

Deep Learning for Computer Vision

CNNs for Human Understanding: Faces

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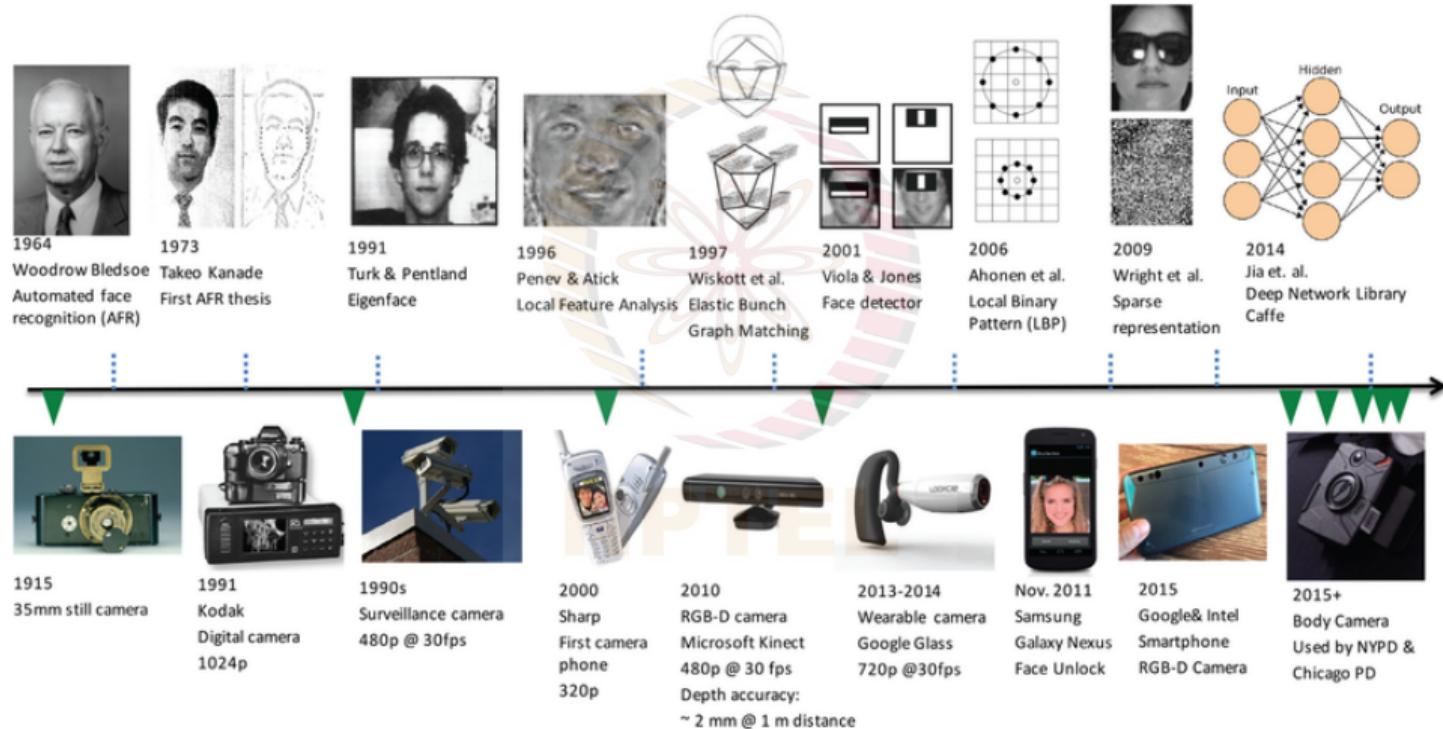
Face Recognition



- Face Recognition (FR): Core vision task with applications in security, finance, healthcare and many other areas of social and financial importance
- Unconstrained FR challenging due to variations in lighting, occlusions, pose/alignment, expressions, etc

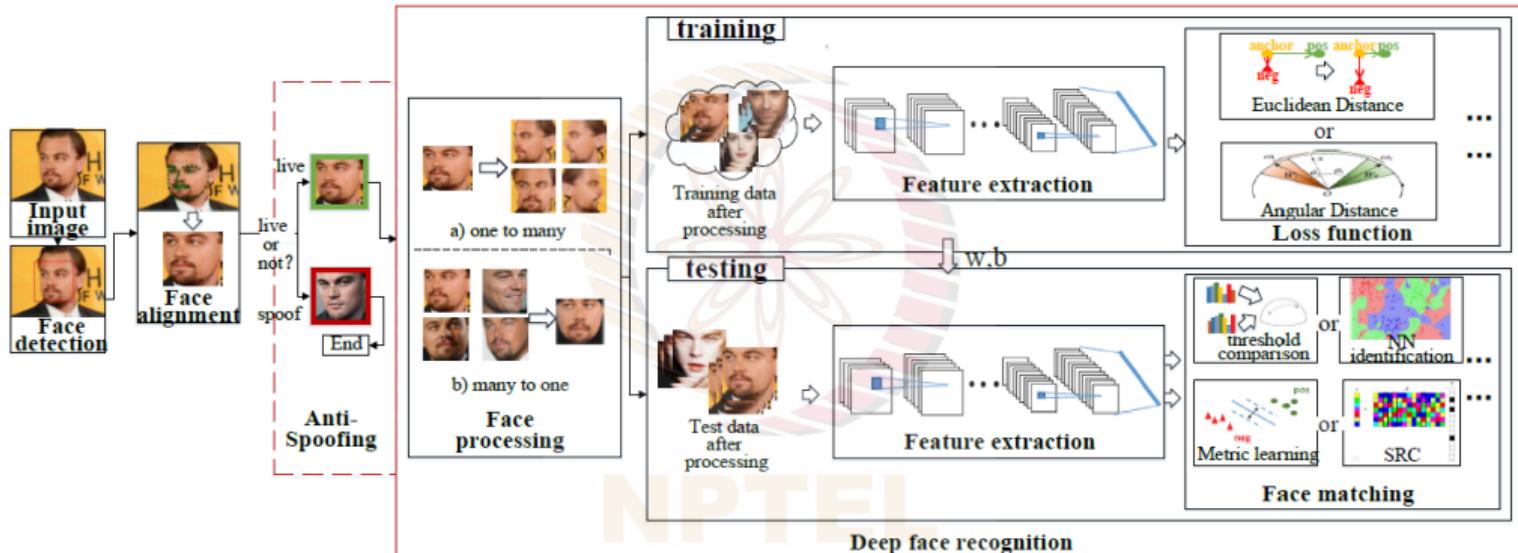
Credit: VGGFace2 Dataset

Face Recognition: History



Credit: Jain et al, 50 Years of Biometric Research: Accomplishments, Challenges, and Opportunities, PR Letters 2016

Face Recognition



- A typical deep FR system's pipeline is shown above
- Face Recognition = Face Detection + Face Alignment + Face Matching

Credit: Wang et al, Deep Face Recognition: A Survey, 2018

Face Recognition System: Key Components

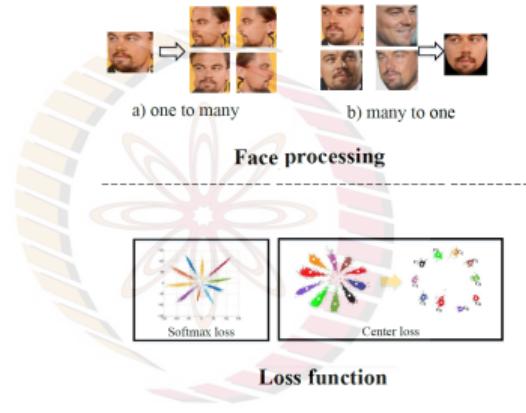
- **Face Processing**

- One-to-many Augmentation
- Many-to-one Normalization

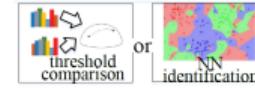
- **Deep Feature Extraction**

- Network Architecture
- Loss Function

- **Face Matching** by Deep Features



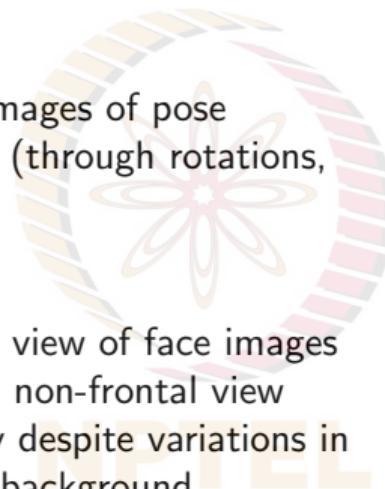
Feature extraction using deep conv. networks



Face matching

Credit: Wang et al, Deep Face Recognition: A Survey, 2018

Face (Pre-)Processing



- **One-to-many Augmentation**

- Generating many patches or images of pose variations from a single image (through rotations, for e.g.)

- **Many-to-one Normalization**

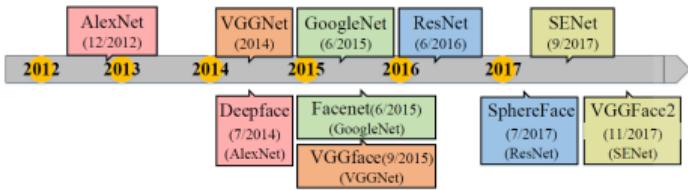
- Attempts to recover canonical view of face images from one or many images of a non-frontal view
- Can help in preserving identity despite variations in pose, lighting, expression and background



Credit: Wang et al, *A Survey on Face Data Augmentation*, *Neural Computing and Applications*, 2019; Qian et al, *Unsupervised Face Normalization With Extreme Pose and Expression in the Wild*, *CVPR 2019*

Network Architectures for Face Recognition

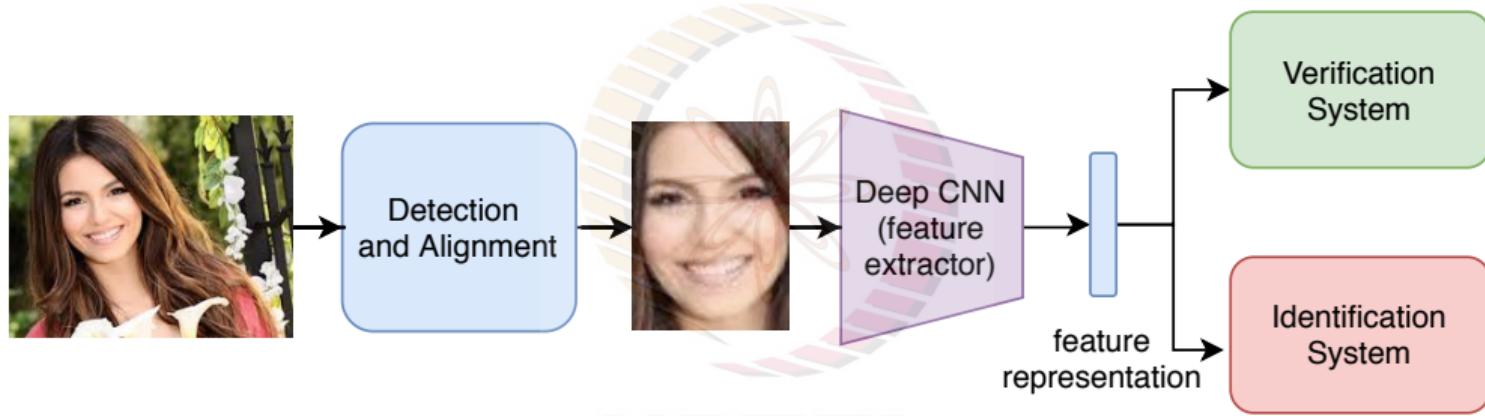
- Few special CNN architectures proposed for deep FR
- However, most successful backbone networks in deep FR shaped around then SOTA deep object classification networks



Method	Public Time	Loss	Architecture	Number of Networks	Training Set	Accuracy±Std(%)
DeepFace [195]	2014	softmax	Alexnet	3	Facebook (4.4M,4K)	97.35±0.25
DeepID2 [187]	2014	contrastive loss	Alexnet	25	CelebFaces+ (0.2M,10K)	99.15±0.13
DeepID3 [188]	2015	contrastive loss	VGGNet-10	50	CelebFaces+ (0.2M,10K)	99.53±0.10
FaceNet [176]	2015	triplet loss	GoogleNet-24	1	Google (500M,10M)	99.63±0.09
Baidu [124]	2015	triplet loss	CNN-9	10	Baidu (1.2M,18K)	99.77
VGGface [149]	2015	triplet loss	VGGNet-16	1	VGGface (2.6M,2.6K)	98.95
light-CNN [225]	2015	softmax	light CNN	1	MS-Celeb-1M (8.4M,100K)	98.8
Center Loss [218]	2016	center loss	Lenet-7	1	CASIA-WebFace, CACD2000, Celebrity+ (0.7M,17K)	99.28
L-softmax [126]	2016	L-softmax	VGGNet-18	1	CASIA-WebFace (0.49M,10K)	98.71
Range Loss [261]	2016	range loss	VGGNet-16	1	MS-Celeb-1M, CASIA-WebFace (5M,100K)	99.52
L2-softmax [157]	2017	L2-softmax	ResNet-101	1	MS-Celeb-1M (3.7M,58K)	99.78
Normface [206]	2017	contrastive loss	ResNet-28	1	CASIA-WebFace (0.49M,10K)	99.19
CoCo loss [130]	2017	CoCo loss	-	1	MS-Celeb-1M (3M,80K)	99.86
vMF loss [75]	2017	vMF loss	ResNet-27	1	MS-Celeb-1M (4.6M,60K)	99.58
Marginal Loss [43]	2017	marginal loss	ResNet-27	1	MS-Celeb-1M (4M,80K)	99.48
SphereFace [125]	2017	A-softmax	ResNet-64	1	CASIA-WebFace (0.49M,10K)	99.42
CCL [155]	2018	center invariant loss	ResNet-27	1	CASIA-WebFace (0.49M,10K)	99.12
AMS loss [205]	2018	AMS loss	ResNet-20	1	CASIA-WebFace (0.49M,10K)	99.12
Cosface [207]	2018	cosface	ResNet-64	1	CASIA-WebFace (0.49M,10K)	99.33
Arcface [42]	2018	arcface	ResNet-100	1	MS-Celeb-1M (3.8M,85K)	99.83
Ring loss [272]	2018	Ring loss	ResNet-64	1	MS-Celeb-1M (3.5M,31K)	99.50

Credit: Wang et al, Deep Face Recognition: A Survey, 2018

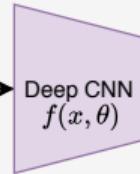
Face Recognition: Verification and Identification



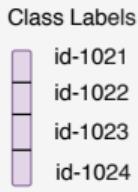
- Face recognition can be broadly divided into two tasks:
 - **Face verification**
 - **Face identification**

Face Identification

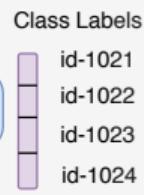
Identification(x)



f

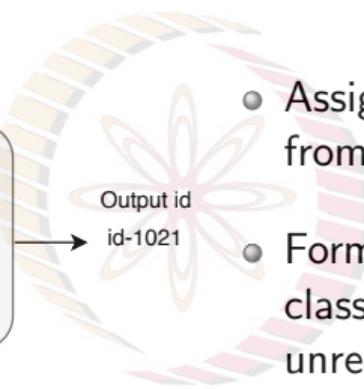


Test Image(x)



Class Labels

id-1021
id-1022
id-1023
id-1024



- Assign input image to person name/id from database (one-to-many matching)
- Formulated as $K+1$ multi-class classification (one additional class for unrecognized faces)

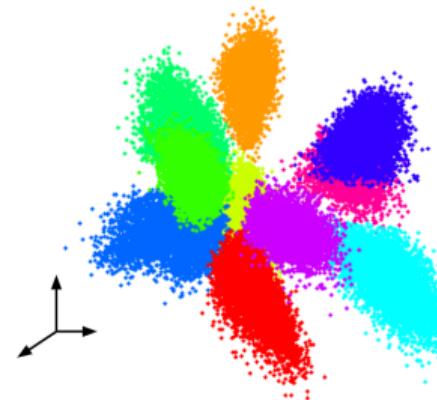
- **Input:** Face image
- **Output:** Identity class/face ID

Softmax + CrossEntropy

- Consider last linear layer W, b parameterizes the subjects i.e., maps feature embeddings on to subject labels, cross-entropy loss is

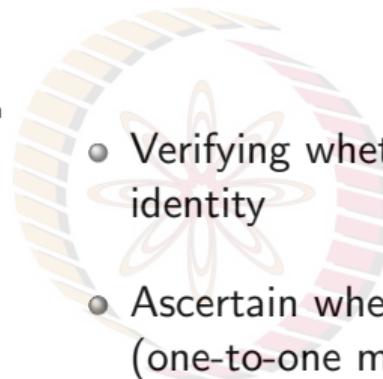
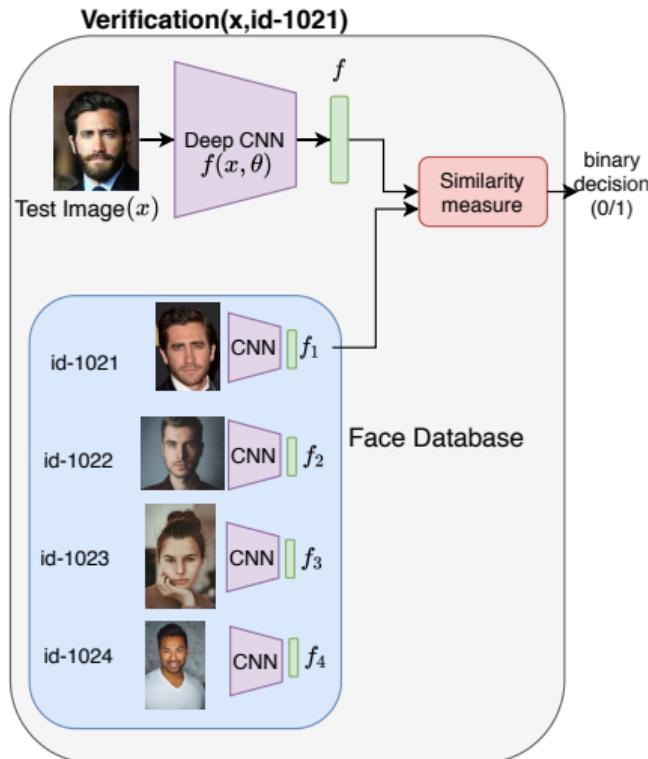
$$\mathcal{L}_{CE} = -\log \left(\frac{e^{W_i x^\top + b_i}}{\sum_j e^{W_j x^\top + b_j}} \right)$$

- Softmax+CE produces feature embeddings that geometrically looks like ellipsoids i.e., large intra-class variance
- The loss enforces good classification (nice boundaries between classes i.e., small inter-class variance) but it does not enforce small intra-class variance



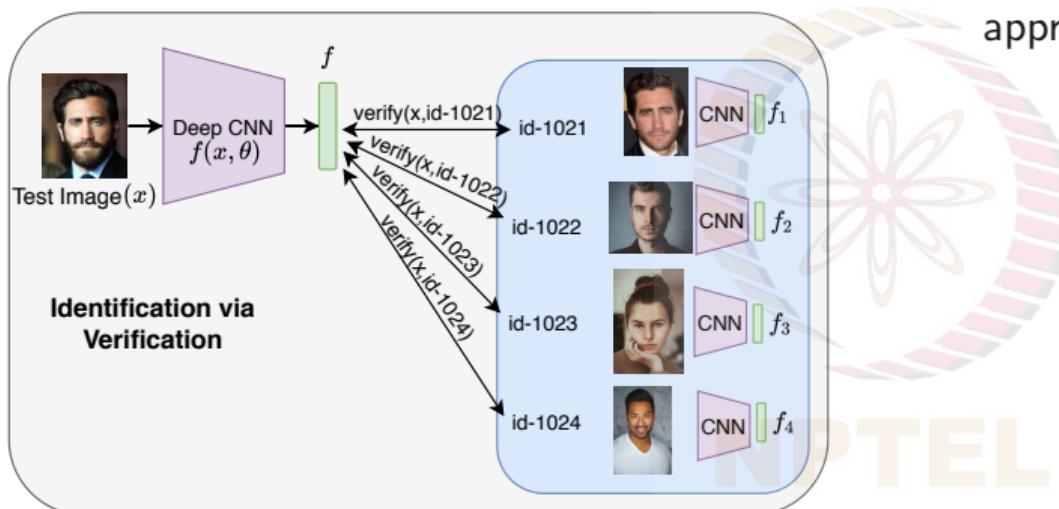
Source: Maci et al. Deep Face Recognition: A Survey, SIBGRAPI'18. [9]

Face Verification



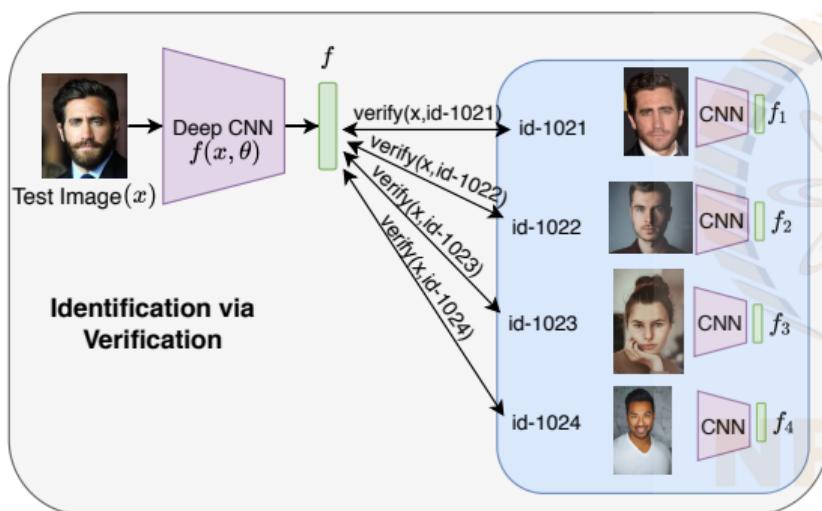
- Verifying whether two images belong to the same identity
- Ascertain whether image is of claimed person/id (one-to-one matching)
- **Input:** Face image, Face ID
Output: Match/Not match (binary classification)

Identification via Verification



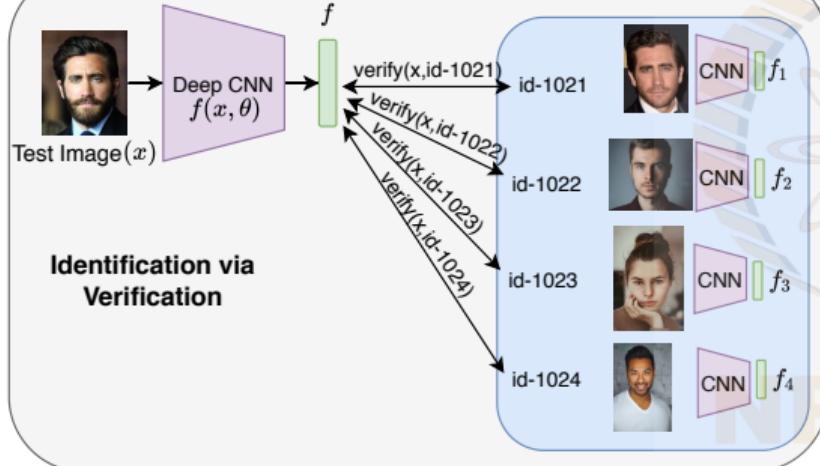
- Identification can be solved via verification approach

Identification via Verification



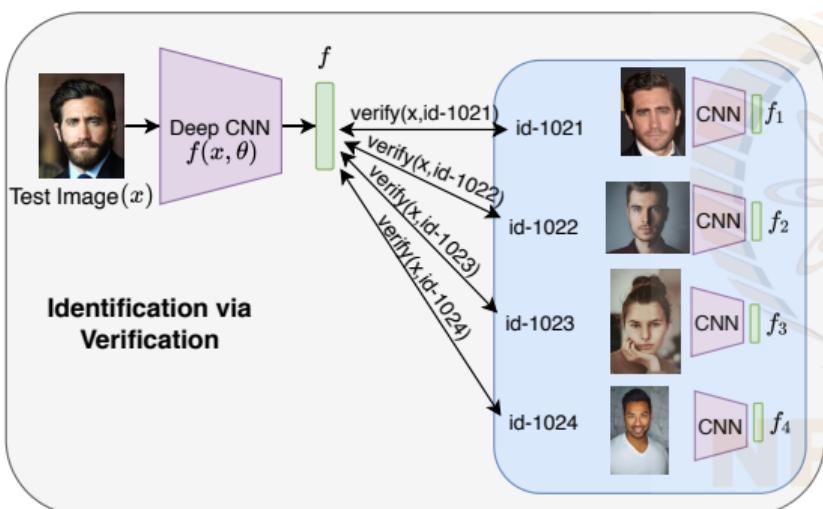
- Identification can be solved via verification approach
- Removes need to retrain model on addition of new face classes to the database \implies more practical/feasible

Identification via Verification



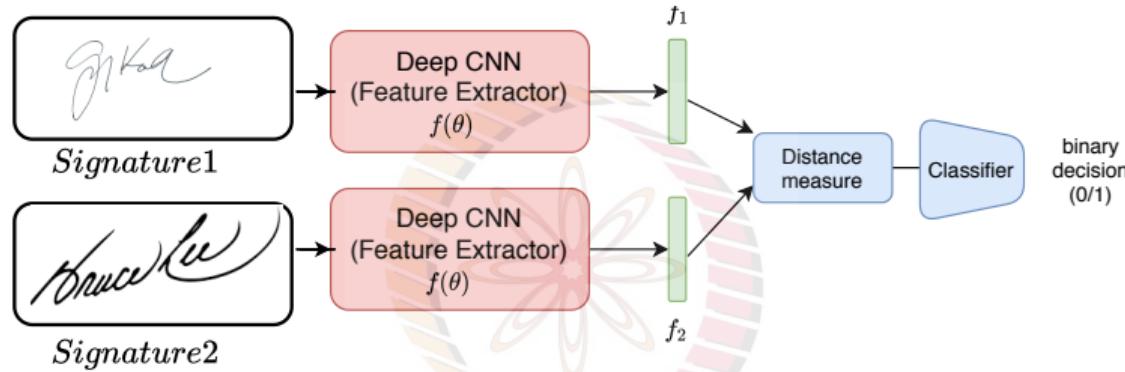
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- Identification involves multiple verification steps \implies error gets amplified

Identification via Verification



- Identification can be solved via verification approach
- Removes need to retrain model on addition of new face classes to the database \implies more practical/feasible
- Identification involves multiple verification steps \implies error gets amplified
- Goal becomes to build an accurate/efficient verification system via learning a robust similarity metric

Verification: Siamese Networks¹



- First proposed for signature verification in 1994
- Two replicas of same architecture parametrized with same weights working in tandem on different inputs
- Network parameters learned via some form of distance measure to extract distinctive features - an idea that is used even today

¹Bromley et al, Signature Verification using a Siamese Time Delay Neural Network, NIPS 1994

DeepFace: Identification²

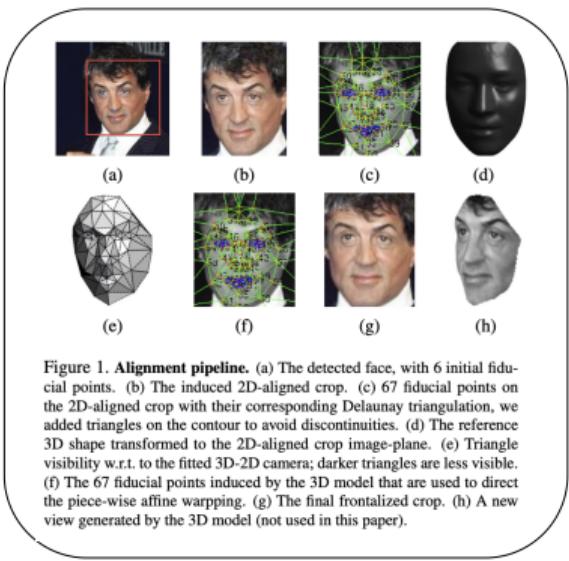


Figure 1. Alignment pipeline. (a) The detected face, with 6 initial fiducial points. (b) The induced 2D-aligned crop. (c) 67 fiducial points on the 2D-aligned crop with their corresponding Delaunay triangulation, we added triangles on the contour to avoid discontinuities. (d) The reference 3D shape transformed to the 2D-aligned crop image-plane. (e) Triangle visibility w.r.t. to the fitted 3D-2D camera; darker triangles are less visible. (f) The 67 fiducial points induced by the 3D model that are used to direct the piece-wise affine warping. (g) The final frontalized crop. (h) A new view generated by the 3D model (not used in this paper).

- **Step 1:** Face localization, fiducial point detection and alignment \implies frontal crop of face
- **Step 2:** Frontal crop passed for identification to deep CNN model with K-way softmax (multi-class classification)

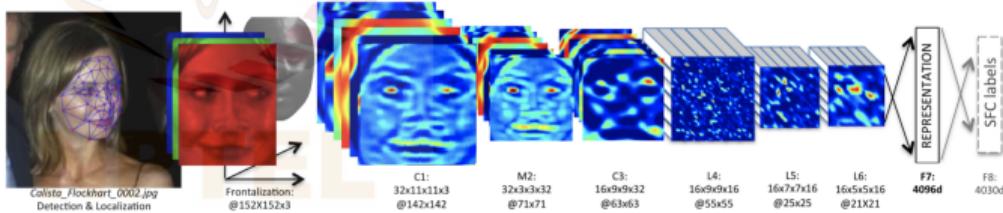
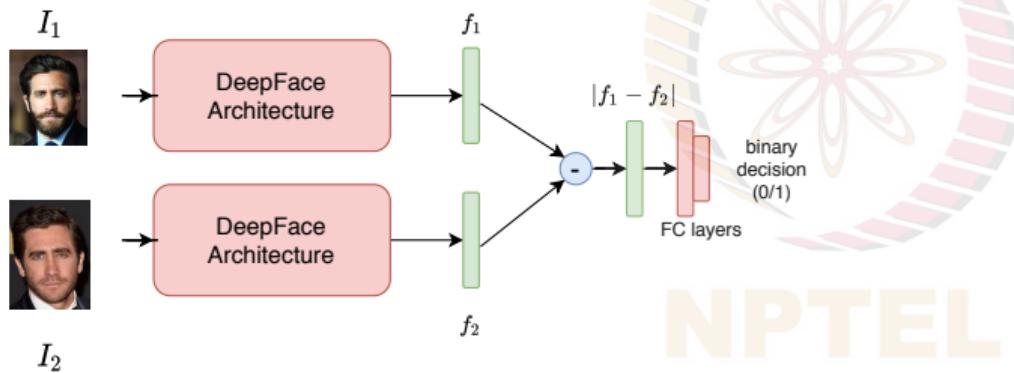


Figure 2. Outline of the DeepFace architecture. A front-end of a single convolution-pooling-convolution filtering on the rectified input, followed by three locally-connected layers and two fully-connected layers. Colors illustrate feature maps produced at each layer. The net includes more than 120 million parameters, where more than 95% come from the local and fully connected layers.

²Taigman et al, DeepFace: Closing the Gap to Human-Level Performance in Face Verification, CVPR 2014

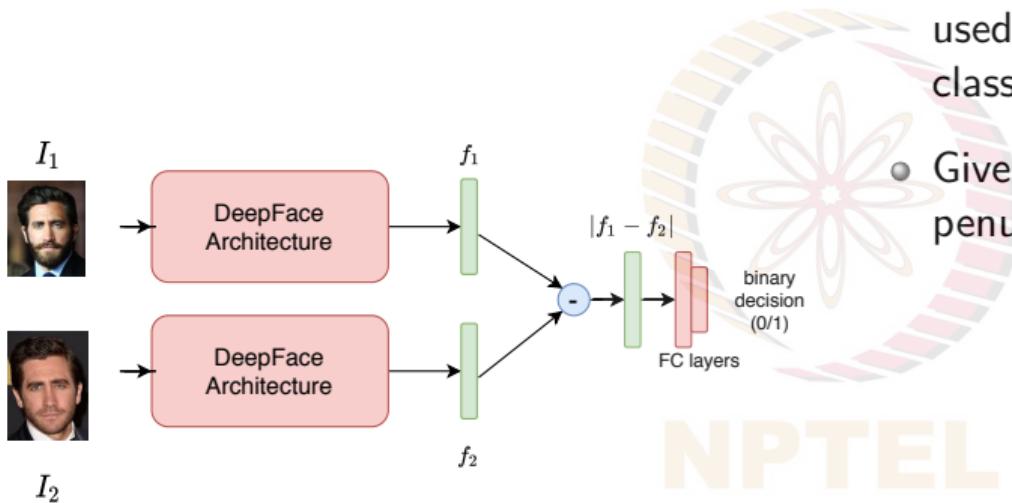
DeepFace: Verification (Siamese Networks)

- Representation learned from identification used for verification \implies freeze classification parameters

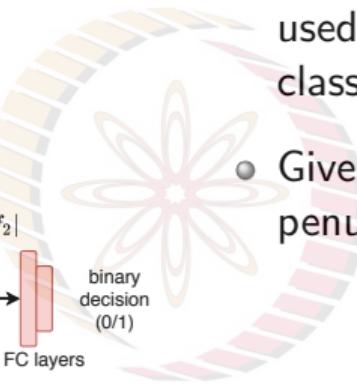


NPTEL

DeepFace: Verification (Siamese Networks)

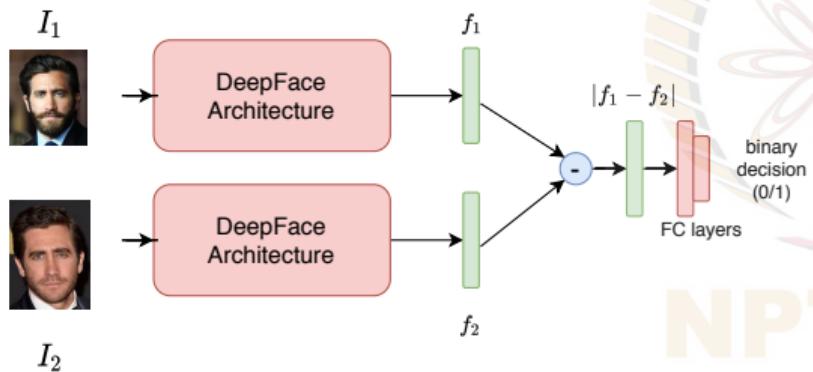


- Representation learned from identification used for verification \implies freeze classification parameters
- Given a face image I , $f = G(I)$ \implies penultimate layer representation for I

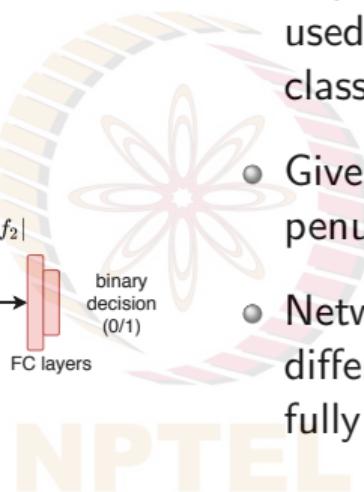


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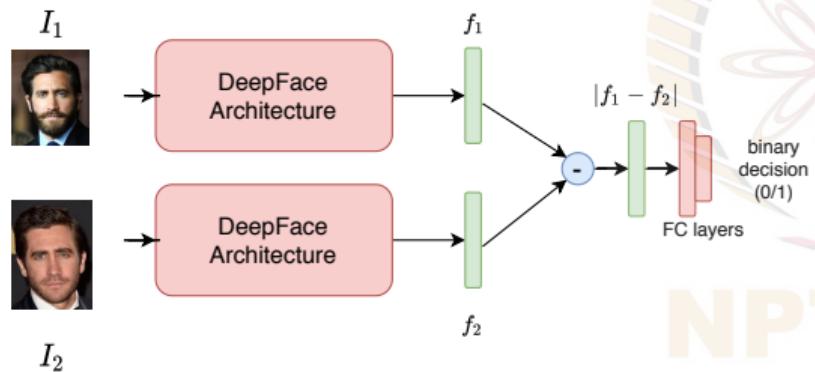
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- Network trained by taking absolute difference between features, followed by a fully connected head

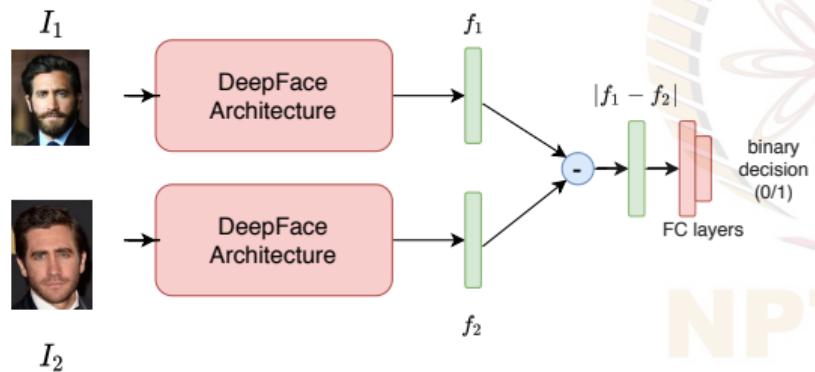


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$$d(f_1, f_2) = \sum_i \alpha_i |f_1[i] - f_2[i]|$$
 where α_i are trainable parameters

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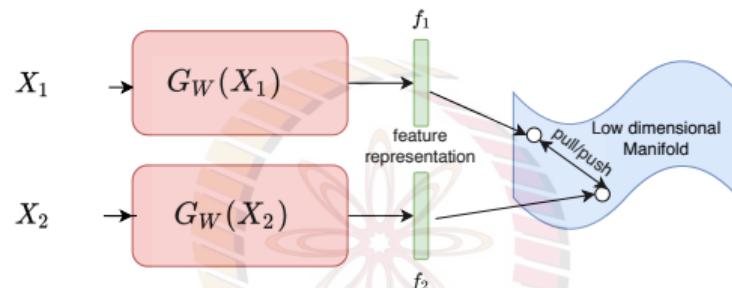
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 where α_i are trainable parameters
- **Output:** Binary decision (same/not same)

Contrastive Loss

- Based on metric learning paradigm
- Used to learn distinctive discriminative feature representations for various downstream computer vision tasks
- **Goal:** Map the input to embedding space where the distance between points corresponds to "semantic similarity" between input points
- Various formulations: Pairwise Contrastive Loss, Ranking Loss, Triplet Loss

We will look at some of these to build verification systems

Pairwise Contrastive Loss



- Hadsell³ et al introduced an approach to learn a mapping
 - invariant to complex transforms
 - “similar” points in input space are mapped to nearby points on a low-dimensional manifold.
 - capable of consistently mapping new points (unseen during training)
- **Objective:** Learn W such that $D_W(X_1, X_2) = ||G_W(X_1) - G_W(X_2)||_2$ approximates the “semantic similarity” of inputs

³Hadsell et al, Dimensionality Reduction by Learning an Invariant Mapping, CVPR 2006

Pairwise Contrastive Loss

Algorithm

The algorithm first generates the training set, then trains the machine.

Step 1: For each input sample \vec{X}_i , do the following:

- Using prior knowledge find the set of samples $S_{\vec{X}_i} = \{\vec{X}_j\}_{j=1}^p$, such that \vec{X}_j is deemed similar to \vec{X}_i .
- Pair the sample \vec{X}_i with all the other training samples and label the pairs so that:
$$Y_{ij} = 0 \text{ if } \vec{X}_j \in S_{\vec{X}_i}, \text{ and } Y_{ij} = 1 \text{ otherwise.}$$

Combine all the pairs to form the labeled training set.

Step 2: Repeat until convergence:

- For each pair (\vec{X}_i, \vec{X}_j) in the training set, do
 - If $Y_{ij} = 0$, then update W to decrease
$$D_W = \|G_W(\vec{X}_i) - G_W(\vec{X}_j)\|_2$$
 - If $Y_{ij} = 1$, then update W to increase
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- Let $\mathbf{x}_1, \mathbf{x}_2 \Rightarrow$ be a pair of high-dimensional input vectors



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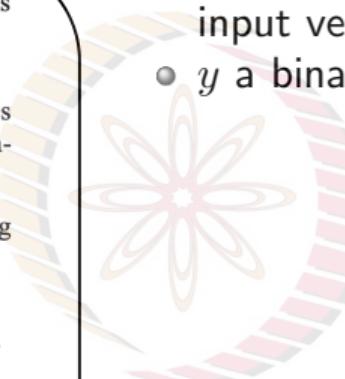
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- Let $\mathbf{x}_1, \mathbf{x}_2 \Rightarrow$ be a pair of high-dimensional input vectors
- y a binary label assigned to this pair:

$$\begin{cases} y = 0 & \text{if } \mathbf{x}_1, \mathbf{x}_2 \text{ are similar} \\ y = 1; & \text{otherwise} \end{cases}$$



Pairwise Contrastive Loss

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- Given $(y, \mathbf{x}_1, \mathbf{x}_2)$ are labeled pairs of data,
Pairwise Contrastive Loss,

$L_{\text{contrastive}}(W, y, \mathbf{x}_1, \mathbf{x}_2)$ given by:

$$\frac{1-y}{2} D_W^2 + \frac{y}{2} \max(0, m - D_W^2)$$

where $m > 0$ is a margin which defines a radius around $G_W(\mathbf{x})$

DeepID2⁴

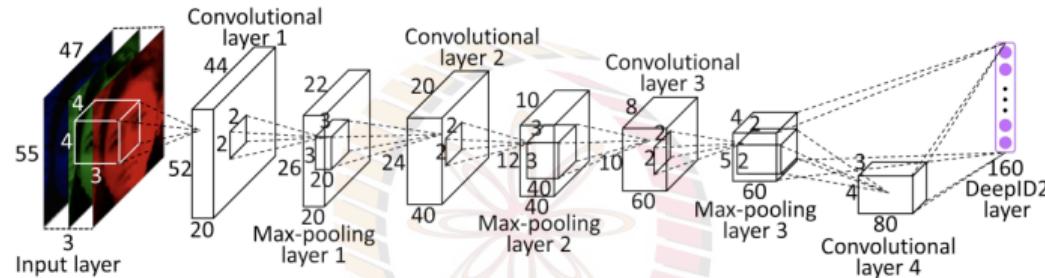


Figure 1: The ConvNet structure for DeepID2 extraction.

- Trains a deep CNN to jointly perform identification and verification

⁴Sun et al, Deep Learning Face Representation by Joint Identification-Verification, NIPS 2014

DeepID2⁴

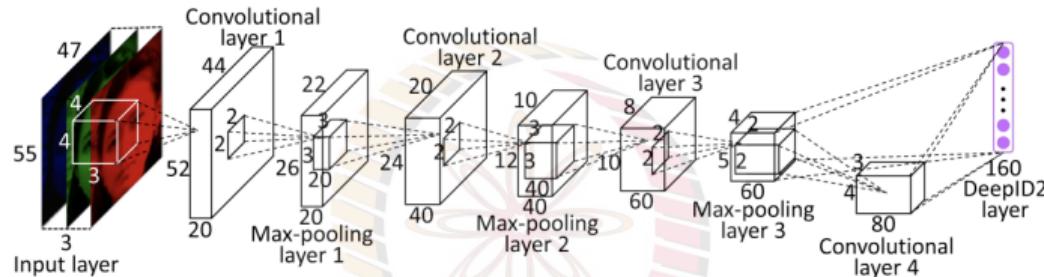


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- Trains a deep CNN to jointly perform identification and verification
- **Identification task:** Increases inter-personal variations by pushing features from different identities apart

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DeepID2⁴

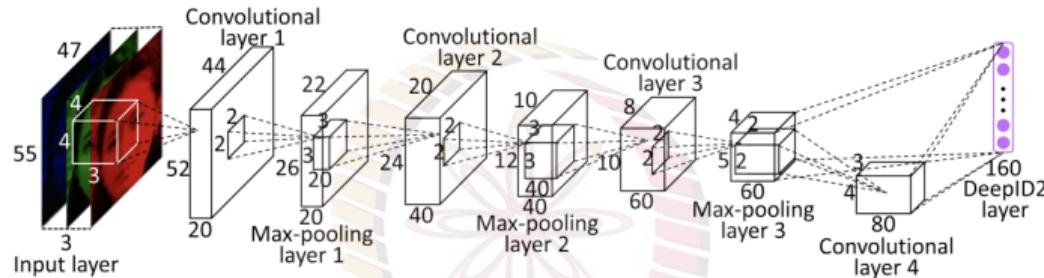


Figure 1: The ConvNet structure for DeepID2 extraction.

- Trains a deep CNN to jointly perform identification and verification
- **Identification task:** Increases inter-personal variations by pushing features from different identities apart
- **Verification task:** Reduces intra-personal variations by pulling features from same identity together

⁴Sun et al, Deep Learning Face Representation by Joint Identification-Verification, NIPS 2014

DeepID2

- **Cross-entropy loss** for training identification parameters θ_{id}
- **Pairwise contrastive loss** for learning verification parameters θ_{ve}

Identification Loss

$$-\sum_{i=1}^n p_i \log \hat{p}_i = -\log \hat{p}_t$$

f : DeepID2 feature vector

t : target class

θ_{id} : softmax layer parameters

p_i : target probability distribution

\hat{p}_i : is predicted probability distribution

Verification Loss

$$L_{contrastive}(\theta_{ve}, y_{ij}, f_i, f_j)$$

f_i, f_j : DeepID2 feature vectors for face images under comparison

θ_{ve} : verification loss parameters

$y_{ij} = 1 \implies f_i$ and f_j are from same identity

$y_{ij} = -1 \implies$ different identities

DeepID2: Algorithm

Table 1: The DeepID2 learning algorithm.

input: training set $\chi = \{(x_i, l_i)\}$, initialized parameters θ_c , θ_{id} , and θ_{ve} , hyperparameter λ , learning rate $\eta(t)$, $t \leftarrow 0$

while not converge **do**

$t \leftarrow t + 1$ sample two training samples (x_i, l_i) and (x_j, l_j) from χ

$f_i = \text{Conv}(x_i, \theta_c)$ and $f_j = \text{Conv}(x_j, \theta_c)$

$$\nabla \theta_{id} = \frac{\partial \text{Ident}(f_i, l_i, \theta_{id})}{\partial \theta_{id}} + \frac{\partial \text{Ident}(f_j, l_j, \theta_{id})}{\partial \theta_{id}}$$

$\nabla \theta_{ve} = \lambda \cdot \frac{\partial \text{Verif}(f_i, f_j, y_{ij}, \theta_{ve})}{\partial \theta_{ve}}$, where $y_{ij} = 1$ if $l_i = l_j$, and $y_{ij} = -1$ otherwise.

$$\nabla f_i = \frac{\partial \text{Ident}(f_i, l_i, \theta_{id})}{\partial f_i} + \lambda \cdot \frac{\partial \text{Verif}(f_i, f_j, y_{ij}, \theta_{ve})}{\partial f_i}$$

$$\nabla f_j = \frac{\partial \text{Ident}(f_j, l_j, \theta_{id})}{\partial f_j} + \lambda \cdot \frac{\partial \text{Verif}(f_i, f_j, y_{ij}, \theta_{ve})}{\partial f_j}$$

$$\nabla \theta_c = \nabla f_i \cdot \frac{\partial \text{Conv}(x_i, \theta_c)}{\partial \theta_c} + \nabla f_j \cdot \frac{\partial \text{Conv}(x_j, \theta_c)}{\partial \theta_c}$$

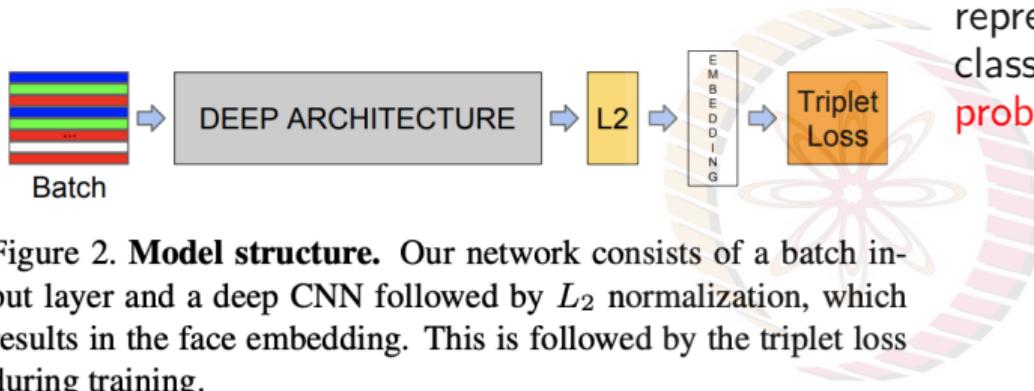
update $\theta_{id} = \theta_{id} - \eta(t) \cdot \theta_{id}$, $\theta_{ve} = \theta_{ve} - \eta(t) \cdot \theta_{ve}$, and $\theta_c = \theta_c - \eta(t) \cdot \theta_c$.

end while

output θ_c

- θ_{id} and θ_{ve} : separately updated via respective objectives; θ_c (backbone CNN parameters): trained via weighted contribution from identification and verification objectives
- enables backbone network to extract inter-personal features (via identification signal), and intra-personal features (via verification signal)

FaceNet⁵



- Previous methods use bottleneck representation from pre-trained classification model. **Do you see any problems?**

Figure 2. Model structure. Our network consists of a batch input layer and a deep CNN followed by L_2 normalization, which results in the face embedding. This is followed by the triplet loss during training.

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⁵Schroff et al, FaceNet: A Unified Embedding for Face Recognition and Clustering, CVPR 2015

FaceNet⁵

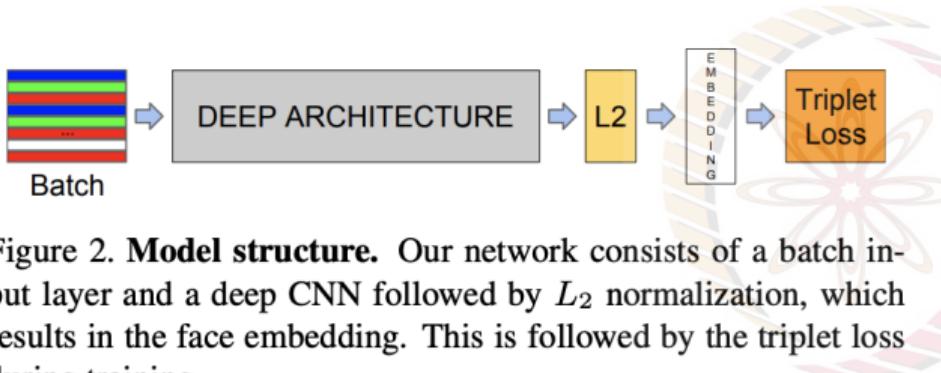


Figure 2. **Model structure.** Our network consists of a batch input layer and a deep CNN followed by L_2 normalization, which results in the face embedding. This is followed by the triplet loss during training.

- Previous methods use bottleneck representation from pre-trained classification model. **Do you see any problems?**
 - Indirectness
 - Possible ineffectiveness; one has to hope that bottleneck representation will generalize to new faces
- FaceNet outputs compact 128-D embedding using a **triplet loss function** (commonly used today)

⁵Schroff et al, FaceNet: A Unified Embedding for Face Recognition and Clustering, CVPR 2015

FaceNet: Triplet Loss

- Alternate formulation of contrastive loss; considers triplet of inputs (namely anchor, positive, negative) instead of input pairs

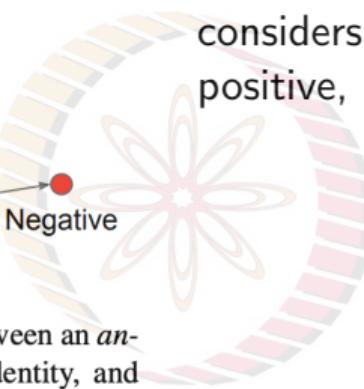
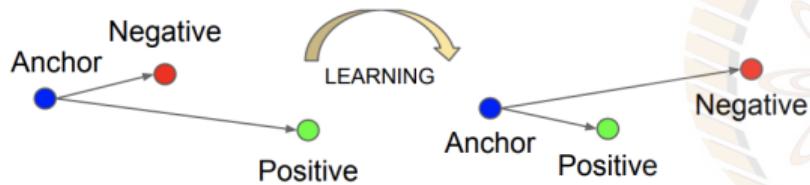


Figure 3. The **Triplet Loss** minimizes the distance between an *anchor* and a *positive*, both of which have the same identity, and maximizes the distance between the *anchor* and a *negative* of a different identity.

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FaceNet: Triplet Loss

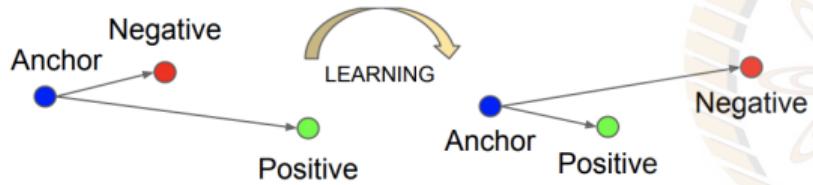


Figure 3. The **Triplet Loss** minimizes the distance between an *anchor* and a *positive*, both of which have the same identity, and maximizes the distance between the *anchor* and a *negative* of a different identity.

- Alternate formulation of contrastive loss; considers triplet of inputs (namely anchor, positive, negative) instead of input pairs
- **Goal:** Ensure distance between anchor (x_a) and negative sample (x_n) representation is at least "margin" more than distance between anchor and positive sample (x_p)

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FaceNet: Triplet Loss

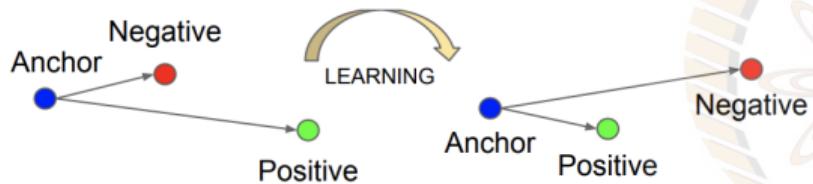


Figure 3. The **Triplet Loss** minimizes the distance between an *anchor* and a *positive*, both of which have the same identity, and maximizes the distance between the *anchor* and a *negative* of a different identity.

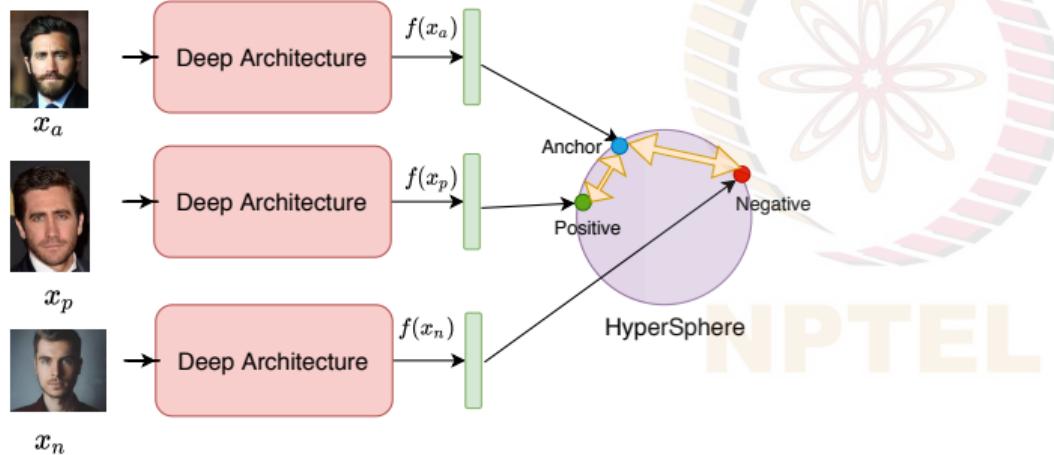
- Alternate formulation of contrastive loss; considers triplet of inputs (namely anchor, positive, negative) instead of input pairs
- **Goal:** Ensure distance between anchor (x_a) and negative sample (x_n) representation is at least "margin" more than distance between anchor and positive sample (x_p)
- **Triplet Constraint:**

$$\|f(x_a) - f(x_p)\|_2^2 + \alpha < \|f(x_a) - f(x_n)\|_2^2$$

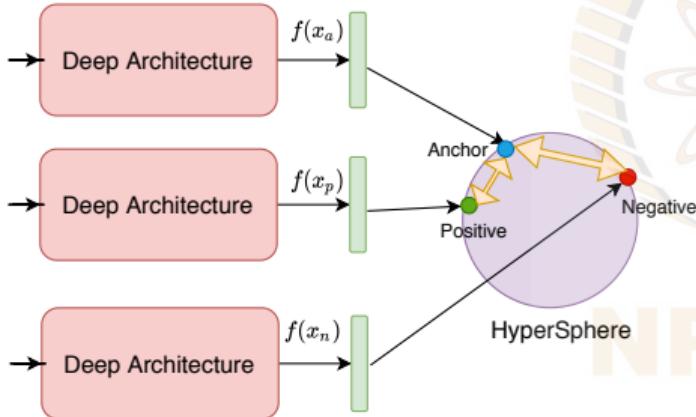
where α is margin

FaceNet: Triplet Loss Formulation

- Let $f(x)$: representation/embedding on d-dimensional hypersphere s.t. $\|f(x)\|_2 = 1$



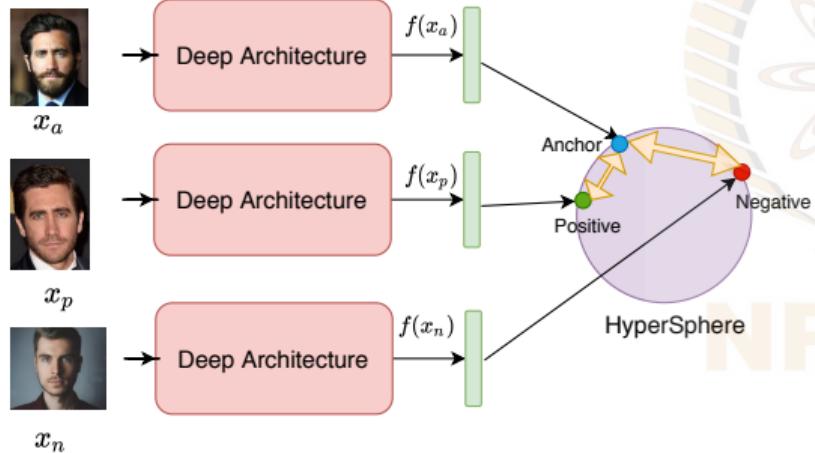
FaceNet: Triplet Loss Formulation



- Let $f(x)$: representation/embedding on d-dimensional hypersphere s.t. $\|f(x)\|_2 = 1$
- Goal:** train θ to ensure that for all triplets x_a (anchor), x_p (positive), x_n (negative):
$$\|f(x_a) - f(x_p)\|_2^2 + \alpha < \|f(x_a) - f(x_n)\|_2^2$$
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FaceNet: Triplet Loss Formulation



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- Goal:** train θ to ensure that for all triplets x_a (anchor), x_p (positive), x_n (negative):
$$\|f(x_a) - f(x_p)\|_2^2 + \alpha < \|f(x_a) - f(x_n)\|_2^2$$
 where α is margin
- Achieved by training parameters θ to minimize:

$$L_{triplet} = \sum_i [\|f(x_a^i) - f(x_p^i)\|_2^2 - \|f(x_a^i) - f(x_n^i)\|_2^2 + \alpha]$$

Triplet Selection Strategy

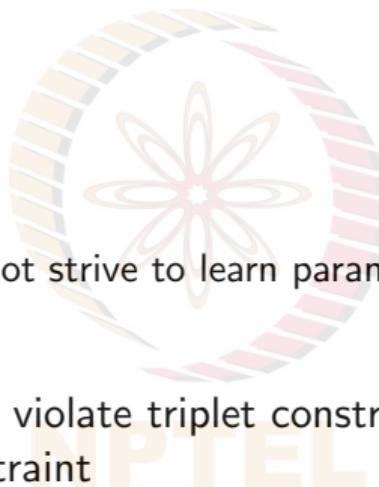
- How to choose triplets?



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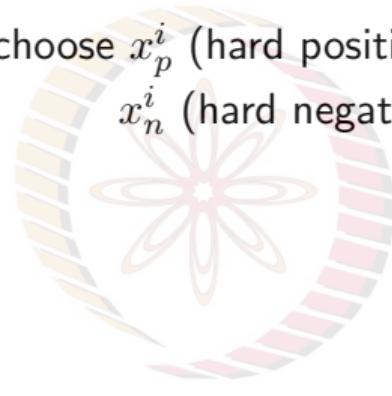
Triplet Selection Strategy

- How to choose triplets?
- “Easy” triplets can:
 - inhibit learning; model does not strive to learn parameters capturing distinctive features
 - have slower convergence
- Important to select triplets that violate triplet constraint initially, enabling the model to “work hard” to satisfy the constraint



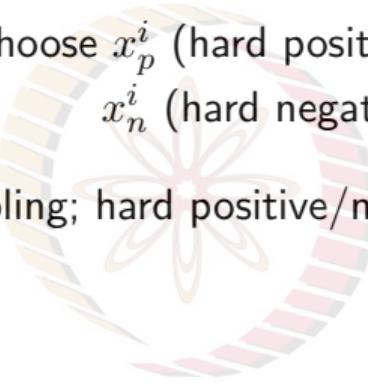
Hard Triplet Mining

- Selecting “hard” triplets \implies choose x_p^i (hard positive): $\arg \max_{x_p^i} \|f(x_a^i) - f(x_p^i)\|_2^2$
 x_n^i (hard negative): $\arg \min_{x_n^i} \|f(x_a^i) - f(x_n^i)\|_2^2$



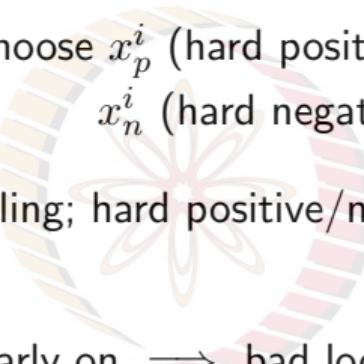
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- FaceNet uses online triplet sampling; hard positive/negatives sampled from every mini-batch



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- **Solution:** “Semi-hard” negatives \implies negatives that lie inside margin α ; how?

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- **Problem:** Very hard negatives early on \implies bad local minima initially, potential training/model collapse
- **Solution:** “Semi-hard” negatives \implies negatives that lie inside margin α ; how? Choose x_n^i (semi-hard): $\|f(x_a) - f(x_p)\|_2^2 < \|f(x_a) - f(x_n)\|_2^2$

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Improving over Triplet Loss: Angular Softmax Loss⁶

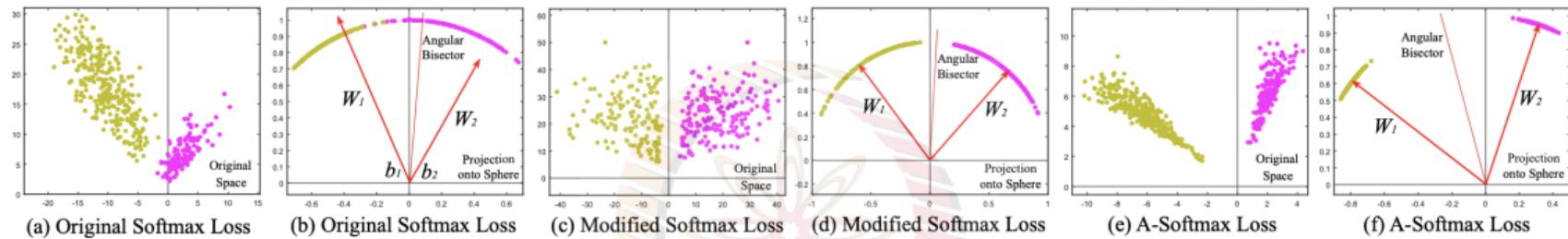


Figure 2: Comparison among softmax loss, modified softmax loss and A-Softmax loss. In this toy experiment, we construct a CNN to learn 2-D features on a subset of the CASIA face dataset. In specific, we set the output dimension of FC1 layer as 2 and visualize the learned features. Yellow dots represent the first class face features, while purple dots represent the second class face features. One can see that features learned by the original softmax loss can not be classified simply via angles, while modified softmax loss can. Our A-Softmax loss can further increase the angular margin of learned features.

- Features learned by softmax loss have intrinsic angular distribution \implies Euclidean margin-based losses incompatible with softmax loss

⁶Liu et al, SphereFace: Deep Hypersphere Embedding for Face Recognition, CVPR 2017

Improving over Triplet Loss: Angular Softmax Loss⁶

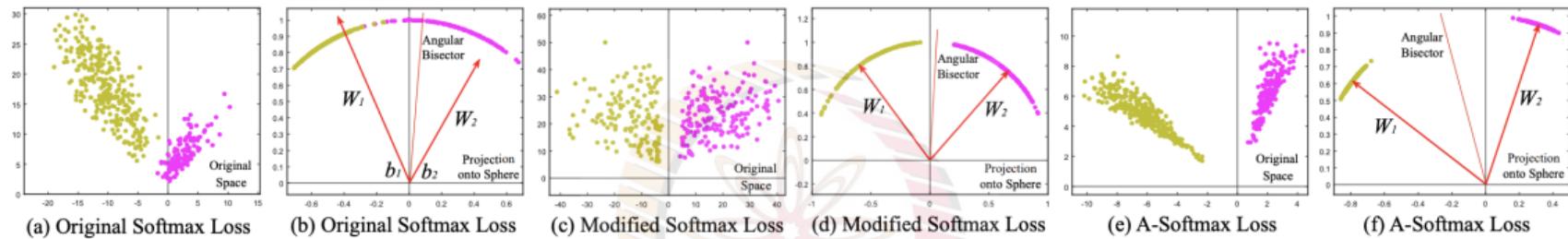


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- Features learned by softmax loss have intrinsic angular distribution \Rightarrow Euclidean margin-based losses incompatible with softmax loss
- **A-Softmax loss** hence uses angle between feature and classification layer vector, both in training and test

⁶Liu et al, SphereFace: Deep Hypersphere Embedding for Face Recognition, CVPR 2017

A-Softmax Loss

- **Softmax Loss:**

$$\mathcal{L}_{softmax} = \frac{1}{N} \sum_i -\log \left(\frac{e^{W_{y_i}^T x_i + b_{y_i}}}{\sum_j e^{W_j^T x_i + b_j}} \right) = \frac{1}{N} \sum_i -\log \left(\frac{e^{\|W_{y_i}\| \|x_i\| \cos(\theta_{y_i}, i) + b_{y_i}}}{\sum_j e^{\|W_j\| \|x_i\| \cos(\theta_j, i) + b_j}} \right)$$

- **Modified Softmax Loss** ($\|W_1\| = \|W_2\| = 1$, $b_1 = b_2 = 0$):

$$\mathcal{L}_{modified} = \frac{1}{N} \sum_i -\log \left(\frac{e^{\|x_i\| \cos(\theta_{y_i}, i)}}{\sum_j e^{\|x_i\| \cos(\theta_j, i)}} \right)$$

- **A-Softmax Loss:**

$$\mathcal{L}_{ang} = \frac{1}{N} \sum_i -\log \left(\frac{e^{\|x_i\| \cos(m\theta_{y_i}, i)}}{e^{\|x_i\| \cos(m\theta_{y_i}, i)} + \sum_{j \neq y_i} e^{\|x_i\| \cos(\theta_j, i)}} \right)$$

A-Softmax Loss: Binary Classification Analysis

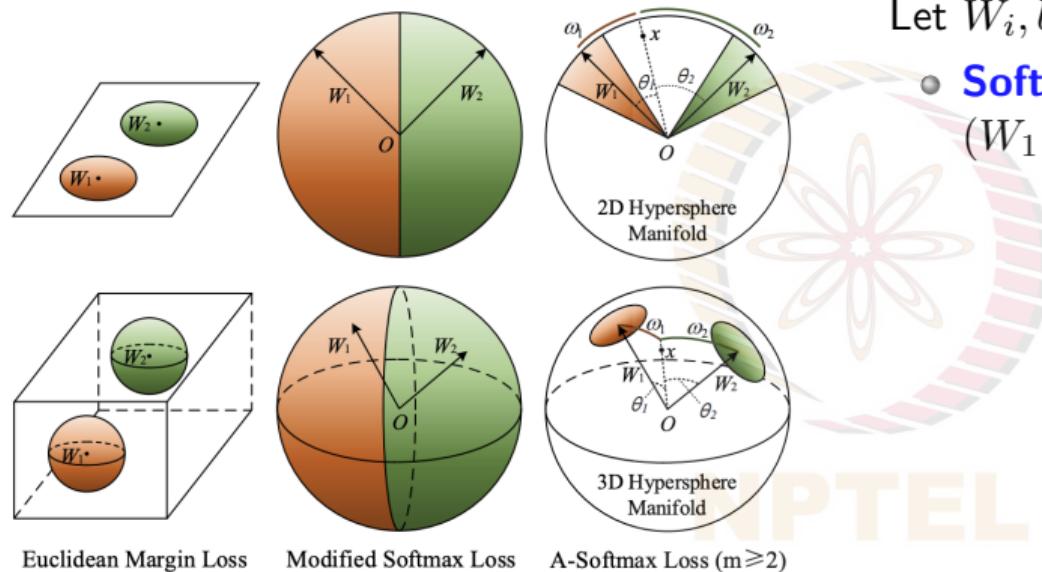


Figure 3: Geometry Interpretation of Euclidean margin loss (e.g. contrastive loss, triplet loss, center loss, etc.), modified softmax loss and A-Softmax loss. The first row is 2D feature constraint, and the second row is 3D feature constraint. The orange region indicates the discriminative constraint for class 1, while the green region is for class 2.

Let W_i, b_i be weights and bias in softmax loss:

- **Softmax** decision boundary \Rightarrow
$$(W_1 - W_2)x + b_1 - b_2 = 0$$

A-Softmax Loss: Binary Classification Analysis

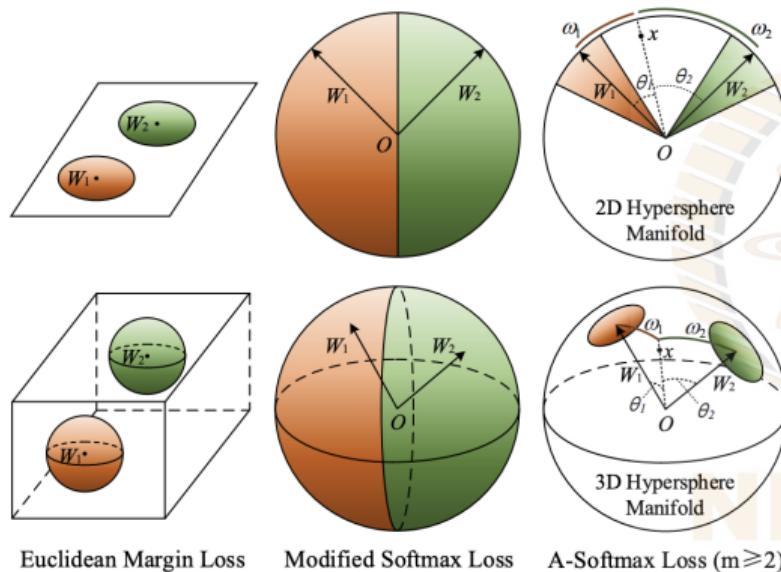


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- **Softmax** decision boundary $\Rightarrow (W_1 - W_2)x + b1 - b2 = 0$
- Constrain $\|W_1\| = \|W_2\| = 1$, $b_1 = b_2 = 0$;
Modified Softmax decision boundary
 $\Rightarrow \|x\|(\cos(\theta_1) - \cos(\theta_2)) = 0$

A-Softmax Loss: Binary Classification Analysis

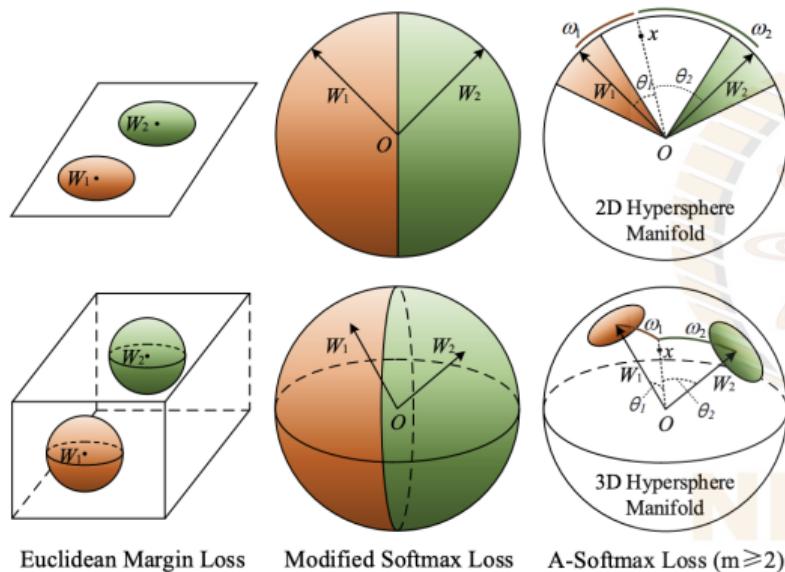


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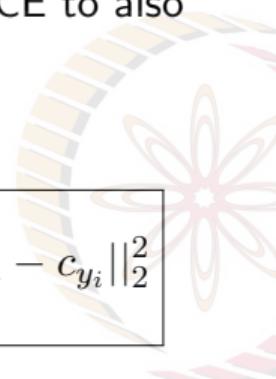
- **Softmax** decision boundary $\Rightarrow (W_1 - W_2)x + b1 - b2 = 0$
- Constrain $\|W_1\| = \|W_2\| = 1$, $b_1 = b_2 = 0$;
Modified Softmax decision boundary $\Rightarrow \|x\|(\cos(\theta_1) - \cos(\theta_2)) = 0$
- Margin $m \geq 1$: quantitatively controls the size of angular margin
A-Softmax decision boundary \Rightarrow
 - class 1: $\|x\|(\cos(m\theta_1) - \cos(\theta_2)) = 0$
 - class 2: $\|x\|(\cos(\theta_1) - \cos(m\theta_2)) = 0$

Other Loss Functions used: CenterLoss⁷

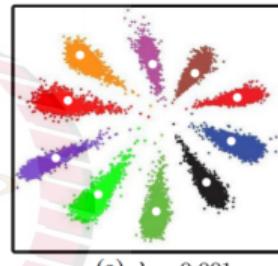
- Intended to augment Softmax+CE to also reduce intra-class variance

$$\mathcal{L}_{new} = \mathcal{L}_{CE} + \lambda \mathcal{L}_{CL}$$

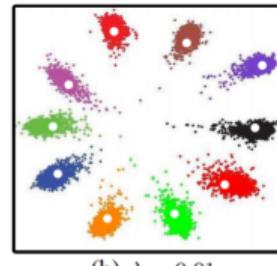
$$= \mathcal{L}_{CE} + \frac{\lambda}{2} \sum_{i=1}^m \|x_i - c_{y_i}\|_2^2$$



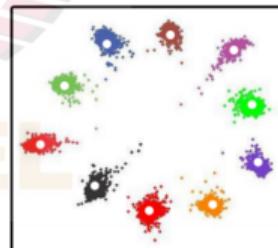
- Added term minimizes intra-class distance between sample x and y_i th class centroid c_{y_i} of deep features
- Centroid is updated online during learning



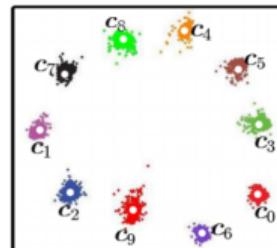
(a) $\lambda = 0.001$



(b) $\lambda = 0.01$



(c) $\lambda = 0.1$



(d) $\lambda = 1$

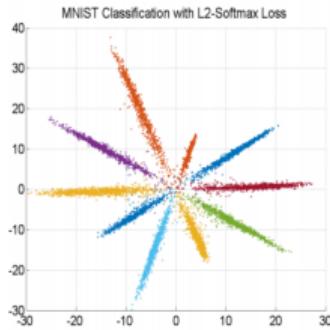
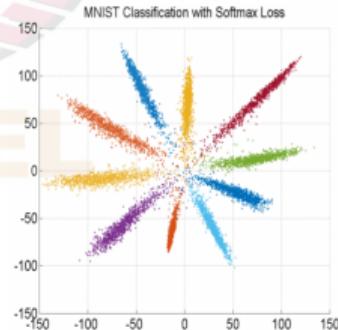
⁷Wen et al, Discriminative Feature Learning Approach for Deep Face Recognition, ECCV 2016

L2-Softmax⁸

- Enforces L2-norm of features to be fixed for every face image by adding an L2 constraint to feature descriptor such that it lies on hypersphere of fixed radius (α)
- Features with **high L2 norm** are **easy** to classify for network (spatially placed at boundaries in feature space)
- Features with **low L2 norm** are **difficult** to classify (spatially located near origin)

$$\underset{x}{\text{minimize}} \quad \mathcal{L}_{CE}$$

subject to $\|f(x_i)\|_2 = \alpha, i = 1, \dots, m.$

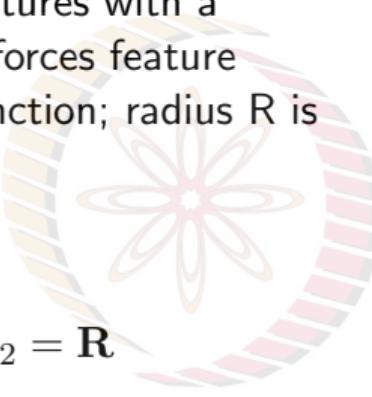


⁸Ranjan et al, L2-constrained Softmax Loss for Discriminative Face Verification, 2017

RingLoss⁹

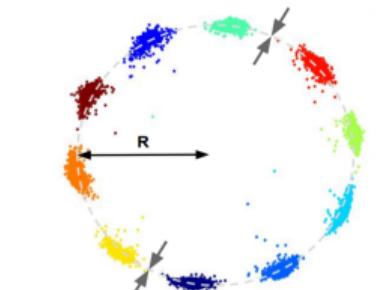
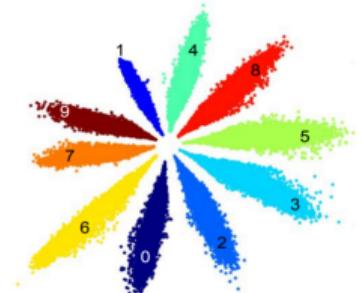
- While L2-Softmax normalizes features with a *projection* method, **RingLoss** enforces feature normalizations directly in loss function; radius R is learned in training process

$$\begin{aligned} & \underset{x}{\text{minimize}} && \mathcal{L}_{CE} \\ & \text{subject to} && \|f(x_i)\|_2 = R \end{aligned}$$



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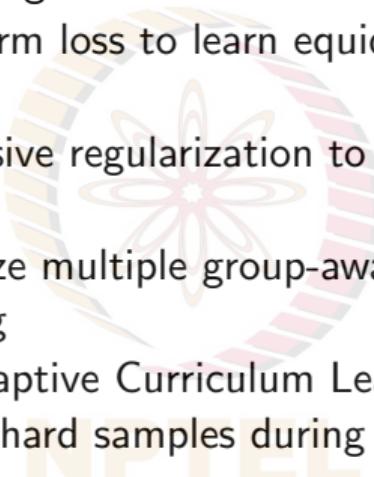
$$\mathcal{L}_R = \frac{\lambda}{2m} \sum_{i=1}^m (\|f(x_i)\|_2 - R)^2$$



⁹Zheng et al, Ring Loss: Convex Feature Normalization for FaceRecognition, CVPR 2018

Other Recent Efforts

- **CosFace**¹⁰: proposes a large margin-based cosine loss (LMCL) for face recognition
- **UniformFace**¹¹: proposes uniform loss to learn equidistributed representations to fully exploit feature space
- **RegularFace**¹²: proposes exclusive regularization to explicitly enlarge angular distance between different identities
- **GroupFace**¹³: proposes to utilize multiple group-aware representations, simultaneously, to improve quality of embedding
- **CurricularFace**¹⁴: proposes Adaptive Curriculum Learning loss to adaptively adjust relative importance of easy and hard samples during different training stages



¹⁰Wang et al, CosFace: Large Margin Cosine Loss for Deep Face Recognition, CVPR 2018

¹¹Duan et al, UniformFace: Learning Deep Equidistributed Representation for Face Recognition, CVPR 2019

¹²Zhao et al, RegularFace: Deep Face Recognition via Exclusive Regularization, CVPR 2019

¹³Kim et al, GroupFace: Learning Latent Groups and Constructing Group-based Representations for Face Recognition, CVPR 2020

¹⁴Huang et al, CurricularFace: Adaptive Curriculum Learning Loss for Deep Face Recognition, CVPR 2020

Face Recognition: Closed-Set vs Open-Set

- **Closed-Set Loss Functions** (all subjects known)

- **Softmax + CrossEntropy**
- **Center Loss** (reduce intra-class variability)
- **L2-Softmax** (reduce intra-class variability)
- **RingLoss** (reduce intra-class variability)
- **Angular Softmax** (increase margin between subjects)

- **Open-Set Loss Functions** (all subjects not known)

- **Double Margin Contrastive Loss** ([Homework!](#))
- **Triplet Loss**

The NPTEL logo is a stylized, semi-transparent watermark in the background of the slide. It features the letters "NPTEL" in a large, bold, sans-serif font. Behind the letters, there is a circular emblem containing a stylized flower or gear-like design.

Source: Masi et al, Deep Face Recognition: A Survey, SIBGRAPI 2018

Homework

Readings

- Raúl Gómez, Understanding Ranking Loss, Contrastive Loss, Margin Loss, Triplet Loss, Hinge Loss and all those confusing names
- A detailed tutorial on deep face recognition by Masi et al
- (Optional) Adrian Rosebrock, Face recognition with OpenCV, Python, and deep learning
- (Optional) Wang et al, Deep Face Recognition: A Survey, Neurocomputing 2018

Question

What is double-margin contrastive loss, and how can it be used for open-set face recognition?
(Hint: Read the tutorial above!)

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- 
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