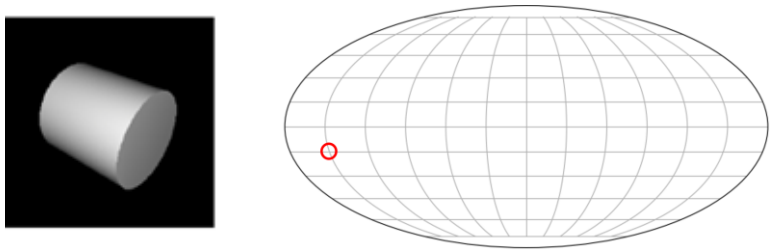
Alignist: CAD-Informed Orientation Distribution Estimation by Fusing Shape and Correspondences

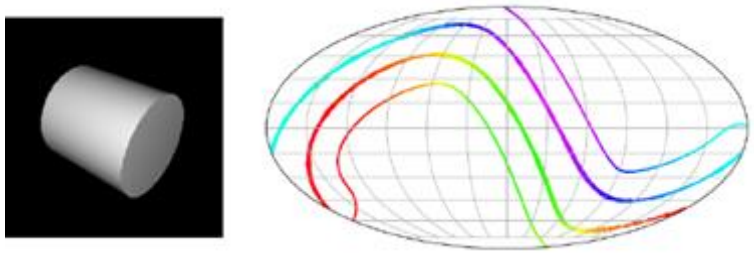
Shishir Reddy Vutukur, Junwen Huang, Rasmus Laurvig Haugaard,
Benjamin Busam, Tolga Birdal

Introduction-Pose Distribution

- Pose Estimation

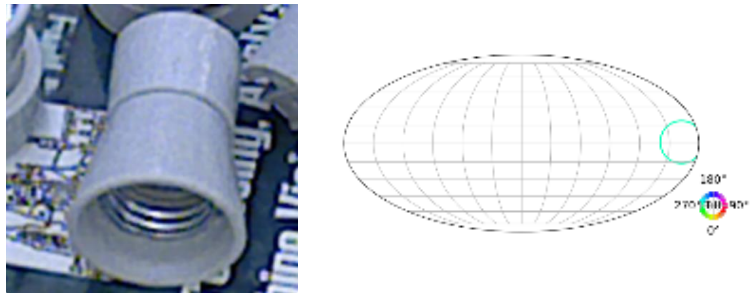


- Pose Distribution Estimation

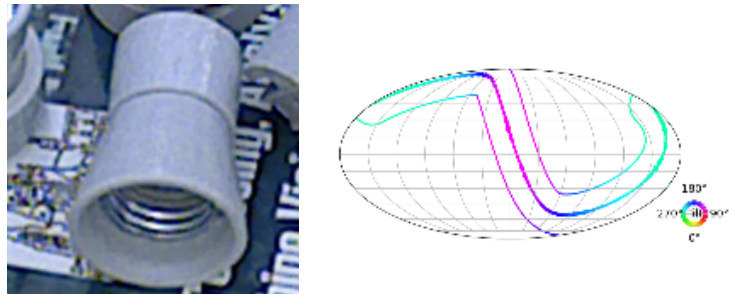


Current Approaches

- Normalizing Flow[1], Implicit-PDF[2], Spyropose[3] learn pose distributions for symmetric objects using a single GT pose label
- Training Data:



Given training data



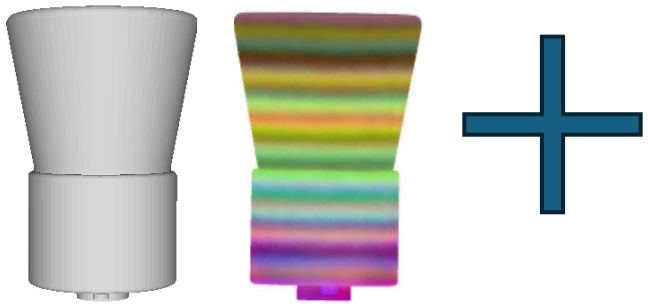
Desired training data

- Can we improve the results further in presence if a CAD model is given?

[1] Yulin Liu, Haoran Liu, Yingda Yin, Yang Wang, Baoquan Chen, He Wang. “Delving into Discrete Normalizing Flows on SO(3) Manifold for Probabilistic Rotation Modeling.”, *CVPR*. 2023
[2] Kieran Murphy, Carlos Esteves, Varun Jampani, Srikumar Ramalingam, Ameesh Makadia. "Implicit-PDF: Non-Parametric Representation of Probability Distributions on the Rotation Manifold." *ICML*. 2021.
[3] Rasmus Laurvig Haugaard, Frederik Hagelskjær, Thorbjørn Mosekjær Iversen. “SpyroPose: SE(3) Pyramids for Object Pose Distribution Estimation .” *ICCVW*, 2023.

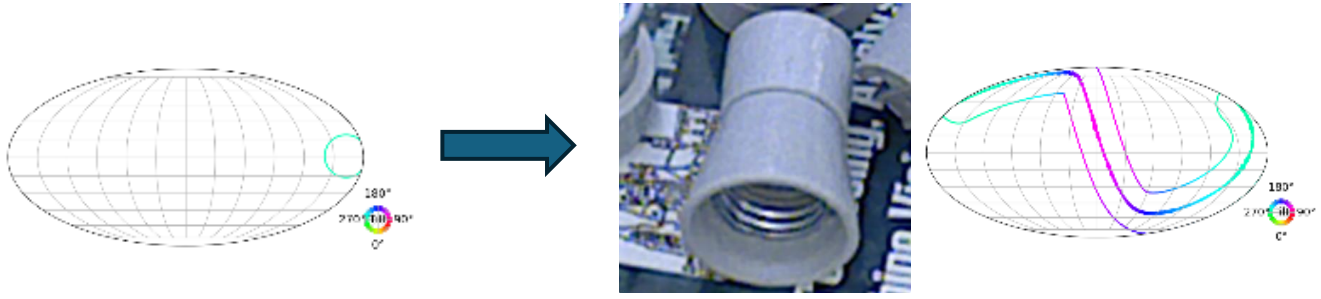
Core Idea

- Convert GT pose label to a complete pose distribution for distribution supervision
- Access to Distribution:
  - Better sampling -> learn sharper distribution
  - All symmetry configurations are learned with a single pose sample



CAD +SurfEMB[1]

GT Pose Label



Pose Distribution label

[1] Rasmus Laurvig Haugaard, Anders Glent Buch. “SurfEmb:Dense and Continuous Correspondence Distributions for Object Pose Estimation with Learnt Surface Embeddings.” *CVPR*, 2022.

Product of Experts

- Reformulate the problem

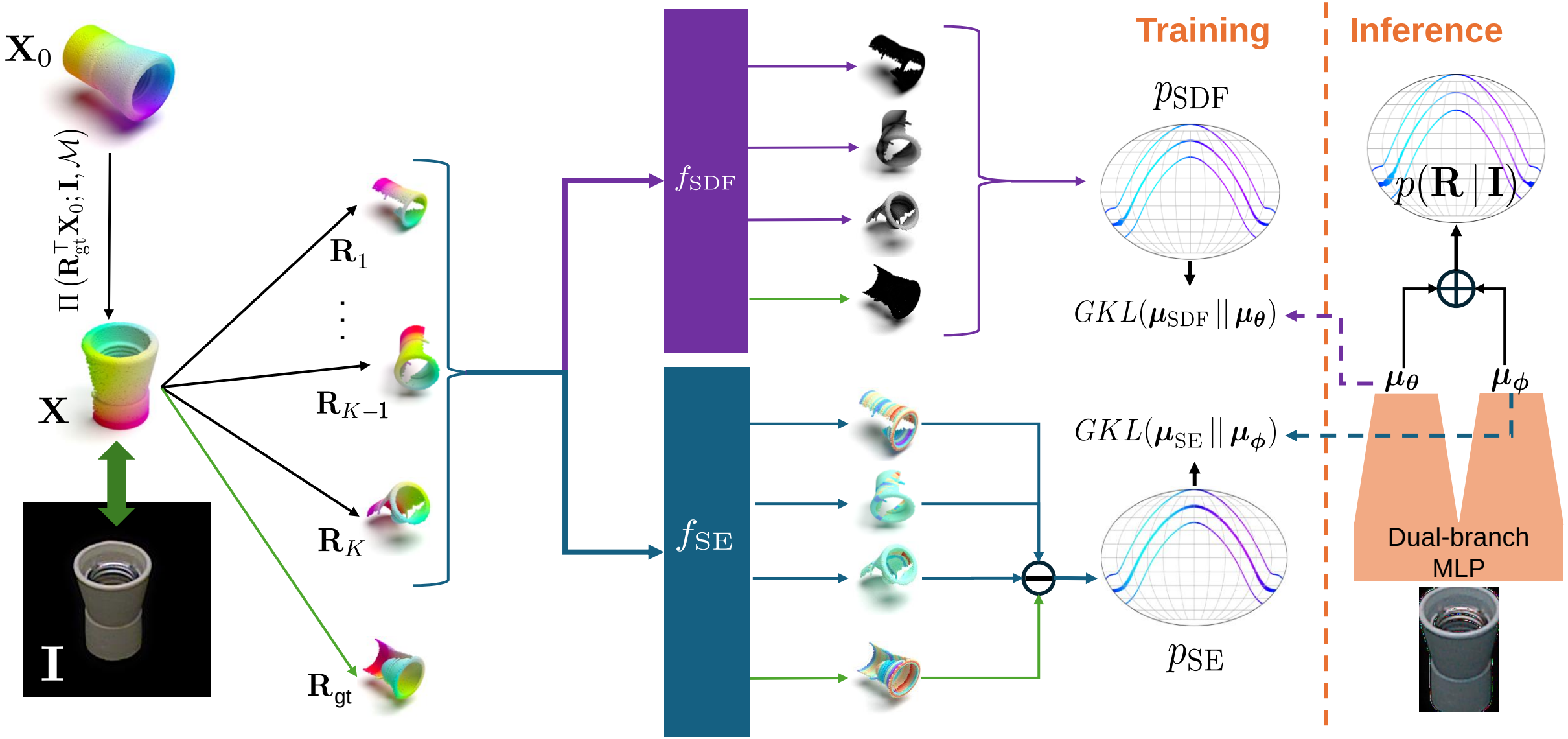
$$p(\mathbf{R}|\mathbf{I}) \propto p(\mathbf{X}'|\mathbf{I})$$

- We employ two experts based on the CAD prior
  - Signed Distance Function(SDF)
  - SurfEmb(SE)

$$p(\mathbf{X}' \mid \mathbf{I}) = \hat{p}_{\mathrm{SDF}}(\mathbf{X}' \mid \mathbf{I})\hat{p}_{\mathrm{SE}}(\mathbf{X}' \mid \mathbf{I})$$

$\mathbf{R}$: Rotation $\mathbf{I}$: Image $\mathbf{X}'$: Pointcloud rotated with $\mathbf{R}$

Pipeline


$\mathbf{X}_0$
$\Pi\left(\mathbf{R}_{\text{gt}}^{\top}\mathbf{X}_0;\mathbf{I},\mathcal{M}\right)$
$\mathbf{X}$
$\mathbf{I}$
$\mathbf{R}_1$
$\mathbf{R}_{K-1}$
$\mathbf{R}_K$
$\mathbf{R}_{\text{gt}}$
f_{SDF}
f_{SE}
Training
Inference
p_{SDF}
$GKL(\boldsymbol{\mu}_{\text{SDF}} \,||\, \boldsymbol{\mu}_{\boldsymbol{\theta}})$
$GKL(\boldsymbol{\mu}_{\text{SE}} \,||\, \boldsymbol{\mu}_{\boldsymbol{\phi}})$
p_{SE}
$p(\mathbf{R}\,|\,\mathbf{I})$
$\boldsymbol{\mu}_{\boldsymbol{\theta}}$
$\boldsymbol{\mu}_{\boldsymbol{\phi}}$
Dual-branch MLP

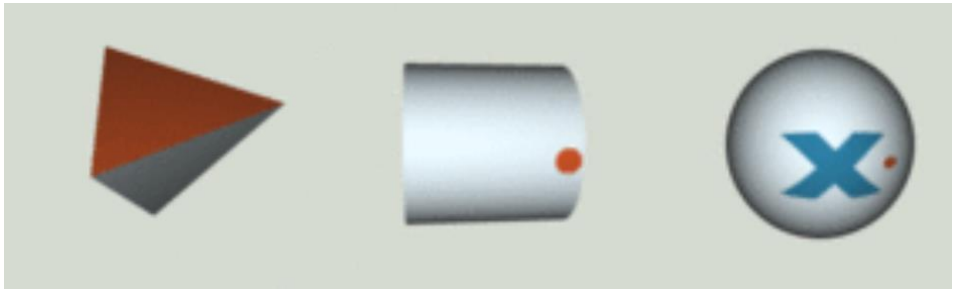
Quantitative Results

- Symsol-I Objects: Textureless symmetric objects

	Deng	Gil.	Prok.	IPDF	SP	NF	NF	NF	NF	Ours	Ours
Models	1	1	1	1	5	1	1	1	1	1	1
Iterations	100k	100k	100k	100k	100k	100k	900k	100k	900k	100k	100k
Images	45k	45k	45k	45k	45k	10k	10k	45k	45k	10k	45k
cone	2.45	6.13	-1.05	6.74	9.91	8.45	8.94	8.42	10.05	9.66	10.10
cube	-2.15	0.00	1.79	7.10	10.92	5.02	9.01	7.13	11.64	11.29	12.24
cyl	1.34	3.17	1.01	6.55	8.75	8.04	6.41	7.83	9.54	9.32	9.40
icosa	-0.16	0.00	-0.10	3.57	7.52	-2.14	-6.03	2.03	8.26	7.99	9.54
tet	2.56	0.00	0.43	7.99	10.98	5.91	10.79	8.98	12.43	11.39	11.96
avg	0.81	1.86	0.42	6.39	9.62	5.06	5.82	6.88	10.38	**9.69**	**10.64**

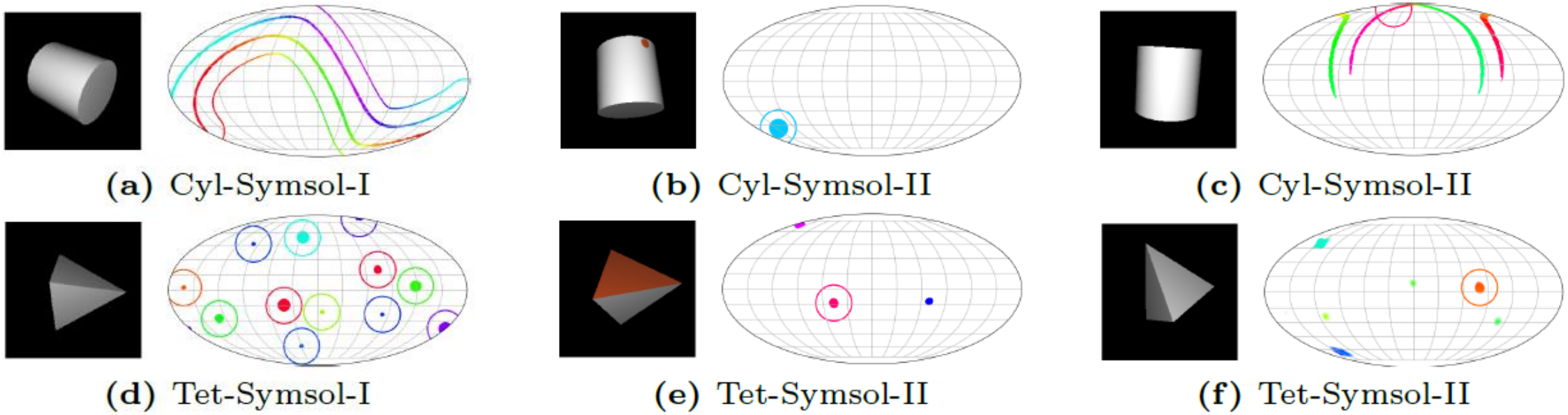
Quantitative Results

- Symsol-II Objects: Symmetric objects with a marker



Obj	Deng	Gil.	Prok.	IPDF	SP	SP-10k	NF-10k	NF	Ours-10k	Ours
SphX	3.41	5.61	-1.90	9.59	11.36	7.67	7.62	12.37	6.32	10.93
cylO	5.28	7.17	6.45	9.20	11.61	9.11	6.99	12.92	11.57	12.18
tetX	5.90	5.19	3.77	10.78	11.70	6.48	3.52	13.53	11.53	12.38
LL	4.86	5.99	2.77	9.86	11.56	7.76	6.04	**12.94**	**9.80**	11.83

Qualitative Results



(a) Cyl-Symsol-I (b) Cyl-Symsol-II (c) Cyl-Symsol-II

(d) Tet-Symsol-I (e) Tet-Symsol-II (f) Tet-Symsol-II

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