EUROPEAN CONFERENCE ON COMPUTER VISION

MILANO 2024

HyperSpaceX: Radial and Angular Exploration of HyperSpherical Dimensions

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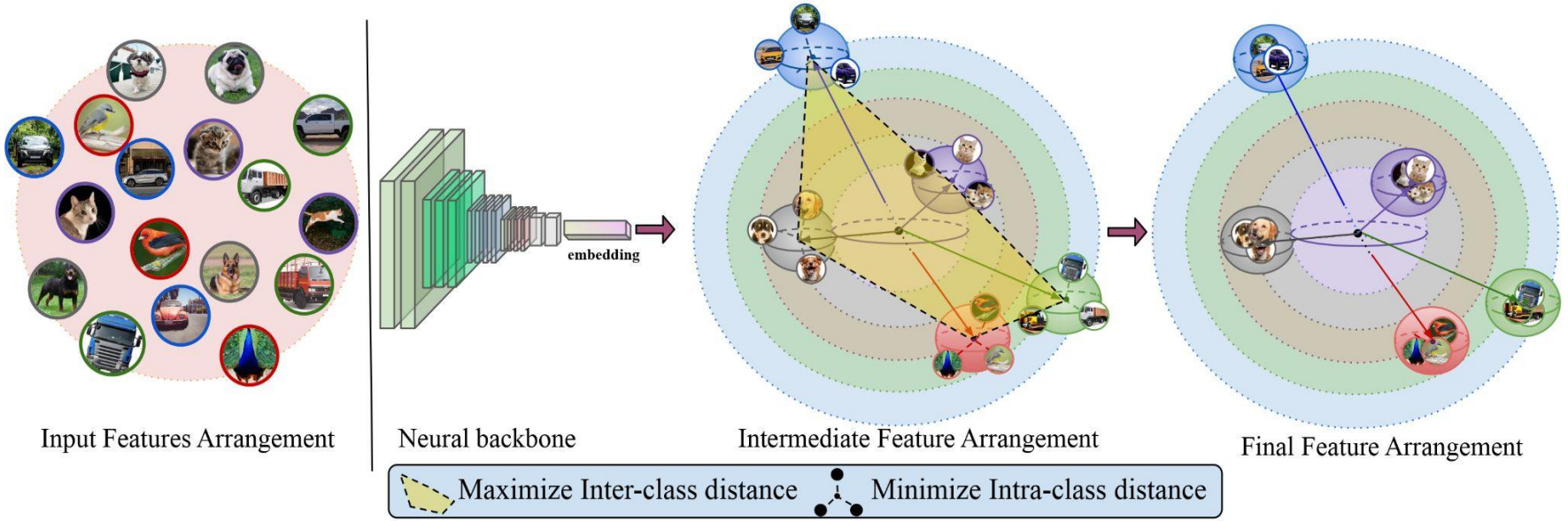
Project page: https://github.com/IAB-IITJ/HyperSpaceX

Paper: https://arxiv.org/abs/2408.02494

IAB
IMAGE ANALYSIS AND BIOMETRICS

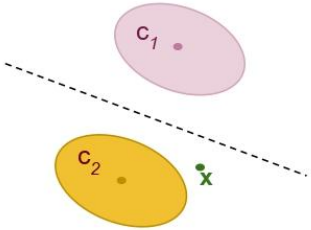
भारतीय प्रौद्योगिकी संस्थान जोधपुर
Indian Institute of Technology Jodhpur
॥ त्वं ज्ञानमयो विज्ञानमयोऽसि ॥

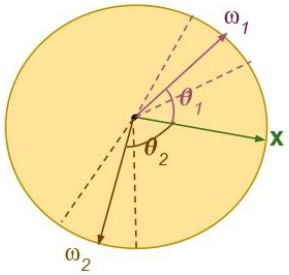
HyperSpaceX Framework: Overview

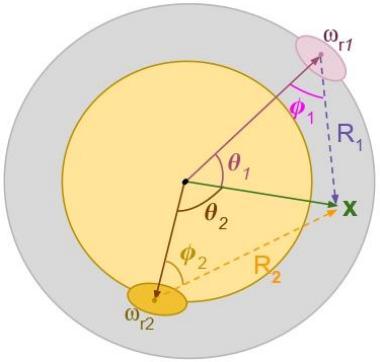


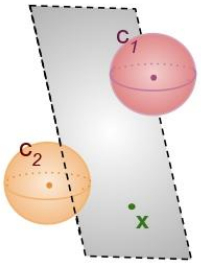
- Introducing HyperSpaceX, a novel discriminative feature representation and arrangement learning framework that explores both radial and angular dimensions in multi-hyperspherical space.
- HyperSpaceX shows its efficacy over multiple small and large-scale image and face recognition datasets.

Framework Comparison



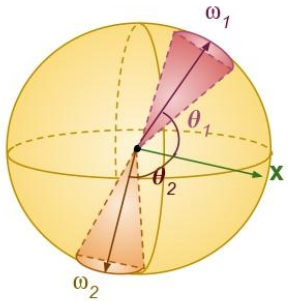






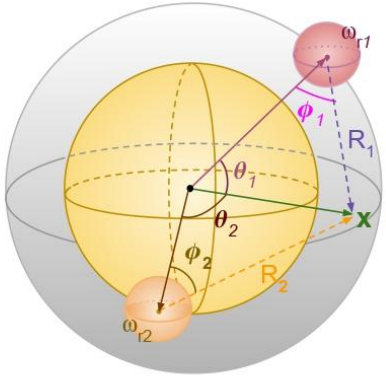
(a)

Metric-based Learning



(b)

Angular Learning



(c)

Radial-Angular Learning

Preliminaries - Existing Loss Functions

$$L_{\text{Con}} = \ y \times D^2 \ + \ (1-y) \times max(\eta - D, 0)^2$$

Contrastive Loss

$$L_{\text{CE}} = -\frac{1}{N}\sum_{i=1}^{N}\log\frac{e^{\omega_{y_i}^T x_i + b_{y_i}}}{\sum_{j=1}^{K} e^{\omega_j^T x_j + b_j}}$$

Cross-Entropy Loss

$$L_{\text{ArcFace}} = -\frac{1}{N}\sum_{i=1}^{N}\log\frac{e^{cos(\theta_{y_i}+m)}}{e^{cos(\theta_{y_i}+m)} + \sum_{j=1, j\neq y_i}^{K} e^{cos\theta_j}}$$

ArcFace Loss

Proposed DistArc Loss

$$L_{\text{DistArc}} = -\frac{1}{N}\sum_{i=1}^{N}\log\frac{e^{\cos(\theta_{y_i}+m)+\cos(\phi_{y_i})-\lambda\delta_{y_i}}}{e^{\cos(\theta_{y_i}+m)}+\sum_{j=1,j\neq y_i}^{K}e^{\cos(\theta_j)-\lambda\delta_j}}$$

Predictive Measure

Resultant computation in terms of θ and φ :

$$||R_i||_2 = ||x||_2\ \cos\phi_i\ +\ ||\omega_{r_i}||_2\ \cos(\pi-(\theta_i+\phi_i))\ \ \forall\in 1,2,3,...$$

A favourable class determining predictive measure for the HyperSpaceX framework with its radial-angular based formulation:

$$\hat{y} = argmin_{R_m}\{R_m \in \mathbb{R}^K : R_m\}$$

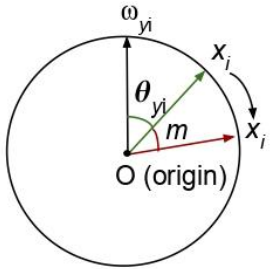
DistArc Loss Components

***cos*(θ)**

$$\cos(\theta_{y_i}) = \hat{\omega}_{y_i} \cdot \hat{x}_i$$

$$\theta_{y_i} = acos(\hat{\omega}_{y_i} \cdot \hat{x}_i)$$

$$\cos(\theta_{y_i} + m) = \cos(acos(\hat{\omega}_{y_i} \cdot \hat{x}_i) + m)$$

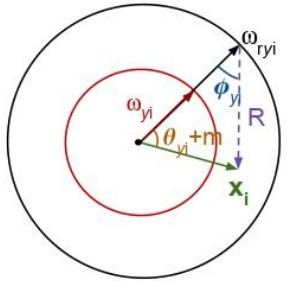


***cos*(φ)**

$$\omega_{r_{y_i}} = \hat{\omega}_{y_i} \times r_{y_i}$$

$$R_{y_i} = -\omega_{r_{y_i}} + x_i$$

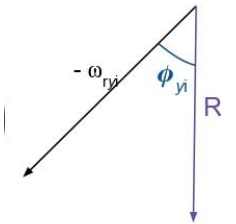
$$\cos(\phi_{y_i}) = \hat{R}_{y_i} \cdot -\hat{\omega}_{r_{y_i}}$$



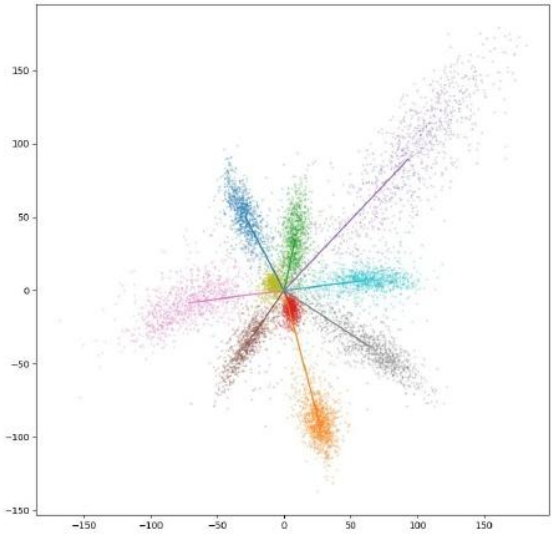
δ

$$\delta_{y_i} = ||\omega_{r_{y_i}} - x_i||_2^2$$

$$\delta_j = ||\omega_{r_j} - x_i||_2^2 \quad , when \;\; j \neq y_i$$

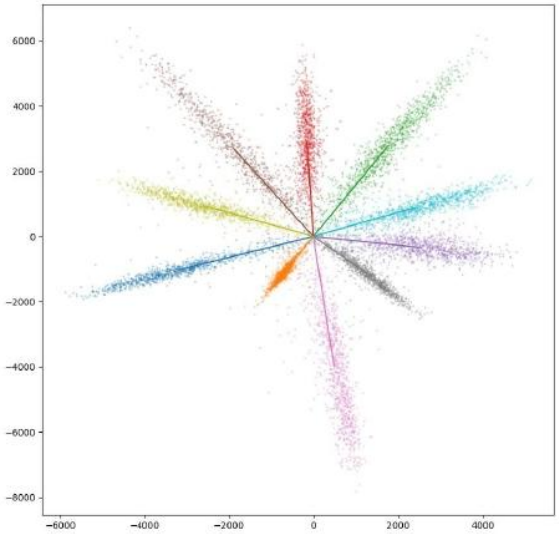


Latent Space Visualization



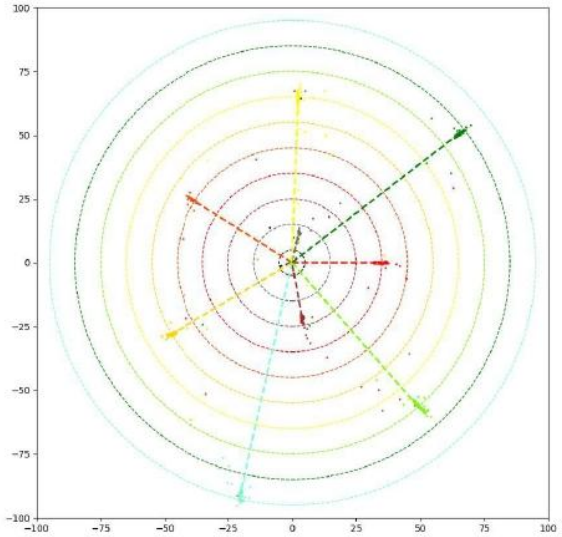
(a)

Cross-Entropy loss



(b)

ArcFace loss



(c)

DistArc loss

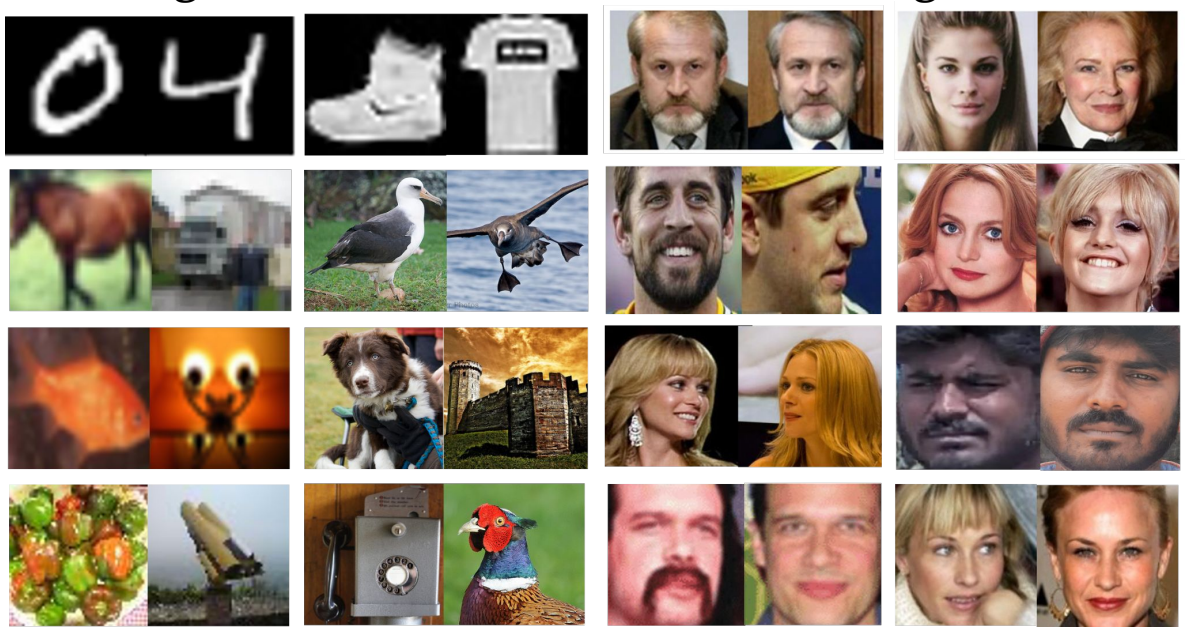
Tasks Improved with HyperSpaceX

Image Classification

Face Recognition

Backbones

iResNet50
RN101
ViT-B
ViT-L
ResNet18

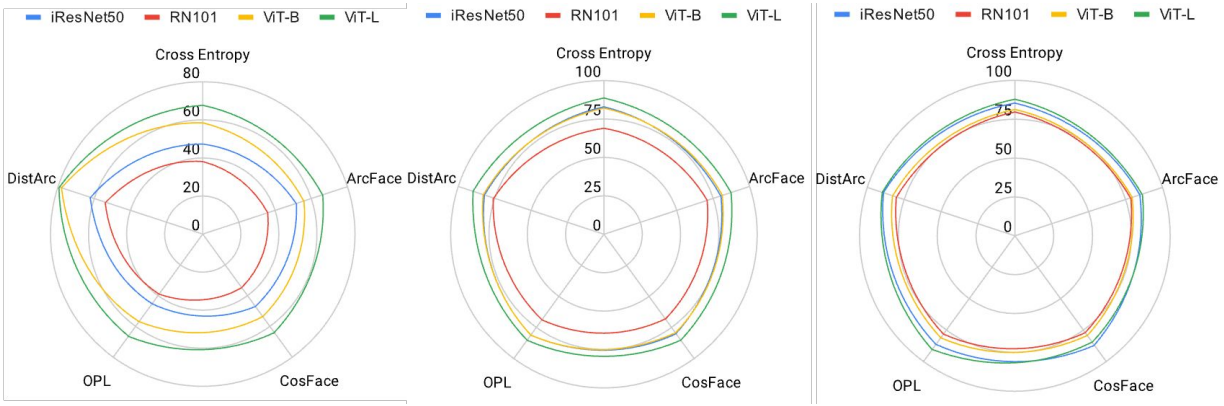


Loss Functions

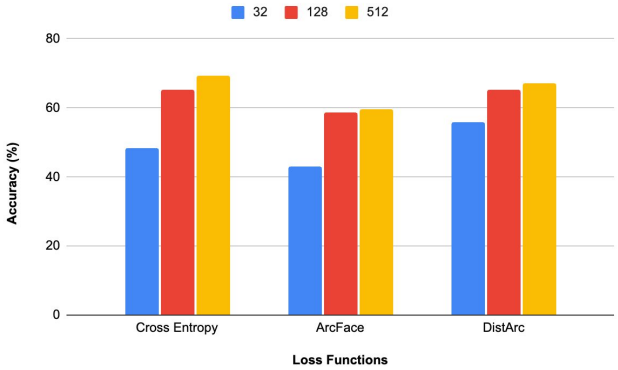
Cross-Entropy
SpherFace
CosFace
ArcFace
SphereFace2
Center
Triplet
DistArc

Small Scale	Large Scale	V. Large Scale	Training	Testing
MNIST Fashion-MNIST CIFAR-10	CIFAR-100 TinyImageNet CUB-200	ImageNet-1K	CASIA-WebFace MS1Mv2 D-LORD	LFW CFP-FP AgeB-30 CA-LFW CP-LFW D-LORD

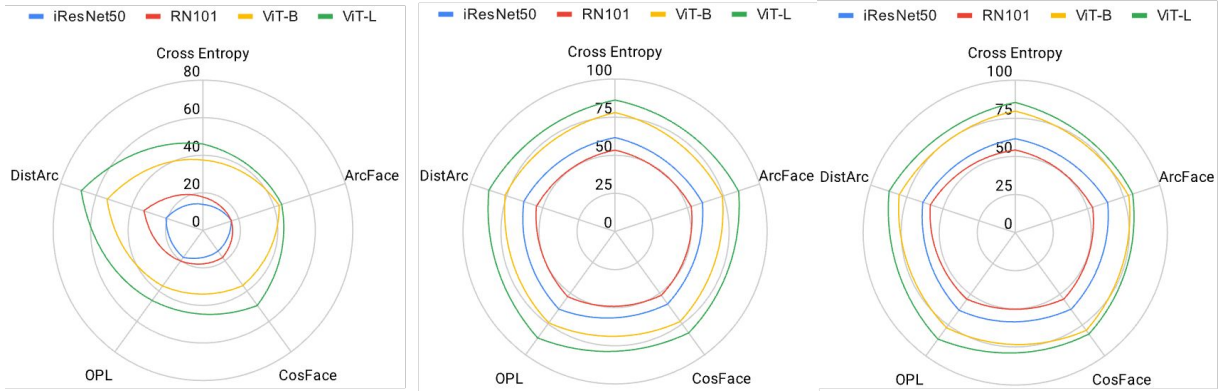
Performance on Image Classification Tasks



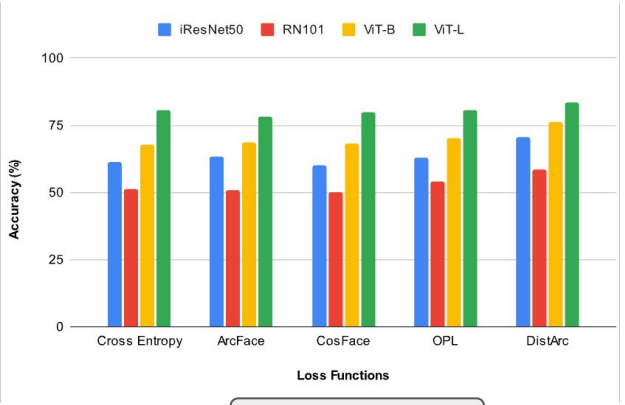
CIFAR-100



ImageNet-1K

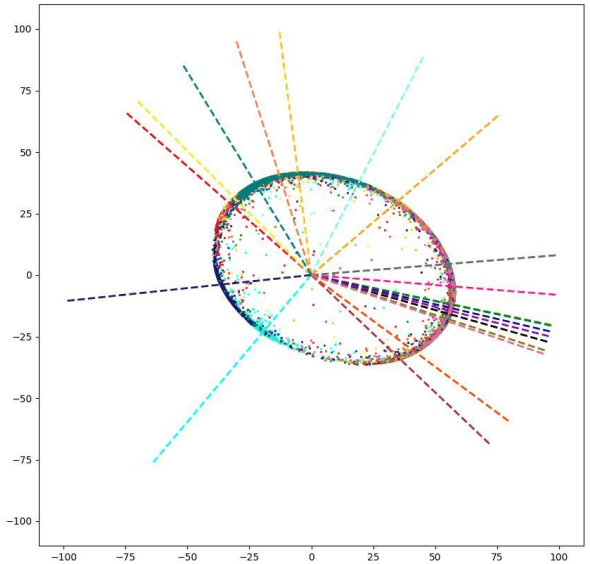


Tiny-ImageNet

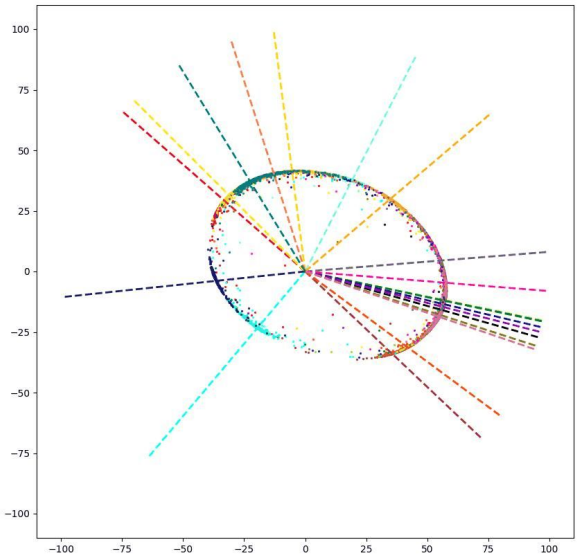


CUB-200

Visualization of Feature arrangement learning in Latent space on CIFAR-100 Dataset

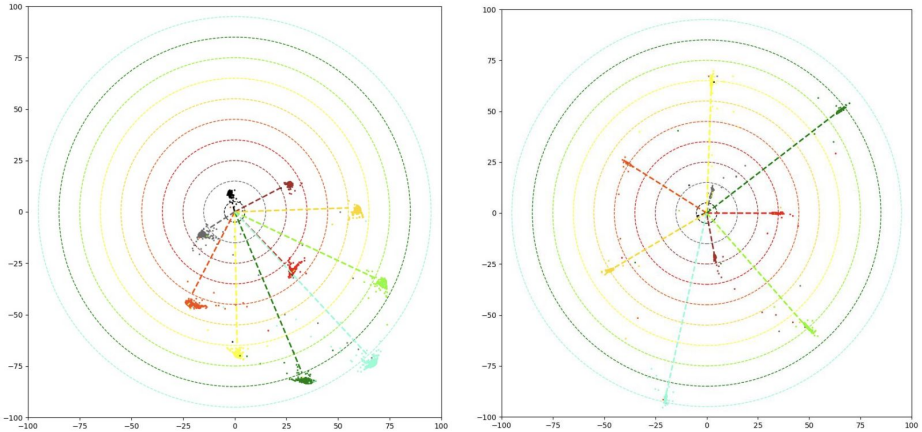


Training Phase



Evaluation Phase

Experimental and Visual Ablation



(a) (b)

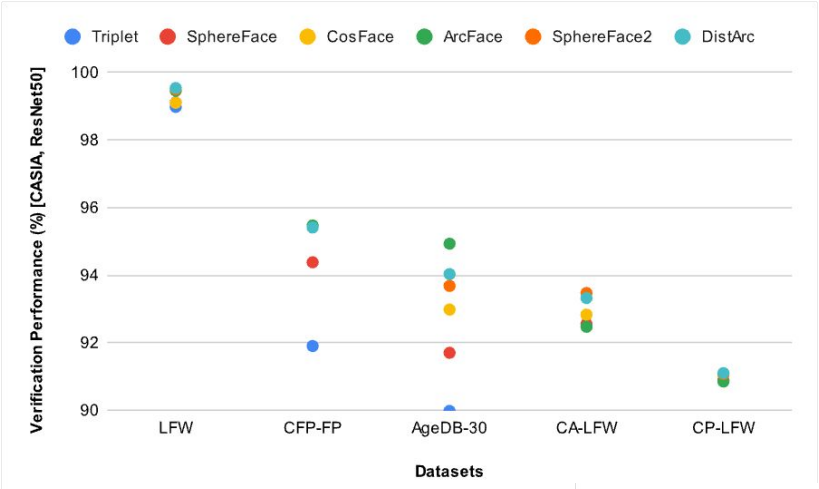
Visual geometric ablation showing significance of (a) cos(θ) and δ, and (b) after incorporation of cos(ϕ).

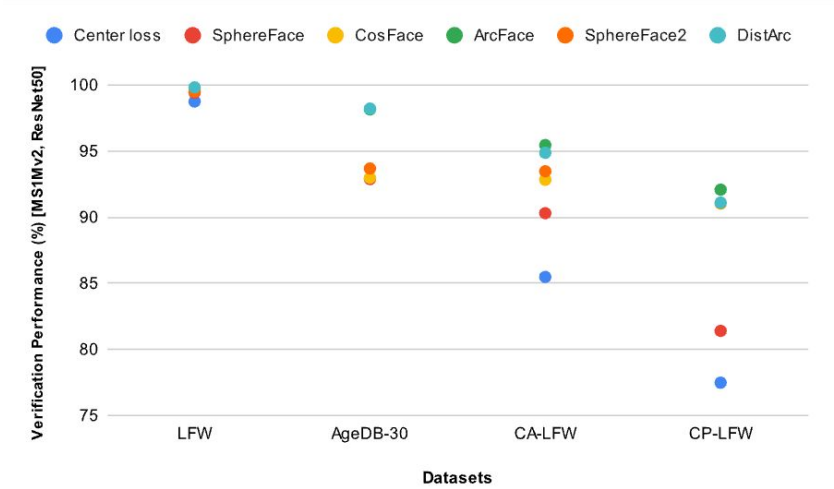
Loss Components	MNIST	Fashion MNIST	CIFAR-10
cos(θ)	98.97	93.69	94.81
cos(θ) & cos(φ)	98.93	93.72	95.16
cos(θ) & δ	99.01	94.83	95.31
cos(θ) & cos(φ) & δ	99.19	95.04	96.03

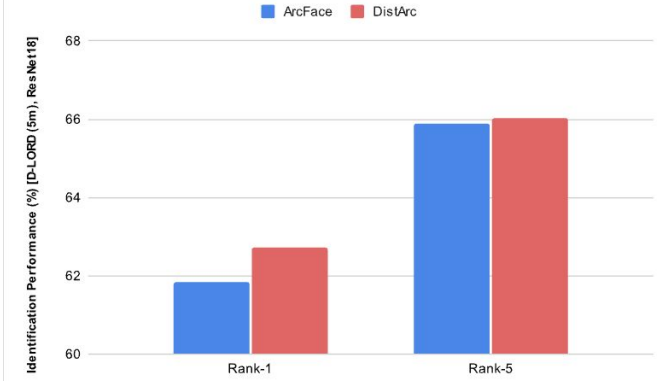
Ablation based on varying radial gap between consecutive hyper-spheres.

Ablation based on varying number of hyper-spheres.

Performance on Face Recognition Tasks







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Thu 3 Oct 2024, Poster #26, Poster Session 6

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Paper: https://arxiv.org/abs/2408.02494

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