Modeling Knitable Surfaces

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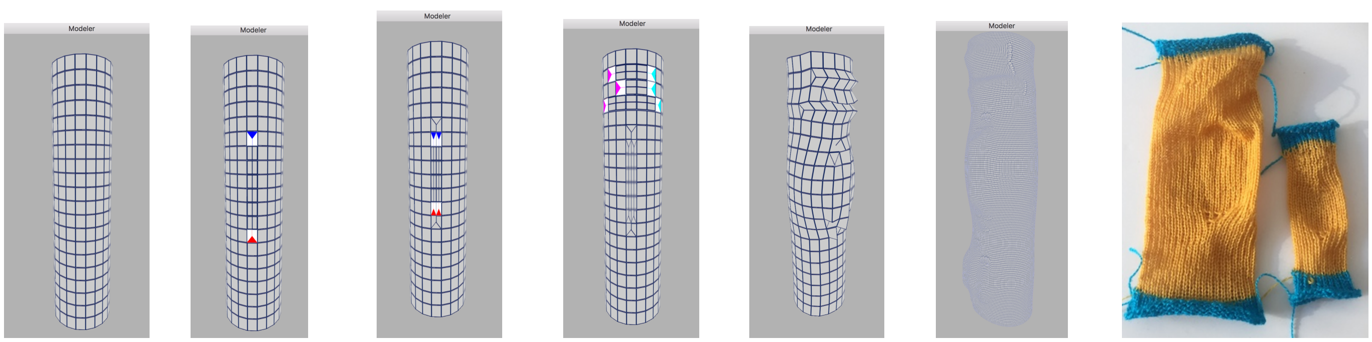
Introduction

The goal of this project was to design a modeling tool for surfaces that can be fabricated on the knitting machine. Motivated by subdivision surface based modeling, the system begins with an initial control mesh that is trivial to knit − a cylinder. It allows editing operations that selectively subdivides the mesh maintaining it as a quad-dominant quad+tri mesh. The editing operations continue to maintain knitability topologically. However, the geometry of the quads that represent stitches do not accurately represent its dimensions after non-uniform subdivision edits. The mesh edges are set to the correct length by iteratively projecting all edges to the correct length in a relaxation step. Once a base mesh has been generated, it can be uniformly subdivided to refine the mesh. The subdivision rules used are similar to Catmull-Clark subdivision, however triangles (introduced by the editing operations) are treated differently. An edge contraction operation is used to ensure the subdivided mesh remains knitable. Each editing and subdivision operation keeps the mesh in the same knitable format allowing the user to edit the mesh at any stage of the pipeline. Subdivision connectivity rules used are shown in Figure 2. Screenshots from a prototype implementation in OpenGL/C++ is shown in Figure 1.

Figure 1: Prototype implementation

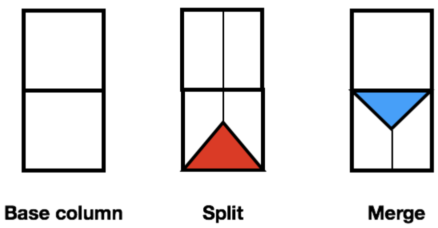


Beginning from a cylindrical quad mesh, the user can edit it to change column and rows (increase/decrease and short-row shaping in knit parlance). The resulting mesh is deformed to maintain uniform edge lengths and then subdivided to refine. As all operations retain knitability, these meshes can be easily fabricated on an industrial knitting machine.

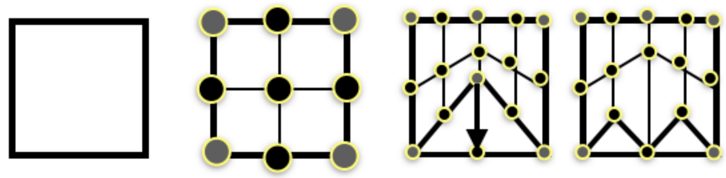
Related work

Stitch meshes [1] introduced a mesh based editing tool for initializing and designing knit surfaces for simulation. The surfaces generated by stitch meshes however are not always knittable. Further, they begin with remeshing and tessellating “well designed” meshes and allow editing of patterns rather than the structure itself. Literature on subdivision surfaces is vast. Surveys [2, 3] and course material [6, 7] were a useful reference to the various subdivision schemes that exist. Without being limited by fabrication constraints, [4] allows adaptive coarsening and refining of a quad-dominant mesh (with triangles and pentagons) that is consistent with Catmull-Clark subdivision. Analysis of the limit surface for Catmull-Clark surfaces [5] shows that these surfaces can be directly evaluated without the need for iterative subdivisions. For general Catmull-Clark surfaces, the number

Figure 2: Connectivity rules



(a) Adaptive subdivision by introducing triangular elements. The base column on the left is subdivided into two columns by splitting a quad into a triangle and 2 quads, the rest of the column above the split node is subdivided by splitting a quad into 2. Two merge two columns into one, two quads are split into a triangle and 2 quads as shown on the right.



(b) Uniform subdivision with modified Catmull-Clark. Quads are subdivided by Catmull-Clark subdivision, triangles undergo an edge contraction(see arrow) to maintain knitability. However, invariance on the number of extraordinary vertices is lost.

of irregular vertices remains constant at subsequent iterations, however in the scheme being used, uniform subdivision doubles the number of irregular surfaces at each iteration and its quality needs to be analyzed.

Conclusions

I found such a modeling tool to be useful to generate quick knitting patterns that are topologically cylindrical. A useful extension in such a system would be to add the ability to merge (pinch) vertices to generate splitting tree like structures as well as generate loops and higher genus surfaces. The additional constraints on the knitability of such surfaces can be incorporated within the modeling tool. Deformation of the base mesh needs to be improved for a more geometrically accurate control mesh.

Analysis and evaluation of the limit surface as well as better geometry rules for extraordinary vertices needs to be further investigated – particulary since extraordinary vertices increase with subdivision iterations, the matrix set up of Stam that assumes at most a single extraordinary vertex per quad is not sufficient and more cases are needed to see if the limit surface converges around extraordinary vertices.

References

[1] Yuksel, Cem, et al. "Stitch meshes for modeling knitted clothing with yarn-level detail." ACM Transactions on Graphics (TOG) 31.4 (2012): 37.

[2] Cashman, Thomas J. "Beyond CatmullClark? A survey of advances in subdivision surface methods." Computer Graphics Forum. Vol. 31. No. 1. Blackwell Publishing Ltd, 2012.

[3] Boier-Martin, Ioana, Denis Zorin, and Fausto Bernardini. "A survey of subdivision-based tools for surface modeling." DIMACS Series in Discrete Mathematics and Theoretical Computer Science 67 (2005): 1.

[4] Panozzo, Daniele, and Enrico Puppo. "Implicit Hierarchical QuadDominant Meshes." Computer Graphics Forum. Vol. 30. No. 6. Blackwell Publishing Ltd, 2011.

[5] Stam, Jos. "Exact evaluation of Catmull-Clark subdivision surfaces at arbitrary parameter values." Proceedings of the 25th annual conference on Computer graphics and interactive techniques. ACM, 1998.

[6] Mirela Ben-Chen https://graphics.stanford.edu/courses/cs348a-09-fall/Handouts/surfaces8.pdf

[7] Siggraph 99 course notes http://www.multires.caltech.edu/pubs/sig99notes.pdf