3D Image Processing summary

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Artificial Intelligence & Information Analysis Lab

3D Data Processing

- 3D volume Filtering
- 3D Volume Inpainting
- 3D Image Interpolation
- Shape from Focus
- 3D Data Registration
- Closed-Form Alignment of Active Surface Models

3D Data Processing

- Convolution Neural Networks (CNN)
- **3D volume Filtering**
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- MeshSDF:Differentiable Iso-Surface Extraction
- 3D Data Registration

3D Volume Filtering

- 3D Volume Filtering is a procedure for modifying or amplifying a given picture. We can apply a given filter K to a specific image I to enchant several features or to eliminate other ones. Processing an image with filtering models we can achieve smoothing, sharpening and edge enhancement operations. Here we will focus on filtering methods like:
  - Finite Impulse Response Method
  - Feature-Preserving Method
  - Warp Filtering
  - **Median Filtering**
  - Joint Image Filtering

Finite Impulse Response Method (FIR)

- 3D linear Finite Impulse Response Filters (FIR) are linear location-invariant systems having a finite region of support.

  - Output of filter: 3D digital filter having a parallelepiped region of support $R_{Q_1Q_2Q_3}$={$(k_1k_2k_3)$: 0≤ $k_1 < Q_1$,0≤ $k_2 < Q_2$,0≤ $k_3 < Q_3$} is defined by the 3D linear convolution of the filter coefficients with the input image:

$$g(n_1,n_2,n_3) = h(n_1,n_2,n_3) \ *** \ f(n_1,n_2,n_3)$$

$$= \sum_{k_1=0}^{Q_1-1} \sum_{k_2=0}^{Q_2-1} \sum_{k_3=0}^{Q_3-1} h(k_1k_2k_3) f(n_1-k_1, n_2-k_2, n_3-k_3)$$

where h(n_1,n_2,n_3) $is\ the\ convolution\ \ filter\ mask\ and\ f(n_1,n_2,n_3)$ the 3D image.

Finite Impulse Response Method (FIR)

- Gaussian function is denoted as:

$$g(x,y,z) = \frac{1}{\sqrt{(2\pi)^3\sigma^3}} e^{-(x^2+y^2+z^2)/2\sigma^2}$$

  - A frequently used 3D low-pass filter.

- If the sequences $f(n_1, n_2, n_3)$ and h(n_1, n_2, n_3) have regions of support $R_{P_1P_2P_3} = [0, P_1) \times [0, P_2) \times [0, P_3)$ and $R_{Q_1Q_2Q_3} = [0, Q_1) \times [0, Q_2) \times [0, Q_3)$ respectively, the linear convolution output has the follow region of support:

$$R_{N_1N_2N_3} = [0, N_1) \times [0, N_2) \times [0, N_3) \qquad N_i = P_i + Q_i + 1 \qquad i = 1,2,3.$$

Finite Impulse Response Method (FIR)

- DFT-based calculation of the 3D linear convolution:

$$g(n_1, n_2, n_3) = h(n_1, n_2, n_3) \circledast\circledast\circledast f(n_1, n_2, n_3)$$
$$\leftrightarrow G(k_1, k_2, k_3) = F(k_1, k_2, k_3)H(k_1, k_2, k_3)$$

where $G(k_1, k_2, k_3)$, $F(k_1, k_2, k_3)$ and $H(k_1, k_2, k_3)$ denoted as the 3D DFTs of the 3D images g, f and h respectively.

- Notation $\leftrightarrow$ is used to denote a transform pair instead of $f \circledast\circledast\circledast h$ which it denotes the circular convolution of the 3D images $f(n_1, n_2, n_3)$ and $h(n_1, n_2, n_3)$.

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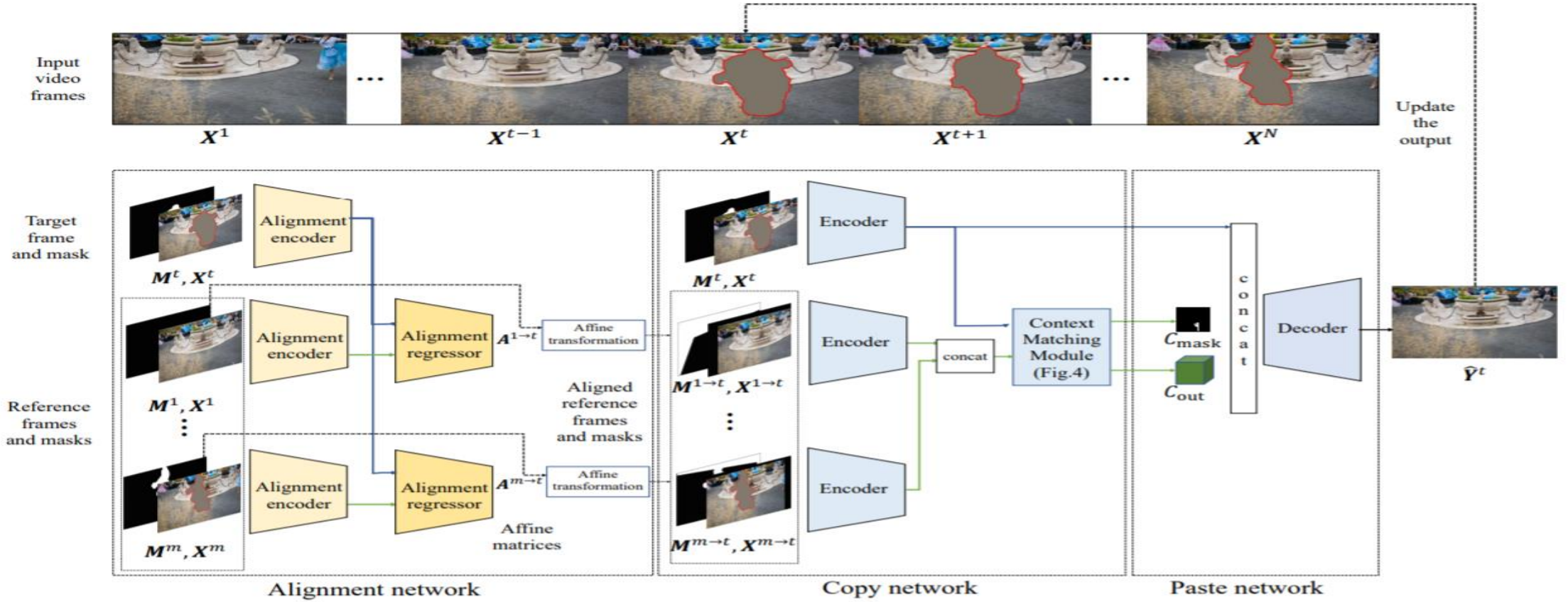
3D Volume Inpainting

- Inpainting is a sustenance process where damaged or missing parts of a picture are filled up to generate a complete image.
- There are several methods for it, but in this view we will centered in CNN methods like:
  - **Volume-Guided View Inpainting**
  - Context Encoders
  - Copy and Paste Network
  - Global & Local
  - Partial Convolution
  - Gated Convolution

Copy and Paste Network

- In contrast with image inpainting, video inpainting have additional challenges due to extra temporal information in order to keep the overall temporal coherency.
- Copy and Paste Network is actually a DNN-based framework which is used for video inpainting taking notice of additional information in each frame of the video.



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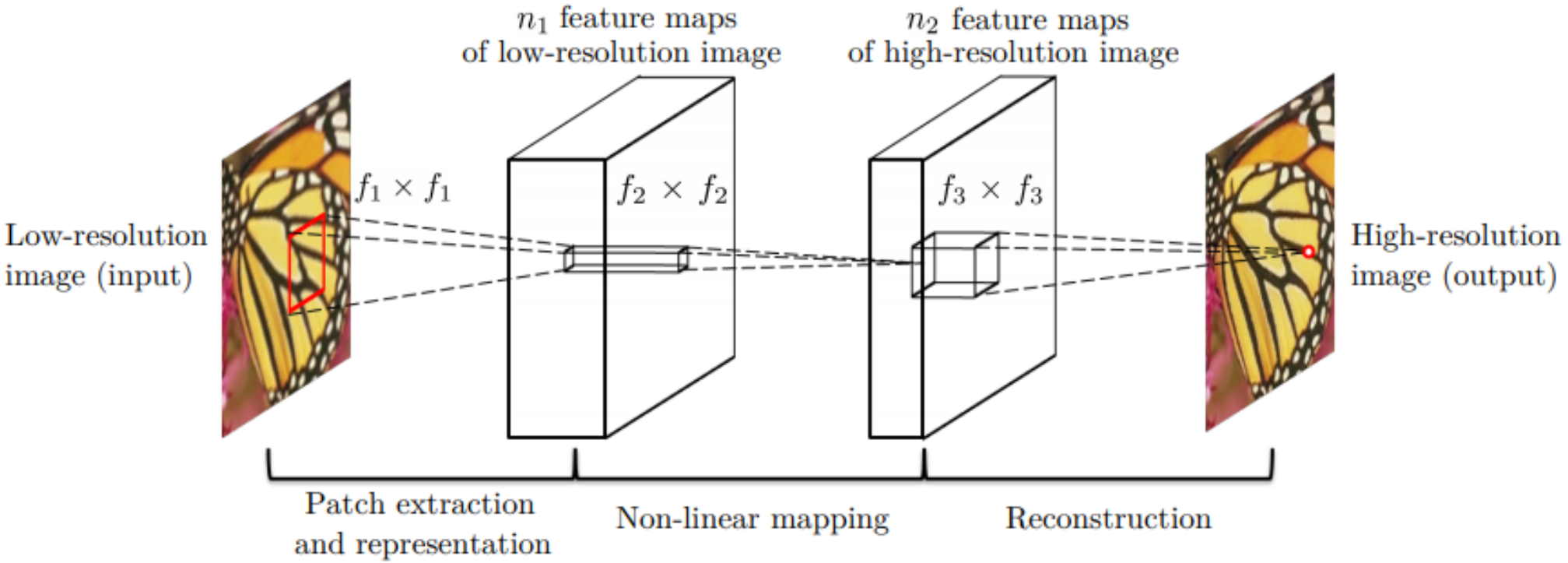
3D Image Interpolation

- In image processing, a significant field is the techniques where we can use to improve the quality of picture applying several methods for that reason. 3D volume (image) interpolation is one such technique. We will focus on Deep Neural Networks techniques instead of the classic one interpolation methods:
  - Linear interpolation
  - Bilinear interpolation
  - Edge-Detection Bicubic Convolution interpolation
  - Nearest Neighbor interpolation
  - **K-space interpolation**
  - Super-Resolution Convolutional Neural Network (SRCNN)
  - Attention Sampling interpolation

Super Resolution Convolutional Neural Network (SRCNN)



Source: [DON2016]

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Shape from Focus

- In Computer vision 3D shape recovery is an issue which must be treated with care. 3D shape of object can be estimated using passive methods like Shape from Focus.

- The image sequence is represented as: $f(i, j, k, d)$
  - where i, j represents pixel position
  - k denote the picture and d the color channel.
  - where $1 \leq j \leq l, 1 \leq j \leq w$, $1 \leq k \leq h, 1 \leq d \leq 3$ and $l \times w \times h \times d$ dimensional of image stack.

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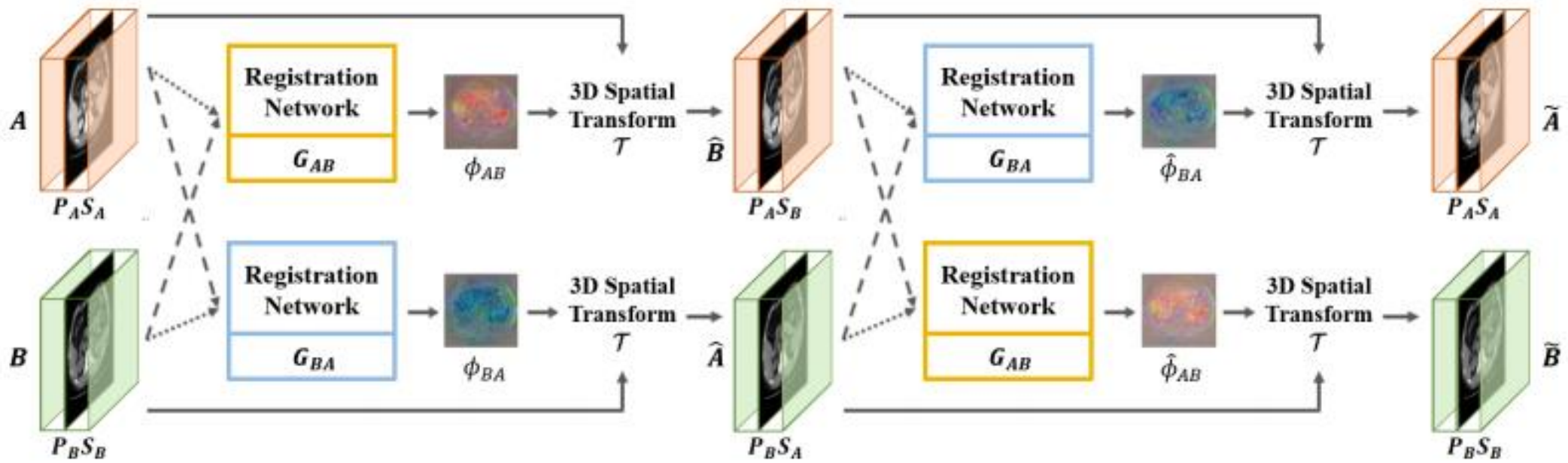
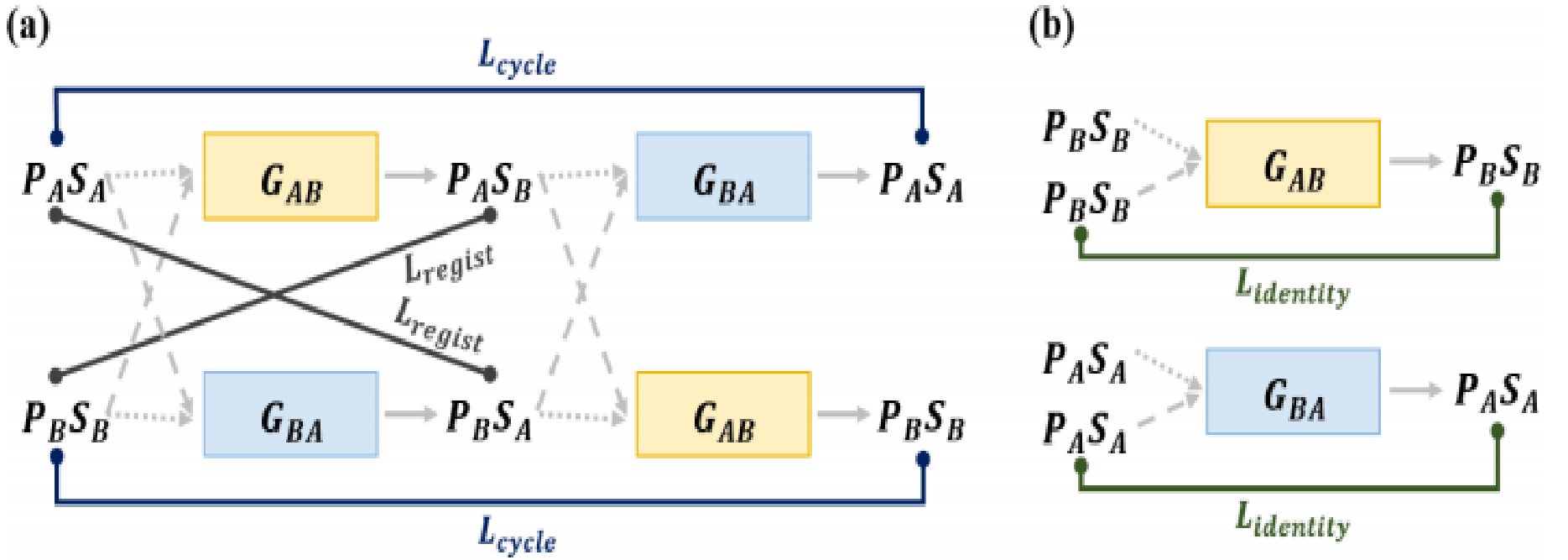
Unsupervised Deformable Image Registration



Source: [KIM2019]

Unsupervised Deformable Image Registration



Loss function architecture

Source: [KIM2019]

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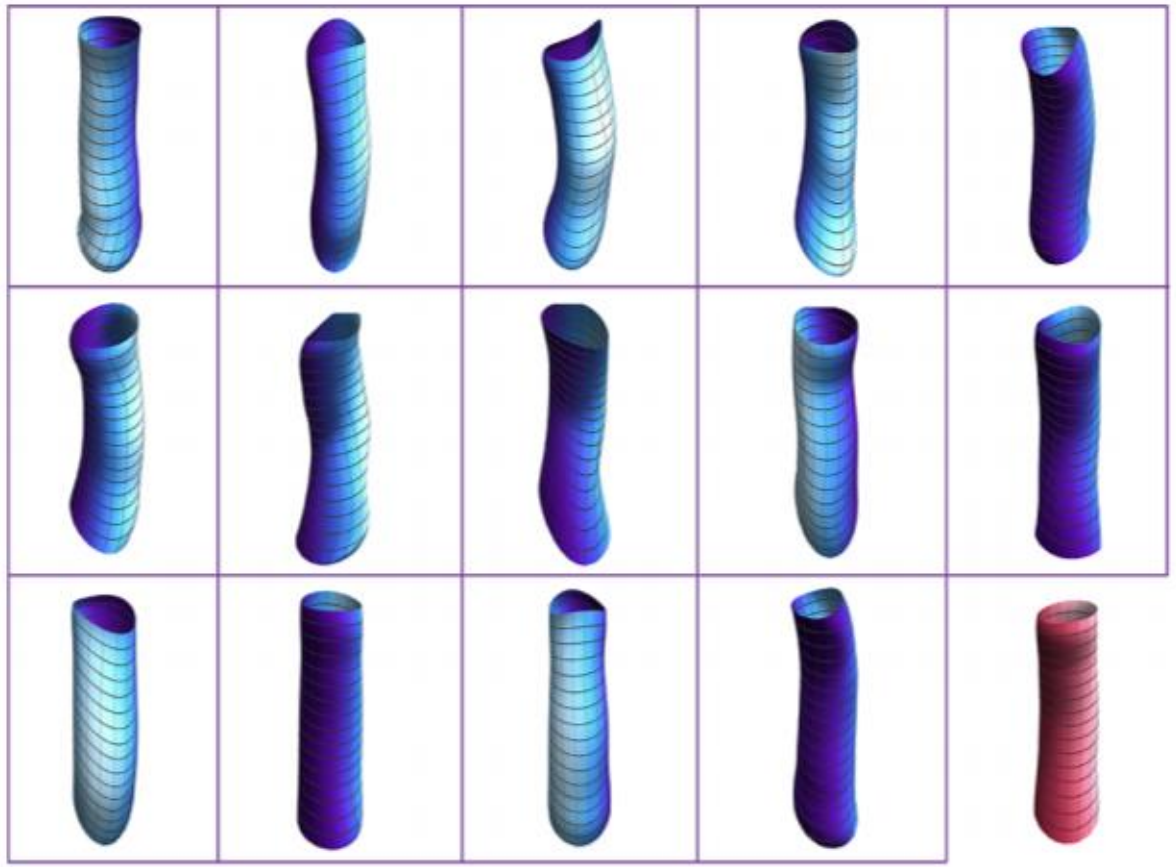
Closed-Form Alignment - Active Surface Models



Source: [SCH2017]

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Q & A

Thank you very much for your attention!

More material in
http://icarus.csd.auth.gr/cvml-web-lecture-series/

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