Knitting Skeletons: Computer-Aided Design Tool for Shaping and Patterning of Knitted Garments

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Motivation
Industrial Knitting
Knitted Results

Infinity scarf with custom lace pattern

Sock with ribbed cuff
Industrial Knitting

- Whole garments from scratch
Industrial Knitting

- Control of individual needles
- Whole garments from scratch
Knitted Garment & Patterns

Many garments are knitted:
• Beanies, scarves
• Gloves, socks and underwear
• Sweaters, sweatpants

Those machine require minimal post-processing (i.e. almost no sewing)
Knitted Garment & Patterns

Those garments have various types of surface patterns.

These can be fully controlled by industrial knitting machines, and the same is true for the size.

= User customization!
Machine Knitting Programming

BUT …

Low-level machine code requires skilled experts

= Knitting masters
(Brief) Machine Knitting

Background
Woven fabric

Weft knitted fabric

Warp knitted fabric
Machine Knitting Terminology

Woven fabric

Weft knitted fabric

Warp knitted fabric
Machine Knitting Terminology

V-bed machine & knitting bed
Knitting Beds and Needles
Machine Knitting Terminology

**Stitch neighborhood (course, wale)**

Stitch increase

Stitch decrease
Machine Knitting Terminology

Stitch neighborhood (course, wale)

Stitch increase

Stitch decrease
Machine Knitting Terminology

Stitch neighborhood (course, wale)

Stitch increase

Stitch decrease
Related Workflows for Machine Knitting Design
Workflow: Low-Level Knit Programming

+ Full control

- Non-parametric
- Expert complexity
- Not accessible (not open)
Workflow: Design on 3D Meshes

+ General 3D shapes
+ Preview / feedback

- Non-parametric
- Large complexity

Automatic Machine Knitting of 3D Meshes
[Narayanan et al. 2018]

Visual Knitting Machine Programming
[Narayanan, Wu et al. 2019]
Workflow: Primitive-based Design

+ Simpler design space

- Parameterization?
- Customization?
- Composition?

A Compiler for 3D Machine Knitting
[McCann et al. 2016]

Shima Templates
[Shima 11]
Inspirations

Modeling Garments
- Sensitive Couture [Umetani et al. 2011]
- Stitch Meshes [Yuksel et al. 2011]

Parametric Design
- Antimony [Keeter 2013]
- Foundry [Vidimce et al. 2016]

DSL
- Inverse Knit
- Knitout
Our Workflow
Time-Needle Bed

Time

Needles
Time-Needle Bed

Full version

Compact(ed) version
Skeleton Graph

- pinky
- ring finger
- middle finger
- index finger
- thumb
- 4-fingers palm
- palm
- cuff
Physics Simulation
Shaping Primitives
Sheet | Tube

Shaping using
“Stitch increase/decrease”

Interfaces:
○ Top
○ Bottom
Sheet | Tube (examples)
Sheet | Tube (examples)
Sheet | Tube (examples)
Sheet | Tube (examples)
Joint

Shaping using “Short rows”

Interfaces:
  ○ Top
  ○ Bottom
Split | Merge

Topological branching

Interfaces:
- Base (1)
- Branches (2+)
Split | Merge

Folded branches (tubular)

Non-folded branches (flat)
Surface Patterning
Pattern Operations

Basic operations

Cross operations

Move operations

Stack Order
Pattern Operations

(a) Knit  

(b) Purl  

(c) Tuck  

(d) Miss  

(e) Move  

(f) Cross
Pattern Operations

(a) Knit □
(b) Purl △
(c) Tuck △
(d) Miss __
(e) Move ⊳
(f) Cross ✗
Pattern Operations

(a) Knit

(b) Purl

(c) Tuck

(d) Miss

(e) Move

(f) Cross
Pattern Operations

(a) Knit  
(b) Purl  
(c) Tuck  
(d) Miss  
(e) Move  
(f) Cross
Pattern Operations

(a) Knit (b) Purl (c) Tuck (d) Miss (e) Move (f) Cross
Pattern Operations

(a) Knit \(\text{\textcircled{\text{\text{-}}}}\)  
(b) Purl \(\text{\textcircled{\text{\text{-}}}}\)  
(c) Tuck \(\text{\textcircled{\text{\text{-}}}}\)  
(d) Miss \(\text{\textcircled{\text{\text{-}}}}\)  
(e) Move \(\text{\textcircled{\text{\text{-}}}}\)  
(f) Cross \(\text{\textcircled{\text{\text{-}}}}\)
Pattern Operations

(a) Knit

(b) Purl

(c) Tuck

(d) Miss

(e) Move

(f) Cross
Pattern Queries

- User programming
- In-browser editor
- Based on Javascript

Query = \texttt{select}

Operation = \texttt{apply}
Drawing Patterns
Pattern Layer Resampling

Base Pattern

Singular layer behaviour
Pattern Layer Resampling

Base Pattern

Scalable layer behaviour
Pattern Layer Resampling

Base Pattern

Tileable layer behaviour
Knitting Results
Knitting | Shaping

Results
Full Garments

Infinity scarf with custom lace pattern

Socks
Challenge 1: Complex Interface Interactions
Challenge 2(a): Supporting full-size garments

- **Computational scalability**: adult-size garments are made of a very large number of stitches
Full Garments

Scarves with customized shape and pattern

Socks
Complex Patterns
Resizing Layers

Cat = *scalable*

Background = *tileable*
Challenge 2(b): Supporting full-size garments

- **Computational scalability**: adult-size garments are made of a very large number of stitches

- **User scalability**: specifying individual stitches for such structures becomes impractical
User Results
Lace Patterns: User 1
Lace Patterns: User 2
Pattern on Wristband

Ref 1

User 1

User 2
Hats

Ref 1

User 2

User 1
Hat of User 1
Glove of User 1: 3 iterations
Challenge 3: Modeling the Manufacturability

- Topological correctness is not sufficient.
- Machine parameters are important.
- When it fails, why does it fail?
Take-aways

Contributions:
○ New **fully parametric** design tool for knitting
○ Complex **pattern design** on top of our primitives
○ Working **customization** for non-expert users

Challenges:
○ Parameterizing **complex shape interactions**
○ Computational and user **scalability**
○ Modeling the full **manufacturability**
Sources and demo on
http://knitskel.csail.mit.edu