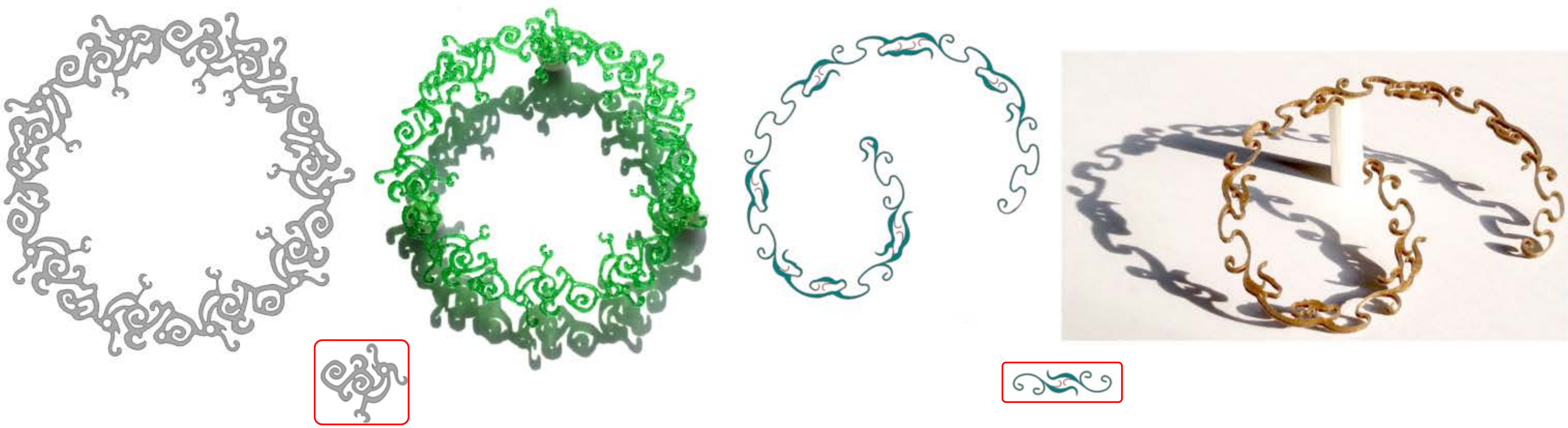
Topology-constrained synthesis of vector patterns



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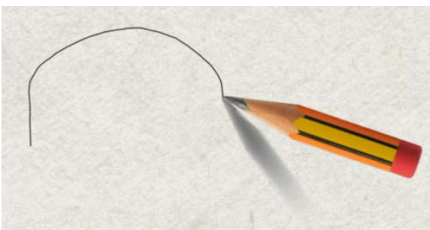
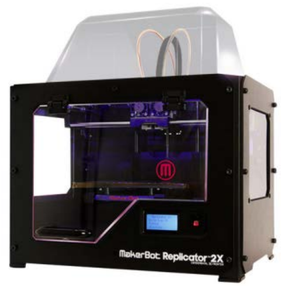
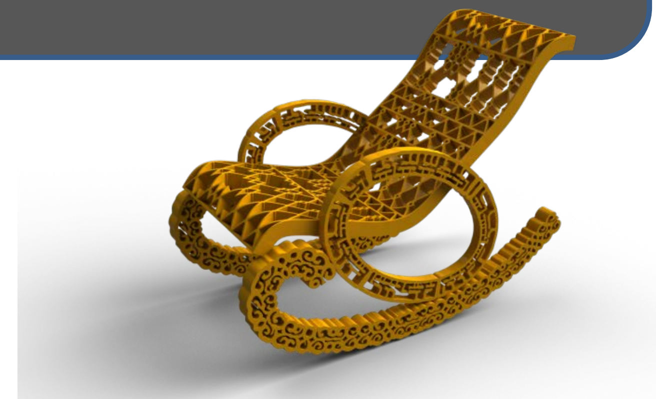
Motivation:

sketches→decorative patterns→physical objects



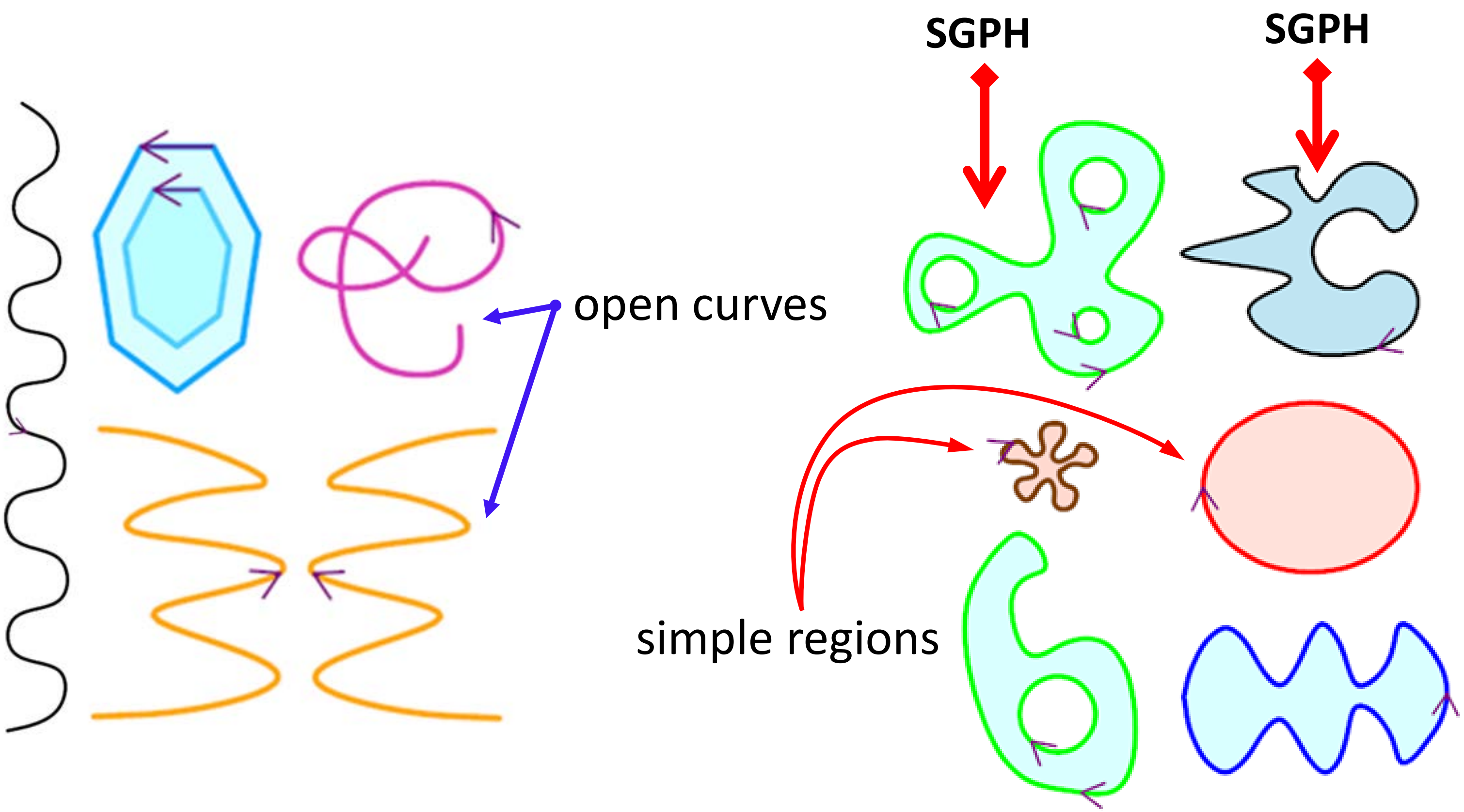




- Structured continuous vector pattern on curves.
- By-example: resembling and variations
- Physical objects that can be fabricated correctly on 3d printers(chairs, wristband, etc.)

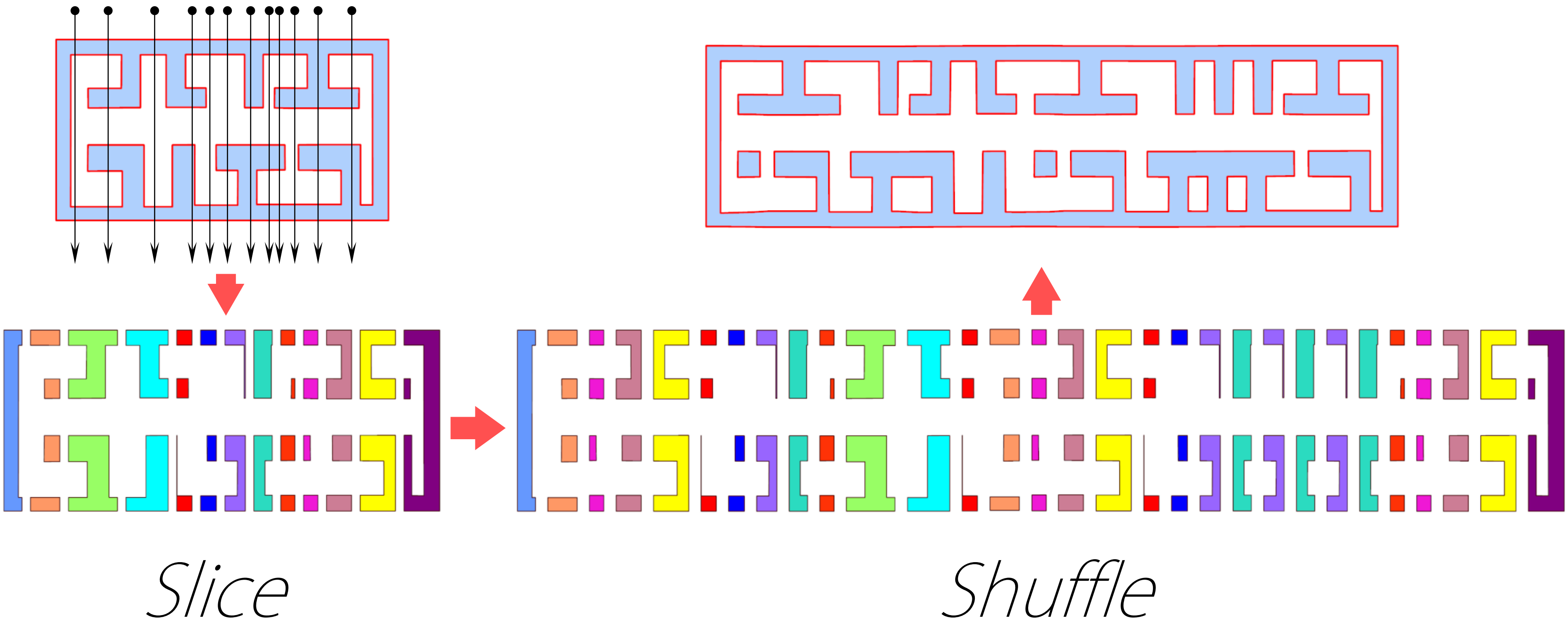
demo

Vector shapes

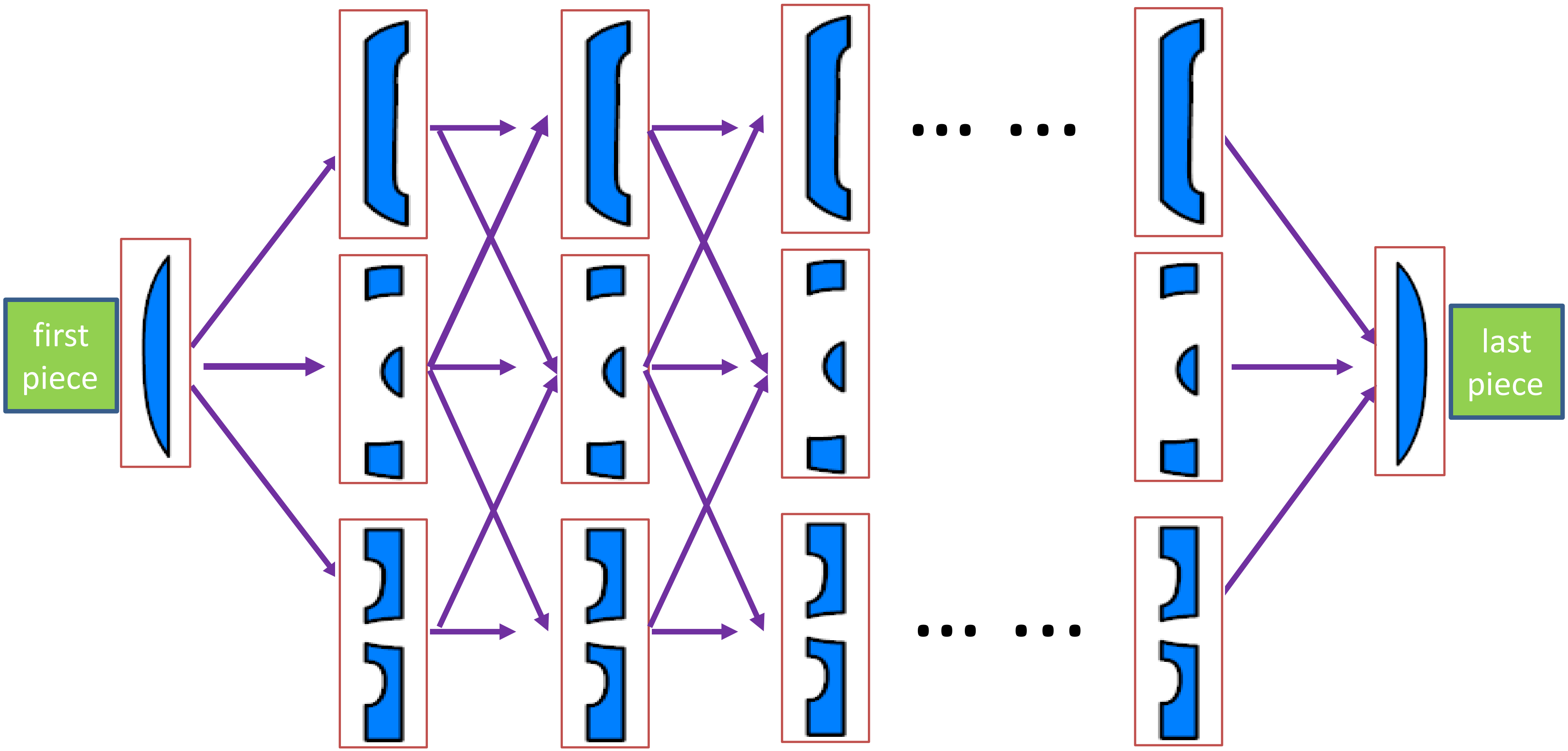


Input : SGPH (Simple General Polygon with Holes)

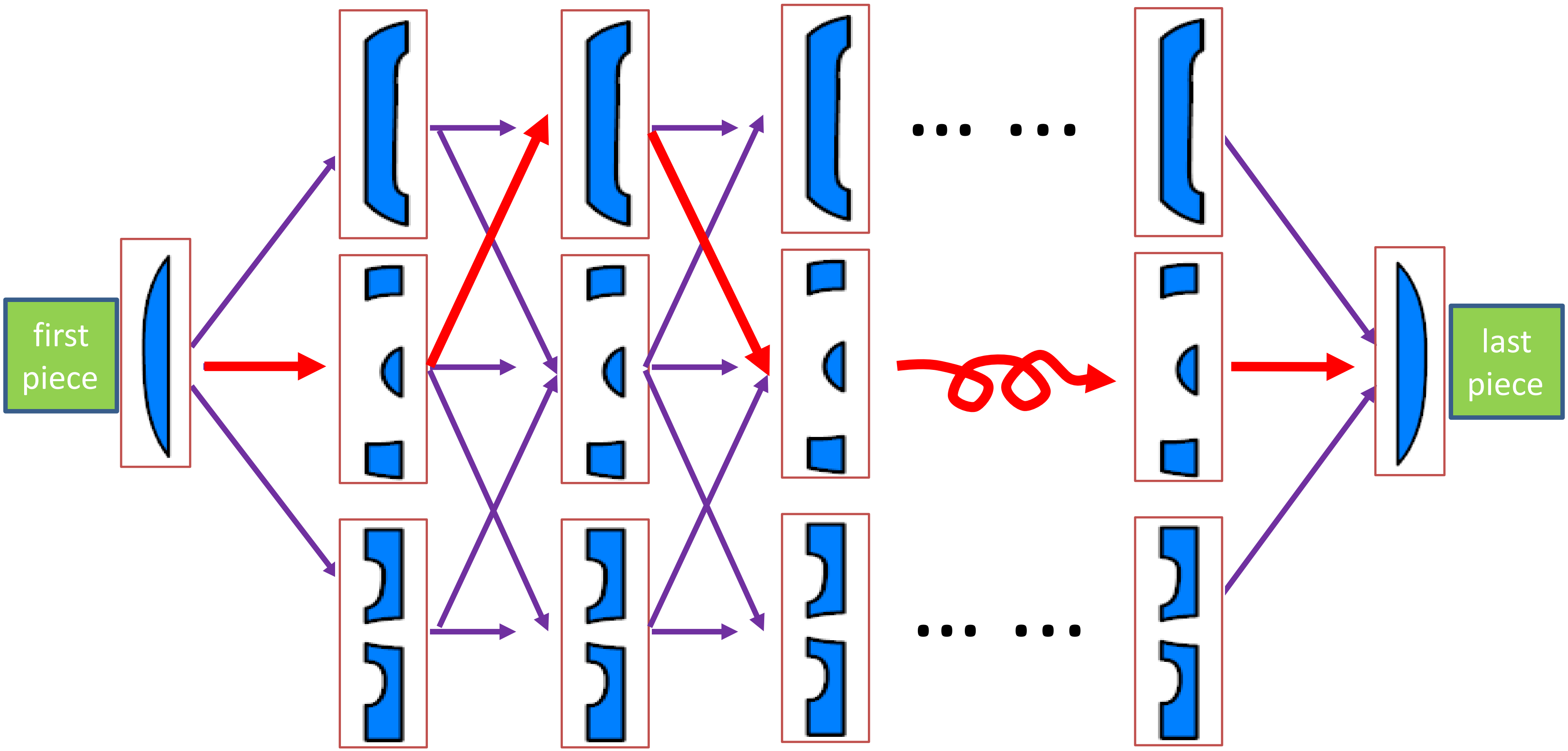
Synthesis Mechanism: Slice and Shuffle



Dynamic Programming

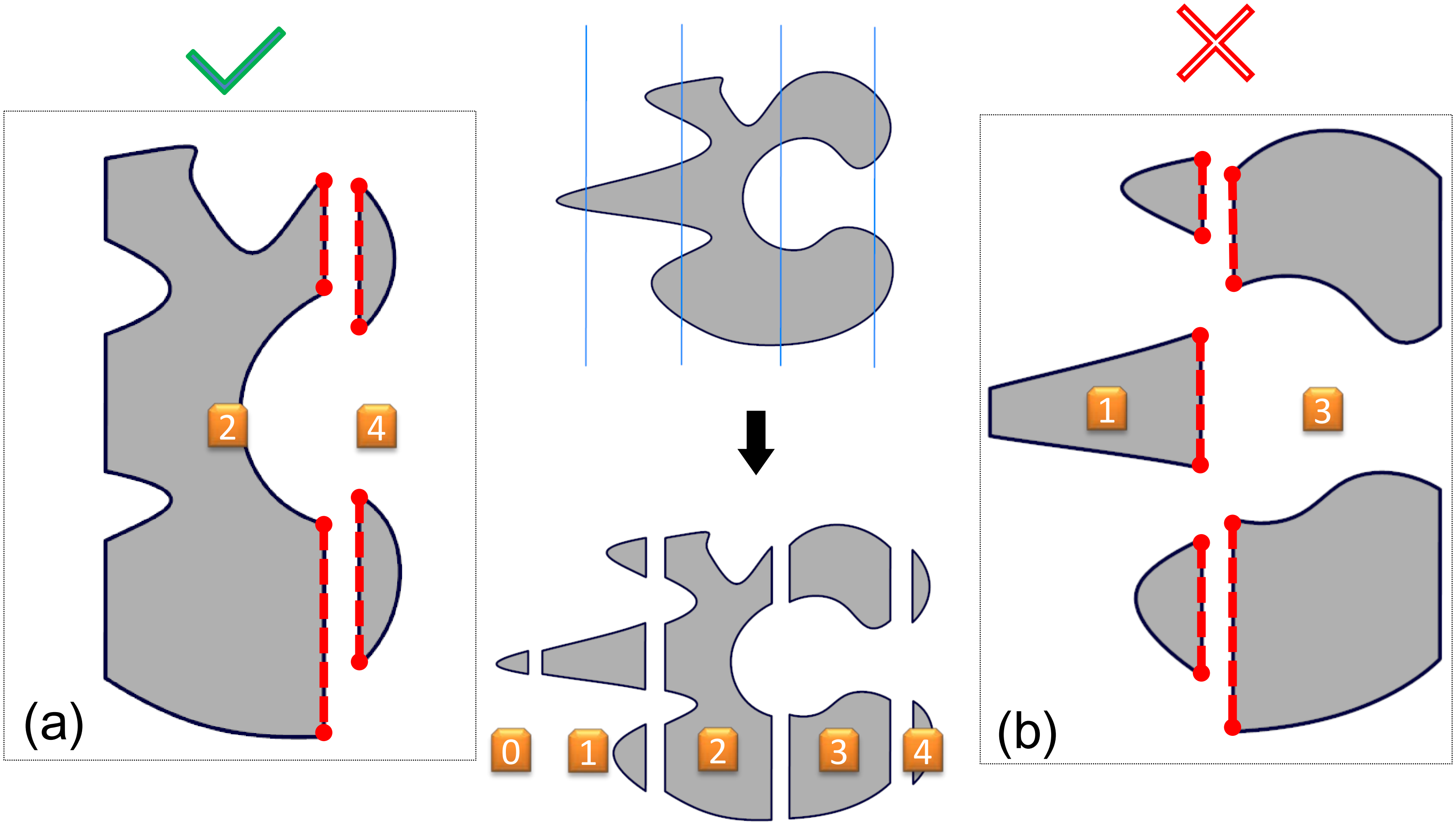


Dynamic Programming



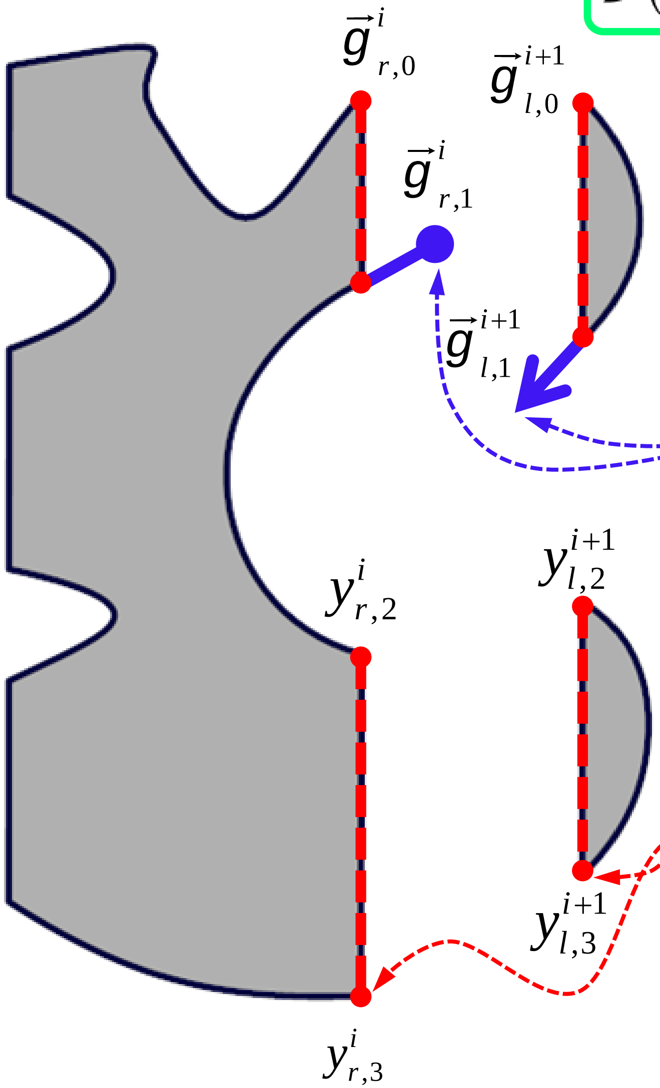
A Path from the first piece to
the last piece gives a new vector pattern.

Merging cost



Merging cost

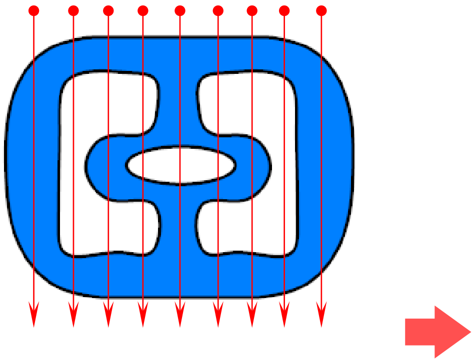
$$\mathcal{D}(i,j) = d_{match}(i,j)\cdot\alpha + (1-\alpha)\cdot d_{tangent}(i,j)$$



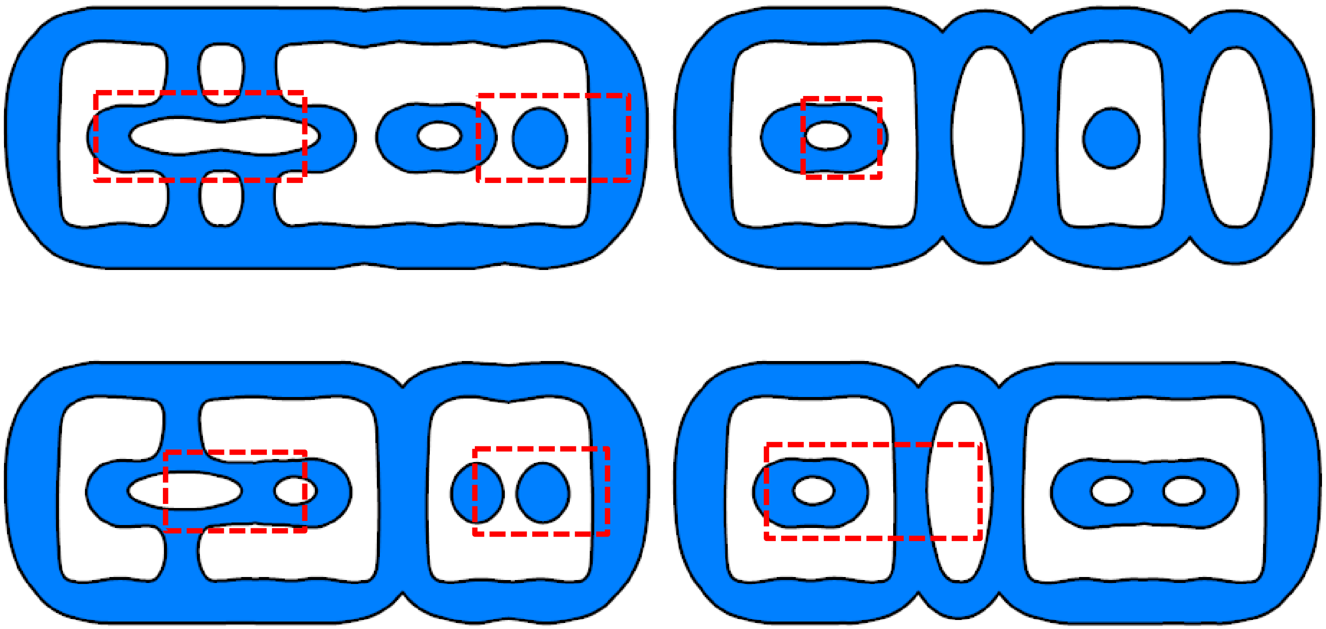
$$d_{tangent}(i,j) = \sum_{k=0}^{M-1} \|1 - \vec{g}^{\,k}_{r,i}\cdot\vec{g}^{\,k}_{l,j}\|$$

$$d_{match}(i,j) = \min_{\tau}\left(\frac{1}{M}\sum_{k=0}^{M-1} ||y^{k}_{l,j} - y^{k}_{r,i} + \tau||^{2}\right)$$

A Simple Example

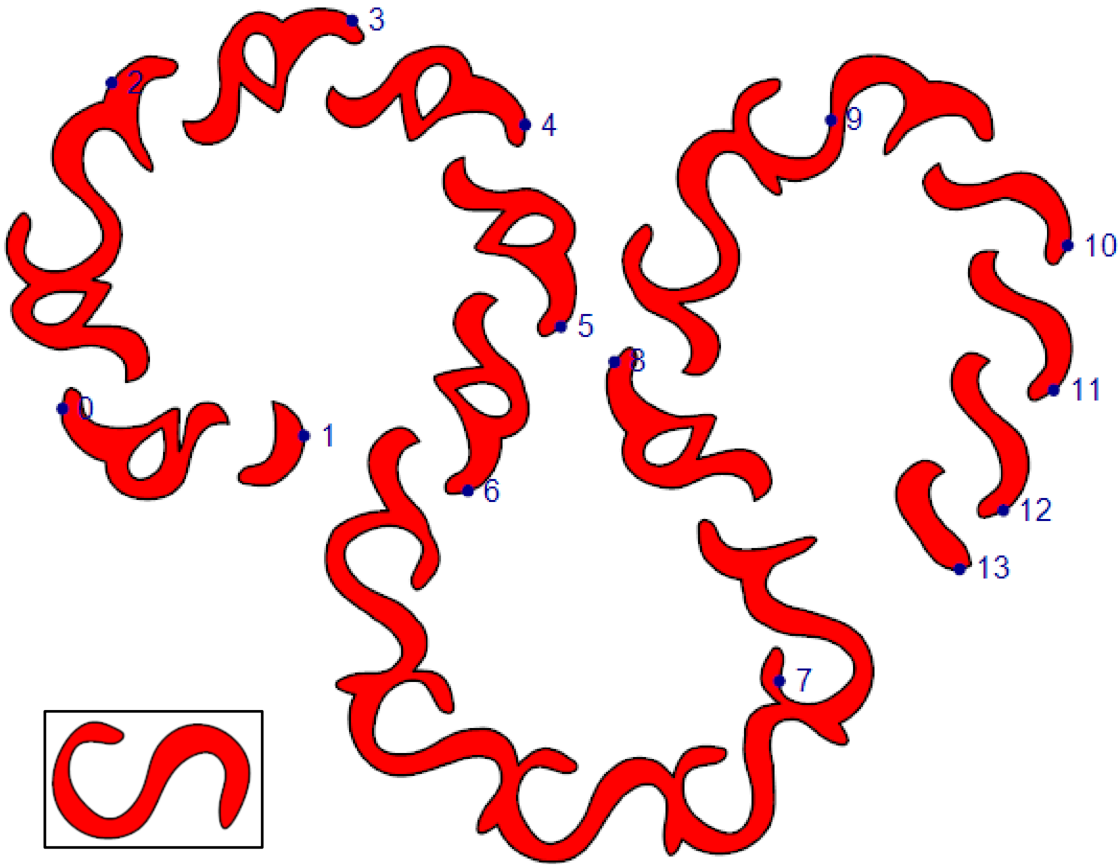


Wait! There are "Islands" in the water..

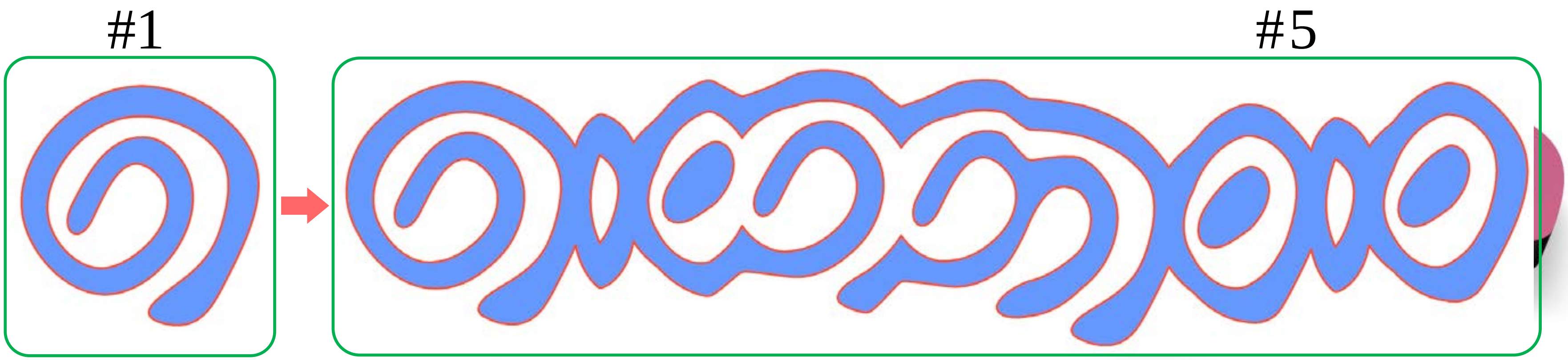


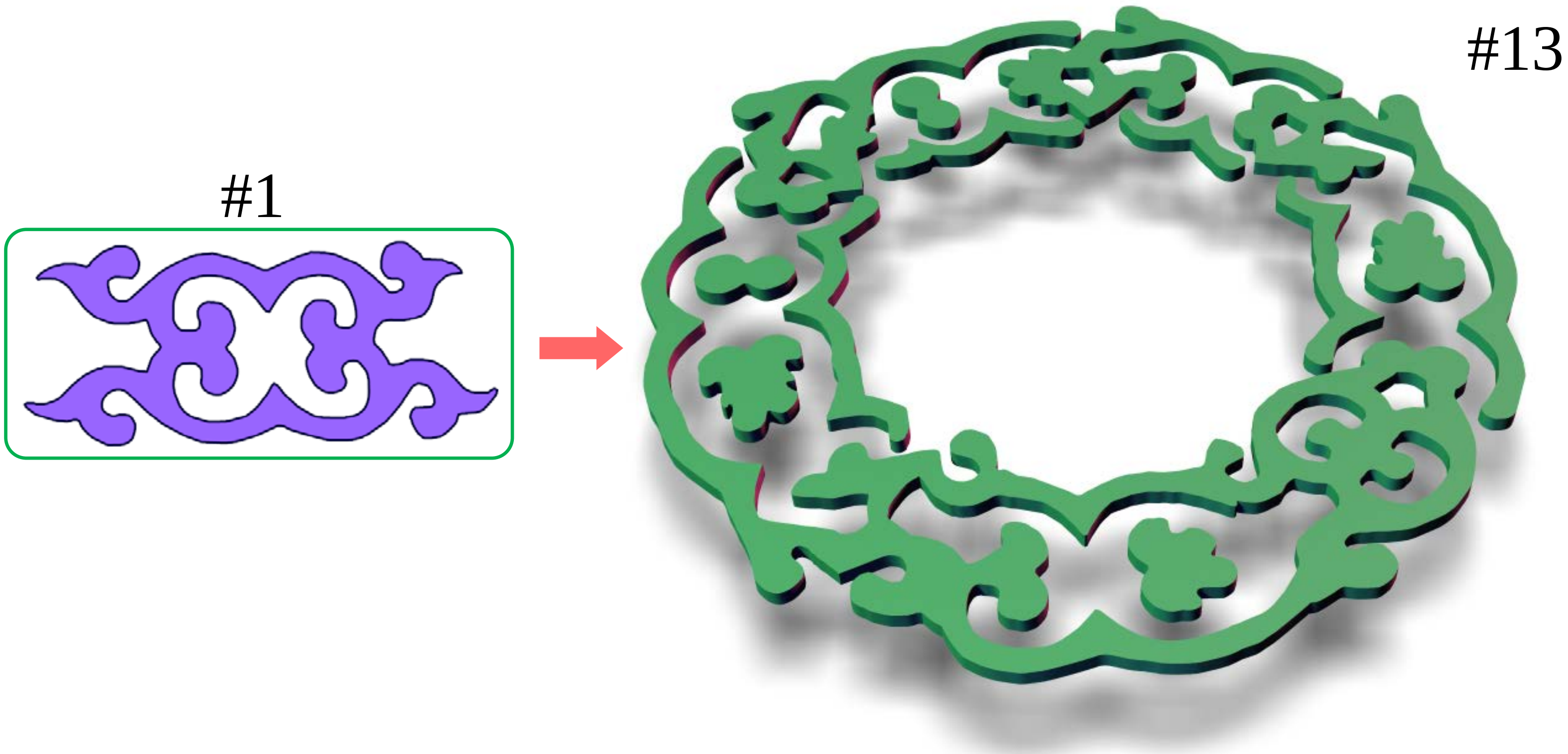
"island": regions enclosed in but disconnected from the outer border

and.. Separate parts☹



Ignore topology → *broken* results





Challenges

- Previous synthesis problem.
  - variety, resemblance
  - interactive feedback, efficient displaying, zoom in/out

1932 MG Six Saloon

A Heritage Motor Centre, Gaydon image for editorial purposes only

- New Challenge!
  - avoiding broken results
  - output data format : domain representation

Surprises

- Topology improves aesthetics.

  “Topology is part of the Structural quality”

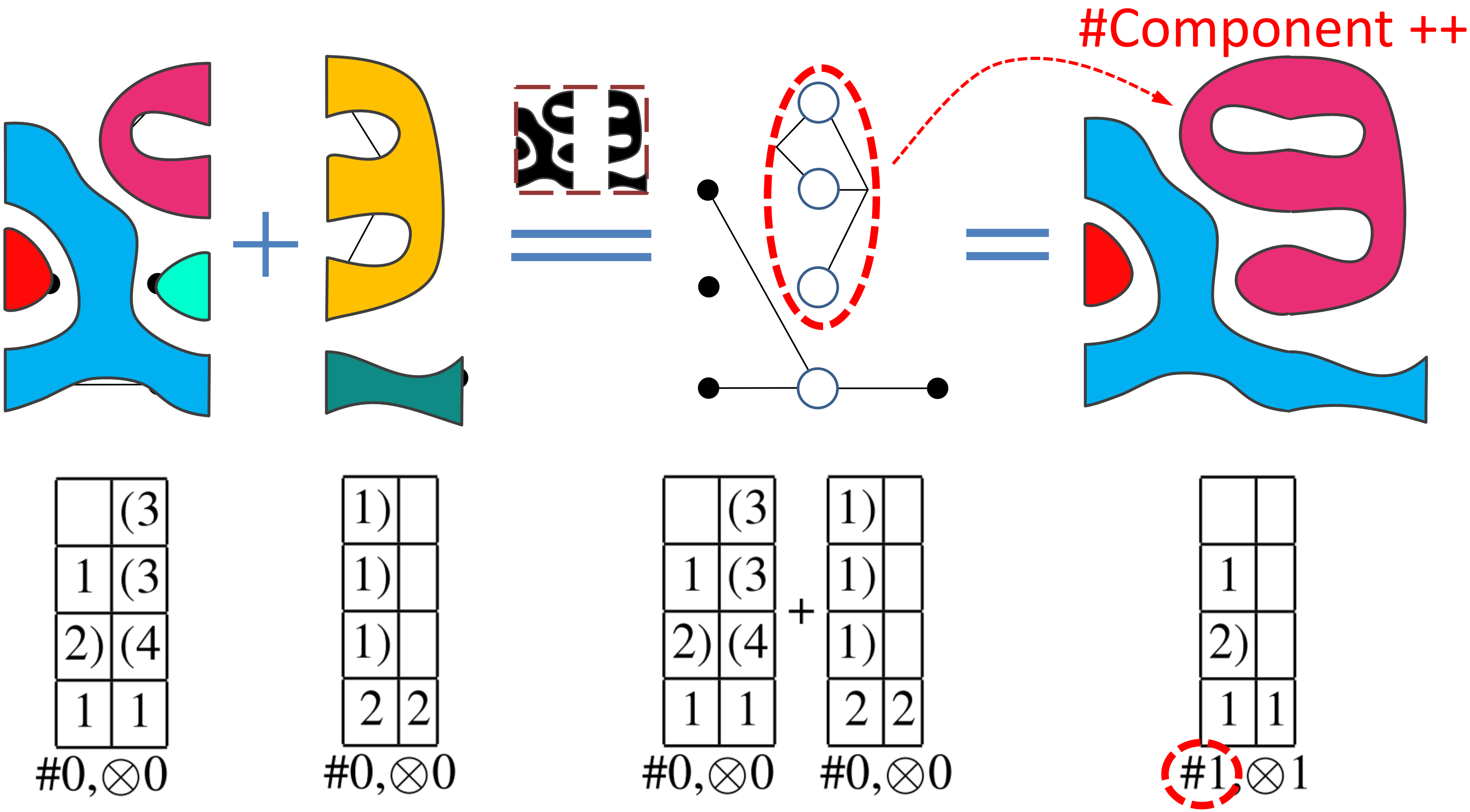
- Users fully control topology by parameters:
  - given #connected-components and #holes

Our solution:
Topology-constrained Synthesis

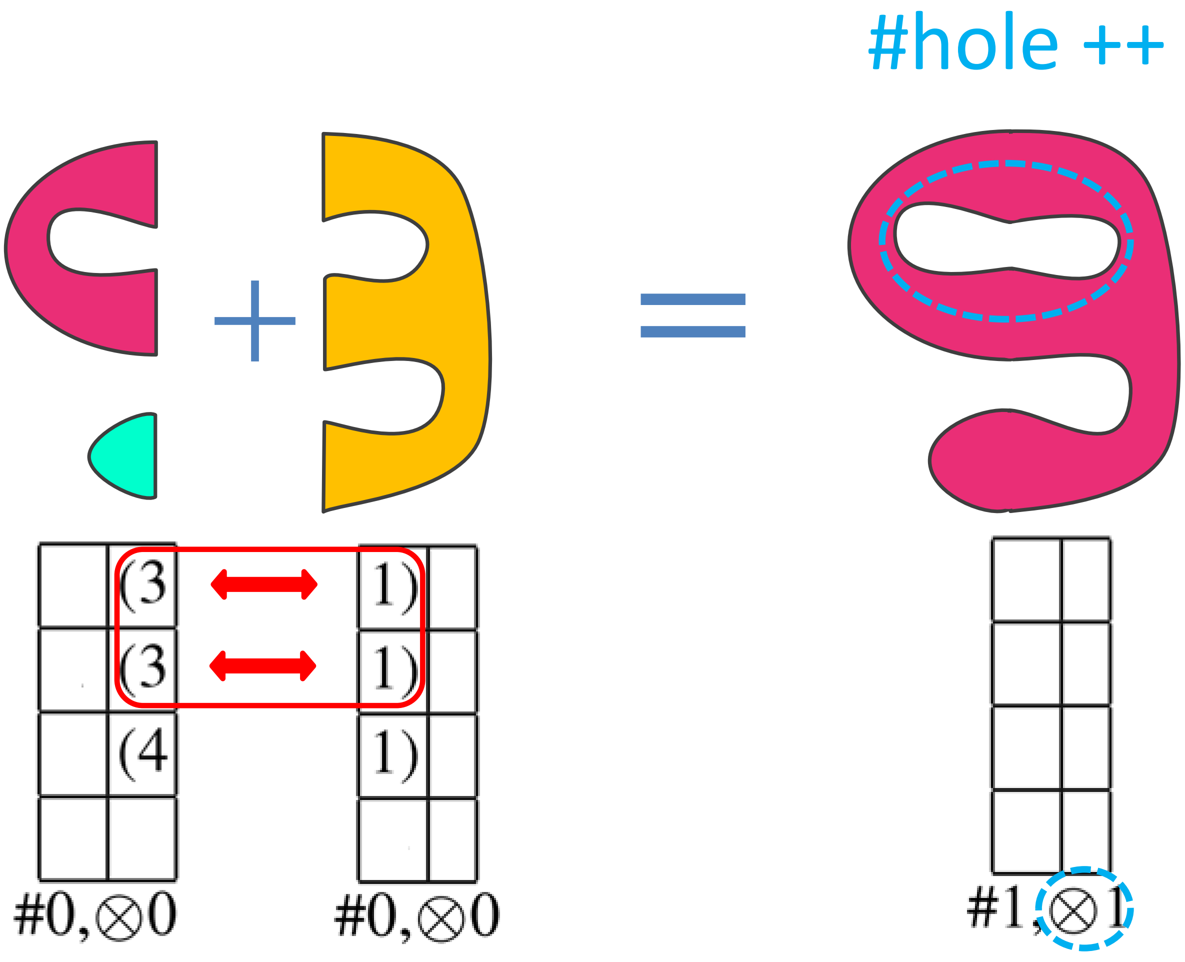
- Analysis from topology
  - Shape analysis for optimal piece-sampling

- Synthesis in two stages
  - Topology solver
  - Geometry solver

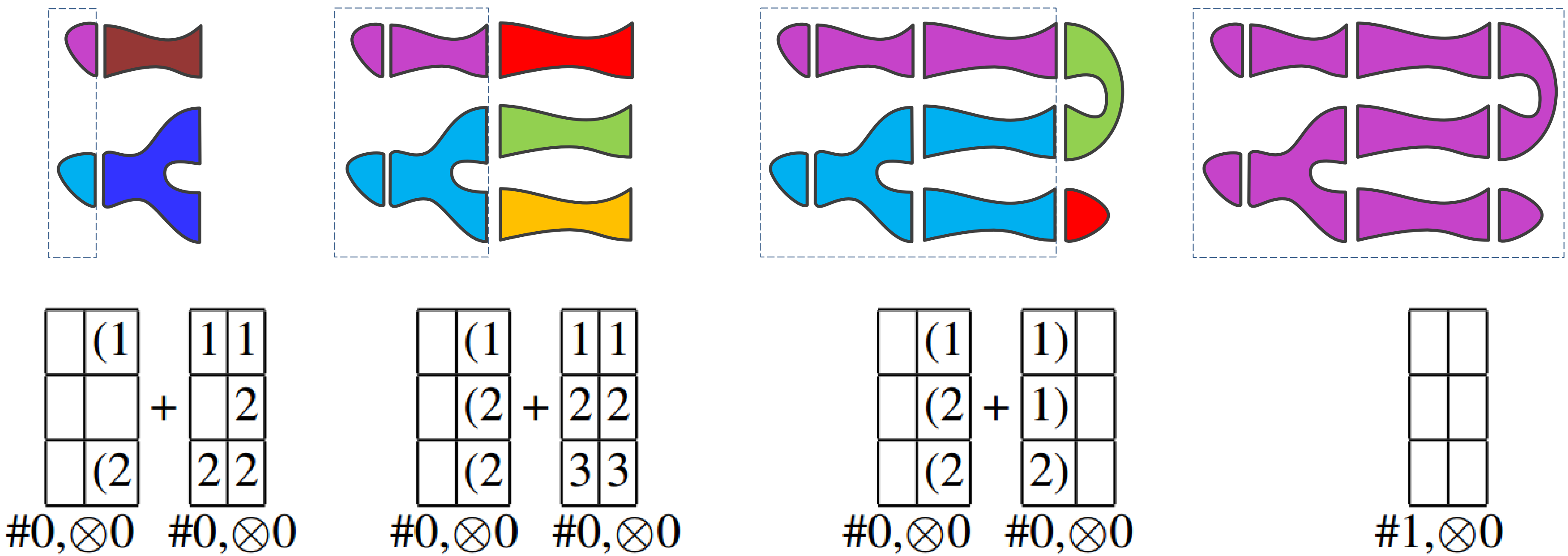
Topology descriptor: Capturing topology changes



Counting the inner holes

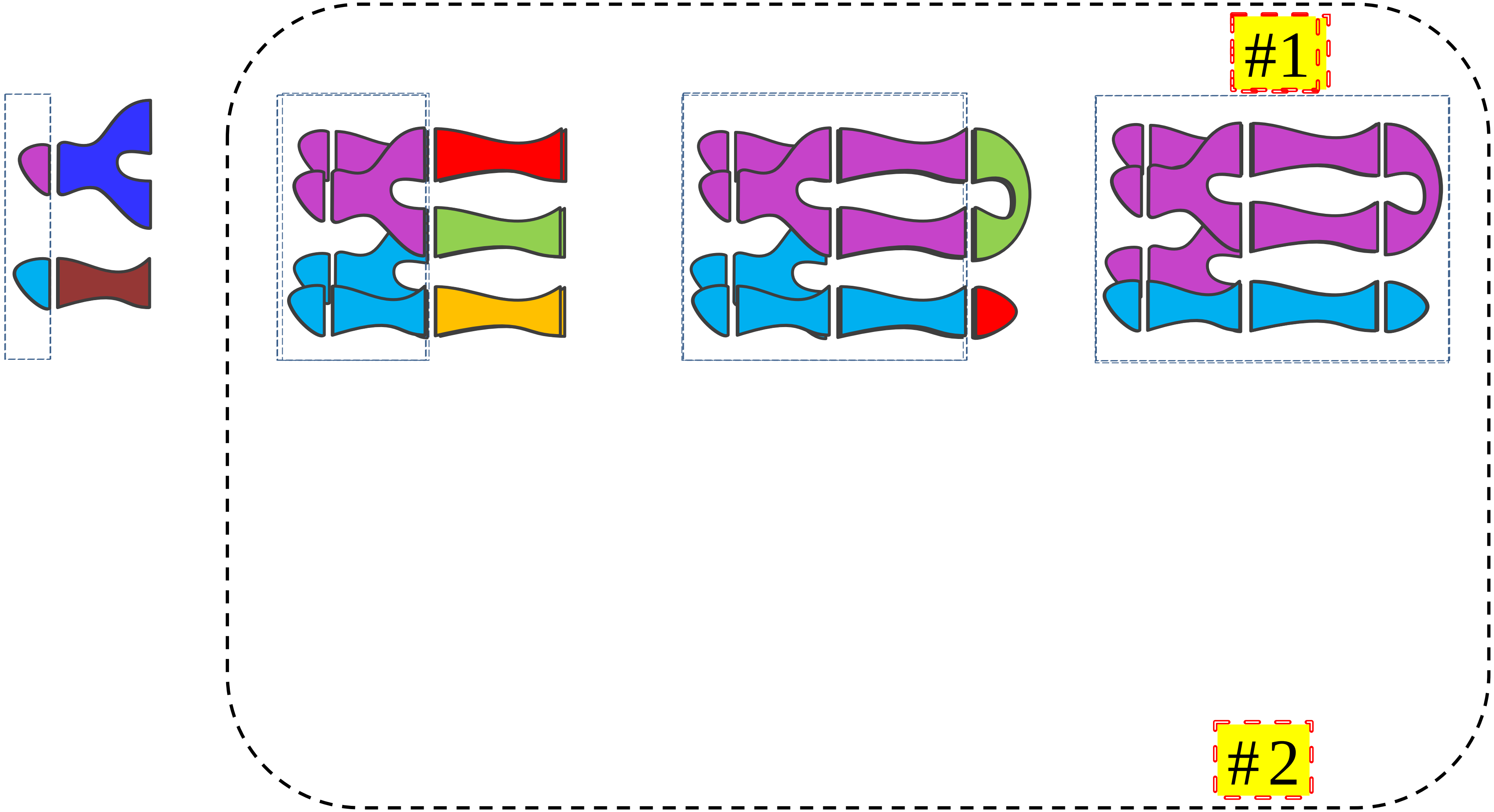


Tracking Topology



On-the-fly topology tracking

- Topology descriptor can not be pre-computed..



Topology equivalent: ≡

Given two DP items **a** **b**.

if(**a** and **b** have

the same #Componets,

the same #inner holes,

the same portal-component correspondences)

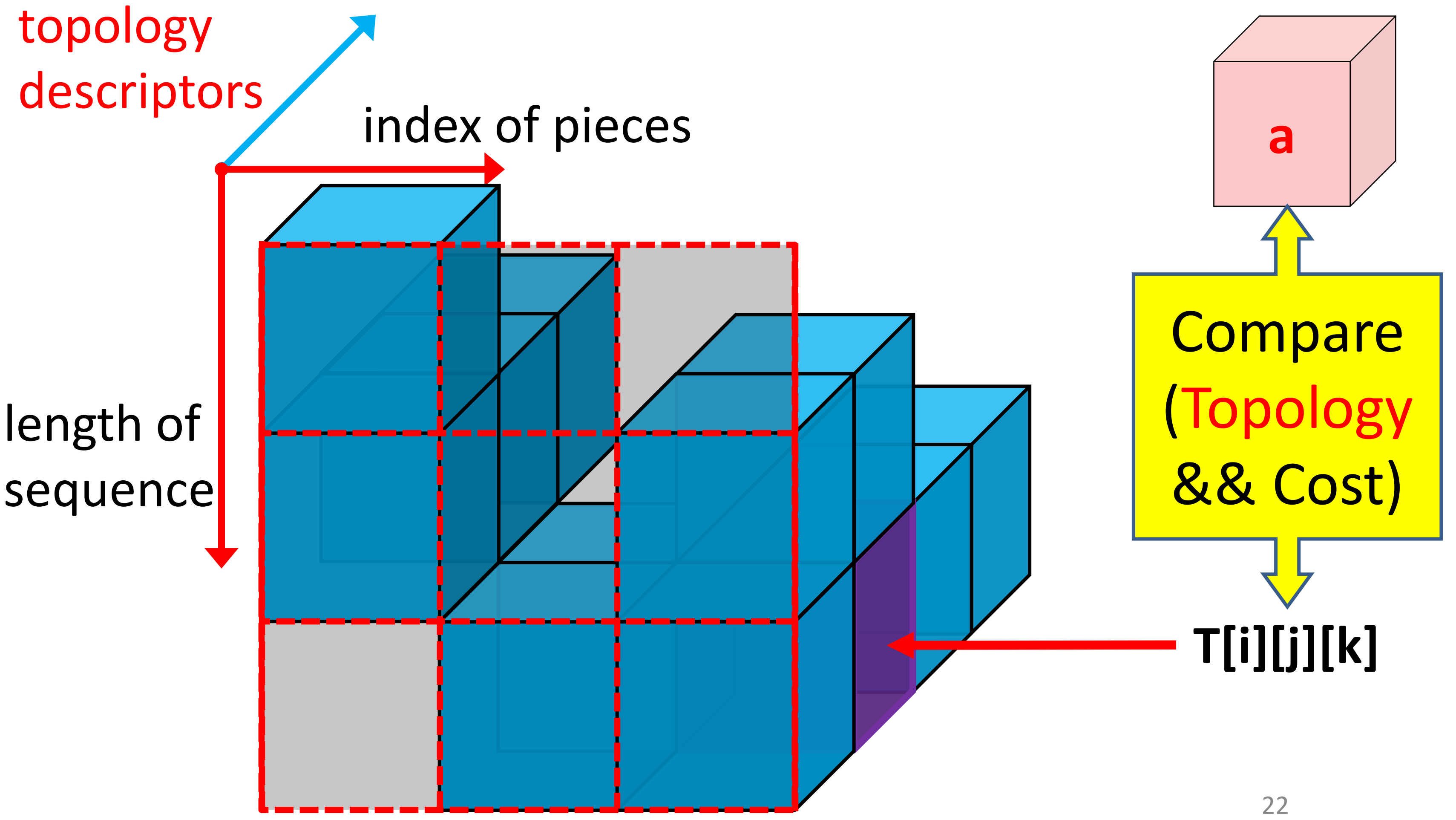
{

a is topoEqual to **b**; /*denoted as **a ≡ b***/

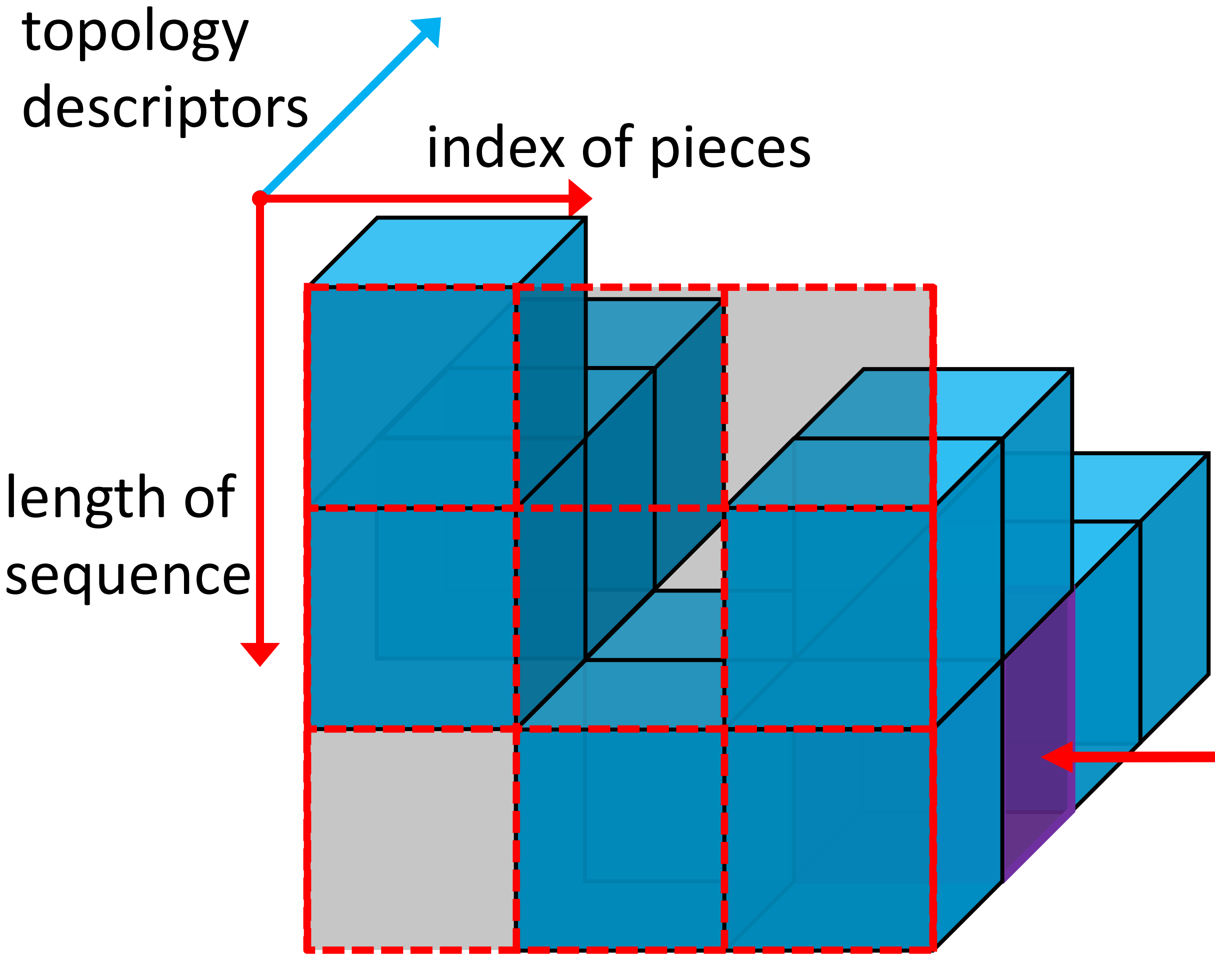
}

Cubic DP

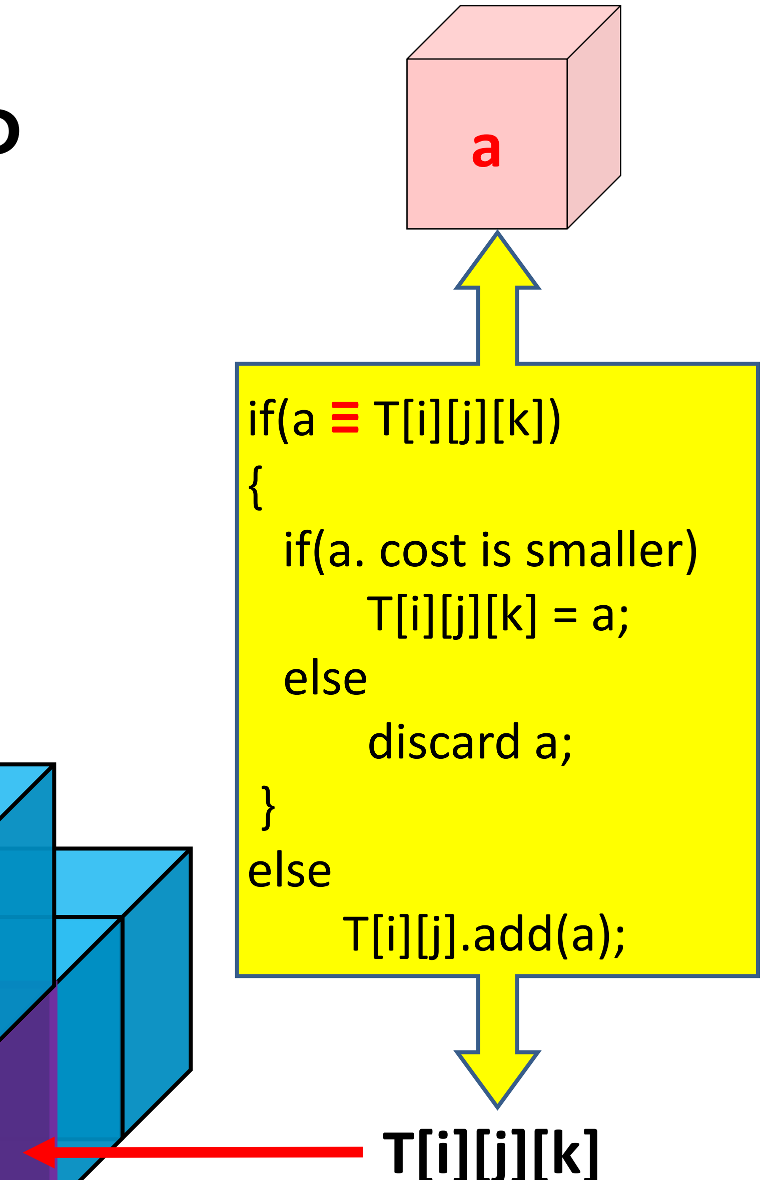
- Allowing arbitrary topology configurations co-exist



Cubic DP



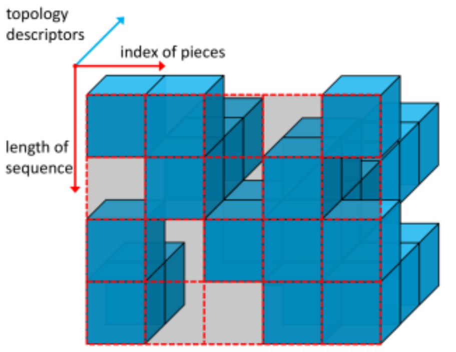
topology descriptors
index of pieces
length of sequence



a
if(a ≡ T[i][j][k])
{
if(a. cost is smaller)
T[i][j][k] = a;
else
discard a;
}
else
T[i][j].add(a);
T[i][j][k]

Backtracking

- The cubic DP gives complete solution space, where we explore by backtracking

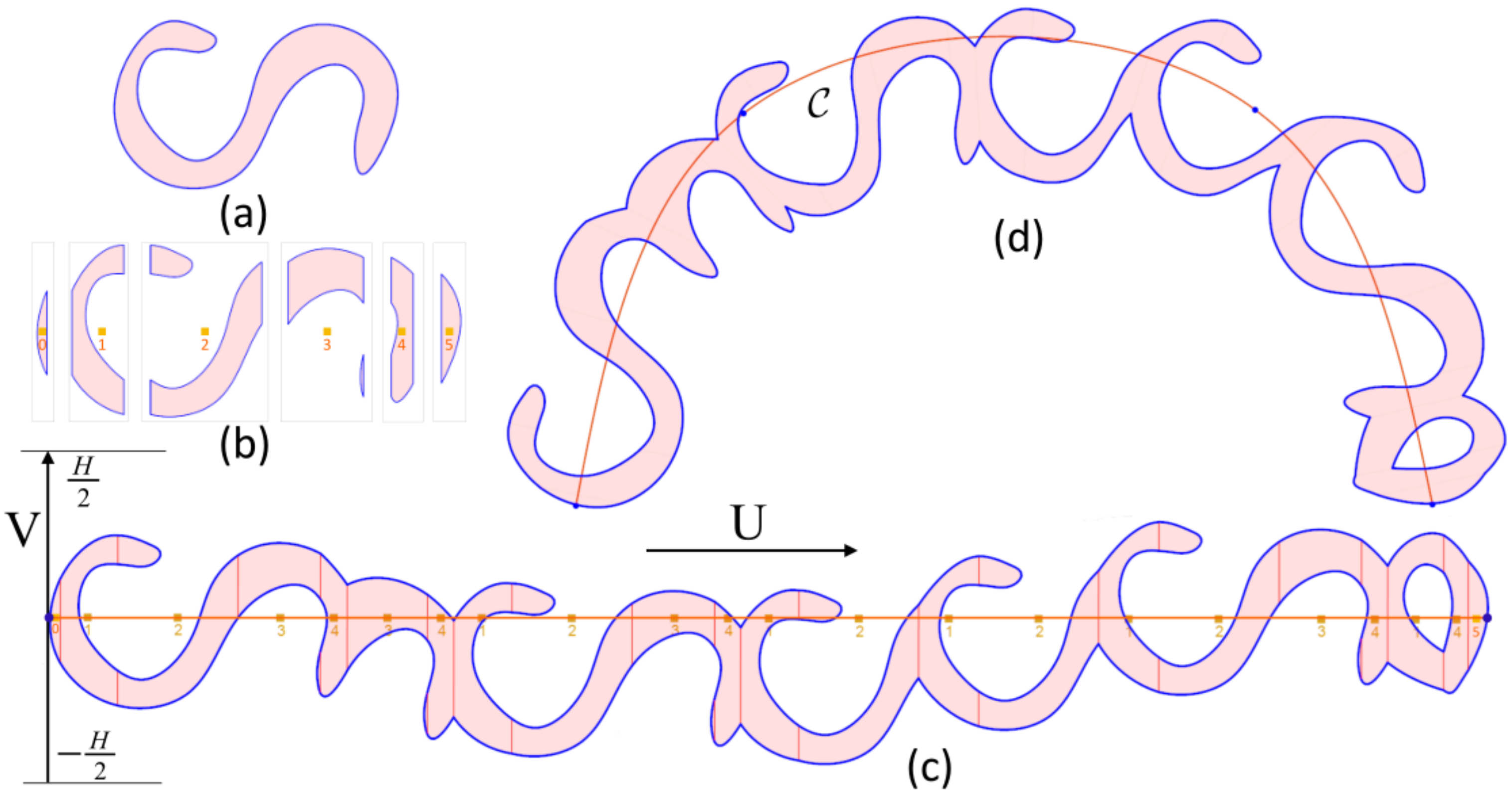


- Simple UI: users specify #holes and #components

- O(K),K is the number of all possible solution.

Patterns on arbitrary curve

- Constituent pieces in parameterization domain

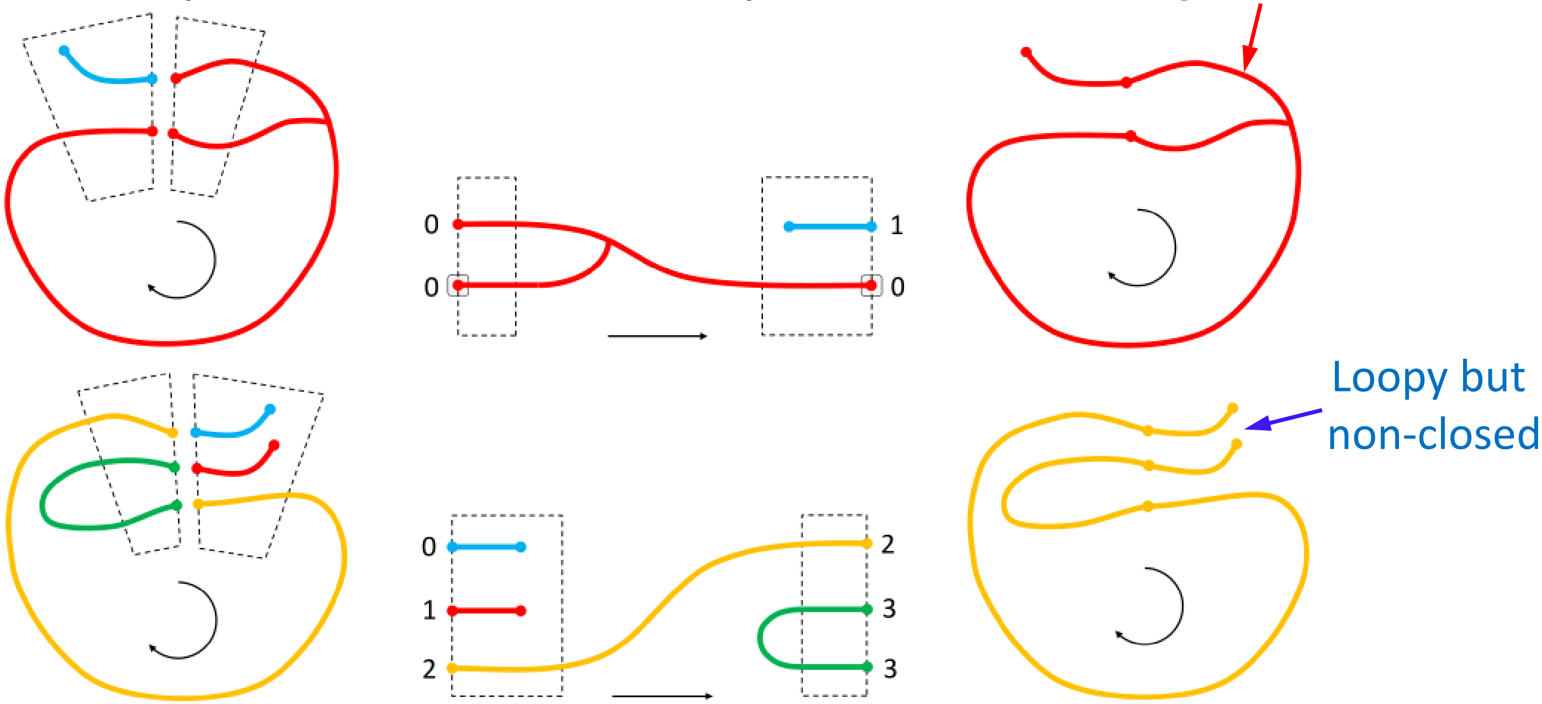


Closed loop

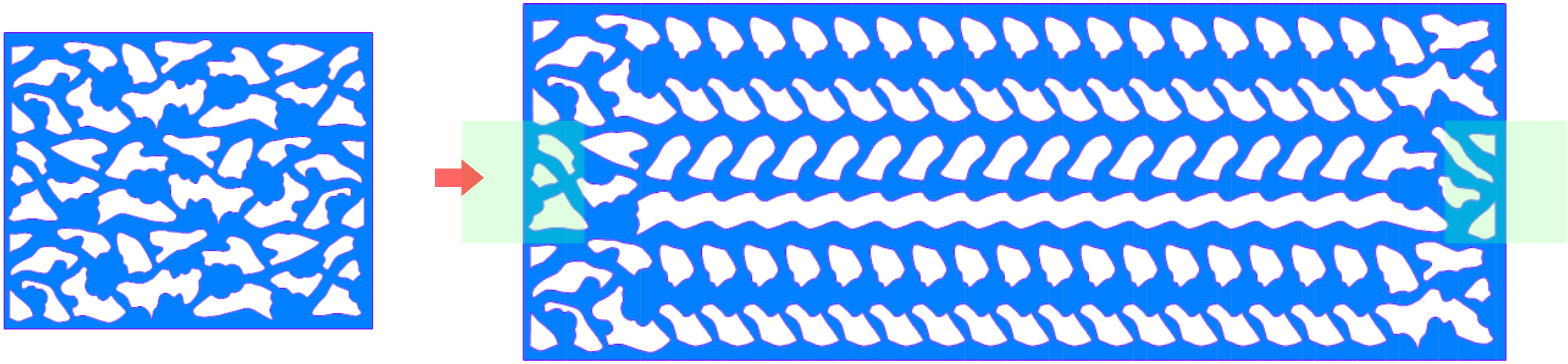
One more virtual piece to close

Bi-directional descriptor, but still O(nLog(n)) ☺

Topo-Descriptor can detect if the pattern is **literally “closed”**

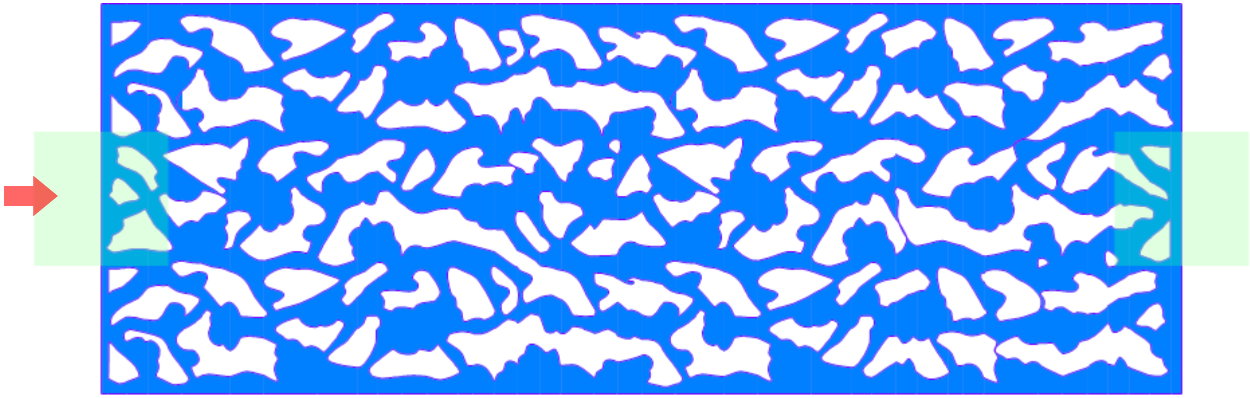


Repetition

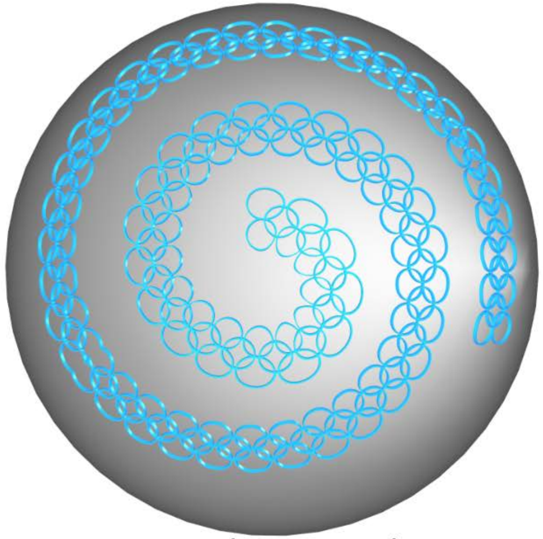


How: by a new cost energy ? Jittering ? Or a function to bring complex structures?

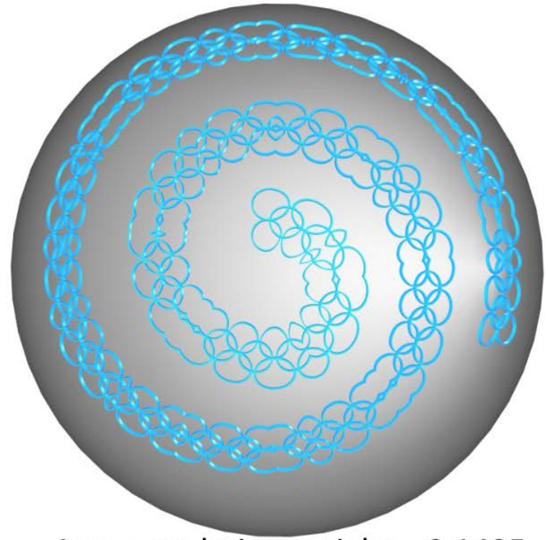
We expect **variety**



Variation control



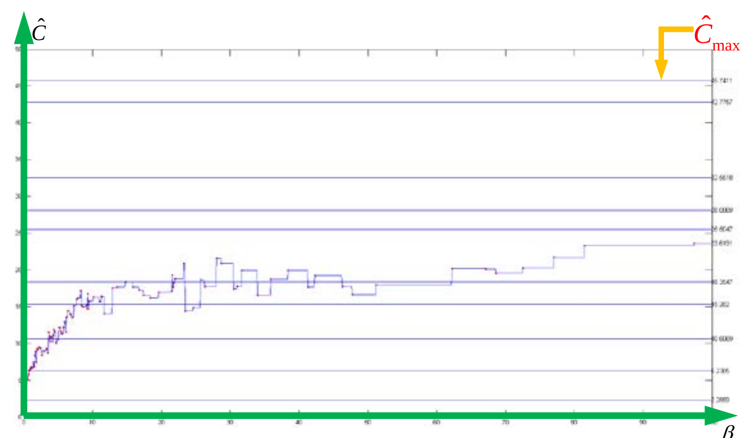
Autocorrelation weight = 0



Autocorrelation weight = 0.1425

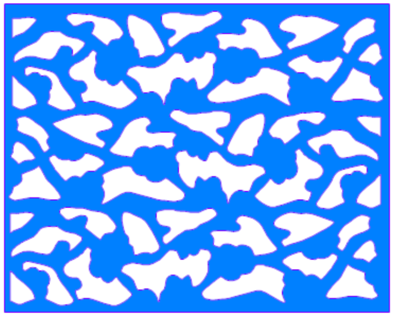
Autocorrelation of index sequence:

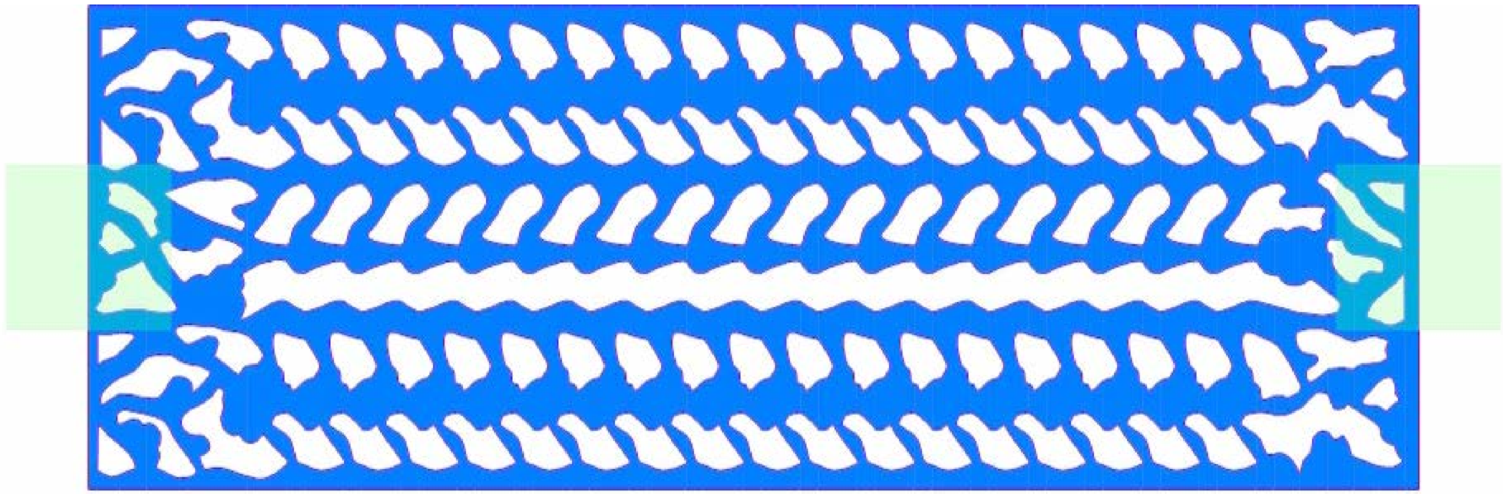
$$A(\eta_0 \ldots \eta_K) = \max_{j \in [0,K]} \left(\sum_{i \in [0, K-j]} e^{-\frac{|\eta_i - \eta_{i+j}|}{\sigma}} \right)$$



Variation versus Quality

Variation control





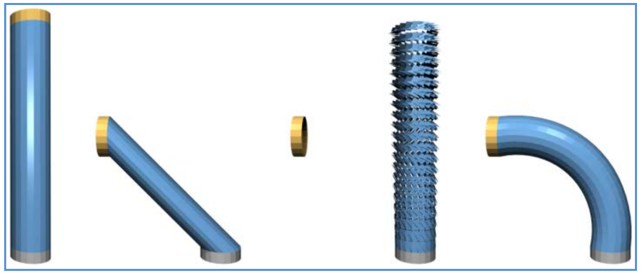
Variation control

Geometry Solver

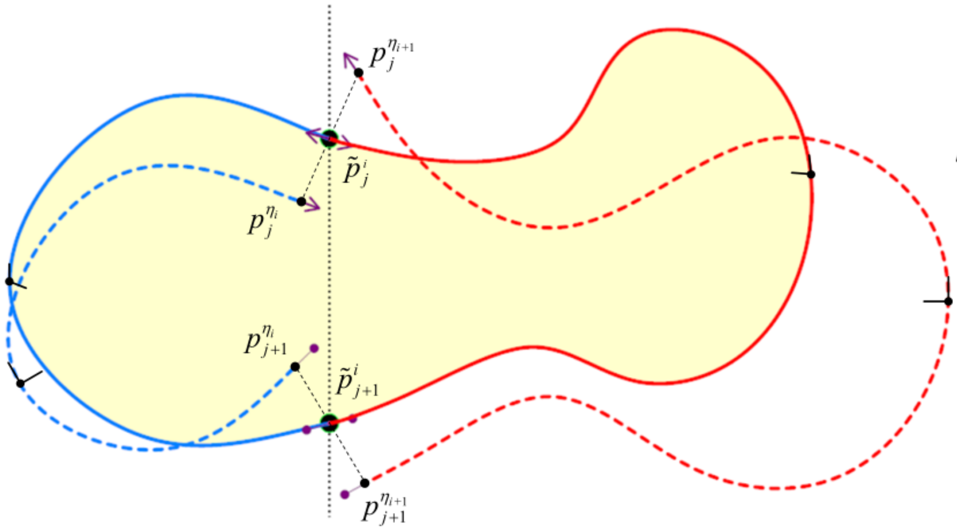
- Positioning pieces
- Gap stitching
- Global band fairing

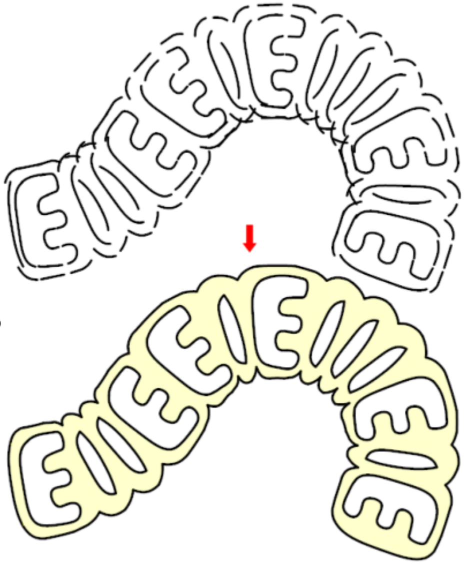
Gap stitching

- linear rotation invariant deformation
  - Endpoint driven
  - Reorient and merge seams in one step



[Lipman, et al. 2005]





Our solution:
Topology-constrained Synthesis

- Analysis from topology
  - Shape analysis for optimal piece-sampling

- Synthesis in two stages
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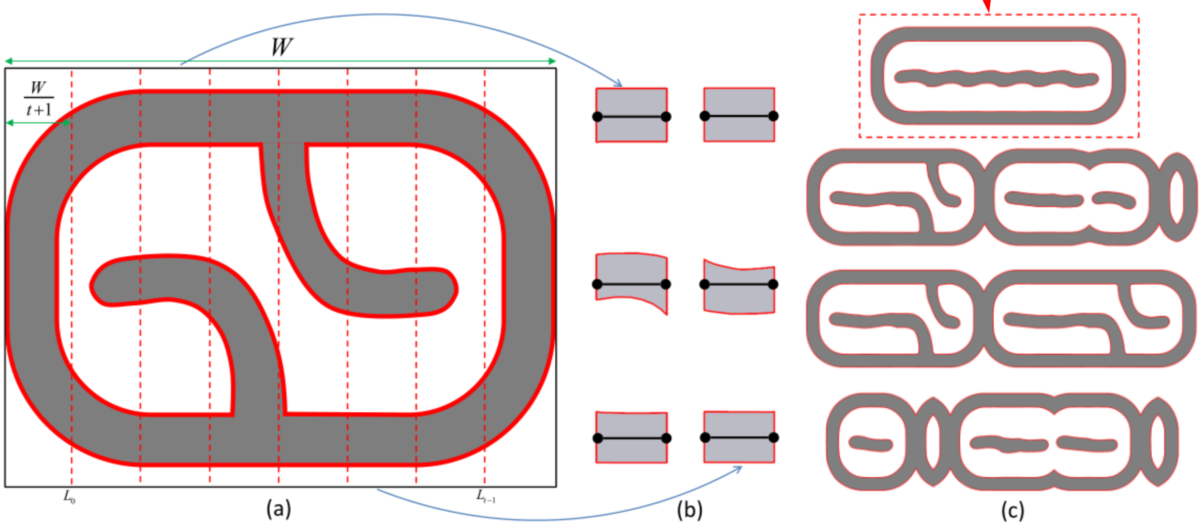
Shape analysis

- Uniform slicing
  - Simple but major drawback
- Non-uniform slicing
  - Best split line searching

Slicing： important to the quality of the final results

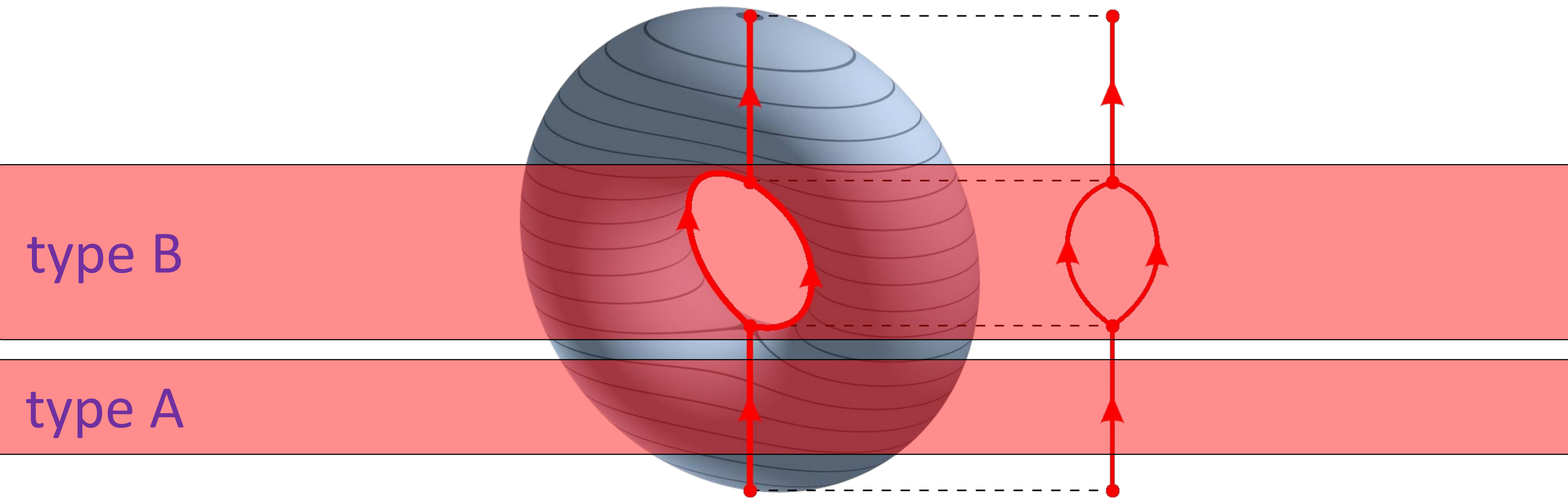
Uniform slicing

- Pros:
  - no need to accumulate band length→lighter DP
  - Variable “N” becomes explicitly known
- **Cons**
  - Trivial pieces → severe trivival repetition
  - Fixed group of topo-events→reduced topology variation



Problematic Piece

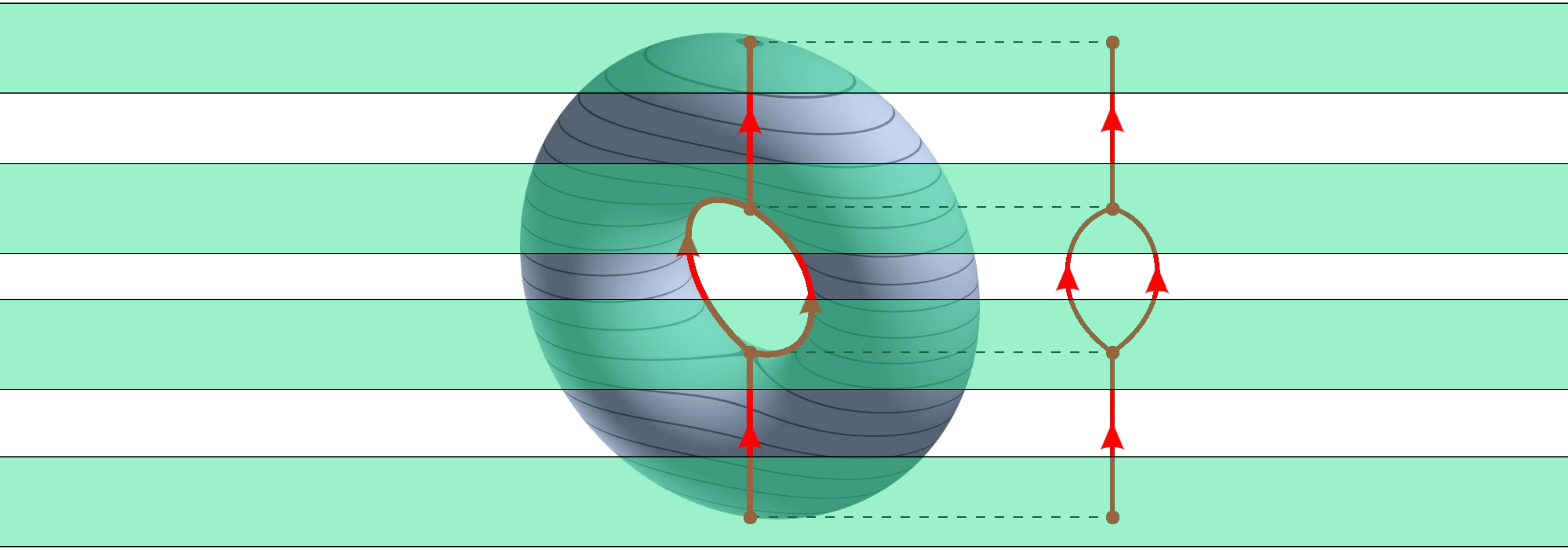
- Pieces contain no topology event



- Piece contain more than 1 topology events

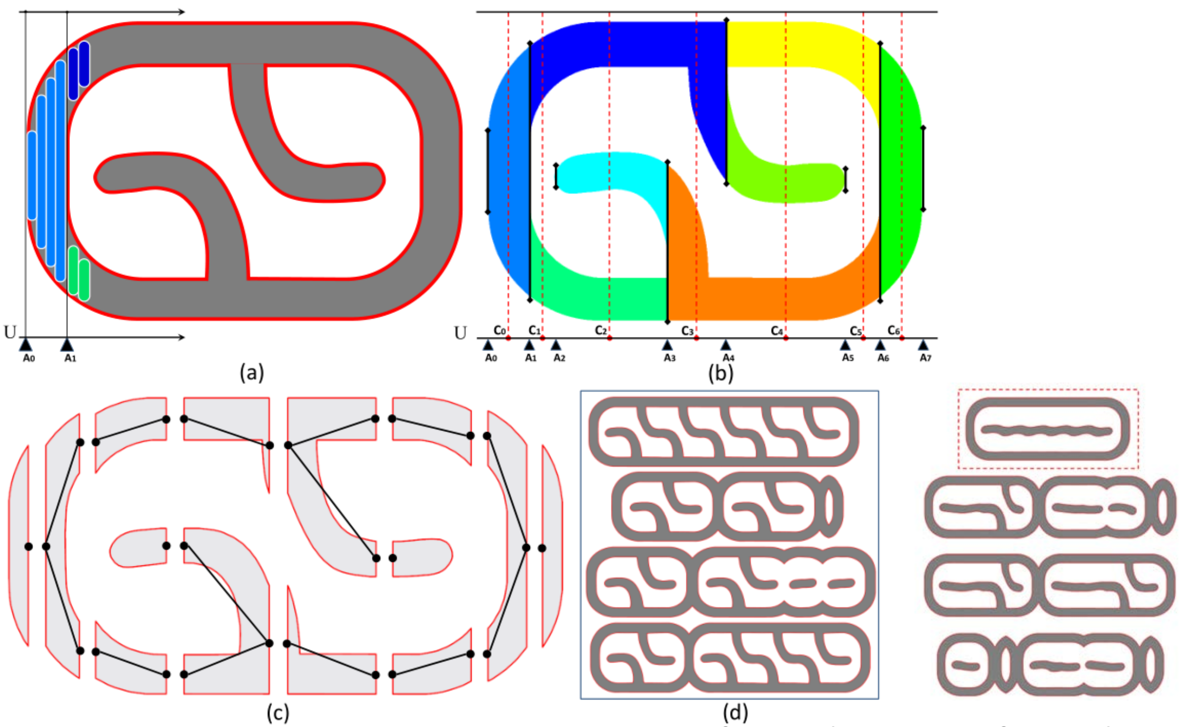
Correct Piece

- Pieces contain exactly one topo-event

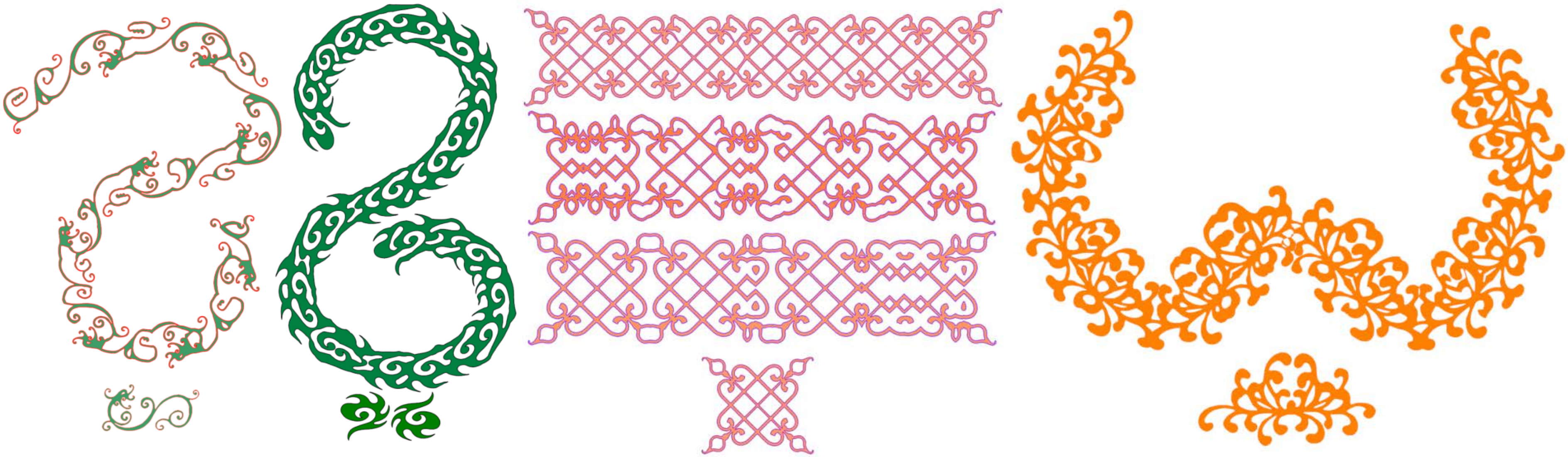


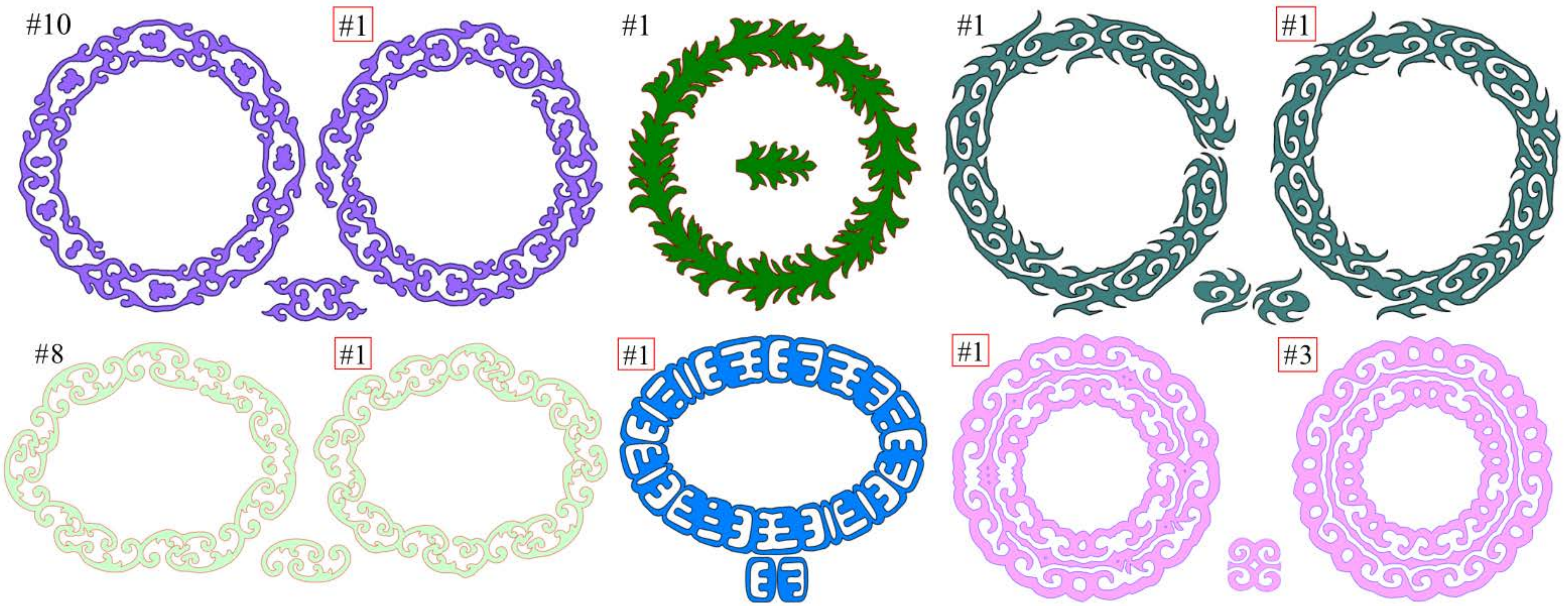
Non-uniform Slicing

- Reeb graph for optimal slicing
  - A discretization for analyzing topology of a continuous manifold
  - Tool for extracting topology information
  - Efficient

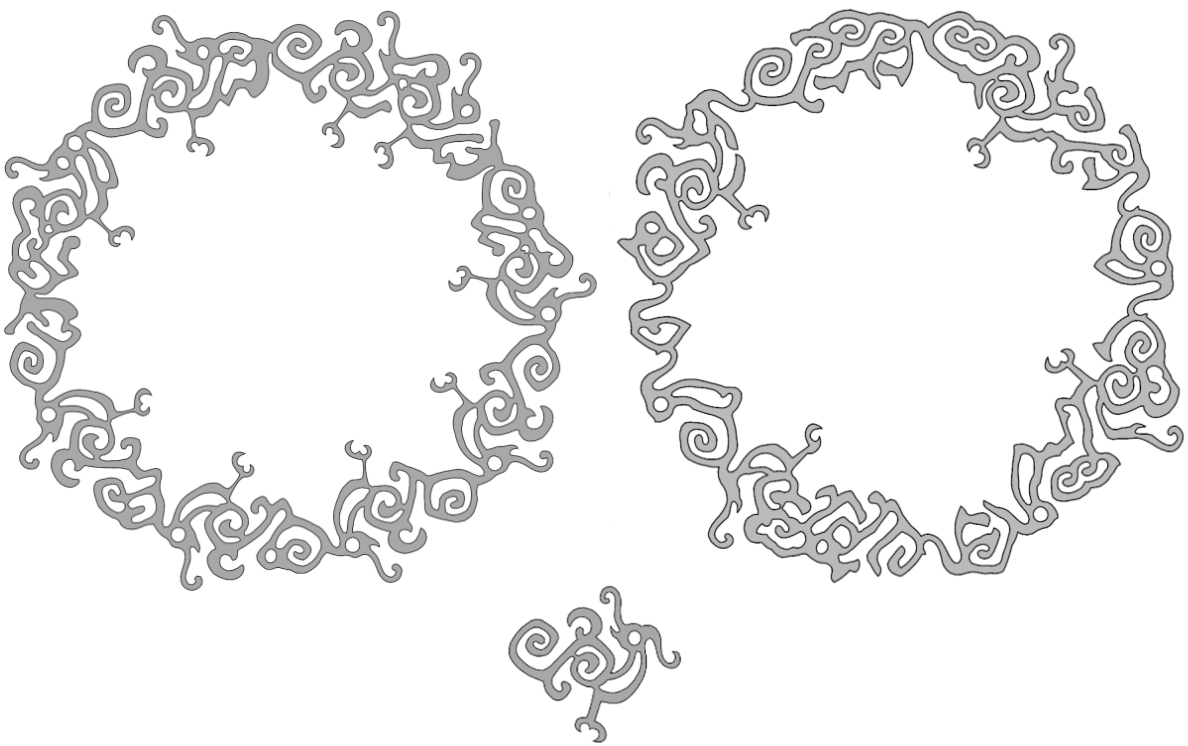


Non-uniform Slicing Uniform slicing

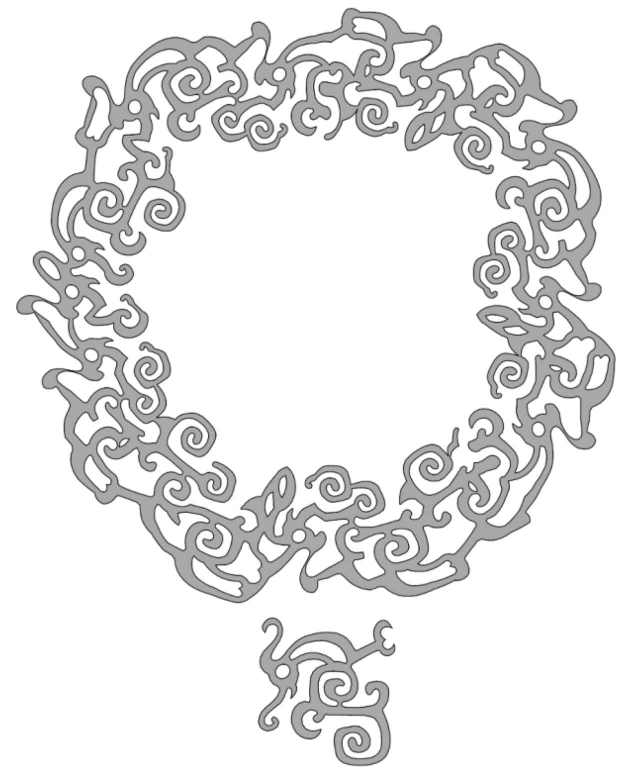




 means “closed loop” constraint is imposed

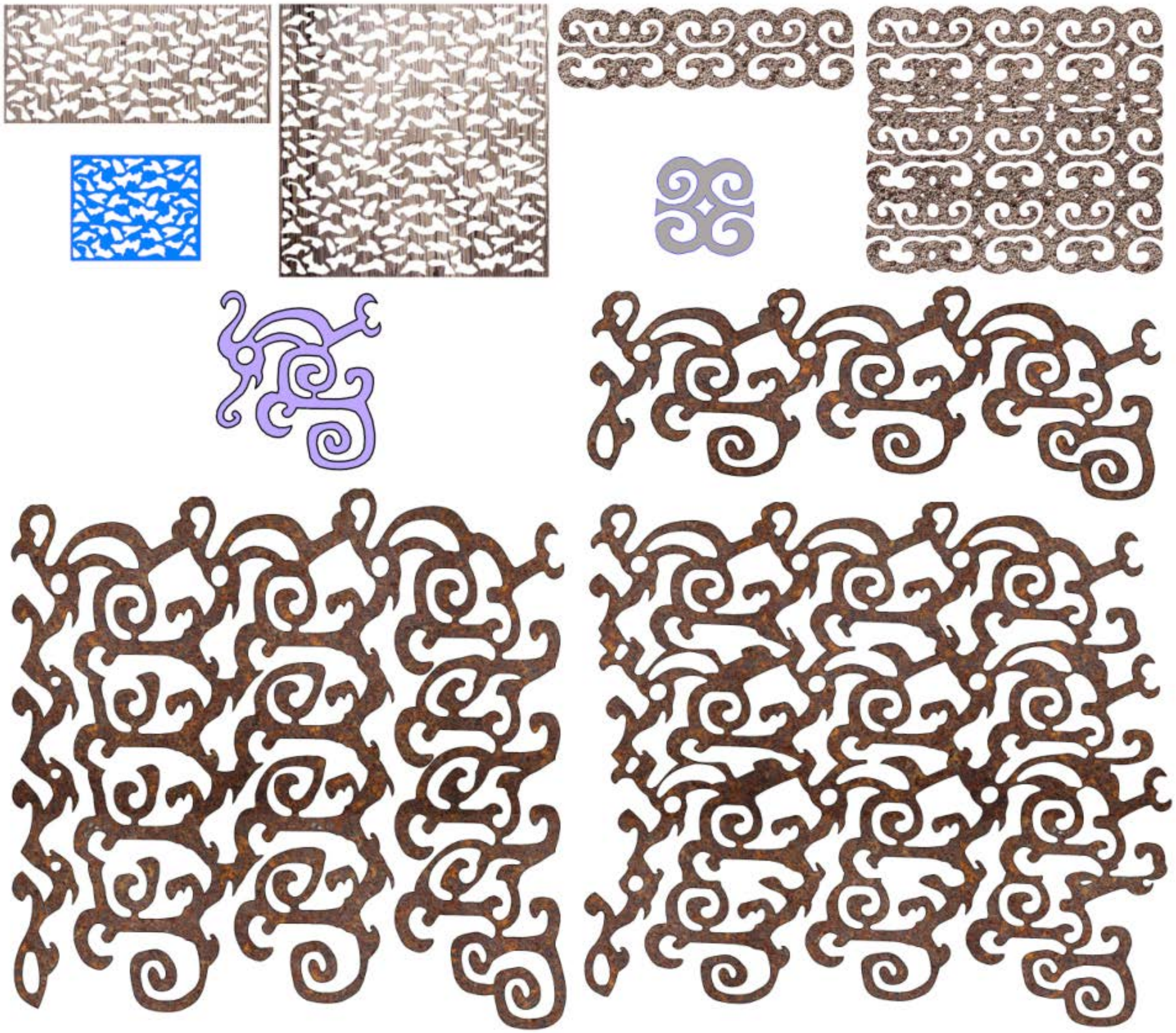


different autocor



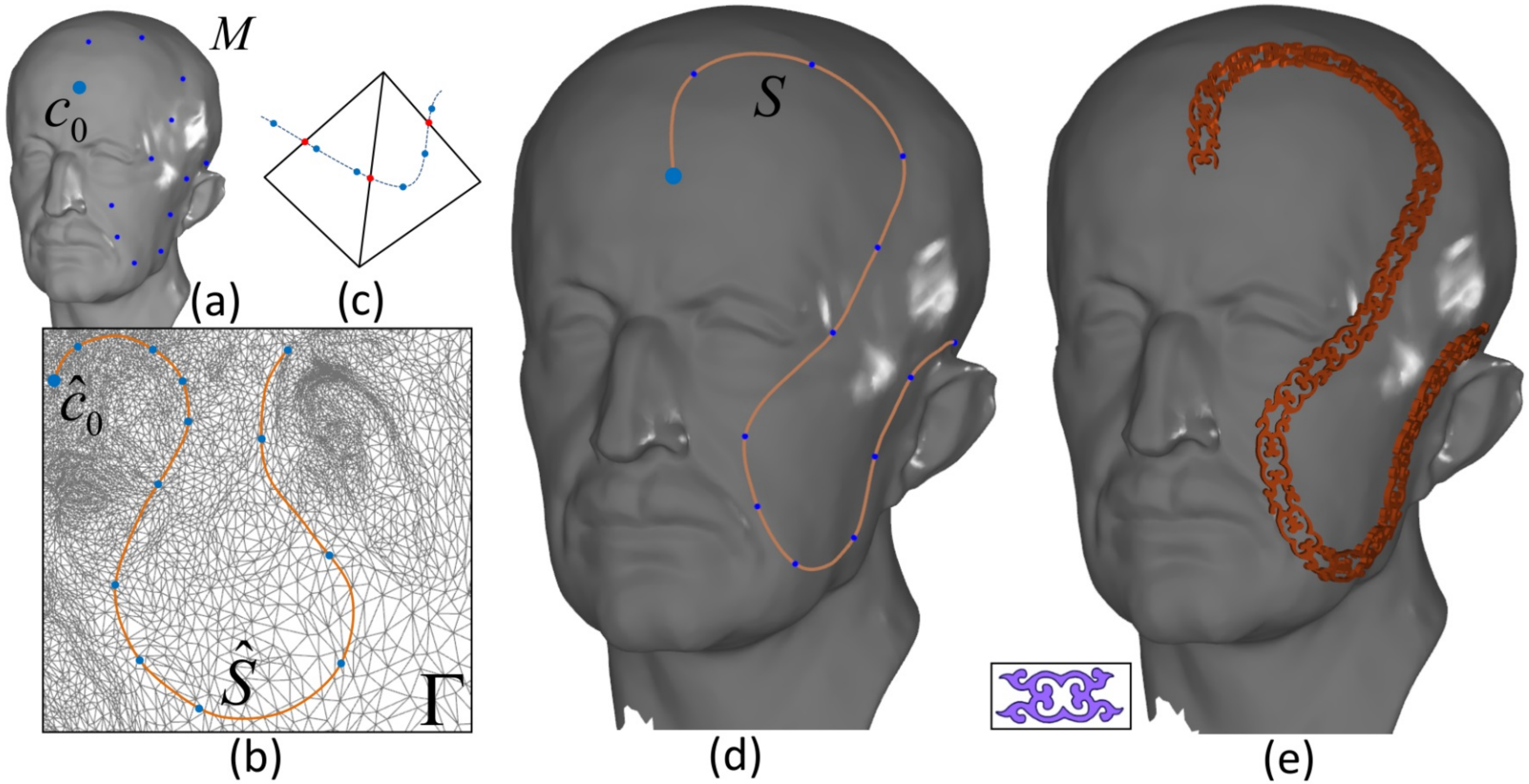
rotated

Synthesizing rectangular patterns



Decorating surfaces

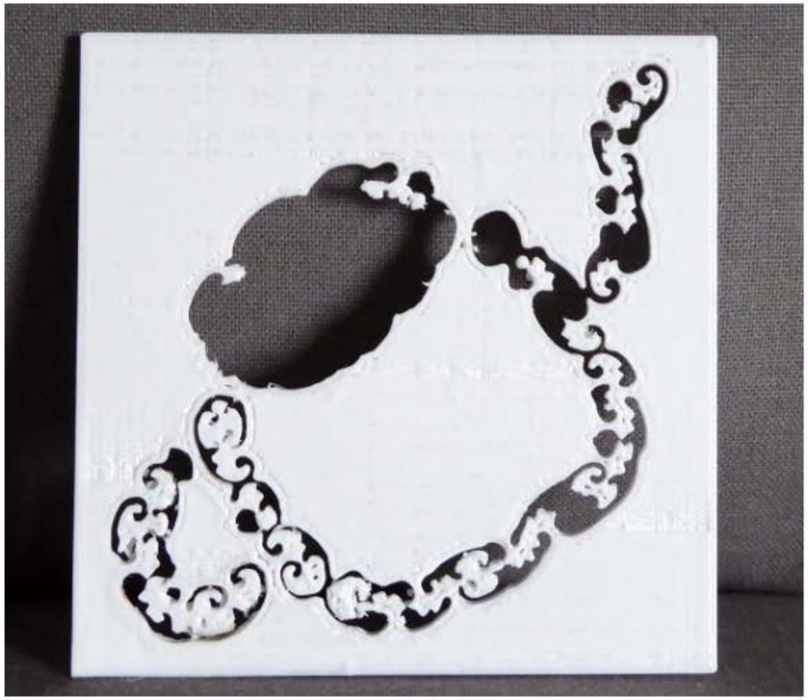
- Sketching patterns directly on a mesh
- Construct 3d bands along prescribed curves



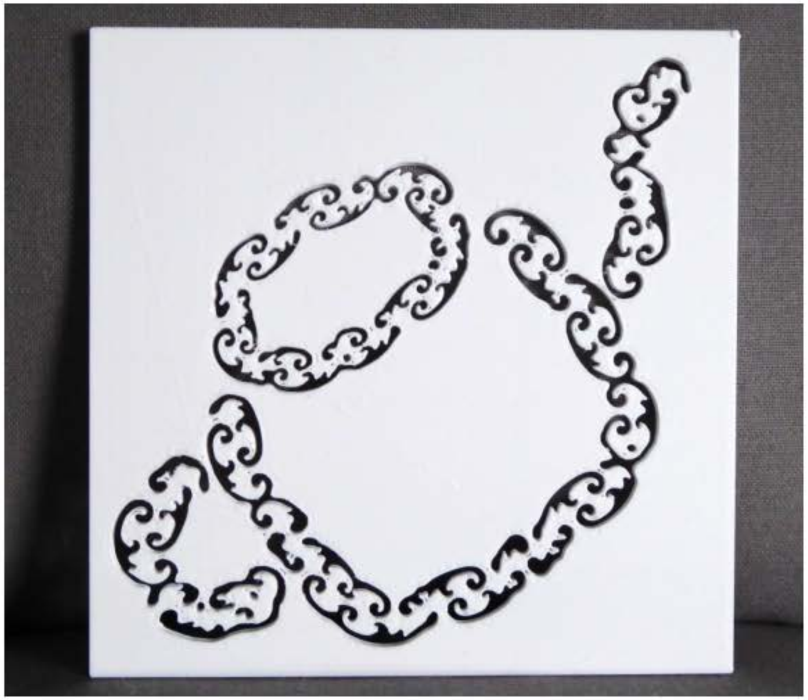
Printed objects

Volumetric modeling Software : [**IceSL**, Sylvain Lefebvre 2013]
3D printing: Fused Filament Fabrication(FFF), Plastics Filament Fab(PLA) ,
ZCorp powder based printer.

Inverse Patterns



#holes = 5

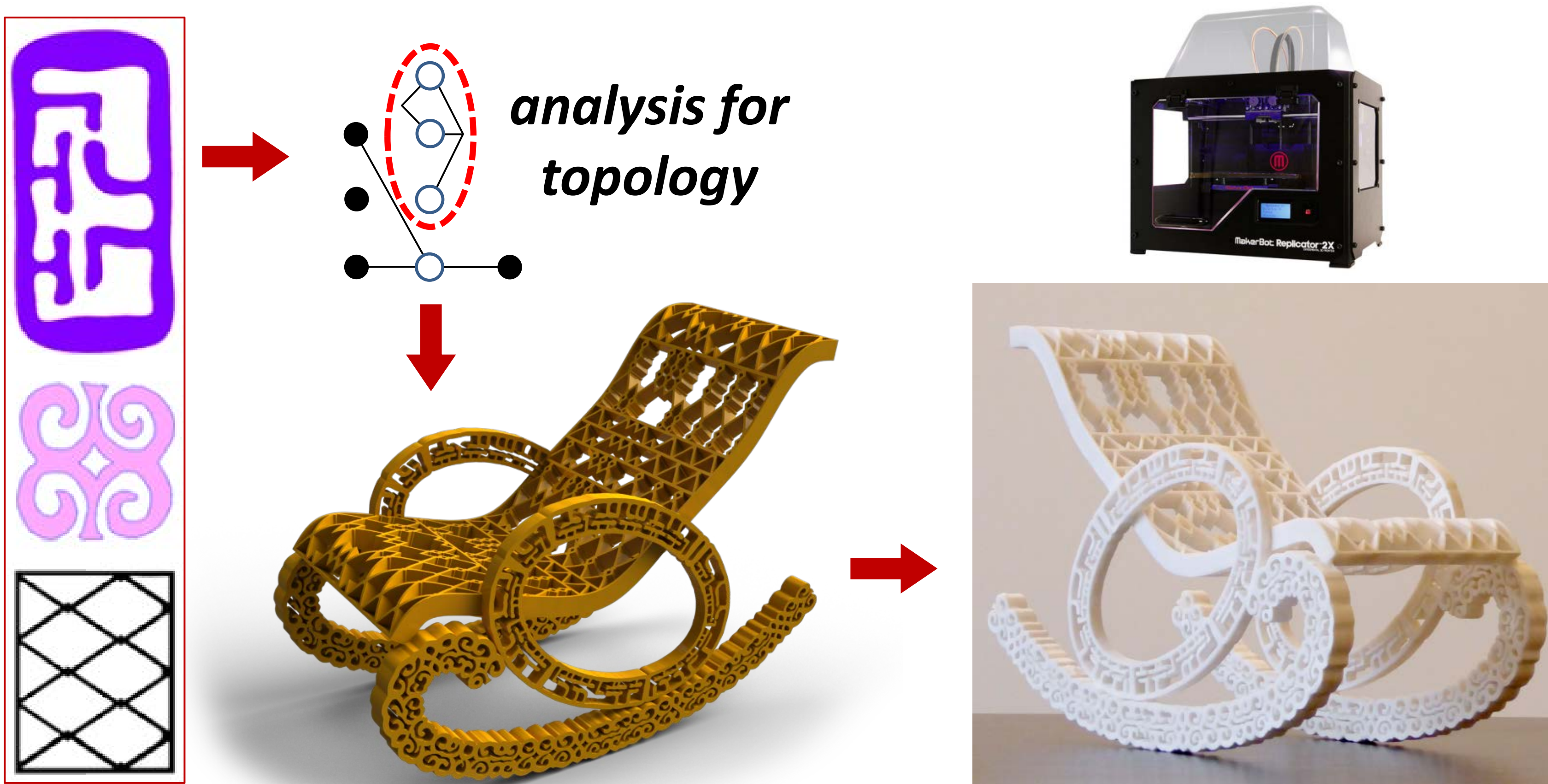


#holes =0

Pure repetition

Strictly repeated

Summary



Input exemplars

single-connected vector shape

Fabricated object

Limitation & Future work

- Stochastic synthesis of vector patterns
  - random exploration of topology descriptor
- Performance
  - accelerating dynamic programming

- Acknowledgement

  We would like to thank colleagues in USTC and Inria for comments.

  We would like to thank anonymous reviewers for their suggestions

- Funding
  - National Science Foundation of China: No.61303147
  - ERC grant ShapeForge (StG-2012-307877)

Thanks!

Welcome