Unsupervised Discovery of Object Landmarks as Structural Representations

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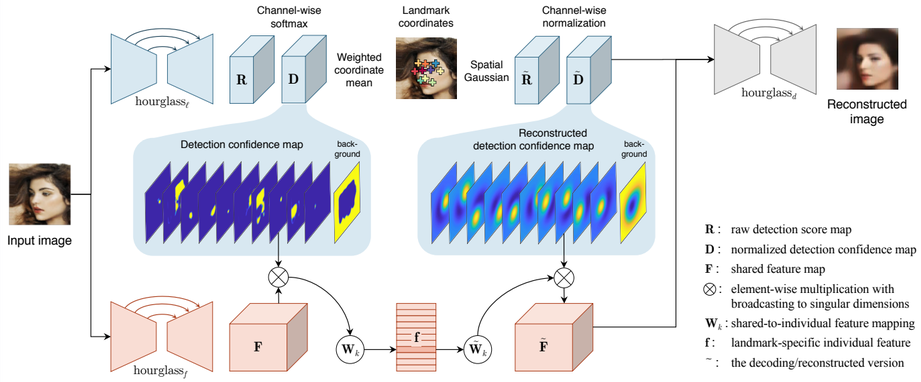
1 Unsupervised Learning of Explicit Representation

- Deep neural networks can model images with rich latent representations but cannot naturally conceptualize structures of object.
- Our method **learns object structures as explicit representations** for image modeling. In particular, we proposed an autoencoder framework to **discover meaningful object landmarks without supervision**.
- Landmarks: Salient points semantically consistent across object instances.

2 Landmarks as Intermediate Representations in Autoencoder



3 Desirable Properties of Object Landmarks as Regularization

- Heatmap concentration constraint: reduce the spatial variance of $\mathbf{D}$

$$L_{\text{conc}} = \frac{\pi e}{2}\left(\sigma^2_{\text{det},u} + \sigma^2_{\text{det},v}\right)^2$$

- Landmark separation constraint: Landmarks cannot be too close

$$L_{\text{sep}} = \sum_{k \neq k'}^{1,\dots,K} \exp\left(-\frac{\|(x_{k'}, y_{k'}) - (x_k, y_k)\|_2^2}{2\sigma^2_{\text{sep}}}\right)$$

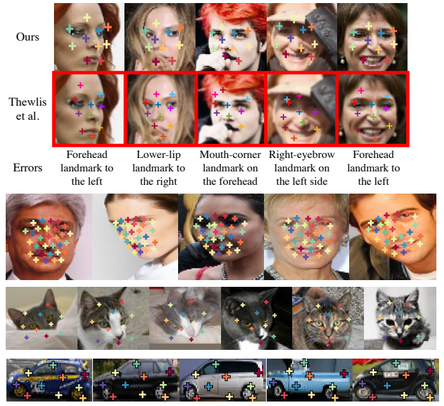
- Equivariance constraint: when the image warps, the landmark coordinates should warp accordingly. Random thin-plate-spline (TPS) warping is used in training.

$$L_{\text{eqv}} = \sum_{k=1}^{K} \|g(x'_k, y'_k) - (x_k, y_k)\|_2^2$$

For videos, also use the optical flows as the transformation g.

4 Landmark Discovery Results

- Our method can discover visually meaningful and stable landmarks on several object categories.



5 Human-annotated Landmark Prediction

- Train a linear regressor to map the discovered landmarks to the human annotated landmarks.

Human facial landmark detection

- Outperforming previous unsupervised methods and off-the-shelf fully supervised methods.

	Method	MAFL	ALFW
Fully supervised	TCDCN	7.95	7.65
	Cascaded CNN	9.73	8.97
	RAR	-	7.23
	MTCNN	5.39	6.90
Unsupervised discovery	Thewlis et al. (50 landmarks)	6.67	10.53
	Thewlis et al. (dense frames)	5.83	8.80
	Ours (10 landmarks)	**3.46**	**7.01**
	Ours (30 landmarks)	**3.15**	**6.58**

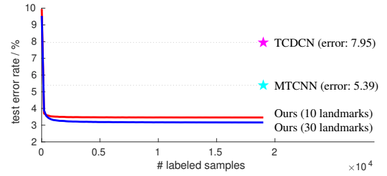
Ablative study on CelebA/MAFL

- All training objectives contribute to the final results.

Full model	No autoencoder	No concentration	No equivariance	No separation
3.15	3.45	3.91	8.42	16.56

Less labeled data for the linear regressor

- Useful for semi-supervised landmark detection
- < 500 labeled samples are enough



Landmark detection on other types of objects

- Wide applicability to many object categories.

Dataset	Car		Cat head		Human3.6M
# target landmarks	5		7		32
# discovered landmarks	10	24	10	20	16
Thewlis et al.	11.42	11.11	26.76	26.94	7.51
Ours	**5.87**	**5.80**	**15.35**	**14.84**	**4.14**

6 Attribute Prediction using Discovered Landmarks

- Our discovered landmarks are effective representations for shape-related facial attribute prediction.

Predicting 13 binary facial attributes related to the facial shape on CelebA.

Method	Feature dimension	Accuracy
Ours (discovered landmarks)	60	83.2
FaceNet (top-layer)	128	80.0
FaceNet (top-layer) + Ours	188	**84.3**
FaceNet (conv-layer)	1792	82.4
FaceNet (conv-layer) + Ours	1852	**84.1**

7 Image Manipulation using Discovered Landmarks

- Our model provides a landmark-conditioned image decoder.
- The discovered landmarks are disentangled from the appearance latent features automatically.

reconstructed manipulated