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Learning Geometry-aware Representations by *Sketching*

THU-PM-259

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Brief overview

Concept

Image

Geometric concepts

ex) position, shape, distance, orientation

z

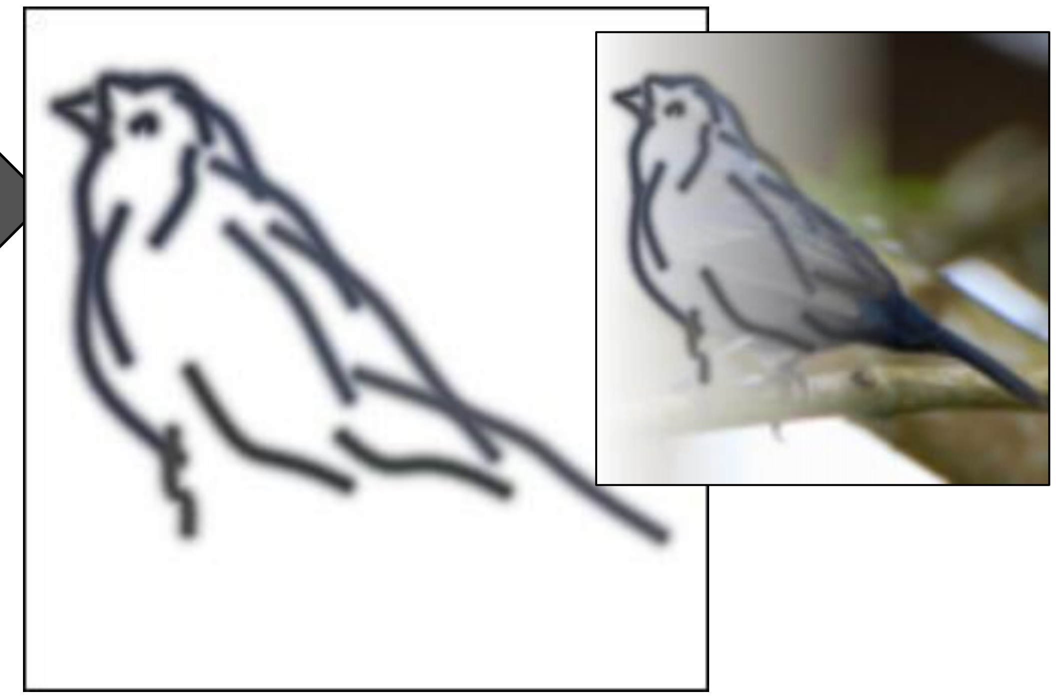
Feature (vector)

Brief overview

Concept

Stroke-based Sketching

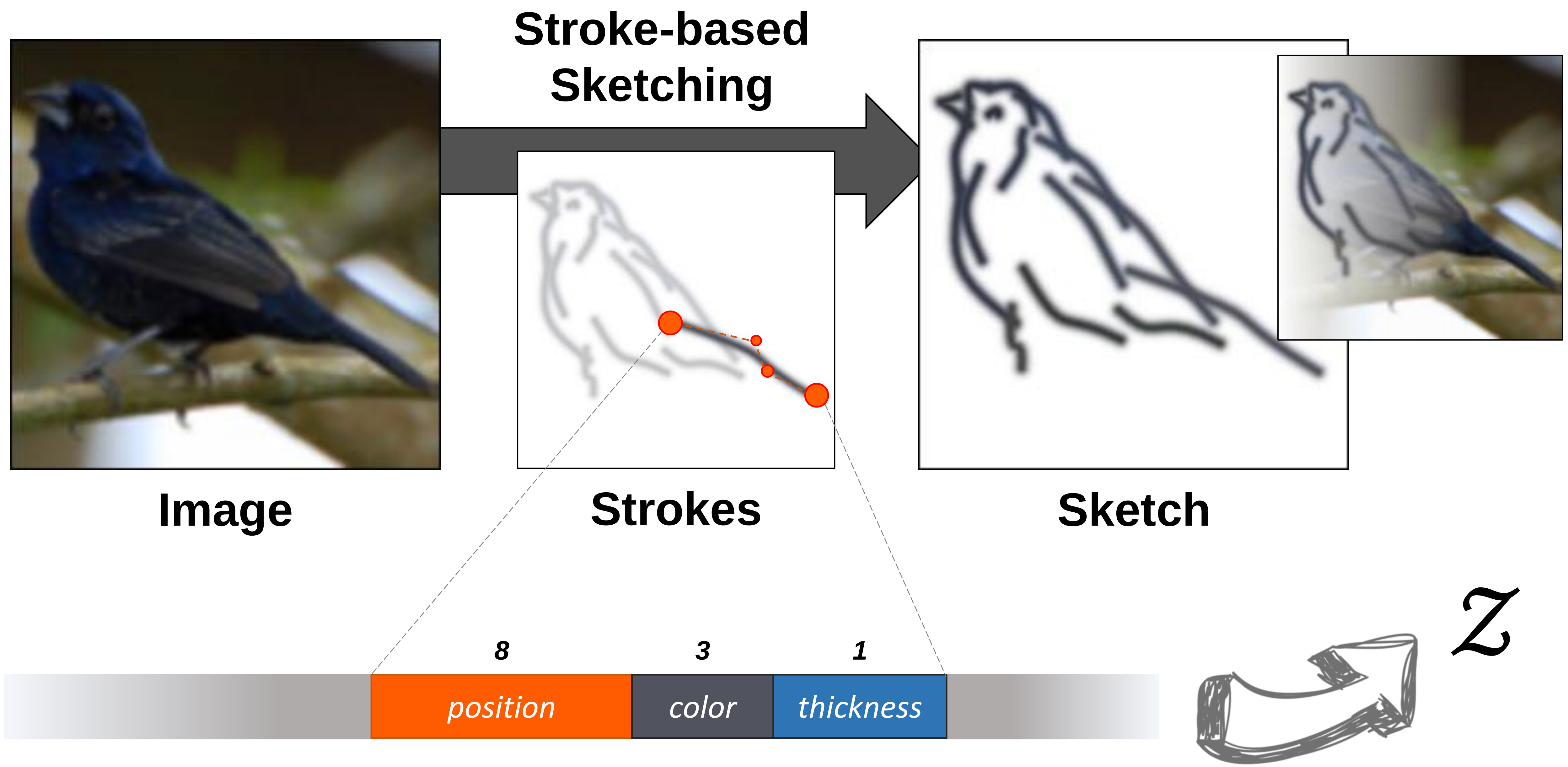
Image



Sketch

Brief overview

Concept



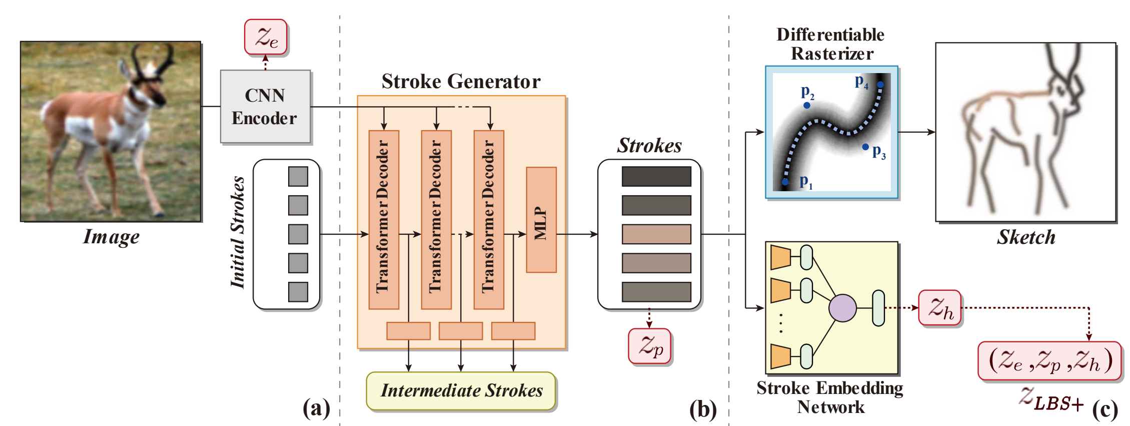
Brief overview

Contributions

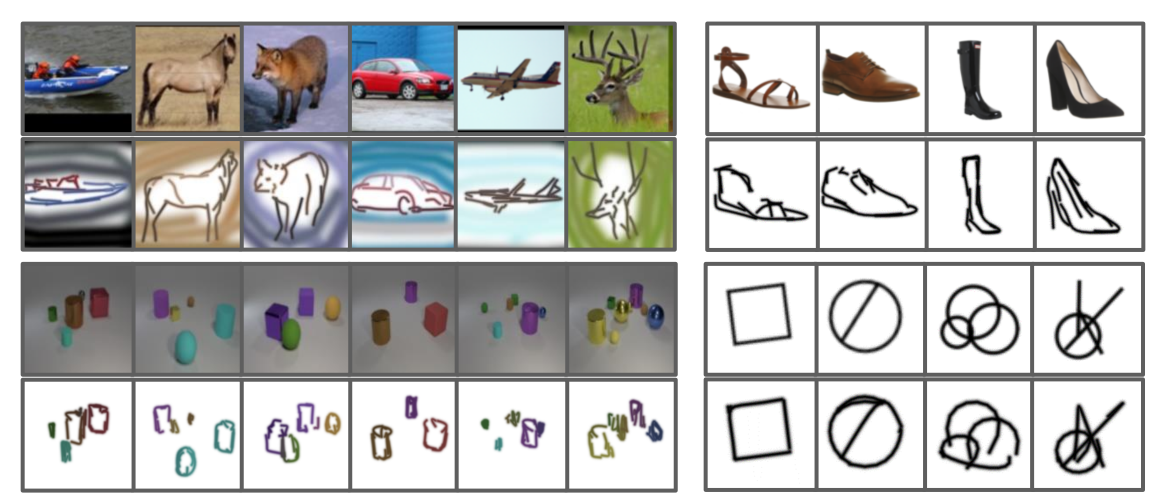
- Theoretically show that **strokes can convey geometric information**

- Design a sketch-based visual representation model,

  coined **LBS (Learning By Sketching)**



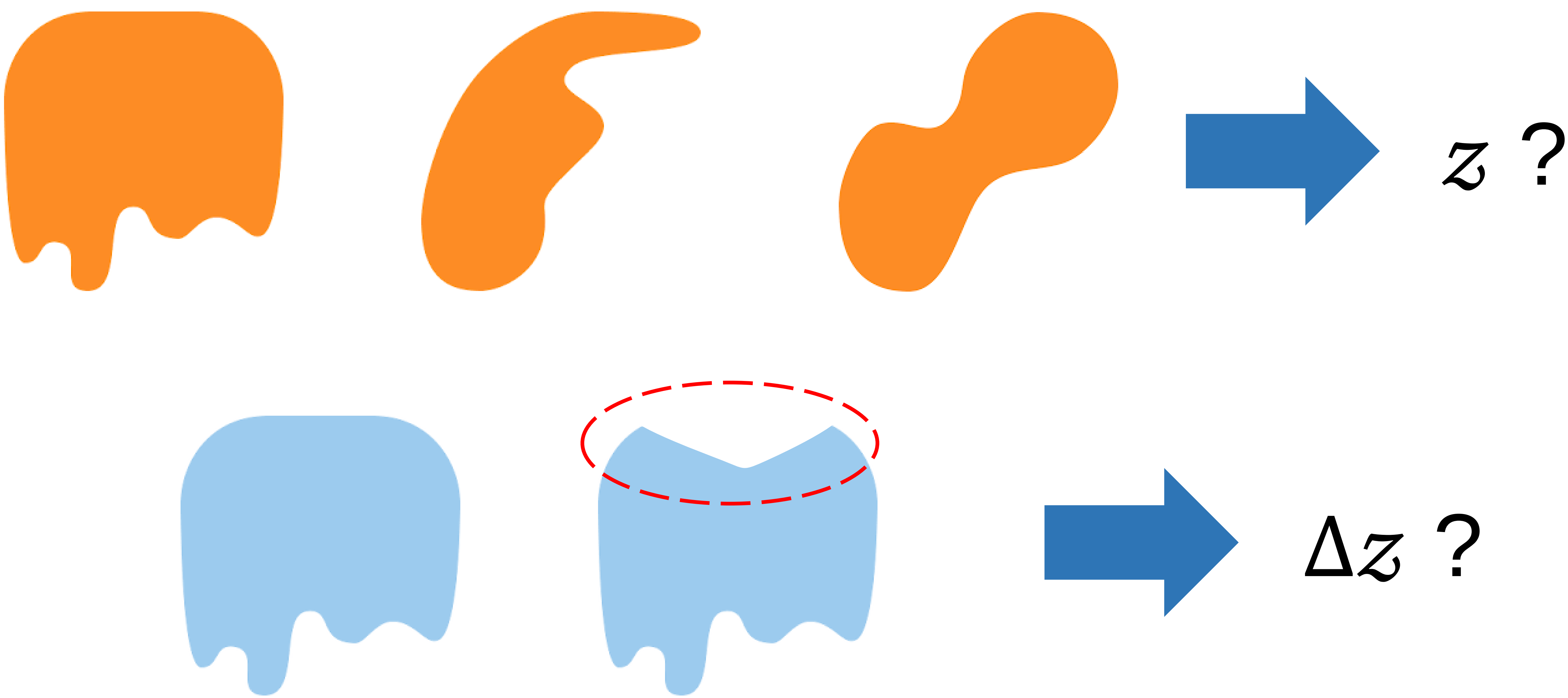
- Experiments for investigating the effectiveness of our approach in various domains and downstream tasks



Question

How do machines represent shape?

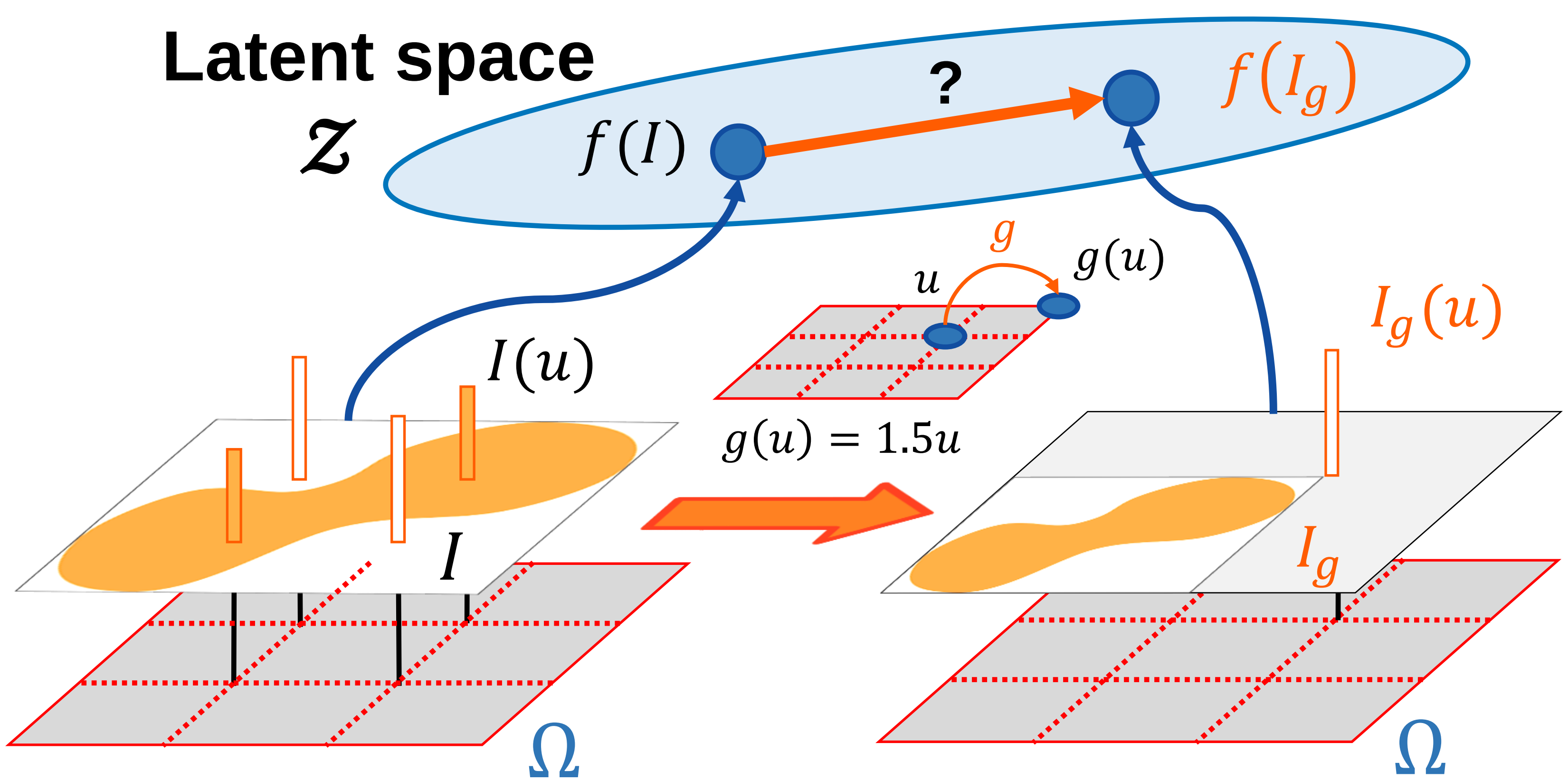
- Are they interpretable, well-aligned for downstream tasks?



Question

How do machines represent geometric concepts?

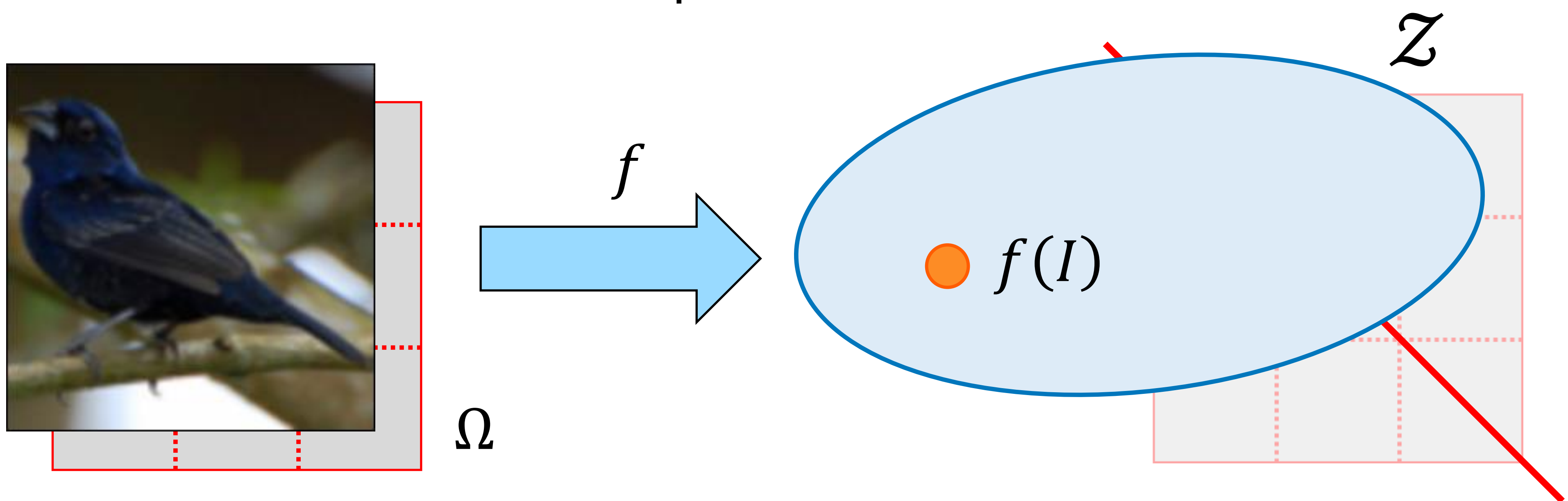
- Ex) position, shape, distance, orientation
- An image I belongs to a physical domain Ω: a 2D grid space
- For given geometric transformation $g: \Omega \rightarrow \Omega$,
  - The transformed image I_g, $I_g(u) = I\left(g^{-1}(u)\right)$
- With given representations $f(I)$ and $f\left(I_g\right)$, can we predict the transformation g?



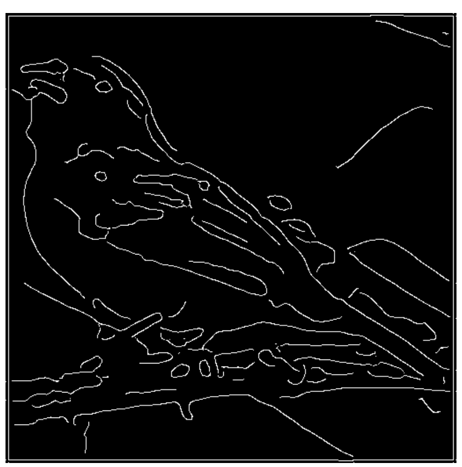
Background

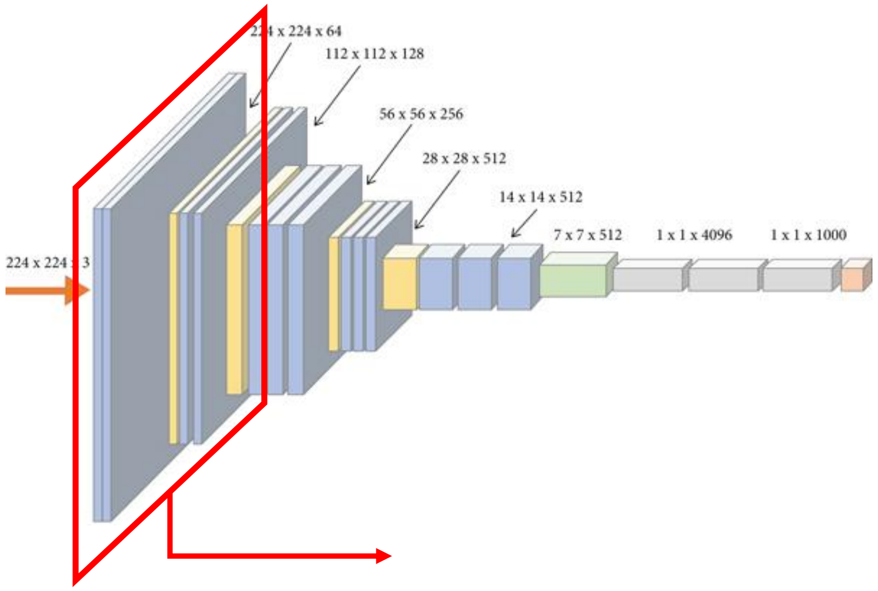
Previous studies

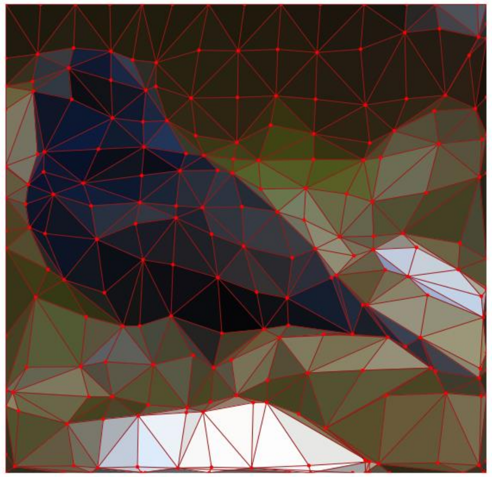
- Representations on semantic latent space



- Representations with same domain Ω





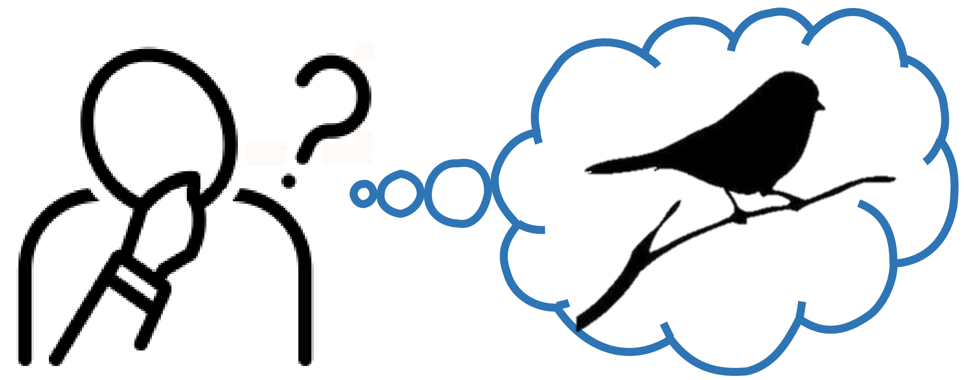


Motivation

How do human represent image?

- Language

Language
"A black bird sitting on a branch"



- Drawing/sketching

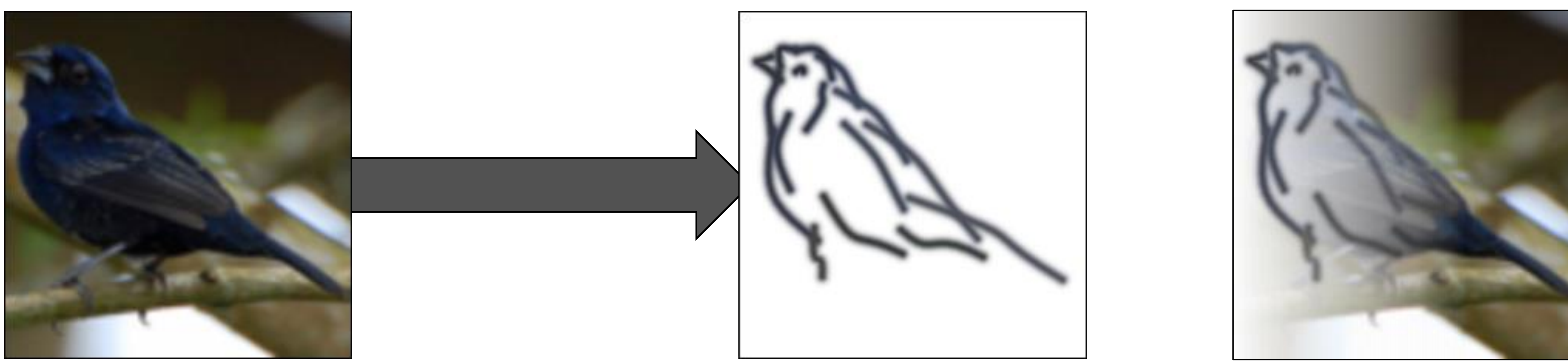
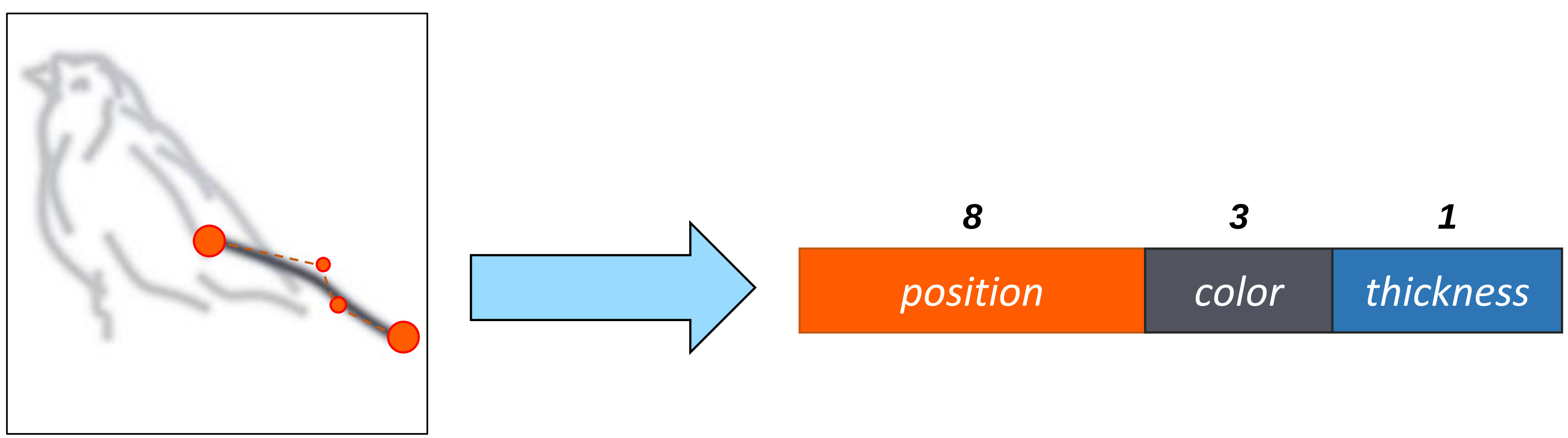


Image **Sketch**

Motivation

Core properties

- Sketching
  - salient features of an image ⇒ abstract image based on set of colored strokes
  - **Preserving geometry**: shares the same physical domain Ω
  - **Abstraction**: representation with limited # of strokes
  - **Compactness**: can be represented as a set of parametric curves



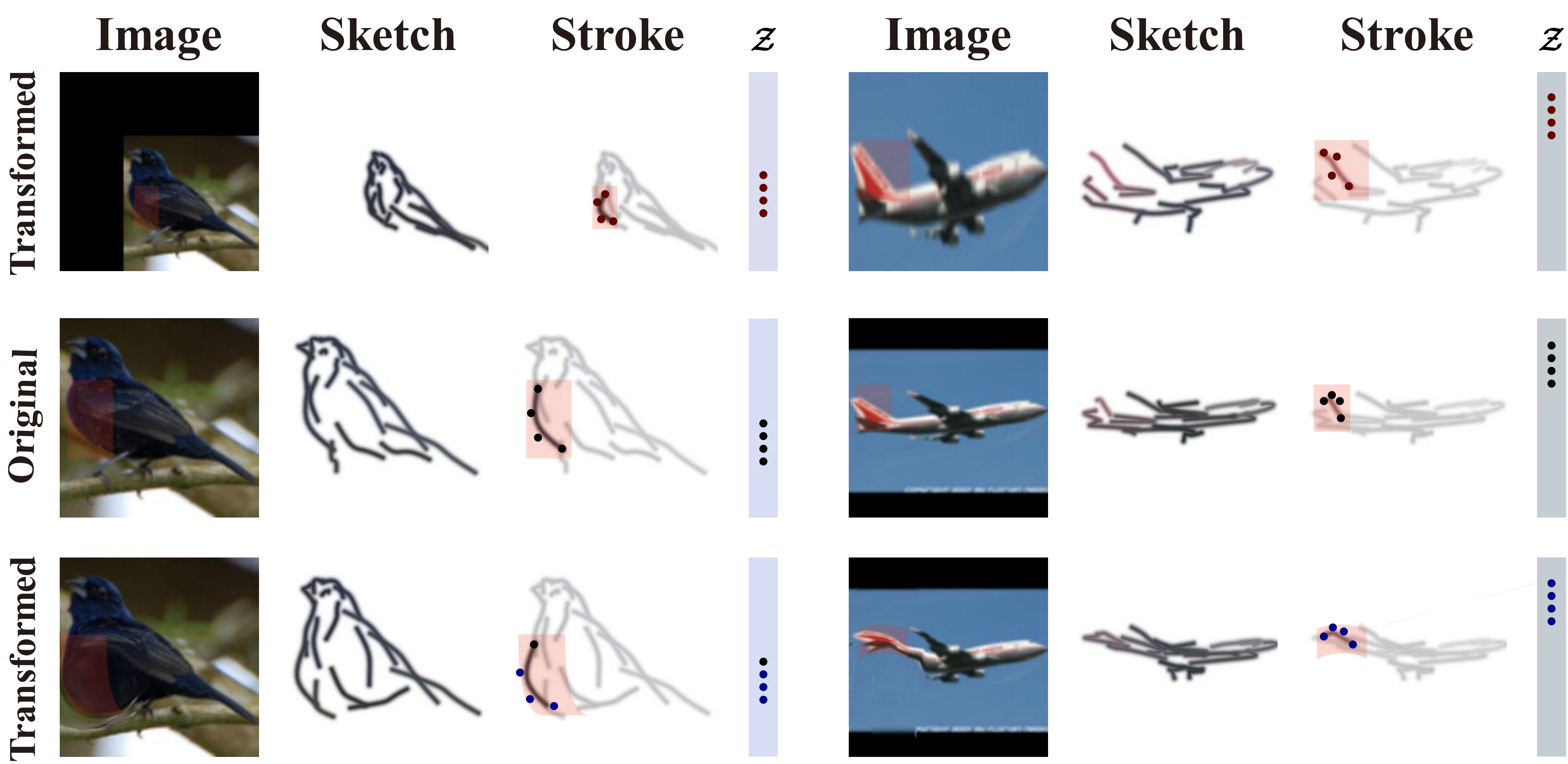
Stroke **Parameterization**

⇒ Based on these properties,
we use **strokes** as a **geometry-aware representation** for various downstream tasks

Mathematical framework

Does sketches & strokes represent geometric information?

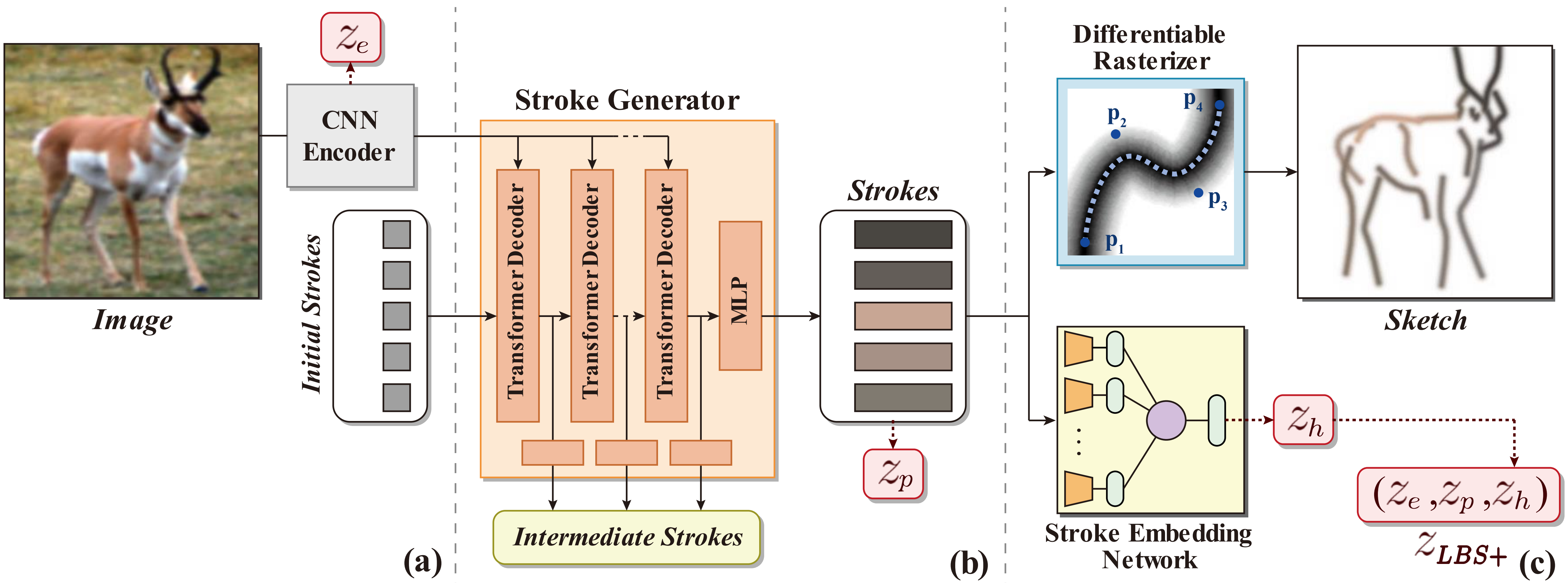
- With given representations $f(I)$ and $f(I_g)$, can we predict the transformation g?
- **$\mathcal{G}$-equivariance**: $\exists \rho' \; s.t. \;\; f(\rho(g) \cdot I) = \rho'(g) \cdot f(I)$
  - Sketching is equivariant to arbitrary geometric transformation $g \in \mathcal{G} \;\; (\rho' = \rho)$
  - Converting into stroke is equivariant to affine transformation $a \in \mathcal{A}$



Architecture

Learning By Sketching (LBS)

- Abstraction & reflecting geometric information in a short inference time
- Without using explicit sketch dataset.

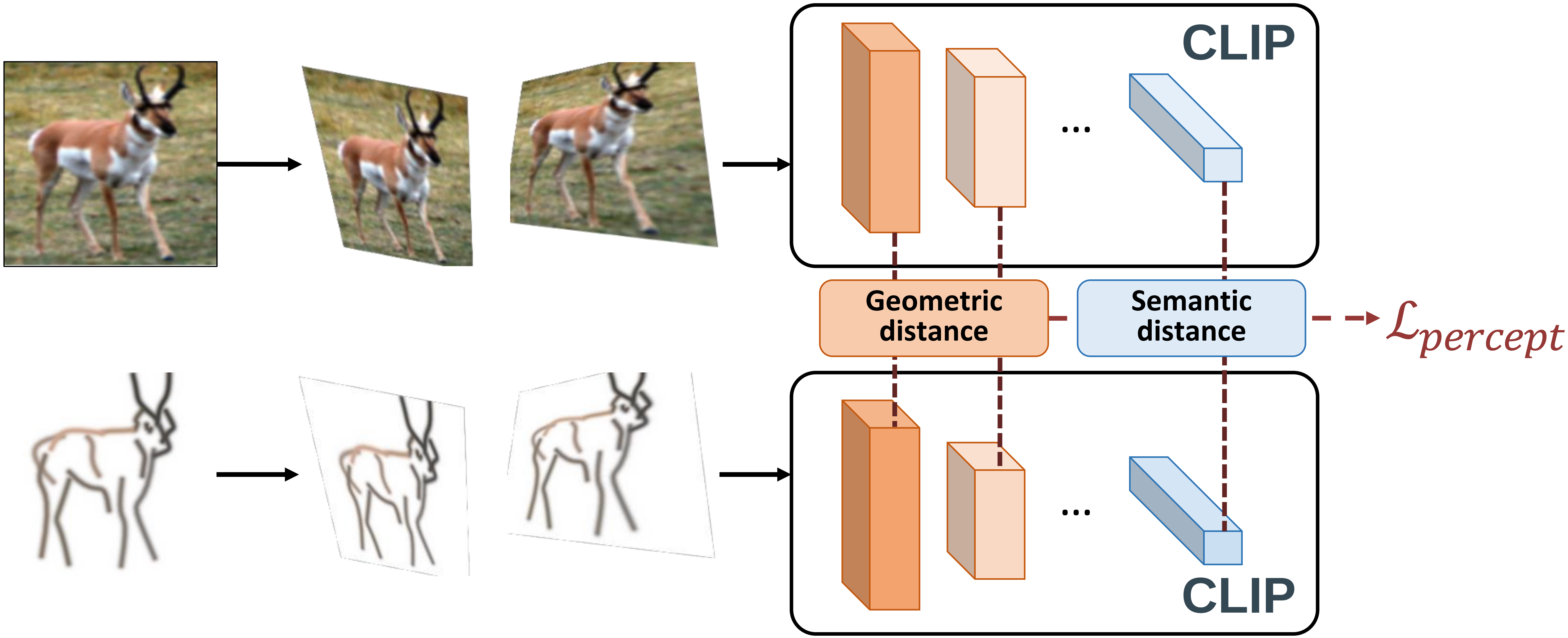


$$\mathcal{L}_{LBS} = \mathcal{L}_{percept} + \lambda_g \cdot \mathcal{L}_{guide} + \lambda_e \cdot \mathcal{L}_{embed}$$

Architecture

Learning By Sketching (LBS)

- $\mathcal{L}_{percept}$: CLIP-based perceptual loss [1]

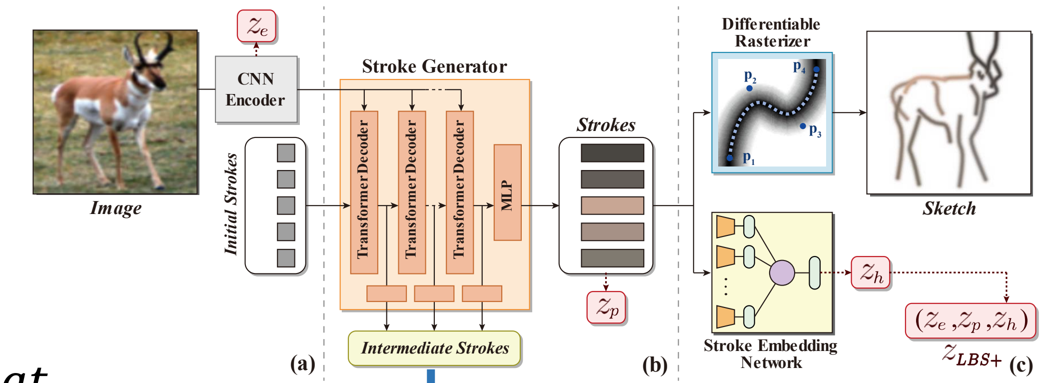


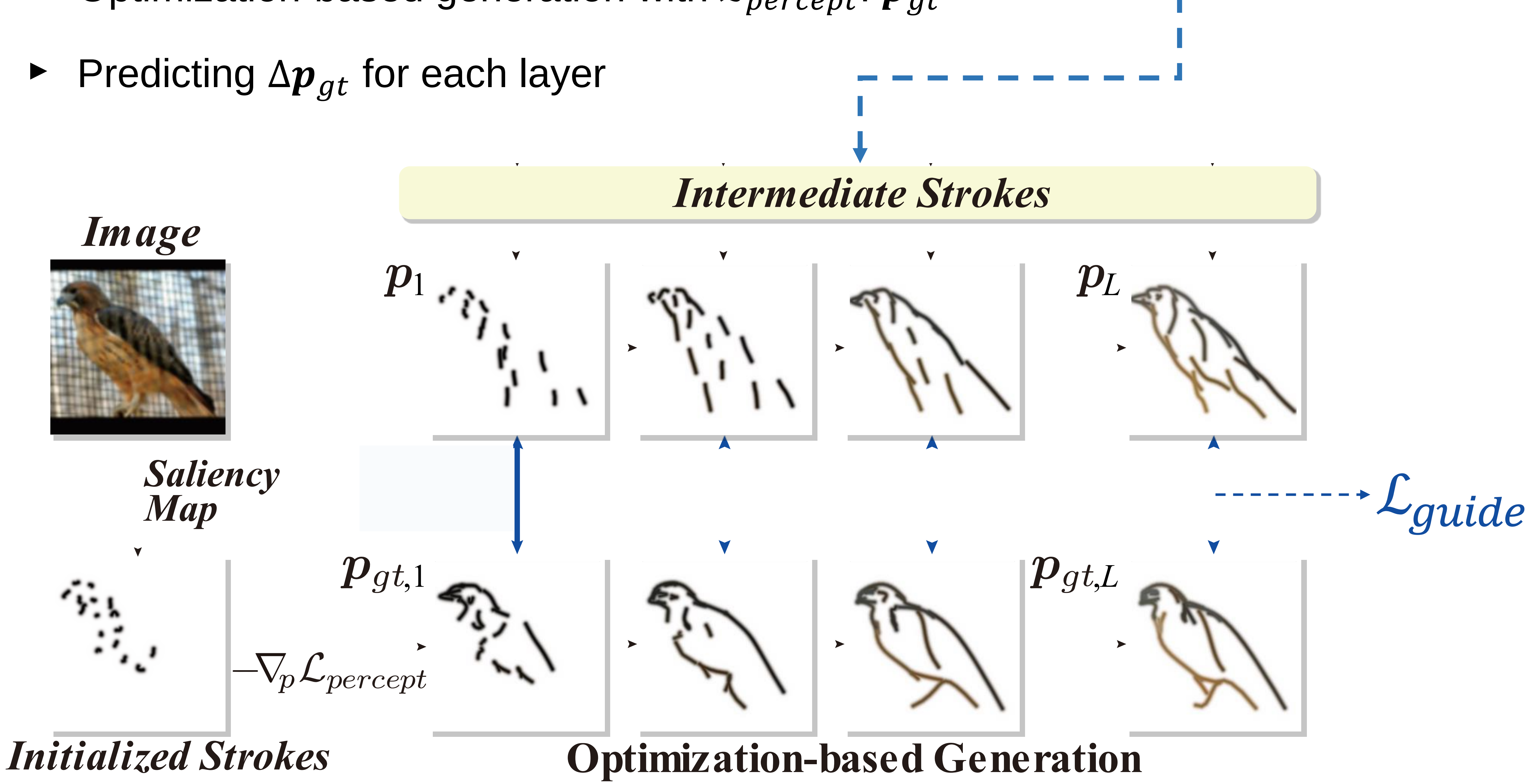
[1] Vinker, Yael, et al. "Clipasso: Semantically-aware object sketching." *ACM Transactions on Graphics (TOG)* 41.4 (2022): 1-11.

Architecture

Learning By Sketching (LBS)

- Guidance loss $\mathcal{L}_{guide}$
  - Optimization-based generation with $\mathcal{L}_{percept}$: $\boldsymbol{p}_{gt}$
  - Predicting $\Delta \boldsymbol{p}_{gt}$ for each layer

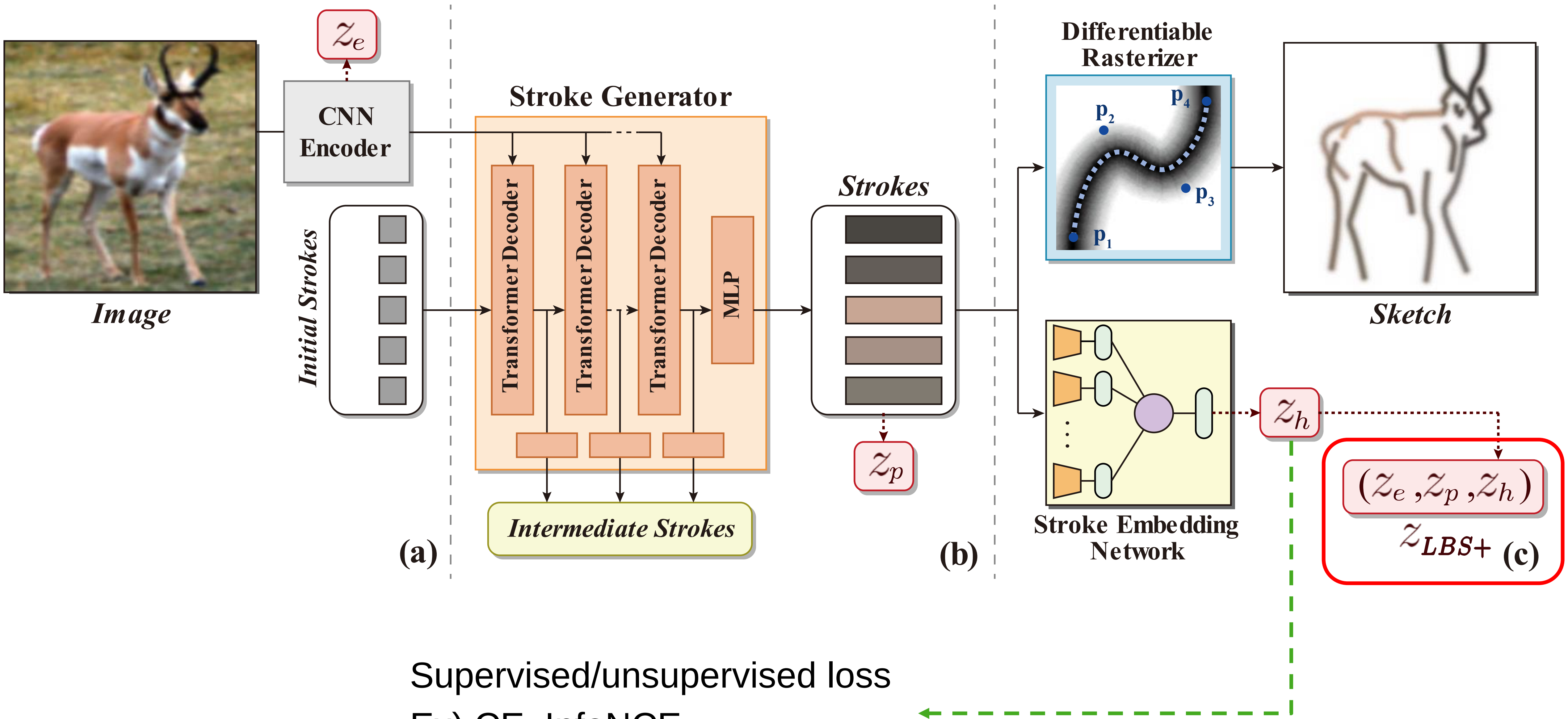




Architecture

Learning By Sketching (LBS)

- Stroke embedding loss $\mathcal{L}_{embed}$
  - z_h: combines the information of all strokes through a stroke embedding network



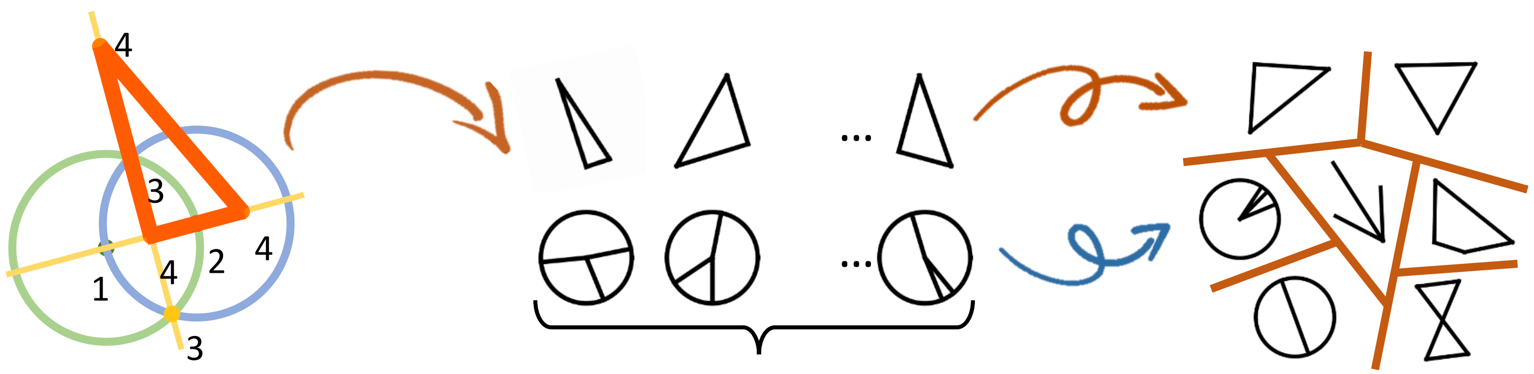
Supervised/unsupervised loss

Ex) CE, InfoNCE, …

Experiments

Quantitative results

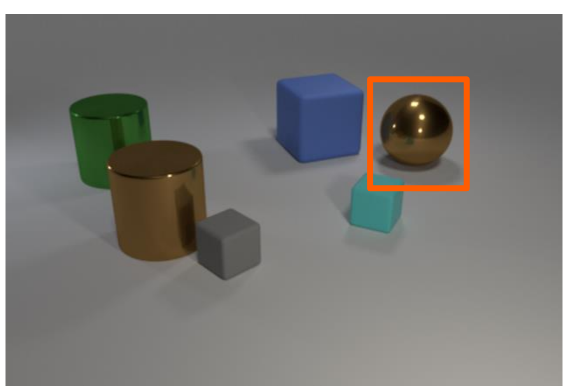
- Understanding geometric primitives & concepts



Euclidean geometry concepts | 10 realizations per class | concept classification

Label	Method	Geoclidean Constraints	Geoclidean Elements
✓	CE	53.89±1.58	70.57±4.29
	SupCon [38]	42.41±3.16	55.83±4.28
	LtD-diff [54]	57.26±2.19	69.47±2.11
	E(2)-CNN [73]	**71.03**±1.94	69.28±1.46
	LBS (CE)	50.01±1.58	**81.06**±3.14
✗	SimCLR [9]	32.04±0.64	65.14±4.11
	β-TCVAE [8]	17.18±1.35	33.82±1.64
	GeoSSL [55]	18.66±3.33	33.47±2.80
	HoG [14]	23.82	52.05
	LBS	**47.43**±1.34	**81.34**±0.16

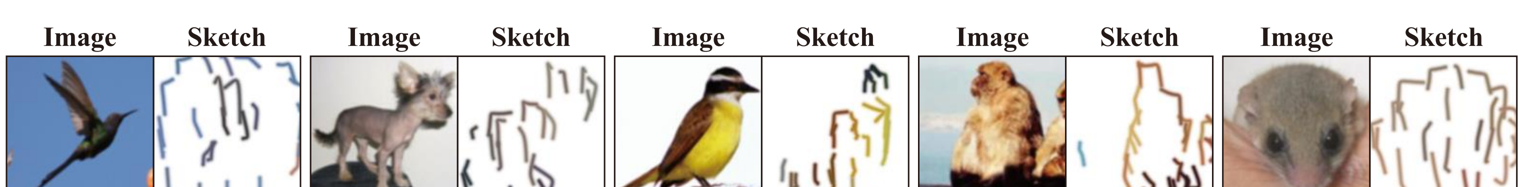
- Local geometric information & Simple spatial reasoning



Q) **Color** of the **leftmost** object?
Q) **Shape** of the rightmost object?
Q) Results after **shifting** the rightmost object?
…
Label: brown

Label	Method	RC	BC	Size	Shape	Third	Shift
✓	CE	98.71±0.10	76.02±0.90	92.51±0.40	49.97±0.29	40.66±0.20	**62.06**±1.62
	SupCon [38]	**98.75**±0.08	66.04±2.65	91.88±0.37	49.15±0.85	37.93±0.27	56.05±2.56
	LtD-diff [54]	62.29±0.48	15.84±0.43	63.98±3.38	43.96±3.05	16.47±0.59	17.21±0.29
	E(2)-CNN [73]	98.50±0.10	73.51±2.50	89.84±0.46	45.85±0.93	**41.95**±0.18	59.29±0.91
	LBS (CE)	97.49±0.22	**84.09**±0.84	**93.22**±0.29	**70.03**±0.68	38.23±0.25	51.56±0.16
✗	SimCLR [9]	60.61±1.24	63.77±2.29	83.35±0.60	41.95±0.33	33.42±0.55	43.05±0.55
	E(2)-CNN [73]	53.50±7.30	55.52±7.60	83.52±1.56	42.06±1.12	30.74±2.84	38.03±4.44
	β-TCVAE [8]	17.09±0.20	20.04±0.71	71.27±0.10	36.30±0.10	15.38±0.19	16.35±0.18
	GeoSSL [55]	20.16±0.63	21.61±0.67	73.79±0.78	44.08±1.10	15.39±0.16	16.94±0.34
	DefGrid [21]	73.81±0.91	73.38±0.80	81.50±0.22	46.34±0.77	24.90±0.27	36.28±0.13
	LBS	**84.31**±0.08	**83.00**±0.39	**92.66**±0.41	**70.01**±0.53	**37.41**±0.29	**49.32**±0.17
	CLIP [59]	37.39	54.98	77.51	66.91	34.75	34.80
	HoG [14]	56.83	58.69	81.73	61.14	24.28	33.25

- Domain transfer

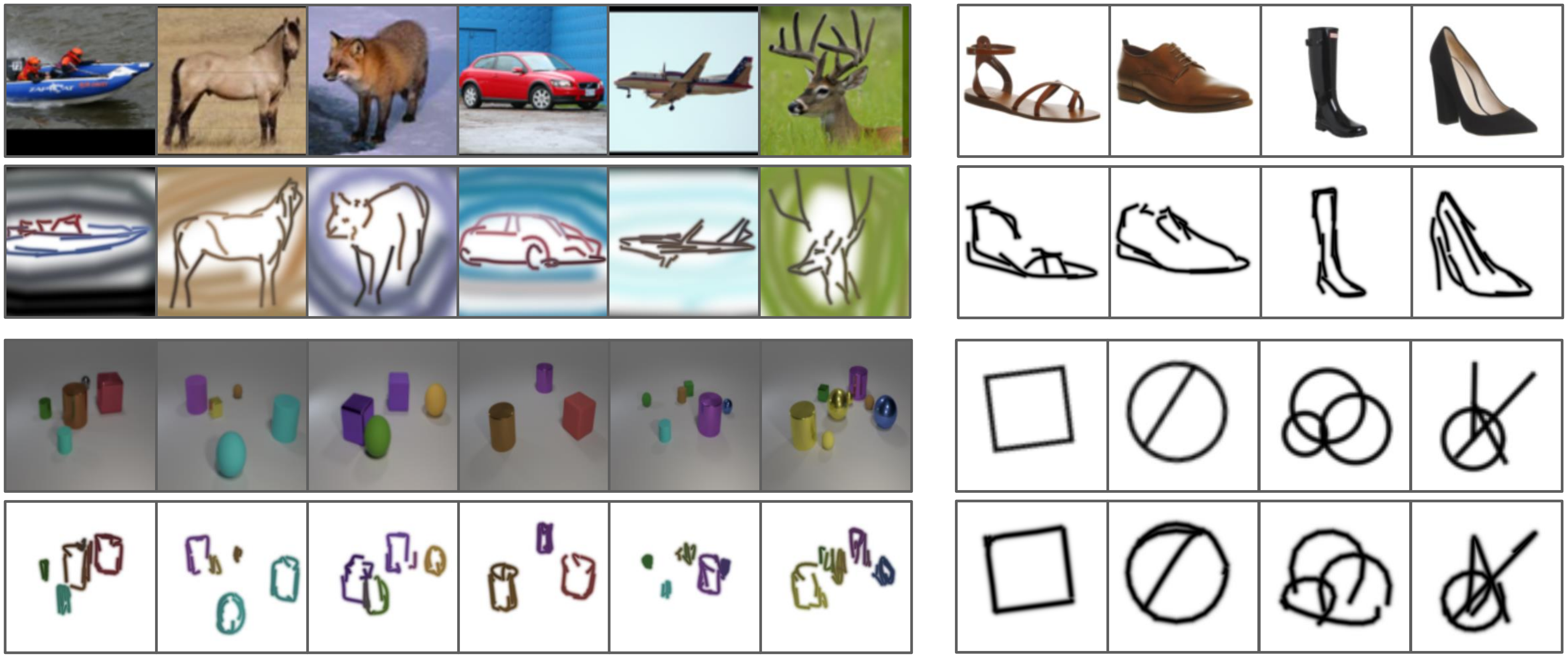


(b) CLEVR → STL-10

Dataset	Labeled Method	Labeled Accuracy	Unlabeled Method	Unlabeled Accuracy
CLEVR ↓ STL-10	CE	46.15±0.12	SimCLR [9]	41.68±0.05
	SupCon [38]	43.41±0.36	β-TCVAE [8]	27.35±0.38
	LtD-diff [54]	50.81±0.67	GeoSSL [55]	35.93±0.96
	E(2)-CNN [73]	45.19±0.84	E(2)-CNN [73]	38.50±0.49
	LBS (CE)	**56.48**±0.89	DefGrid [21]	33.13±0.17
			LBS	**55.35**±0.18

Experiments

Qualitative results



- Progressive optimization process

Thank you