# Towards developable products from a sketch

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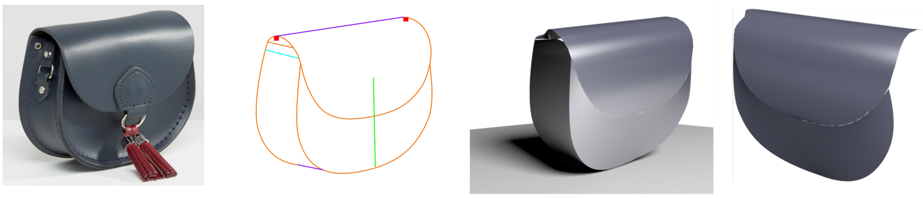


**Figure 1:** *Our method reconstructs 3D volume of piece-wise developable objects from a single annotated sketch.*

## 1. Introduction

Developable surfaces are surfaces that can be unfolded onto a plane, without distortion, and are widely used in industry We propose an end-to-end system for the interactive modeling of developable objects from a single annotated photo, restricted to the case of symmetrical objects made by assemblies of planes and generalized cylinders. Our method is in two parts : we first analyze the 2D annotated photo to extract the location of symmetric points and the rulings of the cylindrical regions. Then we use this 2D information in a global system to lift the shape of the object in 3D. Developable surfaces are ubiquitous in design, architecture and fashion, which has motivated the development of dedicated modeling systems. Many such methods take as input an existing 3D model and deform it to achieve developability [WT04], or approximate it with developable panels [LPW*06, KFC*08, TBWP16]. Alternatively, lofting methods find developable surfaces that interpolate 3D boundary curves [Fre02, RSW*07]. Closer to our work, SketchingFolds [JHR*15], is a sketch-based modeling system that reconstructs fashion items from sketches drawn from two orthogonal viewing directions. In contrast, our input is a network of 2D curves traced over a single picture and we exploit properties of developable surfaces to lift the drawing to 3D while ensuring that the output model is developable. Generally speaking, single-view reconstruction of 3D shapes is an ill-posed problem, as a 2D picture can represent an infinite number of different 3D surfaces. Prior work managed to address this problem in a few specific cases, by complementing re-projection error minimization with specific geometric constraints. These constraints included parallelism and orthogonality [LS07], exact mirror-symmetry [CSMS13], or orthogonality of cross-sections in the case of engineering design sketches [XCS*14]. We complement these approaches with a new constraint on surface developability.

## 2. Interpretation of the 2D curves

Our input is an annotated photo, called sketch : it contains 2D cubic Bezier splines corresponding to the seams, borders, and silhouettes of the object, assumed to be viewed from a close to orthographic projection. Additional information are provided for a subset of curves: each silhouette is marked as being one, and the pairs of symmetrical borders or seams are also indicated. Finally, the user annotates symmetrical features in the photo which are used to recover the normal vector $\vec{n}$ of the symmetry plane. We compute the set of minimal closed contours made by the Bezier splines, and each of them corresponds to a so-called *surface patch*, i.e. the visible border of the orthographic projection of a smooth $C^2$ developable surface.

**Find 2D symmetrical correspondences** Let us consider a 3D object which global mirror-symmetry with respect to a plane of normal $\vec{n}$. All pairs of symmetrical points of the object can therefore be linked by a vector which is collinear to $\vec{n}$. Note that this remains valid for the 2D orthographic projection of the object. Thus, we compute the location of symmetrical points in the 2D sketch by linking points of two curves annotated as symmetrical in 3D with a vector that is collinear to the line of symmetry $\vec{s} = \vec{n}|_{z=0}$.

**Find 2D rulings of the cylindrical parts in the sketch** Developable surfaces are ruled surfaces with a constant tangent plane along each ruling. We consider the specific case of developable cylindrical surfaces, defined as surface for which all rulings are collinear to each other. Indeed, this property also holds on the 2D projection of the surface. Koenderink's theory [Koe84] indicates that the silhouette of a smooth developable surface is a straight line corresponding to a ruling of the surface. We use this criteria to compute the rulings in the specific case of developable cylindrical



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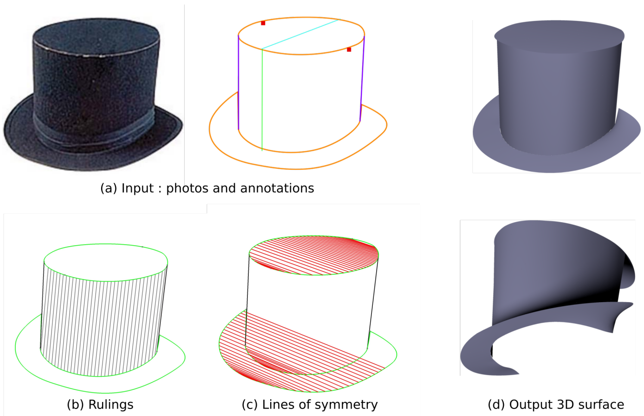
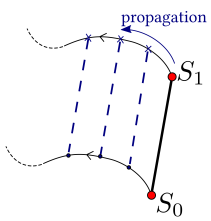



**Figure 2:** *Example of result : 2D interpretation (b,c) and 3D reconstruction (d) of the annotated photo (a)*

surfaces, defined as surface for which all rulings are collinear each other, with a visible silhouette. Our algorithm works as folllows.




*Rulings propagation*
*$S_0S_1$ is the silhouette*

An initial ruling on the surface patch is provided by the straight silhouette segment. We then propagate the rulings using parallel translation through the patch with respect to this first ruling and the symetry analysis output described in the previous secttion, leading therefore to the set of projected rulings of the surface.

## 3. Compute 3D curves and surfaces

We use both the global symmetry assumption and the developability assumption to lift the curves of the sketch into 3D. These curves are represented using cubic Bezier splines, and we keep this representation in the lifting : the variables of our system are the 3D coordinates of the corresponding 2D control points of the curves in the sketch. We minimize a quadratic energy functional $E$ defined as below :

$$E = \omega_0 E_{\text{devel}} + \omega_1 E_{\text{sym}} + \omega_2 E_{\text{minvar}} + \omega_3 E_{\text{proj}} \quad (1)$$

where

- $E_{\text{devel}}$ expresses the criteria of developability : it ensures the planarity of the extremities of each pair of consecutive rulings in a patch
- $E_{\text{sym}}$ expresses the 3D mirror-symmetry of the symmetrical vertices in the curves,
- $E_{\text{minvar}}$ is the minimal variation energy, similar to the one presented in [XCS*14],
- $E_{\text{proj}}$ ensures that the projection of the 3D curves remains close to the sketch.

We then compute a mesh for every patch of the model. Patches containing existing rulings are simply triangulated. All remaining surfaces are computed by using a standard linear variational Laplacian-based method interpolating the given 3D patch boundaries [SHBS16, BK04]. Developability of all non cylindrical patches is finally obtained by applying some local optimization steps [WT04].

## 4. Conclusion

**Results** Some of our results are presented in Fig. 1 and 2.

**Limitations** We restrict our method to developable patches that are cylindrical. The method for propagating rulings remains correct if the patch contains planar parts, since all lines linking two boundary vertice of a planar patch is a ruling of the surface but cannot account for patches that contains conical parts.

## References

[BK04] Botsch M., Kobbelt L.: An intuitive framework for real-time freeform modeling. ACM Trans. Graph. 23, 3 (Aug. 2004), 630–634. 2

[CSMS13] Cordier F., Seo H., Melkemi M., Sapidis N. S.: Inferring mirror symmetric 3D shapes from sketches. Computer-Aided Design 45, 2 (2013), 301–311. 1

[Fre02] Frey W. H.: Boundary triangulations approximating developable surfaces that interpolate a closed space curve. International Journal of Foundations of Computer Science 13, 02 (2002), 285–302. 1

[JHR*15] Jung A., Hahmann S., Rohmer D., Begault A., Boissieux L., Cani M.-P.: Sketching folds: Developable surfaces from non-planar silhouettes. ACM Trans. Graph. 34, 5 (nov 2015), 155:1–155:12. URL: http://doi.acm.org/10.1145/2749458, doi:10.1145/2749458. 1

[KFC*08] Kilian M., Flöry S., Chen Z., Mitra N. J., Sheffer A., Pottmann H.: Curved folding. In ACM Transactions on Graphics (TOG) (2008), vol. 27, ACM, p. 75. 1

[Koe84] Koenderink J. J.: What does the occluding contour tell us about solid shape? Perception 13, 3 (1984), 321–330. 2

[LPW*06] Liu Y., Pottmann H., Wallner J., Yang Y.-L., Wang W.: Geometric modeling with conical meshes and developable surfaces. In ACM Transactions on Graphics (TOG) (2006), vol. 25, ACM, pp. 681–689. 1

[LS07] Lipson H., Shpitalni M.: Optimization-based reconstruction of a 3D object from a single freehand line drawing. In ACM SIGGRAPH Courses Notes (2007). URL: http://doi.acm.org/10.1145/1281500.1281556, doi:10.1145/1281500.1281556. 1

[RSW*07] Rose K., Sheffer A., Wither J., Cani M.-P., Thibert B.: Developable surfaces from arbitrary sketched boundaries. In SGP'07-5th Eurographics Symposium on Geometry Processing (2007), Eurographics Association, pp. 163–172. 1

[SHBS16] Stanko T., Hahmann S., Bonneau G.-P., Saguin-Sprynski N.: Surfacing curve networks with normal control. Computers & Graphics 60 (2016), 1 – 8. 2

[TBWP16] Tang C., Bo P., Wallner J., Pottmann H.: Interactive design of developable surfaces. ACM Transactions on Graphics (TOG) 35, 2 (2016), 12. 1

[WT04] Wang C. C., Tang K.: Achieving developability of a polygonal surface by minimum deformation: a study of global and local optimization approaches. The Visual Computer 20, 8-9 (2004), 521–539. 1, 2

[XCS*14] Xu B., Chang W., Sheffer A., Bousseau A., McCrae J., Singh K.: True2Form: 3D curve networks from 2D sketches via selective regularization. ACM Transactions on Graphics (Proc. SIGGRAPH) 33, 4 (2014). URL: http://www-sop.inria.fr/reves/Basilic/2014/XCSBMS14. 1, 2