Reconstructing Faces from their Signatures using RBF Regression.

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Faces recognition technologies are now omnipresent on the Internet (Google, Facebook, etc. now use face recognition to automatically tag people).

One important question related to privacy is to know if the information encoded by the face signatures (or *face templates* as they are called in the biometrics literature) might be reverse engineered, revealing the identities of the persons in case the database is stolen or made publicly available by mistake. In other words, do face signatures (or face templates, we interchangeably use the two expressions) contain personal information?

This is also a topic of interest for biometric applications where the way templates are encoded is critical [6]. Indeed, stolen templates should not allow reconstruction of images that can be used to break in a system. As face representation and face verification technologies have progressed a lot during the last five years, we believe it is important to know, if and to what extent, people can be recognized from their face templates once their face is reconstructed.

In this context, the objective of this paper is twofold: (i) to propose a novel simple but efficient method for reconstructing face images from face templates with unknown identities; (ii) to show that these reconstructed images allow the recognition of people and can fool modern face recognition algorithms. We believe that the proposed approach could be used each time a new method for representing faces is proposed, to evaluate how anonymity is preserved by the encoding.

In practice, we chose to use the I-LPQ approach of [7] – which is, at the moment, the state-of-the-art unsupervised approach on the LFW [2] and FERET [5] datasets – as a baseline approach for computing face templates. Another reason for using this approach is that it is a good representative of modern approaches for face recognition, most of them being based on histograms of LBP/SIFT/Gabor-like features computed on a regular grid [1, 4, 8].

The proposed reconstruction method is based on radial basis function regression in the face eigenspace. During a training phase, face/signature pairs are used to learn a non linear mapping between signatures and images. This mapping minimizes the reconstruction error of the eigenface representations of the training images. The mapping can then be used directly to reconstruct faces from their signatures.

We consider the case where N image/signature pairs are available. We denote $\mathbf{x}_i$ ($i = 1 \dots N$) the N signatures and, to simplify the notations, we consider the face images as 1-dimensional vectors $\mathbf{y}_i$ of P pixels. We can then define the following quantities:

$$
\begin{aligned}
Y &= [\mathbf{y}_1 \dots \mathbf{y}_N]^T \\
\Phi &= \begin{pmatrix} \phi(\|\mathbf{x}_1 - \mathbf{x}_1\|) & \dots & \phi(\|\mathbf{x}_1 - \mathbf{x}_N\|) \\ \vdots & \ddots & \vdots \\ \phi(\|\mathbf{x}_N - \mathbf{x}_1\|) & \dots & \phi(\|\mathbf{x}_N - \mathbf{x}_N\|) \end{pmatrix} \\
W &= \begin{pmatrix} w_{11} & \dots & w_{1P} \\ \vdots & \ddots & \vdots \\ w_{N1} & \dots & w_{NP} \end{pmatrix}
\end{aligned}
$$

where W are weights to be estimated and $\phi(\|\mathbf{x}_i - \mathbf{x}_j\|) = \sqrt{s^2 + \|\mathbf{x}_i - \mathbf{x}_j\|^2}$ is the multi-quadric function with scale parameter s. We call $H = I_N - \frac{1}{N}\mathbf{1}_N\mathbf{1}_N^T$ the centering operator where $\mathbf{1}_N$ is the N-dimensional vector with all elements equal to 1. Let $\bar{Y} = USv^T$ be the singular value decomposition of $\bar{Y} = HY$, and $\bar{\Phi} = H\Phi H$ be the centered version of Φ. We solve:

$$\min_W \|\bar{\Phi}W - v\|_F^2 \tag{1}$$

where $\|.\|_F$ is the Frobenius norm. This gives $W = \Phi^+ v$ where Φ^+ is the pseudo invert of Φ.

Given a set of M signature $\mathbf{x}'_i$, to reconstruct the corresponding images, we need the matrix Φ' where $\Phi'_{ij} = \phi(\|x'_i - x_j\|)$ and its centered version with respect to Φ, which is $\bar{\Phi}' = (\Phi' - \frac{1}{N}\mathbf{1}_M\mathbf{1}_N^T\Phi)(I_N - \frac{1}{N}\mathbf{1}_N\mathbf{1}_N^T)$. The M corresponding images, stacked as the rows of a $M \times P$ matrix Y', are then reconstructed as:

$$Y' = \left(\bar{\Phi}'(\bar{\Phi}^+ vv^T) + \frac{1}{N}\mathbf{1}_M\mathbf{1}_N^T\right)Y \tag{2}$$

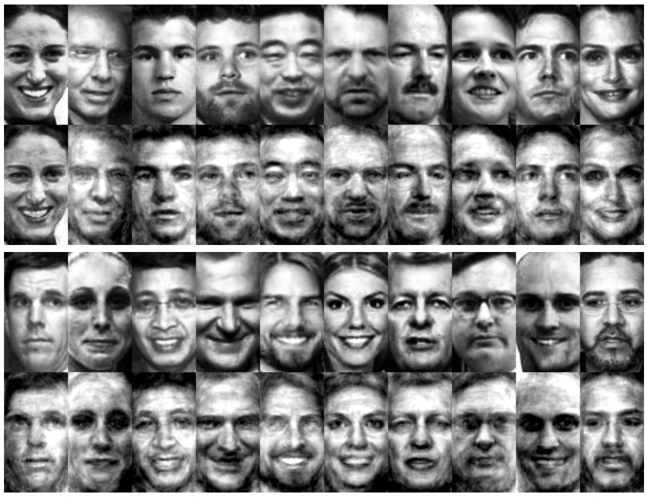

Figure 1: Reconstructing LFW images. Top rows are real faces while bottom ones are faces reconstructed with a decoder trained with 3000 training images.

We evaluated our algorithms on two face databases: FERET [5] and LFW [2]. Qualitative results on the LFW database are shown in figure 1. We also performed quantitative evaluations and observed that our method consistently outperforms the method of Mohanty *et al*. [3] based on multidimensional scaling (MDS) on both datasets.

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