GCM

EPFL

Student Project Proposal

Wire Art With Tension-Constrained Elastic Rods

Joy DANDY – <liliane-joy.dandy@epfl.ch> – BC 349
Michele VIDULIS – <michele.vidulis@epfl.ch> – BC 349

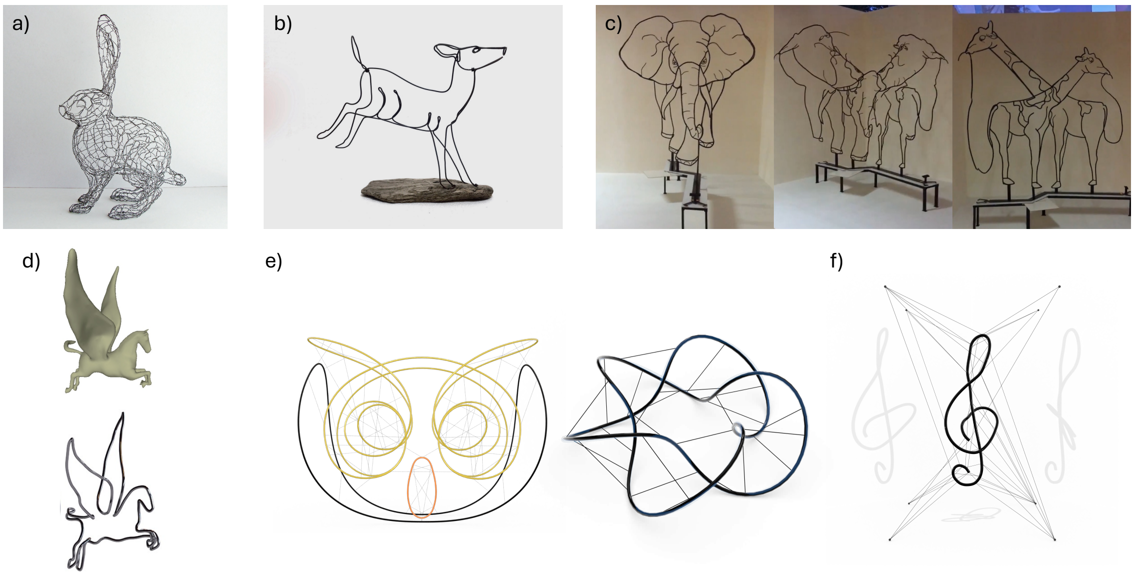

Figure 1: Different types of wire art and rod shaping. *a)* 3D wire art: Jackrabbit by Ruth Jensen. *b)* 2D wire art: Deer by Bud Bullivan. *c)* Multi-view wire art: Elephant-Giraffe anamorphose sculpture from Matthieu Robert-Ortis. *d)* A wire shape obtained from a 3D mesh with the WireRoom framework [6]. *e)* Two examples of *tencers* [2] (tension-constrained elastic rods), approximating an owl's head and a contactless torus knot. *f)* A *tencer* optimized to follow a 3D curve whose projection in the xz-planes draws a treble key. Optimizing this example to fit the treble key drawing in the xz-plane instead of the 3D curve would allow to make a nicer wire sculpture supported by less cables.

Description

Wire art pieces are three dimensional sculptures made from wire that either depict a 3D content - such as the 3D rabbit by Ruth Jensen on Figure 1a) - or, projected on one or several planes, form drawing patterns - see for instance the 2D deer by Bud Bullivan on Figure 1b) or the multi-view wire sculpture by Matthieu Robert-Ortis on Figure 1c). In recent research works, several computational pipelines have been developed for designing wire sculptures from 3D models [6], or creating multi-view wire art [3]. These wire sculptures are generally fabricated with metal wires that are bent either manually - which is quite challenging - or using a wire bending machine, which requires generating a folding algorithm. Other approaches rely on 3D-printing the wires, however this constrains a lot the shape space, as a wire art model may not be 3D-printable in general. To overcome this difficulty, in another study, Tojo et al. [5] propose an algorithm that accounts for fabrication constraints and generates a 3D-printable jig structure for the user to bend the wire.

With the same focus on easing fabrication, we are interested in a different approach: instead of plastically bending rigid wires, we consider using elastic structures. We aim at creating wire art from initially straight elastic rods that we shape by adding a few stretched cables. This kind of structures, where the coupling of elastic forces in the rods and tension forces in the cables allows complex shapes to emerge, are called *tencers* [2], for tension-constrained elastic rods. Figure 1e) shows a few examples of *tencers*: one made of three closed elastic rods that delineates an owl's head, and one made of one closed rod and 25 cables that follows one 3D-parametrization of a torus knot.

In our current *tencer* design and simulation codebase, given as input a set of three-dimensional target curves, we optimize for the number, placement and length of the cables in the structure so that its final shape, at equilibrium, best approximates the target curves. If this computational pipeline provides good results for 3D curves, it is currently not optimal to produce wire art. Figure 1f) illustrates this: the rod follows closely the 3D target curve, however its projection on the plane deviates quickly from the target. As a consequence, a lot of cables are still needed to keep a visually pleasing 2D projection. To overcome this issue, it is possible to optimize only over the rod's 2D projection, letting it deform freely in the third dimension.
In a first simplified setting, when the total length of the rod is kept fixed throughout the simulation, the current pipeline can be adapted with minor modifications to the 2D projection case. A more interesting approach is to include the rod length in the design parameters, along with the spring positions and lengths, in order to give full freedom to the rod to deform in the direction orthogonal to the viewpoint.
If time permits, further research questions can be explored, such as optimizing over the projection on several viewpoints. The challenge of projecting a 3D object on several planes to produce prescribed 2D shapes has been explored in the literature for both wire art, or, in a similar vein, shadow art [4]. Examples include the sculptures made by Matthieu Robert-Ortis such as the one in Figure 1 c), or the study multiview wire art [3].

We provide a C++ code framework with a Python interface to simulate *tencers* made from elastic rods (modeled with the Discrete Elastic Rods model [1]) constrained by springs (the forward simulation), and for the 3D inverse problem.

Milestones

- Get familiar with the *tencers* simulation and inverse design framework. Implement the new optimization problem in a simplified setting, where the total rod length is kept fixed.
- Formulate and implement the full optimization problem (with the length of the rod as an optimization variable).
- Fabricate one optimized model.
- If time permits, explore the possibility of optimizing over several view points.

Prerequisites

Previous experience with C++ and Python is required.

Remarks

This proposal is intended for a Master's research project (8 or 12 credits) and can be adapted to fit the requirements of a Master's Thesis.

References

[1] Miklós Bergou, Max Wardetzky, Stephen Robinson, Basile Audoly, and Eitan Grinspun. Discrete elastic rods. In *ACM SIGGRAPH 2008 papers*, pages 1–12, Los Angeles California, August 2008. ACM.

[2] Liliane-Joy Dandy, Michele Vidulis, Yingying Ren, and Mark Pauly. Tencers: Tension-constrained elastic rods, dec 2024.

[3] Kai-Wen Hsiao, Jia-Bin Huang, and Hung-Kuo Chu. Multi-view wire art. *ACM Transactions on Graphics*, 37(6):1–11, December 2018.

[4] Niloy J. Mitra and Mark Pauly. Shadow art. *ACM Transactions on Graphics*, 28(5):1–7, December 2009.

[5] Kenji Tojo, Ariel Shamir, Bernd Bickel, and Nobuyuki Umetani. Fabricable 3D Wire Art. In *Special Interest Group on Computer Graphics and Interactive Techniques Conference Conference Papers '24*, pages 1–11, Denver CO USA, July 2024. ACM.

[6] Zhijin Yang, Pengfei Xu, Hongbo Fu, and Hui Huang. WireRoom: model-guided explorative design of abstract wire art. *ACM Transactions on Graphics*, 40(4):1–13, August 2021.