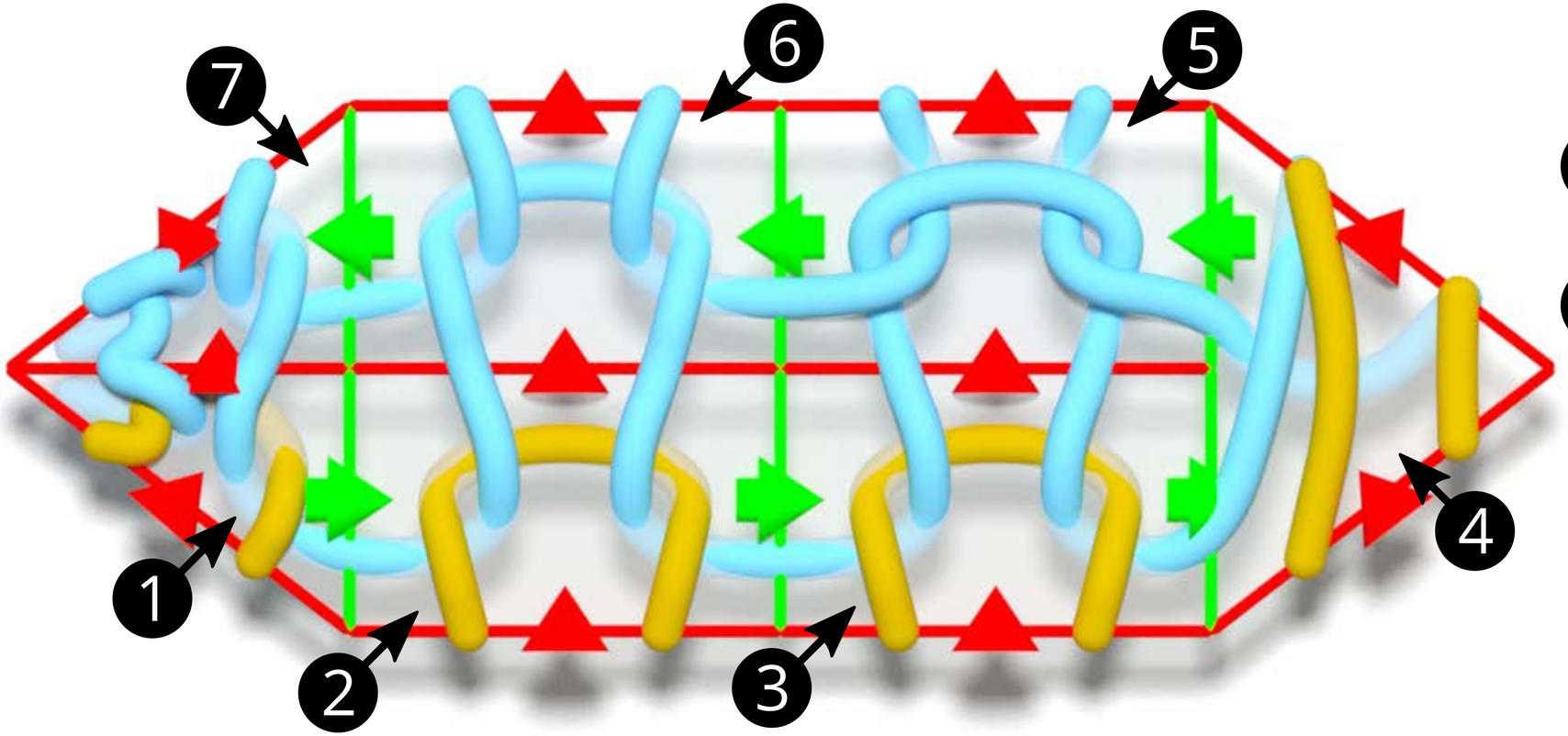
Editing



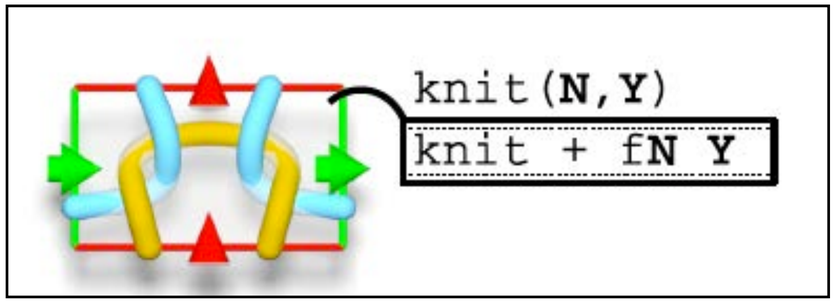
```
knit f0 +
knit f1 +
knit f2 +
knit f3 +
knit f4 +
knit f5 -
xfer f4 f4
…
```

Schedule

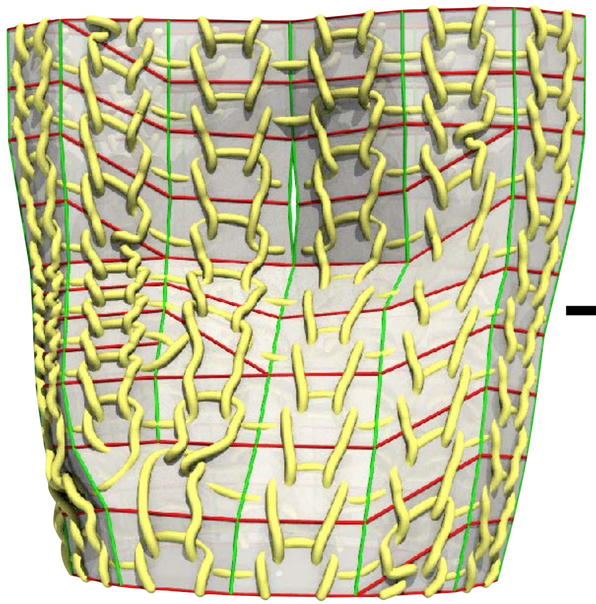
Scheduling stitches on machine needles

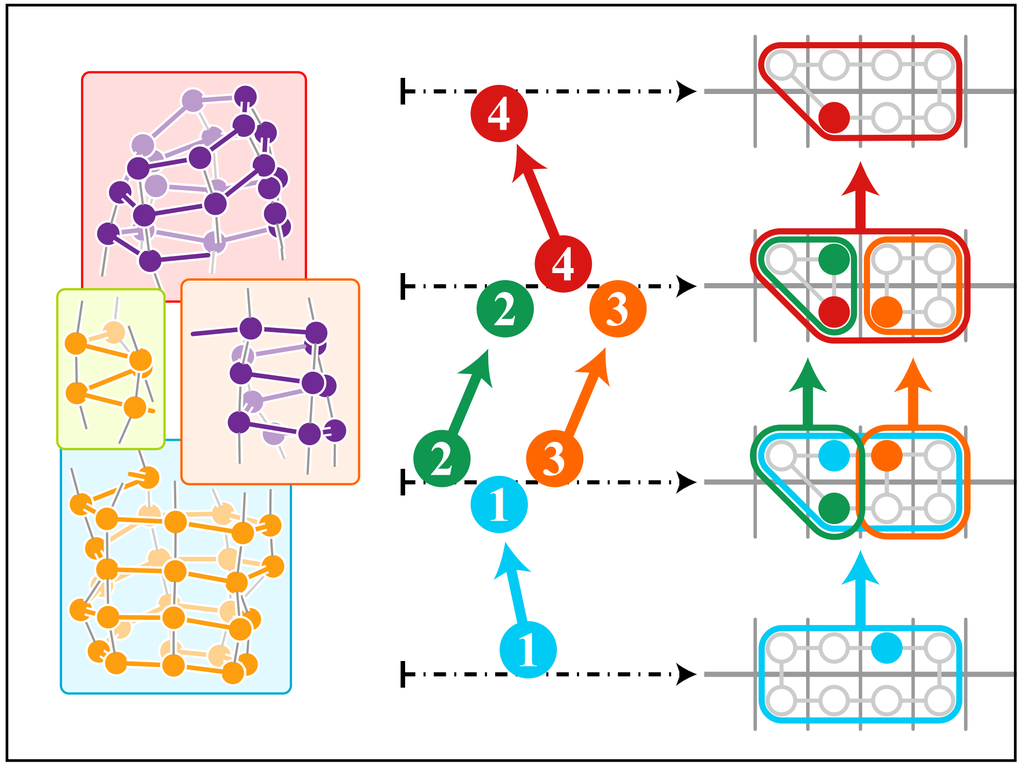



```
1  in A
   knit +     A
2  knit +     A
3  knit +     A
4  tuck +     A
5  xfer
   knit -     A
6  knit -     A
7  knit -     A
   out A
   xfer
```



Generating machine locations for face programs





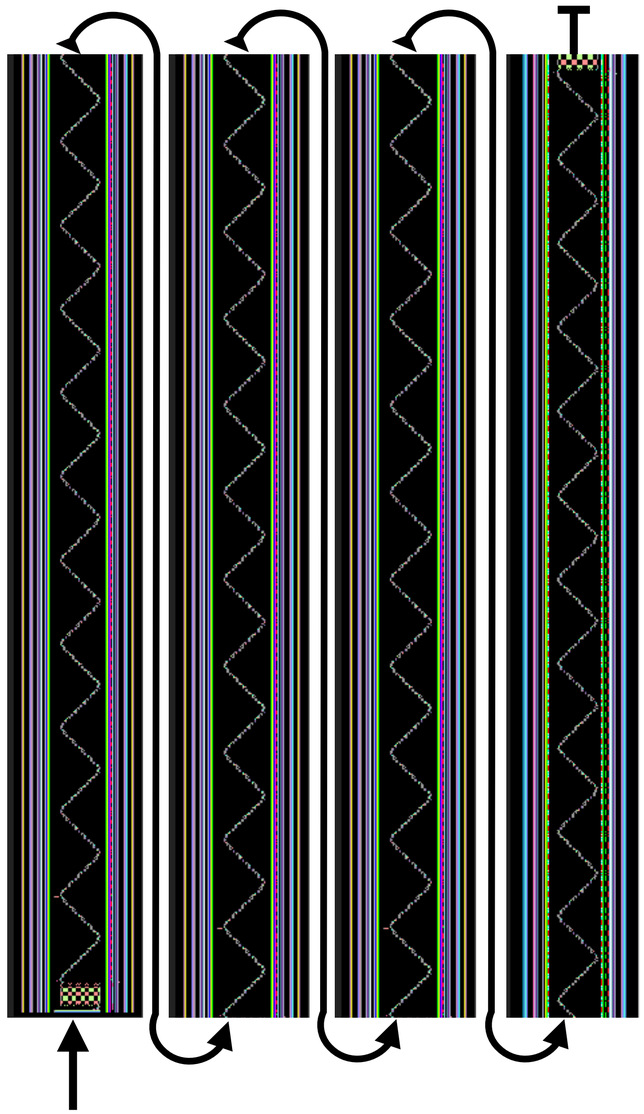

```
knit f0 +
knit f1 +
knit f2 +
knit f3 +
knit f4 +
knit f5 -
xfer f4 f4
…
```

Convert complex faces into individual stitches

[Narayanan et al. ’18]

Interleave face programs

Optimizing *passes* by instruction reordering



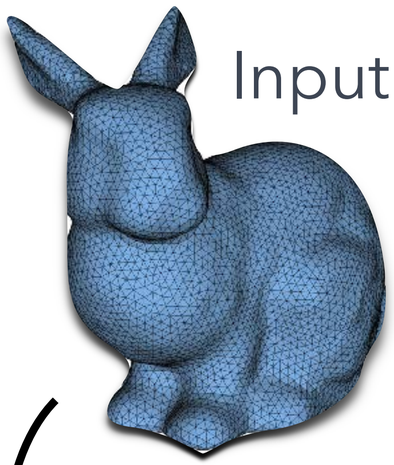
KnitPaint programs
height ~ knitting time

reorder

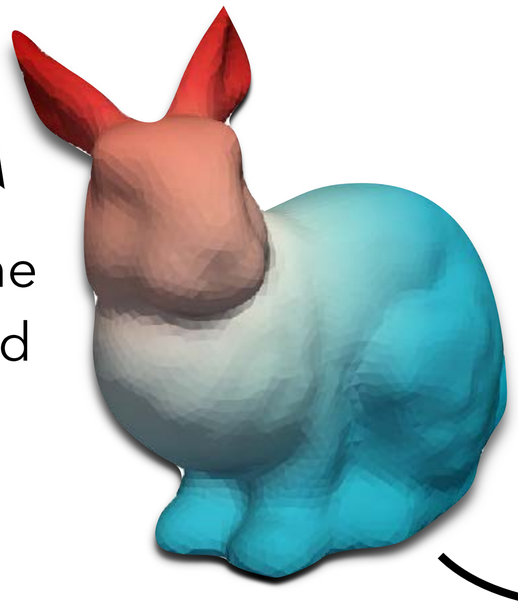
~3 mins

~20 mins

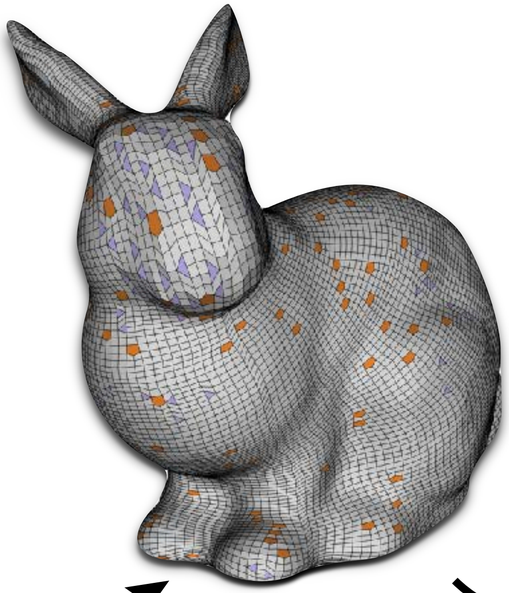
Pipeline of our design system



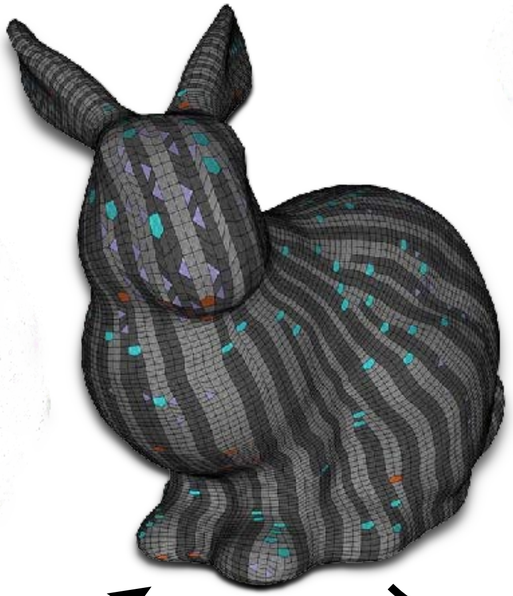
Input



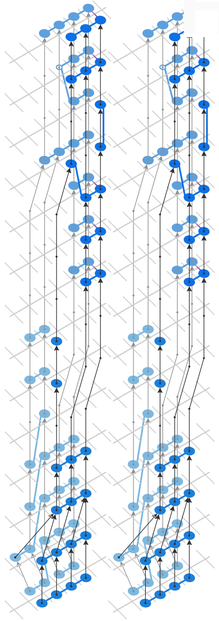
Time field



Mesh generation



Editing



```
knit f0 +
knit f1 +
knit f2 +
knit f3 +
knit f4 +
knit f5 -
xfer f4 f4
…
```

Schedule

All-knits vs textured Stanford bunny

[Narayanan et al. ’18]

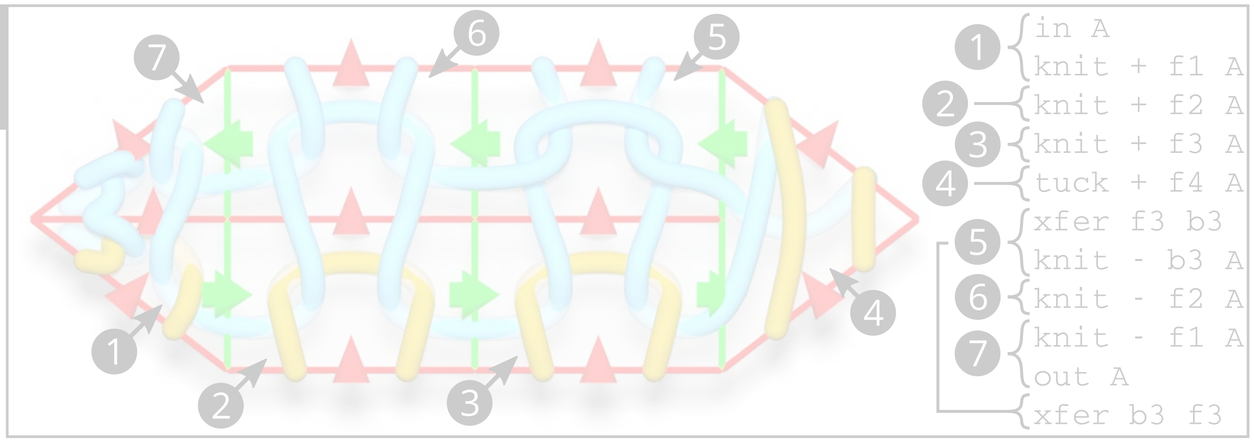
All knits, automatically generated

Ours

Textured with “knits” and “purls” by manually editing

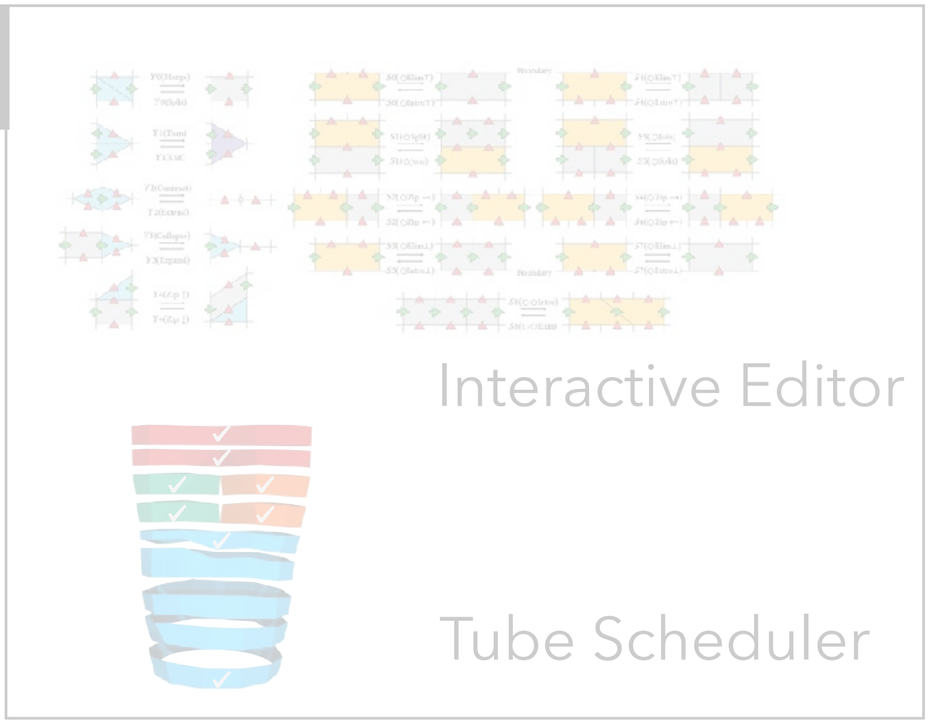
Visual Knitting Machine Programming

1



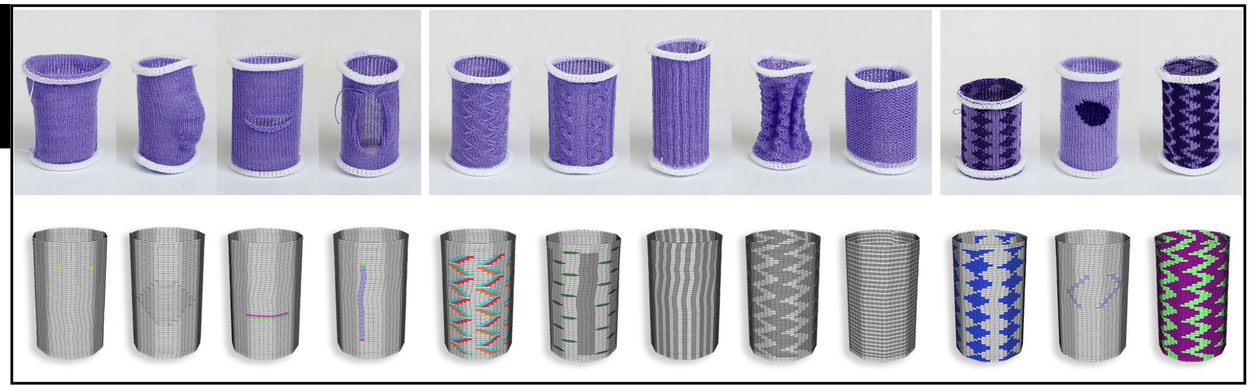
Augmented Stitch Mesh Representation

2



System

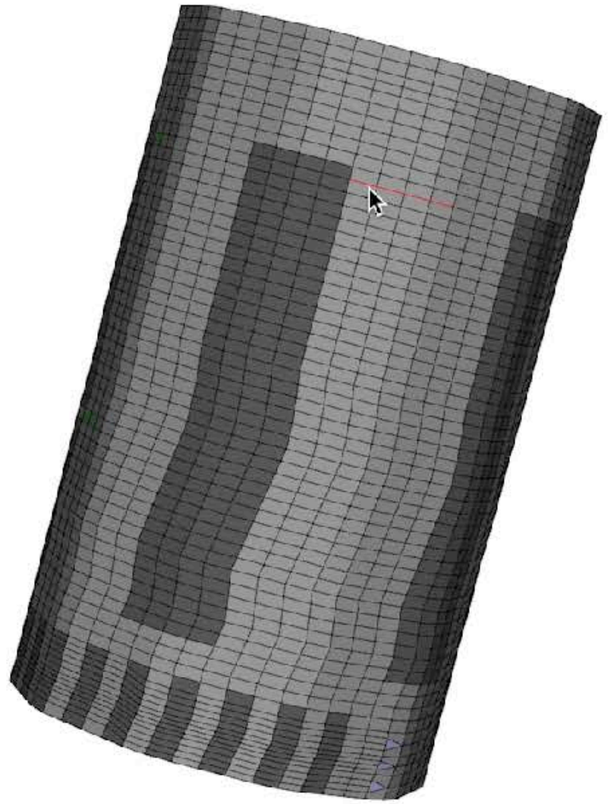
3



Results (Fabricated on a Shima Seiki V-bed whole-garment machine with 2/30 acrylic yarn)

A Hand-warmer with cables and textures

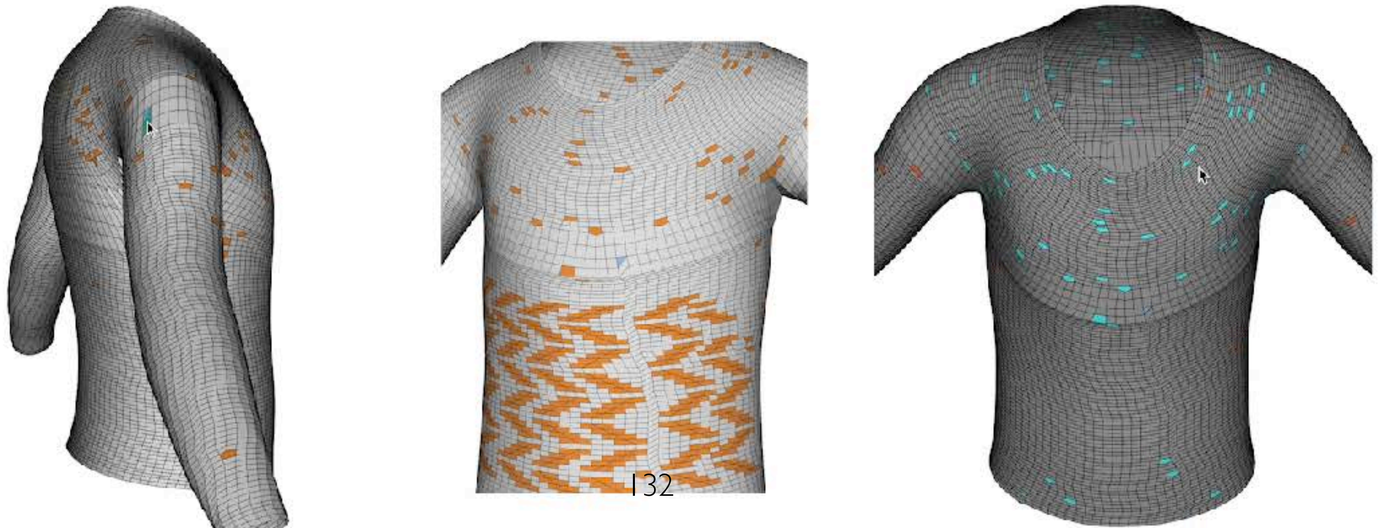
Knitting ~10 mins



Editing ~15 mins

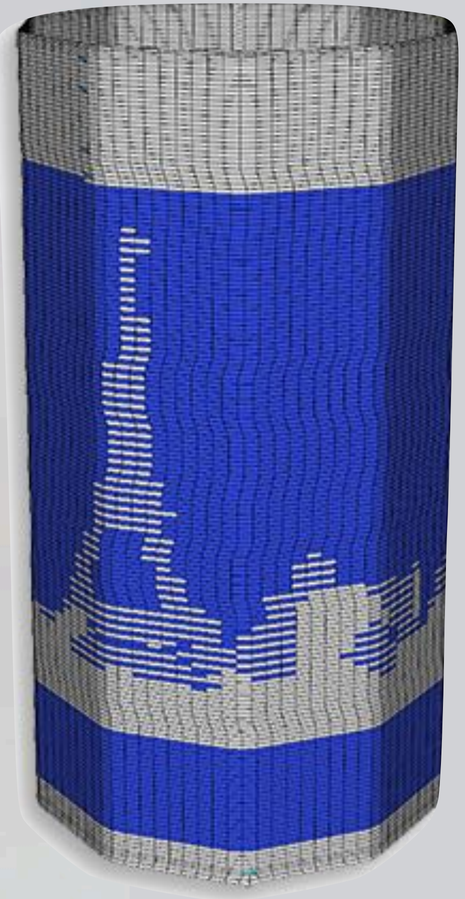
Same mesh w/ multiple styles

Knitting ~35 mins



Editing ~15 mins

Plating an image



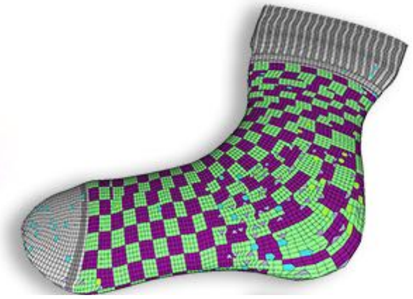
Knitting ~20 mins

Editing ~1 mins

Custom accessories

Knitting ~20 mins

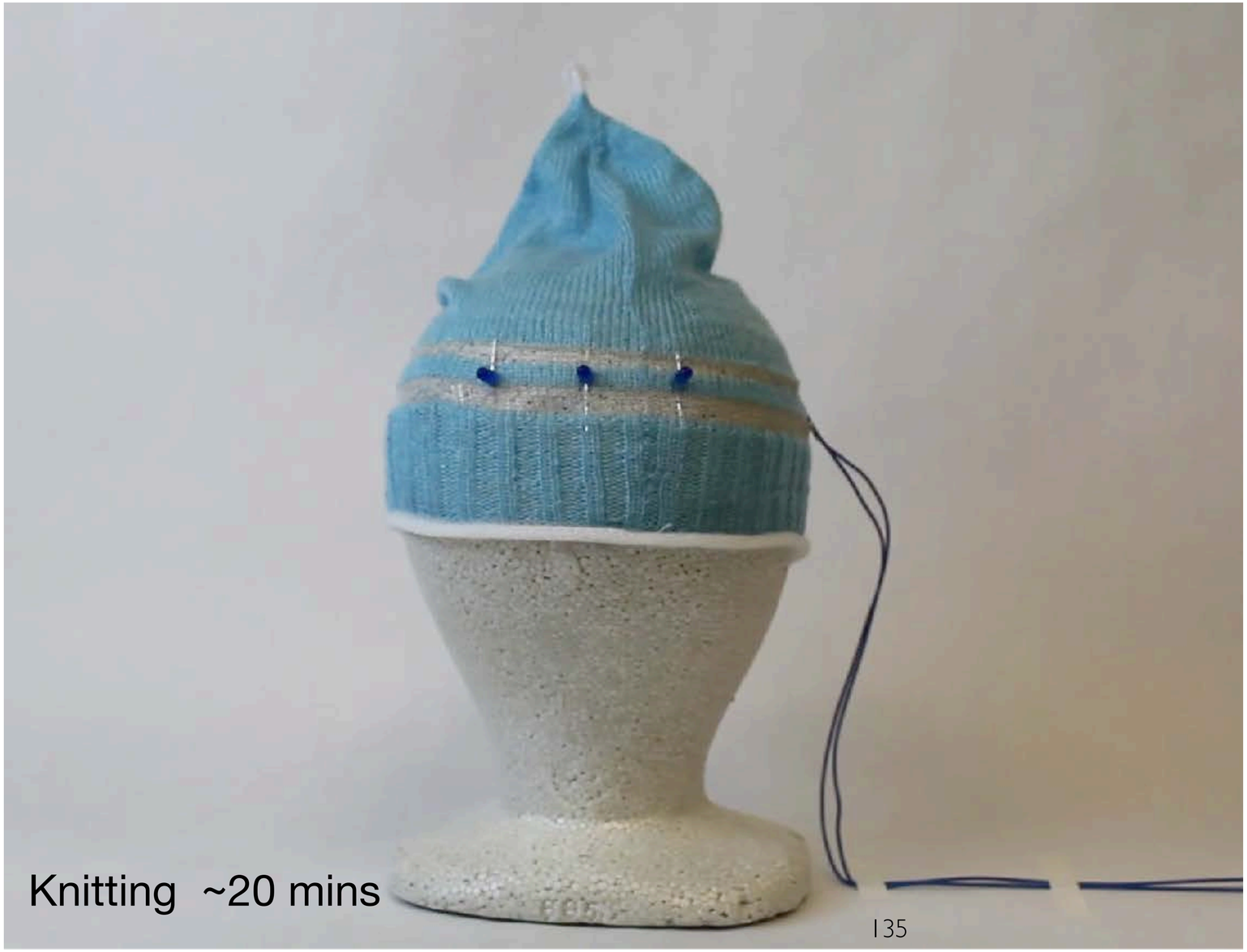
Editing ~5 mins



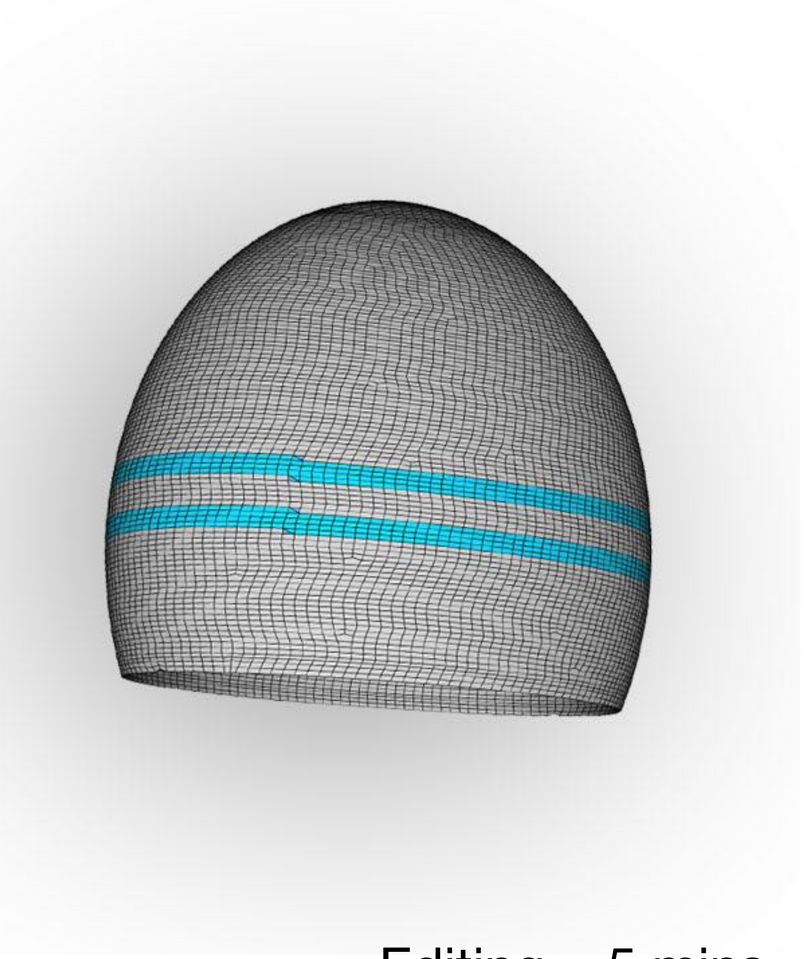
Knitting ~25 mins

Editing ~60 mins

Integrating conductive varn



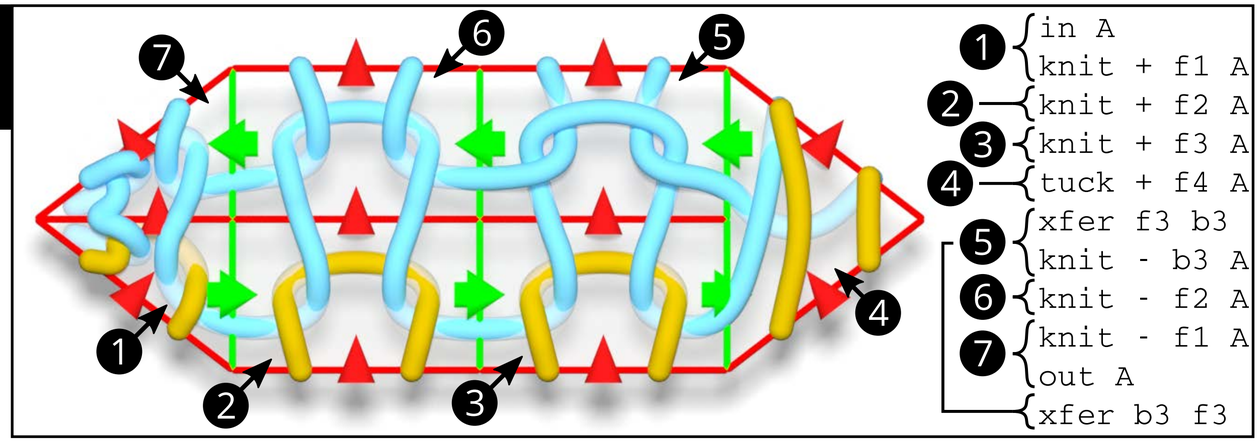
Knitting ~20 mins



Editing ~5 mins

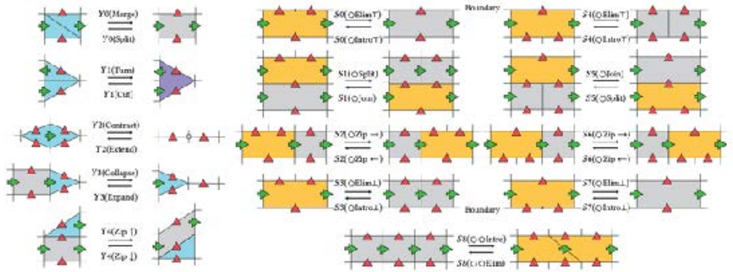
Visual Knitting Machine Programming

1



Augmented Stitch Mesh Representation

2

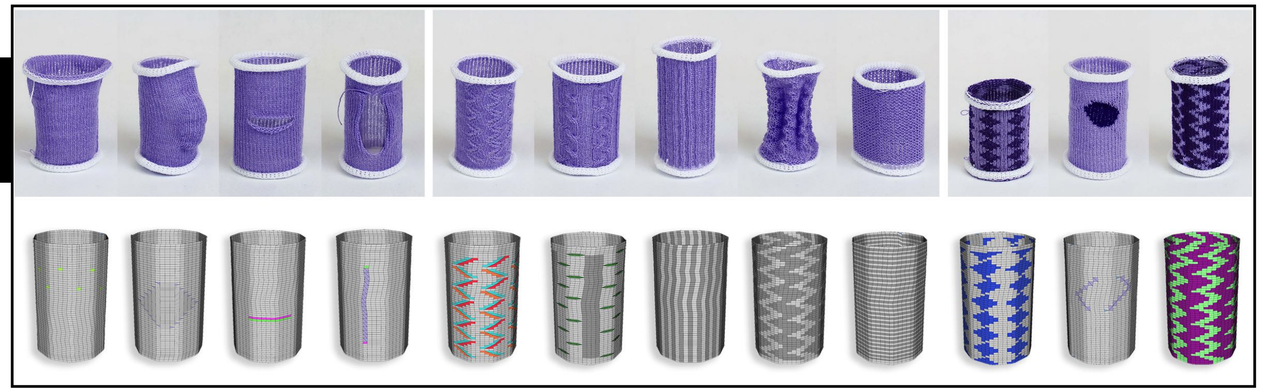


Interactive Editor

Tube Scheduler

System

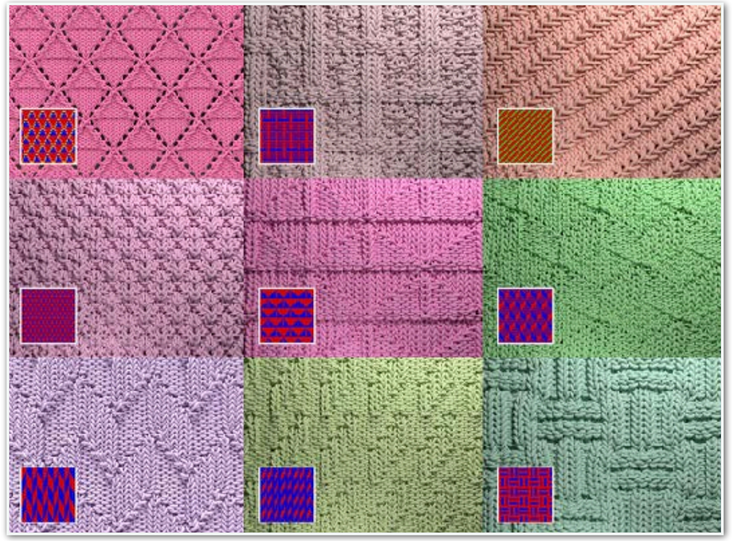
3



Results

What can we do next with machine knitting?

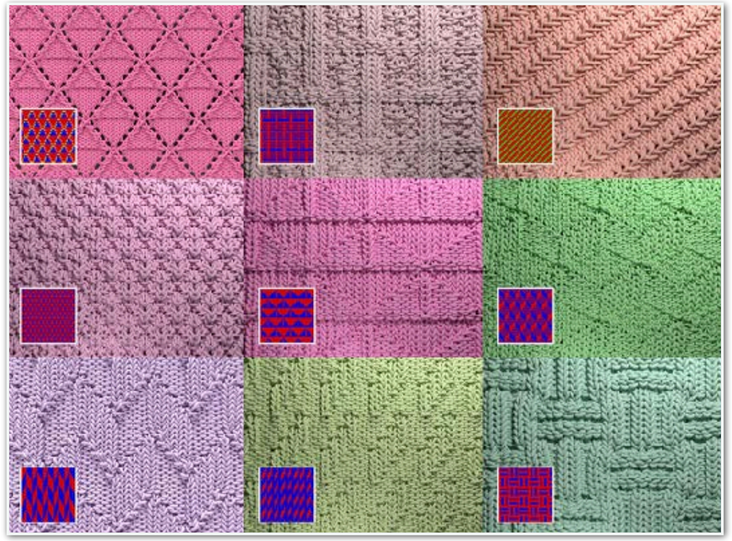
Predictive Simulation



[Leaf et al. ’18]
[Jiang et al. ’17]
[Cirio et al. ’14]
[Kaldor et al. ’08]

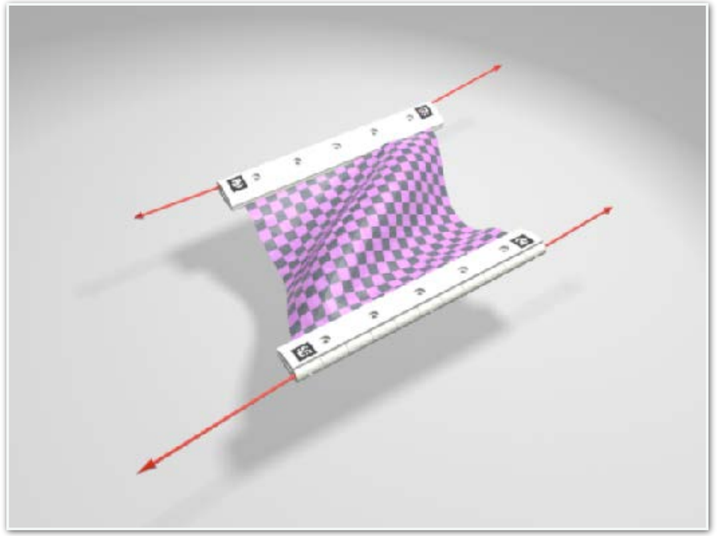
What can we do next with machine knitting?

Predictive Simulation



[Leaf et al. ’18]
[Jiang et al. ’17]
[Cirio et al. ’14]
[Kaldor et al. ’08]

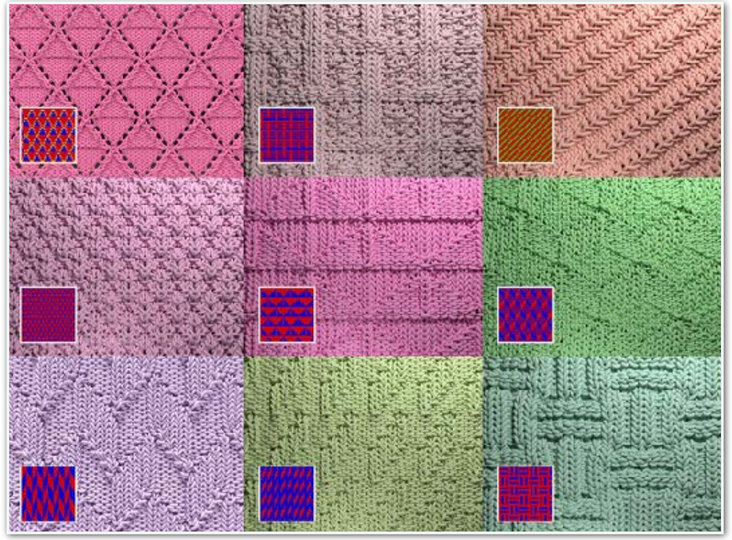
Calibration



[Miguel et al. ’12]
[Wang et al. ’11]

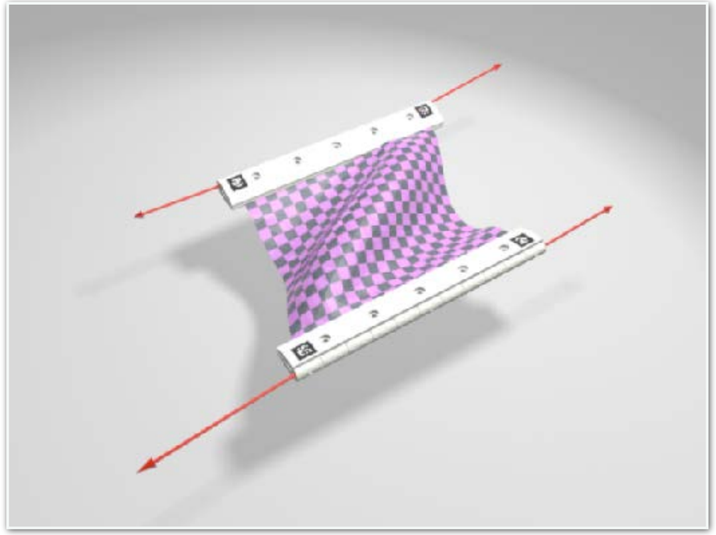
What can we do next with machine knitting?

Predictive Simulation



[Leaf et al. ’18]
[Jiang et al. ’17]
[Cirio et al. ’14]
[Kaldor et al. ’08]

Calibration



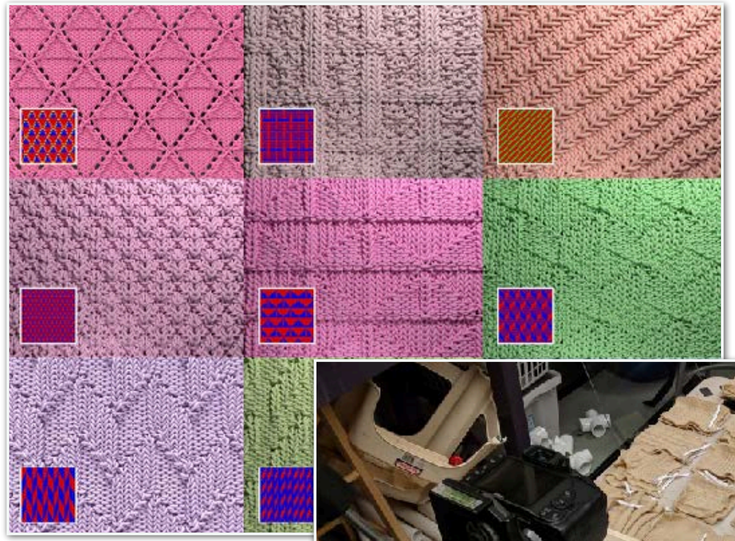
[Miguel et al. ’12]
[Wang et al. ’11]

Applications

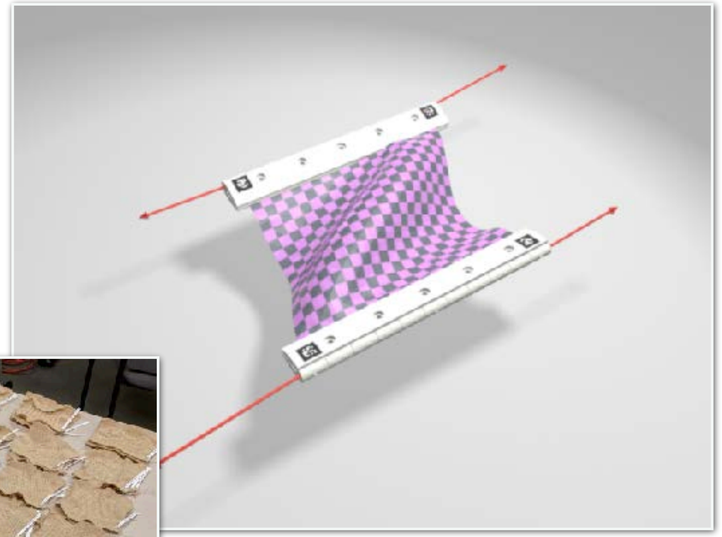
[Pavko-Čuden et al. ’17]
[Knittel et al. ’15]
[Alderson et al. ’12]
[Hu et al.’11]

What can we do next with machine knitting?

Predictive Simulation



Calibration



Applications

Datasets

http://db.knit.zone/ [Hofmann et al.'19]

http://deepknitting.csail.mit.edu/dataset/ [Kasper et al.'19]

contact:
kuiwu@csail.mit.edu

Thank You! Questions ?