SIGGRAPH ASIA
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Digital 3D Smocking Design

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igl
INTERACTIVE GEOMETRY LAB

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Swiss Federal Institute of Technology Zurich

Smocking not smoking!

https://www.pinterest.ch/pin/690669292878820301/

https://www.pinterest.ch/pin/1002332460800168804/

https://www.pinterest.ch/pin/574560864973414366/

British garment “Smocc”

https://collections.vam.ac.uk/item/O954665/harrowing-with-oxen-print-unknown/

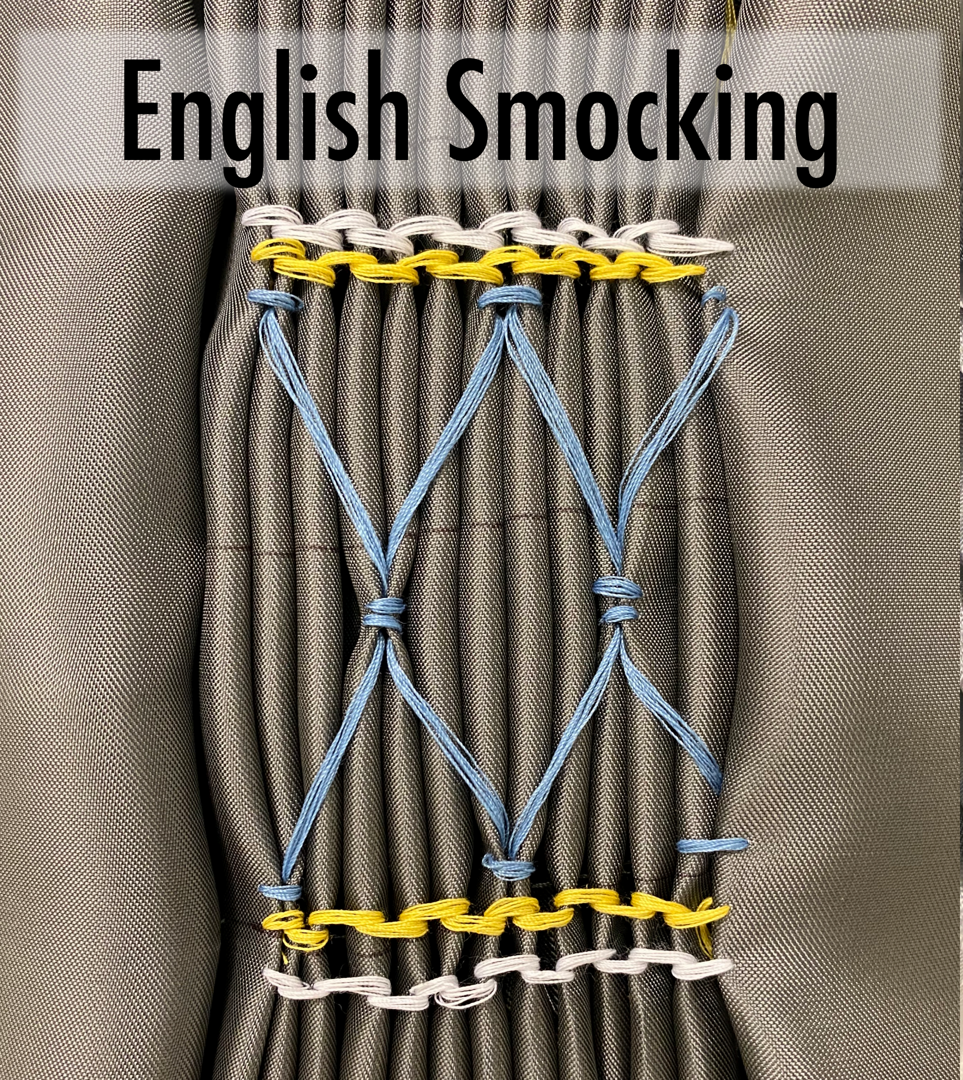
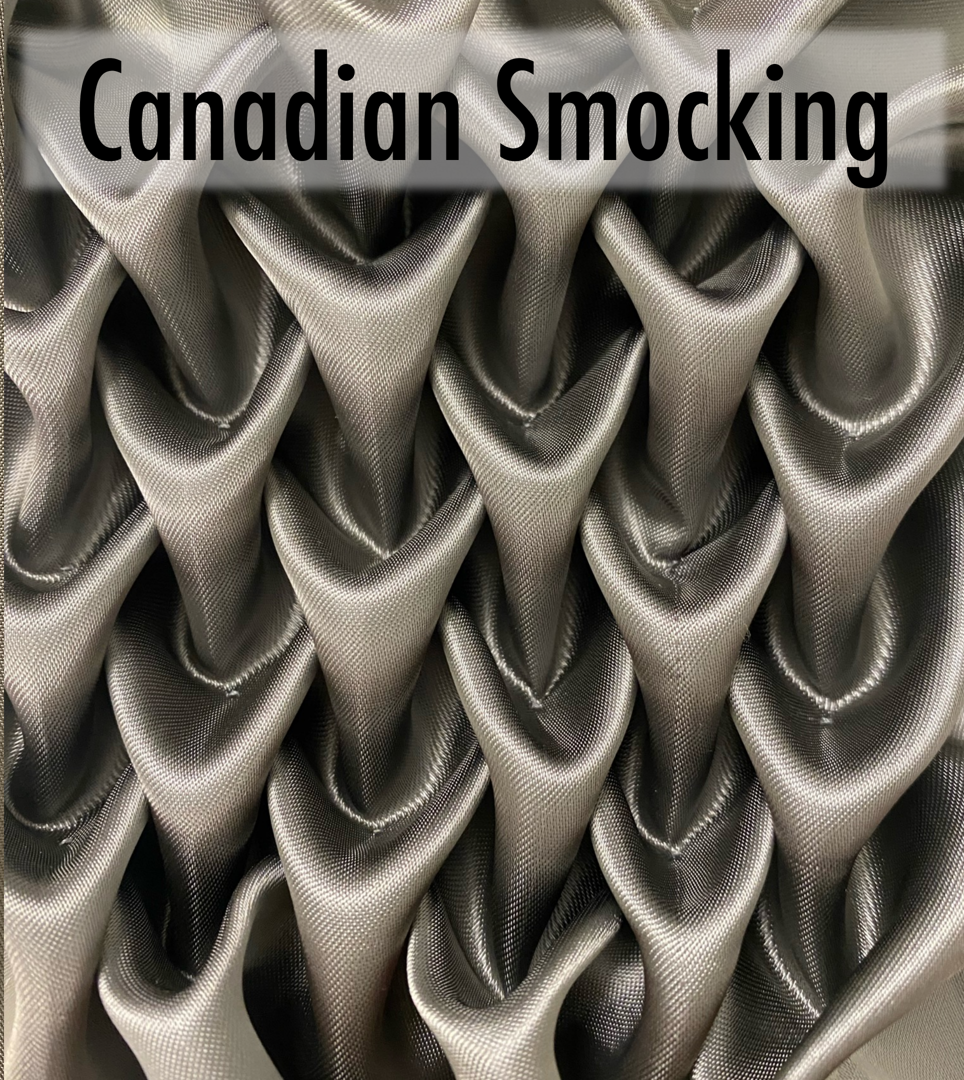
https://collections.vam.ac.uk/item/O57071/national-photographic-record-and-survey-photograph-stone-benjamin-sir/

From “Smocc” to Smocking

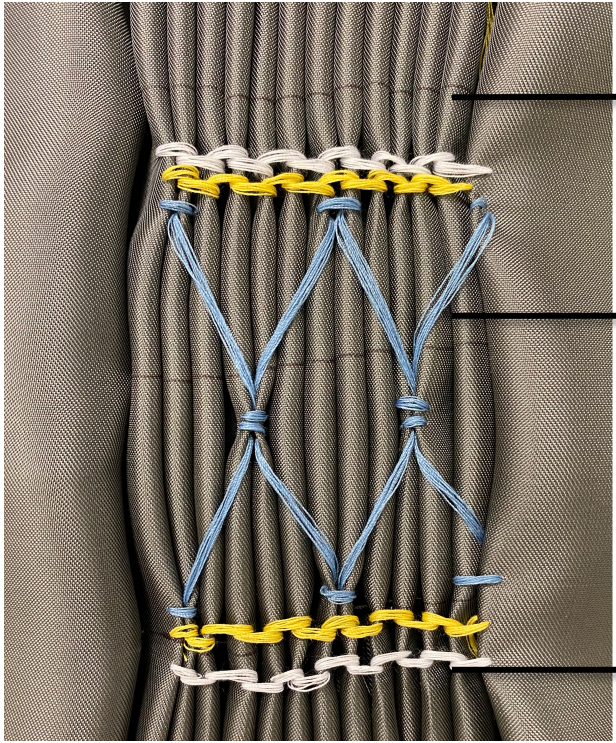
https://collections.vam.ac.uk/item/O354402/smock-smock-unknown/

https://collections.mfa.org/objects/482317

https://collections.vam.ac.uk/item/O138699/vivienne-fashion-doll-latter-axton-ja/


English Smocking

Canadian Smocking

English smocking

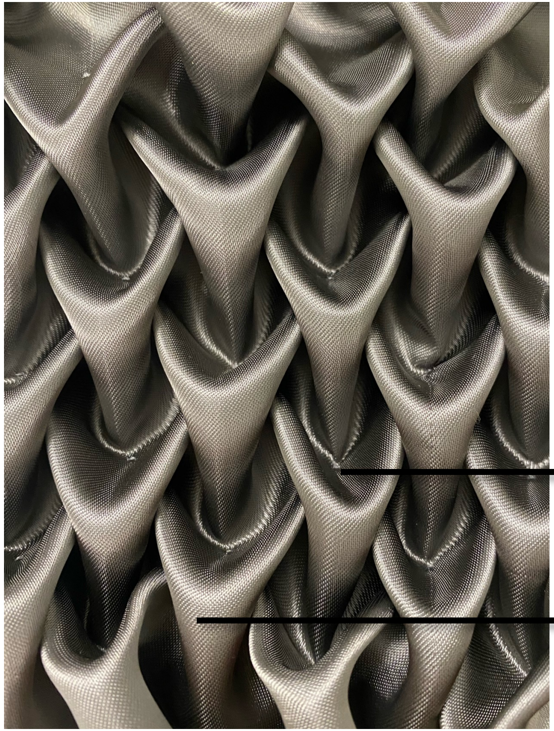


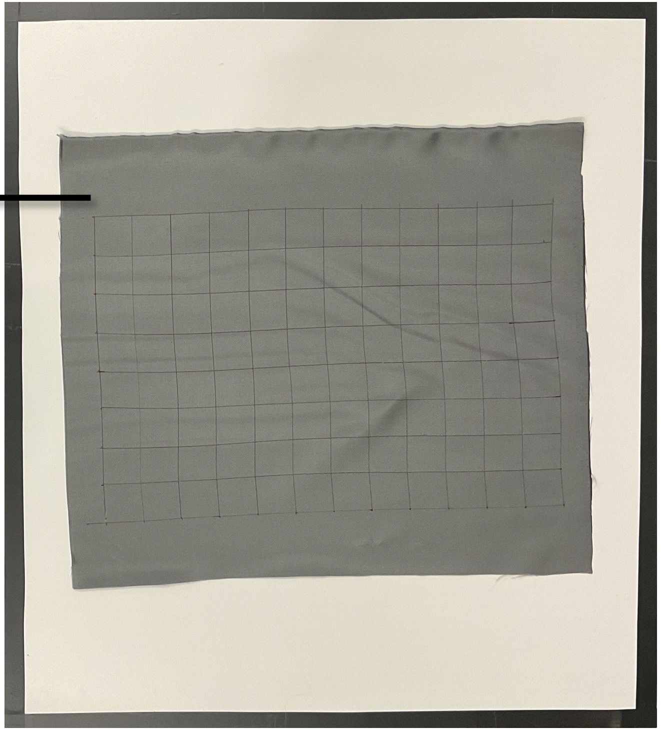
folded pleats

gathered threads

embroidered
visible stitches

Canadian smocking



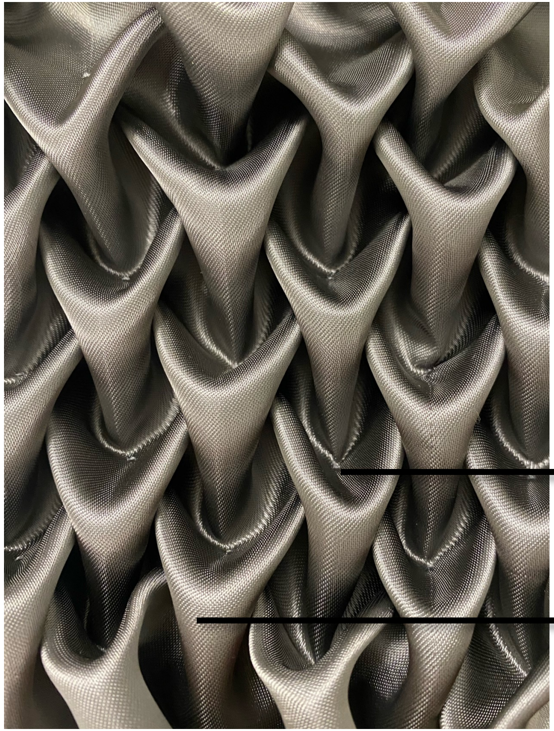


stitching lines
annotated on the back

invisible stitches

geometric textures
from folds

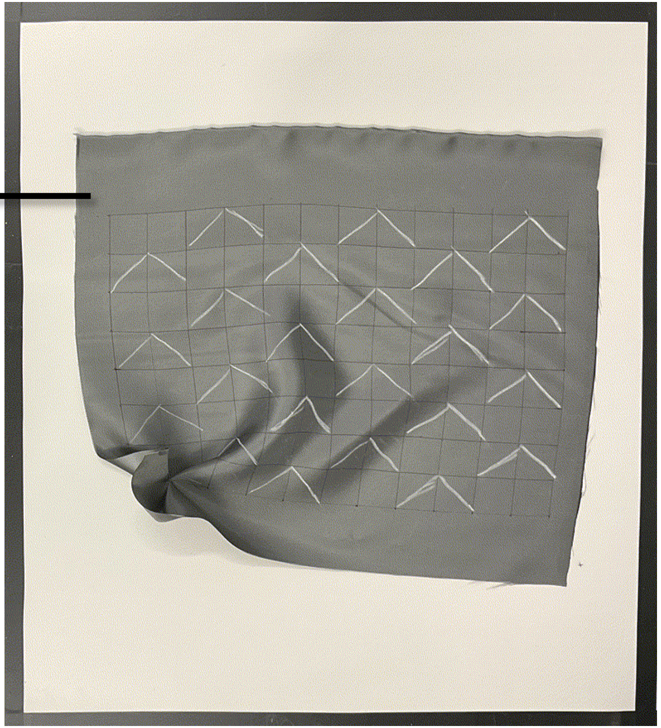
Canadian smocking



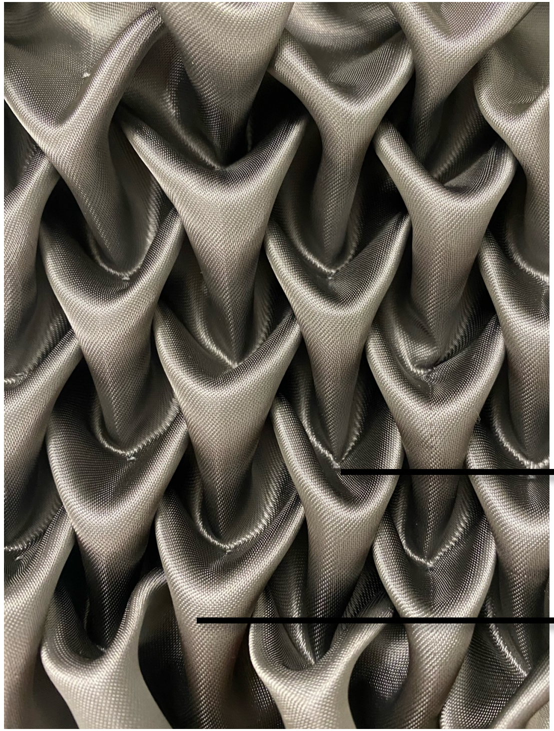
contracting stitches together

invisible stitches

geometric textures from folds



Canadian smocking

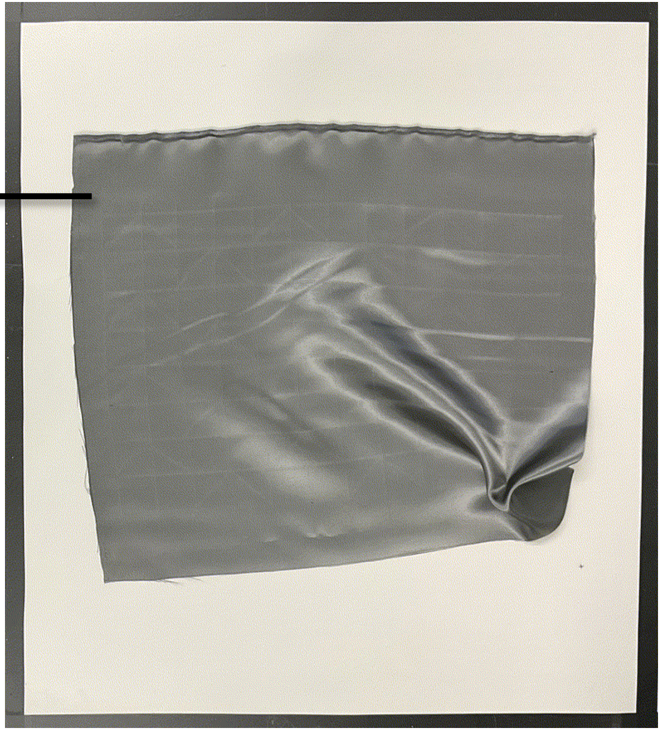


front view

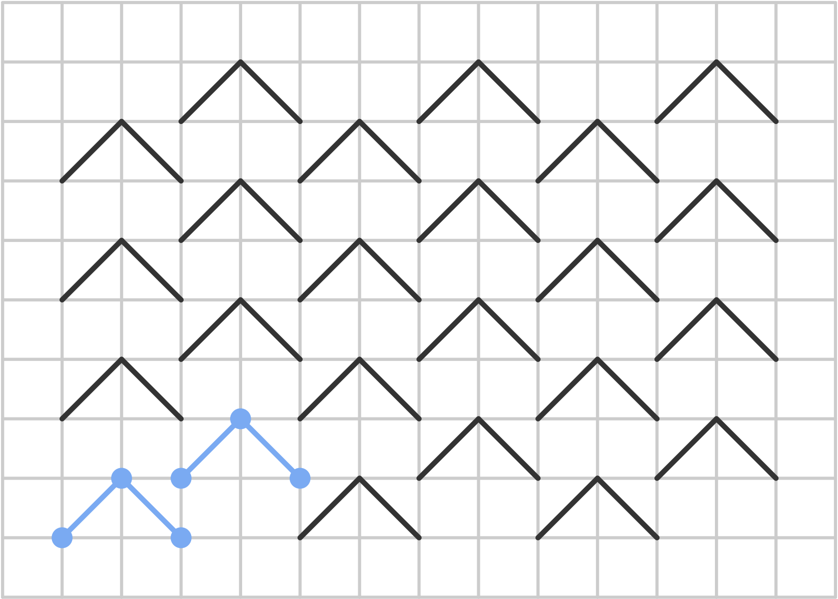
invisible stitches

geometric textures

from folds

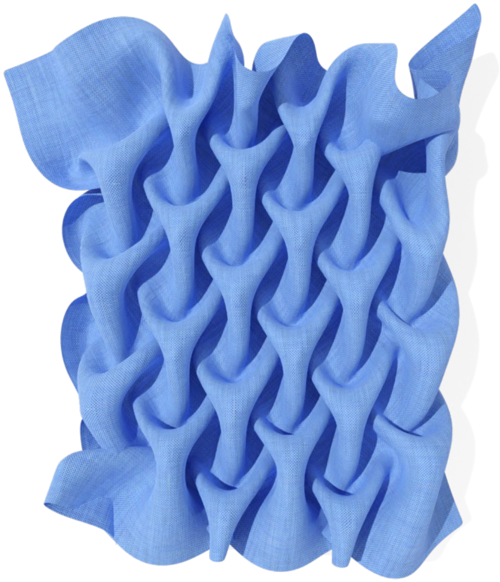


Our goal: smocking preview



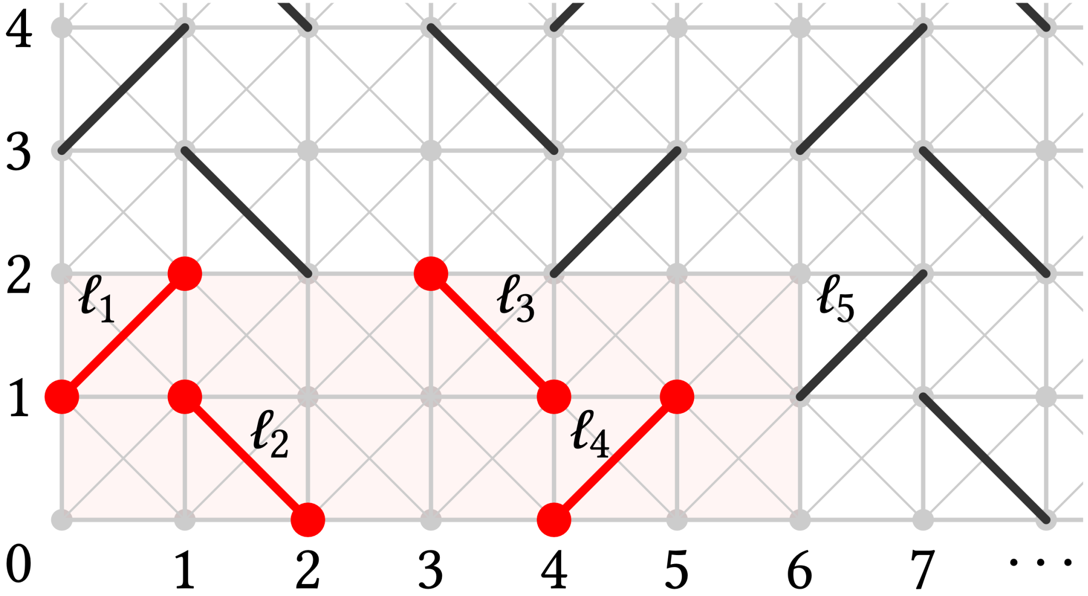
input smocking pattern

after stitching



output smocked result

Smocking: easy to formulate



Smocking pattern

- graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$
- stitching lines $\mathcal{L} = \{\ell_i\}$

for example:

- $\ell_1 = (v_{0,1}, v_{1,2})$
- $\ell_2 = (v_{2,1}, v_{1,1})$
- $\ell_3 = (v_{4,1}, v_{3,2})$
- …

… but not easy to solve

$\bar{e}_{25} = 2.69$ cm

$\bar{e}_{50} = 1.26$ cm

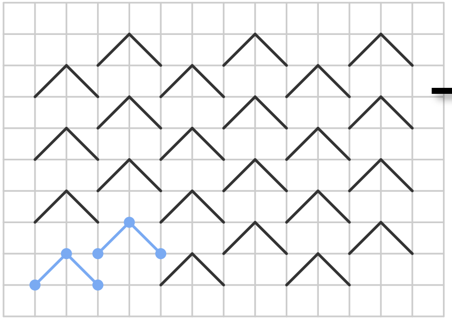
$\bar{e}_{75} = 0.97$ cm

cloth simulation using Blender

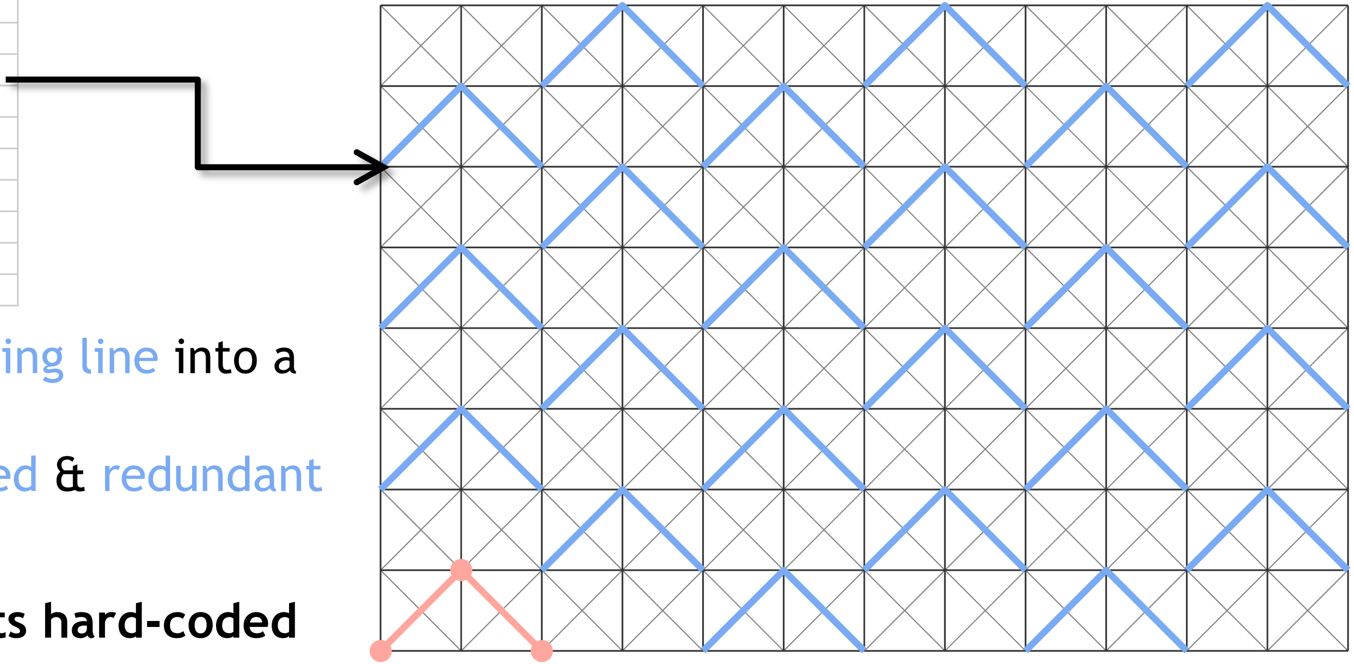
- geometry is unknown before smocking
- no geometry priors → irregular pleats

How to extract geometric priors?

input smocking pattern



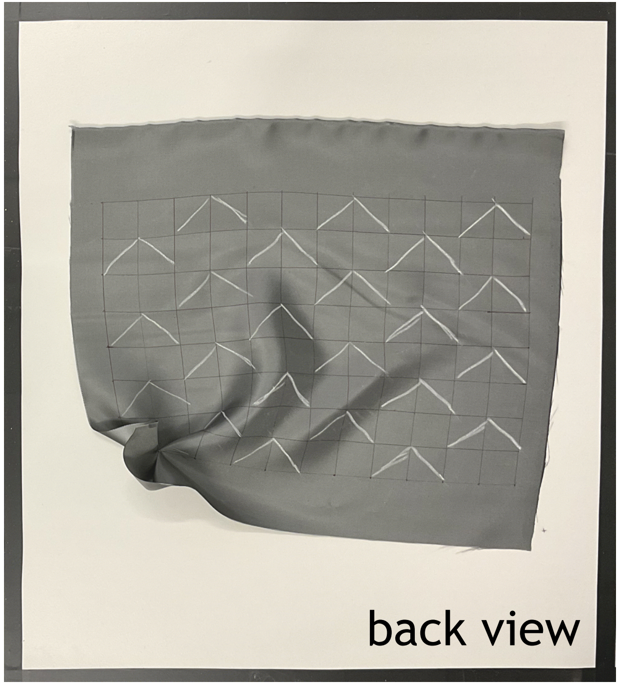
extracted smocked graph

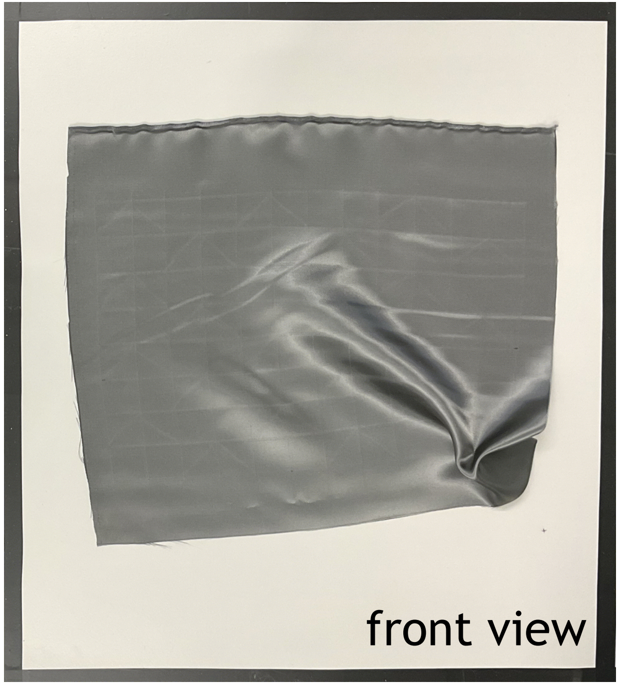


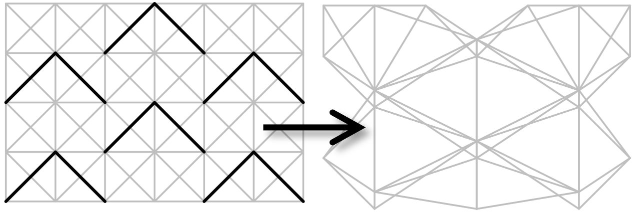
- ❖ merge each stitching line into a single node
- ❖ delete degenerated & redundant edges

✓ **sewing constraints hard-coded**

… capture modified geometry?





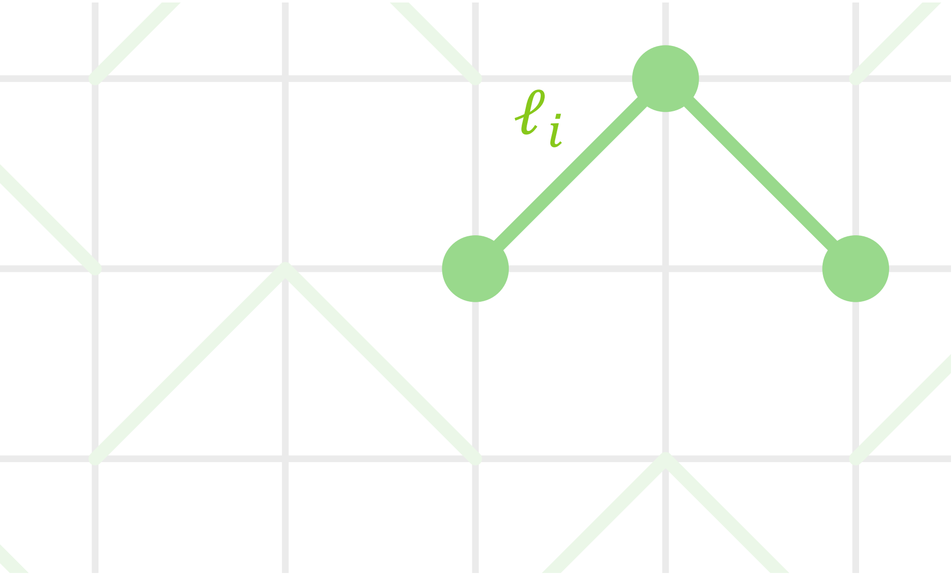


smocked graph

- ✓ sewing constraints hard-coded
- ✗ **modified geometry not considered!**

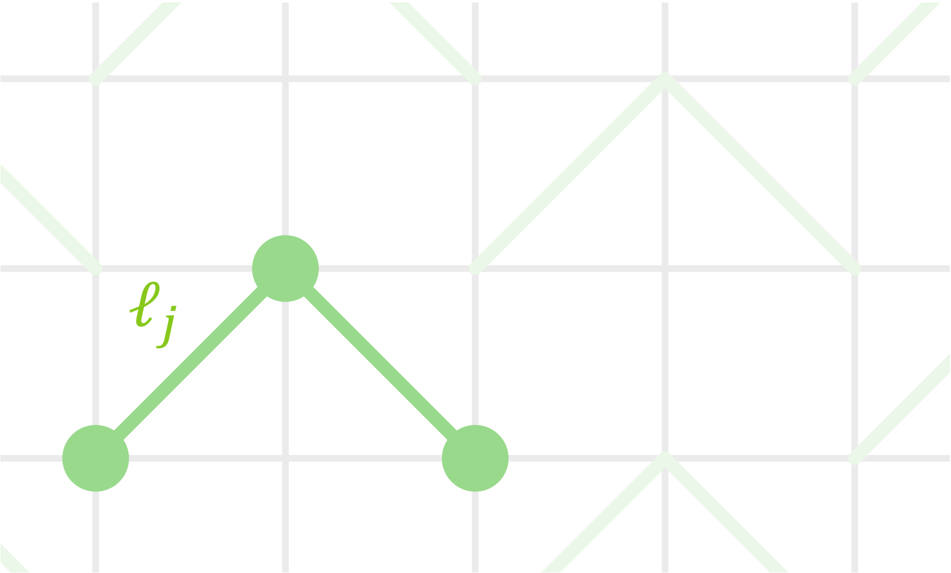
❖ fabric shrinks during the smocking process!

Embedding distance constraint



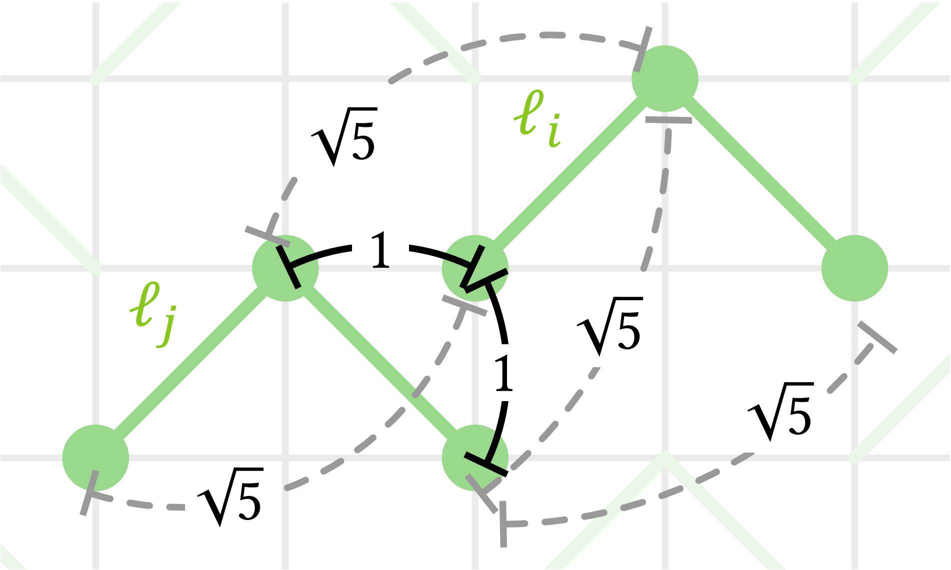
- ℓ_i is embedded at $x_i \in \mathbb{R}^3$

Embedding distance constraint



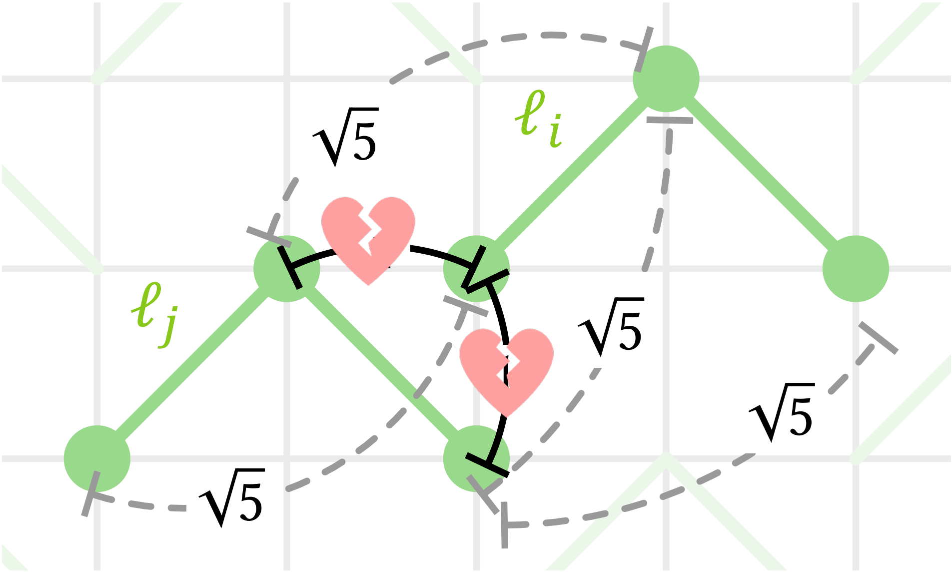
- ℓ_j is embedded at $x_j \in \mathbb{R}^3$

Embedding distance constraint



- ℓ_i is embedded at $x_i \in \mathbb{R}^3$
- ℓ_j is embedded at $x_j \in \mathbb{R}^3$

Embedding distance constraint

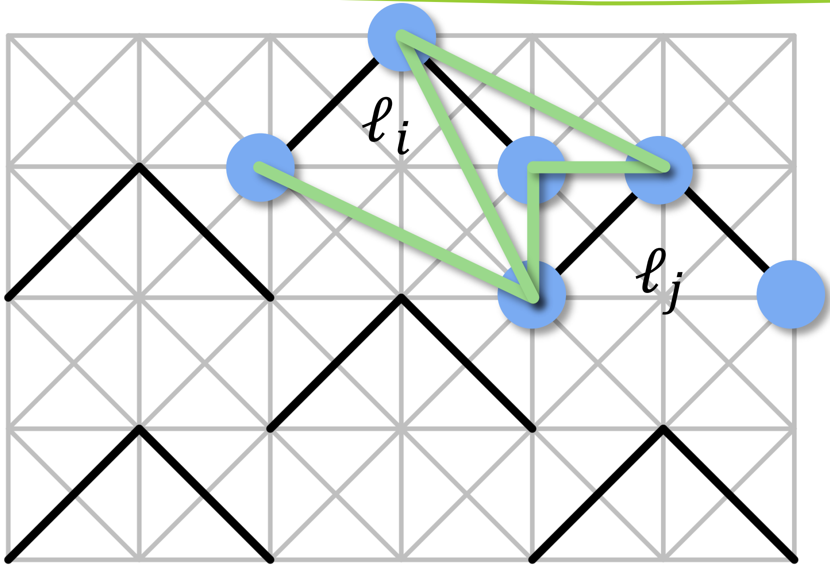


- ℓ_i is embedded at $x_i \in \mathbb{R}^3$
- ℓ_j is embedded at $x_j \in \mathbb{R}^3$

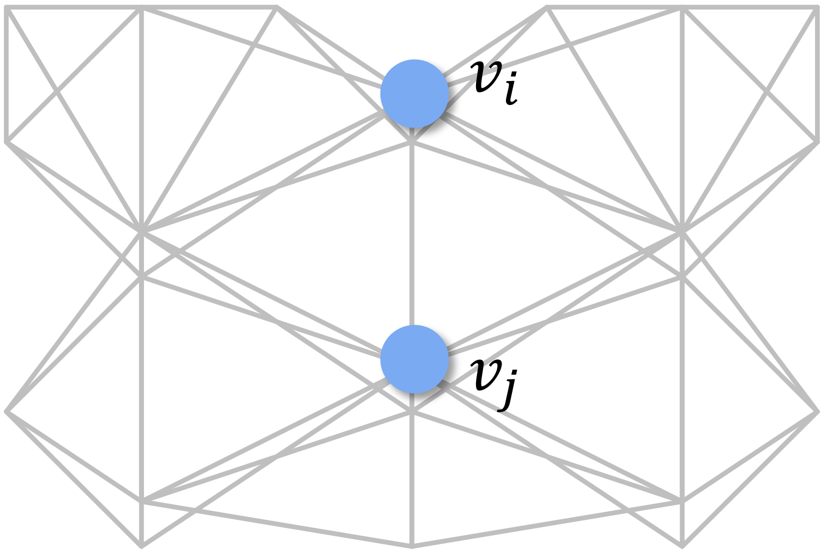
$$\|x_i - x_j\| \le 1$$

- If $\|x_i - x_j\| > 1$, fabric would tear at

Embedding distance constraint



$d(\cdot,\cdot)$: the distance in original fabric

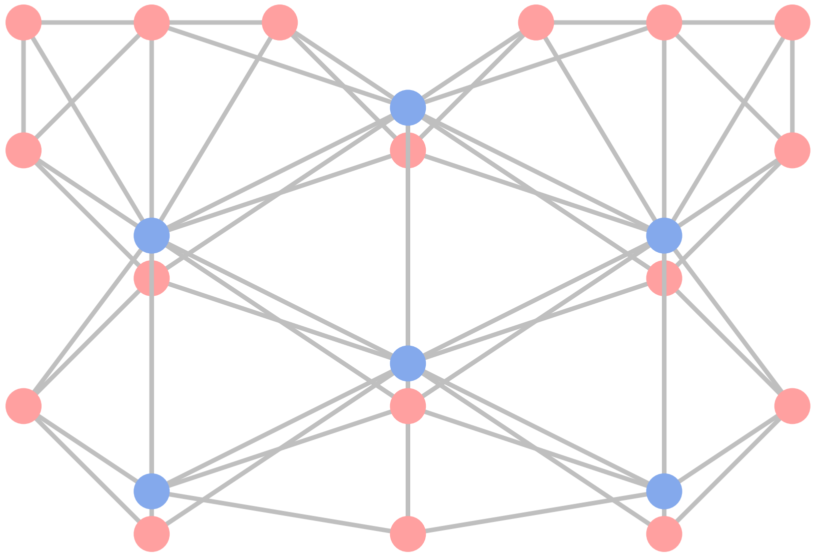


v_i is embedded at $x_i \in \mathbb{R}^3$

$$\|x_i - x_j\| \leq d_{i,j} \text{ where } d_{i,j} = \min_{v_p \in \ell_i, v_q \in \ell_j} d(v_p, v_q)$$

Embedding distance constraint

smocked graph



v_i is embedded at $x_i \in \mathbb{R}^3$

$$\|x_i - x_j\| \le d_{i,j} \;\; \forall i,j$$

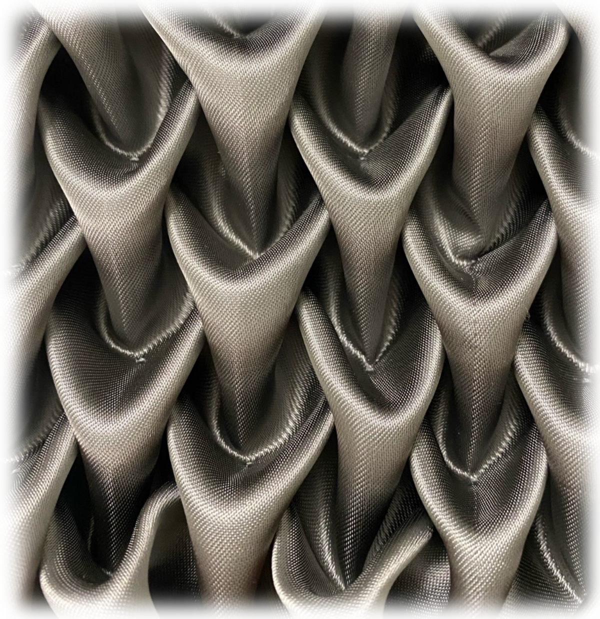
- $d_{i,j}$ encodes the modified geometry
- guarantees that the fabric won't tear after stitching

goal find an embedding that satisfies all the constraints ☺

problem trivial solutions such as $\forall i$ $x_i = (0,0,0)$ are feasible ☹

Observations

valid but cluttered result



expected result

Our formulation for smocking

$$\max_{X \in \mathbb{R}^3} \sum_{i \neq j} \|x_i - x_j\|$$

$$\text{s.t. } \|x_i - x_j\| \leq d_{i,j} \ \forall i \neq j$$

energy avoids cluttered (trivial) solutions

constraints fabric doesn't tear after smocking

challenges

- non-convex problem
- $^{n(n-1)}/_2$ constraints, too many!

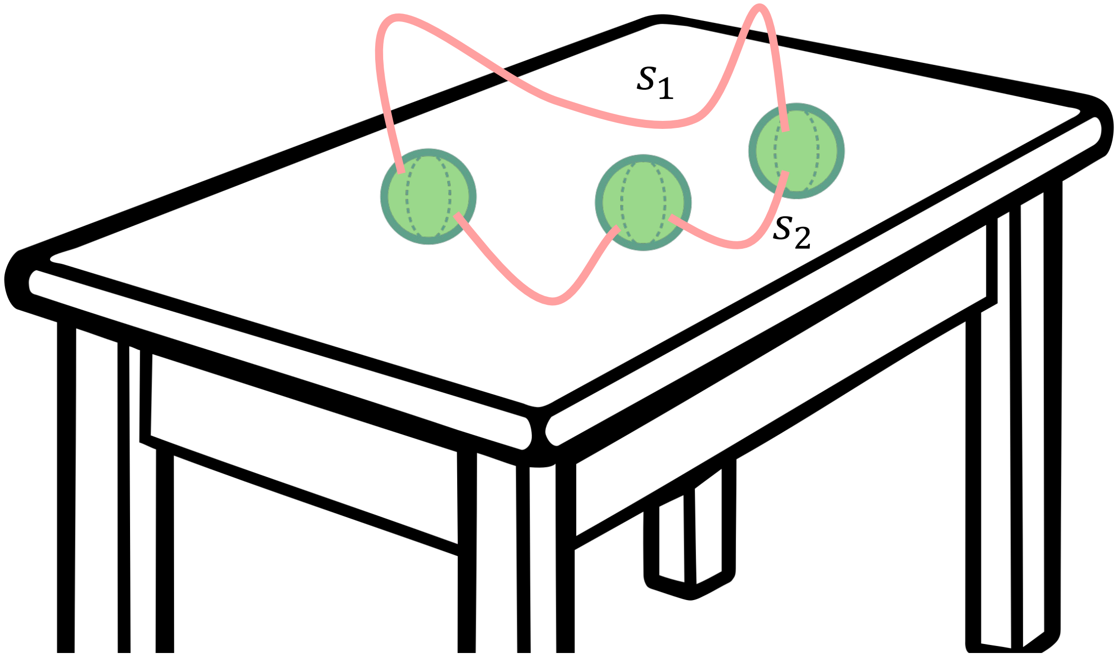
… are all constraints necessary?

$$\max_{X\in\mathbb{R}^3} \sum_{i\neq j} \|x_i - x_j\|$$

s.t. $\|x_i - x_j\| \leq d_{i,j}\ \forall i \neq j$

equivalent setting

- a set of balls can move around
- fragile string connecting balls with length $d_{i,j}$



s_2 will break before s_1 is pulled taut

Simplified formulation

$$\max_{X \in \mathbb{R}^3} \sum_{i \neq j} \|x_i - x_j\|$$

energy avoids cluttered (trivial) solutions

~~s.t. $\|x_i - x_j\| \leq d_{i,j} \; \forall i \neq j$~~

constraints fabric doesn't tear after smocking

$$\|x_i - x_j\| \leq d_{i,j} \quad \forall (i,j) \in \mathcal{E}$$

Only check the vertices that are adjacent

Unconstrained formulation

$$\max_{X \in \mathbb{R}^3} \sum_{i \neq j} \|x_i - x_j\|$$

$$\text{s.t. } \|x_i - x_j\| \leq d_{i,j} \;\; \forall (i,j) \in \mathcal{E}$$

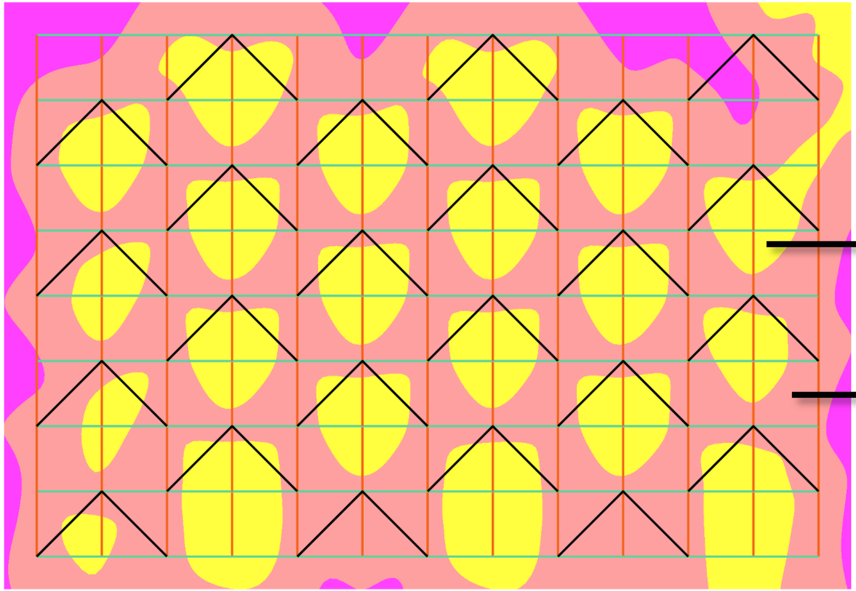
graph embedding problem

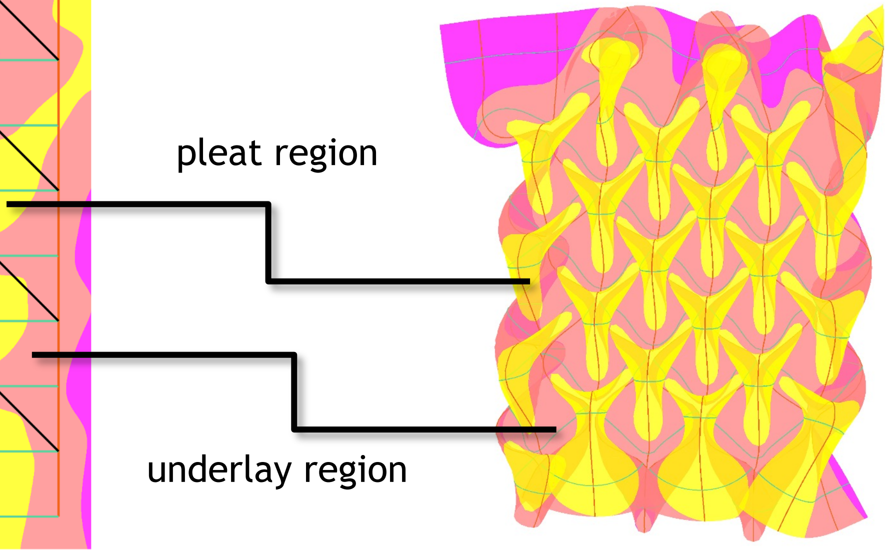
reformulate

$$\min_{X \in \mathbb{R}^3} \sum_{(i,j) \in \mathcal{E}} \left(\|x_i - x_j\| - d_{i,j}\right)^2$$

Motivations

Smocked result = underlay + pleat

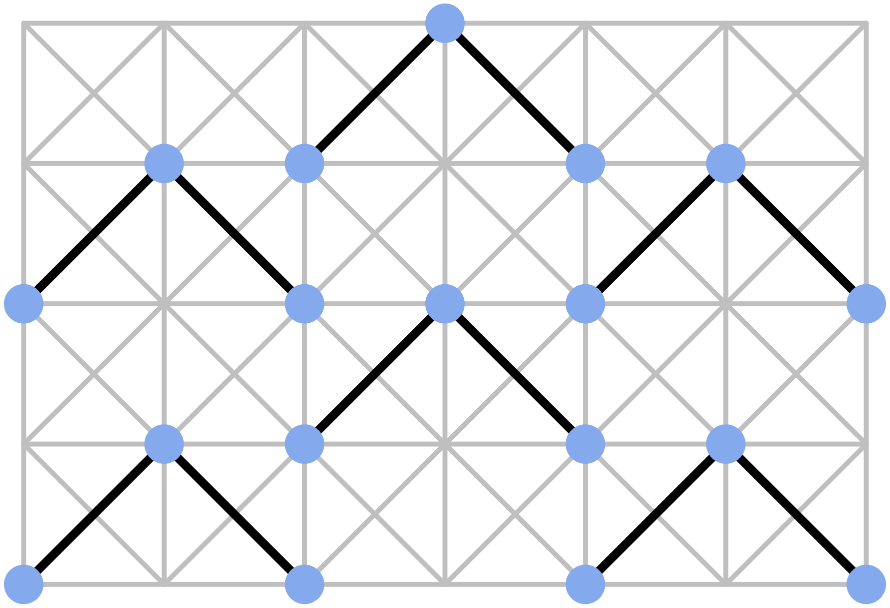




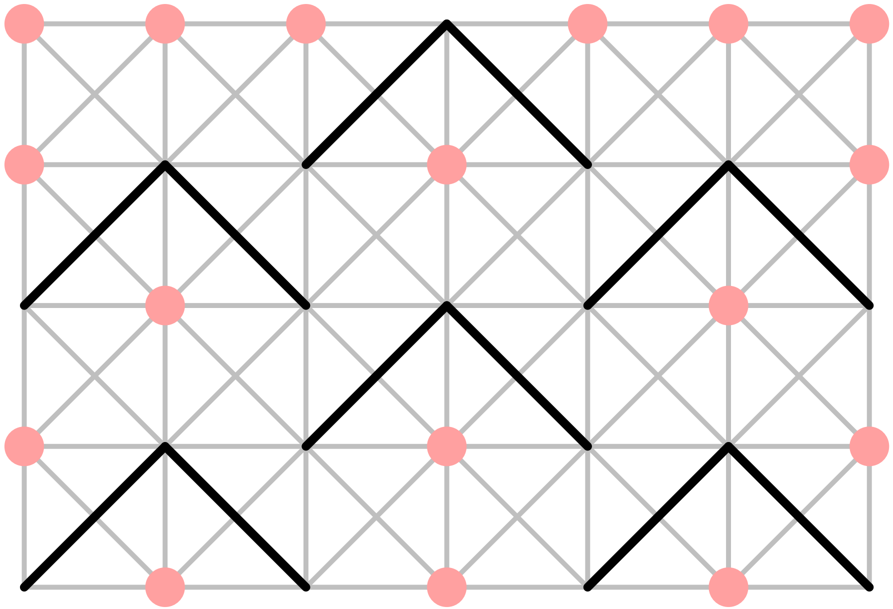
Height map visualization

… categorize vertices!

underlay vertex

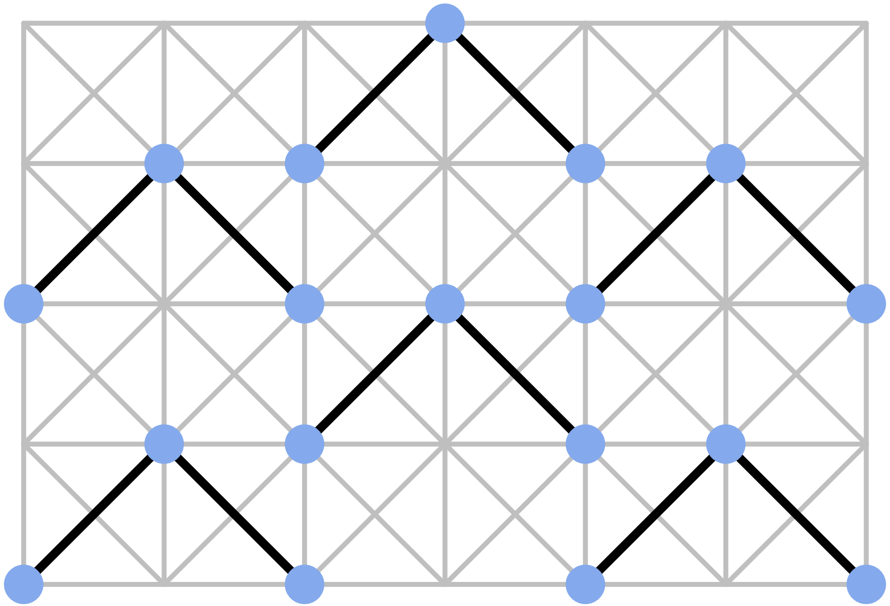


pleat vertex!



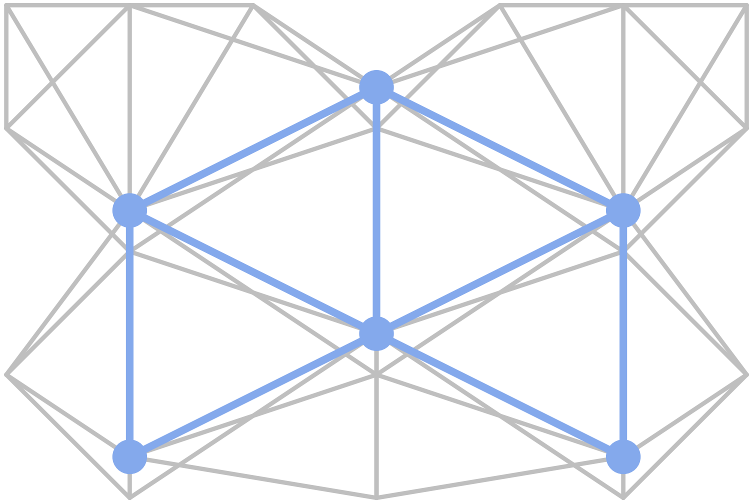
Methodology : underlay graph

smocking pattern



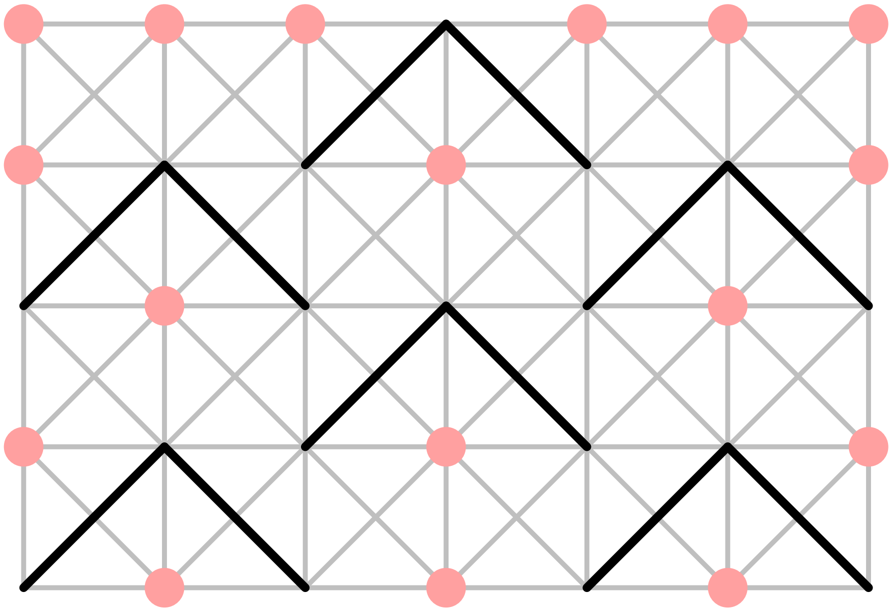
smocked graph

underlay subgraph $(\mathcal{V}_u, \mathcal{E}_u)$



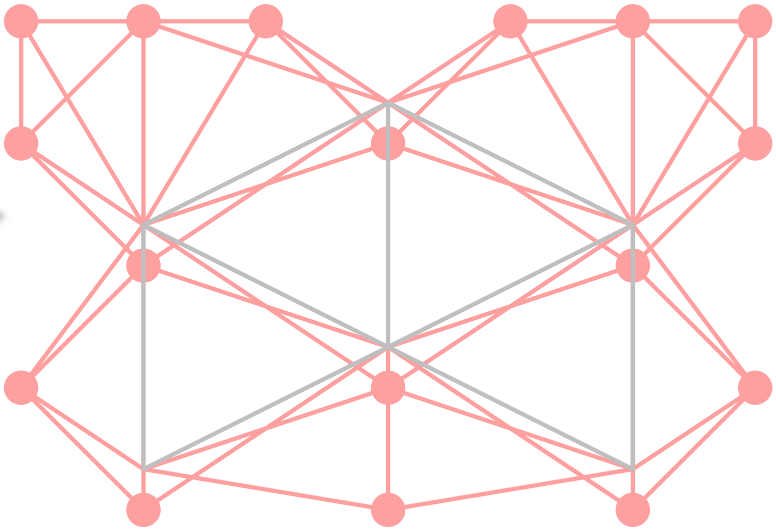
Methodology : pleat graph

smocking pattern



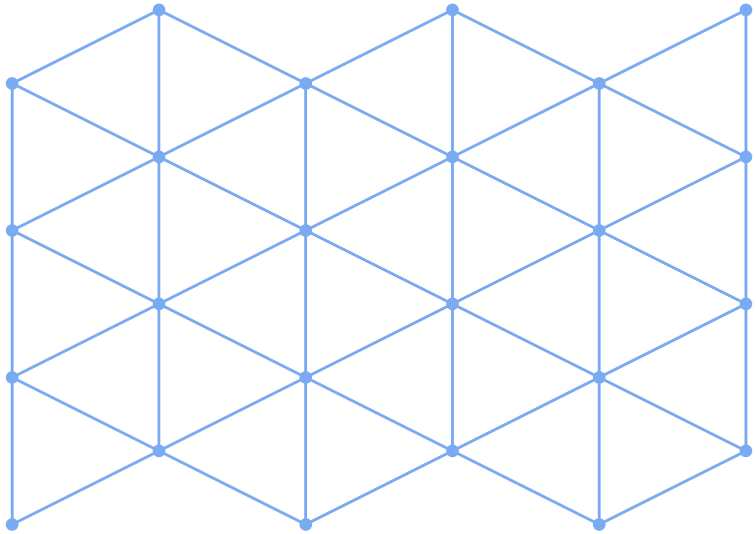
smocked graph

pleat subgraph $(\mathcal{V}_p, \mathcal{E}_p)$



Methodology : two-stage solver

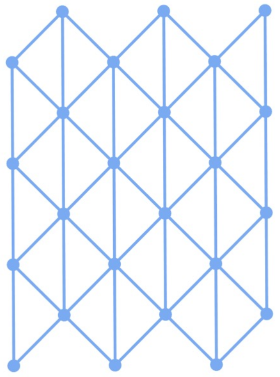
$$\min_{X \in \mathbb{R}^2} \sum_{(i,j) \in \mathcal{E}_u} \left(\|x_i - x_j\| - d_{i,j} \right)^2$$

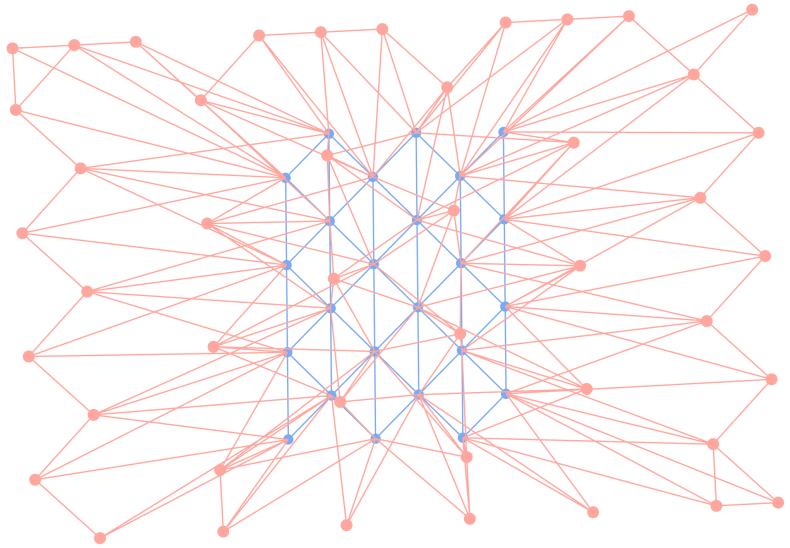


Methodology : two-stage solver

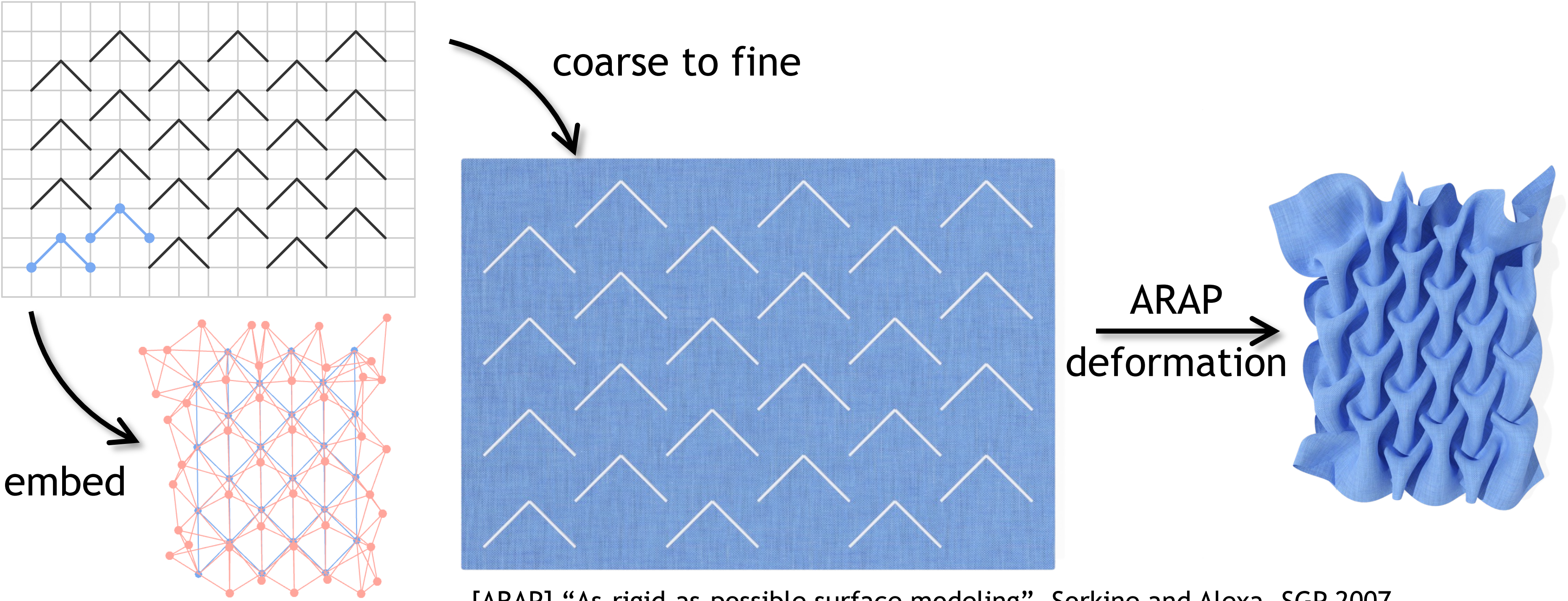
$$\min_{X \in \mathbb{R}^2} \sum_{(i,j) \in \mathcal{E}_u} \left(\|x_i - x_j\| - d_{i,j} \right)^2$$

$$\min_{X \in \mathbb{R}^3} \sum_{(i,j) \in \mathcal{E}_p} \left(\|x_i - x_j\| - d_{i,j} \right)^2$$





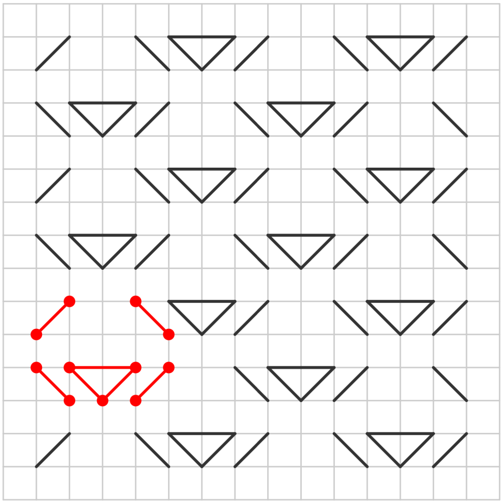
Methodology : ARAP-deformation



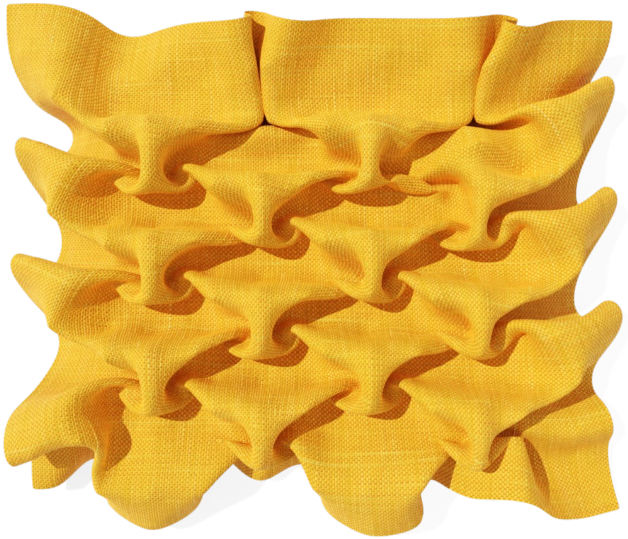
[ARAP] “As-rigid-as-possible surface modeling”, Sorkine and Alexa, SGP 2007

Our results vs. fabrications

smocking pattern



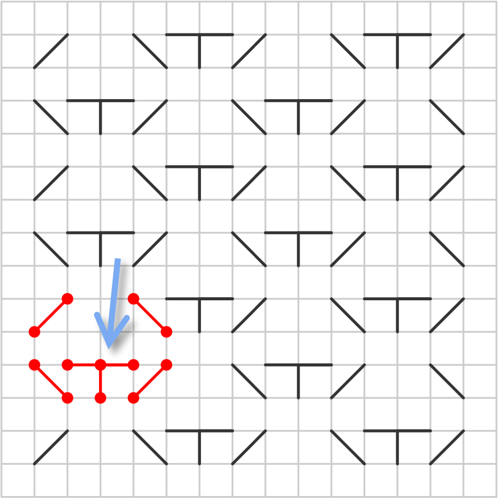
ours



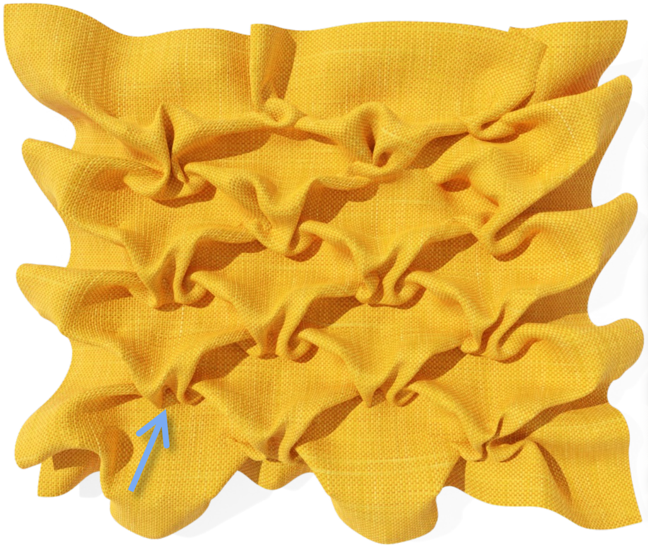
fabrication

Our results vs. fabrications

smocking pattern



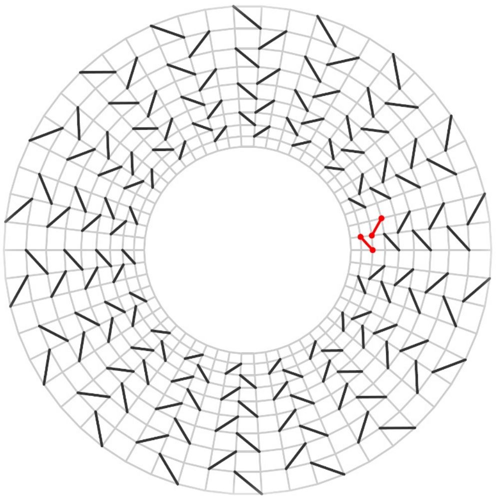
ours



fabrication

Our results : radial grid

smocking pattern

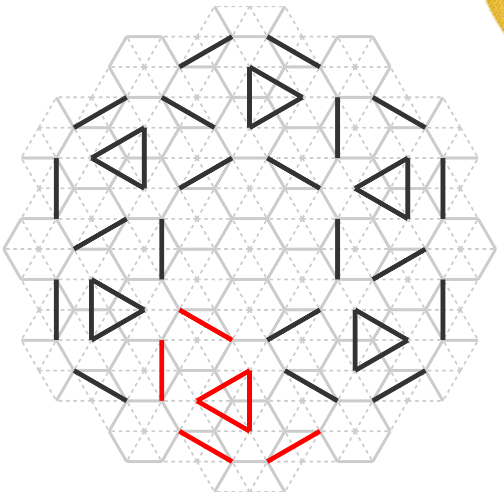


front

back

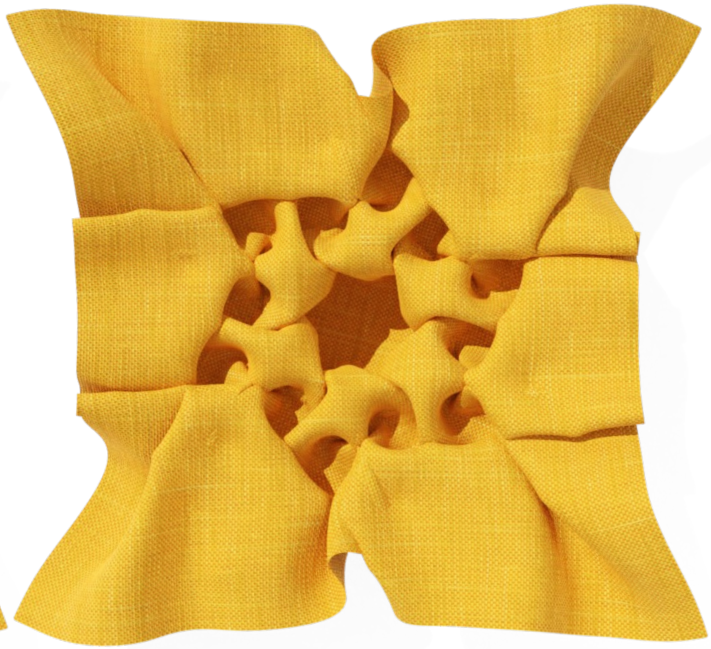
Our results : hexagonal grid

smocking pattern

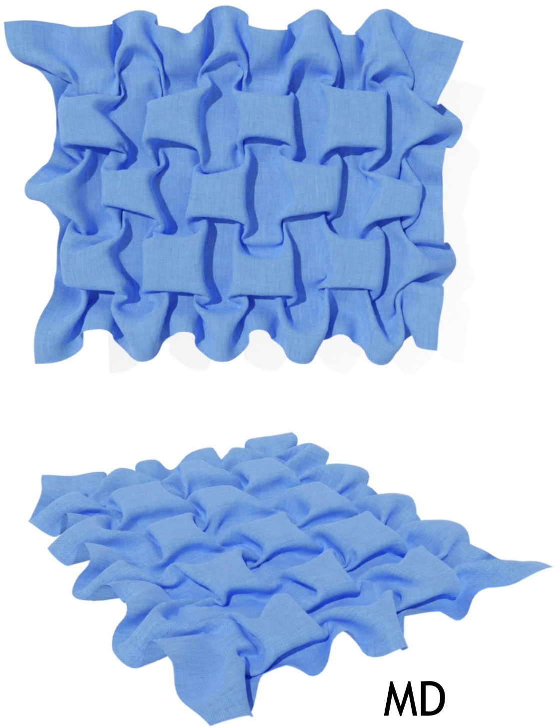


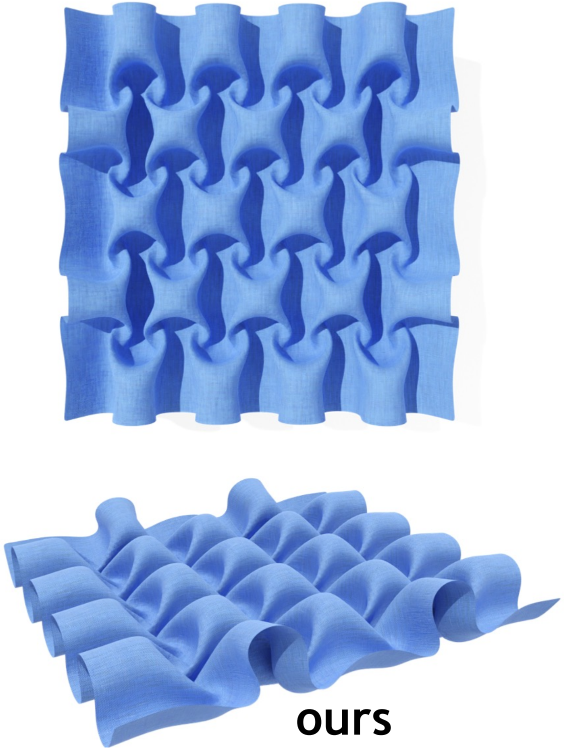
front

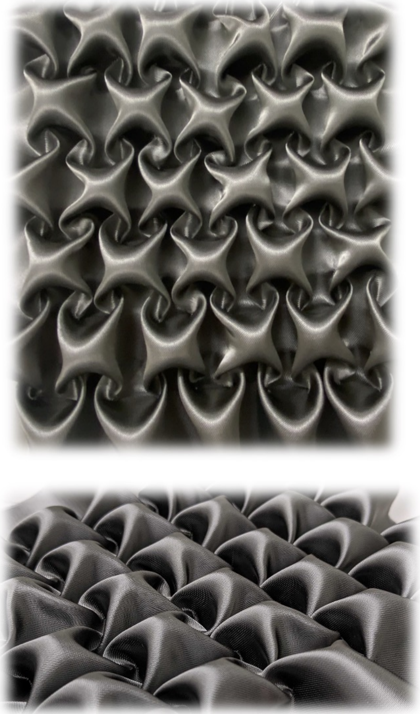
back



Our results vs. Marvelous Designer

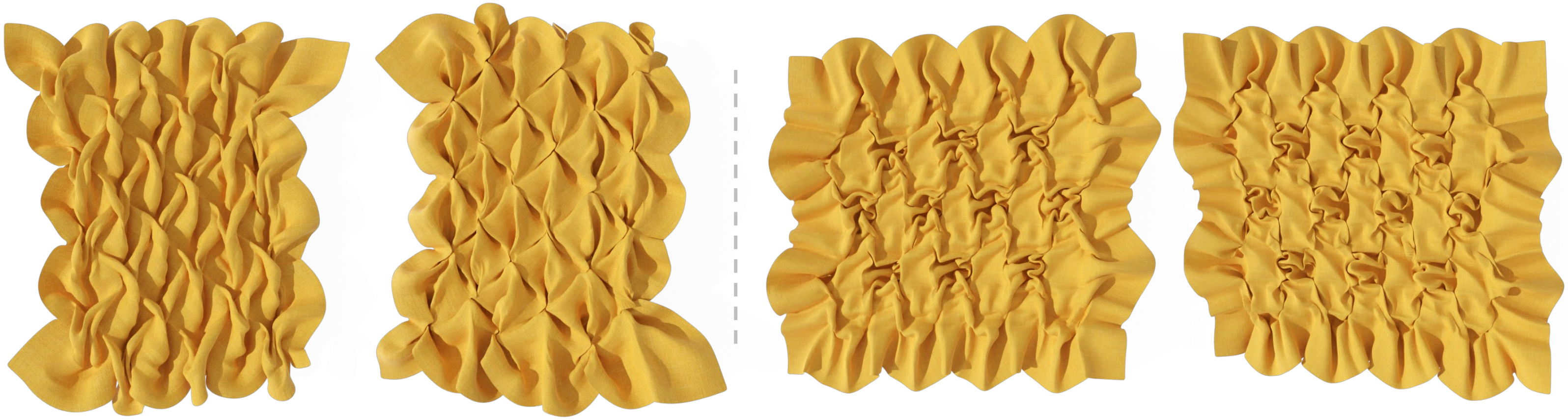




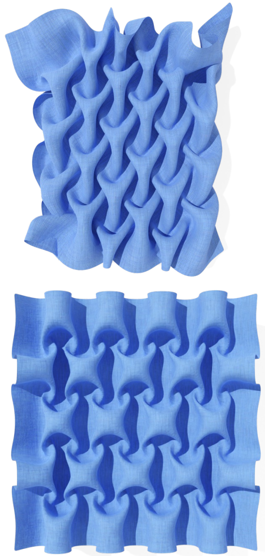


Our results vs. ArcSim

[ArcSim] “Adaptive anisotropic remeshing for cloth simulation”, Narain et al. ACM Transactions on Graphics (TOG), 2012



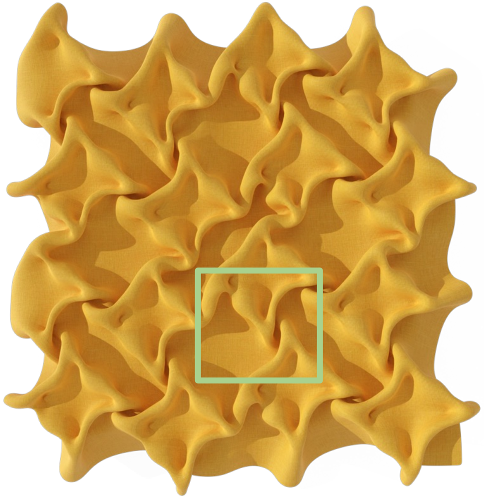
ours



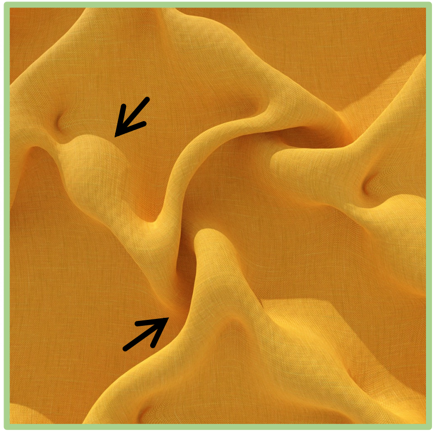
✓ correct aspect ratio after smocking ✗ non-realistic pleats

Our results vs. C-IPC

[C-IPC] “Codimensional Incremental Potential Contact”, Li et al. ACM Transactions on Graphics (TOG), 2021



C-IPC : 6 min



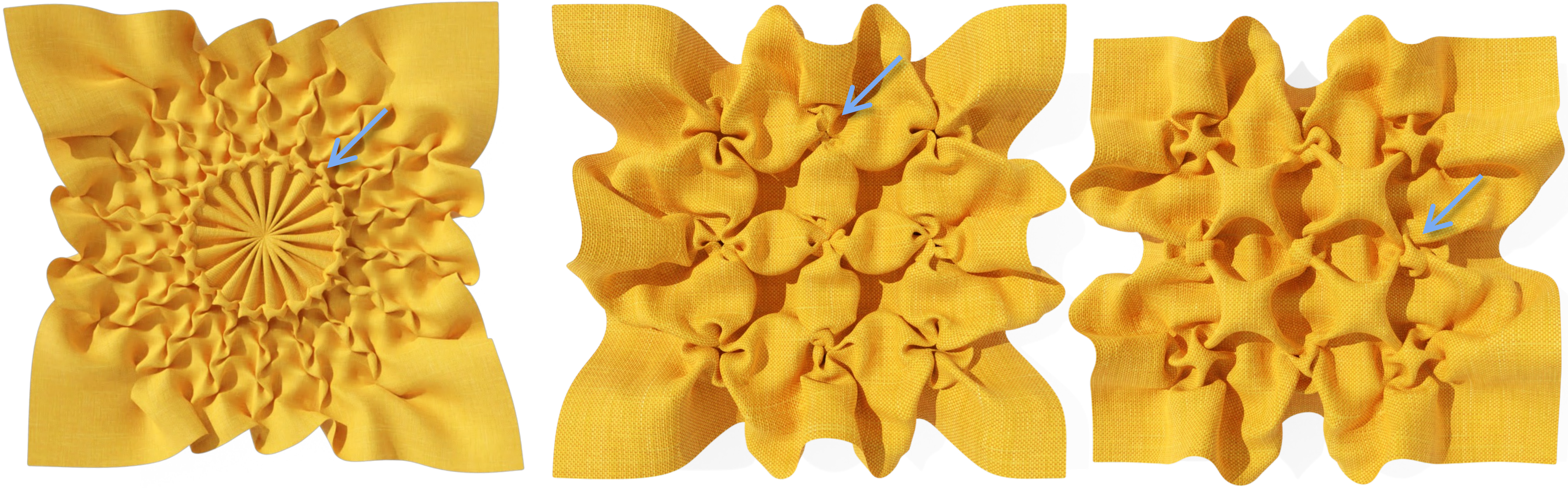
fabrication

ours : 4 sec

- ✓ correct aspect ratio after smocking
- ✓ reasonable but not very accurate pleats
- ✗ computationally expensive
- ✗ non-trivial parameters tunning

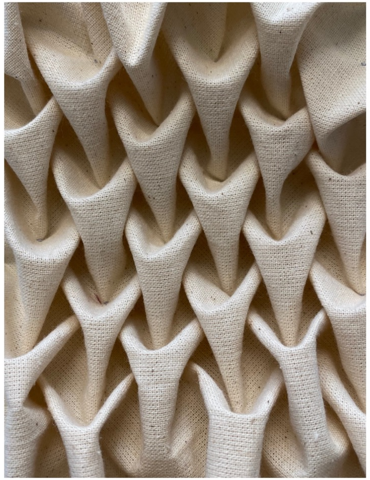
Limitations & future work

No collision handling: self-intersections



Limitations & future work

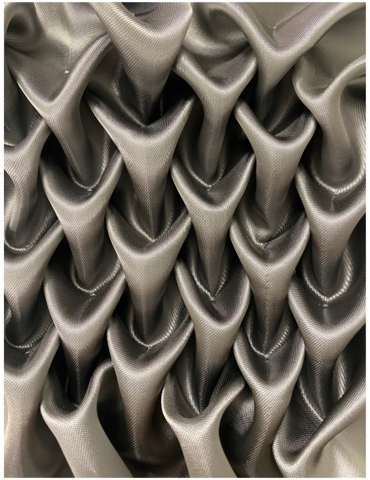
Geometric features vs. material-dependent features



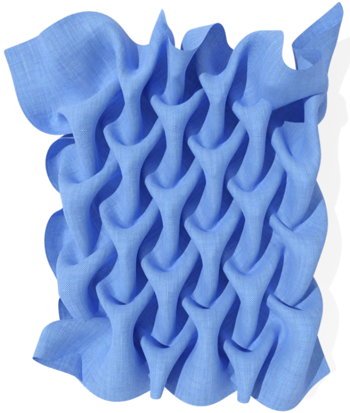
canvas

polyester
(crisp, thin)

polyester
(soft, thick)



satin



ours

Digital 3D Smocking Design

Jing Ren, Aviv Segall, Olga Sorkine-Hornung

erc

SIGGRAPH ASIA
2023 SYDNEY, AUSTRALIA

Thanks for your attention ☺

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Supplementary slides

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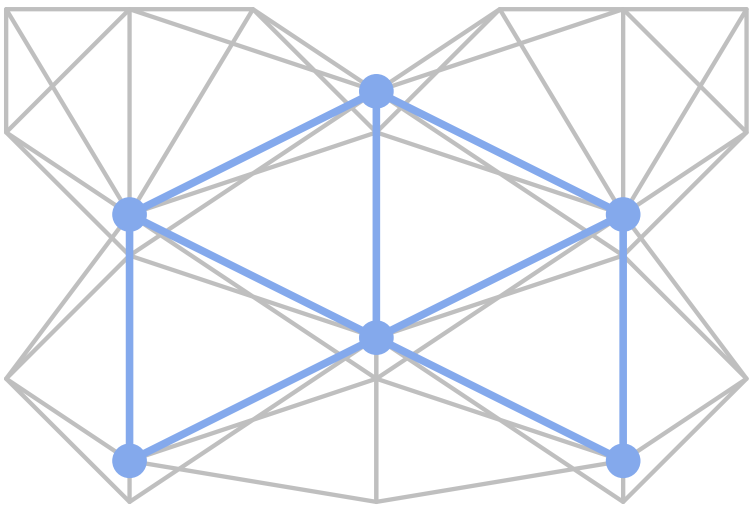
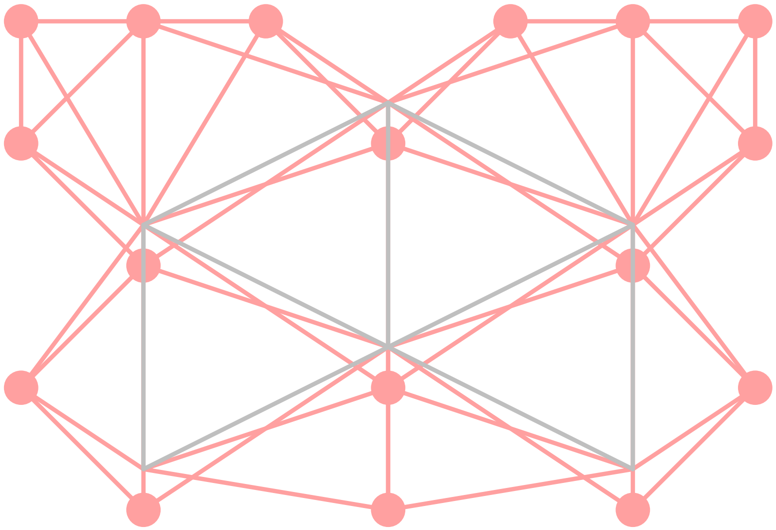
Methodology : two-stage solver

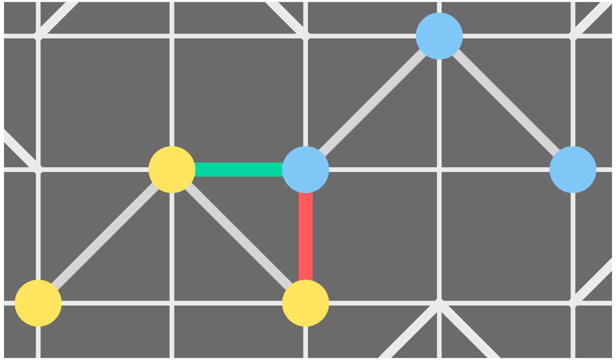
$$\min_{X \in \mathbb{R}^2} \sum_{(i,j)\in\mathcal{E}_u} \left(\|x_i - x_j\| - d_{i,j}\right)^2$$

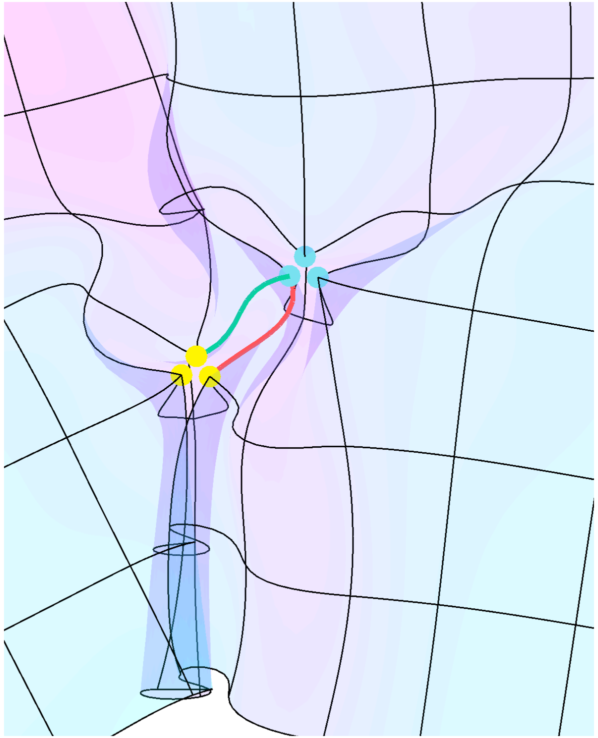


$$\min_{X \in \mathbb{R}^3} \sum_{(i,j)\in\mathcal{E}_p} \left(\|x_i - x_j\| - d_{i,j}\right)^2$$

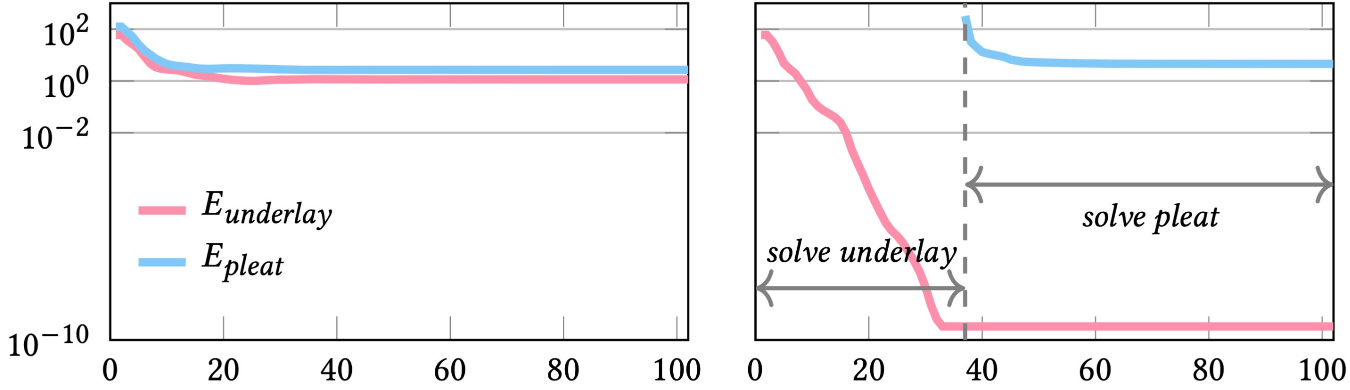


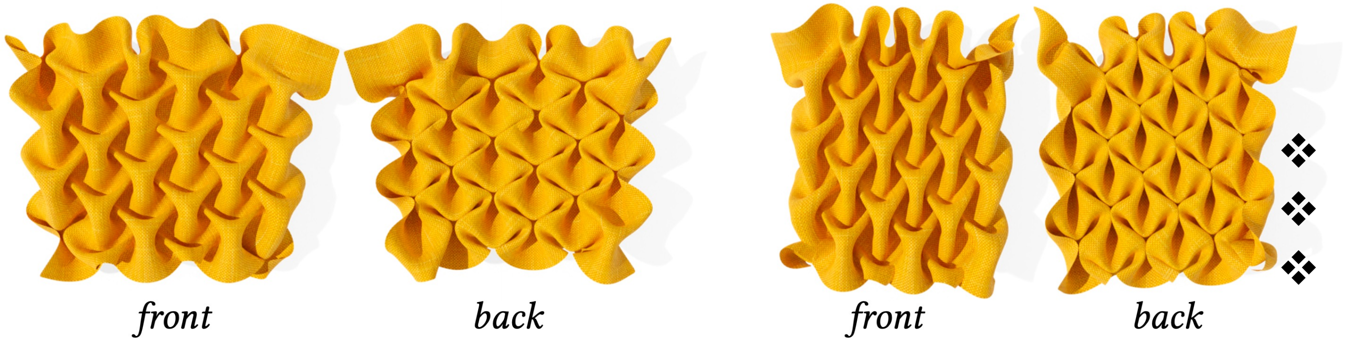
Embedding distance constraint





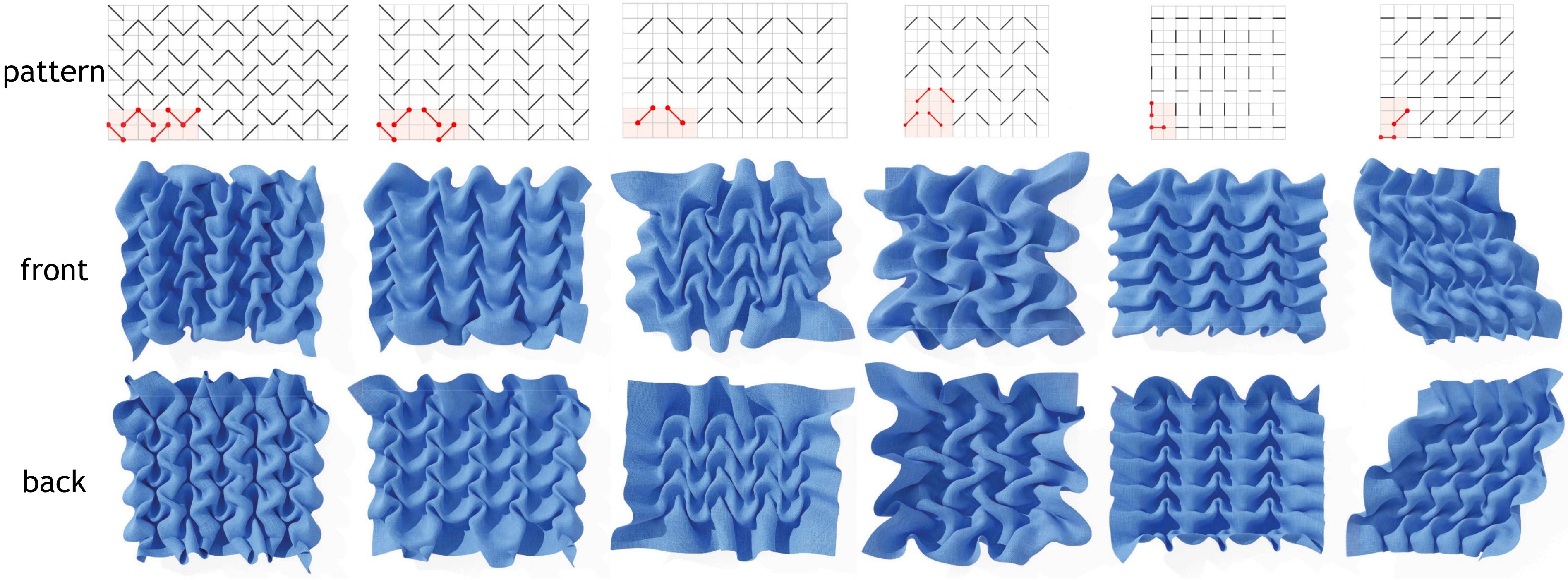
Methodology : two-stage solver



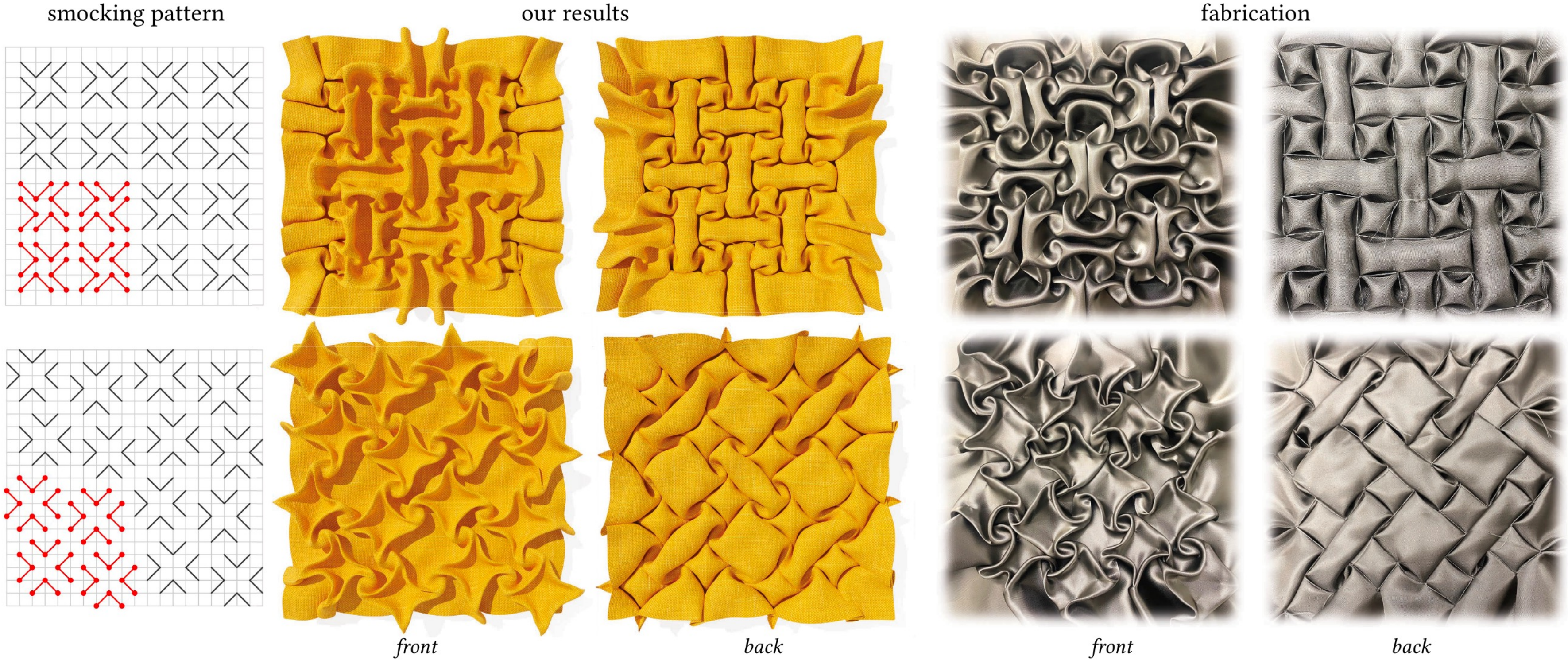


- Faster convergence
- Better local minima
- More realistic results

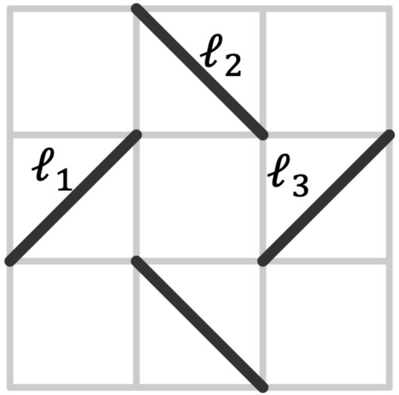
Our results



Our results vs. fabrications



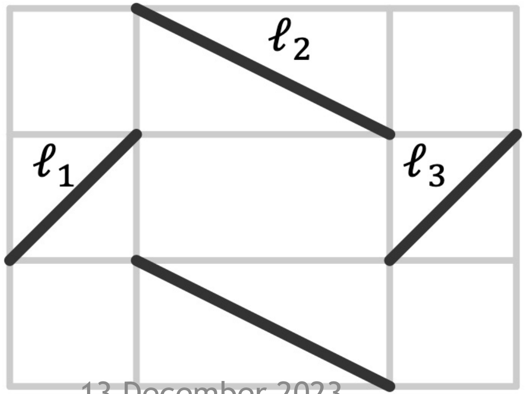
Observations : Underconstrained Pattern



$$d_{1,2} = 1, d_{2,3} = 1, d_{1,3} = \sqrt{2}$$

We can embed ℓ_i at x_i such that:

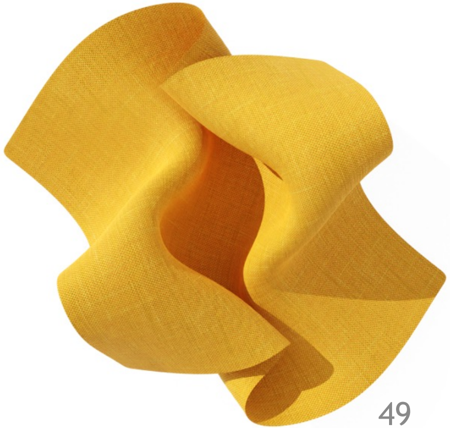
$$\|x_i - x_j\| = d_{i,j}$$



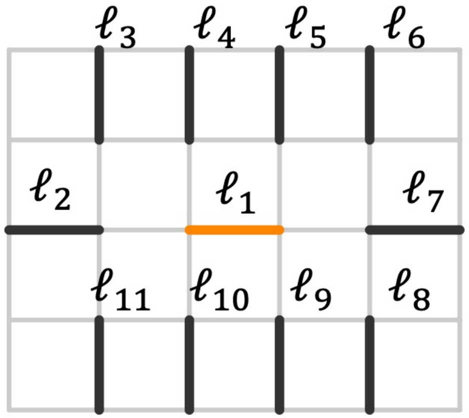
$$d_{1,2} = 1, d_{2,3} = 1, d_{1,3} = \sqrt{5}$$

We have:

$$\|x_1 - x_3\| \leq d_{1,2} + d_{2,3} = 2$$
$$< d_{1,3} = \sqrt{5}$$

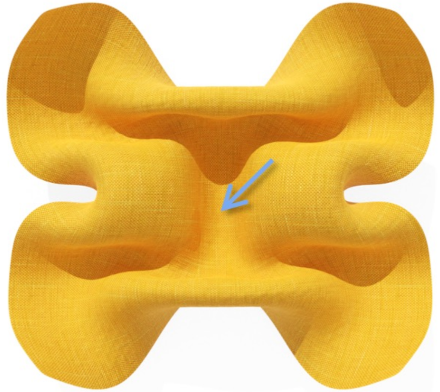


Observations : Overconstrained Pattern

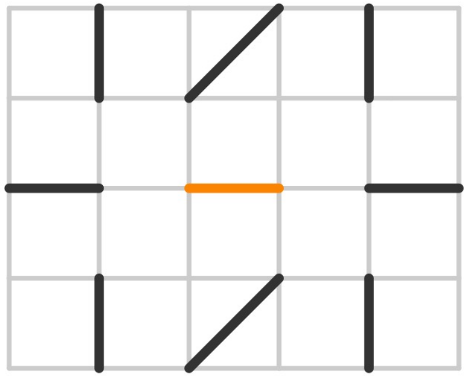


Impossible to embed ℓ_i at $x_i \in \mathbb{R}^2$ such that:

$$\|x_i - x_j\| = d_{i,j}$$



Well-constrained example



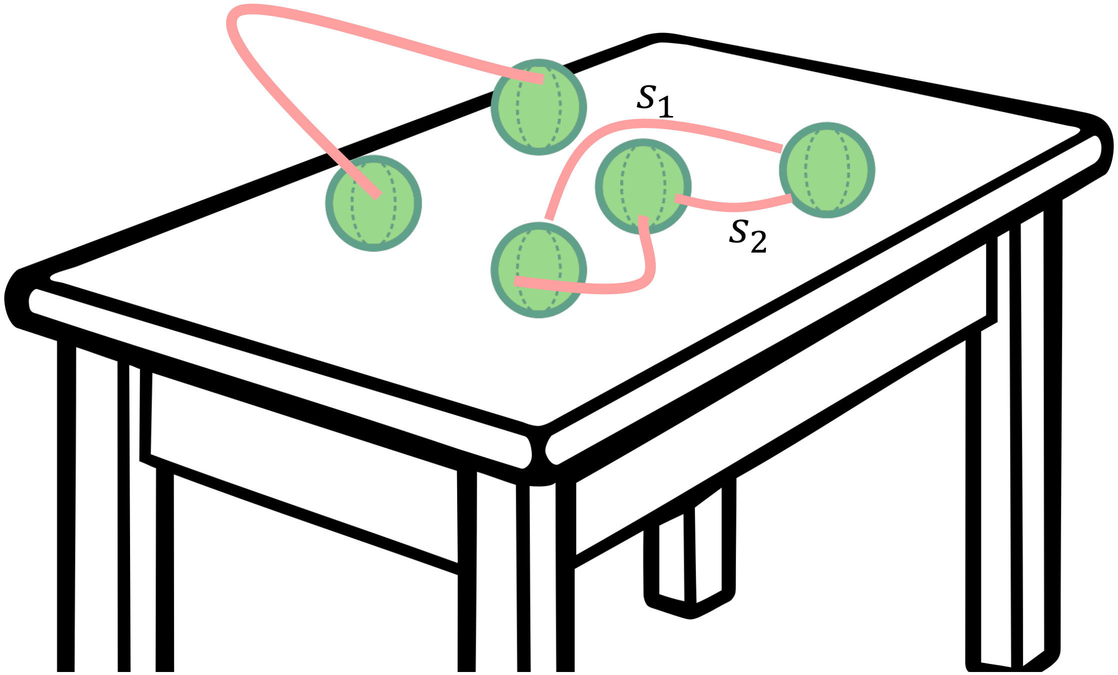
… are all constraints necessary?

$$\max_{X \in \mathbb{R}^3} \sum_{i \neq j} \|x_i - x_j\|$$

$$\text{s.t. } \|x_i - x_j\| \leq d_{i,j} \ \forall i \neq j$$

equivalent setting

- a set of balls can move around
- fragile string connecting balls with length $d_{i,j}$



s_2 will break before s_1 is pulled taut

Methodology : two-stage solver

$$\min_{X \in \mathbb{R}^2} \sum_{(i,j) \in \mathcal{E}_u} \left(\|x_i - x_j\| - d_{i,j} \right)^2$$

$$\min_{X \in \mathbb{R}^3} \sum_{(i,j) \in \mathcal{E}_p} \left(\|x_i - x_j\| - d_{i,j} \right)^2$$